Molecular Gas Studies of Planck-Herschel Selected Extremely Luminous IR Galaxies at z ~ 1.3-3.3

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Outline

Background + Planck pilot Sample

Refined Planck selection method sample

LMT + GBT results of pilot sample

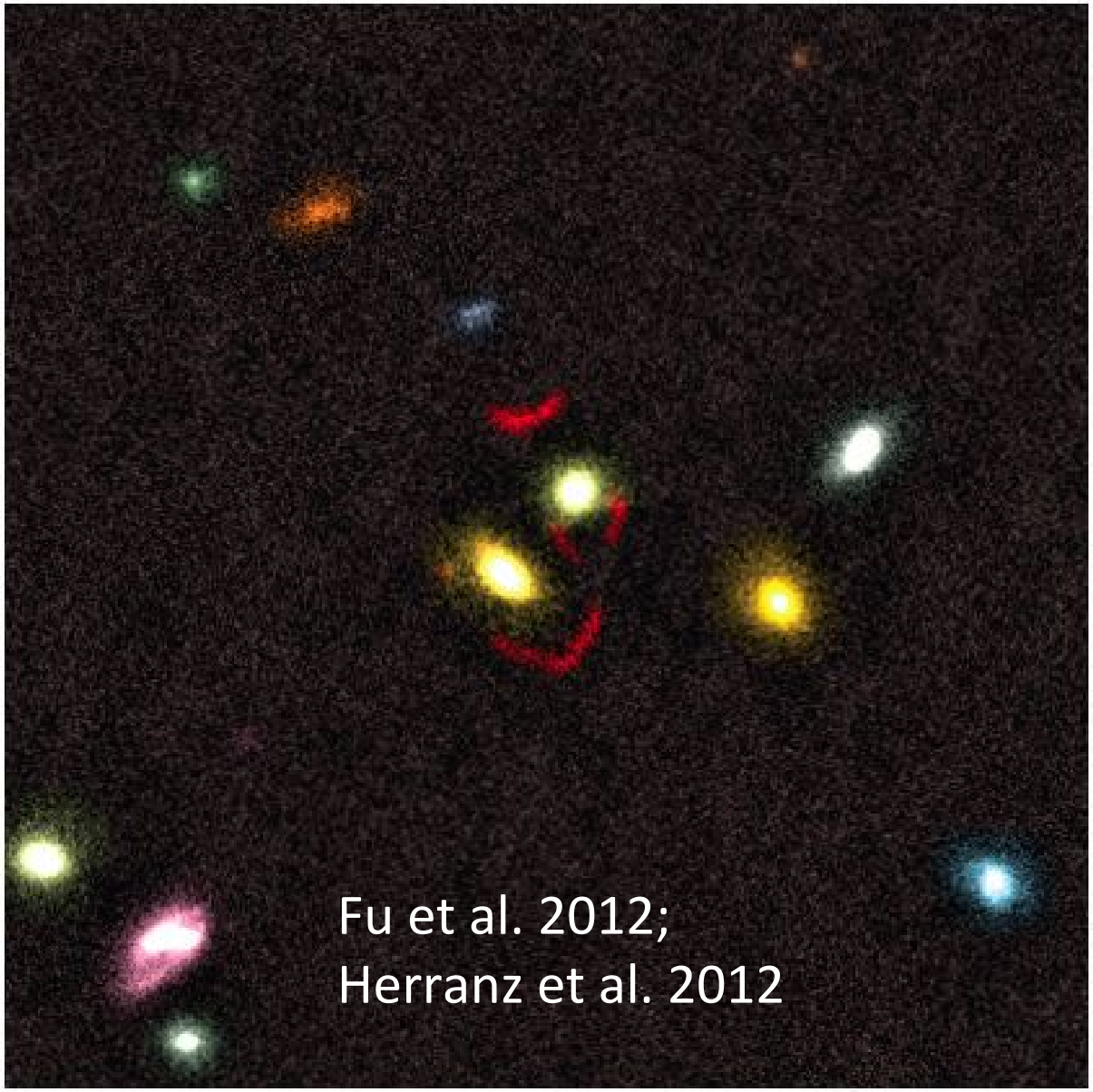
IRAM 30m obs. of pilot sample

Future work

The most extreme high-z objects:

- *Herschel* (.25-.5mm) and *SPT* (1.4+3mm) wide-field surveys on the order of 100-1000 deg^2
  - Larger the survey = higher odds to catch a monster
- Rare, strongly lensed starbursts/AGN/QSOs are advantageous for high S/N studies of star formation and ISM diagnostics
- Goal: exploit all-sky (sub-mm) sensitivity of *Planck*

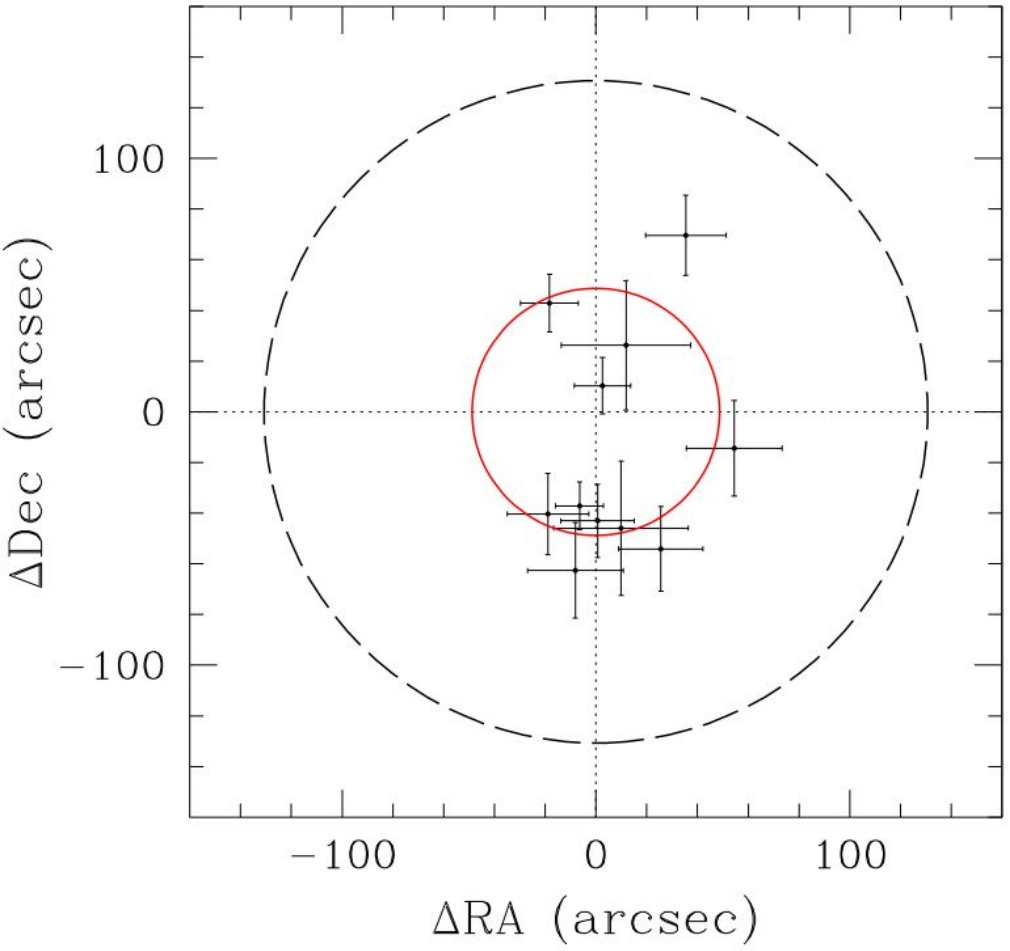
Z = 3.3 Lensed Planck Source (H-ATLAS field)



- Image obtained from Keck K (red), J (green), and ACAM optical (blue) images.

- **H-ATLAS; 570 deg^2 (Eales et al. 2010)**
- **SPT; 2500 deg^2 mm-survey (Carlstrom et al. 2011)**

Selection method: Near position search = 150”



Planck-Herschel Matches:
~370 Herschel counterparts to 56 Planck sources total

Planck-Herschel Match Criteria:

- $S_{350micron} \geq 100$ mJy
- Exclude known sources
- Remove low-z sources using SPIRE color

11 total candidates

LMT OBSERVATIONS w. AzTEC 1.1mm

8 targets observed/detected in Early Science Campaign 2

$S_{1.1mm}$ = 8-147 mJy

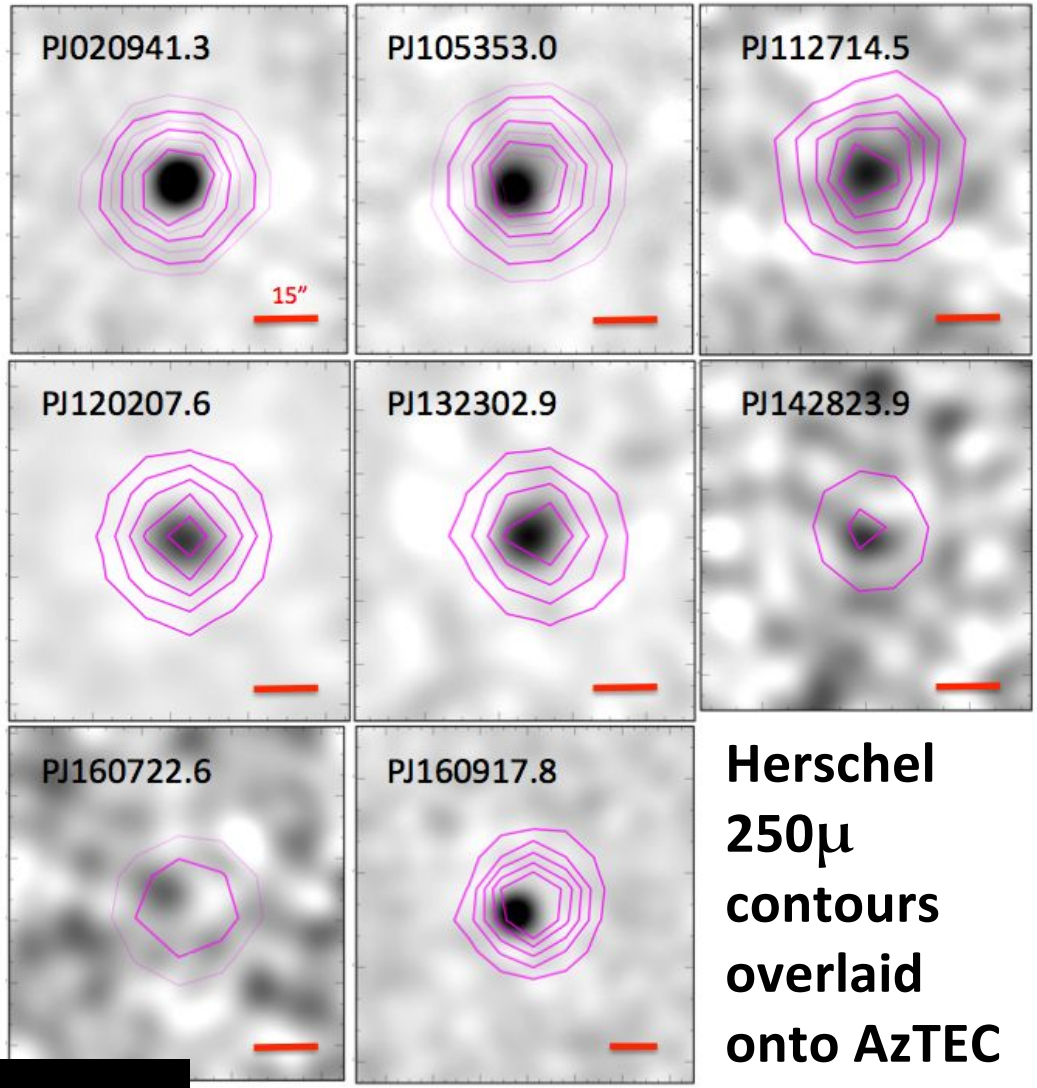
Avg. Int. Time < 0.5 hr

FWHM ~ 8”

