Danmarks Grundforskningsfonds Center for Kosmologi ved Københavns Universitet

Annual Report 2007 (1 Jan – 31 Dec)
Cover image: Prominent images from the highlights of the year are added to the previous year's images to make a visual tableau of science from the start of the Centre. Highlighted results from 2007 include (clockwise from top left) constraints on the dark energy parameter $w$ from the ESSENCE project, centre leader Jens Hjorth receiving the Eliteforsk prize 2007, the High Energy Focussing Telescope balloon-borne instrument, a gravitational arc caused by the galaxy cluster Abell 1689, and an image of the 'bullet cluster' in total mass and X-rays (contours).
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1. Highlights of the Year

*Dark energy and supernovae*

As part of the international collaboration ESSENCE, researchers at the Centre have observed distant supernovae (exploding stars). ESSENCE is an extension of the original team that discovered the acceleration of the Universe. The observations have pushed the limits of technology through observing light from dying stars that was emitted when the Universe was half its current age (a typical ESSENCE observing field is shown right). Using these supernovae they have traced the expansion history of the Universe with unprecedented accuracy and sharpened our knowledge of what it might be that is causing the mysterious acceleration of the expansion of the Universe. The many new theories that have been proposed have been critically assessed in the face of this new data. It was shown that despite the increased sophistication in cosmological models over the past century, the best model remains one that was proposed by Einstein back in 1917, which uses a cosmological constant to describe the acceleration.

*The nature of dark matter*

New insight into the properties of dark matter was obtained by putting one of the specific dark matter candidates, axions, to a test. Axions are particles originating in theories describing “extra” dimensions and axions will slowly decay and produce X-ray photons. In this study, featured on the cover of Physical Review Letters (left), a massive dark-matter concentration in two colliding clusters of galaxies was searched for the X-ray emission from decaying axions. Although no signal from axions was detected, the lifetime of the axions could be constrained to be at least two hundred thousand times the age of the Universe.

For the first time one of the fundamental distinguishing properties between dark and ordinary matter has been measured, namely that the temperature of dark matter has a directional dependence. This was achieved through the use of X-ray data of two highly relaxed galaxy clusters.

The most detailed mass reconstruction of a galaxy cluster to date was obtained through a gravitational lensing investigation of Abell 1689. This well-calibrated mass model will enable Abell 1689 to be used as a gravitational telescope, and potentially to constrain cosmology.

*New thinking on the death of Sun-like stars*

It has been a mystery how certain dying stars, so-called red giants, which are rich in oxygen, blow enormous quantities of material out into the Universe. Researchers at the Centre found that these stars, in contrast to prevailing opinion, may also produce carbon dust as a supplement to the oxygen-bearing dust types. The radiation from the hot core of the star will push the carbon dust out, thereby forcing the star's outer layers into space, where they are ultimately re-cycled into new stars and planets.
First PhD theses
The first two PhD theses by students at the Centre were successfully defended. Kristin K. Madsen studied high-energy X-ray astrophysics working on the deployment of and data analysis from the High Energy Focussing Telescope, subsequently moving on to Caltech as a postdoc. Kim Nilsson studied the Lyα line as a cosmological tool and took up a postdoc position in Heidelberg.

Elitforsk Prize for Jens Hjorth
The Centre Director Jens Hjorth received the national EliteForsk 2007 prize of 1 MDKK from the Danish Ministry of Science.

2. Organization
Centre faculty member Jesper Sollerman was offered and accepted a permanent position as a lecturer at Stockholm University. Consequently he started to gradually ramp down his presence at the Centre from 80 % to 60 % towards the end of 2007. Jesper will continue to be affiliated to the Centre, eventually at a level of 15 % in 2010.

Given the continued growth of activity at the Centre, a need for increased administrative assistance was identified. Consequently, Julie Meier Hansen was hired as an administrative assistant by the end of the year. Julie’s main areas of responsibility include PhD students, visitors and internal communication.

