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The Circumnuclear *Multi-phase* Torus in the Circinus Galaxy Revealed by ALMA

→ *Izumi et al. 2018c, to be submitted*

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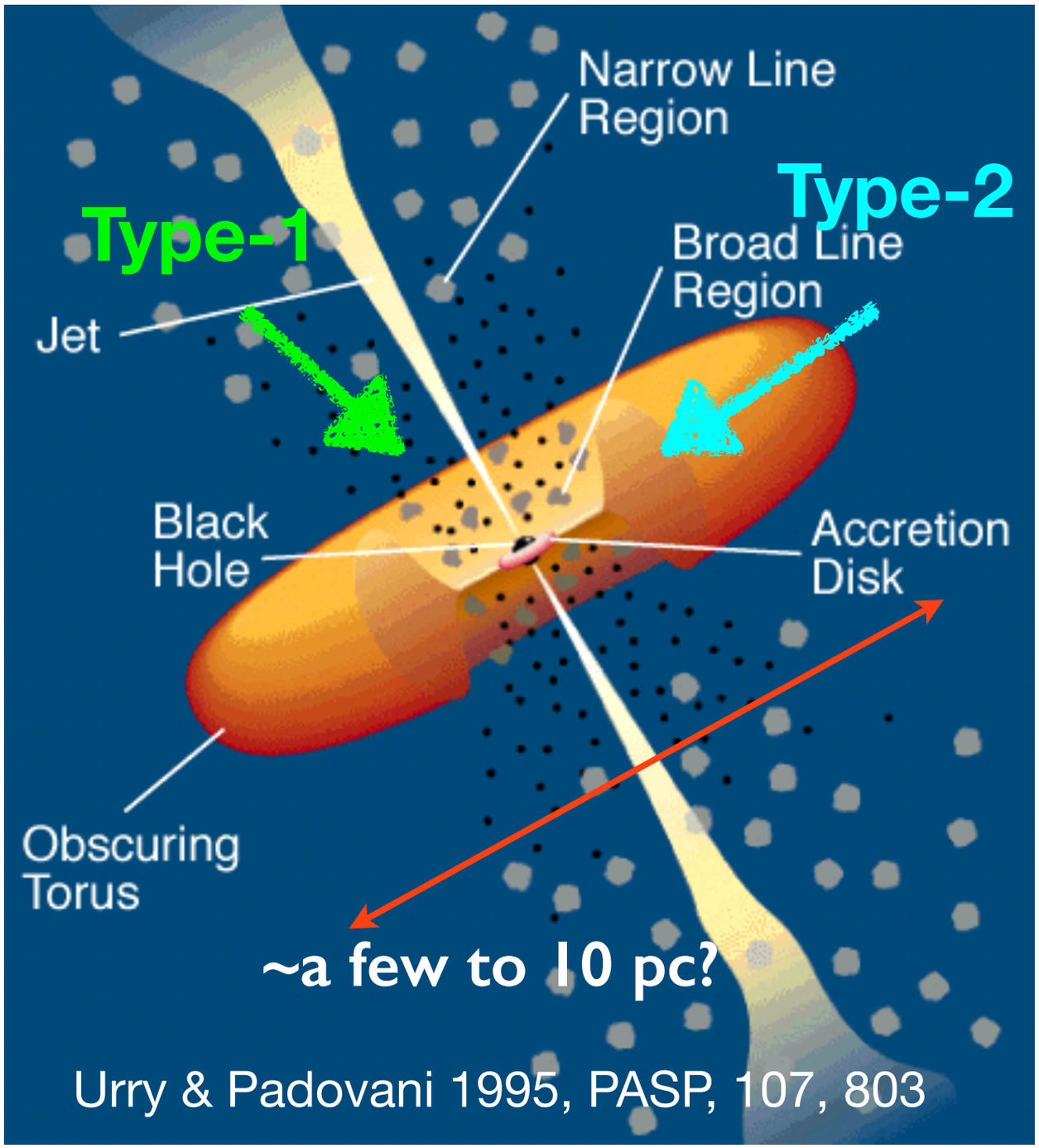
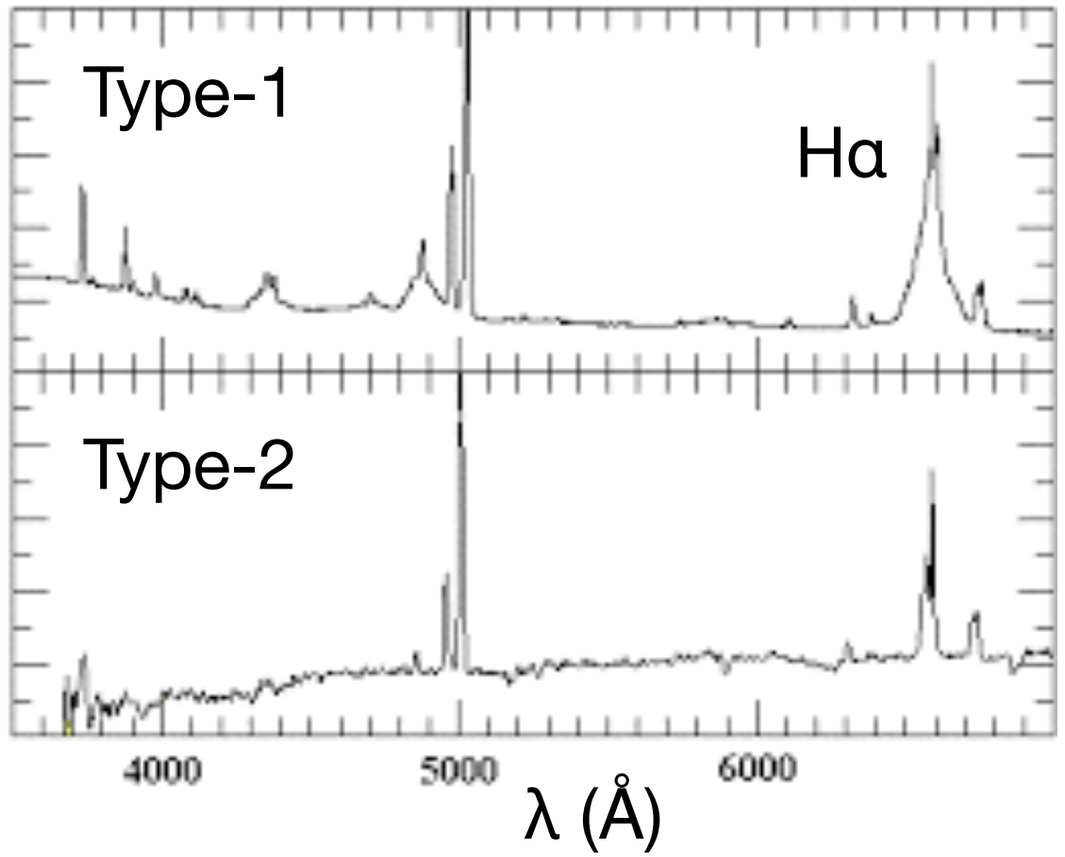
SMBH obscuration: Torus



Urry & Padovani 1995, PASP, 107, 803

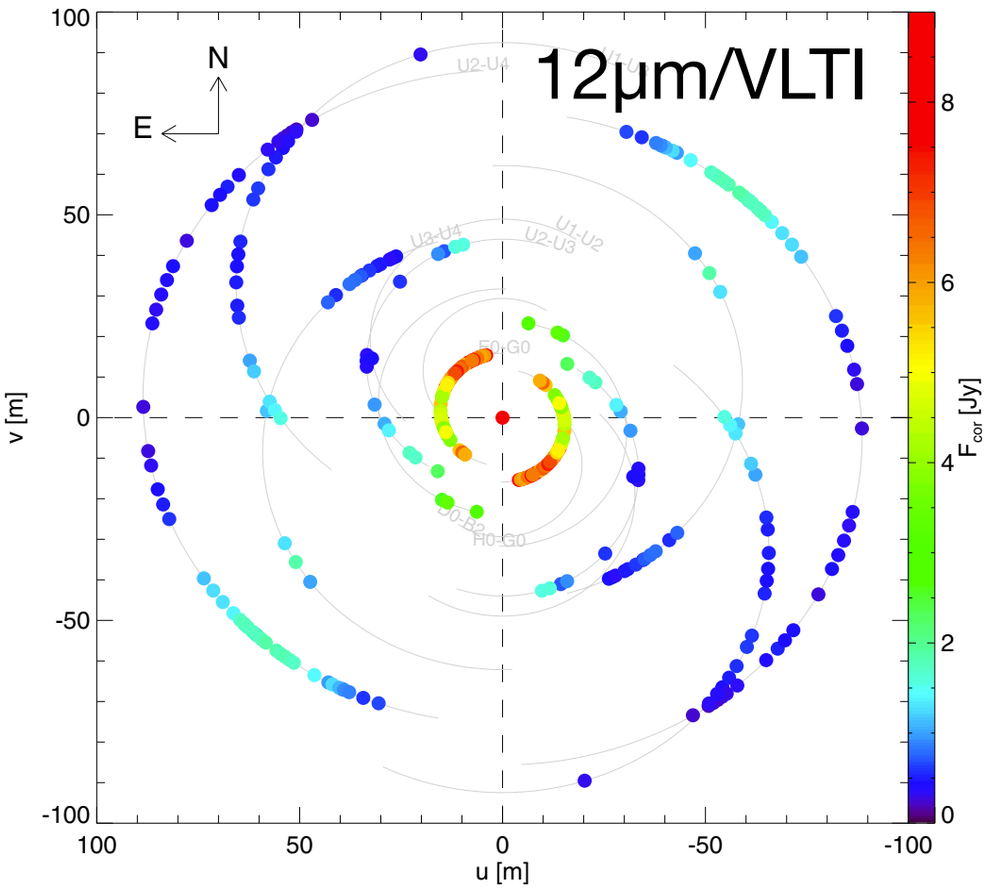
(Strict-) Unified scheme

(e.g., Antonucci 1993, ARA&A, 31, 473)



