Nov 27, 2017
East-Asia ALMA Science Workshop 2017 @KASI/Korea

On the disappearance of a cold molecular torus around the low-luminosity active galactic nucleus of NGC 1097

→ T.Izumi et al. 2017, ApJL, 845, L5

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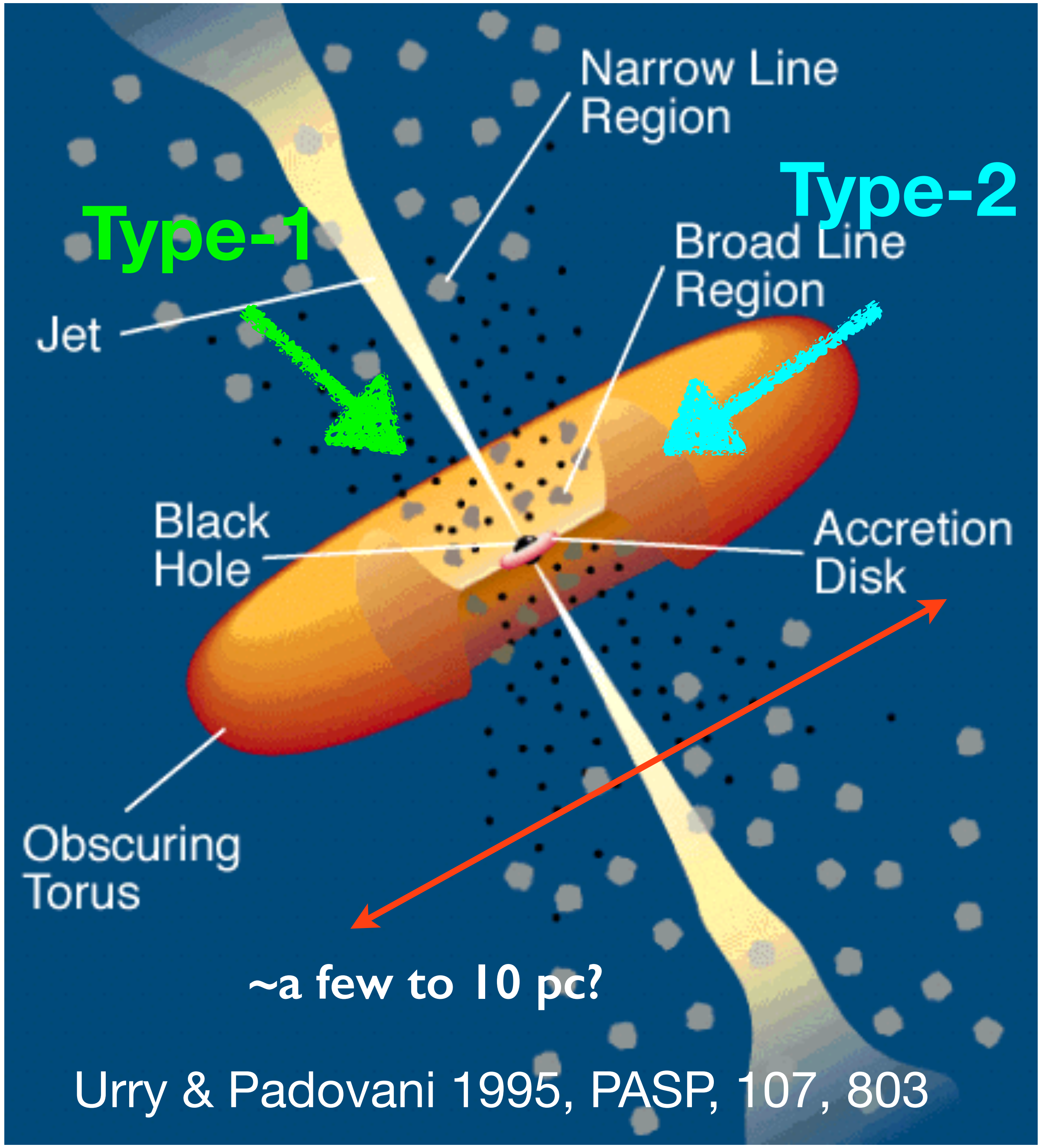
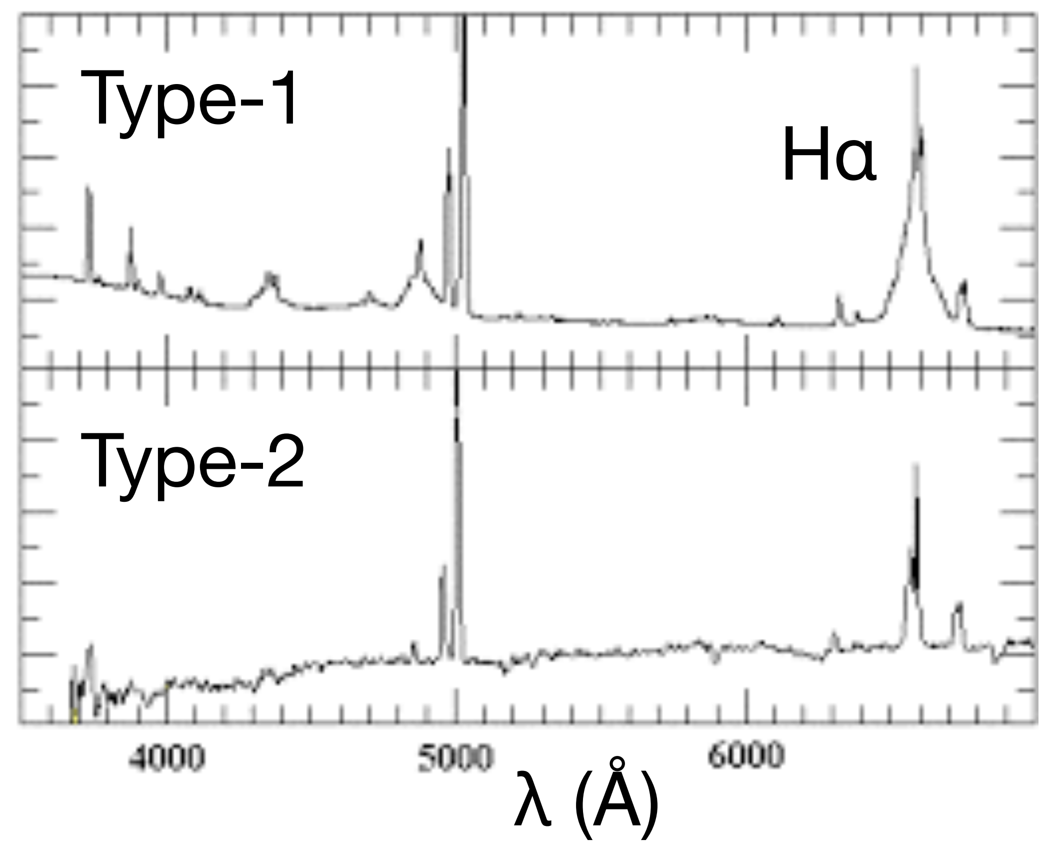
SMBH obscuration: Torus



(Strict-) Unified scheme

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

- **Type-1 : 2 = 1 : 4**
  (e.g., Maiolino & Rieke 1995, ApJ, 454, 94)



Origin (or nature) of the torus has been poorly understood!!

