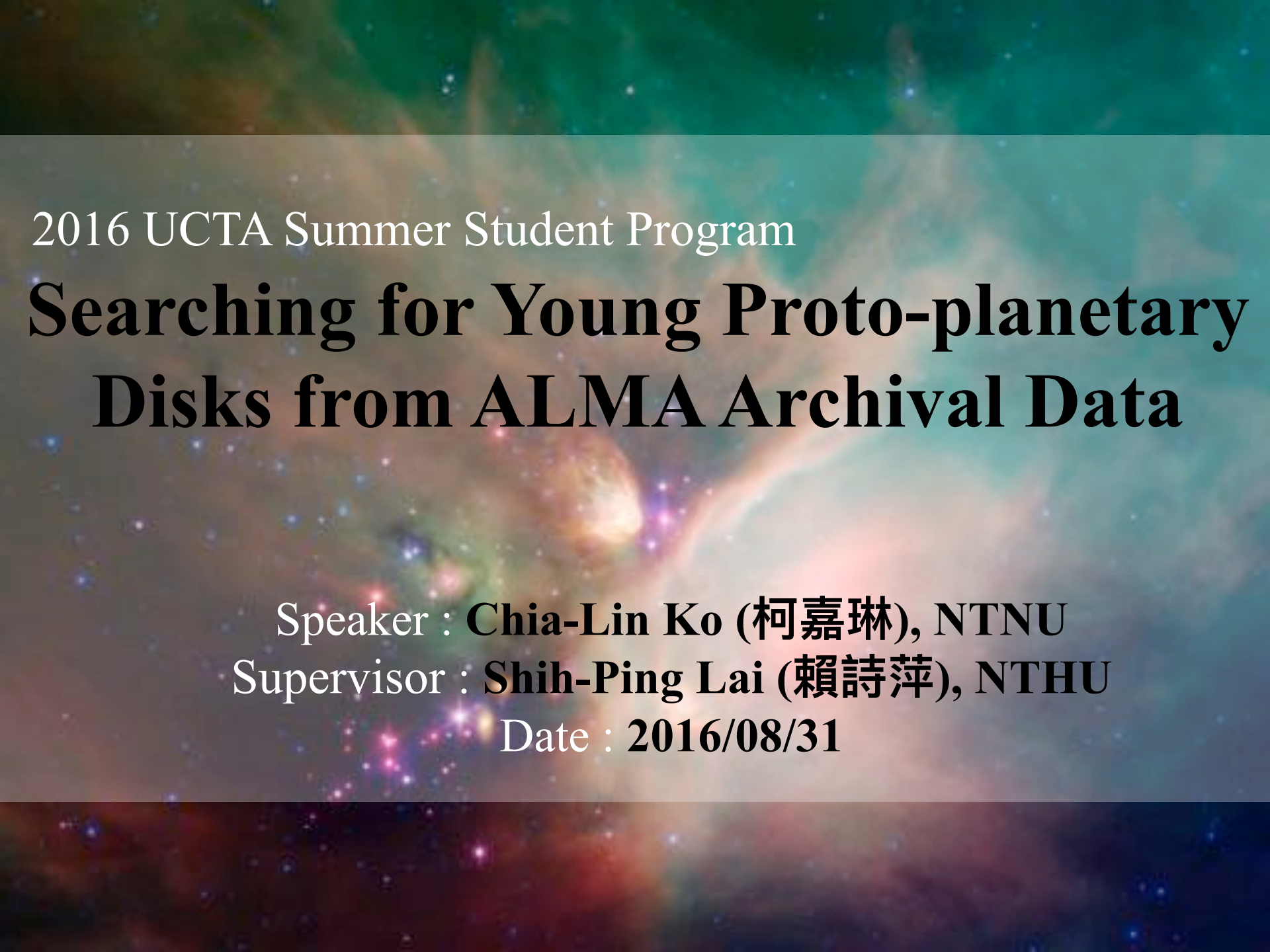




2016 UCTA Summer Student Program

Searching for Young Proto-planetary Disks from ALMA Archival Data

Speaker : **Chia-Lin Ko (柯嘉琳)**, NTNU

Supervisor : **Shih-Ping Lai (賴詩萍)**, NTHU

Date : **2016/08/31**

Outline

Introduction



Analysis

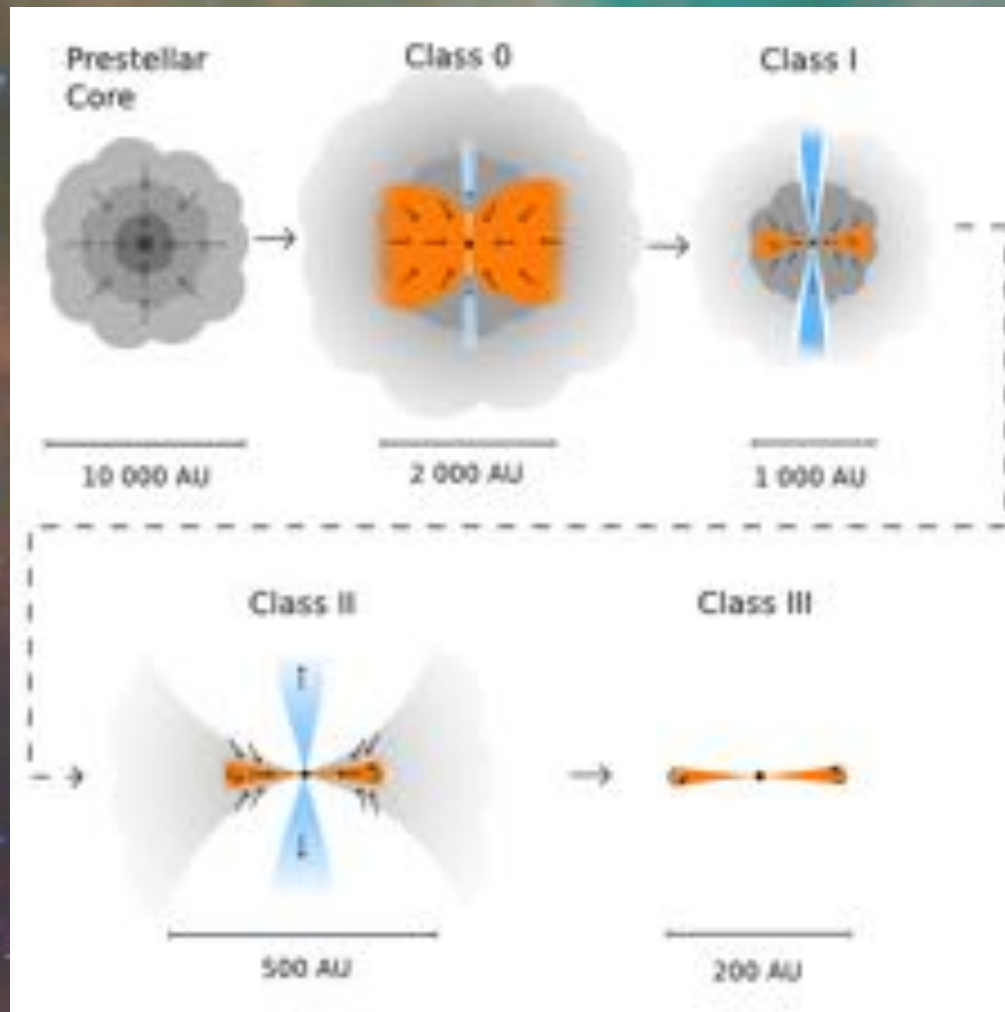


Conclusion



Future work

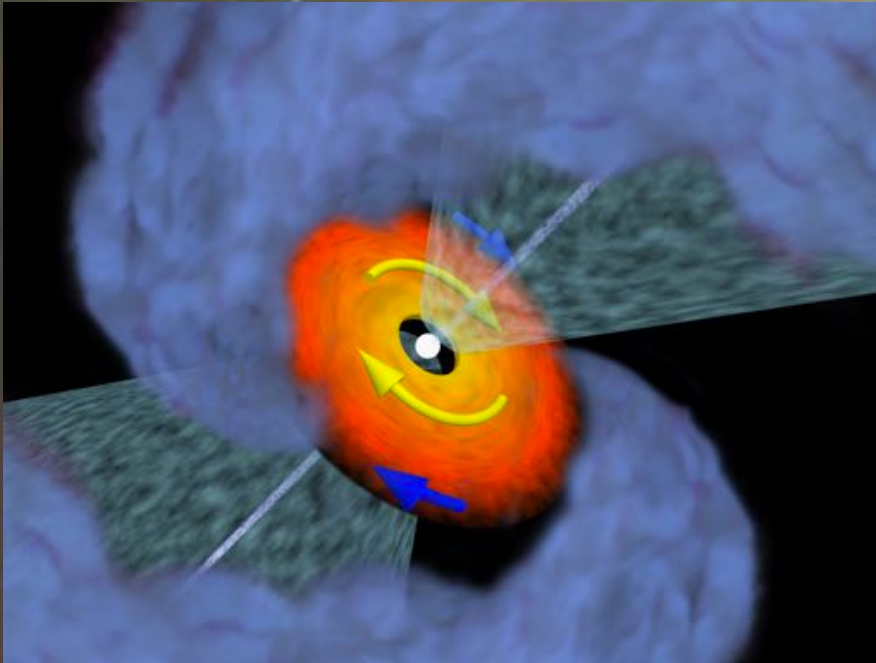
Star formation



(http://vilhelm.nu/research_water.php)

(Photo : <http://www.spitzer.caltech.edu>)

Keplerian Disk



(<http://www.almaobservatory.org/>)

