FRAGMENTATION AND DISK STABILITY IN HIGH-MASS STAR FORMATION

LINKING OBSERVATIONS AND SIMULATIONS

Aida Ahmadi
Henrik Beuther
Joe Mottram
Rolf Kuiper
+ CORE Team

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

Tracing the Flow
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CORE: NOEMA LARGE PROGRAM

- Sample of 20 young high-luminosity regions: $L > 10^4 L_\odot$
- Dust continuum & line observations at 1.3 mm (220 GHz)
- NOEMA: Plateau de Bure + new antennae

A, B, & D configurations in decreasing baseline length

Highest resolution ~ 0.3" => 600 AU at 2 kpc

- 30 m telescope data to cover the missing flux

CORE: MOTIVATION

- What are the fragmentation properties of high mass star forming regions during the early evolutionary stages of cluster formation?
- Can we identify genuine high-mass accretion disks, and if yes, what are their properties?
- How is the gas accumulated into the central cores and what are the larger-scale gas accretion flow and infall properties?
- What are the properties of the energetic outflows and how do they relate to the underlying accretion disks?
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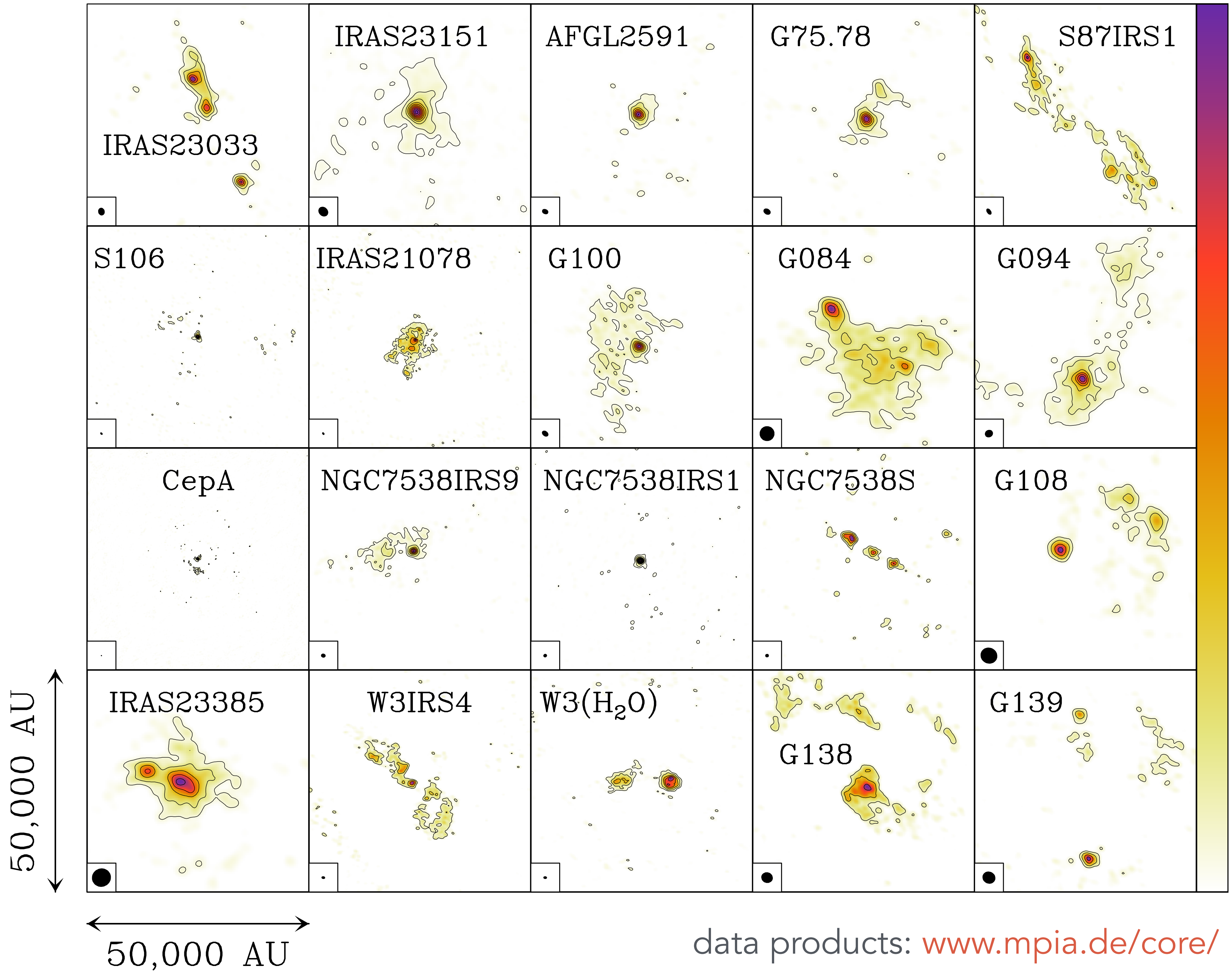
CORE: DUST CONTINUUM

Beuther et al. 2018



data products: www.mpia.de/core/

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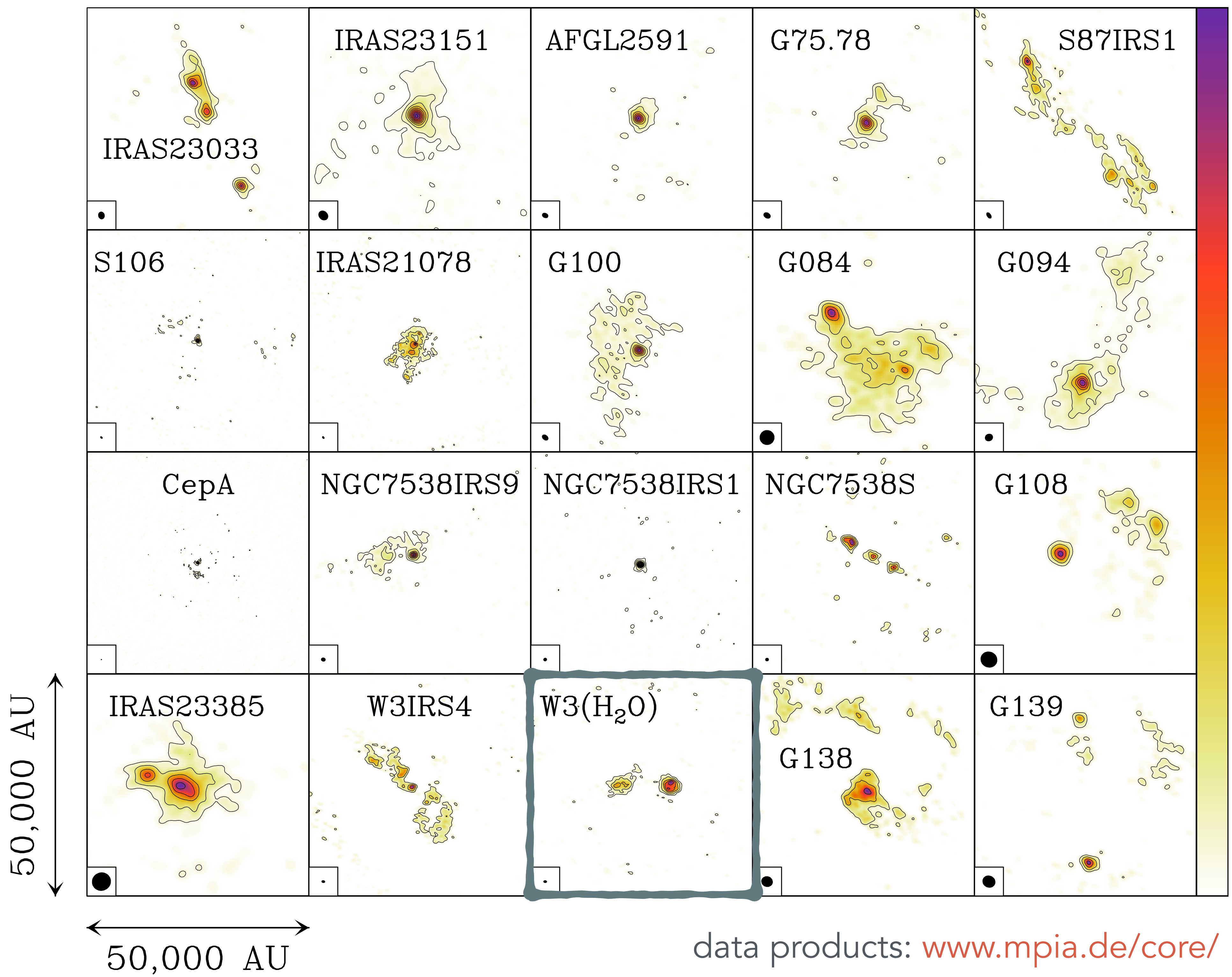

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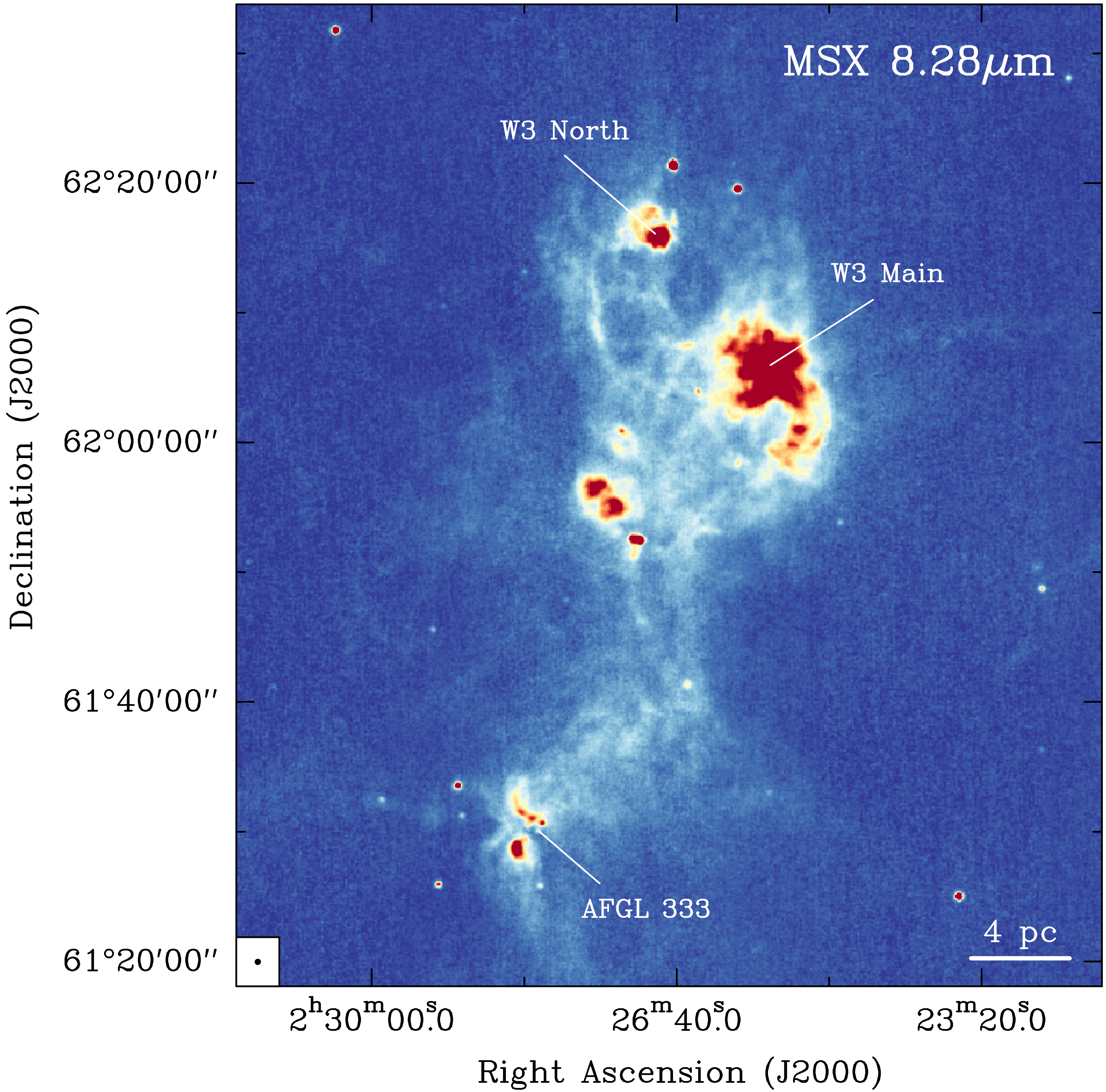
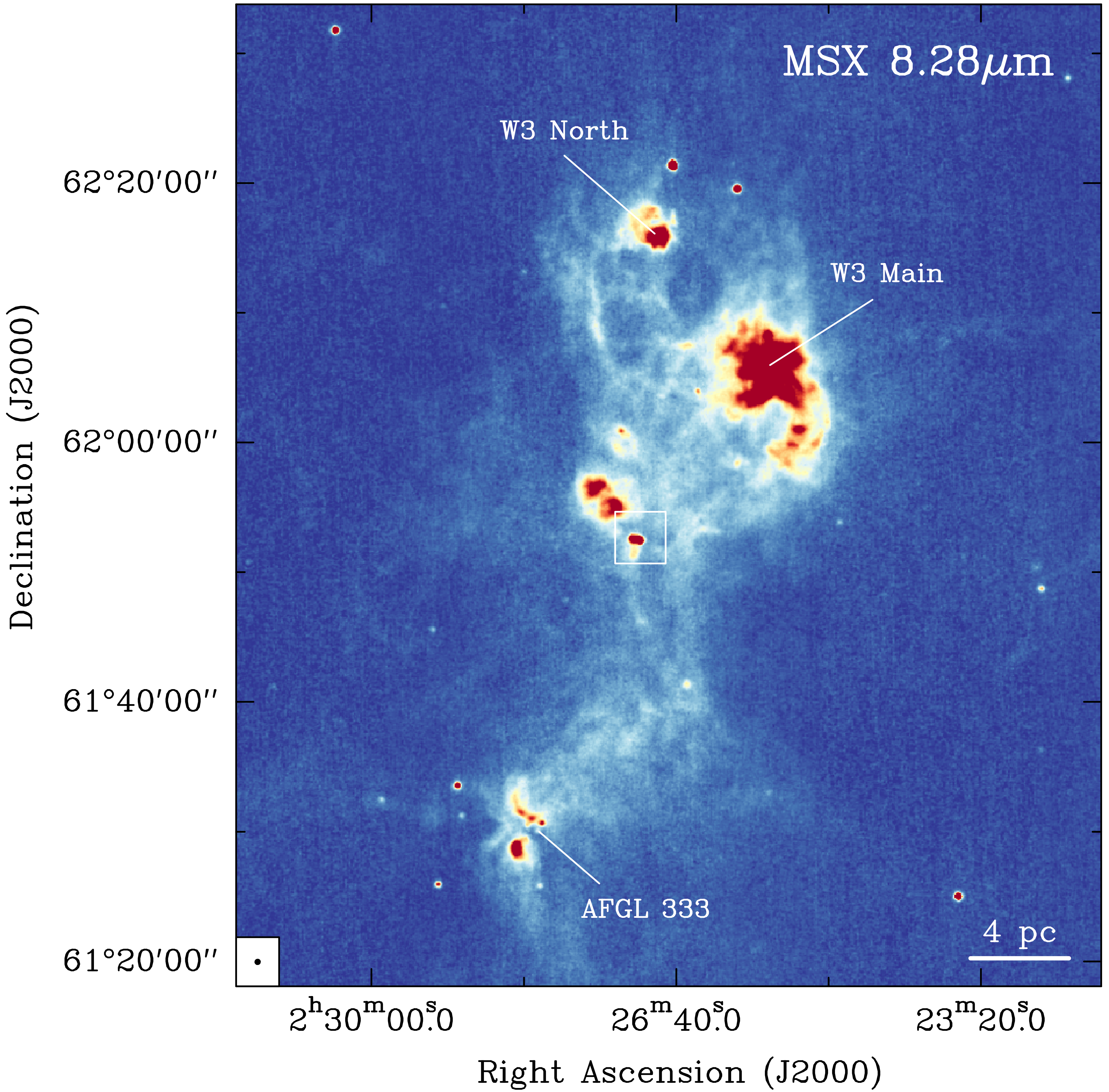


MSX 8.28μm
W3 North
W3 Main
AFGL 333
4 pc
62°20′00″
62°00′00″
61°40′00″
61°20′00″
Declination (J2000)
$2^{h}30^{m}00^{s}.0$
$26^{m}40^{s}.0$
$23^{m}20^{s}.0$
Right Ascension (J2000)



