

COSMIC DAWN CENTER

ANNUAL REPORT 2019





Danmarks Grundforskningsfond Danish National Research Foundation





Image credit: Ole Jakup Joensen

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The Cosmic Dawn Center

From the Director



2019 was the first year where the Cosmic Dawn Center (DAWN) was fully operational. After the initial buildup phase, it has been a pleasure to gradually shift the focus from logistics and negotiations to collaborations and building the community that we call the DAWN family. Through intensive international recruitment, we have transitioned from a group consisting mostly of senior faculty with big ideas and projects to a buzzing team of talented researchers at all levels from undergraduates to Professors working towards a common goal. DAWN is a truly international center, with half of our faculty being affiliated with foreign Universities across North America, Europe and Australia. One of the highlights of the year was during the summer when our international and Danish team members gathered in Copenhagen for the yearly DAWN Summit, to collaborate, socialize and plan the coming year.

In addition to our international faculty, we welcomed a growing group of undergraduate students, mainly from American universities, who engaged in summer research at DAWN. For several years, Charles Steinhardt has organized SURF@DAWN in collaboration with Caltech's Summer Undergraduate Research Fellowship (SURF) program, Princeton University, and the University of Minnesota. Since the start of DAWN in 2018 alone, SURF@DAWN has produced the first scientific publications for seven young scientists (historically, about half of the projects have result in publications). 2019 marked the beginning of the DAWN-IRES Scholars program, an International Research Experience program funded by the National Science Foundation (NSF). These students carried out research projects over 11 weeks in Copenhagen, each under supervision of a local mentor (professor, postdoc or PhD student) and co-mentorship from one of our international associates. In this way, the student acted as the glue between local and international team members. Between these two programs, DAWN was represented by 11 undergraduate posters at the American Astronomical Society Winter Meeting. These programs are regarded as long-term investments both in the students' research careers as well as in DAWN's ability to attract the best international PhD and postdoctoral researchers several years from now.

The DAWN postdoctoral fellowship program continues to be a success, both for DAWN and for the fellows. Our first fellow Francesco Valentino was awarded a Carlsberg Fellowship to continue his research program at DAWN and our two 2018 fellow hires, Daniel Ceverino and Kimihiko Nakajima, both moved to tenure track positions in their home countries after a highly interactive and productive stay at DAWN. Finally, one of our two 2019 fellow hires, lary Davidzon won both a European interaction fellowship and a MCS fellowship to support his research.

As part of our strategic communication plan, we started several new social media initiatives. We have redesigned the layout and added a news stream on our webpage, and built an active Twitter account, with a broader scope aimed towards our colleagues in the field. Our monthly newsletter focuses on the social side of our center's events (e.g., DHL Run and an excursion to the Planetarium for the opening viewing of Apollo 11) and is intended to be a tool for tracking local activities, highlighting diversity, encouraging cultural awareness and building a community with our closest collaborators and stakeholders.

When we had major scientific results with broader appeal, DAWN published press releases in collaboration with professional communication offices of major international organizations such as NASA, ESO, and our host Universities. Often, these press releases were coordinated with releases around the world from our international partners, thereby reaching out to very broad audiences, both through the large social media following of these organizations and through interviews in newspapers, TV and radio which were spawned by the press releases.

The two results described as annual highlights in this year's report are examples of DAWNled results that made the headlines and excited both the astronomical community and the broader public around the world.

In this year's report, we present a series of articles from different members of the DAWN family including undergraduate students, summer students, Masters students, PhD students, and professors sharing research and personal perspectives, as well as new promising research directions.

Enjoy

Smerof



Image credit: NASA

Annual Highlights

Proof of the Origin of the Heavy Elements

By Darach Jafar Watson

In understanding how the universe became what we observer today one of the most fundamental questions is the origin of the elements that make up the periodic table. We took a large bite out of this guestion this year by proving the origin of the heaviest elements. The heavy elements, which make up two thirds of the chemical elements, and include gold, platinum, and uranium, were the last elements to have an unidentified origin. Our paper, (Watson et al., 2019, Nature 574, 497-500) published in October, demonstrated the detection of freshly synthesized heavy elements for the first time, proving that they are forged in the extreme heat of the collisions of neutron stars.



Image credit: ESO/L. Calçada/M. Kornmesser

In 2017 the first gravitational wave signature from the collision of two neutron stars was detected, and we managed to train our telescopes on the galaxy in which this collision occurred, obtaining good quality spectra of the explosion resulting from this neutron star collision. This new type of explosion is now referred to as a kilonova. At the time, there was a lot of excitement about the fact that this kilonova indicated that large amounts of heavy elements were produced. This was the long sought after origin of the rapid neutron capture elements. However, because of the enormous velocities of the explosion that smeared and shifted the spectral lines and because of the complexity of the heavy element spectra with billions of atomic lines expected, no one at the time could show evidence for any individual element, and the community was reduced to making general arguments about the colour and brightness of the kilonova. Over the next two years, we worked on deciphering the

spectra, and we succeeded. We found clear evidence for the element strontium, one of the lightest of the heavy elements, proving that neutron star mergers were definitively the origin of the heaviest elements.

The formation of this element requires huge numbers of neutrons and its detection confirms experimentally the theory of these highly dense objects that we have referred to as neutron stars for so many decades; they do indeed contain large numbers of neutrons as originally hypothesized back in the 1930s.



Image credit: Niels Bohr Institute/DTU Space

The Early Death of Cosmic Giants

By Francesco Valentino

The majority of stars in the nearby universe are part of gigantic spheroidal (basically round), red, and dead old galaxies, with little or no formation of new stars to keep them alive. These cosmic dead giants are thought to be among the first objects to reach a full maturity in the universe: following the collision and merging of smaller gas-rich galaxies, they form stars at furious paces (several hundred times faster than our Milky Way), assembling most of their final mass in a few hundred, million dramatic years. This might be connected to their sudden death, followed by billion years of passive evolution, during which they mainly grow in size by swallowing smaller satellites in their surroundings due to the gravitational attraction. In collaboration with the National Astronomical Observatory of Japan (NAOJ), a team of researchers at DAWN discovered the most distant cosmic dying giant so far: a galaxy with a strongly suppressed star formation and already mature 1.5 billion years after the Big Bang (Tanaka, Valentino et al. 2019; Valentino, Tanaka et al. 2020a). Surprisingly, the motion of stars within the galaxy -- a proxy of the total dynamical mass of the system and a fundamental probe for our models -- is similar to what is observed in closer objects of the



Image credit: Masayuki Tanaka / NAOJ.

same species, showing that no substantial evolution is present for several billion years of the history of these massive galaxies. Moreover, а statistical analysis of the observed properties and number densities of distant quiescent massive objects shows that they were not necessarily extreme systems in their past, but rather similar to typical starforming galaxies in the young universe.

The team led by DAWN's assistant professor Francesco Valentino further showed that stateof-the-art cosmological hydrodynamical simulations can accommodate a significant number of massive quiescent objects in the distant universe and they predict their ``normal" past history. However, such agreement with the observations becomes uncomfortably poor for the closest galaxies to the Big Bang. This points at a possibly necessary revision of the current models of galaxy evolution (and, eventually, of the whole cosmology), if an extremely distant object of this kind were found in the forthcoming observational campaigns with the James Webb Space Telescope.



Centers of Excellence as optimal training grounds for the next generation of independent PIs

Georgios Magdis

2016: Oxford → DARK (DARK/Carlsberg Fellow – Assistant Professor) 2016: Villum Young Verstigator 2018: co – Lef Dawn Center 2019: Sor (DTU/NBI)





Science Progress and Research Update in 2019

Status of James Webb Space Telescope

2019 saw good progress on the James Webb Space Telescope. The assembled telescope proper and its instruments were mated to the spacecraft and began undergoing an extensive observatory testing program that will take up most of 2020. Noteworthy achievements were the successful deployment of the tennis-court sized sunshield which had encountered problems earlier, and the successful deployment of the folded-up telescope. JWST remains on schedule for a March 2021 launch. The four JWST instrument teams submitted their detailed scientific target lists for the Guaranteed Time Observations in July 2019 so that these observations could be marked as reserved in the January 2020 release of the Announcement of Opportunity for General Observers, with a deadline for proposals May 1st.

In preparation for this, an International MIRI GTO collaboration meeting was hosted by DAWN/DTU Space on June 18, 2019. DAWN staff are actively involved in the GTO programs of three of the four JWST instruments: NIRSpec (Jakobsen and Bonaventura), MIRI (Nørgaard-Nielsen, Colina) and NIRISS (Brammer).

For **NIRSpec**, DAWN is responsible for the development of the advanced software needed for using the Multi-shutter Array in an optimal manner. In response to a growing interest outside the GTO team for this software, we conducted two ESA sponsored training workshops on the topic at NASA Goddard Space Flight Center and Space telescope Science Institute on November 18-24, 2019.

For **NIRISS**, DAWN is responsible for developing the analysis software for the observing technique known as "slitless spectroscopy", which probes unique discovery space between classical imaging and spectroscopic surveys by providing low-resolution spectra for *every* object within the instrumental field of view. The NIRISS GTO survey will reveal hundreds of faint star-forming galaxies in the first 3 billion years after the big bang, and with many of them magnified by gravitational lensing of massive foreground galaxy clusters.

For **MIRI**, DAWN team members at DTU-Space are responsible for the Primary Support Structure for the Instrument. This flight hardware has been delivered to NASA. DAWN is chairing the MIRI High-Redshift Universe Working Group. The MIRI GTO program is divided into imaging and spectroscopic components. The imaging part consists of a single very long integration on the so-called "Ultra-Deep Field"—one of the most extensively observed parts of the sky for the search for distant galaxies. These observations will go to orders of magnitude fainter limits than has been possible previously and they will provide unique new information on how the first galaxies formed a few hundred million years after Big Bang. The spectroscopy component of the MIRI GTO survey concentrates on providing new insight in the physical process in selected high redshift sources. This program is performed in close collaboration with the NIRSpec Team.

Due to our direct involvement in three of the JWST instrument teams, DAWN was selected by ESA to host a so-called "JWST Master Class" Proposal Planning Workshop for future JWST users on 15–17 April 2020 in Copenhagen. We had invited potential participants for the workshop from all over Scandinavia, but unfortunately the event was cancelled due to travel and meeting restrictions.



Image credit: NASA/ESA/CSA

Opaque to Transparent (Cosmic Reionization)

The reionization of the Universe may seem like a somewhat technical concept, but it represents one of the most fundamental transitions in the evolution of the Universe. This is the time when the bulk of the normal atomic material in the Universe transitioned from being neutral (electrons being bound to nuclei) to being highly ionized (i.e. with electrons being removed from the nuclei). This happened sometime during the first billion years after Big Bang (which was 13.8 billion years ago). Why did it happen? It happened because some mechanism started producing ionizing photons, i.e. photons with energy higher than 13.6 eV, which is the binding energy of the electron in its ground state in the hydrogen atom. The main contenders for the sources of these ionizing photons are massive stars in newly formed galaxies and accretion disks around the first super-massive black holes. There are still many open questions: when did cosmic reionization happen, which are the dominant sources, and if it was indeed dominated by galaxies, how do ionizing photons escape from the interiors of galaxies? Answering questions like these is one of the key objectives of DAWN.

In 2019, researchers at DAWN have contributed important new results on several of the open questions related to reionization. Several papers with contributions from **Fynbo**, **Nakajima**, and **Finlator** have explored the important issue of photon escape [32,109,160]. Other papers, with contributions from **Oesch**, **Toft**, **Narayanan**, and **Laursen** have more broadly explored the properties of galaxies and proto-clusters at the epoch of reionization [21,40,69,207]. Finally, **Finlator** contributed to papers that look more into the future discussing how JWST will shed new light on this important issue and on how observations of neutral oxygen will constrain reionization [6,148,179].

First Galaxies

The most distant galaxy currently known—nicknamed "GN-z11"—is observed at an epoch just 400 million years after the Big Bang or when the Universe was just 3% of its current age (Oesch et al. 2016, ApJ 819, 129). More remarkable still, GN-z11 has been observed to already contain as many as one billion stars and is forming new stars at a rate 50 times that of our own Milky Way. Objects like GN-z11 are thought to be exceedingly rare compared to the average galaxy expected to contribute the reionization of the universe at similar epochs, but its mere existence poses a number of intriguing questions for understanding the physical processes that govern galaxy formation at these earliest times. For example, when exactly do the first stars and galaxies form? Is the extremely rapid formation of large galaxies such as GN-z11 in fact more common than we expect based on our understanding of galaxies at later times? If so, this would build on recent work by **Steinhardt** on "impossibly early" galaxy formation (Steinhardt et al. 2016, ApJ 824, 21).

Researchers at DAWN are working on a number of projects to discover and characterize the first galaxies—both extreme individual objects like GN-z11 as well as the general population of its less dramatic but more numerous siblings-and to develop a theoretical understanding of how these objects form and evolve. Steinhardt is PI of BUFFALO, the largest highredshift Hubble Space Telescope program awarded in Cycle 25, and Brammer leads the BUFFALO high-redshift working group. In 2019, Ceverino developed hydrodynamical simulations of early galaxies in a cosmological context to predict how they would appear to the next generation of telescopes including JWST [16]. **Oesch** contributed to a study While that galaxy remains an searching for bright candidates such as GN-z11 [133]. extreme outlier in terms of redshift and luminosity, their study yields a total of 19 probable candidate galaxies at 9 < z < 11. At somewhat lower redshifts where galaxies are brighter and more amenable to detailed characterization, Brammer contributed to a spectroscopic study finding that most luminous Lyman-α emitter "CR7" is likely powered by star formation as opposed to an active nucleus and that has a metallicity of 5-20% times the solar value [104]. That object had earlier been thought to have a metallicity an order of magnitude lower, generating much excitement that it could represent star formation from pristine gas consisting of just Hydrogen and Helium and unpolluted by metals from any previous generation of stars. Detecting such "Population III" star formation will thus likely have to wait for the launch of JWST. In a more direct study of the gas properties of the first galaxies, Fujimoto et al. found a prevalence of large halos of ionized carbon gas around galaxies at 5 < z < 7 that are likely remnants of outflowing material driven by earlier star formation activity [34].

Protogalaxies Become Galaxies (Galaxy Evolution)

Galaxy evolution faces the challenge of connecting observations of the earliest galaxies with the more organized structures that are found in the local universe. With the upcoming launch of JWST and other future facilities, our knowledge in this area will increase quickly, building towards a detailed characterization of galaxy evolution. Until then, we instead rely on observations with current facilities, focusing on more local galaxies which can serve as proxies for younger and more distant objects, where we find the brightest targets due to the peak in star formation at redshift z~2. DAWN members such as **Nakajima** proposed Lyman-alpha emitting galaxies (LAEs) as promising analogs of galaxies in the reionization era.

At DAWN, simulations are also used to study galaxy evolution. To overcome the dichotomy between 'observers' and 'theoreticians' and fill the gap between the two fields of expertise, at DAWN we have both a deep knowledge of theoretical models and computer simulations, and the 'noise' affecting real observational data. An example of this is **Davidzon** et al., which connected the intrinsic properties of galaxies with their observables, using an intensive post-processed version of the HORIZON-AGN hydrodynamical simulation [27,66].

On the other hand, the study of absorption systems can provide insight into the complex transformation of galaxies. By observing distant quasars, we can measure the gas reservoirs along the line of sight, serving as an independent and unique way of selecting galaxies based solely on their gas, as opposed to established selection techniques. The observation of gamma-ray bursts (GRBs) can be used to determine the ionizing radiation emitted by massive stars that can ionize and enrich the intergalactic medium, such as shown in Tanvir, **Fynbo** et al. With strong quasar absorbers, galaxy dark matter haloes can also be explored across redshifts [19,109].

