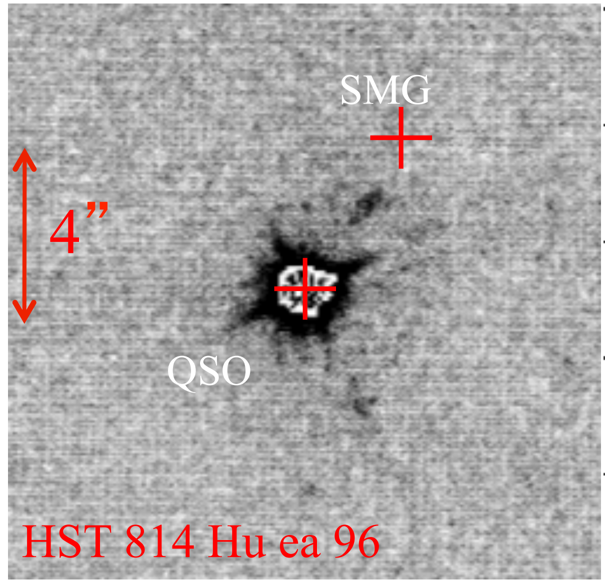
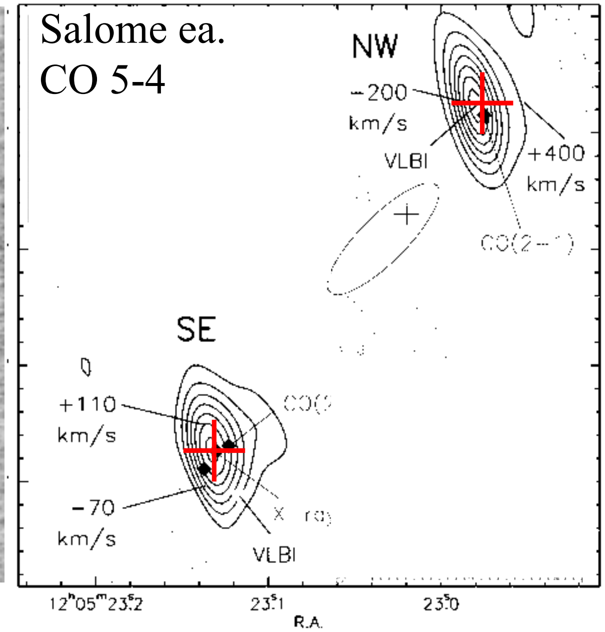
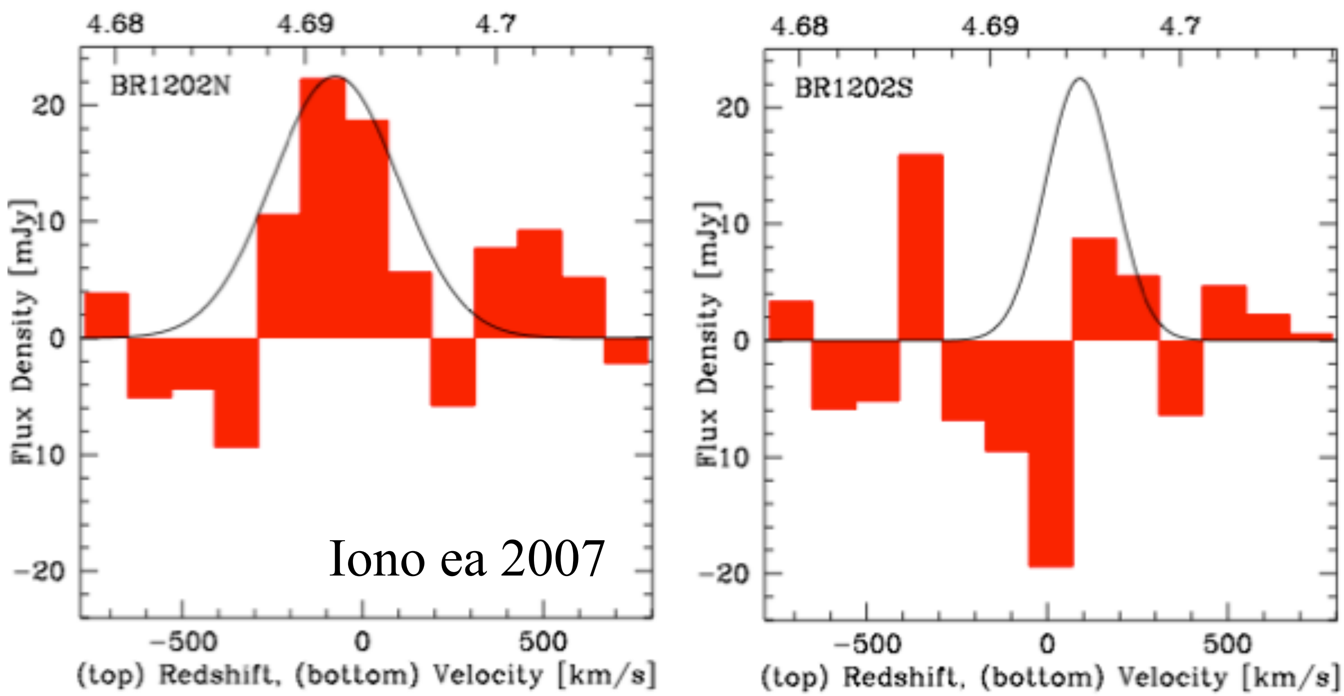
BRI1202-0725 z=4.7