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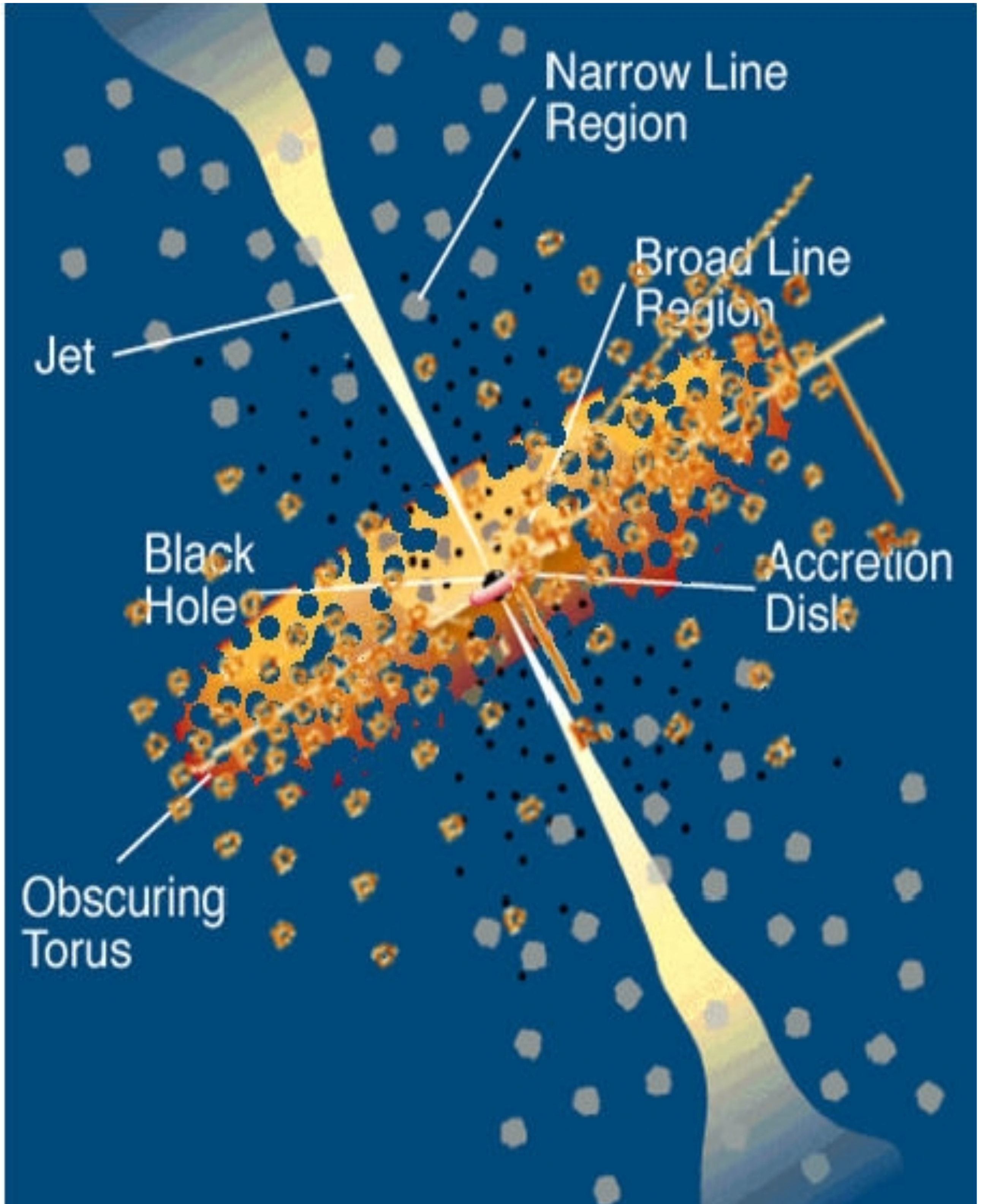

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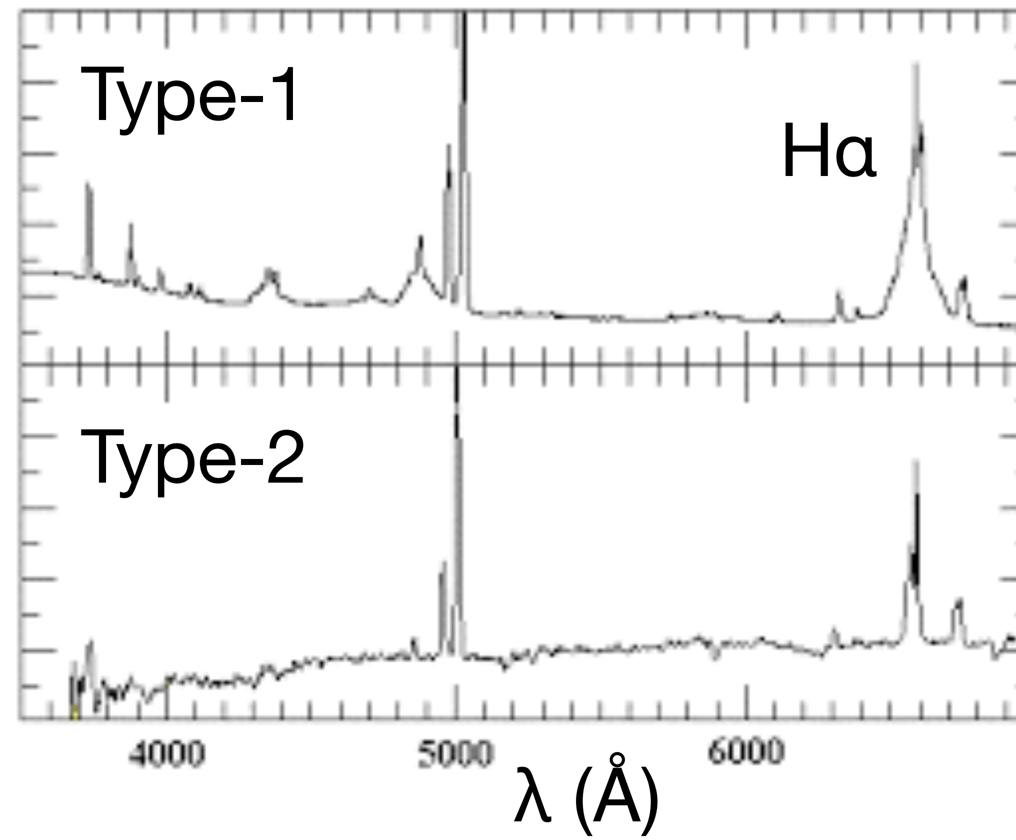


Origin (or nature) of the torus has been poorly understood!!

Several scenarios for the origin

Accretion disk scale

- Disk winds
  (Elitzur & Shlosman 2006; Nomura et al. 2016)

Circumnuclear disk scale (~10-100 pc) → **ALMA**

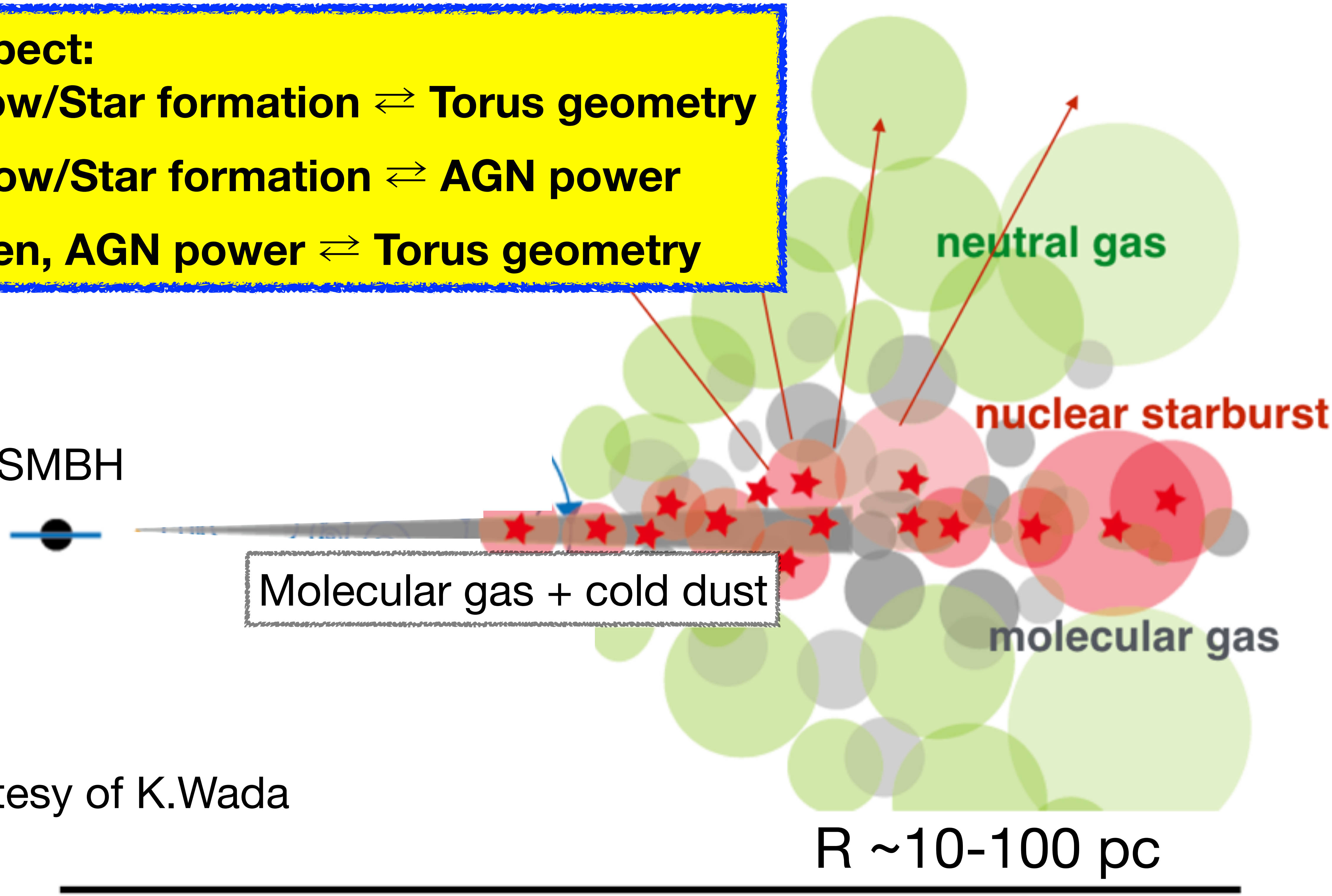
- Energy release from massive inflows (Vollmer et al. 2008)
- Starburst/Supernova feedback (Wada & Norman 2002; Wada 2009)
- Radiation-driven fountain (Wada 2012, 2015)

Host galaxy scale

- (Cold gas/dust in galaxy disks)

CND-scale obscuration: evolutionary?

