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 (01.2004 – 12.2006)

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

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

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

484825 PLN

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 Receiver 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. We are fortunate to have the presence in our group of an expert in CMB data, Bartosz Lew, who we expect to achieve the status of Magister during 2003.

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*

1980 MSc (astronomy) UMK, Toruń
1992 PhD (astronomy) UMK, Toruń

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

since 1992 adiunkt, Centrum Astronomii, UMK, Toruń

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

Brief description of research projects:
Interfermetric observations of radio-loud AGN (RLAGN) aimed to reveal structures of compact i.e. *young* objects. Selection and observations (MERLIN, VLBI) of a new sample of faint compact objects. Measurements of the velocities of the components in such radio structures.

1 Marecki, A., Falcke H., Niezgoda J. Garrington, S.T., Patnaik A.R. (1999) "Gigahertz Peaked Spectrum sources from the Jodrell Bank-VLA Astrometric Survey" A&AS 135, 273

2 Fanti, C. ... Marecki, A., et al. (2000) "ISO observations of a sample of CSS and GHz Peaked Spectrum radio galaxies", A&A 358, 499

3 Browne, I. W. Marecki, A., et al. (2000) "OCRA: a one-centimeter receiver array" SPIE 4015, 299

4 Kunert, M., Marecki, A. et al. (2002) "FIRST-based survey of Compact Steep Spectrum sources. I. MERLIN images of arc-second scale objects" A&A 391, 47

5 Marecki, A. et al. (2003) "Location of Weak CSS Sources on the Evolutionary Path of Radio-Loud AGN", PASA 20, in press (astro-ph/0211253)

6 Marecki, A. et al. (2003) "Weak CSS Sources from the FIRST Survey", PASA 20, in press (astro-ph/0211249)

7 Marecki, A. et al. (2003) "1245+676 - a CSO/GPS source being an extreme case of a double-double" PASA 20, in press (astro-ph/0209212)

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 (comoving) 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 correct and precise as possible. Just as the supernova type Ia method was only one among many methods proposed for measuring local cosmological parameters, but happened to be the most dramatically successful, 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 in the long term 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)
1	parametric modelling of projection and evolution effects of multiple images	6/2004	21653 PLN
2	application to individual candidate pairs	12/2004	21653 PLN
3	purchase computer items	12/2004	44700 PLN
4	international cosmology consultants	12/2004	20400 PLN
5	conferences, public relations	12/2004	47710 PLN
6	predictions of further images	6/2005	21653 PLN
7	statistical analysis of RLAGN catalogues	12/2005	21653 PLN
8	international cosmology consultants	12/2005	20400 PLN
9	conferences, public relations	12/2005	47710 PLN
10	statistical analysis of cluster catalogues, OCRA predictions	6/2006	21653 PLN
11	predictions of further images	12/2006	21653 PLN
12	international cosmology consultants	12/2006	20400 PLN
13	conferences, public relations	12/2006	47710 PLN
Total			378948 PLN

G. PROPOSED BUDGET

No. Item	Funds for each budget year (zł)			Total
	2004	2005	2006	
1 Direct costs, including:				
1/ Salaries and benefits	43306	43306	43306	129918 PLN
2/ Equipment	44700			44700 PLN
3/ Other direct costs				
international cosmology consultants	20400	20400	20400	61200 PLN
conferences, public relations	47710	47710	47710	143130 PLN
Subtotal:	156116	111416	111416	378948 PLN
2 Indirect costs (admin costs to UMK - 25% 1st yr; 30% 2nd, 3rd yrs)				
	39029	33424	33424	105877 PLN
3 Total costs (1+2)	195145	144840	144840	484825 PLN

Details of direct cost items

1) *Salaries and benefits*

Principal Investigator **36** *person-months*

Based on KBN guidelines, 100% of 11800PLN/annum for the principal investigator if dr., 75% for other investigators if dr., 50% of 11800PLN/annum for other investigators if mgr. Hence:

(i) dr Boudewijn Roukema 11800PLN *3 = 35400 PLN

Staff **96** *person-months*

(ii) dr Andrzej Marecki 7906 PLN *3 = 23718 PLN

(iii) mgr Magdalena Kunert 5900 PLN *3 = 17700 PLN

(iv) mgr Sebastian Soberski 5900 PLN *3 = 17700 PLN

(v) mgr Marcin Gawroński 5900 PLN *3 = 17700 PLN

(vi) (2003 mgr) Bartosz Lew 5900 PLN *3 = 17700 PLN

Total: 129918 PLN

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

Justification: These computing facilities are needed for synthesis and analysis of empirical data, and for creating added value of the scientific products of the project (presenting and communicating results). Comparison of pairs of objects in a large catalogue is an N^2 operation, i.e. it is CPU intensive. It can be speeded up by making introducing prior assumptions. However, the history of astronomy shows that making reasonable, but wrong, assumptions often leads to missing a real signal, so having good CPU power would be an advantage to the project.

Purchases are planned for 2004.

(i) inkjet scanner/copier/printer + 3yrs insurance (loss/theft/etc.) (an inkjet PSC 750 costs 900PLN; recycled cartridges cost about 35 PLN B/W, 50 PLN colour) 1 kPLN

(ii) colour laserwriter/scanner/copier + 3yrs insurance (loss/theft/etc.) 7 kPLN

(iii) computer (Gawroński) - AMD Athlon, 2GHz, 512Mb RAM, 100Gb hard disk, CD burner, ethernet card, 19” screen + 3yrs insurance (loss/theft/etc.) 7 kPLN

(iv) computer (Lew) - AMD Athlon, 2GHz, 512Mb RAM, 100Gb hard disk, CD burner, ethernet card, 19” screen + 3yrs insurance (loss/theft/etc.) 7 kPLN

(v) computer (Kunert) - AMD Athlon, 2GHz, 512Mb RAM, 100Gb hard disk, CD burner, ethernet card, 19" screen + 3yrs insurance (loss/theft/etc.) 7 kPLN

(vi) computer peripherals (Marecki) - 2 SCSI 73Gb disks + 3yrs insurance (loss/theft/etc.) 5 kPLN

(vii) computer peripheral (Soberski) - CD burner 200 PLN, 512Mb RAM 500 PLN, total 700 PLN

(viii) portable computer ("notebook") (available to all members of the group) + 3yrs insurance (loss/theft/etc.) 10 kPLN

Total: 44700 PLN

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

These relate to the project plan in that the project is internationally competitive research and so (1) international consultants are required for providing theoretical insights and observational strategies regarding the ways in which RLAGNs and clusters of galaxies can be used as candidate topologically lensed objects, and (2) we need to be able to present our results at international conferences and consult international experts at their home research institutes.

(1) The research environment for an internationally competitive research project requires consultations from international experts for periods of between 1 week and a few months. Three people each for one month, and four people each for a week, per year, yields a total of 12 person-months over the three-year period of the project.

At a rate of 5100 PLN/month for international consultants in cosmology, we have

Total: 61200 PLN

(2) In order to present our results at conferences and other public relations exercises, attendance at two international conferences per fractional person per year would be consistent with international standards.

One conference: typical economy class flight costs (3.5 kPLN) + 1 week's accommodation and per diem in Europe/US/Japan/Australia (2 kPLN) + registration fees (1 kPLN) $\Rightarrow$ 13000 kPLN. Hence, two conferences/year for a 100% person are within the recommended spending limits.

At a rate of 2per effective person, and 3.67 effective people over 3 years, this implies:

Total: 143130 PLN.

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