CHALMERS
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Observations of molecules in high redshift galaxies

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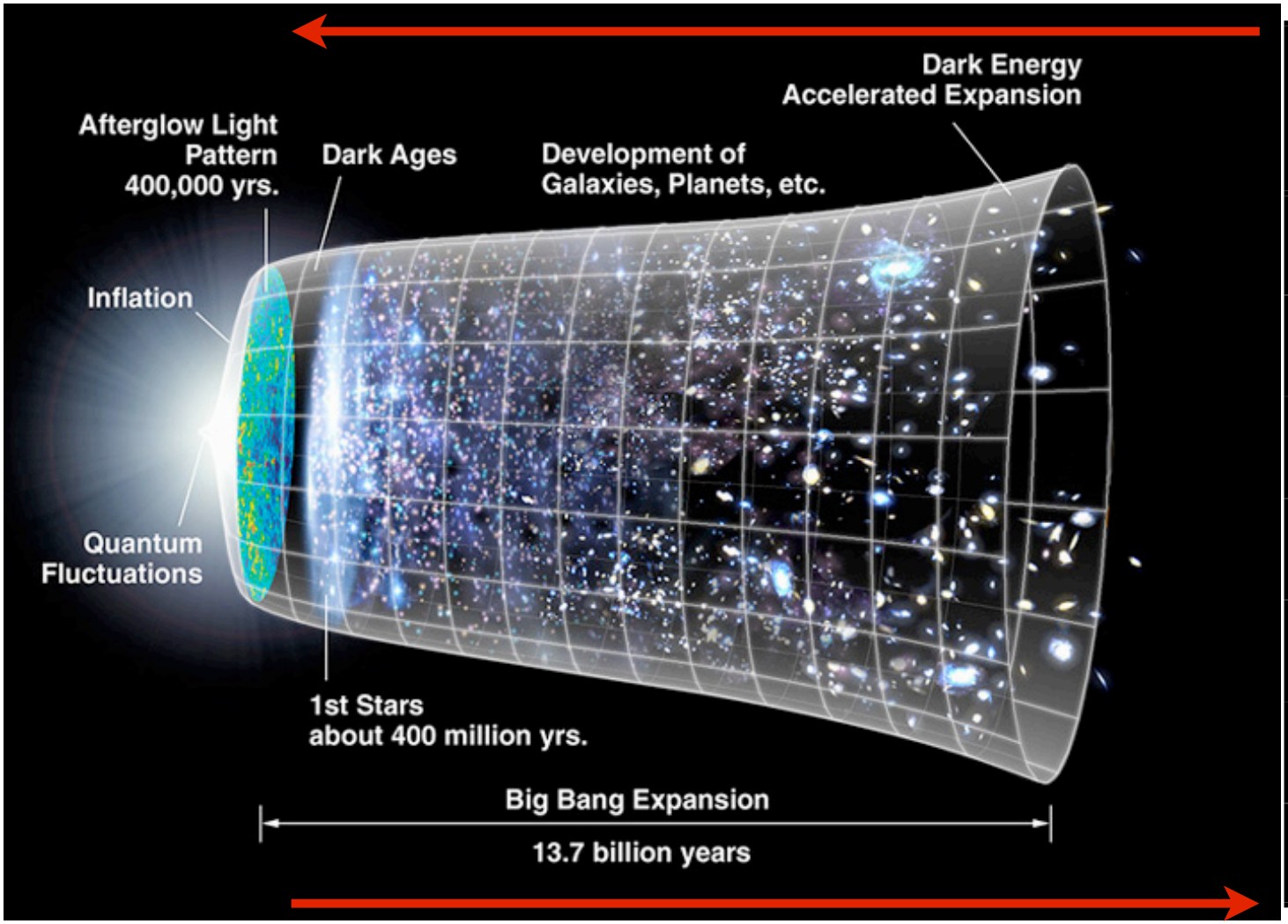
Outline: Small molecules; Large molecules
Excitation ; In the ALMA perspective

IN A GALAXY FAR AWAY ...

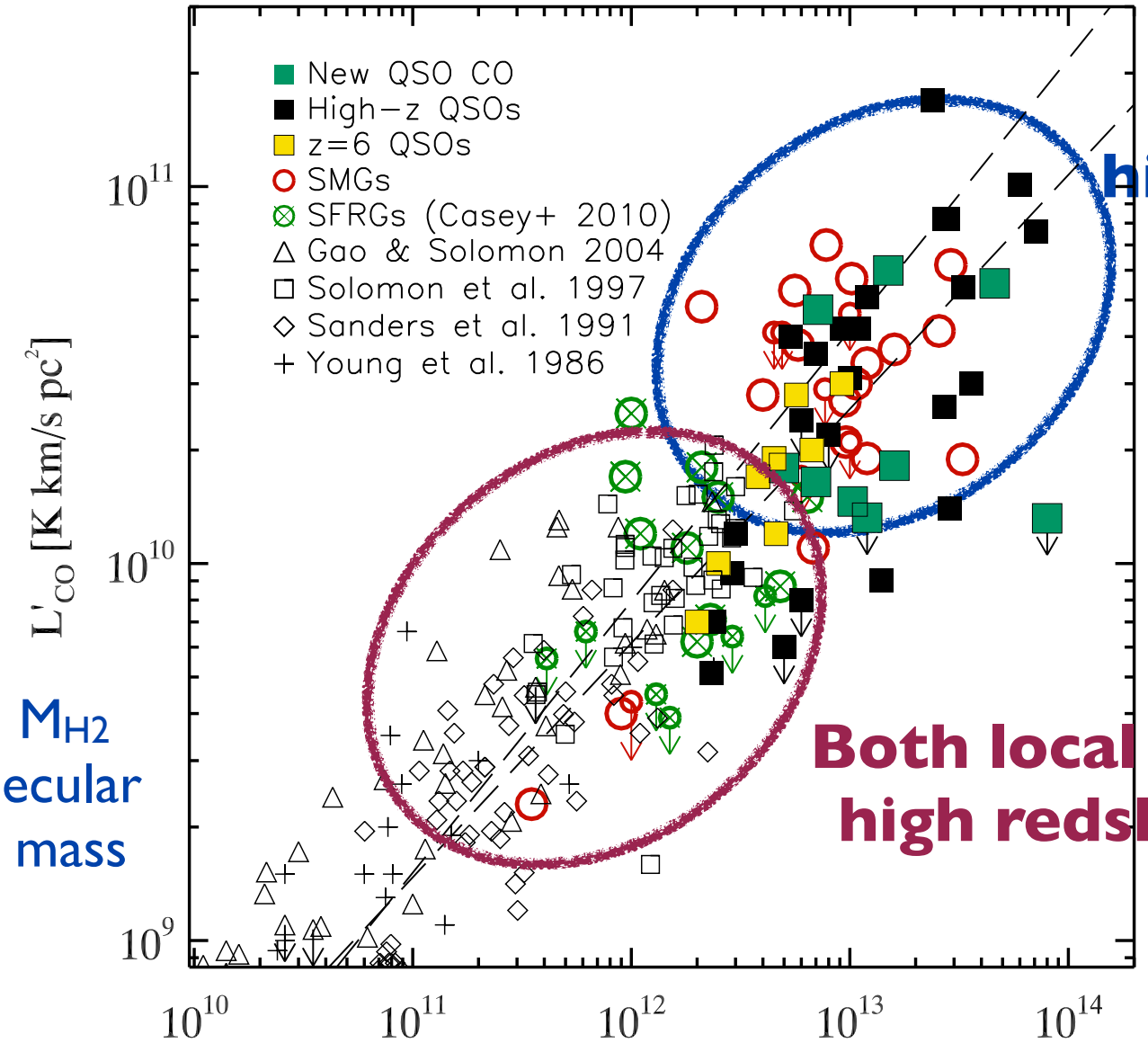
Looking back in time!



Redshift z	Universe age / 10^9 yr
0	13.7
1	5.9
2	3.3
4	1.6
6	0.95
8	0.65
1000	0.0004

Evolution of galaxies: production of stars, metals, and molecules

CO AT HIGH REDSHIFT



Only high redshift

→ M_{H2} molecular gas mass

Both local and high redshift

→ star formation rate

From: a.o. Knudsen et al., 2009, 2011

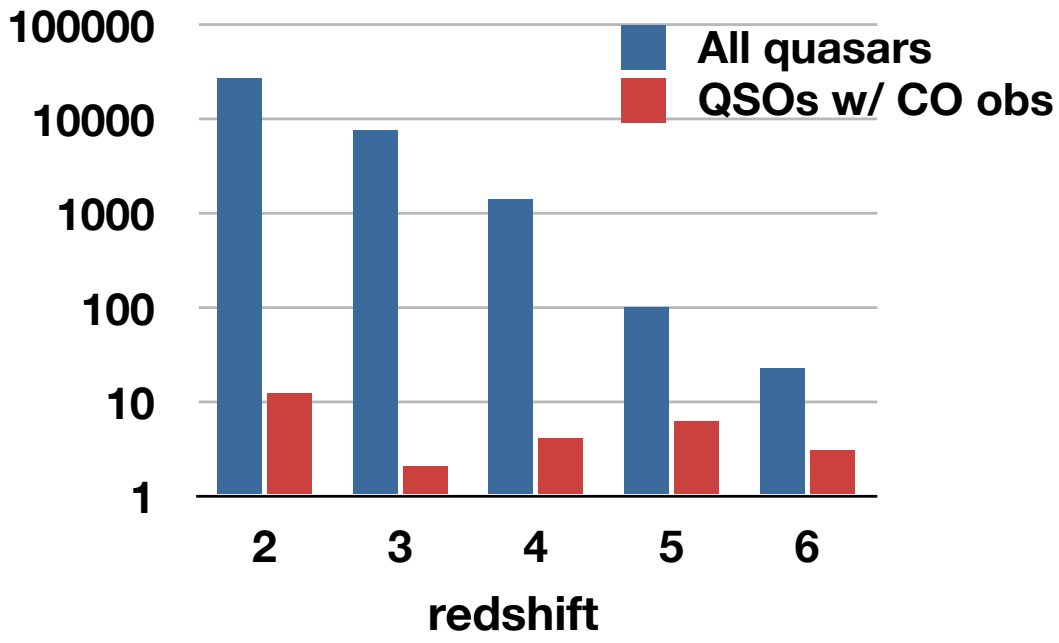
QSOs: Few molecular line observations

- For z>2:

  ~35000 quasars known

  ~30 have CO detections

- Small number due to: sensitivity, bandwidth, ...
- Typically single object studies
- ~ 1/3 QSOs are FIR bright



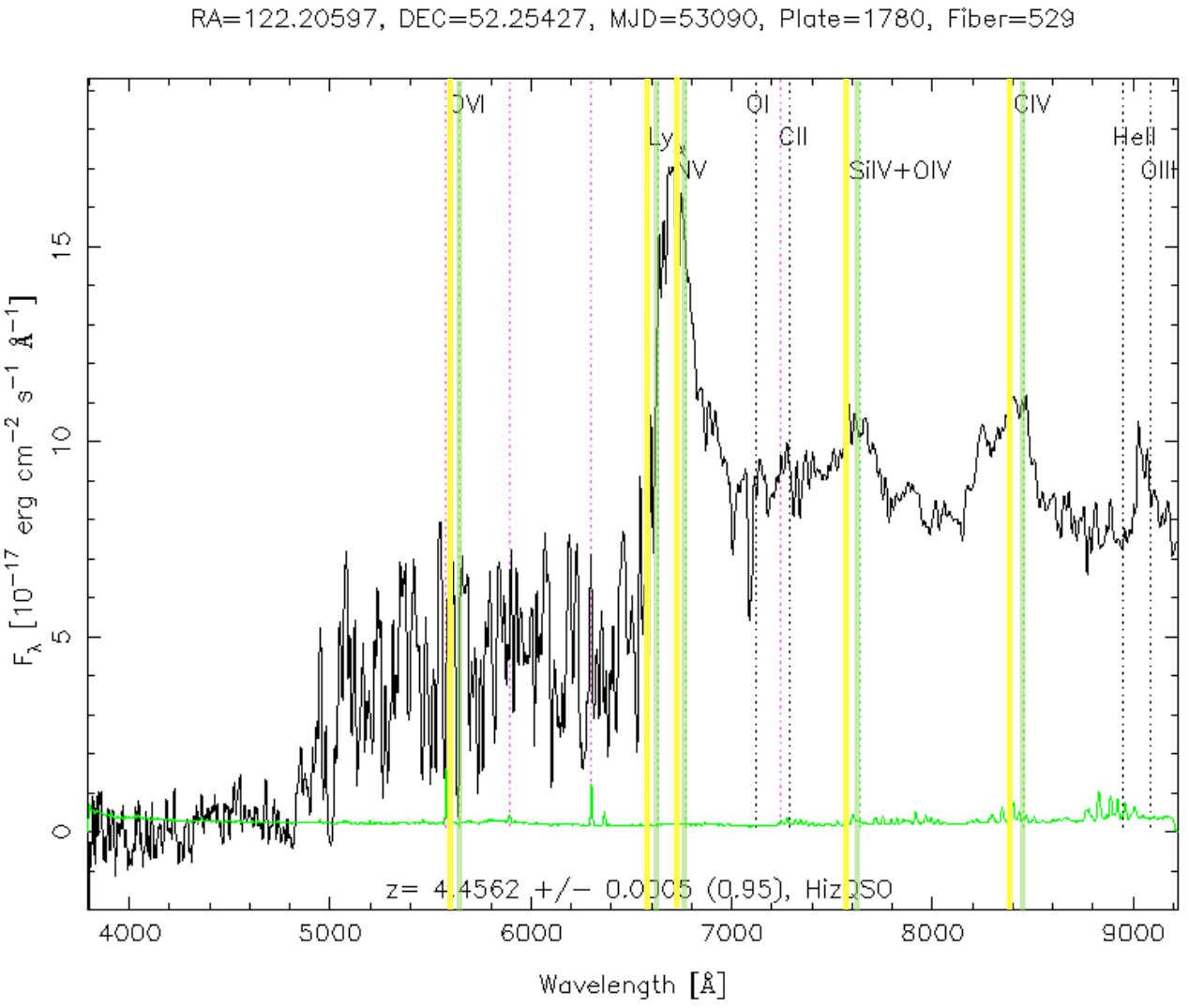
redshift z	0	2	4	6
Universe age	13.7	3.3	1.6	0.95

CO IN z = 4 - 5 QUASARS

REDSHIFT

Example: J0808
z_{sdss}=4.4562,
z_{CO}=4.4173
V_{diff} = -2145 km/s

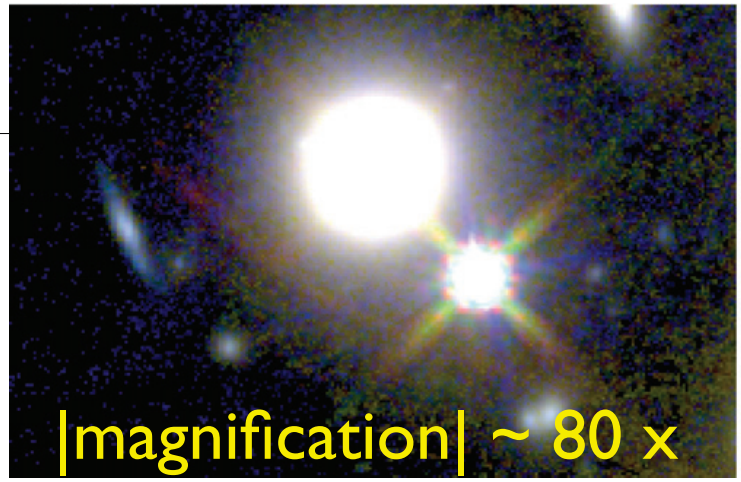
SDSS Plate 1780, MJD 53090, Rerun 26, Fiber 529

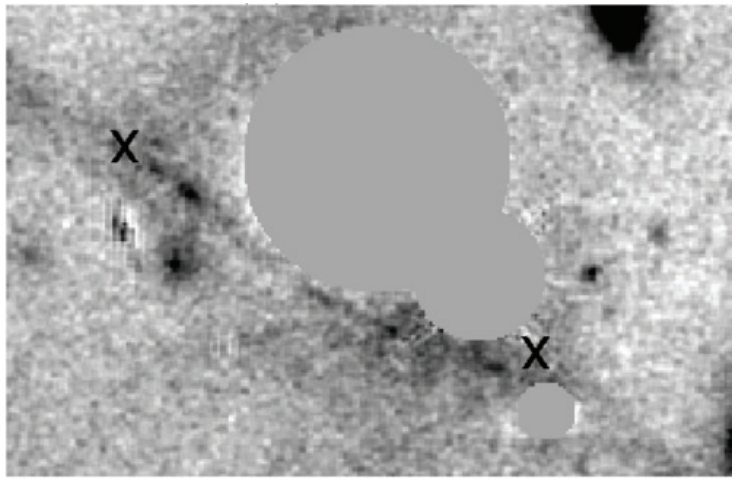


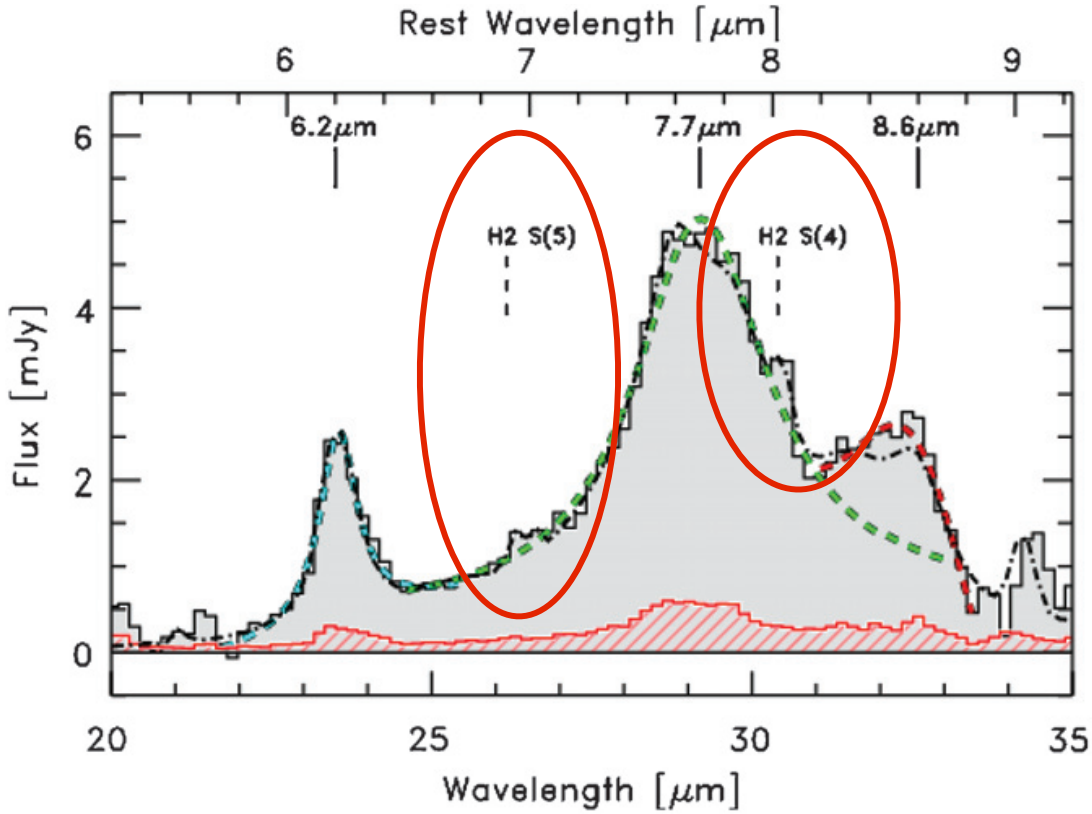
Knudsen, Bertoldi et al.

