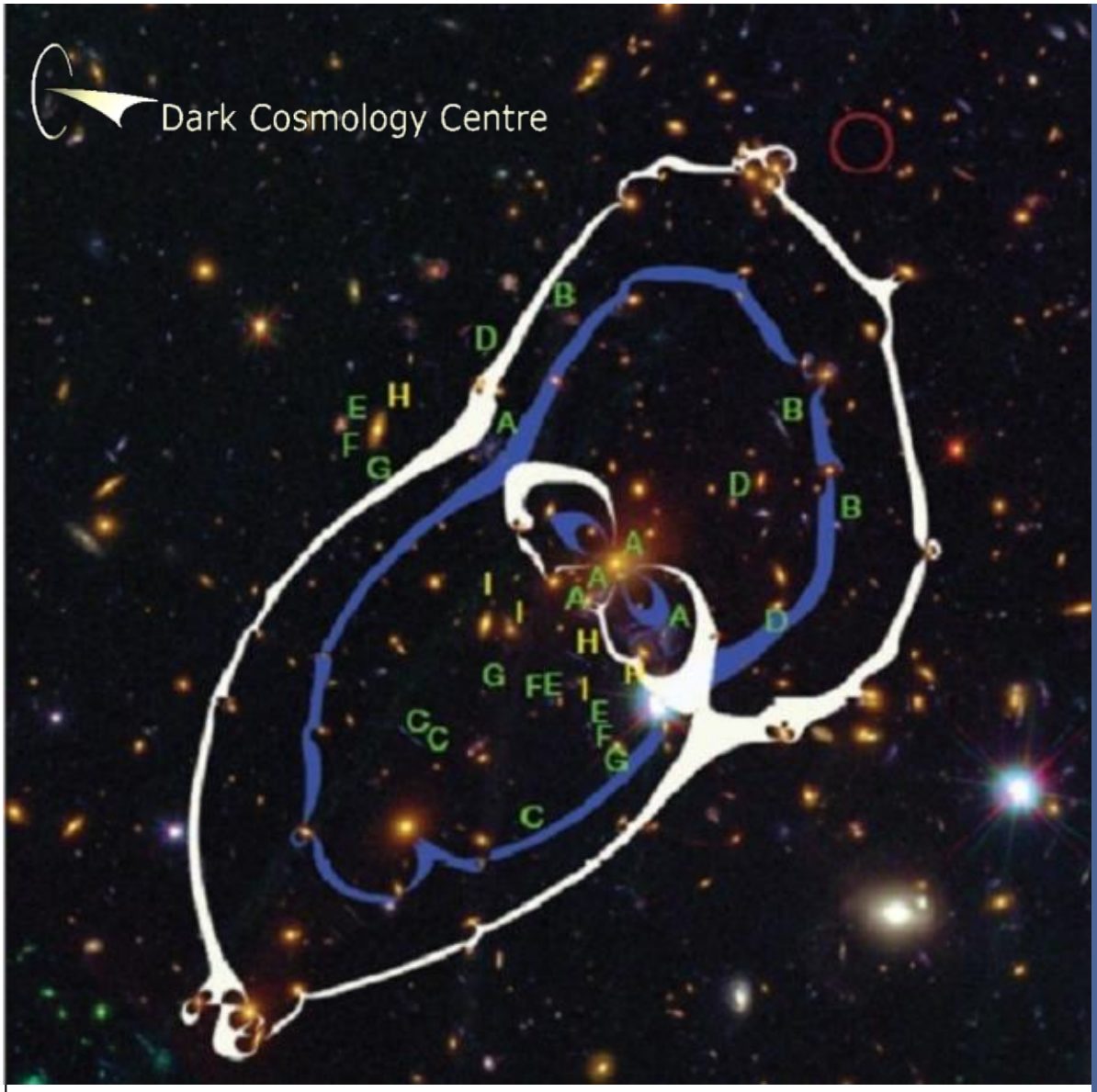

ANNUAL REPORT 2012

THE DANISH NATIONAL RESEARCH FOUNDATION'S
DARK COSMOLOGY CENTRE (DARK)
AT THE NIELS BOHR INSTITUTE
UNIVERSITY OF COPENHAGEN

Cover Illustration:

This figure shows the composite color image of galaxy MACS J1149.6+2223

Credit: The CLASH team/The Space Telescope Science Institute

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Organization

In 2012, we welcomed new research staff, including independent DARK Fellows: Nicola Amorisco, Matteo Barnabè, Tomotsugu Goto, Claudio Grillo, Peter Laursen, and Lars Mattsson; Carlsberg Fellow Ole Høst; and post doc Dong Xu. PhD student, Matteo Catteneo, joined the Centre to work with DARK Fellow David Rapetti. DARK's first joint PhD student, Anthea King, joined the Centre to work with Darach Watson and Marianne Vestergaad, and she is formally enrolled at the University of Queensland and supervised there by former DARK Fellow, Tamara Davis.