- HyLIRG (10^{13} L_o) pair
- SFR ~ few 10^3 M_o yr^{-1}
- M_{H2} ~ 10^{11} M_o





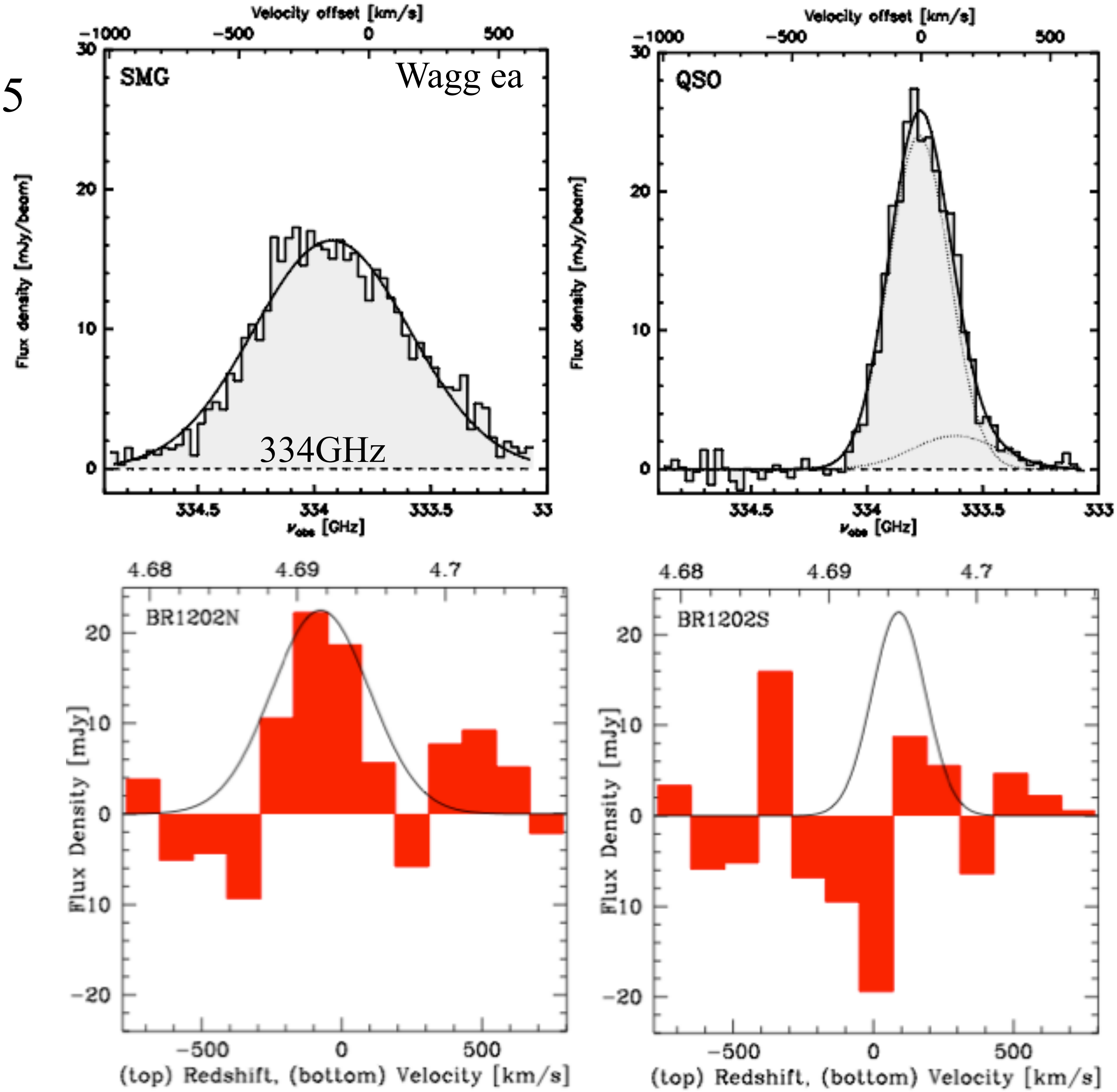
SMA
[CII] 158um
334GHz, 20hrs



[CII] in 1202-0725

ALMA SV
20min, 16 ants

SMA
20hrs

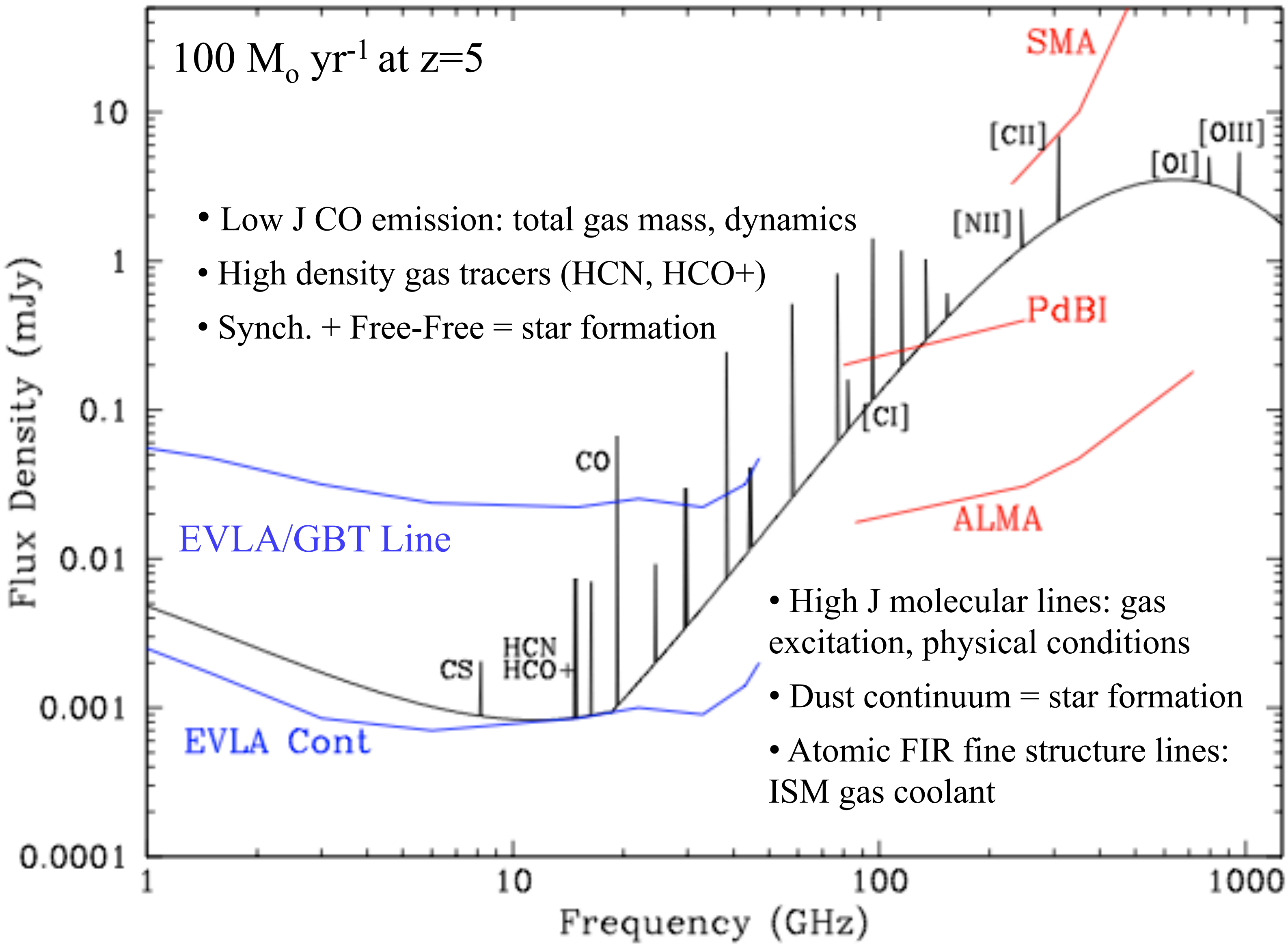


[CII] 158um line and ALMA: a new window on the 1st Galaxies

C. Carilli

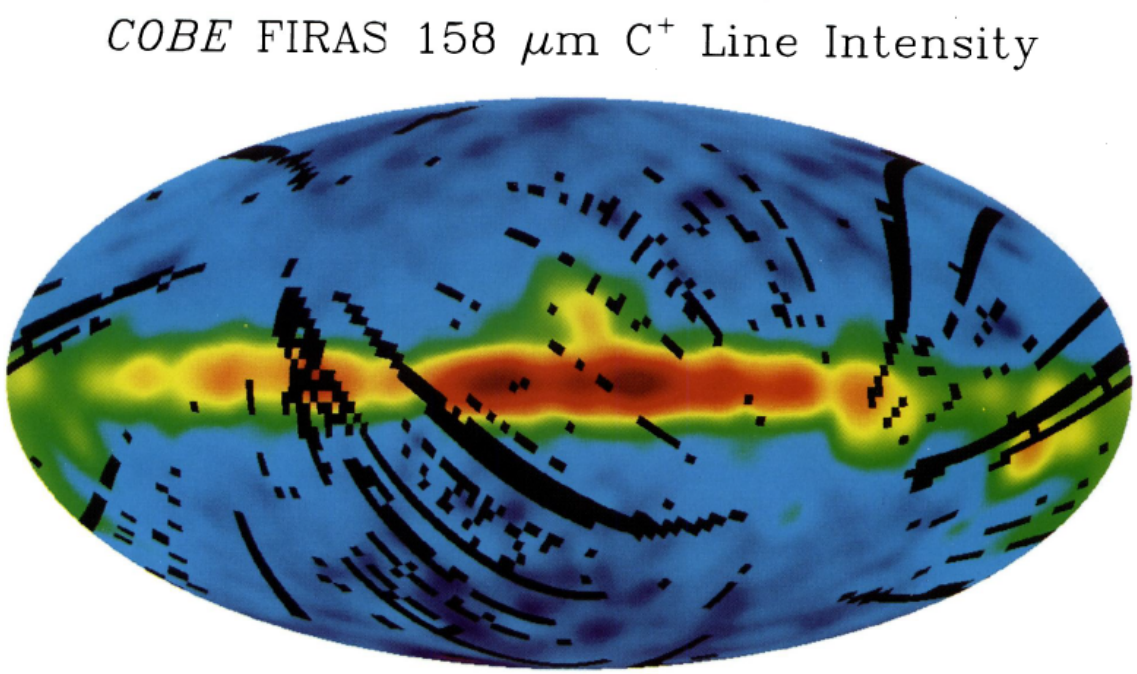
- Dynamics first galaxies
  - Anatomy of early galaxy formation
  - Rotation curves: in search of dark matter
- Build up of dusty ISM in z ~ 6 LBGs
- Redshift frontier: into reionization
  - Early SMBH formation
  - Verify + spec z for z=6 to 8 dropouts

cm → submm diagnostics of cool gas in galaxy formation



Good news: [CII] is everywhere!

- [CII] 158um line: dominant cooling mechanism for cool gas, and most luminous line from star forming galaxies from DC to FIR:
  - 0.3% of FIR luminosity of MW
  - [CII]/$CO_{1\text{-}0}$ ~ 1000
- E_{ion} = 11.2eV => traces ionized and neutral gas => Good dynamical tracer
- Low z requires space Obs, but z > 1 => [CII] redshifts to ALMA bands



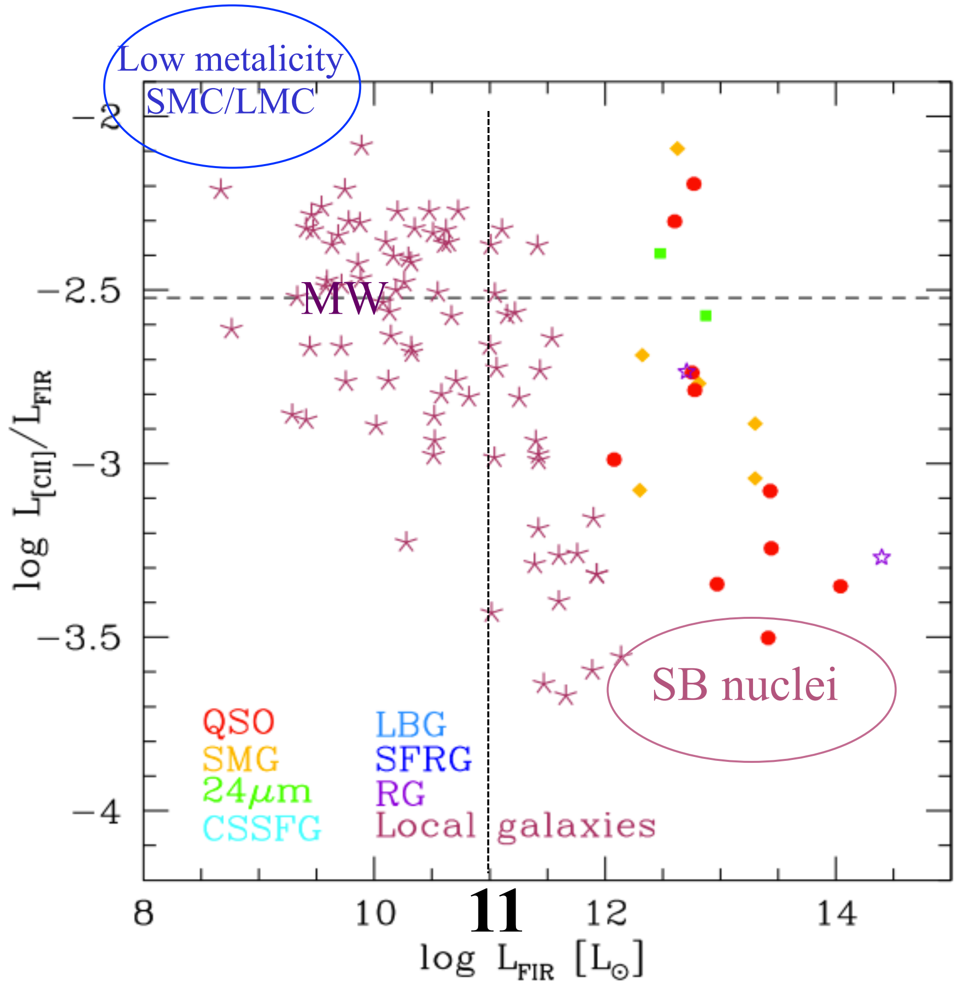
Galactic census (Pineda ea)

- PDRs (30%)
- Cold HI (25%)
- CO–dark H_2 (25%)
- Ionized gas (20%)
- Various with galaxy

Bad news: CII is everywhere!

[CII]/FIR: up to factor ~ 100 scatter!

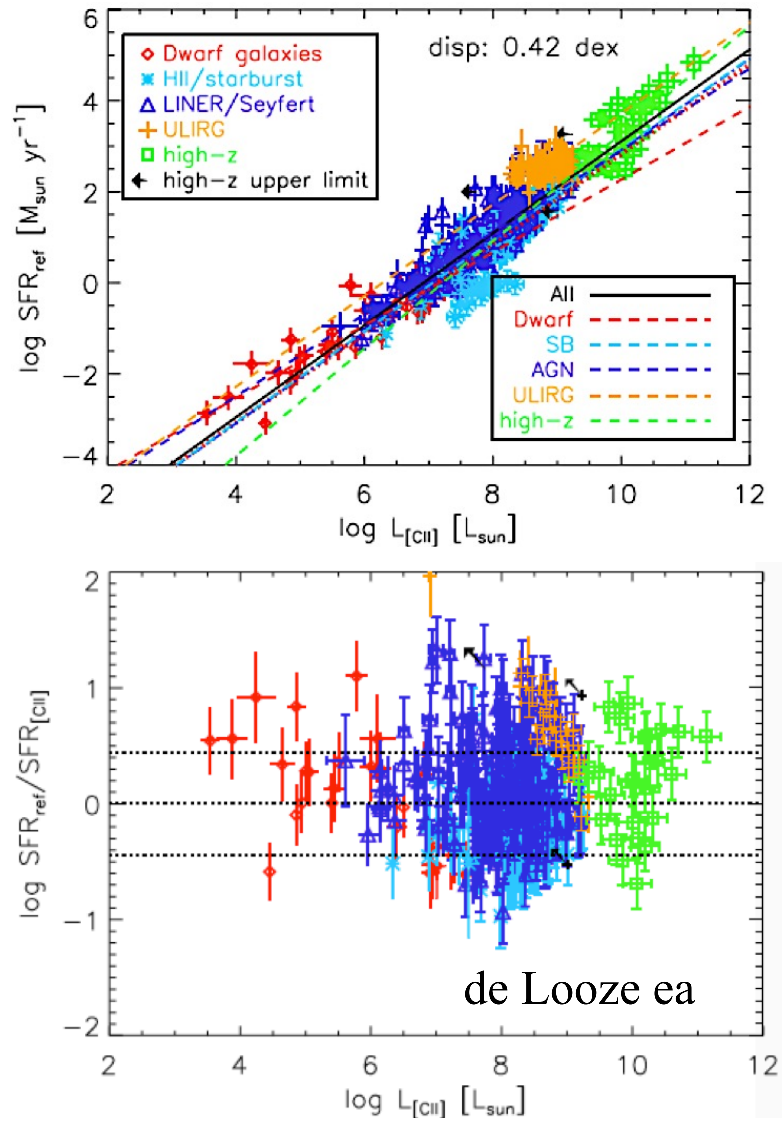
- Quantitative measure of ??
- Can be suppressed in SB nuclei: dust opacity or charged grains?
- Low metallicity: enhanced [CII]/FIR (lower dust attenuation => large UV heating zone)
- Might lose CNM contribution at z > 6 due to CMB contrast (Vallini ea)?



[CII]: the great elixir (or koolaid)?

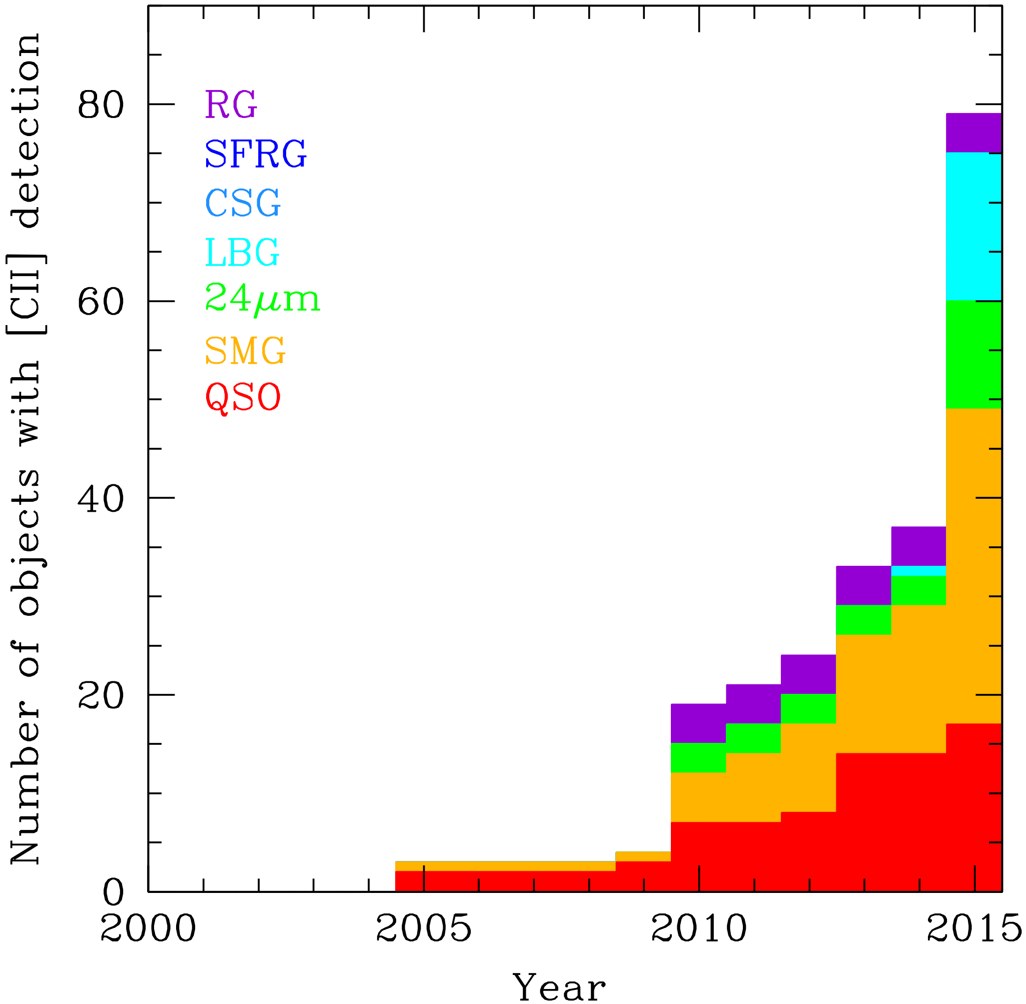
- Claimed to be a tracer of
  - ➢ Star formation rate
  - ➢ H_2, HI, and HII mass
  - ➢ Radiation field
  - ➢ Abundances…
  - ➢ Usually requires other info (T_{dust}, FSL…)

