

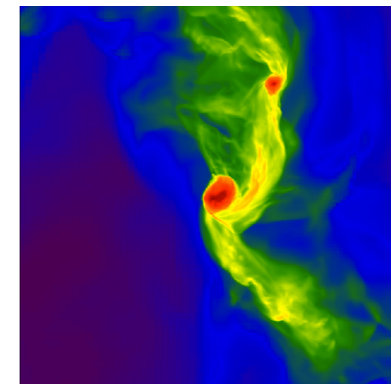
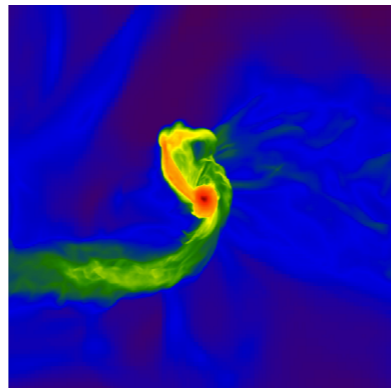
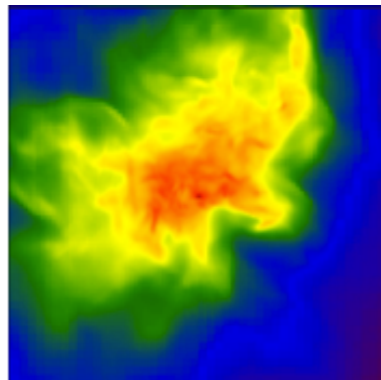
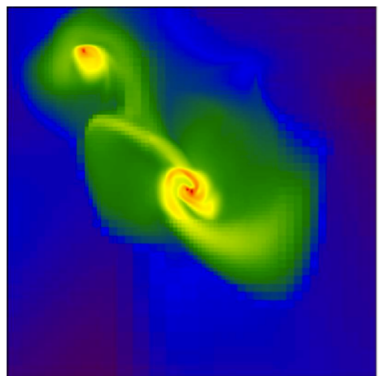
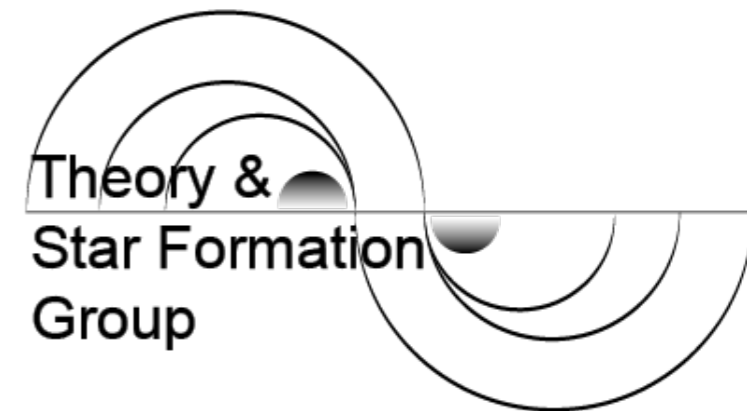


<b>Publication Year</b>	2017
<b>Acceptance in OA</b>	2020-09-09T06:57:07Z
<b>Title</b>	Can Deuteration be Used as A Chemical Clock in Protostellar Cores
<b>Authors</b>	Schleicher, Dominik, Banerjee, R., Boekholt, T., Bovino, S., Fellhauer, M., GALLI, Daniele, Grassi, T., Grete, P., Haugboelle, T., Koertgen, B., Latif, M., Riaz, R., Stutz, A.
<b>Publisher's version (DOI)</b>	10.5281/zenodo.808655
<b>Handle</b>	<a href="http://hdl.handle.net/20.500.12386/27229">http://hdl.handle.net/20.500.12386/27229</a>



# Can deuteration be used as a chemical clock in protostellar cores

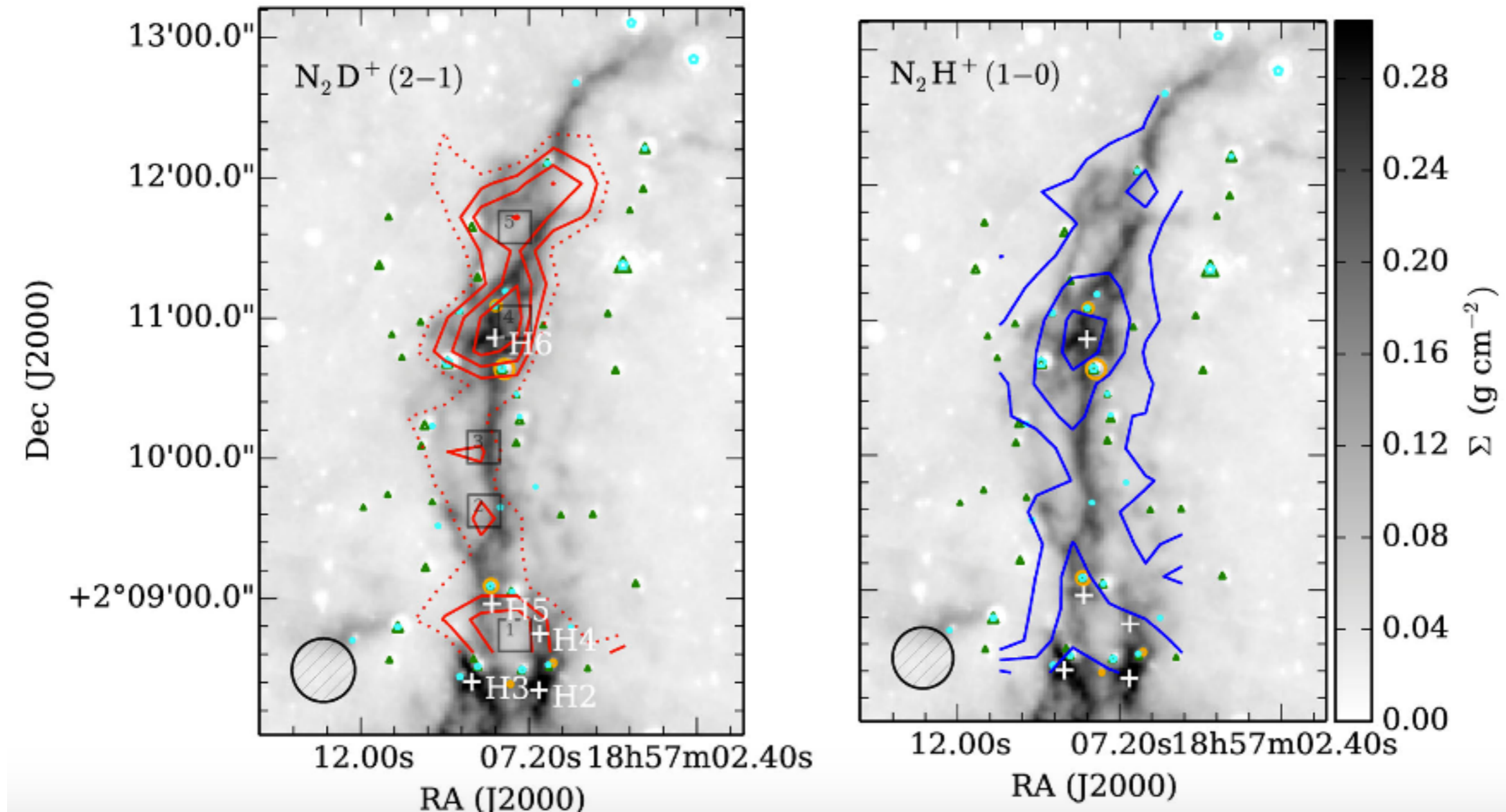
Dominik Schleicher  
Astronomy Department  
Universidad de Concepción



