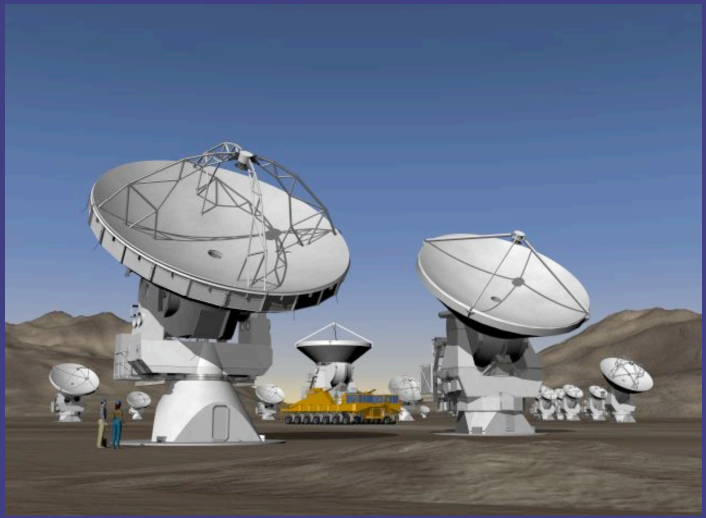
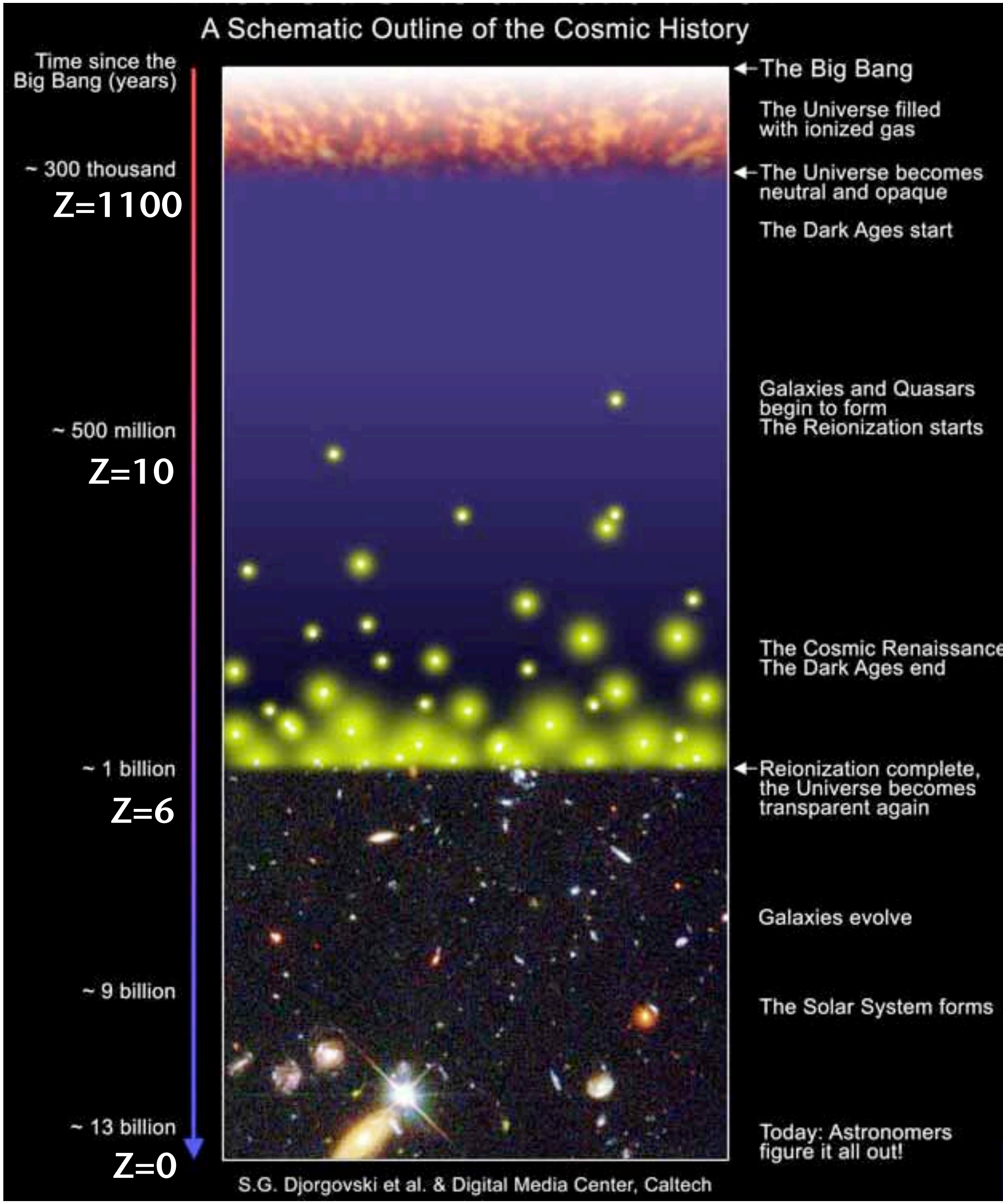


[CII]: A New Tool to Study Star Formation in the Epoch of Reionization

Fabian Walter (MPIA)

Frank Bertoldi, Chris Carilli, Pierre Cox, Roberto Maiolino, Roberto Neri, Dominik Riechers, Ran Wang, Axel Weiss

The z>7 Universe



'Dark Ages'

Epoch of Reionization

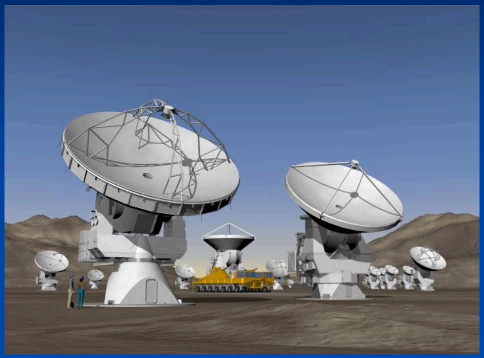
- key benchmark in cosmic structure formation

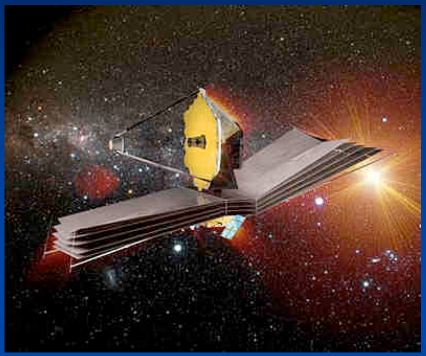
GP & WMAP: EoR 6<z<~15

today

Sources in EoR: Why should we care?

- first luminous sources in universe





- constrain:	SFR	(contribution to reionization)	✔
	M_{gas}	(fuel for SF & evol. state)	✔
	M_{BH}	(early BH formation)	
	M_{dyn}	(hierarchical models, M-σ)	✔
	n_{HI}	(state of IGM)	

ALMA: molecular lines (CO), dust (L_{FIR}) and [CII]

70% of all z~6 SDSS QSOs are now detected in CO!!

