What the submm spectral line emission in Circinus tells us about accretion and feedback in AGN

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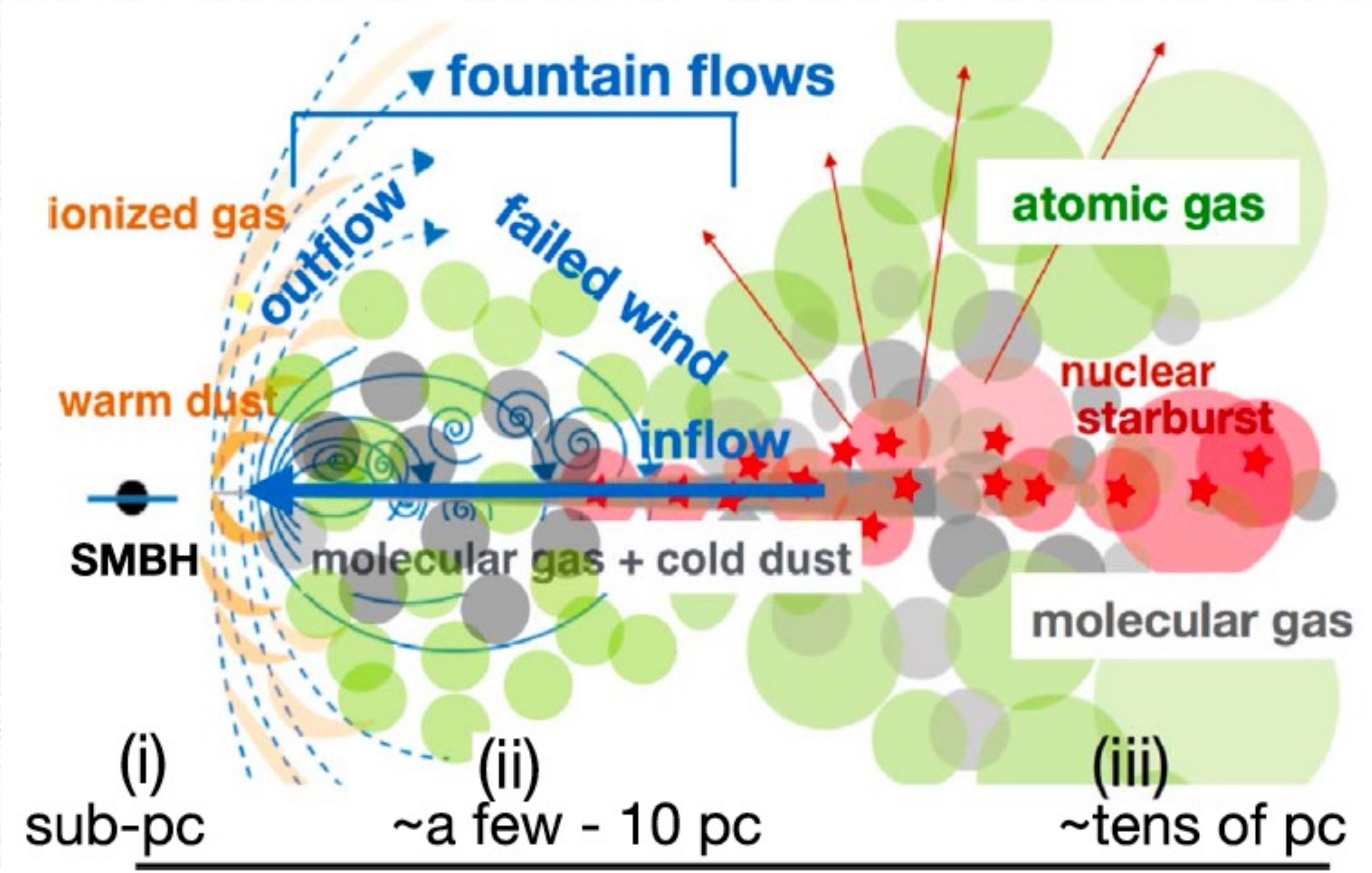
L. Burtscher, F. Combes, S. García-Burillo, S. Martín,

K. Meisenheimer, P. van der Werf

1. Introduction: AGN & the torus



Wada 2012, Izumi et al. 2018

1. Introduction: Observational methods

Relevant scales in nearby galaxies: milliarcseconds

↳ Can only be resolved using interferometers

infrared: VLTI

sub-millimeter: ALMA

courtesy of G. Hüdepohl

ESO PR ann13016a

1. Introduction: Interferometry with the VLTI

- ESO's Very Large Telescope Interferometer (VLTI):
  - located on Cerro Paranal in Northern Chile
  - consist of 4 UTs (8.2m) and 4 ATs (1.8m)

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  - located on Cerro Paranal in Northern Chile
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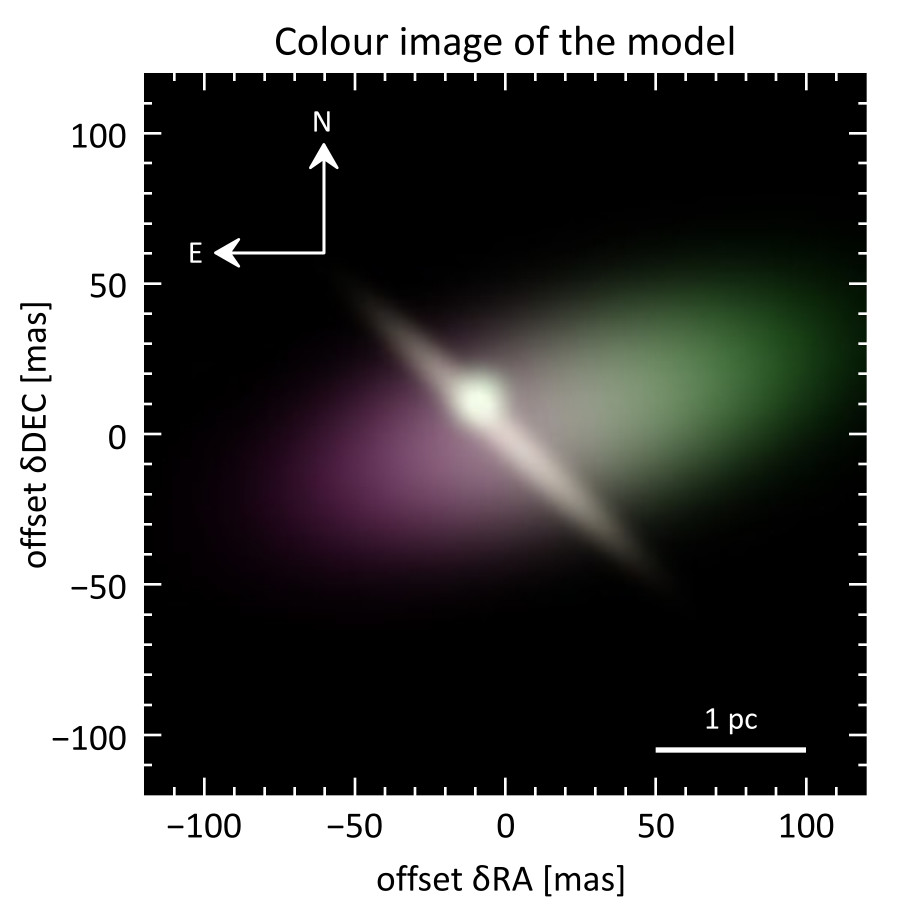
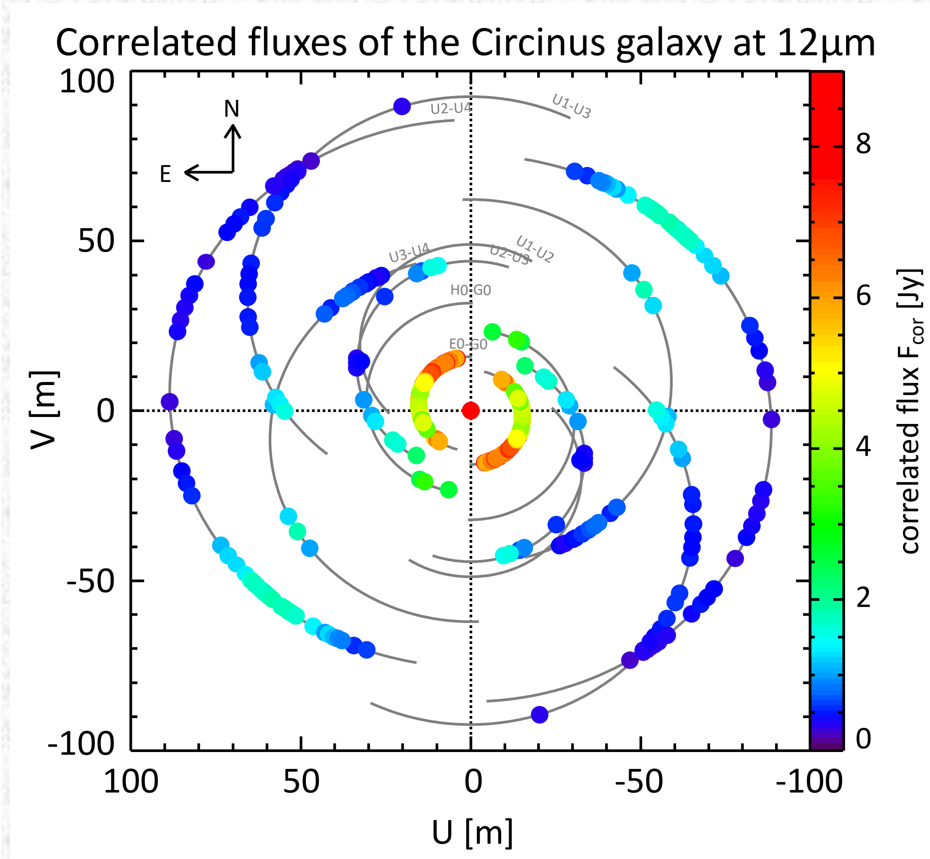
- Former instruments:
  - MIDI (MIR, 2 tel.)
  - AMBER (NIR, 3 tel.)
- Current instruments:
  - PIONIER (NIR, 4 tel.)
  - GRAVITY (NIR, 4 tel.)
  - MATISSE (MIR, 4 tel.)