Keplerian rotation

$$v = \sqrt{\frac{Gm}{r}}$$

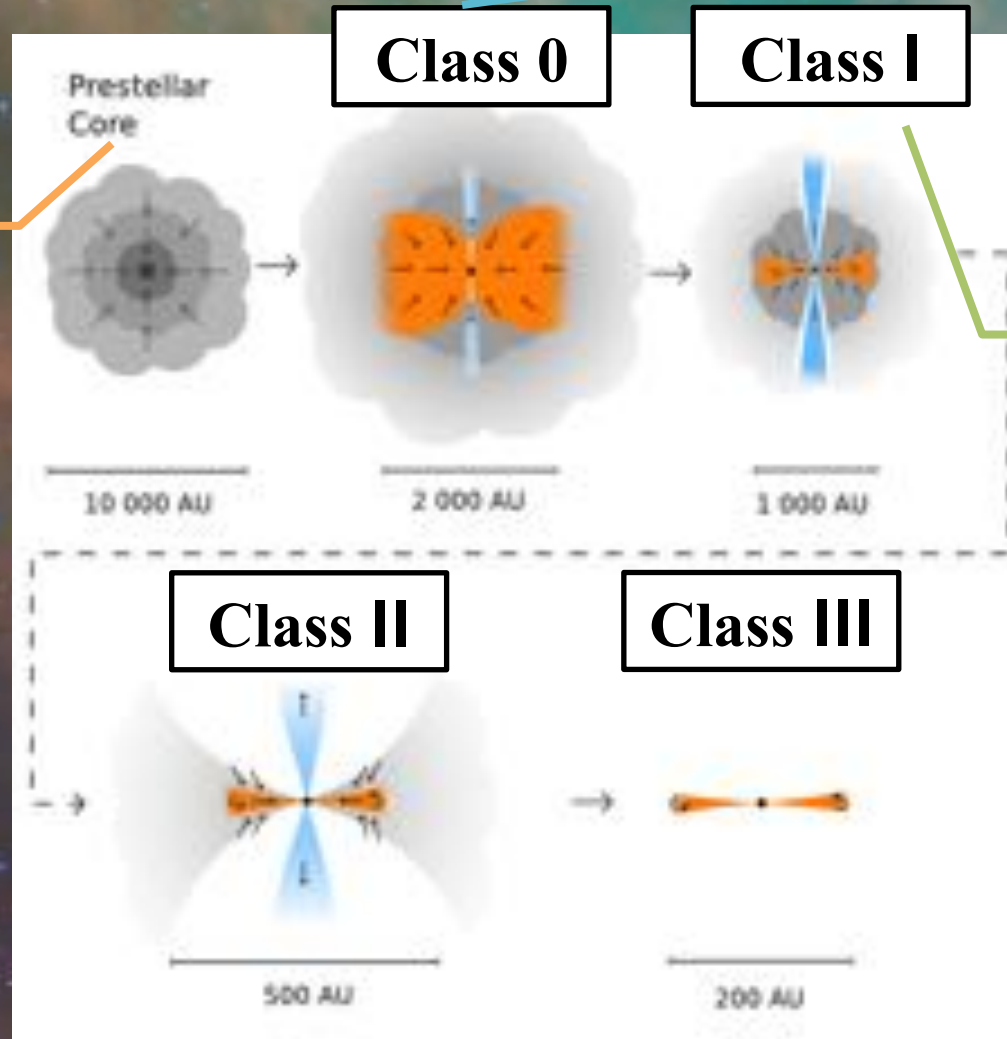
v : velocity of the molecular

G : gravitational constant

m : protostellar mass

r : radius at which the velocity
is being measured

Star formation



VLA1623 B

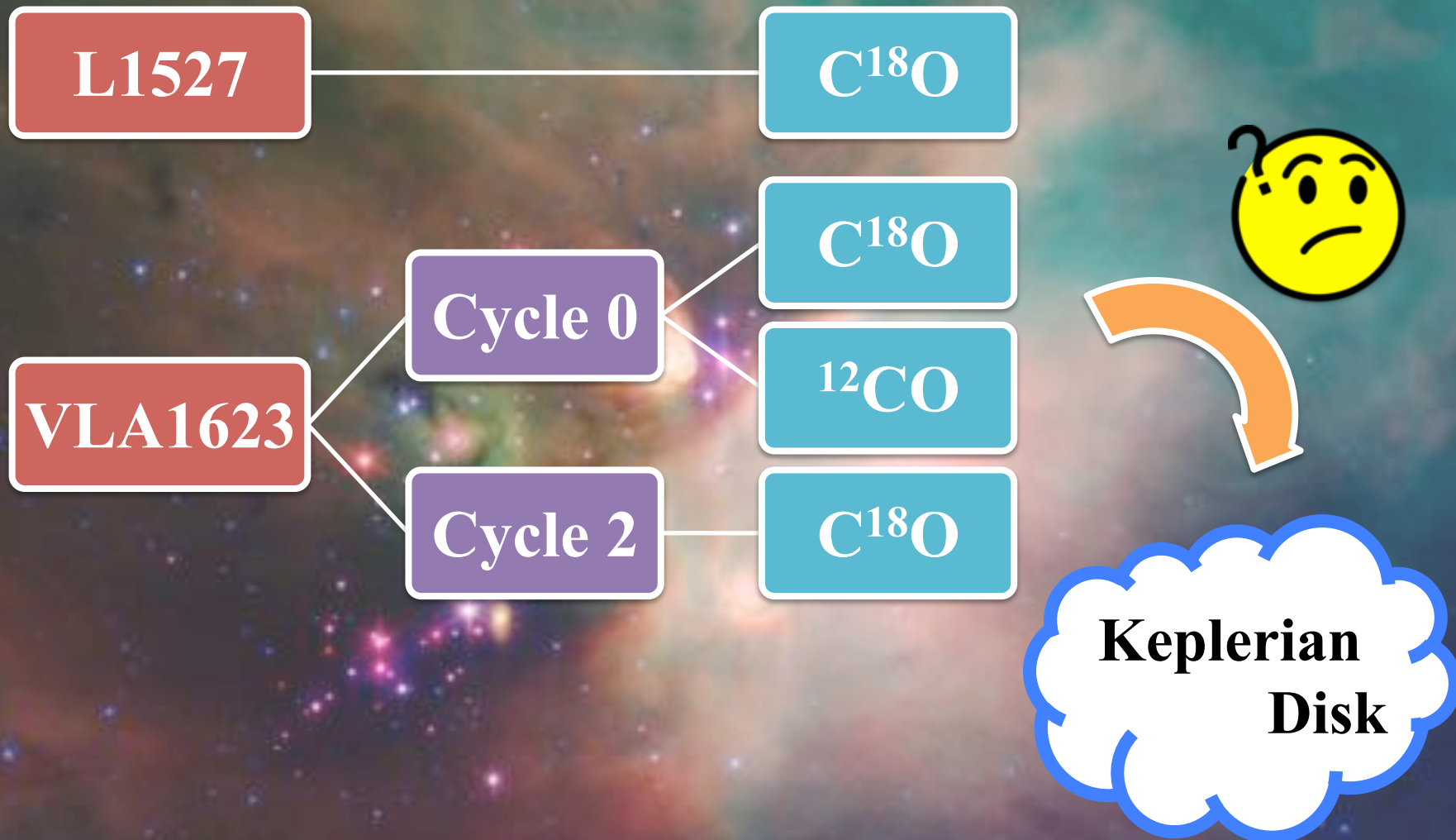
L1527
VLA1623 A

VLA1623 W

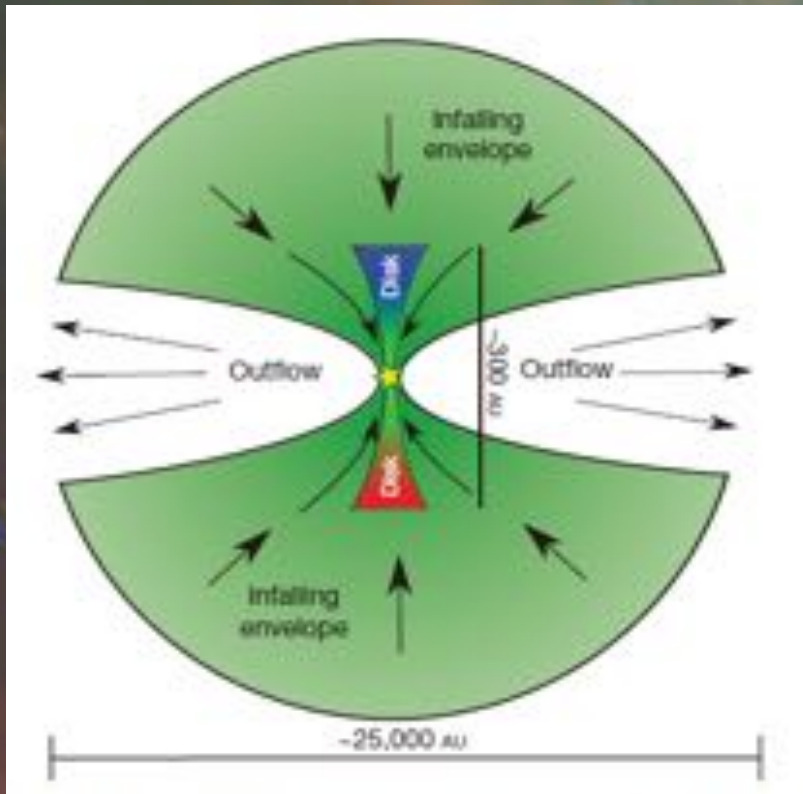
(http://vilhelm.nu/research_water.php)

(Photo : <http://www.spitzer.caltech.edu>)

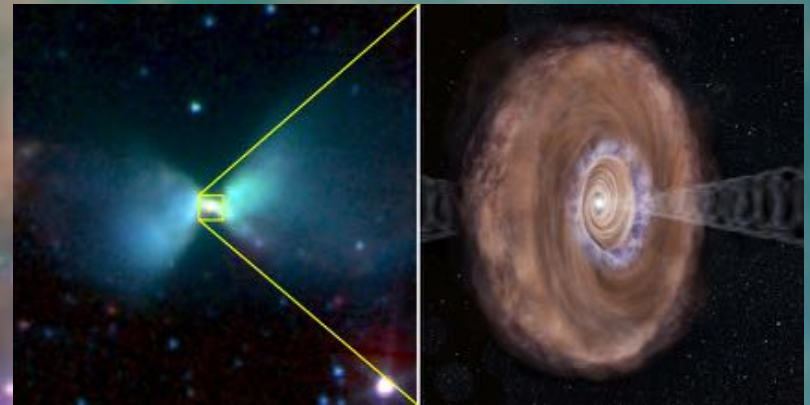
Analysis - Target



L1527



(Tobin et al. 2012)

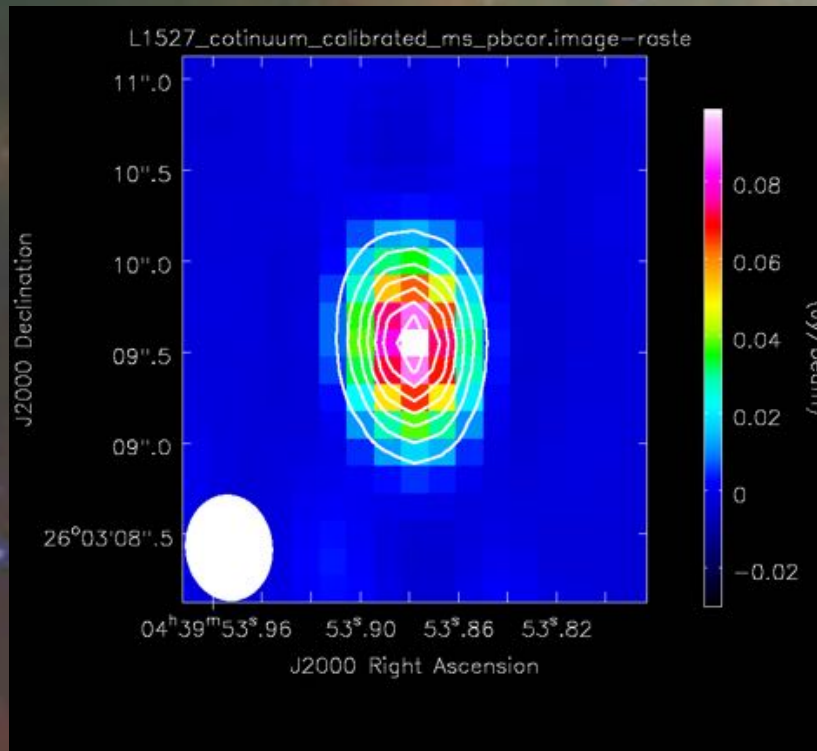


(alma.mtk.nao.ac.jp/e/index.html)

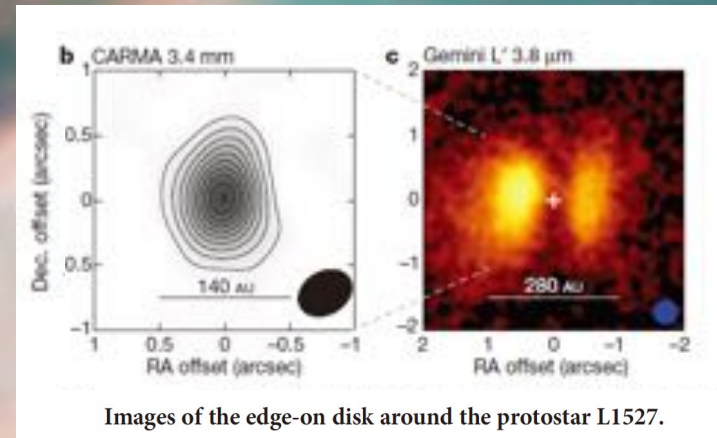
Constellation	Taurus
R.A. (J2000)	4 ^h 39 ^m 53 ^s .9000
Dec (J2000)	26° 03'10".000
Stage	Class 0

(Photo : <http://www.spitzer.caltech.edu>)

L1527



*ALMA archival data
Band 6 (230 GHz)*



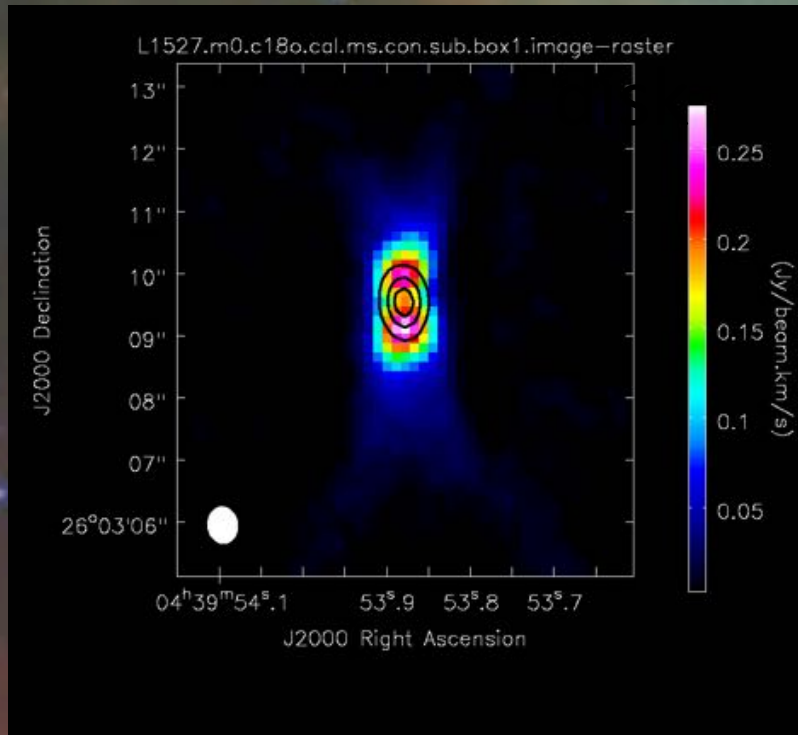
Images of the edge-on disk around the protostar L1527.

(Tobin et al. 2012)

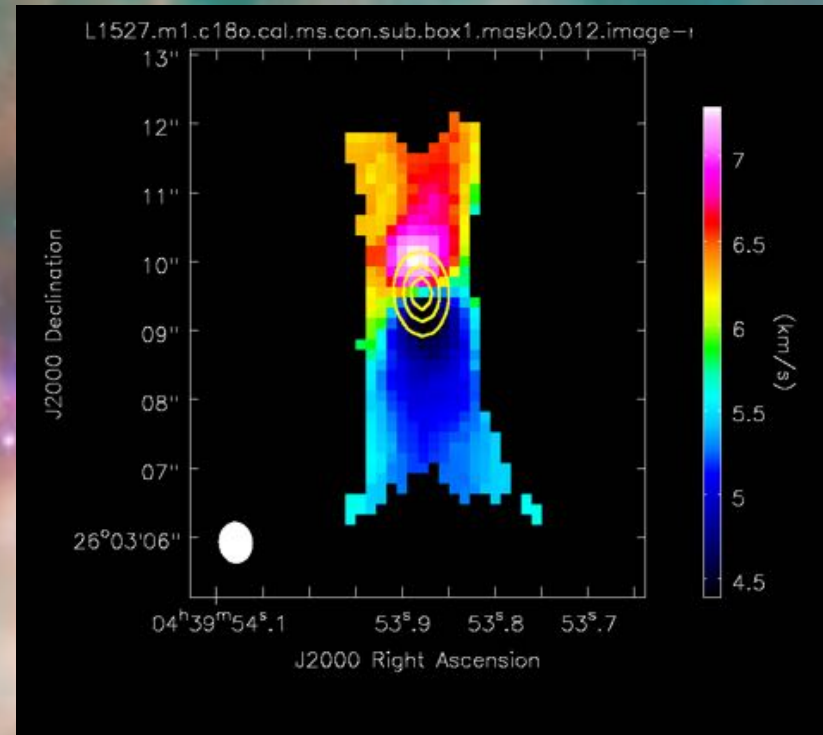
Continuum map : Contours are in steps of 5, 10 ,
15, 20, 25, 30, 35, 40 σ with $\sigma = 2.5$ mJy/beam

L1527 Moment Map of C¹⁸O (2-1)

Integrated intensity map



Average velocity map

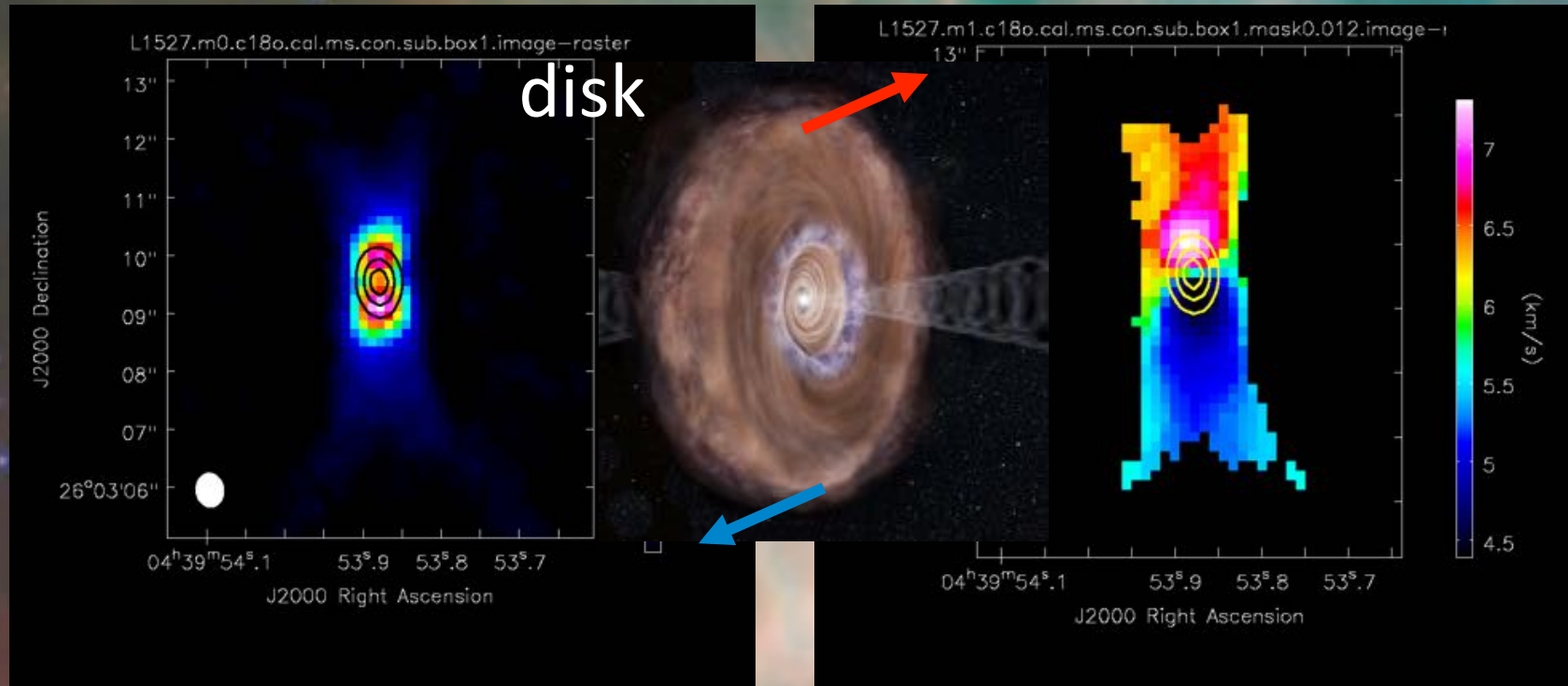


Observed C¹⁸O (2-1). Left : moment 0 map. Right : moment 1 map. Contours are in steps of 3, 9, 15 σ with $\sigma = 5.0$ mJy/beam