Galaxies Die (Exploring and Understanding Quenching)

The most luminous galaxies in the local Universe, like the giant elliptical galaxy M87 ceased converting gas into new stars already billions of years ago. Astronomers call them "red and dead", because of the color of their old stars and the fact that their star formation activity has stopped. Studies based on spectroscopic analysis indicate that the bulk of their stellar population formed very quickly, possible in one single burst, during the first 1-2 billion years of their life at redshift z>2. Then they abruptly stopped forming stars (at $z\sim1-2$, i.e. 8-10 billions year ago) even though at that epoch the Universe was still rich of pristine gas to fuel the process. Physical mechanisms responsible for such a *quenching* phase are still unclear: Did something heat the fresh gas reservoirs around galaxies, preventing it to cool down and collapse into stars? Or perhaps has the gas been completely removed, wiped away by gravitational forces or ram pressure?

The former scenario usually invokes the role of an active galactic nucleus, i.e. the supermassive black hole sitting at the center of each galaxy, as it can release high-energy jets of hot material even beyond the extension of the host galaxy. In the case of gas being stripped away, possible explanations come from different kinds of environmental interactions: tidal forces between the galaxy undergoing the quenching phase and a nearby companion, or gravitational interaction with the dark matter in which the galaxy is embedded. These are only a few theoretical models among those proposed in the last decade, none of which provides a definitive answer. Man & Belli, in their 2018 Nature review, underline the urgency of shading light on this open issue, as quenching is one of the fundamental problem in galaxy evolution: none of the state-of-the-art computer simulations are able to accurately reproduce the observed population of quiescent galaxies and their characteristic.

DAWN is a leader in this research, with a unique combination of theoretical and observational expertise. Our team (PIs: **Whitaker, Stockmann, Toft, Valentino**) has collected exquisite images and spectra in optical and near-infrared, using world-class ground-based telescopes (Keck, ESO/VLT, Subaru) and from space with Hubble and Spitzer. Other DAWN members (**Brammer, Davidzon, Steinhardt, Weaver**) devised advanced techniques to analyze this data and find the most intriguing quiescent galaxies such as the most massive ones and the most distant ones. Together with M. Tanaka, we hold the record for the most distant quiescent galaxy ever observed; this object has a spectroscopic redshift of z=4, implying that it assembled its stellar content (tens of billions solar masses) and suddenly died in less than 2 billion years after the Big Bang. It is one of the best targets to follow up with JWST and this is exactly what we are planning to propose to do for the upcoming Cycle 1 of observations. This result was also subject to international attention of general media, with press releases in Denmark, Japan, and the United States.

Our DAWN associates and close collaborators **Lagos**, Hirschmann, and **Narayanan** bring their expertise in galaxy formation models and simulations, so that we are in the best position to deeply understand quenching mechanisms by comparing observations to theoretical predictions.

Moreover, as we try to describe galaxy evolution with a single, coherent narrative, we are also putting a significant effort into chasing starbursts and post-starbursts galaxies at even higher redshift, since those objects are thought to be the progenitors of quiescent galaxies. In particular, **Cortzen, Kokorev, Magdis, Valentino** are leveraging their knowledge of gas

physics and their unparalleled ALMA and NOEMA data sets in the sub-mm regime to build a statistically significant sample of galaxies "in transition", expected to become red and dead on a (cosmologically) short time-scale.

Dust and Molecules Form (Interstellar Medium)

The rich information derived from deep multi-wavelength extragalactic surveys also allows us to get a glimpse of the raw material that is responsible for the formation, evolution and death of galaxies – the interstellar medium (ISM). The ISM is primarily comprised of dust and gas, spanning a wide range of different environments, from hot ionized regions around young stars, to star-forming cold molecular clouds.

Molecular gas is a key ingredient for new stars, but cannot be observed directly. We therefore require various other tracers in order to be able to estimate the total amount of molecular gas. In a new study, **Cortzen, Magdis**, and **Valentino** developed a novel method to trace molecular hydrogen, in the form of polycyclic aromatic hydrocarbons (PAHs) [23]. This will be highly beneficial with the advent of JWST, which can be used to scan this part of the spectrum to uncover the PAH content of the most distant galaxies.

Continuing the center's ground-breaking research using Atacama Large (sub) Millimeter Array (ALMA), **Magdis** observed four high-redshift dusty star-forming galaxies including the most distant object of this kind discovered to date [56], a potential progenitor of the first massive quiescent galaxies. Studies of systems such as these, allow us to understand how the dust content of galaxies has evolved across cosmic time. In addition, **Fujimoto** was responsible for the first identification of ionized carbon (CII) in halos around star-forming galaxies [34]. The presence of an extended CII halo reveals the dramatic impact of star-forming galaxies on their surrounding environment.

Putting It All Together (Theory)

Given these exciting observed phenomena, it is important to have a theoretical understanding of galaxy formation and the evolution. Using cosmological simulations, it is possible to both predict what future telescopes should see as well as understand current observations. **Steinhardt** created models for galaxy evolution to study the effects of gas temperature on the star formation rate and the stellar initial mass function. **Ceverino** has been leading the work from the FirstLight simulation, and published simulation predictions about the absolute magnitudes, colors, and emission lines of high redshift galaxies [16]. By studying the wide range of spectral energy distributions near cosmic dawn and the recombination lines of oxygen and hydrogen, it will be possible to make predictions about the first galaxies. It is expected that the James Webb Space Telescope (JWST) will be able to confirm these predictions in the future.

At the same time, **Narayanan** has been creating models for dust formation and destruction in the SIMBA galaxy formation simulation for redshifts from 0 to 6 [174]. These models can be used by both observers and modelers to estimate dust to gas ratios and dust to metal ratios given different galaxy physical properties, such as metallicity, stellar mass, and gas fraction, at different redshifts. Additionally, DAWN affiliate **Lagos** has been studying galaxy emissions at different wavelengths and redshifts using both the SHARK model of galaxy formation and the PROSPECT spectral energy distribution generation tool [173]. These simulations will be essential tools to understand Cosmic Dawn and the formation of the first galaxies, especially in preparation for JWST.



Image credit: Ole Jakup Joensen

Photo: Gabriel Brammer, Tivoli

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Feature Articles

The Greenland Telescope - A New Window to the Universe By Thomas R. Greve

One often associates Greenland with breathtaking landscapes and a fierce and proud people and their culture – a people which has flourished despite an unforgiving natural environment. Astronomy, however, is not something one would typically associate with Greenland. Rather, astronomy conjures up images of majestic and awe-inspiring telescopes on high plateaus in the Chilean desert or on top of extinct volcances on Hawaii, where the extremely dry and stable atmospheric conditions are ideal for observing in the far-infrared and millimeter wavelength range. Such conditions can also be found in the extremely cold environments near the poles. In fact, several astronomical telescopes and research stations have for years been based on Antarctica but so far astronomy has not been pursued from the Arctic. This is about to change, and Denmark and the Cosmic Dawn Center are at the forefront of that change.

The Background Story

The Greenland Telescope, or simply the GLT, is a radio-dish antenna with a diameter of 12 meters. It is optimized for observing radiation at wavelengths of about one millimeter. Originally, the GLT was the American proto-type antenna for the Atacama Large Millimeter

Array (ALMA), which is an array of 56 radio telescopes working in unison in the Chilean Atacama Desert. After serving its role as a proto-type antenna, the telescope was awarded to the Academia Sinica (ASIAA) in Taiwan and the Smithsonian Astrophysical Observatory (SAO) in the US. Astronomers at these two institutes chose to bring the telescope to the Arctic in order for it to serve as a northern arm of the world-wide network of radio telescopes called the Event Horizon Telescope (EHT). It was the EHT which in 2019 presented the world with the stunning first picture of a supermassive black hole – a picture which made the EHT famous overnight. This was made possible thanks to the EHTs network of telescopes on the South Pole, Chile, Hawaii, Arizona and Europe. The reason for adding a telescope in the Arctic to the EHT network was primarily to increase the angular resolution of the EHT images. In 2017, ASIAA and SAO brought their telescope to the Arctic, specifically to the Thule Airbase in north-west Greenland, where it officially became the Greenland Telescope. Although the final destination of the GLT is meant to be the Summit Camp in the middle of the Greenlandic ice-sheet, some thousands of kilometers away from its current location, Thule Airbase provides an ideal place for testing the telescope before the big move. As of January 2018, the GLT has been operating as part of the EHT.



The Greenland Telescope at its current location at Thule Airbase. Image credit: Dr,Nimesh Patel (Harward/CfA)

Denmark Joins the Greenland Telescope

Because the telescope is in Greenland, the Danish astronomical community has had an open invitation by the GLT Director, Professor Paul Ho (ASIAA), to find ways that Denmark could join the GLT project. There is strong interest from the Danish astronomical community, with scientific goals ranging from galaxy surveys and astrochemistry to black hole physics, and a national steering group with members from DTU Space and NBI has been set up to coordinate Danish involvement in the GLT (www.greenlandtelescope.dk). This group works under the Instrument Center for Danish Astrophysics (IDA) (https://phys.au.dk/ida/). The group is currently coordinating efforts with which Denmark can contribute and facilitate the GLT. This includes helping with the logistics and transportation of the GLT from its current position at Thule Airbase to the Summit location in the middle of Greenland – a move that is expected to take place in 2022. DAWN is leading an effort to explore the GLT scientifically while it is in Thule. At the time of writing a Letter of Agreement between ASIAA, SAO, DTU Space, and NBI is being drafted to formalize the collaboration.

A Survey of the Cold and Distant Universe from Greenland

In 2018 DAWN proposed to IDA to bring the GISMO camera to the GLT and use it to conduct a large extragalactic survey. With this in mind, DAWN together with DARK and STARPLAN held a conference in Copenhagen in February 2019, with the participation of the main partners from Taiwan and the US. A large extragalactic survey with GISMO was given the highest priority based on scientific merits and feasibility from the Thule location. In January 2019, a team consisting of DAWN members from both DTU Space and NBI was awarded a Carlsberg Infrastructure Grant (1.4MDKK, PI: T. Greve) to bring GISMO to Thule and install on the GLT in order to carry out such a survey.

GISMO was built at NASA (PI: J. Staguhn) and is a 128 element transition edge sensor bolometer camera optimized for observing at wavelengths of 2 mm. Mounted on the GLT it would have a diffraction-limited angular resolution of 42 arc-seconds which would make it highly efficient at detecting sources serendipitously in large sky surveys. With the backgroundlimited performance of the detectors, the camera provides significantly higher imaging sensitivity and mapping speed at 2 mm than has previously been possible. The DAWN and NASA teams will together provide the necessary workforce and expertise required to install GISMO on the GLT, with the necessary technical components and logistics expenses being covered by the Carlsberg grant. GISMO's surveying



The GISMO detector box. The four readout columns with (from inside to out) SQUID multiplexer chip, Nyquist Inductor chip, and Shunt chip can be seen in the picture. Image credit: Johannes Staguhn (NASA)

capabilities were demonstrated on the IRAM 30m Telescope in Spain, but over a tiny region of the sky owing to the limited telescope time available. A survey of the scope that will be possible on the GLT requires thousands of hours of telescope time, which no ordinary telescope can accommodate. Although, the GLT is part of the EHT, the nature of the EHT observations and the limited number of suitable targets available means that only a small fraction of the available GLT time goes towards the EHT. No other projects will be ongoing while the telescope remains in Thule. This will allow us to install GISMO and to carry out the proposed survey effectively within two years.

The primary scientific driver for the GISMO+GLT survey is the new window it will provide for studying the first galaxies. At an observing wavelength of 2 mm, the survey is fine-tuned to detect the most distant, dust-obscured starburst galaxies within the first billion years of the Big Bang (corresponding to redshifts, z > 4). These galaxies, which are nearly invisible in the optical, are thought to be the formative stages of evolved massive galaxies observed at optical and near-IR wavelengths at later times when the universe was 2-3 billion years old. The notion of such an evolutionary link is not new but lacks firm observational support. This impasse is due to missing samples of uniformly selected starburst galaxies at z > 4. Unlike surveys at wavelengths < 1 mm, of which there are many, surveys at 2 mm, of which there are very few, effectively filters out the foreground population of dust-obscured galaxies, resulting in high-grade samples of z > 4 galaxies.

The GISMO+GLT survey will cover about 4 square degrees area in the Euclid North Ecliptic Pole (NEP) field, which is the prime extragalactic deep field observable from Greenland. Based on our state-of-the-art simulations of the extragalactic source number counts on the sky at 2 mm, a 4 square degree surveys with a uniform rms sensitivity of ~ 0.2 mJy is the optimum survey strategy. At this survey depth and area, we expect to uncover a total of \sim 400 sources, which is sufficient to address our science goals. Based on a conservative estimate of the noise performance and the mapping speed of GISMO on the GLT, we expect 2000 hr of observing time is required for the completion of the survey. The Euclid Space Mission will provide unparalleled near-IR imaging, using instrumentation funded in part by Carlsberg. Our team has acquired extremely deep mid-IR and optical imaging across the NEP with the Spitzer Space Telescope and the Subaru telescope in Hawaii, and is involved in large ground-based spectroscopic surveys, which will give us spectra for thousands of distant galaxies in the NEP. The synergy between these data and the GISMO survey opens up new ways of studying the formation and evolution of the first massive galaxies. For the first time, we will accurately determine their clustering properties and stellar masses, and link them to their dark matter halo masses. Our survey has the area required to avoid cosmic variance (> 2 square degrees) and properly sample cosmic large-scale structure and the build-up of massive galaxies in the early Universe.



Image credit: Dr. Nimesh Patel (Harward/CfA)

Using Machine Learning to Complete a Census of Cosmic Dawn By Charles Steinhardt

The current generation of high-redshift surveys has been made possible by the discovery that galaxies do not take on the full range of theoretically possible properties. Instead, it has been observed that the most important properties of galaxies are closely related to each other. A small fraction of the possible combinations of stellar mass, dark matter mass, star formation rate, redshift, dust content, and other properties are quite common, but most combinations never occur. Thus, a survey with only a few pieces of information about each galaxy, if that information is chosen carefully, can provide measurements of all of these properties.

As a result, nearly everything we know about galaxies at Cosmic Dawn comes from photometric surveys, in which images of large patches of sky are taken through just a few filters at carefully selected wavelengths. We then use templates derived from physical models of local galaxies, including knowledge of which combinations are common, to determine their properties. Gabe Brammer has been a pioneer in developing photometric template fitting techniques for the current generation of Hubble Space Telescope surveys, including the discovery of the most distant known galaxy along with Pascal Oesch. Photometry has been responsible for most recent discoveries in galaxy evolution, and upcoming missions and telescopes including Euclid, JWST, and LSST have been designed as photometric surveys.

However, this technique can only find high-redshift galaxies which look like templates. If a galaxy does not match any of the possible templates, then it is necessary to guess at its properties. A poorly-fit galaxy is typically interpreted as a far more common low-redshift galaxy rather than a rare, ultra-high redshift one. Thus, catalogues at Cosmic Dawn are currently incomplete, and I recently found that as many as half of all high-redshift galaxies have been mistakenly interpreted as lower redshift.

My students and I have been developing an alternative, model-independent approach based on machine learning, working from observed spectra rather than assumptions about the underlying physics. Although spectra are only available for a small subset of these large catalogues, it is further assumed that objects with



Image credit: Rychard Bouwens



Image credit: Beryl Hovis-Afflerbach and Charles Steinhardt

"similar" colors should have "similar" spectra. However, this runs into a series of problems known as the "curse of dimensionality": as more photometric bands are available, the full N-dimensional space becomes sparse, so that objects are closer to a boundary than to any meaningful neighbor. We thus use dimensionality reduction algorithms such as the self-organizing map and t-SNE to produce lower-dimensional maps which have many neighbors but retain the structure of the original observations.

Initial explorations of this technique have immediately produced meaningful improvements in long-standing problems. Using t-SNE, we have been able to identify over 95% of the galaxies with catastrophic redshift errors based upon discrepancies with neighboring objects. This technique is already in use for both the BUFFALO and COSMOS 2020 surveys led by DAWN. We are also developing neural networks for improved star-galaxy separation at high redshift. Bachelor and PhD students have played key roles in all of these efforts, as well as applying these same techniques to a wide range of additional problems.

