Institut de Planétologie et d'Astrophysique de Grenoble

Tracing the interstellar heritage of protosolar nebulae: the nitrogen isotopic ratio

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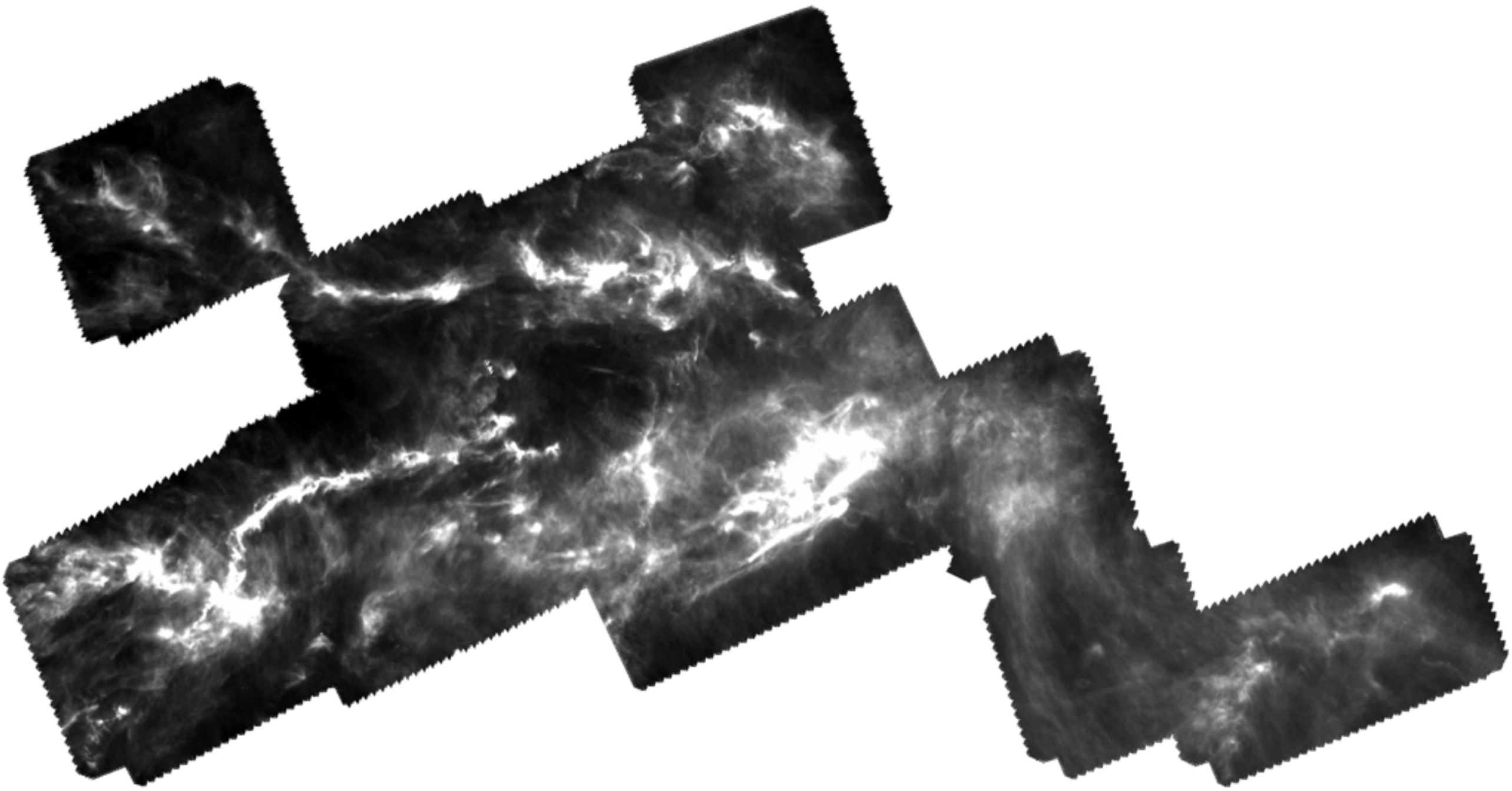
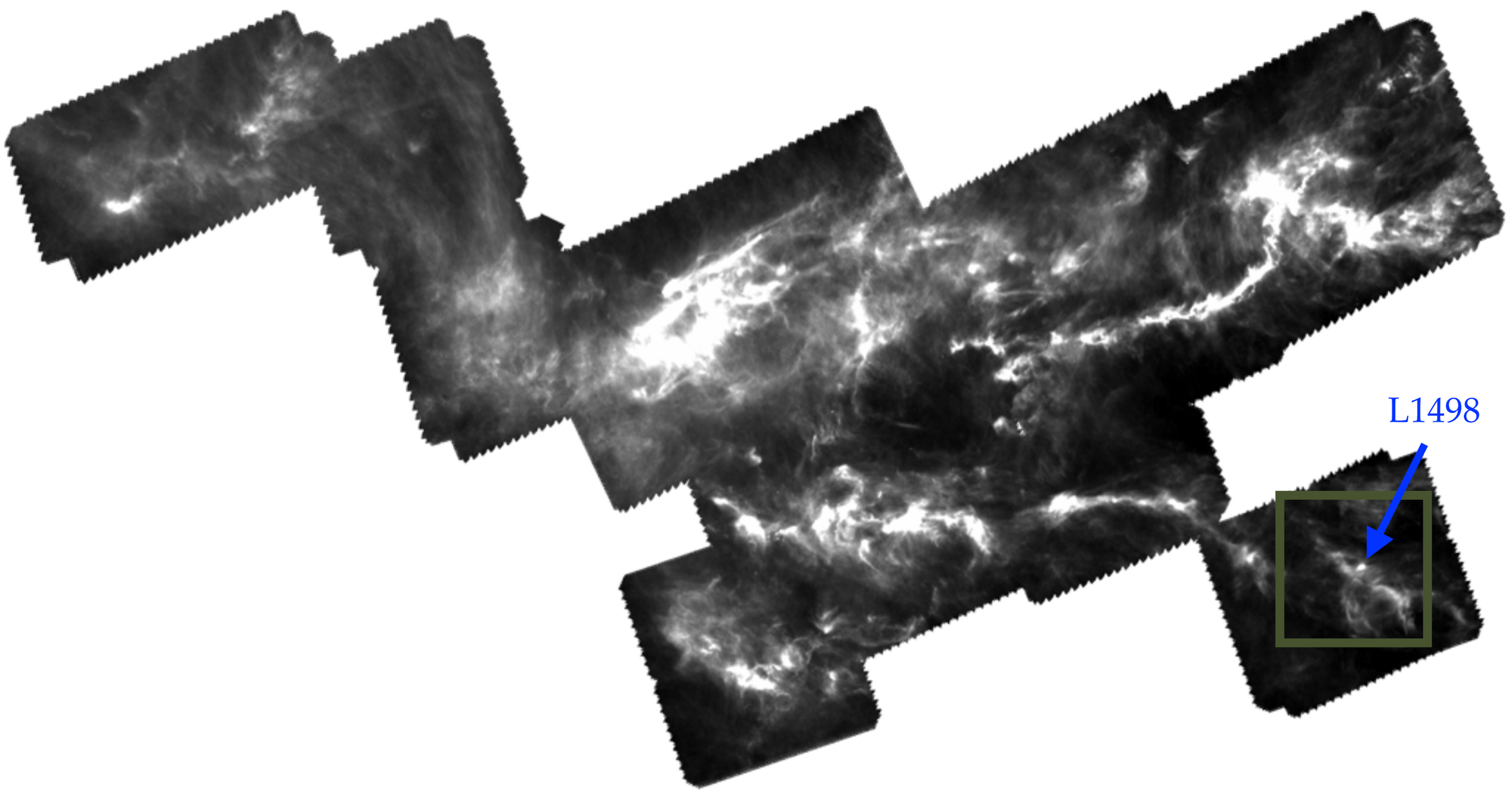
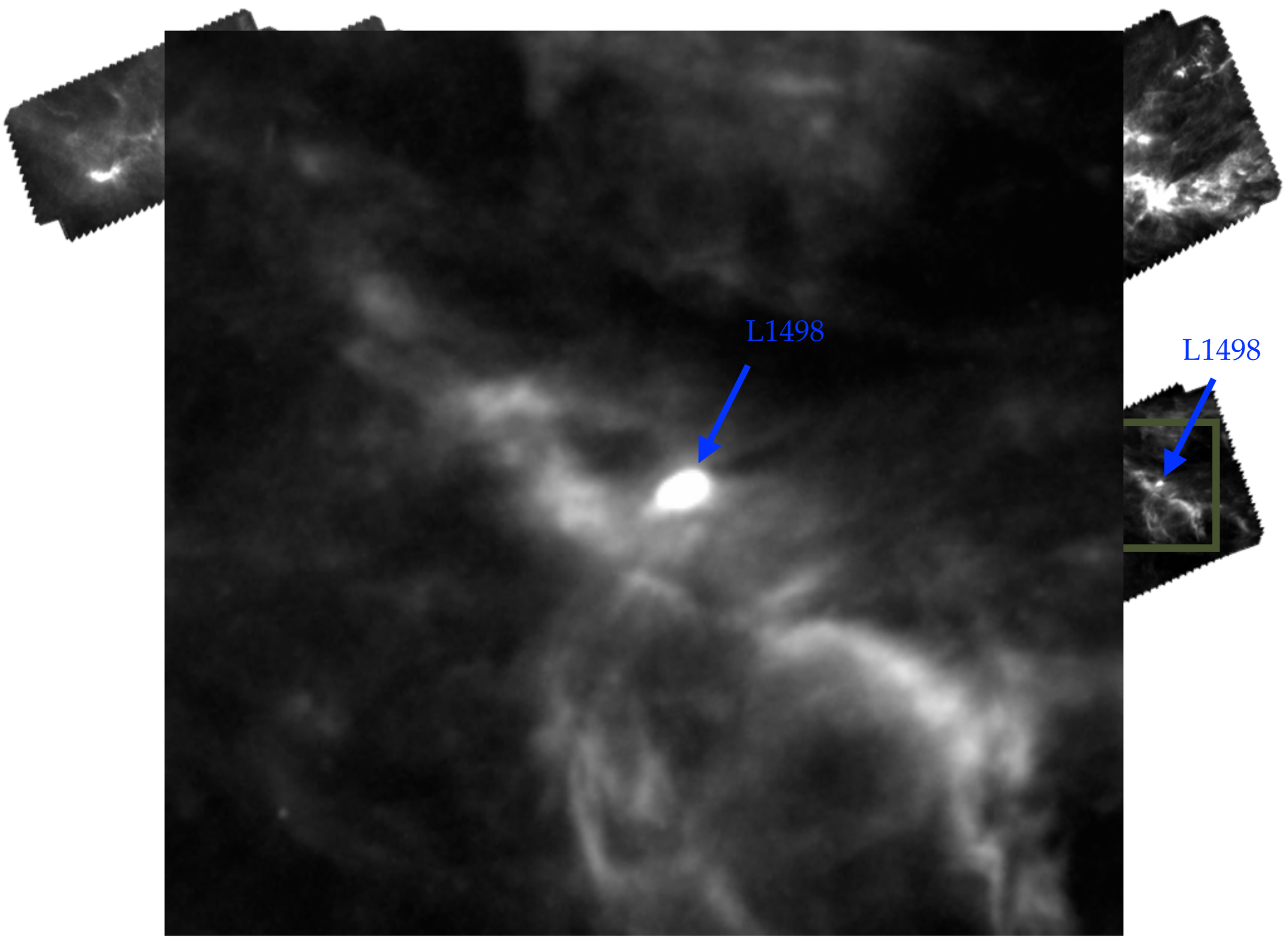
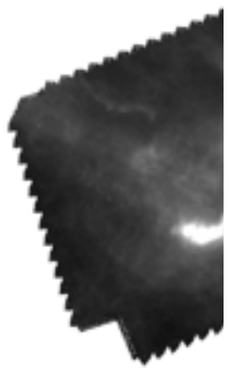
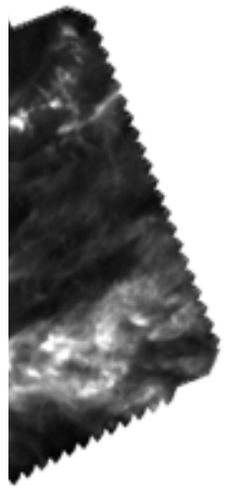
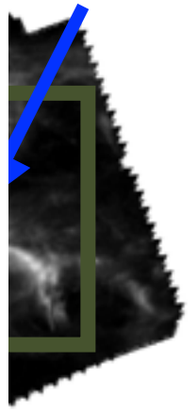



