Bright CO from the interaction of a runaway O star with diffuse ISM

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BENCHMARKING STELLAR FEEDBACK

- Context : **star formation** and its **feedback** on the ISM

- Individual processes:
  - ionization
  - radiation pressure on dust + friction on gas
  - stellar winds

- Difficult to disentangle in massive star forming regions (eg Orion)

- Massive runaway stars are ideal to study relative importance of the physical processes
  - Not that rare
  - Can be found in clean environment (no recent SF, no high outside ISRF)
  - Fast speed => study of **out of equilibrium** effects

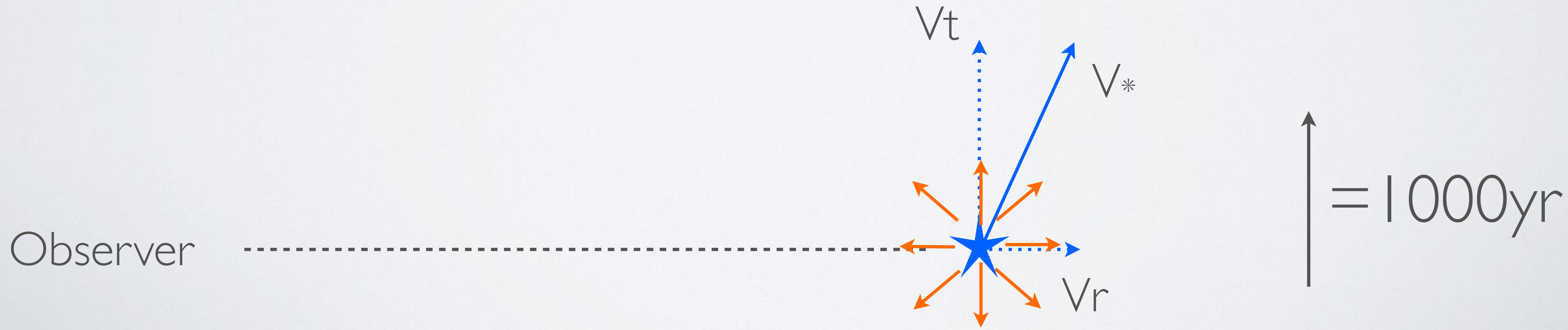
The Star: AE Aurigae (HD34078)

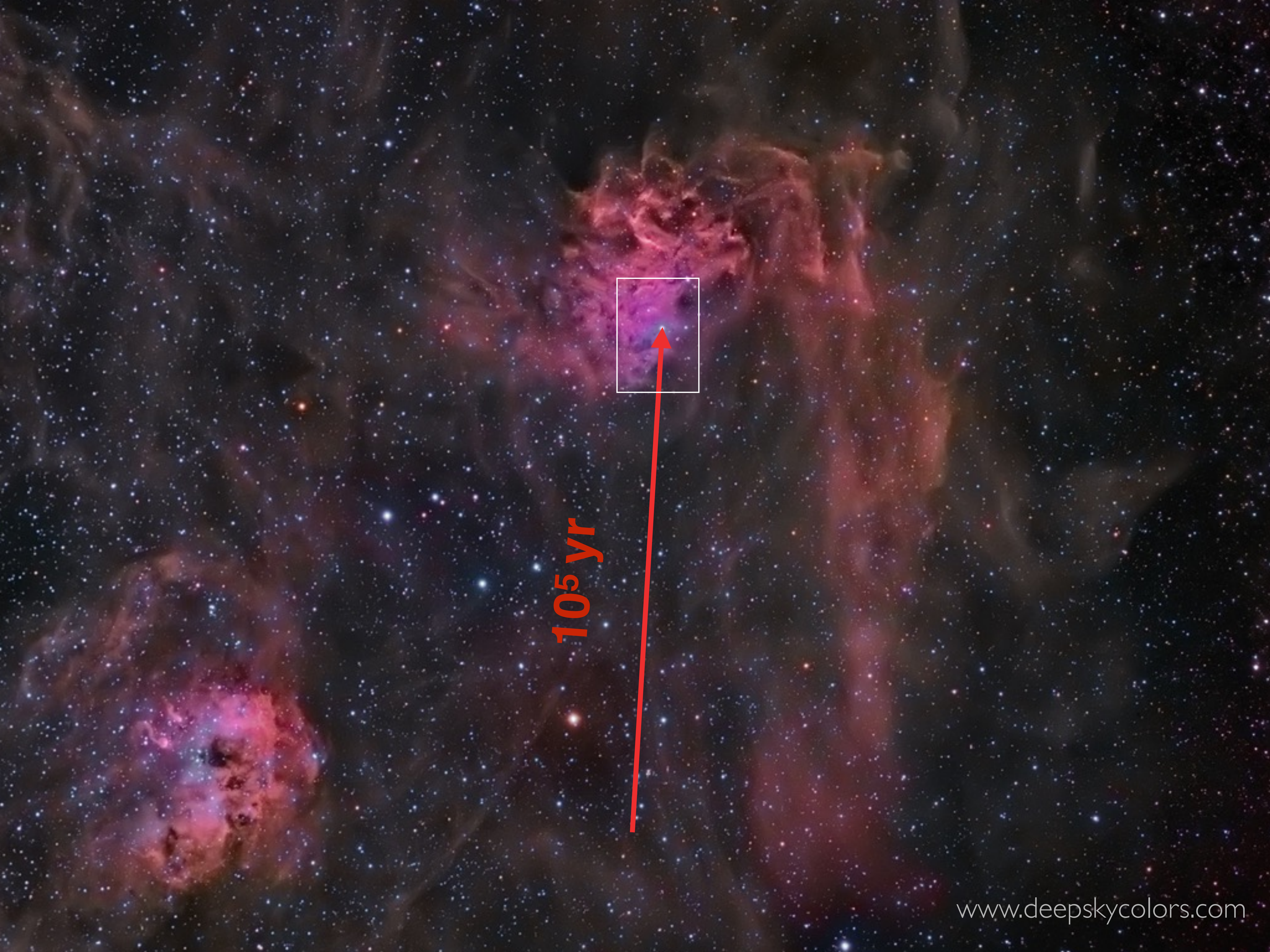
- HD34078 is an O9.5V runaway star :
  - Traced back to binary-binary collision in Orion Trapezium region 2.5×10^{6} years ago (other ejected star: mu Columbae)