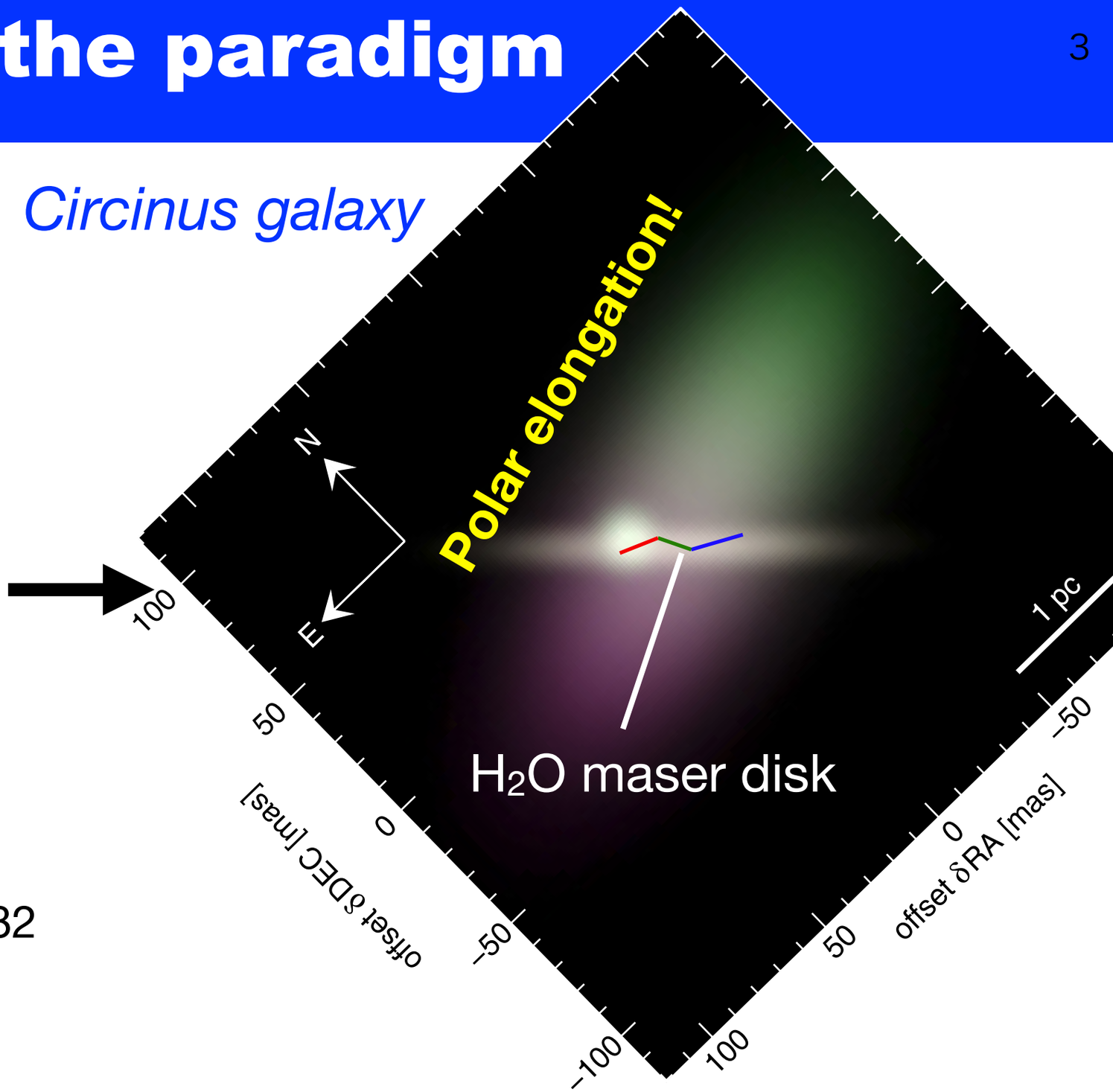
Q. Physical origin of the torus??

