Following the flow: From molecular clouds to protostars

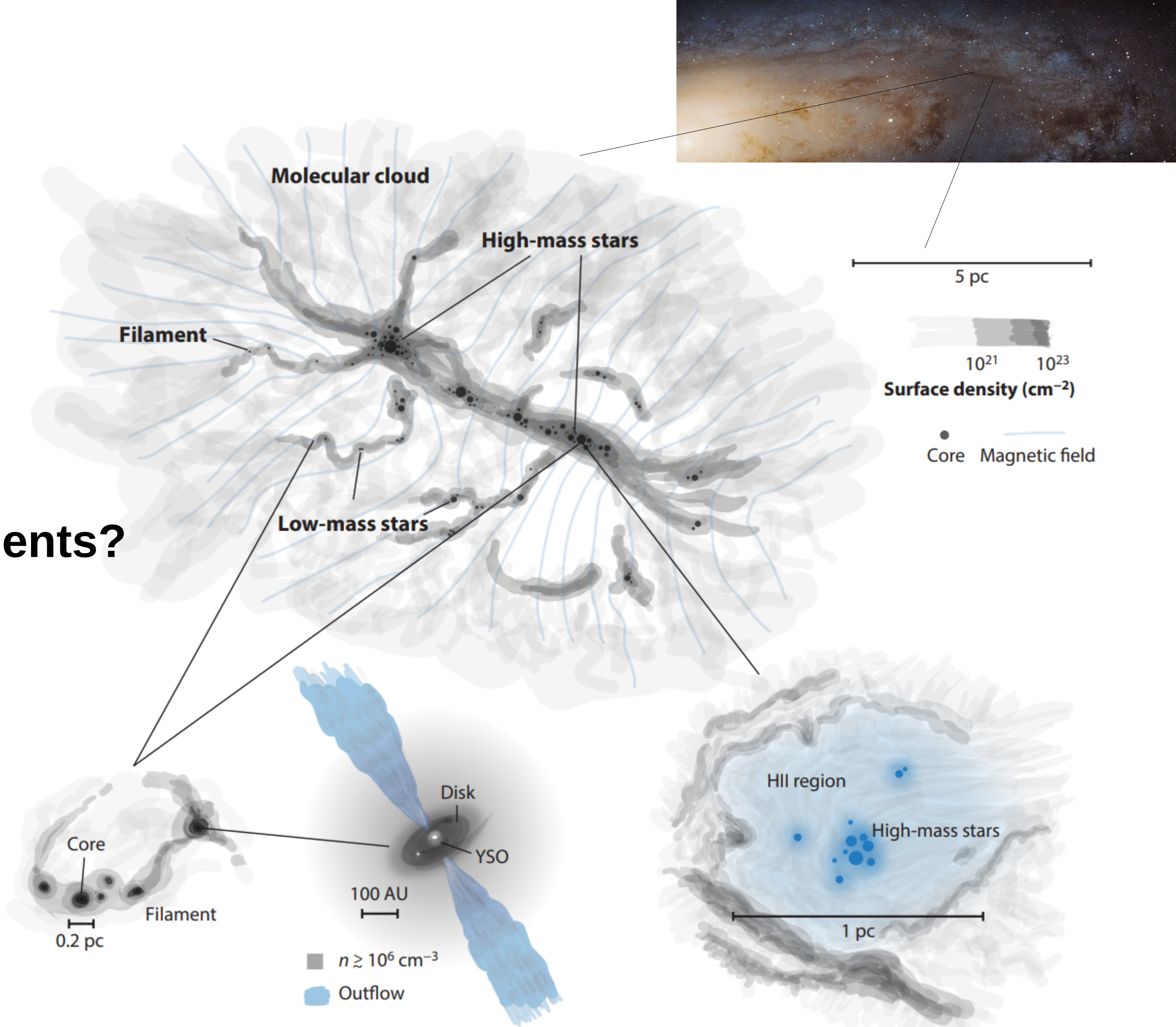
Caroline Gieser
Max Planck Institute for Astronomy Heidelberg
gieser@mpia.de

Ludwig Biermann Award Talk
September 8, 2026

stars are crucial building blocks of cosmic structure

stars are crucial building blocks of cosmic structure

how does star formation proceed in different environments?



recent reviews by Motte+2018, Rosen+2020, Pineda+2023, Beuther+2025

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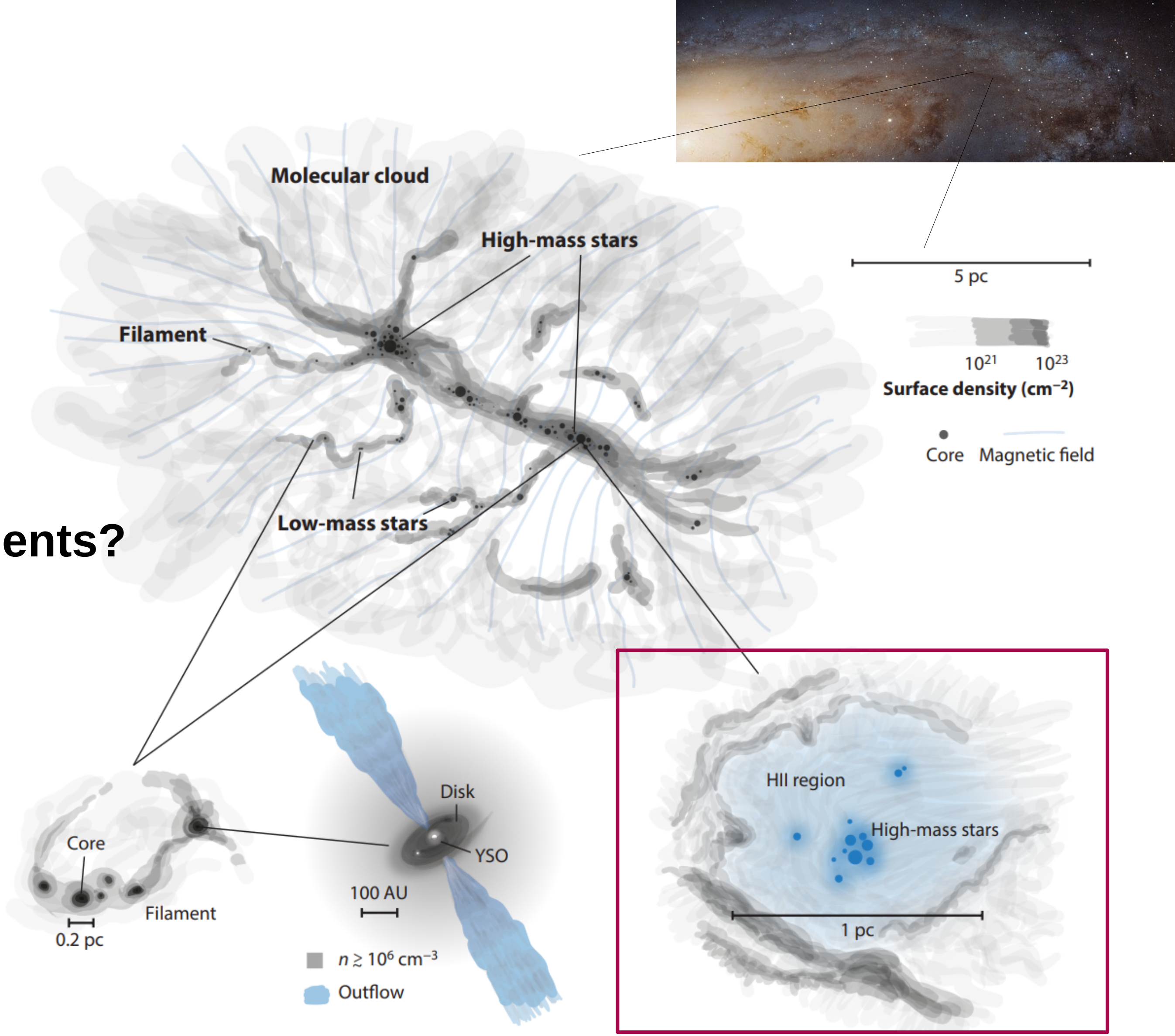

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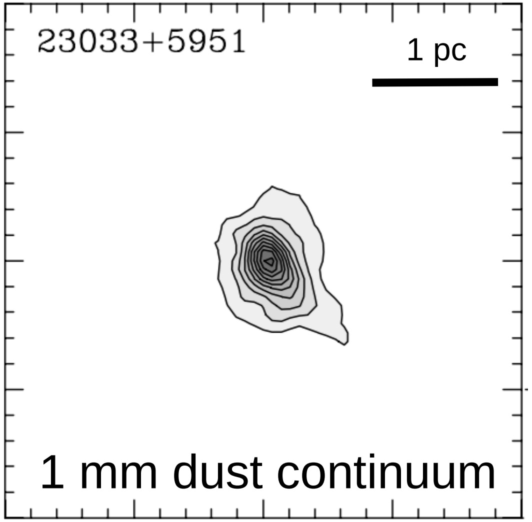
the physical-chemical properties of protostellar cores in high-mass star-forming regions

CORE(+extension)
NOEMA/IRAM 30m large program
PI: Henrik Beuther
20(+2) high-mass star-forming regions
1.4 mm / few 1000 au scales

clump scales



Beuther+2002

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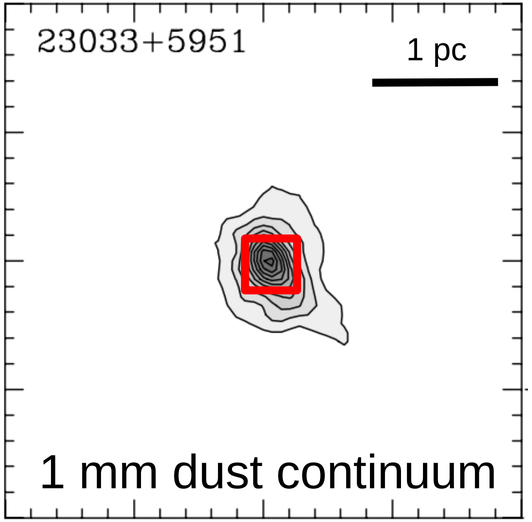