- Focus: Bright [CII] tool for
  - ➢ Gas dynamics
  - ➢ ISM evolution
  - ➢ Spectroscopic redshifts for z>6 candidates



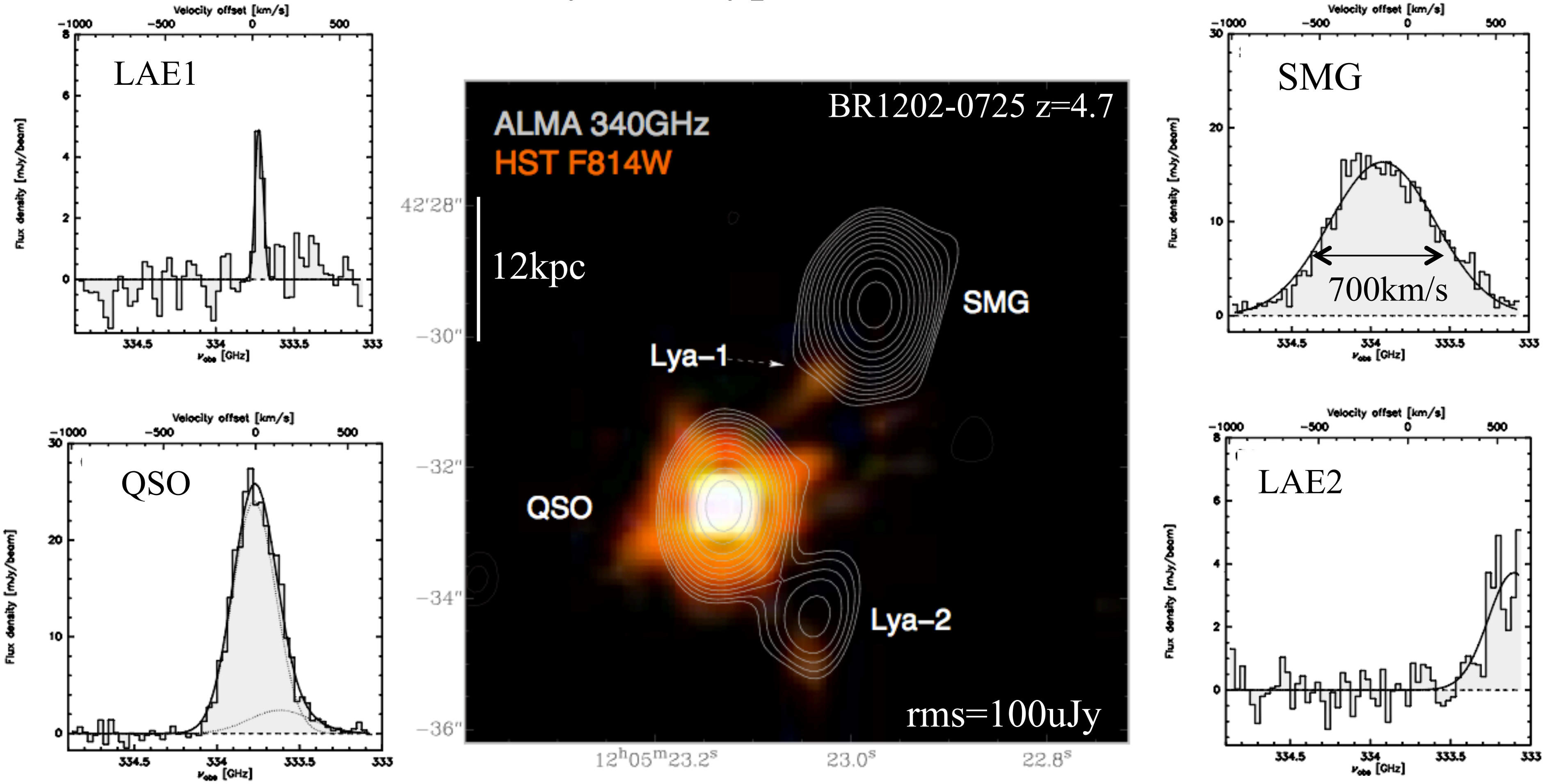
'This ubiquity of C+ with the varying contributions of these different components of the interstellar medium to the total energy radiated by C+ in different galaxies makes calibration of the [CII] versus star–formation rate a difficult task.' Goldsmith ea

The new age of [CII]: number of detections at z>1



Results within last year: ‘show and tell’

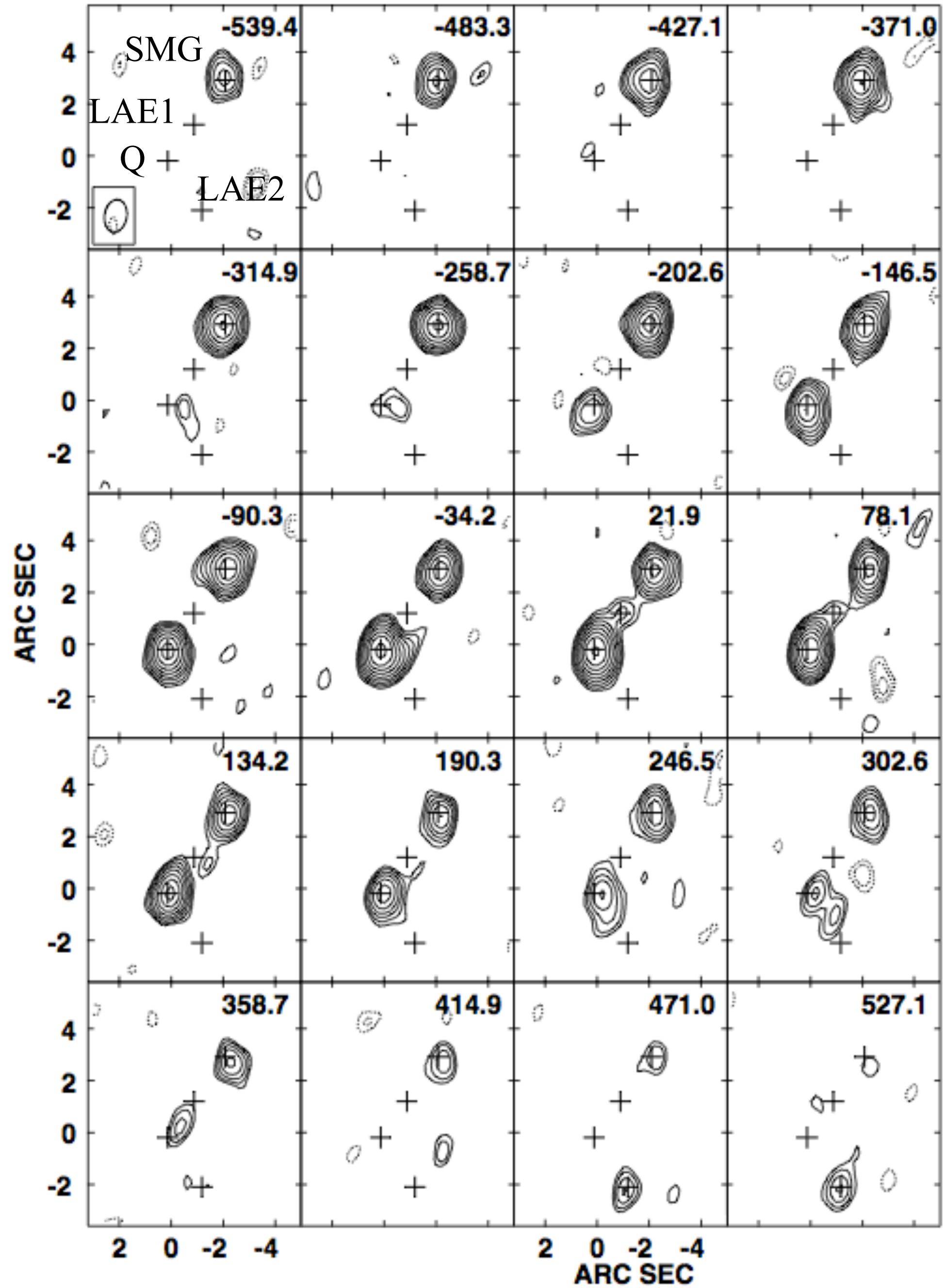
Imaging + Dynamics
Anatomy of a hyper-starburst at z=4.7



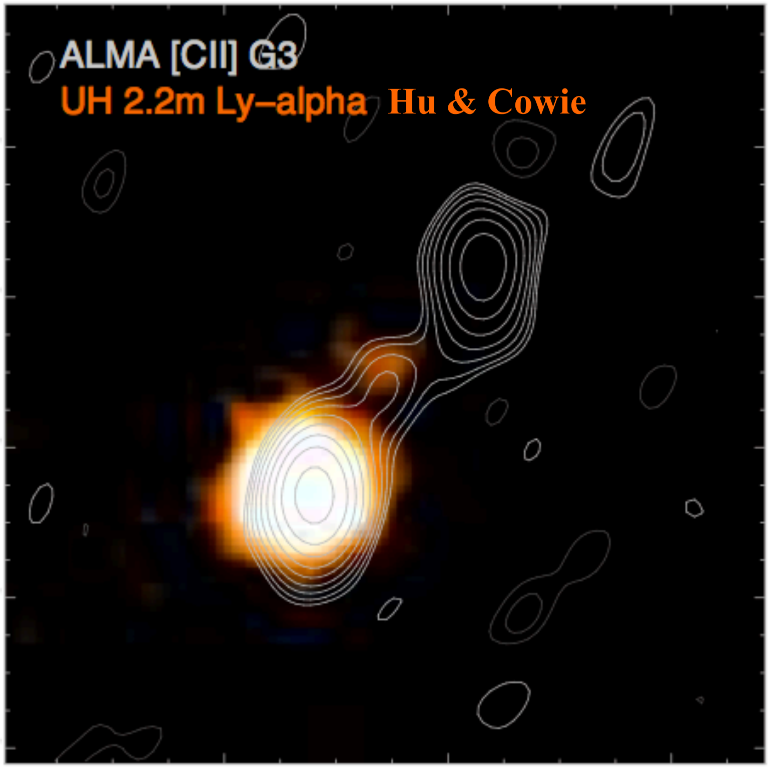
- Two hyper-starbursts (SMG and BAL quasar host): FIR ~ 3×10^{13} L_o ; SFR ~ 3×10^3 M_o/yr; M_{BH} ~ 10^9 M_o
- Two 'normal' LAE: SFR ~ 10^2 M_o/yr

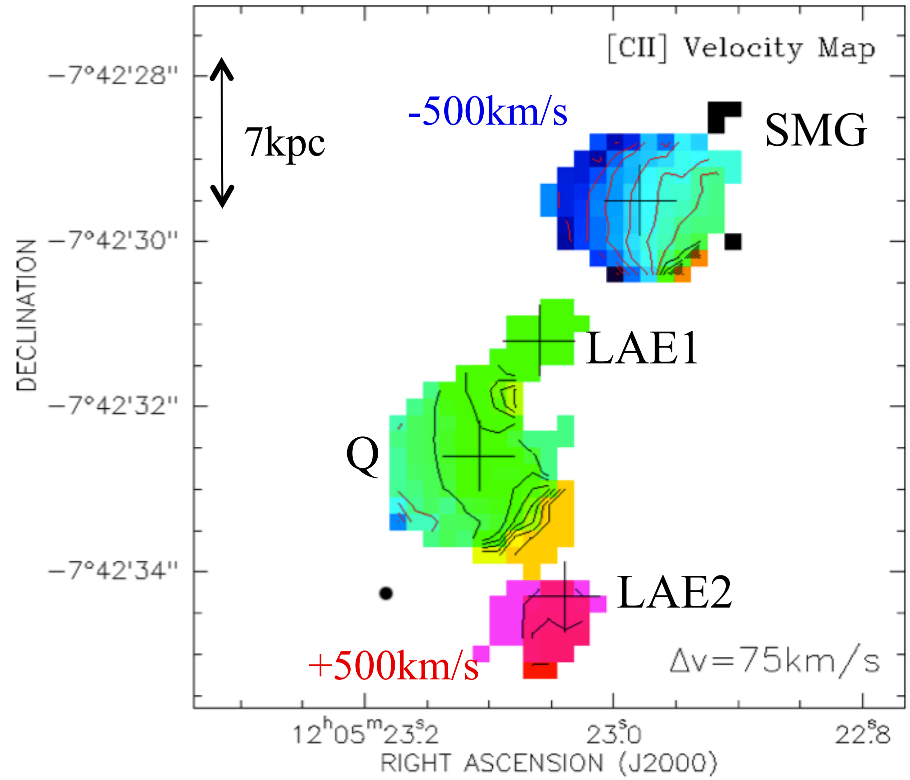
[CII] in 1202: Imaging cool gas dynamics at z=4.7