- Distance : 530 pc
- Proper motion : **μ** = 43 mas/yr (Vt = 140 km/s)
- Radial velocity : Vr = 50 km/s
- V_{wind} ~ 800 km/s $dM/dt \sim 10^{-9.5}\ M_{sun}/yr$ $L_{bol} \sim 8\times10^{4}\ L_{sun}$

→ Vspace ~150 km/s

- Visible absorption: studying the au-scale diffuse ISM (Rollinde et al 2003 Boissé et al 2005)




10^5 yr
www.deepskycolors.com

THE AMBIENT MEDIUM: IC405

- Blaauw 1953 and Herbig 1958 noted the recent **interaction** with Flaming Star Nebula (IC405).
  - Star cleaned southern part of dust and gas
- B Band image : dust scattering enhanced in the forward direction
- This interaction was confirmed by Boissé et al. 2005 through UV absorption studies (large amount of excited H_2)
- **Diffuse environment**: no CO detection in Dame et al. (or Planck maps)

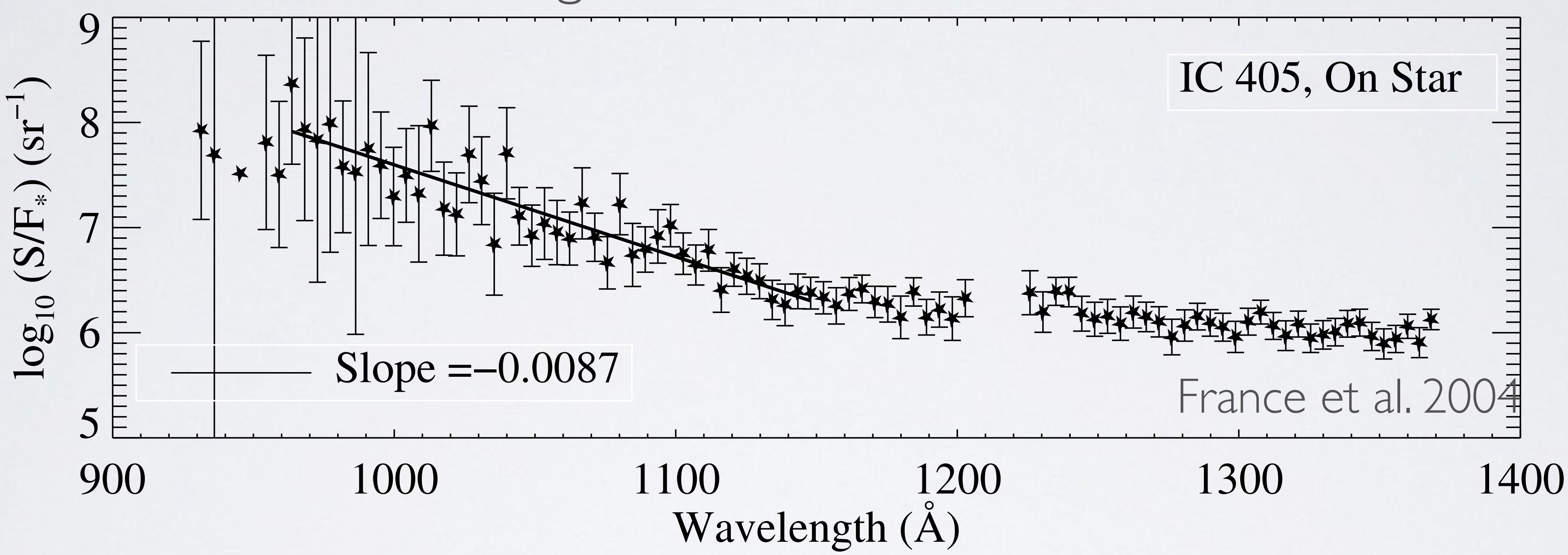
Red: Halpha, Blue : B band

Adam Block/Mount Lemmon SkyCenter/Univ. of Arizona

What is Known from UV/Vis Absorption

- Rocket-borne ultraviolet (France et al. 2004):
  - **ratio of nebular/star spectra increase in the blue region of the spectrum**
  - Predict a small (<20'') fragment in front of the star

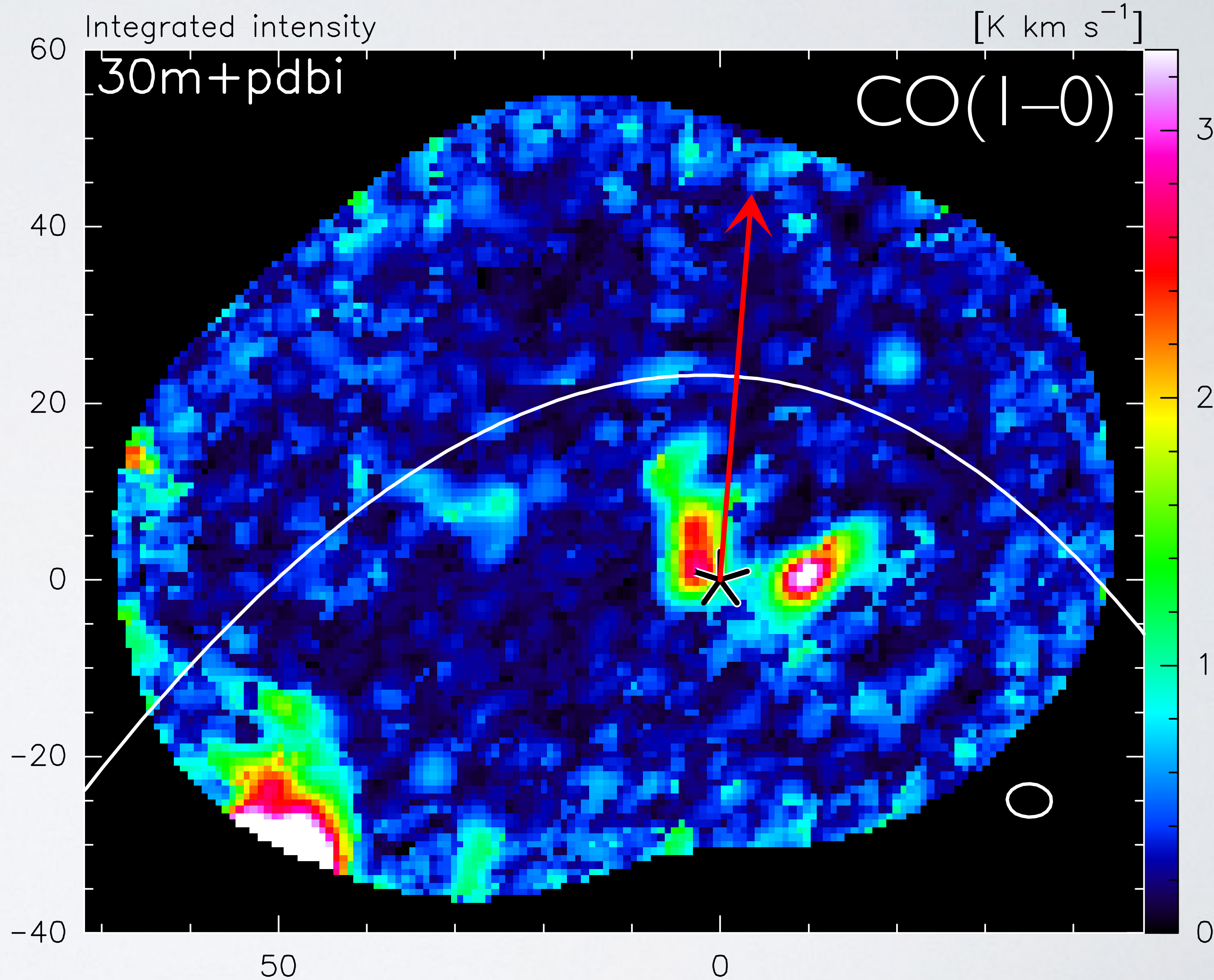
  Ratio of nebular surface brightness to star flux :



