Monitoring the Large Proper Motions of Radio Sources in the Orion BN/KL Region

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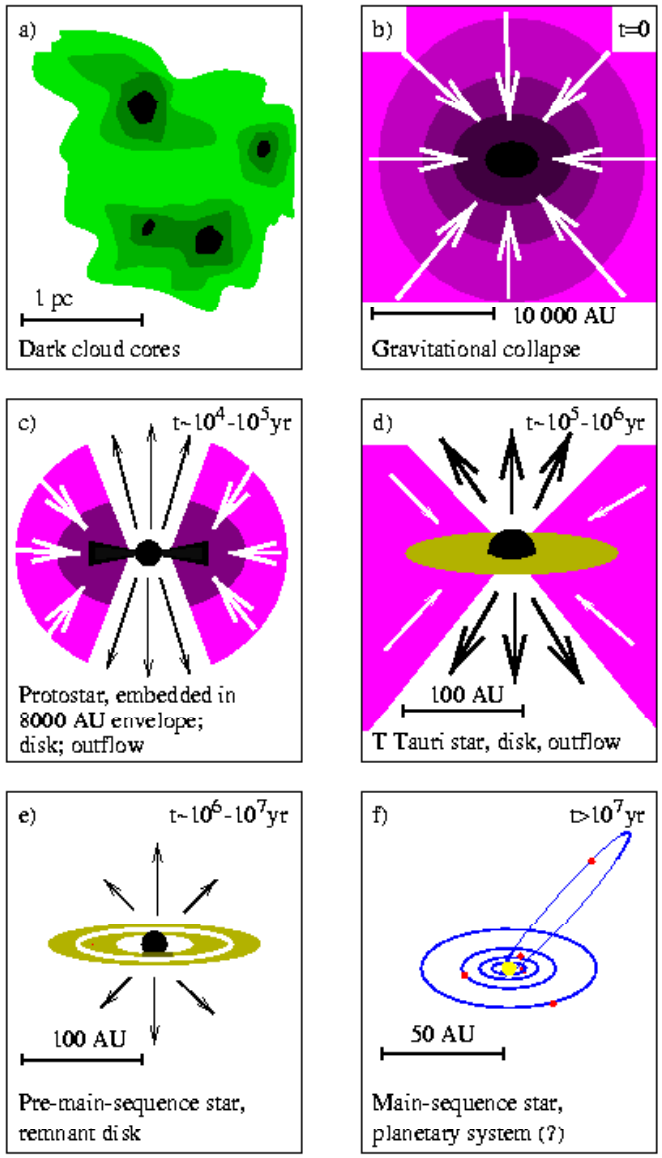
- Motivation
- The paradigm for low-mass star formation
- Merging of low mass stars to form massive stars?
- Conclusions