Big challenge to the paradigm



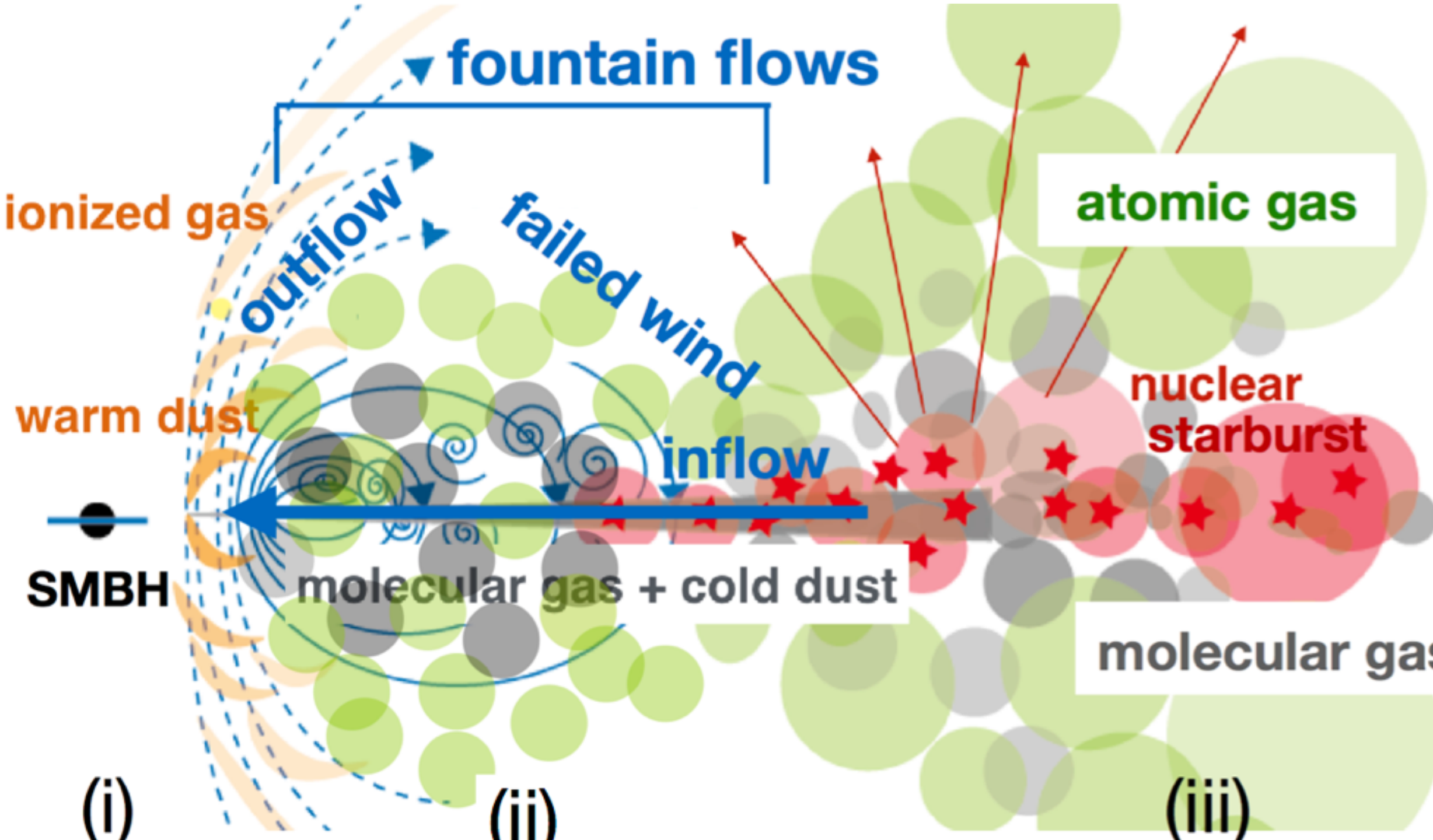
Tristram et al. 2014, A&A, 563, A82

Circinus galaxy

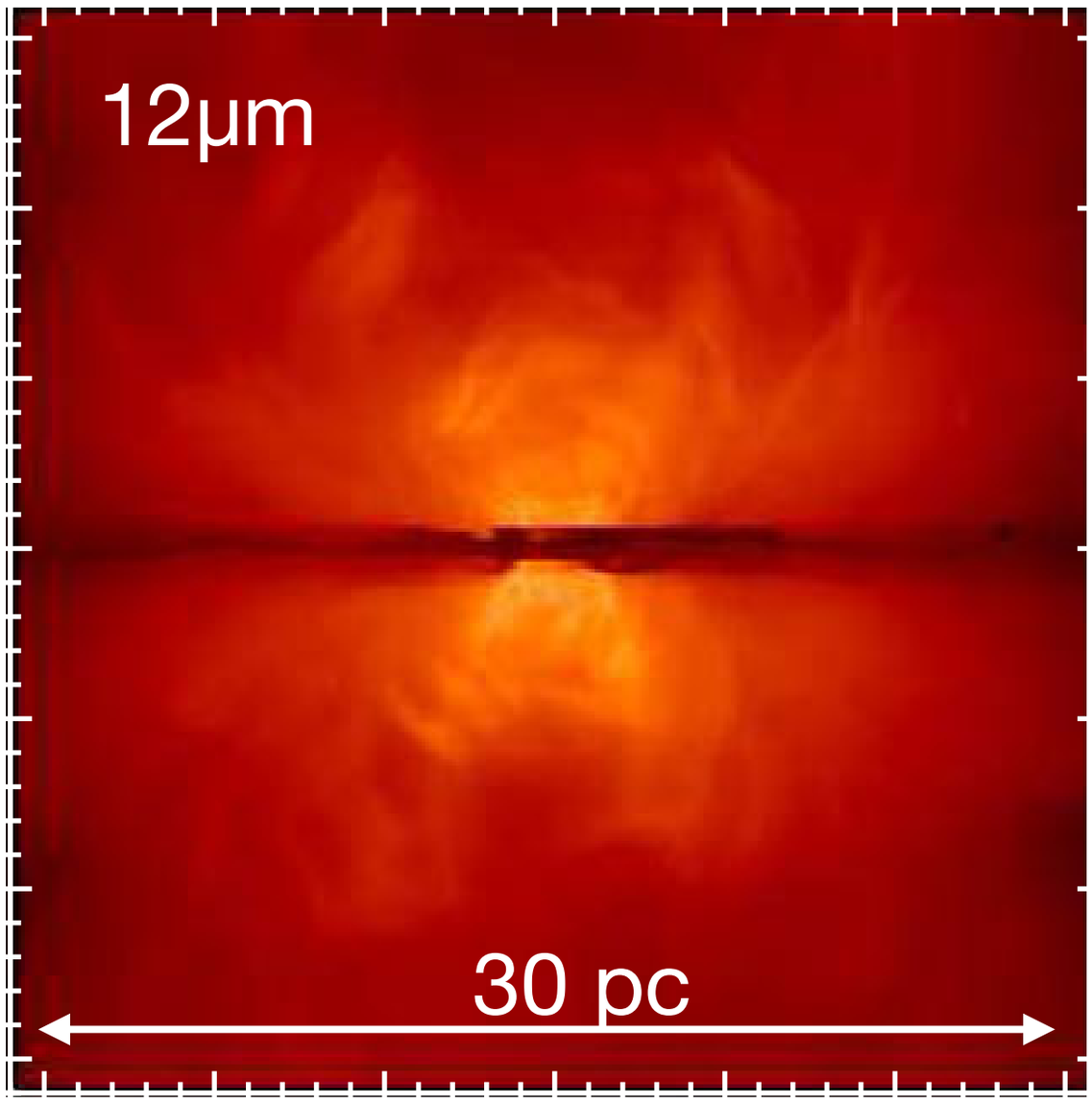


- Polar elongation in MIR continuum of the Circinus galaxy!?
- Statistical confirmation (e.g., Lopez-Gonzaga et al. 2016)

Multi-phase Dynamic Torus model



Fountain scheme + Dust rad. transfer

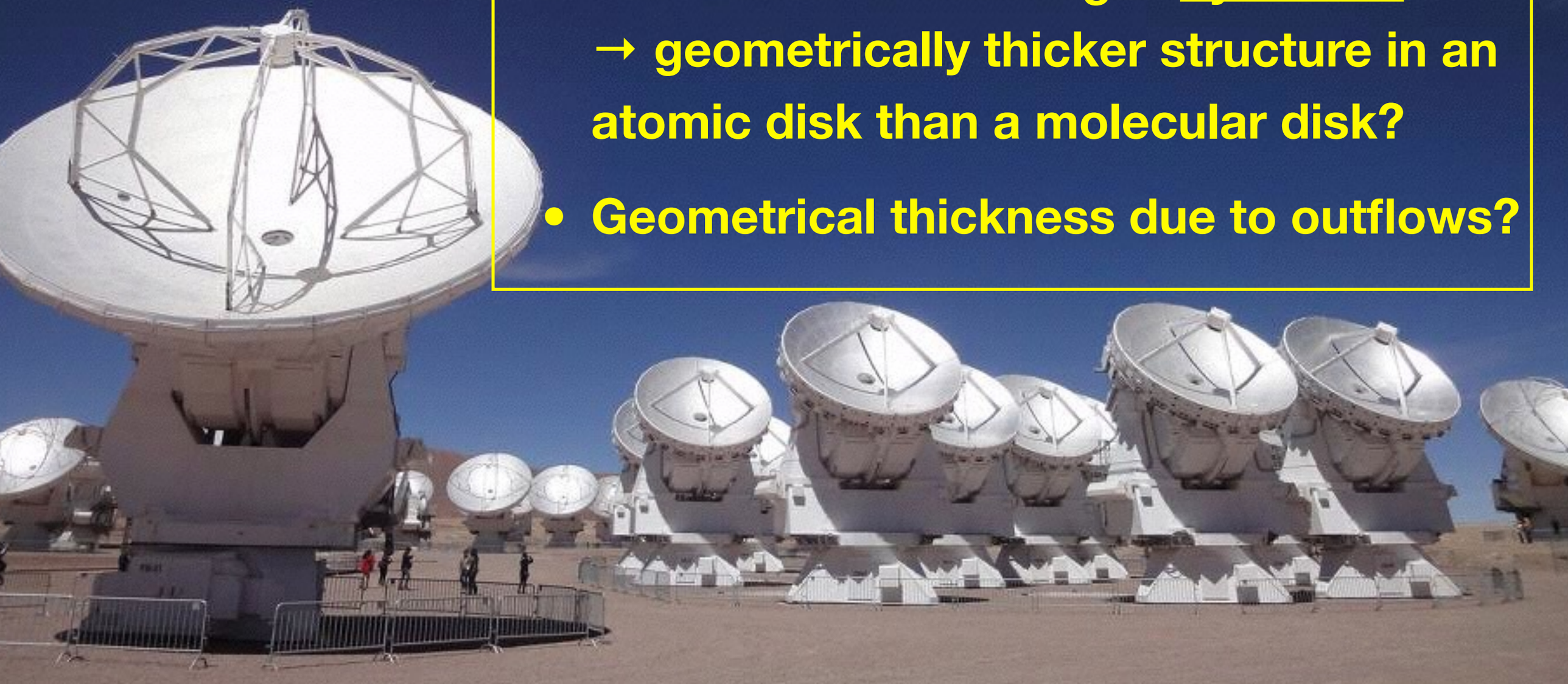


Schartmann et al. 2014,
MNRAS, 445, 3878

- Indeed, MIR polar elongation was reproduced
- IR SED is well-explained, too.
- Consistent with observations (morphological/photometric manner)

