SPIRE-FTS spectroscopy near and far: the starburst galaxy IC342 and the lensed "Eyelash" submm galaxy

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SPIRE- SAG 1

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SPIRE- SAG 2

SPIRE

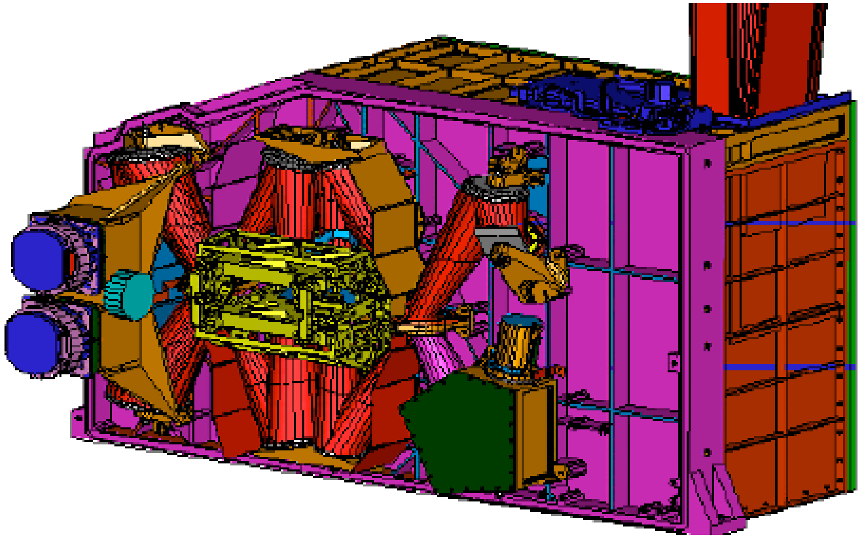
Herschel First Results Meeting, ESLAB 2010, ESTEC, May 4-7, 2010

esa HERSCHEL

Talk Outline

- Why we want to do FIR spectroscopy (or why SPIRE -- FTS is so great)
- Probing the atomic, ionized molecular ISM: how and why
- A two- part story:
  - Nearby Galaxies
  - Distant Galaxies
- Prospects for the future

SPIRE FTS capabilities



- Wavelength range: 194 – 671 μm
- Entire range covered simultaneously
- Continuum measured as well as spectral lines
- 35 and 19 detectors in SSW and SLW arrays
  - Imaging spectroscopy over ~ 2.6 arcmin fov
- Spectral resolution (adjustable)
  - High: 1.2 GHz
  - Medium: 6.7 GHz
  - Low: 25 GHz

FIR Spectroscopy : the basics

FIR lines of abundant elements (O,C,N,Si,SIII) either in neutral or ionized state contribute most of the gas cooling of the ISM

Ionized atoms → tracers of HII regions

Neutral ISM → main cooling through [CII], [OI]

Molecular gas → cooling mostly due to [CI] and CO
gain insight into gas heating rate
dominated by incident FUV radiation
due to massive stars

→ Probe SB activity

The first story: SPIRE-FTS spectroscopy of IC 342

2MASS (JHK) picture of IC342

D=3.3 Mpc 1''~16 pc (Saha ea 2002)

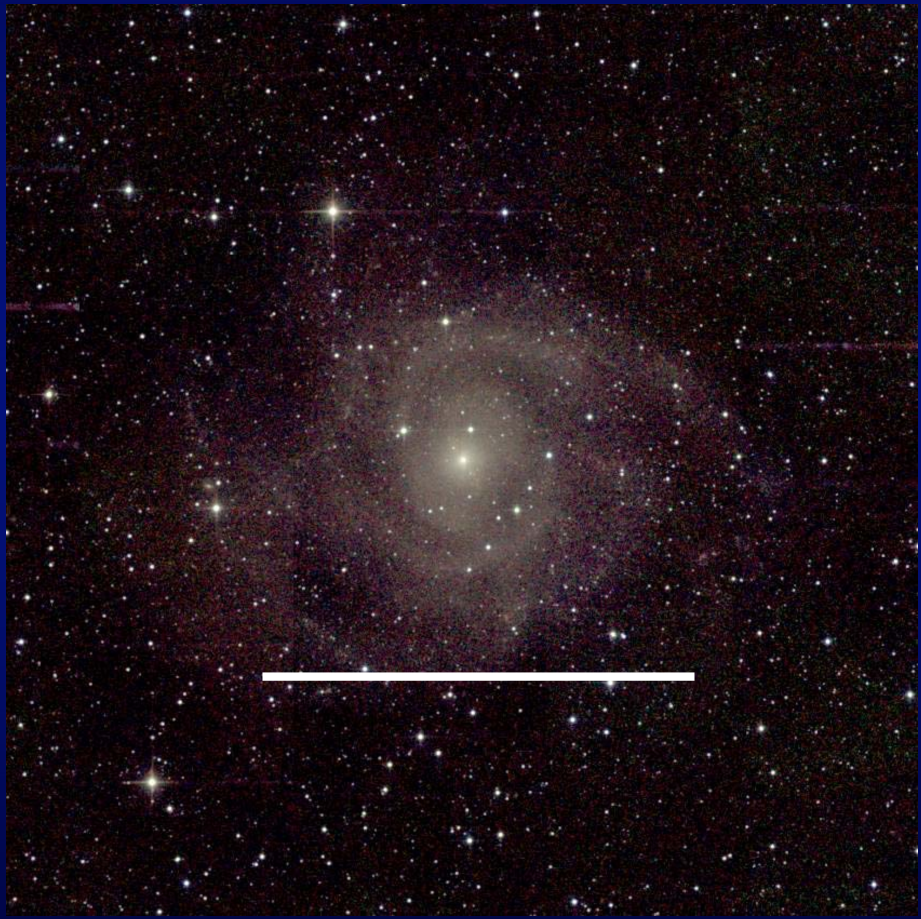
Diameter: ~ 24 arcmin

Face-on, late type spiral

Moderate intensity star -burst events (Boeker ea 1997)

