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ACCRETION DISKS IN LUMINOUS YOUNG STELLAR OBJECTS

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REVIEW ARTICLE

Accretion disks in luminous young stellar objects

M. T. Beltrán[1] · W. J. de Wit[2]

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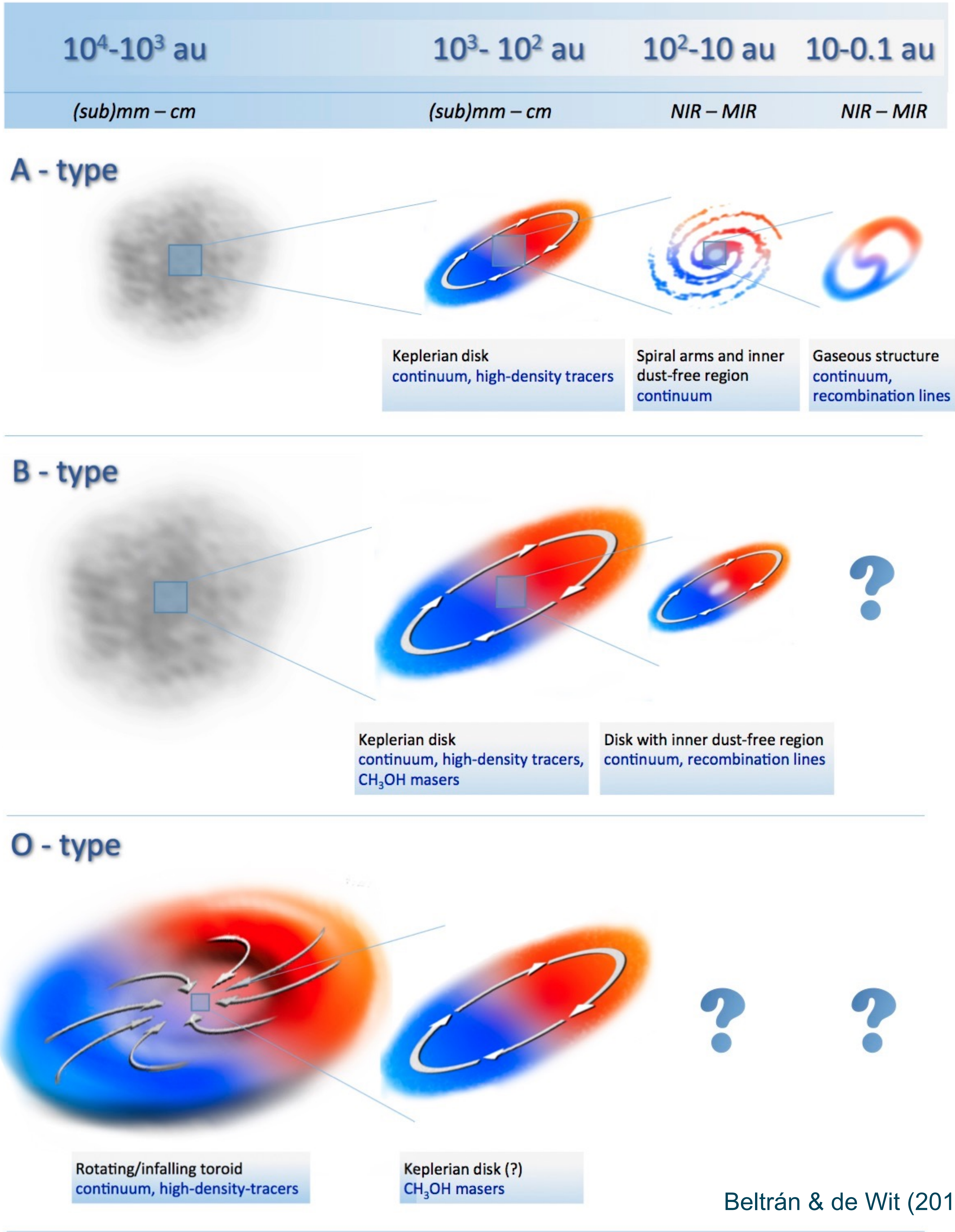
Abstract An observational review is provided of the properties of accretion disks around young stars. It concerns the primordial disks of intermediate- and high-mass young stellar objects in embedded and optically revealed phases. The properties were derived from spatially resolved observations and, therefore, predominantly obtained with interferometric means, either in the radio/(sub)millimeter or in the optical/infrared wavelength regions. We make summaries and comparisons of the physical properties, kinematics, and dynamics of these circumstellar structures and delineate trends where possible. Amongst others, we report on a quadratic trend of mass accretion rates with mass from T Tauri stars to the highest mass young stellar objects and on the systematic difference in mass infall and accretion rates.

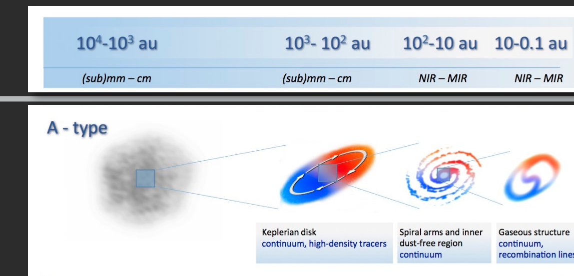
Keywords Accretion: accretion disks · Techniques: high angular resolution · Techniques: interferometric · Stars: formation

SUMMARY



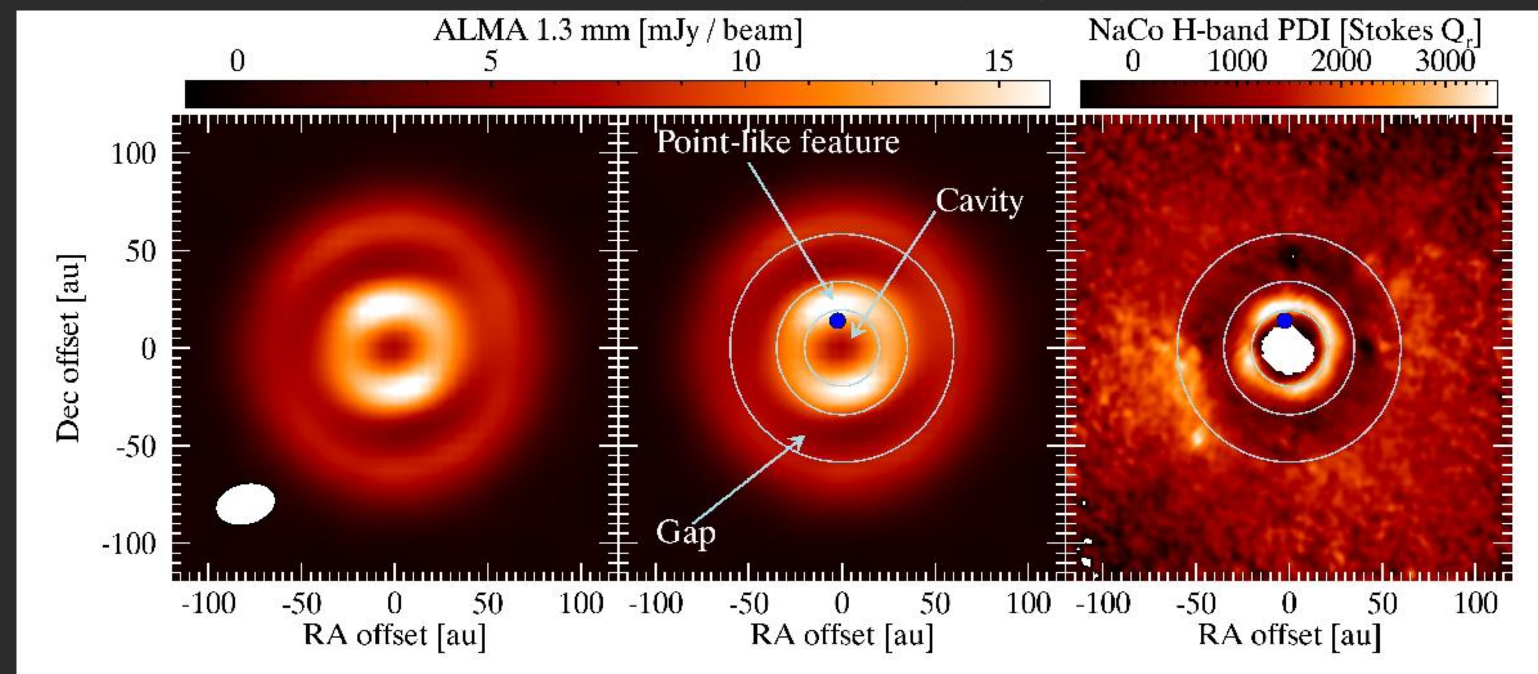
Beltrán & de Wit (2016)

A-TYPE STARS



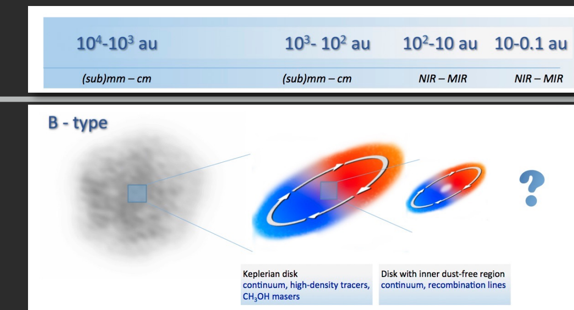
- Disks found near PMS stars up 8 $M_\odot$, and in Keplerian rotation (e.g., HD163296: de Gregorio-Monsalvo+ 2013)
- ALMA shows discontinuous radial and azimuthal dust distributions (Isella+ 2016, Fedele+ 2017) and dissimilar distributions of dust and gas: signatures of protoplanets
- Near-IR scattered light images (with VLT/SPHERE or NACO, dust scattering) in HAeBe stars indicate large disk cavities (>5AU) which are at the base of the differences in IR SEDs (Garufi+ 2017).

HD 169142 (A5)



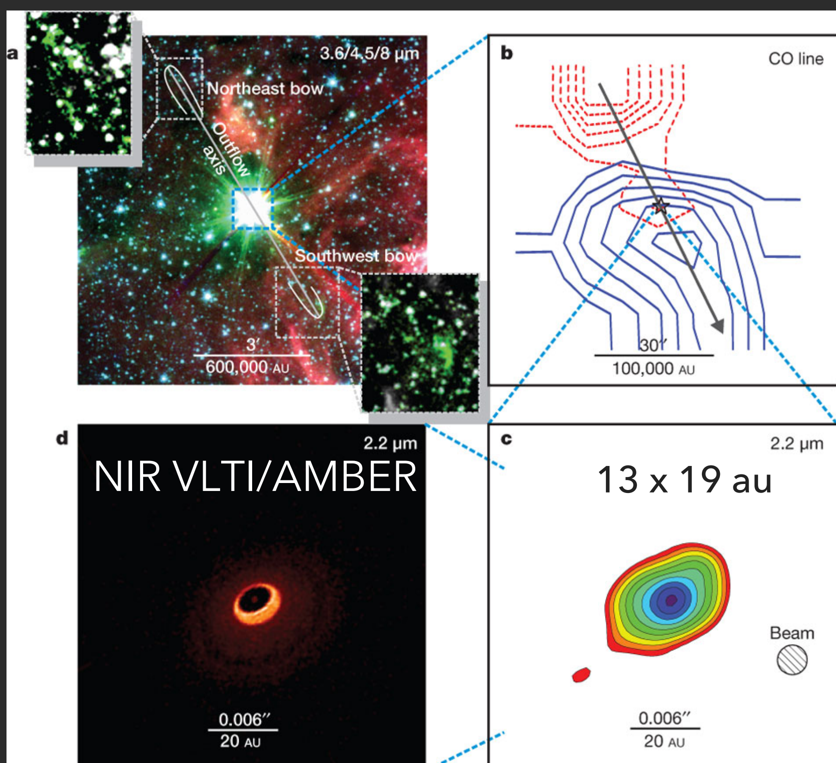
Fedele+ (2017)

