Relationships between Gas and Dust in Local Dusty Galaxies

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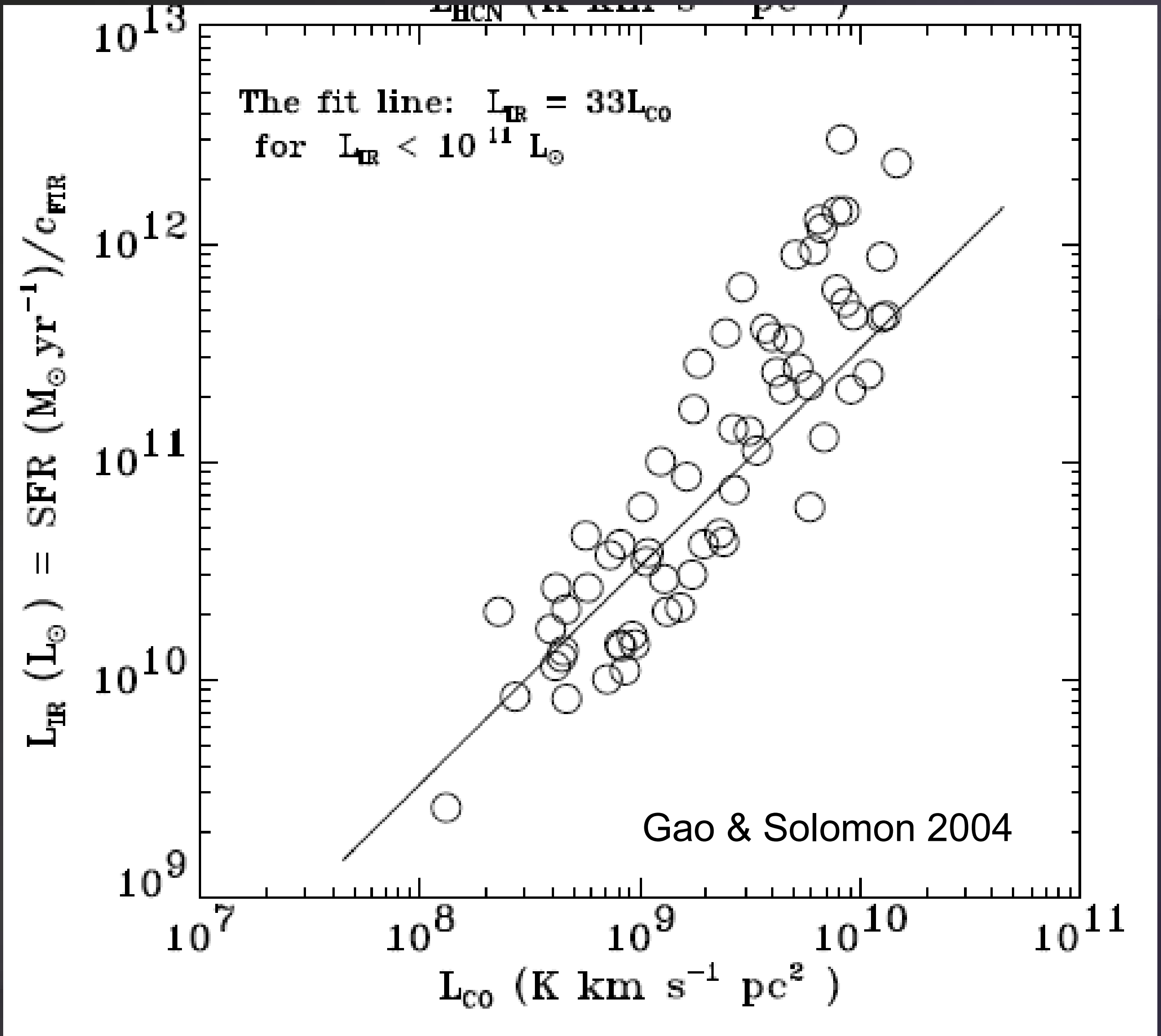
How is sub-mm emission related to the ISM in galaxies?



- We know there are links between the dust and molecular & atomic gas phases in galaxies
- FIR emission is commonly used as an SFR indicator
- The SFR itself is related to the gas content
- Dust also linked to gas content via dust/gas ratio

How is sub-mm emission related to the ISM in galaxies?

Dust also exists in several "phases" of the ISM:

- Does Herschel detect dust heated by young stars?
- Does it trace the SFR?

  - long-running debate
  e.g. Lonsdale Persson & Helou 1987; Walterbos & Greenawalt 1996;

  - recent evidence – e.g. Bendo et al. 2011; Boquien et al. 2011; Totani et al. 2011; Boselli et al.2012; etc etc

