Particle Physics and Astronomy Research Council
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PATT2
Version 07/97

APPLICATION FOR TELESCOPE TIME (OPTICAL AND INFRARED)

1 TELESCOPE *Specify one of AAT,WHT,INT,JKT,UKIRT*	**INT**
2 SEMESTER	**98B**

Reference Date Stamp

3 PRINCIPAL APPLICANT

Surname: **Ciliegi** Title: Dr Initials: P
Post held: Research associate
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Is the applicant a possible observer? Yes

4 COLLABORATORS

Name:	Institute:	Observer?
R. McMahon	Institute of Astronomy, Cambridge	Yes
A. Caccianiga	Osservatorio di Brera, Milano , Italy	Yes
T. Maccacaro	Osservatorio di Brera, Milano, Italy	No

5 SHORT TITLE OF PROPOSAL *(maximum 12 words)*

A complete sample of X-ray luminous radio sources

6 SUMMARY OF PROPOSED OBSERVATIONS

We propose to obtain CCD identifications of a complete sample of 46 optically unidentified radio loud X-ray sources. The parent sample of 395 sources with F_x(0.5-2.0keV)$> 5 \times 10^{-14}$ erg cm^{-2} s^{-1} and $S_{20cm} > 10$ mJy, covers $\sim$500 deg^2 and explores a new regime in multi-wavelength parameter space, and will provide unparalled constraints on the numbers of BL Lacs, obscured AGN and high redshift radio loud quasars. By using UBR colours alone we shall be able to make a preliminary classification of the optical counterparts without recourse to an indiscriminate redshift campaign. In addition, as an important bye-product of the large field of view of the INT WFC, we shall obtain multi-colour CCD colours over an area of 9deg^2, which contains a few hundred faint X-ray and radio sources and ~ 1000 UVX quasars, allowing for the first time systematic, unbiased, statistically significant($N/\sqrt{N} > 10$) multi-wavelength AGN studies from radio though optical to X-rays at low X-ray and radio fluxes.

7 FOCAL STATION, INSTRUMENT AND DETECTOR

Focal station:	Instrument:	Detector(s):	Gratings/Filters:
Prime	**WFC**	EEV	U,B,R

AAT applicants will be sent an instrument scheduling form by email

8 OBSERVING TIME REQUESTED THIS SEMESTER

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Time requested this semester	**2**			
Minimum useful allocation this semester	2			

UKIRT applicants requiring dark time must justify this in section 16

9 COMPLETE THIS SECTION ONLY IF THIS IS A LONG TERM PROPOSAL

	Dark:	Grey:	Bright:	specify nights *or* weeks:
Total time requested	**5**			

Justification for long term status must be given in section 15

10 SCHEDULING INFORMATION

Preferred dates:	Aug-Nov
Impossible dates:	Dec-Jan
Give justification for impossible dates	RA range
If observations are to be simultaneous with other telescopes or satellites, give details:	
Any other scheduling constraints: *Include likely clashes with other time applications, constraints on lunar position or quarter, instrument preparation requirements, etc*	