B-TYPE STARS



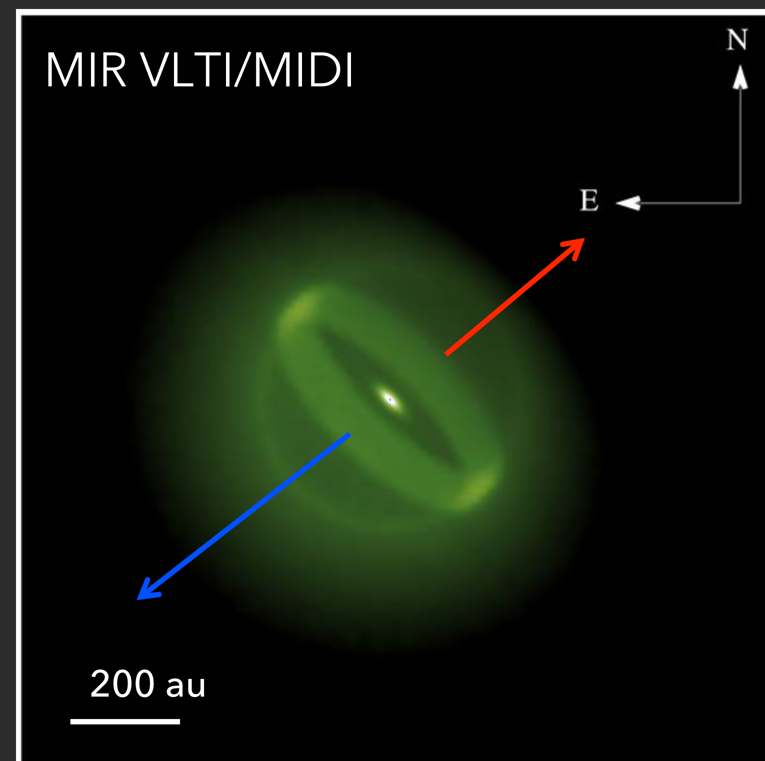
$L_{bol} < 10^5\, L_\odot \Rightarrow M_\star \lesssim 25\, M_\odot$

IRAS 13481-6214 : ~ 20 $M_\odot$



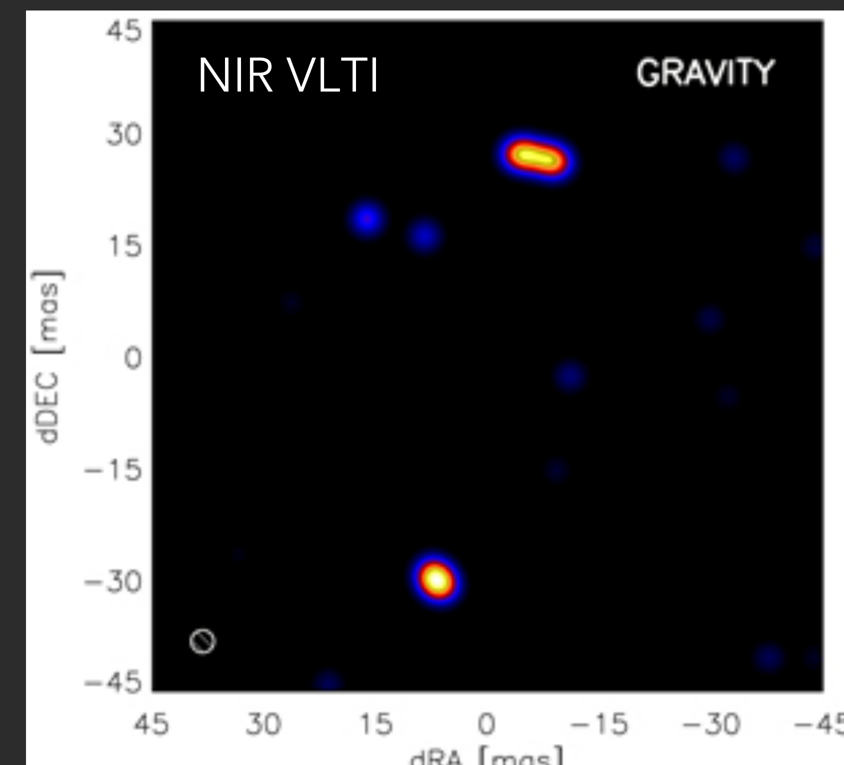
Kraus+ (2010)

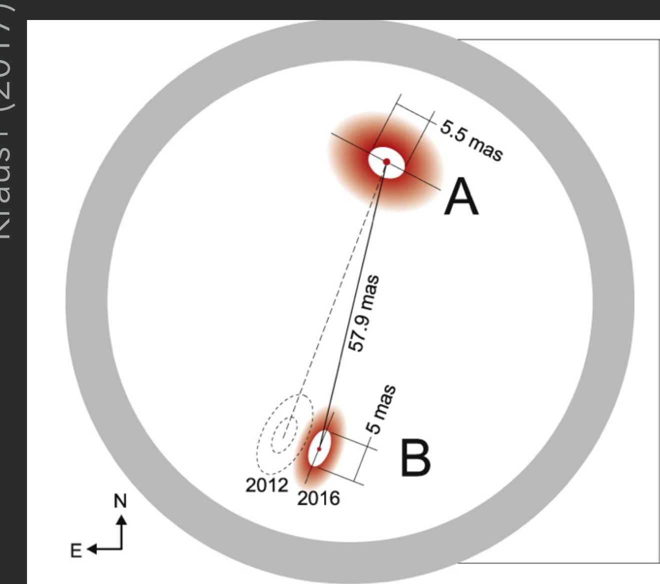
CRL 2136: ~ 20 $M_\odot$



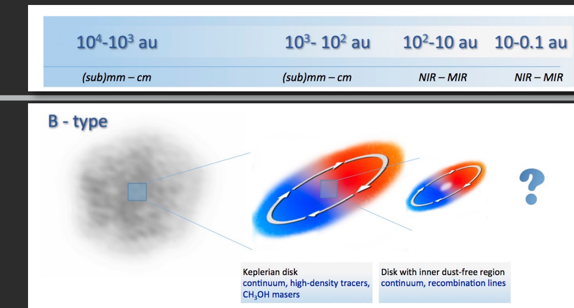
de Wit+ (2011)

IRAS 17216-3801: 20 and 18 $M_\odot$





Kraus+ (2017)



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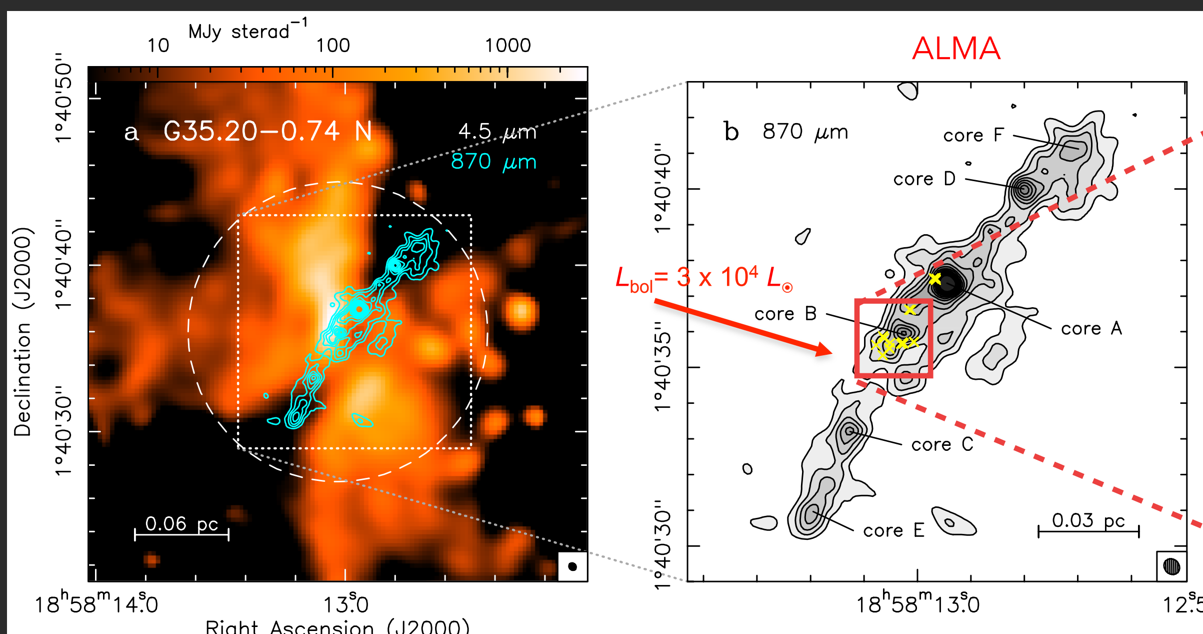
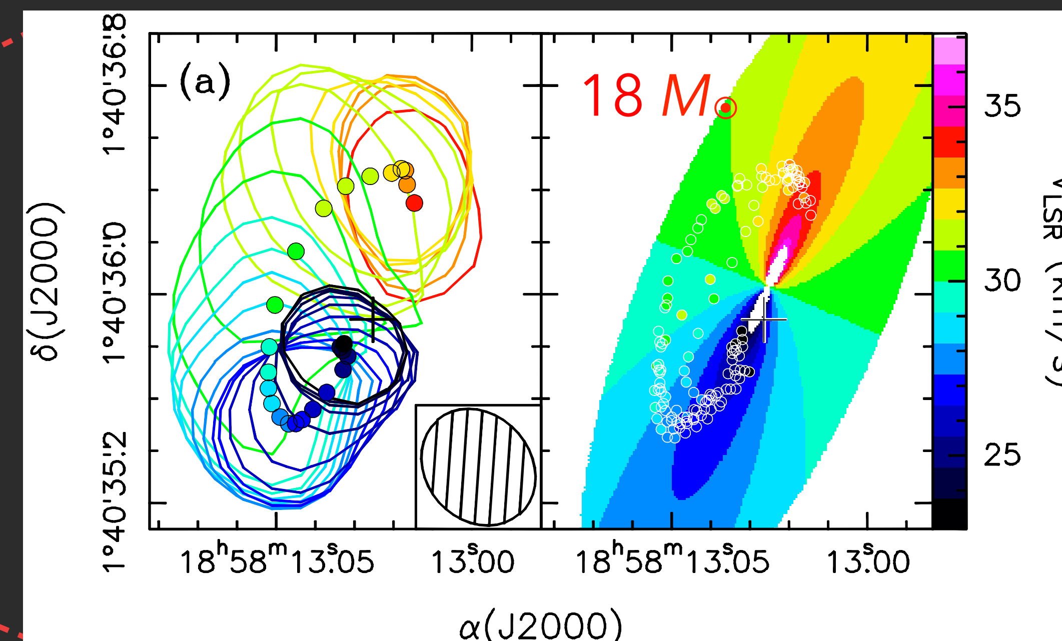
G35.20-0.74N

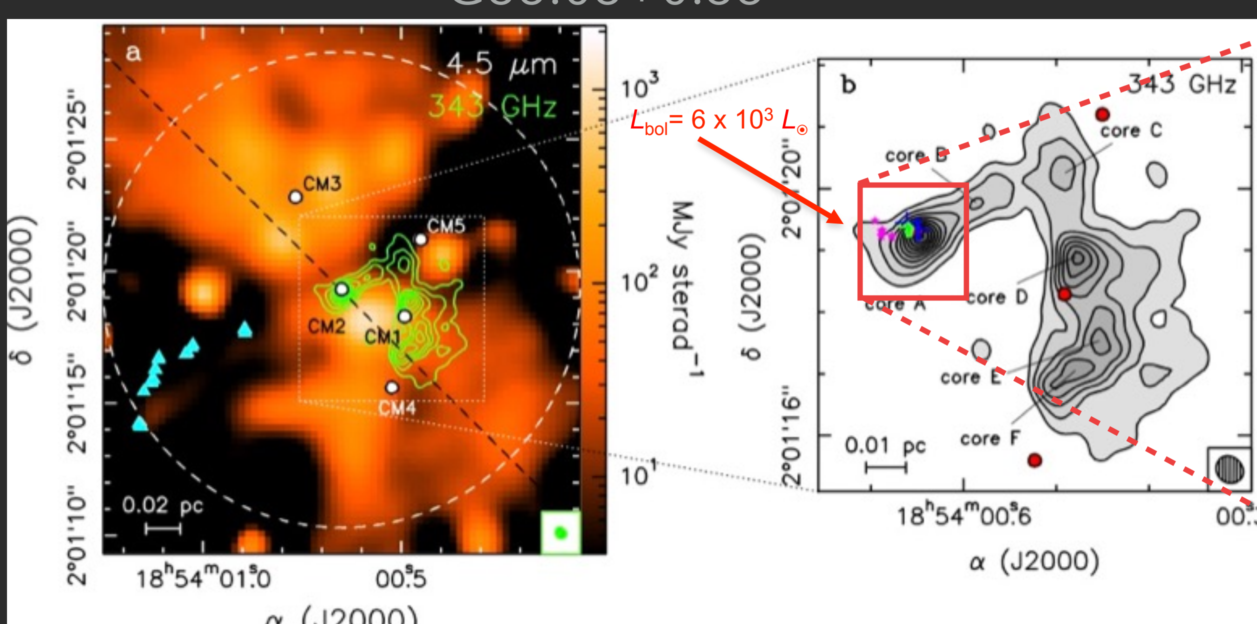


Sánchez-Monge+ (2014)