We expect:
(i) Inflow/Star formation ⇄ Torus geometry
(ii) Inflow/Star formation ⇄ AGN power
(iii) Then, AGN power ⇄ Torus geometry



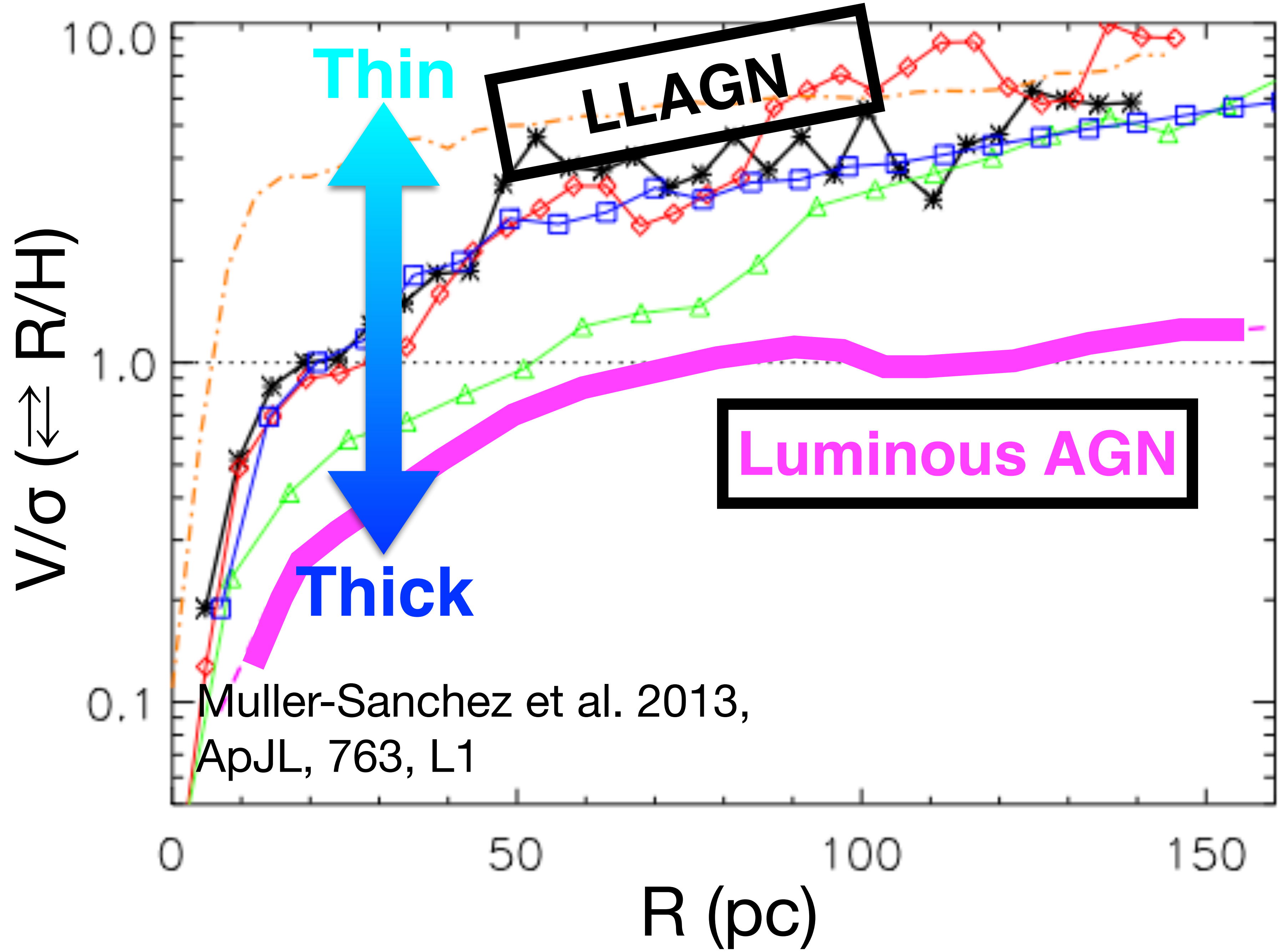
Courtesy of K.Wada

E.g., Wada & Norman 2002, Elitzur & Shlosman 2006, Vollmer et al. 2008, Wada 2012

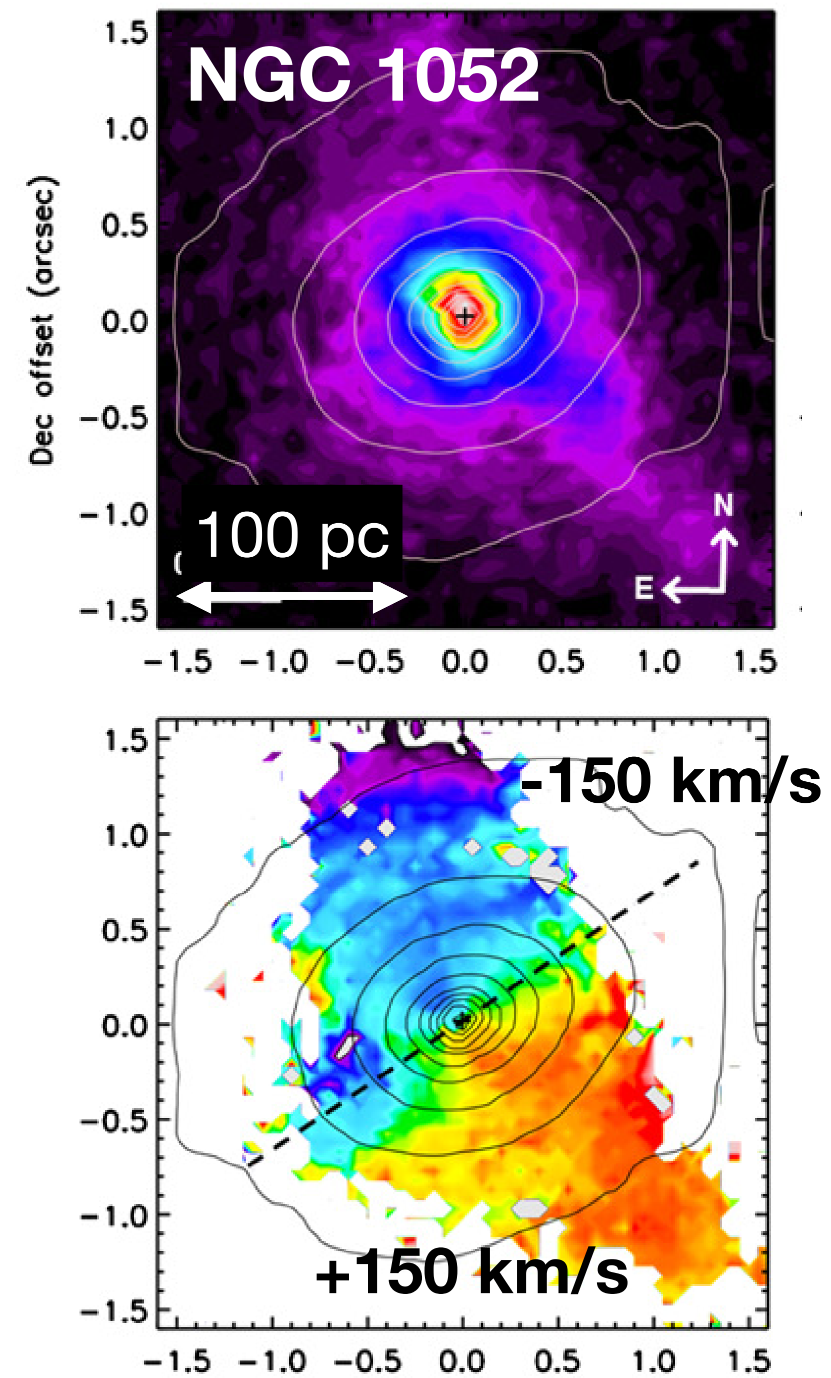
Disappearance of tori in LLAGNs?