11 SERVICE OBSERVING

yes:	no:	maybe:
		x

12 SUPPORT ASTRONOMER REQUESTED AT TELESCOPE

every night:	no:	first night only:
		x

13 LIST OF PRINCIPAL TARGETS

Object(s):	RA(h,m):	Dec(degs):	Mag(type):	Colour:	Exp. Time:
REXJ00+13	00 29	+13 47	R>20	UBR	600 s per band
REXJ00−12	00 25	−12 23	R>20	UBR	600 s
REXJ01+85	01 00	+85 07	R>20	UBR	600 s
REXJ01+01	01 39	+01 19	R>20	UBR	600 s
REXJ02+15	02 08	+15 44	R>20	UBR	600 s
REXJ02+00	02 53	+00 06	R>20	UBR	600 s
REXJ04−08	04 35	−08 11	R>20	UBR	600 s
REXJ04−01	04 37	−01 59	R>20	UBR	600 s
REXJ04+04	04 22	+04 51	R>20	UBR	600 s
REXJ04+03	04 59	+03 23	R>20	UBR	600 s
REXJ19−10	19 42	−10 39	R>20	UBR	600 s
REXJ20−02	20 45	−02 18	R>20	UBR	600 s
REXJ21+13	21 53	+13 40	R>20	UBR	600 s
REXJ21−11	21 05	−11 25	R>20	UBR	600 s
REXJ22+03	22 44	+03 12	R>20	UBR	600 s
REXJ22+14	22 51	+14 48	R>20	UBR	600 s
REXJ23−08	23 04	−08 16	R>20	UBR	600 s
REXJ23+09	23 26	+09 08	R>20	UBR	600 s
REXJ23+08	23 44	+08 38	R>20	UBR	600 s

14 OTHER APPLICATIONS FOR OBSERVING TIME FOR THIS OR SIMILAR PROGRAMMES IN THIS SEMESTER

Include all other telescope and satellite applications whether via PATT or any other time assignment committee

Telescope/satellite:	Title of programme:

15 SCIENTIFIC JUSTIFICATION

Case not to exceed this A4 page. Figures and/or references can be included on page 4a

Introduction The systematic optical identification of sources detected at radio and X-ray wavelengths has been of fundamental importance in determining our knowledge of the nature and physical processes in active galaxies. Unlike purely optical surveys for AGN, X-ray and radio selected sample are much more diverse primarily since such samples are less prone to orientation and obscuration related effects. Up until now studies of the properties of AGN have been primarily based on samples selected at bright radio (eg 3–7C, PKS) or bright X-ray fluxes(eg Piccinotti et al. 1982, EMSS (Maccacaro et al. 1994), RASS). Studies at lower fluxes have been thwarted by the lack of radio and X-ray data at low fluxes. The situation has undergone a radical change in the last two years with the advent of deep all-sky radio surveys (e.g. the NVSS, Condon et al. 1998, the FIRST survey, Becker et al. 1995) and large area coverage to faint X-rays fluxes via serendipitous sources in ROSAT PSPC images. These surveys offer a great opportunity to derive new sizable sample of AGN ie ($N/\sqrt{N} > 10$).

Through a positional cross-correlation of sources detected in the NVSS and ROSAT fields (Caccianiga et al 1998), we have derived a sample of *Radio Emitting X-ray sources (REX)* which are expected to contain a high fraction of AGN (radio loud QSO, BL Lacs, Seyfert galaxies) and radio galaxies (Maccacaro et al, 1998). Considering the X-ray sources with PSPC off-axis angles less than $35'$, Fx(0.5-2.0keV)$> 5 \times 10^{-14}$ erg cm^{-2} s^{-1}, S(20cm)$>$ 10 mJy, $\delta > -20$, the REX sample covers 590 deg^2, and contains 395 sources.

The primary goal of the REX project is the selection of a statistically complete sample of AGN by using simultaneously the information derived from the NVSS survey and from pointed ROSAT PSPC images. The project complements and extends by a decade lower in both radio and X-ray fluxes the efforts of Brinkman et al. (1997) who have used the brighter flux limits of the ROSAT All Sky Survey and GreenBank radio surveys. In addition, the survey is a factor of $\sim$100 larger than the previous most comparable work by Ciliegi et al. (1995) who studied the radio properties of the CRSS survey. The primary interest of the Milan group is in the properties of the BL Lac's within the above sample. The Cambridge group are primarily interested in the evolution of the quasar luminosity function at low radio and X-ray luminosities and particularly in the use of the REX sample in the discovery of quasars at high redshift. In the longer term, such studies will use the much larger samples that will come available from XMM which shall the launched in 18months and thus the current proposal is a cornerstone in long term planning for the exploitation of XMM. In the context of the search for high redshift quasars this program is an extension of the work by Hook & McMahon(1998) who have discovered two z>4 radio loud, X-ray luminous quasars with z=4.30 and 4.72 (Fabian et al., 1997) based on the ROSAT All Sky Survey and brighter radio catalogues.