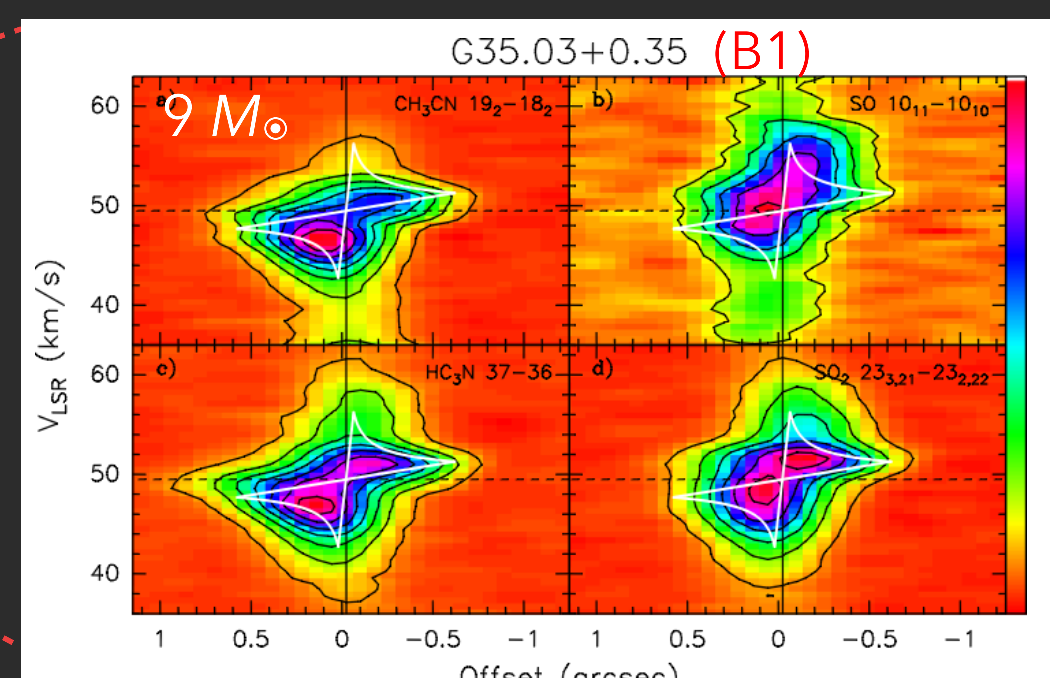


Sánchez-Monge+ (2013)

G35.03+0.35



Beltrán+ (2014)



Beltrán+ (2014)

“DISKS”

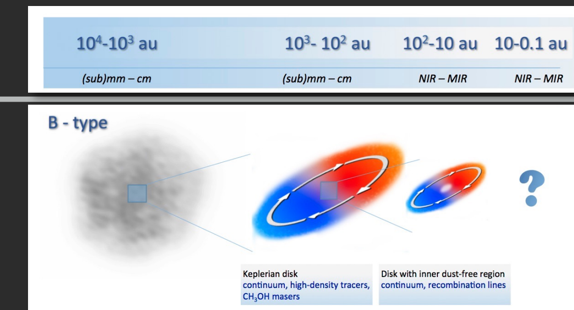
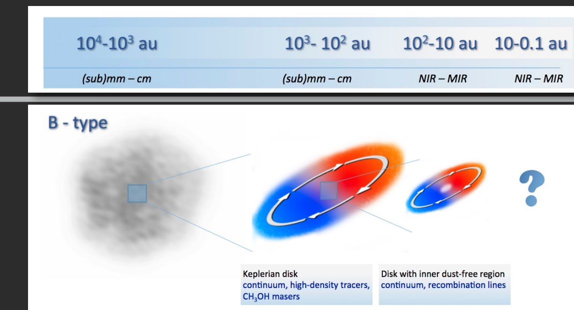


Table 1. List of rotating disks around B-type (proto)stars

Core	d (kpc)	L_{bol} ($L_\odot$)	$M_{gas}^{OH94\ b}$ ($M_\odot$)	R (au)	V_{rot} (km s^{-1})	$M^c_{\star\,Lyman}$ ($M_\odot$)	$M^c_{\star\,cluster}$ ($M_\odot$)	ΔV (km s^{-1})	$\dot{M}_{out}$ ($M_\odot$/yr)
IRAS 20126+4104	1.7	1×10^4	0.9	3600	1.3	7	12	3.0	1.3×10^{-3}
Cepheus A HW2	0.725	2.5×10^4	2.2	360	3.5	15	15	4.0	1.7×10^{-3}
GH2O 92.67+3.07	0.80	4.7×10^3	12	7200	1.2	6	9	3.0	2.7×10^{-4}
G35.20+0.74 N A	2.19	3×10^4	1.0	1500	1.5	—	16	4.5	—
G35.20+0.74 N B	2.19	3×10^4	0.9	2600	1.0	18	16	2.8	—
G35.03+0.35 A	3.2	6.3×10^3	0.75	2200	2.0	11	10	8.5	—
AFGL 2591 VLA3	1.0	2×10^5	0.41	400	2.2	16	32	1.5	—
AFGL 490	1.0	2×10^3	4.1	1600	1.3	8	7	3.0	—
IRAS 18162−2048 MM1	1.7	2×10^4	4.9	800	2.0	—	14	5.5	—
IRAS 18089−1732	3.6	3.2×10^4	68	3600	3.0	—	16.6	6.0^n	—
NGC7538S MM2	2.7	1.5×10^4	5.0	1000	1.0	—	13	4.0	—
NGC7538IRS1	2.7	8×10^4	18.0	1000	3.0	30	23	10.0	—
G192.16−3.82	2.0	3×10^3	11	2100	3.0	8	8	1.5	3.8×10^{-4}
IRAS 16547−4247	2.9	6.2×10^4	22	1500	1.7	—	21	7.6	—
IRAS 16562−3959	1.7	7×10^4	7.6	3000	2.2	15	22	5.0	—
NGC6334I SMA1 Main	1.7	1×10^5	37	280	5.1	—	25	8.0	—
NGC6334 I(N) SMA1b	1.3	1×10^3	4.3	800	3.5	—	5.5	8.8	—
IRAS 04579+4703	2.5	4×10^3	8	5000	1.0	7	8.5	3.6	1.7×10^{-4}
IRAS 18151−1208	3.0	2×10^4	43	5000	2.0	15	14	1.9	—
G23.01−0.41	4.6	1×10^4	41	6000	0.6	18	12	8.3	2.0×10^{-4}
IRDC 18223−1243	3.7	1×10^2	47	14000	1.5	—	—	1.8	5.5×10^{-3}
G240.31+0.07	5.3	3.2×10^4	133	10000	2.5	—	16.6	1.7	6.4×10^{-3}

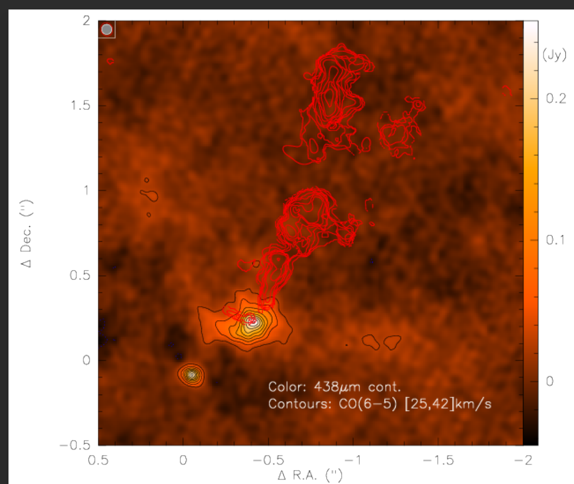
- $L_{bol} < 10^5\,L_\odot$ ➪ $M_\star$ = 7-25 $M_\odot$
- R_{disk} a few 100 - 10^3 au
- M_{disk} ~ a few $M_\odot$ ➪ $M_{disk} \lesssim M_\star$

B-TYPE STARS → LATE O-TYPE STARS



G351.77-0.54 (10^4-10^5 $L_\odot$)

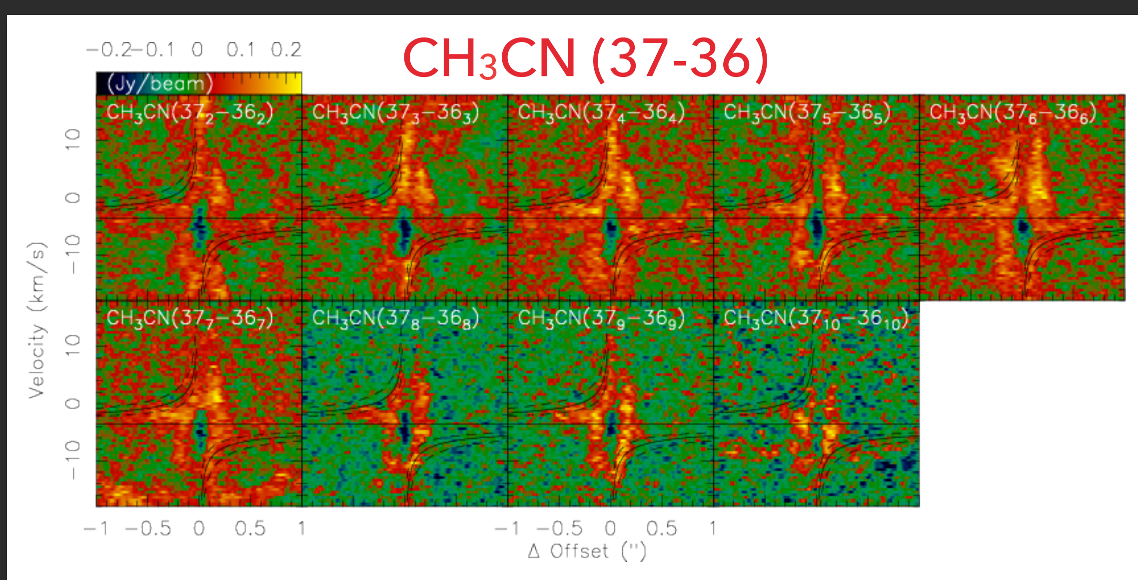
Beuther+ (2017)



θ = 0.06″ = 60 - 130 au

↓

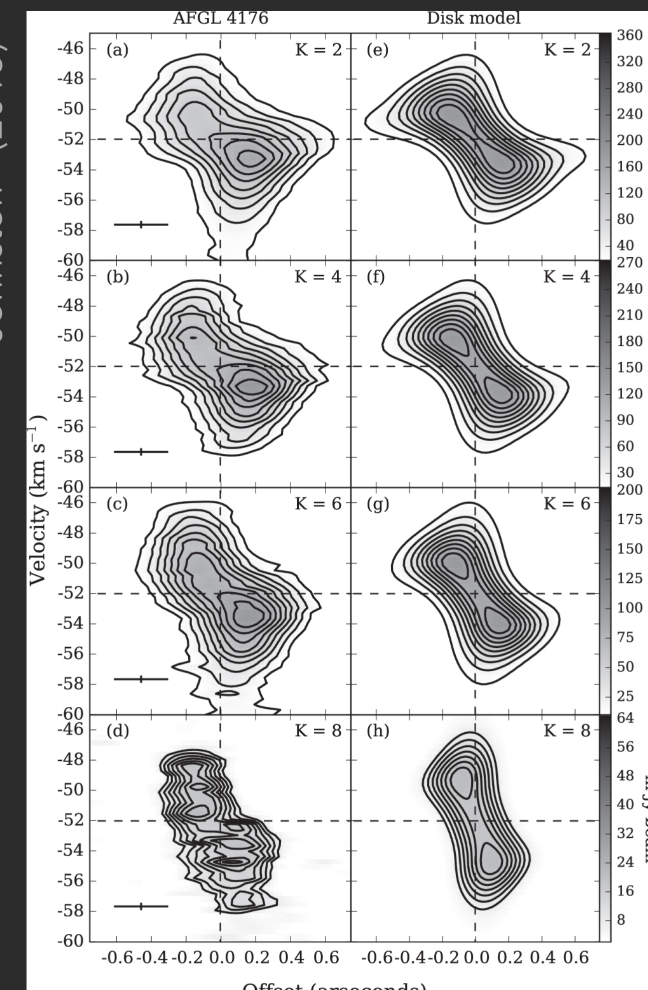
Comparable to NIR -MIR



- Keplerian rotation?
- $M_\star$ ~ 4.5 -10 $M_\odot$
- Disk of R ~ 250-500 au and M_{disk} ~0.1-0.5 $M_\odot$
- $M_{disk} \lesssim M_\star$

