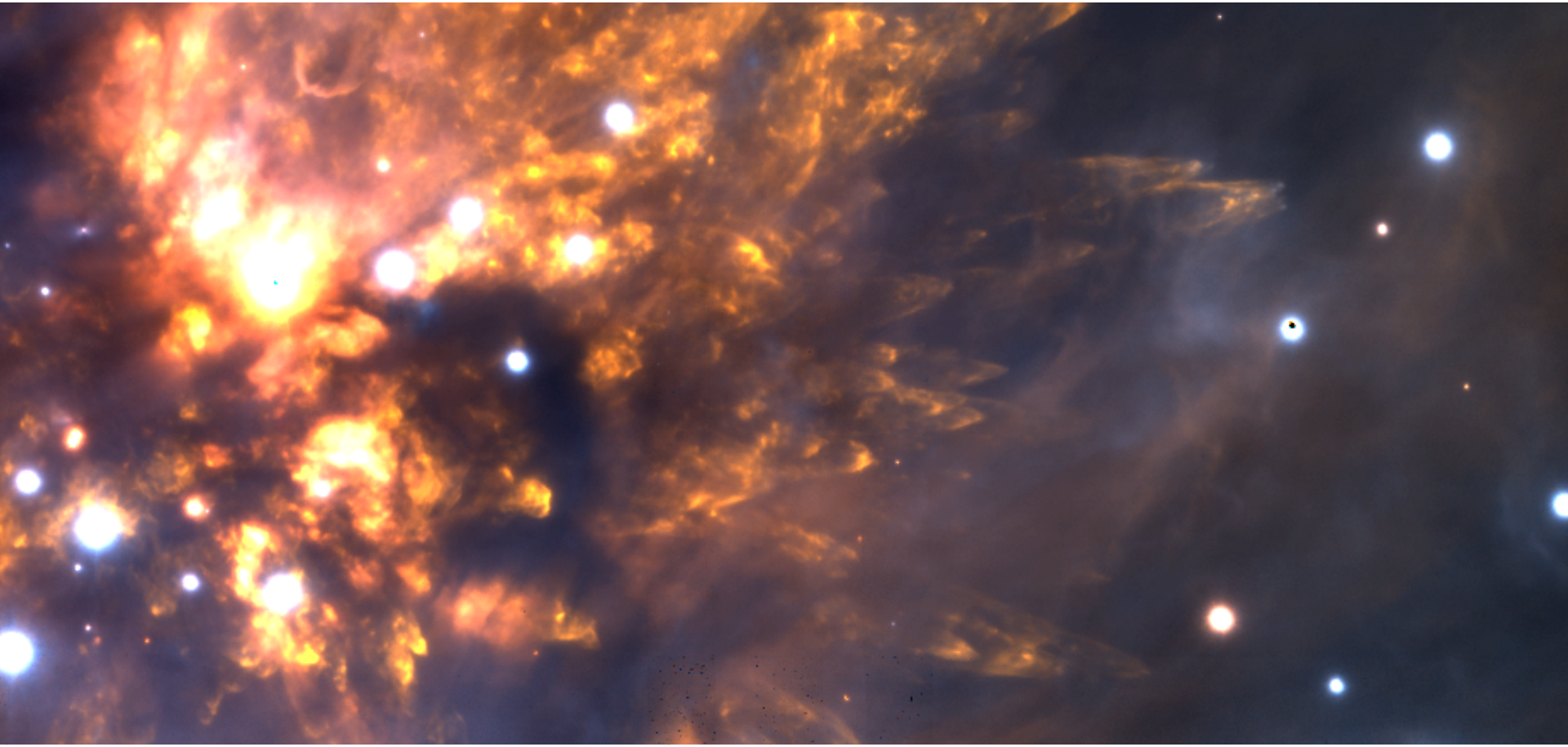
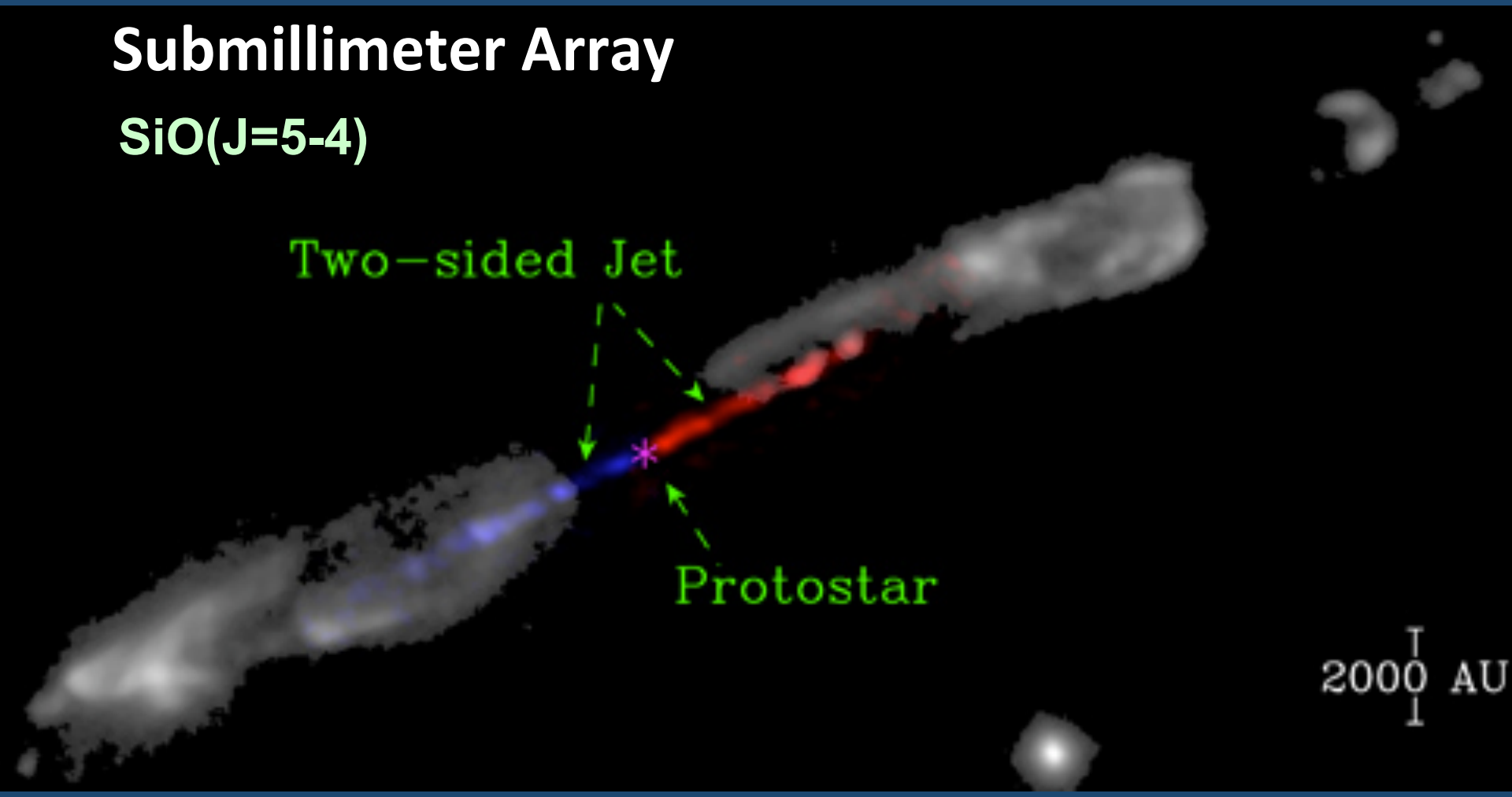
The Submillimeter Array:
First Decade of Discovery



Explosive Outflows Revealed by the *Submillimeter Array*

Luis Zapata, CRyA-UNAM, México

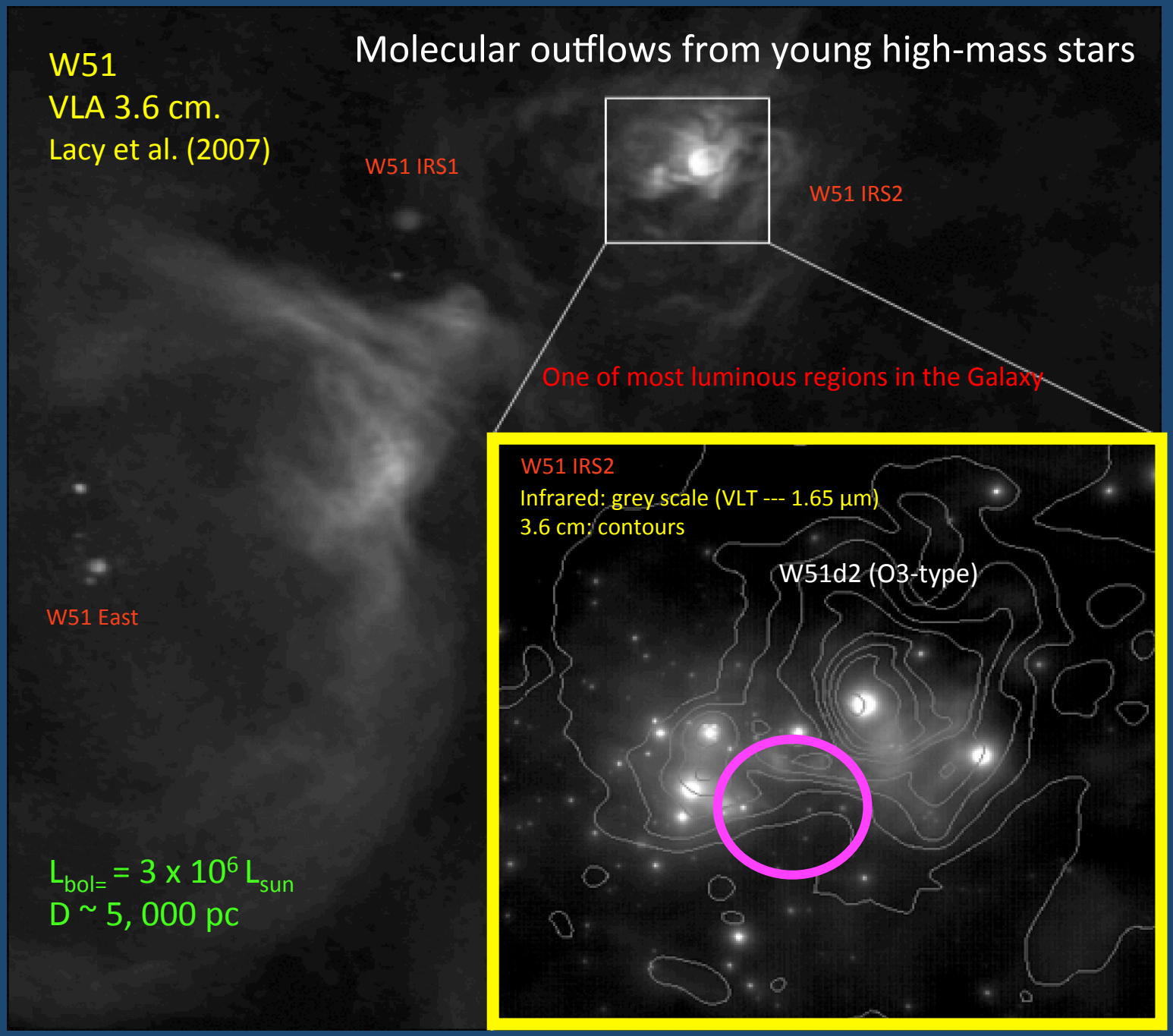
Molecular outflows from young low-mass stars

