Molecular multi-line and dust continuum studies of high mass star forming regions

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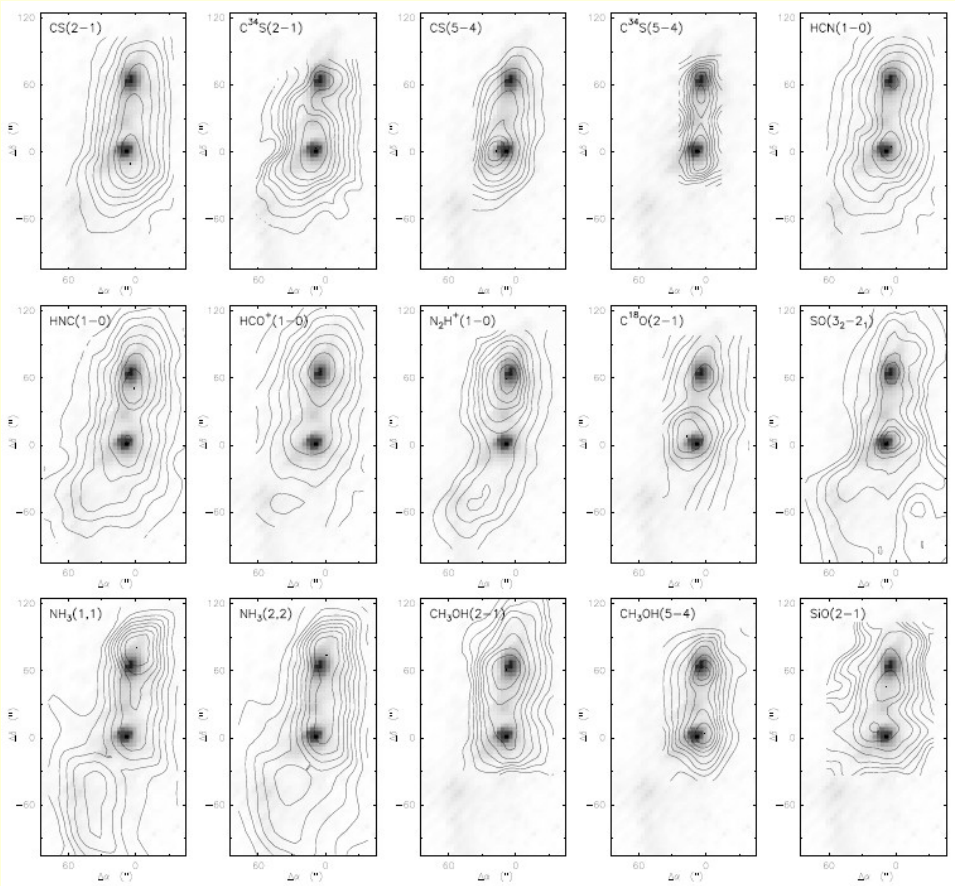
Introduction

- High mass star formation attracts an enhanced attention nowadays due to many unsolved problems related to this process.
- In recent years we surveyed several tens of high mass star forming regions in various molecular lines (HCN, HCO^+, CS, $C^{18}O$, NH_3, HNCO, SO, N_2H^+, etc.) and in dust continuum emission (Zinchenko et al. 1995, 1998, 2000; Pirogov 1999; Pirogov et al. 2003, 2007). However, many other lines were observed simultaneously during some of these surveys.
- Selected sources have been observed in other lines including $H^{13}CN$, $H^{13}CO^+$, HNC, $HN^{13}C$, CH_3OH, SiO, CH_3C_2H, etc.
- As a result of these observations basic physical and chemical properties of dense cores in these regions were derived and their statistical properties were analyzed (e.g. Zinchenko et al. 2005). Here we outline the main findings of these studies and present some new results including possible new molecular detections, unusual spectral features, galactic gradients, etc.