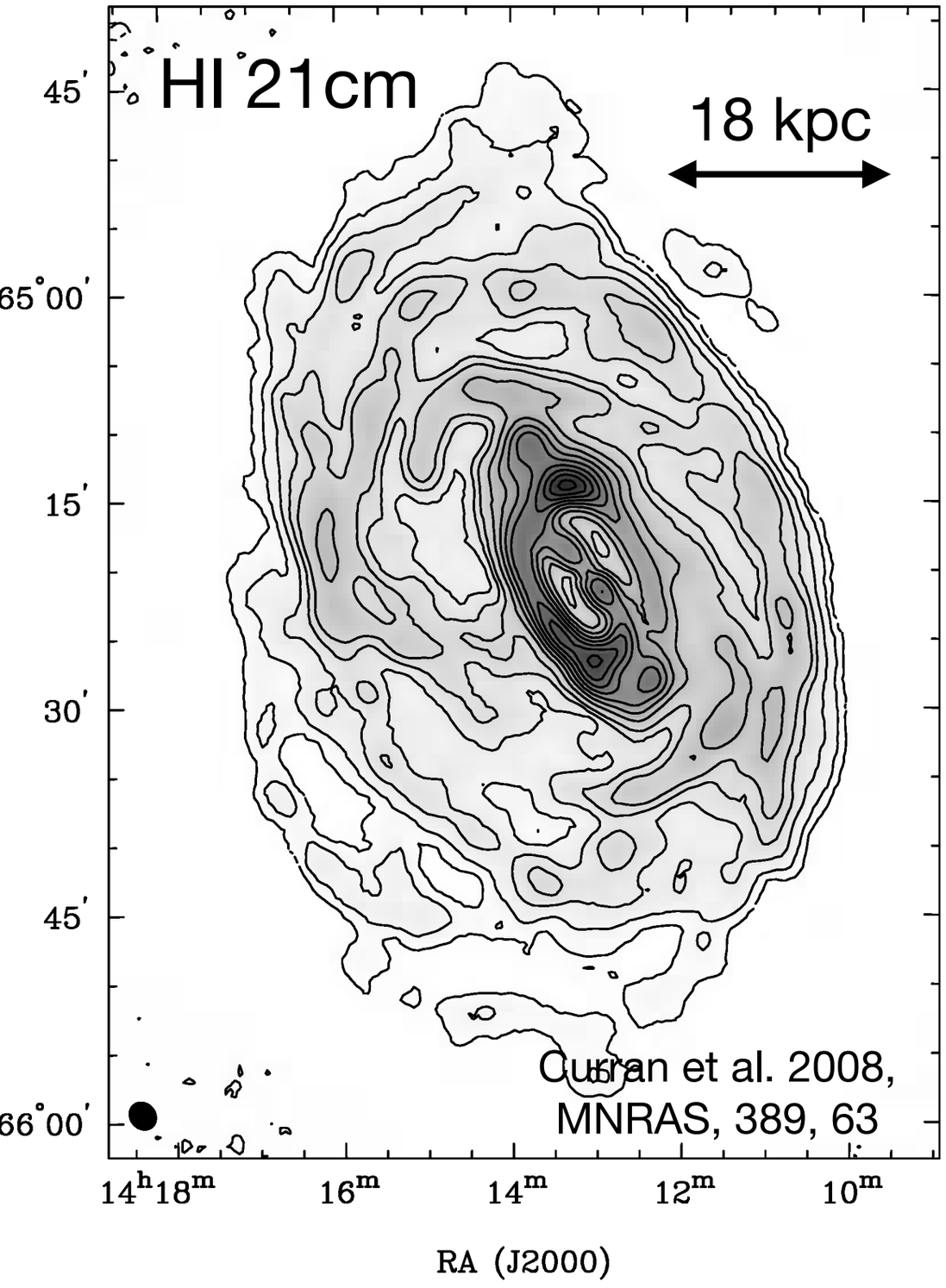
Out Study: Multi-phase circumnuclear obscuring structures studied with ALMA

- **Atomic vs molecular gas dynamics?**
  → geometrically thicker structure in an atomic disk than a molecular disk?
- **Geometrical thickness due to outflows?**



ALMA Cycle 4 Observations (Band 7 + 8)

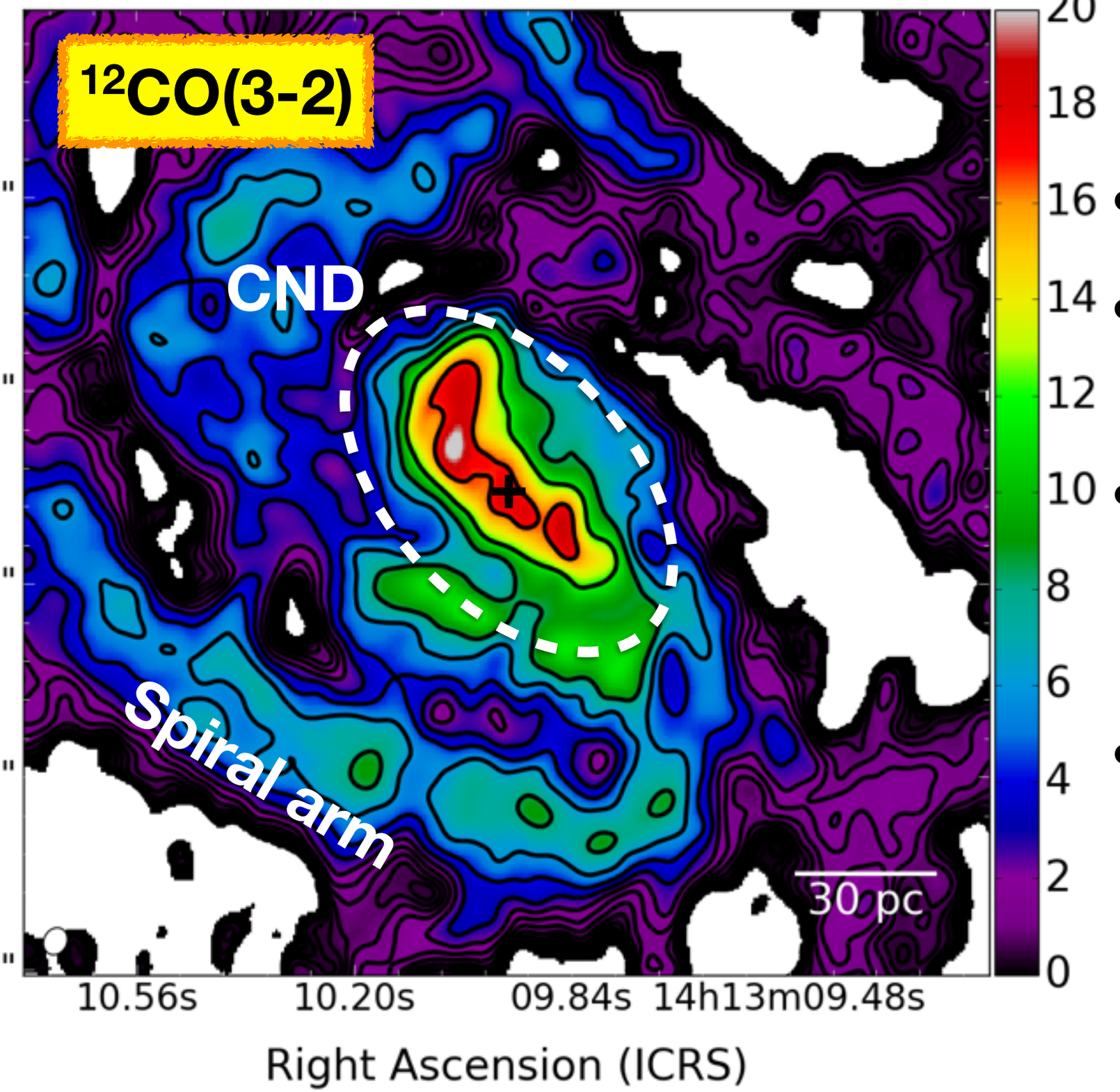
The Circinus Galaxy (4.2 Mpc)



- Compton-thick AGN (Arevalo+2014)
  - N_H ~(6-10) × 10^{24} cm^{-2}
  - $L_{2\text{-}10keV}$ ~ (2-5) × 10^{42} erg/s
- Low SFR (i.e., weak SN-feedback)
  → **Test the fountain scheme**
- High resolution **CO(3-2)** + **[CI](1-0)** in ALMA Cycle 4 (PI: T.Izumi)
  → molecular + atomic structures and their dynamical differences
- θ ~ 5 pc (CO) & ~15 pc (CI)