L1527 Moment Map of C¹⁸O (2-1)

Integrated intensity map

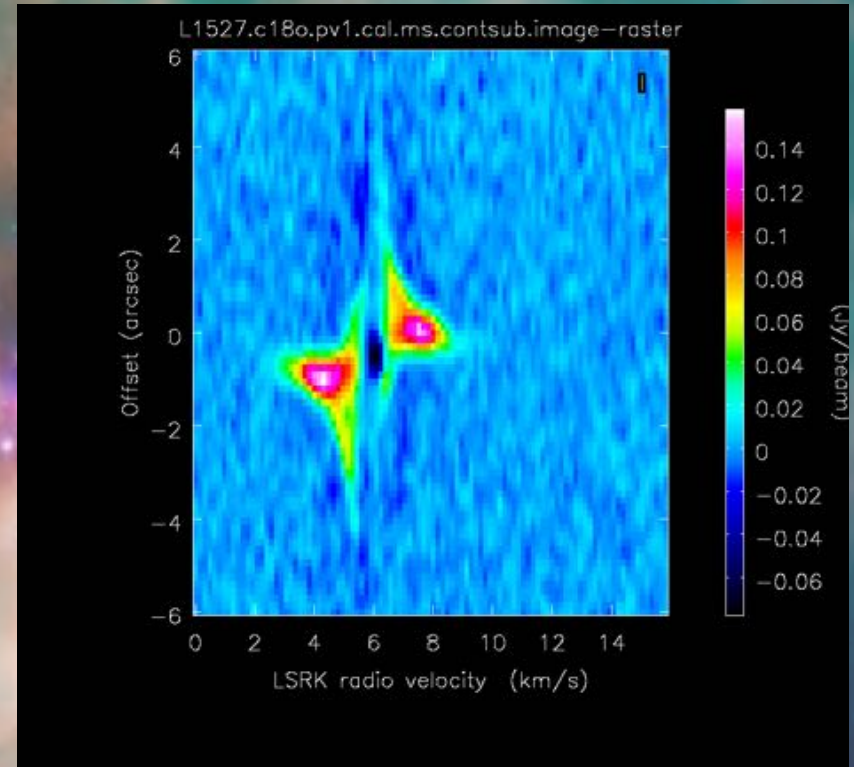
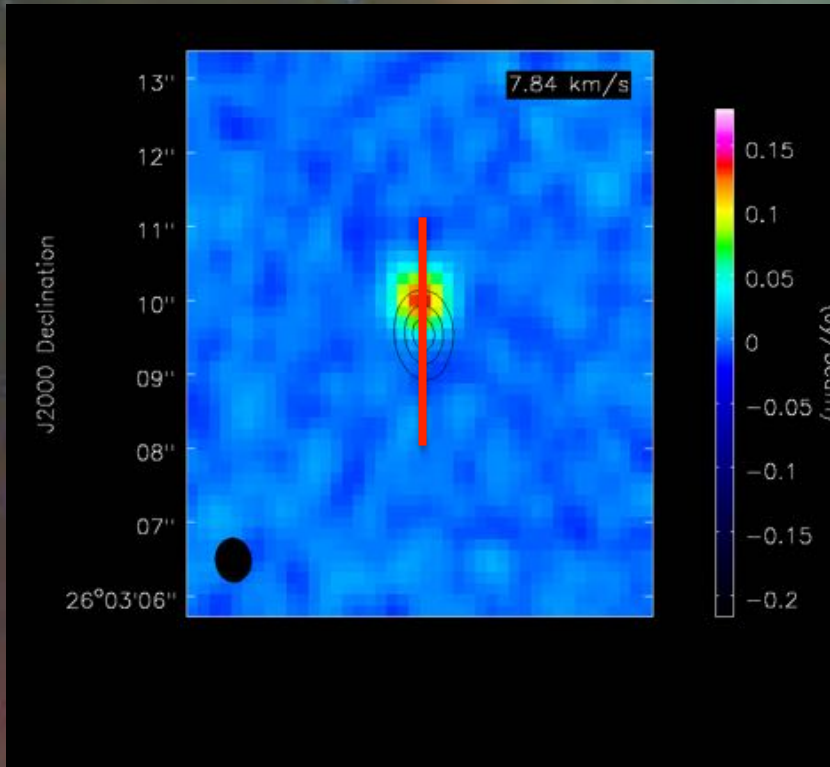
Average velocity map



Observed C¹⁸O (2-1). Left : moment 0 map. Right : moment 1 map. Contours are in steps of 3, 9, 15 σ with $\sigma = 5.0$ mJy/beam

L1527 Position-Velocity diagram of C¹⁸O (2-1)

Channel map



P-V diagram : Contours are in steps of 3, 9, 15 σ with $\sigma = 5.0$ mJy/beam

L1527 Position-Velocity diagram of C¹⁸O (2-1)

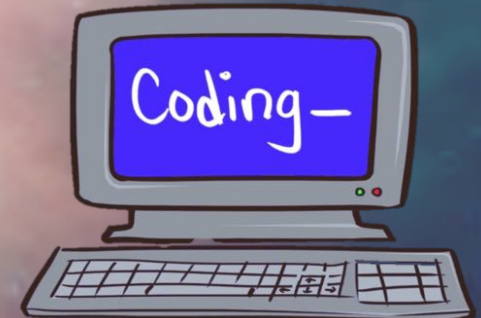
CASA

- impv
- exportfits
(image → fits)

Python

- fits
- Keplerian line

keplerian disk ?
protostellar mass ?

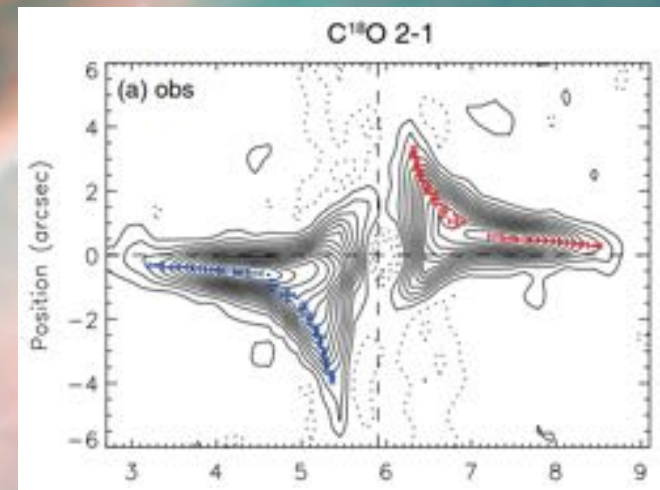
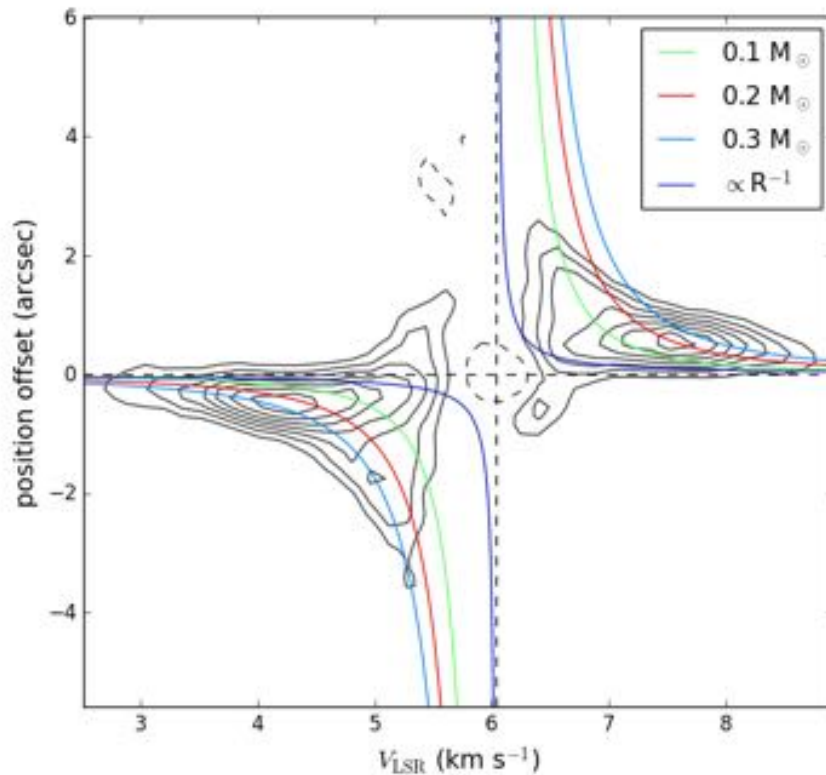


L1527 Position-Velocity diagram of C¹⁸O (2-1)

Protostellar mass :

$$0.196 \pm 0.04 M_{\odot}$$

(Tobin et al. 2012)

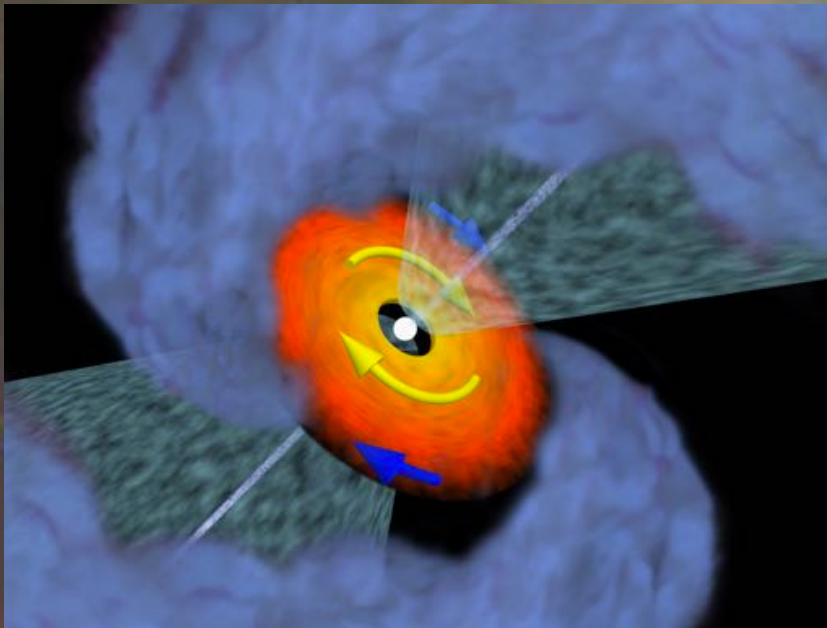


(Ohashi et al. 2014)

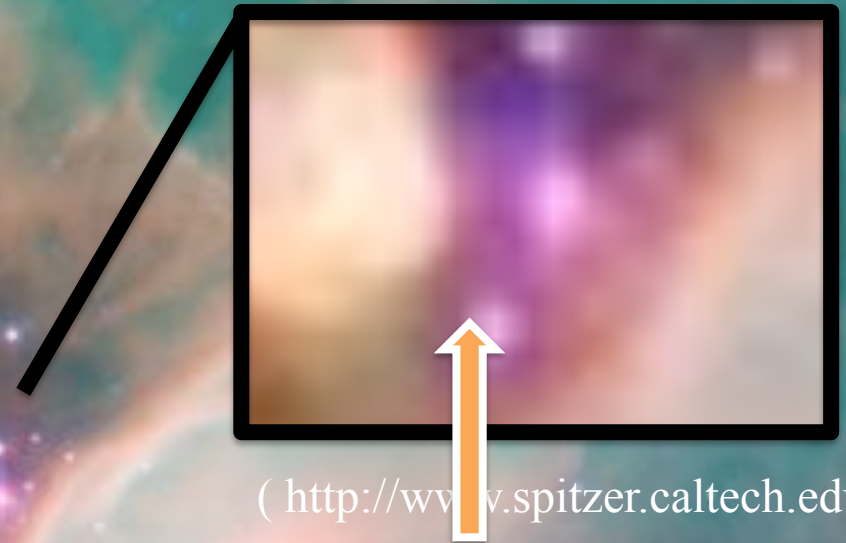
Contours are in steps of 3, 6, 9, 12, 15, 18, 21, 24, 27 σ with $\sigma = 6.6$ mJy/beam. **Curves** : the kepler's third law, different colors represent different masses of the proto-star. (except blue line: infall)

(Photo : <http://www.spitzer.caltech.edu>)

VLA1623



(<http://www.almaobservatory.org/>)



(<http://www.spitzer.caltech.edu>)

Constellation	Ophiuchus
R.A. (J2000)	16 ^h 26 ^m 26 ^s .390
Dec (J2000)	-24° 24'30".688

(Photo : <http://www.spitzer.caltech.edu>)



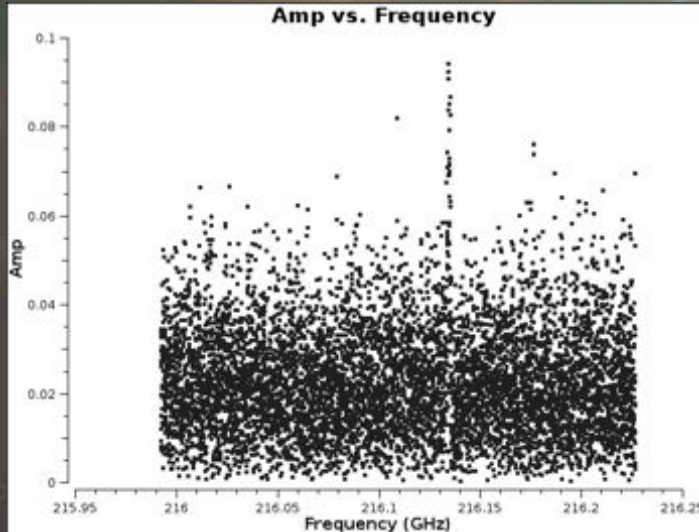
ALMA Cycle 0 Data

*On April 8, 2012
Band 6 (230 GHz)*

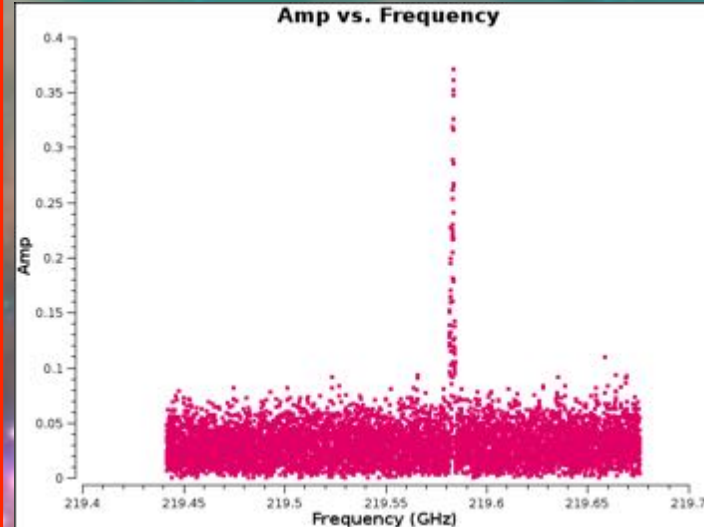
Amp-Frequency

Spectral line

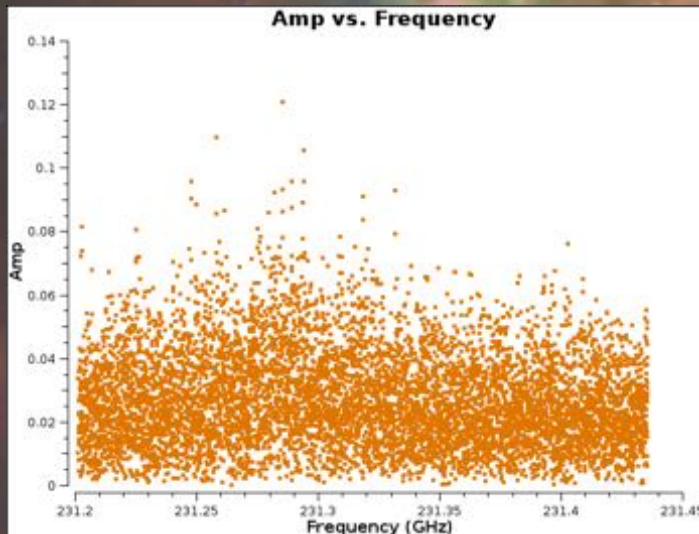
Spw 0
DCO⁺
(3-2)



