dissecting disks around B-type protostars

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SCIENTIFIC GOALS

- theoretical scenarios predict the formation of circumstellar disks [e.g., Bonnel & Bate 2006; Keto 2007; Krumholz et al 2009] but observational evidences for only a few B-type protostars [e.g. Cesaroni et al 2007; Kraus et al 2010; Beuther et al 2012]
- **search for and increase** the number of known, convincing (sub)Keplerian **disks in B-type protostars**
- **study the structure and kinematics of disks**
- determine the disk rotation curve

ALMA OBSERVATIONS

- band 7 [334.8 - 338.8 GHz] & [346.8 - 350.8 GHz]
  spectral resolution: 0.4 km/s
- most extended Cycle 0 array configuration
  angular resolution: 0.4 arcsec
  primary beam (field of view): 18 arcsec
  maximum observable structure: 2 arcsec
- correlator setup: CH_3CN(19-18), CH_3OH(7-6), SiO(8-7), $C^{34}S$(7-6), $C^{17}O$(3-2), $H^{13}CO^+$(3-2), and many others

TARGET CHARACTERISTICS

G35.20-0.74 N @ 2.2 kpc
R.A. = 18:58:13 Dec. = 01:40:36

G35.03+0.35 @ 3.4 kpc
R.A. = 18:54:00 Dec. = 02:01:19

- luminosities of $\sim 10^4$ $L_\odot$ ⟹ **B-type protostars**
- associated with free-free emission (VLA data) ⟹ **thermal jets / HII regions**
- bipolar nebulosities & green 'fuzzies' (IR data) ⟹ **bipolar outflows**
- prominent SiO emission (single-dish data) ⟹ **jets?**
- prominent CH_3CN emission (single-dish data) ⟹ **hot molecular cores?**

G35.20-0.74 N

1. description of the region

- NE-SW infrared (IR) bipolar nebulosity
- NE-SW molecular outflow (in CO, HCO^+)
- N-S thermal radiojet in cm continuum

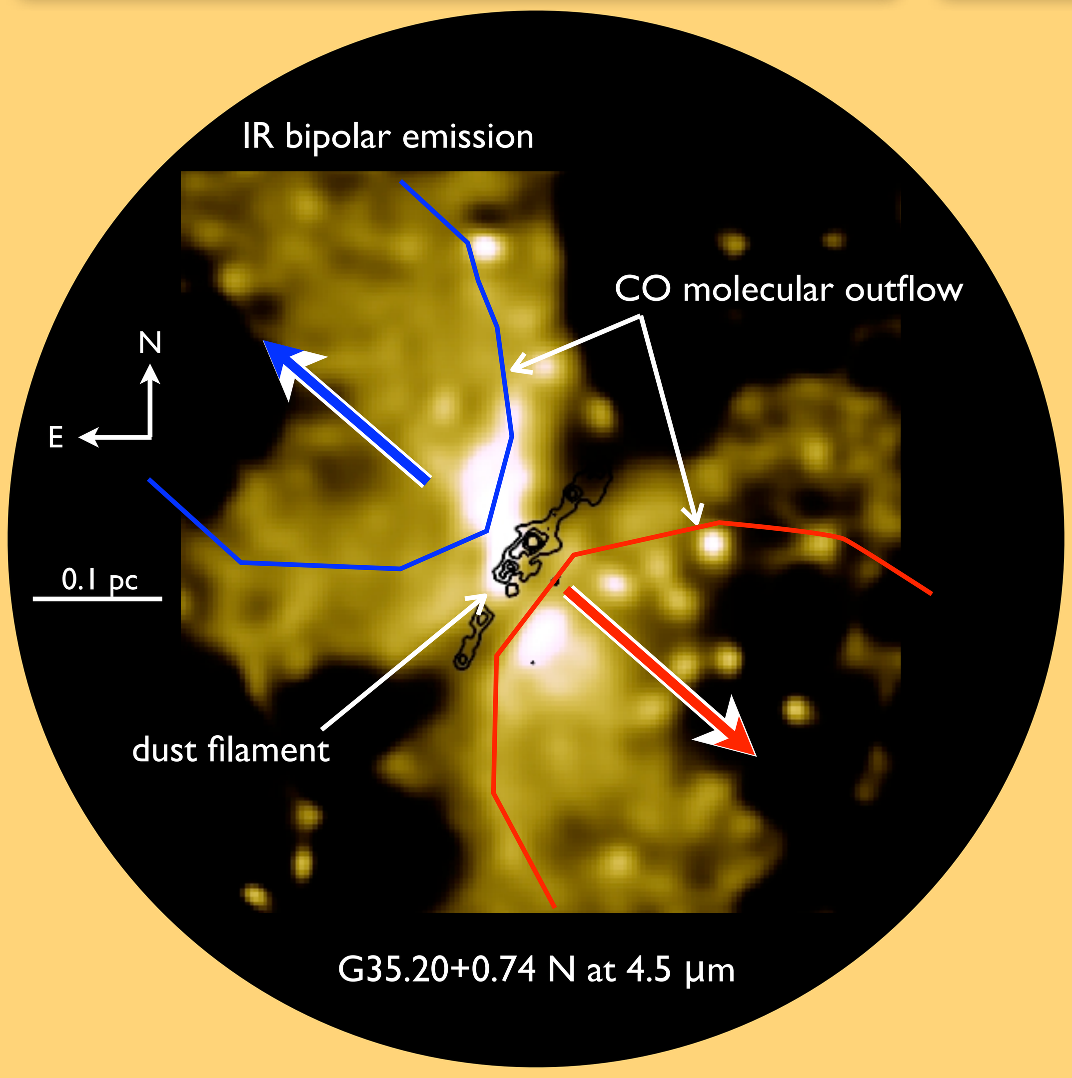
[Gibb et al 2003; De Buizer 2006; Wang et al 2013]

