NEW IR SOURCES FOR STUDYING THE ISM ON SIGHTLINES TOWARD THE GALACTIC CENTER: A HIGHLY SUCCESSFUL POOR WEATHER PROGRAM

T. R. Geballe *(Gemini Observatory),* E. Lambrides *(American Museum of Natural History),* S. C. C. Yeh *(Subaru Telescope)*
M Goto *(University of Munich Observatory)*, B. Schlegelmilch (*UCLA*), C. Westrick and T. Oka *(U. Chicago)*

SUMMARY

We are nearing completion of a low spectral resolution *K*-band survey of ~500 highly reddened point-like objects in the Central Molecular Zone (CMZ) of the Galaxy. The goal is to find bright objects with intrinsically featureless or nearly featureless spectra that are suitable for high resolution 2-5μm absorption spectroscopy of the Galactic center's interstellar gas, on sightlines spread across the CMZ. Until recently very few such objects have been known outside of the Quintuplet, and Central clusters. We have used Spitzer (GLIMPSE) and 2MASS photometry to aid us in selecting candidates, and over the last several years have been acquiring low resolution K-band spectra of them to determine their natures. Although by far the majority of objects have (as expected) turned out to be cool and/or highly reddened red giants with complex spectra unsuitable for measuring faint interstellar lines, approximately ten percent of them have featureless or nearly featureless spectra. Most of these have *K*-band continua rising steeply to longer wavelengths and are luminous stars that are embedded in dust cocoons. Based on incomplete follow- up spectroscopy of CO and H_3^+ almost all are within the Galactic center. (GC).

SCIENTIFIC JUSTIFICATION

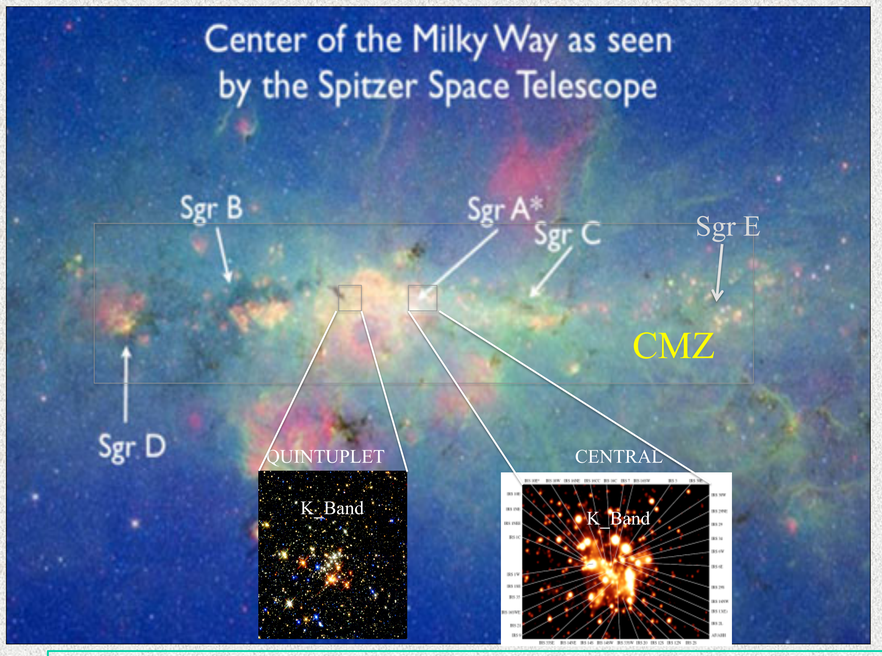
Until recently, it was thought that the interstellar gas within the central few hundred parsecs of the Galaxy, usually referred to as the Central Molecular Zone (CMZ) consisted of three major components (Morris & Serabyn 1996; Lazio & Cordes 1998): ultra high temperature X-ray-emitting plasma; ionized gas at T ~ 104–6 K responsible for the fine structure and radio recombination line emission and enhanced scattering of radiation from background sources; and dense molecular clouds.

