On the gas and dust components of a high redshift galaxy

Pham Tuan Anh

On behalf of Dept. of Astrophysics of VNSC/VAST

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Content

INTRODUCTION

RX J0911.4+0551 (z~2.8)

1. CO(7-6) (PdBI)
2. CO(10-9) and (11-10) (ALMA)
3. 358 GHz continuum (ALMA)

CONCLUSION

Introduction

Four main actors of galaxy evolution (early cosmic times):

- Supermassive black hole: optical and X rays
- Gas reservoir: millimetre/sub-millimetre
- Dust content: infrared
- Stars: optical

Dark matter is not directly accessible to observation

Only recently few quasar hosts could be spatially resolved both dust & gas components

Mergers: identified by comparing the respective locations of the optical, gas and dust components; seen as important sources of dust away from the central black hole

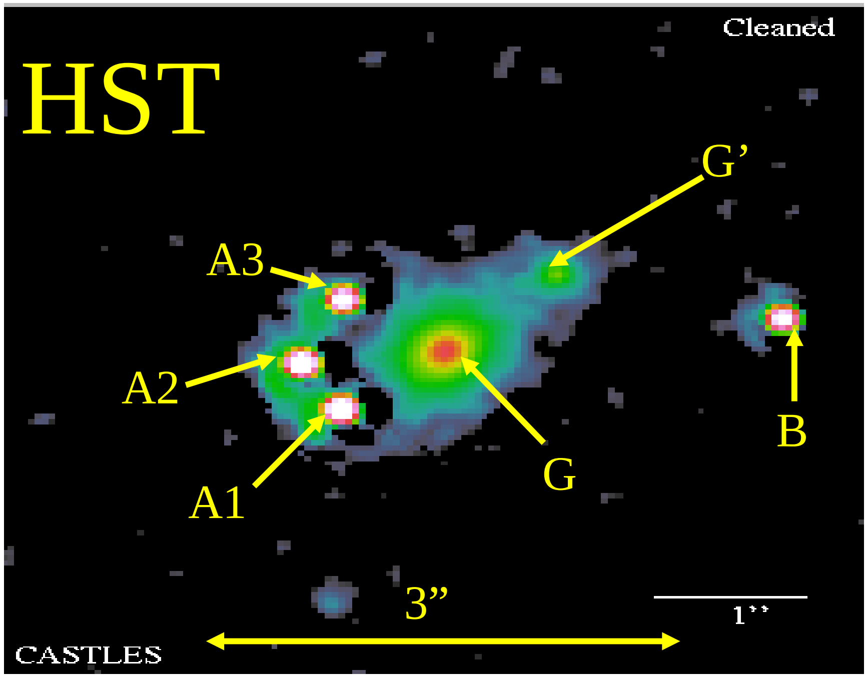
However few quasar hosts with $2<z<4.5$ have both the sizes of the gas and dust components measured. Examples are listed below. Many show evidence for merging.

Name	z	Ref. line	Ref. continuum	Ref. lens	Mergers
J123707+6214	2.5	CO(1-0) & (5-4)[20]	1.4 GHz, [20,21]	unlensed	M, 20
Cloverleaf	2.56	CO(7-6) [6]	122 microns [7]	[6]	NM, 0.8
SPT0538-50	2.78	CO(1-0) &(3-2) [8]	860 microns [9]	[8,9]	M, 1.6
RX J0911	2.8	CO(7-6) [1,2,4]	[5]	[3,4]	NM, 0.8
SMMJ02399-0136	2.81	CO(1-0) [10]	122 microns [7]	weakly lensed [11]	M, 25
SDP.81	3.04	CO(5-4) & (8-7) [12,14]	236 and 290 GHz [12,13]	[13,14]	M, 8
APM 08279+5255	3.91	CO(1-0) [15]	2.6 mm [15]	[15]	NM, 0.5
PSS J2322+1944	4.12	CO(2-1) [16]	1.4 GHz [17]	[16,17]	NM, 2
BRI 1335-0417	4.41	CO(2-1) [18]	1.4 GHz [19]	unlensed	M, 5

1) Weiss et al. 2012; 2) Tuan-Anh et al. 2013; 3) Hoai et al. 2013; 4) Tuan-Anh 2014; 5) ALMA archive, this work; 6) Venturini & Solomon 2003; 7) Ferkinhoff et al. 2015; 8) Spilker et al. 2015; 9) Hezaveh et al. 2013; 10) Ivison et al. 2010; 11) Richard et al., 2009, ArXiv e-prints; 12) ALMA Partnership et al. 2015; 13) Rybak et al. 2015a; 14) Rybak et al. 2015b; 15) Riechers et al. 2009; 16) Riechers et al. 2008; 17) Carilli et al. 2001 and 2003; 18) Riechers et al. 2008; 19) Momjian et al. 2007; 20) Riechers et al. 2011; 21) Morrison et al. 2010.

RX J0911.4+0551

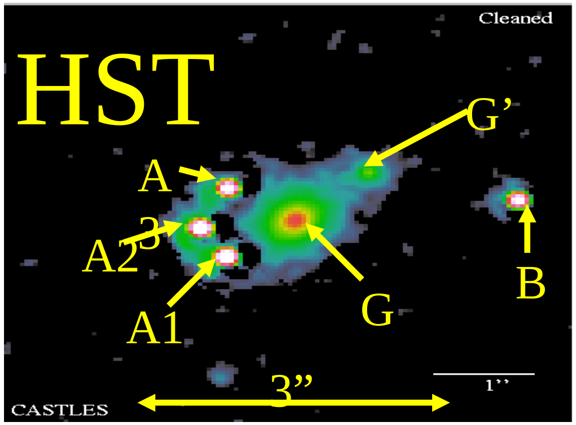
- Discovered in 1995 by ROSAT
- Observations(visible & near infrared) resolved it in 4 images (z~2.8)
- Lensing is dominated by a galaxy at at z~0.8 with some influence from the cluster to which it belongs.
- A black hole mass of ~1.6 10^8 solar masses is estimated from measured X ray luminosity. Black hole masses increase from 10^8 solar masses at *z*~0.2 to 10^9 solar masses at *z*~2.

