FAR-INFRARED FINE STRUCTURE COOLING IN DARK MOLECULAR CLOUDS

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CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

MARIE CURIE ACTIONS

BACKGROUND & MOTIVATION

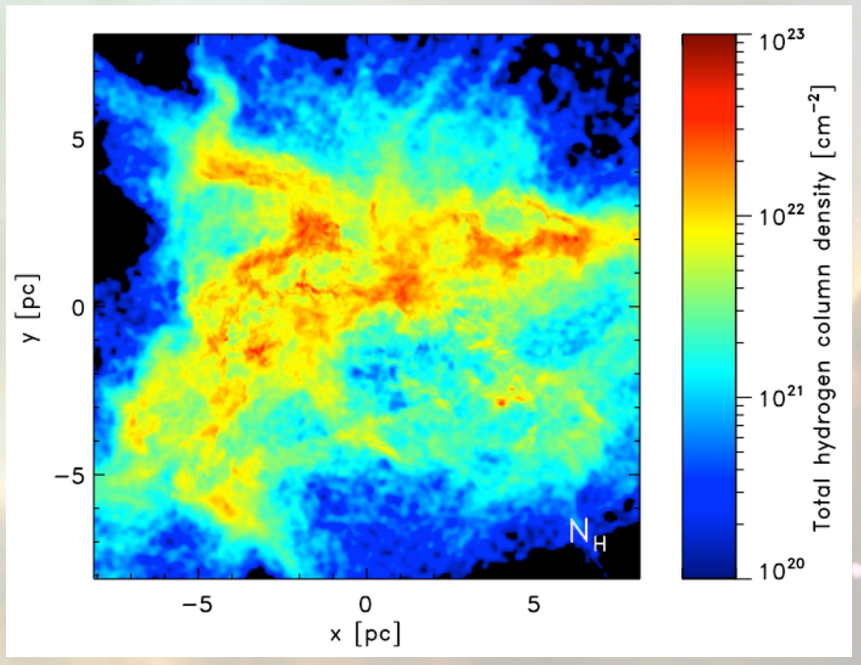
- Star formation depends on cloud formation
- Cloud formation depends on environment
- FIR fine structure lines give new constraints on both!

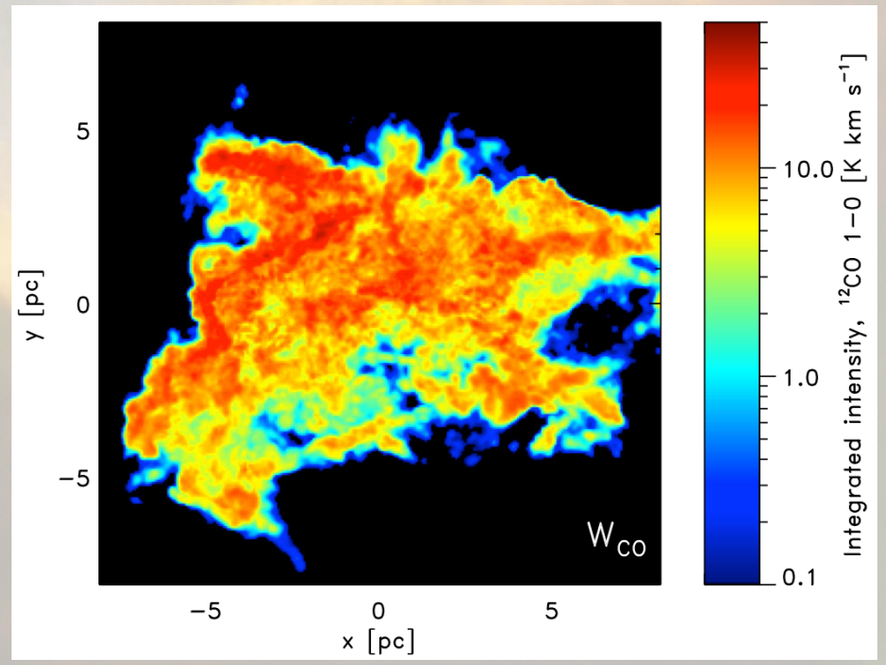
OUTLINE

- Modelling cooling in the CMZ: how does cooling change in extreme environments?
  - Bertram, Glover, Clark, Ragan, & Klessen (2016, & in prep.)
  - Clark, Glover, Ragan, Shetty & Klessen (2013)
- Probing the ionised, atomic and molecular phases of carbon in IRDCs: a velocity-resolved study of the dynamics of cloud formation
  - Beuther, Ragan et al. (2014)
- Cooling in IRDCs: using FIFI-LS to explore environmental dependence of cooling in IRDCs
  - Ragan, Linz et al. (in prep.)

SIMULATIONS

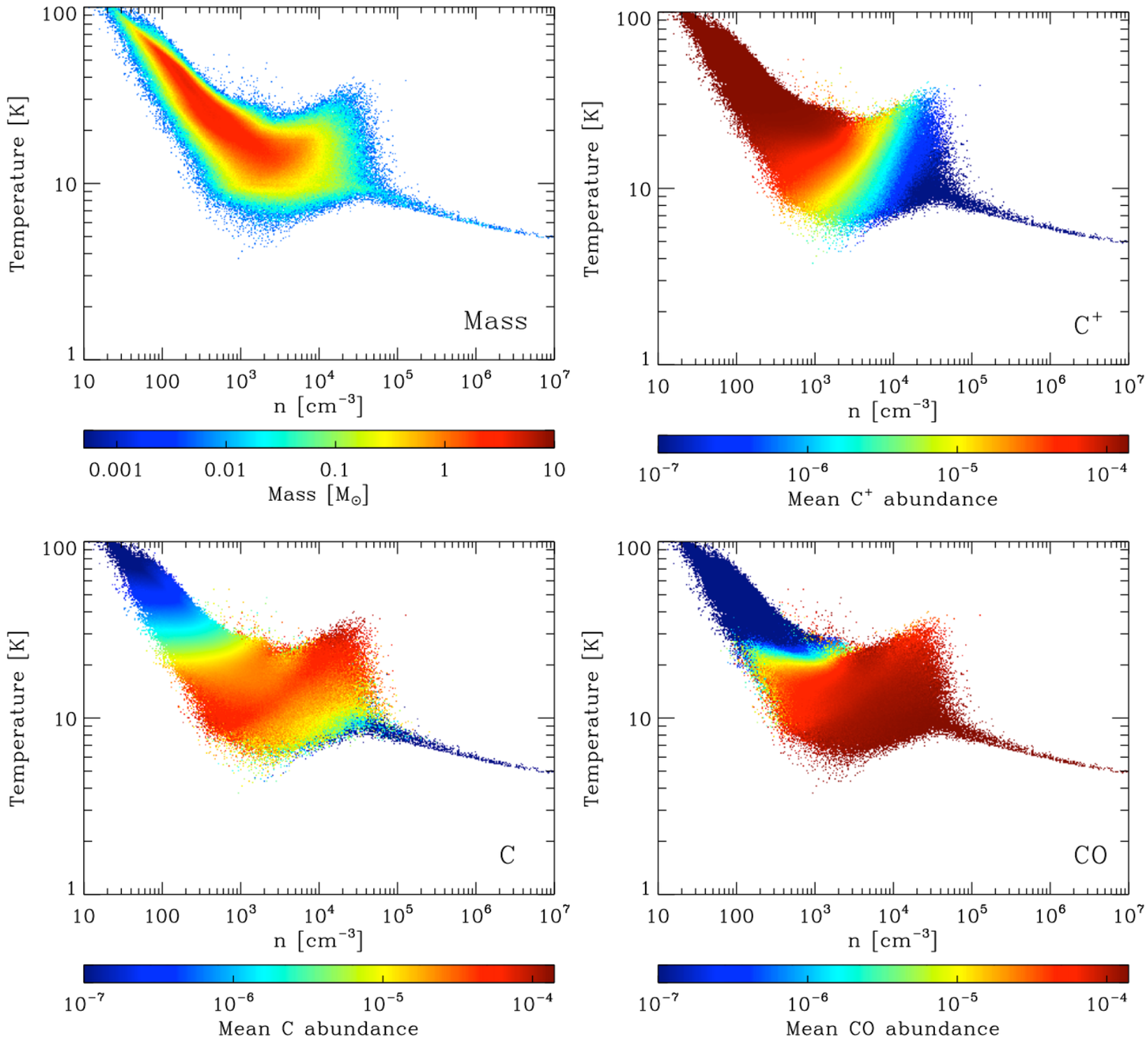
- Turbulent molecular clouds modelled with GADGET-2 & AREPO
- Simple treatment of gas chemistry (Glover & MacLow 2007)
- Atomic & molecular cooling function (Glover et al 2010)
- ISRF attenuation (Clark et al 2012)
- Post-processing with RADMC-3D (Dullemond)





Glover et al. (2015)

SIMULATIONS: CARBON TRACERS IN TURBULENT MOLECULAR CLOUDS



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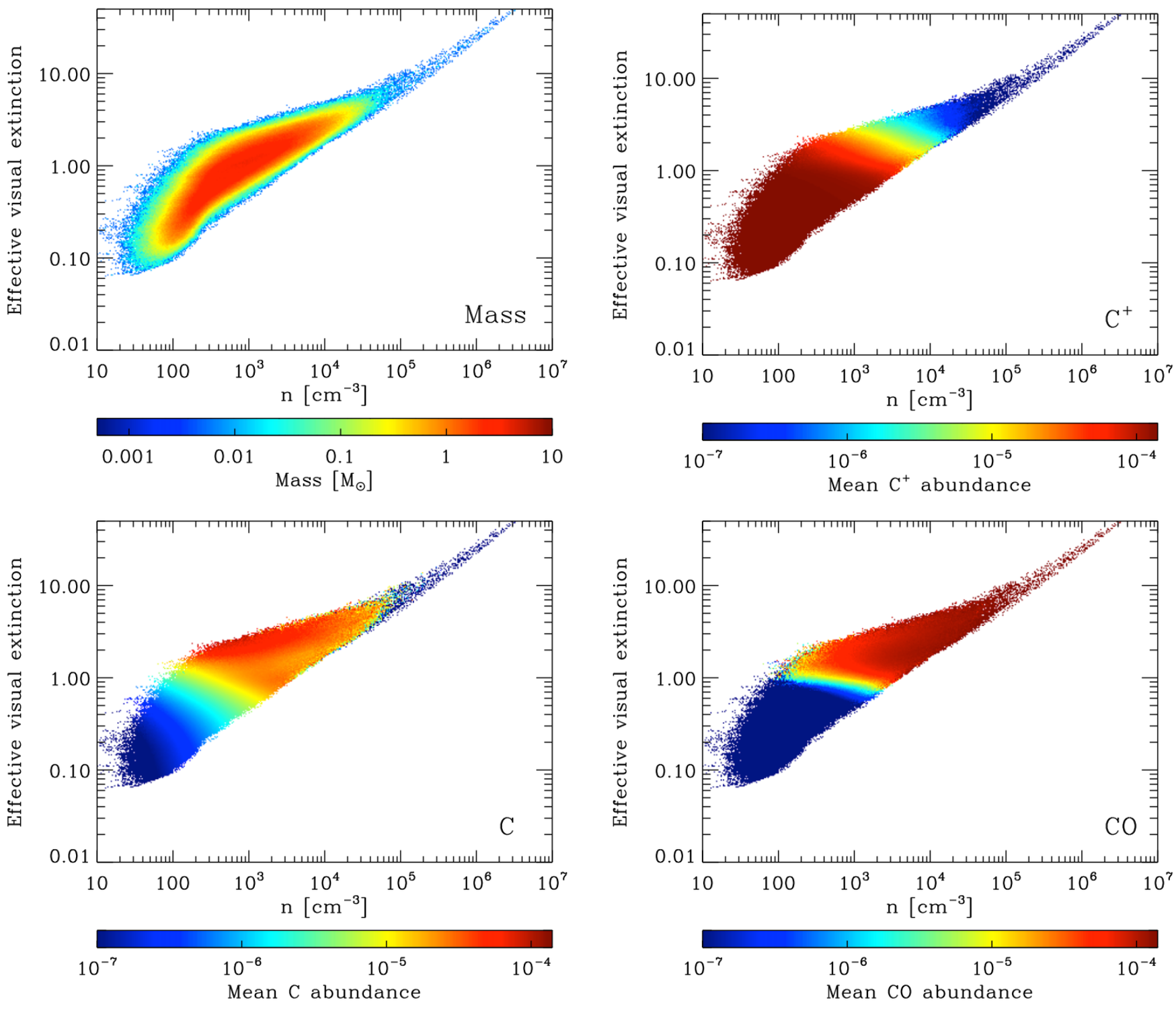

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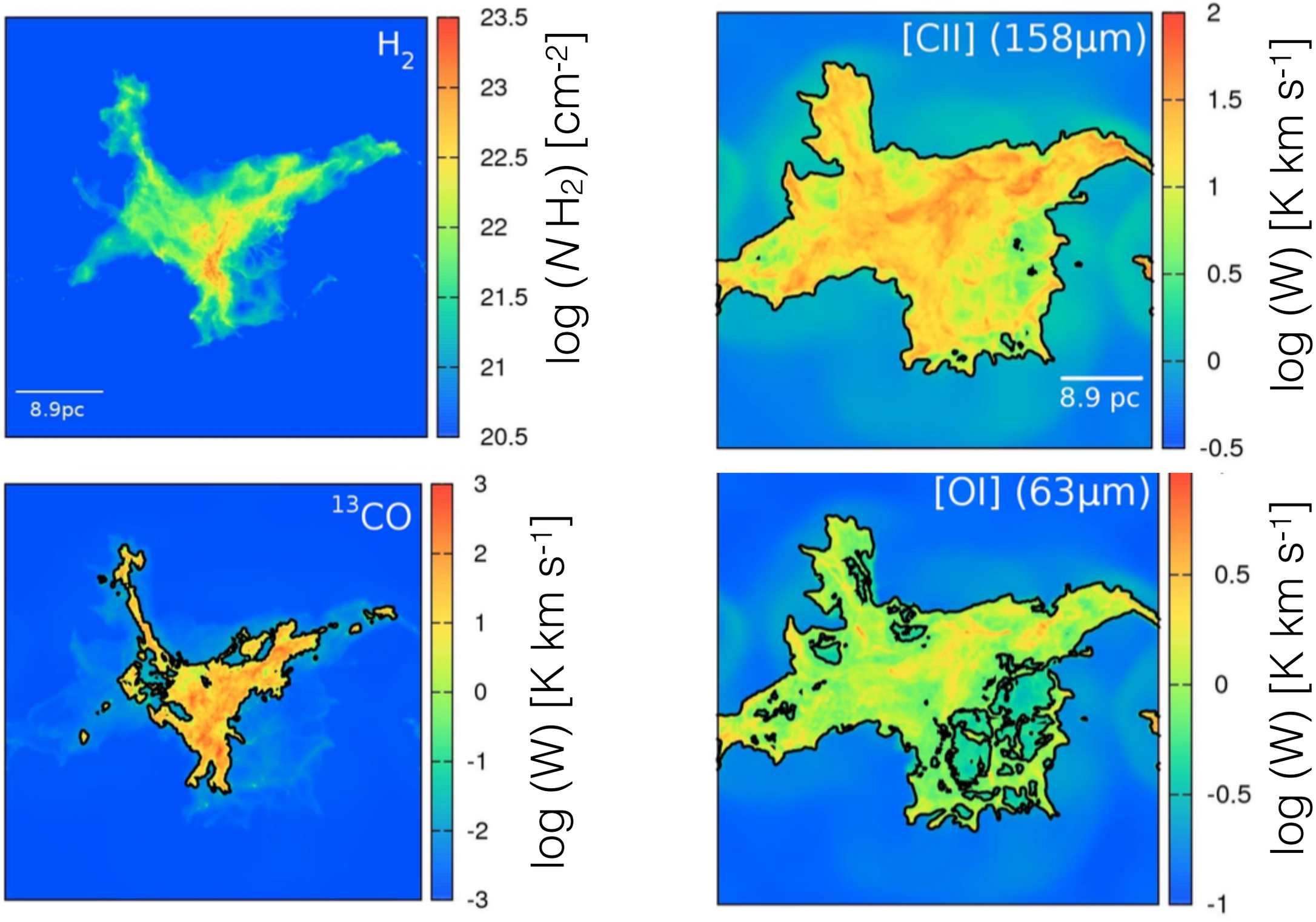

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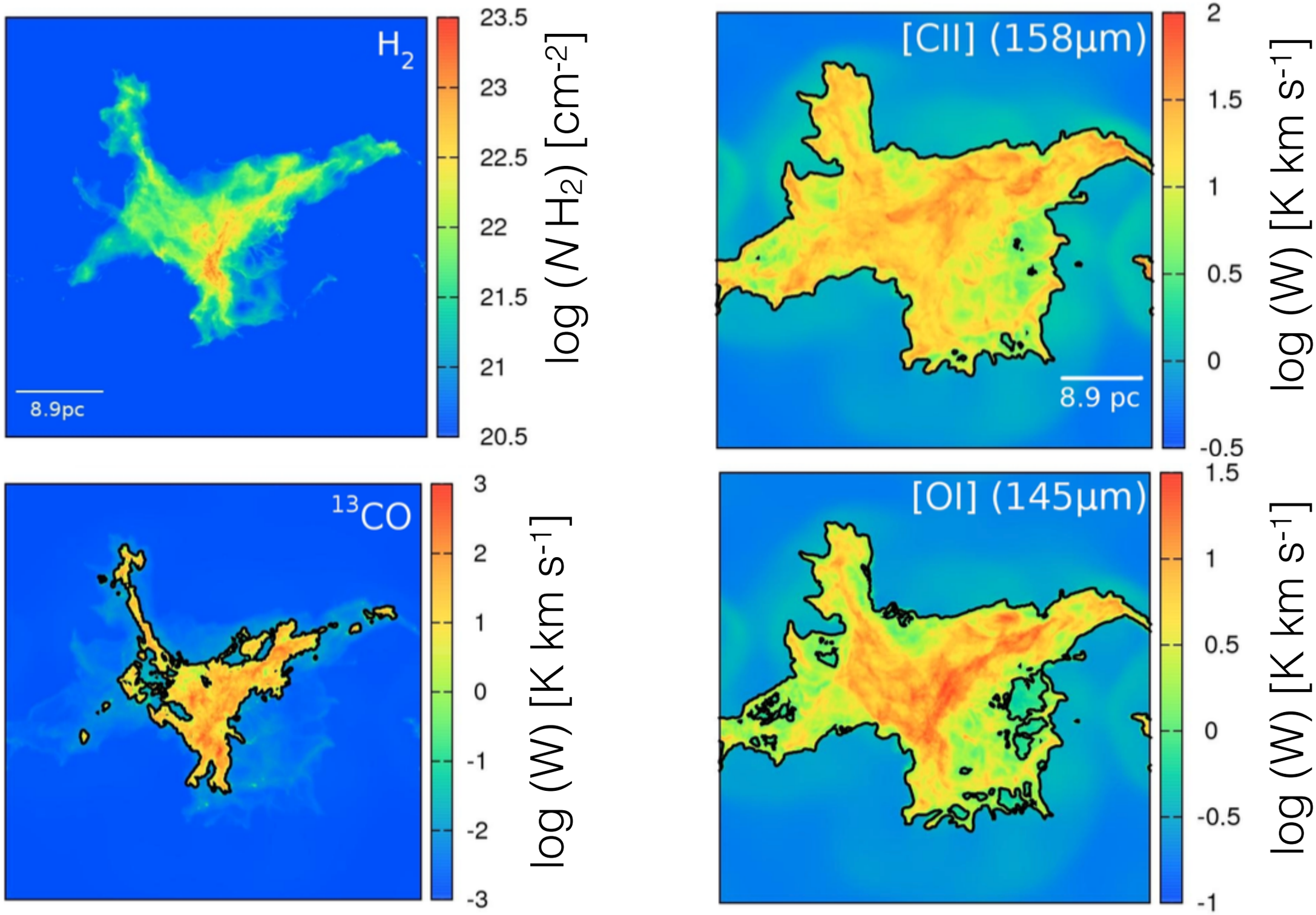

