

Star Formation with SOFIA and beyond

Henrik Beuther, MPIA

SOFIA - Scientific Highlights and Future Perspectives @ Stuttgart

April 24, 2024



Star Formation science covered with SOFIA

- present here at the conference -

Overview —> Zinnecker

Magnetic fields —> Andre, Wolf, Pillai, Redaelli, Rodriguez ...

Feedback —> Kabanovic, Goicoechea, Tielens, Pabst ...

High-mass star formation (SOMA) —> Oakey, Tan ...

Infall —> Wyrowski

Accretion bursts —> Stecklum, Wolf, Andreas ...

Envelopes around high-mass stars —> Menten

Water —> Indriolo, Li

Outflows —> Oakey, Karska, Eisloffel ...

Vel. resolved fine-structure lines —> Goldsmith

Physical and chemical structure —> Spezzano

PDRs —> Mookerjea

What did SOFIA offer?

Large polarization camera

—> Magnetic field mapping

FIR to MIR cameras

—> Coverage of the peak of the SED

Low-resolution spectroscopy

—> Galactic and extragalactic maps

High-resolution spectroscopy

—> Unprecedented ISM maps

Star Formation science covered with SOFIA

- present here at the conference -

Large polarization camera
—> Magnetic field mapping

Overview —> Zinnecker

Magnetic fields —> Andre, Wolf, Pillai, Redaelli, Rodriguez ...

Feedback —> Kabanovic, Goicoechea, Tielens, Pabst ...

High-mass star formation (SOMA) —> Oakey, Tan ...

Infall —> Wyrowski

Accretion bursts —> Stecklum, Wolf, Andreas ...

Envelopes around high-mass stars —> Menten

Water —> Indriolo, Li

Outflows —> Oakey, Karska, Eisloffel ...

Vel. resolved fine-structure lines —> Goldsmith

Physical and chemical structure —> Spezzano

PDRs —> Mookerjea

Star Formation science covered with SOFIA

- present here at the conference -

FIR to MIR cameras

—> Coverage of the peak of the SED

Overview —> Zinnecker

Magnetic fields —> Andre, Wolf, Pillai, Redaelli, Rodriguez ...

Feedback —> Kabanovic, Goicoechea, Tielens, Pabst ...

High-mass star formation (SOMA) —> Oakey, Tan ...

Infall —> Wyrowski

Accretion bursts —> Stecklum, Wolf, Andreas ...

Envelopes around high-mass stars —> Menten

Water —> Indriolo, Li

Outflows —> Oakey, Karska, Eisloffel ...

Vel. resolved fine-structure lines —> Goldsmith

Physical and chemical structure —> Spezzano

PDRs —> Mookerjea

Star Formation science covered with SOFIA

- present here at the conference -

Low-resolution spectroscopy
—> **Galactic and extragalactic maps**

Overview —> Zinnecker

Magnetic fields —> Andre, Wolf, Pillai, Redaelli, Rodriguez ...

Feedback —> Kabanovic, Goicoechea, Tielens, Pabst ...

High-mass star formation (SOMA) —> Oakey, Tan ...

Infall —> Wyrowski

Accretion bursts —> Stecklum, Wolf, Andreas ...

Envelopes around high-mass stars —> Menten

Water —> Indriolo, Li

Outflows —> Oakey, Karska, Eisloffel ...

Vel. resolved fine-structure lines —> Goldsmith

Physical and chemical structure —> Spezzano

PDRs —> Mookerjea

Star Formation science covered with SOFIA

- present here at the conference -

High-resolution spectroscopy
—> **Unprecedented ISM maps**

Overview —> Zinnecker

Magnetic fields —> Andre, Wolf, Pillai, Redaelli, Rodriguez ...

Feedback —> Kabanovic, Goicoechea, Tielens, Pabst ...

High-mass star formation (SOMA) —> Oakey, Tan ...

Infall —> Wyrowski

Accretion bursts —> Stecklum, Wolf, Andreas ...

Envelopes around high-mass stars —> Menten

Water —> Indriolo, Li

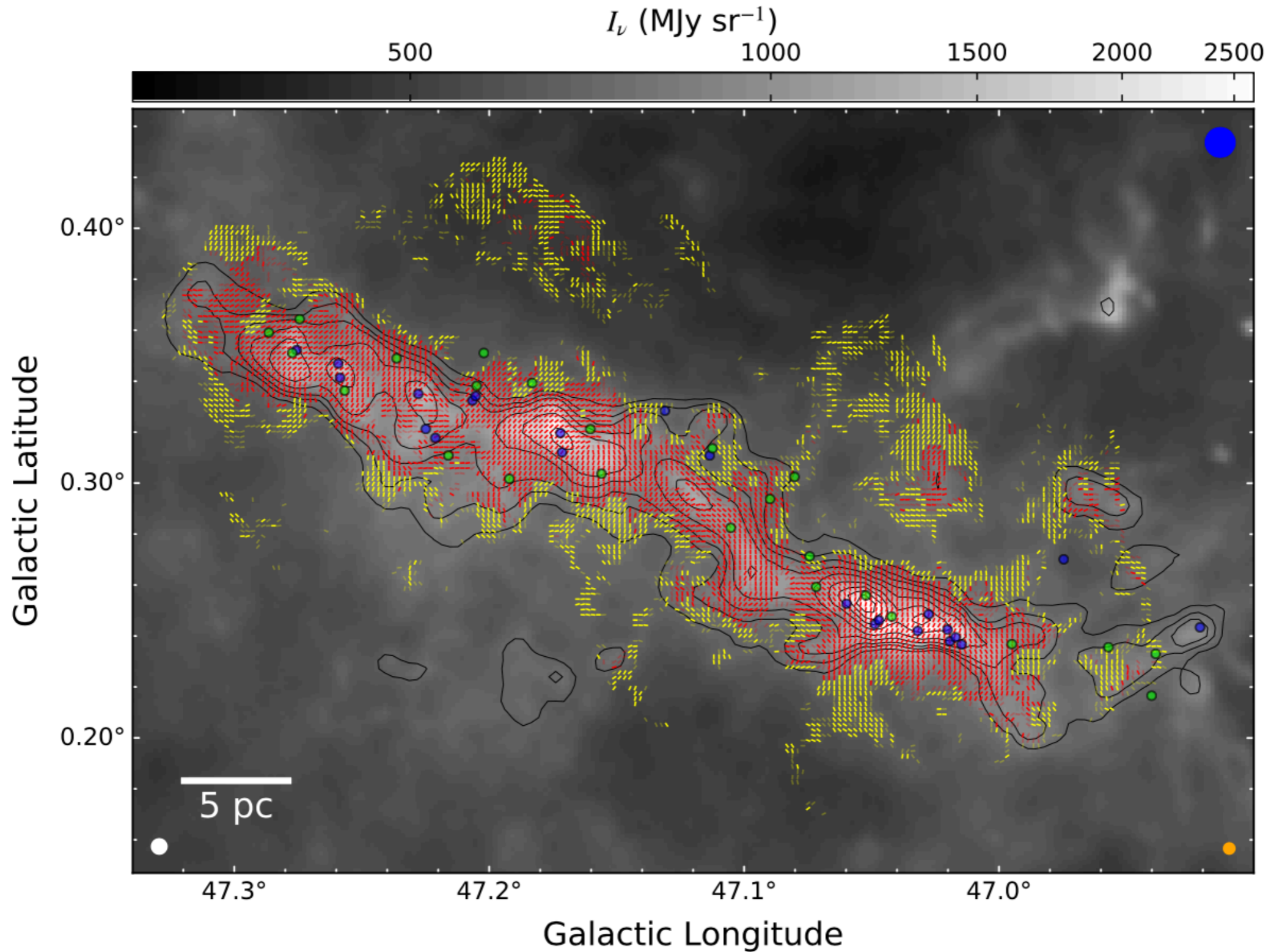
Outflows —> Oakey, Karska, Eisloffel ...

Vel. resolved fine-structure lines —> Goldsmith

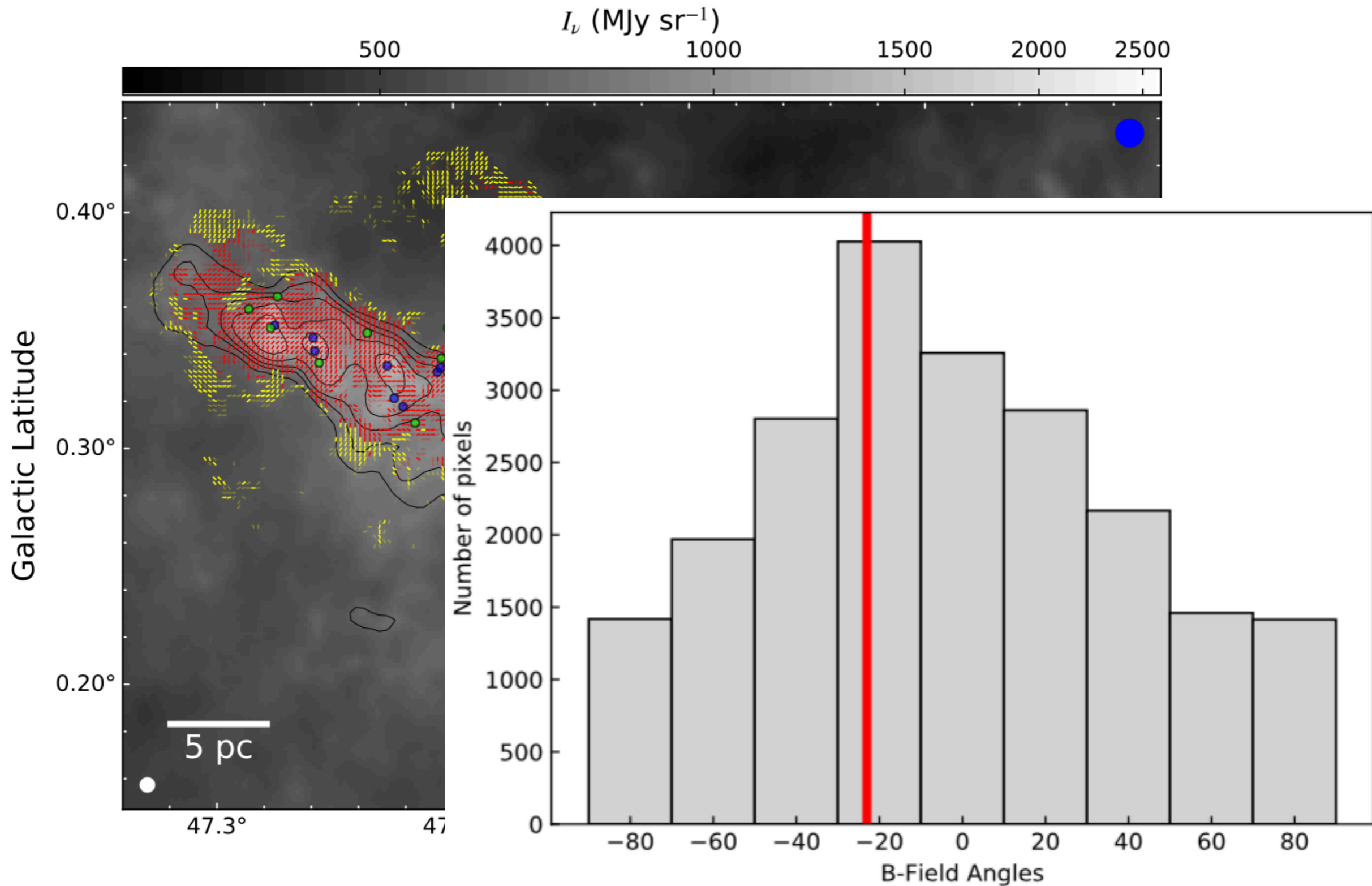
Physical and chemical structure —> Spezzano