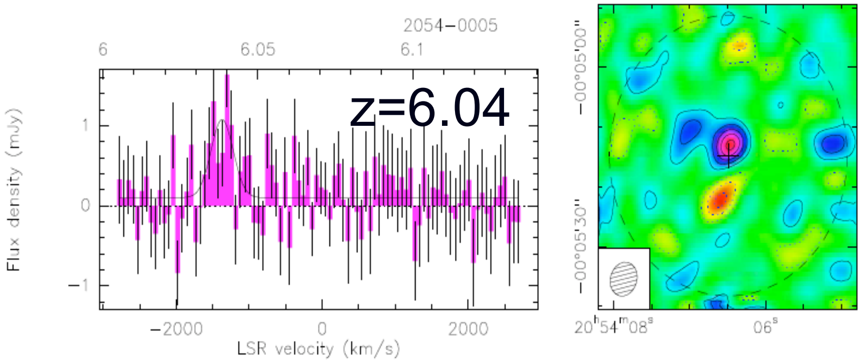


Figure 1: The spectrum and velocity-integrated image of J2054-0005.

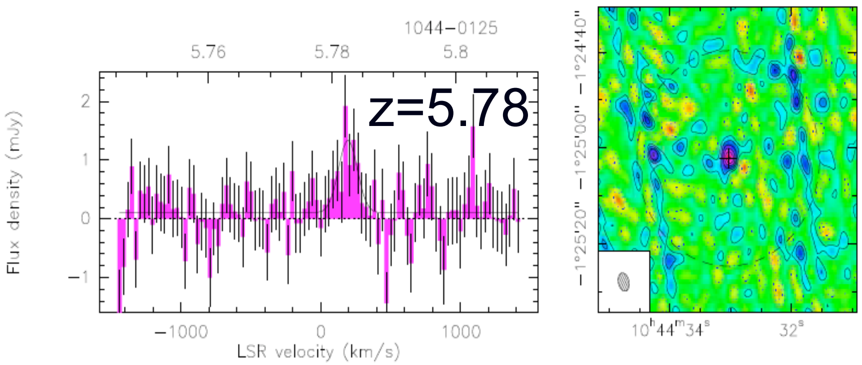


Figure 2: The spectrum and velocity-integrated image of J1044-0125.

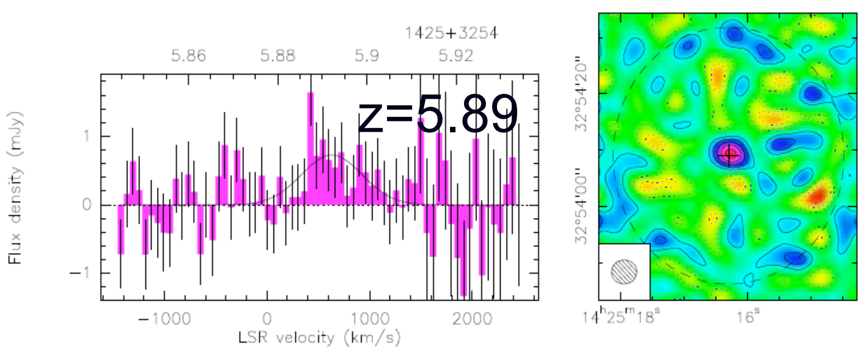


Figure 6: The spectrum and velocity-integrated image of J1425+3254.

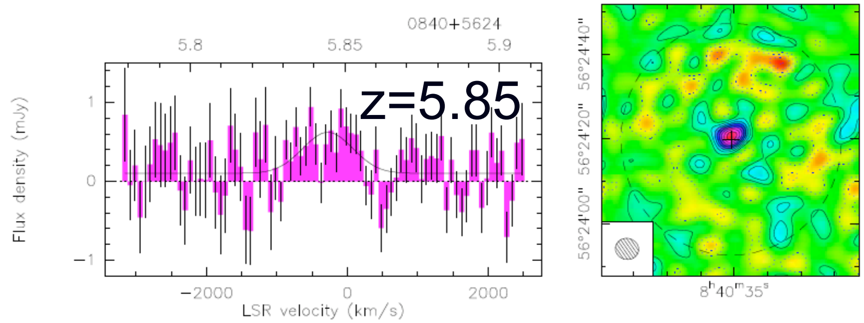


Figure 3: The spectrum and velocity-integrated image of J0840+5624.

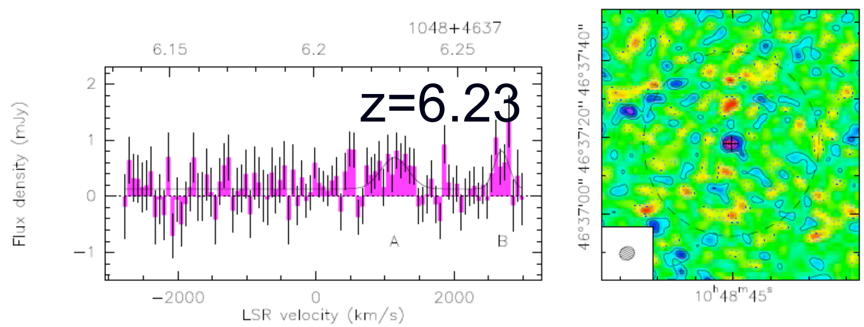


Figure 4: The spectrum and velocity-integrated image of J1048+4637.