AFGL 4176: ~ 25 $M_\odot$ (O7)

Johnston+ (2015)

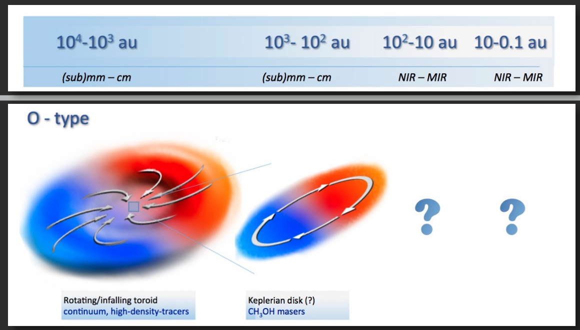


- Keplerian flared disk of R ~ 2000 au and M_{disk} ~8 $M_\odot$
- $M_{disk} \lesssim M_\star$
- 2.3 μm CO bandhead emission suggests a Keplerian disk of 10 au (Ilee+ 2013)

➢ Ilee+ (2016): G11.92-0.61

➢ See Poster #71 on G23.01-0.41 (Alberto Sanna)

(EARLY) O-TYPE STARS

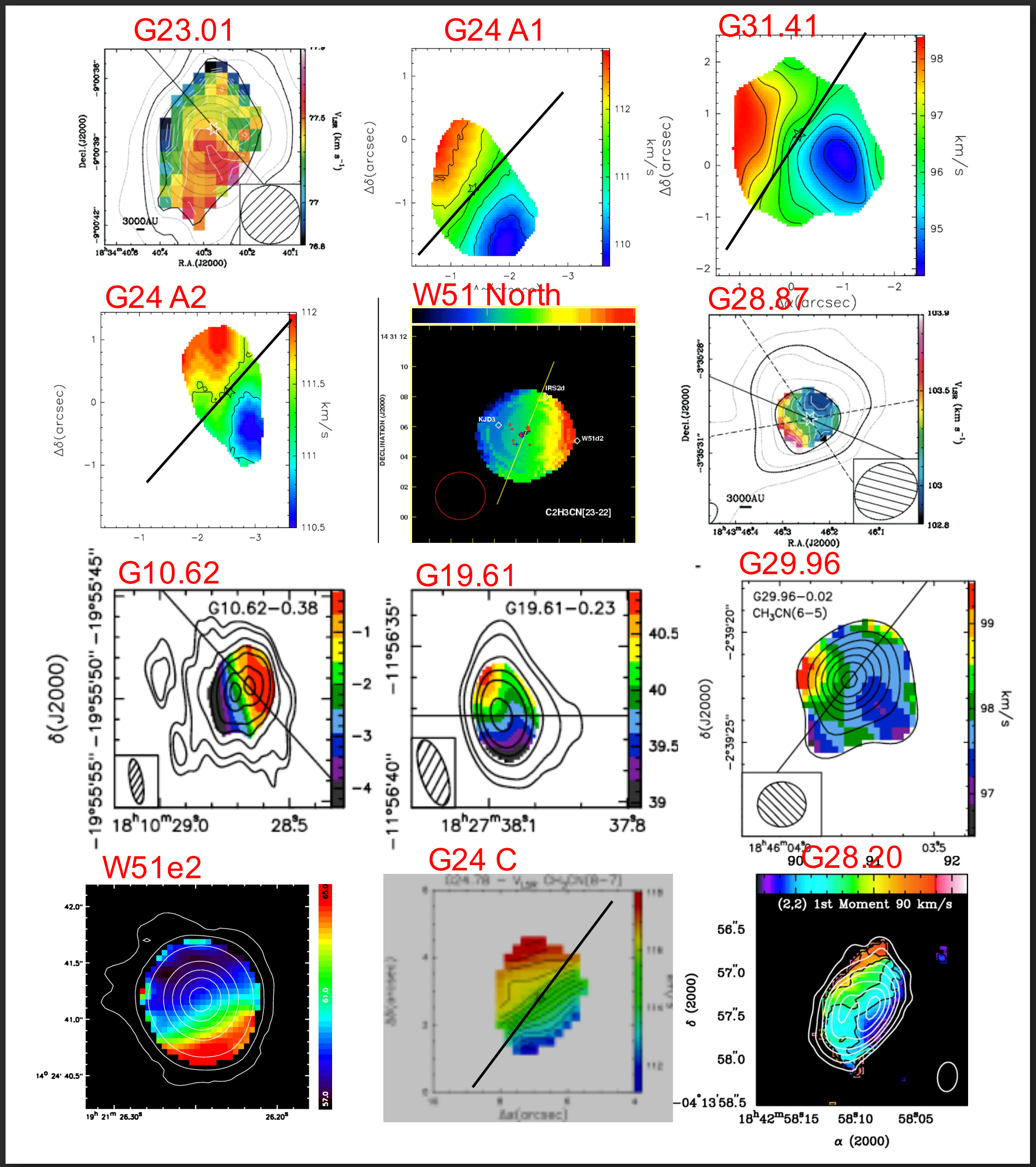


$L_{bol} > 10^5 L_\odot$ ➪ $M_\star > 25 M_\odot$

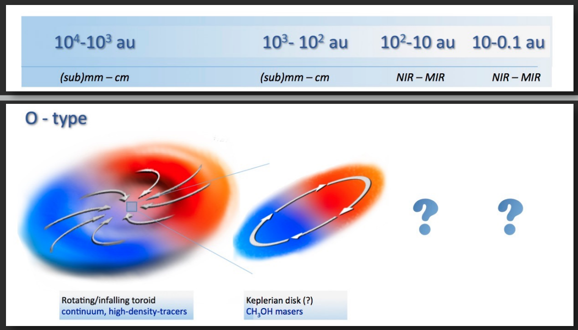
- R_{toroid} several 1000 au
- M_{toroid} ~ a few 100 $M_\odot$ ➪ $M_{toroid} \gg M_\star$

- $M_{toroid} >> M_\star$: **No Keplerian rotation** on scales of 10^4 au. The gravitational potential of the system is dominated by the massive toroid not by central star.

- $M_{toroid} > M_{dyn}$ suggests that toroids are **not centrifugally supported**, may be unstable and **undergoing fragmentation** and **collapse**.



Beltrán+ (2004, 2011), Furuya+(2008), Keto & Klaassen (2008), Sollins + (2005), Zapata+(2008)



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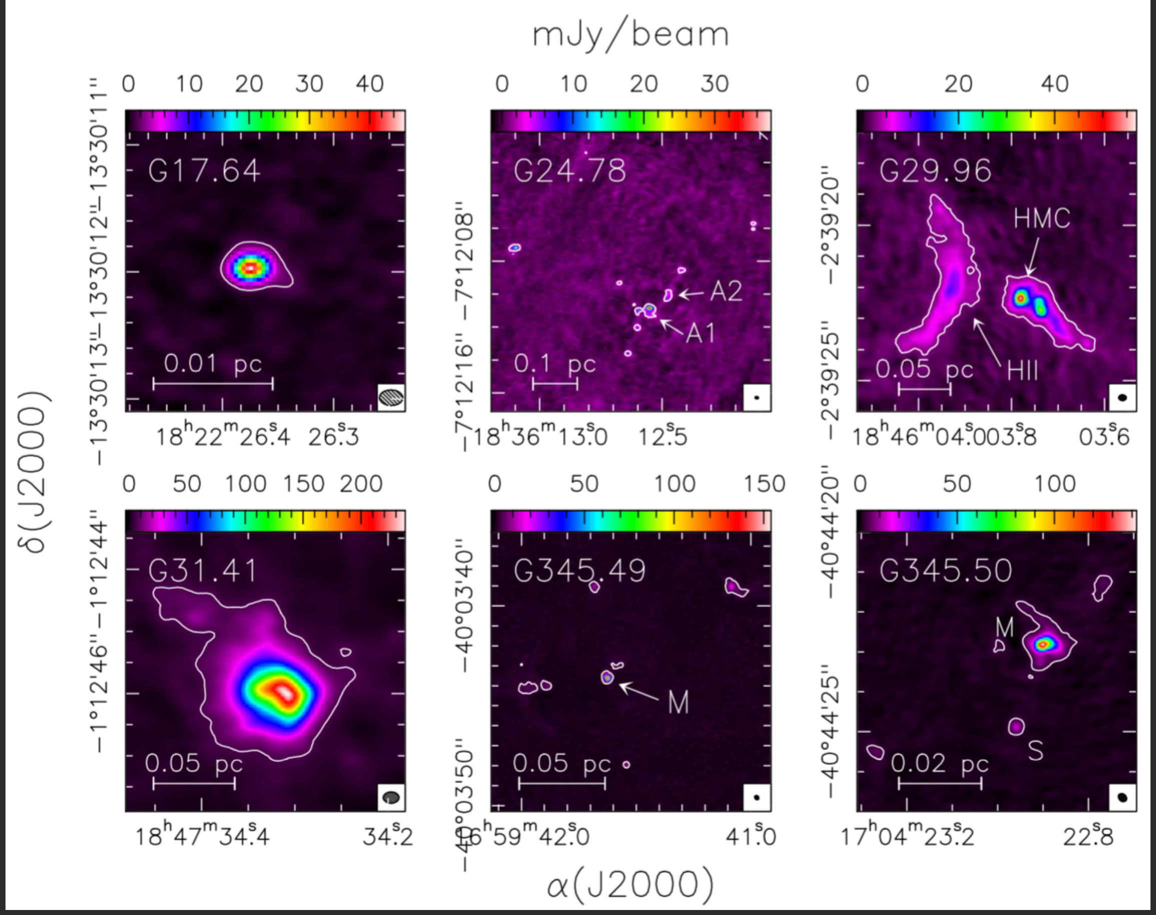
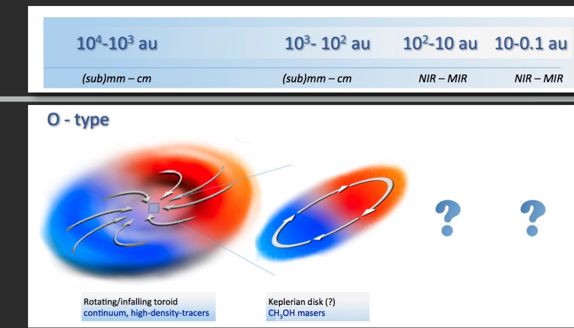


Cesaroni+ (2017)

0.2″ ALMA

(400 au – 1600 au resolution)