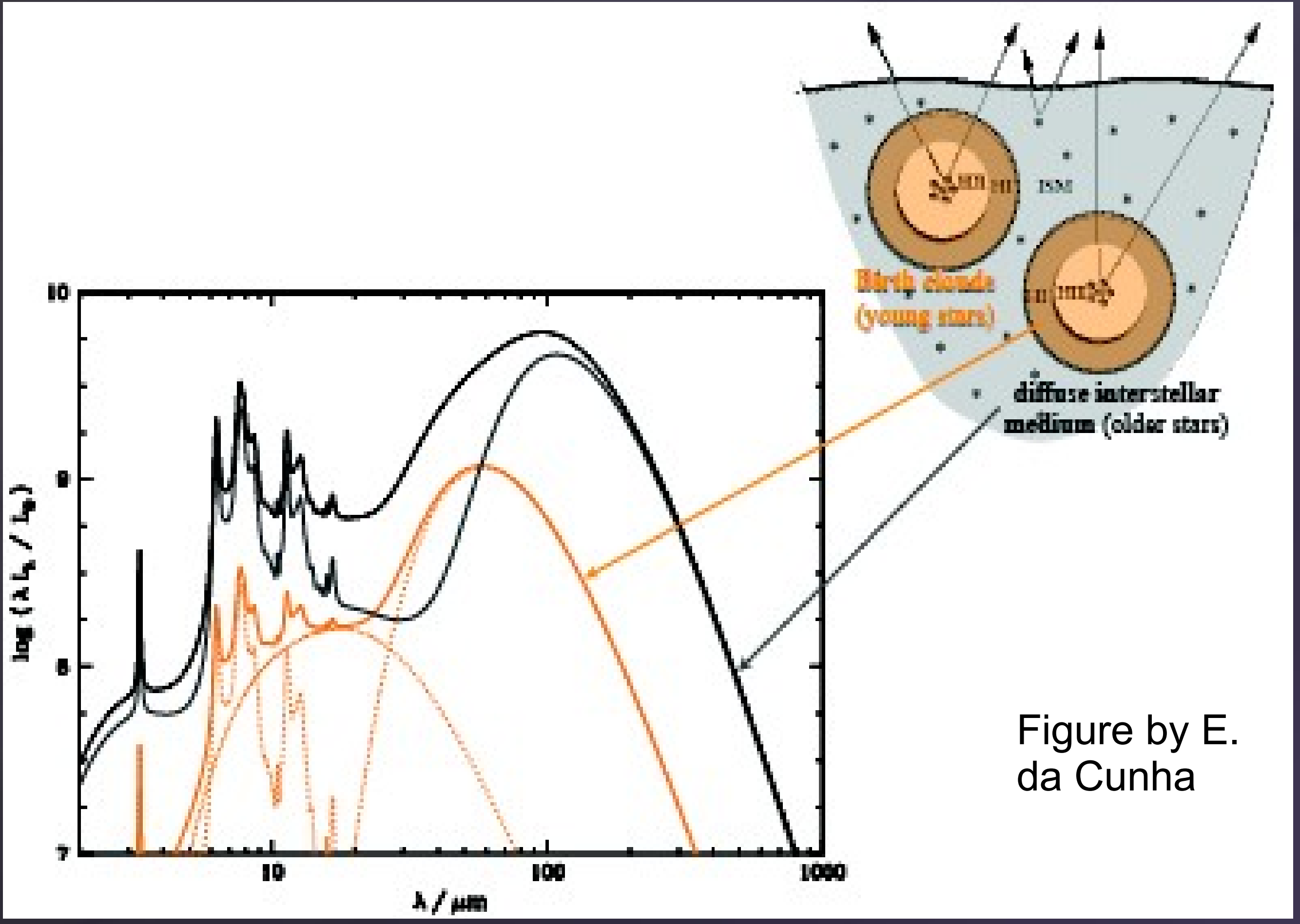


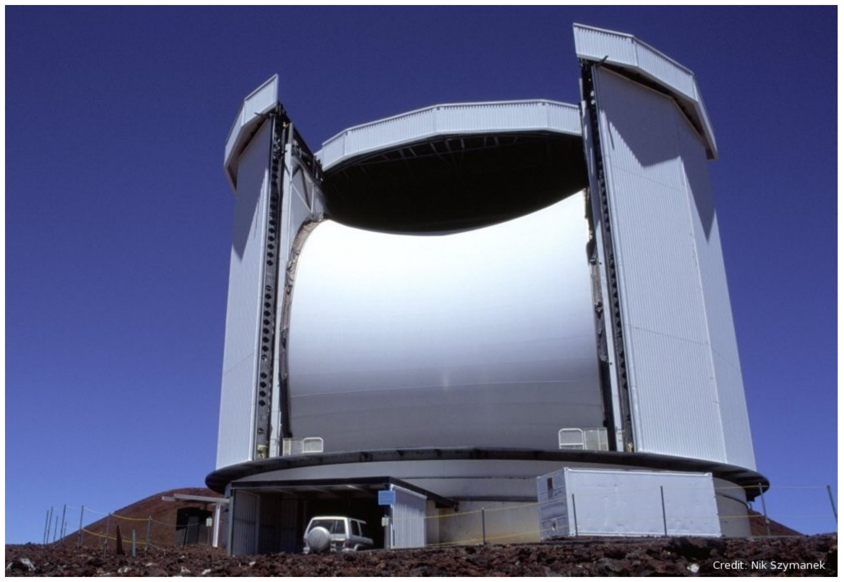
Figure by E. da Cunha

Sample and observations

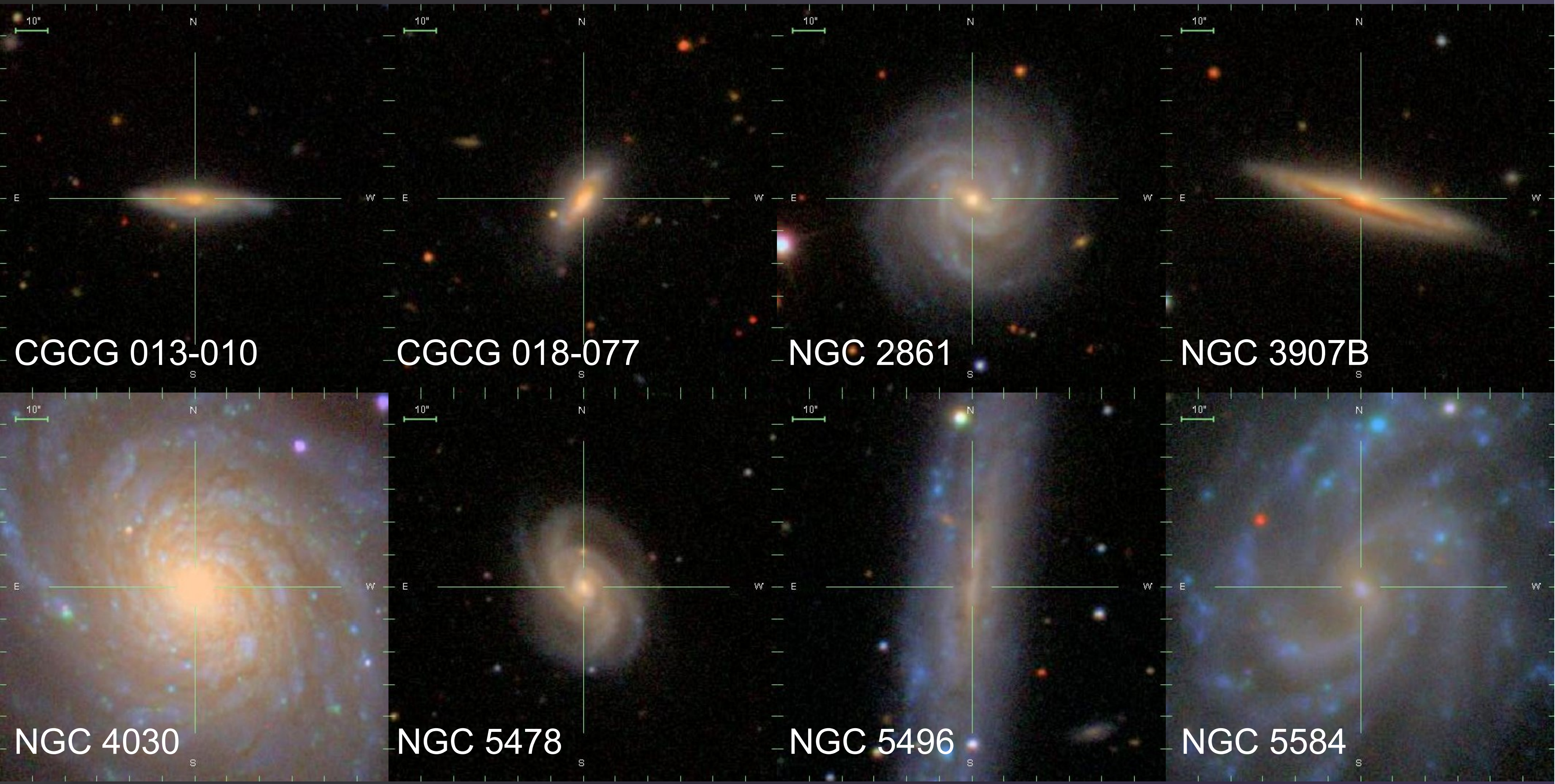
- 20 local (z<0.05) galaxies from H-ATLAS equatorial fields
- 500μm flux-limited sample
- FIR data covering the peak of the SED
- Cold SEDs – not bright IRAS sources, but (mostly) spirals whose gas and dust content have not been studied previously
- The dustiest galaxies in the local Universe

Need to test the correlation between sub-mm flux and CO tracers of the dense molecular gas

- CO observations at JCMT:
  - CO(3-2) on HARP
  - CO(2-1) on RxA
- Detecting total extended flux from CO in each of the galaxies
- Archival HI data from HIPASS

