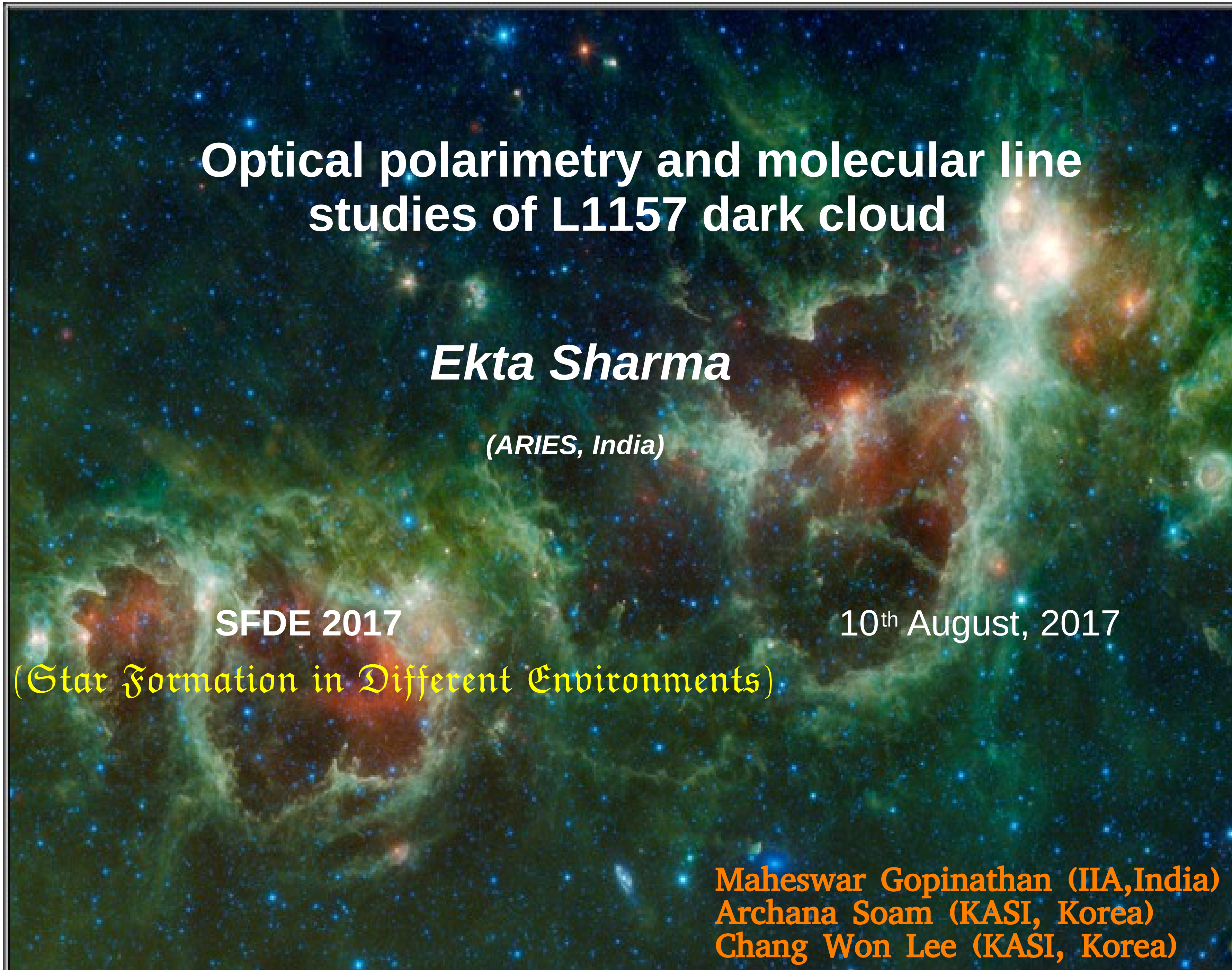

Optical polarimetry and molecular line studies of L1157 dark cloud

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Image credit : WISE

Outline of my Talk

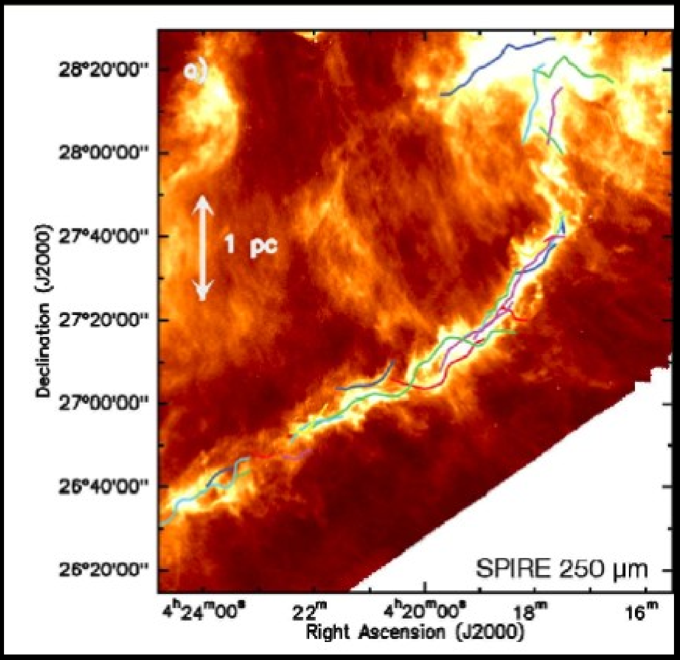
- ***Introduction***
  - ***Magnetic field***
  - ***Molecular lines***

- ***Polarimetric observations***
- ***Results***

- ***Molecular line studies***
- ***Line Parameters***
- ***Conclusion***

Introduction

- **Molecular clouds are dense regions in the Interstellar medium where the gas is primarily molecular. Typical temperature is around 10-15K.**
- **Herschel has revealed that the all ISM is of filamentary morphology which are ubiquitous.**
- **Exploring the clumpy and filamentary structures of molecular clouds is one of the key problems in modern astrophysics . So far, we have acquired limited knowledge of the processes that cause this physical structure.**



Andre et al. 2010

Key questions??

Why Magnetic fields???

How magnetic fields are exerting forces on the filament???

How they are aligned with the outflow axis?

