From pre-stellar cores to protoplanetary disks

Paola Caselli

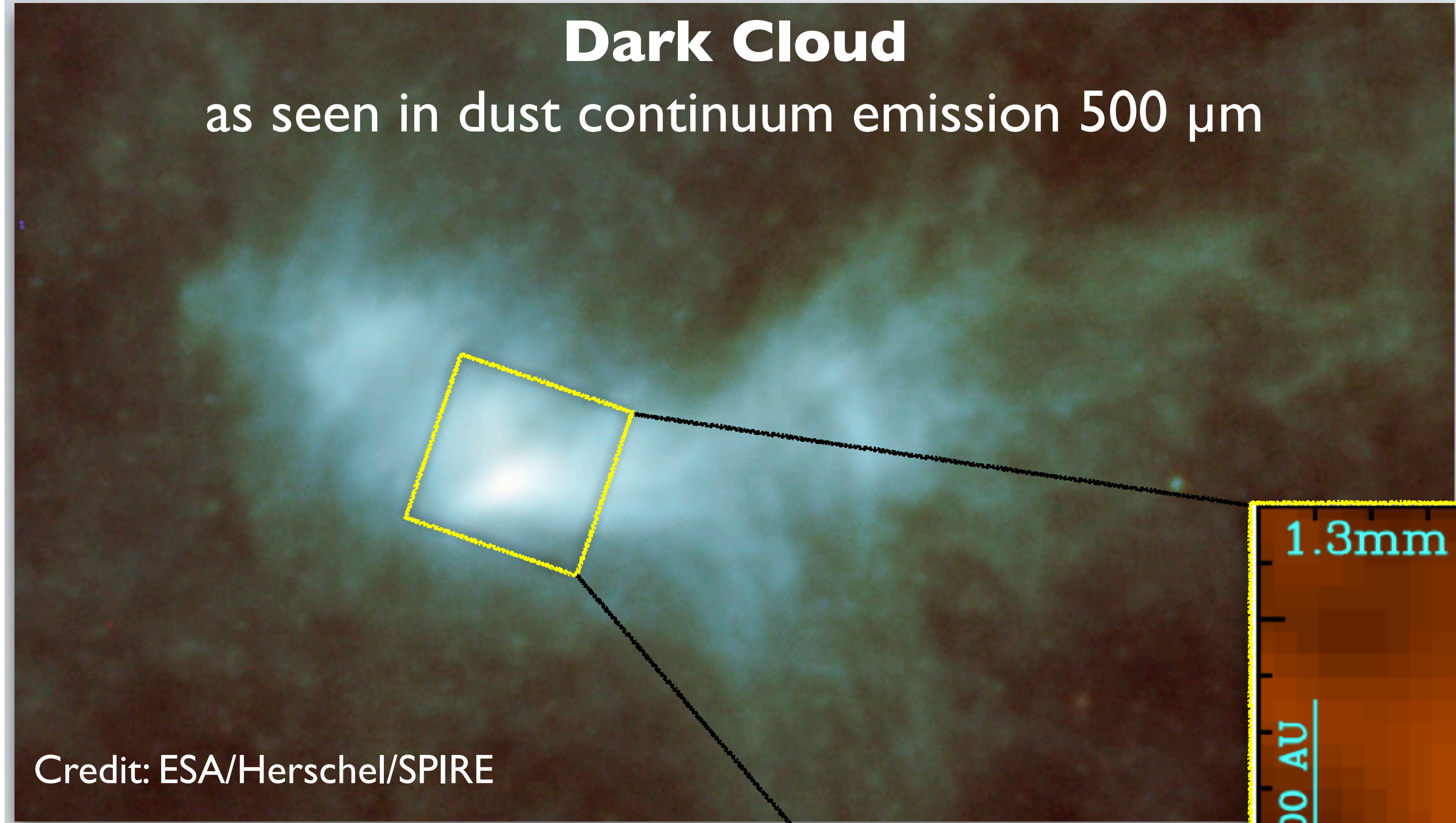
Center for Astrochemical Studies,

Max-Planck-Institute for extraterrestrial Physics

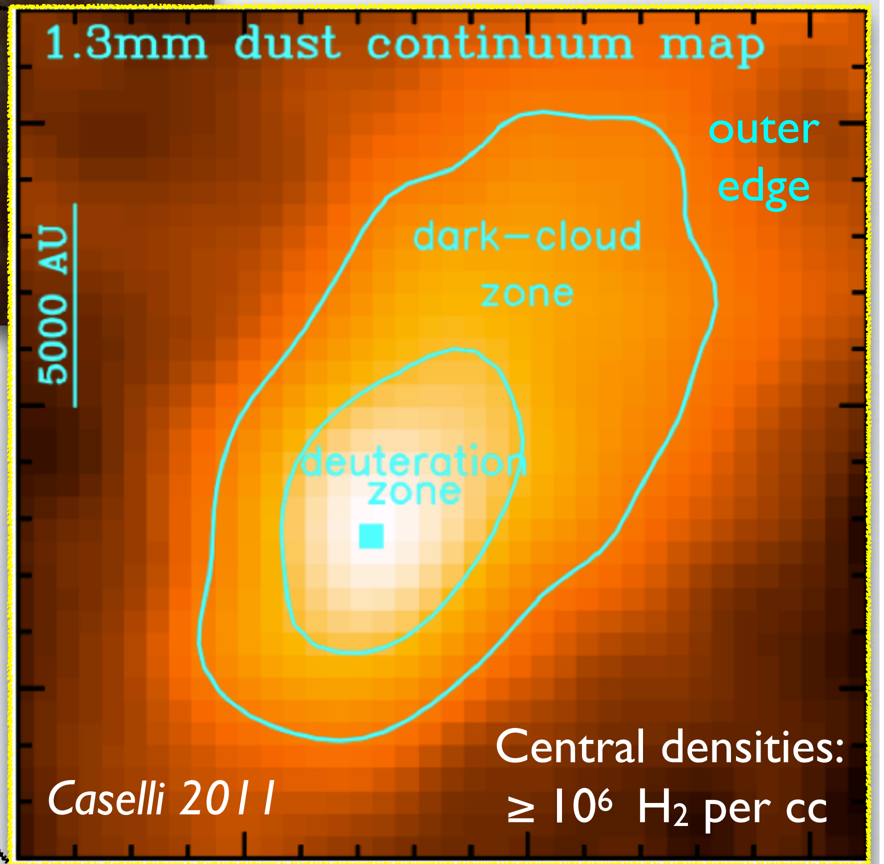