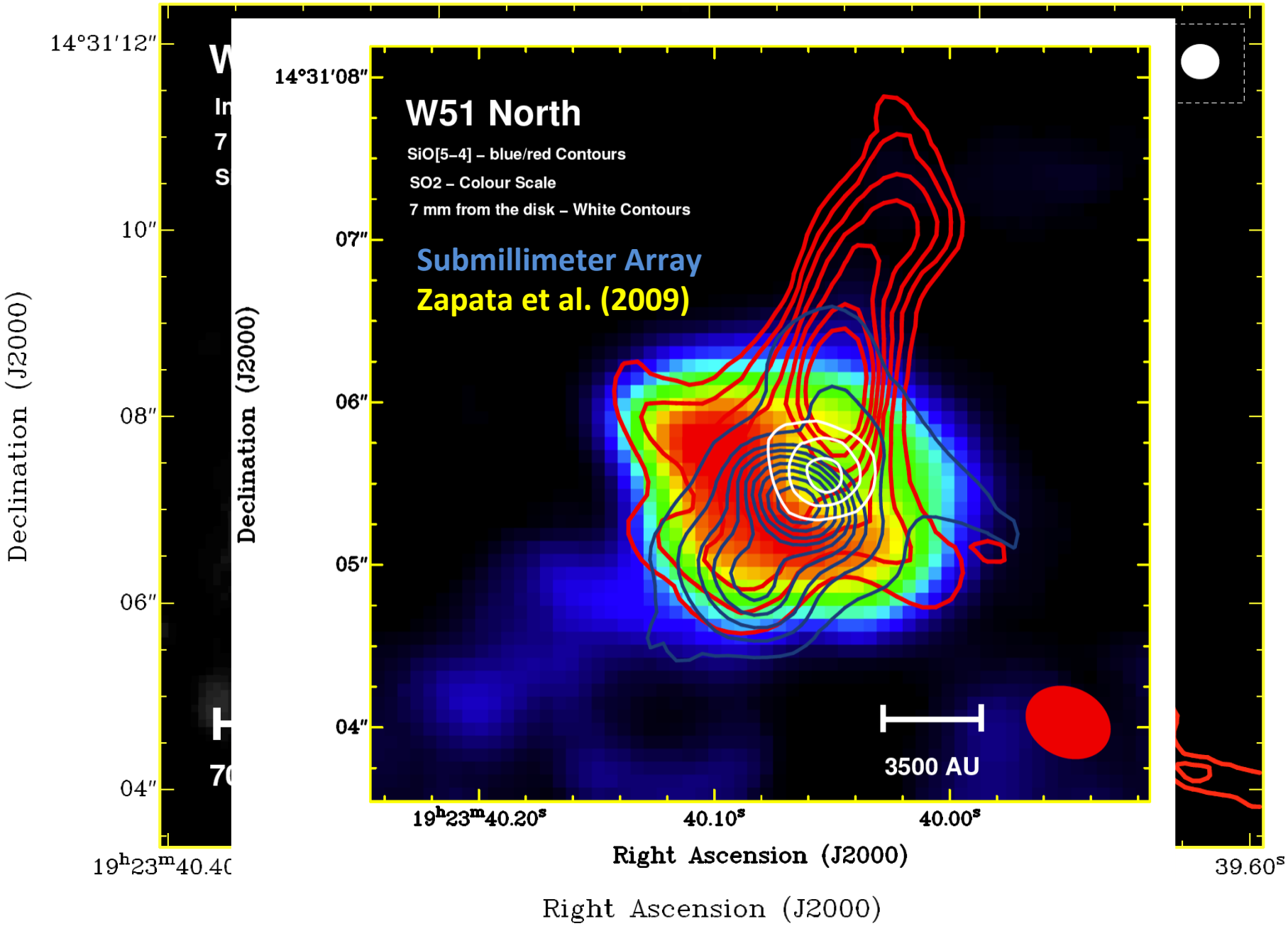


Collimation Factor: ~10°

Palau et al. (2005), Lee et al (2007), Hirano et al. (2006)

Molecular outflows from young high-mass stars




W51 North
SiO[5–4] – blue/red Contours
SO2 – Colour Scale
7 mm from the disk – White Contours
Submillimeter Array
Zapata et al. (2009)
3500 AU
14°31′08″
07″
06″
05″
04″
19h23m40.20s
40.10s
40.00s
Right Ascension (J2000)
Declination (J2000)
14°31′12″
10″
08″
06″
04″
19h23m40.40
39.60s
Right Ascension (J2000)
Declination (J2000)

Becklin-Neugebauer (BN)
and the Kleinman-Low (KL)
(Becklin & Neugebauer 1967; Kleinmann & Low 1967)

Closest massive star forming region

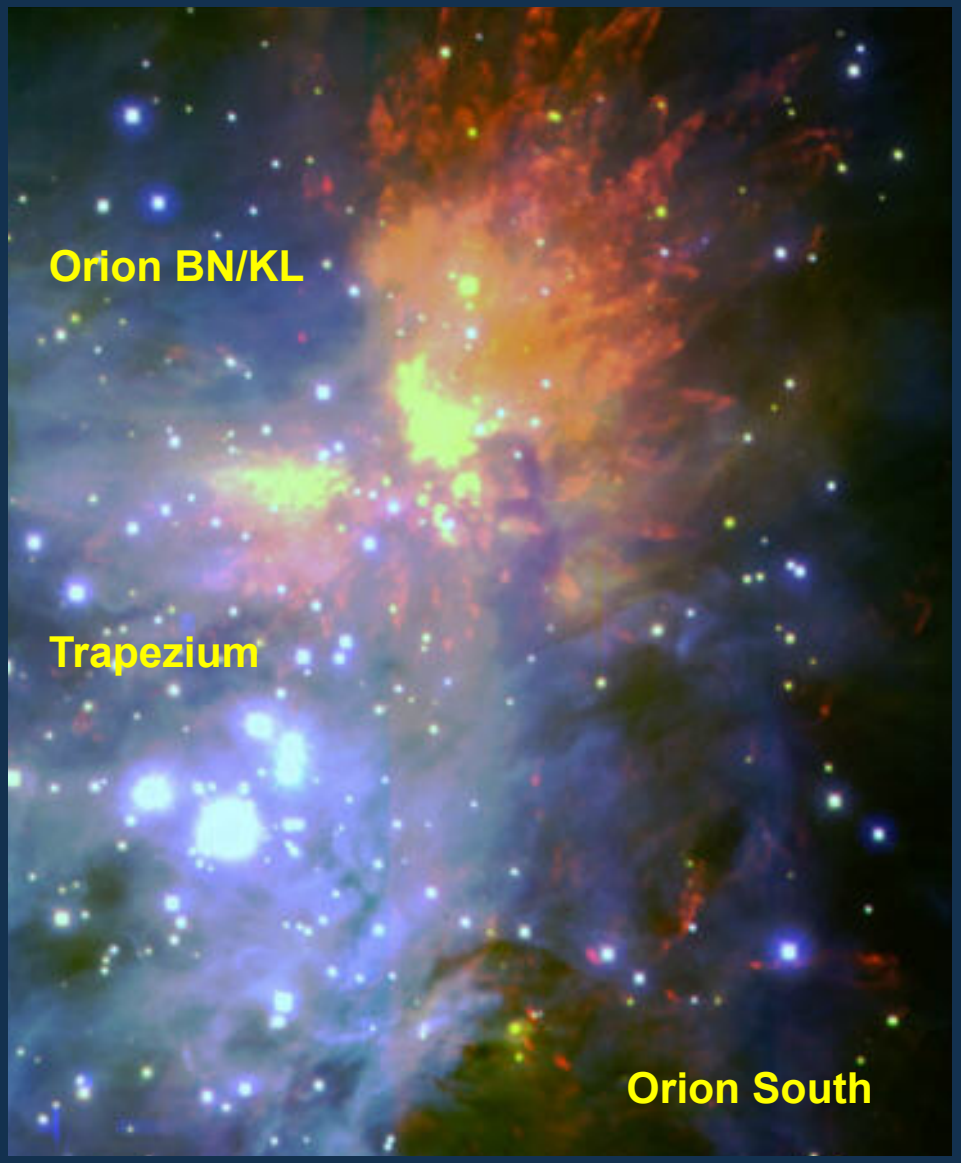
Luminosity: about 10^5 L_{sun}

Mass: about 1000 M_{sun}

Distance: 415 pc

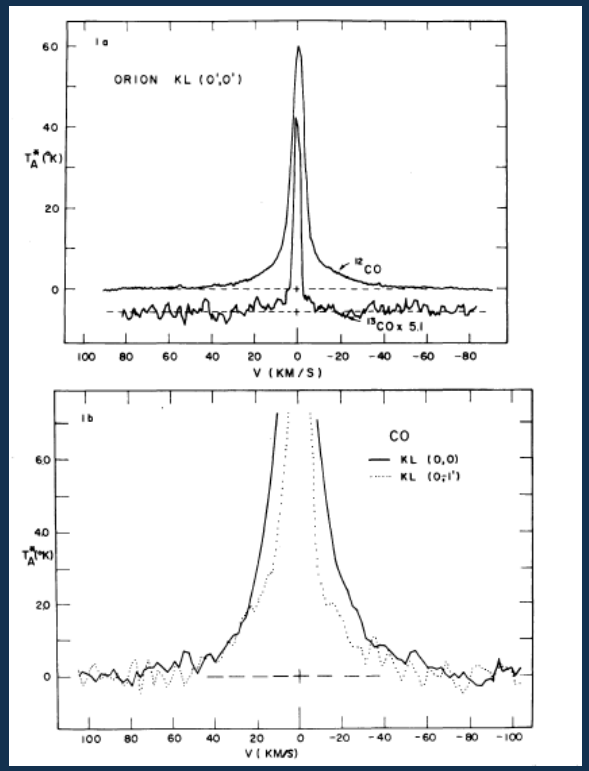
Strong maser and thermal emission from many species:

H_2O, OH, SiO, CH3CN, CH3OH, …

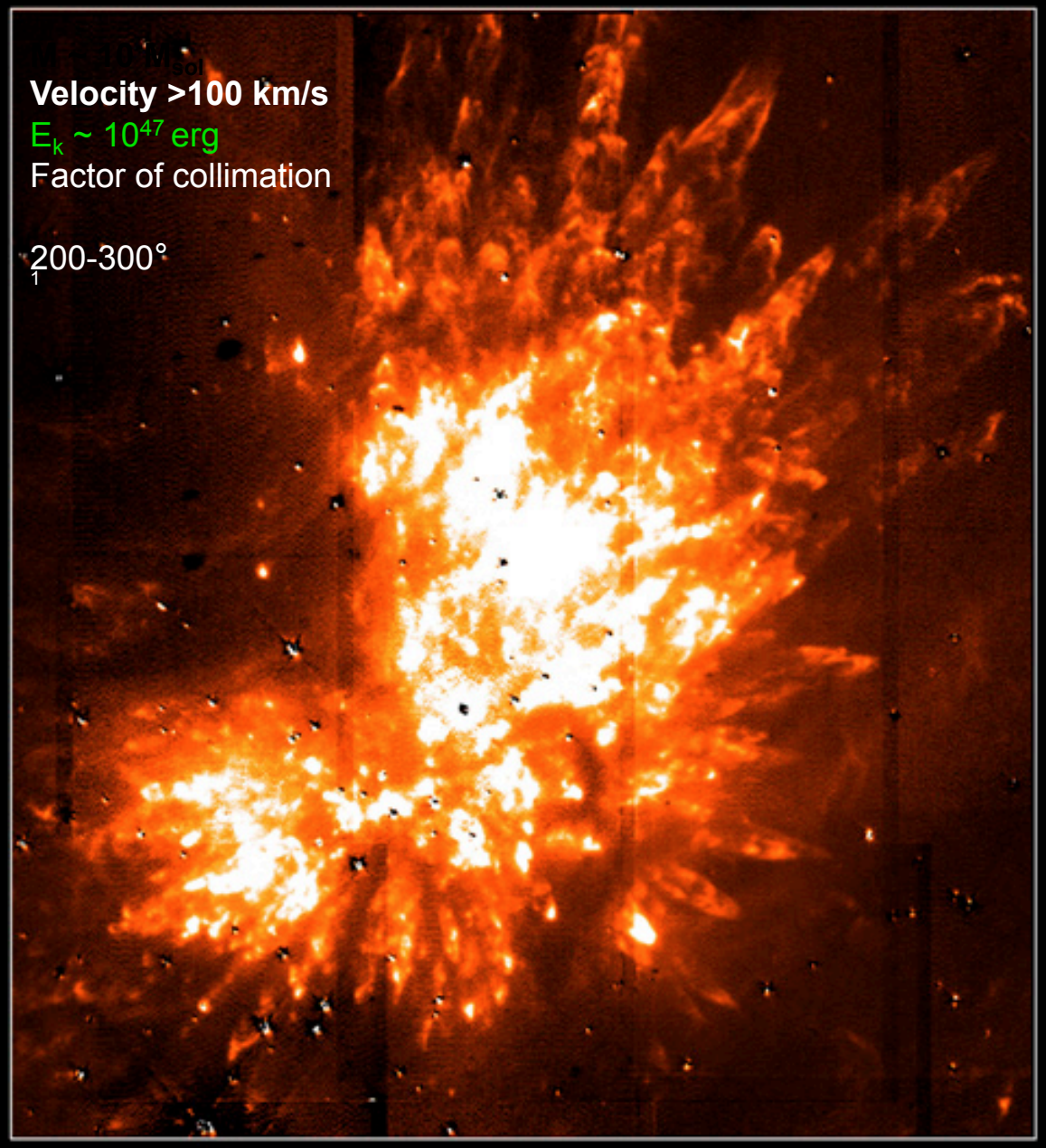


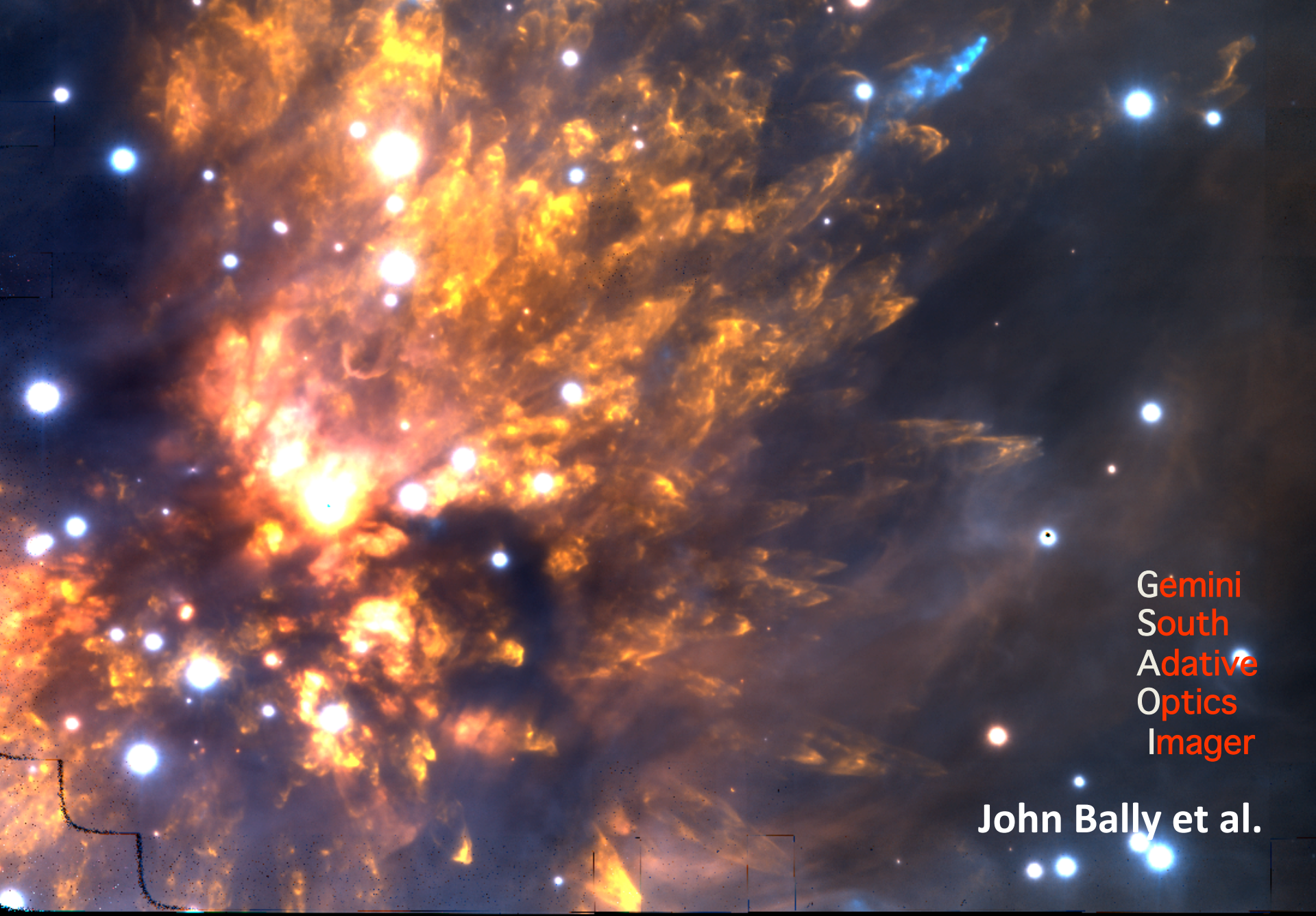
Allen & Burton (1993)

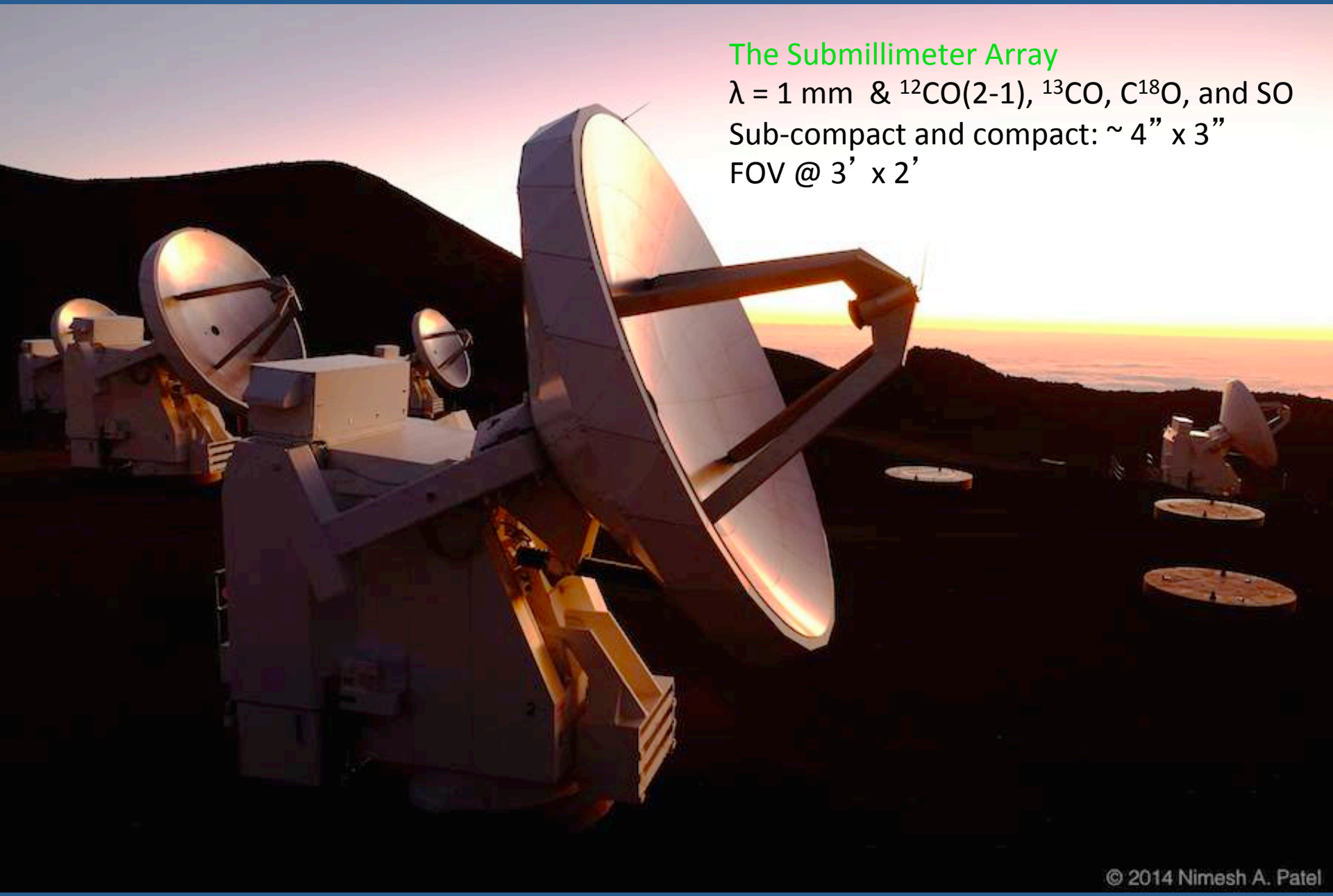
Bullets of material maybe from a SN?



Kwan and Scoville (1976)

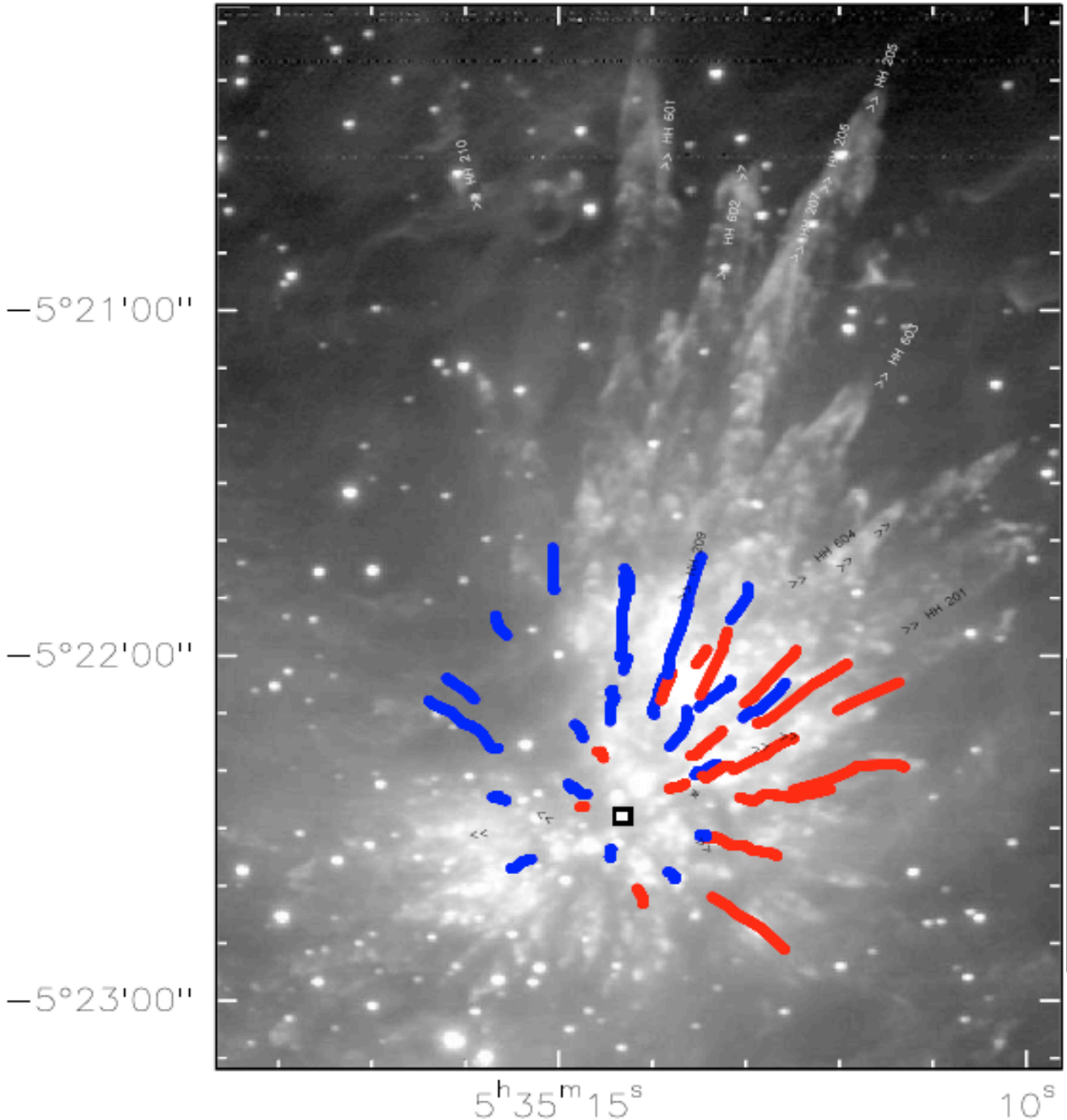



Gemini
South
Adative
Optics
Imager
John Bally et al.

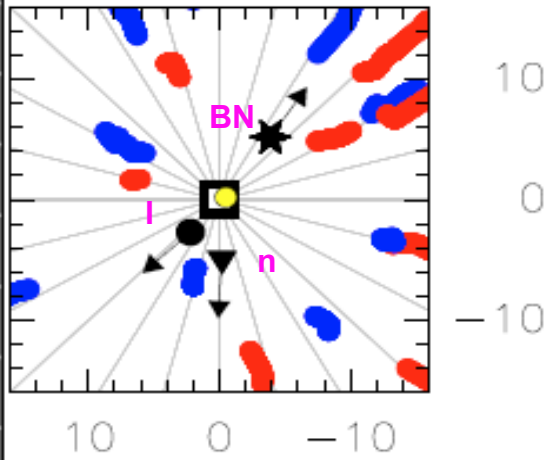

The Submillimeter Array
λ = 1 mm & $^{12}CO(2-1)$, ^{13}CO, $C^{18}O$, and SO
Sub-compact and compact: ~ 4" x 3"
FOV @ 3' x 2'
© 2014 Nimesh A. Patel

SMA CO(2-1)