Observational status During the last two years we have performed optical spectroscopic observations at ESO and Mauna Kea of the brighter sources (m(R)<20) that were identified on APM catalogues derived from POSS and UKST plates and have identified and spectroscopically classified 154(39%) of the 395 REX sources. In total, the identified fraction of the REX sample of 395 sources (both from literature and from our own observations) consists of 24 BL Lac's(6%), $\sim$ 75 broad line AGN(14%) and $\sim$55 narrow lined AGN or radio galaxies(19%).

Of the unidentified sources, the majority(195) remain unidentified because optical spectra have not been obtained for all likely candidates. However there are 46 REX sources in which there are no optical candidate brighter than the APM catalog limits ($\sim$20 mag in O ($\sim B$) band and $\sim$21.5 mag in $E(\sim R)$ band). On page 4a we describe the technique that we used to define a REX source as an optical blank field. In figure 3 we show the X-ray and radio flux distributions of the REX sample. The filled distributions represent the 46 REX sources with optical blank fields. As shown in Figure 3, they are not primarily the faintest X-ray or radio objects in the REX sample. One possibility is that these sources are extremely high redshift (z>3.5) or obscured AGN.

Proposed INT observations We propose to obtain U, B and R CCD observations of the complete sample of 46 optically unidentified radio loud X-ray sources. Using the U-B, B-R colours alone we shall be be able to make a preliminary classification of the optical counterparts into BL Lacs, galaxies, low redshift(z<2) or high redshift(z>3) quasars, cluster of galaxies or obscured AGN and thus we can plan our follow-up spectroscopic phase based on more specific scientific goals.

16 TECHNICAL INFORMATION (I)

Give details of the technical feasibility of the proposal (S/N,etc) AND any non-standard technical requirements

Optical Identifications There are a total of 395 sources with $F_x > 5 \times 10^{-14}$ erg cm^{-2} s^{-1} and S_ν(20cm)>10mJy. Of these 349(88%) have optical counterparts(as described below) detected on APM scans on the UKST(m(B_J)<22.0) or POSS1 (E(m_R)<20.0); O(m_O)<21.5) plates. In Figure 1 we show the magnitude distribution of these 349 sources (in the case of detections on the UKST B plates we have converted this to E using a spectral index;ν^α of -0.5). This fractional identification rate(88%) is similar to that of CRSS(91%; Boyle, McMahon, Wilkes, Elvis, 1995, MNRAS, 272, 462) and RIXOS(90%; Carrera et al, preprint), which have similar X-ray flux limits.

Definition of an optical blank field In order to find an optical counterpart we searched for optical objects in the APM catalog within a circle of radius $1'$ centered on the combined ROSAT-NVSS position. For each optical object we have calculated the likelihood ratio which is the ratio of the probability of finding the correct optical counterpart based on the positional uncertainty relative to that of finding a similar chance background objects (eg Sutherland and Saunders, 1992, MNRAS, 259, 413). In Figure 2 we show the likelihood ratio of all the optical objects that we found in the APM catalog (both in within a circle of $1'$ centered on the REX position) as function of the distance between the optical object and the REX source. As shown in Figure 2, only the optical objects within $\sim 10''$ the REX position have a likelihood ratio greater than 10 (*i.e.* have a probability greater that 90 per cent to be the true identification). Therefore we define as a blank field all the REX sources without an APM object within a circle of radius $10''$. Of the 395 REX sources we find that the number of empty fields defined in this manner is 46(19 with b(galactic latitude) <-30 and 27 with b>30).

