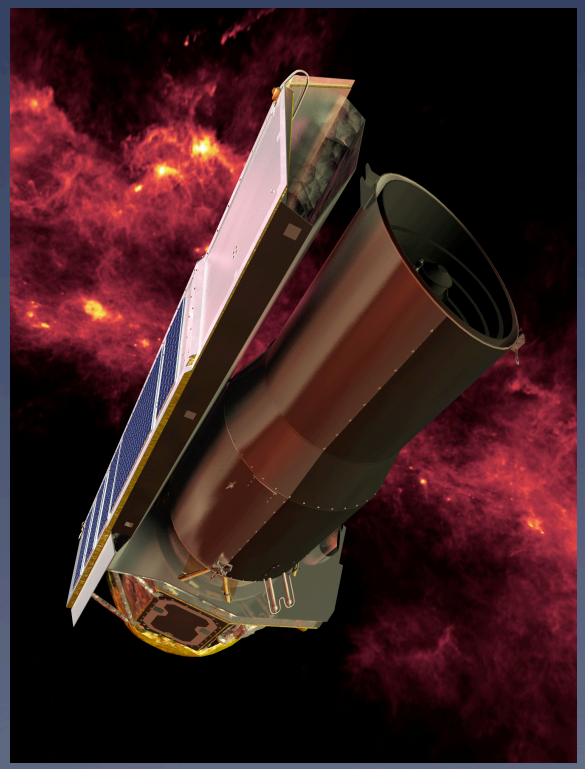
The Potential of Nearby Star Forming Galaxies



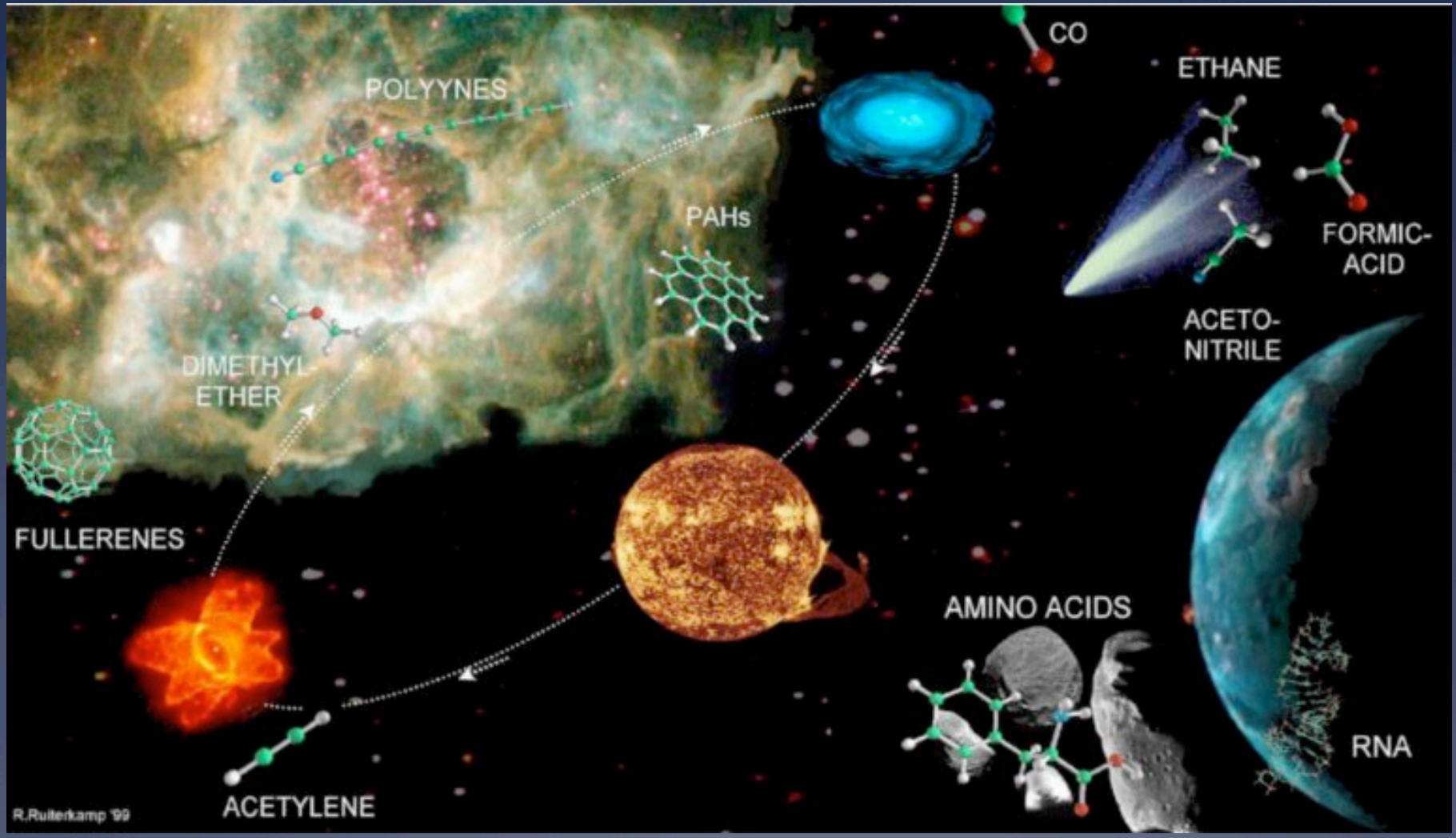
Eva Schinnerer (MPIA)

Disclaimer

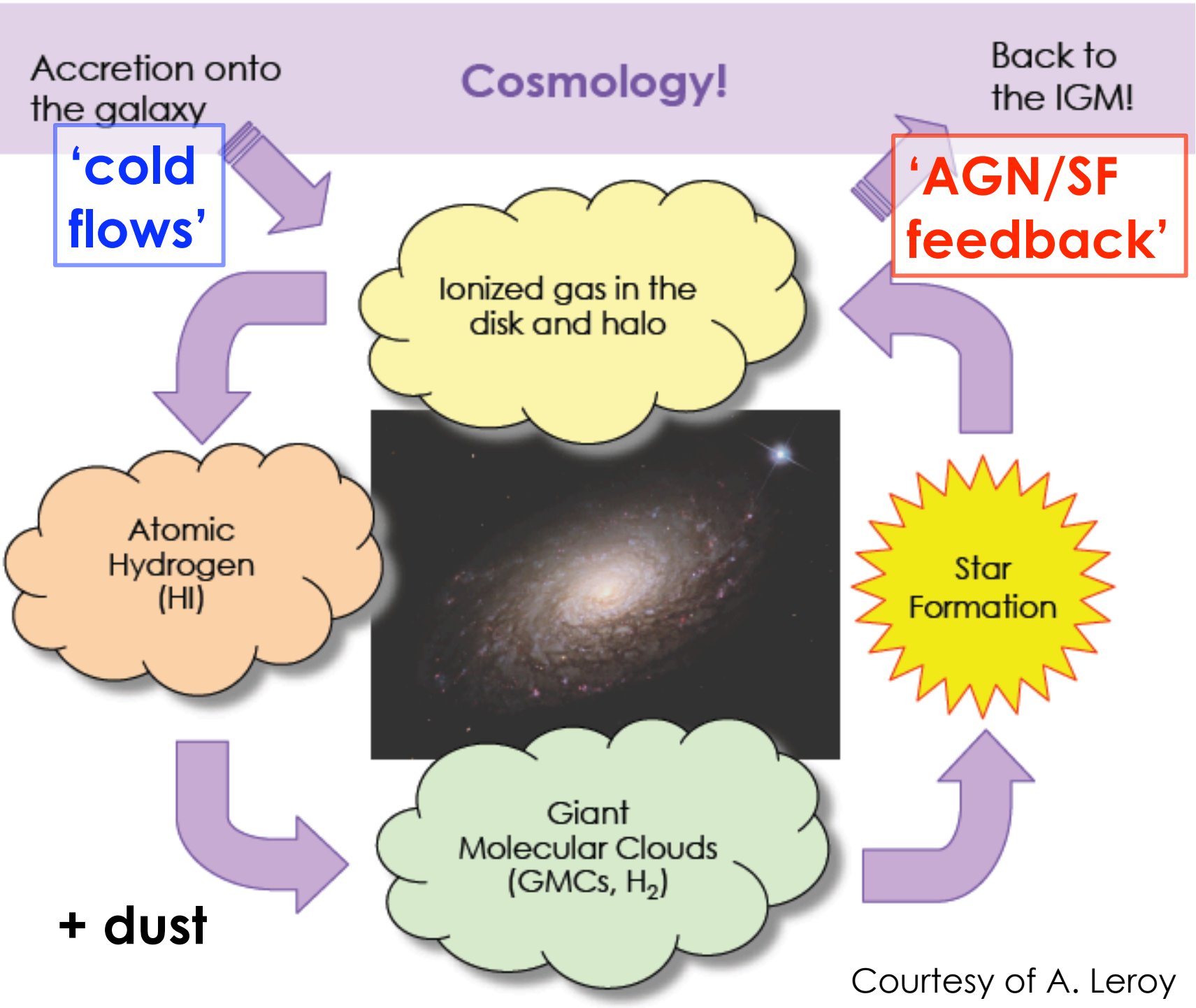
Eierlegende Wollmilchsau
(="egg-laying wool-milk-sow")

Physics of the ISM

Galactic Context



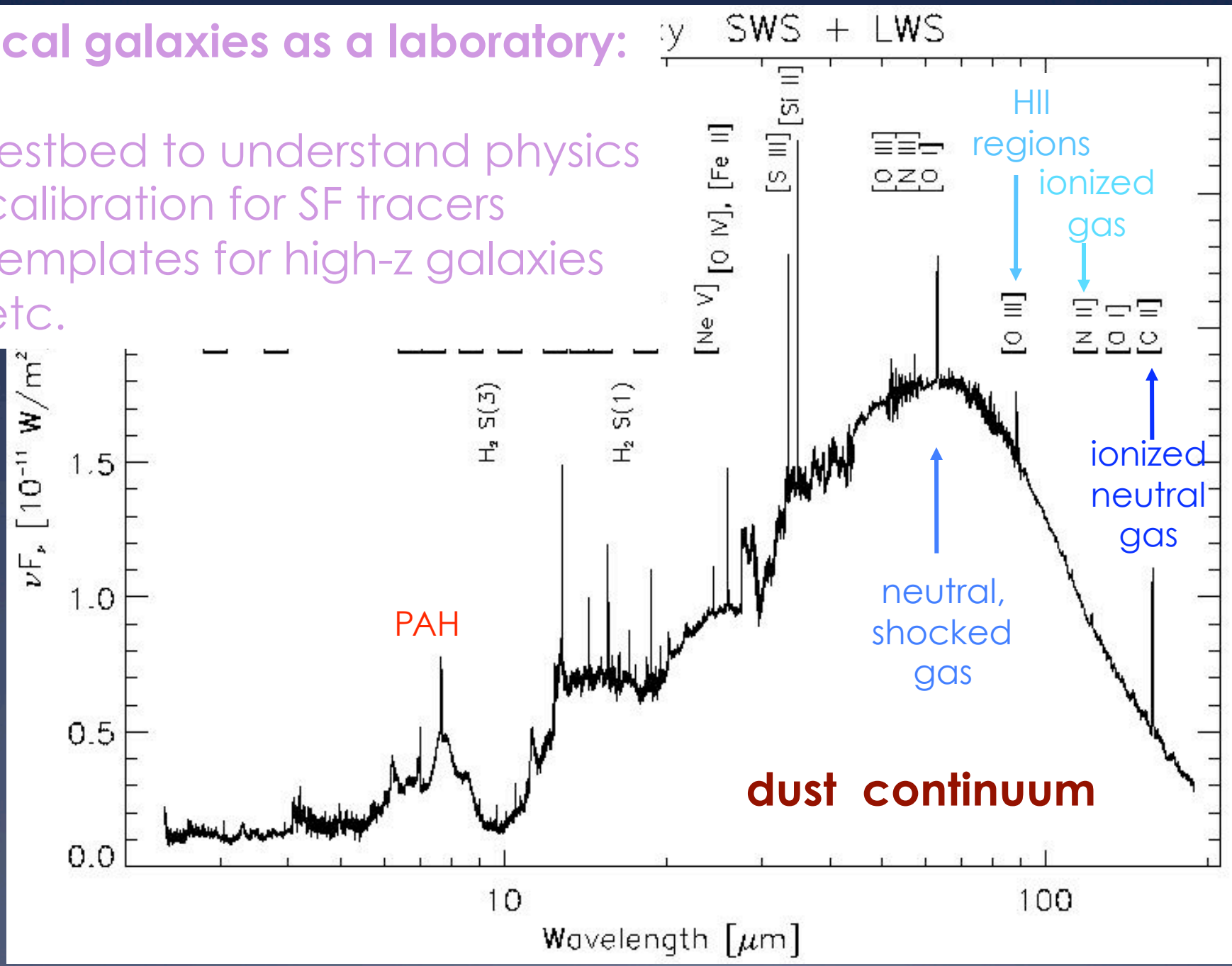
Ehrenfreund & Charnley (2000)



Courtesy of A. Leroy

Local galaxies as a laboratory:

- testbed to understand physics
- calibration for SF tracers
- templates for high-z galaxies
- etc.



Moorwood (1997)

First Herschel Results

For nearby galaxies only:

~ 31 preprints on astro-ph (till June 1st)

Of those used data from:

88 % PACS and/or SPIRE photometry
6 % PACS spectroscopy
6 % SPIRE FTS spectroscopy

[no HIFI spectroscopy yet]

First Herschel Results

Main areas:

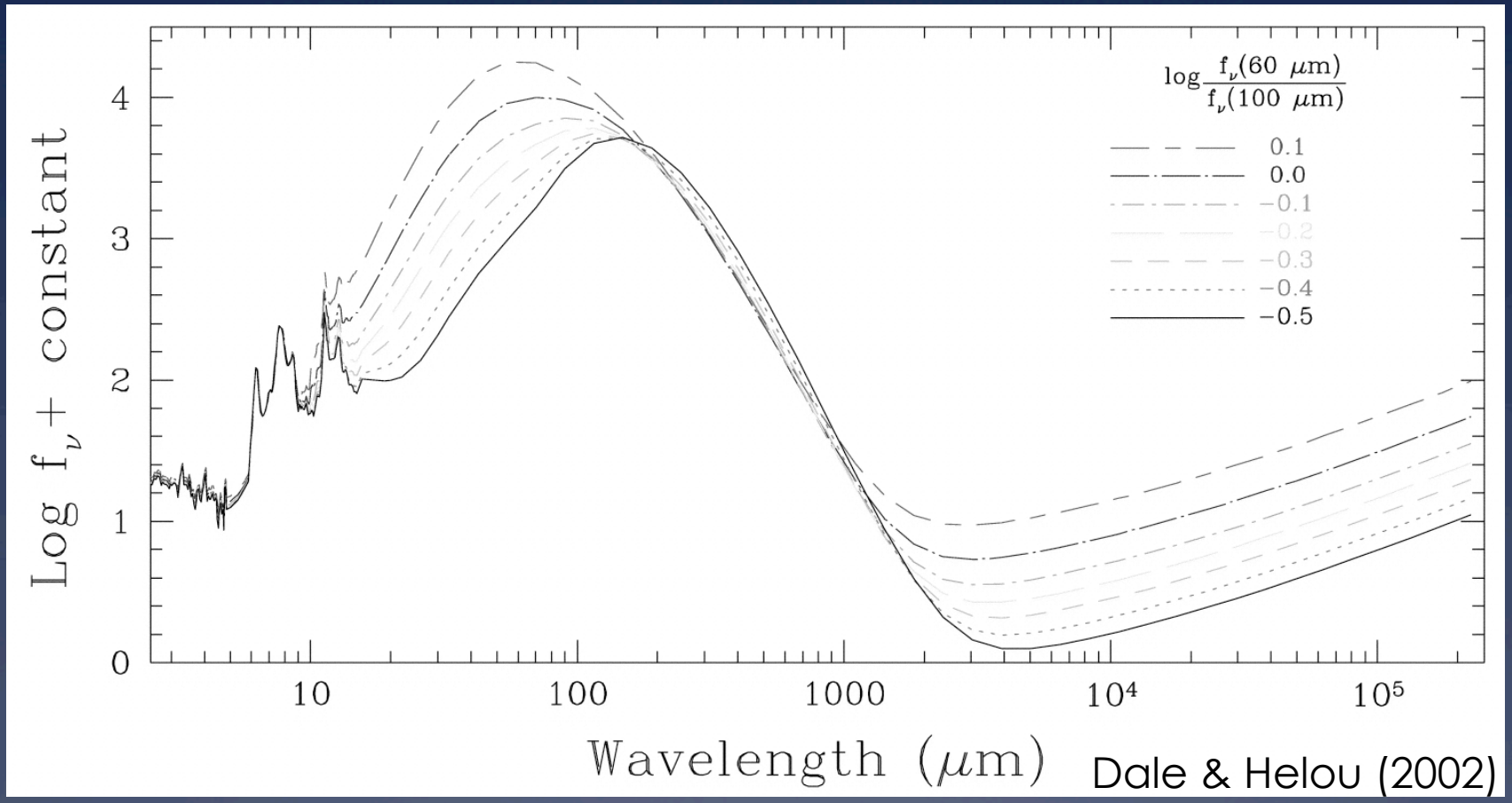
- **infra-red SED: dust temperature, location (dust composition)**

- dust/gas relation

- star formation rate (SFR) tracers

- (ISM cooling lines)