Beuther+2002

NOEMA
field of view
but factor 30 increase
in angular resolution

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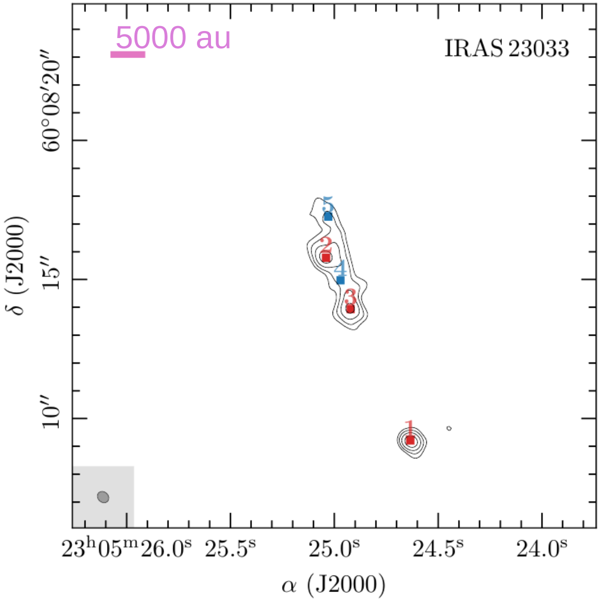
core fragmentation: Beuther+2018, 2022
disk stability: Ahmadi+2018, 2019, 2023
physical-chemical properties: Gieser+2019, 2021, 2022

core scales



1 mm dust continuum

Gieser+2021

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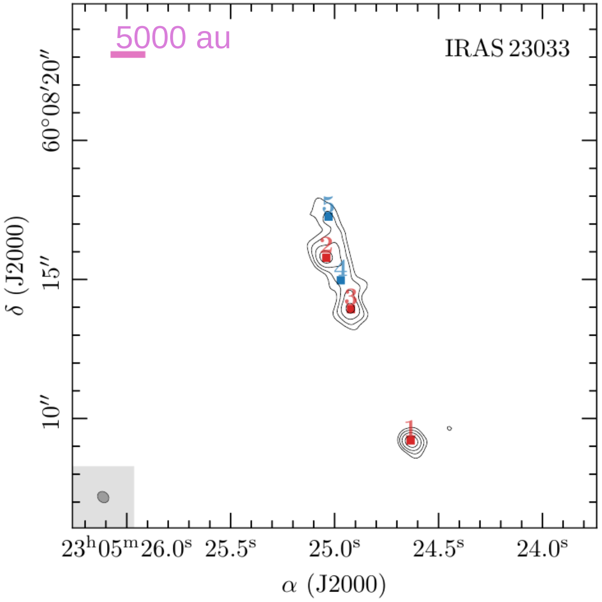

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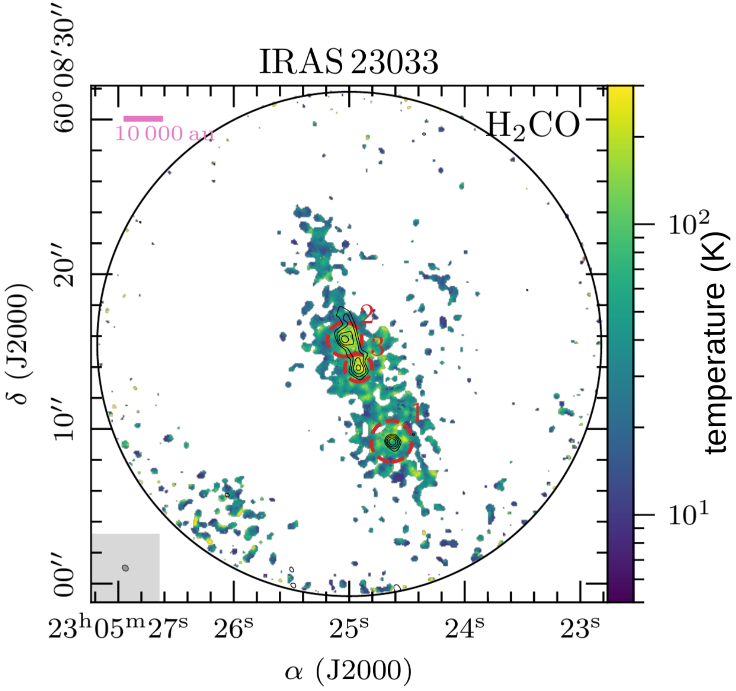

temperature map

Gieser+2021

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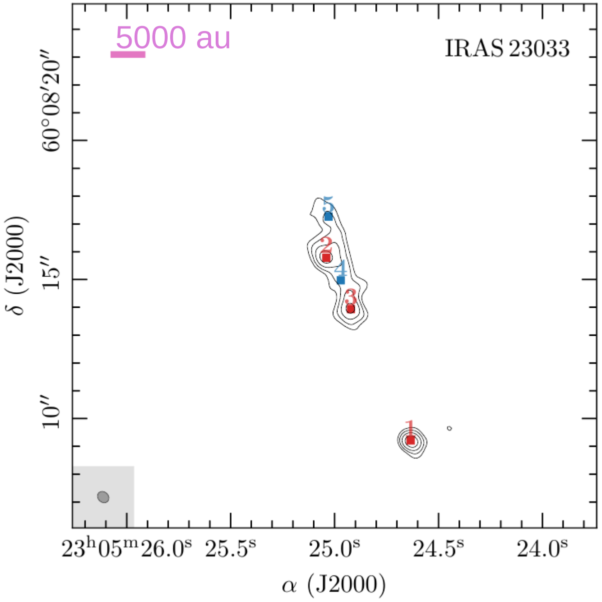

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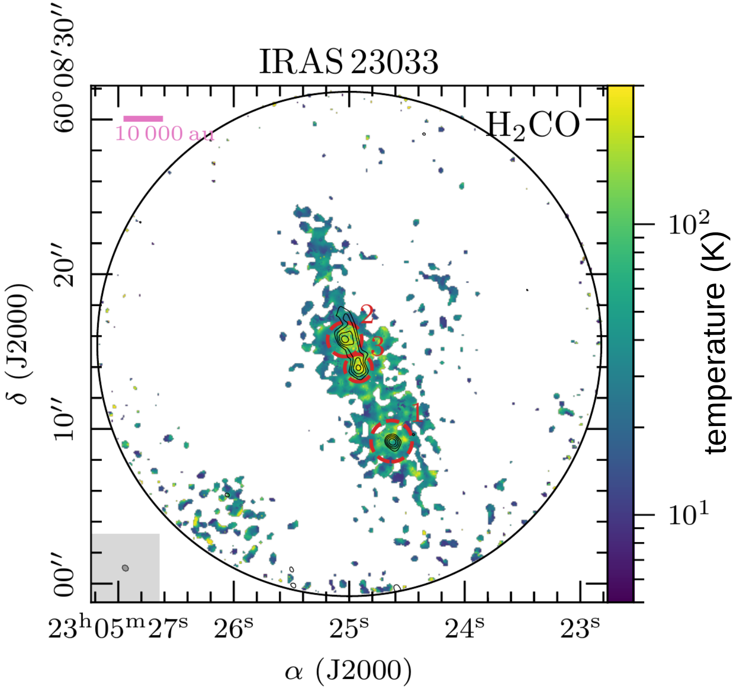

temperature map

temperature structure:
H_2CO and CH_3CN

$$T(r) = T_{\text{in}} \times \left(\frac{r}{r_{\text{in}}}\right)^{-q}$$

density structure:
continuum visibility

$$n(r) = n_{\text{in}} \times \left(\frac{r}{r_{\text{in}}}\right)^{-p}$$

Gieser+2021

the physical-chemical properties of protostellar cores in high-mass star-forming regions

statistical analysis of 22 star-forming cores in the CORE sample

Gieser+2021

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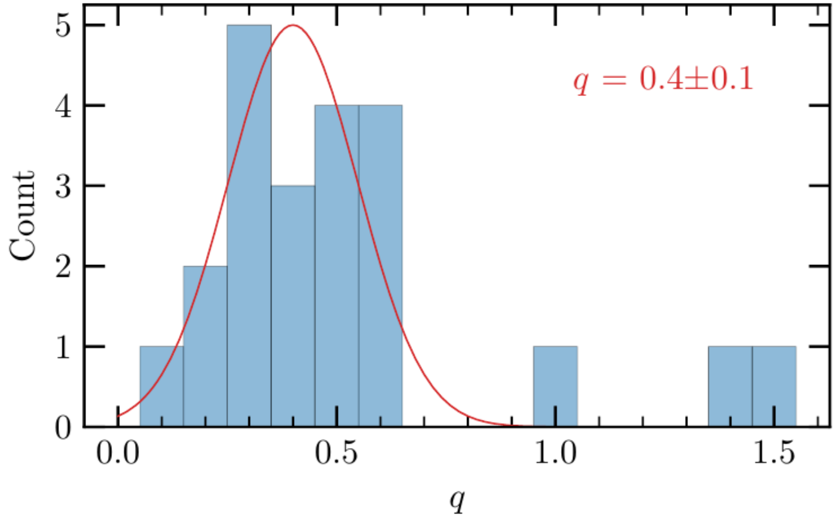

temperature index q

Gieser+2021

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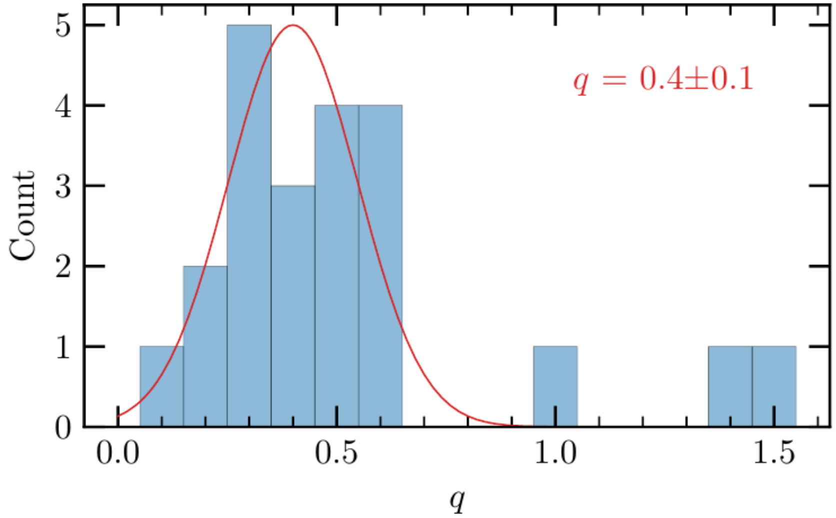