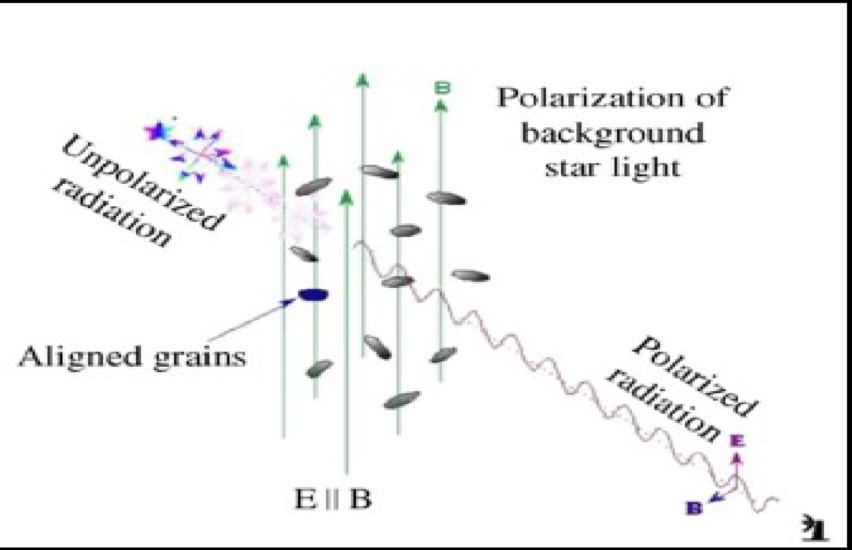
Why kinematics ???

If the collapse is taking place through filamentary structure, what is causing the condensations at different places so that the protostar formation is taking place?

Need to know the velocity structure along the filament!!

Probe for magnetic field ??

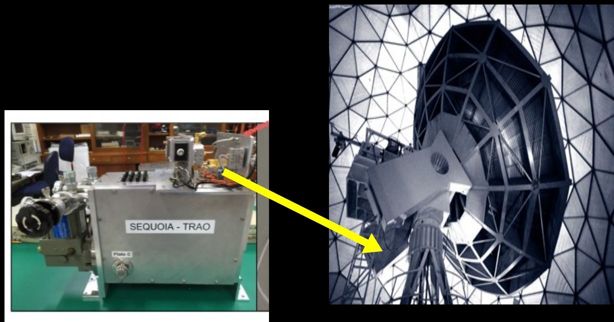
- *At different extinction scales, different probes of magnetic field are used.*
- *In outer parts of the cloud , (A_v~1-2 mag), optical polarimetry is used to determine the direction of B-field.*



Lazarian 2007

Polarisation is caused by the selective extinction of the light as it passes through elongated dust grains.

Dust grains are aligned with their minor axis parallel to the local magnetic fields of the cloud.

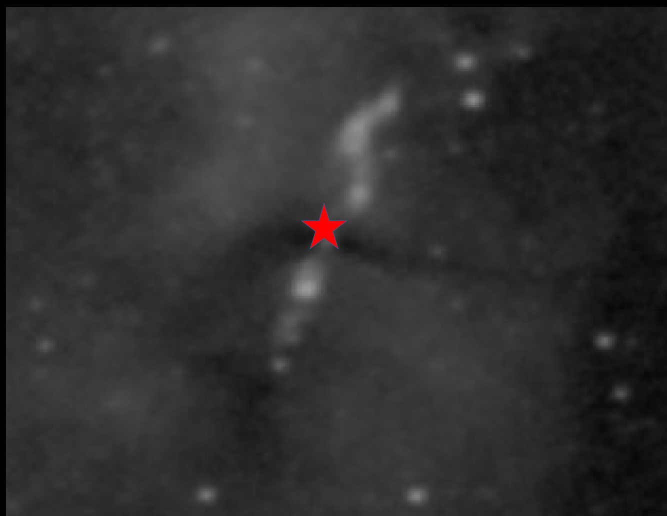


Observations

- Molecular line studies have been done using 13.7 m TRAO (Taeudek Radio Astrophysical Observatory) using SEQUOIA as back end instrument using OTF (On the Fly) technique.
- Velocity and spatial resolution used are 0.12 km/s and 44” respectively.
- ^{12}CO, ^{13}CO, $C^{18}O$, HCO^+, N_2H^+ (J=1-0) transitions have been observed towards l1157 cloud.

- Optical polarimetric observations have been done using Aries Imaging Polarimeter (AIMPOL). Field of View (FOV) is 4 arcmin.
- half wave plate, modulator and Wollaston Prism beam splitter. HWP is rotated at four different angles of 0°, 22.5°, 45°, 67.5°.
- R_{kc} filter : 0.76 μm (Efficiency : 63%)
- Standard IRAF were used to reduce and analyse the data.

LDN 1157



WISE 11um: skyview

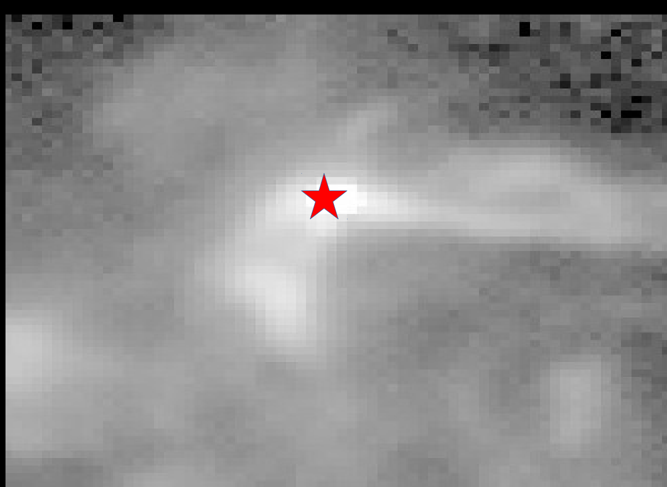


Image credit: Herschel

- It has a class 0 protostar- youngest of all the sources with bipolar outflow ejecting out from it. Protostar with low luminosity ~11 $L_{\odot}$ (*Gueth et al. 1997)*
- Spatial extent of outflow ~ 5' (0.6 pc) *(Umemoto et al. 1992)*
- Located in cepheus flare region, it is at a distance of 250 pc. *(Looney et al. 2007)*
- Inclination angle of bipolar outflow: 10° with respect to the plane-of-the-sky *(Gueth et al. 1996).*
- Position angle of outflow : 155°

Calculations for stokes parameters

Polarization is calculated in terms of four Stokes parameters: I, Q, U, V where I gives total intensity of light. Q and U explain the state of linearly polarized light. V shows circularly polarized state.