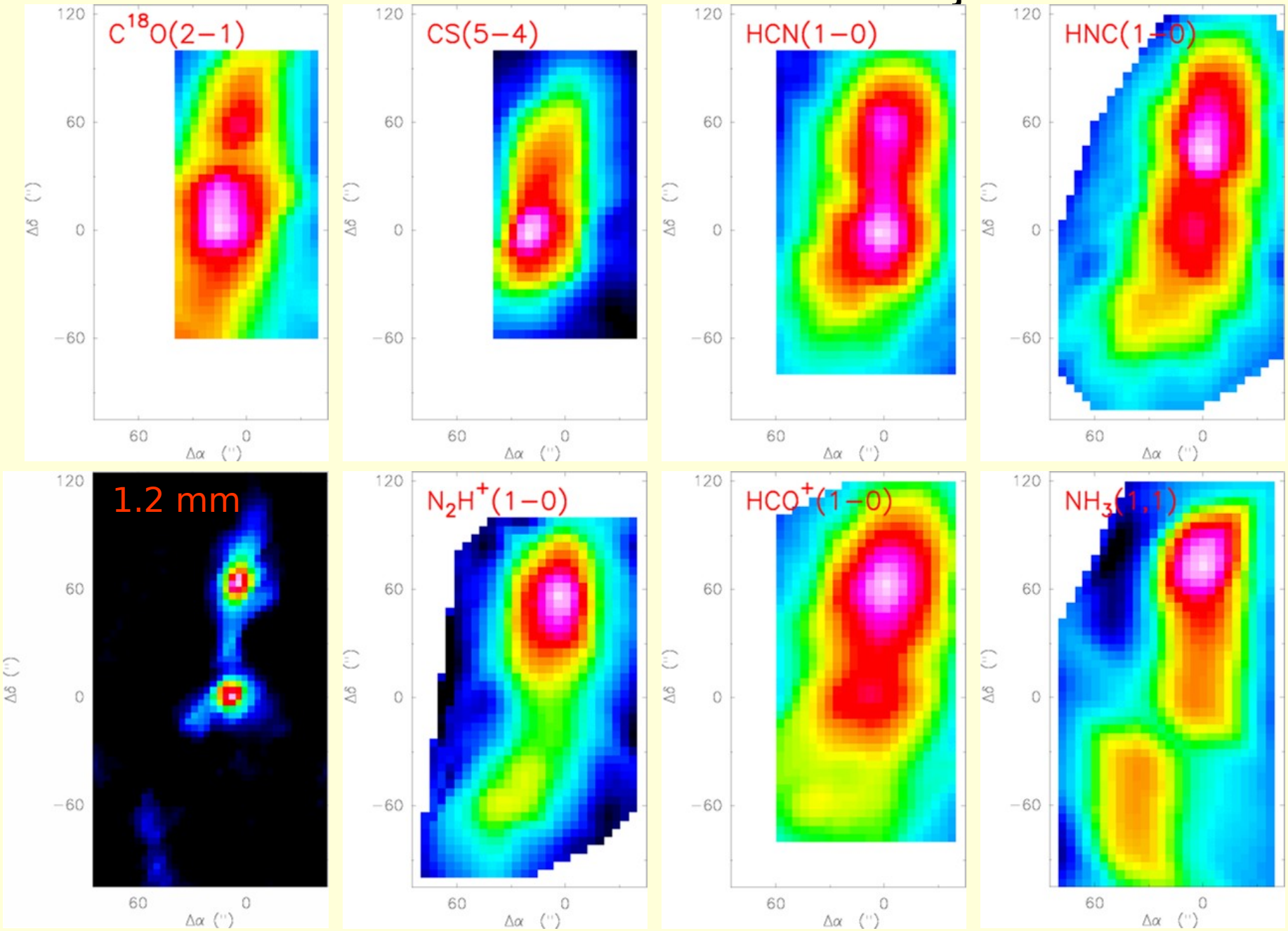
Chemical variations



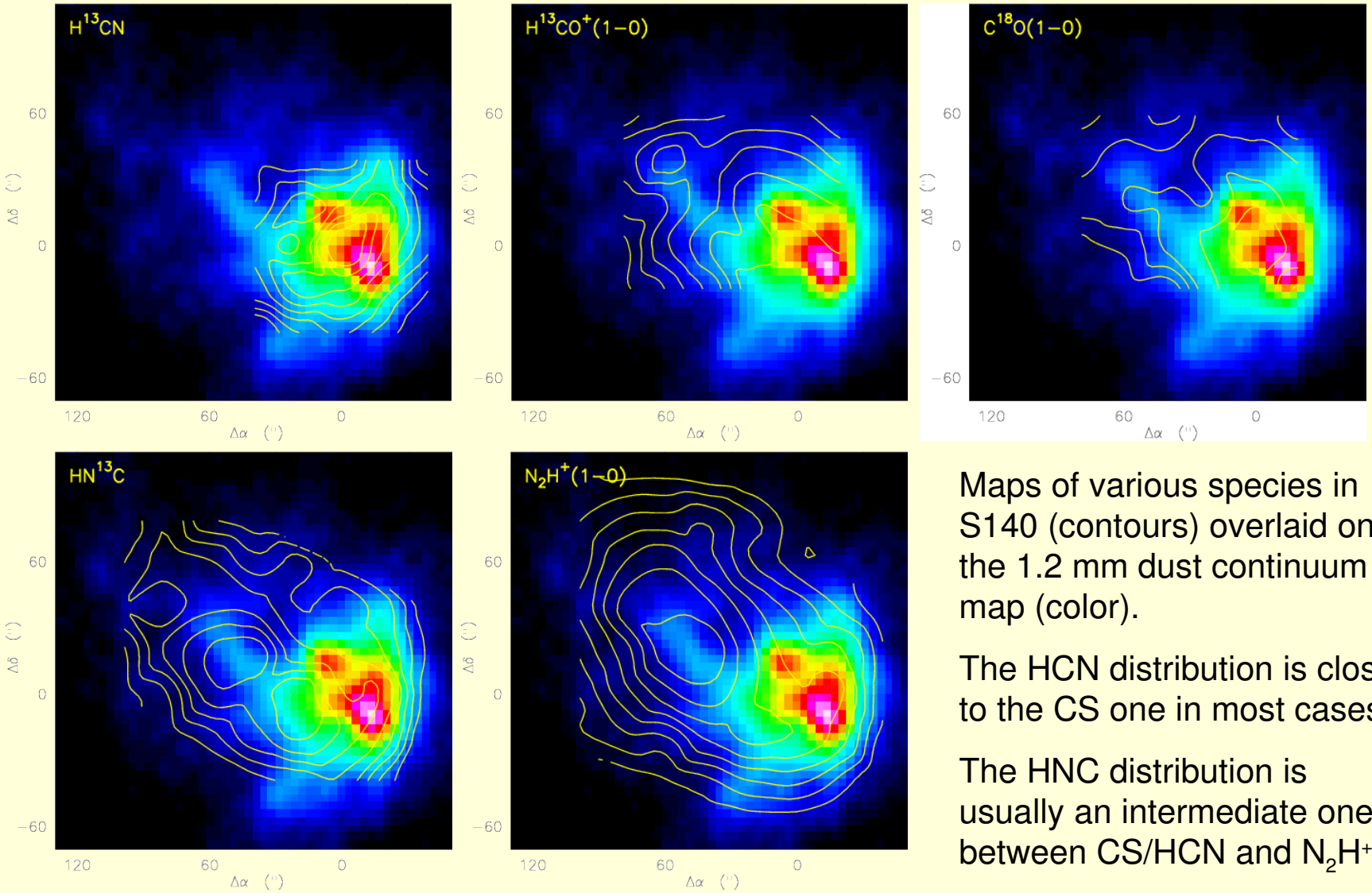
Maps of S255 in various molecular lines overlaid on the dust continuum image