(EARLY) O-TYPE STARS



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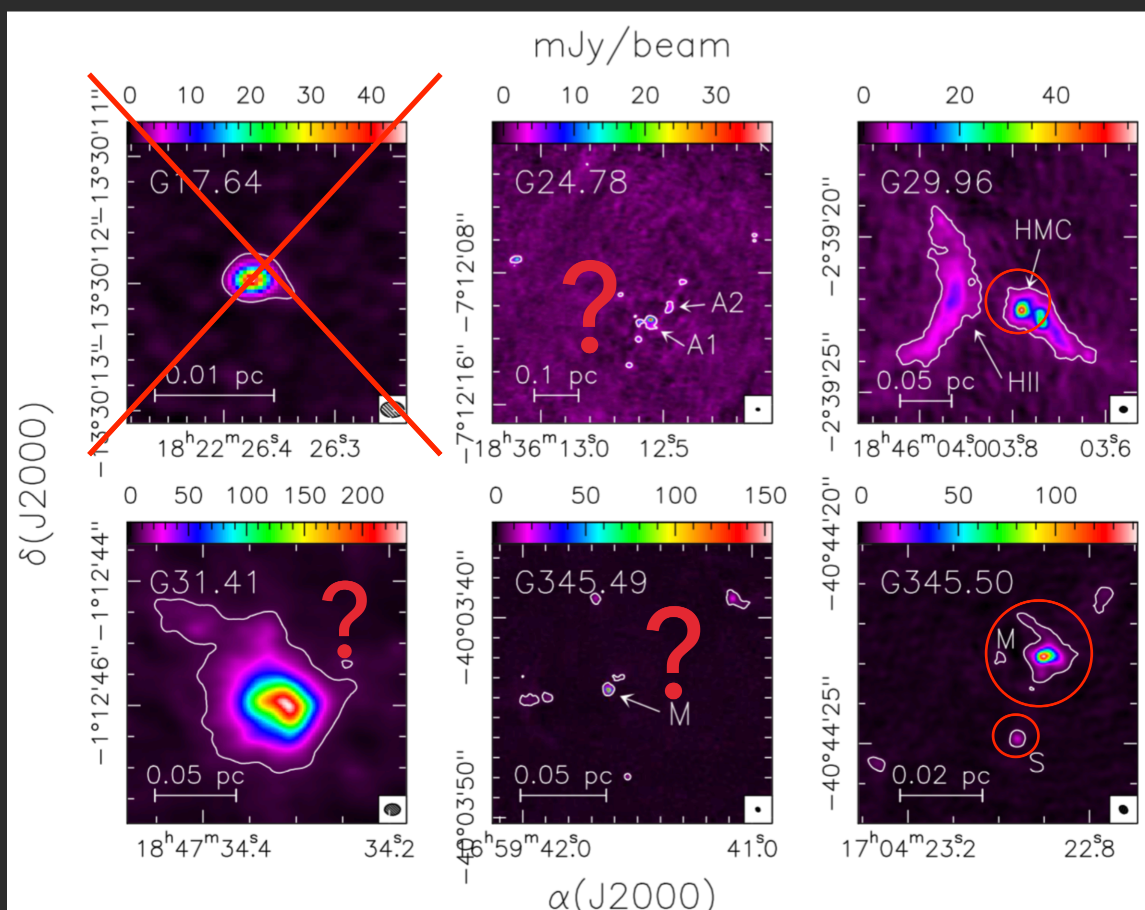
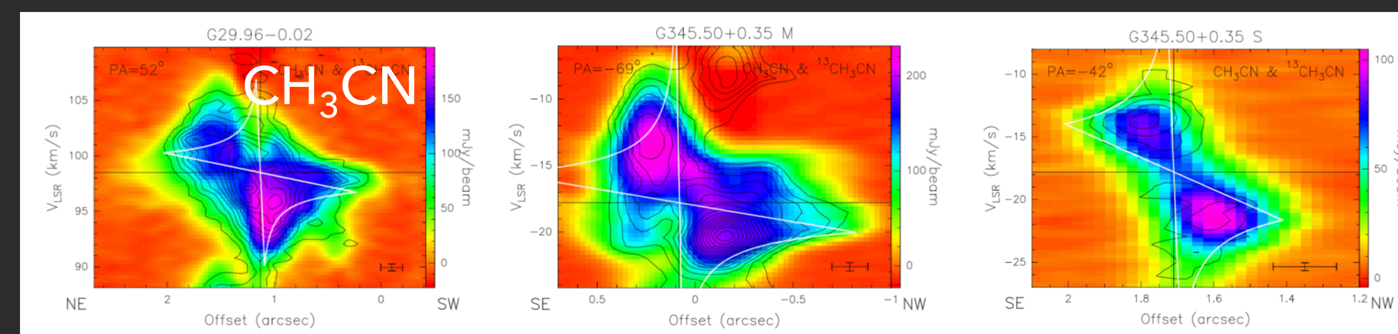


Cesaroni+ (2017)

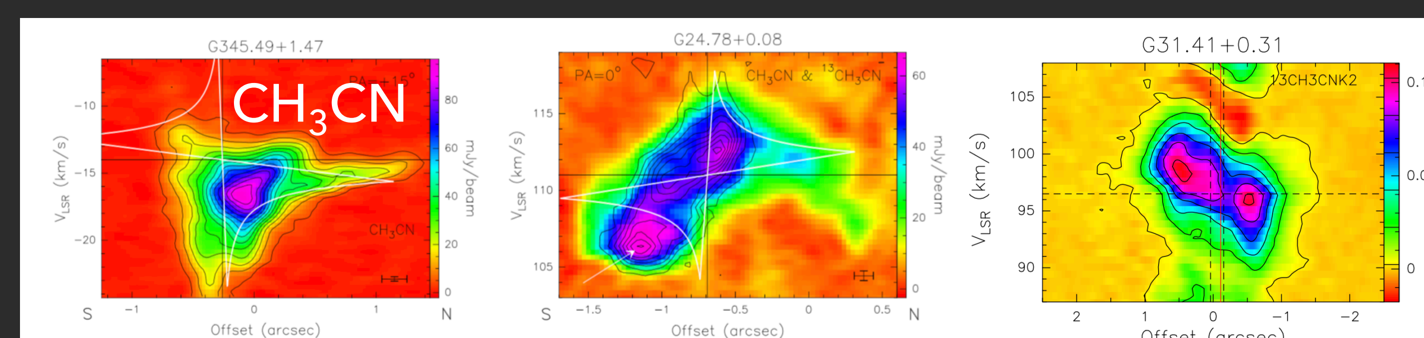
0.2"   ALMA

(400 au – 1600 au resolution)

Keplerian-like rotation



Rotation, but Keplerian?



Cesaroni+ (2017)

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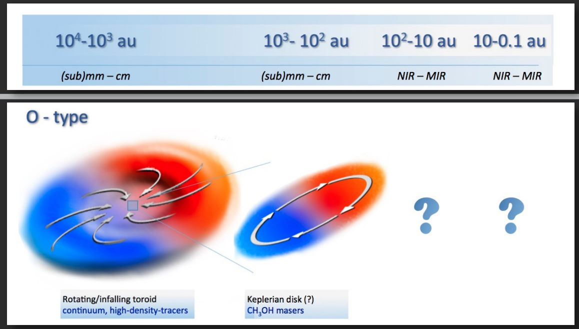
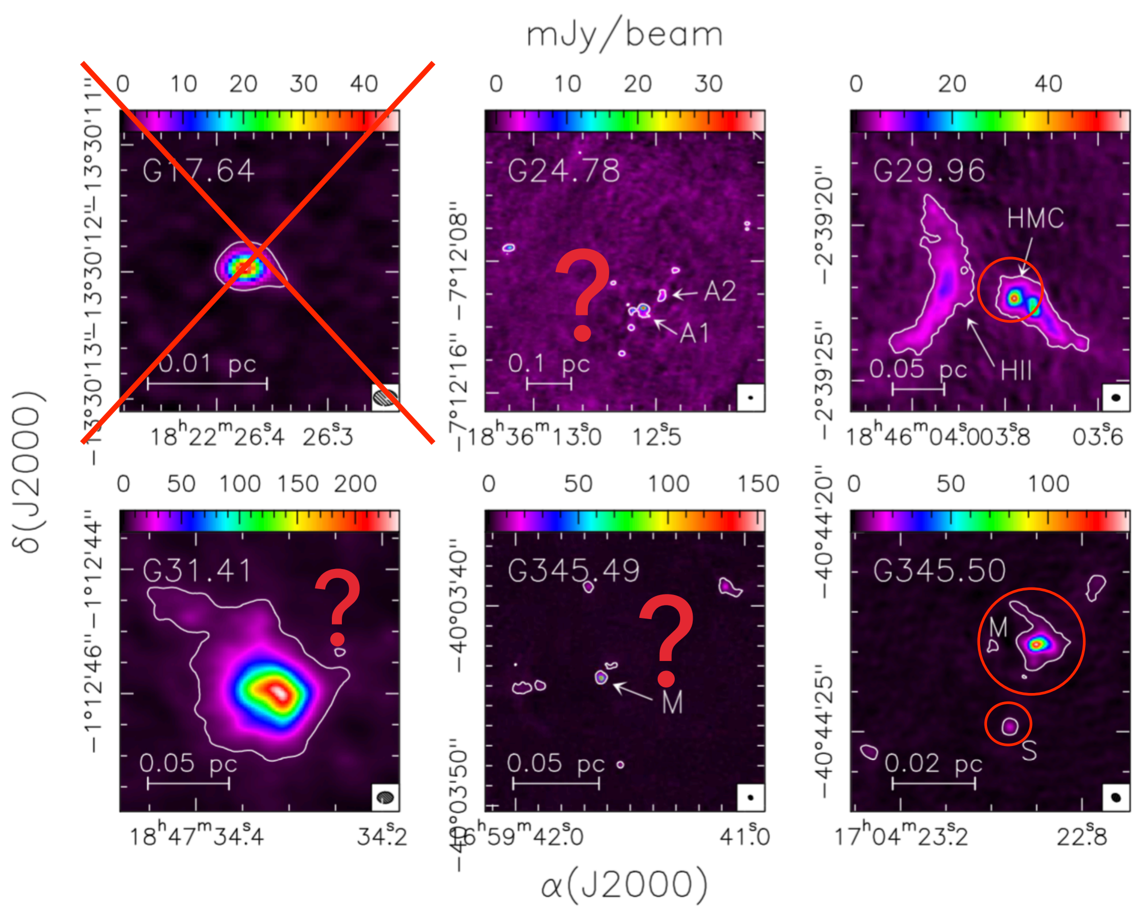


$L_{bol} > 10^5\ L_\odot \Rightarrow M_\star > 25\ M_\odot$



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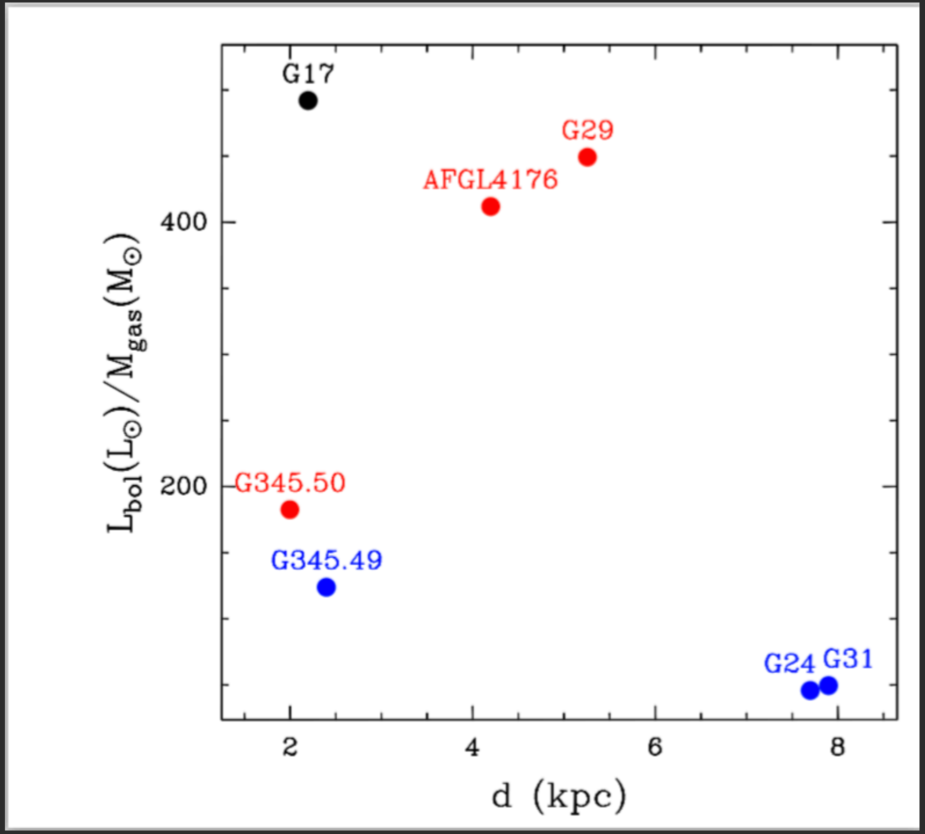
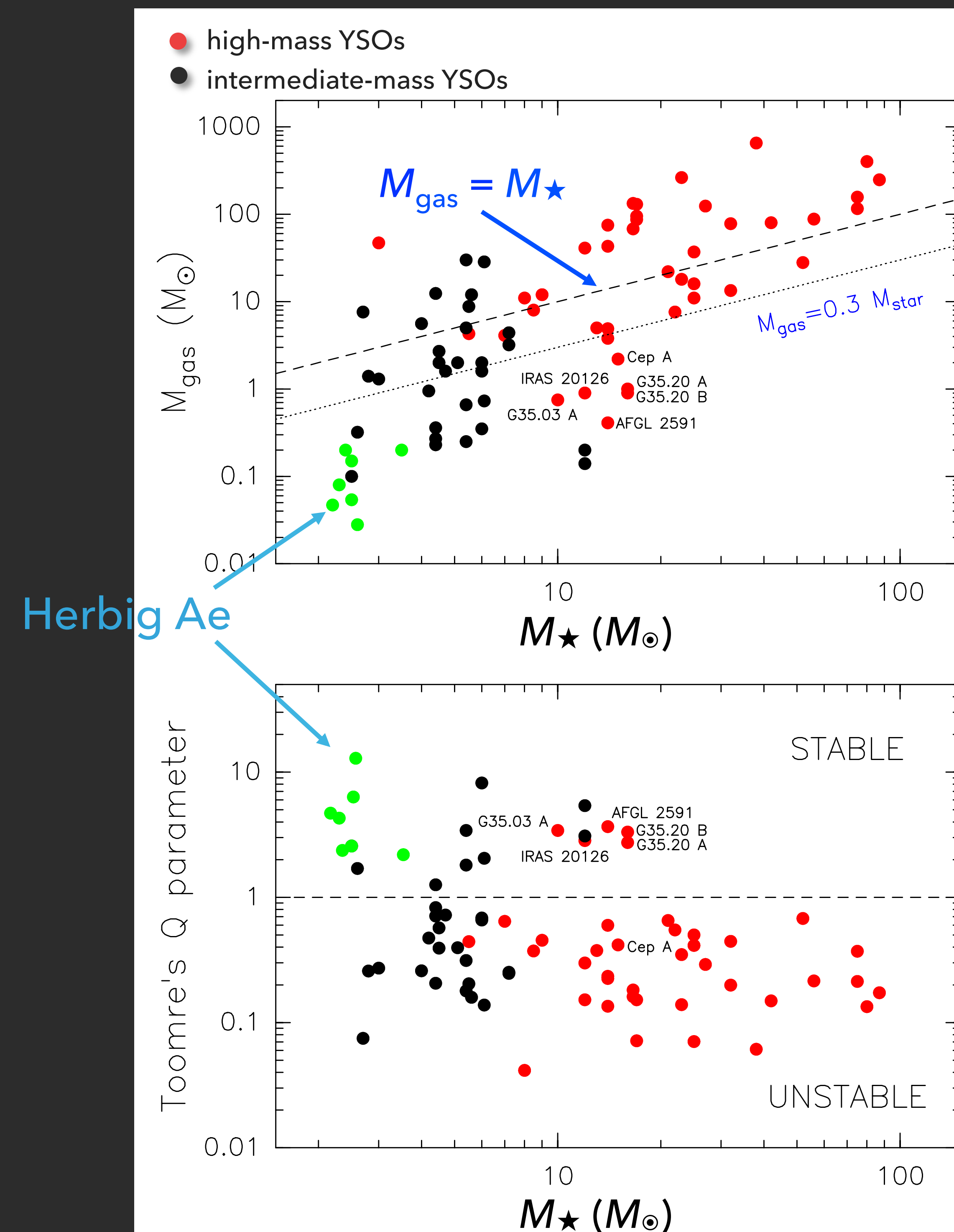