Low-luminosity AGN (L_{Bol} < 1e42 erg/s) ⇄ Geometrically thin torus

VLT/SINFONI 2.12 μm H_2 (warm gas)



Muller-Sanchez et al. 2013, ApJL, 763, L1



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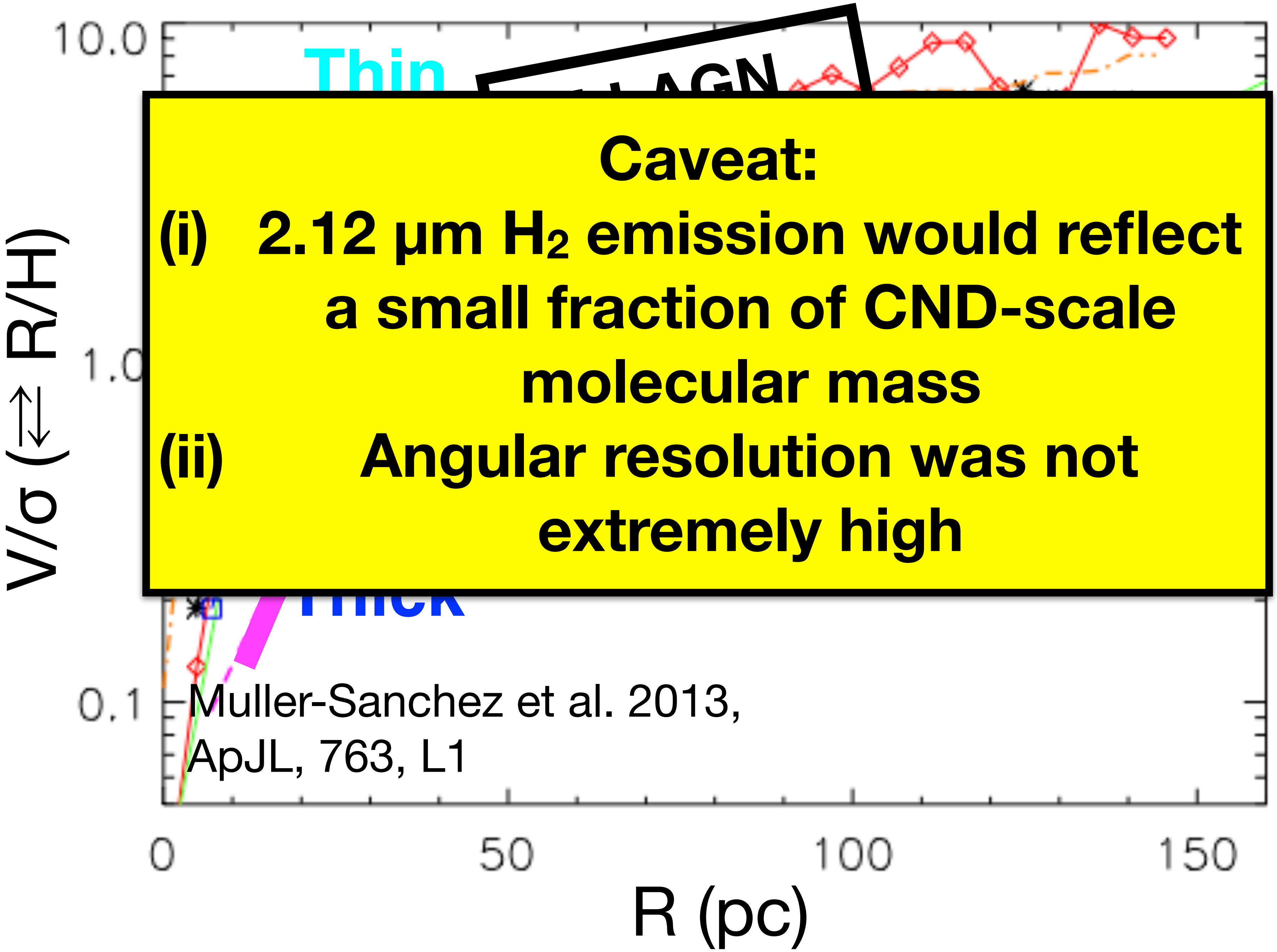
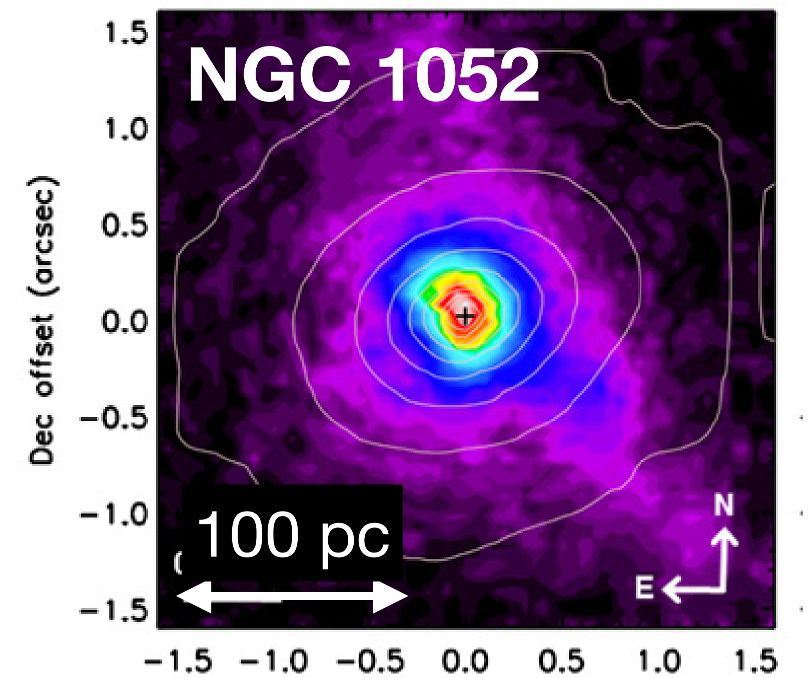
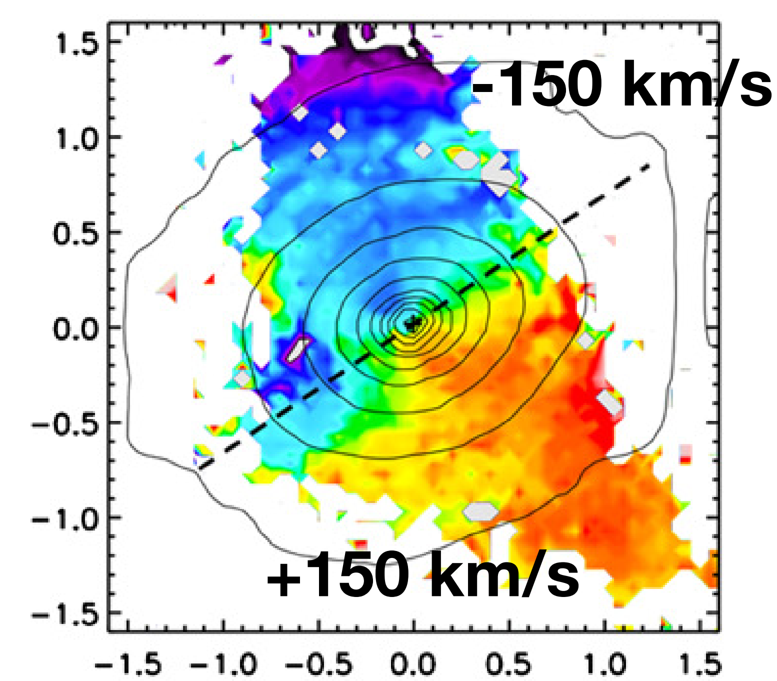


Caveat:

(i) 2.12 μm H_2 emission would reflect a small fraction of CND-scale molecular mass