Dust Model SEDs



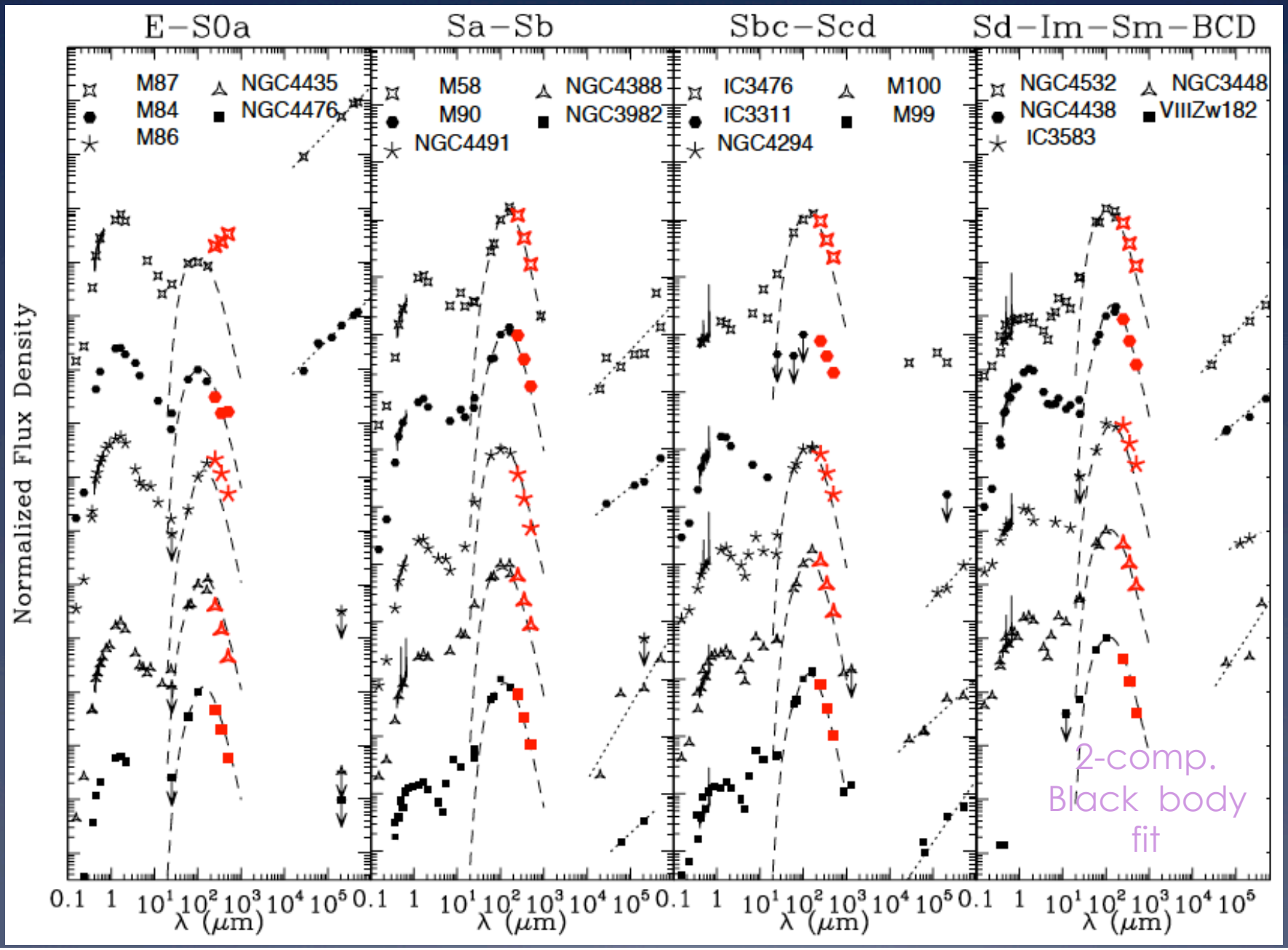
Dale & Helou (2002)

Templates used at high-z: based on 'interpolation' of (few) local galaxies (e.g. Dale & Helou 2002, Chary & Elbaz 2001)

Models (different dust grains, radiative transfer etc.) not well constrained:

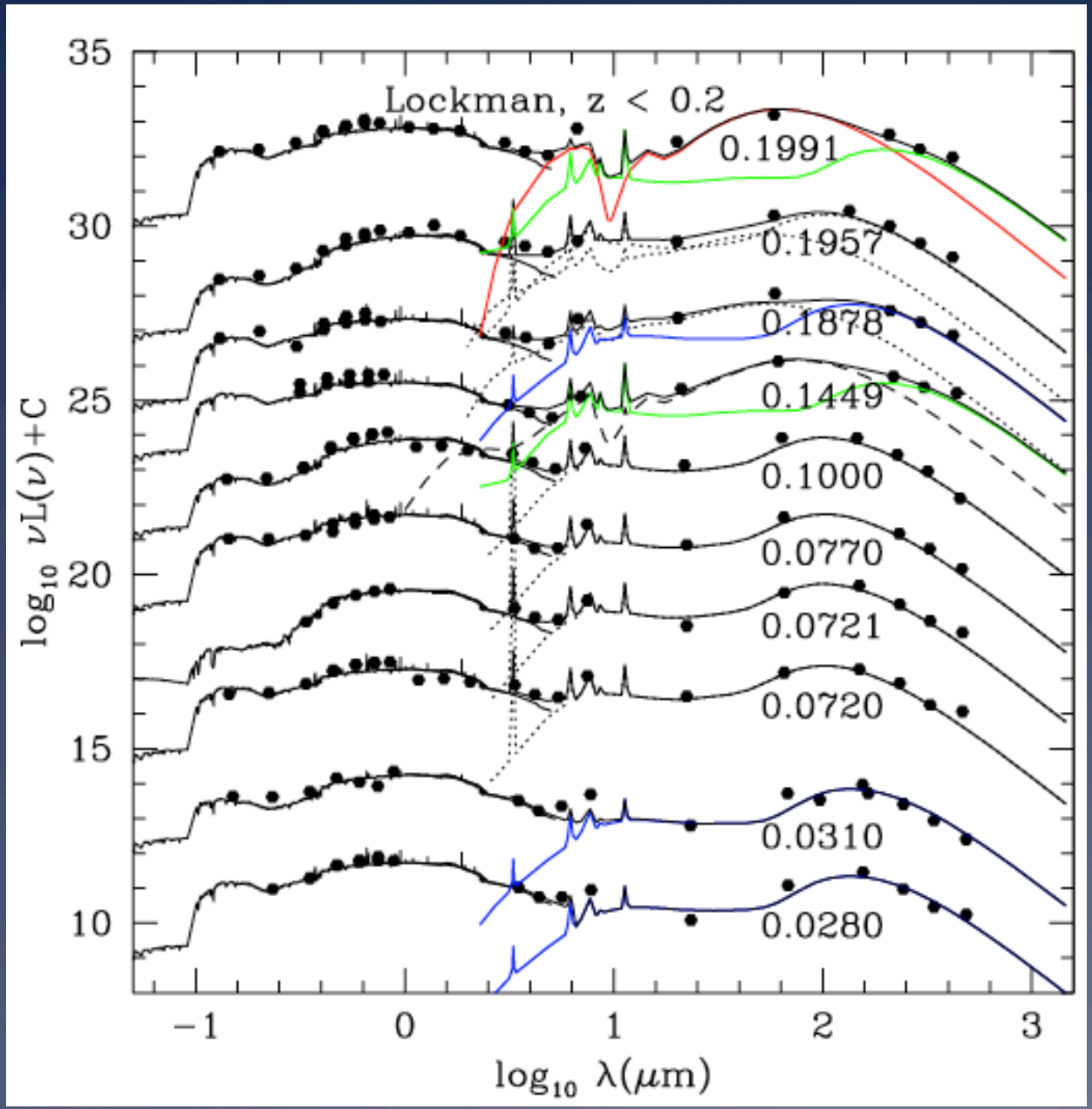
e.g. DUSTY (Ivesic et al. 1998)
GRASIL (Silva et al. 1998)
Draine & Li (2007)

Dust SEDs from Herschel: Global



Boselli et al. (2010)

Dust SEDs from Herschel: Global



Rowan-Robinson et al. (2010)

Need new templates:

young starburst w/ deep silicate absorption

quiescent 'cirrus'

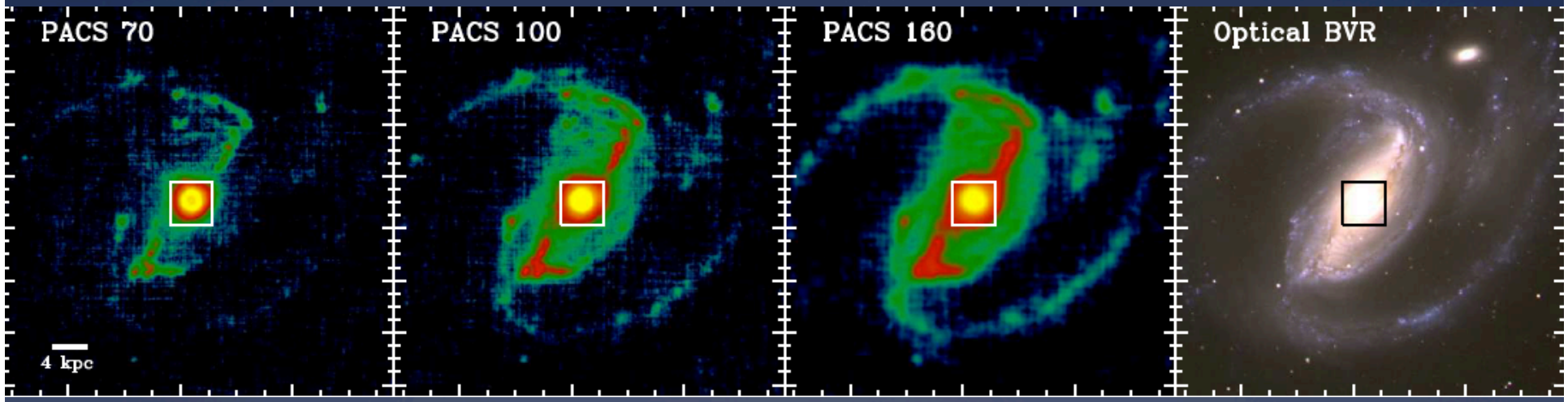
T ~ 17.5 K

T ~ 12 K

lower T due to less intense radiation field

Starburst Rings: NGC 1097

KINGFISH target (PI Kennicutt)



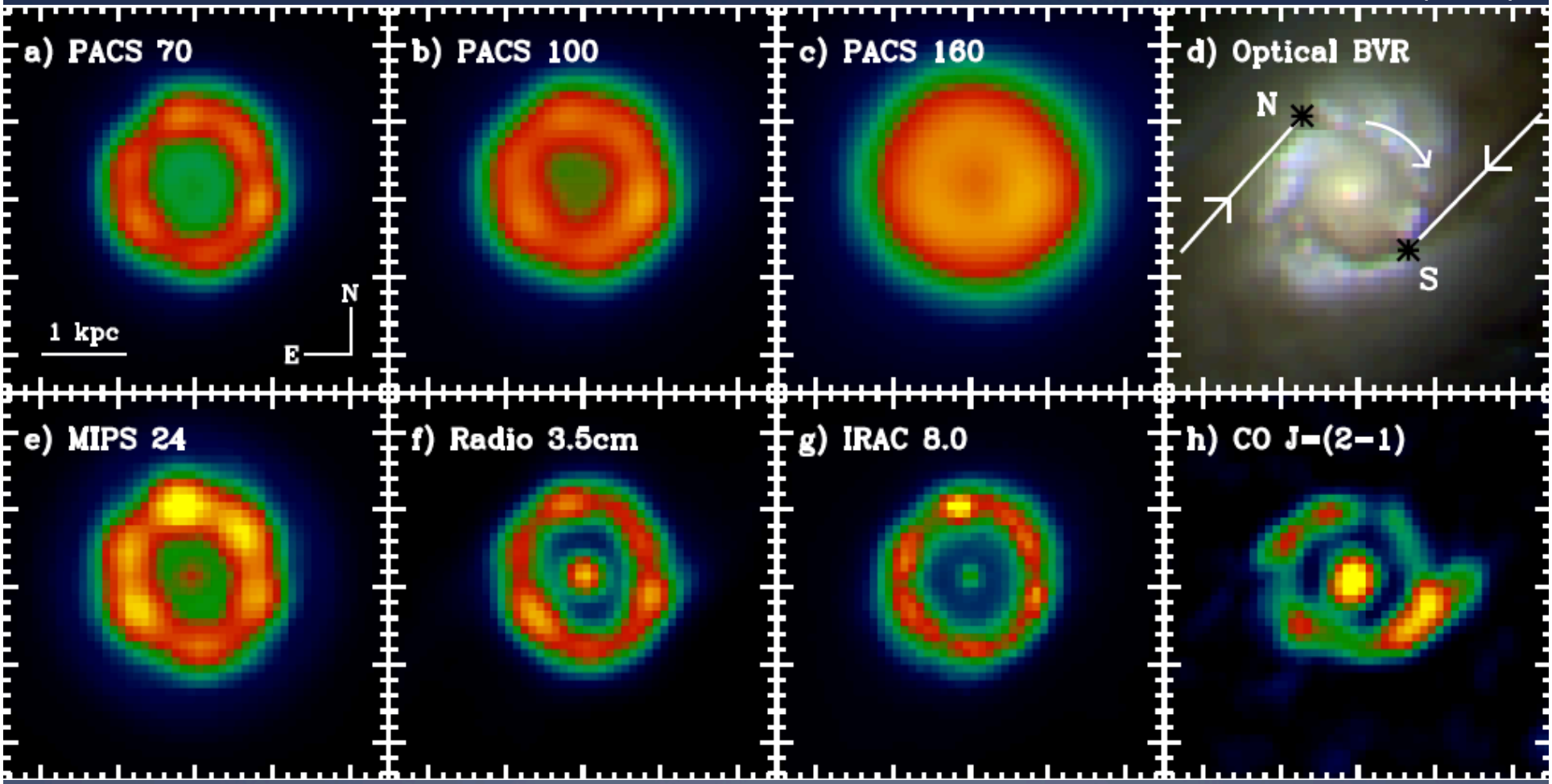
Sandstrom et al. (2010)

Starburst ring dominates IR emission :

75% at 70μm
60% at 100μm
55% at 160μm

Starburst Rings: NGC 1097

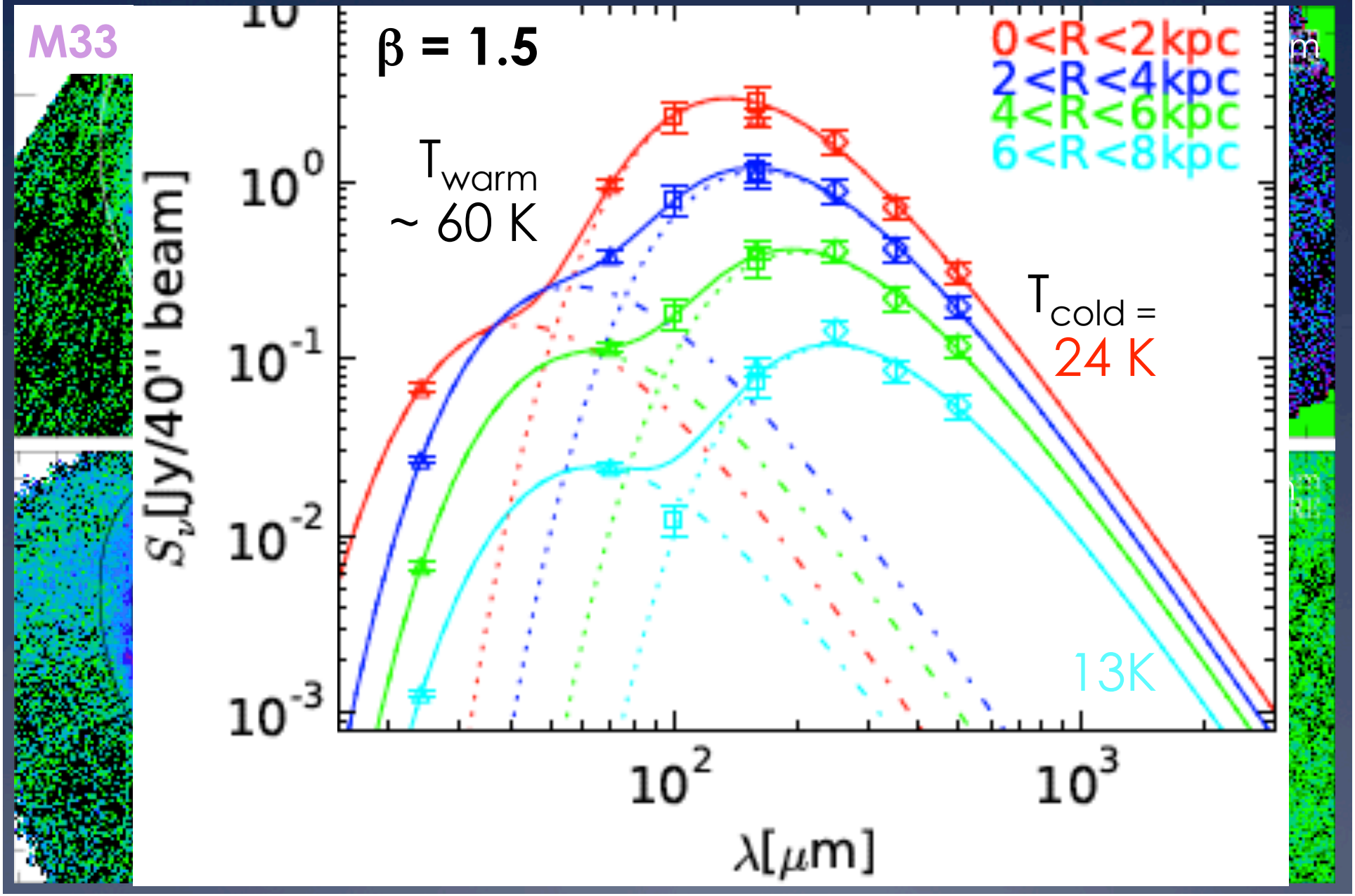
Sandstrom et al. (2010)