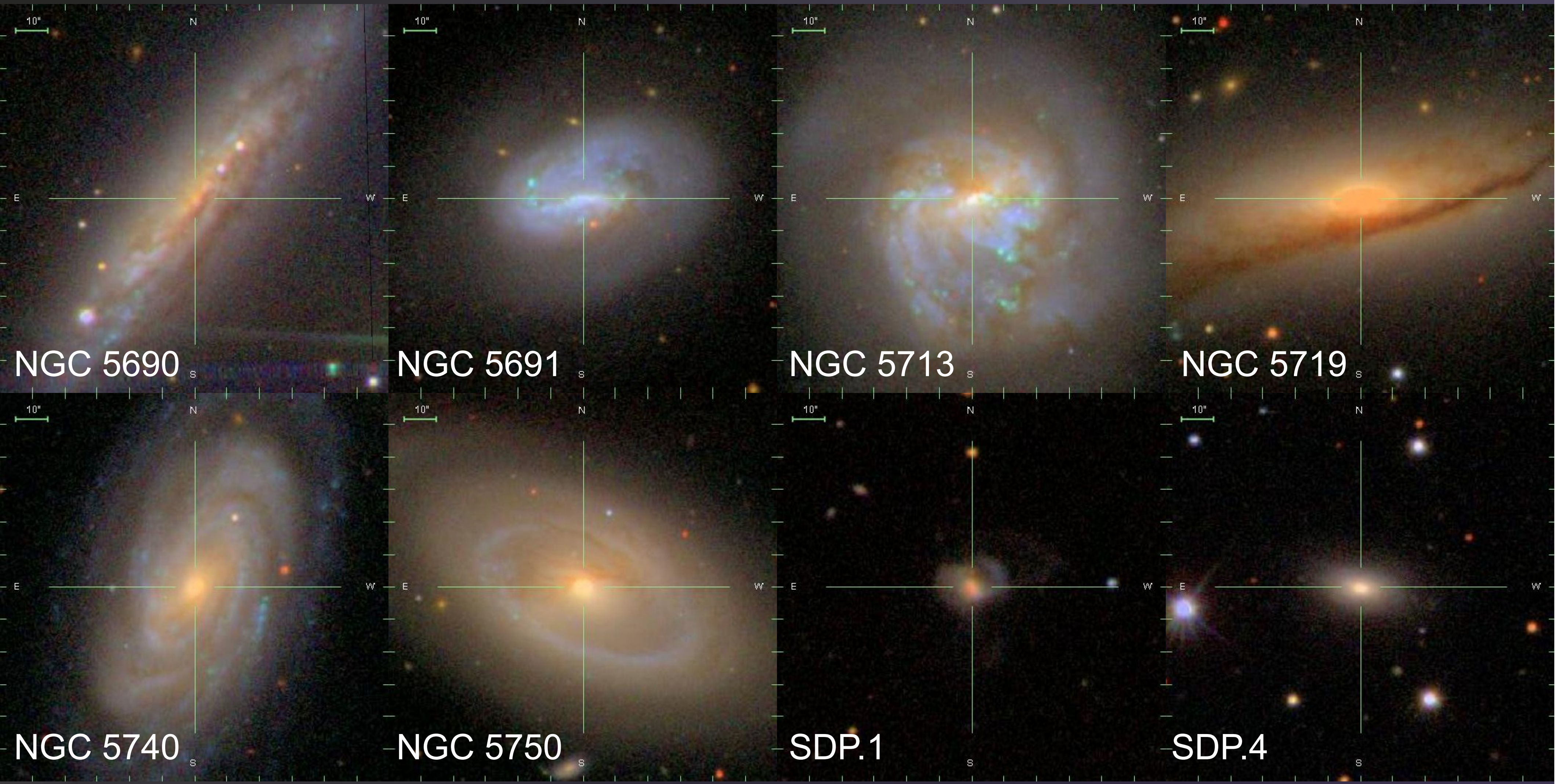


500μm-selected galaxies



- Blue and dusty spirals; extended sources; generally isolated
- Also included the two brightest early-types in SDP from Rowlands et al. 2012.

500μm-selected galaxies



- Blue and dusty spirals; extended sources; generally isolated
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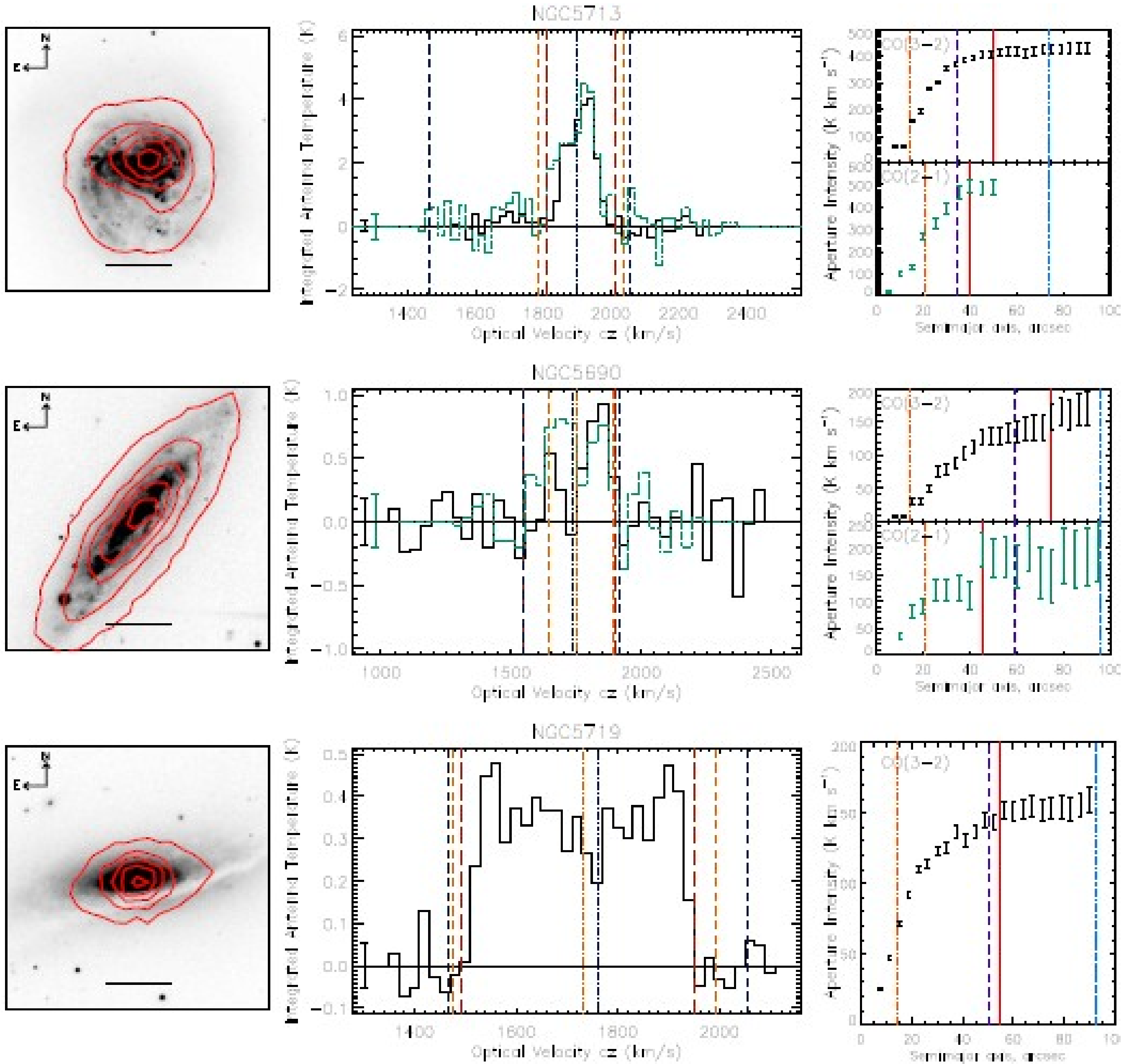
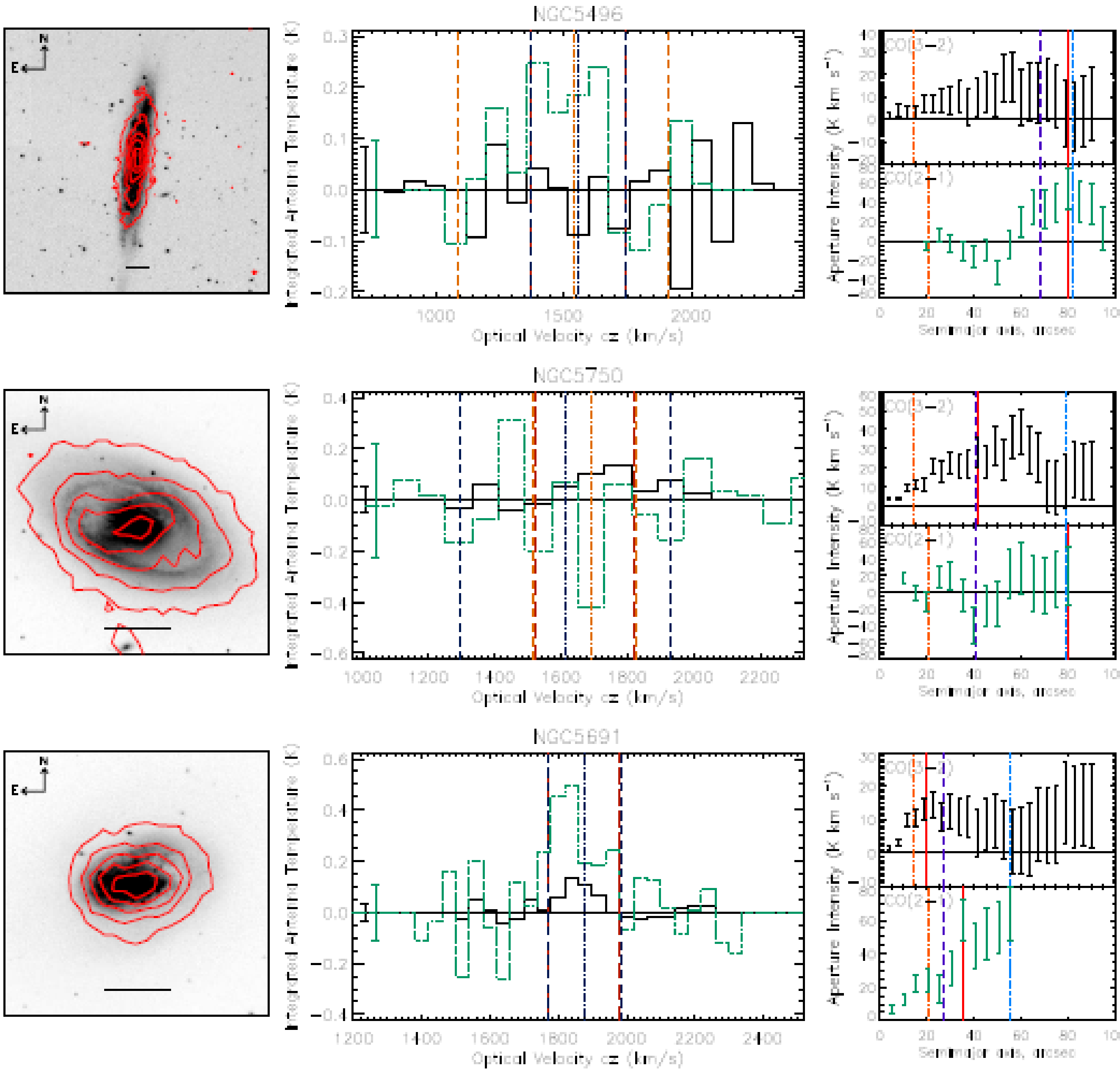
CO Data

