The chemical nature of Orion protostars: Are ORANGES different from PEACHES?

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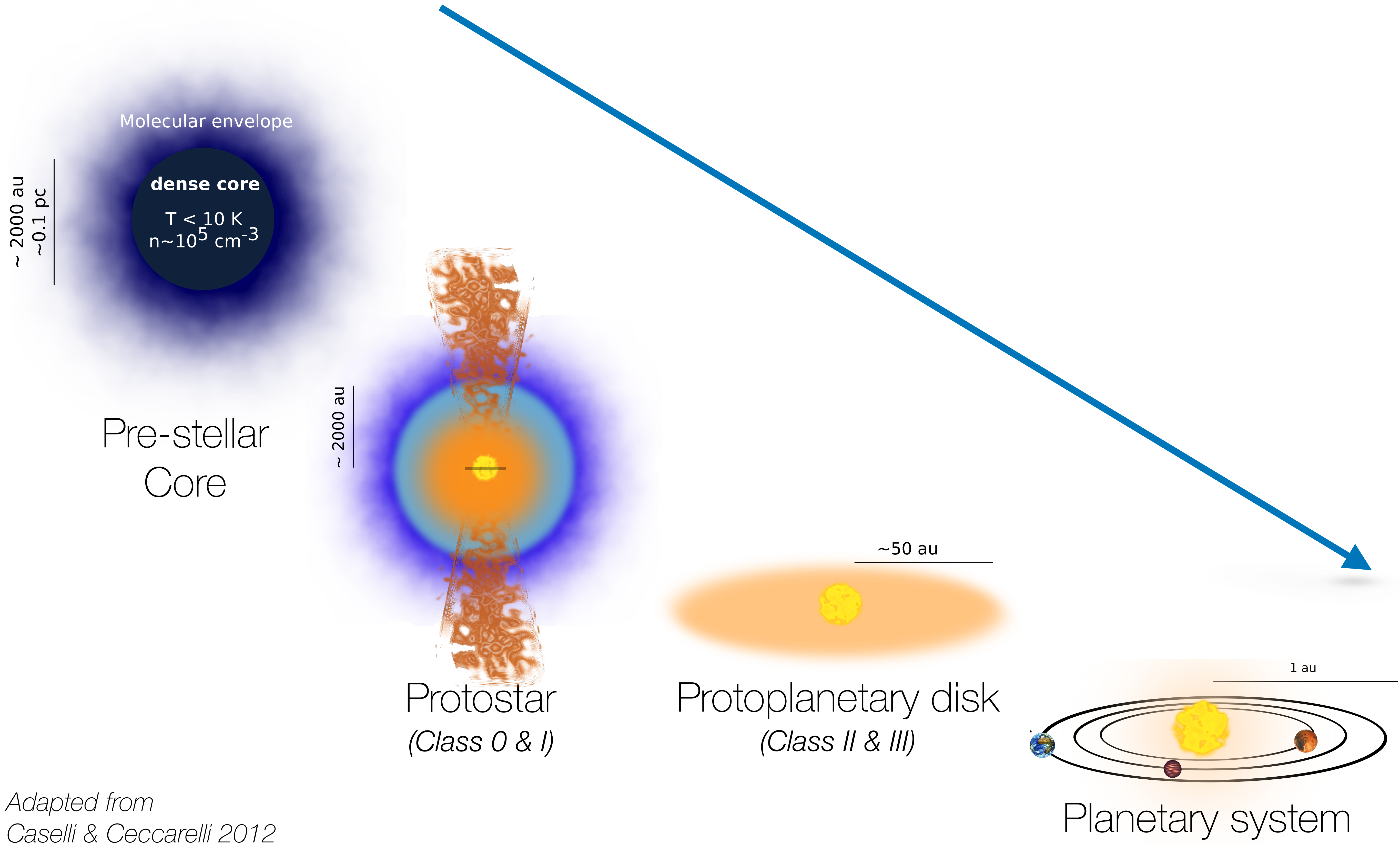
[4]The University of Tokyo, Japan
[5]Research Center for the Early Universe, The University of Tokyo, Japan

Image credit: ESO/VISTA

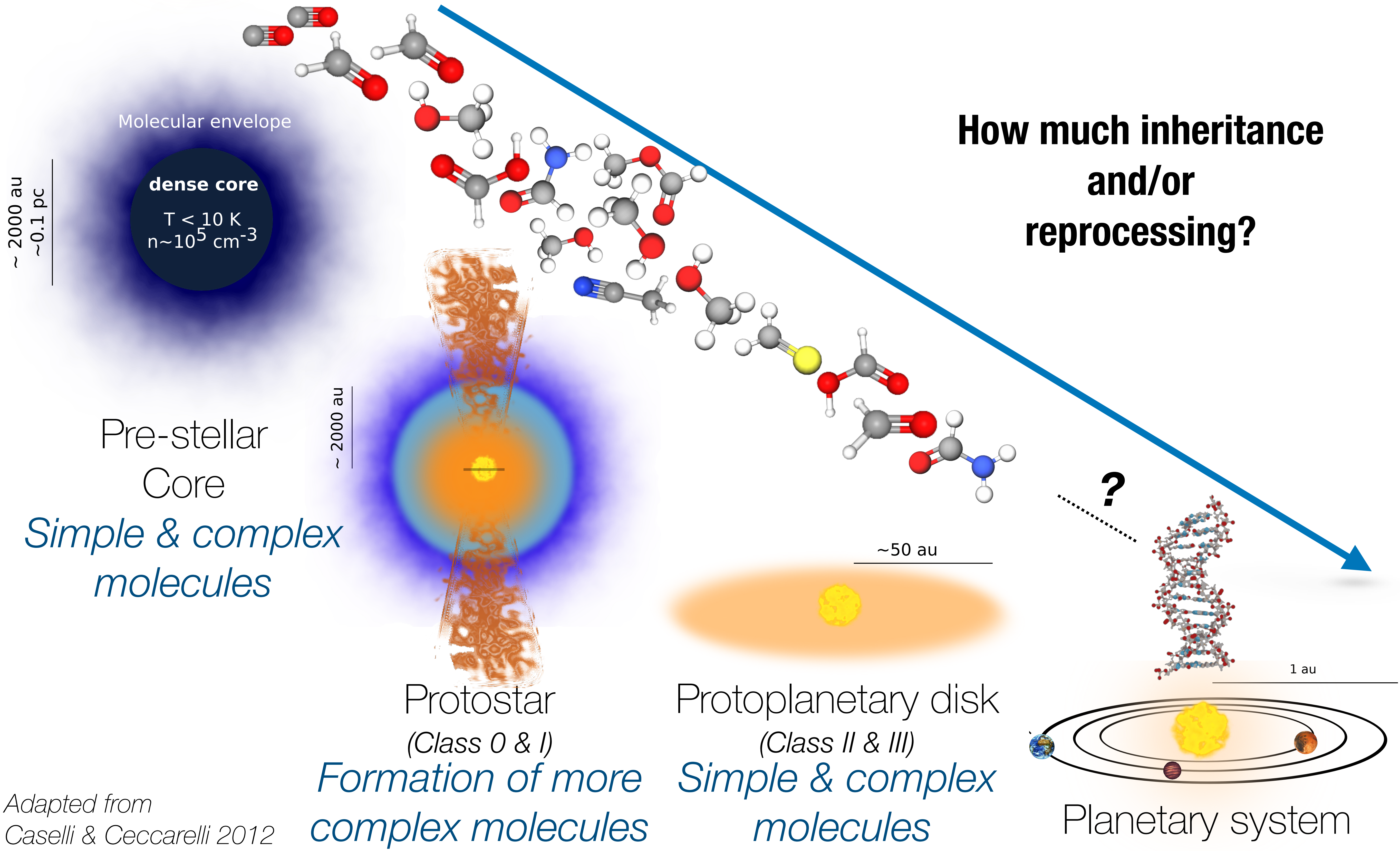
How does a solar-mass star form?



Adapted from Caselli & Ceccarelli 2012

How does a solar-mass star form?

How much inheritance and/or reprocessing?



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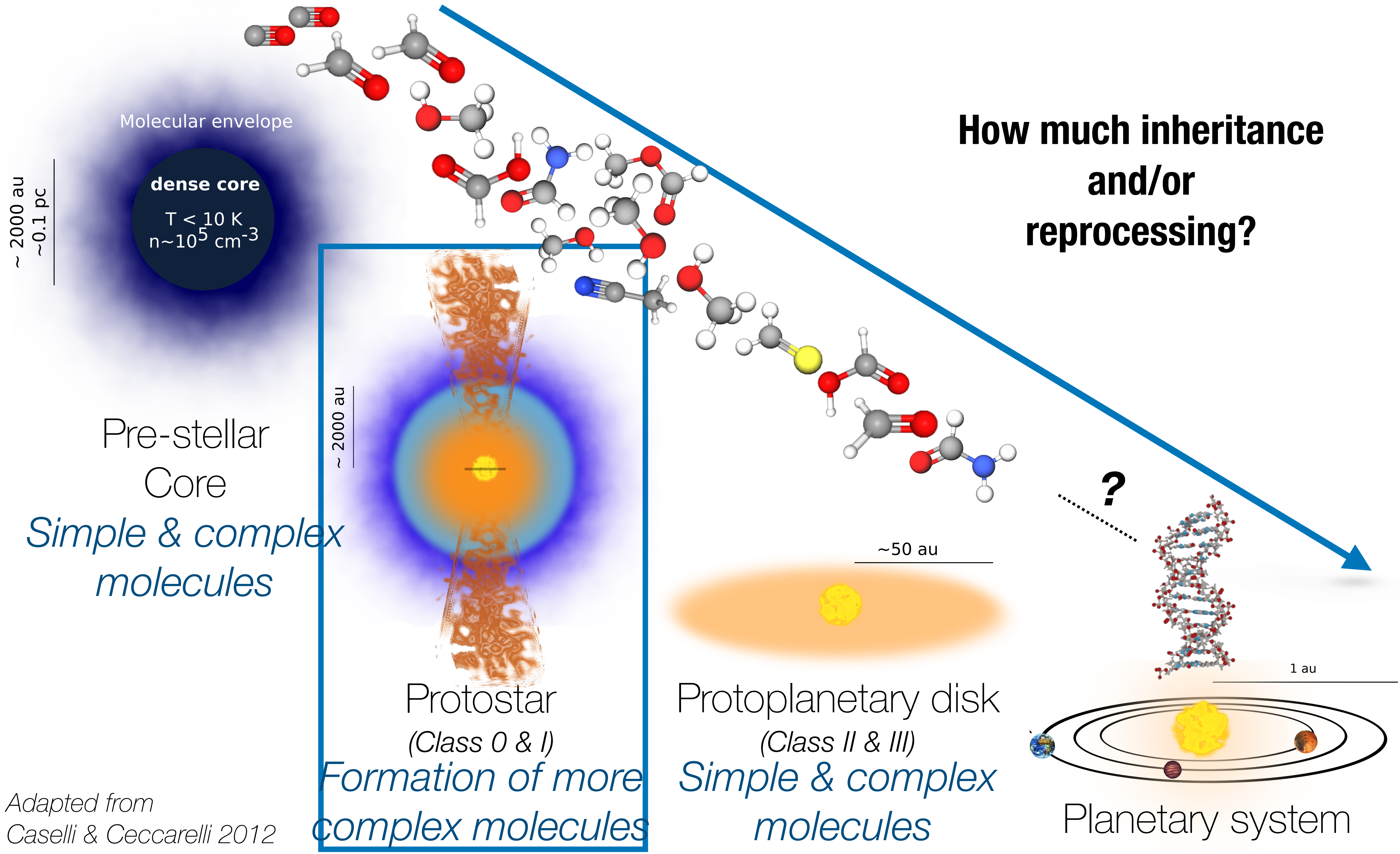

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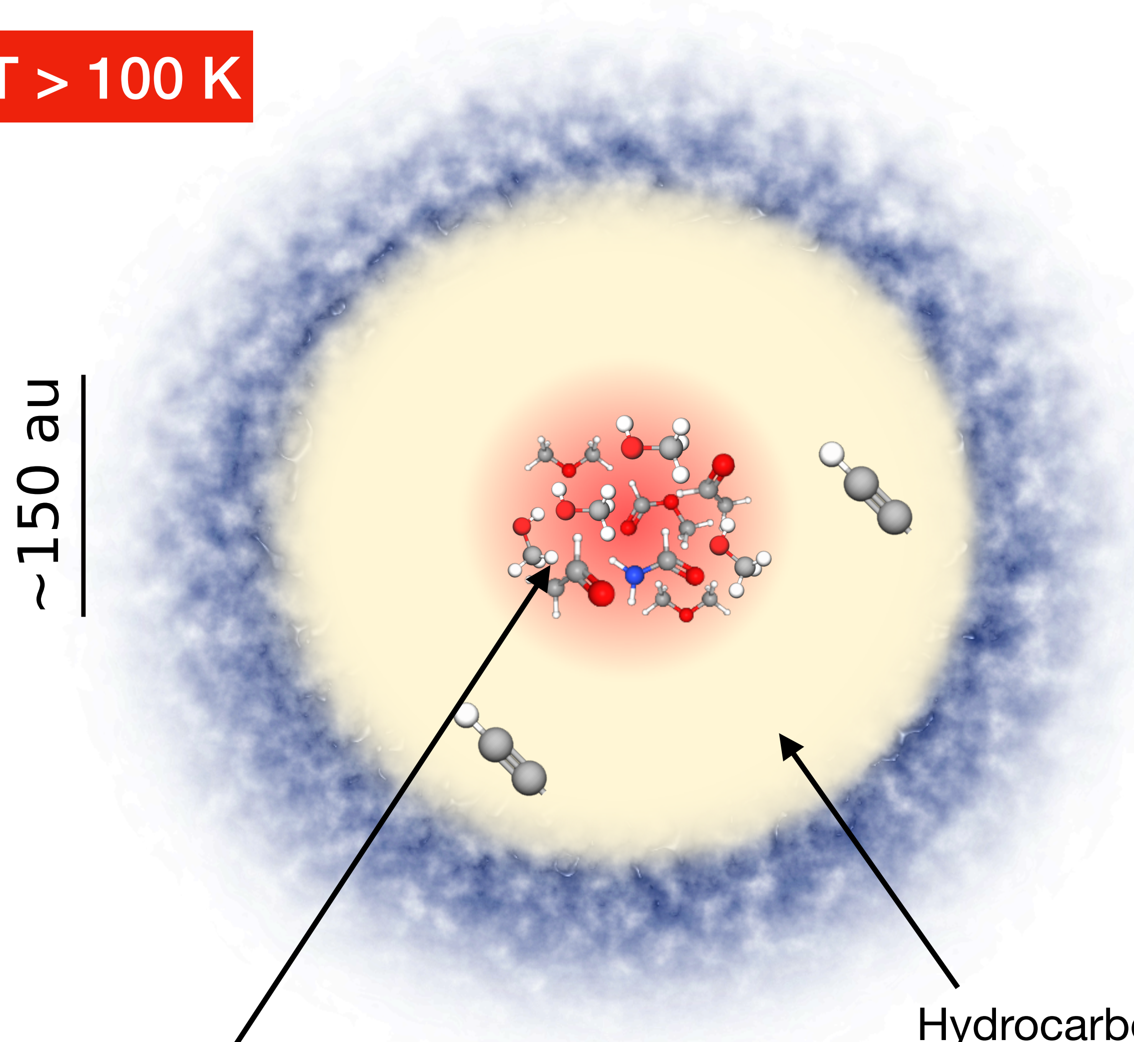
The protostellar stage: A rich chemistry

