Research at DAP

Department of Astrophysics,
Vietnam National Space Centre

Pham Tuan-Anh

on behalf of the Department of AstroPhysics (DAP)

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EAO, Hilo, May 2019

Outline

Astrophysics in Vietnam
Astrophysics at DAP/VNSC
A dying star: EP Aqr
A forming star: GG Tau
A high redshift galaxy: RXJ0911

Names such as Jane Luu, Trinh Xuan Thuan or Nguyen Quang Rieu, of Vietnamese-born astrophysicists having left the country half a century or so ago, are well known. The latter, a radio astronomer working in France, has played an important role in promoting astrophysics in Vietnam and inspiring and guiding the main current actors of astrophysics research in the country: Dinh Van Trung at Hanoi's Institute of Physics, Phan Bao Ngoc at the Viet Nam International University in Ho Chi Minh City and the team of the Department of Astrophysics in the Viet Nam Space Centre in Ha Noi

Dinh Van Trung

Recently appointed head of the Institute of Physics of the Vietnam Academy of Sciences and Technology, Professor Dinh Van Trung was trained in France and spent several years in Taiwan with Academia Sinica before returning to Viet Nam. With expertise in radio astronomy and molecular gas, he publishes his research work together with members of international collaborations and has initiated several hardware efforts at IOP (LIDAR, mirror construction, etc…)

Authors		arXiv	First author	Journal	Topic
VN	~~VN~~				
1	2	1710.05543	D.V. Trung	ApJ 851(2017)65D	IRC+10420
1	5	1710.06186	J. Lim	ApJ 850(2017)31L	NGC1275
1	3	1807.10205	J.H. He	ApJ 845(2017)38H	IRC+10216
1	5	-	S. Matsushita	PKAS 30(2015)349M	AGN M51
1	5	1410.7863	S. Matsushita	ApJ 799(2015)26M	M51 NGC5194
1	19	1407.3235	L.P. David	ApJ 792(2014)94D	NGC 5044
1	19	1404.7667	S. Muller	A&A 566A(2014)112M	PKS-1830.211
1	13	-	S. Muller	A&A 566(2014)L6	PKS-1830.211

Phan Bao Ngoc

Like Professor Dinh Van Trung, Associate Professor Phan Bao Ngoc was trained in France and worked as a postdoc in Taiwan's Academia Sinica.

He is a world expert in the field of Brown Dwarfs, to which he made important contributions. He currently leads the Physics Department of the VNU International University in HCMC.

Authors		arXiv	First author	Journal	Topic
VN	~~VN~~				
2	5	1612.09370	P.B. Ngoc	A&A 600A(2017)19P	Late-M dwarfs
2	0	1602.06357	C. Dang-Duc	A&A 588(2016)L2	Taurus
2	0	1602.06357	C. Dang-Duc	A&A 588L(2016)	Taurus
2	3	1408.4506	P.B. Ngoc	ApJ 795(2014)70P	Gas/substellar
1	3	1403.1926	P.B. Ngoc	A&A564(2014)A32	J041757

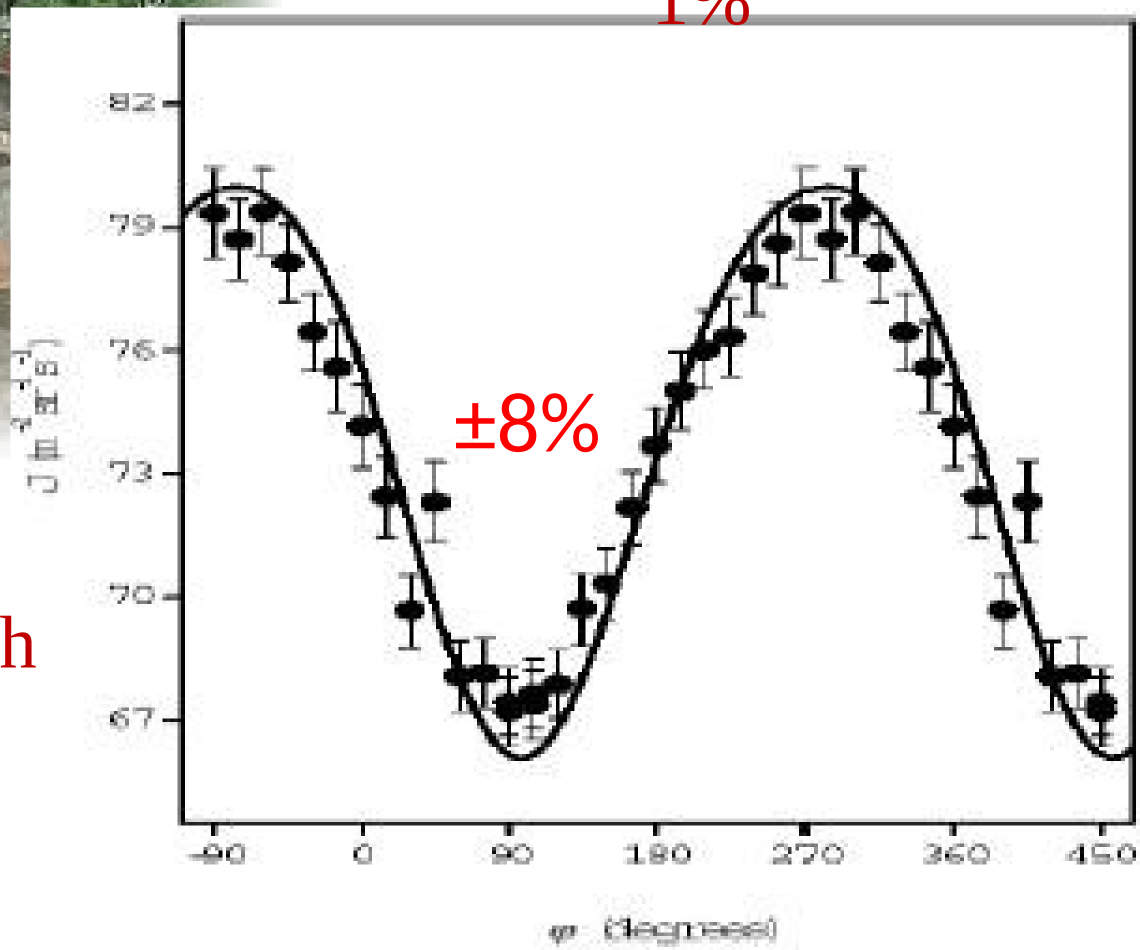
DAP/VNSC

DAP/VNSC

P.N. Diep, P.T.T. Nhung, N.T. Thao, P.Tuan-Anh, D.T. Hoai, N.T. Phuong, T.T. Thai, P.V. Loc, P. Darriulat

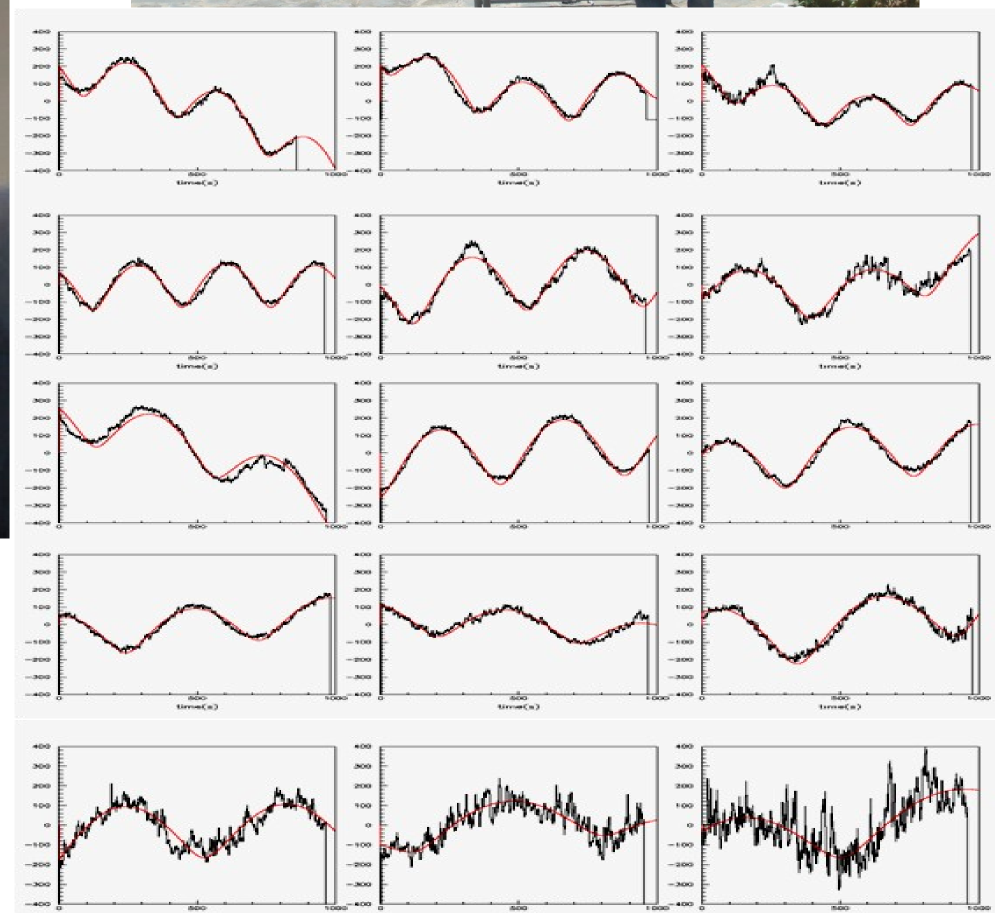
For some ten years, the main interest of the team was the study of very high energy extragalactic cosmic rays in collaboration with the Pierre Auger Observatory in Argentina. Three of us have made our PhD theses in this field. We made significant contributions to the very successful achievements of this program. We also developed and operated detectors of our own at home, with which we measured the flux and asymmetry of atmospheric cosmic neutrinos on the geomagnetic equator [Nuclear Physics B, 627(2002)29, 661(2003)302 and 678(2004)3].

The home built wooden scintillator telescope measured the muon fluxes with a precision of 1%



Muon azimuthal distribution at 50^{o} zenith angle.

Over five years ago, we decided to switch our main interest from cosmic rays to radio astronomy. We were motivated by the progress made by the field in recent years, by the availability of archival ALMA observations soon after they were taken, by the better match to the constraints attached to training students and to building a research team in Viet Nam. We were encouraged by Professor Nguyen Quang Rieu who had given Viet Nam a Yagi interferometer, which I could use for my master work on solar observations (the first Vietnamese master thesis in astrophysics).



Professor
Nguyen Quang Rieu

The radio telescope

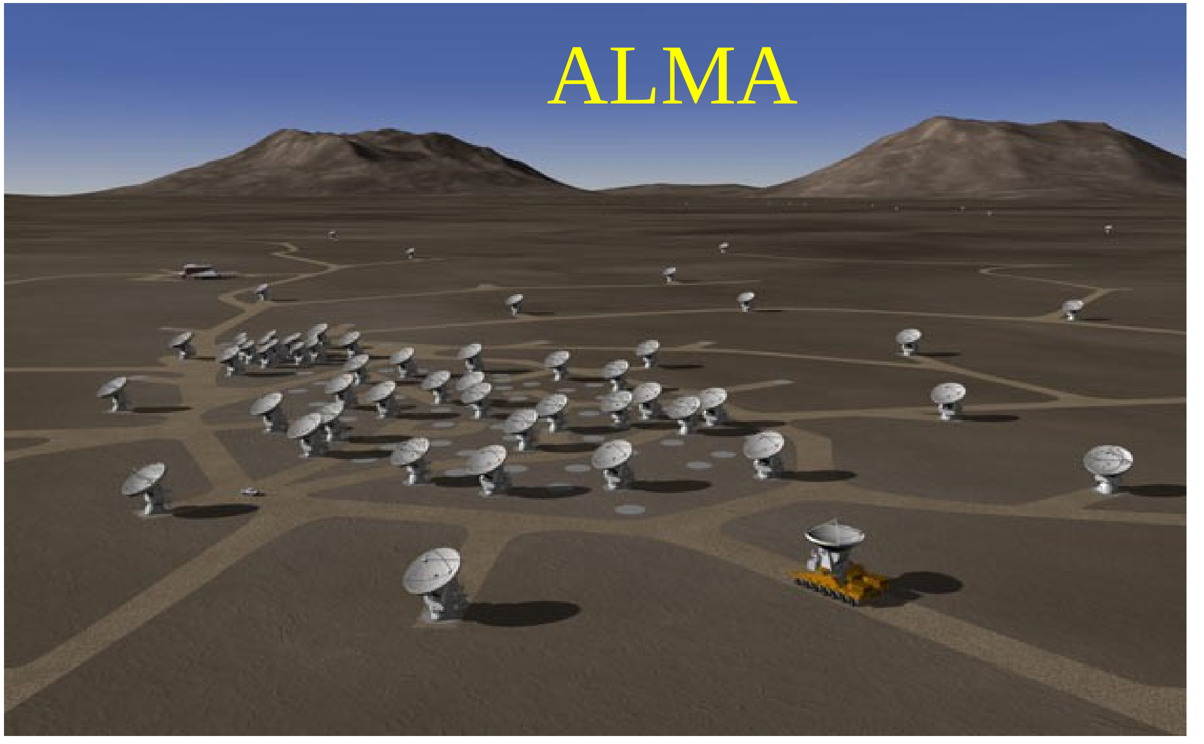
We bought a 2.6 m diameter radio telescope tuned on the HI line, with which we observed the Milky Way, the Moon and the Sun (seven publications: two in international journals, five in Comm. Phys. Vietnam and two master theses).

