GEMINI OBSERVATORY

observing time request summary

Semester: 2012A **Observing Mode:** queue

Instruments: NIFS **Time Awarded:** **Gemini Reference:**

Thesis:
no

Band 3 Acceptable:
No

Title: **A detailed investigation of the benchmark HLIRG IRAS F10214+4724 at <100pc scales**

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Partner Submission Details *(multiple entries for joint proposals)*

Partner	Partner Lead Scientist	Time Requested	Minimum Time Requested	NTAC Reference Number	NTAC Reco-mmended Time	NTAC Minimum Time Reco-mmended	NTAC Rank
UK	Tecza	11.6 hours	11.6 hours		0.0	0.0	
	Total Time	*11.6 hours*					

Abstract *(200 words)*

IRAS F10214+4724 is one of the most heavily investigated extragalactic sources in the Universe. This strongly-lensed hyperluminous infrared galaxy is a composite starburst+AGN system. We propose new sensitive observations at unrivalled spatial resolution to investigate the nature of this source in the rest-frame optical using the NIFS-IFU with AO+LGS. We have recently found evidence of a three component model for this source comprising a compact AGN core+jet, an extended starburst and a complex narrow-line region that lie close to the caustics of the lens potential causing them to be preferntially magnified with different levels of magnification. According to our state-of-the art gravitational lensing model these components can be spatially resolved on scales of 0.1" in the image plane and thus we propose to test our model by direct observational evidence traced by optical nebular emission lines. We will be able to map line emission from the broad and narrow lines components on spatial scales of <100pc in the source plane. As such the requested data will provide an new perspective on the structure of this source which, together with our complementary deep & high spatial resolution radio, CO and HST data, provide a new detailed view on this benchmark galaxy.

Science Justification *(1047 words)*

Despite two decades of studies on the hyperluminous infrared galaxy (HLIRG) IRAS F10214+4724 (hereafter F10214, [RR91], we still lack a clear understanding of the detailed nature and physical properties of this notorious source. With a luminosity in excess of >1e14 Lsol and at a redshift of z~2.286, F10214 resides at an epoch of the Universe when both star-formation and black-hole activity were at their peaks. While rare locally, such IR luminous galaxies show a rapid increase in number density to z~1-2 and are plausibly the progenitors of present-day massive galaxies. F10214's extreme luminosity is akin to SMGs and dusty quasars that are now being routinely detected in deep surveys conducted by Spitzer, SCUBA and Herschel [N10]. As such, F10214 remains the benchmark source to which the properties of SMGs and dusty quasars at high-z are compared.

Through HST imaging it became apparent that F10214's high luminosity could be attributed to gravitationally lensing by a foreground galaxy or group of galaxies at z=0.9 [C95,BL95,G96,L98] with wavelength dependent magnifications of 5-100 (e.g. BL95,D95,S95,T95]. As lensing is achromatic, this wavelength dependence suggests that distinct emission regionsin F10214 undergo differing levels of magnification [L98,E99,D11]. We know that F10214 is a composite starburst+AGN system. Significant ongoing star-formation [S95,E06] is required to explain its far-IR emission. F10214 also hosts an active galactic nucleus (AGN) that is viewed with the torus edge-on (Seyfert 2 optical spectrum [E94; So95; I95; S95]). Its highly polarised emission is consistent with reflected light from an AGN [L93]. An absence of hard X-ray emission suggests that the AGN is Compton-thick [A05,I05]. The mid-IR Spitzer/IRS spectrum is also characteristic of an obscured AGN with a strong MIR continuum and lack of strong PAH features [T06]. Curiously, however this spectrum also shows strong silicate emission [T06], a feature that is predicted for type-1 sources where the inner hot torus is exposed. The strength of this feature in a type 2 source remains problematic to explain [T06,E06] and preferntial magnification may play a role.

Recently, our team has made significant progress in understanding the properties of F10214 -

1. A new hot dust component in IRAS F10214 [E11]

We have developed a new model for the emission of F10214 using new constraint from Spitzer and Herschel [E11,S10]. The SED is fully explained by an edge-on tours, a concurrent starburst and three discrete distributions of dust clouds in the narrow-line region (NLR) [E11]. The SED cannot be explained by a continuous dust distribution in the NLR suggesting a scenario where there have been episodic outflows of material that forms dust [E11,L98].