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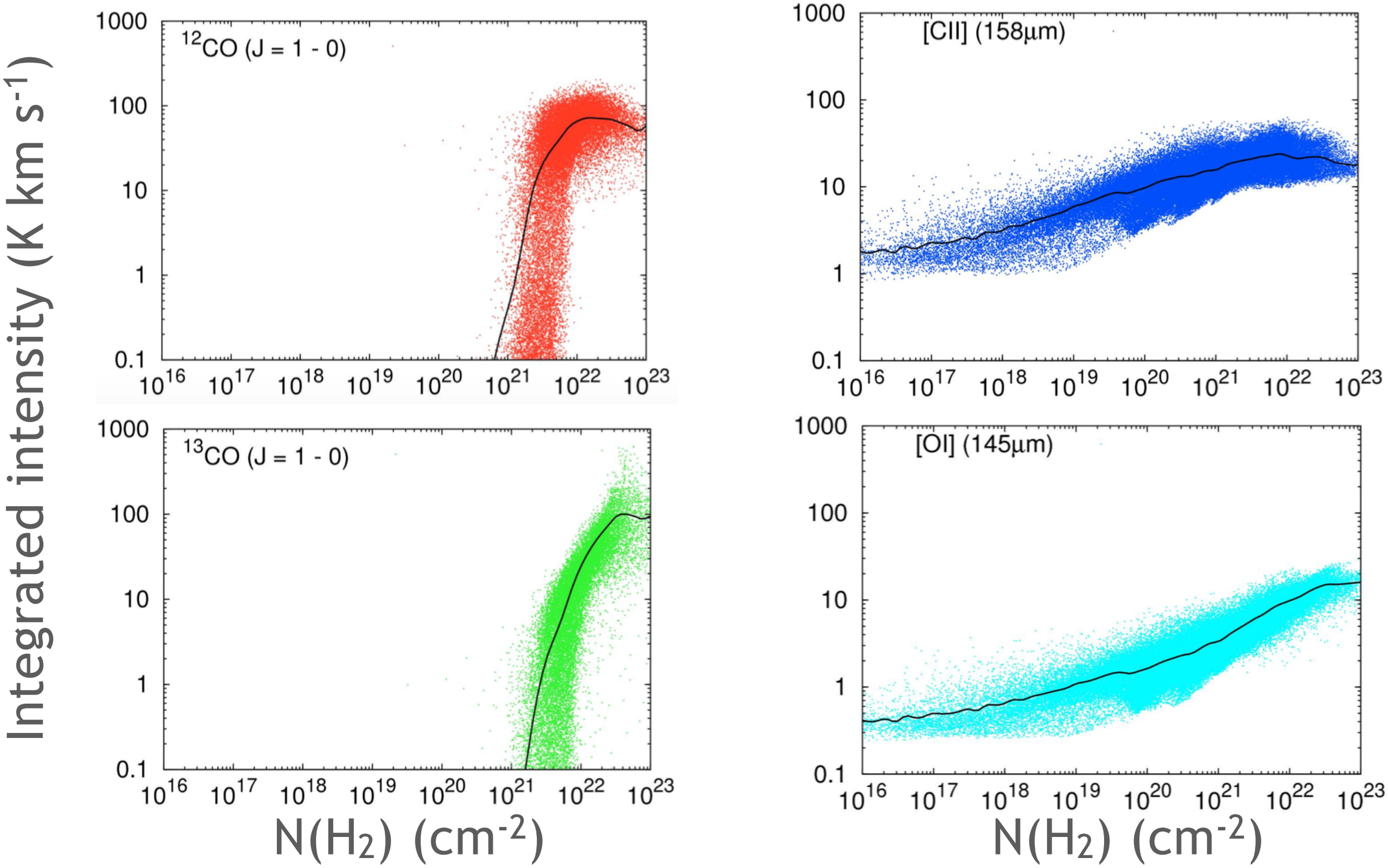

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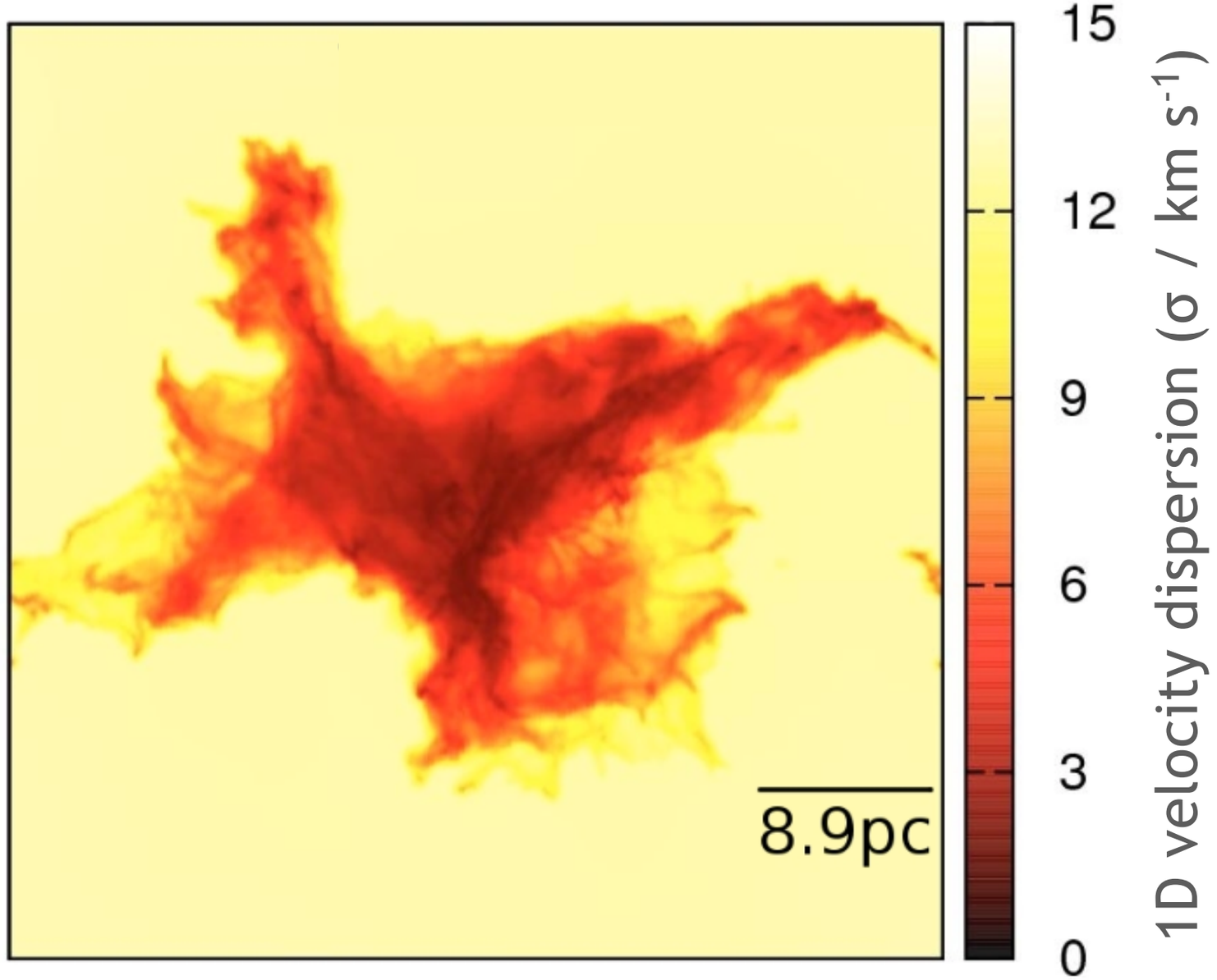

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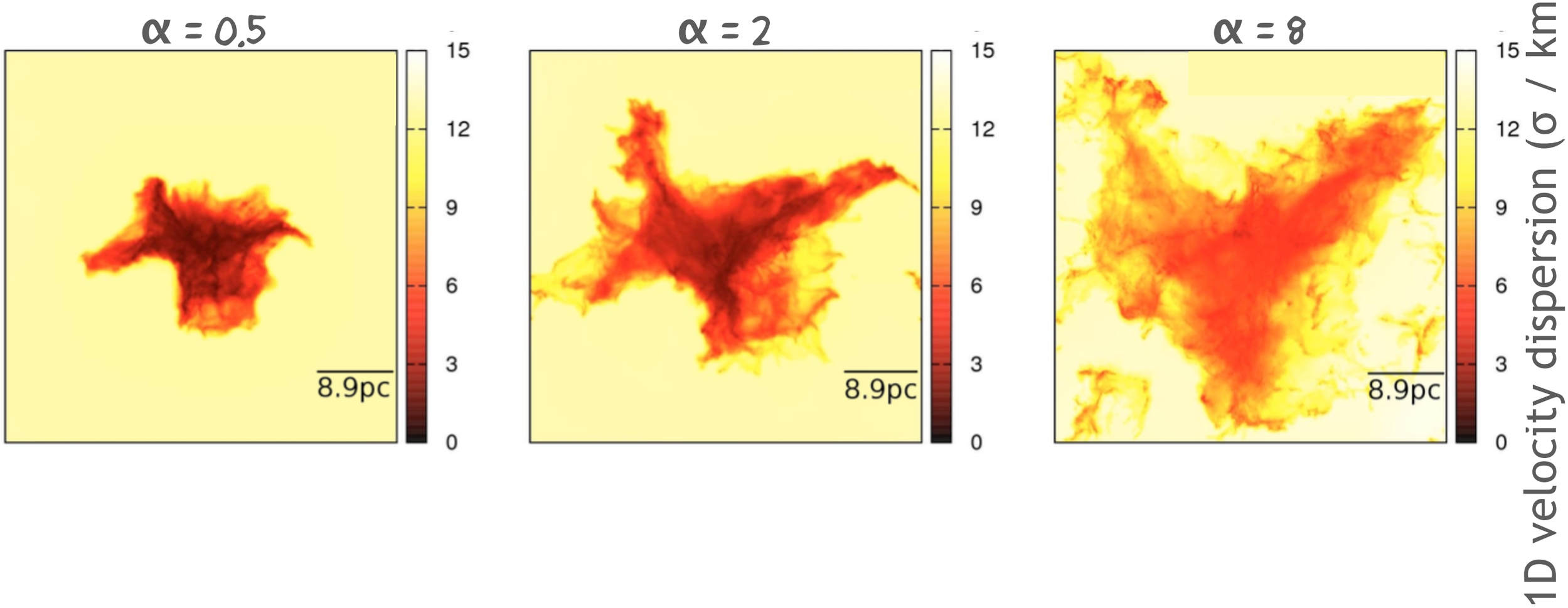

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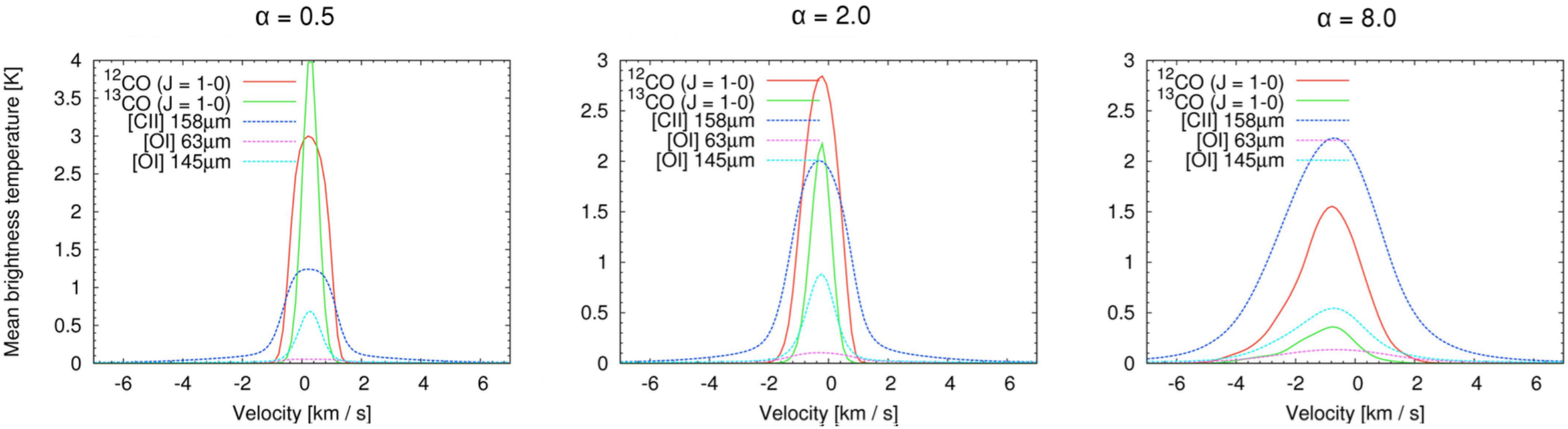

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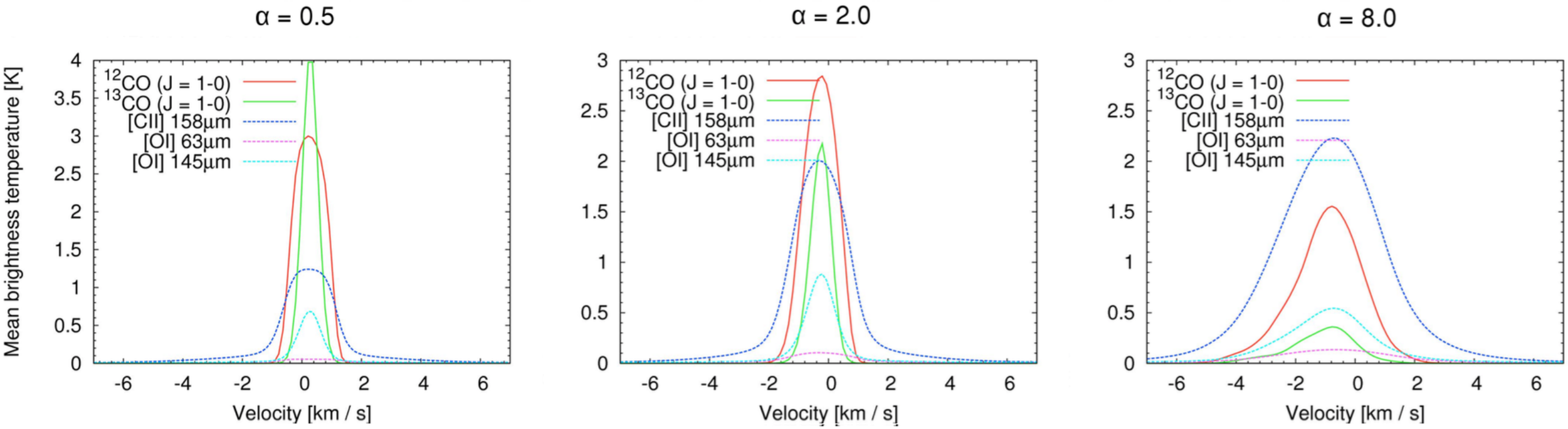

α	Total mass $[\mathrm{km\,s^{-1}}]$	[CII] (158 μm) $[\mathrm{km\,s^{-1}}]$	[OI] (145 μm) $[\mathrm{km\,s^{-1}}]$	[OI] (63 μm) $[\mathrm{km\,s^{-1}}]$	^{12}CO (2600 μm) $[\mathrm{km\,s^{-1}}]$	^{13}CO (2720 μm) $[\mathrm{km\,s^{-1}}]$
0.5	3.0	1.9	3.2	4.0	0.6	0.5
2.0	3.6	2.4	4.3	4.8	0.7	0.7
8.0	6.0	4.2	8.2	7.9	1.2	1.3

SIMULATIONS: FSL TRACERS IN TURBULENT MOLECULAR CLOUDS

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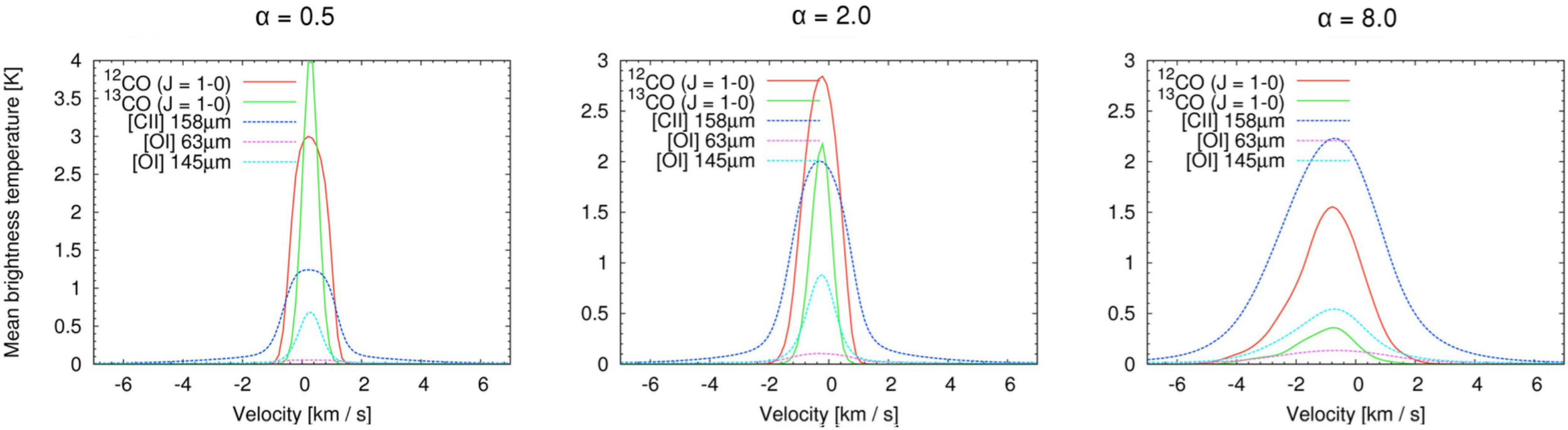
OI (145μm) is the best tracer of the true velocity dispersion.



