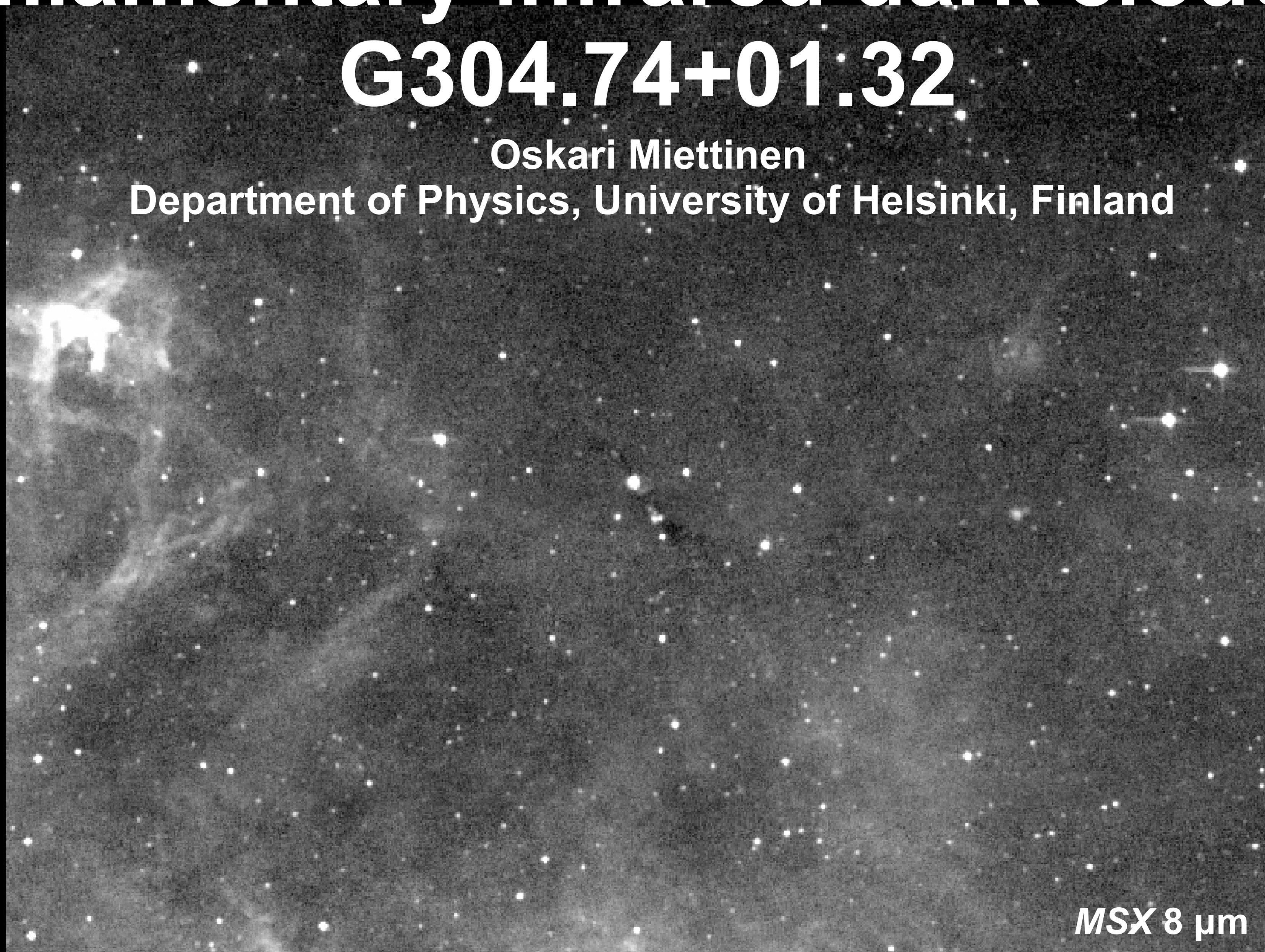
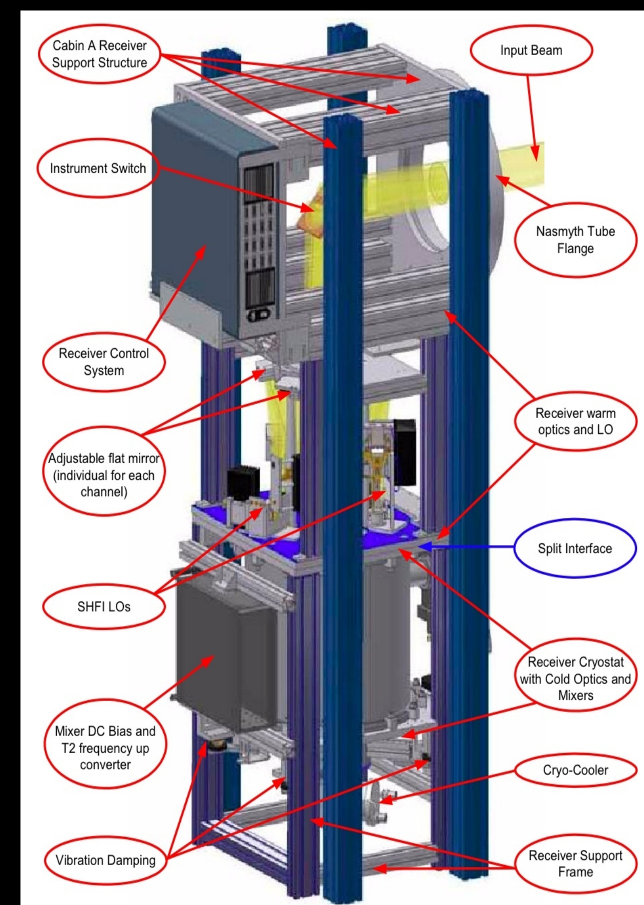
# APEX (sub)millimetre study of the filamentary infrared dark cloud G304.74+01.32