Cesaroni+ (2017)

- Disks found at intermediate evolutionary stage
- At later evolutionary stage, the molecular gas is dispersed
- For the younger sources, emission of disks difficult to disentangle from that of the envelopes. Disks might start small and grow up with time

STABILITY

- 41 rotating structures around O and B-type
- 30 rotating structures around IMs
- $M_{disk} < 0.3\ M_\star$ and Toomre's stability parameter Q > 1 ➜ accretion disks are gravitationally stable (Shu+ 1990; Laughlin & Bodenheimer 1994; Yorke 1995; Toomre 1964)
- Herbig Ae + **IRAS 20126+4104** (Cesaroni+ 2005), **Cepheus A HW2** (Patel+ 2005), **G35.20-0.74N** (Sánchez-Monge+ 2013), **G35.03+0.35** (Beltrán+ 2014), **AFGL 2591 VLA3** (Wang+ 2012) accretion disks are stable against collapse **+ G351.77-0.54 (Beuther+ 2017) + AFGL 4176 (Johnston+ 2015)**
- Toroids are unstable against axisymmetric instabilities



Beltrán & de Wit (2016)

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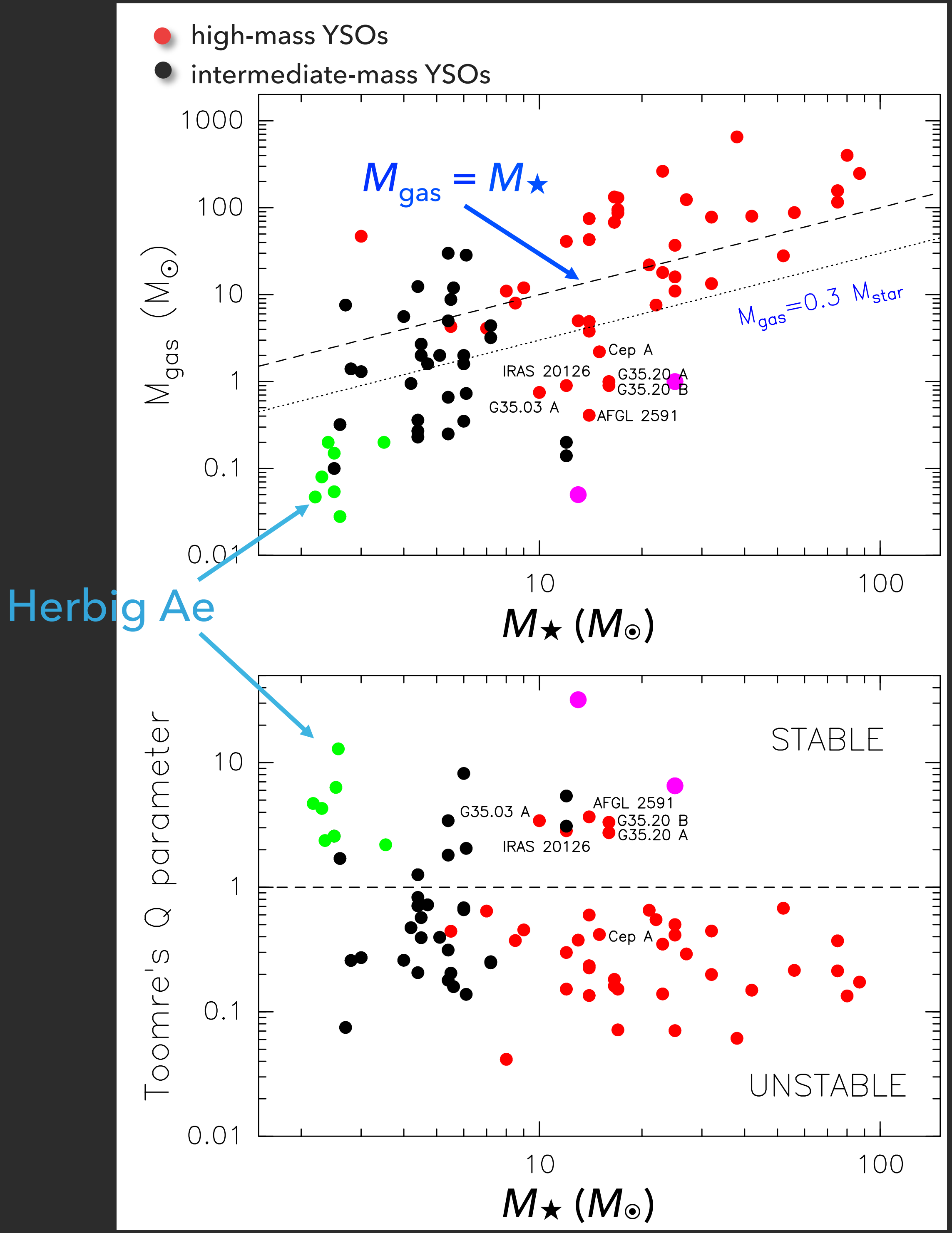
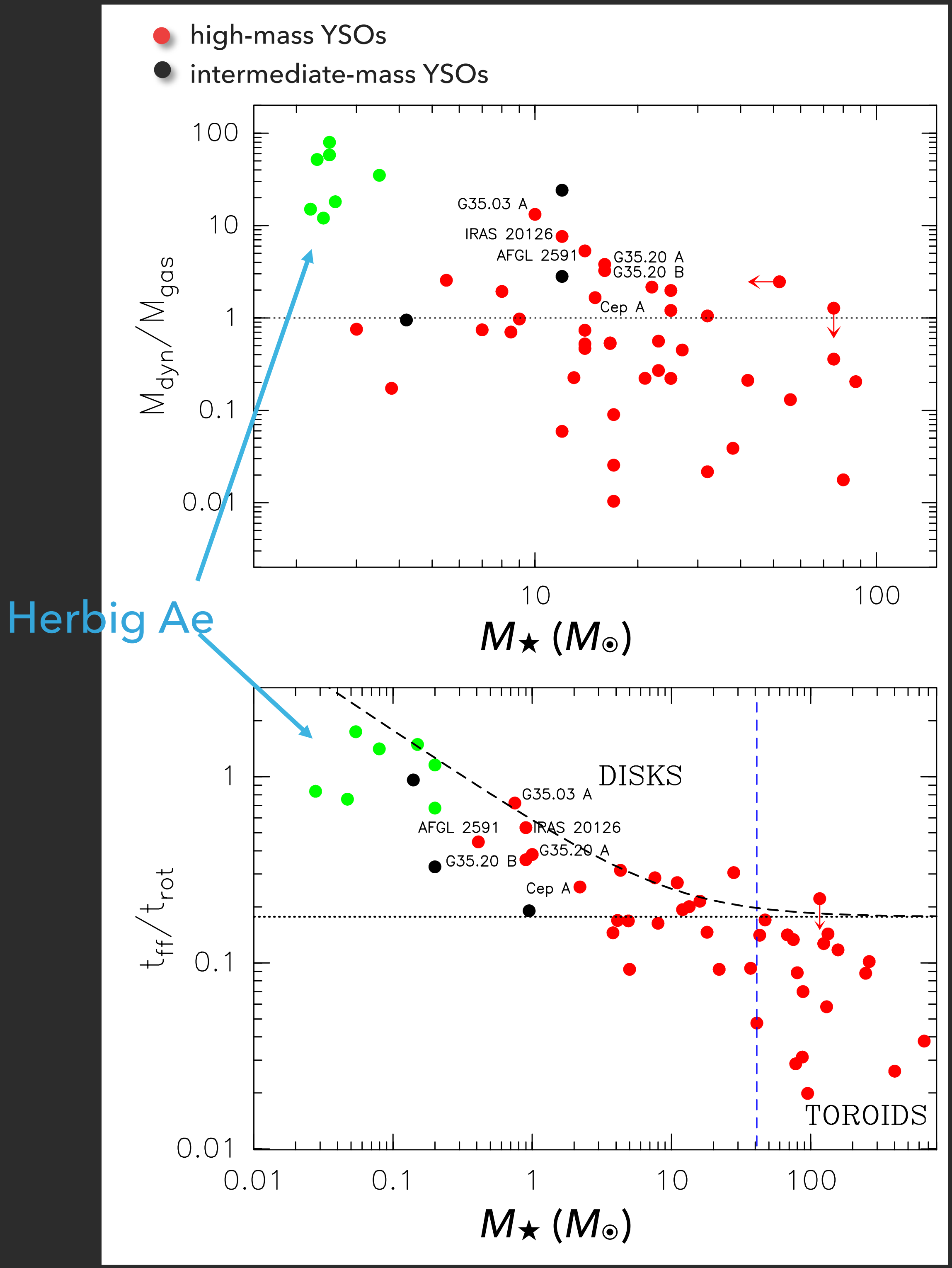


Beltrán & de Wit (2016)

DYNAMICS

- Toroids ($M_{gas} >> M_{\star}$) and disks are also dynamically different
- $M_{\star} < 25\ M_{\odot}$ + bona fide B-type Keplerian disks: $M_{dyn}/M_{gas} > 1$ ➔ centrifugally supported
- $M_{\star} > 25\text{-}30\ M_{\odot}$ ➔ $M_{dyn}/M_{gas} << 1$
- Toroids could **never reach equilibrium** and be **transient** entities with timescales of the order of t_{ff} ~10^4 yr



Beltrán & de Wit (2016)

- If structure rotates fast and t_{ff}/t_{rot} **high** ➔ infalling material that incorporates into the fast rotating structure has enough time to settle into a centrifugally supported **disk**

- If structure rotates slowly and t_{ff}/t_{rot} **low** ➔ infalling material does not have enough time to reach centrifugal equilibrium and the rotating structure is a transient **toroid** (rotation plays no role in their support)