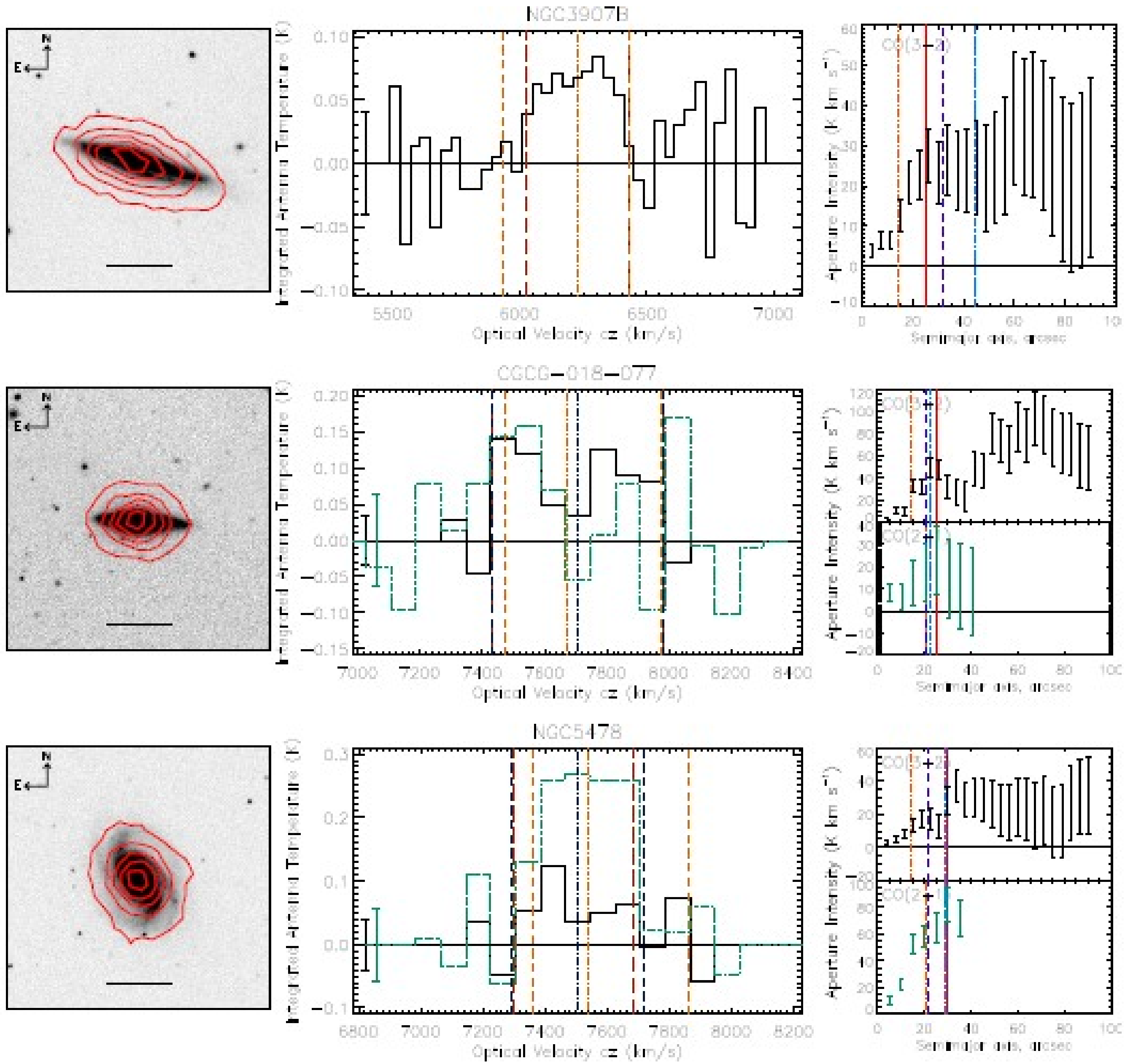


NGC5713
Optical Velocity cz (km/s)
CO(3−2)
CO(2−1)
Aperture Intensity (K km s⁻¹)
NGC5690
Optical Velocity cz (km/s)
CO(3−2)
CO(2−1)
NGC5719
Optical Velocity cz (km/s)
CO(3−2)

CO Data

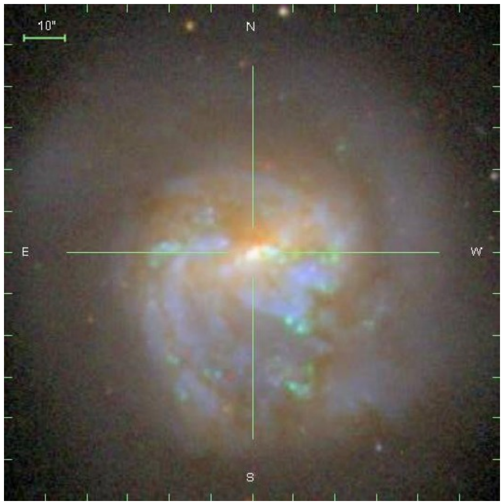

NGC5496
NGC5750
NGC5691
Optical Velocity cz (km/s)
Integrated Antenna Temperature (K)
Aperture Intensity (K km s^{-1})
CO(3−2)
CO(2−1)
Semimajor axis, arcsec