Collaborators:

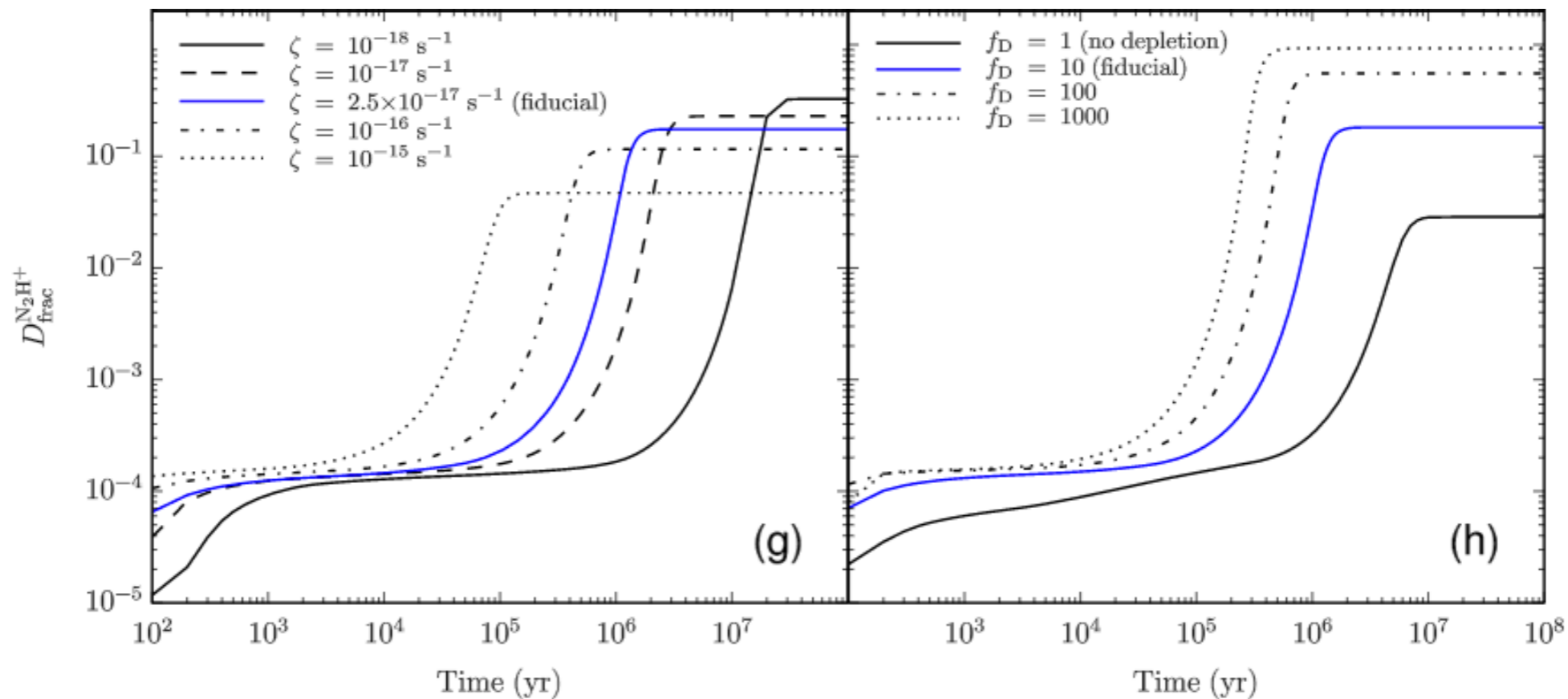
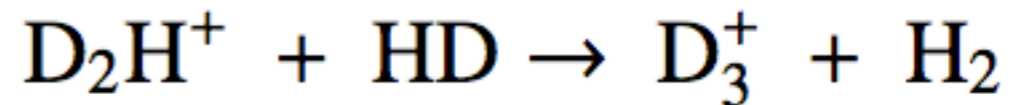
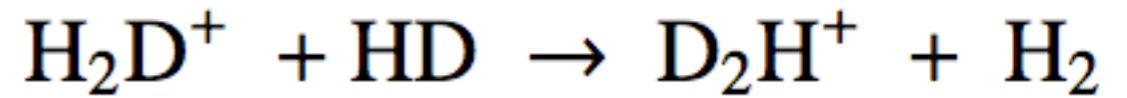
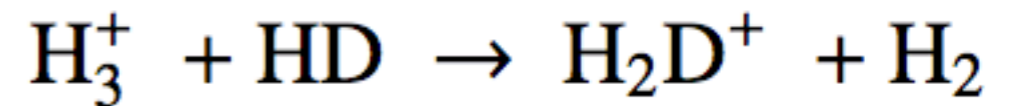
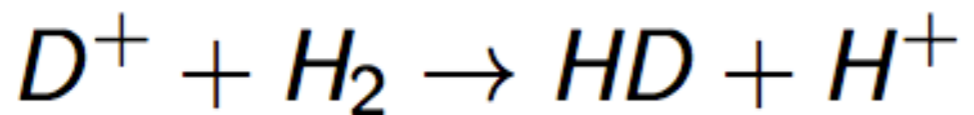
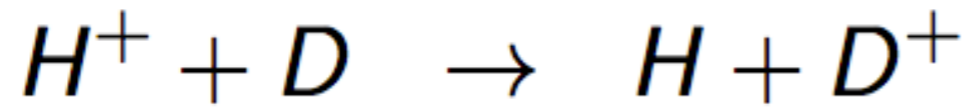
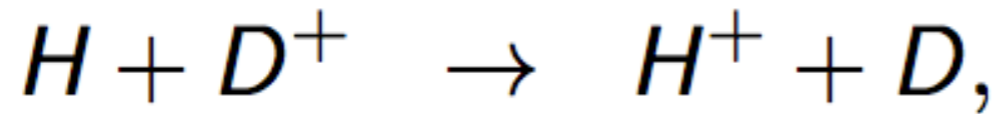
Robi Banerjee (Hamburg), Tjarda Boekholt (Concepción), **Stefano Bovino** (Hamburg), Michael Fellhauer (Concepción), Daniele Galli (Florence), Tommaso Grassi (Copenhagen), Philipp Grete (Michigan), Troels Haugboelle (Copenhagen), **Bastian Koertgen** (Hamburg), Muhammad Latif (Islamabad), Rafeel Riaz (Concepción), Amelia Stutz (Concepción)