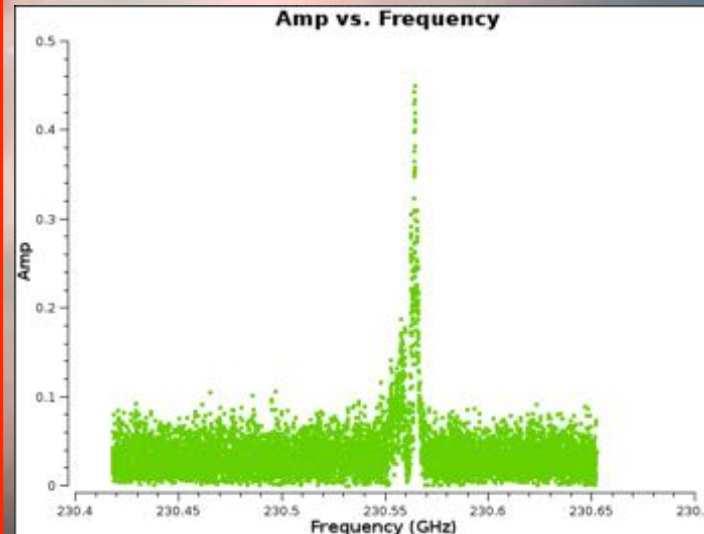
Spw 1
C¹⁸O
(2-1)



Spw 2
N₂D⁺
(3-2)

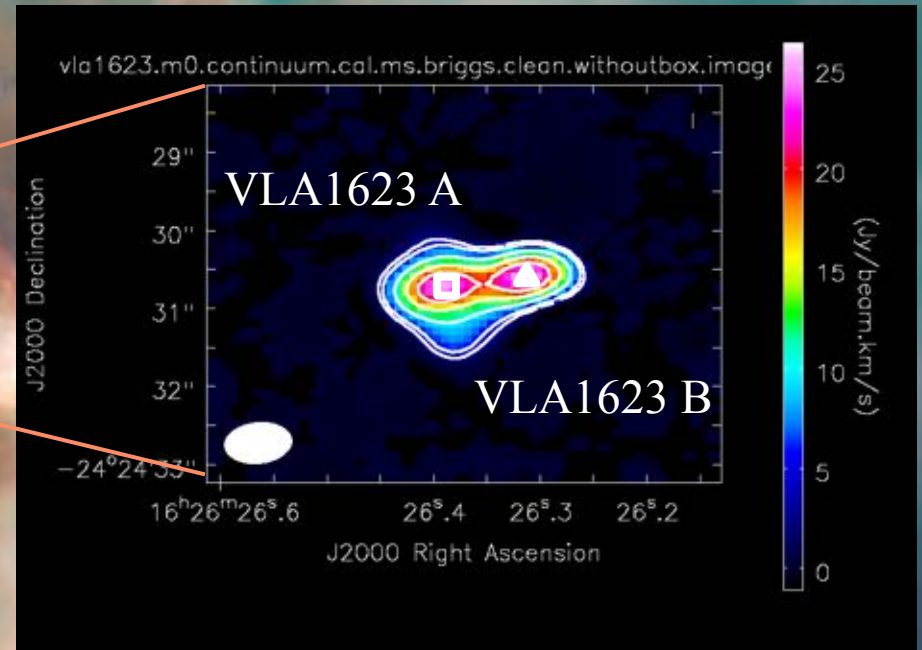
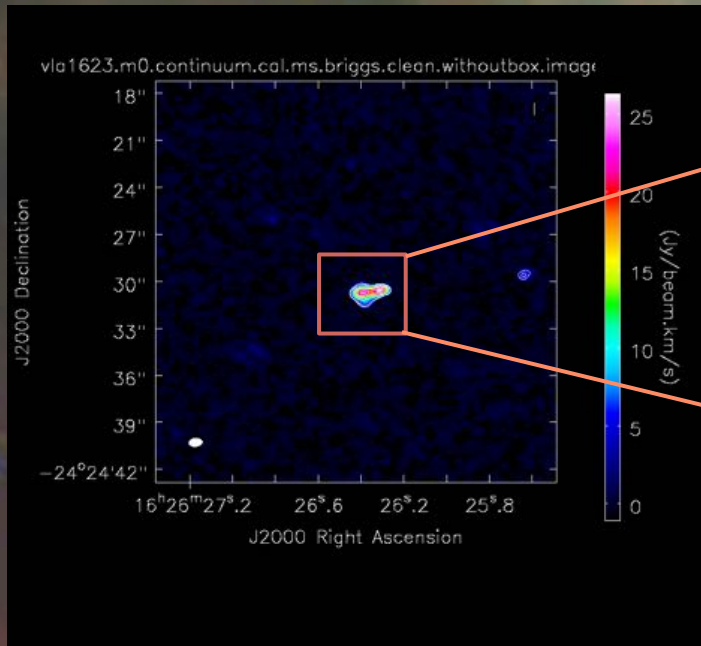


Spw 3
¹²CO
(2-1)



VLA1623

Continuum map



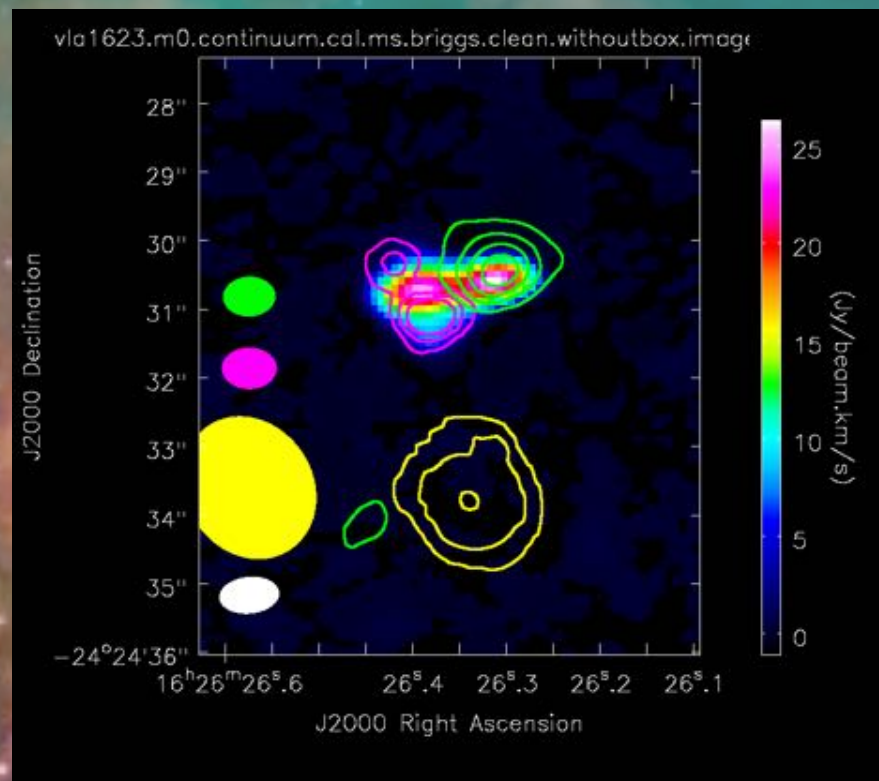
Contours are in steps of 15, 25, 50, 75, 100 σ with $\sigma = 200 \text{ mJy/beam}$ for continuum.

VLA1623

Spw0 DCO⁺

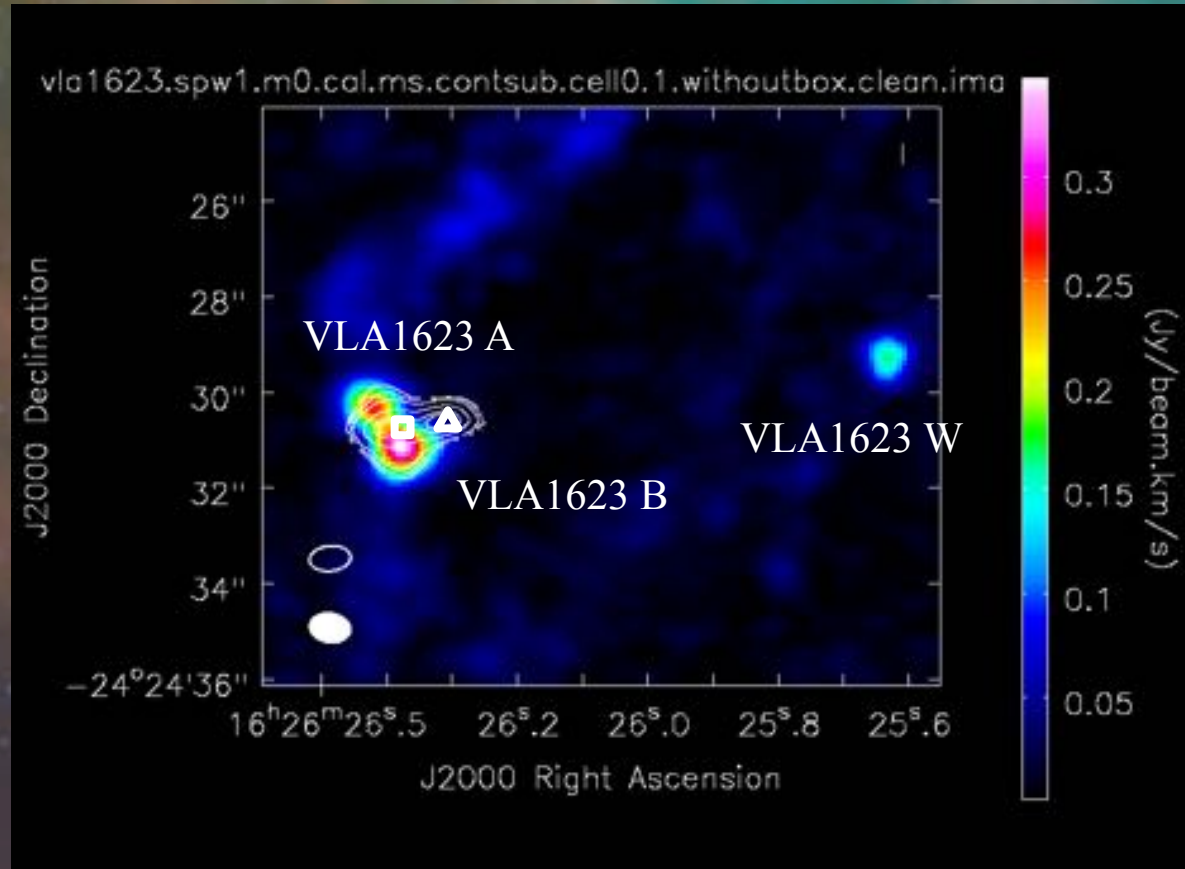
Spw1 C¹⁸O

Spw3 ¹²CO



Yellow contours are in steps of 3, 4, 5 σ with $\sigma = 40 \text{ mJy} \cdot \text{beam}^{-1} \cdot \text{km} \cdot \text{s}^{-1}$ for DCO⁺. Magenta contours are in steps of 10, 15, 20 σ with $\sigma = 12 \text{ mJy} \cdot \text{beam}^{-1} \cdot \text{km} \cdot \text{s}^{-1}$ for C¹⁸O. Green contours are in steps of 50, 100, 150, 200 σ with $\sigma = 25 \text{ mJy} \cdot \text{beam}^{-1} \cdot \text{km} \cdot \text{s}^{-1}$ for ¹²CO.