A key aspect of these new techniques is that they are model independent, Thus, the studies for which these algorithms are most successful are ones for which the physical models used are poor descriptions. This is precisely the situation at Cosmic Dawn; historically, the most interesting results of exploring a new regime have come from populations that were not anticipated. By developing these techniques based solely on observed data, it will be possible to produce a more complete census at Cosmic Dawn, providing a unique perspective on the leading surveys and missions over the next decade.

Studying the Metallicity at Cosmic Dawn Thanks to the FirstLight Simulations By Ivanna Langan

Right after the Big Bang, the Universe was only made of hydrogen and helium atoms. However, as we all know the world we live in is not only made of hydrogen and helium, we are not only made of hydrogen and helium atoms; 'we are made of star stuff'. Everything that surrounds us today was at some point created in stars, like the oxygen we breathe or the lithium in our smartphone's battery. Oxygen, lithium or any element heavier than hydrogen and helium are what astronomers call *metals*. Galaxies were first made of only hydrogen and helium before metals started to form. That is why; we expect galaxies to get richer and richer as more metals accrete with time.

Therefore, studying the creation of metals, gives us strong insights about starformation processes and galaxy growth. It tells us how the universe evolved from only hydrogen and helium atoms to the incredible variety of atoms we live with today. In addition, the metals are not only a way to trace how the Universe has evolved, it is also a key part of the story. For instance, the rate at which gas cools into new stars depends partly on the metallicity, i.e the abundance of metals.

That is why, we want to measure the metallicity at high redshift (early times), so we can better understand the story. However, with the current generation of telescopes, we cannot measure the metallicity at Cosmic Dawn, that is, 150 million to one billion years after the Big Bang or in astronomy terms redshift z=5-15. Since we cannot actually observe galaxies and measure their metallicities, we instead rely on simulations. Simulations are a powerful tool to help astronomers understand the Universe when observation and theory are limited. As said before, observation is not an option when it comes to metallicity at high redshift for technology reasons. Theory with a pen and a blackboard is also not an option, because we simply have far too many parameters to take into account to study it by hand. It would take us years to do what computers did in a month. Simulations like the FirstLight project, of which Dr. Ceverino is the Principal Investigator, are therefore necessary for us to follow the evolution of the first galaxies formed in the Universe. These simulations also allow us to study properties of high-redshift (very distant) galaxies that we presently cannot



Image credit: Daniel Ceverino

directly measure with the current generation of telescopes. As a result, my project focused on studying the metallicity of those simulated primeval galaxies.

The galaxy gas-phase metallicity is strongly related to the galaxy stellar mass. In fact, this scaling relation, called the mass-metallicity relation (MZR) has been observed from the local Universe (redshift z=0) to cosmic noon (redshift z=1-3.5) and we do not know if it holds at high redshifts. If it does, then it means that very early in the evolution of the Universe, the metallicity and the mass of a galaxy are already strongly correlated which is good news for observational works. Indeed, this correlation means that we only need to observe one of those two properties to get the other, which is a very important factor to design telescopes surveys. If the MZR does not hold at high redshift on the other hand, then it means there is something else that must have happened in order for the mass and the metallicity to be correlated the way they are in current observations. A major goal of my internship was to study this relation at higher redshift and determine how the metallicity evolves with redshift.

The mass-metallicity relation is confirmed from redshift z=5-8. We observe the same scaling relation from the data generated by the FirstLight simulations as the one actually observed by telescopes. Following the evolution of the metallicity with redshift showed us a slight increase of metallicity with redshift, that is to say, more distant galaxies are richer in metals than less distant ones. This result can be quite surprising because it contradicts the expected result which is galaxies getting richer in metals with time. Our result is explained by the fact that this evolution is driven by slowly increasing gas fractions during the epoch of gas reservoir buildup. Why is the gas fraction increasing? That we do not know. More work on that matter will be done. There are always new questions arising while looking for answers for the initial questions.

Another goal of my internship was to make predictions of luminosity emission lines against metallicity and stellar mass relations. This way, we provide metal-sensitive observables that can be used in the calibration of future measurements of the next generation of telescopes, such as the James Webb Space Telescope (JWST).

It was very exciting to work on the metallicity of primeval galaxies and make predictions that will be tested in the upcoming years. Thanks to the support of my supervisor, I also published my results in a first-author paper on 'Weak Evolution of the Mass-Metallicity Relation at Cosmic Dawn in the FirstLight Simulations', which is a very exciting step to take as a first-year MSc student.

Baby Globular Clusters By Meghana Killi

Globular clusters (GCs) are spherical structures made of stars bound by gravity. Most are only a few tens of light years across - minuscule by cosmic standards. The Milky Way, in contrast, spans a hundred thousand light years.



A color-corrected image of the second largest and second brightest globular cluster called NGC or 47 Tucanae (looks great for a 13 billion-year-old!). Image credit: ESO

There are currently over 150 known GCs in the Milky Way's halo, but despite their ubiquity, we know precious little about how they form and evolve: Are they conceived in a single bout of starformation or are they the culmination of several generations of stars? Why don't they have a lot of gas or dust or dark matter; do they start out with these accessories but lose them over time? Do they form along with their host galaxies, or are they captured later?

It is difficult to answer these questions now, because we have not yet been able to find a GC before it is middle aged. The youngest known clusters are at least 10 billion years old, with the oldest having lived for 13 billion years. Considering that the accepted age of the Universe is 13.8 billion years, these objects are quite ancient indeed. How did they even

manage to assemble so early in the history of the Universe?

Thanks to the finite speed of light, a peculiar perk of astronomy is that we can peer further back in time by looking farther into space. Given this seemingly omnipotent quirk, one might think that the only thing necessary to find a baby GC is to look deep enough into space. However, observing distant globular clusters poses a unique challenge because of their relatively small size and brightness (compared to galaxies).

Ground-based telescopes cannot pinpoint small objects, because Earth's pesky atmosphere gets in the way; ground-based images are bright, but blurry. On the



Illustration of observations with space telescope (left) - faint, but sharp VS ground-based telescope (right) - bright, but blurry (Object: Messier 7, also known as NGC 6475. Image Credit: ESO)

other hand, space telescopes *can* pinpoint small objects, but cannot pick out a small collection of stars from nearby bright objects and stray radiation, because they're **not** big enough to collect a lot of light; space telescope images are faint, but sharp.

Therefore, if we combine the *brightness* of ground-based observations with the *sharpness* of space based observations, we can catch baby GCs in their infancy! This is why, in my project, I compare data from the Hubble Space Telescope (HST) with that from the ground-based Very Large Telescope (VLT) in Chile, to get the best of both worlds.

Hubble has found extremely tiny regions over 11 billion light years away that are emitting the Hydrogen signature indicative of star formation. So, these objects used to live 11 billion years ago, meaning we could observe a baby GC only 2 billion years old! At that point in time, the regions in question appear to have been a thousand light years across, but over the next several billion years, they could come together under gravity to form today's GCs!

Analyzing the corresponding VLT data might reveal that GCs are simply failed galaxies: they were captured and stripped of gas and/or dark matter too soon, and thus smothered. Or it might show that they were the quick and dirty side-projects of bigger galaxies. If we're lucky, it might even unveil an entirely new mechanism of cosmic structure formation.

With ever-advancing technology, and more powerful space telescopes like the JWST on the horizon, we can look forward to better and more extensive data on baby GCs. Exciting science is mere moments away... on globular cluster timescales, at least.

Moving Closer to the Stars By Christian Kragh Jespersen

To this day, the memory of falling asleep looking at the awe-inspiring night sky as a young boy still brings a smile to my face and reminds me of my love for all that is unknown. It is that insatiable curiosity that has brought me to study physics and to a position at DAWN. My curiosity has brought me all over the world, studying everything from languages to business and most lately, physics. Many scientific areas have many very interesting and fascinating problems, but most of them suffer from a lack of verifiability compared to physics. I thus became infatuated with the pursuit of truth and how to verify what we think is true. During high school, I got involved in summer schools, the Physics Olympiad, and UNF, the Youth Association of Science, as a member of the PR-team, a position I also held when organizing physics camps with UNF. Coming out of high school with the highest grade point average in the country and filled to the brim with motivation from my extracurricular activities, I was advised to find some additional occupation during the first year of my bachelor's degree, and I soon came to be aware of DAWN.

I managed an appointment due to my previous experiences, and hoping for a kind of job, I went to meet Center Director Sune Toft for the first time, which was very exciting, and afterwards I was sent to meet with Charles Steinhardt. Prof. Steinhardt immediately provided me with a series of physics challenges to test my aptitude for solving unorthodox problems, which was very interesting and a lot of fun! The one that has stuck the most is a simple yet fascinating question. Why are the rings of Saturn stable? We here have a problem where we can observationally obtain the result that the rings must be stable, but we don't know why. Every child knows that the rings exist and continue to exist but explaining why took two centuries after their original discovery. It was a great introduction to the kind of problem solving which would later work with in a more professional capacity at DAWN. Our goal was to explain the incredible events that are indisputably presented to us by the universe. Later, Prof. Steinhardt brought up a project that two fellow bachelor students and I could work on, namely investigating whether modern unsupervised machine learning techniques could be implemented to solve until now seemingly impossible classification tasks in Astronomy. The project was amazing, interesting, challenging and with plenty of room to learn a lot, and about half a year later, we had an original scientific result ready to be printed as a scientific paper, which is currently under review for the Astrophysical Journal. Being able to work on original research was a fantastic opportunity, which was also extremely rewarding in terms of all three of us being able to better zone in on what we wanted to do with our academic careers, as well as furthering our abilities as physicists and researchers.

Prof. Steinhardt also introduced me to a concept very foreign to Scandinavian students; working as a researcher during the summer. With his aid, I was accepted a 10-week project working David Stevenson at Caltech on computationally investigating how silicate- and iron-rich planets respond to very high internal temperatures stemming from energy retained from their gravitational collapse. The

project was successful and is set to be written up as a paper, also for the Astrophysical Journal. This project gave me an opportunity to further broaden my scope as a scientist, not only developing my "scientific toolbox" with programming tools and geophysical knowledge, but also getting in touch with the differing academic traditions between regions, as well as having my eyes opened to the possibility of going abroad for my MSc and/or PhD. I cannot stress enough how important my employment at DAWN has been in allowing me to seek out these amazing opportunities.

Both research projects were presented at the American Astronomical Society's 235th

meeting in Honolulu, Hawaii. I took charge in presenting the work done with Prof. Stevenson, while Prof. Steinhardt presented the work that we had carried out together at DAWN.

Working with web management, social media and public outreach at DAWN, has also both developed my communication skills and highlighted the traps and pitfalls that are possible to fall into when communicating with the "curse of knowledge". However, the greatest non-academic insight I



Christian K. Jespersen presenting the work done at Caltech for a judge at the Chambliss poster competition, Image credit: AAS

have gained has come from working with our Center Coordinator, Guarn Nissen. The familiarity I have gained with managing a research center is something unique for someone with a strong preference for an academic career, but I have become increasingly convinced that the understanding of what actually makes the wheels turn in academia is going to be indispensable for the future, if I want to pursue a future as an independent PI, or team leader.

Working at DAWN has gifted me the possibility to be an active part of the scientific community, surrounded by brilliant and motivated people every day, as well as being challenged and learning about the world of original research, at the same time as having the freedom to investigate what I want to do with my future. It has allowed me to learn more and go further in my education than most of my peers. I couldn't think of a better start to the life of a young physicist, and I am very grateful for all that has been done for me so far. I'd strongly recommend that other bachelor students seek similar employment/projects, and that Centers encourage employees to seek out talented students or employ students as academic assistants. In North America and the UK, bachelor students are recognized as valuable resources, and hopefully that is something that will soon be brought to the academic work in Northern Europe.

Notes from Summer 2019: Studying the Early Universe in Copenhagen, Denmark

By Darren Stroupe, UNC Asheville Physics Major at the Cosmic Dawn Center



This summer I had the great privilege of participating in the <u>DAWN-IRES</u> (International Research Experience for Students) Scholar Program. I conducted research at The Cosmic Dawn Center (DAWN) in Copenhagen at the Niels Bohr Institute, where the early Universe and first galaxies are studied through observation, theory and simulation. My research focused on classifying the quality of redshift fits using low-resolution grism spectra and machine learning classification models. The work was intense but gave me insight into many different areas of knowledge (e.g. the high-redshift universe, emission lines, telescope instrumentation, statistics) and provided me with new tools and sharpened skills that I will use throughout my career

(e.g. GRIZLI, EAZY, Python, machine learning). My mentor, Dr. Gabe Brammer (who developed GRIZLI and EAZY) provided strong guidance and generated a flood of knowledge every time we met about the project. He and the rest of the staff and students at DAWN are at the forefront of their field and set a high bar for caliber of research. It was humbling to be welcomed by them.

DAWN also scheduled talks by astronomers and astrophysicists from around the world on subjects ranging from gravitational lensing to galaxy formation and simulations, with Q&A sessions shared by the speakers and the Scholar cohort. Astrophysicist Dr. Joseph Silk, namesake of Silk Damping and author of *The Big Bang* – a book that was very influential in igniting my interest in astronomy – gave one of the talks, which afforded me the honor of meeting him and shaking his hand.

We were also treated to a trip by ferry to the island of Hven, where Tycho Brahe made the arcminute-precision measurements of the positions of astronomical objects that led to Kepler's three laws of planetary motion that, in turn, helped lay the foundation for Newton's theory of universal gravitation. The museum there housed some of his instruments and writings, as well as artifacts from the now longgone observatories.

With the workday finished, I could ruminate on the latest obstacle in my research while exploring



A statue of Danish Astronomer Tycho Brahe at Østervold Observatory , image credit: Darren Stroupe

Copenhagen by foot, bicycle (also provided by DAWN), boat, bus, or train. The Viking settlement-turned-European capital city offers a lifetime's-worth of cultural, architectural and historical riches to enjoy: the 17th century fortifications that were repurposed as lush parks and gardens that form a ring around the inner city; the many museums that include the National Gallery of Denmark, the National Museum, the Workers Museum and Design Museum Danmark; the free-to-the-public pipe organ concerts in many of the city's cathedrals; the canals that could be traversed by boat for a different perspective of the buildings and palaces that span centuries in age and design, or simply enjoyed by sitting upon their banks with a cold beverage. I found no way to avoid having a great experience.

While I was unfortunately unable to visit the Niels Bohr Archive, his presence loomed large, nonetheless. I would often, on my walks, find myself at a historical landmark

or some tribute to Bohr – or Brahe – reminding me of the deep legacy of physics and astronomy to which I hope to contribute. I cannot fully express my gratitude to Dr. Kate Whitaker and the DAWN-IRES organizers, Dr. Brammer and the DAWN staff



Nyhavn was one of my favorite places to visit in Copenhagen. Image credit: Darren Stroupe

and students, and Drs. Britt Lundgren and David Wake at the UNC Asheville Department of Physics and Astronomy for the encouragement, support, skills and knowledge they have gifted me over the course of this experience. With this experience, I feel confident I can contribute to and share in the legacy of those who came before and those who continue to extend the realm of knowledge in physics and astronomy.

Transition from Academia to Industry

Cecilie Sand Nørholm

My name is Cecilie and I completed my Master's degree in September 2019, having done my Master's thesis at the Cosmic Dawn Center. I am currently employed as an astrophysicist at Tycho Brahe Planetarium in Copenhagen.

While astronomy has always been my passion, I developed a growing interest in science communication during my time as a student. After completing my Master's degree, I got the opportunity to take on a full-time position at the Planetarium, where I also worked while studying.



As part of my education in astrophysics, I chose to take courses in scientific communication and didactics, mainly to improve my personal skills in communicating science to a broader audience. However, the combination of my interest in communication and my passion for astrophysics turned out to lead me towards a job in science communication.

Through my physics studies I have learned to assess scientific results, apply critical thinking, as well as to be investigative in my work, and through my experience with science communication I have learned how to be reflective and aware of the recipients when speaking or writing. As a part of my work, I seek out new scientific knowledge that could raise people's interest in science and help create content for lectures, exhibitions and teaching programs. I feel lucky to have a job in which, every day, I am able to apply some of the skills I gained through my education.

While working on my Master's thesis, I was considering whether to pursue a career in academia or in science communication. For this reason I also experienced some challenges after starting my career outside academia.