2. High resolution radio imaging, molecular line mapping and deeper HST 160W data [D11]

We have recently obtained a 24hr MERLIN 1.6GHz resolved detection of F10214 revealing an extended emission component and a dominant core seen in 8GHz (VLA) maps that is offset from the peak of the 814W image (fig 1a-d). The latter is interpreted as scattered quasar light. Deane et al. suggest that the extended 1.6GHz emission is a radio jet owing to its offset from the VLA core and the spectral index. Reanalysed HST/NICMOS160W data clearly shows extended substructure both along and perpendicular to the arc (figs 1c,2b). The bright central arc is attributed to scattered light from the AGN (dominates the 814W map) and the more extended to an extended starburst (fig 2a). We are currently obtining 10x deeper observations at 1.6 GHz (EVN) and 6.7GHz (EVLA) in which Eisntein ring and AGN core should be detected.

3. A new detailed lens model for F10214 Co-I Deane has developed a detailed Bayesian MCMC code for deriving a new gravitational lens model of F10214 as well as expalining its multi-wavelength SED [D11]. This sophisticated model explains the NLR, jet and starburst component images, requiring a neighbouring galaxy to the NE to be included in the lensing potential. The source plane reconstruted image showing the AGN core, radio lobe and scattered light is showing with predicted magnification factors (fig 3).

Can we confirm if our three component model of F10214 comprising an AGN core, NLR and extended starburst is plausible? Rest-frame optical emission lines of Halpha+NII, [OIII]5007,4959 provide an opportunity to do so as they are already known to have complex profiles with broad and narrow components [K96,S98,L98, fig2b-c]. These components will trace gas located close to the AGN core, the NLR and the extended starburst and thus can be compared with our findings from our existing deep HST, radio and CO data. We therefore propose AO-assisted (LGS) integral-field observations of F10214 with NIFS to measure these rest-frame optical lines on 0.1-0.2" scales (~100pc in the source-plane for the starburst) and at high spectral resolution (60km/s). The NIFS data will deliver the first line and kinematic maps of F10214 at high angular resolution that we will use to test our three component model. While a wealth of science can be drawn from these observations, we highlight some of our immediate objectives:

- If the 8Ghz peak pin-points the AGN core, we would expect the BLR map to show a concentration of broad-line emission at this position that is offset from the rest-frame optical arc (fig 2a).

- The arc is a blend of 3 images. based on the HST160W images [D11] suggest that it also comprises two components: a wide arc from the extended star-forming disk (extended in the EW direction), and a more centrally concentrated component that traces the NLR (extends in the EW+NS direction). We will use the line maps to search for distinct kinematic signatures that will confirm the presence of two different line emitting regions.

- We will resolve sub-strucutre within the extended starburst arc and NLR. We will place the short side of the NIFS spaxels along the arc (0.04"). As the bulk of the lensing is tangential this will provide high spatial resolution imaging spectroscopy of the extended starburst on <100pc scales. We will use our lens model to reconstruct line maps of F10214 in the source plane. As our ancillary data probes similar spatial scales we will be able to derive spatially resolved properties of the starburst such as star-fromation rates, star-formation efficiency, metallicities and excitation.

- We will map turbulent gas, outflows and winds searching for red or blue extended wings in the emission lines (seen in OIII in long-slit data [L98])

