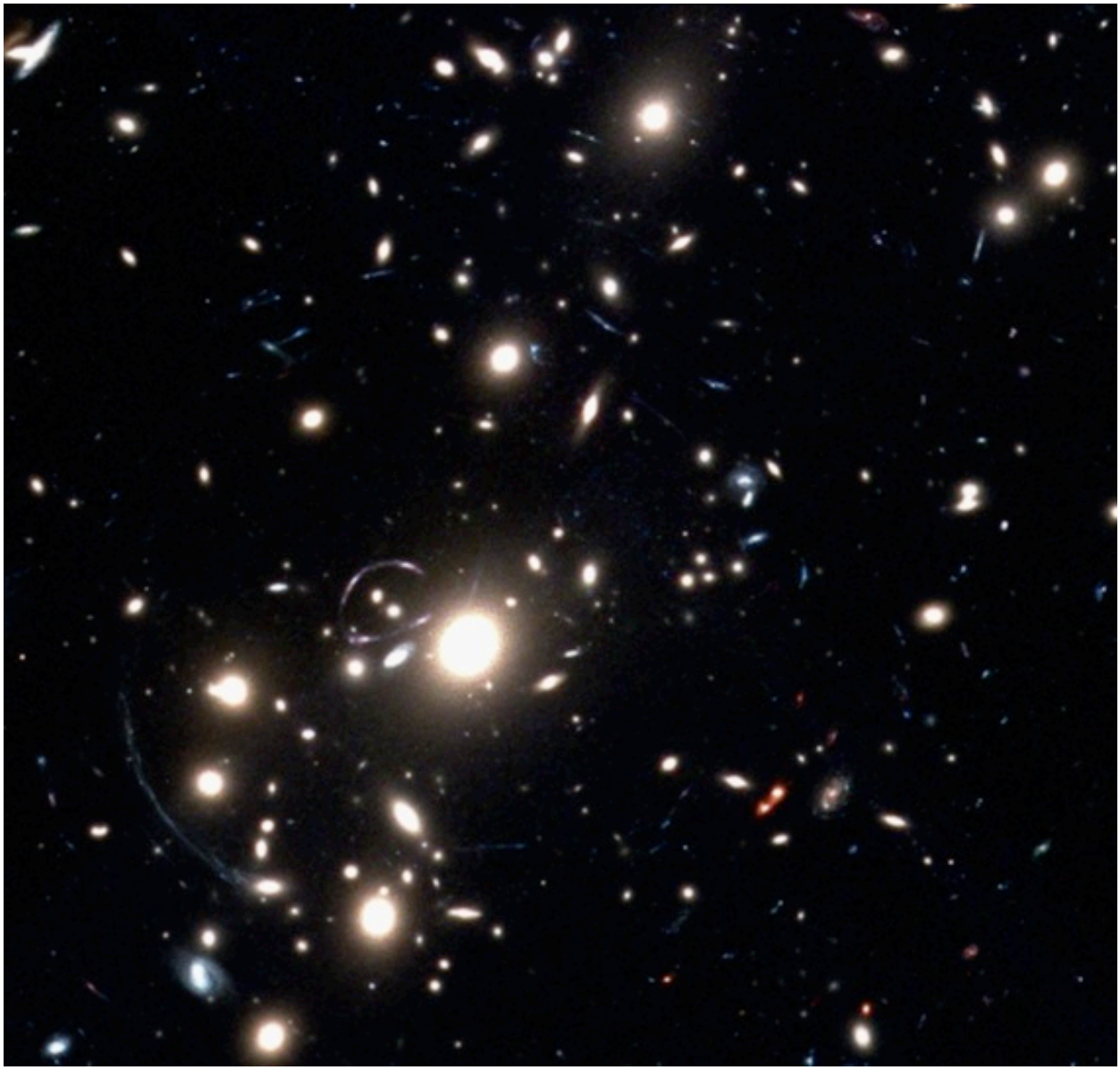
Dark Cosmology Centre



Danmarks Grundforskningsfonds Center for Kosmologi ved Københavns Universitet

ANNUAL REPORT 2008 (1 JAN – 31 DEC)

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Cover image:
The galaxy cluster Abell 1703 featuring spectacular gravitational lensing of background galaxies (Limousin et al., 2008, A&A, 489, 23)