The biggest challenge for me was the shift from working on a scientific project, focusing on a specific topic, participating actively in producing scientific results, to communicate science in a very broad perspective, and not working on any science myself. Another challenge was the communication itself; delivering a message in a short and precise way can be difficult, especially when the content is complex and one wishes to underline how important it is or why people should be excited about it.

Fortunately, this was all something that I overcame mostly by experience and learning-by-doing. Even though any new task might always always be challenging at first, like in every other field of work, it is also what motivates me to become better at what I do.

I am currently part of a workplace where my colleagues have widely different educational backgrounds. As a result, we all have different workflows, which also took some getting used to - this is, however, also an advantage as it forces me to think about things differently and offers a whole other perspective. Even though I am still not completely certain what career path I would like to follow, my job has also taught me that there are more opportunities within my field of interest than I initially thought - and that it is not impossible to change your mind about what you would like to work with. The most important thing for me is that I am working on something that I find exciting and interesting - and I think this could be a good thing to keep in mind when looking for professions, either within or outside academia.



Finding the Rare Beasts of the First One Billion Years By John Weaver

It was Herman Melville in the 19th century sea-faring tale Moby Dick, who said of the sailor:

"I am tormented with an everlasting itch for things remote.

I love to sail forbidden seas..."

Like the sailors and map-makers of old, we astronomers harbor this same sense of visceral curiosity. It is what drives us to peer deeper into the dark night sky in search of new mysteries; answers to which will help us better understand our place within our universe.

Since the dawn of recorded history, humans have been charting the positions of stars. Millenia has passed, and yet the activity of charting the points of light in the heavens holds fast.

The reason is straight-forward: before we can study the most interesting things in the universe and make groundbreaking discoveries about their nature, we first must find them.

Galaxies span a tremendous range in their brightness. However, some are further away than others. The effect is that the most distant galaxies, although having billions of stars, appear to us as being extremely faint in our night sky. To find them we must take repeated images of the sky so that we may gather as much light as possible.

The past quarter-century of astronomy has been marked by ultra-deep imaging, whereby we are able to catch sight of extremely distant galaxies. The more distant a galaxy, the earlier we see it in the history of the universe, stretching back 13.7 billion years to the Big Bang. Hence, only the deepest images are able to capture the first galaxies.



A slice of the COSMOS survey seen in near-infrared light - Image credit: H.J. McCracken/ULtraVISTA Survey
Once we find them, we only have a set of coordinates in hand. In order to start to understand what kind of galaxy we are looking at, we must measure its light.

Traditionally, the brightness of galaxies is computed by adding up all of the light within some fixed boundary. The exact definition of this boundary has been the subject of study for decades, with different definitions providing different results.

However, our understanding of the shapes of galaxies has advanced significantly. Galaxies can be round or oblique, and can have different orientations. The important detail is that their shapes are *not random*.

This realization has prompted a revolution in how we measure the light from galaxies. Instead of using a fixed boundary, we employ a parameterized model. This model is then "fit" to the galaxy in the image by searching for the shape and brightness which together best describe the real galaxy. The brightness can then be robustly measured *without* assuming a fixed boundary.



Our real universe realized as a model - Image credit: J. Weaver/Sabaru Telescope

This is especially important for faint galaxies where they are nearly indistinguishable from random noise. With a model, you are able to cut though the noise and measure the true brightness.

This is the premise behind the next generation of cosmic cartography: to chart the faintest galaxies with robust, model-based techniques. This technique has been realized at DAWN as part of our efforts to pursue the first galaxies.

We are currently applying our custom model-based measurement software, The Farmer, to the prodigious and discipline-leading 2deg² COSMOS survey where we have located and measured over 1 million galaxies. This work is in anticipation for the Cosmic Dawn Survey, which will incorporate imaging from the visible to the radio over 20deg² and will *define the state-of-the-art* for the coming decade.

Photo: Gabriel Brammer, Grundvigskirken **Public Outreach and Awards**

Public Outreach

First Image of a Supermassive Black Hole

By Thomas R. Greve

On April 2019 the Cosmic Dawn Center at DTU Space hosted the Danish Press Conference announcing the ground-breaking discovery by the Event Horizon Telescope (EHT) of the first ever image taken of a supermassive black hole. We were approached by the Director of the Greenland Telescope, and EHT member, Prof. Paul Ho (ASIAA, Taiwan) if we would be interested in arranging a public event in connection with the discovery. Given the significance of the discovery, and the incredible opportunity it presented to highlight the Greenland Telescope in Denmark, we decided to host a press conference.



Image credit: DR and Guarn Nissen, DAWN

The press conference took place at 3pm, on April 10th 2019, and was synchronized with similar live announcements at several major research organizations in Europe, the US and Asia. The press conference was attended in person by several guests of honor. This included Prof. Paul Ho, who is a co-discoverer. The Taiwanese Ambassador to Denmark, Representative Frank Lee was also present, and highlighted the importance of Danish-Taiwanese collaboration on the Greenland Telescope. Members from all the major news outlets in Denmark were also present, as were a significant section of the astronomical community in Denmark. The entire press conference was streamed live on Youtube and on Facebook, and got significant mention in the press (TV, radio, newspaper, and online media) in days after the event. On Twitter, the event was mentioned by the American Embassy in Copenhagen. Judged on the massive interests from national media and the public, the

DAWN press conference on the EHT results was one of the most highlighted and successful scientific public outreach events in Denmark in recent years.



Undoubtedly, the discovery and the press conference hosted by DAWN at DTU Space created a huge and long-lived increase in the public's interest in black holes and astronomy in general. In the months after the event, several DAWN members have given public talks as well as interviews on the supermassive black holes lurking at the centers of galaxies.

TV, Radio & Social Media

DR interview with Professor Johan Fynbo regarding "Banebrydende Rum-Opdagelser fra 2010'erne".

Radio 24/7 interview with Professor Johan Fynbo regarding the Nobel Prize in Physics 2019.

Carlsberg Film "Almost Human" and outreach initiative "Stay Curious" with Professor Johan Fynbo.

Carlsberg Films "Stars and Sand Grains" with Senior Researcher Peter Laursen.

Radio 24/7 interview with Senior Researcher Peter Laursen regarding beta Pictoris c.

NRK P1 interview with Senior Researcher Peter Laursen regarding "The autumn night sky".

Tycho Brahe Planetarium video advertisement with Senior Researcher Peter Laursen regarding the Planetarium's 30th birthday.

TED Talk on galaxies at a private birthday party with Senior Researcher Peter Laursen.

Weekend Avisen interview with Professor Thomas Greve regarding the first image of a supermassive black hole, "Hullets Hukommelse", July 2019

Radio 24/7, Go' Morgen P3, and and P1 interviews with Professor Thomas Greve regarding the first image of a supermassive black hole, "Hullets Hukommelse", April 2019

DR1 and TV2 live interviews with Professor Thomas Greve regarding the first image of a supermassive black hole, "Hullets Hukommelse", April 2019

ATS Politiken, "Det Sorte Hul er en Kosmisk Donut", Interview with Thomas Greve

Articles and Features

Videnskab.dk interview with Senior Researcher Peter Laursen regarding "Past Collision of the Milky Way with Smaller Galaxy" (article appearing in Nature, Helmi et al. 2018).

Videnskab.dk interview with Senior Researcher Peter Laursen regarding "Hvor Mange Stjerner Findes Der?"

ABC Nyheter interview with Senior Researcher Peter Laursen regarding Flat Earth Conspiracists.

Open observatory at the WKO observatory in Tisvilde - Showing the night sky to the public with Professor Johan Fynbo.

Astrobites – Astronomy Publication Digest - web article "QUESTing for an answer: Elucidating the Role of Gas in Star-formation" by PhD Student John Weaver.

Astrobites – Astronomy Publication Digest - web article "Deciphering Spitzer's Legacy: Signs of Dead Galaxies at Cosmic Dawn" by PhD Student John Weaver.

Astrobites – Astronomy Publication Digest-Web article "Plenty of Gas Left in Giant Dead Disk Galaxies" by PhD Student John Weaver.

Talks and Presentations

Virum Kirke	10 January 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Fredericia Gymnasium og Folkeuniversitet Lillebælt	16 January 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Folkeuniversitet Emdrup	28 January 2019	Universets Gåder	Johan Fynbo
Humlebæk Kirke	6 February 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Mosede Kirke i Greve	7 February 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo

Gymnasieklasse hos NBI	4 March 2019	Galaksedannelse	Johan Fynbo
Ringsted Kirke	13 March 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Dyssegård bibliotek	20 March 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
NBI	26 March 2019	Foredrag om galakser	Johan Fynbo
Nødebo præstegård	7 May 2019	Samtale mellem Hans Fynbo, Niels Henrik Gregersen og Johan Fynbo om Videnskab og Tro	Johan Fynbo
Sions Kirke	22 May 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Tisvilde	4 June 2019	Samtale med en gruppe lægerom kosmologien	Johan Fynbo
Sognegården i Kgs. Lyngby	28 June 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Herning	21 September 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Rødding højskole	8 October 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Davinde Kirke	27 October 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
AOF Nordsjælland	30 October 2019	Gammaglimt	Johan Fynbo
Hørning Kirke	4 November 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Ringe sognegård (Midtfyn)	6 November 2019	"Hvad er et menneske?" I naturvidenskabens perspektiv	Johan Fynbo
Brorfelde observatorium	13 November 2019	Astronomiens udvikling i 19-tallet	Johan Fynbo
Sorgenfri Kirke	27 November 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
Løgumkloster - foredrag for præsternes Emeritiforening	9 December 2019	Astronomiens Verdensbillede og Videnskab og Tro	Johan Fynbo
AOF Nordsjælland	11 December 2019	De fjerneste objekter i Universet	Johan Fynbo
Athena School for highly gifted children	23 September 2019	Cosmology	Peter Laursen
Det Fri Gymnasium, Copenhagen	25 september 2019	Cosmology	Peter Laursen

Viborg Gymnasium at NBI	7 February 2019	Hvorfor er det Mørkt om Natten?	Peter Jakobsen
Sukkertoppen Gymnasium	19 March 2019	Hvorfor er det Mørkt om Natten?	Peter Jakobsen
Folkeuniversitetet	10 October 2019	Lecture "Cosmic Dawn"	Sune Toft
Copenhagen Planetarium's 30th birthday	1 November 2019	About my research	Peter Laursen
High schools visiting DAWN	22 November 2019	Galaxies	Peter Laursen
Scientific talk in Stockholm	13 June 2019	Lyα cooling radiation at Nordita Zoom-in-and-out workshop	Peter Laursen
Scientific talk at DAWN Summit	11 July 2019	Lyman	Peter Laursen
Scientific talk in London	31 October 2019	UCL Seminar	Peter Laursen
Public Lecture, Seattle Astronomical Society	16 October 2019	Puzzles in Galaxy Evolution	Charles Steinhardt
NOVA - Nordsjællands Astronomiforening	30 September 2019	Stjernedannelse i galakser	Isabella Cortzen
Astronomy on Tap! - short talk	8 February 2019	Mapping Cosmic Collisions	John Weaver
Forskningens Døgn, Brorfelde Observatorium	29 April 2019	Universet set fra Hawaii	Thomas R. Greve
Forskningens Døgn, Brorfelde Observatorium	26 April 2019	Universet set fra Hawaii	Thomas R. Greve
IDA	27 May 2019	Sorte Huller . en utrolig rejse i rum og tid	Thomas R. Greve
Tycho Brahe Planetariet	21 November 2019	ScienceSlam	Thomas R. Greve

Awards

Best outreach/research dissemination 2019" on ForskerZonen	Peter Laursen
Transnational Access Programme, RadioNet visit support at IRAM Grenoble	Isabella Cortzen



Image credit: Guarn Nissen, DAWN

Press Releases

30 September 2019 - "Record breaking observations find most remote protocluster of galaxies, linking dark matter to galaxy formation"

Record breaking observations find most remote protocluster of galaxies, linking dark matter to galaxy formation

FIRST GALAXIES: An international team of astronomers with participation by researchers from DAWN, Niels Bohr Institute, University of Copenhagen has discovered a protocluster of galaxies 13.0 billion light years away using the Subaru, Keck, and Gemini Telescopes in Hawaii. A protocluster is a structure of galaxies still in the process of forming a cluster. This protocluster is the most distant protocluster ever found. The discovery suggests that a large structure such as a protocluster already existed at a time when the universe was only about 800 million years old or 6 percent of its present age. Finding a protocluster this far away makes finding the needle in the haystack seem an easy task, but more importantly, it holds important information on the history of the Universe. The result is now published in Astrophysical Journals



DAWN Director **Sune Toft** and DAWN Postdoc **Seiji Fujimoto** are part of the international team of astronomers that participated in this discovery, which was covered by the University of Copenhagen, the Niels Bohr Institute (NBI), the National Astronomical Observatory of Japan (NAOJ) and more. You can find the NBI press release here:

https://www.nbi.ku.dk/english/news/ news19/record-breakingobservations-find-most-remoteprotocluster-of-galaxies-linking-darkmatter-to-galaxy-formation/

23 October 2019 - "Discovery of the origin of heavy elements"

eso1917 - Science Release

First Identification of a Heavy Element Born from Neutron Star Collision



Newly created strontium, an element used in fireworks, detected in space for the first time following observations with ESO telescope 23 October 2019



For the first time, a freshly made heavy element, strontium, has been detected in space, in the aftermath of a merger of two neutron stars. This finding was observed by ESO's X-shooter spectrograph on the Very Large Telescope (VLT) and is published today in Nature. The detection confirms that the heavier elements in the Universe can form in neutron star mergers, providing a missing piece of the puzzle of chemical element formation.

In 2017, following the detection of gravitational waves passing the Earth, ESD pointed its telescopes in Chile, including the VLT, to the source: a neutron star merger named GW170817. Astronomers asspected that, if heavier elements did form in neutron star collisions, signatures of those elements could be detected in islonowse, the explosive aftermath of these mergers. This is what a team of European researchers has now done, using data from the X-shocler instrument on ESO's VLT. DAWN Researcher **Darach Watson** lead the team that identified a heavy element born from a neutron star collision for the first time. The paper was published in Nature and was covered, among others, by the European Southern Observatory (ESO) in the following press release:

https://www.eso.org/public/ unitedkingdom/news/eso1917/

11-13 December 2019 - "Discovery of the most distant dusty star forming galaxy"

PhD Student **Sinclaire Manning**, from UT Austin and visitor at DAWN for five months, was part of the team that discovered the most distant dusty star forming galaxy without using gravitational lenses. The discovery was covered by multiple sources, such as a press release in Danish by the University of Copenhagen – Niels Bohr Institute – that can be found here:

https://www.nbi.ku.dk/Nyheder/nyheder_2019/astronomer-opdager-fjern-kaempe-galakseder-stammer-fra-universets-babystadie/

A press release by the ALMA Observatory:

https://www.almaobservatory.org/en/press-release/alma-spots-most-distant-dusty-galaxyhidden-in-plain-sight/

Another DAWN member, **Georgios Magdis**, also contributed to the article published in Astrophysical Journal about the discovery. He spoke about it to DTU Space: <u>https://www.space.dtu.dk/english/news/Nyhed?</u> id=%7B8D6DB06E-4EA4-4E40-98DC-2D62434B8BB2%7D

Astronomer opdager fjern kæmpegalakse, der stammer fra universets babystadie

KÆMPE-GALAKSE Forskere har fået øje på en stor, støvet og ekstremt stjernedannende galakse 13 milliarder lysår væk, og det gør den til den fjerneste galakse af denne type, man til dato har kunnet måle afstanden til. Mambo-9, som galaksen hedder, er opdaget med ALMA-teleskopet i et samarbejde mellem en række internationale universiteter og Københavns Universitet og DTU



11 December, 2019

Plain Sight



Astronomers using the Atacama Large Millimeter/submillimeter Array (ALMA) have spotted the light of a massive galaxy seen only 970 million years after the Big Bang. This galaxy, called MAMBO-9, is the most distant dusty star-forming galaxy that has ever been observed without the helo of a gravitational lens.

