Astrochemistry: From primordial gas to present-day clouds

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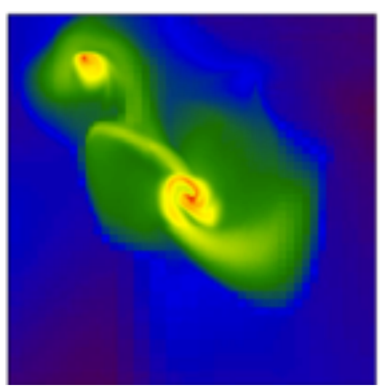
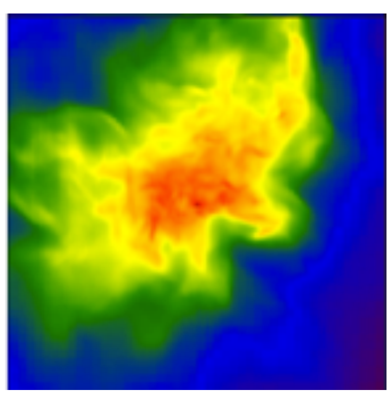
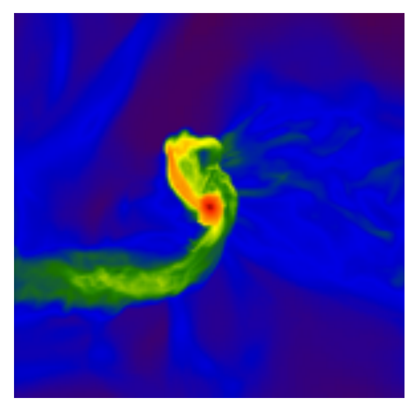
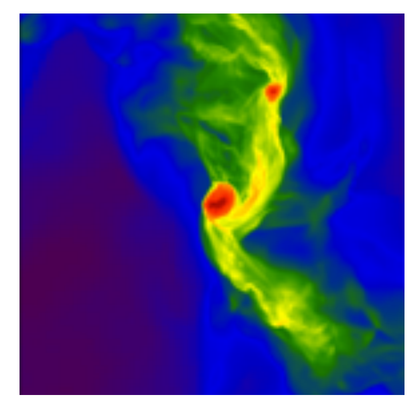
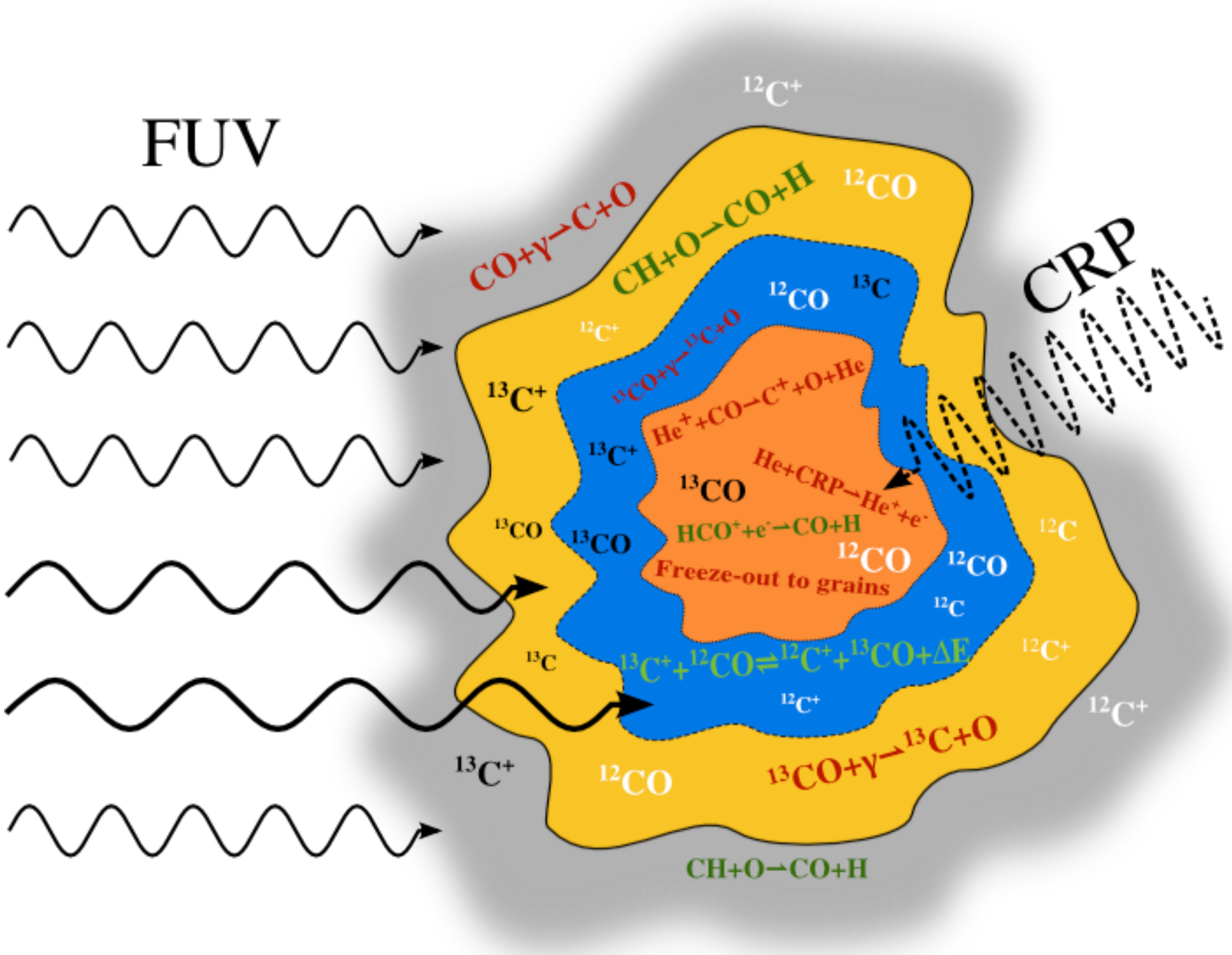





