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MID-INFRARED SUB-ARCSECOND SPECTROSCOPY OF ACTIVE GALAXY NUCLEI

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RESUMEN

Presento observaciones espectroscópicas recientes de AGN cercanos obtenidas en 8-13 μm con TReCS en Gemini-S. Las observaciones revelan variaciones en la profundidad de absorción en escalas de subsegundos de arco en Circinus y NGC 5506 y delinean las regiones de gas ionizado y la región de emisión PAH en Circinus. Varias galaxias activas cercanas muestran evidencias estructuras circunnucleares de polvo, resueltas con tamaños de decenas de parsecs. Los perfiles de absorción de silicato hacia los núcleos más fuertemente oscurecidos son más angostos que aquellos de las galaxias con $\tau_{(9.7\mu\mathrm{m})} < 3$, reflejando posiblemente tamaños de los granos en promedio mayores que los de estas últimas, como resultado de la destrucción de los granos más pequeños por el AGN.

ABSTRACT

I present recent spectroscopic observations of nearby AGN obtained at 8-13 μm with TReCS on Gemini-S. The observations reveal variations in absorption depth on subarcsecond scales in Circinus and NGC 5506 and delineate the regions of ionized gas and PAH emission region in Circinus. Several nearby active galaxies show evidence of resolved circumnuclear dusty structures with sizes of 10s of parsecs. The silicate absorption profile towards the most heavily obscured nuclei are narrower than those in the galaxies with $\tau_{(9.7\mu\mathrm{m})} < 3$, possibly reflecting larger average grain sizes in the latter resulting from destruction of the smallest grains by the AGN.

Key Words: **DUST, EXTINCTION — GALAXIES: ACTIVE — ISM**

1. INTRODUCTION

Mid-infrared observations with large ground-based telescopes provide the opportunity to investigate the structure of dust emitting and absorbing regions in nearby AGN on scales of 10s of parsecs. In order to explain many of the observed properties of AGN, a circumnuclear torus - a dense dusty structure, inclined to line of sight, and obscuring direct view in Seyferts of type 2 - is invoked (e.g. Antonucci 1993). The detailed circumnuclear structure is very uncertain but the inner edge may be set by evaporation of dust. An AGN with L= $2\times10^{10} L_{\odot}$, will produce T$>$ 1000K at R$<$ 0.1pc and T$\sim$ 300K at R$\sim$ 1pc (0.05 at 4Mpc). For direct heating of dust grains, the mid-IR-emitting disk is unresolved but a cool outer disk may be traced by its absorption and in particular by the 9.7 μm silicate absorption band. Emission from stochastically-heated small grains may arise from a much more extended region, but there is good evidence small grains are destroyed by AGN photons (Aitken & Roche 1985).

2. OBSERVATIONS

Long slit spectra between 8 and 13 μm were obtained at the 8-m Gemini South telescope in clearing skies with the facility mid-infrared imager/spectrometer, T-ReCS (Telesco et al. 1998), in May 2004. The bright nuclei were centred in the slit before taking the spectroscopic observations. Spectra were obtained with standard chop and nod techniques (chop throw 15 arcsec) after centering the compact nucleus in the 0.36 arcsec wide slit. The instrument was configured with the low resolution (11 line/mm) grating giving a dispersion of 0.0223 μm/pixel and a spectral resolution of 0.08μm. T-ReCS has a detector scale of 0.089 arcsec per pixel which provides a 25 arcsec long slit in the spatial direction and coverage of the full N photometric band, limited by the N filter bandpass, in the dispersion direction.

3. RESULTS

3.1. *Silicate Profiles*

Spectroscopy enables us to investigate grain properties at high spatial resolution, providing information on silicate profiles and composition and has revealed resolved structures on subarcsec scales in several nearby active galactic nuclei. In NGC 5506 (Roche et al. 2007) and the Circinus galaxy (Roche et al. 2006) there are significant variations in the absorption column measured by the depth