H2
Red: 35 to 130 km s^{-1}
blue -35 to -120 km s^{-1}

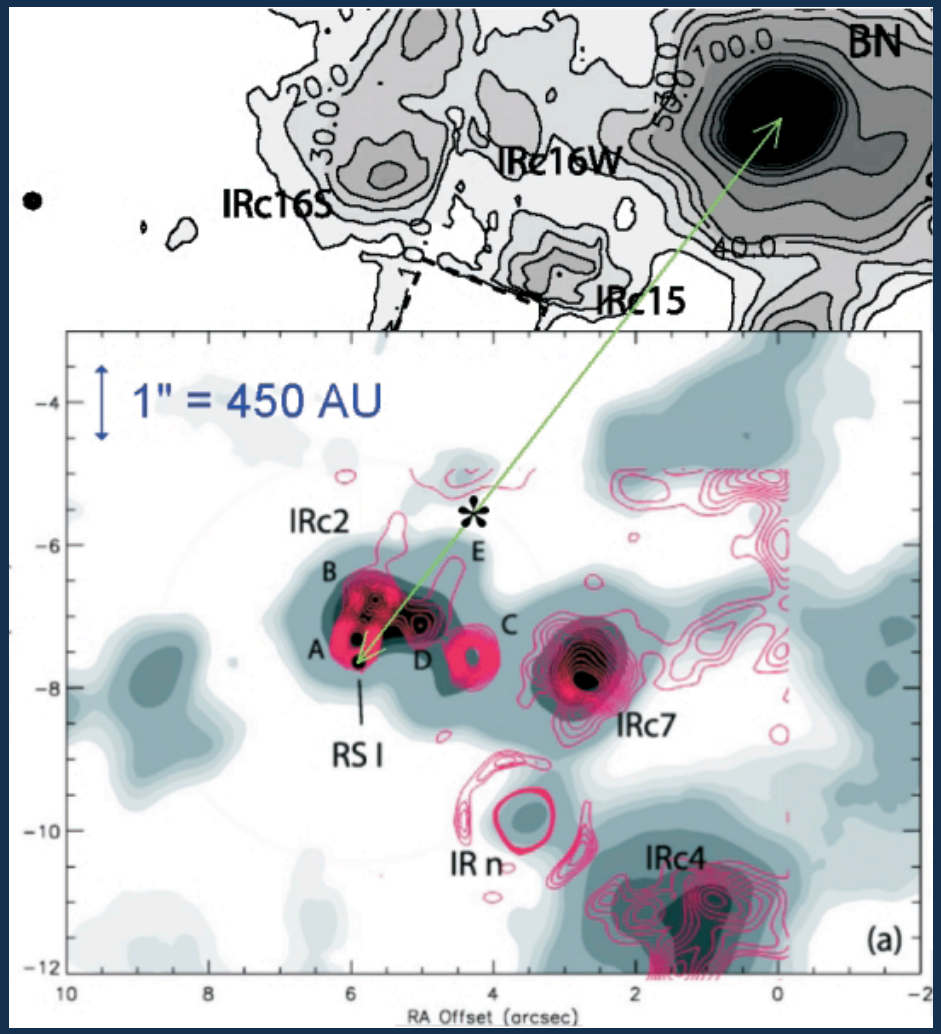


Common center



Runaway Stars in BN-KL

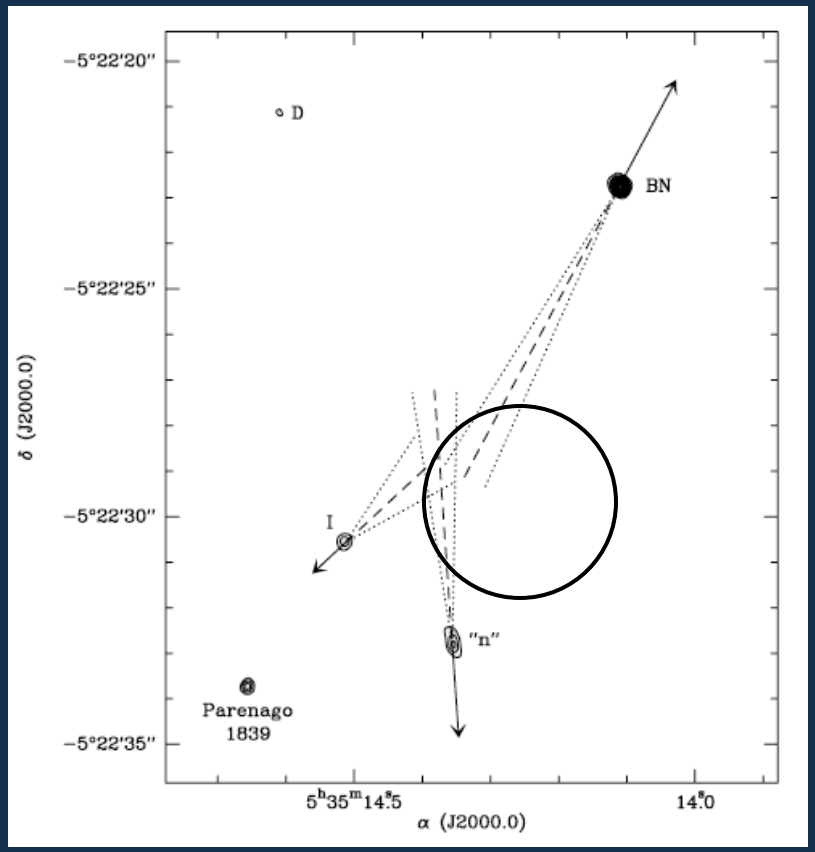
BN, I y n form part of a stellar system that densintegrated some 500 yrs.



Rodríguez et al. (2005)

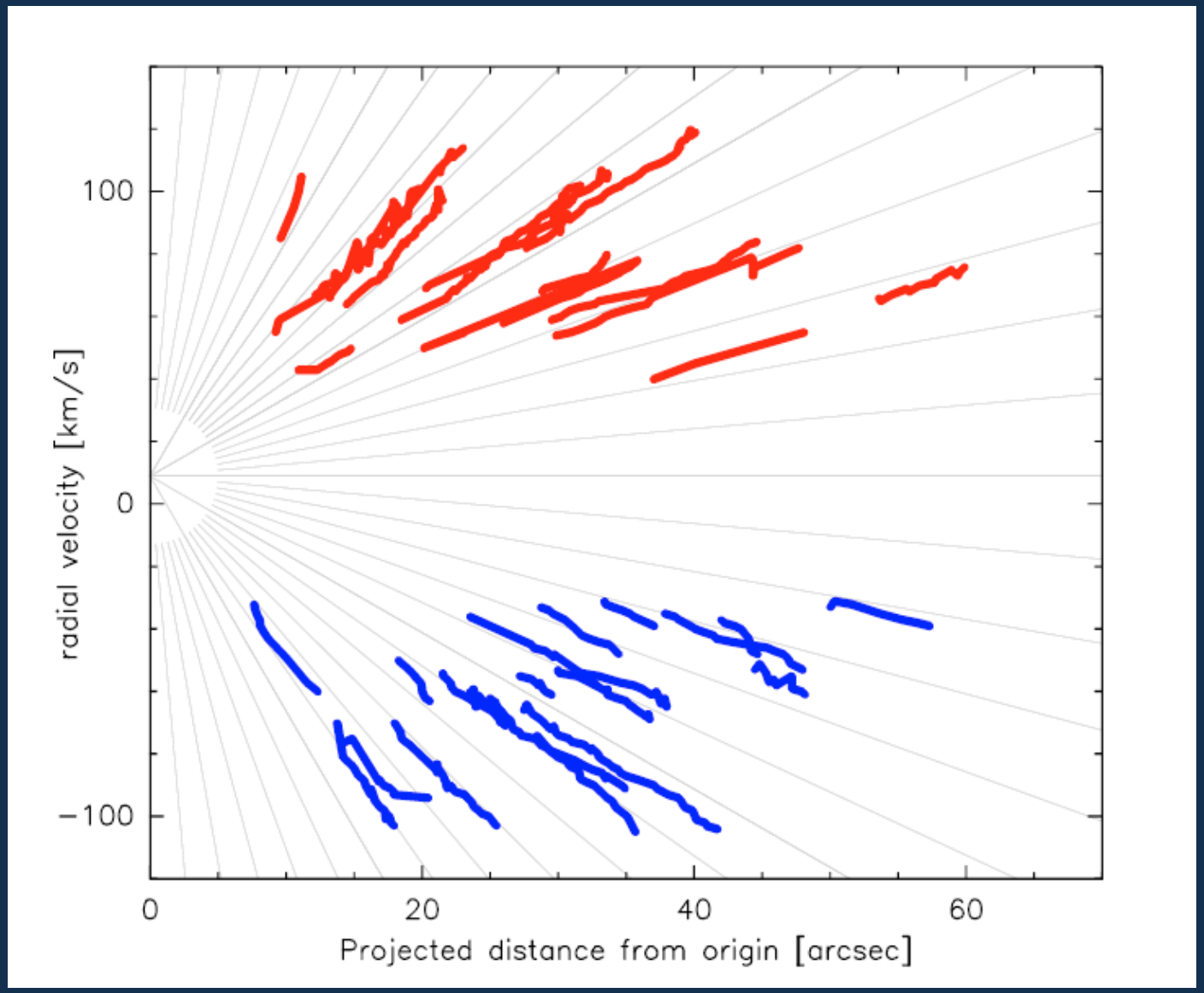
V_T ~ about 20 -30 km s^{-1}
Dynamical Age ~ 500 yrs

E ~ 10^{47} erg

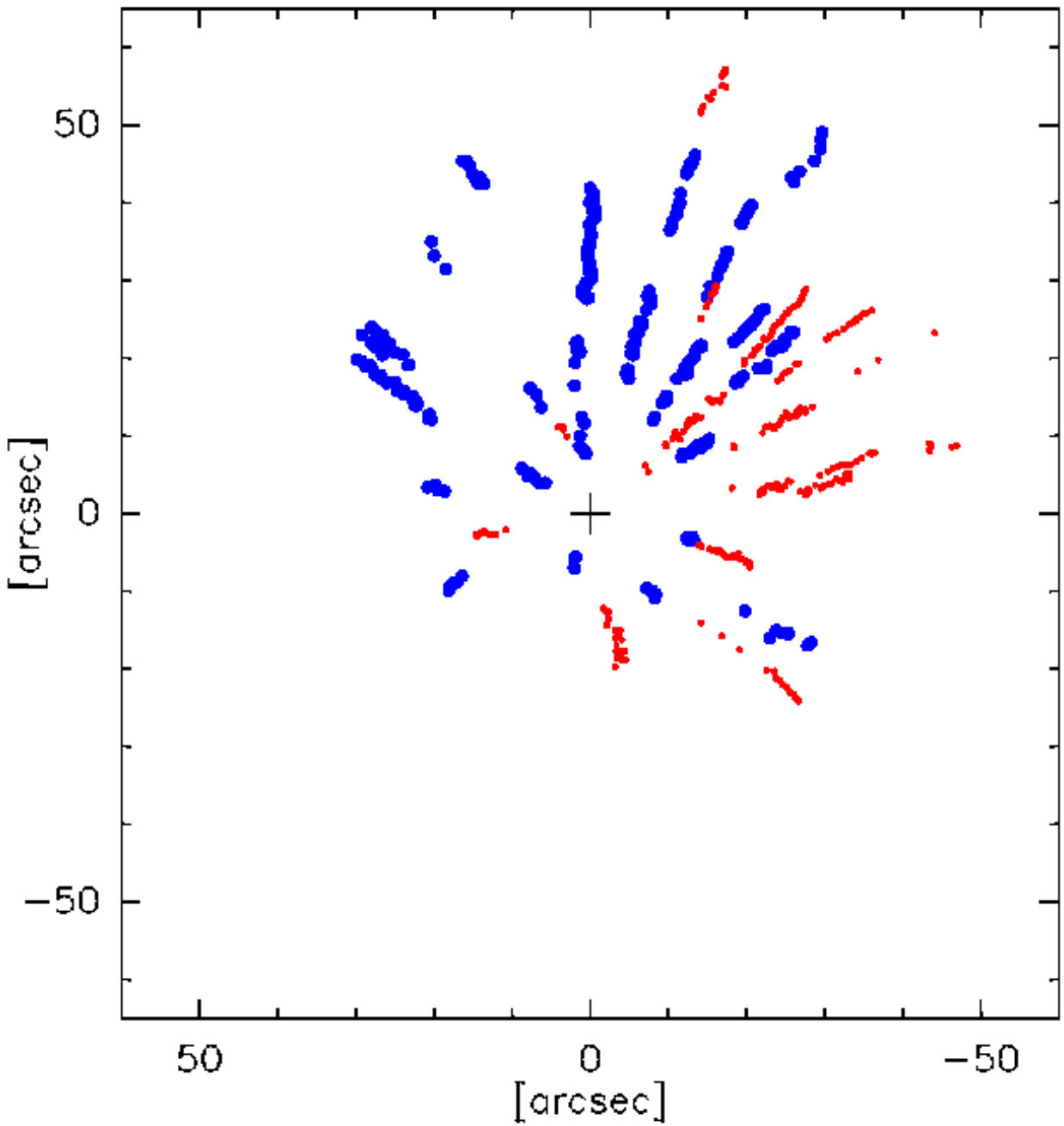


Gómez et al. (2005, 2008)