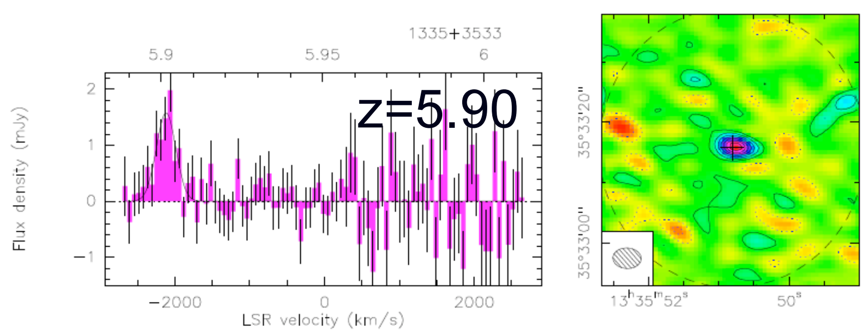
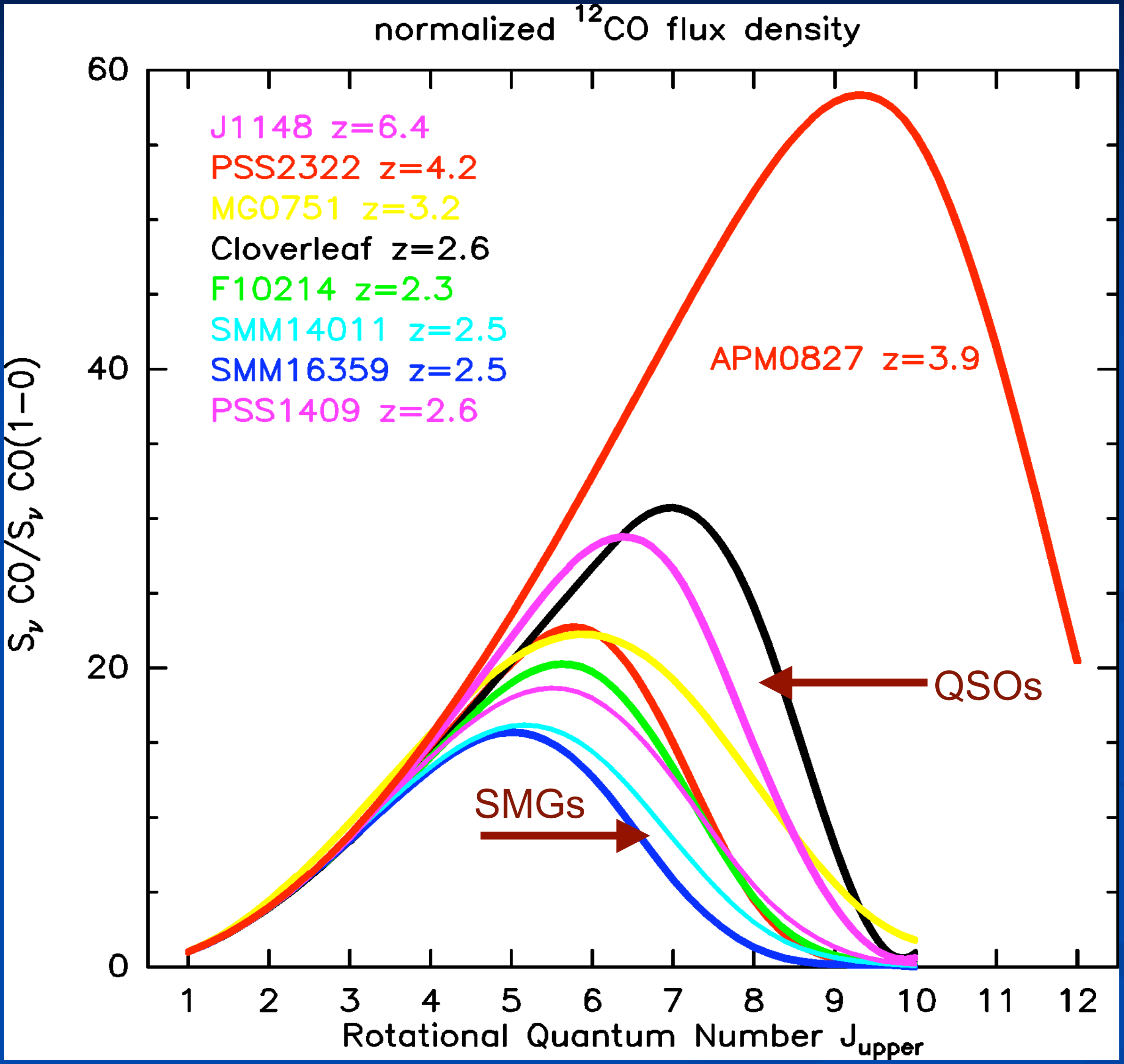


Figure 5: The spectrum and velocity-integrated image of J1335+3533.

Wang et al. 2009: CO(6-5) lines

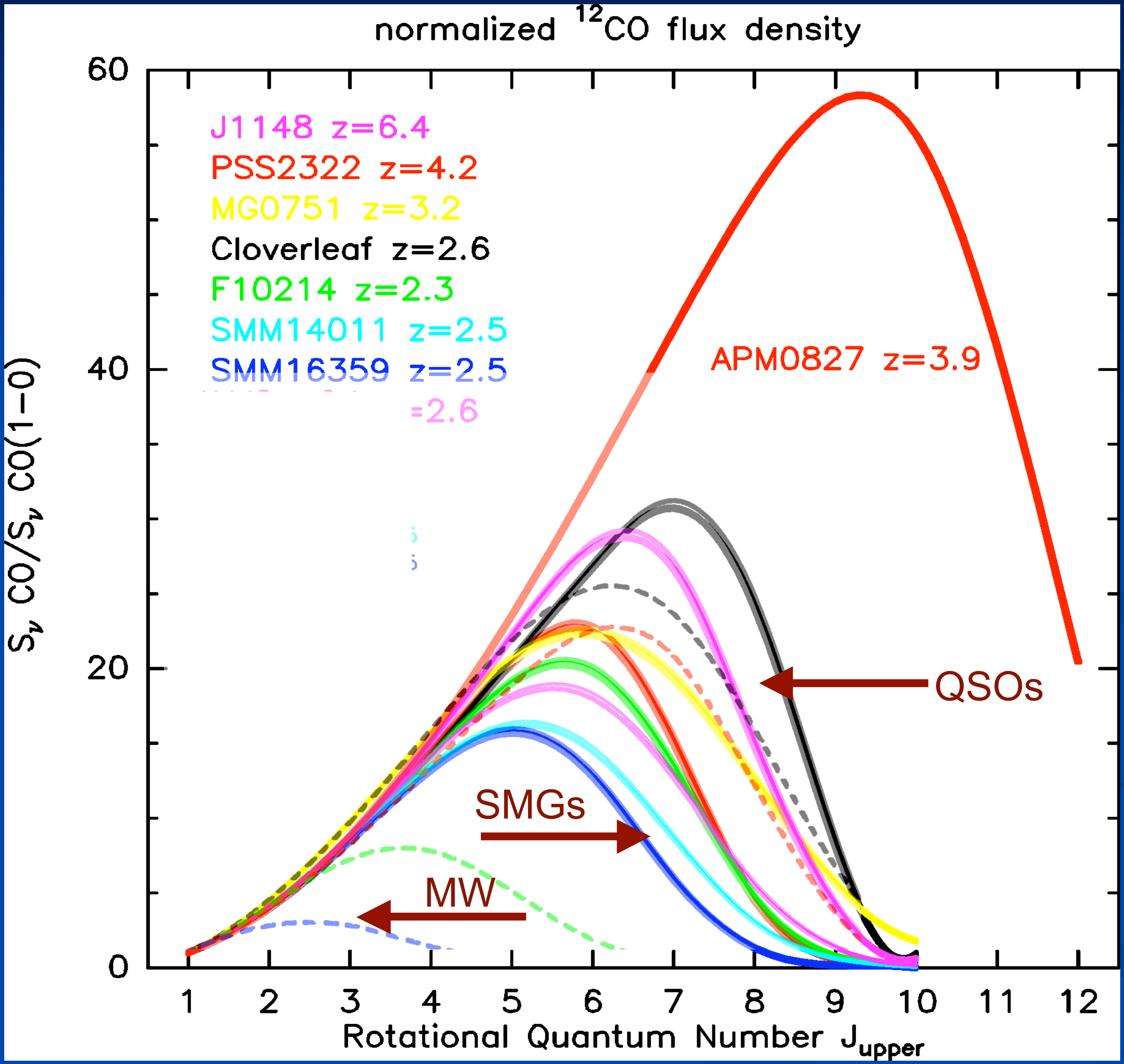
So will it be a piece of cake for ALMA to do this?



CO excitation

Weiss et al., in prep.

CO Line SEDs



CO excitation

Weiss et al., in prep.

