Searching the First Hydrostatic Cores in the Perseus Molecular Cloud

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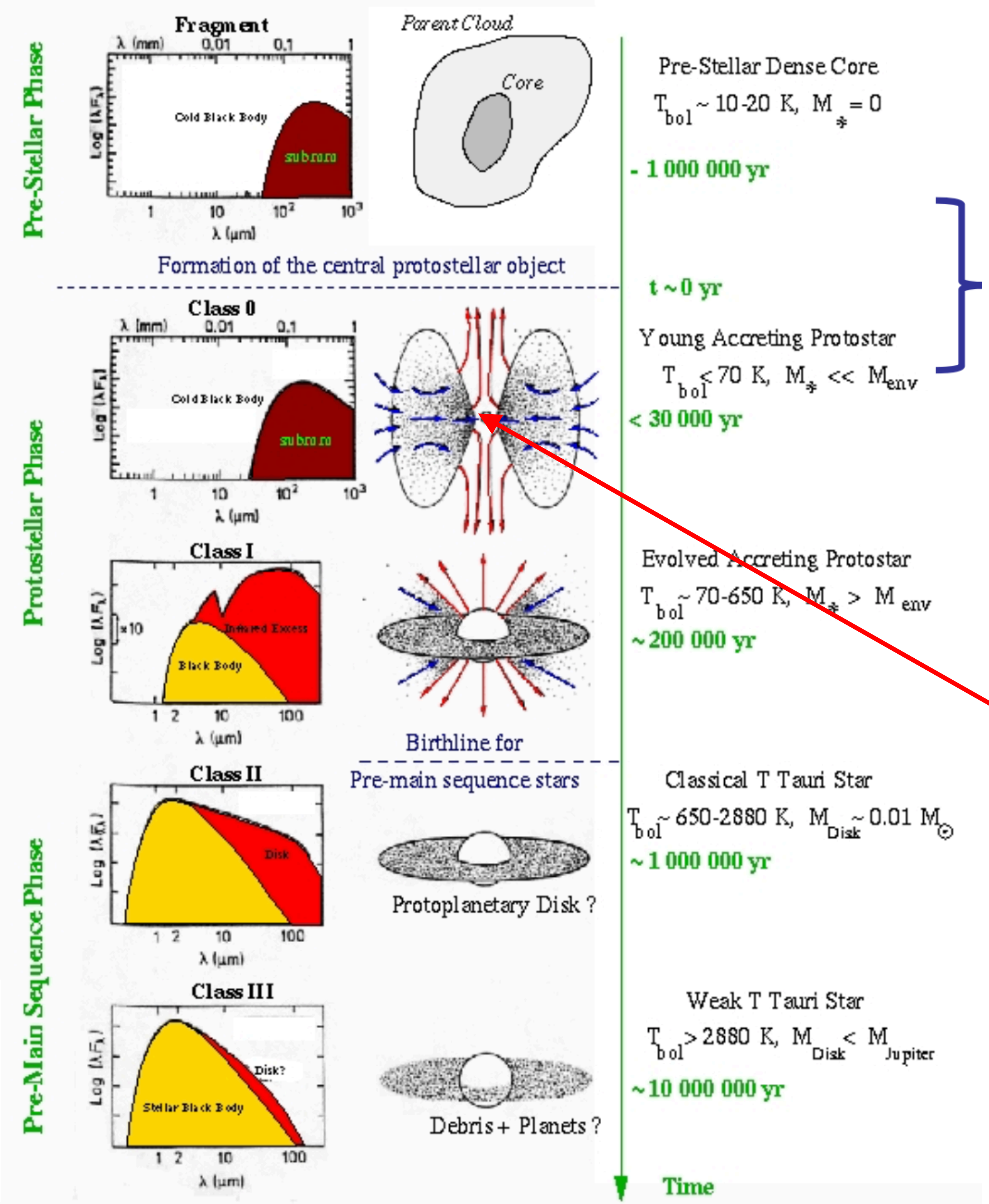


First collapse

Compressional heating

Radiative cooling

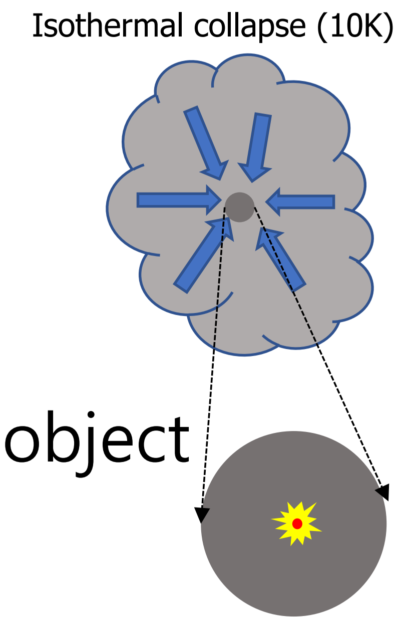
T~200K

First Core Here!

a quasi-adiabatic hydrostatic object

mostly H_2

shock form at the surface



Second collapse

Release gravitational energy

consumed by H_2 dissociation

Second core / Class 0 protostar

mostly H atom

First Hydrostatic Core (FHC)

- The transient phase between prestellar cores and Class 0 protostars.
- Short lifetime (10^3 – 10^4 yr, Boss & Yorke 1995).
- No near infrared continuum.
- Slow outflows (a few km/s).
- Can be heated over ~100K in a very short period ~ 5000 yr.
  due to the accretion shocks (Masunaga & Inutsuka 2000).
- Size about ~AU
- Extremely difficult to be detected directly.
- It is a key to understand the earliest stage of star formation.

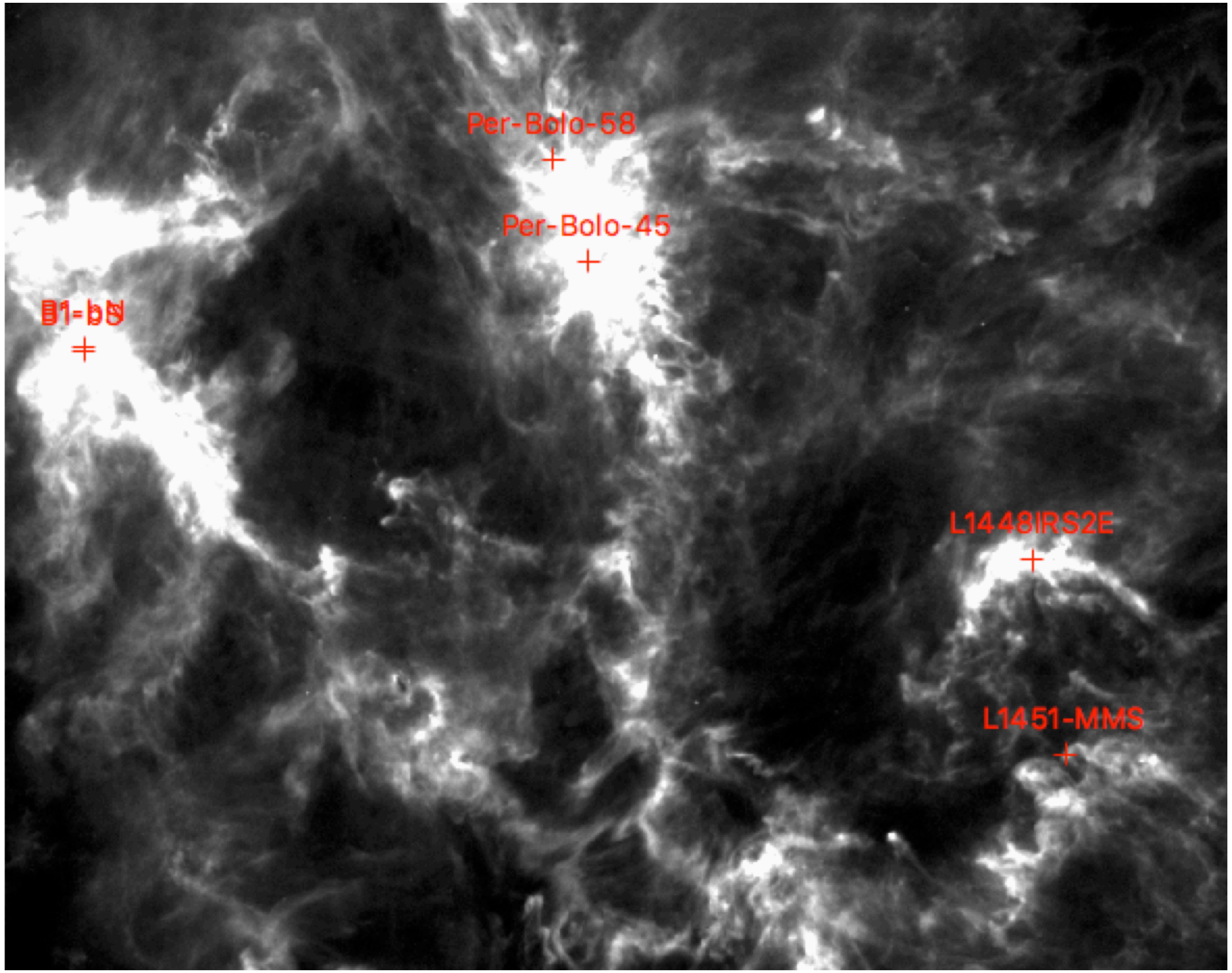
The aim of this project

- Several FHCs candidates were suggested (< 10), but none of them have been confirmed.
- In this work, we produce synthesis images using CASA simulation based on a simple density profile model. We match the simulated images to the First Core candidates B1-bN with SMA, ALMA and VLA observational results.
- Our simulations show that with ALMA observations, we can decouple the FHC component from envelope.
- The identification of FHCs will make great strides in our understanding of star formation.

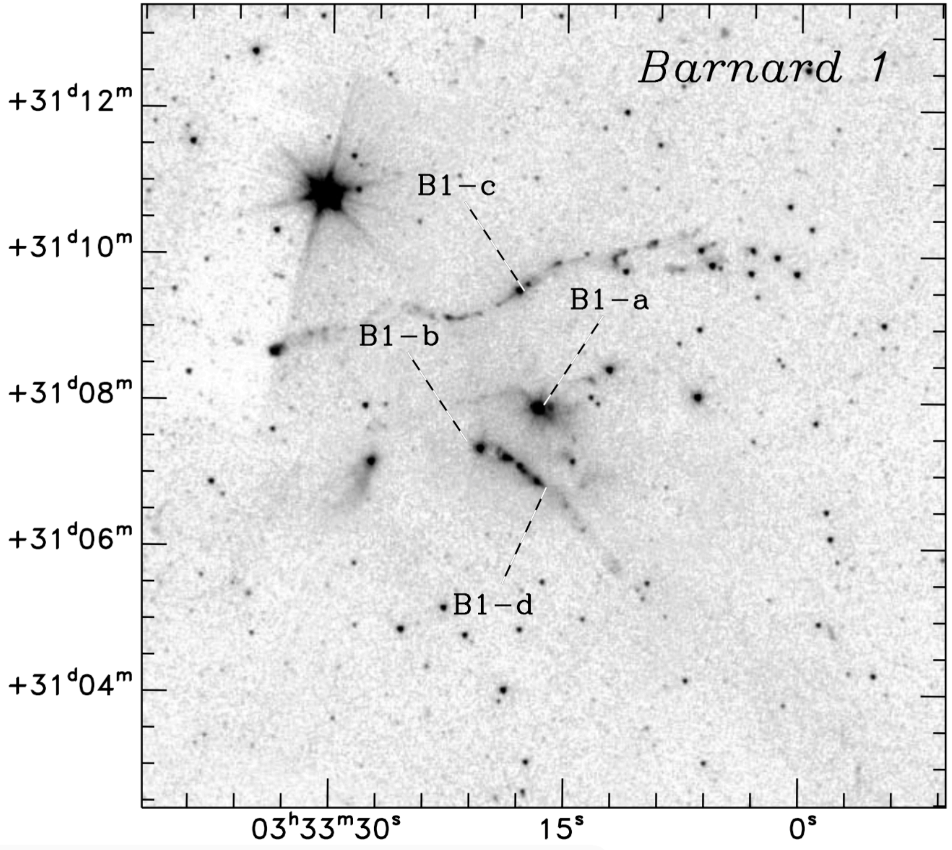
First Core candidates

- Chamaeleon-MMS1 (Belloche et al. 2006) (Tsitali et al. 2013) (Väisälä et al. 2014)
- L1448 IRS2E (Chen et al. 2010)
- Per-bolo 58 (Enoch et al. 2010) (Dunham et al. 2011)
- L1451-mm (Pineda et al. 2011) (Maureira et al. 2017)
- Per-Bolo 45 (Schnee et al. 2012)
- CB 17 (Chen et al. 2012) (Schmalzl et al. 2014)
- B1-bS and B1-bN (Pezzuto et al. 2012) (Huang & Hirano 2013) (Hirano & Liu. 2014) (Gerin et al. 2015)
- IC 348-SMM2E (Palau et al. 2014)

