Where are the first hydrostatic cores?

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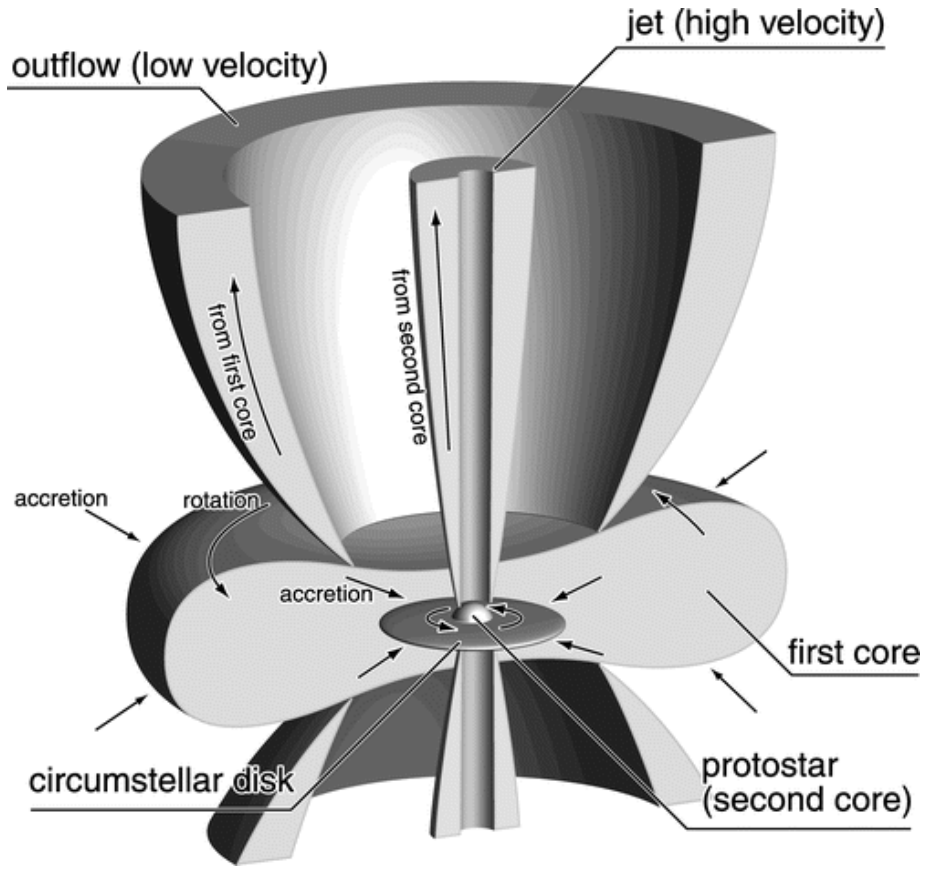
First core theory



From Machida+ 2008

A necessary phase of star formation?

- Low mass cores (≲40 Msun)

Length of FHSC phase?

- few 100 years for cloud cores ≲10 Msun (Bhandare+ 2018)
- Few 1000 years with rotation/ B field support

FHSC properties

- Low mass <0.05 Msun
- Faint and embedded <0.01 Lsun
- Cool (200-2000 K)

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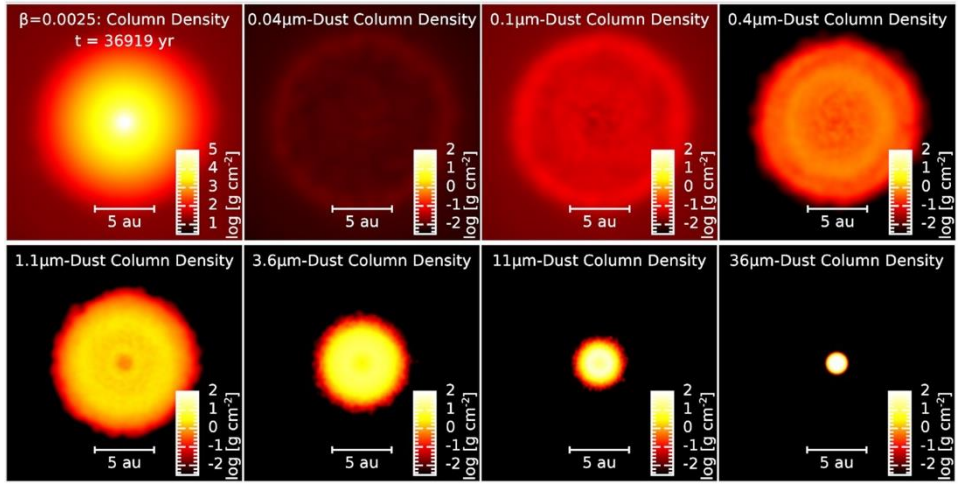
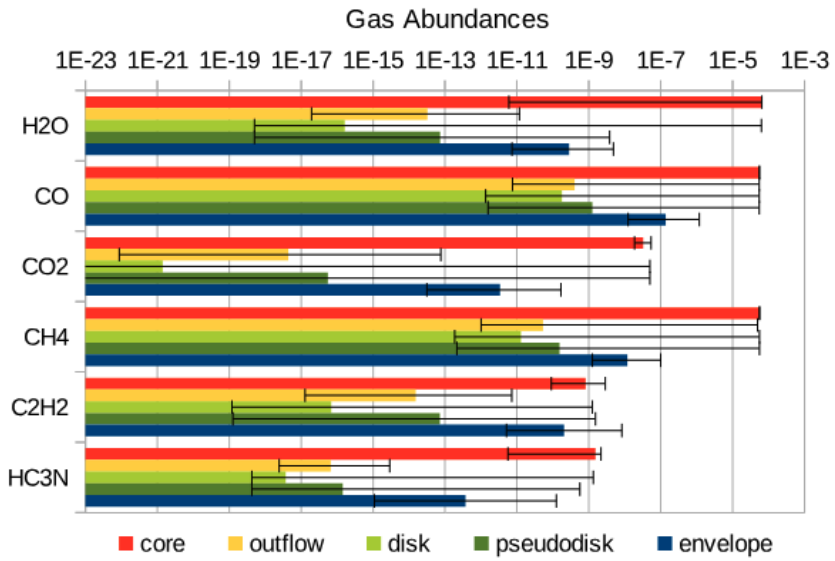
Why is the first core important?