# Deuteration in IRDC G035.39–00.33



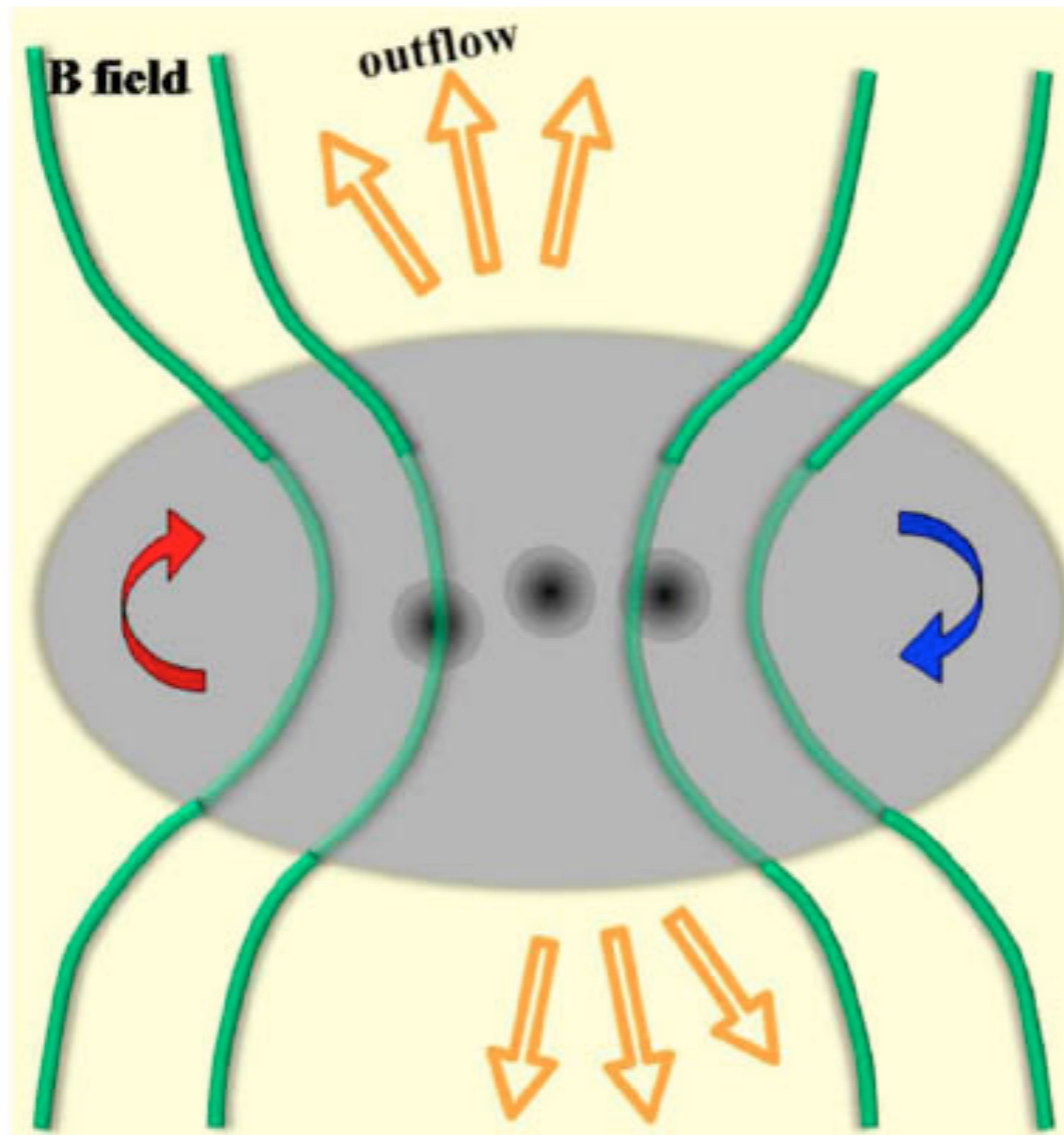
Barnes et al. (2016)

# Deuteration of molecules



Kong et al. (2015)