(ii) Angular resolution was not extremely high

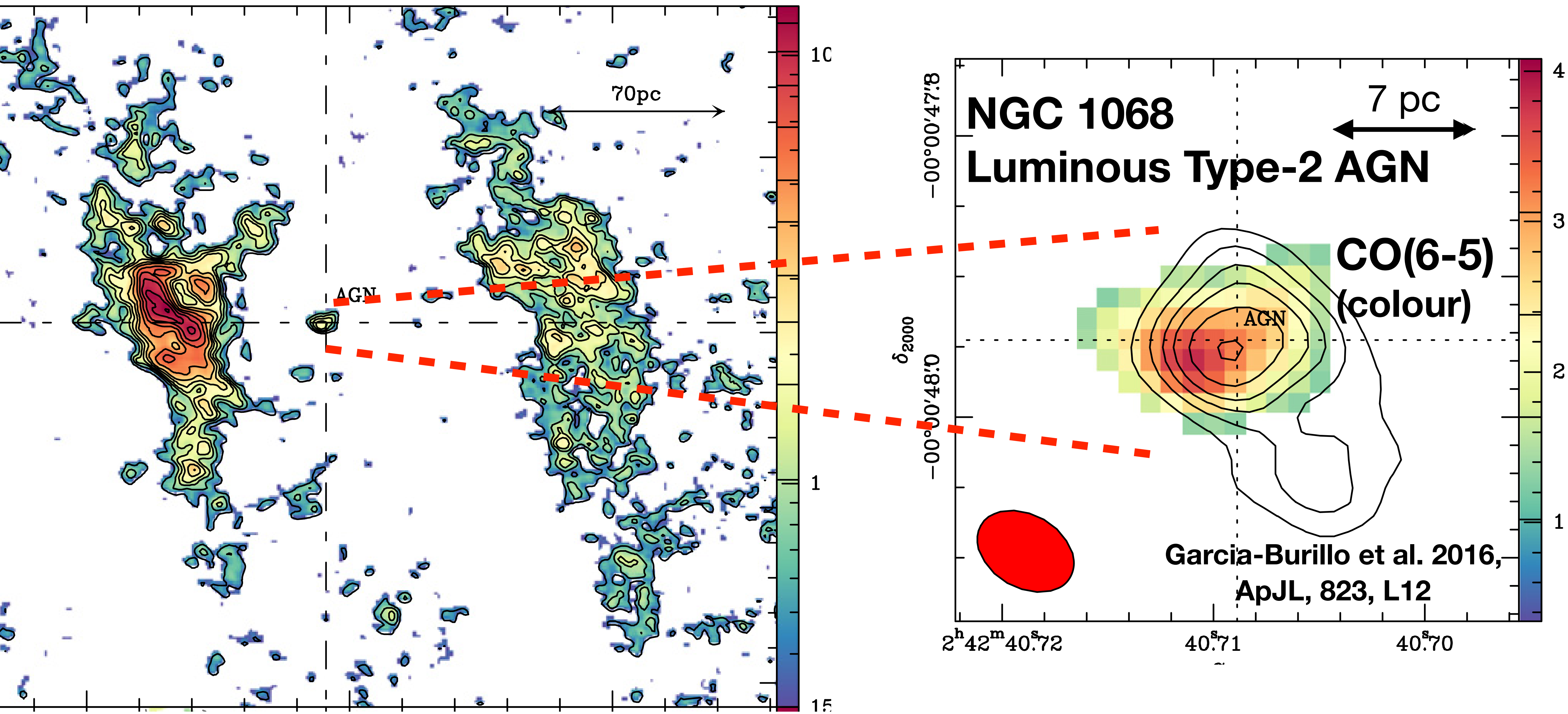




ALMA, for this study

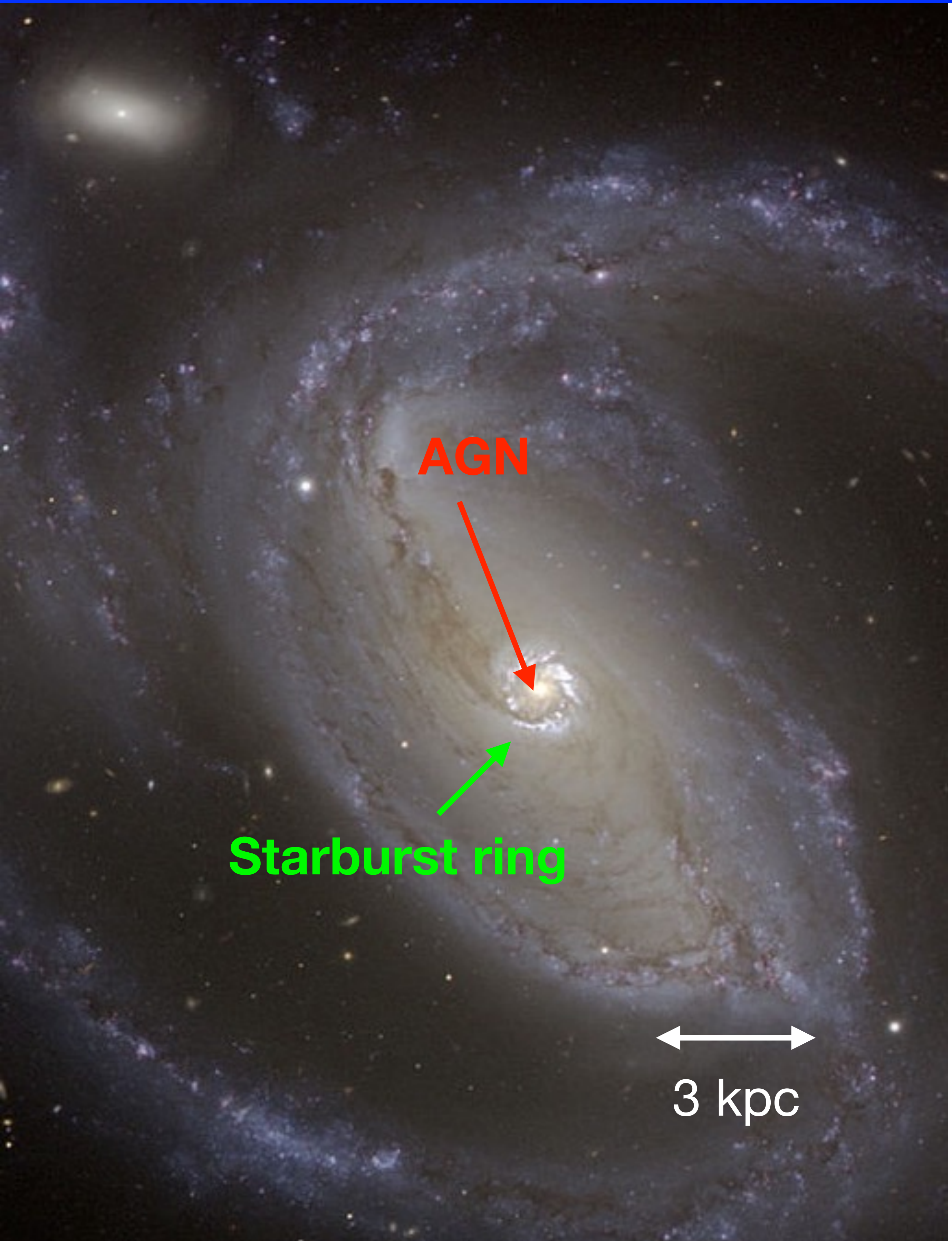
- <u>Cold molecular gas</u>
  - reflects bulk of CND-scale gas mass
  - suitable to probe connections with, e.g., star formation
- <u>High angular resolution and sensitivity</u>
  - torus: ~ 10 pc structure (<~ 0.1”)
  (- now θ is even higher than the VLT observations)
- <u>Quite high *spectral* resolution</u> → essential for dynamical modelings

CO torus of NGC 1068 (L_{Bol} ~ 7e44 erg/s)



- Nearby <u>luminous</u> type-2 AGN
- Clear concentration of the CO(6-5) emission at the center → <u>**Torus**</u> → **M_{gas} ~ 1e5 M_{sun}**; **σ/V_{rot} > 1** (i.e., <u>**H/R > 1 = geometrically thick**</u>)