Astrophysics

TUESDAY 17 DEC 19-1

Researchers have spotted that an enormous galaxy grew very big surprisingly fast after Big Bang. This has been discovered using the ALMA telescope in an international collaboration with contributions from DTU Space and the University of Copenhagen.

An international team of researchers has discovered that a giant galaxy composed of a large number of stars, gases and stardust must have grown surprinsingly quick.

At 13 billion light years away, it is the most distant dusty star-forming galaxy ever to have been seen directly. It also means that the galaxy called mambo-9 it was formed relatively short time after the Big Bang occurred some 13.8 billion years ago. The research results are now published in Astrophysical Journal.

That we have been able to observe this type of galaxy, so near the Big Bang, is a fantastic achievement. We are surprised that a 13 billion-year-old galaxy is so large and massive so shortly after the Big Bang. We wonder how a galaxy could whysicist Georgios Magdis, an

t published in Astrophysical Journal.

he Niels Bohr Institute at the

16 December 2019 - "Carbon cocoons surround growing galaxies far beyond previous beliefs, says new study from the Niels Bohr Institute"

Carbon cocoons surround growing galaxies far beyond previous beliefs, says new study from the Niels Bohr Institute

ASTROPHYSICS: Researchers have discovered gigantic clouds of gaseous carbon spanning more than a radius of 30,000 light-years around young galaxies using the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. This is the first confirmation that carbon atoms produced inside of stars in the early Universe have spread beyond galaxies. No theoretical studies have predicted such huge carbon cocoons around growing galaxies, which raises questions about our current understanding of cosmic evolution. The result was obtained by Seiii Fujimoto and his colleagues, rather unconventionally, by examining data from former observations. He is currently employed at The Cosmic Dawn Center at the Niels Bohr Institute, University of Copenhagen. The study is now published in Astrophysical Journal.



DAWN Postdoc Seiji Fujimoto lead the discovery of gigantic clouds of gaseous carbon surrounding galaxies far beyond previous beliefs. The Niels Bohr Institute did the following press release: https://www.nbi.ku.dk/english/news/news19/carboncocoons-surround-growing-galaxies-far-beyond-previousbeliefs/

NHK World-Japan News covered the discovery and the live press release that took place in Japan on December 2019. You can find it here: https:// www3.nhk.or.jp/nhkworld/en/news/20191216 34/



18 December 2019 - "The cores of massive galaxies found to have formed a billion years earlier than previously thought"

The 'Cores' Of Massive Galaxies Found To Have Formed A Billion Years Earlier Than Previously Thought

Posted December 18, 2019



massive than our Milky Way --- with more than a trillion stars - has revealed that the 'cores' of massive galaxies in the universe had already formed 1.5 billion years after the Big Bang, about 1 billion years earlier than previous measurements revealed.

A blow-up of a small portion of the Sub Newton Deep Field. The red galaxy at the center is a dying galaxy at 12 billion years ago. Astronomers measured the motion of stars in the galaxy and found that the core of the galaxy is nearly fully formed.

Researchers published their analysis in the November 6 issue of The Astrophysical Journal Letters, a journal of the American Astronomical Society

"If we point a telescope to the sky and take a deep image, we can see so many galaxies out there said Masayuki Tanaka, lead author and associate

professor of astronomical science in the Graduate University for Advanced Studies and the National Astronomical Observatory of Japan. *But our understanding of how these galaxies form and grow is still quite limited - especially when it comes to massive galaxies."

Galaxies are broadly categorized as dead or alive: dead galaxies are no longer forming stars, while living galaxies are still bright with star formation activity.

A 'quenching' galaxy is one that is in the process of dying - meaning its star formation is significantly suppressed. Quenching galaxies are not as bright as fully alive galaxies, but they're not as dark as dead galaxies. Researchers use this spectrum of brightness as the first line of identification when observing the universe

DAWN Assistant Profesor Francesco Valentino co-led this discovery, with participation of other DAWN members such as Sune Toft and Georgios Magdis, which was made with the help of the telescopes at W. M. Keck Observatory on Maunakea in Hawaii. The Keck Observatory released the following news coverage of the discovery:

http://www.keckobservatory.org/ galaxy-cores/



the survey of the property.



Conferences, DAWN Summit and Summer Programs

Conferences

Organization of International Conferences, Symposia, Seminars etc.

BUFFALO Collaboration Meeting: (Nevada, USA, February 2019) Principal Organizer, Charles Steinhardt

Cosmic Dawn Summit: (Copenhagen, Denmark, July 2019) Organizer, Cosmic DAWN Center

Royal Astronomical Society Meeting:"Neutron star and black hole binary mergers: The first results of the LIGO-Virgo era" (London UK, May 2019) Principal Organizer, Darach Watson.

International conference: "The Art of Measuring Galaxy Physical Properties" (Milan, Italy, 18-22/11/2019) Principal Organizer, I. Davidzon

JWST Mini-Workshop at DTU: "JWST Instruments and General Tools" (Copenhagen DK, November 2019) Principal Organizers, Hans Ulrik Nørgaard and Luis Colina

Attended Events

Event	Place	Atendee
The Interstellar medium of high redshift galaxies	Sesto, Bolzano, Italy	Kimihiko Nakajima
Colloquium, Puzzles in Galaxy Evolution	University of Washington	Charles Steinhardt
Joint Colloquium, Puzzles in Galaxy Evolution	University of Virginia/NRAO	Charles Steinhardt
Invited Talk, Puzzles in Galaxy Evolution	Harvard University	Charles Steinhardt
Invited Talk, Thermal Regulation of Star Formation	University of Chicago	Charles Steinhardt
Invited Talk, Puzzles in Galaxy Evolution	University of Texas	Charles Steinhardt
Invited Talk, Lyman α — a window to the distant Universe	University College London	Peter Laursen
Quasars in Crisis	Edinburgh, UK	John Weaver
COSMOS Team meeting	NYC, USA	John Weaver
Astronomy Lunch Seminar	University of St Andrews, UK	John Weaver
Tea Talk, Exploring the Origins of Post- Starburst Galaxies at z<0.1	CalTech, USA	John Weaver
FREDDIE Talk, Exploring the Origins of Post-Starburst Galaxies at z<0.1	Institute for Astronomy, Hawaii, USA	John Weaver
The growth of galaxies in the Early Universe - VI	Sesto, Bolzano, Italy	Gabriel Brammer, lary Davidzon
Seminar on Machine Learning in Astrophysics	European Southern Observatory (Garching, Germany)	lary Davidzon
COSMOS Meeting; Talk titel: In Search of Molecular Hydrogen, Constraining the Gas Content of Star-forming Galaxies	Flatiron Institute, New York	Vasily Kokorev
Art of Measuring Galaxy Properties	INAF, Milan	Vasily Kokorev

Buffalo Survey Meeting; Talk titel: In Search of Molecular Hydrogen	University of Nevada Las Vegas, Las Vegas	Vasily Kokorev
Views on the Interstellar Medium in galaxies in the ALMA era	Giorgio Prodi lecture hall, Bologna (Italy)	Isabella Cortzen
North Exliptic Pole Meeting	Taipei, Taiwan	Sune Toft
Subaru Users Meeting	NAOJ, Tokyo, Japan	Sune Toft
Subaru 20th Aniversery meeting	Hawaii, USA	Sune Toft
Cosmos Meeting	Flatiron Institute (CCA), New York City	Sune Toft
NBIA Colloquiem	Niels Bohr International Academy	Sune Toft
The nature of the most extreme starburst galaxies in the Universe Formation of Stars and Massive Clusters in	Loerentz Centr, Leiden, Netherlands	Georgios Magdis
the Early Universe	Lorentz Center, Leiden, Nederlands	Daniel Ceverino
IAU Symposium 352	Oporto, Portugal	Daniel Ceverino
Feedback workshop	Spetses, Greece	Daniel Ceverino
Invited Talk, New Frontiers for Cosmological Simulations: interpreting observations across cosmic timeNew Frontiers for Cosmological Simulations: interpreting observations across cosmic time	Oscar Klein Institute, Stockholm Universiity	Thomas R. Greve
Invited Talk, The Greenland Telescope	DTU Arctic	Thomas R. Greve
Invited Talk, Dense gas tracers and C- isotopes in strongly lensed starburst galaxies	Sesto, Bolzano, Italy	Thomas R. Greve
Invited Talk, Star formation across the Universe	University of Hertfordshire	Thomas R. Greve
Invited Talk, Down the Dusty Road Gems from Large (sub-)millimetre Surveys	Cambridge Unversity, IoA	Thomas R. Greve

DAWN Summit

DAWN Summit 2019 took place during the week of July 8-12. This is the time of year when the international DAWN family gathers in Copenhagen for scientific discussion, planning and fun social activities. Some of our associates came for extended periods over the summer, some came for the week, and a few called in via video conferencing. The meeting had sessions in both of DAWNs institutes (NBI and DTU-Space) and also in the common area of the researcher apartment complex in the Carlsberg district, where several DAWN team members live.

During the first two days there were sessions dedicated to discussing progress in each of DAWNs science themes, with reviews of the most important advances of the fields of the past year, and contributed talk from DAWN students, postdocs and faculty. There were also session dedicated to novel methods, new initiatives and "crazy ideas", and a fascinating talk by Peter Jakobsen about the work and intriguing life of Tycho Brahe. The latter served as an introduction to a full day outing to the island of Hven the following day, where we visited the Tycho Brahe observatory and museum, biked around the island and had dinner and optional whiskey tasting at the Spirit of Hven. This was a great event including everyone in the center, also the Summer students. The last two days of the meeting were dedicated to discussions of organization, branding, outreach, social media and planning of future events.



Image credit: Guarn Nissen

DAWN-IRES



Image credit: Kate Whitaker

The DAWN-IRES Scholars Program is primarily designed to enhance the progress of science through a unique global educational training experience for a diverse cohort of US students. The themes defining the broader impact of the program include *diversity*, *training*, *dissemination*, and *community*. The program incorporates a wide range of professional development activities that are focused on advancing scientific communication skills (e.g., weekly seminars, hack days, oral presentations abroad and stateside). The students will also build professional research toolkits, including learning programming, data analysis and presentation techniques.

Dissemination of research will occur through the DAWN-IRES Scholars Symposium at the end of each summer in Copenhagen, together with a presentation at the students' local institutions and the national American Astronomical Society meeting.

SURF @ Cosmic DAWN Center

The Cosmic Dawn Center runs an undergraduate summer research program in conjunction with major international universities. Between this and predecessor programs run by Charles Steinhardt, to date students have been responsible for 11 papers, over 1300 citations (over 500 with students as first author), and top undergraduate research awards from the American Astronomical Society and Caltech. Students are funded through a partnership between DAWN, private donors, and Universities which have included Caltech, Princeton, Harvard, MIT, Riverside, Minnesota, and Connecticut.

Students do research in Denmark with DAWN mentors for 11 weeks, one of which is devoted to a vacation in order to see other parts of Europe. At the conclusion of the summer, students give talks both in Copenhagen and at their home Universities, and in many cases at major international conferences. Approximately half of student projects result in publications, including an anticipated five from students in the summer of 2019. These include projects central to the core themes of DAWN.

A unique aspect of SURF@DAWN is an eagerness to work with talented but inexperienced students, and three of the five students in 2019 arrived following their first (of four) years as undergraduates. Since the start of DAWN in 2018, seven students have authored their first publication due to this program. In addition, work completed over the summer by three first-year KU students will result in their first publication, a significant result in understanding gamma-ray bursts.

A final goal of the program is to broaden the scientific interests of both our summer students and other DAWN members. SURF@DAWN includes a weekly lecture series by nonastronomers, and last summer topics ranged from the "war" between bacteria and phages to communication on Viking Age longships. Past students are now in graduate programs at Harvard, MIT, Caltech, Stanford, Berkeley, Washington, and the University of Massachusetts, and in 2021 we anticipate receiving our first postdoctoral application from a past summer student.



Guest Speakers and Visitors

Visitors

Visitor	Arrival & Departure	Affiliation	Talk Title
Johannes Staguhn	18/12/2019 - 19/12/2019	The Johns Hopkins University	(Sub)millimeter Observations of Hidden Star Formation and the Formation of Dust Through Cosmic Times
Pratika Dayal	27/11/2019 - 30/11/2019	University of Groningen	Early Galaxy Formation and its Large-scale Effects
Göran Östlin	28/11/2019	University of Stockholm	The Nature of High Redshift Objects
Giacomo Girelli	16/10/2019 - 15/01/2020	Instituto Nazionale di Astrofisica	 The Stellar-to-Halo Mass Relation Over the Last 12 Gyr Massive and Old Quiescent Galaxies at High Redshift
Rachel Bezanson	22/10/2019 - 23/10/2019	University of Pittsburgh	The Formation of Massive Galaxies: Deep, High-Redshift Spectroscopy from the LEGA- C Survey and Beyond
Koki Kakiichi	07/10/2019	University College London	Radiation Hydrodynamics of Turbulence, Jets, and Winds in HII Regions: Implications to Reionisation-Era Galaxies
Vicente Estrada- Carpenter	19/08/2019 - 23/08/2019	Texas A&M University	Stellar Population Properties of Massive Quiescent Galaxies Derived from Deep Hubble Space Telescope Grism Data
Rebecca Bowler	20/08/2019 - 26/08/2019	University of Oxford	Euclid Lyman-Break Galaxy
Kate Gould	19/08/2019 - 23/08/2019	University of St Andrews	Searching for Strongly Lensed Quiescent Galaxies at z>2 in the COSMOS and XMM- LSS Fields
Alkistis Pourtsidou	17/06/2019 - 21/06/2019	Queen Mary University of London	Cosmology with the World's Leading Dark Energy Experiments
Kasper Elm Heintz	06/05/2019	University of Copenhagen	Direct Calibration of the [CI] Luminosity to Molecular Gas Mass from High-z GRB and Quasar Absorbers

Daisey Leung	28/04/2019 - 07/05/2019	Cornell University - Flatiron Institute	The Interstellar Medium of High Redshift Galaxies
Roderik Overzier	03/04/2019 - 04/04/2019	Observatório Nacional do Rio de Janeiro	The Shining Rise of Clusters, Galaxies and Black Holes
Chris Flynn	25/02/2019 - 26/02/2019	Swinburne University of Technology	Finding the Host Galaxies of Fast Radio Bursts with UTMOST
Andreas Faisst	20/02/2019 - 28/02/2019	California Institute of Technology (Caltech)	Galaxies in the Early Universe: The View from the Newest Observations with Spitzer, ALMA, and HST
Emil (Thøger) Rivera-Thorsen	04/02/2019 - 07/02/2019	University of Oslo	Neutral Gas Kinematics and its Influence on the Escape of Lyman Radiation
Raphael Gobat	28/01/2019 - 30/01/2019	Pontificia Universidad Católica de Valparaíso	 The shape of intracluster Gas at High Redshift: Toward Constraining the Pressure Profile of Early Galaxy Clusters The Habitability of Galaxies Through Time
Asger Grønnow	07/01/2019 - 09/01/2019	University of Sidney	Magnetised Clouds in the Galactic Corona: Fuel for Future Star Formation?
David Sanders	23/01/2019 - 25/01/2019	Institute for Astronomy, University of Hawaii)	Hawaii Two-0: The Evolution of Massive Galaxies at 3 < z < 7

Guest Researchers

Collaborator	Arrival	Departure	Affiliation
Yoshinobu Fudamoto	25/02/2019	29/02/2019	Observatoire de Geneve
Pascal Oesch	25/02/2019	29/02/2019	Observatoire de Geneve
Daniel Perley	19/06/2019	22/06/2019	Liverpool John Moores University
Rebecca Bowler	23/09/2019	27/09/2019	University of Oxford
Gael Noirot	04/11/2019	22/11/2019	Saint Mary's University, Canada
Pablo Pérez-González	26/11/2019	29/11/2019	Universidad Complutense de Madrid

PhD Censors

Carlos Gómez Guijarro successfully defended his PhD on May 9th 2019. **David Elbaz**, from CEA Saclay, and **Natascha M. Förster Schreiber**, from the Max-Planck-Institut für extraterrestrische Physik, censored his thesis entitled "Connecting the Extremes – High-Redshift Progenitors of Massive Galaxies"



From left to right: Sune Toft (main supervisor), David Elbaz (censor), Carlos Gómez Guijarro and Georgios Magdis (co-supervisor). Image credit: Guarn Nissen.