- H_2 with FUSE (Boissé et al 2005)
  - **Large amount of excited H_2 (J>5) on the line of sight**
  - Photodissociation Region close to the star ($\chi = 5\times10^2$–10^4 @ 0.2pc, $n_H = 5\times10^3$–5×10^4 cm^{-3})
  - Rare occurrence : one of 2 known such stars (other HD37903)

High resolution CO towards HD34078

- PdBI observations (Gratier et al 2014, A&A)
- CO(1-0) @ 4.4” resolution
- Bright globulettes (1-3K peak temperature)
- One just in front of and close (0.2pc) to the star
  => Explains the peculiar properties



HIGH RESOLUTION CO TOWARDS HD34078

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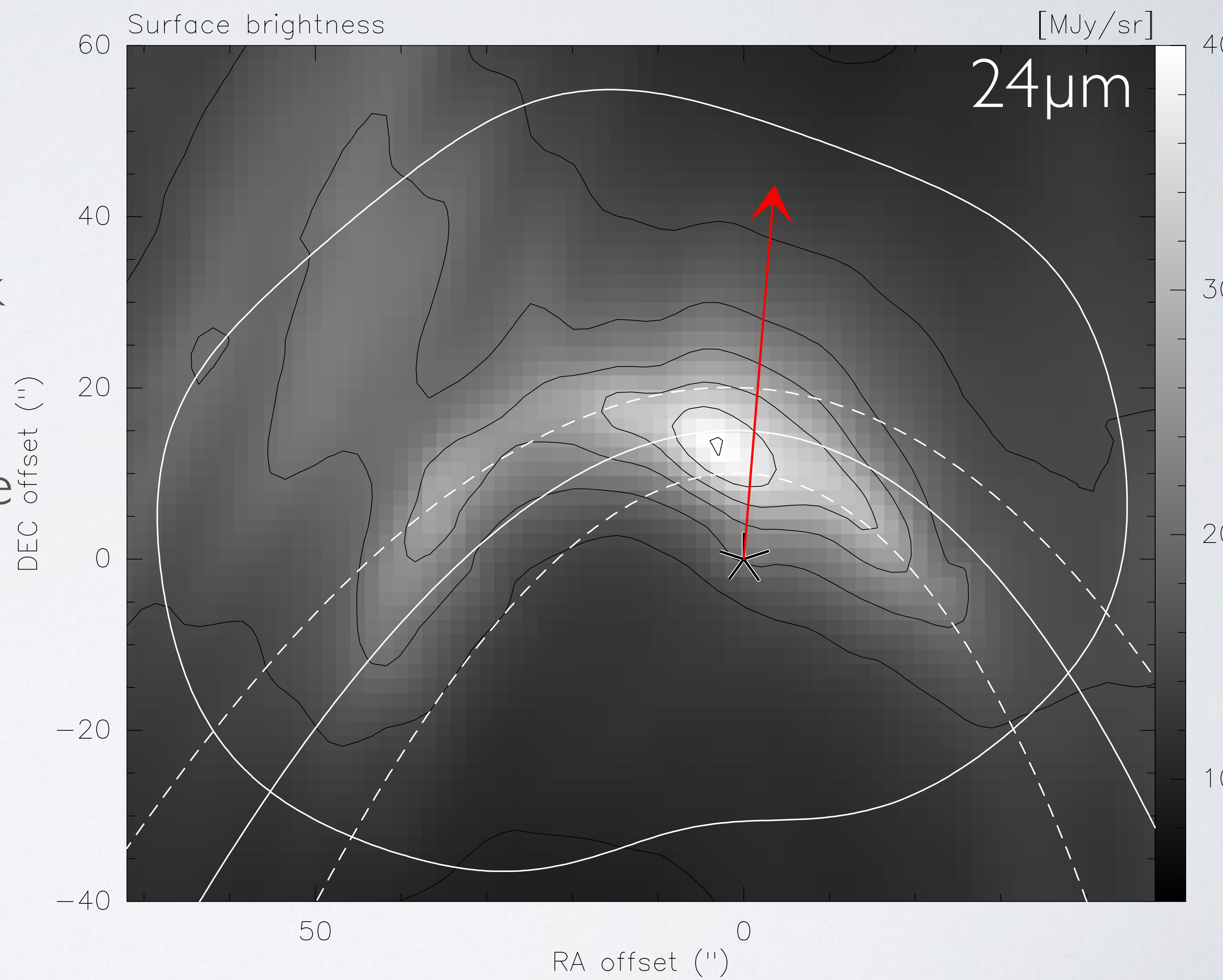
- Distance star – IR arc
  wind mass flux may be 300-1000 times larger the UV measurements