- Quasar, SMG: Broad, strong lines
- Tidal bridge across LAE1, as expected in gas-rich merger
- Possible quasar outflow, or further tidal feature, toward LAE2



Dynamics => major merger of gas rich galaxies driving massive galaxy/BH formation at t_{univ} ~ 1Gyr

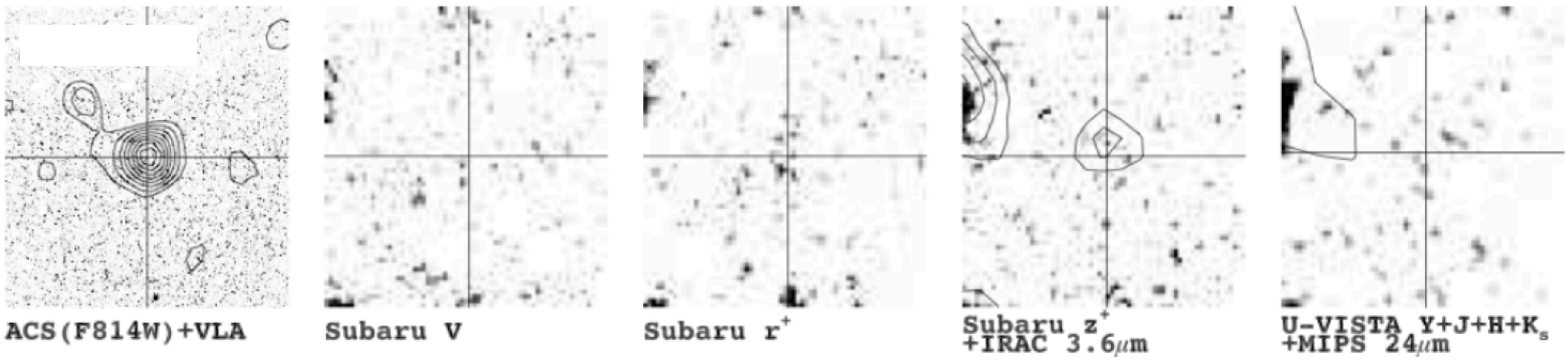




- Tidal stream connecting hyper-starbursts, narrow ΔV
- SMG: warped gas disk
- HyLIRG QSO host, with outflow in [CII] and CO, high ΔV
- LAE1: Ly-alpha + [CII] in tidal gas stream?
- LAE2: dust and [CII] in outflow?

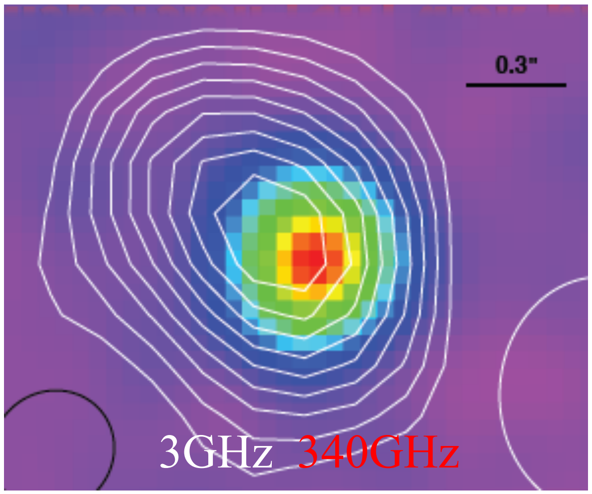
Cosmos SMG: disk dynamics at z=4.5 (Karim ea.)

ALMA 340 GHz: 20min, 30 ant, 0.35" res



Isolated SMG in Cosmos

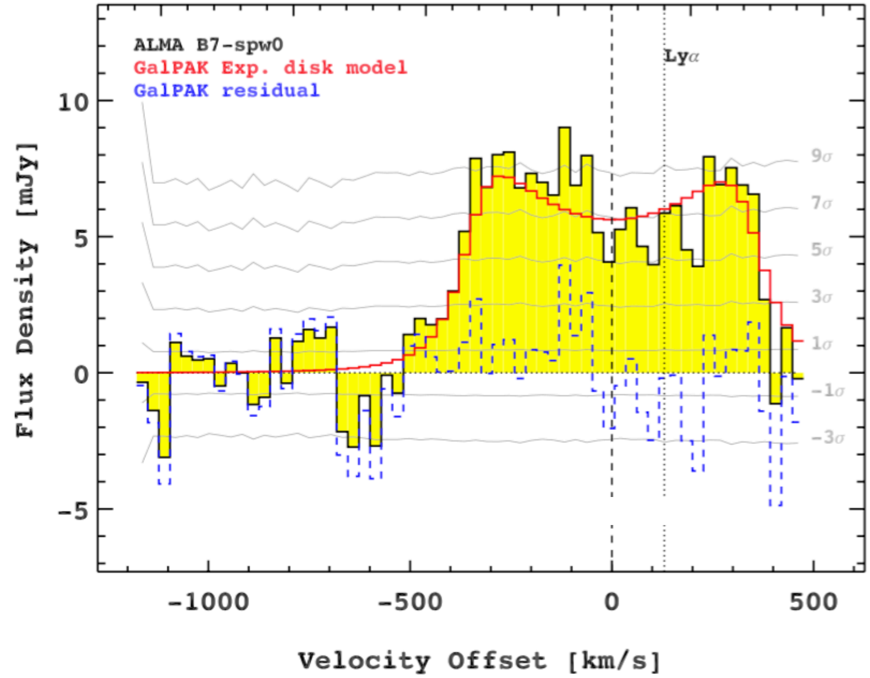
- No ACS/I detection
- FIR = 0.7e13 L_o
- SFR = 700 M_o yr^{-1}
- Dust size < 0.2"

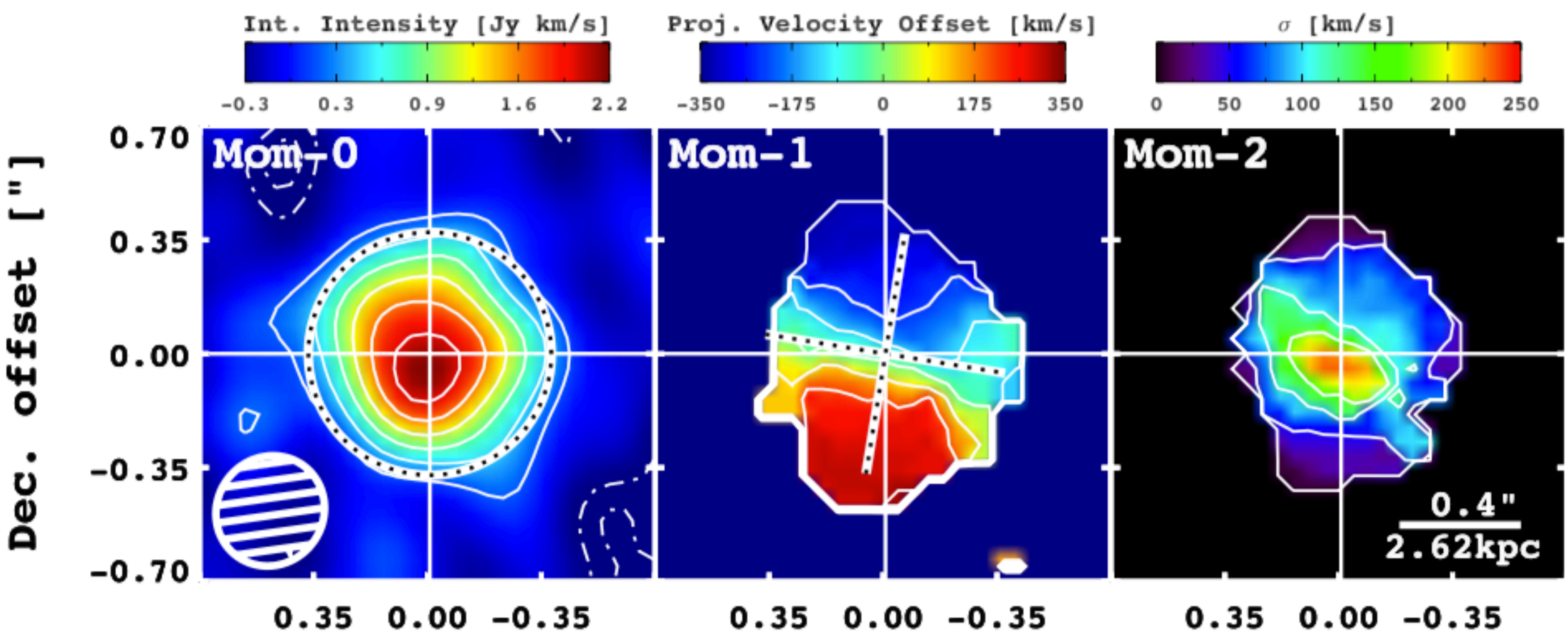


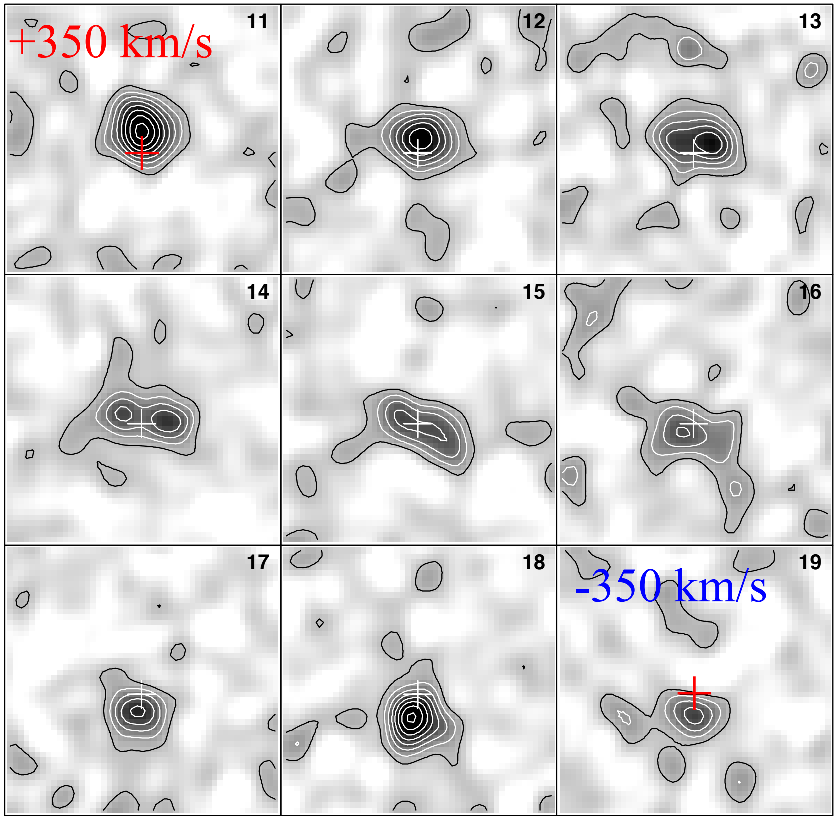
- JVLA: 50uJy at 3Ghz
- ALMA: 3mJy at 340 GHz

ALMA [CII] (Karim ea)