Molecular & Atomic gas distributions

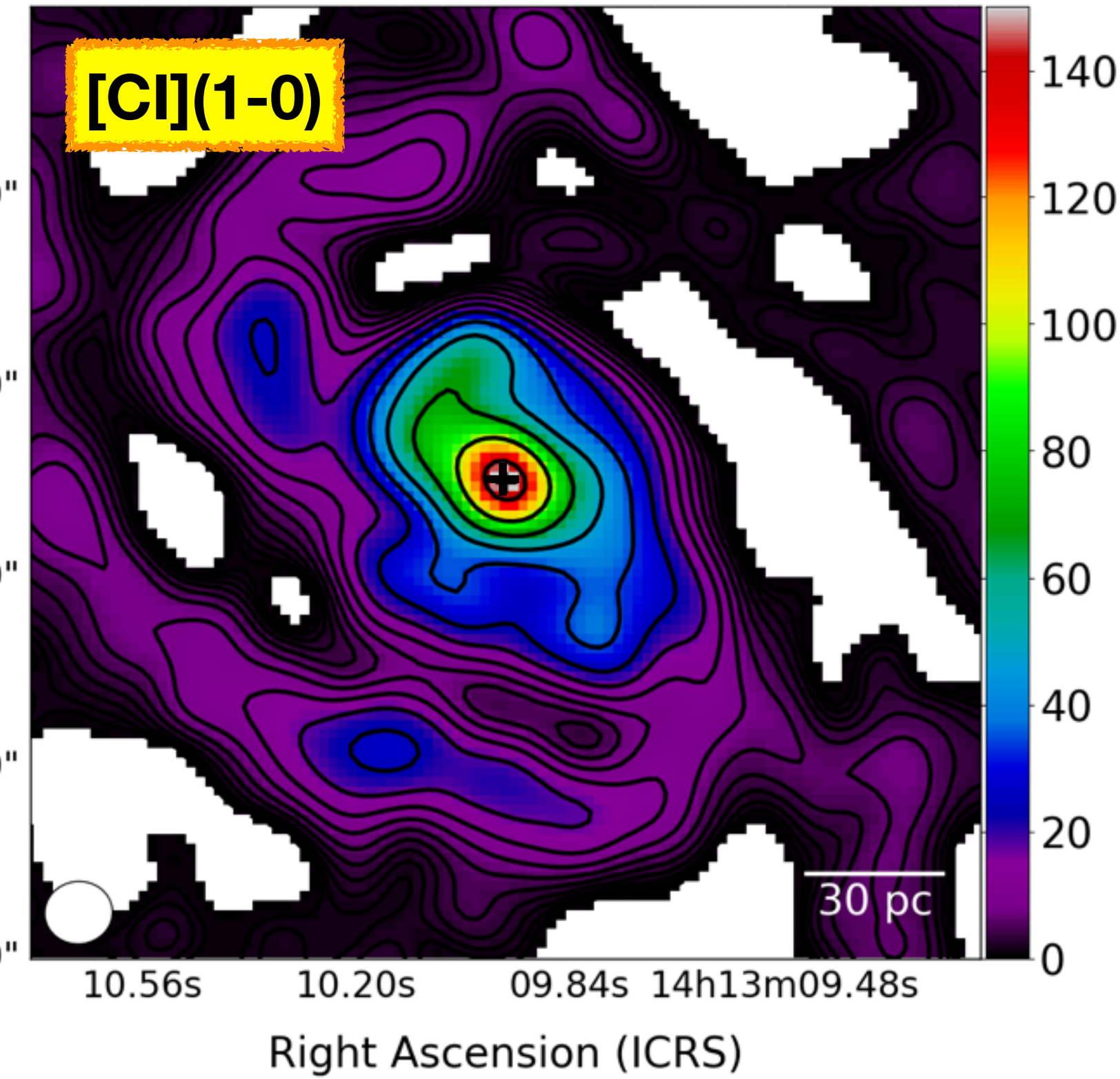
Izumi et al. 2018c, to be submitted



- CND (D ~70 pc) + Spirals
- **M_{H2} ~ 3×10^6 M_{sun} (CND)**
  - c.f., M_{BH} ~ 2×10^6 M_{sun}
- **N_{H2} ~ 5×10^{23} cm^{-2} (AGN)**
  - *beam-averaged*
  - N_H (Xray) ~ 6×10^{24} cm^{-2}
- **CND will be a significant nuclear obscurer!**

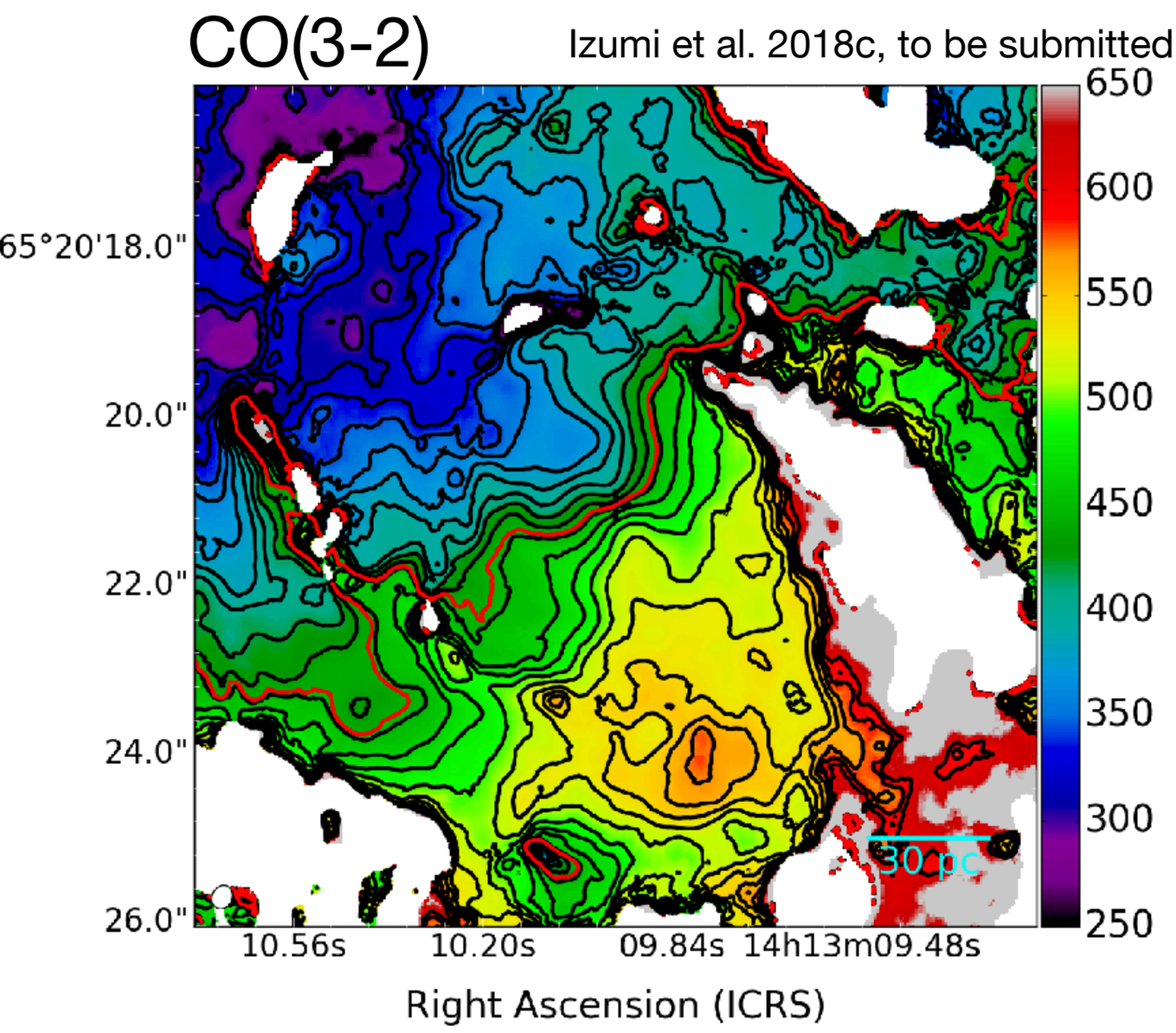
Molecular & Atomic gas distributions

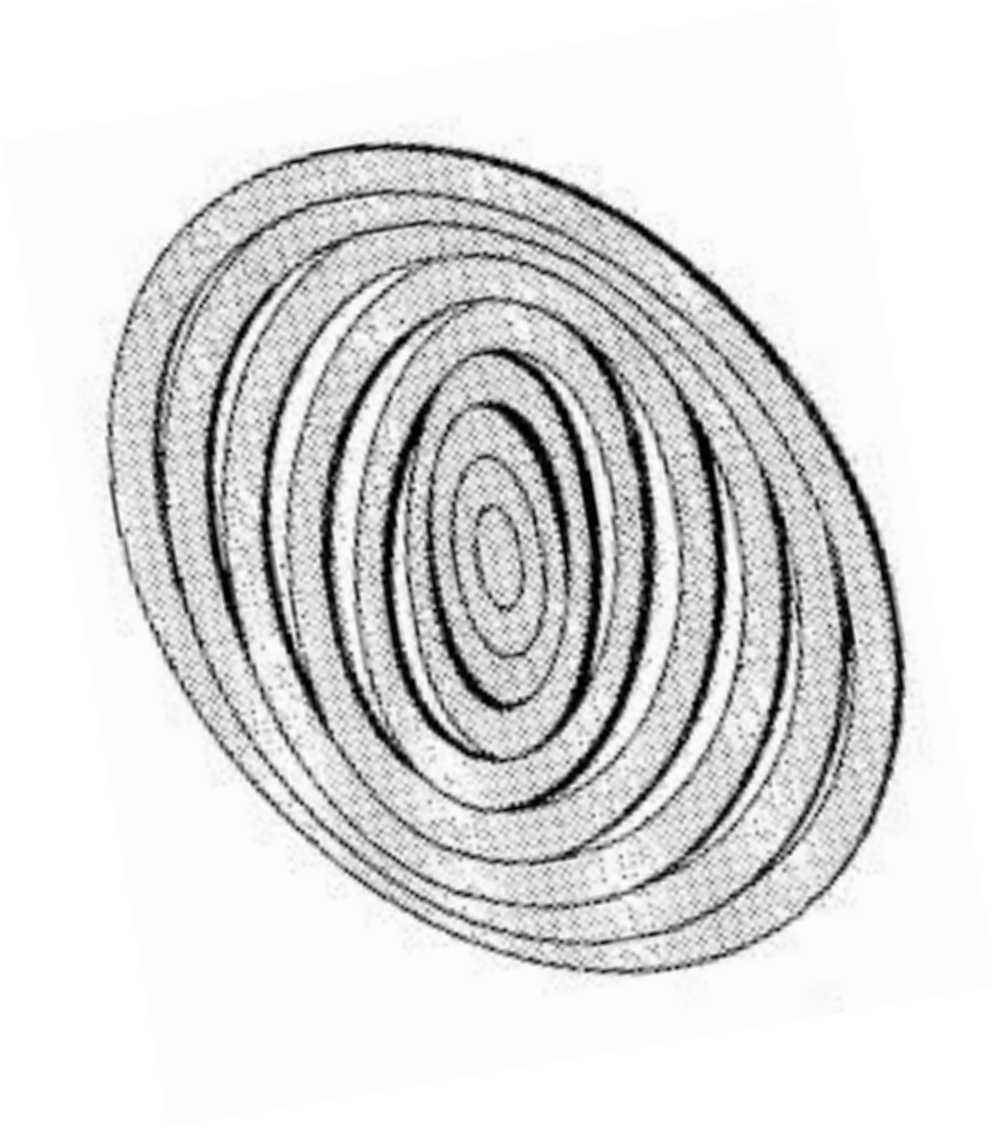
Izumi et al. 2018c, to be submitted



- *Similar 2D distribution* to the CO(3-2)
- Tracing the same volume???
- But we don't know <u>3D structures!</u>

