(A biased view of)

Star Formation with the SKA

Wouter Vlemmings (Chalmers)

with: Gabriele Surcis, Huib Jan van Langevelde, Chema Torrelles, Busaba Hutawarakorn-Kramer, Kalle Torstensson, Melvin Hoare et al.

Issues during star formation

- Outflows
  - loss of angular momentum
  - clearing of proto-stellar envelope / feedback
- Disks (and disk winds)
  - radiation pressure outflows
- Fragmentation
  - binary formation
- Distances
- Magnetic fields
- Heavy (pre-biotic) molecules?

Issues during star formation

✓ Outflows

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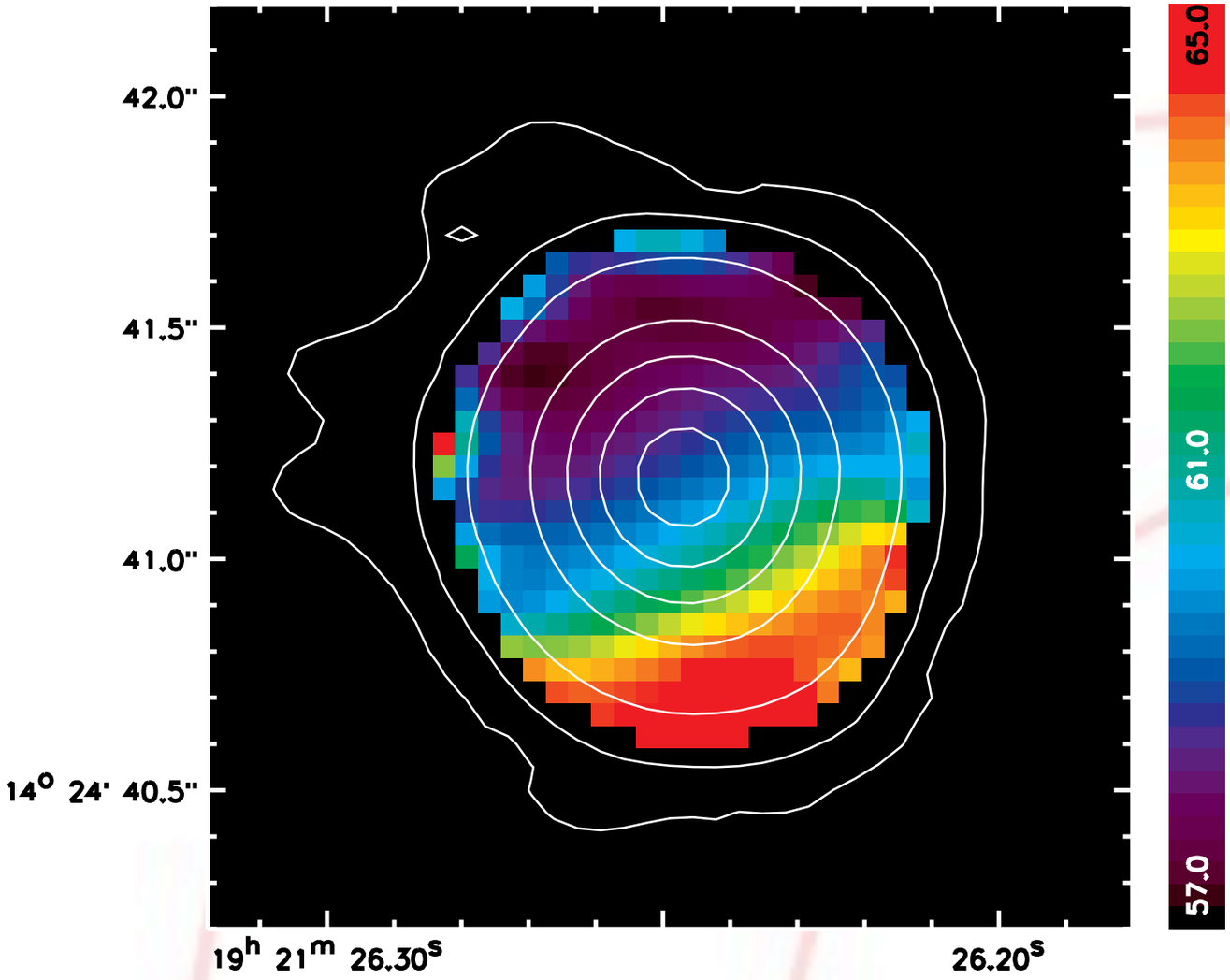
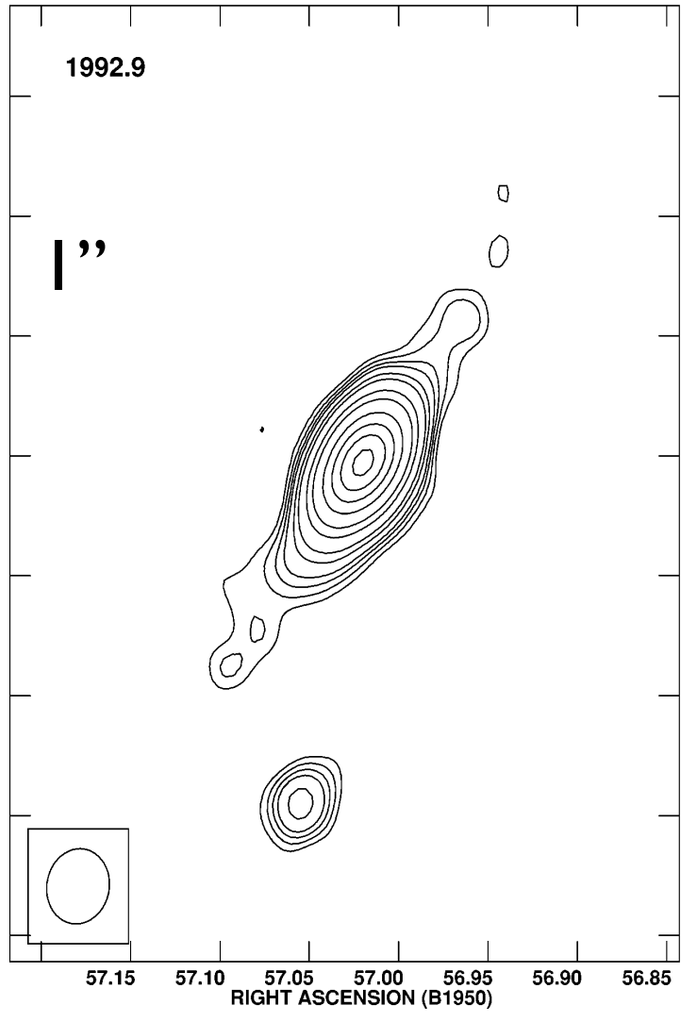
- clearing of proto-stellar envelope / feedback



