MAX PLANCK INSTITUTE FOR ASTRONOMY

Unveiling the formation of single and multiple protostellar systems

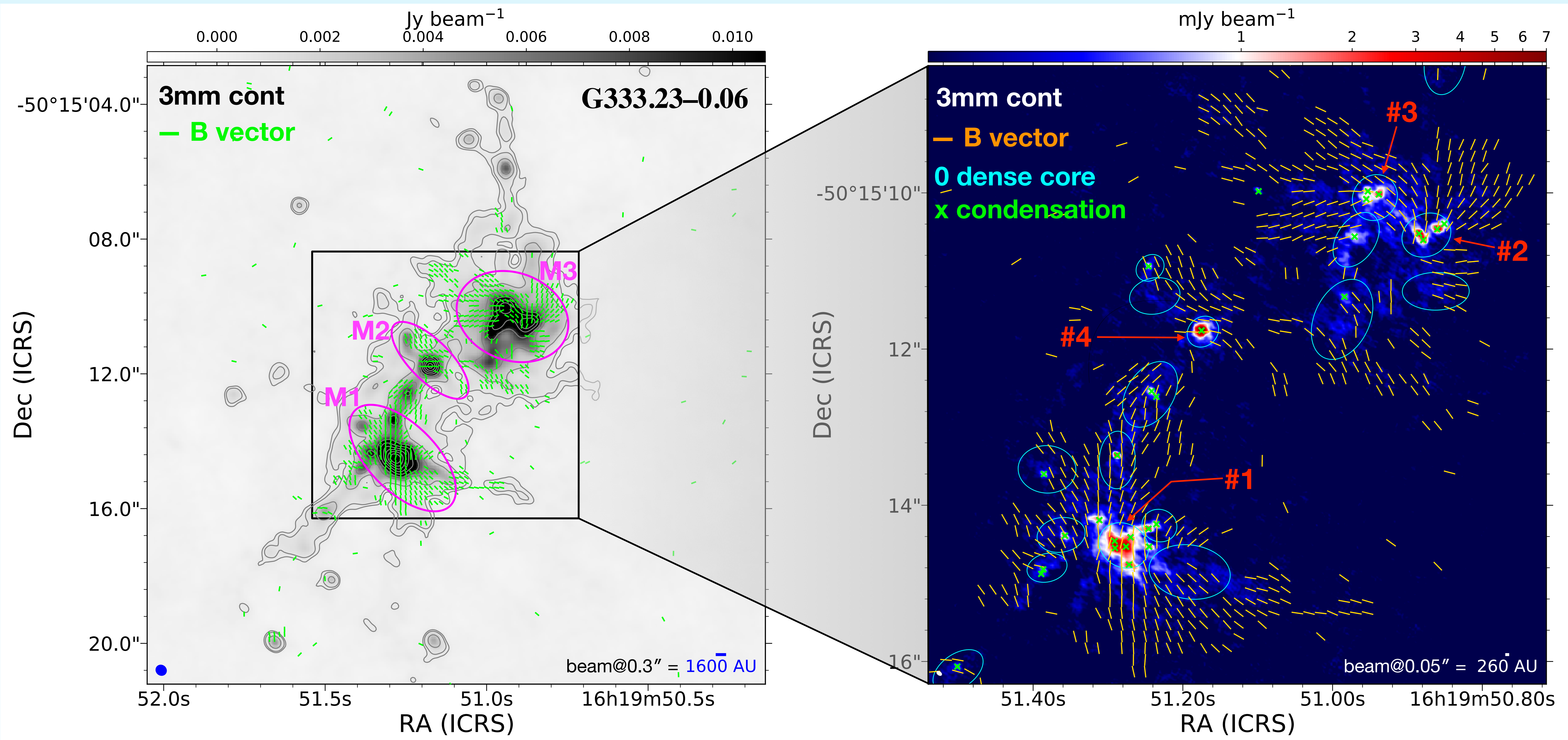
Shanghuo Li[1], Patricio Sanhueza[2], Henrik Beuther[1], Junhao Liu[2], Qizhou Zhang[3], et al.

1. Max Planck Institute for Astronomy; 2. National Astronomical Observatory of Japan; 3. Center for Astrophysics | Harvard & Smithsonian

Fragmentation is a ubiquitous physical process that is a key to enable the formation of multiple system from a dense core and govern the properties of stellar clusters. However, the dynamical role of magnetic fields in the fragmentation from core to single, binary, or high-order multiple system remain unclear.

We have investigated the impact of magnetic field on the formation of single and multiple protostellar systems within a high-mass protocluster forming region, G333.23–0.06. **The parent structure of single protostellar object appears to be magnetically supported**, with magnetic energy dominates over gravitational potential energy and kinetic energy. In contrast, gravitational potential energy and kinetic energy exceed magnetic energy for the parent structures of multiple systems. This indicates that **magnetic fields cannot prevent gravitational collapse/fragment for these parent structures of multiple systems**. In addition, the density profiles of parent cores of single protostellar object are steeper than those of multiple systems. Our results indicate that **magnetic fields play an inhibitory role in the formation of multiple systems**.

