ALMA Long Baseline Observations of the Strongly Lensed Submillimeter Galaxy HATLAS J090311.6+003906 at z = 3.042

ALMA Partnership et al. (2015)

Tsuyoshi ISHIDA (2015/11/06 Journal Club)

Abstract

ABSTRACT

We present initial results of very high resolution Atacama Large Millimeter/submillimeter Array (ALMA) observations of the z=3.042 gravitationally lensed submillimeter galaxy HATLAS J090311.6+003906 (SDP.81). These observations were carried out using a very extended configuration as part of Science Verification for the 2014 ALMA Long Baseline Campaign, with baselines of up to ∼15 km. We present continuum imaging at 151, 236 and 290 GHz, at unprecedented angular resolutions as fine as 23 milliarcseconds (mas), corresponding to an un-magnified spatial scale of ∼180 pc at z=3.042. The ALMA images clearly show two main gravitational arc components of an Einstein ring, with emission tracing a radius of ∼1.5″. We also present imaging of CO J=10-9, J=8-7, J=5-4 and H_2O ($2_{02} - 1_{11}$) line emission. The CO emission, at an angular resolution of ∼170 mas, is found to broadly trace the gravitational arc structures but with differing morphologies between the CO transitions and compared to the dust continuum. Our detection of H_2O line emission, using only the shortest baselines, provides the most resolved detection to date of thermal H_2O emission in an extragalactic source. The ALMA continuum and spectral line fluxes are consistent with previous Plateau de Bure Interferometer and Submillimeter Array observations despite the impressive increase in angular resolution. Finally, we detect weak unresolved continuum emission from a position that is spatially coincident with the center of the lens, with a spectral index that is consistent with emission from the core of the foreground lensing galaxy.

Introduction

- DSFGs は z = 2-3 で SFRD の大半を占め、**重力レンズ効果**により詳しい性質を調べることが出来る
  - H-ATLAS, HerMES, SPTS, HLS, etc…
- submm atomic/molecular lines から lensed source の性質を探る
  - ISM, star formation, AGN, structure, dynamics, etc…
  - lensing により **CO** 以外にもいろいろな lines が受かる
    - **HCO^+**, **HCN**, **H_2O**, etc…

Introduction

- H-ATLAS J090311.6+003906 (**SDP.81**)
  - lensed SMG @ z = 3.042 (<-> lensing galaxy @ z = 0.299)
  - lense model (Dye+13, Bussmann+14) -> $\mu \sim 11$
  - $L = 5.1 \times 10^{12}\ L_{Sun}$, SFR = 527 $M_{Sun}\ yr^{-1}$ (Negrello+14)
  - dust continuum by SMA, molecular lines by PdBI
    - **then followed-up by ALMA!**

Observations

- 2014 ALMA Long Baseline Campaign
  - baseline lengths ranged from ~15 m-15 km with 22-36 antennas
- Band 4, 6, 7 with 4 spws (2.0 mm, 1.3 mm, 1.0mm, spectral lines)
- integrated time = ~9-12 hrs per band
- synthesized beam size = ~23-60 mas
  - by uv-tapering CO line: ~170 mas, H_2O line: ~0.9″