Hogerheijde 1998, after Shu et al. 1987

LOW MASS STAR FORMATION

a) Fragmentation of cloud

b) Gravitational contraction

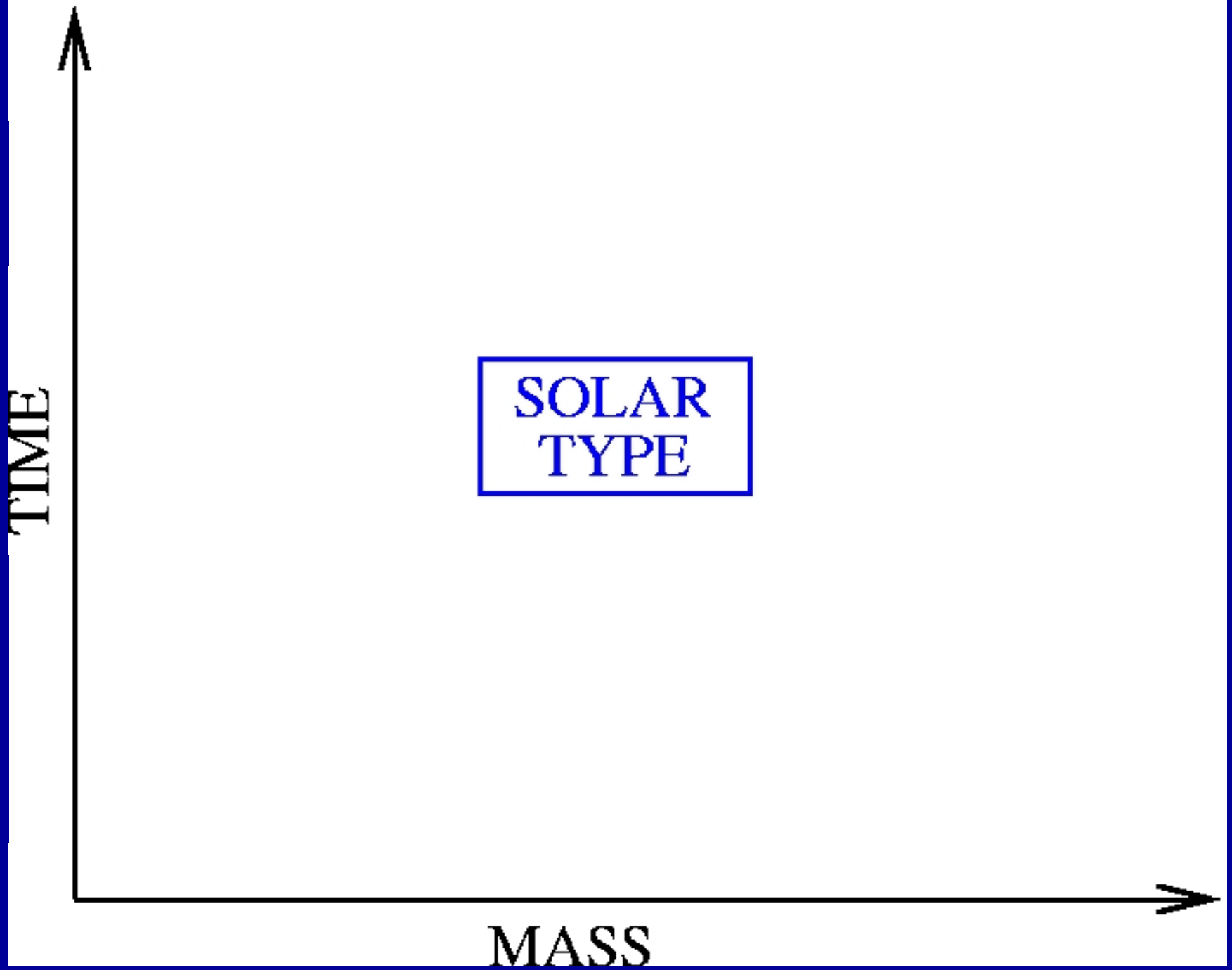
c) Accretion and ejection

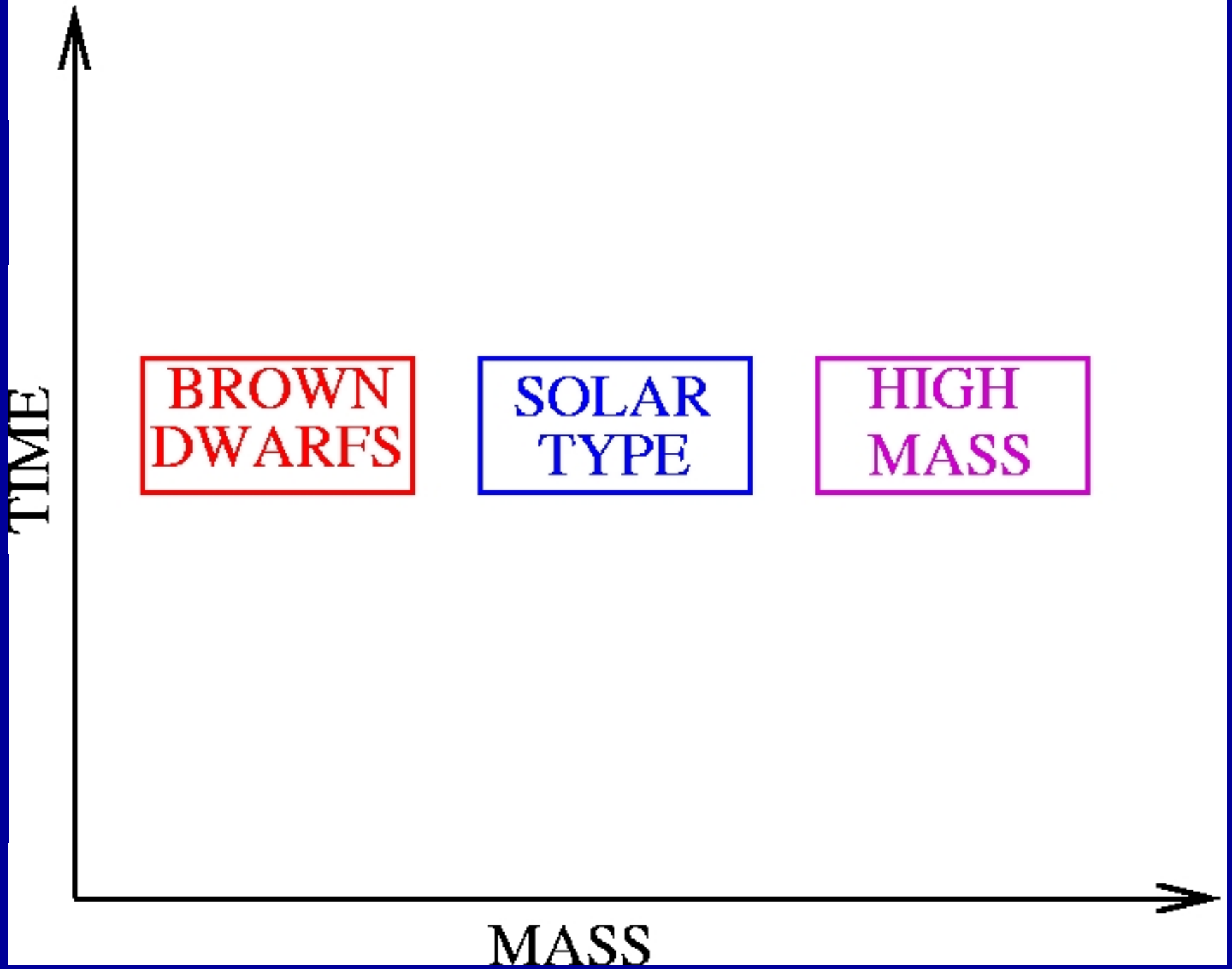
d) Formation of disk

e) Residual disk

f) Formation of planets

(Shu, Adams & Lizano 1987)


TIME
SOLAR
TYPE
MASS

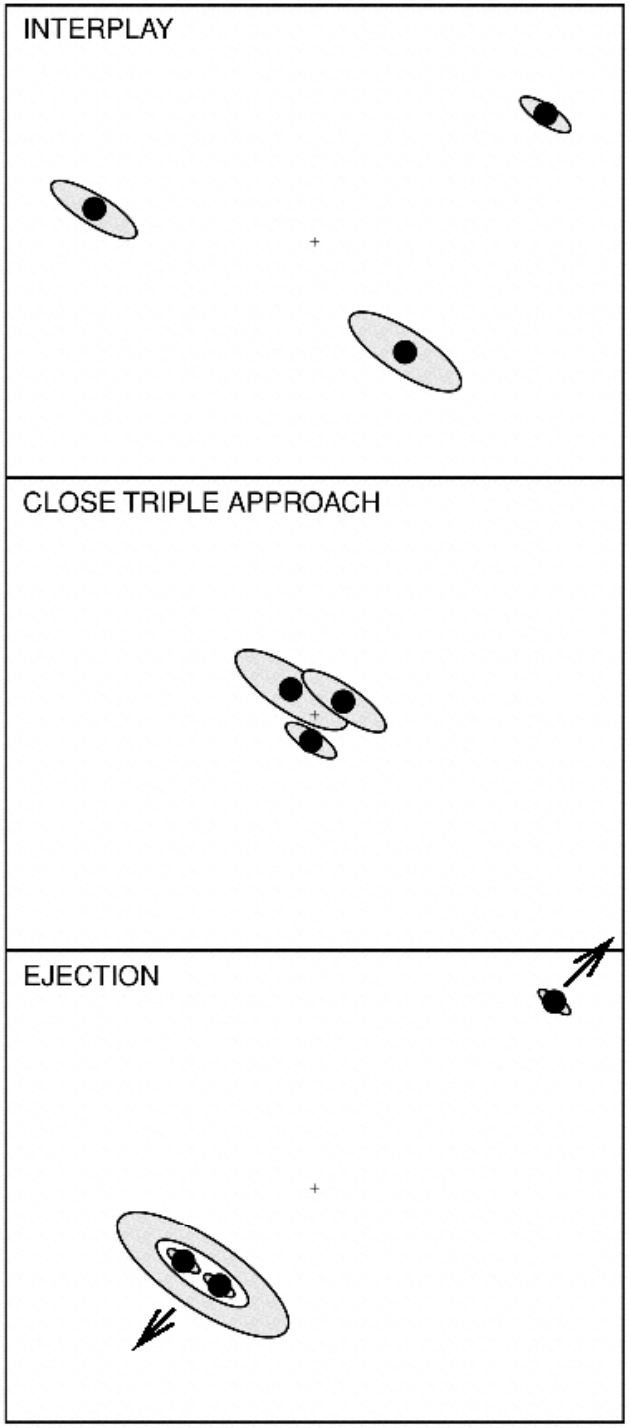

TIME
BROWN DWARFS
SOLAR TYPE
HIGH MASS
MASS

Formation of Massive Stars

- With great advances achieved in our understanding of low mass star formation, it is tempting to think of high mass star formation simply as an extension of low mass star formation.
- That is, assume that the accretion into the star continues until we have a massive object.
- However…