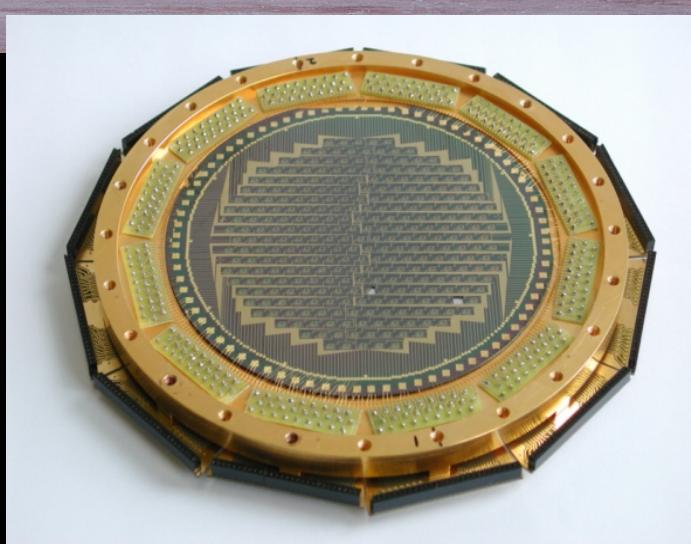

Oskari Miettinen
Department of Physics, University of Helsinki, Finland

# Observations with the ESO's 12-m APEX telescope

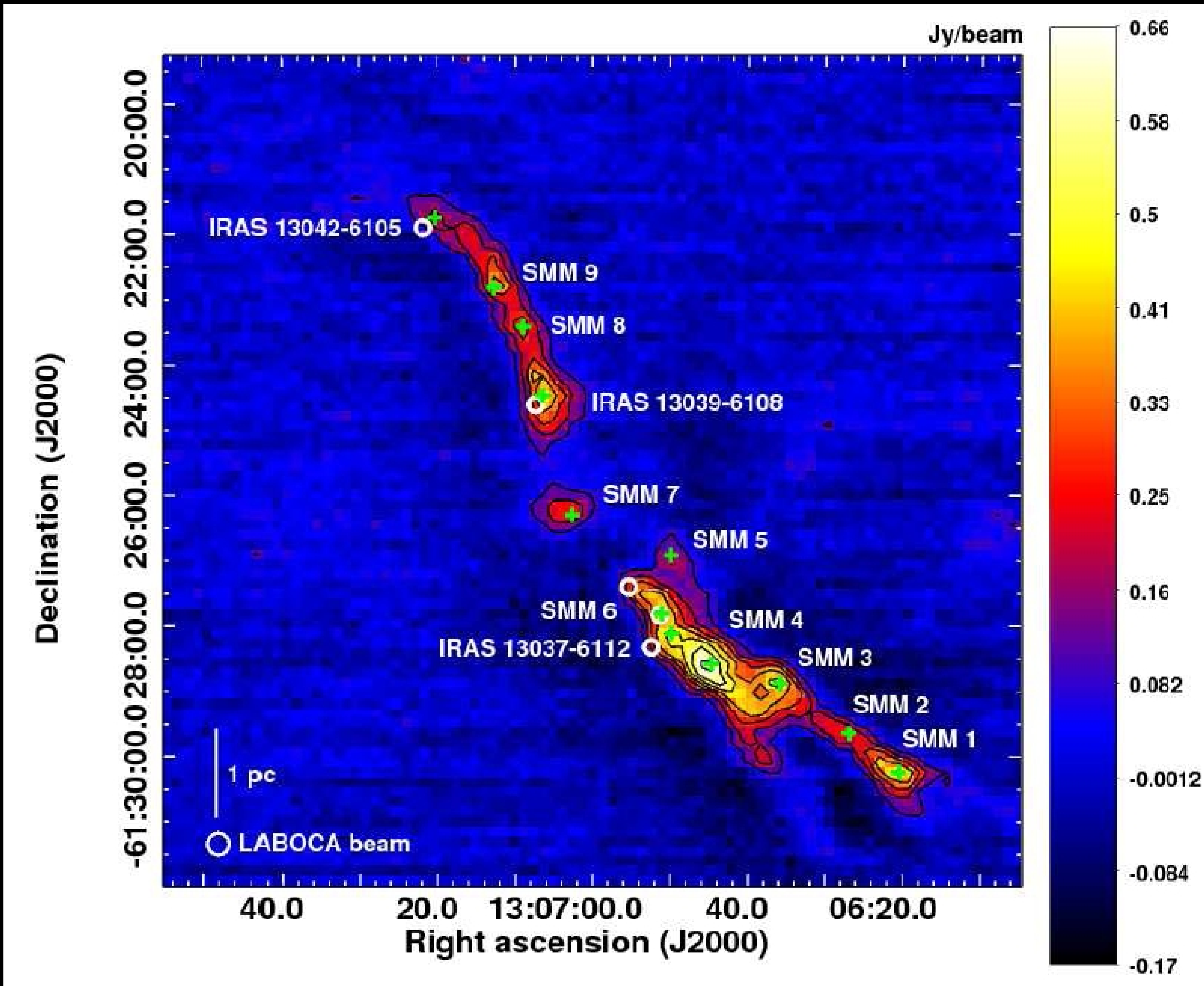

SHeFI heterodyne receiver



LABOCA bolometer
(MPIfR Bonn, APEX team)

# LABOCA 870-μm dust continuum map of the IRDC G304.74



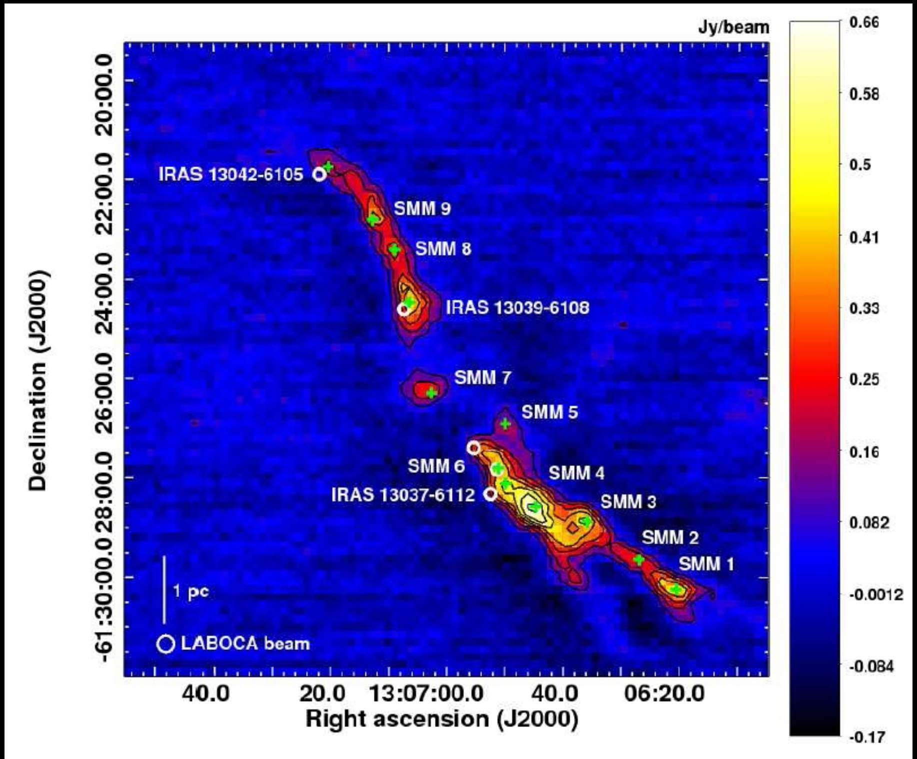

OTF map size 34' x 34'

5 maps → total telescope time ~5.2 h

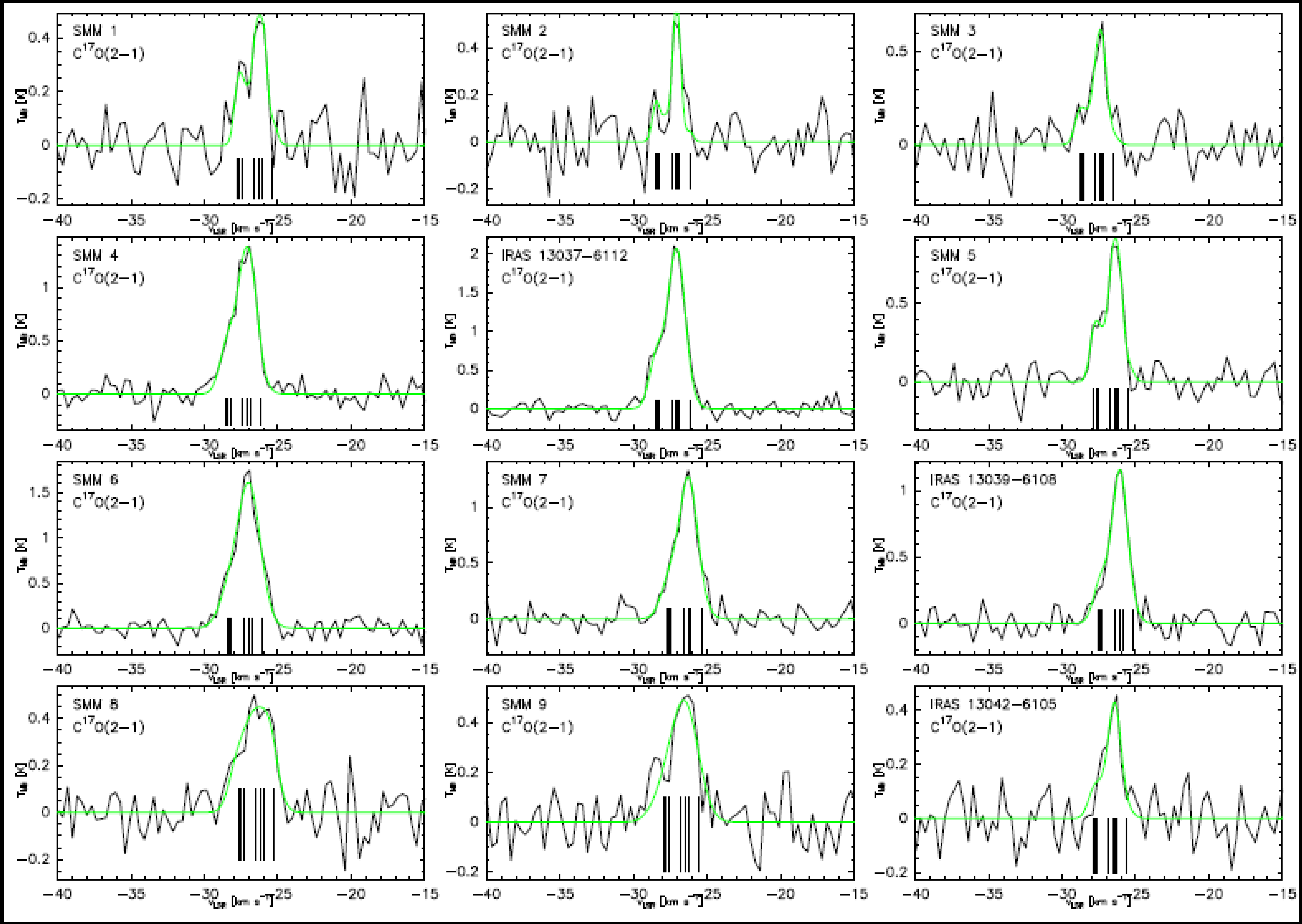
Final 1$\sigma$ sensitivity ~30 mJy/beam

