Molecular gas under the influence of nearby massive stars: the case of G353.2+0.9

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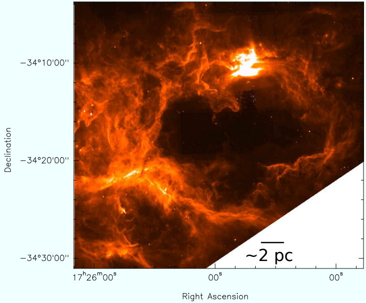
NGC6357

NGC6357 (2.5 kpc) - 8 μm



- Presence of a large cavity (or a number of smaller ones)

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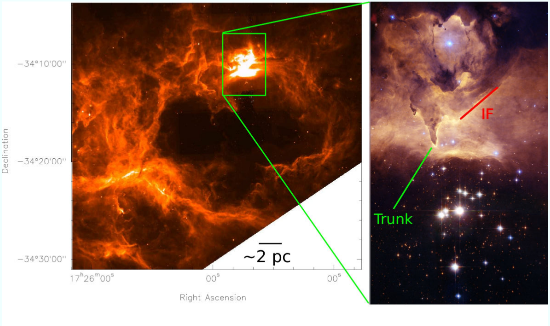

NOTE — Taken from hubblesite.org

- Presence of a large cavity (or a number of smaller ones)
- G353.2+0.9 coincides with the brightest emission

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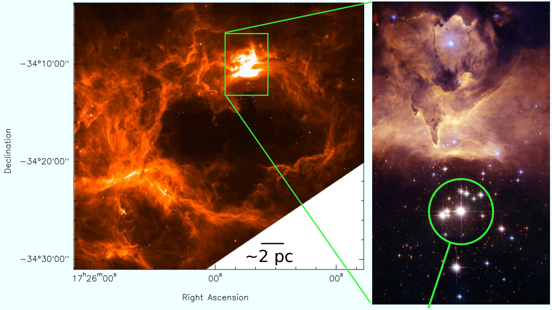


30-40 OB stars (2 O3.5)

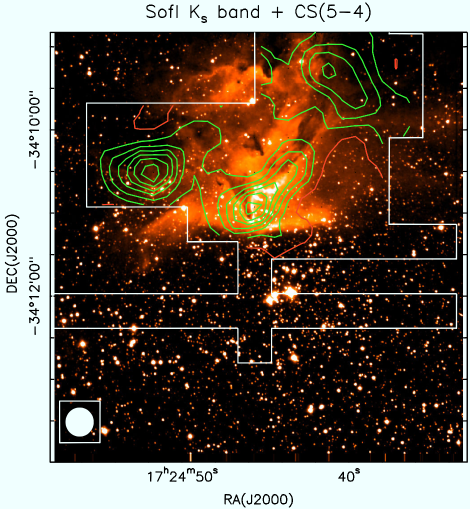
NOTE — Taken from hubblesite.org

- Presence of a large cavity (or a number of smaller ones)
- G353.2+0.9 coincides with the brightest emission
- Pismis 24 is found south of this region

Why G353.2+0.9?

- Perfect region to study the interaction between molecular gas and massive stars
  - Main IF seen edge-on
  - Optimal for studying fragmentation and chemical stratification
- Connection between G353.2+0.9 and Pismis 24: Just ionization or also triggered SF?