Results

- Dust continuum emission

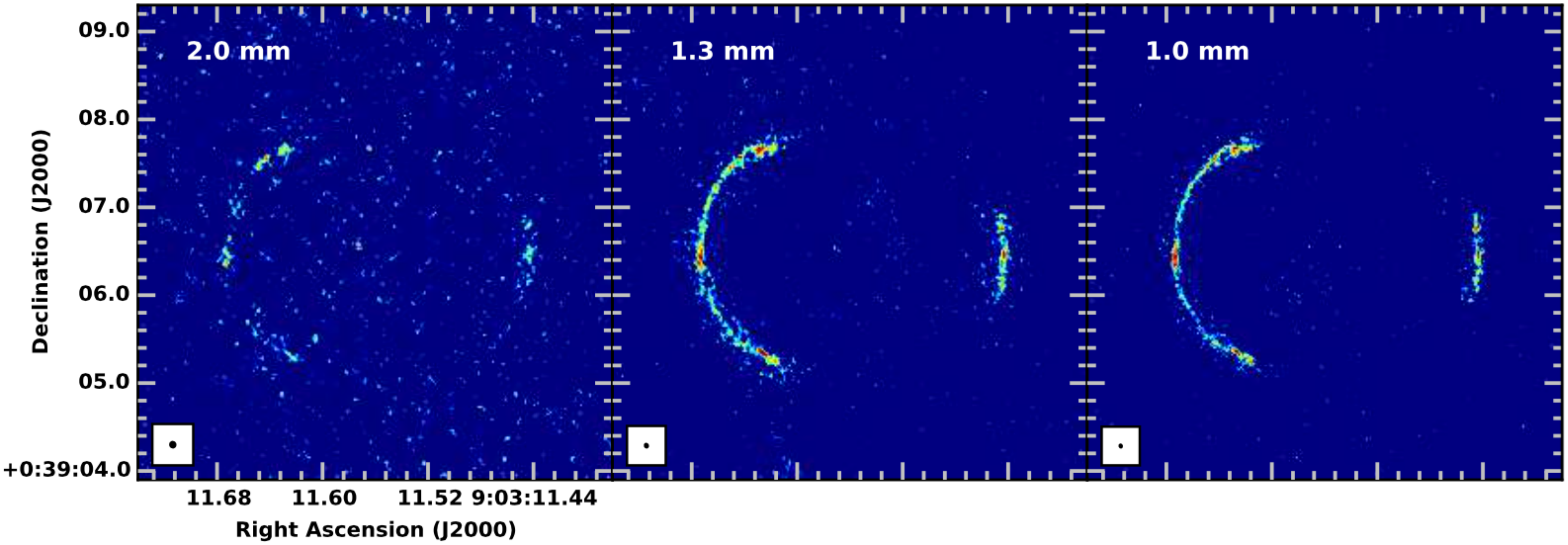


Fig.1 ALMA high resolution image of SDP.81

Results

- Dust continuum emission

Band	Frequency (GHz)	Component	S_ν pk [μJy beam^{-1}]	σ_{rms} [μ Jy]	θ_b [mas (deg)]	S_ν [mJy]	σ_{rms} [μ Jy]	θ_{taper} [mas (deg)]
4	151	Total	...	8	56×50 (18)	3.5±0.1	11	134×118 (61)
	(2.0 mm)	E	520± 8			2.8±0.1		
		W	353±8			0.7±0.1		
6	236	Total	...	10	39×30 (20)	26.3±1.3	21	164×114 (47)
	(1.3 mm)	E	141±10			19.3±1.3		
		W	112±10			7.0±0.4		
7	290	Total	...	9	31×23 (16)	37.7±1.5	21	170×106 (43)
	(1.0 mm)	E	124±9			27.7±1.0		
		W	112±9			10.0±0.2		
6&7	262	Total	...	...	...	32.9±1.0	15	163×110 (44)
	(1.14 mm)	E	806±15	...	...	23.5±0.5		
		W	627±15	...	...	7.0 ±0.2		

NOTE. — Column (3) Spatial components: eastern arc (E), western arc (W) and the total over all the emission. (4) Peak flux density in the specified arc component. Values were measured in the high resolution images whose beam sizes, θ_b, are listed in column (6), except for the combined Band 6&7 data for which we used the *uv*-tapered image (see Section 2). Uncertainties are 1σ where σ is the RMS noise level in the high resolution images, given in (5). For Band 6&7 the 1σ uncertainty is the RMS noise value given in (8). (7) The integrated flux density over the E and W arcs separately, and the total emission over all the arc components (see Section 3.1). Values are measured in the tapered images, whose beam sizes, θ_{taper}, are given in column (9). Uncertainties were calculated from the larger of either the rms variation of the flux density in apertures placed at source-free locations in the images or [no. independent beams]$^{0.5}$ $\times 3\sigma$ where σ is the RMS noise level given in (8). Values do not include 5% absolute flux calibration uncertainty. (8) RMS noise level in the *uv*-tapered images. Synthesized beam sizes of the high resolution and tapered images, and the beam position angle, are given in (6) and (9), respectively.