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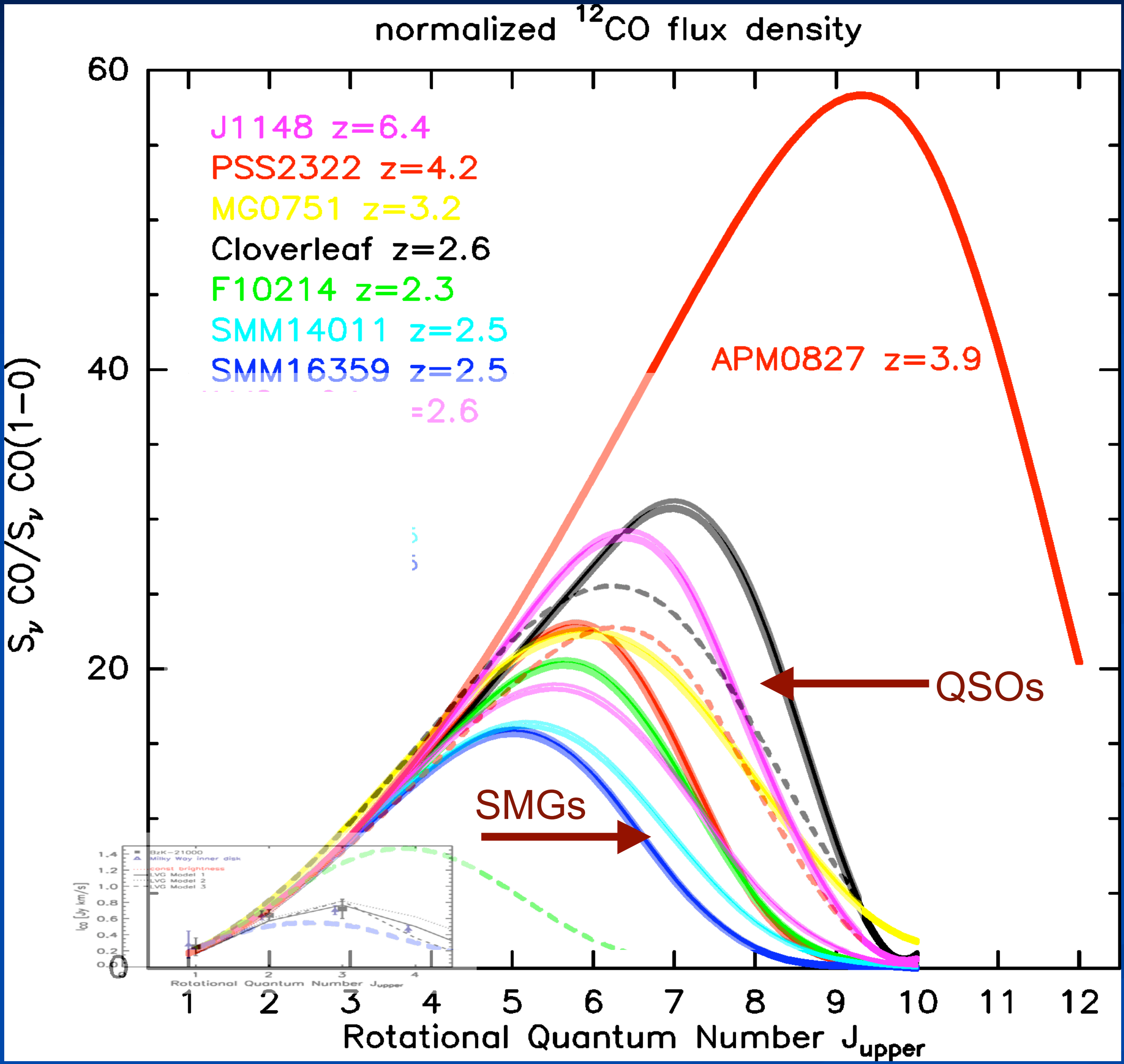
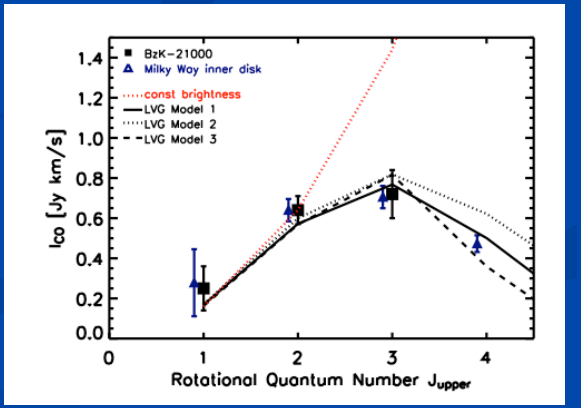


CO excitation

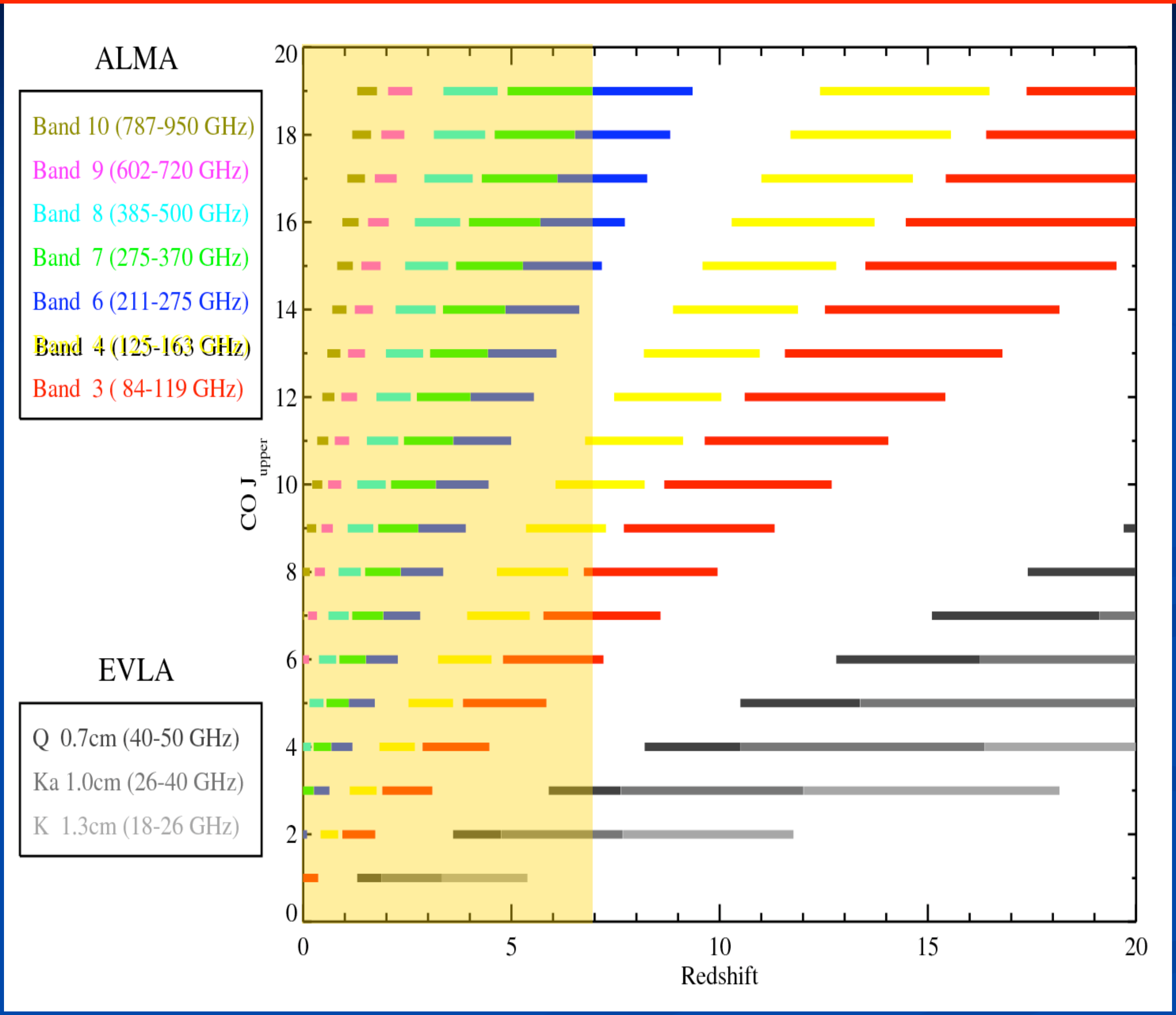
z~1.5 BzK galaxies:
~MW excitation!!