The Centre conducted its annual internal review in October. The review consisted of four parts: (i) review of Centre organization (core staff) (ii) review of science (core staff) (iii) yearly visit by the DNRF (Chairman of the Board Klaus Bock, Director Thomas Sinkjaer, Research Advisor Klaus Robert Svendsen) (iv) decision meeting (core staff). Based on the discussions and input a list of action items were drawn up and are being put into effect.

Following the annual internal review in 2006, a need was identified for an effective internal communications tool, an intranet for administration, scientific communication and social purposes. The first roll-out of this has occurred in 2007, based on the Plone software. A major revision of the first release is now underway with additional IT support hired dedicated to this revision (Diana Juncher).

The Centre has reached its full capacity for PhD students and is now a major training site for young researchers. By the end of 2007 the Centre was home to 14 PhD students in addition to the two who graduated in 2007 (male/female: 6/8, international/Danish: 10/4).

The first batch of postdocs hired shortly after the start of the Centre completed their appointments and moved on: Max Stritzinger has taken up a position at Las Campanas
Observatory (Chile), Marceau Limousin has taken up a position at the University of Toulouse (France) and Tamara Davis accepted a long-term appointment at the University of Queensland (Australia) while maintaining a part-time position at the Centre. All of them continue to be affiliated with the Centre and individual agreements on conditions for regular, long return visits have been signed. Paul Vreeswijk arrived in July on a Marie Curie Fellowship from ESO, Chile. Dr. Vreeswijk specializes in rapid response, high-resolution observations of GRB afterglows and leads the field worldwide in this area. Jin An, an experienced theorist working on gravitational lensing and dark-matter distributions, arrived at the Centre in September with outstanding recommendations from some of the leaders in the field after successful spells at Cambridge under Wyn Evans and at MIT with Paul Schechter. Dr. An was hired in collaboration with the Niels Bohr International Academy.

The staffing profile of the Centre is international with a fairly balanced gender representation. By the end of 2007 the Centre had a total of 34 staff, PhD, and MSc students, of which 18 were international members and 14 female members, representing 16 different nationalities.

3. Research 2007

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, cosmic dust) expressed as three key projects and a series of smaller or more risky projects.

Key Project 1: Probing the end of the dark ages

The remaining white spot on the map of cosmic history (in addition to the first 10–12 seconds after the Big Bang) is the period often referred to as the ‘dark ages’. The dark ages represent the period between the release of the cosmic microwave background radiation about 300,000 yr after the Big Bang and the formation of the first radiant objects, a few hundred million years after the Big Bang. This period was dark in the sense that there were no sources of visible light in the Universe. Yet, it is crucial for our understanding of cosmogony as this was when the first (non-linear) structures formed through gravitational instability, in particular the first stars, galaxies and super-massive black holes. A ‘First Stars’ workshop was devoted to this Key Project (see Appendix B).

At the Centre several strategies are followed in the pursuit of the end of the dark ages. The main lines of research involve:

Gamma-ray bursts as cosmic lighthouses

GRBs are so powerful that they easily can be detected even at very large distances. The challenge is to detect the most distant GRBs and within a few hours secure spectroscopic observations.

The Centre is now world-leading in the ground-based rapid follow-up of GRBs. In particular, an ESO programme led by Centre faculty member Johan Fynbo and Marie Curie Fellow Paul Vreeswijk (who joined the Centre in July 2007) has been essential in obtaining spectroscopic measurements of GRB afterglows (13 redshifts were measured in 2007). The report on the currently most distant GRB studied at the Centre (the 2nd most distant GRB known) was published in the Astrophysical Journal (Ruiz-Velasco et al.). The lead author is from Mexico. She completed her master's thesis at the Centre and the paper represents the main part of her thesis. The DARK Summer Programme on ‘GRBs, star-formation, and stellar death’ was conducted as part of this Key Project.