1. Introduction: The Circinus Galaxy

- Spiral galaxy SA(s)b, $i = 65^\circ$
- Seyfert type 2
- $4 \times 10^6\ M_\odot$ nucleus
- Distance ~4 Mpc
- → 50 mas ~ 1 pc
- Circumnuclear starburst
- H_2O maser disk

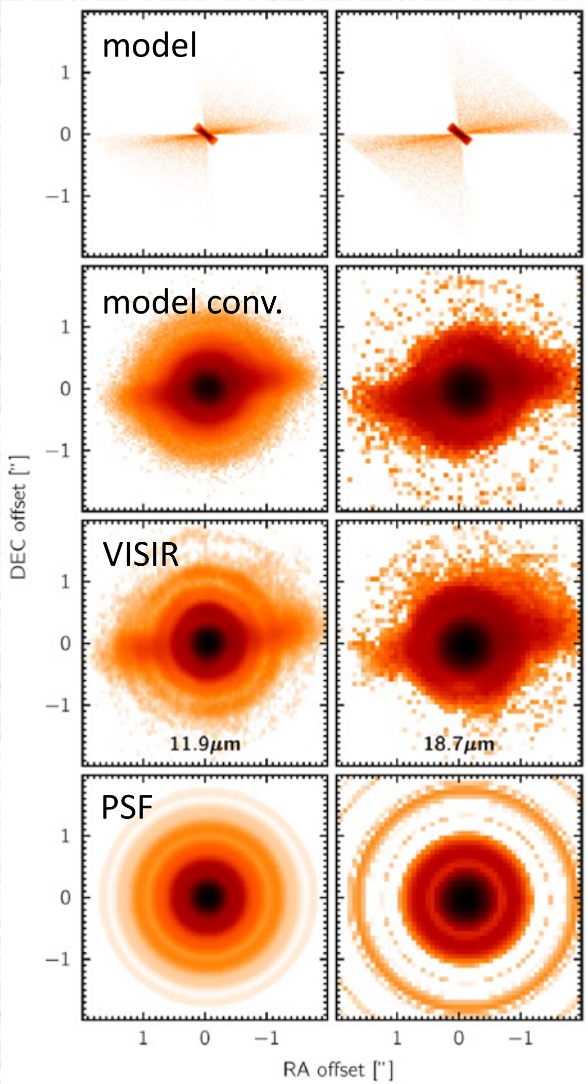
1. Introduction: MIDI results

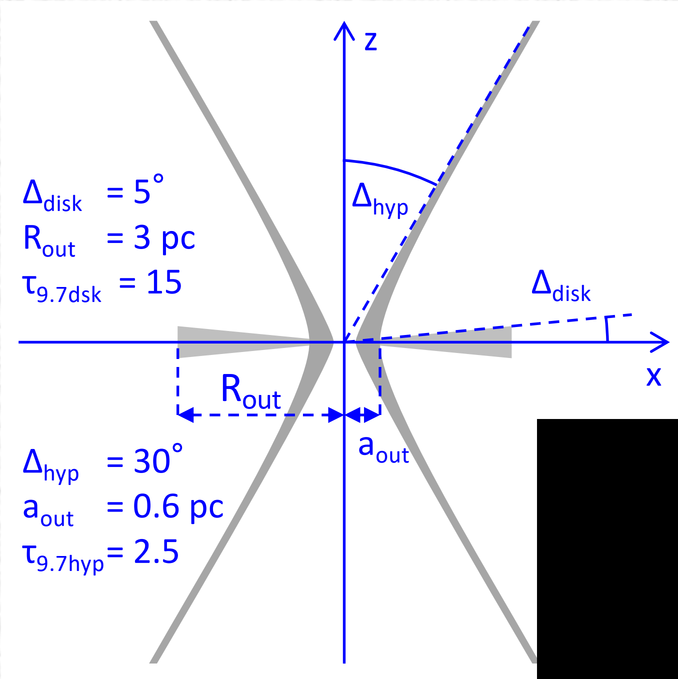


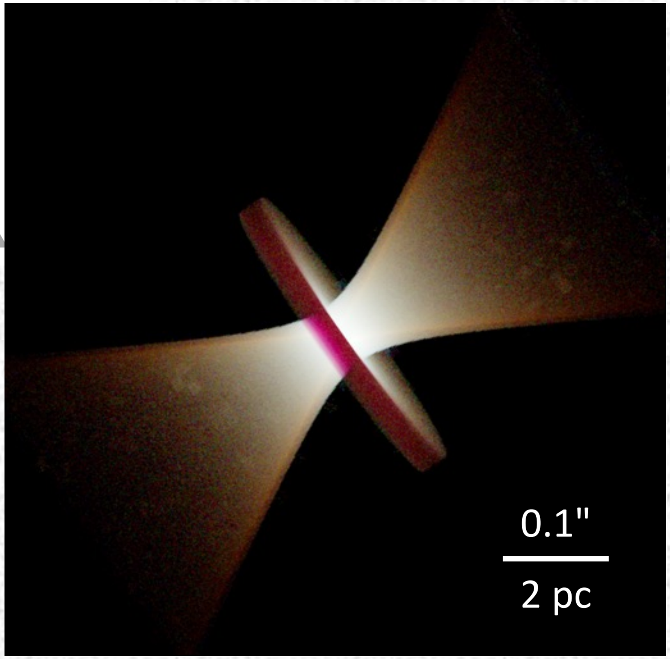


Tristram et al. 2014

1. Introduction: Radiative transfer modelling

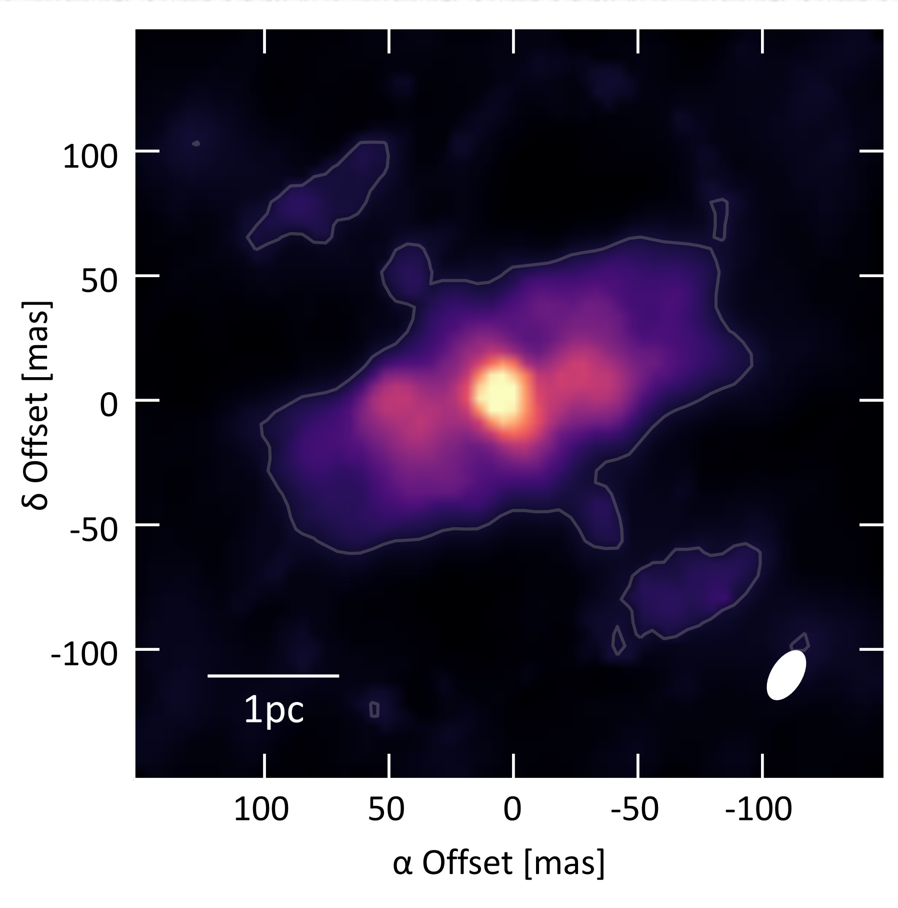


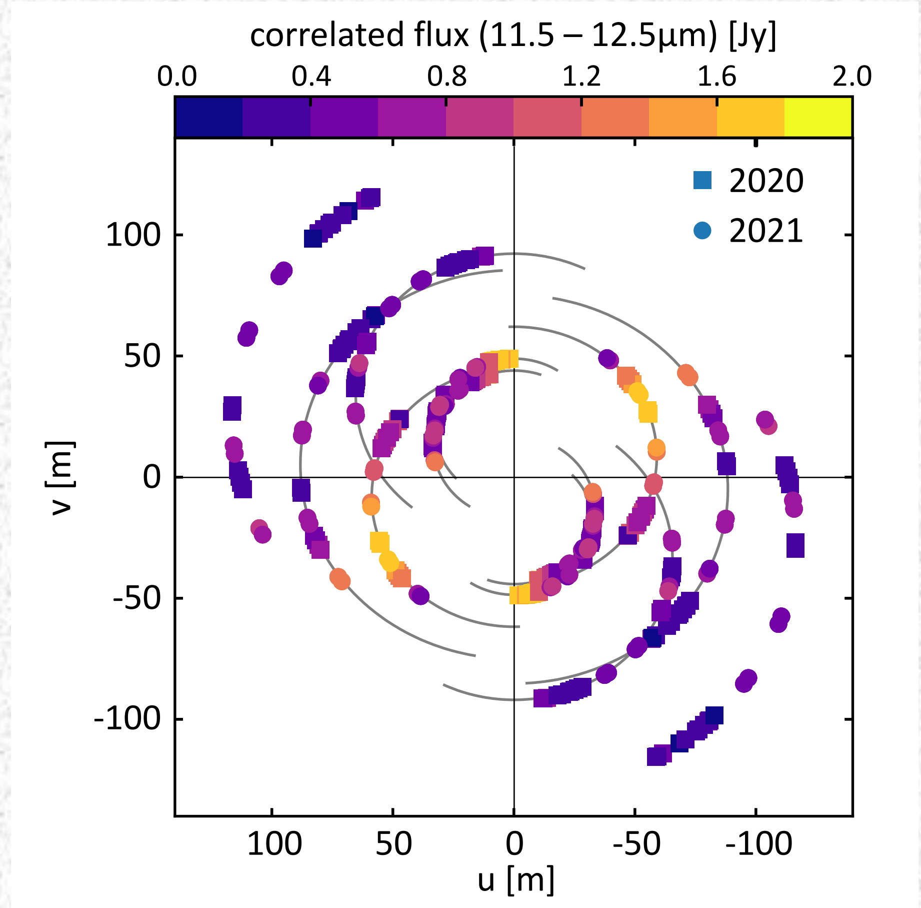




Stalevski et al. 2017 & 2019
(see also Vollmer et al. 2018)

1. Introduction: MATISSE results





Isbell et al. 2022

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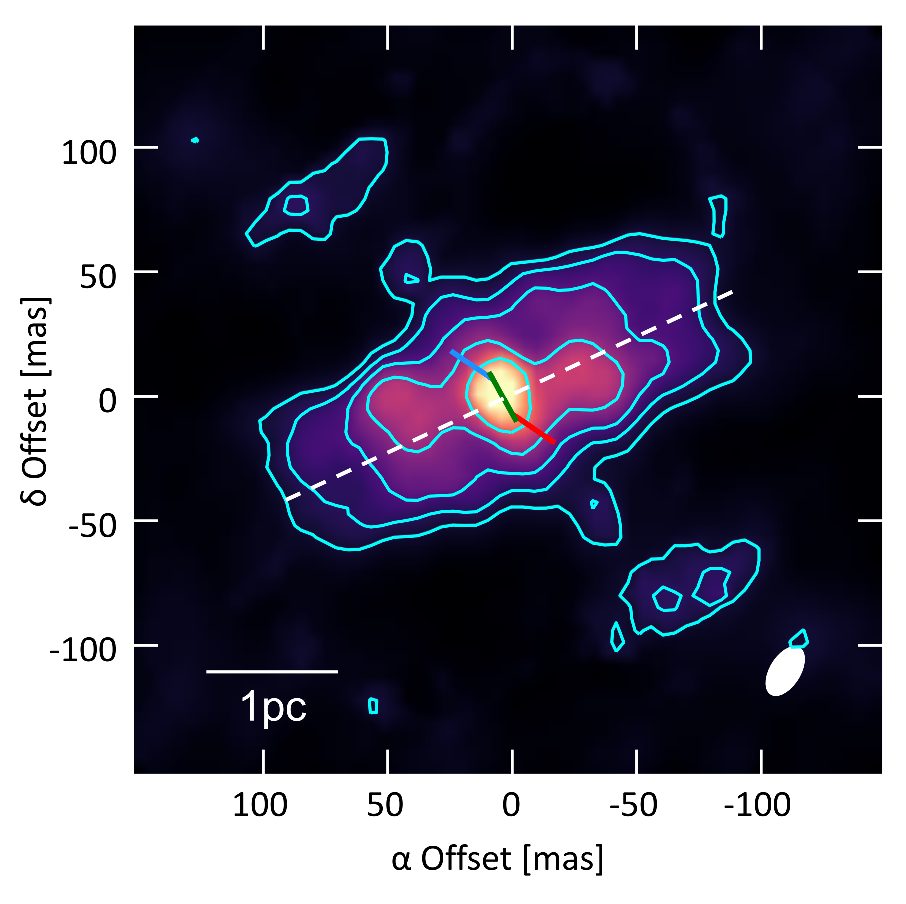