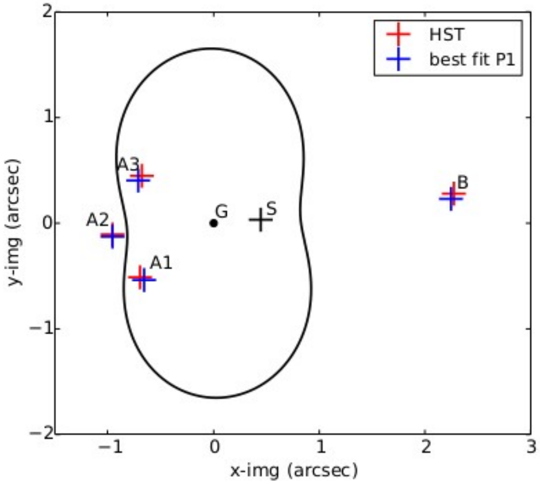


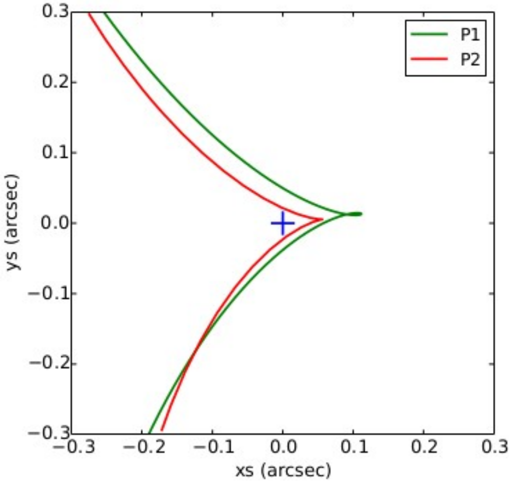
Good knowledge of the lensing potential is obtained from HST observations.

Configuration is typical of a quad with the source near a cusp of the minor axis of the caustic curve.

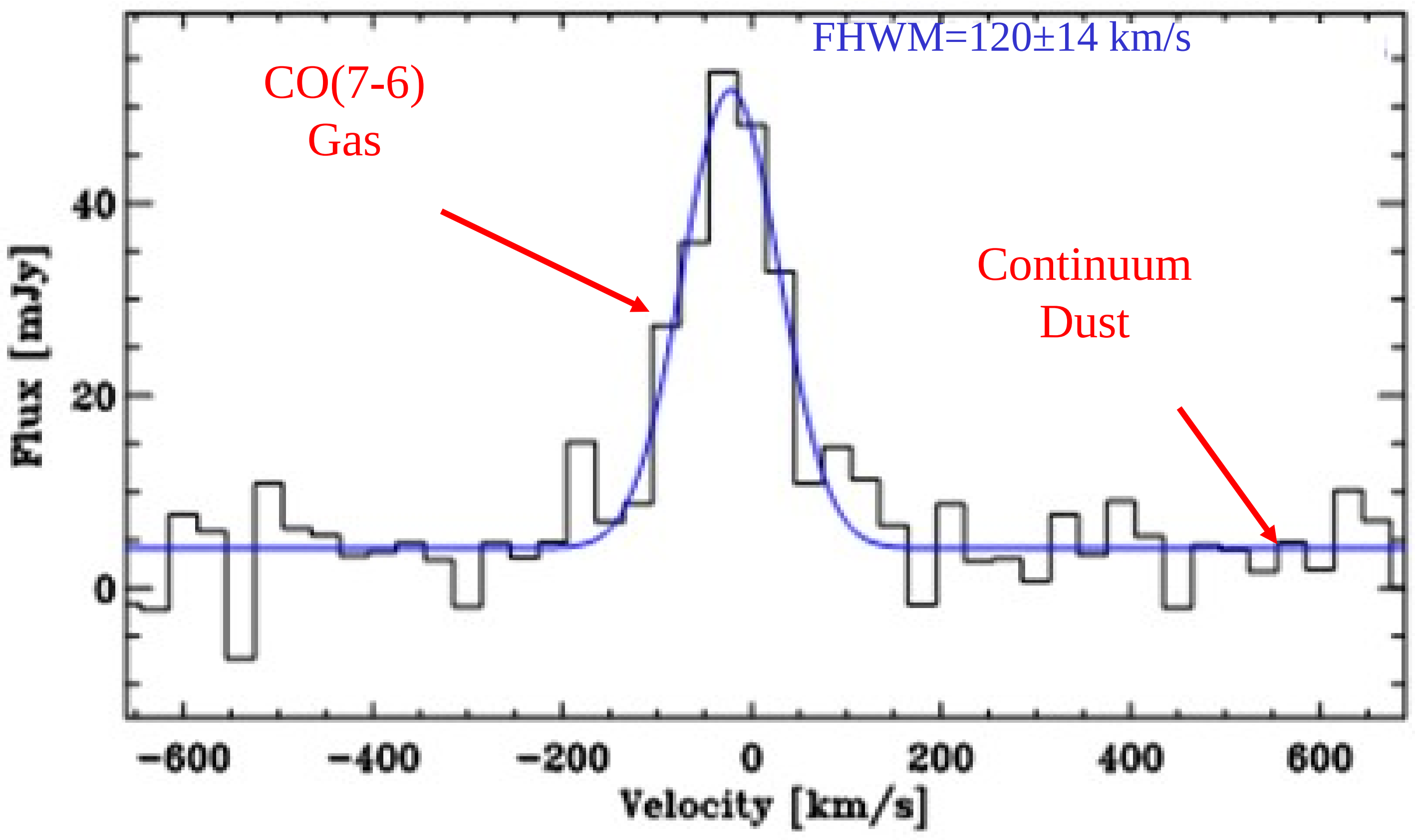
Two different lensing potentials: to evaluate the uncertainties attached to the result; (here only one of them, an elliptical lens with a shear term, for simplicity).