L1498


L1498
L1498



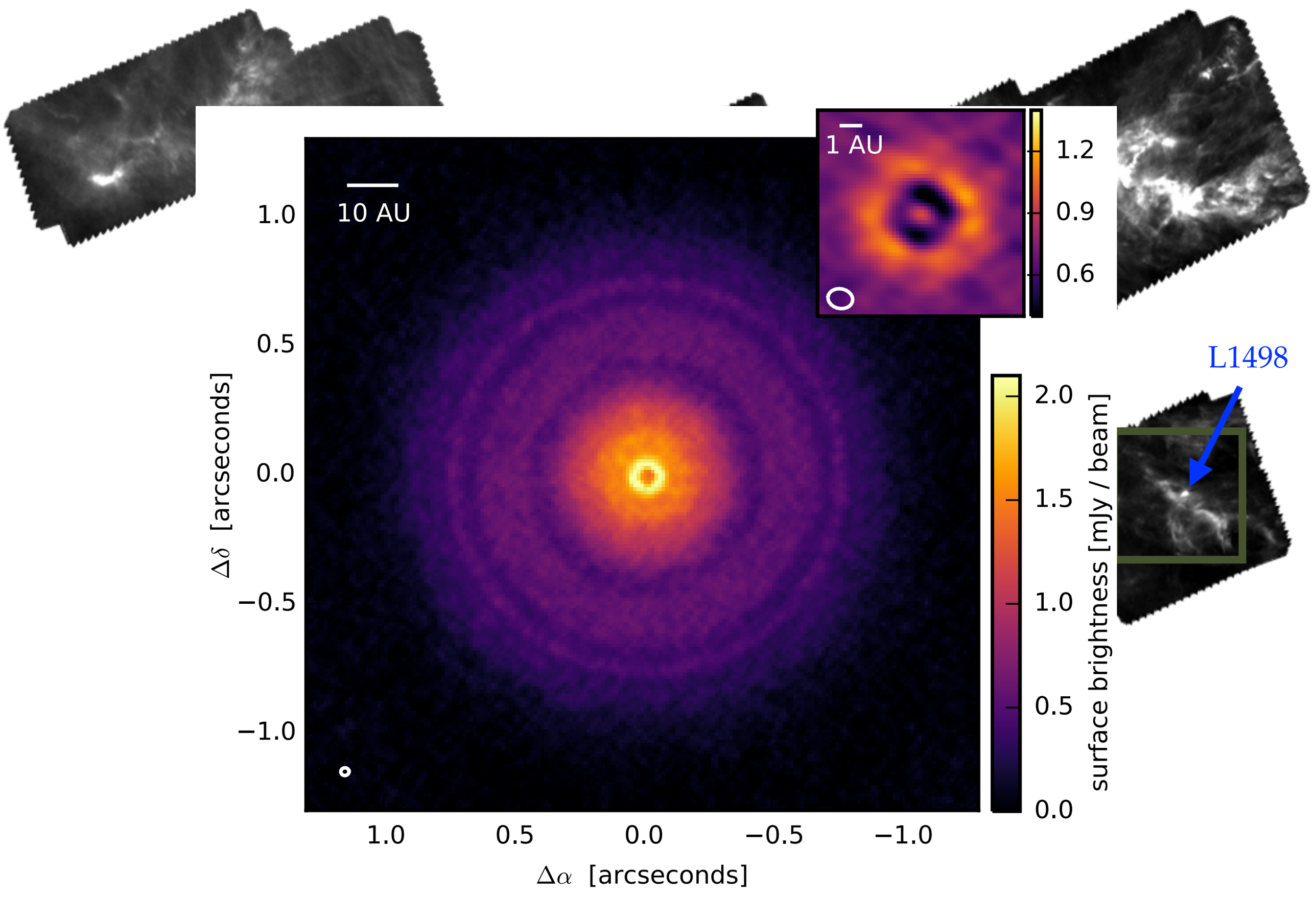


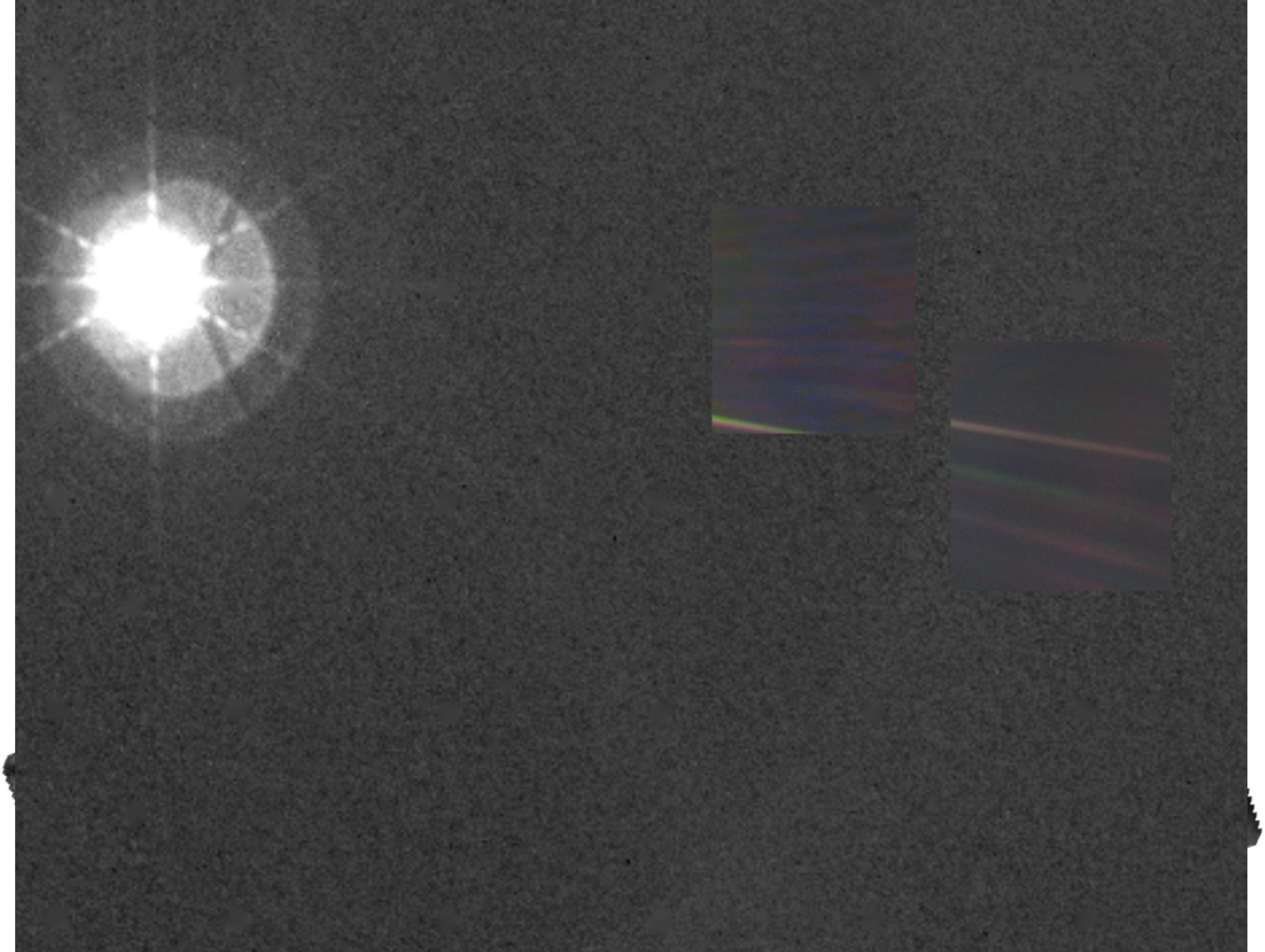


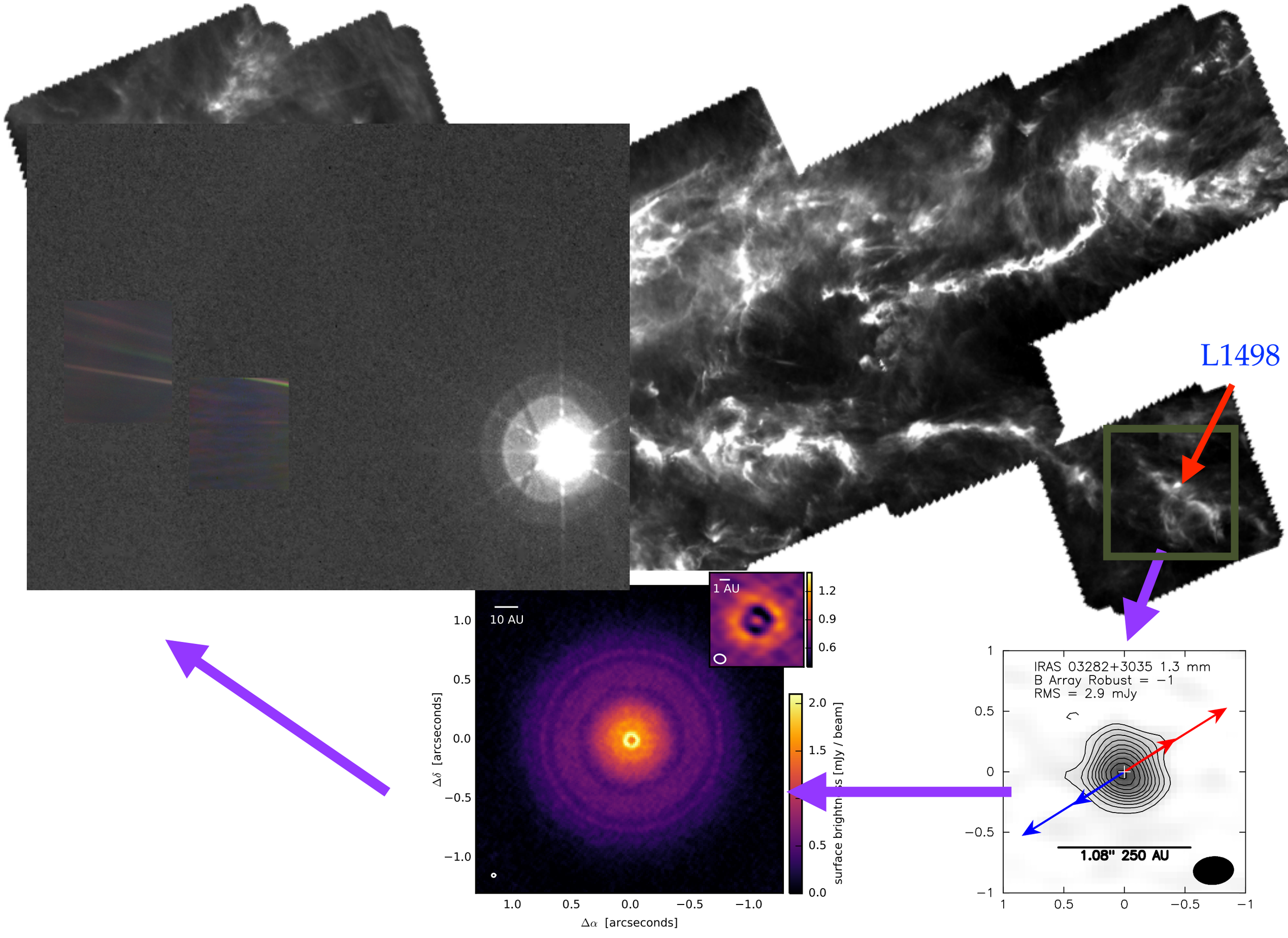
IRAS 03282+3035 1.3 mm
B Array Robust = −1
RMS = 2.9 mJy

1.08" 250 AU

1
0.5
0
−0.5
−1
1
0.5
0
−0.5
−1


10 AU
1 AU
1.2
0.9
0.6
L1498
2.0
1.5
1.0
0.5
0.0
surface brightness [mJy / beam]
1.0
0.5
0.0
−0.5
−1.0
$\Delta\delta$ [arcseconds]
1.0
0.5
0.0