Radio-recombination lines

Keto & Klaassen 2008



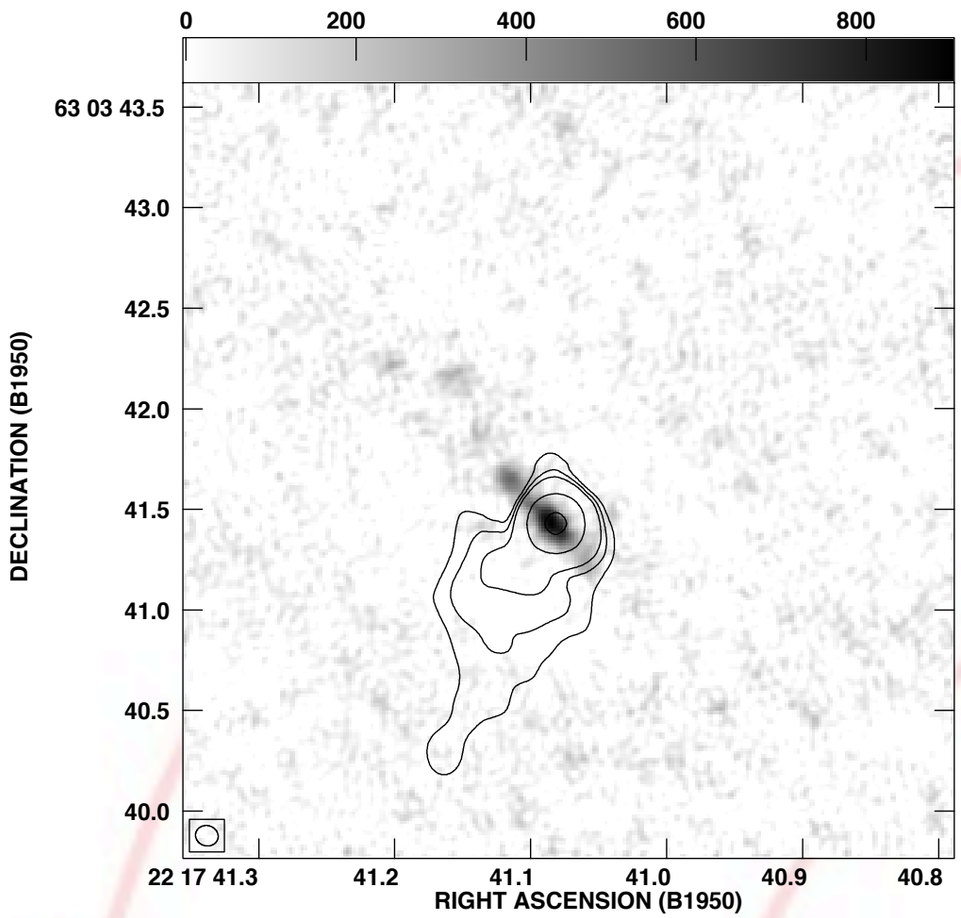
Ionised continuum

Rodriguez et al. 2000

Issues during star formation

✓ Disks (and disk winds)

- radiation pressure outflows



5 GHz continuum

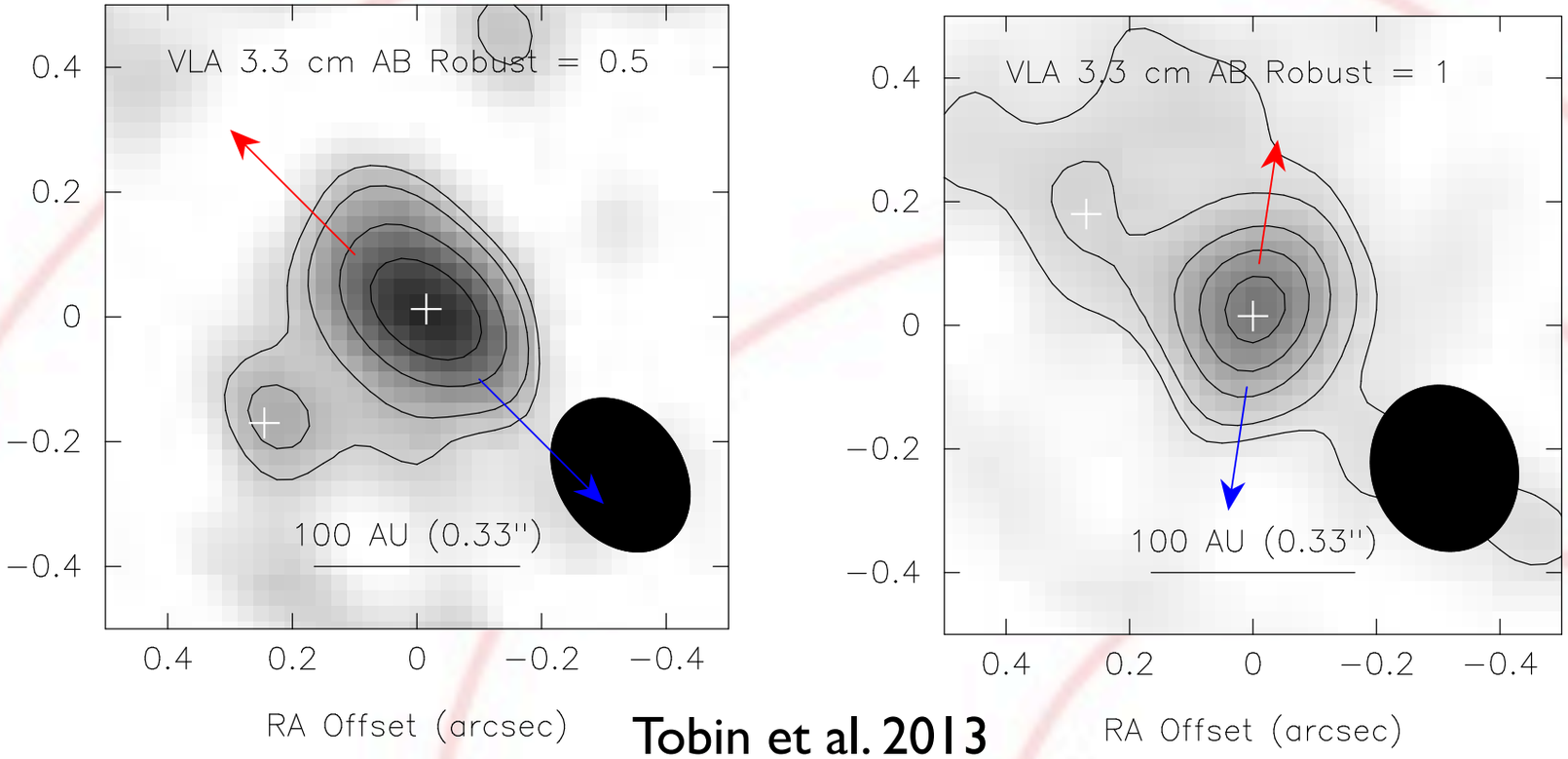
Hoare 2004

Compare bipolar jets with equatorial outflows (evolutionary effect?)