Q: What are the initial conditions of star and protoplanetary disk formation?

Image credit: Alves+(2001)

From dark clouds to pre-stellar cores



Pre-stellar core



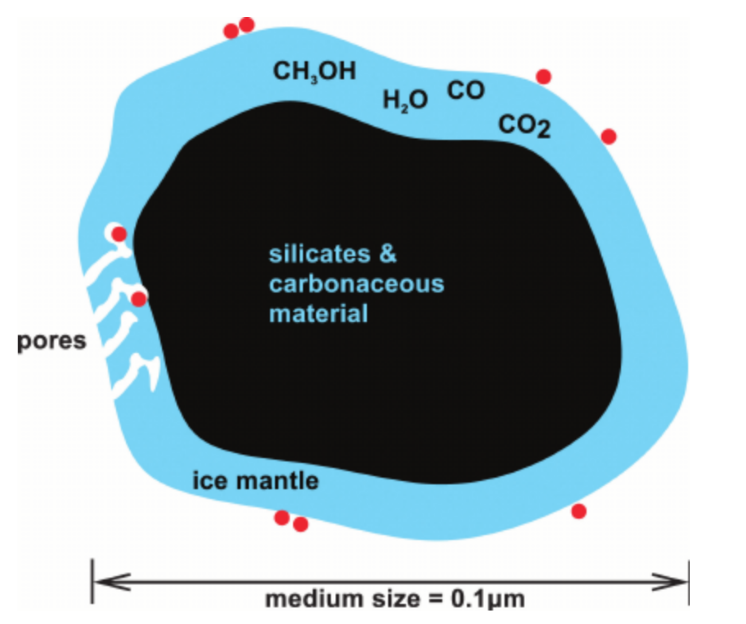
In pre-stellar cores, the gas temperature drops to ~6 K