PDRs —> Mookerjea

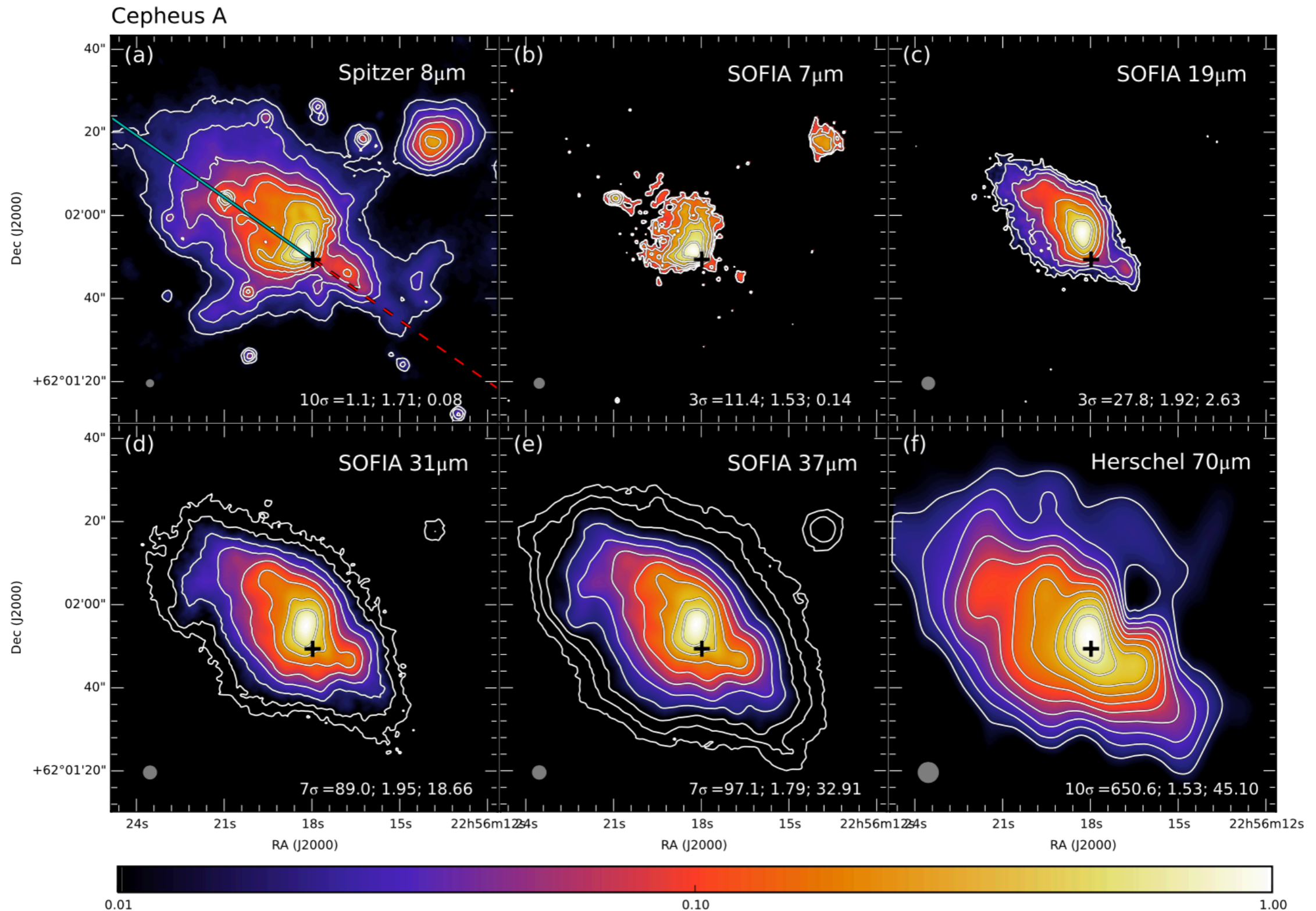
Magnetic fields in Giant Molecular Filaments - FIELDMAPS -



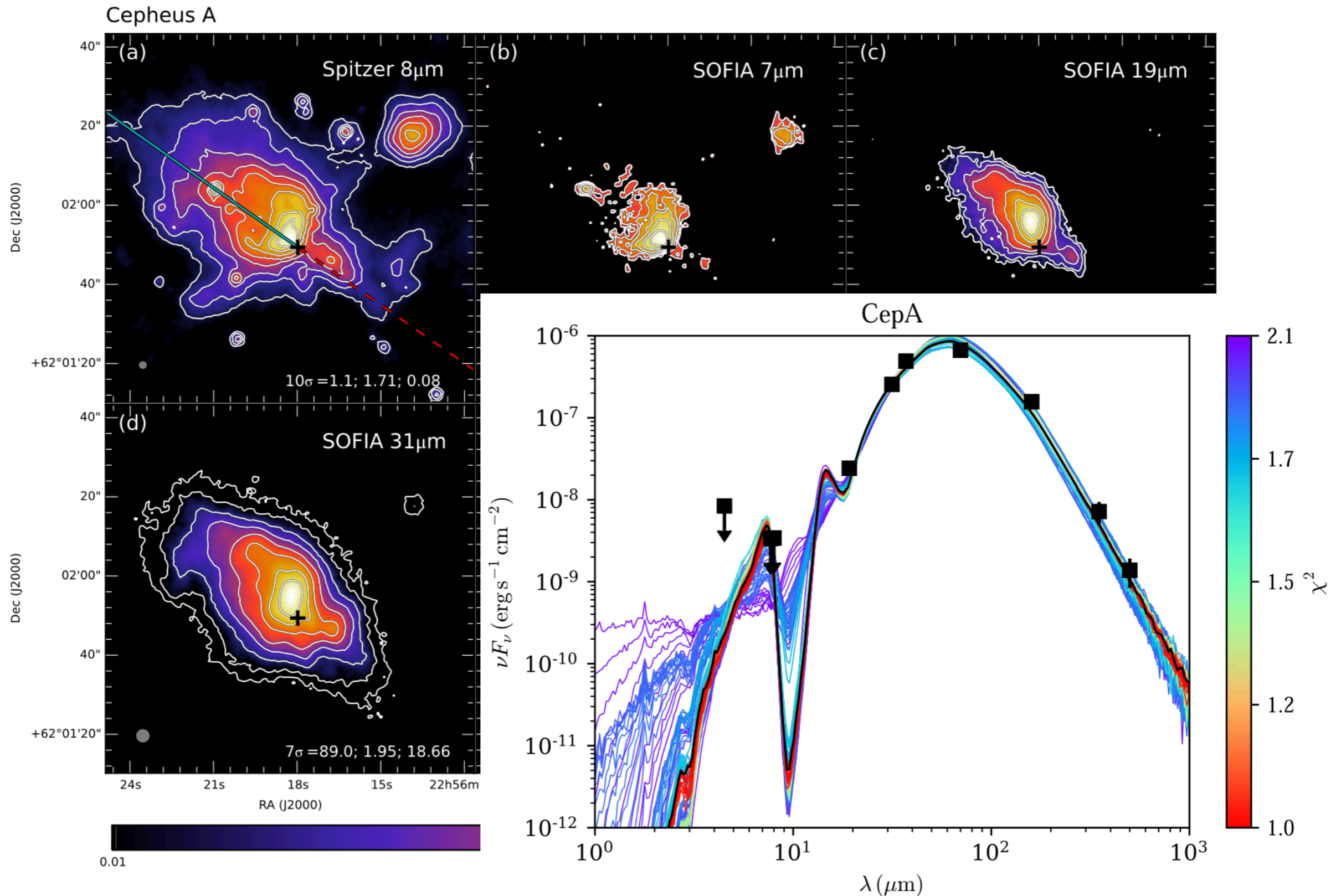
Magnetic fields in Giant Molecular Filaments - FIELDMAPS -