Weak HI emission from disks/ outflows (currently impossible)

Issues during star formation

- Fragmentation
  - binary formation
  - Resolve weak radio emission from protostars and possible companions
  - Needs highest SKA resolution



Tobin et al. 2013

Issues during star formation

✓ Distances

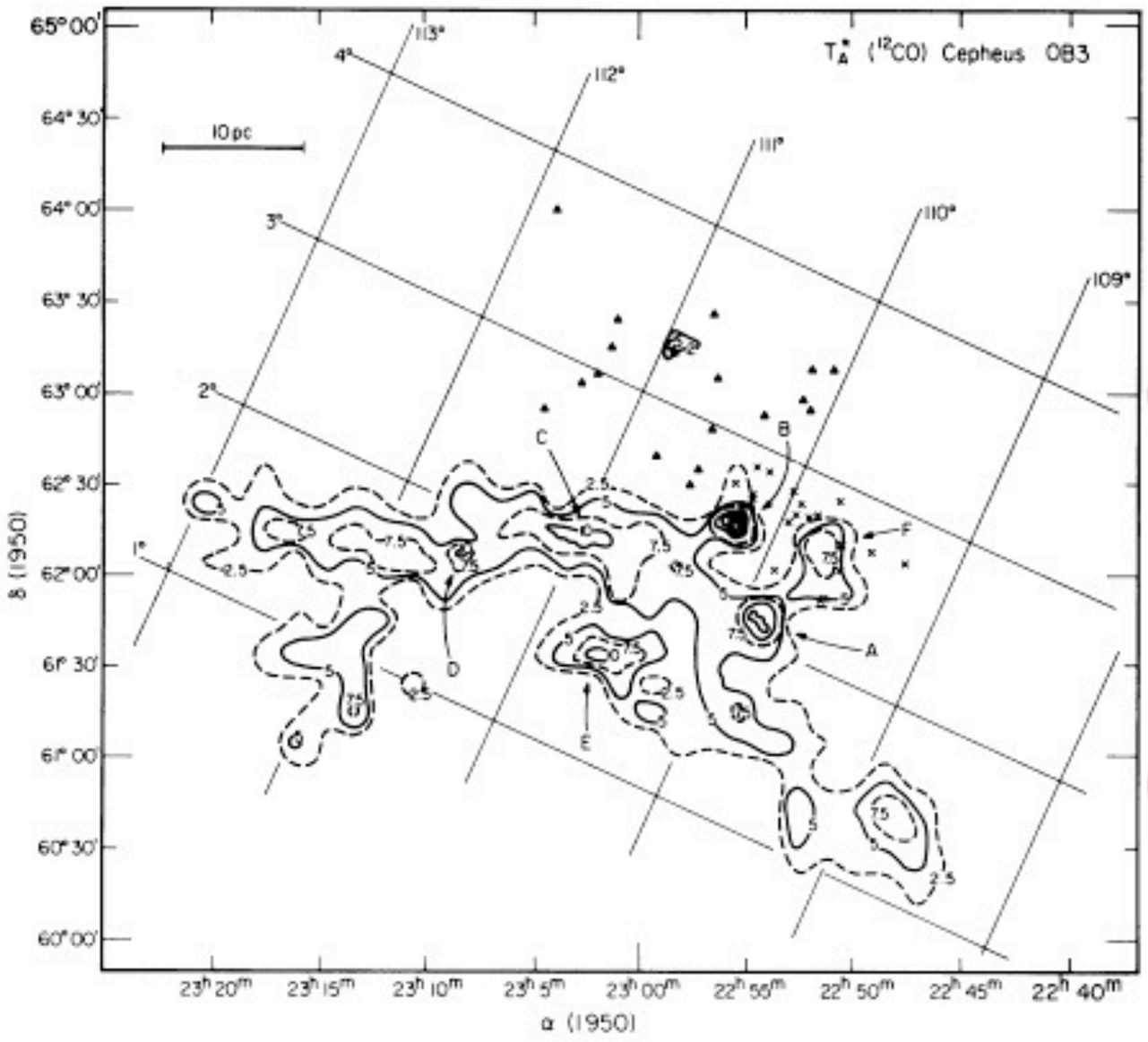
- Parallaxes of masers or faint radio stars
- Phase 1 SKA needs SNR 50-100 for good positional accuracy (doable for methanol masers)
- SKA as VLBI station with EVN!
- Distances out to 10 kpc for star forming regions unreachable by GAIA

Issues during star formation

✓ Magnetic fields

- Ambipolar diffusion/outflow launching
  - At cm wavelengths will be able to probe within optically thick dust
  - Complementing ALMA dust and CN observations probing different density regimes
  - HI, OH, CCS (11 GHz) and masers
  - Faraday rotation of background sources