testbench for probing ISM

high resolution
~1751 sec
single pointing staring



Past ground based observations of FIR/submm lines

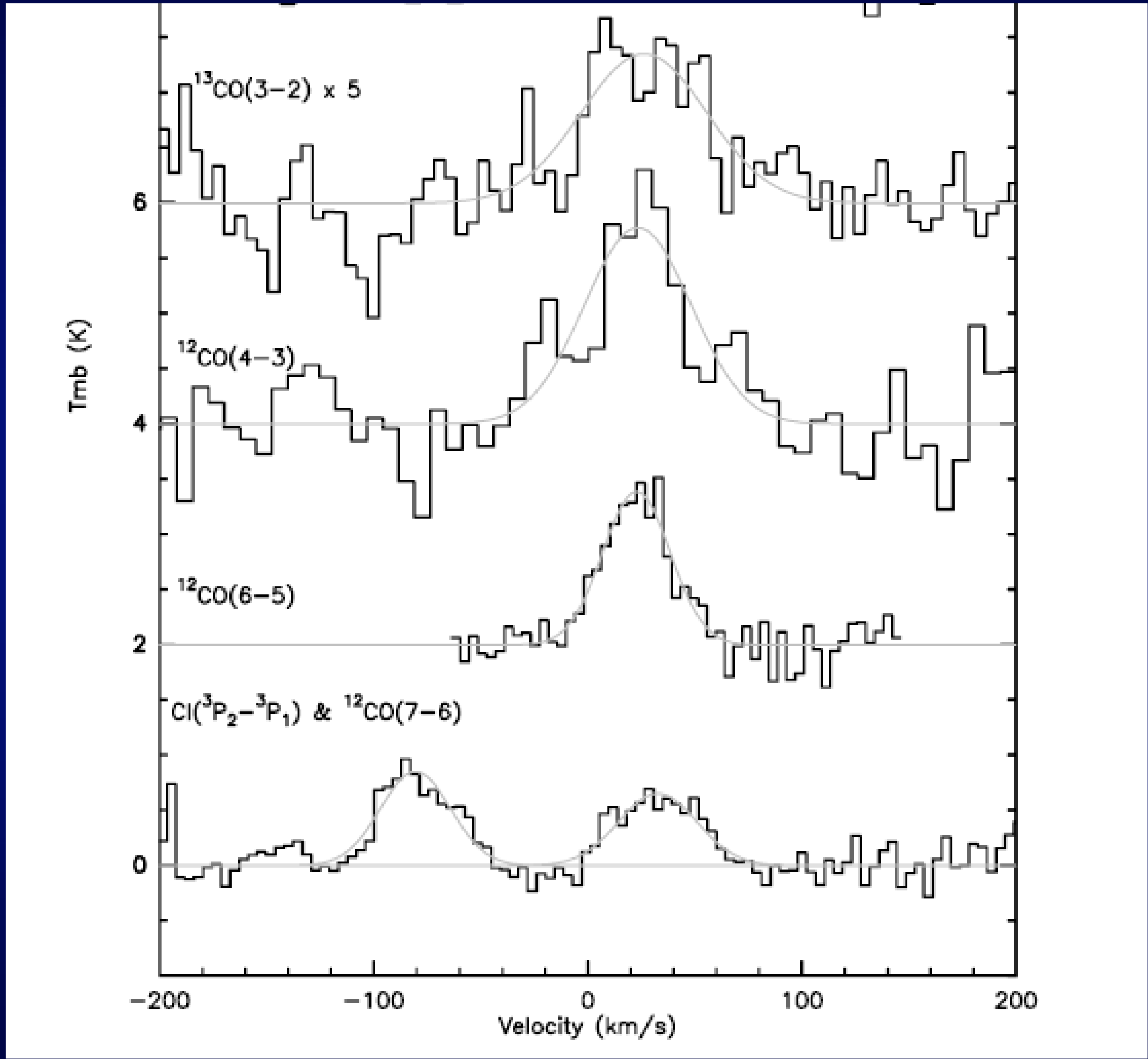
Israel & Baas 2002