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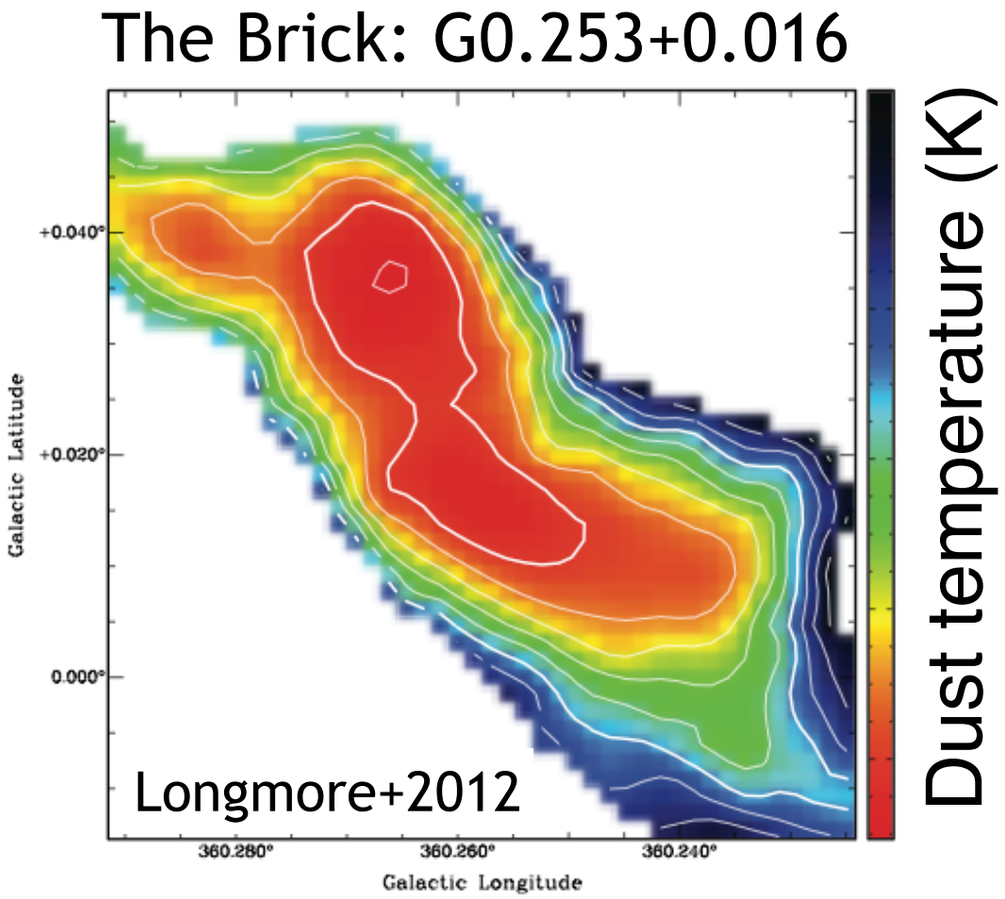
MODELLING THE COOLING BUDGET IN THE CMZ

TEMPERATURE STRUCTURE OF CMZ CLOUD: G0.253+0.016



< n > ~ 7 x 10^4 cm^{-3}

< T_{dust} > ~ 20K (Longmore+2012)

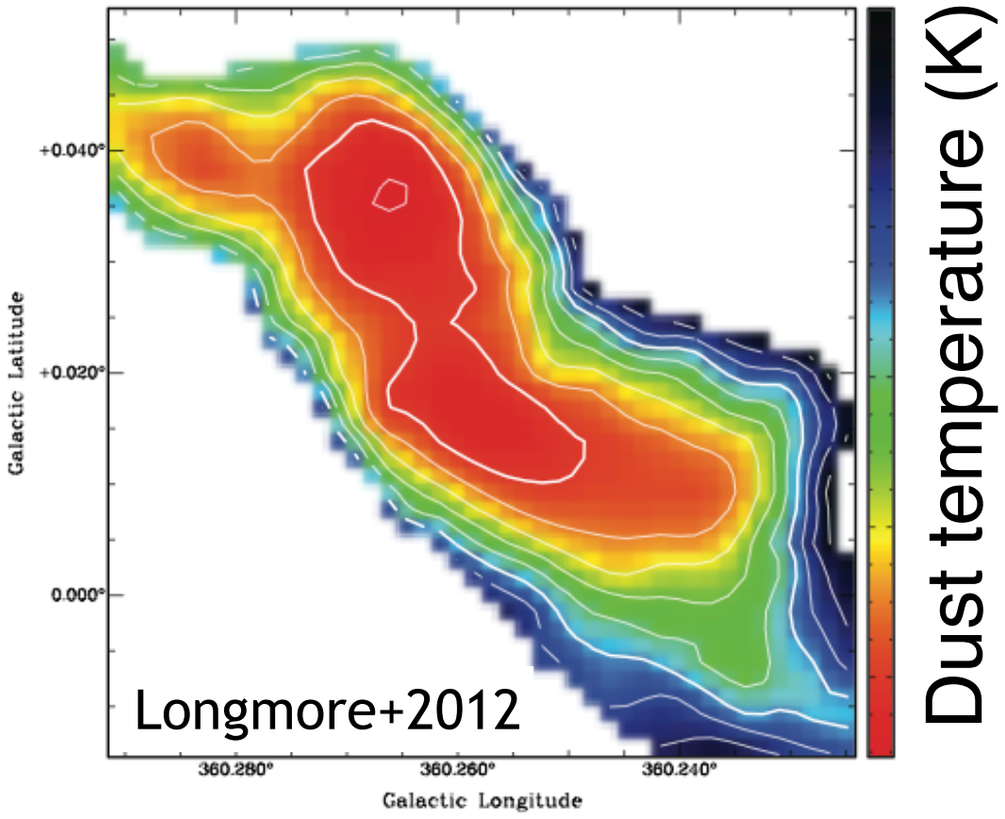
see also Marsh et al (2016)

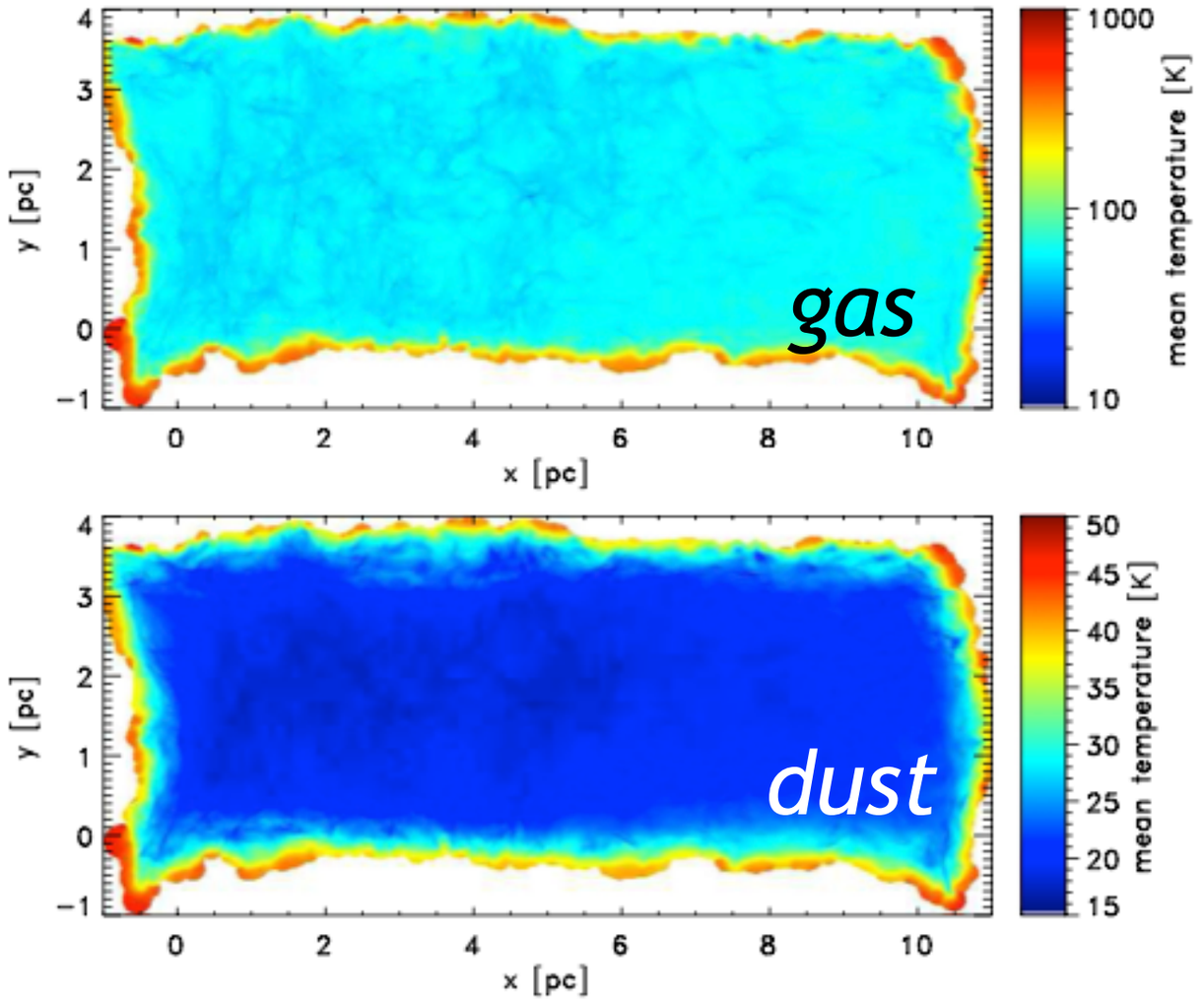
< T_{gas} > ~ 80K (Güsten+1981)

see also Mills et al (2013)

TEMPERATURE STRUCTURE OF CMZ CLOUD: G0.253+0.016

The Brick: G0.253+0.016





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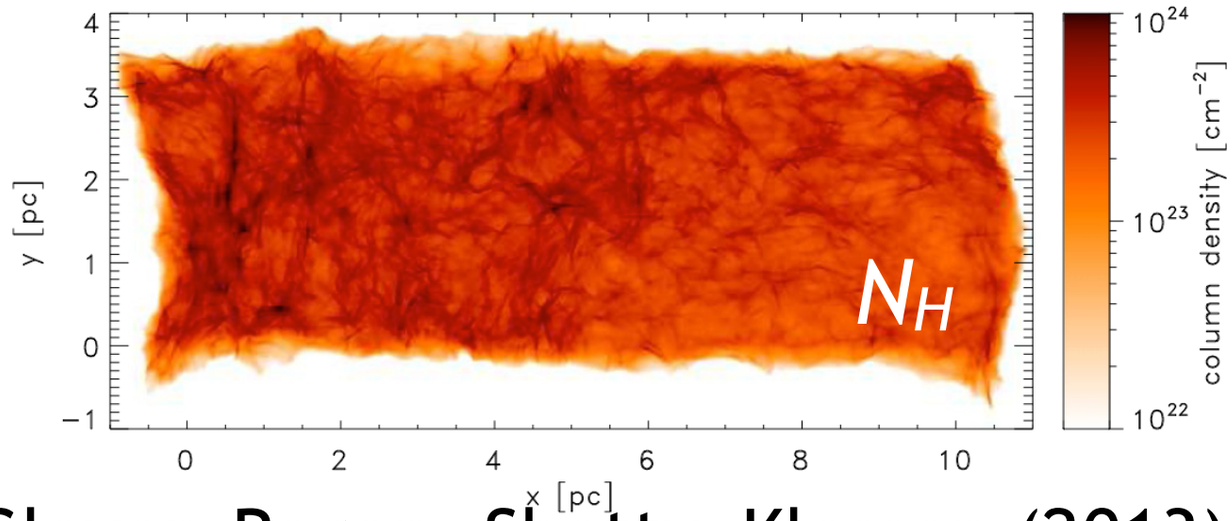

Clark, Glover, Ragan, Shetty, Klessen (2013)

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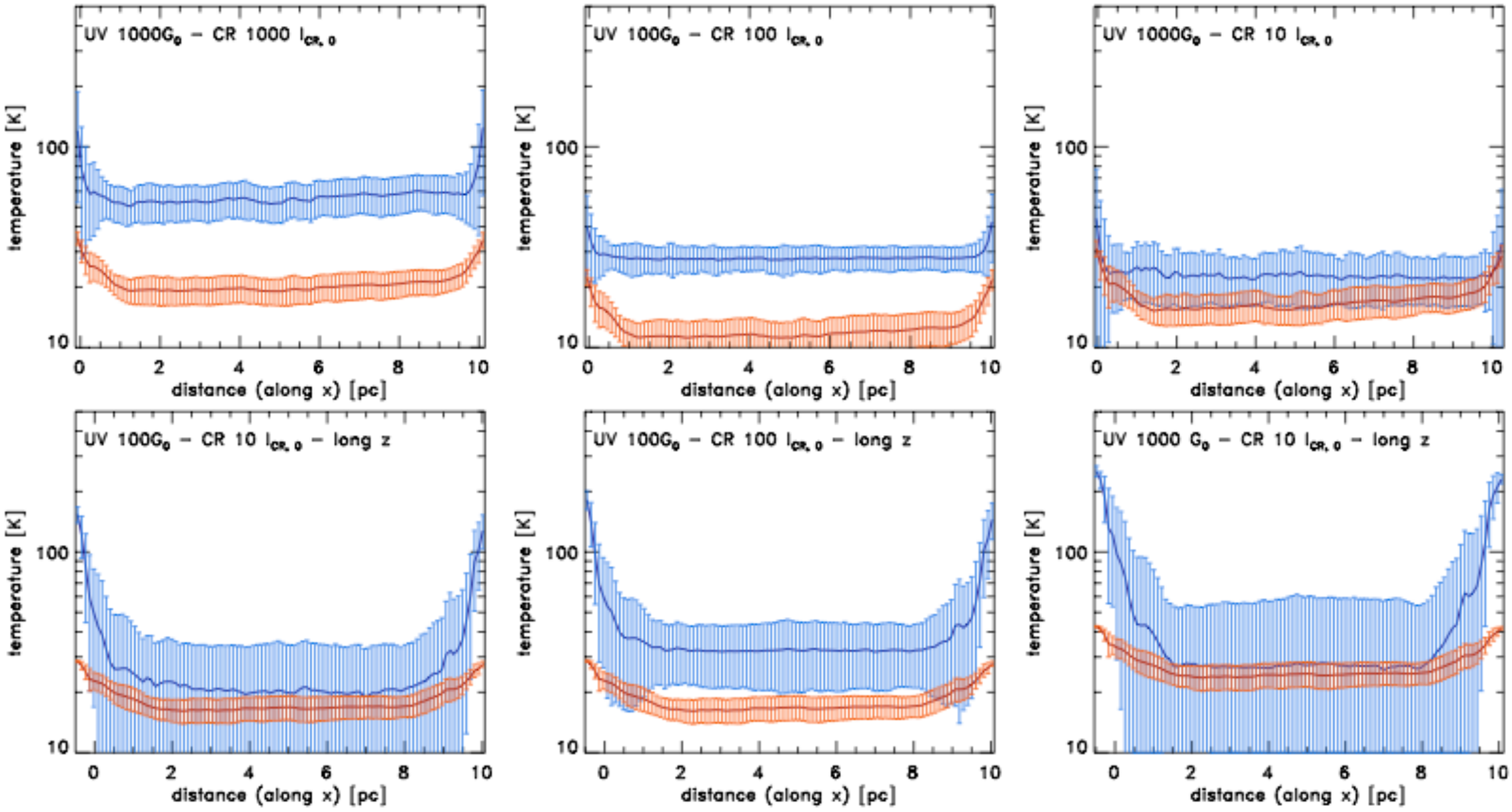

BLUE = GAS TEMPERATURE, RED = DUST TEMPERATURE

TEMPERATURE STRUCTURE OF CMZ CLOUD: G0.253+0.016

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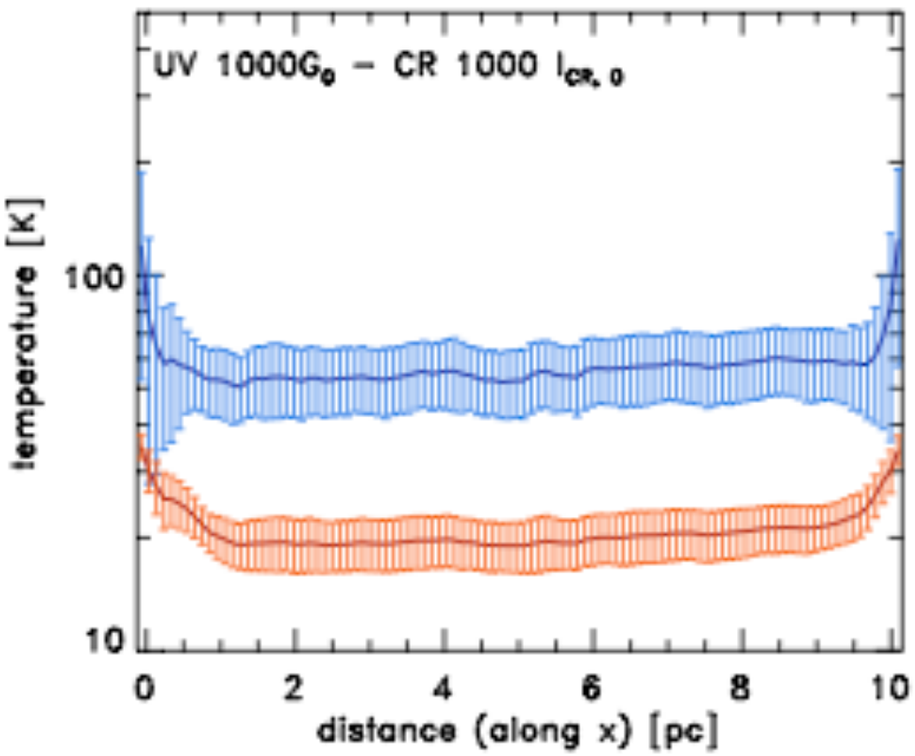