Example: Cepheus A



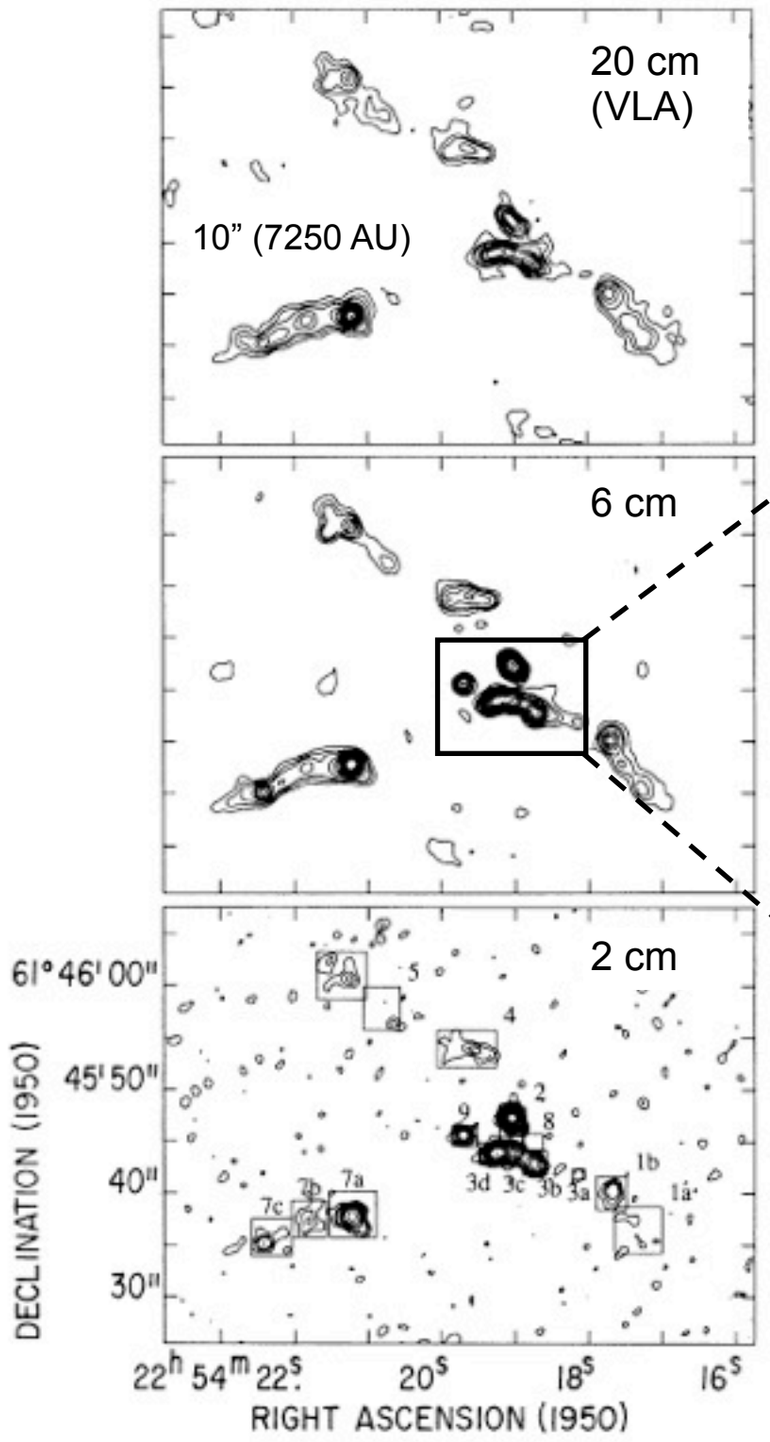
Cepheus OB3 molecular complex of ~ 10^5 $M_\odot$

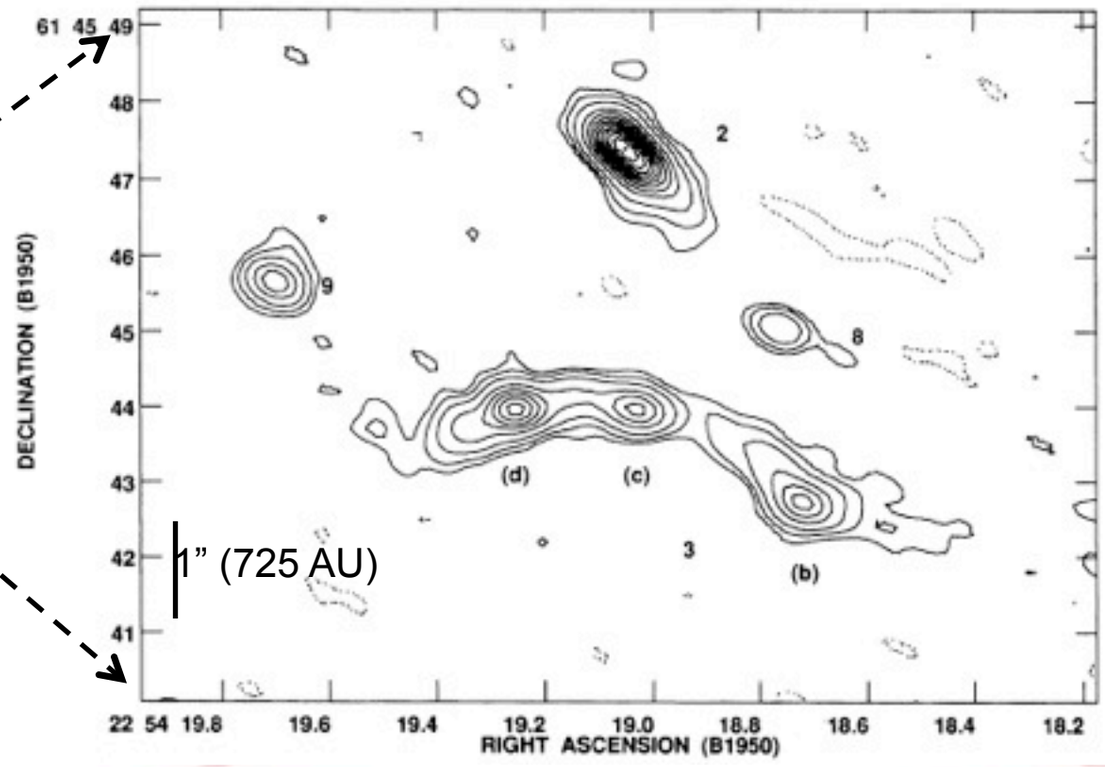
(@ 700 pc, the second nearest high-mass star forming region after Orion)

HW Radio Continuum Sources

(Hugues & Wouterloot 1984)

(16 sources in a region of ≈ 30” size)