- One of the findings of our surveys was a significant chemical differentiation in HMSF regions.
- CS, HCN, $C^{18}O$ and some other molecules trace well the total mass distribution outlined by the dust emission while N_2H^+ abundance in many cases drops towards the peaks of the CS/dust emission (Pirogov et al. 2007). A similar effect is observed in HNC.
- The proposed explanations for this behavior involve an accelerated collapse model (Lintott et al. 2005) and variations of the ionization fraction.

Multi-line observations of selected objects: S255



Chemical variations



Maps of various species in S140 (contours) overlaid on the 1.2 mm dust continuum map (color).

The HCN distribution is close to the CS one in most cases.

The HNC distribution is usually an intermediate one between CS/HCN and N_2H^+.

Abundances

	$C^{18}O$ $\times 10^{7}$	$C^{34}S$ $\times 10^{10}$	N_2H^+ $\times 10^{10}$	$H^{13}CN$ $\times 10^{10}$	$H^{13}CO^+$ $\times 10^{10}$	$HN^{13}C$ $\times 10^{10}$
CS peaks	~ 1	~ 5	~ 0.3-3	~ 1	~ 0.6	~ 0.3
N_2H^+ peaks	~ 1	~ 5	~5	~ 1	~ 1	~ 1

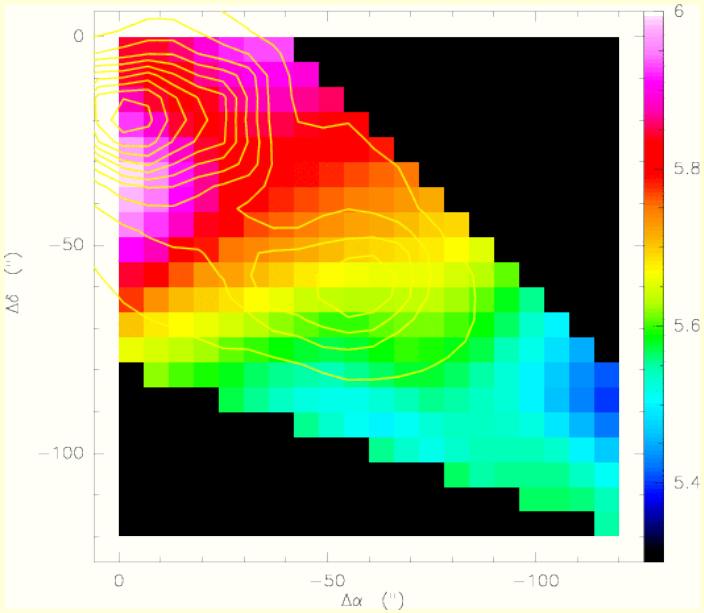
- The CS relative abundance is more or less constant. There is no sign of CS or CO freeze-out.
- The N_2H^+ relative abundance is ~ $5 \cdot 10^{-10}$ towards the N_2H^+ peaks and drops to ~ $0.3 \cdot 10^{-10}$ towards the CS/dust peaks in some sources.
- The HNC behavior resembles that of N_2H^+.
- The HCO^+ abundance also decreases towards the CS/dust peaks.

Temperatures from CH_3C_2H observations

CH_3CCH J = 6–5 transitions were observed at Onsala towards "CS" and "N_2H^+" peaks in several sources.
The J=13-12 transitions were observed at IRAM 30m.