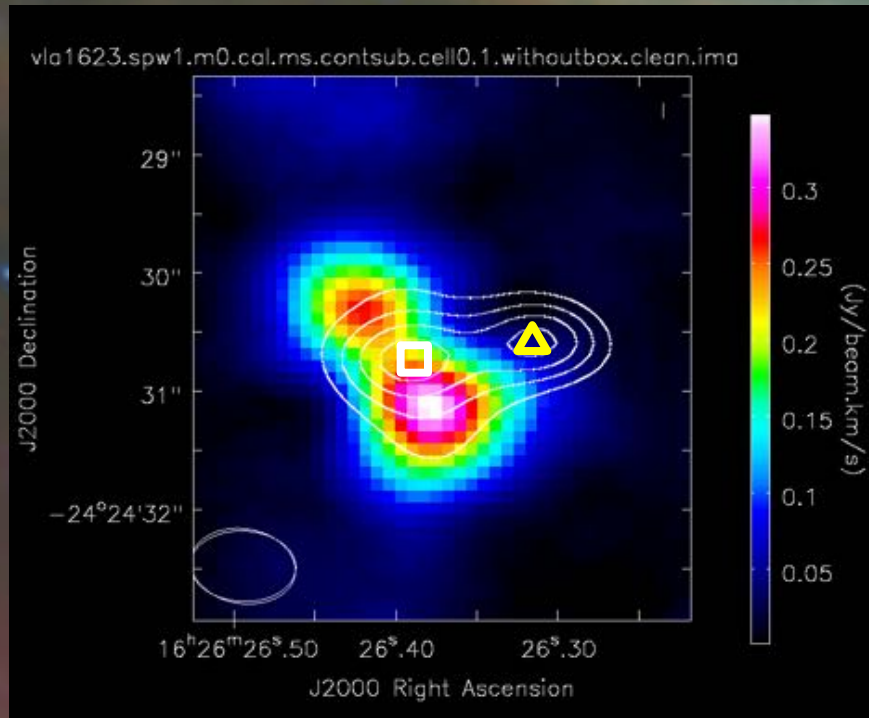
VLA1623 Integrated intensity of C¹⁸O (2-1)



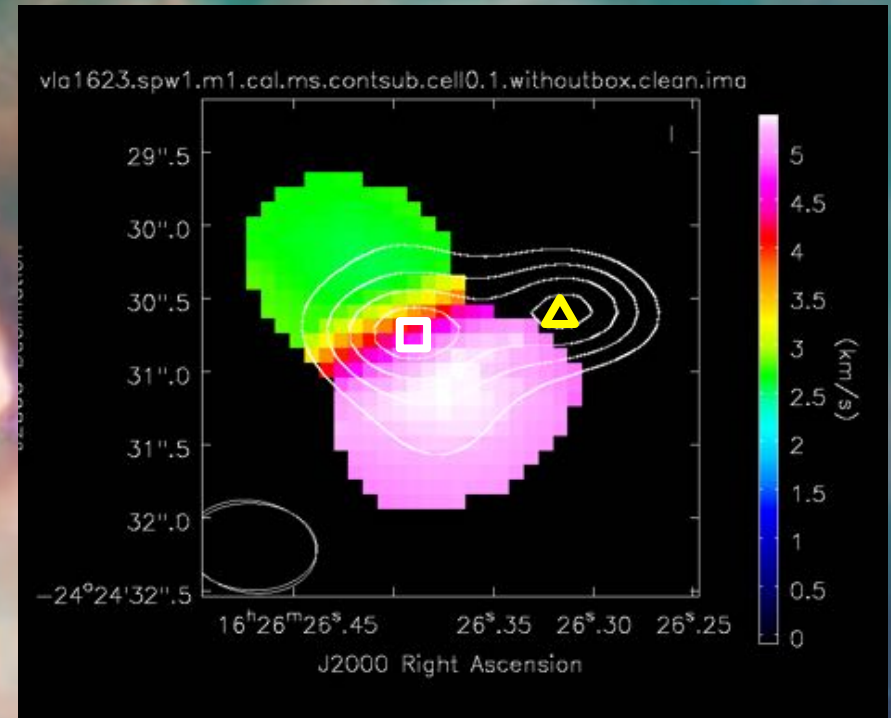
Moment 0 map : white contours are in steps of 3, 10, 30, 90, 150, 180 σ with $\sigma = 120$ mJy/beam for C¹⁸O

VLA1623 Moment Map of C¹⁸O (2-1)

Integrated intensity map



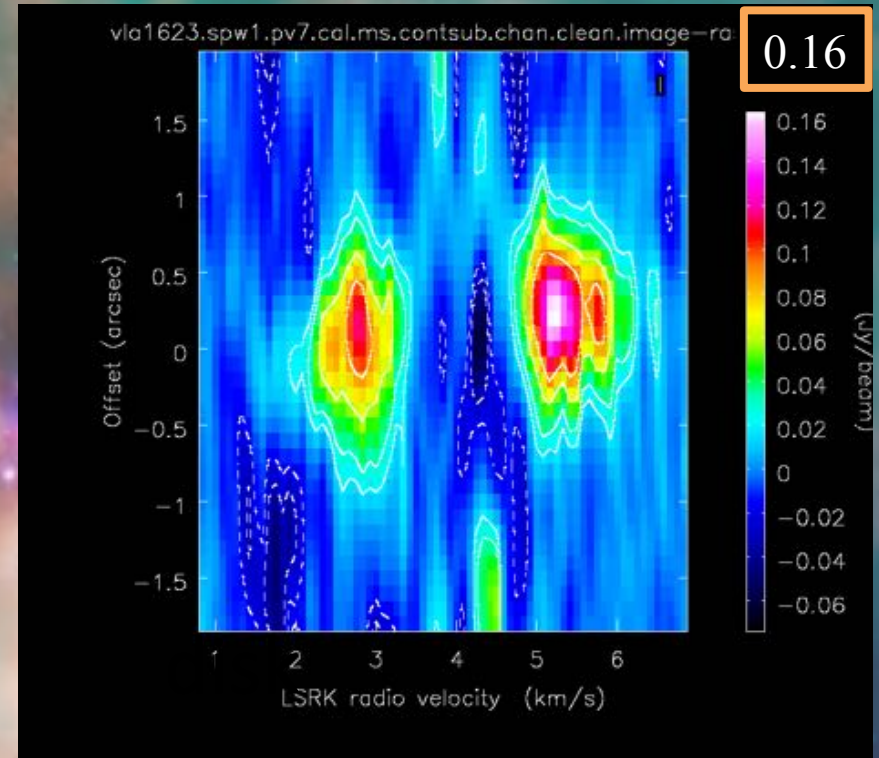
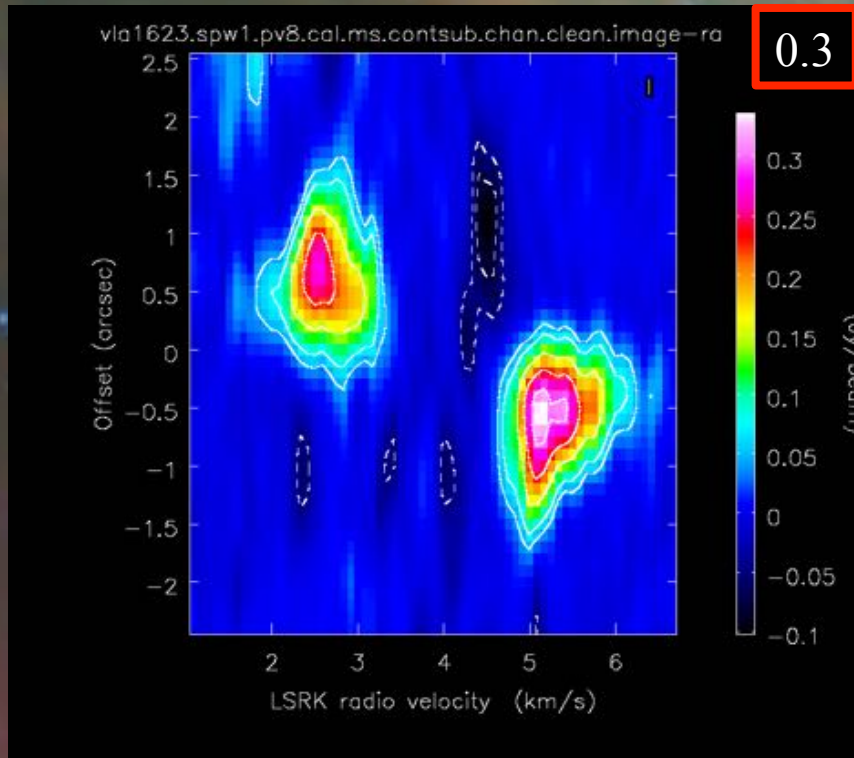
Average velocity map



Left : moment 0 map. Right : moment 1 map.

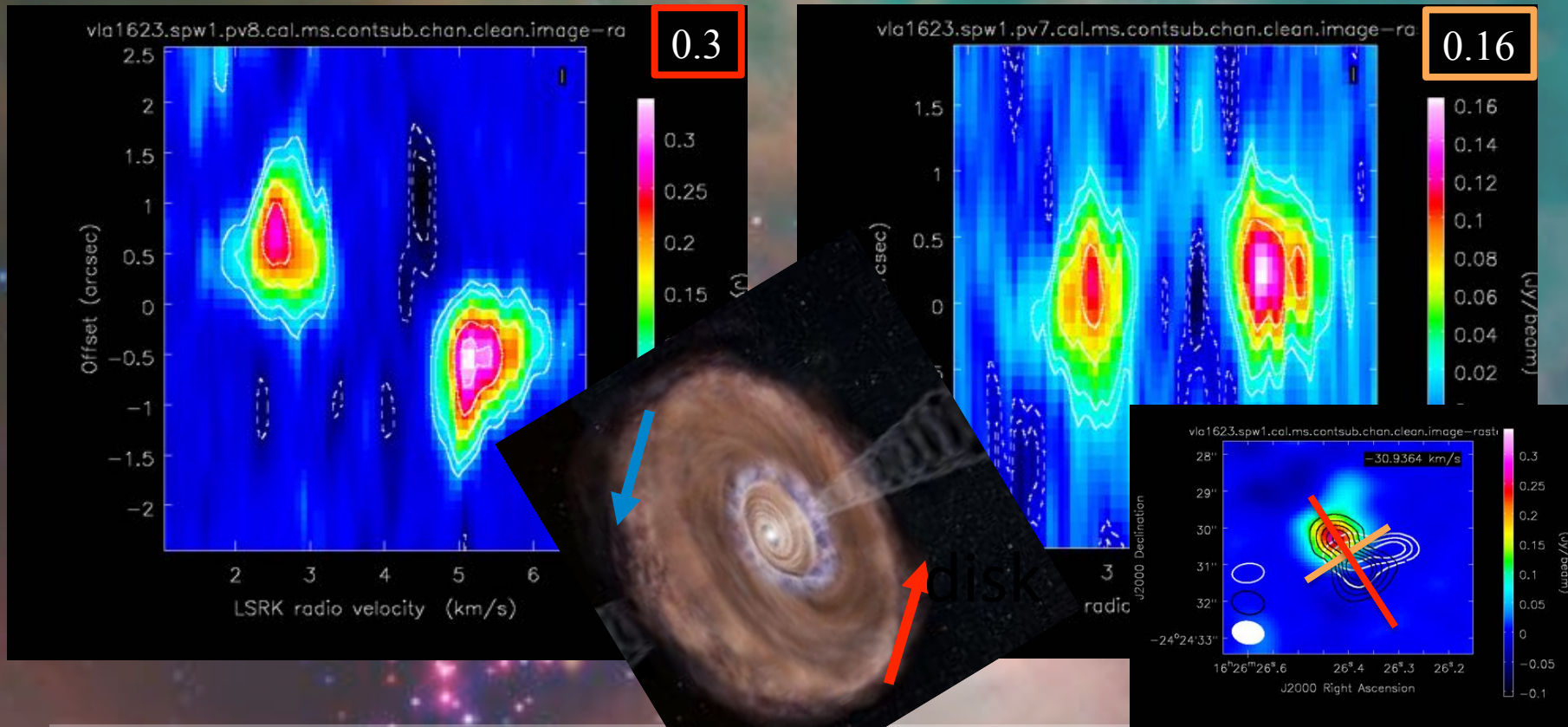
White contours are in steps of 3, 5, 7, 9, 11σ with σ = 10.0 mJy/beam C¹⁸O (2-1).

VLA1623 Position-Velocity diagram of C¹⁸O (2-1)



White contours are in steps of -9, -3, 3, 9, 15, 21, 27 σ with $\sigma = 3.7 \text{ mJy/beam}$ for C¹⁸O (2-1).

VLA1623 Position-Velocity diagram of C¹⁸O (2-1)



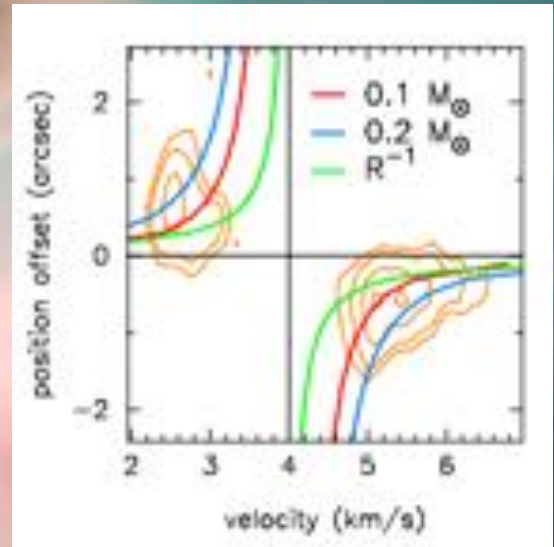
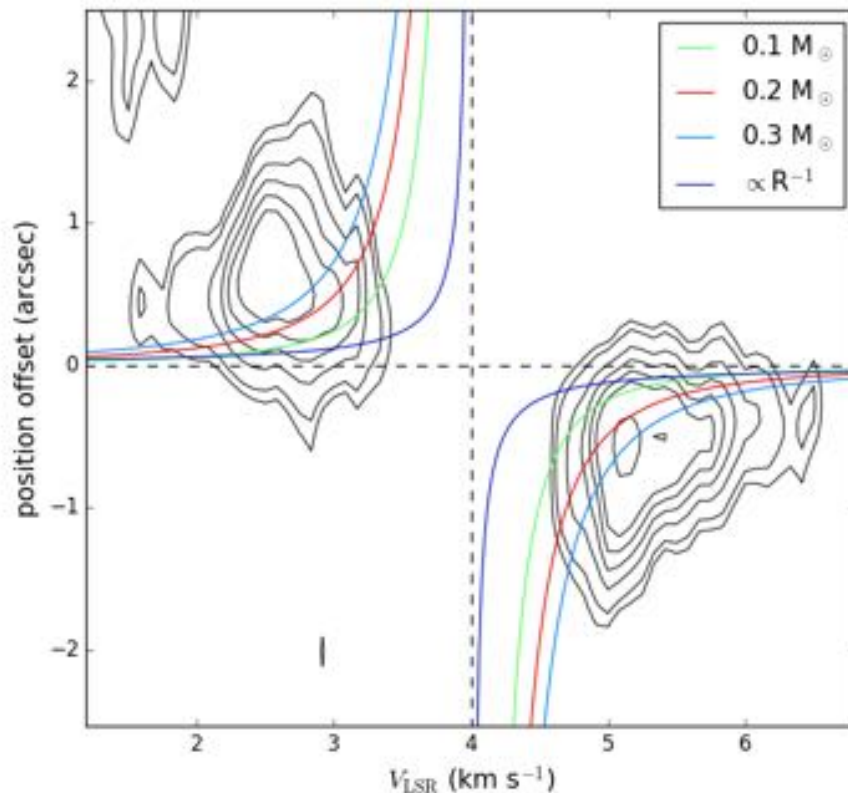
White contours are in steps of -9, -3, 3, 9, 15, 21, 27 σ with $\sigma = 3.7 \text{ mJy/beam}$ for C¹⁸O (2-1).