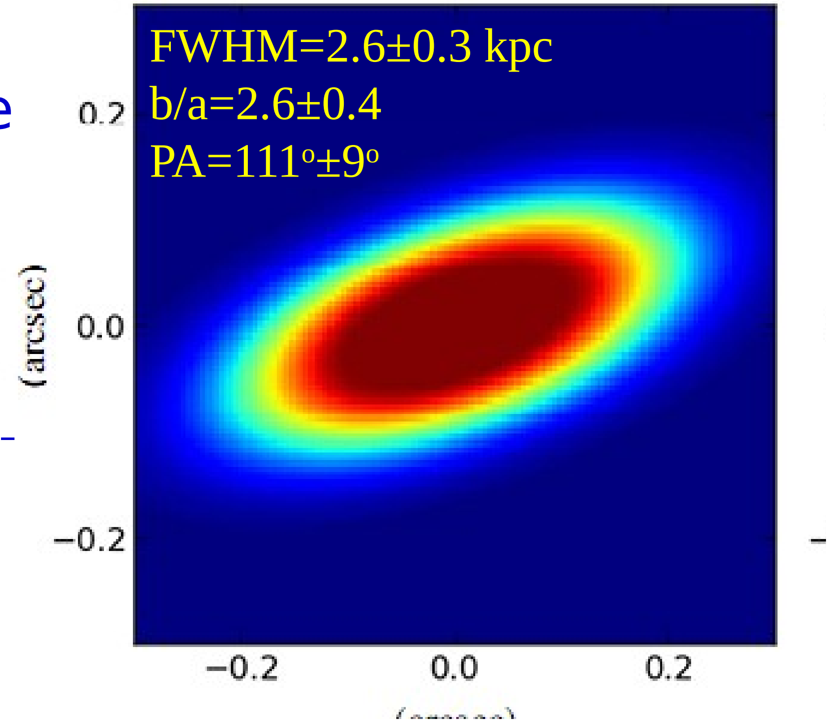


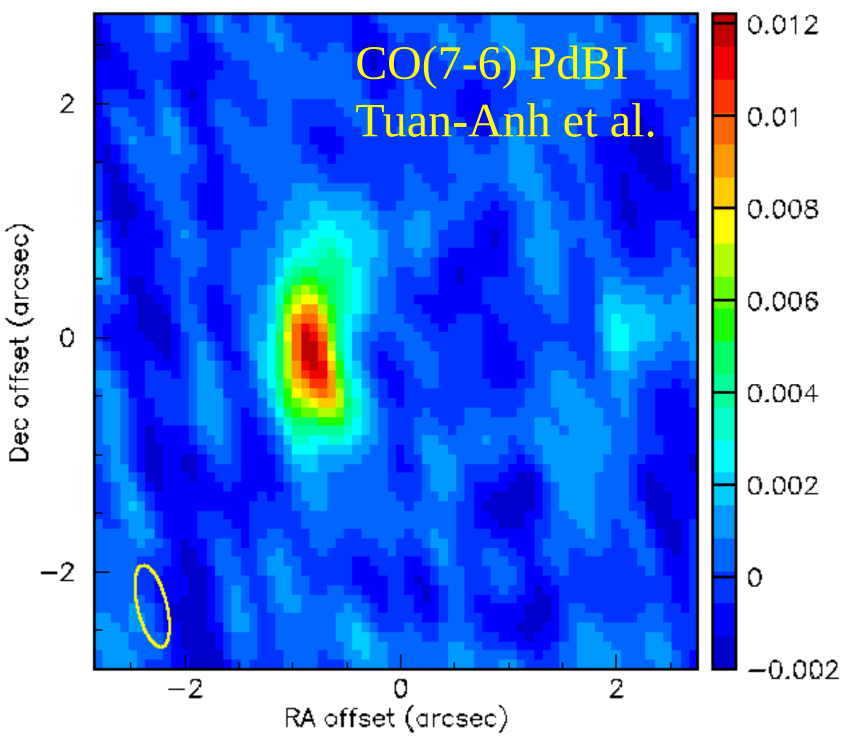


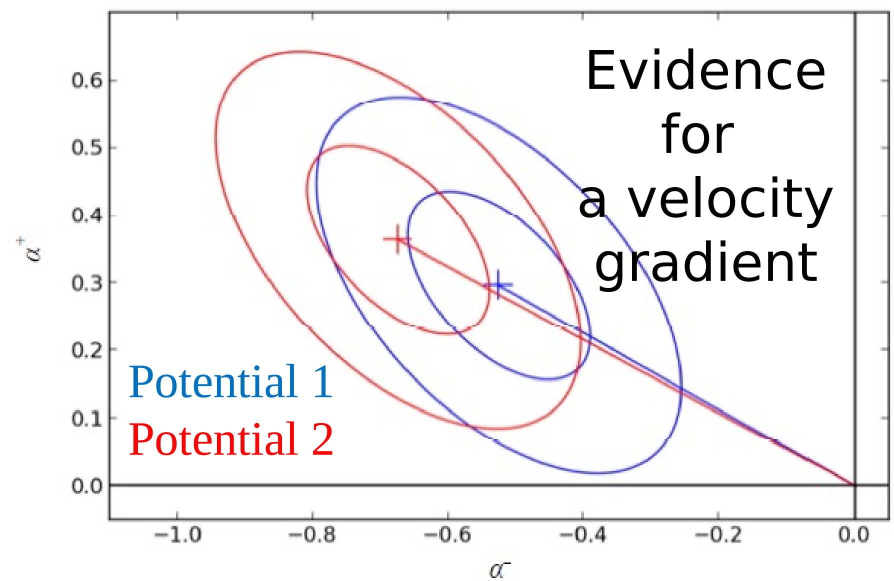
Early observations were made in CO(1-0) at the VLA (Riechers & al., unresolved) and in CO(7-6) at PdBI (Weiss et al. 2012). They were followed by better spatial resolution PdBI observations (Tuan-Anh et al. 2013) which allowed for a measurement of the shape and size of the gas source (next slide). All line measurements report a very narrow line, 107±20 km s^{-1} on average.