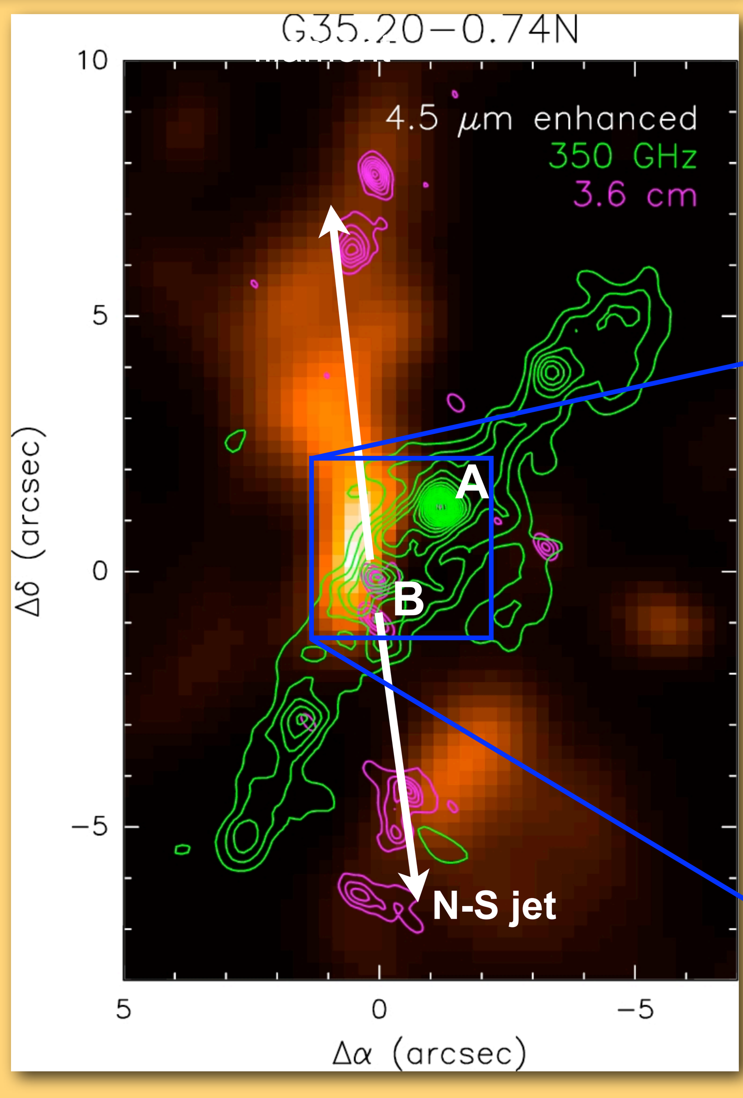
2. ALMA 350 GHz continuum emission

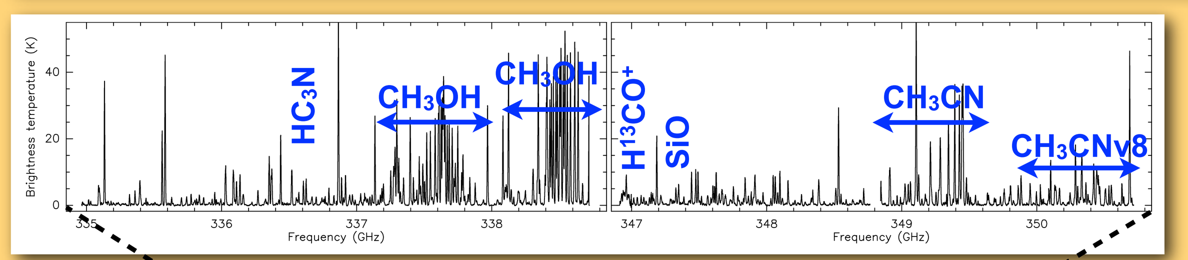
- **80 $M_\odot$ filament**, perpendicular to the IR bipolar nebulosity
- **multiple cores** found along the filament
- core A is the strongest dust condensation
- core B lies at the center of N-S jet, detected in cm & IR