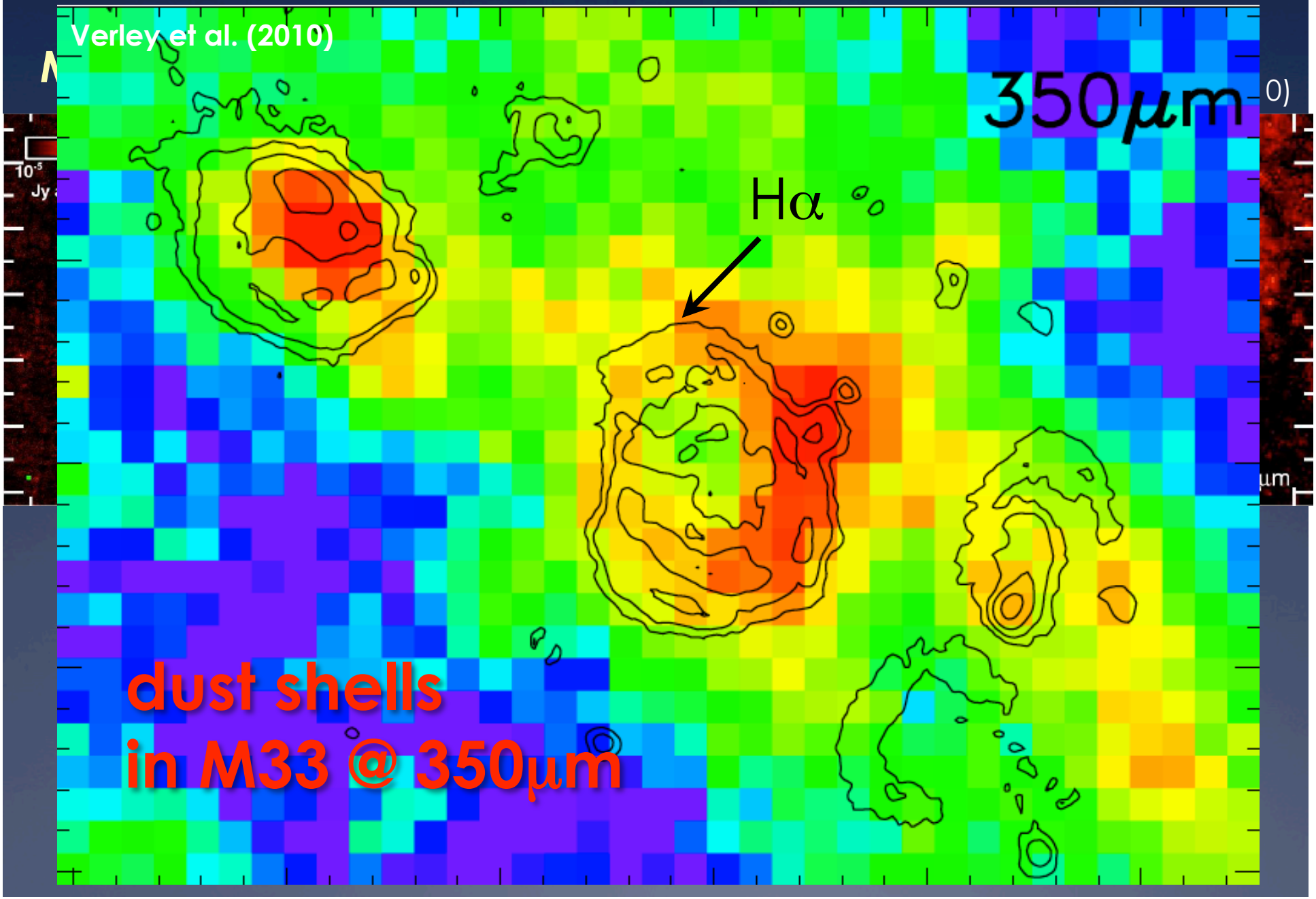
Dust properties unexpectedly uniform,
ISM cooling lines arising from ring (Beirao et al. 2010)

Dust SEDs from Herschel: Resolved

Kramer et al. (2010)



Dust SEDs from Herschel: Resolved



Dust SEDs of Nearby Galaxies:

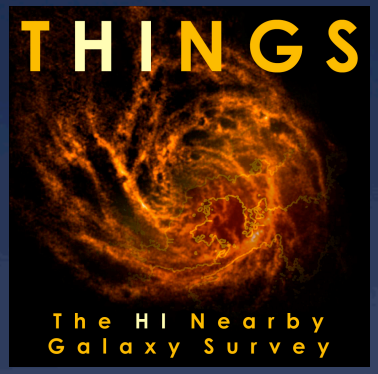
- are now very well sampled

- resolved studies now possible (contaminants)

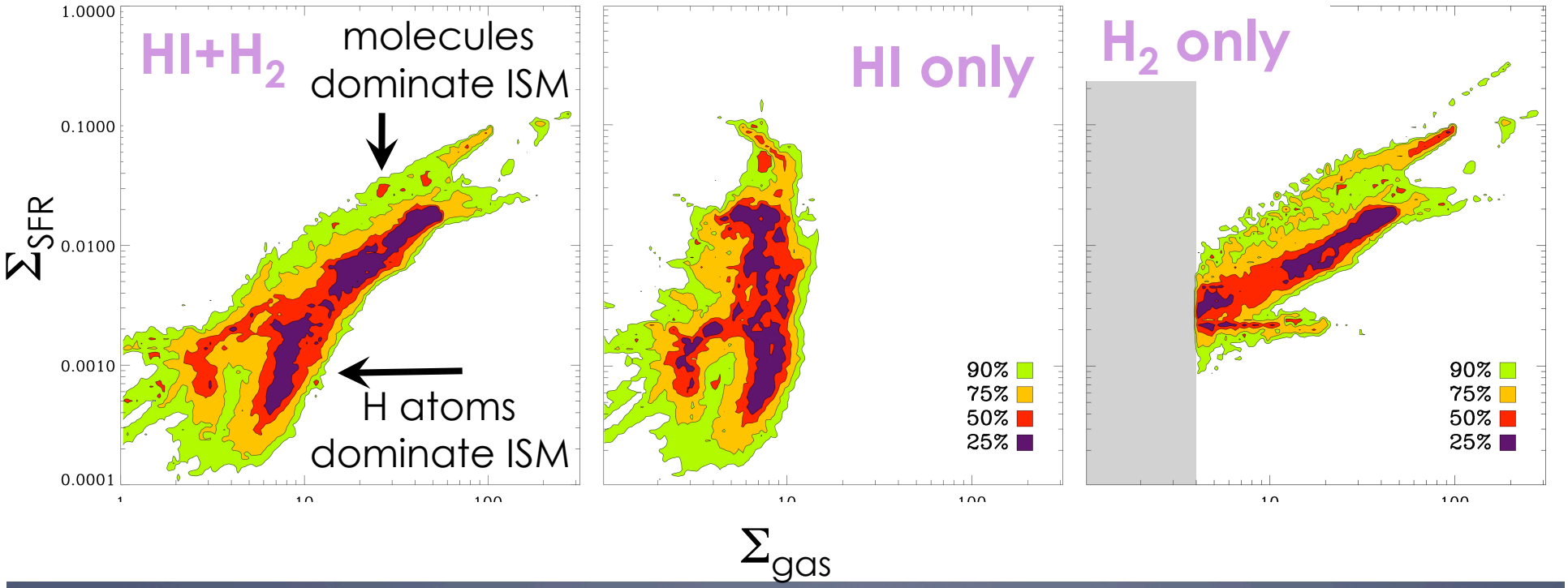
- presence of very cold (T ~ 10K) dust: TBD

- Is line contamination a worry?

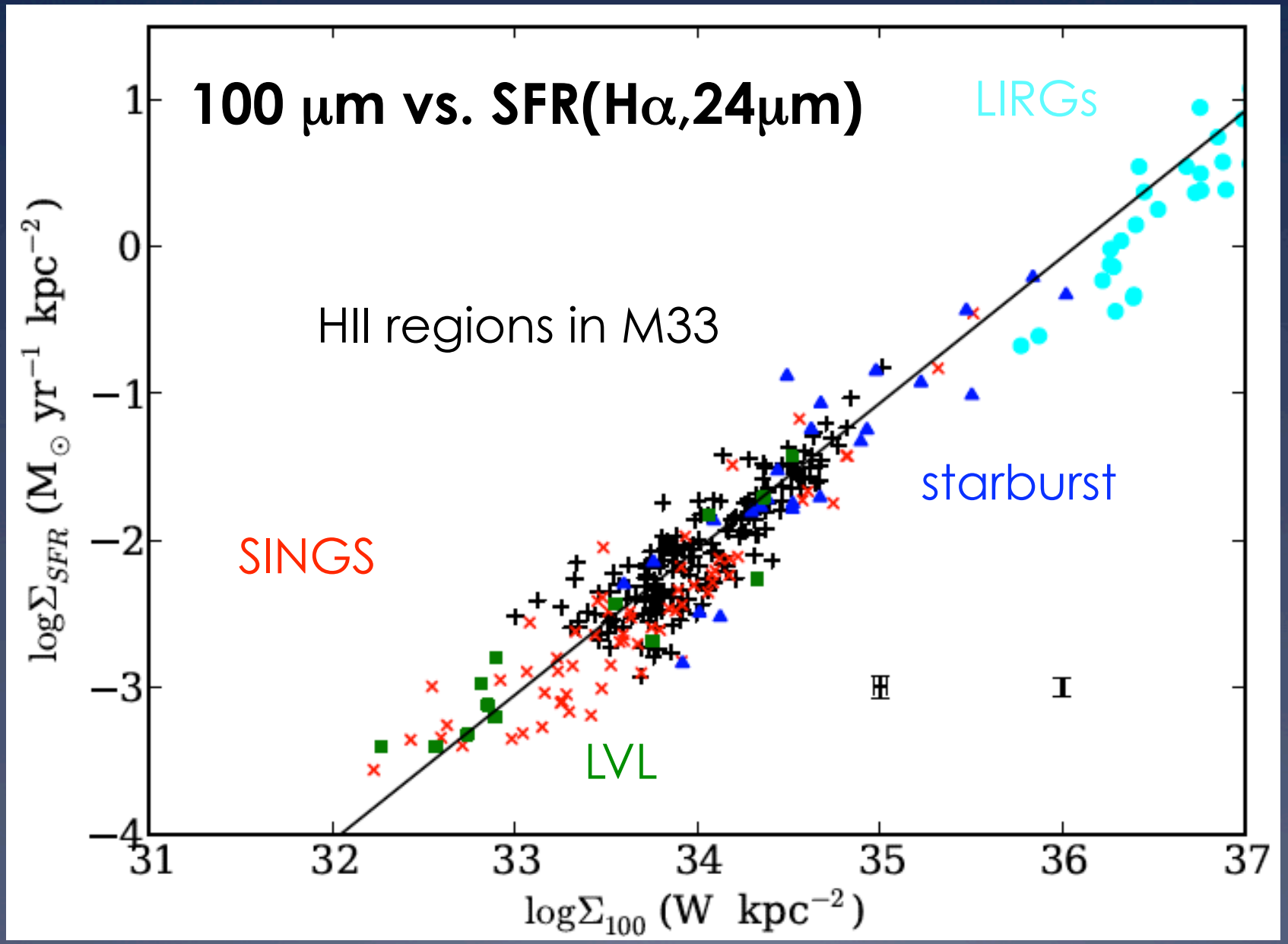
SF Law: Schmitt-Kennicutt Revisited



Bigiel et al. (2008), Leroy et al. (2008)



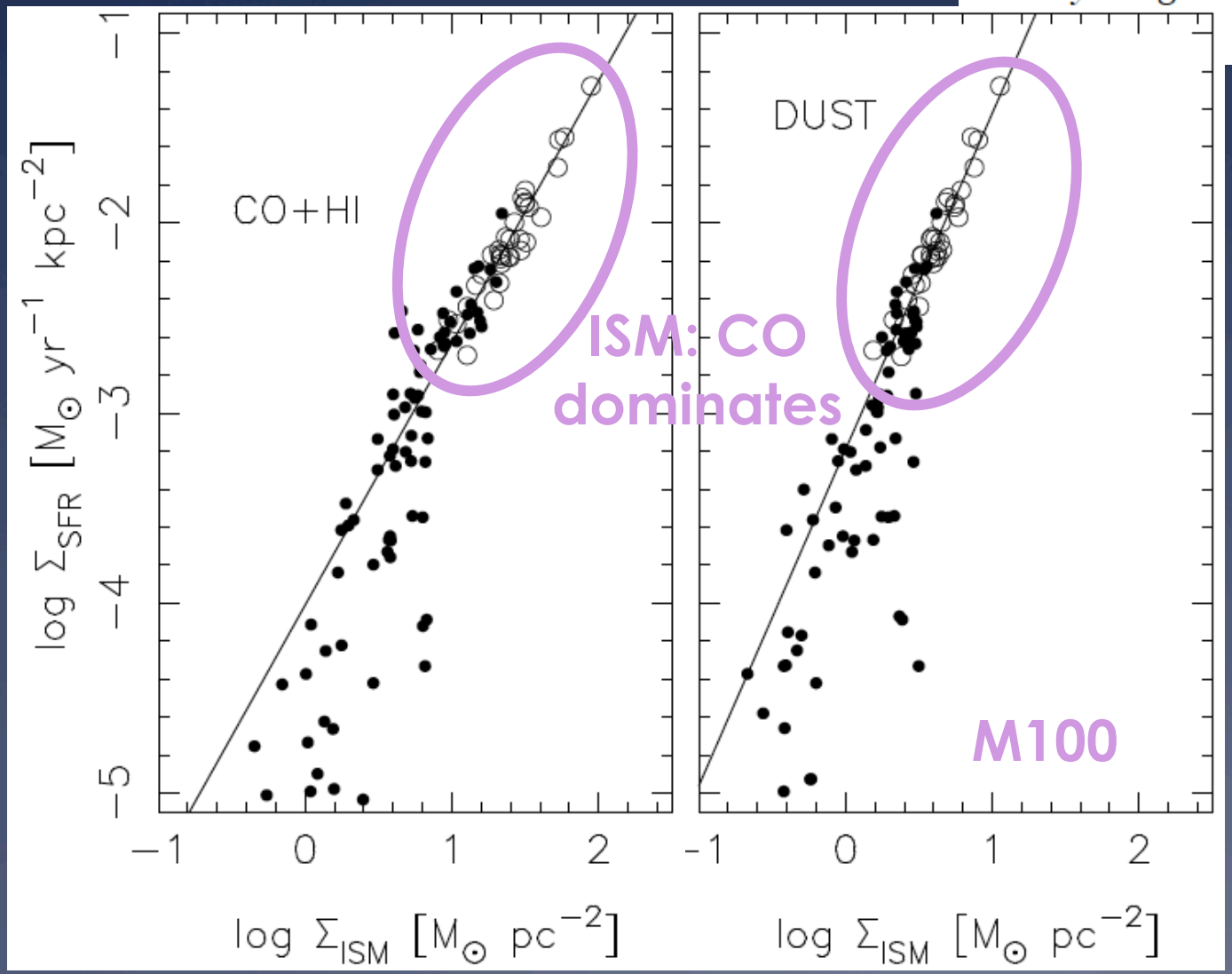
Best SFR Tracers are at λ < 160



Boquien et al. (2010)

FIR as Proxy for Gaseous ISM

Eales et al. (2010)



$$M_{hydrogen} = \frac{S_\nu D^2}{\kappa_\nu B_\nu(T) Z \epsilon f}$$

James et al. (2002)

M_{metals}/M_{HI+H2}

$$\frac{M_{metals}(\text{dust})}{M_{metals}\ (\text{total})}$$

dust opacity

Herschel will:

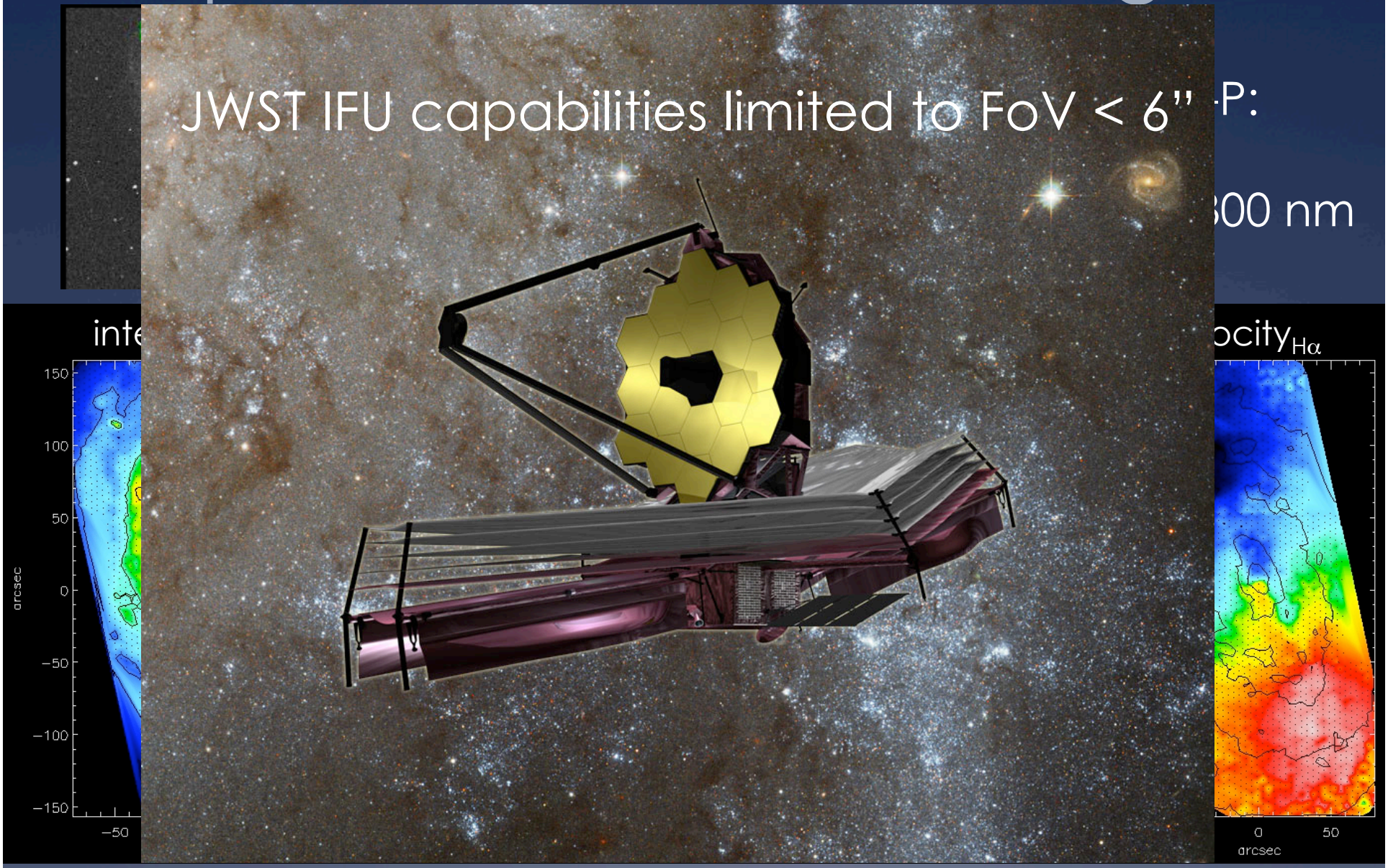
- map dust in many (!) nearby galaxies (~ 900)

- usually at MIPS/PACS + SPIRE wavelengths

➔Will need follow-up instrument w/ large FoV to test physics (lines, velocity, etc.)