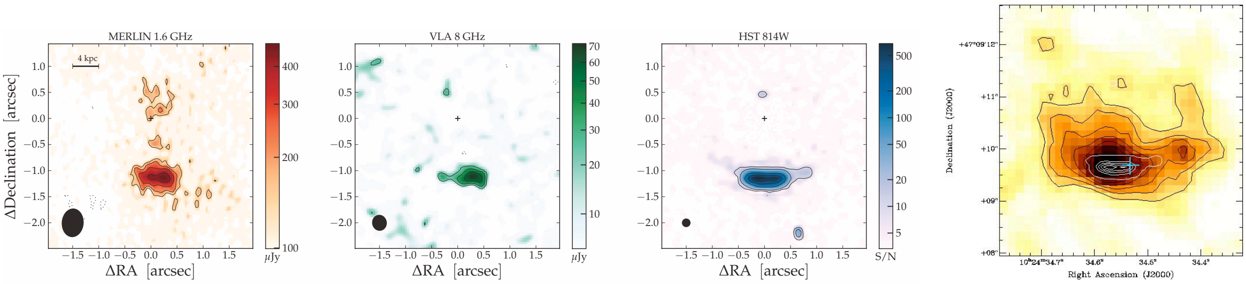

Figure 1: **(a)** MERLIN 1.6 GHz map **(b)** 8 GHz VLA map **(c)** HST814W map with counter-image and arc (the lens has been removed with GALFIT). The FWHM of all PSFs are shown in the lower left of each frame. In all panels the cross indicates the centroid of lensing galaxy as measured from the HST160W map. The figures show an offset between the compact 8GHz source and the centre of the 814W emission. The former is interpreted as the AGN core and the latter the NLR+starburst. **(d)** The peak in (c) is shown on a deep CO(1-0) map [D11] with HST 814W (fig 1c) contours over plotted in white showing the offset between these peaks. The arc-like structure is consistent with the expected part Einstein ring that should result from a larger-scale extent of the molecular disk

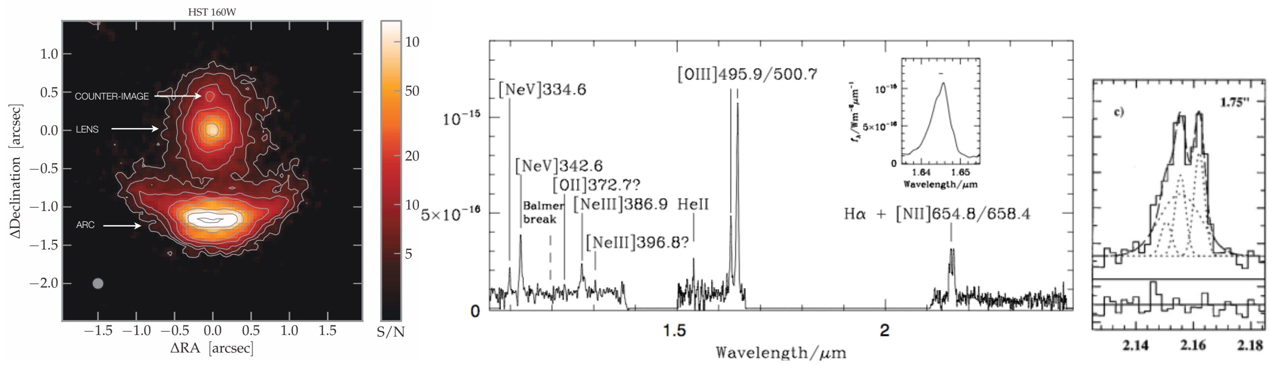

Figure 2: **(a)** HST 160W map with lensing galaxy, counter-image and the arc. The arc shows two clear components: an extensive, faint arc, as well as a larger, more dominant component. We attribute the latter to the scattered quasar light (that dominates the HST814W map) as well as a more extended, lower magnification host galaxy component. This is supported by the global SED as well as the 4000 $\AA$ break first identified by L98. The 160W PSF (FWHM ∼150 mas) is illustrated by the grey circle in the lower left. **(b)** The long-slit NIR spectrum of [L98] (in W/m2/um) **(c)** Multiple components fit to the H-alpha line [K96].

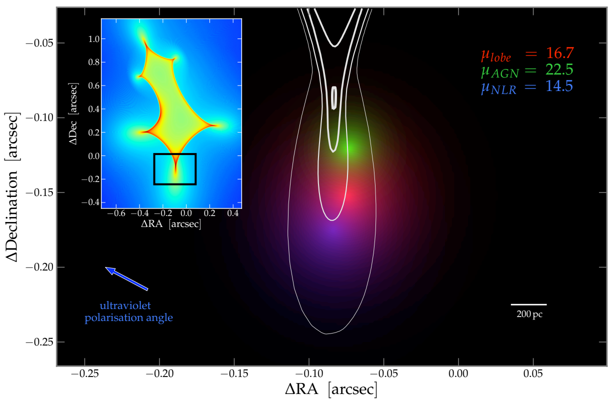

Figure 3 Source plane reconstruction of IRAS 10214 showing the AGN core (green), scattered quasar light (blue), and radio lobe (red). The white contours represent lines of equal magnification extending from the caustic at levels μ = 10,20,50,100,150. The inset shows the full lens caustic with colour scale representing magnification and the black rectangle showing the borders of the enlarged region. The magnification of each source could be computed from the convolution of each source with this magnification map. In practice we integrate the model flux in the image plane and the source plane and take the ratio.

