EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

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APPLICATION FOR OBSERVING TIME PERIOD: **63**

To be submitted only to: proposal@eso.org
Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title Panel: **P–4**

Host galaxies when quasars were young: IR spectroscopy of $z \sim 2.5$ radio galaxies

2. Abstract

In this programme we observe the early evolutionary phases of objects destined to become the giant ellipticals of today. By selecting powerful radio galaxies — where the obscuration of the quasar by opaque material in its immediate environment acts as a 'natural coronograph' — at redshifts corresponding the epoch of maximum quasar space density, the relationship between the formation of the AGN and the accumulation of its host galaxy can be examined. Using the Keck spectropolarimeter, we have already measured the restframe ultraviolet spectrum of a sample of 9 sources. We propose to use use the unique capability of ISAAC to measure the restframe optical emission lines and continuum in an overlapping sample of powerful radio galaxies with $2 \leq z \leq 2.6$ to measure the properties of the ionized ISM and of the evolved stellar population.

3.

Run	Telescope	Instrument	Time	Month	Moon	Seeing	Obs. Mode
A	UT1	ISAAC	2n	apr	n	$\leq 1.4''$	v
B	UT1	ISAAC	2n	sep	n	$\leq 1.4''$	v

4.

Number of nights/hours	Telescope(s)	Amount of time
a) initially requested for this project:	UT1	4n
b) already awarded to this project:	UT1	0
c) required to complete this project:	UT1	4n

5. Special remarks

6. Principal Investigator: R.A.E. Fosbury (ST-ECF, ESA, rfosbury@eso.org)

CoI(s): A Cimatti (Arcetri, I), S di Serego Alighieri (Arcetri, I), J Vernet (ESO, ESO), M Villar-Martín (IAP, F), I van Bemmel (ESO, ESO), M Cohen (Caltech, USA), P McCarthy (OCIW, USA)

7. Is this proposal linked to the PhD thesis preparation of one of the applicants?

Yes / J. Vernet / mid-course

8. Description of the proposed programme

A) Scientific Rationale: Our current belief is that the hosts of powerful radio sources in the distant Universe are destined to become the giant ellipticals of today: the most massive galactic systems we know. While some may have commenced their formation at very high redshift, it is clear that the process of assembly is very active at $z \sim 2.5$. This corresponds to the epoch when quasars appear to have had their maximum space density (Dunlop 1994, in *Frontiers of Space and Ground-Based Astronomy*, Wamsteker et al. (eds), p. 395, Kluwer). Indeed, a major goal of this programme is to understand the causal relationship between the formation of the massive black hole and that of the galaxy within which it resides. Our approach has been to identify, catalogue and measure the components which contribute to the observed spectral energy distribution of active galaxies at different redshifts. The realisation that reprocessed AGN radiation makes a very significant contribution to the blue and ultraviolet spectrum showed how difficult it is to measure the stellar population in the galaxy using these regions of the restframe spectrum where the scattered continuum and AGN excited emission lines often dominate.

Our approach of observing radio galaxies rather than the host of objects classified as quasars relies on the now well-justified assumption that these are similar objects viewed from different directions. The presence of opaque material in the nuclear regions of the galaxy results in a 'natural coronograph' which greatly facilitates the study of the underlying stellar galaxy and its ISM. Members of our team have, over recent years, been responsible for significant discoveries in the field. In particular, in the late 1980's and early 90's we pioneered the use of polarimetry to study the scattered radiation from the hidden quasar in radio galaxies and showed that the reprocessed AGN light is a major contributor to the 'alignment effect' (eg. Tadhunter et al. 1988 in *BL Lac objects, 10 years after*, L. Maraschi (ed.), Springer.; Cimatti et al. 1993, MNRAS 264, 421; 1994, ApJ 422, 562; di Serego Alighieri et al. 1993, ApJ 404, 584; 1994, ApJ, 431, 123).