VLA1623 P-V diagram of C¹⁸O (2-1)

Protostellar mass :

$$0.22 \pm 0.02 M_{\odot}$$

(Murillo et al. 2013)

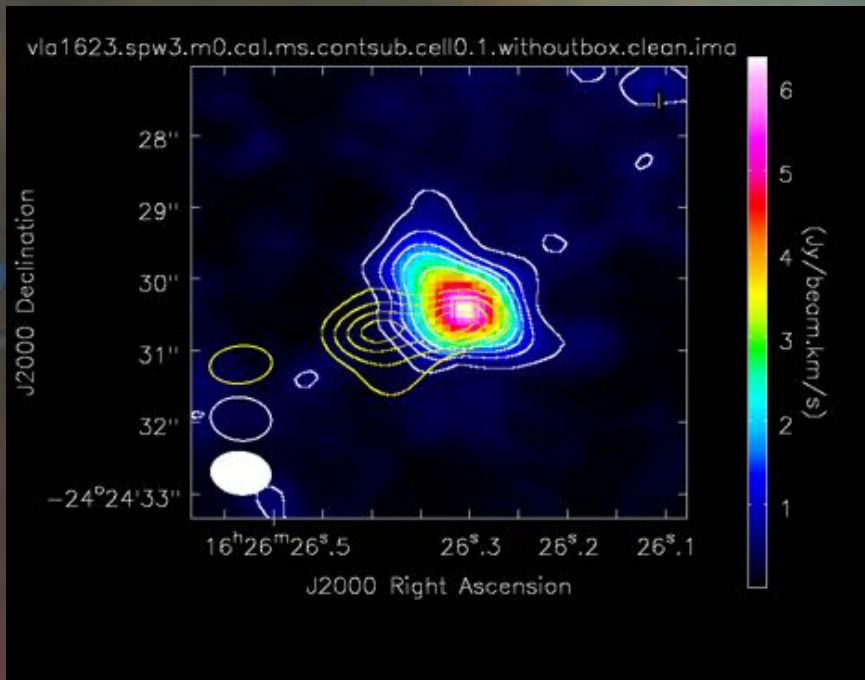


(Murillo et al. 2013)

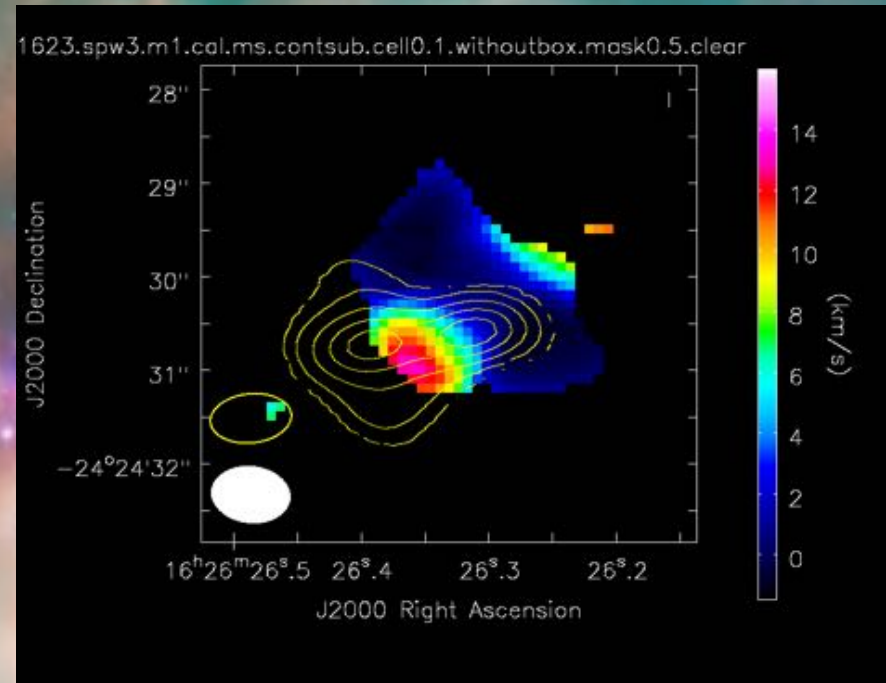
Contours are in steps of 3, 5, 10, 15, 20, 25, 39 σ with $\sigma = 7.9$ mJy/beam .
Curves : the kepler's third law, different colors represent different masses of the proto-star. (except blue line: infall)

VLA1623 Moment Map of ^{12}CO (2-1)

Integrated intensity map



Average velocity map



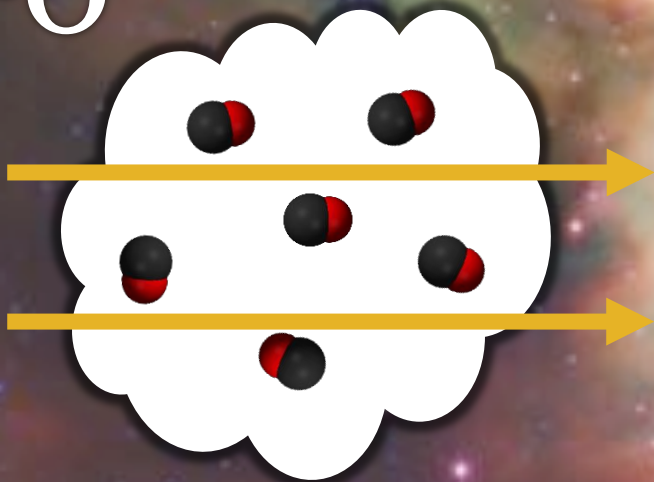
Observed ^{12}CO (2-1). Left : moment 0 map. Right : moment 1 map. Yellow contours are in steps of 30, 80, 130, 180 with $\sigma = 16$ mJy/beam. White contours are in steps of 3, 6, 9, 12, 18σ with $\sigma = 120$ mJy $\cdot$ beam $^{-1}\cdot$ km $\cdot$ s $^{-1}$.

Optical depth

Why $C^{18}O$?

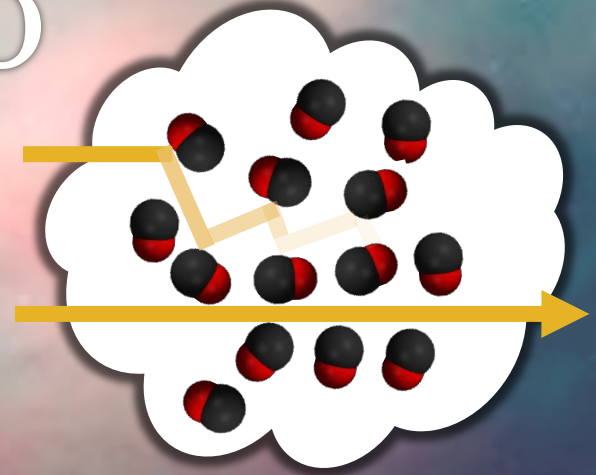
Optically thin

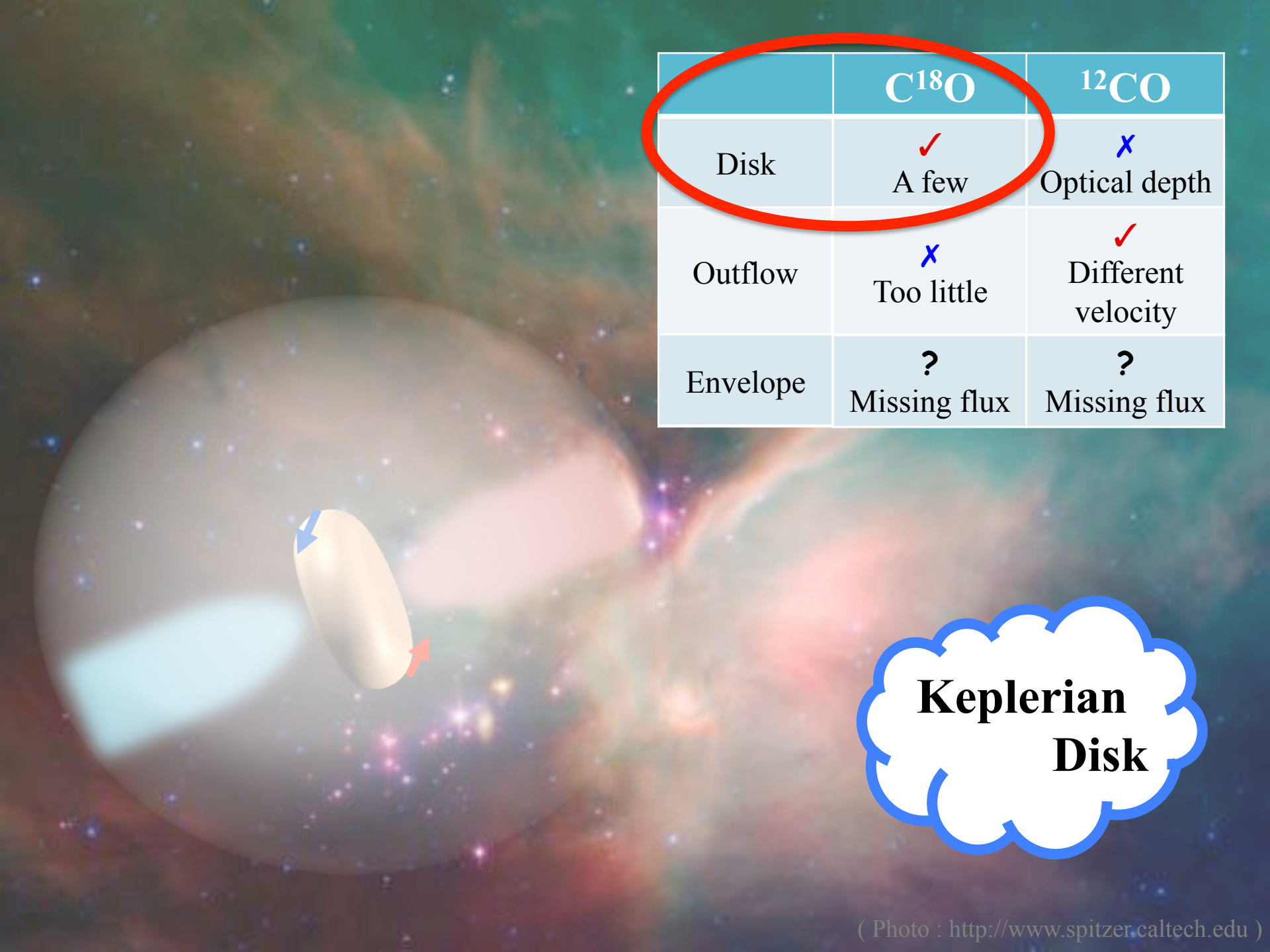
$C^{18}O$



Optically thick

^{12}CO





The background image shows a protostar, a large, glowing sphere of gas and dust. A protoplanetary disk, a flattened disk of gas and dust, is visible around the star. The disk is shown in a perspective view, with a blue arrow indicating rotation. A red arrow points to the disk's surface. The disk is surrounded by a large, diffuse envelope of gas and dust. The entire scene is set against a dark, star-filled background.

	C ¹⁸ O	¹² CO
Disk	✓ A few	✗ Optical depth
Outflow	✗ Too little	✓ Different velocity
Envelope	? Missing flux	? Missing flux

**Keplerian
Disk**

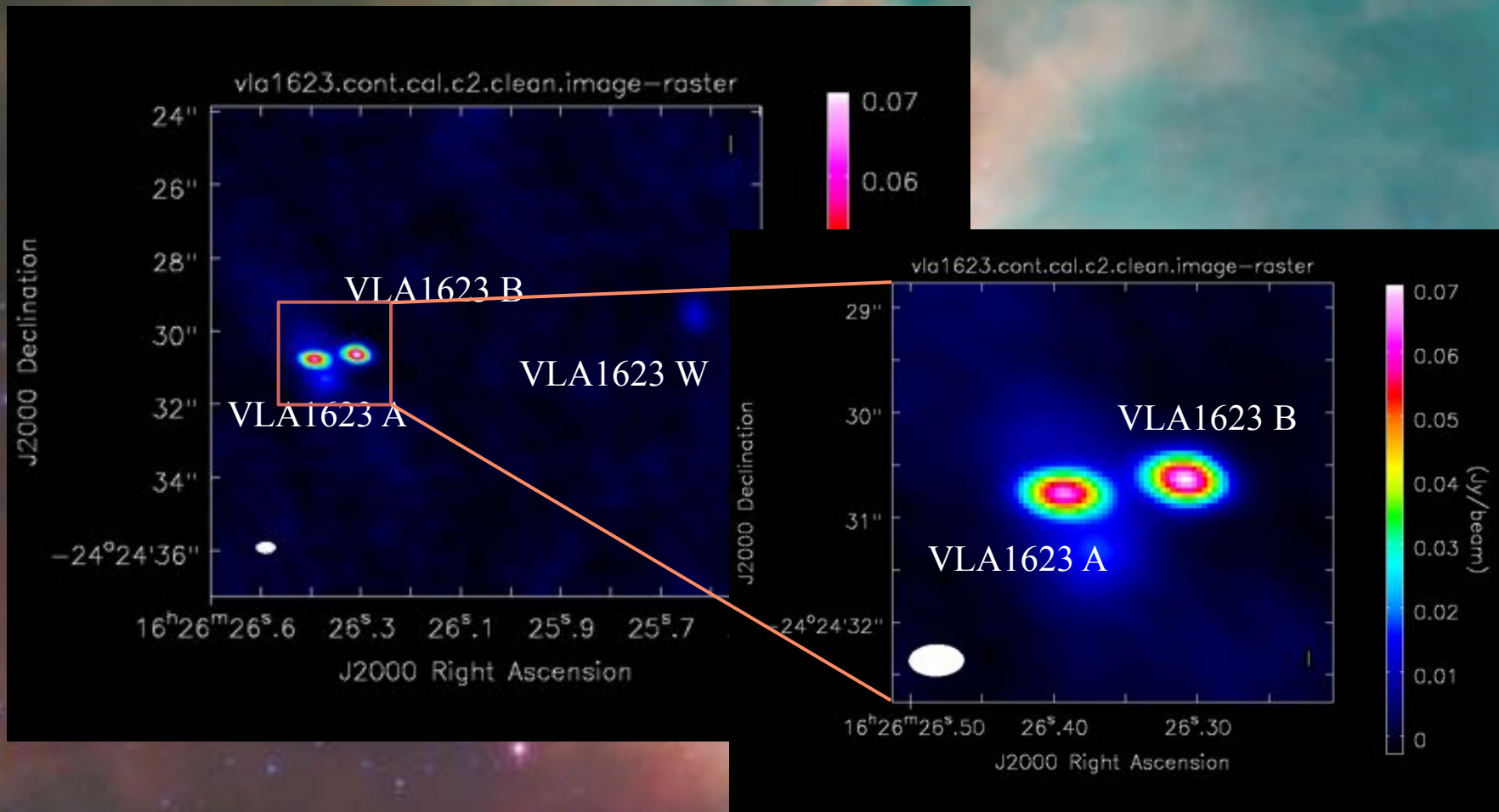


ALMA Cycle 2 Data

*On January 3, 2015
Band 6 (230 GHz)*

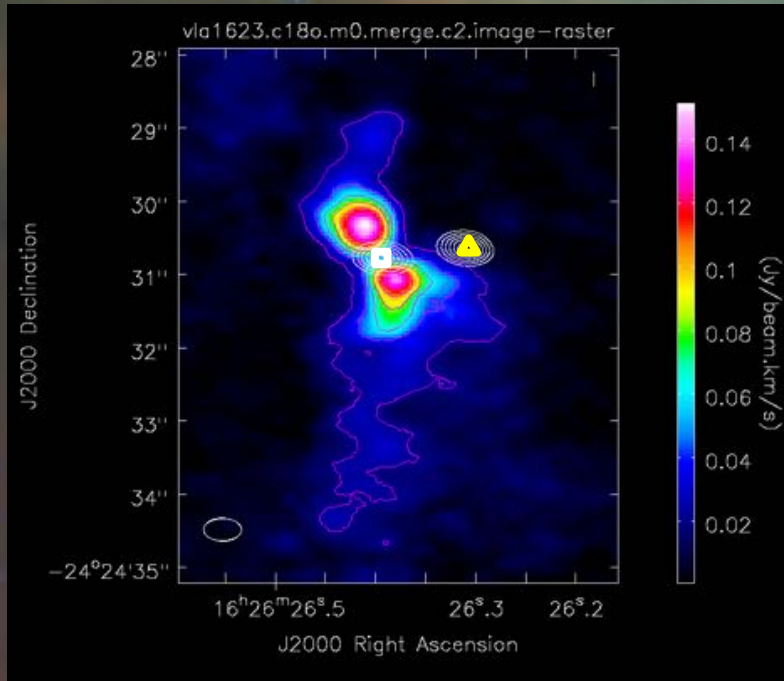
VLA1623

Continuum map

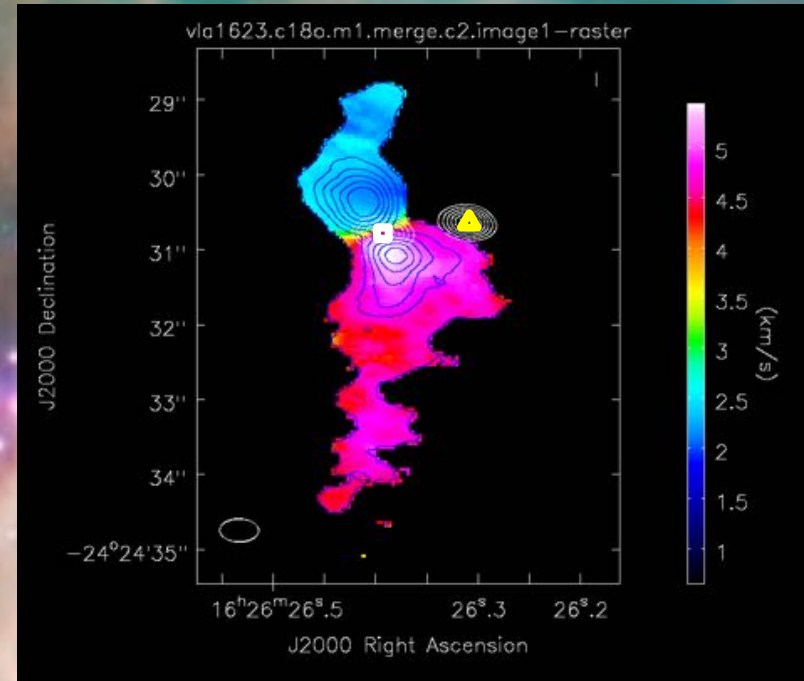


VLA1623 Moment Map of C¹⁸O (2-1)