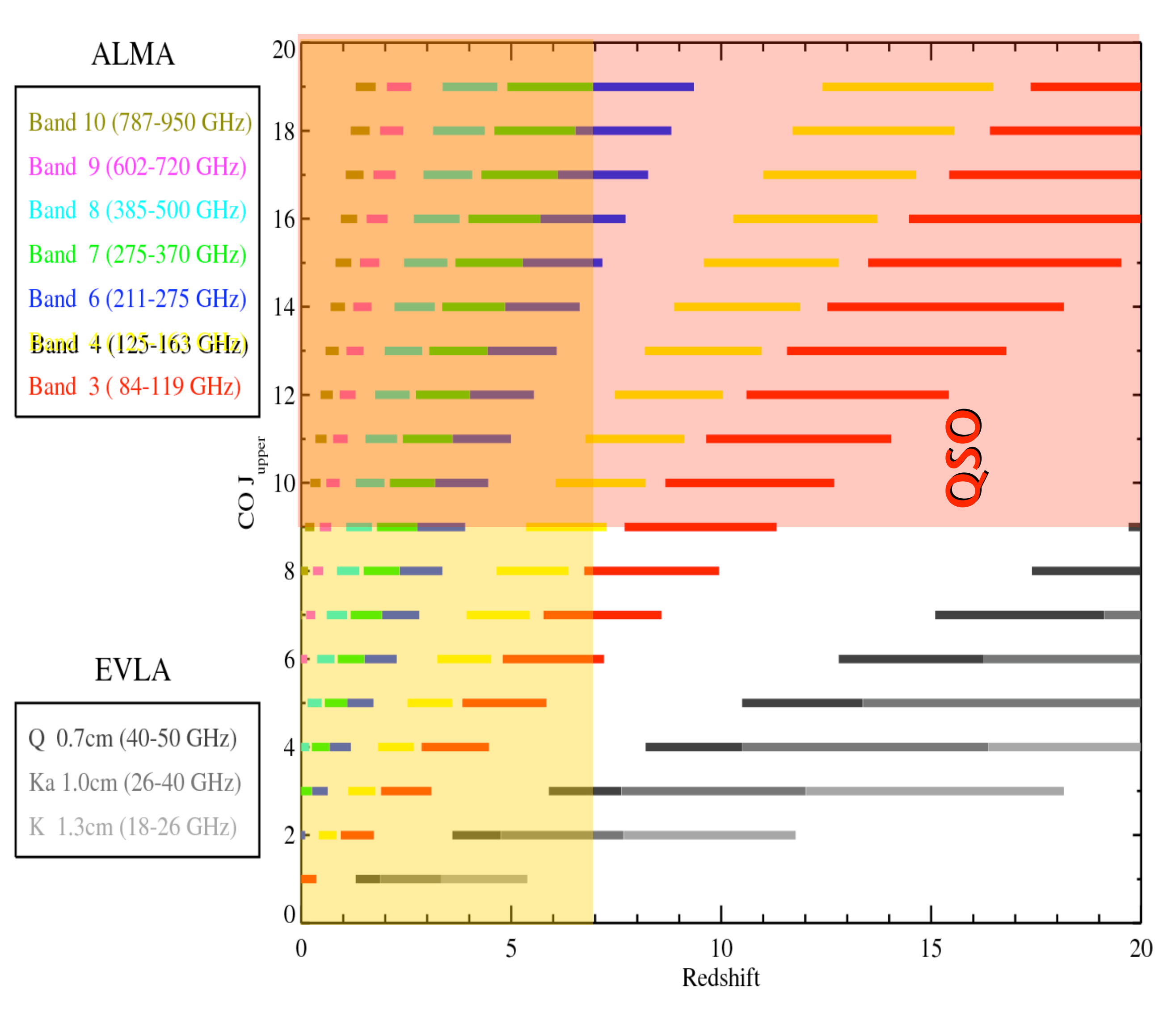
Weiss et al., in prep.

Daddi et al., in prep.