Miettinen & Harju 2010

- The cloud was resolved into 12 clumps
    - 2D Clumpfind (Williams et al. 1994)
- Four *MSX*-bright, eight *MSX*-dark
- Two *IRAS* sources (13037-6112, 13039-6108) have $L_{bol}$~1.5-2$\times 10^3$ $L_\odot$
    - → HMSF or stellar cluster/intermediate-mass SF ?



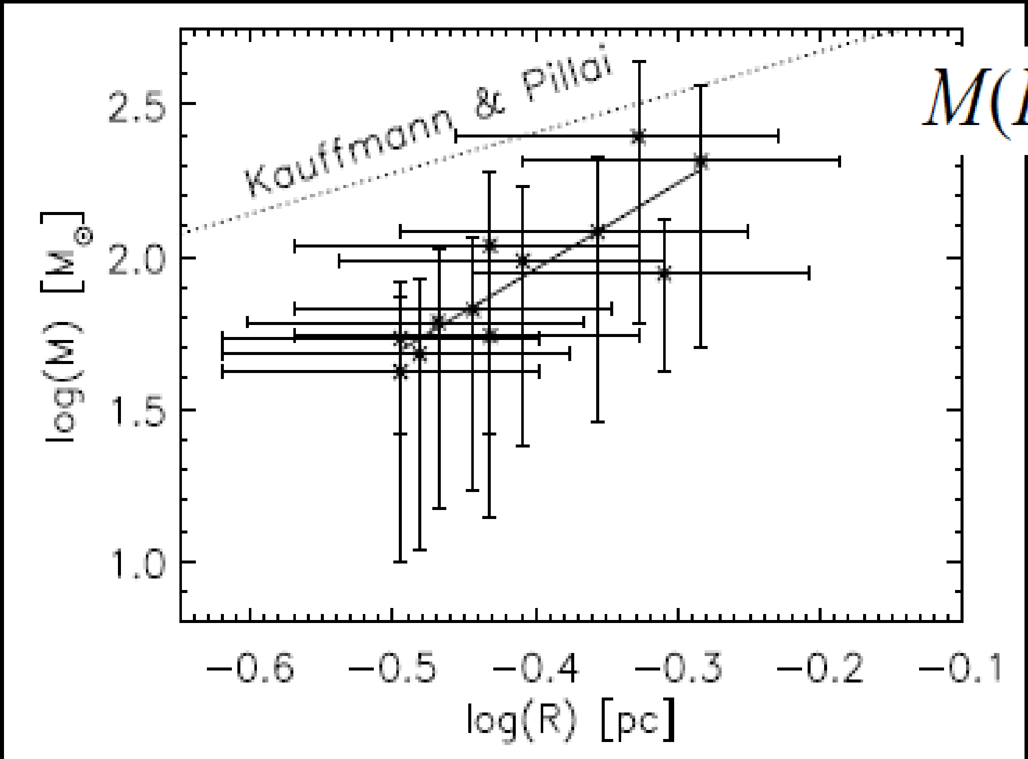
- All submm peaks were observed in $C^{17}O(2-1)$
  - The first line observations along the whole filament




Miettinen 2012

Uniform radial velocity along the cloud → *a coherent filamentary structure*

- The LSR velocity data + the Reid et al. (2009) rotation curve→ the near kinematic distance is **2.54±0.66 kpc**
  - Galactocentric distance is ~7.26 kpc
  - The far distance ~7.1 kpc is very unlikely
- ⇒ revised clump radii and masses are ~0.3 – 0.5 pc and ~40 – 250 $M_\odot$ (*T*=15 or 22 K)