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1. Highlights of the Year

Brightest ever gamma-ray burst

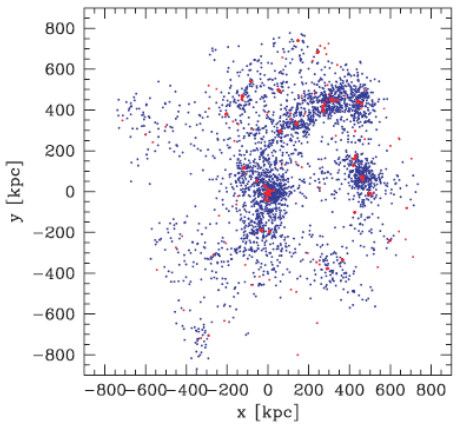
The brightest ever gamma-ray burst was discovered on 19 March 2008 and was visible to the naked eye for some seconds even though it occurred in a galaxy 7.5 billion light years away, making it the most distant object visible to the naked eye. The distance was determined by staff at the Centre and was enabled by the so-called Rapid Response Mode at the Very Large Telescope, which was developed with contributions from DARK Marie Curie Fellow Paul Vreeswijk.

Cosmic dust

The Centre's investigations of its fourth research theme, Cosmic Dust, gathered pace this year, with the detection of the earliest signs yet of dust associated with evolved galaxies, and the discovery of a gamma-ray burst afterglow so obscured by dust that it was detected exclusively at infrared wavelengths. The unequivocal detection of the evolved dust signature has allowed us to open a new avenue of investigation on the origin and carrier of this signature, a problem which is now four decades old and may be related to the formation of planets.

Missing metals

A long-standing mystery in cosmology is the deficit in cosmic accounting: most of the heavy elements ("metals" in astrophysical terminology) produced by stars since the Big Bang are missing. New computer simulations of galaxy formation and evolution show these "missing" metals in a state of hot plasma that is largely invisible to current instrumentation. An observational study showed that most of these warm phase metals are associated with faint galaxies that are missing in most surveys of distant galaxies.



DARK space research accentuated

The excellence of space research at the Centre was confirmed in a new evaluation of Danish space research, called for by the Danish Agency for Science, Technology, and Innovation, and executed by a senior panel of international experts in space science. According to the report, DARK is carrying out research of "particularly high quality" and "exhibits numerous examples of best practice in terms of personnel management, career development, and general organization". DARK was the only space research group in Denmark to receive the highest possible grade in the evaluation.

Research Prize awarded to Anja C. Andersen

Anja C. Andersen was awarded the research prize of *Dansk Magisterforening* for 2008 (receiving DKK 50,000) for her outstanding ability to combine research at an international level with communication of her scientific results to a broad audience.

Justyn Maund, the first Sophie and Tycho Brahe Fellow

In a bid to recruit the best young scientists, a joint fellowship programme, funded by the DNRF, between DARK and world-class research institutions abroad was initiated. The first Sophie and Tycho Brahe fellow, Justyn Maund, arrived at DARK in September where he will work for two years and then move to the University of California, Santa Cruz for the last year of the Fellowship.

4 PhD degrees awarded

After three years, DARK is beginning to see a large number of its PhD students successfully conclude their theses. Four PhD students at the Centre were awarded their degrees this year: Árdís Elíasdóttir, José María Castro Cerón, Christina Thöne, and Chloé Féron. The first three have already taken up postdoc positions at internationally renowned institutions. Dr. Féron is taking time out travelling before her next move.

2. Organization

There were no major changes to the organization in 2008. Major decisions, including hirings, are made at weekly faculty meetings. These meetings provide a formalised setting for decision-making, sharing information and distributing tasks. The need for support staff has grown due to success in obtaining external funding and manpower. The Centre policy now is that any external funding must contribute directly to the extra cost of the added activity. Moreover, the need for a high-level Centre coordinator has become apparant and, consequently, such a job was advertised.

The Centre has established an intranet and issues a weekly newsletter. Organised discussion of recent arXiv preprints occurs every morning Mon–Thu over coffee at 11 o'clock in the Centre's lounge; on Fridays, the discussions are reserved for coffee and interaction with the other astrophysics research groups at Niels Bohr Institute. The PhD students run a popular weekly DARK Cake Meeting, which is a seminar series enjoyed with cake and coffee.

In place of the Centre's annual internal reviews, in-depth discussions leading up to the research plan for 2010-15 were conducted. These discussions focused on future science directions and organization. The kick-off meeting, a one-day agenda-less meeting held at the Royal Danish Academy of Sciences and Letters, was followed by five half-day meetings devoted to specific issues, supplemented by on-line discussions on the Centre's intranet. One important outcome of these meetings was the decision to invite members of the Centre's advisory board for a site-visit in 2009.