G353.2+0.9: SEST

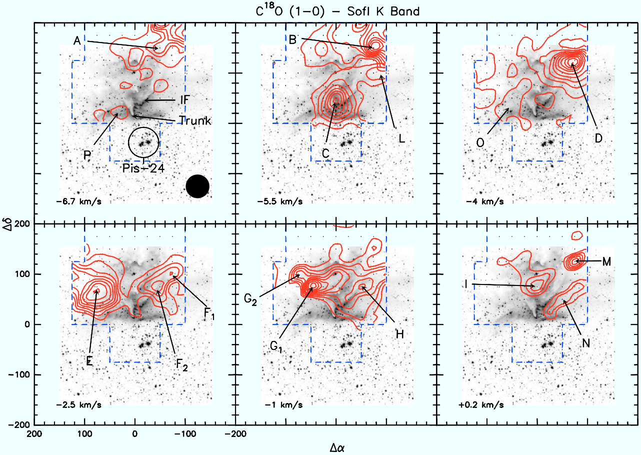


White line: Observed region

- Observed transitions: $C^{18}O$(1-0), $C^{18}O$(2-1), CN(1-0), CN(2-1), CS(2-1), $C^{34}S$(2-1), CS(3-2), CS(5-4), $H_2CO(2_{1,2}$-$1_{1,1})$, SiO(5-4), CH_3CCH(6-5)
- Molecular gas found in the North
- Aligned along the IF
- Associated with the elephant trunk

Individual Clumps

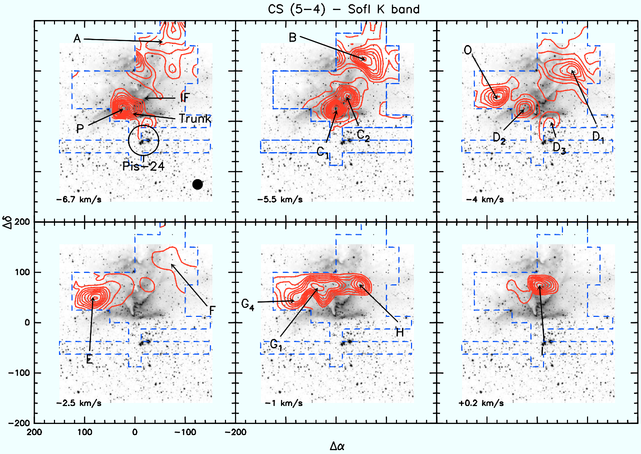
$C^{18}O(1\text{-}0)$



Dashed blue line: Observed region

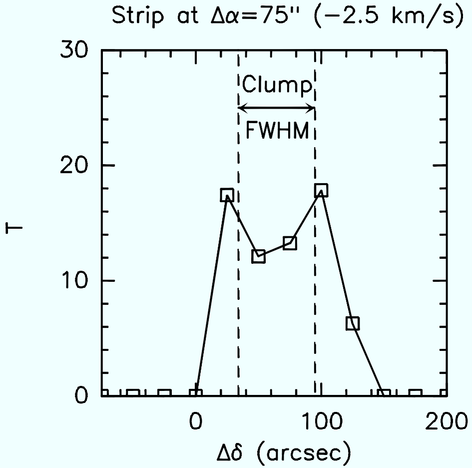
Individual Clumps

CS(5-4)



Dashed blue line: Observed region

Excitation Temperatures



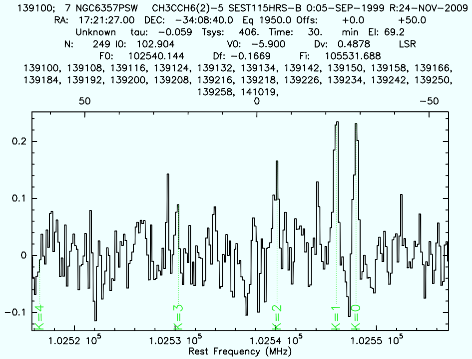
$$\frac{T_{\mathrm{MB,C^{18}O(2-1)}}}{T_{\mathrm{MB,C^{18}O(1-0)}}} = 4\mathrm{e}^{-10.50/\mathrm{T_{ex}}}$$

$$N = f(T_{\mathrm{ex}})\frac{\tau}{1-\mathrm{e}^{-\tau}}\int T_{\mathrm{MB}}dv$$