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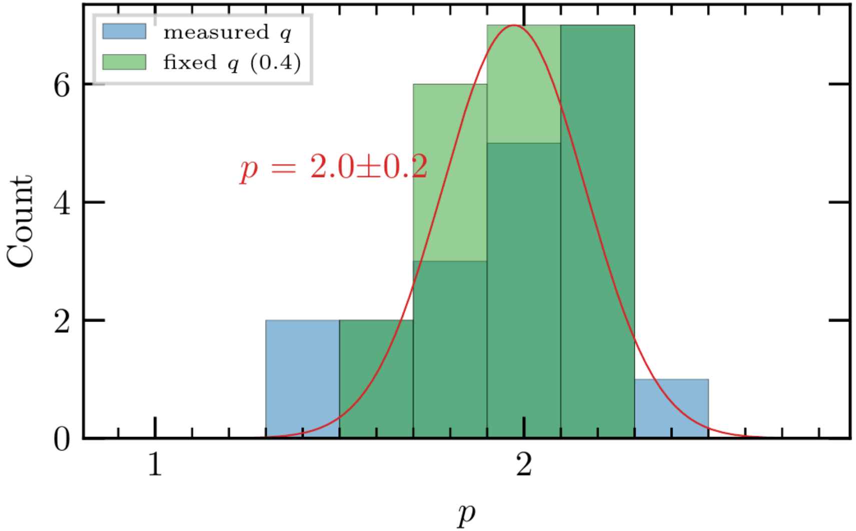

density index p

Gieser+2021

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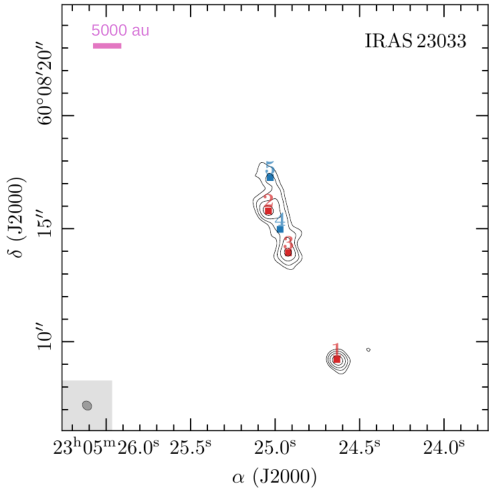

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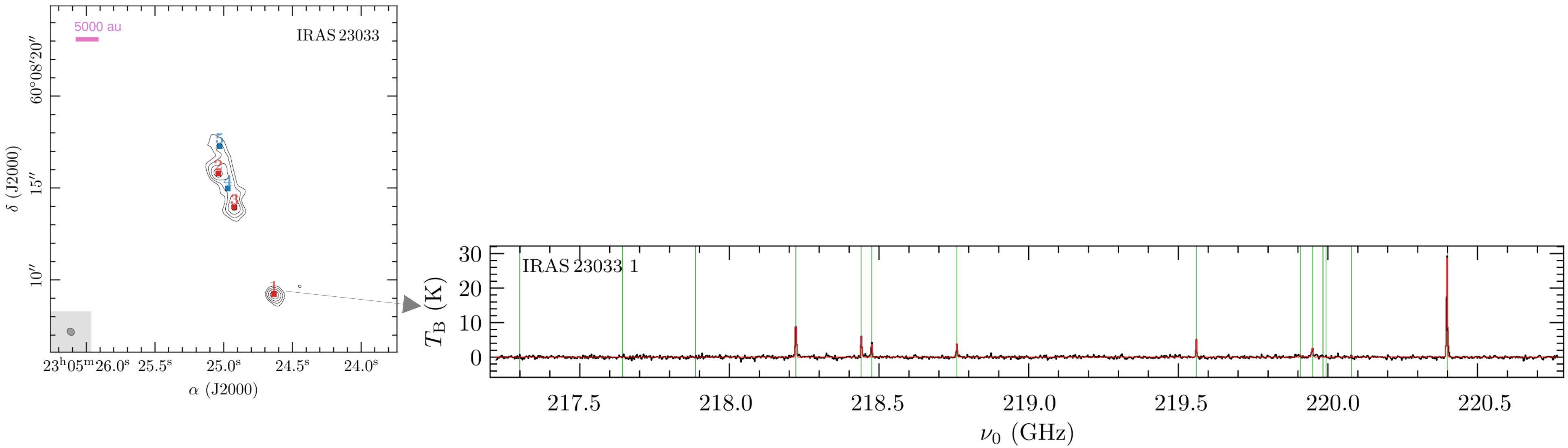

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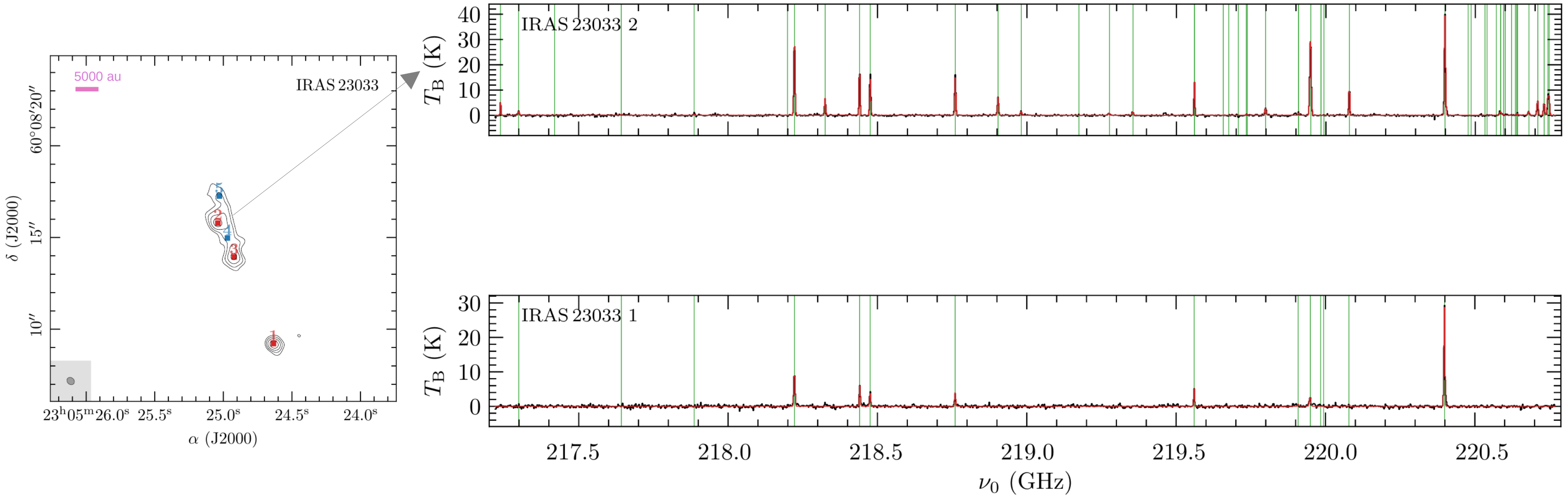

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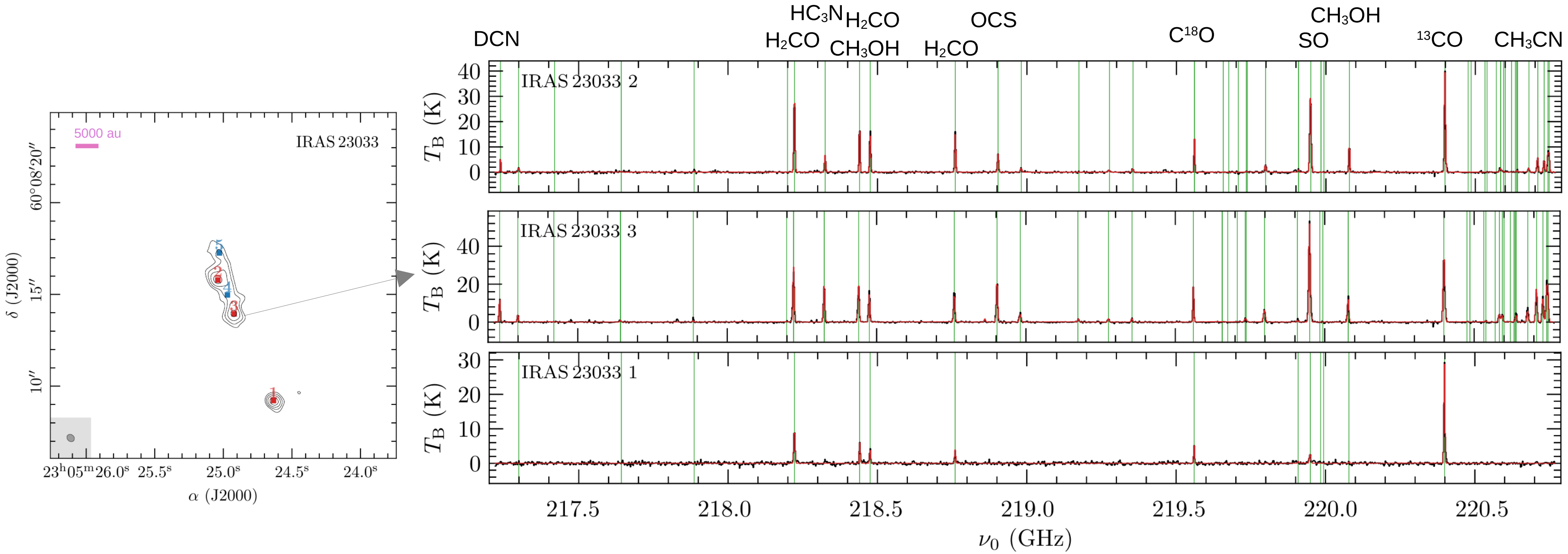
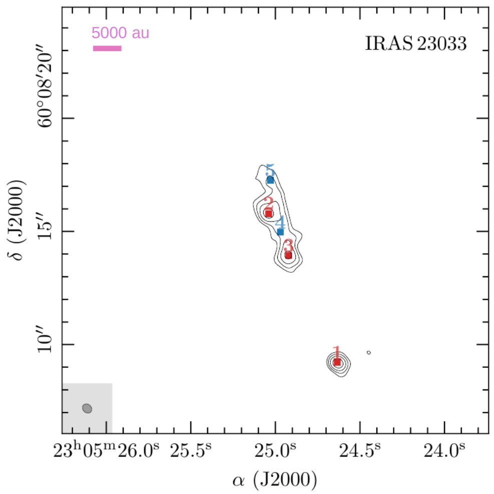
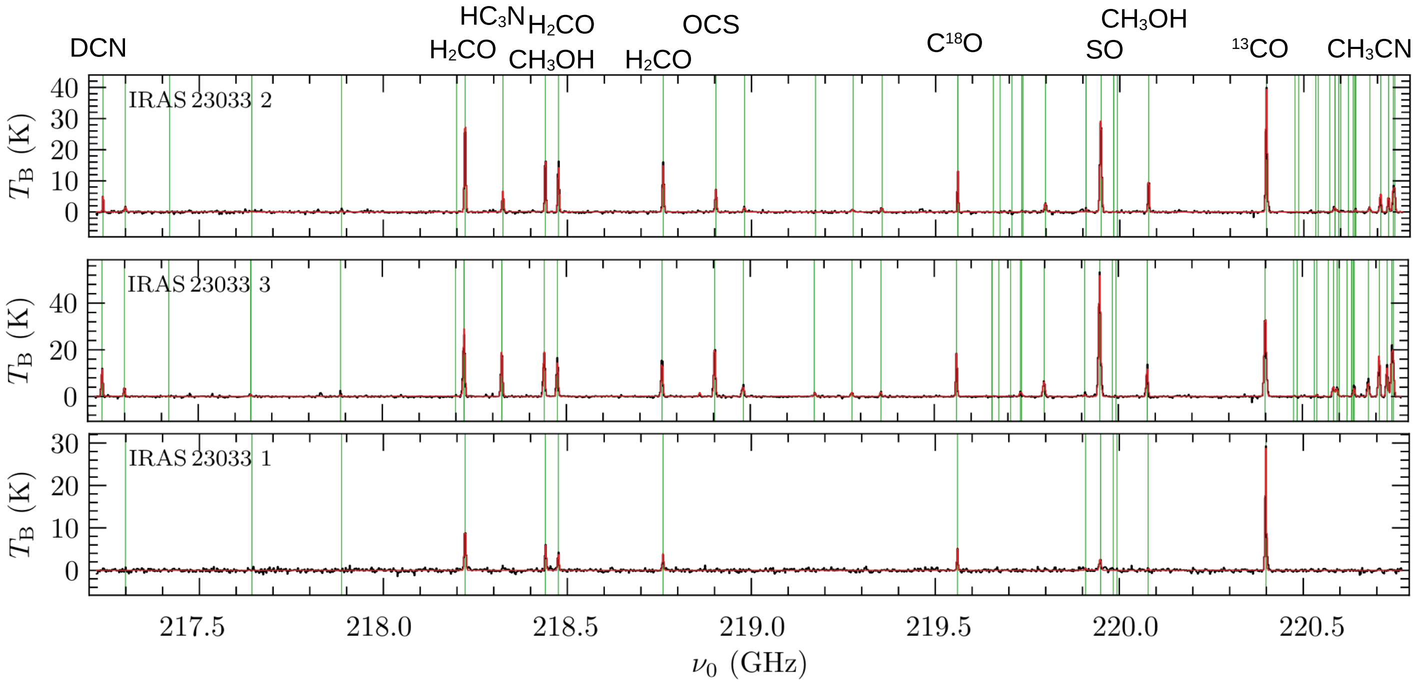