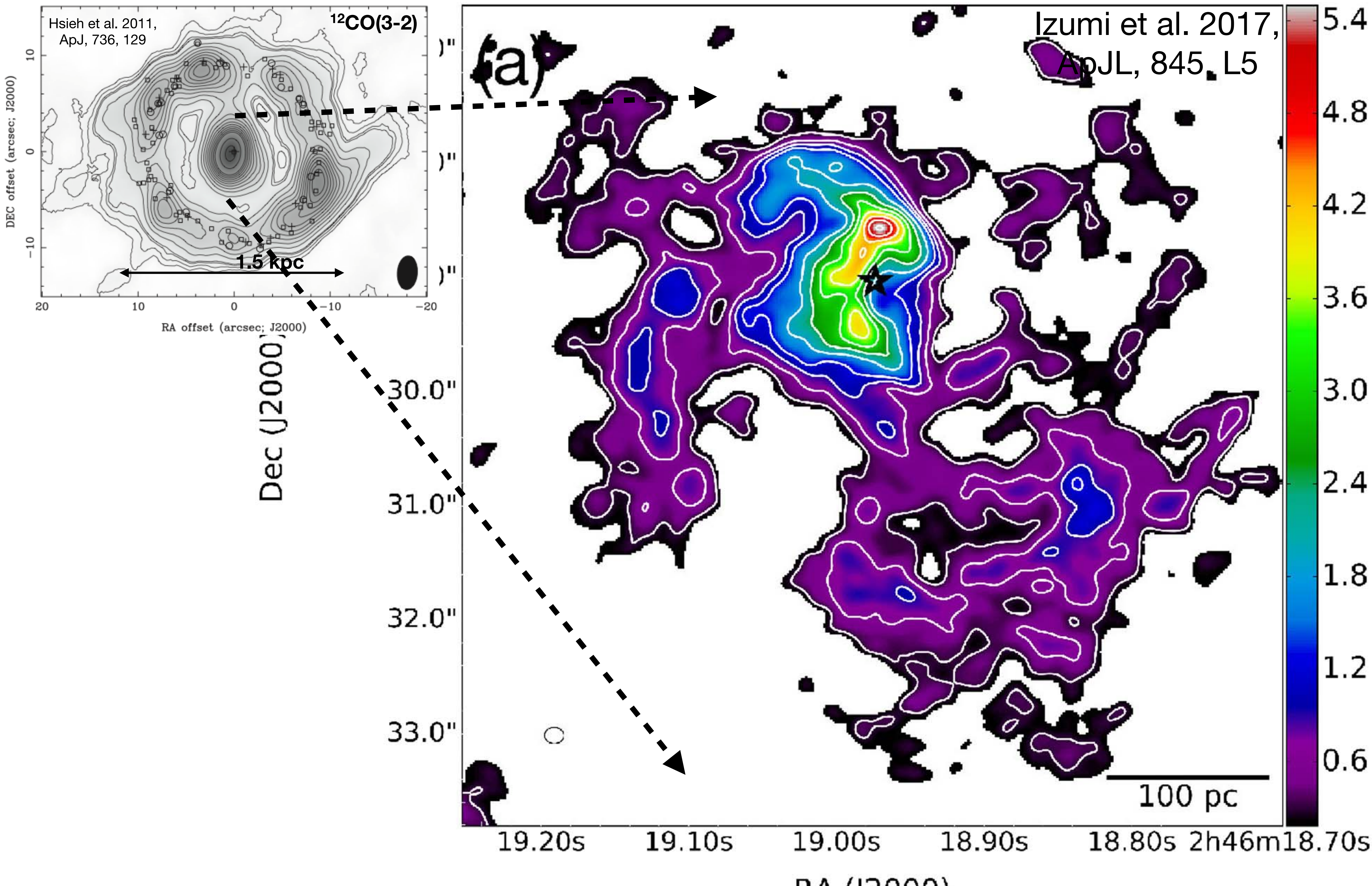
This study: LLAGN NGC 1097 (L_{Bol} ~ 8e41 erg/s)



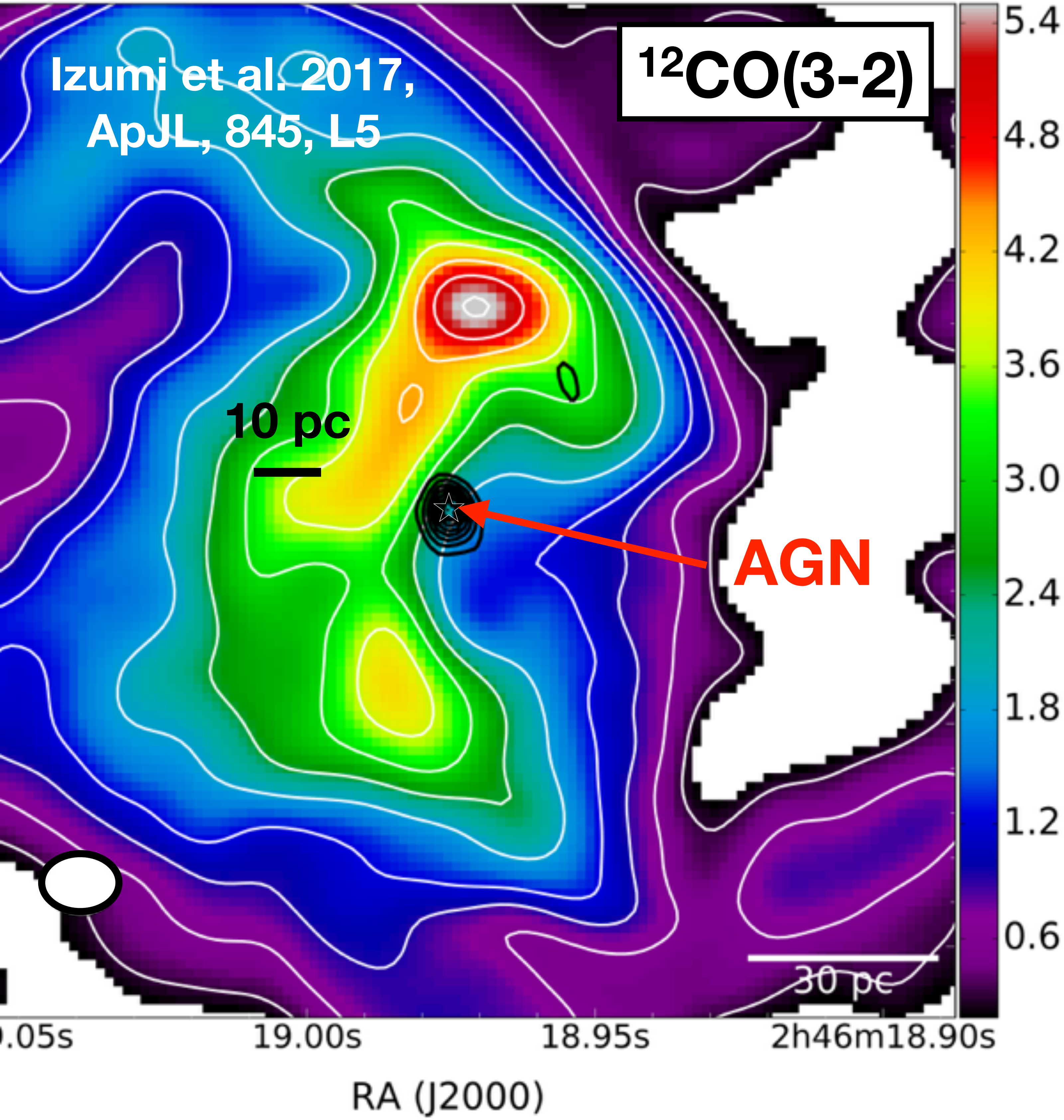
- Low-luminosity AGN (LLAGN)
  - L_{Bol} = 8e41 erg/s
  (= 1/875 of NGC 1068)
- D = 14.5 Mpc (1" = 70 pc)
- Extensively studied at mm/submm
  (e.g., Izumi et al. 2013)
- ALMA Band 7 study in Cycle 1+3
  - ^{12}CO(3-2) + 860 μm continuum

	Resolution	Sensitivity
860μm cont.	0.11" x 0.08"	~50 μJy/b
^{12}CO(3-2)	0.17" x 0.11"	0.84 mJy/b (dV=10 km/s)