- Typical range of temperatures: $\sim 15 - 20\ \mathrm{K}$
- Small rise in temperature coinciding with the ionization front
- $C^{18}O$ shows a relative minimum coinciding with the center of some clumps: Internal layers are cooler

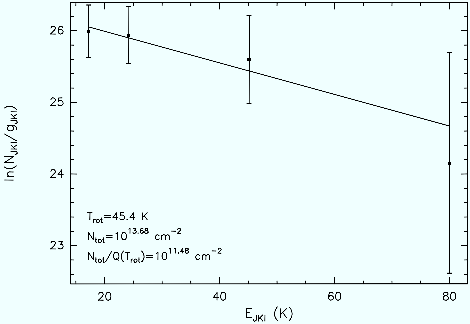
Excitation Temperatures

CH_3CCH J=6–5



- Efficient kinetic temperature tracer

Excitation Temperatures

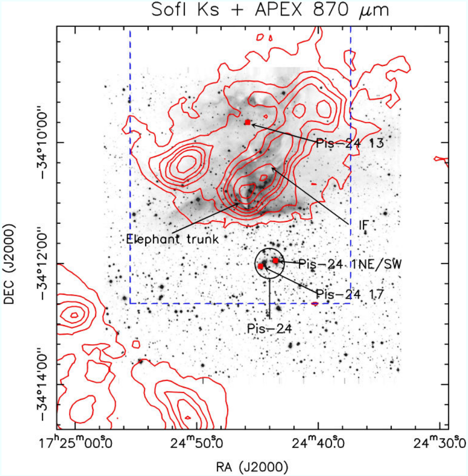


Boltzmann plot:

slope $\propto T^{-1}$
intercept $\propto \log(N)$

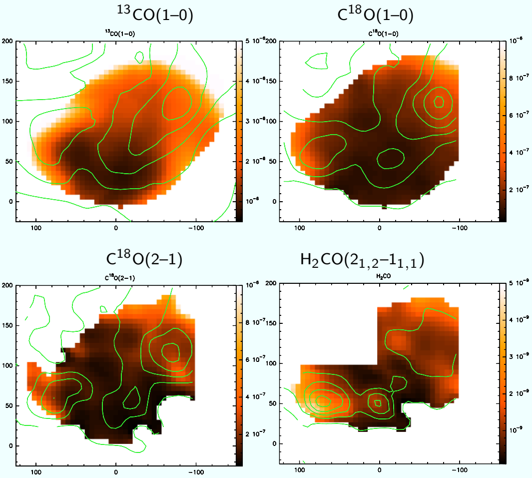
- Efficient kinetic temperature tracer
- High-density layers can be hotter
- Internal heating sources

H_2 Column Densities



- Independent way to derive the mass and column density of the dust, and thus those of the gas, assuming a value for the gas-to-dust ratio
- Other assumptions:
  - Grey body emission
  - Temperature
- Morphology of emission similar to integrated molecular emission, and following IR obscuration features

Abundances



Colours scale: molecular abundance; Contours: Column density

- Determined dividing N_{mol} maps by N_{H_2} (smoothed!) maps from APEX image
- Abundances have similar patterns for all molecules considered
- Increase with distance from the ionizing stars
- $[^{13}CO/H_2]$: $1.0 - 2.2 \times 10^{-6}$
- $[C^{18}O/H_2]$: $0.9 - 2.3 \times 10^{-7}$
- $[H_2CO/H_2]$: $0.6 - 1.5 \times 10^{-9}$

Non-LTE Analysis: The Bayesian Approach

- Large grid of RADEX models with different parameters (T_k, N_{mol}, n_{H_2})

Probability:

$$P(T_k, N_{mol}, n_{H_2}|\mathrm{data}) = \phi P(\mathrm{data}|T_k, N_{mol}, n_{H_2}) P(T_k, N_{mol}, n_{H_2})$$