The PdBI CO(7-6) observations (Tuan-Anh et al. 2013) had a good enough spatial resolution to resolve the source and measure its ellipticity and orientation (3 s.d. from zero), but the B image was weak. They also gave evidence for a velocity gradient of 25 km s^{-1} kpc^{-1} at 4.5 s.d. from zero.

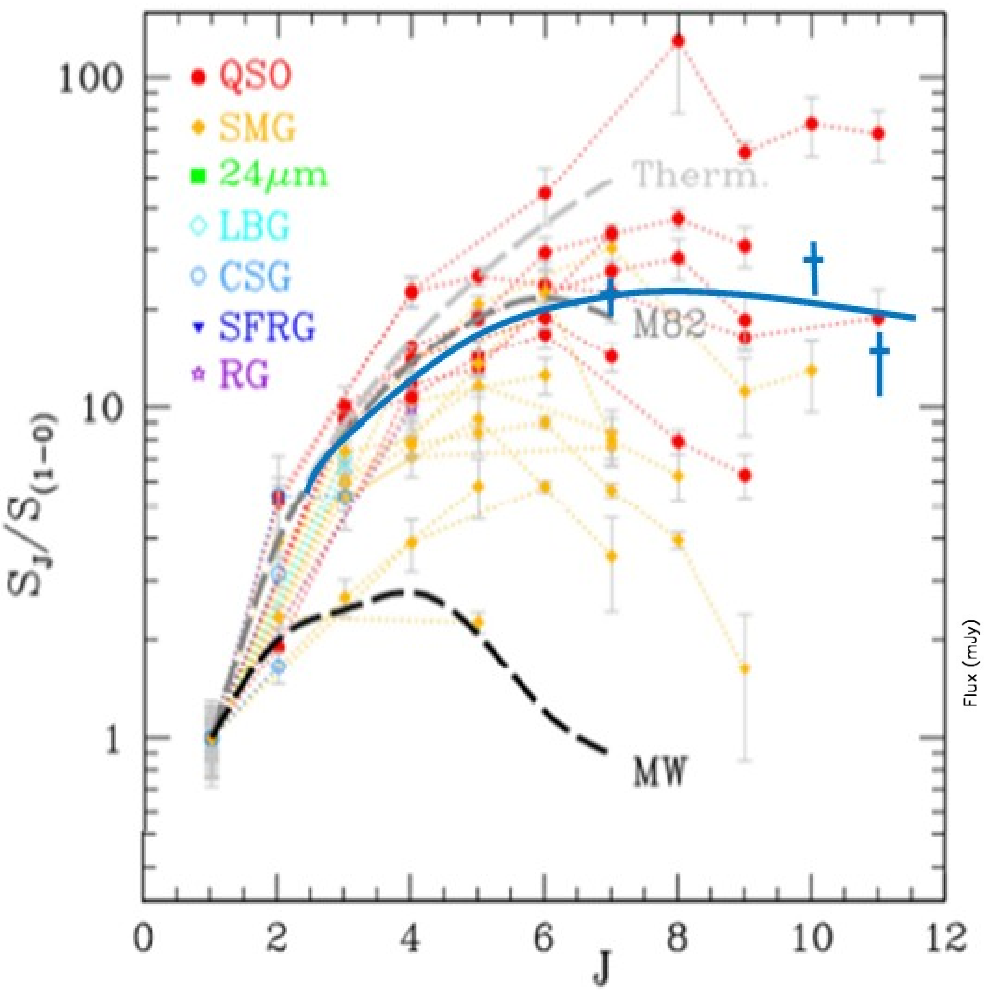


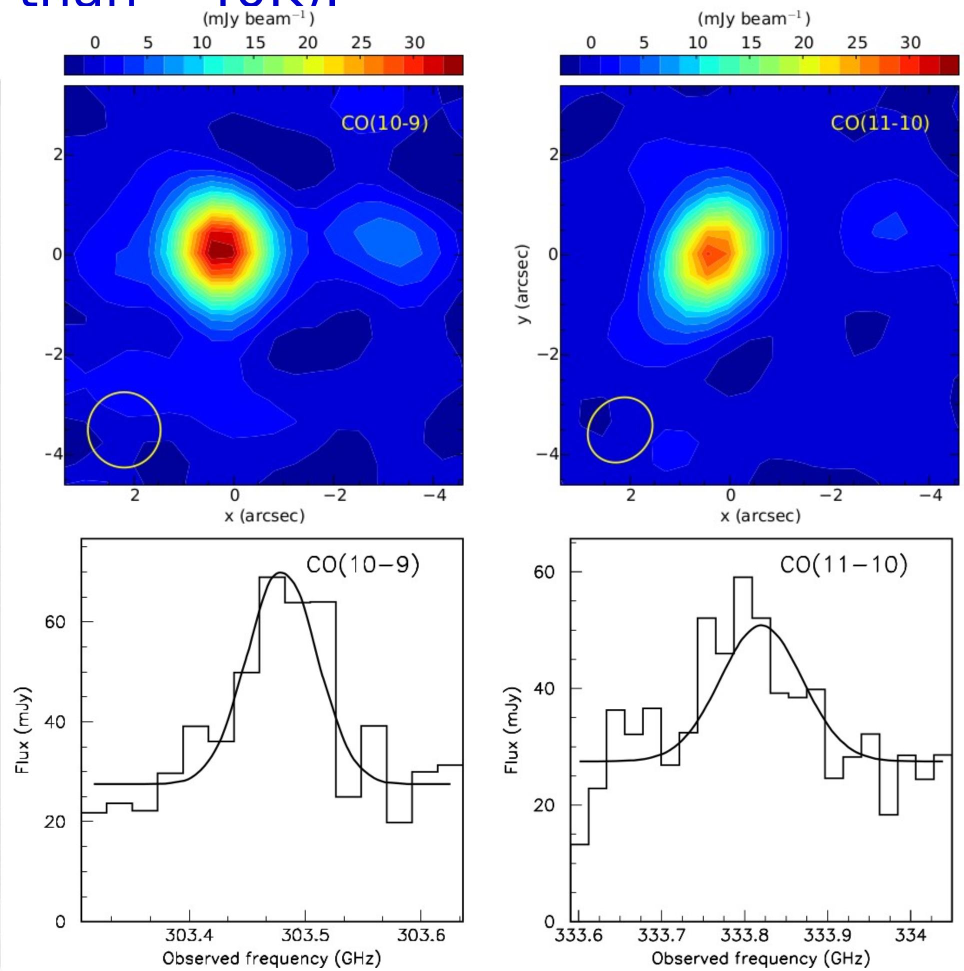




CO lines measured by ALMA

The new ALMA measurement extend beyond the typical ladder predicted by a single