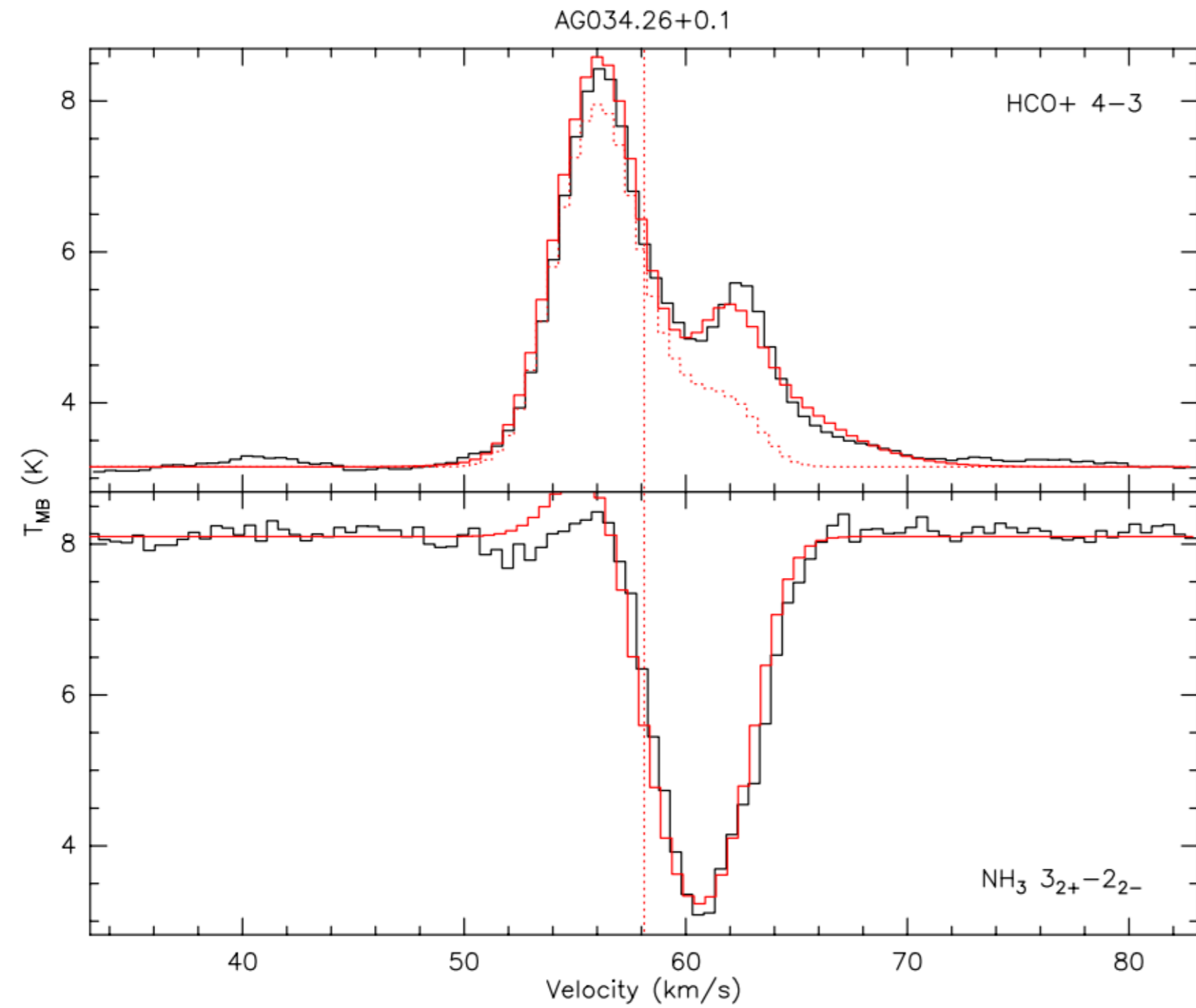
High-mass star formation — SOMA



High-mass star formation — SOMA

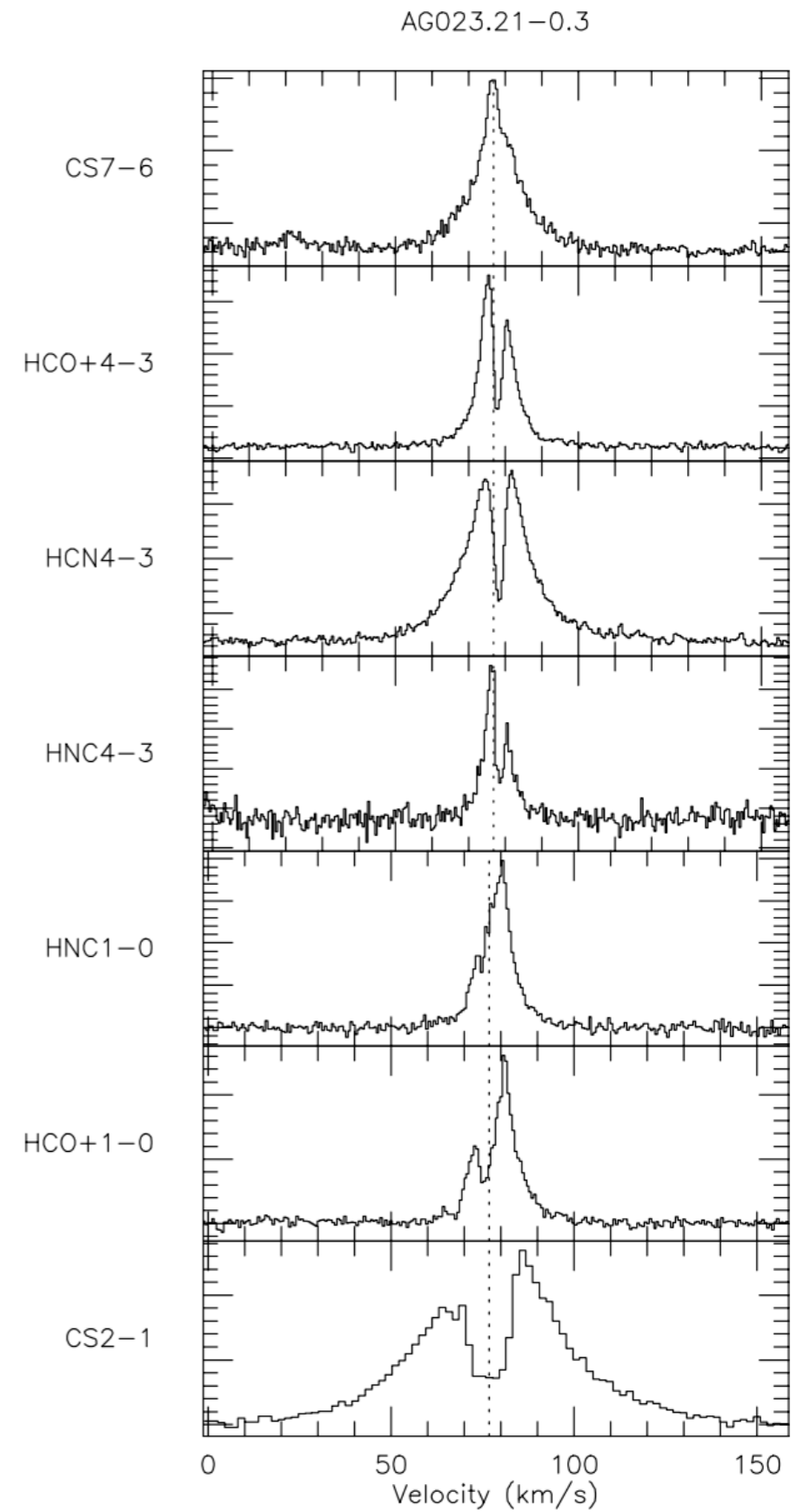
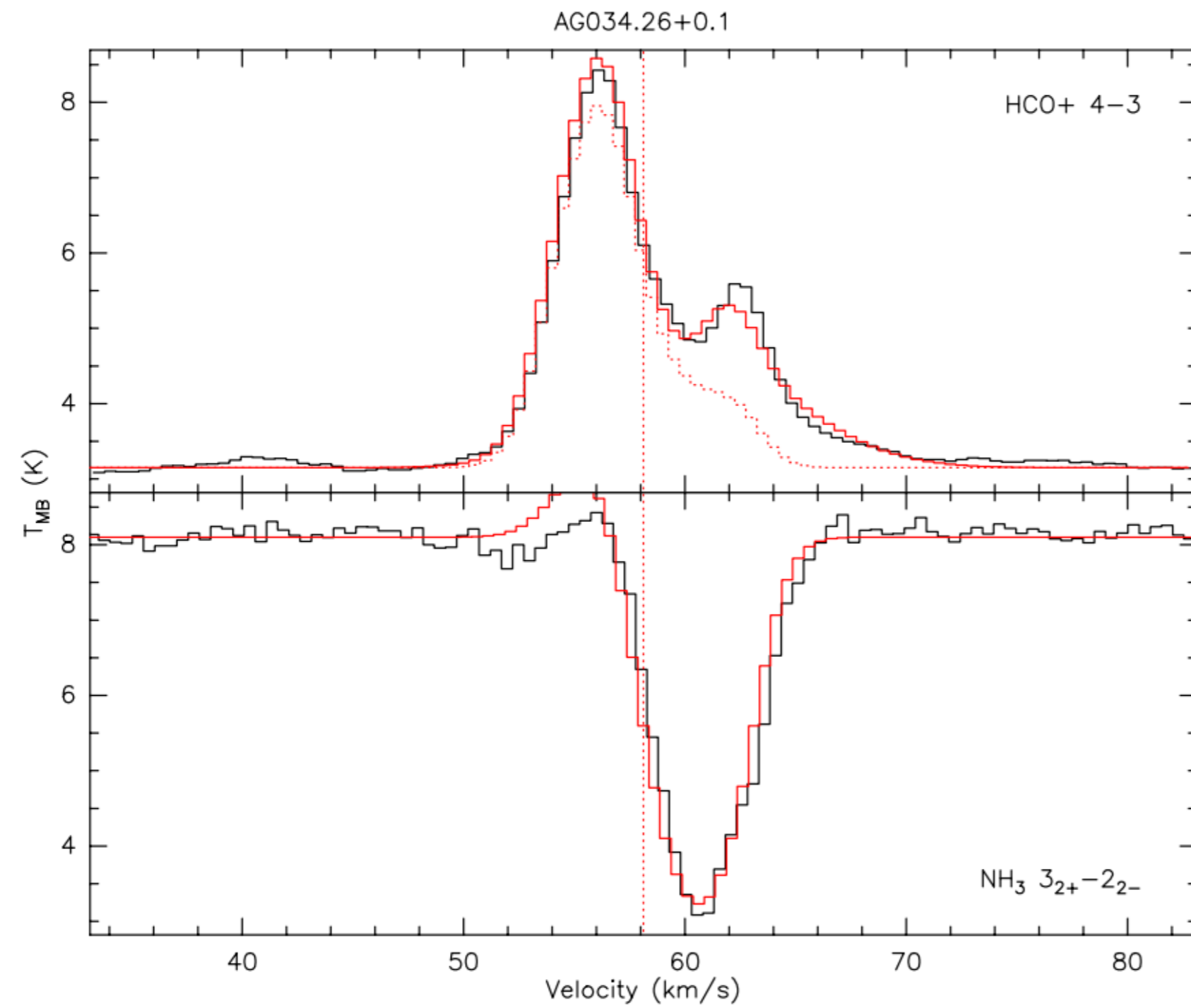


Infall



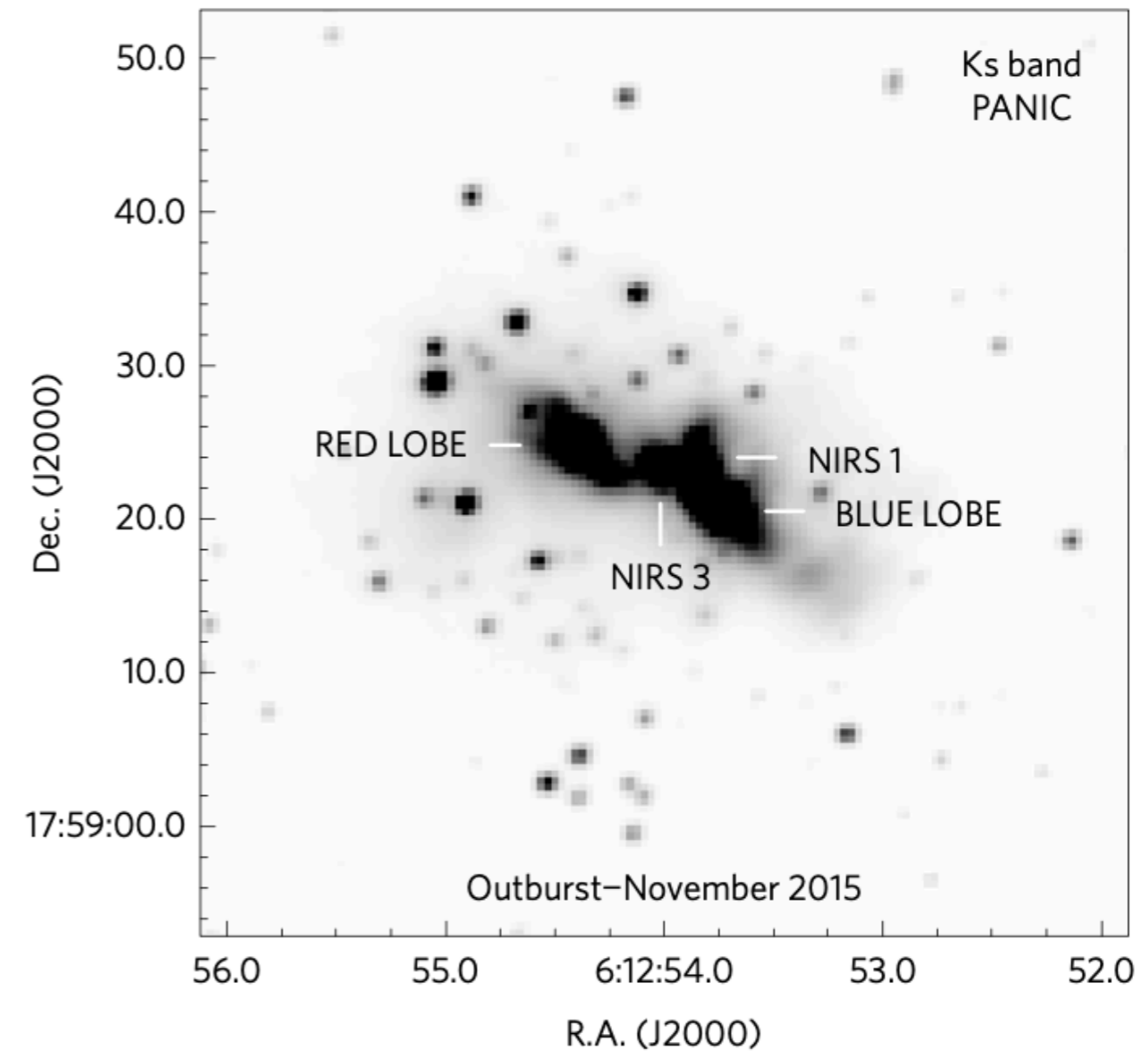
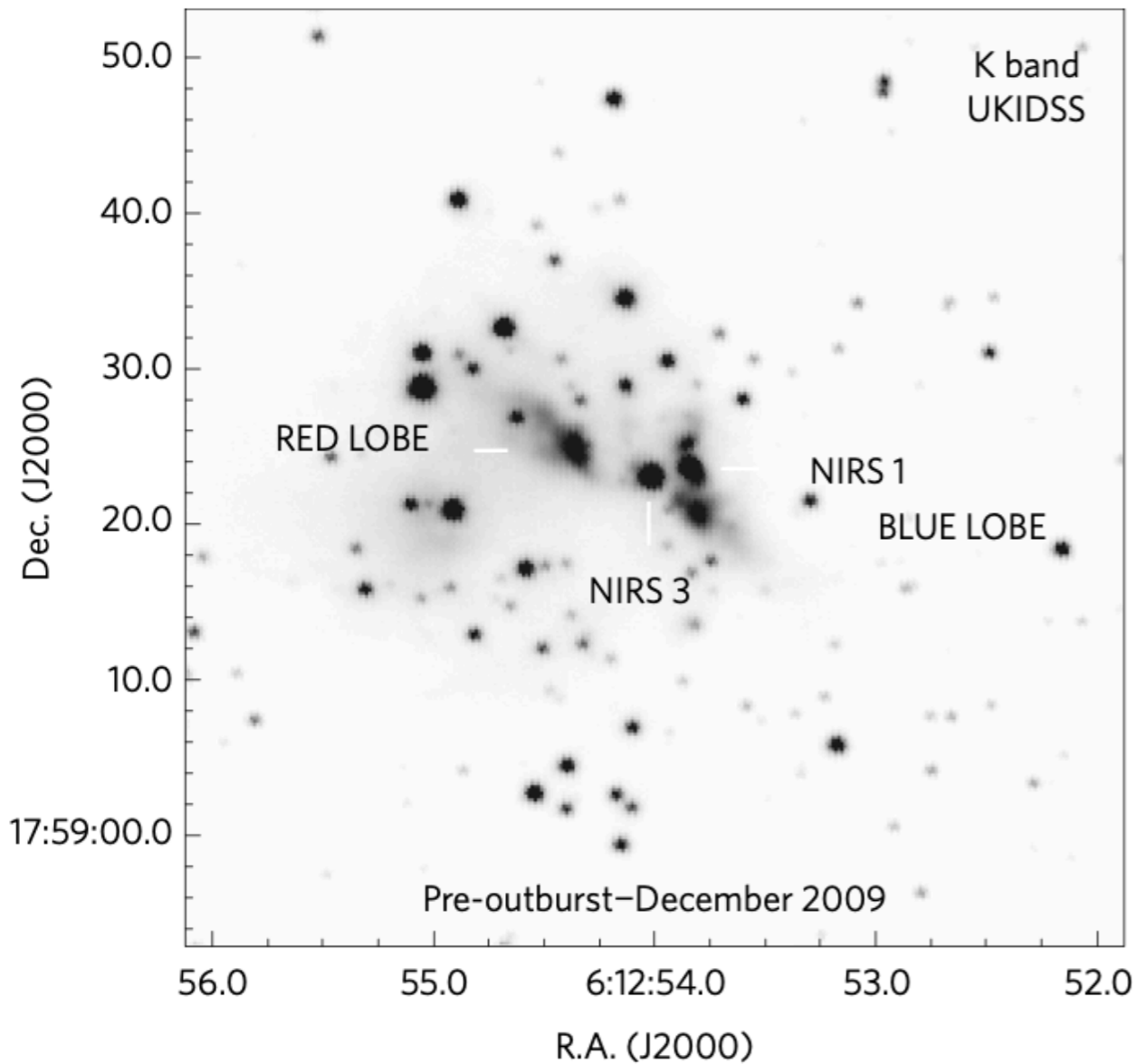
Infall rates typically around $10^{-3} M_{\text{sun}}/\text{yr}$