The first Sophie and Tycho Brahe Fellow, Justyn Maund, joined the Centre in September. Dr. Maund is a leading figure in the field of supernovae. During his fellowship, he will maintain a strong interaction with University of Santa Cruz, California, where he will work for the third year of his fellowship. Andrea Morandi joined the Centre as a postdoc to strengthen studies of galaxy clusters through X-ray and Sunyaev-Zeldovich measurement. Besides the four PhD students graduating and subsequently moving on (three of them to postdoctoral positions at renowned institutions), Lisbeth Fogh Olsen terminated her project funded by the Danish Council for Independent Research|National Sciences and left the Centre for taking up a career in a public pension company.

The Centre has reached its full capacity for PhD students and is now a major training site for young researchers. In 2008, the Centre was home to 15 PhD students, 4 of which graduated during the course of the year (male/female: 6/9, international/Danish: 11/4).

3. Research 2008

As described in the research plan, the Centre's projects revolve around using "cosmic lighthouses" like supernovae and gamma-ray bursts (GRBs) for constraining cosmological parameters and studying distant galaxies. The Centre operates around four scientific themes (dark energy, dark matter, dark ages, and cosmic dust) implemented through three key projects and a series of smaller or more risky projects.

In this section we briefly address progress on the 2008 milestones (see boxes). We next provide some supplementary comments on the key projects and finally we list 2009 milestones.

Research goals and milestones for 2008

Probing the end of the dark ages

1. *Completion of a major work on spectroscopy of GRB afterglows using data accumulated over the past years.*
   All spectra have been reduced and analysed and the paper is currently being written up.

2. *Completion of the GRB host galaxy survey. The full dataset will be available in 2008.*
   The two-year observational program on GRB host galaxies was completed on time. Data on about 70 galaxies are now available and is being analysed. Preliminary findings were presented at conferences.

3. *The successful installation of the X-shooter spectrograph on the ESO VLT.*
   The UV and visible arms of the X-shooter spectrograph on the ESO VLT were successfully commissioned. The infrared arm was delayed, but is being commissioned at the time of writing.

4. *Selection and design of the observing programme for the guaranteed time on X-shooter.*
   An observing programme for the guaranteed nights was selected and designed.

5. *Hiring of a dedicated scientist devoted to the UltraVISTA survey.*
   Bo Milvang Jensen has been hired partly to work on the UltraVISTA and partly as an expert on X-shooter data analysis.

6. *Initial studies for the use of a galaxy cluster as a gravitational telescope.*
   Several studies on lensing by galaxy clusters were completed (Tu et al. 2008, Limousin et al. 2008, Riemer-Sørensen et al. 2008). The cluster Abell 1689 was selected for spectroscopy within the X-shooter guaranteed time program.

The nature of dark matter

1. *Finalize a pipeline for simulating data obtained with the X-ray satellite, XMM-Newton from galaxy clusters.*
   A pipeline for simulating X-ray data from the XMM-Newton satellite was completed.

2. *Quantify the allowed range of properties of dark matter based on archival data from the EGRET gamma-ray satellite.*
   Archival data from the EGRET gamma-ray satellite was studied in order to search for a signal from dark matter, but no firm constraints on dark matter could be obtained due to the low statistics in the high-energy range.

3. *Set up procedures for simulating a dark-matter annihilation signal, which might be observed by the GLAST satellite.*
   Another research group published a fairly complete study of this making this study obsolete.

4. *Establish more firmly the measurement of the velocity anisotropy by:*
   a. *investigating a large sample of relaxed clusters, with emphasis on the potential difference between two types of galaxy clusters (cool-core or not).*
   b. *identifying a connection between the observed gas temperature and the dark matter "temperature". This connection has only been suggested on theoretical grounds, and has yet to be demonstrated through numerical simulations.*
   Numerical simulations were used to confirm and quantify the connection between the observational gas temperature and the dark matter temperature. We used this to firmly establish the measurement of the velocity anisotropy in a sample of 16 galaxy clusters (Host et al., 2009).

5. *A dream is to extend the theoretical investigation of dark-matter structures to include the angular momentum profile, i.e. the rotation, which numerical simulations have been considering for over 5 years. This has never successfully been attempted before.*
   The angular momentum profile of dark matter structures was derived, and the results showed excellent agreement with the results of high-resolution numerical simulations (Schmidt et al. 2009).