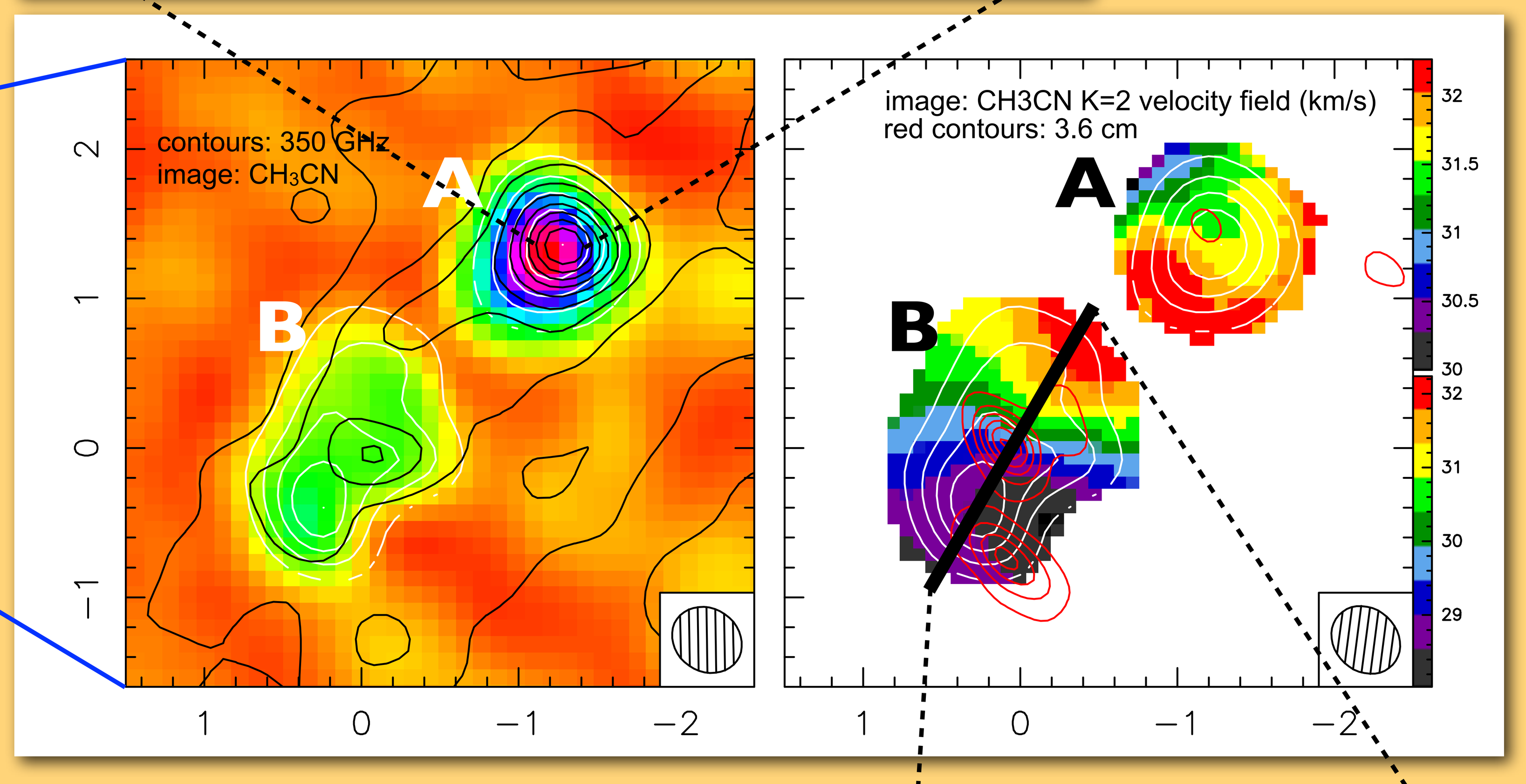
3. ALMA molecular line emission

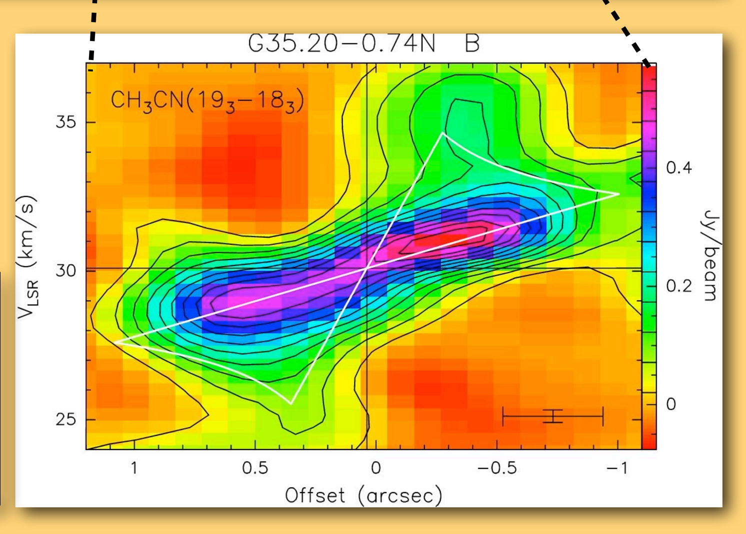
- cores A and B show **rich spectra**, with many **hot-core tracers**
- emission of core B is more elongated and fragmented than core A
- M_{gas} (A) = 4.4 $M_\odot$ and M_{gas} (B) = 2.8 $M_\odot$ for a T = 100 K
- **velocity gradients perpendicular to the bipolar outflow/IR-nebulosity**