Rapid dust growth within first core (up to 100 micron)

Bate (2022)



Hincelin+ 2016 Chemistry at first core stage

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Why is the first core important?

Addresses theoretical questions:

- Resolving the fragmentation limit
- How do close binaries form?

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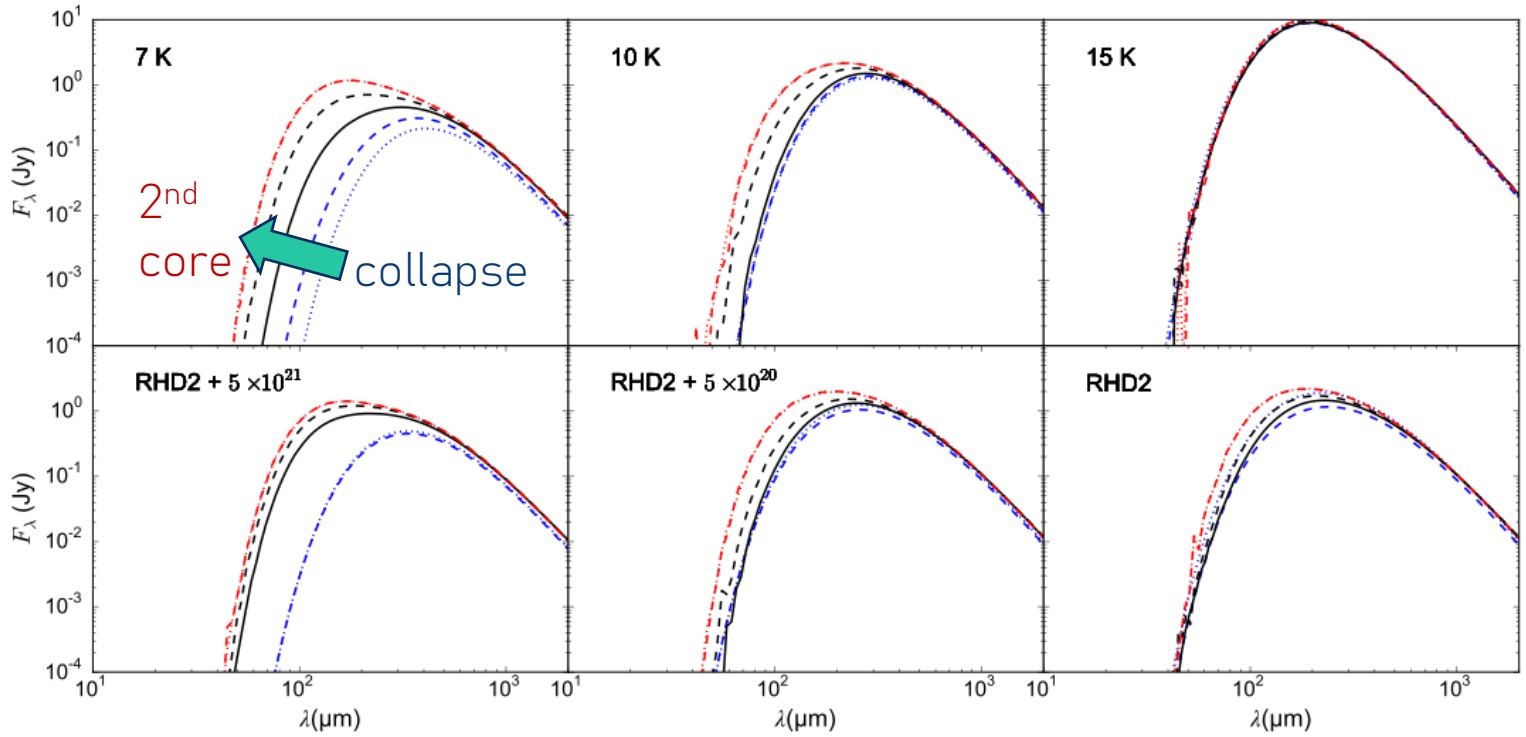
How do we identify first cores then?

Synthetic SEDs

Young+ 2018



Central density (g cm^{-3})
- blue dotted: 1.4×10^{-18}
- blue dashed: 10^{-12} FHSC
- solid black: 5×10^{-11} FHSC
- black dashed: 10^{-9} FHSC
- red dotted: 10^{-4} (2^{nd} collapse)
- red dashed: 10^{-2} (2^{nd} core formed)