Circumnuclear disk of NGC 1097



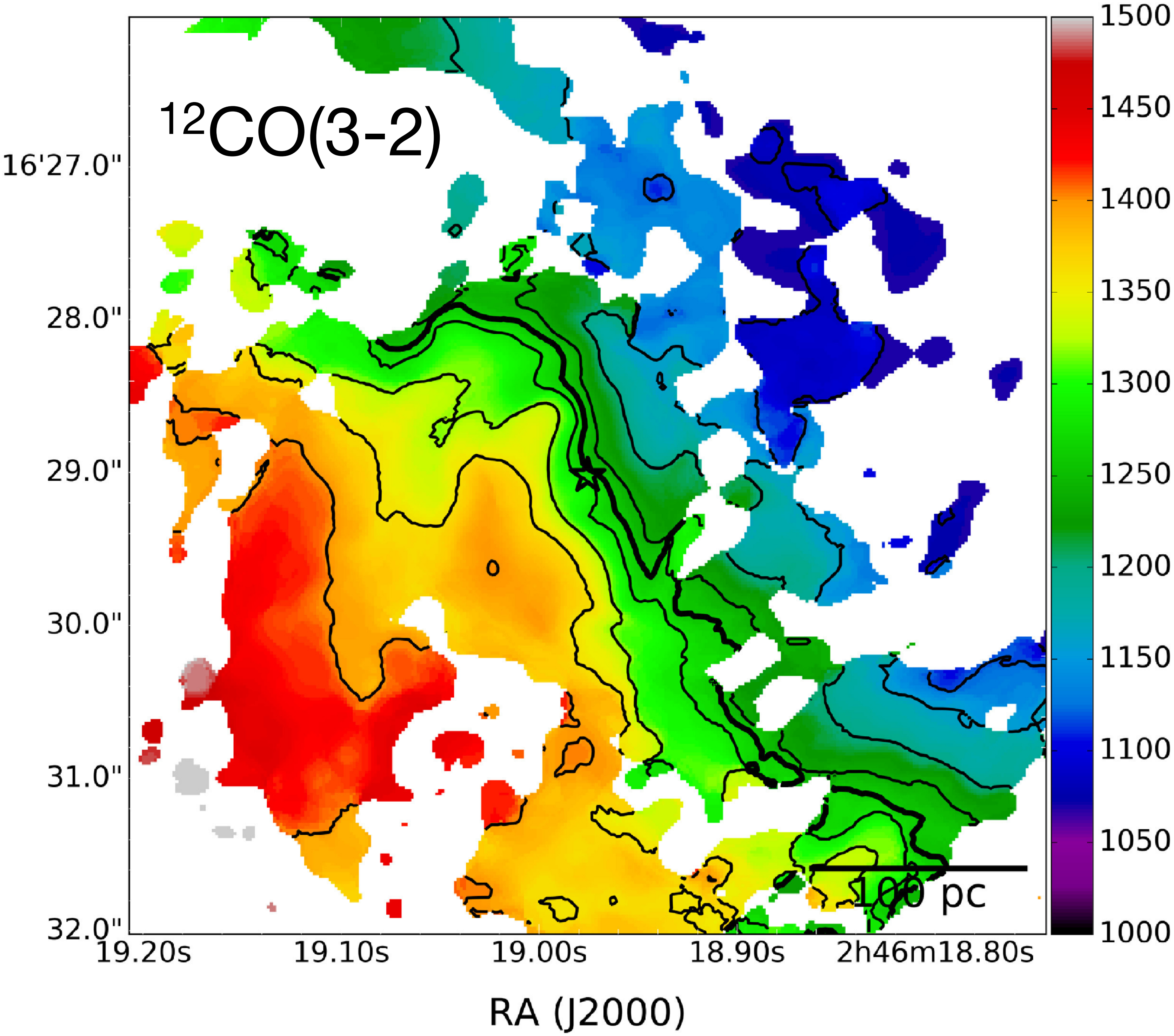
Close-up view of this LLAGN



- **No clear CO peak** at the AGN (continuum) position
- M_{gas} ~ 5e4 M_{sun} there (1/2 - 1/3 of NGC 1068) → less gas (***optically thinner torus***) in NGC 1097 than NGC 1068
- <u>*Less active inflows/star-formation (i.e., energy-input)*</u> there!
  → **Expect: geometrically thinner torus (w.r.t NGC 1068)**

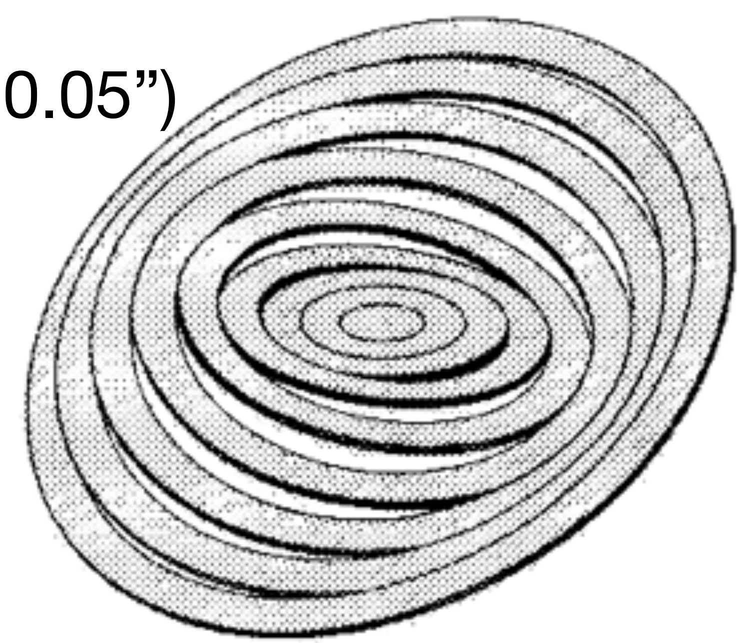
Constraints on the torus geometry

Izumi et al. 2017, ApJL, 845, L5



- Regular rotation is dominant
- We decomposed rotation and dispersion, with a titled-ring model (^{3D}Barolo code)
- Fit: V_{rot}, σ, inclination, PA, center, V_{sys}, intensity

(Δr = 0.05")



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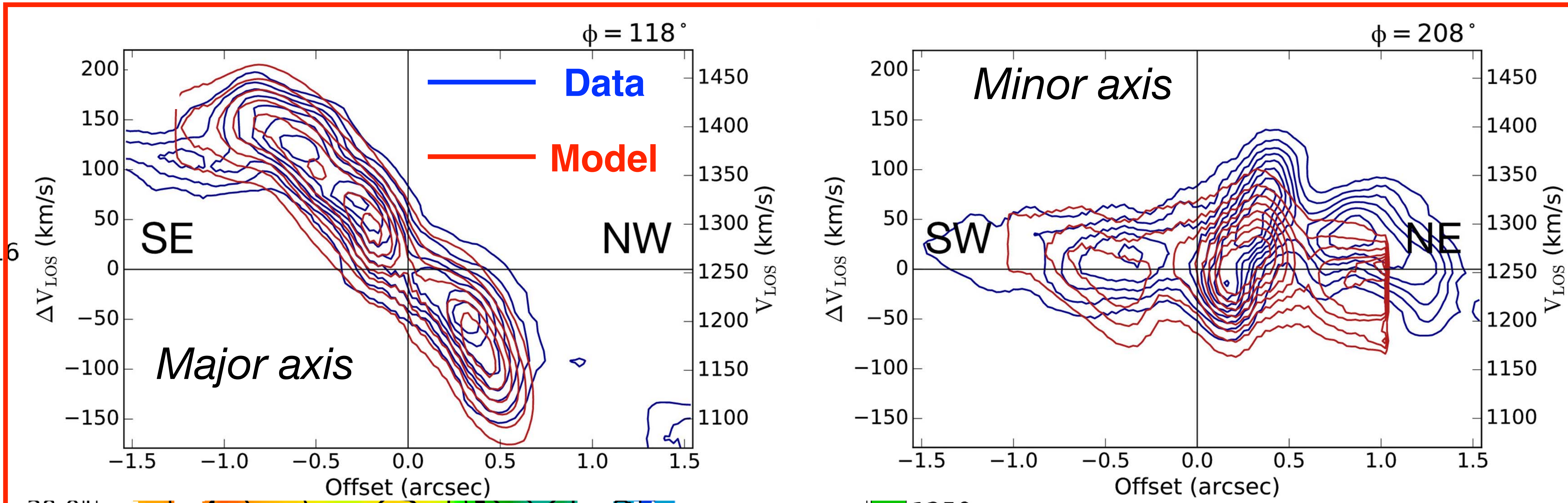

