State Committee for Scientific Research – KBN For KBN use only

00-529 Warszawa Nr.

ul. Wspólna 1/3 Group

POLAND

GRANT APPLICATION

Project Title:

Search for Topological Lensing
of Radio-Loud Active Galactic Nuclei and Galaxy Clusters

A. APPLICANT DATA

1. Name and address of the organization where work will be performed (include department, institute, laboratory, and chair, as applicable):

Toruń Centre for Astronomy, Nicolas Copernicus University, ul. Gagarina, 11, Toruń 87-100; director prof. hab. dr Andrzej Kus

2. Principal Investigator (include title, first name, last name):

dr Boudewijn Roukema

3. Principal Investigator's employer, if different from above organization (include department, institute, laboratory, and chair, as applicable):

(same as above)

B. GENERAL DATA

1. Funding period: **36**..months

2. Number of personnel involved in the project: **6**

3. Type of project (pick one): **Individual Project**

4. Requested funding amount (in Polish zlotys Polish zloty annual 2002 mid - rate against the euro is estimated at 3,95 (Ministry of Finance - draft budget for the Year 2002) - zł):

[200-300 kzł seems reasonable, will depend on breakdown below]

5. Keywords:

observational cosmology, cosmic topology, radio-loud active galactic nuclei, clusters of galaxies

6. **Project summary** (not to exceed 1 page; may be published by KBN if grant is awarded):

Search for Topological Lensing of Radio-Loud Active Galactic Nuclei and Galaxy Clusters

The Hilbert-Einstein equations are insufficient to describe the geometry of the Universe, as they only constrain a local geometrical property: curvature. A global knowledge of the geometry of space, if possible, would require measurement of the topology of the Universe. Since the subject was discussed in 1900 by Schwarzschild, observational attempts to measure global topology have been rare for most of this century, but have accelerated in the 1990's due to the rapidly increasing amount of observations of non-negligible fractions of the observational sphere.

The basic physical test for measuring the topology of the Universe is simple from a naïve theoretical point of view: it is sufficient to see multiple images of extragalactic objects whose light travels to the observer via straight lines (geodesics) in different directions, or in other words that crosses the Universe from different directions or more than once. Hence, the term "topological lensing", since whatever theory might in the future explain the global shape of the Universe will presumably be an extension of general relativity, and just as general relativity is tested by gravitational lensing, where single objects such as high redshift galaxies are seen several times, the future theory (probably a theory of quantum gravity) should be constrained by topological lensing.

In practice, just as the individual and statistical observational properties of extragalactic objects have made determination of local cosmological parameters (such as the matter density parameter, the cosmological constant and the Hubble constant) much more difficult than was hoped, their properties make the search for topological lensing difficult.

The most promising objects at high redshifts for detecting topological lensing are those we can see in large numbers and across large volumes of space: (1) active galactic nuclei (AGNs) and (2) clusters of galaxies.

In the Toruń Centre for Astronomy, we have a combination of

(i) existing observational expertise in radio-loud AGNs (RLAGNs) including the study of the evolution of RLAGNs (Marecki, Kunert, Gawroński); and

(ii) with the OCRA (One-cm Radio Array) project, we hope to soon obtain a catalogue of thousands of clusters of galaxies at high redshifts via the Sunyaev-Zel'dovich Effect (Soberski); and

(iii) the PI (Roukema) has developed observational strategies for investigating cosmic topology.

For this reason, we have an excellent opportunity at TCfA to excel in this field. Although our focus will be on the use of RLAGNs and clusters of galaxies, knowledge of cosmic microwave background (CMB) observational analyses will be crucial for independently checking any serious candidates for topological lensing; hence the inclusion of Lew who is presently studying CMB data.

C. STAFF INFORMATION

For the Principal Investigator and each senior staff member, provide the following biographical information:

1. *Name*

dr Boudewijn Roukema

2. *Educational history including, for each degree, the field, institution, and date obtained*

1989-93: Doctor of Philosophy (Ph.D.) in Astronomy and Astrophysics, Mt Stromlo and Siding Spring Observatories (M.S.S.S.O.), Australian National University (A.N.U.), Canberra.