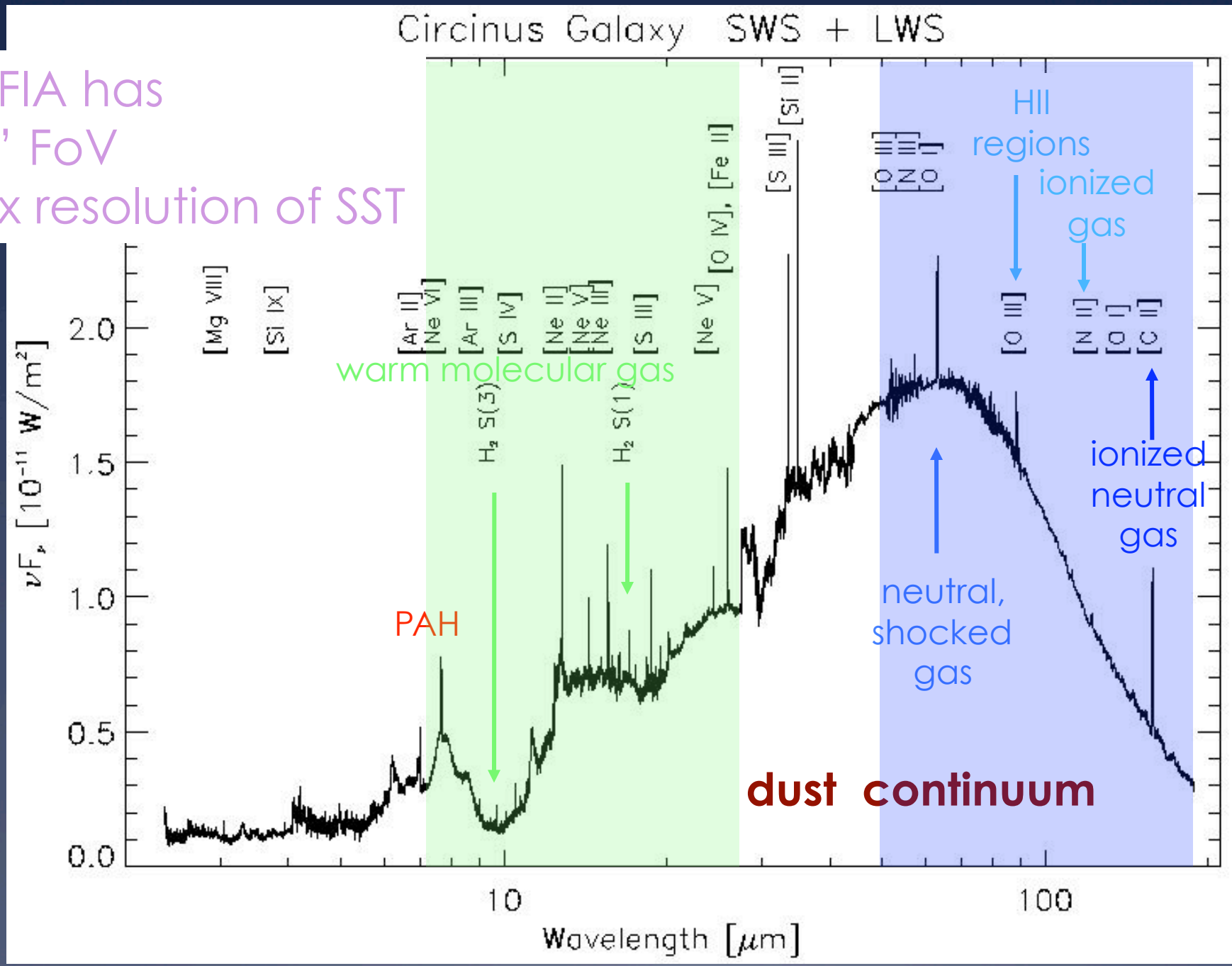
Optical wide-field IFUs, e.g.

JWST IFU capabilities limited to FoV < 6”



http://www.as.utexas.edu/~gblancm/venga.html

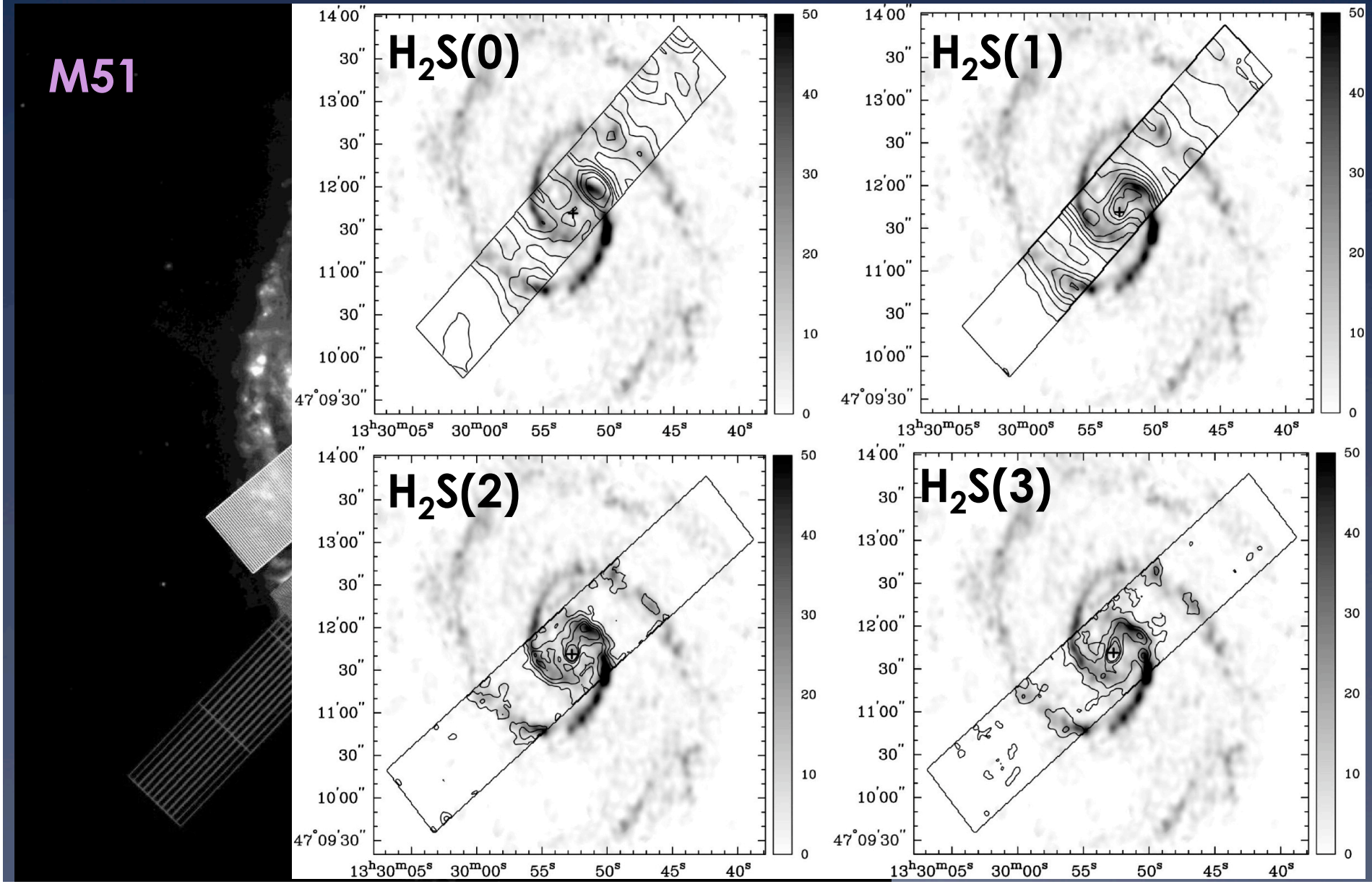
SOFIA has
8' FoV
7x resolution of SST



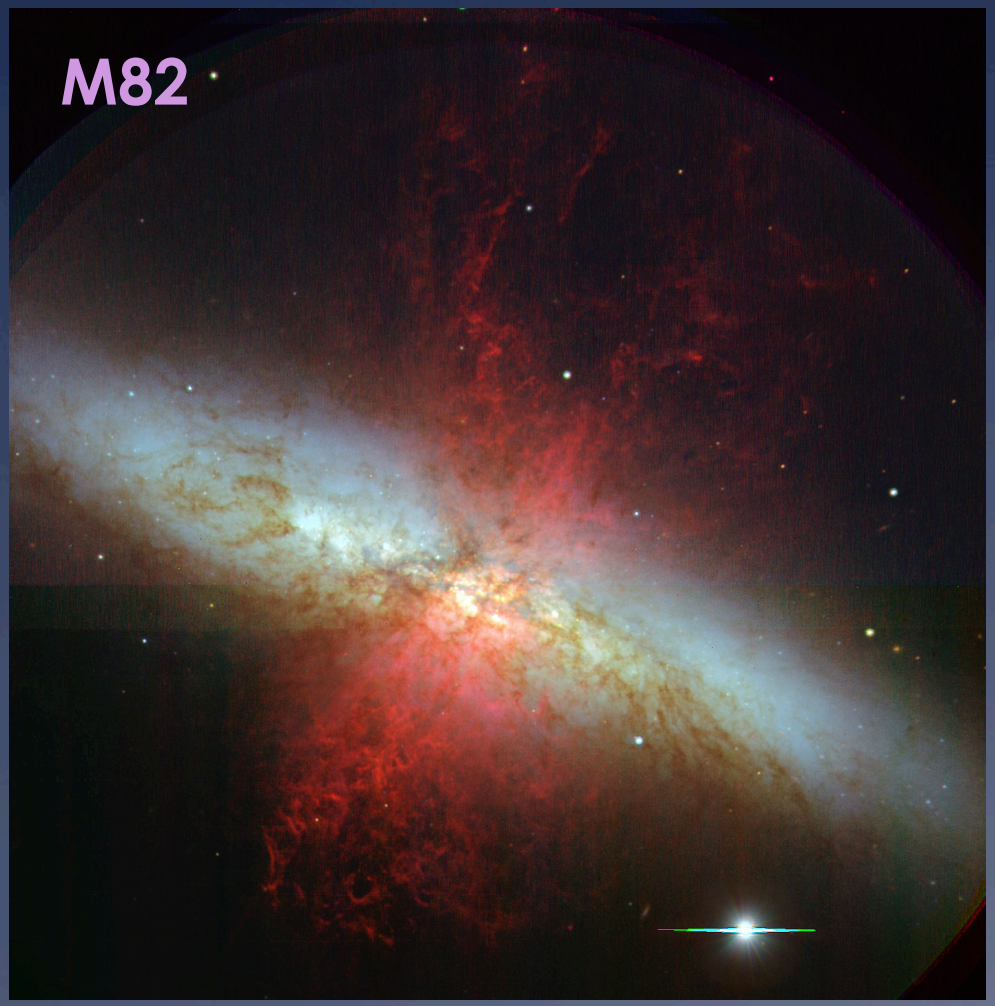
Moorwood (1997)

The Case for a (mid-)IR Analog: H_2

Brunner et al. (2008)



ISM cooling lines: Outflows, Rotation, etc.

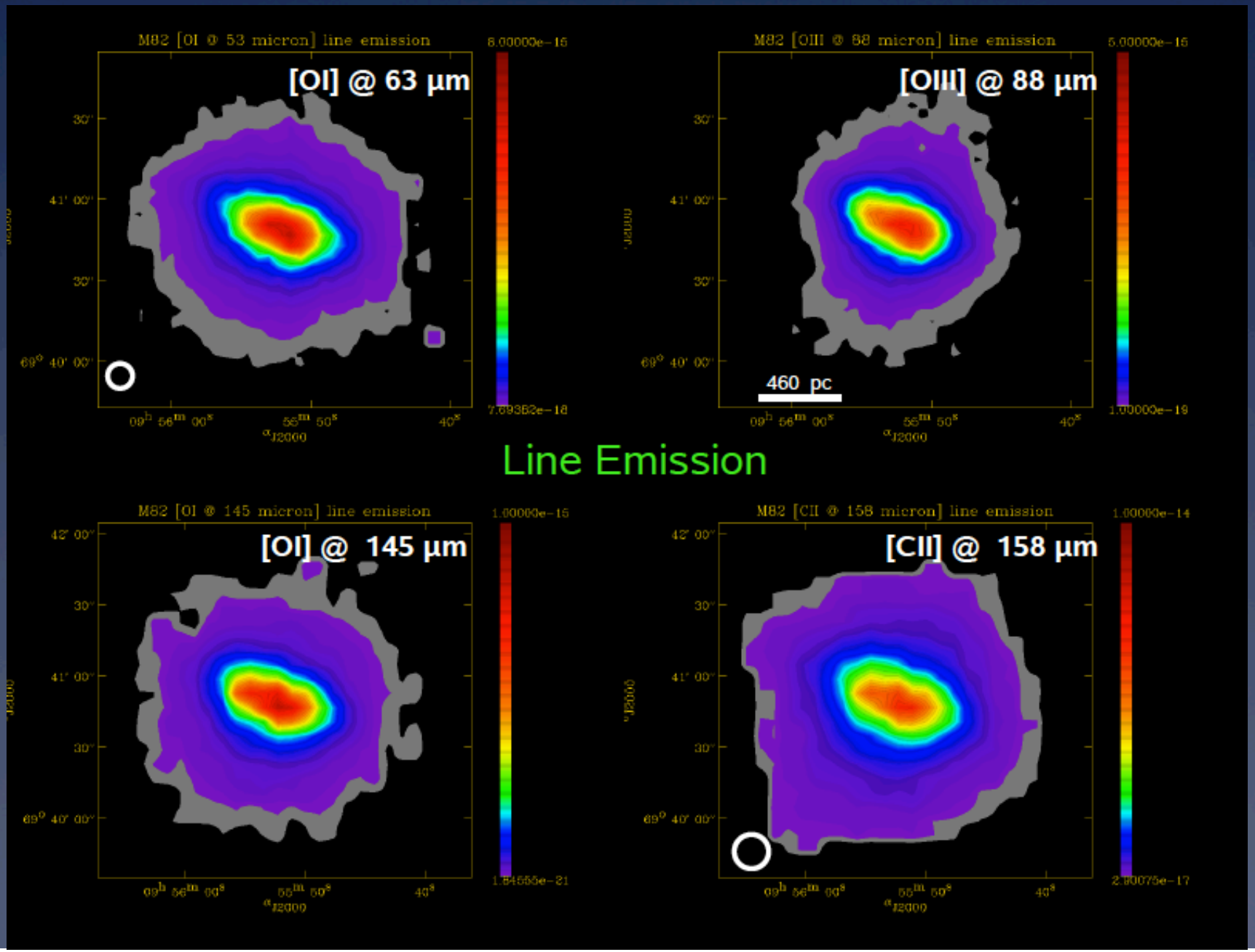


Herschel (SHINING):

- [CII],[OI] from PDRs (neutral ISM)
- main cooling lines
- [CII] also ionized ISM
- [OIII] only ionized ISM