$\mu M_d = (0.3 - 2.2) \times 10^{10}\ M\odot$

$\mu M_{ISM} = (0.7\text{-}11) \times 10^{12}\ M\odot$

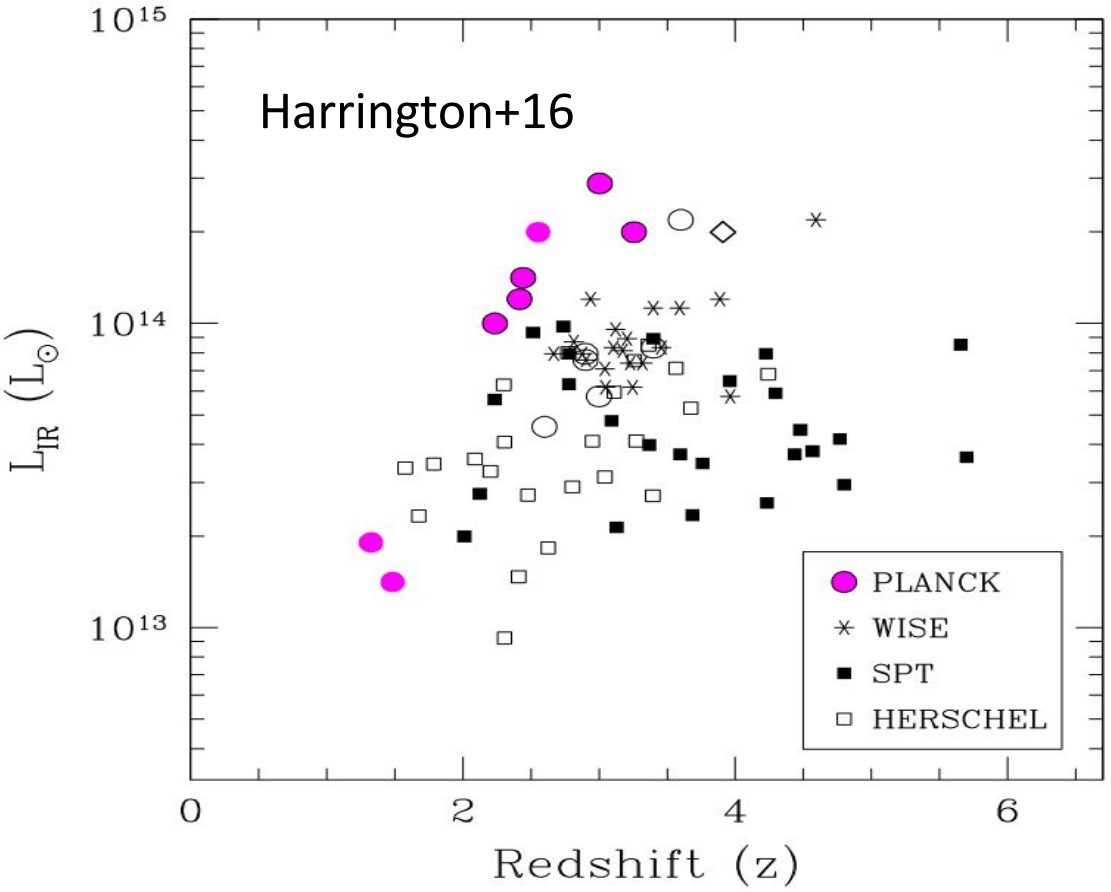
ISM mass calculations (assuming Td = 35 K): Scoville+16



Harrington+16

Herschel 250μ contours overlaid onto AzTEC images

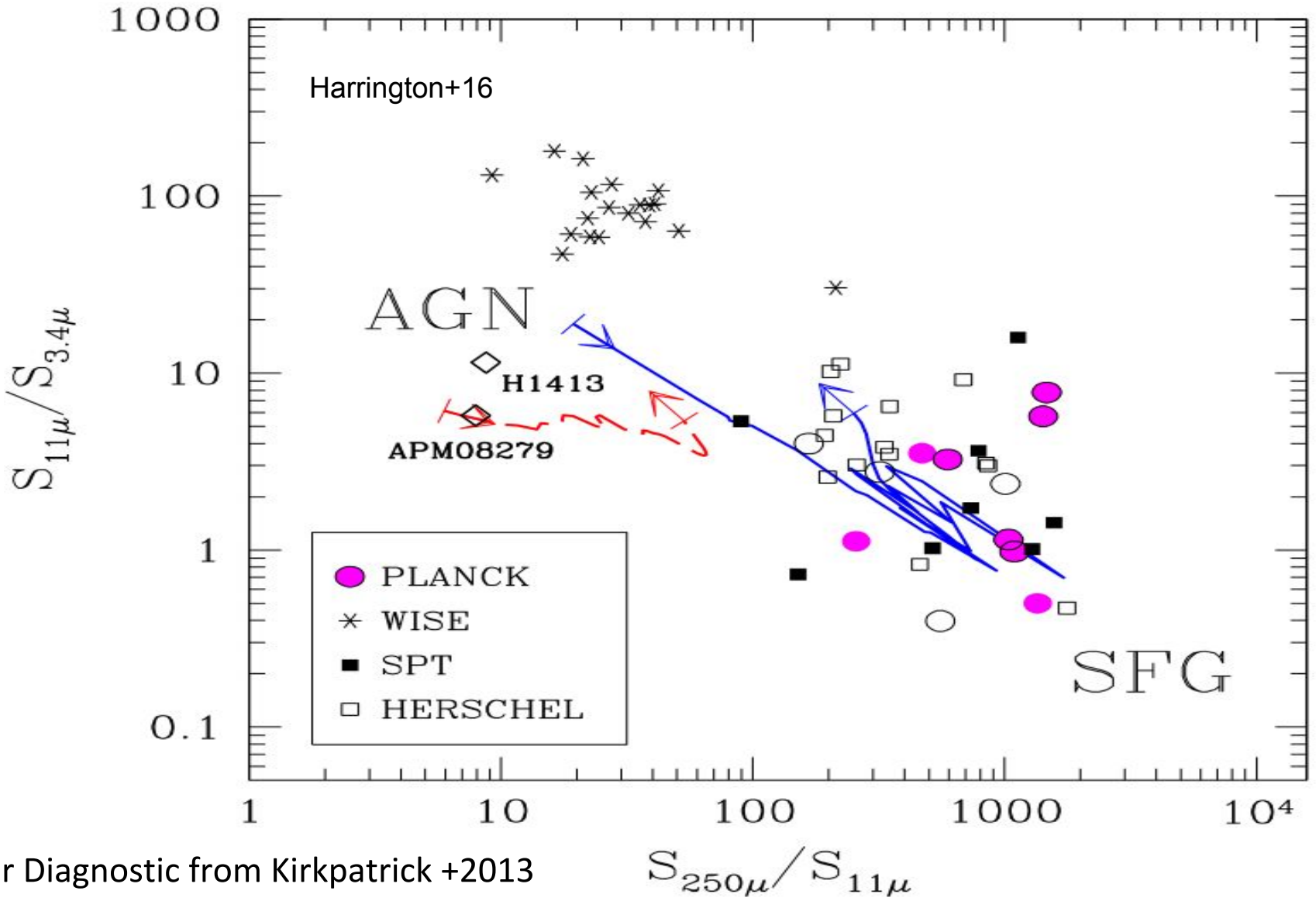
Comparing L_{IR} of *Planck- Herschel* sources



$L_{IR} = 1.3 \times 10^{13}\ L_\odot$
$S_{300\mu} = 100$ mJy
@ z = 2
(Efstathiou et al. 2000; Casey et al. 2012)

SPT (Vieira+13; Weiß+13); Herschel (Bussmann+13; Wardlow+13); WISE (Tsai+15) ; Canameras+15