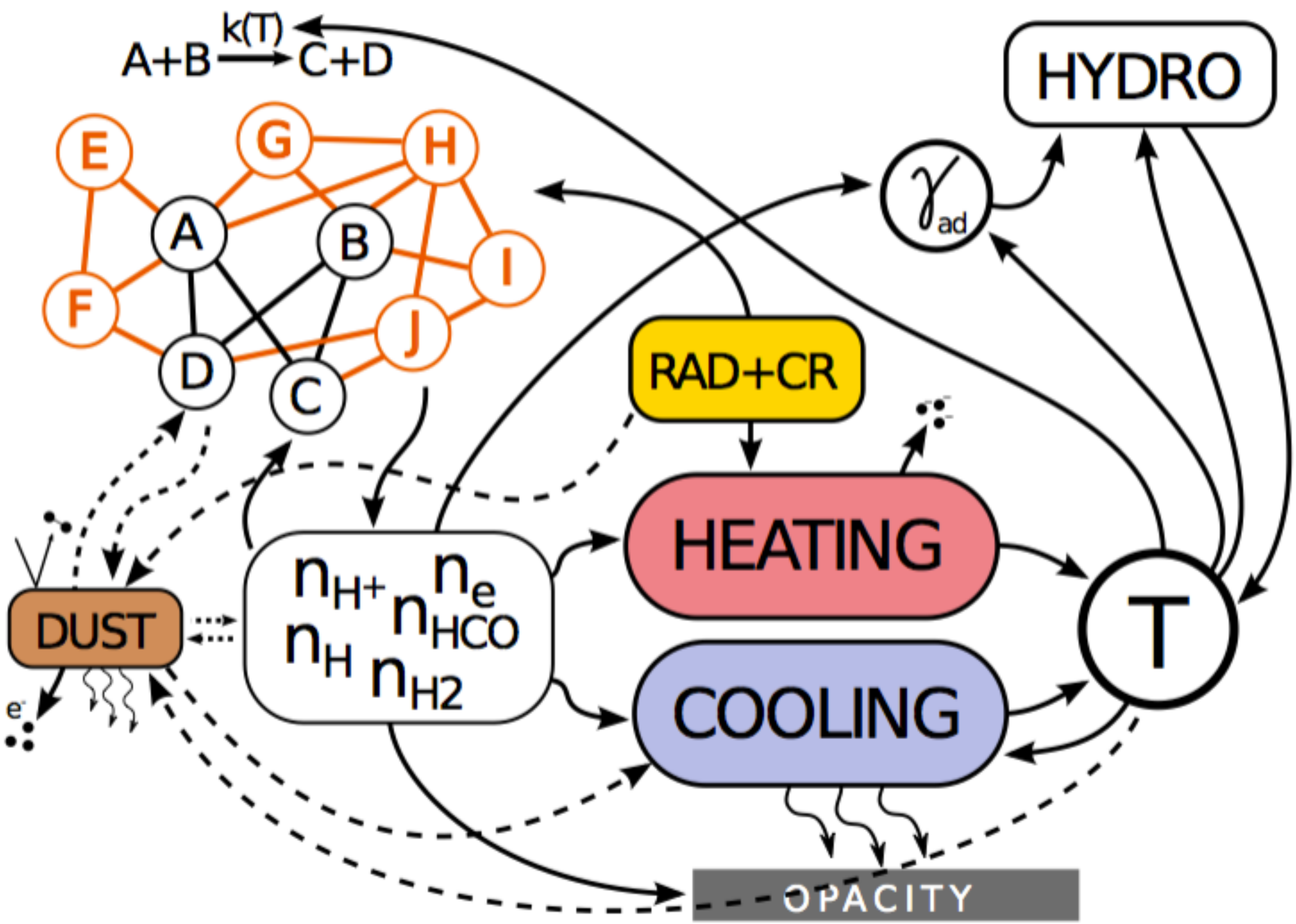
Collaborators:
Robi Banerjee (Hamburg), Tjarda Boekholt (Leiden), **Stefano Bovino** (Hamburg), Michael Fellhauer (Concepción), Daniele Galli (Florence), **Tommaso Grassi** (Copenhagen), Philipp Grete (Michigan), Ralf Klessen (Heidelberg), Bastian Koertgen (Hamburg), Hongli Liu (Concepción), Muhammad Latif (Islamabad), Rafeel Riaz (Concepción), Jennifer Schober (Stockholm), Amelia Stutz (Concepción)

Chemical complexity in molecular clouds



Szücs et al. (2014)

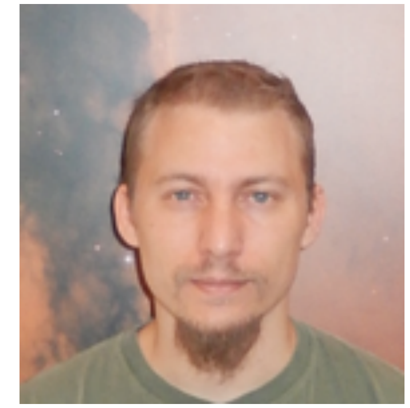
Chemistry in the gas and the dust



Grassi, Bovino, Schleicher et al. (2014)