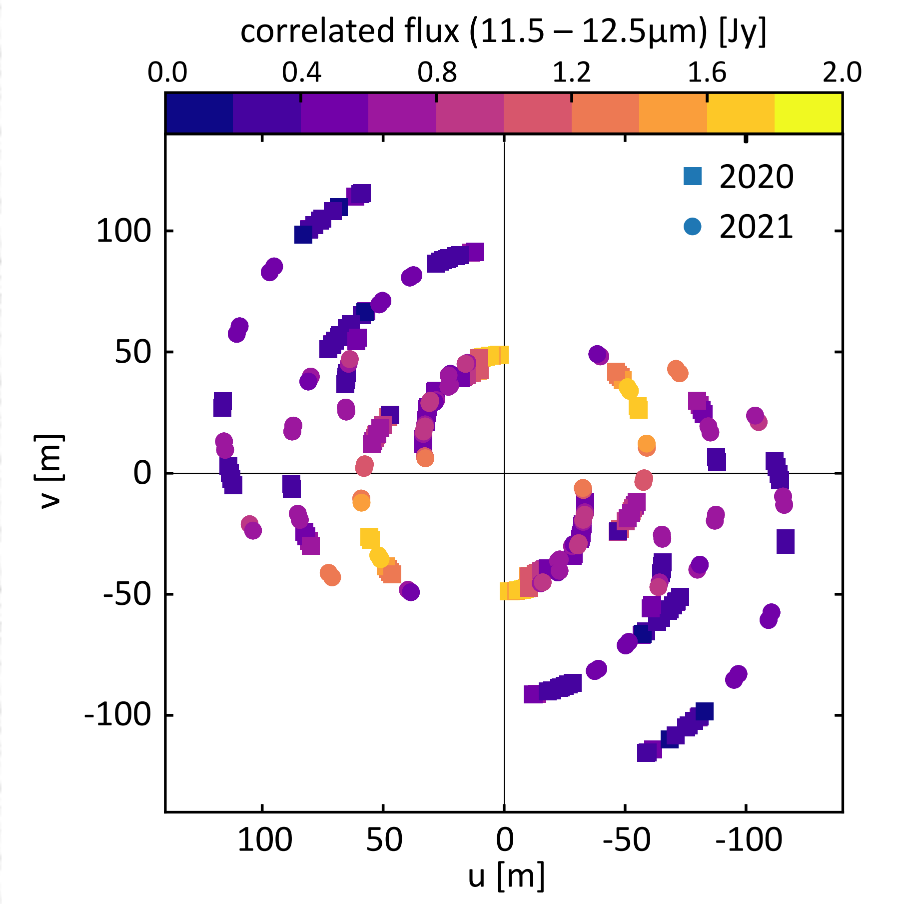

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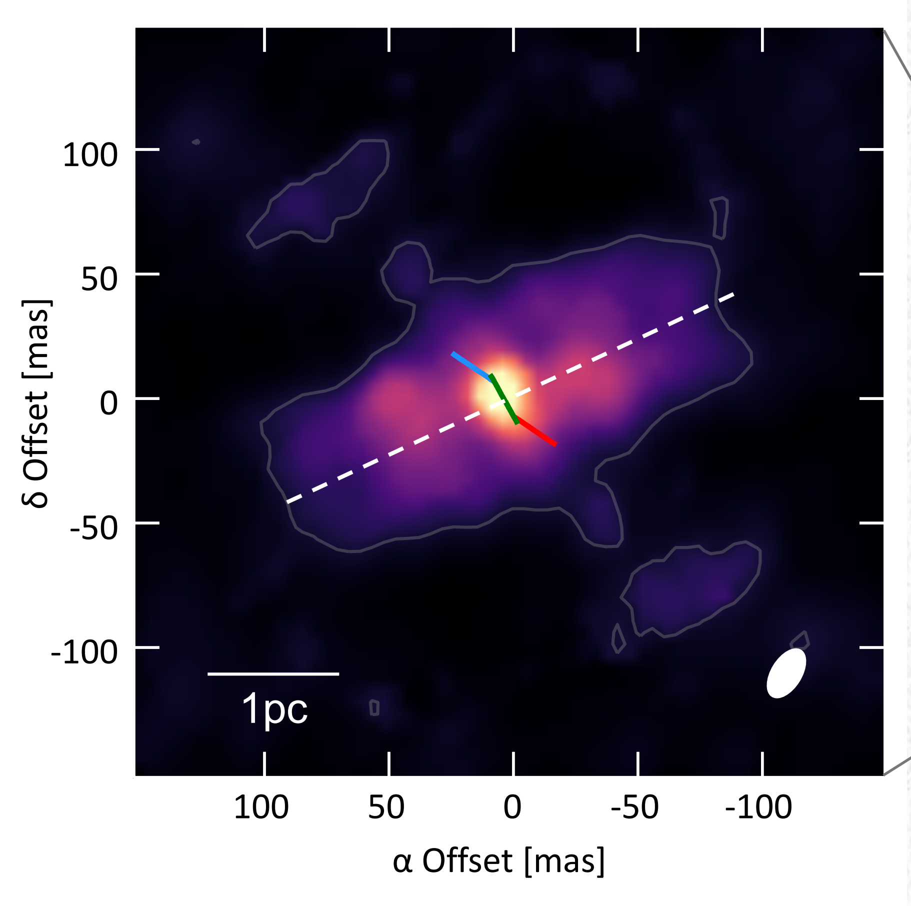

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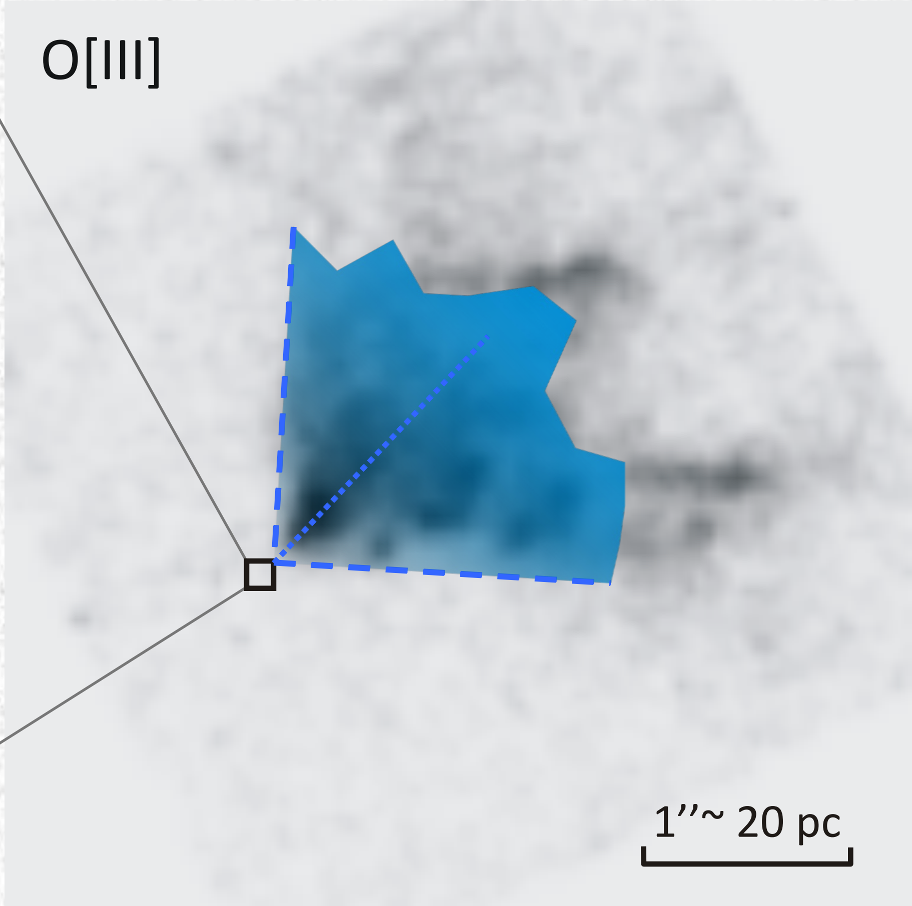