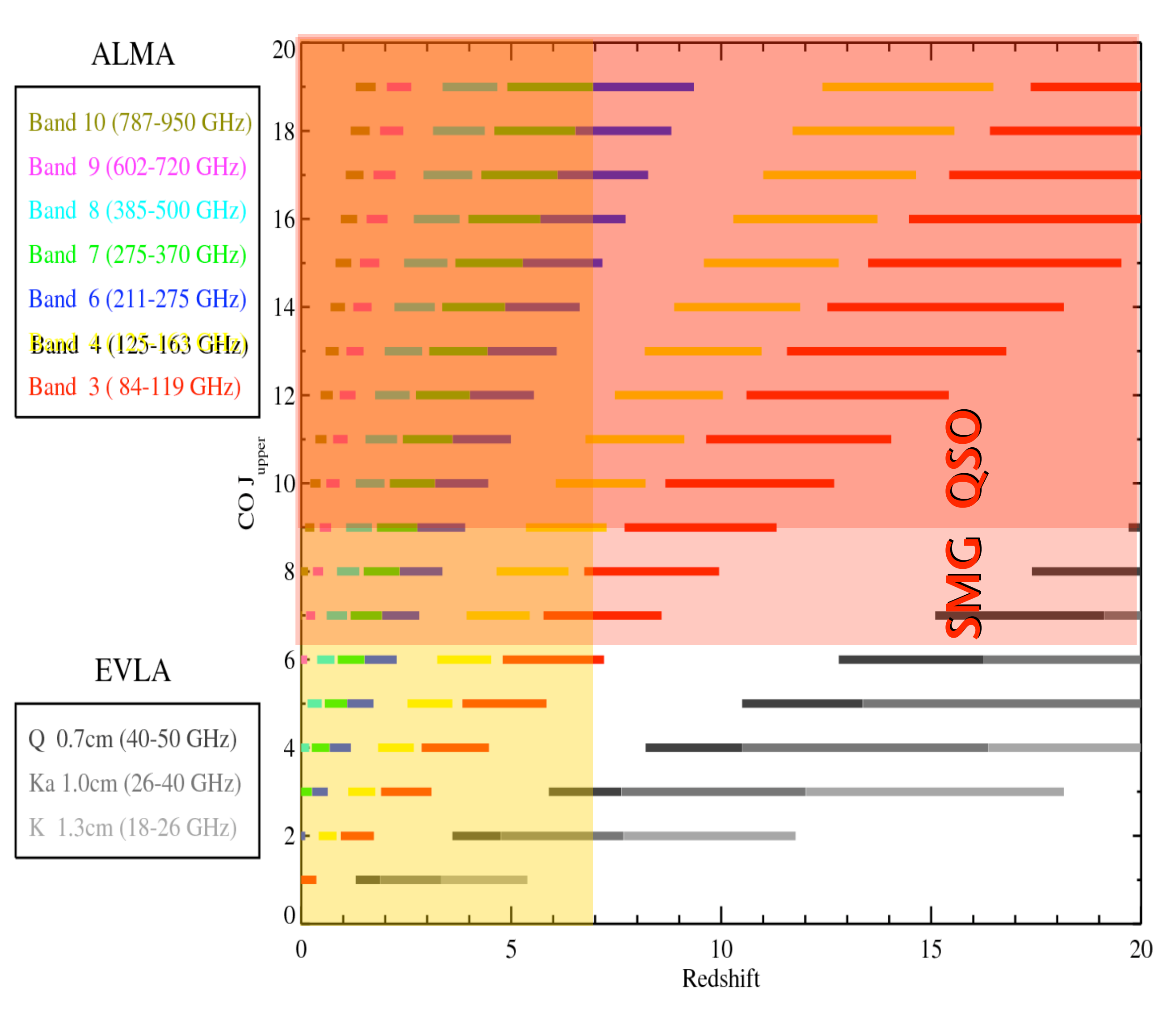
z>7 Sources: ALMA CO discovery space



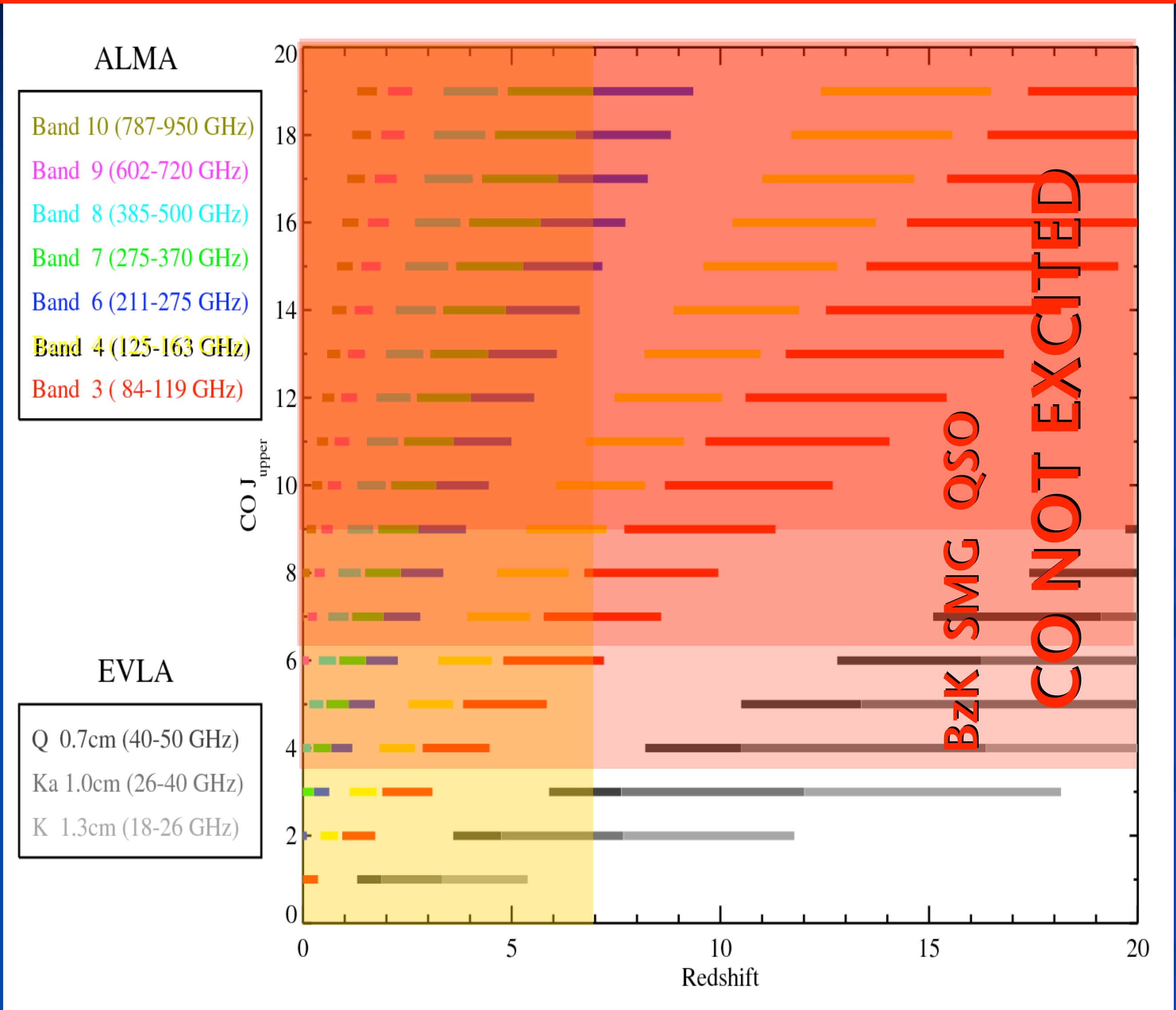
z>7 Sources: ALMA CO discovery space



z>7 Sources: ALMA CO discovery space



z>7 Sources: ALMA CO discovery space



…bad news for ISM studies in EoR!

To the Rescue: [CII]

[CII] (ionized carbon): major cooling line of the ISM

$^2P_{3/2}$-$^2P_{1/2}$ fine-structure line -- PDR / SF tracer

Rest frequency: 1900 GHz (158 microns)
-> z=0 observations from ground prohibitive

ISO observations:
[CII] carries *high fraction of L_{FIR}*

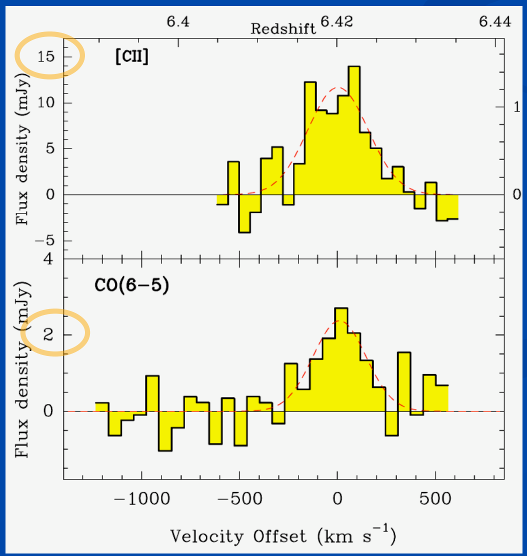
Low-metallicity dwarfs: ~1 %
Starforming galaxies: ~0.5 %
ULRIGS: ~0.05 %

J1148+5251 (z=6.42)
Maiolino et al. 2005 (30m)

$L_{[CII]} = 4.4 \times 10^9\ L_{sun}$

$L_{FIR} = 2 \times 10^{13}\ L_{sun}$

$L_{[CII]}/L_{FIR} = 0.02\%$



Note: six times brighter than brightest CO line!