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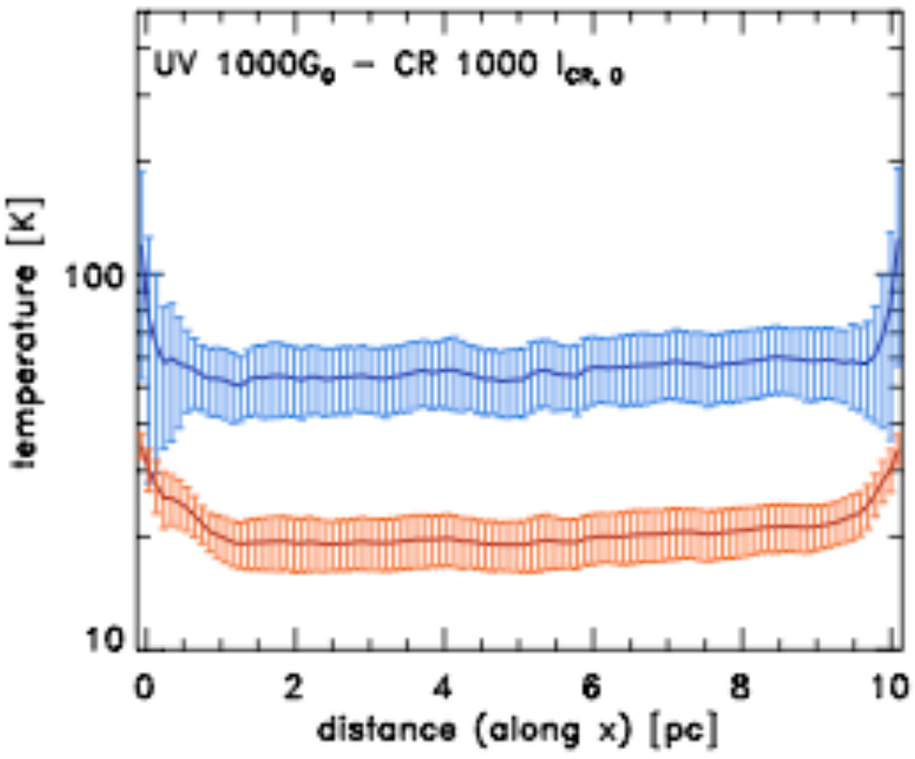
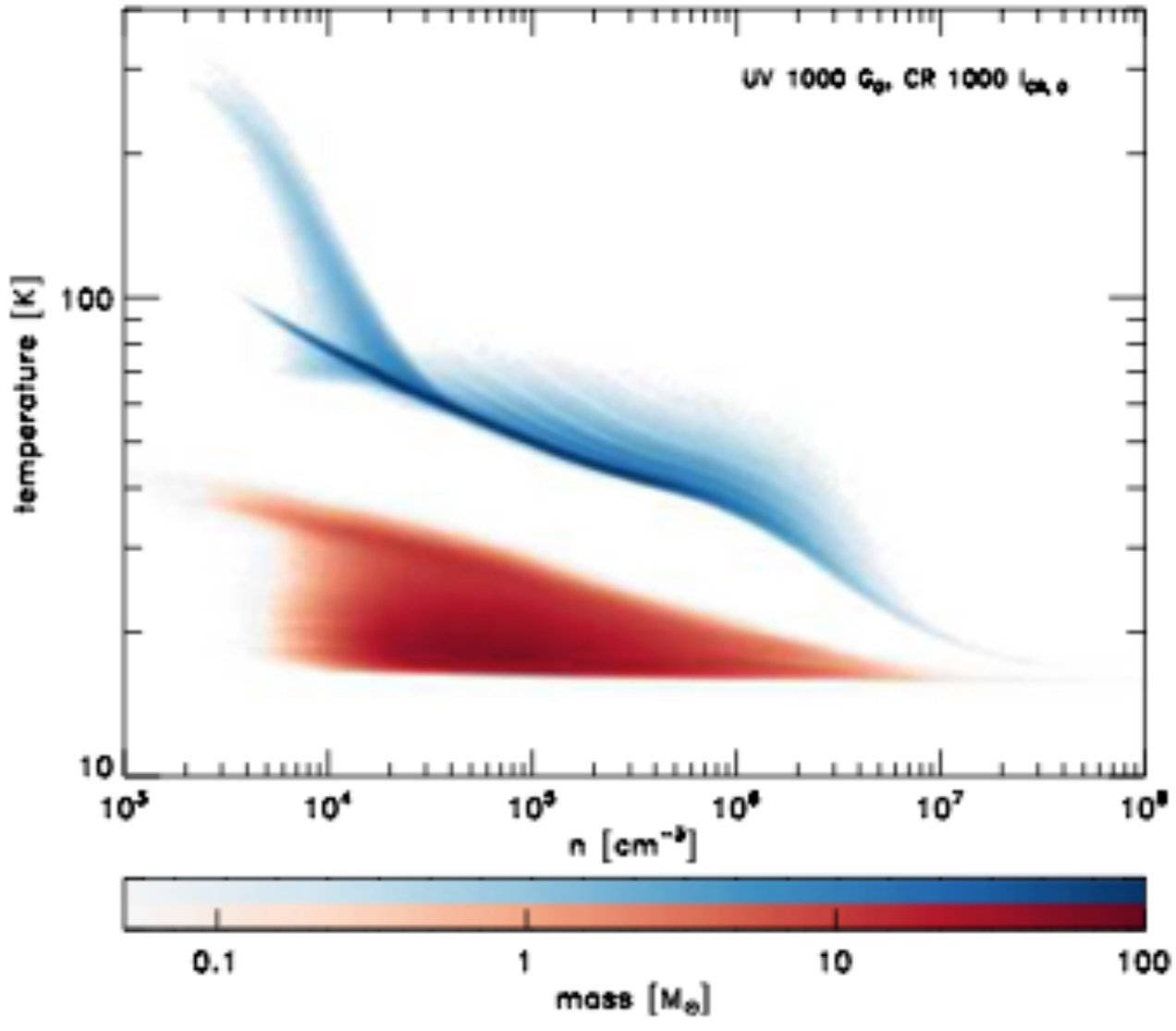
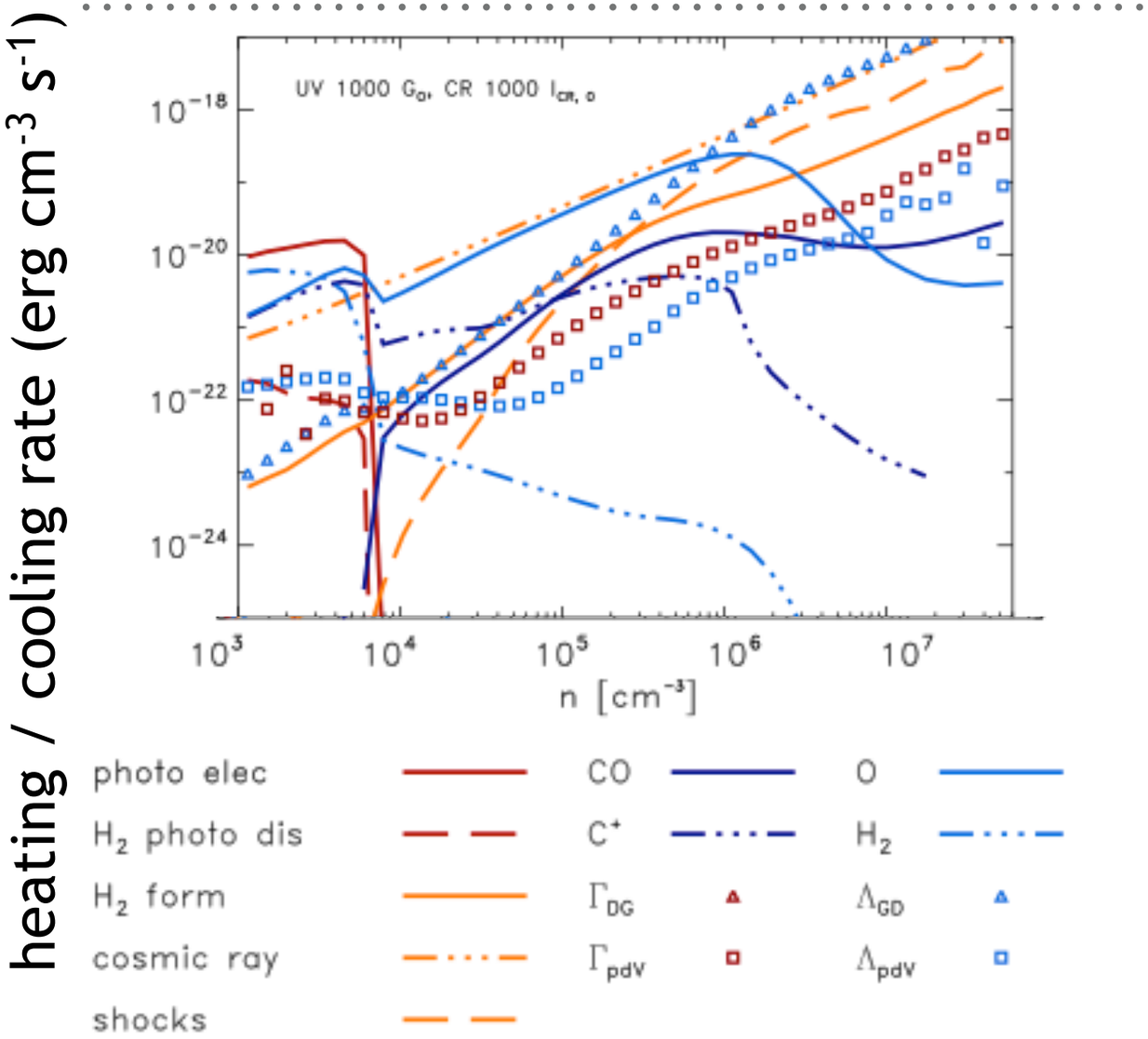


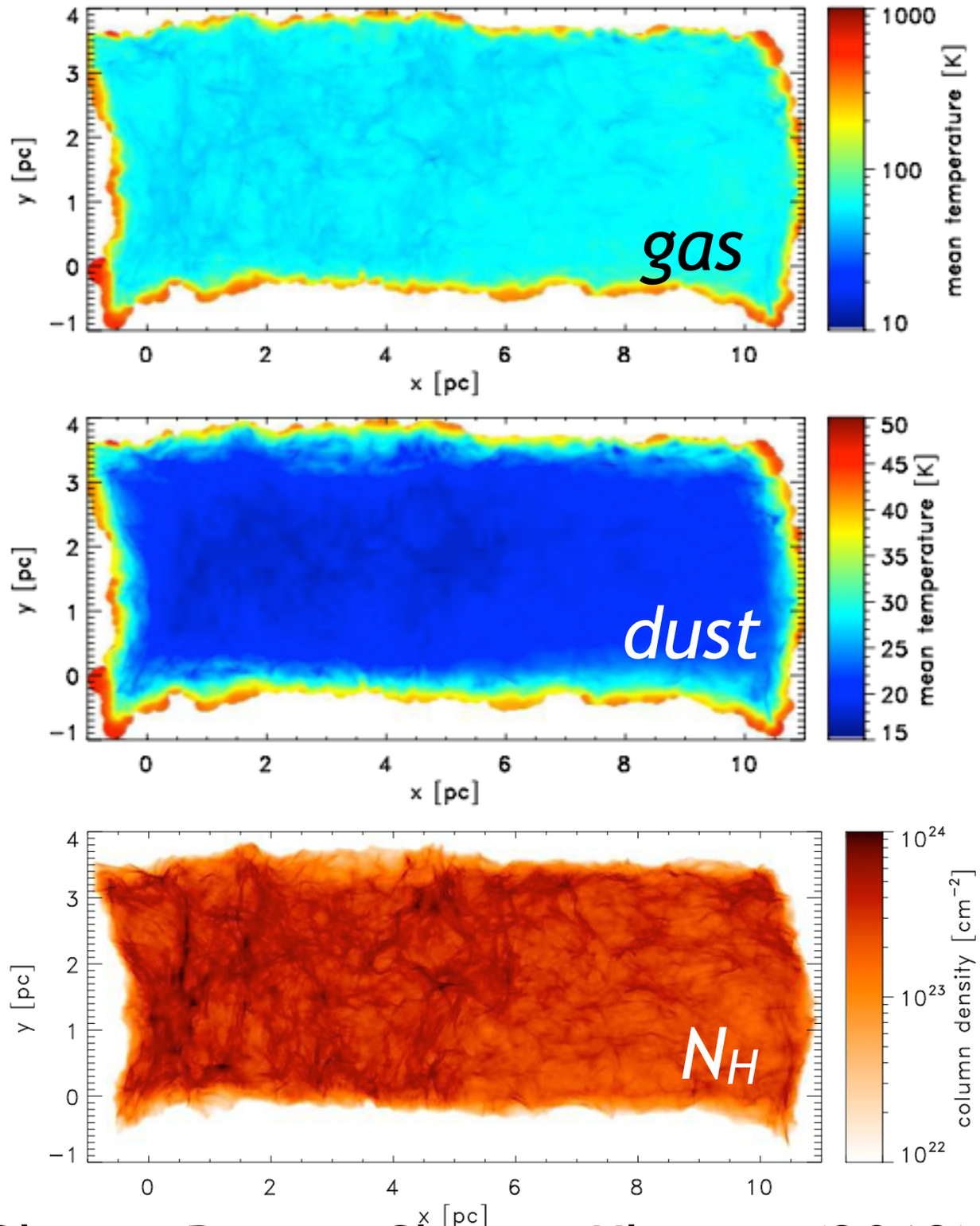


Gas and dust are only thermally coupled at $n > 10^{6\text{-}7}$ cm^{-3}

COOLING PREDICTIONS FOR CMZ CLOUD: G0.253+0.016



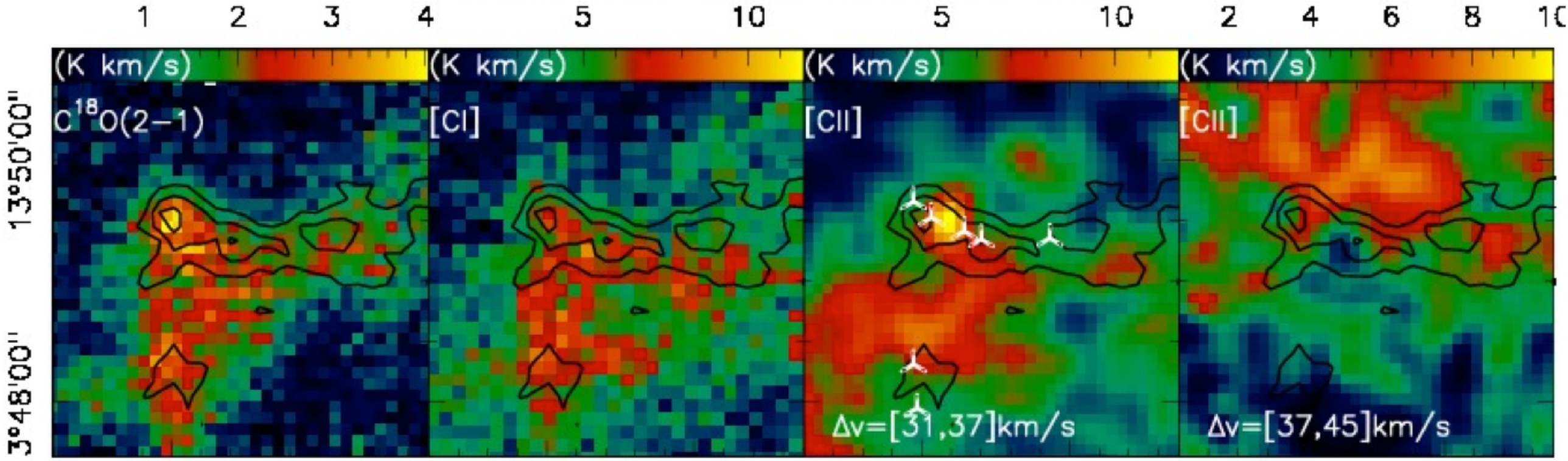
density regime	dominant coolant
low	[CII], [OI], H_2
intermediate	**[OI]**
high	dust

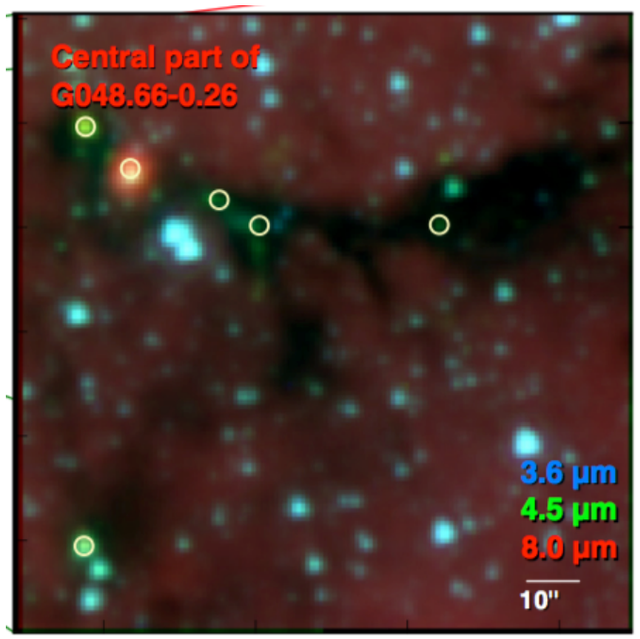


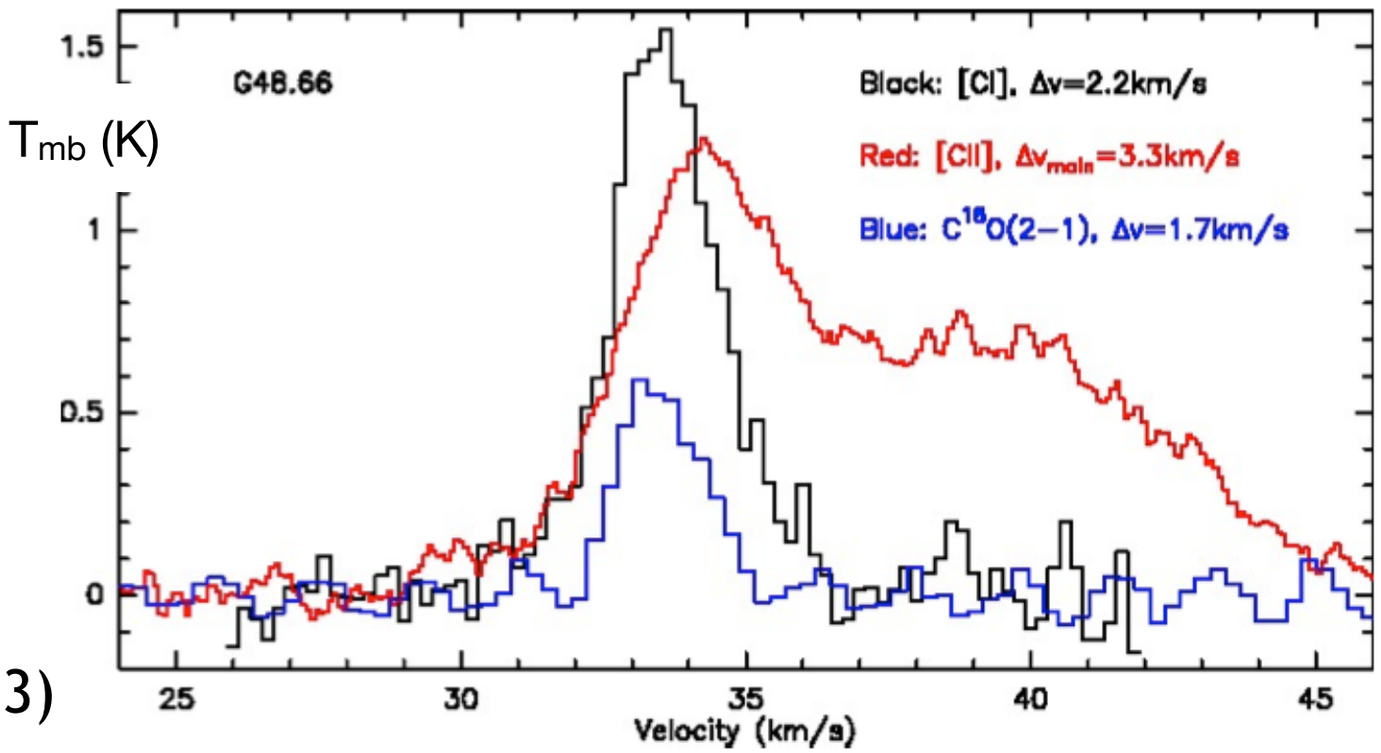
Clark, Glover, Ragan, Shetty, Klessen (2013)