For over five years, we have been doing research in Astrophysics:
Stellar Physics and Early Universe

On our own using ALMA archival data

In collaboration with Paris (T. Le Bertre and J.M. Winters) on evolved stars (ALMA and IRAM)

In collaboration with Bordeaux (A. Dutrey and S. Guilloteau) on proto-stars (ALMA and IRAM)


ALMA

NOEMA

Pico
Veleta

We have gained major expertise in the interpretation of gravitationally lensed images and in the de-projection of radio interferometer data.
De-projection is a strongly under-constrained problem, only 3 out of 6 coordinates being measured: projection on sky plane and Doppler velocity.

Much of our work in the recent past has concentrated on the study of a proto-star, GG Tau, of a dying star, EP Aquarii, and of a high redshift galaxy, RX J0911.

I shall briefly comment on each of these.

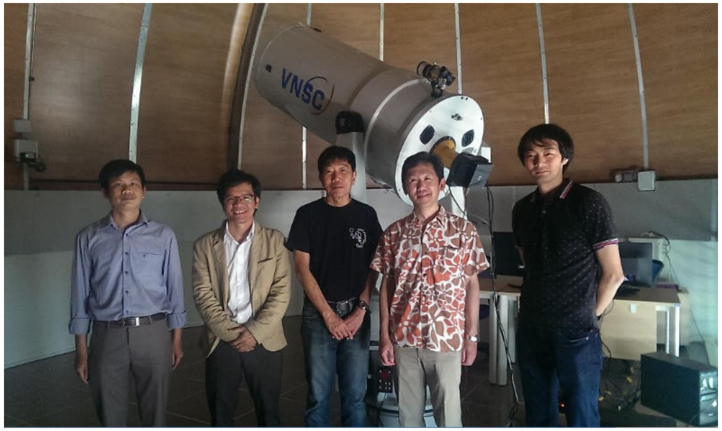
Between 2014 and 2018 we have published 18 articles in international refereed journals with one of us as first author and only 17% of other authors. See more at: https://dap.vnsc.org.vn/publications.htm

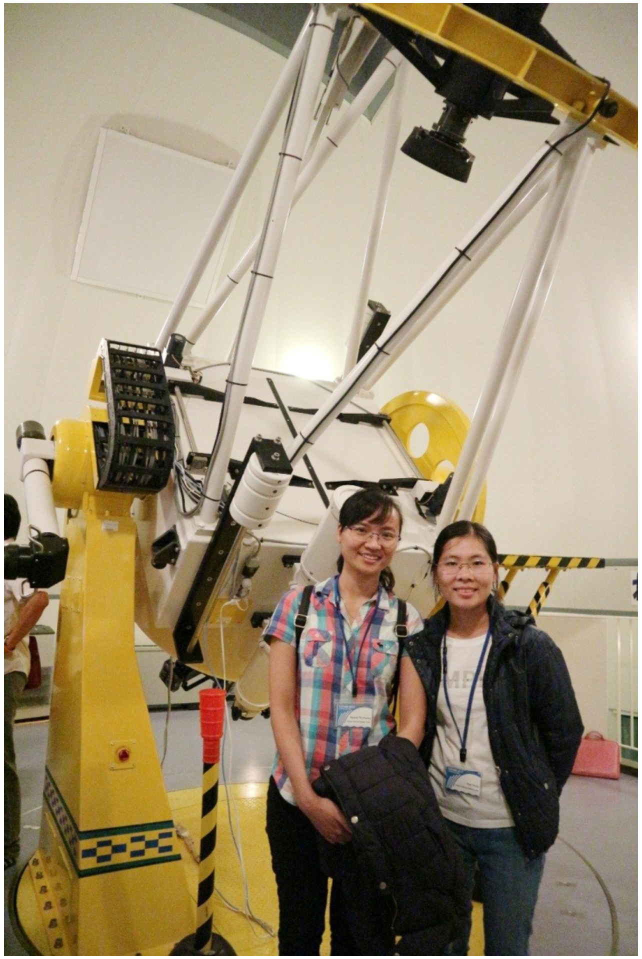
Authors		arXiv	First author	Journal	Topic
VN	~~VN~~				
7	2	1901.00974	Hoai	MNRAS	EP Aqr
6	2	1810.04423	Nhung	RAA (2018)	EP Aqr
6	2	1807.10205	Nhung	MNRAS (2018)	De-projection
7	4	1801.00861	Phuong	RAA 18(2018)3	GG Tau
7	0	1701.02131	Nhung	MNRAS 469(2017)4726	49 Ceti
7	0	1609.03271	Tuan-Anh	MNRAS 467(2017)3513	RXJ0911
7	0	1604.03801	Tuan-Anh	MNRAS 463(2016)3563	L1527
7	0	1603.02405	Diep	MNRAS 461(2016)4276	De-projection
7	0	1603.00148	Nhung	MNRAS 460(2016)673	Mira Ceti
7	3	-		ASPC 502(2016)61D	AGB stars CO/HI
7	0	1601.04834	Nhung	RAA 16(2016)111	Pi Gru
7	0	1601.01439	Hoai	RAA 16(2016)106	W Aql
7	2	1508.05208	Nhung	2015 A&A	EP Aqr
3	3	-	Nhung	RAA15(2015)713N	RS Cnc
7	0	1503.00858	Tuan-Anh	RAA(2015)2213	Red Rectangle
8	0	1405.1525	Diep	PASA 31(2014)29D	Solar osc.
2	5	1403.2163	Hoai	A&A 565A(2014)54H	RS Cnc
8	0	-	Hiep	SolPhys 289(2014)939H	Solar osc.

We contribute to outreach by helping with the installation of a Space Museum and a 50 cm telescope in Hoa Lac (near Hanoi), by helping with the organization of the yearly Science Day, by training the Vietnamese team to the International Astronomy and Astrophysics Olympiads, by having frequent contacts with amateur astronomy clubs, etc…

Four of us are lecturing for bachelor and master courses at the University of Science and Technology of Ha Noi.

We are actively contributing to the South East Asia Astronomer Network (SEAAN), to the East Asian Observatory that operates the James Clerk Maxwell Telescope, to the International Centre for Interdisciplinary Science and Education in Quy Nhon, helping with the organization of conferences and schools. Last year, we organised in Nha Trang, together with the National Astronomical Research Institute of Thailand, a workshop of the International Training Centre for Astronomy aimed at training ASEAN university lecturers.

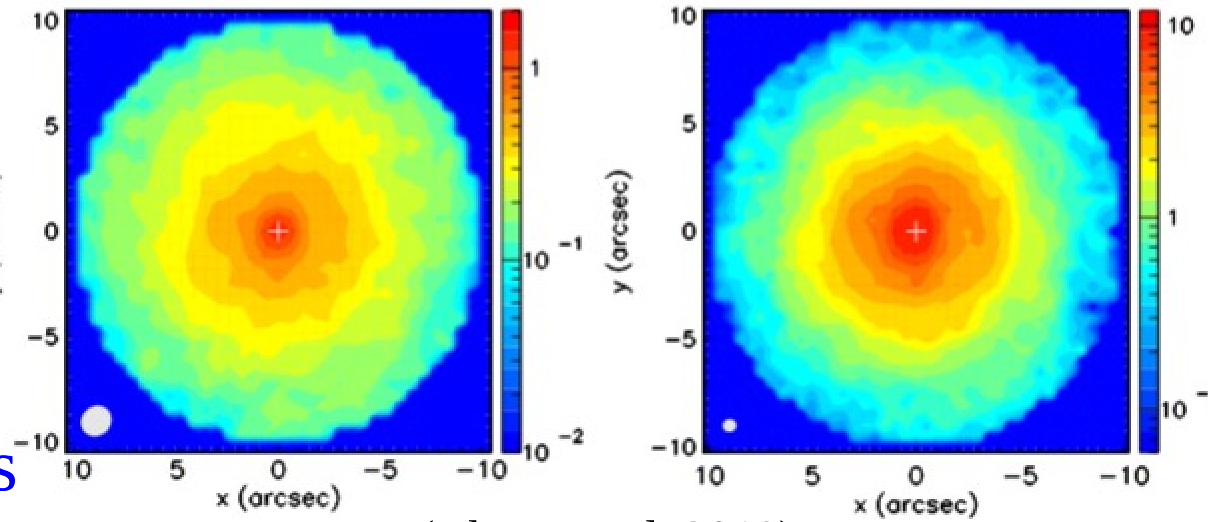




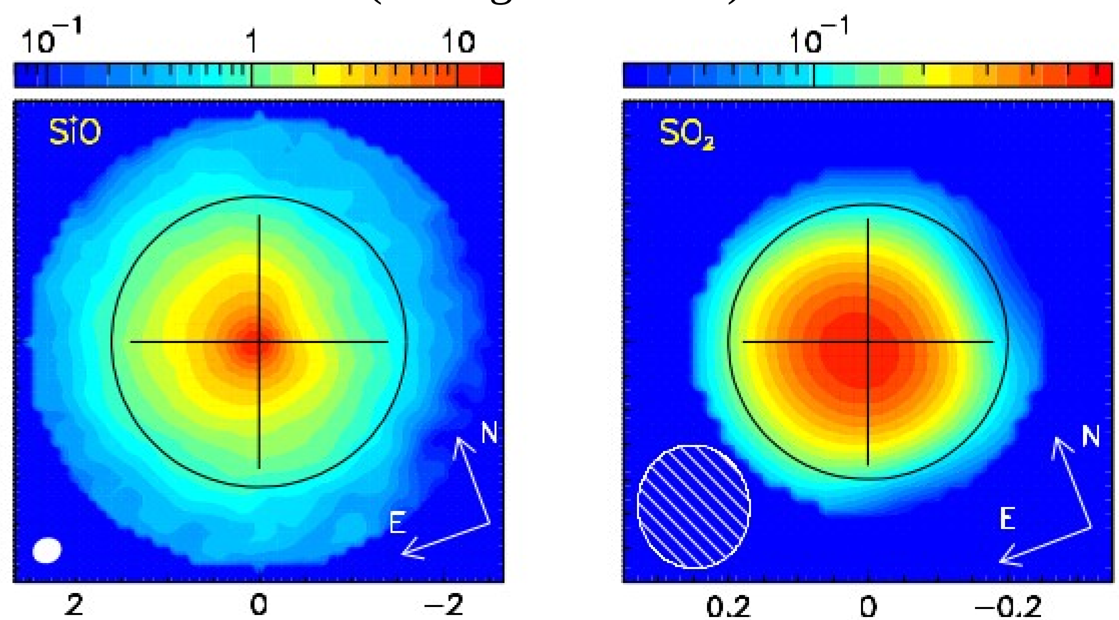
A dying star: EP Aquarii

EP Aqr is a nearby oxygen star that has been losing mass for ~10^4 to ~10^5 years at a distance of ~100 pc. We observe emission from four rotation lines at millimetre wavelength: $SO_2(16_{6,10}\text{-}17_{5,13})$, SiO(5-4) and two CO lines, CO(1-0) and CO(2-1). Spatial resolution is ~0.1 arcsec and spectral resolution ~0.1 km/s.

CO(1-0) CO(2-1)



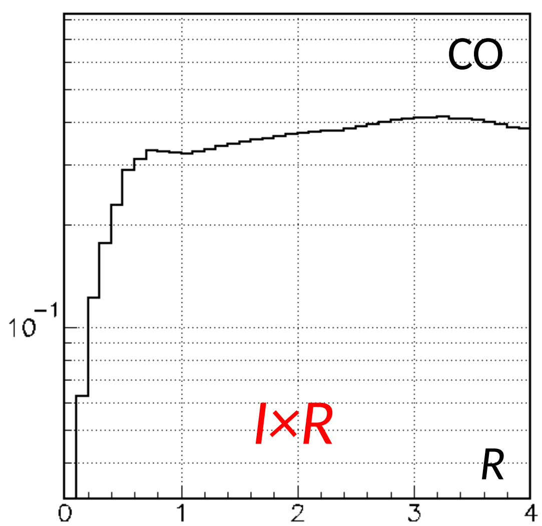
(Nhung et al. 2019)

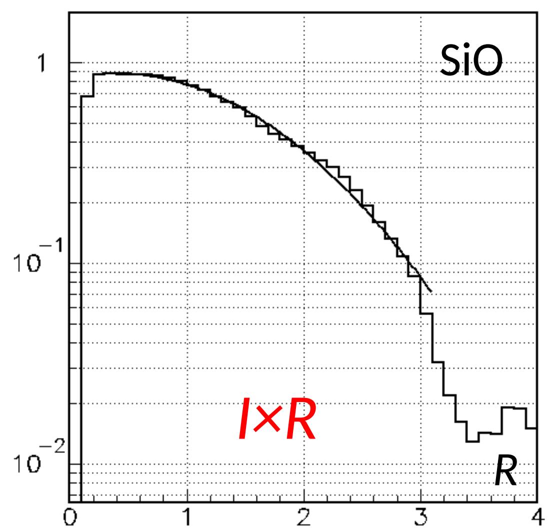


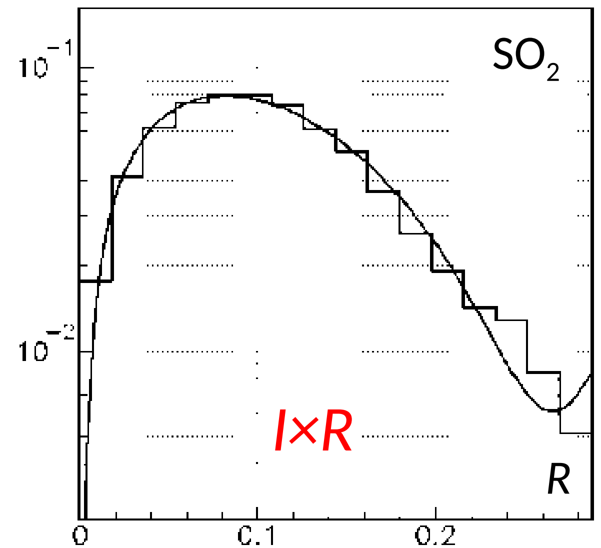
Tuan-Anh et al. 2019

While CO emission extends to large distances from the star, SiO and SO_2 emissions tell us about the close environment of the star; SiO aggregates into dust grains and is confined to *r*<2.5 arcsec.