- Assumptions:
  - Source size fixed as determined from CS(5-4)
  - Gaussian uncertainties for measured line temperatures, fluxes, τ
  - Constant priors for CS (i.e. all the values for the parameters are equally probable)
  - Gaussian prior for T_k ($\mu = 35$ K, $\sigma = 30$ K) for CN

Non-LTE Analysis: Results

CS results

Offset ($''$)	Cl.	T_K (K)	1σ (K)	n_{H_2} ($10^4 \times cm^{-3}$)	1σ ($10^4 \times cm^{-3}$)	N_{CS} ($10^{13} \times cm^{-2}$)	1σ ($10^{13} \times cm^{-2}$)	[CS/H$_2$] (10^{-9})	τ_{21}	τ_{32}	τ_{54}	$\tau_{C^{34}S,21}$	$T_{ex,21}$ (K)	$T_{ex,32}$ (K)	$T_{ex,54}$ (K)	$T_{ex\ C^{34}S,21}$ (K)
(-100,200)	A	33	10 – 64	17	4.8 – 36	4.2	3.9 – 4.9	26	0.7	1.5	0.5	0.05	14	10	7	12
(-50,150)	B	25	11 – 35	18	8.3 – 30	7.4	6.1 – 7.7	5.2	1.4	2.5	1.2	0.09	13	10	6	11
(0,0)	C	40	10 – 72	5.3	1.9 – 8.3	4.3	3.1 – 6.1	9.5	1.2	1.4	0.1	0.08	8	6	6	6
(0,50)	C	18	11 – 20	25	14 – 52	21	14 – 52	2.7	2.4	4.1	2.2	0.17	13	11	6	10
(-50,100)	D	26	10 – 40	22	5.8 – 63	16	15 – 19	3.4	1.6	3.1	2.0	0.12	16	12	7	13
(100,50)	E	11	10 – 15	260	130 – 480	18	15 – 19	40	3.8	5.1	2.7	0.20	11	11	9	11
(-100,100)	F	29	10 – 40	14	5.8 – 25	2.1	1.6 – 2.5	0.7	0.5	0.8	0.1	0.03	11	7	6	10

CN results

Offset ($''$)	Cl.	T_K (K)	1σ (K)	n_{H_2} ($10^5 \times cm^{-3}$)	1σ ($10^5 \times cm^{-3}$)	N_{CN} ($10^{14} \times cm^{-2}$)	1σ ($10^{14} \times cm^{-2}$)	τ_{10}	τ_{21}	$T_{ex,10}$ (K)	$T_{ex,21}$ (K)
(-50,150)	A	35	21 – 57	2.8	1.2 – 7.6	2.6	2.2 – 3.4	1.2	4.0	17	10
(-75,150)	B	25	11 – 35	2.3	0.8 – 7.6	0.7	0.6 – 0.9	0.9	1.6	9	6
(0,50)	C	33	26 – 40	18	11 – 28	2.3	1.9 – 3.0	0.2	1.6	67	18
(-50,100)	D	45	30 – 68	3.3	1.7 – 6.3	2.2	1.6 – 3.0	0.7	3.2	26	11
(75,50)	E	34	28 – 42	37	23 – 69	1.8	1.4 – 2.2	0.2	1.1	62	25
(50,75)	G	41	28 – 58	6.8	3.0 – 16	1.9	1.4 – 2.5	0.2	2.2	62	14
(-50,100)	H	33	21 – 57	2.5	1.0 – 6.3	1.7	1.4 – 2.2	1.2	3.5	15	8

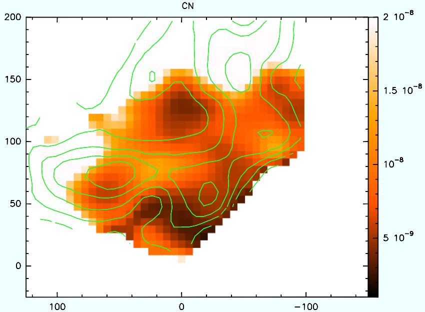
- T_k derived from CN is on average slightly higher that that derived from CS
- n_{H_2} derived from CN is higher that that derived from CS, and increases toward Pismis 24