Following our early imaging- and spectro-polarimetry with 4m-class telescopes, we are currently engaged in a programme using the Keck spectropolarimeter LRISp (developed by one of our team) on a sample of radio galaxies with redshifts ranging from 2 to 3.5. This redshift range represents the epoch during which the quasars had their highest space density — which increases the probability of finding young AGN compared with local sources. It also gives us access from the ground to the spectral region containing the strong ultraviolet resonance lines seen in the spectrum of OB stars, to the strong UV emission lines from Lyα to C III] and to the wavelengths where dust has a significant extinction feature. We have so far observed nine sources with integrations ranging from about 4 to 8 hours per source. All data have been reduced, a paper reporting the results of the first two of them has been published (Cimatti et al. 1998, ApJ, 499, L21) and a report on the results from six sources, combined with HST visible and NIR imaging, appeared in Fosbury et al. (1998, in *NICMOS and the VLT*, W. Freudling & R. Hook (eds), ESO Conference and Workshop Proceedings No. 55, 191). Here we summarize the principal results to date.

1. All sources show a strong 'alignment effect' between their UV and radio morphologies although the structures are complex. One case, 4C 23.56 (Knopp & Chambers 1997, ApJ S, 109, 367), shows a beautiful 'ionization cone' in Lyα. The brightest UV emission is extended and does not necessarily coincide with the nucleus (radio core).
2. The continuum colours are remarkably similar to one another and can be fitted by a power law absorbed by a standard Galactic (in the RG rest-frame) extinction law showing the 2200Å dust absorption feature — seen in Galactic spectra — with $E_{B-V} \sim 0.1$, which corresponds to $\tau \sim 1$ at 1500Å. The fit to the average spectrum is shown in Fig 1 and the fits to the individual objects are, in most cases, convincing on their own.
3. Interstellar absorption lines are seen and, in some objects, there is evidence for wind and photospheric absorption lines from hot stars. Several sources show complex, spatially extended absoption structures at Lyα (see also van Ojik et al. 1997, A&A, 317, 358).
4. The emission lines are spatially extended (up to $\sim$ 20 arcsec or $\sim$ 150 kpc for Lyα) and show complex kinematic structures extending over $\pm$2000 km s^{-1} (see Fig 3).
5. The emission line spectra indicate a rather constant level of ionization with a small range in the observed CIII]/CIV and HeII/CIV line ratios.
6. The continuum linear polarization, measured just longward of Lyα/NV, ranges from $< 3\%$ to $\sim 20\%$. The E-vector is perpendicular to the UV extension as seen at HST resolution (but not necessarily precisely to the radio axis).
7. Among the spatially integrated properties, the strongest correlations, shown in Fig 2, are observed to be between the continuum polarization P and the NV/CIV emission line ratio, and between P and the Lyα/CIV ratio (anticorrelation).

The second of these correlations is most probably a natural consequence of the destruction of Lyα photons by dust — although the geometric configuration of the dust with respect to the illuminated nebulosity must be important. The first correlation we believe to be a genuine effect of variations in the nitrogen/carbon abundance ratio since it is too large to be explained as an ionization effect in sources with such similar HeII/CIV and CIII]/CIV ratios. This abundance ratio is critical for understanding the history of early star formation as the effect of either primary or secondary nitrogen nucleosynthesis. It may be that we have found a way of dating the major starburst event related to the birth of the quasar in these massive galaxies. Elucidating the nature

8. Description of the proposed programme (continued)

of such a relationship is now a major goal of this program.
We have an HST Cycle 7 NICMOS programme to image radio galaxies, some of which are in the Keck and VLT samples. The first of the sources to be analysed is described in McCarthy et al. (1999, ApJ, submitted) Where other HST images from are available in the public archive, we have extracted, re-calibrated and correlated them with the long-slit spectroscopy. For those sources which have not yet been observed, we have requested Cycle 8 time to observe them in the broad optical/UV band with the HST STIS 'CCD50' camera.