# High deuteration fractions: magnetically dominated star formation?



Magnetic flux =  $\Phi = B A$

Magnetic field

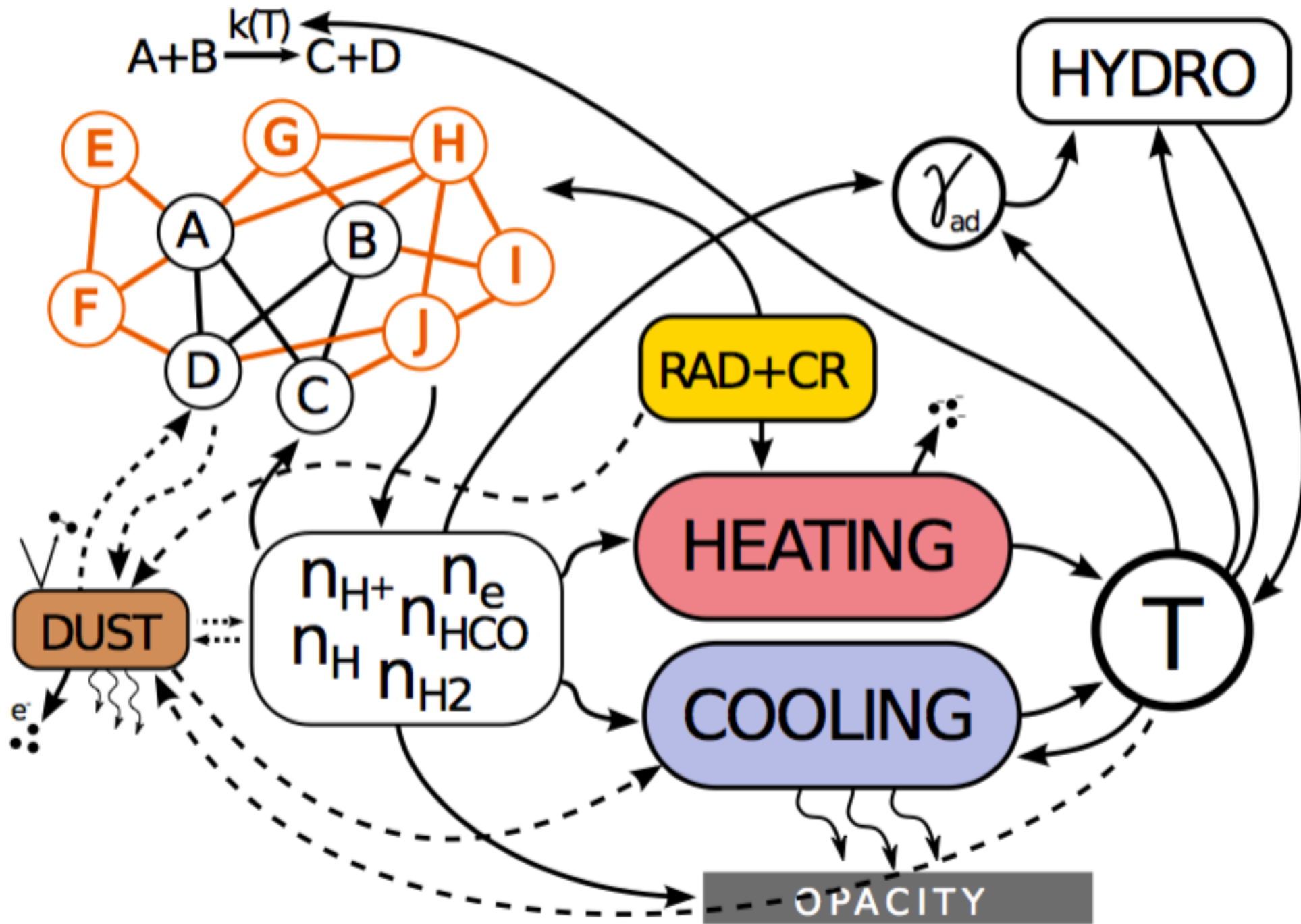
Area perpendicular to magnetic field B

critical mass to collapse:

$$M_J^B = \frac{\Phi}{2\pi\sqrt{G}}$$

magnetic field -> slow collapse -> time for deuteration?