REFERENCES: [A05] Alexander et al., 2005, 357, L16 [BL95] Broadhurst & Lehar, 1995, ApJ, 450, L41 [C85] Close et al, 1995, ApJ, 453, 616 [D11] Deane et al. 2011 thesis & in prep. [D95] Downes, Solomon & Radford, 1995, 453, L65 [E06] Efstathiou et al. 2006, MNRAS, 371, L70 [E11] Efstathiou et al. in prep. [E94] Elston et al. 1994, AJ, 107, 910 [E99] Evans et al. 1999, ApJ, 518, 145 [G96] Green & Rowan-Robinson, 1995, MNRAS, 279, 884 [I96] Iwamuro et al., 1995, PASJ, 47, 265 [I05] Iwasawa et al. 2005, MNRAS, 362, L201 [K96] Kroker et al. 1996, ApJ, 462, L55 [L98] Lacy, Rawlings & Serjeant, 1998, MNRAS, 299, L1220 [L93] Lawrence et al., 1993, MNRAS, 260, L28 [N10] Negrello M., et al. 2010, Science, 330, 800 [RR91] Rowan-Robinson et al. 1991, Nat. 352, 677 [S95] Serjeant et al., 1995, MNRAS, 276, L9 [So95] Soifer et al. 1995, ApJ, 443, L65 [S10] Sturm et al. 2010, A&A, 518, L36 [T06] Teplitz et al. 2006 ApJ, 638, L1 [T95] Trentham, 1995, MNRAS, 277, 616

Technical Justification *(923 words)*

Fortuitously the redshift of F10214 places the bright emission lines of Halpha+NII, [OII]3727, [OIII]5007,4959 in very "clean" parts of the H&K bands - free from bright sky lines and low atmospheric absorption features.

ALTAIR details

We proposal to use the LGS with ATLAIR. A star lies within 13.7" of F10214. It is faint however, R=17.74 & V=18.3 mag based on the SDSS DR8 photometry and conversion of sloan to Johnson for stars (Lupton 05). Therefore this observation will be in the low strehl regime. As a result we have elected to use SB=80% to allow successful guiding on the tip/tilt star. We expect a correction of 10% in the H & K bands and less in the J-band.

NIFS Observations

From exisiting spectroscopic measurements we design our observations based on the MPE3D results from Kroker et al. We base our flux requirement on the faintest broad component seen in the MPE3d images in a 2.5" diameter aperture. The broad component of the Halpha+NII line has a level of 0.2mJy (figure 2 in Kroker et al. 96, see also fig 2d). Assuming this light originates from the the extent of the arc+diffuse emission (~1 sq. arcsec.) this gives a surface brightness of 2e-4 Jy/sq. arcsec (assuming it's uniform over this extent). This is equivalent to a sensitivity of 7e-22 W/m2/(Km/s). With NIFS the resolution element (that is Nyquist sampled by the detector) is 57km/s - thus the data will be sensitive to fluxes of 4e-20 W/m2 per resolution element (3sigma). The assumption of uniform brightness in this aperture is very conservative allowing us to discern even faint broad components. The peak of the line emission will be signficantly brighter than this. This conservative limit just means that we will be sensitive to any diffuse or extended emission from the background host galaxy. We therefore adopt this conservative estimate as our 3-sigma detection limit.

For the purposes ofthe ITC we use

- an extended source with uniform surface brightness of 2e-4 Jy/sq arcsec in the K-band (to represent the faintest broad component of Halpha as described above).

- Power-law spectrum (flat) Sv=v^0

- H-K filter+K grating+central wavelength 2.156um (the redshifted wavelength of Halpha)

- very low background

- Altair wavefront sensor with AO guide star sep 13.7" & R=17.74mag, LGS+Field lens IN

- IQ=70, CC=50 (required for LGS observations), WV=Any, SB=80, airmass <1.2 (appropriate for the Dec of this source assuming it is observed close to transit)

- 9x600s integration

- per 1x2 IFU (at centre) - 0.103"x0.084"

gives an SNR of ~3.2 per binned spectral pixel element at 2.15um

While this seems low at first glance, it should be noted that this is a conservative estimate for the faintest ~peak of the broad component in Halpha - the integrated flux over the broad component will be e.g. ~4x higher for a 1000 km/s line. Also the peak emission of the total Halpha line will be even higher. It is important to achieve high SNR on these lines so that we can decompose the line profiles into the different components, be sensitive to the fainter diffuse components and not just be dominated by emission from the core.