gas-phase molecular column densities: radiative transer modeling with XCLASS (Möller+2017)

Gieser+2021

the physical-chemical properties of protostellar cores in high-mass star-forming regions





gas-phase molecular column densities: radiative transer modeling with XCLASS (Möller+2017)

physical-chemical modeling with MUSCLE (Gerner+2014,2015)
including the time-dependent gas-grain chemical network ALCHEMIC (Semenov+2010)
→ chemical timescale for each core

Gieser+2021

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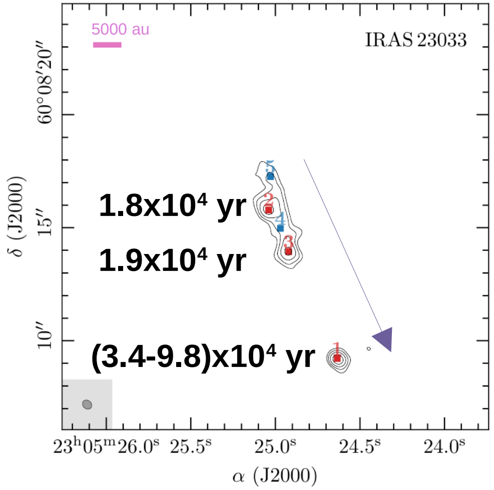

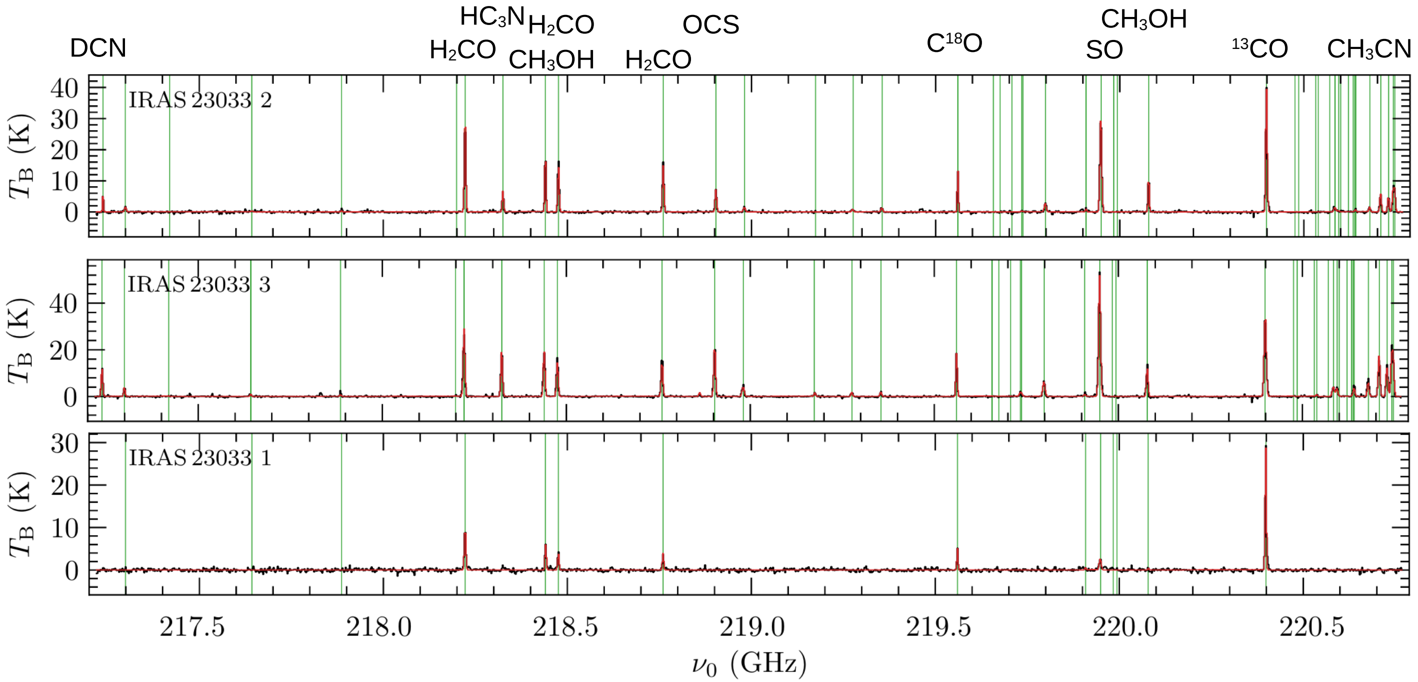

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Gieser+2021

the physical-chemical properties of protostellar cores in high-mass star-forming regions

How do the physical-chemical properties evolve during the entire evolutionary sequence of high-mass star formation?
Infrared Dark Cloud (IRDC) → High-Mass Protostellar Object (HMPO) → Hot Molecular Core (HMC) → Ultra-Compact (UC) HII Region

Gieser+2023a

the physical-chemical properties of protostellar cores in high-mass star-forming regions

ALMA program
PI: Caroline Gieser
11 high-mass star-forming regions
3 spectral setups @ 3 mm / few 1000 au scales

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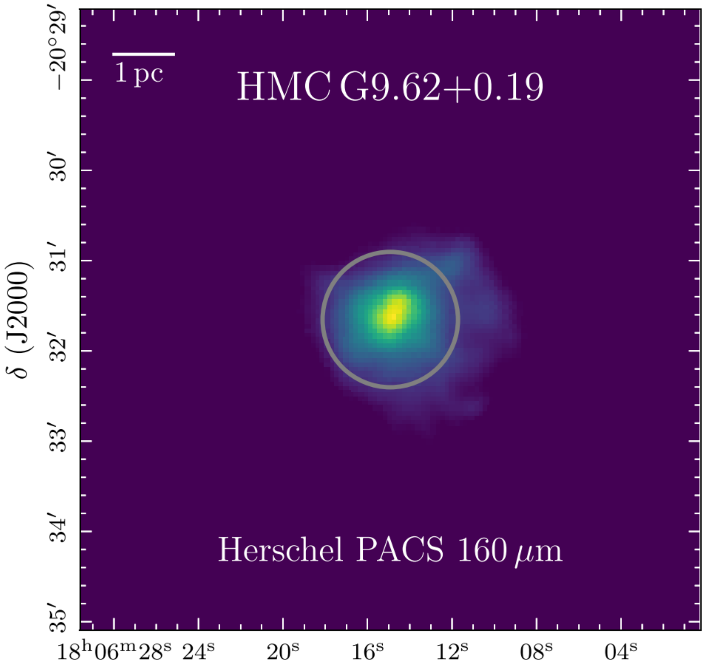