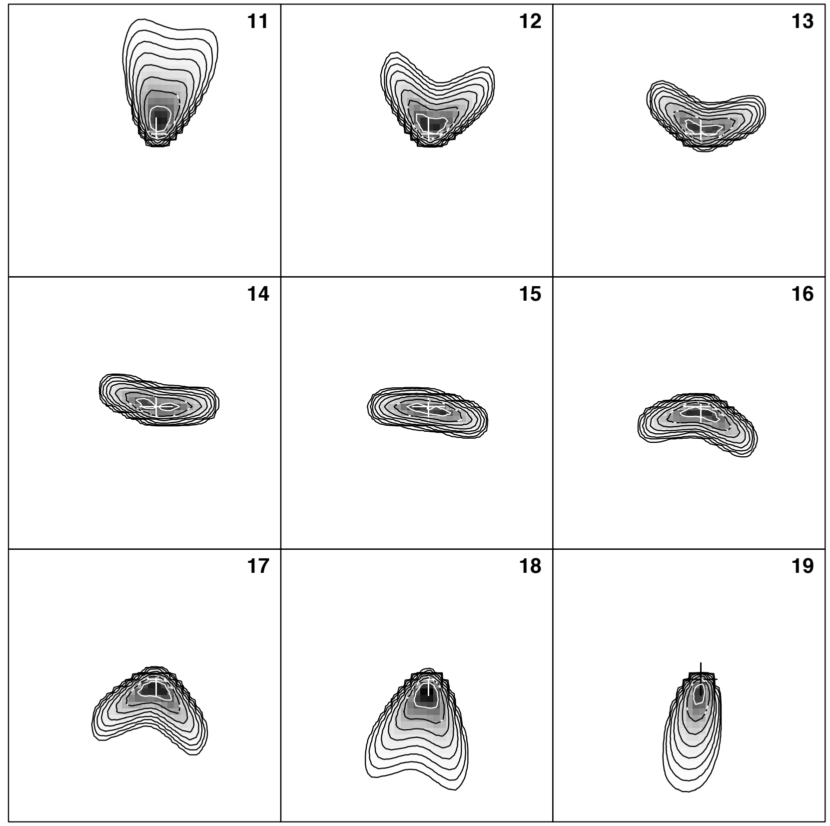
- 'double horn': width ~ 700 km/s
- [CII] = 5e9 L_o ~ 100x MW
- [CII]/FIR ~ 0.0008 ~ 0.25 x MW
- Clear velocity gradient ~ 1"







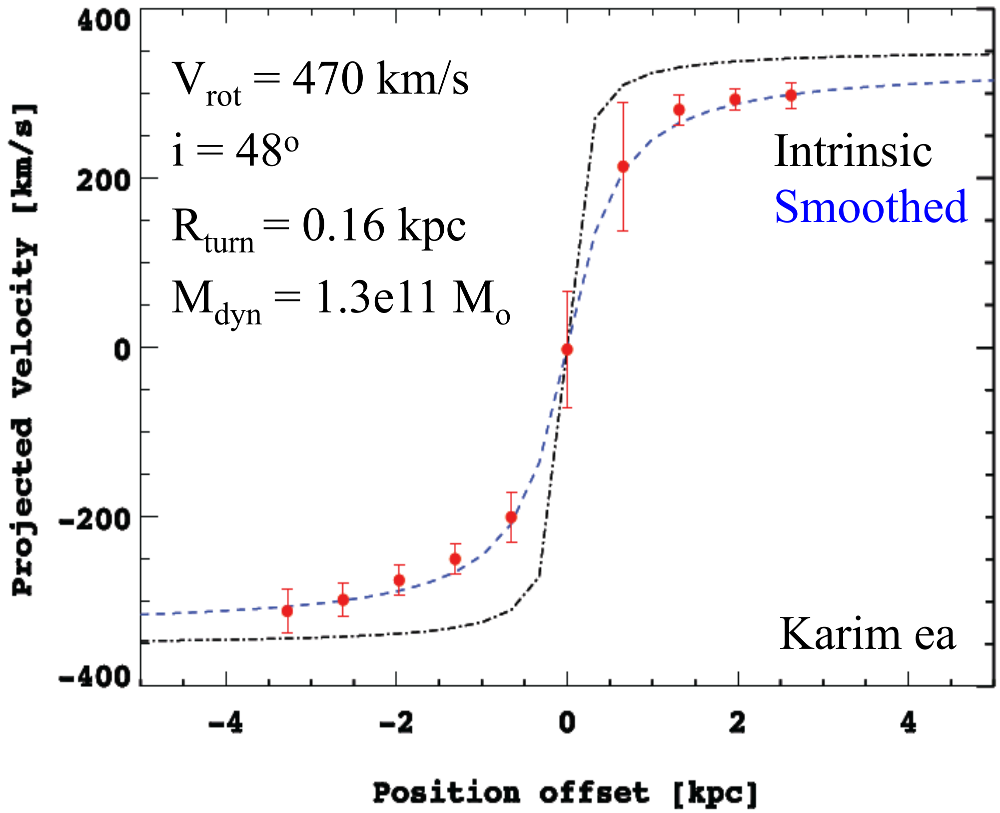
Karim ea

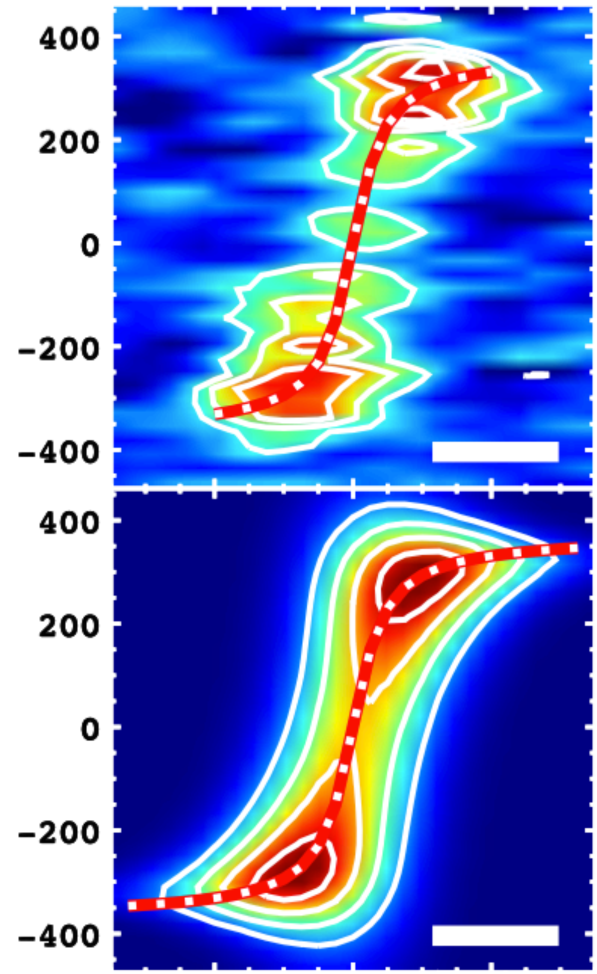


GALPAK (Bouchet): exponential disk

Disk galaxy rotation: butterfly pattern!

Flat rotation curve: Search for dark matter in 1st galaxies



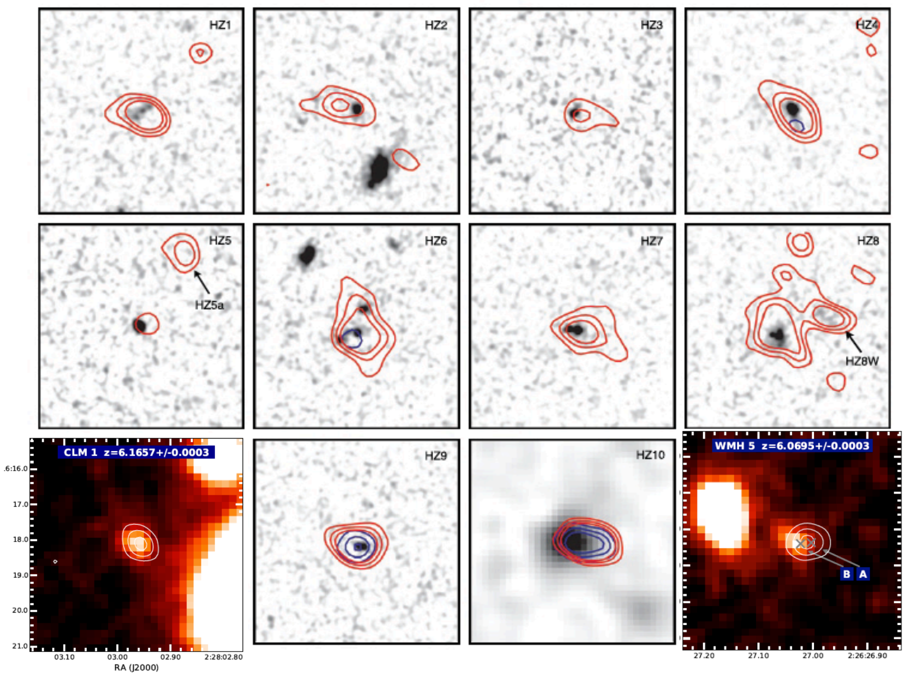


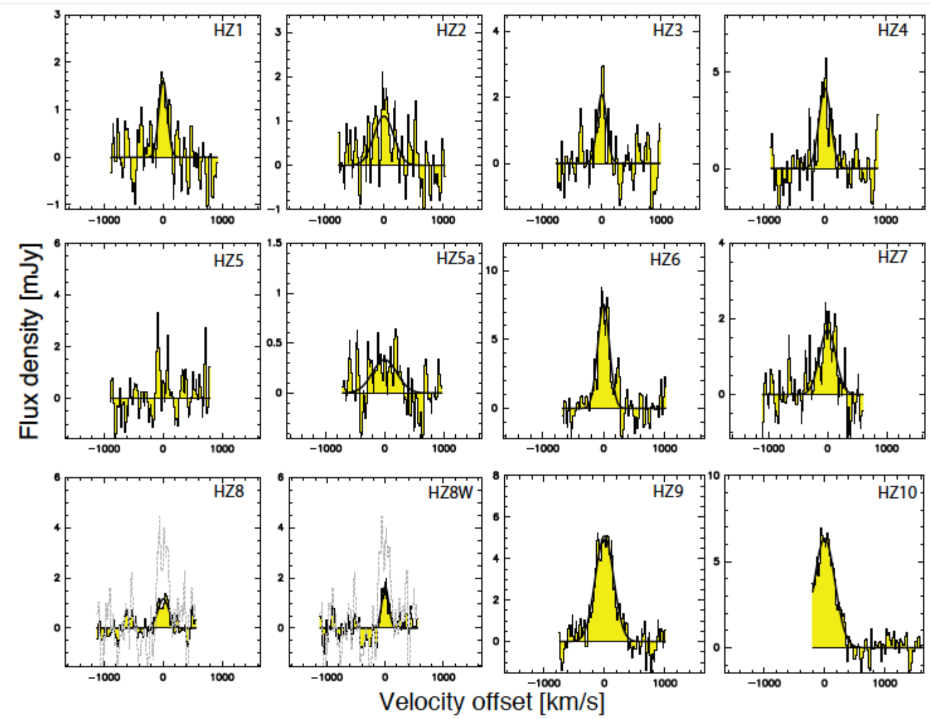
- Search for dark matter
  - ➢ Flat rotation curve: 1st step
  - ➢ Need distribution stars + cool gas
- Generally: [CII] + ALMA => dynamical imaging at z > 4 comparable to HI in nearby galaxies