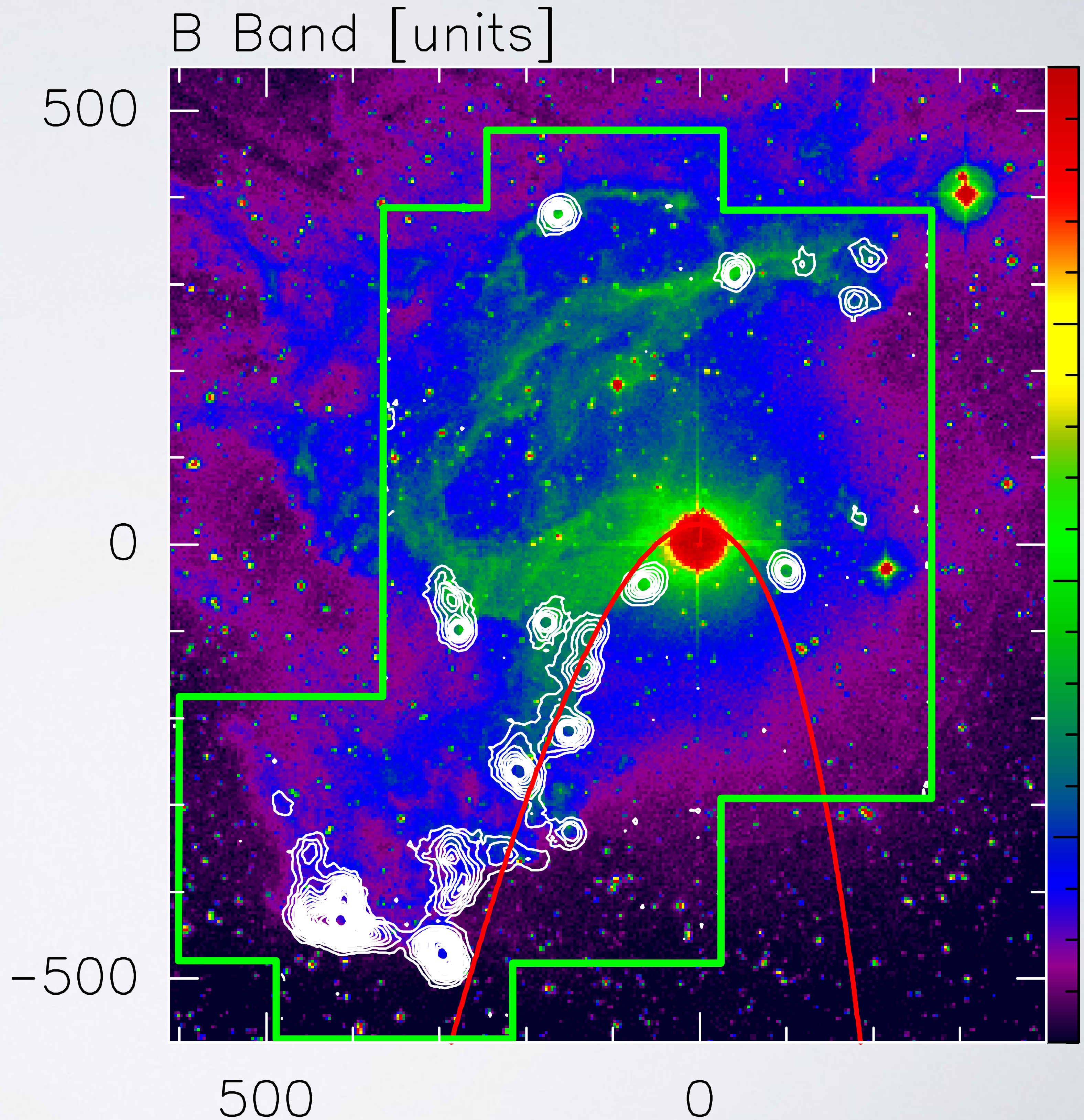


(see **weak wind** problem e.g. zeta Oph (Gvaramadze et al. 2012))

WIDE FOV CO WITH IRAM 30M

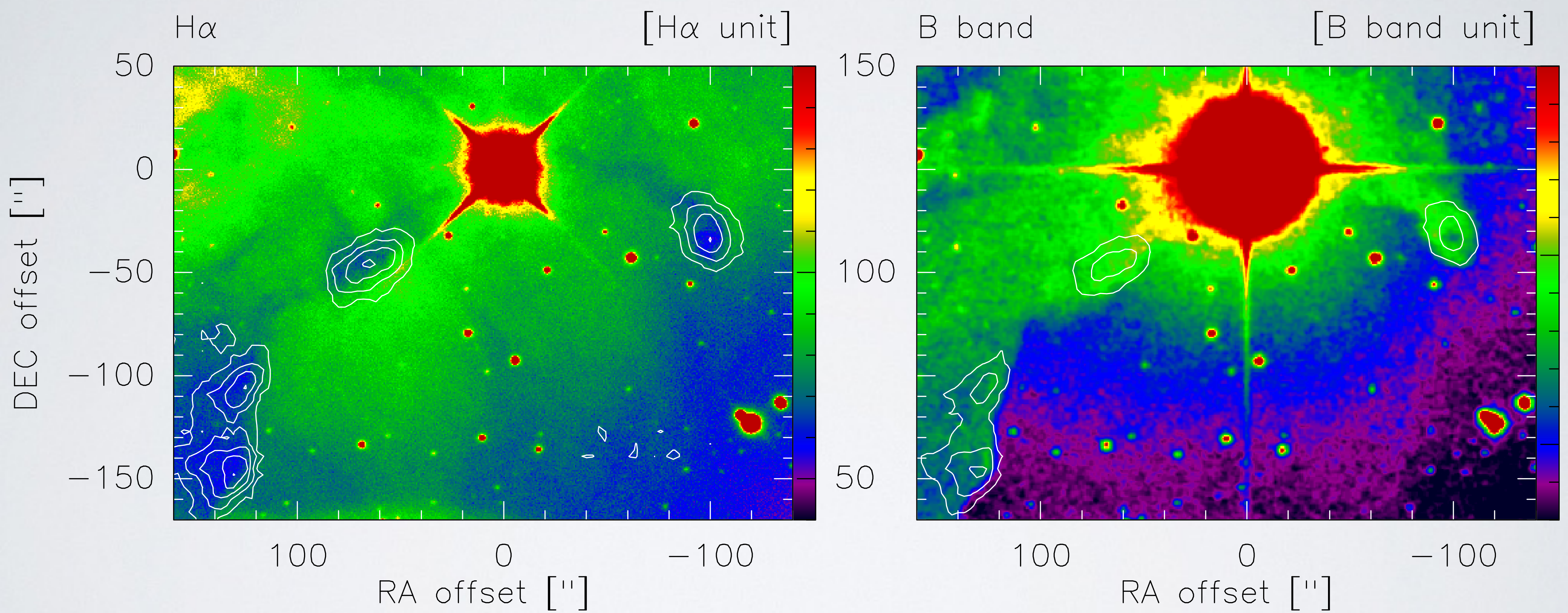
- Simultaneous:
  $^{12}CO(1\text{-}0)$, $^{12}CO(2\text{-}1)$,
  $^{13}CO(1\text{-}0)$, $^{12}CN(1\text{-}0)$.
- No signal in Dame et al. survey (9') or Planck (15') @ 1K Km/s sensitivity
- ~25 globules (~10K Tpeak) mainly along dust ridge
- timescale for CO photodissociation
  - $t=3\times10^5$ yr/chi (A_v = 0.1-1mag, nH = 100 cm^{-3})
  - chi = 10^2-10^4 G0
  - few 10^2 yr