Table.2 ALMA continuum parameters

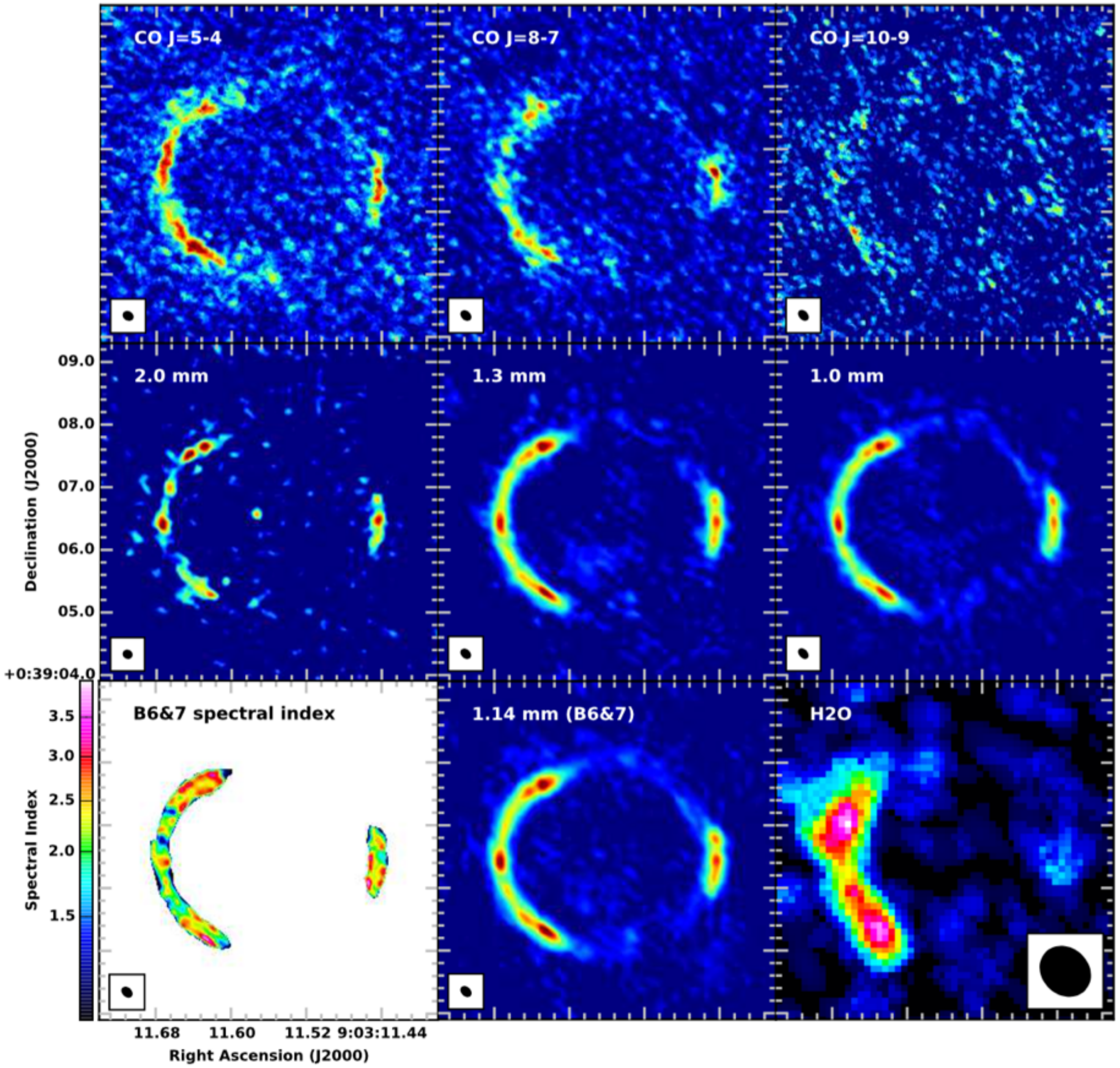


Fig.2 ALMA image with uv-tapering

Results

- **Unresolved centroid emission**
  - NO detection of CO & H_2O
  - inconsistent with SED model (Negrello+14)
  - spectral index = -0.49±0.13 => foreground galaxy?