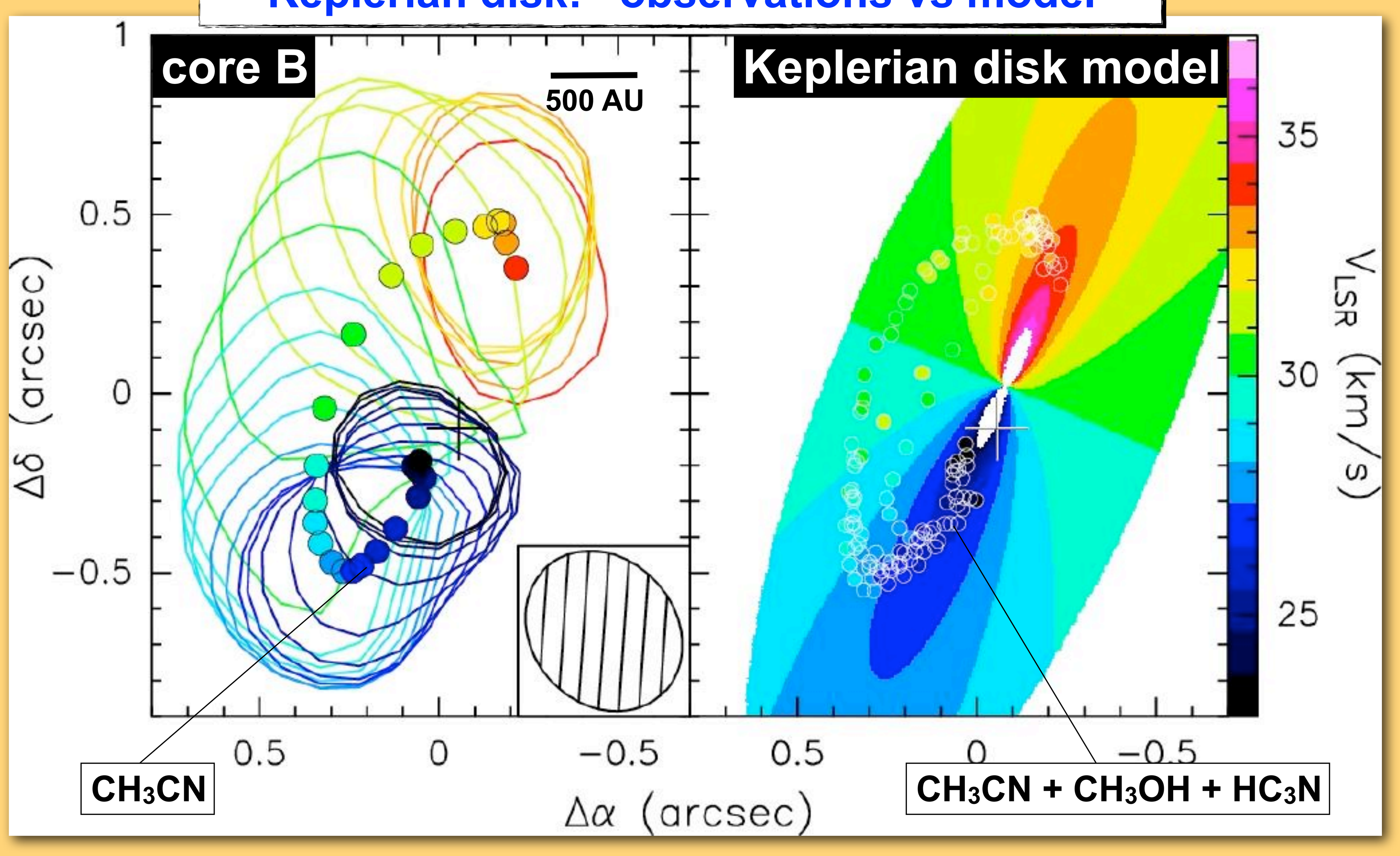




4. position-velocity plot across core B

- the white pattern encompasses the region where emission is expected from a **Keplerian disk** inclined by 19º and rotating about an **18 $M_\odot$ star**