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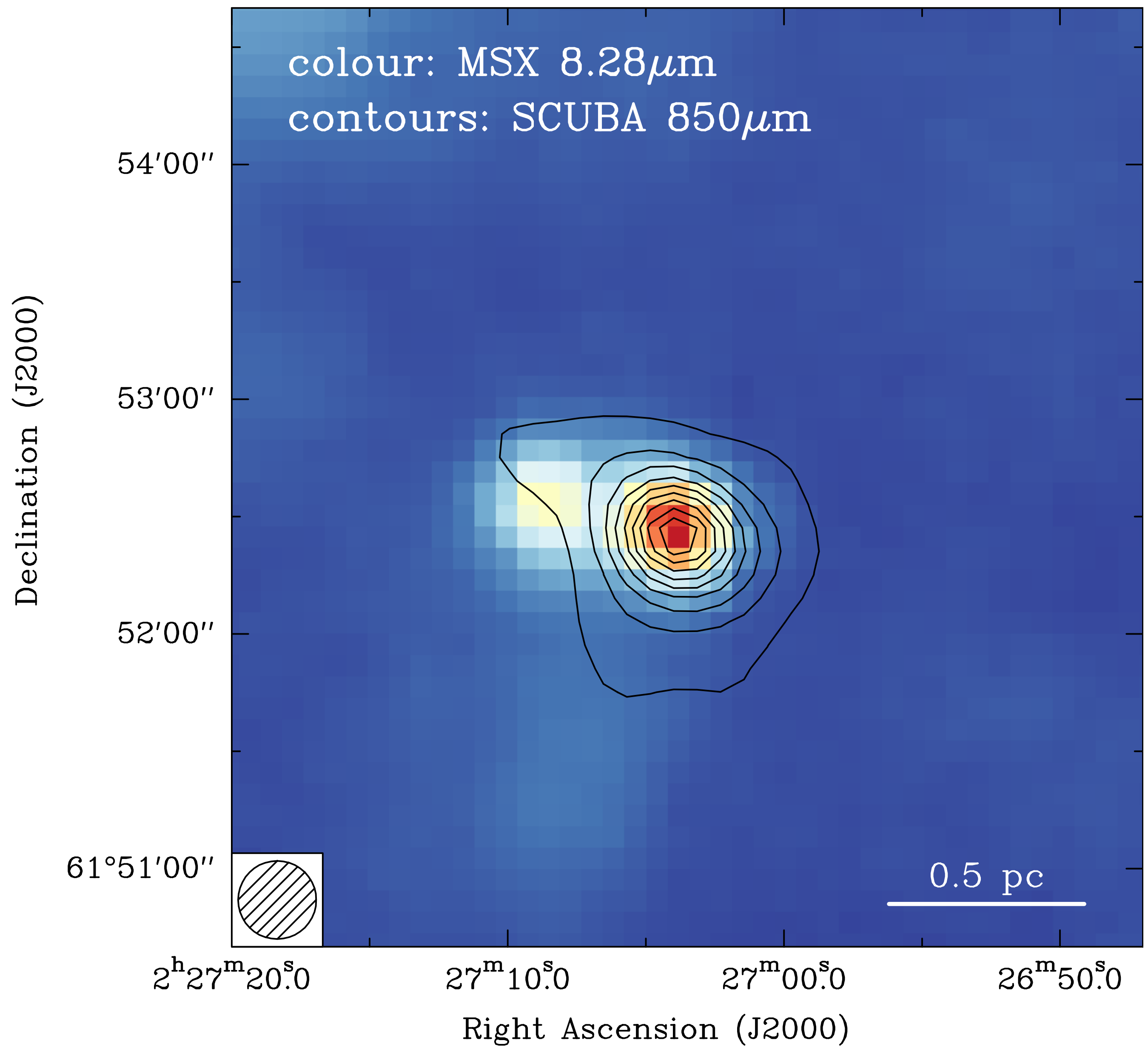
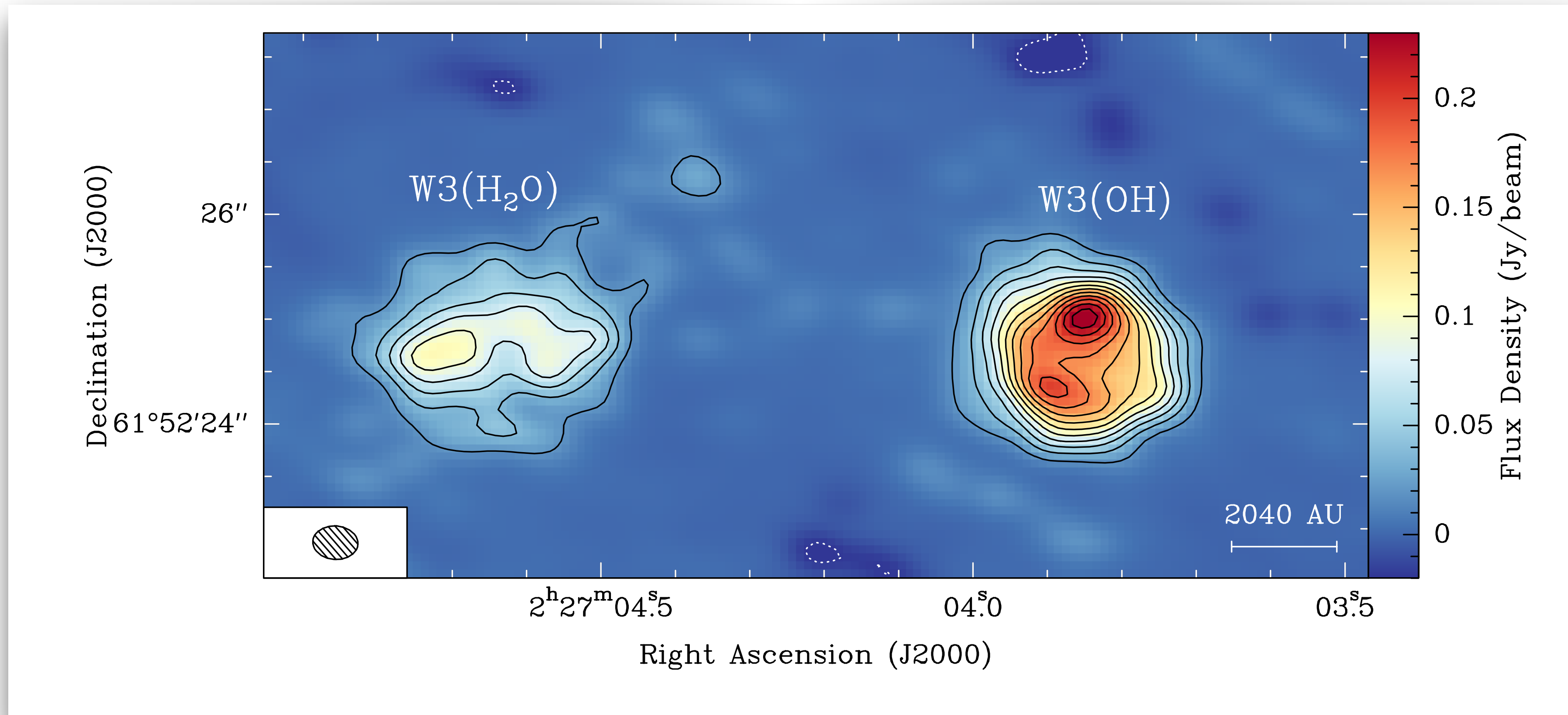

colour: MSX 8.28μm
contours: SCUBA 850μm
0.5 pc
54′00″
53′00″
52′00″
61°51′00″
Declination (J2000)
2h27m20s.0
27m10s.0
27m00s.0
26m50s.0
Right Ascension (J2000)

NOEMA'S VIEW AT MM WAVELENGTH

- A+B+D array resolution: 0.35″ (700 AU @ 2 kpc)



W3(H_2O)

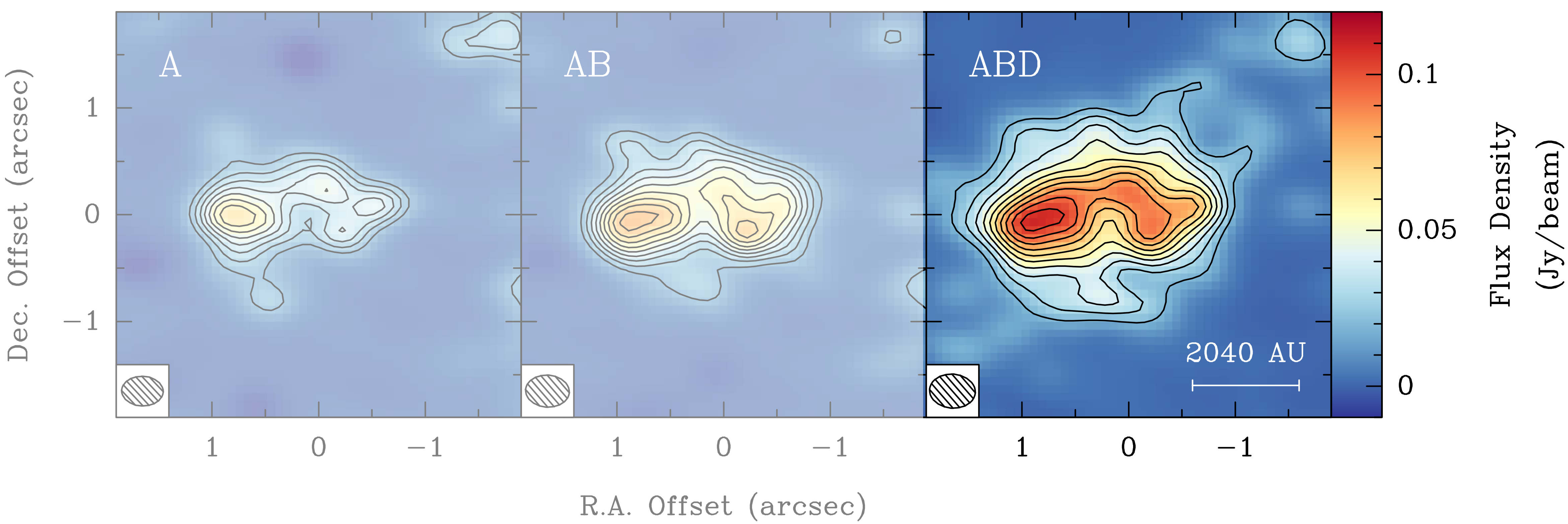
- a.k.a: Turner-Welch object
- M ~ 30 $M_\odot$
- L ~ 10^4 $L_\odot$

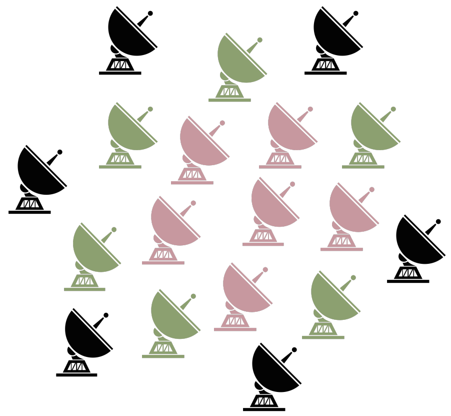
W3(OH)

- Ultracompact HII region
- Ionized by young OB stars
- M ~ 10-20 $M_\odot$

W3(H_2O) FRAGMENTATION: CONTINUUM

- Two fragments resolved as resolution is improved





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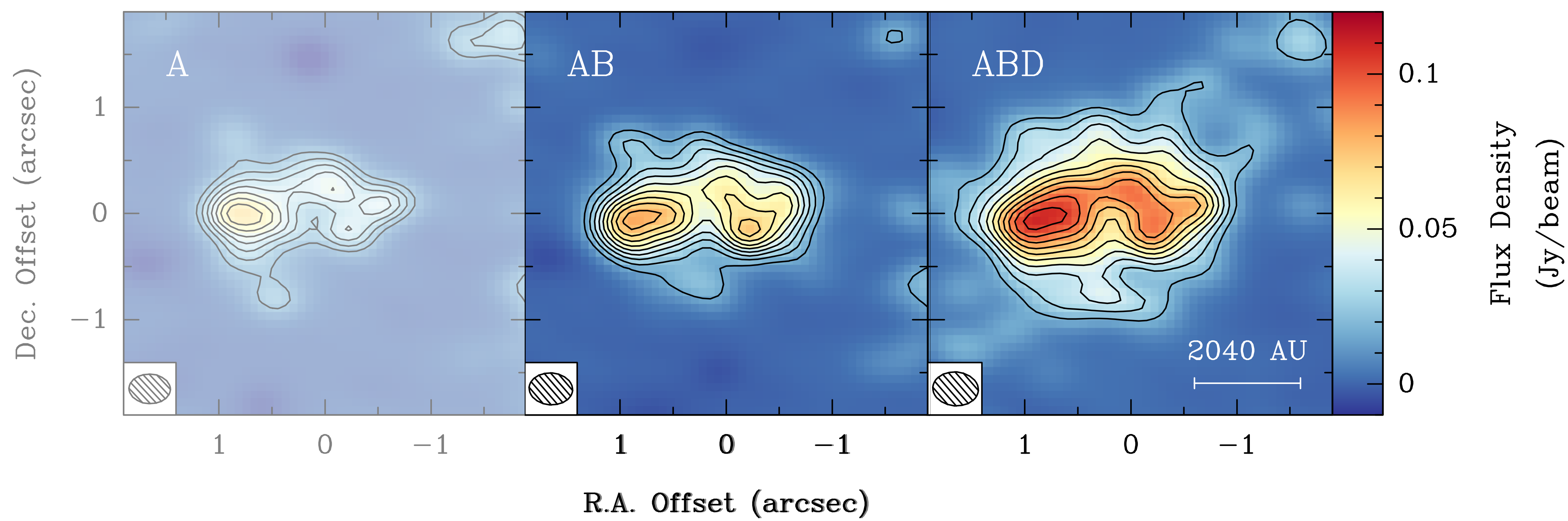

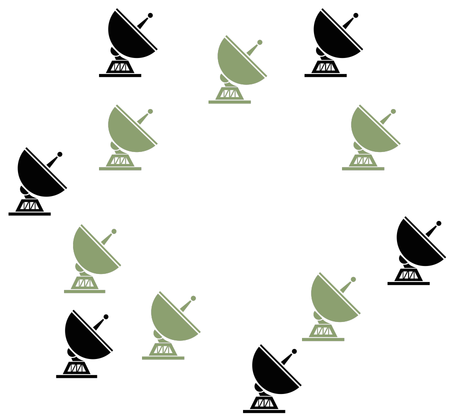

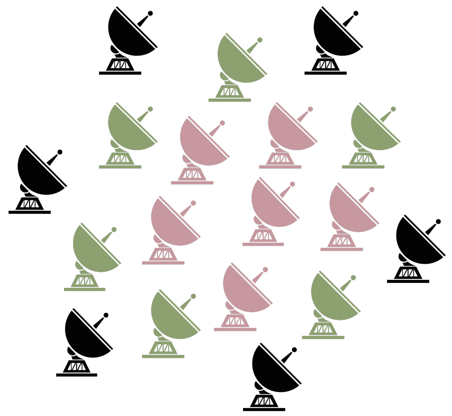

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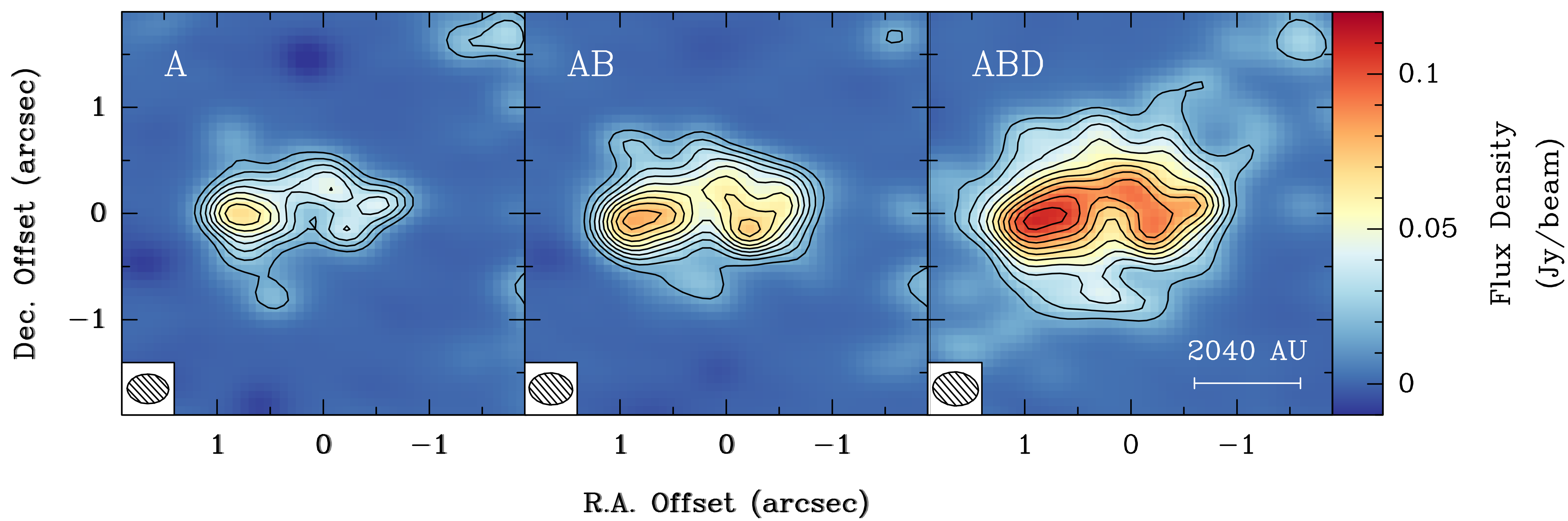
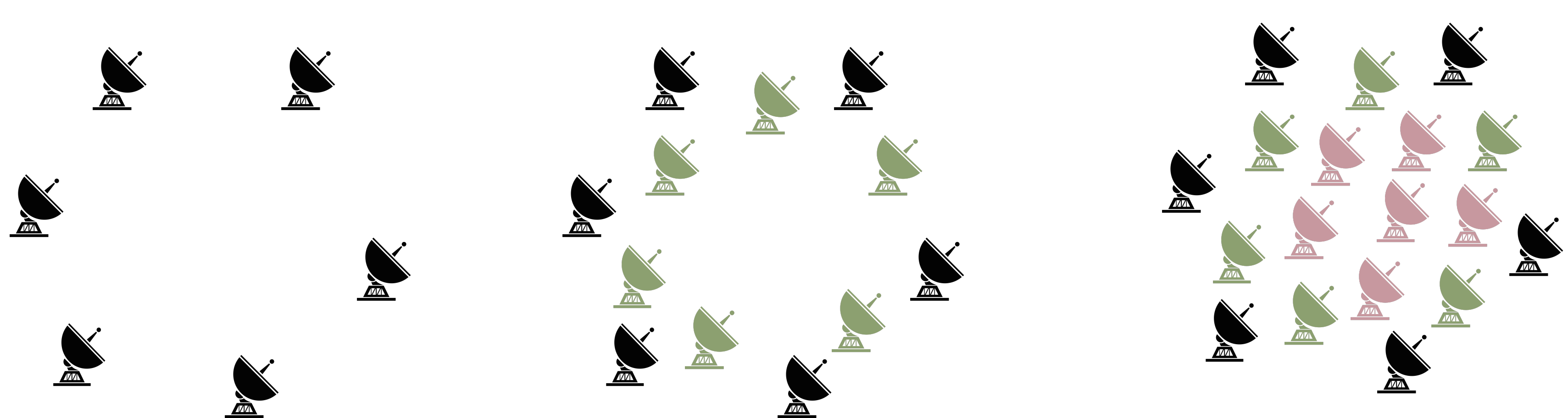
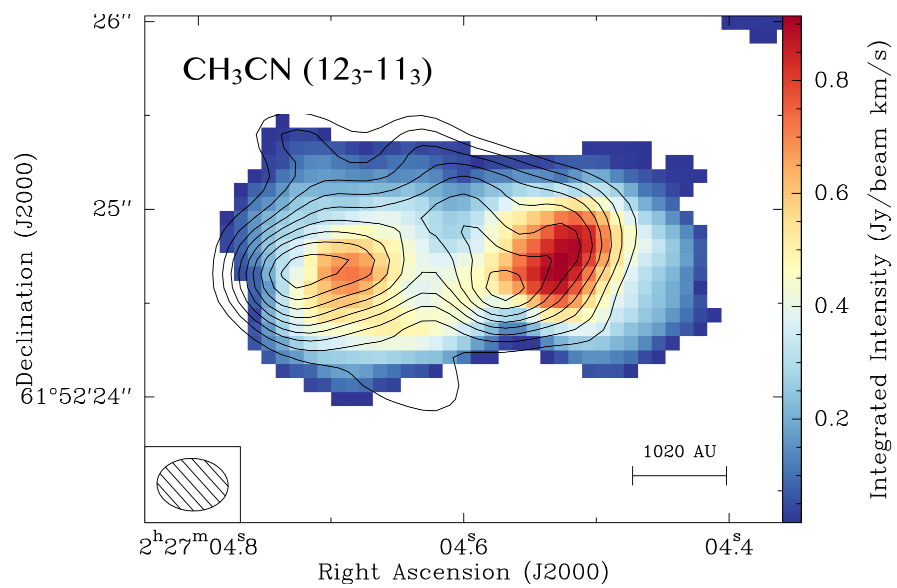
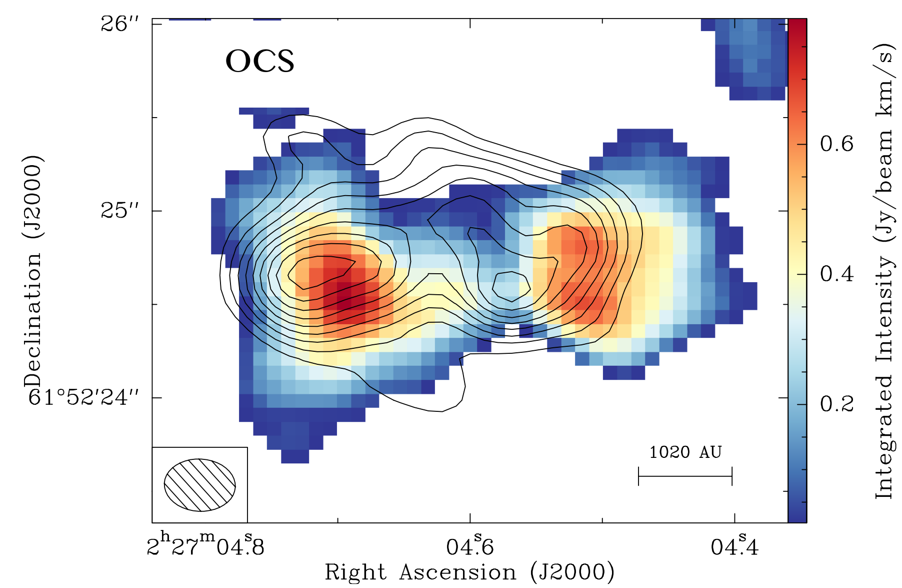