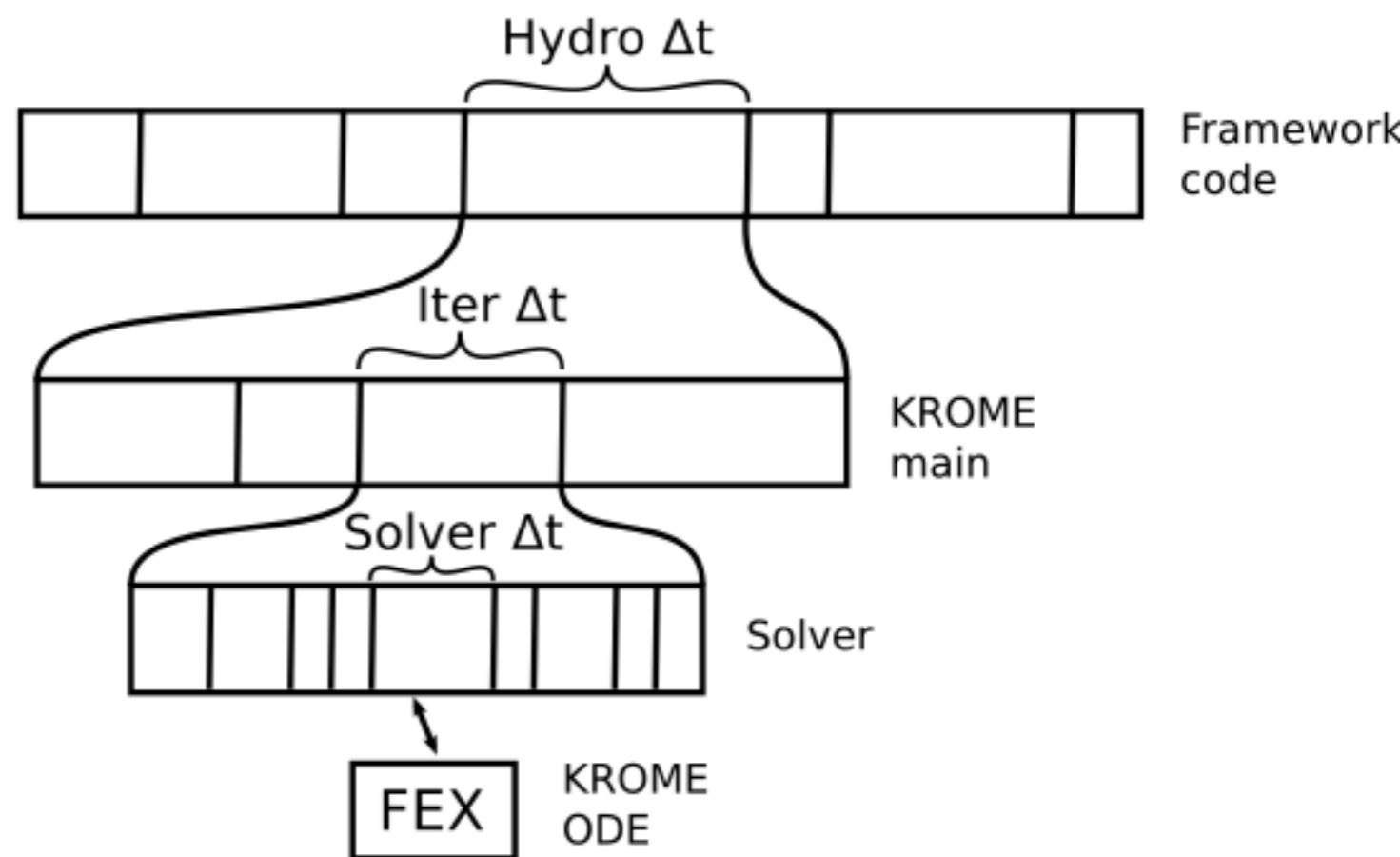
# Chemical complexity



Grassi, Bovino, Schleicher et al. (2014)

# The chemistry package KROME

- KROME:  
python module to **create Fortran subroutine**  
**for existing chemical networks.**
- The subroutine is then included in the framework code.
- Existing **interfaces for Enzo, Flash, Gasoline, Ramses**  
(plus wrapper for C++).
- Several example networks  
as well as user-defined  
networks.
- **Publicly available:**  
[www.kromepackage.org](http://www.kromepackage.org)



Grassi, Bovino, Schleicher et al. (2014)

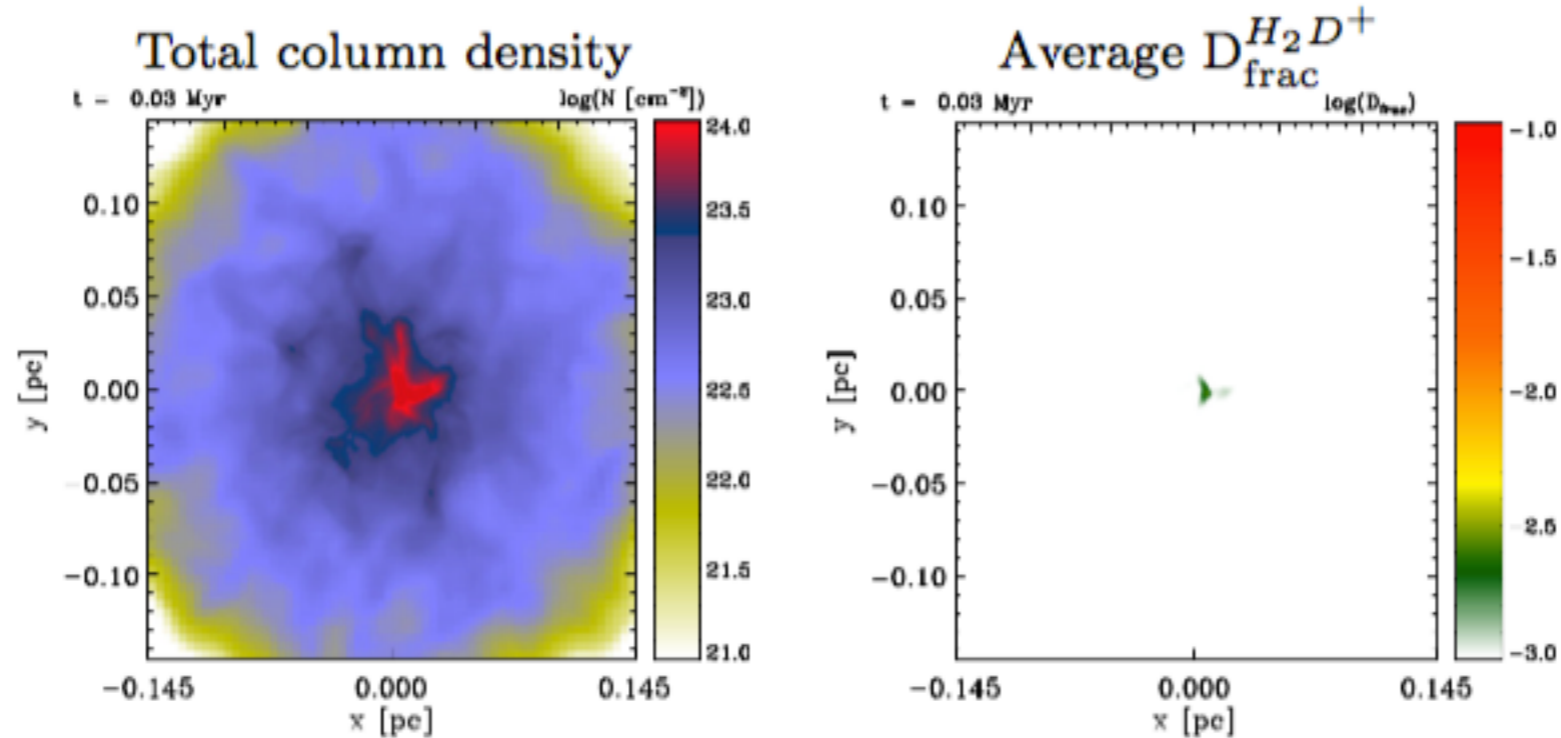
# Test with 3D numerical simulations

- 60 solar mass core, 0.17 pc, 15 K, turbulent Mach number of 2
- mass to flux ratio:  $\sim 10$  above critical value
- maximum resolution: 235 AU
- magneto-hydrodynamics + self-gravity solved with the FLASH code
- network for deuteration chemistry based on Walmsley et al. (2004)