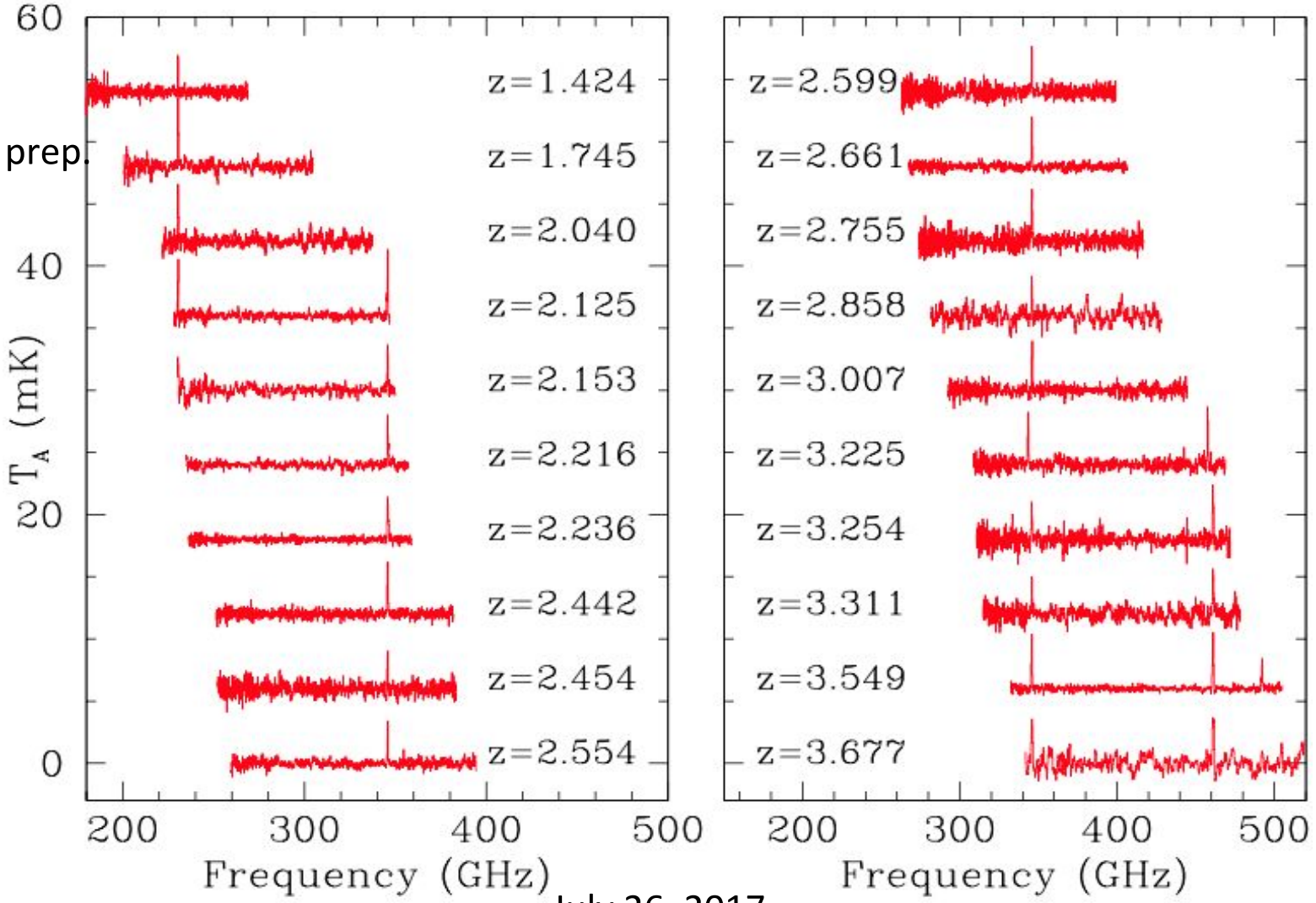
AGN vs. SF



Color Diagnostic from Kirkpatrick +2013

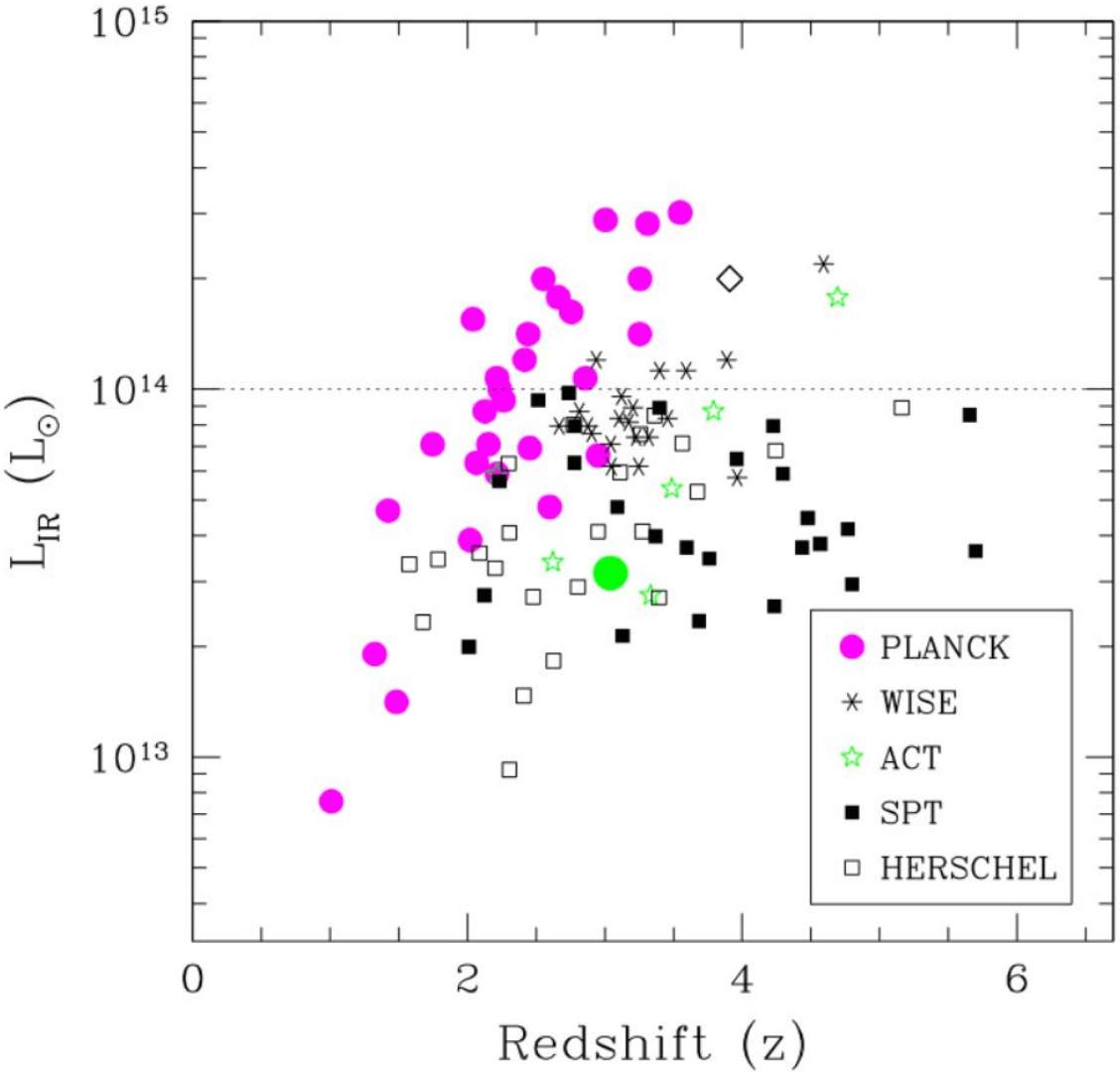
Refining Planck-LMT Selection + GBT CO (1-0) follow-up part 2…

Yun+ in prep.

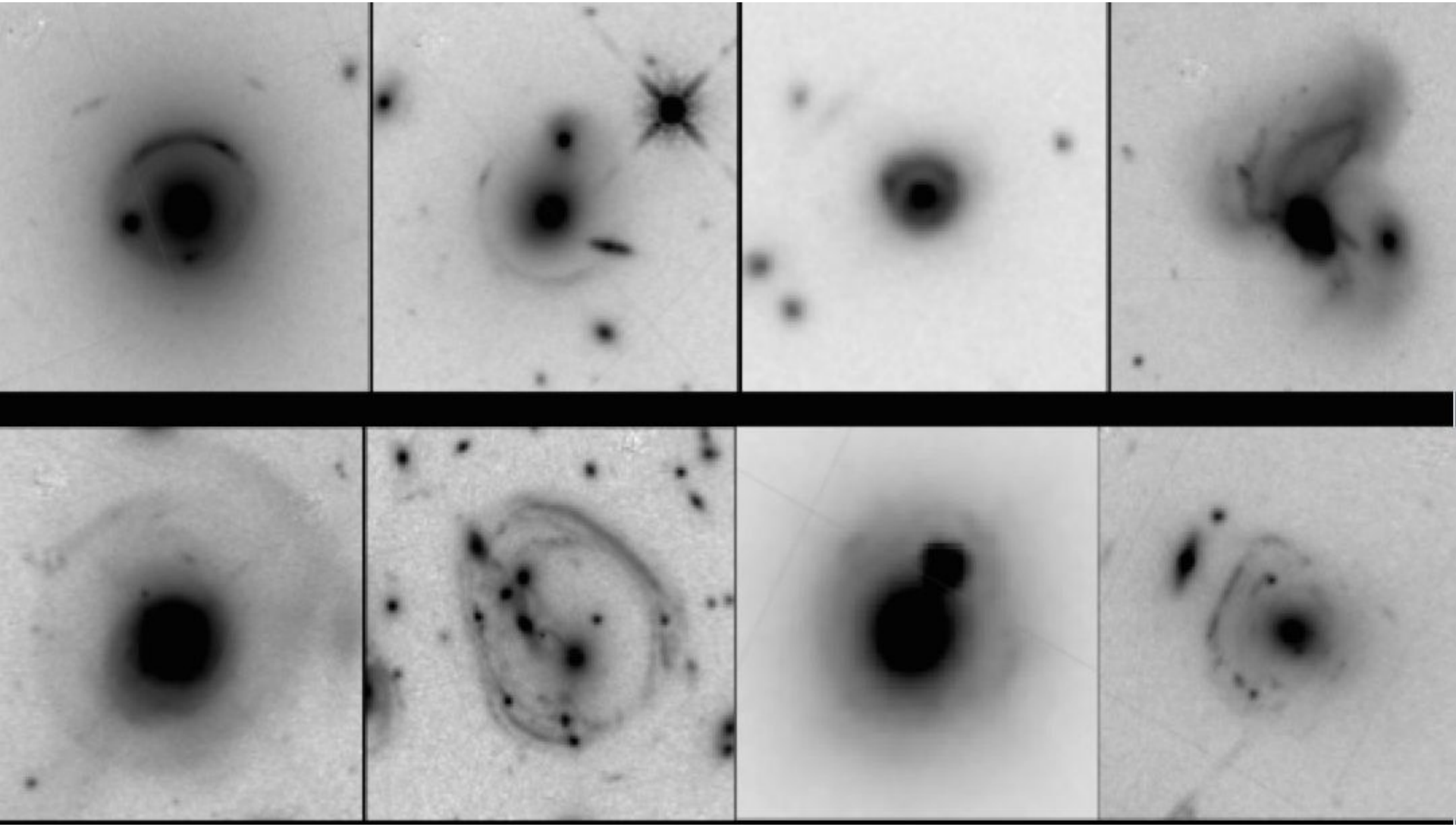


Expanded Planck-LMT Sample

Yun+ in prep.