ISM evolution in first 'normal' galaxies

ALMA observations of z ~ 6 LBGs

1hr per source, 30 ants, 0.5" res

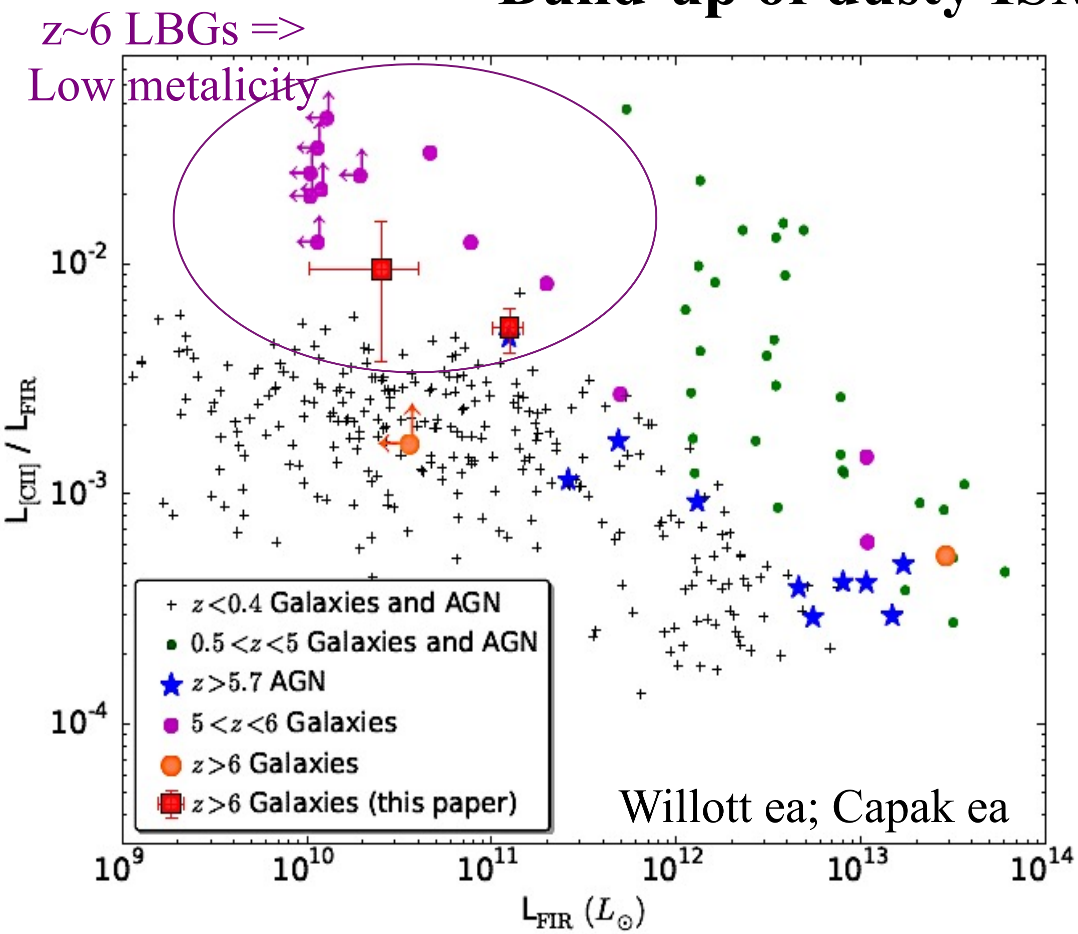


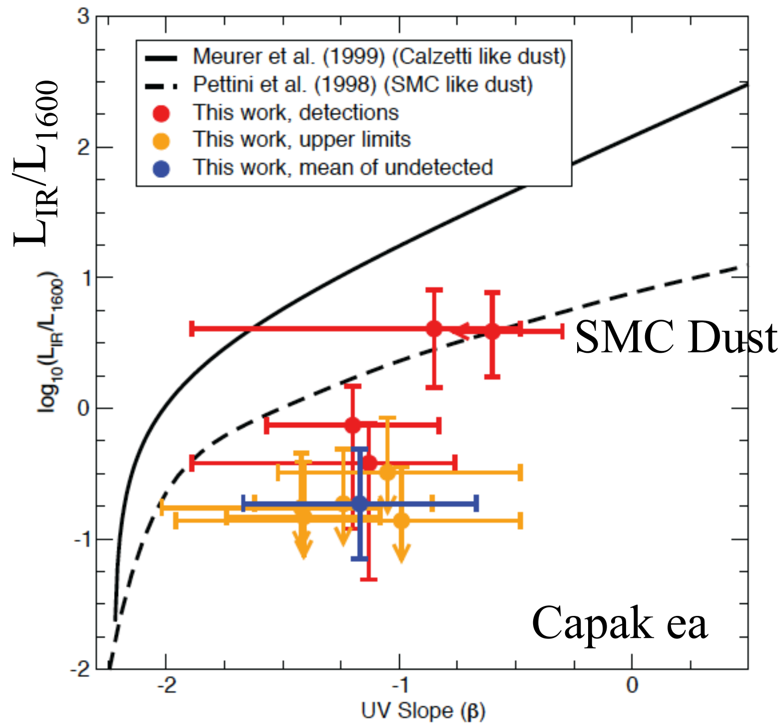


- Capak ea.: 10 LBGs at z ~ 5.5
- Willott ea.: 2 LBGs at z ~ 6.1
- SFR ~ few to 100 M_o yr^{-1}

- 11 of 12 detected in [CII] (non-detection = AGN)
- 4 or 5 in dust continuum
- Most are extended ~ 1"

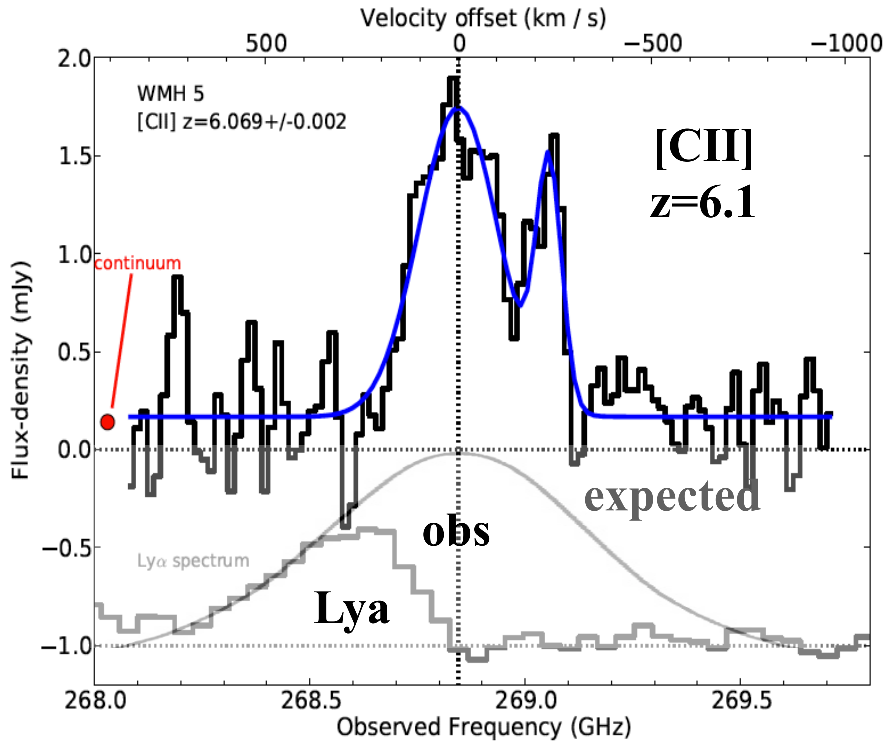
Build-up of dusty ISM at z ~ 6



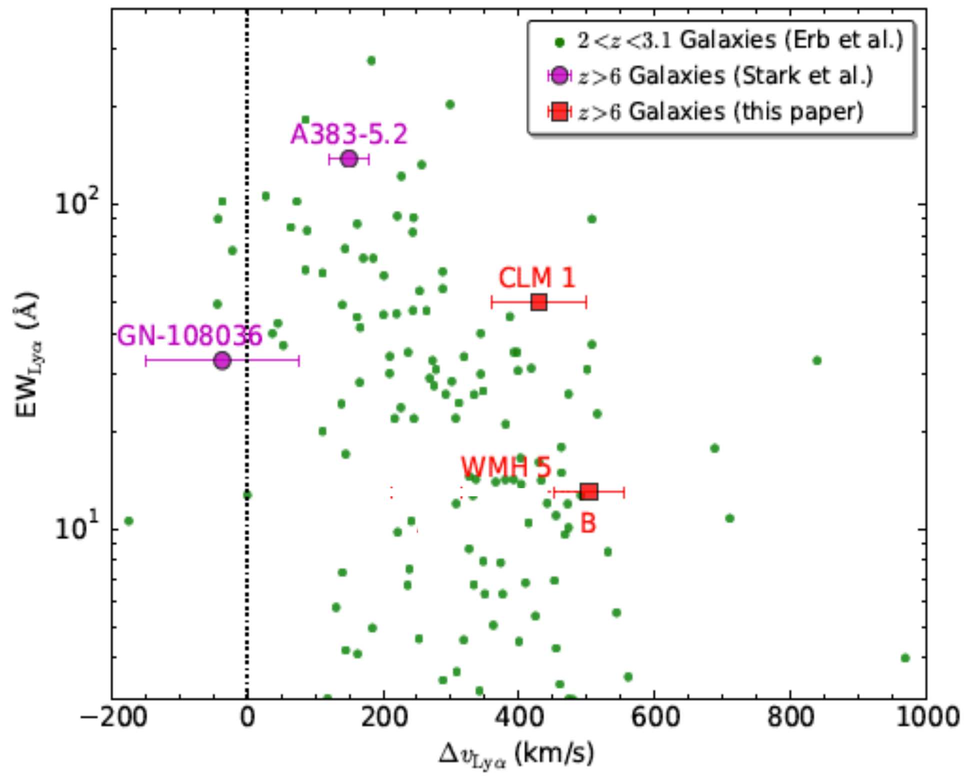


- [CII]/FIR ~ SMC/LMC => low metalicity (ie. Dust/Gas)
- IR/1600 => SMC-type dust (silicates, amorphous carbon?) => changes SFHU?
- Generally: [CII] can be strong w/o dust => don't select on dust!

Qualitative Evidence for increasingly neutral IGM z>6?



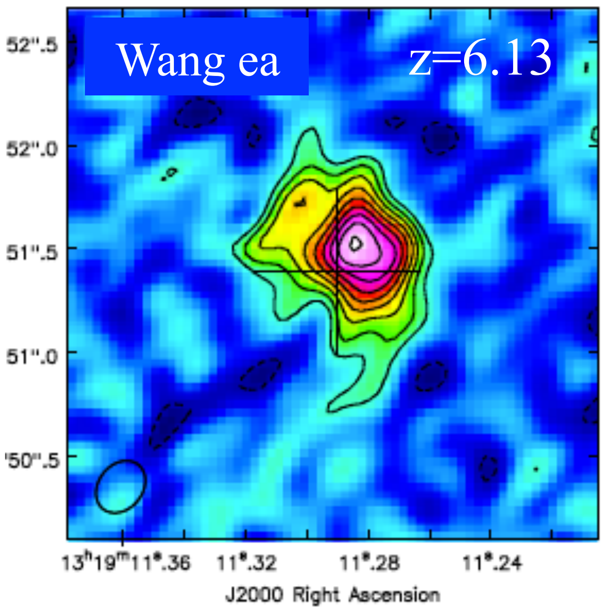
Willott ea

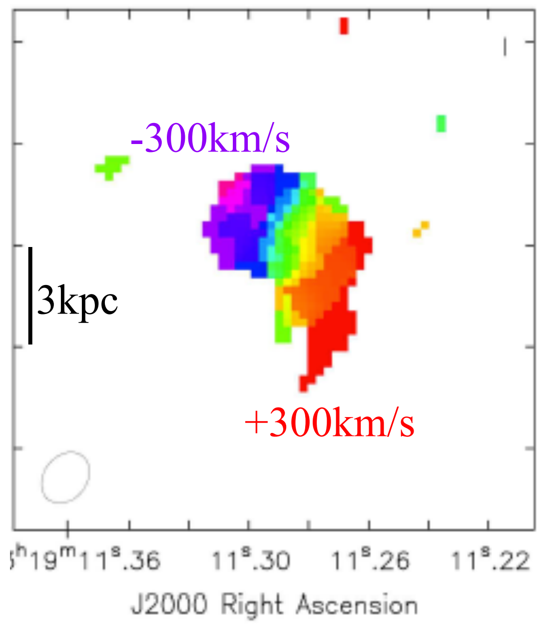


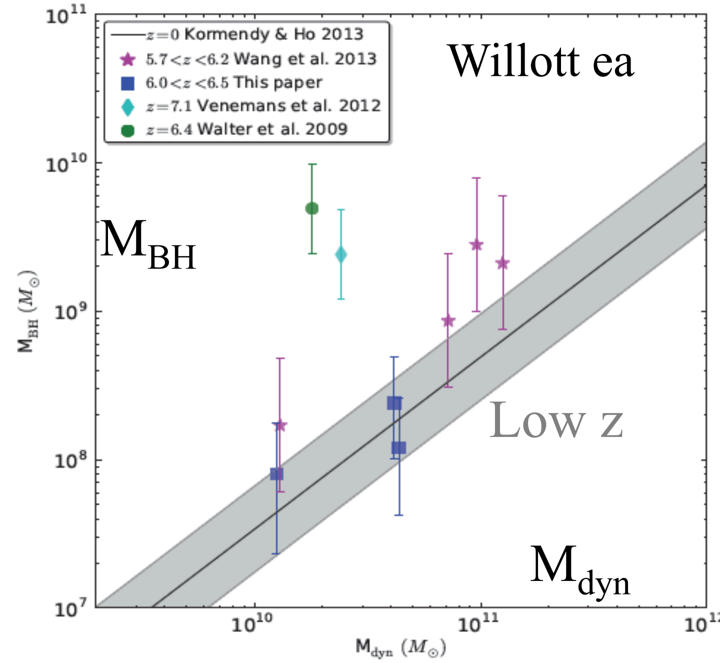
Weak, asymmetric Lya w. large velocity offset =>
resonant scattering by neutral IGM (Gunn-Petterson)?