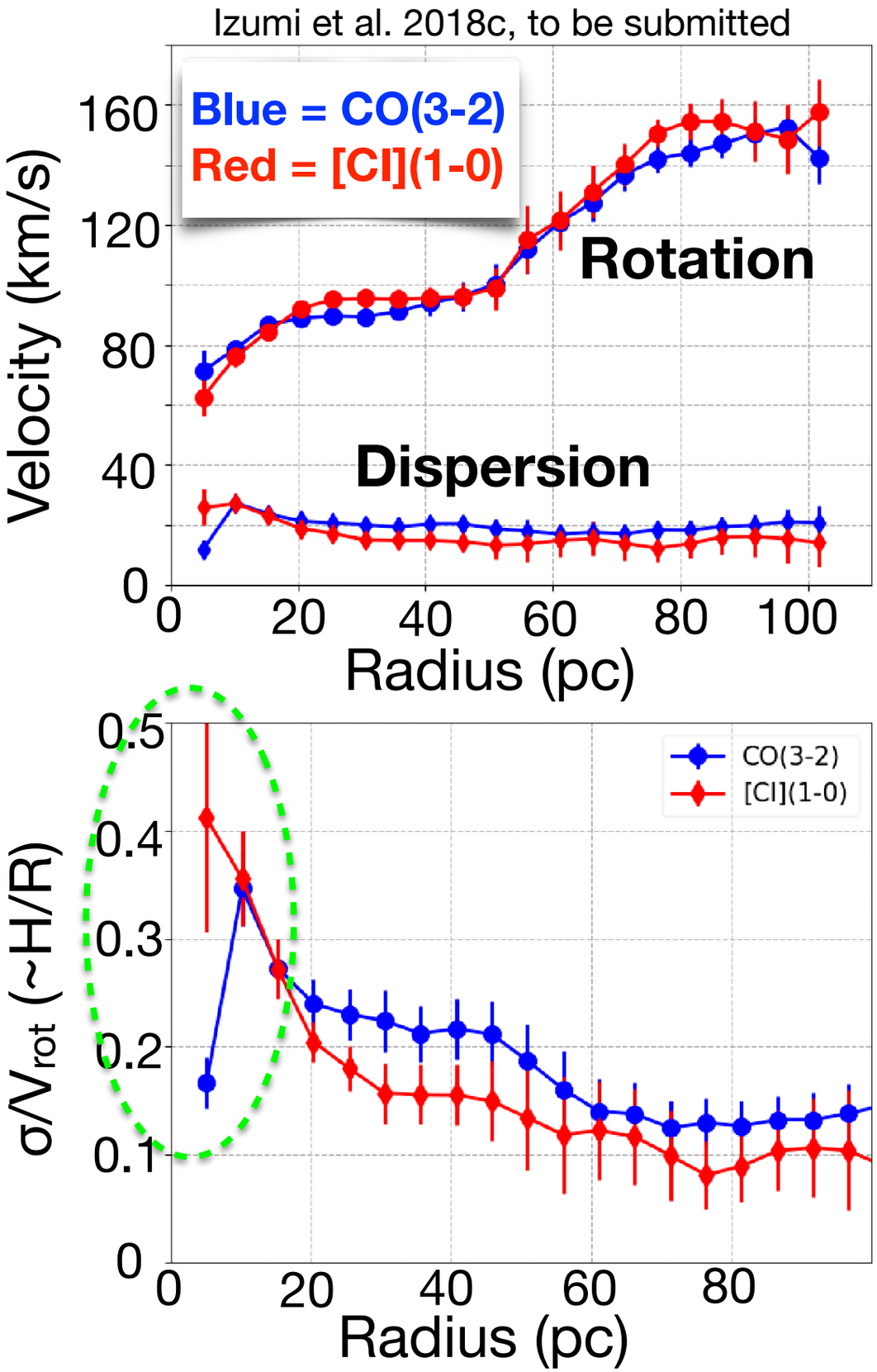
Decomposition of Cold Gas Dynamics

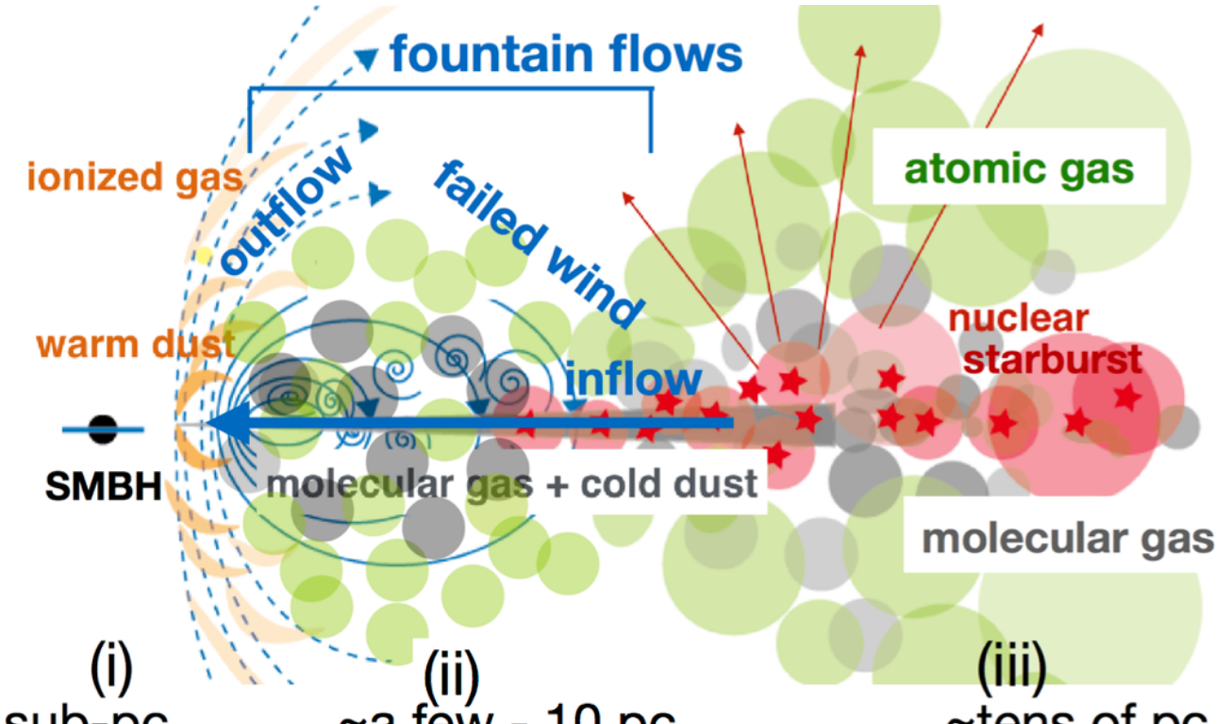




- Global motion is dominated by rotation
- We decomposed the dynamics with tilted-ring models
  - V_{rot}, σ, inclination, P.A.