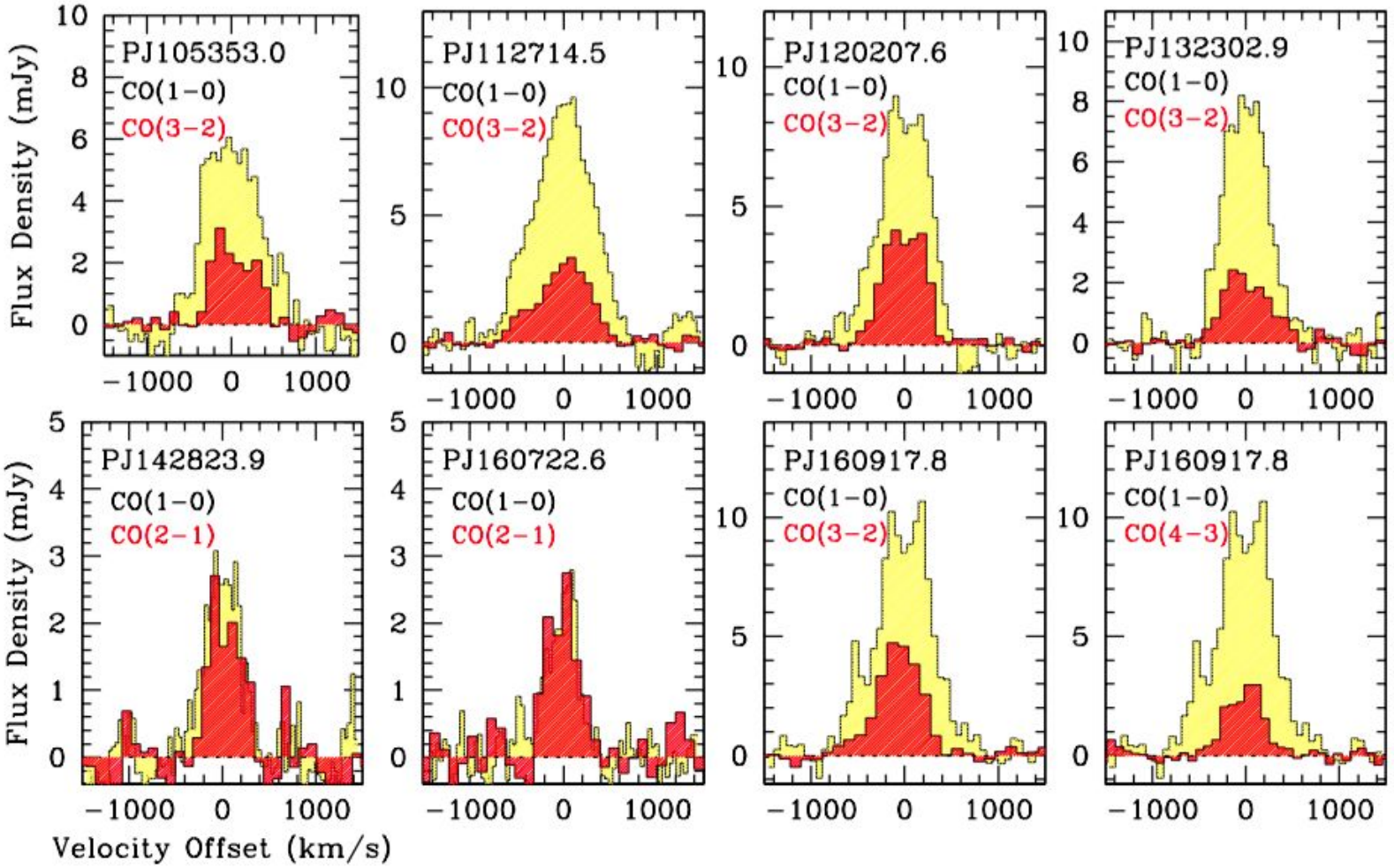


HST Cyc24 - WFC3 Imaging (F160W)



Lowenthal+ in prep.

Low-J LMT CO + CO(1-0) GBT



GBT CO (1-0) FWHM + gas mass (αCO = 0.8) :

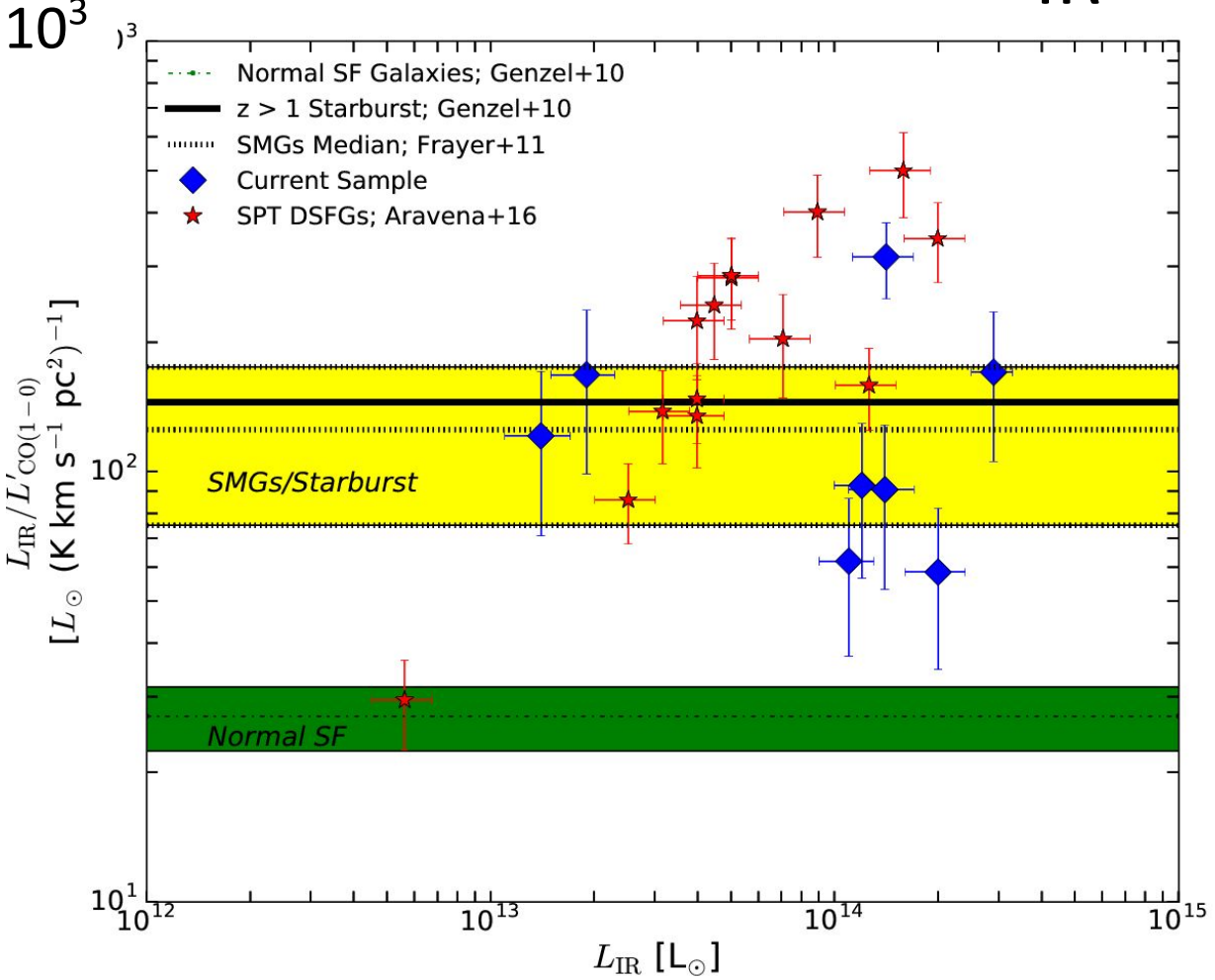
$370 < \Delta V < 740$ km/s

$\mu M_{H2} = (0.09\text{-}27.4) \times 10^{12}\ M_\odot$

Harrington+17, in prep

Proxy for SF Efficiency: L_{IR}-$L'_{CO(1-0)}$

LIR/L'CO(1-0)



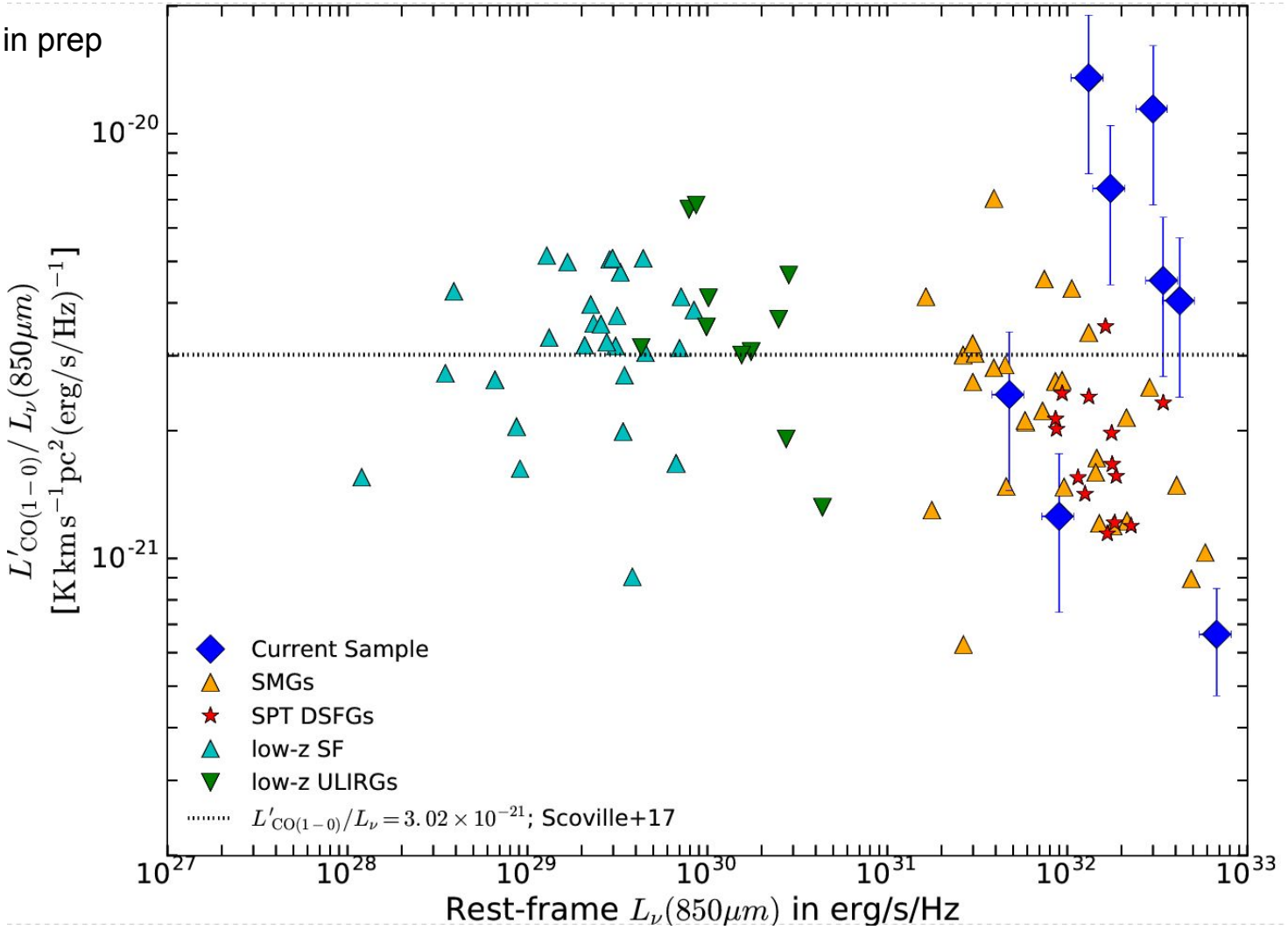
$< T_{depletion} >$ = 80 Myr

L_{IR} [$L_\odot$]