Wilson et al. 2000

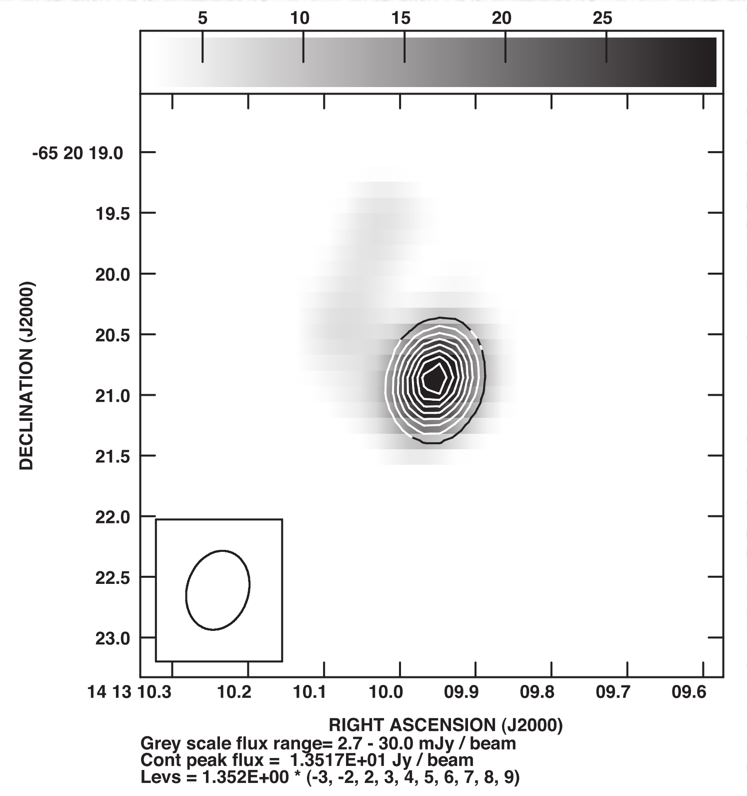
2. Interferometry with ALMA

Atacama Large Millimeter/submillimeter Array

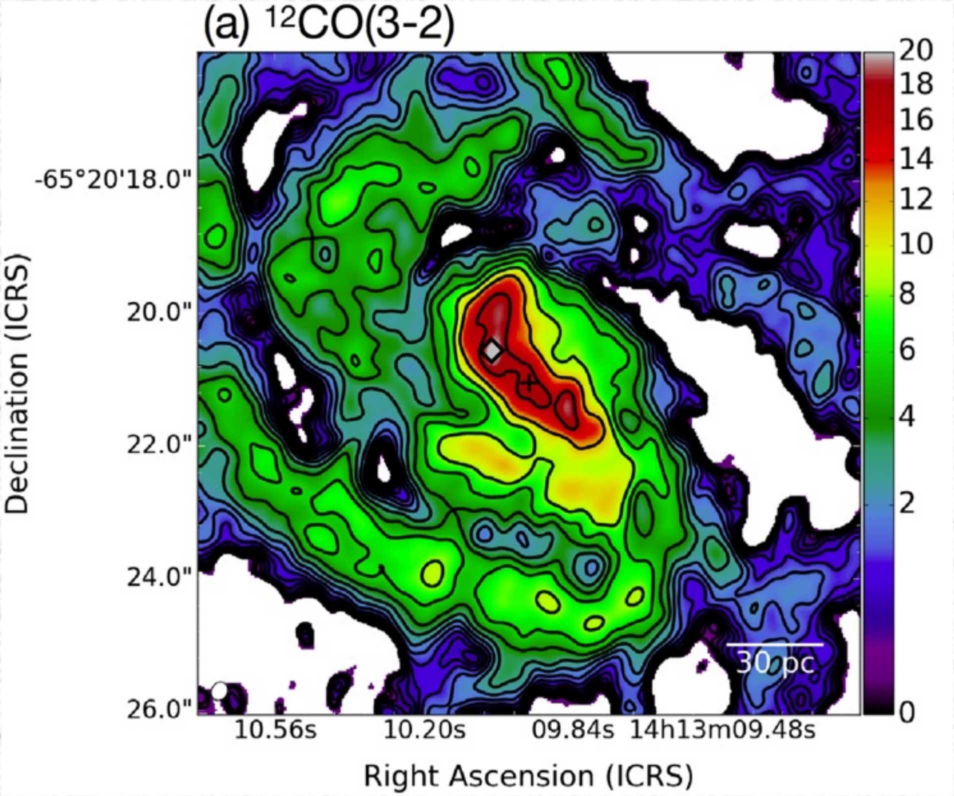
- Located in northern Chile at 5000m altitude
- ESO / NRAO / NRC / NAOJ / ASIAA
- 66 antenna submm interferometer
- 0.32 to 3.6 mm
- 31 to 1000 GHz

Credit: ESO/C. Malin

2. Previous ALMA results



Hagiwara et al. 2013



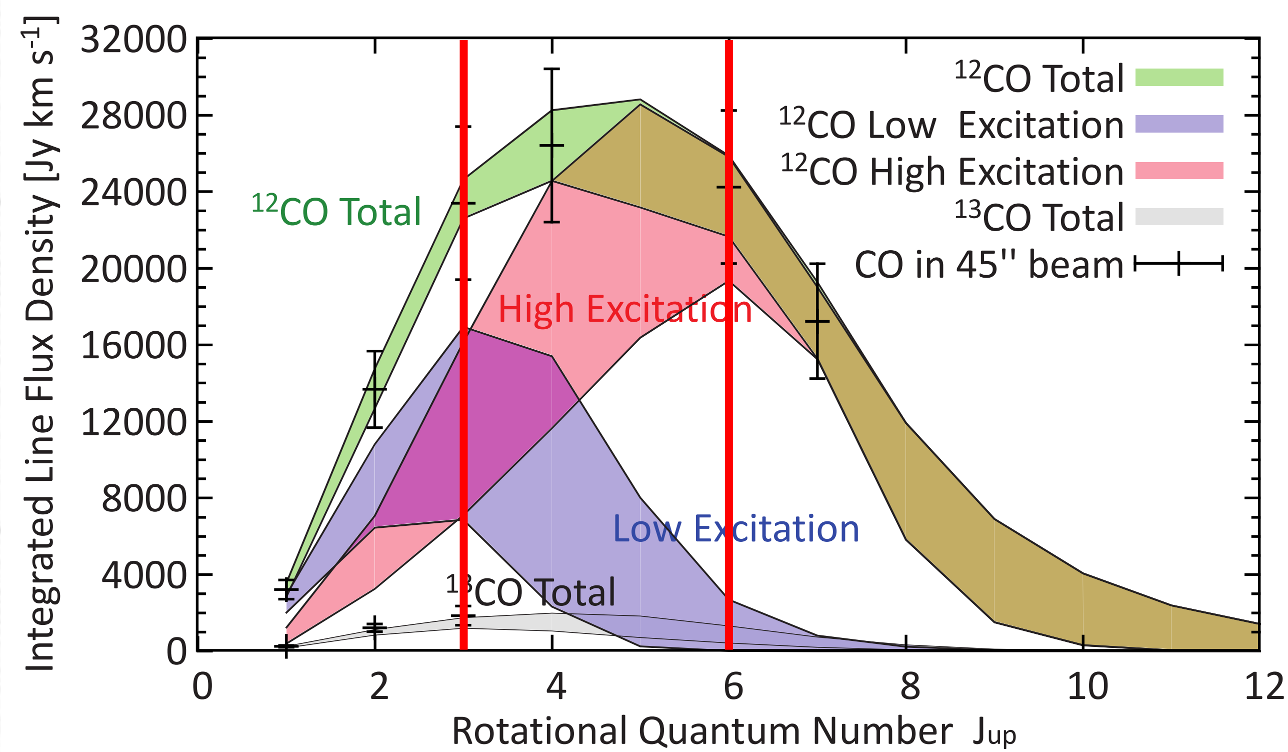
Izumi et al. 2018

Detection of H_2O maser and continuum at 321 GHz

CO(3-2) & [C I](1-0)
↳ radiation-driven fountain

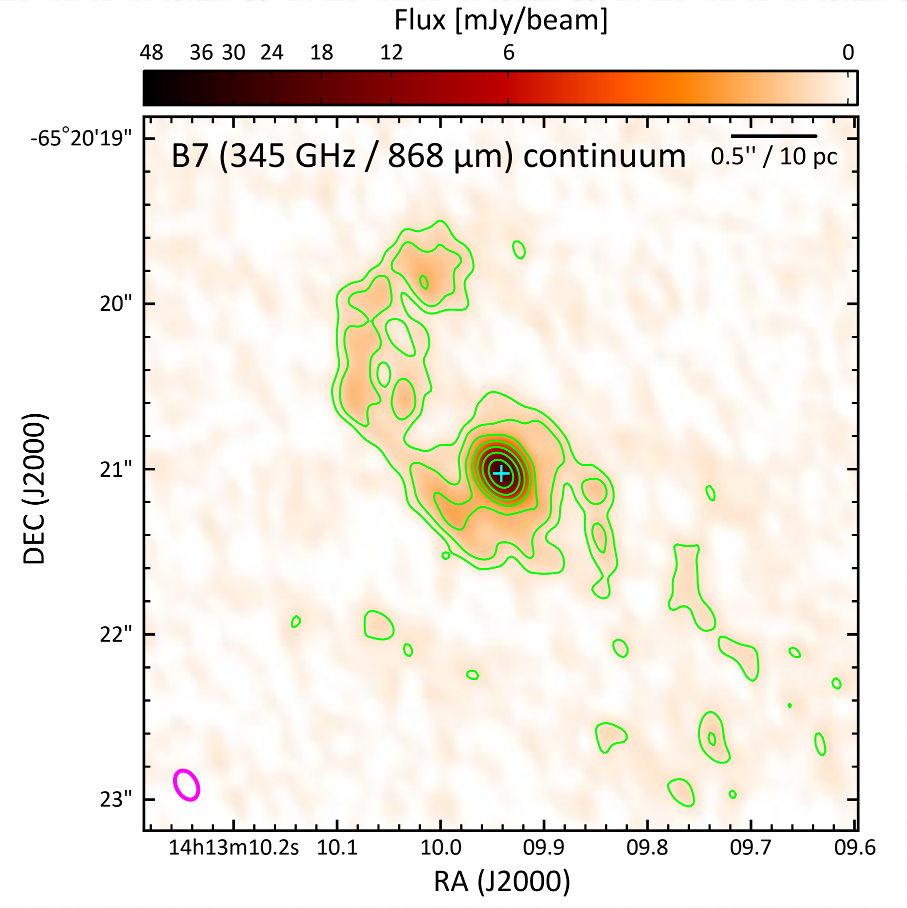
2. ALMA: Our Observations in band 7 and 9

- Observations targeted at CO(3-2) at 345GHz (868µm) and CO(6-5) at 691GHz (434µm)
- Continuum and other emission lines