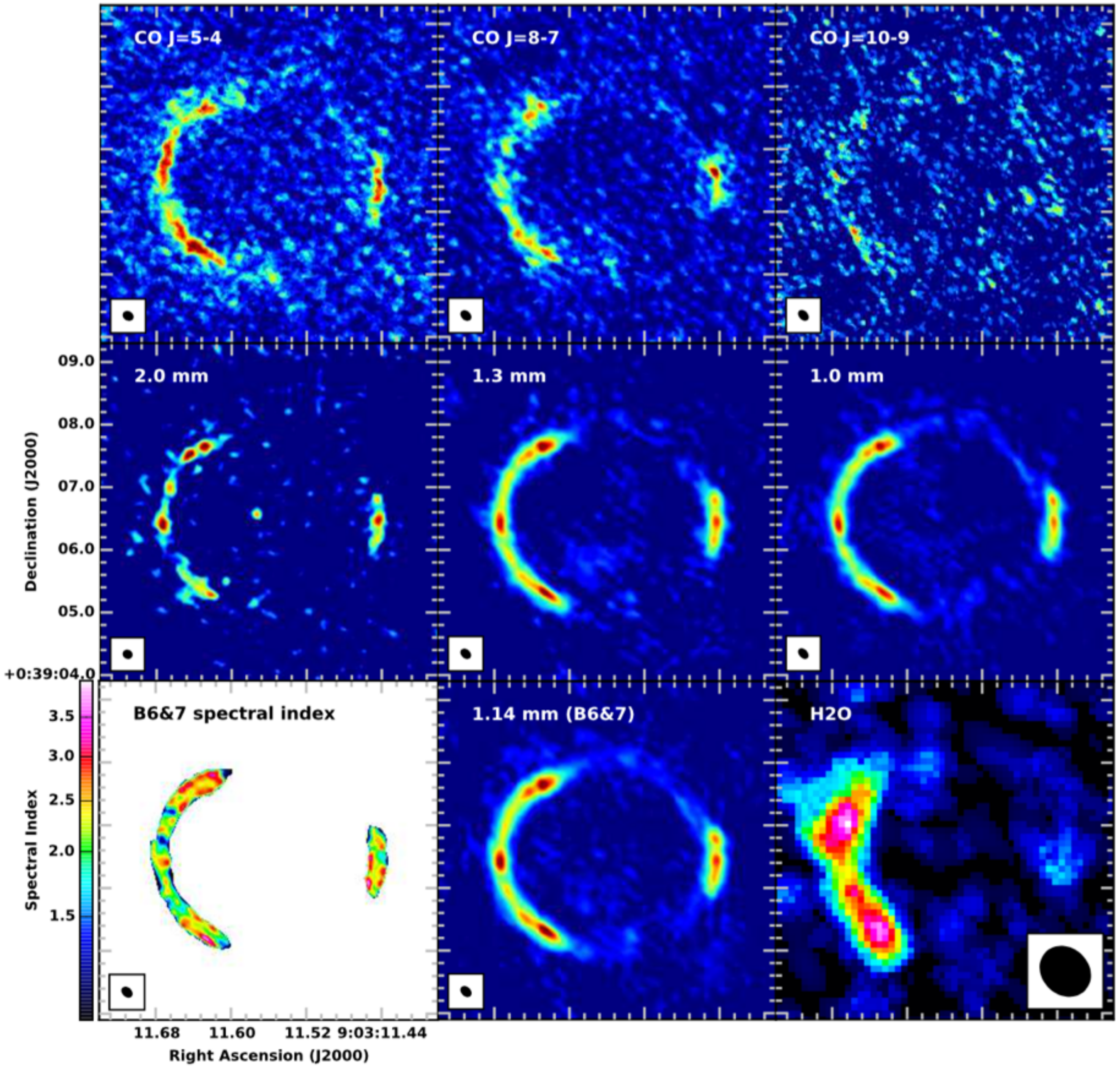


Fig.2 ALMA image with uv-tapering

Results

- **Properties of CO images**
  - spatial morphology is quite different with continuum
    - difference of origin?
    - low S/N in CO J = 10-9?