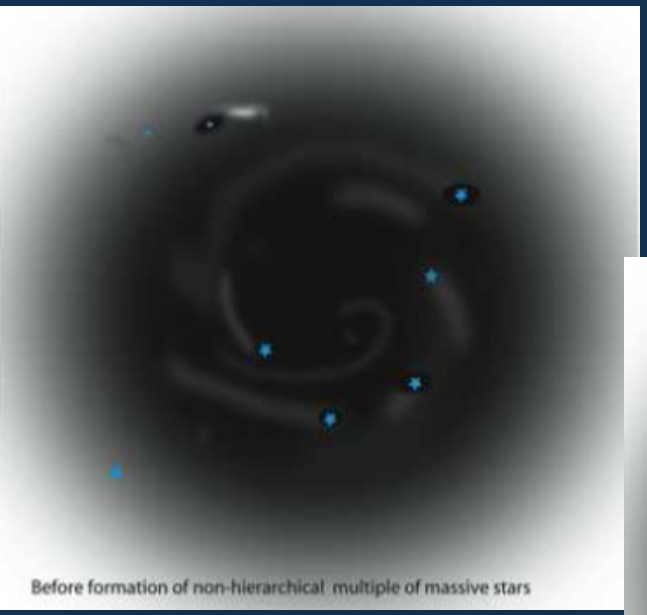
Kinematics from an explosion

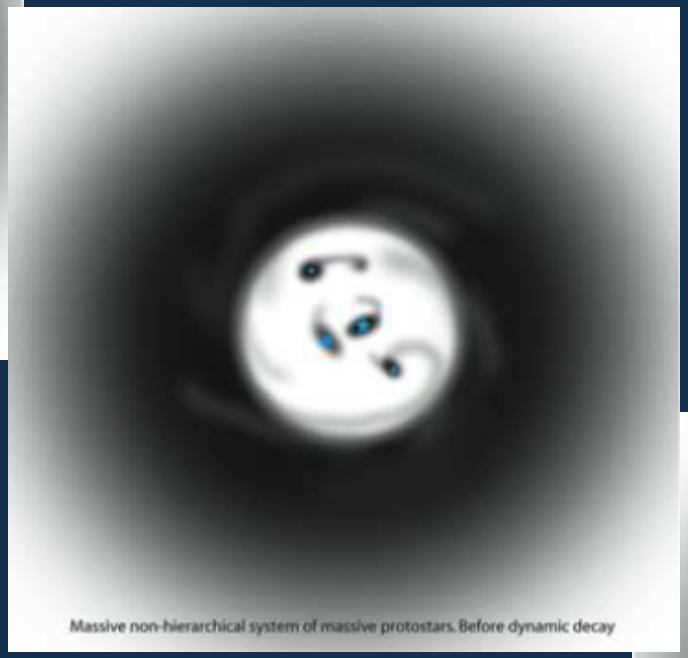


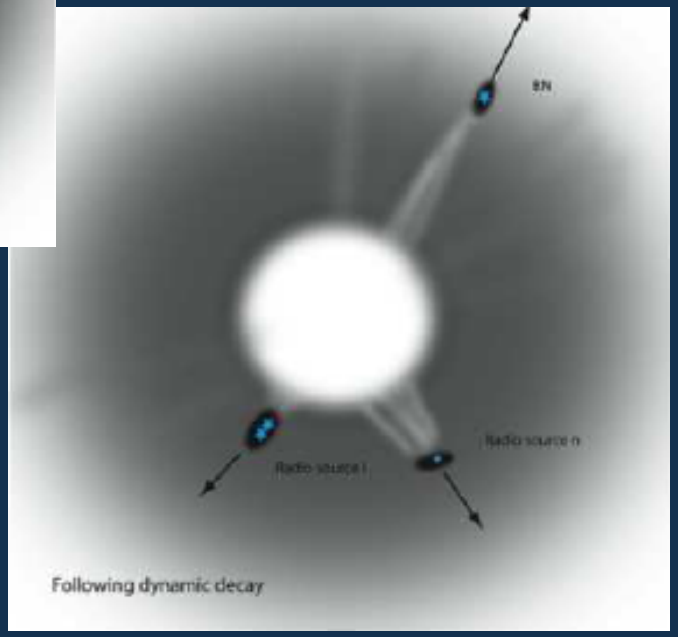
V = 9.0 ± 2 km s^{-1}


50
0
−50
[arcsec]
50
0
−50
[arcsec]

Violent desintegration of a stellar system

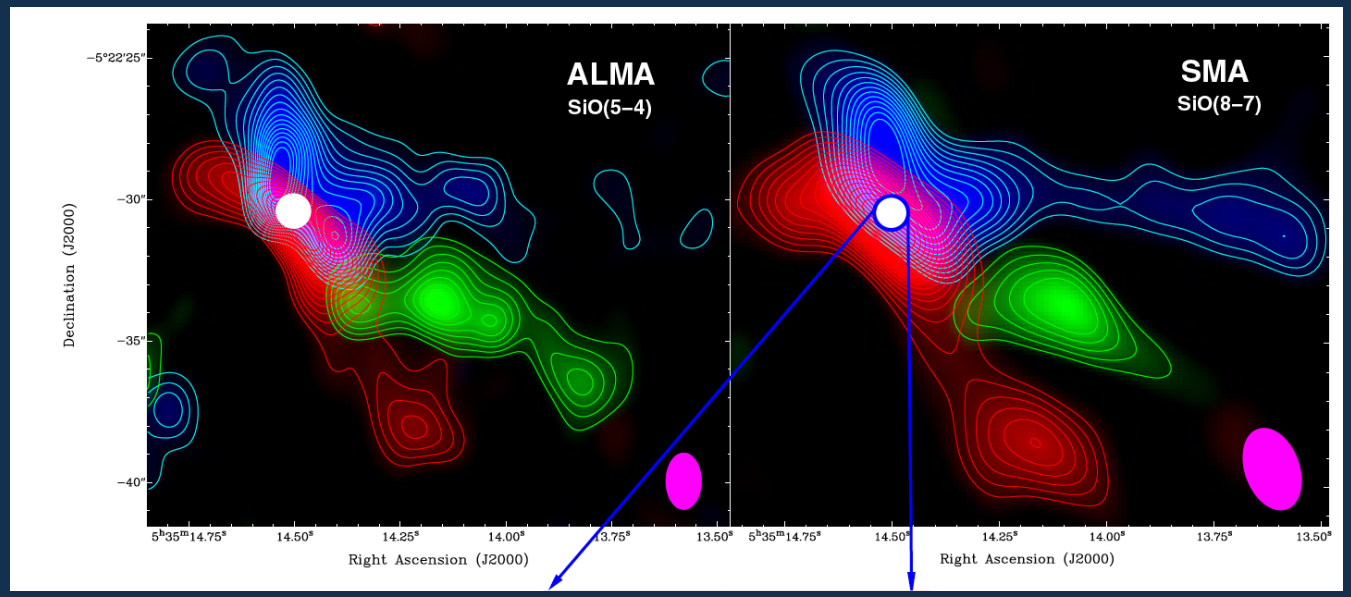




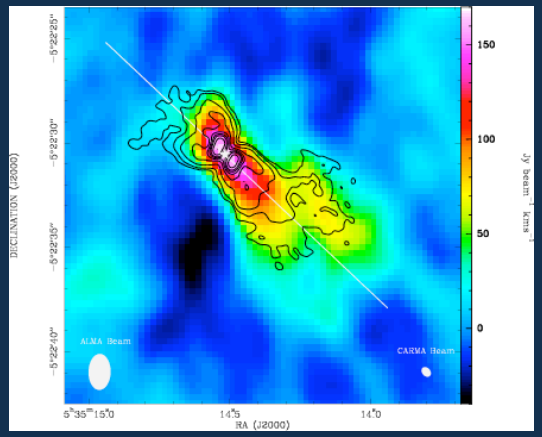


Bally and Zinnecker (2005); Reipurth (2000)

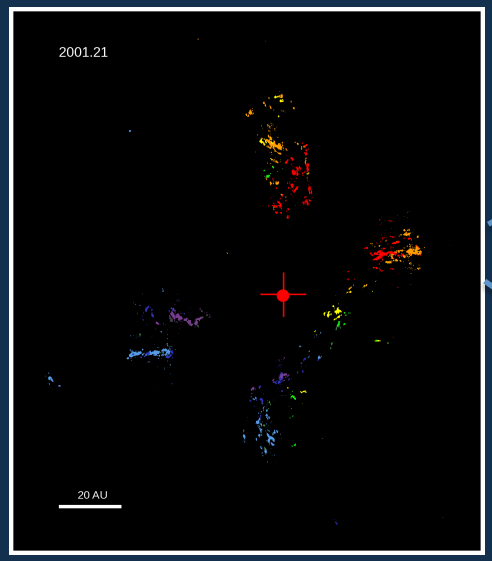
Source I: A merge of two young stars?



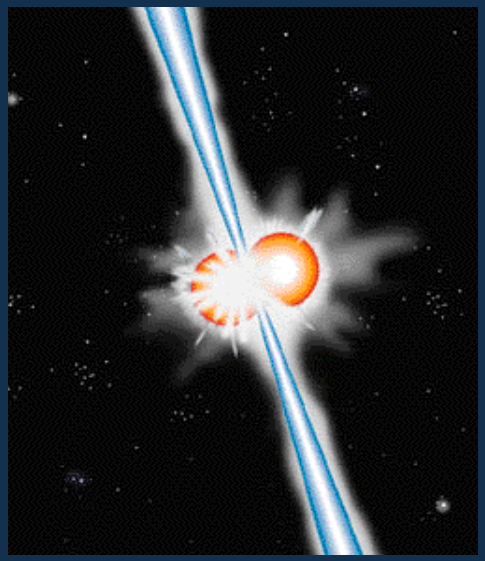
Zapata et al. (2012)



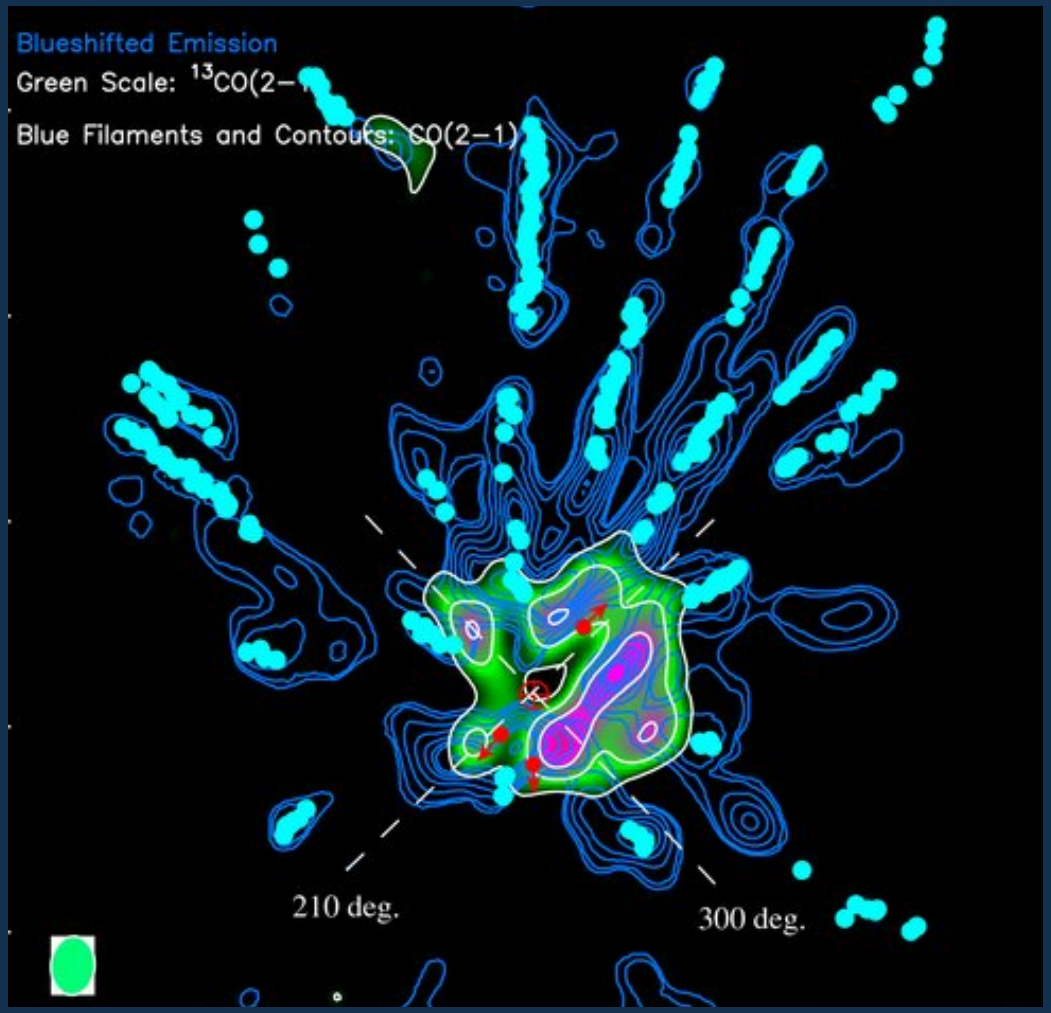
CARMA – Plambeck et al.