VELOCITY-RESOLVED STUDY OF ALL CARBON PHASES IN IRDCS

IONISED, ATOMIC & MOLECULAR CARBON IN IRDCS

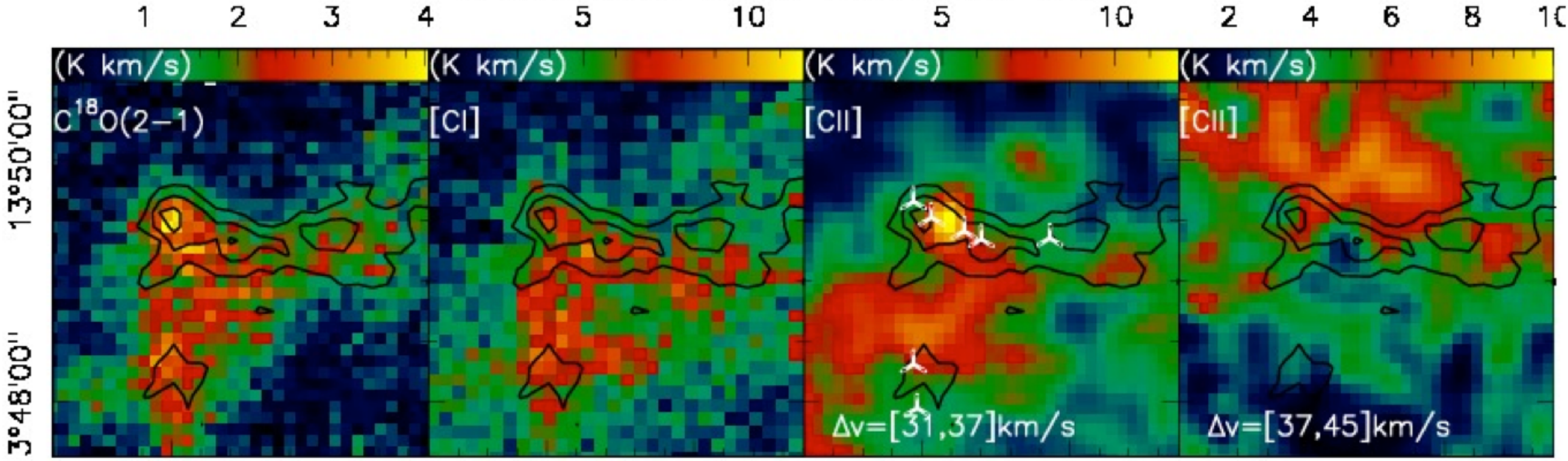


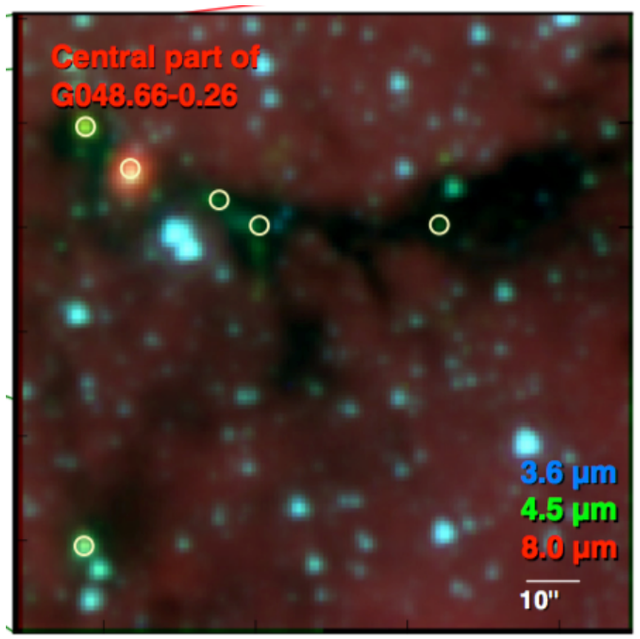


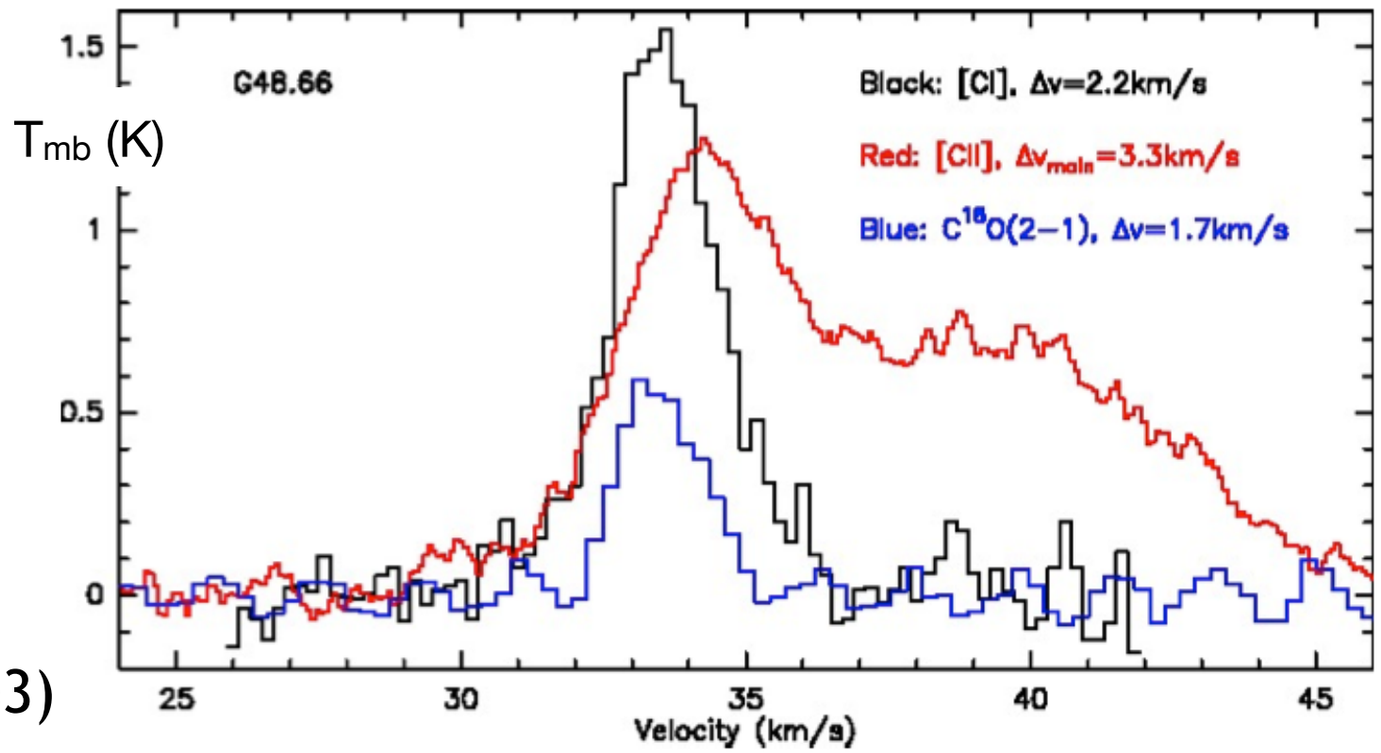


Beuther, Ragan et al. (2014, A&A, 571, 53)

IONISED, ATOMIC & MOLECULAR CARBON IN IRDCS







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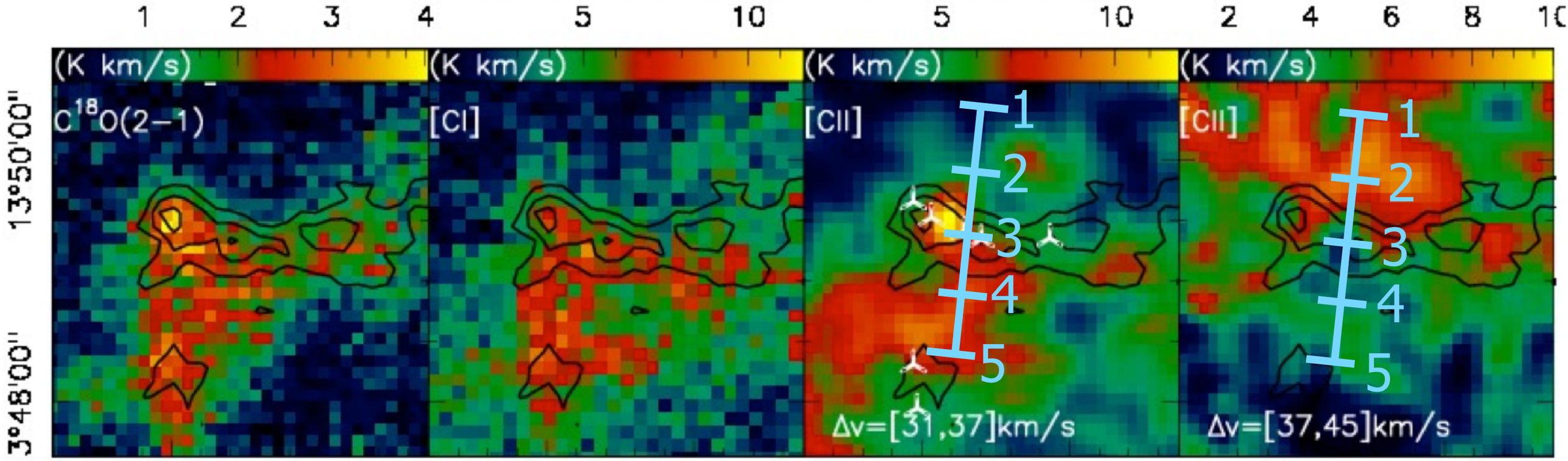

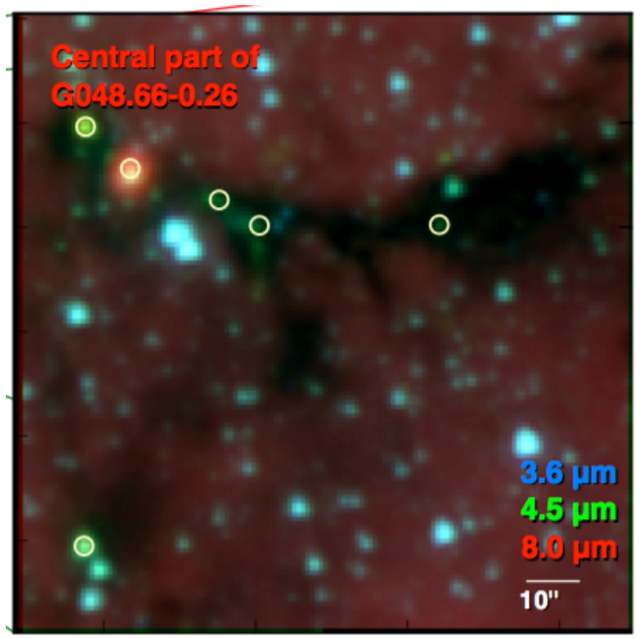

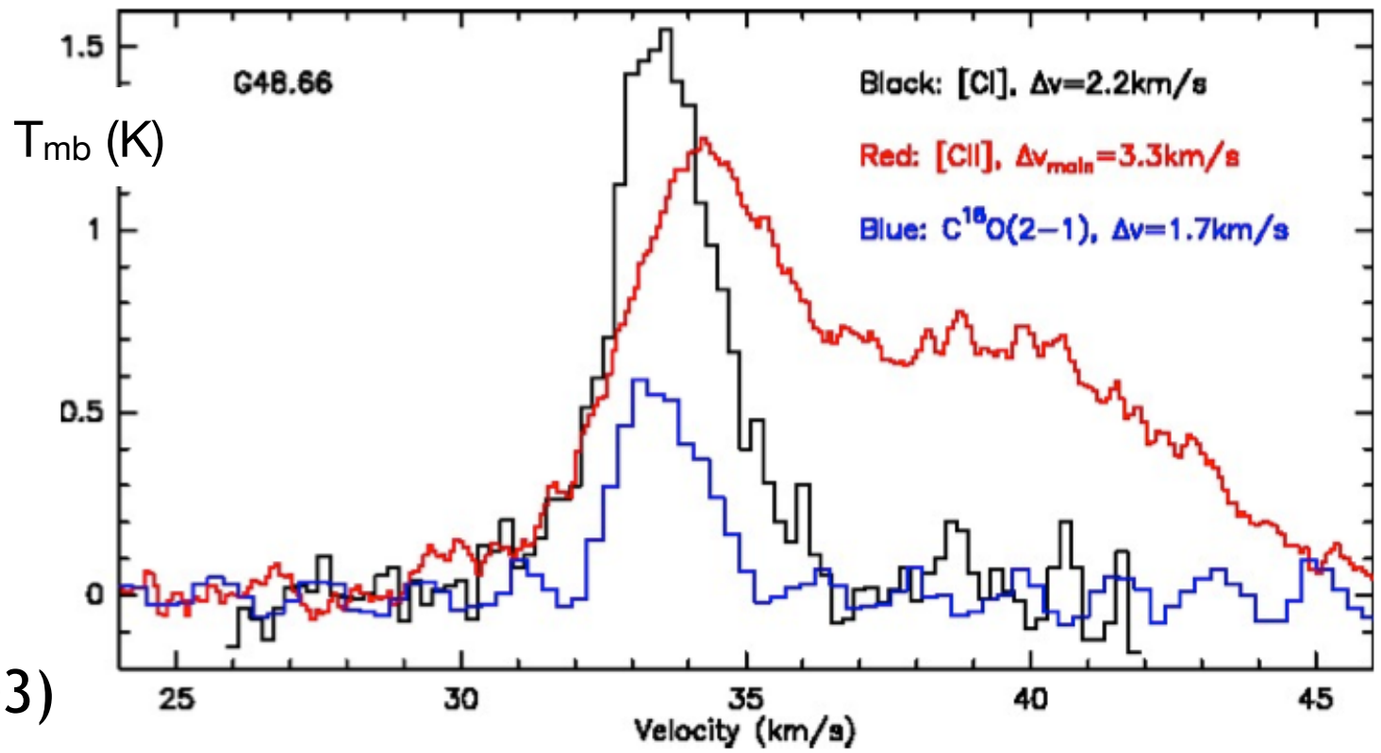

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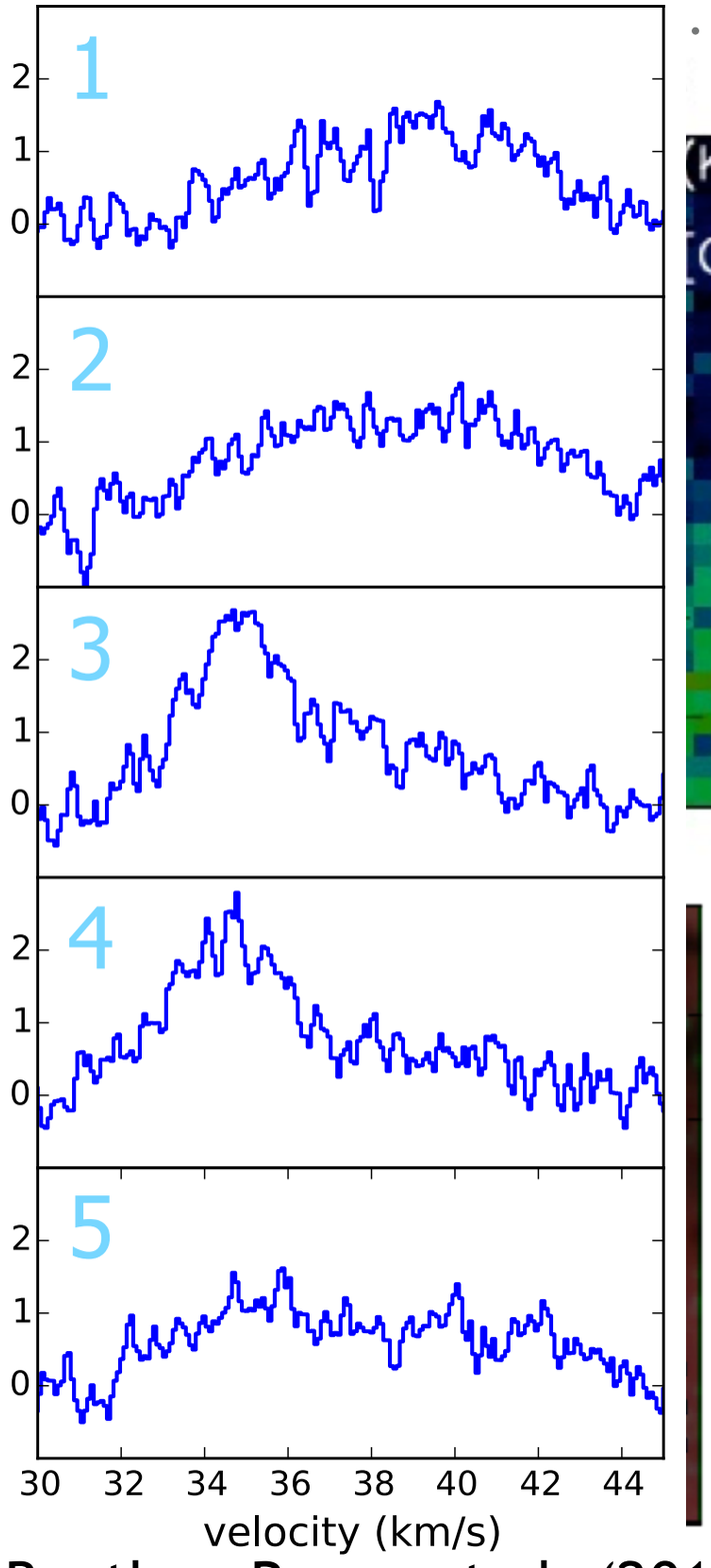