→ molecular freeze-out

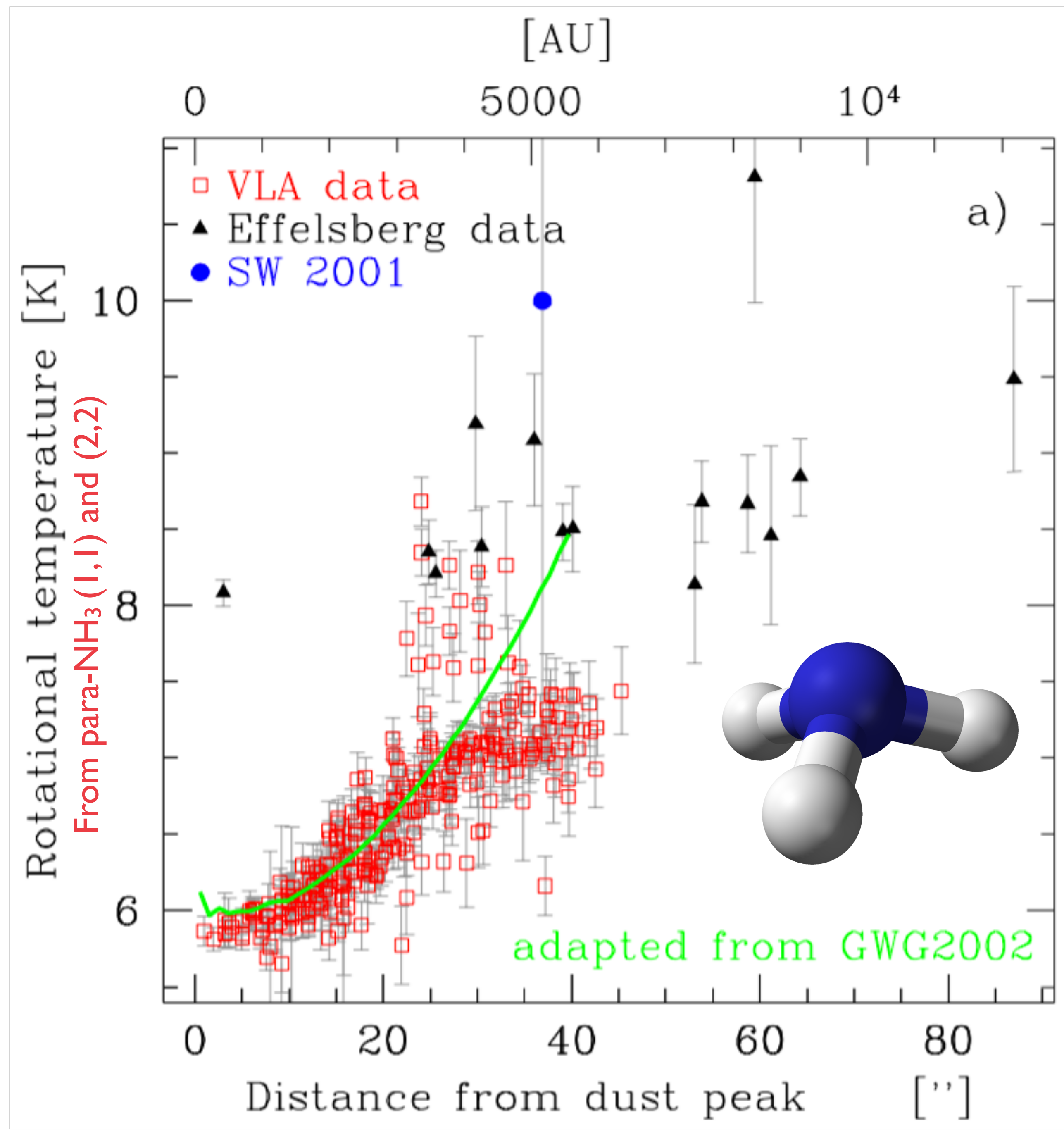
(>90% CO in ice; *Caselli+1999*)

and D-fractionation

(D/H > 20%; Redaelli+2019).