In a complementary effort, under the leadership of Jens Hjorth, the Centre is conducting a large survey of galaxies hosting GRBs at the ESO VLT. With a very broad redshift distribution and a mean redshift of 2.8, GRBs are useful tracers of star-forming galaxies. The study of GRB host
galaxies represents an independent selection method, complementary to, and in some respects superior to, other techniques to study galaxies. During the course of this programme additional dedicated manpower was secured: Dr. Daniele Malesani joined the Centre in November 2006 to take care of the photometry and daily management of the programme. Another postdoc, Dr. Bo Milvang-Jensen was hired to do all the spectroscopy of the Lyα runs. International collaboration meetings were held on 11–12 December 2006 and 22–26 October 2007 at the Centre. The survey has been presented at conferences and in papers on individual galaxies.

**Searches for 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. Kim Nilsson completed her PhD thesis on this topic.

In 2007 the UltraVISTA survey co-led by Johan Fynbo was finally approved. The UltraVISTA survey will start in early 2009 and run for 5 years. The goal is to detect the most distant, i.e. the earliest galaxies that formed after the Big Bang.

**Key Project 2: Supernova cosmology**

The Centre continued to investigate the dark energy component of the Universe. This was largely done through existing and newly initiated collaborations related to the leading supernova surveys.

The long-term (6-year) ESSENCE project released their first datasets and faculty member Jesper Sollerman and postdoc Tamara Davis played an important role in this endeavour. The Centre led one of the three papers that comprised this release (Davis et al.), and as of March 2008 it has already received 85 citations. The other two papers are Wood-Vasey et al. and Mikkaitis et al. with 160 and 45 citations respectively. With the publication of the first three years dataset (60 supernovae) from ESSENCE the Centre is already close to the main goal of this Key Project, namely to measure the equation of state of the dark energy to 10% accuracy.

As part of the Sloan Digital Sky Survey (SDSS II) supernova collaboration, Jesper Sollerman, postdoc Max Stritzinger, and PhD student Giorgos Leloudas conducted observing runs both at the ESO NTT telescope in Chile and at the NOT on La Palma, resulting in numerous supernova identifications and about 15 CBET circulars. The Centre is now well established within the SDSS II supernova collaboration and a European node meeting took during the Centre’s Dark Energy workshop (see Appendix B). The workshop had participants from members of the SDSS II and ESSENCE groups as well as the SuperNova Legacy Survey, which is the third large collaboration on cosmological supernova search. A collaboration regarding gravitational lensing of supernovae was initiated.

Other research includes using supernovae to probe the local velocity field (Haugbolle et al.), studies in the use of supernovae as standard candles (Davis et al.) and detailed observations of Type Ia supernovae (e.g. Stritzinger & Sollerman).

In an effort to understand theoretically how dust forms in stellar environments, a new universal mechanism for mass loss in cool stars has been proposed (Höfner & Andersen). It has long been a mystery how the majority of (oxygen-rich) cool giant stars loose a substantial fraction of their mass and inject chemical elements and dust grains into the interstellar medium towards the ends of their lives. While the (carbon) dust-driven winds of carbon-rich stars are well understood, the mechanism behind mass loss in oxygen-rich stars remained a mystery because silicate grains, dominating in oxygen-rich environments, fail to provide sufficient acceleration for driving stellar winds. The new finding is that non-equilibrium effects, sufficient to free up a fraction of carbon for dust formation, leads to a universal mass loss mechanism in both carbon-rich and oxygen-rich stars, with silicates forming as a by-product. This mechanism strongly favours the presence of magnesium silicates over iron silicates in the interstellar medium, as also seen in comets. With this finding a significant number of recent observations can now be explained.
As part of the project on dust production in supernovae, the Centre participated in an important study using the Spitzer Space Telescope (Meikle et al.). These observations are aiding the Centre’s current attempts to model the environment of dust formation in supernova progenitor stars and supernova remnants.