1985-88: Bachelor of Science (Hons), Australian National University, Canberra, Australia (awarded National Undergraduate Scholarship for this degree)

3. *Academic and professional appointments, in reverse chronological order*

since 2002: adiunkt, Toruń Centre for Astronomy, Uniwersytet Mikołaja Kopernika, Toruń, Poland
2001: visitor, DARC/LUTH (Laboratoire de l'Univers et ses Théories), Observatoire de Meudon, France
1998–2000: postdoctoral fellow, Inter-University Centre for Astronomy & Astrophysics, Pune, India
Feb–July 1998: visitor, CAMK, Warszawa
1996–1997: Centre of Excellence foreign visiting fellow, NAOJ, Mitaka, Tokyo, Japan
1994–1995: postdoctoral research fellow, Astronomy Centre, University of Sussex, U.K.
Jan/Feb 1994: visitor, Institute of Astronomy, University of Cambridge, United Kingdom
1993: postdoctoral fellow, Institut d'Astrophysique de Paris, CNRS, France

4. *Brief descriptions of research projects completed in the last four years, including up to 10 publications (provide publication data).*

Main Research Interests
(i) *Observational Cosmology* and (ii) *Galaxy Formation*: (i) Observational constraints on statistics of "large scale" structure, observational constraints on local cosmological parameters (such as the density parameter and the cosmological constant), and observational programmes to try to constrain global cosmological parameters; (ii) Merging-history-tree based galaxy formation models in a cosmological context and their comparison with observational galaxy statistics.

1 Roukema, B.F. & Bajtlik, S., 1999. *Transverse Galaxy Velocities from Multiple Topological Images, Monthly Notices of the Royal Astronomical Society,* **308,** 309 (arXiv:astro-ph/9903038)

2 Roukema, B.F., 2000a. *COBE and Global Topology: An Example of the Application of the Circles Principle,* *Monthly Notices of the Royal Astronomical Society,* **312,** 712 (arXiv:astro-ph/9910272)

3 Roukema, B.F. & Mamon, G.A., 2000. *Tangential Large Scale Structure as a Standard Ruler: Curvature Parameters from Quasars,* *Astronomy & Astrophysics,* **358,** 395 (arXiv:astro-ph/9911413)

4 Roukema, B.F., 2000b. *A Counterexample to Claimed COBE Constraints on Compact Toroidal Universe Models,* *Classical and Quantum Gravity,* **17,** 3951 (arXiv:astro-ph/0007140)

5 Roukema, B.F., 2000c. *The Topology of the Universe,* *Bulletin of the Astronomical Society of India,* **28,** 483 (arXiv:astro-ph/0010185)

6 Roukema, B.F. & Mamon, G.A., 2001. *Lifting cosmic degeneracy within a single data set,* *Astronomy & Astrophysics,* **366,** 1 (arXiv:astro-ph/0010511)

7 Roukema, B.F., 2001b. *How to distinguish a nearly flat Universe from a flat Universe using the orientation independence of a standard ruler,* *Astronomy & Astrophysics,* **369,** 729 (arXiv:astro-ph/0102095)

8 Roukema, B.F., 2001d. *On the comoving distance as an arc-length in four dimensions,* *Monthly Notices of the Royal Astronomical Society,* **325,** 138 (arXiv:astro-ph/0102099)

9 Roukema, B.F., Ninin, S., Devriendt, J., Bouchet, F.B., Guiderdoni, B., Mamon, G.A., 2001. *Star Formation Losses Due to Tidal Debris in 'Hierarchical' Galaxy Formation,* *Astronomy & Astrophysics,* **373,** 494 (arXiv:astro-ph/0105152)

10 Roukema, B.F., Mamon, G.A., & Bajtlik, S., 2002. *The Cosmological Constant and Quintessence from a Correlation Function Comoving Fine Feature in the 2dF Quasar Redshift Survey,* *Astronomy & Astrophysics,* **382,** 397 (arXiv:astro-ph/0106135)

5. *Awards received*

1. *Name*

dr Andrzej Marecki

2. *Educational history including, for each degree, the field, institution, and date obtained*

3. *Academic and professional appointments, in reverse chronological order*

4. *Brief descriptions of research projects completed in the last four years, including up to 10 publications (provide publication data).*

5. *Awards received*

D. PROJECT DESCRIPTION, METHODOLOGY, AND EXPECTED RESULTS

What problem is being proposed and why? Why should this work be undertaken in Poland?

The problem being posed is to try to measure the shape of the Universe. This is important because the Universe is the object in which we live and it is of obvious scientific and cultural interest to be aware of the shape of the object in which we live.

It should be undertaken here because we have a combination of present and developing observational expertise in radio-loud active galactic nuclei (RLAGNs) and clusters of galaxies via the Sunyaev-Zel'dovich Effect respectively, plus expertise in the development of observational strategies for measuring cosmic topology.

Poland has obvious historical precedents in showing that the Earth is not the centre of the Universe, and that planets around other stars exist. It would clearly be good to continue the tradition on a much larger length scale (Gigaparsecs).

What is the present state of knowledge in the field, and to what extent does this project verify it? How will the project advance discovery and understanding in its field or across fields? Is this a new or a continued problem?