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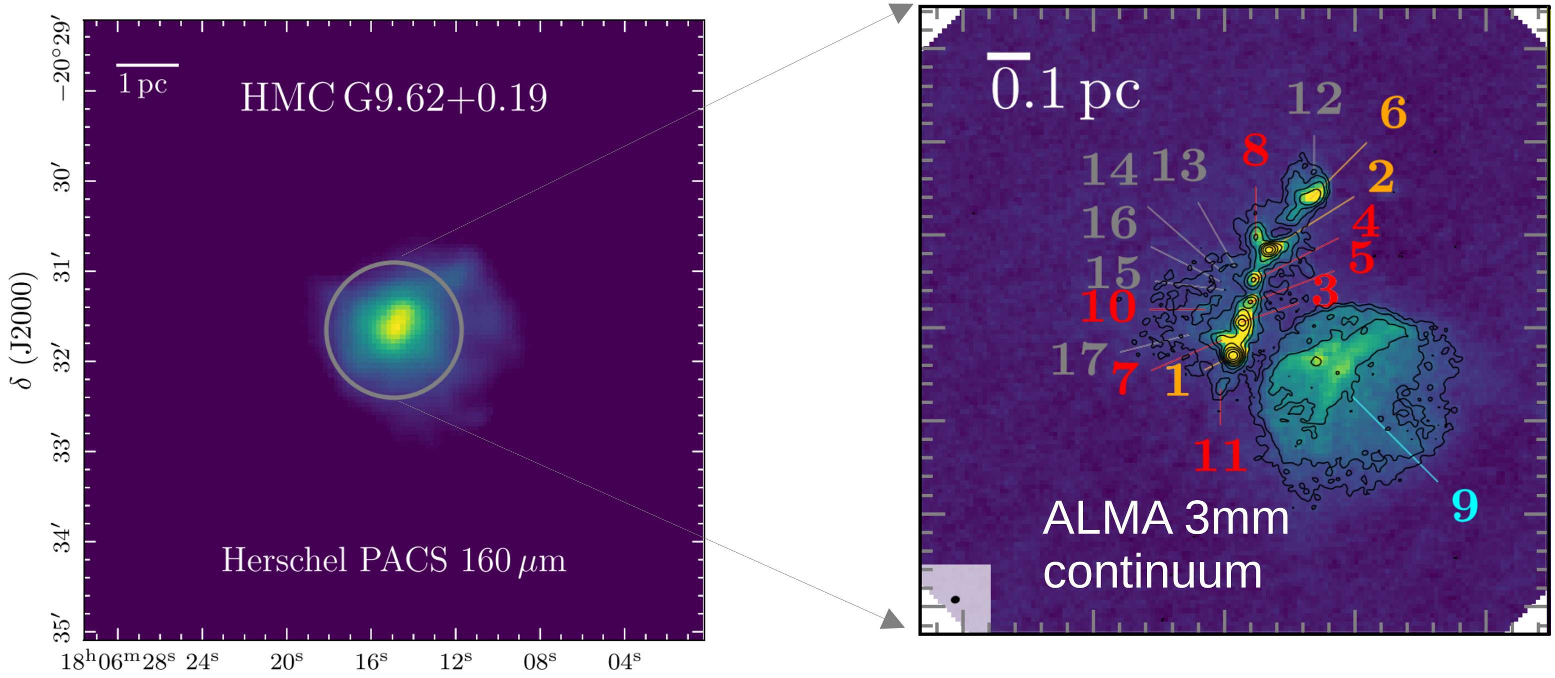


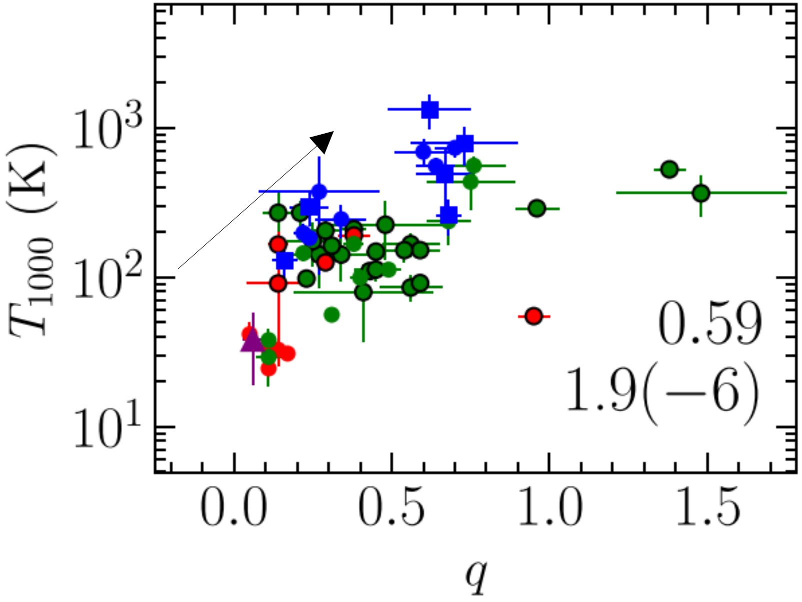
Gieser+2023a

the physical-chemical properties of protostellar cores in high-mass star-forming regions

statistical analysis of 31 star-forming cores in the ALMA sample

Infrared Dark Cloud (IRDC) → High-Mass Protostellar Object (HMPO) → Hot Molecular Core (HMC) → Ultra-Compact (UC) HII Region

temperature at 1000 au



temperature index q

$$T(r) = T_{\mathrm{in}} \times \left(\frac{r}{r_{\mathrm{in}}}\right)^{-q}$$

[including the results from CORE(+exension) Gieser+2021, 2022]

Gieser+2023a

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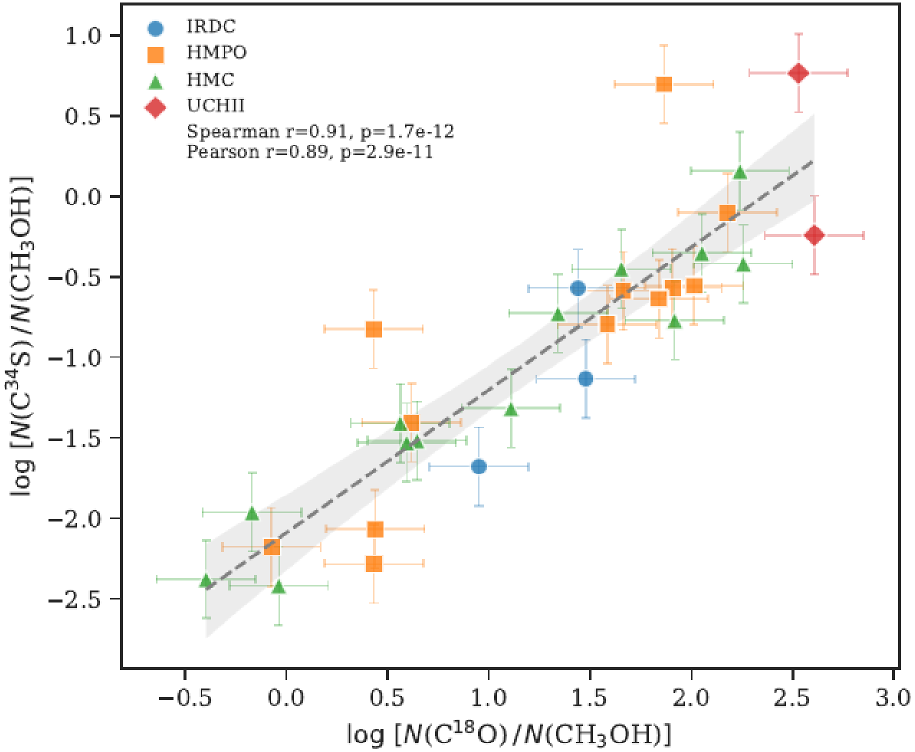


Sarah Böttinger

sarah.boettinger@stud.uni-heidelberg.de

looking for a PhD position!

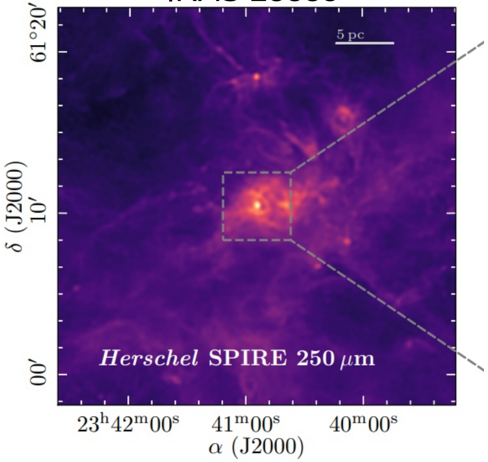
full analysis of the chemical inventory of the entire sample of 11 high-mass star-forming regions:
Master's thesis project by Sarah Böttinger
next step: physical-chemical modeling of the sample

Böttinger in prep.

The cold and warm material probed with NOEMA and JWST

JOYS
JWST GTO program with MIRI MRS
PI: Ewine van Dishoeck
MIRI-MRS
~30 protostellar systems
CORE+
PI: Caroline Gieser
NOEMA/IRAM 30m telescope
3mm
3 high-mass star-forming regions

IRAS 23385



Gieser+2023b

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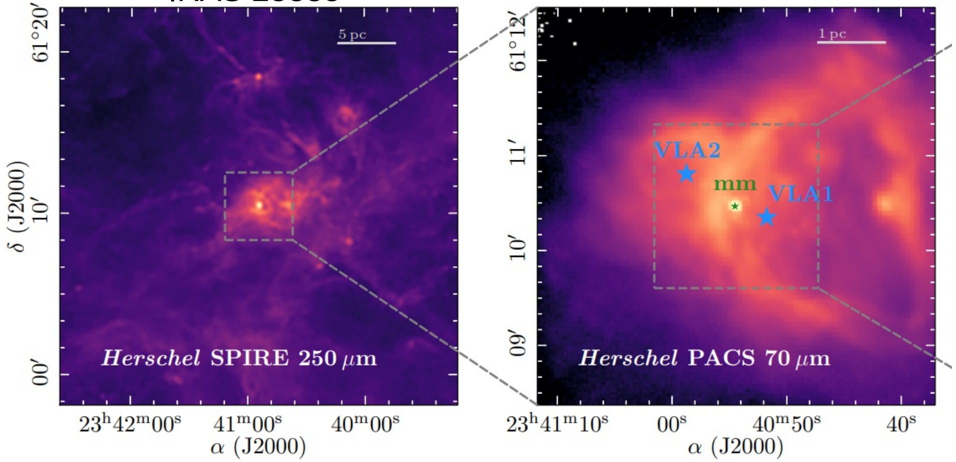