Some other cases have large differences in literature redshifts with V_{diff} up to 7000 km/s

H_2 AT z=2.8







Lensed dwarf galaxy

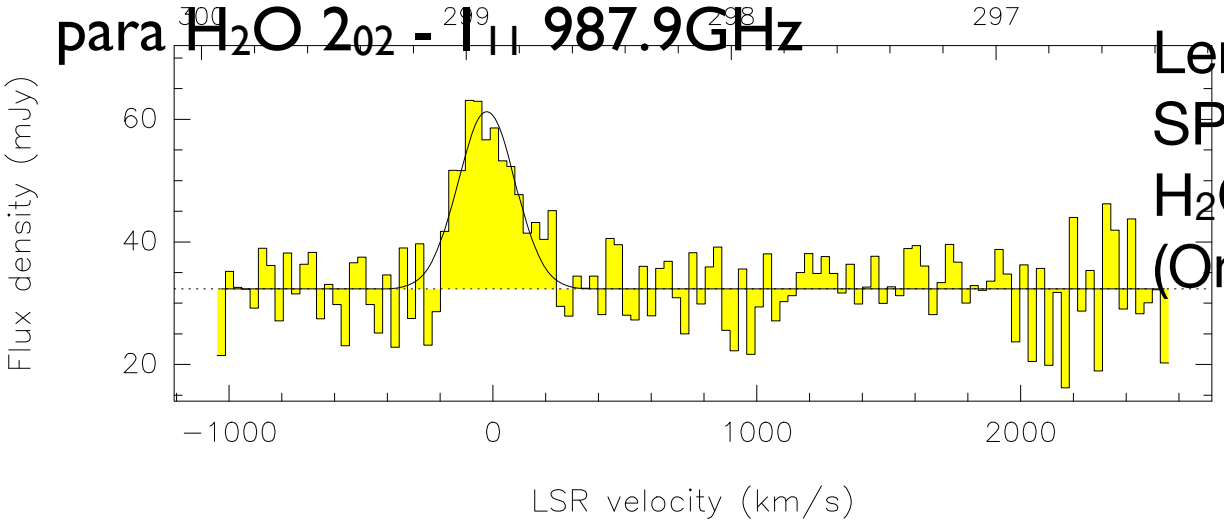
$M_* \sim 4 \times 10^9 M_{sun}$

H_2: $T_{ex} = 377$ K

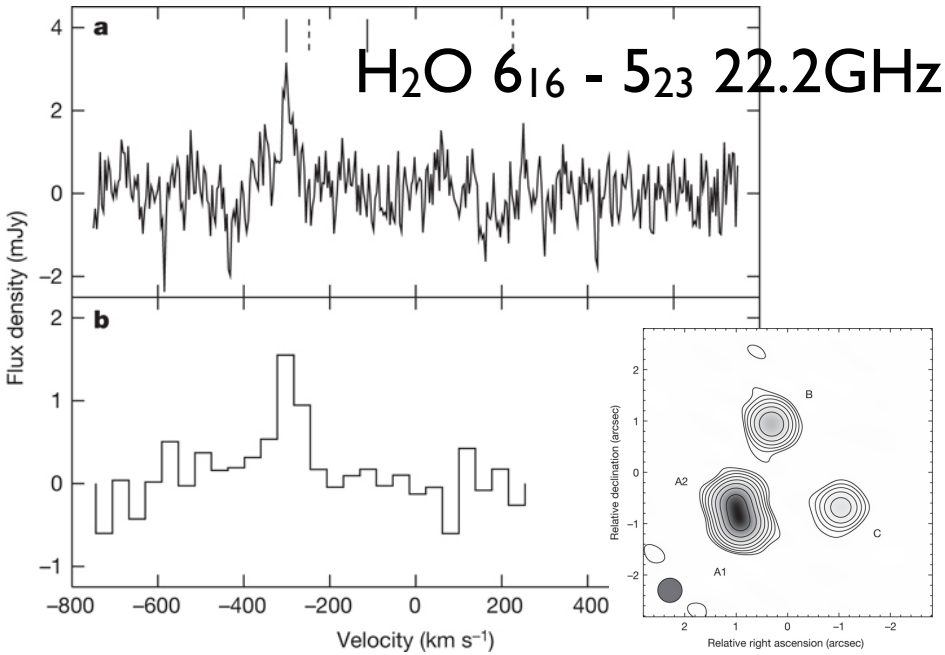
$M_{H2} = 2 \times 10^8 M_{sun}$

Gonzalez et al. 2010

H_2O AT HIGH REDSHIFT



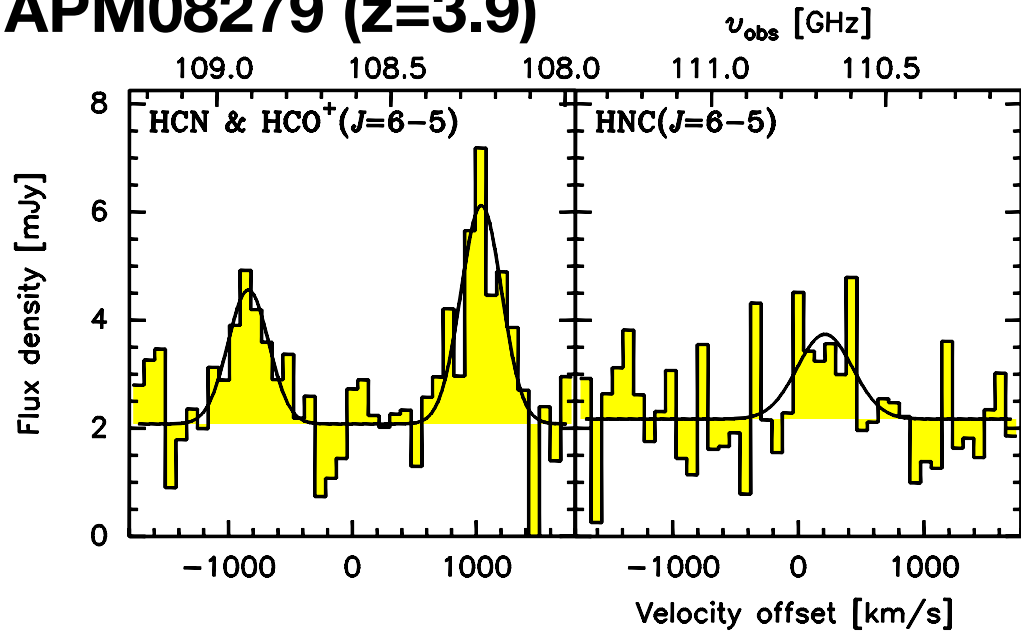
Lensed *Herschel* source:
SPD.17b, z=2.305
H_2O / CO similar to Mrk231
(Omont et al. 2011)

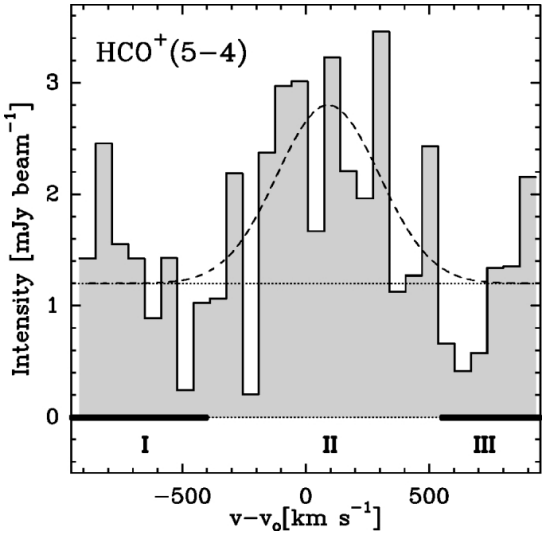


Lensed quasar:
MG 0414+0534, z=2.64
Possibly associated with circum-nuclear accretion disk or jet
(Impellizzeri et al. 2008)