Sangeeta Malhotra and James Rhoads arrived in Copenhagen in August to spend their sabbatical year at DARK. They are both associate professors at the School of Earth and Space Exploration at Arizona State University and are collaborating with several DARK scientists on projects related to galaxy formation and evolution, interstellar dust in near and far galaxies and gamma-ray burst science.

Director of the Space Science Center and one of DARK's original cofounders, Kristian Pedersen, left the Centre this year to become of the Director of the National Space Institute at DTU. ALMA Fellow Thomas Greve left the Centre for a permanent position at University College London. Jesper Rasmussen finished his Carlsberg Fellowship project this year. DARK Fellow Anna Gallazzi took up a research position at the Astrophysics Observatory in Arcetri.

Discussions among the senior staff in 2012 focused mainly around the future of the Centre after 2015, organizationally and in terms of future science. In the spring, the senior and administrative staff held a retreat in Paris, where staff members' career, scientific and personal objectives where discussed and several organizational scenarios developed. The science discussions have continued throughout the year, and the organizational scenarios were also discussed with Centre's board members, Anne Kinney (NASA), Richard Ellis (CalTech) and Chryssa Kouveloutiou (NASA), who weighed in with suggestions. A follow up meeting with the full board is planned for 2013.

The research staff continues to suggest and implement new knowledge-sharing platforms. DARKTime is a new initiative with month-long topic-based discussions and events to "fill in the gaps" of knowledge on various topics of astronomy using the local expertise, as well as visitors'. DARKTime events varied, including an on-line discussion forum, short talks, "drive-by" questions, "naïve" question of the week, and several small-group discussions.

In November Jens Hjorth led a group of senior staff from the University and the DNRF to visit and discuss Danish participation and support for telescope facilities in Chile, including the Very Large Telescope, Atacama Large Millimeter/submillimeter Array and future site of the Extremely Large Telescope.

DARK staff in Lisbon

In November the entire staff went to Lisbon for a 3-day retreat called *Creativity and science: a practical exercise.* All were encouraged to develop their most ambitious ideas or project. To set the stage, we discussed the science of creativity, the role of nutrition, exercise and meditation on the brain, and supported four distinct phases: discovery, dream, design, destiny. Speakers included Peter Vuust (Aarhus), DARK Brahe Professors Enrico Ramirez-Ruiz (UC Santa Cruz), Josh Bloom (UC Berkeley) and Steve Allen (Stanford) and DARK adjunct professor, Peter Jakobsen.

The Centre's secretary, Corrine Toulouse-Aastrup, was promoted to Project Manager in 2012, to recognize the need in the Centre to dedicate resources to projects that help DARK plan for the future. Centre Coordinator, Michelle Cumming Løkkegaard, was appointed team leader for administration for all staff in the four research groups in the Rockefeller building and now attends regular Institute leadership meetings. A new receptionist was hired; Marie Sandnes is now also providing direct support to the DARK, in addition to serving other research groups. The part-time IT assistant position, held by Damon Kasacjak, was re-classified to Systems Analyst and increased to full-time in recognition of the growing number of research staff to support at the Centre in 2012, planning for the future growth in staffing 2013-14 and to meet DARK's increasing data processing and storage needs.

Research

In this section we briefly address progress on the 2012 targets we set in 2011. We next provide some a description of progress on the Centre's key projects and other science areas, and finally we list 2013 milestones. Citations in the text refer directly to the publication number [xx] in the appendix, *All DARK Publications 2005-2015*. DARK continues to publish at a very high rate, this year with 116 publications in international refereed journals.

2012 MILESTONES

Submit paper reporting spectroscopic investigations of a *z*~3.3 massive galaxy

This work was originally planned to be based on X-shooter data only. However, additional data from the Keck and GTC telescopes have been acquired which will significantly improve the results, but has delayed submission.

Publish paper testing of the origin of the quasar narrow absorbers is a disk wind near the central black hole

A single-author paper by Marianne Vestergaard, testing disk-wind models for active galactic nuclei, was submitted.