Infall

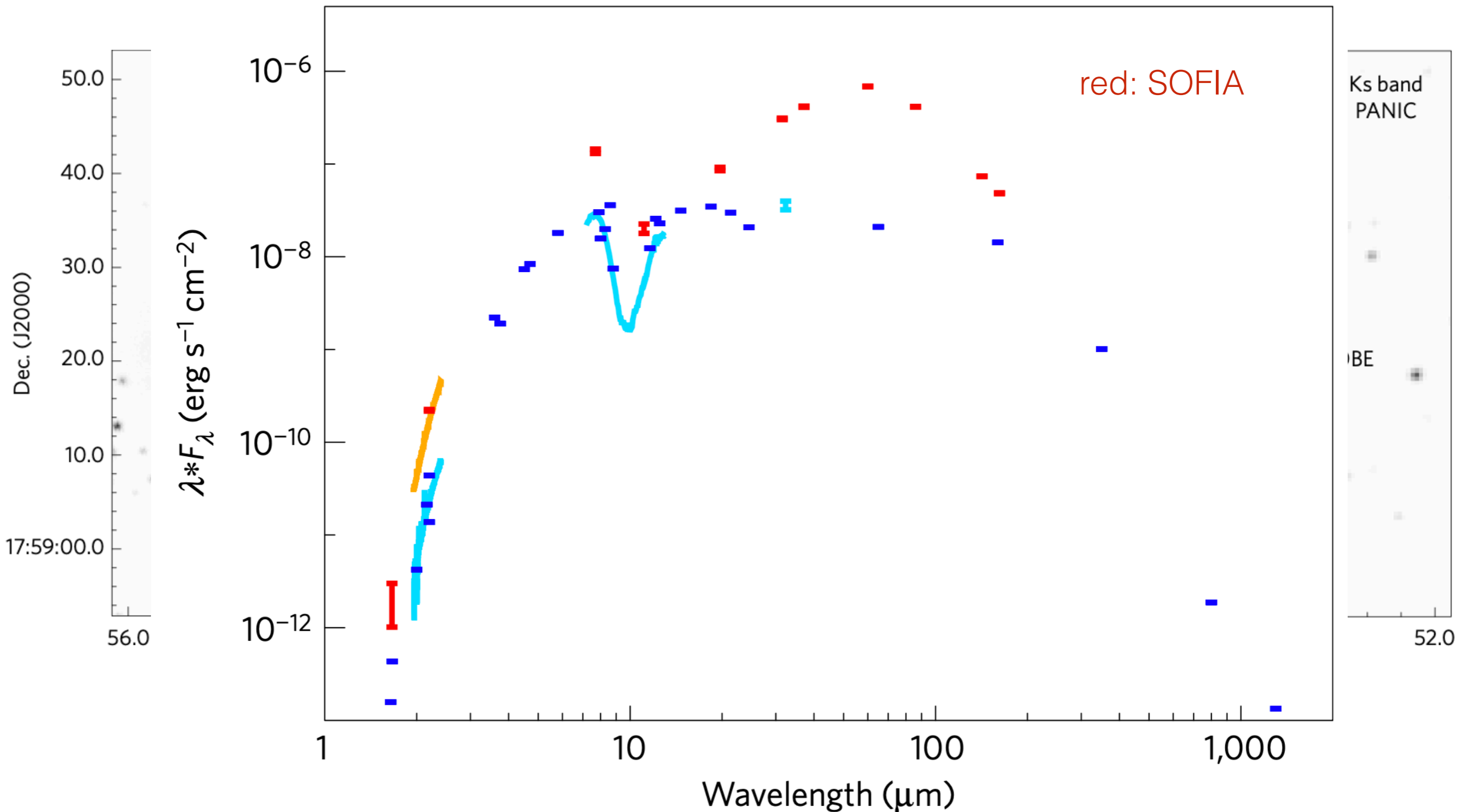


Infall rates typically around $10^{-3} M_{\text{sun}}/\text{yr}$

Accretion bursts and variability

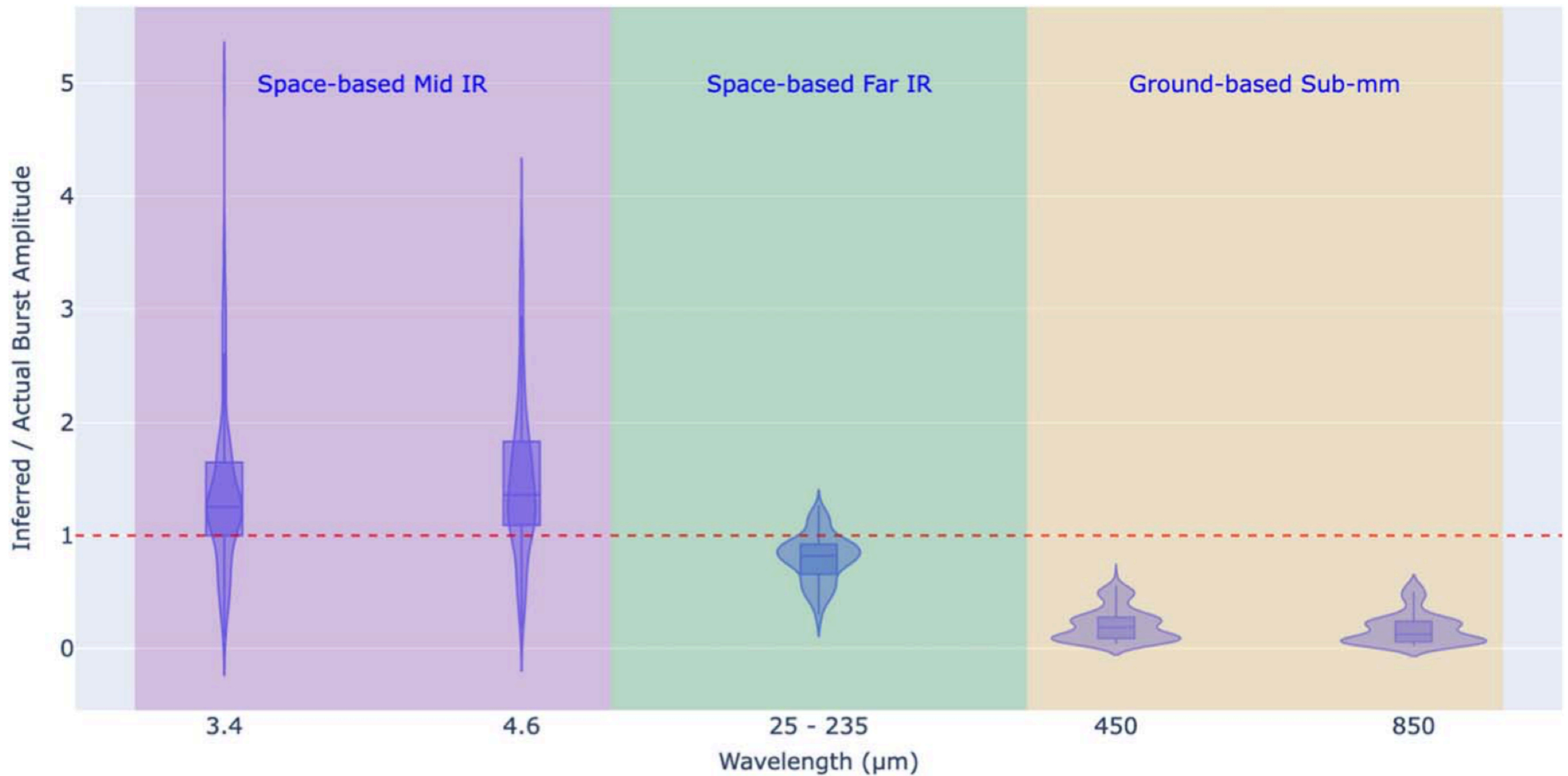


Accretion bursts and variability

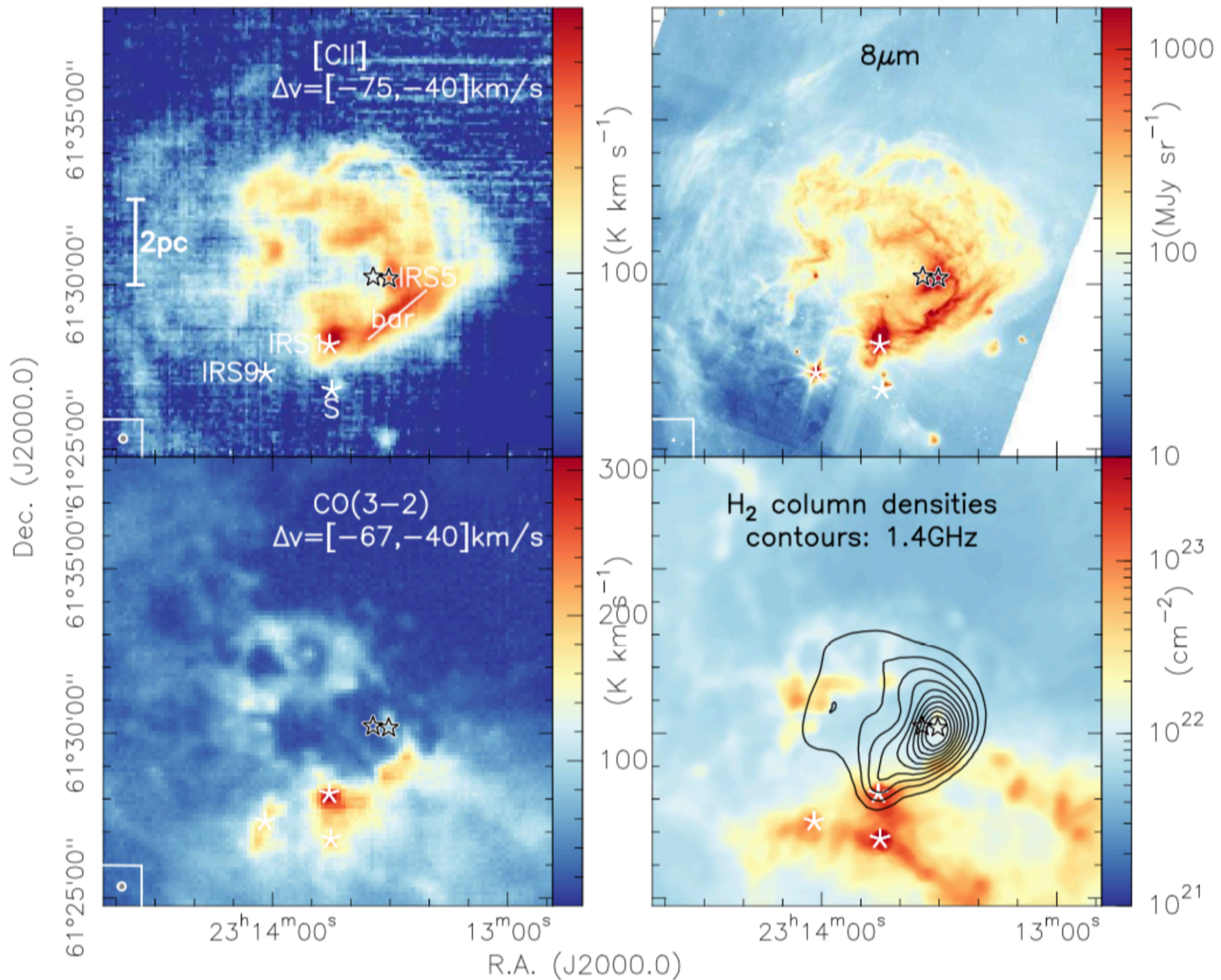


Accretion rate $\sim 5 \times 10^{-3} M_{\text{sun}}/\text{yr}$

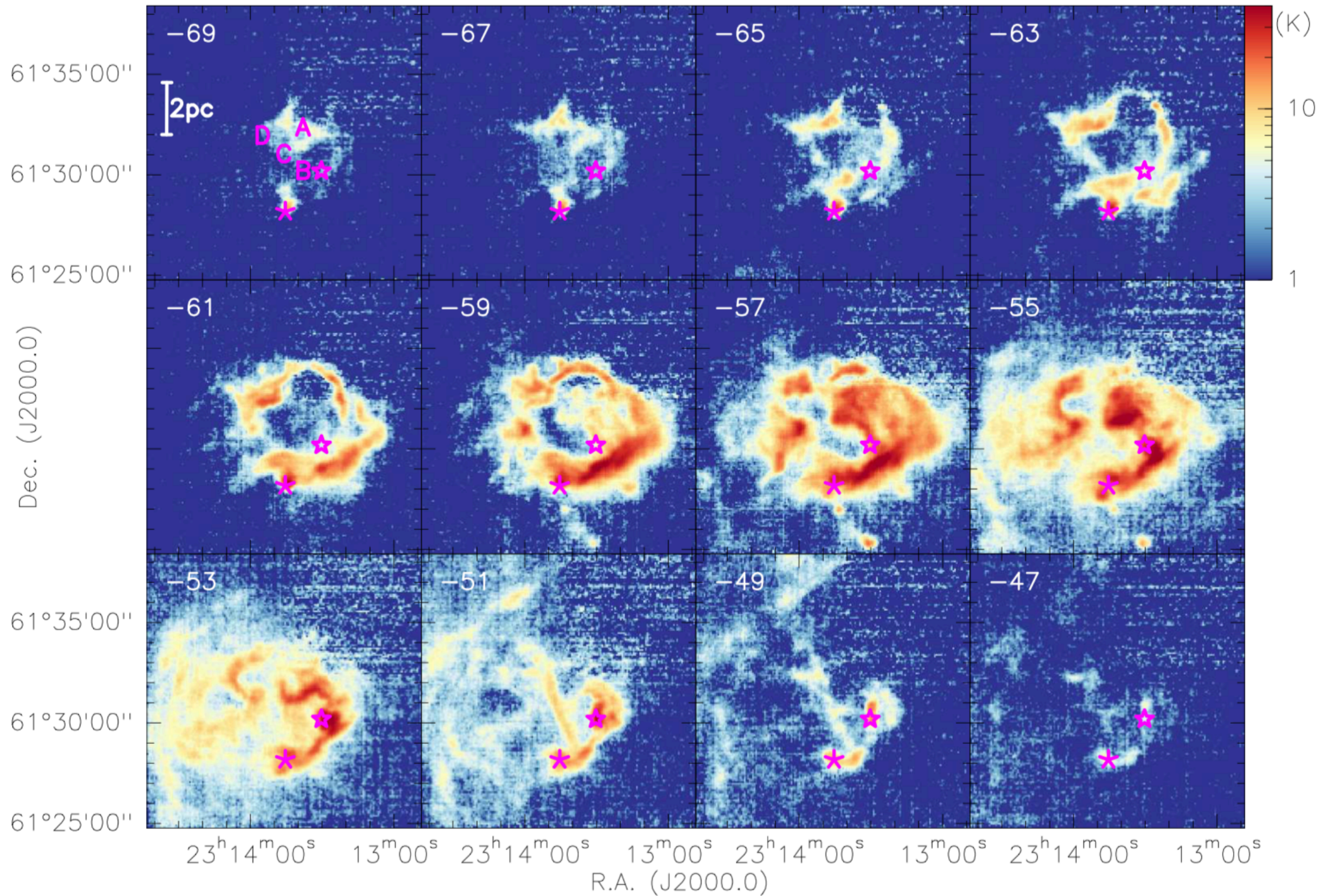
Burst amplitudes at different wavelengths