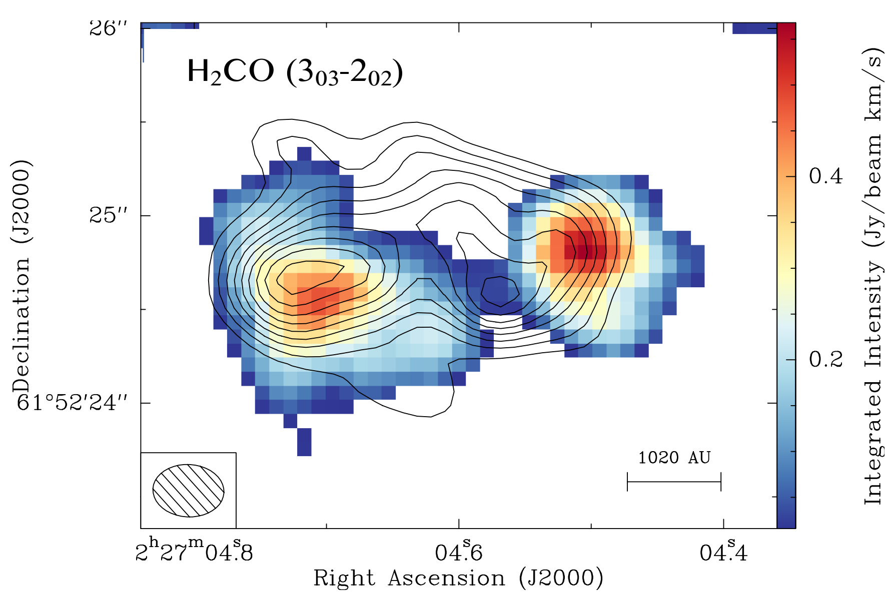


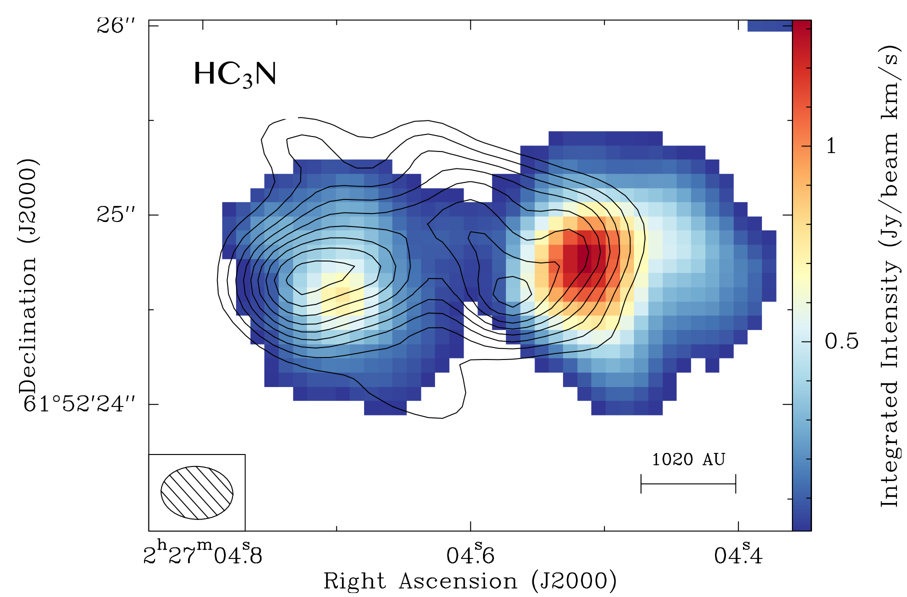
W3(H_2O) FRAGMENTATION: LINES

- Two fragments resolved at ~ 800AU scales with multiple tracers



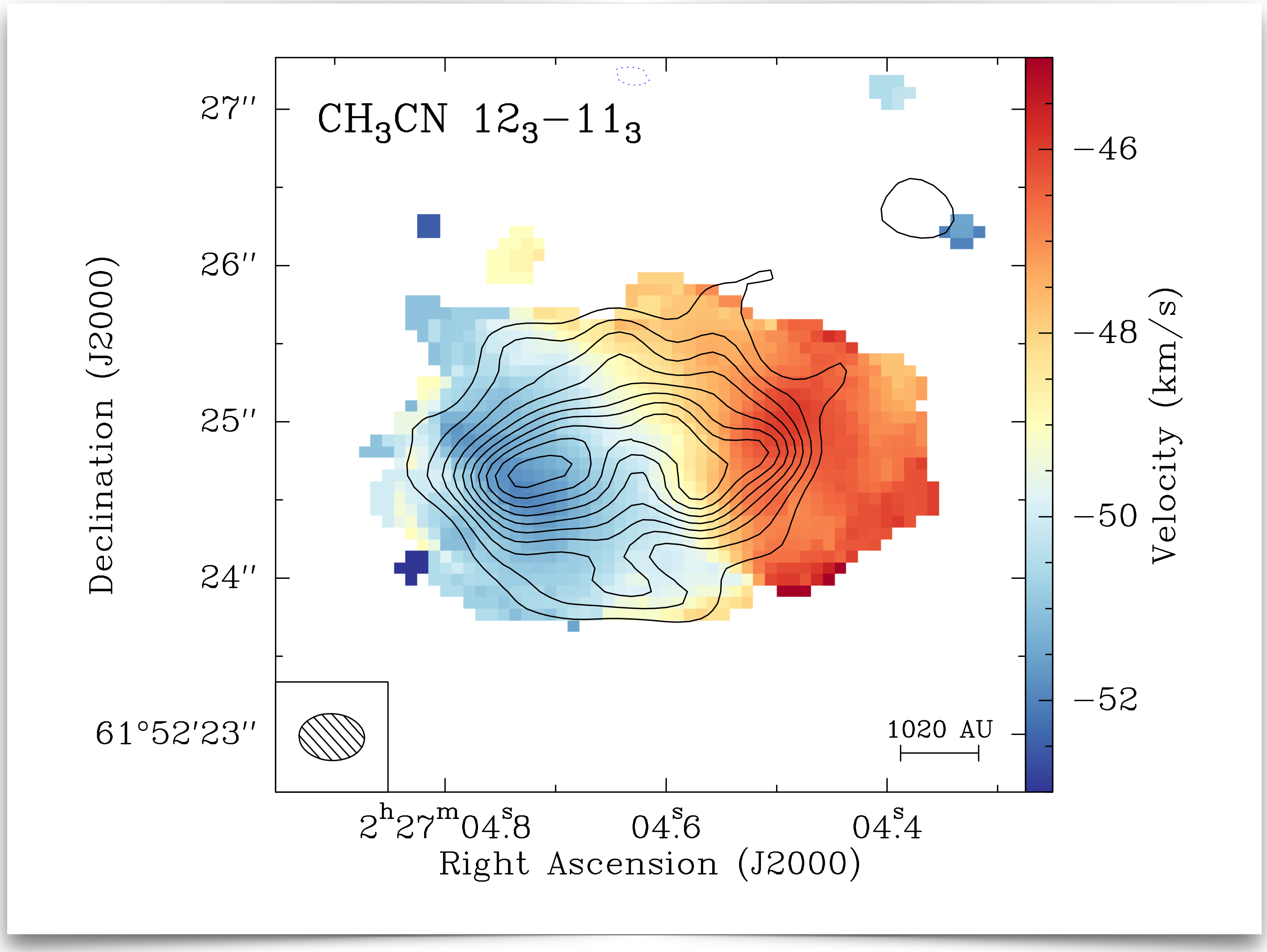






VELOCITY STRUCTURE

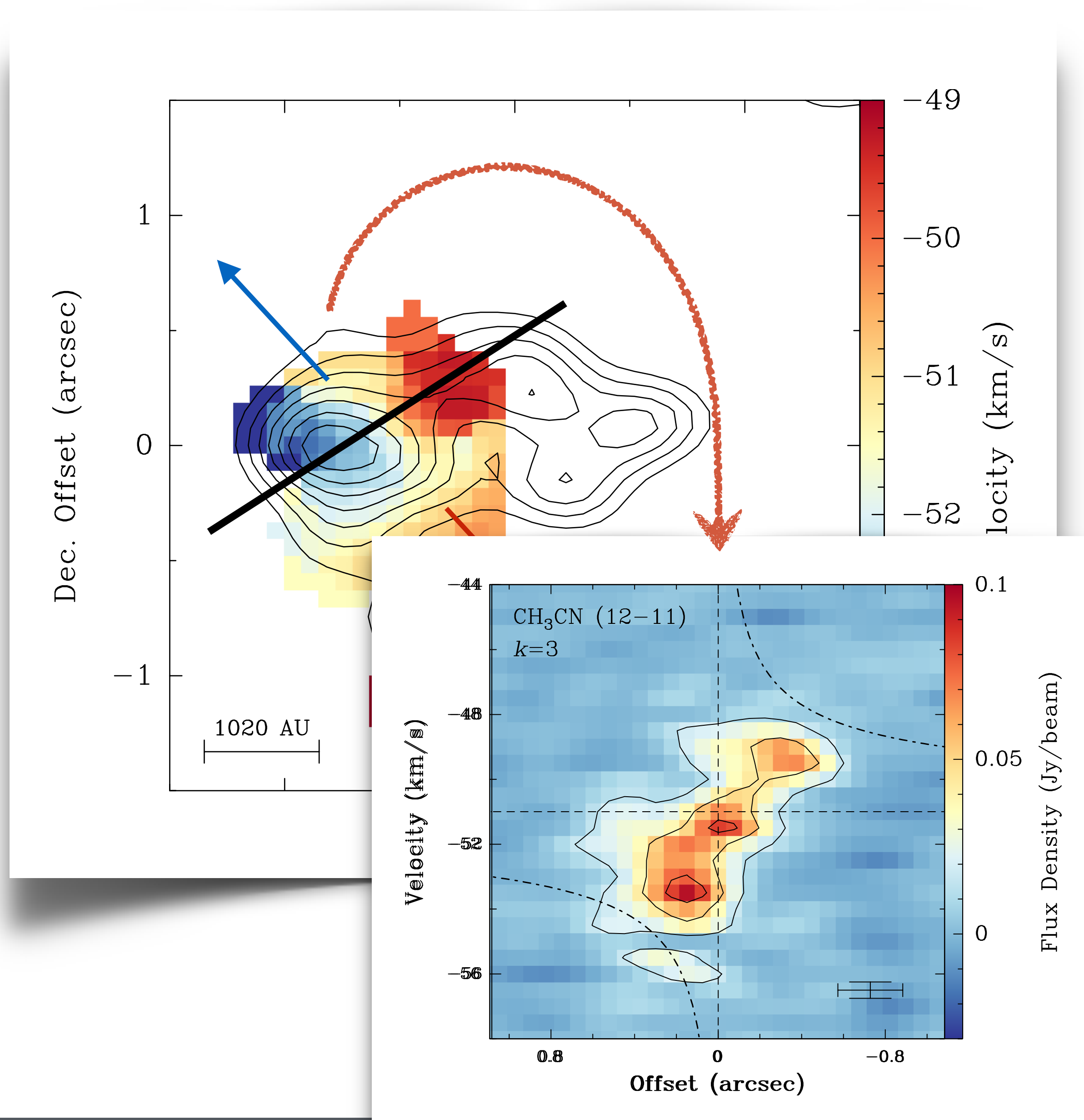
- Velocity map of the region in CH_3CN (12_3-11_3) shows clear gradient in the E-W direction



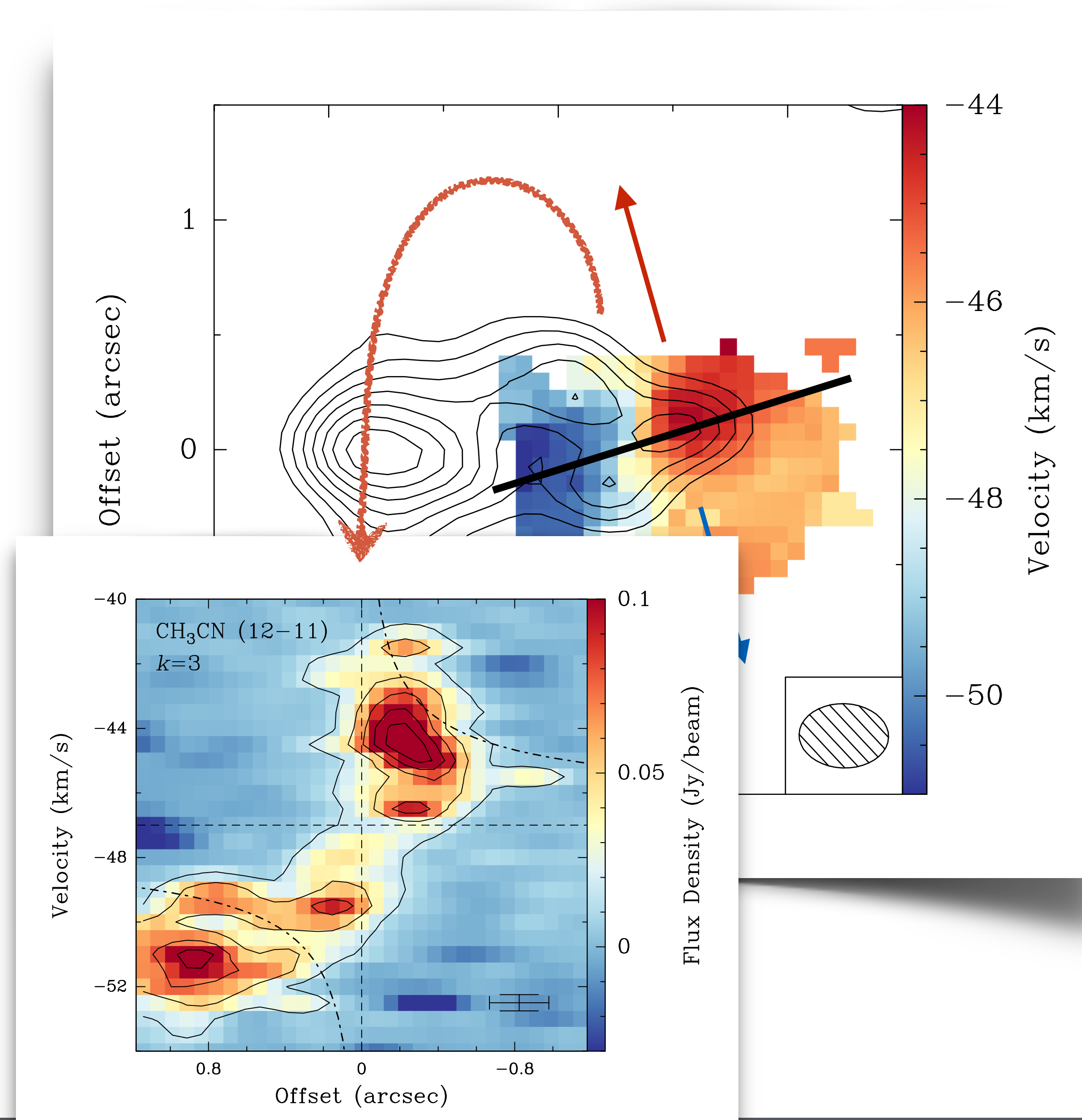
KINEMATICS OF FRAGMENTS

- Velocity gradient observed for each fragment consistent with molecular outflows