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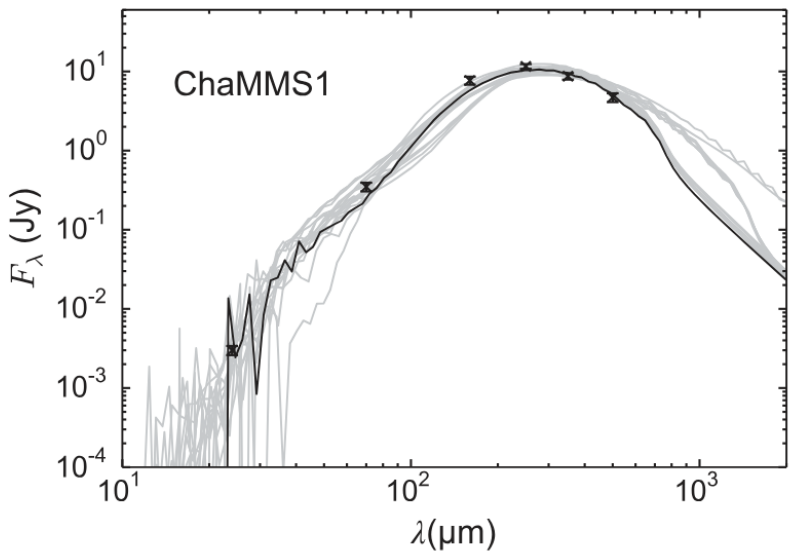
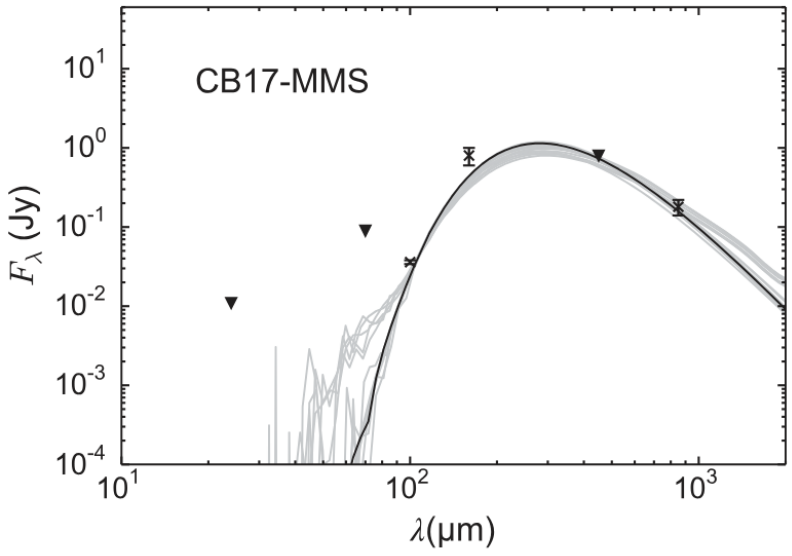
SED fitting

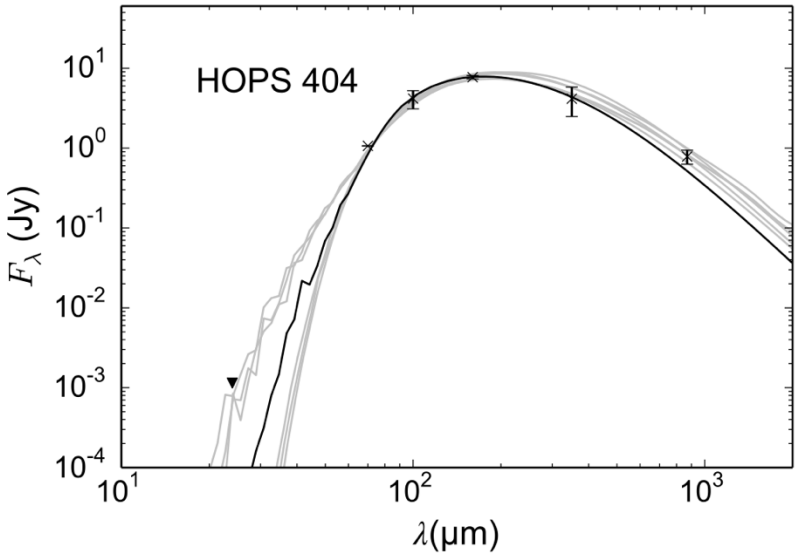
Young+ 2018 & PhD Thesis



Fit only by extreme parameters (fast rotation, viewed face-on, large grains)



Fit best by first collapse models



Fit best by rotating late FHSC models

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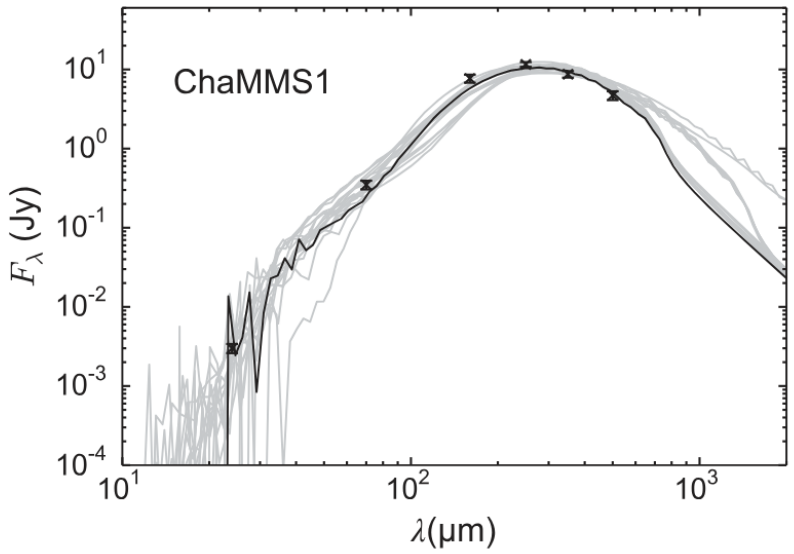
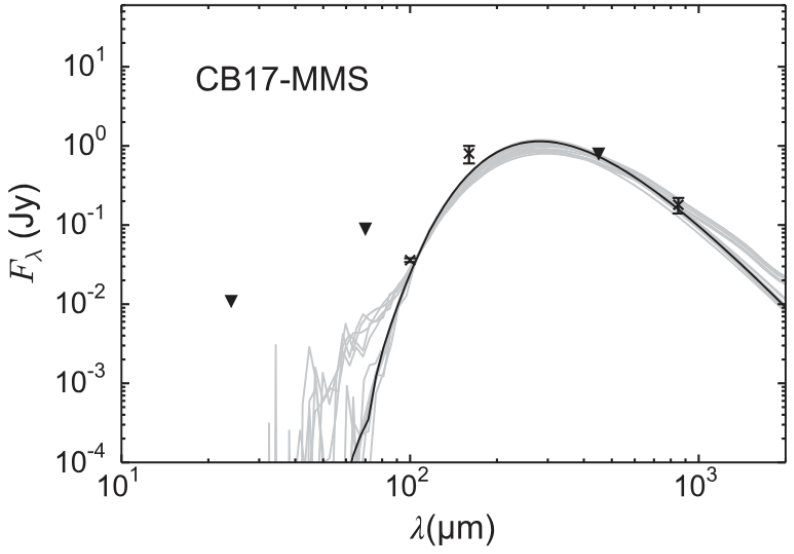
SED fitting – was it correct?