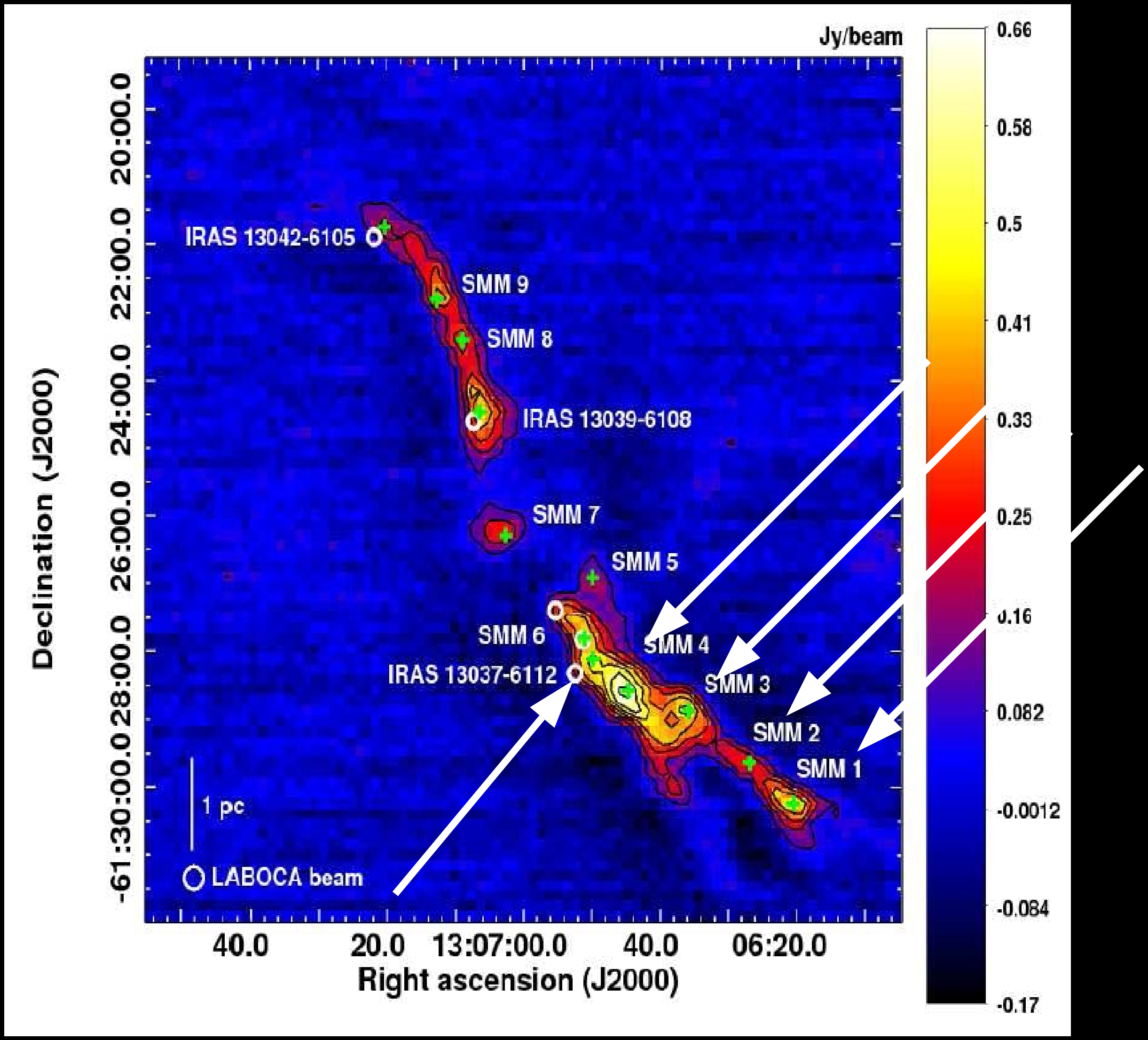


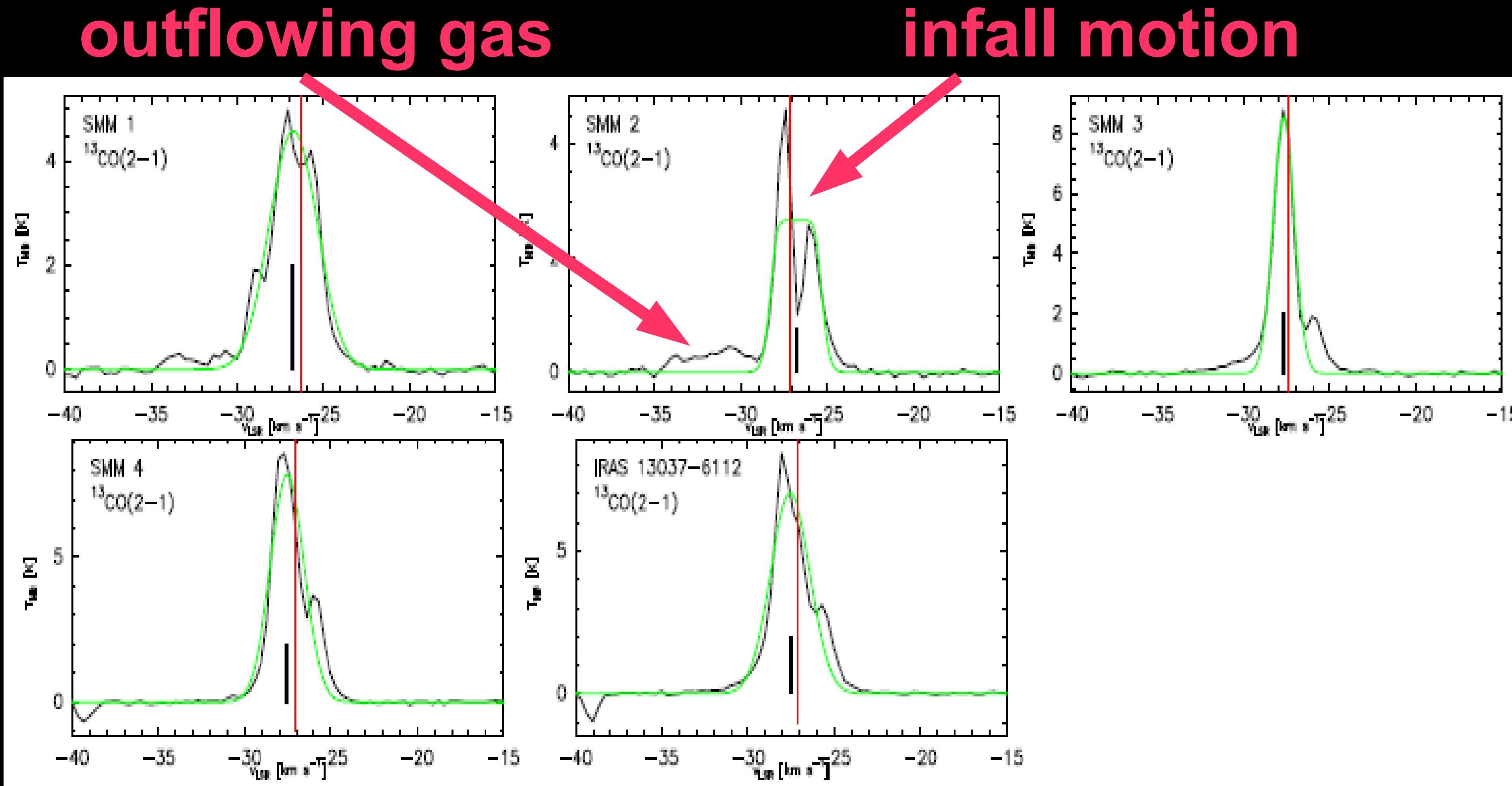

$$M(R) = 870\ \mathrm{M}_\odot \times (R/\mathrm{pc})^{1.33}$$

HMSF threshold
(Kauffmann & Pillai 2010)

→ no high-mass star formation ?

- Selected positions in the southern filament were also observed in $^{13}CO(2\text{-}1)$, SiO(5-4), and $CH_3OH(5_k\text{-}4_k)$






Infall velocities ~0.03 – 0.20 km/s

$$V_{\rm inf} \approx \frac{\sigma^2}{V_{\rm red} - V_{\rm blue}} \ln\left(\frac{1 + e \times T_{\rm BD}/T_{\rm dip}}{1 + e \times T_{\rm RD}/T_{\rm dip}}\right)$$

Myers et al. 1996

$$\dot{M}_{\rm inf} = \frac{dM}{dt} = \frac{dM}{dr}\frac{dr}{dt} = 4\pi r_{\rm inf}^2 \rho V_{\rm inf}$$

$$\tau_{\rm inf} = \frac{M}{\dot{M}_{\rm inf}}$$

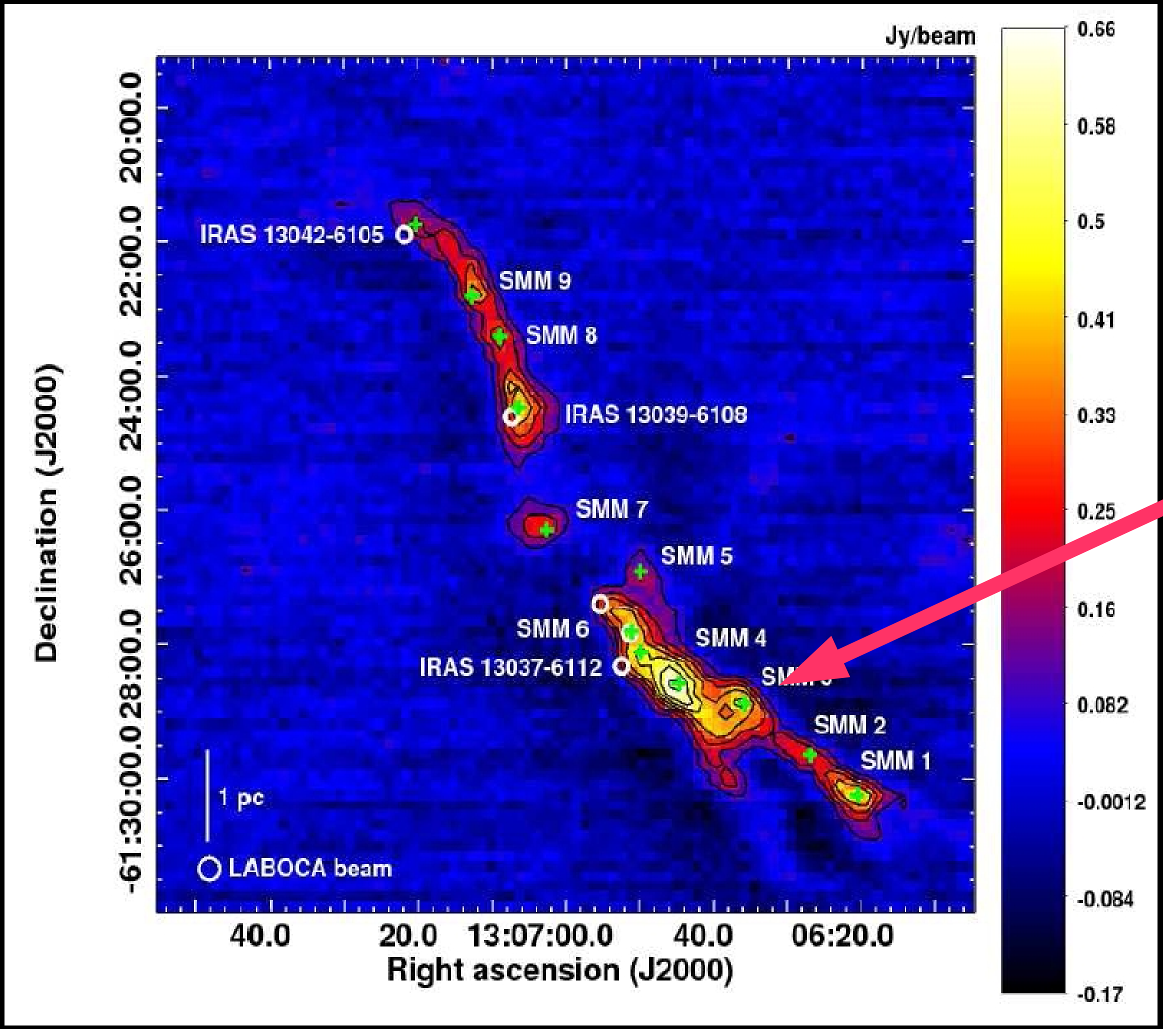
$\sim 2 - 36 \times 10^{-5}\ M_{\odot}\ {\rm yr}^{-1}$ $\sim 6 - 46 \times 10^{5}$ yr