Key Project 3: The nature of dark matter
A sample of 30 X-ray luminous clusters was studied using X-ray observations and weak gravitational lensing in order to determine the normalization of the mass—temperature relation for nearby galaxy clusters (Pedersen & Dahle). The normalization is consistent with other studies, but the scatter around the relation is fairly large. This indicates that it is not straightforward to determine cluster masses accurately for distant clusters based on the global X-ray temperature, and hence to use this method to constrain cosmological parameters.

Some dark-matter candidates are predicted to produce photons when decaying, which might be detectable in the X-ray or γ-ray bands. The Centre has analyzed X-ray observations of dark-matter concentrations of ‘dark blobs’ in galaxy clusters in order to constrain the lifetime of axions as well as the mass and mixing angle of sterile neutrinos. The simplest models of sterile neutrino production in the early Universe are now ruled out by the X-ray data (Riemer-Sörensen et al.). The tighter constraints on the axion lifetime were obtained in collaboration with the team behind the CERN Axion Solar Telescope who are trying to detect axions produced in the Sun in a laboratory experiment at CERN (Riemer-Sörensen et al.). Combining data from cosmic X-ray and γ-ray observations with laboratory experiments appears to be a promising route to home in on the nature of dark matter.

Numerical simulations have, over the last 10–15 years, indicated that cosmological dark matter structures have non-zero velocity anisotropy, which means that the local concept of “temperature” is highly non-trivial. Such counter-intuitive behaviour of the dark matter has always been looked upon with suspicion, mainly because this was believed to be impossible to measure. The Centre has made two major contributions to this field of research over the last year: (1) For the first time the dark-matter anisotropy has been measured directly. This was achieved through the use of X-ray data of two relaxed galaxy clusters (Hansen & Piffaretti). The fact that a non-zero velocity anisotropy was found confirms that dark matter really is collisionless, and that dark matter behaves fundamentally different from normal matter. (2) It was shown that future terrestrial detectors will be able to measure this velocity anisotropy of our Galactic halo directly (Host et al.). This will be possible since directionally sensitive underground detectors are now being developed.

Smaller or more risky projects

Modeling Lyα emission from early galaxies
This year saw the publication of results based on fully cosmological simulations of galaxy formation, showing the effects of resonant Lyman-α scattering on the appearance of young galaxies reported briefly last year (Laursen & Sommer-Larsen), as well as modelling of the production of Lyman continuum emission in galaxies at high redshift, showing that effects of gas infall and clumping diminishes the far-UV emission in spite of increasing star-formation rates at redshifts from 3.6 to 2.4 (Razoumov & Sommer-Larsen). Furthermore, simulations were used to interpret observations of coincident 100 kpc-scale absorbers, indicating that they are likely to originate in separate small galaxies, and that coincident line-of-sight absorbers may significantly affect abundance estimates of damped Lyman-α absorbers (Ellison et al.).

Measurement of extinction curves using afterglows of GRBs
A high-impact target of opportunity programme with the Spitzer Space Telescope was approved this year (PI D. Watson) to observe a bright GRB afterglow to determine, for the first time, the absolute extinction curve of a star-forming galaxy in the early universe. The programme runs for one year from June 2007. To date the correct circumstances have yet to occur to trigger activation.
**Obscured star-formation**
Analysis of available Spitzer Space Telescope imaging on GRB host galaxies has been completed and results submitted (Castro Cerón et al.). Modelling of the complete spectral energy distributions of GRB hosts has been very recently published (Michalowski et al.) and will be reported for the year 2008.