SO_2 forms at the surface of the star, from oxygen atoms freed by shock waves produced by the pulsations of the star, and is quickly excited and dissociated by the UV radiation from the star. It is confined to *r*<0.25 arcsec.





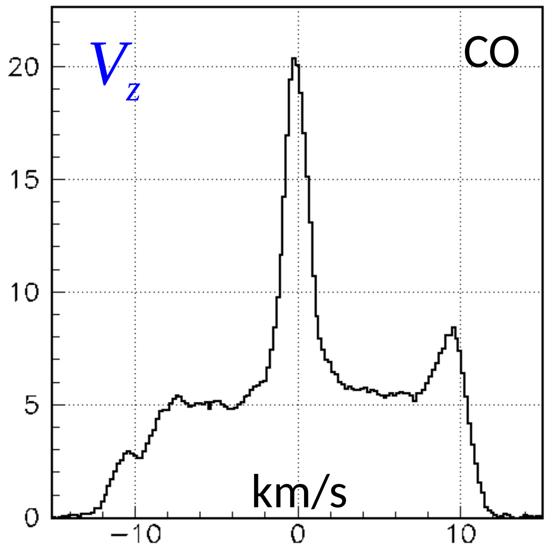


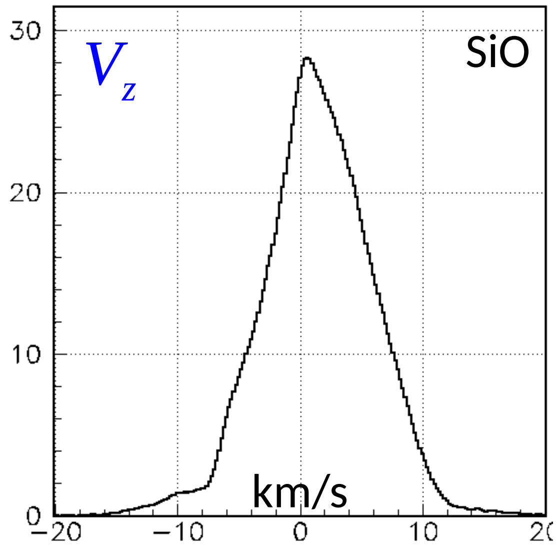
As a result, each of the three emissions probes a different radial range:

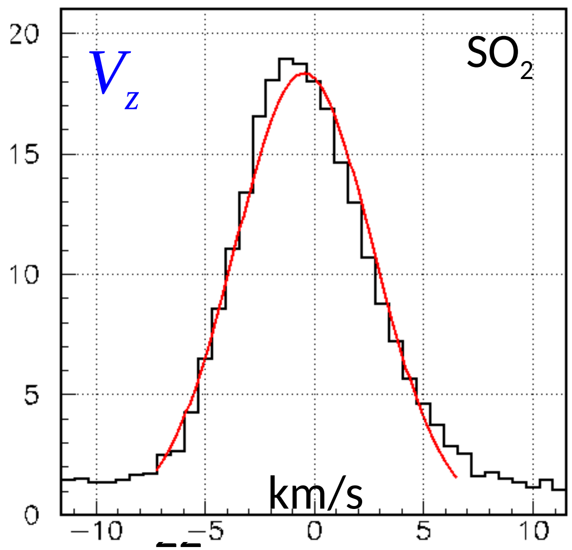
SO_2 probes up to ~20 au above the star surface where the wind has not yet developed; it gives evidence for rotation.

SiO probes up to ~200 au from the star where the wind develops: expansion starts dominating over rotation.

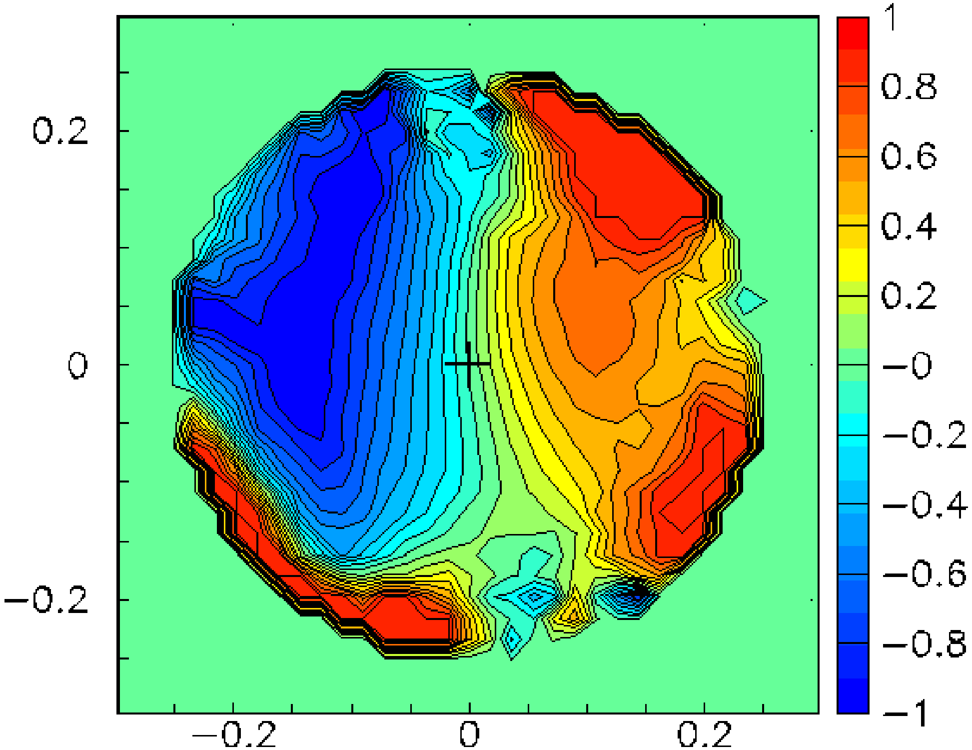
CO probes large distances from the star, dominated by a constant radial wind above ~200 au from the star.



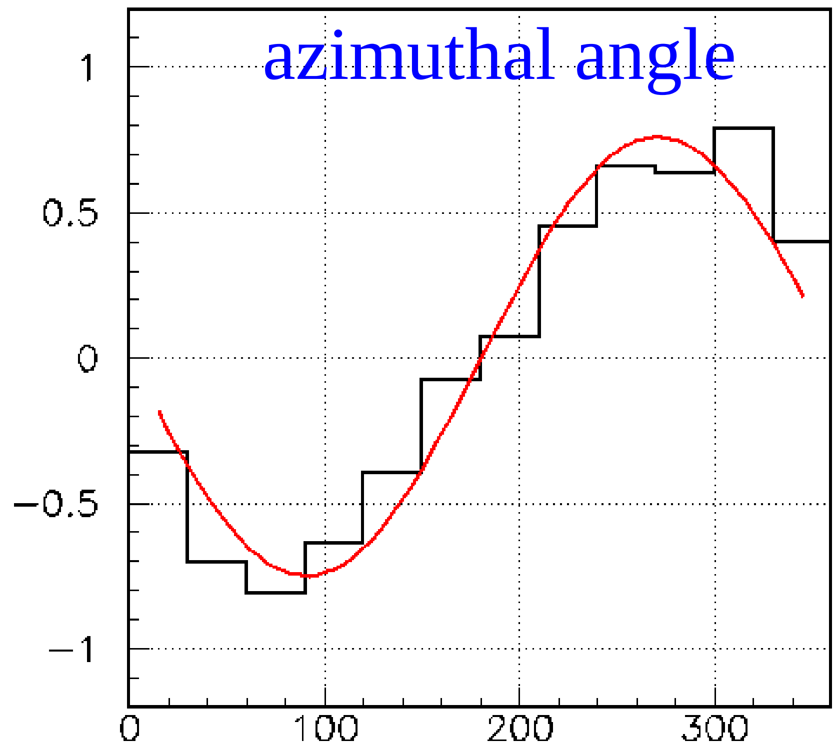




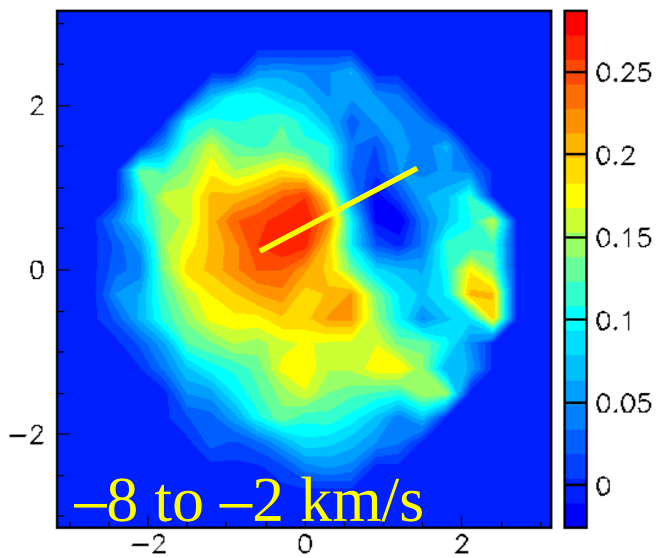
SO_2 emission: evidence for rotation; it can be detected because the star axis is slightly inclined with respect to the line of sight (10°). The dependence of the mean Doppler velocity on position angle implies a rotation velocity of the order of 4 to 5 km/s.