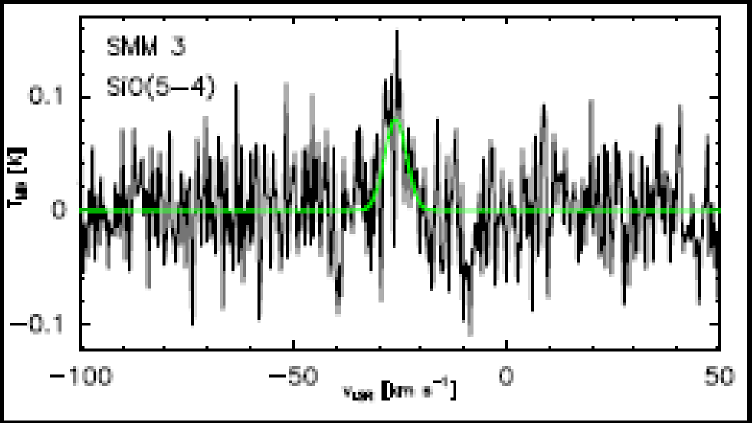
$$V_{\rm ff} = \sqrt{\frac{2GM}{R}} >> V_{\rm inf}$$

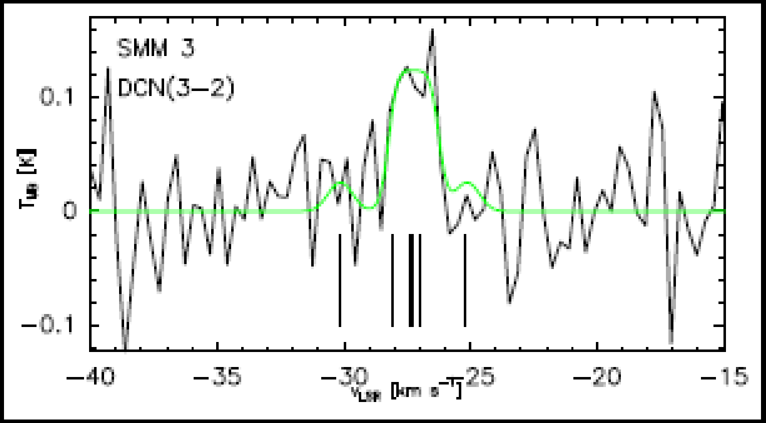
→ infall is not gravitationally dominated

→ the role of **B**-field ?

- SiO(5-4) was detected in only one source (SMM 3), but with DCN(3-2) in the same band

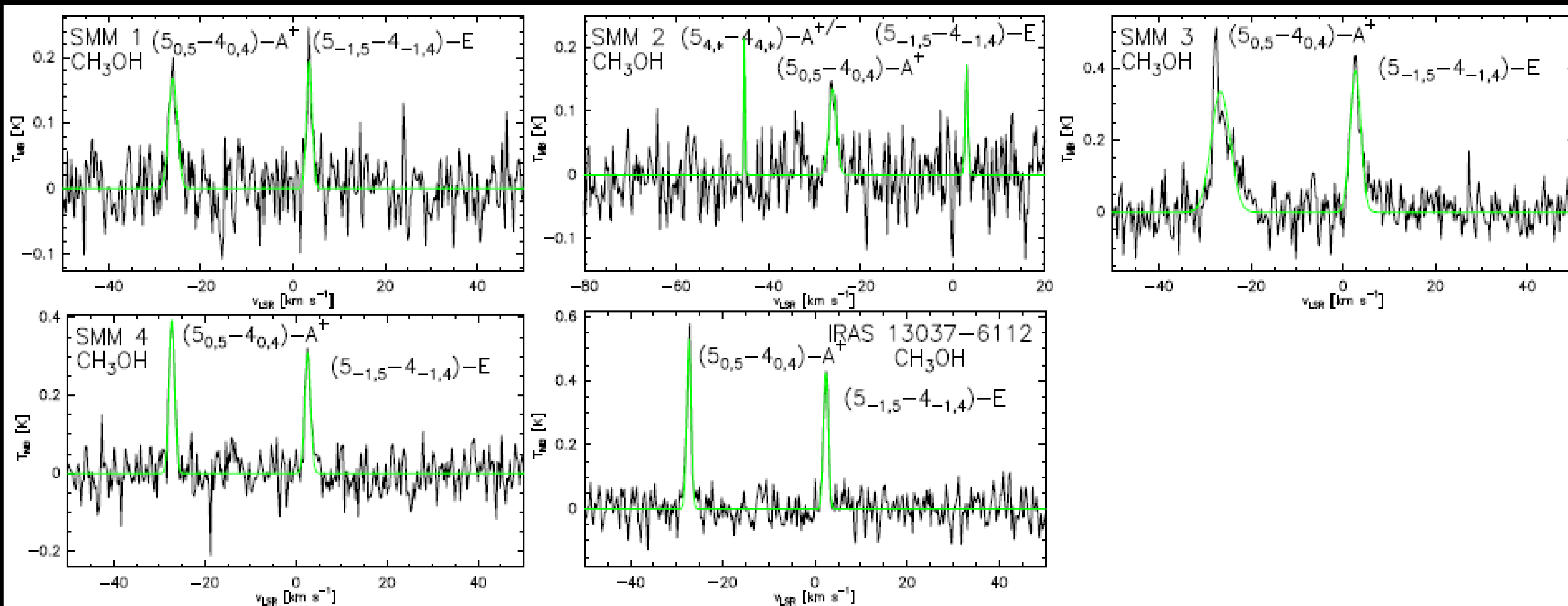



→ outflow-shocked gas in the MIR-dark clump SMM 3

- Methanol was seen towards all target positions
  - $J=5_k-4_k$ lines @ ~241.8 GHz




- Abundances in the range $\sim 0.2–12 \times 10^{-9}$
- Hard to make in the gas phase → grain mantle evaporation needed → outflows
- No hot-core abundances of $\sim 10^{-7}$ detected