Two opposite cases in the protostars chemical diversity spectrum

Hot corinos

Ceccarelli 2004, Ceccarelli et al. 2007

T > 100 K



Enriched in iCOMs**
e.g. **CH_3OH**, CH_3OCH_3, NH_2CHO

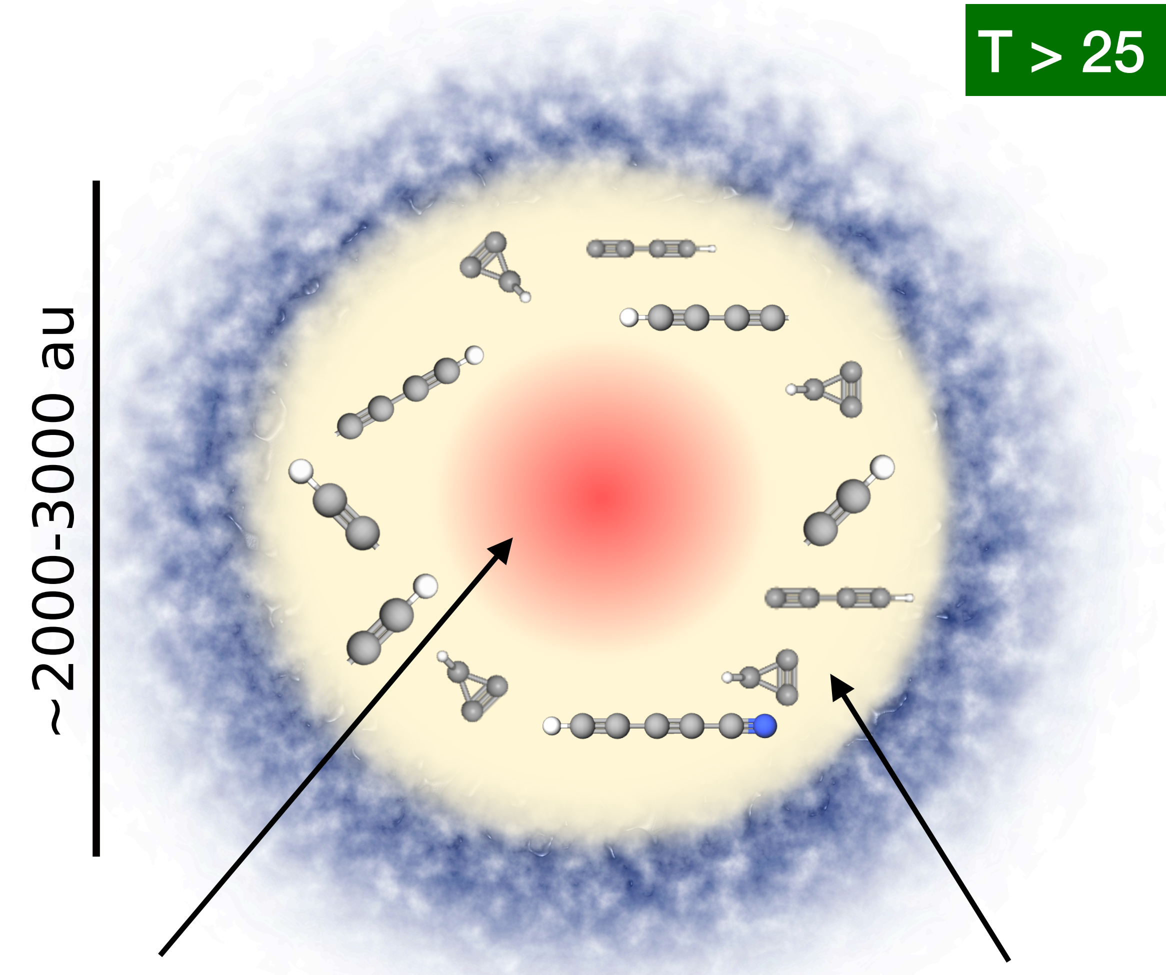
Hydrocarbons deficiency in envelope

interstellar **Complex **O**rganic **M**olecules*

WCCC* sources

Sakai et al. 2008, Sakai & Yamamoto 2013

T > 25 K



iCOMs deficiency in inner region

Enriched in unsaturated (long) carbon chains
e.g. **CCH**, C_6H, C_4H_2

Warm **C**arbon **C**hain **C**hemistry*

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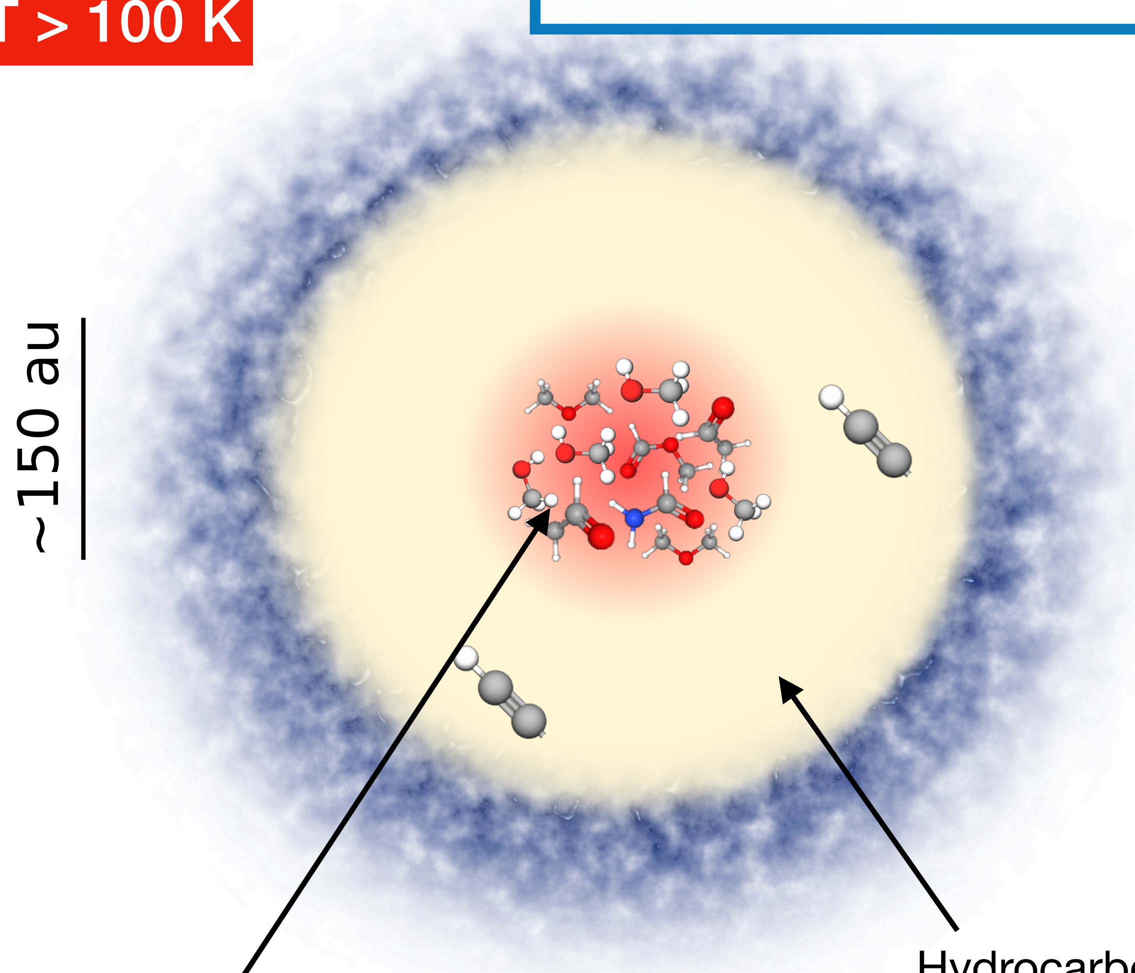

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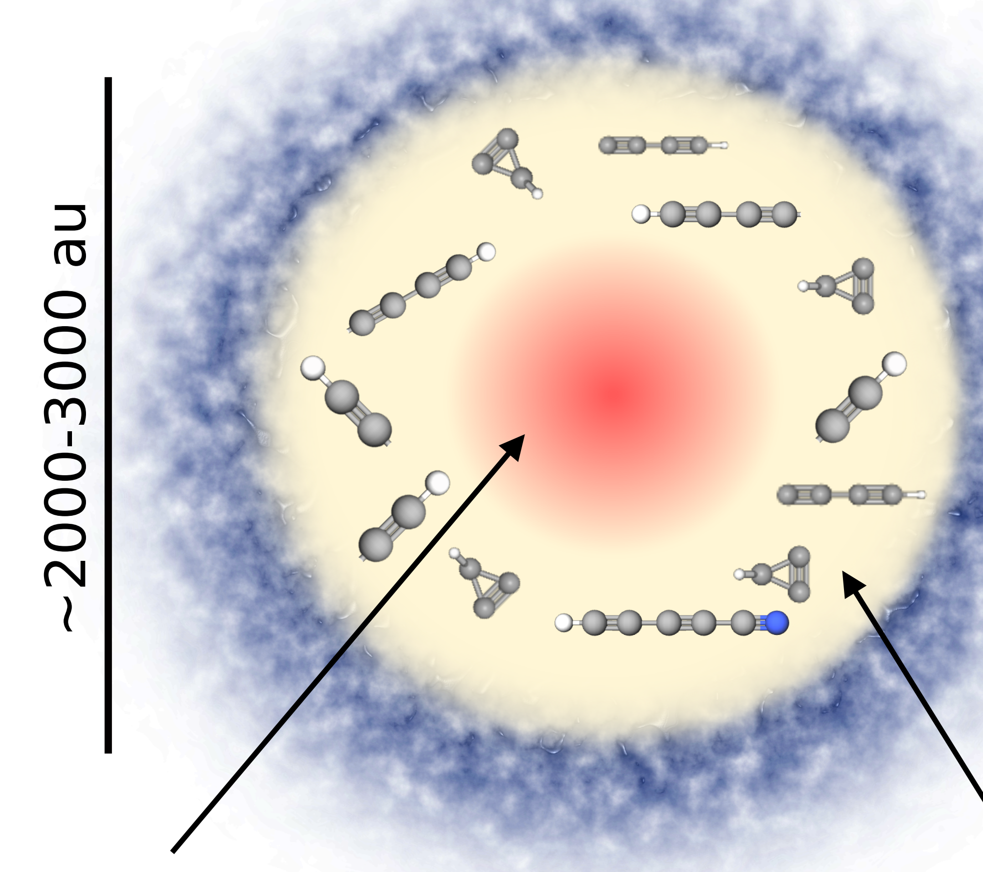

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Why is there a chemical diversity?

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Why is there a chemical diversity?

Chemical difference of the ice mantle of grains

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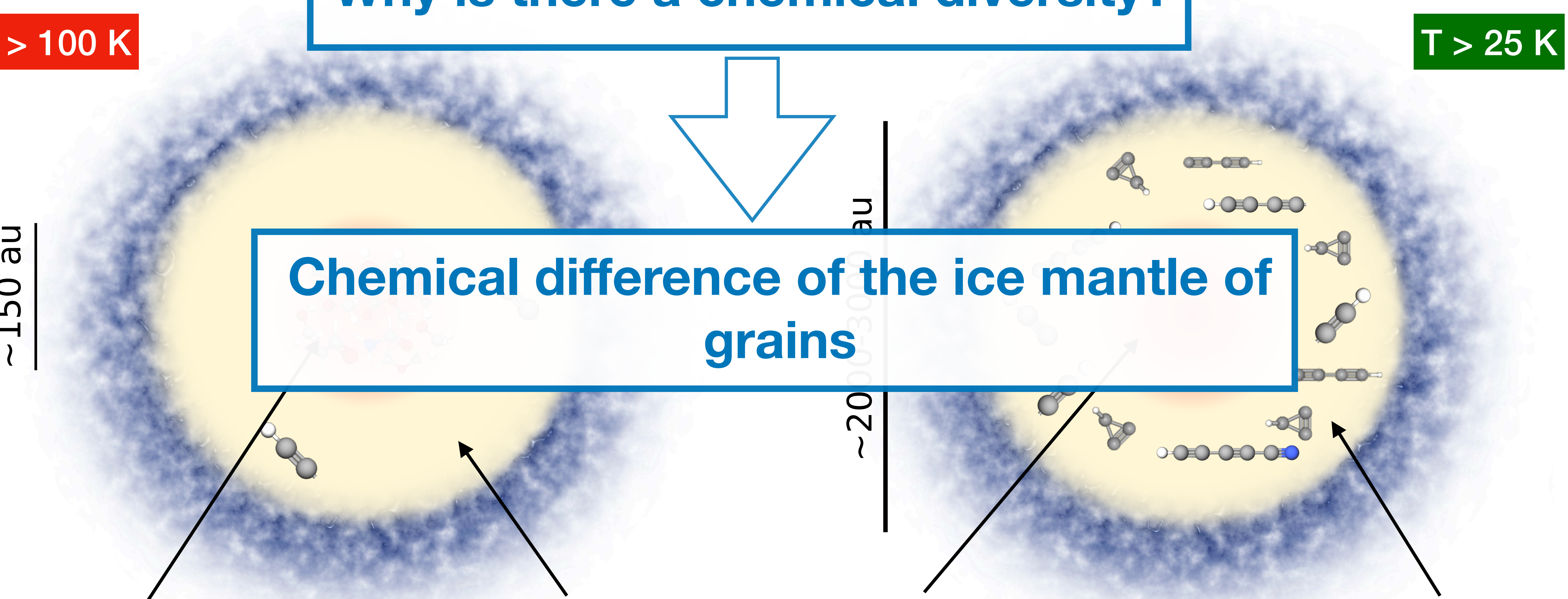

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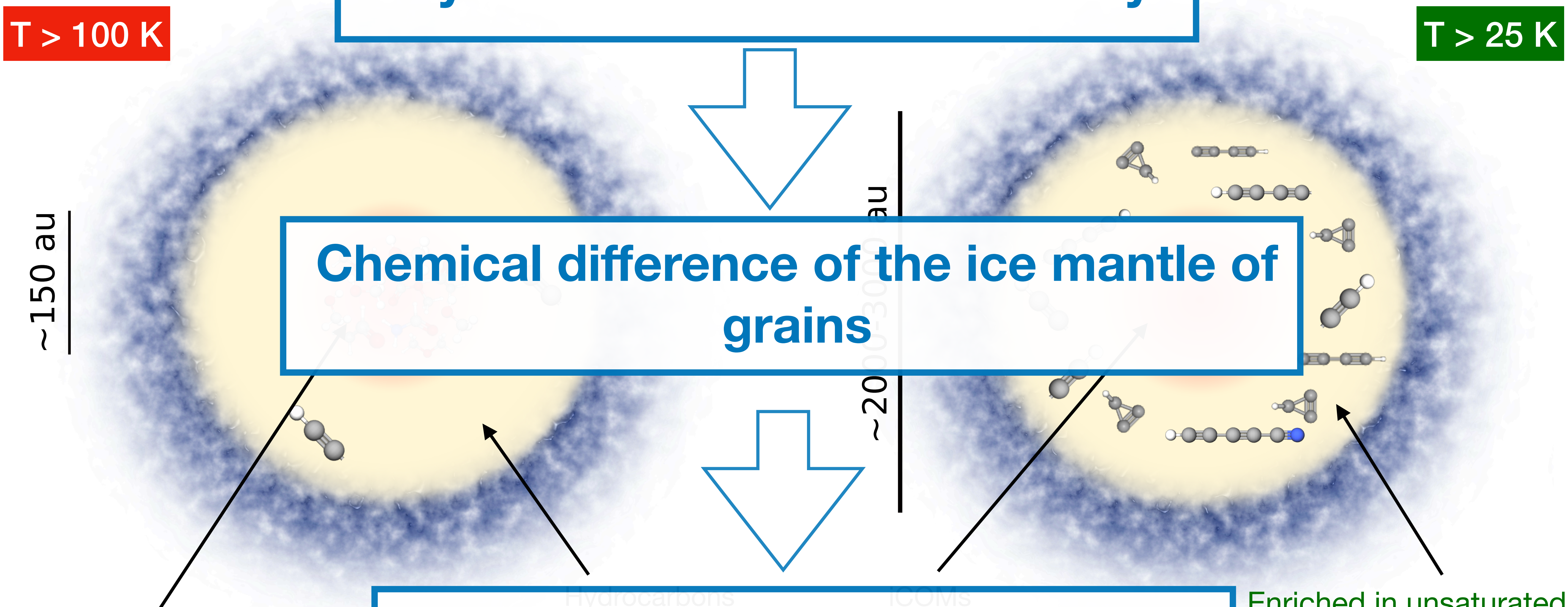

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What causes this difference ?

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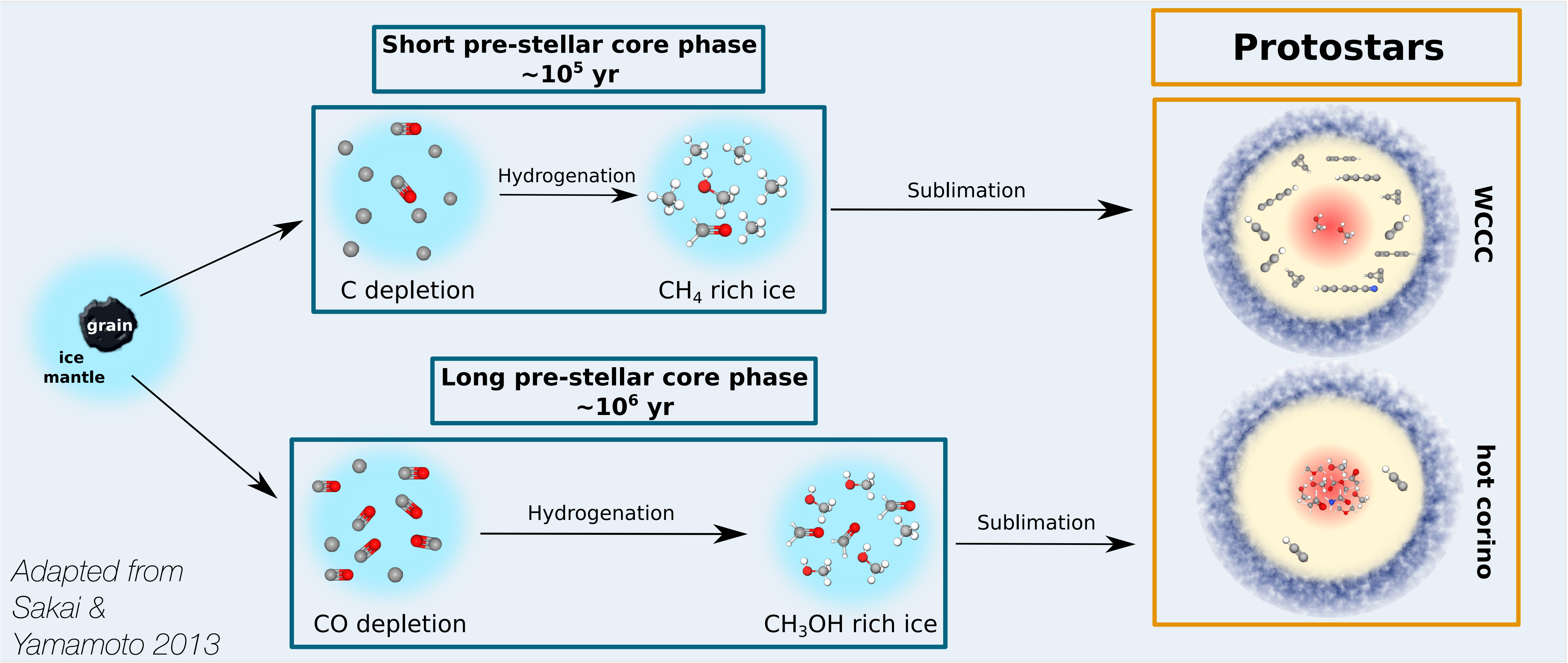
Hypothesis n°1: Difference of timescale of the pre-stellar core phase Sakai et al. 2008a, 2009a



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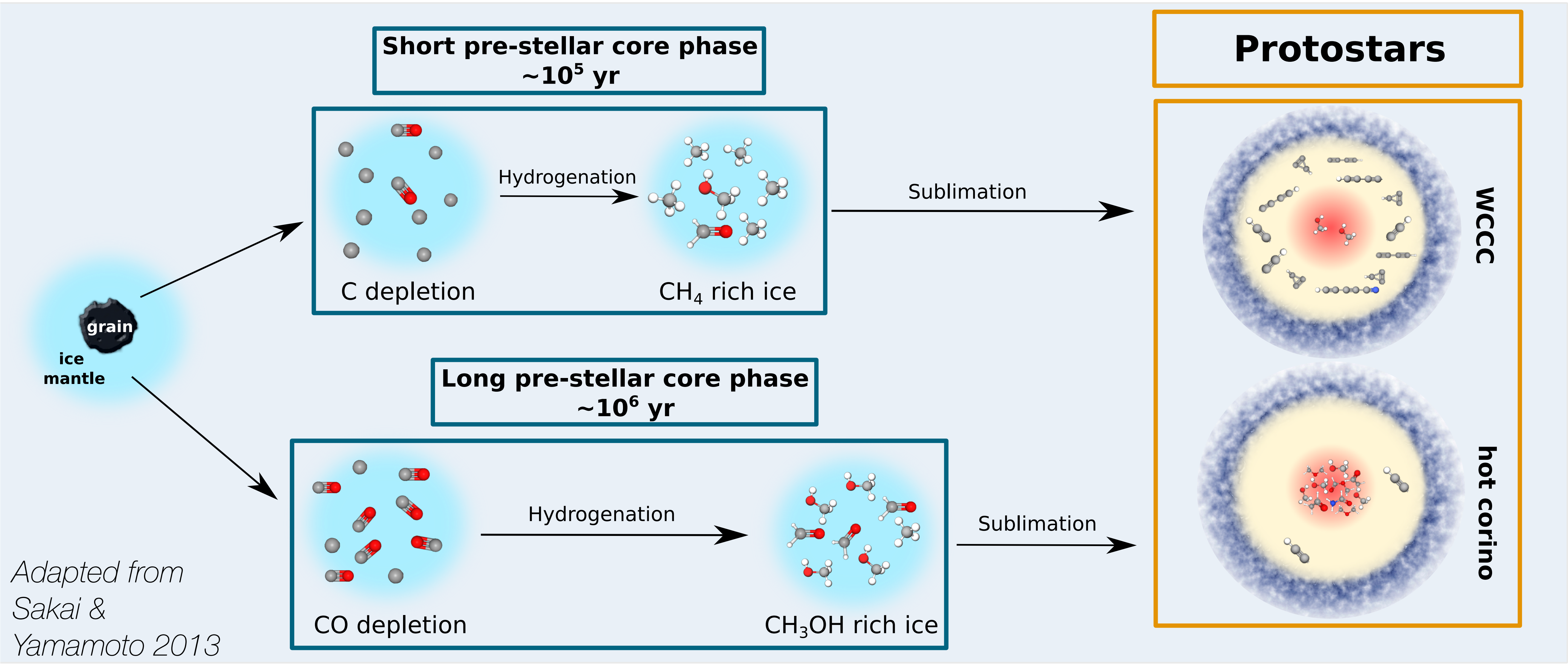

Interpretation challenged by Aikawa et al. (2020): hot corinos and hybrid sources can be reproduced but not pure WCCC sources

What causes this chemical differentiation?