First Core candidates in the Perseus Molecular Cloud

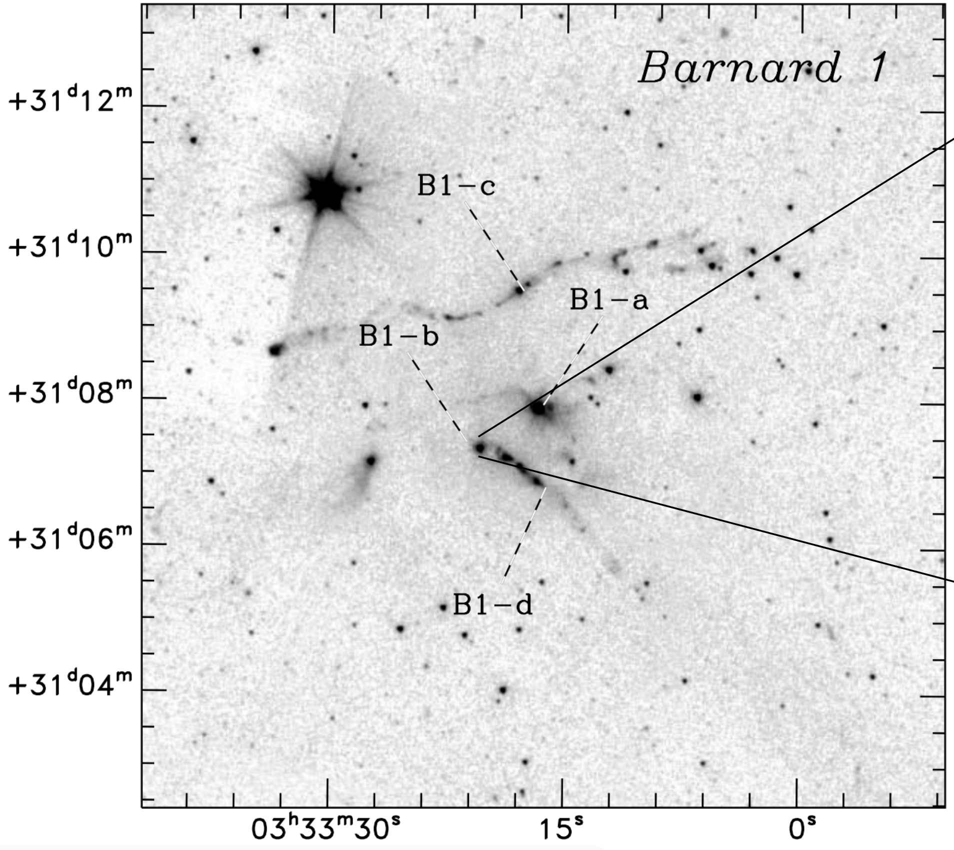


B1-bN & B1-bS



JØøRGENSEN ET AL. 2006 SPITZER c2d SURVEY. III.

B1-bN & B1-bS



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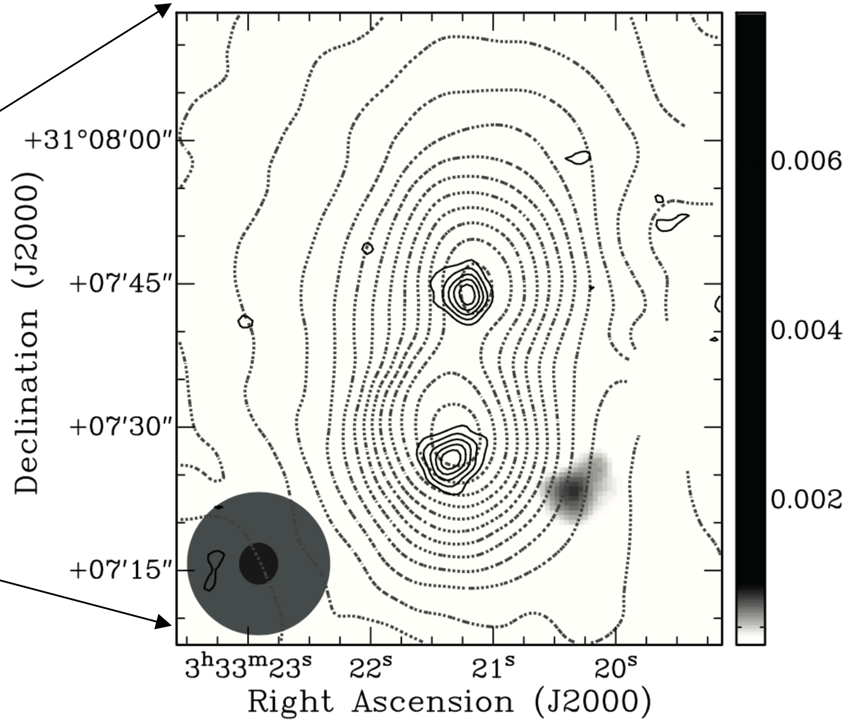
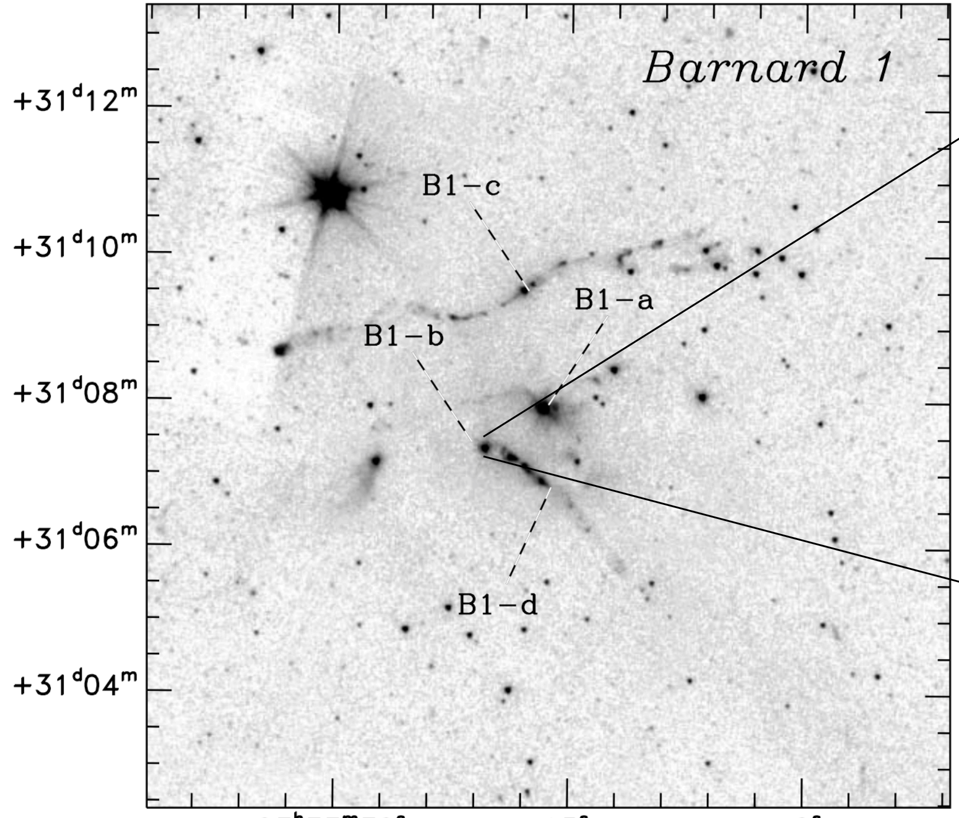


Hirano & Liu. 2014
850 µm (dot contours) and 3.3 mm (solid contours) continuum maps of the B1-b region on top of the Spitzer MIPS 24 µm image (gray scale).

B1-bN & B1-bS



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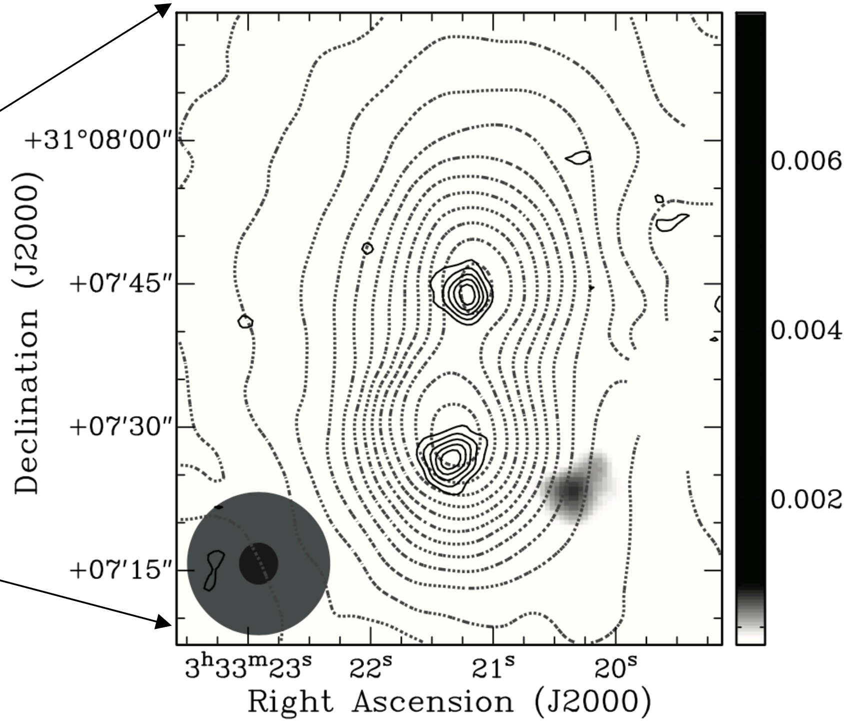

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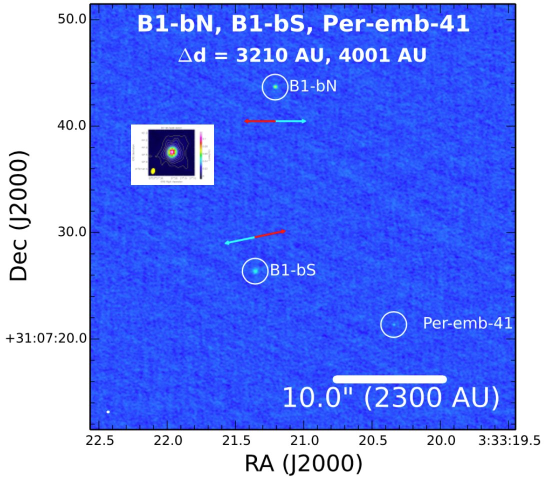
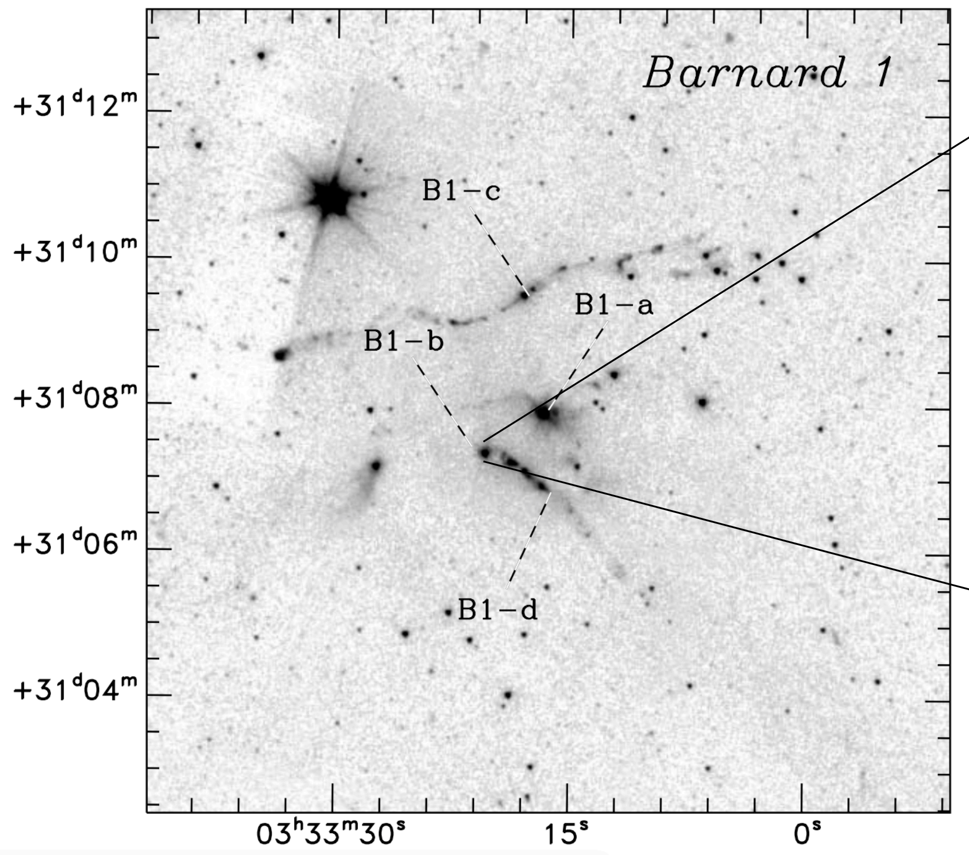


VLA:
Tobin et al. 2016 VANDAM

ALMA band7:
Gerin et al project code: 2015.1.00025.S

B1-bN & B1-bS

Synthesis images from interferometer:
Resolve out the envelope and Resolve the First Core directly?