Zhang et al. 2014

2. ALMA: continuum emission B7 and B9



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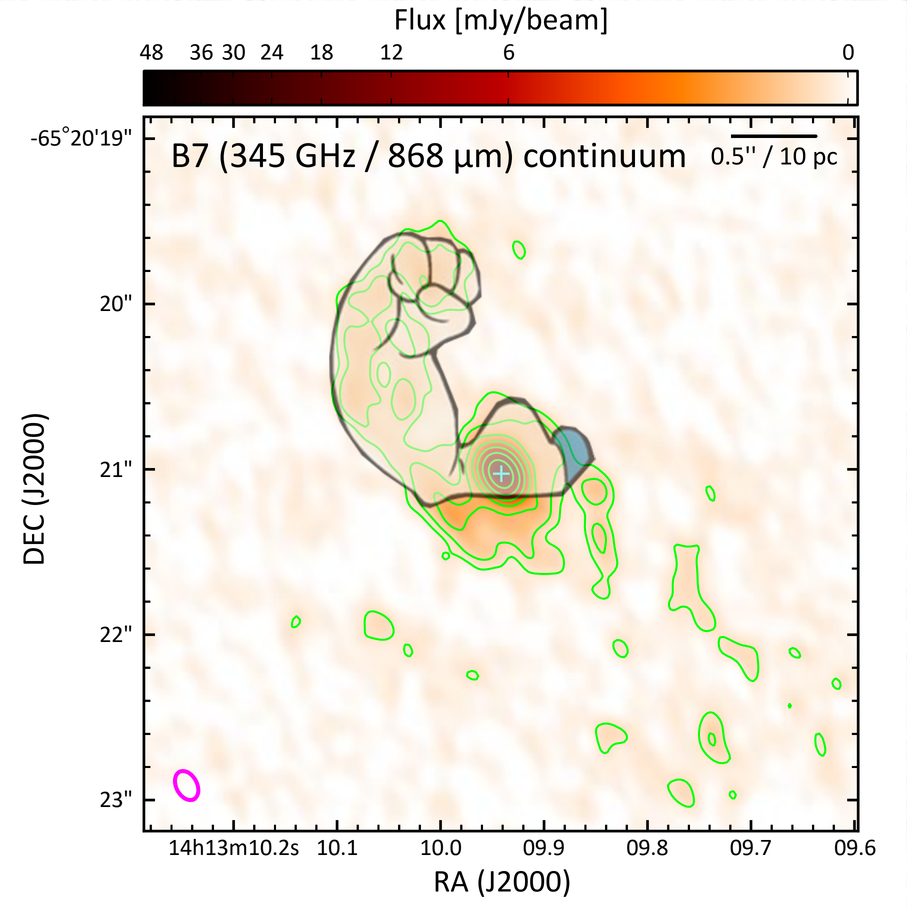
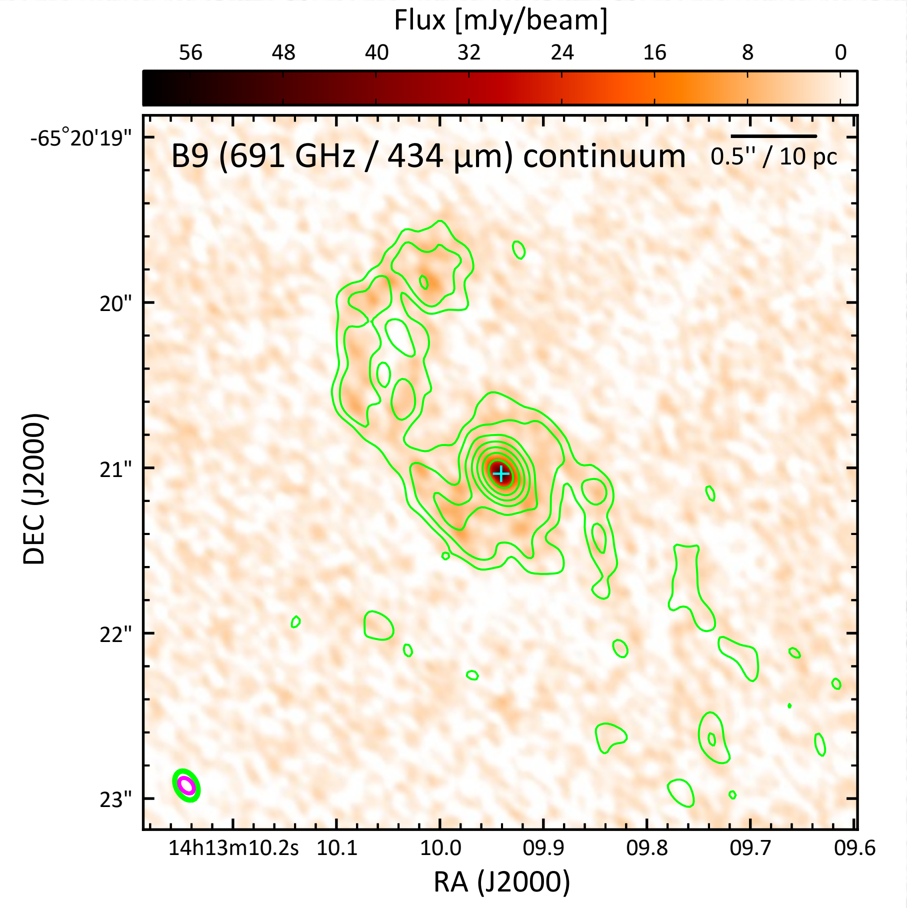




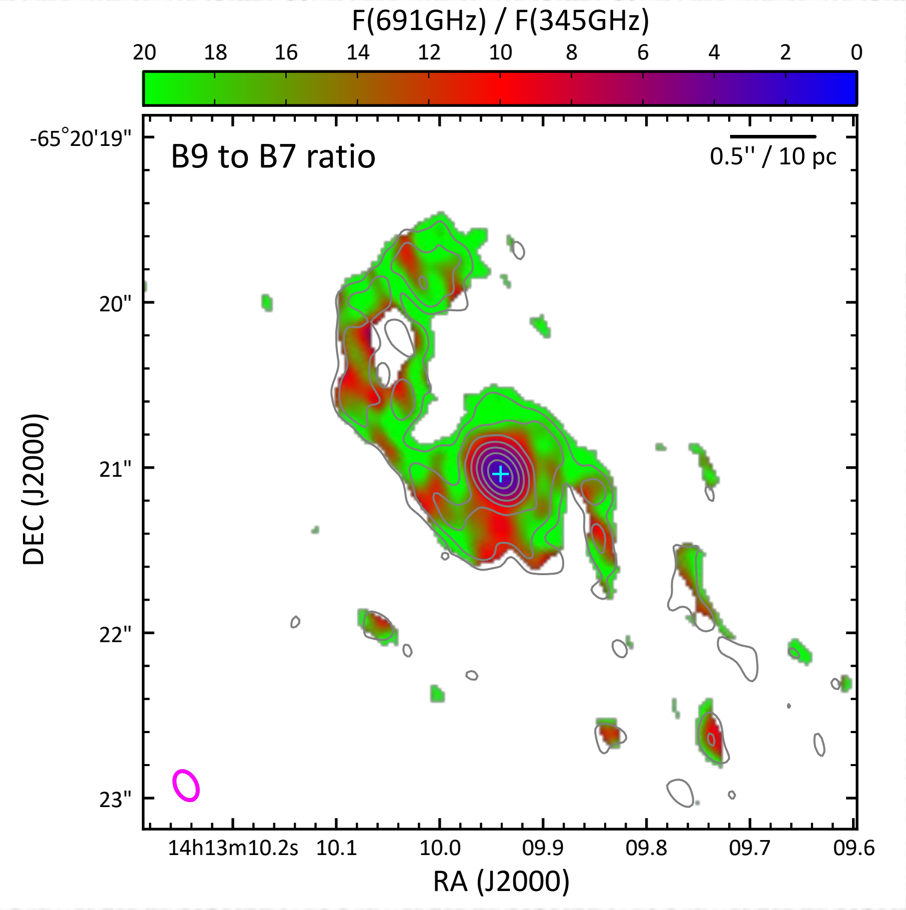
Find S-shaped morphology, plus core.

2. ALMA: Origin of the continuum emission

- Continuum in the submm has powerlaw spectral indices (for $F_\nu \propto \nu^\alpha$):
  - dust: α = 3 … 4
  - free-free: α = -0.1
  - synchrotron: α = -0.7
- At r > 6pc: 3.3 < α < 4.3

  ↳ dust emission
- Nucleus: α ~ 2

  ↳ different origin?



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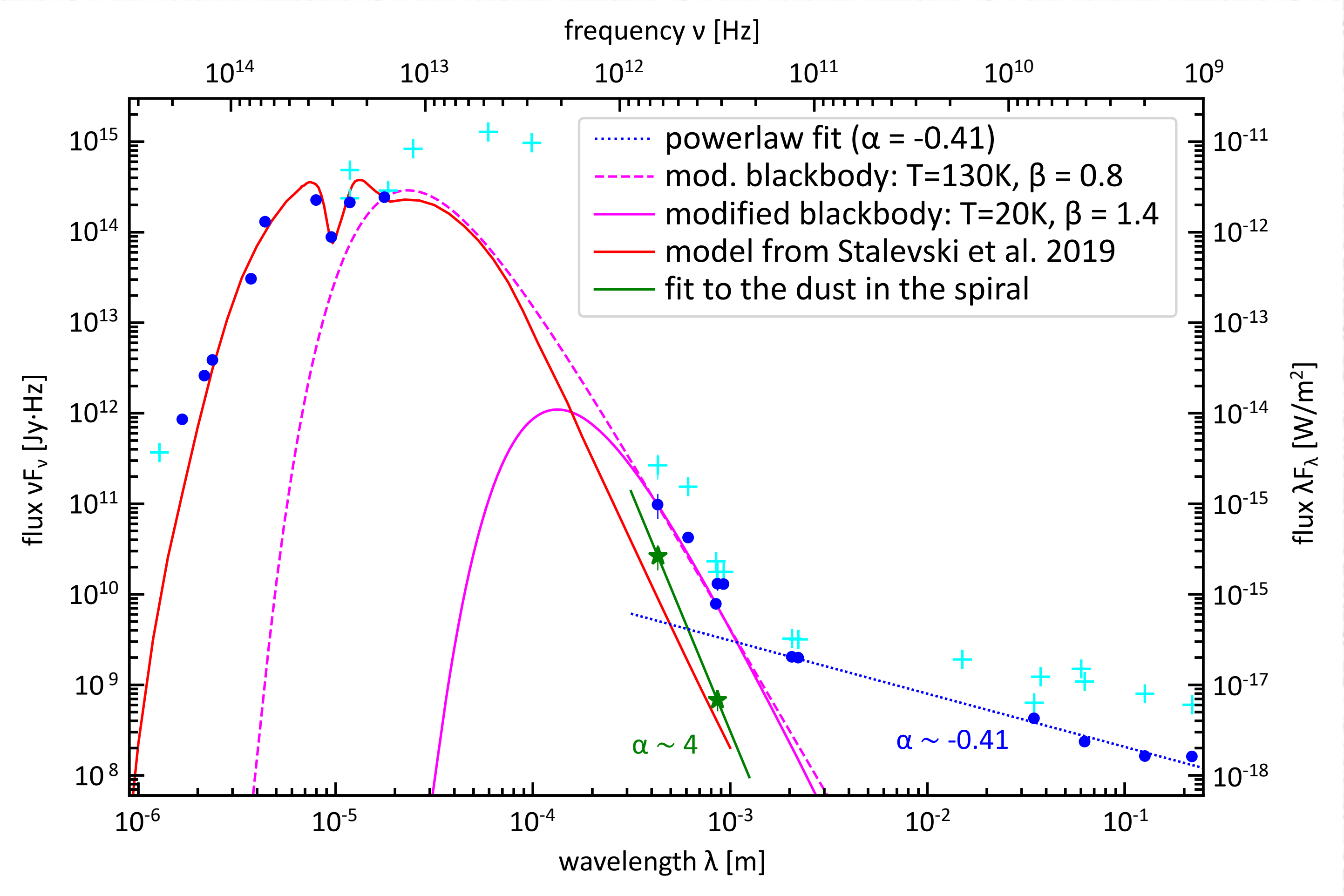
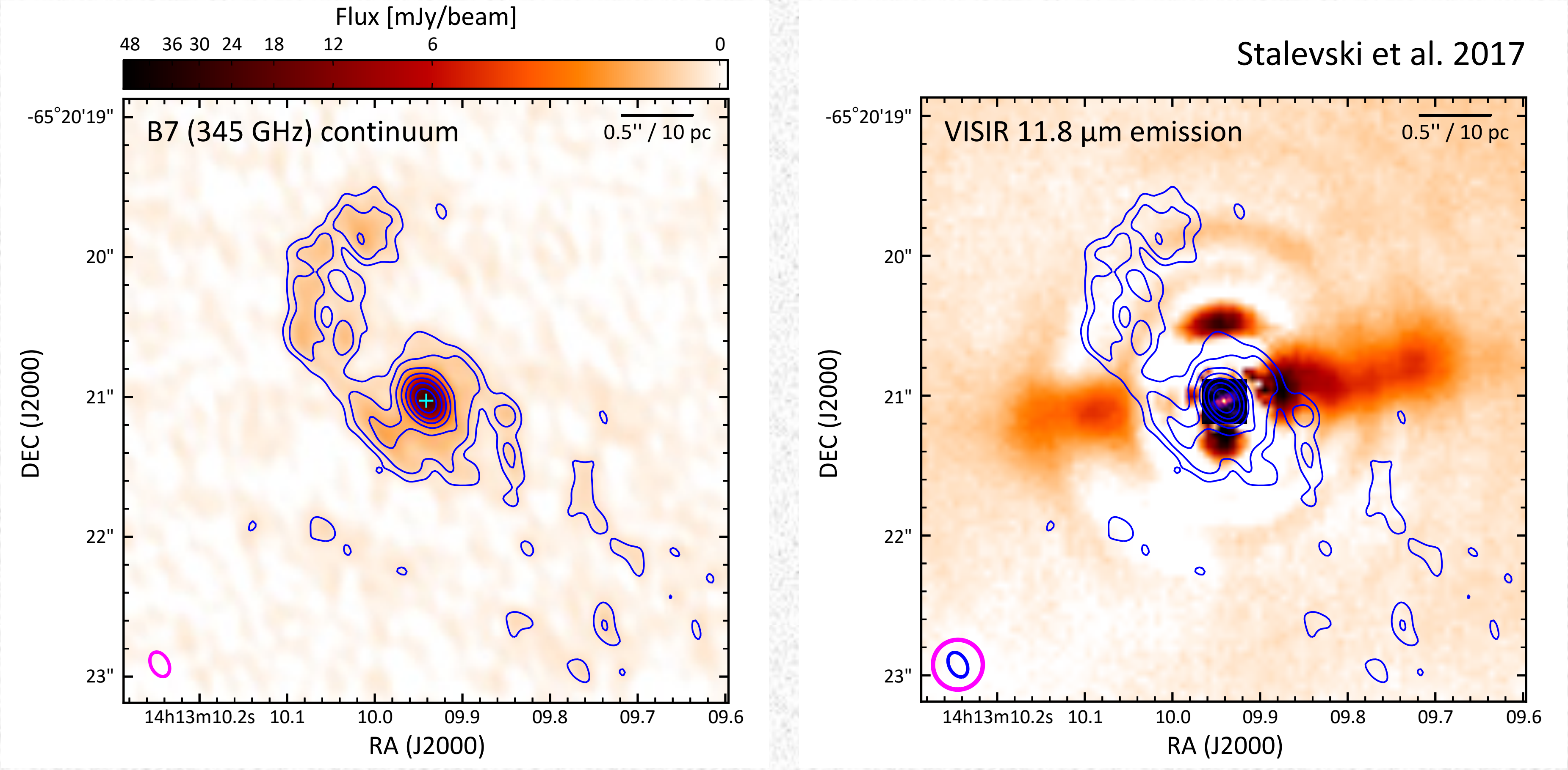