Weighing z > 6 quasar host galaxies

[CII] 300GHz, 0.5" res, 1hr, 17ant







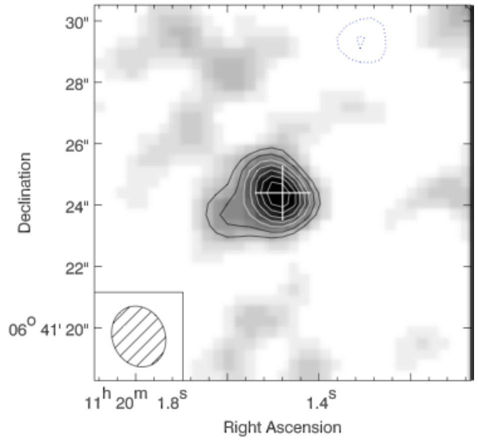
- 7/7 detected [CII] + dust
- Sizes ~ 2 – 5 kpc, clear velocity gradients
- Maximal SB disk ~ 1000 M_o yr^{-1} kpc^{-2}

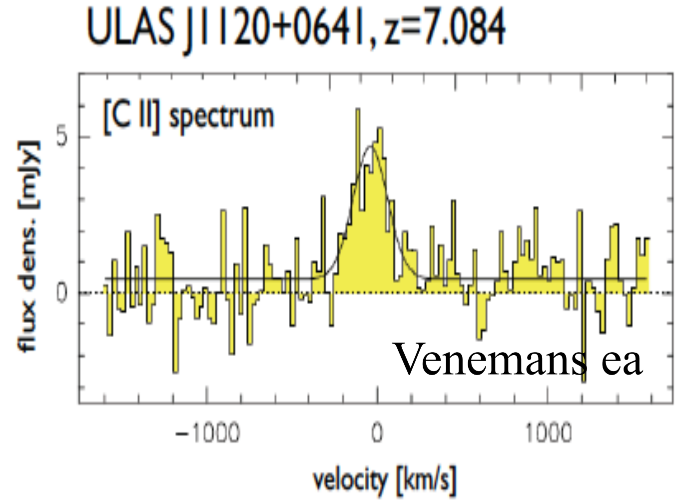
- M_{dyn} ~ few e10 to 1e11 M_o
- M_{BH} ~ 1e8 to 1e10 M_o
- Larger BHs than expected in some cases?
- Generally: [CII], CO only way to get M_{gal}

Redshift frontier: z > 7

Quasar host z=7.0 (Bure)

- Weak dust continuum
- Early, inhomogeneous enrichment IGM
- Host redshift + DLA profile => neutral IGM

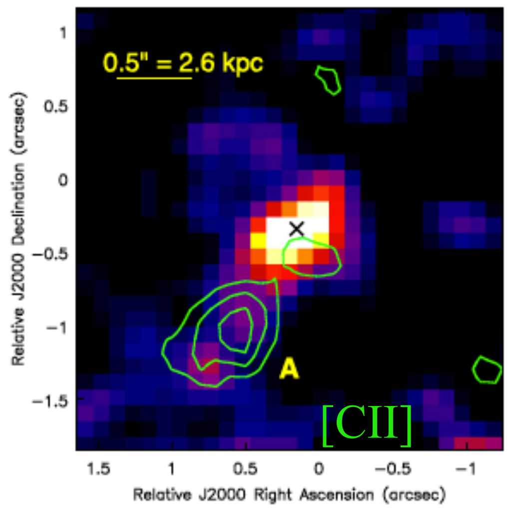


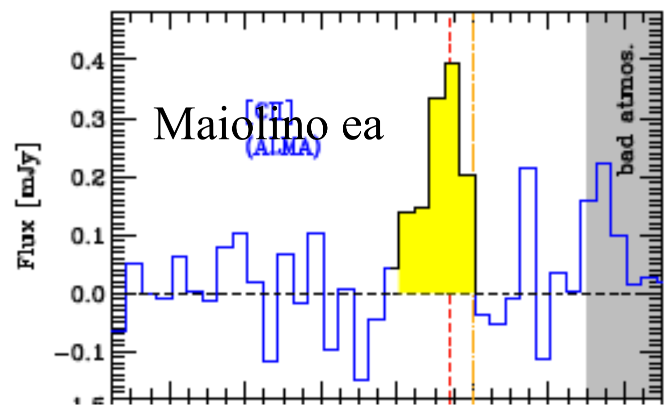


Venemans ea

Lyman Break galaxy z=7.1

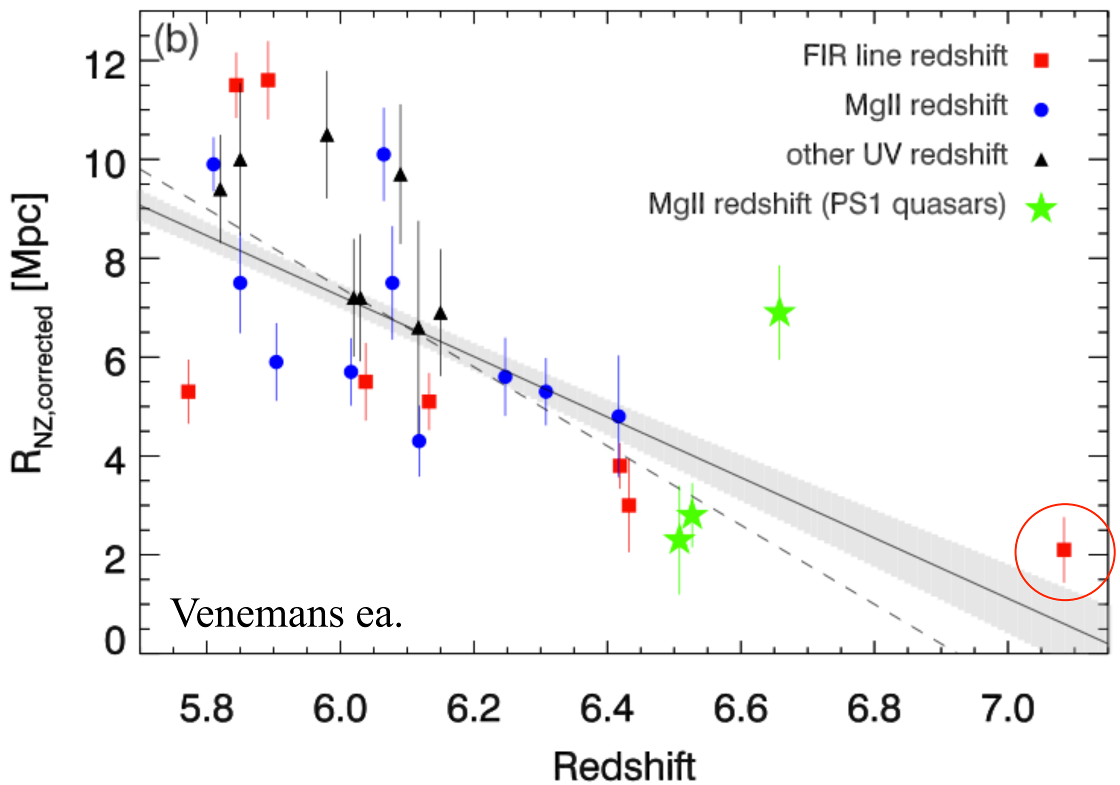
- Offset => satellite accretion?

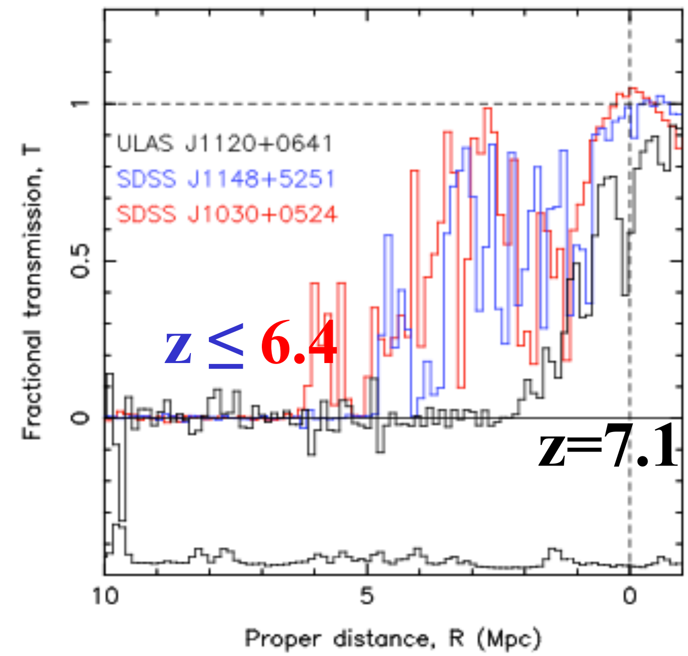




Maiolino ea

Quasar Near-Zones: R_{NZ} vs redshift [normalized to M_{1450} = -27]

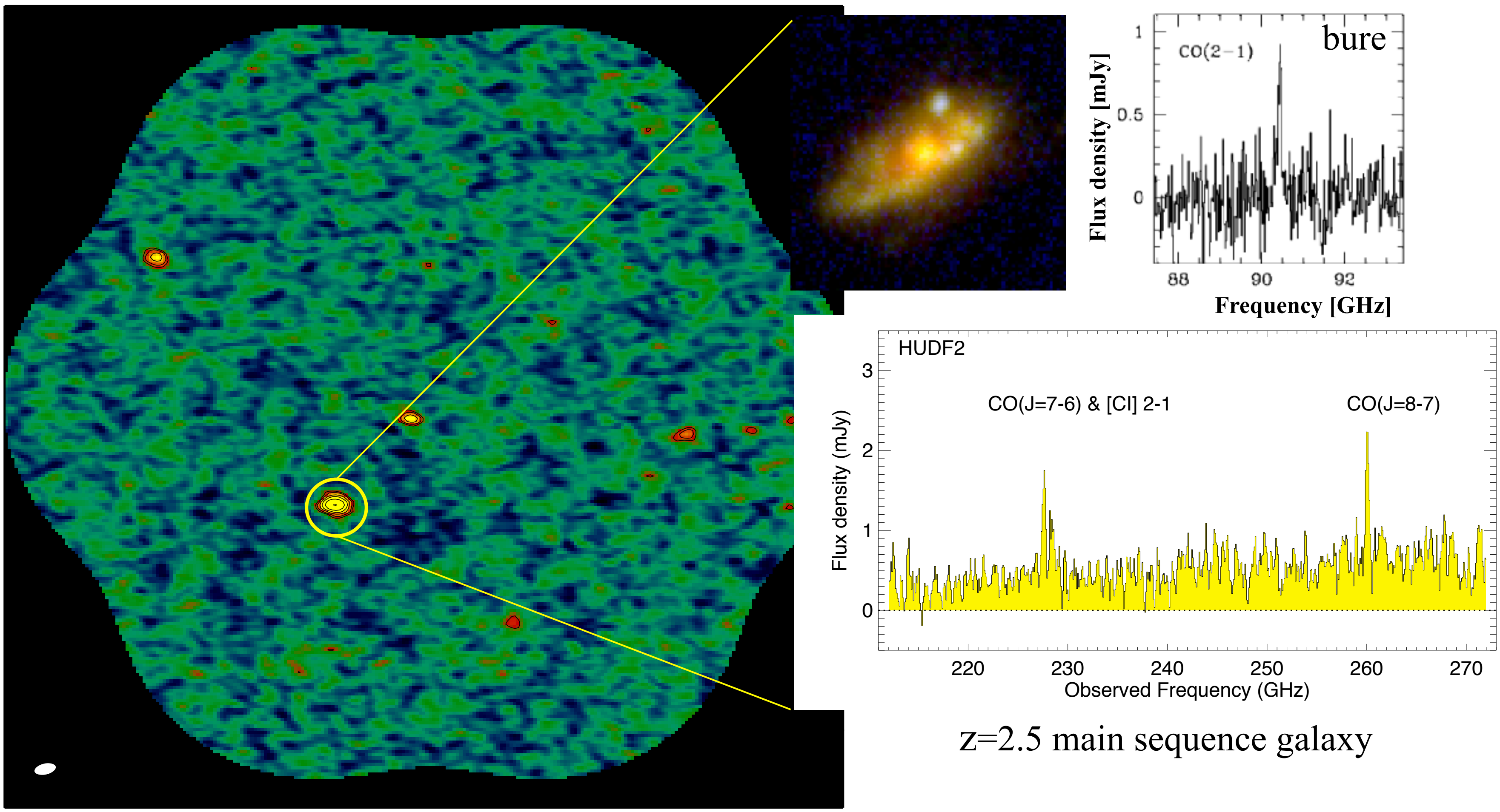




- $\langle R_{NZ} \rangle$ decreases by factor ~ 9 from z=5.7 to 7.1
- If CSS => F(HI) ≥ 0.04 by z ~ 7.1 (Venemans ea)

ALMA 1.2mm spectroscopy of the Hubble Ultra Deep Field (Aravena ea)