CO Data

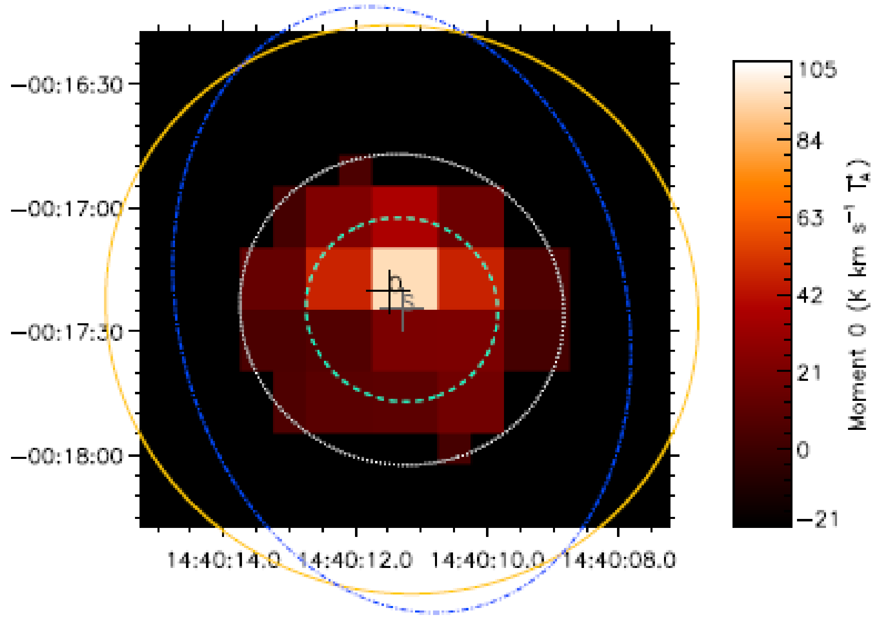

NGC3907B
Optical Velocity cz (km/s)
Integrated Antenna Temperature (K)
Aperture Intensity (K km s^{-1})
Semimajor axis, arcsec
CO(3–2)
CGCG–018–077
CO(2–1)
NGC5478

e.g. NGC 5713

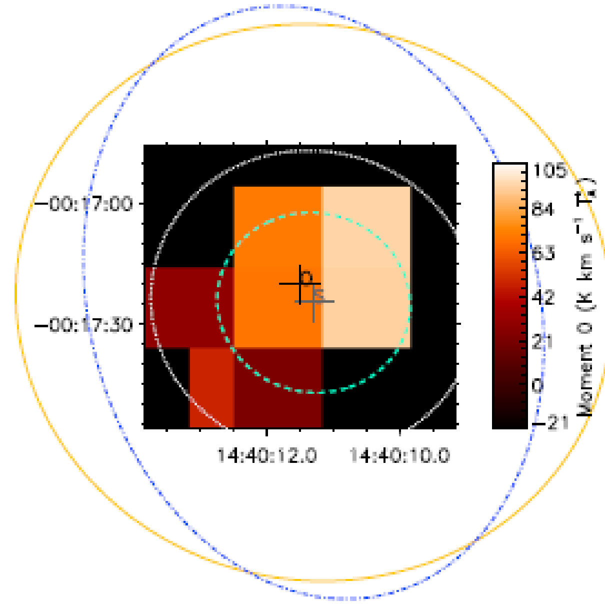
Sloan

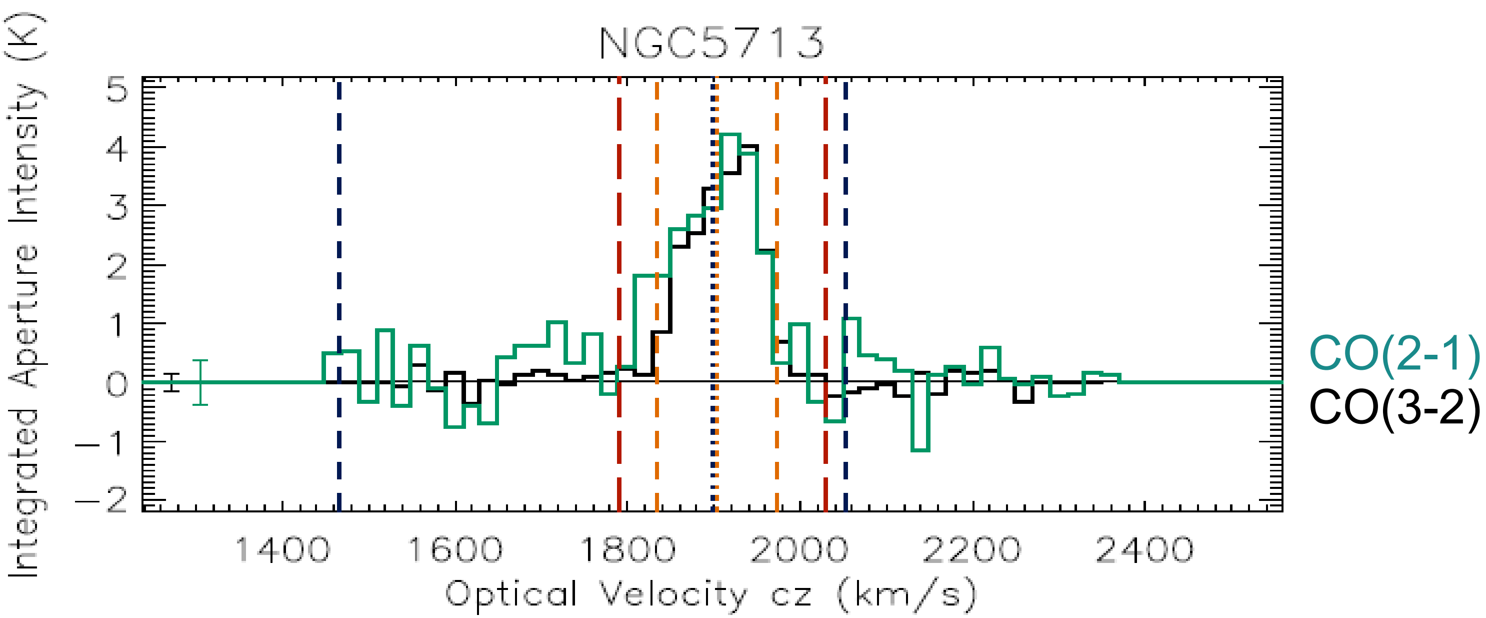


CO(3-2)



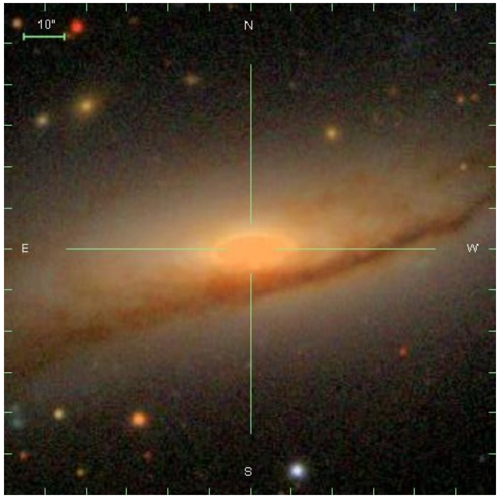
CO(2-1)