Complete a series of papers on dust extinction in *z*~6 quasars and supernovae

A series of independent but related papers led by Jens Hjorth, Christa Gall, and Lars Mattsson, respectively, were completed and submitted for publication in early 2013. Other DARK members of the teams included Anja C. Andersen and Darach Watson. In related work, led by Johan PU Fynbo, extinction towards reddened lower-redshift quasars was published.

Organize and host international *Euclid* conference

350 scientists visited Copenhagen in May 2012 for the *Euclid* conference. Kristian Pedersen, with support from DARK and the Space Science Center, was in charge of organising this conference, which was the largest astronomy conference ever in Denmark.

Secure funding for the Danish hardware contribution to *Euclid*

Funding was secured from the Carlsberg Foundation and FNU.

Publish properties of particles ejected during dark-matter mergers

This work was submitted for publication by Steen H Hansen and co-workers.

Establish the origin of X-ray absorption in gamma-ray bursts

Darach Watson and his team solved this long-standing problem and showed in a paper in press that the X-ray absoprtion is primarily caused by helium in natal H II regions. This breakthrough could lead to the measurement of the sizes of HII regions surrounding GRB progenitors at all redshifts as envisioned in the Centre's proposal.

Complete the The Optically Unbiased Gamma-ray burst Host (TOUGH) survey (4 additional papers to be completed)

The core survey papers for the TOUGH project was submitted and published in papers led by Jens Hjorth, Bo Milvang-Jensen, Thomas Krühler and Michal Michalowski. Other key DARK members were Daniele Malesani, Johan PU Fynbo and Darach Watson.

Publish first paper on high-redshift supernova host galaxies

Two papers on the first high-redshift Type Ia supernova discovered in the CANDELS survey were published. The redshift of $z = 1.55$ was established using X-shooter observations. This paper was led by DARK PhD student Teddy F Frederiksen. Other DARK team members were Jens Hjorth and Justyn R Maund.

Get two papers on gravitationally lensed galaxies accepted for publication

Two papers based on X-shooter observations of faint galaxies lensed (and amplified) by foreground clusters of galaxies were published by Lise Christensen. Other DARK team members were Jens Hjorth, Peter Laursen and Bo Milvang-Jensen, as well as former Brahe Fellow Johan Richard.

Find an attractor for hot gas in galaxy clusters

A paper on an attractor for the dynamical state of the intracluster medium was published by DARK master student Diana Juncher and Steen H Hansen.

Complete the first statistical study of the properties of the galaxies hosting Damped Lyman-α Absorbers at $z > 2$

DARK PhD student Jens-Kristian Krogager published a study on the sizes of $z \gtrsim 2$ damped Lyα absorbing galaxies. Several DARK members were involved, including Johan PU Fynbo.

Make the first public release of UltraVISTA data

The first public release of UltraVISTA data was announced in an ESO press release and in a paper published by the UltraVISTA core team, involving Johan PU Fynbo and Bo Milvang-Jensen.

Submit first paper on the effects of spectral quality and line shape on the accuracy of quasar black hole mass determinations

Due to bad weather at the telescope this project was delayed.

Establish how the dark-matter velocity anisotropy depends on direction in dark-matter halos

Three papers on this issue were published by two independent teams, led by DARK PhD students Martin Sparre and Andreas Skielboe, respectively. Other team members were Steen H Hansen, Kristian Pedersen and Radek Wojtak. In a third approach Radek Wojtak completed work submitted in early 2013.

Publish two papers on modeling the growth and destruction of dust grains in the interstellar medium

Two papers were published by Lars Mattsson and Anja C Andersen.

KEY PROJECT 1: GAMMA-RAY BURSTS AND QUASARS IN THE ERA OF REIONIZATION

Astronomers are making substantial inroads in discovering galaxies at around the epoch of reionization at redshifts (*z*) of 6 to 12. DARK researchers participate in or lead some of these efforts.

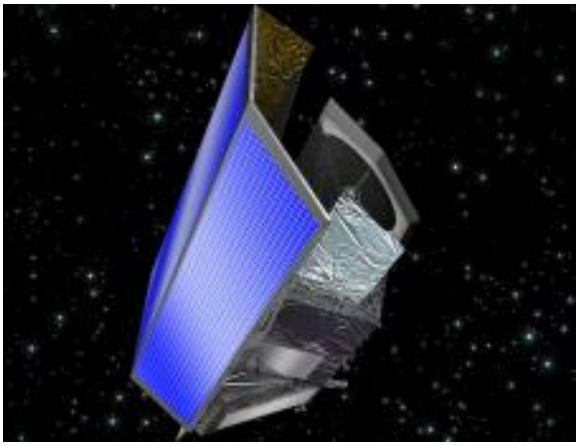
1.1 High-redshift gamma-ray bursts (GRBs) and quasar (QSOs)