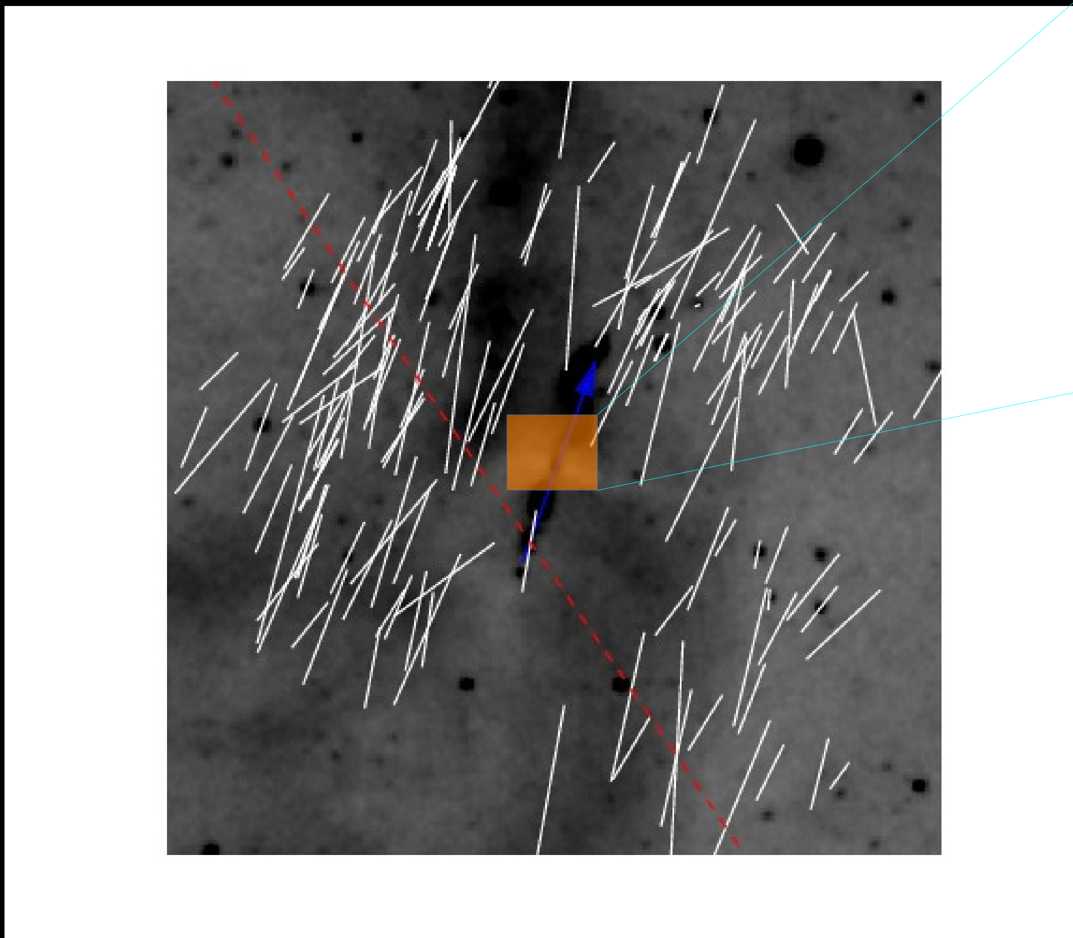
P and Ɵ are calculated from ordinary and extraordinary fluxes by standard aperture photometry using IRAF and IDL

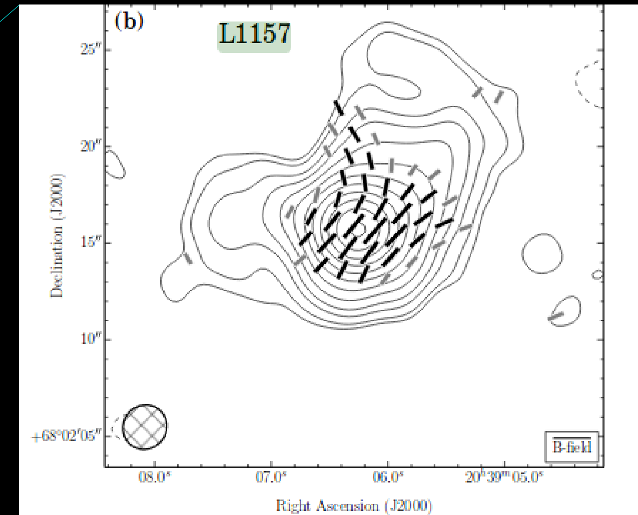
$$R(\alpha) = \frac{\frac{I_e(\alpha)}{I_o(\alpha)} - 1}{\frac{I_e(\alpha)}{I_o(\alpha)} + 1} = P \times \cos(2\theta - 4\alpha),$$