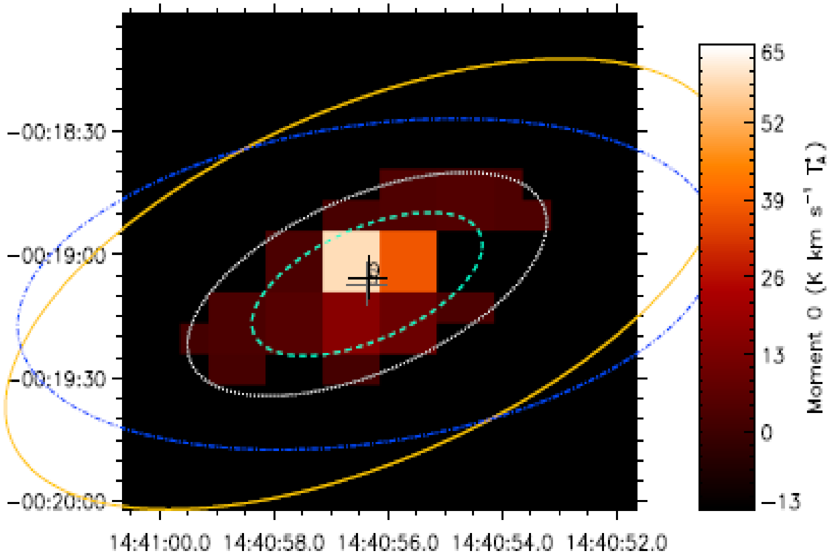


e.g. NGC 5719

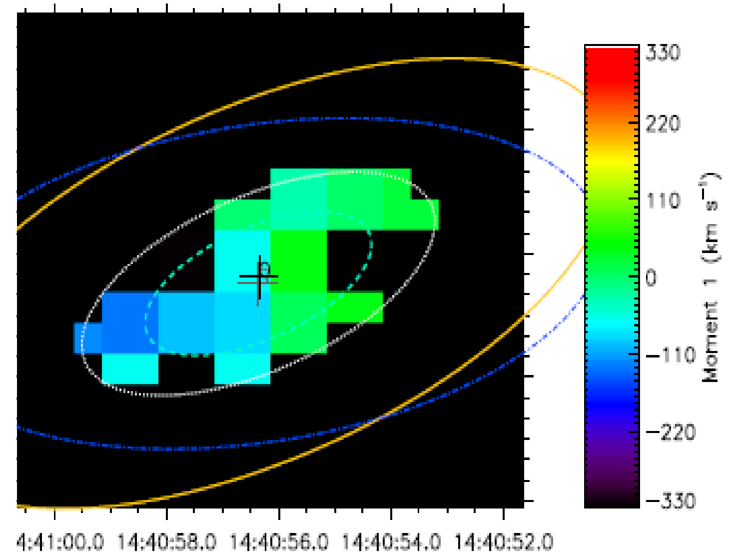
Sloan

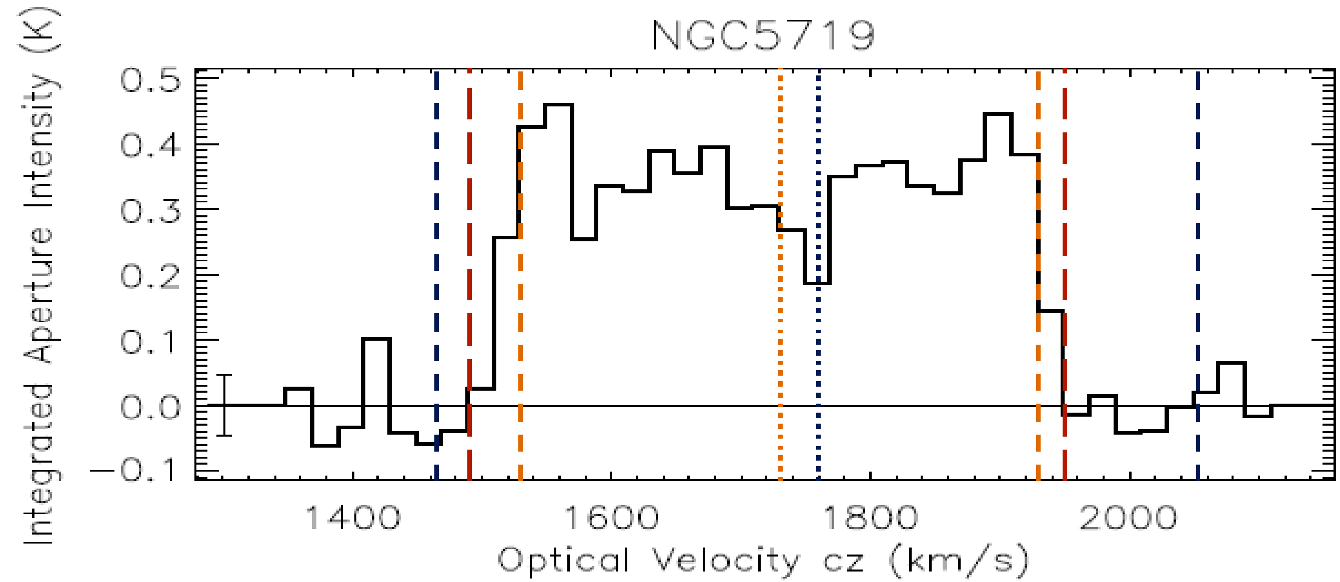


CO(3-2) moment 0



CO(3-2) moment 1





CO(3-2)

Looking for correlations in the results

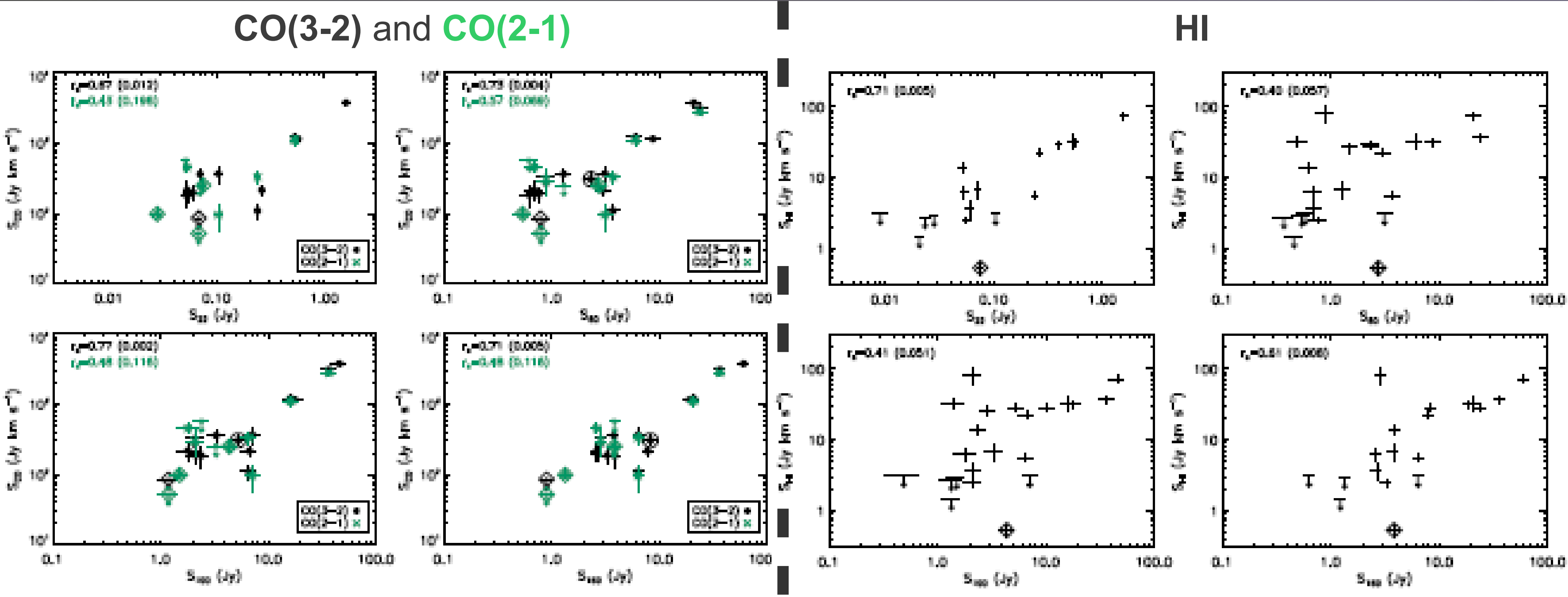
- Total CO fluxes
  CO(3-2) → warm, dense H_2
  CO(2-1) → cooler, more diffuse H_2 ; total molecular mass

- HI from HIPASS → total atomic mass

- 22μm from WISE;
  60, 100μm from IRAS; → warm dust; total L_{IR}
  160μm from PACS