Gerin & Phillips 2000

Bayet et al. 2004

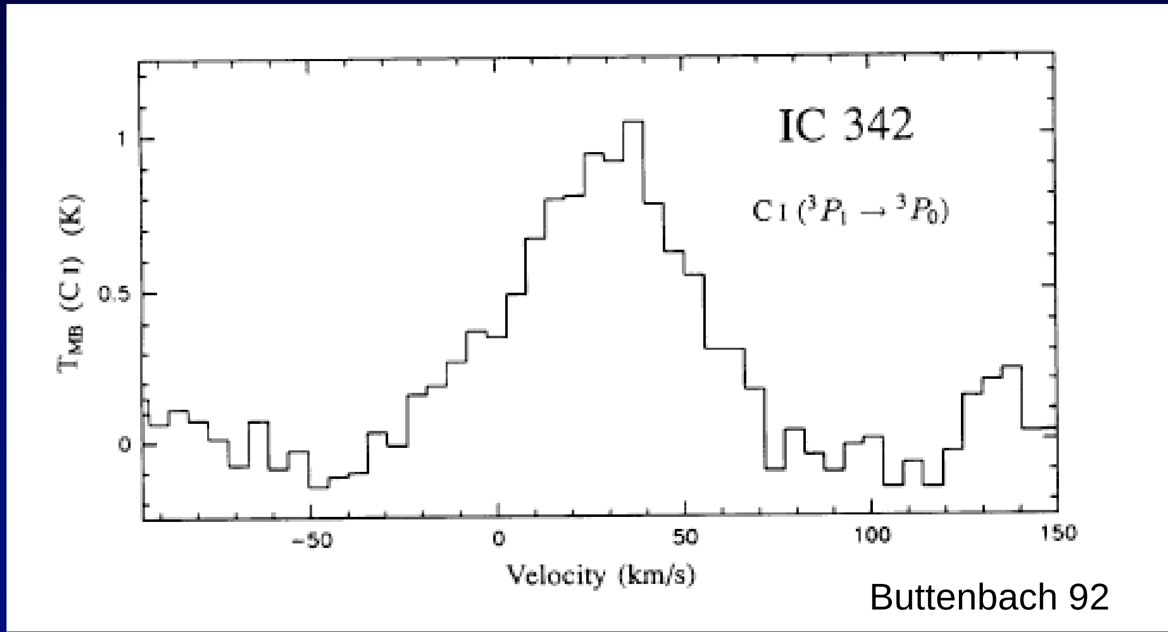
Bayet et al. 2006

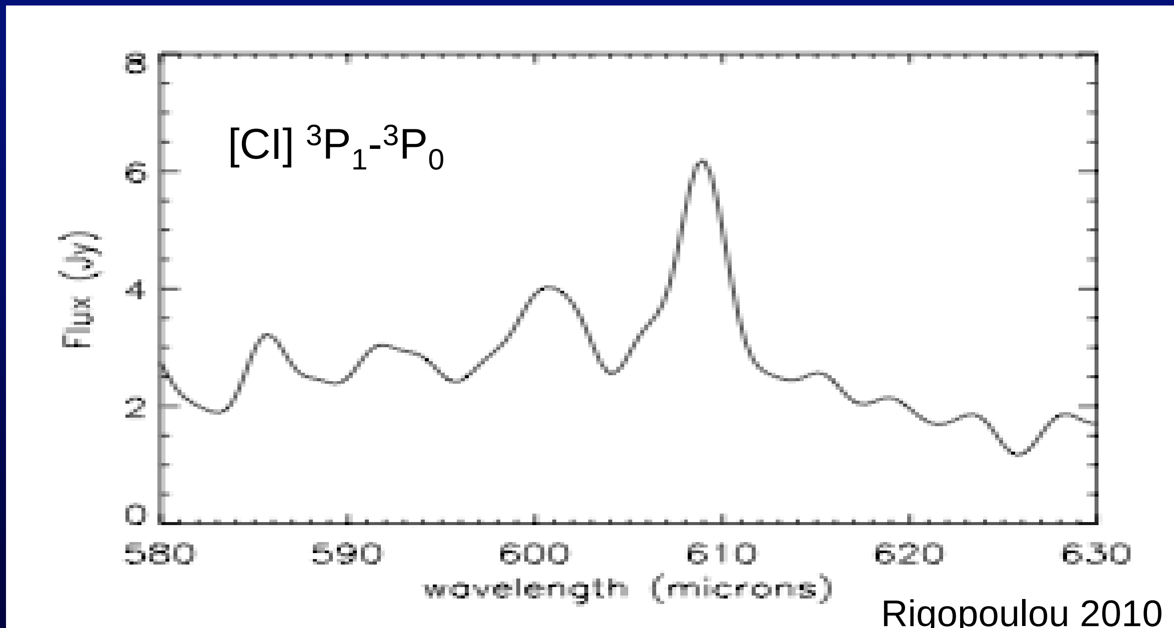
(not including CO higher transitions)