B) Immediate Objective: This proposal is to extend our study of the restframe ultraviolet spectrum to the optical region where we have access to the rich forbidden line spectrum from the ionized ISM and to the photospheric light from the evolved stellar population. Such infrared spectroscopy has been attempted with 2–4m class telescopes (eg. McCarthy et al. 1992, ApJ, 387, L29; Evans 1998, ApJ, 498, 553) but is then only able to detect the strong lines. Measurement of the continuum with anything other than marginal s/n has not been possible.
The strong emission lines from H, O^+, O^{++}, N^+ and, in some cases, O, He^+, Ne^{++} and S^+, can be observed in transparent regions of the J, H and K bands for objects with $2 \leq z \leq 2.6$. These lines enable us to carry out an analysis similar to that carried out on low-z radio galaxies by Robinson et al. (1987, MNRAS, 227, 97) but using more recent versions of the ionization modelling codes (eg, Villar-Martín et al., 1997, A&A 323, 21). Such measurements allow us to diagnose the ionization mechanism and estimate chemical abundances in a way which is free of many of the geometric and line transfer difficulties which accompany the analysis of the UV permitted and resonance lines. Comparisons with our UV spectra will give us additional reddening indicators from hydrogen and helium lines. For some sources with narrow UV lines, we may see broad Hα.
The same observations enable us to measure the continuum in regions spanning the restframe optical spectrum and sampling any evolved stellar population not visible from our restframe UV spectroscopy. These spectral observations remove the emission line/continuum ambiguity which has plagued broad band photometric observations of these faint sources.
Our strategy is to observe the J and H and K windows at low resolution to give line fluxes and continuum. In addition, we will observe the Hα-[NII] region at medium resolution in order to de-blend these important lines. Our target list is similar in source properties to our Keck sample and we expect to have several sources in common.

C) Telescope Justification: Experience with 4m telescopes has shown that, while it is possible to reach the strongest of the emission lines in this type of object, the detailed analysis of lines and continuum which we propose here is available for the first time with ISAAC.

D) Observing Mode Justification (visitor or service): We require VM for real-time data assessment and for fine-tuning the telescope pointing on these resolved objects. Our s/n calculations are, for some sources, based on broad band photometry and an assumed line/continuum ratio. This may necessitate exposure time reallocations from source to source.

E) Strategy for Data Reduction and Analysis: Our team has extensive experience in the reduction of spectroscopic data in the optical and IR and we have access to all the necessary tools and hardware. The bulk of the reduction will be done as part of a thesis project. For the analysis phase, we are familiar (Villar-Martín) with the use of codes such as 'MAPPINGS' for performing ionization and abundance calculations. We have developed techniques and libraries for stellar and AGN continuum synthesis over this spectral range. With our HST experience and associated space programmes, we are in an excellent position to benefit from the combination of the space and groundbased data.