- 250, 350, 500μm from SPIRE → cold dust; total dust mass

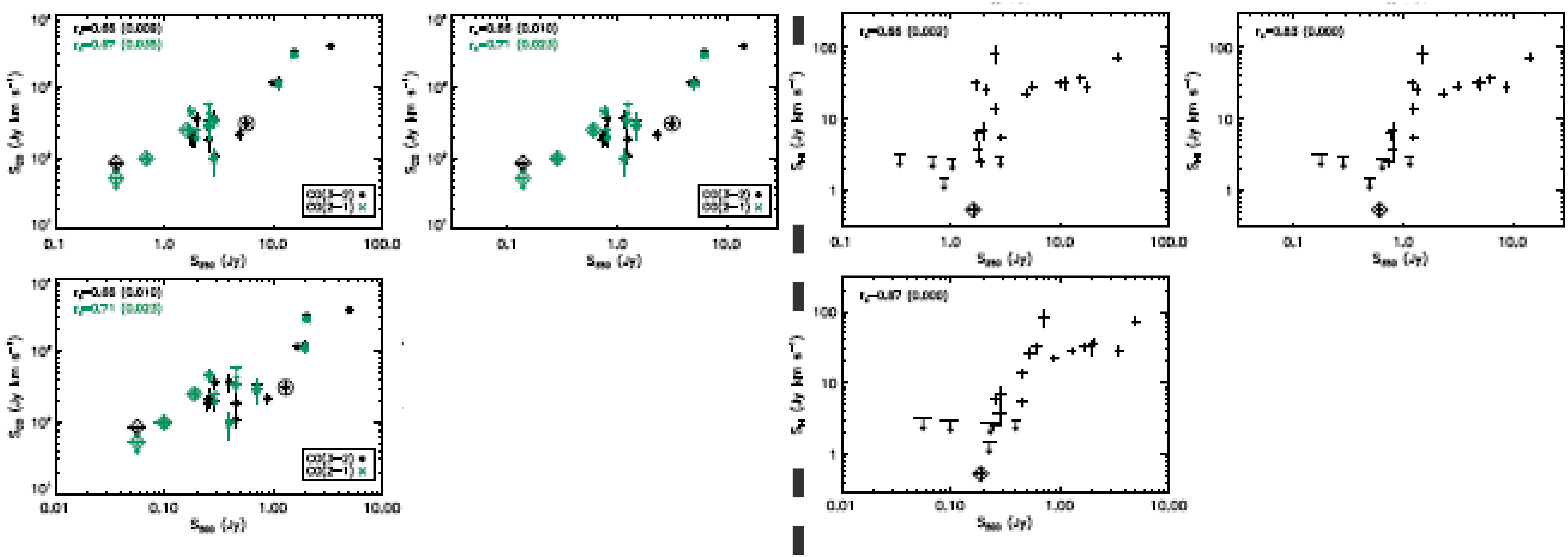
22-160μm (FIR)



- Scatter in CO(3-2) – FIR correlation decreases with FIR wavelength
- Reversed trend in HI

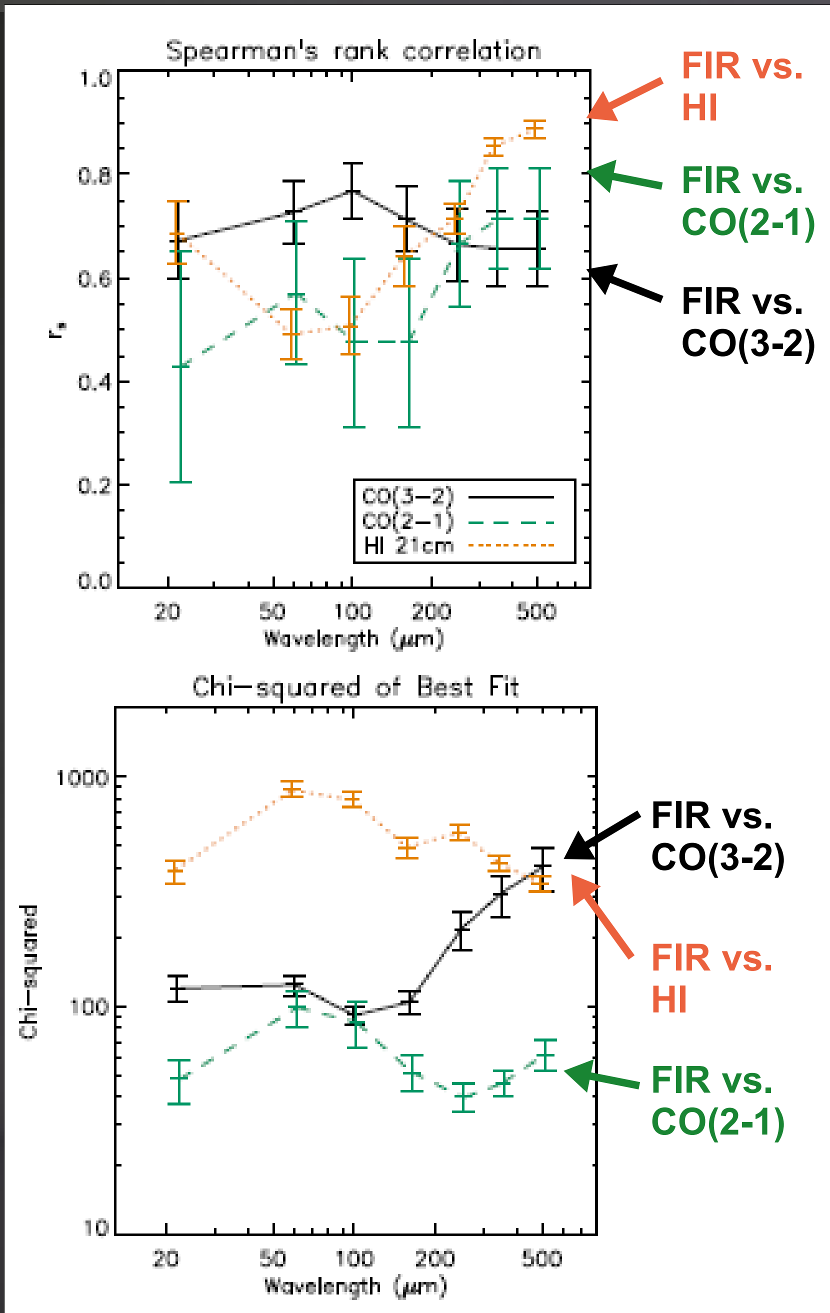
250-500μm (sub-mm)

CO(3-2) and CO(2-1) | HI



- Scatter in CO(3-2) – FIR correlation *increases* with wavelengths in the sub-mm
- Reversed trend in HI again

100μm traces dense gas; >250μm traces diffuse?



- CO(3-2) flux correlates best with 100μm; scatter increases in sub-mm
- HI fluxes correlate better with flux in sub-mm
- 22-60μm bucks the trend
- CO(2-1) less clear

Suggesting that:

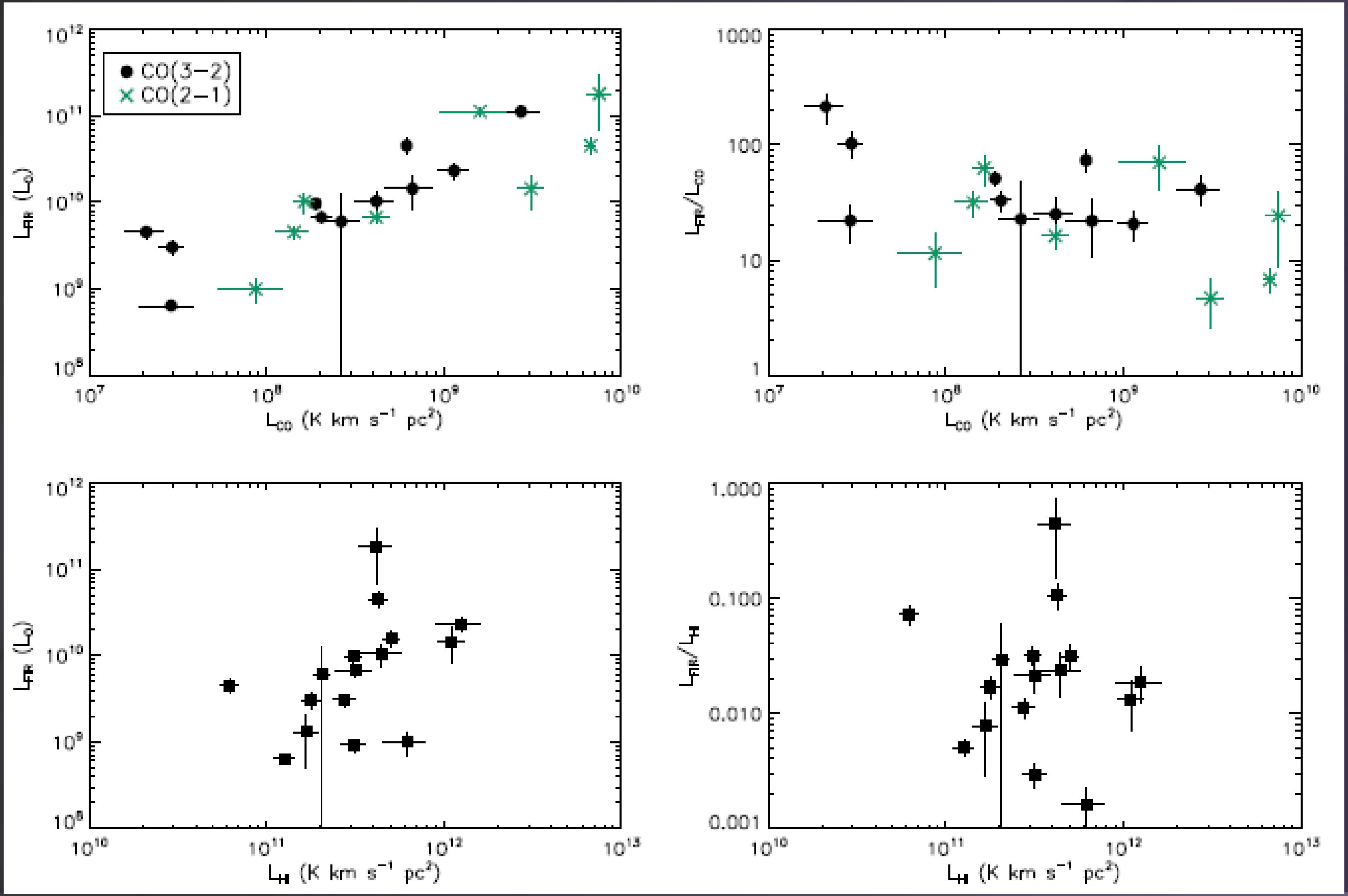
- Global sub-mm fluxes (>250μm) trace total gas mass
- But they are a poor tracer of dense molecular gas that fuels star formation
- Does this mean the cold dust is heated by evolved stars instead of young ones?
- 22-60μm fluxes contaminated by VSGs?

Cold dust heating by evolved stars

- Consistent with results from FIR colours in galaxies...
  - HRS galaxies – Boselli+2012
  - M33 – Boquien+2011 (HERM33ES) and Komugi+2011
  - JCMT Nearby Galaxies Legacy Survey (NGLS) – Bendo+2012
  - M31 – Smith+2012 (HELGA) , see also modelling by Groves+2012
- And recent results on the FIR – CO relationship in other samples
  - Virgo cluster spirals – Corbelli+2012 (HeVICS)
  - HI-selected galaxies in NGLS – Wilson+2012
- But also possible that diffuse dust is heated by UV light escaping from birth clouds

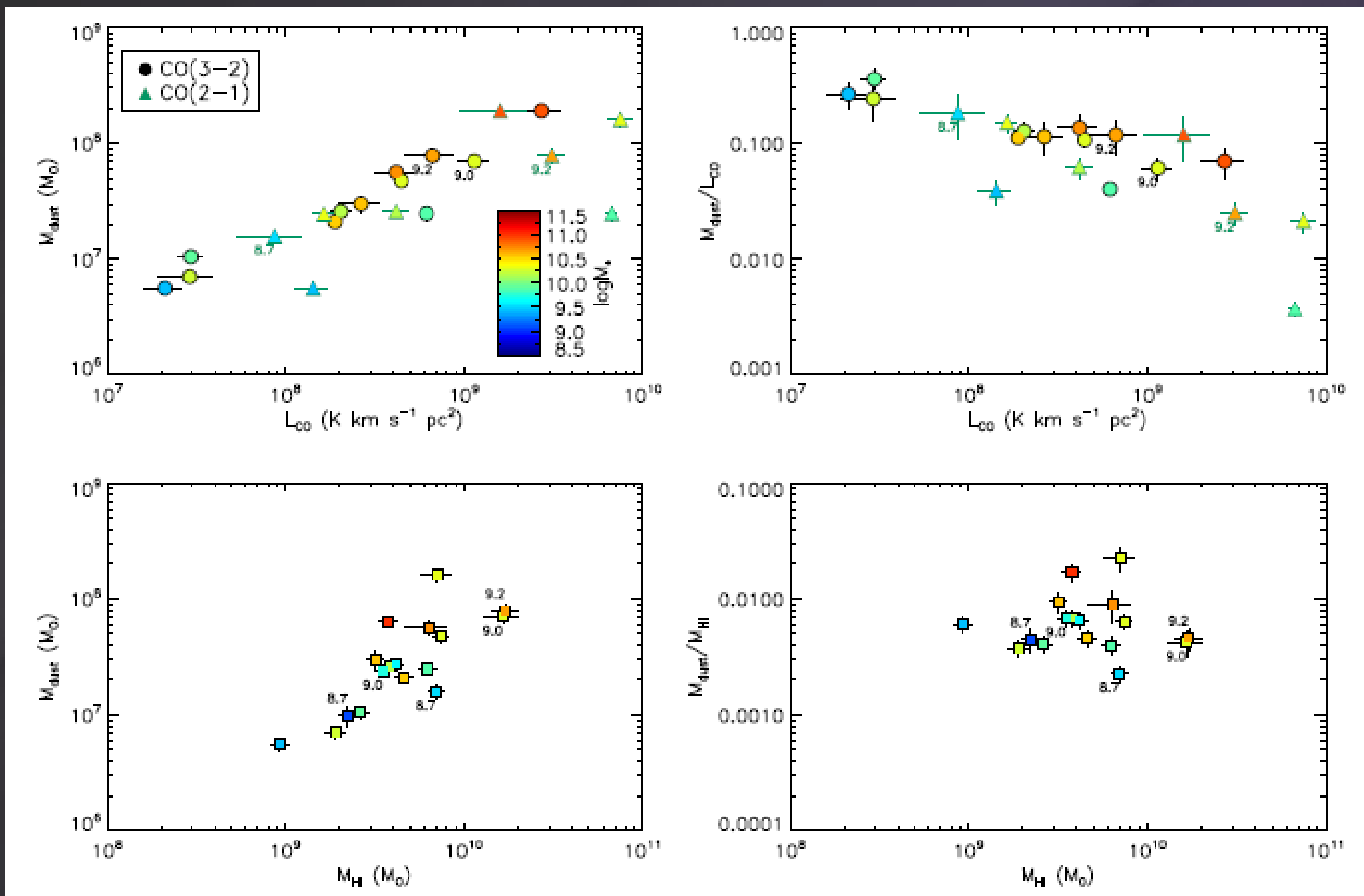
The Schmidt Law

- Integrated FIR from warm dust traces SFR
- Correlated with dense CO tracer, consistent with normal star-forming galaxies



Dust/gas ratio and metallicity

- Dust mass correlated with L_{CO} – but sub-linear – why?
- Underlying dependencies: dust/gas, CO/H2, metallicity, CO excitation



Conclusions

- Scatter in the correlation between dust and gas tracers varies as a function of FIR wavelength and emission line tracer, suggesting that:
    - CO(3-2), i.e. dense gas, is better correlated with FIR emission at the SED peak, 100μm
    - CO(2-1), tracing cooler diffuse gas, may be better correlated with 250-500μm, although more data are needed for confidence
    - HI is also better correlated with sub-mm
    - Poor correlation between CO(3-2) and sub-mm is consistent with cold dust being heated by old stellar population
    - 22-60μm fluxes buck the trends in the correlations with wavelength, and may contain a significant small-grain component, not correlated with SFR
- Relationships between CO, H_2, HI and dust masses are unclear due to dependence on metallicity, temperature and excitation, but CO luminosity may be well correlated with dust mass due to a combination of factors