Keplerian disk: observations vs model



5. Keplerian disk in core B?

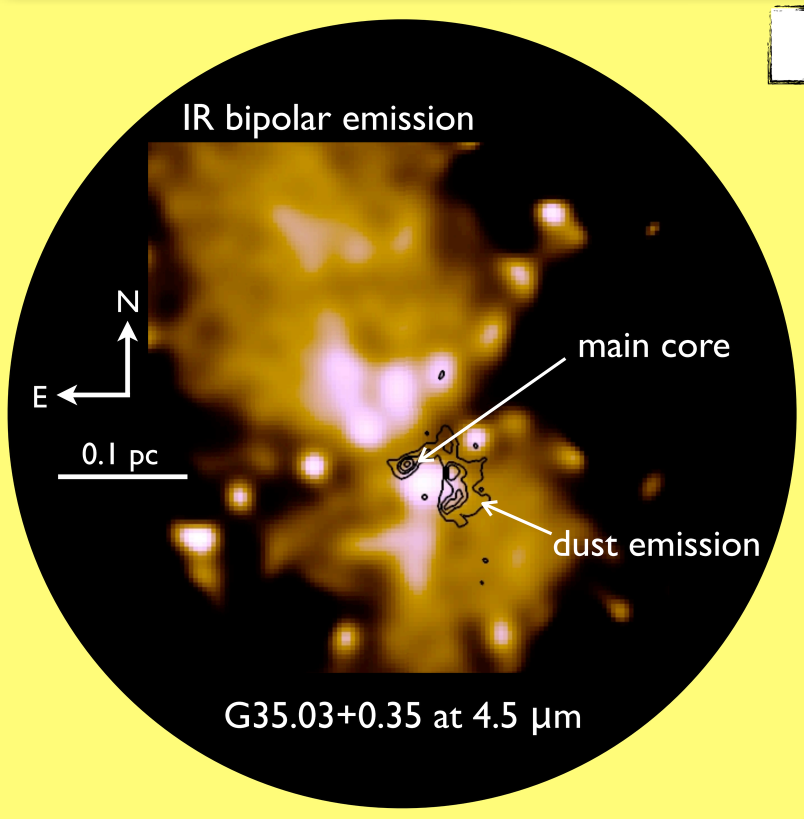
[see recent publication: Sanchez-Monge et al 2013, A&A, 552, L10]

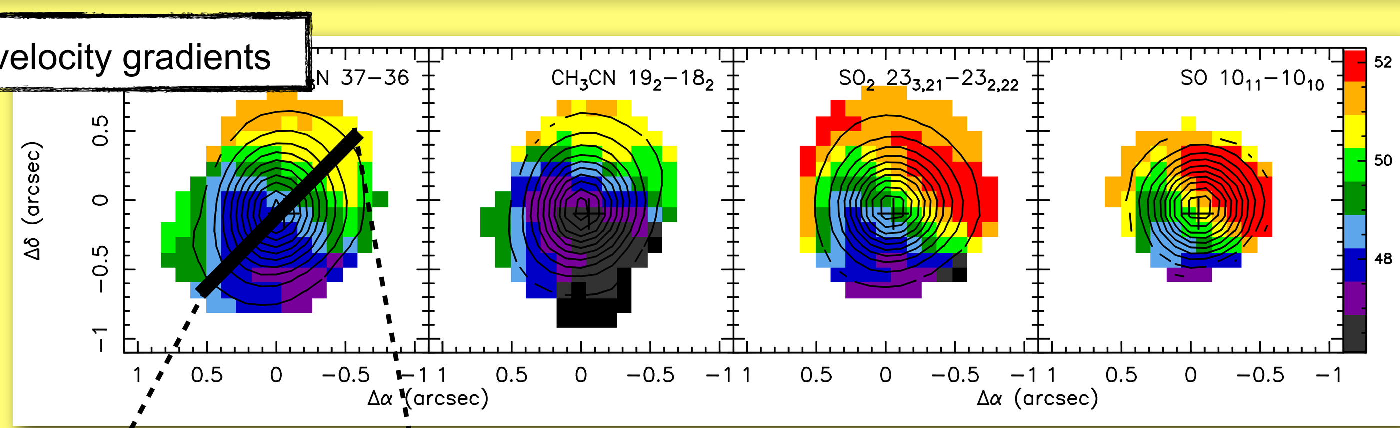
left panel - peaks (from 2D-Gaussian fits) and 50% contour levels of CH_3CN emission
colors correspond to velocities (ie, different channels), the cross marks the continuum peak