8. Attachments (Figures)

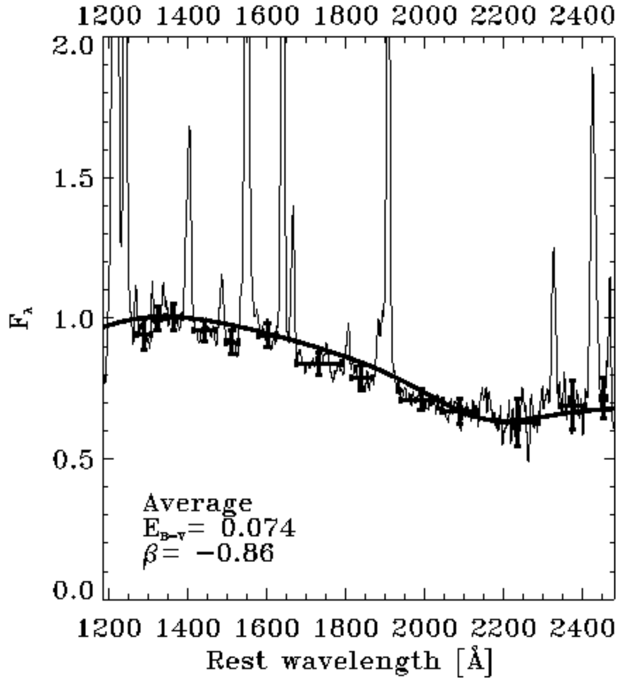

Fig.1 - average HzRG spectrum

Nomalized average Keck/LRISp spectrum of six $z \approx 2.5$ radio galaxies in our sample, scaled to show the continuum. The crosses mark continuum bins chosen to be free of emission lines and atmospheric absorption features with the vertical bars representing 1σ statistical errors. The fitted curve is a two parameter fit of a power law (with index β in F_λ) absorbed with Galactic extinction curve in the rest-frame of the radio galaxies. The 2200Å feature is clearly seen in this average and in the individual contributors to it.

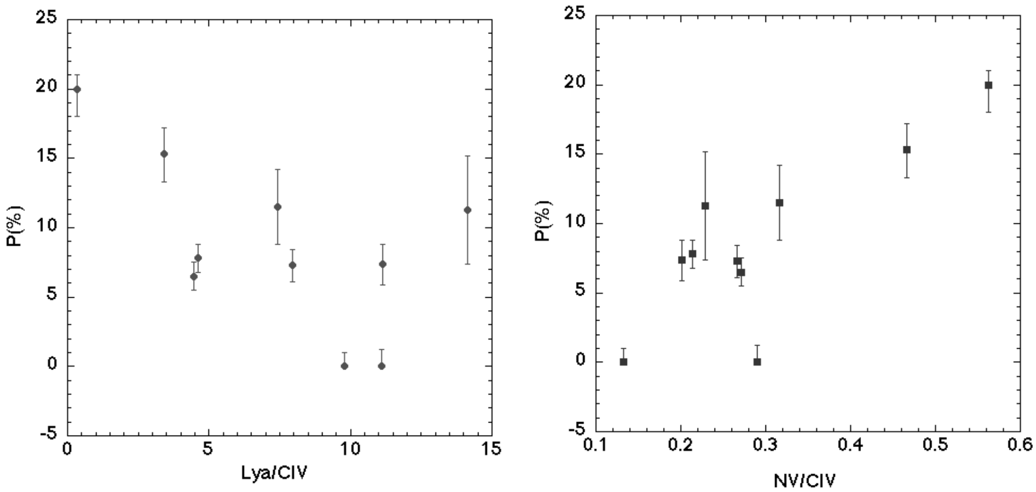

Fig.2 - correlations

Plots of the fractional continuum polarization with 1σ error-bars against (a) the Ly-α/CIV emission line ratio and, (b) the NV/CIV ratio. The sources in the plots are the nine objects from our program together with 4C+41.17 (z = 3.798, Dey et al. 1997) from similar Keck data. The point with the largest error bars is 4C+03.24, (z = 3.57): this is the highest redshift object in our sample and the polarization measurement is of marginal significance.