Supernova cosmology

1. *Publication of the full six-year dataset from ESSENCE (almost 200 supernovae), which will conclude this major endeavour.*
   Spectroscopic results to constrain supernova evolution and time dilation were published (Foley et al. 2008, Blodin et al. 2008). The full 6-year photometry was also analysed, but before this can be published further systematic effects need to be addressed.

2. *Publication of the first-year data (90 supernovae) at intermediate redshifts from the SDSS II search*
   The first series of SDSS-II papers were published, including a technical summary and details on the survey (Frieman et al. 2008, Zhen et al. 2008). The main cosmology paper from the first-year data is near completion.

3. *Complete a thorough investigation of the idealized assumption in current supernova dust-forming models and thus provide reliability estimates for the current results.*
   Results were obtained on how the forward and reverse shock develops in the gas with time in a supernova remnant. Including the dust description introduced some unforeseen numerical challenges, which we are currently resolving. First results were presented at two international conferences.

Key Project 1: Probing the end of the dark ages

Studying the dark ages is a very challenging task and will continue to be so for the coming decade. At the Centre, we investigate the sources that ended the dark ages by studying distant gamma-ray bursts (GRBs) and distant Lyman-α emitting galaxies. Lyman-α emission is the result of hydrogen gas that recombines after having been ionized by hot stars. The first galaxies were full of hydrogen gas and hot stars, so the Lyman-α emission line is expected to be very strong from these objects.

It has for some time been apparent that most of the expected heavy elements, "metals", in the distant Universe are not detected. New computer simulations of galaxy formation and evolution show that about ¾ of the metals in the distant Universe are expected to be located in faint galaxies, which are not observable with current telescopes. An observational study of distant galaxies selected in two completely different ways (galaxies hosting a gamma-ray burst and galaxies absorbing light from background quasar, so-called damped Lyman alpha systems) shows that both types of galaxies represent a population of distant star forming galaxies. Indeed more than ¾ of the distant

Smaller or more risky projects

1. *Based on simulations, investigate how well the mass of a galaxy cluster can be derived from Sunyaev-Zeldovich observations.*
   Using simulations and real data from CBI and CBI2, procedures for determining the cluster mass profile have been established and results will be obtained in 2009.

2. *Investigate procedures for combining X-ray data and Sunyaev-Zeldovich data for measuring cluster masses to large cluster-centric radii.*
   Analysis methods for joint analysis of X-ray, SZ, and lensing data have been initiated. This allows for studying the external regions of clusters, well beyond the volumes resolved with X-ray observations.

3. *Make prescription for how to derive cluster masses from Sunyaev-Zeldovich data.*
   Prescriptions for deriving cluster masses from SZ data for a wide range of dark matter models have been set up.

4. *Obtain cluster masses for a couple of clusters for which X-ray and Sunyaev-Zeldovich data are available.*
   A joint X-ray and SZ analysis has been applied to two clusters, A2204 and A2163, and the cluster mass reconstruction is currently being carried out.

5. *Trigger Spitzer ToO observation to obtain the first total extinction curve of a high-redshift galaxy.*
   A Spitzer ToO programme was approved (PI Watson) and was triggered on GRB 080603B in June 2008 and detected the afterglow. The data is in hand and will be analysed in 2009.

6. *Begin a systematic analysis of metal column densities in GRB host galaxies compared to dust column densities.*
   The high redshift GRB 050904 was studied as a learning example for determining the spectral energy distributions of GRB afterglows. This will be the basis for a systematic analysis of metal column densities in GRBs and their comparison with dust columns densities.

7. *Publish the first observationally complete spectral energy distribution of a GRB host galaxy.*
   The first observationally complete spectral energy distribution of a GRB host (HG031203) has been produced and will appear in a publication to be submitted in 2009.

8. *Carry out a combined X-ray/gravitational lensing analysis of the mass distribution of the galaxy cluster Abell 1689 based on all available X-ray and lensing data.*
   A combined X-ray/gravitational lensing analysis of the mass distribution in the galaxy cluster Abell 1689 was carried out and a paper submitted to Astrophysical Journal, lead by three DARK PhD students (Riemer-Sørensen et al. 2009).

galaxy population is likely below current detection limits and they should contain most of the metals in the Universe at these cosmic epochs.