30h: 200 square arcminutes
0.2 K @ 22'' and 0.5 km/s channels



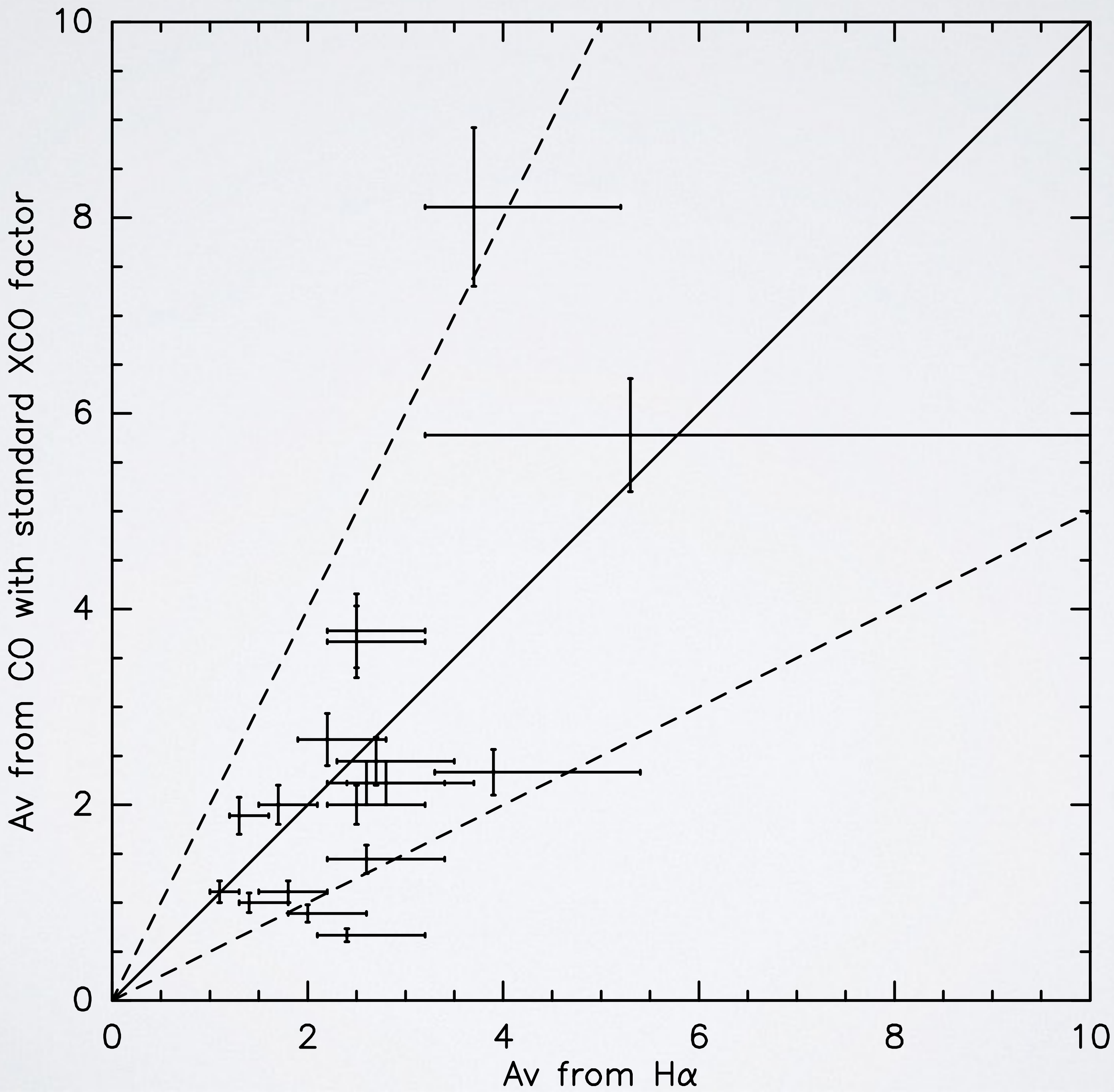
Wide FOV CO with IRAM 30m

- Zooming in on the closest clumps to the star
- CO coincides with dust bright/Halpha dark ridge



H_2-CO FACTOR IN TRANSLUSCENT GAS

- Dust **extinction** measured from Halpha
- Av ~ 2-3 => Transluscent gas
- Standard X factor ($N_{H2}/I_{CO} = 2 \times 10^{20}$ cm^{-2}/(Kkm/s) can be used.



