PACS Spectroscopy of Early Type Galaxies

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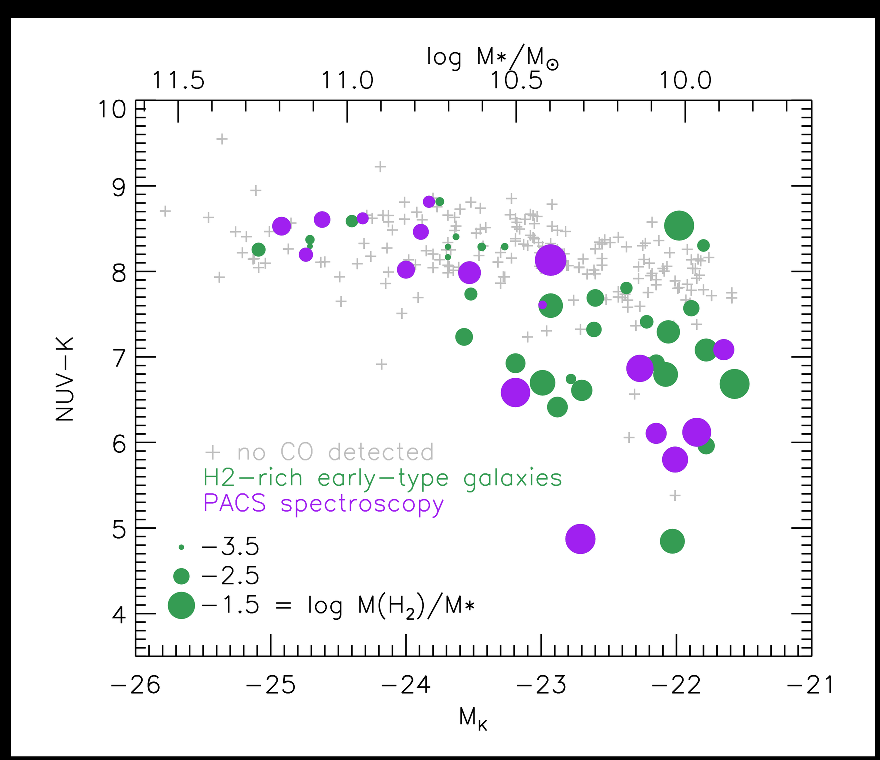
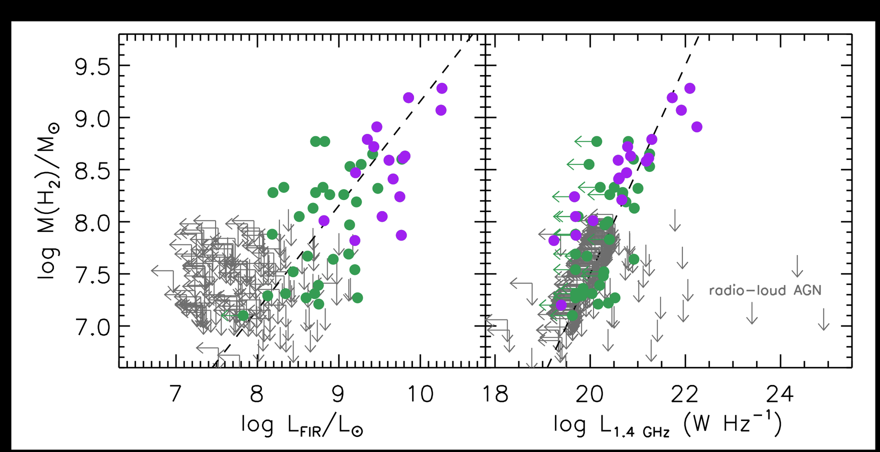
Sample Selection