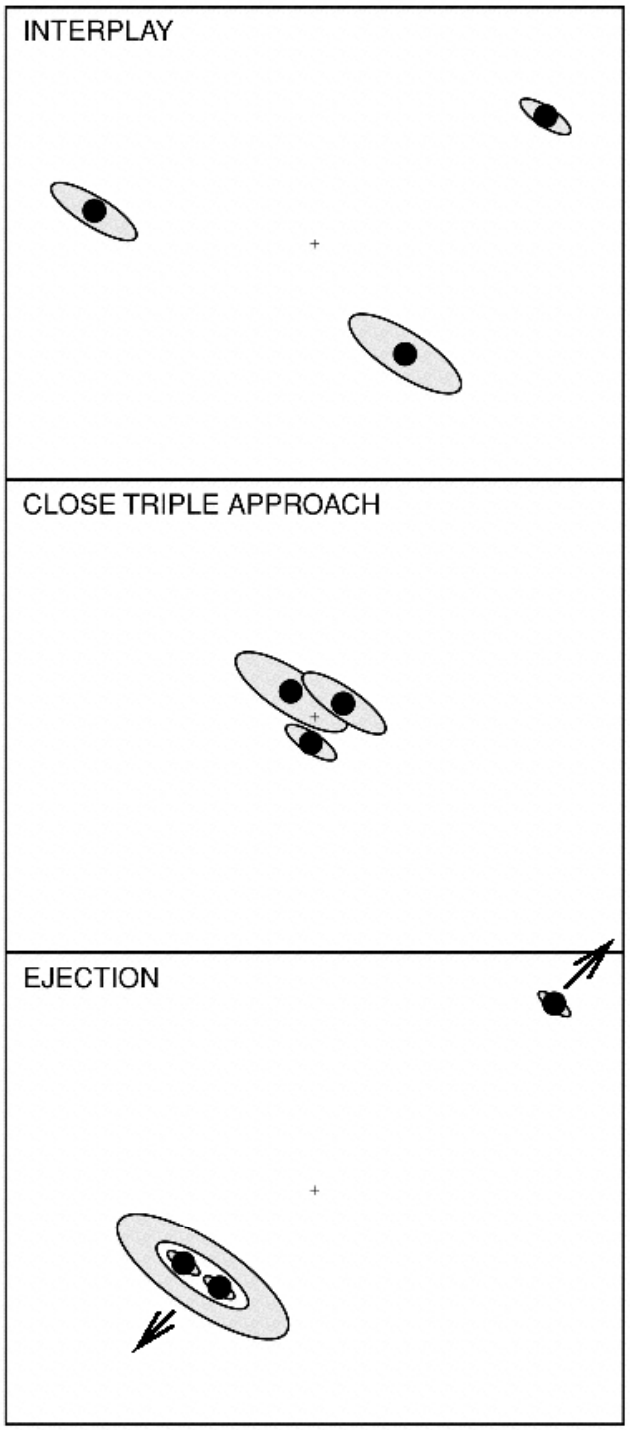
Some problems with extending the picture of low-mass star formation to massive stars:

- Radiation pressure acting on dust grains can become large enough to reverse the infall of matter:
  - $F_{\mathrm{grav}} = GM_{*}m/r^2$
  - $F_{\mathrm{rad}} = L\sigma/4\pi r^2 c$
  - *Above 10* M_{sun} *radiation pressure could reverse infall*
- Form massive stars through collisions of intermediate-mass stars in clusters?
  - Possible problem with cross section for coalescence
  - Observational consequences of such collisions?



Encounters in multiple stellar systems can lead to the formation of close binaries or even mergers with eruptive outflows (Bally & Zinnecker 2005).

Reipurth (2000)



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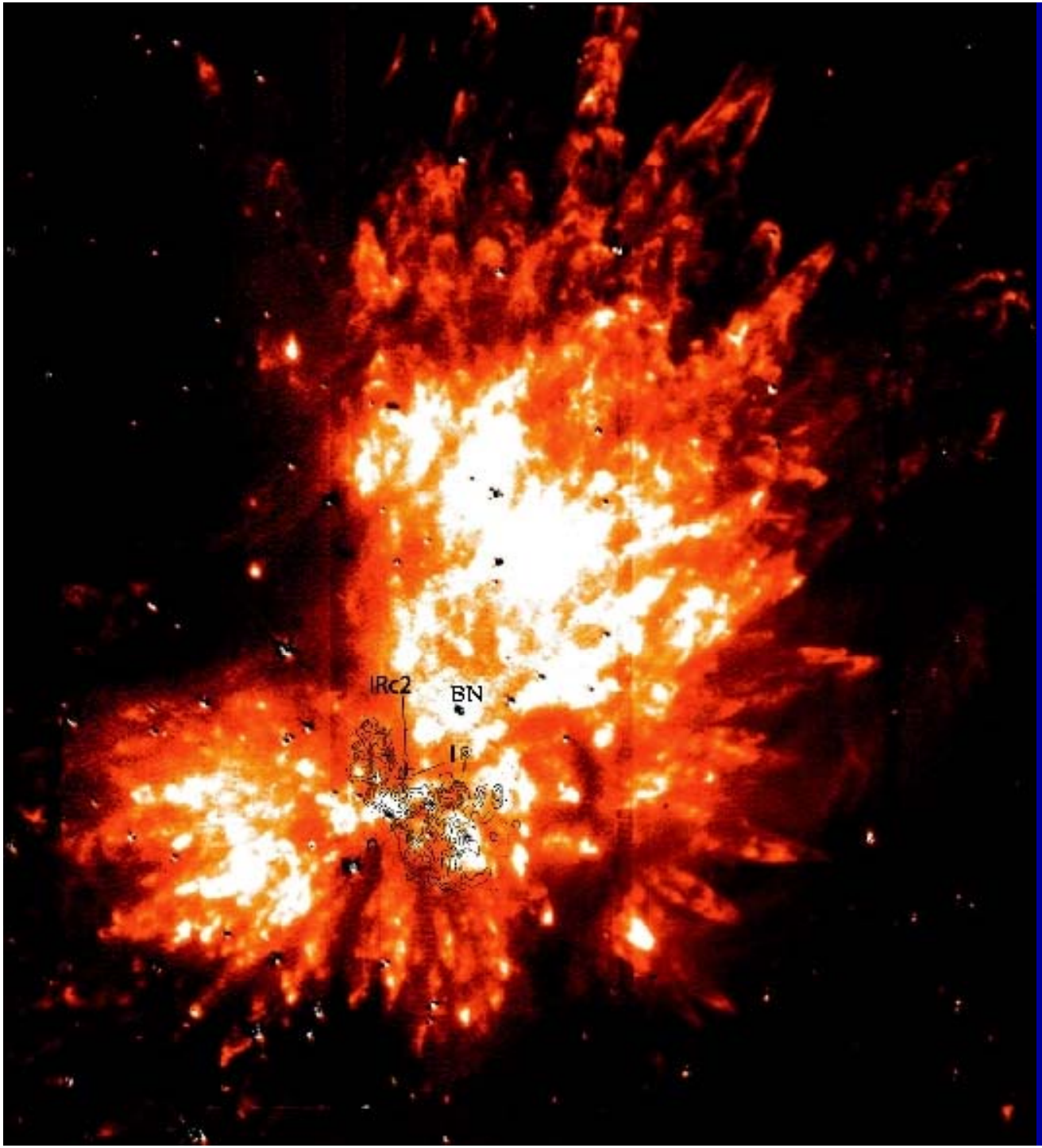
=> Search for fast-moving young stars!