left fragment



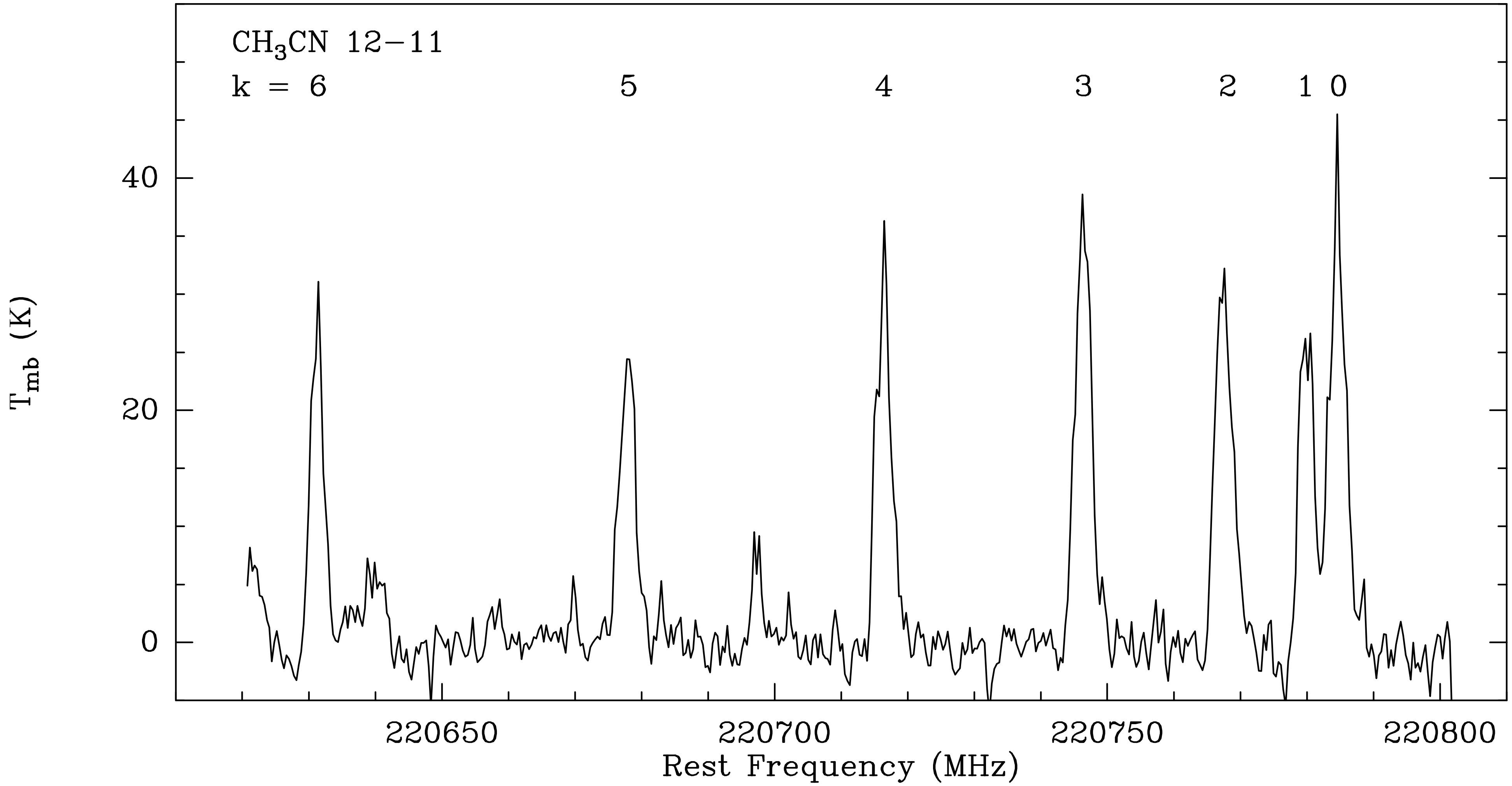
right fragment



(EXTENDED CASA LINE ANALYSIS SOFTWARE SUITE)

MODELLING WITH XCLASS

- XCLASS: solves the radiative transfer equation under LTE and generates synthetic spectra that can be compared to the real spectra
- Fitting **CH_3CN (12-11) k=4 to k =6** lines simultaneously along with their $CH_3^{13}CN$ isotopologues



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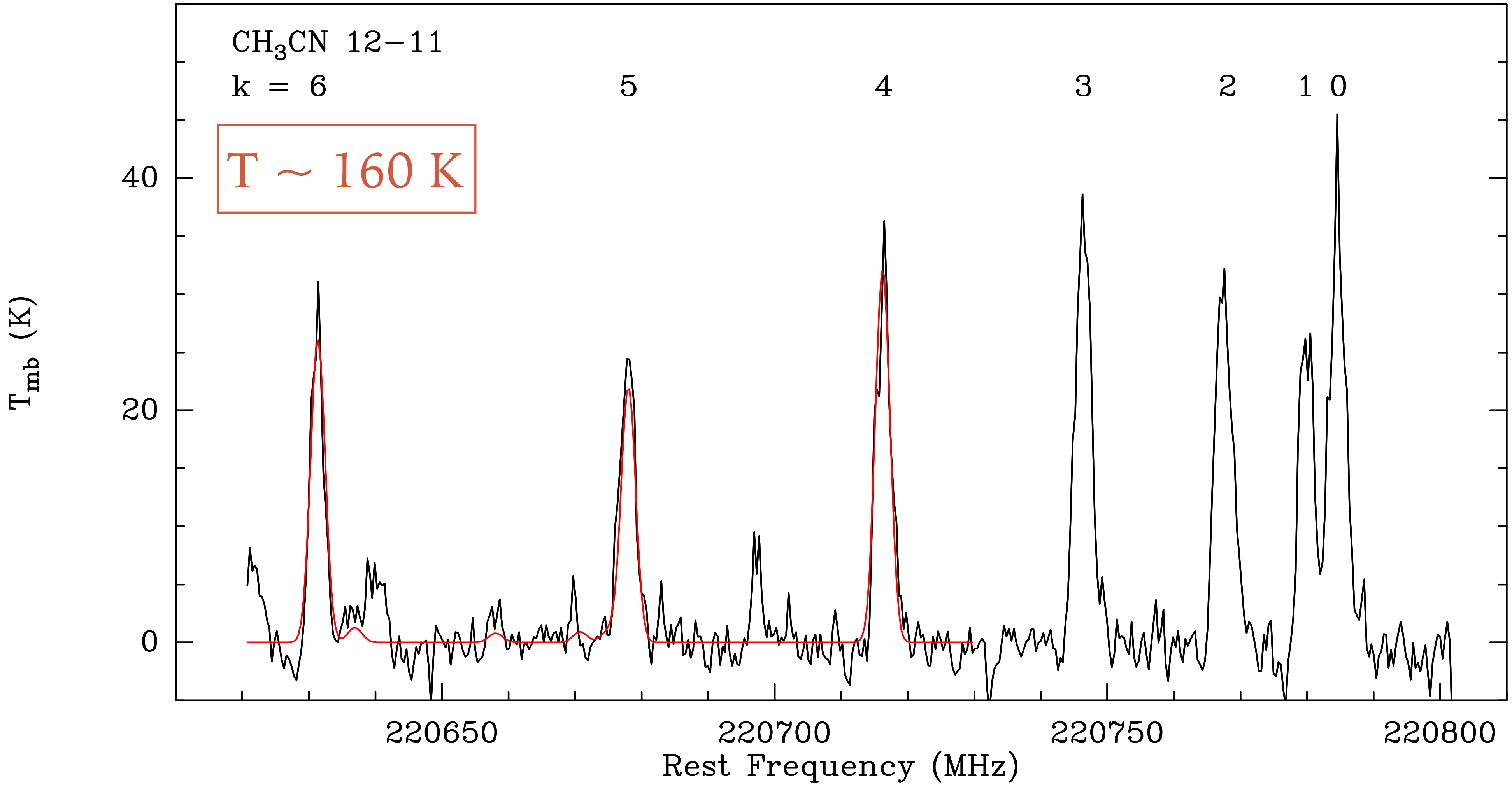
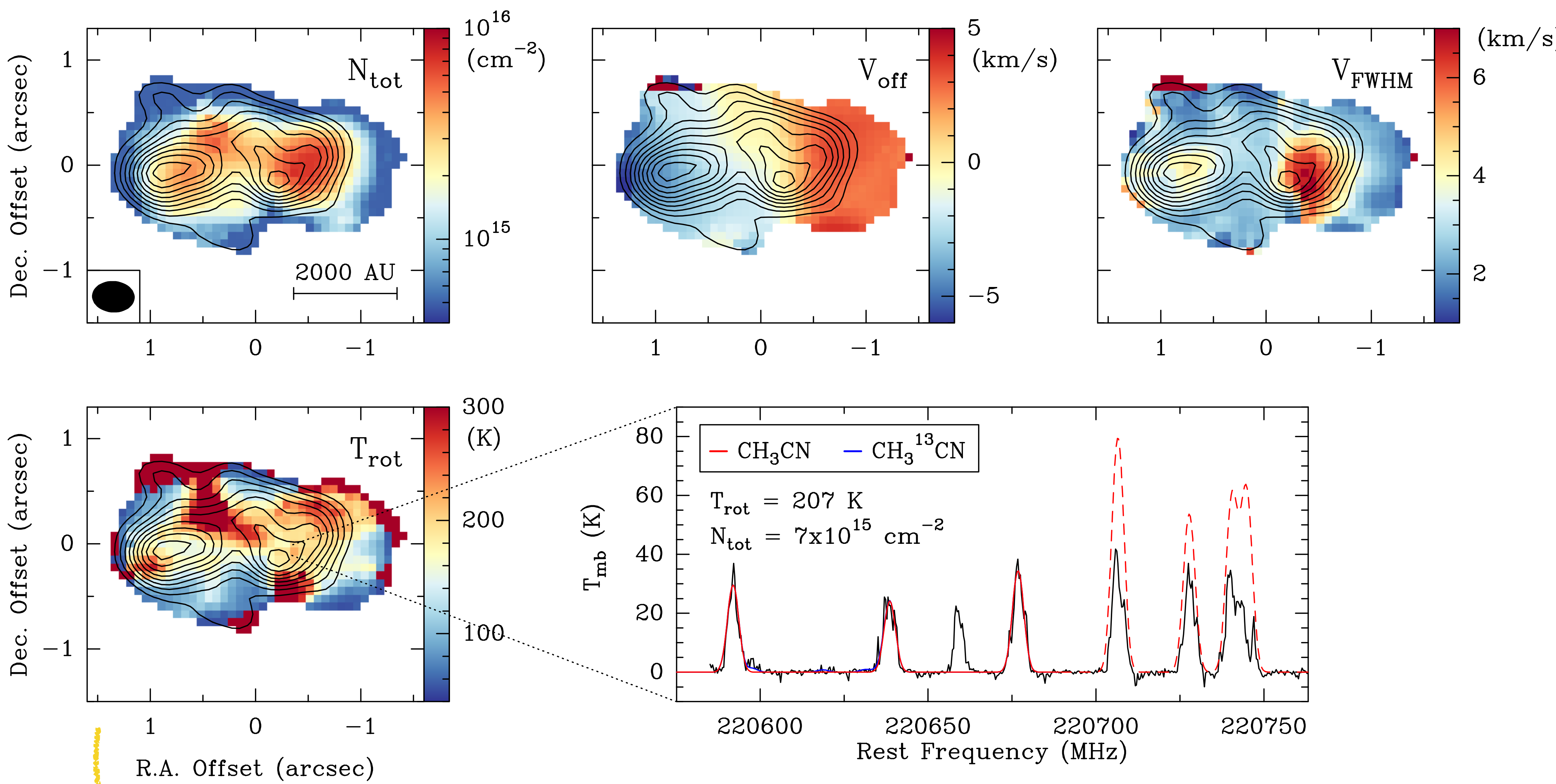


MODELLING WITH XCLASS: OUTPUT



Average temperature is **warm: ~180 K**

TOOMRE STABILITY

- For a differentially rotating disk, the shear force can provide added stability against collapse
- Quantified by Toomre (1964) via

sound speed

epicyclic frequency of the disk
= angular velocity for Keplerian rotation

$$Q = \frac{c_s \Omega}{\pi G \Sigma}$$

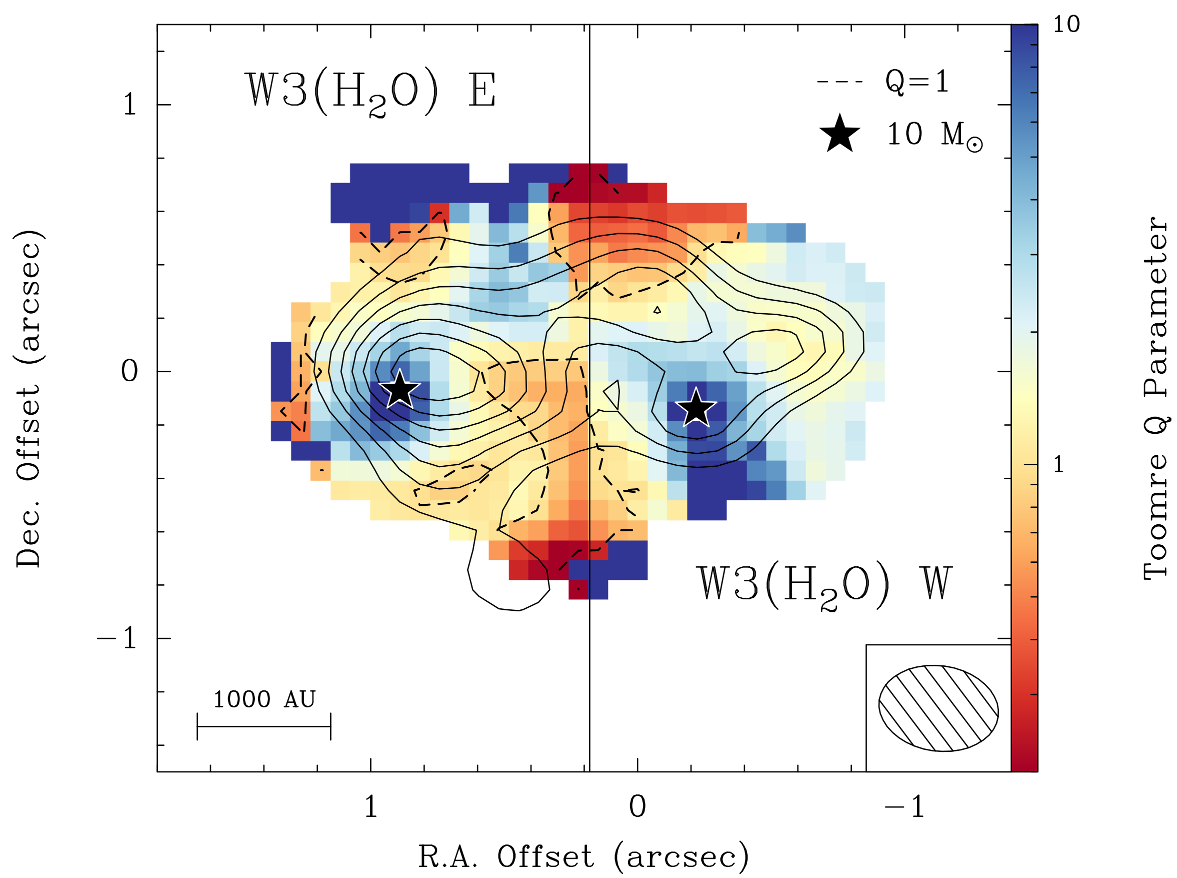
surface density of the disk

- A thin disk becomes **unstable** against axisymmetric gravitational instabilities if **Q < 1**

TOOMRE STABILITY

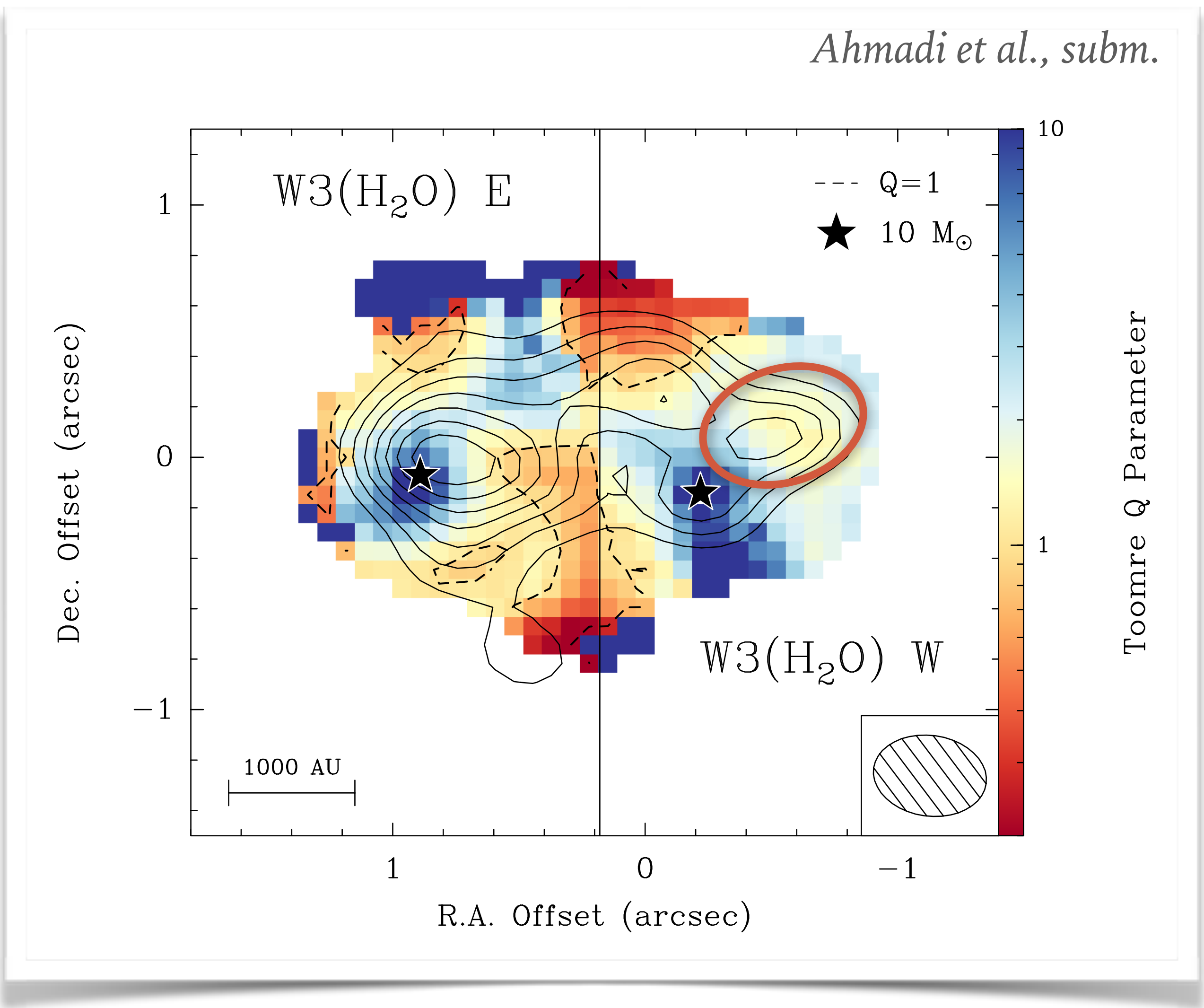
- Outer rotating structure is Toomre-unstable in parts

Ahmadi et al., subm.