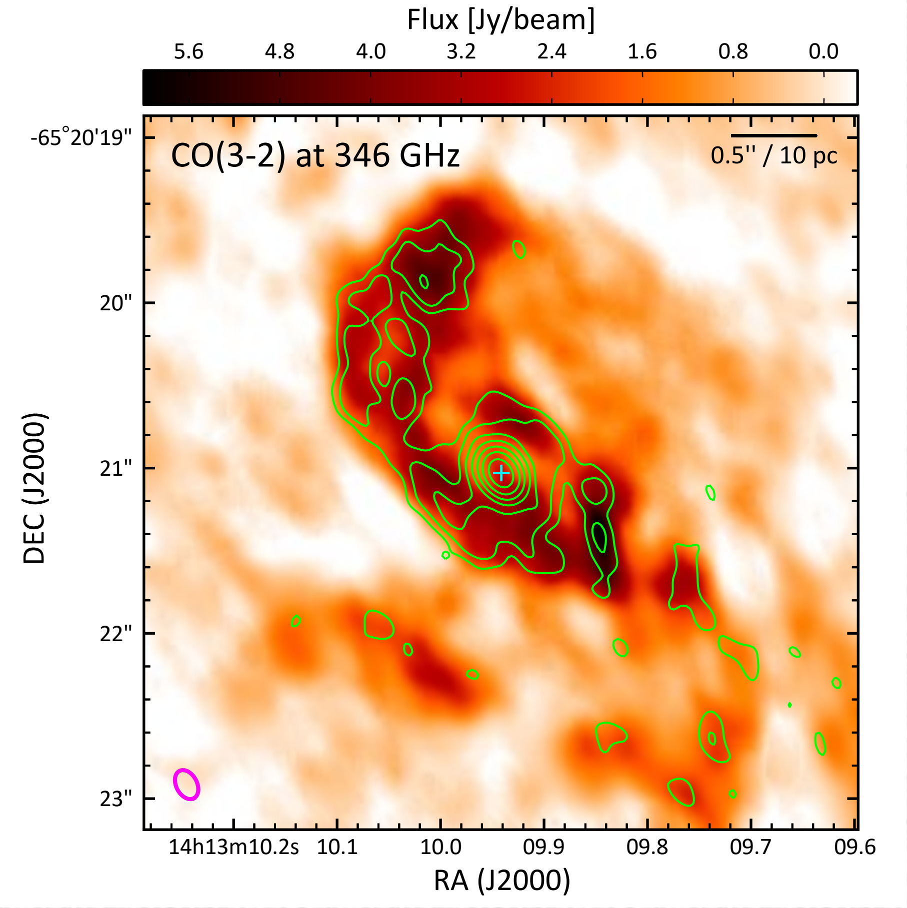
↳ significant contribution from non-dust emission in B7