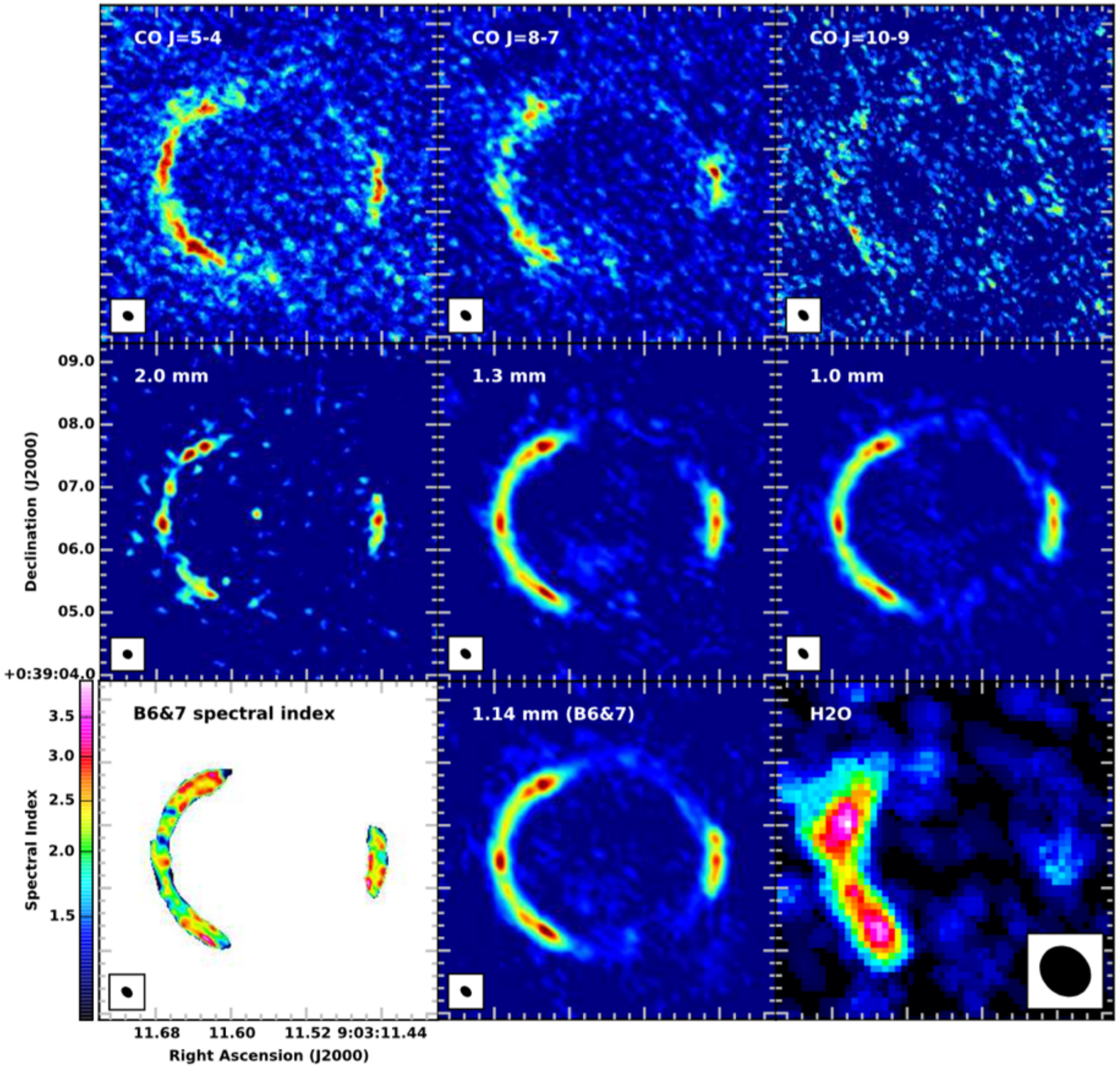


Fig.2 ALMA image with uv-tapering

Results

- **Properties of CO images**
  - consistent with Omont+13
  - B is brighter in higher-J
    => originates from hotter gas
  - line width is typical in SMGs