On October 23rd 2019, **Mikkel Stockmann** successfully defended his PhD. His thesis, "Genesis of Giants – Massive Galaxy Evolution Over the Past 10 Billion Years" was censored by **Rachel Bezanson**, from the University of Pittsburgh, and **Olivier Ilbert**, from Laboratoire d'Astrophysique de Marseille.



From left to right: Olivier Ilbert (censor), Rachel Bezanson (censor), Mikkel Stockmann and Sune Toft (supervisor). Image credit: Clara Giménez Arteaga















The Organization

Housing of the Center

According to the NBI management, the best estimate of the move in date in the Niels Bohr Building (NBB) is January 2021 at the earliest. DAWN will most likely move into the part of NBB on the north side of Jagtvej that consist only of office spaces. This part of the building is finished and in principle ready to move into. However, as the main part of the NBB on the south side of Jagtvei with all the labs is still under construction, the University will not accept the building, and we are not able to move in yet. The Niels Bohr Institute part of DAWN is thus still in temporary housing at the Vibenshus office hotel. This building is overall a nice facility, but there are several challenges. The most important are that the center is broken up into three pieces (on the same floor) and that most of the team is working in a large open plan office which is not optimal for academic work. Three offices have been allocated to DAWN at DTU Space. They currently hold Assoc Prof. Georgios Magdis and Assoc. Prof. Thomas Greve, with one office being used for external visitors. In August 2020, two new DAWN-funded PhD students are expected to start at DTU Space, and they will be placed in the office that is currently being used for visitors. By that time, we would like DTU Space to provide a fourth office that can be used for visitors and DAWN-NBI people. A DAWN postdoc will also start at DTU this August, who needs at least 1/3 of an office (6m²). The three offices currently allocated to DAWN at DTU are next to each other as stated in the DG contract - but are placed far away from the offices of Prof. Lars Buchhave or indeed the offices of other astronomers at DTU. As part of an upcoming office shuffle at DTU Space we would like DAWN-DTU people to be located close to other astronomers at DTU Space.

Status of the Hiring Plan

The independent DAWN postdoctoral fellowship program continues to be competitive with the major international fellowships in astronomy. We advertise every year in the late fall and make offers with a deadline for acceptance in February. We consistently receive 80-100 applications from around the world. In 2019 we hired two new fellows, Seiji Fujimoto, a recent graduate from the University of Tokyo, and Iary Davidzon, an experienced postdoc from Caltech.

Our strategy of investing in supporting independent fellows has so far been successful. With a prestigious named fellowship, DAWN is competitive for the strongest, most independent international young scientists who can bring new ideas and projects to the center. The high profile of the fellows makes them good candidates for winning their own independent fellowship and young group leader grants. As a testament to the high quality of the fellows we have been able to attract with our program, our first DAWN fellow, Francesco Valentino in 2019 won a Carlsberg fellowship to continue his own independent research program at DAWN. The two fellows that were hired in 2018 have already moved on to tenure track positions in their home countries. Daniel Ceverino at Universidad Autonoma de Madrid, and Kimihiko Nakajima at the National Astronomical Observatory of Japan.

Due to a delay from the University of Copenhagen HR department in advertising our PhD fellowship program, we were not able to be competitive for the best international PhD candidates in 2019, and ended up postponing hiring the second generation of DAWN PhD students to 2020. The pool from this year looks excellent and we expect to start at 3-4 new students in the fall.

The embedment associate professor position at DTU-Space was filled on 1/9/2019 by Georgios Magdis, following a broad internationally advertised call. The embedment associate professor position at NBI has been advertised and applicants have been assessed. Currently we are hoping interviews will take place in the summer of 2020 and that the position will be filled later in the year.

Recruitment and Gender Strategy

As outlined in last year's annual report, DAWN continues to focus its recruitment internationally to maximize access to the best talent worldwide. For this reason, we time our hiring cycle with the international PhD and postdoc recruitment calendar, and focus on hiring outstanding, independent fellows with a broad range of diverse backgrounds to our flagship DAWN fellowship. In 2019 our first fellowship offer was made to an excellent Dutch female candidate. She accepted initially, but later had to decline because her partner was offered a tenure track position elsewhere. Our other offer went to Seiji Fujimoto, an amazing young Japanese postdoc. We did not hire any new PhD students in 2019. We had two long term PhD student visitors, one male and one female. Diversity is important to us, and our drive to increase the diversity of DAWN is apparent in our 2019 Center photograph.

Research Integrity

We reiterate here our commitment to the highest levels of research integrity as outlined in last year's annual report. We add here our continued commitment to open access to our research products via <u>arXiv.org</u> and/or primarily delayed open access journals and the use of public data repositories.

We also take the opportunity to comment on some of the most important aspects of research integrity not highlighted in most codes of ethics. At DAWN we feel a strong sense of social responsibility, and care for each other is a central tenet of our ethos. We refuse to be a part of a trend that exploits people on short-term contracts and then discards them after many years of service. We therefore work with senior postdocs and scientific/technical staff on fixed term contracts in two ways, first to develop their skills portfolio with a view to future careers outside of a strict academic research environment, and second, until they find such careers, they fill important scientific support roles at DAWN if such are available. This is winwin, as we get extremely expert individuals with a strong scientific background and a deep commitment and understanding of the work. We regard this as an important aspect of building a trusted, caring, and supportive environment, vital for any successful research team. This environment encourages freedom of thought and creative new ideas and is incredibly powerful in the race to attract the most gifted and dedicated researchers.



Image credit: Guarn Nissen

Meet the COSMIC DAWN TEAM

Sune Toft | Center Director



I am a professor of Cosmology and Extragalactic Astrophysics at the Niels Bohr Institute. I received my BSc (1998), MSc (2000) and PhD (2003) degrees from the Niels Bohr Institute (NBI), under supervision of Jens Hjorth.

I spent 5 years abroad as a postdoctoral research associate at Yale University (with Pieter van Dokkum) and an independent ESO fellow at the European Southern Observatory headquarters in Germany. Since 2009 I have led a research group at NBI, funded by a Lundbeck Junior Group Leader fellowship (2009-2014) an ERC consolidator grant (2015-2020), and

a DNRF center of excellence grant (2018-2024). My research focuses on understanding the cosmic origin and evolution of galaxies, primarily through observations with the largest ground and space-based observatories. I am part of several major international research teams, including COSMOS (member of the Scientific Steering Committee), Euclid (Co-lead of the Primeval Universe Working Group), Ultravista (core-member), Hawaii-Two-0 (CoI), Euclid/WFIRST Spitzer Legacy Survey (CoI), BUFFALO (CoI), RELICS (CoI), ALPINE (CoI). Since 2009 I have taught the undergraduate course "Cosmology", and supervised postdoc and student research projects on all levels (BSc, MSc, PhD).

Thomas Greve | Center Co-Director



I am an Associate Professor at the National Space Institute of Denmark, (DTU Space) where I am heading the Cosmic Dawn Center. I obtained my PhD in 2005 from the Institute for Astronomy Edinburgh. I am currently on leave of absence from University College London where I have been an associate professor since 2012. Prior to that I have held research positions at the California Institute of Technology and the Max-Planck Institute for Astronomy.

My research deals with the origin and evolution of massive galaxies. I study them using radio and optical telescopes on the ground and in space. Interfacing with numerical simulations is an important part of this work. I enjoy teaching, supervising students, as well as public outreach.

I am extremely proud and excited to have established the Cosmic Dawn Center together with an amazing group of colleagues and friends. What started out as a dream is now an actual research center brimming with fantastic scientists, administrators, and students.

Guarn Elizabeth Nissen | Senior Coordinator



With focus on creating and maintaining a scientific and social environment that encourages innovative thinking and well-being, I enjoy witnessing scientific discoveries. Providing administrative guidance and support to enable and enhance groundbreaking scientific research for DAWN and our collaborating partners is truly exciting to me.

I received my Bachelor of Science degree from Fontbonne University in St. Louis MO. I have held the positions of Marketing Coordinator at Novo Nordisk A/S and Administrative Coordinator at the Genotoxic Stress Center

of Excellence (GSC), located at the Danish Cancer Society and under the leadership of Professors Jiri Lukas and Jiri Bartek. Like DAWN, GSC received major funding from the Danish National Research Foundation (DNRF).

Johan Peter Uldall Fynbo | Head of Section



I am an astronomy professor based at the Cosmic Dawn Center at the Niels Bohr Institute. I received my Master's degree in 1998 and PhD degree in 2000 from the University of Aarhus advised by Bjarne Thomsen and Palle Møller. Before taking up my current position at the Niels Bohr Institute I worked at the European Southern Observatory headquarters in Germany. My research focuses on the assembly and evolution of galaxies across the history of the Universe, through direct observation with optical and infrared telescopes from both space and the ground. My particular interests are chemical evolution, quasar absorption line systems, and

transient sources like gamma-ray bursts, supernovae, gravitational wave sources and fast radio bursts. I am also involved in the development of new instrumentation.

I teach a range of courses in astronomy ranging from introductory astronomy courses to master level courses. In collaboration with colleagues from the University of Aarhus, I also teach a summer course in astronomical observations at the Nordic Optical Observatory on La Palma.

Beyond academia, I am a frequent contributor to public outreach, I am board member of the Danish Astronomical Society and I give many public talks on science.

Dorte Garde Nielsen | Secretary



I provide administrative assistance to DAWN; I enjoy making sure that everything runs smoothly, and that the day-to-day tasks are handled efficiently and with the highest standard of work.

I enjoy witnessing scientific talks and being around enthusiastic people and part of the team.

I am a trained office assistant and have a Bachelor of Arts degree in English from University of Copenhagen. I have more than 10 years of experience providing administrative support to colleagues from previous positions in Danish companies.

Charles Steinhardt | Associate Professor



I am an associate professor at the Cosmic Dawn Center working on several topics in galaxy evolution and related problems in computer science. I am currently PI of the BUFFALO HST survey, a large program awarded in Cycle 25 expanding Hubble coverage of the Frontier Fields. I have also recently been exploring the tension between observations of high-redshift luminous galaxies and theoretical predictions of galactic assembly and developing models for cosmic raydominated evolution. In addition, I develop novel machine learning and astrostatistical methods for working with large datasets.

Previously, I was a postdoc at Caltech working with Peter Capak and Kavli IPMU working with John Silverman, after getting my PhD from Harvard with Martin Elvis.

Darach Jafar Watson | Associate Professor



I am an associate professor based at the Cosmic Dawn Center at the Niels Bohr Institute. I received my PhD degree in 2000 from the UCD in Dublin advised by professor Brian McBreen. Before moving to the Niels Bohr Institute, I worked at the University of Leicester as a post.doc. My research interest span a broad range of topics from interstellar dust, gamma-ray bursts, the first galaxies, and sources of gravitational waves. I am mainly observationally oriented and have of the course of my career applied a wide range of techniques and wavelengths ranging from X-rays (using satellites) to the infrared (using ALMA).

I teach a range of courses in physics and astronomy ranging from experimental quantum mechanics to observational astrophysics. I have supervised a large number of students at all levels from BSc to PhDs. I am also a keen advocate for increased diversity in academia and have published several papers, including in Nature, on this issue.

Georgios Magdis | Associate Professor



I am an Associate Professor of astrophysics at National Space Institute of Denmark (DTU Space) and NBI/KU, a core member of the Cosmic DAWN Center of Excellence, and serve as a chair for the Cosmic DAWN postdoctoral Fellowships. I received my DPhil in astrophysics from the University of Oxford and I have been a post-doctoral researcher at CEA/ Saclay, a Research Fellow at the University of Oxford, and a DARK/ Carlsberg Fellow and Assistant Professor at the DARK Cosmology Center, NBI/KU (2015-2018).

As of 2016 I am also the leader of the ISM/Galaxy-Evolution group, funded by a research grant (*Gas to stars, stars to dust – Tracing the evolution of*

star formation activity across Cosmic time) that I was awarded by the Velux Foundation. My group and I, focus on the study of distant galaxies aiming to shed light on their formation, their growth (mass build-up), and evolution of their interstellar medium throughout cosmic time. For my research, I use multi-wavelength datasets and I specialise in infrared/submm/ radio space as well as ground-based observations.

Gabriel Brammer | Associate Professor



I am an Associate Professor at the Cosmic Dawn Center. I received my PhD degree from Yale University in 2010, and prior to coming to DAWN I was a postdoctoral Fellow at the European Southern Observatory (Chile) then an ESA/AURA Astronomer at the Space Telescope Science Institute in Baltimore, Maryland (USA).

My research involves studying the formation and evolution of galaxies across much of cosmic time, from relatively nearby massive, evolved objects to infant galaxies at the current limit of the observable Universe. I discover and characterize these objects by and exploiting large imaging and spectroscopic surveys with the *Hubble Space*

Telescope, and I am helping to develop next-generation projects with the Guaranteed Time Observer and Early Release Science programs on the *James Webb Space Telescope*, due to be launched in 2021.

I also enjoy photography with much smaller glass, including nightsky astrophotography and analog film.

Peter Jakobsen | Affiliated Professor



I received my Masters degree from the University of Copenhagen in 1979 and my PhD from the University of California, Berkeley in 1983. I was with the European Space Agency (ESA) from 1984 to my retirement from ESA at the end of 2011.

While at ESA I served as the Project Scientist for Europe's participation in the Hubble Space Telescope (HST) until 1995. From 1997 to 2011 I held the same position for Europe's contributions to the James Webb Space Telescope (JWST). In the latter capacity I oversaw the design and development of the NIRSpec multi-object spectrograph onboard JWST, an instrument that I am still actively

involved in.

My scientific interests include astronomical space instrumentation, applied statistics, and the physics of the early universe with emphasis on quasar absorption lines and reionization. I also engage in scientific evangelism, and periodically give public lectures at high schools and other venues across Denmark.

Hans Ulrik Nørregaard-Nielsen | Senior Scientist



I received from Masters Degree in July 1976 and my PhD in December 1981 from Copenhagen University Observatory. Since 1999 I have had a senior scientist position at DTU Space.

I have been Principal Investigator for the Planck Reflector Programme and for the JWST MIRI Primary Support Structure. I have been member of the Planck Science Team since 1997 and Chairman of the MIRI High – z Universe Working Group since 2010.

My scientific interest is concentrated on the early phases of the evolution of the Universe, by exploiting the Planck CMB temperature

and polarization data and on the planned MIRI Deep Imaging Survey.

Francesco Valentino | Assistant Professor



I am an assistant professor based at the Cosmic Dawn Center. I study the evolution of massive galaxies from their initial formation to the last stages of their lives, exploiting the capabilities of powerful telescopes covering the whole electromagnetic spectrum. I am particularly interested in how gas is transformed into stars and how galaxies die, ceasing the formation of new stars. This is the core of my "Galaxies: Rise And Death" (GRAD) project supported by the Carlsberg Foundation for the coming years 2019-2021.

I moved to Copenhagen as a DARK fellow at the Dark Cosmology Centre and then I joined the Cosmic Dawn Center as a DAWN fellow, working in close collaboration with Prof. Georgios Magdis on the project "*Gas to Stars - Stars to Dust: Tracing star formation across cosmic time*" supported by a Velux Foundation Grant.

I obtained my PhD in 2016 from the Université Paris Diderot (Paris 7) under the supervision of Dr. Emanuele Daddi at the Commissariat à l'Énergie Atomique (CEA) in Saclay.

Allan Hornstrup | Head of Astrophysics and Atmospheric Physics, DTU-Space



My interests are focused on cosmology, including the large scale structure of the universe; on space instrumentation and space research in general. I also fancy exoplanetary studies, including the search for extraterrestrial life. I enjoy physics, teaching, public outreach and management.