On 13 September, the so-far most distant GRB was detected (redshift 6.7) and DARK played a crucial role in this pioneering work by determining the redshift of the burst. More importantly, we have become a central partner in a proposal for a NASA SMEX mission called JANUS (Joint Astrophysics Nacent Universe Satellite). The purpose of JANUS is to detect the most distant GRBs and quasars. DARK is contributing the optics of the Near-InfraRed Telescope on the satellite. The mission is up for final approval by NASA in the summer of 2009 and is planned for launch in 2013 if approved.

The UltraVISTA survey will detect Lyman-α galaxies at redshift $z=8.8$. The survey is co-led by DARK faculty member Johan Fynbo. The UltraVISTA survey was expected to start in early 2009, but due to delays in completing the construction of the VISTA telescope the survey will be delayed. The expected starting time is now December 2009. The X-shooter spectrograph at the ESO VLT is functioning within specifications. DARK has access to 33 guaranteed nights (GTO) with the X-shooter over 2009-2012 and at least a third of those nights will be used on projects that advance the dark ages science.

Key Project 2: Supernova cosmology

The Centre continued to investigate the dark energy component of the Universe, but according to the research plan, with activities in supernova cosmology reduced during 2008. Staff member Jesper Sollerman worked at DARK at a 40% level during 2008 and Tamara Davis worked at DARK at a 20% level during an intense summer period. Much work was focused on the SDSS-II supernova collaboration. Initial results were published (Frieman et al. 2008, Zheng et al. 2008) and all data are now in hand for this project. Studies of their cosmological implications are underway.

Results from our spectroscopic campaigns within the ESSENCE project were also released. We were able to set constraints on the potential evolution of the supernova standard candles from spectroscopy (Foley et al. 2008). One interesting tangent using these data was our dedicated target-of-opportunity VLT follow-up programme (PI Sollerman) to obtain multipl-epoch spectra of a few high-redshift SNe Ia, and use their time evolution to constrain cosmological time dilation (Blondin et al. 2008). PhD student Taia Kronborg also investigated the prospects and pitfalls of gravitational lensing in large supernova surveys (Jönsson et al. 2008).

For modelling of dust formation we have focused on developing a self-consistent code for predicting dust nucleation and grain growth scenario and the possible survival of these grains during the forward and reverse shock of supernova. The work is done in collaboration with Ernst Dorfi from Vienna University and Susanne Höfner from Uppsala University. We also established collaboration with Rafaella Schneider from Arctri Observatory in Florence who will come for extended visit every Summer the next years.

Key Project 3: The nature of dark matter

The dark matter profiles of cosmic structures remain a mystery, and only one promising theoretical description has emerged over the last 10 years, suggesting a universal phase-space density profile. Using high-resolution numerical simulations we demonstrated that this phase-space density is not universal (Schmidt et al. 2009), thus rejecting this theoretical suggestion.

Direct dark matter detection in underground experiments depends on the velocity distribution of the dark matter particles. For the first time, we used realistic velocity distributions, like the ones extracted from numerical N-body simulations, and we quantified the observable importance for a range of target materials, considering both the annual modulation and the total rate (Vergados et al. 2008).

Work is ongoing for using the XMM-Newton X-ray data analysis pipeline to study biases and scatter in X-ray methods for measuring the mass profile of galaxy clusters. The Centre is investigating the possibility of using the Sunyaev-Zeldovich effect of annihilating electron-positron pairs to constrain some types of SUSY dark matter. The electron-proton spectra are simulated by the public software DarkSUSY and propagated to equilibrium. Preliminary results show that the dark matter signature is too similar to the thermal Sunyaev-Zeldovich effect and that the abundance of electron-proton pairs is too low for the SZ effect to be measured with current and future planned experiments.

Smaller or more risky projects

We obtained the first-ever spectroscopic programme with the Spitzer Space Telescope on a GRB host galaxy (PI Watson, GRB 031203). Analysis of that data is now complete. The paper reporting the results is in progress and will also include the results of our successful radio and sub-mm observing programmes on this galaxy. This work will complete this part of the project. An analysis of galaxies at a range of redshifts using the restframe NIR and UV to derive accurate stellar masses for a sample of GRB hosts has been submitted for publication.

Modeling of spectral energy distributions (SEDs) of GRB host galaxies was published (Michalowski et al. 2008). We obtained data using the Caltech Sub-mm Observatory and the Atacama Pathfinder Experiment (APEX, the precursor to ALMA) on three GRB host galaxies. Moreover we performed a radio survey of 20 GRB host galaxies using Australia Telescope Compact Array, Giant Metrewave Radio Telescope, Very Large Array and Westerbork Synthesis Radio Telescope. We used our cosmological simulations to make predictions of the observability of high redshift star-forming galaxies via the CO line with ALMA (Greve & Sommer-Larsen 2008).