Clump Properties

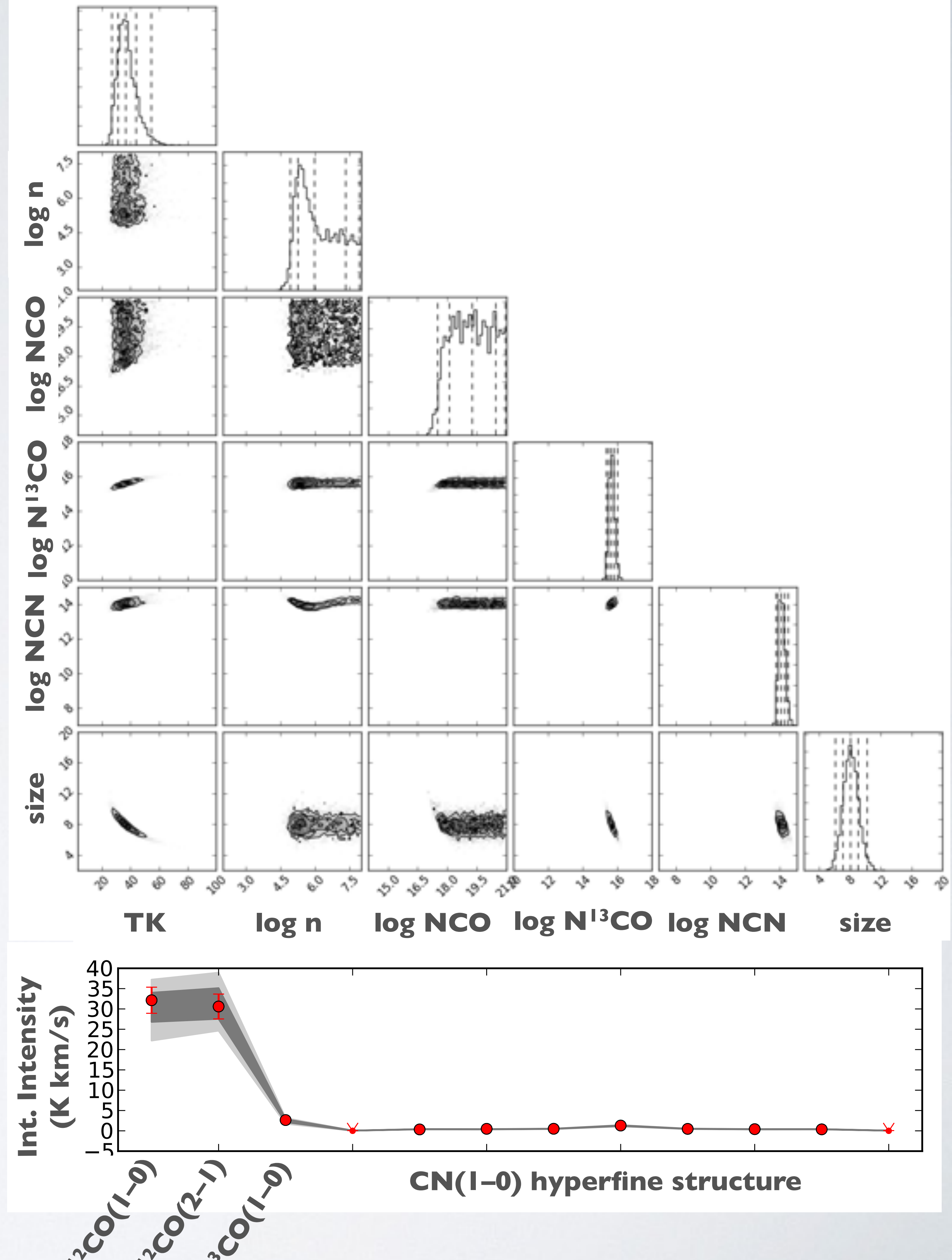
- LVG modelling (RADEX+MCMC) of all observed lines (including upper limits)

- Typical results (molecular gas)
  - **dense (10^5-10^6 cm-3)**
  - **cool (20 – 40K)**
  - **mass: 0.1–1 Msun**

- Molecularly rich: detected species in the clumps closest to star (chi~10^3)

  C_2H, C_3H_2, C_4H, HCN, HCO^+, HNC, CS, CN, $C^{18}O$, ^{13}CO

- Chemistry at 10^3–10^4 yr timescales



Clump Dynamics

- Energy balance thermal+turb, gravitational terms

$$2\mathcal{T} = \frac{3M\Delta V_{\mathrm{FWHM}}^2}{8\ln 2} \quad \mathcal{G} = \eta\frac{GM^2}{R}$$

- Pressure terms:
  - Ionisation pressure

$$\mathcal{I}_{\mathcal{RDI}} = 2\pi R^3 P = \frac{4R^2 k_{\mathrm{B}} T_{\mathrm{II}}}{D}\left(\frac{3\pi\dot{\mathcal{N}}_{\mathrm{LyC}} R}{\alpha_\star}\right)^{1/2}$$

RDI

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Ambient HII region

  - Radiation pressure

$$\mathcal{P} = 2\pi R^3 P_{rad} = 2\pi R^3 \alpha \frac{L_{\mathrm{bol}}}{4\pi c D^2} = \frac{\alpha R^3 L_{\mathrm{bol}}}{2cD^2}$$

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Dominant expanding term

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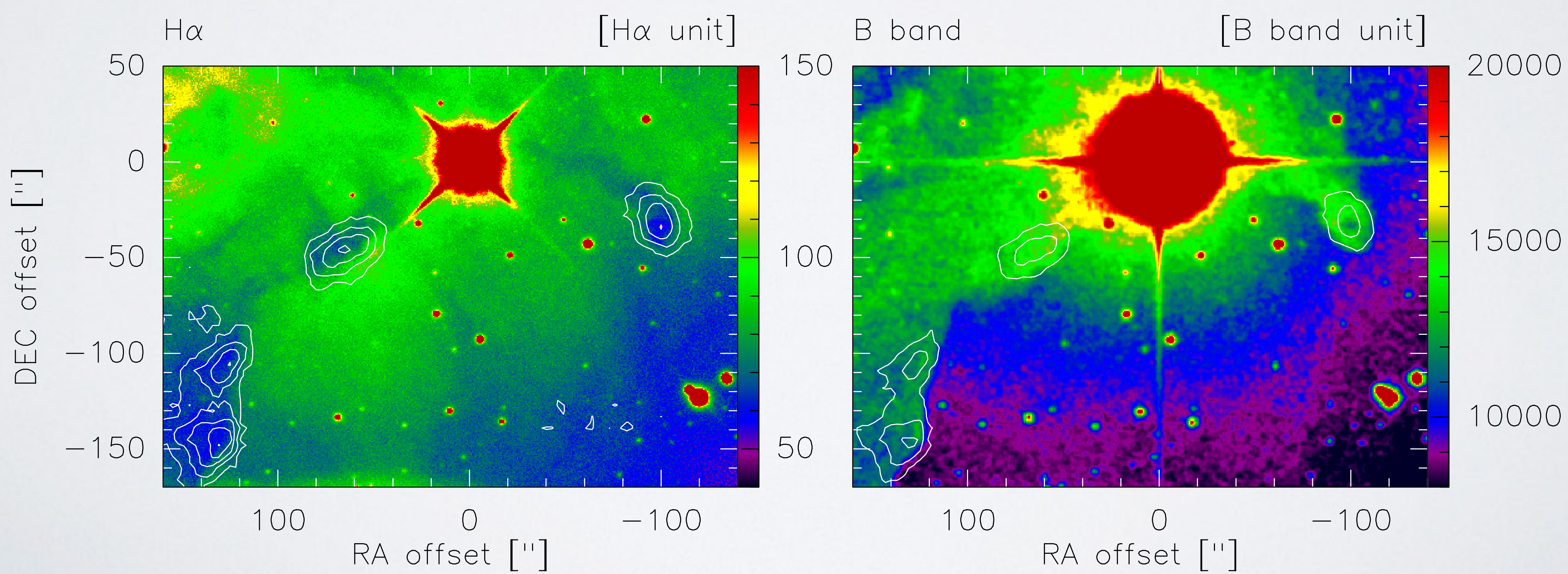
QUESTIONS TO BE ANSWERED