Probably Class 0



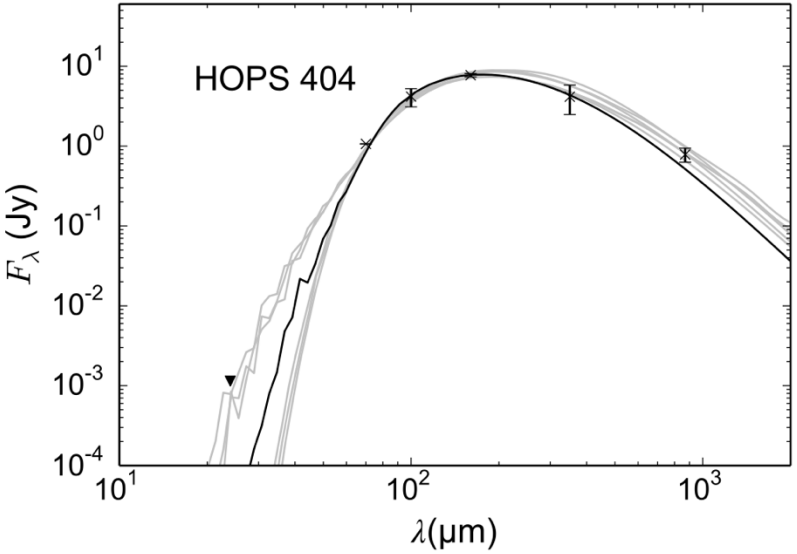
Fit only by extreme parameters (fast rotation, viewed face-on, large grains)

Probably starless core



Fit best by first collapse models

? Slow outflow



Fit best by rotating late FHSC models

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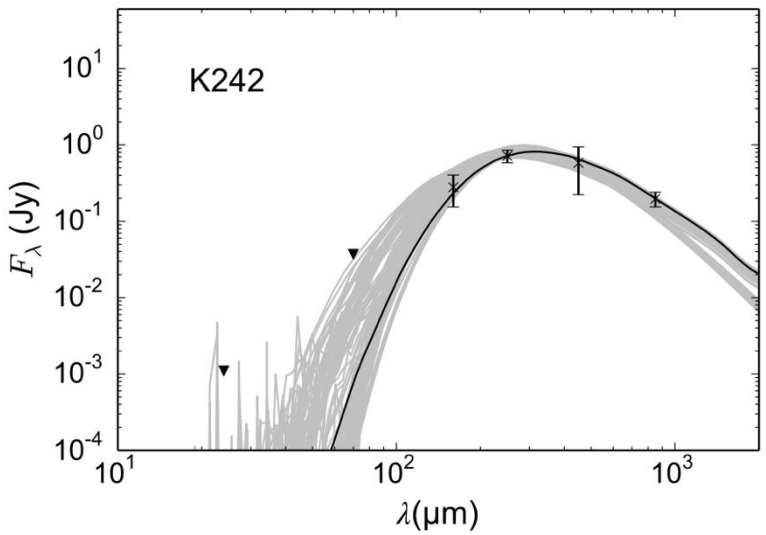
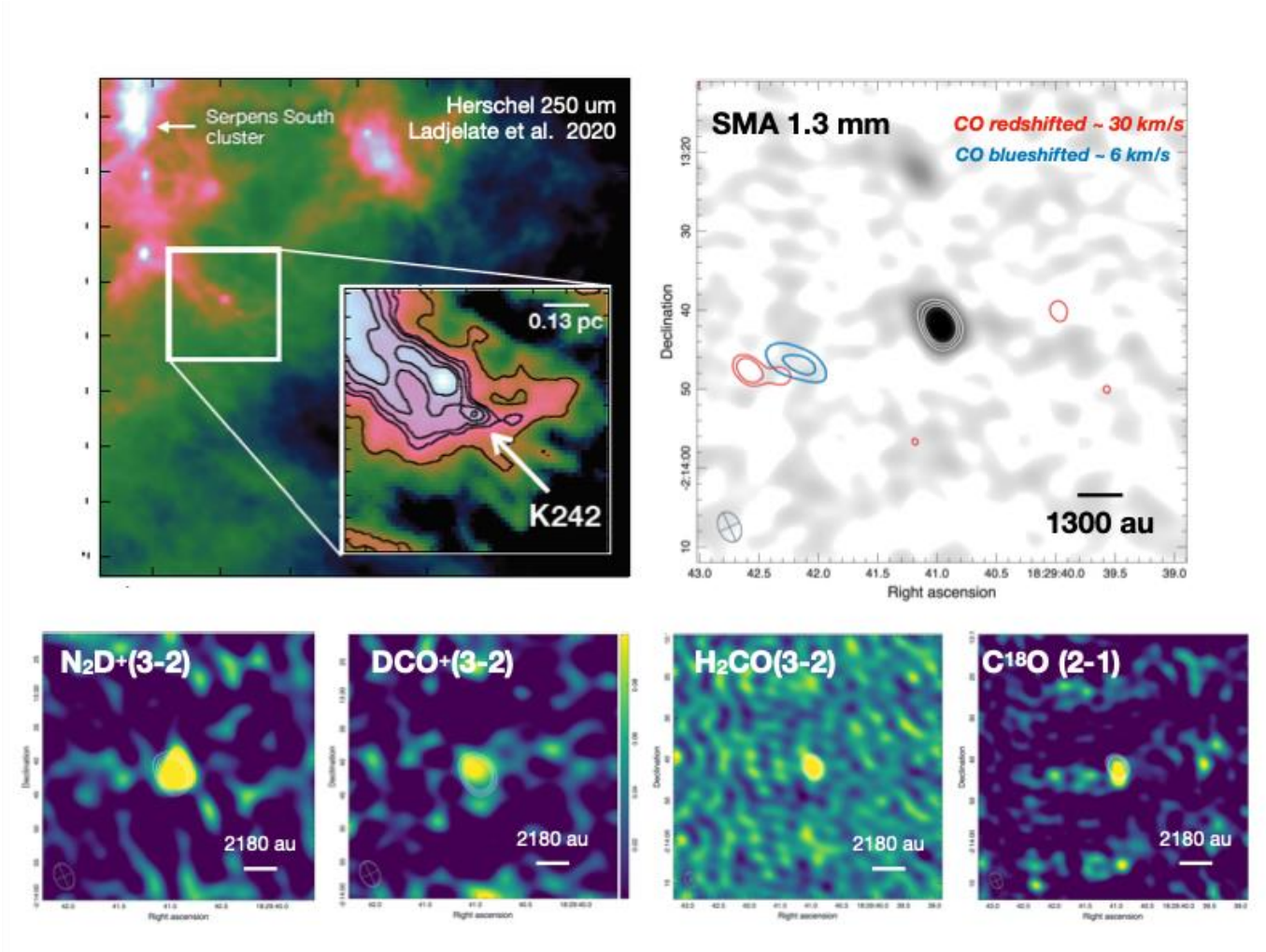
SED fitting – was it correct?