$$P = \mathrm{Sqrt}(q^2 + u^2)$$

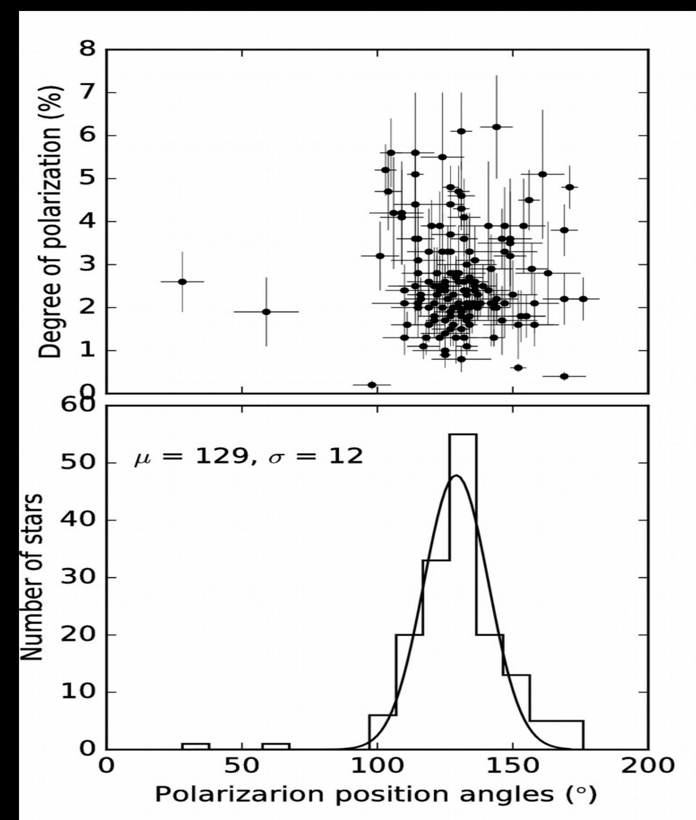
$$\Theta = 1/2 \tan^{-1}(u/q)$$

Results





Hull et al. 2014



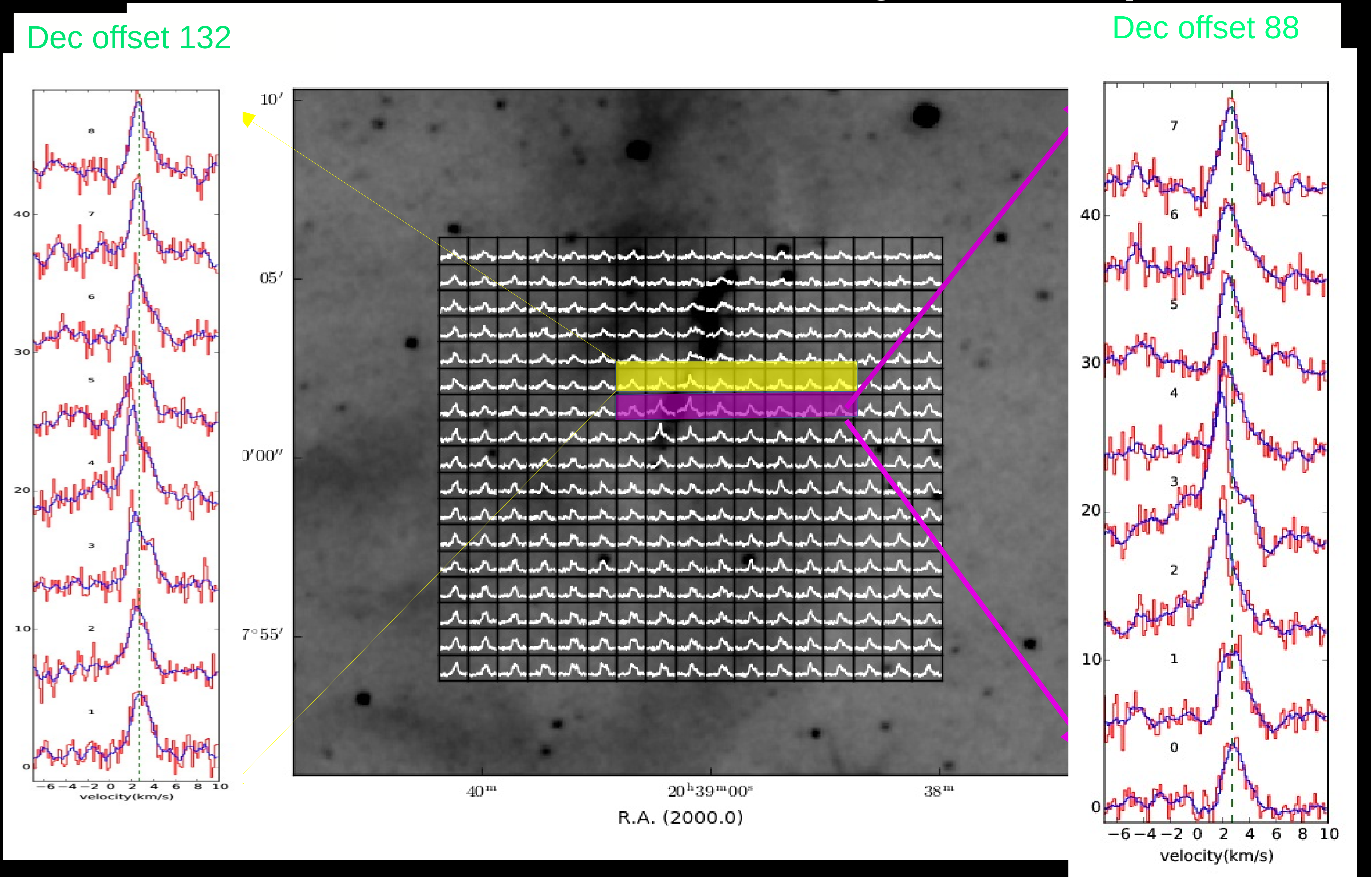
Mean value of polarization : 2.3%+0.1%

Mean polarization angle: 130º ± 12°

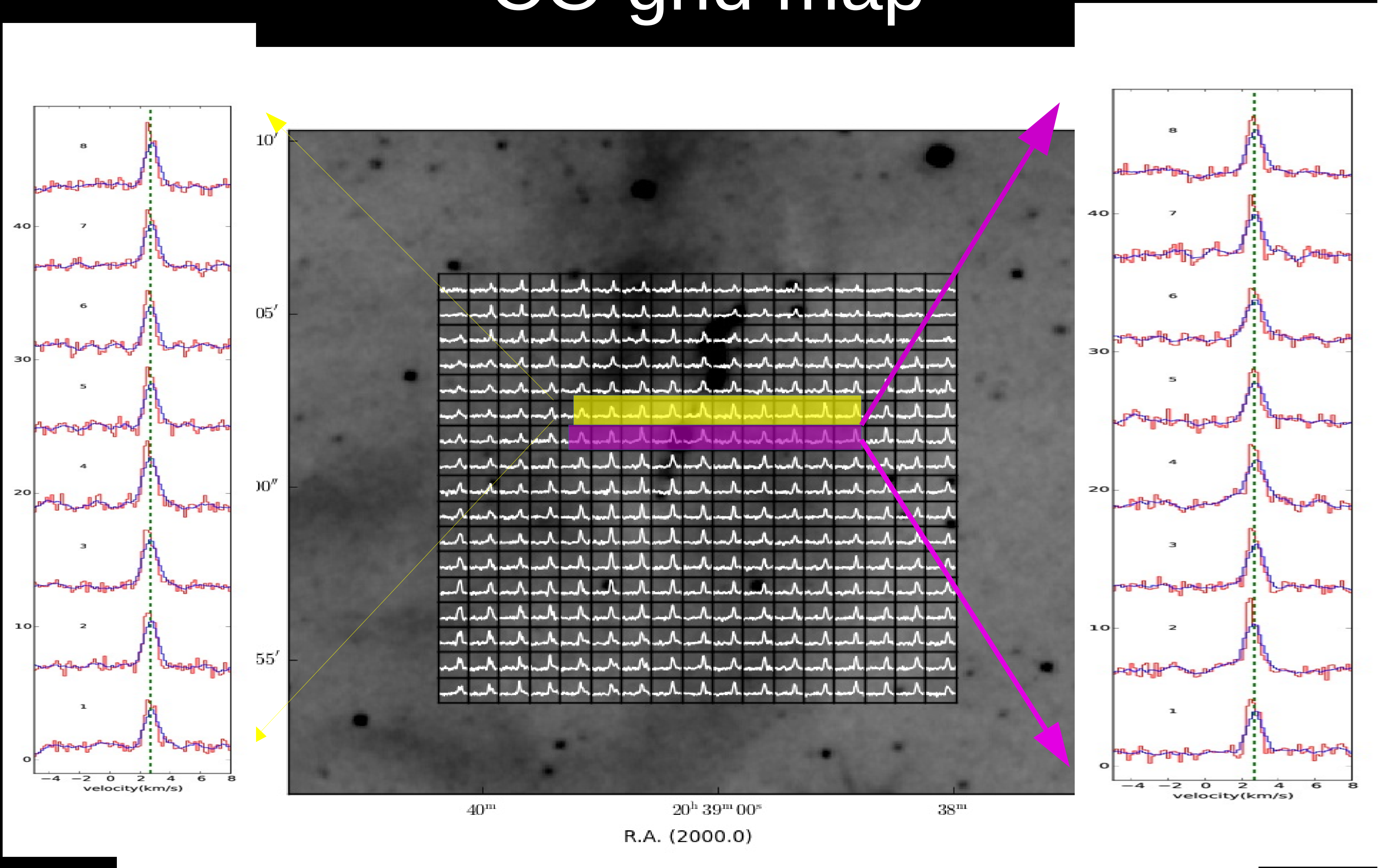
*Strength of magnetic field ~ **50 ± 10** uG*