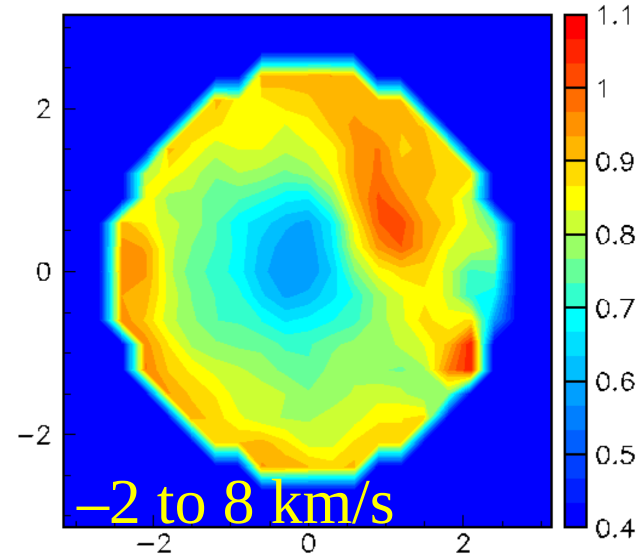


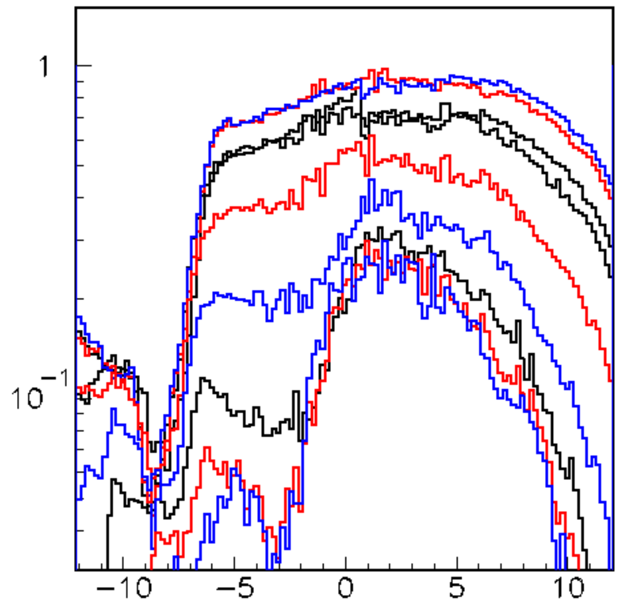
Mean *Vz* vs. azimuthal angle



SiO displays strong east-red/blue-west asymmetry



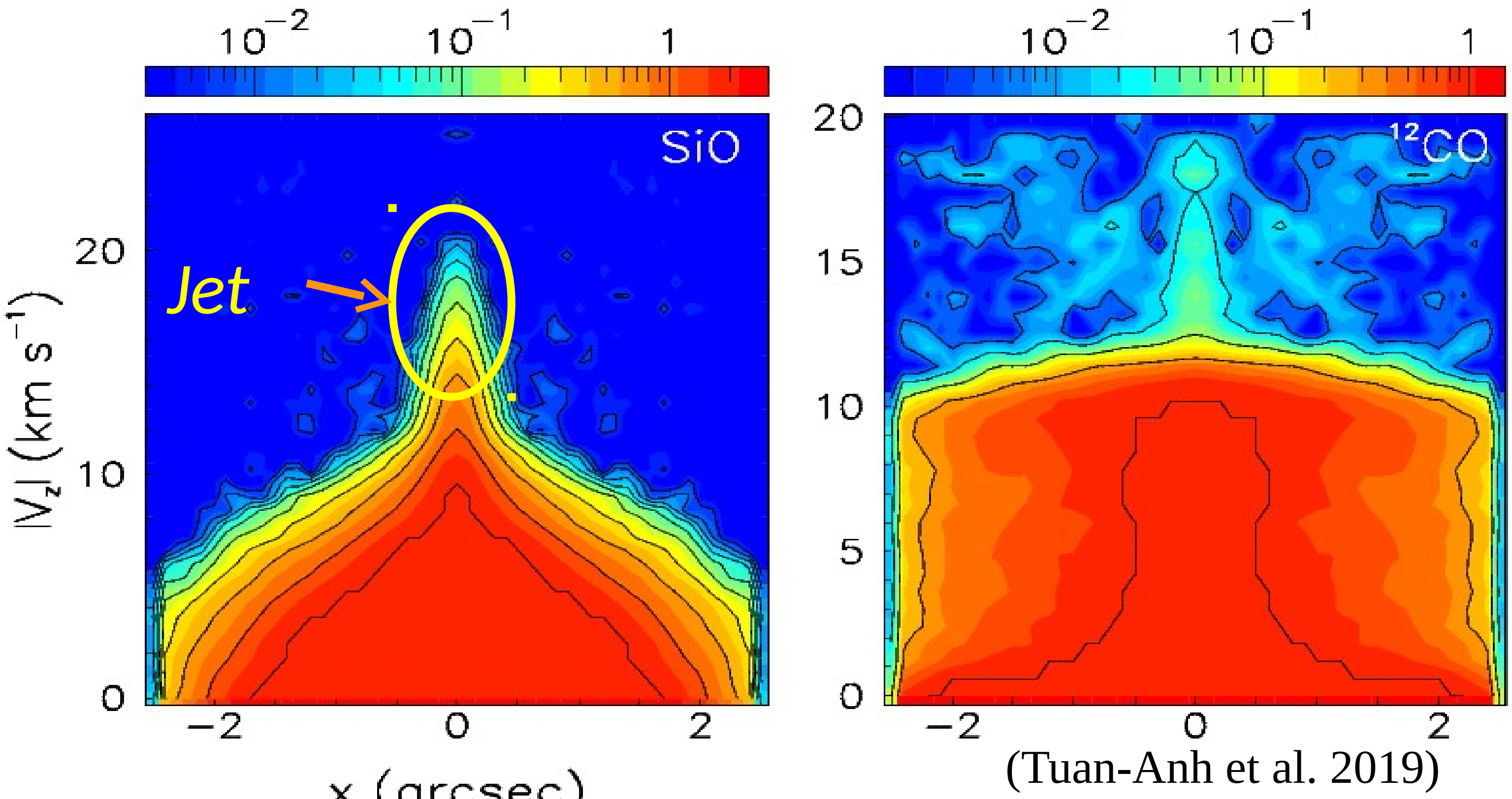




Scanning across the yellow line displays spectacular variation of the Doppler velocity spectrum

SiO data give evidence for narrow polar jets

Two polar jets with a terminal velocity of some 20 km s^{-1} are launched from less than 25 au projected distance from the mass-losing star. The absence of detection of jet emission in the SO_2 data suggests that the jets acquire velocity over distances from the star between ~20 au and ~100 au



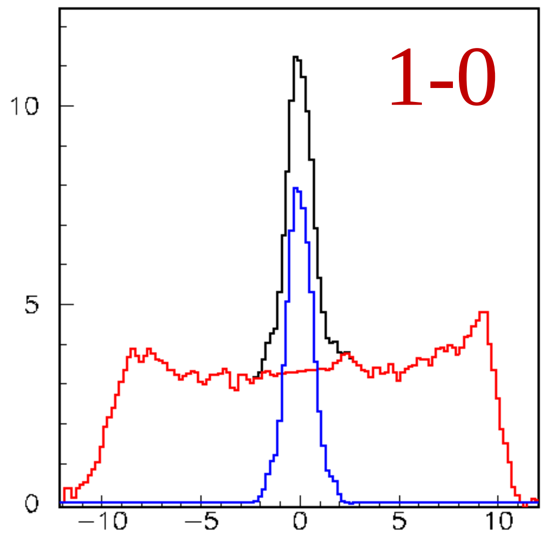
(Tuan-Anh et al. 2019)

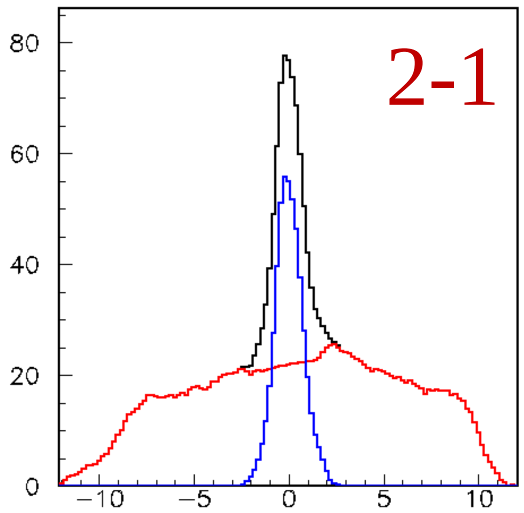
They are much weaker in CO than SiO emission, suggesting that they slow down and/or diverge at large distances from the star.

CO emission provides more detailed information than the previous lines because it explores a simple morpho-kinetic regime, because it extends over a much broader region (up to ~1000 au) and because two lines, CO(1-0) and CO(2-1) have been observed.

This makes it possible to measure the temperature and evaluate the absorption, and ultimately measuring the flux of matter that is found to peak at intermediate star latitudes and to add up to ~(1.6±0.4) 10^{-7} solar masses per year.

Hoai et al. 2019





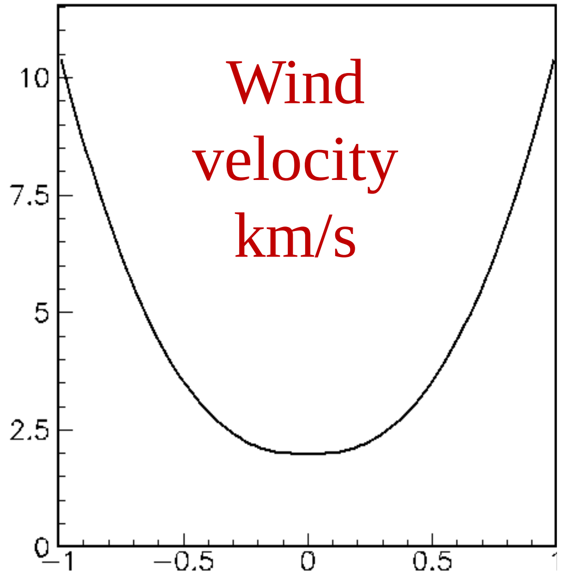
Summed Doppler velocity distributions km/s

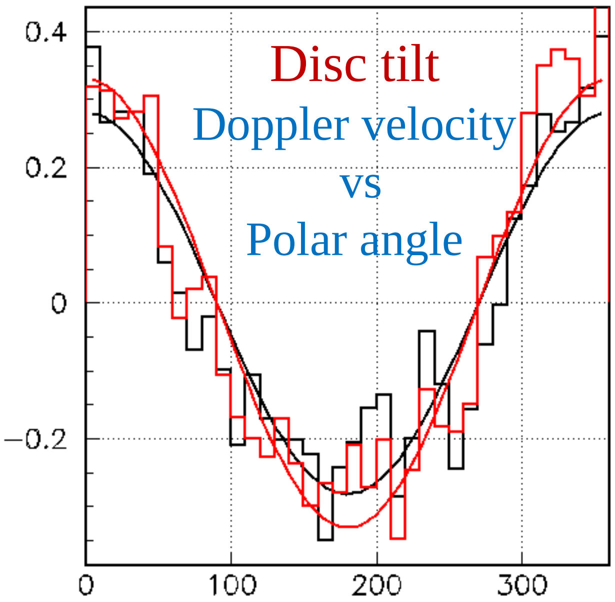
We split the data cubes into two parts: a narrow component and a broad component.

From a detailed study of the symmetries of the data cubes, we show that the star axis makes an angle of ~10^o with the line of sight and projects ~20^o west of north.

We also show that the narrow component is equatorial and expands at low velocity, the broad component being polar and expanding at high velocity.

Rotation/expansion is limited to 38% and line widths (1.2 km/s FWHM) limit the equatorial flaring to ±17^{o} (FWHM).

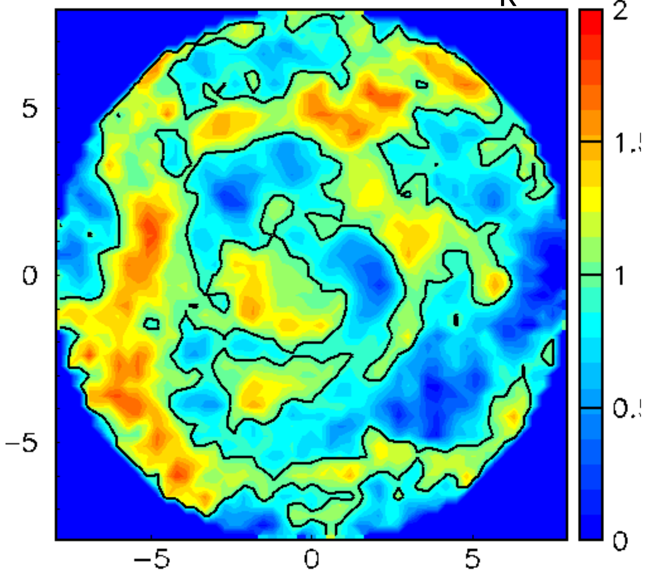




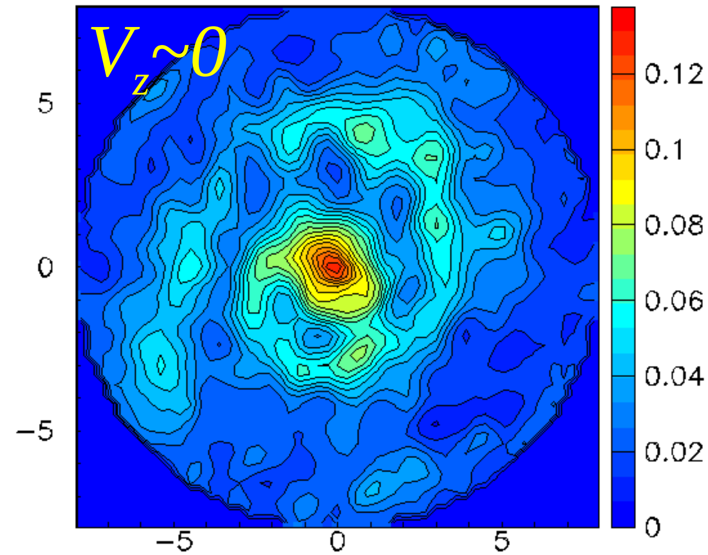
Hoai et al. 2019

Inhomogeneity tells us about the mass loss history, at the scale of ~2500 yr

$\Phi(x, y) = F(x, y) / \langle F \rangle_R$

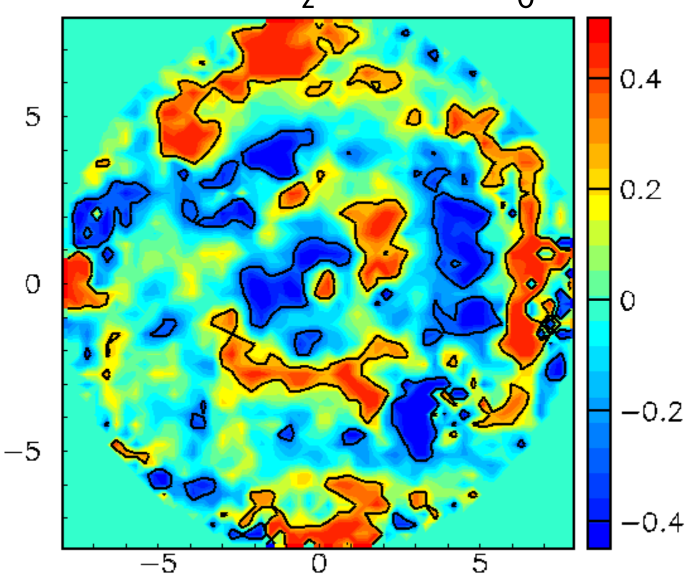


Brightness shows a spiral: evidence for a companion?