TOOMRE STABILITY

- Outer rotating structure is Toomre-unstable in parts
  - Further **disk fragmentation** possible



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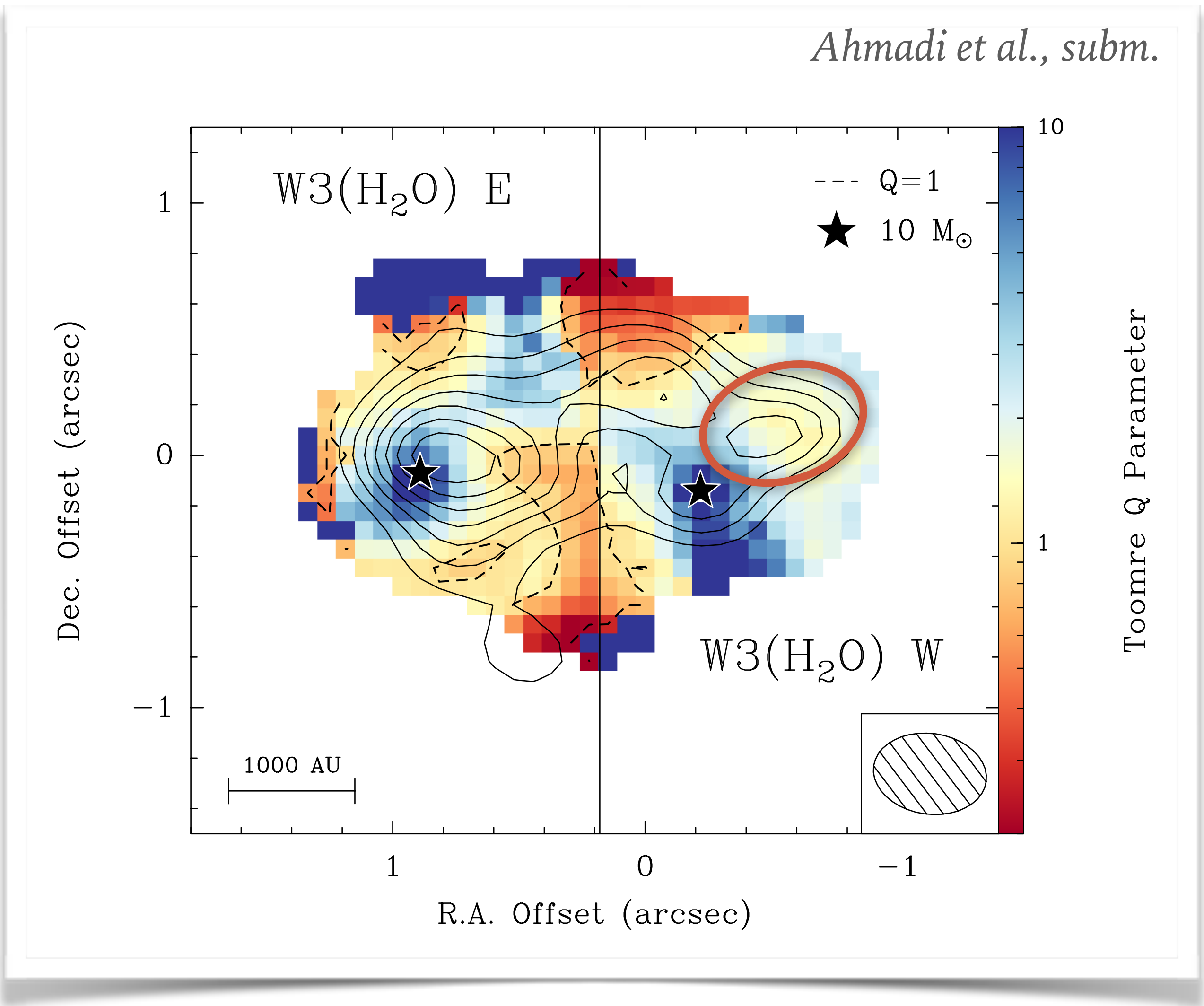
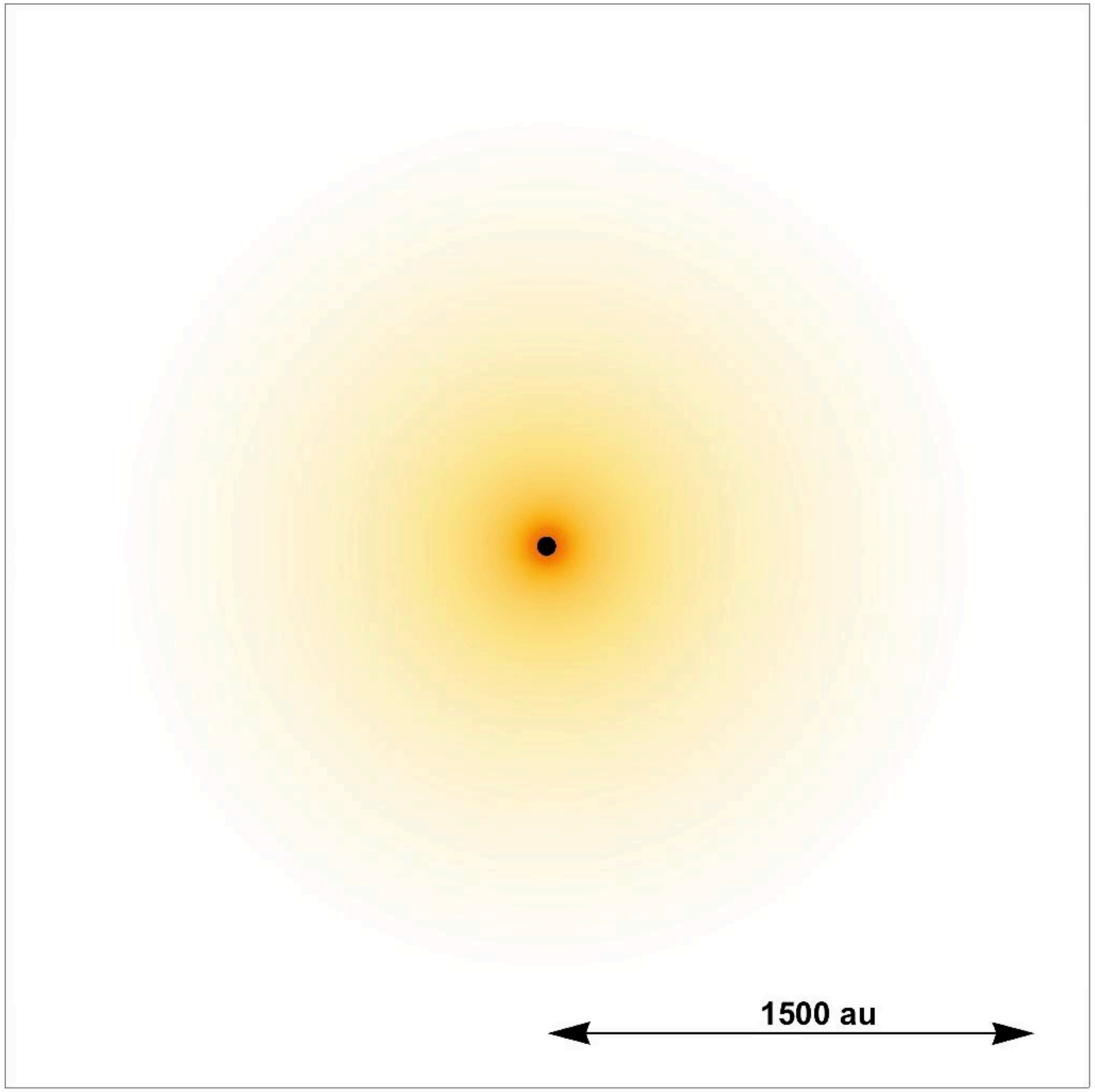


UNCERTAINTIES

- Inclination angle
- Mass of disk & central object

RADIATION HYDRO SIMULATIONS

- Starting with 200 $M_\odot$ in a 0.1 pc cube (see poster by R. Kuiper)

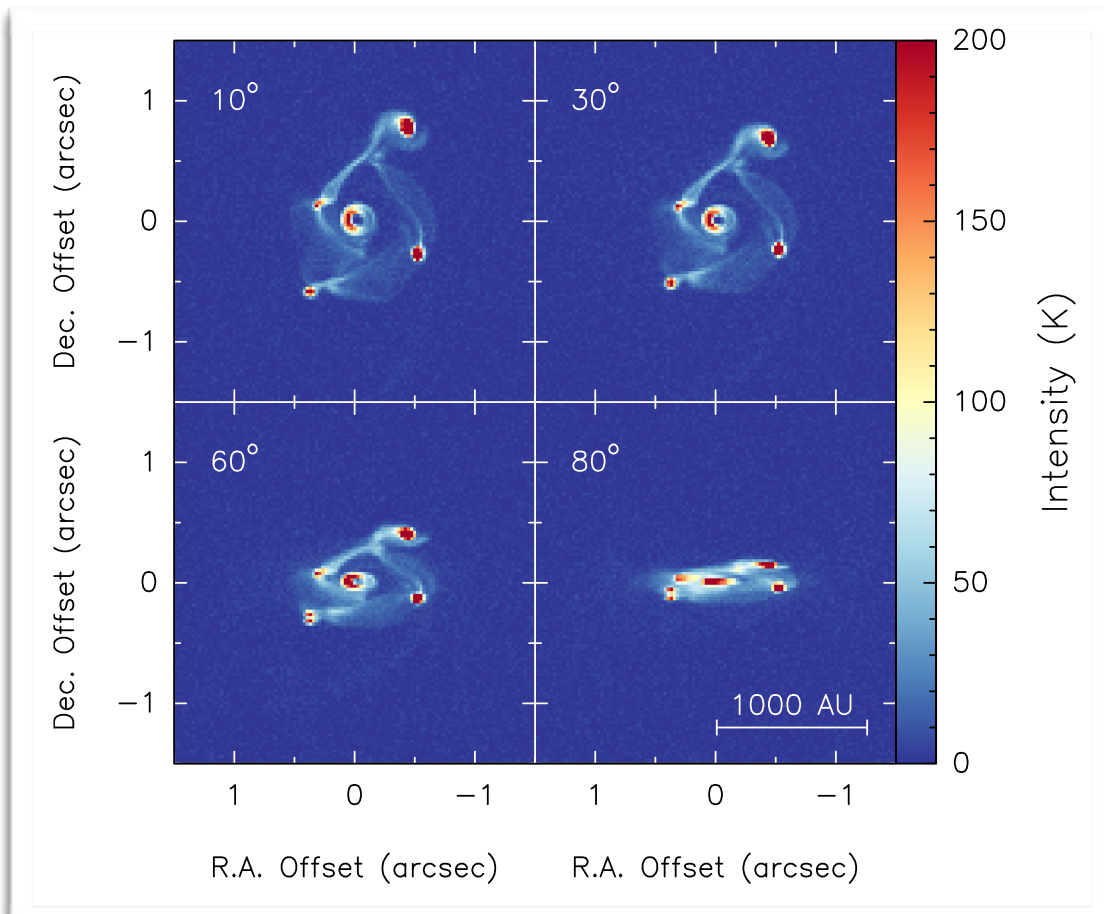


Ahmadi, Kuiper, Beuther, et al. (in prep.)

1.3 MM DUST CONTINUUM

distance: 800 pc

- simulations



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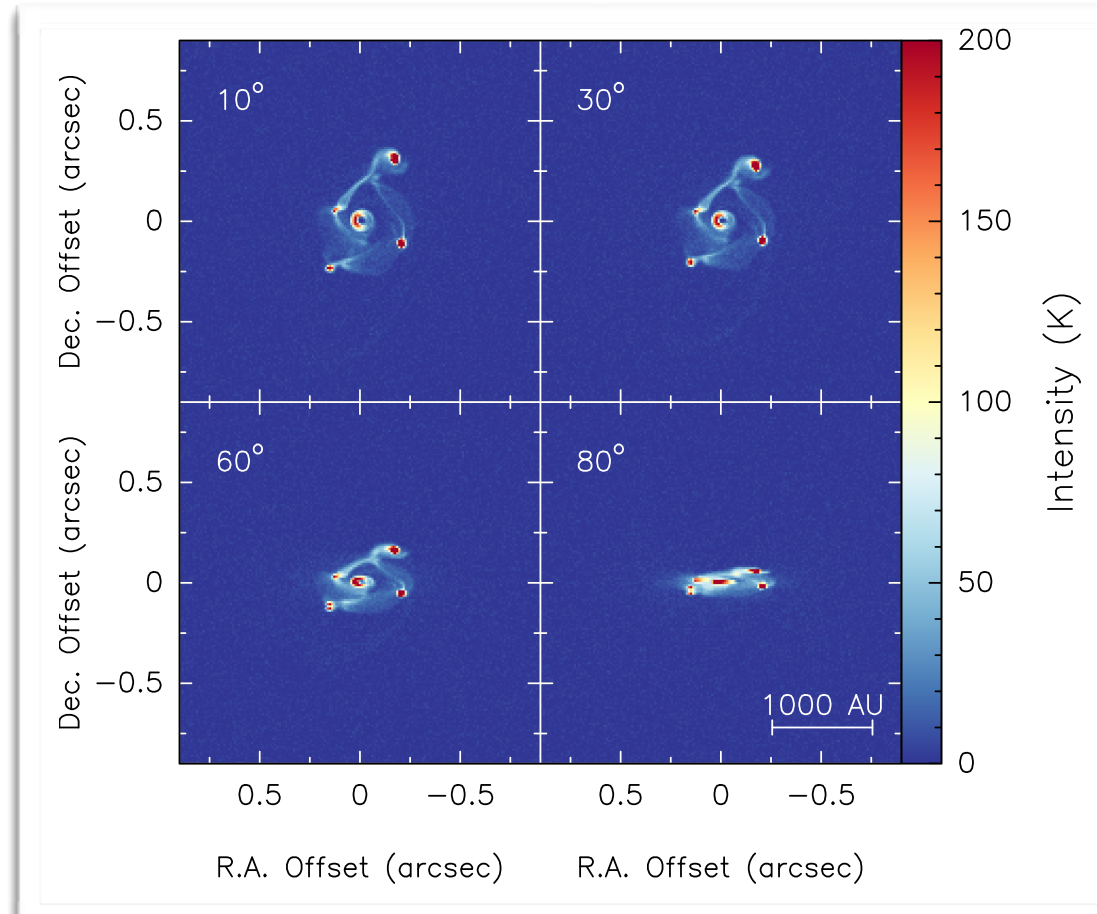
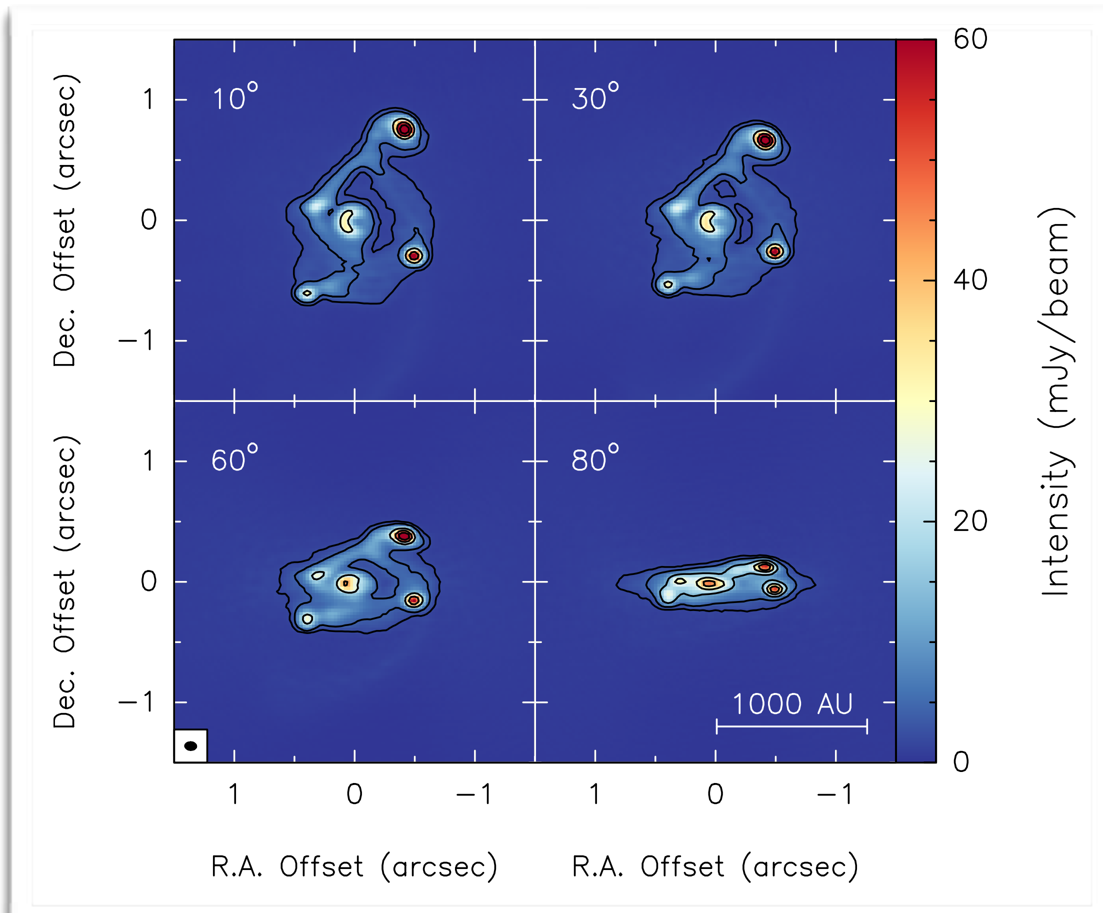