**Measuring dark matter in distant galaxies and galaxy clusters; Gravitational lensing**
Activity in the area of gravitational lensing was particularly pronounced in 2007. The most robust reconstruction to date of the mass distribution of the galaxy cluster Abell 1689 was made, using detected strong lensing features, paving the way for the use of Abell 1689 as a gravitational telescope and for cosmology (Limousin et al.). A similar analysis was performed for Abell 68, using the cluster to probe the faint end of the galaxy Lyα luminosity function (Richard et al.). The massive galaxy cluster MS 2053.7–0449 was shown to have a bimodal mass distribution (Verdugo et al.), and a procedure developed and presented that can model strong lensing galaxy clusters and to rank the models using Bayesian evidence (Jullo et al.). The strong lensing properties of the Sérsic and Navarro, Frenk & White dark matter profiles were compared and the use of the Sérsic profile was found to be potentially important (Elíasdóttir & Möller). Galaxy-galaxy lensing in galaxy clusters was also used to show the effective truncation of dark matter halos in dense environments (Limousin et al.).

**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 several years.
2. Completion of the GRB host galaxy survey. The full dataset will be available in 2008.
3. The successful installation of the X-shooter spectrograph on the ESO VLT.
4. Selection and design of the observing programme for the guaranteed time on X-shooter.
5. Hiring of a dedicated scientist devoted to the UltraVISTA survey.
6. Initial studies for the use of a galaxy cluster as a gravitational telescope.

**Supernova cosmology**
1. Publication of the full six-year dataset from ESSENCE (almost 200 supernovae) which will conclude this major endeavour.
2. Publication of the first-year data (90 supernovae) at intermediate redshifts from the SDSS II search.
3. Complete a thorough investigation of the idealized assumption in current supernova dust-forming models and thus provide reliability estimates for the current results.

**The nature of dark matter**
1. Finalize a pipeline for simulating data obtained with the X-ray satellite, XMM-Newton from galaxy clusters.
2. Quantify the allowed range of properties of dark matter based on archival data from the EGRET gamma-ray satellite.
3. Set up procedures for simulating a dark-matter annihilation signal, which might be observed by the GLAST satellite.
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.
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.

**Small or more risky projects**

1. Based on simulations, investigate how well the mass of a galaxy cluster can be derived from Sunyaev-Zeldovich observations.
2. Investigate procedures for combining X-ray data and Sunyaev-Zeldovich data for measuring cluster masses to large cluster-centric radii.
3. Make prescription for how to derive cluster masses from Sunyaev-Zeldovich data.
4. Obtain cluster masses for a couple of clusters for which X-ray and Sunyaev-Zeldovich data are available.
5. Trigger Spitzer ToO observation to obtain the first total extinction curve of a high-redshift galaxy.
6. Begin a systematic analysis of metal column densities in GRB host galaxies compared to dust column densities.
7. Publish the first observationally complete spectral energy distribution of a GRB host galaxy.
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.

**4A. External relations**

The research conducted at the Centre is highly international, as evidenced by the fact that the refereed papers published in 2007 have authors affiliated to over a hundred institutions from dozens of countries worldwide. This comes from established networks and consortia but is 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 the Appendix, including Centre associate scientists and IARU contacts. 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”. The network has partially funded PhD students Árdís Eliašdóttir and Chloé Féron and postdoc Benjamin Dobke. There is also collaboration with all Danish astrophysics research institutes.

The Centre has continued its visitor programme, including collaboration with its associates. The visitor programme is also used to invite speakers for local collaboration meetings. 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. Lists of past, current, and future visitors are maintained at the Centre web site (http://www.dark-cosmology.dk/visitors/).

**4B. Conferences**

The Centre held the 2007 Niels Bohr Summer Institute, hosted and partly funded by the Niels Bohr International Academy (http://nbia.dk/?con=NBSI.html). The Summer Institute consisted of three workshops addressing three of the main research themes of the Centre: (1) A ‘First Stars’ workshop (related to the Dark Ages theme) was held 16–20 April. About 40 international scientists gathered, with expertise in a range of fields related to the nature of the first stars formed after the Big Bang, very distant galaxies and GRBs. (2) The goal of the ‘Dark Matter’ workshop was to increase understanding of dark-matter structures. Approximately 35 theoreticians, numerical simulators and observers gathered during 20–24 August. The discussions and presentations were aimed at achieving an understanding of the physics responsible for the universalities of dark-matter structures. (3) During 27–31 August, the Centre arranged a ‘Dark Energy’ meeting at which 21
supernova experts from around the world worked alongside local participants in workshops on dark energy.