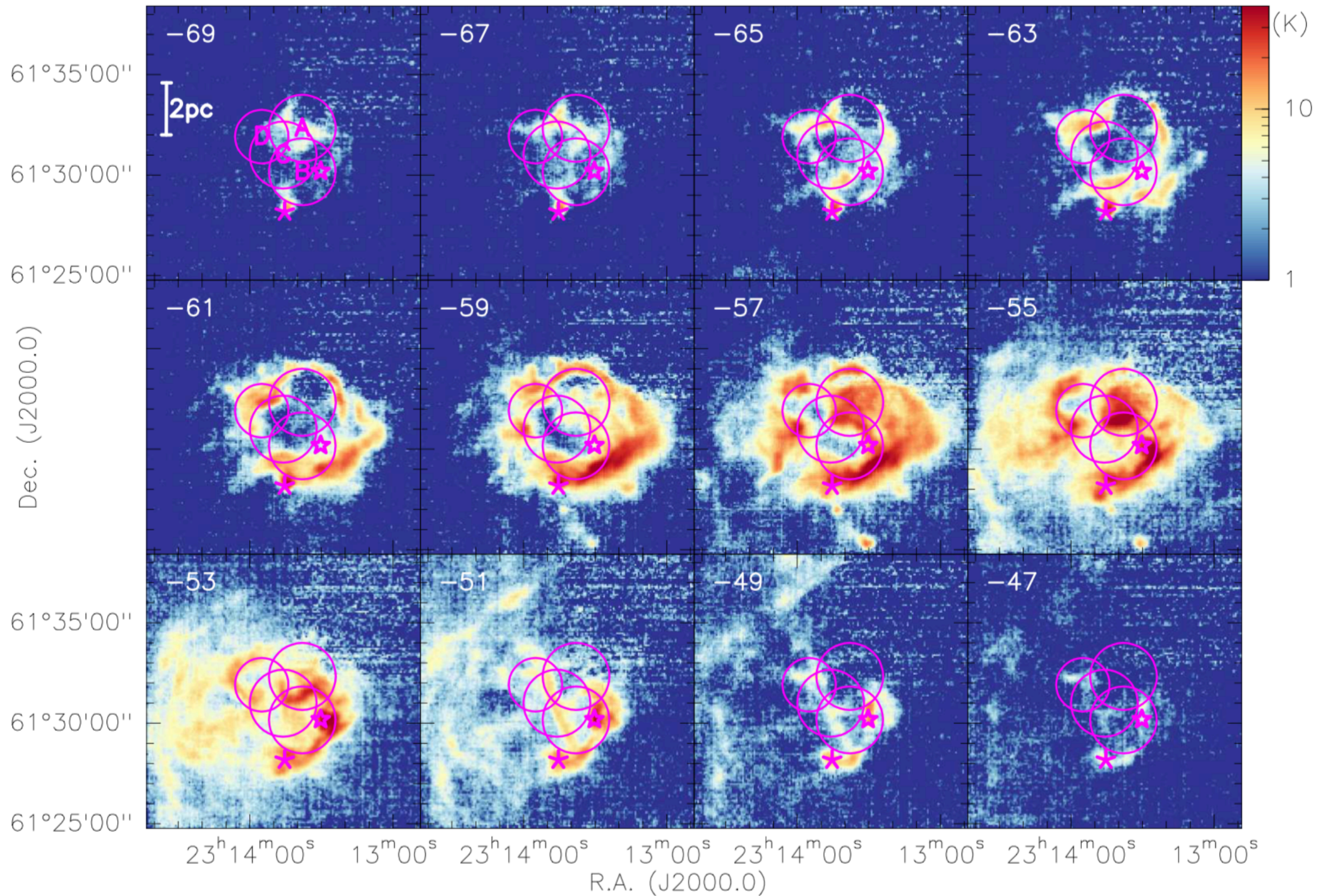
FEEDBACK in NGC7538



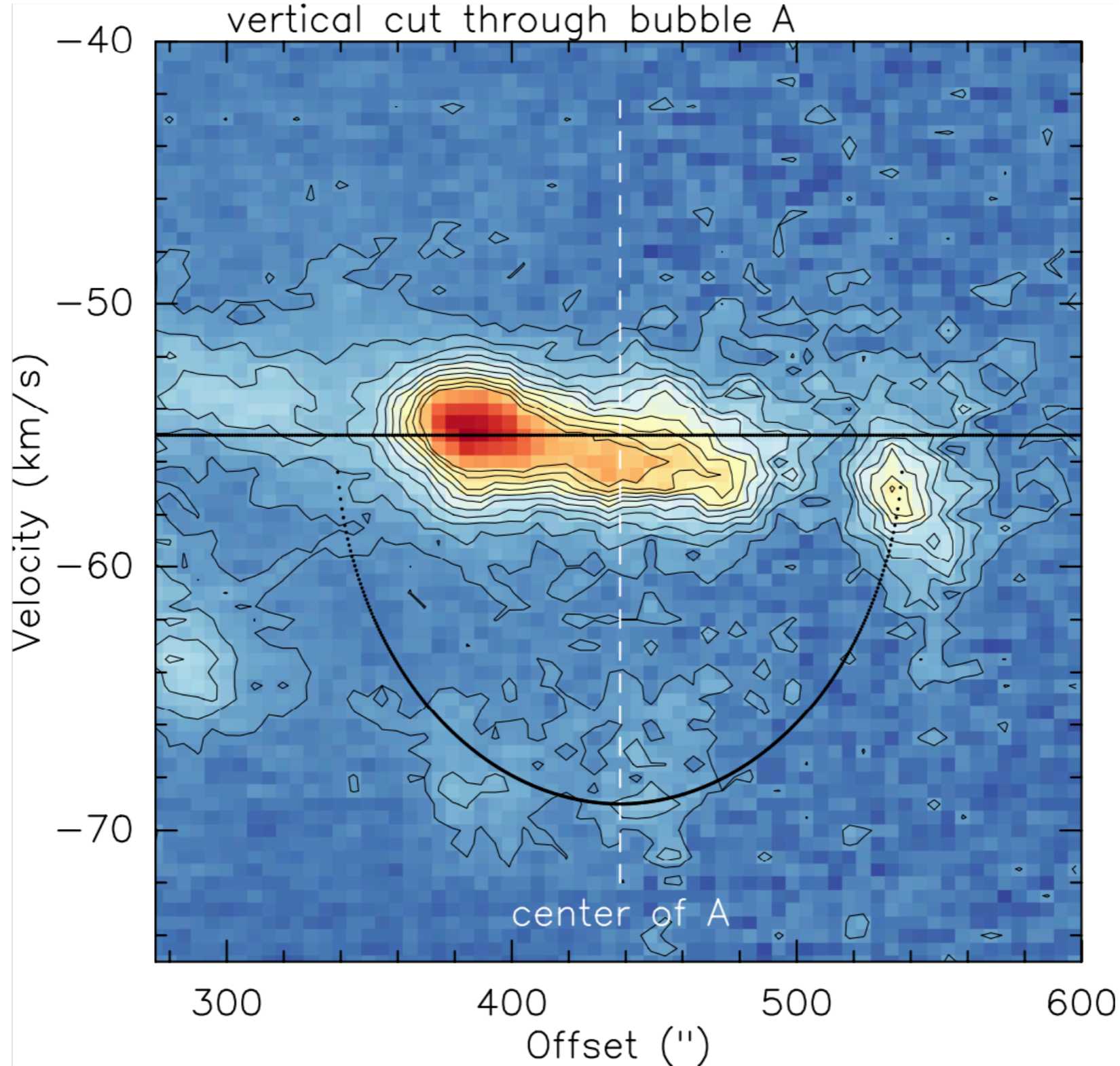
Bubbly HII region NGC7538



Bubbly HII region NGC7538

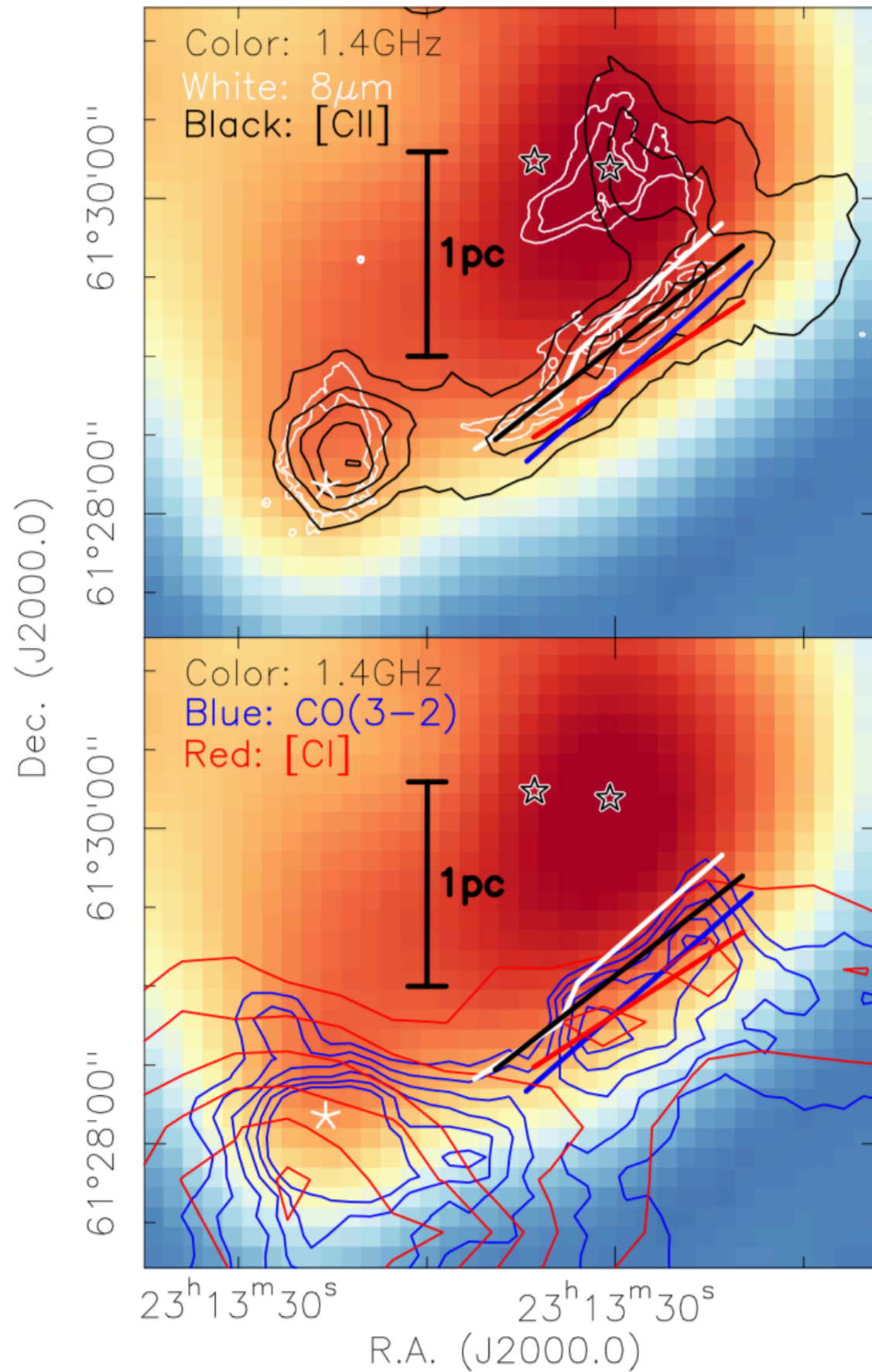


Position-velocity cut