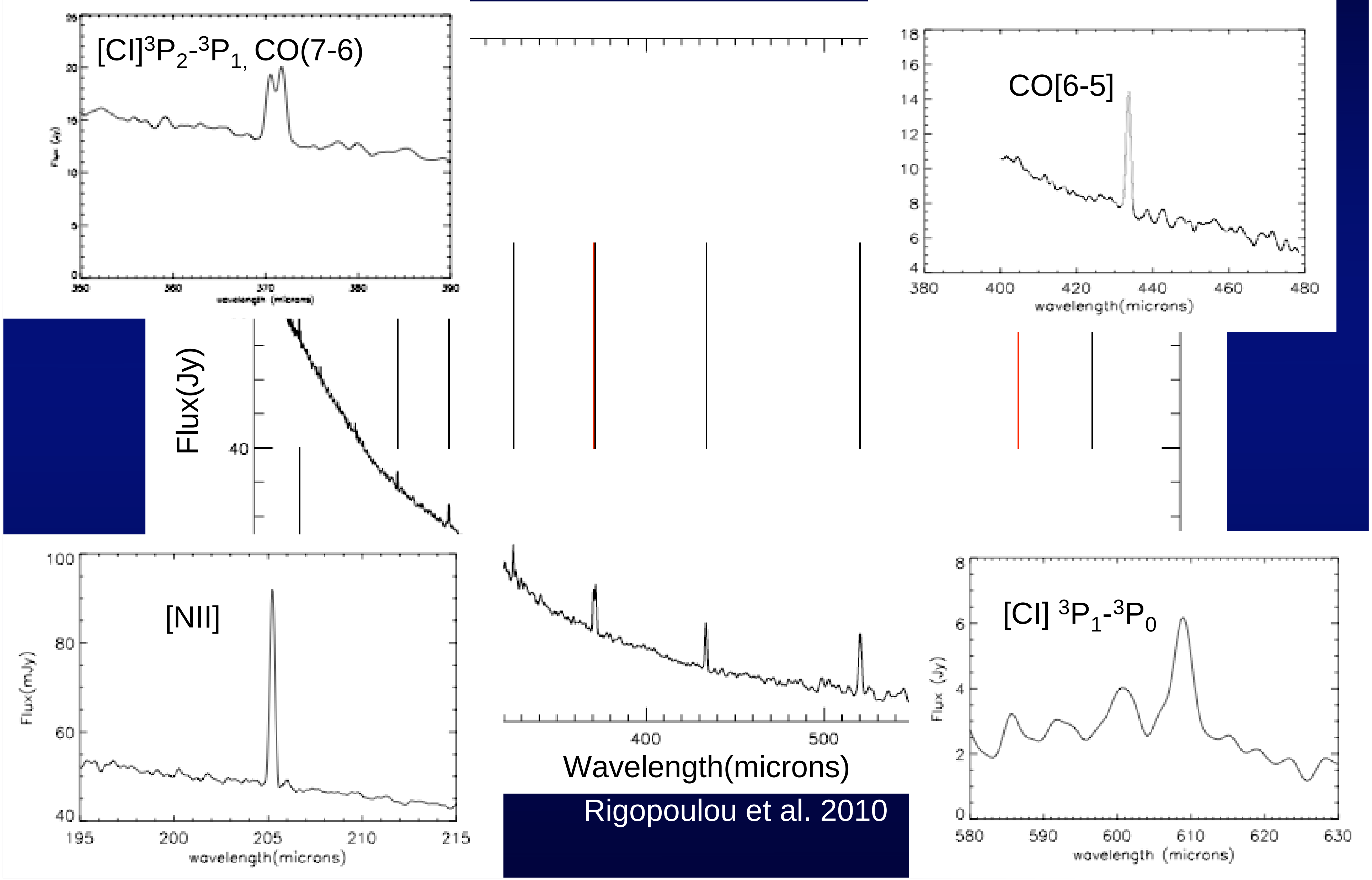
(From Bayet et al. 06)

The first CI detection from the ground (top) & SPIRE-FTS (bottom)





Full SPIRE-FTS spectrum 192 - 672 μm

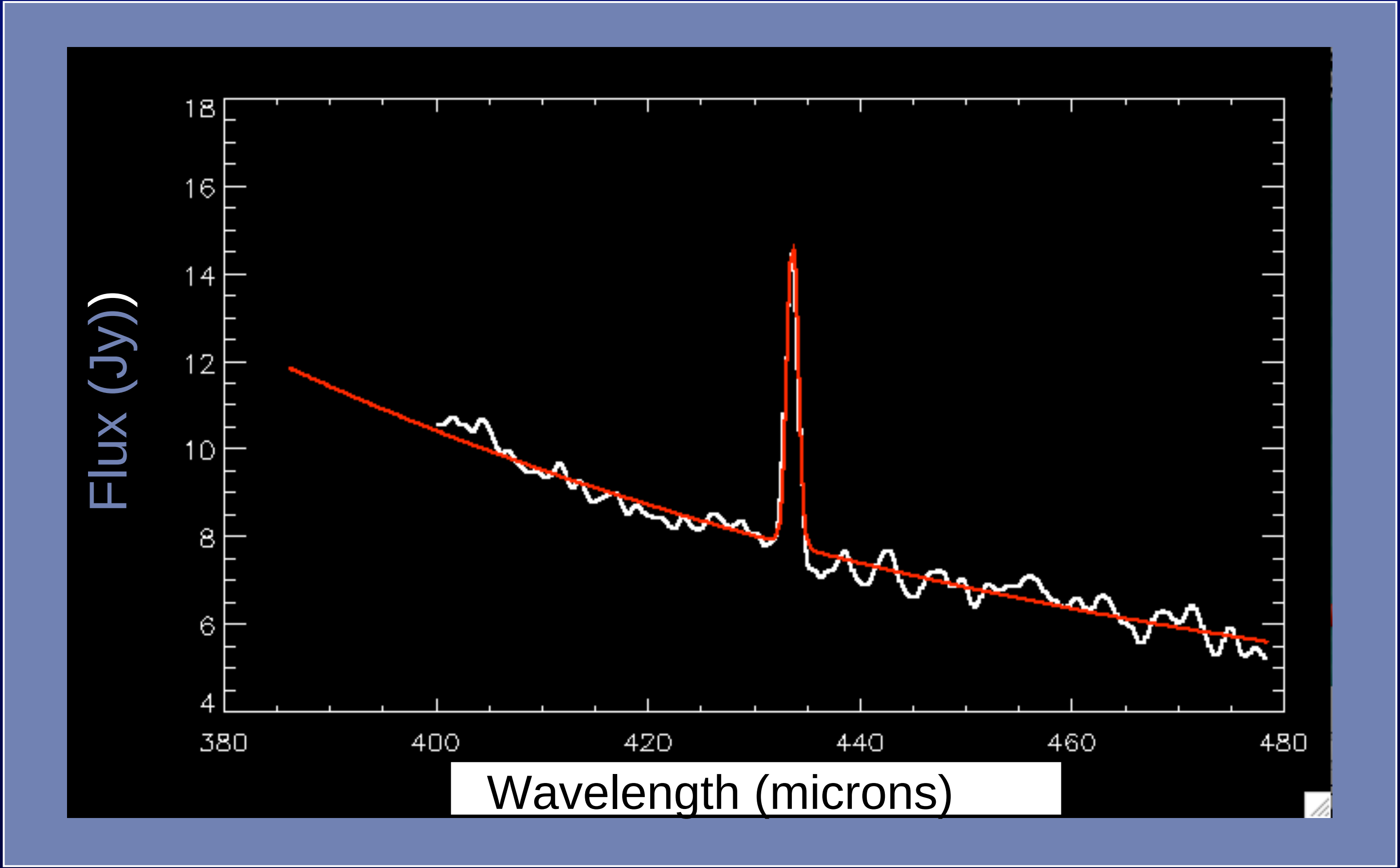


Rigopoulou et al. 2010

Extracting individual lines:

N=6 polynomial fitting line and continuum simultaneously

$$f(x) = A_0 e^{-z^2/2} + A_3 + A_4 x + A_5 x^2$$



Detected lines:

- ^{12} CO J(4-3) up to J(13-12)

- 2 [CI] and [NII] lines

- possibly one ^{13} CO line (but noisy region TBC)

-30% fluxes error

Using population diagram to determine physical parameters of the molecular clouds

For a molecule in LTE all Excitation temperatures are the same (T)and the Population of each level:

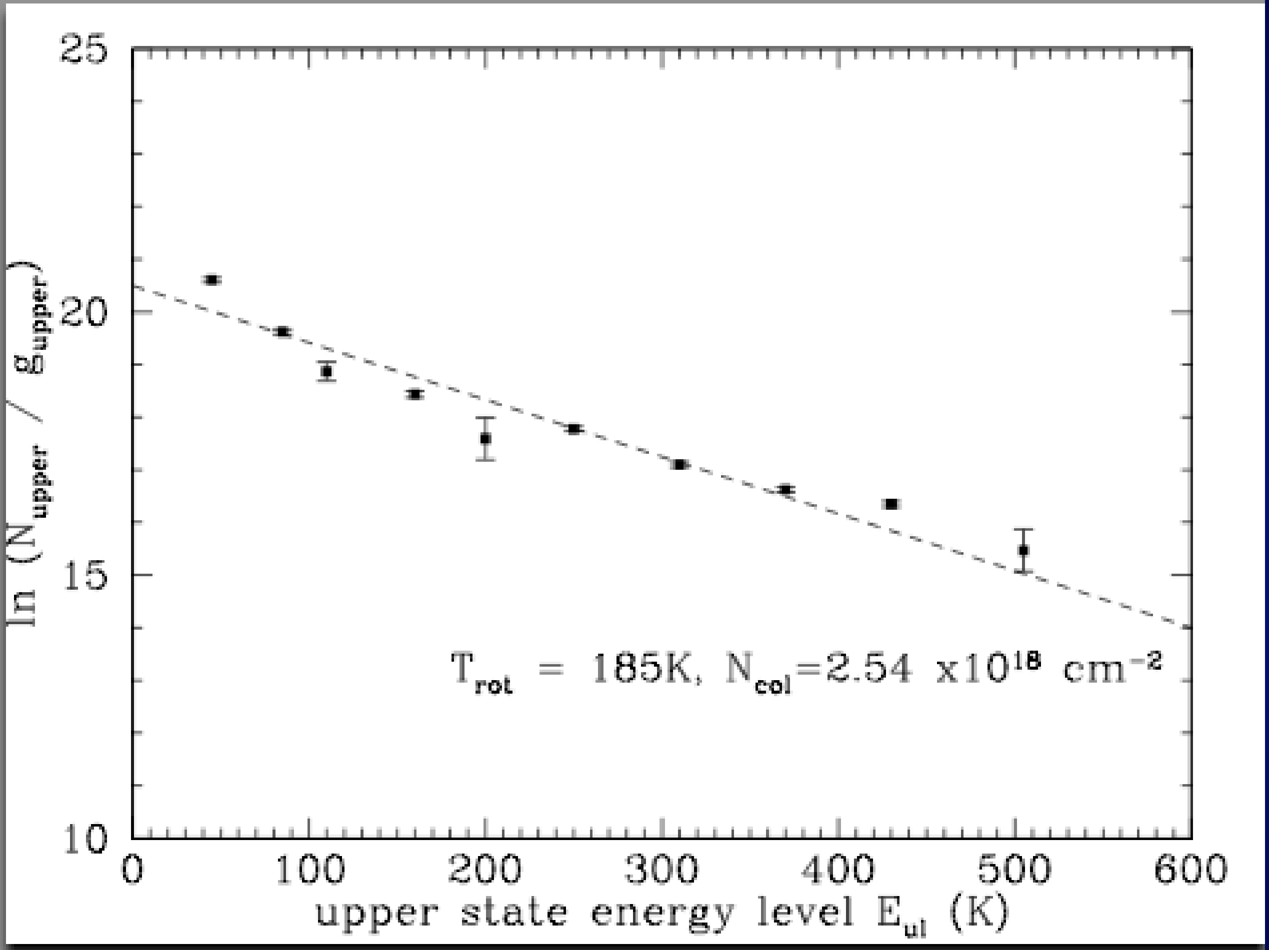
$$N_u = \frac{N}{Z} g_u e^{-E_u/kT}$$

N: total column density
Z: partition function

$$Z = \sum_{\text{all levels}} N_i$$

If all level population in LTE then:

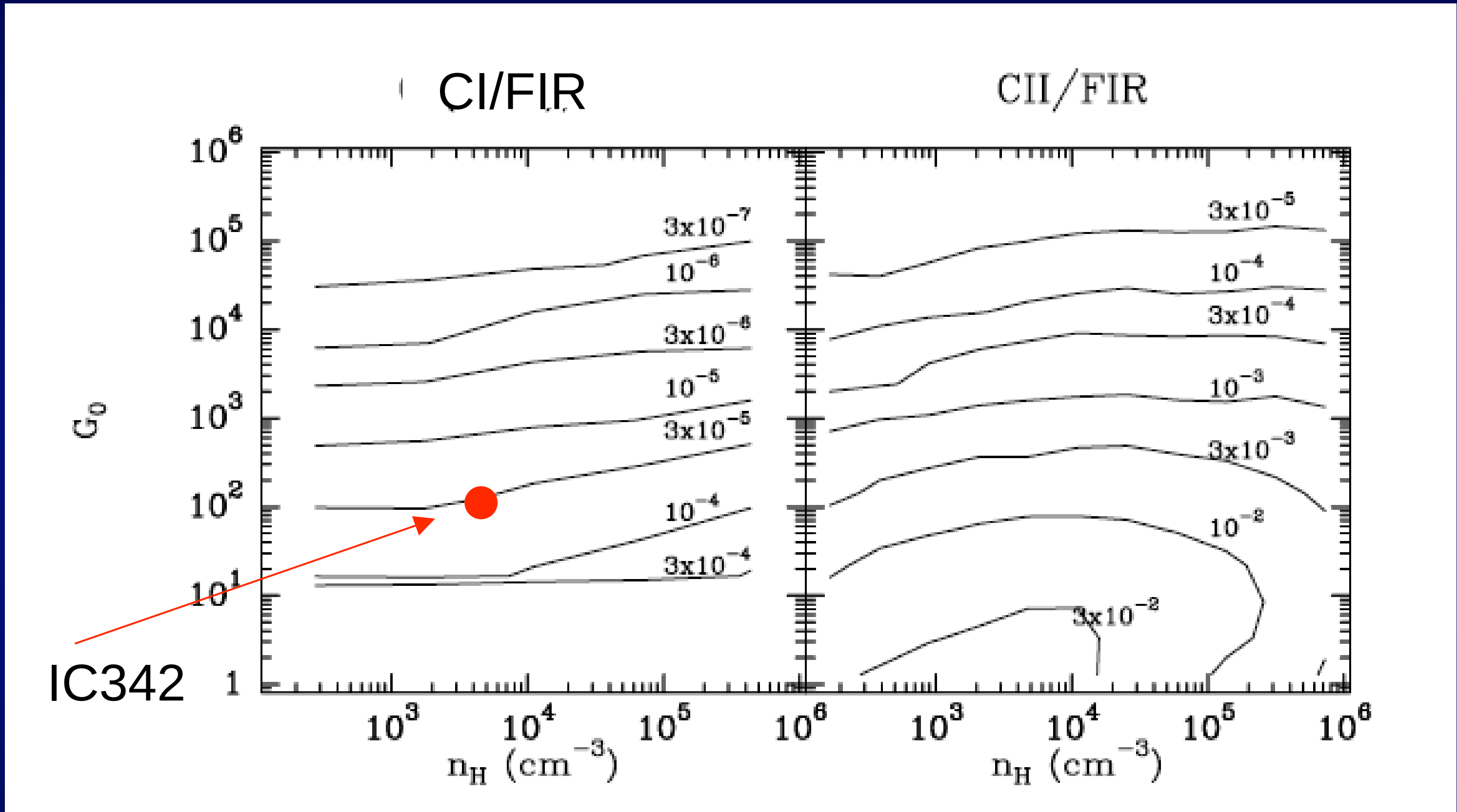
$$\ln \frac{N_u}{g_u} = \ln N - \ln Z - \frac{E_u}{kT}$$



Rigopoulou et al. 2010

c.f H_2: T~ 170 (S(1)-S(0), T~365 (S(5)-S(7) Rigopoulou et al 2002

Physical parameters of the ISM
Using CI and FIR (also CII and FIR)