component LVG approximation, suggesting a temperature and/or density of the gas on the high side (typically ~60K rather than ~40K).



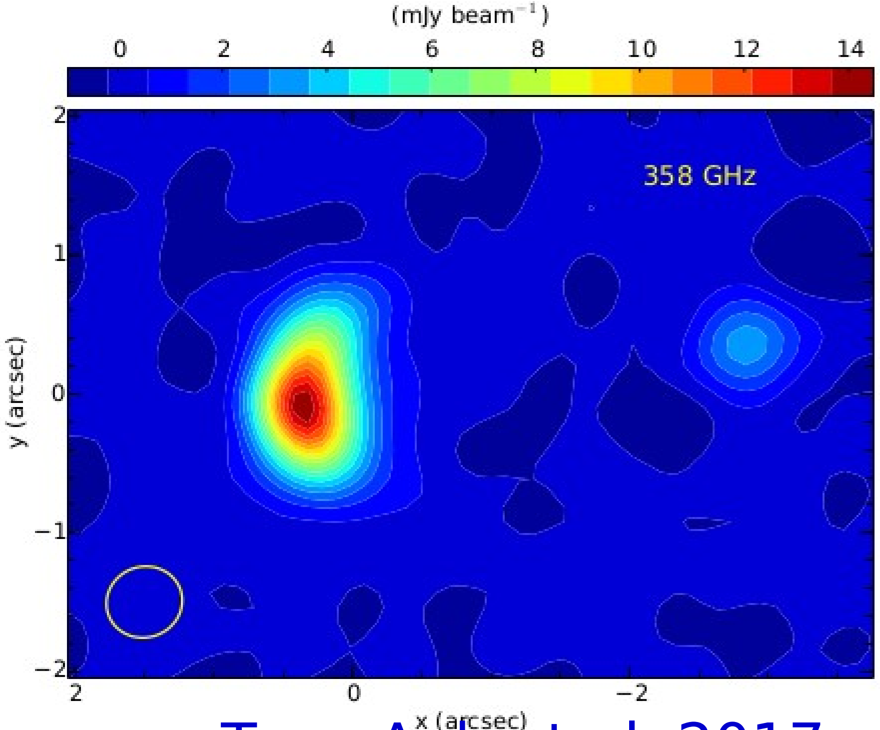


Tuan-Anh et al. 2017

ALMA 358 GHz continuum

The good sensitivity of the ALMA observation in the continuum (358 GHz) makes it possible to resolve the dust source and measure its size.

The size of the source is measured as FWHM = 0.76±0.08 kpc, 3.4±0.4 times smaller than the gas source measured in CO(7-6).