Hypothesis n°2: Role of environmental factors (density, temperature, UV or CR irradiation) during the pre-stellar core phase e.g. Spezzano et al. 2016, 2020, Higuchi et al. 2018, Aikawa et al. 2020, Lattanzi et al. 2020, Kalvāns 2021

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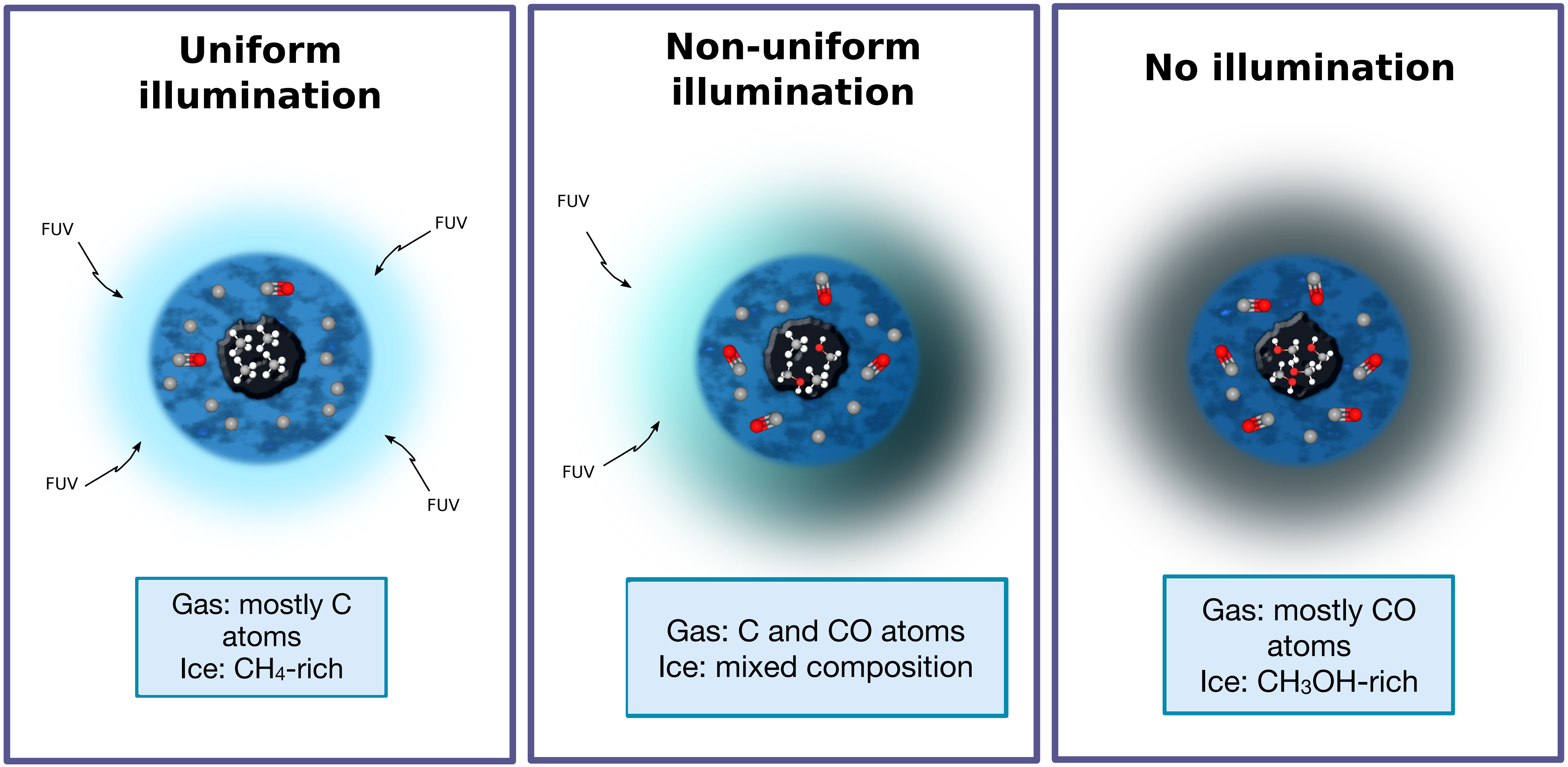

Adapted from Spezzano et al. 2016

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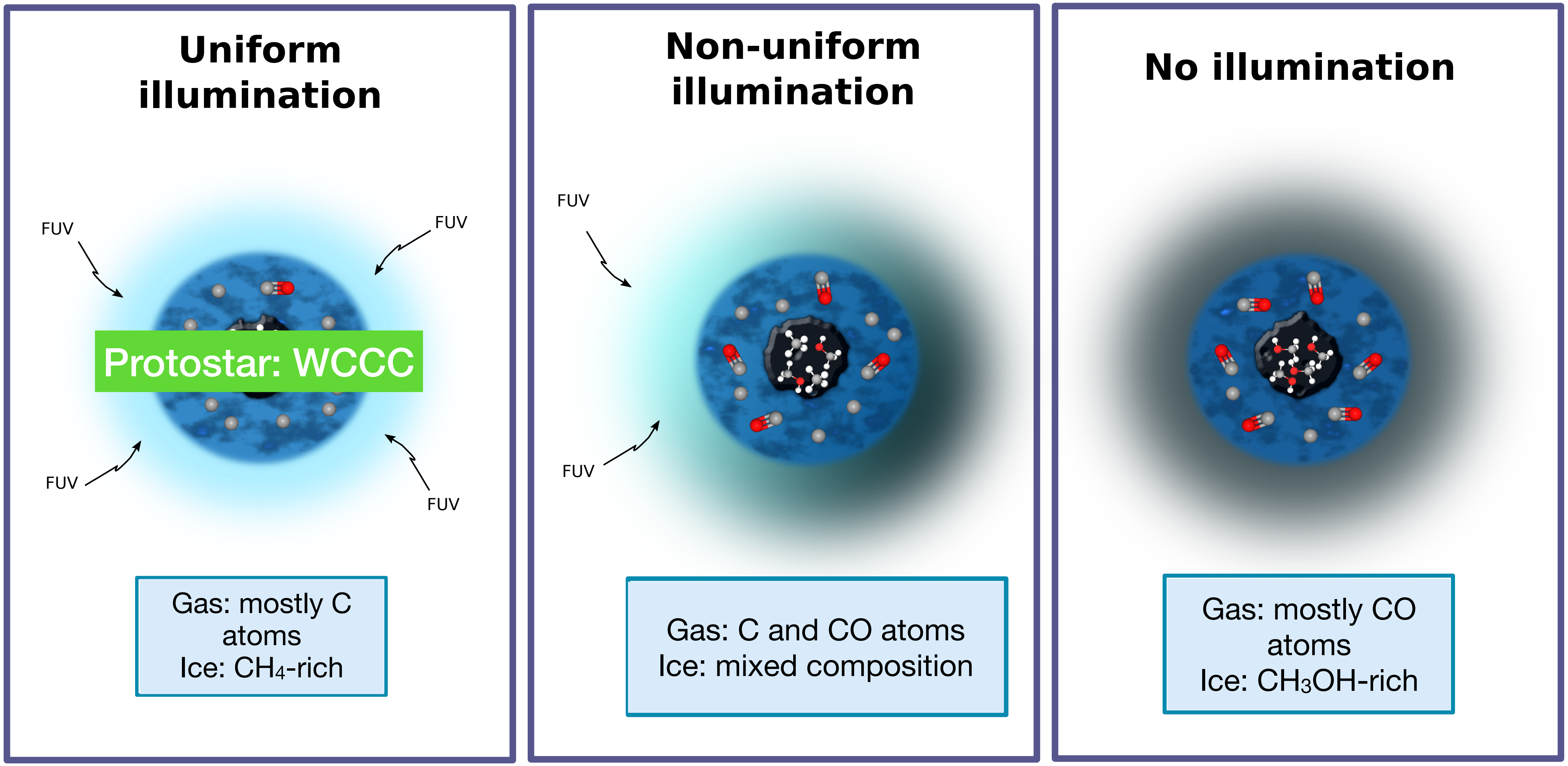

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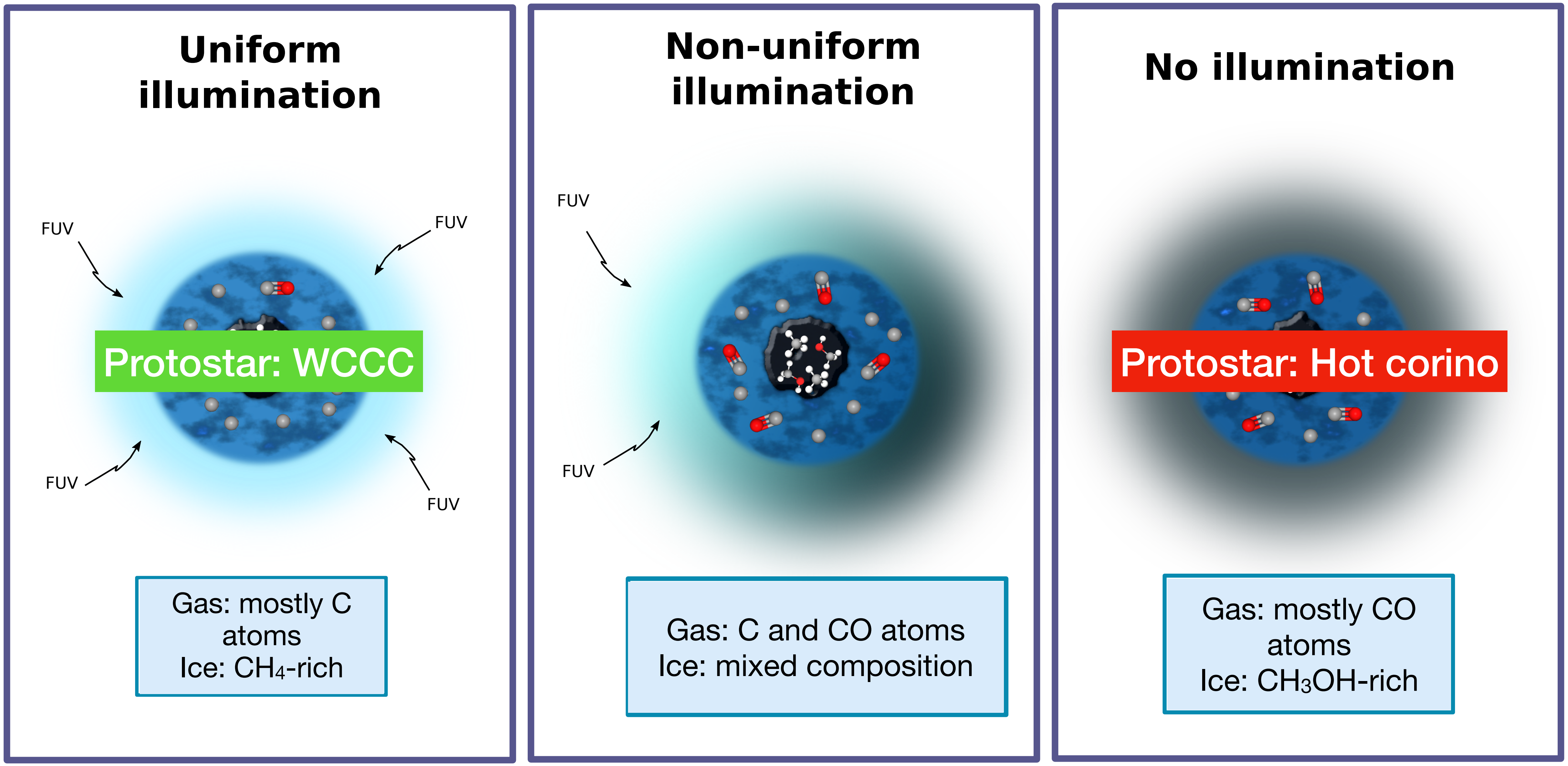

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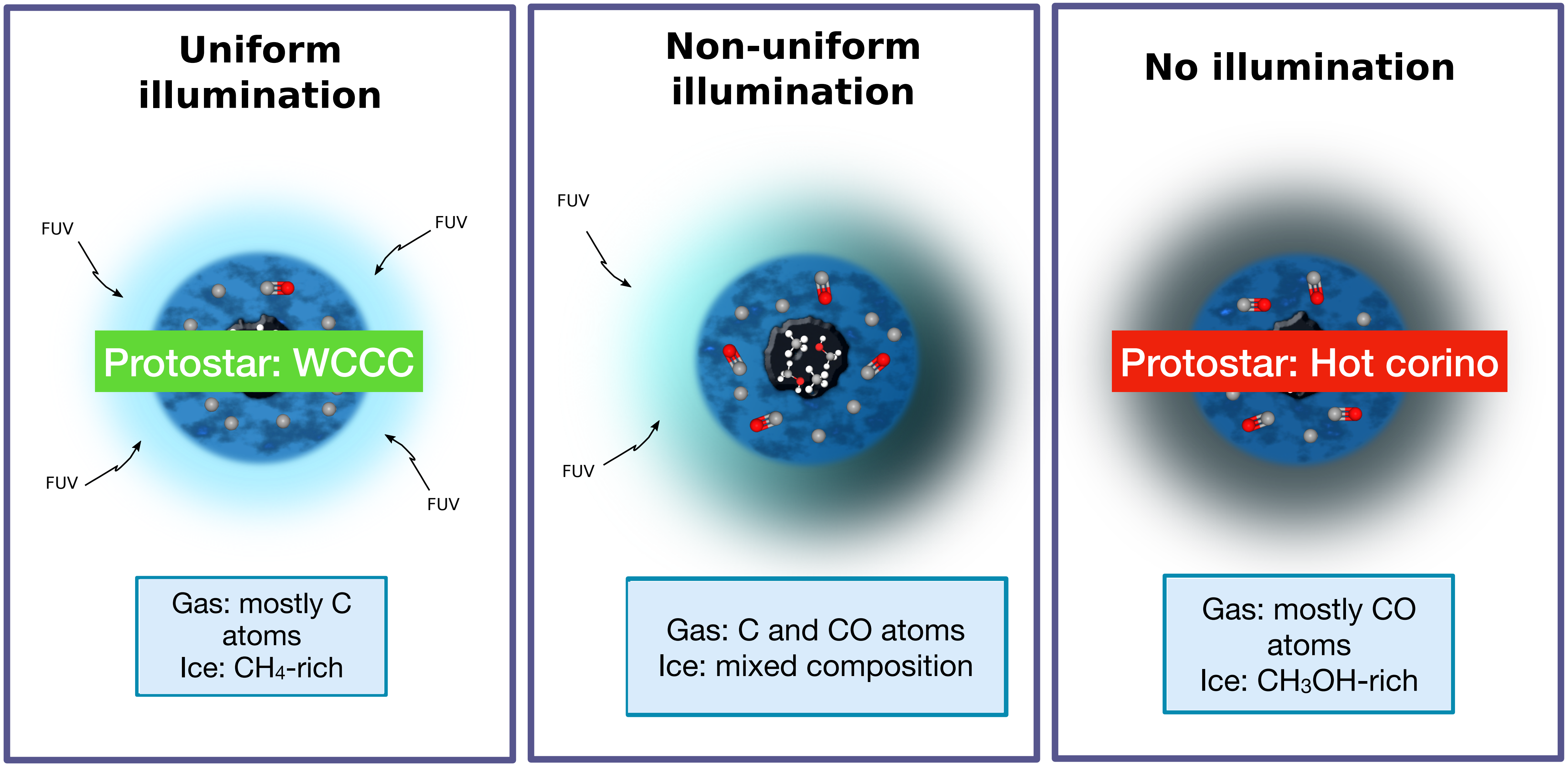

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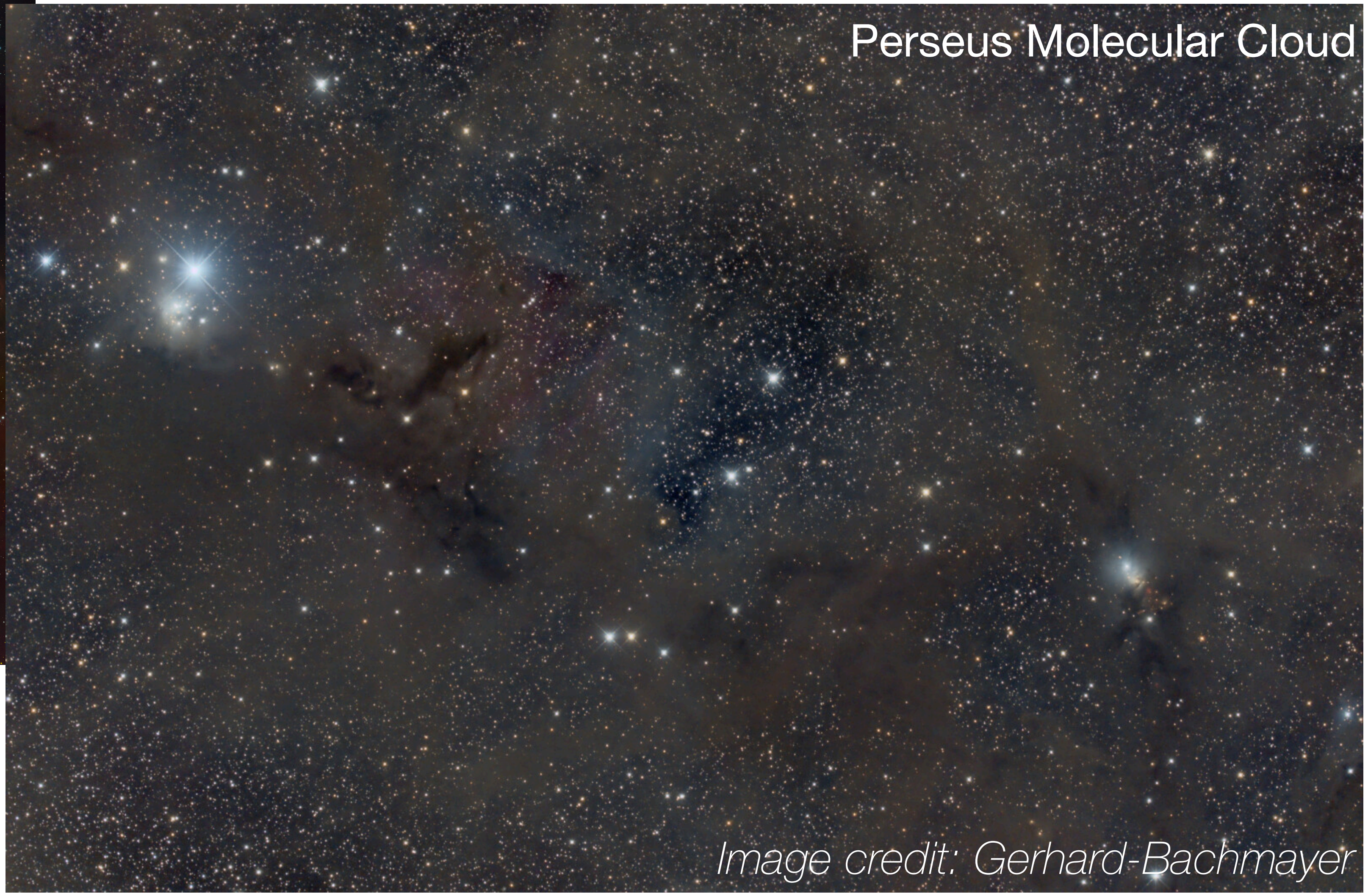
E.g. lower density, lower temperature and higher irradiation favour WCCC sources
e.g. Aikawa et al. 2020, Kalvāns 2021

Does the environment affects the chemical nature of solar-mass protostars?