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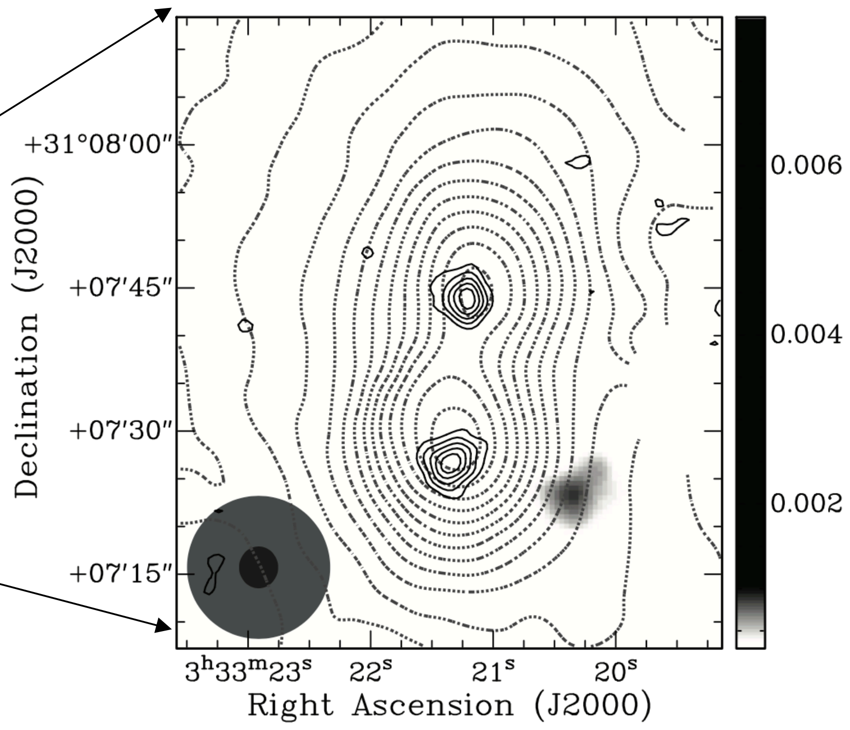

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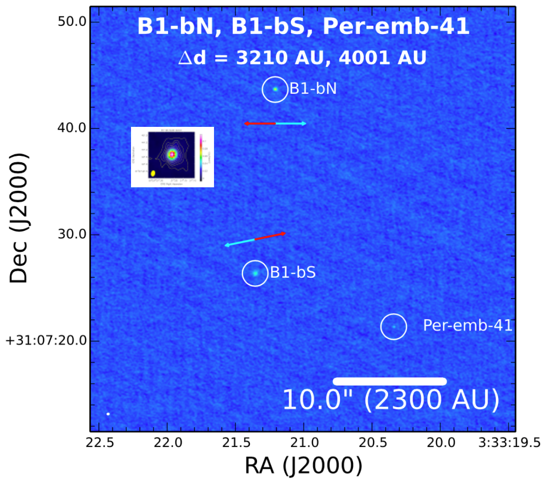

VLA:
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ALMA band7:
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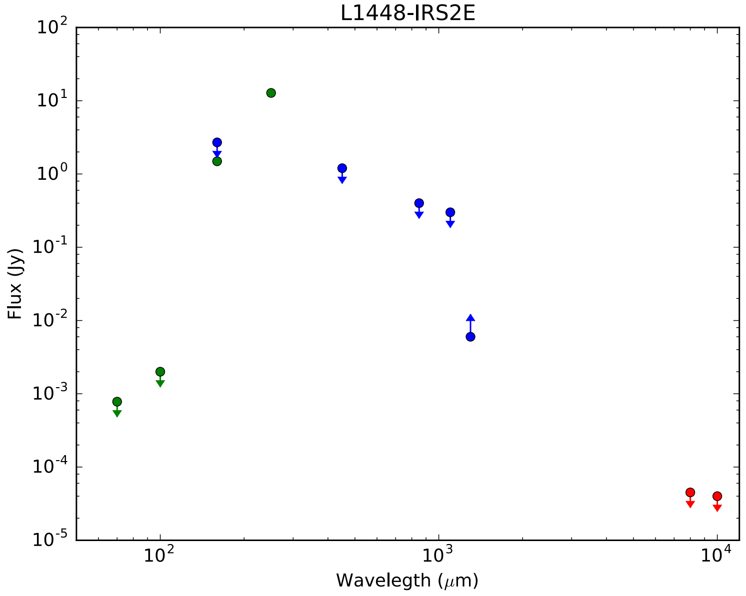
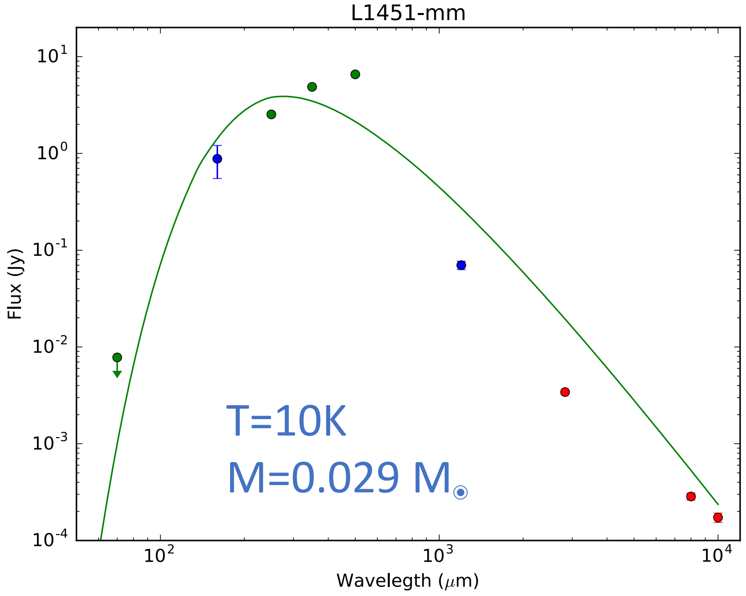
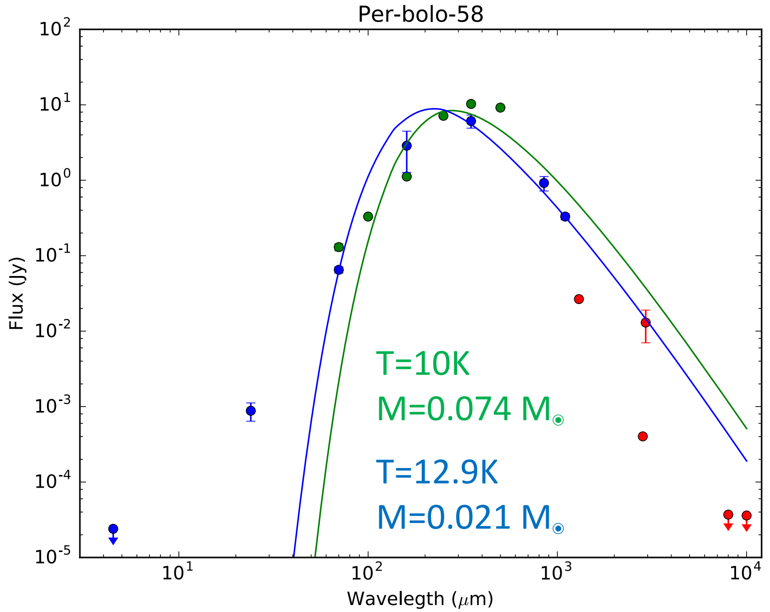
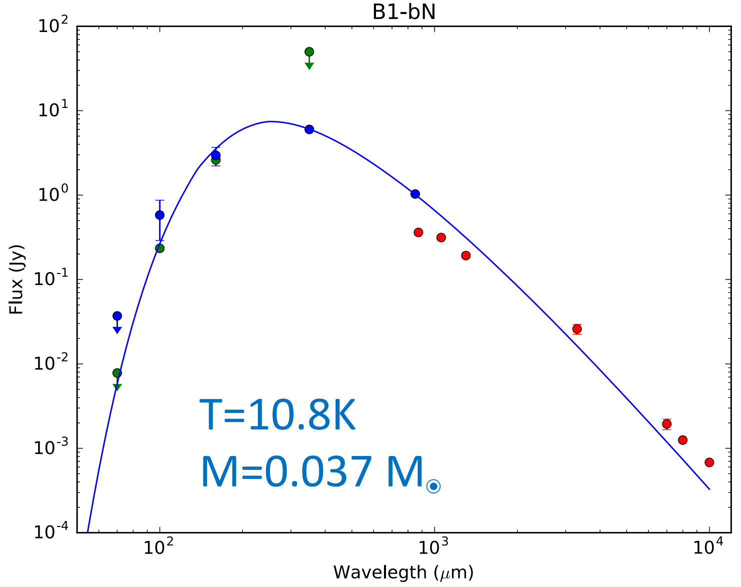
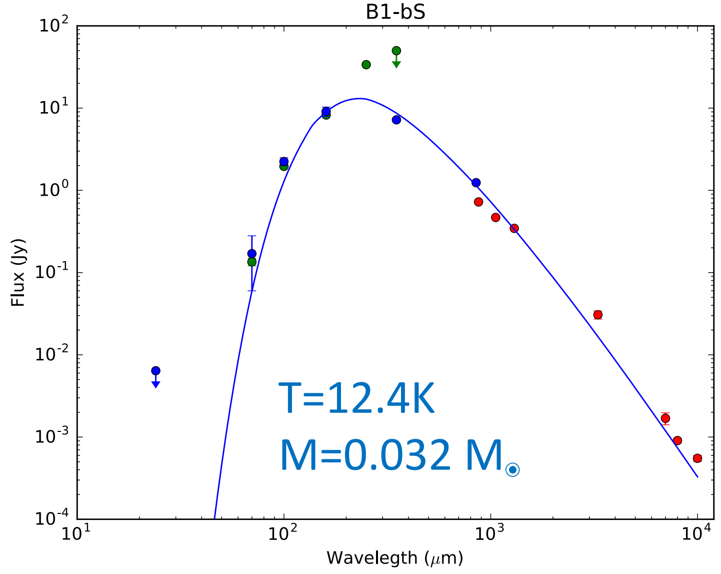
SEDs of First Hydrostatic Core











The radiation of short wavelength emitted by the FHCs are essentially completely reprocessed by the dusts which surround the FHCs in the parent envelopes to longer wavelength.