The chemistry package KROME

KROME
better science through chemistry



- KROME is a package which helps users to build their own microphysics
- KROME is open source
- KROME is flexible and can be customized
- coupled with many hydro-codes
  - RAMSES, ENZO, FLASH, GASOLINE, GIZMO, CHANGA
- www.kromepackage.org
- since 2013, ~30 papers published from different groups

Grassi, Bovino+2014 MNRAS

KROME Computational Schools

- three KROME schools organized
  - Göttingen, 2014 → 28 participants
  - Copenhagen, 2015 → 30 participants
  - Florence, 2016 → 30 participants

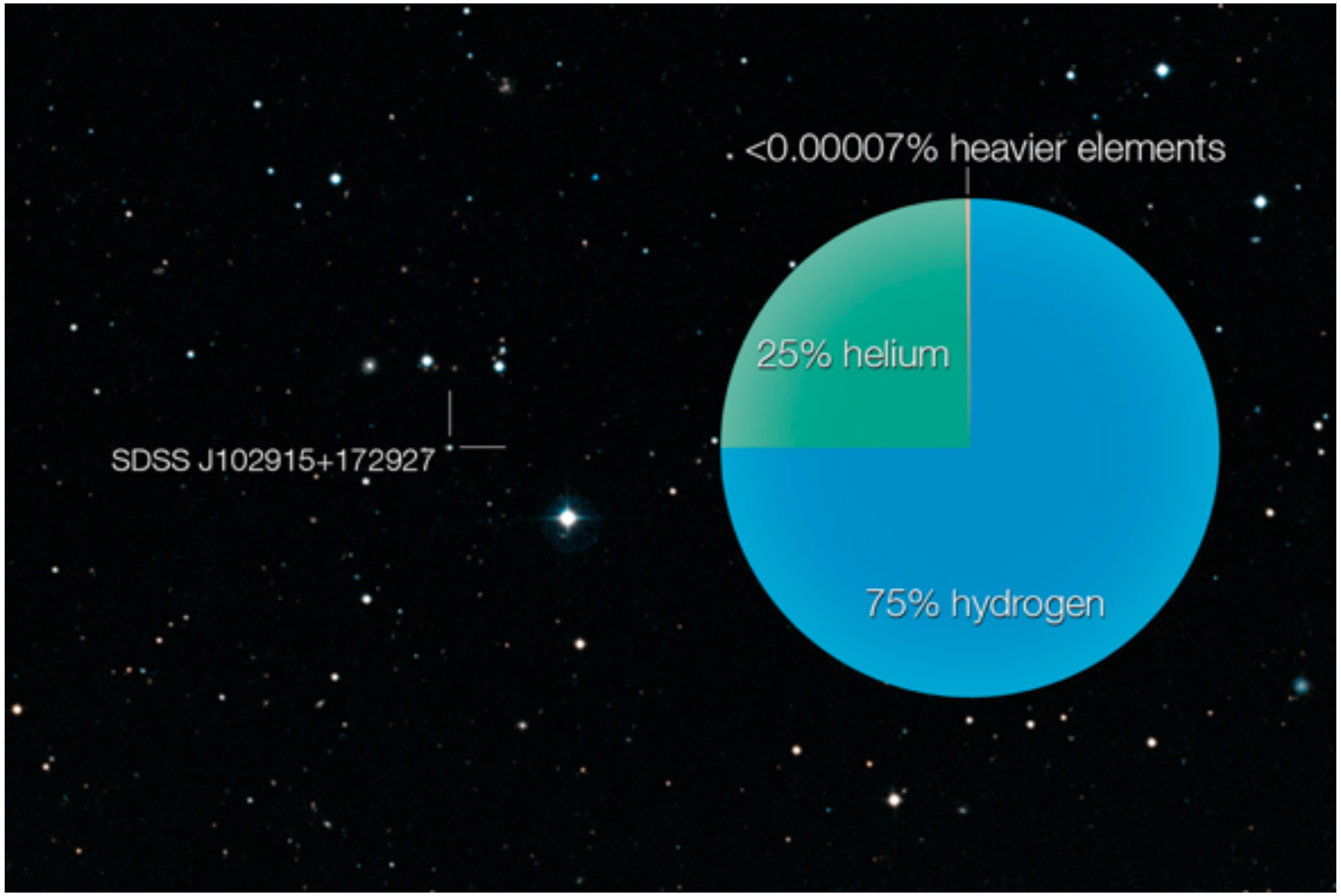
TO TAKE HOME → PRIMORDIAL

VULNERABLE	H2, HD	FUV dissociation
UNFAVORABLE	Molecules	CMB, rec'n phot
SUSCEPTIBLE	Disks	fragmentation
UNAVOIDABLE	Low-mass *	fragmentation
IMPOSSIBLE ELUSIVE	Pop III *	detection
INDISPENSABLE (CRITICAL)	Pop III/II	metallicity