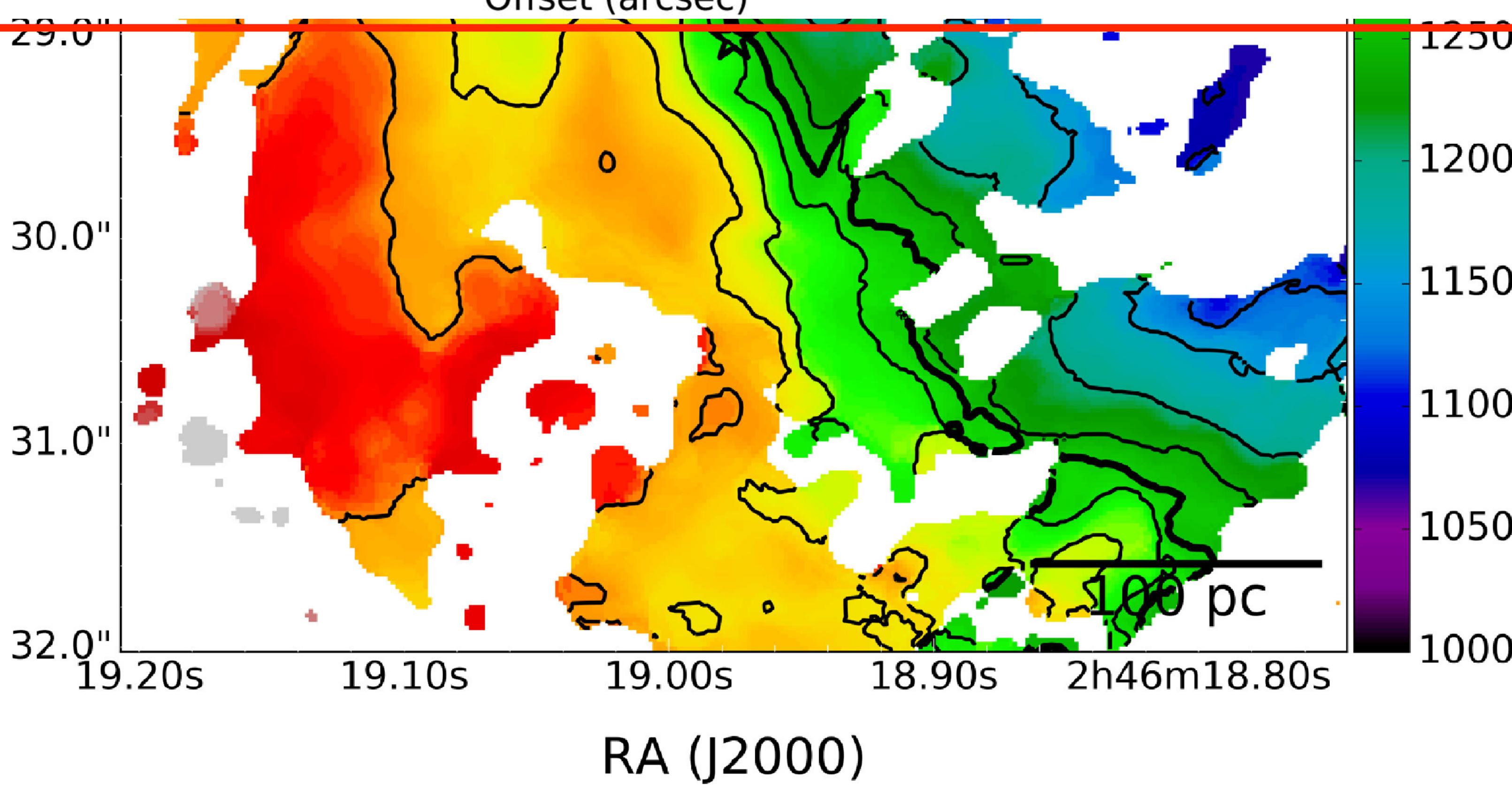

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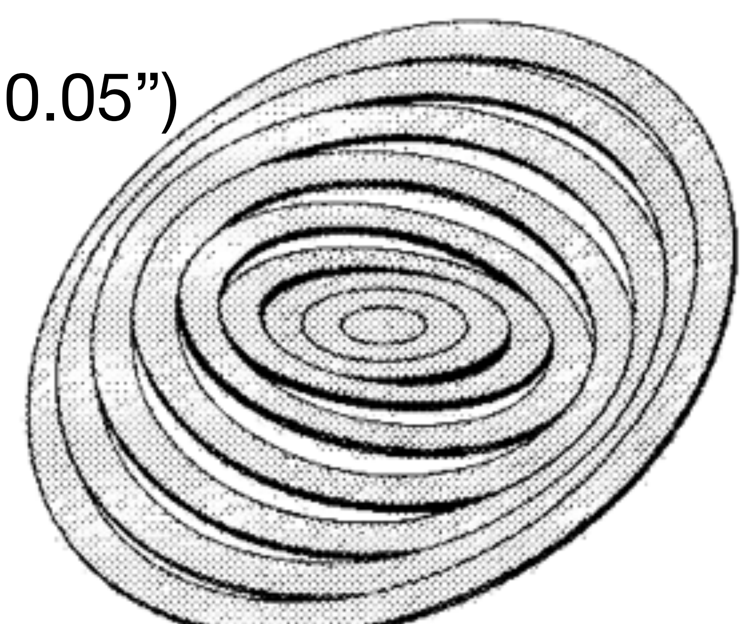

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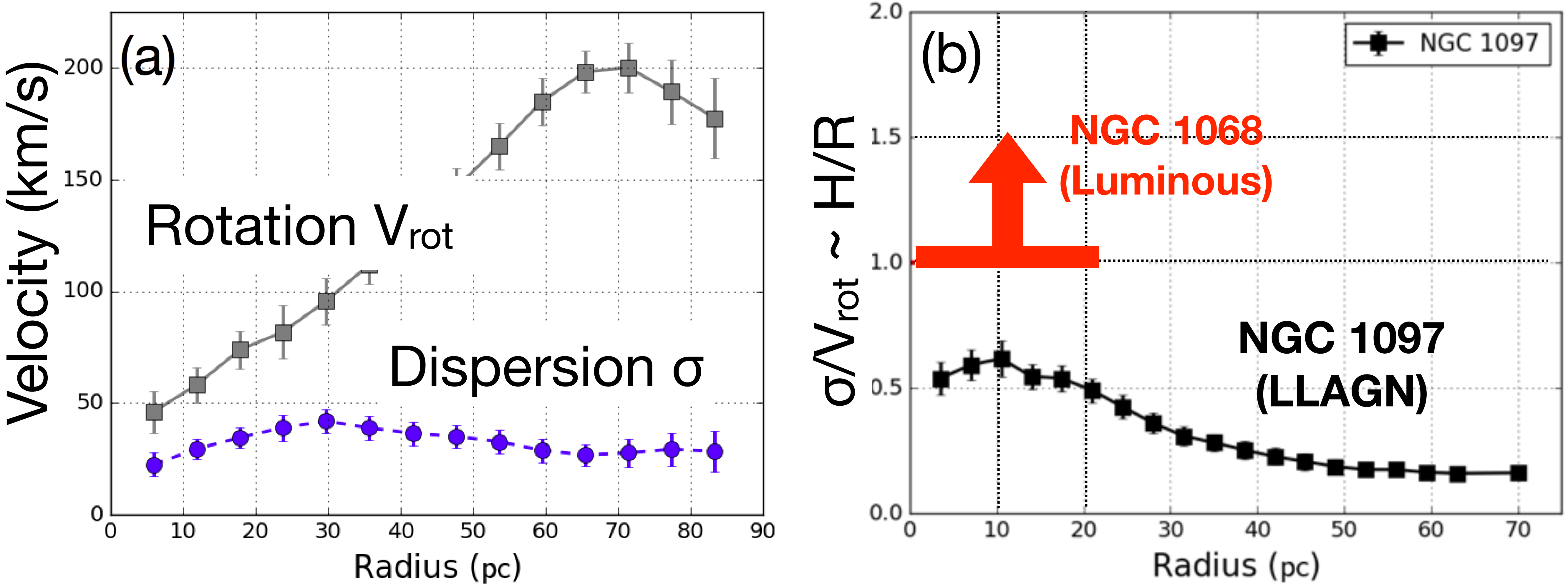

- The velocity structure was decomposed to (i) rotation and (ii) dispersion
- σ/V_{rot} = **0.5** in NGC 1097 (LLAGN) vs. **>1 (likely >3!)** in NGC 1068 (luminous)
- **A CND-scale torus geometry would depend on the AGN power (→ via inflows and/or star formation…?)**

Summary: High-resolution CO study

- **<u>Torus geometry</u>** would depend on the AGN power (via massive inflows and/or star formation): theoretical prediction
- No clear concentration of CO(3-2) at the AGN position of NGC 1097
- ~10 pc scale comparison between <u>NGC 1097 (LLAGN)</u> and <u>NGC 1068 (luminous AGN)</u>

	NGC 1097	NGC 1068
L_{Bol}	8e41 erg/s	7e44 erg/s
M_{gas}	5e4 M_{sun}	1e5 M_{sun}
σ/V_{rot}	~0.5 Thin	>1 Thick