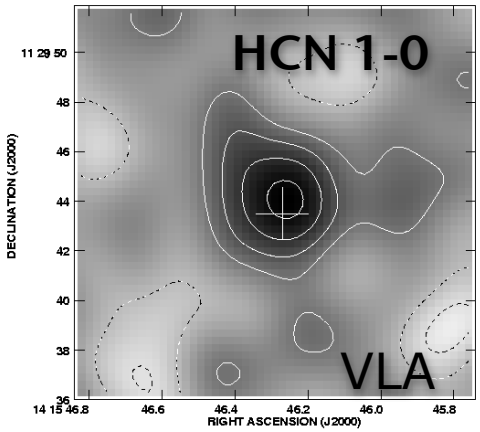
HIGH DENSITY TRACERS

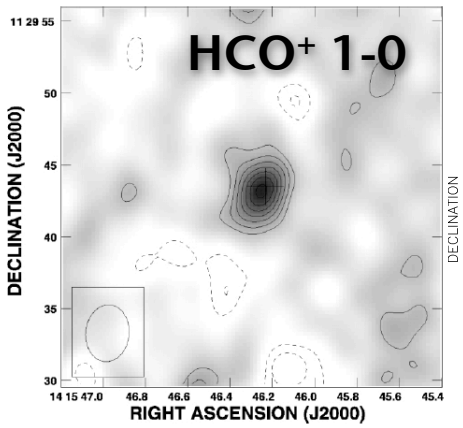
APM08279 (z=3.9)

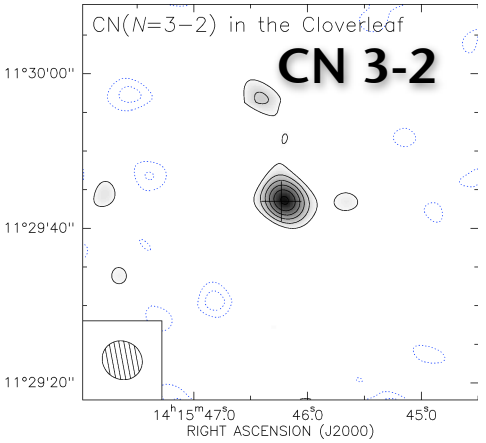


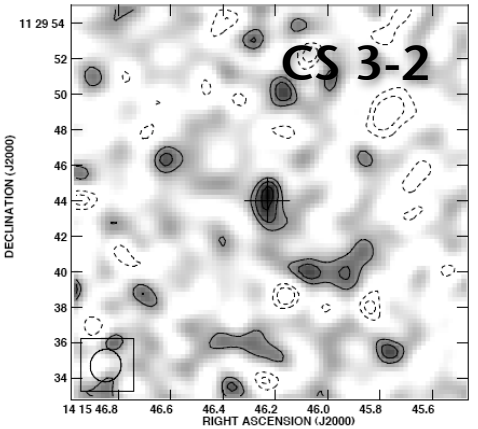


Cloverleaf (z=2.6)



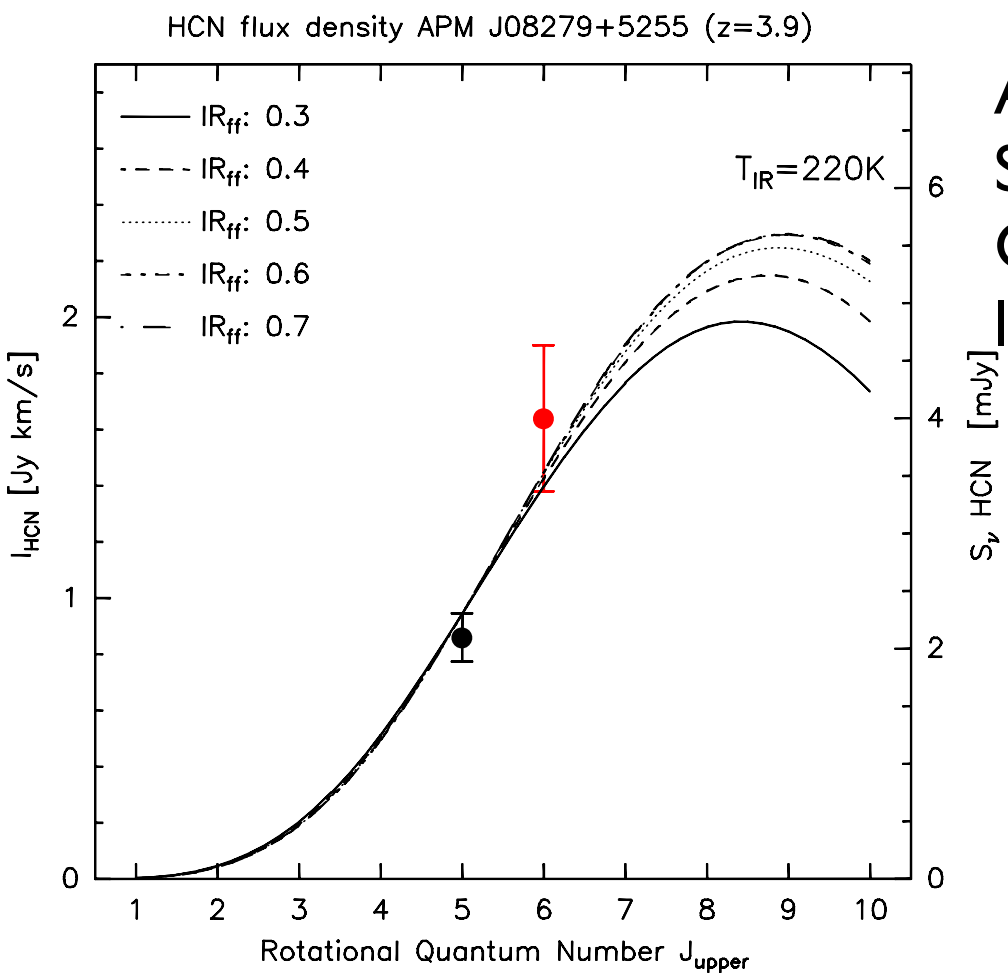






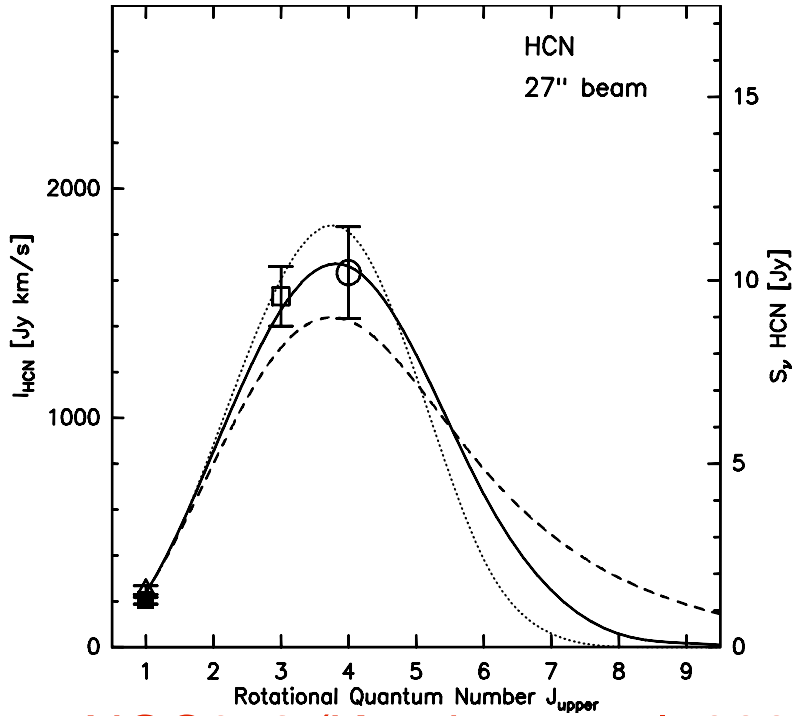
e.g. Solomon et al. 2003; Garcia-Burillo et al. 2006; Riechers et al. 2007, 2009, 2011

HIGH DENSITY TRACERS (HCN)