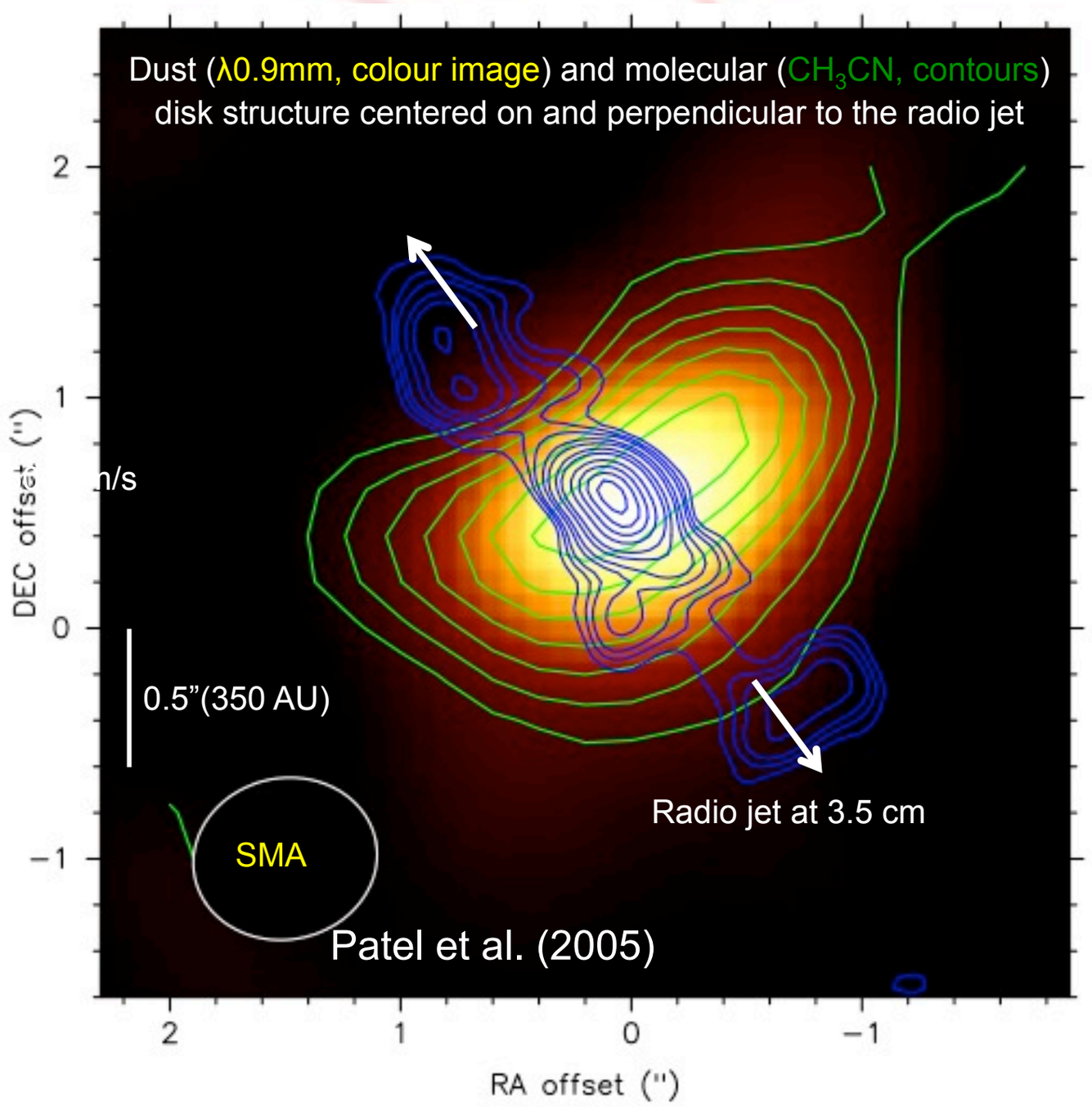


HW2: thermal bipolar radio jet excited by a massive protostar (15-20 $M_\odot$, Rodríguez et al. 1994) highly obscured ($A_V \sim 10^3$ mag, Torrelles et al. 1993)

SKA-mid resolution of 0.3” at 20 cm

Example: Cepheus A

- Cepheus A HW2 ~20 $M_\odot$ @ 700 pc
  (Jiménez-Serra et al. 2007; Moscadelli et al. 2009)
- Thermal radio jet, ionized gas at ~500 km/s (Curiel et al. 2006)
- Rotating dust (R~330 AU) and molecular gas (R~580 AU) disk structure ⊥ to outflow (Patel et al. 2005, Jiménez-Serra et al. 2007, Torrelles et al. 2007)
  - made up of at least 3 YSOs (e.g. Comito et al. 2007)
- Flattened 6.7 GHz methanol maser structure near disk plane (R~650 AU, h~300 AU)
  - infall at ~1.7 km/s (Torstensson et al. 2010, Sugiyama et al. 2013)