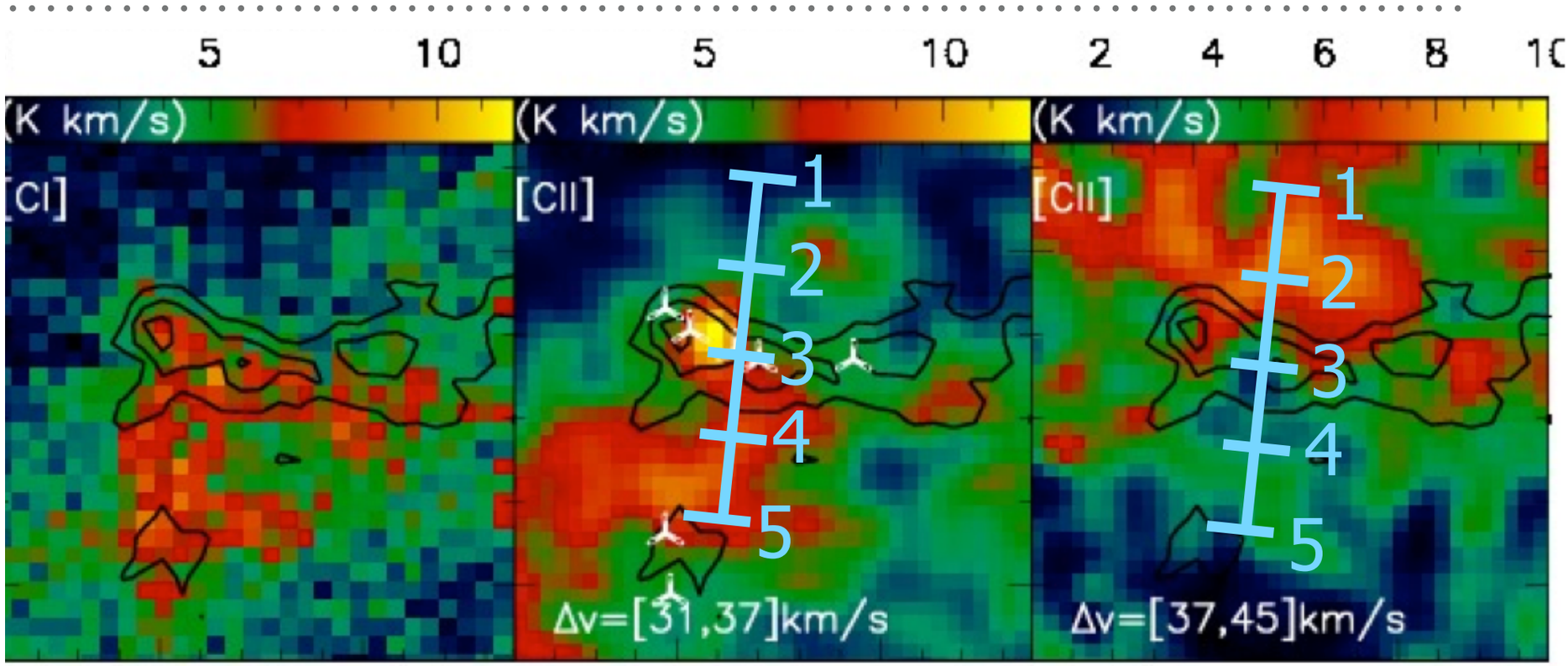

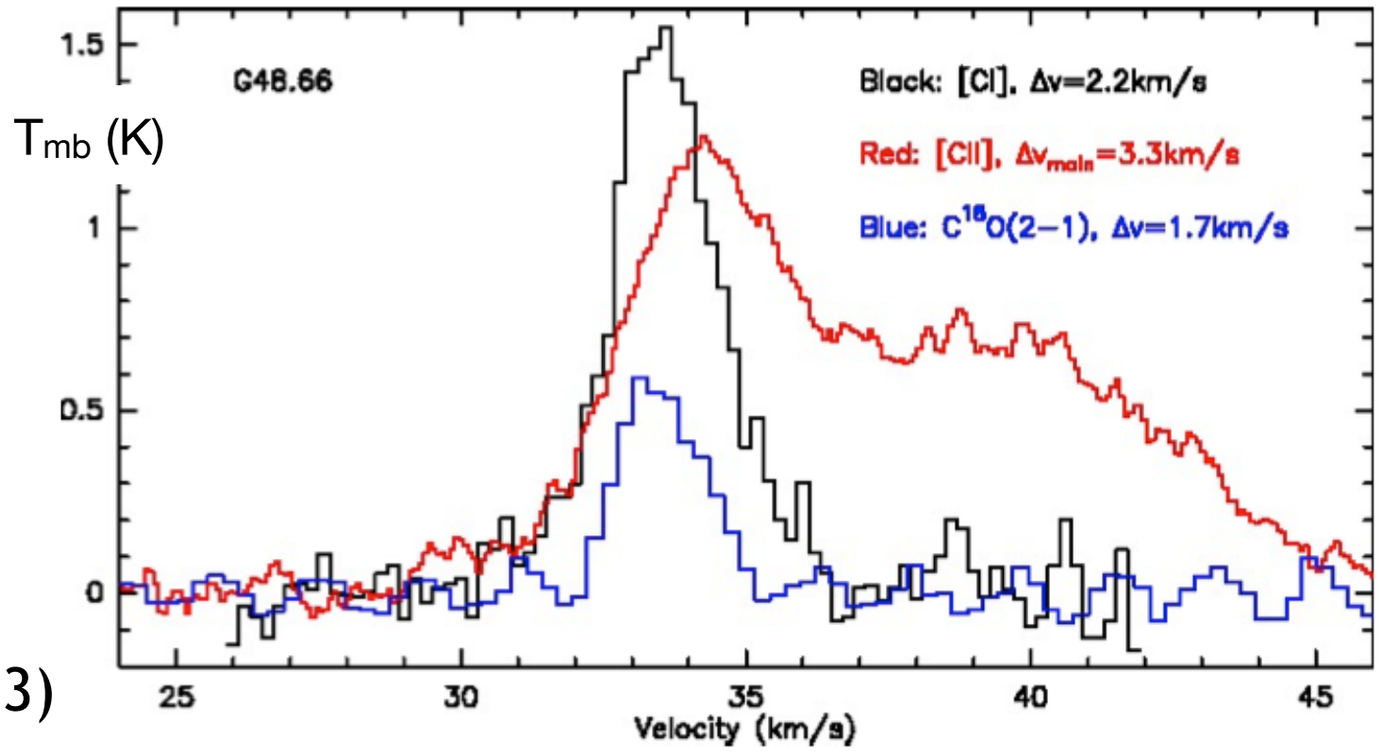

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IONISED, ATOMIC & MOLECULAR CARBON IN IRDCS

BEUTHER, RAGAN ET AL.
(2014, A&A, 571, 53)

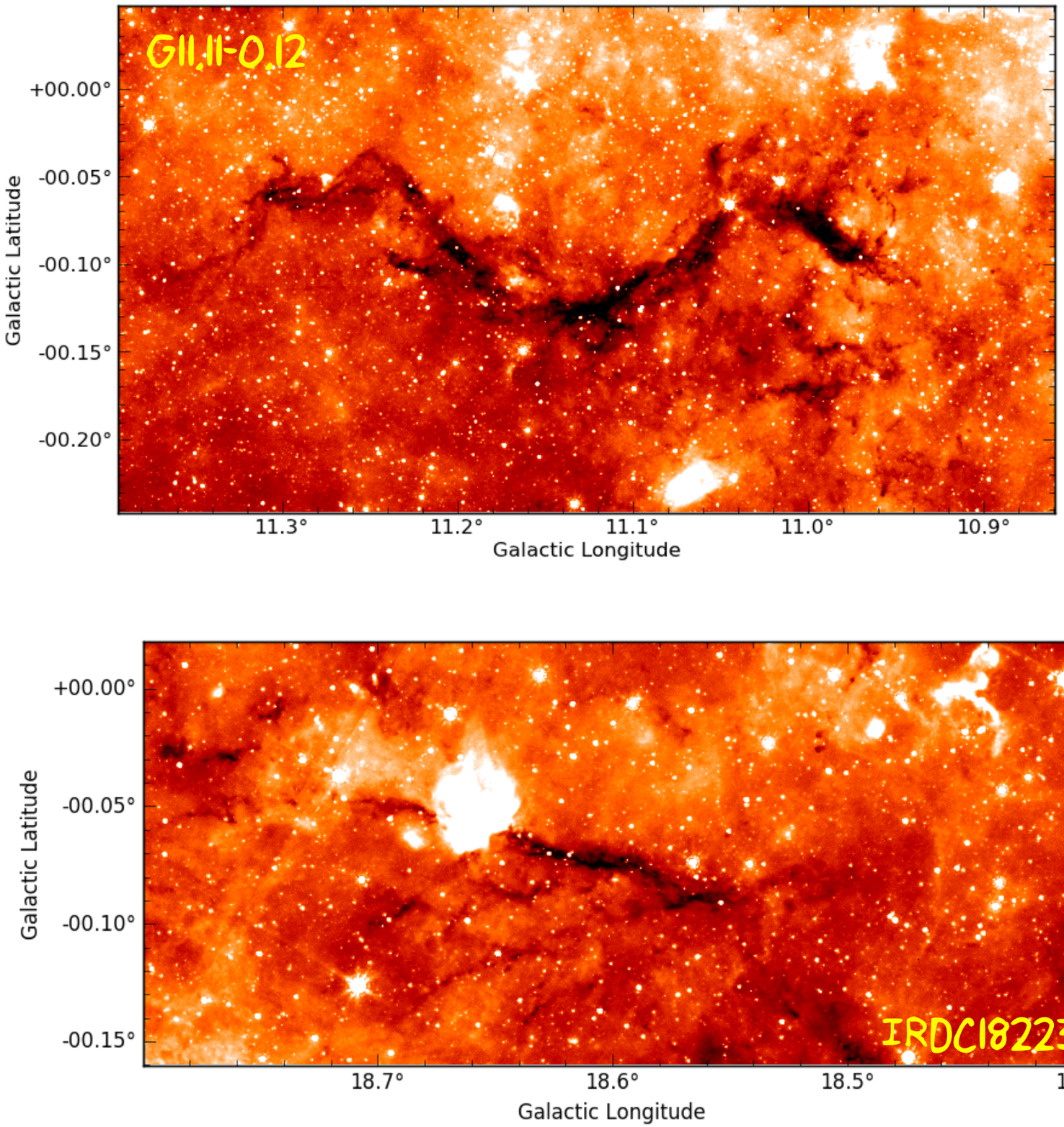
Δv (km s^{-1})	$C^{18}O$	CI	CII
G11.11	2.4	4.0	—
IRDC18223	2.7	3.4	6.8
G48.66	1.7	2.2	3.3

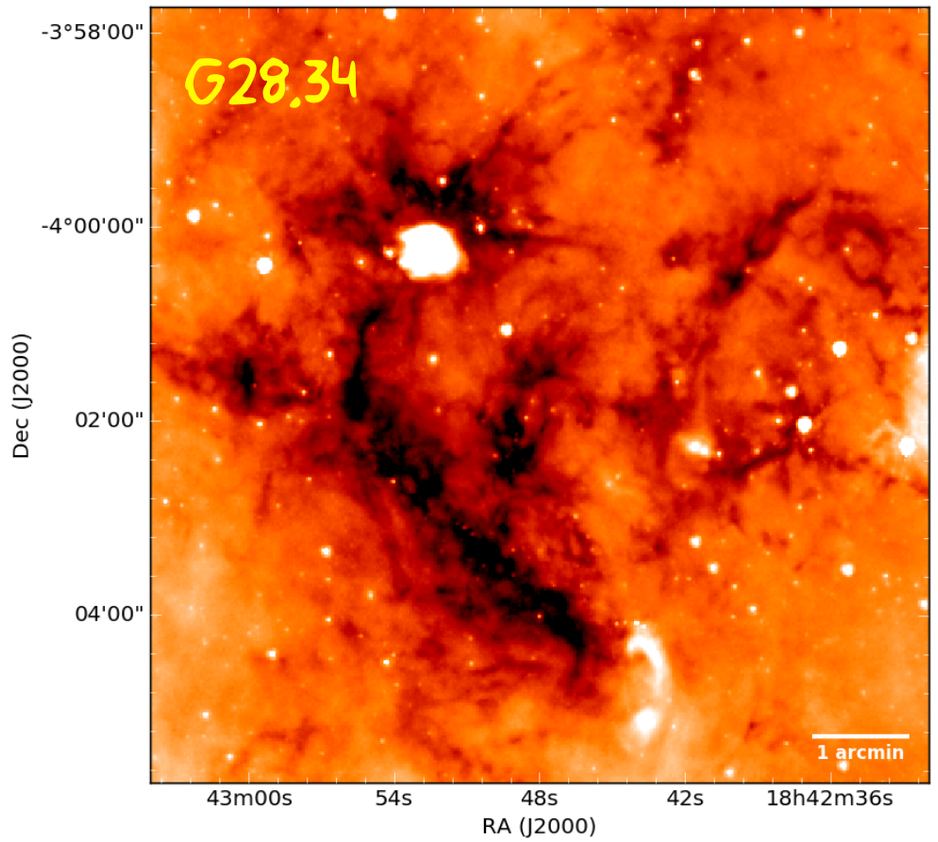
FIFI-LS: COOLING IN DARK CLOUDS

First look at commissioning observations (2014)

FIRST LOOK: FIFI-LS OBSERVATIONS OF FSLS IN IRDCS

Ragan, Linz et al (in prep)





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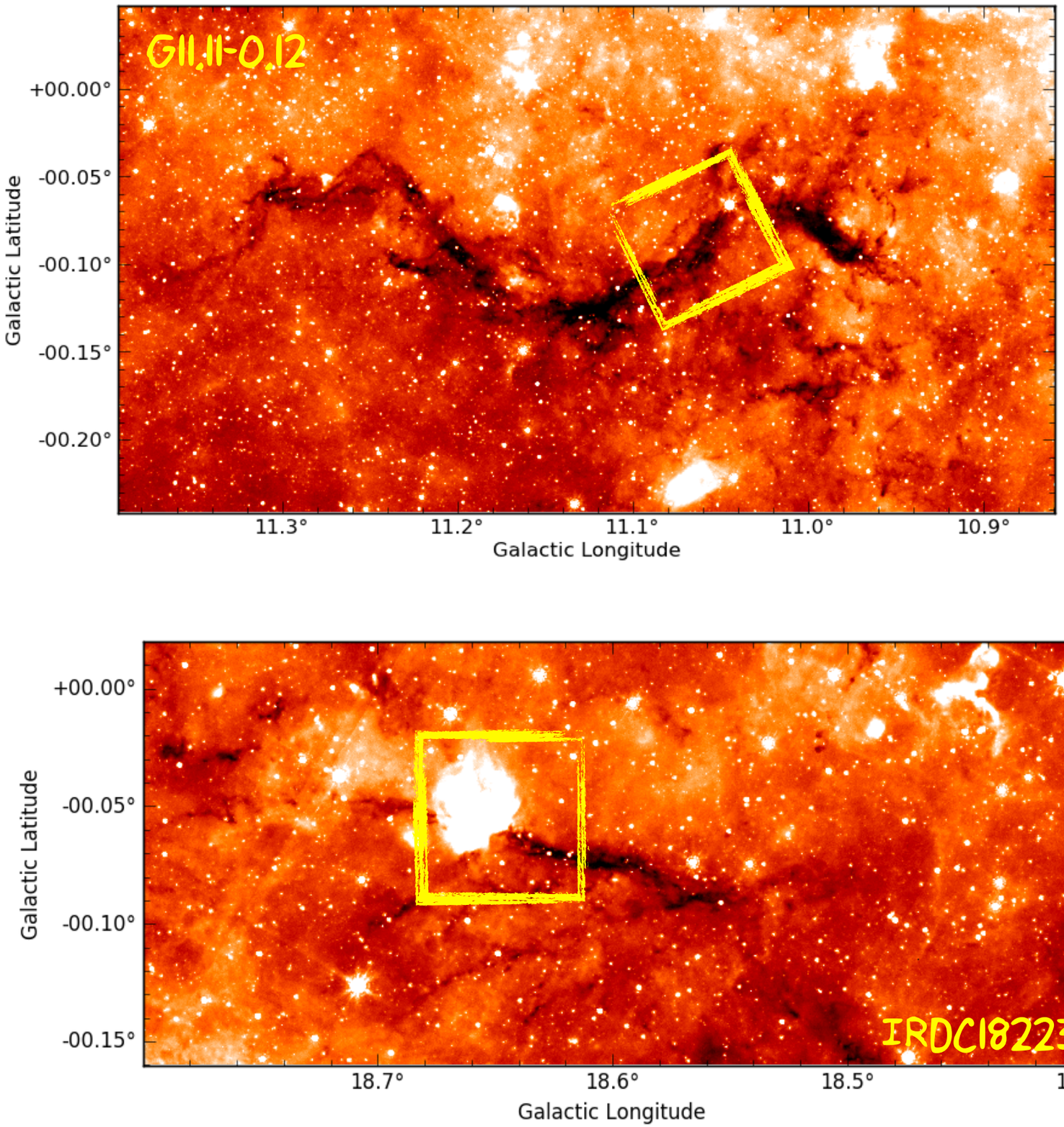

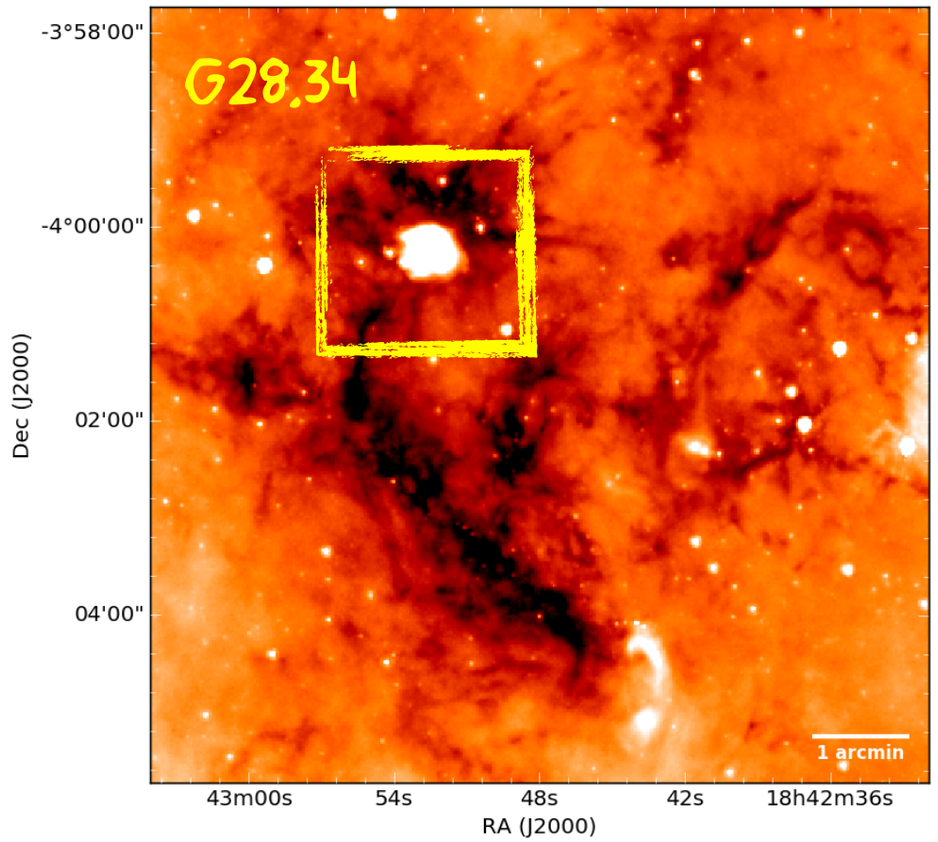

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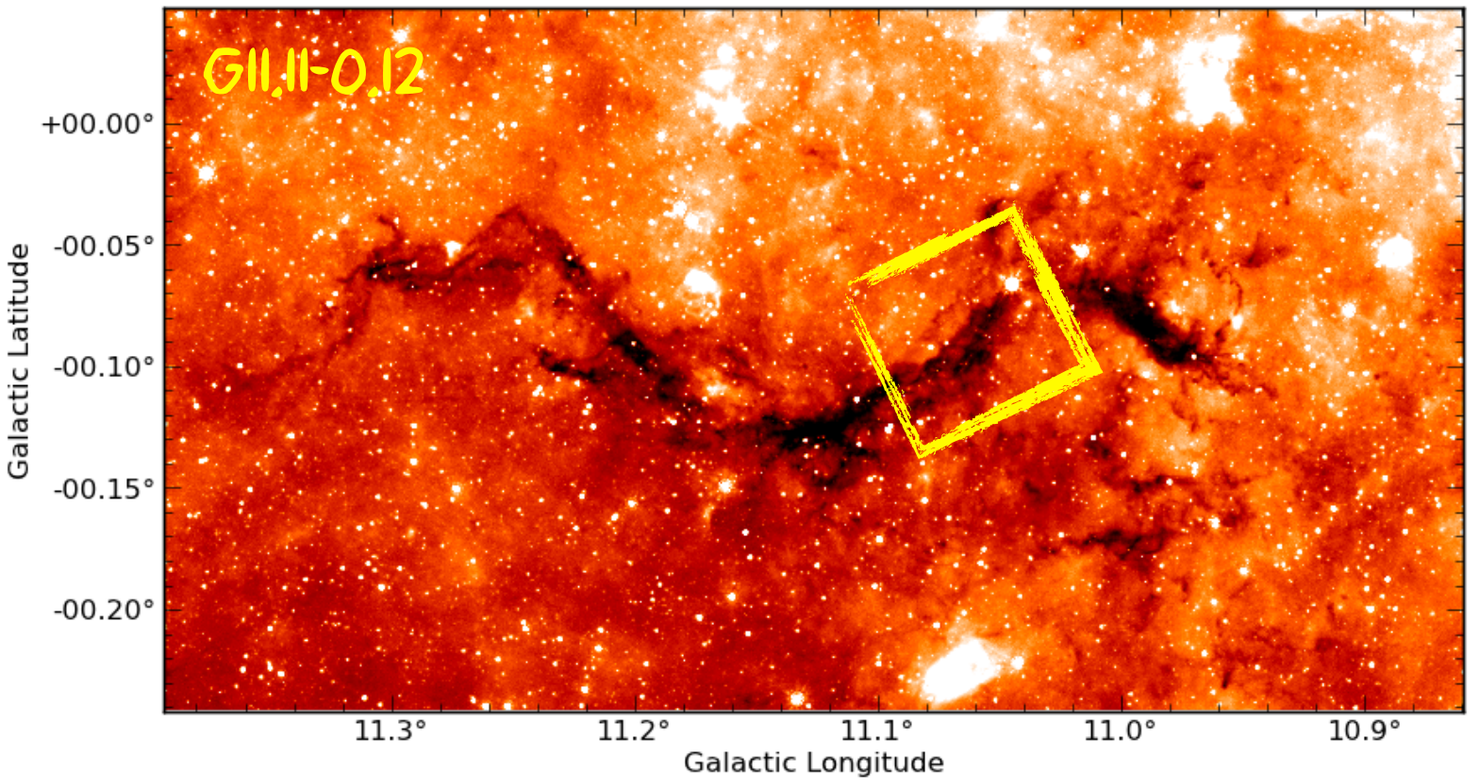