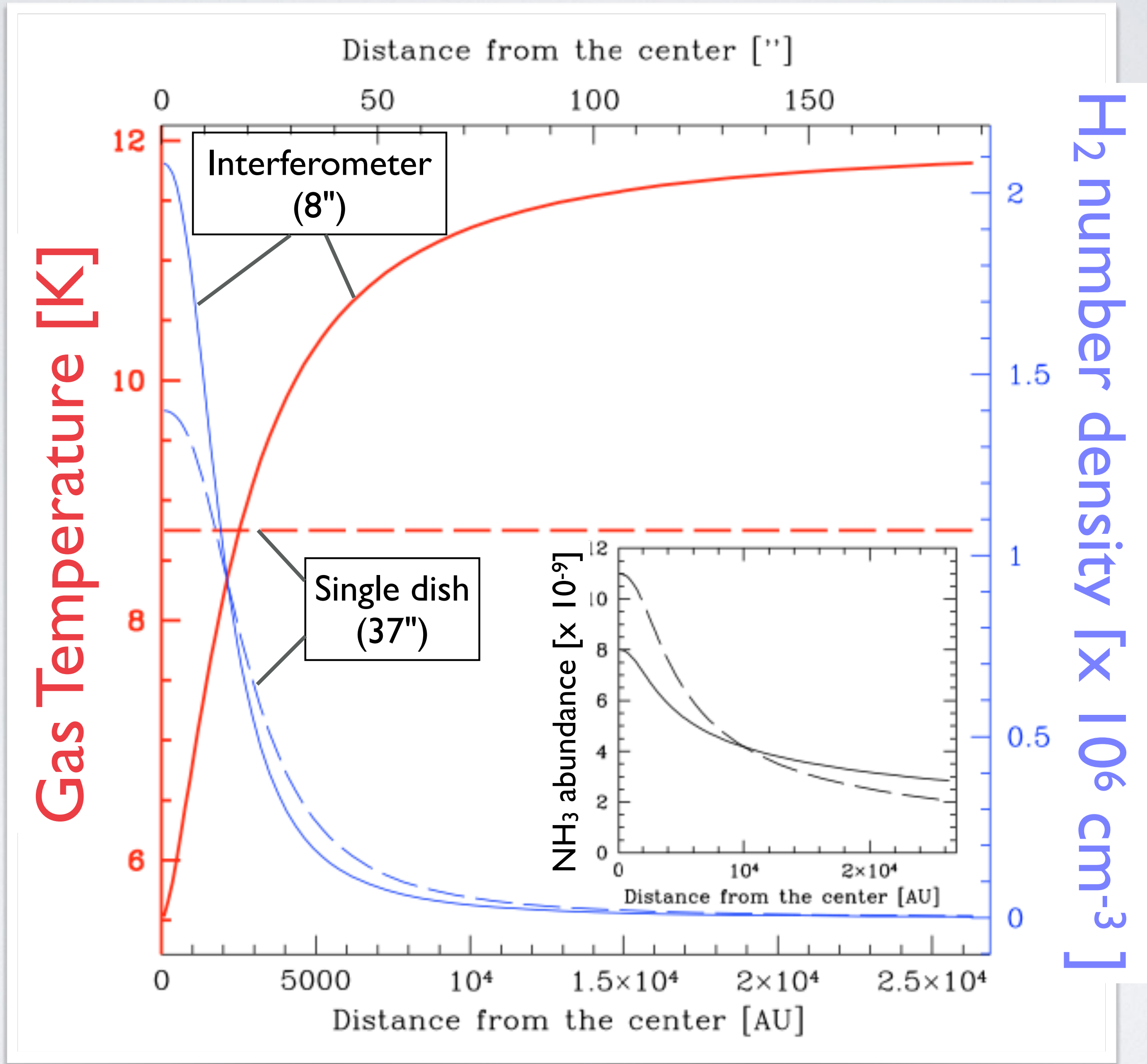
Karssemejer et al. 2012, PCCP



Crapsi, Caselli, Walmsley, Tafalla 2007

Do we really understand molecular emission?