Compact object observed by Maria Jose Maureira! (Unpublished)



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What happened to the candidate first cores?

Source	Mass [$M_\odot$]	Outflow[a]	Features	First core?
Aqu-MM1	0.27[a1]	?	SED fitted by fast rotating first core models[2]	?
B1-bN	0.36[3]	4.5 km s^{-1}, few hundred au extent[3]	Class 0 protostar	No
B1-bS	0.36[3]	7 km s^{-1}, few hundred au extent[3,4]	~ 100 au compact object[3]	No
CB17 MMS	0.04[5]	(2.5 km s^{-1} but now attributed to nearby protostar[6])	Starless core- no compact mm source detected[6]	No
Cha-MM1	1.44[b,7]	up to 17 km s^{-1}[8], extends up to 2,700 au[9]	Probably very young Class 0 protostar	No
HOPS 404	0.45 [b10]	extent <700 au, ≤2 km s^{-1}	SED fitted by late first core models[11]	?
K242	0.4 [b11]	?	Fit by FHSC SEDs[2]	?
L1451-mm	0.36[b12]	1.5 km s^{-1}, 500 au extent[9,13]	Methanol and SiO emission detected[21]	No
L1448 IRS 2E	(0.04[13])	(25 km s^{-1}, 9,600 au lobe[14])	Outflow attributed to different source and there is no star forming core here.[9]	No
MC35-mm	?	2–4 km s^{-1}, extends around 2000 au[15]	N_2D^+(3–2) emission peaks with continuum (cold centre)[15]	?
Oph A N6	0.025–0.03[16]	Possible slow redshifted lobe[16]	compact ~100 au source[16]	?
Oph A SM1N	0.03[16]	Possible slow, broad, not obviously bipolar[16]	elongated continuum[17], unresolved emission[16]	?
Per-bolo 45	?	No clear outflow[9]	Very low luminosity[18], could be prestellar[9]	?
Per-bolo 58	0.8[b19]	7 km s^{-1}[20]	Large central warm region[9] heated by a central protostar	No

Table from Young (2023)