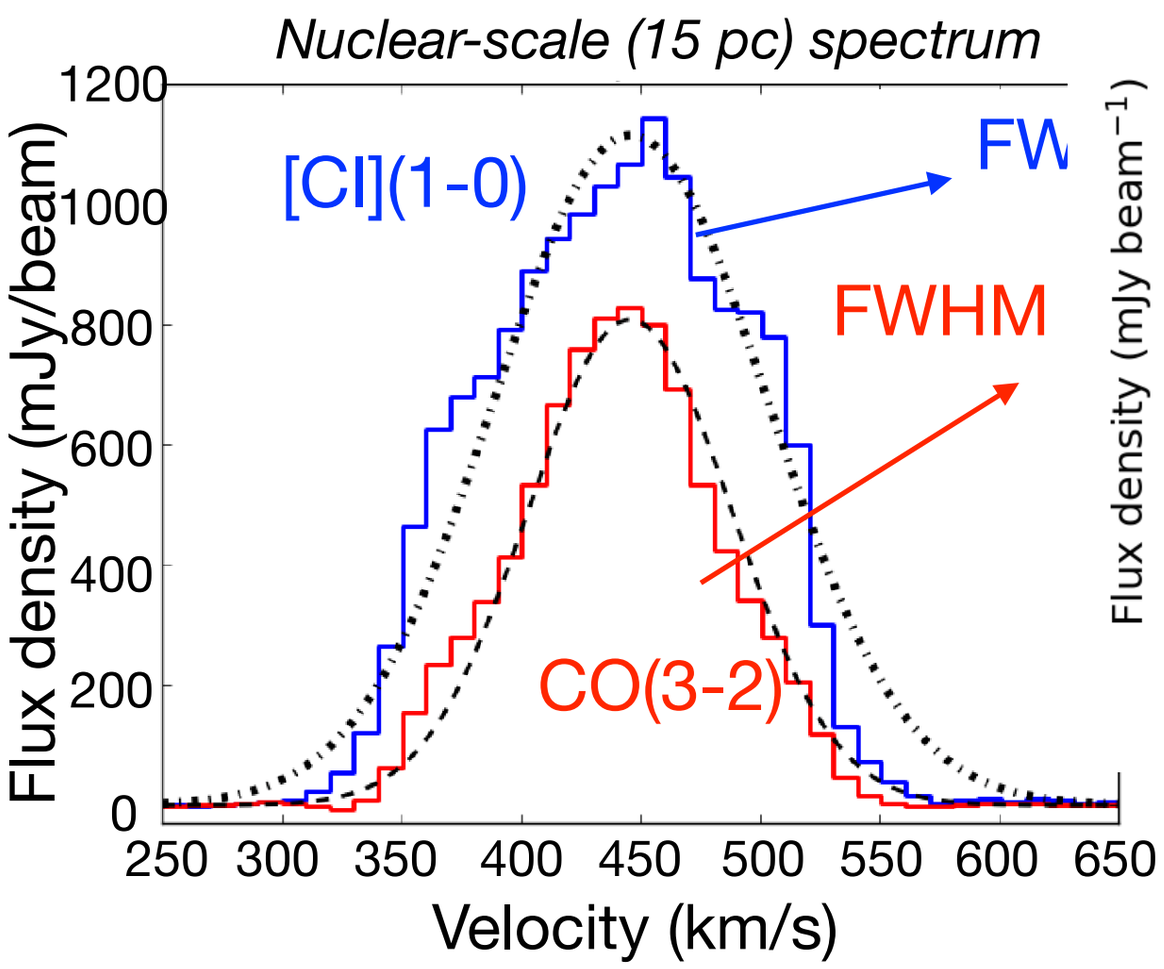
CI vs CO: Multi-phase Torus Dynamics

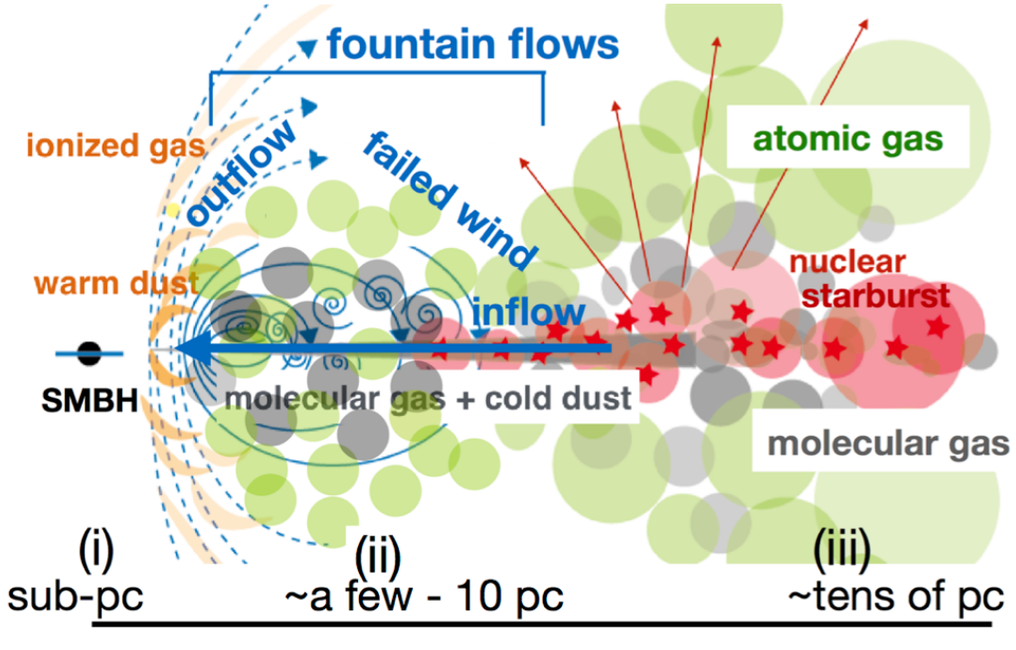


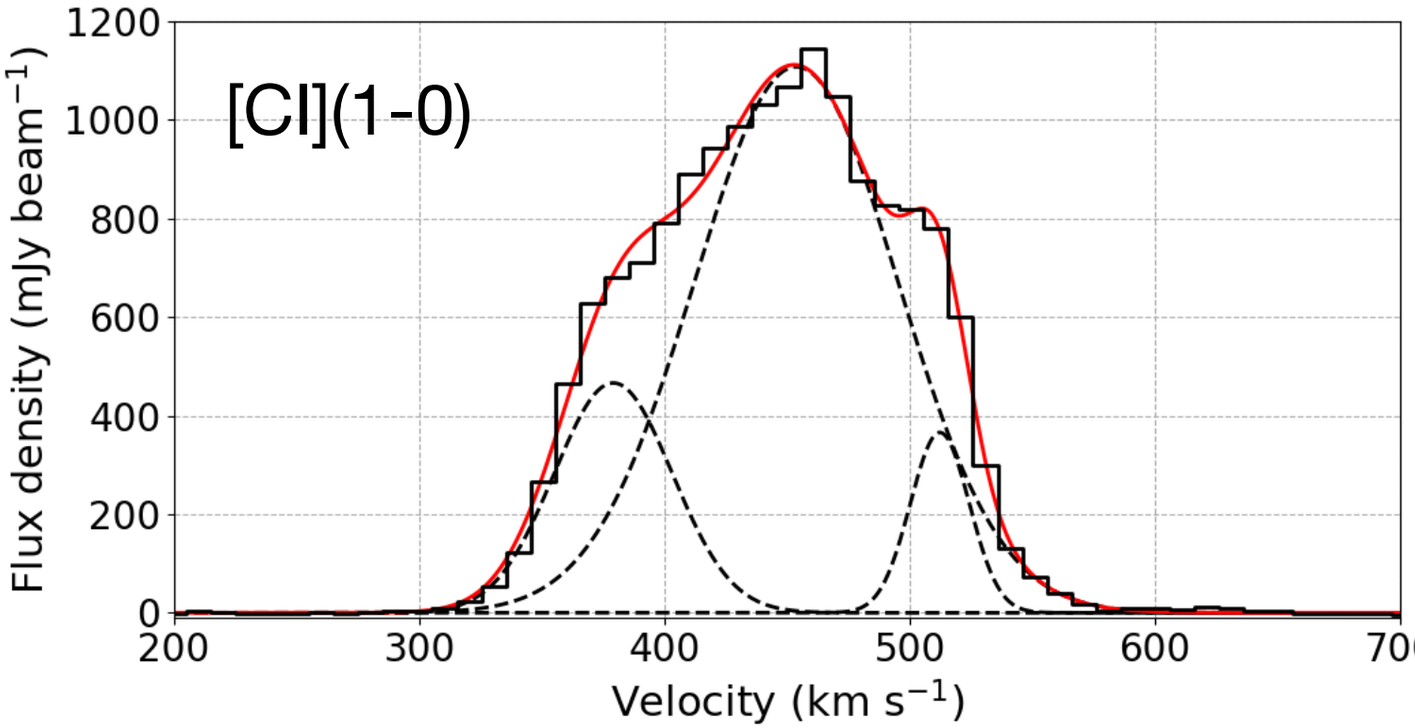


- Geometrically thin mol. & atomic disks at r > 20 pc (c.f., low-SFR in Circinus)
- **Geometrically thicker atomic disk than the dense mol. disk at r < 10 pc!**
  → Multi-phase geometrical structures!

Then, what makes the geometrical thickness?