Adapted from Gerin +Phillips 2000

G0 corresponds to a temperature of ~ 230 K

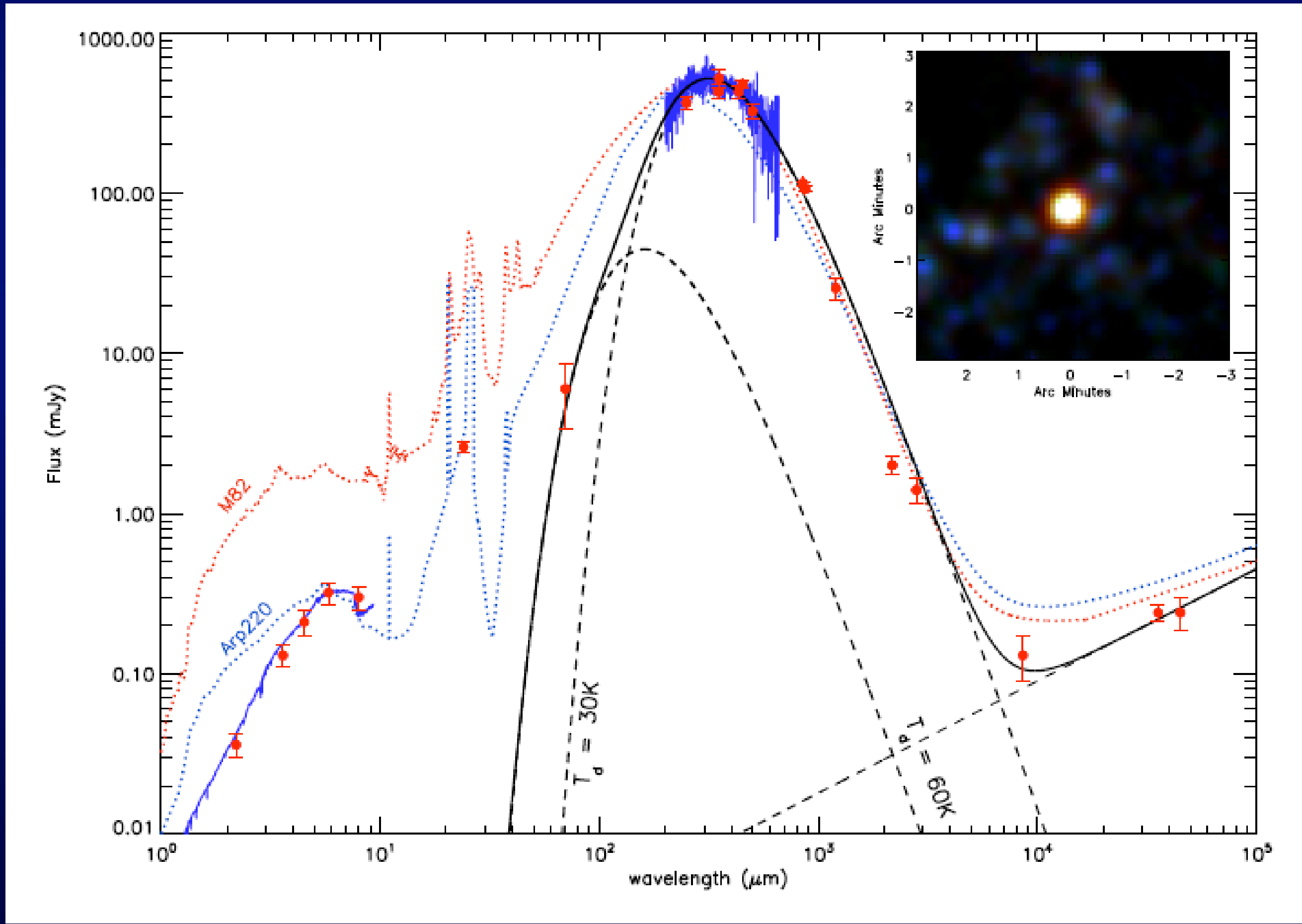
Distant galaxies: SPIRE-FTS spectroscopy of a z~2.3 lensed submm galaxy

SMM J2135: discovered through deep APEX/LABOCA surveys, lensed (x32) submm galaxy at z=2.326 (Swinbank et al 2010, Nature)

SPIRE250/350/500
S_{350}: 429+/-64 mJy

SCUBA-2
S_{850}:115+/-13mJy

LABOCA/SABOCA



Ivison ea 2010, Swinbank ea 2010

Table 1. Photometry

Wavelength	Flux[a] (mJy)	Observatory/Instrument
250 μm	366 ± 55	*Herschel*/SPIRE
350 μm	429 ± 64	*Herschel*/SPIRE
352 μm	520 ± 70	APEX/SABOCA[b]
434 μm	430 ± 40	SMA[b]
450 μm	480 ± 54	SCUBA-2
500 μm	325 ± 49	*Herschel*/SPIRE
850 μm	115 ± 13	SCUBA-2
870 μm	106 ± 12	APEX/LABOCA[b]
1.2 mm	26 ± 4	SMA[b]
2.17 mm	2.0 ± 0.25	PdBI[b]
2.80 mm	1.4 ± 0.25	PdBI[b]
8.57 mm	0.13 ± 0.05	GBT/Zpectrometer[b]
3.55 cm	0.240 ± 0.030	VLA/X
4.49 cm	0.240 ± 0.055	VLA/C

[a] Errors include uncertainty in absolute flux calibration.
[b] See Swinbank et al. (2010), also for $\lambda_{\rm obs} < 250\,\mu$m.

FTS observations: 7.2 ks full 197-670μm spectrum

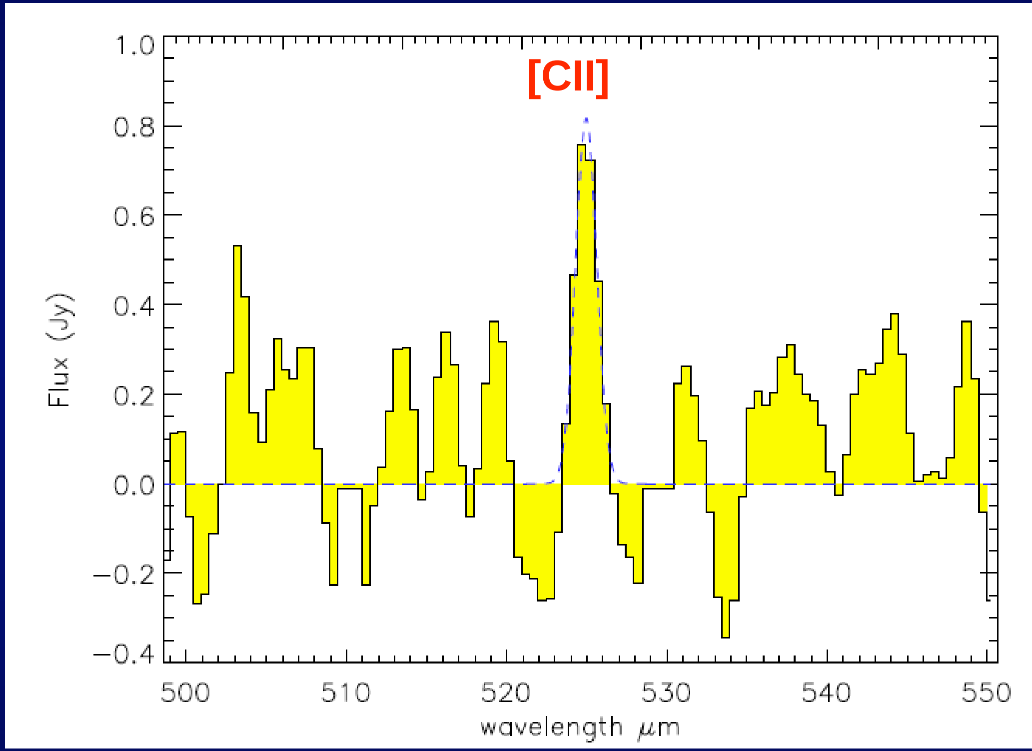
- 4.3 σ detection of [CII]λ 158μm
  Flux =1.7x10 $^{-17}$ Wm^{-2}