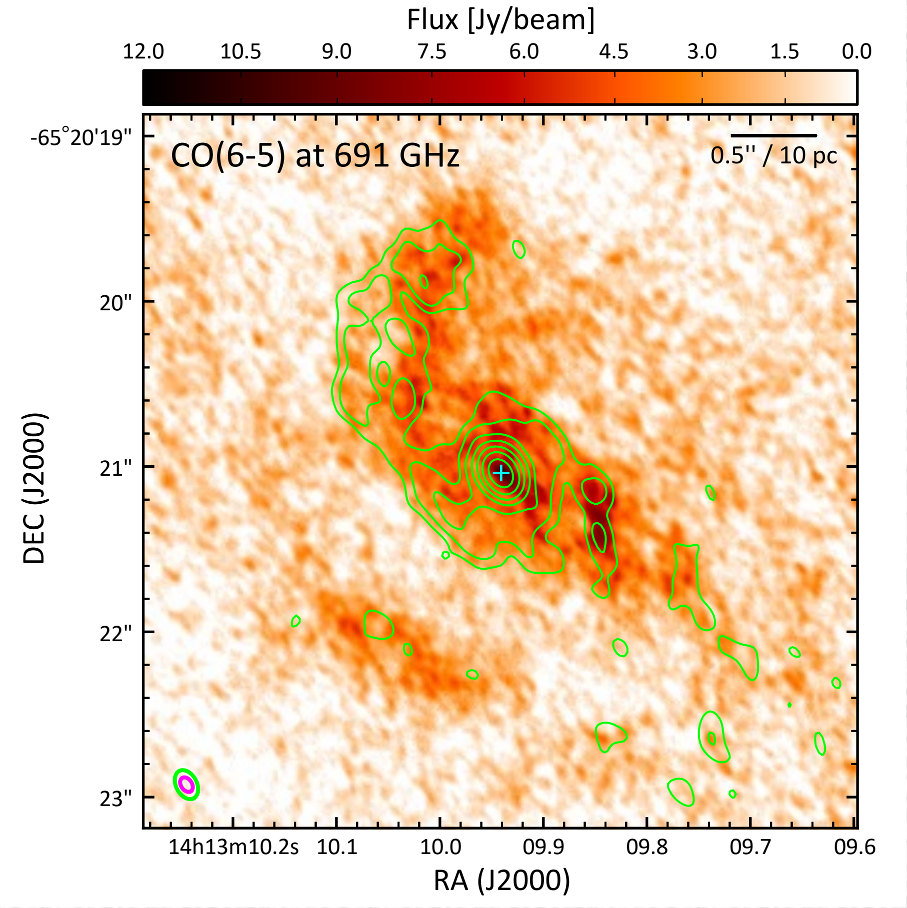
2. ALMA: Comparison to the MIR emission



↳ Looking at two different dust components: hot vs. cold

3. ALMA line emission: CO morphology





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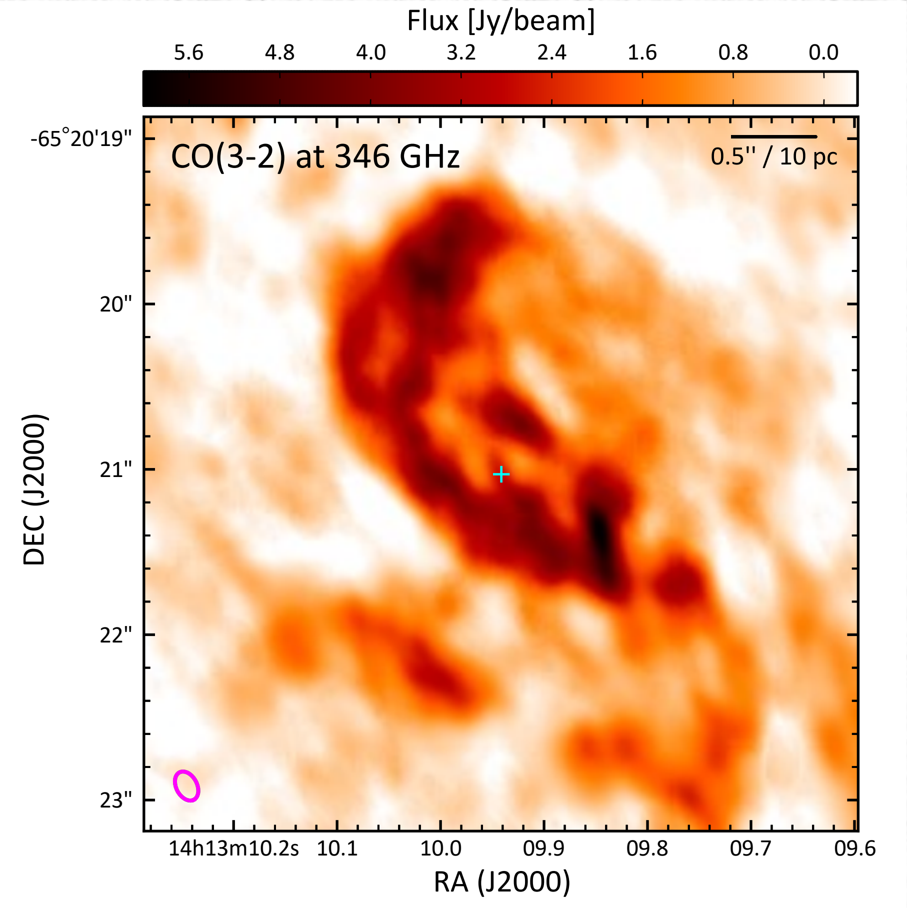
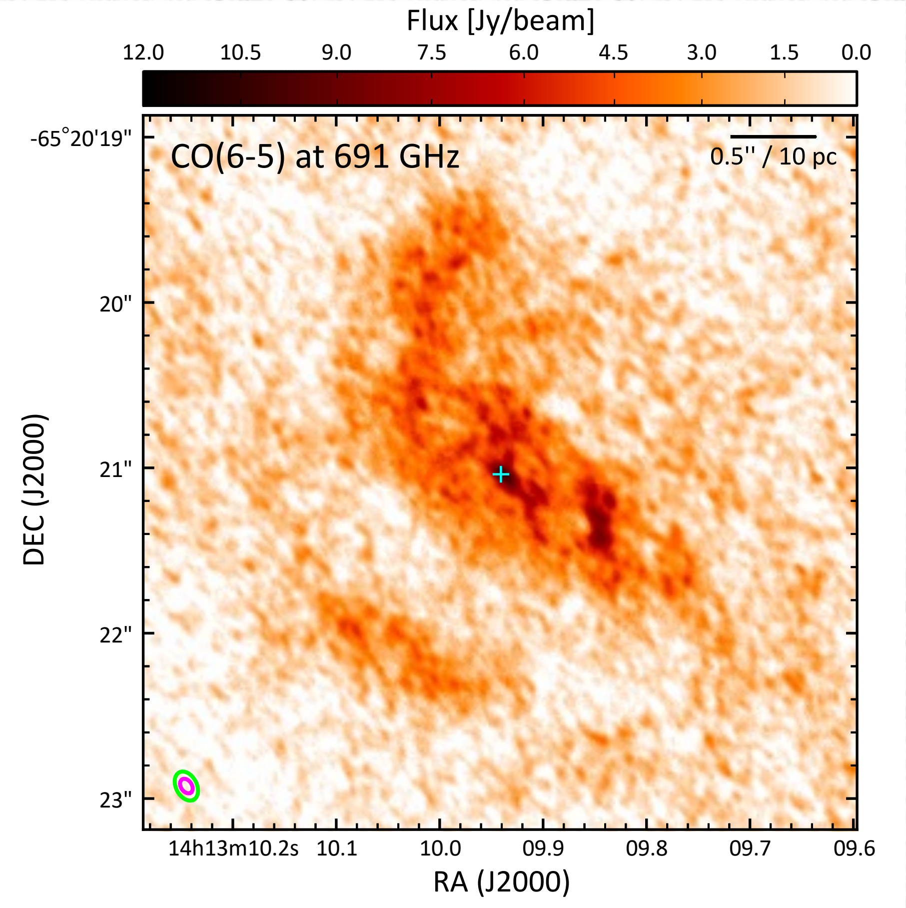
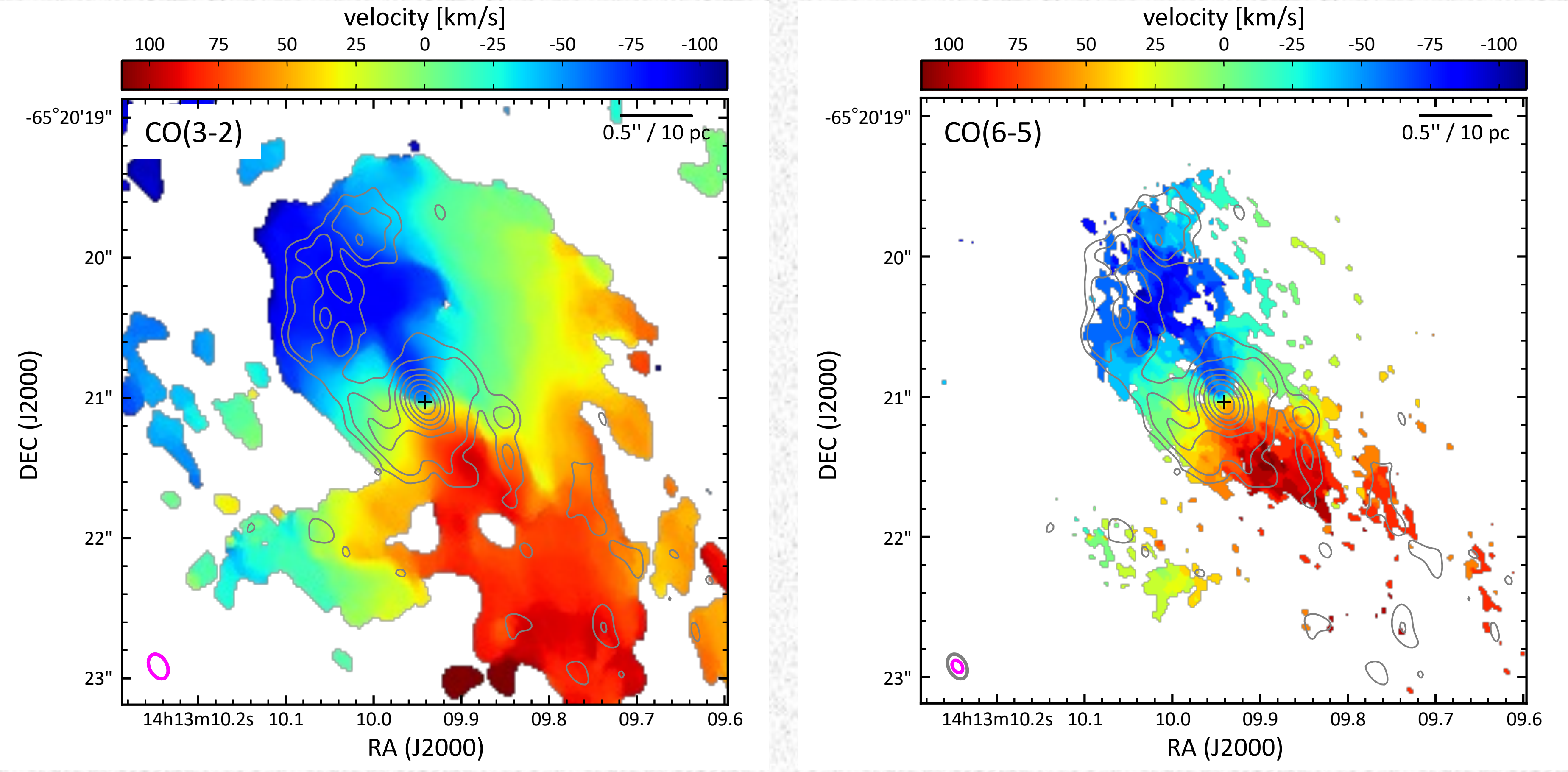




↳ CO(3-2) hole due to excitation / self-absorption

3. ALMA line emission: kinematics



↳ Kinematics dominated by rotation

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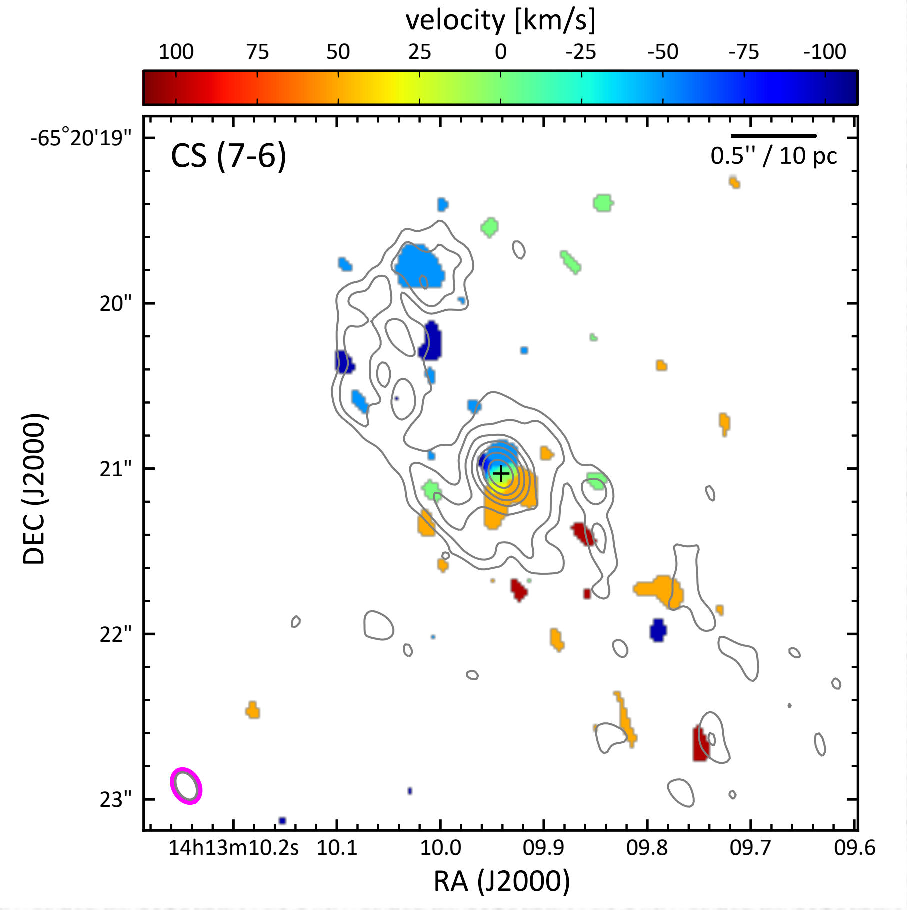