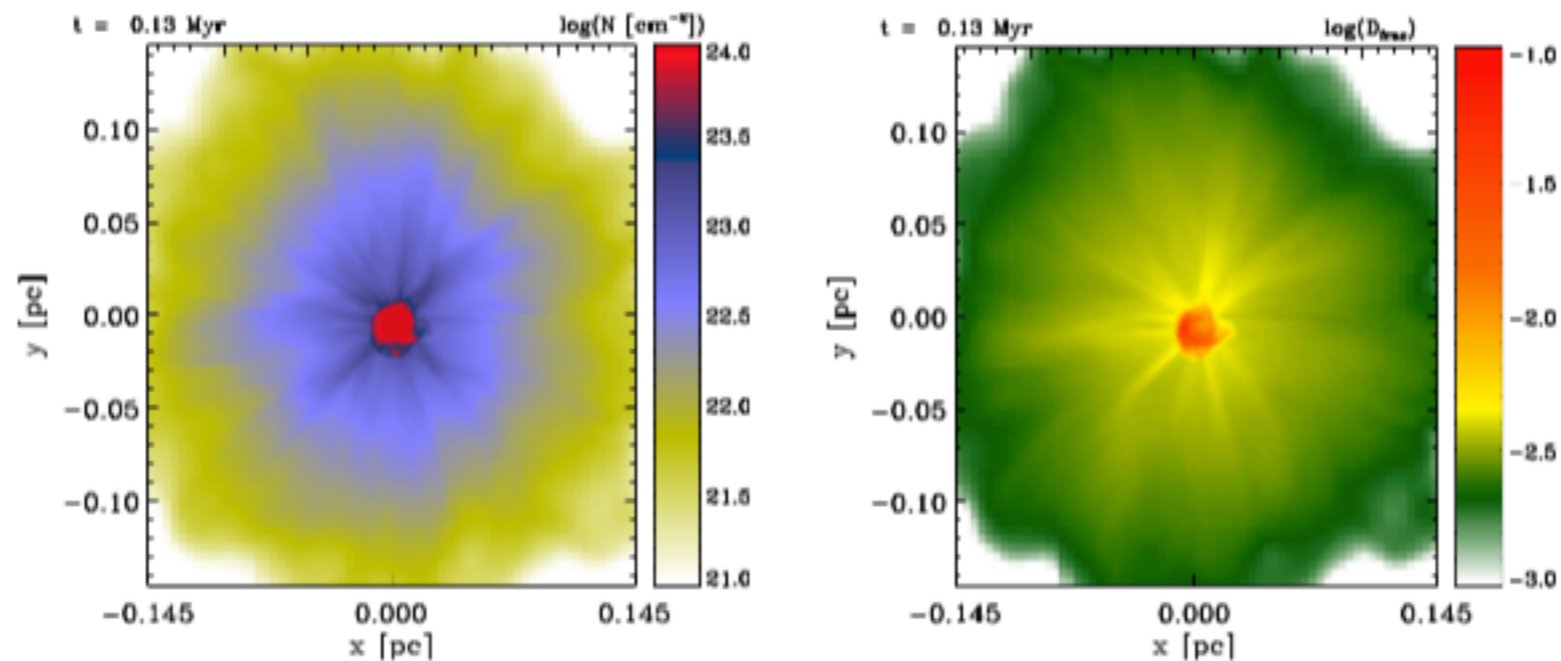
Koertgen, Bovino, Schleicher et al., submitted  
(arXiv:1703.01201)

# Results reference run

30 kyrs:



130 kyrs:



Koertgen, Bovino, Schleicher et al., submitted  
(arXiv:1703.01201)

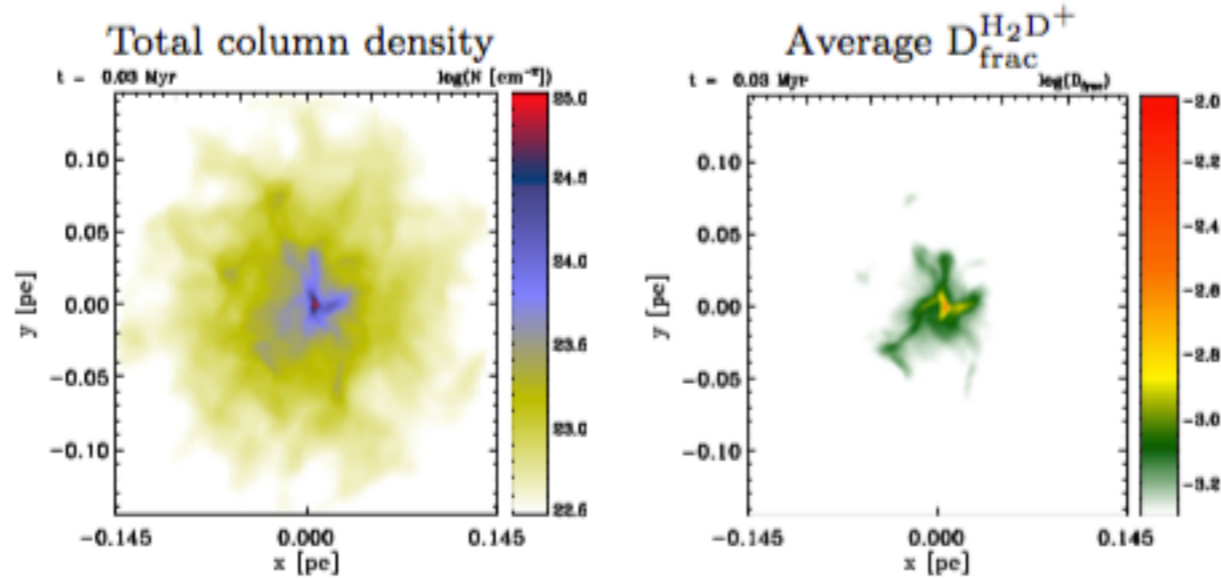
# Total number of simulations

Surface density ( $\text{g}/\text{cm}^2$ )	Core radius (pc)	Core mass ( $M_{\odot}$ )	Av. Field strength ( $\mu\text{G}$ )	Mass-to-flux ratio <sup>a</sup> $\mu/\mu_{\text{crit}}$	Mach number $\mathcal{M}_{\text{turb}}$	Virial parameter $\alpha_{\text{vir}}$
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