(Chandrashekhar- Fermi method)

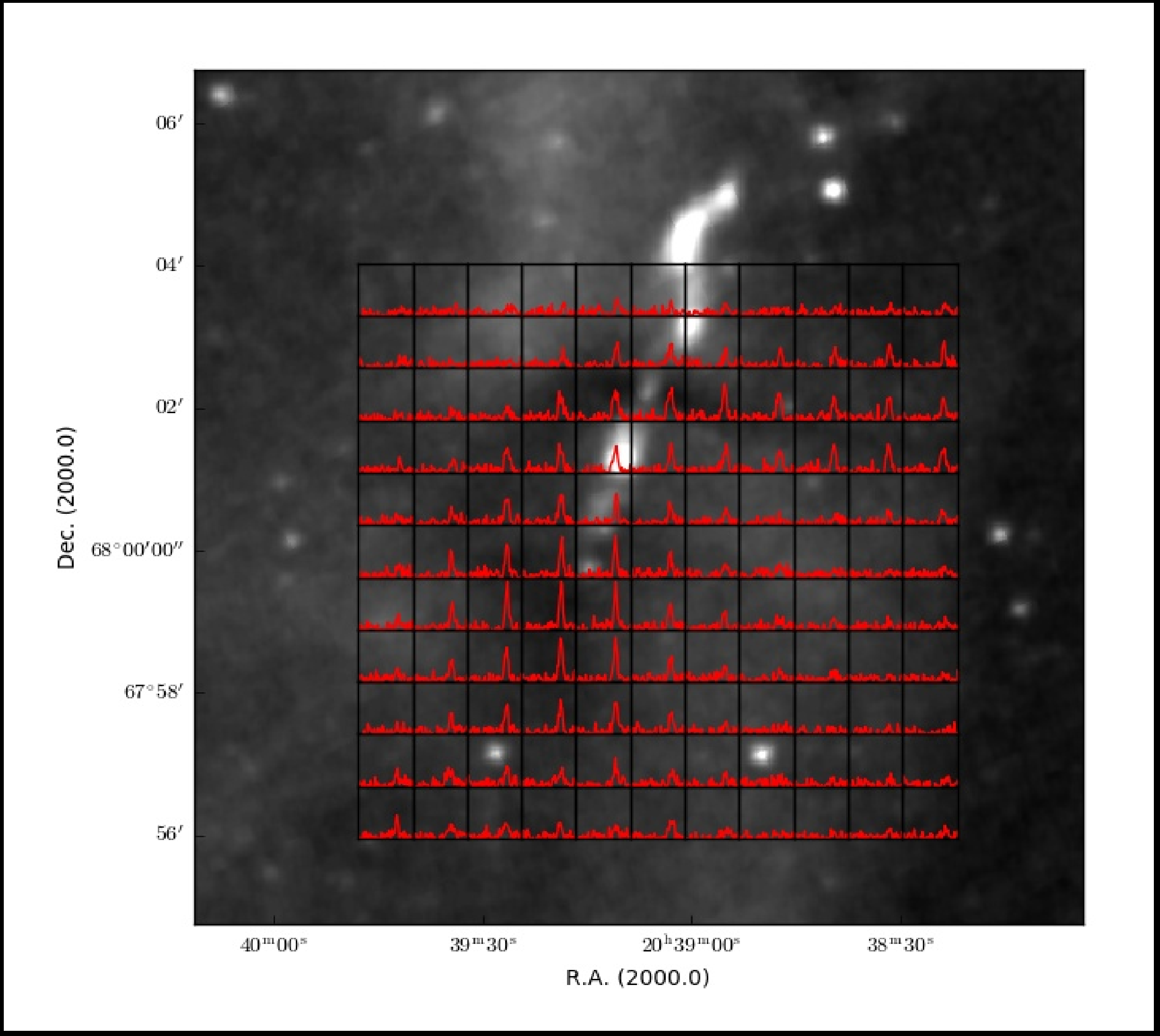
^{12}CO molecular line grid map



^{13}CO grid map

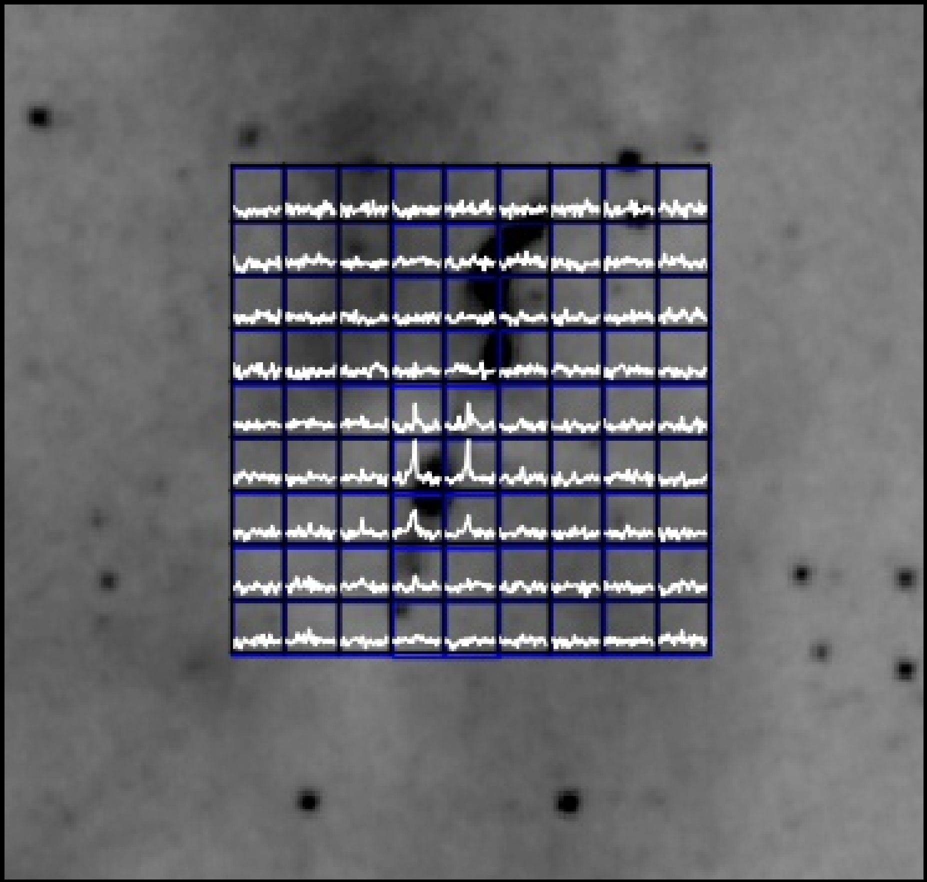


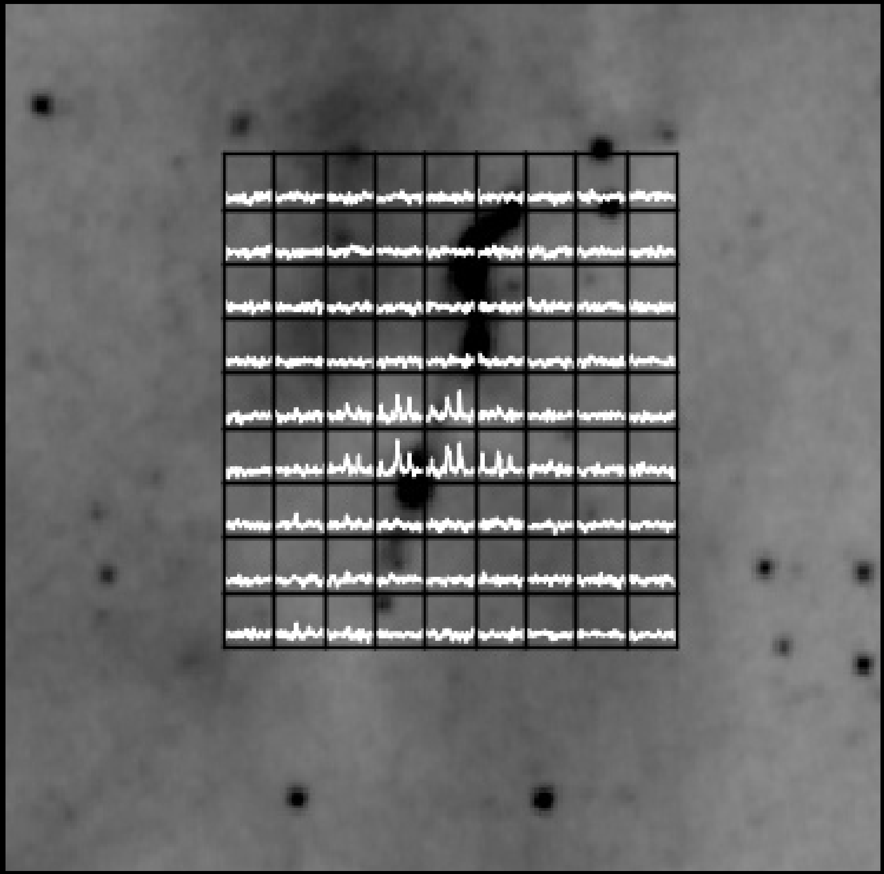
$C^{18}O$ grid map



- **Molecular line emission overplotted on WISE 0.22° X 0.22° image.**