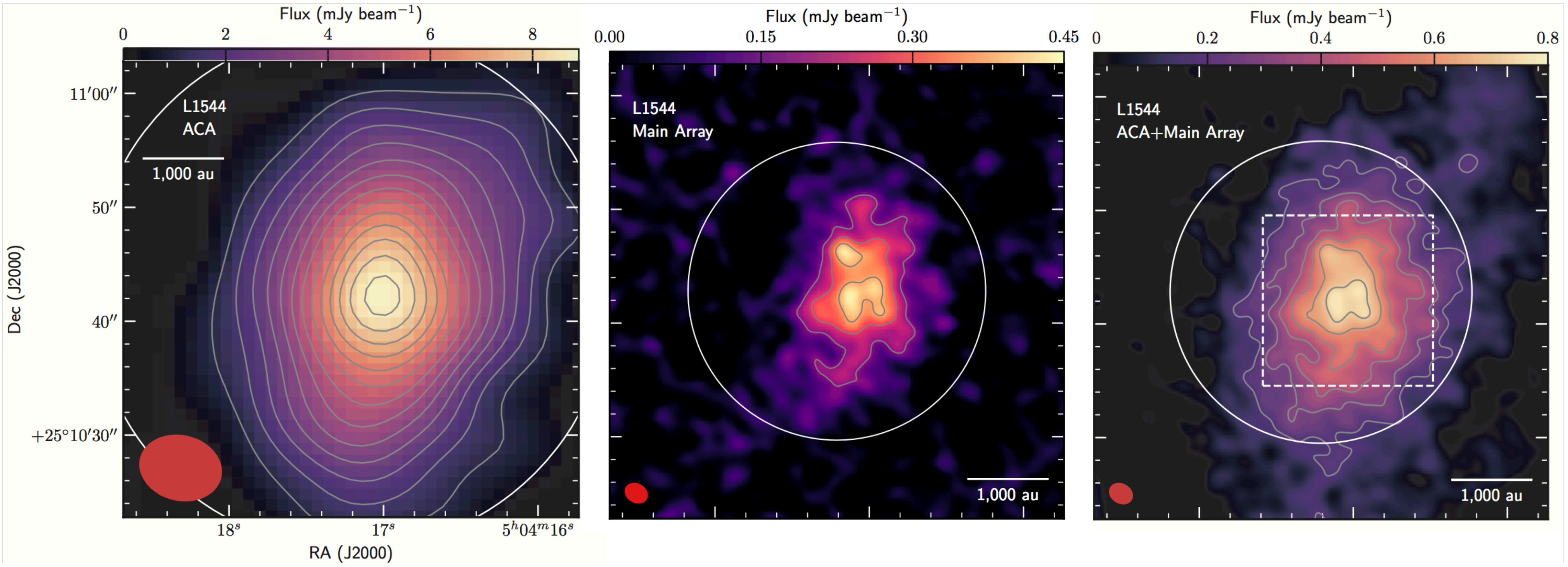
With VLA observations: higher central density, lower temperature and lower NH_3 abundance than with single dish



Crapsi, Caselli, Walmsley, Tafalla 2007

ALMA observations of a 8 $M_{\odot}$ pre-stellar core reveal a dense (10^6 cm^{-3}) "kernel" of 0.1 $M_{\odot}$ and radius 1400 au