−0.5
−1.0
$\Delta\alpha$ [arcseconds]




L1498
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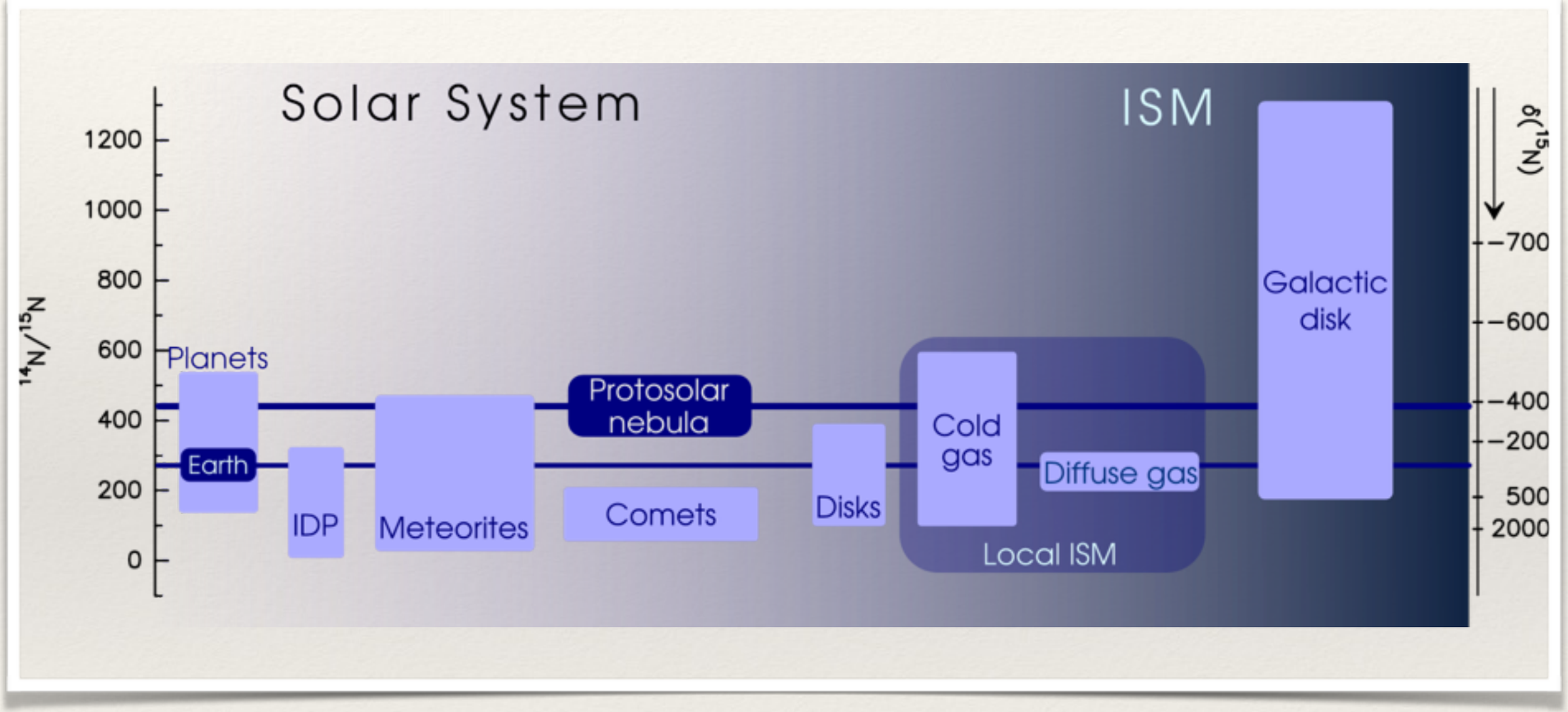
0.9
0.6
2.0
1.5
0.5
0.0
surface brightness [mJy / beam]
1.0
0.5
0.0
−0.5
−1.0
$\Delta\delta$ [arcseconds]
$\Delta\alpha$ [arcseconds]
IRAS 03282+3035 1.3 mm
B Array Robust = −1
RMS = 2.9 mJy
1.08" 250 AU
1
0.5
0
−0.5
−1

How to identify the heritage of PSNe?