In the last dozen years absorption spectroscopy of H_3^+ at 3.5-4.0 μm and CO at 2.3 μm and 4.7 μm (eg, Oka et al. 2005) has unexpectedly revealed the presence of another gaseous environment in the CMZ which has the characteristics of Galactic diffuse cloud material, but is considerably warmer (200–300 K). The measured column densities of H_3^+ toward objects in the Central Cluster and in and near the Quintuplet Cluster (30pc to the east) indicate absorption path lengths for this gas that are significant fractions of the dimensions of the CMZ, and thus suggest a large volume filling factor for it.

To test if this is correct and to study the motions of the CMZ gas., absorption spectra are needed on widely spaced sightlines though the CMZ. Until recently, however, only a handful of stars, all located in or close to the aforementioned two clusters, were known to be sufficiently bright for high-resolution spectroscopy and to have sufficiently featureless spectra (so that faint interstellar lines are uncontaminated by photospheric absorption lines).

OBSERVATIONS

Over the last seven years we have been conducting a *K*-band spectroscopic survey of bright and highly reddened IR objects in the CMZ to search for objects with suitably smooth spectra. Most of the spectra have been obtained in poor weather conditions or at other times when it was difficult or impossible to carry out other (higher priority) science programs. Red giants (unsuitable for spectroscopy of the ISM) are easily identifiable by their strong CO bands at 2.3-2.4 μm .



SURVEY CRITERIA (approx.)

358.8°< G_lon < 1.2°
-0.3° < G_lat < 0.3°
***L* (IRAC1) < 8 (from SPITZER/GLIMPSE)**
***J* ≥ *14*, *J* – *K* ≥ 5 (from 2MASS)**
***L* - *8* (IRAC1-IRAC4) ≥ 1.5 (GLIMPSE)**
(expect the vast majority of objects to be red giants)

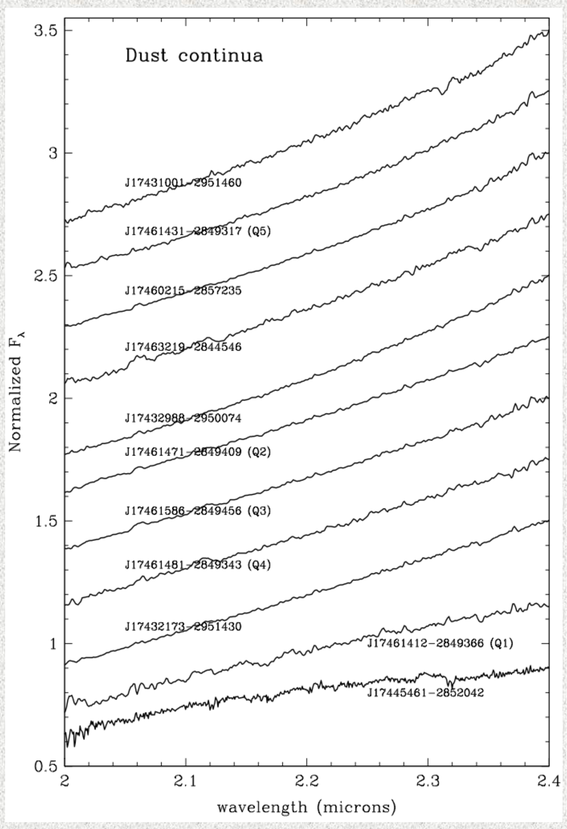
SPECTRA OBTAINED (477)

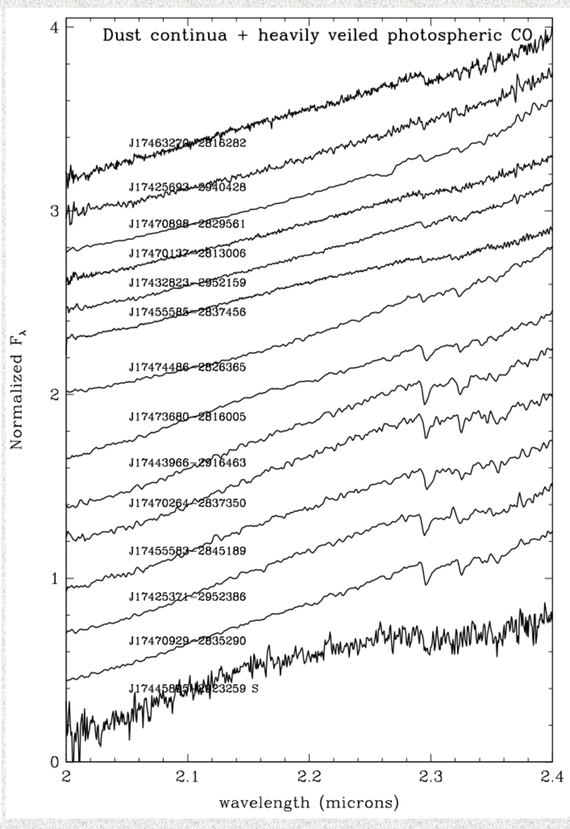
UKIRT / UIST (2008): 72
GEMINI NORTH / NIRI, GNIRS: (2010-2015): 269 and counting
IRTF / SPEX (2010, 2014): 63
SUBARU / IRCS (2013): 9
GEMINI SOUTH (FLAMINGOS-2 (2014/5): 64 and counting