Observational program and strategy We propose to optically identify, classify and derive optical colours for these 46 unidentified sources (19 in the SGC region; 27 in the NGC region) to give us a complete sample of 395 sources. As well as optically identifying the sources we propose to use colours to make an initial astrophysical classification so that a follow-up spectroscopic program can be designed on this basis, rather than carrying out an indiscriminate redshift campaign. Based on previous work at brighter radio fluxes (eg Hook & McMahon, 1998), we might expect that 75% of these optically unidentified (on photographic sky survey) sources shall be identified to R=23 giving us a completeness rate of 97% after this phase. Of course it may be higher. *One purpose of this proposal is to derive this value.* Whilst this may be optimistic since we are studying radio sources 20 times fainter, in radio flux, we have to start somewhere and to invest time on longer exposures at this stage would be unjustified. From Figure 1, one can already see that the magnitude distribution is converging so that by R=23 we would expect all the sources to identified. Expectations from Signal (version 11.2) for WFC, EEV, INT and $1''$ seeing:

- 600s exposures in R; S/N=15 at R=23.0
- 600s exposures in B; S/N=10 at B=24.4
- 600s exposures in U; S/N=10 at U=22.8

Since we need to carry out image classification we require a S/N>10 at the envisaged limit. We need a colour limit of B−R>1.5 to identify any z>3 quasars. Good quality colours are required ie 0.1-0.2 magnitudes so a S/N of 10 is required. Ideally one would like the U limit to correspond to U−B=−0.3 at the B band limit to allow discrimination of z<2.2 quasars but this would require 4500s. 600s is therefore a justifiable compromise since we do not actually know the underlying magnitude distribution. ie for the brighter identications this will be adequate.

Observational requirements We have 19 sources that are observable in semester 98B. Assuming read out of 120seconds per source gives a total observing time of and a typical observing efficiency of 80% (ie allowing time for slewing, guide star acquisition and standards) the total time for UBR imaging is 14.25 hrs. We therefore request 2 nights in the Autumn. In the semester 99A we have 27 unidentified sources and we therefore request 3 nights for this phase of the program.

16 TECHNICAL INFORMATION (II)

References and Figures

References:

Becker, R.H., White R.L., and Helfand D.J, 1995, ApJ, 450, 559

Brinkman, W et al, A&A, 323, 739, 1997.

Caccianga et al, AJ, submitted

Ciliegi P. et al, 1995, MNRAS, 277, 1463

Condon et al. 1998, in preparation

Dunlop J. et al, 1996, Nature, 381, 581

Fabian A. C. et al., 1997, MNRAS, 291, L17.

Hook & McMahon, 1998, MNRAS, 294, 7

Maccacaro T., Caccianiga A., Della Ceca R., Wolter A. and Gioia I., 1998, Astron. Nachr, 319, 15

Maccacaro T. et al. , 1994, ApL,29, 267

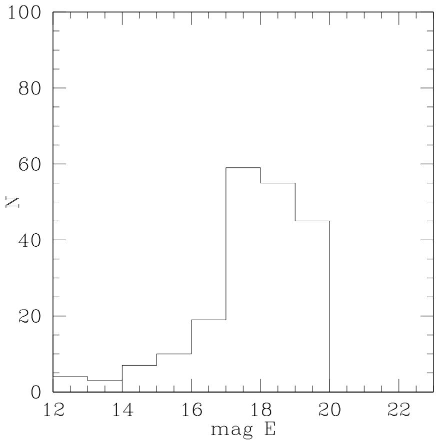

Figure 1. The E mag distribution of the APM objects with a likelihood ratio greater than 10 within a circle of 10″ around the REX position.