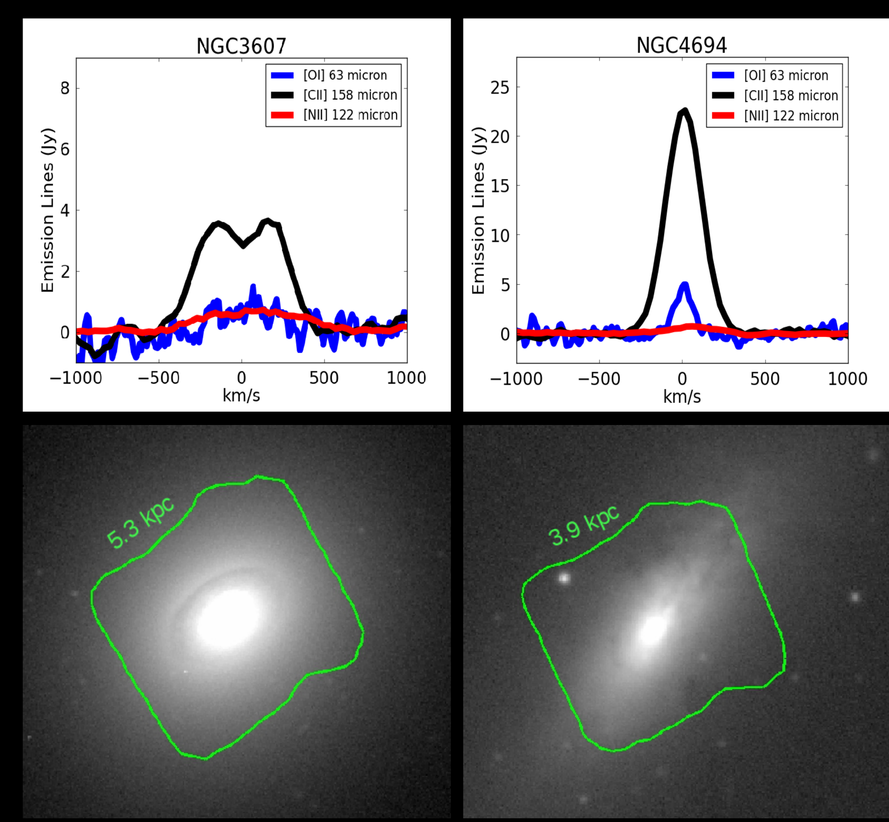


The galaxies chosen for observation are rich in H_2, but are still mainly on the red sequence and span a wide range of magnitude and NUV-K. They are selected out of the 260 Atlas3D volume limited sample with MK < -21.5 (log $M_\star/M_{sol}$> 9.9), Distance < 41 Mpc, and no spiral structure. The actual selection was made based on IRAS luminosities.

Color-Magnitude plot (above) and IRAS luminosities for observation candidates (left) (Young et al. in prep). The dashed line is an extrapoloation of Gao & Solomon's (2004) CO - FIR relation for spiral galaxies and a radio/ FIR ratio from Yun et al (2001).