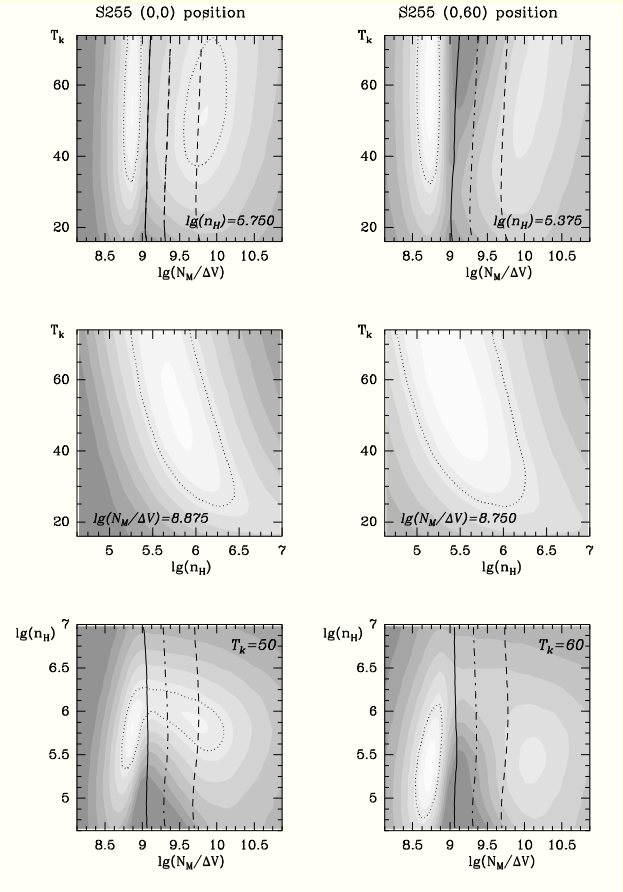
Source	Peak	T_{kin}^{6-5}	T_{kin}^{13-12}
W3	"CS"	52.6 ± 3.1	58.4 ± 1.5
	"N_2H^+"	30.7 ± 0.8	37.3 ± 2.2
DR21(NH_3)	"CS"	33.3 ± 2.6	44.0 ± 1.4
	"N_2H^+"	28.8 ± 0.1	34.8 ± 1.1
S140	"CS"	30.6 ± 0.7	42.4 ± 1.0
	"N_2H^+"	27.8 ± 1.6	37.7 ± 2.2
S255	"CS"	34.5 ± 1.0	38.8 ± 0.9
	"N_2H^+"	34.9 ± 1.4	39.6 ± 0.4

Density variations



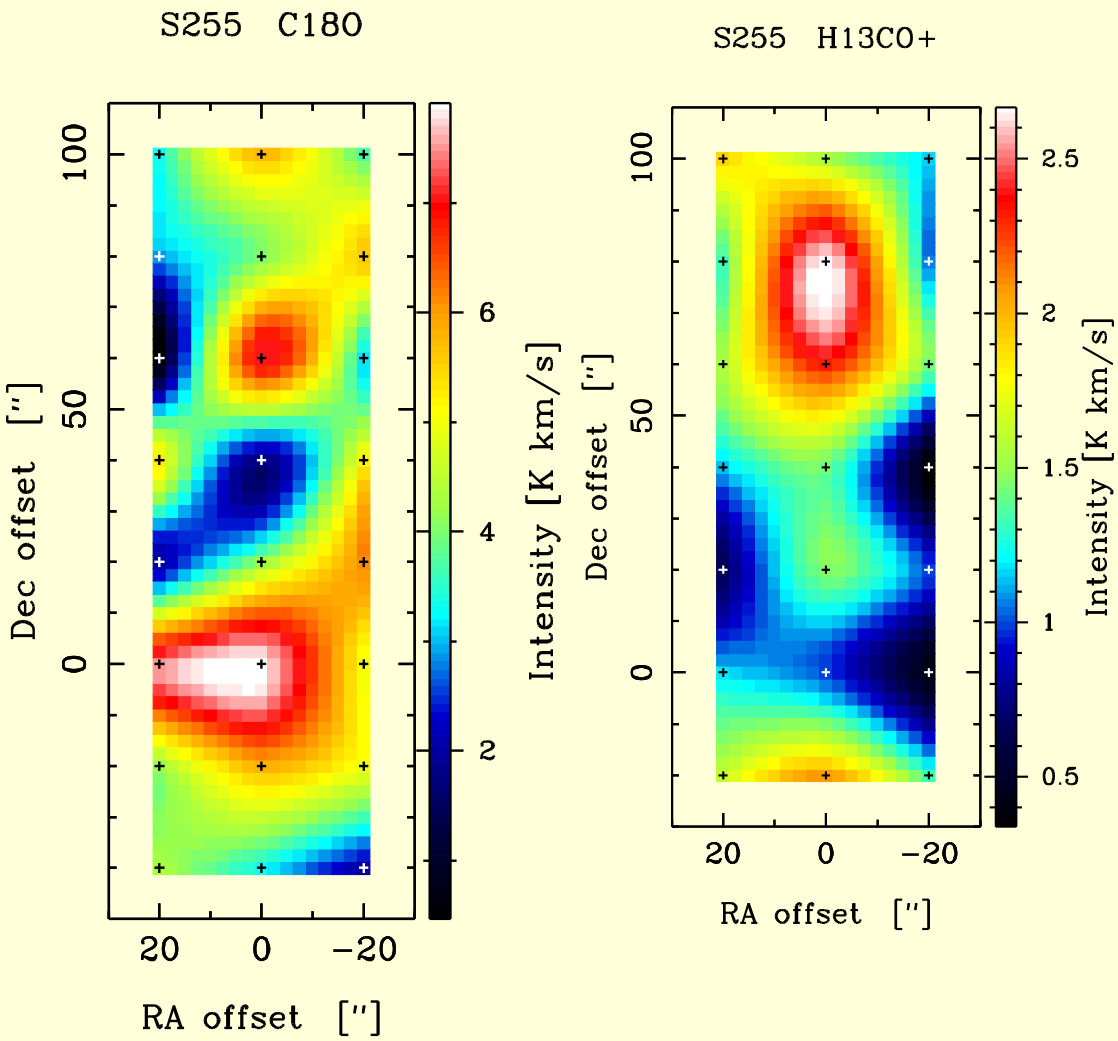
An example of LVG density estimates (in G285.26-0.05) based on CS J=5-4 and J=2-1 data. The yellow contours represent the CS(5-4) map.