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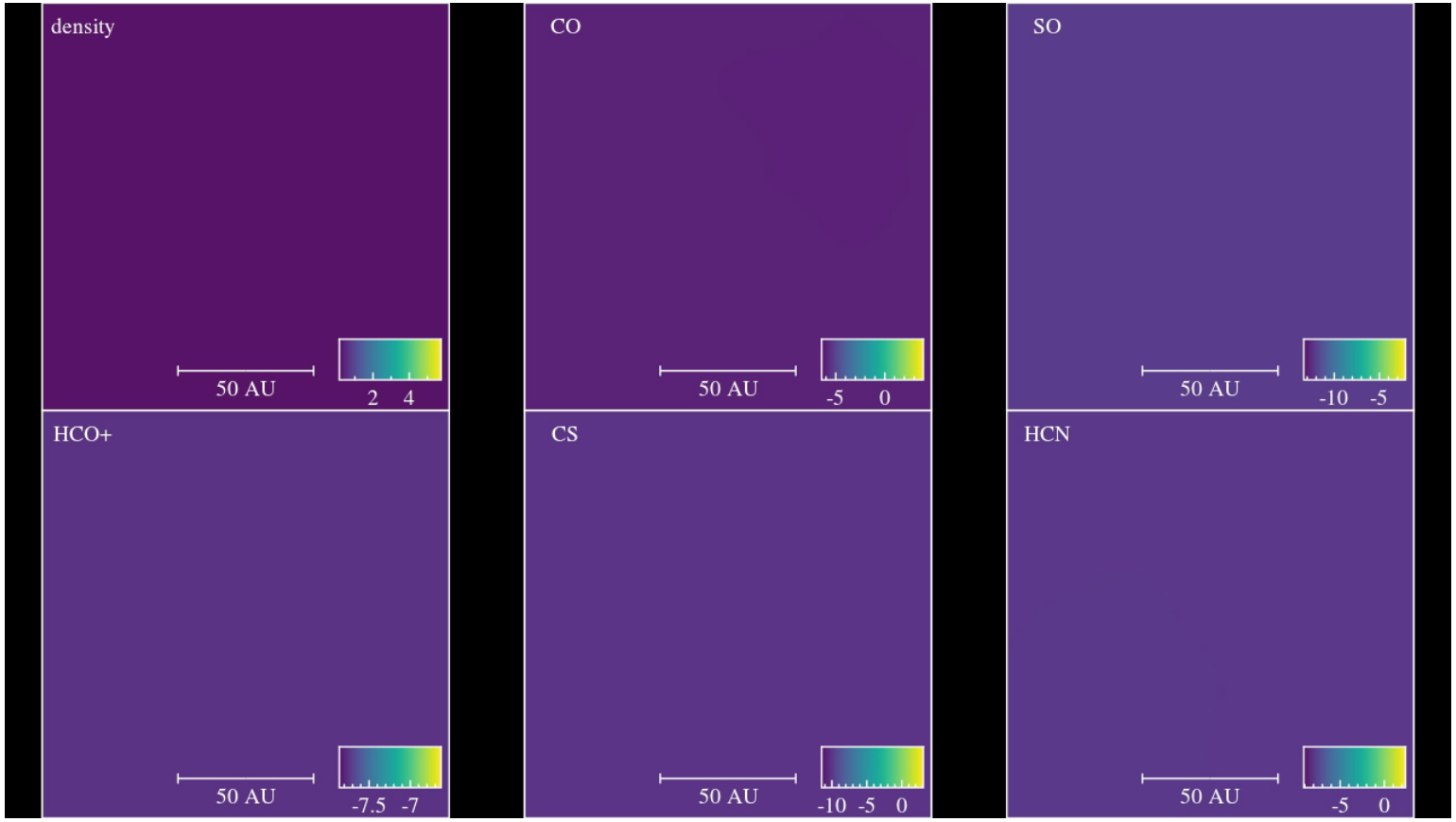
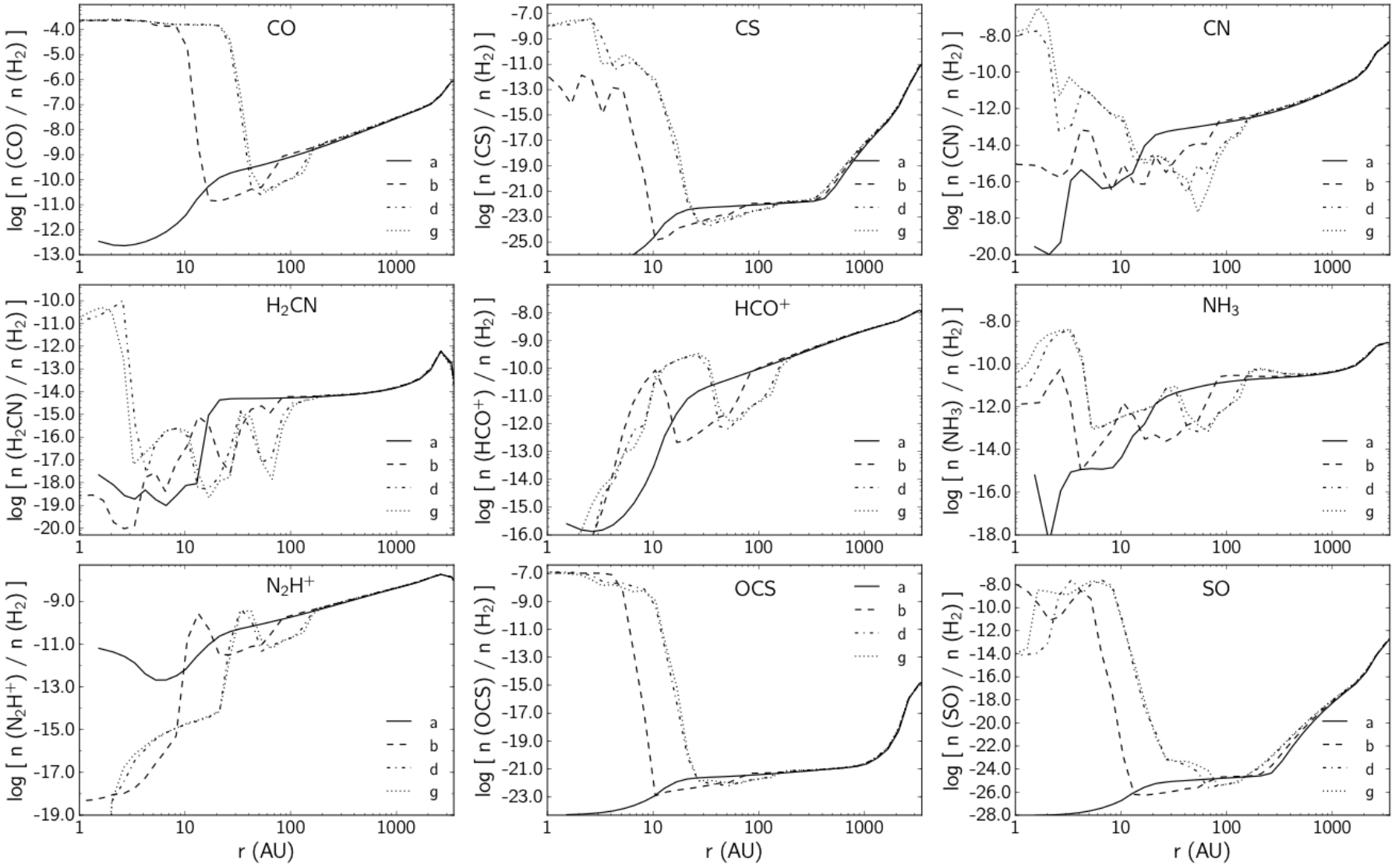
Chemical evolution