post-processed simulations at different inclinations

1.3 MM DUST CONTINUUM

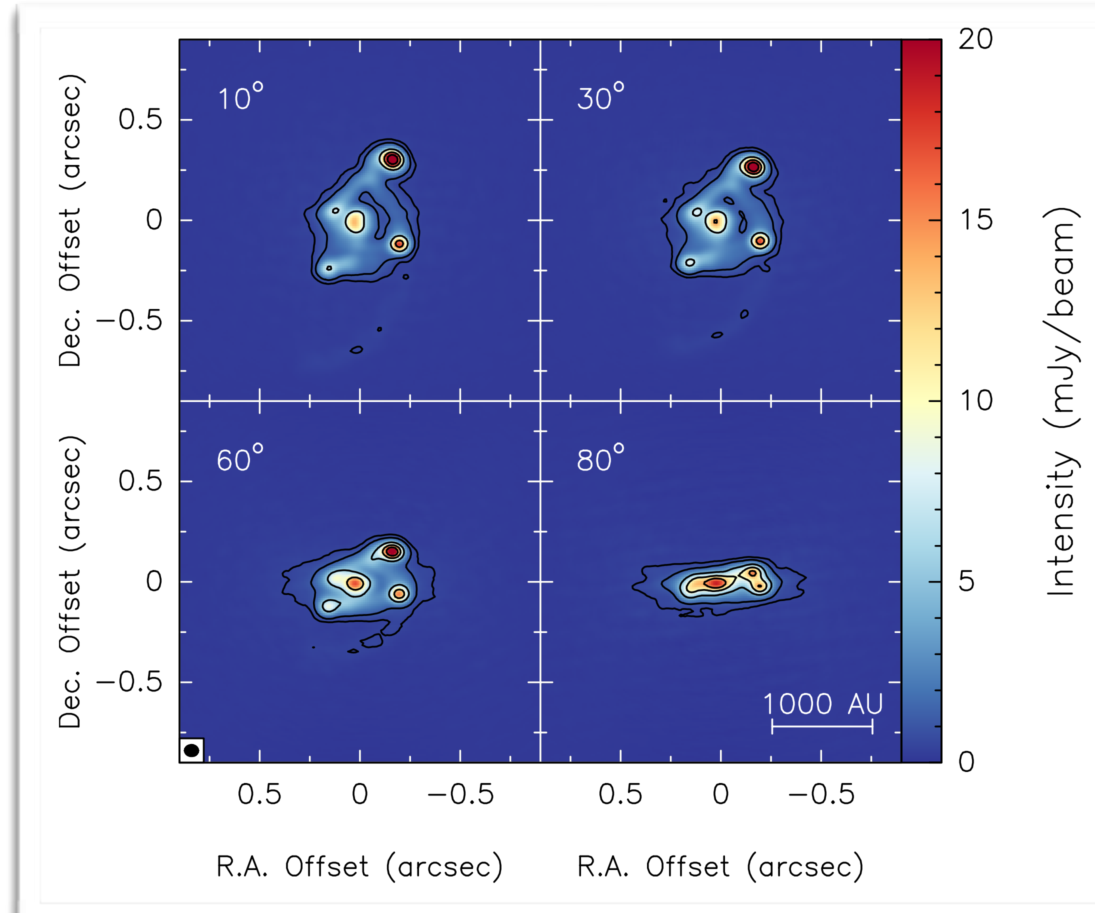
distance: 800 pc

- ALMA's view (0.07″ -> 56 AU)



distance: 2000 pc

- ALMA's view (0.07″ -> 140 AU)



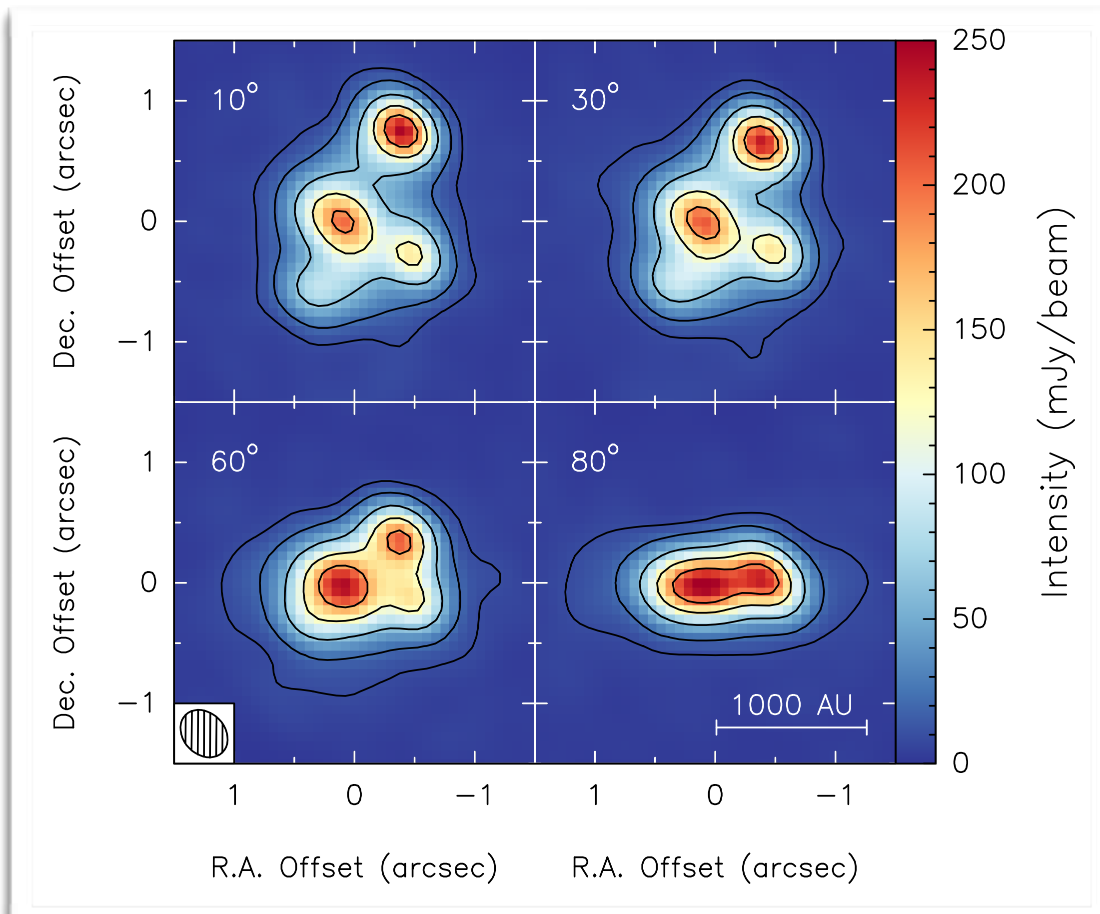
ALMA would resolve all fragments

1.3 MM DUST CONTINUUM

NOEMA x12
NOEMA
NOrthern Extended Millimeter Array

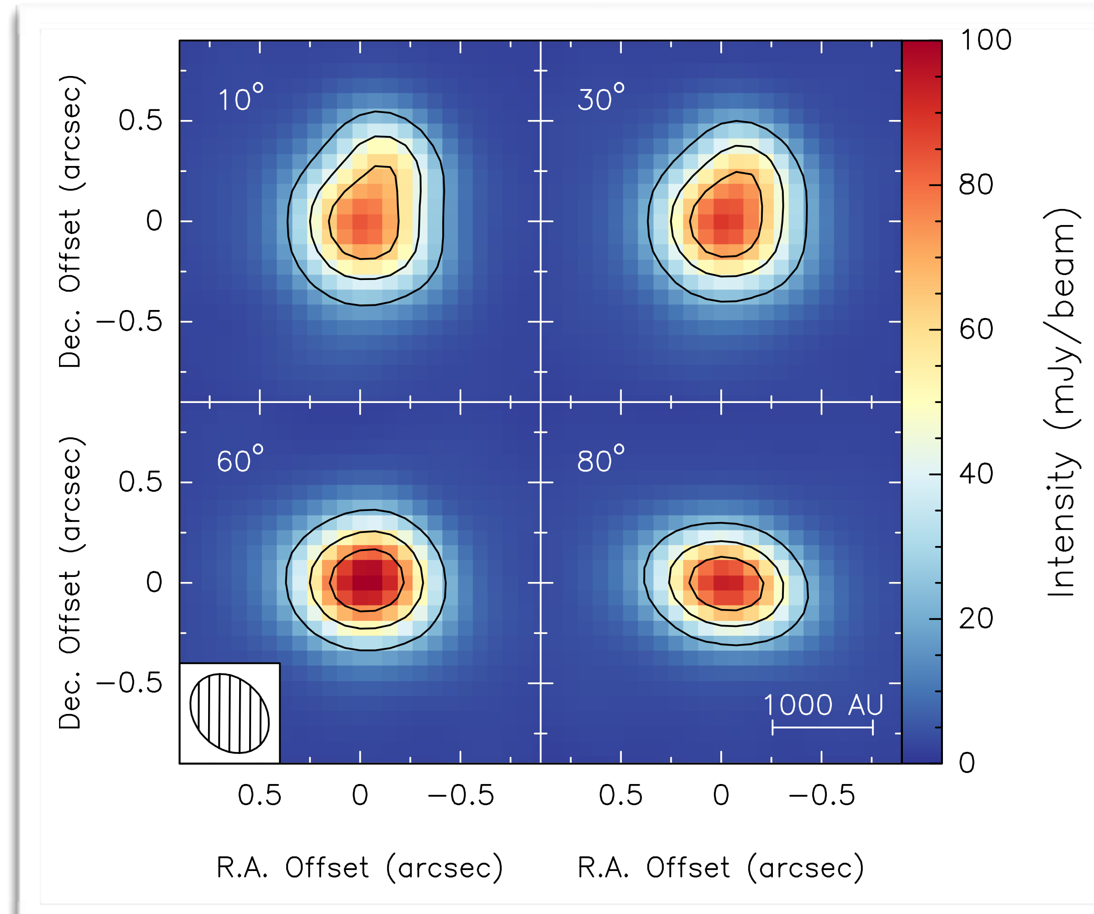
distance: 800 pc

- NOEMA's view (0.4″ -> 320 AU)



distance: 2000 pc

- NOEMA's view (0.4″ -> 800 AU)

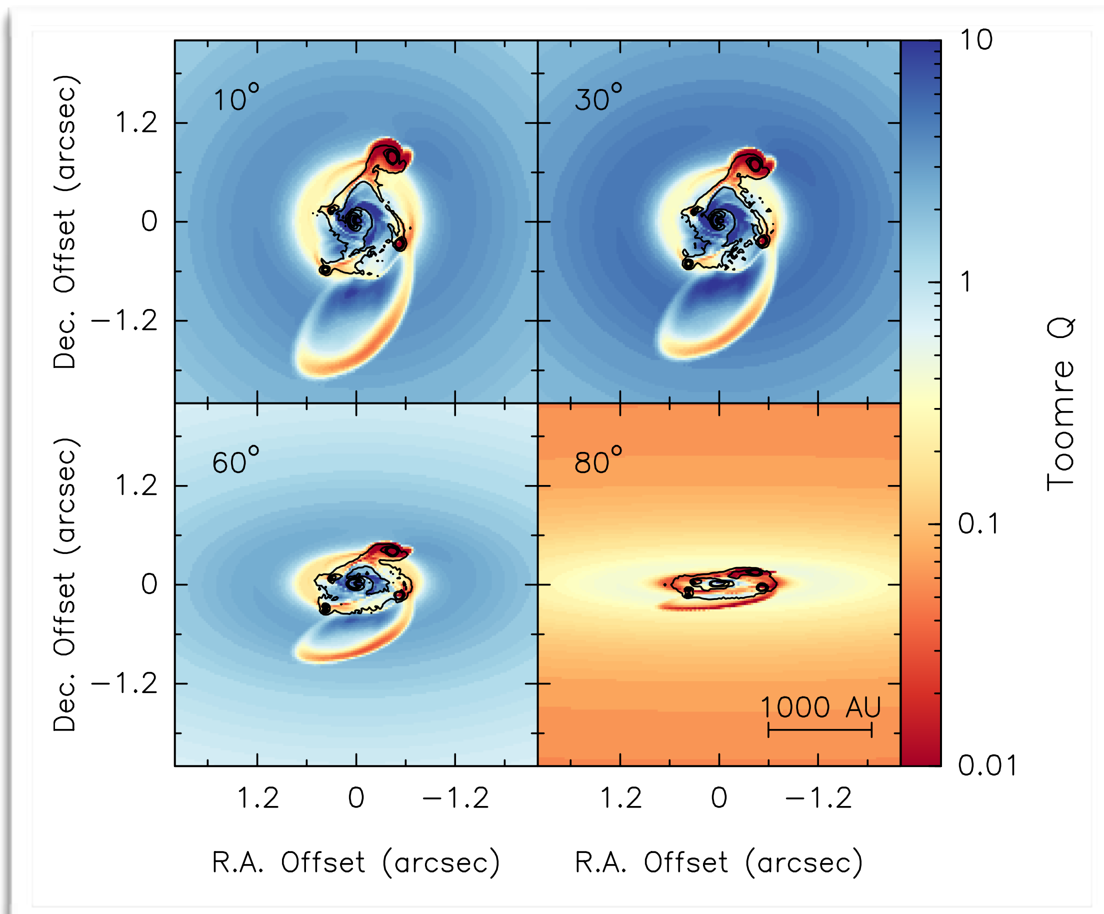


NOEMA would resolve most of the fragments only if the source is close

TOOMRE STABILITY: INCLINATIONS

distance: 800 pc

- simulations



distance: 2000 pc

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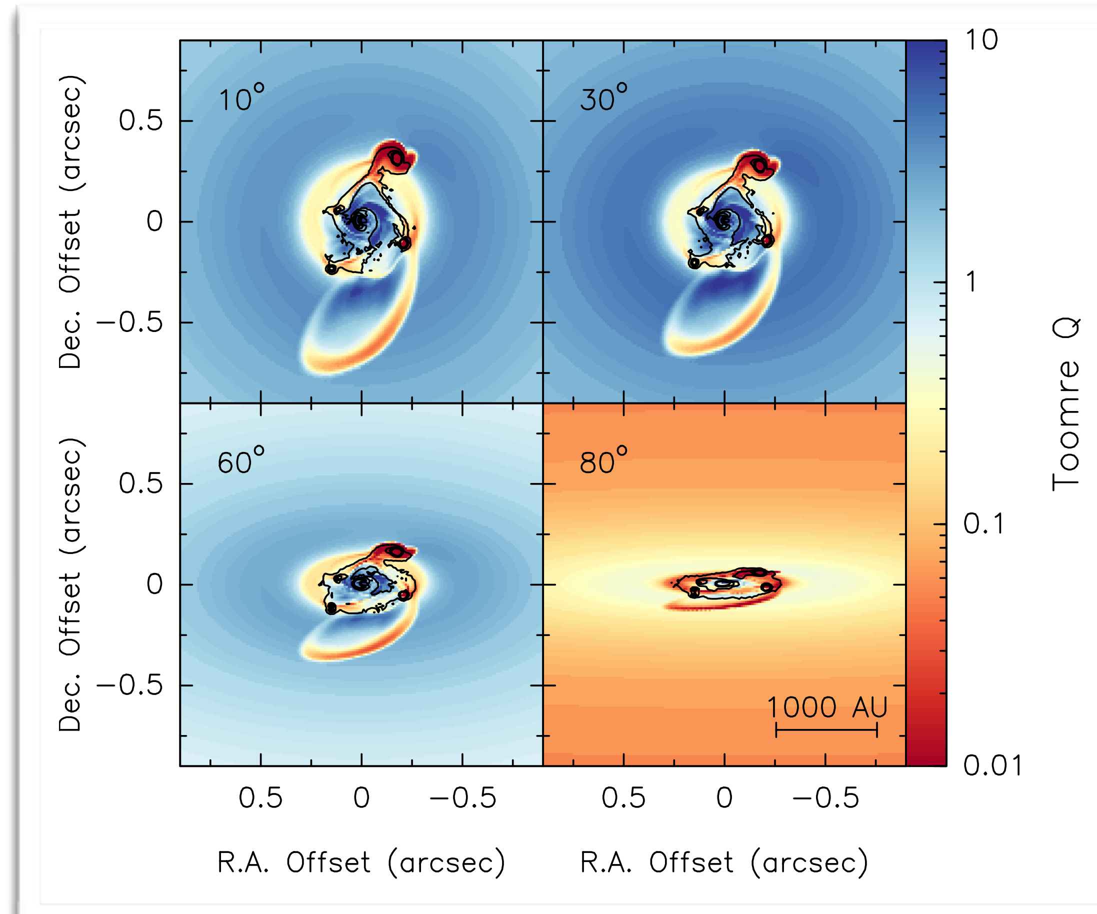