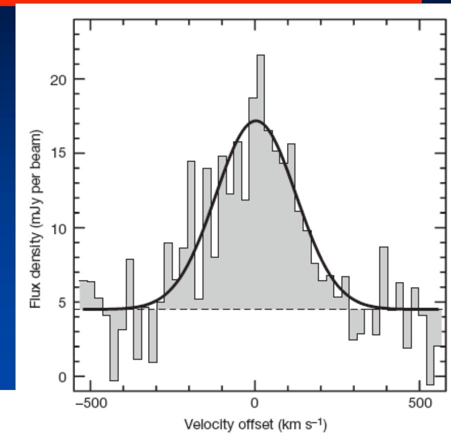
Even though 'worst case', still detectable in [CII]

Vol 457 | 5 February 2009 | doi:10.1038/nature07681
nature
LETTERS

A kiloparsec-scale hyper-starburst in a quasar host less than 1 gigayear after the Big Bang

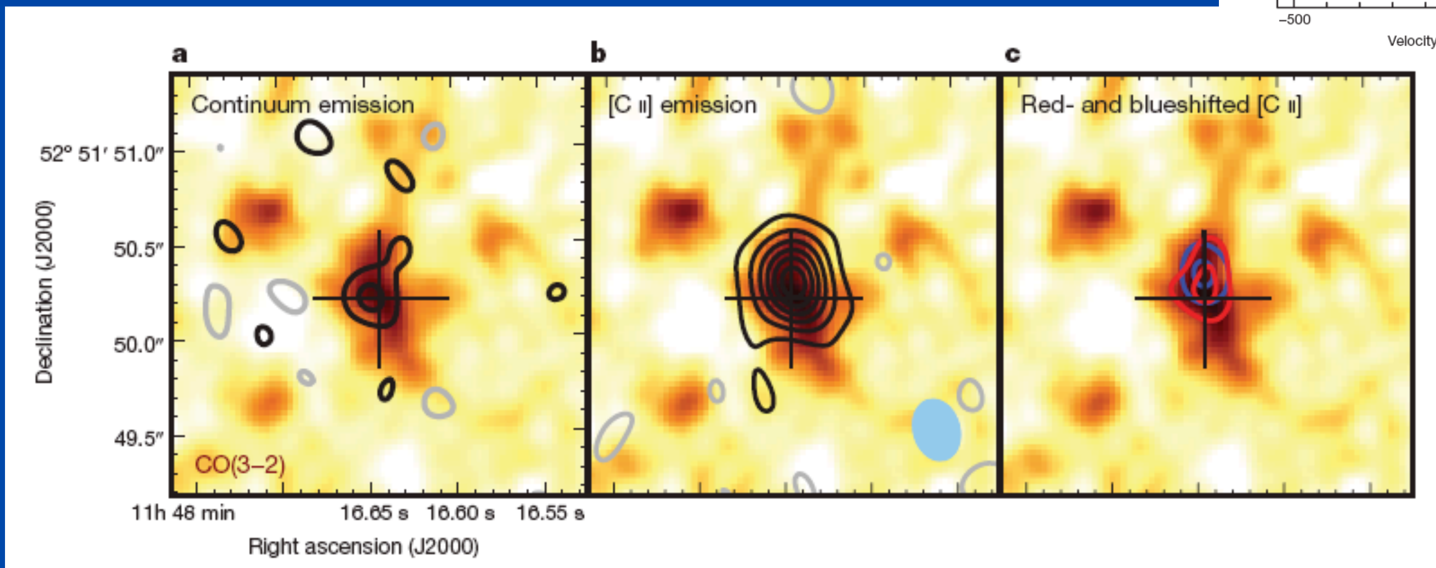
Fabian Walter[1], Dominik Riechers[1,2], Pierre Cox[3], Roberto Neri[3], Chris Carilli[4], Frank Bertoldi[5], Axel Weiss[6] & Roberto Maiolino[7]

[CII] resolved at z=6.4



1.9THz line observed at 258 GHz

beamsize: 0.35”, spatially resolved on 2kpc scales



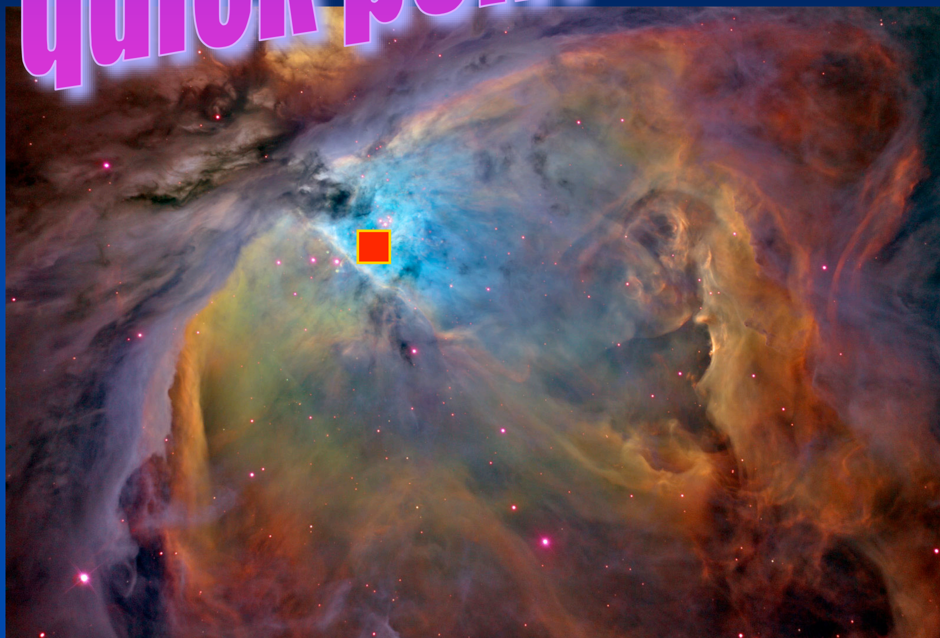
Walter et al. 09

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

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

SFRSD=1000 M_{sun} yr^{-1} kpc^{-2} !!??

quick poll!



Comparison to star formation rate surface density in Orion?!

$SFRSD_{J1148}$=1000 M_{sun} yr^{-1} kpc^{-2}

A) $SFRSD_{Orion}$ = 10^{-6} x $SFRSD_{J1148}$
B) = 10^{-3} x $SFRSD_{J1148}$
C) = 1 x $SFRSD_{J1148}$

SFRSD=1000 M_{sun} yr^{-1} kpc^{-2} !!??

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- ✖ A) $SFRSD_{Orion} = 10^{-6} \times SFRSD_{J1148}$
- ✖ B) $= 10^{-3} \times SFRSD_{J1148}$
- ✔ C) $= 1 \times SFRSD_{J1148}$

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quick poll!

Comparison to star formation rate surface density in Orion??

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The Astrophysical Journal, 630:167–185, 2005 September 1

RADIATION PRESSURE–SUPPORTED STARBURST DISKS AND ACTIVE GALACTIC NUCLEUS FUELING

Todd A. Thompson,[1,2] Eliot Quataert,[2] and Norman Murray[3,4,5]
Received 2005 March 1; accepted 2005 May 14