- ALMA 212 – 272GHz, 1 arcmin^2 => [CII] z=6 to 8
- rms_{cont} = 12uJy/beam => 10 M_o yr^{-1}
- [CII] limits ~ few M_o yr^{-1}

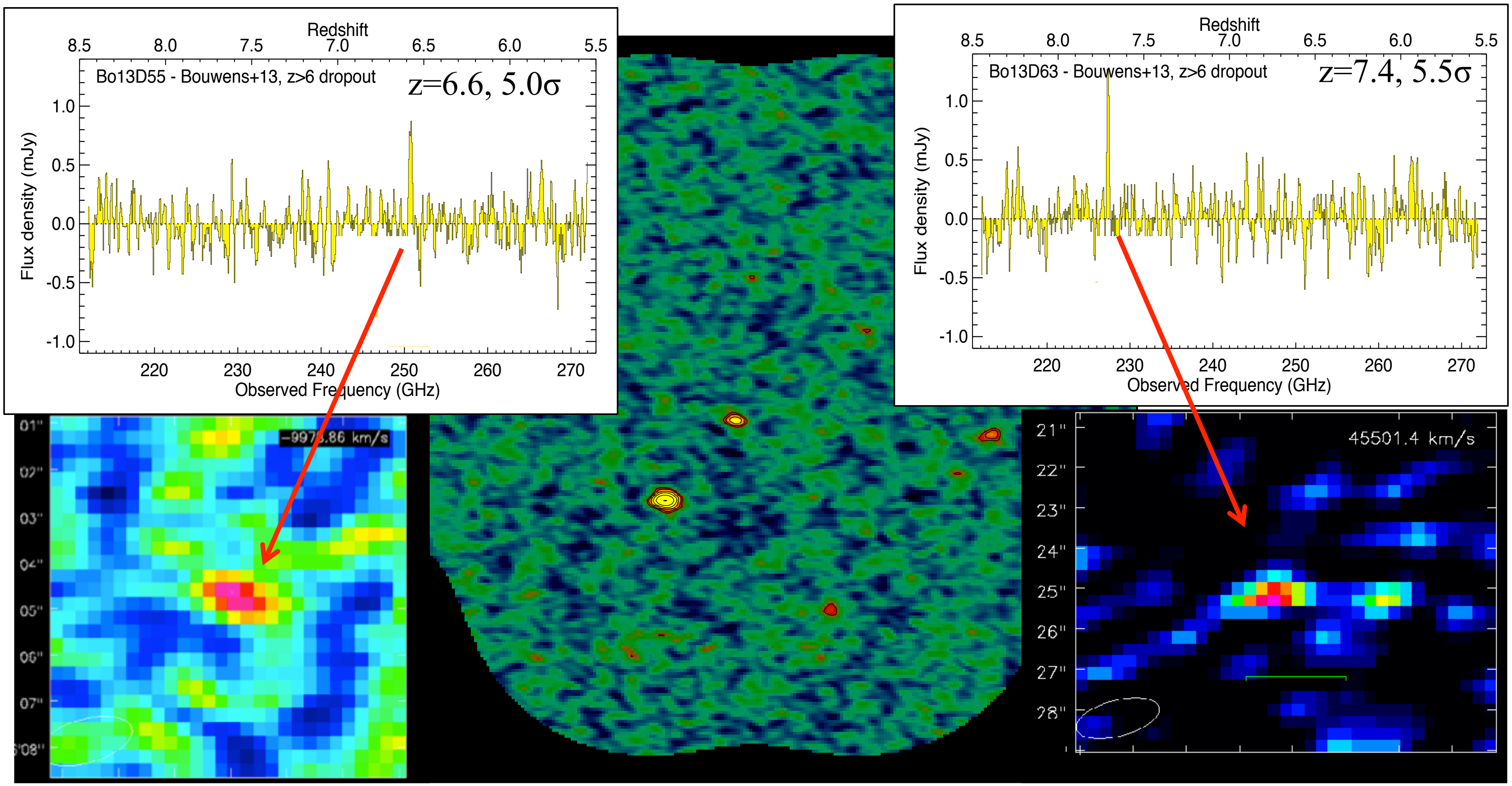


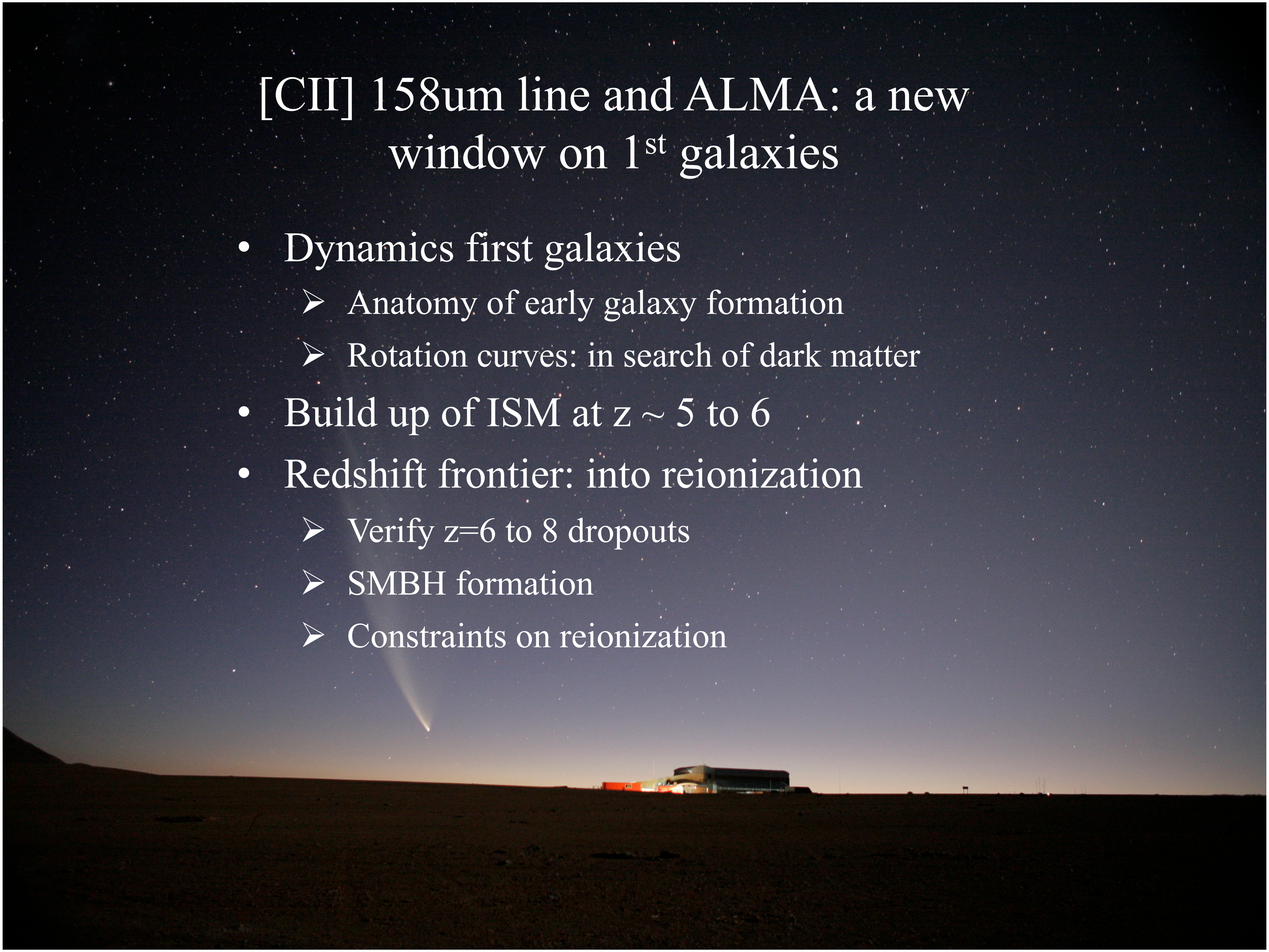
z=2.5 main sequence galaxy

ALMA 1.2mm spectroscopy of the Hubble Ultra Deep Field (Aravena ea)

20 candidate dropouts z ~ 6 to 8: Verify + Spec. z

- 6 [CII] lines at z=5.6 – 7.4 at > 4σ
- Line widths ~ 200 to 400 km/s
- L_{CII} => SFR ~ few to 10 M_o year^{-1}



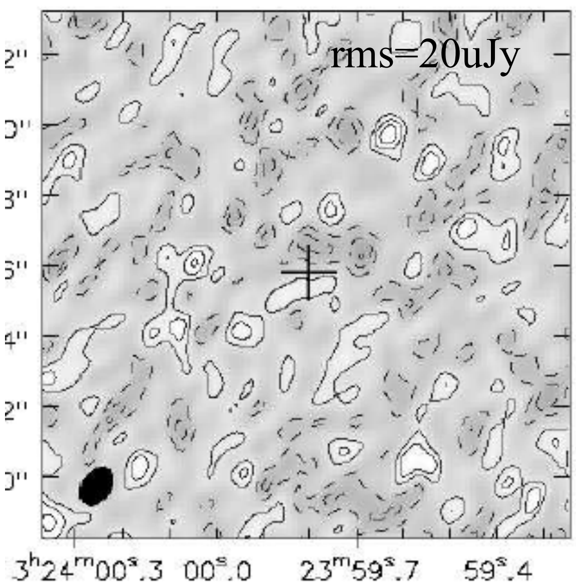


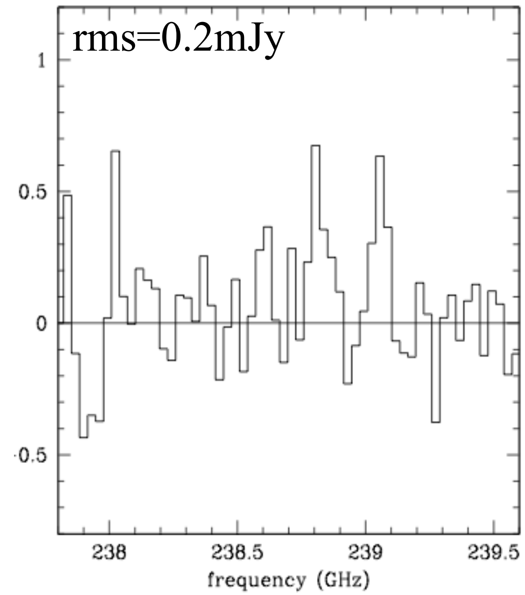
[CII] 158um line and ALMA: a new window on 1st galaxies

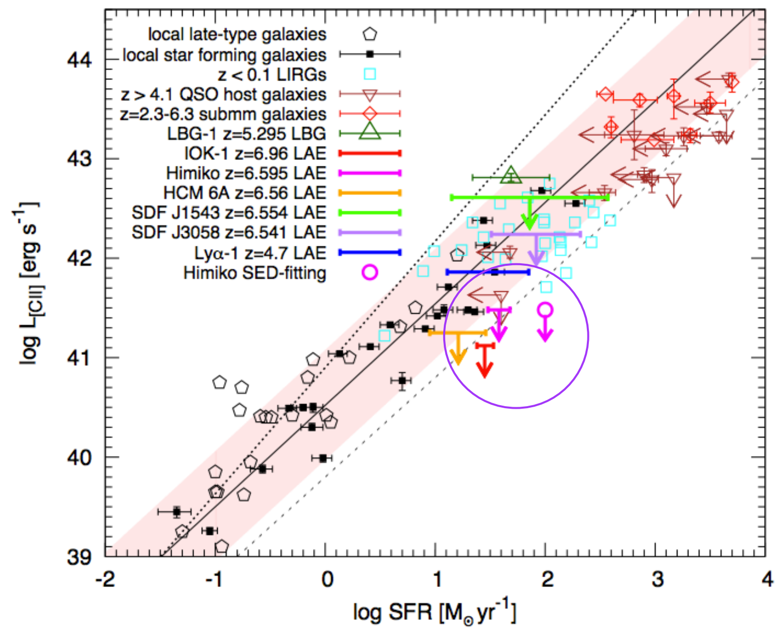
- Dynamics first galaxies
  - Anatomy of early galaxy formation
  - Rotation curves: in search of dark matter
- Build up of ISM at z ~ 5 to 6
- Redshift frontier: into reionization
  - Verify z=6 to 8 dropouts
  - SMBH formation
  - Constraints on reionization

Notable non-detections: LAEs z ~ 6.5 – 7

Himiko (Ouchi ea.) IOK-1 (Ota ea.)







- Below SFR – [CII] relation: support idea immature ISM (metalicity, dust) at z>6
- "LAEs in the reionization epoch have significantly lower gas and dust enrichment than AGN-powered systems and starbursts at similar/lower redshifts, as well as local star-forming galaxies"