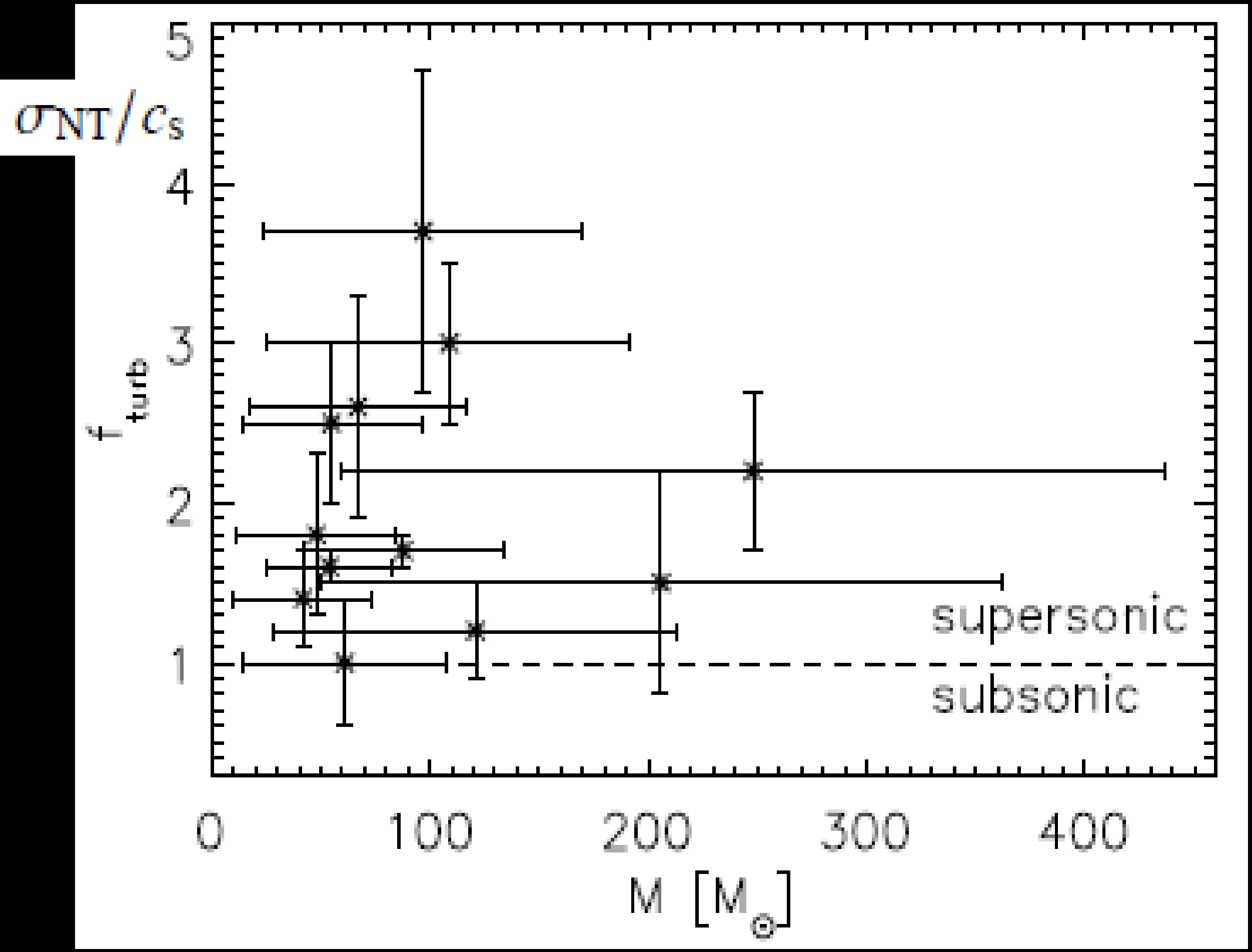
- $C^{17}O$ observations were used to study the amount of CO depletion
- CO depletion factor is

$$f_D = \frac{x(\mathrm{CO})_{\mathrm{can}}}{x(\mathrm{CO})_{\mathrm{obs}}}$$

$$\begin{aligned} x(\mathrm{C^{17}O})_{\mathrm{can}} &= \frac{x(\mathrm{CO})_{\mathrm{can}}}{[^{18}\mathrm{O}]/[^{17}\mathrm{O}] \times [^{16}\mathrm{O}]/[^{18}\mathrm{O}]} \\ &= \frac{x(\mathrm{CO})_{\mathrm{can}}}{3.52 \times (58.8 \times R_{GC}[\mathrm{kpc}] + 37.1)} \end{aligned}$$

→ depletion factors are only ~0.2 – 2.3
→ CO is in the gas-phase (*on the scale of clumps!*)

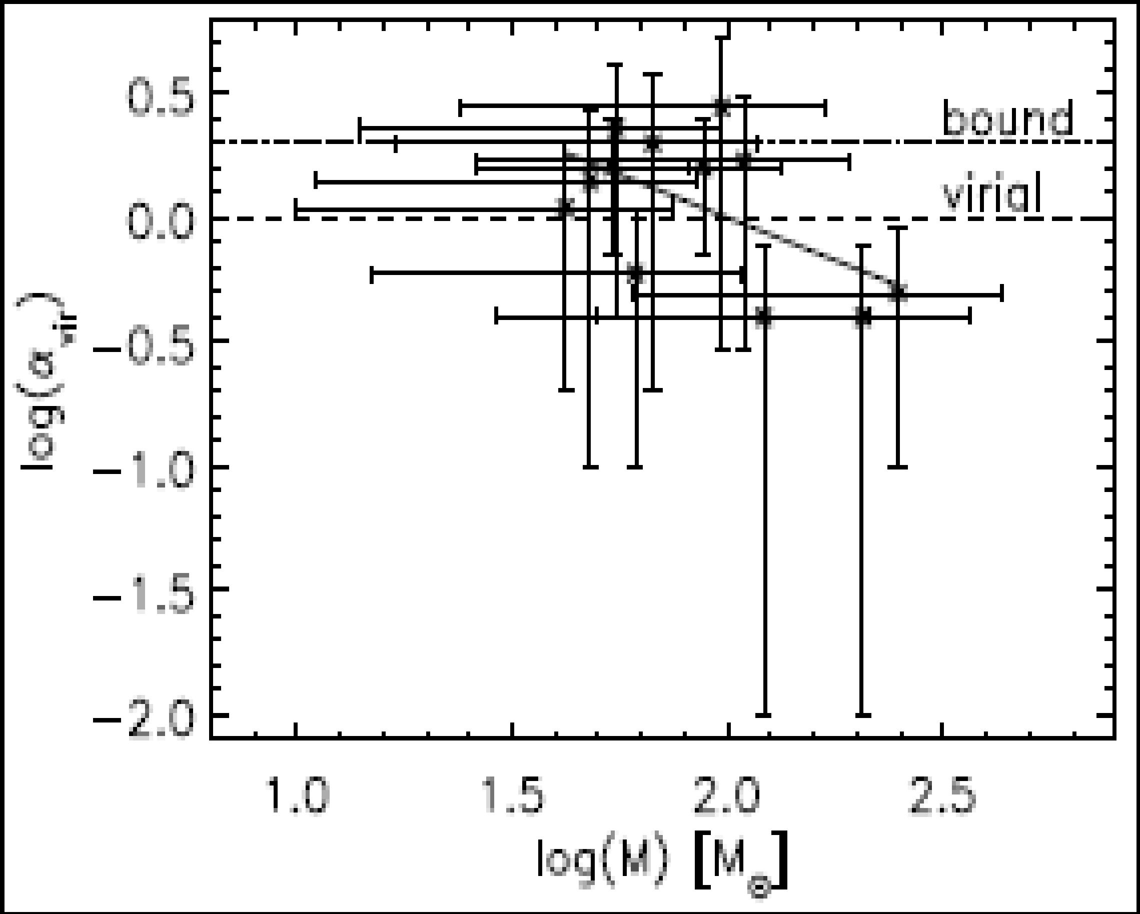
- Line observations also enable us to investigate the gas *kinematics* and *dynamics*
- Non-thermal velocity dispersion was estimated from the $C^{17}O$ lines:




$$\sigma_{NT} = \sqrt{\sigma_{obs}^2 - \frac{k_B T_{kin}}{m_{C^{17}O}}}$$

The filament is dominated by supersonic NT motions

• Dynamical state of the clumps ?