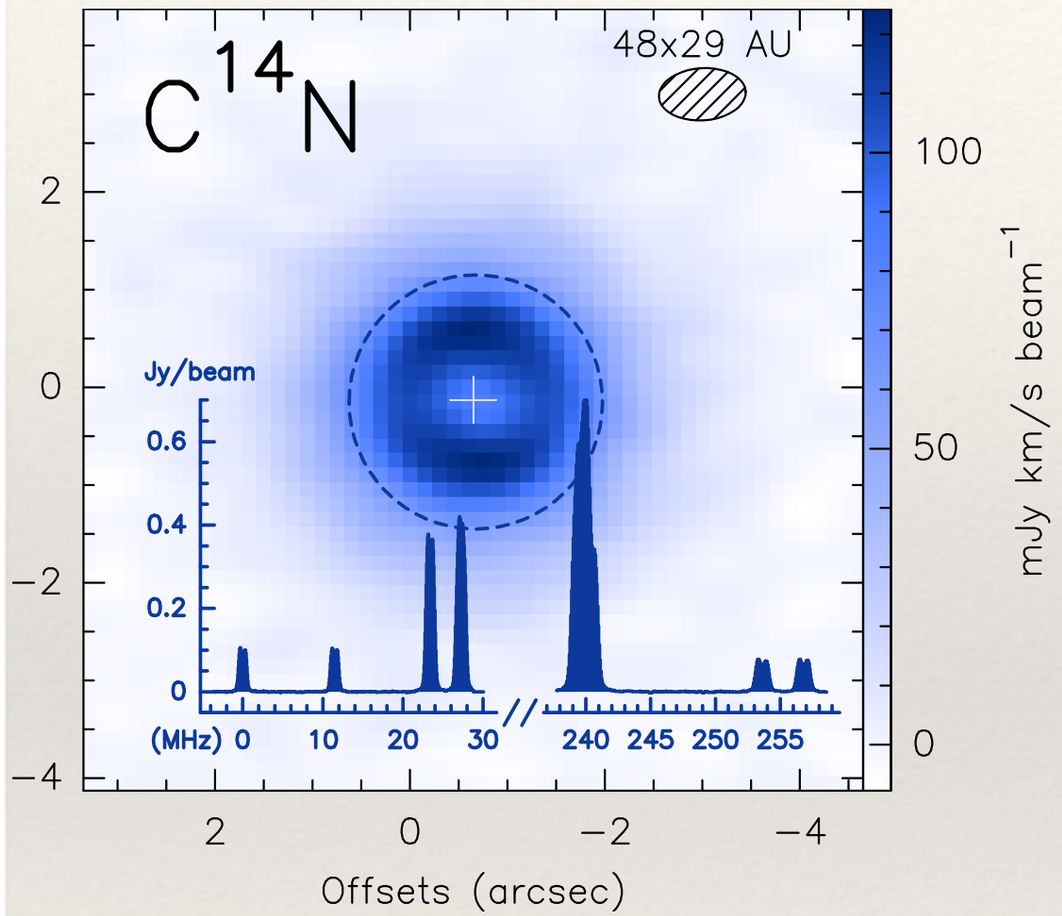
- In the ISM atoms in different phases and carriers, some unobservable.
  eg. for N: N and N_2, in the gas phase, NH_3 in the ices.
  - These are called reservoirs.
- Did cosmomaterials (meteorites, comets, etc) record the interstellar heritage of protosolar nebulae (PSNe) reservoirs?
- Isotopic ratios allow to identify species linked to reservoirs.
  - Ex: D/H, prestellar water reservoir (partially) preserved in Earth's water (Cleeves et al 2014).

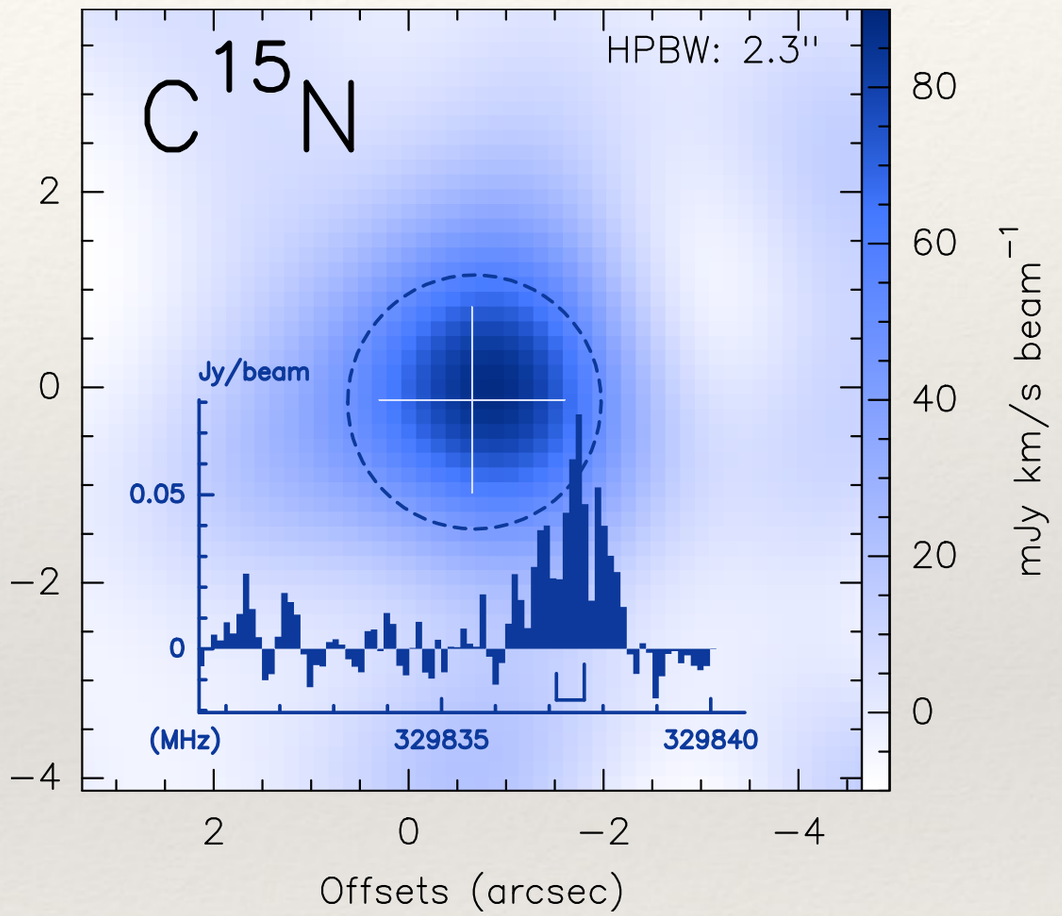
The wide picture of the N Isotopic ratio, R



What causes this variability?

R(CN) in the PSN analog TW Hydra

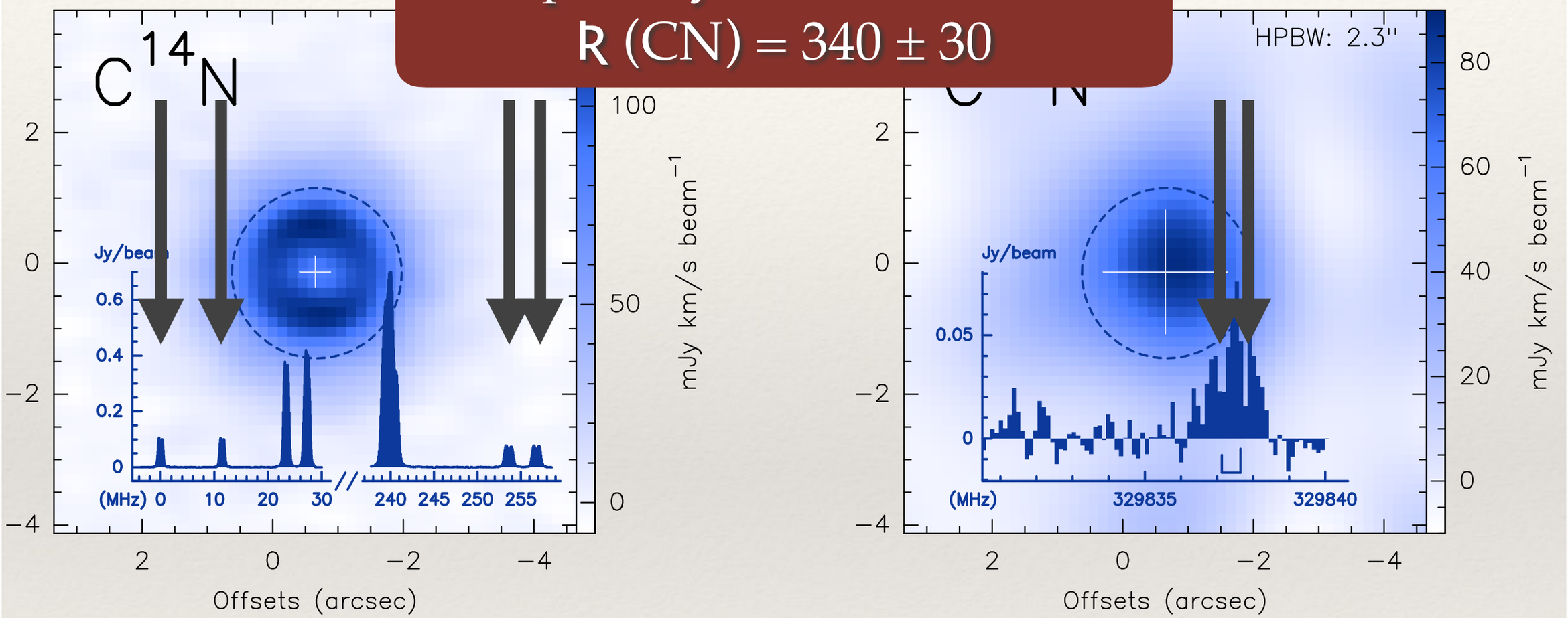




- R(CN) through direct fits in the UV plane to optically thin lines, ALMA Band 7 data.
- R(HCN) = 200 ± 100 (MWC 480, Guzman et al 2015), improved to 130 ± 30, ALMA Band 5 data.