Francesco´s conference summary
(Göttingen, 12.10.2012)

http://low-met.astro.physik.uni-goettingen.de/talks/palla.pdf

SDSS J102915+172927:
A challenge for current star formation models

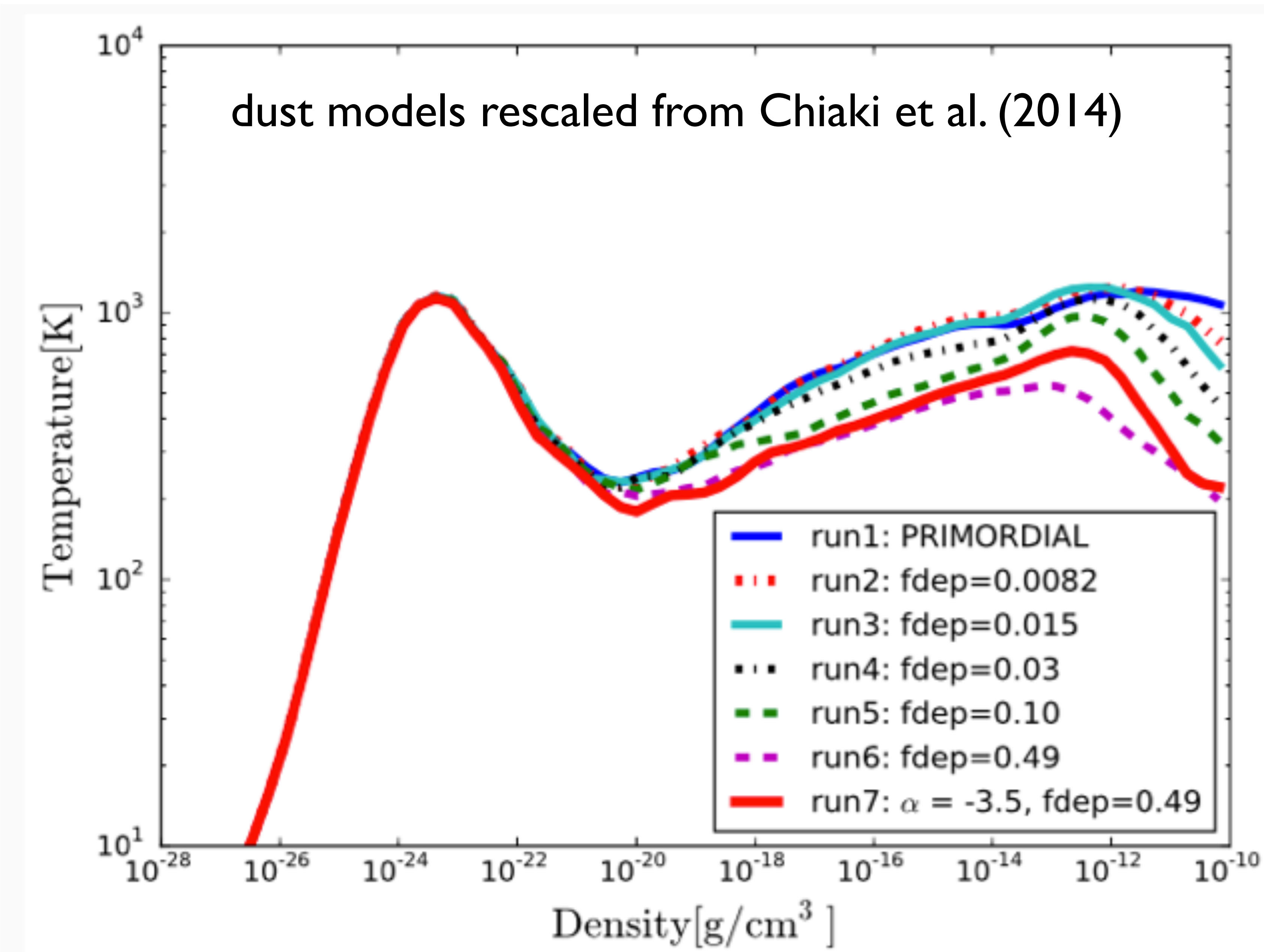


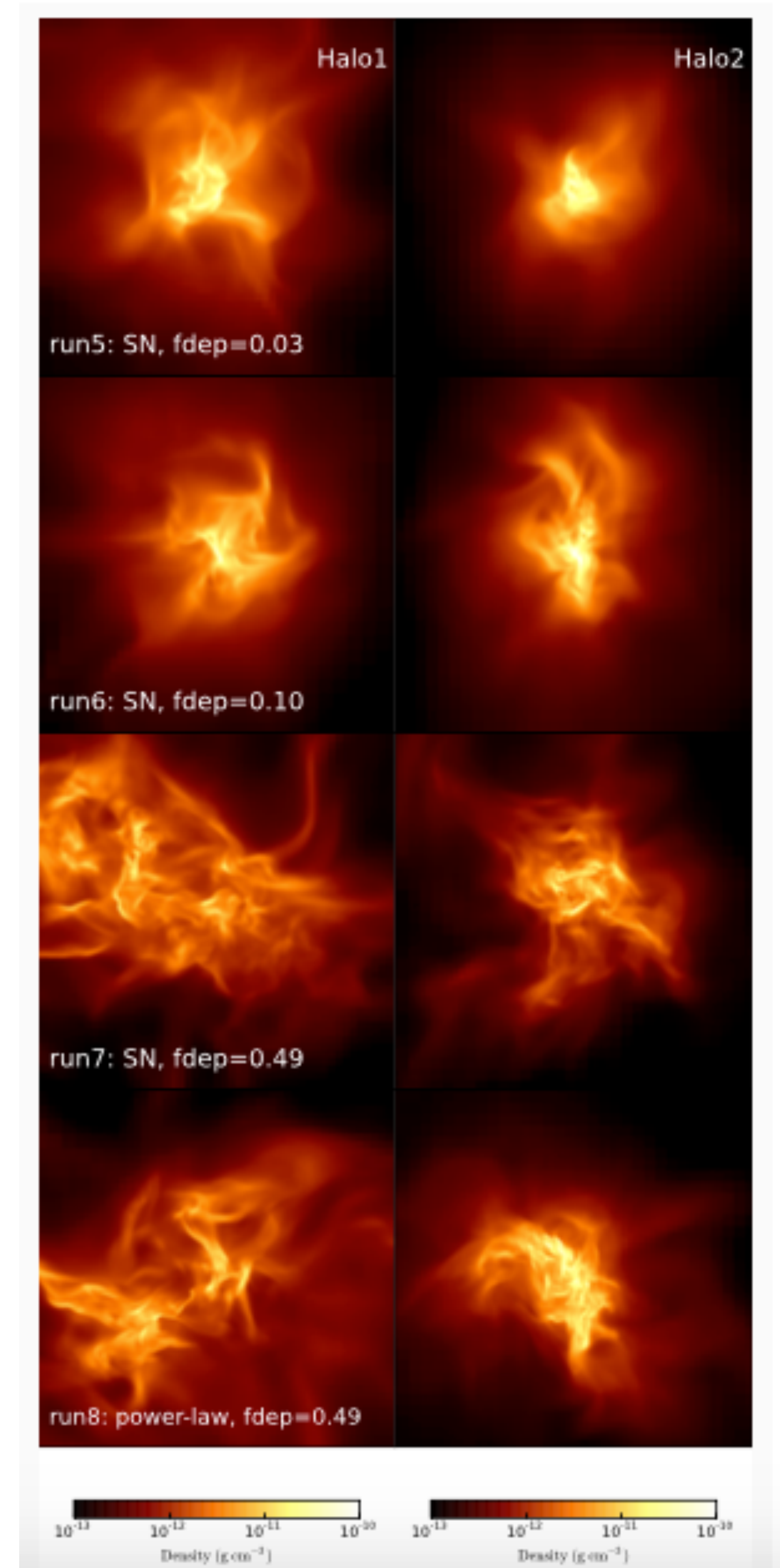
Element abundances:
- [Fe/H]=-4.89
- [C/H]<-3.8
- [N/H]<-4.1
- [O/H]~-4.29