Young+ 2019

FHSC chemical evolution

a = first collapse
b & d = FHSC
g = stellar core



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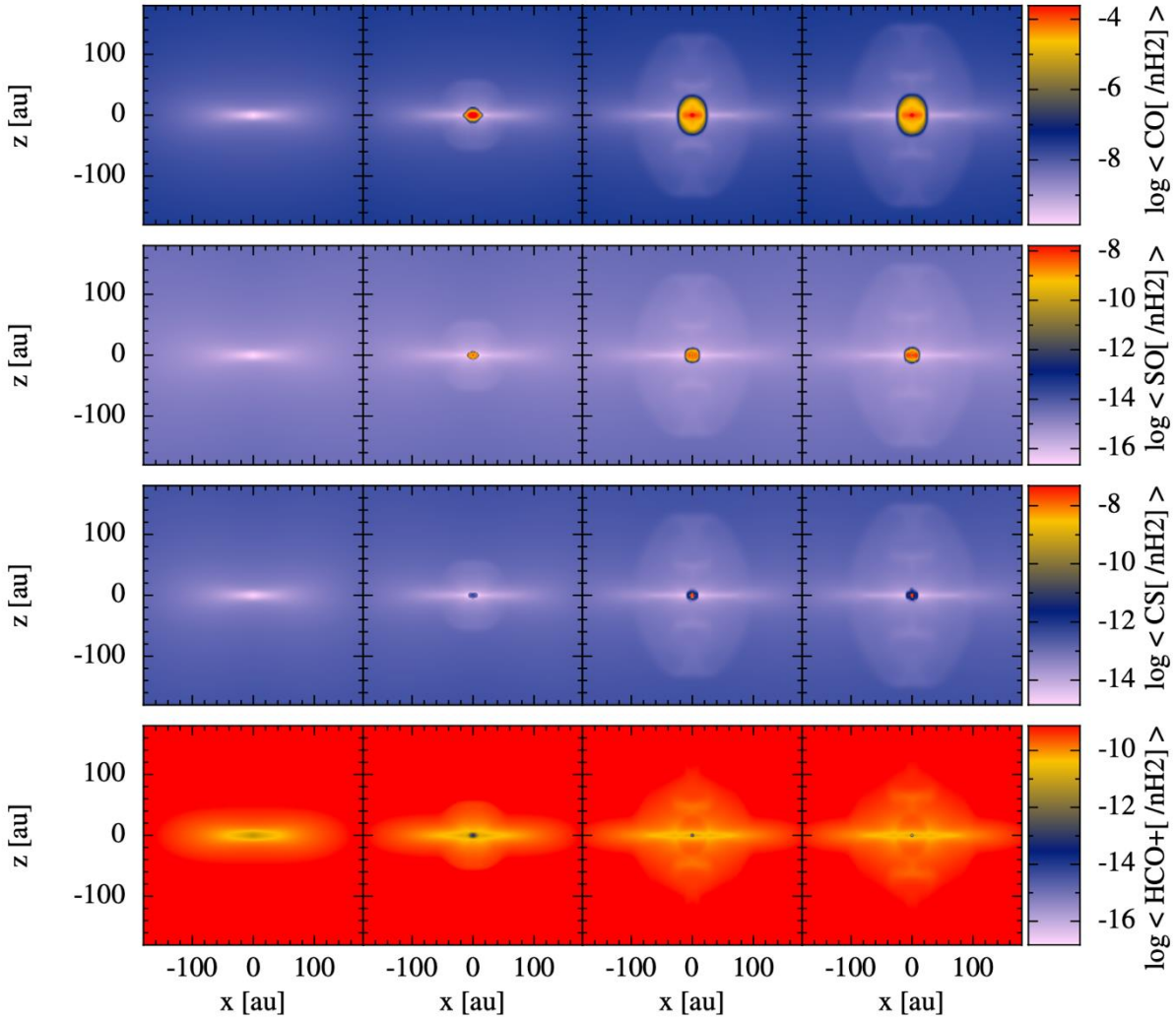
FHSC chemical evolution

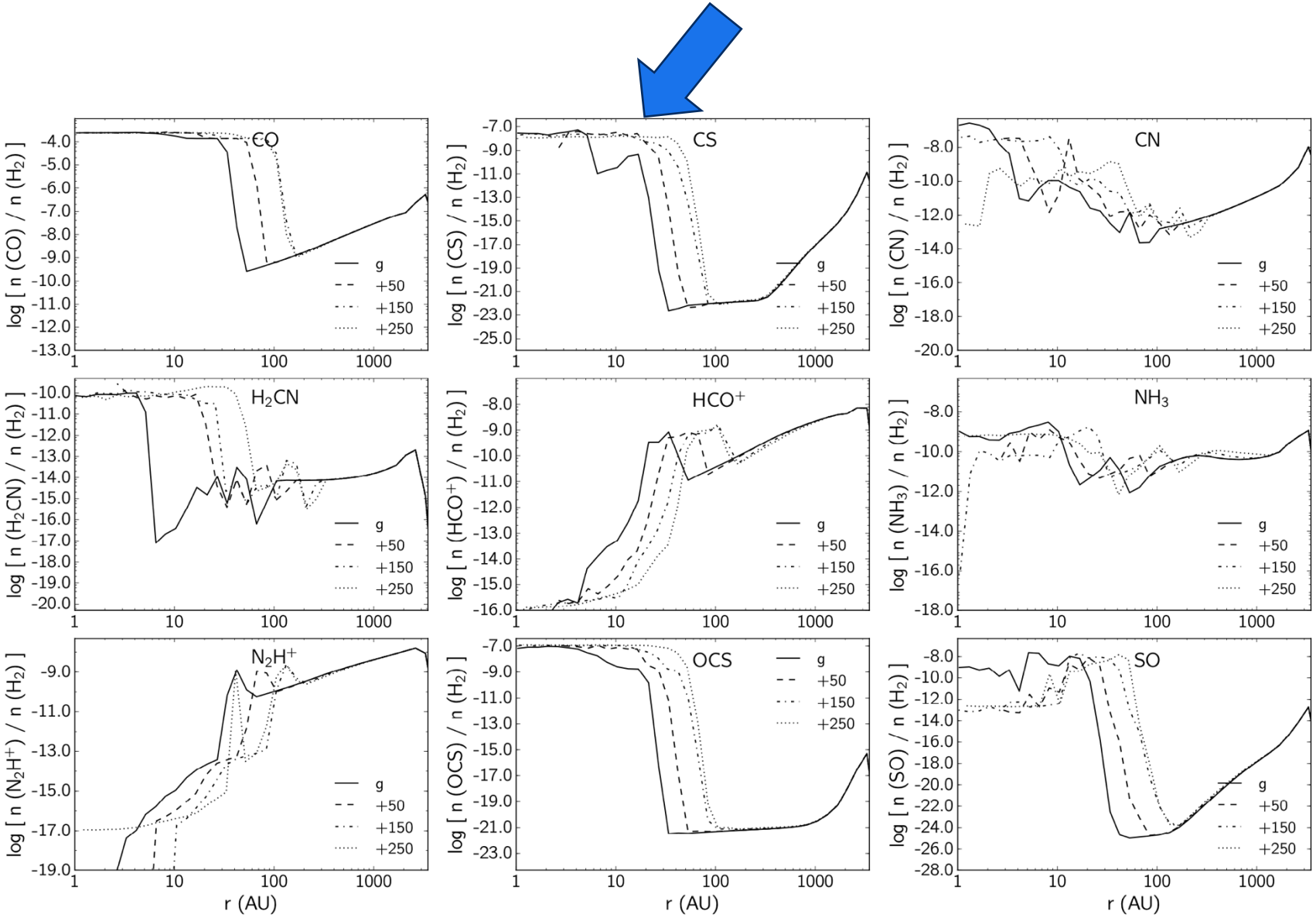


Young+ 2019

Post-FHSC

Years after stellar core formation

- g
- +50
- +150
- +250



Young (PhD Thesis)