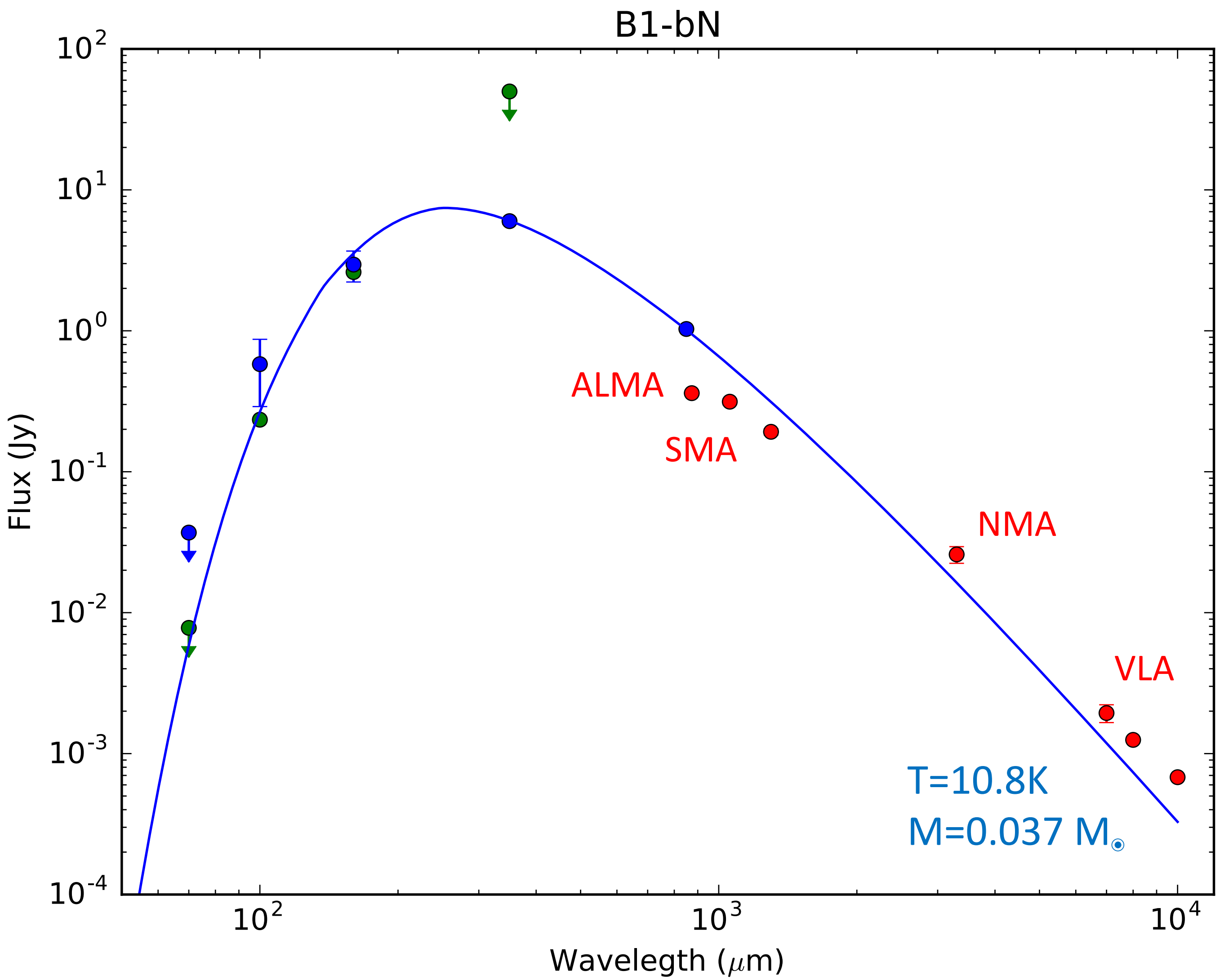
- Interferometer
- • • Single dish

SED of B1-bN (Envelope + Compact core?)

Table 1. Photometric Data of B1-bN

wavelength	Instrument	Flux Density (Jy)	Error (Jy)	Reference	κ_ν [d] (cm^2/g)
70μm	Herschel PACS	$<3.7\times10^{-2}$		Pezzuto et al. (2012)	65.19
70μm	Herschel PACS	$<7.8\times10^{-3}$		This work [a]	65.19
100μm	Herschel PACS	5.8×10^{-1}	0.29	Pezzuto et al. (2012)	28.38
100μm	Herschel PACS	0.324	0.008	This work [a]	28.38
160μm	Herschel PACS	2.95	0.73	Pezzuto et al. (2012)	10.43
160μm	Herschel PACS	2.61	0.018	This work [a]	10.43
350μm	Herschel SPIRE	<49.91 [b]	0.027 [b]	This work [a]	1.973
350μm	CSO SHARC	6.0	0.3	Hirano & Liu (2014)	1.973
850μm	JCMT SCUBA	1.03	0.03	Hirano & Liu (2014)	0.4083
870μm	ALMA band7	3.61×10^{-1}		This work [c]	0.3914
1.1mm	SMA	3.14×10^{-1}	1.5×10^{-2}	Hirano & Liu (2014)	0.2737
1.3mm	SMA	1.92×10^{-1}	1.0×10^{-2}	Hirano & Liu (2014)	0.2118
3mm	NMA	2.59×10^{-2}	3.5×10^{-3}	Hirano & Liu (2014)	0.0606
7mm	VLA	1.94×10^{-3}	2.8×10^{-4}	Hirano & Liu (2014)	0.01472
8mm	VLA	1.251×10^{-3}	3.6×10^{-5}	Tobin et al. (2016)	0.01177
10mm	VLA	6.80×10^{-4}	6.0×10^{-5}	Tobin et al. (2016)	0.008052

NOTE—
[a] PSF photometry result using StarFinder. - http://www.bo.astro.it/StarFinder/index.htm
[b] The source is blended on Herschel SPIRE image.
[c] Aperture photometry result from the data taken by Gerin et al (project code: 2015.1.00025.S).
[d] κ_ν value from Weingartner & Draine (2001).



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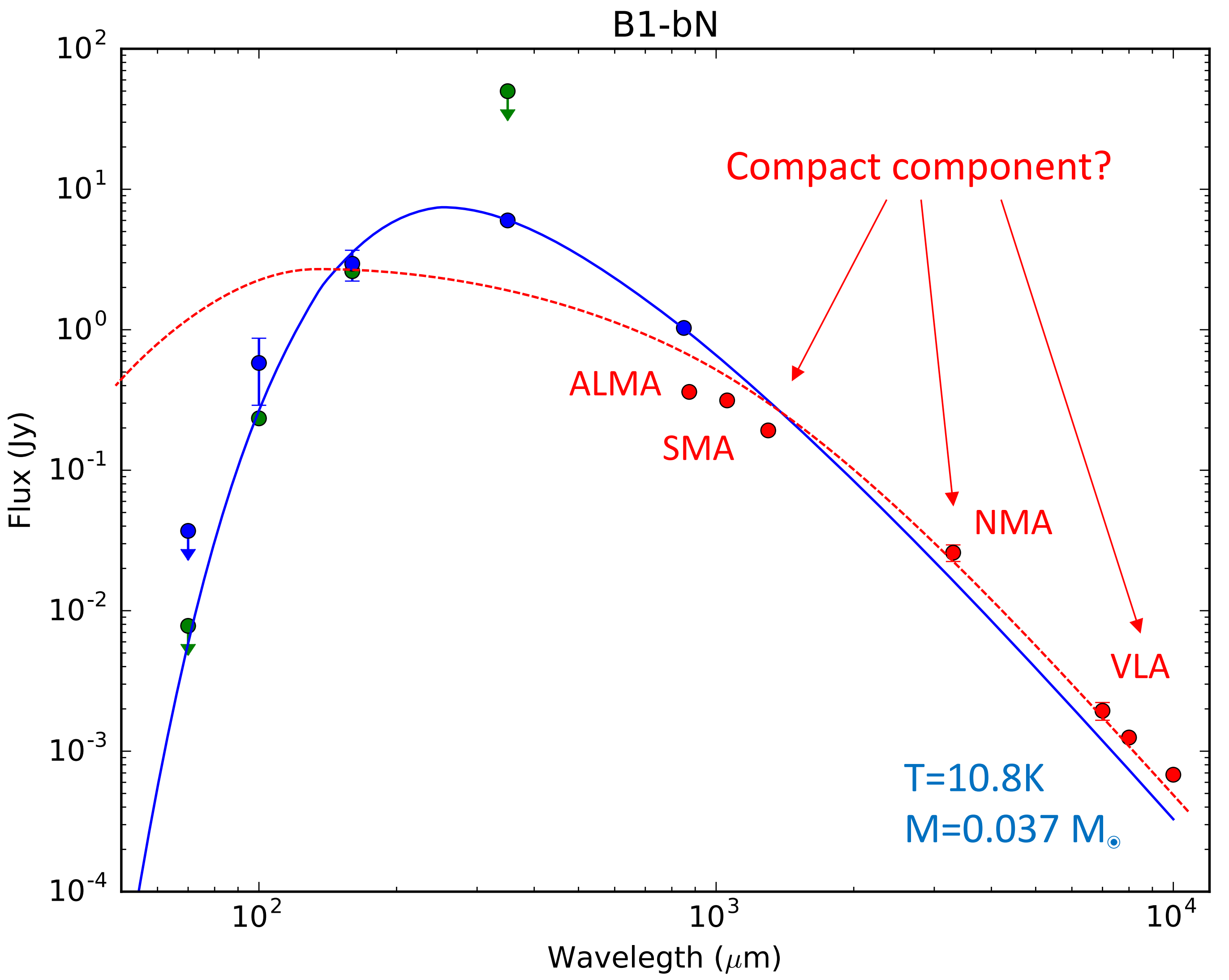
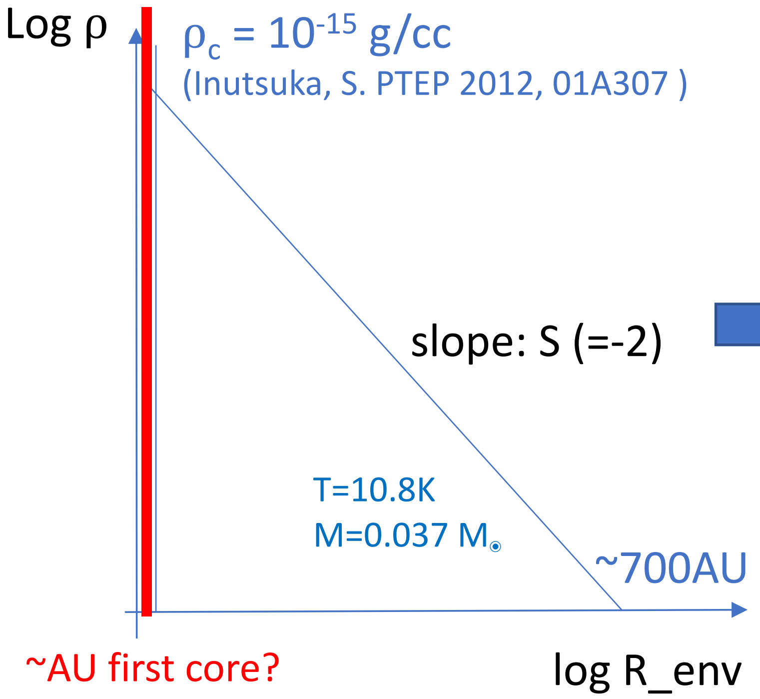


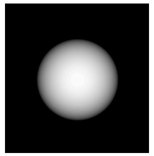
Build a First Core model

- ➢The idea is to build a First Core model (Envelope + Compact component).
- ➢Using B1-bN as a standard.
- ➢ The envelope is constrained by single dish observations.
- ➢The compact component can be resolved by the interferometry.
- ➢We run CASA “simobserve” task to produce synthesis images of our model.
- ➢Compare our model to B1-bN.

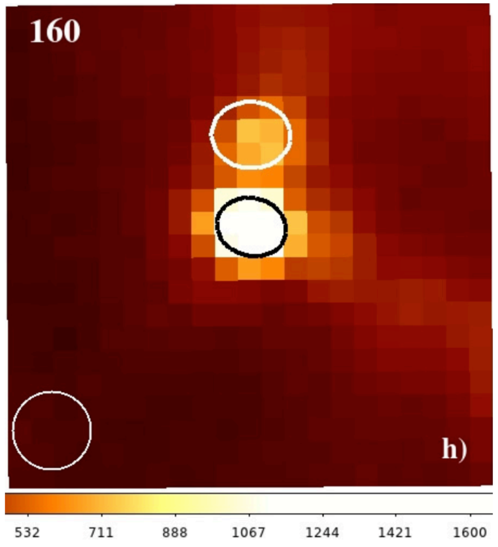
Build a First Core model

$$I_{\nu}(s) = I_{\nu}(s_0)e^{-\tau_{\nu}(s_0,s)} + \int_{s_0}^{s} j_{\nu}(s')e^{-\tau_{\nu}(s',s)}ds'$$

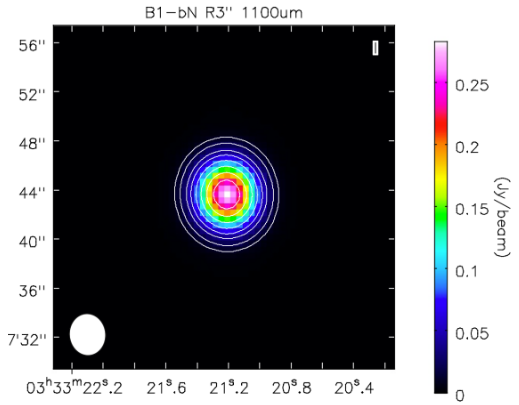




CASA “simobserve” tasks



Pezzuto et al. 2012



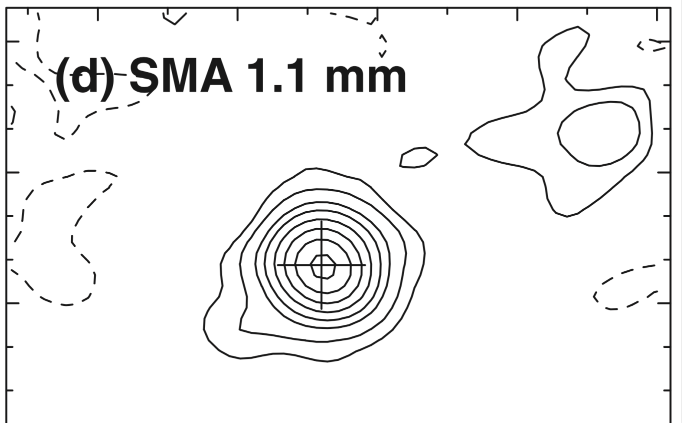
Compare the synthesised images to real observations

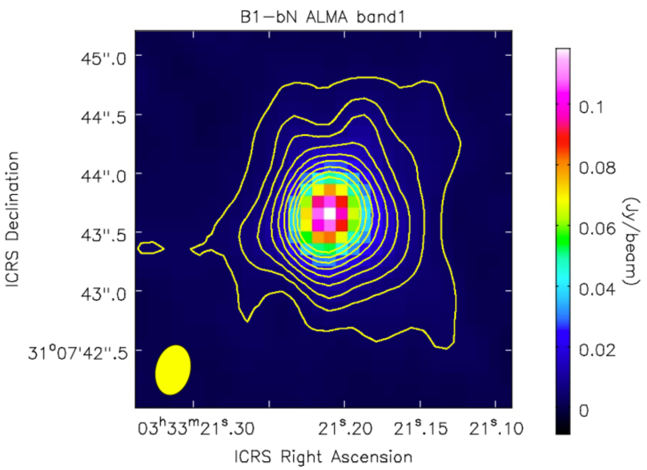
Estimate $M_{env,\ dust}$ and T_{dust} from SED.