Metal abundances too low for metal line cooling, dust cooling as only possibility.

Caffau et al. (2011)

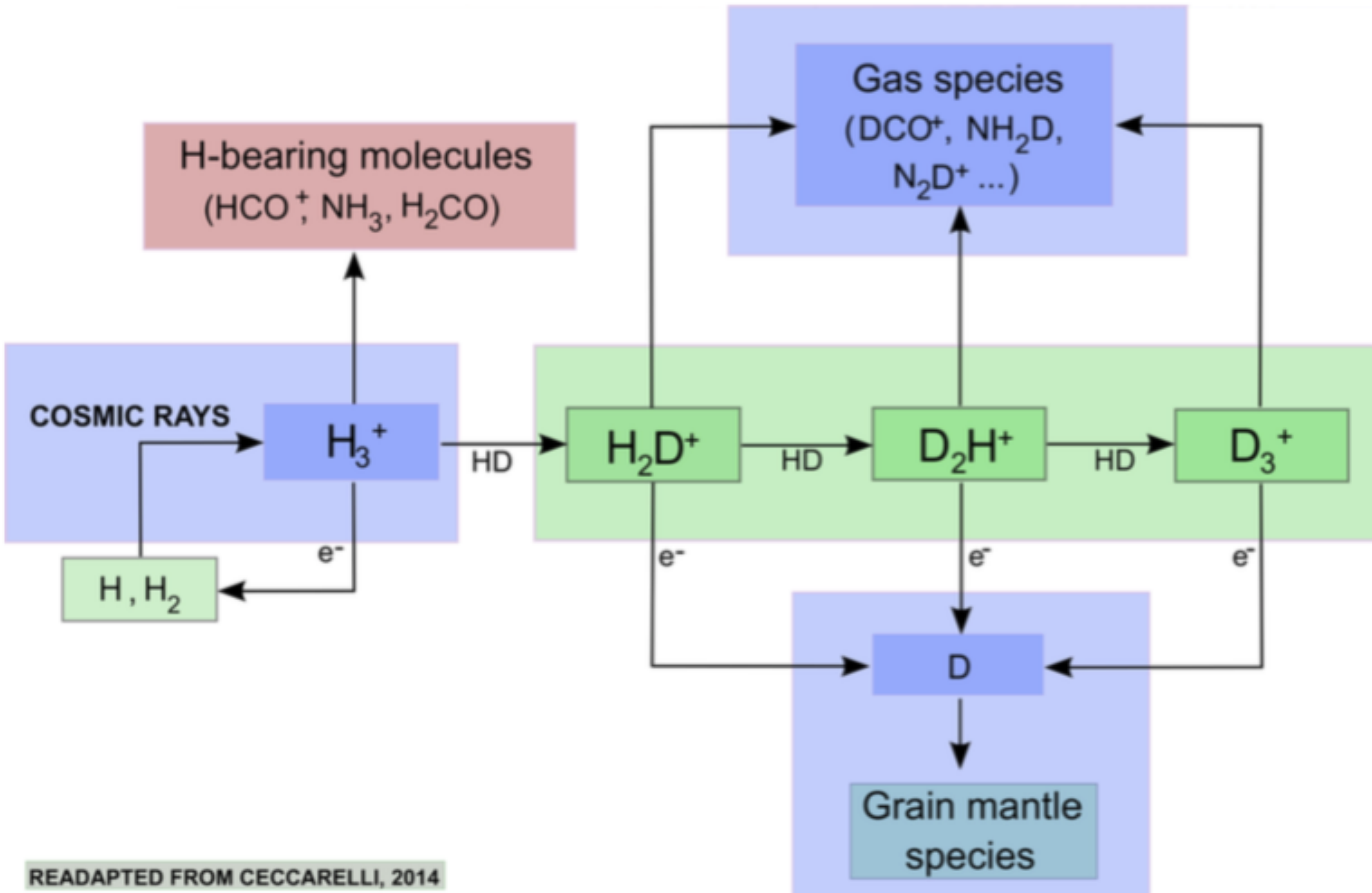
Thermodynamics and fragmentation





Bovino, Grassi, Schleicher et al. (2016)