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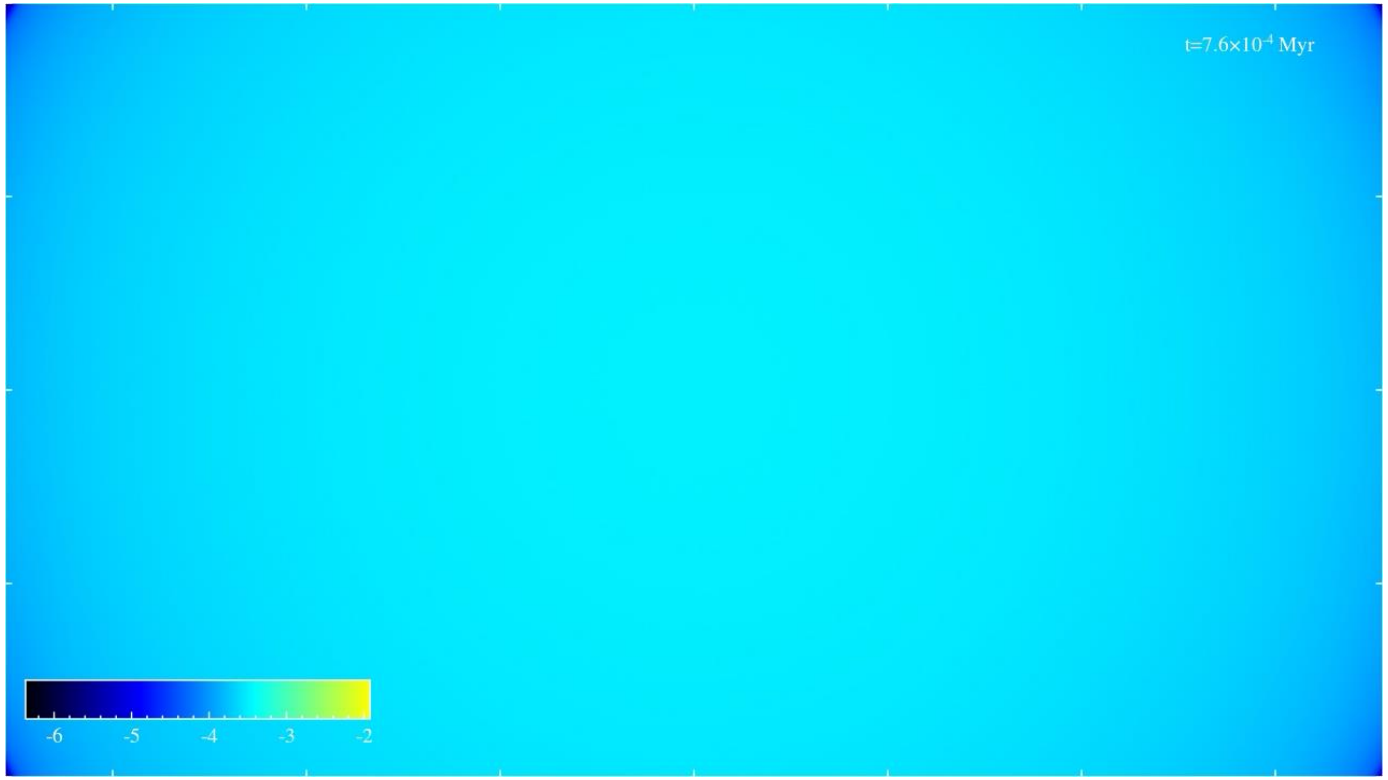
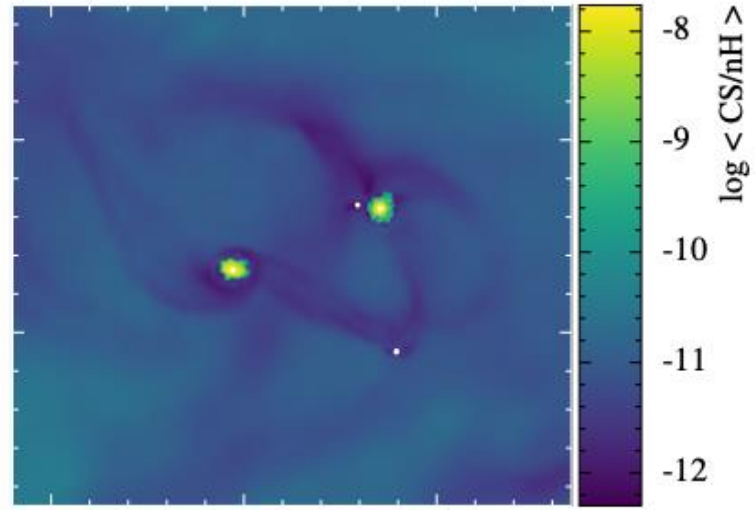
Whole cluster CO relative abundance evolution





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Identification approach

Faint (undetected) at 24 microns

Rule out starless cores by lack of compact continuum, and chemistry

Rule out protostars by compact CS emission (and extended outflow if present)

But... Statistics is still a problem

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Is there a better question?

How do we find the FHSC in observations?

- Risky observing proposals -> rejected :'(
- What science can we learn from finding/deep observations of very faint protostars?

What difference does the FHSC phase make to e.g. chemistry, dust?

Can we deduce FHSC from its effects on the protostellar core or disc?

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