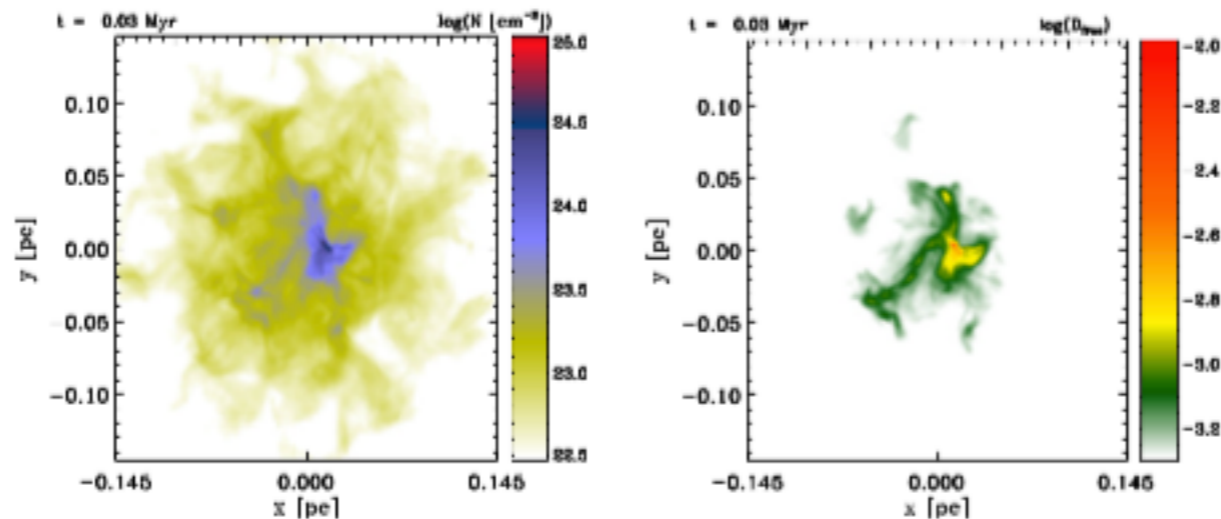
Koertgen, Bovino, Schleicher et al., submitted  
(arXiv:1703.01201)