8. Attachments (Figures)

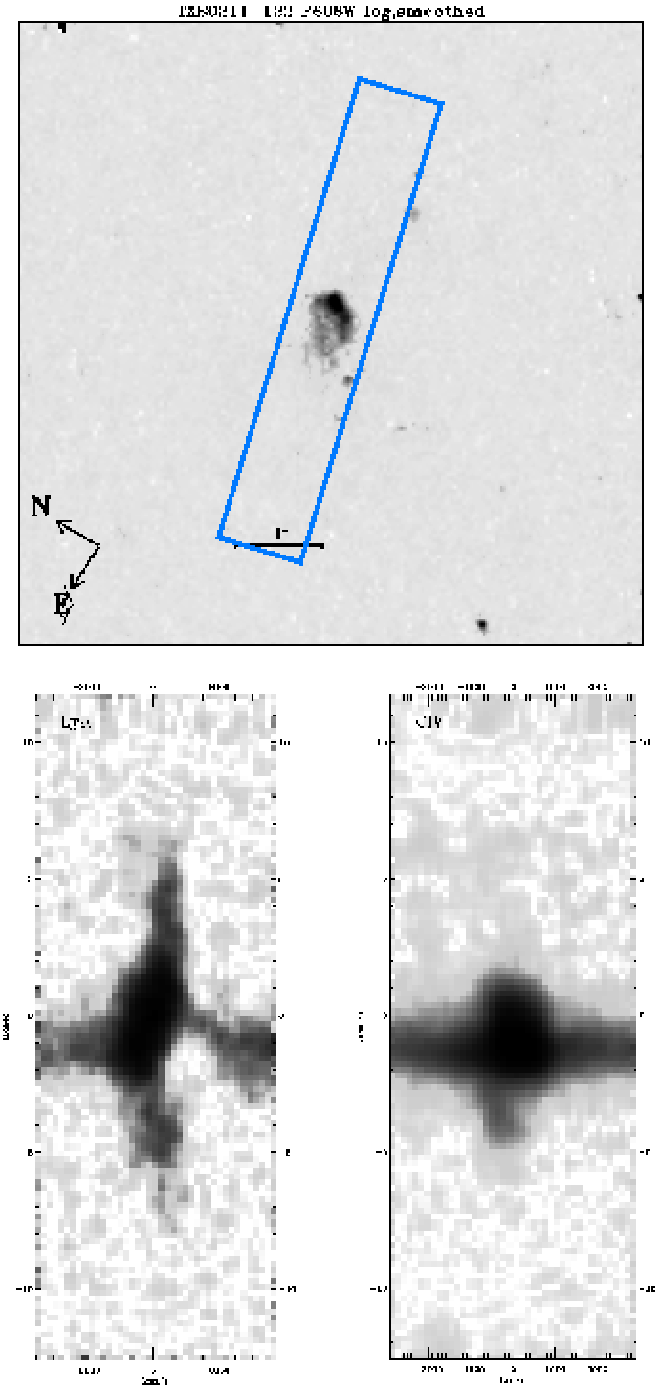

Fig.3 - TXS 0211-122

KeckII/LRISp two dimensional spectra of the extended Lyα and C IV lines of TXS 0211-122 displayed with slit overlayed on the HST/WFPC2 F606W image.

9. Justification of requested observing time and lunar phase

Time Justification: s/n calculations are based on 'typical' line-free continuum magnitudes of K=19, H=20 and J=21 and use the current versions of the SOFI-V2.2 (for comparison) and ISAAC-V2.2 ETCs.

J-band (LR)
ISAAC 1.3mu 0.354nm/pix 1h mag=21 s/n∼3

H-band (LR)
ISAAC 1.3mu 0.472nm/pix 1h mag=20 s/n∼5

K-band (MR mode for emission line resolution, LR for continuum)
ISAAC 2.03mu 0.709nm/pix 1h mag=19 s/n∼2
ISAAC 2.03mu 0.124nm/pix 1h mag=19 s/n∼1

We aim to reach a continuum s/n comparable with our UV spectra, ie, $3 < s/n < 10$ per spectral resolution element in the LR mode. These calculations indicate that, including acquisition imaging, two half-nights per source will give acceptable data for our typical source. Consequently, we request a total of four nights split into two runs.

Lunar Phase Justification: Unless the results of ISAAC commissioning indicate otherwise, we should not be restricted by moonlight.