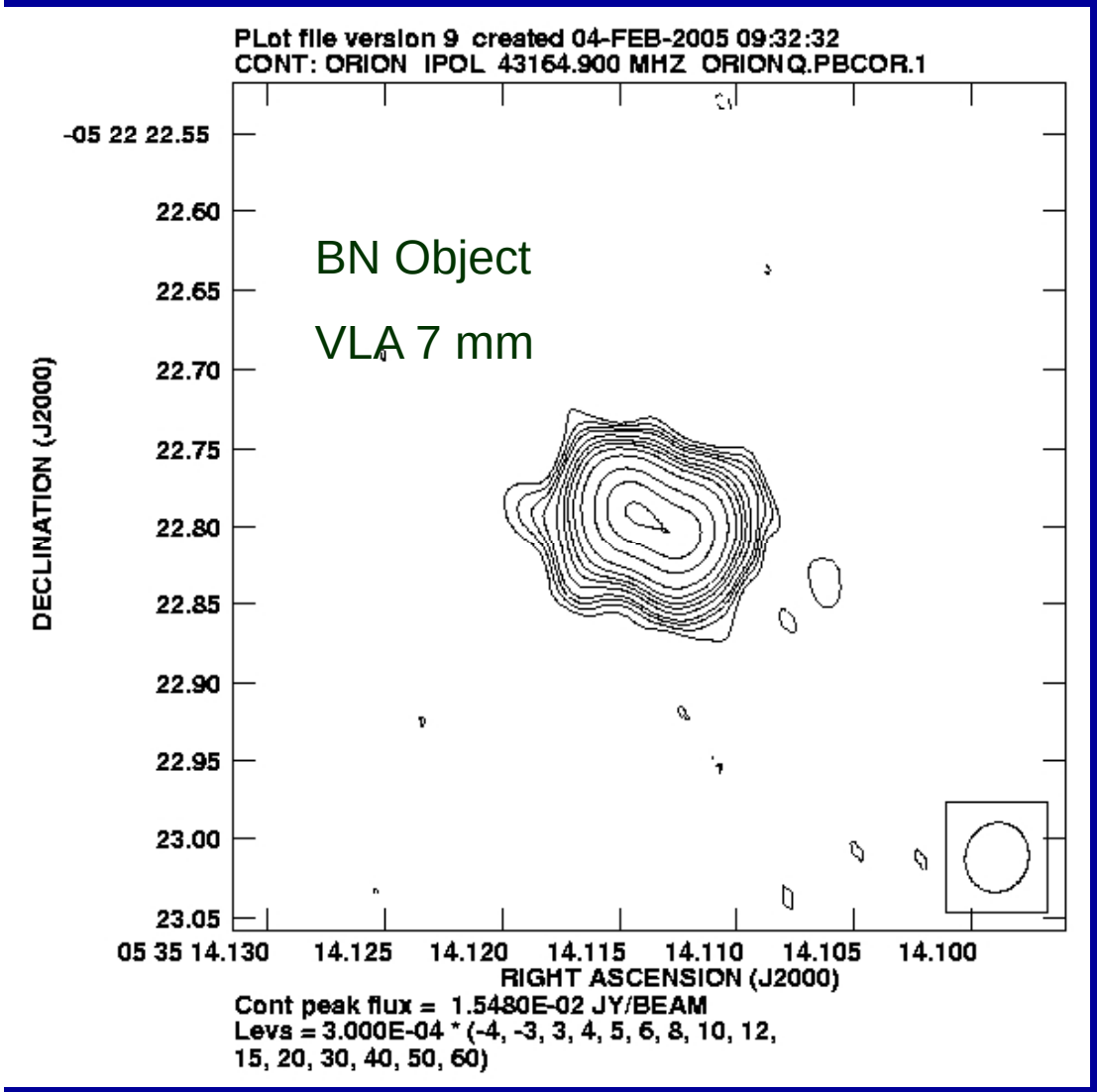
Reipurth (2000)



In the Orion BN/KL region there is an example of a powerful, uncollimated outflow. At its center there are several young sources.

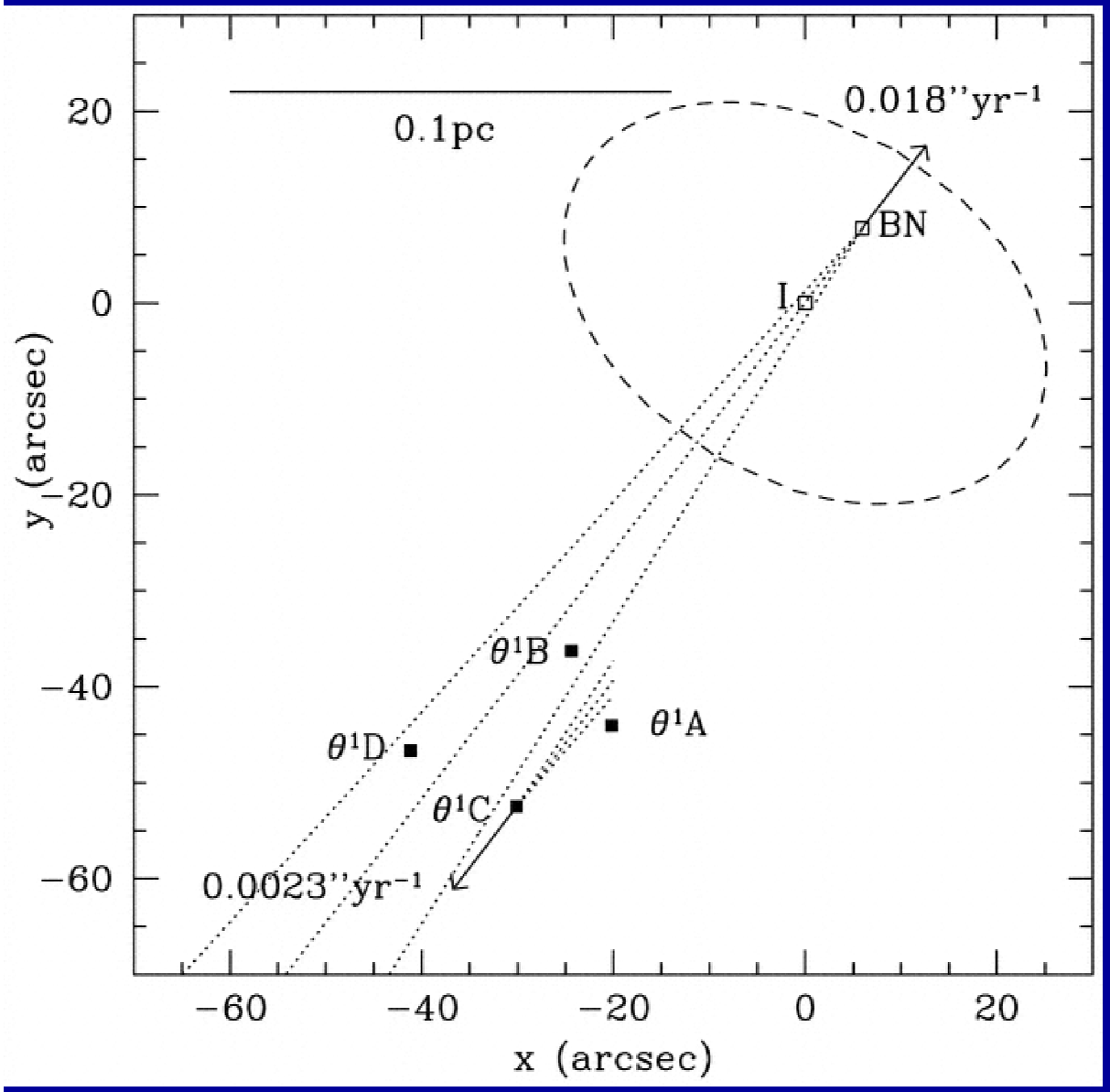
H2 image with NH3 contours (Shuping et al. 2004; Wilson et al. 2000)