As noted in the highlights section, a major landmark reached in 2012 was the publication of a long-term DARK key project on the host galaxies of gamma-ray bursts (Hjorth et al. [551]), Jakobsson et al. [516], Krühler et al. [563], Michalowski et al. [538]). This study led to strict observational constraints on the fraction of very high-redshift gamma-ray bursts of at most 14% (5%) at $z > 6$ ($z > 7$). Interestingly, the fraction of gamma-ray bursts at high

redshift ($z > 3$) appears to be in excess of predictions based on assumptions that it should follow conventional determinations of the star formation history of the Universe. In another study of the host galaxies of $z > 5$ host galaxies of gamma-ray bursts (Tanvir et al. [525]), none was detected with the *Hubble Space Telescope*. This shows that the host galaxies of gamma-ray bursts are very faint, which may be a common property of the galaxies that reionized the Universe.

1.2 Proposing the JANUS Mission

The proposed JANUS mission was not selected for further studies by NASA. Consequently, the Centre has re-focused space instrumentation efforts towards the European Space Agency's *Euclid* mission, which was selected for launch in 2019. DARK and the Space Science Center hosted the *Euclid* conference in May 2012. Several DARK researchers are now members of the *Euclid* Consortium and many are active members of Science Working Groups.



Artist conception of *Euclid* (Credit: ESA)

1.3 Other projects related to the transient Universe

The X-shooter sample of gamma-ray bursts has essentially been completed, and 2012 was a good year in terms of the quality of the data collected. One highlight was the detection of molecular absorption from two systems, which led to a better understanding of when and where we see molecular absorption in high redshift absorbers. We are currently in the process of writing up a substantial number of papers on individual bursts and a number of sample papers are being prepared for submission in 2013.

We also laid the groundwork for explaining the origin of X-ray absorption in GRB afterglows by showing that low redshift GRBs are more dust extinguished than equivalent bursts at high redshift (Watson & Jakobsson [534]). We then followed this up with a paper explaining the origin of the X-ray absorption as being due to primordial helium in the HII regions in which GRBs explode. This result is a major achievement and could lead to the measurement of the sizes of HII regions surrounding GRB progenitors at all redshifts as envisioned in our proposal.

In the study of the connection between gamma-ray bursts and supernovae, the highly energetic expansion of SN 2010bh associated with GRB 100316D was published (Bufano et al. [521], Olivares E. et al. [496]), while a massive observational campaign was conducted on the connection between GRB 120422A and SN 2012bh. An influential review on the topic was also published (Hjorth & Bloom [570]).

DARK signed a letter of intent to contribute to the Large Synoptic Survey Telescope (LSST), a US-based wide-field telescope facility that will, for the first time, provide time-lapse digital imaging of faint astronomical objects across the entire sky. LSST is scheduled to go on-line in 2019.

KEY PROJECT 2: GALAXY CLUSTERS AS GEOMETRY PROBES, DARK-MATTER LABS AND GRAVITATIONAL TELESCOPES

Clusters of galaxies are studied by a large and lively group of DARK researchers, from a variety of theoretical and observational approaches.

2.1 A 'Cluster Ultra Deep Field' as dark-matter lab

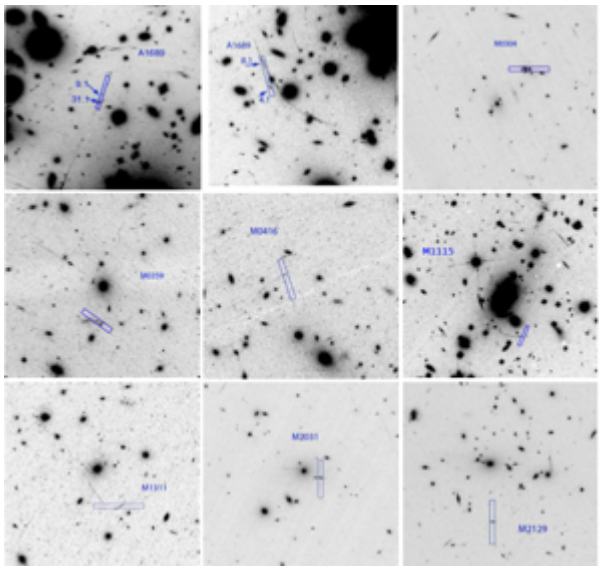
As reported last year, the idea of a very deep observation of a cluster field with the *Hubble Space Telescope* had been put on hold in 2011 because of competing projects being executed, including the one highlighted in this annual report. In 2012 the Space Telescope Science Institute announced the opportunity to propose deep public surveys. DARK participated in this process and in the end a survey along the lines suggested in the DARK research plan was decided as the next *HST* flagship project: The Frontier Fields. This consists of no less than 6 clusters of galaxies to be observed for a total of 840 orbits over the next 3 years. In other words, this project is now going ahead and will be conducted during 2013-2015.