A pioneer study of spectroscopic selection of disk galaxy lenses in the Sloan Digital Sky Survey was carried out. Several good candidates were found and a paper will be published in 2009. Constraints on the slope of the inner dark matter distribution in a cluster of galaxies were derived with strong lensing in Abell 1703 (Limousin et al. 2008) and a technique outlining the use of Einstein rings to probe the dark-matter distribution outside the strong-lensing regions of gravitationally lensing clusters was published (Tu et al. 2008). MOND with classical neutrinos as an alternative to dark matter for cluster lensing effects was tested and ruled out (Natarajan & Zhao 2008).

A Bayesian code has been built for a joint X-ray and Sunyaev-Zel'dovich (SZ) data analysis. This allows us to study the external regions of clusters, i.e. to the virial radius. From SZ data and with a given model for the dark matter distribution, the paramameters of the dark matter model, and hence the mass distribution, can be determined under the assumption of hydrostatic equilibrium.
Given the strong constraints from X-ray+SZ+lensing data, the cluster masses are being reconstructed to large distances from the cluster centre.

Research goals and milestones for 2009

Probing the end of the dark ages

1. Completion of major work on spectroscopy of GRB afterglows using data accumulated over the past several years.
2. Submit the first four survey papers based on the GRB host program for publication in refereed journal.
3. Approval of the JANUS mission for launch.

Supernova cosmology

4. Submission of paper on the final dataset from ESSENCE (almost 200 supernovae), which will conclude this major endeavour.
5. Submission of paper on the first-year data (71 SNe Ia at intermediate redshifts) from the SDSS II search. This will include a cosmological analysis, and a DARK lead paper discussing more exotic cosmological models.
6. Investigate how much of the dust budget in the early universe can be contributed by intermediate mass stars.

The nature of dark matter

7. Initiate a thorough statistical analysis of a set of X-ray observed galaxy clusters, with the purpose of distinguishing between various predicted dark matter profiles.
8. Use high-resolution numerically simulated data to test to which extent one can predict the shape of the velocity distribution function, with the purpose of deriving the velocity anisotropy.
9. Use XMM-Newton pipeline to study biases and scatter in X-ray methods for measuring cluster mass profiles.

Smaller and more risky projects

10. Produce the extinction curve of one of the most distant GRBs, 050904. Produce the absolute extinction curve using the data from the Spitzer target of opportunity observation triggered in 2008. Re-examine the evidence for unusual extinction curves at high redshift, publishing our results in 2009.
11. The first mid-infrared spectrum and the first observationally complete SED of a GRB host galaxy (HG031203) will be published in 2009. Publish modelling of a sample of sub-mm–selected galaxies.
12. Obtain a first measure of the temperature, density, gas mass and total mass fraction at large cluster-centric distances of at least one cluster by combining X-ray, SZ, and gravitational lensing data.
13. Study the feasibility of using time delays and lens velocity dispersions to determine cosmological parameters. Measure time delays and prepare for measurement of velocity dispersions.
14. Prepare for future lensing programs, leading up to the proposed second period, through a small lensing thinkshop or extended visits by collaborators.

4A. External relations

The research conducted at the Centre is highly international, as evidenced by the fact that the refereed papers published in 2008 have authors affiliated to over a hundred institutions from dozens of countries worldwide. These papers are the result of established networks and consortia, but are also often formed on a case-by-case basis, especially where observational data from many facilities around the world are combined in a collaborative work. A subset of the Centre's collaborators is listed in Appendix A, including Centre associate scientists and IARU contacts.

The Centre is engaged in several high-profile international collaborations. The Centre is one of the founding institutions for the UltraVISTA survey, which is a collaboration within ESO between University of Edinburgh, Leiden Observatory, University of Marseilles, and the Centre. The Sophie and Tycho Brahe Fellowship programme launched by the Centre has currently a joint fellow with University of California, Santa Cruz. Another programme is being set up jointly with University of California, Berkeley. The Centre is a partner in the NASA JANUS space mission, which is lead by Penn State University and is due for down selection in mid-2009. Centre members are co-investigators of this mission with collaborators in Spain, France, UK and a number of institutions in the US. Two Centre staff members are leading Nordic networks: Jesper Sollerman is leading the Nordic Network of Astrophysics and Cosmology, which is a network of Nordic centres of excellence facilitating interaction between centre members across the Nordic countries. Steen H.