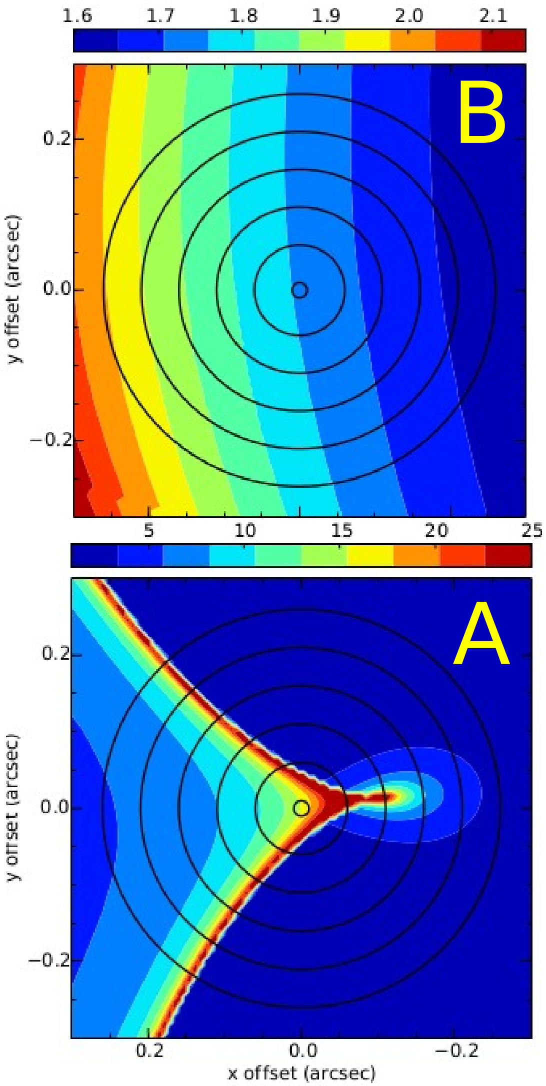


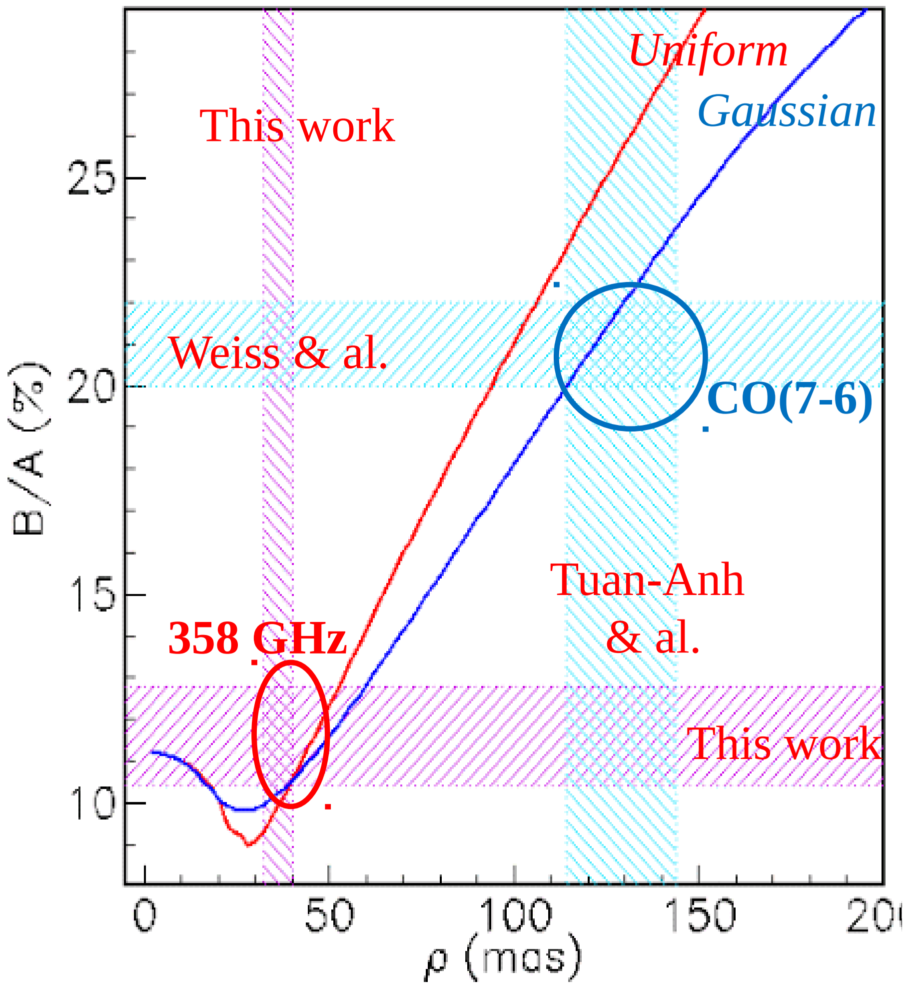
Tuan-Anh et al. 2017

Fits are made in the *uv* plane as well as on the clean map.

An independent evaluation of the continuum source size

A nice confirmation of the validity of the preceding result is obtained from the measurement of the B/A brightness ratio, 11.6±1.2% (when the size of the source increases, images A1 and A3 disappear but B is always there).

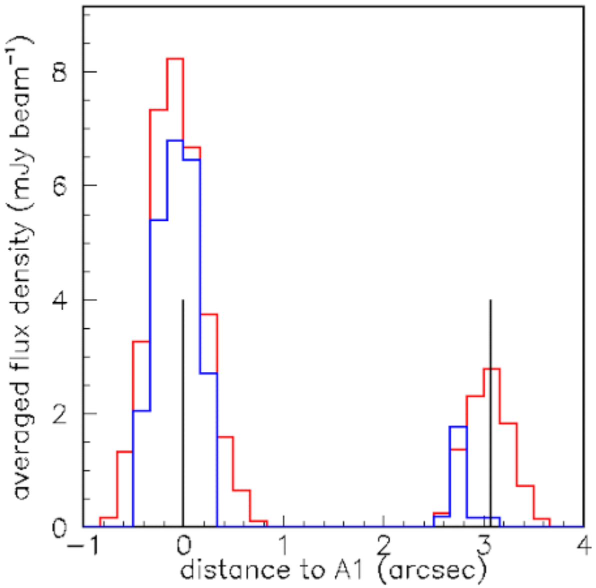


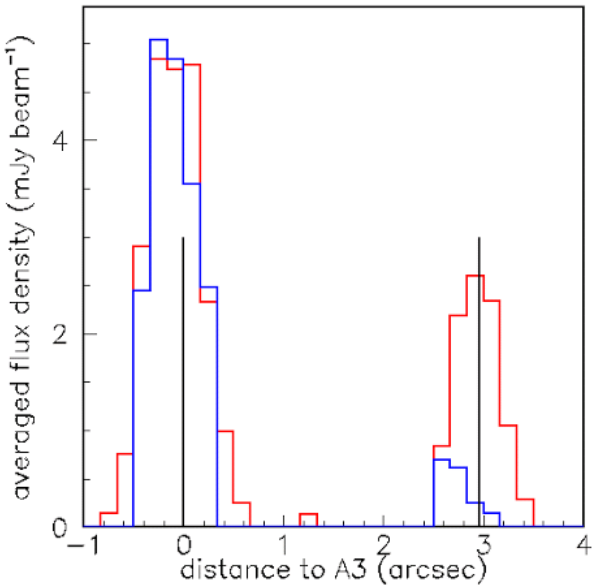


Concentricity of the sources

We found that the BA1 and BA3 distances are good proxys of the source position.