10. Report on the last use of ESO facilities

61.B-0418 / M. Villar-Martín / Shocks vs. AGN illumination in high redshift radio galaxies

Telescope	Instrument	Obs. Dates	Completion (%)	Time lost (%)	Reason
NTT	EMMI	25-27 July 1998	80%	20%	technical

Current status of obtained data: reduced

Remarks:

11. Applicant's publications related to the subject of this application during the past two years

Ogle, P.M., Cohen, M.H., Miller, J.S., Tran, H.D., Fosbury, R.A.E. & Goodrich, R.W., 1997, ApJ L, 482, L37: Scattered Nuclear Continuum and Broad Hα in Cygnus A

Cimatti A., Dey A., van Breugel W., Hurt T. & Antonucci R. 1997, ApJ, 476, 677: Keck spectropolarimetry of two radio galaxies at $z \sim 1$: discerning the components of the alignment effect

Cimatti, A, di Serego Alighieri, S., Vernet, J., Cohen, M.H. & Fosbury, R.A.E. 1998, ApJ L 499, L21: The UV radiation from $z \sim 2.5$ radio galaxies: Keck spectropolarimetry of 4C+23.56 and 4C-00.54

Fosbury, R.A.E., Vernet, J., Villar-Martín, M., Cohen, M., Cimatti, a., di Serego Alighieri, S. & McCarthy, P.J. 1998, in 'NICMOS and the VLT', W. Freudling & R. Hook (eds), ESO C & W Proc. No. 55, 19l: The Structure and Composition of High Redshift Radio Galaxies

Tran, H.D., Cohen, M.H., Ogle, P.M., Goodrich, R.W. & di Serego Alighieri, S. 1998, ApJ, 500, 660: Scattered Radiation from Obscured Quasars in Distant Radio Galaxies

Villar-Martín, M., Binette, L.& Fosbury, R.A.E. 1996, A&A, 312, 751: The effects of resonance scattering and dust on the UV line spectrum of radio galaxies,

Villar-Martín M., Tadhunter C.N.& Clark N.E., 1997, A&A 323, 21: The ionization mechanism of the extended gas in high redshift radio galaxies: shocks vs. AGN photoionization?

McCarthy, P.J., Miley,G.K., Fosbury, R.A.E., Rush, B., Rottgering, H., Pentericci, L., Persson, S.E. and van Breugel, W, 1999, ApJ, submitted: NICMOS and WFPC2 Imaging of the Distant Radio Galaxy MRC 0943-242: Implications for the Alignment Effect

nb. this is a selected subset of the most relevant of some 33 related papers published by members of this collaboration during this period

12. List of targets proposed in this programme

Run	Target name	α	δ	Equinox	Mag.	Diam.	Additional information
B	TXS0211-122*	02 11 51.5	-12 12 43.6	B1950			z=2.34
A	MRC1106-258	11 06 02.8	-25 49 01.0	B1950	18.35		z=2.43
A	MRC1138-262	11 38 17.5	-26 12 32.2	B1950	16.28		z=2.17
A	MRC1324-262	13 24 08.8	-26 16 08.7	B1950	18.35		z=2.28
A	4C-00.54*	14 10 41.2	-00 09 00.0	B1950			z=2.36
A	4C-00.62	15 58 43.2	-00 20 25.6	B1950			z=2.53
B	4C+10.48	17 07 44.9	+10 34 47.6	B1950			z=2.35
B	MRC2025-218	20 25 04.2	-21 50 55.0	B1950			z=2.63
B	MRC2104-242	21 04 03.7	-24 17 17.0	B1950			z=2.49
B	MRC2139-292	21 39 21.7	-29 12 24.0	B1950	17.73		z=2.55

Target Notes: *=observed with LRISp; magnitudes, where shown, are K in a 4 arcsec aperture and include line and continuum radiation. The V magnitudes are between 21.5 and 23.5. We will select a total of four sources from this list, two for each run.

13. Scheduling requirements

14. Instrument configuration

Telescope	Instrument	Parameter	Value or list
UT1	ISAAC	Spectroscopy	Short Wavelength