Harrington+17, in prep

Global Gas-to-Dust Comparison

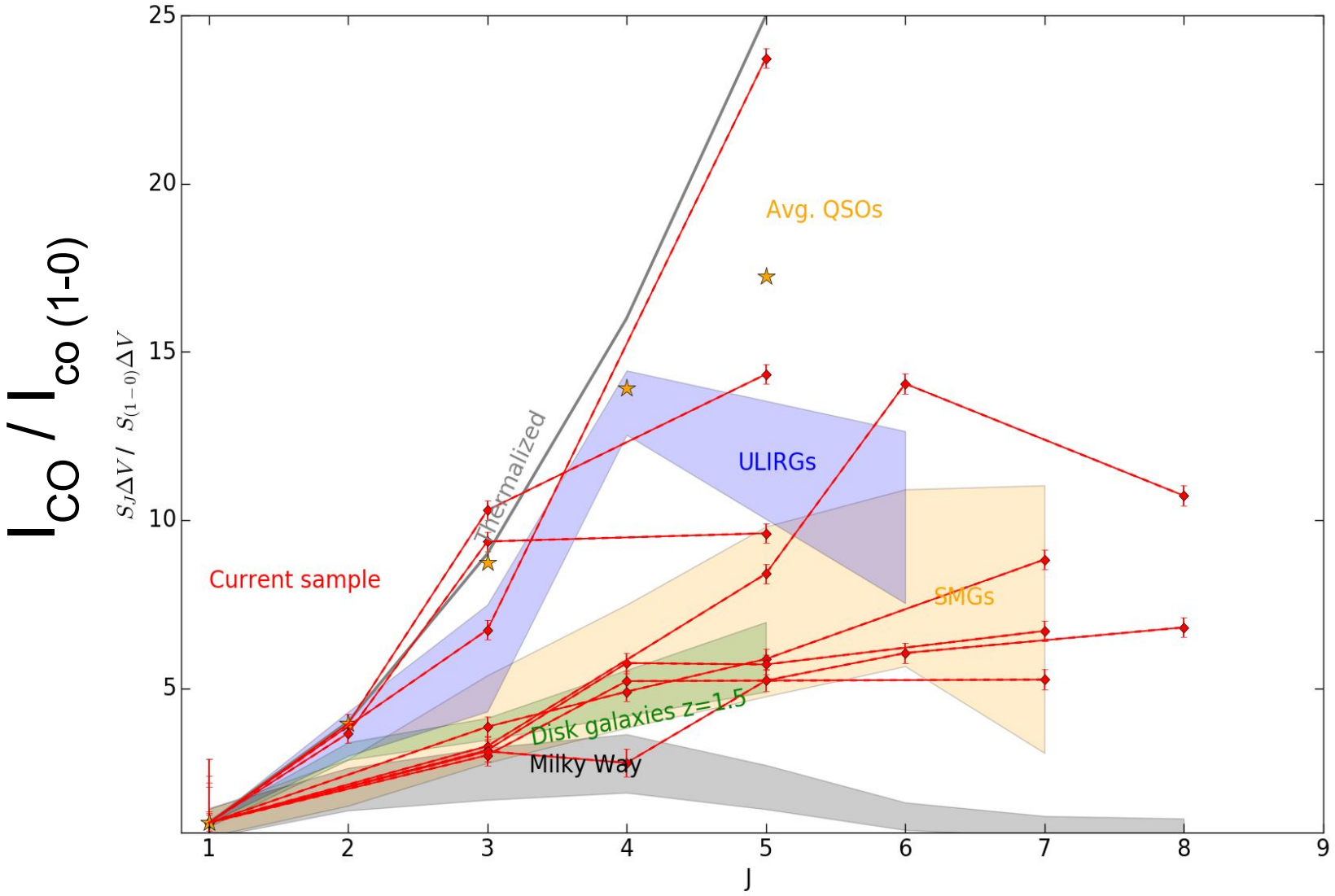
Harrington+17, in prep



L'CO(1-0) / L_{850}

rest-frame L_{850} [erg/s/Hz]

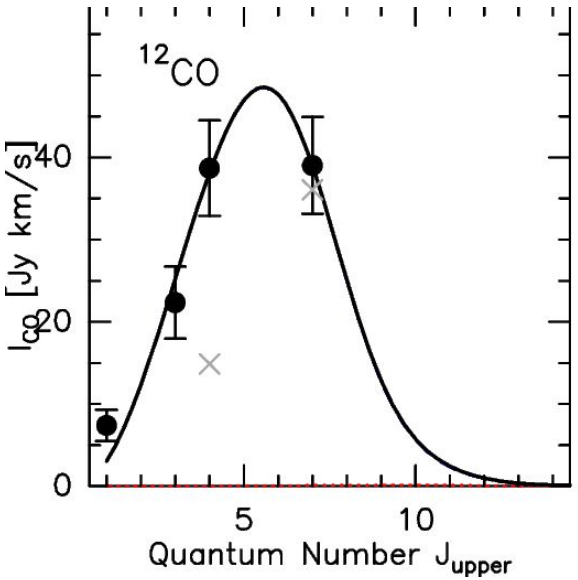
CO SLEDs (observed)

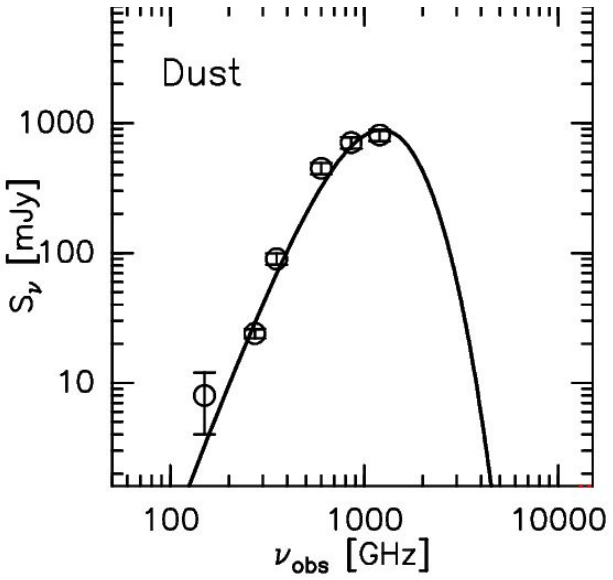


Harrington+17, in prep

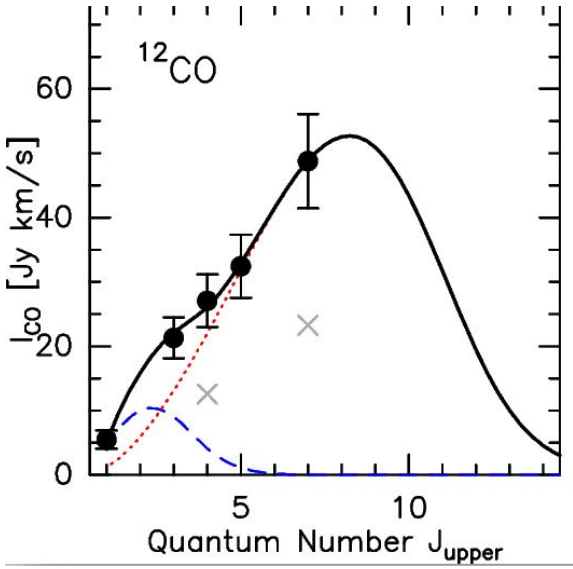
July 26, 2017

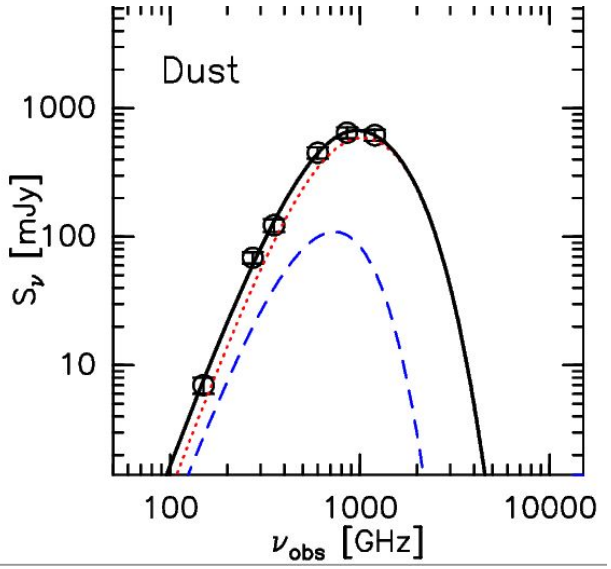
non-LTE LVG model results (prelim.)