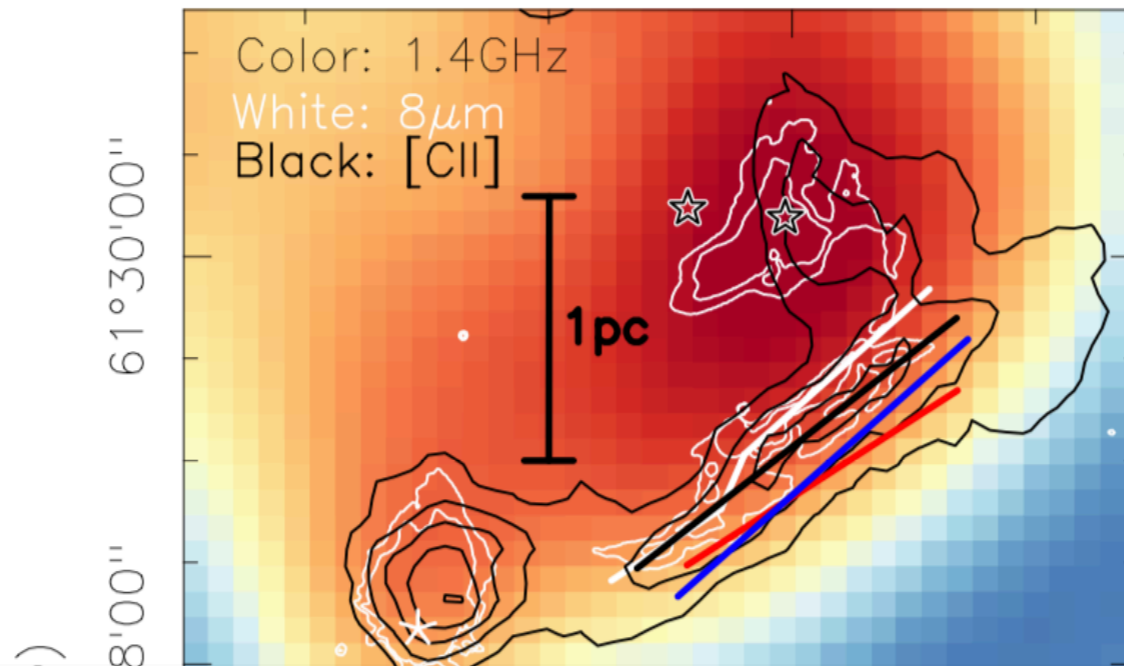


—> only wind-driving can explain pv-diagram

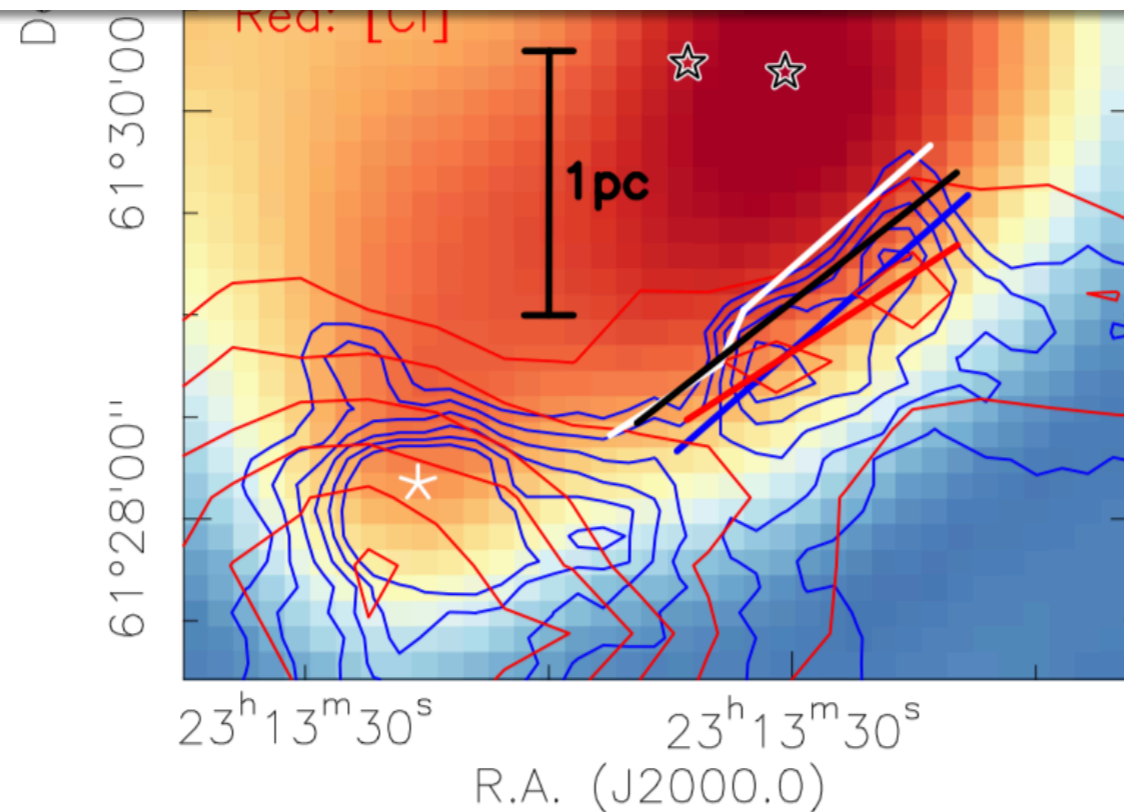
Bar-shaped PDR



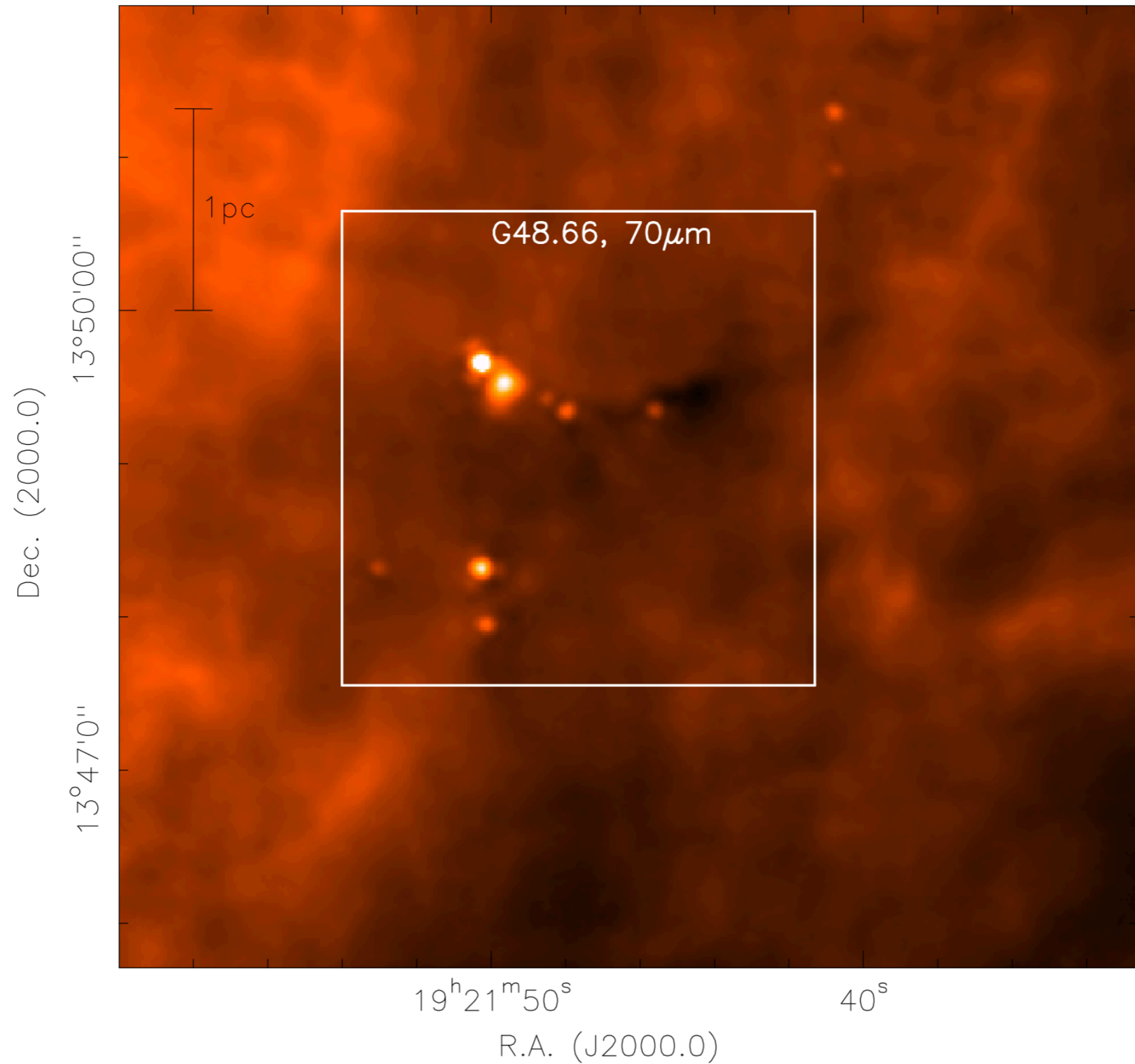
Bar-shaped PDR



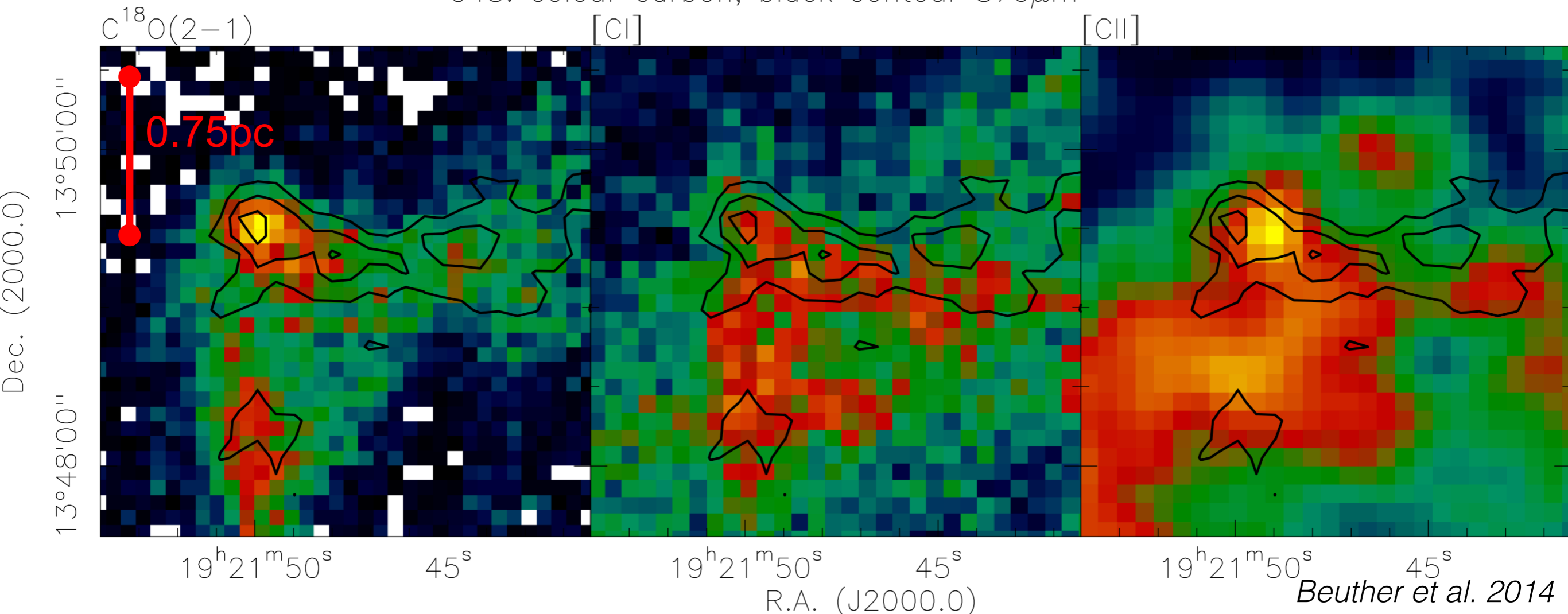