# Dependence on turbulent Mach number

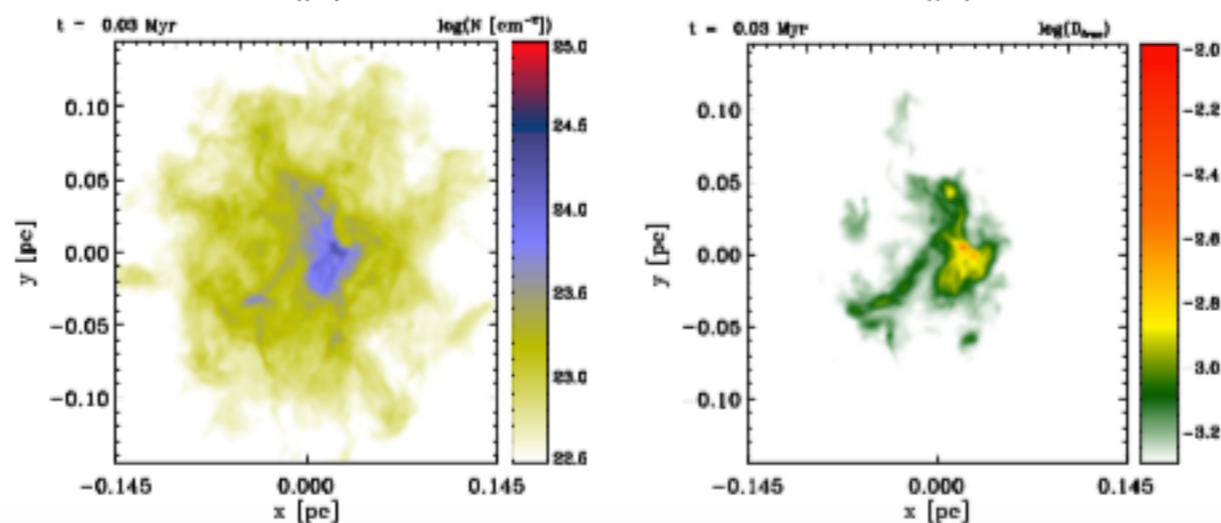
M=2



M=4

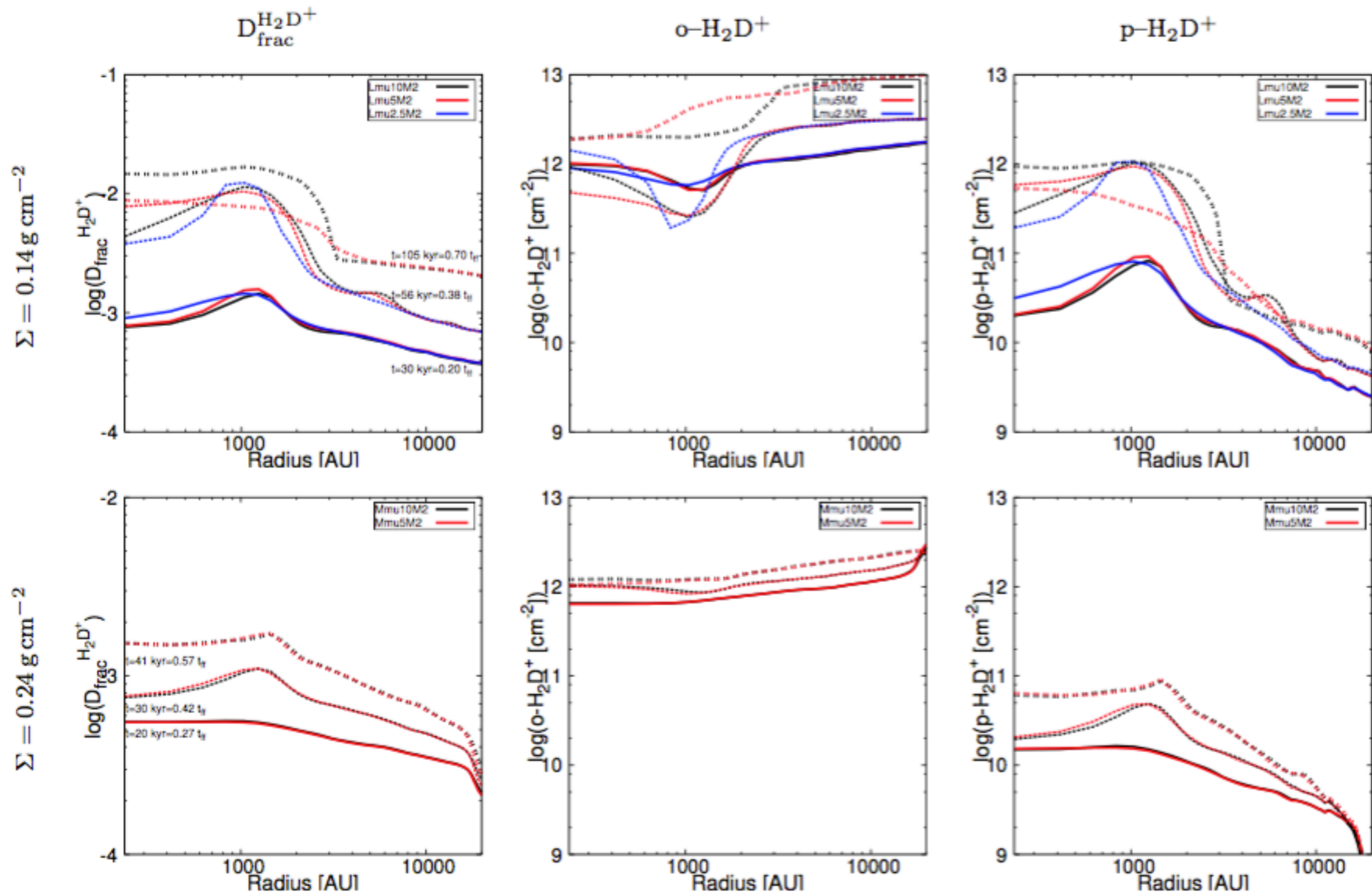


M=6



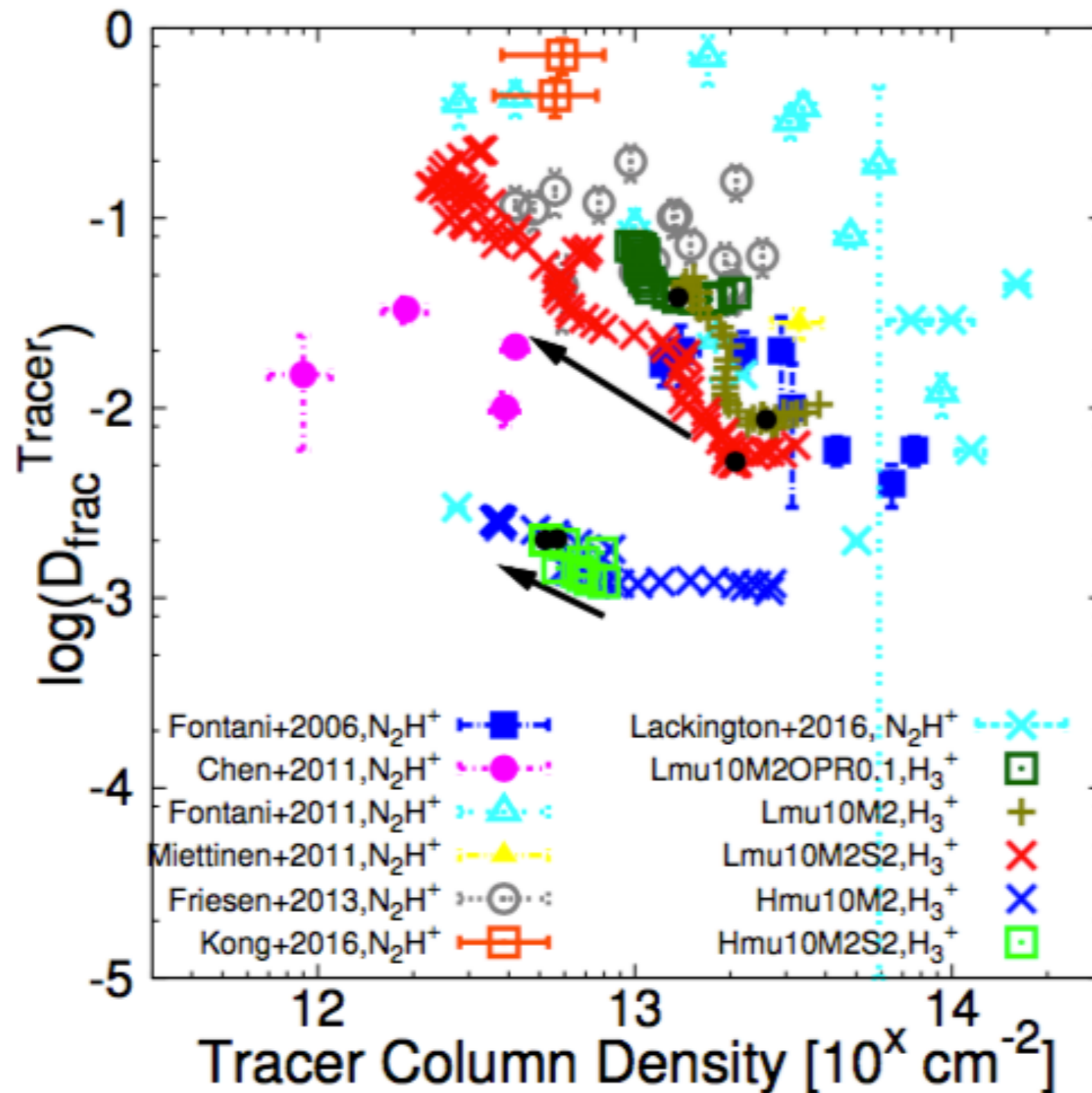
Koertgen et al., submitted

# Dependence on mass-to-flux ratio



Koertgen, Bovino, Schleicher et al., submitted  
(arXiv:1703.01201)

# Comparison with observational data



Koertgen, Bovino, Schleicher et al., submitted  
(arXiv:1703.01201)

# Summary

- Observed deuteration fraction can be readily reproduced in numerical simulations.
- The deuteration fraction is roughly independent of the magnetic field, and depends weakly on the initial surface density and turbulent Mach number.
- Important to explore chemical uncertainties like incomplete depletion both with high-resolution observations as well as chemical investigations.
- Need to better understand the initial conditions:  
What is the ortho-to-para ratio on large scales? How good is the approximation of high depletion?