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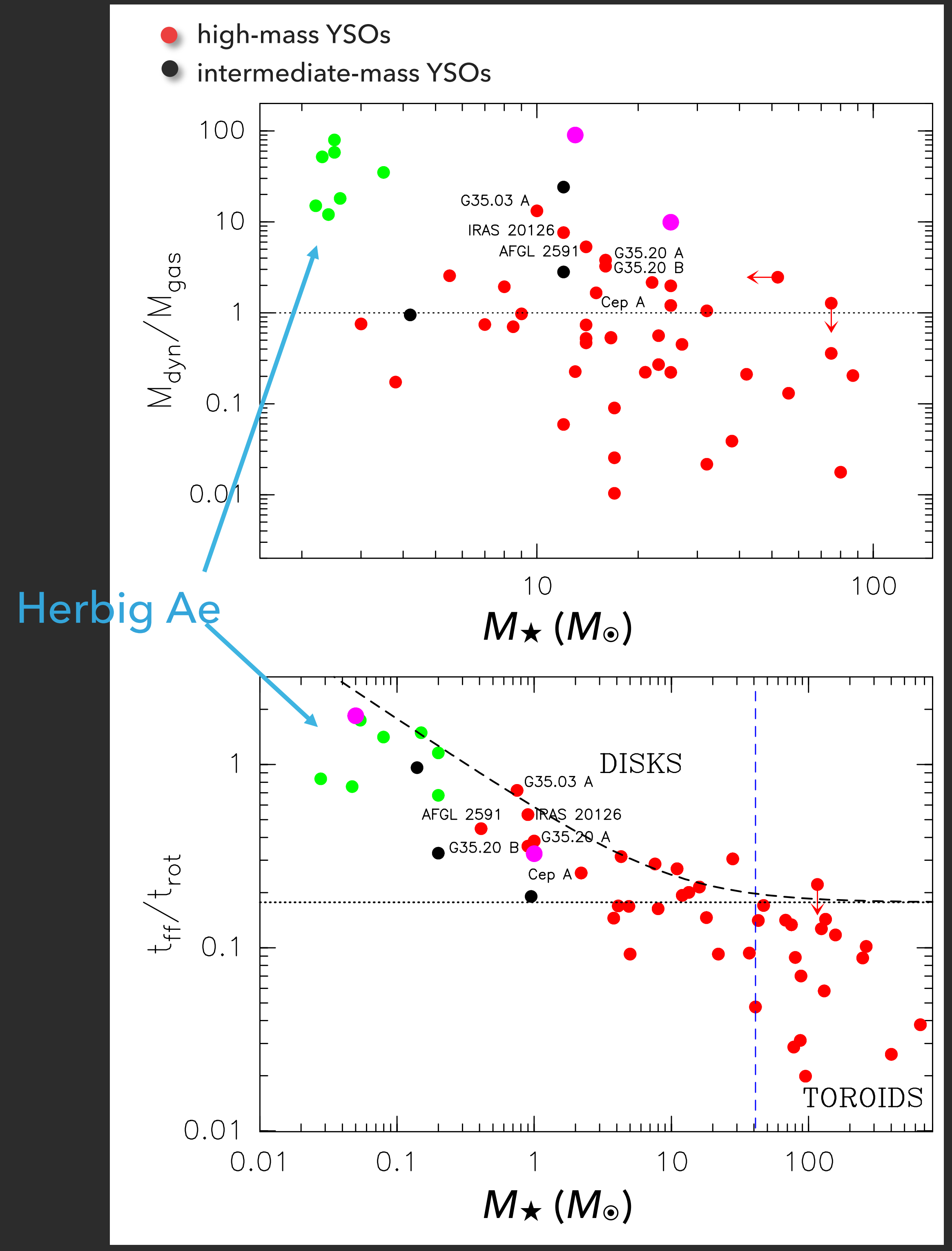

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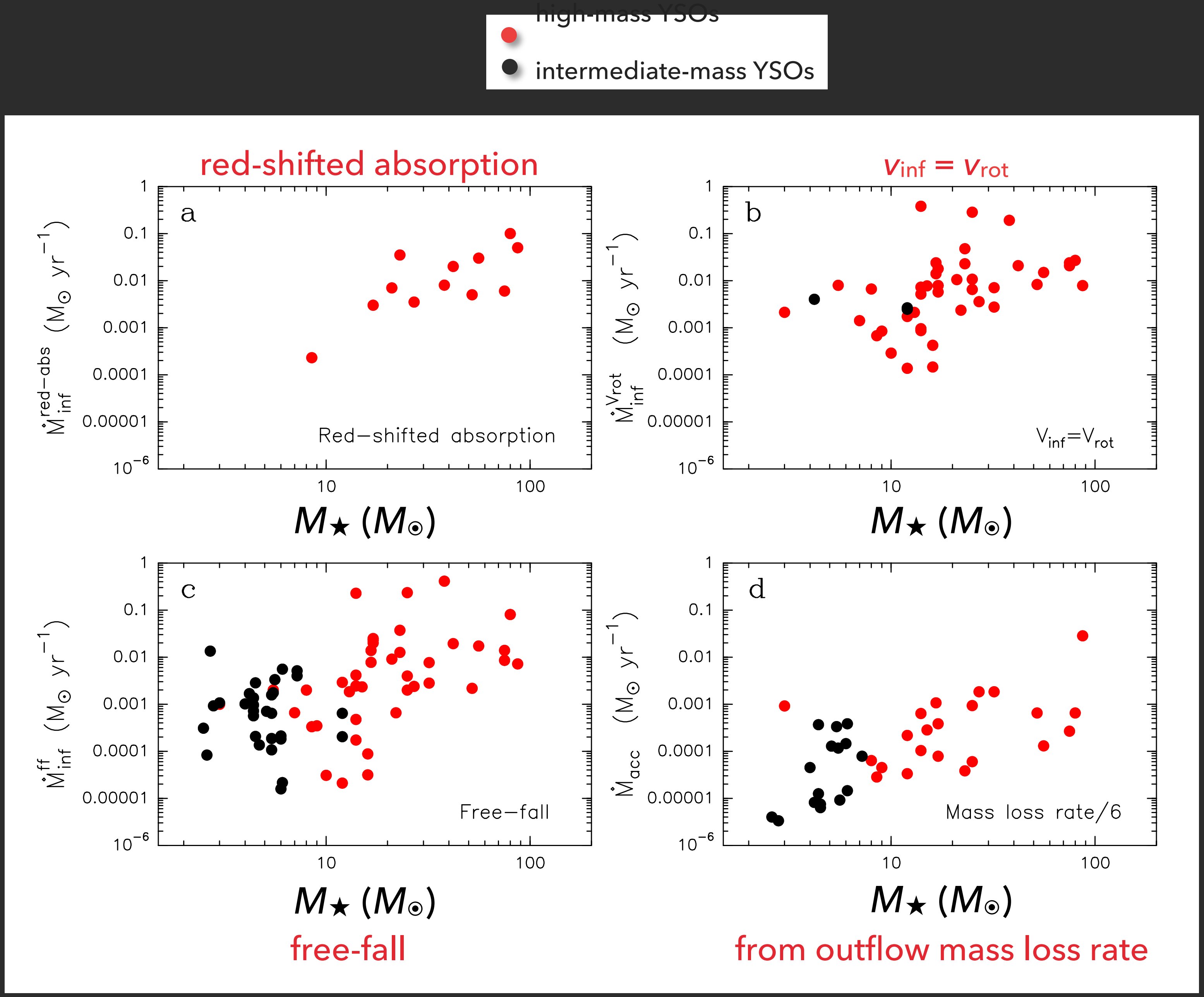
INFALL VS. ACCRETION

1. Red-shifted absorption
2. $v_{inf}=v_{rot}$
3. Free-fall → $\dot{M}_{inf} = M_{gas}\, t_{ff}$
4. Mass loss rate → $\dot{M}_{out} = 20\, \dot{M}_{jet} = 6\, \dot{M}_{acc}$ (Tomisaka 1998; Shu+ 1999)



Beltrán & de Wit (2016)

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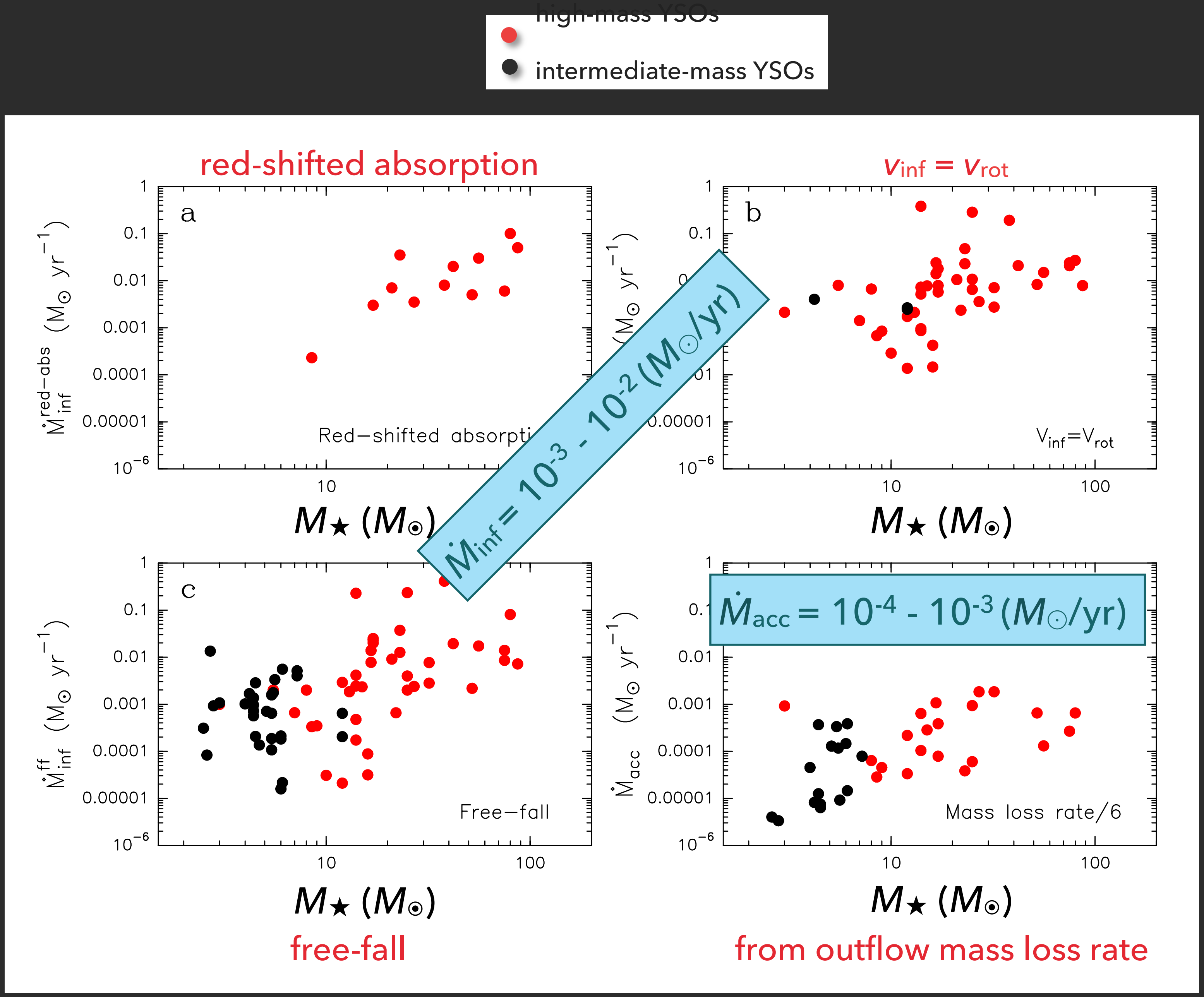
4. Mass loss rate → $\dot{M}_{out} = 20\,\dot{M}_{jet} = 6\,\dot{M}_{acc}$ (Tomisaka 1998; Shu+ 1999)