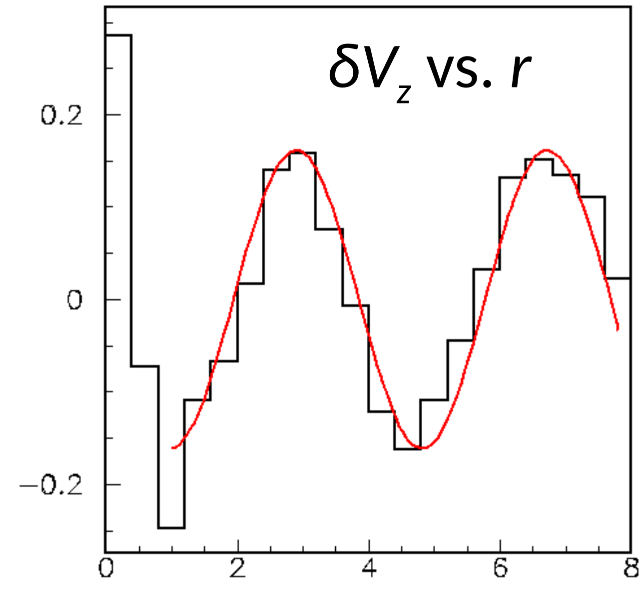


Hoai et al. 2019

$\delta V(x, y) = \langle V_z \rangle - \langle V \rangle_0 \cos\psi$

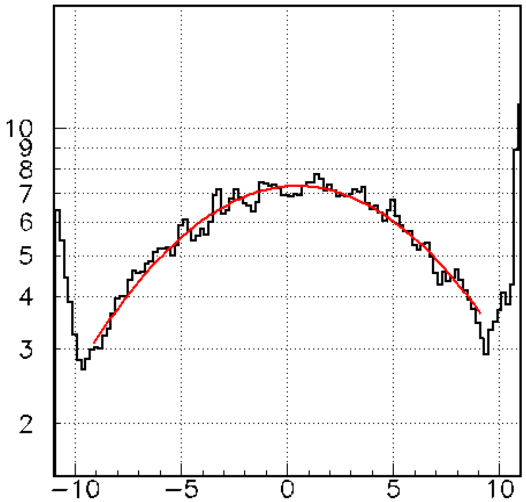


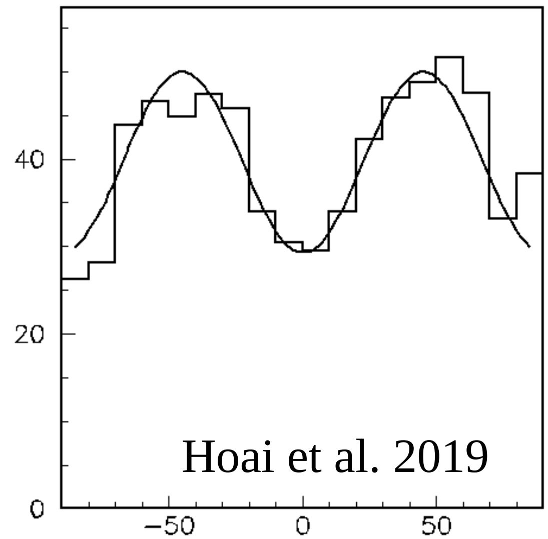
Doppler velocity shows concentric circles but uncorrelated with the spiral

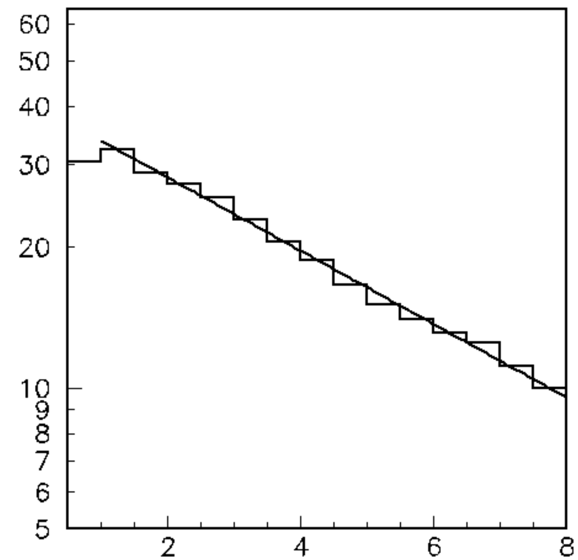


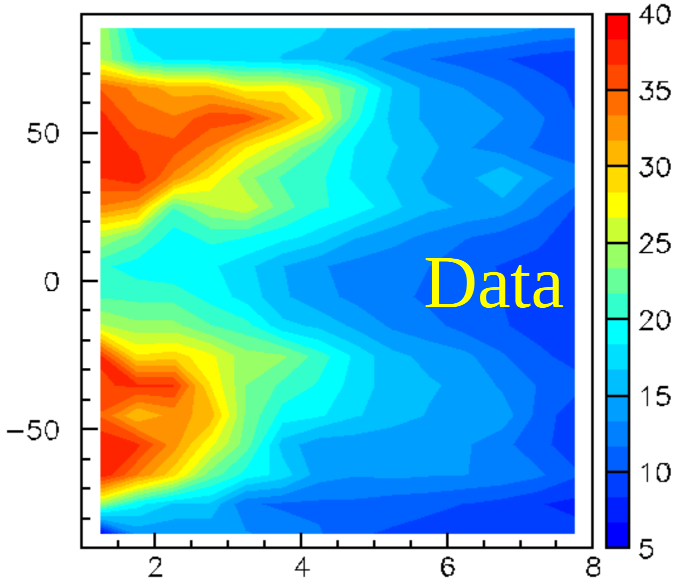
TEMPERATURE

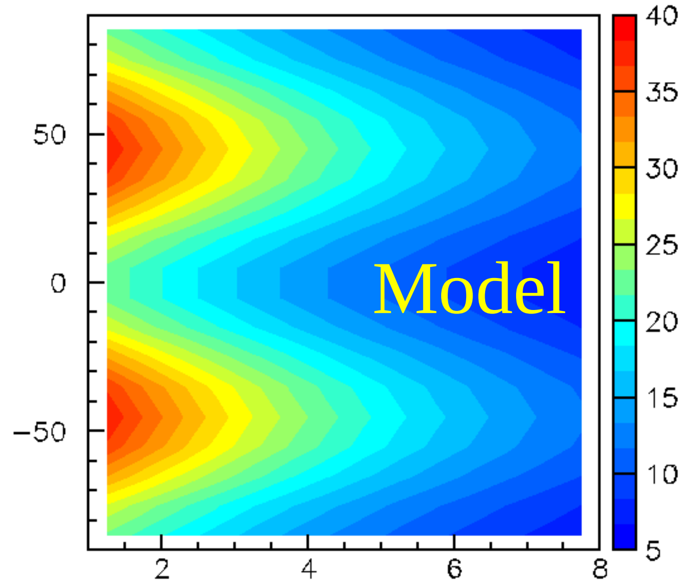
(2-1)/(1-0) | vs latitude | vs distance





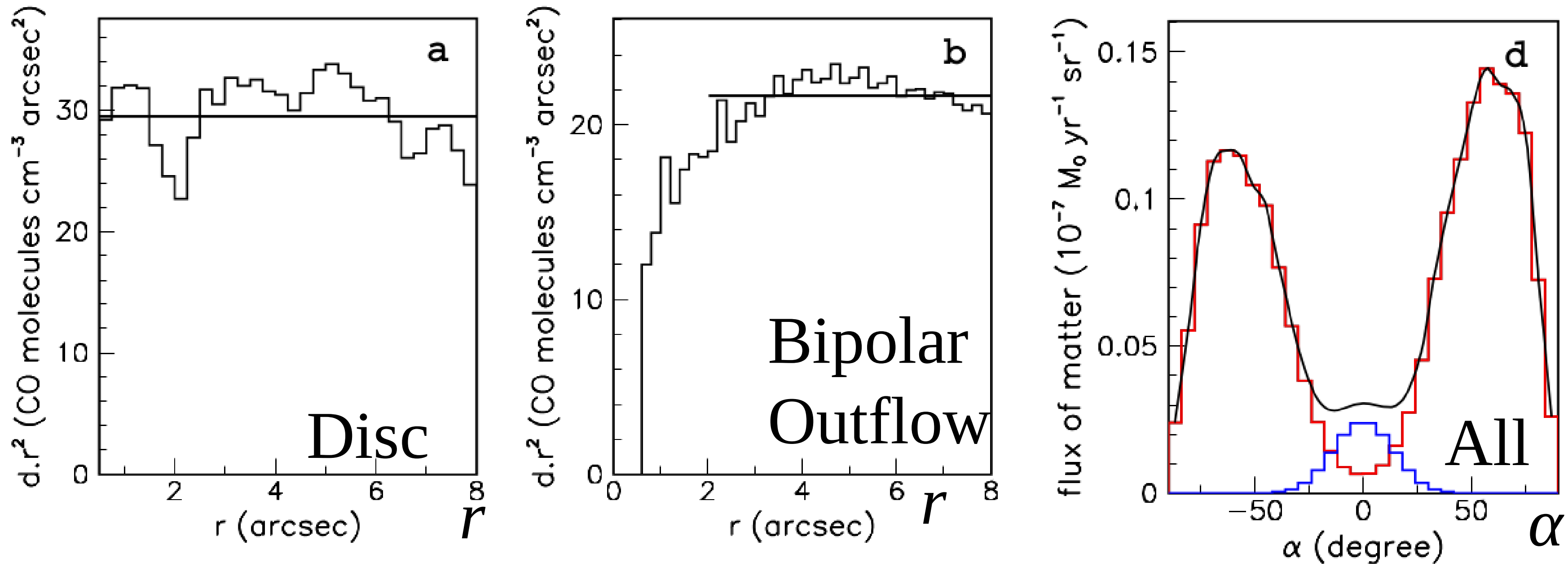






Temperature in latitude vs distance plane

To within ~±10% we measure a constant mass loss rate for ~2500 years of ~(1.6±0.4) 10^{-7} solar masses per year peaking at intermediate latitudes of which the disc contributes only 10%

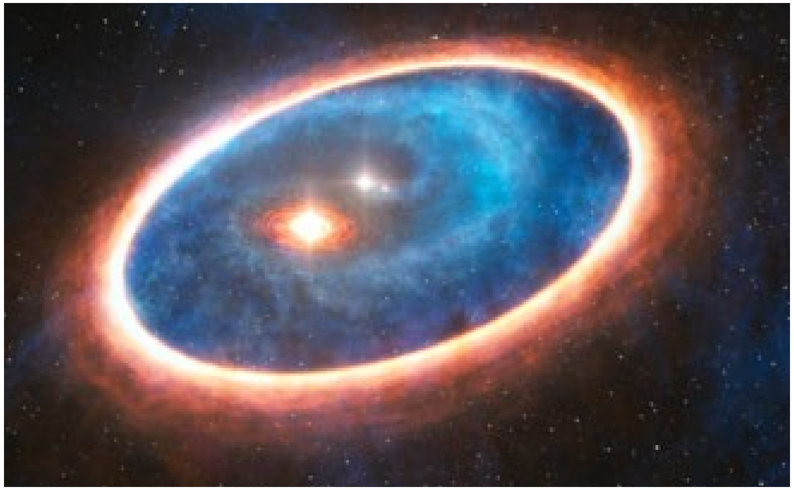


Hoai et al. 2019

A protostar: GG Tau

A protostar: GG Tau

GG Tau is a triple star, with respective separations of 35 au and 4.5 au. It is located at 140 pc in the Taurus molecular cloud (1arcsec=140 au). Surrounded by a circumbinary envelope of gas and dust with a ring spanning from ~190 to 280 au and an outer disc extending up to ~800 au from the protostar with a total mass ~0.15 solar masses.

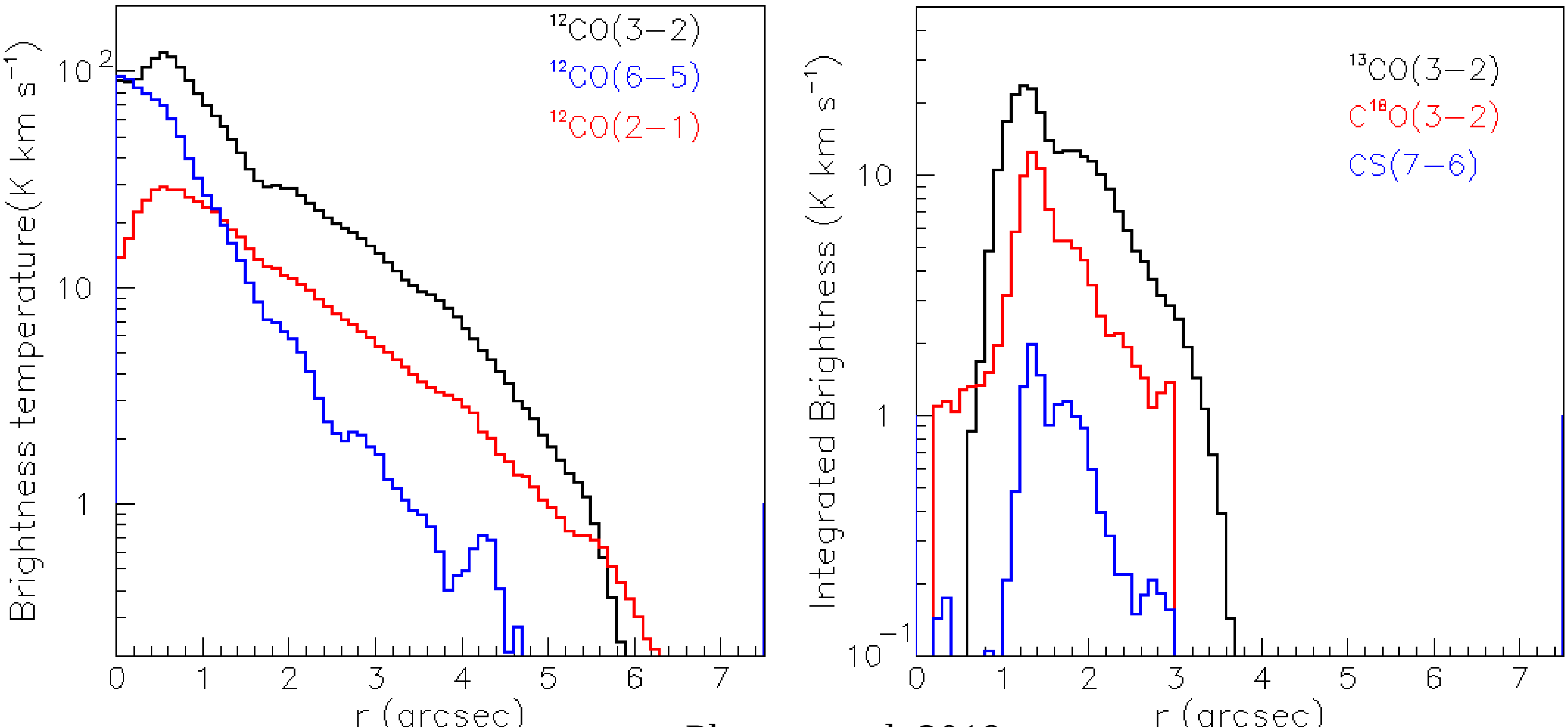


Artist view

Main questions address the morphology and kinematics of the surrounding gas and dust, the complex chemistry at stake (strongly influenced by dust grains) and the possible formation of planets.