The BN object, a “moving” UCHII region…

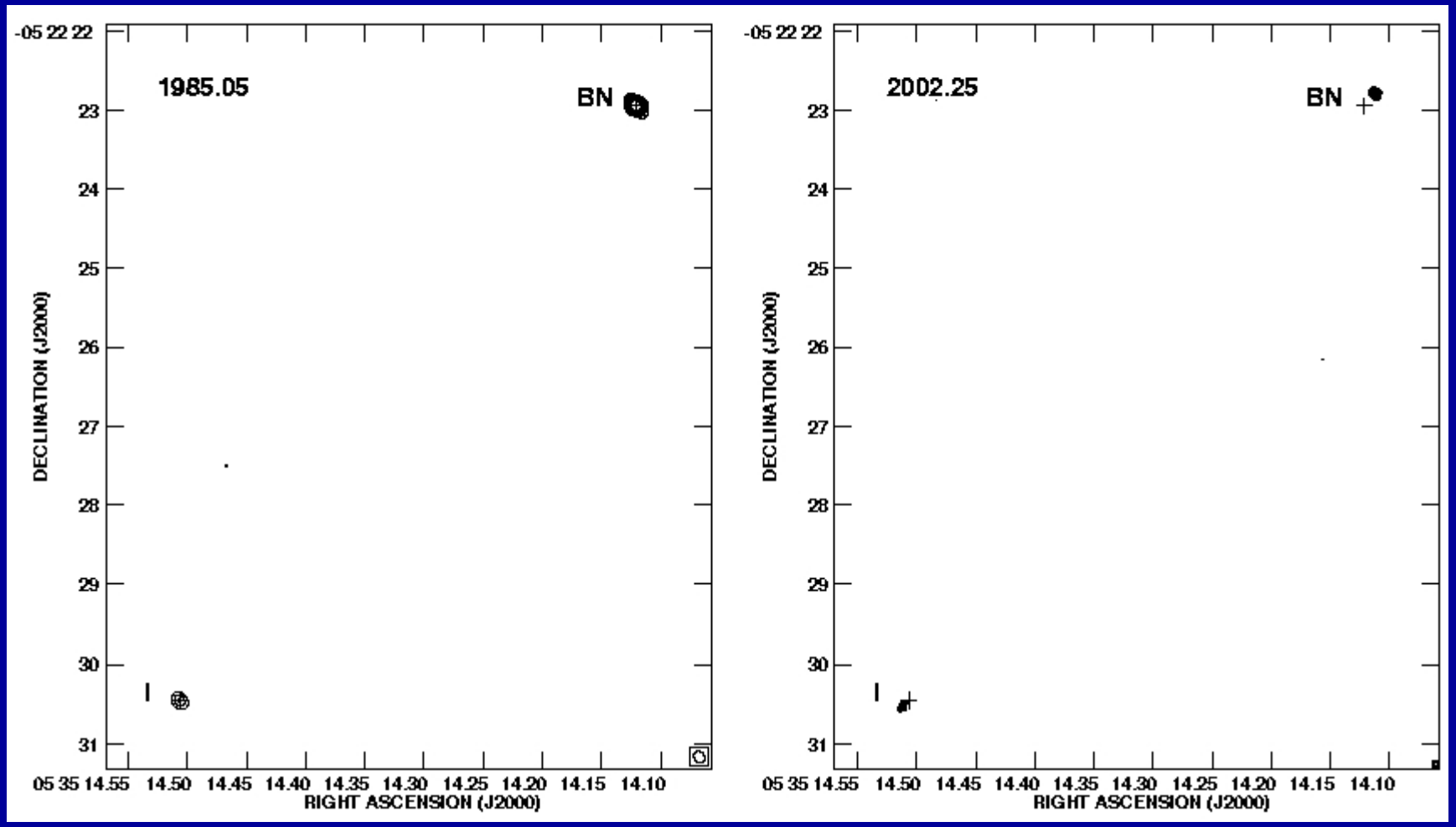


In the radio, the BN object in the Orion BN/KL region is detected as an UCHII region ionized by a B-type star.

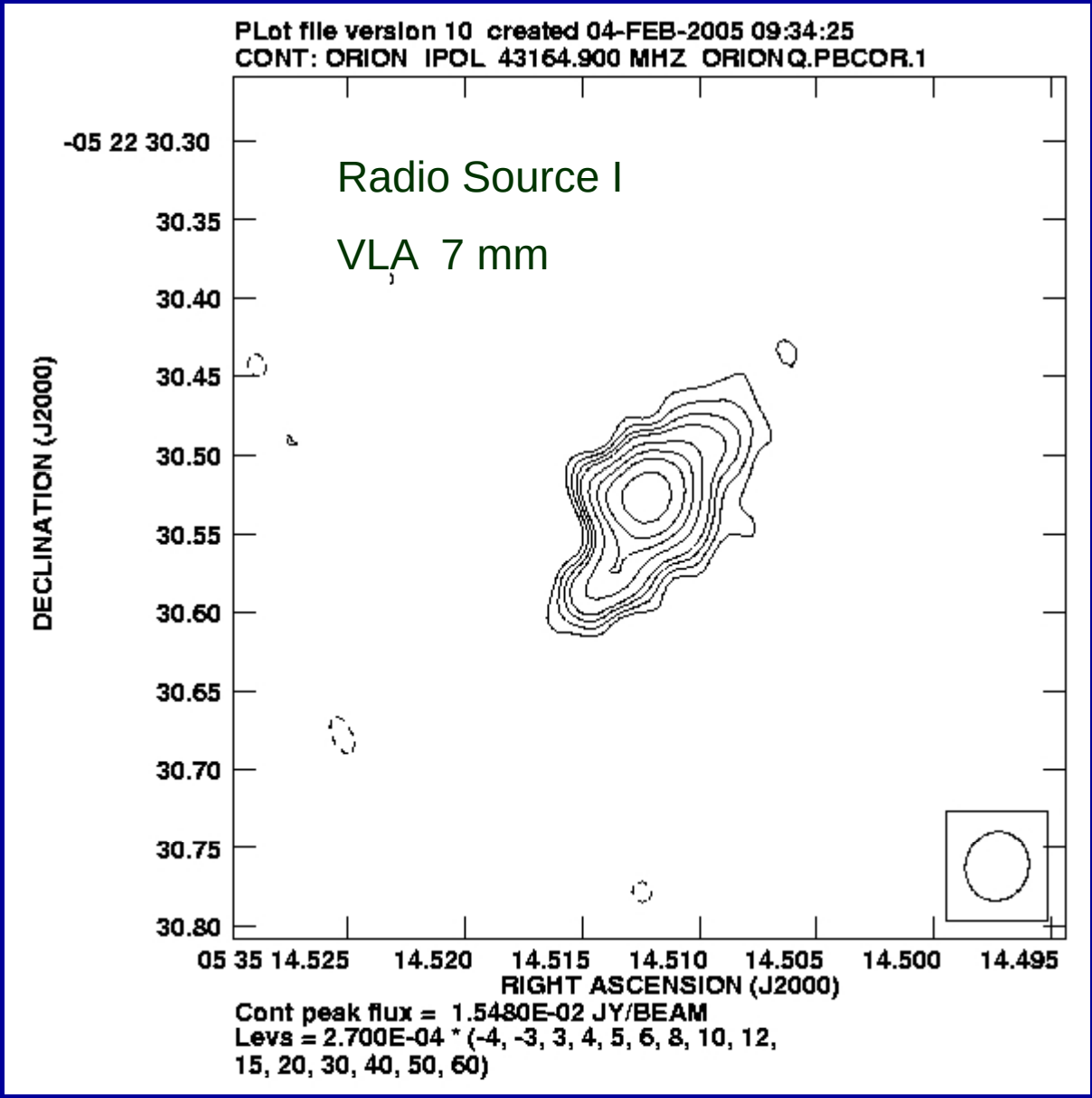
Since 1995, Plambeck et al. reported large proper motions (tens of km s^{-1}) to the NW.