2.2 Precision cosmology

PhD student Xue Li published a paper on estimating the number of multiply imaged supernovae behind clusters of galaxies (Li et al. [572]), showing that while such events, e.g., in the Frontier Fields, would be very important for constraining cosmological parameters, notably the scale of the Universe, they are rare and mostly probe the scales of individual galaxies in the clusters, not the large-dark matter potential of the clusters. PhD student Teddy F Frederiksen continued his work on detecting very distant supernovae (Frederiksen et al. [577]; Rodney et al. [489]), including some towards the fields of clusters of galaxies, although so far none have been found to be highly magnified.

2.3 Distant galaxies at the focus of a gravitational telescope

Taking advantage of the magnification of background galaxies by massive foreground galaxy clusters, the physical properties of 12 galaxies at the faint end of the luminosity function were explored. The lensed galaxies were used to extend the recently discovered "fundamental metallicity relation" for star-forming galaxies, which links various galaxy properties in observed relations between parameters, towards lower mass and higher redshifts than previously investigated (Christensen et al. [579]). Three lensed galaxies proved to be unusually rich in emission lines, allowing calculation of the physical conditions in these galaxies to a level of detail was previously only possible for galaxies at much lower redshifts (Christensen et al. [580]).



Thumbnail *HST* images of the clusters around the targeted sources [579]. Credit: STSCI

Searching for galaxies amplified by the gravitational lensing effect of a massive cluster of galaxies, a large international team (Zheng et al. [556]), including DARK Fellow Claudio Grillo, used *HST* to discover a galaxy at a record redshift of 9.6, at an epoch just 500 million years after the Big Bang, when the Universe was just 3.6 percent of its current age. Such galaxies may be the dominant source for the early re-ionization of the intergalactic medium.

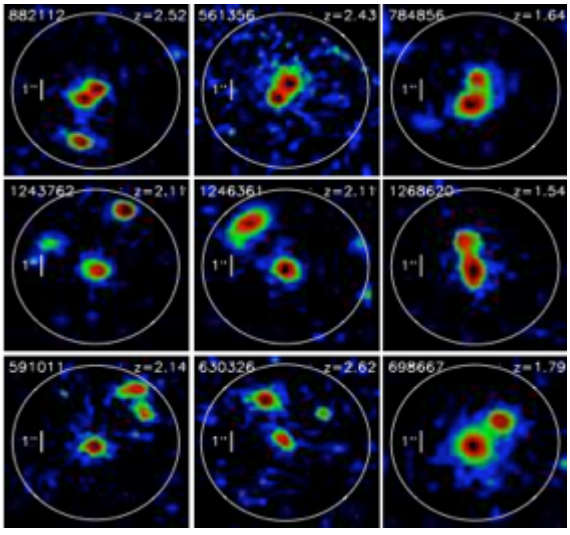
KEY PROJECT 3: HIGH-REDSHIFT GALAXY FORMATION

The formation of galaxies is a complex problem, a delicate interplay between dark matter, gas, dust and star formation, regulated by feedback from supernovae, black holes and merging. In the local Universe most galaxies are either regularly rotating star-forming disk galaxies or old quiescent elliptical galaxies, and follow a number of tight scaling relations between e.g., stellar mass, total mass, black hole mass, star-formation activity, metallicity and size. As we study galaxies at increasingly higher redshift (i.e., back in time) these relations start to deteriorate, and galaxies start to "fall apart". By studying how they formed, their properties and the properties of their central black holes as a function of redshift, we can begin to understand the timing and process of reionization, galaxy formation and evolution.

3.1 UltraVISTA: Finding galaxies in the reionization epoch

The UltraVISTA survey is progressing, albeit at a slower pace than originally foreseen. The slower progress is mainly related to larger than anticipated overheads (i.e., time used for read-out, slewing of the telescope, etc.). A major achievement in the project was the first data release from the survey, for which Bo Milvang-Jensen and PhD student Johannes Zabl played major roles. The public availability of the data was marked by a press release from the European Southern Observatory (http://www.eso.org/public/images/eso1213a/). Associated with the release was the first publication based on UltraVISTA data (McCracken et al. [533]).