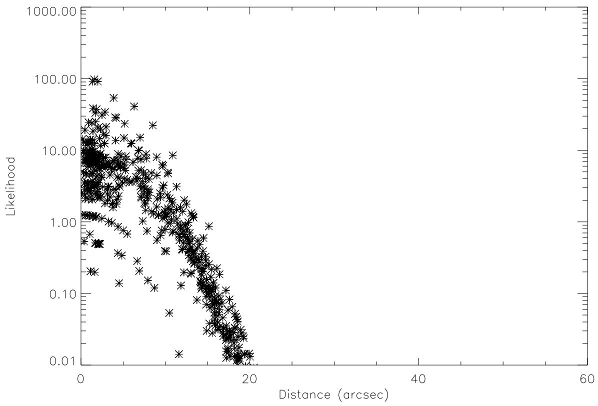

Figure 2. The Likelihood ratio of the APM sources within a circle of 1′ centered on the REX (NVSS) position as function of the distance between the optical object and the REX source.

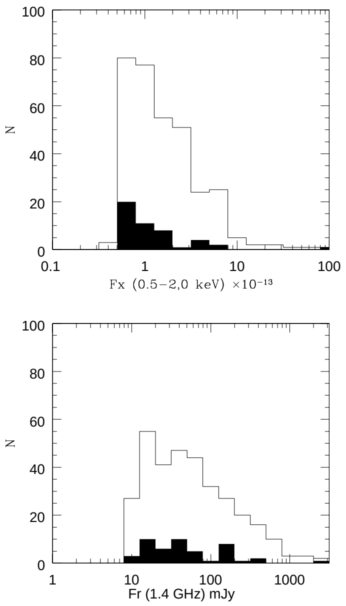

Figure 3. The X-ray (upper panel) and radio (lower panel) distributions of the REX sample. The filled distributions represent the 46 REX sources with optical blank field

17 SUMMARY OF BACKUP PROGRAMME FOR POOR OBSERVING CONDITIONS
If instrumentation or setup differs from main programme, give full details

We will concentrate on R band imaging.

18 RELATED PATT APPLICATIONS OVER THE LAST FOUR SEMESTERS *(including unsuccesful applications)*

PATT reference:	Award:	Clear nights:	Comments:

19 PUBLICATIONS BASED ON PATT TIME PUBLISHED DURING THE LAST FOUR SEMESTERS *(maximum 6)*

'The APM z>4 QSO Survey: Spectra and Intervening Absorption Systems' Storrie-Lombardi, L.J., McMahon, R.G., Irwin, M., Hazard, C., 1996, ApJ, 468, 121–138.
'The APM z>4 QSO survey for Damped Lyman alpha systems' Storrie-Lombardi, L.J., McMahon, R.G., Irwin, M., 1996, MNRAS, 282, 1330-1342.
'Evolution of Neutral Gas at High Redshift – Implications for the Epoch of Galaxy Formation' Storrie-Lombardi, L.J., McMahon, R.G., Irwin, M. , 1996, MNRAS, 283, L79-L83.
'A survey for high redshift radio loud quasars II Optical spectroscopy of a complete sample of radio sources' Hook, I.M., McMahon, R.G., Irwin, M.J, Hazard, C., 1996, MNRAS, 282, 1274–1298.
'Discovery of radio-loud quasars with z=4.72 and z=4.01' Hook, I.M., R. G. McMahon, R.G., 1998, MNRAS, 294, L7-L12.

20 EXPERIENCE OF INTENDED OBSERVERS WHO HAVE NOT PREVIOUSLY USED THIS TELESCOPE

21 COMPLETE IF THE OBSERVATIONS ARE PRIMARILY FOR A STUDENT RESEARCH TRAINING PROGRAMME

Name of student:	
Project title:	

22 COMPLETE IF THE OBSERVATIONS ARE ASSOCIATED WITH A CURRENT PPARC/SERC RESEARCH GRANT

Name of principal investigator:	Dr P C Hewett
Grant title:	PATT Travel for the IoA
Grant number:	GR/J33319

23 NON-STANDARD TRAVEL AND SUBSISTENCE REQUIREMENTS *(UK observers only)*
Justify requests for travel and subsistence for more than one person:

Details of any other expenditure (eg freight, remote observing):

PATT2 LaTeX style file v1.0 10 July 97.