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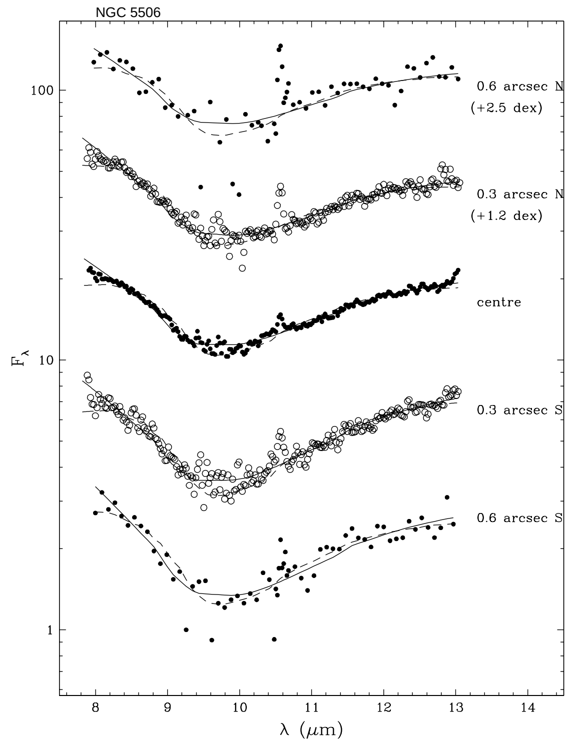

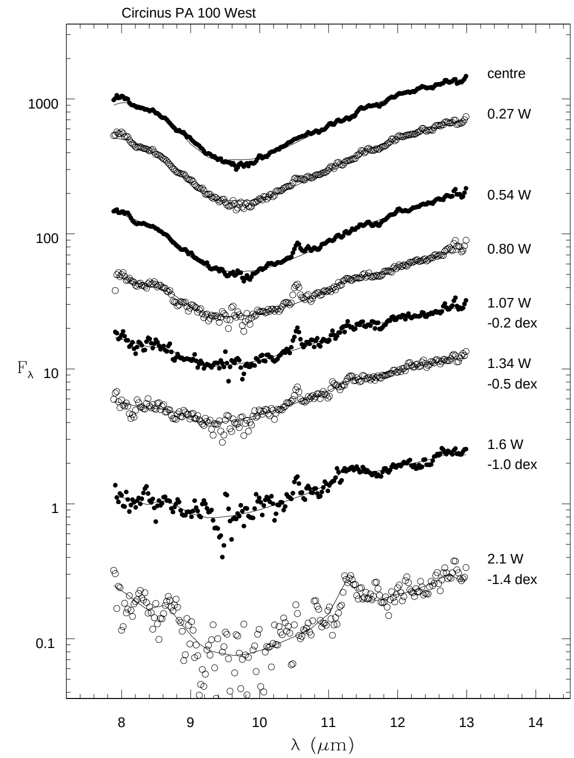

Fig. 1. Left: The spectra of NGC 5506, showing the increase in the depth of the silicate absorption band from N to S and the increase in the equivalent width of the 10.5 μm [SIV] emission line away from the nucleus. The solid lines represent fits to the spectra with the Trapezium silicate curve while the dashed lines use that obtained from the circumstellar shell of μ Cep. Flux is in units of 10^{-20}Wcm$^{-2}\mu$m^{-1}. The spectra at 0.6 arcsec S and N have been smoothed to improve the S/N ratio per point, except in the vicinity of the [S IV] emission line. Right: Spatially resolved spectra of the nucleus of the Circinus galaxy extending from the nucleus to 2 arcsec W, showing decreasing absorption optical depth with increasing distance from the nucleus. The [SIV] emission line becomes prominent 1 arcsec W of the nucleus, with the PAH features becoming dominent as the high excitation emission line intensity decreases. The dust continuum and [SIV] line emission is more heavily obscured on the east side of the nucleus (Roche et al. 2006)

of the silicate absorption feature on scales of 10s of parsecs, similar to the structures inferred in the nucleus of NGC 1068 (Rhee & Larkin 2006; Mason et al. 2006) and other galaxies presented at this meeting (T. Diaz-Santos & S. Young) (Figure 1). The extended continuum emission in these galaxies appears to exist within, and to be less extended than, the ionized regions traced by the mid-infrared emission lines. This dust has very weak or absent emission structure, indicating that it is not produced by small silicate or PAH grains. It may consist of relatively large grains or species such as corundum or nanodiamonds that do not have the characteristic silicate emissivity structure. However, the prominent silicate absorption bands and the variations in absorption optical depth indicate that silicate grains are the dominant species in the cooler regions where most of the mid-IR absorption arises.