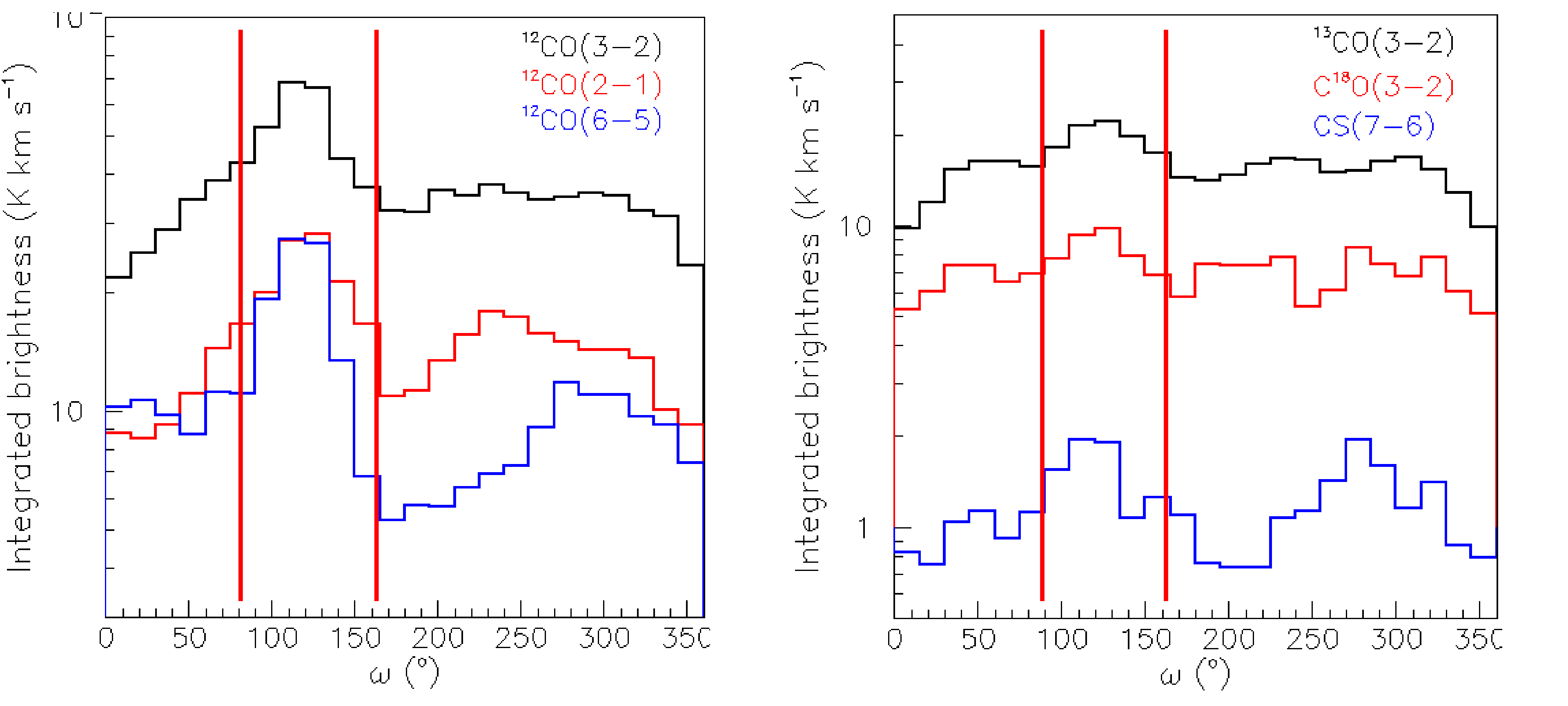
$^{12}C^{16}O$ emission covers a broad region around the central binary, R<~5 arcsec, peaking at the centre. Differences between the three lines result from a small temperature gradient, T [K]~ 36/R [arcsec].

On the contrary, $^{13}C^{16}O$, $^{12}C^{18}O$ and CS emissions populate a ring in the ~0.8 to ~2.5 arcsec range of r.

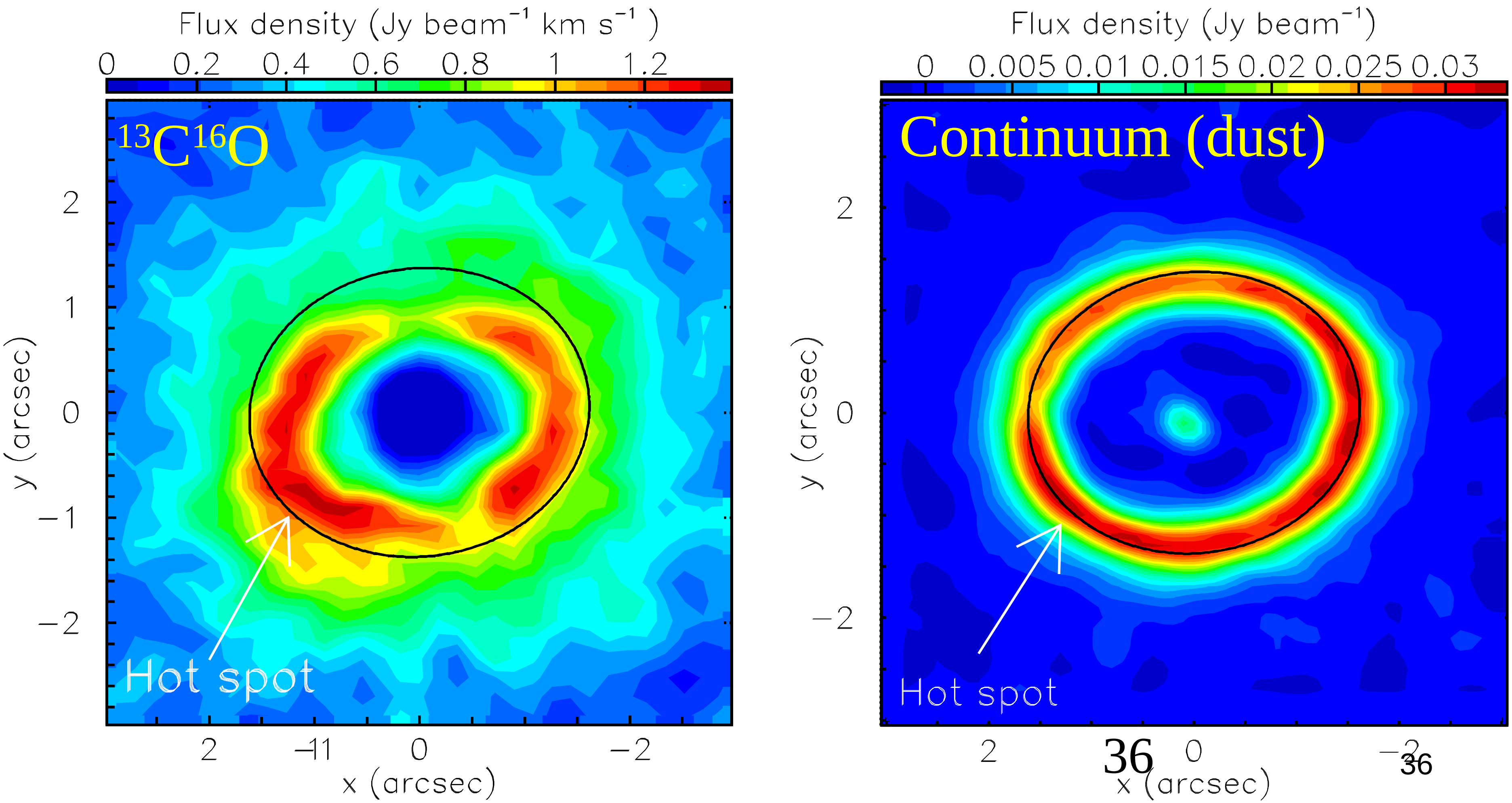


Phuong et al. 2018a

The dependence of brightness on position angle in the ring (1.2<R<2 arcsec) displays a significant enhancement in the south-eastern quadrant for $^{12}C^{16}O$ that may reveal a possible planet in formation. However, it is much less clear for the other lines, shedding doubt on such an interpretation.



Continuum (dust) emission shows no evidence for a hot spot. The ring has a major axis of 1.62 arcsec and a minor axis of 1.37 arcsec, implying an inclination of ~32° with respect to the sky plane.