'true' Toomre Q maps at different inclinations

Q < 1 at the positions of fragments

TOOMRE STABILITY: INCLINATIONS

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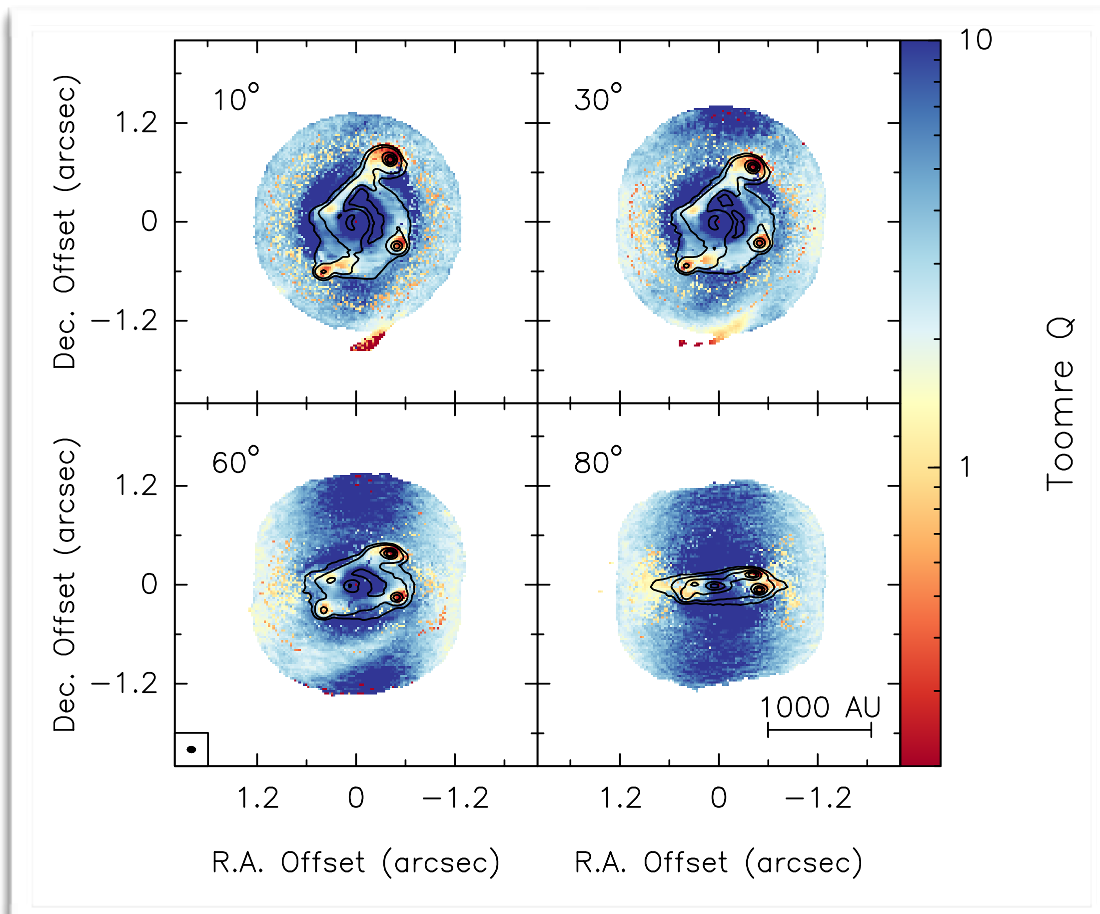

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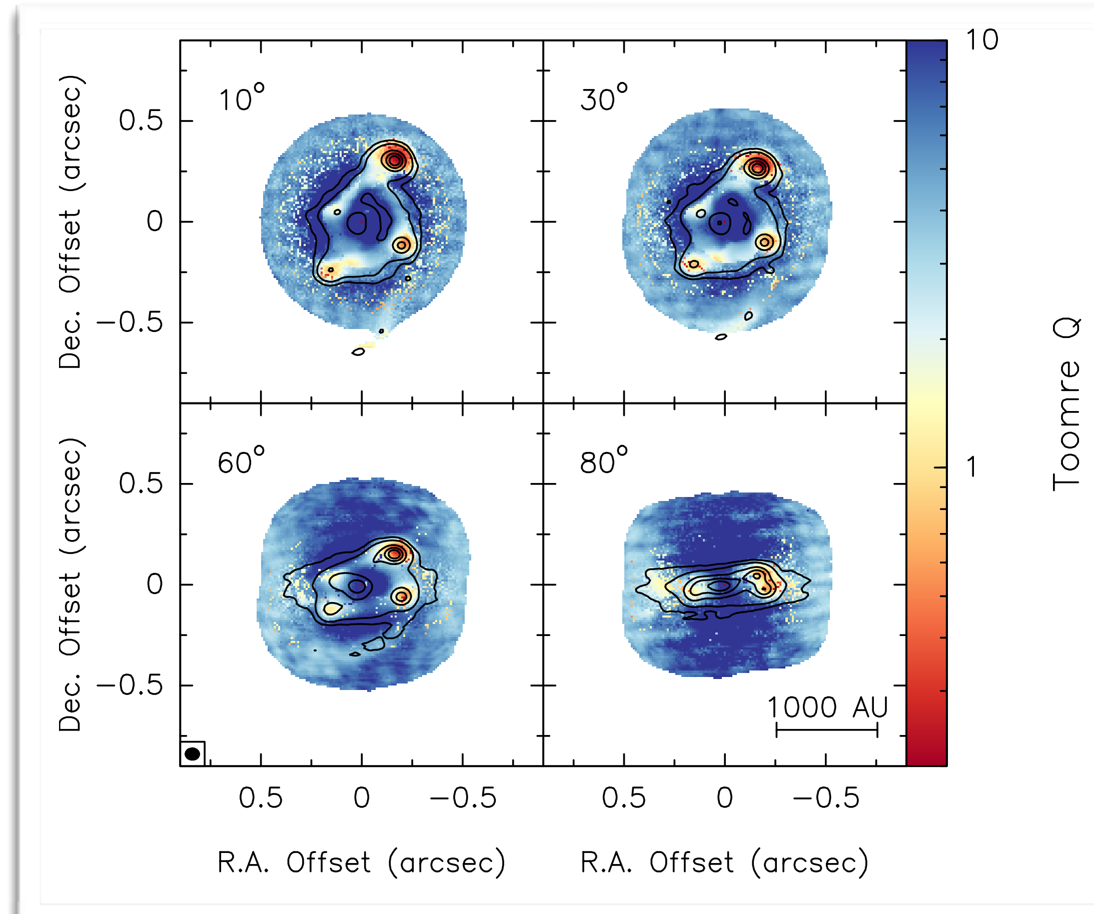

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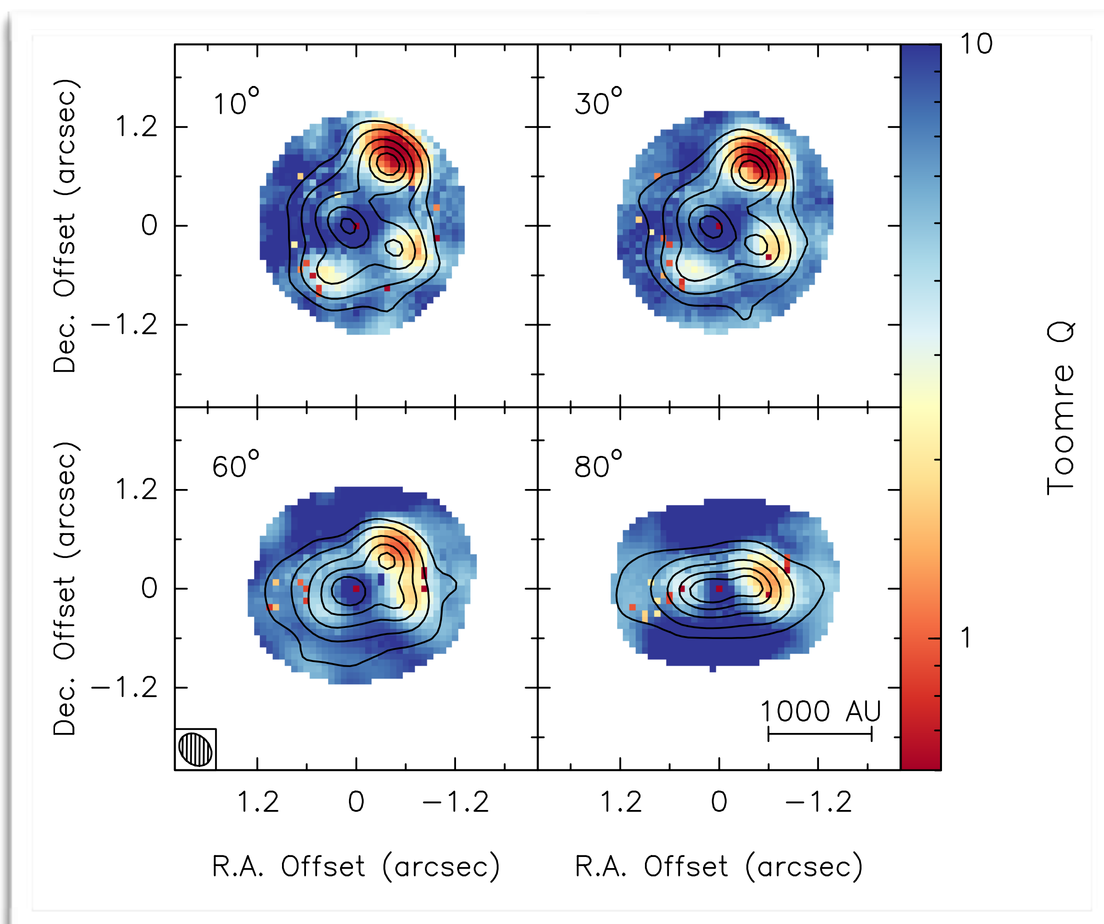

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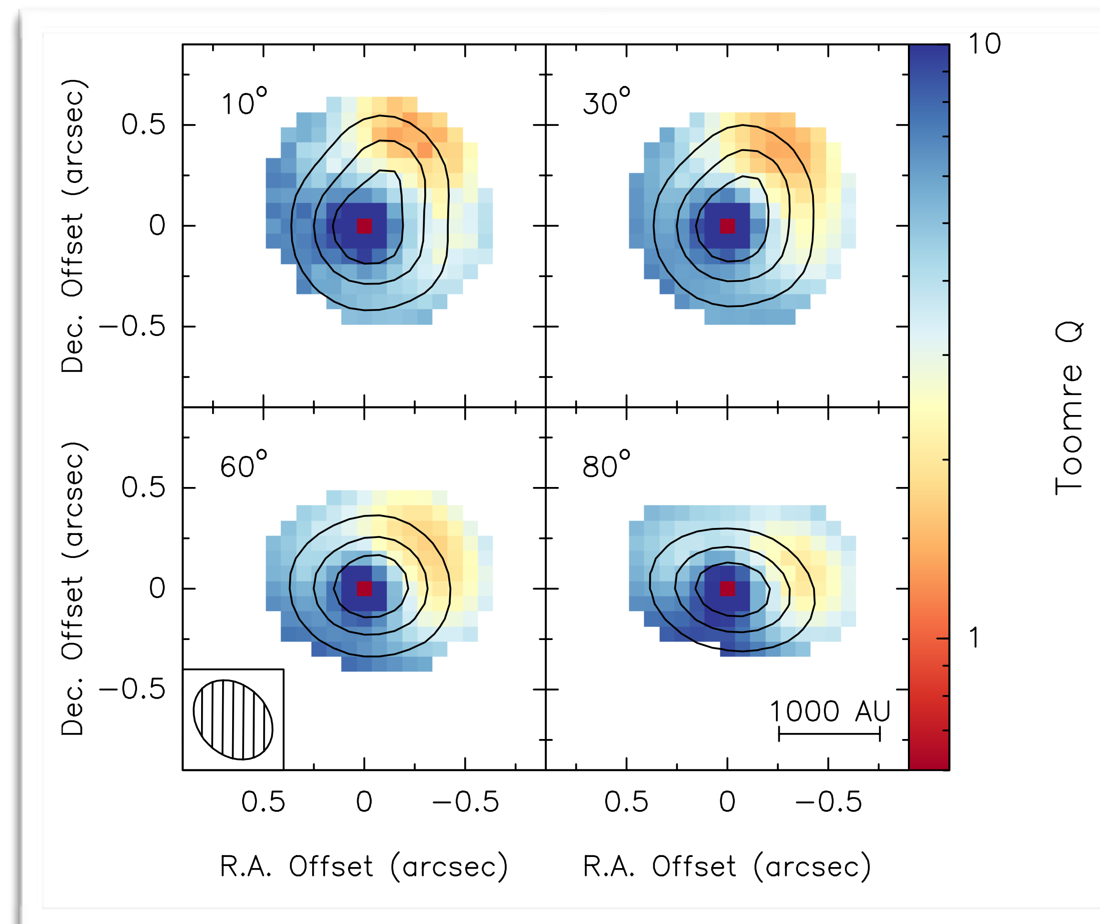
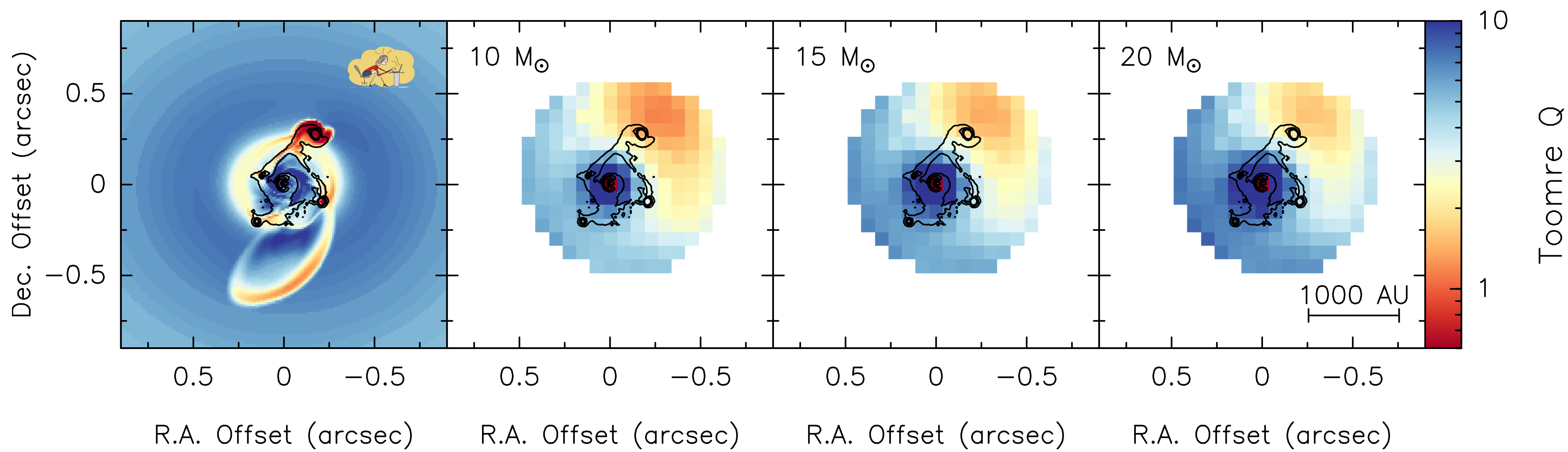


Although NOEMA wouldn't resolve fragments at 2000 pc, the disk is asymmetrically stable and **fragmentation is predicted** nonetheless