Integrated intensity map



Average velocity map



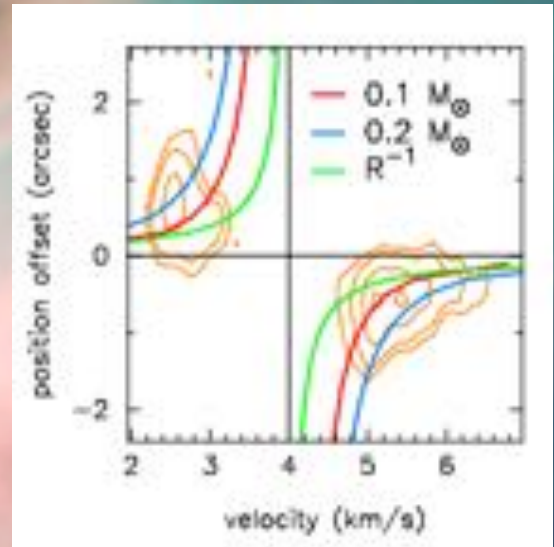
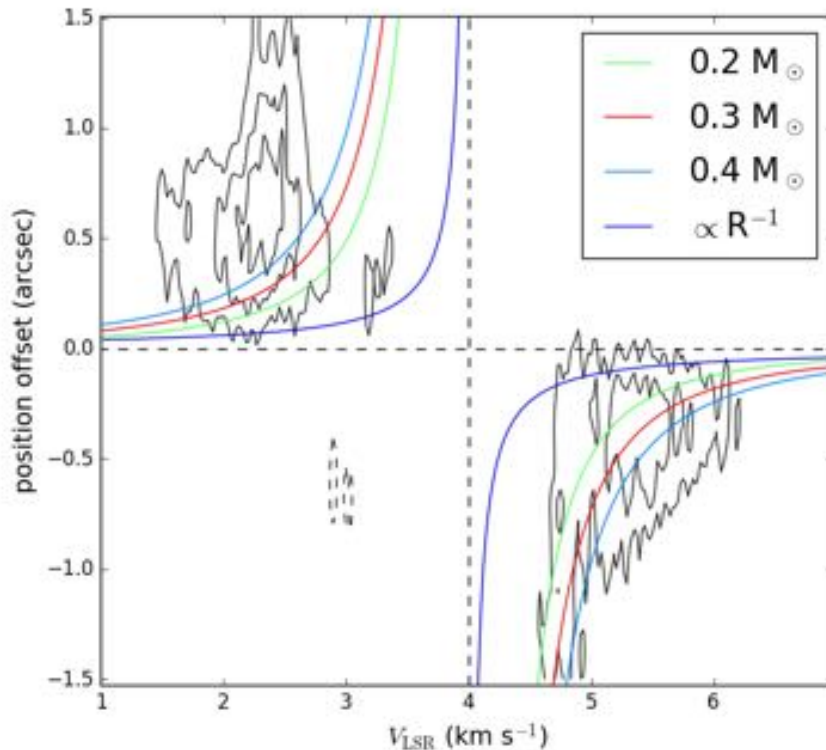
Left : moment 0 map. Right : moment 1 map. Magenta (Blue) contours are in steps of 3, 6, 9, 12, 15, 18 σ with $\sigma = 7 \text{ mJy} \cdot \text{beam}^{-1} \cdot \text{km} \cdot \text{s}^{-1}$ for C¹⁸O integrated intensity map. White contours are in steps of 3, 4, 5, 6, 7, 8 σ with $\sigma = 8 \text{ mJy/beam}$ for continuum.

VLA1623 P-V diagram of C¹⁸O (2-1)

Protostellar mass :

$$0.22 \pm 0.02 M_{\odot}$$

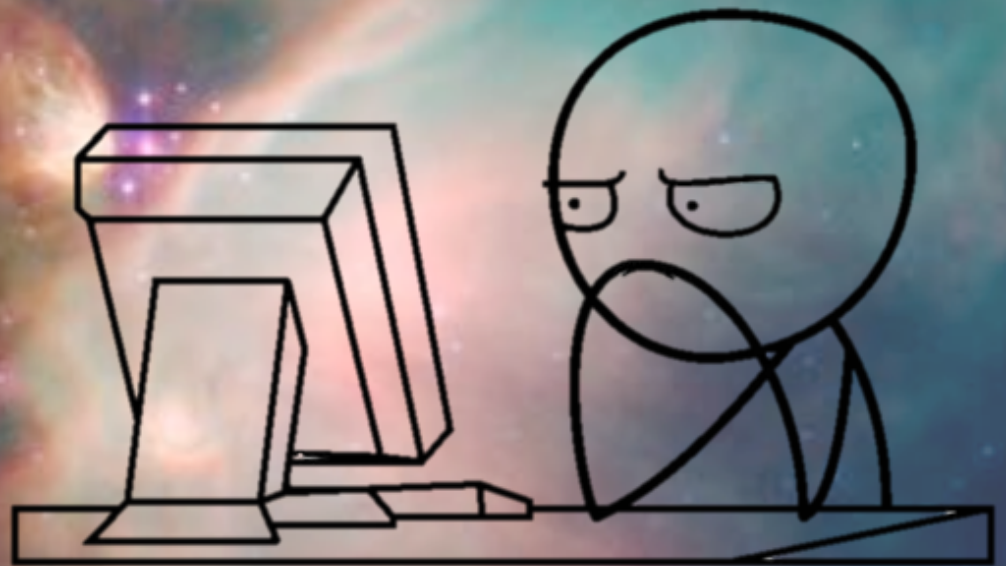
(Murillo et al. 2013)



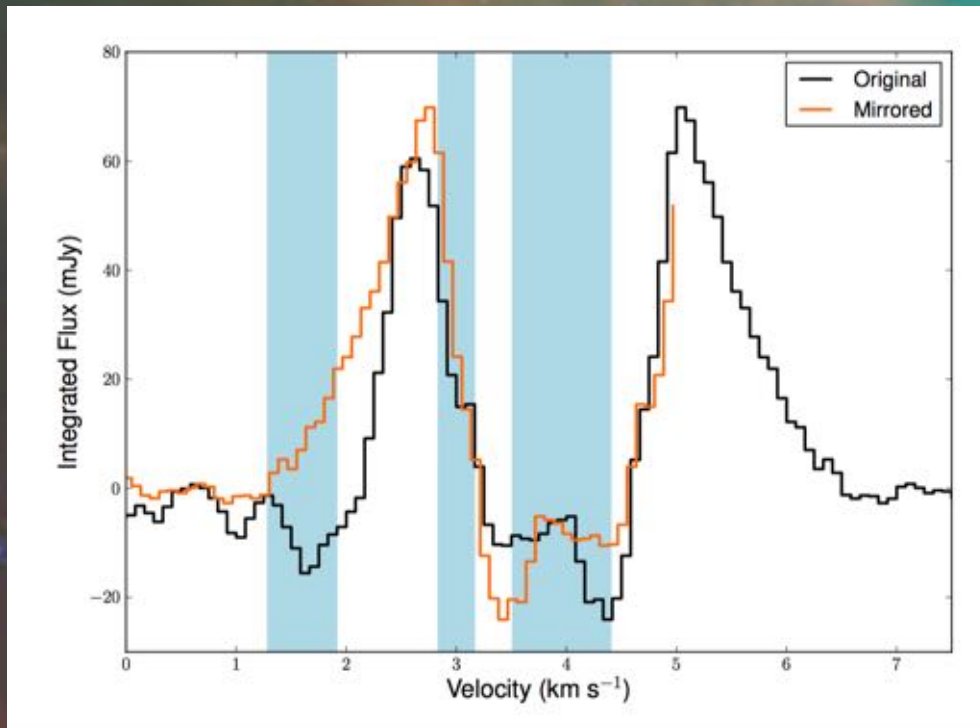
(Murillo et al. 2013)

Contours are in steps of -4, 4, 8, 12 with $\sigma = 11$ mJy/beam for C¹⁸O(J=2-1). **Curves** : the kepler's third law, different colors represent different masses of the proto-star. (except blue line: infall)

Model



VLA1623 Model



(Murillo et al. 2013)

Absorbing material parameters

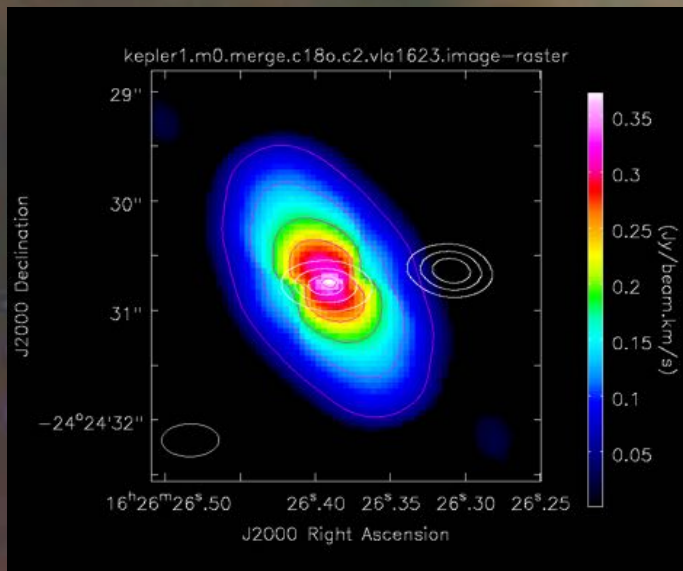
$$\tau(v) \propto \exp\left(-0.5 \left(\frac{v - v_0}{\sigma}\right)^2\right)$$

	Keplerian
<i>Envelope</i>	
velocity (km s ⁻¹)	4.0
opacity	7.0
width (km s ⁻¹)	0.99
<i>Foreground 1</i>	
velocity (km s ⁻¹)	1.6
opacity	5.0
width (km s ⁻¹)	0.64
<i>Foreground 2</i>	
velocity (km s ⁻¹)	3.0
opacity	0.29
width (km s ⁻¹)	0.34

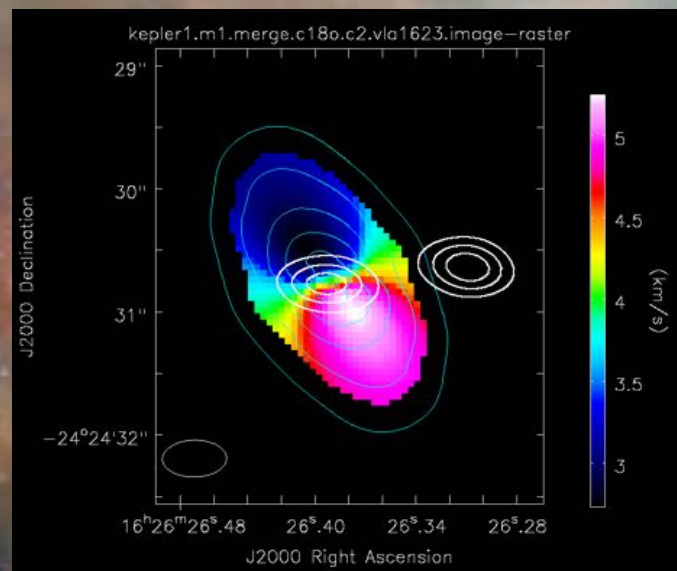
VLA1623 Moment Map of C¹⁸O (2-1)

Model without foreground

Integrated intensity map



Average velocity map



Mass : 0.2 M_⊙
Inclination : 55 (deg)
PA: -57.46 (deg)
V_{LSR} : 4 km/s
Without foreground

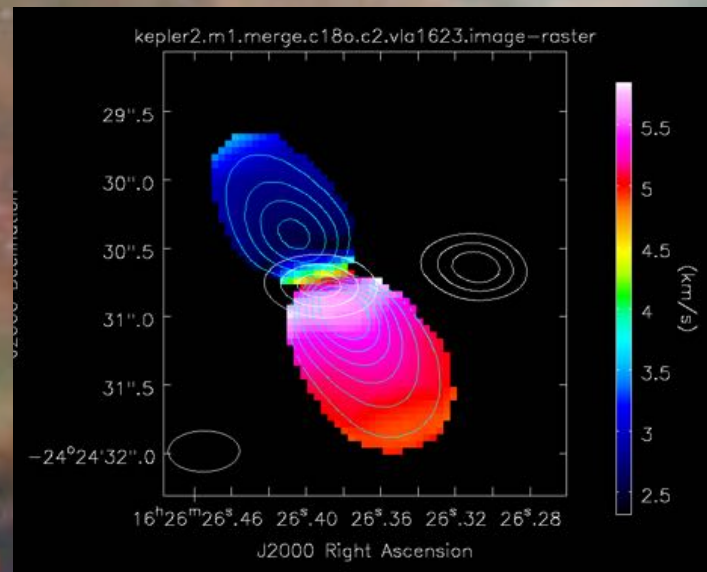
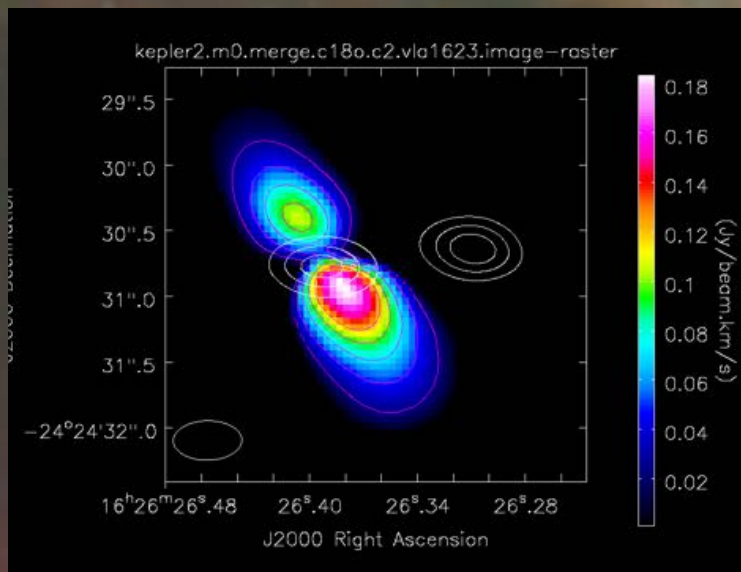
Left : moment 0 map. Right : moment 1 map. Magenta (Blue) contours are in steps of 3, 6, 9, 12, 15, 18 σ with $\sigma = 20 \text{ mJy} \cdot \text{beam}^{-1} \cdot \text{km} \cdot \text{s}^{-1}$ for C¹⁸O integrated intensity map. White contours are in steps of 3, 5, 7 σ with $\sigma = 8 \text{ mJy/beam}$ for continuum.