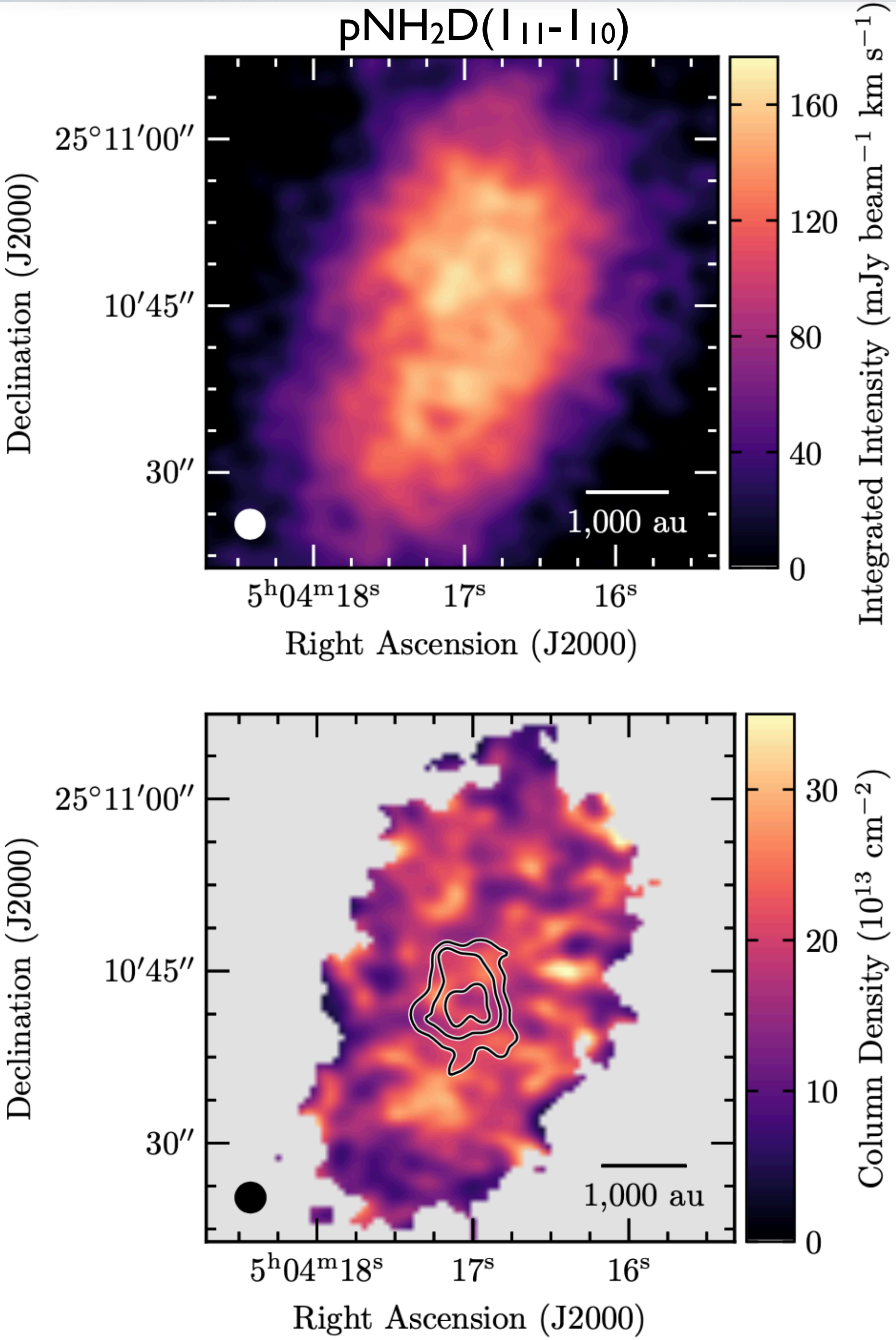
1.3mm continuum of L1544 with 2" resolution



consistent with *non-ideal MHD simulations* of a contracting pre-stellar cores with peak density ~10^7 cm^{-3}.

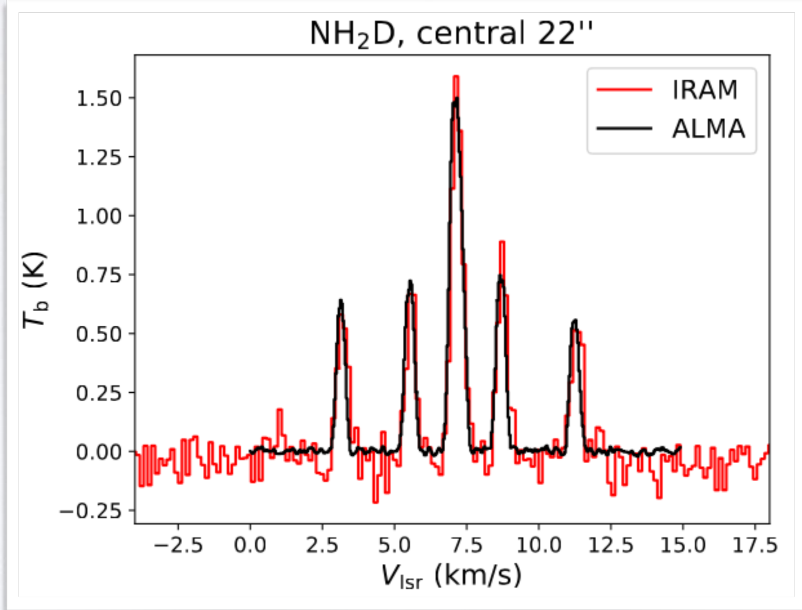
Caselli, Pineda, Zhao+ 2019 *(see also Keto, Caselli & Rawlings 2015)*