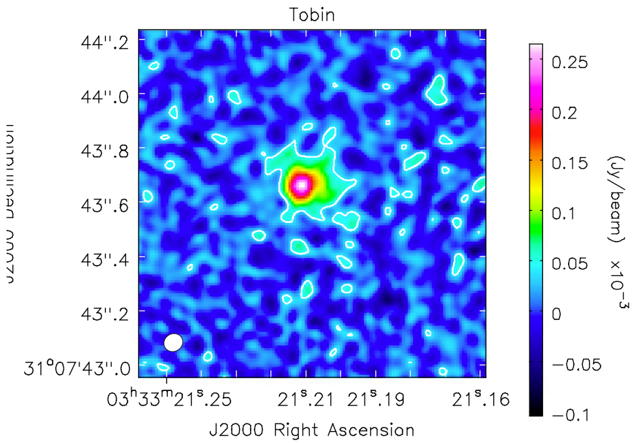
$$M_{(env,dust)} = \frac{F_{\nu}D^2}{\kappa_{\nu}B_{\nu}(T_{dust})}$$

Compare the model images to real observations

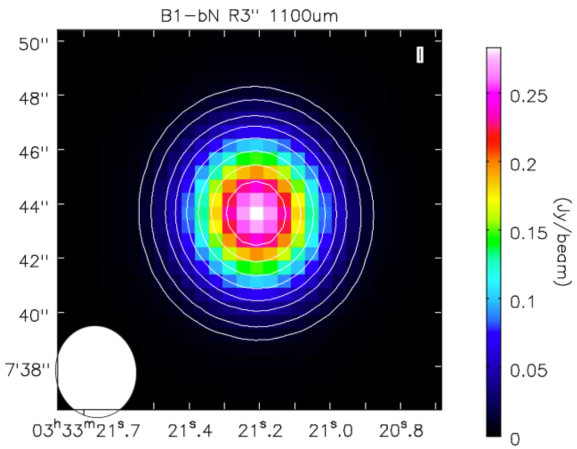
Real observations

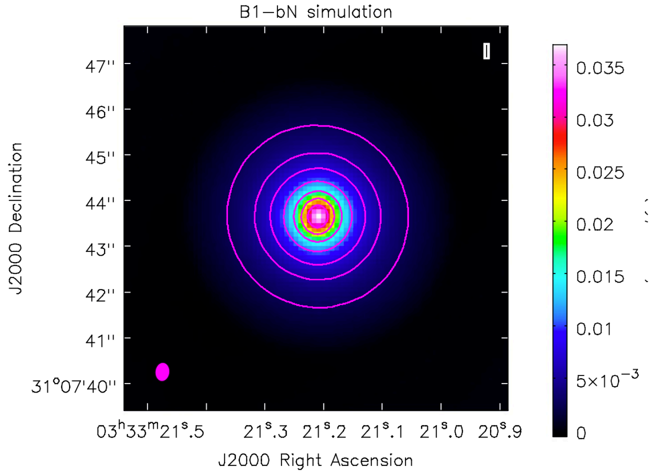


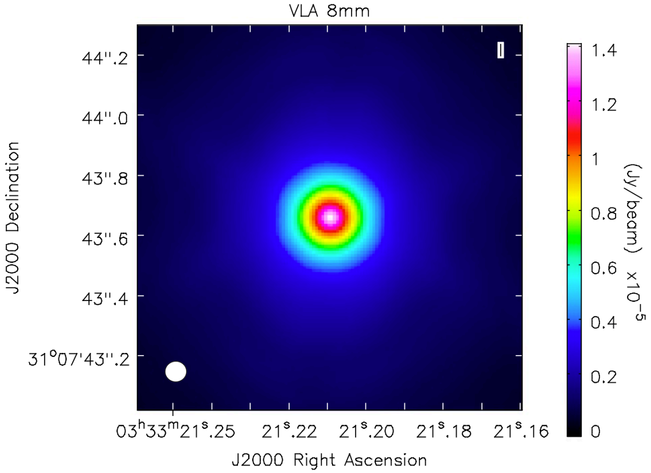




synthesised images of models



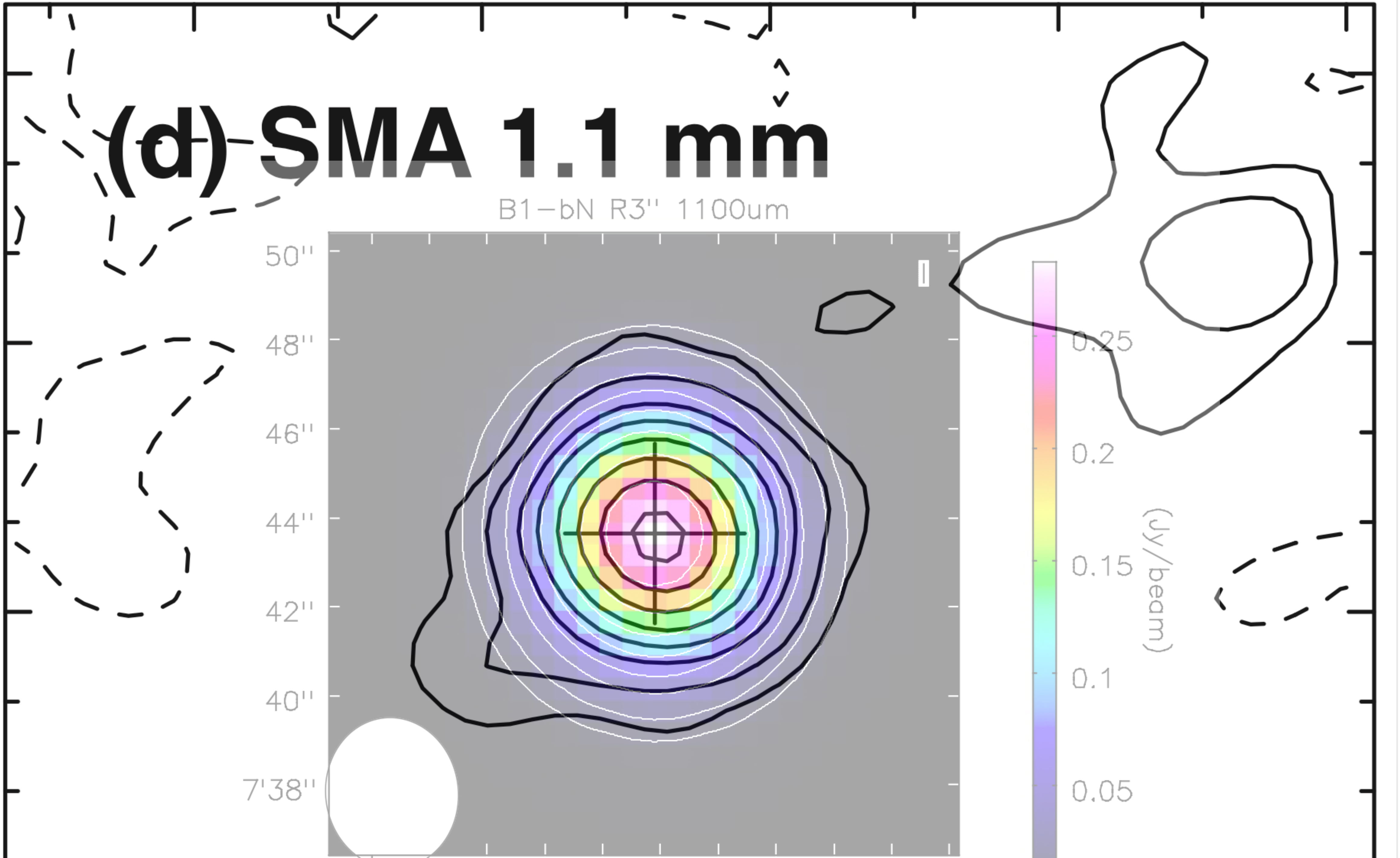




SMA 1.1mm Hirano & Liu. 2014

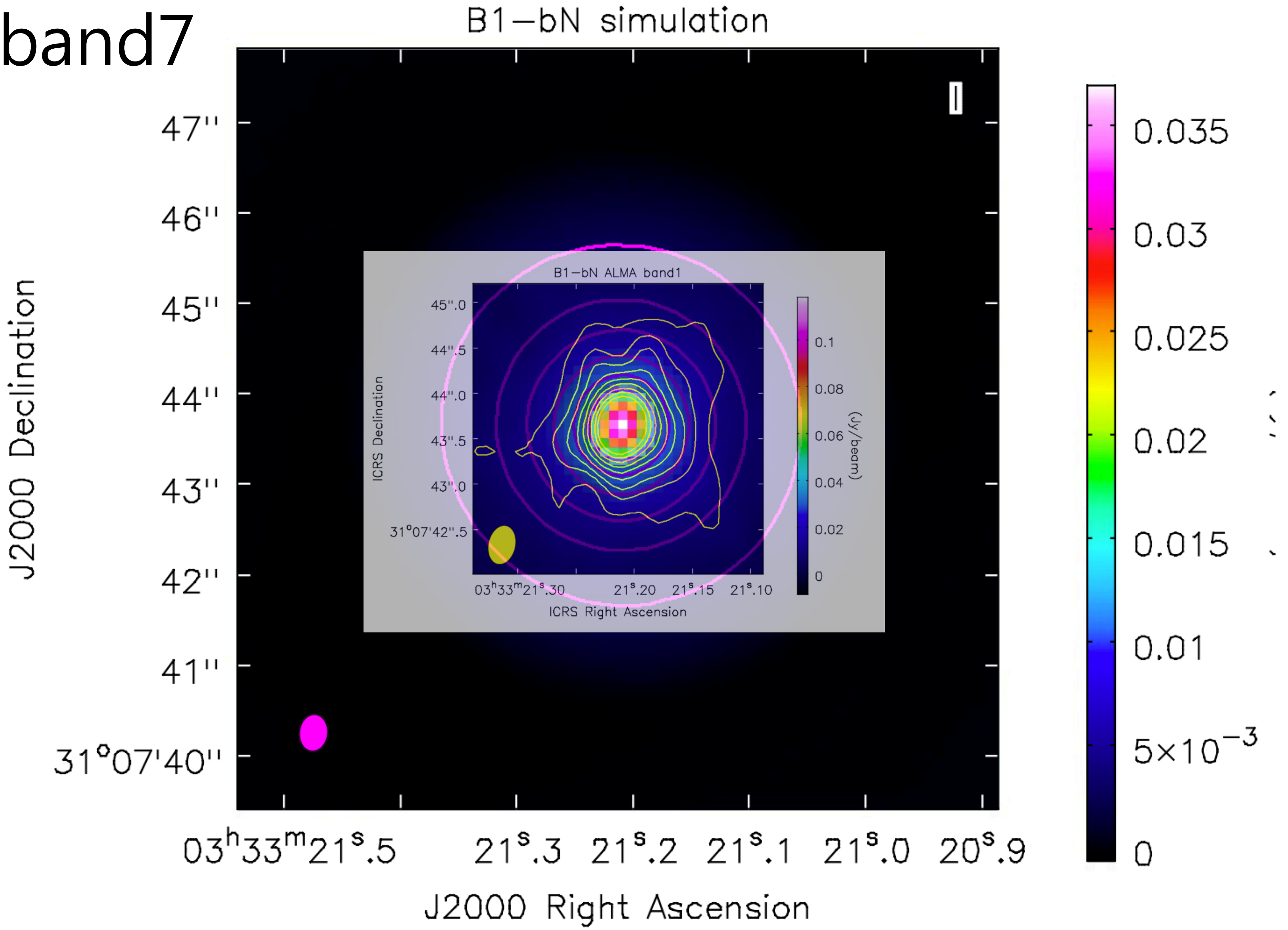
ALMA band7: Gerin et al
project code: 2015.1.00025.S