3.2 Unveiling the nature of massive, quiescent, compact high-redshift galaxies



9 examples of selected galaxy pairs [473]

A campaign to obtain deep near-infrared spectroscopy of compact quiescent galaxies is progressing and has produced the first publications. Sune Toft [524] led a paper in which unprecedented constraints on the dynamical mass, metallicity and mean stellar age of these galaxies were derived.

In a paper led by PhD student Allison WS Man [473] this expectation was observationally confirmed. Galaxy mergers have been hypothesized to drive the size evolution of quenched galaxies. In a paper led by Andrew Zirm [475] it was shown that quenched galaxies in a dense proto cluster at $z = 2$ are on average larger than galaxies of similar mass in lower density environments, consistent with this picture. This is the first time it has been shown that structural evolution (in addition to the evolution of stellar populations) is accelerated in dense environments.

3.3 Quasars and their role in galaxy formation and evolution

Our investigations of the host galaxy properties of distant quasars is progressing. Preliminary analysis of *HST* restframe UV imaging of massive quasars at z~4 confirms that stars are being formed at an impressive rate of ~1500 $M_{\odot}$/year (paper in preparation). However, it has proven too difficult to obtain further data on quasar host galaxies at *z* = 4-5 with *HST*.

We have employed a new strategy until *James Webb Space Telescope* (*JWST*) becomes available: new *HST* observations to investigate these same issues for quasars at lower redshifts. As these targets reside at the epoch when both black hole/quasar activity and cosmic star formation activity peaked, this study may provide additional important clues to the connection between active black holes, their host galaxies and the connection to quiescent galaxies as well as an important reference sample for future studies of very distant systems with *JWST*.

Important progress was made toward improving black hole mass measurements. Our studies revealed that a broader range of issues, such as data quality and line shape, affect the robustness of the mass estimates and to a greater extent than previously expected. We have thus extended our investigation. Our simulations have now established quantitatively the fragility of the current velocity parameters, typically employed for mass determinations, to spectral noise, absorption and measurement method. These results formed the basis of the Master's thesis of Jens Juel Jensen. Denney [568] studied line profile differences and found additional new clues to the velocity structures of the CIV and Hβ emitting regions and how they differ. These new results are of vital importance for our ability to obtain improved, robust black hole mass measurements.

KEY PROJECT 4: THEORETICAL INVESTIGATIONS OF DARK MATTER AND DUST

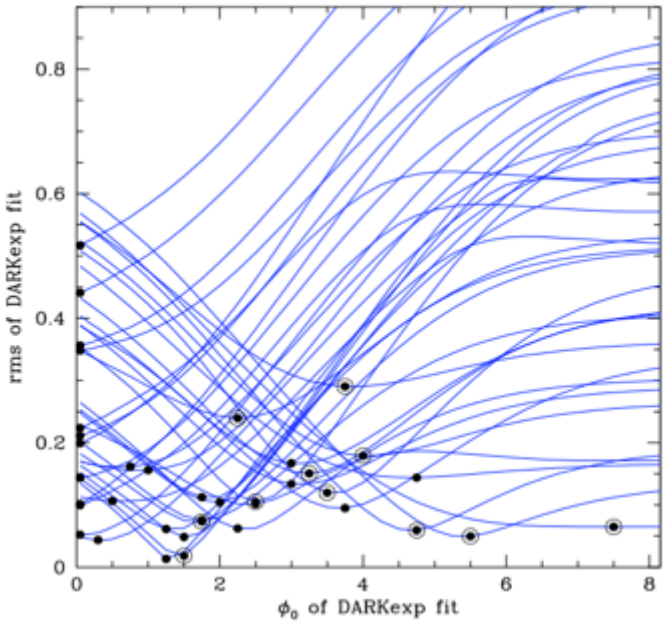
Astronomy and cosmology are observationally driven fields, hence most DARK projects relate to observations, one way or the other. On the other hand, DARK continues to build up theoretical expertise, now also extending to the areas of gravitational lensing and galaxy formation. Meanwhile, theoretical investigations in the area of dark matter and cosmic dust continue to be core research areas at DARK.

4.1 Cosmological structures

A major step was made towards reaching the milestones of measuring the distribution of dark matter. We identified first in numerical simulations and later in real galaxy data, that the cosmological structures are not spherical in velocity space (Sparre & Hansen [566], Skielboe et al. [564]). This implies that even equilibrated cosmological structures retain memory about their merger history.

Another milestone is to understand the profiles of gas in cosmological systems. This was reached since the dark matter attractor (which we identified over a year ago) was found to also hold for gaseous systems (Juncher et al. [492]).