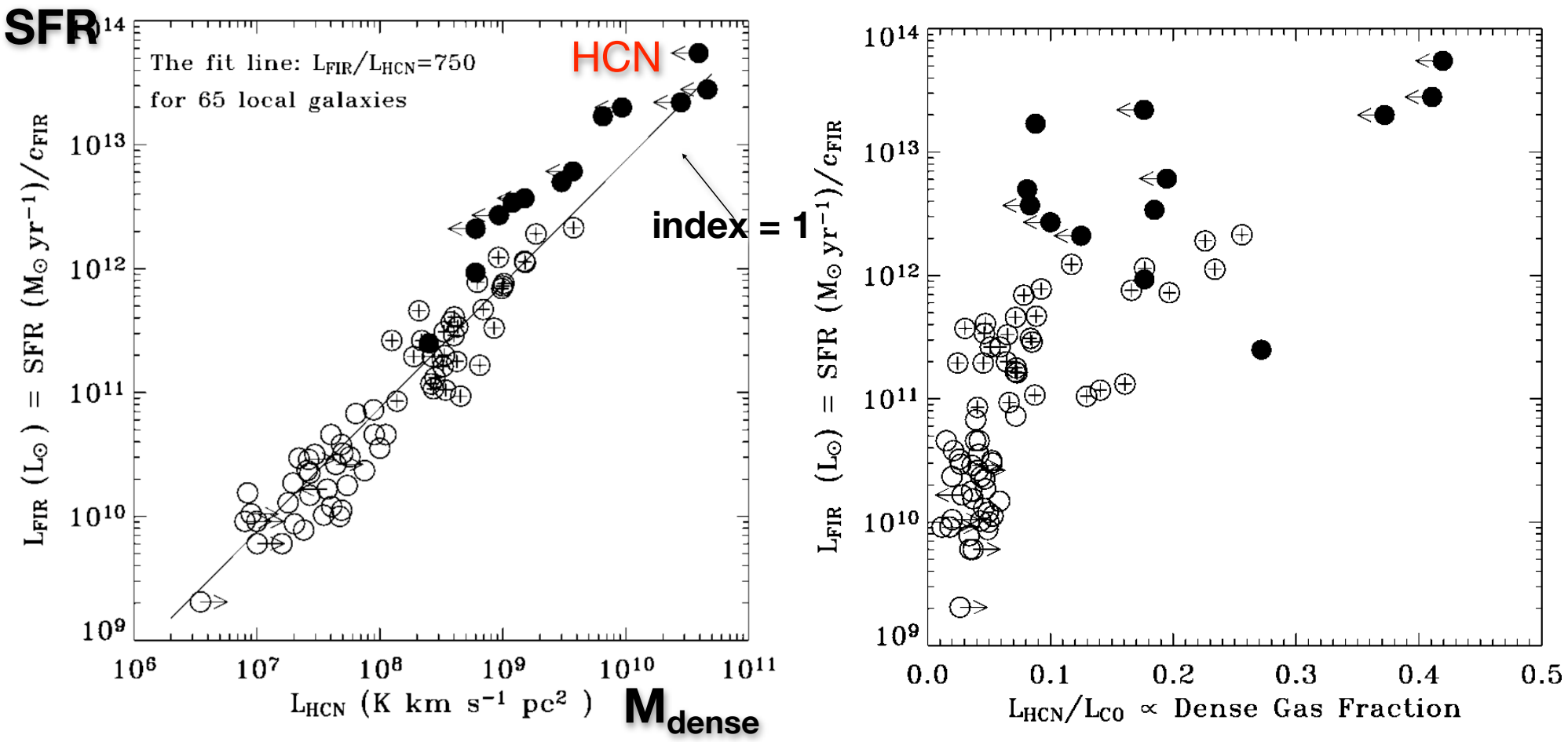
Riechers et al. 2011

APM08279:
Strong IR radiation field.
Collisional excitation not enough, likely radiative excitation



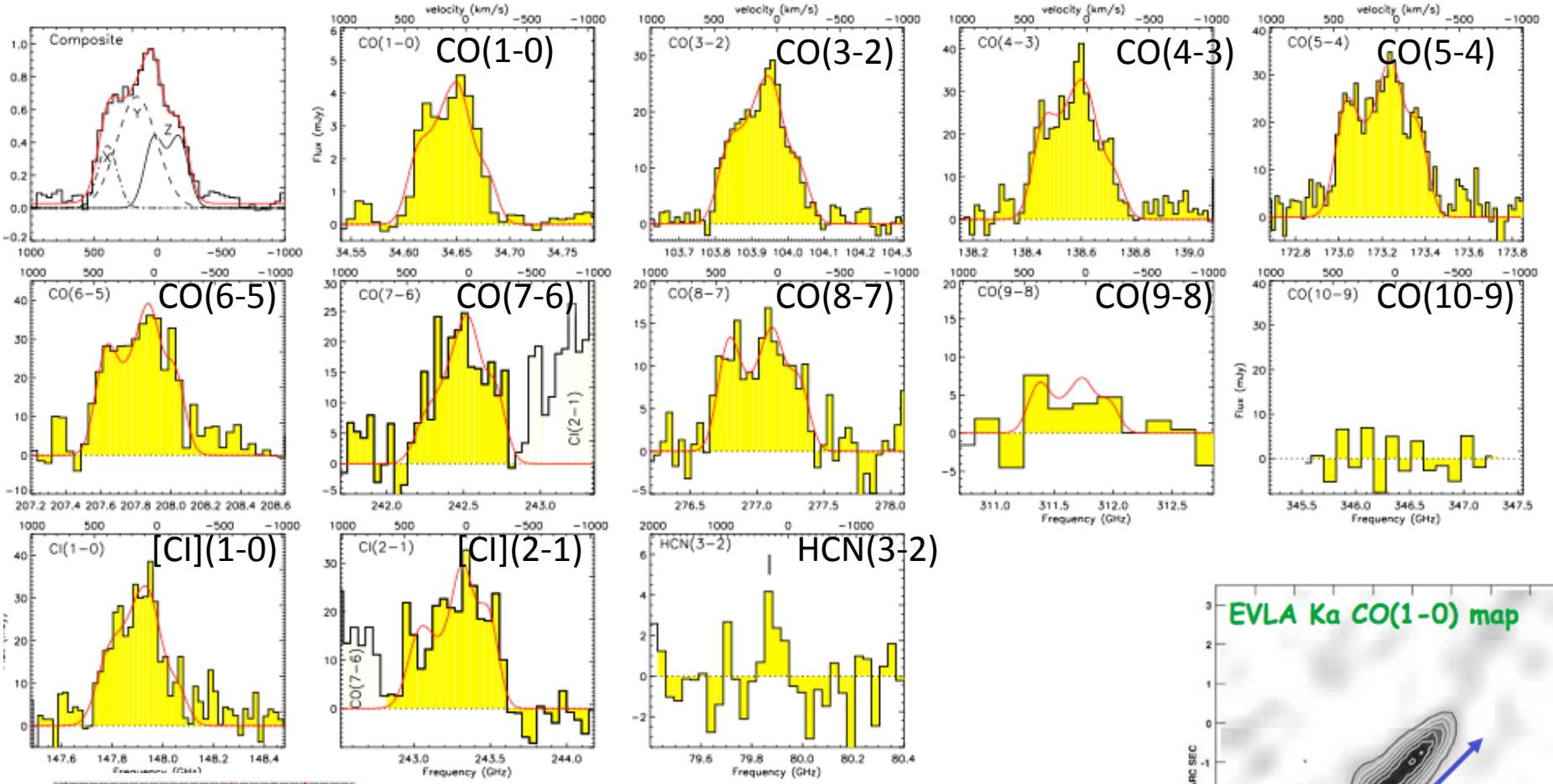
NGC253 (Knudsen et al. 2007)

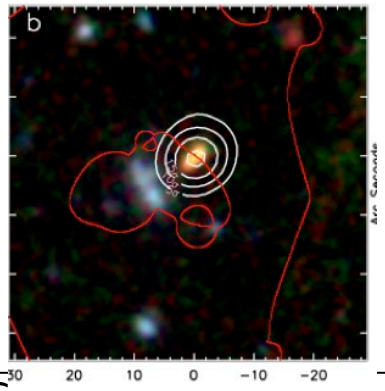
HIGH DENSITY TRACERS (HCN):