Tobin et al. 2016 VANDAM

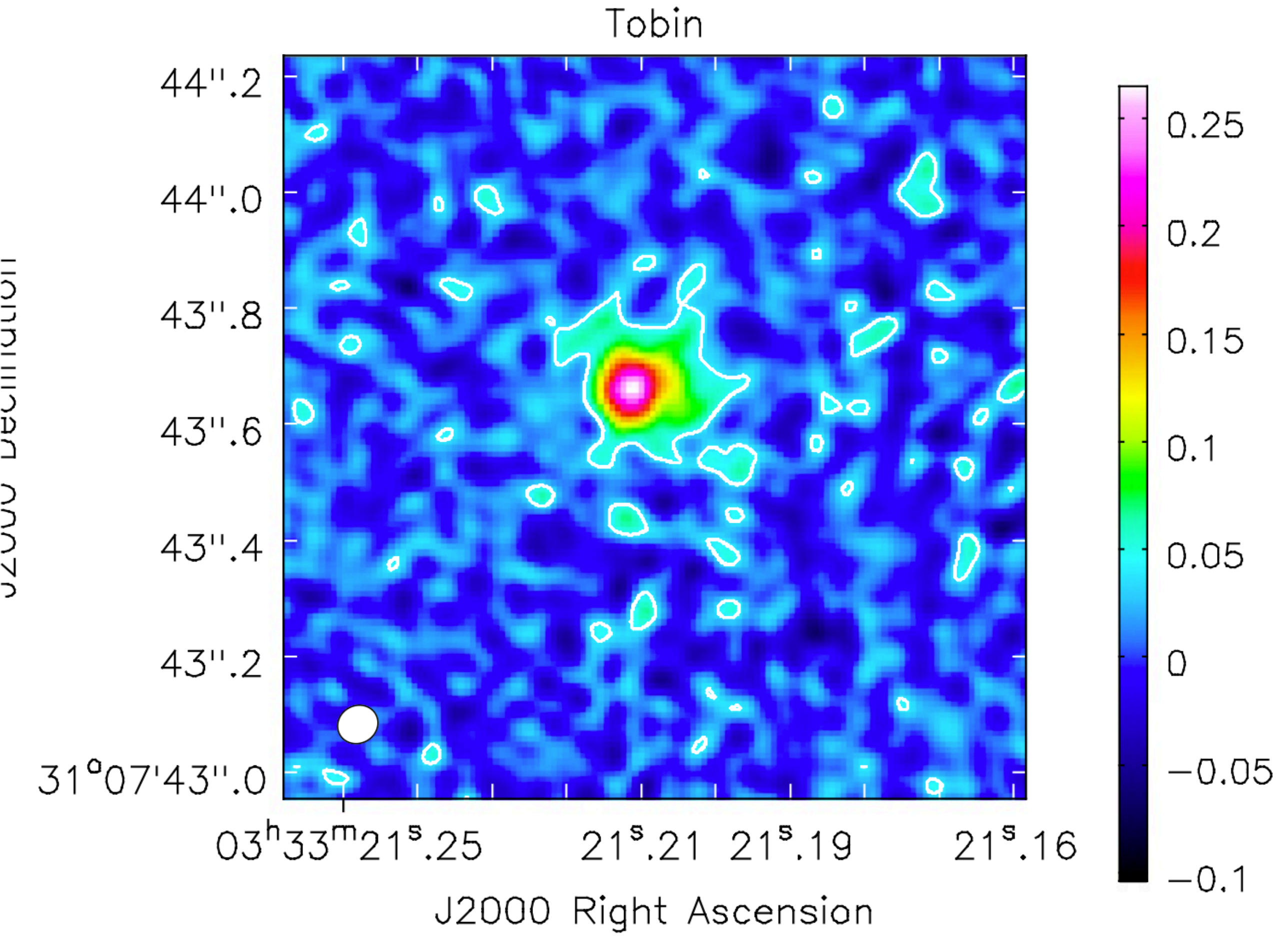


(d) SMA 1.1 mm
B1-bN R3'' 1100um
50''
48''
46''
44''
42''
40''
7'38''
0.25
0.2
0.15
0.1
0.05
(Jy/beam)

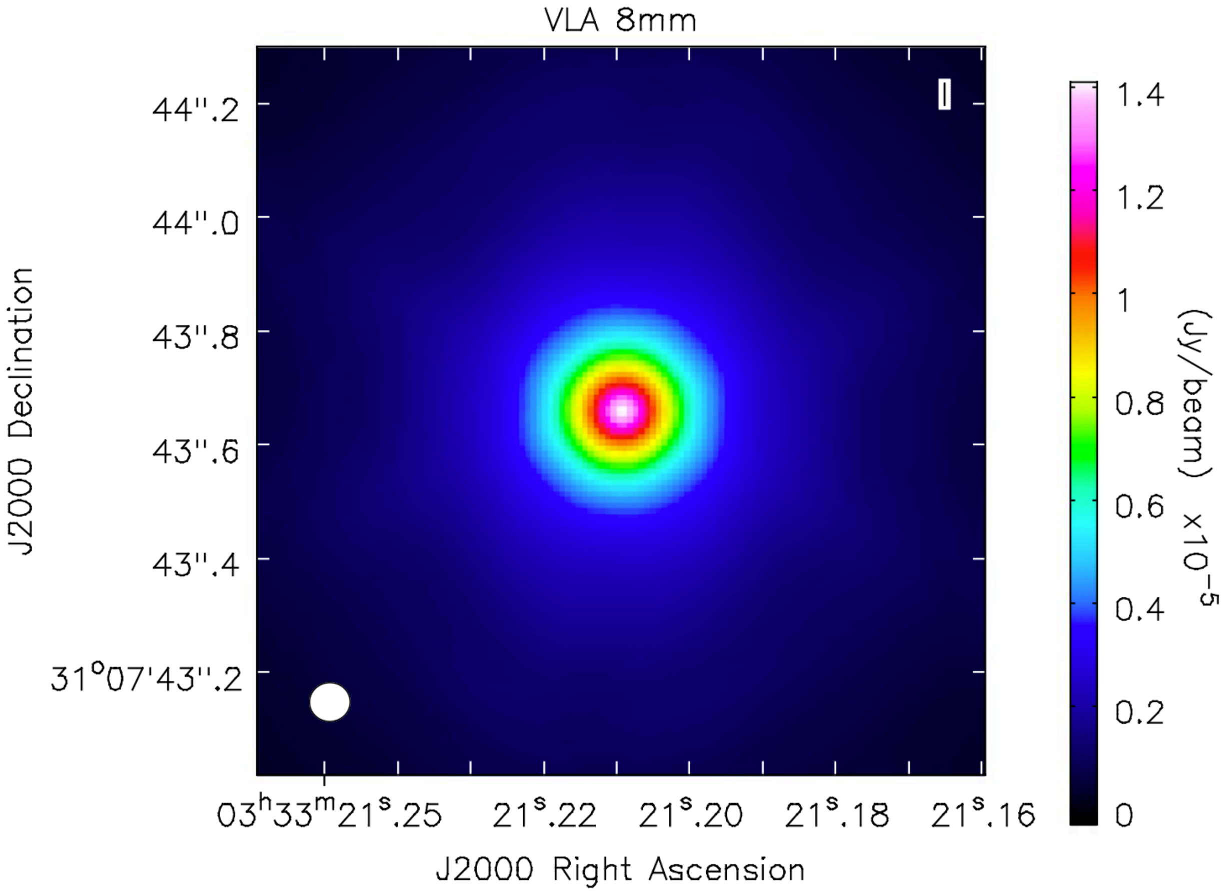
ALMA band7



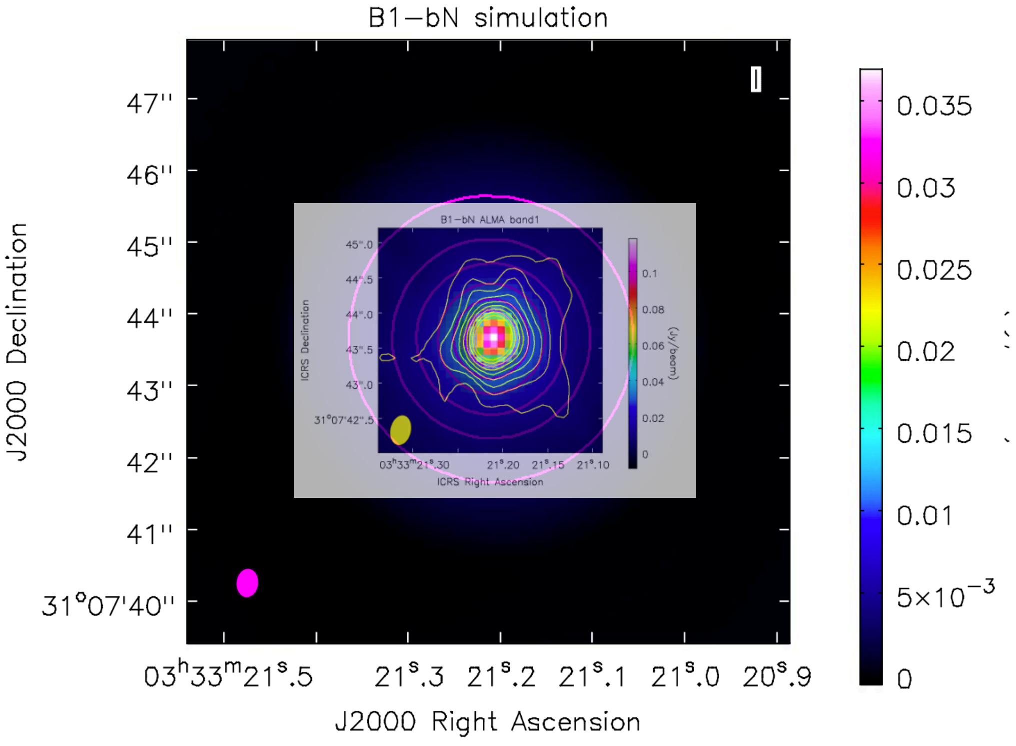
B1−bN simulation
I
47''
46''
45''
44''
43''
42''
41''
31°07'40''
J2000 Declination
03h33m21s.5
21s.3
21s.2
21s.1
21s.0
20s.9
J2000 Right Ascension
0.035
0.03
0.025
0.02
0.015
0.01
5×10−3
0
B1−bN ALMA band1
45''.0
44''.5
44''.0
43''.5
43''.0
31°07'42''.5
ICRS Declination
03h33m21s.30
21s.20
21s.15
21s.10
ICRS Right Ascension
0.1
0.08
0.06
0.04
0.02
0
(Jy/beam)


Tobin
44''.2
44''.0
43''.8
43''.6
43''.4
43''.2
31°07'43''.0
03h33m21s.25
21s.21
21s.19
21s.16
J2000 Right Ascension
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
(Jy/beam) x10−3