- Are the clumps preexisting or created by the interaction.
  - What is the minimal initial overdensity needed to create 10^5–10^6 cm^{-3} globules?
- Why are there no clumps and no dust to the south.
- Shape of the bow shock (cubic) / radiation pressure on dust (parabola)



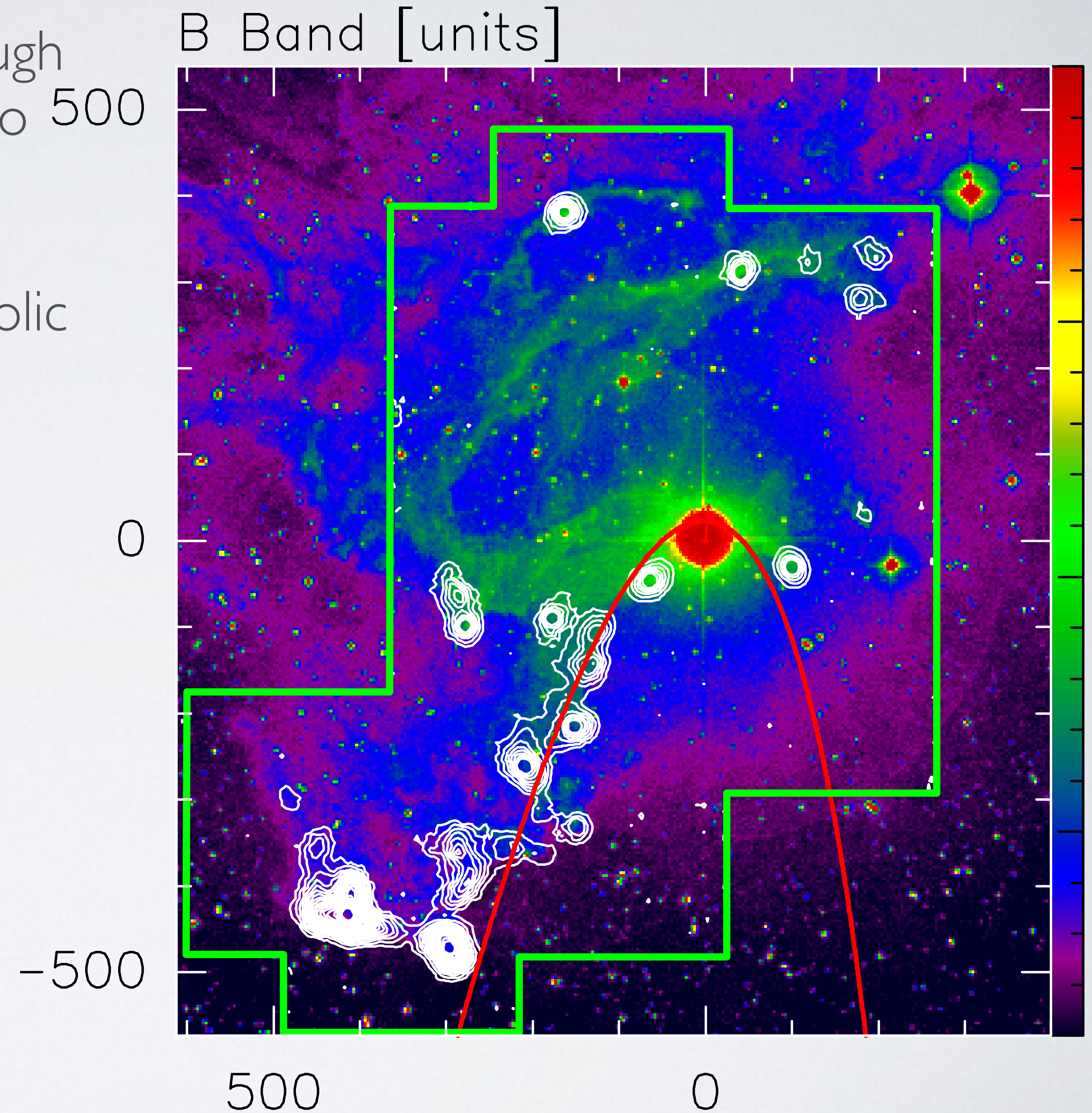
A COHERENT PICTURE ?

- Ionization from HD34078 enhances inhomogeneity through RDI => formation of clumps to the north

- Dust as accumulates on parabolic interface because of radiation pressure.