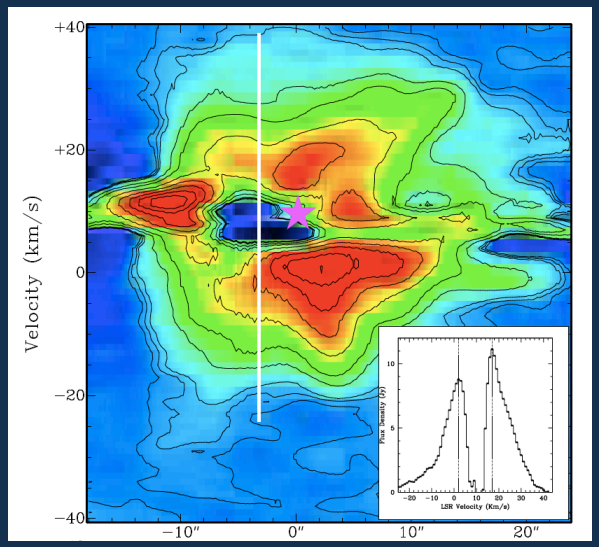


Goddi et al. (2009)



REMNANTS FROM THE EXPLOSIVE DESINTEGRATION



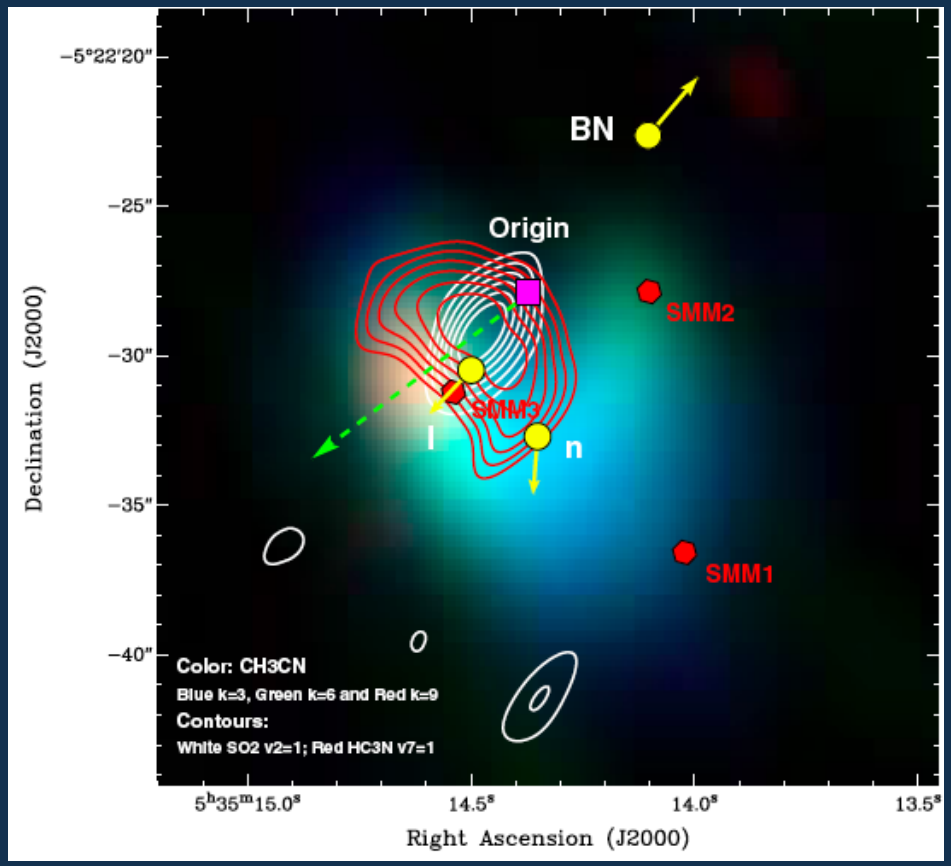


Molecular expanding shell
Age about 500 yrs

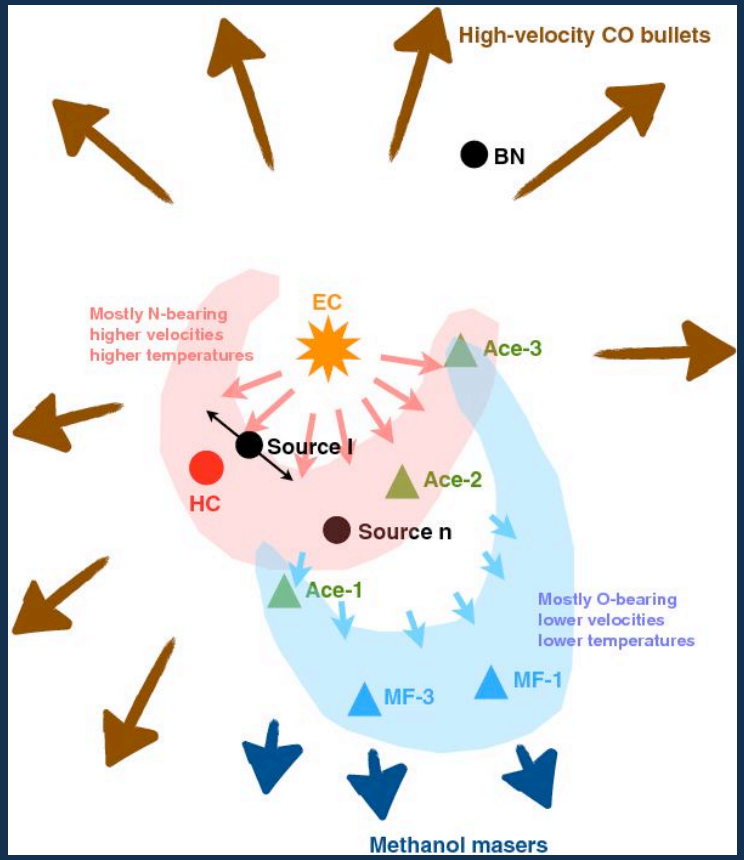
REMNANTS FROM THE EXPLOSIVE DESINTEGRATION

Hot Molecular Core - Orion

Zapata et al. (2009)



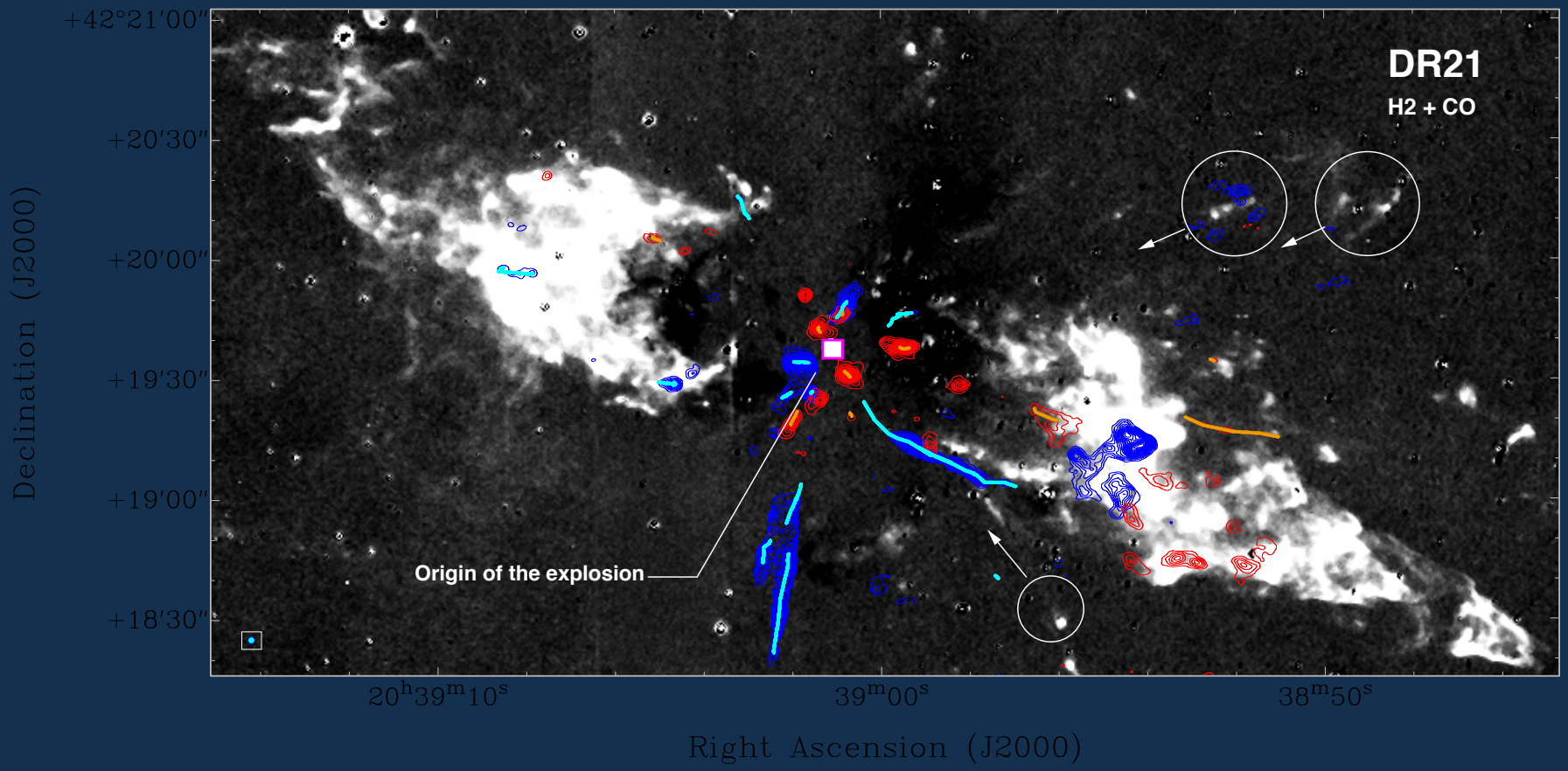
Peng et al. (2013)
Liu, Girart, et al. (2002)



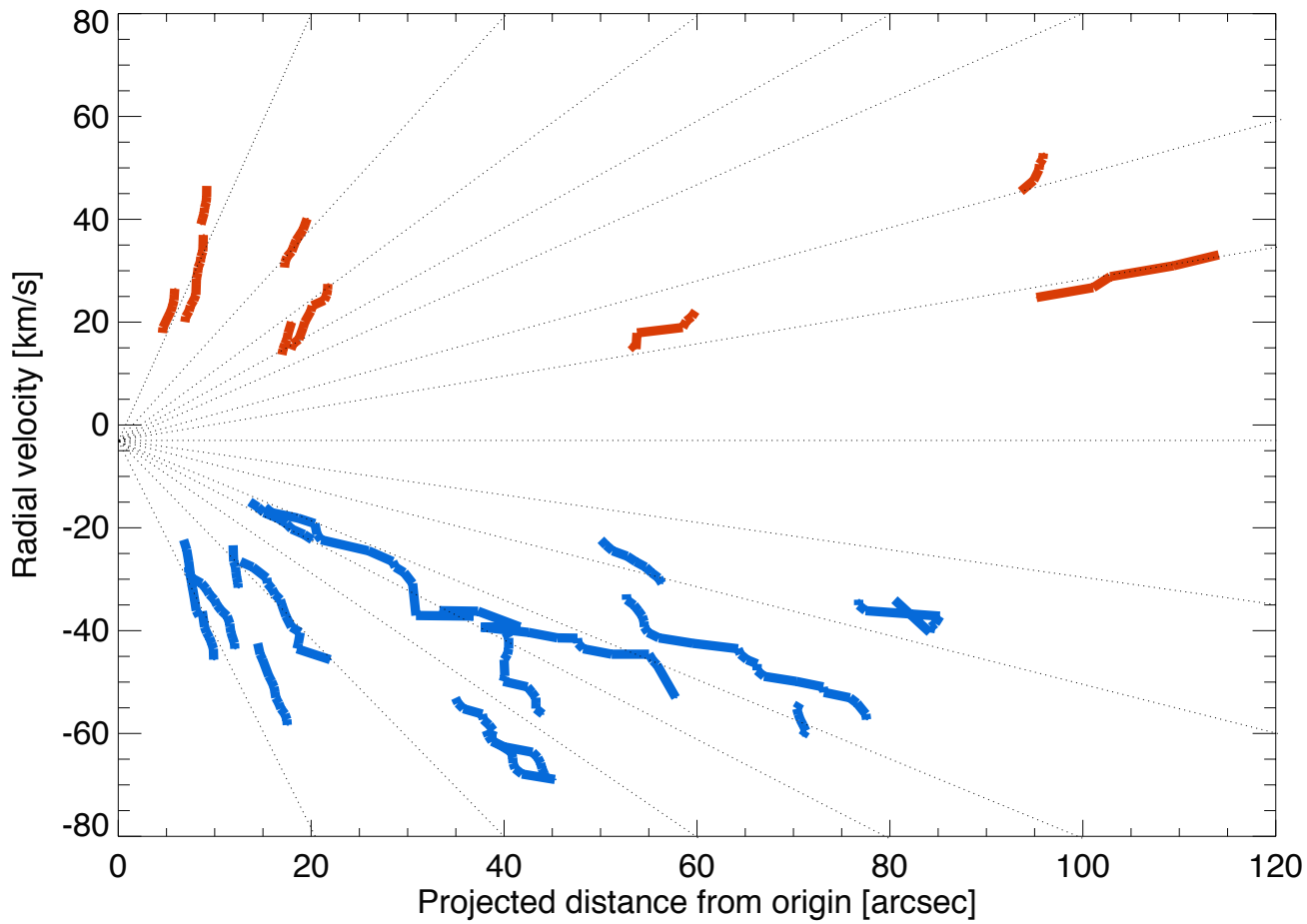
IS THERE MORE CASES LIKE BN-KL?