The Centre also launched a new initiative, the ‘DARK Summer Programme’ aiming to focus on a specific topic among Centre members and key visitors. The 2007 programme on the topic of ‘GRBs, star-formation, and stellar death’ involved about 10 visiting scientists during a month in July–August.

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. Contributions to national meetings or seminars are not listed. 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. The Centre strives to achieve this by lively and informal contact between PhD student and supervisor on a daily basis in the Centre’s international environment. 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. 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.

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. Faculty members of the Centre contributed to the organization of DARS as well as planning and giving DARS courses for PhD students, in particular the annual DARS meeting in Ebeltoft, January 2007, and the DARS summer school on observational astrophysics at the Nordic Optical Telescope, August 2007.

Faculty members at the Centre are offering KU students MSc and BSc projects within cosmology in order to attract the most talented students. In 2007, 3 MSc theses and 7 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 our research plan (dark matter, dark energy, and to some degree galaxy formation) as well as running a major share of the undergraduate teaching in astronomy at KU. The Centre produced a total of 1126 student-ECTS points in 2007.

International Talent Recruitment Programme
Upon announcement and evaluation by the DNRF, the Centre was granted 1 PhD stipend and expenses for inviting a handful of international candidates PhD students for interviews as well as funding of two summer internships.

The idea behind the summer internships was to attract bright international students and potentially recruit them as PhD students. The internships were organized as two-month visits at the Centre where the students worked on small research projects in close collaboration with Centre faculty to assess the scientific potential of the students. The internships were announced internationally at the beginning of June shortly after the grant was obtained, mainly through our collaborators abroad and on the Centre web site. Thirteen applications were received from Mexico (2 applications), Spain, Romania, Iran (3 applications), Serbia, Finland, Brazil, Russia, France, and Turkey. Of these, 8 applicants were qualified and the two applicants on top of the list were selected (Milica Milosavljevic, Serbia, and Felipe A. Santos, Brazil).

Prior to arrival, each student was assigned a Centre faculty member and the supervisors and students discussed ideas for projects. Upon arrival, project plans were finalized and for each student, a Centre student-mentor was appointed, who helped out with the practicalities of student life at the Centre and in Copenhagen in general.
At the end of the summer internship, each student gave an informal talk on the projects and submitted a short project report. Both interns have maintained contact with Centre scientists and are currently working on extensions of the summer projects.

The PhD stipend was announced on July 1 and 17 applications were received. Five candidates visited the Centre for a week in the end of August for a written test followed by an interview. The purpose of the week-long stay was to assess how the applicants approached the problems posed in the written test (for which they had two full days) and to see how they interacted with Centre staff and students. Since the two summer interns were also considered for the PhD stipend, they answered the written test and were interviewed as well. Tayyaba Zafar from Pakistan was offered, and accepted, the PhD stipend and she was subsequently enrolled as PhD student at the Centre, University of Copenhagen, by December 20.

The Centre has obtained funding from the DNRF for the Sophie and Tycho Brahe Programme. The first Brahe professor, Enrico Ramirez-Ruiz from the University of California, Santa Cruz was appointed in 2007. The first fellow (Dr. Justyn Maund, currently at the University of Texas, Austin) was selected from strong international competition in association with the University of California, Santa Cruz, and should arrive at the Centre in Autumn 2008. The competition for the Brahe Fellowship was substantially more intense than postdocs recruited in the traditional manner. Dr. Maund is expected to work for two years at the Centre initially, followed by one year at the University of California, Santa Cruz.

4E. External funding

External funding in 2007 exceeded that foreseen in the contract. The value of the external funding for salary alone (excluding salary contributions for permanent staff from the host institute), 5.7 MDKK, is equivalent to almost 70% of the funding received from the DNRF in 2007.