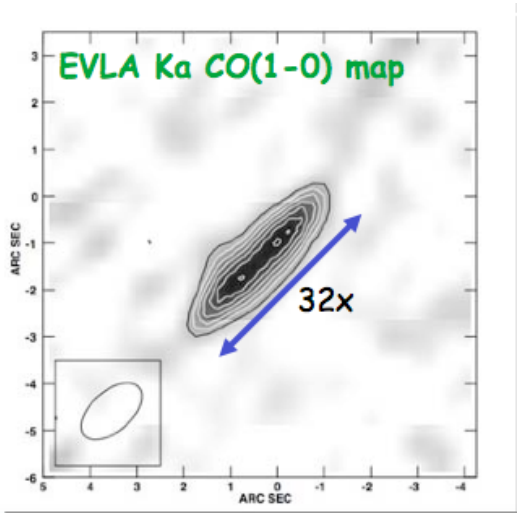


e.g. Gao ea. 2007

THE EYELASH - EXAMPLE OF LENSING



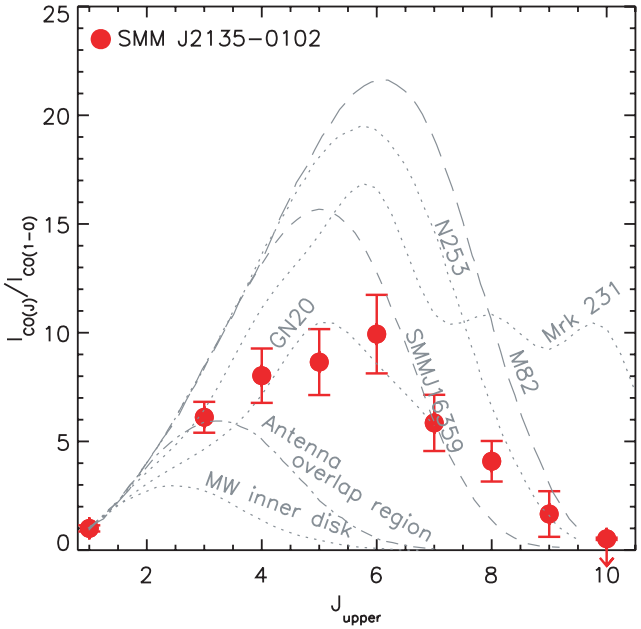




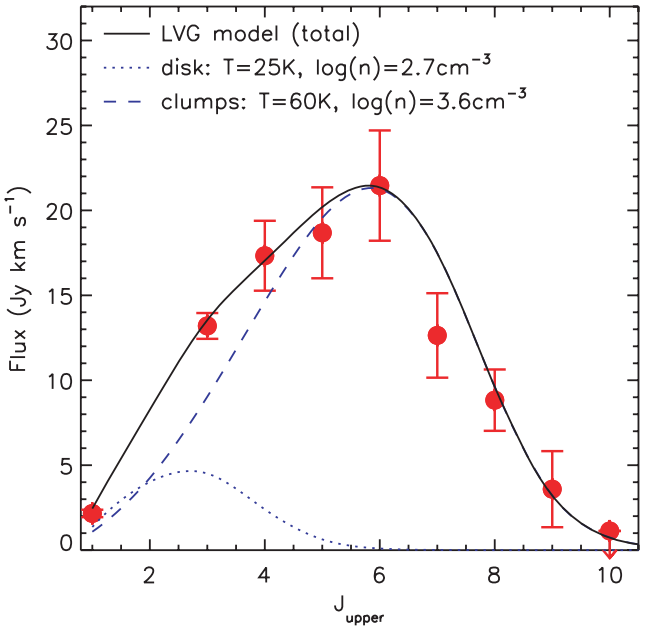
The 'Eyelash' –
the (apparently) brightest source known
[serendipitous LABOCA detection]
lensing gives 200pc resolution
in source plane
→very luminous, compact HII reg.

Danielson et al. 2011

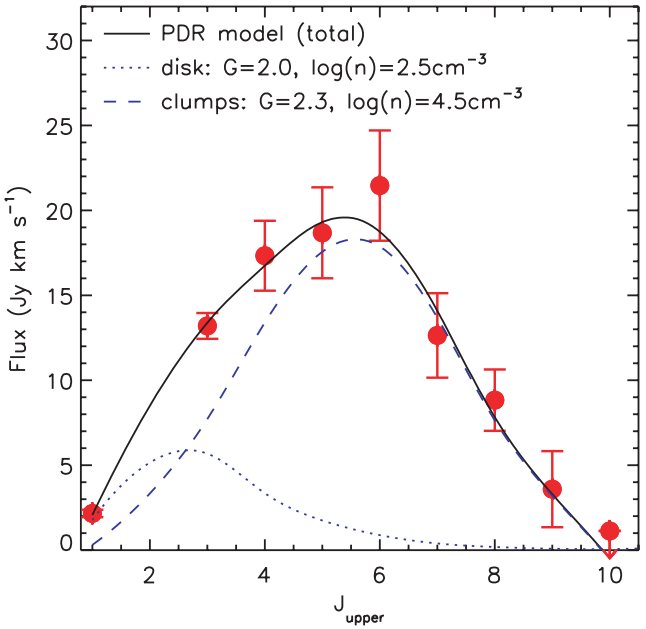
THE EYELASH - EXAMPLE OF LENSING

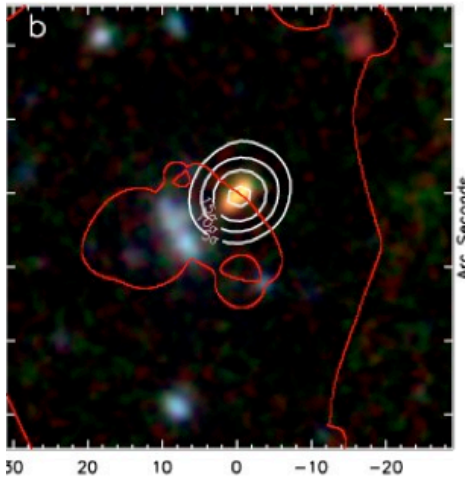


LVG model



PDR model





The ‘Eyelash’ –
two components based on CO excitation and dust emission:

1) low-dense, ~25K, 1-2kpc
2) high-dense, ~60K, ~200pc

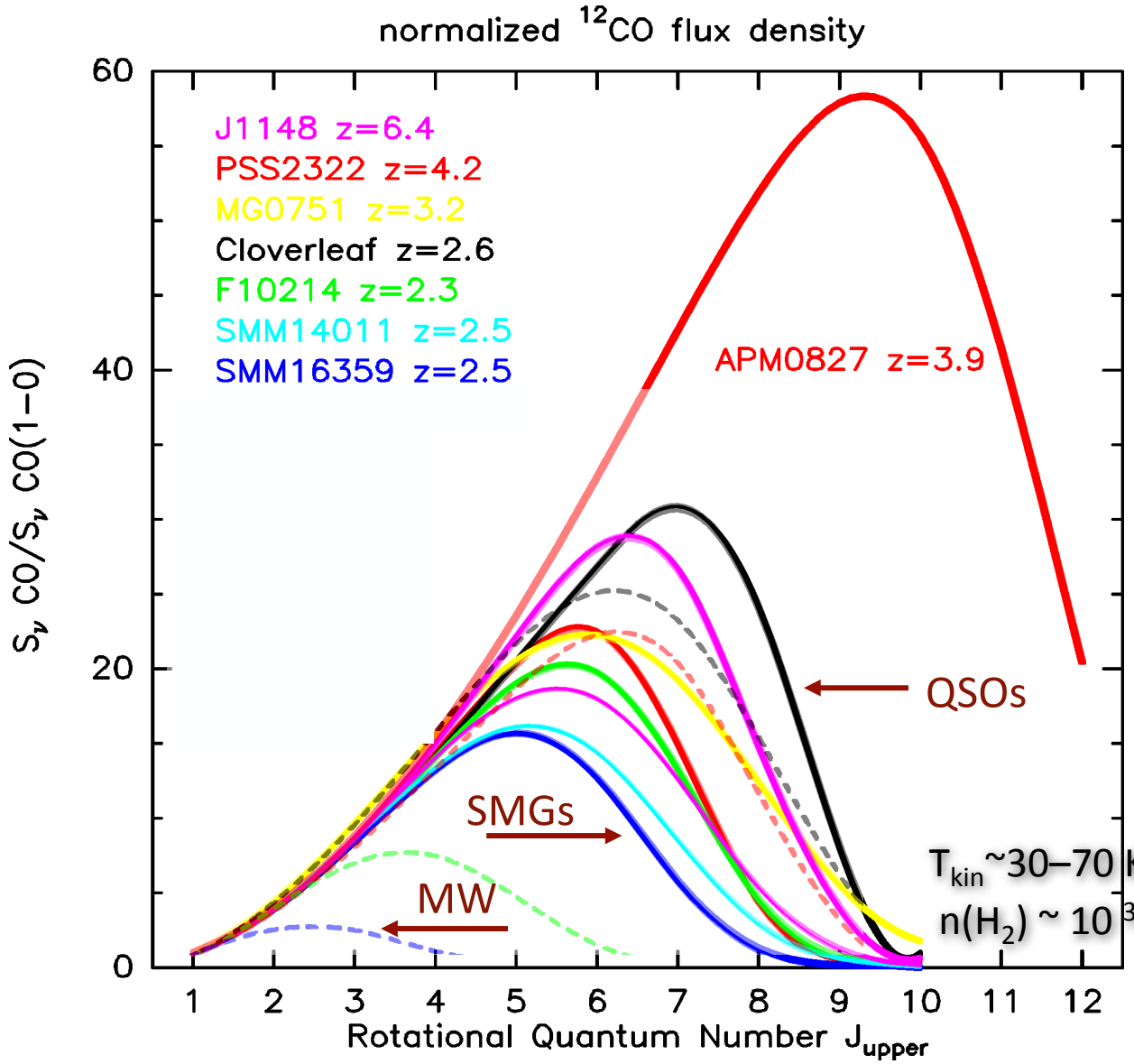
Danielson et al. 2011

CO LINE SEDS

IRAM 30m CO SED survey
(1, 2, 3mm bands)

Weiss, Walter, Downes, Henkel, in prep.

CO LINE SEDs

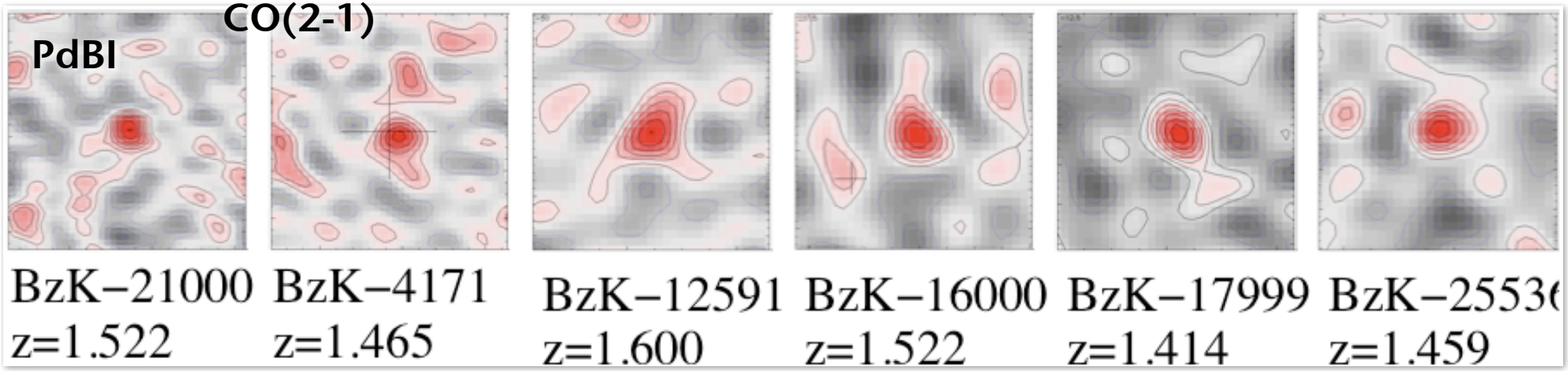


- single gas component
- QSO turnover: >6-5
- SMM turnover: 5-4
- compact (<1.5kpc)
- no indication for extended comp.