ABSTRACT

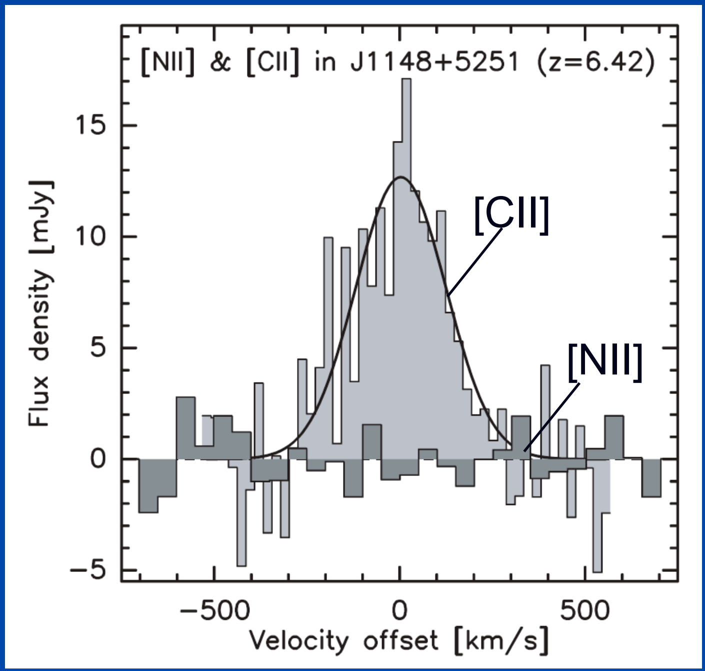
We consider the structure of marginally Toomre-stable starburst disks under the assumption that radiation pressure on dust grains provides the dominant vertical support against gravity. This assumption is particularly appropriate when the disk is optically thick to its own infrared radiation, as in the central regions of ULIRGs. We argue that because the disk radiates at its Eddington limit (for dust), the "Schmidt law" for star formation changes in the optically thick limit, with the star formation rate per unit area scaling as $\dot{\Sigma}_\star \propto \Sigma_g/\kappa$, where Σ_g is the gas surface density and κ is the mean opacity of the disk. Our calculations further show that optically thick starburst disks have a characteristic flux, star formation rate per unit area, and dust effective temperature of $F \sim 10^{13}\ L_\odot\ \mathrm{kpc^{-2}}$, $\dot{\Sigma}_\star \sim 10^3\ M_\odot\ \mathrm{yr^{-1}\ kpc^{-2}}$, and $T_{\rm eff} \sim 90$ K, respectively. We compare our model predictions with observations of ULIRGs and find good agreement. We extend our model of starburst disks from many hundred parsec scales to subparsec

density and κ is the mean opacity of the disk. Our calculations further show that optically thick starburst disks have a characteristic flux, star formation rate per unit area, and dust effective temperature of $F \sim 10^{13}\ L_\odot\ \mathrm{kpc^{-2}}$, $\dot{\Sigma}_\star \sim 10^3\ M_\odot\ \mathrm{yr^{-1}\ kpc^{-2}}$, and $T_{\rm eff} \sim 90$ K, respectively. We compare our model predictions with observations of ULIRGs

the starburst disk on parsec scales can approach ..., perhaps accounting for the nuclear obscuration in some type 2 AGNs. We also argue that the disk of young stars in the Galactic center may be the remnant of such a compact nuclear starburst.

Other atomic fine structure lines

Other lines in ISM: e.g., [OI], [OIII], [NII] (mostly higher ν than [CII])
-> key diagnostics of the starforming ISM
Rich discovery potential for ALMA!



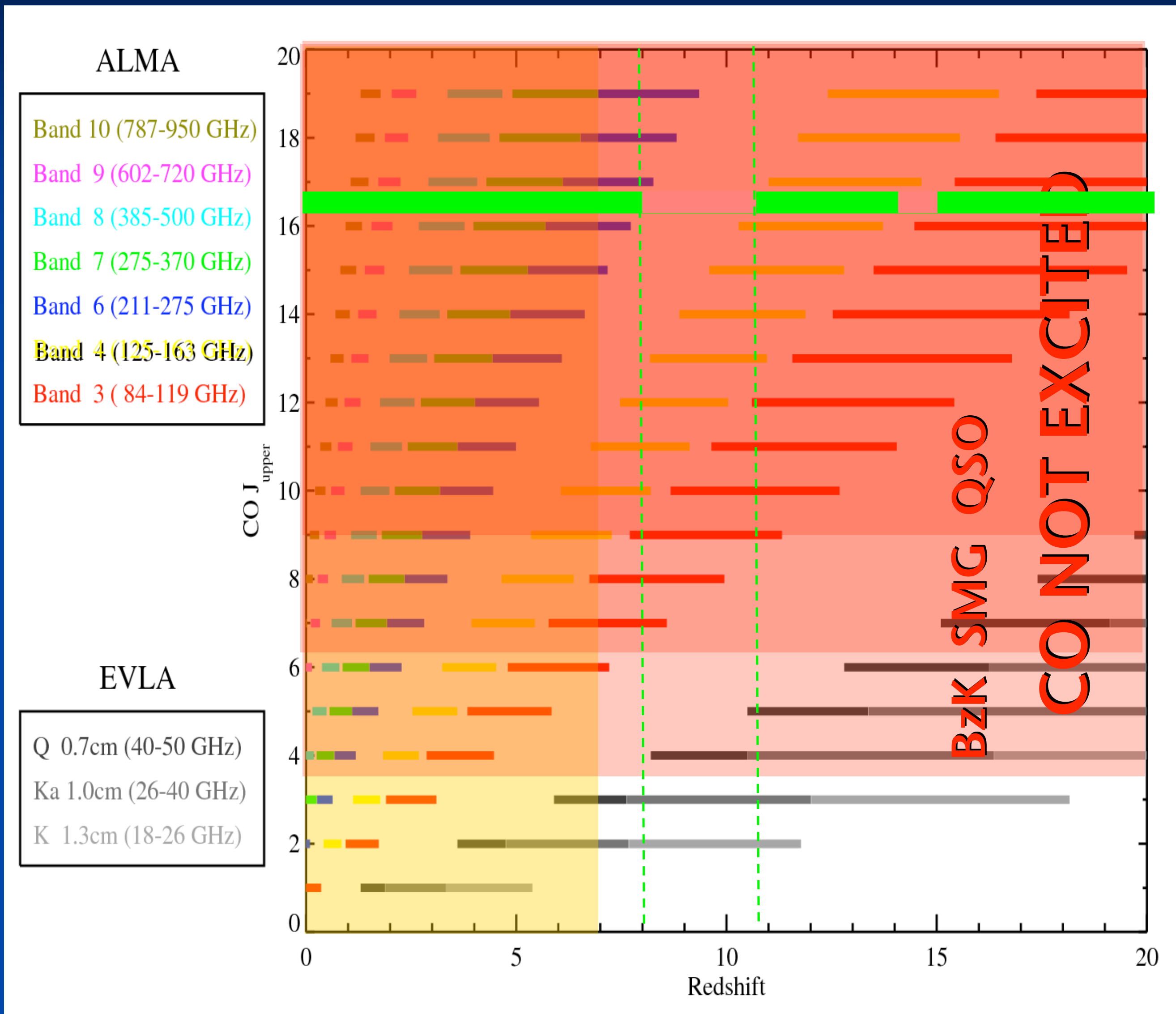
Search for [NII] emission in z=6.42 quasar J1148
unsuccessful
(Walter et al. 2009, ApJL)

Limit: $L_{[NII]}/L_{FIR}=2x10^{-5}$

…similar to M82, MW

…at the limit of the capabilities of current facilities…

[CII] will (almost) make our day at z>7



[CII] line

Need Band 5!

Summary

- ELT, ALMA and JWST:
  instrumental to characterize sources in EoR
  M_{dyn}, M_{gas}, morphology

- Today's workhorse diagnostic line of ISM (CO):
  not excited for most objects!

- resolved [CII] observations of z=6.4 QSO:
  star formation rates surface densities, dyn.

- [CII] (and possibly other fine structure lines):
  ->the ALMA workhorse line for EoR studies

THE END