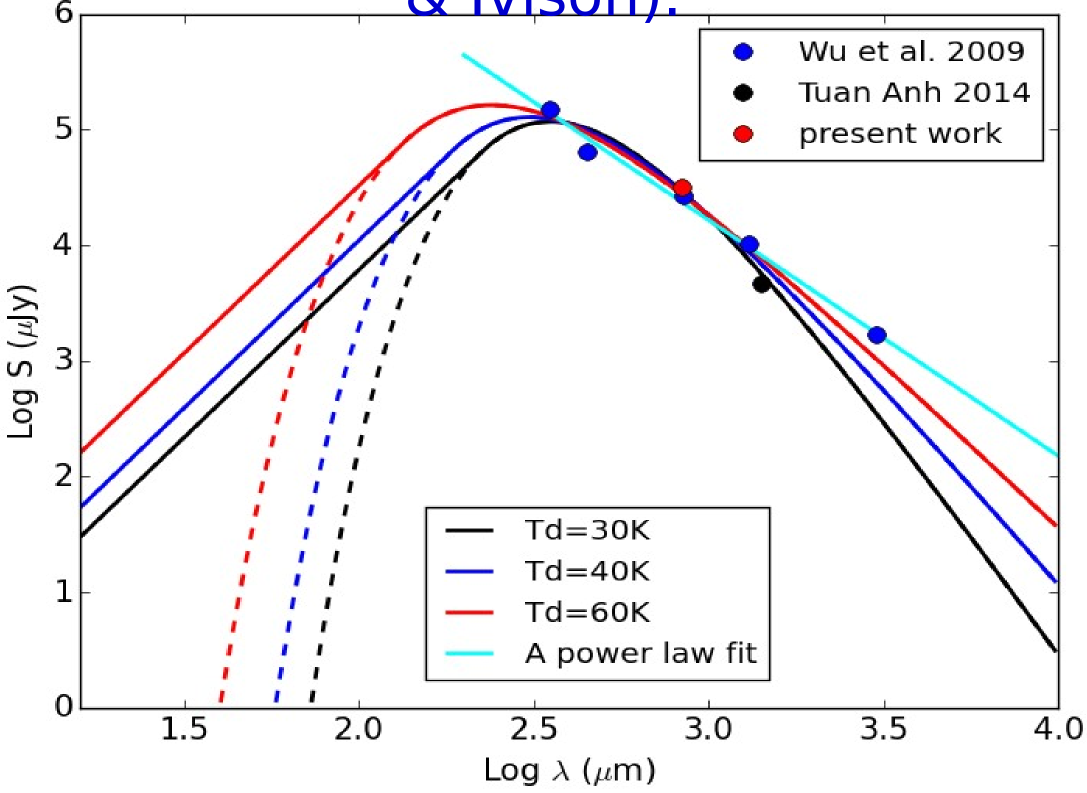
The concentricity of the three sources (HST, PdBI and ALMA) is measured to better than 0.31 kpc for the quasar versus 358 GHz continuum emissions and to better than 1.10 kpc for the quasar versus CO(7-6) emissions, pleading against any important and recent merger contribution.





Dust luminosity

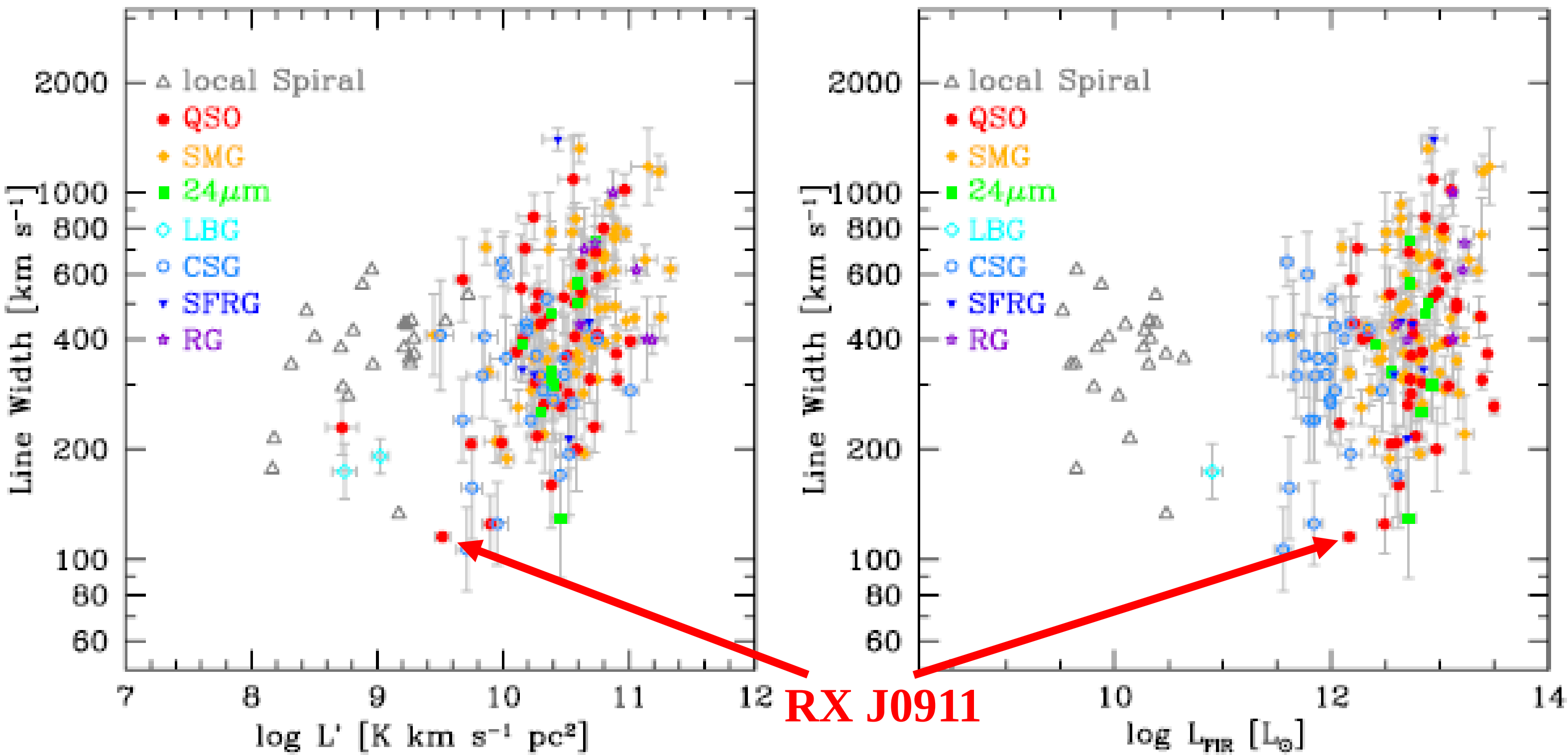
The dust luminosity at 358 GHz, measured at the level of 31.7±0.5 mJy, is in excellent agreement with earlier measurements but does not help with the evaluation of the dust temperature. The suggestion of a high dust temperature occasionally mentioned in the literature rests on a single measurement of 1.7±0.3 mJy at 3 mm wavelength (Barvainis & Ivison).