Weiss et al., in prep.

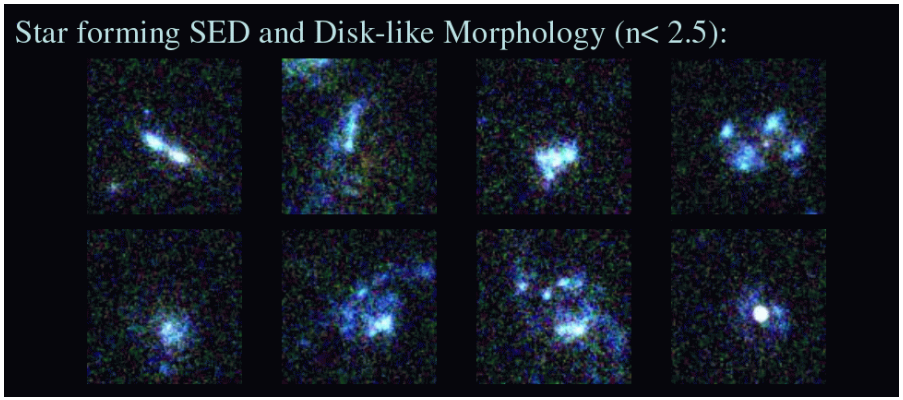
MASSIVE GAS RESERVOIRS

z~2 gal's: not extreme starbursts, but massive gas reservoirs



- 6 of 6 detected in CO, ~10 kpc size
- $M_{gas} > 10^{10} M_o$ ~ high-z HyLIRG (SMG, QSO host)

HST



But:

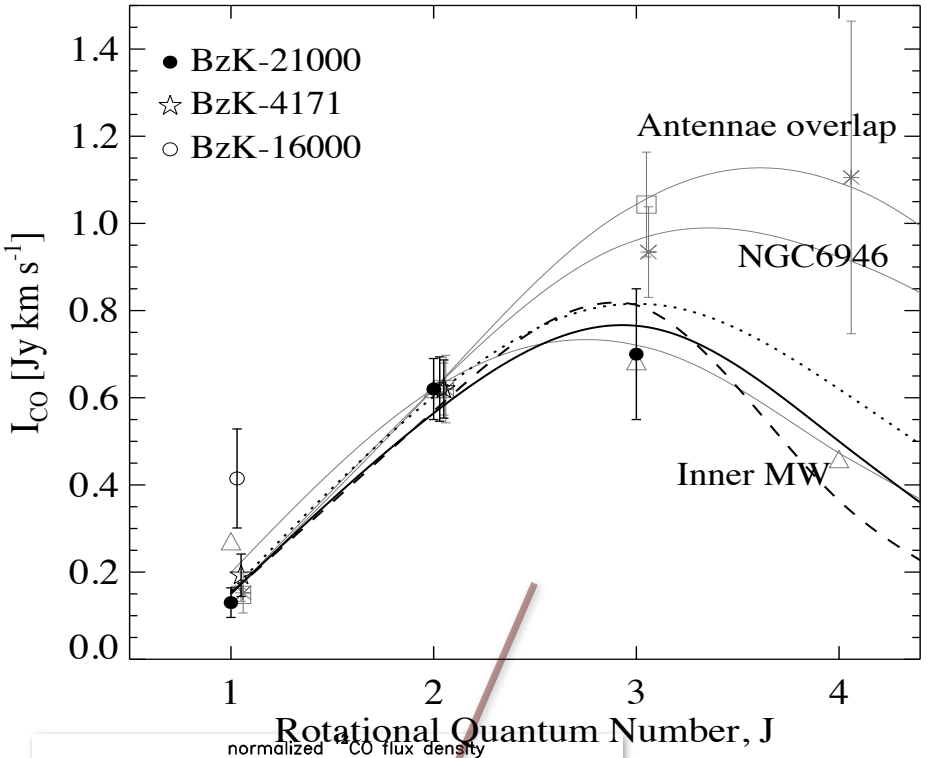
- SFR < 10% HyLIRG
- 5 arcmin^{-2} (vs 0.05 for SMGs)

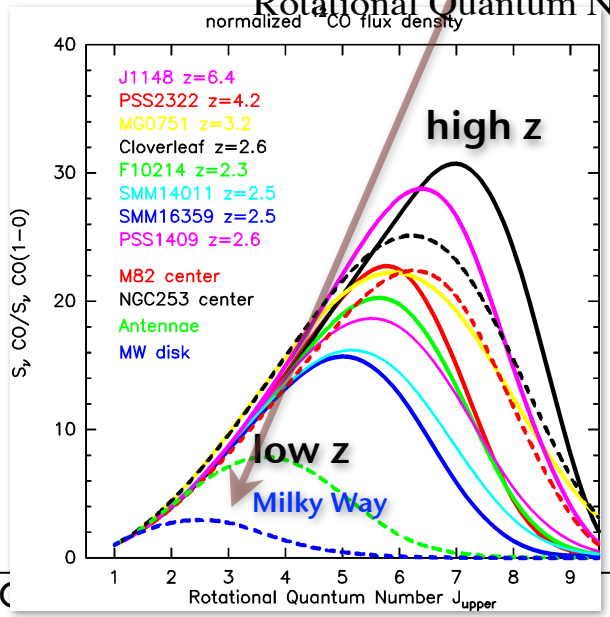
=> common, 'normal' high-z galaxies

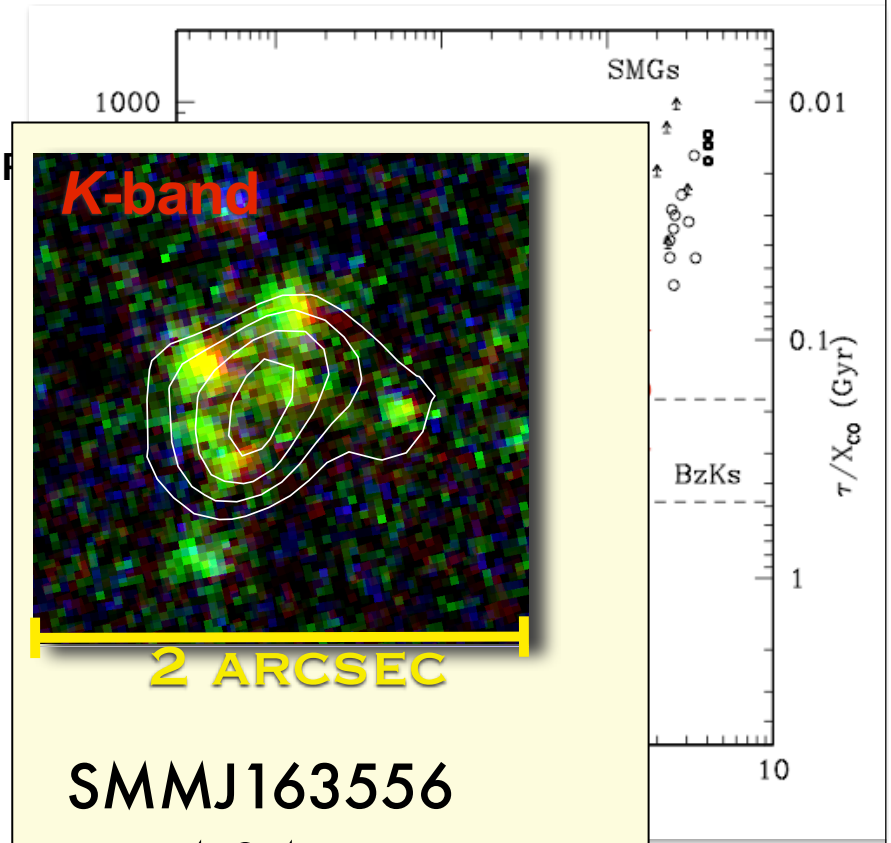
- SFR/M_* const. w/ M_*: 'pre-downsizing'

Daddi ea. 2007, 2008, 2009, Tacconi et al. 2010, Genzel et al. 2010

OTHER GALAXIES, DIFFERENT EXCITATION







SMMJ163556
z = 4.04
no CO(4-3) - why?
(Knudsen et al. 2010)