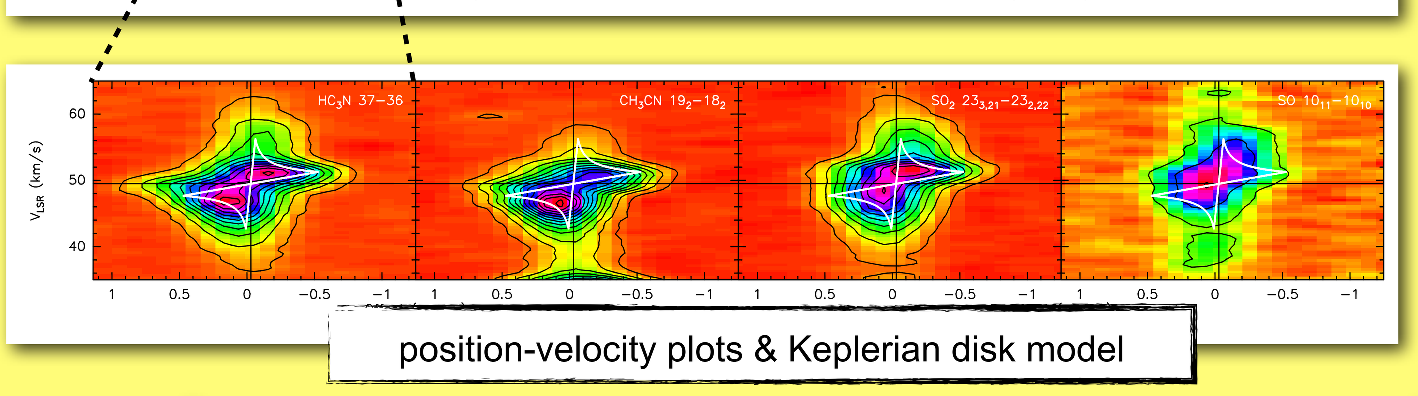
right panel - solid circles: peaks of emission at different velocities of CH_3CN, CH_3OH and HC_3N
color: best-fit **Keplerian disk** model inclined by 19º and **rotating about an 18 $M_\odot$ object**

- why line emission is detected only from the upper part of the disk?
  possible opacity effect due to disk inclination w.r.t. the line of sight (may work for a flared disk)
- the dynamical mass (18 $M_\odot$) implies $\geq 3\cdot10^4$ $L_\odot$, greater than the bolometric luminosity of G35.20-0.74N
  this problem may be solved by postulating a close **binary system in Core B**

G35.03+0.35







1. ALMA 350 GHz continuum and line emission

- filament (with multiple cores) surrounding the IR emission
- **main core** at the center of the bipolar infrared nebulosity, and associated with weak cm free-free emission

[Cyganowski et al 2008; Codella et al 2010; Brogan et al 2011]

2. velocity maps and pv-plots

- clear **velocity gradient** SE-NW, perpendicular to bipolar nebulosity
- position-velocity plots along the velocity gradient (PA=-45º)
- white patterns encompass the region where emission is expected from a **Keplerian disk** rotating about a **6 $M_\odot$ central object**

SUMMARY

- **ALMA observations** of circumstellar disks in B-type protostars
- detection of **dust filaments** (~ 80 $M_\odot$) with elongations perpendicular to IR bipolar nebulosities and outflows/jets
- **several cores** (with masses 1 - 5 $M_\odot$) **along the filaments**, some of them showing rich chemistry (hot molecular cores)
- **velocity gradients** perpendicular to the IR bipolar nebulosities, likely tracing the kinematics of **rotating** structures
- **G35.20-0.74 N**
  core B is resolved and can be modeled with an almost edge-on **Keplerian disk around an 18 $M_\odot$ source**, possibly a **binary system** [see Sanchez-Monge et al 2013, A&A, 552, L10]
- **G35.03+0.35**
  the main dense core shows **Keplerian-like rotation around a ≥ 6 $M_\odot$ star**

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