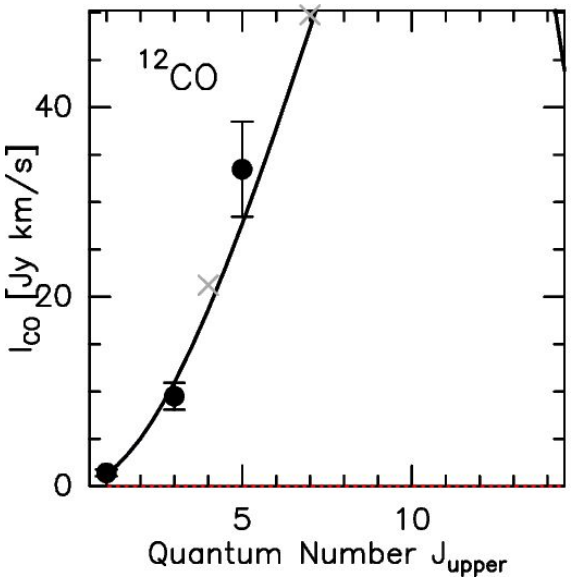
J11

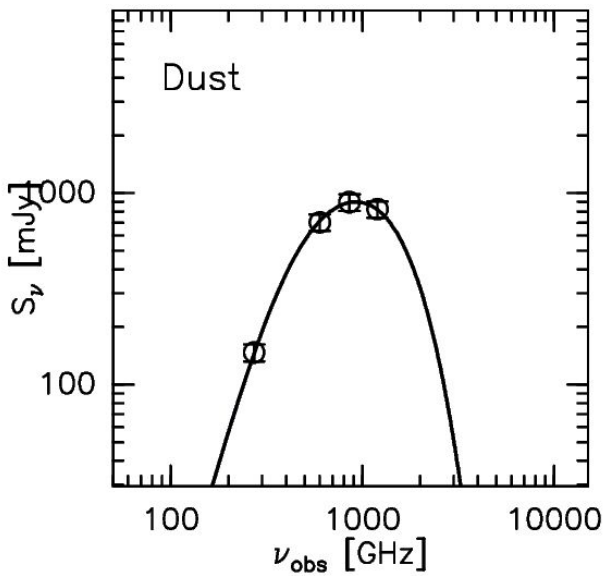




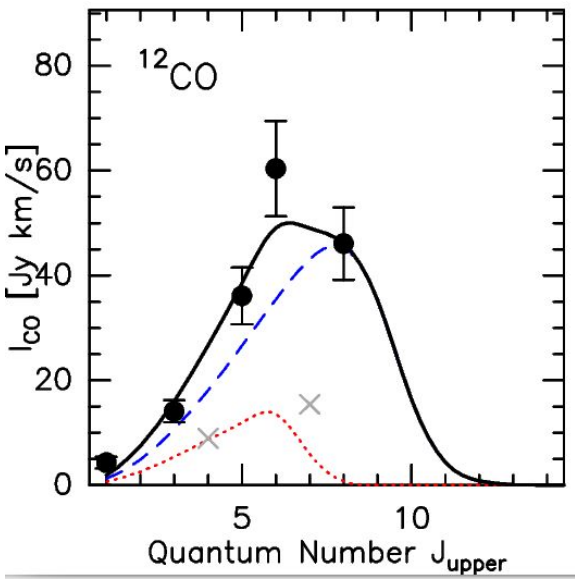
J12

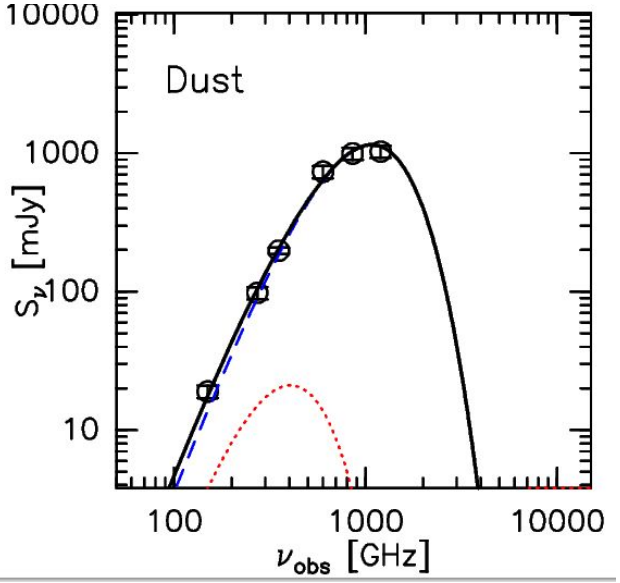
non-LTE LVG model results (prelim.)





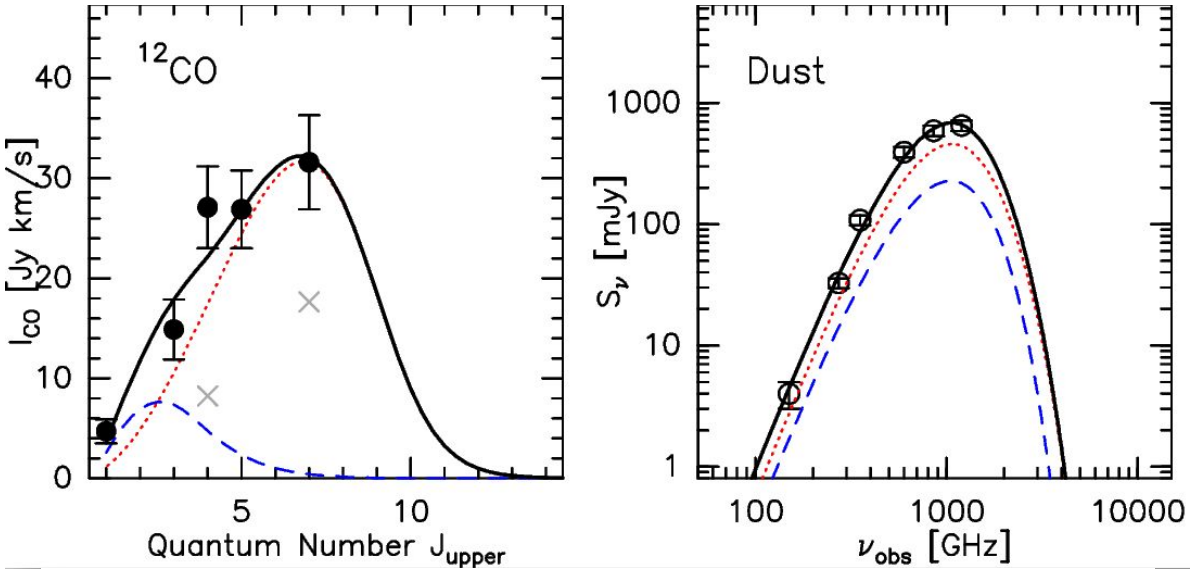
J02



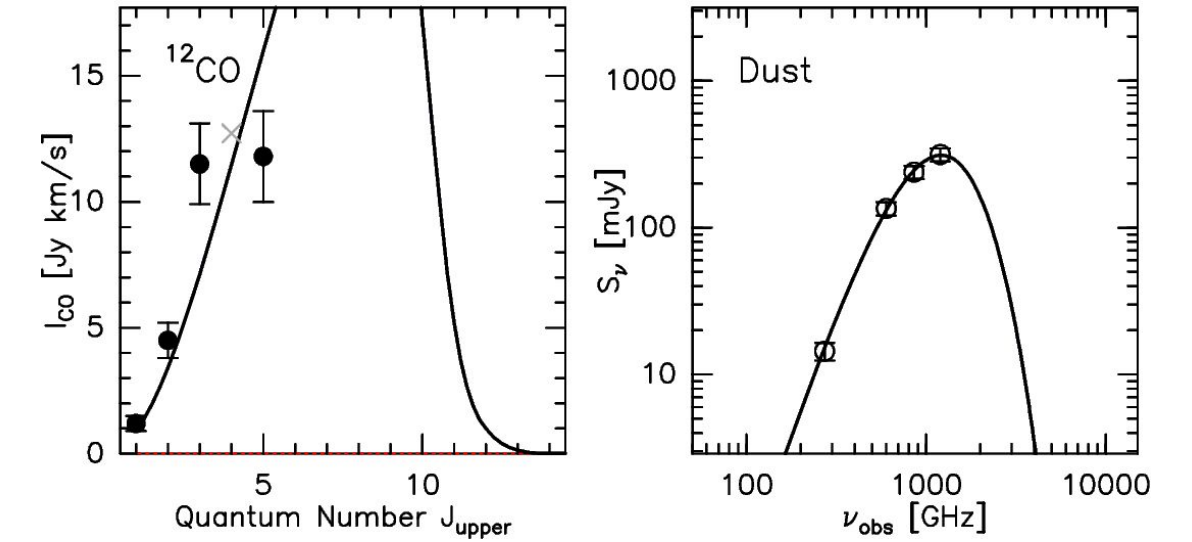


J10

non-LTE LVG model results (prelim.)

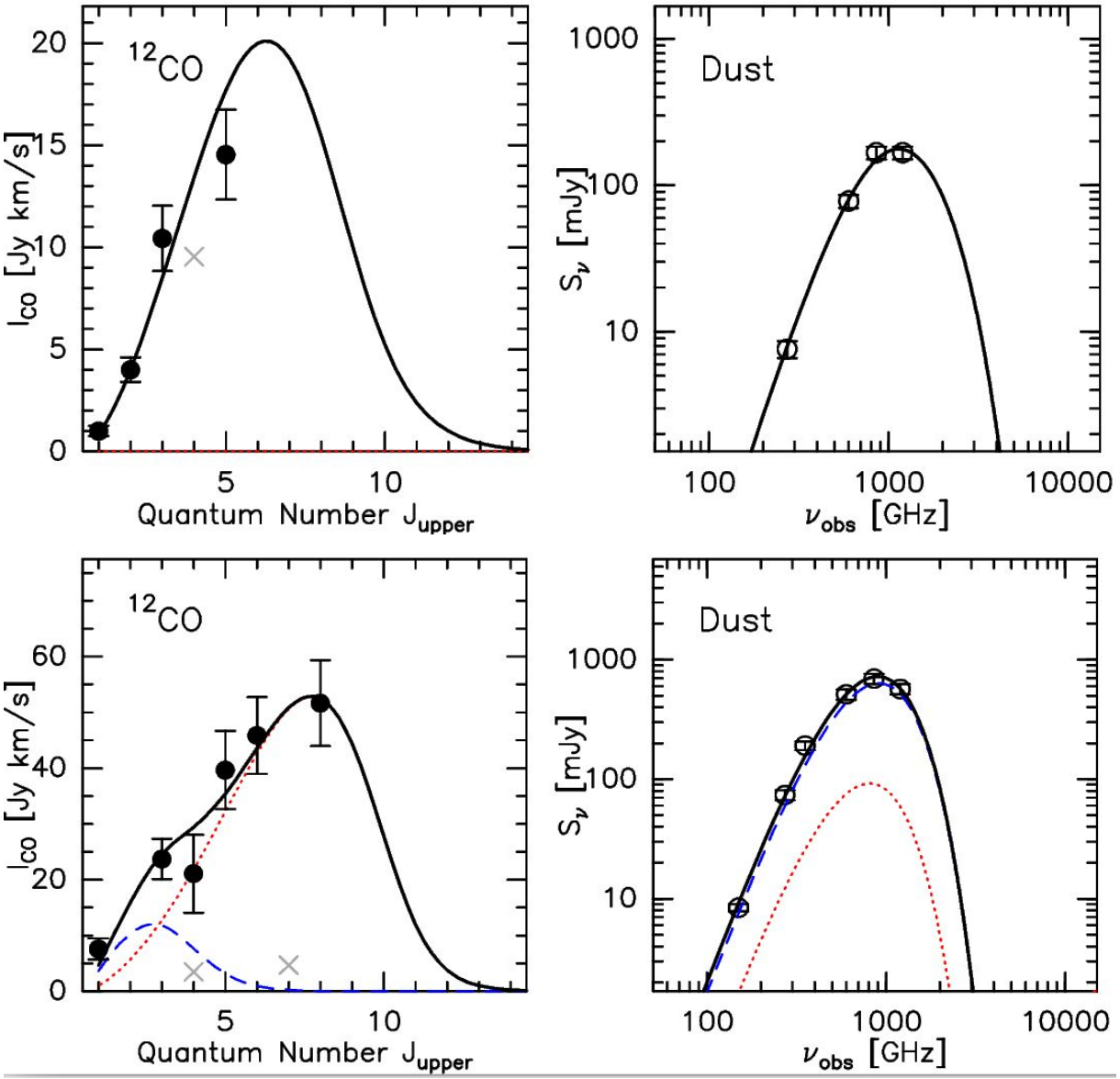


J13



J14

non-LTE LVG model results (prelim.)