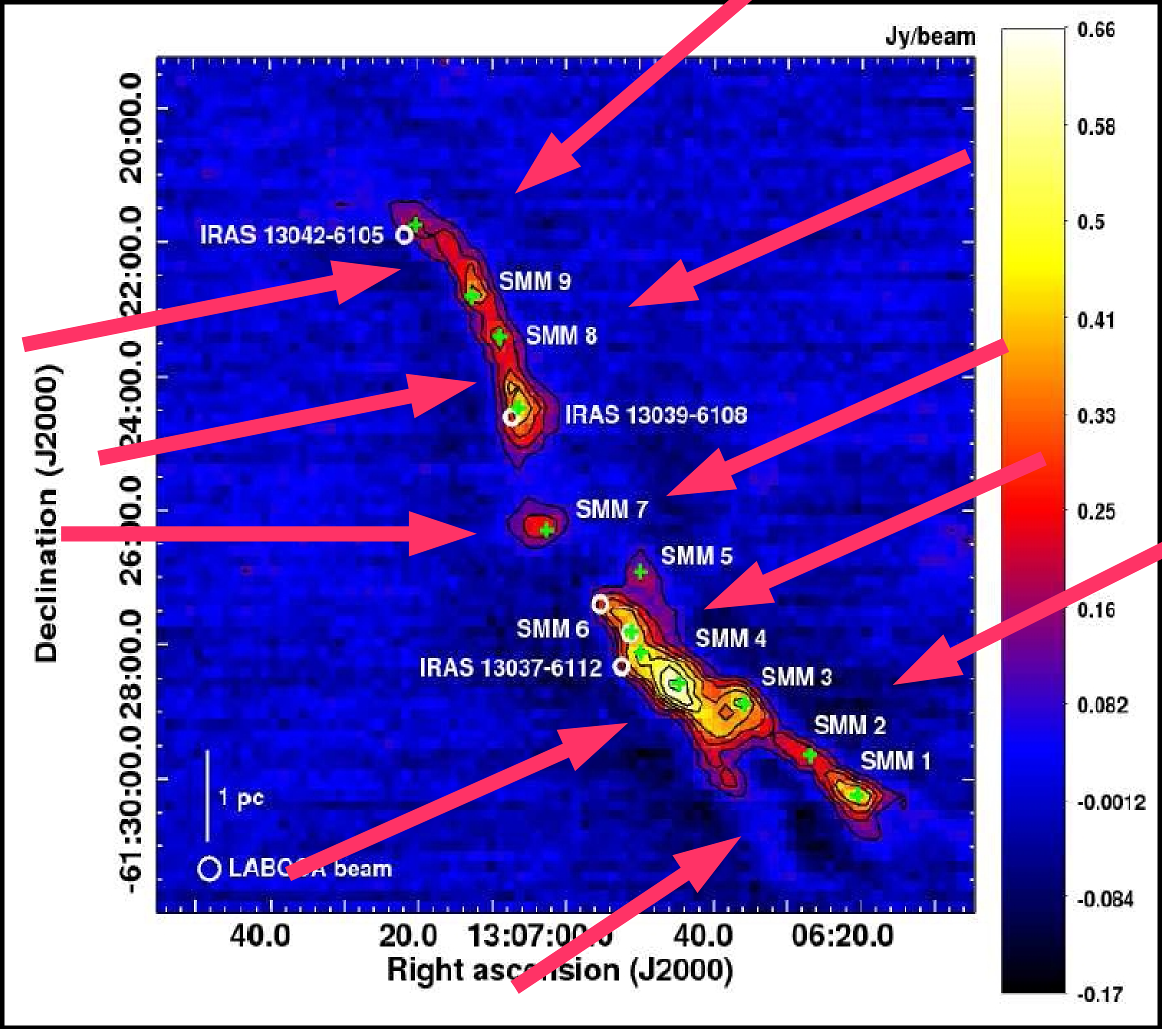

$$M_{vir} = \frac{5}{8 \ln 2} \frac{R \Delta v_{ave}^2}{aG}$$

$$\alpha_{vir} = \frac{2T}{|W|} = \frac{M_{vir}}{M}$$

→ Most of the clumps appear to be *gravitationally bound*

In addition $\alpha_{vir} \propto M^{-0.69}$ → close to the pressure-confinement slope -2/3 (Bertoldi & McKee 1992)

- → the external pressure may (still) play an important role




Turbulent flow motions ?

$$2(\langle \mathcal{T} \rangle - \langle \mathcal{T}_{ext} \rangle) + \langle \mathcal{W} \rangle = 0$$

$$P_{kin} - P_{ext} - P_{grav} = 0$$

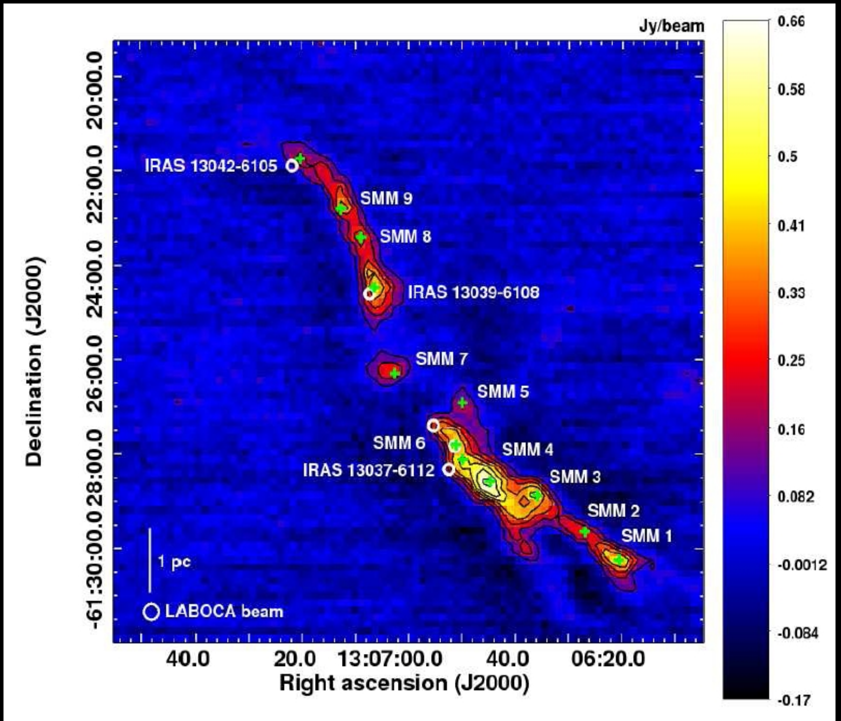
- The average $P_{ext}$ required for VE is ~$3.3 \times 10^5$ K cm$^{-3}$
- The turbulent ram pressure as estimated from the $^{13}CO(2\text{-}1)$ lines is very similar to $\langle P_{ext} \rangle$ :

$$P_{\rm ram} = \rho \sigma_{\rm NT}^2 \sim 3 \times 10^5 \, {\rm K \; cm^{-3}}$$

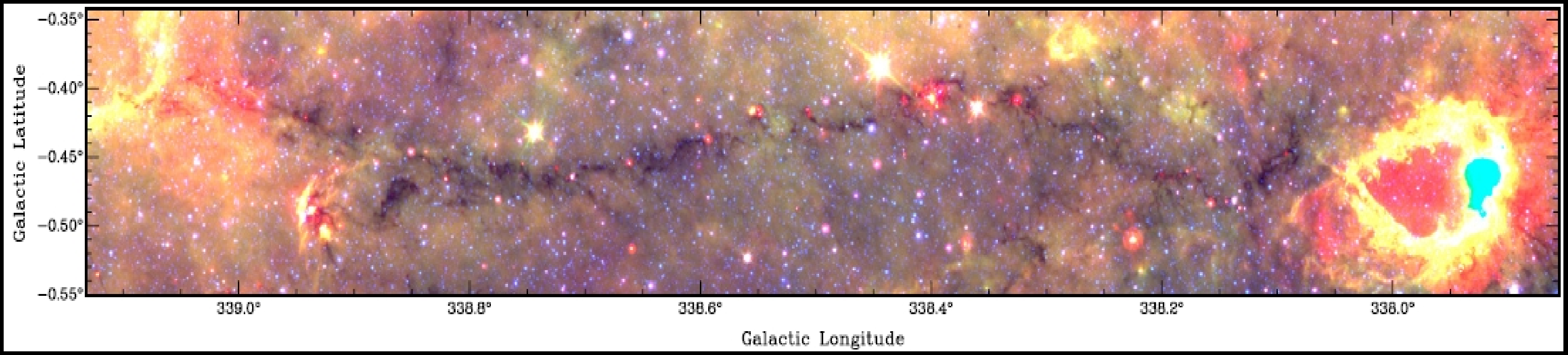
- But, $P_{ext}^{eq}$ is *negative* for the clumps in the southern part of the filament!
  - → these clumps are warmer (>15 K) and/or have some additional internal pressure ?
  - → warmer *T* was implied by the 8/870 $\mu$m opacity ratio (M&H 2010) $I_{870} \simeq B_{870}(T_{\rm d}) \tau_{870}$ $\frac{\kappa_8}{\kappa_{870}} = \frac{\tau_8}{\tau_{870}}$