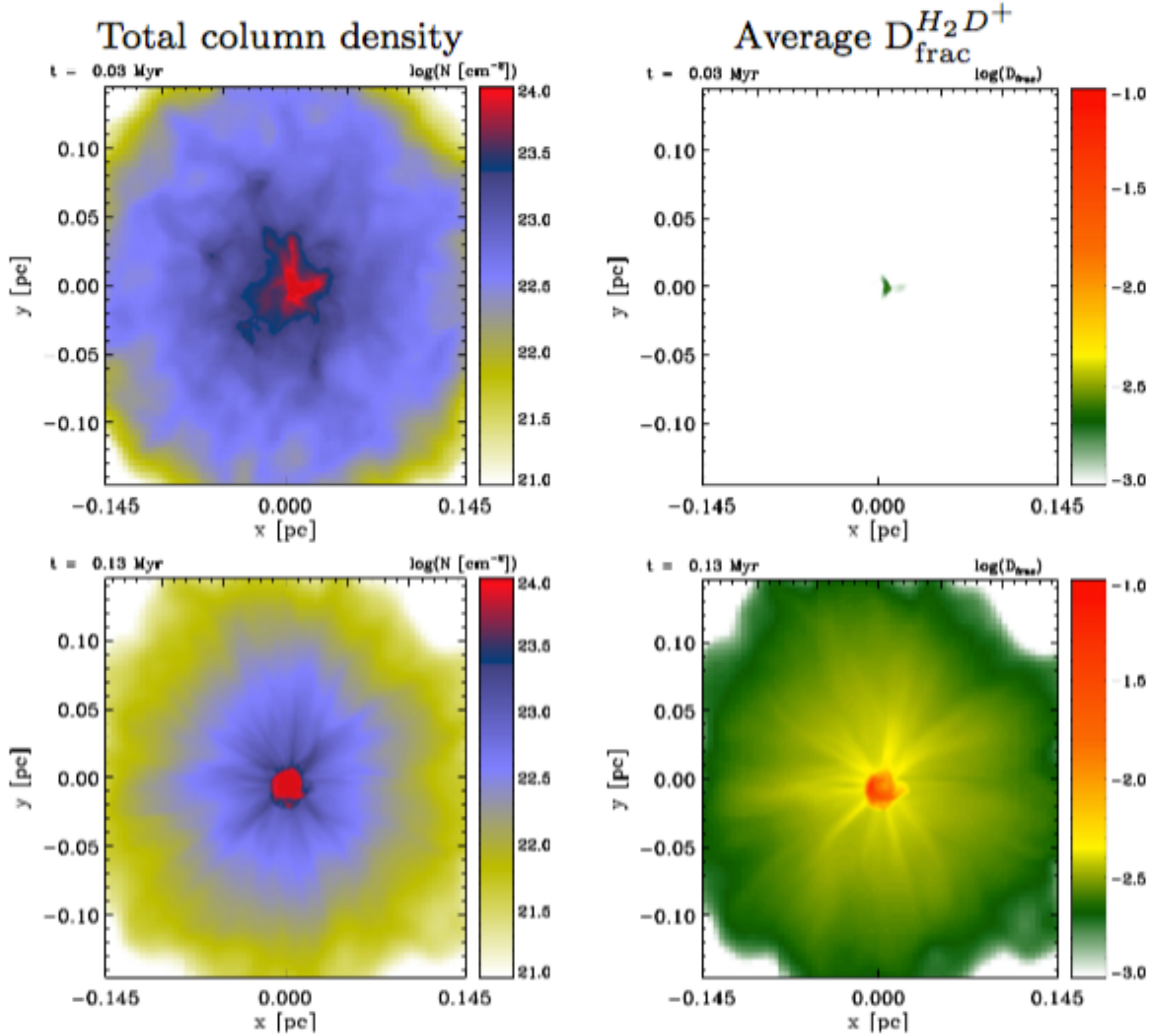
Deuteration of molecules



Fiducial case: collapse of 60 M_{sol} core

30 kyrs:

130 kyrs:



chemical network by Walmsley et al. (2004)

see Koertgen, Bovino et al. (2017)

Total number of simulations

Surface density $\left(g/cm^2\right)$	Core radius (pc)	Core mass $(M_\odot)$	Av. Field strength (μG)	Mass–to–flux ratio[a] μ/μ_{crit}	Mach number $\mathcal{M}_{turb}$	Virial parameter α_{vir}
0.14	0.17	60	27	10	1	0.16
0.14	0.17	60	27	10	2	0.64
0.14	0.17	60	27	10	2	0.64
0.14	0.17	60	27	10	2	0.64
0.14	0.17	60	27	10	2	0.64
0.14	0.17	60	27	10	4	2.56
0.14	0.17	60	27	10	6	5.76
0.14	0.17	60	27	10	12	23.04
0.14	0.17	60	54	5	2	0.64
0.14	0.17	60	54	5	4	2.56
0.14	0.17	60	108	2.5	0.5	0.04
0.14	0.17	60	108	2.5	2	0.64
0.14	0.17	60	108	2.5	6	5.76
0.24	0.08	27	49	10	2	0.71
0.24	0.08	27	98	5	2	0.71
0.39	0.1	60	76	10	0.5	0.03
0.39	0.1	60	76	10	2	0.48
0.39	0.1	60	76	10	2	0.48
0.39	0.1	60	152	5	2	0.48
0.39	0.1	60	304	2.5	2	0.48
0.39	0.1	60	304	2.5	4	1.92