The last major goal is to understand dark matter profiles. We have attacked this problem with two very different and purely theoretical studies. Both approaches provided progress; however, we are still far from a clear conclusion about the fundamental reason for the dark matter profiles (Hansen & Sparre [54], Williams et al. [528]).



The curves represent DARKexp fits to 38 globular clusters; DARKexp models have already been shown to fit the results of dark matter N-body simulations. [528]

4.2 Origin of cosmic dust in the early Universe

Lars Mattsson and Anja C. Andersen addressed theoretical constraints on the effects of destruction by supernovae and growth of dust grains in the interstellar medium on the radial distribution of dust in late-type galaxies. It was shown that the gradient could be used as a diagnostic tool to determine between stellar and non-stellar dust formation scenarios in such galaxies (Mattsson et al. [517]).

The theoretical model for the buildup of the dust component in spiral galaxies was compared with radial dust distributions derived from a larger observing campaign. The observed galaxies there seem to be evidence for significant non-stellar dust production and do not show evidence for dust destruction due to supernova shock waves (Mattsson & Andersen [518]).

OTHER SCIENCE AREAS

The nature of damped Lyman-alpha galaxies

Significant progress was made on elucidating the nature of galaxies found as absorption lines in observations of distant quasars. In a statistical study of such galaxies at redshifts larger than about 2 (lookback times in excess of 10 billion years), PhD student Jens-Kristian Krogager [529] confirmed earlier work by the team that relates mass, metallicity and galaxy size. Such fundamental relations must have been set up already at these relatively early stages of galaxy formation. This line of work is followed up by new observations obtained with the *Hubble Space Telescope* and in studies of the evolution of the mass-metallicity relation for these galaxies.

Dust extinction of gamma-ray bursts

We doubled the number of GRB host galaxies known with the atypical feature at 2175 Å in their extinction spectra (indicating processed dust) from only two to four and showed that the strength of the feature was low, but that our GRB afterglow methodology had the sensitivity to detect these features better than had so far been achieved in the nearby Magellanic Clouds (Zafar et al. [522]). By examining one of these host galaxies in optical and NIR spectroscopy with X-shooter, we confirmed that it was indeed a mature, metal-rich host galaxy, clearly demonstrating that GRB host galaxies can be metal-rich and the link between the 2175 Å feature and older host galaxies in one clear case (Krühler et al. [557]).

In Schady et al. [569] we examined GRB host galaxies and found that the UV extinction curve in these distant star-forming galaxies is steeper than that found on average for galaxies in our local group (the Milky Way and the Magellanic Clouds). The findings could indicate a dependence between the dust properties (i.e. the wavelength dependence of its extinction) and the youth of the stellar population in those galaxies as has been previously speculated.

Progress on a new cosmological distance indicator

Since the discovery of the AGN distance indicator in 2011 (Watson et al. [445]), significant activity has developed in this area. PhD student Anthea King is working on simulations to establish the optimum survey design to place the best constraints on the Dark Energy equation of state using AGN. PhD student Andreas Skielboe is working on detailed simulations of AGN variability to examine how to improve the accuracy of the method.

2013 MILESTONES

Researchers at DARK will strive to meet the following milestones:

0 Overall goals

0.1 Host a series of international scientific workshops and programs

0.2 Continue efforts towards publishing a higher fraction of high-impact papers

1 Fundamental cosmology and dark-matter phenomenology

1.1 Address the cosmological world model in view of the Planck results

1.2 Solve the mystery behind the "Jeans Swindle"

1.3 Understand the mechanism behind dark matter particles being ejected during mergers

1.4 Attempt to find a method to observe cosmological sheets or pancakes

1.5 Incorporate velocity anisotropy in the DARKexp model of dark-matter halos

2 Dusty starburst galaxies and the origin of cosmic dust

2.1 Use dust to constrain galaxy evolution, including the importance of supernovae, the duration of starbursts, the relation to metal abundance, and the initial mass function

2.2 Establish a connection between compact galaxies at $z \sim 2$ and the highest redshift sub-millimeter galaxies

2.3 Examine if it is physically possible for dust-driven winds in carbon stars to develop at low metallicities

2.4 Publish a paper on the extinction curves of quasars with anomalous extinction

2.4 Derive redshifts of Herschel lenses based on X-shooter data

3 Gamma-ray bursts, supernovae, and their host galaxies

3.1 Understand the origin of thermal emission in X-ray afterglows of GRBs

3.2 Announce the discoveries of the highest redshift supernovae, a new class of ultra long gamma-ray bursts, and molecular absorption in the host galaxies of gamma-ray bursts