R(CN) in the PSN analog TW Hydra

Optically thin emission!
R (CN) = 340 ± 30

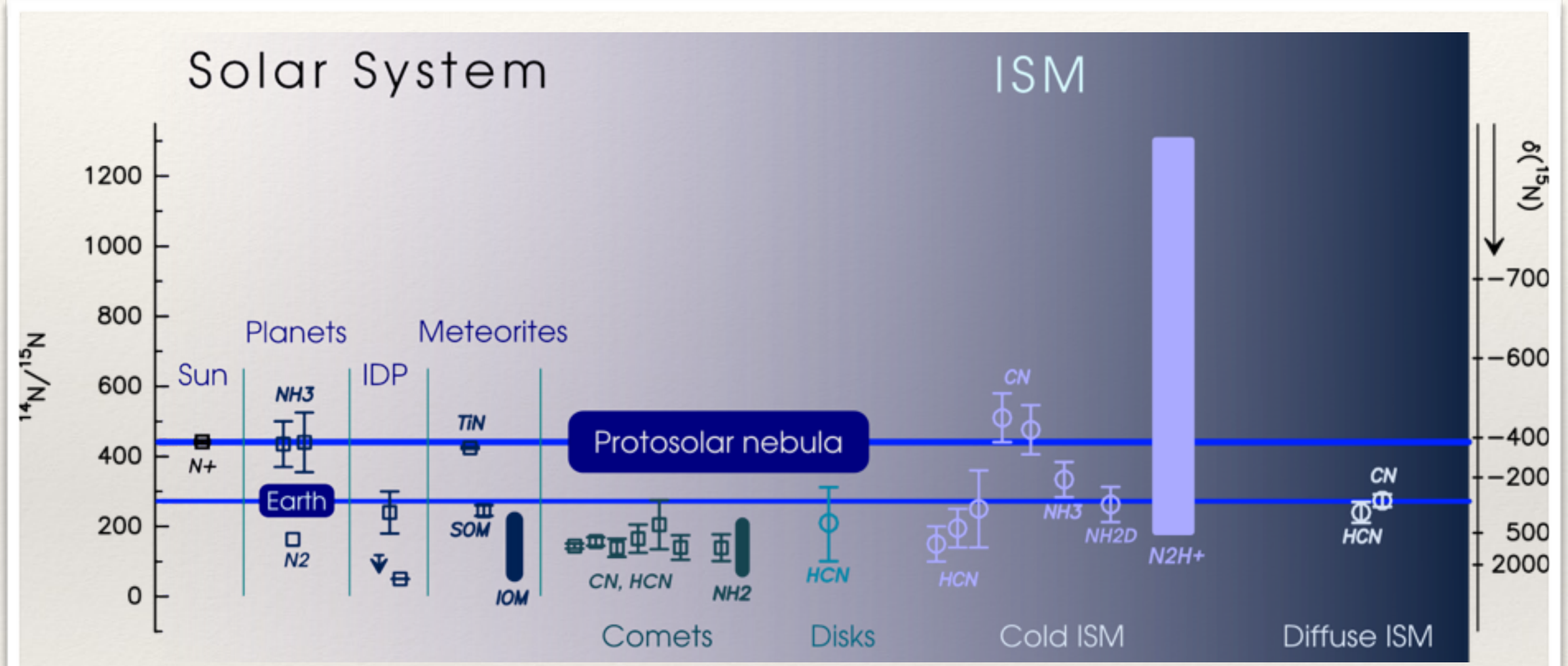


- R(CN) through direct fits in the UV plane to optically thin lines, ALMA Band 7 data.
- R(HCN) = 200 ± 100 (MWC 480, Guzman et al 2015), improved to 130 ± 30, ALMA Band 5 data.

R variability in PSNe

- If real and not due to systematics:
  - Two reservoirs of N in PSNe.
  - Variation seen in the SS not due to evolution:
    - Heritage from the PSN.

Prestellar origin of R



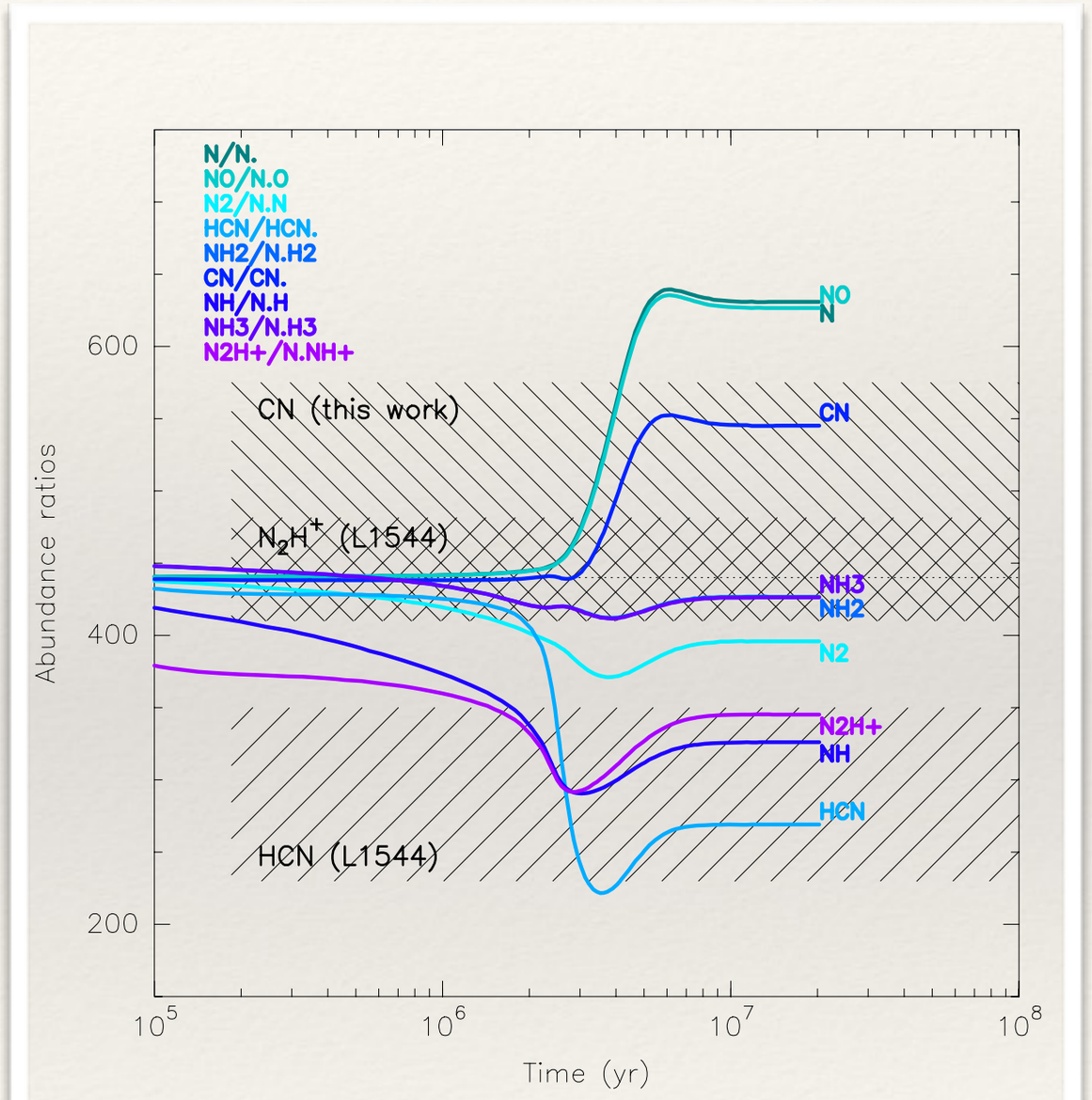
- Large scatter of R in the ISM:
  - Extreme case: N_2H^+ (e.g. Bizzocchi et al 2013; Fontani et al 2015).
- Is this the origin of the variability in the PSN?

Measuring R in PSCs

- It can be measured directly, ex:

$$R(\mathrm{NH_2D}) = \frac{\mathrm{NH_2D}}{^{15}\mathrm{NH_2D}}$$

- Different zero point energies in reaction paths (chemical fractionation, CF) different R in different carriers. (Terzieva & Herbst 2000; Hily-Blant et al 2013).
- CF only efficient in low temperature environments: PSCs
- may not be efficient at all for N (Roueff et al 2015).