In cosmology, I have studied clusters of galaxies in general (the content) and in particular worked on using clusters of galaxies for cosmological purposes e.g. through the cluster development with time. Since 2007, I have been head of astrophysics at DTU Space and later

included atmospheric physics. The group has grown from about a dozen to now almost 60 scientists and technicians. I hold a MSc in PhD in technical physics and an executive MBA

astrophysics, a PhD in technical physics and an executive MBA.

lary Davidzon | DAWN Fellow



I am a DAWN fellow at the Cosmic Dawn Center, working with Sune Toft and his group on several projects based on ultra-deep extragalactic observations collected under the name of Cosmic Dawn Survey.

My main goal is to leverage this exquisite data in the exploration of the first 2-3 billion years of universe's life, investigating star formation mechanisms in primeval galaxies, especially the most massive ones. I am also interested in the connection of these baryonic processes to the underlying dark matter structure. I study galaxy environment also in

large-scale surveys (VIPERS) and galaxy clusters (BUFFALO).

Before moving to Copenhagen I joined Peter Capak's group at the California Institute of Technology, contributing to introduce novel machine learning methods in the research field of galaxy evolution. Previously I worked in Marseille (France) within the COSMOS collaboration, and before that I was a graduate student in Bologna, where I obtained my PhD in 2014 under the supervision of Micol Bolzonella and Lauro Moscardini.

In the spare time I like playing ukulele and tinkering with my bikes, which is a quite appropriate hobby now that I live in (probably) the best cycling city in the world.

Seiji Fujimoto | DAWN Fellow



I am a DAWN fellow based at the Cosmic Dawn Center at the Niels Bohr Institute. I received my BCs (2014), MSc (2016), and PhD (2019) degrees from the University of Tokyo, under the supervision of Prof. Masami Ouchi. The thesis title was "Demographics of Cold Universe with ALMA: From Inter-stellar and Circum-galactic Media to Cosmic Structures", where I carried out a large statistical study for the restframe far-infrared properties in high-redshift galaxies. After my PhD, I worked at the University of Waseda with Prof. Akio Inoue as an ALMA project researcher. I am living in Copenhagen as of December 2019.

My research interest is the early Universe, including the topics of the formation and evolution of massive galaxies and black holes, the structure formation, and the interplay between a galaxy and its environment. I'm working in international projects of e.g., "The ALMA Large Program to Investigate CII at Early Times (ALPINE)", "ALMA Lensing Cluster Survey (ALCS)", and "Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP)". I also work as one of the external collaborators in the cosmology group in Scuola

Normale Superiore headed by Prof. Andrea Ferrara. You will find more details on my personal website.

Bo Milvang-Jensen | Researcher



I am a researcher based at the Cosmic Dawn Center. I received my master's degree from the University of Copenhagen, having carried out the research for my thesis at the University of Texas at Austin. I received my PhD from the University of Nottingham, where my PhD advisor was Alfonso Aragón-Salamanca. Subsequently, I was a postdoc at the Max Planck Institute for Extraterrestrial Physics in Garching, followed by a number of years at the Dark Cosmology Centre in Copenhagen, and now at DAWN.

I work on observational extragalactic astrophysics, using optical and infrared spectroscopy and imaging (including narrow-band imaging). In particular I have contributed to the EDisCS project studying cluster galaxies, and the UltraVISTA project studying high-redshift galaxies. I also work on gamma-ray bursts, including their host galaxies, and follow-up of gravitational-wave events. Additionally I am instrument scientist for the NTE (NOT Transient Explorer) instrument being designed and built by the Niels Bohr Institute (PI Johan Fynbo).

Nina Bonaventura | Postdoc



I am an astrophysics post-doctoral researcher at the Cosmic Dawn Center working with Dr. Peter Jakobsen on the Near Infrared Spectrograph (NIRSpec) onboard the James Webb Space Telescope (JWST), a joint mission of NASA and the European and Canadian Space Agencies. In preparation for the March 2021 launch of JWST, I design algorithms to optimize observations taken in the NIRSpec Multi-object Spectroscopy (MOS) mode, alongside my international collaborators on the NIRSpec Guaranteed-Time Observer (GTO) Team. I am also involved in various studies of galaxy formation and evolution with members of the Dawn team, as well as the Spitzer

Adaptation of the Red-sequence Cluster Survey (SpARCS) collaboration.

I received my PhD degree in Physics in 2017 from McGill University under the supervision of Dr. Tracy Webb (McGill Space Institute), for my contribution to the unexpected discovery of significant star formation activity occurring within a special class of galaxies previously known to be 'dead' and inactive.

Previously, I held a NASA Smithsonian Astrophysical Observatory (SAO) Data Specialist position at the Chandra X-ray Center, working on a variety of scientific and technical projects as a member of the Science Data Systems team. I have also worked as a telescope support scientist at Lowell Observatory while a graduate Master's student at Boston University, personally utilizing and assisting others in the operation of infrared and optical imaging and spectroscopic instruments.

Peter Laursen | DAWN Affiliated



I study galaxies; in particular the light coming from processes that have to do with galaxy formation. I use computer simulations to predict and interpret "real" observations. More specifically, I use hydrodynamical galaxy formation simulations with Monte Carlo Lyman α radiative transfer. I got my PhD from the Dark Cosmology Centre (DARK), Copenhagen, moved on to a postdoc at the Oskar Klein Centre, Stockholm, came back to DARK, and am now in Oslo. Being Copenhagen-based, I am affiliated with (and spend 70% of my time at) DAWN.

I enjoy communicating science to the public, frequently giving popular talks, tweeting about astronomy, and answering questions on my Q&A column and on the StackExchange site for physics and astronomy.

Kimihiko Nakajima | Postdoc



Current employer: National Observatory of Japan

I am a DAWN Fellow based at the Cosmic Dawn Center. I received my PhD degree in 2014 from the University of Tokyo advised by K. Shimasaku and M. Ouchi. My main research focus is the sources of Cosmic Reionization.

My interest also includes the stellar population, inter-stellar medium conditions in galaxies, and their evolution across comic time, through spectroscopic observation in conjunction with photo-ionization modelling.

I am a member of international collaborations of the VIMOS Ultra Deep Survey and the Hyper Suprime-Cam Subaru Strategic Program. Previously, I worked as a post-doc fellow at the Geneva Observatory,

European Southern Observatory, and the National Astronomical Observatory of Japan. I also stayed at the University College London as a senior visiting scientist.

Daniel Ceverino| Postdoc



Current employment: Researcher: University of Madrid

Born in Sevilla (Spain), Daniel Ceverino focuses on the formation of first galaxy using cosmological hydro-dynamical simulations. He is the Principal Investigator of the FirstLight project that aims to follow the formation of the first galaxies in the early Universe. These galaxies will be observed by future telescopes, like the James Webb Space Telescope (JWST) and this project will make detailed predictions about the properties of these first galaxies. His general research interests include galaxy and star formation, as well as related feedback processes.

Before coming to DAWN, Dr Ceverino was a postdoctoral researcher at the Institute for Theoretical Astrophysics (Heidelberg, Germany) and a 'Juan de la Cierva' fellow in the department of theoretical physics of the Universidad Autonoma de Madrid (Spain). Previously, he did a Post-Doc at the Hebrew University of Jerusalem (Israel) in the cosmology group of Prof. Avishai Dekel. In 2008, Dr Ceverino finished his PhD thesis at New Mexico State University (USA), under the supervision of Prof. Anatoly Klypin.

Luis Colina | International Associate





I am a senior research scientist of the Spanish National Research Council (CSIC) at the Centro de Astrobiología (CAB) in Madrid (Spain), and International Associate at the Cosmic Dawn Center. I received my Master Degree at the University Complutense of Madrid (Spain) in 1982, and my PhD in Natural Sciences at the University of Goettingen (Germany) in 1987. I have worked as an ESA postdoctoral fellow (1989-1990), and ESA staff astronomer (1993-1998) at the Space Telescope Science Institute (Baltimore, USA). I was Associate Professor at the University of Valencia before joining the Spanish National Research Council in 2000. I have been involved with the

James Webb Space Telescope (JWST) as MIRI European coPI and Spanish PI since 2000. I
am co-chair of the European MIRI High-redshift GTO team, and col of the MIRI Nearby Galaxies GTO team since 2010. My research interests focus mostly on the study of the formation and evolution of dusty star-forming galaxies and AGNs at both low- and high redshifts using different multi-wavelength imaging and integral field spectroscopy techniques from the ground (ALMA, VLT), and space (HST, Spitzer, JWST)

Birgitta Nordstrom | Emeritus



Birgitta Nordström was born in Sweden and studied physics and astronomy at Stockholm University until she was awarded her PhD in 1970. After postdoc positions in Switzerland and Canada, she came to the Niels Bohr Institute in 1972, where she has worked since then as a scientist and in the administration. Her Danish affiliation has been interrupted by several guest professorships in the USA (Center for Astrophysics, Cambridge) and in Europe (Lund in Sweden, Paris in France, Kiel in Germany and Vienna in Austria). Birgitta's research has been centered around the chemical and dynamical evolution of galaxies,

using the Milky Way as a prototype. Her most-cited paper is the Geneva-Copenhagen Survey of the Solar Neighbourhood (Nordström et al. A&A, 2004), which revealed that the structure of the Milky Way disk is much more complex than previously believed. Other large research projects focus on studying probable remnants of minor dwarfs galaxy mergers in the disk and on the oldest and most metal poor stars in the Milky Way halo (Cayrel et al. 2004, Bonifacio et al. 2009) and the formation of the chemical elements in the early Universe (Hansen et al. 2015). Birgitta has also devoted part of her career to work in international organisations such as the European Southern Observatory, the European Space Agency, the International Astronomical Union, and the Journal Astronomy & Astrophysics. She is member and ex-Chair of the Board of Directors of A&A. She represents Denmark in European Astronomical Society and the COST actions ChETEC (ChemicalElements as Tracers of the Evolution of the Cosmos, http://www.chetec.eu/) and MW-Gaia (https:// www.mw-gaia.org/).

Peter Capak | International Associate



Until February 2020 I was a Senior Research Scientist with the Euclid NASA Science Center at the California Institute of Technology where I studied the formation and evolution of structure in the universe. I have since joined the Oculus team at Facebook as Architect of Perception Systems for Augmented and Virtual reality. I received my BSc (1999) from the University of British Columbia, and my MSc (2002) and PhD (2004) from the University of Hawaii at Manoa.

My research interests focused in two areas: the physical processes that govern the formation and evolution of the most

massive galaxies in the early universe (z>2) and large area surveys to measure galaxy properties and probe Dark Energy and Dark Matter. I am a founding member of the Euclid consortia, developed the redshift estimation pipeline and simulations for the NASA SPHEREx mission, and was a member of the WFIRST cosmology science definition teams. I was also principal investigator of the Spitzer Legacy Survey and the SPLASH Spitzer Exploration Science programs which were two of the largest ever carried out on the Spitzer Space Telescope using a year of time. Previously I was lead of the COSMOS project, lead of the CCAT high-z science working group, and leading to effort to produce enhanced imaging products and a source list for the Spitzer archive. I have also been co-organizer of the PHAT project aimed at

developing a set of best practices for photometric redshifts and made significant contributions to the GOODS Legacy project including deep imaging of The Hawaii Hubble Deep Field North.

Kate Whitaker | International Associate



I am an Assistant Professor at the University of Massachusetts, and Associate Faculty at the Cosmic Dawn Center. I received my PhD degree from Yale University in 2012, after which point I was awarded a NASA Postdoctoral Program Fellowship at Goddard Space Flight Center in Greenbelt, Maryland (USA), then a Hubble Fellowship at the University of Massachusetts Amherst (USA).

As an observational extragalactic astronomer, I study galaxy formation and evolution over the past twelve billion years of cosmic time. My students and I actively collaborate with DAWN, working towards pushing our detection quiescent "read and dead" galaxies even earlier in time (within a billion years of the Big Bang itself!). We would like to understand

the detailed physics of the structures and underlying stellar populations of these early massive galaxies. With exquisite Hubble Space Telescope imaging and spectroscopy, we explore the rich uncharted territory of the distant universe and continually piece together an intriguing timeline of the cosmos.

I also enjoy dancing, photography, handcrafts, and spending time with my family.

Kristian Finlator | International Associate



I received my PhD from the University of Arizona in 2009. After this, I held a Hubble Fellowship at UC Santa Barbara from 2009-2012 and a DARK fellowship at the Dark Centre for Cosmology from 2013-2015. Since fall 2015, I have been an Assistant Professor at NMSU.

I am interested in the processes that couple galaxies with their environments. Although I have previously studied the relationship between galactic outflows and the mass-metallicity relation, the research that I lead nowadays is anchored in detailed comparisons between predictions from cosmological simulations and observations of galaxies, the circumgalactic medium, and the intergalactic medium. My goal is always to learn how observations constrain the feedback

processes that regulate galaxy growth and reionization.

I enjoy learning Danish, jogging, and playing with my two young children. Long ago $(z\sim10^{-9})$ I also played in orchestras; I am sure I will get back to that at some point.

Claudia Lagos | International Associate



I am a Senior Research Fellow and Lecturer at the International Centre for Radio Astronomy Research at the University of Western Australia and I am an international Associate at the Cosmic Dawn Center. I received my PhD degree from Durham University in 2013 and prior to coming to my current position I was a Research Fellow at the European Southern Observatory (Germany) and then a Discovery Early Career Researcher at ICRAR/UWA (Australia).

My research involves studying galaxy formation and evolution using state-of-the-art cosmological simulations of galaxy formation and large galaxy surveys. I am the main developer of the new Shark semi-analytic

model of galaxy formation and one of the members of the EAGLE Simulations collaboration. I am also a member of several galaxy surveys including several being carried out with the Australian Square Kilometre Array Pathfinder, the Anglo-Australian Telescope and the future 4MOST instrument at Paranal, Chile.

Karina Caputi | International Associate



I am an Associate Professor at the University of Groningen (Netherlands) and Associate Staff (zero appointment) at the Cosmic Dawn Center. I received my PhD degree from the University of Edinburgh in 2005, and then worked as a Postdoctoral Researcher at the IAS, Orsay, France, and the ETH Zurich, Switzerland. Between 2009 and 2011, I was a Leverhulme Trust Early Career Fellow at the University of Edinburgh, just before I joined the University of Groningen in 2012.

My research involves studying the formation and evolution of galaxies in the first half of cosmic time. I mainly work with space infrared telescopes (e.g. Spitzer) and ground-based telescopes (e.g. VLT). In addition, I am part of the European Guaranteed-Time Science Consortium for the

MidInfrared Instrument (MIRI) that will be on board the James Webb Space Telescope, due to be launched in 2021.

Desika Narayanan | International Associate



I am currently an Assistant Professor at the University of Florida in the US. Prior to this, I was an Assistant Professor at Haverford College in the Department of Physics and Astronomy. I grew up in Florida, went to undergrad school at the University of Florida and graduate school at the University of Arizona. I did postdocs at Harvard (CfA Fellowship) and Arizona (Bok Fellowship).

My research focuses on theoretical models primarily related to cosmological galaxy evolution, star formation, and the interstellar medium (ISM). I principally develop and utilize large scale numerical simulations to simulate the interplay between small scale star formation, ISM physics, and global galaxy evolution.

I love (American) college football, surfing, snowboarding, jam bands, hiking, and hockey.

Fabian Walter | International Associate



I am a Senior Scientist and Group Leader at the Max Planck Institute for Astronomy (MPIA) in Heidelberg, Germany. I received my Master Degree at the University of New Mexico (USA) in 1995, and my PhD in astronomy at Bonn University (Germany). I held a postdoctoral appointment at Caltech (Pasadena, USA) from 1999-2002 in the Owens Valley Radio Observatory group. After that, I received the Jansky Fellowship of the National Radio Astronomy Observatory (NRAO), which I took to the VLA headquarters in Socorro, New Mexico (USA). Since 2004 I am a staff member at the MPIA (tenured in 2008), and am still an Adjunct Associate Astronomer at NRAO. I am also a Scientific Editor for the AAS Journals (American Astronomical Society).

