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

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Funded by:
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 (e.g., 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 2.5x10^6 years ago (other ejected star: mu Columbae)

- Distance: 530 pc
- Proper motion: \( \mu = 43 \text{ mas/yr} \) (\( V_t = 140 \text{ km/s} \))
- Radial velocity: \( V_r = 50 \text{ km/s} \)
- \( V_{wind} \sim 800 \text{ km/s} \) \( dM/dt \sim 10^{-9.5} \text{ M}_{\odot}/\text{yr} \) \( L_{bol} \sim 8 \times 10^4 \text{ L}_{\odot} \)

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

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

![Graph showing the ratio of nebular surface brightness to star flux](image)

- 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, \(n_H = 5\times10^3–5\times10^4\) 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
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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(1-0), $^{12}$CO(2-1), $^{13}$CO(1-0), $^{12}$CN(1-0).

• 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
  • $t = 3 \times 10^5$ yr/$\chi$
  (Av = 0.1-1 mag, 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
• Zooming in on the closest clumps to the star
• CO coincides with dust bright/Hα dark ridge
H$_2$-CO FACTOR IN TRANSLUSCENT GAS

- Dust extinction measured from Halpha
- $A_v \sim 2-3 \Rightarrow$ Transluscent gas
- Standard X factor ($N_{\text{H}_2}/I_{\text{CO}} = 2 \times 10^{20} \text{ cm}^{-2}/(K\text{km/s})$) can be used.
**Clump Properties**

- LVG modelling (RADEX+MCMC) of all observed lines (including upper limits)
- Typical results (molecular gas)
  - dense \((10^5 - 10^6 \, \text{cm}^{-3})\)
  - cool \((20 - 40 \, \text{K})\)
  - mass: \(0.1 - 1 \, \text{Msun}\)
- Molecularly rich: detected species in the clumps closest to star \((\text{chi} \sim 10^3)\)
  - \(\text{C}_2\text{H}, \text{C}_3\text{H}_2, \text{C}_4\text{H}, \text{HCN}, \text{HCO}^+, \text{HNC}, \text{CS}, \text{CN}, \text{C}^{18}\text{O}, \text{^{13}CO}\)
- Chemistry at \(10^3 - 10^4 \, \text{yr} \) timescales
**Clump Dynamics**

- Energy balance thermal + turb, gravitational terms

\[ 2T = \frac{3M\Delta V_{\text{FWHM}}^2}{8 \ln 2} \quad G = \eta \frac{GM^2}{R} \]

- Pressure terms:
  - Ionisation pressure

\[ I_{RDI} = 2\pi R^3 P = \frac{4R^2 k_B T_{\Pi}}{D} \left( \frac{3\pi \dot{N}_{\text{LyC}} R}{\alpha_*} \right)^{1/2} \quad \text{RDI} \]

\[ I_{\text{HII}} = 4\pi R^3 P = \frac{4\pi R^3 n_{\text{HII}} k_B T_{\Pi}}{D} \quad \text{Ambient HII region} \]

- Radiation pressure

\[ P = 2\pi R^3 P_{\text{rad}} = 2\pi R^3 \alpha \frac{L_{\text{bol}}}{4\pi c D^2} = \frac{\alpha R^3 L_{\text{bol}}}{2c D^2} \]

- Stellar winds
Clump Dynamics

- Energy balance thermal+turb, gravitational terms

\[
2\mathcal{T} = \frac{3M\Delta V_{\text{FWHM}}^2}{8 \ln 2}
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Dominant expanding term

\[
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\]

Pressure terms:
- Ionisation pressure

\[
I_{\text{RI}} = 2\pi R^3 P = \frac{4R^2 k_B T_{\text{II}}}{D} \left( \frac{3\pi \dot{N}_{\text{LyC}} R}{\alpha_*} \right)^{1/2}
\]

Dominant confining term

\[
I_{\text{HII}} = 4\pi R^3 P = \frac{4\pi R^3 n_{\text{II}} k_B T_{\text{II}}}{D}
\]

Ambient HII region

- Radiation pressure

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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
• 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