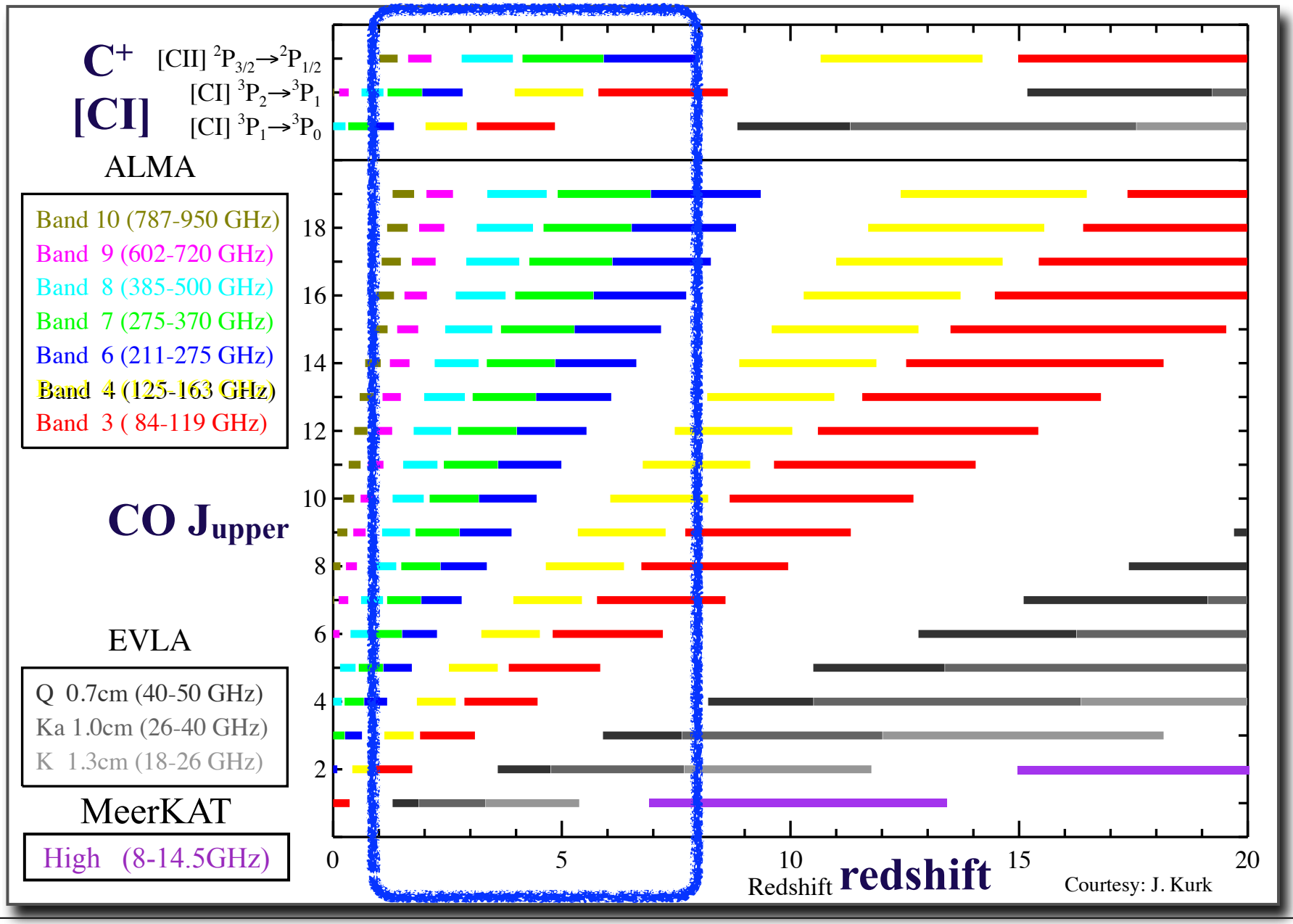
- CO excitation
- L_{FIR}/L'_{CO} = MW
- Gas depletion timescales > few x10^8 yrs

(Dannerbauer et al. 2009; Aravena et al. 2010)

DISK DIMMING DUE TO CMB

From Axel Weiss

CO, C+, [CI] AT HIGH REDSHIFT



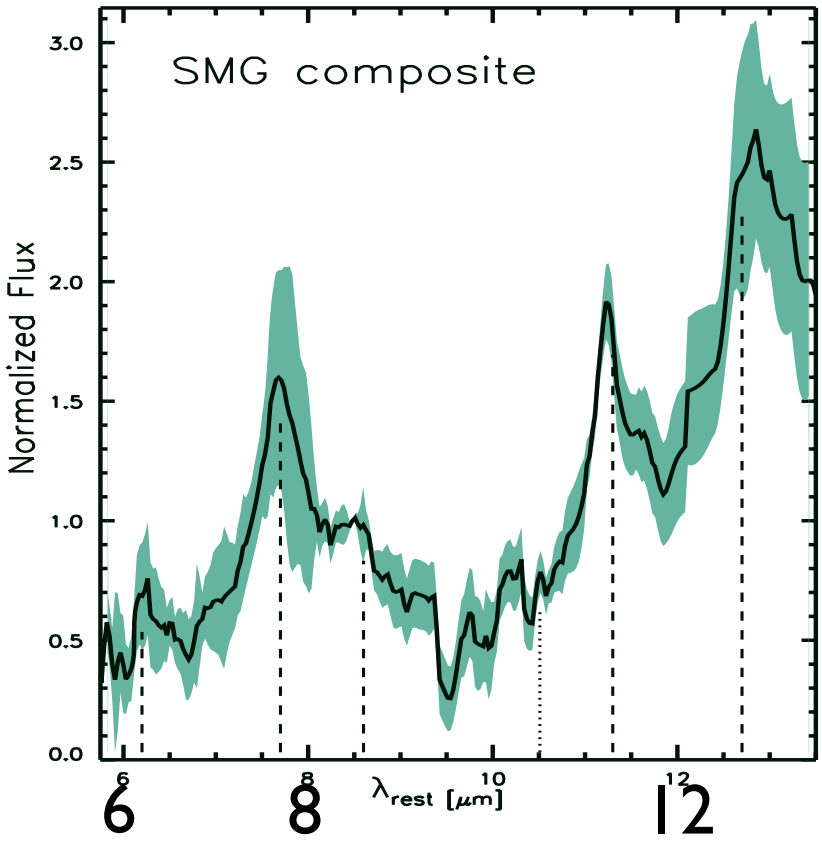
MASSIVE GALAXIES AT Z=1.5-2.5, ALMA SIMULATIONS

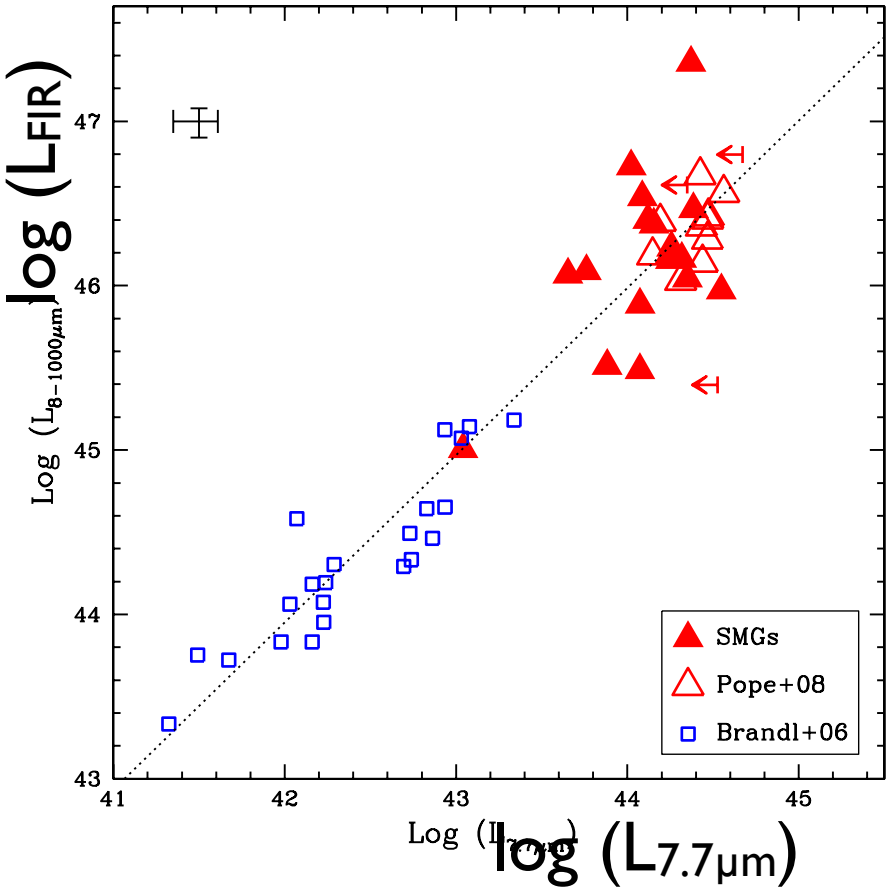
From: Fabian Walter

QSOs AT Z=6 WITH ALMA

From: Fabian Walter

PAHs IN HIGH-Z GALAXIES





- **Low AGN contribution, intense starburst activity**
- **Differences with local starbursts, possibly due to extinction**

e.g. Menendez-Delmestre et al. 2009; Pope et al. 2008

SUMMARY

- Growing number of detections of molecular gas at high-z!
- Detections of HCN, HCO^+, CN, H_2O, only in a few extreme objects (quasars and lensed starburst galaxies).
- Excitation of gas shows a variety of conditions
  - Example: The Eyelash - CO line SED shows the a composite of low-dense and high-dense gas.
- Massive galaxies with low excitation molecular gas.
- At high-z, the CMB will impact the observations of cold, diffuse gas in e.g. disks.
- High-z PAH studies allowing to probe differences between high-z starbursts and local ULIRGs.
- With full-array ALMA, astrochemistry in high-z galaxies will become possible.