Conclusion:

CN is indeed a good PDR tracer

LTE values completely different! Non-LTE analysis is fundamental to infer the physical properties of the gas from some molecules; the Bayesian approach is powerful for this

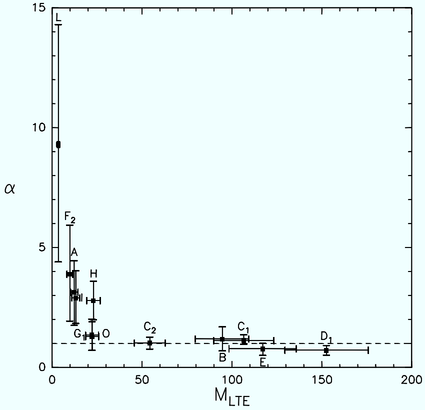
CN Abundance



Colours scale: molecular abundance; Contours: Column density

- Similar pattern for the abundance as the other molecules
- $[CN/H_2]$: $5.0 - 7.9 \times 10^{-9}$
- Smaller variation w.r.t. the other molecules: corroborates the idea that most of its emission comes from the PDR

A (simple) Stability Analysis



- $\alpha \equiv M_{vir}/M_{LTE}$
- No magnetic or rotational support
- For $M \gtrsim 50\ \mathrm{M}_{\odot}$, $\alpha \sim 1$

Selective Photodissociation

Radiation field G_0:

$$G_0 = \frac{1}{1.6 \times 10^{-3} \mathrm{erg\ cm^{-2}\ s^{-1}}} \frac{L}{4\pi D^2}$$

Considering the luminosity of the three most luminous stars (2 O3.5, 1 O4):

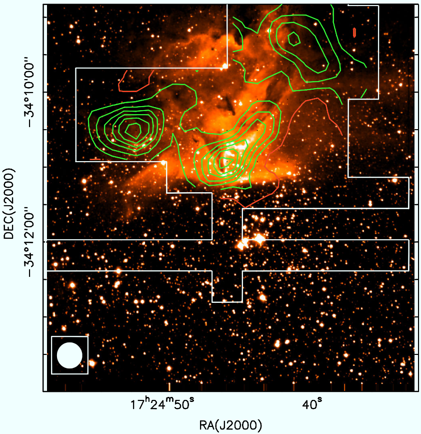
- $G_0 \sim 5.6 \times 10^4$ at the location of the elephant trunk
- $G_0 \sim 2.0 \times 10^4$ at the location of the IF
- Relative $^{13}CO/C^{18}O$ abundance in agreement with the PDR models for the regions near the IF
- The measured $^{13}CO/C^{18}O$ can be explained in terms of selective photodissociation

Summary

- Gas temperature between $\sim 10 - 50\ \mathrm{K}$
- The gas appears already fragmented at these low angular resolution
- Obtained abundance maps: molecular abundances decrease toward the IF
- n_{H_2} between $\sim 10^3\ \mathrm{cm}^{-3}$ ($C^{18}O$) and $\sim 10^{5-6}\ \mathrm{cm}^{-3}$ (CS and CN) increasing toward the IF
- CN is indeed an efficient PDR tracer
- Non-LTE analysis is fundamental to infer the physical properties of the gas
- The Bayesian approach is extremely powerful for this
- Clumps with masses $M \gtrsim 50\mathrm{M}_\odot$ appear to be gravitationally bound
- Selective photodissociation decrease the $C^{18}O$ abundance w.r.t. that of ^{13}CO, near the IF