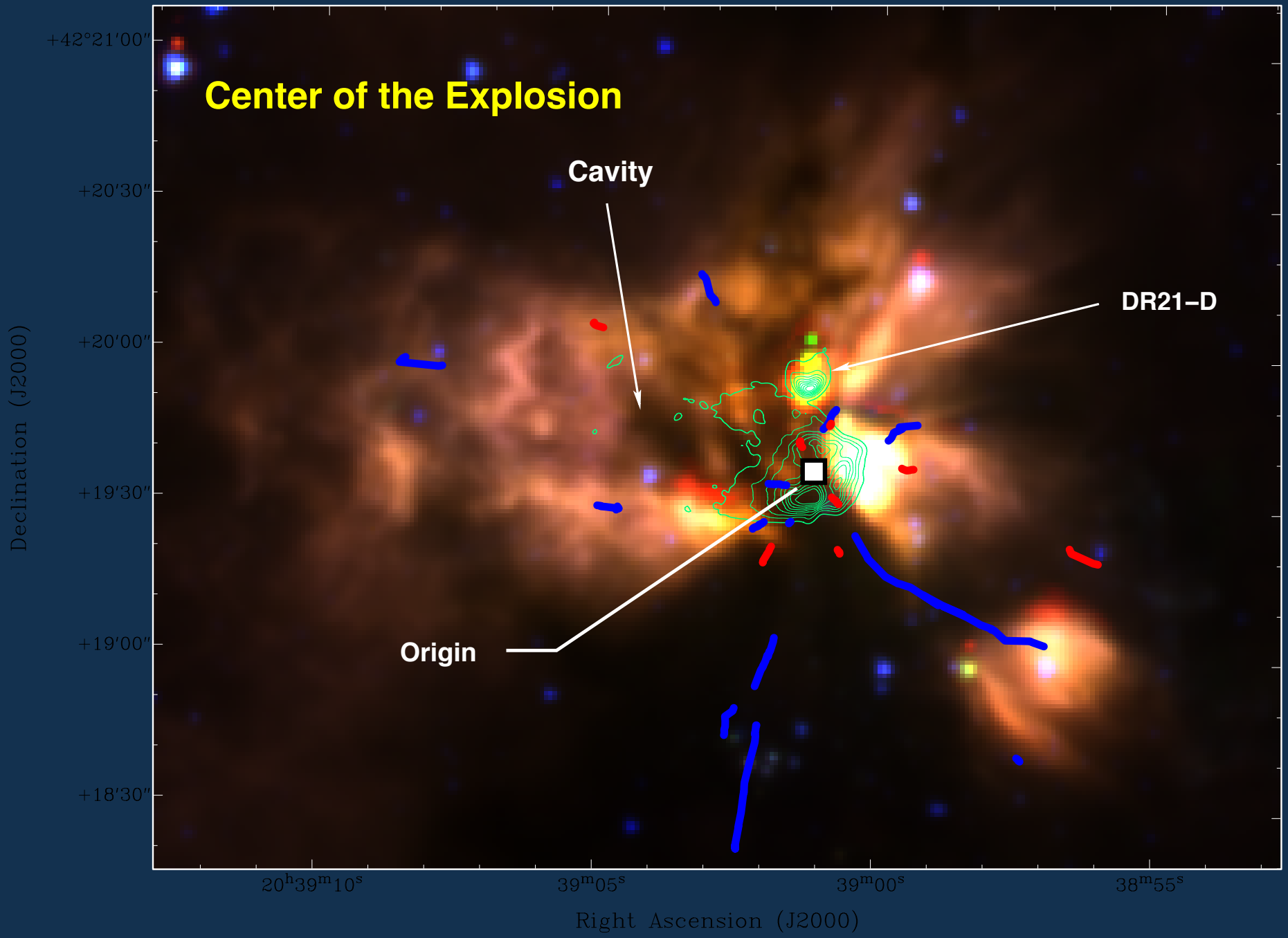

Molecular Outflows in DR21
Mass – 3000 Msol
E_k - 2 x 10^{48} Lsol
High Velocity >50 km s^{-1}
Spitzer
4.5 μm
J-K-H_2
μm
3.6
Davis et al. (2007)

10,000 years explosion in DR21



Kinematics from an explosion



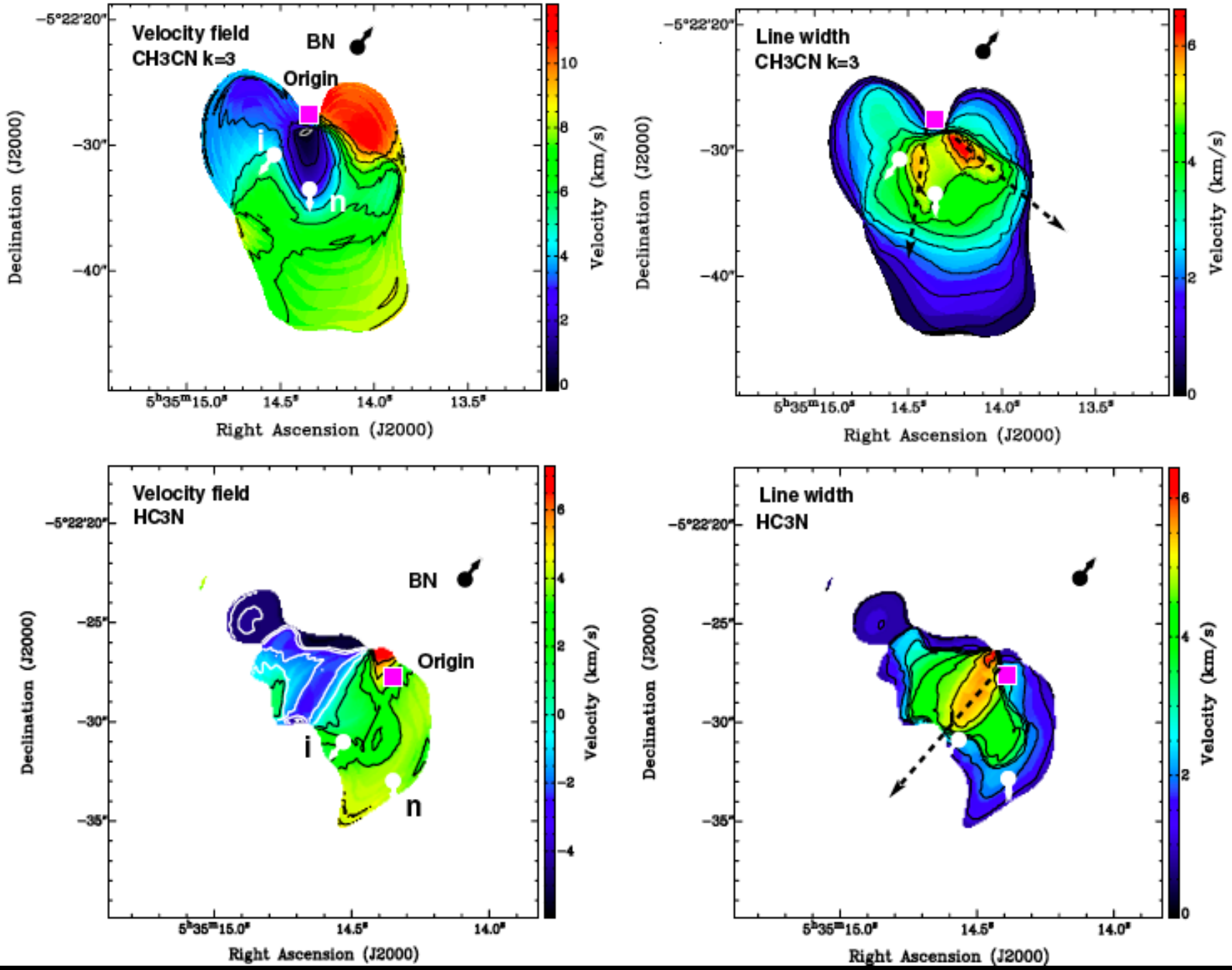

Center of the Explosion
Cavity
DR21–D
Origin
+42°21′00″
+20′30″
+20′00″
+19′30″
+19′00″
+18′30″
Declination (J2000)
20h39m10s
39m05s
39m00s
38m55s
Right Ascension (J2000)

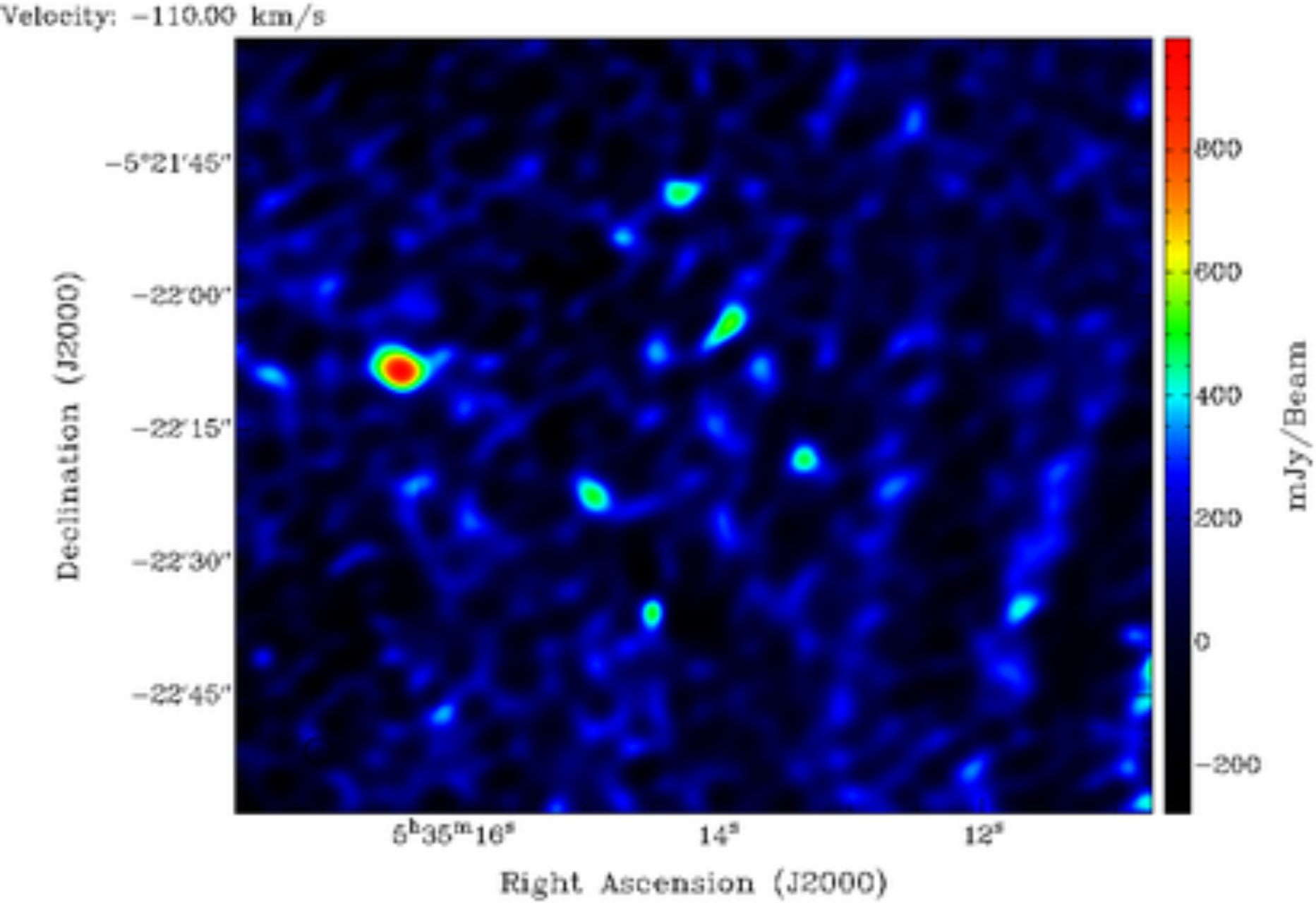
Main conclusion

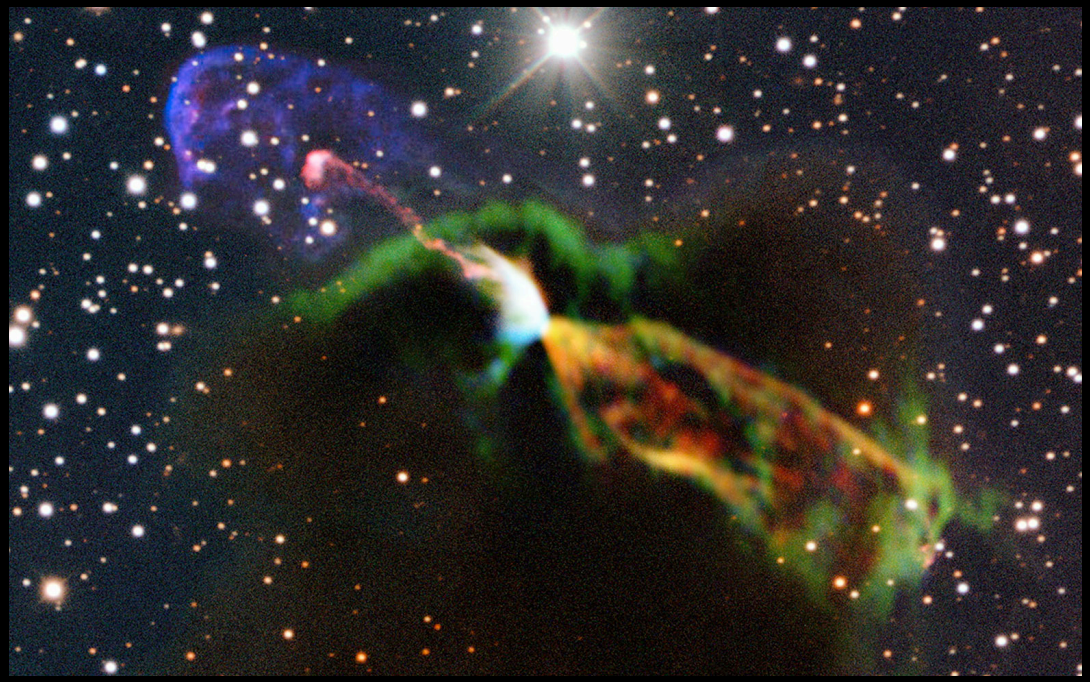
The outflow in **BN/KL** and **DR21** are NOT the typical outflows associated with the formation of a single massive (proto)star.