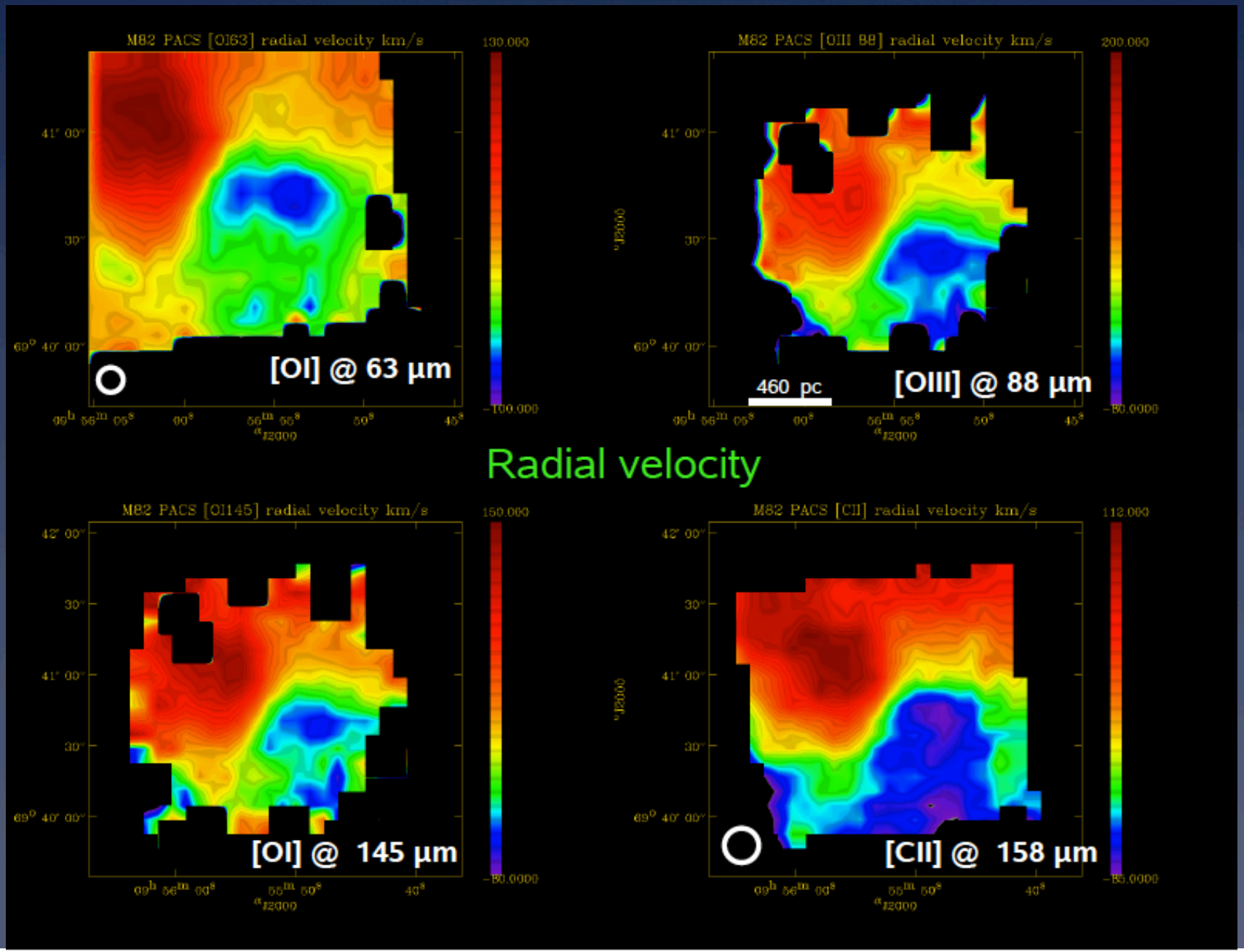
Contursi et al. (in prep.)

ISM cooling lines: Outflows, Rotation, etc.

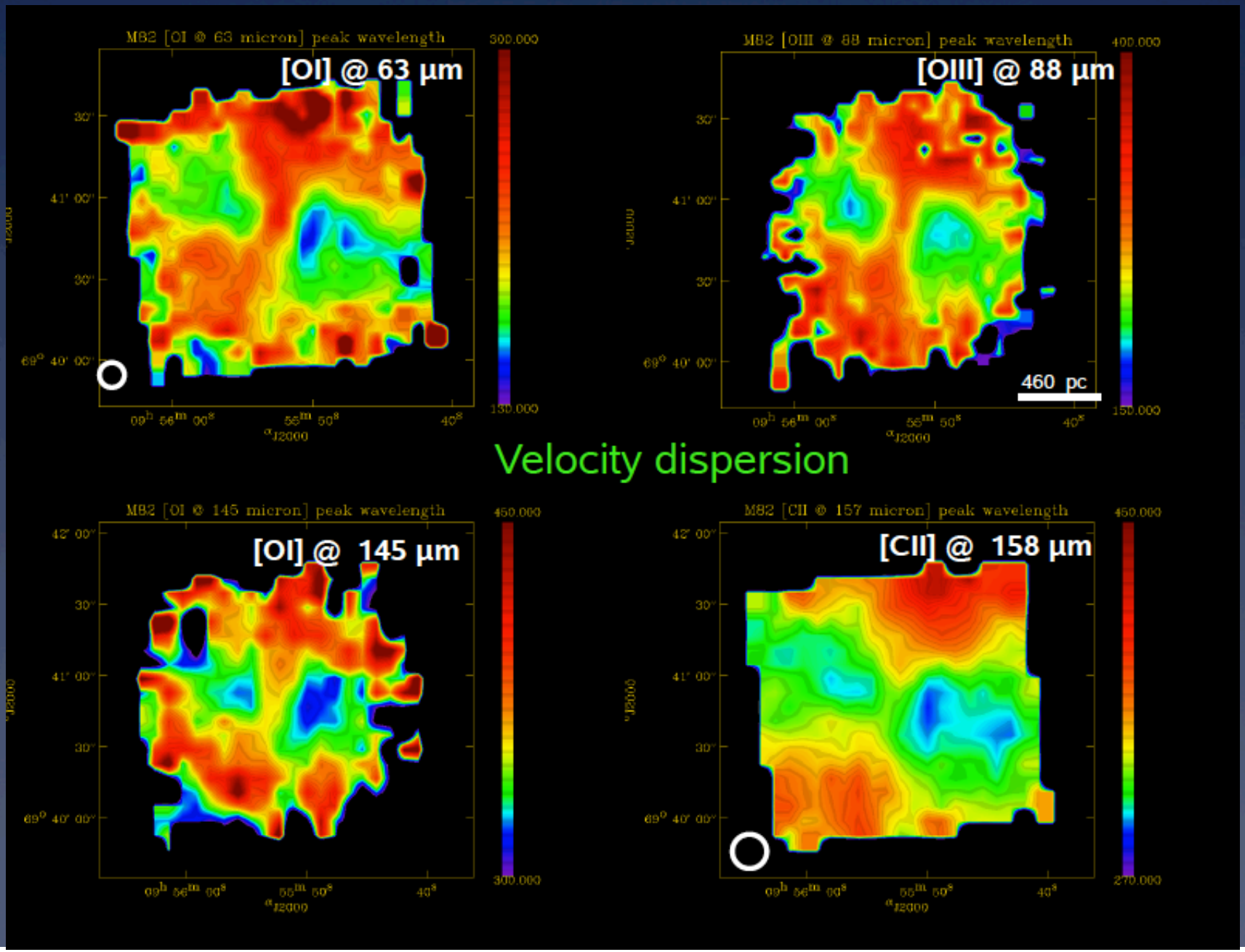


Contursi et al. (in prep.)

ISM cooling lines: Outflows, Rotation, etc.

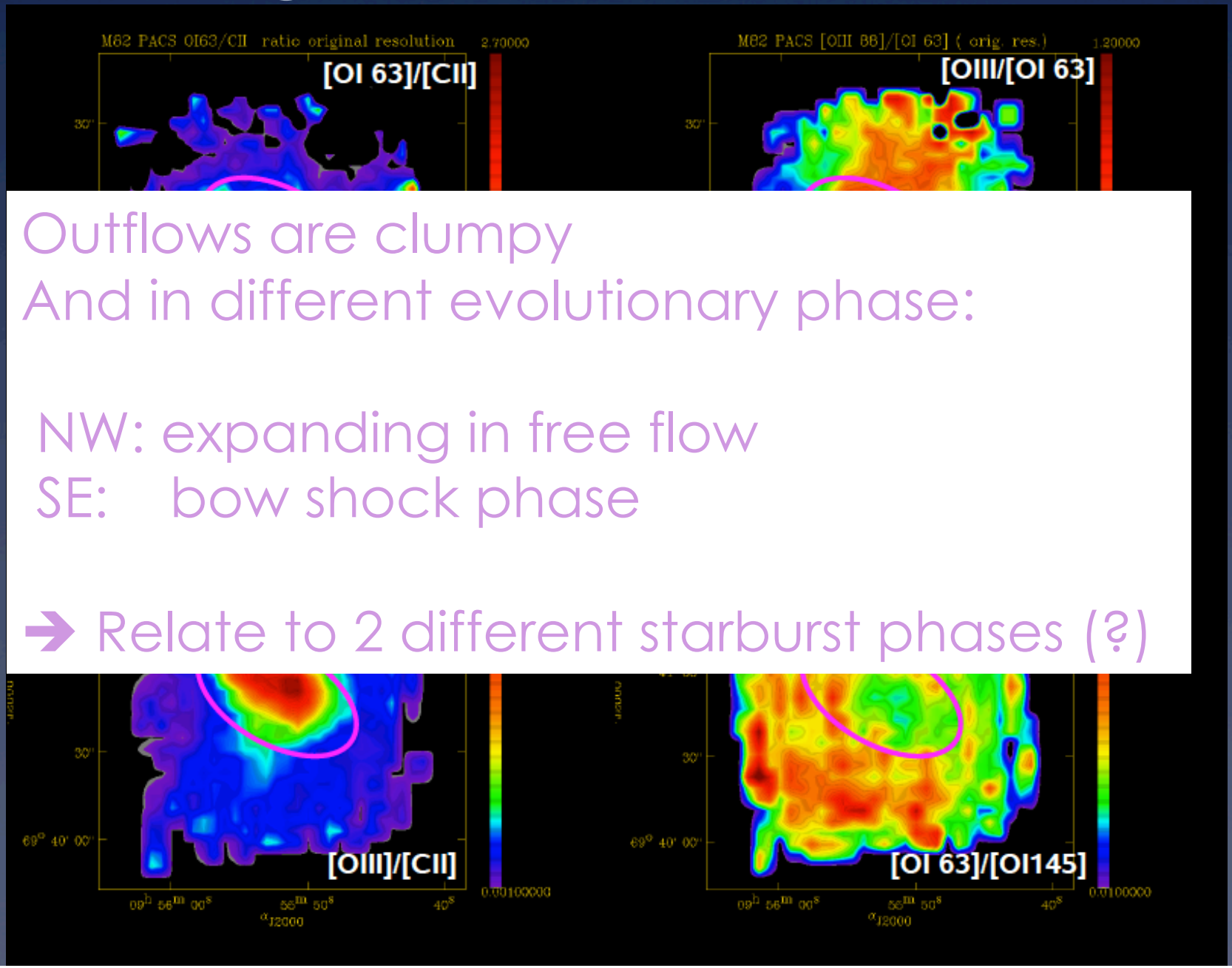


ISM cooling lines: Outflows, Rotation, etc.



Contursi et al. (in prep.)

ISM cooling lines: Outflows, Rotation, etc.



Outflows are clumpy
And in different evolutionary phase:

NW: expanding in free flow
SE: bow shock phase

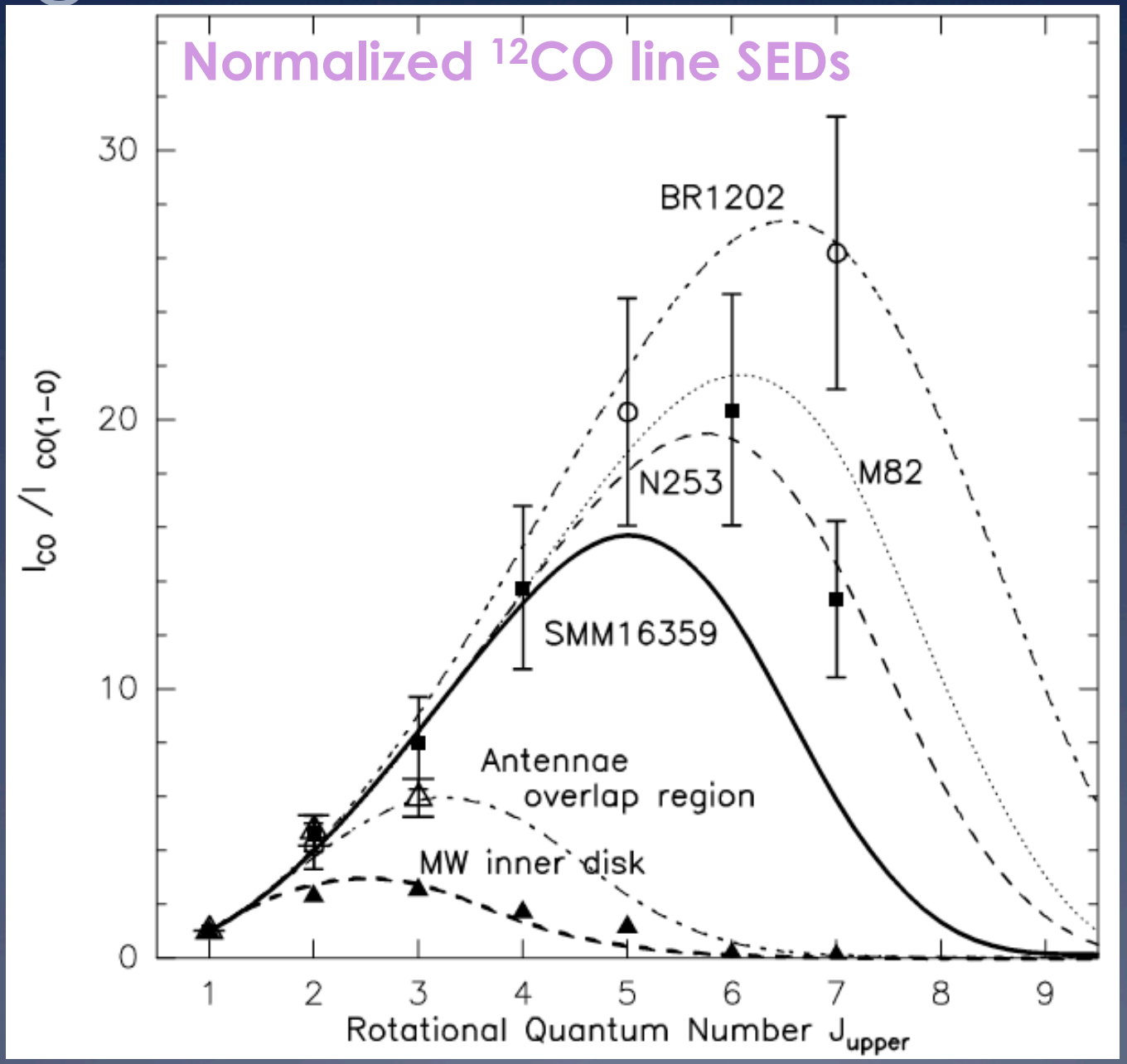
➔ Relate to 2 different starburst phases (?)

Contursi et al. (in prep.)

Far-IR emission lines:

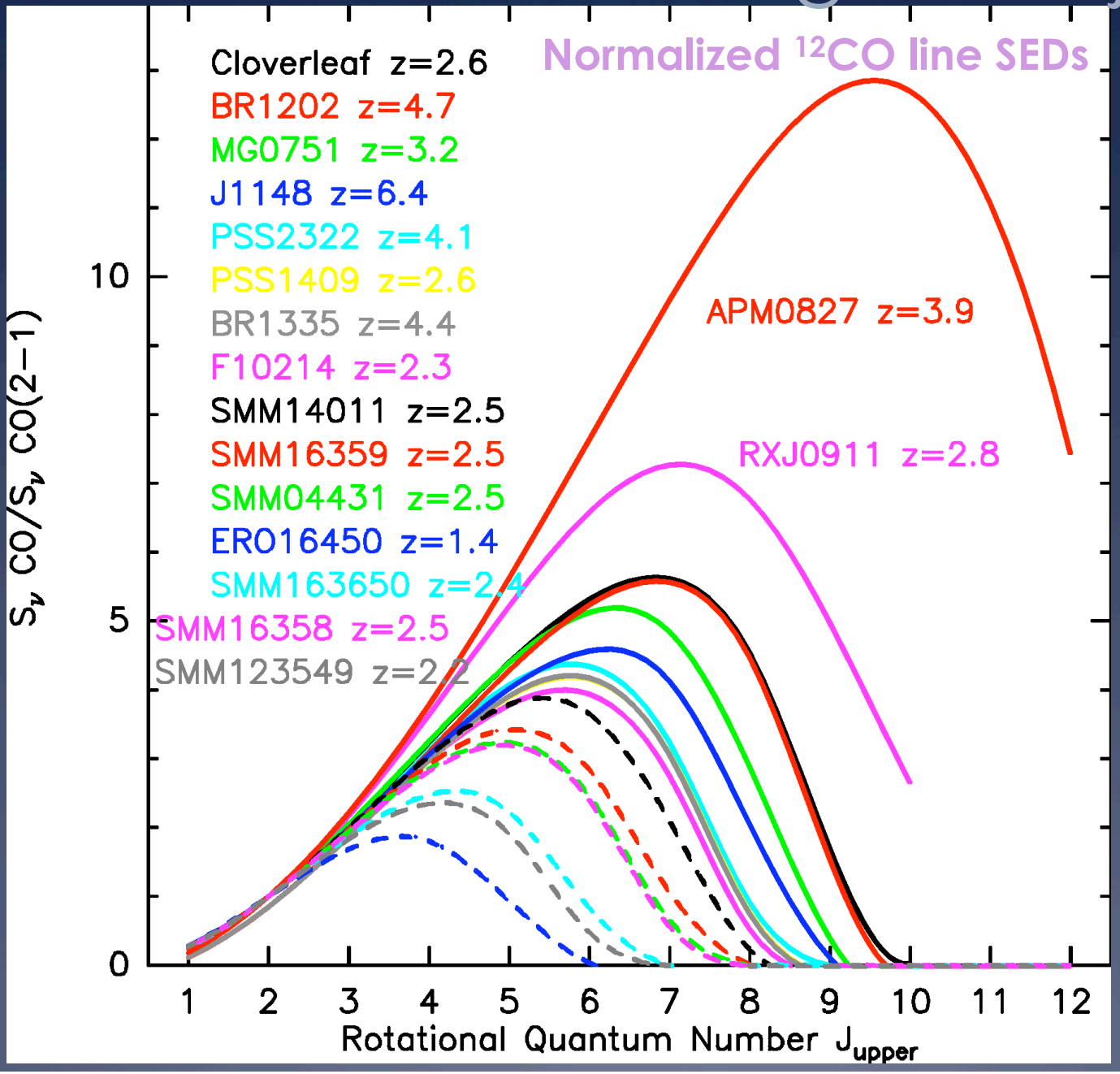
CO & friends

High-J Transitions in Galaxies

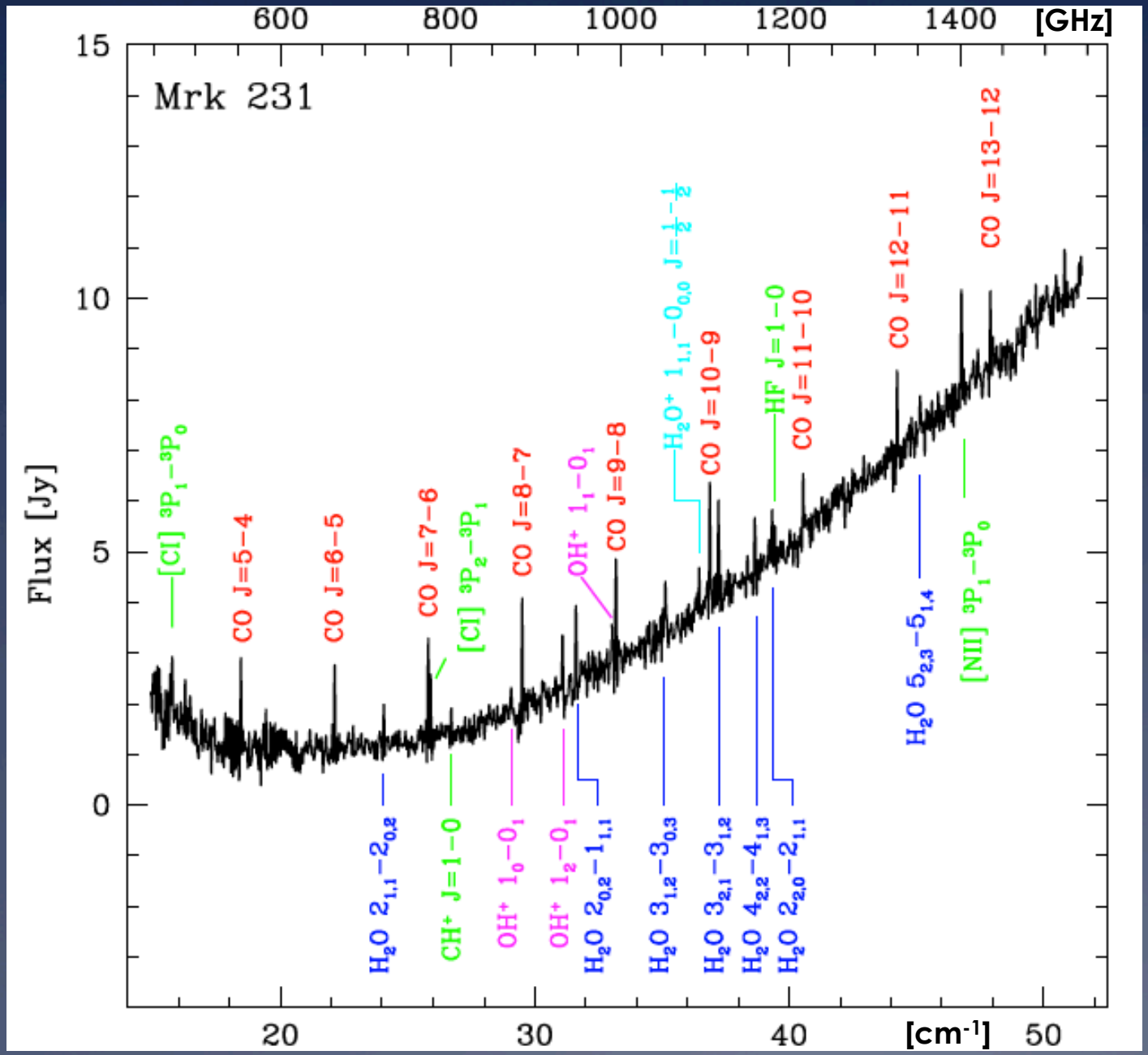


Weiß et al. (2005)

Most CO line SEDs for high-z Objects



SPIRE FTS observations of Mrk231



van der Werf et al. (2010)

HerCULES
(PI van der Werf)

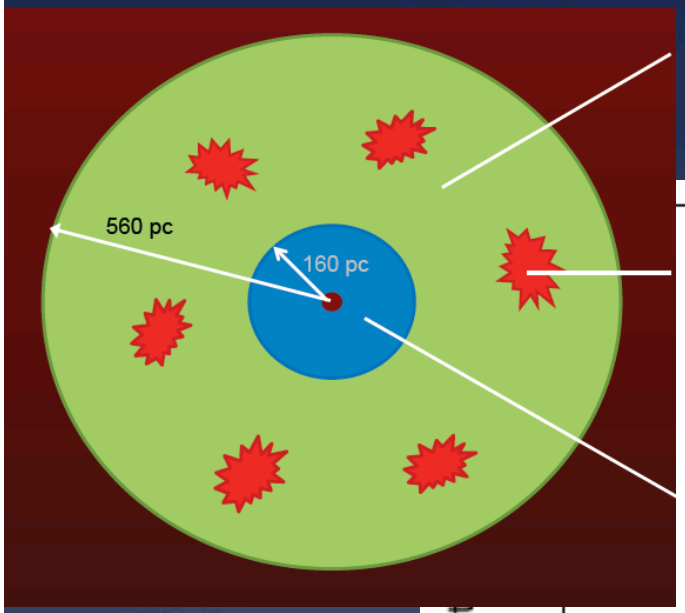
SPIRE/FTS

200-670μm
R ~ 600

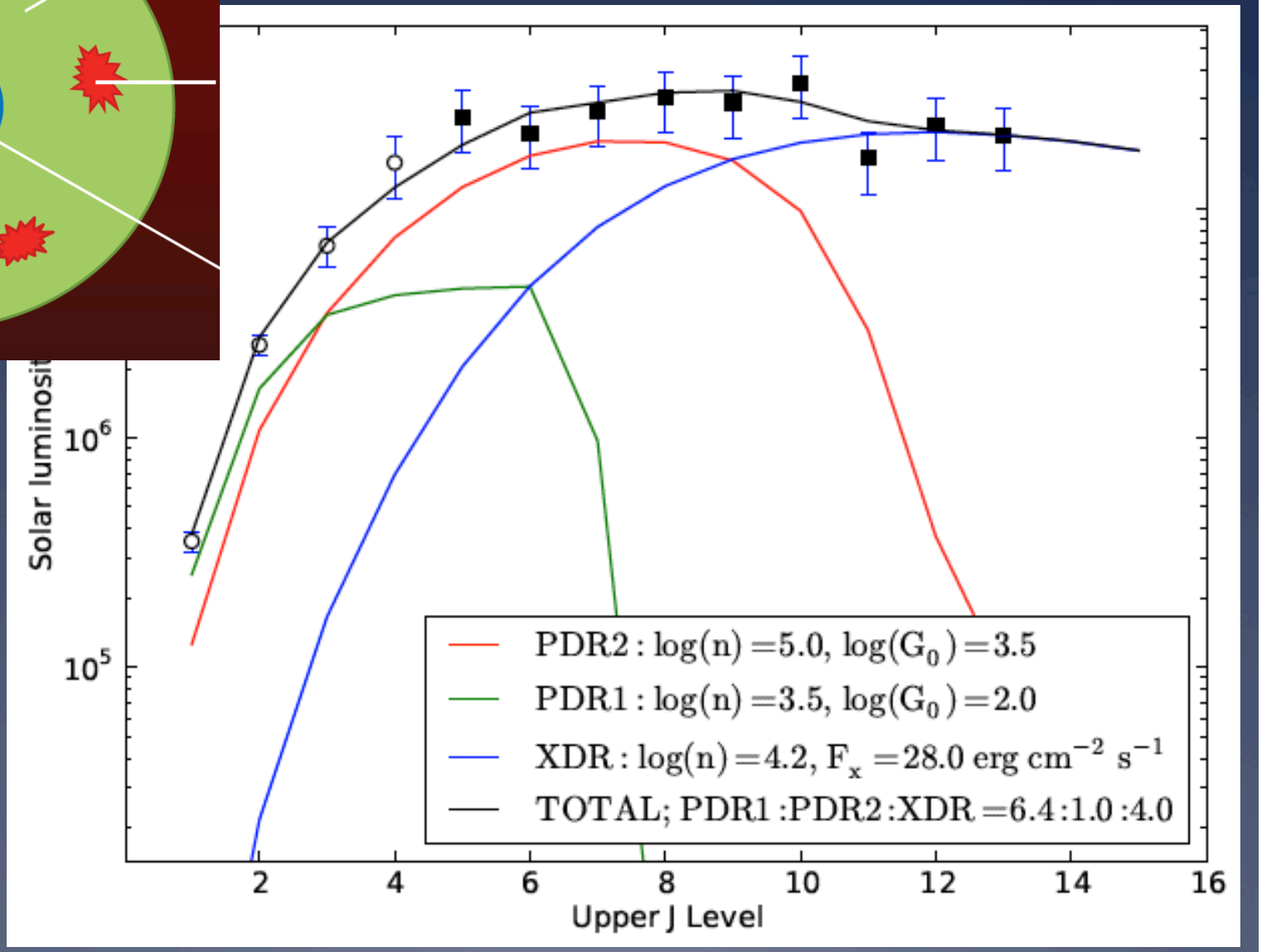
29 (U)LIRGs

➔
Local analogs

Mrk231: X-ray driven excitation



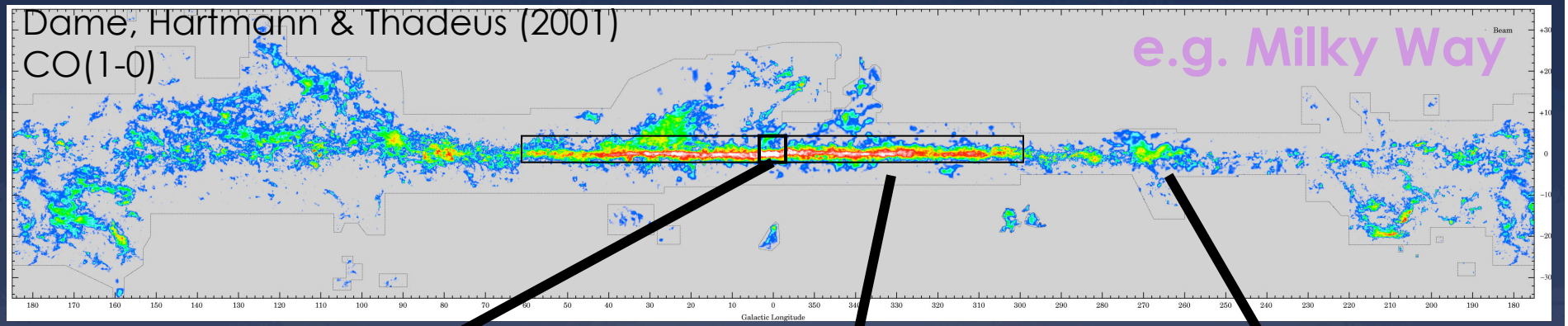
2 photon (UV) dominated regions (PDRs) = SF disk
X-ray dominated region (XDR) = AGN

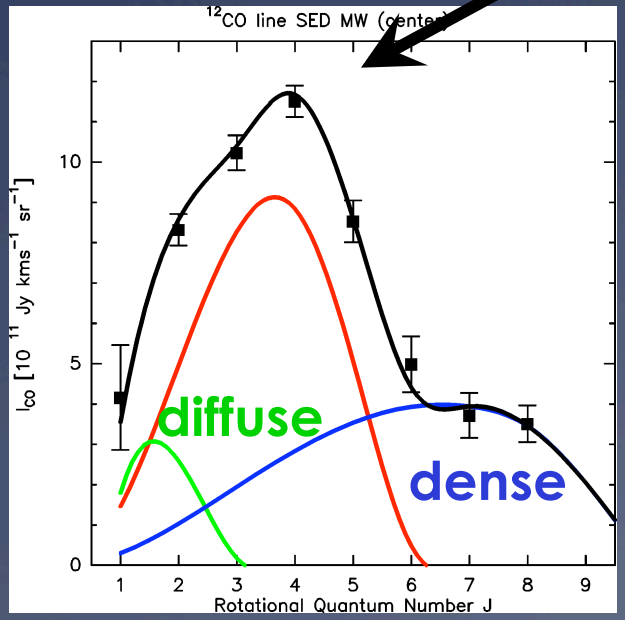


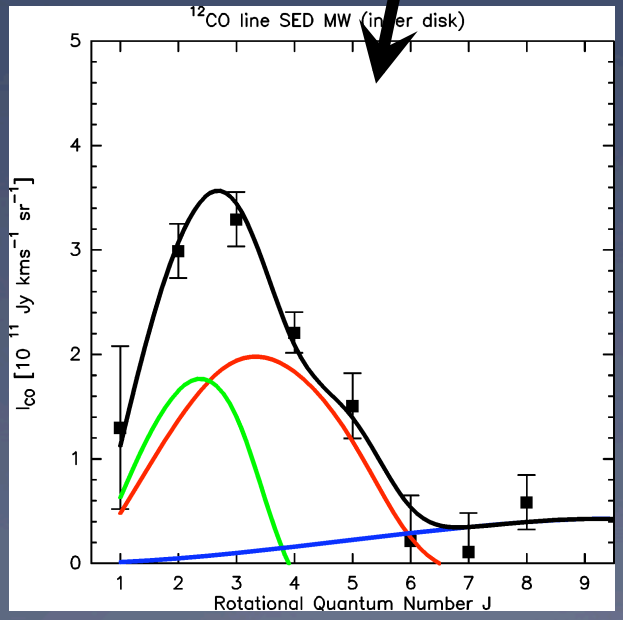
van der Werf et al. (2010)

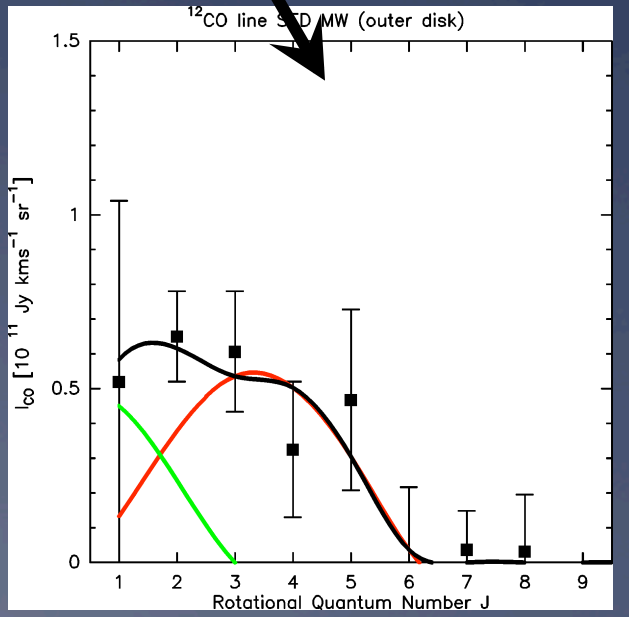
Resolved CO Line SEDs in Nearby Galaxies

Using COBE (Fixsen et al 1999) data for MW:





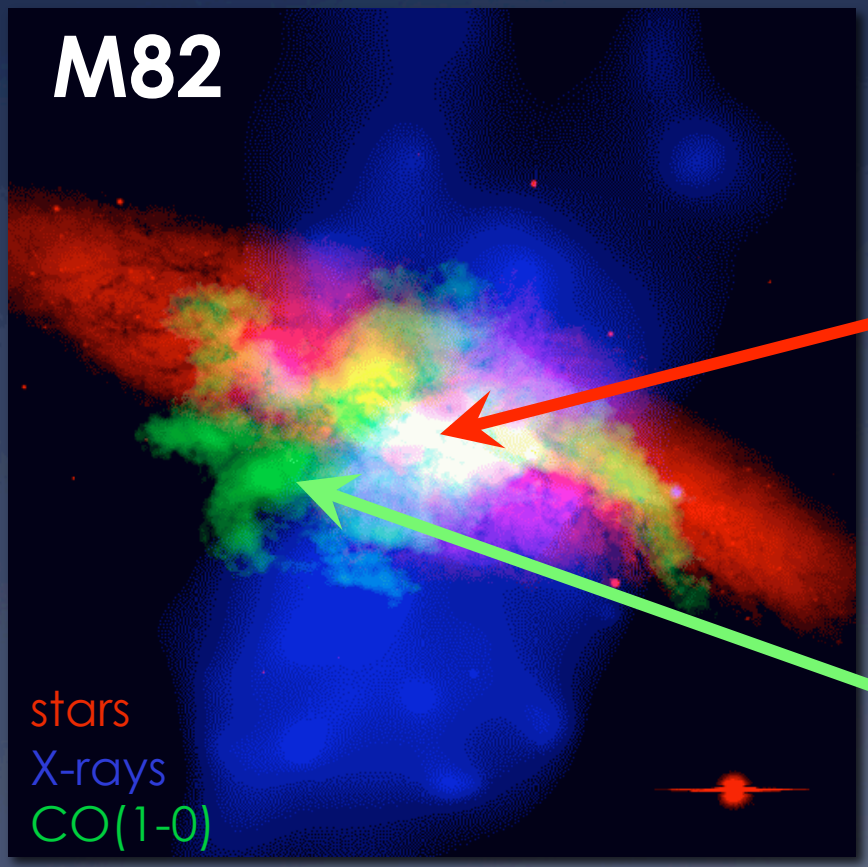




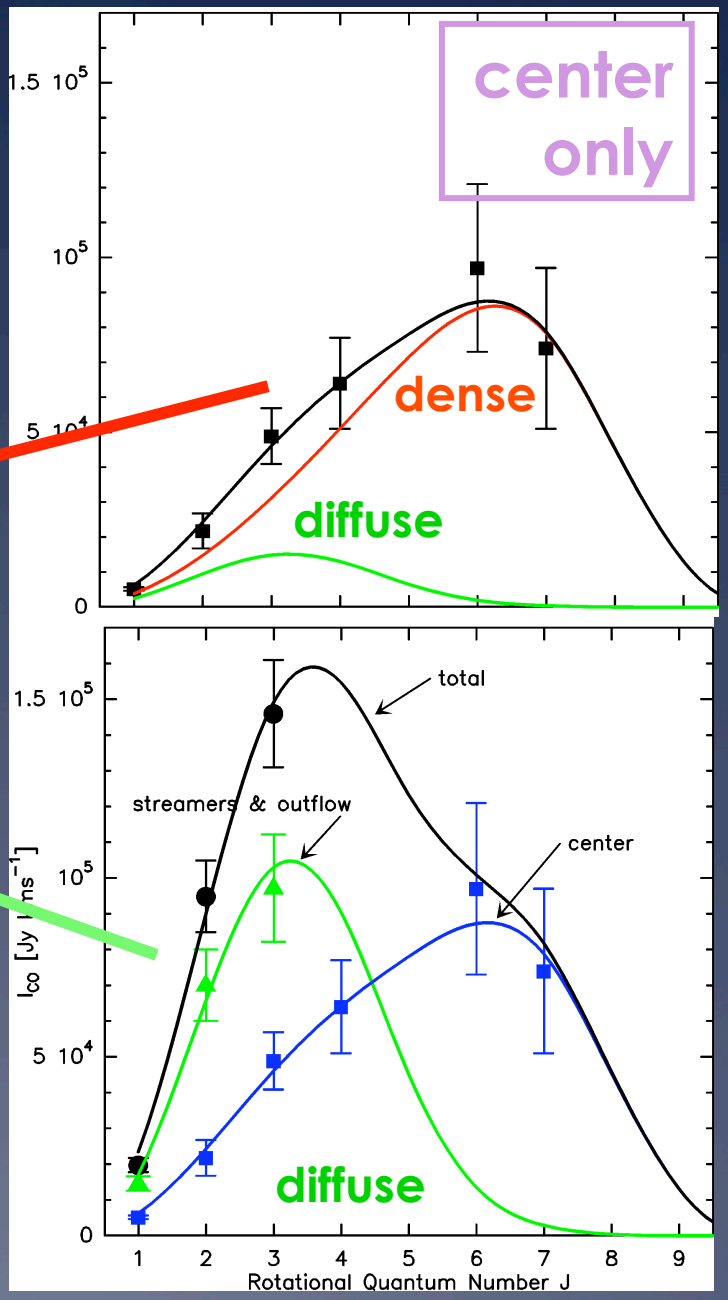
➔ multi-phase ISM

Weiß et al. (in prep.)

LSEDs: Tool to Study Multi-Phase ISM



Walter et al. (2002)

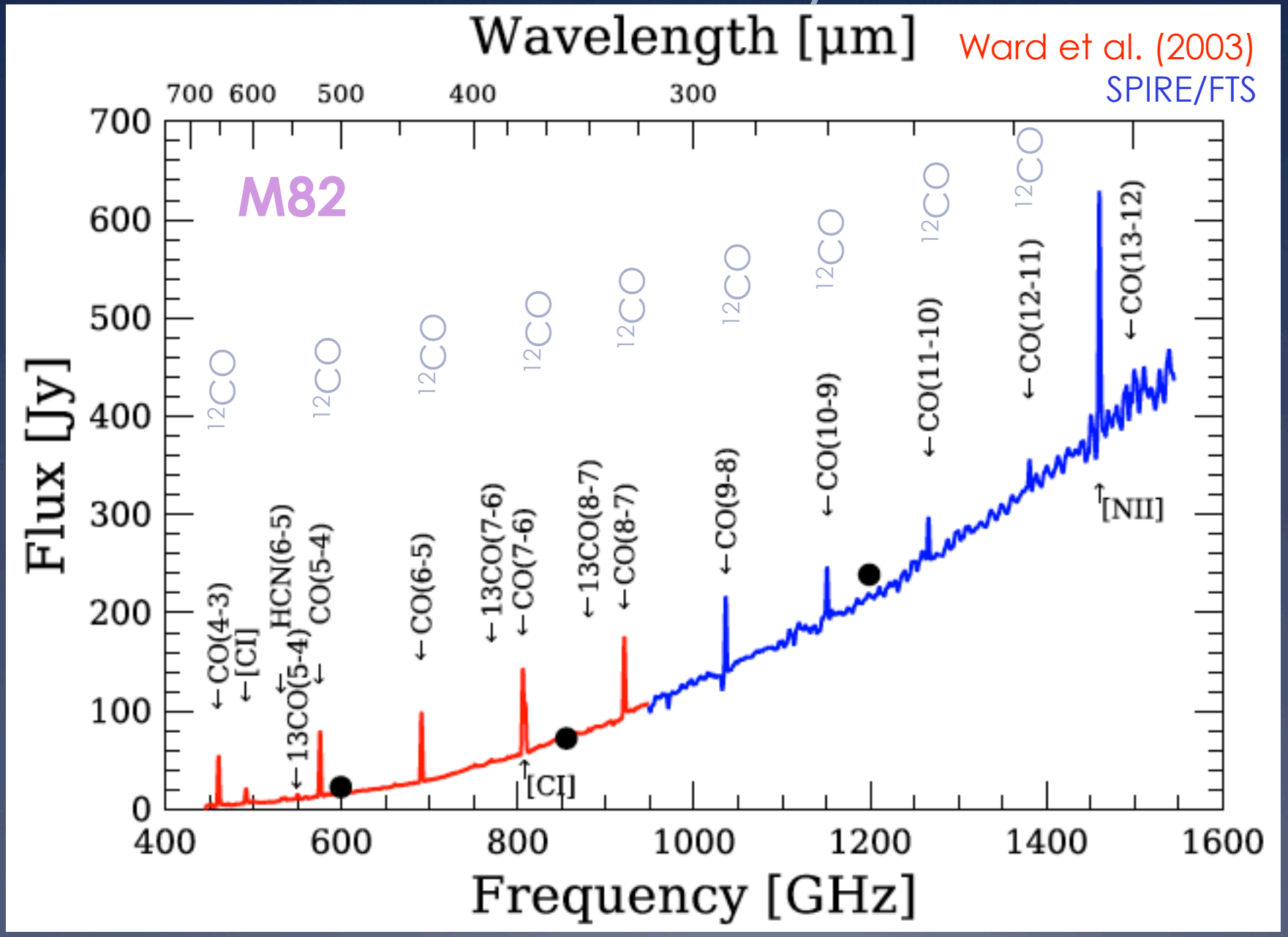


Weiß et al. (2005)

CO gas in outflow/halo

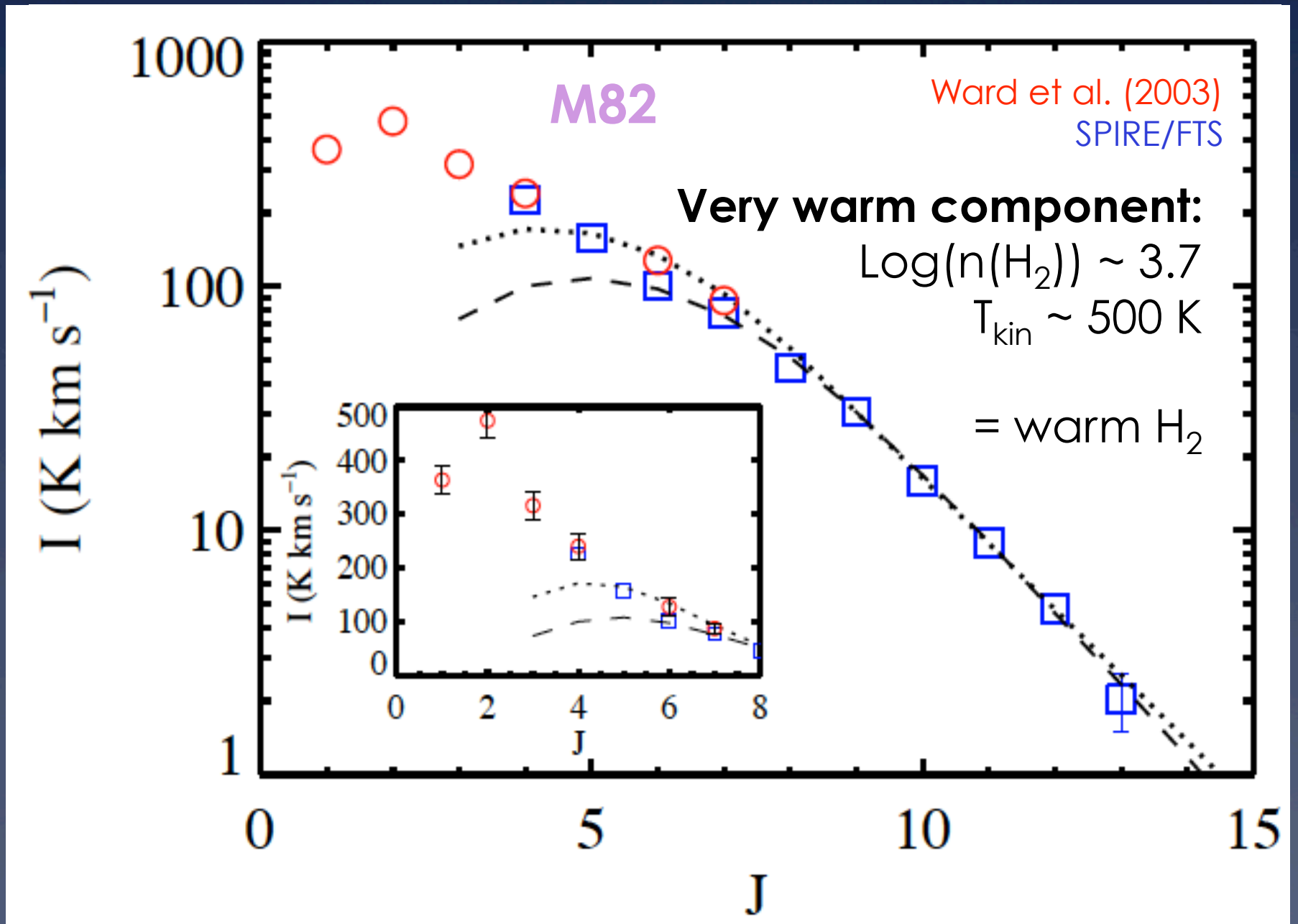
M_{H2} in disk:halo:streamer= 1:1:1

SPIRE/FTS: Heated by Turbulence



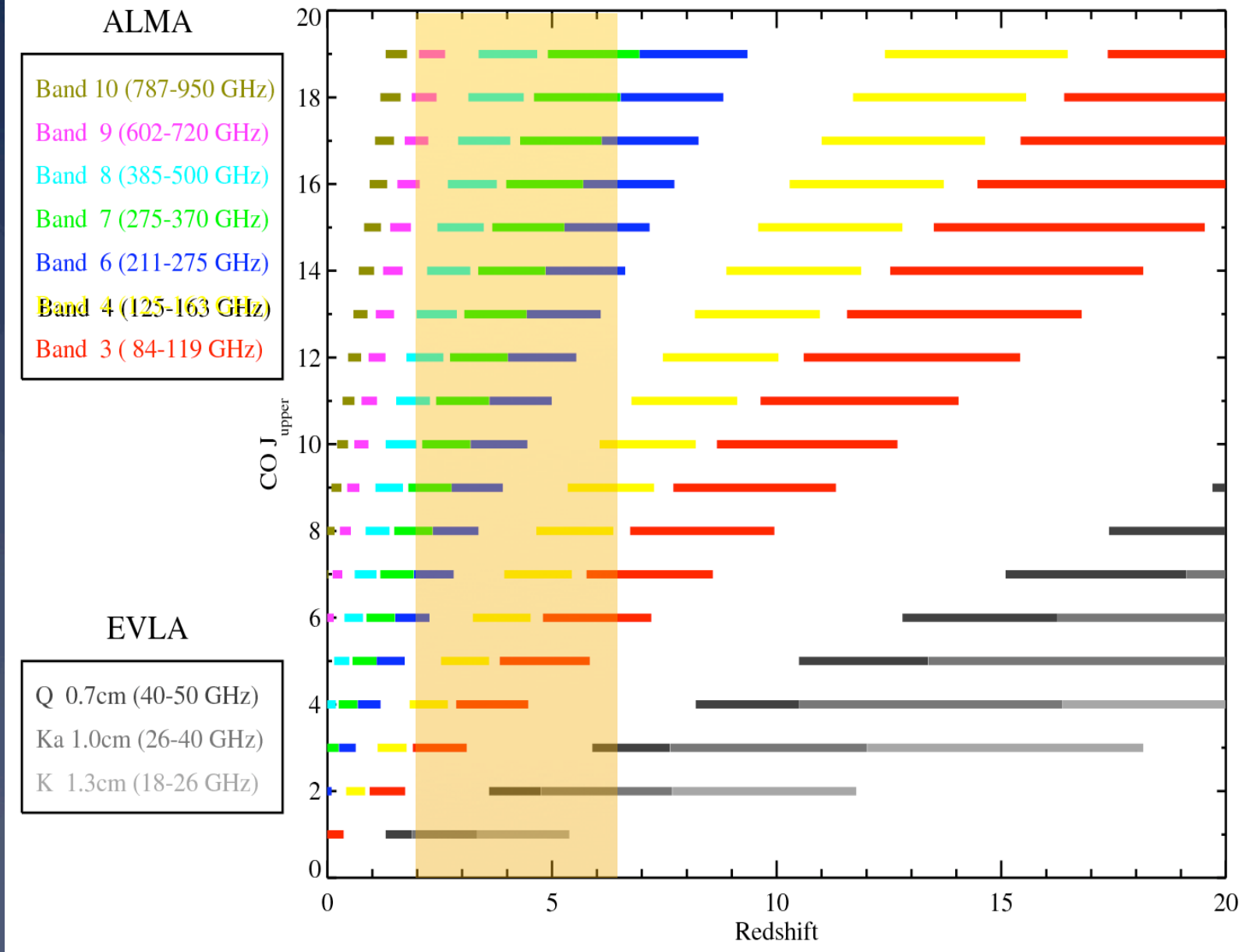
Panuzzo et al. (2010)

SPIRE/FTS: Heated by Stellar Winds/SN



Panuzzo et al. (2010)

Synergy with ALMA & EVLA



Walter & Carilli (2008)

SOFIA's niche: Full Line SEDs

Herschel SPIRE/FTS & PACS/IFS:

CO(5-4) → CO(13-12): no spatial information
CO(14-13) → CO(43-42): line cubes only

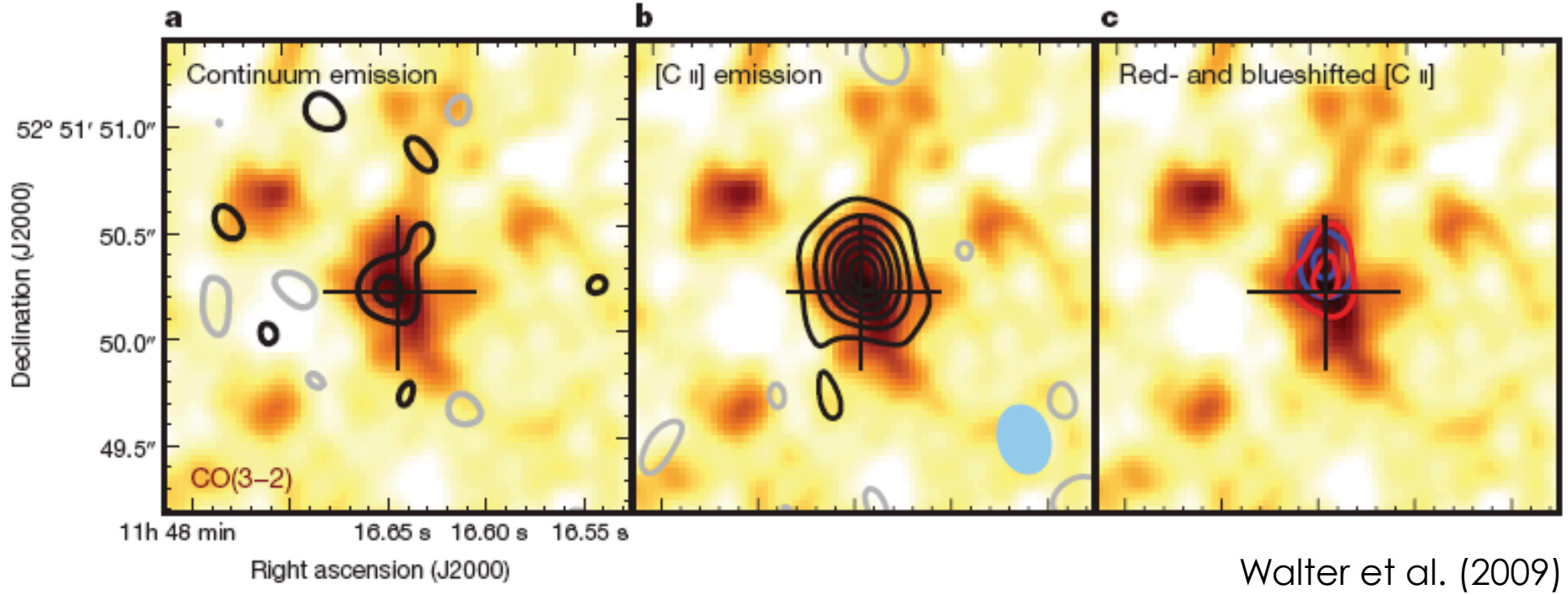
My wish instrument:

A full infra-red SED scanner
w/ limited spatial information
needs to start at (2-1) as low-J's are crucial

Possible?