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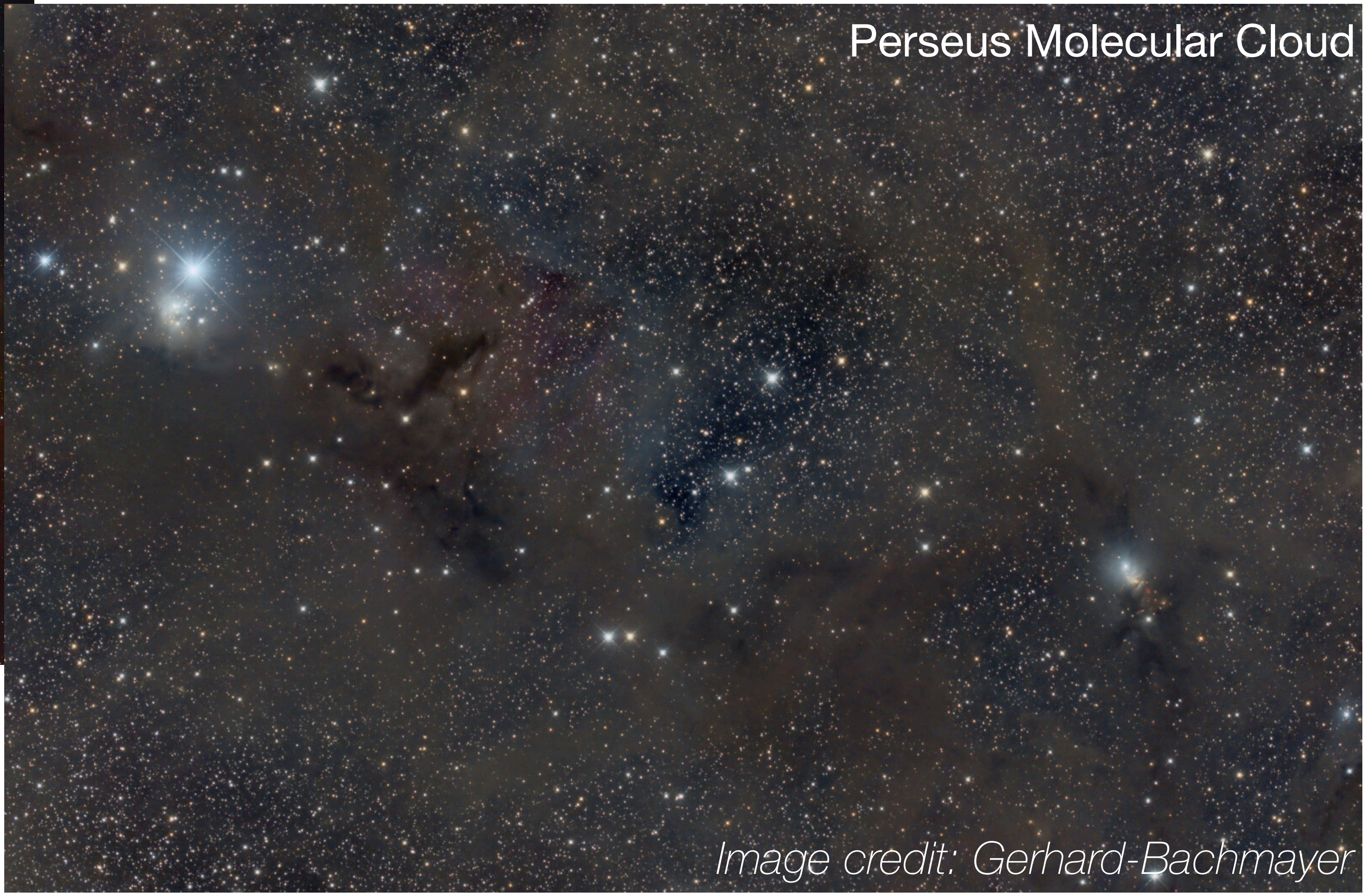
Study of solar-mass protostars chemical composition

- at small scales to avoid external contamination *Bouvier et al. 2020*
- in different environments



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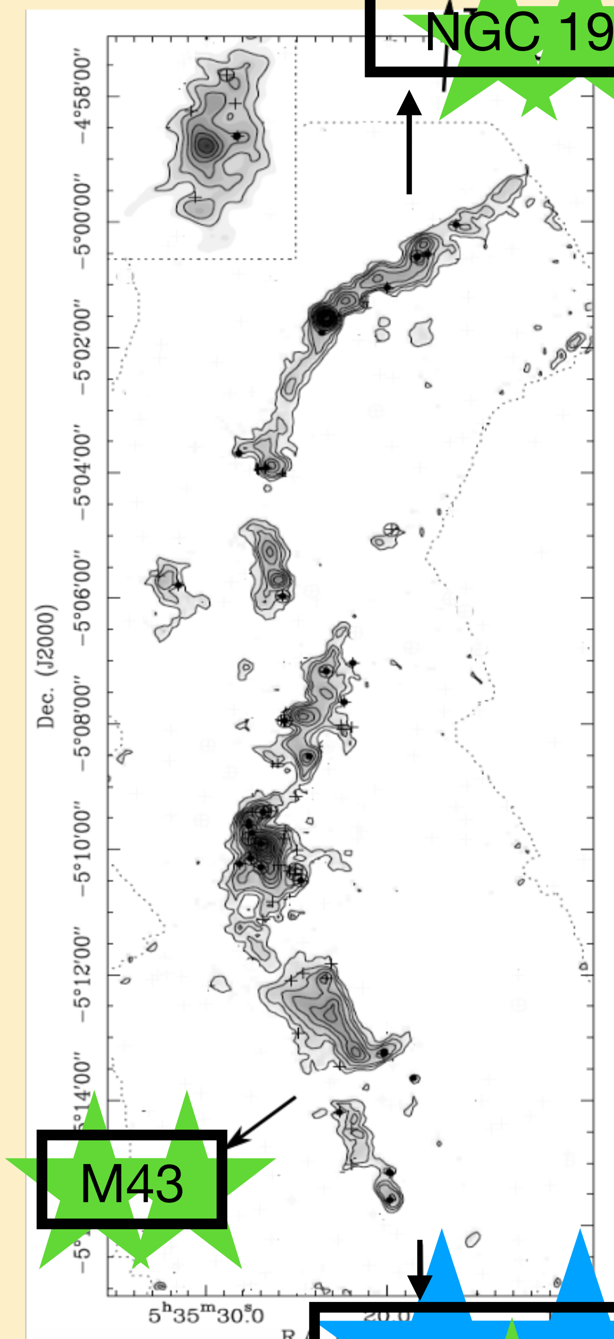
Goals of PEACHES and ORANGES

ORANGES and PEACHES

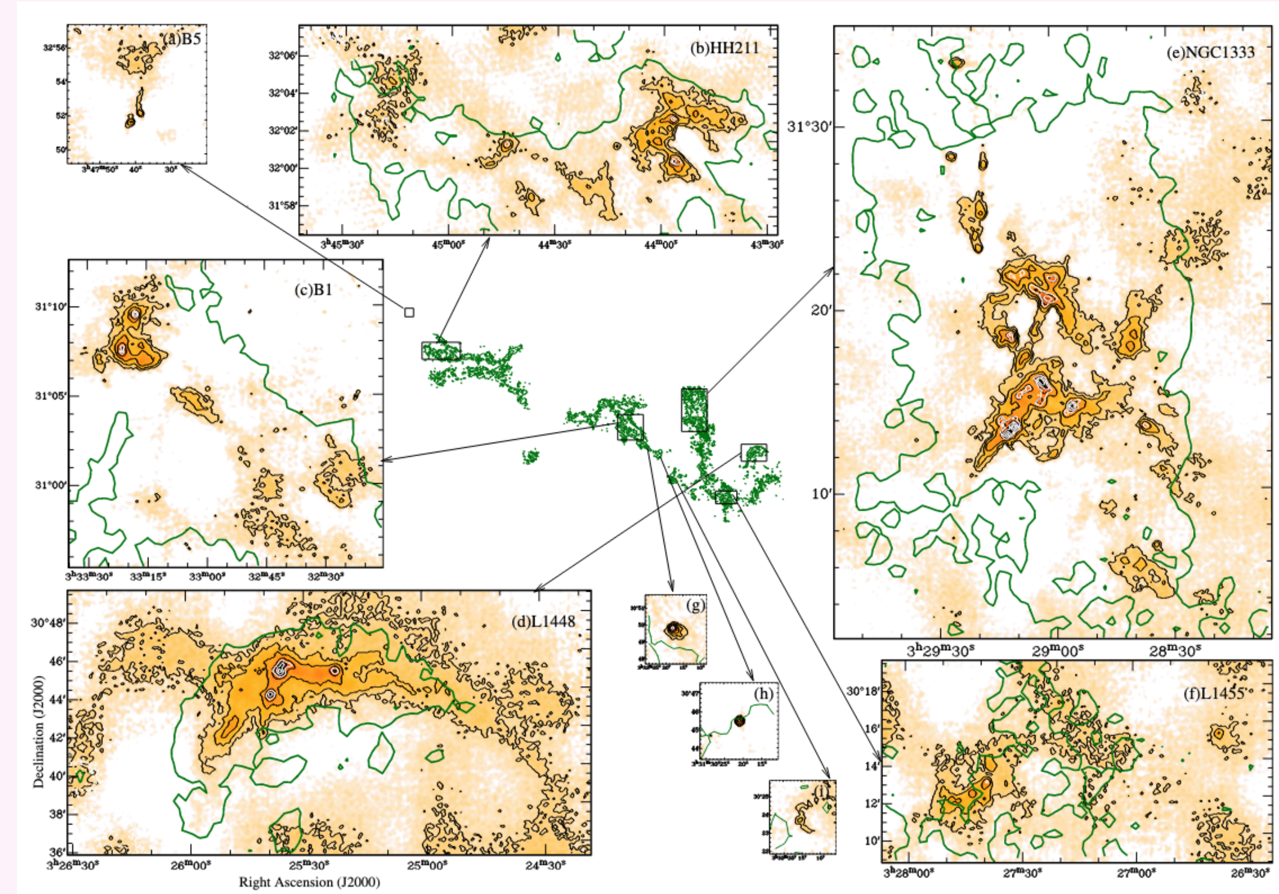
ORion ALMA New GEneration Survey



Nielbock et al. 2003

P.I.: A. López-Sepulcre
Region: OMC-2/3 filament
Distance: ~390 pc Großschedl et al. 2018, 2021
Characteristics: Dense proto-cluster, hosts several massive stars
Sample: 19 solar-mass protostars
Hot corinos: ?

PErseus ALMA CHEmistry Survey



Hatchell et al. 2005

P.I.: N. Sakai
Region: Perseus Molecular Cloud Complex
Distance: ~300 pc Zucker et al. 2018
Environment: Loose proto-cluster, devoid of high-mass stars
Sample: 50 solar-mass protostars
Hot corinos: 56 (14) % - Abundant Yang et al. 2021

ORANGES and PEACHES

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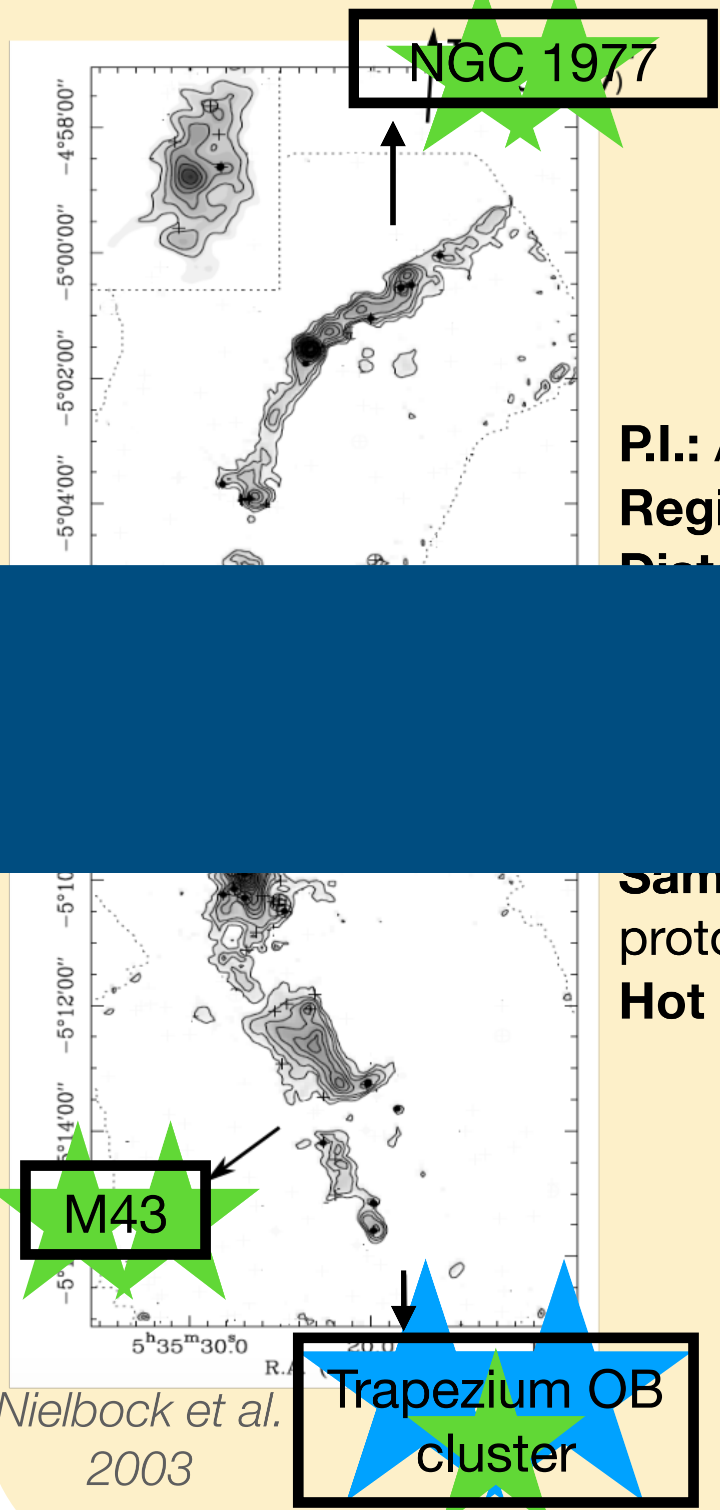

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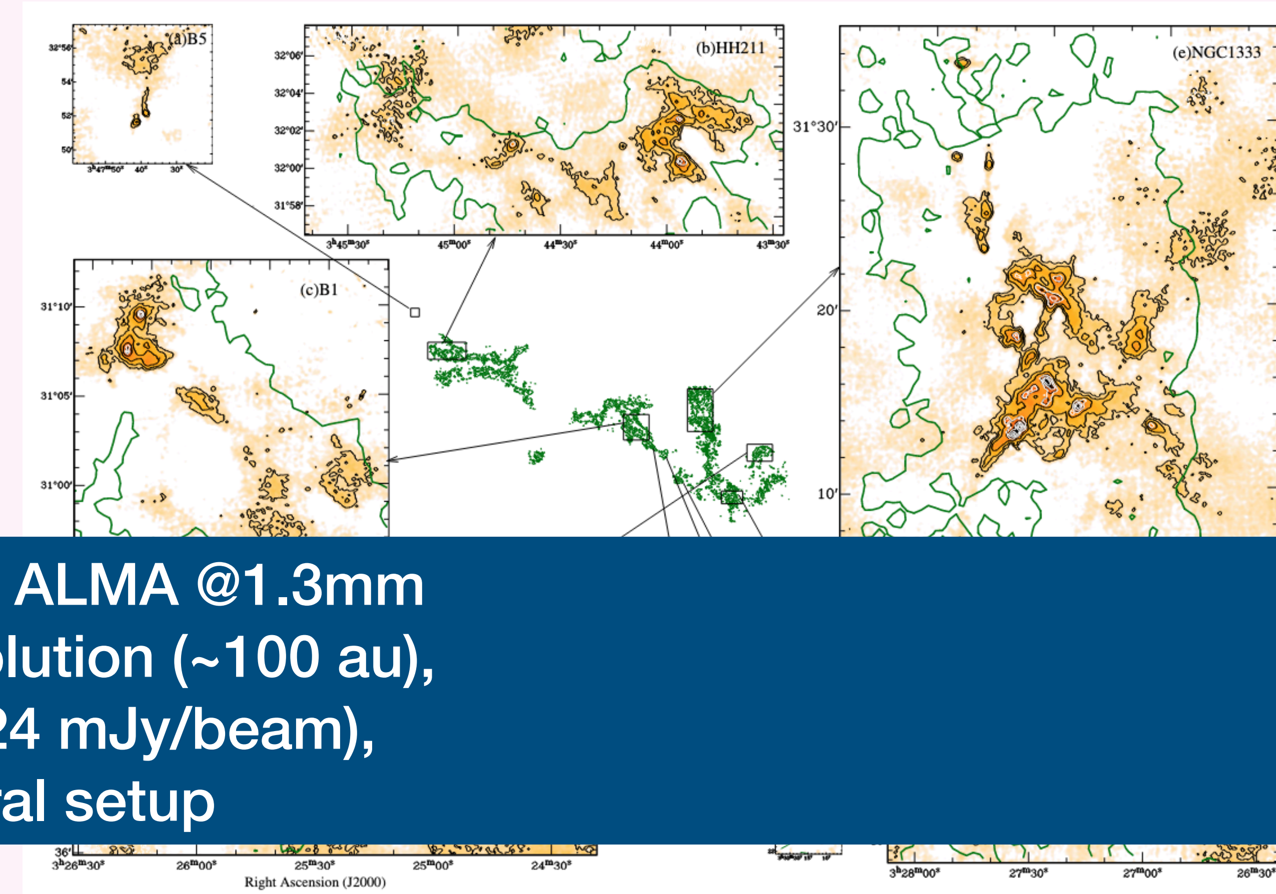