Hansen is heading the network Particle Physics and Cosmology: From the Smallest Scales to the Largest, giving young Nordic researchers more frequent possibilities to exchange ideas and results among fellow nordic researchers. The Centre continued its participation as a node in the EU Framework 6 Marie Curie Research Training Network "Astrophysics Network on Galaxy Lens Systems – ANGLES", which partially funded PhD student Chloé Féron. There is also collaboration with all Danish astrophysics research institutes.

The Centre has an extensive visitor programme, including collaborations with its associates. The programme includes everything from very short visits (people passing through or quick collaboration meetings) to longer-term visits, of order weeks up to a month. The visitor programme is also used to invite speakers for local collaboration meetings. Lists of past, current, and future visitors are maintained at the Centre's web (http://www.dark-cosmology.dk/visitors/).

4B. Conferences

Important aspects of the Centre's research activities are to present results from the Centre and interact with researchers at other institutions through organizing and attending meetings/workshops/conferences.

The Nordic Workshop/Summer School on Supernovae and Gamma-Ray Bursts in Abisko, Sweden, August 22-28, was organized jointly with Stockholm Univertity through the Nordic Network of Astrophysics and Cosmology. The Centre was a co-organizer of the IAU Symposium 254: 'The Galaxy Disk in Cosmological Context', June 9-13, Copenhagen. This was the largest ever astrophysics conference in Denmark gathering 250 international astrophysicists to present and discuss the origin and evolution of the Milky Way galaxy.

Centre members participated in 41 conferences in 12 countries where they presented 54 talks (of which 22 were invited talks) and 9 posters. Finally, several Centre members served on Scientific Organizing Committees (SOCs) for conferences abroad. Appendix B lists conferences held and contributed to through SOC membership or presentations given. Danish vs. international scientists are categorized according to affiliation rather than citizenship.

4C. Educational activities

The aim of the Centre's training activities is to train original and independent researchers at an internationally competitive level. All PhD students are involved in on-going international collaborations, in particular by spending part of their PhD abroad working in associated research groups and by attending international conferences. There is a lively and informal contact between PhD student and supervisor on a daily basis in the Centre's international environment. Other research training foci for the Centre include recruiting the best international students, maintaining a high fraction of international MSc and PhD students, and to have a balanced MSc and PhD student gender profile.

Of the four PhD students who graduated from the Centre, three have taken up postdoctoral positions at Princeton (USA), ESA Villafranca (Spain), and Brera Observatory (Italy), respectively.
All PhD students at the Centre are automatically associated with the Danish Astrophysics Research School (DARS), which organizes courses and meetings for Danish astrophysics PhD students. The Centre is one of three founding institutions behind DARS. DARK faculty members contributed to the organization of DARS, as well as the planning and giving of DARS courses for PhD students; particularly in connection with the annual DARS meeting in Ebeltoft, January 2008, and to the DARS summer school on observational astrophysics at the Nordic Optical Telescope, August 2008.

Faculty members at the Centre offered students at University of Copenhagen MSc and BSc projects within cosmology in order to attract the most talented students. In 2008, 3 MSc theses and 4 BSc theses were awarded under the supervision of the Centre's staff. Also, the Centre is offering a number of graduate courses in the fields covered by the Centre's research themes as well as running a major share of the undergraduate teaching in astronomy at University of Copenhagen. The Centre produced slightly more than 1000 student-ECTS points in 2008.

International Talent Recruitment Programme

In order to attract the brightest international young researchers and students the Centre launched an international talent recruitment programme, funded by two dedicated grants from the DNRF. The PhD student hired through this programme, Tayyaba Zafar, soon integrated well into the group of DARK PhD students and quickly obtained most of the required course points for her entire PhD programme. She also engaged eagerly on her research project on distant galaxies and the properties of gamma-ray burst hosts. By the end of 2008, she was in a position to begin to harvest the first fruits of her work and first results are expected during 2009.

The Centre has obtained funding from the DNRF for the Sophie and Tycho Brahe Programme. The first Brahe fellow, Justyn Maund, joined DARK in September 2008 and has been active here since his arrival. The connection with Santa Cruz is very strong, with Dr. Maund visiting twice already in 2008. The second Brahe professor was identified, Joshua Bloom from the University of California, Berkeley and was appointed in 2008. The second fellow, Berian James (currently at the University of Edinburgh), was selected by a committee from DARK and Berkeley, from strong international competition. James will join DARK in Autumn 2009. The field for the Brahe Fellowship was as large as in 2007, but with an even greater number of excellent candidates, and it appears that the Fellowship already has a significant profile in the community. James is expected to work for two years at the Centre initially, followed by one year at the University of California, Berkeley.