Furthermore, for the typical R of NIFS in the K-band this will yield ~60km/s spectral resolution - depending on the component of the line emission we are investigating we can adaptively bin the data to achieve signficantly higher SNR on the broad and narrow components by binning over both spectral and spatial pixels (more IFU elements).

Thus we will be able to clearly detect any broad components to this depth at a spatial resolution of ~0.1" in 90mins on source. We will align the short side along the arc so that the greatest spatial resolution is achieved in this direction.

As the source encompasses the NIFS FoV it is not possible to nod on IFU therefore we must perform an equal number of sky observations. Assuming the 40% offsetting efficiency recommended on the NIFS web pages this results in a total observation time of 5 hours - assuming the target is visited 2 times we add 2x25min of acquistion/setup overhead giving a total of 5.8hr.

We similarly perform H-band observations to target the [OIII] doublet. We use the same setup and integration time as the K-band with the exception of - J-H filter+H grating+central wavelength 1.645um (the redshifted wavelength of OIII5007) this results in a SNR~3 at 1.65 um. As in the K-band, this will allow us to probe faint diffuse emission lines and spectral line component while delivering high SNR (~20) on the two OIII lines

We also note that our spectra will include measurements of the foreground lens for which we will determine an accurate velocity dispersion using the redshifted Ca triplet absorption lines in the H-band. The dispersion is an important ingredient of the lens model and exisiting measure are from low resolution spectrographs. An accurate dispersion will break lens modelling degeneracies between theEeinstein radii of the main lens and neighbouring galaxy (Fig3 caustics but not shown) and the ellipticity of the main lens. While the galaxy is faint it is also centrally concentrated meaning that our AO assisted observations will make this measurement feasible after binning spectrally and spatially over the galaxy. This is a strong, essential constraint.

Total time: our total time request is therefore 2x5.8hr = 11.2hr

[Note, L98 claim to have already reached 100pc scales however this is based on the previously assumed linear magnification factor of (100) - this has since been revised, our new model suggest factors of 10-25]

Band 3 Information

This proposal cannot be scheduled in Band 3.

Observation Details

Observation	**RA**	**Dec**	**Brightness**	**Total Time** *(including overheads)*
IRAS F10214+4724	10:24:34.56	47:09:9.59		11.6 hours
U1350_07766563(aowfs)	10:24:35.837	47:09:10.08	17.5 mag	separation 0.22
Observing conditions: NIFS/LGS		resources: NIFS		

Observing Conditions

Name	**Image Quality**	**Sky Background**	**Water Vapor**	**Cloud Cover**
Global Default	Any	Any	Any	Any
NIFS/LGS	70 %	80 %	Any	50 %

Resources

- Gemini North
  - NIFS
    - Disperser
      - H-grating
      - K-grating
    - Filter
      - JH
      - HK
    - Adaptive Optics
      - Altair
      - Field lens
      - Laser guide star

Scheduling Information

Scheduling constraints and non-usable dates

- (impossible):
- (optimal):
- (synchronous):

Additional Information

Keyword Category: extraGalactic
Keywords: Active galaxies
Dust
Dynamics
Emission lines
Gravitational lensing
IR-luminous galaxies
Seyfert galaxies
Starburst galaxies

Publications:

- Tecza M., et al. 2004, ApJ, 605, L109: SPIFFI Observations of the Starburst SMM J14011+0252:Already Old, Fat, and Rich by z=2.565
- Nesvadba N., Lehnert M., Davies R.I., Verma A., Eisenhauer F., 2008, A&A, 479, 67: Integral-field spectroscopy of a Lyman-break galaxy at z = 3.2: evidence for merging
- Forster Schreiber et al. 2006, ApJ, 645, 1062
- Genzel et al. 2006, Nature, 442, 786
- Forster Schreiber N., inter alios, Verma A., et al., 2009, ApJ, 706, 1364: The SINS Survey: SINFONI Integral Field Spectroscopy of z ~ 2 Star-forming Galaxies
- Negrello M., et al., 2010, Science 330, 800: The Detection of a Population of Submillimeter Bright, Strongly Lensed Galaxies
- Tecza et al., 2009 SVLT Conference: HARMONI: A Narrow Field Near-infrared Integral Field Spectrograph for the E-ELT