In a recent analysis of the data, Tan (2004) proposed that the BN object was ejected some 4,000 years ago by interactions in a multiple system located at θ^1C Ori, the brightest star of the Orion Trapezium.

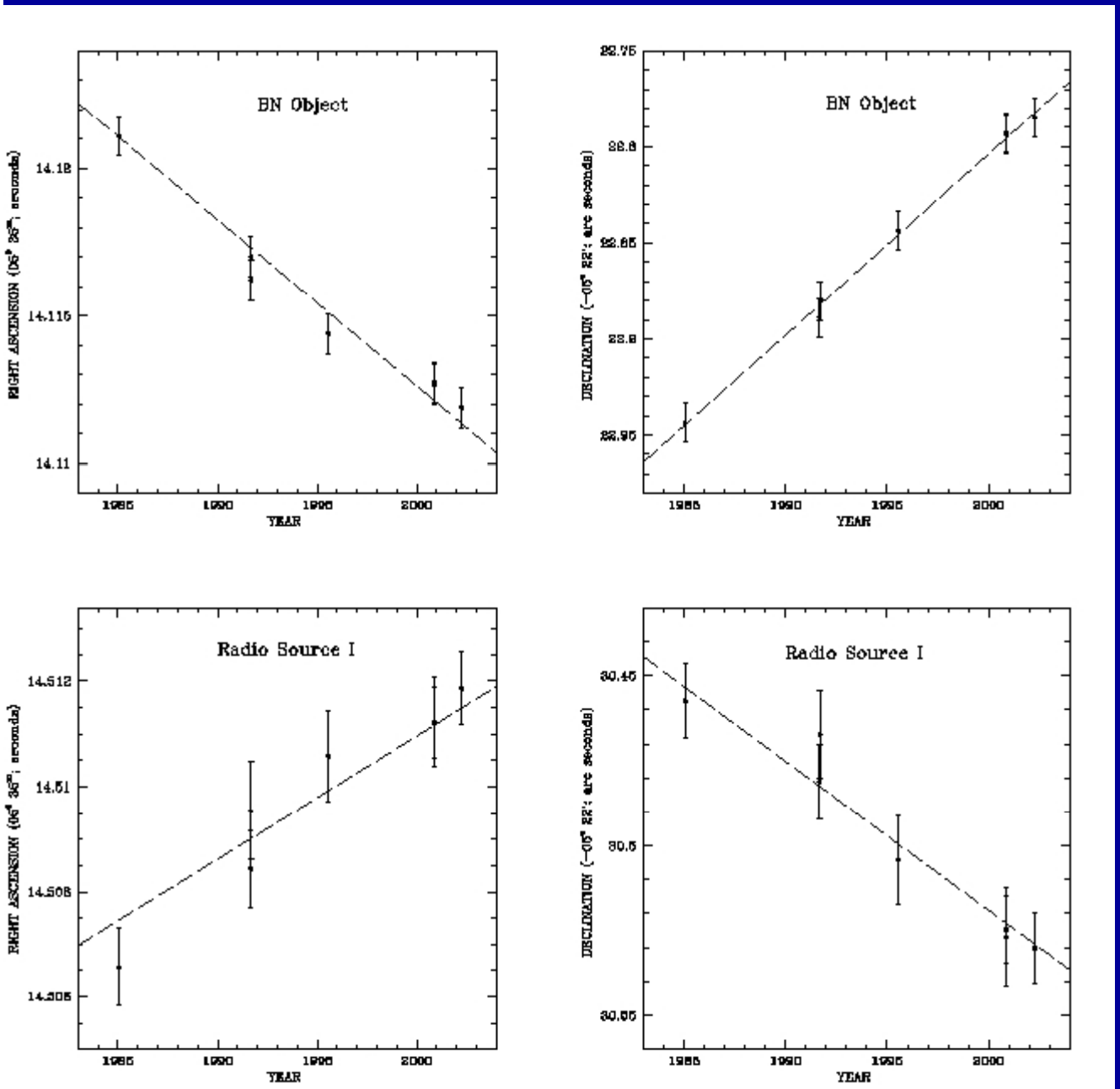


However, an analysis of VLA data taken over the last two decades suggests that the radio source I (apparently a thermal jet), is also moving in the sky, receding from a point between it and the BN object.