# Filament fragmentation

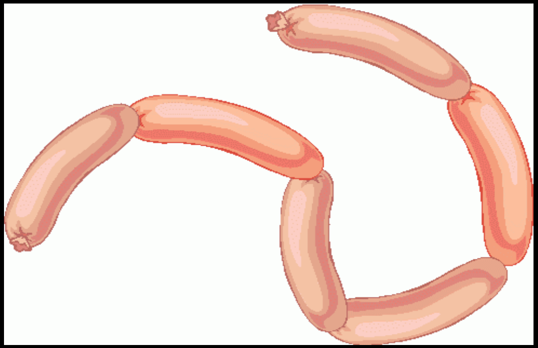
- Average projected clump separation is ~0.75 pc
- Thermal Jeans length is ~0.05 pc (15 K gas) << the spatial resolution
- Non-thermal Jeans length is ~0.24 pc
- → some other fragmentation mechanism is needed (*on the observed clump scale*)

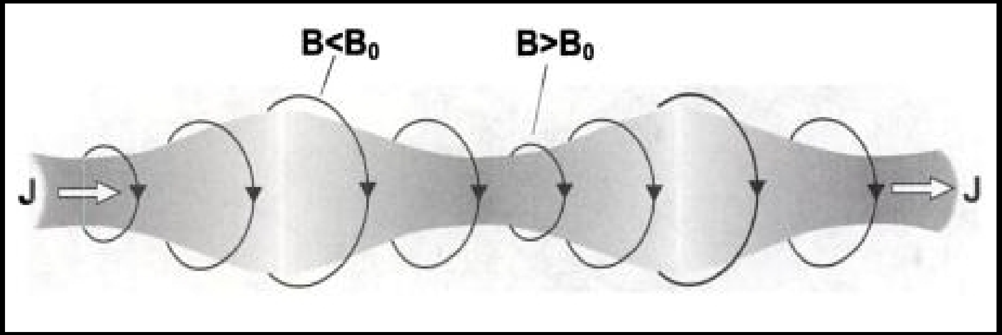


- How about the MHD “sausage”-type fluid instability like in the Nessie IRDC ?




Jackson et al. 2010





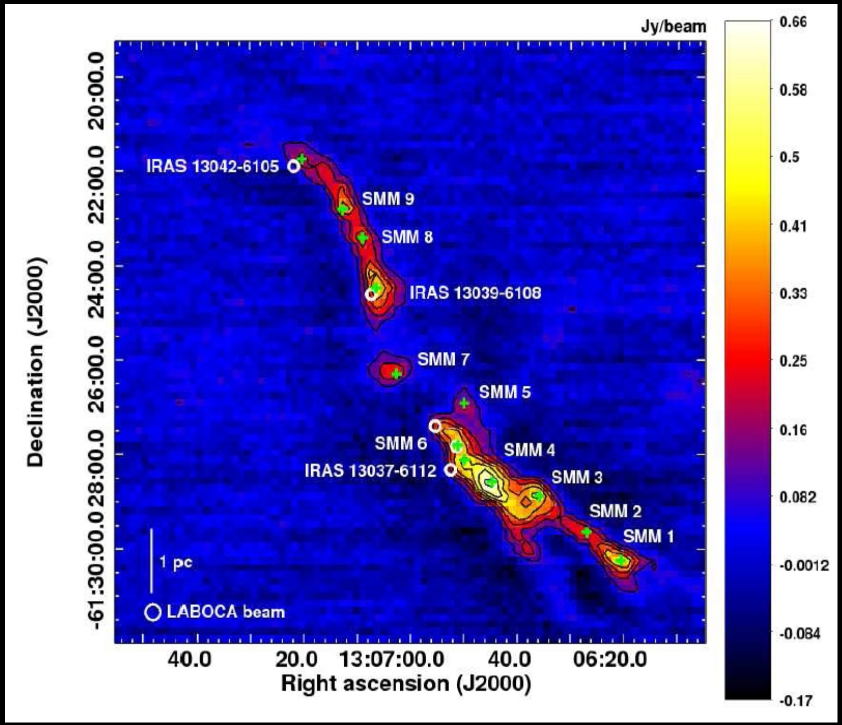

Perturbation squeezes the plasma → the local **B**-pressure increases (Bittencourt 2004)

- If an isothermal, infinitely long fluid cylinder is dominated by NT motions, the wavelength of the fastest growing mode is

$$\lambda_{max} \simeq 22 H_{eff} = 22 \frac{c_{eff}}{\sqrt{4\pi G \rho_0}} \simeq 6.2 \times \frac{c_{eff}}{\sqrt{G\rho_0}}$$

“Effective” scale height

- Assuming that the central density along the cylinder is $10^5 cm^{-3}$, we derive $\lambda_{max}$ ~0.7 pc
- → Close to the observed clump separation!
  - Also comparable to the average width of ~0.8 pc!




The projected length of the filament is 8.9 pc and its total mass is ~1200 $M_\odot$

→ the mass per unit length is ~135 $M_\odot$ $pc^{-1}$

$$M \sim \lambda_{max} M_{line}$$

→ clump masses expected to be less than ~95 $M_\odot$ (true for 8/12)

- The critical line mass corresponds to the virial mass per unit length:

$$m_{\rm vir} = \frac{2\langle\sigma^2\rangle}{G}$$

~136 $M_\odot$ $pc^{-1}$

→ the filament as a whole appears to be close to virial equilibrium: $m/m_{vir}$~1

- Virial equation for a filamentary cloud is

$$\frac{P_S}{\langle P\rangle} = 1 - \frac{m}{m_{\rm vir}}\left(1 - \frac{\mathcal{M}}{|\mathcal{W}|}\right)$$

external pressure → $P_S$

average internal pressure → $\langle P\rangle$

Fiege & Pudritz 2000

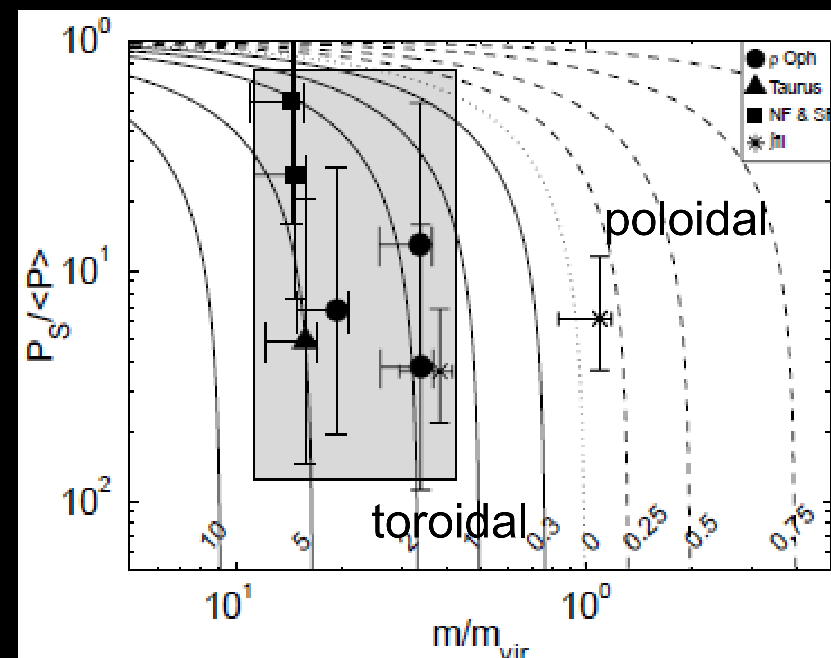
- Assuming that G304.74 is in VE, and using the average $P_{ext}^{eq}/P_{kin}$ ratio of ~0.49, we get

$$\mathcal{M}/|\mathcal{W}| \simeq 0.49$$

⇒ 1) The filament is magnetically supported
2) **B**-field is poloidally dominated

Same was found for the Snake IRDC by Fiege et al. (2004)!

Helical field models by Fiege & Pudritz (2000)



# SABOCA 350-$\mu$m data of G304.74 is coming!

→ colour temperatures

→ further fragmentation ?