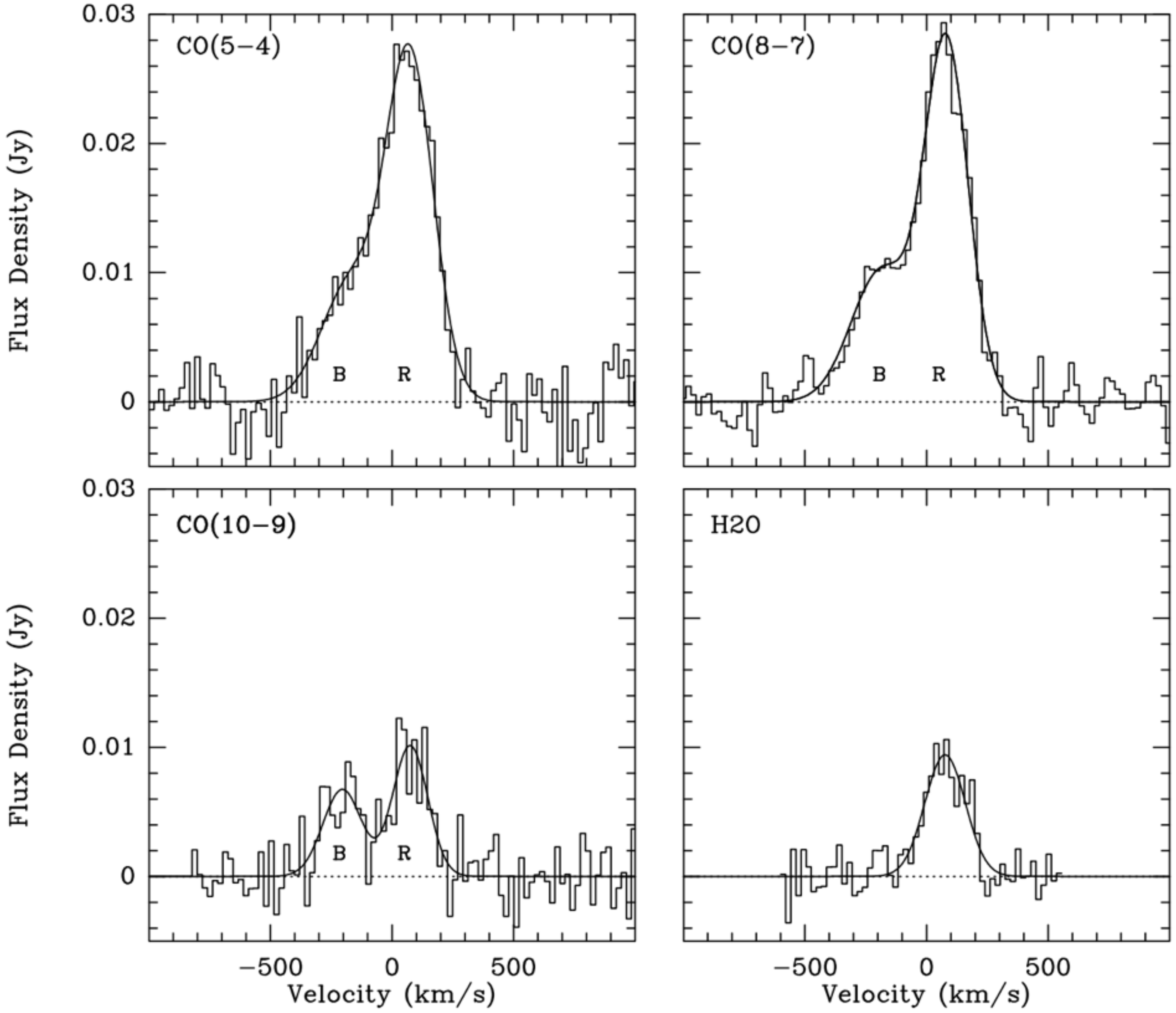


Fig.3 ALMA CO and H_2O spectra

Results

- Velocity structure of CO

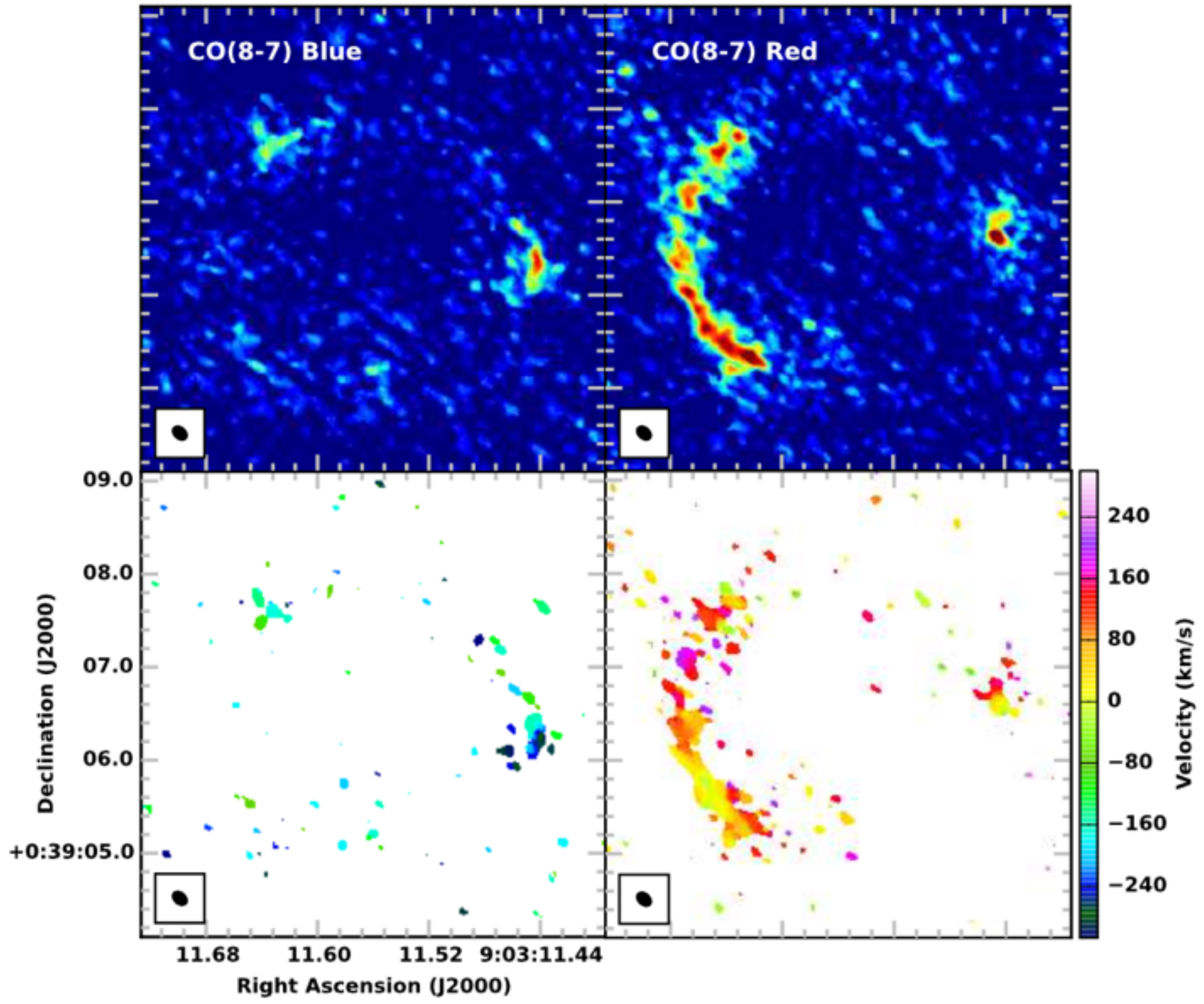


Fig.5 integrated intensity fo CO J=8-7

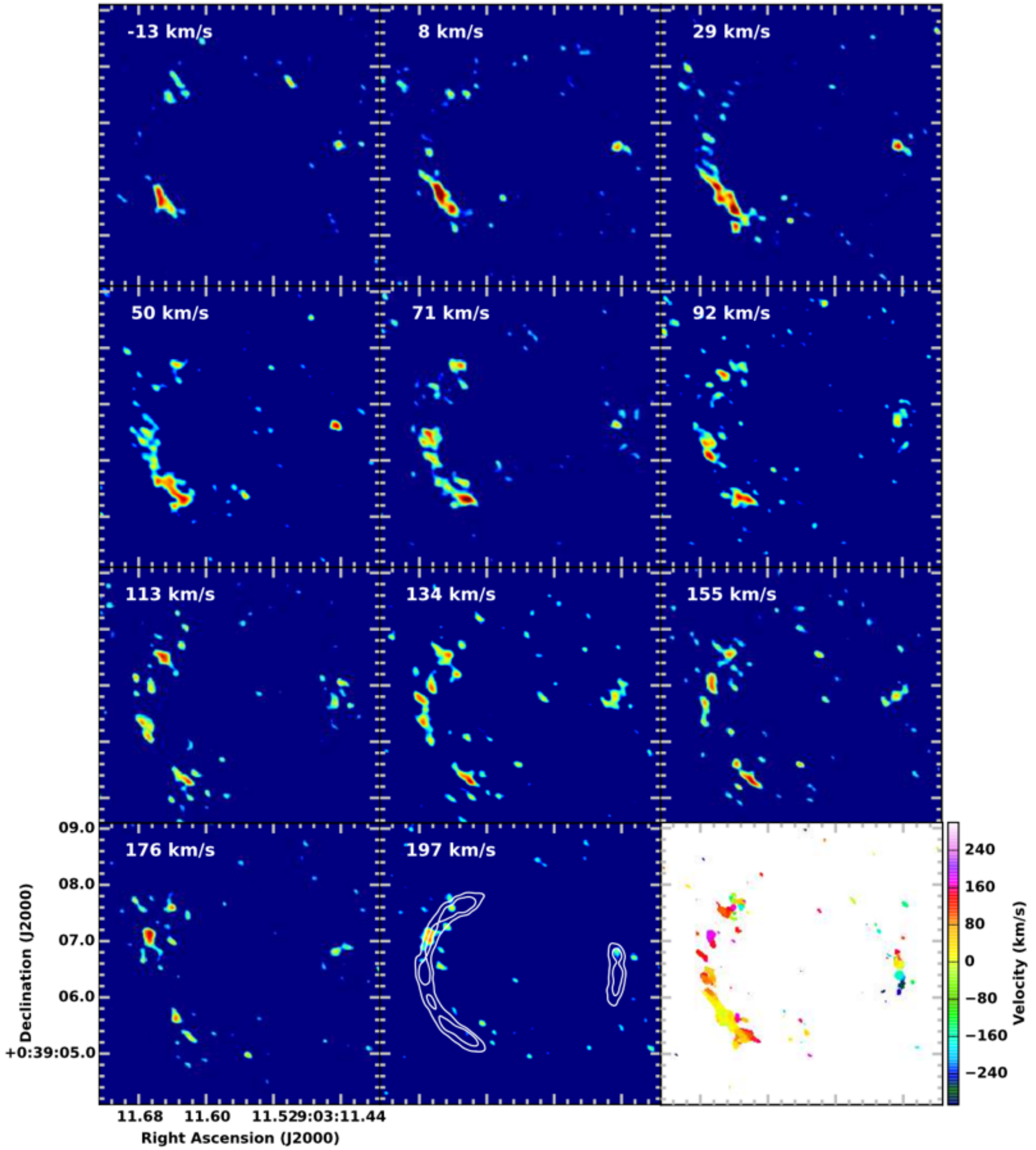


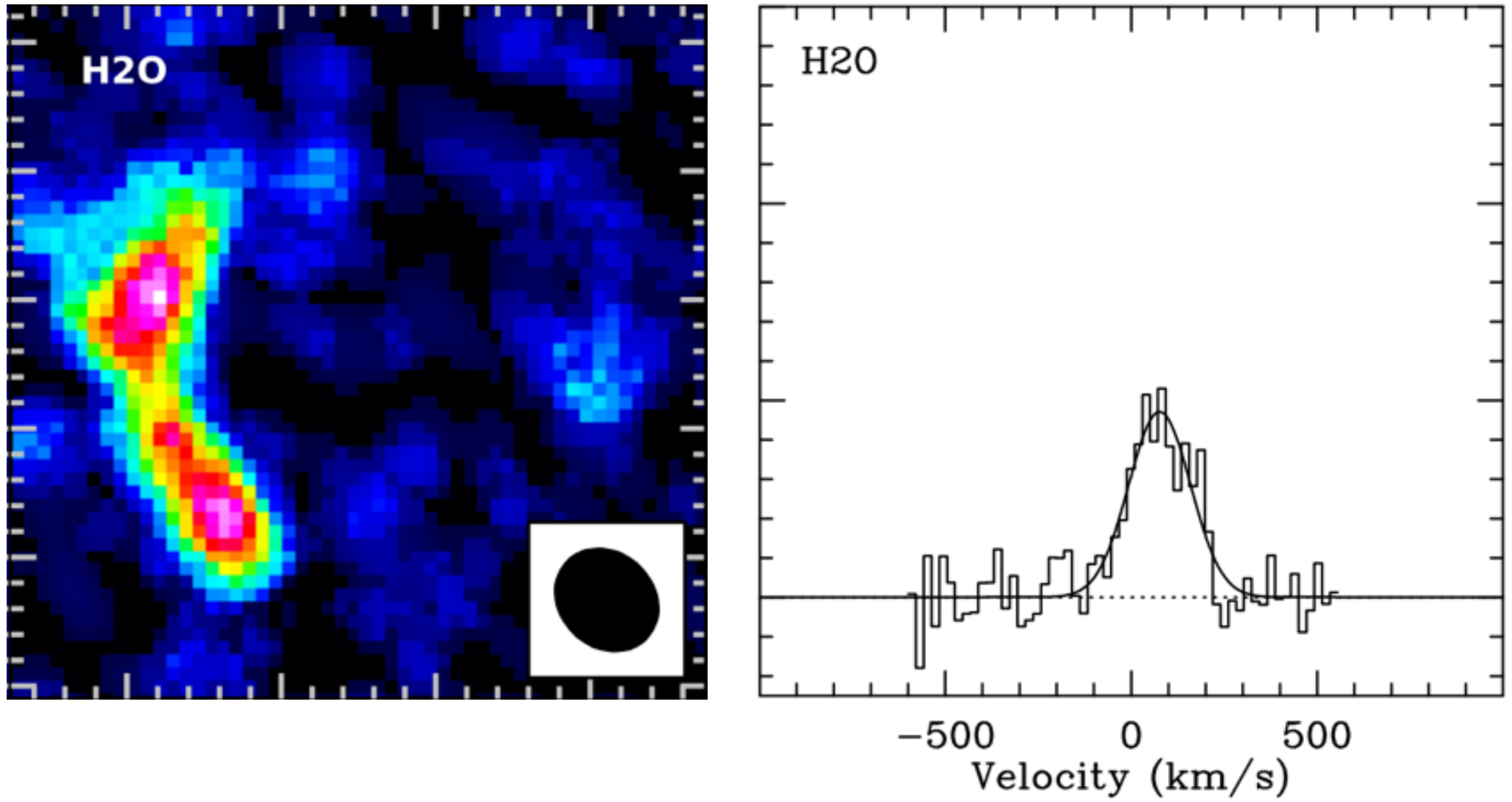
Fig.4 channel maps for CO J=8-7

Results

- **CO line ratios**
  - r_{85} = 0.5±0.1, r_{108} = 0.2±0.1, r_{105} = 0.1±0.1, r_{31} = 0.3±0.1
    => presence of low-excitation gas
  - most SMGs have a lot of cool, moderate-density, extended gas?
  - L_{IR} / L'_{CO} = 346±62 L_{Sun} (K km s^{-1} $pc^2)^{-1}$
    - upper end values of local ULIRGs (Solomon+97)
    - typical values of SMGs (Greve+05)

Results

- Water emission
  - highest resolution to date!
  - originates from R component
- H_2O line ratios
  - diagnostic of PDR v.s. XDR
  - I_{H2O} / $I_{CO\ J=8-7}$ = 0.2 ± 0.1 => relatively low for active galaxies
  - L_{H2O} / L_{IR} = 6.7×10^{-6} => lower end values of high-z sources



Discussion

- weak continuum emission at the center of lens
  => **foreground AGN with very low accretion rate**
- similarity in the spatial/spectral distributions of the CO and H_2O
  => **both species have a common origin**
- subthermal (<<1) CO line ratios and strong high-J CO lines
  => **presence of extended cool and moderate-density gas**
- higher-J CO lines are less luminous
  => **AGN present would be subdominant**

Discussion

- H_2O / CO(8-7) is lower than other high-z sources
  => **missing extended H_2O emission or H_2O/CO excitation is low**
  - former does not seem likely given the ALMA and PdBI similarity
  - **differential lensing** causes relatively weak H_2O emission?
- **Future Works**
  - detailed foreground mass modeling
  - constraints on the differential lensing b/w stellar & dust emission