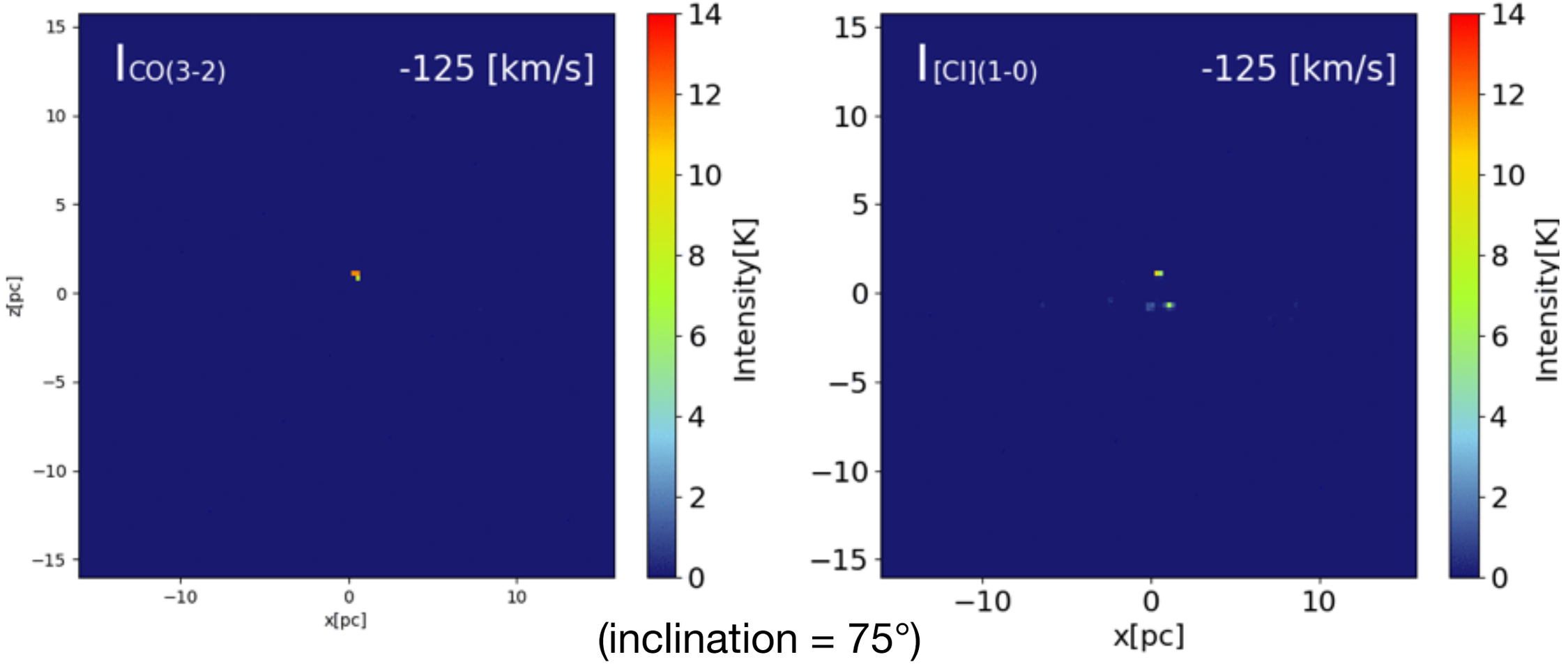




- Nuclear [CI](1-0) spectrum shows a larger FWHM than CO(3-2).
- Multi-Gaussians yielded a better fit
  → Almost symmetric emergence of the additional blue- and red-components
- **Coherent motion like outflows??**
  - consistent with the fountain model
  - will fall back to the disk (failed wind)

Quantitative comparison with our model

CO(3-2): T_B [CI](1-0): T_B



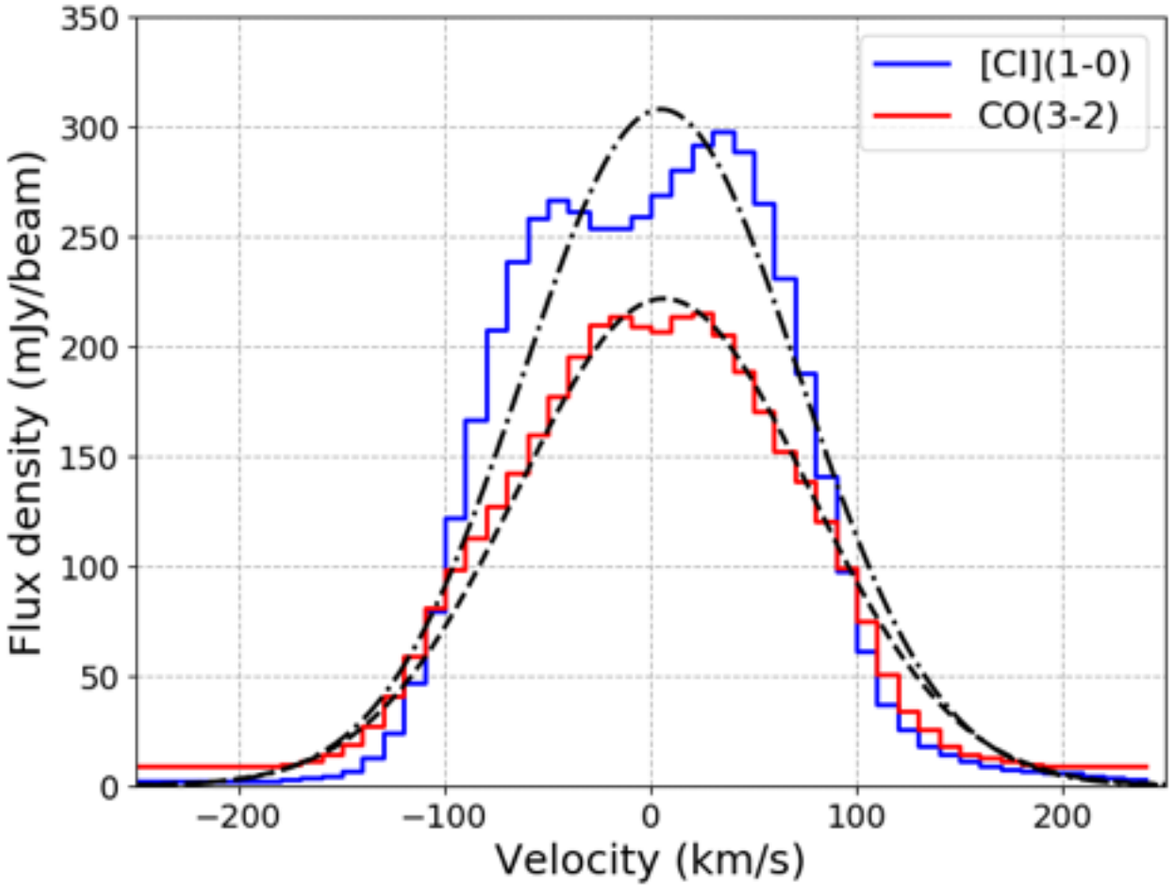
(inclination = 75°)

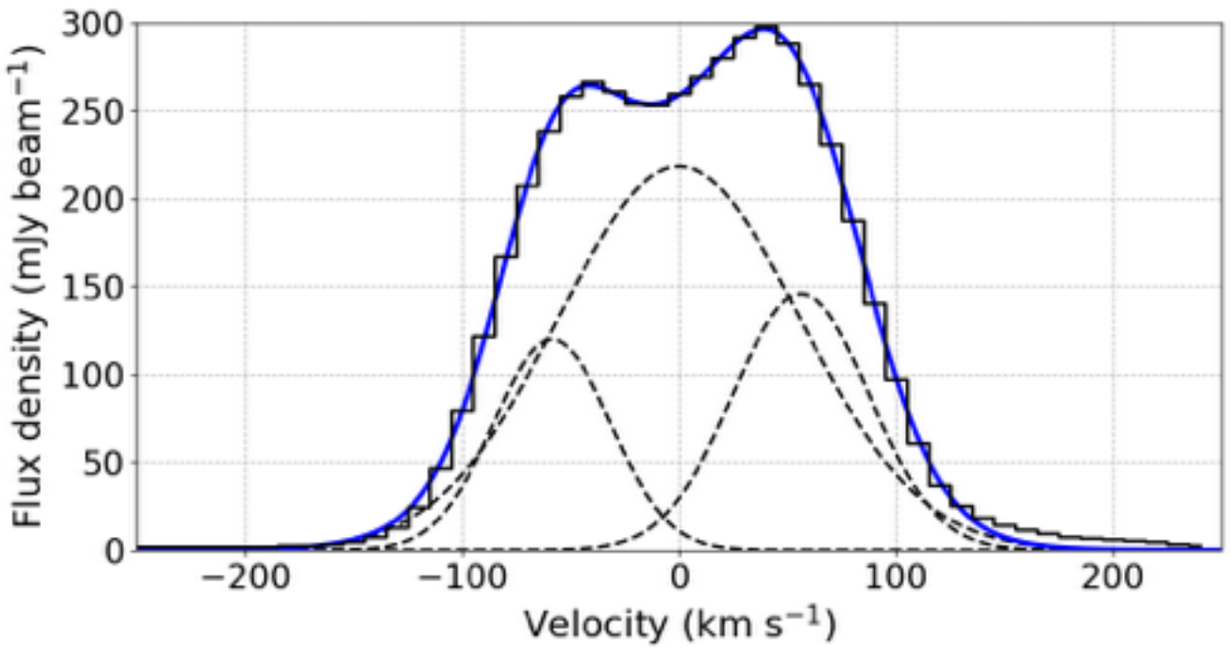
Izumi et al. 2018c, to be submitted

- M_{BH}, Eddington ratio, CND-scale M_{gas}: Circinus-like values
- **Hydrodynamic simulation + XDR chemistry (Wada+16) + rad. transfer**
- CO(3-2) → mid-plane of the CND/torus
- [CI](1-0) → mid-plane + **puffed-up component due to outflows**

Quantitative comparison with our model

Izumi et al. 2018c, to be submitted





- Indeed, we found different line profiles for the simulated CO(3-2) and [CI](1-0)
- *Triple-Gaussians* can well fit the profile → outflow components stand out
- Good consistency between ALMA obs. and our simulation
  → Support the fountain scheme, where atomic outflows play the key role in determining the “torus” geometry.

Summary

- Now we are testing the multi-phase dynamic torus model with ALMA: ~5-15 pc resolution CO(3-2) and [CI](1-0) data are in hand.
- Gas (and dust) distributions = CND/torus + spiral arms.
- The CND can provide a significant nuclear obscuration (as a torus).
- CI (atom) gas is in a geometrically thicker volume than the CO (molecule) gas at r < 10 pc.
  → multi-phase gas dynamics in the torus!
- The thickness of the atomic disk would be due to nuclear atomic outflows, as expected in our fountain model
  → **Physical origin of the torus!?**