4E. External funding

External funding in 2008 once again exceeded that foreseen in the contract with grants obtained from various national and international sources, including the EU (two Marie Curie grants) and the Lundbeck Foundation. The value of the external funding for salary alone obtained (but not spent) in 2008 (excluding contributions from the host institute), was more than 10 MDKK, and is equivalent to more than 100% of the funding received from the DNRF in 2008.

4F. Awards and recognitions

Every year so far, members of DARK have been honoured for their achievements, by their national governments, by international bodies, or by non-governmental organizations. This year was no exception. PhD student, Dong Xu, was recognized with the Chinese Government Award for Outstanding Self-financed Students Abroad, a prestigious honour and a prize worth 25,000 DKK. Among the faculty, Anja C. Andersen was presented with the 2008 Research Prize of the Danish Association of Masters and PhDs (Dansk Magisterforening), a significant national recognition.

4G. Public outreach

The Centre is engaged in a highly public and comprehensive outreach programme and has established itself in the Danish community and media as a widely known research centre. The Centre primarily targets media, the general public and decision makers, and secondly teachers and students in high school and primary school. The fruitful and operational collaboration with the communications office of the Niels Bohr Institute has been consolidated. Besides the Centre's own

public outreach programme, DARK contributes to public outreach at the Niels Bohr Institute at the same level as the Institute's other research groups. Two press releases were issued in 2008, resulting in wide media coverage in Denmark as well as internationally:

- Brightest ever gamma-ray burst observed (Niels Bohr Institute press release)
- Anja C. Andersen receives the Danish Association of Masters and PhDs research prize 2008 (DM press release)

In addition, 5 news stories were issued through the Niels Bohr Institute communications office. Members of the DARK staff made significant public outreach contributions via books published for the Danish market in 2008: Anja C. Andersen co-authored the book *Pigen der ville give sin mor en stjerne* from Forlaget DRmultimedie and Kristian Pedersen wrote a chapter in the primary school book *Regnbuen 7* from Geografforlaget. 31 popular articles were published on topics ranging from dark energy to life in the Universe. Anja C. Andersen has been a regular columnist for *Weekendavisen*. Centre staff appeared in 25 electronic media (TV, radio, web) productions, and gave 39 popular talks to school classes or the general public.

With faculty serving on several public committees, the Centre is also deeply involved in influencing communication of science nationally and locally. In 2008, Anja C. Andersen served as a member of the Council for the Danish Technical University, the Advisory Board for DTU-Space, board member for Dansk Naturvidenskabsformidling, and as member of the præsidium for Experimentarium. Kristian Pedersen was a member of the Niels Bohr Institute board for communications and he is the national coordinator for the International Year of Astronomy 2009.

4I. Publications

The Centre's scientific output is focussed on the most prestigious and highest impact publication avenues in the astrophysical community: the major international peer-reviewed journals. Less emphasis is placed on conference proceedings. DARK also produces a large number of community-service bulletins—CBET circulars and GCN notices—that are highly valued as tools of the trade. All preprints are posted prior to publication to the arXiv Open Source preprint archive (http://www.arxiv.org). On the Centre website a daily-updated list of published papers sorted by year (all hyperlinked) is maintained, as well as a list of all, as yet unpublished, preprints posted (as of 31 March 2009 there are 43 unpublished papers).

The Centre has once again achieved a high rate of scientific productivity, publishing on average almost one paper every week in 2008 (50 peer-reviewed papers). The citation rate was again high, with an impact factor 30% higher than the community average in these high-impact journals (ApJ, A&A, MNRAS, AJ, JCAP). As of 31 March 2008, the 50 papers published in international refereed journals have received a total of 321 citations according to ADS. It is worth noting that the Centre targets publication in the high-impact journals: the citation rate for papers in these journals is almost twice the average of the total peer-reviewed articles in astrophysics. All statistics are derived from the NASA Astrophysics Data Service (ADS).

Ved underskriften bekræftes det, at beretning og regnskab med tilhørende noter og oversigter indeholder alle oplysninger, som vedrører årets aktiviteter i Danmarks Grundforskningscenter for Kosmologi ved Københavns Universitet.

Jens Hjorth København 31. marts 2009