Gieser+2023b

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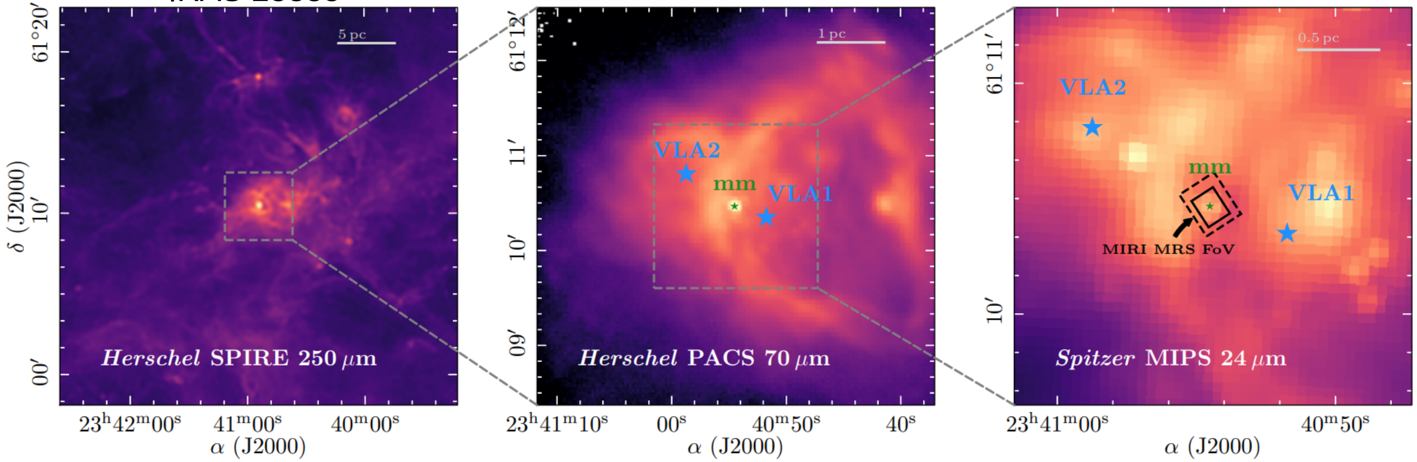

Gieser+2023b

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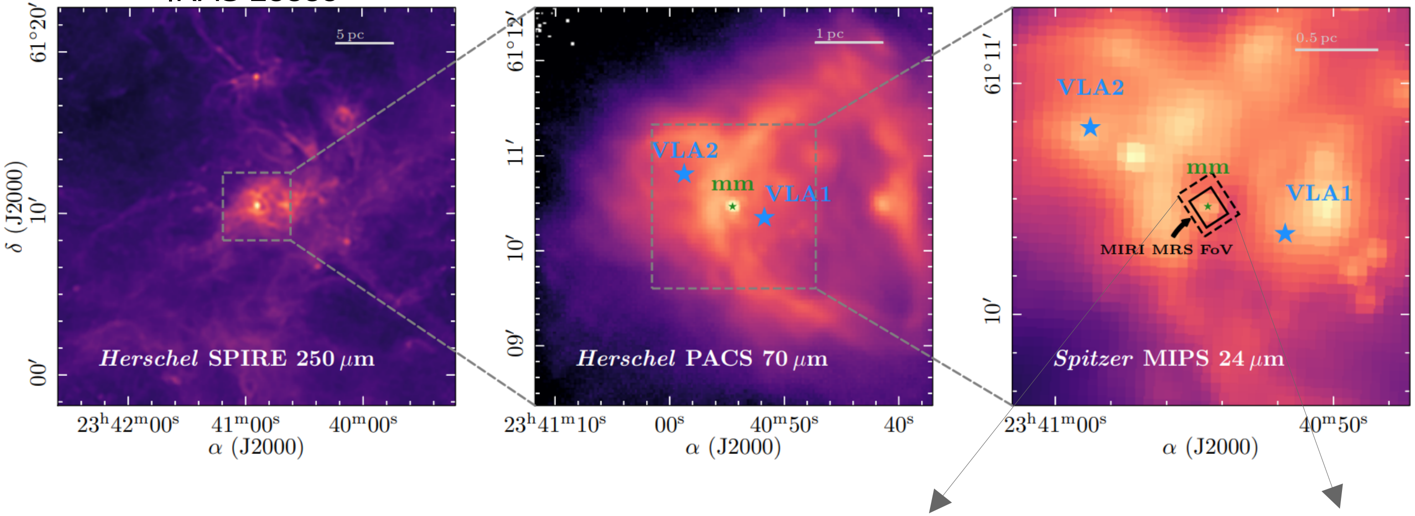

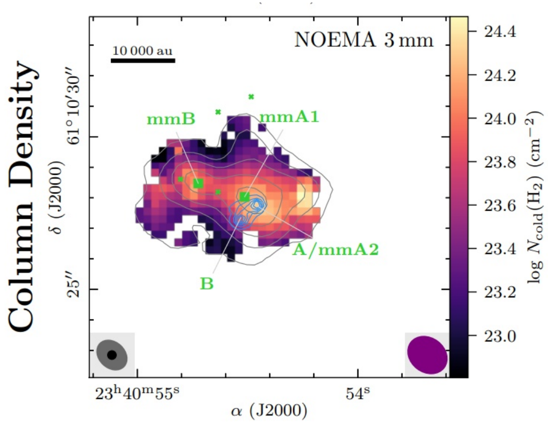

grey contours: 3mm continuum
blue contours: 5 micron continuum

T ~ 50 K

Gieser+2023b

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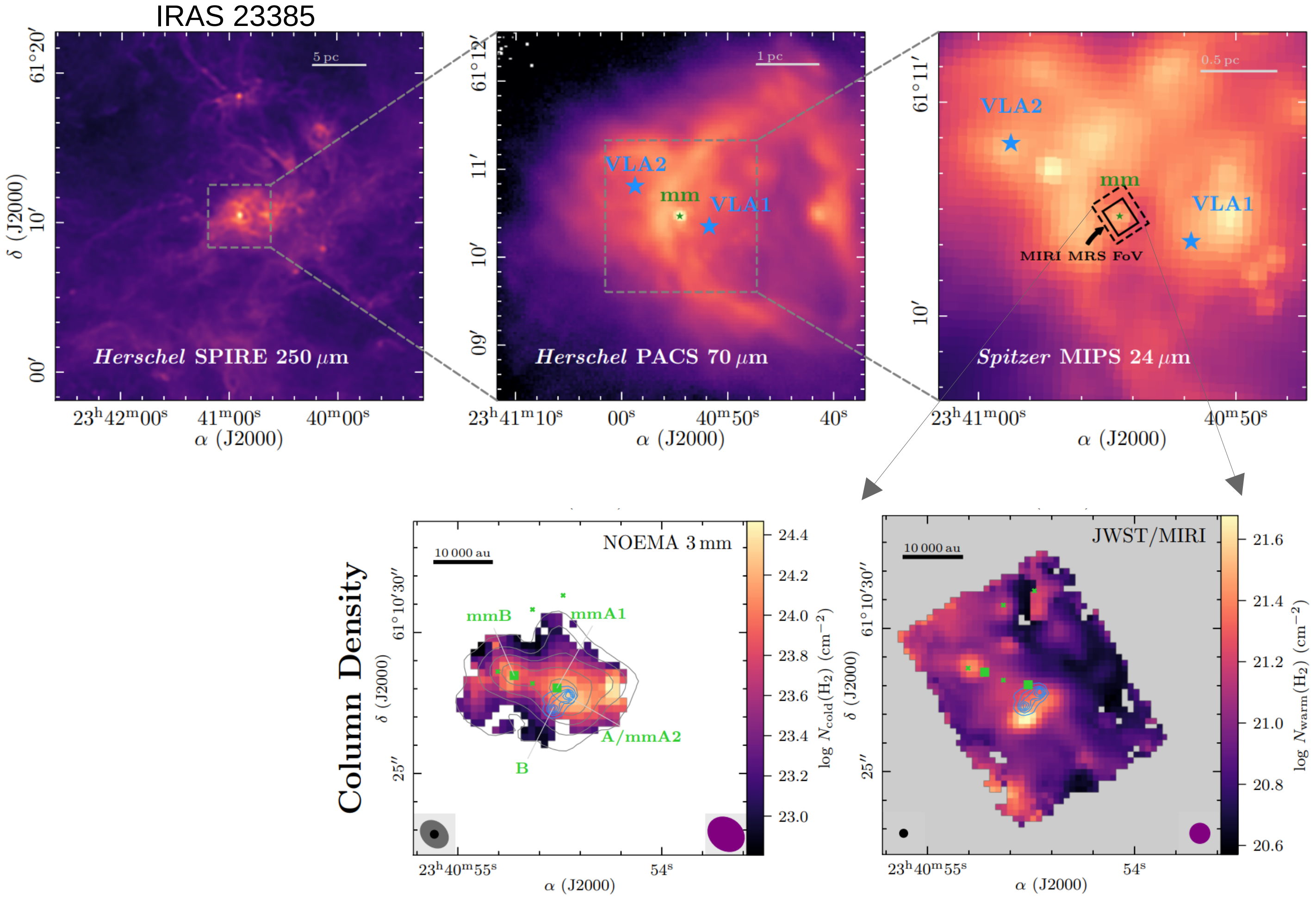


grey contours: 3mm continuum
blue contours: 5 micron continuum

T ~ 50 K

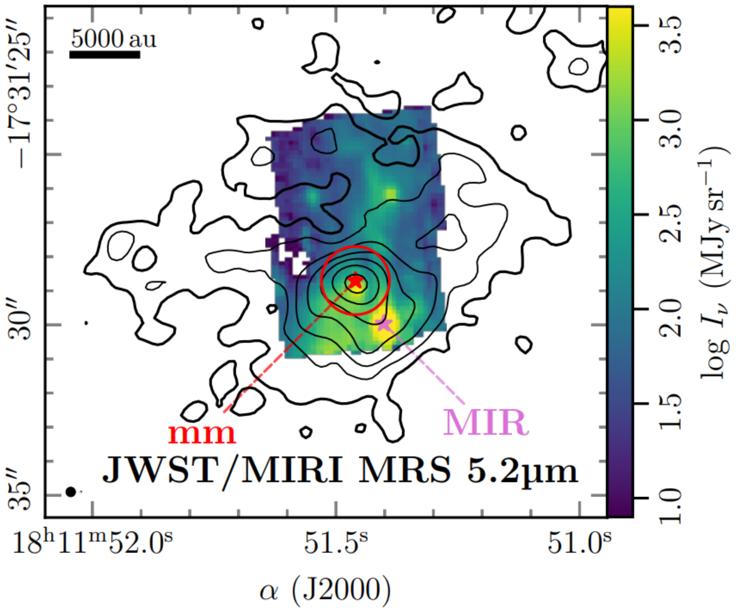
T ~ few 100 K

Gieser+2023b

Complex ice composition revealed by JWST

JOYS
JWST GTO program with MIRI MRS
PI: Ewine van Dishoeck
MIRI-MRS
~30 protostellar systems
ALMA Cycle 6 program
PI: Caroline Gieser
11 high-mass star-forming regions
3 spectral setups @ 3 mm / few 1000 au scales