- **The emission is completely gaussian with velocity width more than thermal width found in cold dark clouds.**
- **Tracing filamentary structure with single component of the cloud in its emission.**

Grid maps of HCO^+ & N_2H^+

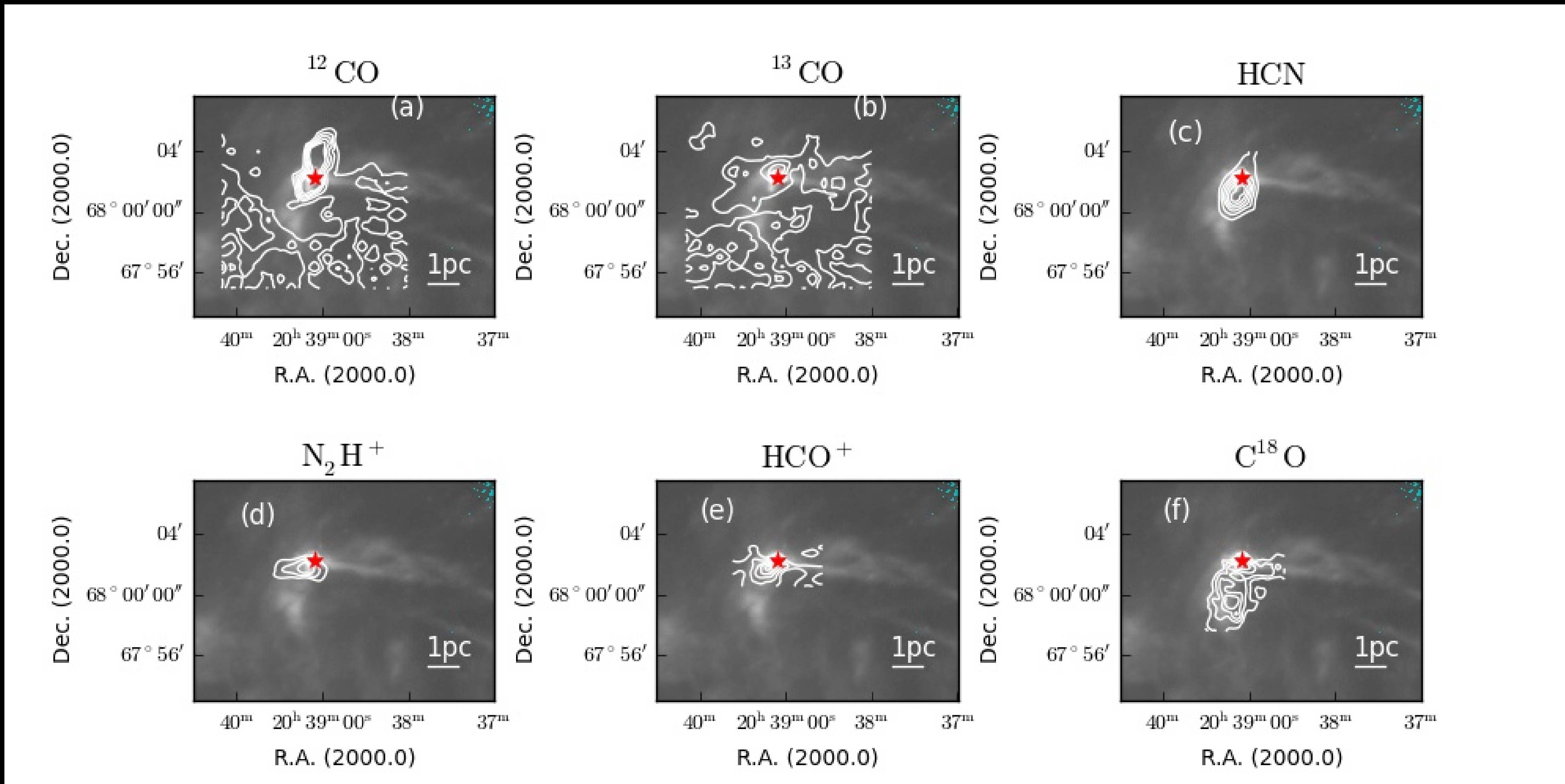




HCO^+ lines appear to be shifted towards bluer side in the regions of outflow regions.