TOOMRE STABILITY: MASS SENSITIVITY

- Varying the mass in the Toomre equation

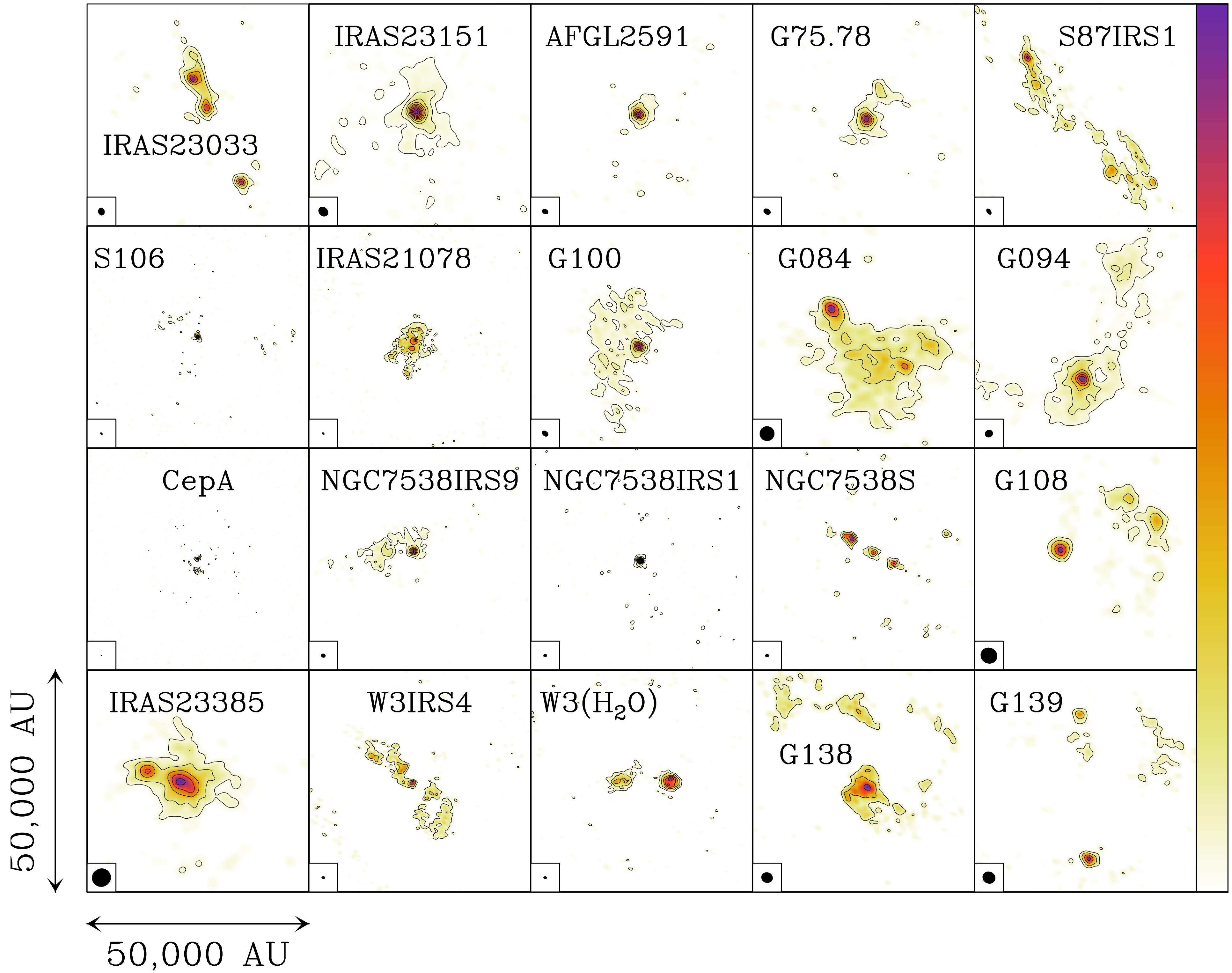
distance: 2000 pc



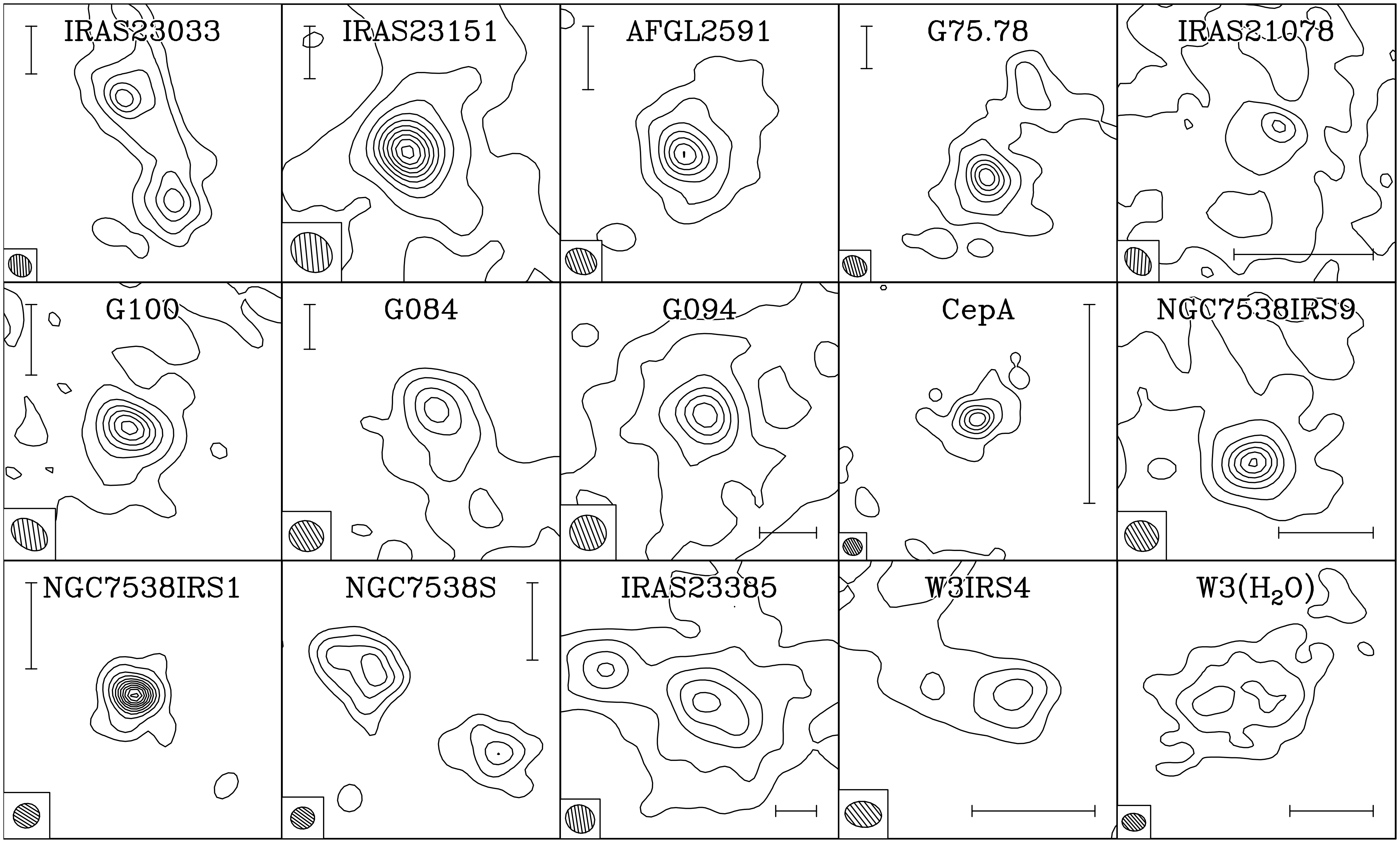
Toomre Q analysis **not sensitive** to small variations in **mass**

CORE : DUST CONTINUUM

Beuther et al. 2018



CORE: KINEMATICS



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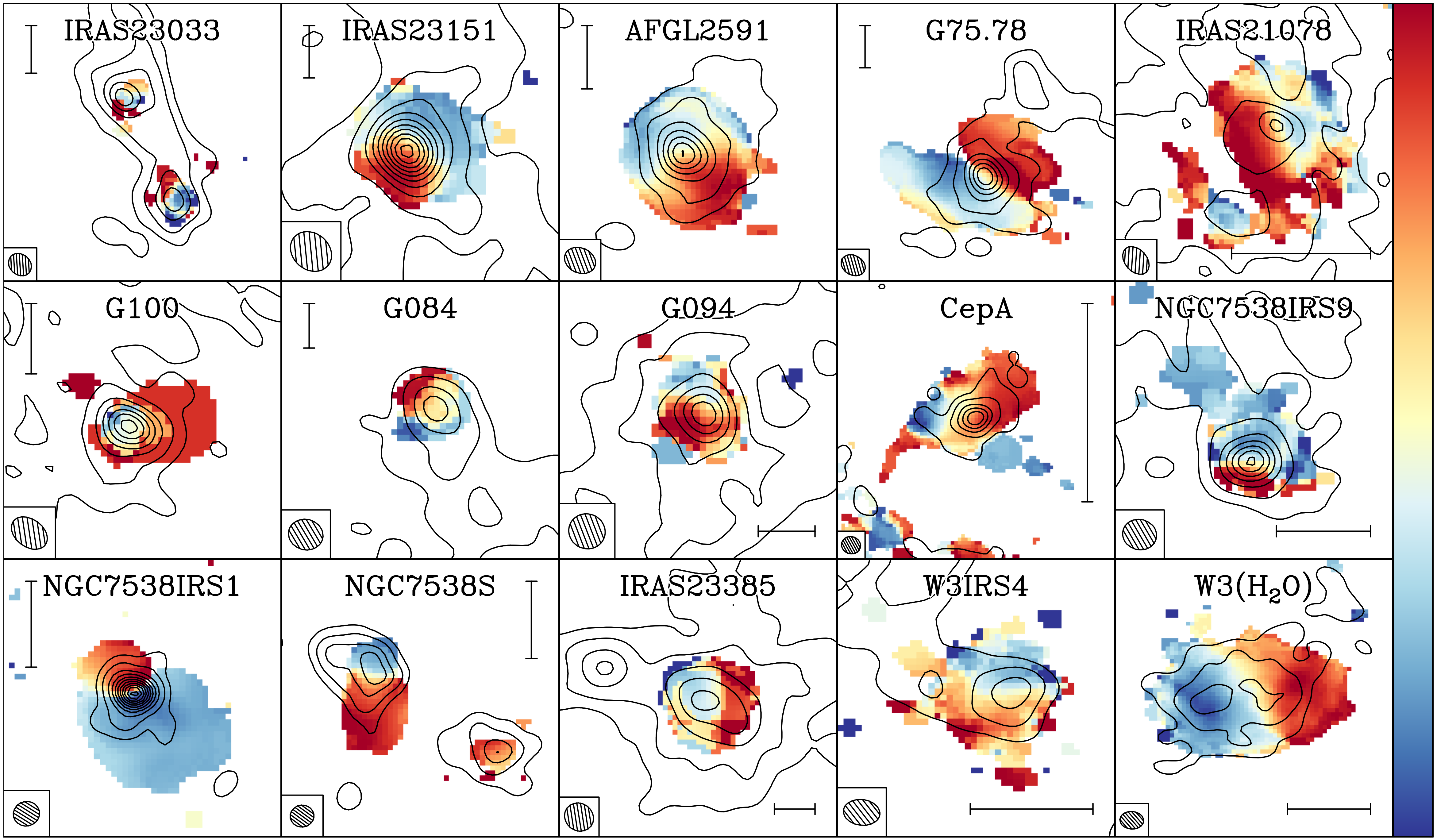

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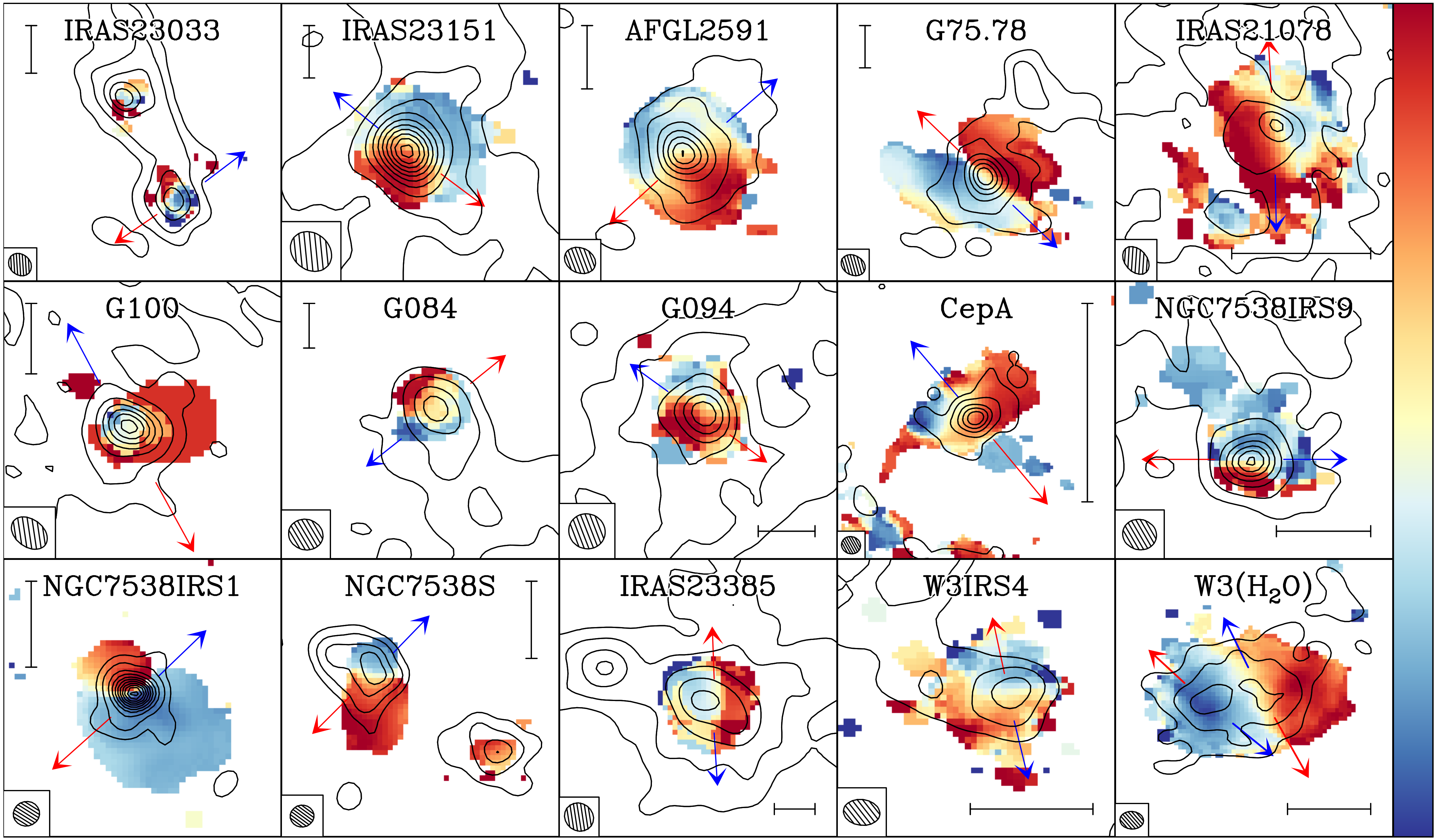
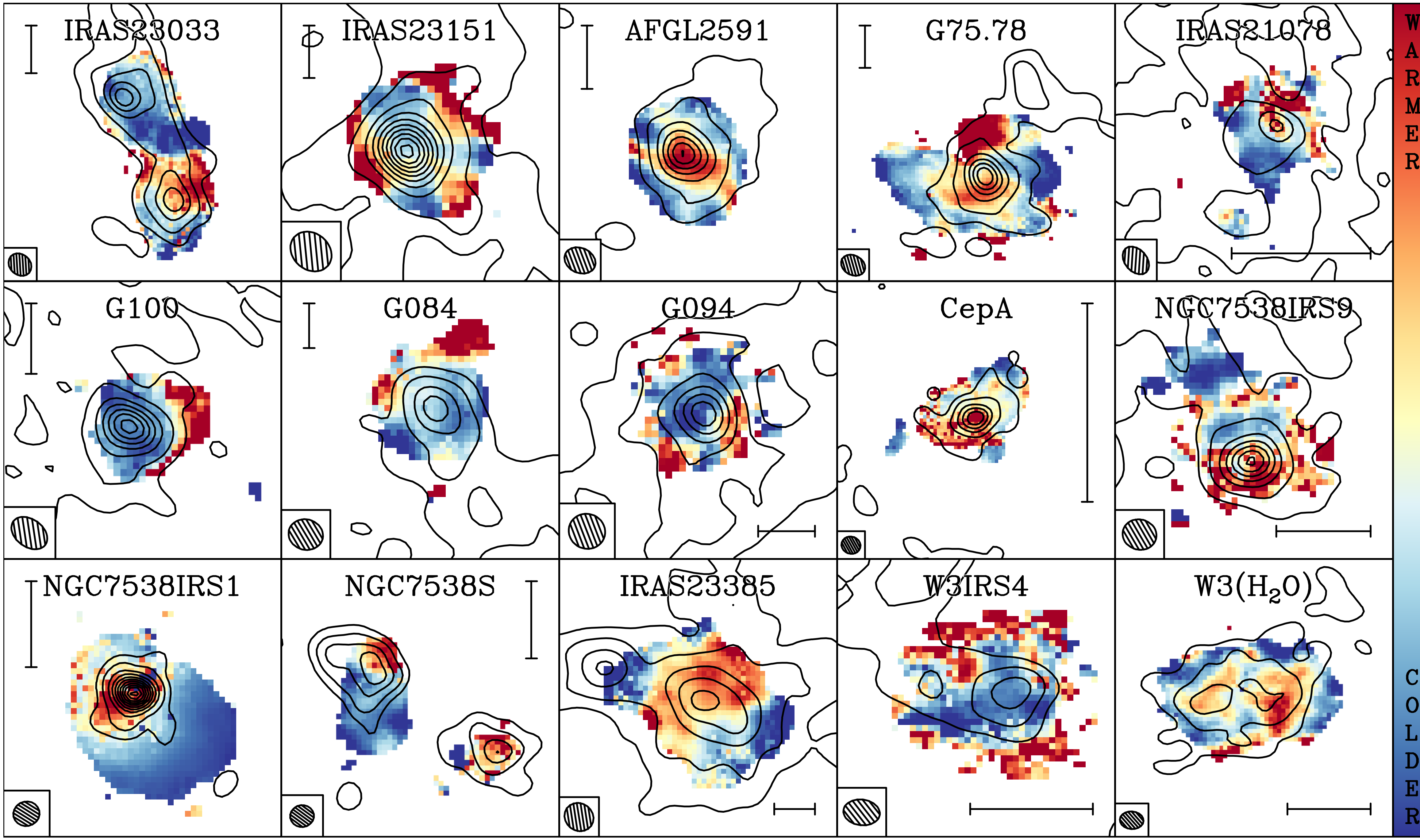


CORE : TEMPERATURES



CONCLUSIONS

- High resolution observations needed to study early phase of high-mass star formation -> CORE survey
- Rotating structures detected around most objects
- Different modes of fragmentation
  - Isolated cores vs. highly fragmented clumps
  - Core fragmentation on large scales & disk fragmentation on small scales

OUTLOOK

- Apply similar analyses to all other sources and study fragmentation and disk kinematics in a statistical way

THANK YOU!
QUESTIONS?

credit: Andre Rambaud