G333.23–0.06 is a typical high-mass star-forming region at a distance of 5.2 kpc associated with Class II CH_3OH maser emission. It has a mass reservoir of ~3000 $M_\odot$ with a mean column density of 1.6×10^{23} cm^{-2} within a 1.2 pc radius.



The impact of magnetic fields on formation of multiple systems

Name	$B_{\rm pos}$ (mG)	$B_{\rm pos,tot}$ (mG)	$B_{\rm tot}$ (mG)	M/Φ_B	$\mathcal{M}_A$
M1	0.95	0.95	1.17	1.2	1.7
M2	2.43	5.62	6.88	0.5	0.7
M3	2.26	2.29	2.80	0.5	1.0

Mass-to-flux ratio **M/Φ_B**

Alfvén Mach number **M_A**

$M/\Phi_B > 1$ (magnetically supercritical): magnetic fields cannot prevent gravitational collapse/fragment. $M/\Phi_B < 1$ (magnetically subcritical): magnetically supported.

$M_A < 1$ (sub-Alfvénic): the magnetic energy larger than the non-thermal kinematic energy; $M_A > 1$ (super-Alfvénic): indicates converse.

The region M2 appears to be magnetically supported, with $M/\Phi_B < 1$ and $M_A < 1$.

Mass-to-flux ratio (M/Φ_B) and Alfvén Mach number (M_A) toward M2 are smaller than those of M1 and M3.

1. Magnetic fields prevent core fragmentation toward M2, where is no multiple systems formed.

2. Gravitational potential energy dominates over magnetic energy in M1 and M3, leading to the formation of multiple.

3. Our findings suggest that magnetic fields inhibit the formation of multiple systems.

Dense core fragmentation:

Core #1 fragment into a quintuple system.

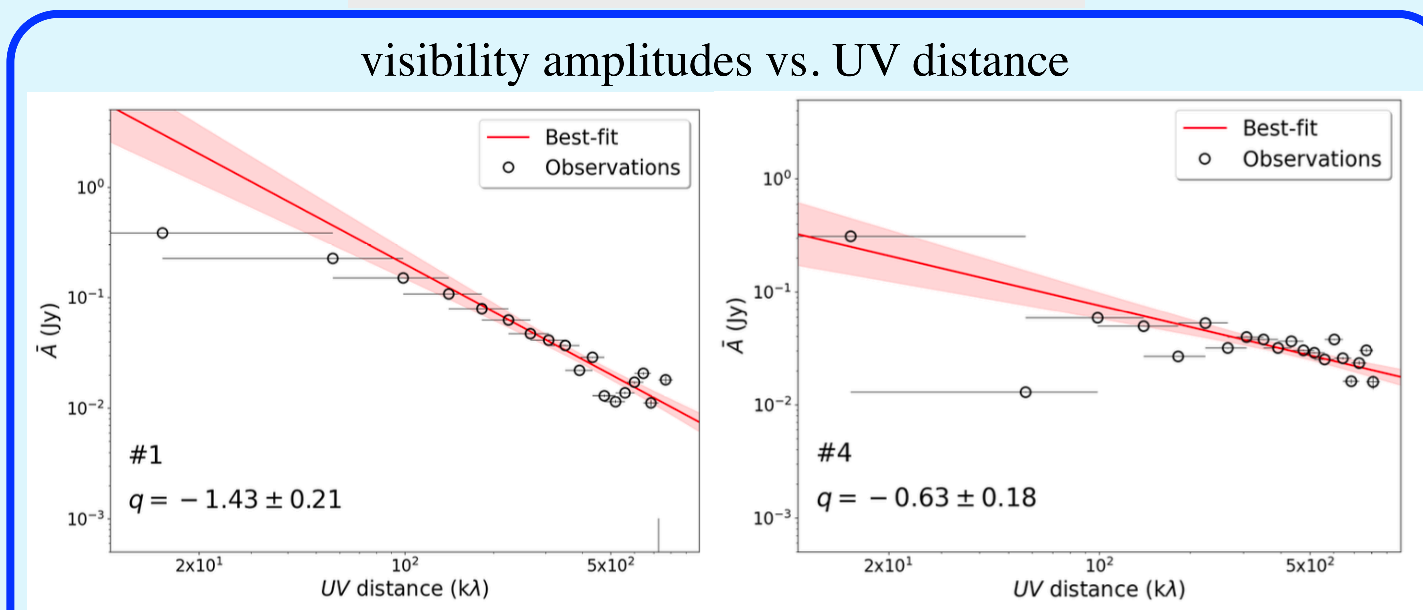
Core #2 fragment into a quadruple system.

Core #3 fragment into a triple system.

Core #4 shows no fragmentation at the current spatial resolution.

Density profile of parent cores

visibility amplitudes vs. UV distance



temperature profile $T_r \propto r^{-a}$

density profile $\rho_r \propto r^{-b}$

visibility profile $A_{\rm uv} \propto R_{\rm uv}^{a+b-3}$

a = 0.5

#	b
#1	1.1
#2	1.3
#3	1.2
#4	2.1

Core #4 shows steeper density profile than those of #1/#2/#3.

The density profiles of parent cores of single protostellar object are steeper than those of multiple systems

Refs: Li et al 2024, 8, 472, Nature Astronomy; Li et al 2025, in prep.

https://shanghuoli.github.io
shanghuo.li@gmail.com;
li@mpia.de