Typical LVG gas densities towards the CS peaks are ~ 10^6 cm^{-3}. The densities towards the N_2H^+ peaks are ~ 2 times lower.



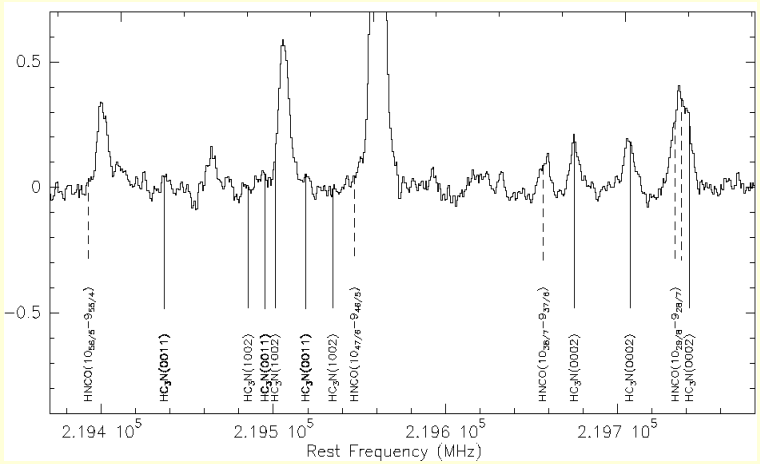
Estimates of S255 parameters from CH_3OH 2-1 and 5-4 series of transitions (S. Salii et al.)

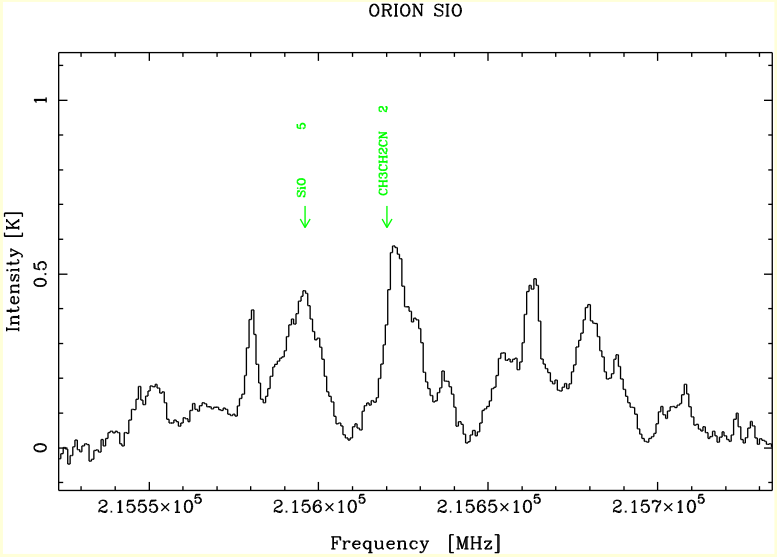
Ionization fraction



- The ionization fraction can be derived from the HCO^+/CO and DCO^+/HCO^+ ratios (e.g. Bergin et al. 1999).
- The second one is very low in our sample and we estimated the HCO^+/CO ratio from $H^{13}CO^+$(1-0) and $C^{18}O$(1-0) observations in several sources.
- Significant variations of this ratio were observed which indicate significant variations of the ionization fraction.