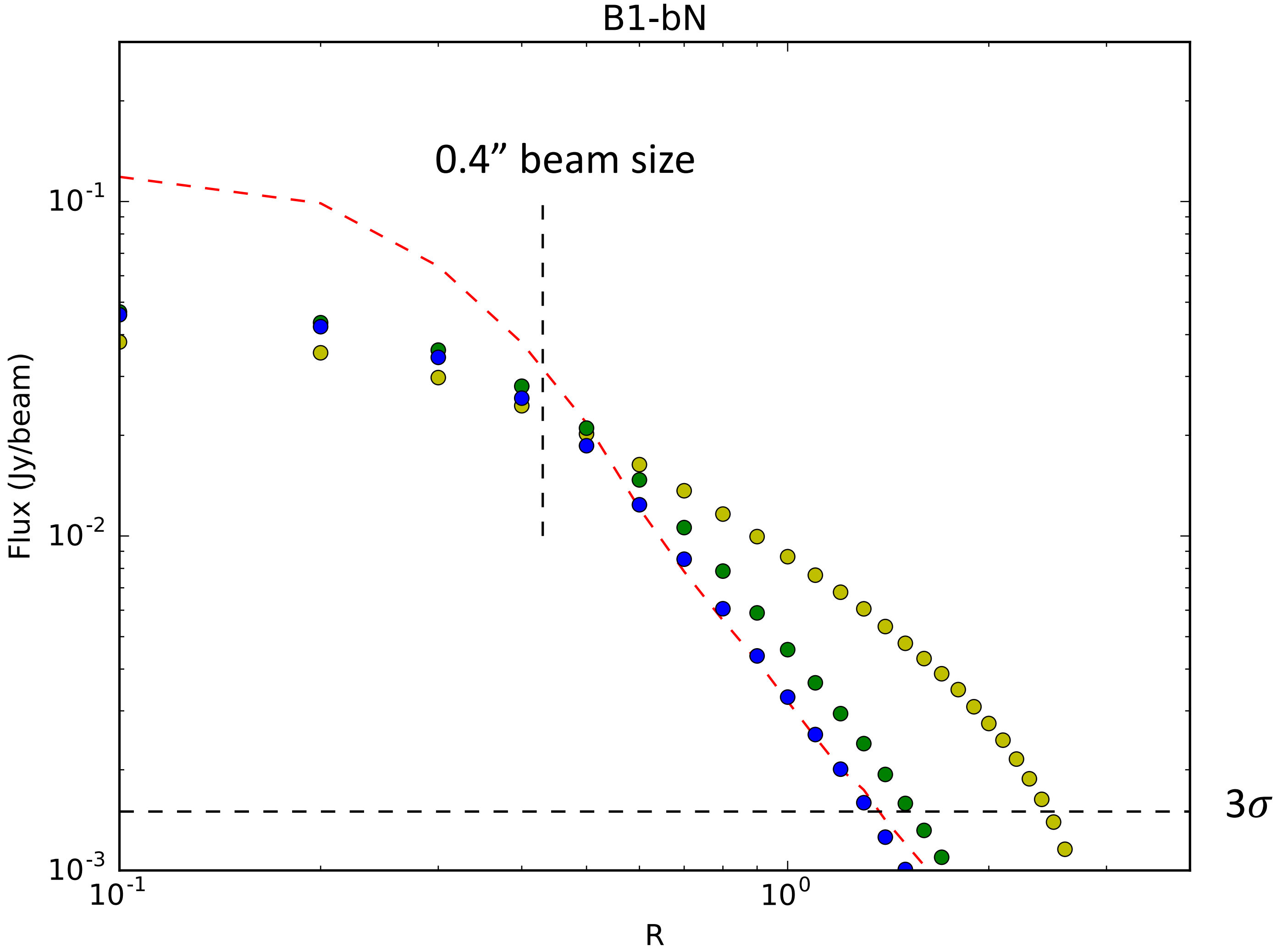
VLA 8mm


VLA 8mm
44''.2
44''.0
43''.8
43''.6
43''.4
31°07'43''.2
J2000 Declination
03h33m21s.25
21s.22
21s.20
21s.18
21s.16
J2000 Right Ascension
1.4
1.2
1
0.8
0.6
0.4
0.2
0
(Jy/beam) x10−5