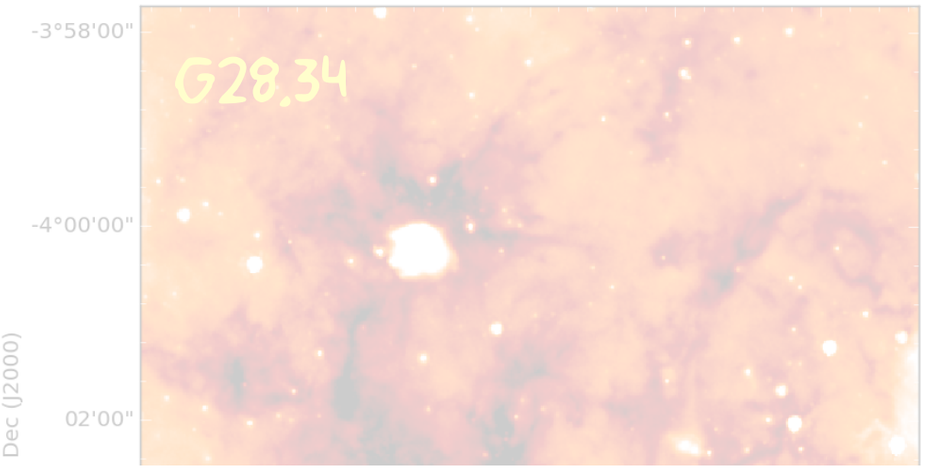

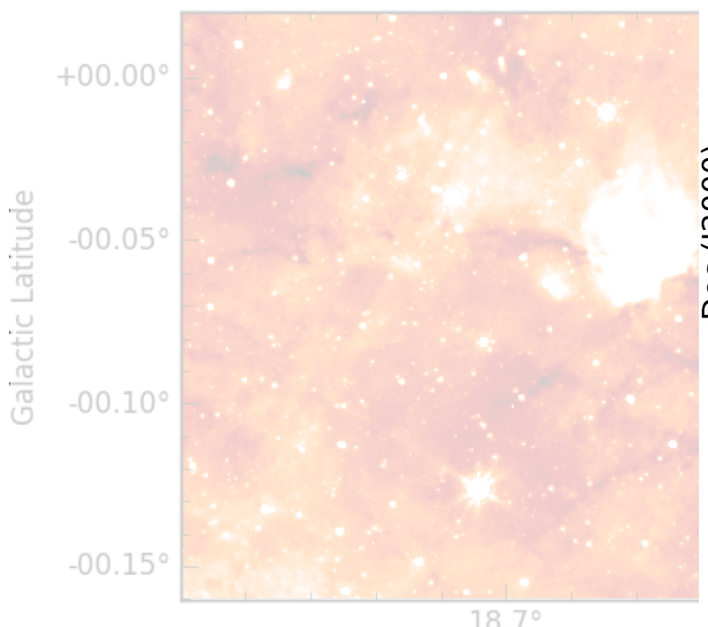

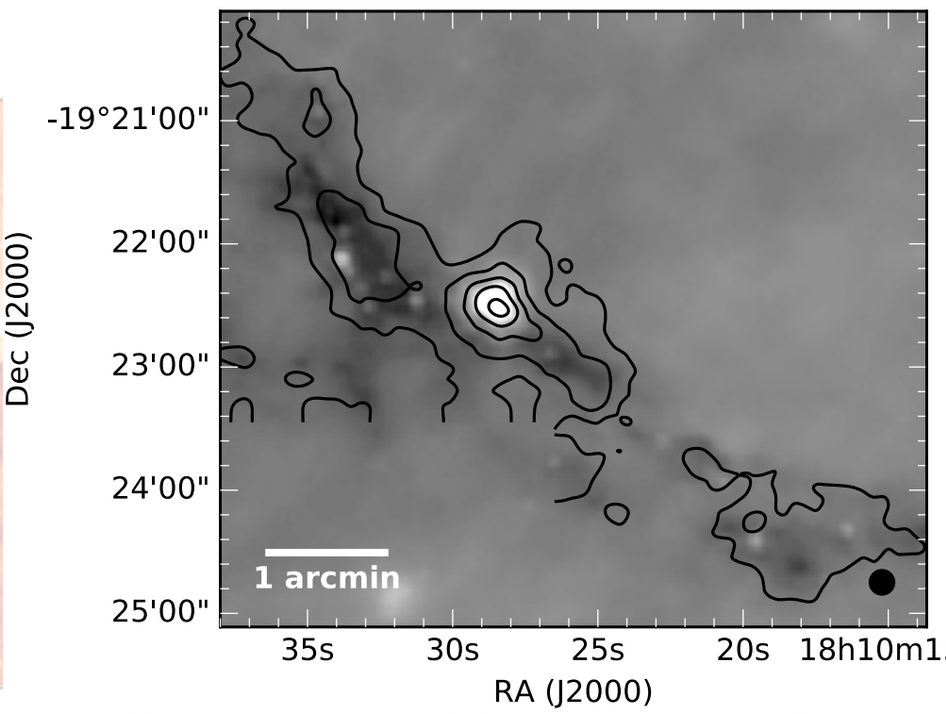

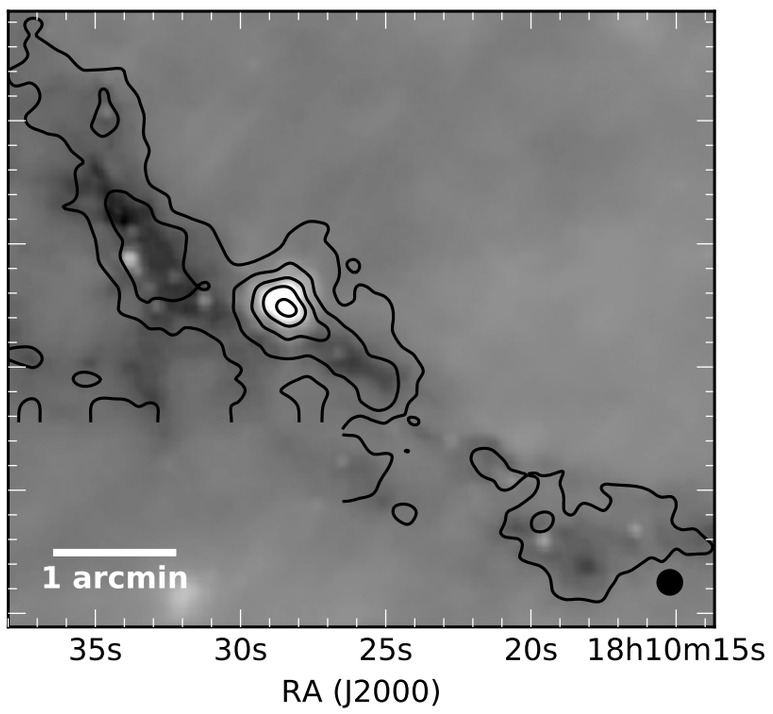

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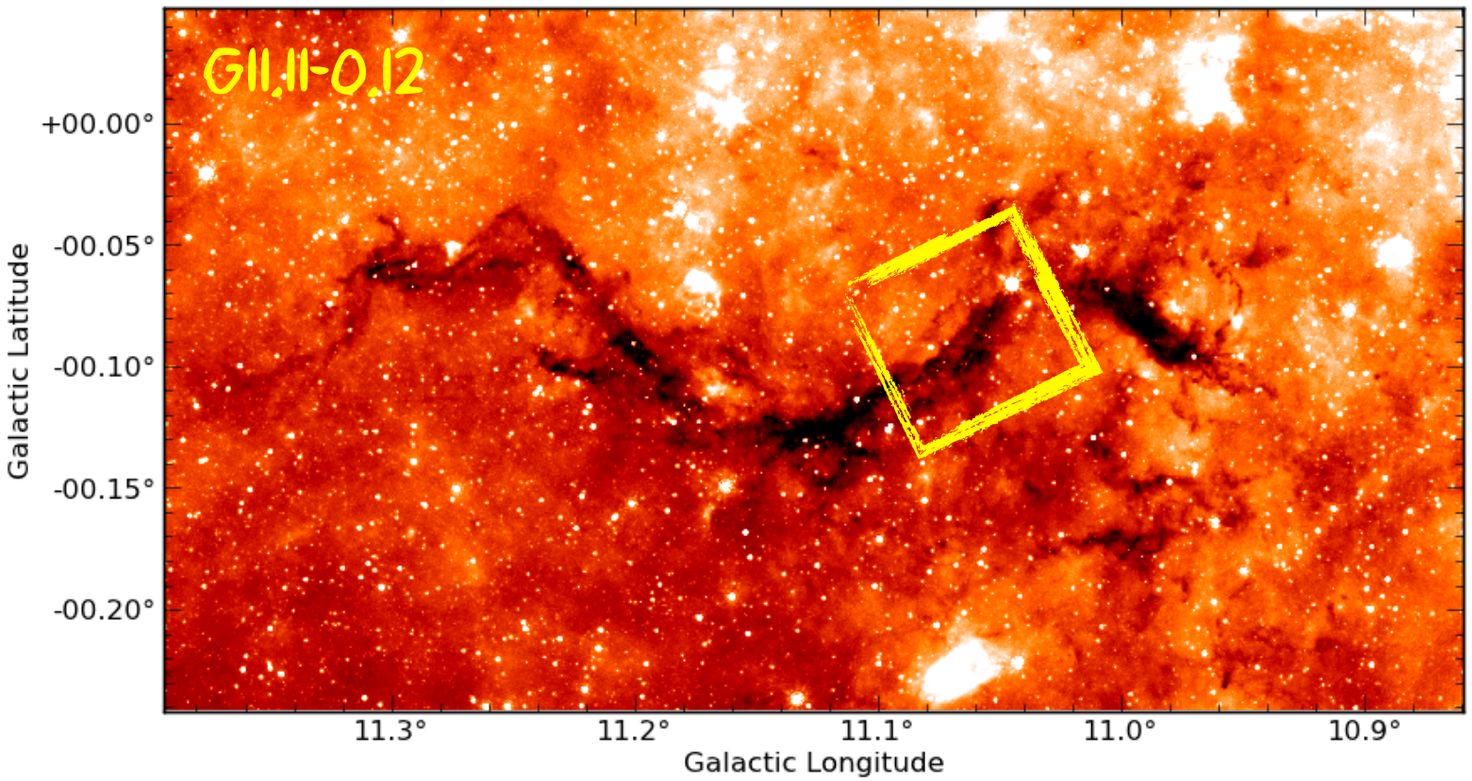
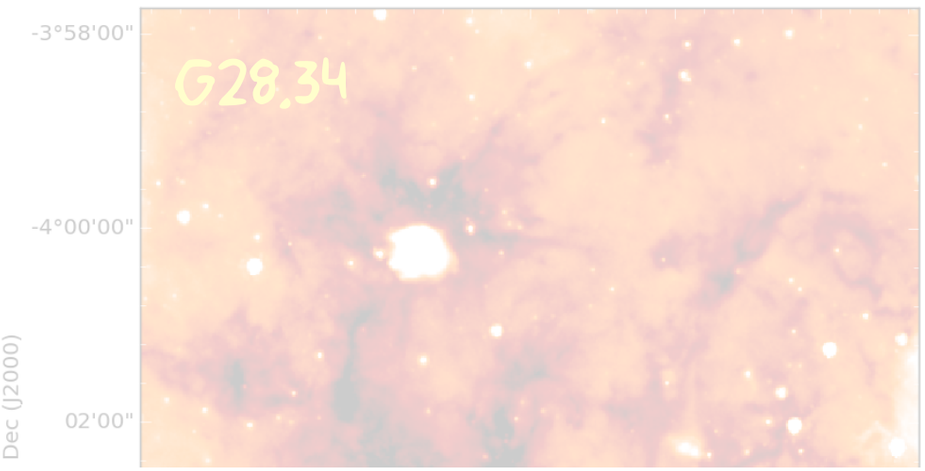
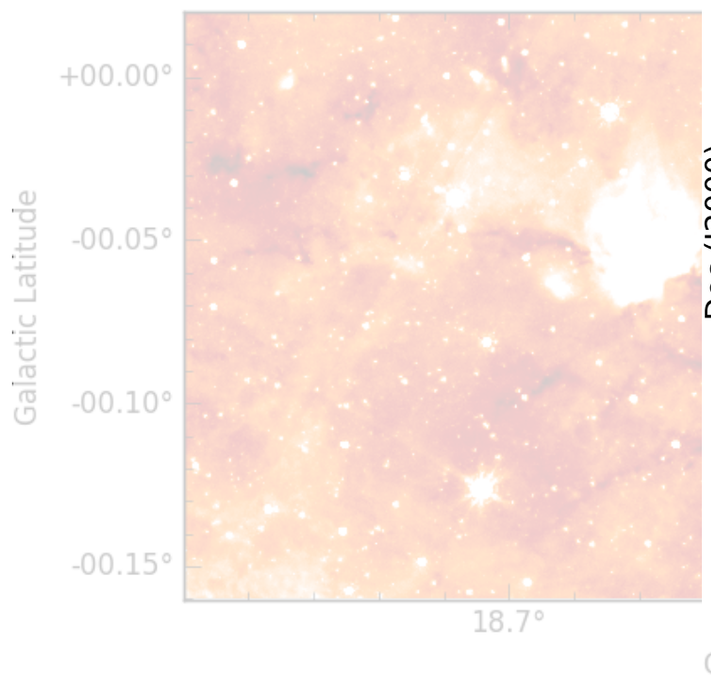
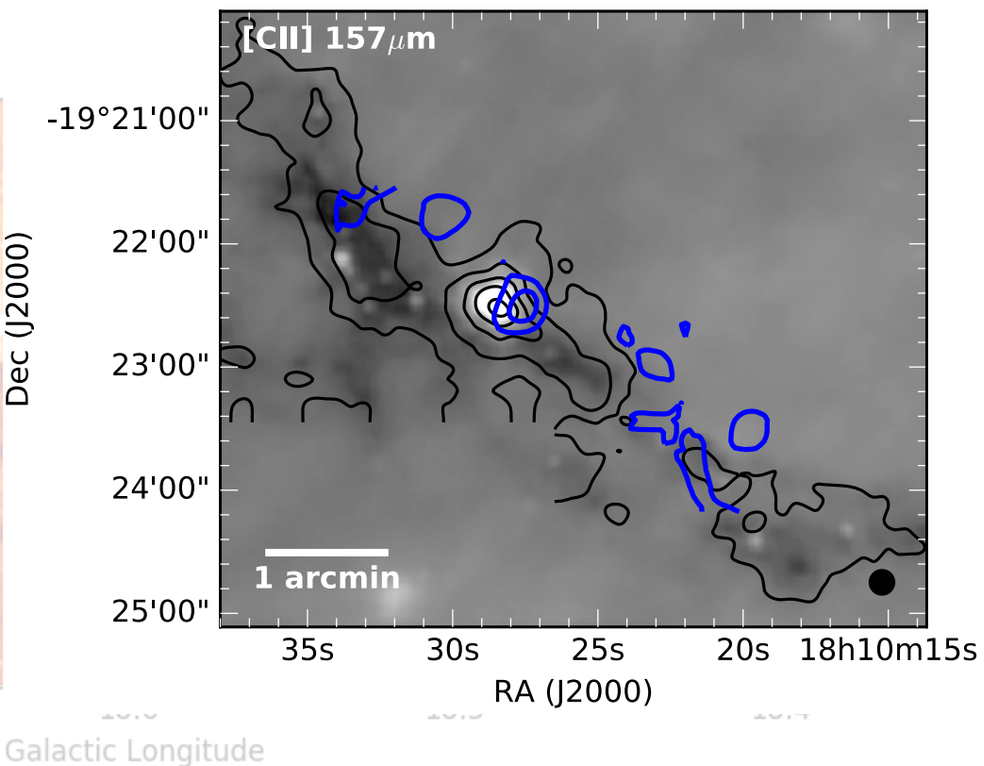
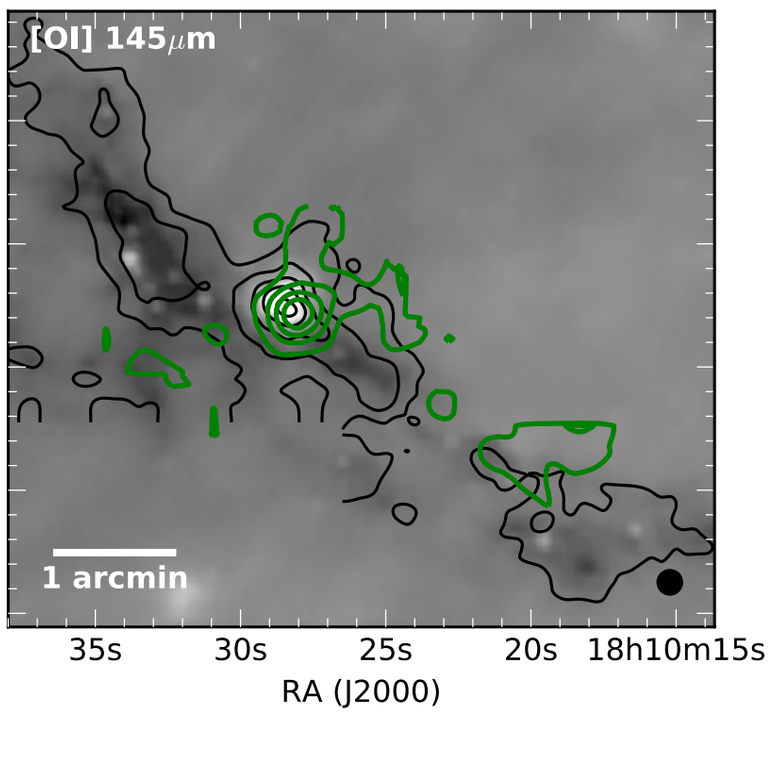