It is clear that topological lensing on scales of a few hundred Megaparsecs is extremely unlikely. Attempted constraints on scales from 1 Gigaparsec ($1h^{-1}$Gpc) to the horizon diameter of about $20h^{-1}$Gpc are much weaker and generally very model dependent.

This project will use RLAGNs and clusters of galaxies up to redshifts of about $z \sim 2-3$ as tracers, covering a volume of about half the diameter of the observable Universe, i.e. about $10h^{-1}$Gpc. It will advance discovery and understanding by using these tracers as realistically as possible given understanding of their evolution and properties. This problem dates back to the pre-relativistic era (Schwarzschild 1900), but has only been tackled non-trivially since the early 1990s. Work on this theme is still in the pioneering stage.

What is the proposed methodology? How will it solve the problem? What equipment will be used? Does the applicant have the required equipment skills and access?

The methodology is to use a range of methods, from studies of individual objects to statistical studies of large catalogues, and to parametrise understanding of the properties of the tracers in order to make these methods as observationally precise as possible. Just as the supernova type Ia method was just one among many methods for measuring local cosmological parameters, it is impossible to predict beforehand which specific method for measuring topological lensing will first yield highly significant results.

Although the TCfA 32m telescope will be used for part of the general understanding of RLAGNs and for the OCRA project, which should yield large numbers of high-redshift clusters of galaxies, use of existing public catalogues such as those available at the Centre de Données astronomiques de Strasbourg (CDS) and the information processing analysis requires the use of computers and computer peripherals.

We do have access to these telescopes and databases and have experience managing computer resources.

What are the expected results of this project ("know-how", patents, methods, equipment), and how will they be disseminated (publications, conference presentations, PhD theses)?

This is a **research** project, not a **development** project, and the required theory which goes beyond general relativity has not yet been developed, so while we would hope to detect topological lensing, the results cannot be predicted before they are found.

Articles on the results will of course be published in refereed journals, presented at conferences, and professionals and non-professionals will be able to follow (and maybe participate) in the research on our web pages via the normal methods of internet culture such as publicly archived mailing lists and wiki pages.

E. SOLICITED PROJECTS ONLY: DOES THE APPLICANT MEET THE CALL CRITERIA, PARTICULARLY THOSE CONCERNING INTERNATIONAL COOPERATION?

N/A

F. PROJECT SCHEDULE - ANTICIPATED TASKS

No. Name and description of task Expected completion date (mm/yy) Expected cost (zł)
Total

G. PROPOSED BUDGET

No. Item Funds for each budget year (zł) Total
1 Direct costs, including:
1/ Salaries and benefits
2/ Equipment
3/ Other direct costs
201550PLN
2 Indirect costs admin costs to UMK - 25⇒≈ 50kPLN
3 Total costs (1+2) 260kPLN

Details of direct cost items

1) Salaries and benefits

Principal Investigator person-months

Based on KBN guidelines, 100% of 11500PLN/annum for the principal investigator and 50% of 11500PLN/annum for other investigators is considered reasonable. Hence:

i dr Boudewijn Roukema 11500PLN *3 = 34500 PLN

Staff person-months

i dr Andrzej Marecki 5750PLN *3 = 17250 PLN

ii mgr Magda Kunert 5750PLN *3 = 17250 PLN

iii mgr Sebastian Soberski 5750PLN *3 = 17250 PLN

iv mgr Marcin Gawroński 5750PLN *3 = 17250 PLN

v (future mgr) Bartosz Lew 5750PLN *3 = 17250 PLN (from time of award of Magister degree)

Total: 120.75 kPLN

2) Equipment (type, estimated cost, planned month of purchase, and justification)

* inkjet scanner/copier/printer? + 3yrs insurance (loss/theft/etc.) (an inkjet PSC 750 costs 900PLN but the cartridges are expensive) 1kPLN
* colour laserwriter/scanner/copier? + 3yrs insurance (loss/theft/etc.) 7kPLN?
* portable computer ("notebook")? + 3yrs insurance (loss/theft/etc.) 7kPLN?
* non-portable computer - AMD Athlon? + 3yrs insurance (loss/theft/etc.) 7kPLN
Total: 22kPLN
(should be OK over two years within spending recommendations)

3) Other direct costs (type of expenditure, amount, and relation to project plan)

4900PLN(???)/month for visitors
12 person-months -> 58800PLN

Date	*Grantee organization* Kierownik: Prorektor ds Nauki i Współpracy z Zagranicą prof dr. hab. Marek Zaidlewicz Kwestor mgr Henryk Heldt	*Principal Investigator*; dr Boudewijn Roukema
	Signature	Signature