3.3 Make new inroads into the statistical properties GRBs: expand on the origin of the X-ray absorption and the importance of dust obscuration in gamma-ray burst afterglows by providing a major statistical sample of dust extinctions and X-ray absorptions; increase the redshift completeness of the TOUGH sample and further characterise the redshift distribution of GRBs and their host galaxies

3.4 Establish a luminosity—width relation for supernovae related to GRBs

4 Galaxies and active galactic nuclei

4.1 Publish two papers on *Hubble Space Telescope* observations of $z > 2$ damped Lyman-alpha galaxies

4.2 Publish the first paper based on the near-infrared narrow-band observations of the COSMOS field

4.3 Explore the relation between stellar mass and emission line width for galaxies at $z > 1$

4.4 Submit a paper on X-shooter observations of gravitationally lensed quiescent $z \sim 2$ galaxies

External relations

Official *Euclid* Mission Conference photo taken at the Black Diamond in Copenhagen. Credit: University of Copenhagen's Space Science Center

Research conducted at the Centre continues to be highly international. In 2012, DARK produced 116 refereed publications, and all except six were written in concert with researchers outside of Denmark. The Centre supports a busy visitors programme, welcoming more than 100 guest researchers again in 2012.

In May 2012 the Space Science Centre and DARK hosted 350 participants for the Euclid Mission Conference. Several DARK researchers are now active in Euclid Science Working Groups.

Brahe Professor Enrico Ramirez-Ruiz (UC Santa Cruz) organized a 2-week workshop at DARK. 18 participants – including students, post docs and faculty – from 9 different institutions discussed fundamental issues associated with the evolution of *Supernova Remnants*.

Researchers from 14 different institutions came to DARK in the summer for a 2-week collaborative workshop entitled *Black Hole Masses in Active Galactic Nuclei*. The organizers, Marianne Vestergaard and Kelly Denney, put significant emphasis on small working groups with the goal of forming new collaborations and pool resources to begin actively working together at the workshop and beyond.

DARK led a workshop for the first time in Georgia, co-sponsored by the Georgian National Science Foundation in a grant won by DARK PhD student, Ia Kochiashvili. The main goal of *The Dark Universe* workshop was to foster interaction between Georgian and Danish Astronomers and students of Master and PhD level, and for DARK scientists to provide input for future development of the Abastumani Observatory.

DARK is responsible for the narrow-band of the UltraVISTA survey, a collaboration within the European Southern Observatory between University of Edinburgh, Leiden Observatory, University of Marseilles, and DARK. Marianne Vestergaard is part of the management committee, and the representative for Denmark for the European Cooperation in Science and Technology (COST) Action MP0905: Black Holes in a Violent Universe, as well as a member of COST 's international working group on supermassive black holes.

Educational activities

Centre staff led or contributed significantly to five University bachelor's courses in 2012. Three master's courses were given with DARK faculty as lead lecturer, and six master students finished their theses, among the 11 who were in progress at different points throughout the year. DARK organized a course for PhD students *How to publish in peer-reviewed journals.*

Significant staff resources were used in 2012 to improve astronomy education at the University. Marianne Vestergaard is leading a committee looking at upgrading the entire curriculum. Two new courses were developed and approved by the Faculty of Science in 2012, to be offered annually starting in 2013: *Livets og bevidsthedens oprindelse: Astronom*i will be led by Anja C Andersen, offered to bachelor students in the humanities, social sciences and theology as an optional course; and *Astronomical Data Processing* for master's students in physics, led by Lise Christensen and Marianne Vestergaard. Darach Watson developed a new section for the master's course, *Numerisk Astrofysik: Stjerne- og Planetdannelse***.**

External funding

DARK's researchers continue to win external funding, and the Centre is actively using external funding possibilities to attract high quality post-doctoral researchers. Marie Curie Fellow Kelly Denney started in 2012, as did Carlsberg-funded post-doctoral researcher Ole Høst. FNU continues to fund the Instrument Centre for Danish Astrophysics, a project to support Danish research and instrumentation that has been administered by DARK since the beginning of the Centre. As detailed further in Appendix D, DARK's external funding accounted for 14.7 MDKK in spending in 2012, mostly on research staff and PhD salaries and to support meetings and workshops.

By signing I confirm that this annual report and the accounts therein, including notes and summaries, contain all relevant information relating to this year's main activities in the Danish National Research Foundation's Dark Cosmology Centre.

Jens Hjorth
Professor and Director
2 April 2013