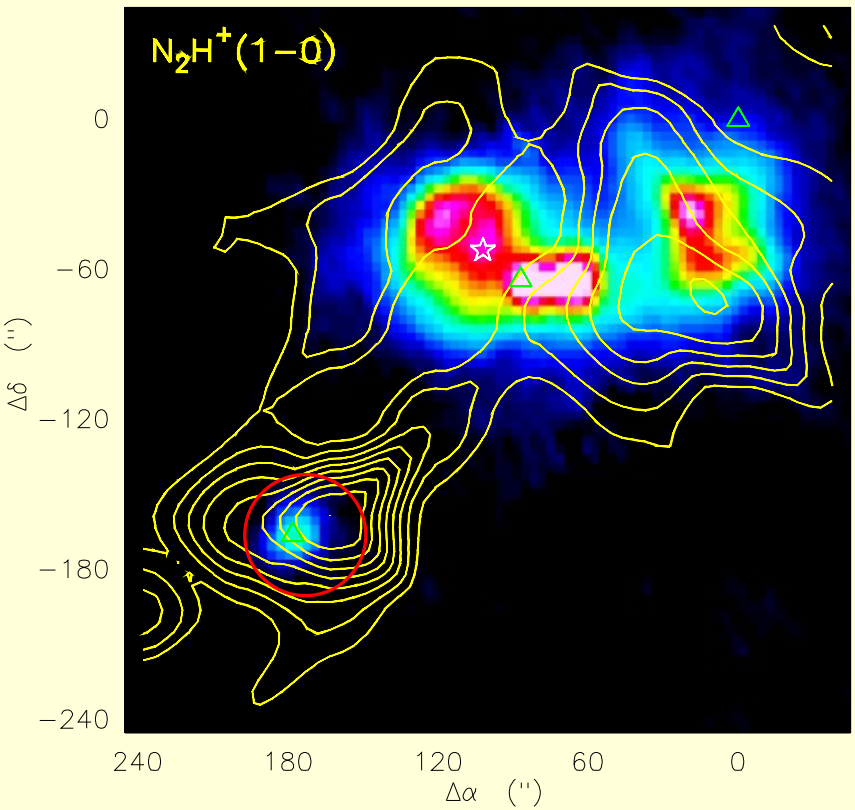
Hot cores (seen in high excitation lines)

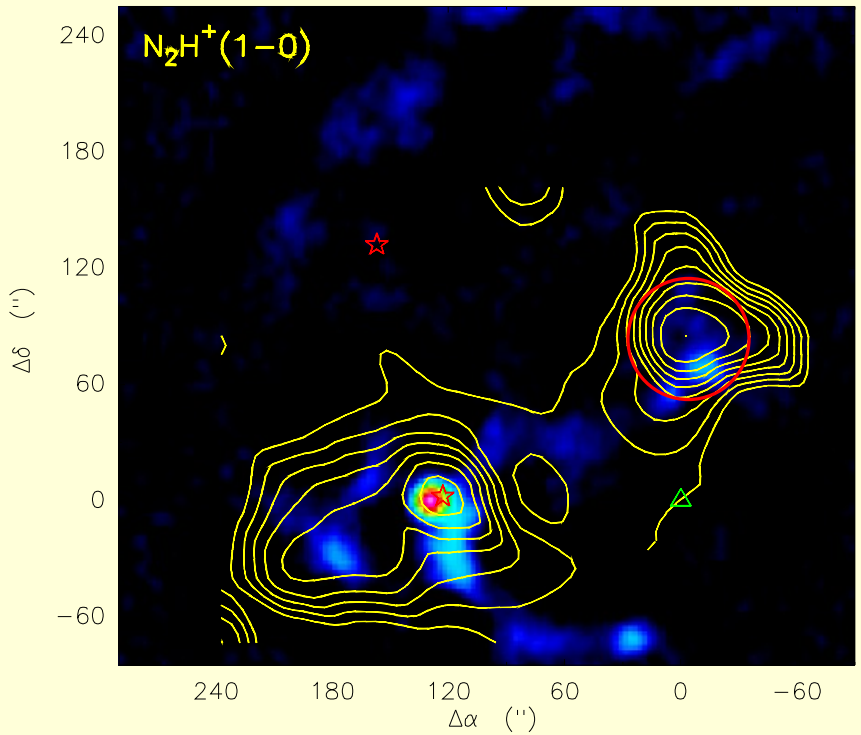




- Some of the lines detected during the surveys correspond to high excitation molecular transitions.
- In particular lines of vibrationally excited HC_3N with excitation energy up to ~ 1000 K were detected in G351.78-0.54. However, this is the only such source in our sample (except Orion) which shows that this phenomenon is rather rare in this sample.
- In Orion in addition to these lines the vibrationally excited SiO J=5-4 (v=1) line is probably seen (*E* ~ 1800 K). Earlier we reported also HNCO lines with the excitation energies ~ 1300 K (Zinchenko et al. 2000).

Chemical signatures of massive protostars?

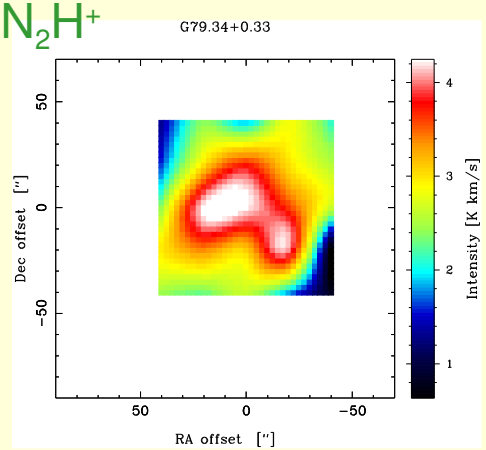


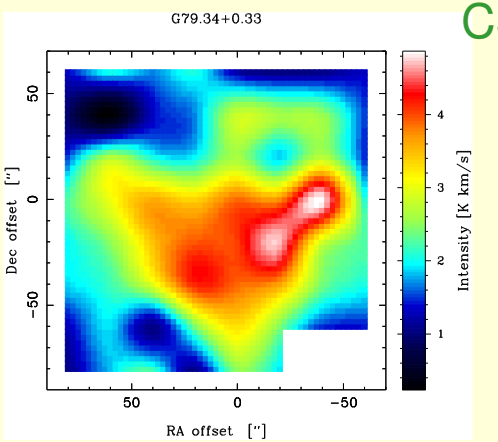


N_2H^+ seems to be a good indicator of the earliest phases of massive star formation