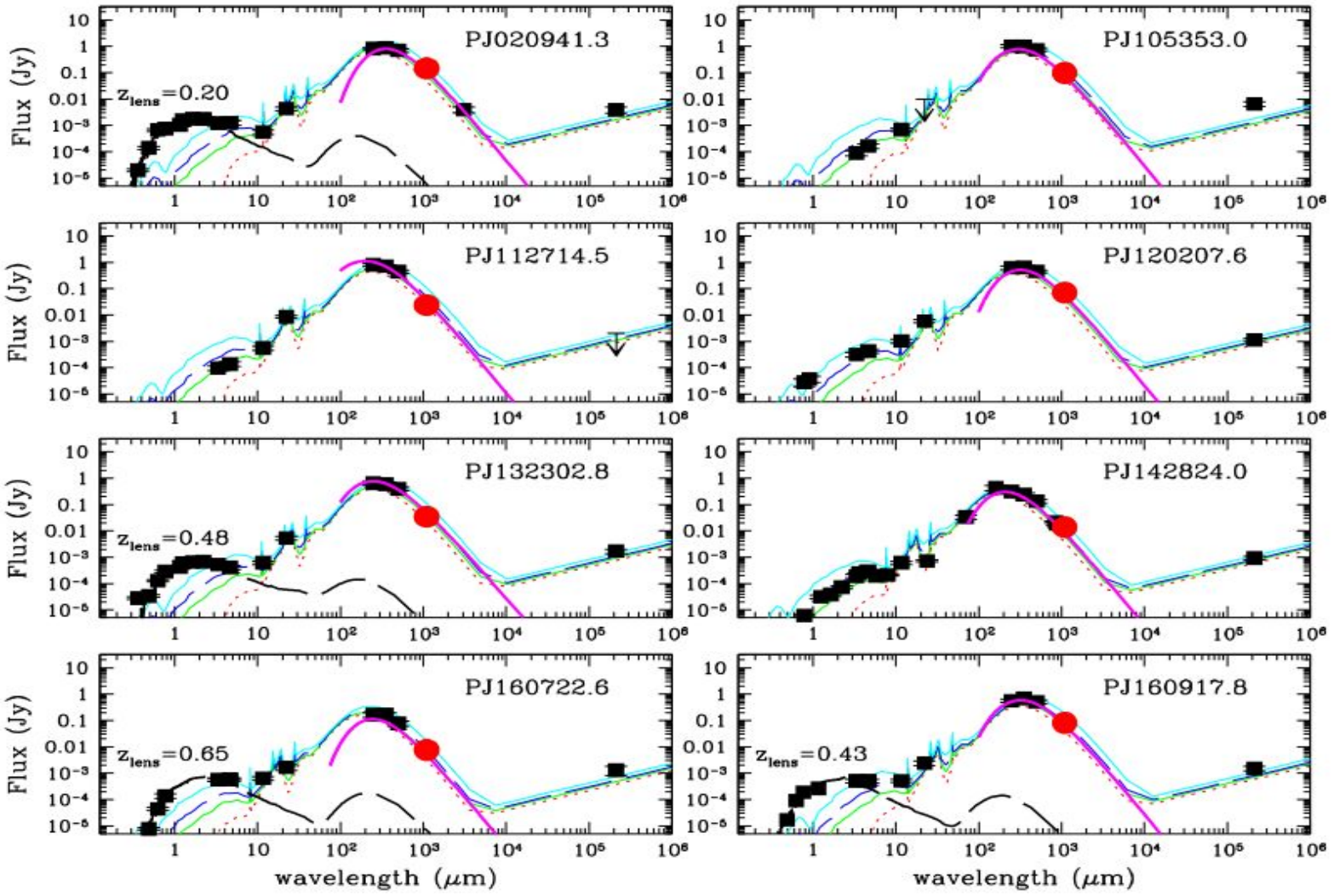
LVG model results (preliminary!)

- log(n(H2)) (cm^{-3})= 2.2-6.3
- T-kin (K) = 18-129
- T-dust (K) = 16-75
- GDMR = 68-183
- radius (kpc) = 1.1-19.7
- $M_{H2}(M\odot) = 1.8 \times 10^{11} - 1.1 \times 10^{13}$
- large error bars on radius & density without high-J lines

Summary & Follow-up

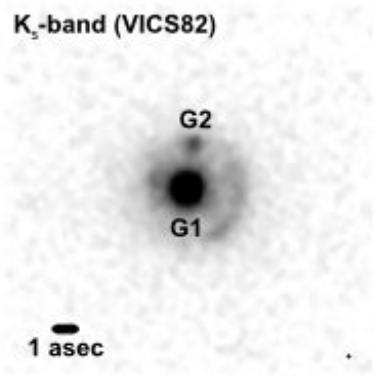
- Complementarity of Planck and Herschel
- LMT+GBT follow-up:
  - CO FWHM ~500 km/s on avg.
  - $\mu M_d = (0.3 – 2.2) \times 10^{10}\ M\odot$
  - $\mu M_{H2} = (1 - 27) \times 10^{11}\ M\odot$
  - $\mu L_{IR} = (0.1 - 3.5) \times 10^{14}\ L\odot$
- Follow up work already under way
  - IRAM 30m mid-high-J CO line analyses
  - Expanded selection methods using Planck
  - Ongoing HST Cyc24 Imaging

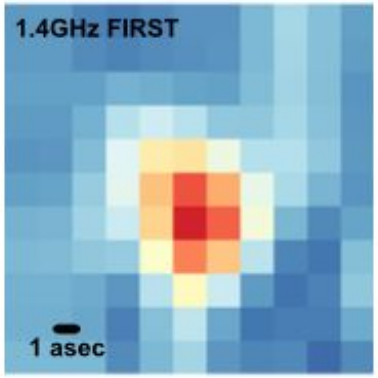
thank you!

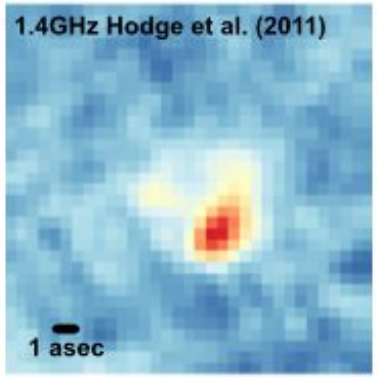


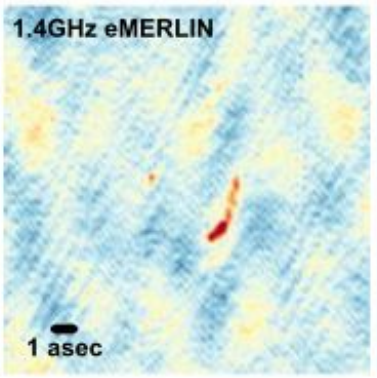
Apparent μL_{IR}: $10^{13\text{-}14.5}$ L⊙ !!!

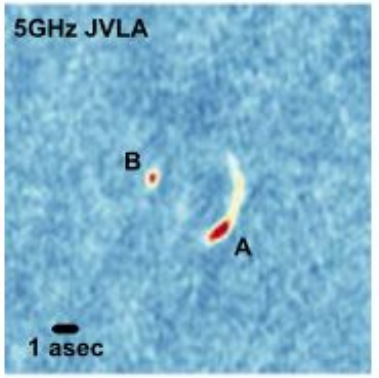
Geach et al. 15: 'THE RED RADIO RING'