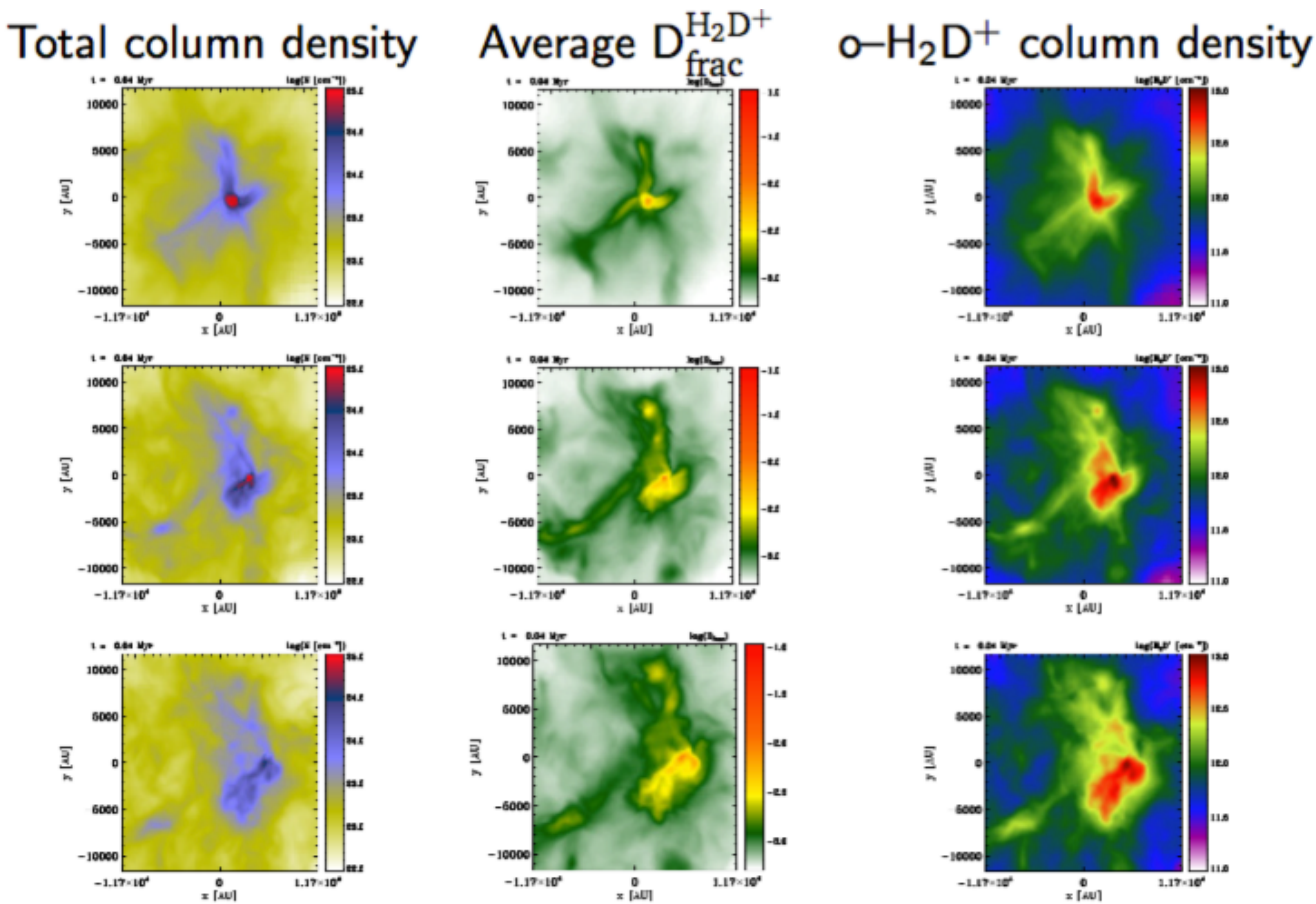
Koertgen, Bovino, Schleicher et al. (2017)