My research focuses on studies of the evolution of galaxies and quasars, from the end of cosmic reionization to today. My particular focus is on the studies of the interstellar medium

that is a requirement for star formation to proceed. In my research, I intensively use the ALMA, IRAM NOEMA, and VLA radio/millimeter interferometers. In this context I have led a number of large initiatives, such as the THINGS survey of HI emission in nearby galaxies, the HERACLES survey to map the distribution of molecular gas in nearby galaxies, surveys to characterize the interstellar medium in the most distant quasars, and a large ALMA program that studies the molecular gas and dust content in the Hubble Ultra-Deep Field (ASPECS).

Trity Pourbahrami | Communication Consultant



I am a science communications practitioner and educator with the ultimate goal of supporting scientists to communicate more effectively and to have greater impact. As a natural boundary spanner, I decided to obtain my undergraduate degrees in Physics and Physiology and my graduate degrees in Social Welfare and Public Administration. I am a strategic thinker, and community builder with over 15 years of experience in strategic communications, public relations, marketing, and advocacy spanning the non-profit, government, higher education, and corporate sectors. I have a proven track record of effectively engaging diverse groups and organizations in transforming strategy into operational goals, objectives, and measurable outcomes.

In addition to being a practitioner of communications I am an educator and have designed and delivered a variety of customized trainings as well as a new graduate course on effective oral, written, and media communications.

I also enjoy building community through serving on various local, national, and international community groups including the Federation of Zoroastrian Associations of North America and Leadership Pasadena.

Isabella Cortzen | PhD Student



I am a PhD student at the Cosmic Dawn Center with Sune Toft and Georgios Magdis as my main advisors. The main focus of my PhD is to study the molecular gas in star-forming galaxies across cosmic time with the use of facilities including ALMA and NOEMA.

In a recent project, we presented a new method to study the molecular gas content by using the emission from Polycyclic Aromatic Hydrocarbons (PAHs) which is strongly correlated with the cold diffuse gas in galaxies on integrated scales.

I obtained my master's degree in Physics and Astrophysics from the Dark Cosmology Centre in 2016, where I studied the star formation and gas properties in a large sample of starburst and main-sequence galaxies at 0 < z < 6 using IR emission as a tracer of the star formation rate, and carbon monoxide (CO) and hydrogen cyanide (HCN) line observations to trace the molecular and dense gas in galaxies, respectively.

John R. Weaver | PhD Student



I am a PhD student based at the Cosmic Dawn Center advised by Sune Toft, with Peter Capak (IPAC), Henry McCracken (IAP), and Dave Sanders (IfA). I received my Masters degree in 2018 from the University of St Andrews advised by Vivienne Wild. My research focuses on the assembly and evolution of galaxies across the 1.37 billion year history of our Universe, through direct observation with optical and infrared telescopes from both space and from the ground.

Previously, I have interned as a summer researcher at the Max-

Planck Institute for Astronomy, Leiden Observatory, and the Maria Mitchell Observatory. I am also the project director of the spectroscopy database at the American Association of Variable Star Observers.

Beyond academia, I am a frequent contributor to popular science publications, and have been a long-time volunteer at public observatories.

Meghana Killi | PhD Student



I am a student in the integrated MSc+PhD programme at the Cosmic DAWN Center, advised by Dr. Darach Watson.

Beginning in eighth grade, I underwent intensive training for the prestigious Indian Institute of Technology (IIT) entrance exam. I was accepted into the Mechanical Engineering programme at IIT Kharagpur, but after graduating in 2015, I decided to switch tracks and follow my childhood passion for Astronomy.

In 2016, I moved to the US, and began a second Bachelor's degree in Astronomy at the University of Texas at Austin, where I worked with Dr. Caitlin Casey on submillimeter galaxy observations, and with Dr. Volker Bromm on dark matter theory. Two intense and

transformative years later, I graduated with highest honors, and was accepted to DAWN.

I am currently studying the origin of various elements in the universe. More broadly, my research interests lie in our cosmic origins, first stars and galaxies, and events in the very early universe just after the Big Bang.

Vasily Kokorev | PhD Student



I am a PhD student at the Cosmic Dawn Centre working under the supervision of Georgios Magdis. My current research focuses on the evolution of molecular gas in galaxies with redshift. My other research interests include the formation of first galaxies and the epoch of reionisation. I received my master's degree in Physics with Astrophysics at the University of Sussex in 2018, where I have carried out work related to the 21 cm radio astronomy, while being advised by Mark Sargent.

Sinclaire Manning | Guest PhD Student



I am a PhD student and National Science Foundation (NSF) Graduate Research Fellow at the University of Texas at Austin working with Caitlin Casey. Through the NSF in collaboration with the Danish National Research Foundation, I received a grant to travel to Copenhagen for five months and complete a research project related to my thesis with Georgios Magdis at DAWN. While at DAWN I will be characterizing a small sample of high redshift dusty star-forming galaxies (DSFGs) which have recently been detected in a new, deep 2mm map with ALMA. With these new observations we hope to put constraints on the prevalence of obscured starbursts at z>4 and infer

their number density. I will also work to use ancillary data from the COSMOS/CANDELS

survey, combined with deep near-infrared coverage, to characterize multiwavelength counterparts of these 2mm detected galaxies.

Originally from Seattle, Washington, I moved to Washington, D.C. and obtained my B.S. in Physics and B.A. in Spanish from Howard University in 2015.

Clara Giménez Arteaga | MSc



I am a Master's student at the Cosmic Dawn Center, advised by Gabriel Brammer. My thesis is on high-resolution reddening maps of nearby galaxies, where I am using recently obtained and processed images from the Hubble Space Telescope to measure Balmer and Paschen emission line maps that probe sites of ongoing star formation activity and dust reddening.

These maps will serve as a high-fidelity reference that will be compared to theoretical simulations and low resolution images of galaxies at high redshift.

I obtained my Bachelor's degree in Physics in 2018 at the University of Barcelona, where I am originally from.

Athanasios Anastasiou | MSc



I am a MSc student at the Cosmic Dawn center working on my Thesis with Georgios Magdis. My thesis focuses on cross-validating the new photometric data of the Cosmos 2020 catalogue with previous versions and other surveys in the literature. More specifically, I'm examining the properties of galaxies such as photometric redshift, color classification and stellar mass. This is done with the use of updated photometric data from 15 different filters from 4 different telescopes (CFHT, VISTA, Subaru and Spitzer). With this work we hope to obtain deeper data, less outliers between photometric and spectroscopic redshift, possibly new galaxy populations and a better galaxy mass assembly constraint.

I originally come from Greece where I graduated from the University of Athens in 2018 and obtained my BSc degree.

Simon Pochinda | MSc



I am an MSc student at the Cosmic DAWN Center, advised by Georgios Magdis and Gabriel Brammer.

I obtained my Bachelor's degree in Physics in 2018 at the University of Southern Denmark under the supervision of Mads Toudal Frandsen, where I worked on numerically determining the dark matter distribution of merging galaxy clusters. Following my Bachelor's degree in Physics I moved to the University of Copenhagen to pursue my lifelong interest in Astronomy. During my time at the University of Copenhagen, I have also studied abroad at the Department of Physics and Astronomy at University College London and participated

in the Nordic Optical Telescope Summer School at La Palma offered by the Instrument Center for Danish Astrophysics.

My current work involves characterization of high redshift dusty galaxies within the GOODS-S legacy field using multiwavelength observational data. This involves

determination of photometric redshifts through fitting computationally generated galaxy templates using the EaZY code.

Simone Vejlgaard | BSc



I am currently writing my bachelor thesis at the Cosmic DAWN Center, advised by prof. Johan Fynbo.

After graduating from the Danish Talent Center (ATU) in the European Council for High Ability and my local Danish high school in 2017, I received the 'Carlsen-Langes Legatstiftelse' for diligence and highest grade point average of the year. I then decided to move to Copenhagen to study my passion, astrophysics, at the University of Copenhagen.

My journey continued as I was accepted to join the Nordic Optical Telescope Summer School 2019, where I gained my first experience on the use of different telescopes and instruments. Inspired by the talented team of teachers and the instructive experience, they provided me with, I successfully applied to the prestigious Vatican Observatory Summer School which I will be attending the summer of 2020.

Since my research interests lie in the mysteries of the early universe and the formation of the first galaxies, I am very pleased with working and learning at DAWN.

Christian Kragh Jespersen | Content Creator/Undergraduate Researcher



I am an undergraduate physics student based at the University of Copenhagen. I have been working at DAWN since November 18, primarily overseeing the website, solving different day-to-day tasks and contributing my own research working with Professor Charles Steinhardt on classifying Gamma Ray Bursts. Furthermore, I have worked with Professor David J. Stevenson at Caltech on the dynamics of hot planetary interiors

Beyond academia, I am a member of the Danish Youth Association of Science, where I dedicate my time to primarily PR and teaching high school – students with a particular interest in physics. In

extension to this, I arrange inspiration lectures for physics students every Friday afternoon. I also enjoy many different kinds of watersports, having been on the Danish National Windsurfing Team for quite a long time, along with rock climbing, linguistics (having lived many different places) and general puzzle solving.

Giacomo Girelli | Intern



I am a PhD student at the National Institute for Astrophysics (INAF) in Bologna (Italy) working under the supervision of Lucia Pozzetti and Micol Bolzonella.

I received a Marco Polo grant from the University of Bologna to spend three months in Copenhagen at the DAWN Institute working with Dr. Iary Davidzon. While at DAWN, I worked on developing a method to empirically assign galaxy properties to dark matter N-body simulations (Millennium, DUSTGRAIN) in order to create galaxy mock catalogs. With these mocks we hope to help optimising the scientific exploitation of ongoing and future large surveys, such as Euclid and H2O, by means of understanding and minimising systematic uncertainties and selection effects.

I am also interested in the study of massive and quiescent galaxies in the young Universe, by means of color selections and SED-fitting techniques.

On free time I enjoy sports, outdoor activities and, in general, staying in touch with nature.

Bidisha Sen | Intern



I am interning at DAWN for a year as part of an international internship program through MIT, called MISTI, during a gap year after completing my B.S. in Physics and Mathematical Economics from MIT and before attending graduate school. Currently, I am working with Prof. Charles Steinhardt on a project relating to the difference in the measurement of the Hubble constant between the Pantheon dataset and the Planck estimate. We have been quantifying the effect of using supernova redshifts instead of host galaxy redshifts among other systematic errors to reconcile these numbers.

Ivanna Langan | Intern



I am a French master's student from Université de Montpellier. I finished my dual undergraduate degree and my master's degree first year at La Sorbonne. This scholar year, I decided to take a year off in my studies to gain more diverse experience. I will be working at Dawn for 4 months, under the supervision of Gabriel Brammer. During this internship I'll be studying the Galaxy Mass-Size relationship in massive galaxy clusters in the Early Universe.

Besides astrophysics, I like to travel the world and record my adventures in vlogs.

Alumni

Carlos Gómez-Guijarro



I am a PhD graduate from the Cosmic Dawn Center advised by Sune Toft. My research focuses on galaxy formation and evolution across the history of the Universe. I am interested in the evolutionary pathways of massive galaxies. Particularly, the nature and role of dusty star-forming galaxies as their progenitors, how and what made star-forming galaxies to stop forming stars. I use observations from X-rays to radio wavelengths from both space and the ground. Before coming to Copenhagen for my PhD I was a student at the

Complutense University of Madrid, where I received my Bachelor and Master degrees in Physics and Astrophysics and started my scientific career. I did internships as a summer student at the Instituto de Astrofísica de Canarias (IAC, Spain) and the Instituto de Radioastronomía y Astrofísica (IRyA, Mexico). During my PhD I have

also worked closely with scientists at the Argelander-Institut für Astronomie (AlfA, Germany) and Cornell University (USA), where I spent a few months.

Mikkel Stockmann



I am a Danish PhD graduate from the Cosmic Dawn Center, after starting my PhD at the Dark Cosmology Centre under the Supervision of Sune Toft. My main research has been concentrated on the evolution of massive galaxies and their death across the last 10 billion years.

I utilized the Danish build X-Shooter instrument attached to the Very Large Telescope located in Paranal, Chile for my thesis. Together with time granted on the prestigious Hubble Space Telescope I have studied the structural properties and stellar populations of the largest sample of massive quiescent galaxies at z>2. In a closely related project, I was awarded additional time with X-Shooter, to study these massive dead galaxies with very high resolution by taking advantage of the beautiful effect called gravitational lensing. I take part in public outreach both via

Astronomy On Tap events and popular scientific talks. Outside astronomy I like to rock climb and enjoy the cultural life of Copenhagen. I was awarded my doctorate degree after successfully defending my thesis on the 23rd of October.

Cecilie S. Nørholm



I am a MSc graduate from the Cosmic Dawn Center, advised by Francesco Valentino, Georgios Magdis, and Sune Toft. My thesis was on environmental effects on galaxy evolution, where I am investigating galaxies in clusters and protoclusters through data obtained with the Very Large Telescope. I obtained my Bachelor's degree in 2017, also at the University of Copenhagen, with Marianne Vestergaard as supervisor.

I enjoy being able to work with observational data, which was something I first experienced in 2016. Here, I attended a course on observational astronomy where I, together with a group of fellow students, planned and executed observations at the Nordic Optical

Telescope.

When not working, I am very interested in communication of science, which I enjoy doing through my student job at the Tycho Brahe Planetarium as well as by giving lectures to secondary school students attending internships at University of Copenhagen.

Christina Konstantopoulou



I am a MSc graduate from the the Cosmic Dawn Center supervised by Johan Peter Uldall Fynbo. I received my Bachelor degree in 2017 from the University of Patras. My master's thesis focuses on red quasars, and the aim is to characterize the efficiency of quasar selection based on astrometry, which does not suffer from most of the selection biases of other existing methods. Direct observations are obtained with the Nordic Optical Telescope (NOT) and astrometry is provided by the ESA Gaia mission.

I completed my internship at the Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS), National Observatory of Athens, supervised by Vassilis Charmandaris.

Suk Joo Ko



I am Suk Joo Ko, a MSc Graduate formerly based at the Cosmic Dawn Center where I was advised by Johan Fynbo. I received my Bachelor degree in 2017 from University of Copenhagen advised by Sune Toft at the Dark Cosmology Centre.

My master's thesis is focused on the spectroscopy of red quasars, the selection of quasars of red spectral energy. The motivation is to study missed population of red quasars from previous technique of selecting quasars.

I chose to write my thesis at DAWN to learn techniques of observational astrophysics and study the early Universe, galaxies and quasars.





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Publications

Appendix: DAWN Publications, 01.01.2019 – 31.12.2019

Below we have compiled all of the articles in the refereed literature that include one or more authors from the Cosmic Dawn Center and its international associates. These are items limited to publication dates between 01 Jan 2019 - 31 Dec 2019 obtained from the <u>NASA</u> <u>Astrophysics Data System (ADS)</u>. All of the publications listed here have been peer reviewed and have been published by the journals indicated in the bibliographic entries. Digital Object Identifiers (DOIs) are provided for all entries where available (all but [3]). The journals indicated have a variety of Open Access (OA) policies; a query on these paper DOIs at the <u>Web of Knowledge</u> indicates that 133 articles are currently available with Open Access.

Some summary statistics of the Dawn publications extracted from ADS are as follows:

- 213 = Total number of refereed journal articles with contributions from Cosmic Dawn Center members
- 123 = Articles from Dawn members in Copenhagen
- **28** = Articles including collaboration between both our local members and international associates
- 10 = Primary (i.e., first) author publications from Dawn members (local and associates)
 - **4** = Publications in the prestigious cross-disciplinary journals *Nature* (3) and *Nature Astronomy* (1)
- **19** = Citation -index
- 73 = Number of articles already with ten or more citations (*i10*-index)
- **1086** = Number of unique articles citing the 213 Dawn papers

Often-used journal names are abbreviated as:

AJ – The Astronomical Journal

ApJ – The Astrophysical Journal

ApJSS – The Astrophysical Journal Supplements Series

A&A – Astronomy & Astrophysics

MNRAS - Monthly Notices of the Royal Astronomical Society

PASA – Publications of the Astronomical Society of Australia

PASJ – Publications of the Astronomical Society of Japan

PASP – Publications of the Astronomical Society of the Pacific

DAWN @ Copenhagen

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