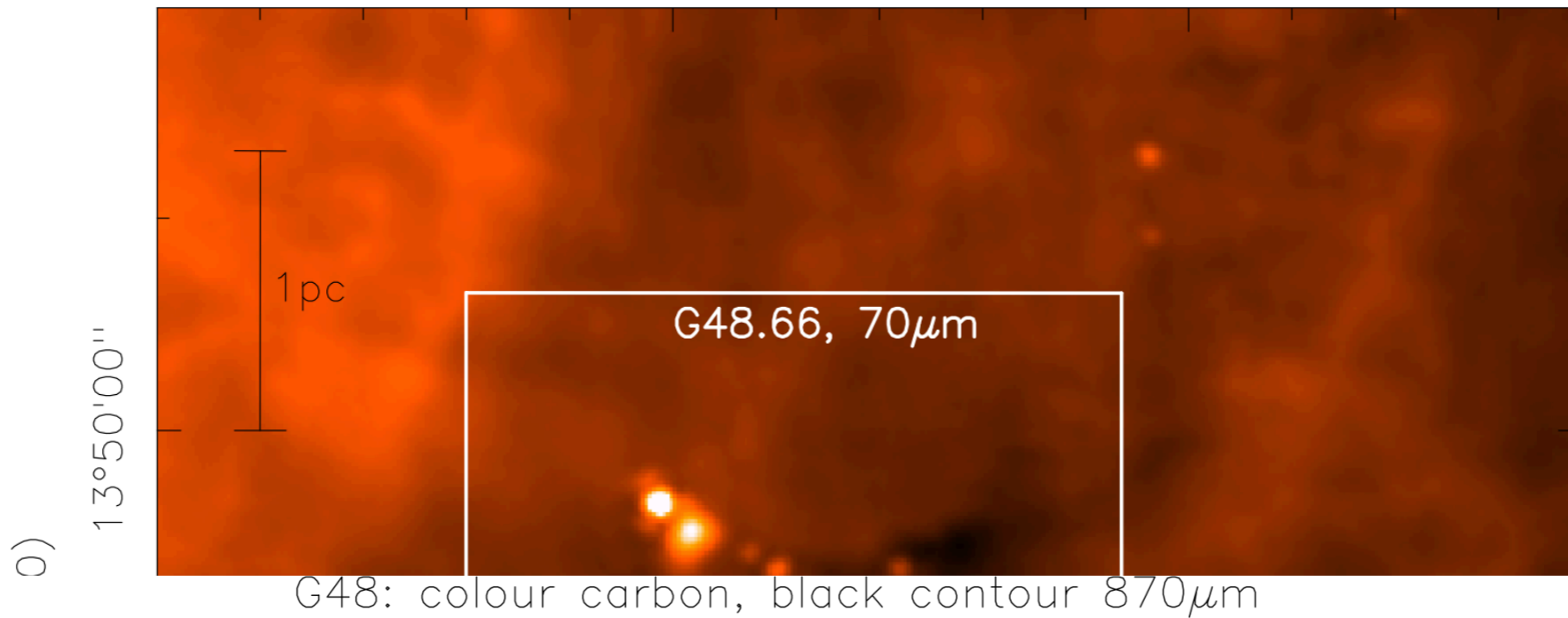
Mass molecular		atomic		ionised carbon
0.8		0.5		3.6 M_{sun}



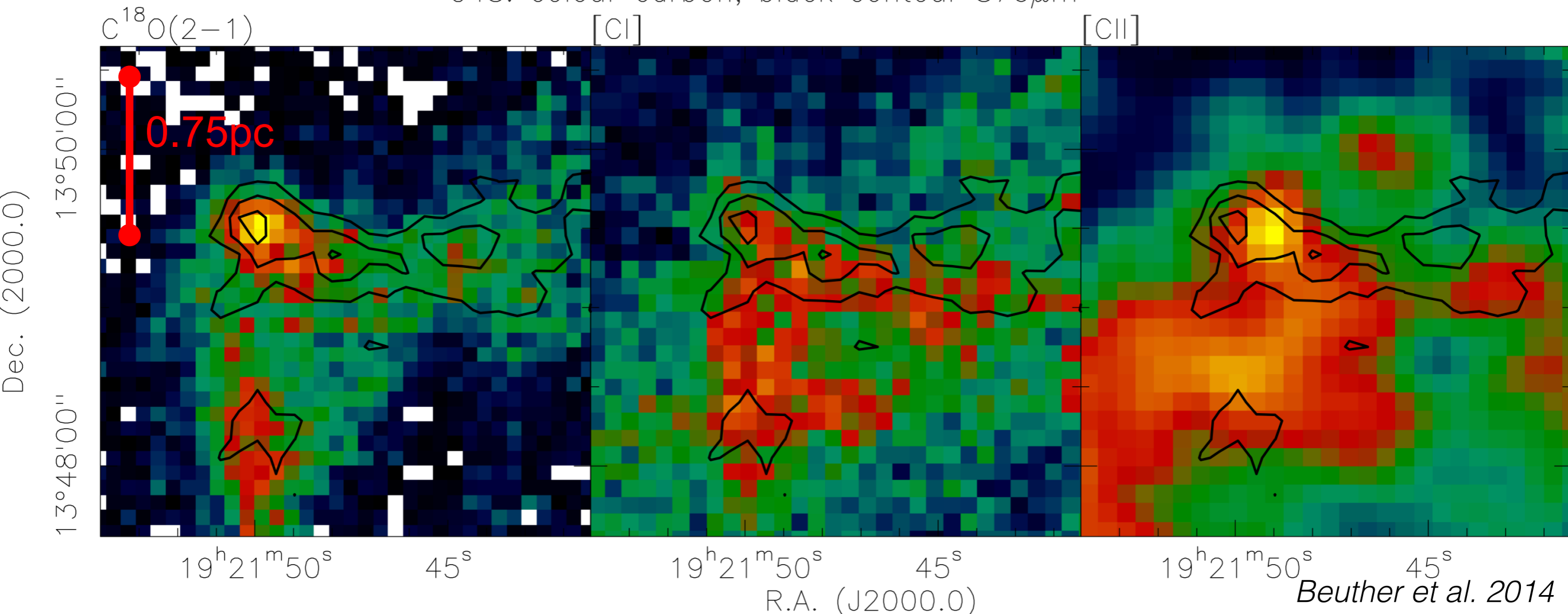
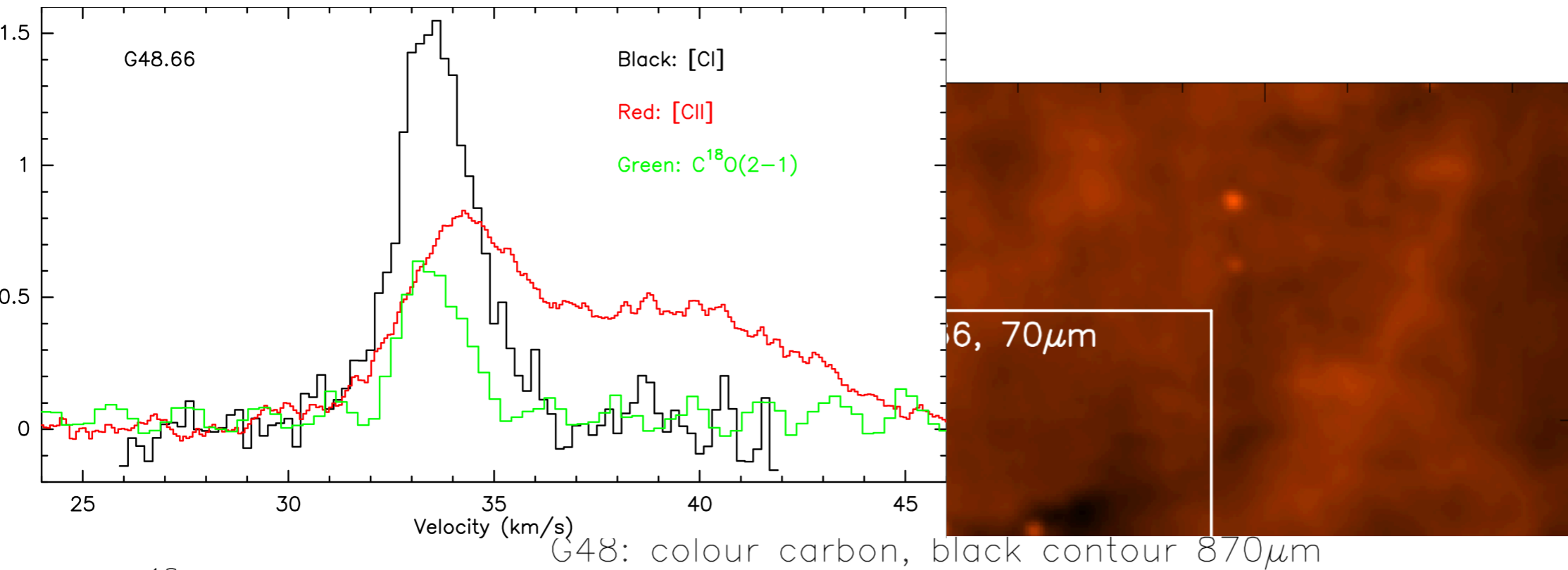
[CII] during cloud formation