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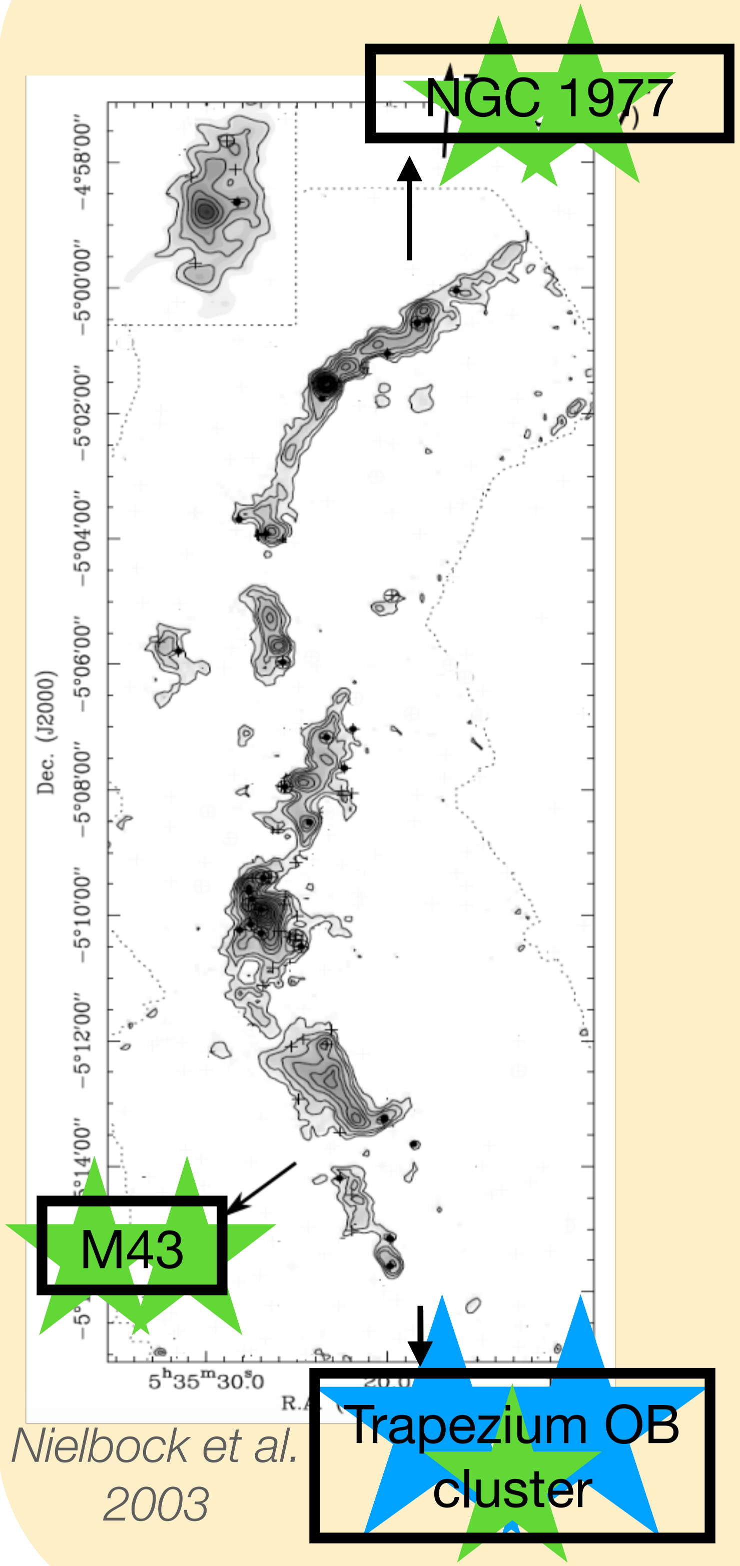
Two surveys using ALMA @1.3mm
Similar spatial resolution (~100 au),
sensitivity (~22-24 mJy/beam),
and spectral setup

Are ORANGES different from PEACHES?



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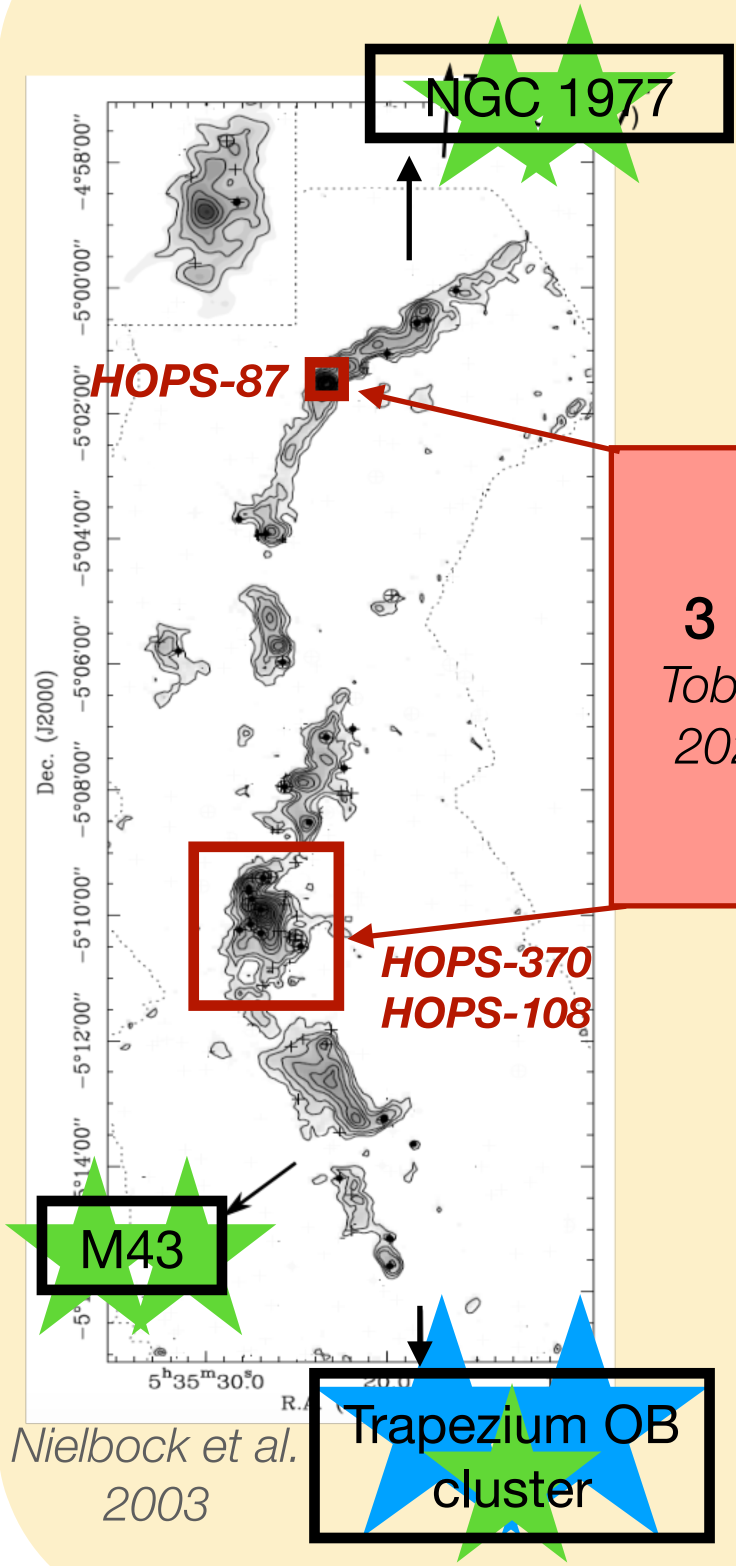

Nielbock et al. 2003

Before ORANGES

3 known hot corinos

Tobin et al. 2019, Hsu et al. 2020, Chahine et al. 2021

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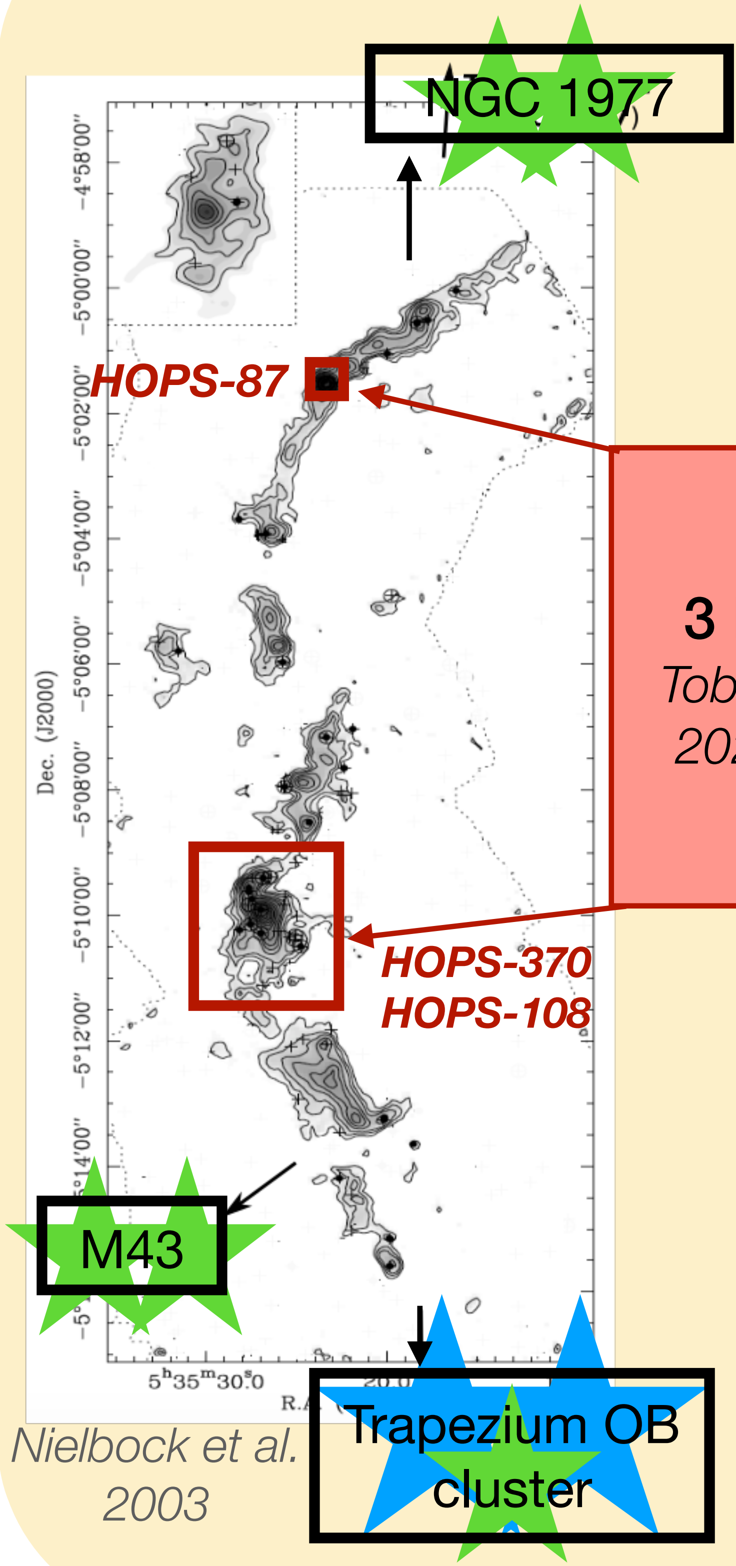

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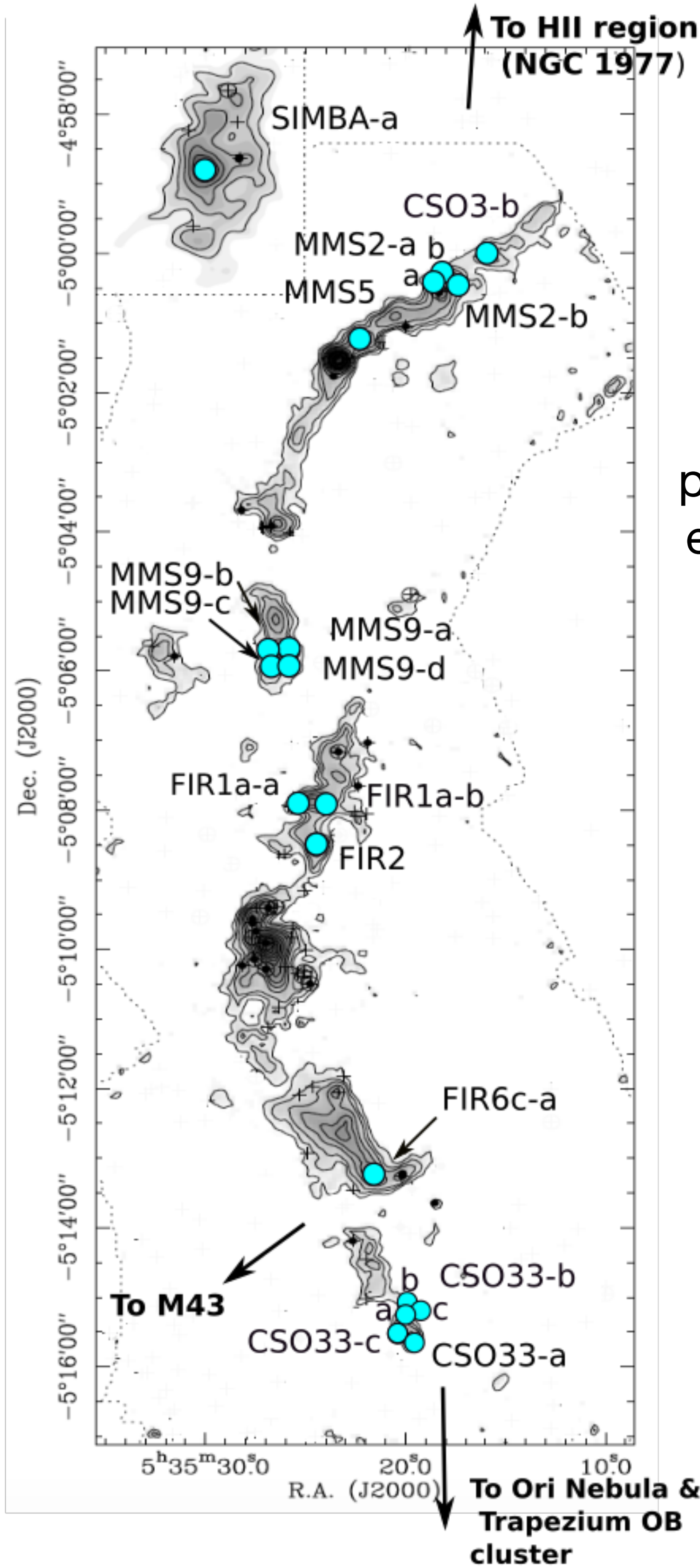

Target sources:

19 solar-mass protostars (based on Tobin et al. 2020, Bouvier et al. 2021)

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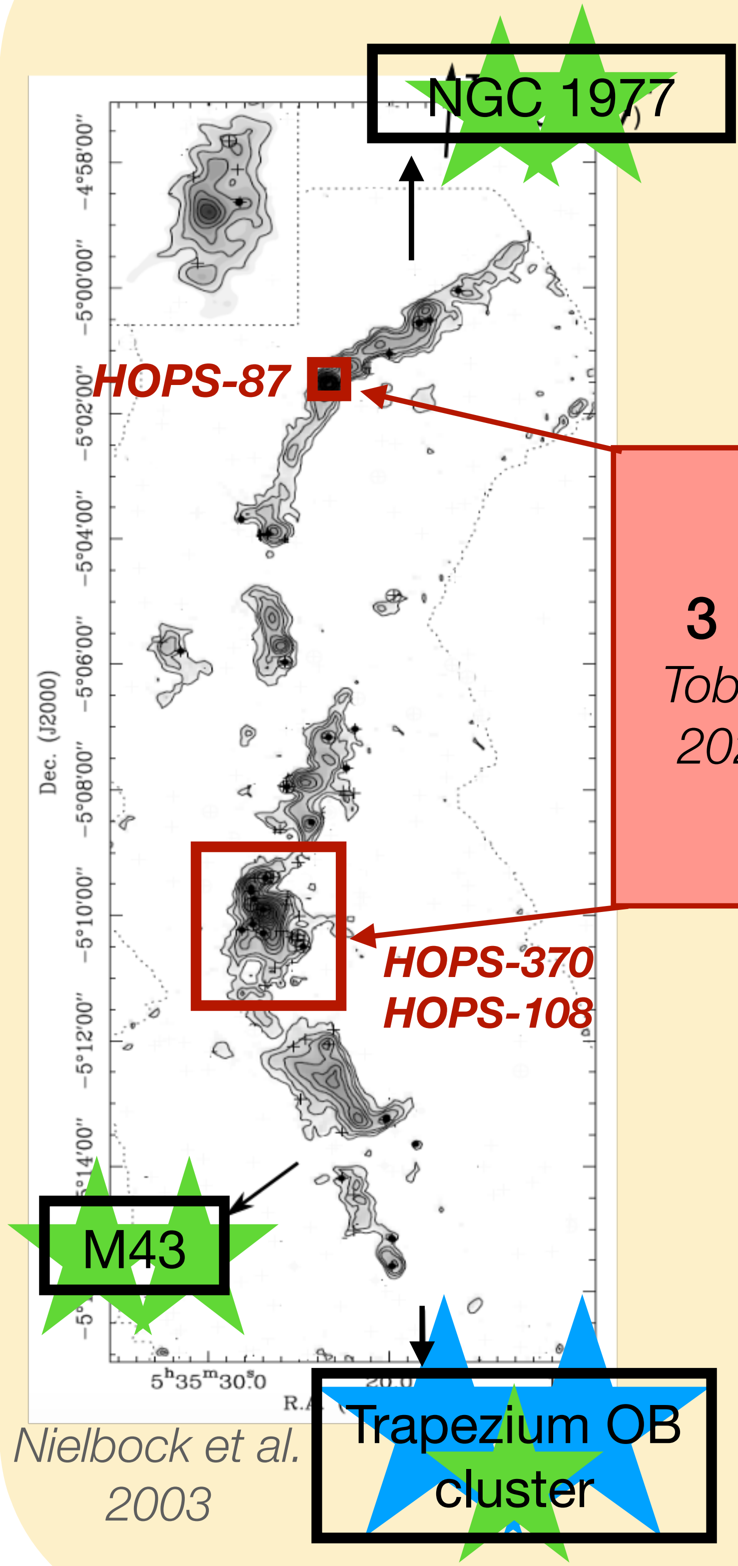