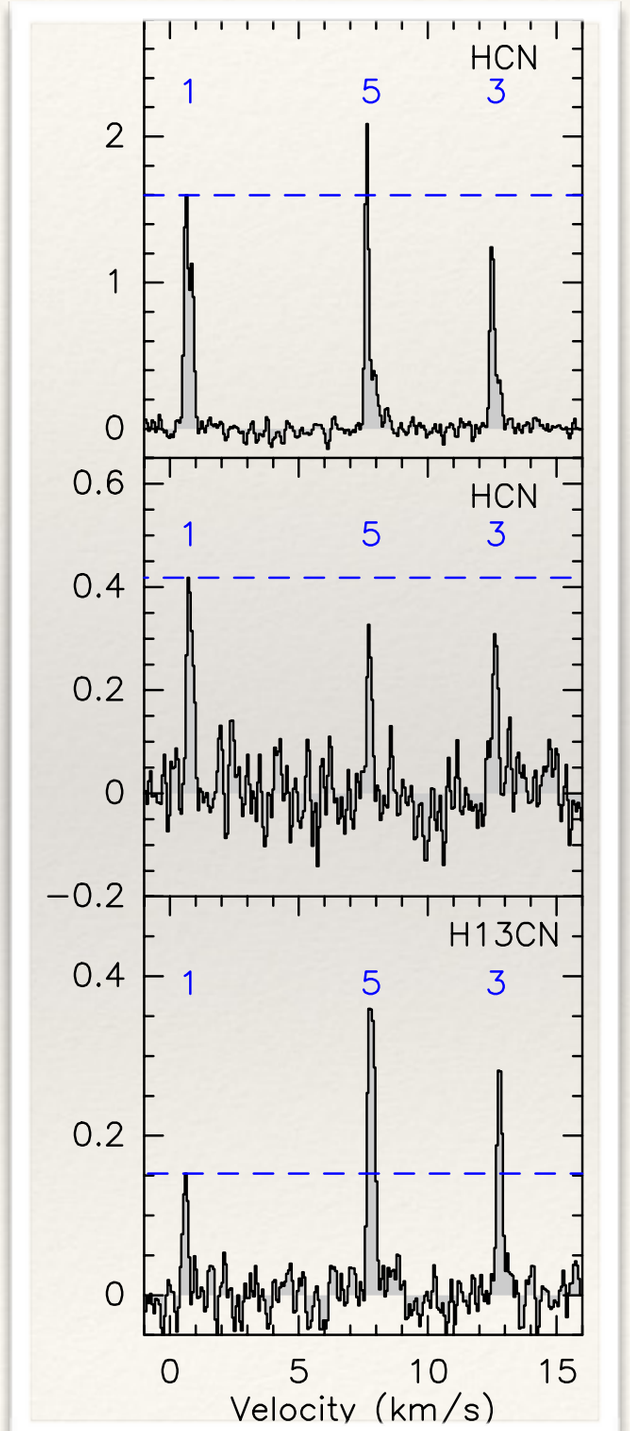


Carbon CF in HCN, problems for R?

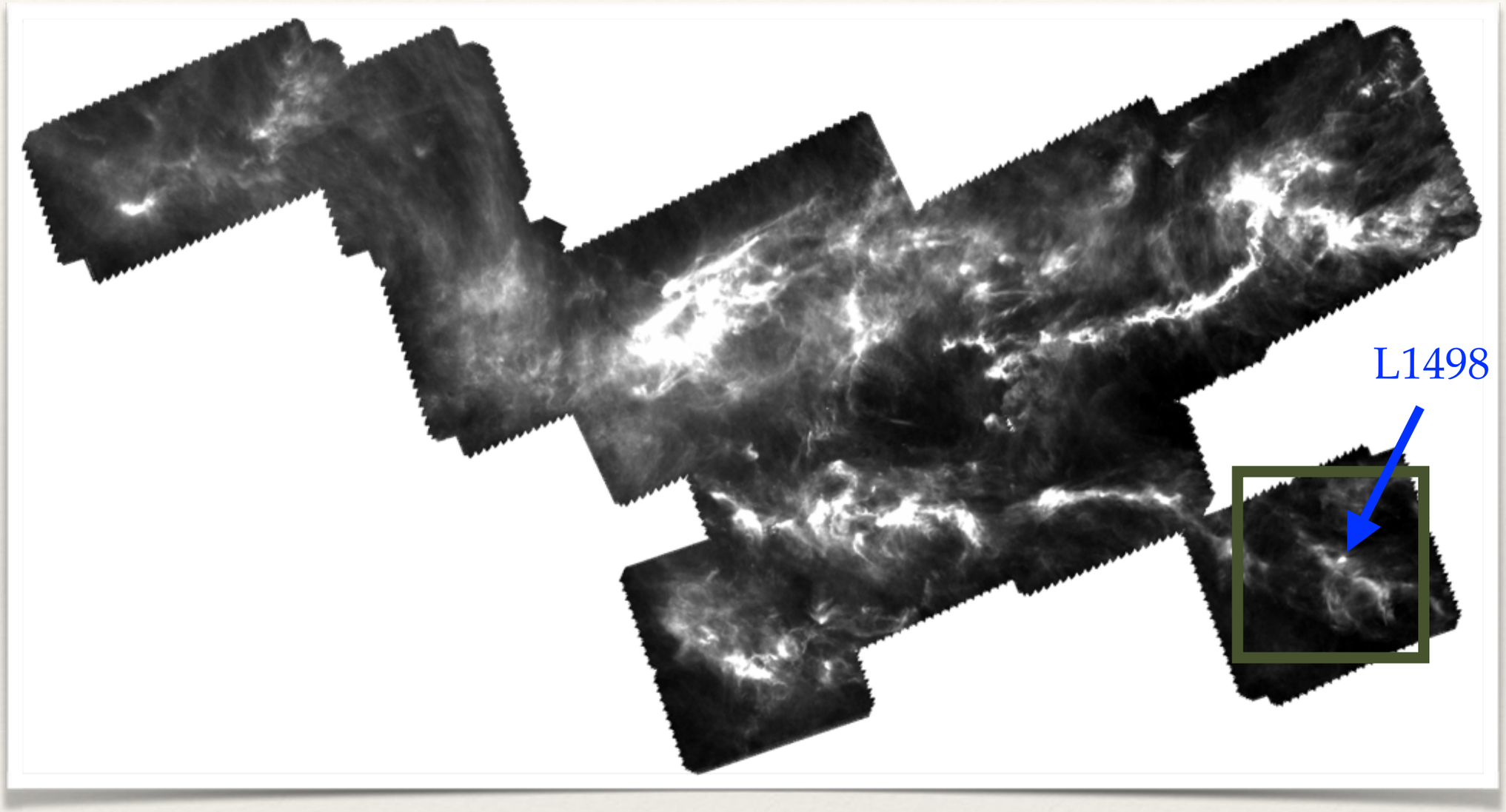
- Problem: In PSCs main isotopologue is usually optically thick (e.g. CN, HCN, NH3 -> $\tau \gtrsim 10$).
  - Workaround for C bearing species, R obtained through double isotopologues, ex:

$$R(\mathrm{HCN}) = \frac{\mathrm{HCN}}{\mathrm{HC^{15}N}} \approx \frac{\mathrm{H^{13}CN}}{\mathrm{HC^{15}N}} \times \frac{^{12}\mathrm{C}}{^{13}\mathrm{C}} \qquad R_C \sim 70$$

- Old problem: HCN hyperfine (HF) anomalies (e.g. Kwan & Scoville 1974).
- Solution: Radiative transfer (RT) simulations.
  - Target to reproduce:
    L1498 a well studied PSC (e.g. Tafalla et al 2004 & 2006; Padovani et al. 2011).
  - Constrain physical structure.
  - RT of all isotopologues together.