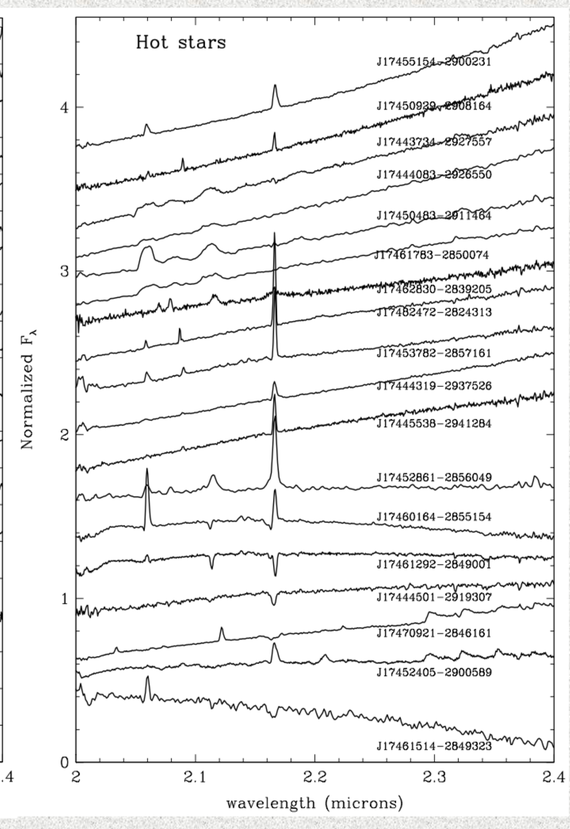
437 spectra reduced to date, 21 to be reduced, 19 redundancies

RESULTS

- **~40 suitably smooth-spectrum sources detected outside of the Central Cluster (only a handful known previously).**
- **~380 spectra of red giants observed, covering a wide range of temperatures, foreground extinction, and extinction/emission by circumstellar dust.**
- **Several new emission line stars discovered**



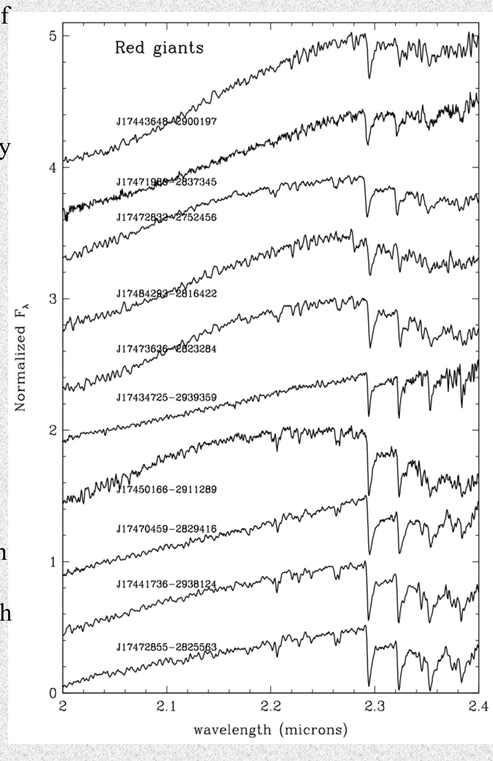




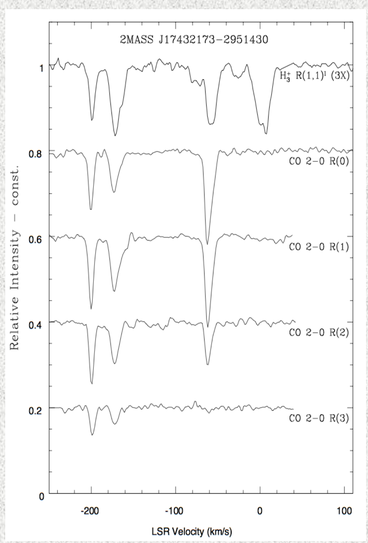
The figures show 2.0-2.4 μm spectra of four groups of objects. Each spectrum is normalized at the wavelength of maximum continuum signal.