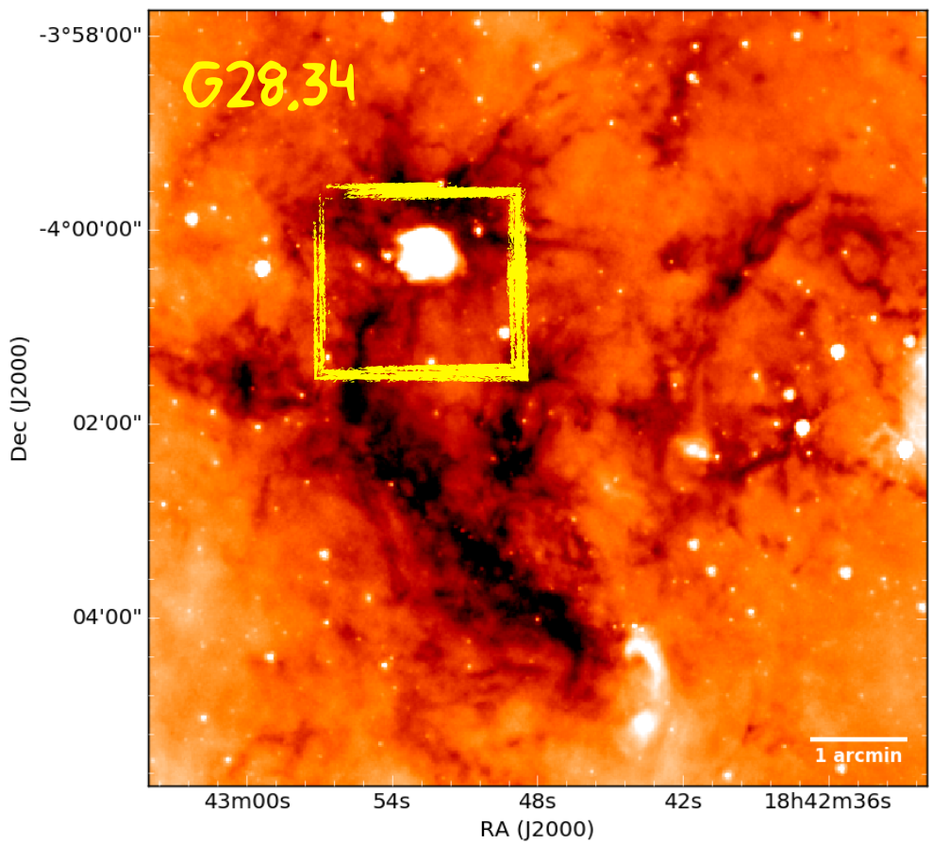


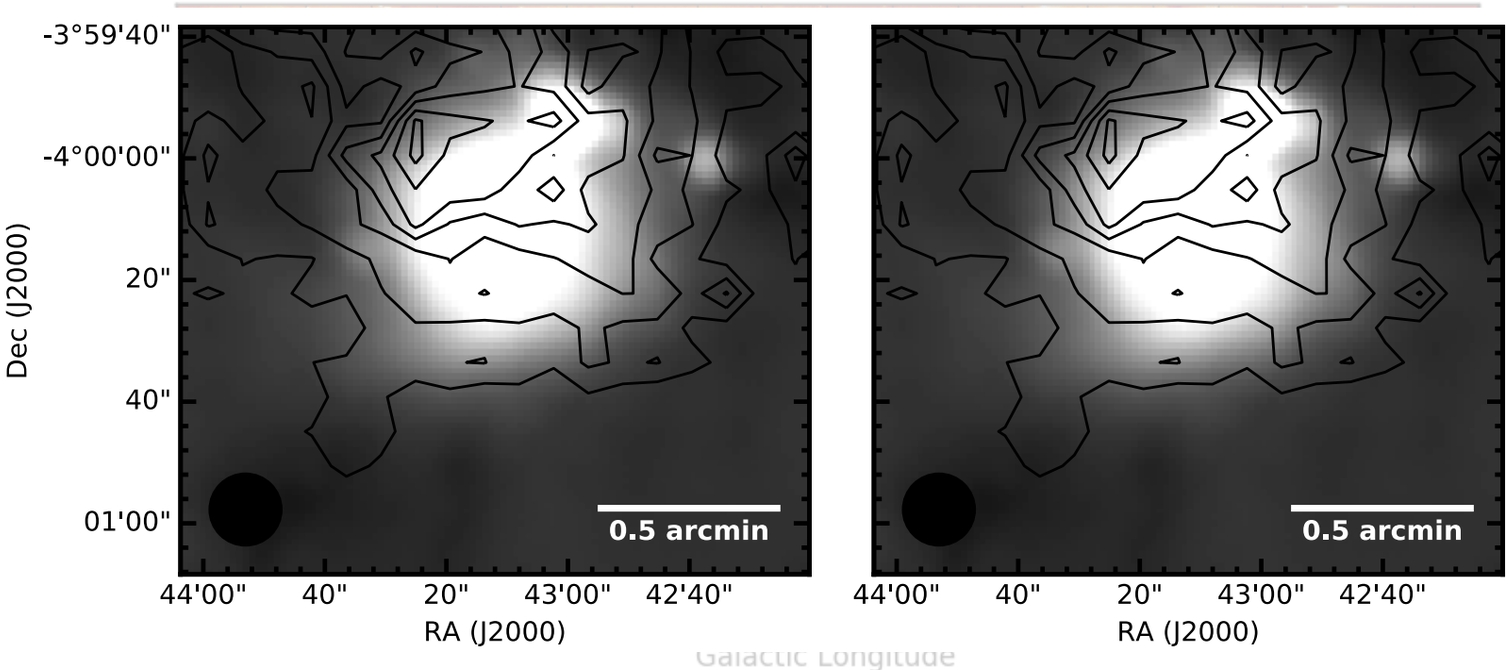




FIRST LOOK: FIFI-LS OBSERVATIONS OF FSLS IN IRDCS

Ragan, Linz et al (in prep)





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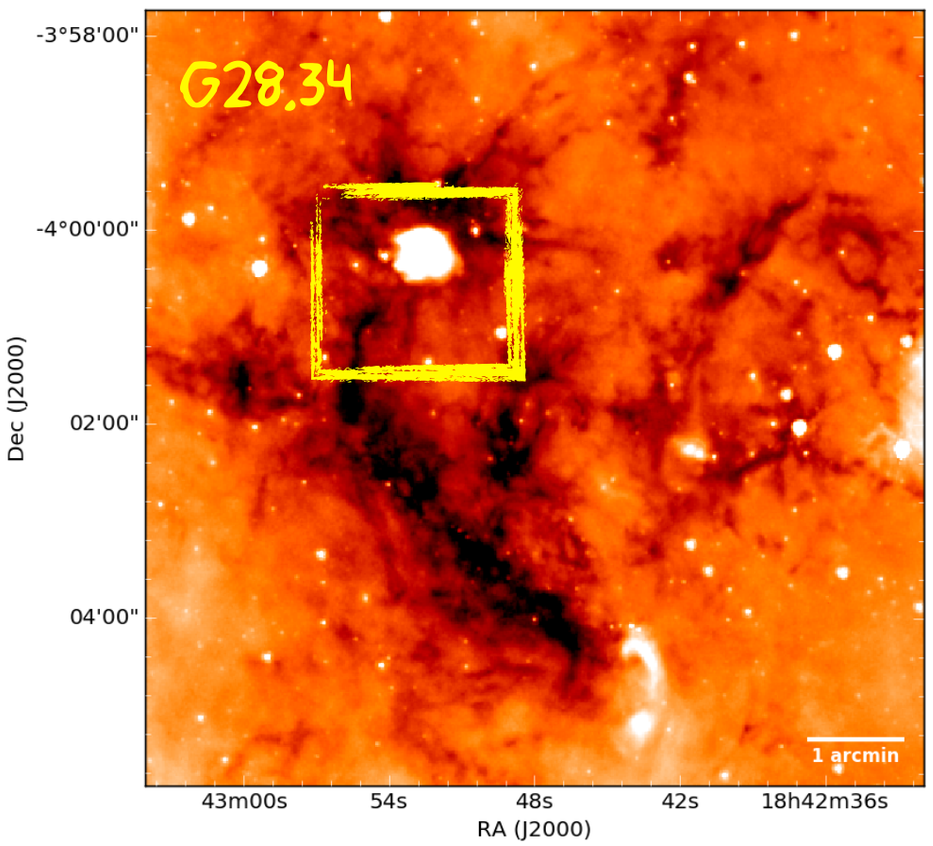

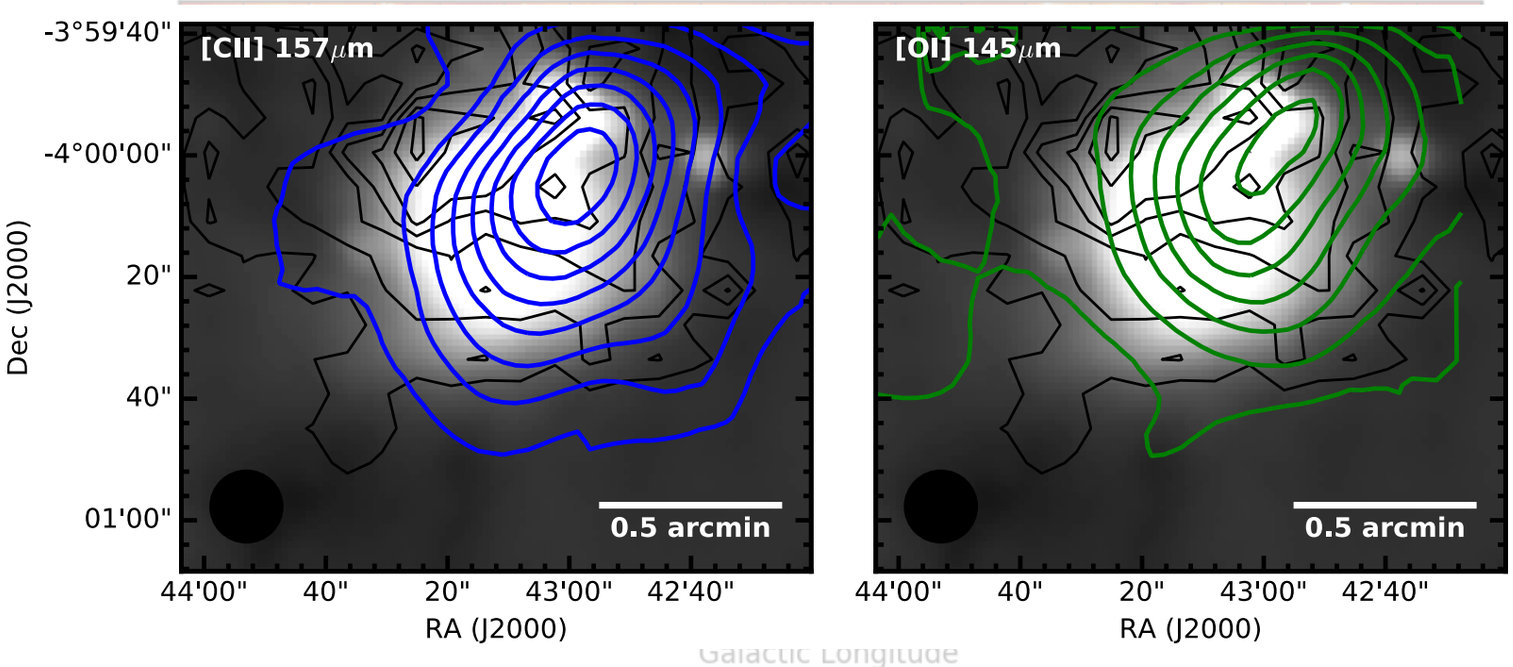

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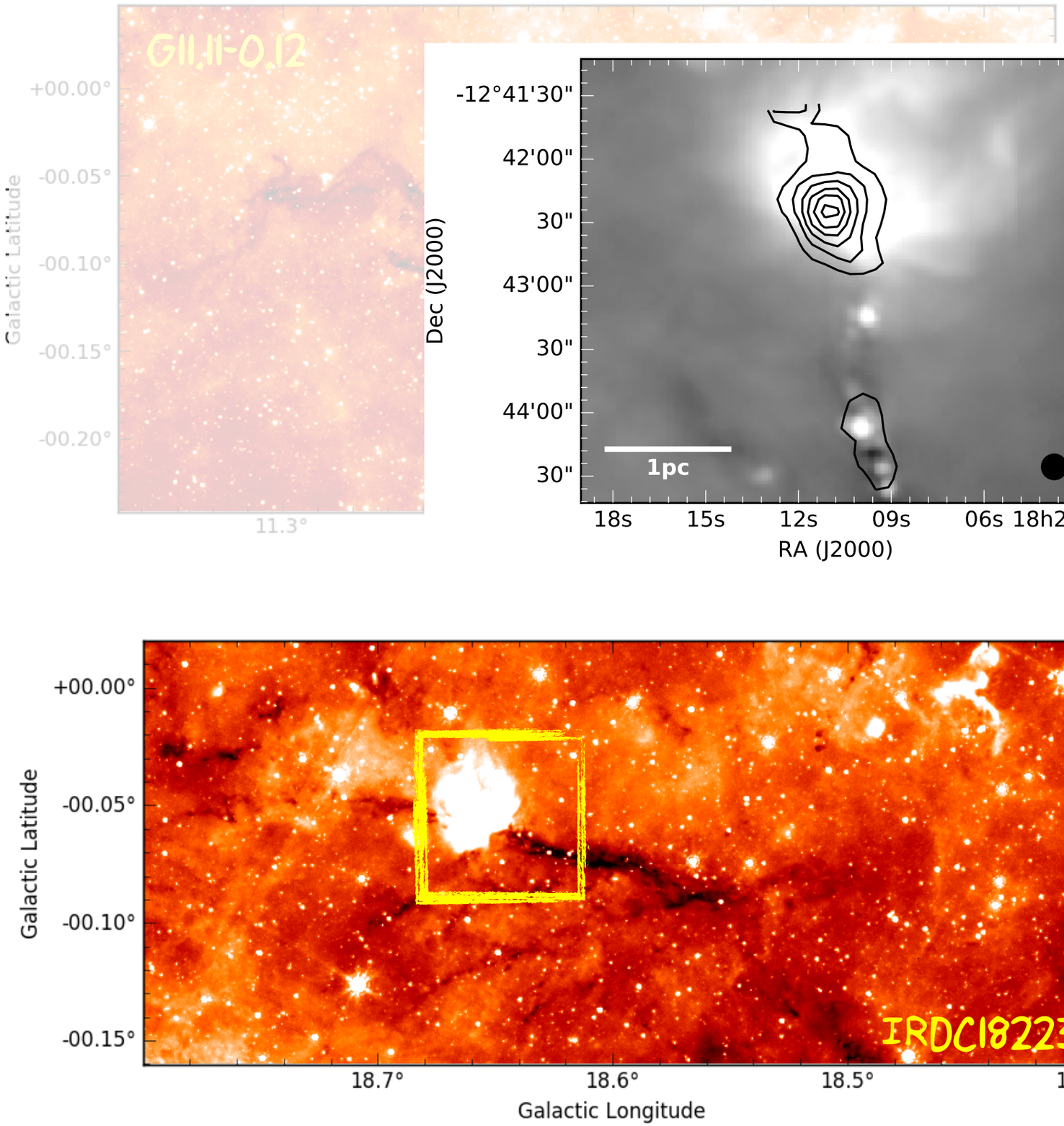

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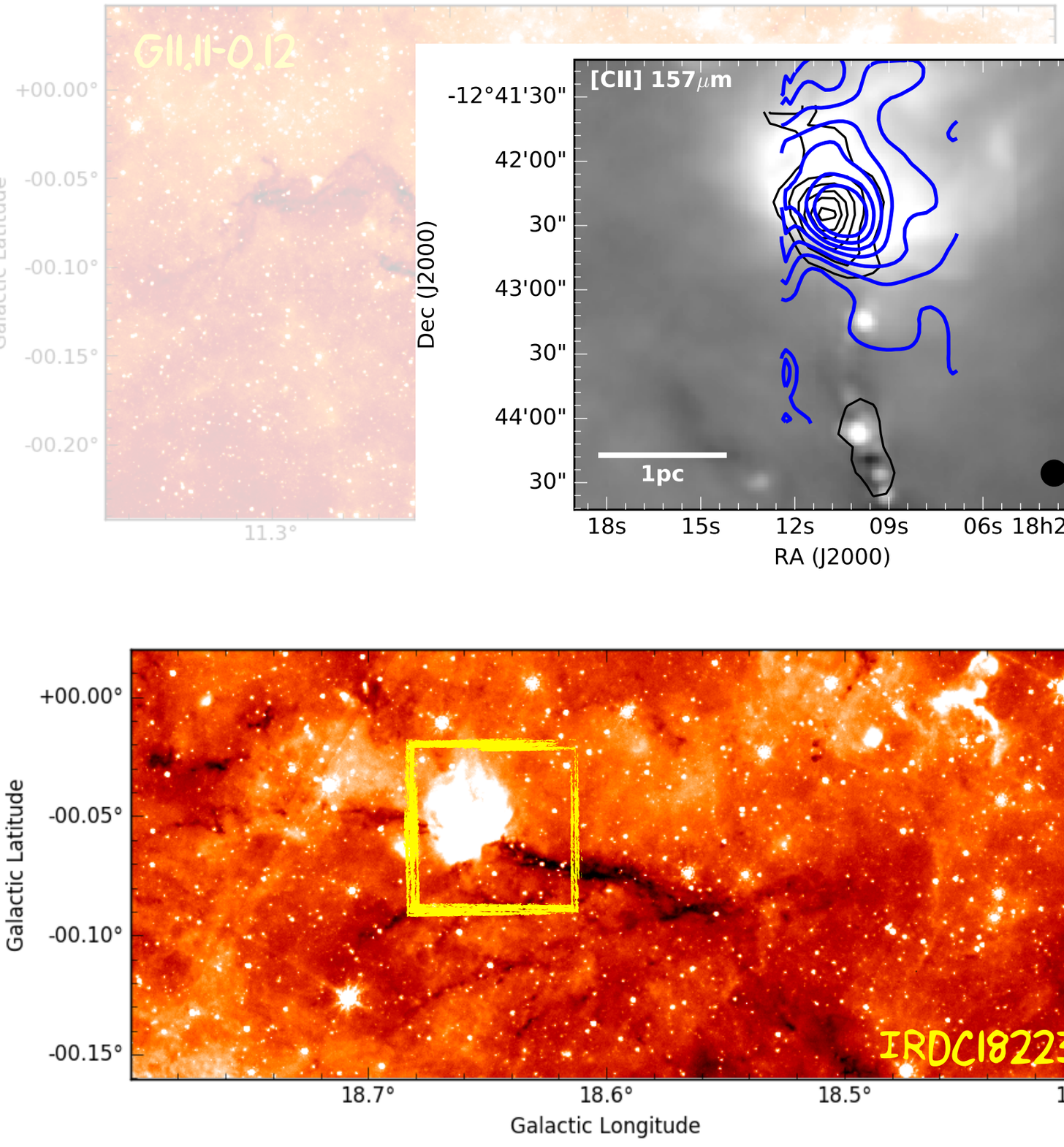

FIRST LOOK: FIFI-LS OBSERVATIONS OF FSLS IN IRDCS

RAGAN, LINZ ET AL (IN PREP)

CII / OI	on FIR source	off FIR source
G11.11	0.25	3
IRDC18223	1	4
G28.34	0.7	3

REALLY, REALLY PRELIMINARY!!!

SUMMARY & CONCLUSIONS

- [OI] and [CII] are better tracers (compared to CO) of dynamics in turbulent molecular clouds

- [OI] predicted to become more dominant coolant in CMZ-type environments

- [CII] observations in IRDCs show dynamical signatures possibly due to cloud formation processes

- Both [OI] lines detected in IRDCs with FIFI-LS

SUMMARY & CONCLUSIONS

what next?

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Finally, some boundary conditions for cloud formation simulations!

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Thanks!