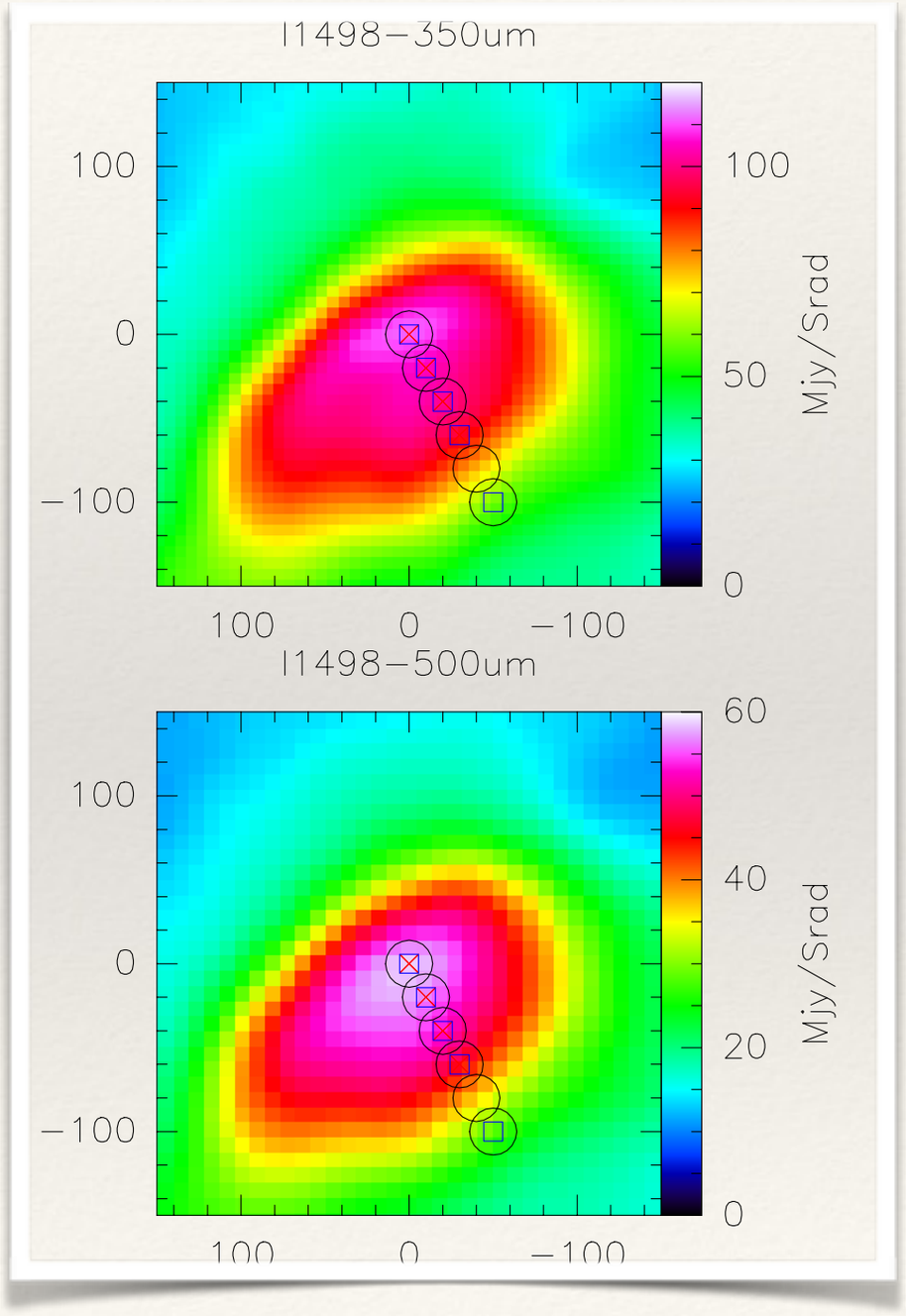


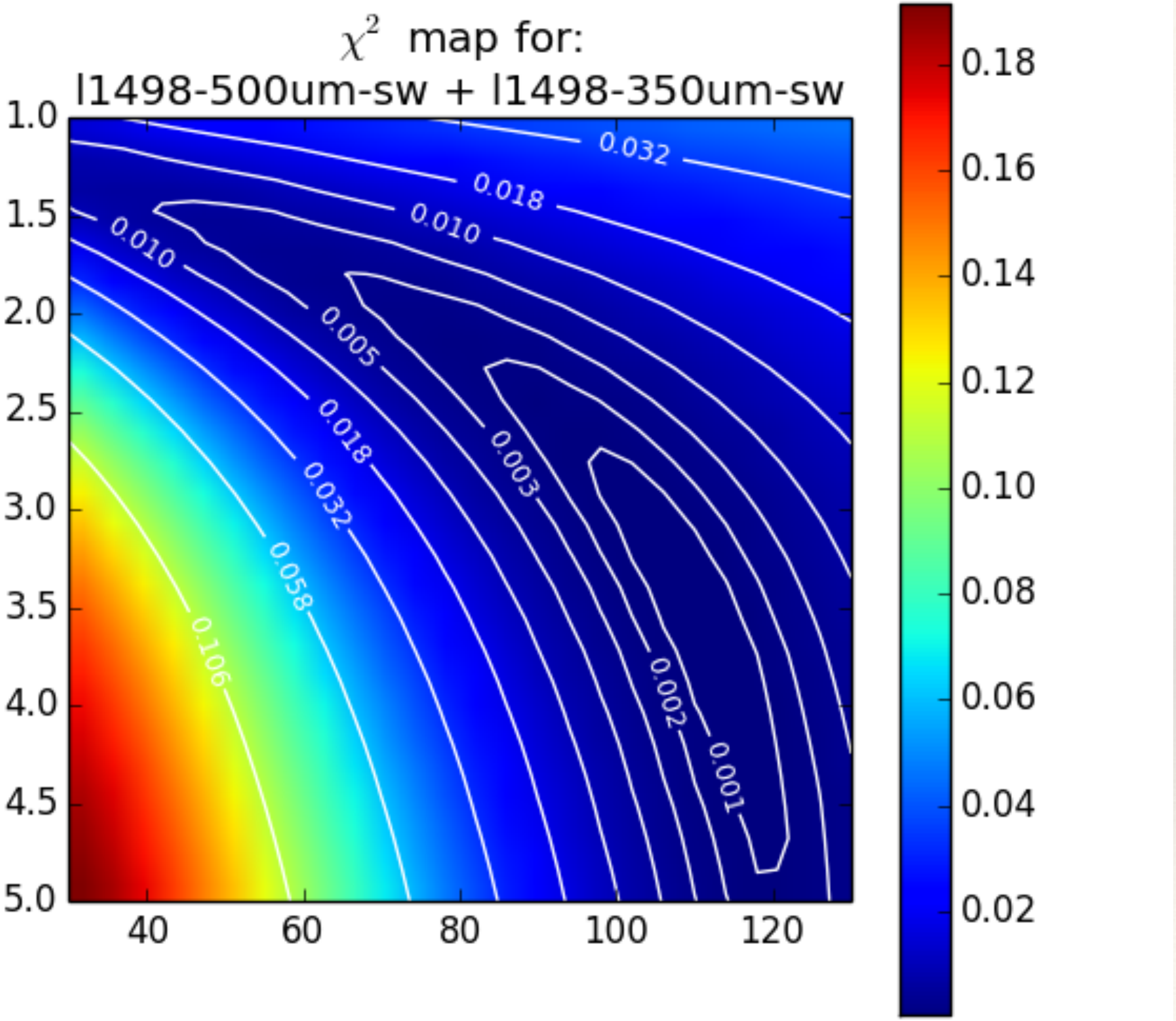
L1498 in context

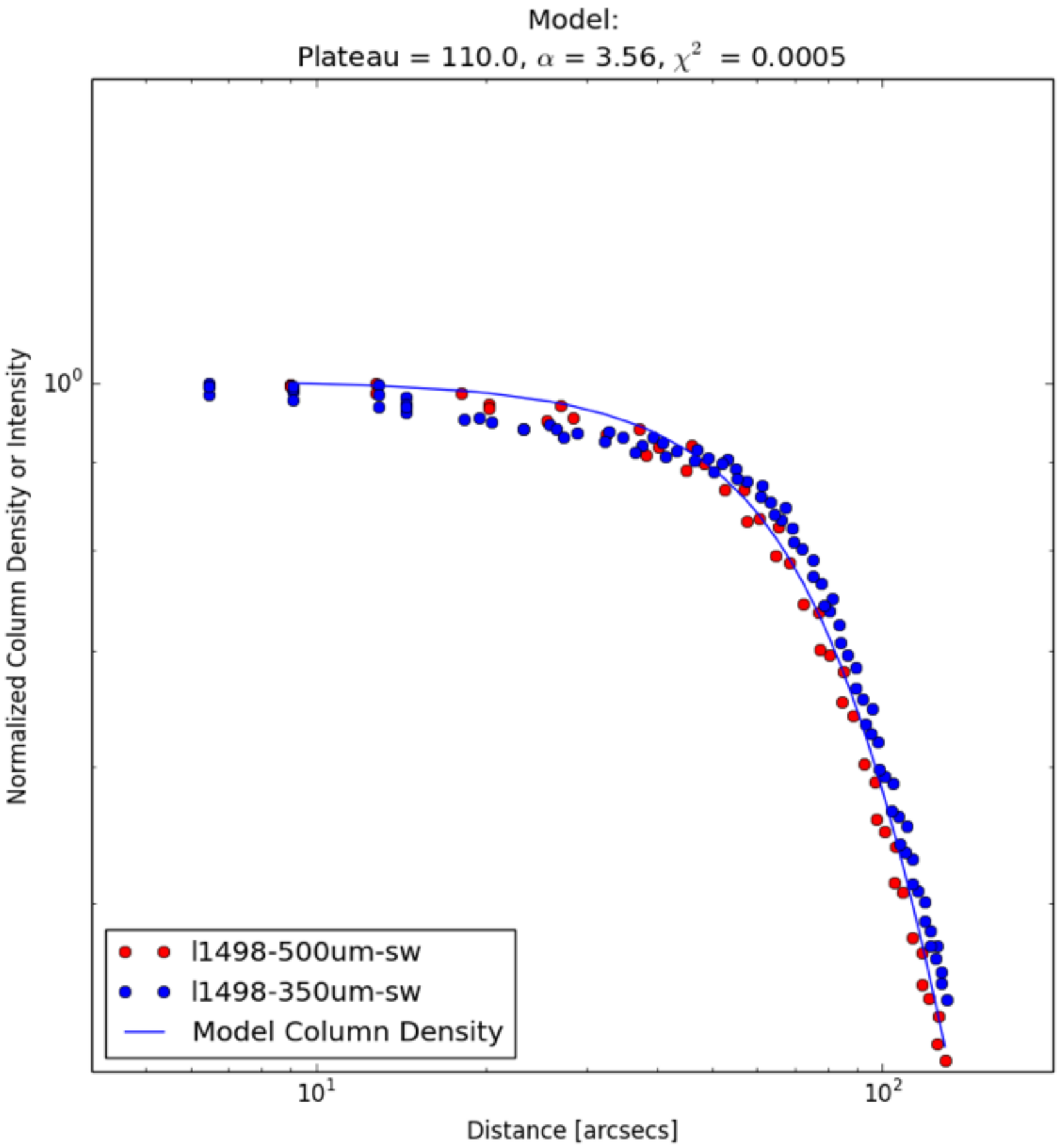


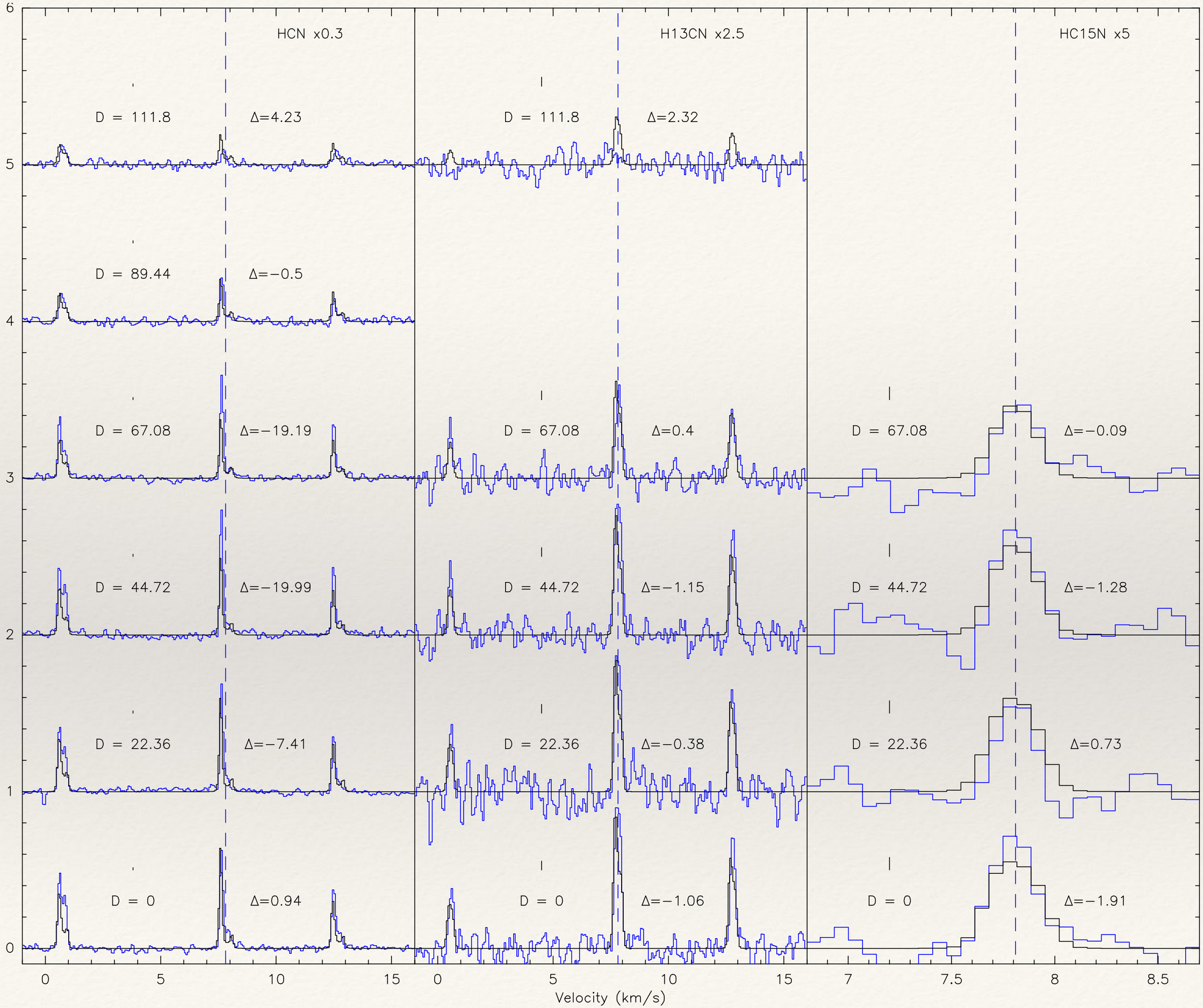
Physical structure of L1498

- To do the RT a good model of the physical structure is needed.
- Herschel-SPIRE continuum data has been used to constrain the density structure of L1498.
- The physical structure obtained is consistent with previous works (e.g. Tafalla et al 2004).




χ^2 map for:
l1498-500um-sw + l1498-350um-sw
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
40
60
80
100
120
0.032
0.018
0.010
0.010
0.005
0.018
0.032
0.003
0.058
0.106
0.002
0.001
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02

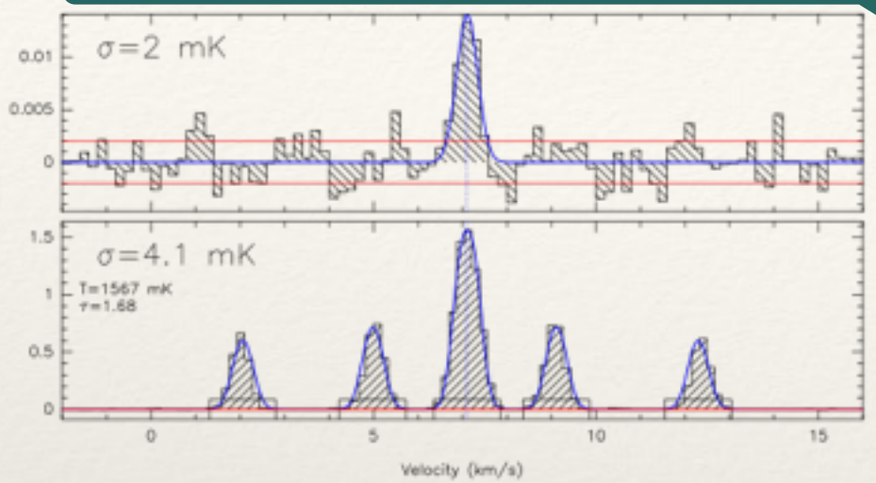

Model:
Plateau = 110.0, α = 3.56, χ^2 = 0.0005
Normalized Column Density or Intensity
10^0
10^1
10^2
Distance [arcsecs]
l1498-500um-sw
l1498-350um-sw
Model Column Density


HCN x0.3
H13CN x2.5
HC15N x5
D = 111.8
Δ=4.23
D = 111.8
Δ=2.32
D = 89.44
Δ=−0.5
D = 67.08
Δ=−19.19
D = 67.08
Δ=0.4
D = 67.08
Δ=−0.09
D = 44.72
Δ=−19.99
D = 44.72
Δ=−1.15
D = 44.72
Δ=−1.28
D = 22.36
Δ=−7.41
D = 22.36
Δ=−0.38
D = 22.36
Δ=0.73
D = 0
Δ=0.94
D = 0
Δ=−1.06
D = 0
Δ=−1.91
6
5
4
3
2
1
0
0
5
10
15
0
5
10
15
7