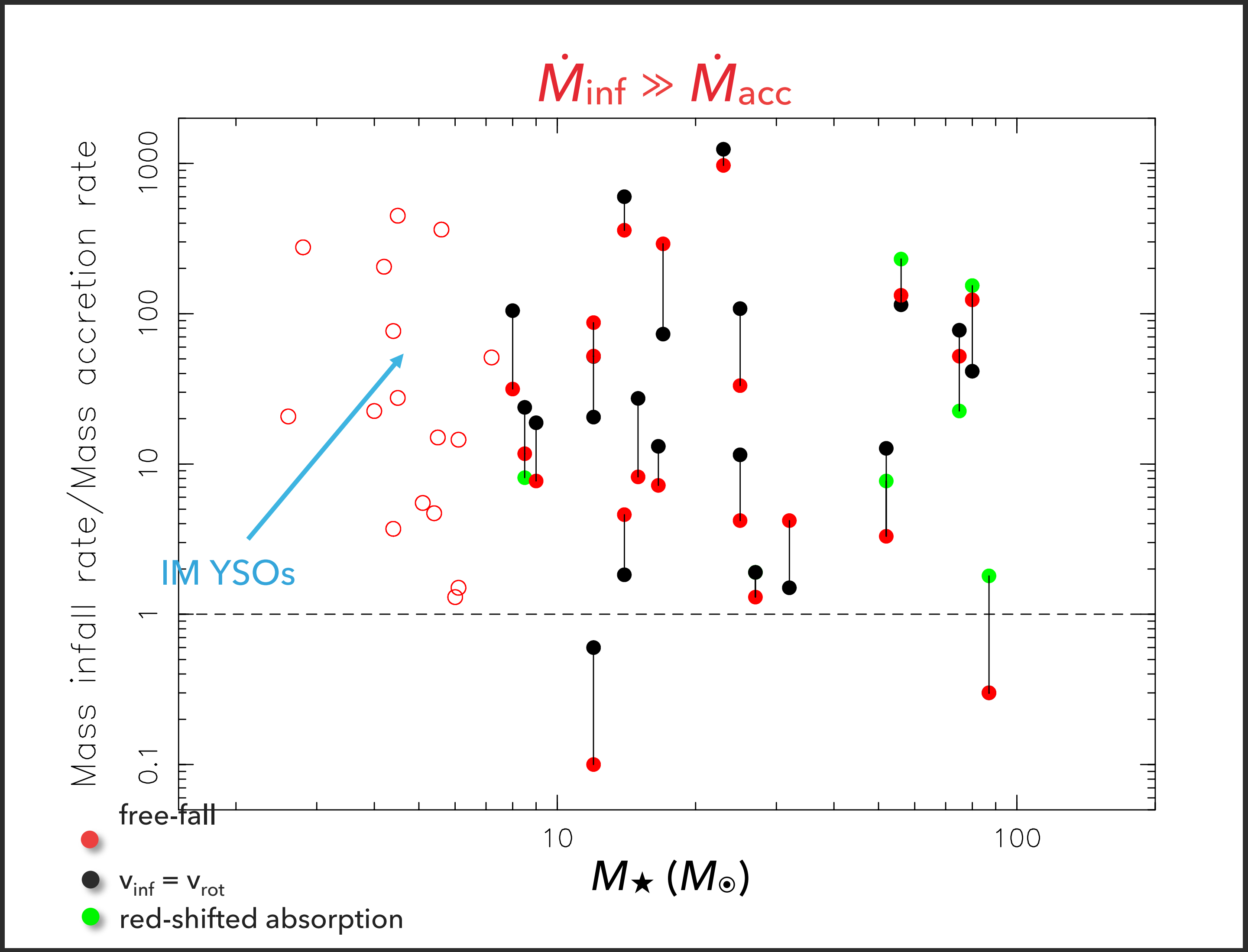
- Infall rate increases with mass of central star
- $\dot{M}_{inf} > \dot{M}_{acc}$ independently of method used



Beltrán & de Wit (2016)

INFALL VS. ACCRETION

- $\dot{M}_{inf} > \dot{M}_{acc}$ independently of method used
- Stellar multiplicity
- Infalling rate onto the disk different from accretion onto star → material piles up and results in disk masses which are tens to hundreds of solar masses. This is massive and suggests a gravitationally unstable disk-inducing variable, “FUOri-like” accretion events onto the central object.



Beltrán & de Wit (2016)

FIRST DISK-MEDIATED ACCRETION BURST FROM A HMYSO

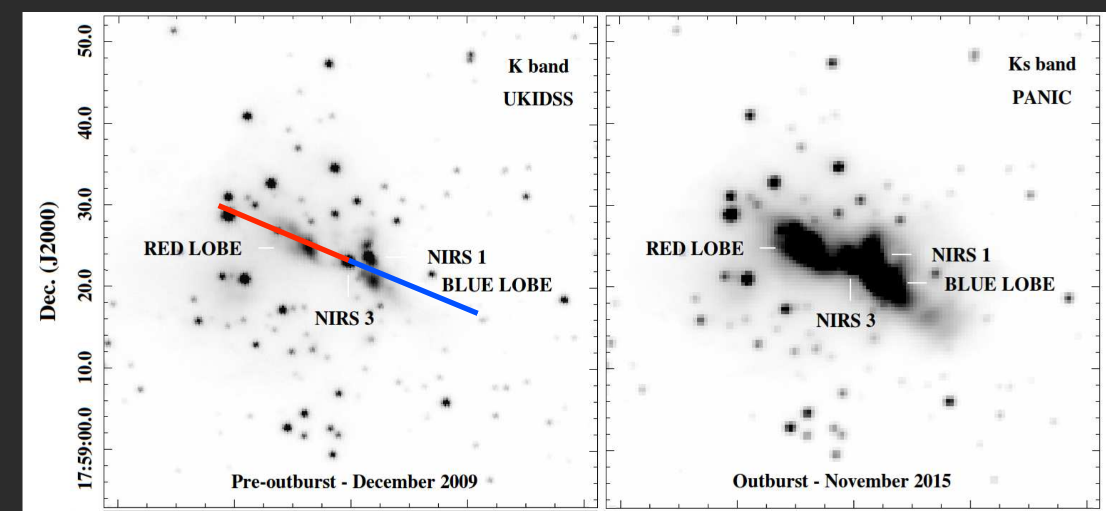
- S255 NIR 3: 2.4 x10^4 $L_\odot$ (~15 $M_\odot$)
- NIR photometry reveals an increase in brightness of 2.5-3.5 magnitudes and NIR spectroscopy reveals emission lines typical of accretion bursts in low-mass protostars, but orders of magnitude more luminous.
- The energy released and the inferred mass-accretion rate are also orders of magnitude larger.
- $\dot{M}_{acc} \sim 5 \times 10^{-3}$ $M_\odot$/yr (for 20 $M_\odot$ and 10 $R_\odot$)

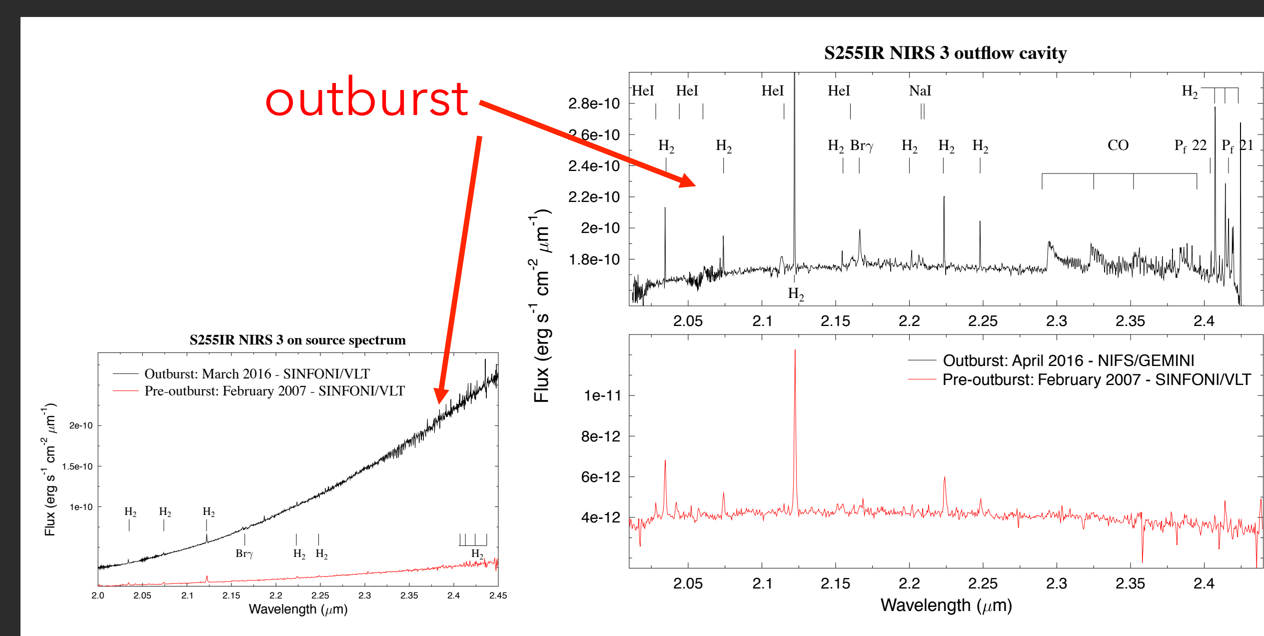
> ➢ See Poster #36 (Caratti o Garatti)

➢ See also Kumar+ (2016)

➢ Also NGC 6334I-MMI shows bursts at submm λ's (Hunter+ 2017)

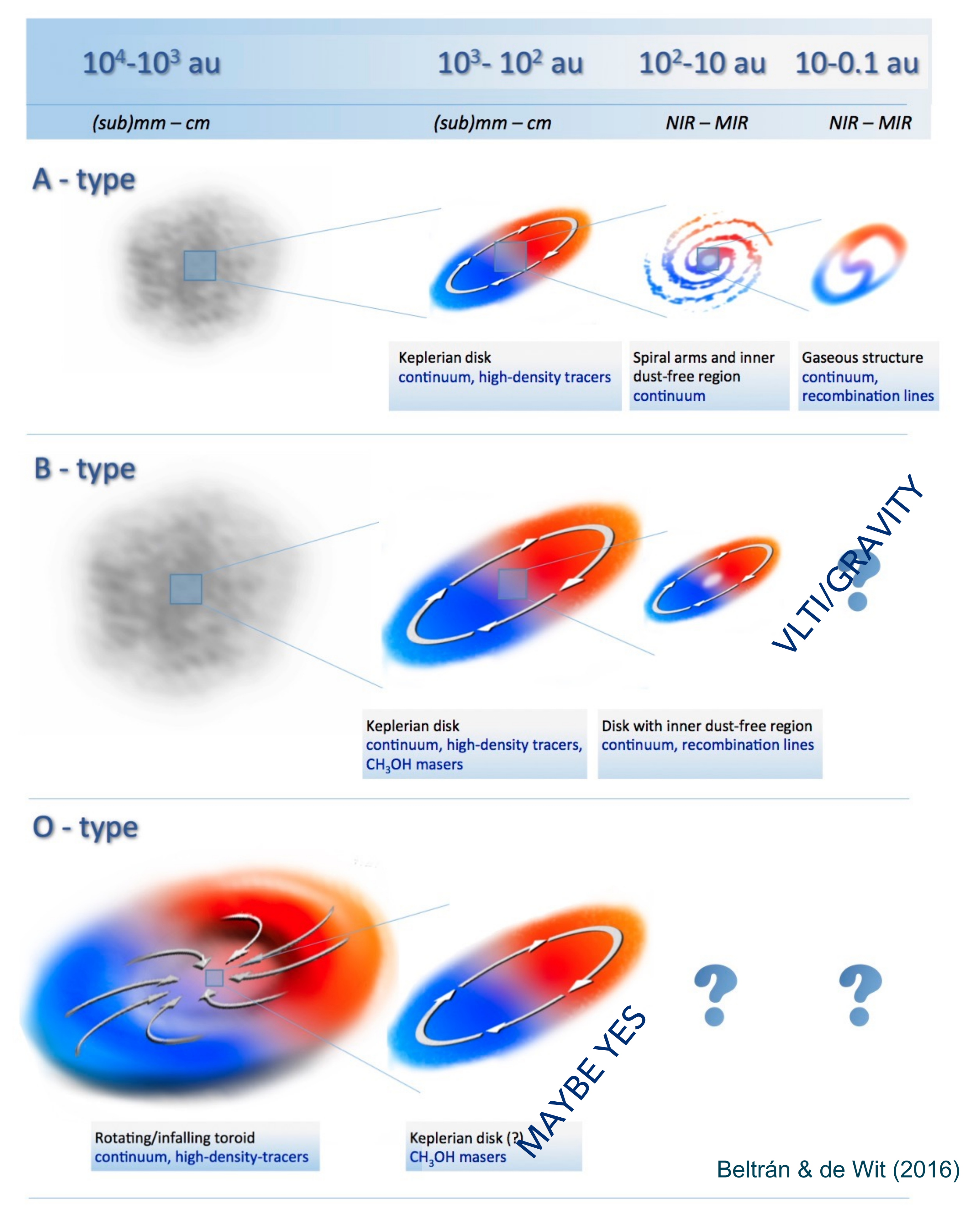
S255 NIR 3





Caratti o Garatti+ (2016)

SUMMARY



10^4-10^3 au
10^3- 10^2 au
10^2-10 au
10-0.1 au
(sub)mm – cm
(sub)mm – cm
NIR – MIR
NIR – MIR
A - type
Keplerian disk
continuum, high-density tracers
Spiral arms and inner dust-free region
continuum
Gaseous structure
continuum, recombination lines
B - type
VLTI/GRAVITY
Keplerian disk
continuum, high-density tracers, CH_3OH masers
Disk with inner dust-free region
continuum, recombination lines
O - type
Rotating/infalling toroid
continuum, high-density-tracers
Keplerian disk (?)
CH_3OH masers
MAYBE YES
Beltrán & de Wit (2016)