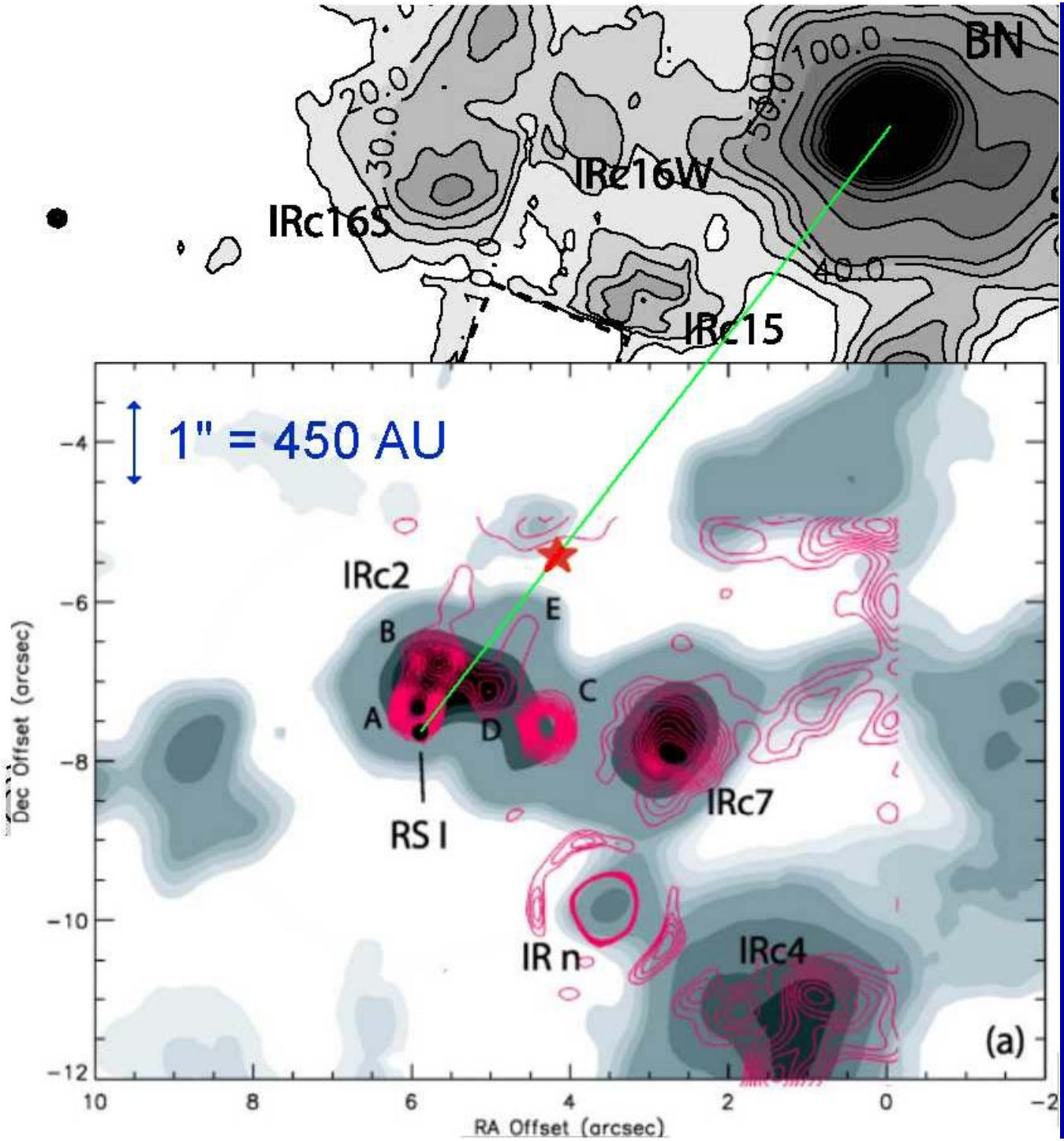
The Radio Source I is also moving in the sky, to the SE.

Controversial nature: thermal jet or ionized disk?



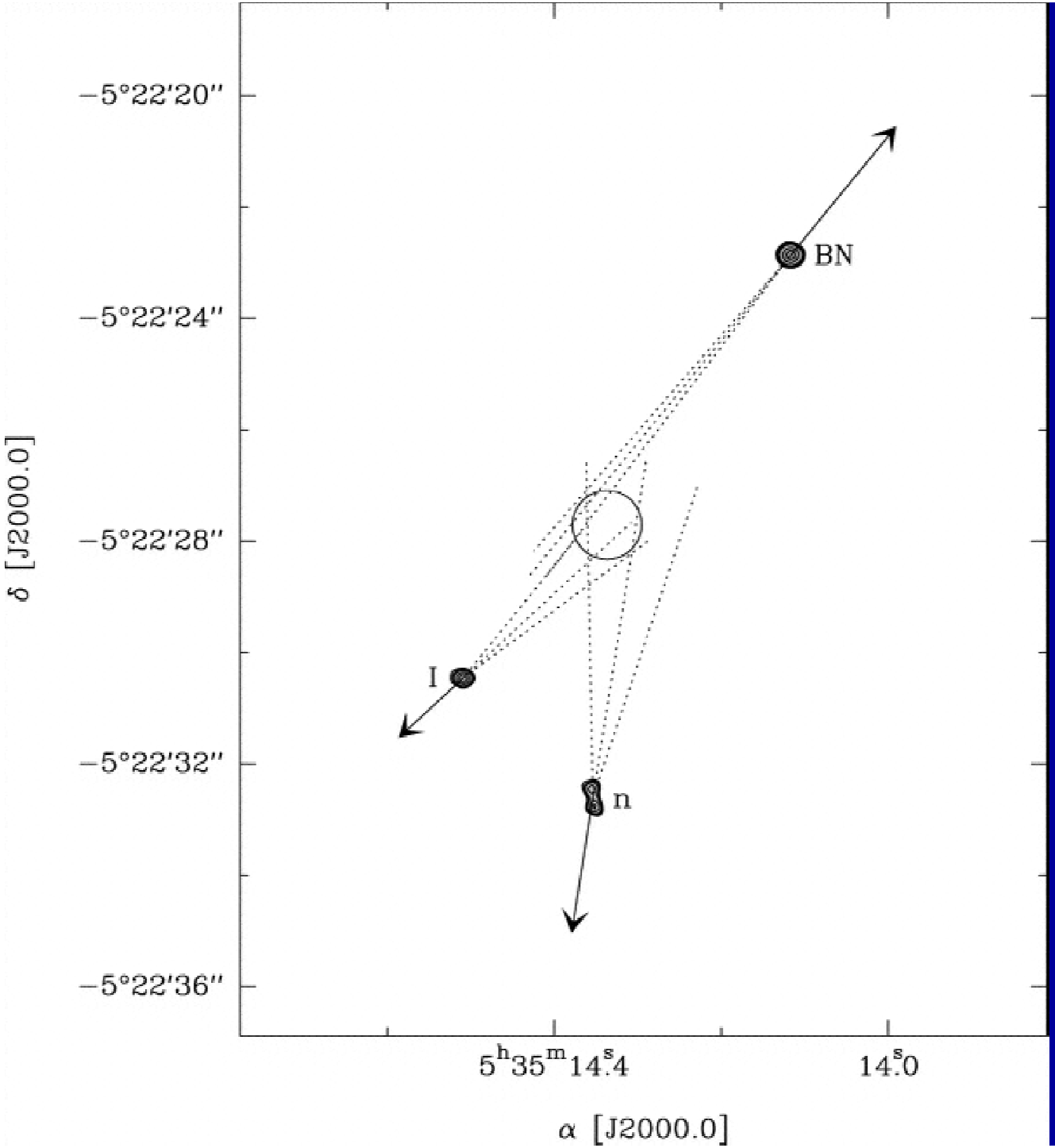
BN moves to the NW at 27+-1 km s^{-1}.

I moves to the SE at 12+-2 km s^{-1}.