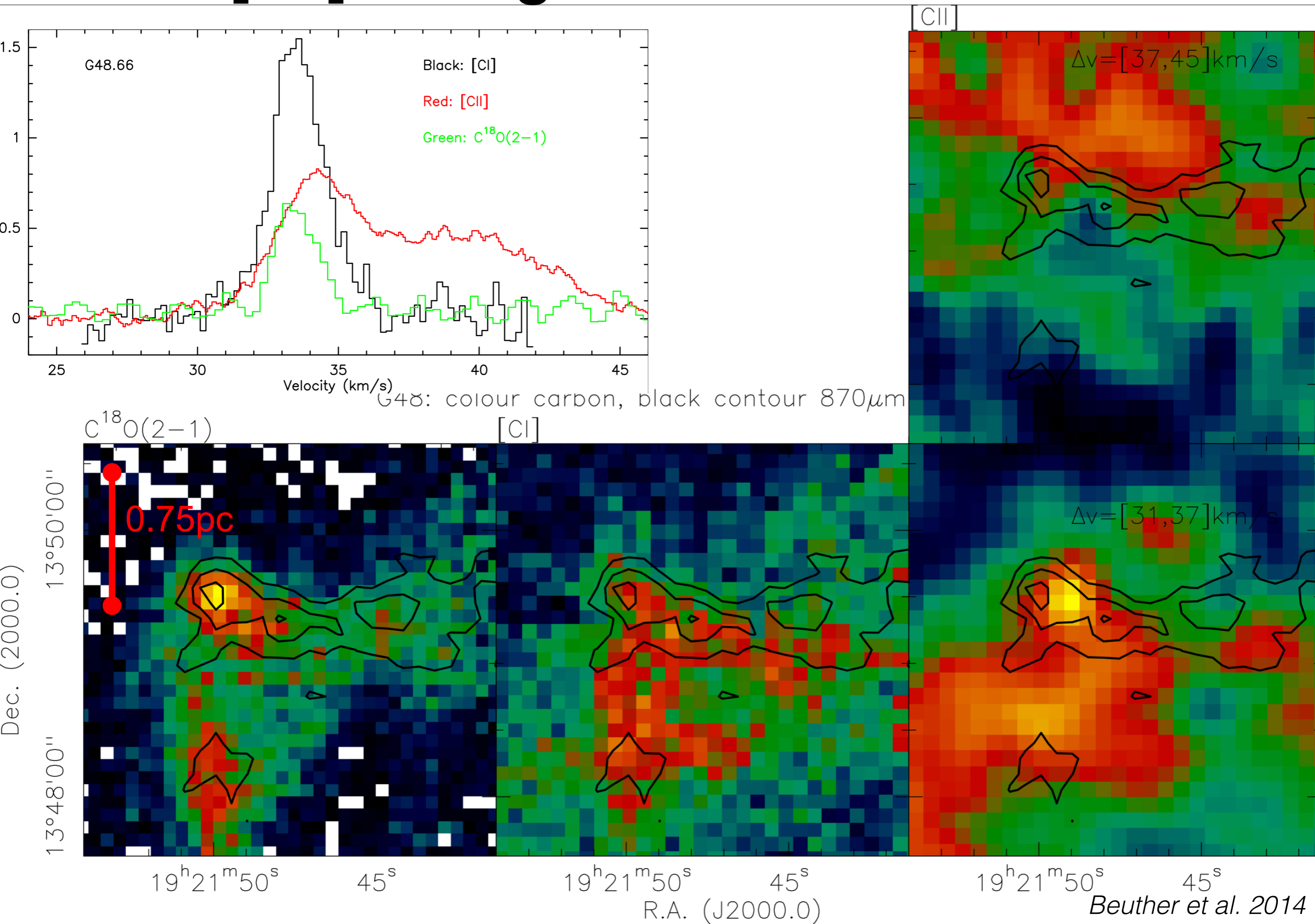
[CII] during cloud formation



[CII] during cloud formation



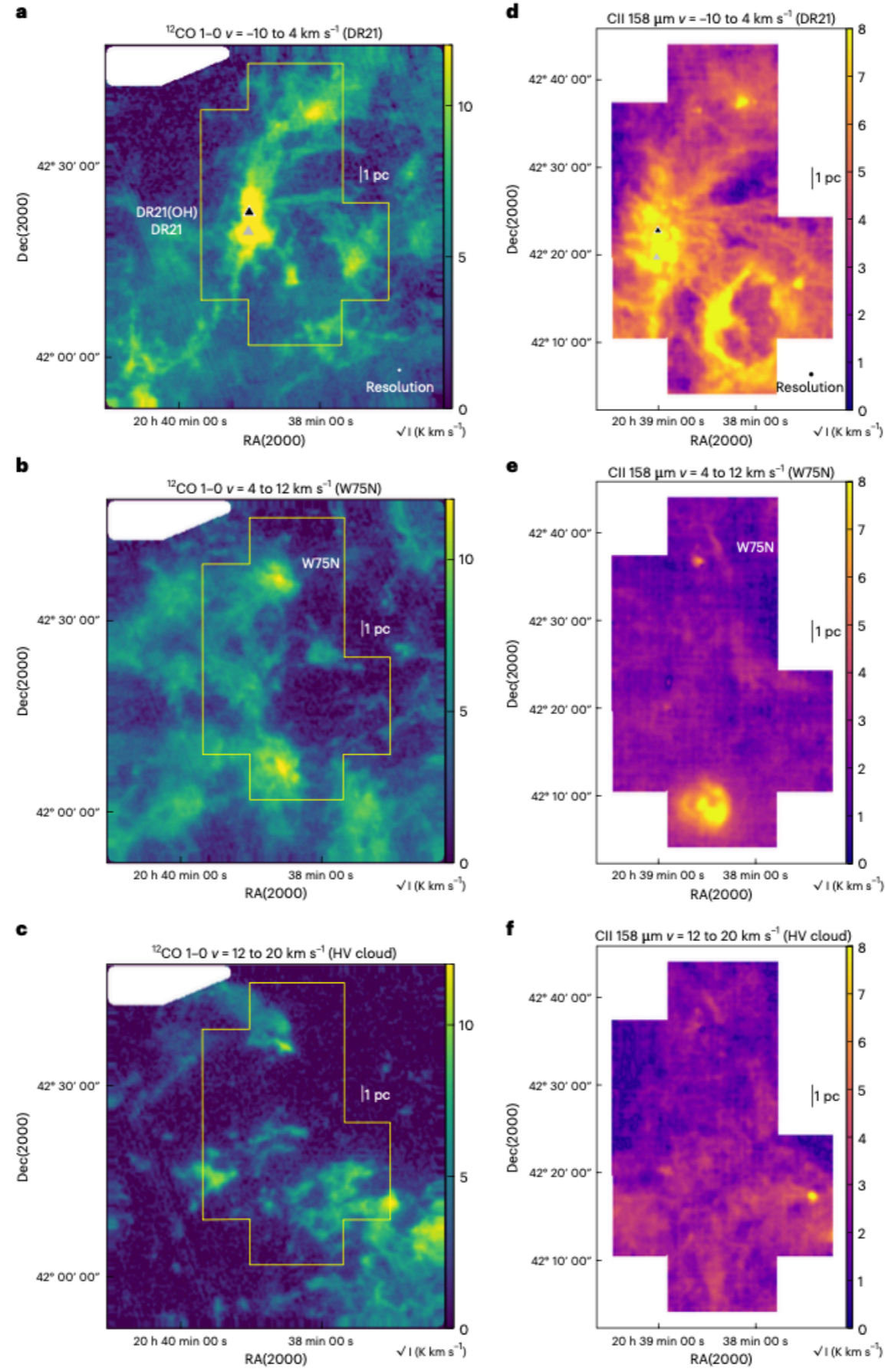
[CII] during cloud formation



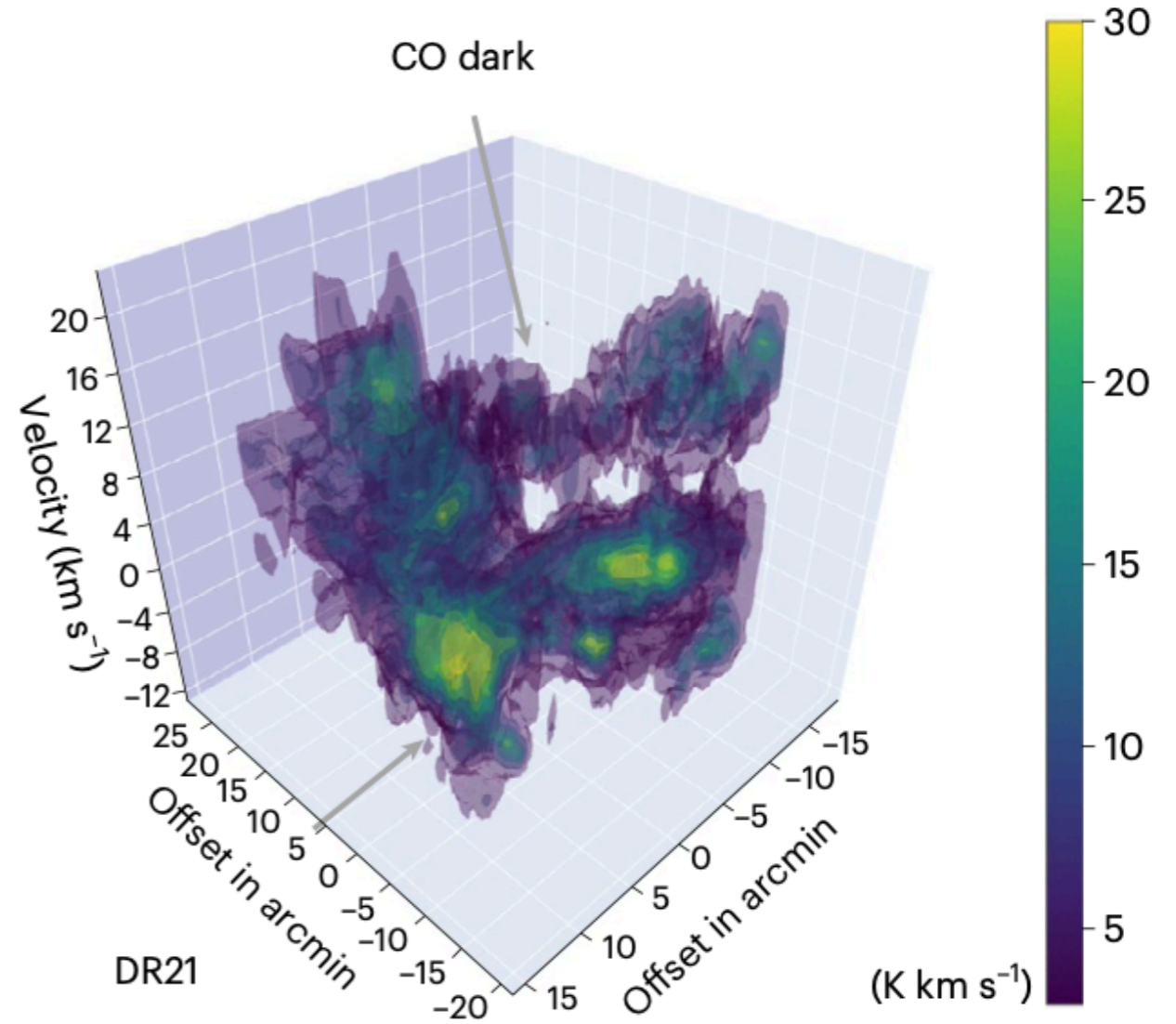
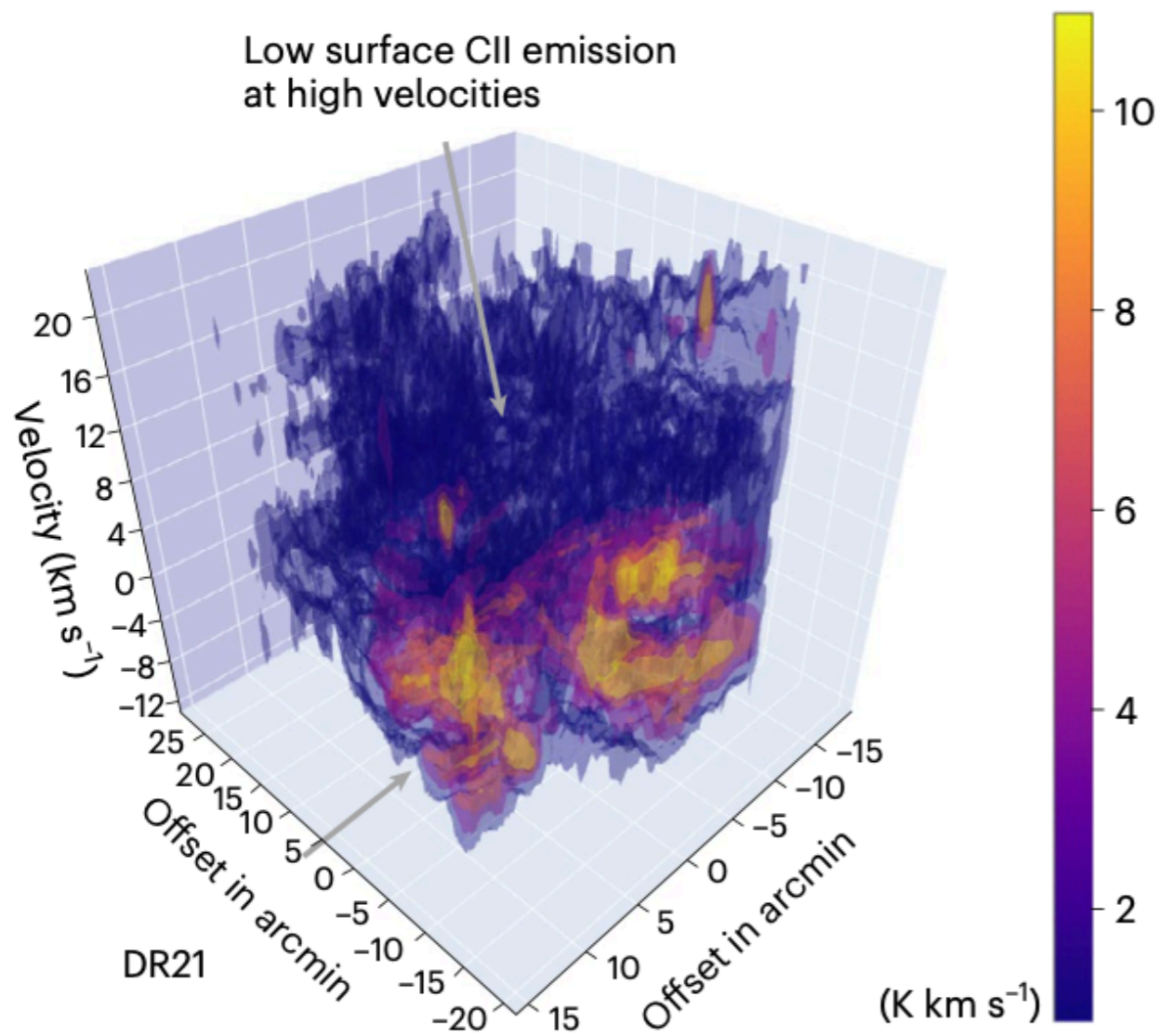
[CII] as cloud formation tracer

CO

[CII]



[CII] as cloud formation tracer



What other facilities, now and future

Balloons:

BLASPOL: Polarization and magnetic fields

GUSTO: (launch Dec 31, 2023, 55+ days):

[CII], [OI], and [NII] at 158, 63, and 205 mm

ASTHROS: (launch Dec. 2024): [NII]

NASA PROBES:

PRIMA: 1.8m, low-res spectroscopy 24-235 μ m,
polarization

SALTUS: 14m, low-res (34-230) & high-res (56-660 μ m)
spectroscopy

FIRSST: 1.8m, 35-600 μ m, high spectral resolution,
heterodyne focal plane array

Summary

Paraphrasing Erick Young:

You can't escape the far-infrared!