IRAS 18089: A high-mass protostellar object (HMPO) evolving into a hot molecular core (HMC)



black contours: 3mm continuum

Gieser+2026

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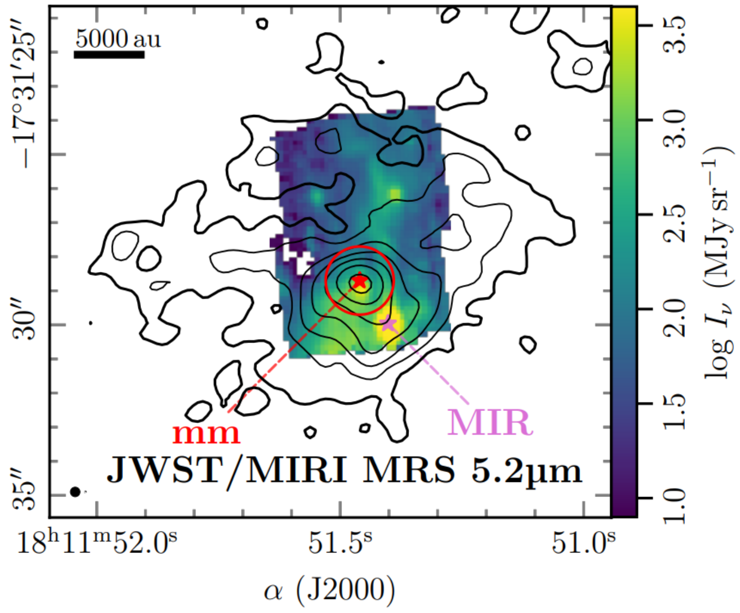

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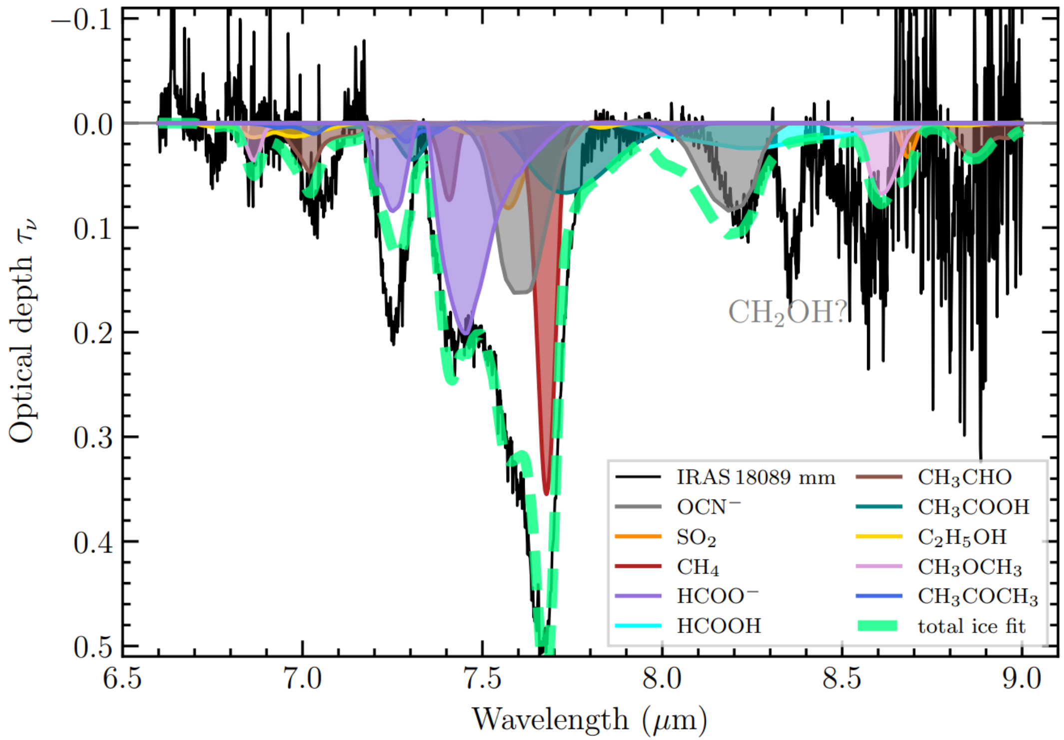
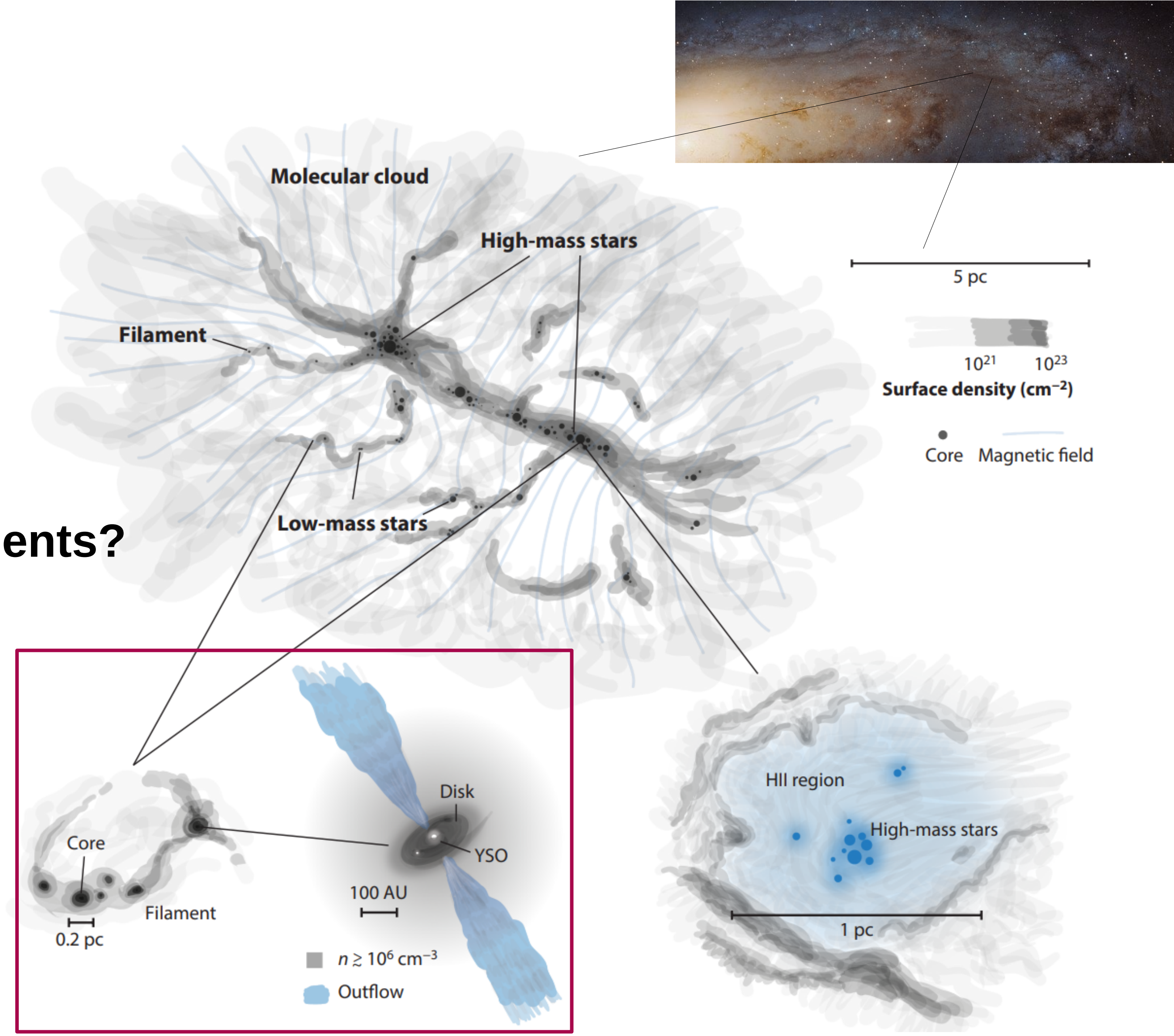


Gieser+2026

stars are crucial building blocks of cosmic structure

how does star formation proceed in different environments?



recent reviews by Rosen+2020, Pineda+2023,Beuther+2025

Isolated low-mass protostars?

streamer?

ALMA long baseline
continuum data:
wide binary system?

Reynolds+2021

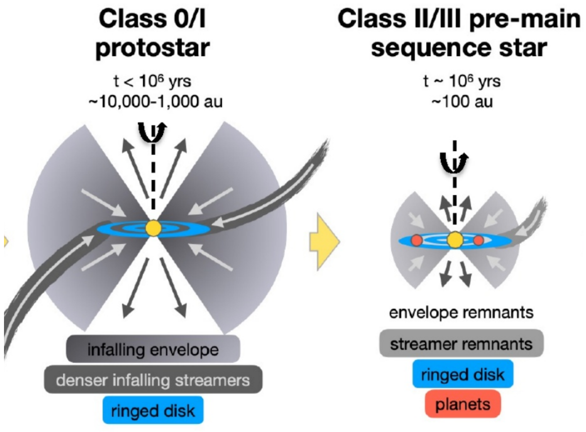
Tobin+2016,2018,Reynolds+2021,2024, Looney+2025

Isolated low-mass protostars?