VLA1623 Moment Map of C¹⁸O (2-1)

Model with foreground

Integrated intensity map

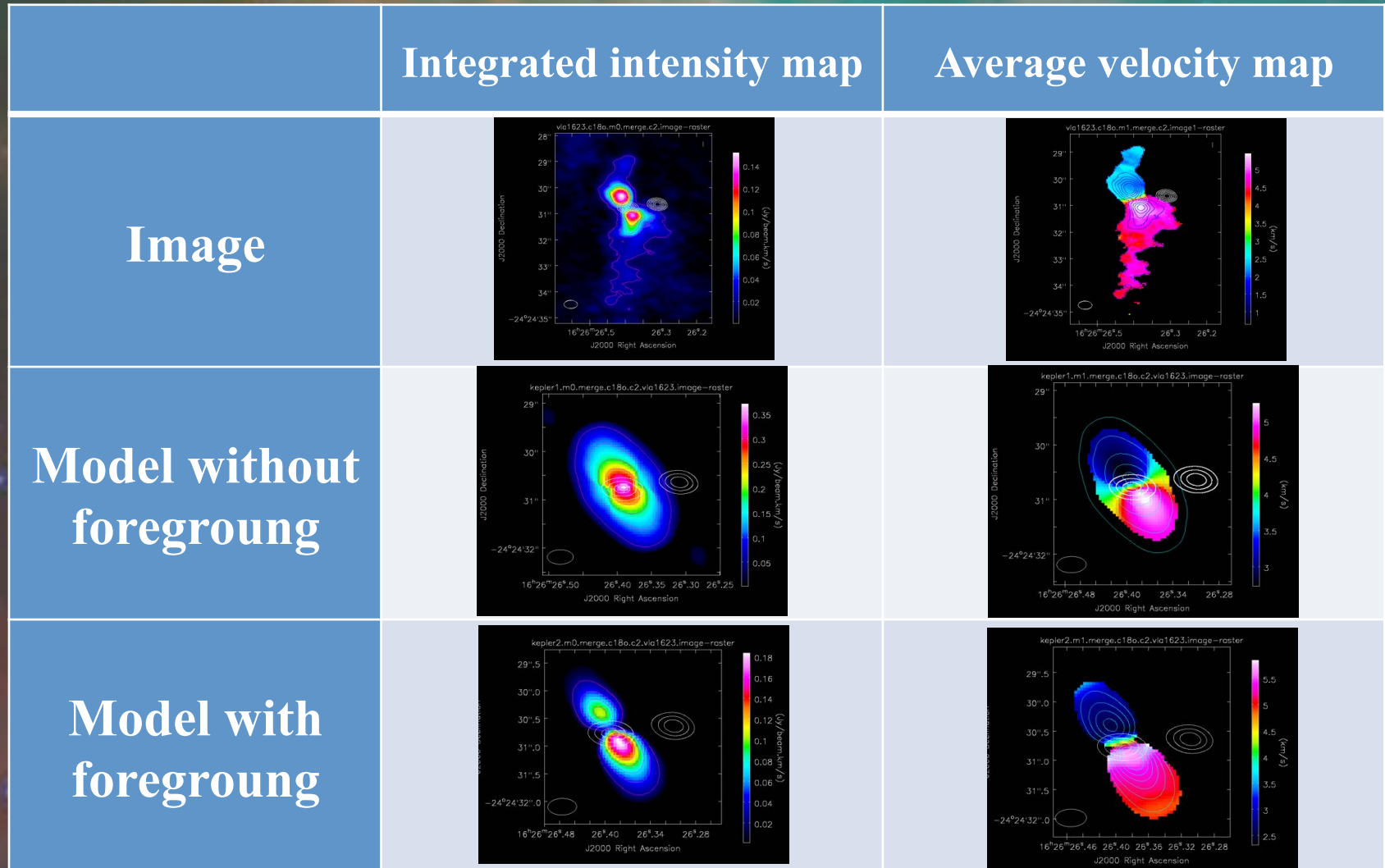
Average velocity map



Mass : 0.2 M_⊙
Inclination : 55 (deg)
PA: -57.46 (deg)
V_{LSR} : 4 km/s
Foreground
(tau, dv, vpos)
7, 0.99, 4
5, 0.64, 1.6
0.29, 0.34, 3

Left : moment 0 map. Right : moment 1 map. Magenta (Blue) contours are in steps of 3, 6, 9, 12, 15, 18 σ with $\sigma = 8 \text{ mJy} \cdot \text{beam}^{-1} \cdot \text{km} \cdot \text{s}^{-1}$ for C¹⁸O integrated intensity map. White contours are in steps of 3, 5, 7 σ with $\sigma = 8 \text{ mJy/beam}$ for continuum.

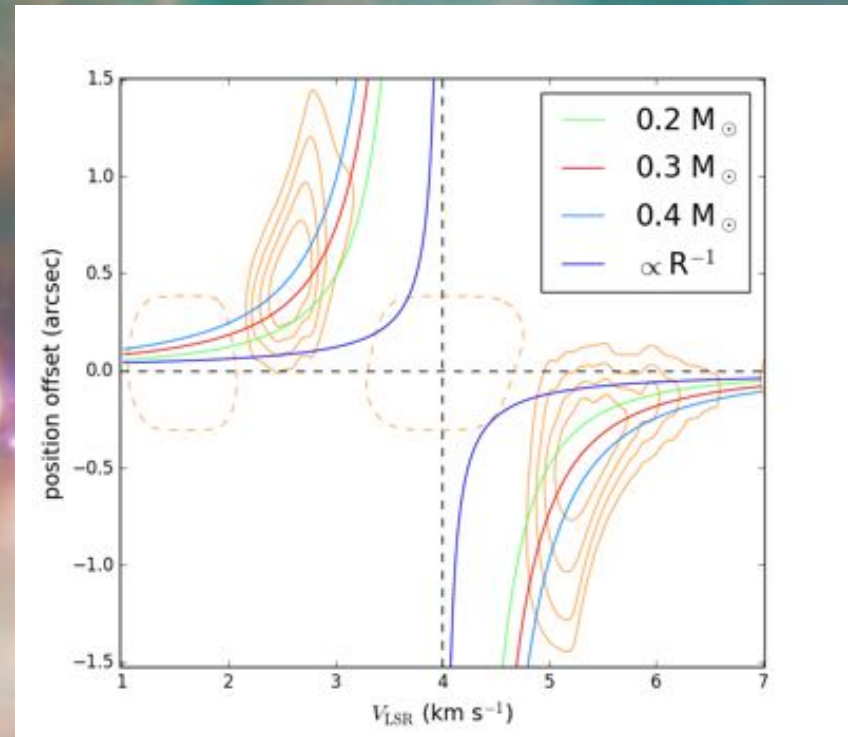
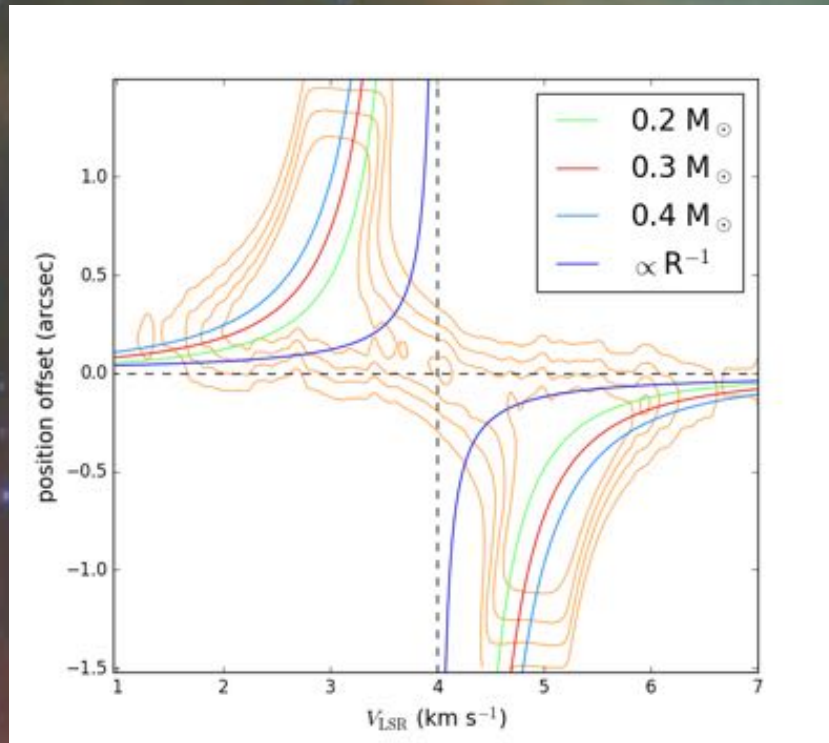
VLA1623 Moment Map of C¹⁸O (2-1)



VLA1623 P-V diagram of C¹⁸O (2-1)

Without foreground

Foreground

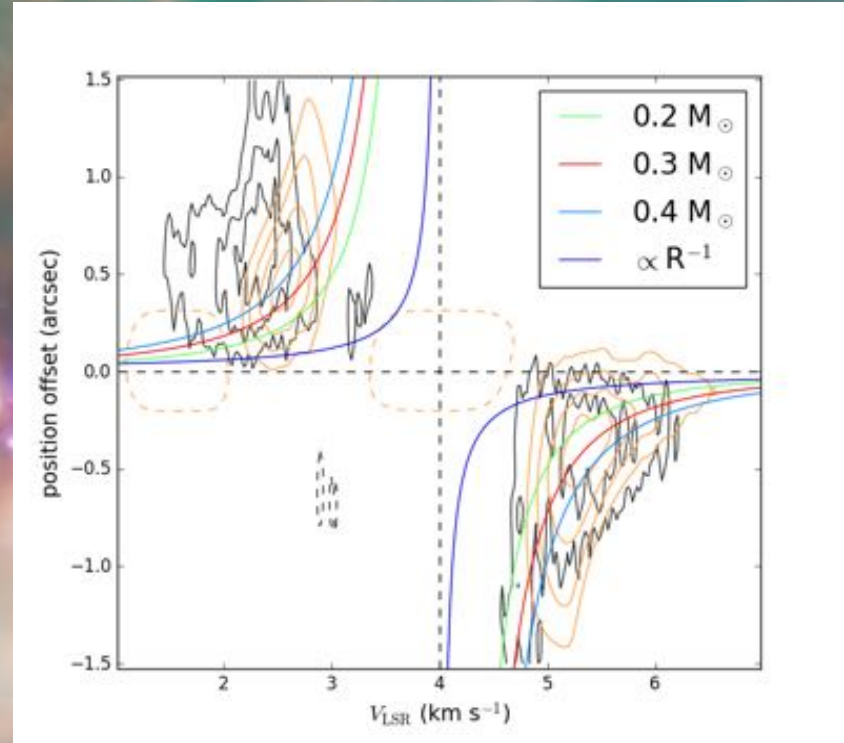
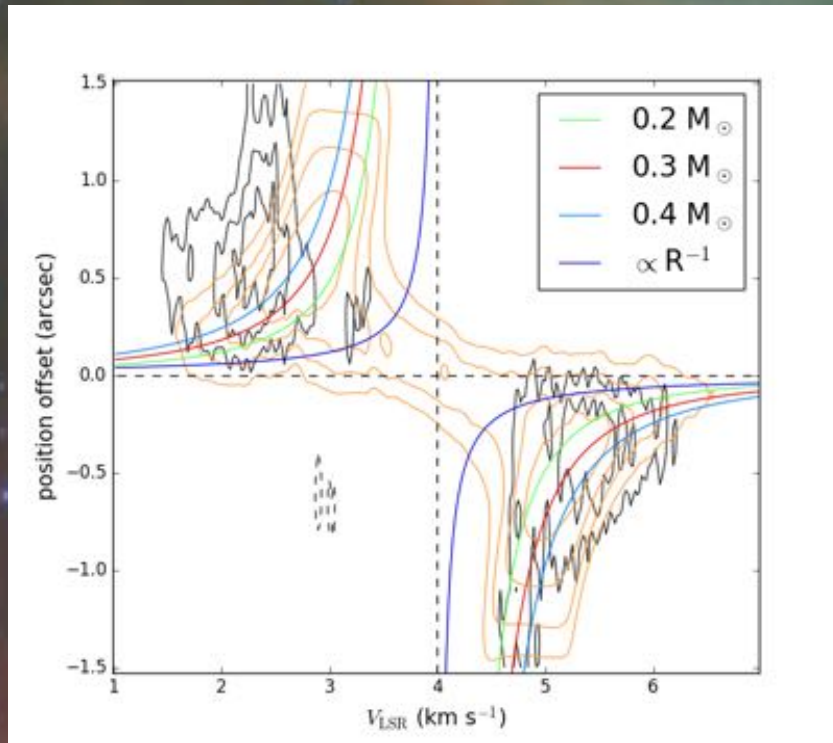


Contours are in steps of of -3, 3, 6, 9, 12 with $\sigma = 12$ mJy/beam for C¹⁸O(J=2-1). Curves : the kepler's third law, different colors represent different masses of the proto-star. (except blue line: infall)

VLA1623 P-V diagram of C¹⁸O (2-1)

Without foreground

Foreground



Contours are in steps of -3, 3, 6, 9, 12 with $\sigma = 12 \text{ mJy/beam}$ for C¹⁸O(J=2-1). Curves : the kepler's third law, different colors represent different masses of the proto-star. (except blue line: infall)

Conclusions

Protostar	Line	Keplerian Disk
L1527	C ¹⁸ O	✓
VLA1623 A	C ¹⁸ O	✓
VLA1623 A	¹² CO	✗

VLA1623 A	C ¹⁸ O	¹² CO
Disk	✓ A few	✗ Optical depth
Outflow	✗ Too little	✓ Different velocity
Envelope	? Missing flux	? Missing flux

Future work



Simulate the model data



Modify the model



Different spectral line (molecules)

*Thank
you*