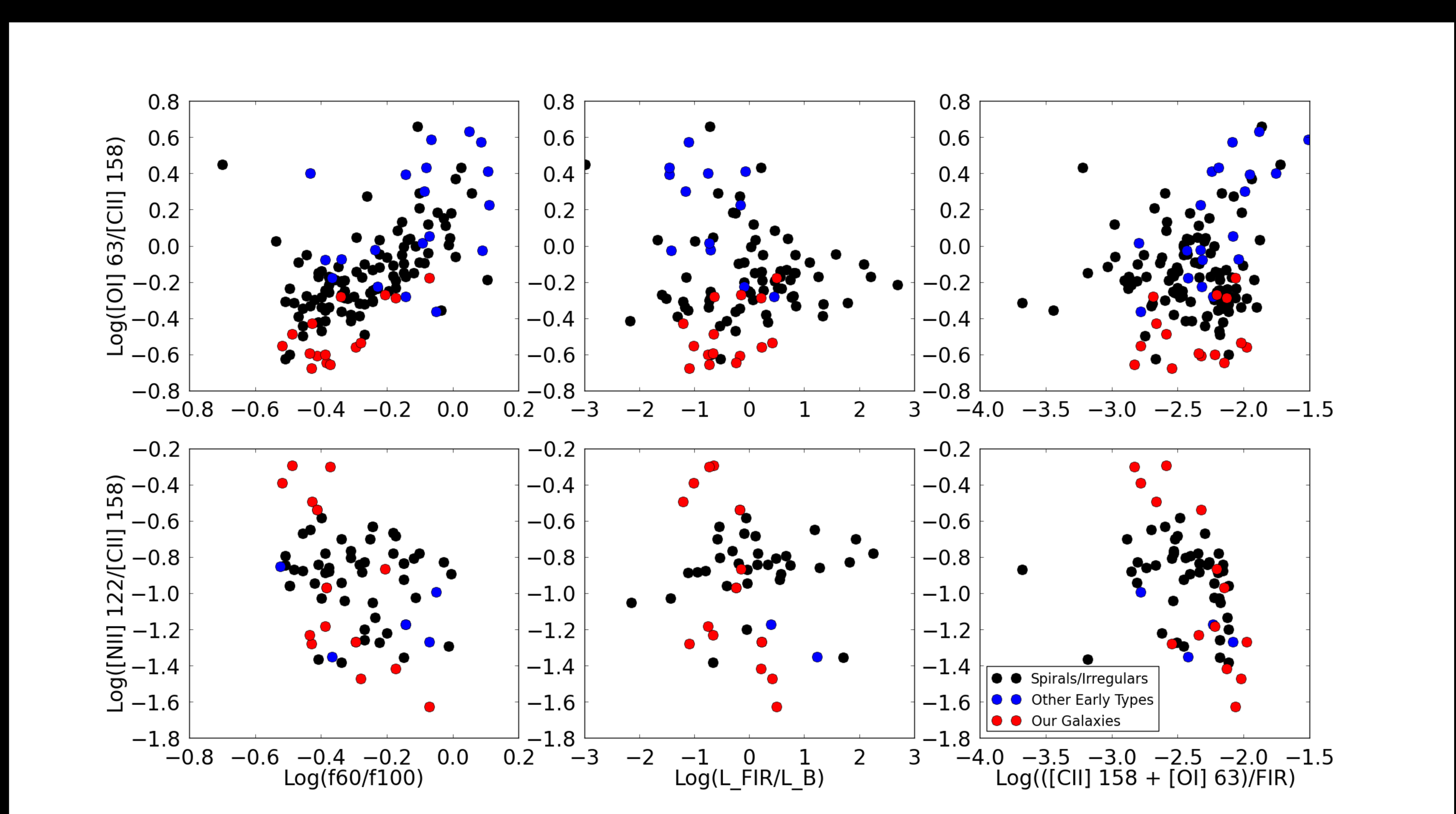
Data Reduction

The PACS spectra were processed in HIPE using the Chop/Nod LineScan pipeline. Post-pipeline the built-in linear baseline subtraction tool was applied, then an elliptical aperture was used to sum the spectra from every channel into a final spectrum which could be integrated to obtain a flux for the CII 158, OI 63, and NII 122 micron cooling lines.



An example of reduced PACS spectroscopy for [CII] 158, [OI] 63, and [NII] 122 micron cooling lines (above), and the [CII] 158 footprint overlaid on SDSS g images for the corresponding galaxies (below)