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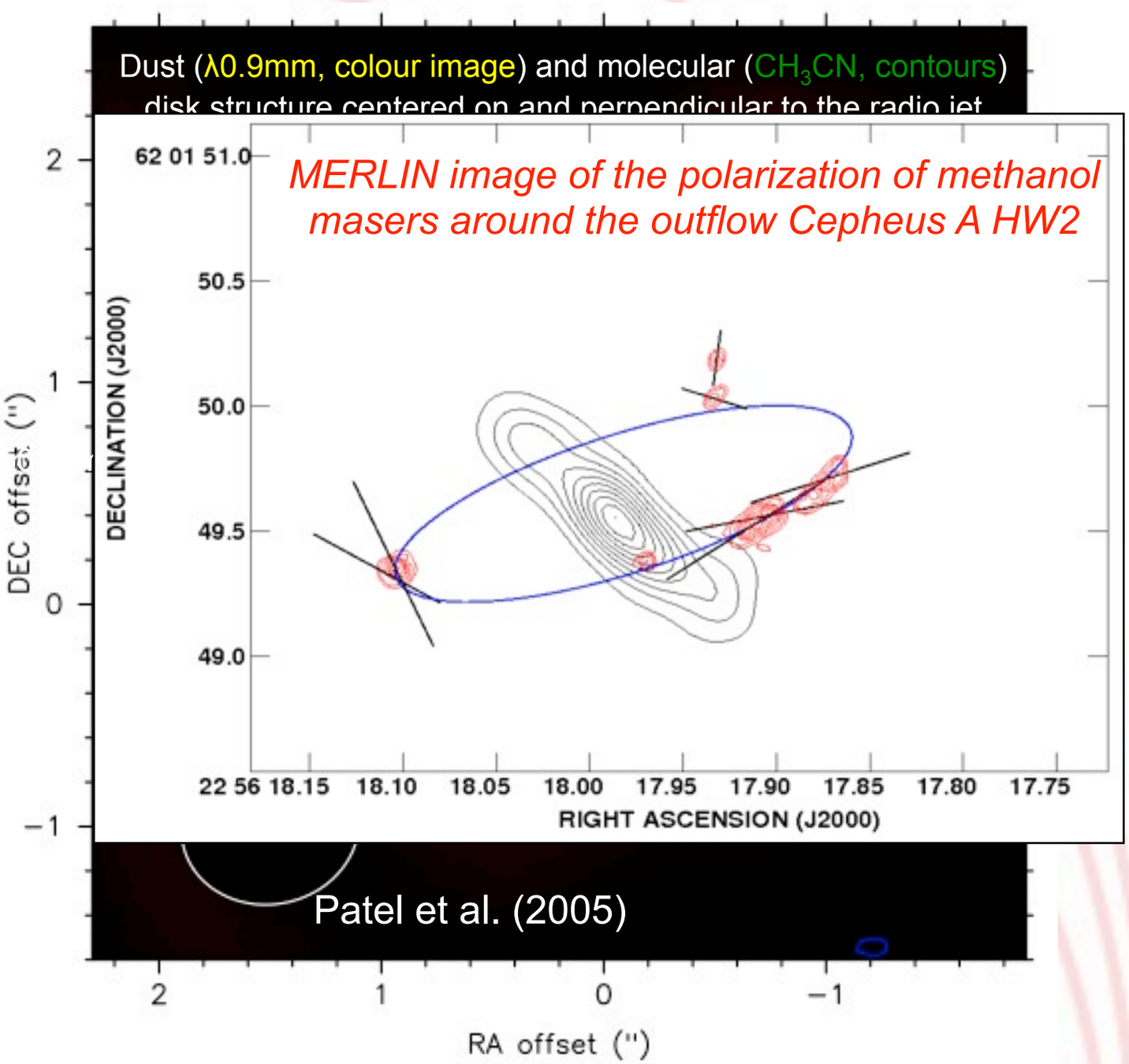
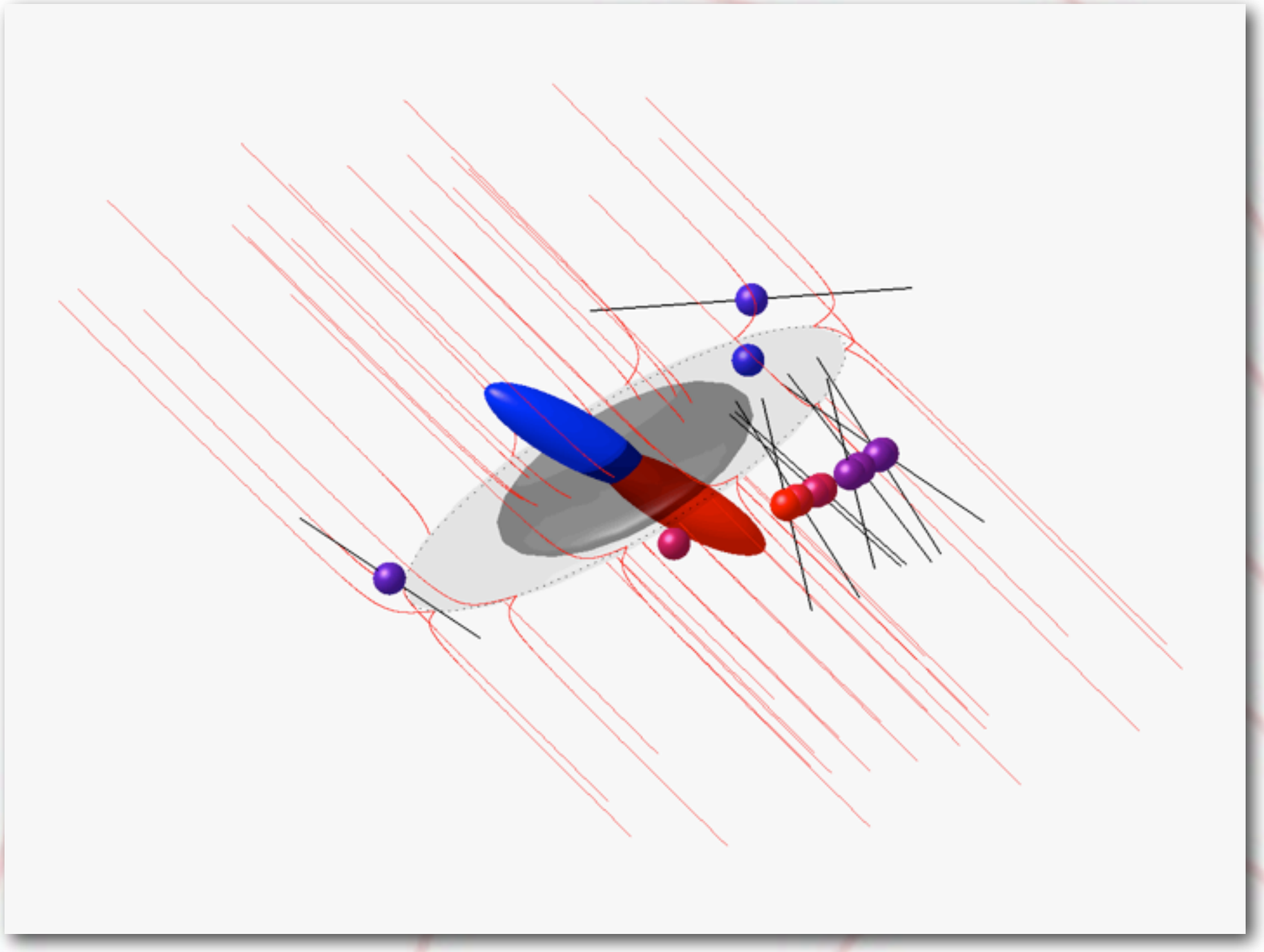