N_2H^+ line shows 7 hyperfine structures. Hyperfine fitting has been done using CLASS routine and total optical depth of all the components have been calculated.

Integrated Intensity contours for observed molecular emission towards L1157 dark cloud



Contour levels: ^{12}CO: 5.65 K km/ to 11.79 K km/s (1.5 K km/s)

^{13}CO: 1.59 K km/s to 2.99 K km/s (0.5 K km/s)

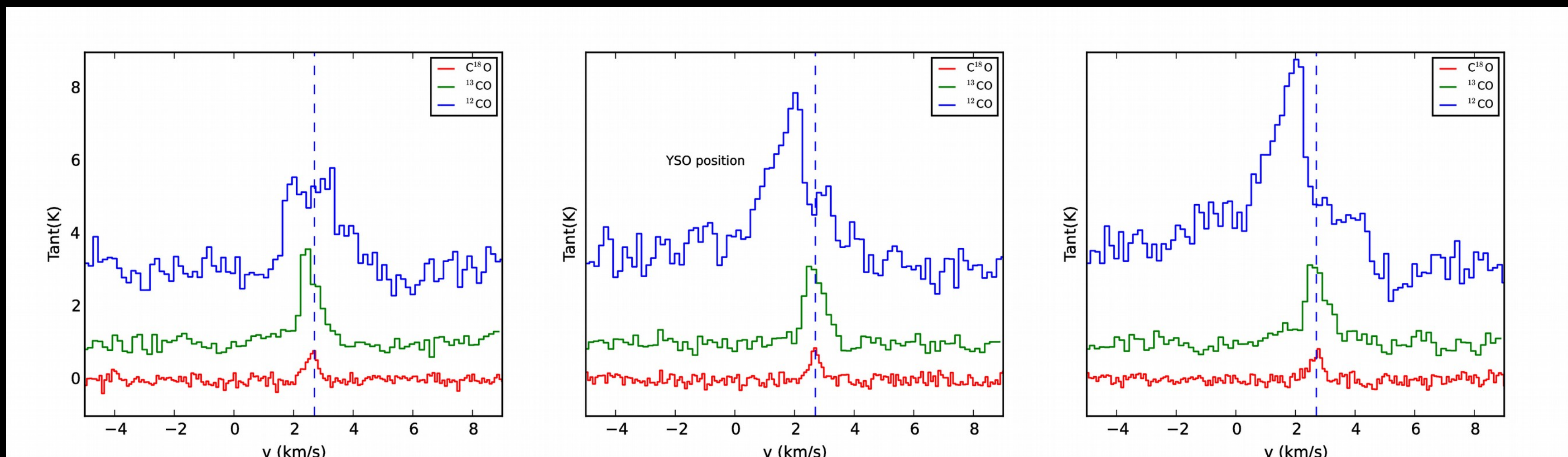
C^{18}O: 0.25 K km/s to 0.63 K km/s (0.1 K km/s)

HCN : 1.2 K km/s to 5.1 K km/s (0.8 K km/s)

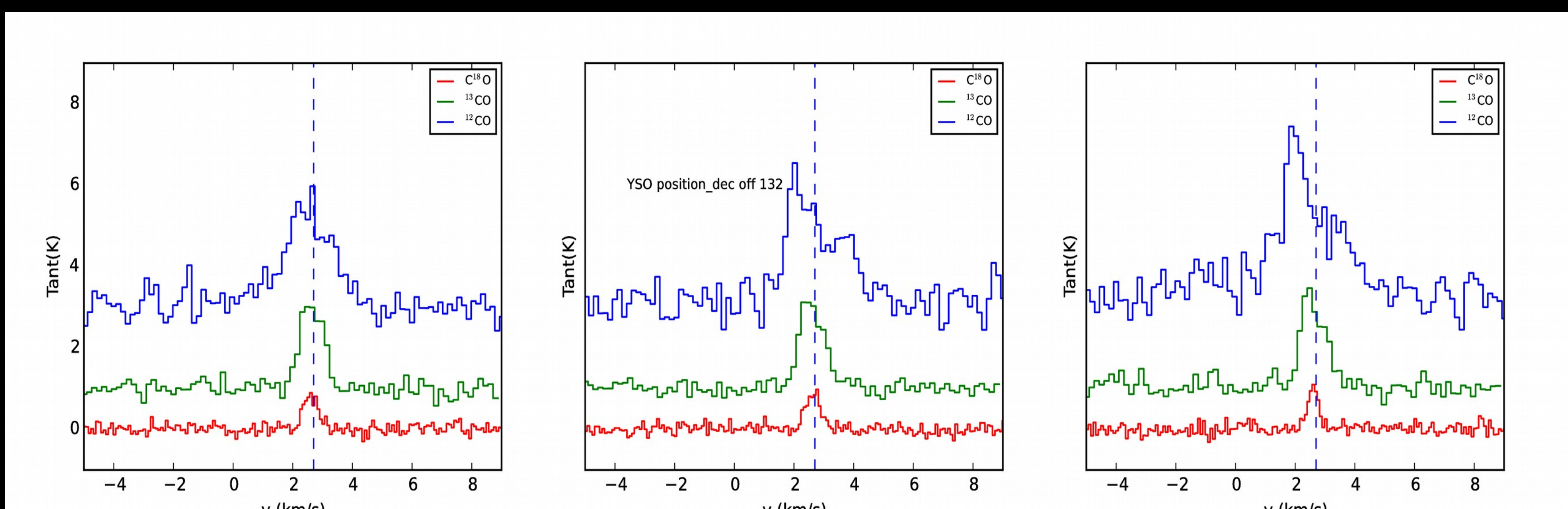
N_2H^+ : 0.5 K km/s to 1.47 K km/s (0.2 K km/s)

HCO^+: 0.2 K km/s to 3.6 K km/s (0.5 K km/s)