[CII]: Important SFR Tracer @ high-z

[CII] resolved at z=6.4: 0.35" ~ 2 kpc

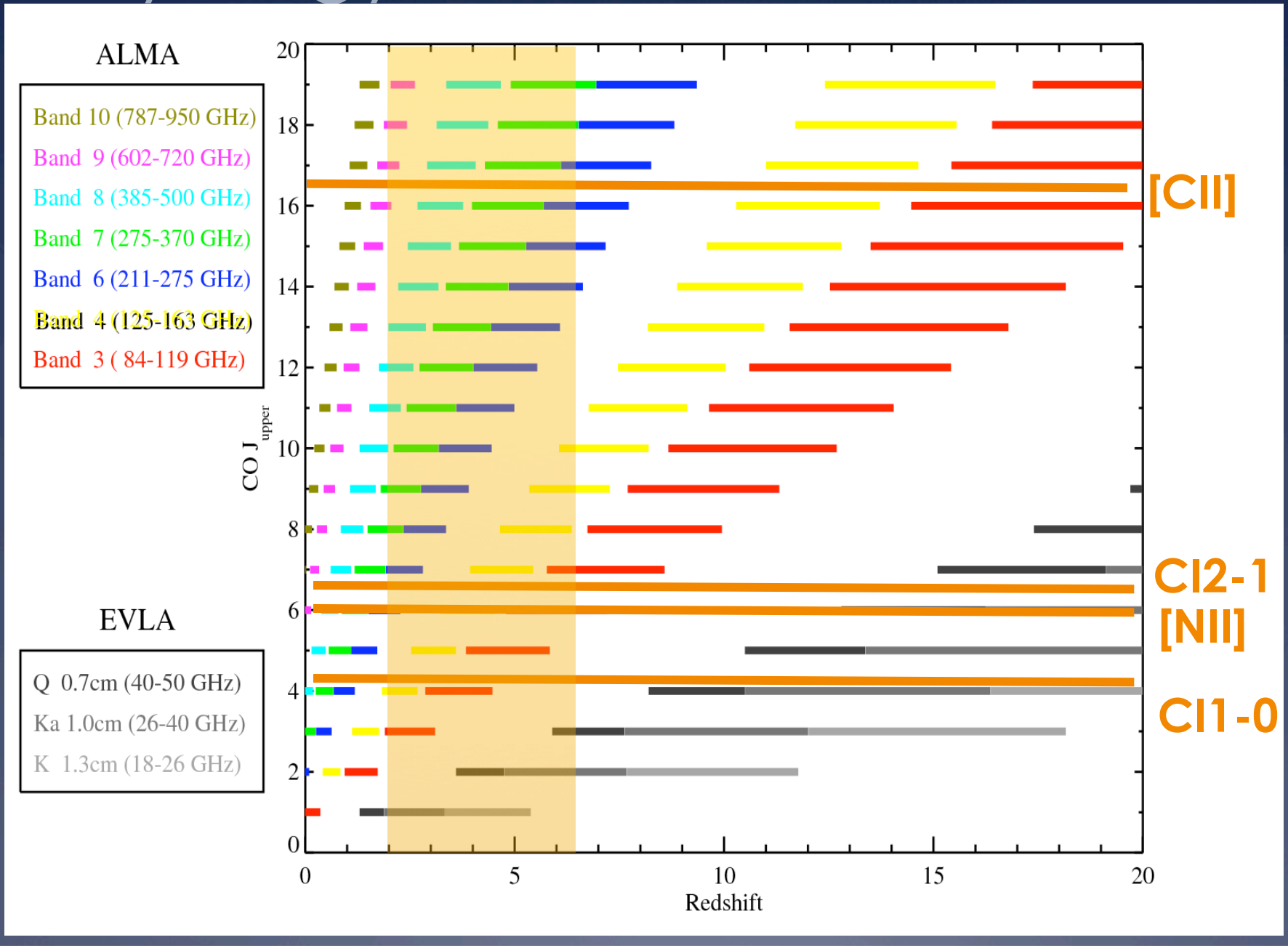


Walter et al. (2009)

Direct evidence for formation of stellar disk/ bulge in host galaxy < 1Gyr after big bang

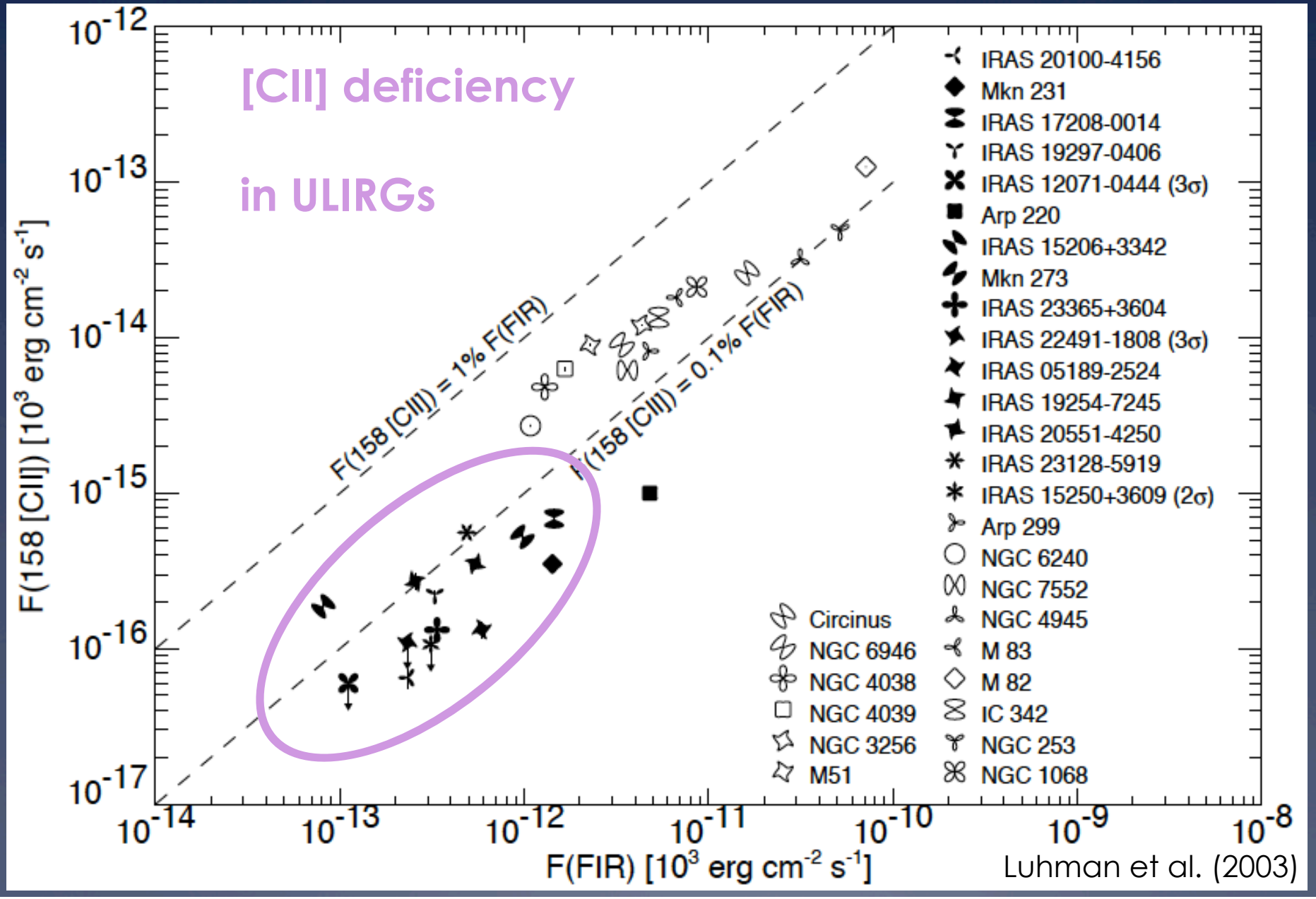
SFRD = 1000 M_{sun} yr^{-1} kpc^{-2}

Synergy with ALMA & EVLA



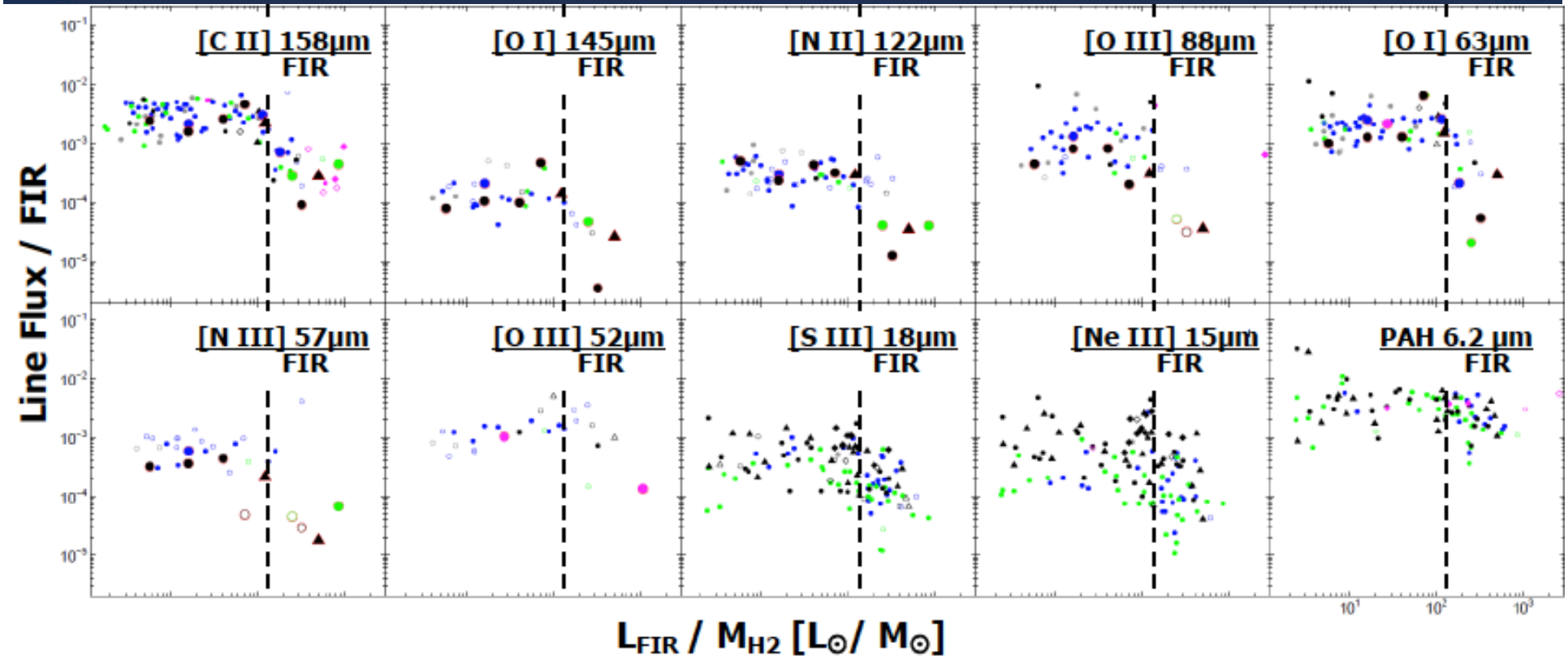
Walter & Carilli (2008)

[CII] in local galaxies: ISO



Luhman et al. (2003)

Herschel: No [CII] deficiency



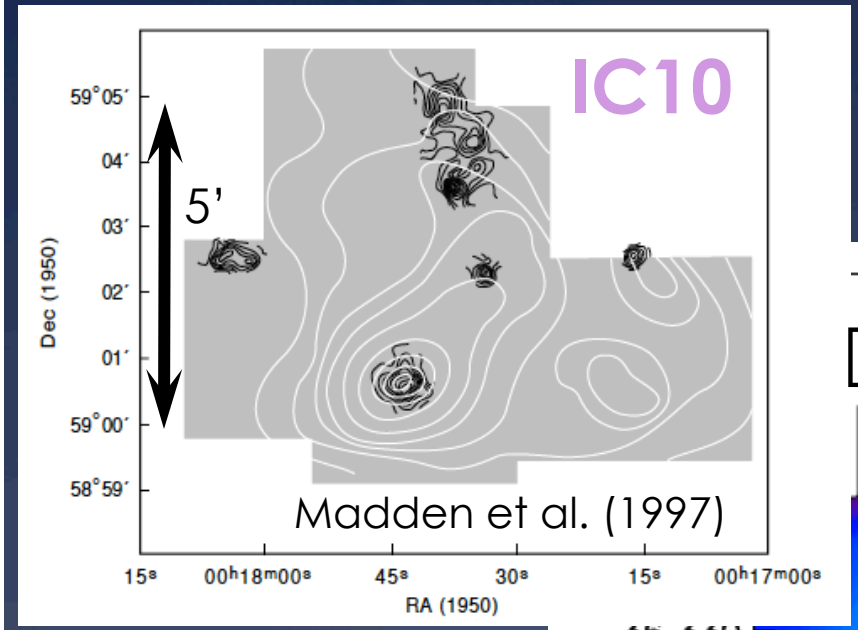
Garcia-Garpio et al. (in prep.)

All lines show deficiency:

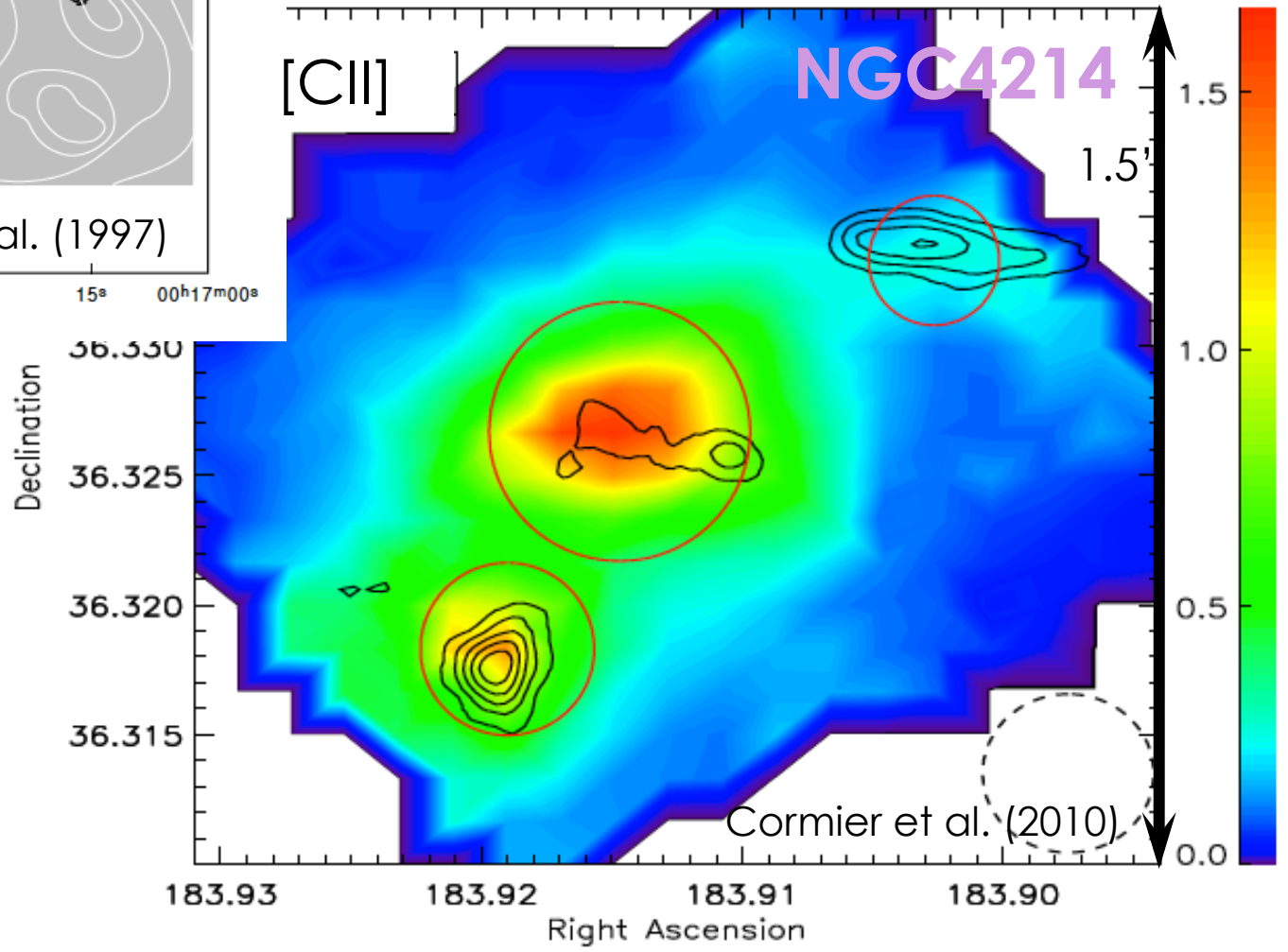
High SFE → compact star formation → high U

→ low line/FIR ratio

A [CII] imager for nearby galaxies



CO (black contours)



SOFIA:

8' FoV

18" resolution
=
1.6 kpc @ 20Mpc

SOFIA's Future Potential:

Utilizing SOFIA's large FoV of 8':

- (mid-)IR integral field spectrometer
  sampling full disk of nearby galaxies

- a [CII] imager
  (~ similar resolution to ALMA high-z objects)

Utilizing SOFIA's large wavelength coverage:

- a full (far-)IR SED scanner
  (resolved) line SEDs in local galaxies