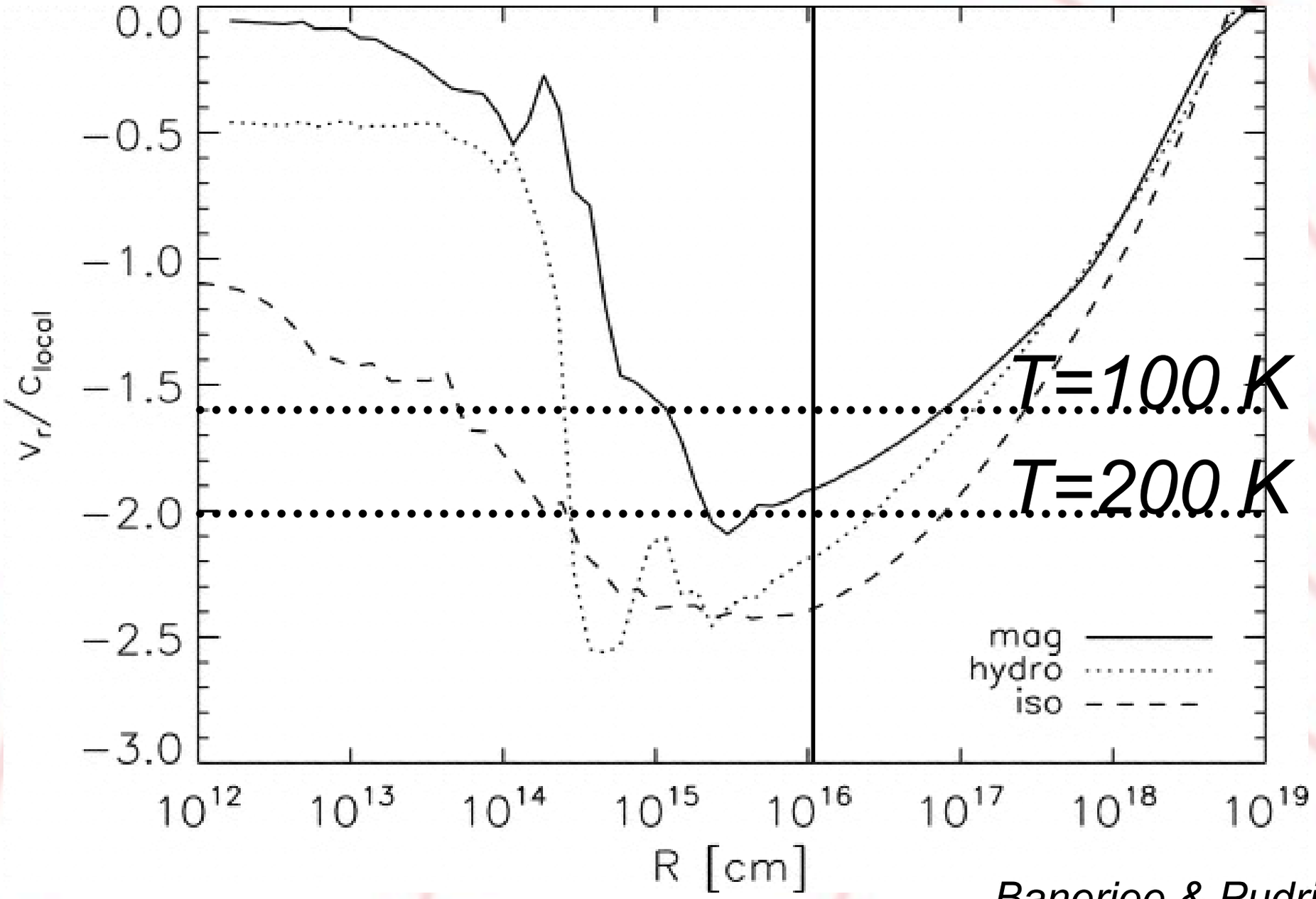
3D magnetic field structure



Methanol masers at 6.7 GHz using MERLIN (Vlemmings et al. MNRAS 2010)