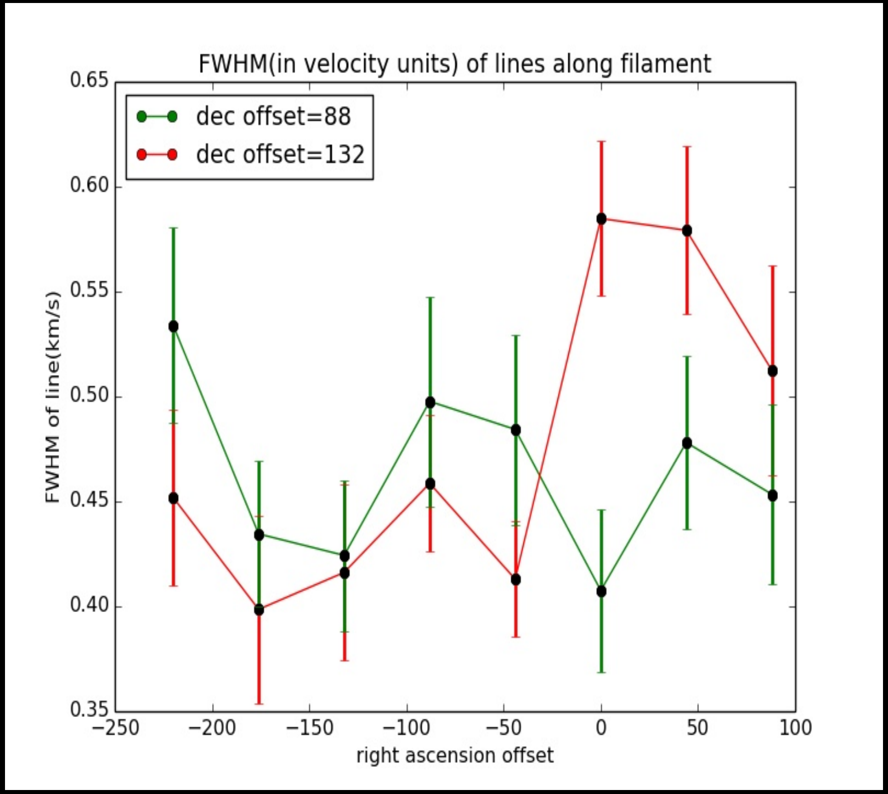
Spectra of ^{12}CO,^{13}CO,$C^{18}O$ around the protostar

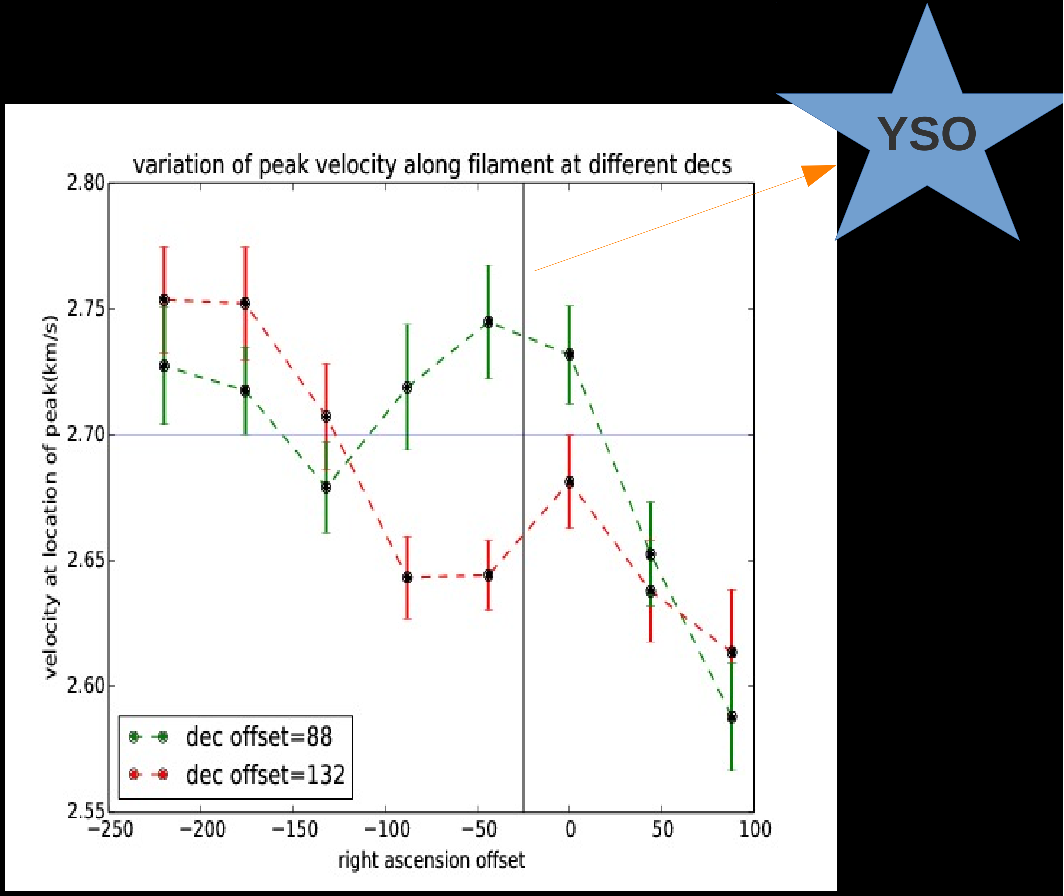


Dec offset 88



Dec offset 132





- *Around protostar, it shows that the material is more dynamic as compared to the outer region.*
- *FWHM is higher which may be because of non-thermal component in velocity widths.*

Calculations

Excitation temperature is calculated from

$$T_b^{12} = T_0^{12}[f_{12}(T_x) - f_{12}(2.7)]$$

Where T_0^{12} is the temperature corresponding to energy difference between two levels .

$$f(T) = 1/[\exp(T_0/T) - 1]$$

Optical depth for $C^{18}O$ is calculated from peak brightness temperature and excitation temperature.

$$T_R = T_0[f(T_x) - f(2.7)](1 - e^{-\tau}) .$$

Number Density :

$$N = \frac{3h\Delta v}{8\pi^3\mu^2}\left\{\frac{\tau Q}{[1 - \exp(-T_0/T_x)]}\right\}$$

Where Q is the partition function, u is permanent dipole moment (u=0.112 debye) and Δv is line full width at half maxima in velocity units

Line parameters calculated using ^{12}CO & $C^{18}O$

- ✔ **Mean excitation temperature (T_x) ~ 8 K**
- ✔ **Optical depth (τ^{18}) ~ 0.24**
- ✔ **Column Density (N_{18}) ~ 4×10^{14} cm^{-2}**
- ✔ **Velocity width (FWHM) ~ 0.5 km/s**

Hydrogen column density ~ 4×10^{21} cm^{-2}

Typically, column density in Taurus dense cloud cores ~ 7×10^{21} cm^{-2}

Onishi et al. 1996

Results

- ***The plane-of-the sky component of magnetic field is found to be perpendicular to the filament.***
- ***Magnetic field plays an important role in the dynamics of the cloud. Observed offset between B-field (outer) and outflow axis is 25°.***

  Considering outflow as a proxy of rotation axis, this result could have important consequences on disk formation.
- ***Kinematical study shows that the cloud is highly dynamical.***
- ***The filamentary structure of the cloud has been established using molecular tracers of different critical density. We have found signatures of infall around the position of protostar.***
- ***Non thermal widths have been found giving clue about the presence of turbulence.***

Thanks !!!