The properties of the cool, absorbing silicate grains are similar to those found in the Galactic interstellar medium. The galaxies with the deepest silicate absorption bands have narrow silicate profiles that are well matched by the silicate profile derived from the circumstellar shell in oxygen rich giant stars and characteristic of the diffuse ISM in the galaxy (Roche & Aitken 1984). The less heavily obscured nuclei have silicate profiles that are better fit by a broader Trapezium-like silicate band that is characteristic of molecular material in the Galaxy (Whittet et al. 1988). This may indicate that the grains in these objects are larger on average, perhaps reflecting destruction of the smallest grains, or that they are located in dense regions. Despite the good correspondence between the silicate profiles in the heavily obscured galaxies and the Galactic diffuse ISM, the ratio of the depth of the hydrocarbon absorption band at 3.4 μm to the silicate feature are significantly lower than in the Galaxy (e.g. Imanishi 2000).

Observations with Spitzer have revealed the signatures of crystalline silicate grains in the spectra of several deeply-embedded galaxies, with $\tau_{(9.7\mu\mathrm{m})} > 3$, and additional absorption bands from hydrocarbons at 6.85 and 7.25 μm and a number of molecular species (Spoon et al. 2006). The TReCS spectrum of NGC 3094 shows structure near 11 μm which may be due to crystalline grains; deep ground-based observations of the most heavily obscured nuclei will allow us to ma out the crystalline grain component.

3.2. *Extended Nuclear Emission*

The bright compact nucleus of the nearby ($\sim$ 4 Mpc) Circinus galaxy allows detailed study. The nuclear emission arises from relatively featureless emission, suffering silicate absorption with an optical depth $\tau_{(9.7\mu\mathrm{m})} \sim 3$ The absorption increases to the east suggesting an extended dusty structure, possibly aligned with the the parcsec-scale disk traced by VLBA maser emission (Greenhill et al. 2003). The nucleus is embedded in ionized gas which, if the underlying emission is symmetric, also suffers increased extinction to the east. The 11.3 μm PAH emission band becomes increasingly prominent with distance from the nucleus. The PAH emission is not affected by the additional extinction to the east, indicating that it arises preferentially from a more extended region, outside the coronal zone, consistent with destruction of small grains close to the nucleus. If the extended dusty structure is a disk, it must extend to at least tens of parsecs at 10 μm. The additional optical depth between the east and west sides, $\tau_{9.7\mu\mathrm{m}}$ $\sim$1.6, corresponds to A_V $\sim$25 mag (Roche & Aitken 1984) or a column density of $n_H \sim 5 \times 10^{22}$ cm^{-2} if the dust to gas ratio is similar to the Galactic interstellar medium. Integrating this over a disk radius of 30 pc, and allowing for the inclination gives a total mass of $\sim 4 \times 10^5$ $M_\odot$ for a uniform column density. This compares to an upper limit of 4×10^5 $M_\odot$ for the mass of the disk inside 0.4pc derived by Greenhill et al. (2003) for the molecular disk containing the water masers. The structure detected in the mid-infrared is much less dense than the inner disk, but still has a very substantial optical thickness at a radius of 30 pc, and could have a much greater value closer to the nucleus.

Similar, though smaller variations in optical depth are seen in NGC 1068 and NGC 5506 on scales of about 50pc, again suggesting that large scale, dusty absorbing structures may be present around many type 2 AGN.

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REFERENCES

Aitken D. K., & Roche P. F. 1985, MNRAS, 213, 777
Antonucci, R. 1993, ARA&A, 31, 473
Greenhill, L. J., et al. 2003, ApJ, 590, 162
Imanishi, M. 2000, MNRAS, 319, 331
Mason, R. E., Geballe, T. R., Packham, C., Levenson, N. A., Elitzur, M., Fisher, R. S., & Perlman, E. 2006, ApJ, 640, 612
Rhee, J. H., & Larkin, J. E. 2006, ApJ, 640, 625
Roche, P. F., & Aitken, D. K. 1984, MNRAS, 208, 481
Roche, P. F., et al. 2006, MNRAS, 367,1689
Roche, P. F., Packham, C., Aitken, D. K., & Mason, R. E. 2007, MNRAS, 375, 99
Spoon, H. W. W., et al. 2006, ApJ, 638, 759
Telesco C. M., Pina R. K., Hanna K. T., Julian J. A., Hon D. B., & Kisko T. M. 1998, Proc. SPIE, 3354, 534
Whittet, D. C. B., Bode, M. F., Longmore, A. J., Adamson, A. J., McFadzean, A. D., Aitken, D. K., & Roche, P. F. 1988, MNRAS, 233, 321