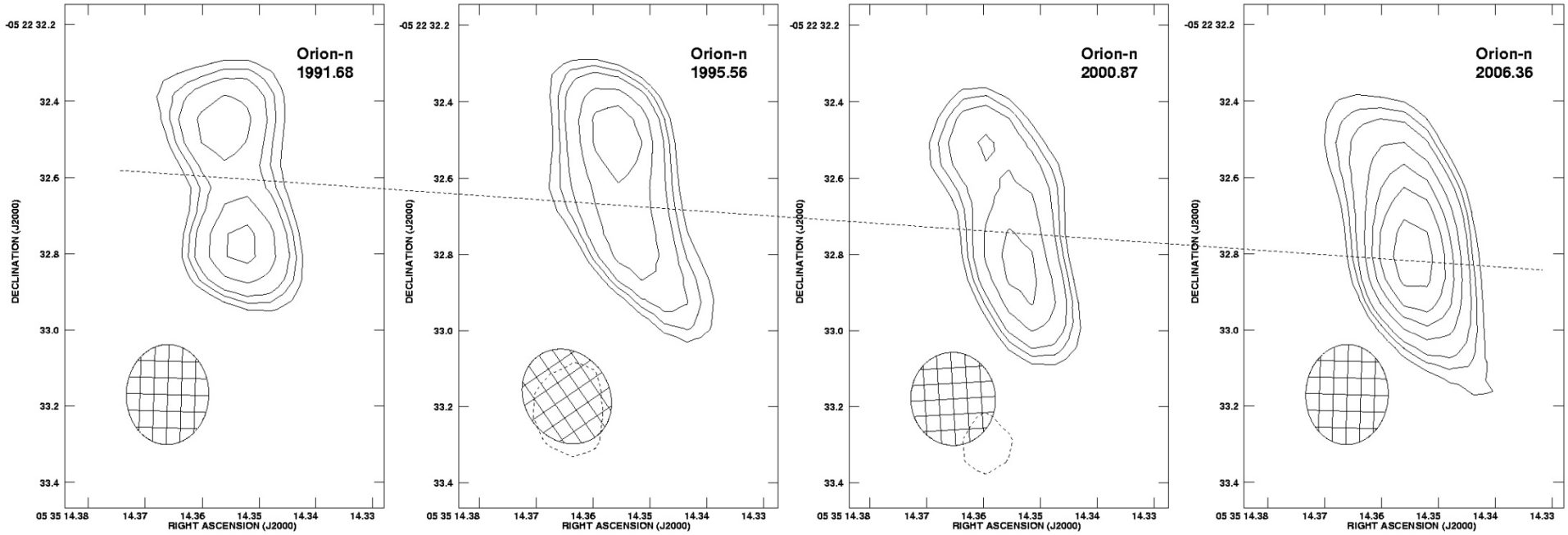


The data suggest that some 500 years ago, a multiple stellar system, formed at least by BN and I had a close encounter and the stars were expeled in antiparallel directions

BN or I have to be close binary systems for this scenario to work

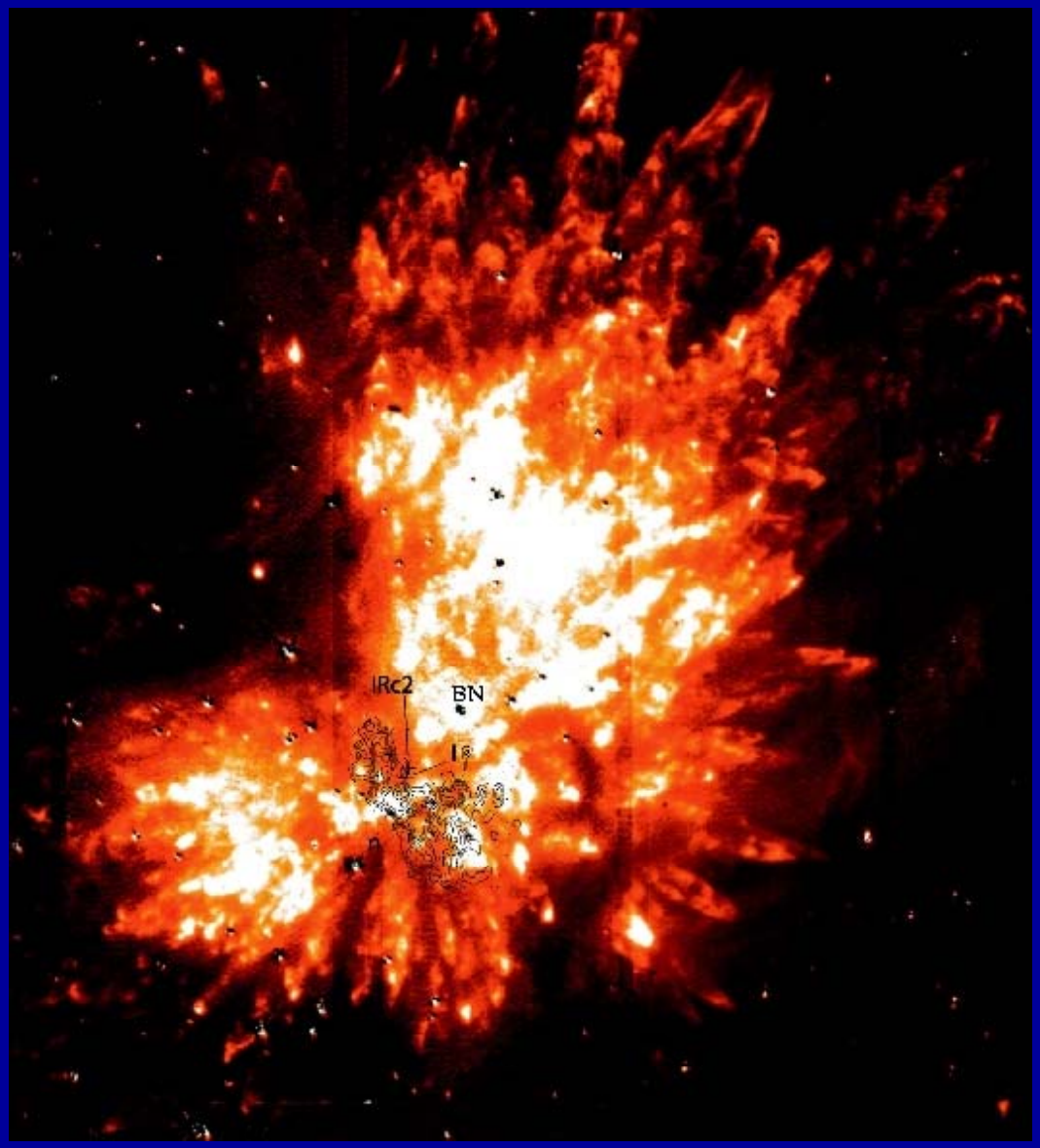


Things even more complicated because a third source (n) is also receding from the same point (Gomez et al. 2005, 2007)



Orion-n: In the radio we are possibly seeing a “thermal” jet, the expulsion of ionized gas in two antiparallel directions.

It is moving to the south at velocities of order 26 km/s.



Indeed, around the BN/KL region there is the well known outflow with an age of about 1000 years.

It is possible that the outflow and the ejection of BN and I were result of the same phenomenon.

Energy in outflow is of order $4X10^{47}$ ergs, perhaps produced by release of energy from the formation of close binary or merger.

Still many open questions in massive star formation...

- Are disks and jets always present?
- Accretion seems needed given presence of outflow phenomena.
- Are mergers playing a role?
- We need to find more fast-moving young stars.
- Dynamical models by Poveda & Allen.

Thank you