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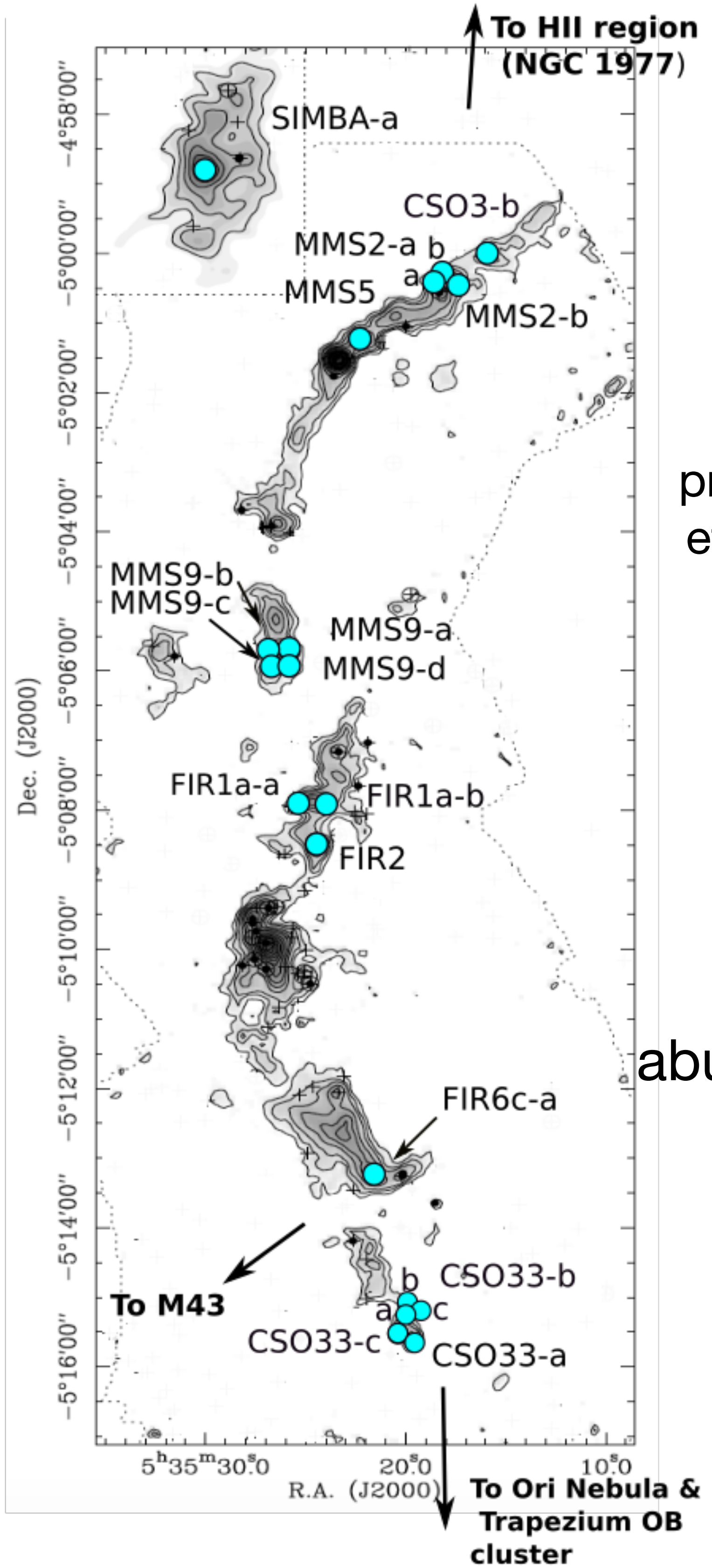

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Target species

CH_3OH

Simplest & most abundant iCOM found in hot corinos

Are ORANGES different from PEACHES?

Bouvier et al. 2022

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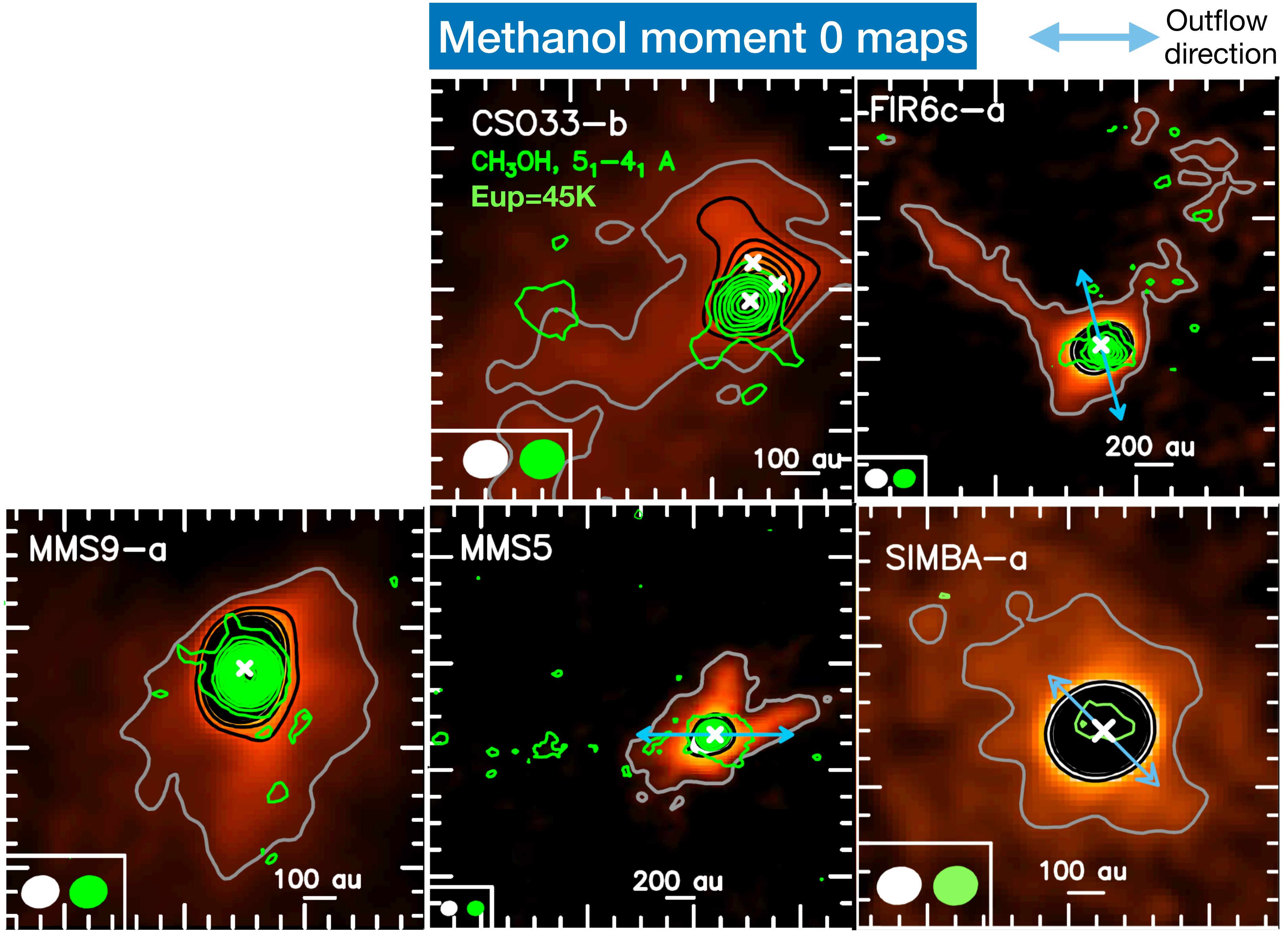

Bouvier et al. 2022

Are ORANGES different from PEACHES?

CH_3OH transitions

Molecule	Frequency (MHz)	Transition	E_{up} (K)
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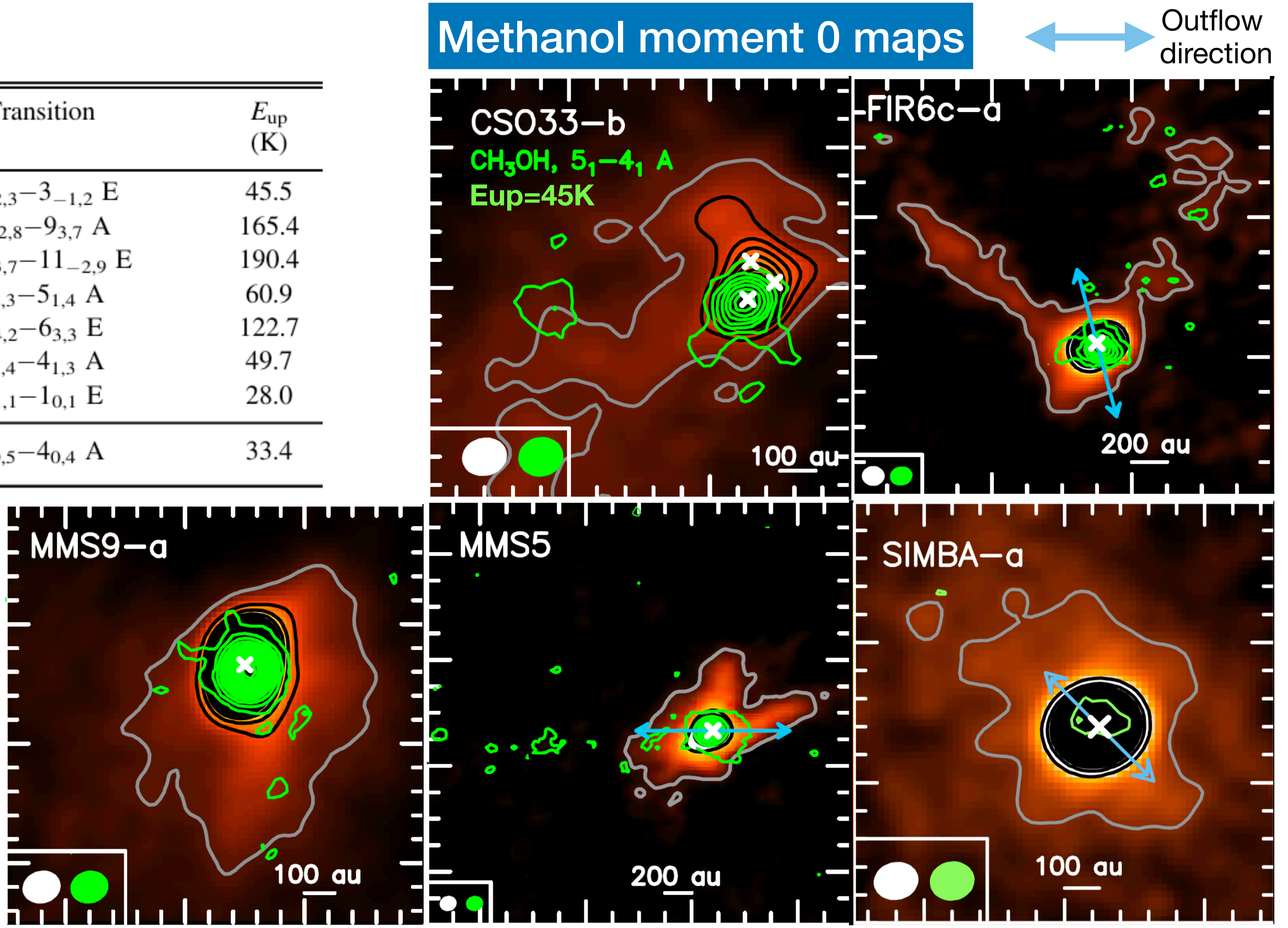
Methanol moment 0 maps



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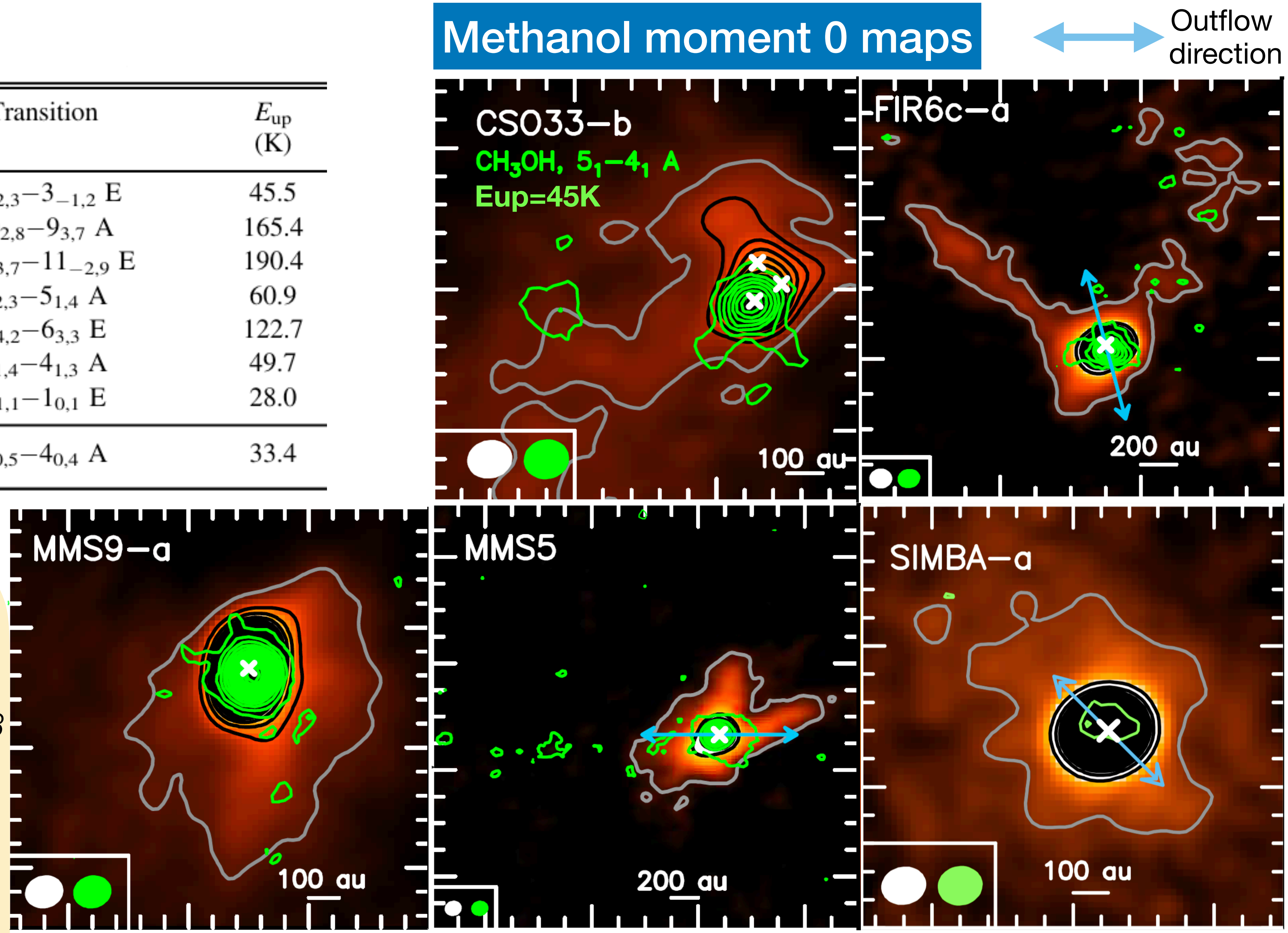

Non-LTE
Large Velocity Gradient (LVG) analysis
Code developed by Ceccarelli et al. 2003

Emitting region of CH_3OH

- $n_{H2} > 3.10^6$ cm^{-3}
- $T_{kin} > 80$ K
- θ ~0.1 - 0.6” —> 40 - 236 au (diameter)

Region hot, dense and compact

Bouvier et al. 2022

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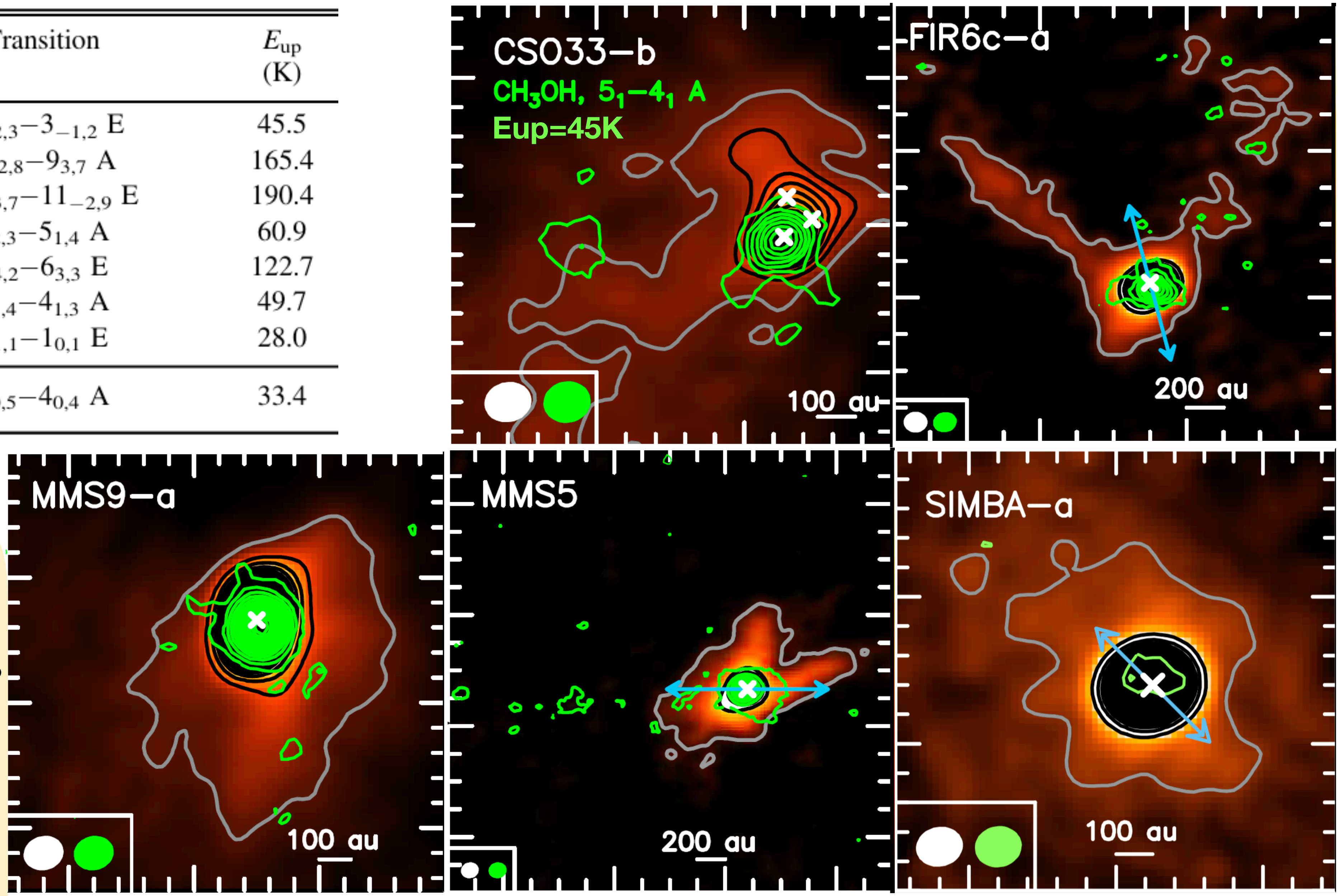
Methanol moment 0 maps