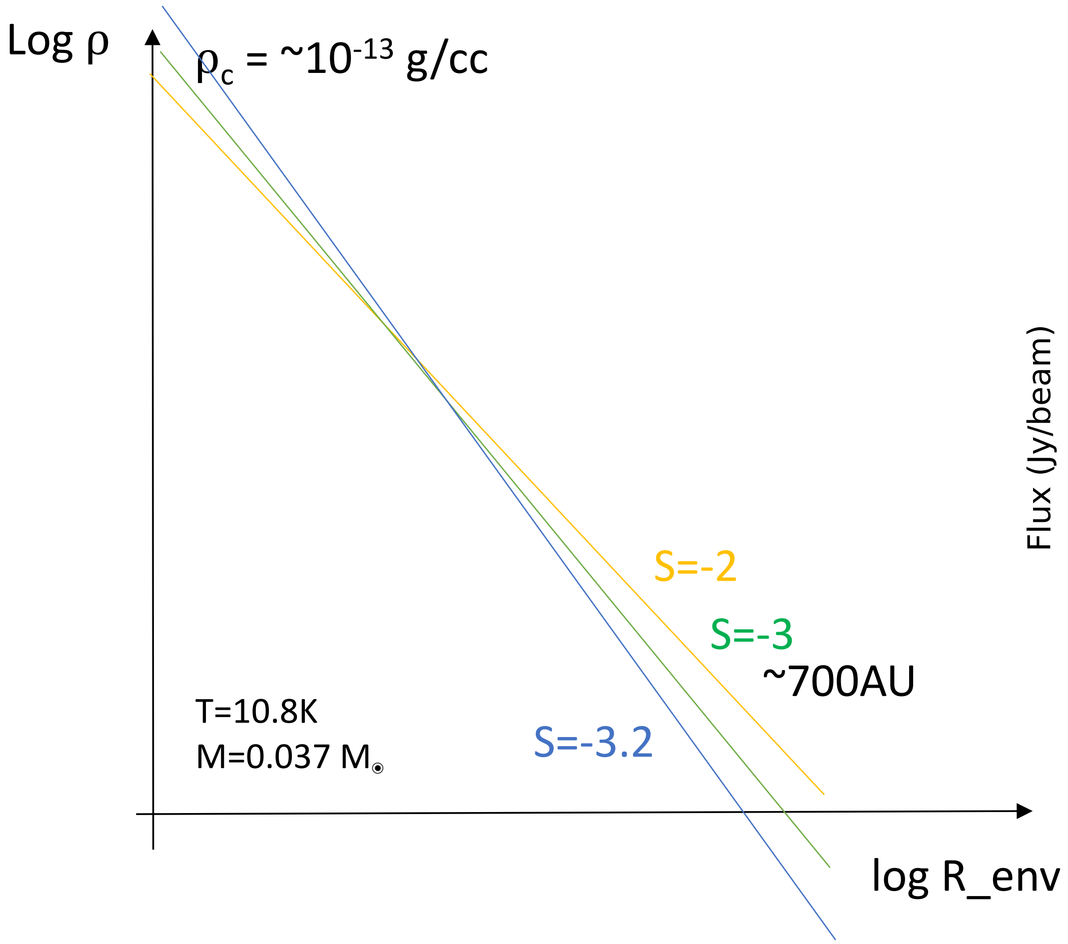
Annular analysis

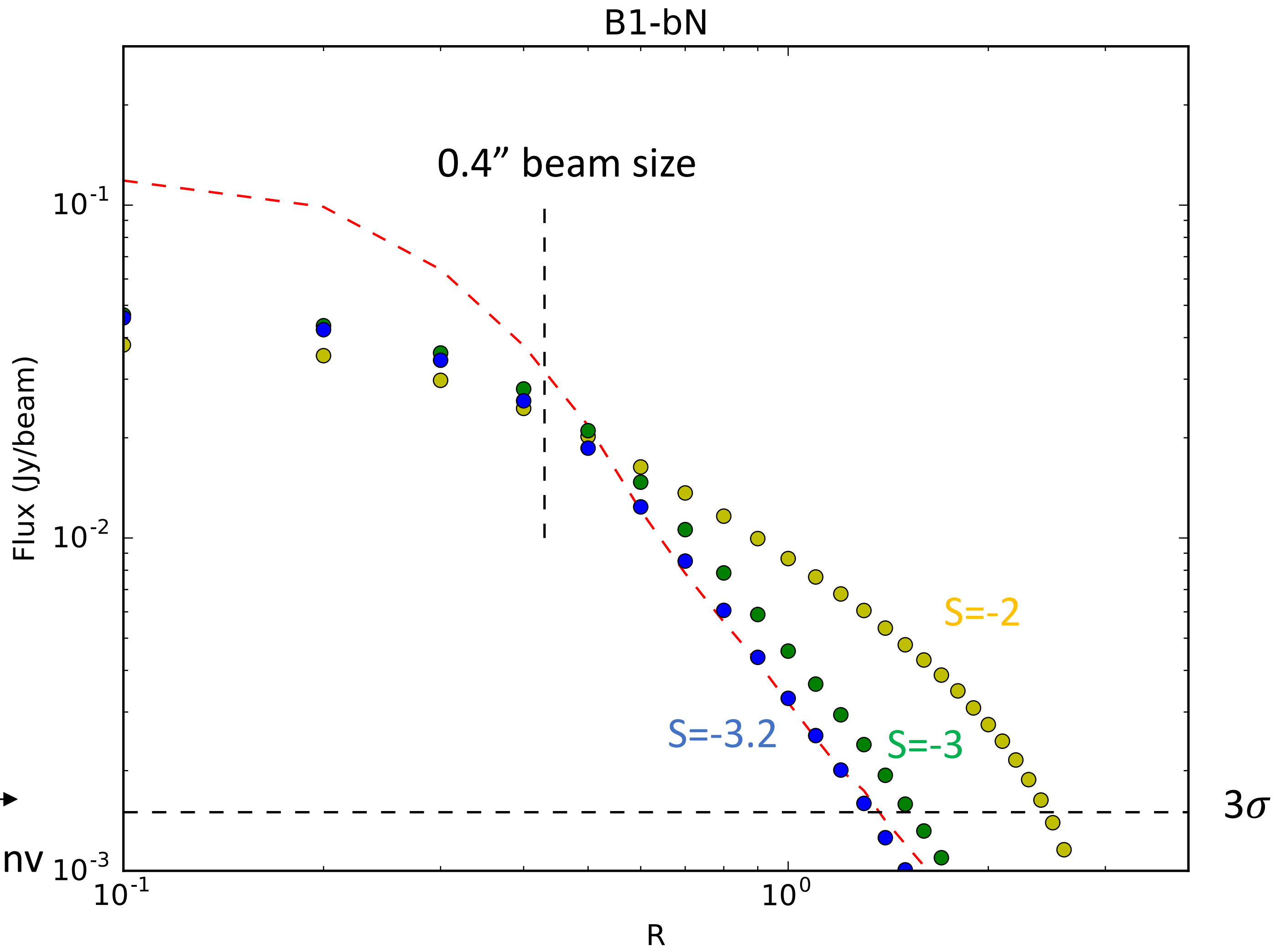


ALMA band7



Testing different parameters of our model





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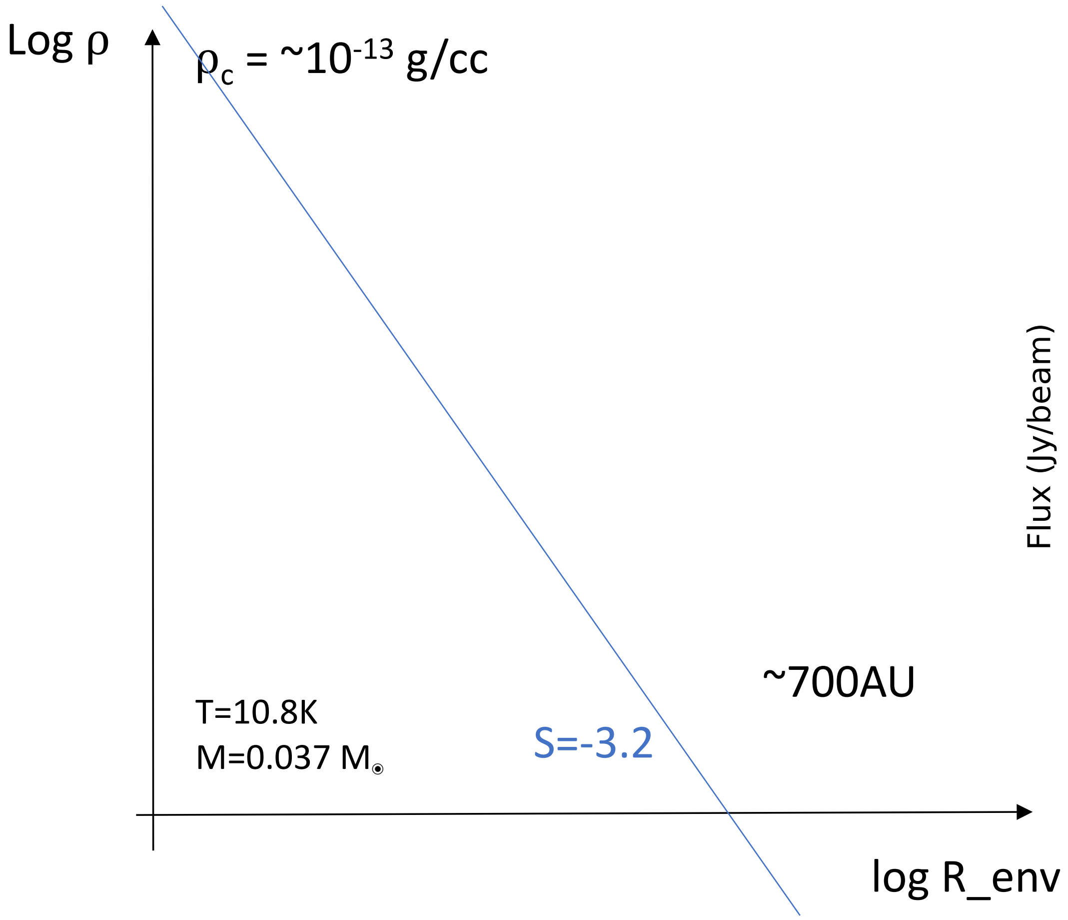
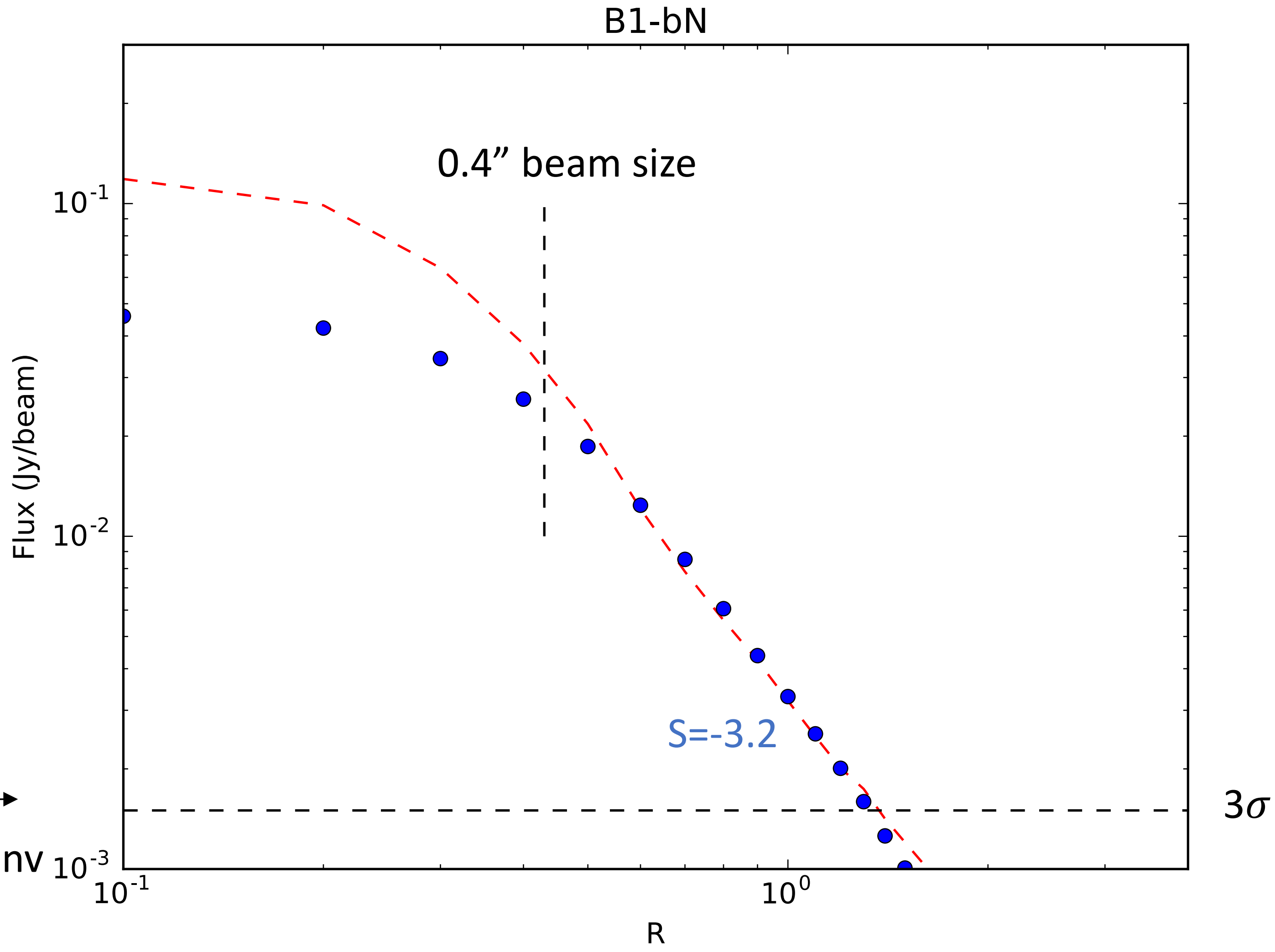
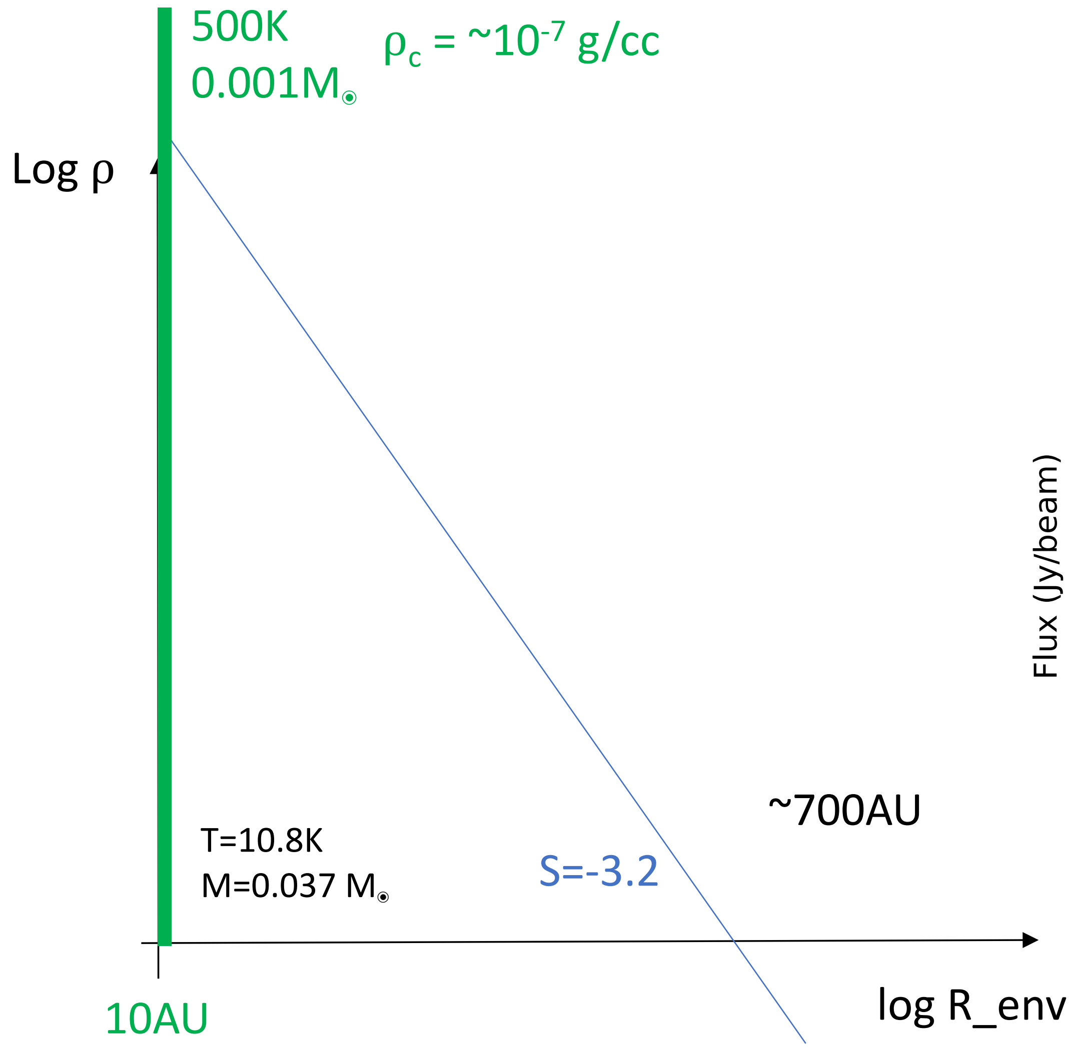
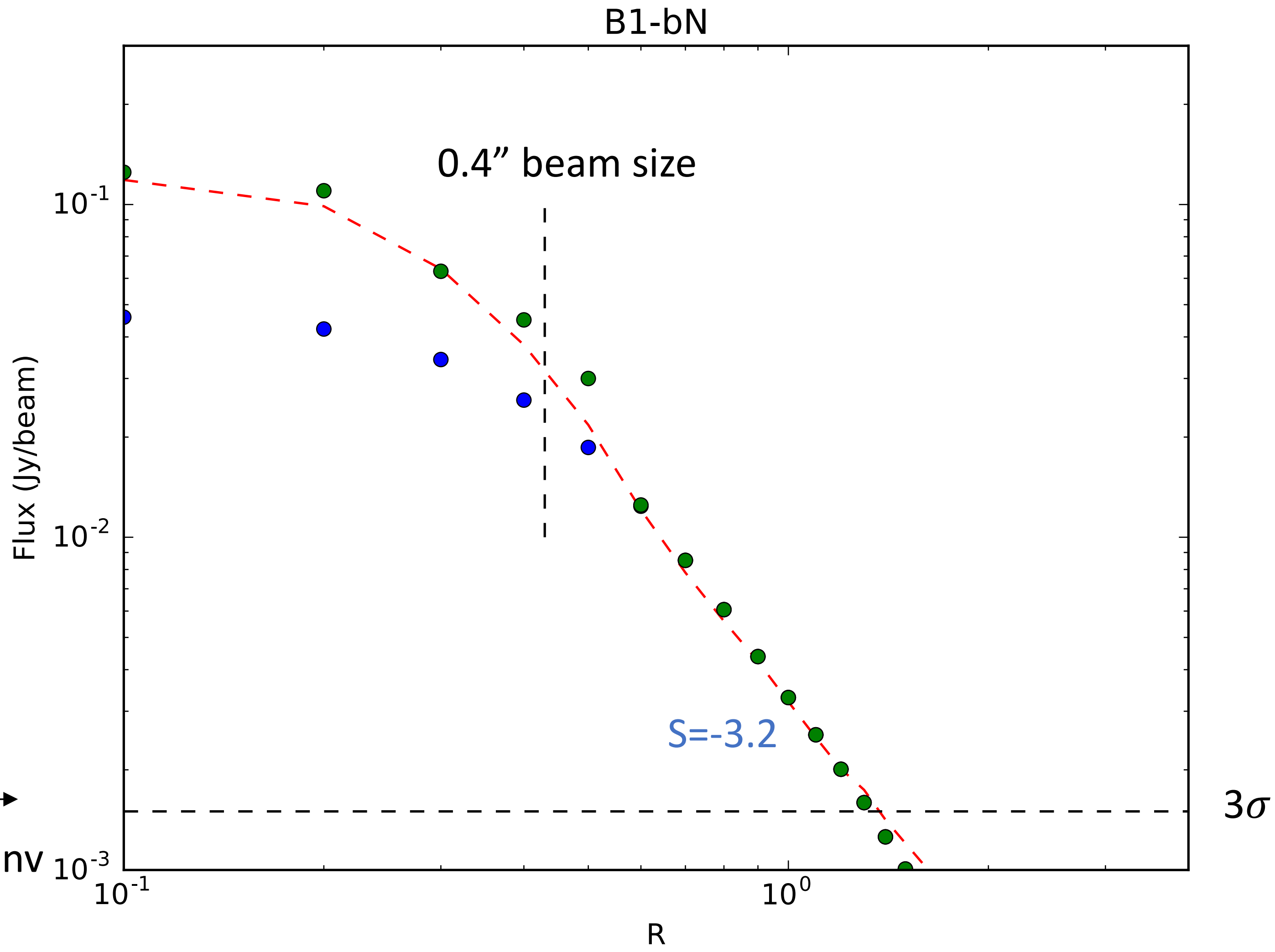




Preliminary result





Summary

- We produce FHC synthesis images using CASA 'simobserve' based on a simple model.
- The aim is to see whether the First Core can be resolve by the interferometry or not.
- We mimic the the simulated image of B1-bN to match the observational results from :
  - ✓ Hirano & Liu (2014), which present SMA 1.1mm continuum images,
  - ✓ Tobin et al. (2016), which present VLA 8mm continuum images,
  - ✓ ALMA band 7 continuum images(Gerin et al. 2015).
- We test different density profiles of our model, the slope of the density profile of envelope may be ~$\rho \propto r^{-3.2}$
- A hot compact object must be added at the center (FHC?).
- This model may be use to identify First Hydrostatic Cores!