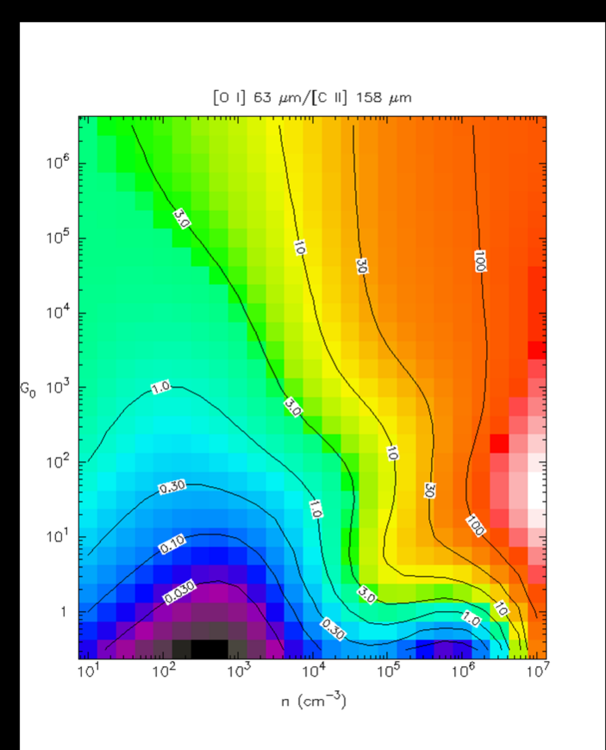
FIR Cooling Line Ratios

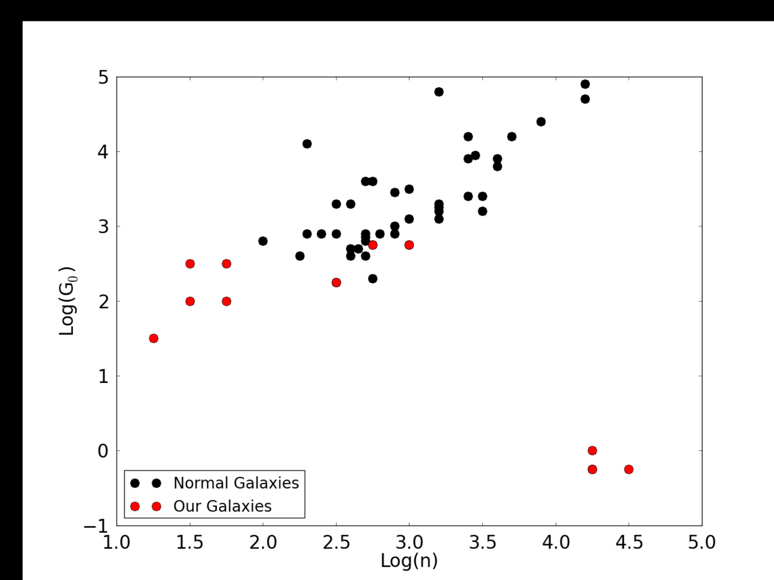


The most interesting line ratios we examined were the [OI]63/[CII]158 and [NII]122/[CII]158 ratios. The legend is the same for each panel: red points represent our sample, blue points represent other early type galaxies, and black points represent spirals and irregulars. The comparison sample is taken from Brauher, Dale, and Helou (2008).

In general, most line ratios were broadly similar to regular spirals and other early type galaxies (i.e. [CII]158/FIR, [OI]63/ FIR), but some had notable differences. The [OI]63/[CII]158 is systematically low in the Atlas3D galaxies. This is likely due to a low atomic gas fraction with the majority of the carbon being ionized. Additionally, some galaxies exhibit large [NII]122/[CII]158 ratios. This could be interpreted several ways: the gas density is large, the density of ionizing photons is large, or abundance effects could play a role.

PDR Models





An example of a contour plot produced by the PDR Toolbox (left), and the PDRT results for our sample compared to the sample from Malthotra +2001 of mostly spiral galaxies (above)

Line ratios can also be used in modeling to estimate the intensity of the local UV radiation field as well as the gas density. We used the online PDR Toolbox to make such estimations with our [CII] 158, [OI] 63, and FIR values. Four galaxies appear to be in a high gas density regime (two data points overlap), and of these three have high [NII]122/ [CII]158 ratios, while the other has another possible solution at a lower gas density and higher radiation field strength.

Future Work

In the immediate future we will be using the SPIRE [NII] 205 micron line to further analyze the large [NII]122/[CII]158 ratios. Additionally we will use the SPIRE [CI] lines to better understand the carbon distribution (molecular,ionized and neutral). We will also be considering the gas kinematics and spatial variations in line ratios, molecular chemistry, Spitzer IRS spectra (some), PAH 8μm maps, gas-phase metallicity from optical emission lines, if the gas metallicity is different from the stellar metallicity, and deep radio continuum observations tracing star formation and low level AGN activity.

Acknowledgements

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References

Brauher+2008, Cappellari+ 2011a, Gao & Solomon 2004,
Kaufmann+1999, Malhotra+2001, Yun+2001