Outflow direction



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Bouvier et al. 2022

ORANGES and PEACHES

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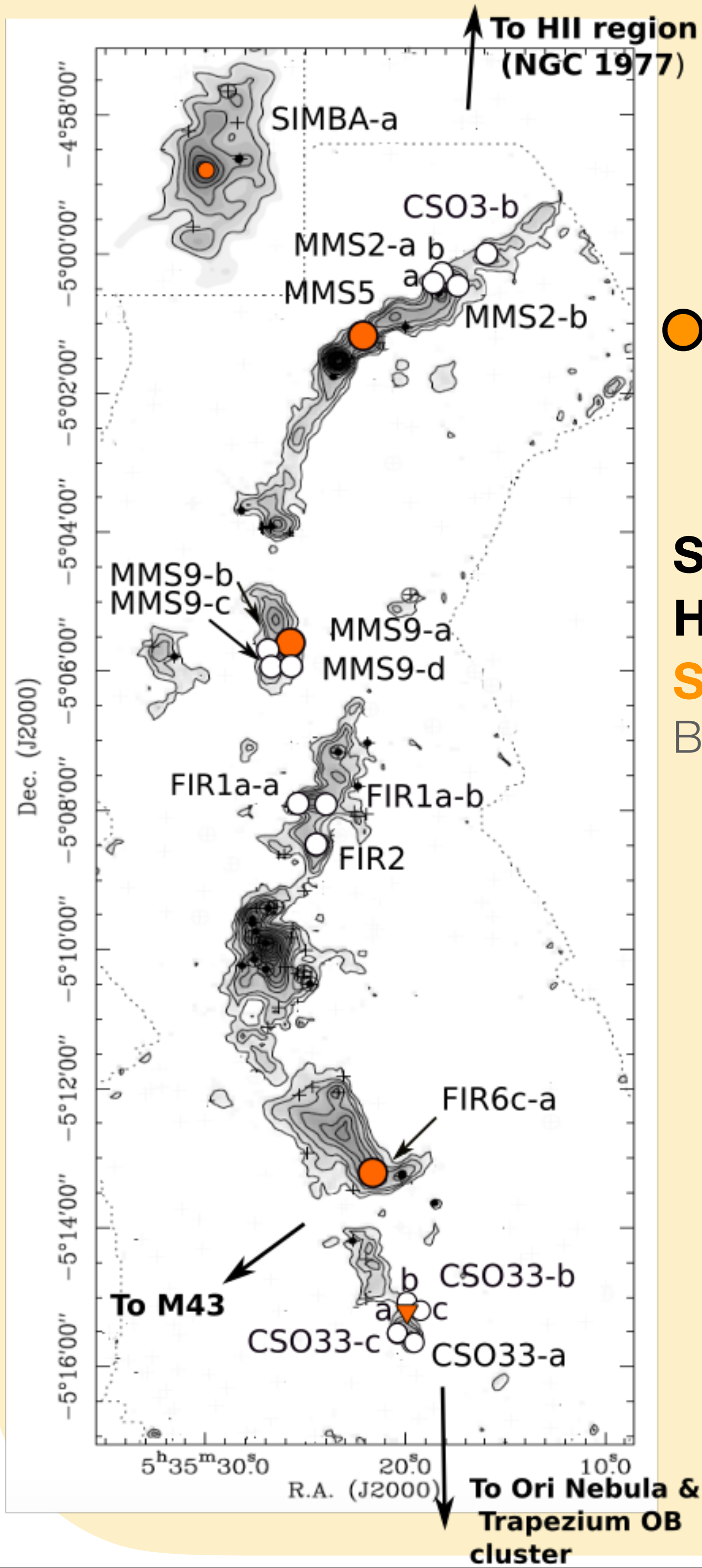

Hot corino

Sample: 19 protostars

Hot corinos: 26 (23)% - Scarce

Bouvier et al. 2022

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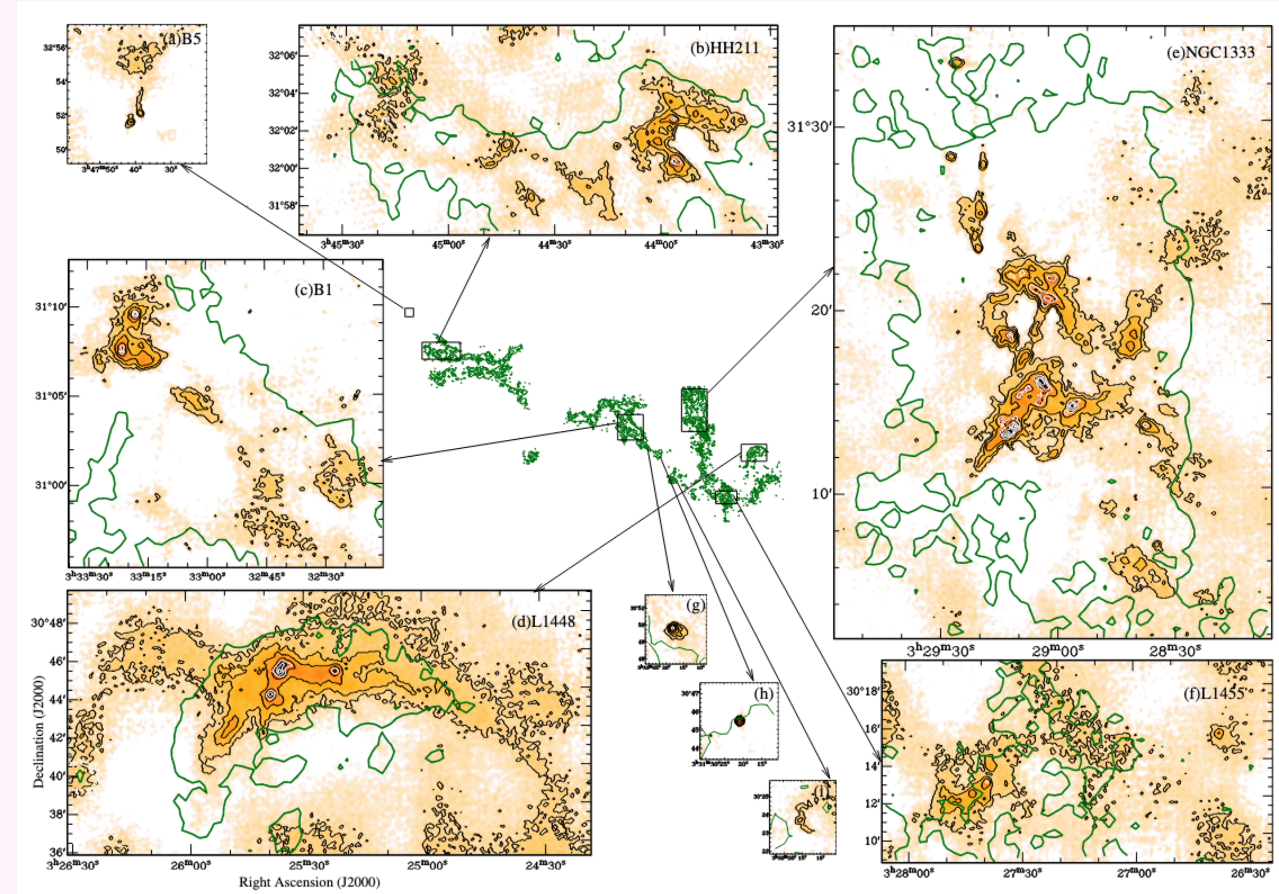

Hatchell et al. 2005

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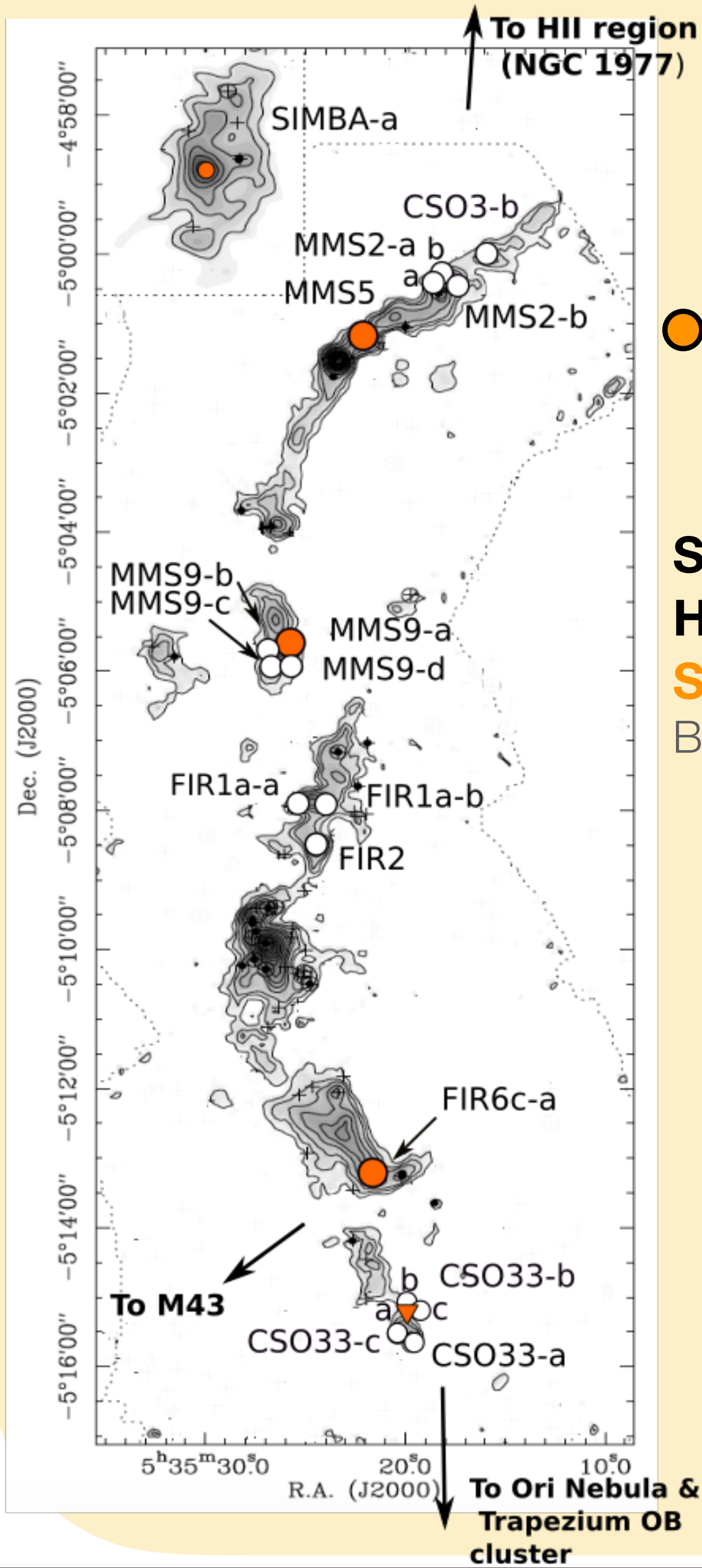

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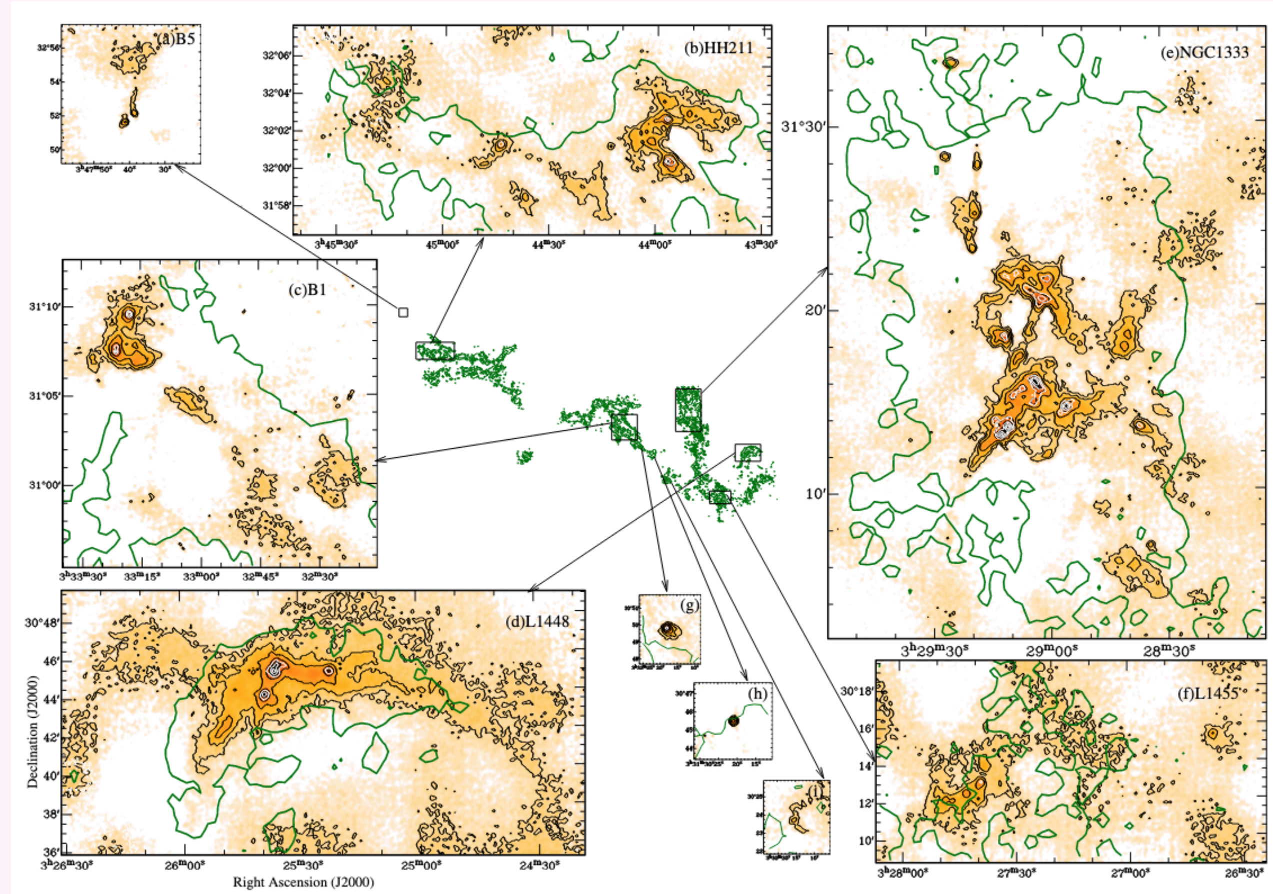

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ORANGES appears to be different from PEACHES!

Are ORANGES different from PEACHES?

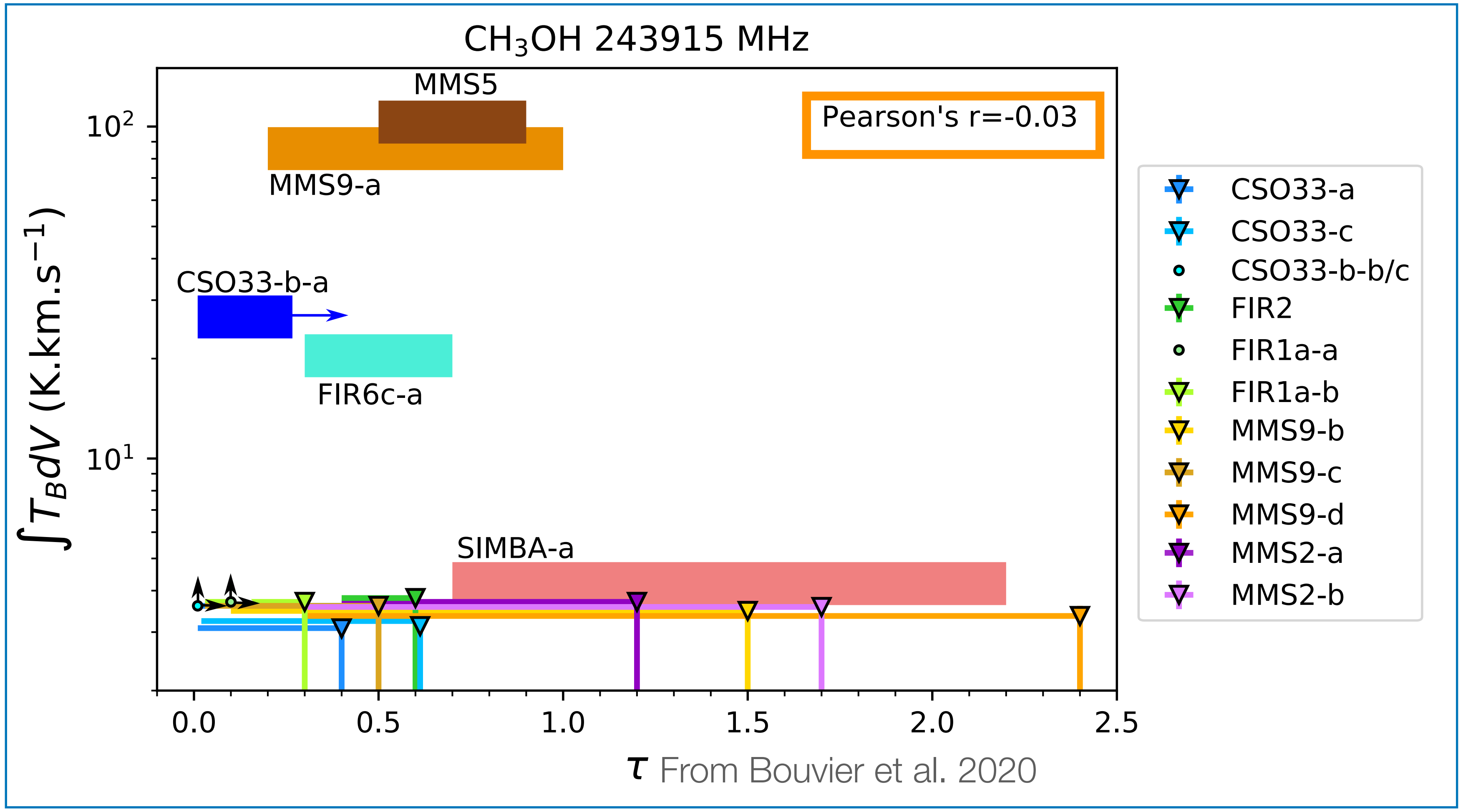
(Possible) CAVEATS

1. Sample size

Large statistical error in ORANGES due to small sample. We need to improve statistics to firmly conclude.