To the left are objects suitable for study of interstellar lines. At far left and immediate left are objects with pure dust continua and with atomic lines, respectively, suitable for spectroscopy in the *K* band and longer wavelengths. At middle left are red giants that are heavily embedded in dust shells, suitable for spectroscopy at 3 μm and beyond. We have used the most extreme of these for spectroscopy of interstellar overtone CO lines at low *J* near 2.35 μm.

At right are spectra of a small selection of red giants. Those with continua increasing steeply to longer wavelength are probably embedded in dust shells and may be be suitable for spectroscopy of interstellar gas at longer infrared wavelengths.



The figure at right is an example of how we are using these objects to study the interstellar gas on lines of sight to the Galactic center and within the CMZ. Velocity profiles of lines of H_3^+ and CO toward the dust continuum object 2MASS J17432173-2951430, (*K* spectrum above) located near the negative longitude edge of the CMZ. The data were obtained with Phoenix at Gemini South. The absorption near -50 km/s arises in dense clouds in the 3 kpc expanding arm of the Galaxy. The absorption near -172 and -200 km/s, also due to dense molecular clouds are associated with Sgr E. The absorption near 0 km/s, which is not seen in CO but is also present in the 1-0 *R*(3,3)l line of H_3^+, arises in warm, diffuse gas in the CMZ.

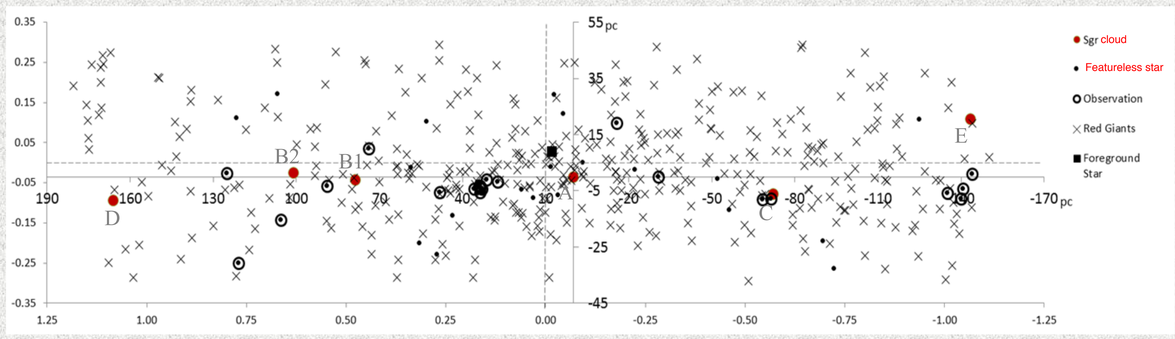


REFERENCES

Lazio, T. J. & Cordes, J. M. 1998, ApJ, 505, 715
Morris, M. & Serabyn, E. 1996, ARAA, 34, 645
Oka, T., Geballe, T. R., Goto, M., Usuda, T., McCall, B. J. 2005, *Ap*J, 632, 882

ACKNOWLEDGEMENTS

Based partly on research done and observations partly obtained at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (US), the Science and Technology Facilities Council (UK), the National Research Council (Canada), CONICYT (Chile), the Australian Research Council (Australia), Ministério da Ciência e Tecnologia (Brazil) and Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina).



The above figure shows the CMZ, with Galactic longitude horizontal and latitude vertical. Filled circles mark the locations of sources with featureless spectra, atomic lines, and heavily veiled photospheres. Open circles are those which infrared spectroscopy of interstellar gas has been obtained. Each X marks the position of a red giant. Note the concentration toward the Galactic plane of objects with (nearly) featureless spectra.