CO line width & luminosity

Carilli & Walter 2013

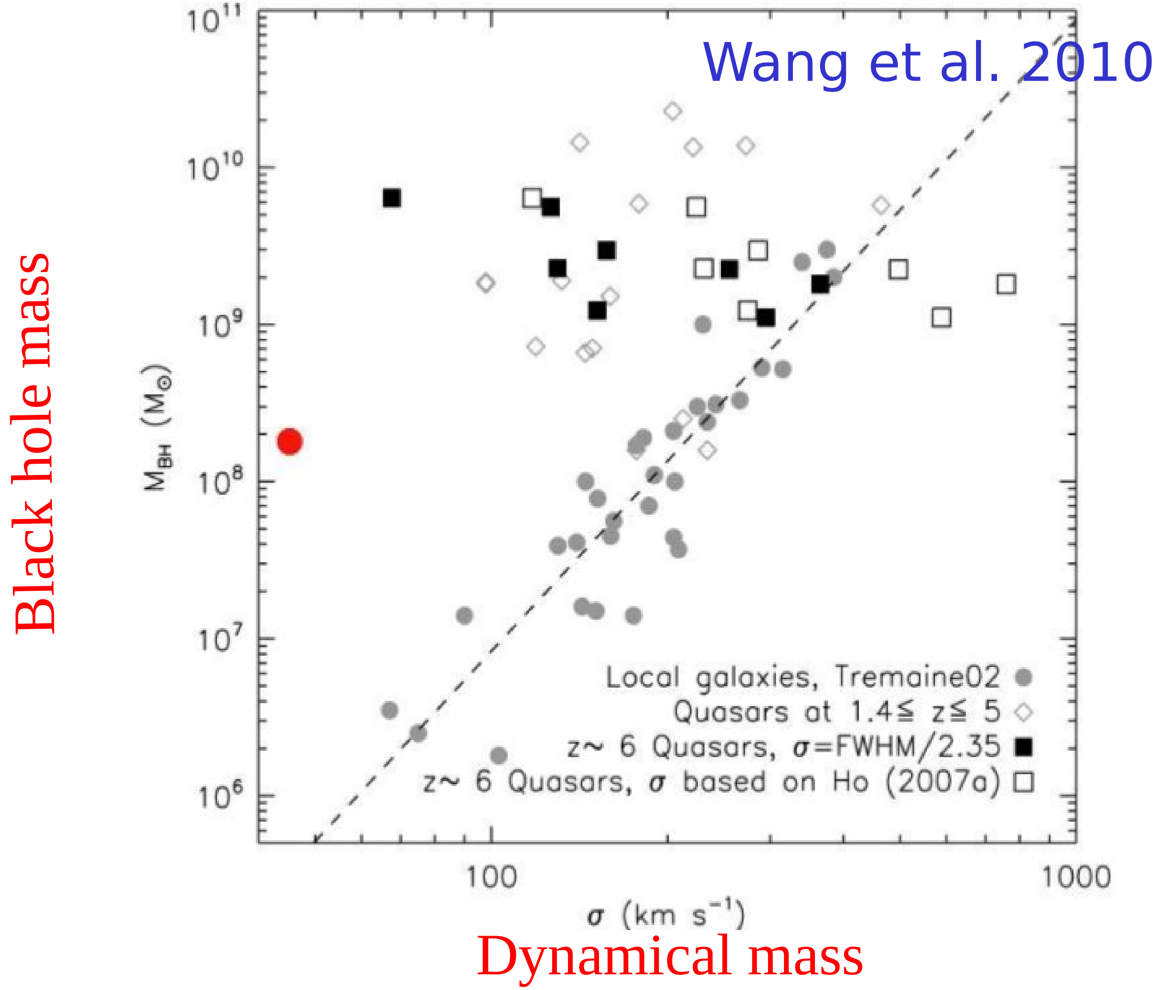
Measures dynamical gas mass



Measures gas mass

Measures dust mass and SFR

RX J0911 has an outstandingly small line width, which could be interpreted as a rotating disk seen face on. However, the aspect ratio we found points to a significant inclination (70 degrees) and the low dynamical mass we derive with this inclination is consistent with the relatively low molecular gas mass. Hence, our interpretation is that RX J0911 resides in a relatively small galaxy (when compared to other high-z quasars).



Together with the low values (Tuan-Anh 2014) of the gas mass (~3.9 10^9 solar masses), of the dust mass (~1.3 10^8 solar masses) and of the dynamical mass (~4.7 10^9 solar masses), the low mass of the central black hole makes RX J0911 an atypical quasar host, a kind of scaled down version of typical quasar hosts at redshifts ~3.

Summary

- We have measured the sizes of the CO(7-6) and 358 GHz continuum components of the host galaxy of RX J0911 as 2.6±0.3 and 0.76±0.08 kpc FWHM respectively. Both are compact. They are concentric to within 0.31 kpc (gas vs dust) and 1.1 kpc (gas or dust vs black hole). This result pleades against any evidence for an important and recent merger contribution.

- Fits were made in the uv plane as well as on the clean map and independent estimated were obtained from measurements of the B/A brightness ratio. Evidences for an important ellipticity (aspect ratio of 2.6±0.4) and for a velocity gradient of the CO(7-6) source.

- Measurements of the CO ladder, CO(7-6), CO(10-9) and CO(11-10), give evidence for a higher excitation, implying higher temperature and/or density, than for typical quasar hosts at this redshift.

ACKNOWLEDGEMENTS

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Thank you for your attention!