2. Dust

Optically thick dust can hide hot corinos at mm wavelengths! De Simone et al. 2020



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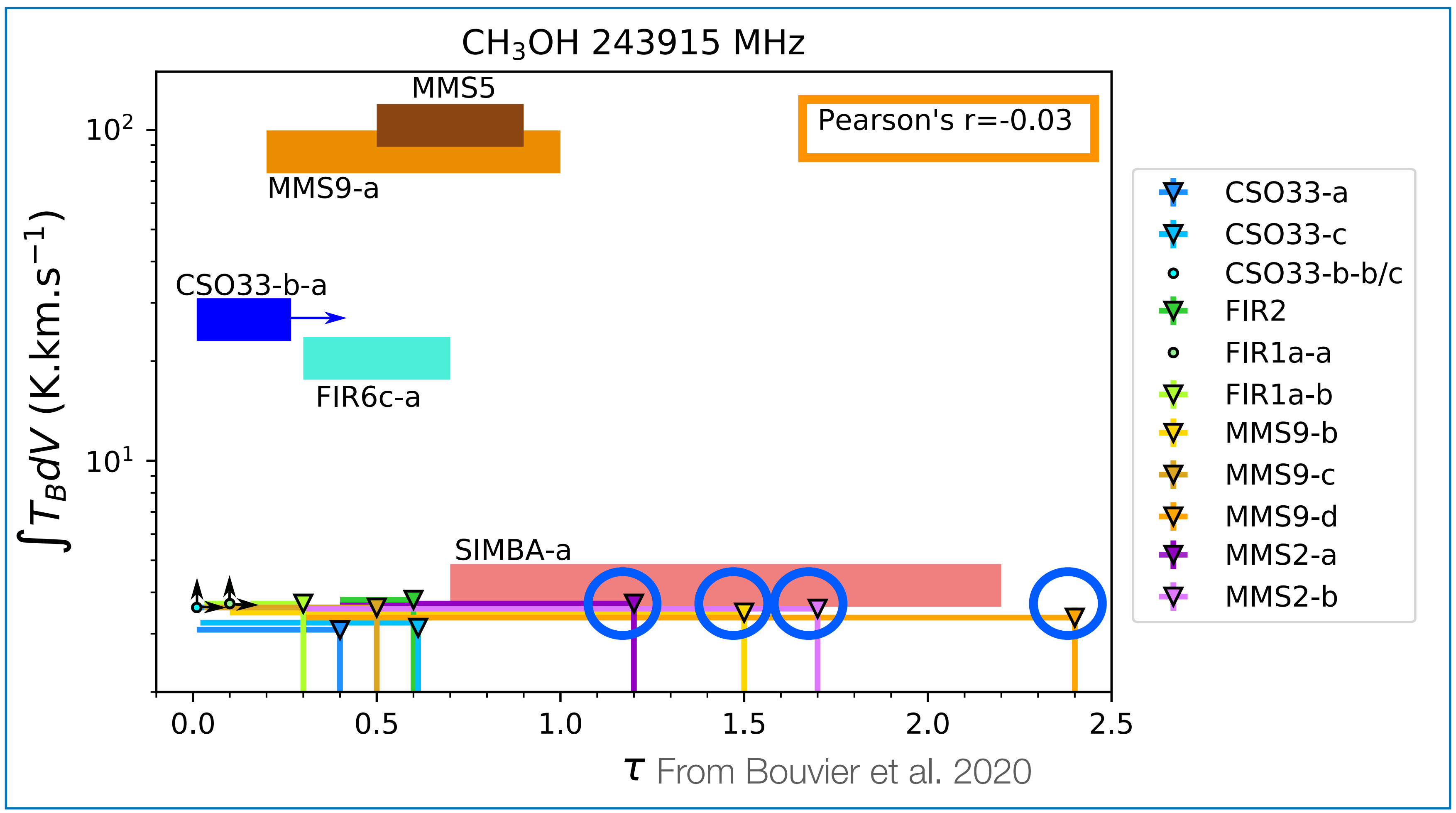

Some sources with $\tau_D > 1$: Are there other hot corinos hiding in the dust?

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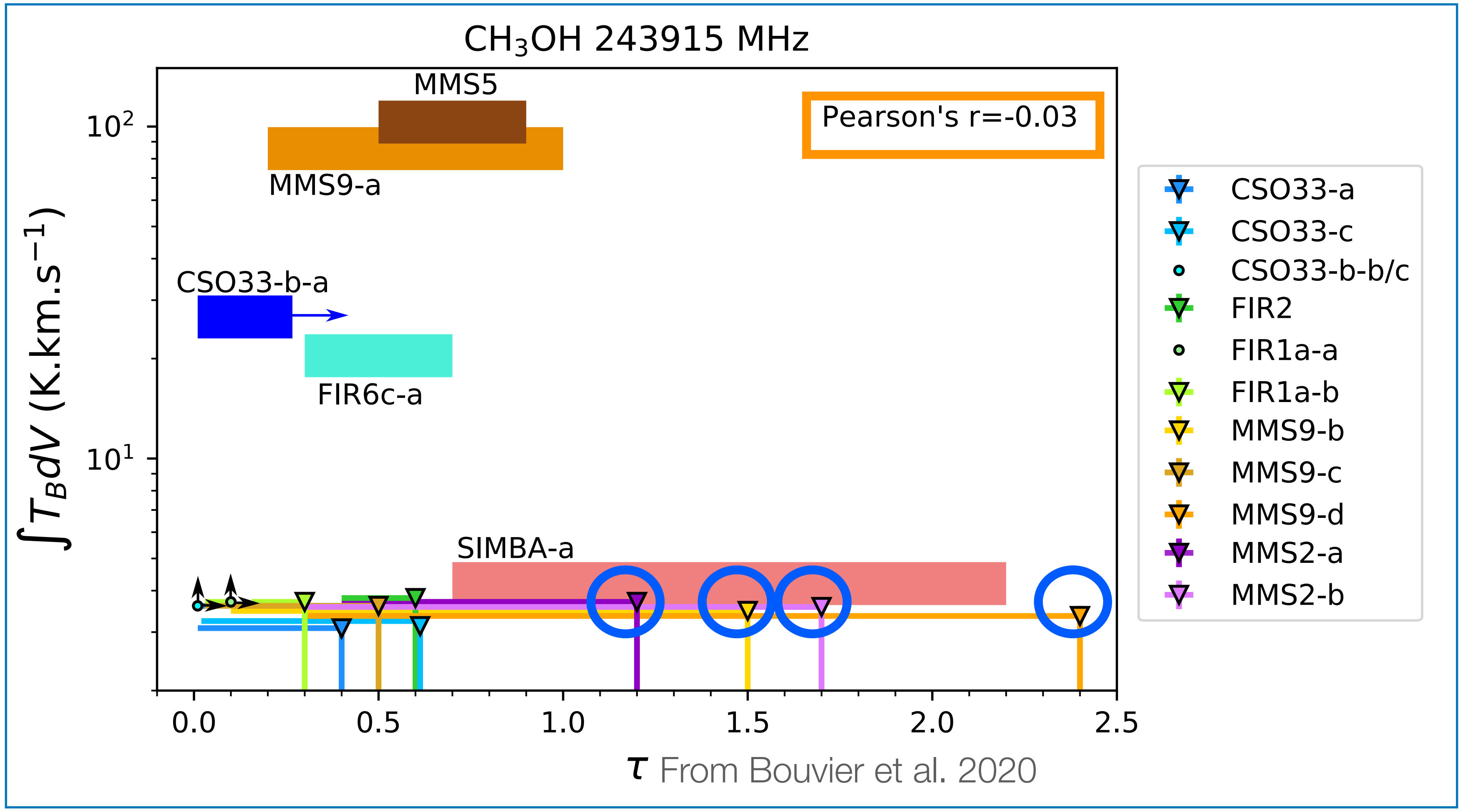


Some sources with $\tau_D > 1$: Are there other hot corinos hiding in the dust?

JVLA observations (P.I. M. Bouvier) of CH_3OH towards one of the source with $\tau_D > 1$ at 25 GHz

Observations ongoing, stay tuned!

Take home messages

- 5 new hot corinos detected in the OMC-2/3 filament!
- Hot corinos are scarce (<30%) in Orion whilst they are abundant (~60%) in Perseus.
- To caveats:
  - the poor sample or ORANGES. We need to increase statistics
  - Due to the possible role of dust, we might have underestimated the number of hot corinos.

ORANGES may be different from PEACHES and the environment may be the culprit affecting the protostellar chemical nature.

Extra-galactic astrochemistry: A new era

Collaborators: Serena Viti, and the MOPPEX team*

What is the effect of the environment at much larger scales, in nearby galaxies? How is the chemistry in external galaxies affected by the various environments (i.e. AGN, starburst)?

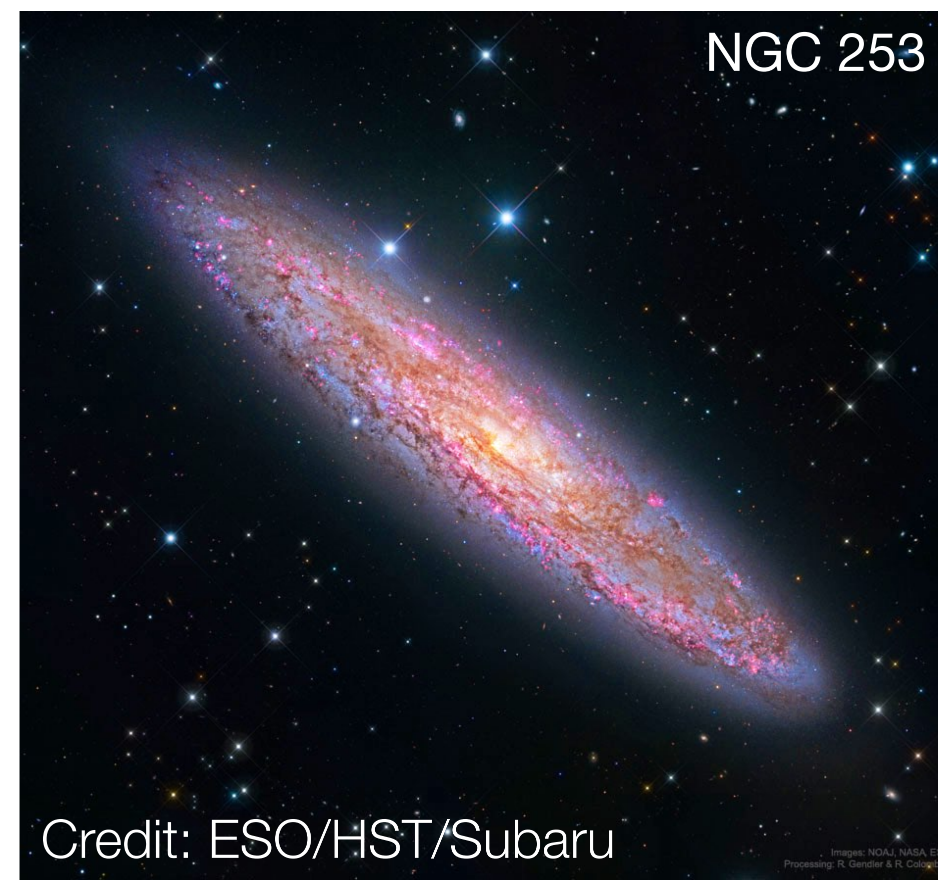

NGC 1068

Credit: NASA,ESA, A. van der Hoeven

MOPPEX: **MO**lecules as **P**robe of the **P**hysics of **EX**ternal galaxies (P.I.: S. Viti)

Goal: Establish a set of unique molecular tracers characterising various regions in different nearby galaxies, the AGN-starburst composite NGC 1068 and the pure starburst NGC 253.

ALCHEMI (**AL**MA **C**omprehensive **H**igh-resolution **E**xtragalactic **M**olecular **I**nventory) Large Program
(P.Is: S. Martín, N. Harada, J. Mangum)


NGC 253

Credit: ESO/HST/Subaru

**Leiden University, Leiden Observatory, The Netherlands*

Universiteit Leiden
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MOPPEX

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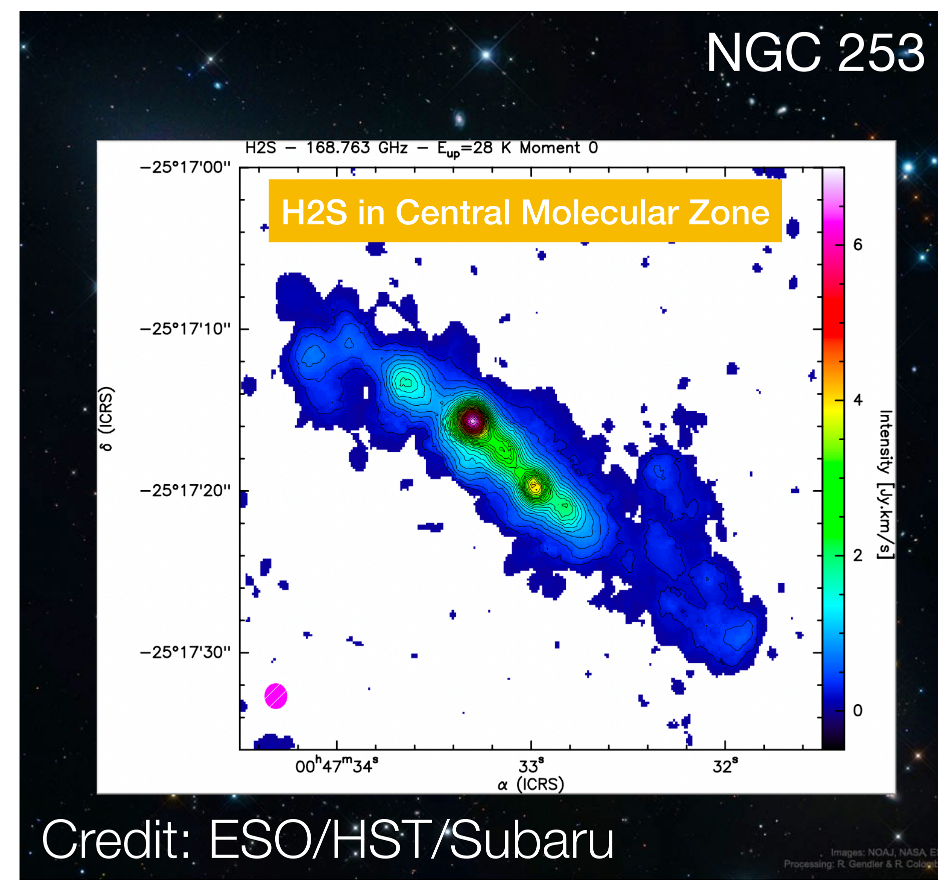

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Current projet: H_2S and S-bearing species in NGC 253, what do they trace?

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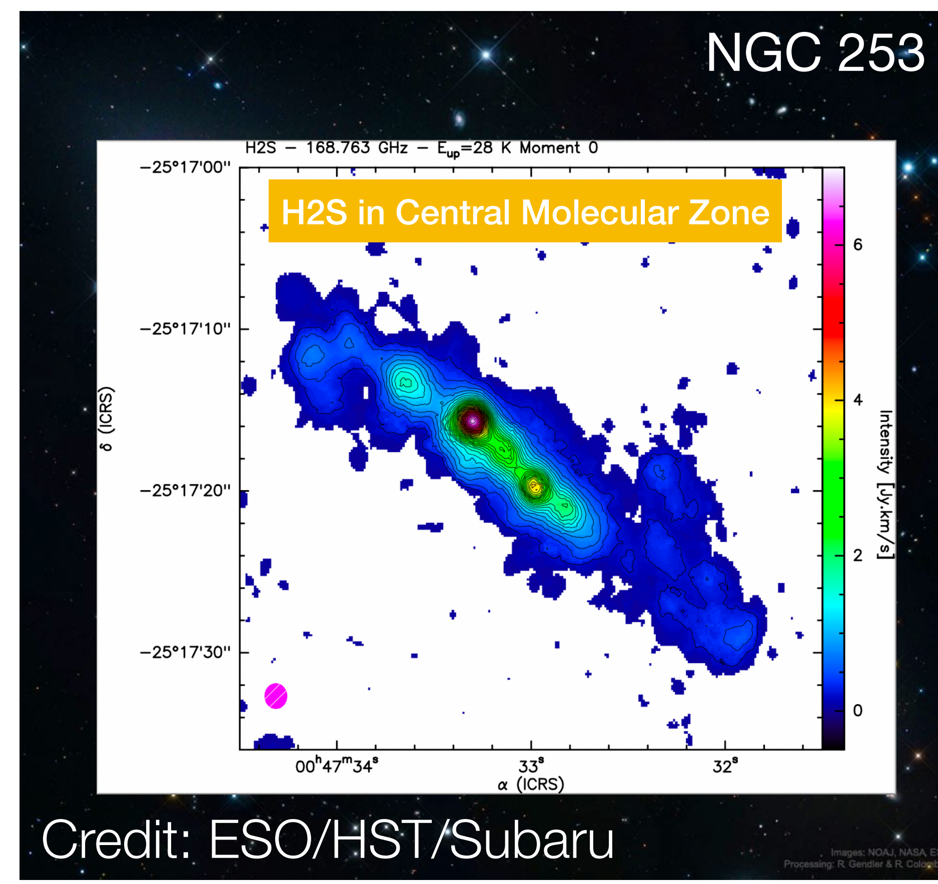
Stay tuned!



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ERC DOC: https://doc.osug.fr/

Thanks for your attention!

ERC MOPPEX: https://moppex.github.io/