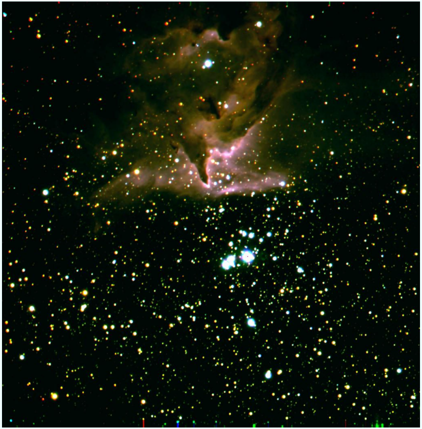
EVLA NH_3(1,1) and (2,2) Observations

Sofl K_s band + CS(5−4)



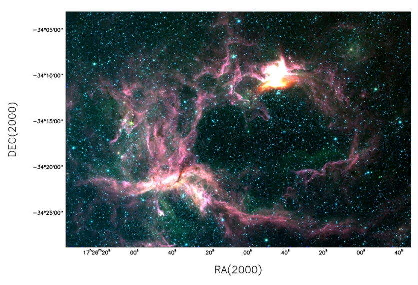
- Efficient tracer of dense gas
- High sensitivity and angular resolution ($\theta \sim 1''$, CnB)
- Study of the fragmentation along and across the PDR
- Investigate the small-scale, ordered motions of and in the clumps
- Evaluate the impact of embedded, newly formed stars

NIR (J, H, K_s) RGB image



- Submitted proposal for ALMA cycle 0
- Multiple transitions from several molecules (H_2CO, CCH, SiO, CO isotopologues, etc.)
- Aim: study the chemical stratification along and across the PDR

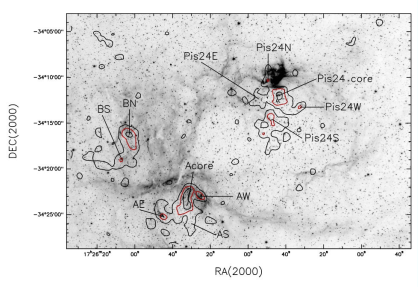
Spitzer IRAC



Massi, Beltrán, Brand, Giannetti et al., in prep.

- Apparently 3 more clusters in the complex
- Pismis 24 has a Salpeter IMF
- YSOs identification in the whole region with IRAC color-color diagrams
- G353.2+0.9: Study of the YSOs in J, H, K, 4 IRAC bands and X

Spitzer IRAC



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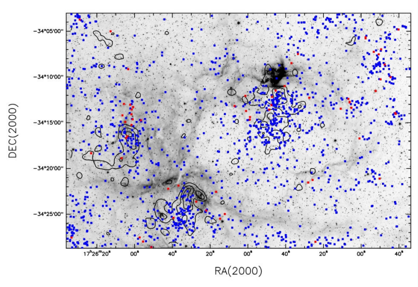

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Probability:

$$P(T_k, N_{mol}, n_{H_2}|\mathrm{data}) = \phi P(\mathrm{data}|T_k, N_{mol}, n_{H_2}) P(T_k, N_{mol}, n_{H_2})$$

CS:

$$P(data|T_{\mathrm{K}}, N_{mol}, n_{H_2}) = \frac{1}{\varphi}\left[\prod_{i=1}^{4}(\mathrm{e}^{-(\mathrm{l_i}-\mu_{\mathrm{i}})^2/(2\sigma^2_{\mathrm{l,i}})})\right] P(\tau_{\mathrm{C^{34}S}}),$$

CN:

$$P(data|T_{\mathrm{K}}, N_{mol}, n_{H_2}) = \frac{1}{\varphi}\left[\prod_{i=1}^{2}(\mathrm{e}^{-(\mathrm{F_i}-\mathrm{F_{m,i}})^2/(2\sigma^2_{\mathrm{F,i}})})\right] \mathrm{e}^{-(\tau_{\mathrm{tot},(1-0)}-\tau_{\mathrm{m},(1-0)})/(2\sigma^2_{\tau})},$$