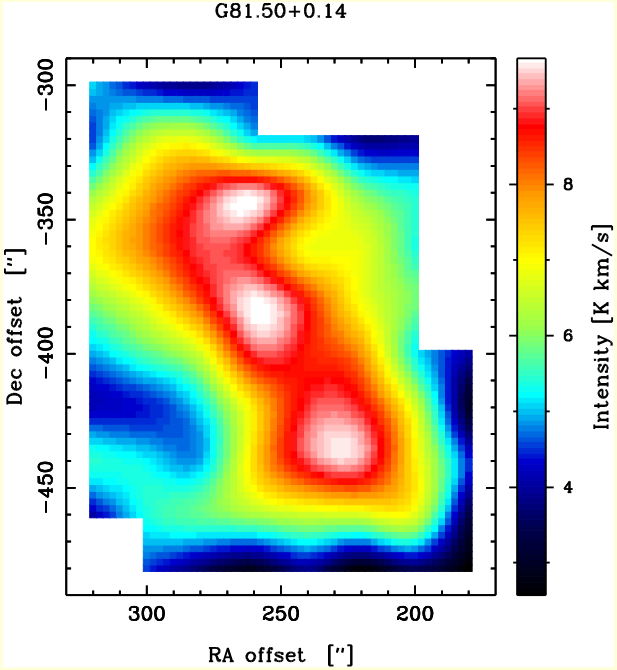
High density tracers in IRDC

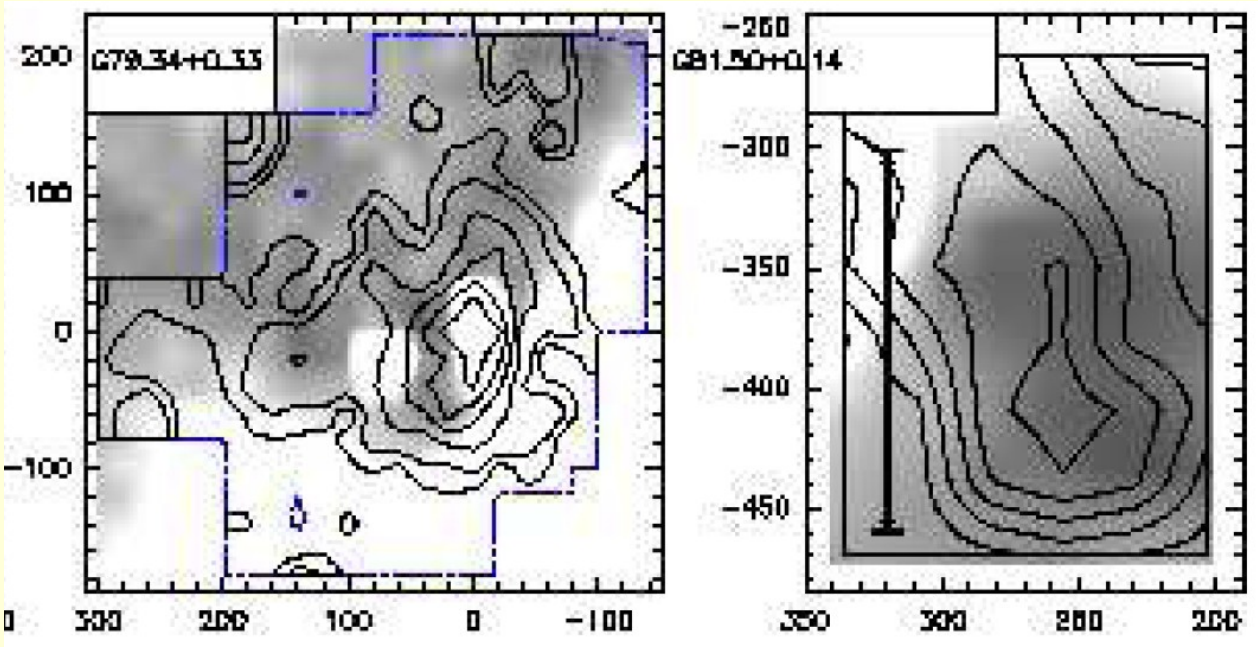
N_2H^+





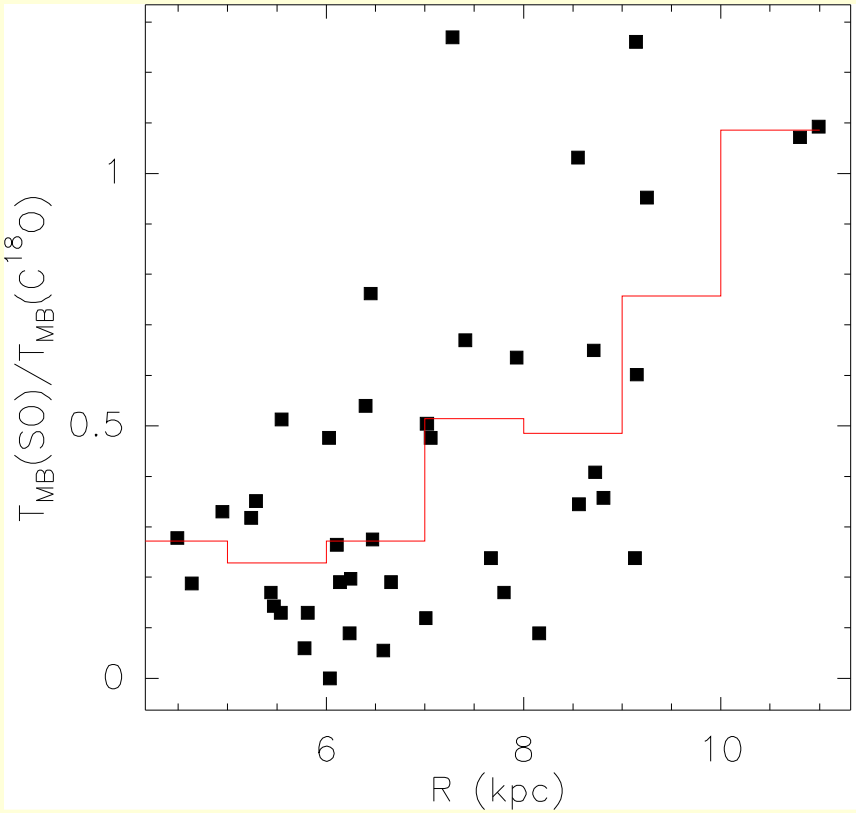
CS





NH_3 (from Pillai et al. 2006)

Galactic gradients



- Earlier we reported a possible gradient of the mean density of dense cores along the galactic radius (Zinchenko et al. 1998).
- An analysis of the simultaneous SO and $C^{18}O$ observations at 1.3 mm shows that the ratio of the line intensities varies significantly with the galactocentric radius R_g. A similar (although weaker) trend is seen in the SO/CS ratio. These gradients can be influenced by excitation effects.
- It is known that these abundance ratios are sensitive to the evolutionary status (increasing with the age) and to the initial C/O ratio. The observed gradients may indicate their variation with R_g.

Publications

- Lintott, C. J.; Viti, S.; Rawlings, J. M. C.; Williams, D. A.; Hartquist, T. W.; Caselli, P.; Zinchenko, I.; Myers, P. Molecular Abundance Ratios as a Tracer of Accelerated Collapse in Regions of High-Mass Star Formation. ApJ 620, 795-799 (2005)
- Pirogov, L. J=1-0 HCN toward bright far-infrared sources in the outer Galaxy. A&A 348, 600-613 (1999)
- Pirogov, L.; Zinchenko, I.; Caselli, P.; Johansson, L. E. B.; Myers, P. C. N2H+(1-0) survey of massive molecular cloud cores. A&A 405, 639-654 (2003)
- Pirogov, L.; Zinchenko, I.; Caselli, P.; Johansson, L. E. B. Chemical differentiation in regions of high-mass star formation. CS, dust, and N2H+ in southern sources. A&A 461, 523-535 (2007)