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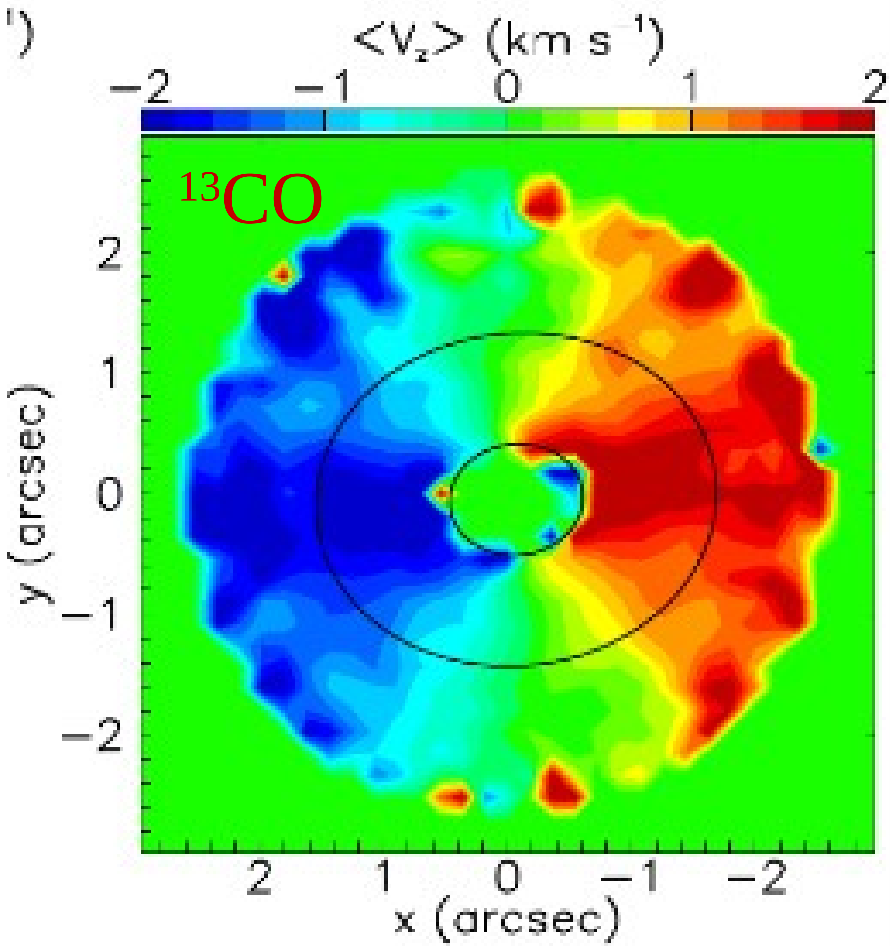
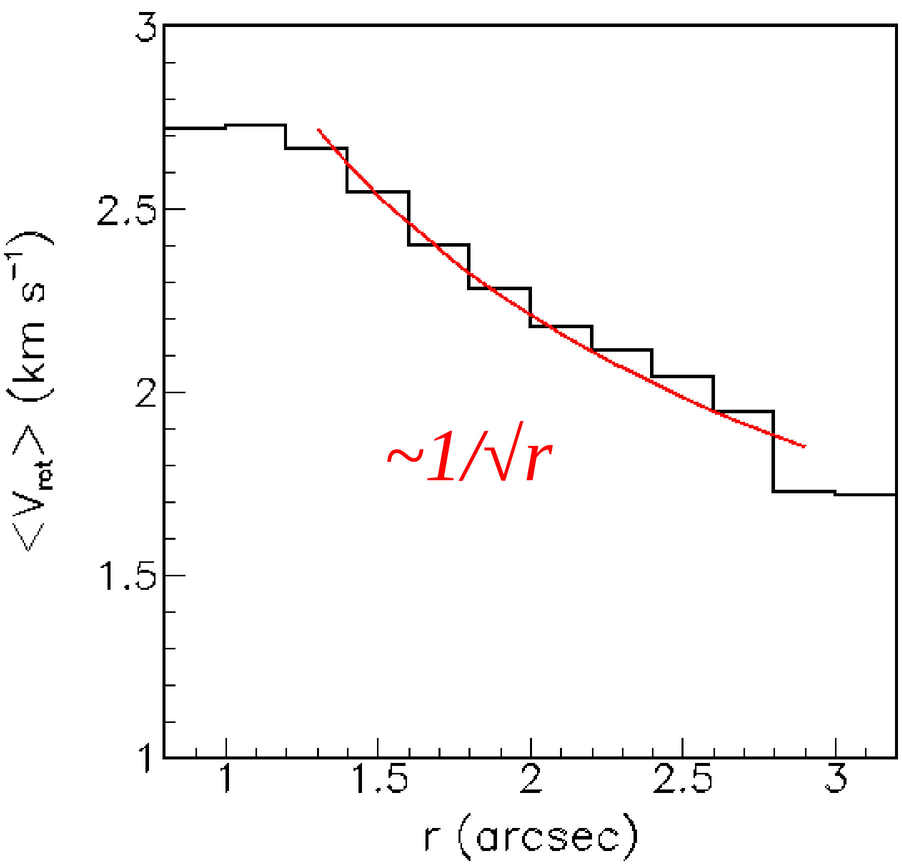
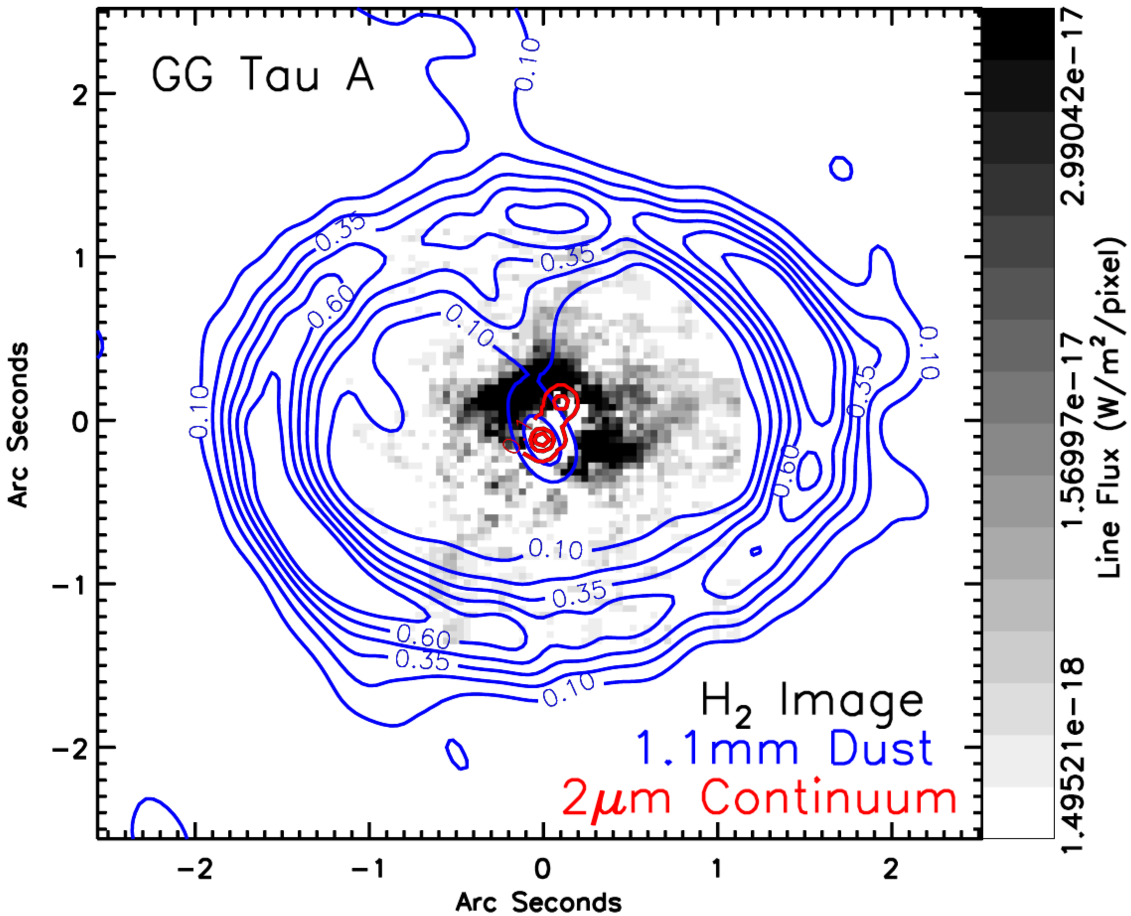
The ring is observed to be in Keplerian rotation with V_{rot} [km/s]= 2.21(r [arcsec]/2)$^{-0.48}$



Phuong et al. 2018a

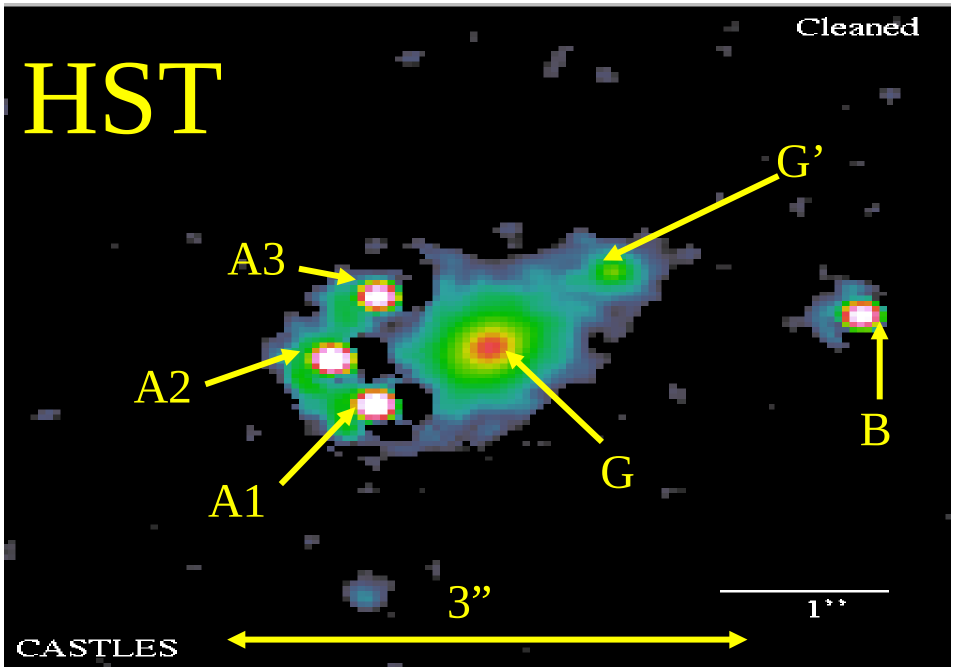


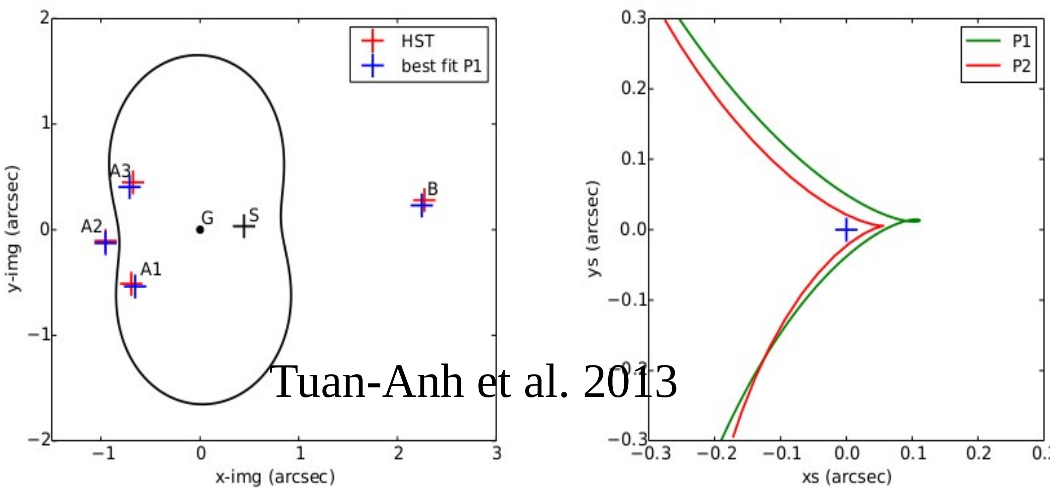
Understanding the dynamics inside the cavity is one of the main challenges. The H_2 image (near infrared) may reveal shock excited mass infall onto the binary, in agreement with dust enhancement observed at 1.1 mm wavelength.



A High Redshift Galaxy: RX J0911

RX J0911.4+0551 (z~2.8)





Tuan-Anh et al. 2013

Gravitationally lensed quasar into 4 images; the lensing potential is well understood. The source is near a cusp of the minor axis of the caustic curve.

A black hole mass of ~1.6 10^8 solar masses is estimated from measured X ray luminosity.

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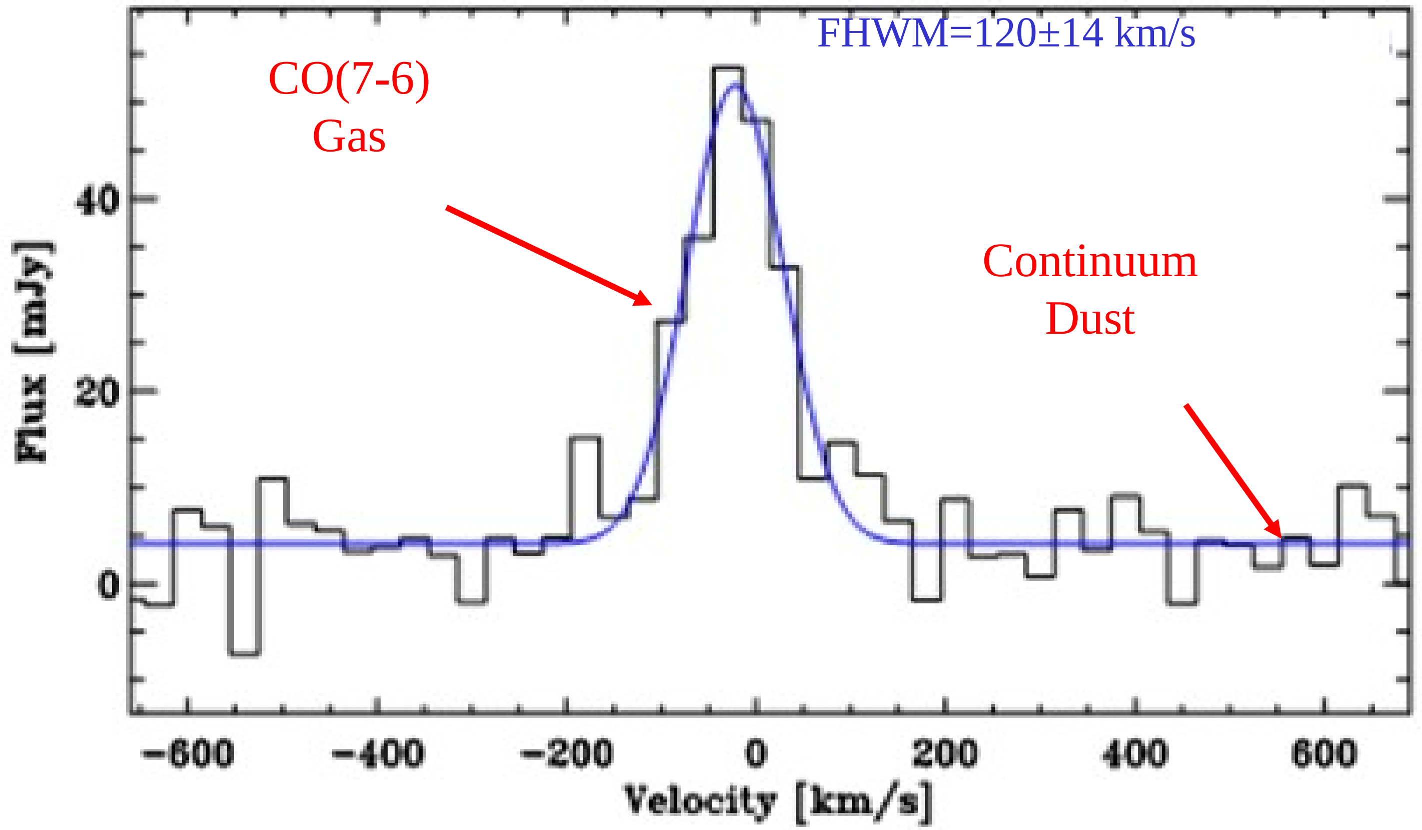
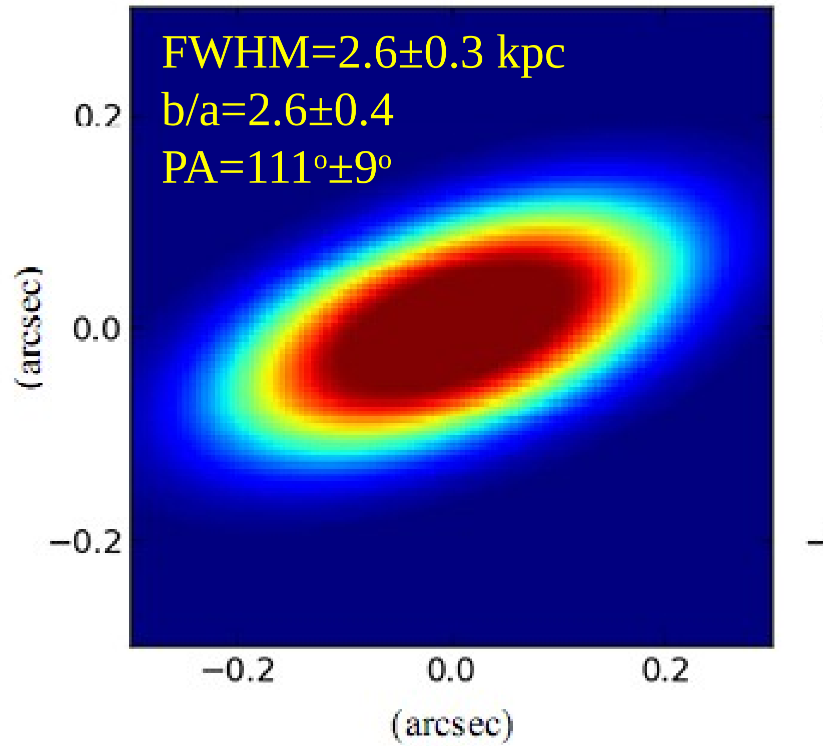
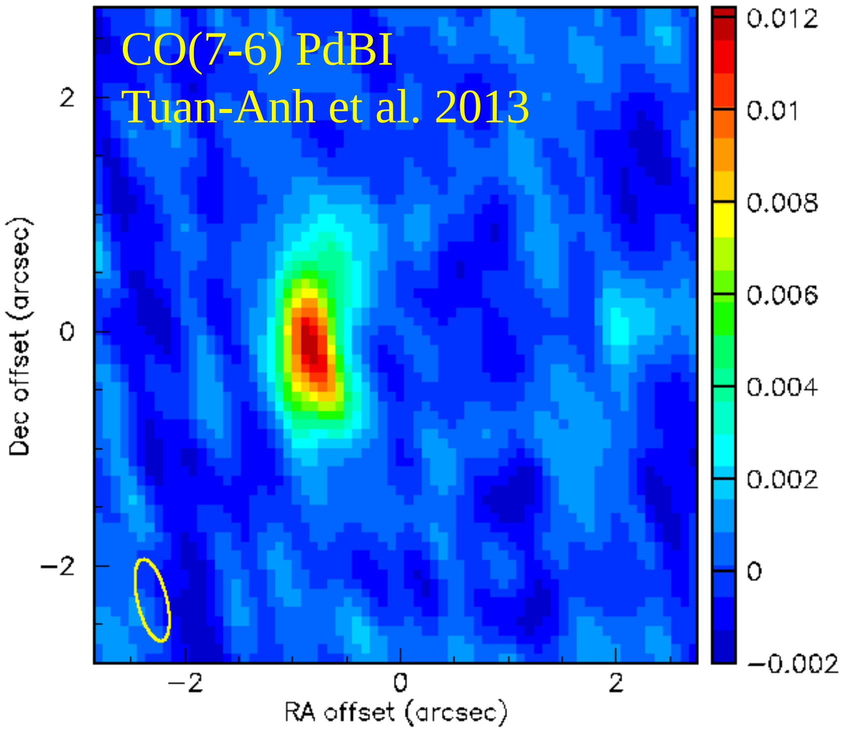
We observe CO(7-6), CO(10-9), CO(11-10) and continuum emissions. All line measurements report a very narrow line, 107±20 km s^{-1} on average.