7.5
8
8.5
Velocity (km/s)

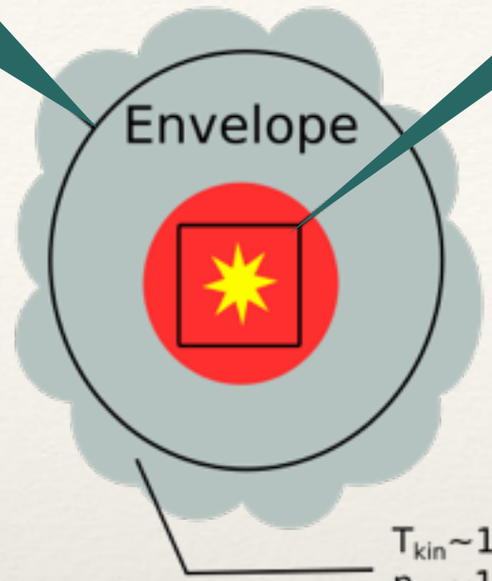
A new possibility: fractionation in the ices

- Roueff et al. 2015 no gas phase CF for N.
- Small R towards B1 (Daniel et al. 2013):
  - Other mechanism at work?
- Is this new mechanism in the ices?
  - Deuteration and D/H exchanges are known to occur in ices (e.g. Faure et al. 2015)

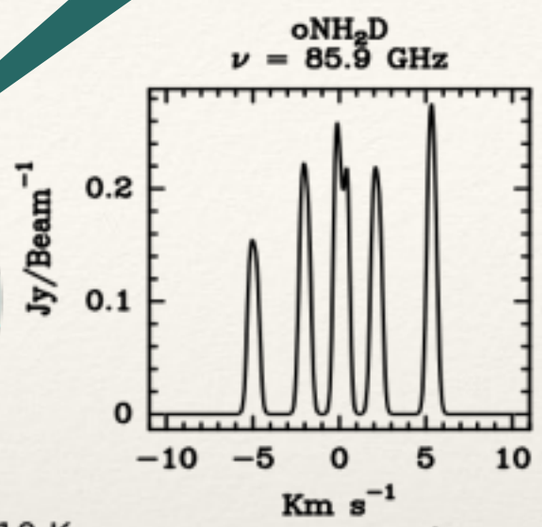
IRAM-30m Observations

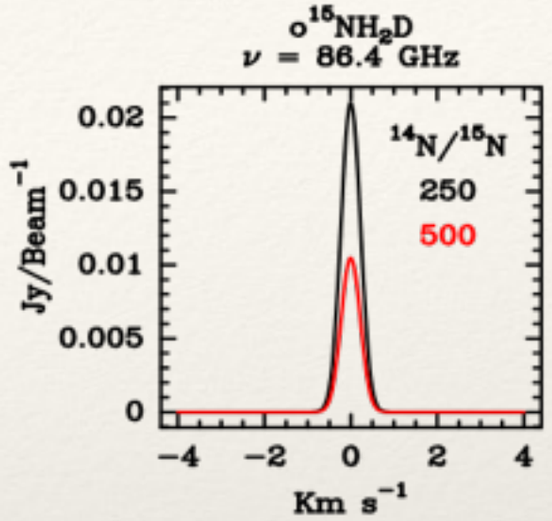


$R_0 \sim 250$



Model predictions for NOEMA





$R_0' = ?$

Source: IRAS 03282, Protostar

Fractionation in ices

- Towards cold envelope -> R_0
- Towards evaporating ice -> R'_0
- If $R_0 \neq R'_0$ => N fractionation processes are occurring in the ices.

Conclusions and perspectives

- R has been measured in two PSN analogs (CN, TW Hya; HCN, MWC 480), perhaps the first clue for two reservoirs of N in PSNe.
- Could these reservoirs have a prestellar origin?
  - To do so, we are addressing carbon fractionation issue in HCN together with solving the problem of its HF anomalies:
    - Inner motions + turbulent envelope -> a 40 year old problem is now solved.
- A new possibility for R variability in the PS phase:
  Fractionation in ices.
  - 30m + NOEMA.
  - ALMA cycle 4 proposal.