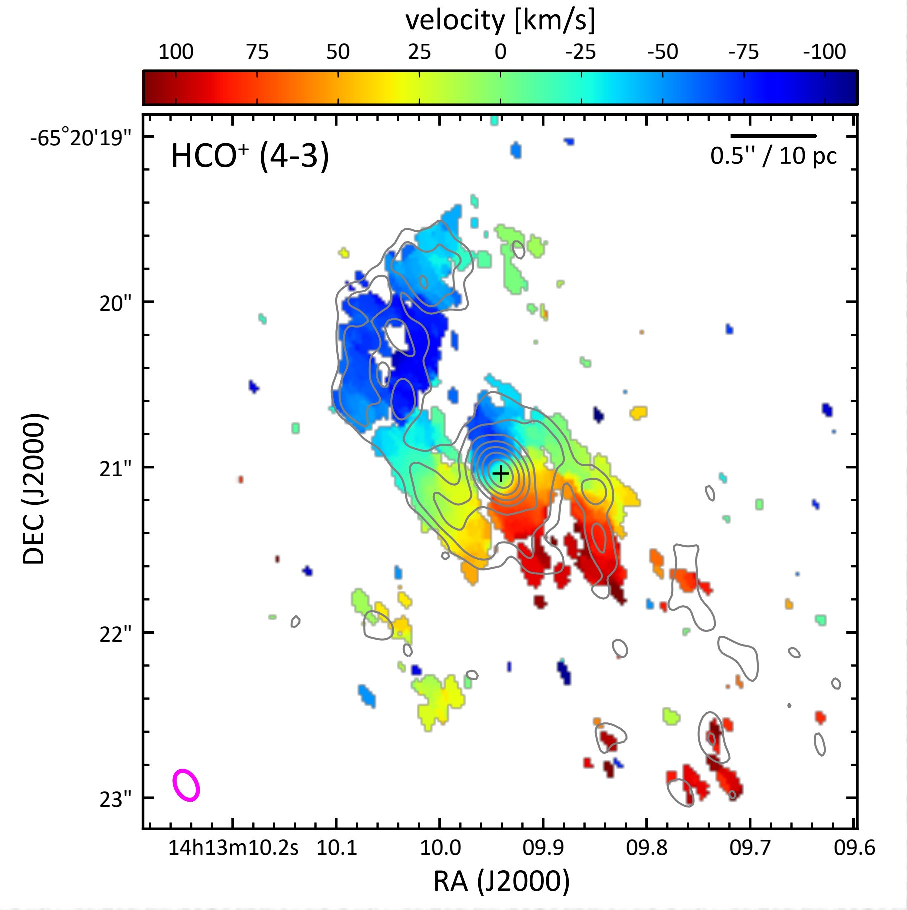

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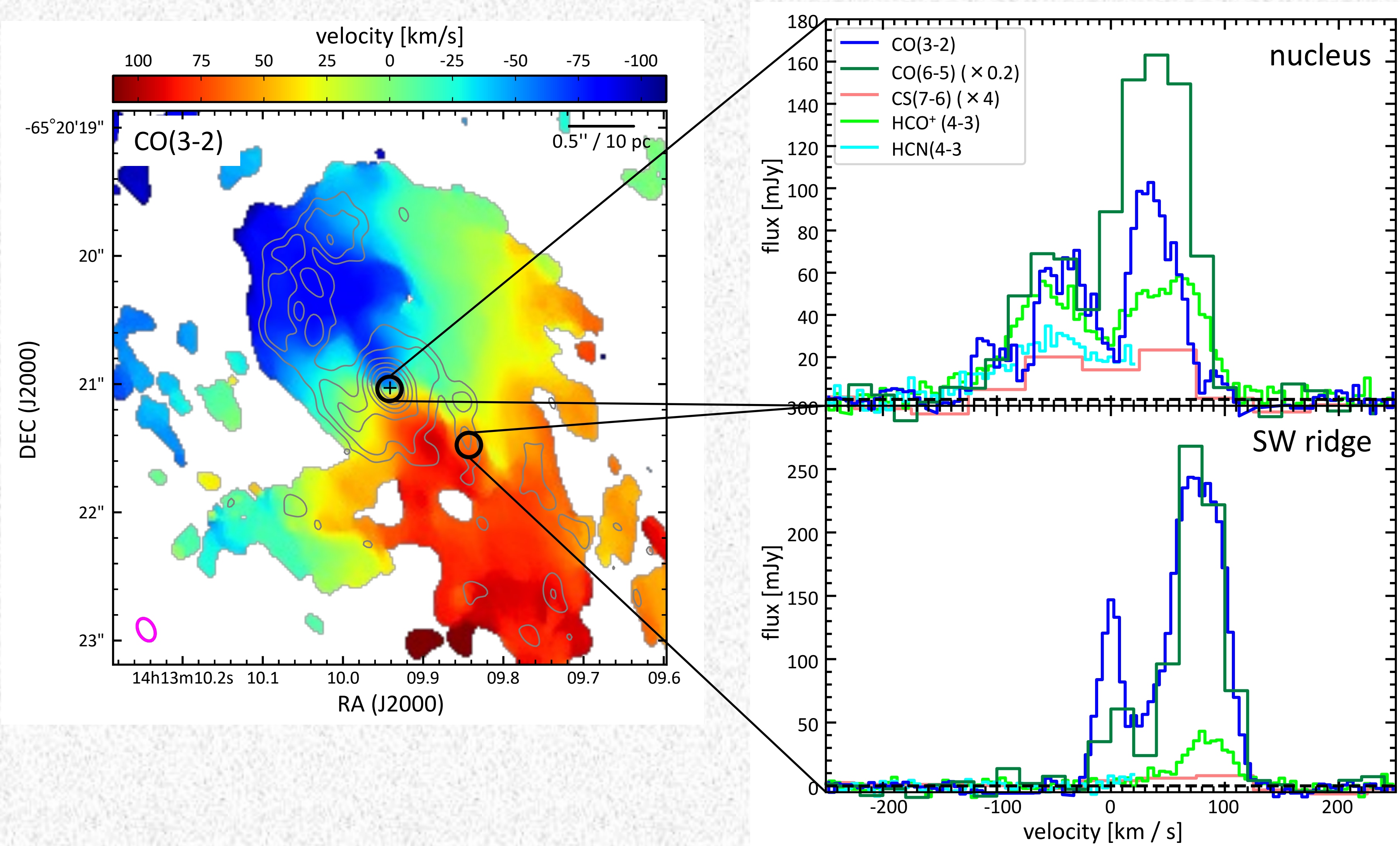
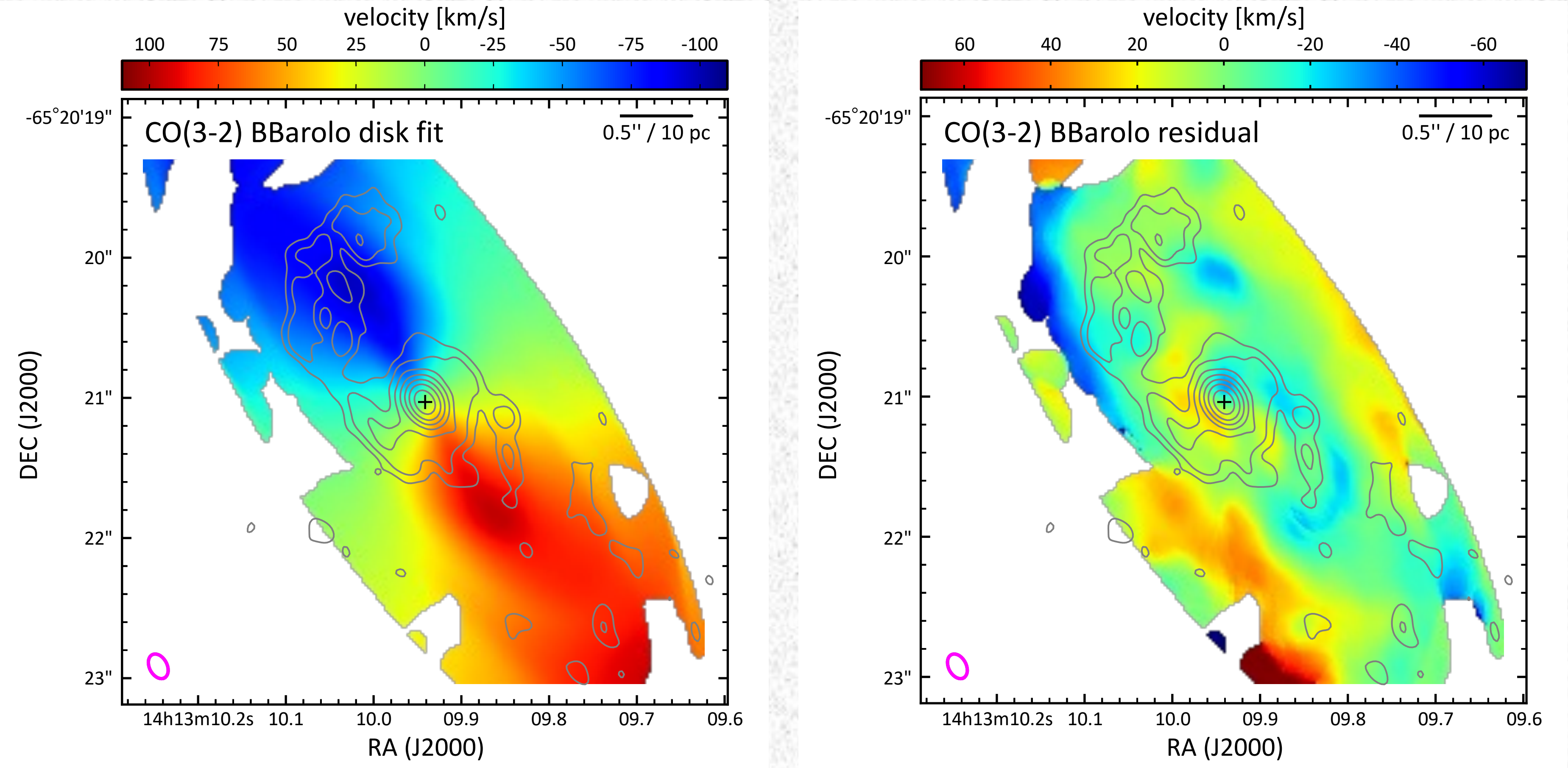


3. ALMA line emission: kinematic fit



Kinematic fit using 3D-Barolo (Di Teodoro & Fraternali 2015)

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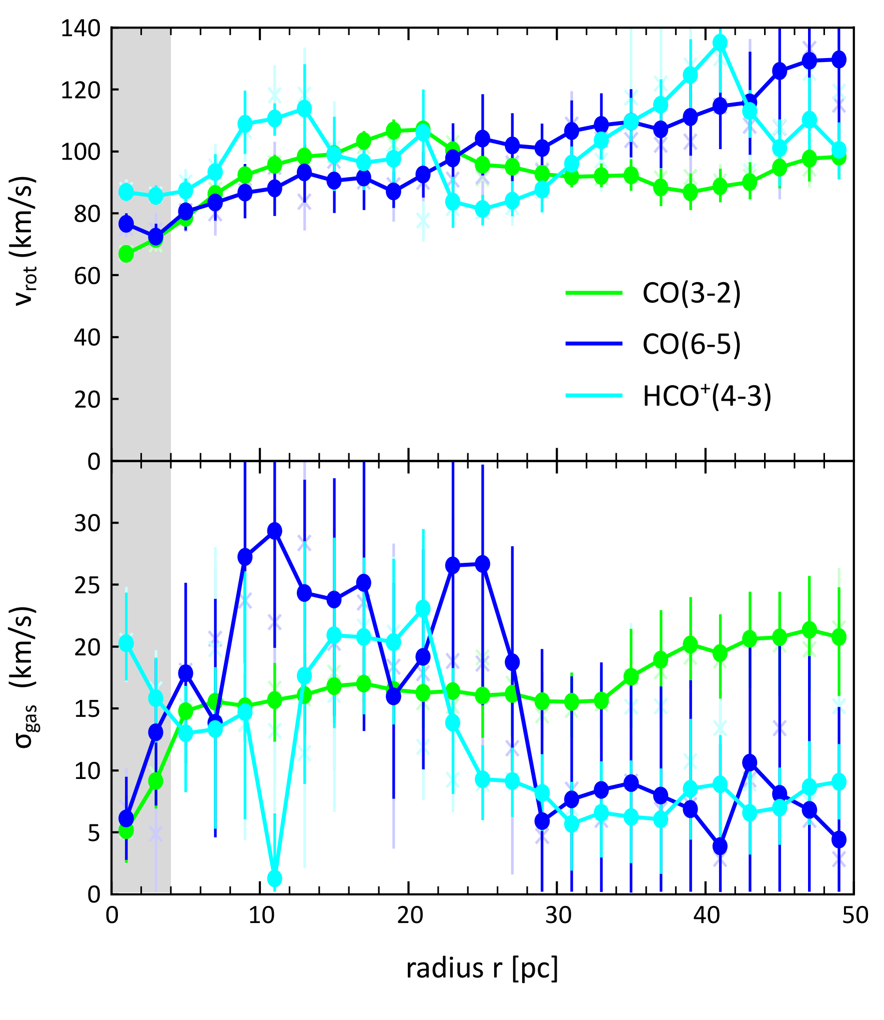

- Estimate disk scale height on scales of 10 parsec:
  1. self-gravitating (thin) disk: $h/r < 0.1$
  2. hydrostatical equilibrium $h/r < 0.3$:

➪ Main obscuration and collimation ($h/r \sim 1$) on (sub-)parsec scales

Conclusion: A picture of what is going on

- dust continuum: two components
  - cool dust in the midplane of a disk
  - warm dust in polar direction (wind)
- molecular material:
  - dense and excited
  - dominated by rotation
  - disk on 10 pc too thin for collimation