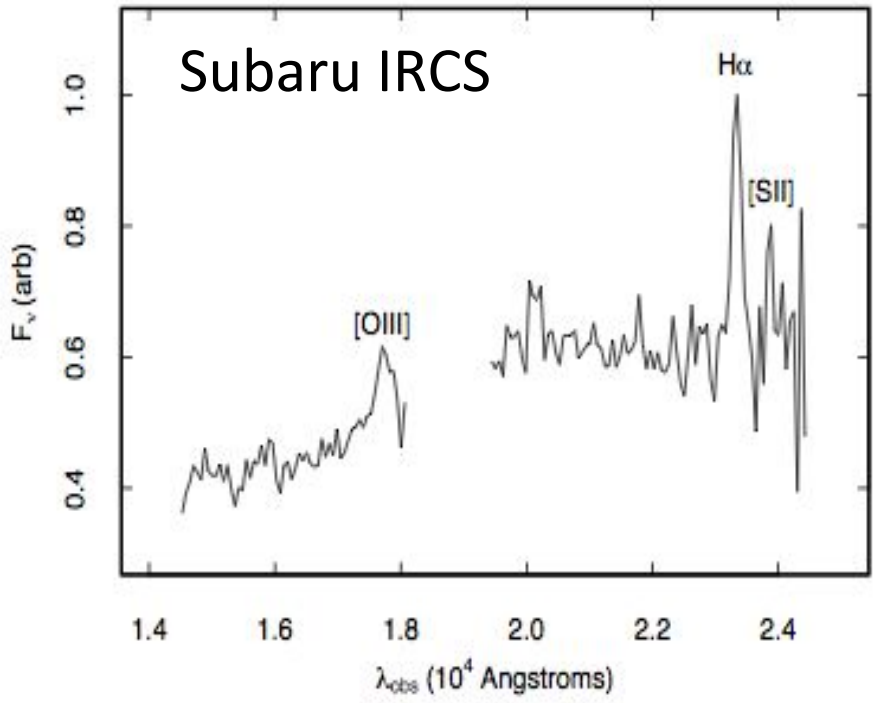


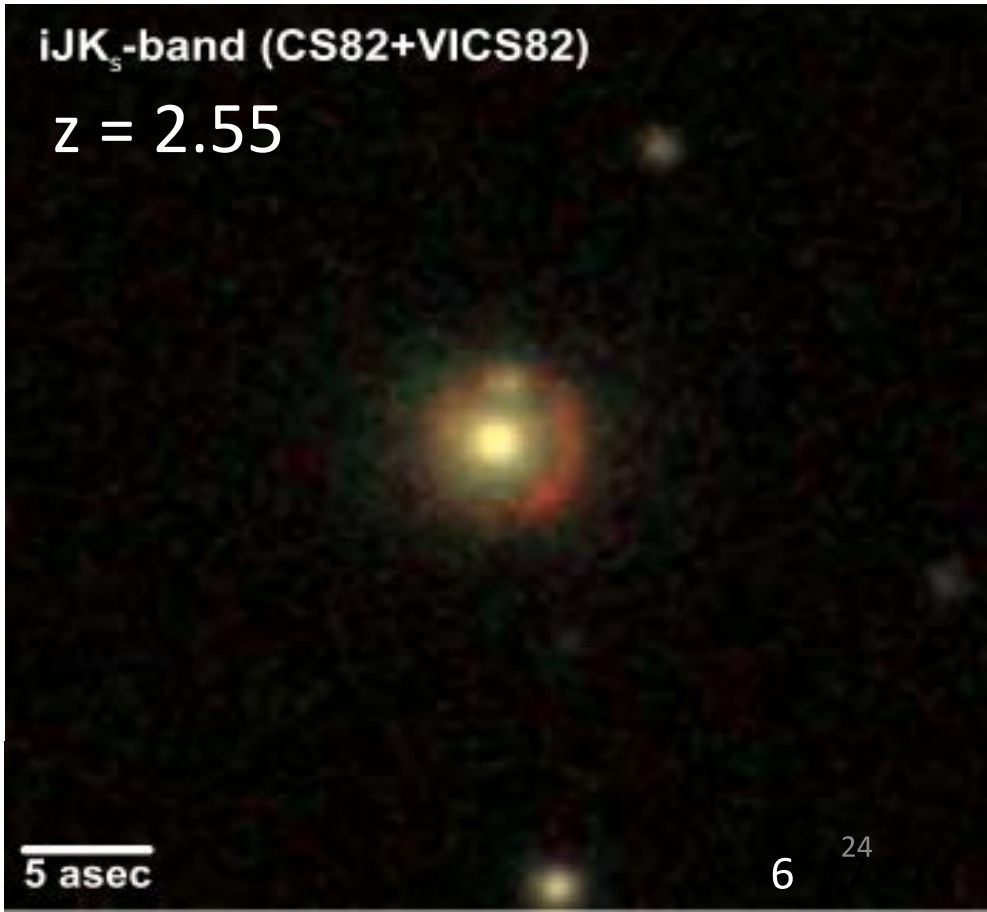




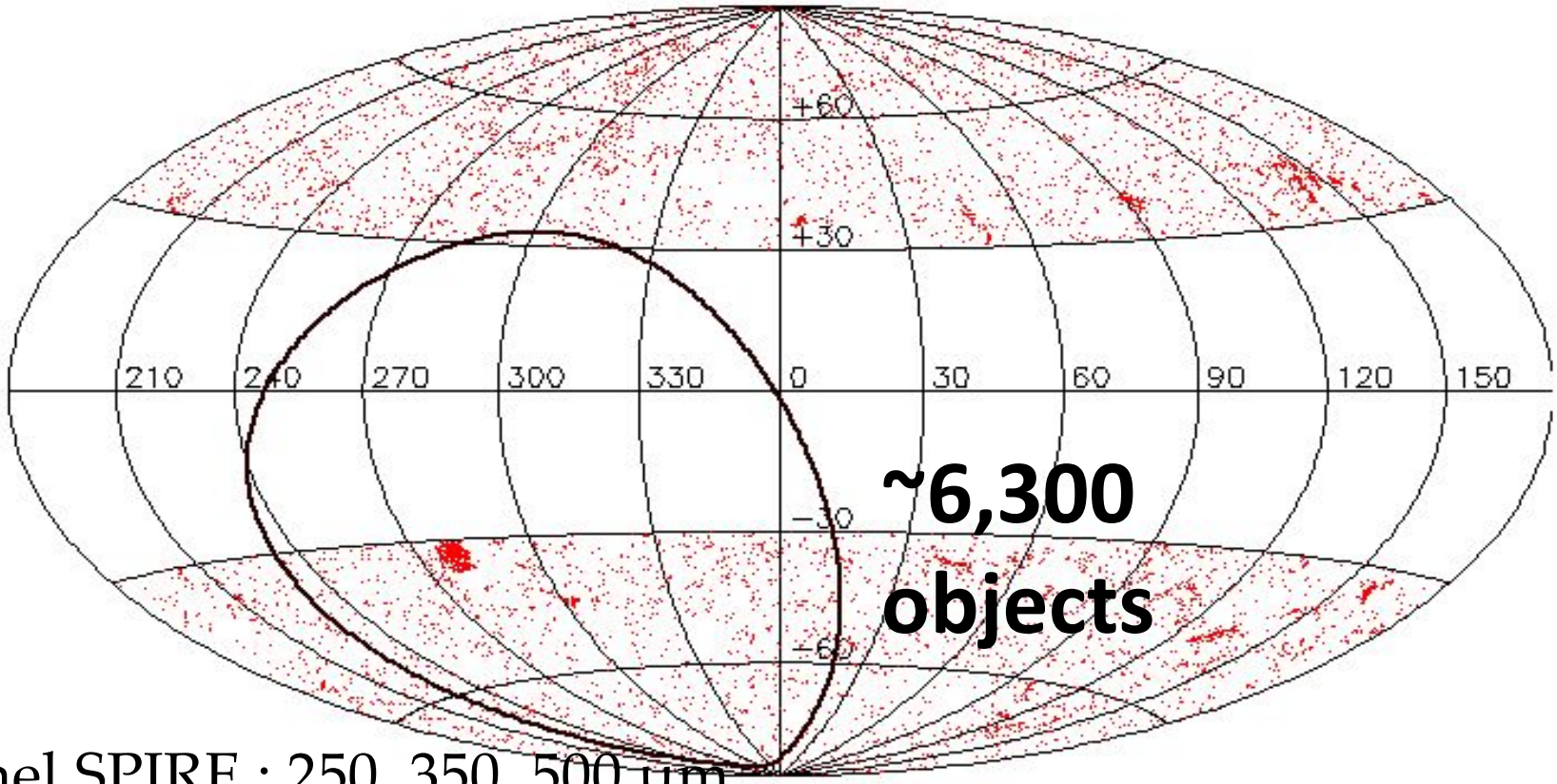








With μ = 11-13x, L_{IR} ~10^{13} $L_\odot$ &
SFR = 2500 $M_\odot$/yr



Herschel SPIRE : 250, 350, 500 μm

- ~175 sq. deg
  - HerMES + DDT-`Must-Do' (Canameras ea 15) +Hers-82 Fields ~ 167,000 point sources
  - **θ = 25 " @ 350μm**

Non-LTE line + dust radiative transfer analysis

Parameters:

Physical
- H_2 density
- kinetic temperature
- turbulence $\delta v/\delta r$; dv_{turb}
- size of the emission region ($\Omega_s\ b_{ff} = \pi\ r_0^2$)

Chemical
- [mol]/[H_2]
- Gas to dust mass ratio (GDMR)

Radiation Field:
- Background CMB + Dust ($T_{dust}\ \beta\ \lambda_{\tau=1}$)

$\tau \sim N/dv \sim [mol]/[H_2]\ n(H_2)\ \delta v/\delta r^{-1}$

$N(H2) \sim n(H_2)\ \delta v/\delta r^{-1}\ dv_{turb}$

$M(H2) \sim r_0^2\ n(H_2)\ \delta v/\delta r^{-1}\ dv_{turb}$

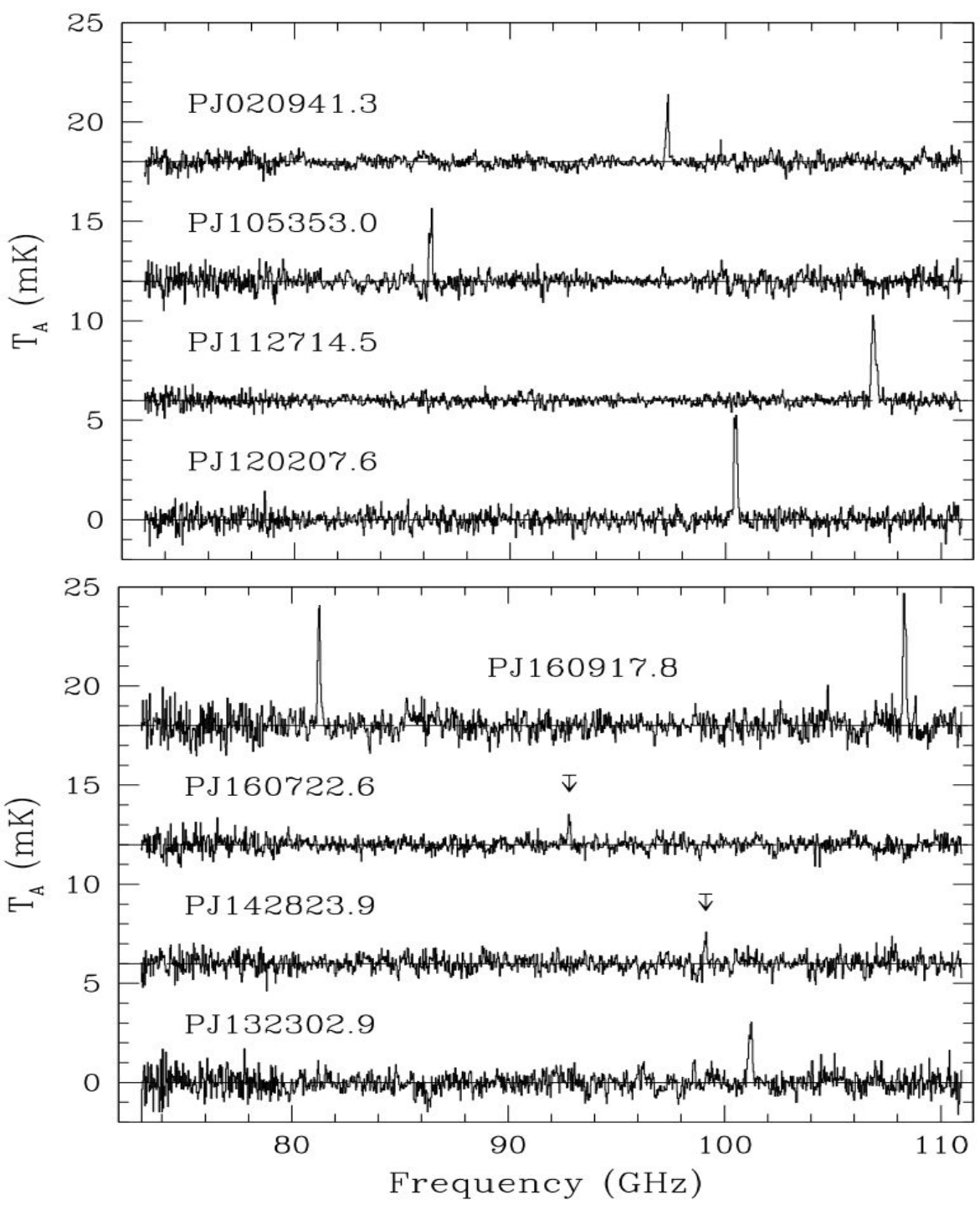
$v_{\tau=1} \sim (GDMR/N(H2))^{1/\beta}$

Virialized gas:
$\delta v/\delta r \sim sqrt(\ n(H_2)\ )$

Dust and gas are linked at several levels:
- dust is background for lines
- gas columns from lines linked to dust opacity
- Tkin >= 0.5*Tdust

Model fitting: 2 components using a MC "bee search" algorithm (typically 1e7 models per galaxy to sample PDs)

slide credit: A. Weiß



LMT Results with RSR:

- CO 4-3, 3-2, 2-1 lines detected
- $1.38 < z < 3.26$