- Troitsky, N. R.; Pirogov, L. E.; Zinchenko, I. I.; Yang, J. Survey of the Star-Formation Regions Associated with Infrared Sources Observed in the J = 1-0 Line of the CO Molecule and Its Isotopes. Radiophysics and Quantum Electronics 48, 491-499 (2005)
- Zinchenko, I.; Mattila, K.; Toriseva, M. Studies of dense molecular cores in regions of massive star formation. II. CS J=2-1 survey of southern H2O masers in the longitude range l=260-310deg. A&A Suppl. 111, 95 (1995)
- Zinchenko, I.; Henning, Th.; Schreyer, K. Studies of dense cores in regions of massive star formation. V. Structure and kinematics of dense cores from ammonia observations. A&A Suppl. 124 385-395 (1997)
- Zinchenko, I.; Pirogov, L.; Toriseva, M. Studies of dense molecular cores in regions of massive star formation. VII. Core properties on the galactic scale. A&A Suppl. 133, 337-352 (1998)
- Zinchenko, I.; Henkel, C.; Mao, R. Q. HNCO in massive galactic dense cores. A&A 361, 1079-1094 (2000)
- Zinchenko, Igor; Pirogov, Lev; Caselli, Paola; Johansson, Lars E. B.; Malafeev, Sergey; Turner, Barry Physical and chemical structure of dense cores in regions of high mass star formation. Massive star birth: A crossroads of Astrophysics, IAU Symposium Proceedings of the IAU 227, Held 16-20 May, Italy, edited by Cesaroni, R.; Felli, M.; Churchwell, E.; Walmsley, M. Cambridge: Cambridge University Press, 2005., pp.92-97