Future

- Theoretical model to explain the decay of the stellar systems
- Is Source I a real close binary?
- Test the "external heating model" of the hot molecular core
- From which objects are arising the large luminosities?


Velocity field
CH3CN k=3
BN
Origin
i
n
Line width
CH3CN k=3
Velocity field
HC3N
Line width
HC3N
Declination (J2000)
Right Ascension (J2000)
Velocity (km/s)


Velocity: −110.00 km/s
−5°21′45″
−22′00″
−22′15″
−22′30″
−22′45″
Declination (J2000)
5h35m16s
14s
12s
Right Ascension (J2000)
800
600
400
200
0
−200
mJy/Beam



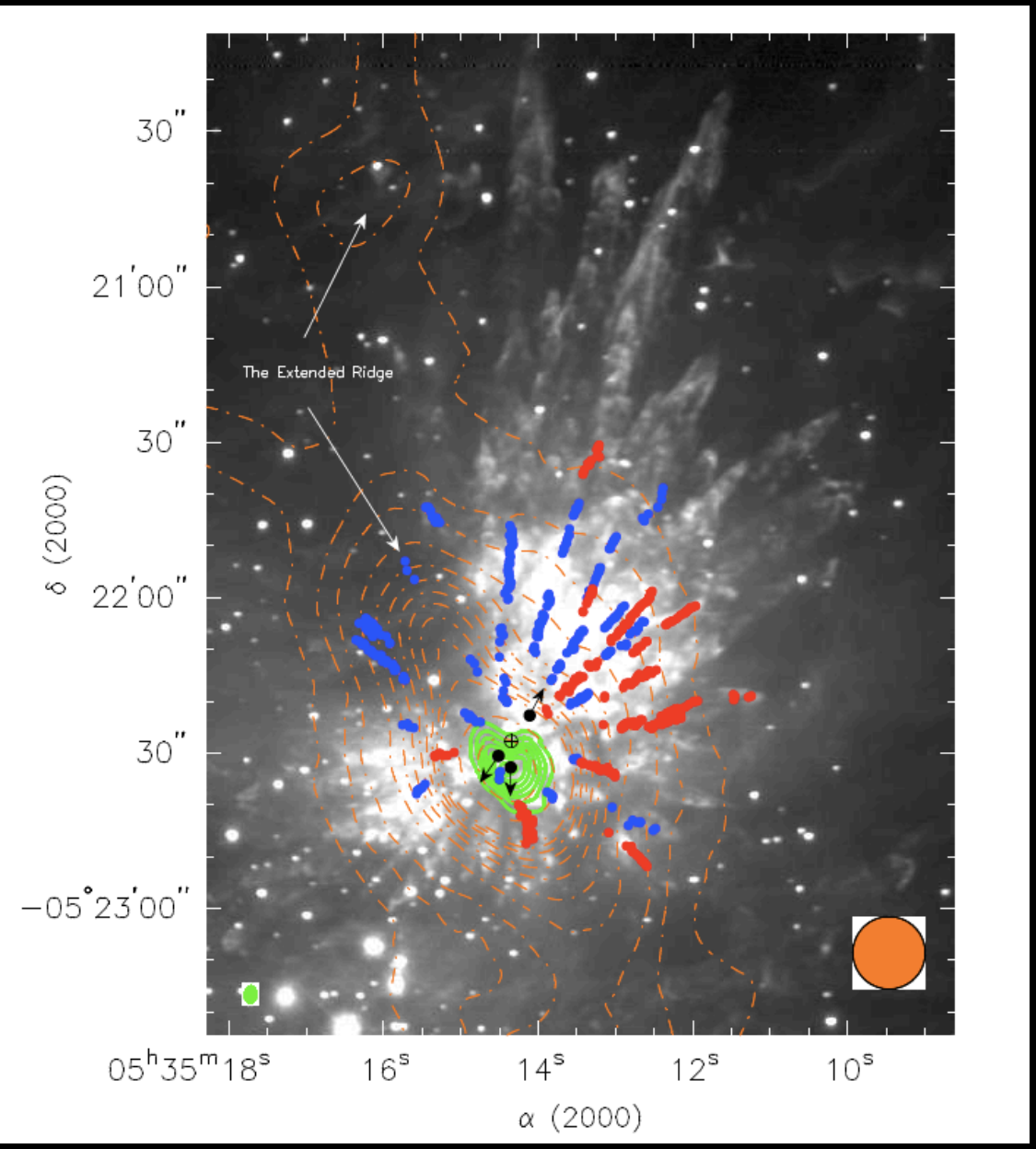
ALMA - *HH 46/47*
Arce et al. (2013)
CO

Hartigan et al.

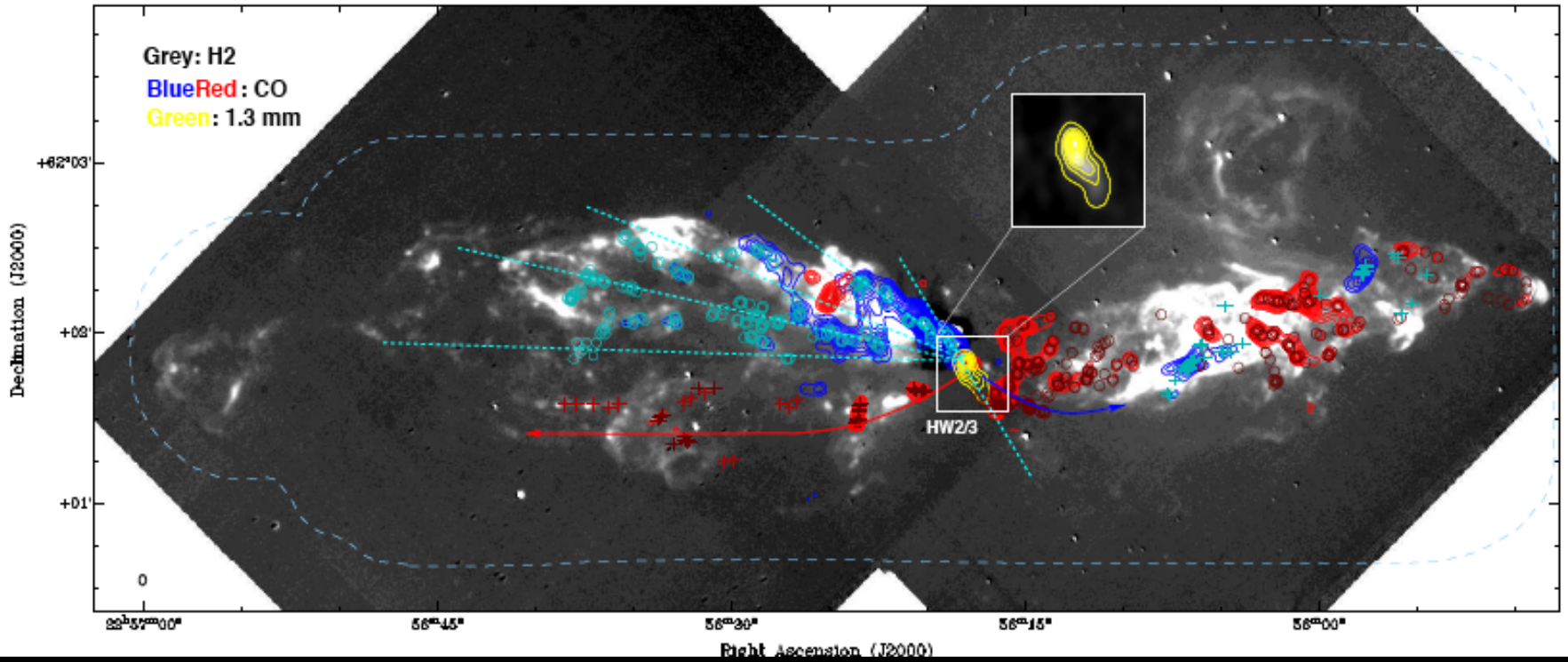
HST
Hα – red
SII – blue

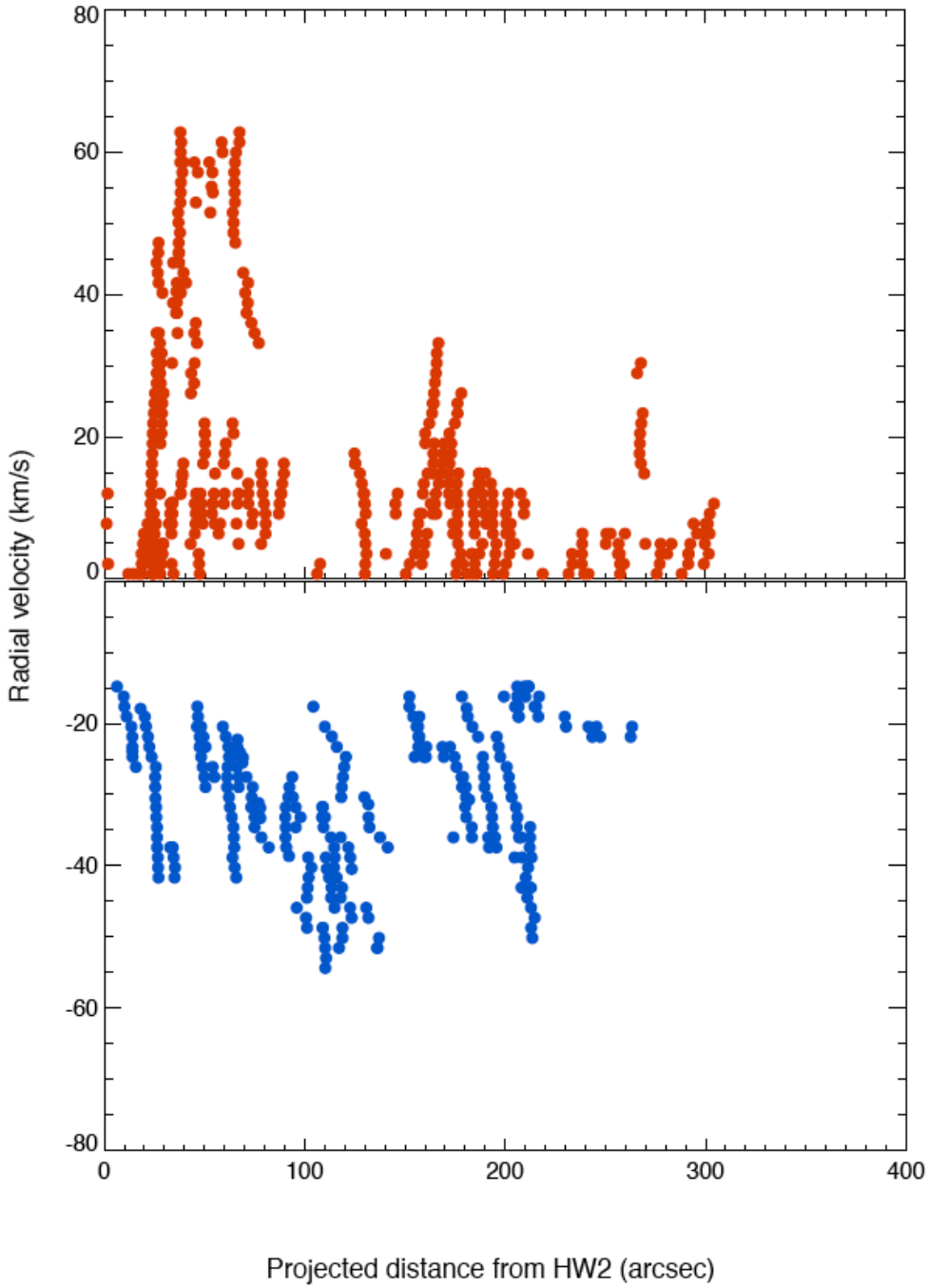
HH47

1994



CH_3CN (12-11) k=3 -- SMA
880 μm – SCUBA-JCMT
CO(2-1) & H2


Grey: H2
BlueRed: CO
Green: 1.3 mm
HW2/3
+62°03'
+02'
+01'
Declination (J2000)
22h57m00s
56m45s
56m30s
56m15s
56m00s
Right Ascension (J2000)


80
60
40
20
0
-20
-40
-60
-80
Radial velocity (km/s)
0
100
200
300
400
Projected distance from HW2 (arcsec)