PdBI CO(7-6) observations resolve the source, measure its ellipticity and orientation and give evidence for a velocity gradient of 25 km s^{-1} kpc^{-1} at 4.5 s.d. from zero. This excludes that the small linewidth might be due to face-on view.

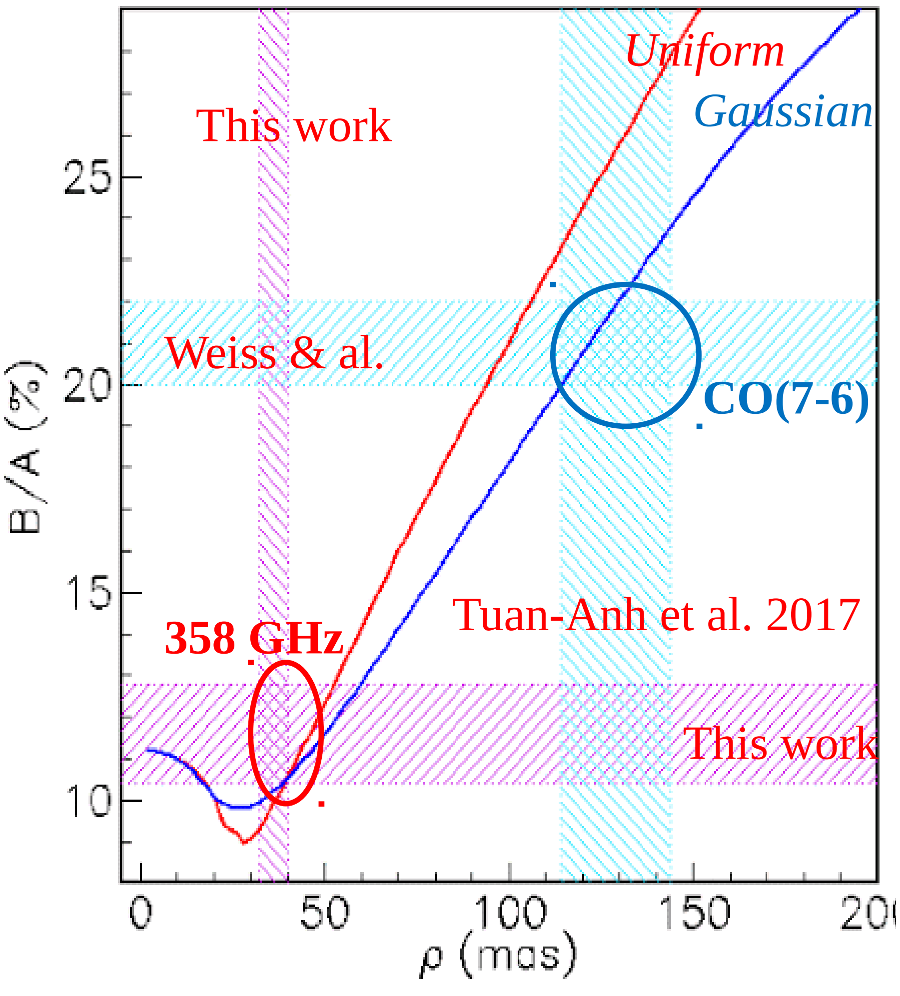




ALMA measurements of CO(10-9) and CO(11-10) suggest a temperature and/or density of the gas on the high side (typically ~60K rather than ~40K).

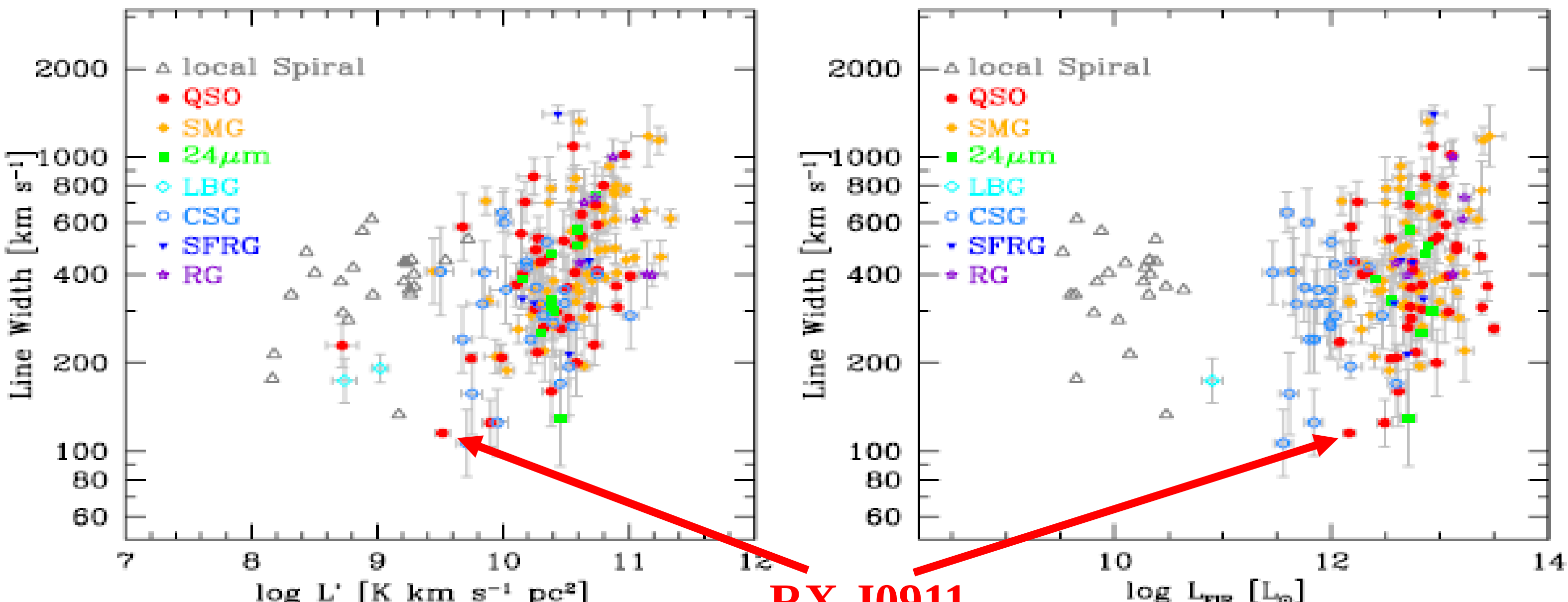
CONTINUUM EMISSION

The size of the source in the continuum (358 GHz) is measured (ALMA) as FWHM = 0.76±0.08 kpc, 3.4±0.4 times smaller than the gas source measured in CO(7-6).
Nicely confirmed by a measurement of the brightness ratio between western and eastern images 11.6±1.2%.



CO line width & luminosity

Measures dynamical gas mass



RX J0911

Measures gas mass

Measures dust mass and SFR

The small line width implies that RX J0911 resides in a relatively small galaxy (when compared to other high-z quasars).

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

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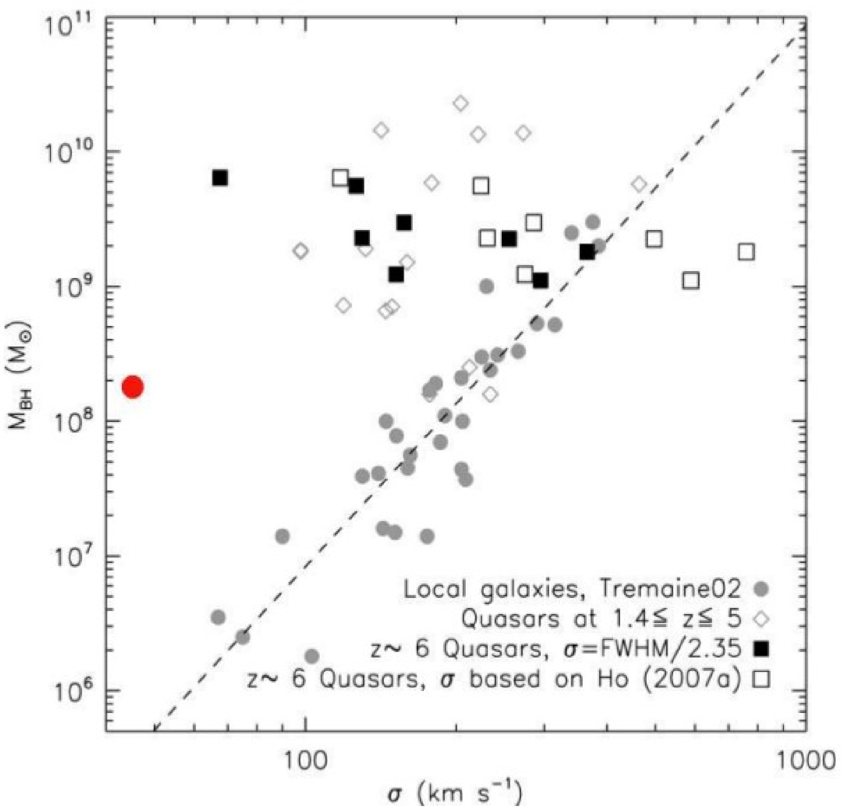
Central Black Hole

Black hole mass



Dynamical mass
(line width)

Together with the low values 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 and conclusion

The example of EP Aqr has given evidence for an important contribution of star pulsations and rotation in the generation of the nascent wind, the presence of a narrow polar jet having sharp boundaries and terminal wind velocities displaying a two-component structure associated with equatorial and bipolar outflows, the flux of matter peaking at intermediate star latitudes.

The example of GG Tau has given evidence for a protostellar Keplerian disc, displaying a ring structure strongly related to the the chemistry at stake in the formation of the nascent stars.

The example of RXJ 0911 has illustrated how information on the formation of stars and galaxies in the early Universe can be obtained from separate millimeter observations of gas and dust emission. This particular galaxy, a quasar host, was found to be atypical in many respects.

We are making extensive use of the open data policy of the ALMA collaboration who make their observations publicly available one year after collection. This generous policy is an invaluable asset to teams such as ours, working in developing countries having otherwise no direct access to frontier astrophysics. We are immensely indebted and grateful to the ALMA partnership.

We are working toward collaborating with Asian countries, in particular Japan, South Korea, Taiwan and China. We do our utmost to promote fundamental research in the country by teaching in various universities and taking part in outreach events of various kinds, in particular having contacts with amateur astronomer clubs.

THANK YOU
FOR YOUR
ATTENTION