  M $_{[CII]}$ = 4 x 10^{9} M$_{\odot}$
  25% of CO mass

  (similar to ratio in SBs)

- 3x brighter than in ULIRGs

- Tentative detections of :
  [OI] λ145μm & [NII] λ122μm
  (presently at 2--3 σ level)
  more observations underway



Ivison ea 2010, A&A in press

Physical properties of the ISM in a lensed (but otherwise typical) z~2.3 galaxy

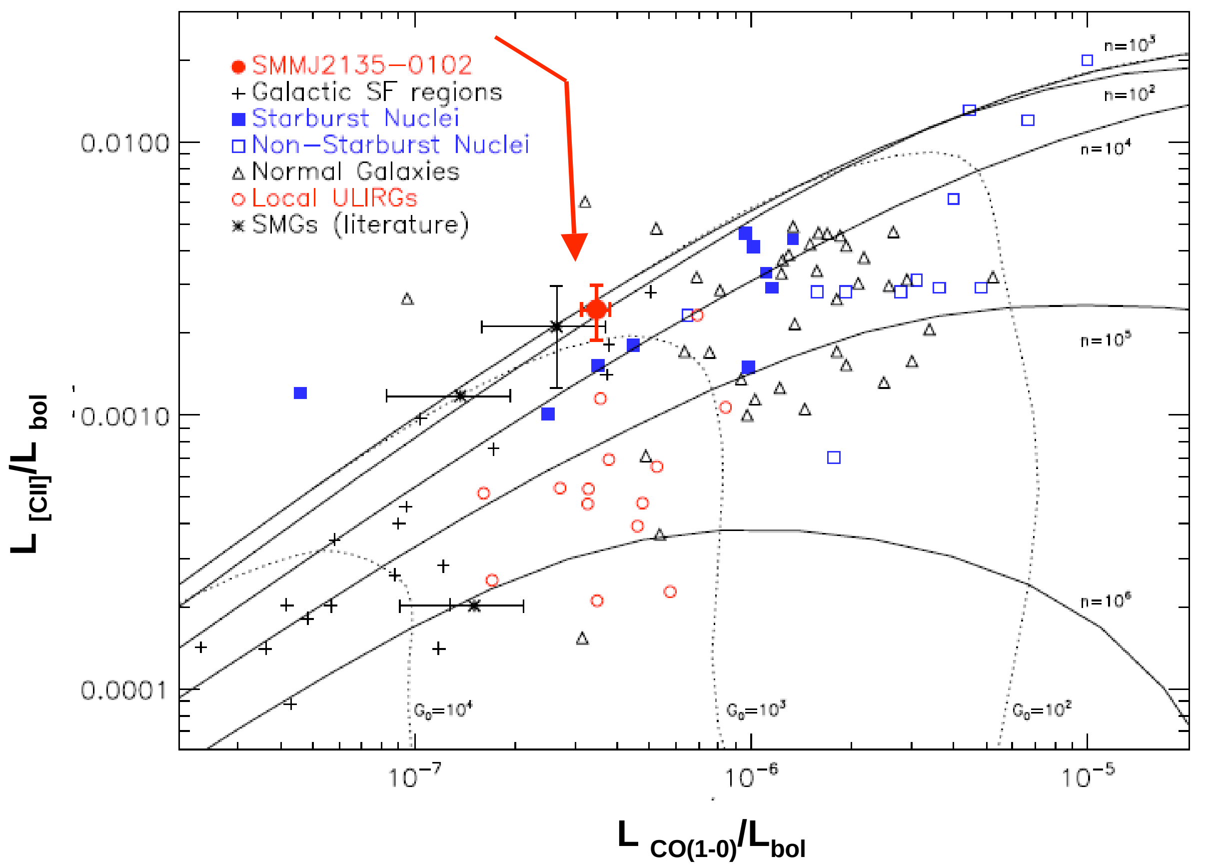
$L_{FIR} = 2.3 \times 10^{12} L_\odot$

$L_{CO(1-0)} / L_{bol}$ --> η

$L_{[CII]} / L_{bol}$ --> G_0 / T

- $G_0 \sim \times 10^3$ (10^3 MW)
- T ~400 K
- $\eta = 10^3$ cm $^{-3}$

(Kaufman ea 99)



Ivison ea 2010 (adapted from Hailey-Dunsheath 2010

SFR intensity similar to that of ULIRGs but distributed over a larger volume
$L_{[CII]}/L_{bol}$ ratio reflects the lower density of the extended medium

Conclusions and Future Prospects

- SPIRE-FTS studies of local galaxies provide full details on properties of molecular/atomic clouds (huge improvement in sensitivity)
- provide f/b for theoretical models
- spatially sampled observations

- SPIRE-FTS spectroscopy is invaluable in gaining insight into the physical properties of suitable bright (lensed) high-z targets
- Not suitable for blind searches
- provide a natural link to scientific investigation that will be carried out with ALMA