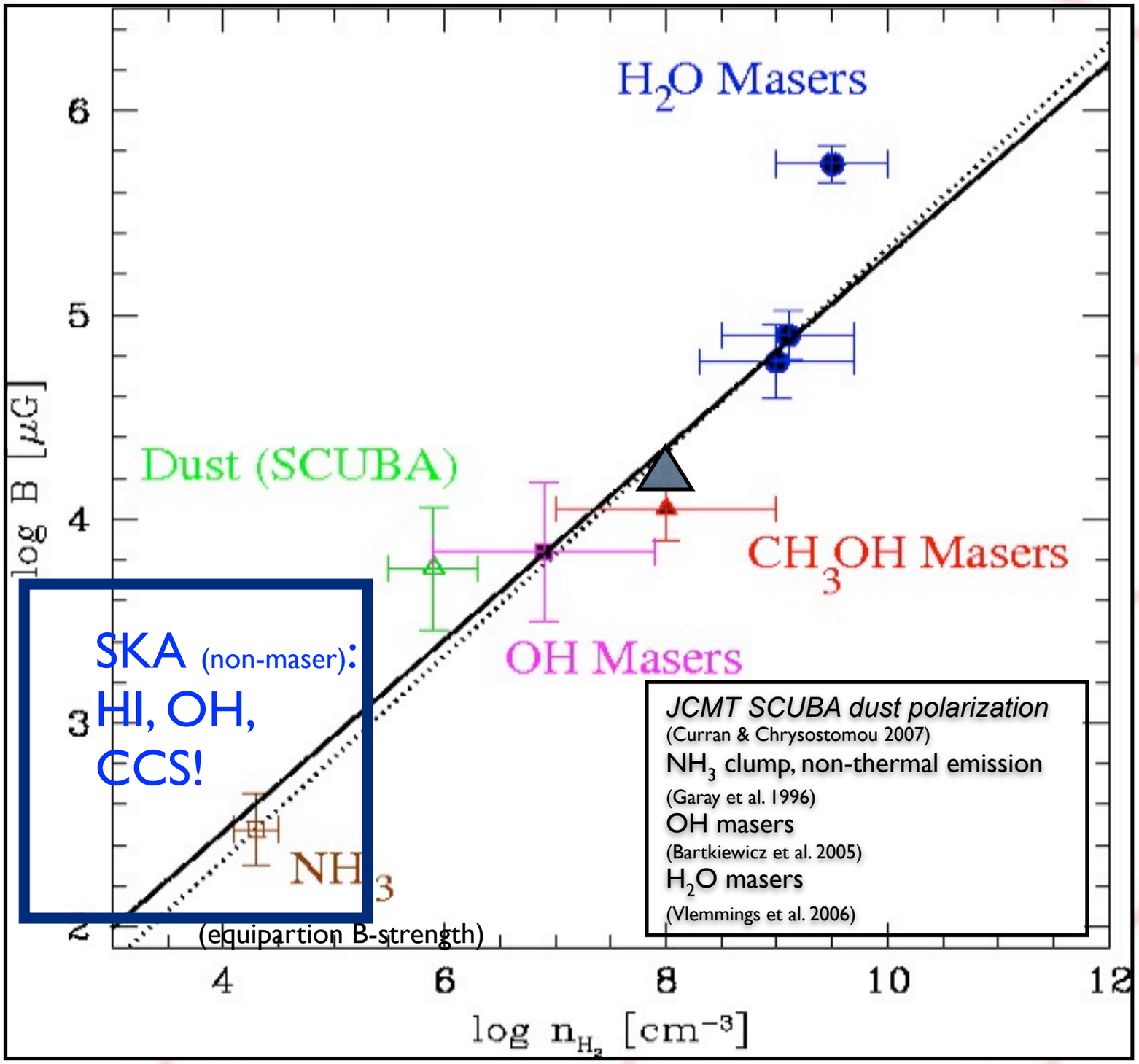
Model comparison

Infall motions consistent with current models of magnetic accretion

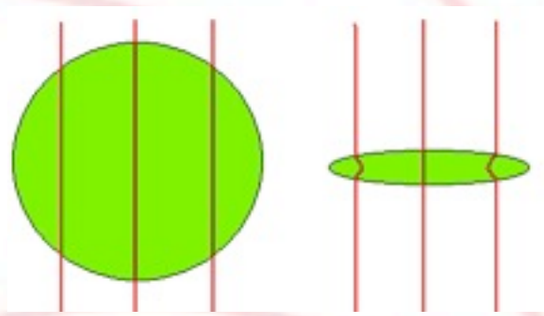


Banerjee & Pudritz 2007

B vs. n relation



- Single power-law fit for different observations gives:
  - $B \propto n^{0.47\pm0.08}$
- Magnetic field at inclination: $\theta = 73° \pm 5°$
  - $|B| = 23$ mG → 4 x turbulent energy
    - dominated energetics
  - mass-magnetic flux: $\lambda \approx 1.7$ (slightly supercritical)
    - collapse proceeding along field lines

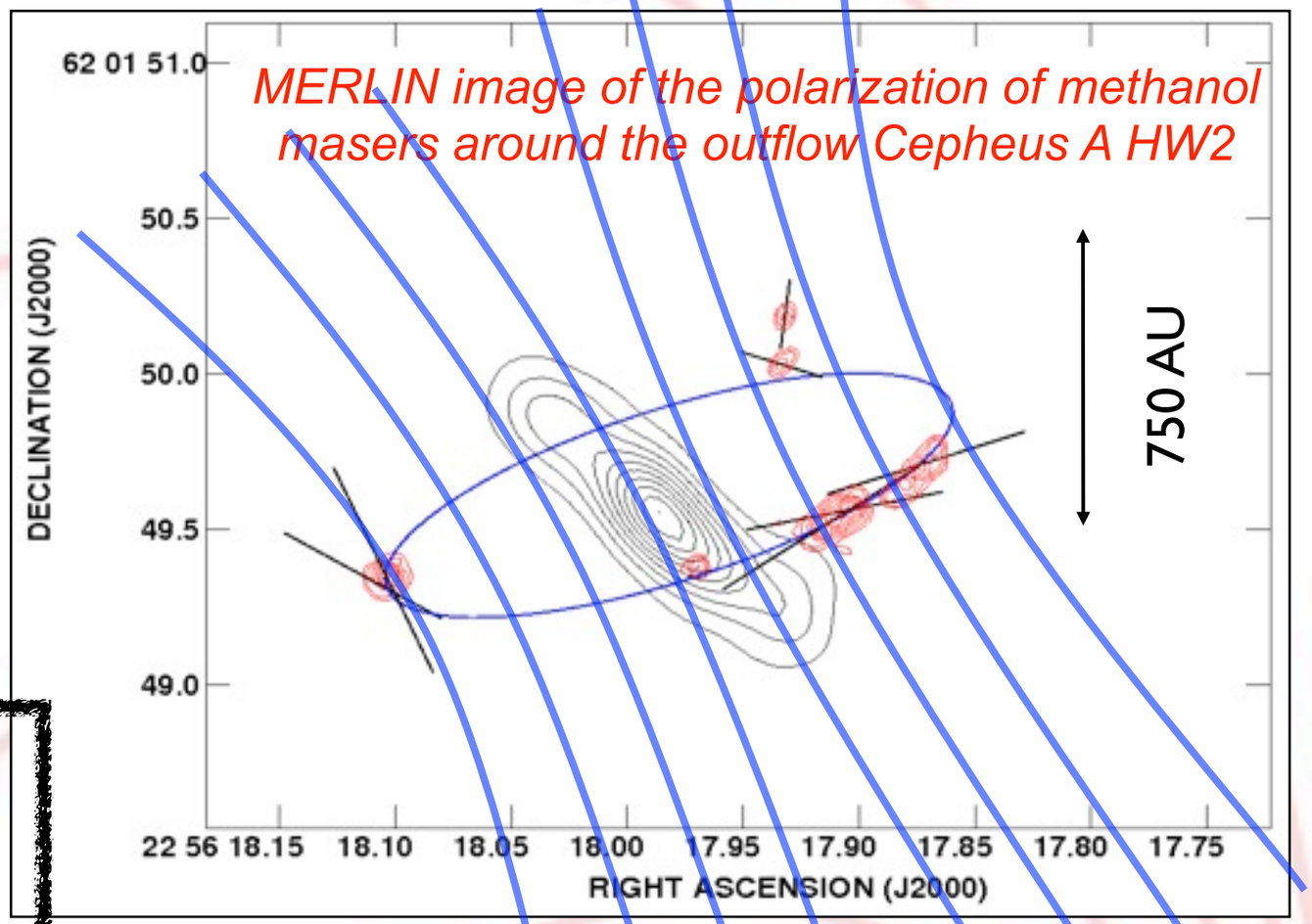


=> magnetic field regulated infall onto a protostellar disk!

‘Feedback during massive star formation’

e-MERLIN legacy project
PIs: W. Vlemmings (Onsala), M. Hoare (Leeds)

- e-MERLIN will be used to map continuum emission of ~100 massive star-forming regions
  - Outflow morphology, MHD jet launching etc.
  - Maser polarization observations
    - 3D magnetic field structure



SKA-mid:

Improves line and continuum sensitivity by factor 30 (though ~1/3 resolution)
Many more maser line of sights for more detailed 3D B-field reconstruction

SKA phase 1 & star formation

- Radio-recombination lines of youngest embedded sources
  - outflow kinematics, disks and disk winds
- Continuum of disks, outflows and protostars
  - Fragmentation, ionization and radiation pressure
- Distances to embedded star forming regions out to 10 kpc
  - (or even extragalactic using SKA VLBI)
- Biggest gain in magnetic field studies
  - currently prohibitively expensive in observing time
  - maser 3D field reconstruction