4F. Awards and recognitions

In addition to the awards and recognitions listed in Appendix F (excluding grants) it is noted that Jesper Sollerman was offered and accepted a permanent position as a lecturer at Stockholm University.

4G. Public outreach

It is one of the Centre’s outstanding strengths that it is engaged in a highly public and wide-ranging outreach programme and has established itself in the Danish community and media as a widely known research centre. The Centre has defined a communications strategy, which is effectuated by the communication officer who also serves as the single point of contact regarding all communications enquiries and issues. With faculty serving on many public committees, the Centre is also deeply involved in the development of science nationally and locally.

Four major press releases were issued in 2007, resulting in wide media coverage in Denmark as well as internationally:

- Dark energy may be vacuum: New results on the expansion history of the Universe from the ESSENCE supernova survey (Niels Bohr Institute press release)
- Controlled by cosmic explosions: VLT automatically takes detailed spectra of gamma-ray burst afterglows only minutes after discovery (ESO press release)
- New thinking on the death of Sun-like stars (Niels Bohr Institute press release)
- Dark matter has a long lifetime: X-ray search for decaying dark matter particles (Niels Bohr Institute press release)

The Centre made significant public outreach contributions via books published for the Danish market in 2007: *Stjernetvøg og Galakser* ved Forlaget DRmultimedie, and *Stjernesunder* ved Borgens forlag.
Popular articles were published on topics ranging from cosmic dust to dark energy, and in particular the series of six popular articles for *Naturens Verden* on the science the Centre focuses on was completed. Anja C. Andersen and Kristian Pedersen were engaged as permanent column writers in the weekly science section of the national newspaper *Politiken* for the first half of the year. For the second half of the year Anja C. Andersen has been a regular columnist for *Weekendavisen*.

The Centre was engaged in numerous TV, radio, newspaper, and magazine interviews, and popular talks to school classes as well as the general public.

In 2007 Anja C. Andersen served on the following committees: Expert Panel Member for the European Commission’s Descartes Science Communication Prize, member of the Danish Academy of Technical Sciences Think Tank. Kristian Pedersen was a member of the Niels Bohr Institute board for communications, a member of the board of the Danish Physical Society, and is the national coordinator for the International Year of Astronomy 2009.

4I. Publications

As noted in previous reports, the Centre focuses on publications with high standing in the scientific community internationally, i.e. publications in the most prestigious journals in the field, and places little emphasis on publications in proceedings from conferences (though there is a significant output of rapid-release community-service bulletins—IAU circulars and GCN notices—which are also highly-valued as tools of the trade in the GRB and supernova communities). 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 at the arXiv archive (as of 31 March 2008 there are 27 unpublished papers). All preprints are posted prior to publication to the arXiv Open Source preprint archive (http://www.arxiv.org).

Any newly initiated research centre would be expected to take some lead-in time to reach a high level of scientific output given considerations such as time taken to construct and hone an administrative set-up and to hire researchers and other staff. In this regard, however, the Centre has hit the ground running: its first one and a half-year of operation were, by any standards, remarkably successful. The year 2007 continued to be marked by very high output of scientific papers and very high citation rate. Through ADS, CITEBASE or SLAC/SPIRES there is ready access to citation statistics for the Centre publications. As of 31 March 2008 the 58 papers published in international refereed journals in 2007 have received a total of 730 citations according to ADS, 260% the average citation rate in this period for the journals in which the Centre published (including *Nature* and *Science*). It is worth noting that the Centre publishes predominantly in the high-impact journals: the citation rate for Centre papers is in fact more than 4 times the average of the total peer-reviewed astrophysics literature in 2007—the Centre was responsible for 0.3% of the peer-reviewed astrophysics papers published worldwide and 1.4% of the citations. (To date, the 57 papers listed in the 2005 and 2006 annual reports have received 1566 citations).


Jens Hjorth

København 3. april 2007

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