PRODIGE
PI: Paola Caselli & Thomas Henning
NOEMA
1mm at 300 au resolution
30 protostellar systems in the Perseus molecular cloud

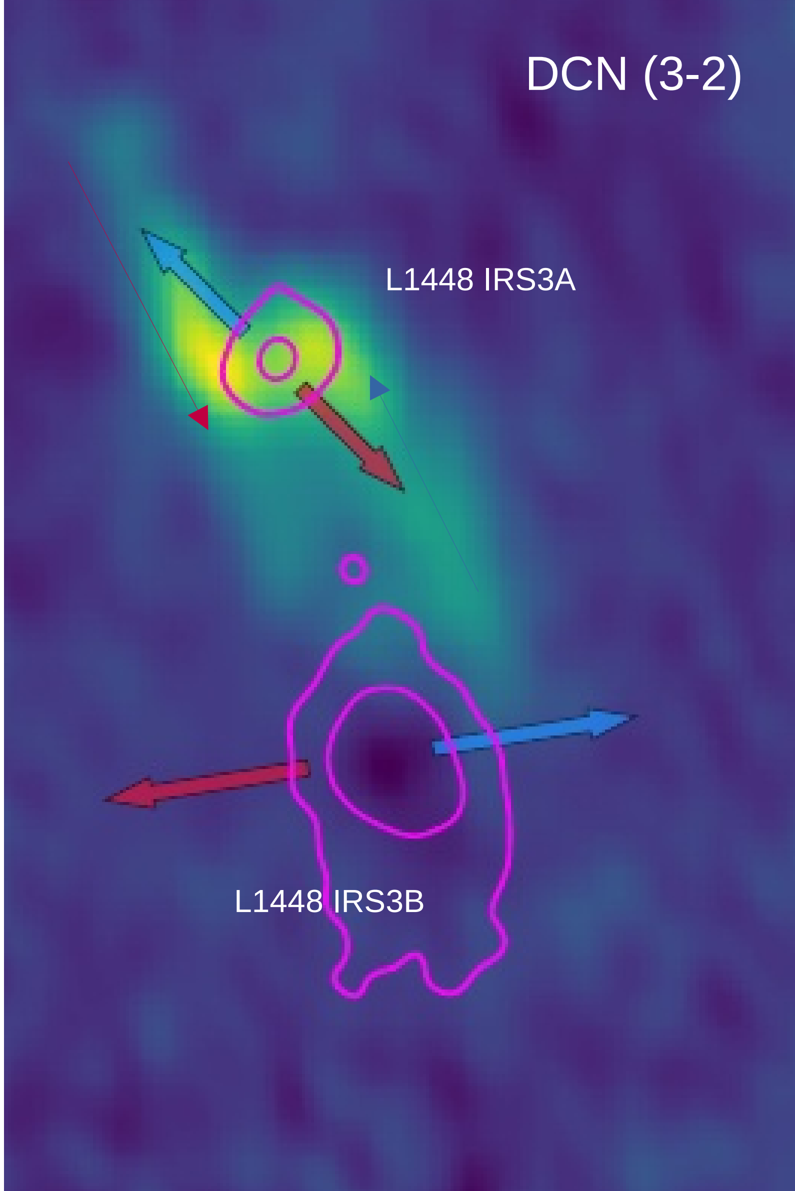
NOEMA
molecular line data:
a gas bridge!

infall motions onto IRS3A:
a double streamer



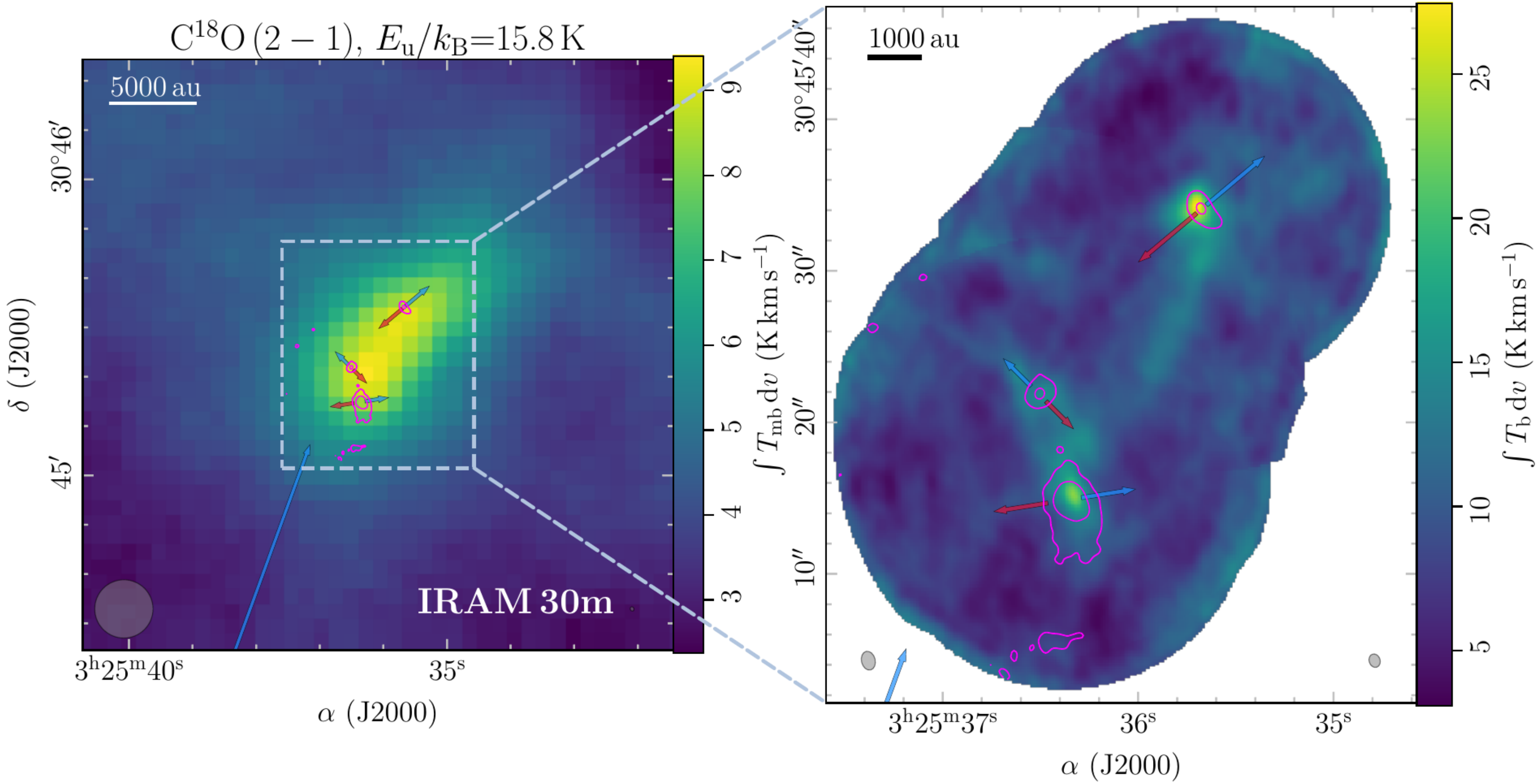
Pineda+2023

Gieser+2024



Continued infall from the environment through streamers ?

ANTIHEROES
PI: Caroline Gieser
IRAM 30m telescope large program
1mm at 3000 au resolution
30 protostellar systems in the Perseus molecular cloud



Gieser+2025

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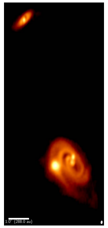
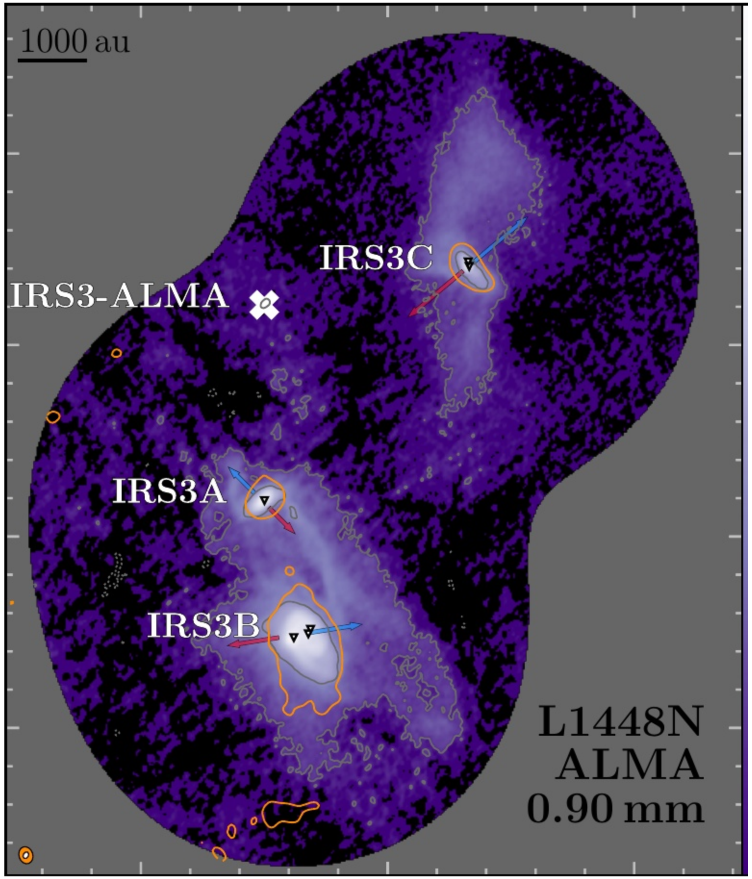


Reynolds+2021



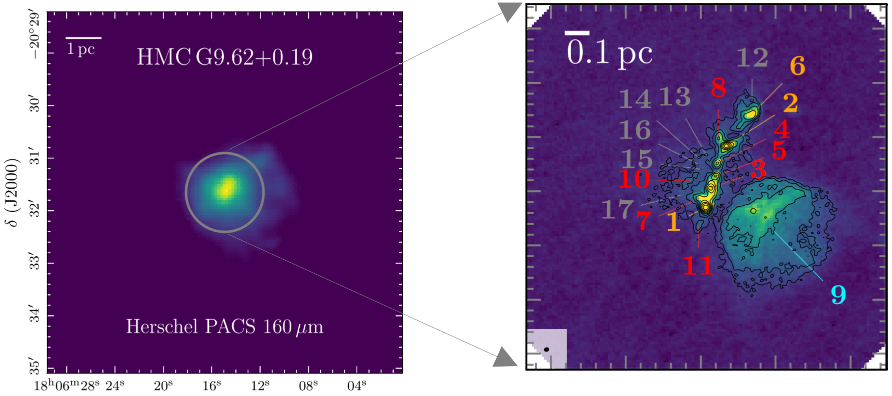
Gieser+in prep.

ALMA Perseus Polarization Survey (ALPPS)
Cortes+2025

Conclusions: Using physics and chemistry to probe high-mass protostellar cores

- (sub)mm interferometers NOEMA and ALMA:
  probe protostellar cores (<0.1 pc in size)
  in high-mass star-forming regions
- complementary JWST observations in the IR:
  warm and hot material + ices

- combining the observed physical-chemical
  properties with modeling
  → **chemical timescales**
  → **constraints on the evolution of high-mass star-forming cores**



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Splinter Session on Thursday + Friday:
Star Formation across Scales: Synthesizing Local and Global Perspectives