- Gas and biggest grains are decoupled

- CO rapidly photodissociates inside the parabola



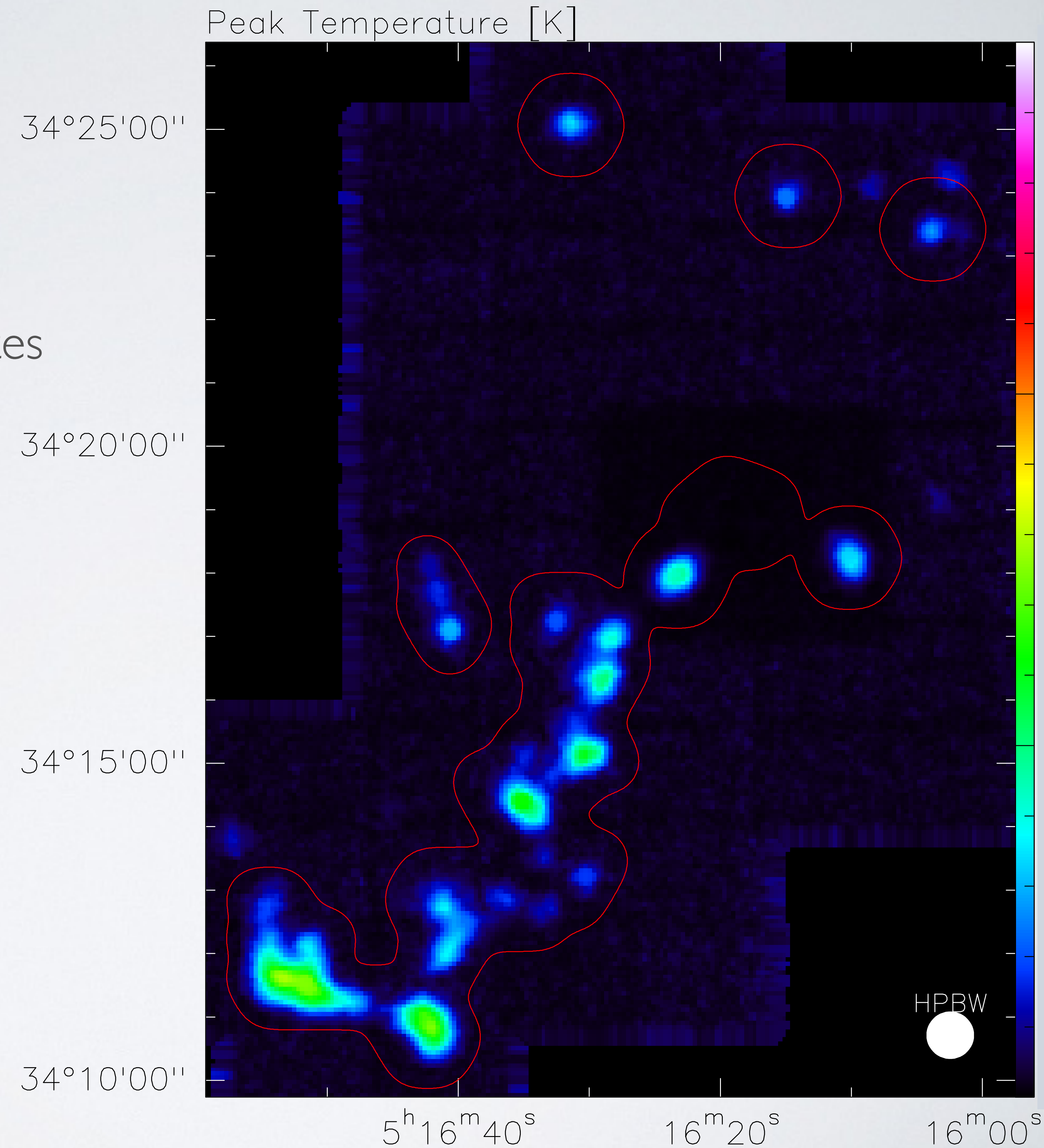
NOEMA: Wide FOV + High Angular Res.

- PDBI 150 pointing mosaic @ 5''

- some clumps subdivide
- new even smaller globulettes

- few tens of Mjup

- clumps are brighter : 30K peak temperature



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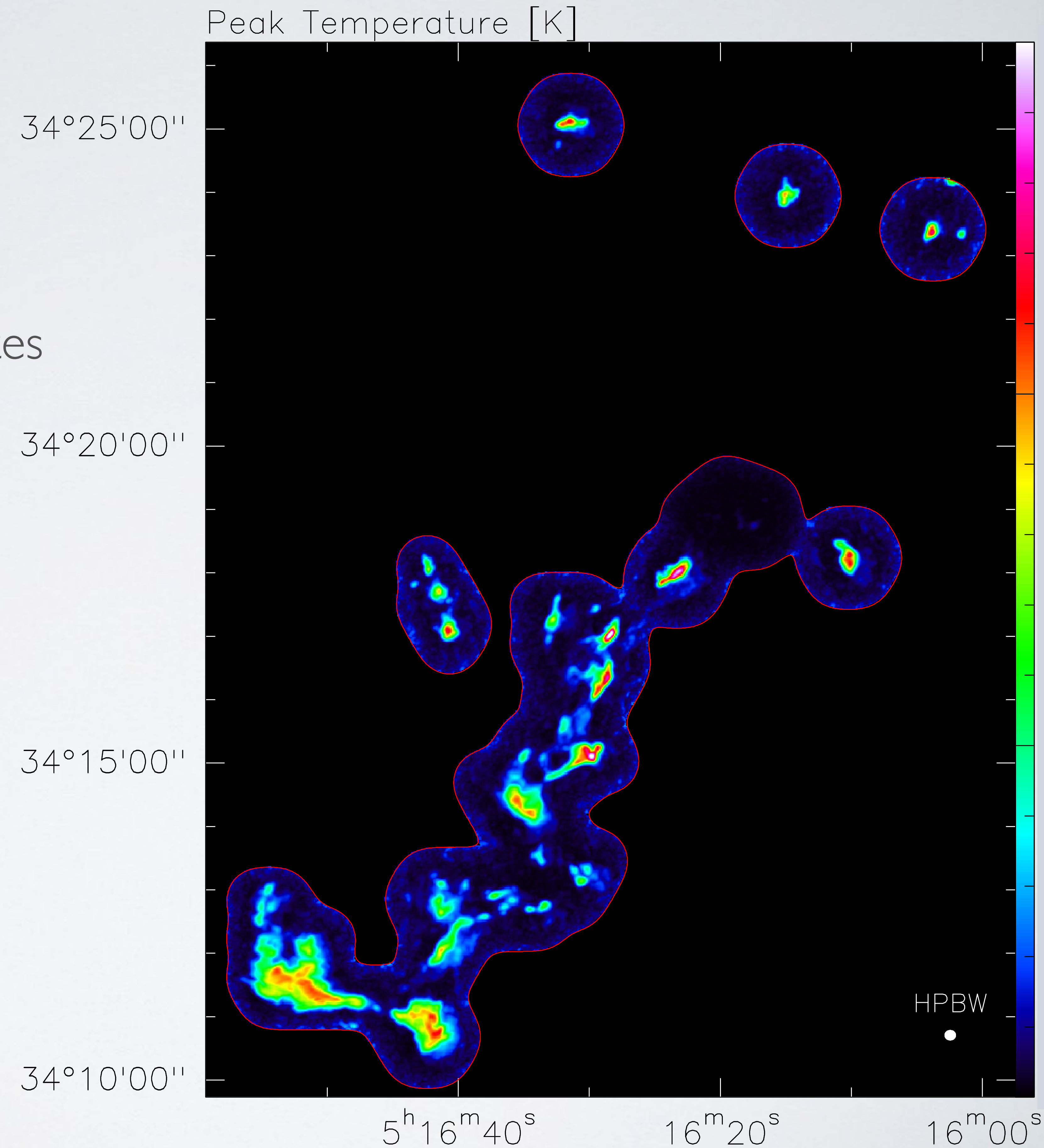

FINAL WORDS

- Bright CO detected near fast O type star in an otherwise diffuse nebula

- Transluscent, dense, cold globules that are found (mostly) along a parabolic dust ridge

- **Study elementary stellar feedback processes**

- How common is this ?

  - **survey** of runaway stars in CO with 30m telescope

  - detection in 2 of 4 sources