Dependence on turbulent Mach number

M=2

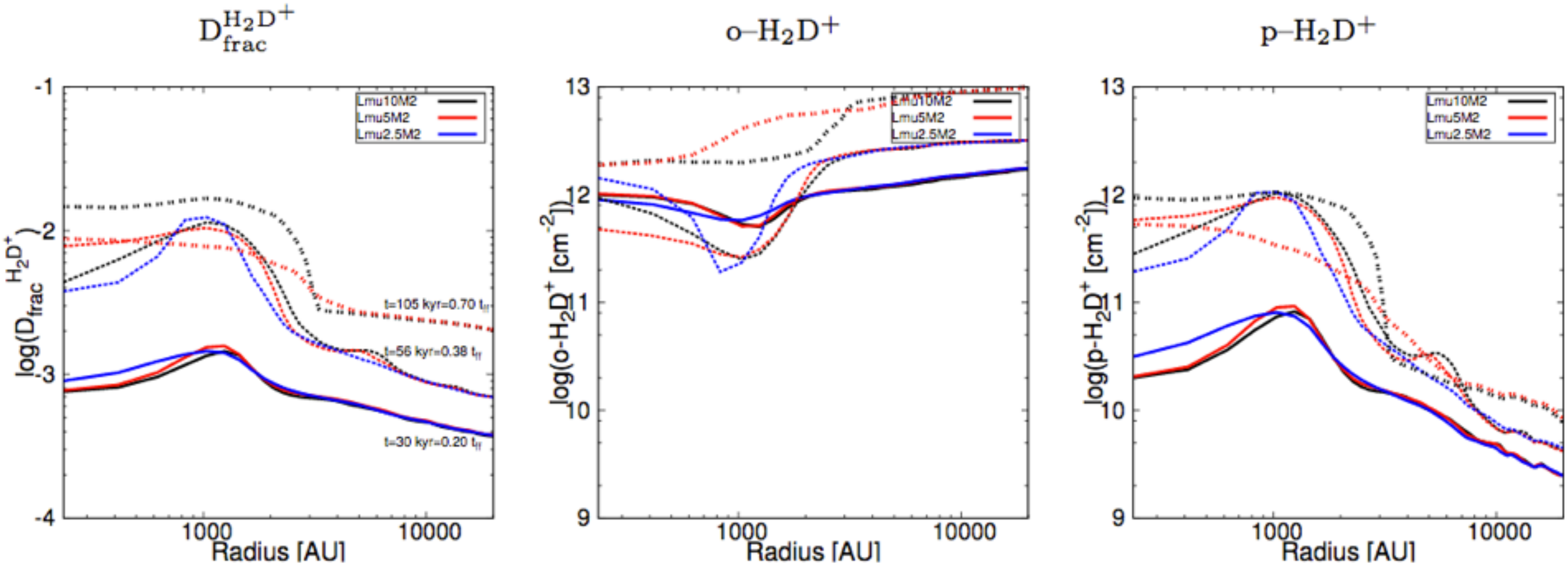
M=4

M=6



Koertgen, Bovino, Schleicher et al. (2017)

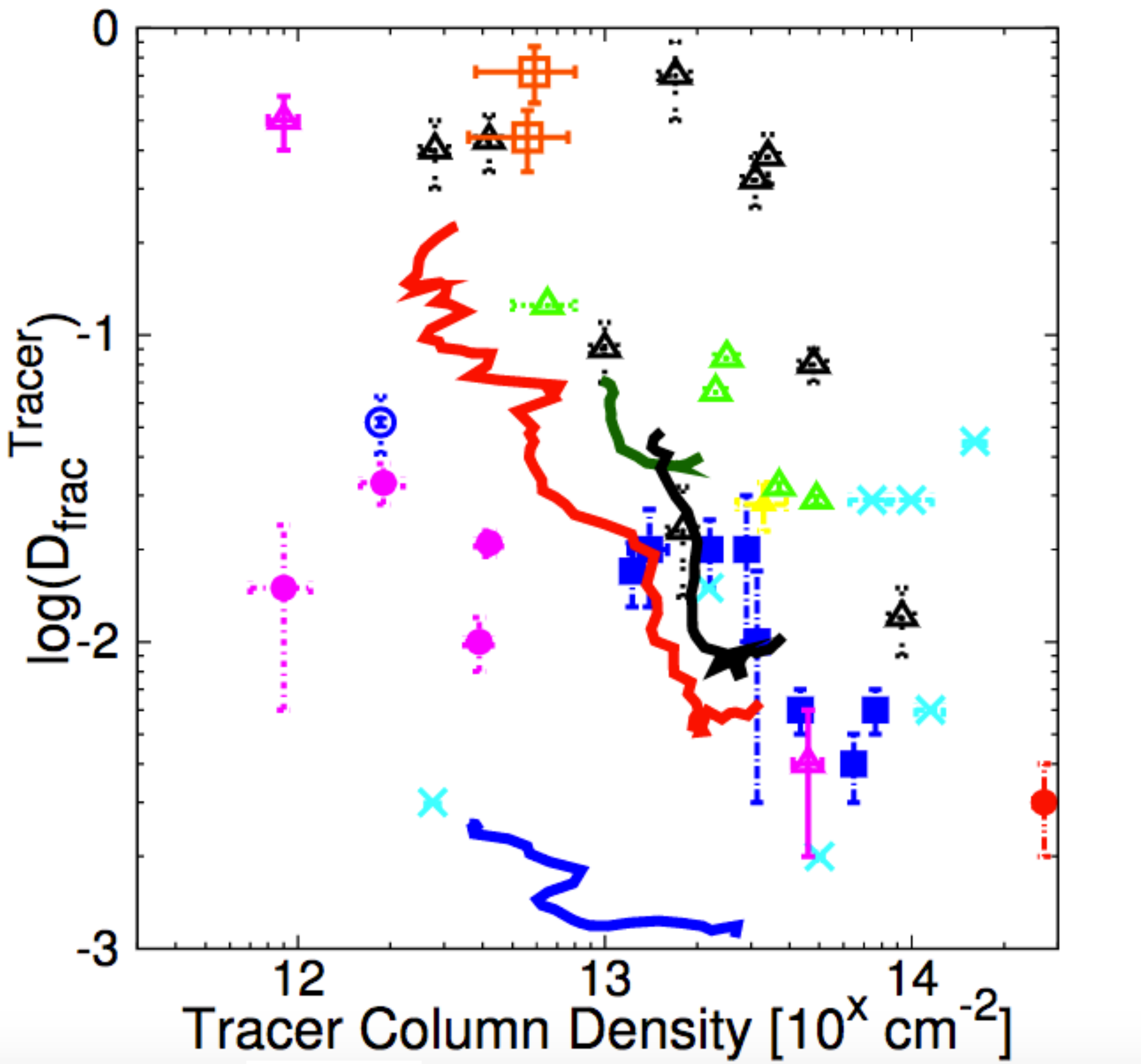
Dependence on mass-to-flux ratio



Dependence on time stronger than dependence on mass-to-flux

Koertgen, Bovino, Schleicher et al. (2017)

Comparison with observational data



Theory and Star Formation group in Concepción

http://theory-starformation-group.cl/

First Stars VI in Concepción

First Stars VI in Concepción (March 2020)

First Stars V in Heidelberg (August 2015)