Deuterated ammonia toward the L1544 kernel



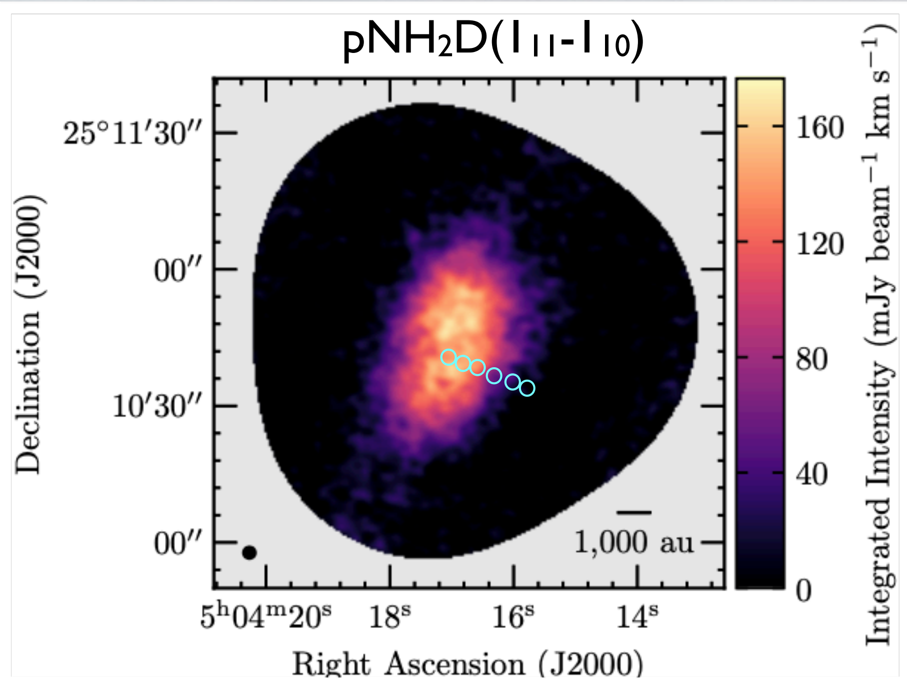
L1544 ALMA (12m+ACA) Band 3 mosaic observations of $pNH_2D(1_{11}-1_{10})$ with angular resolution 2.5" (338 au).

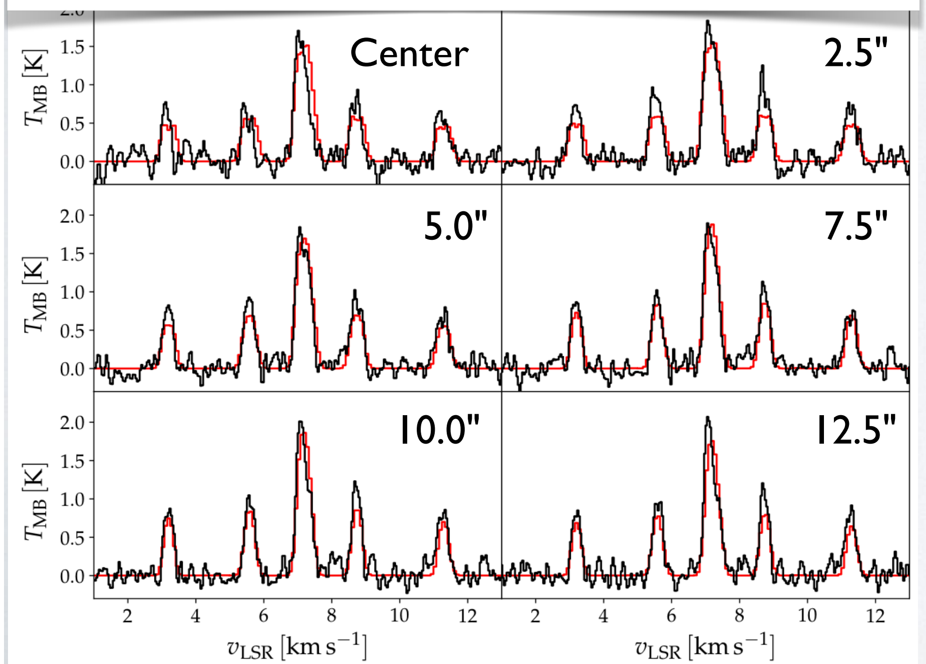
No missing flux, beautiful lines :)



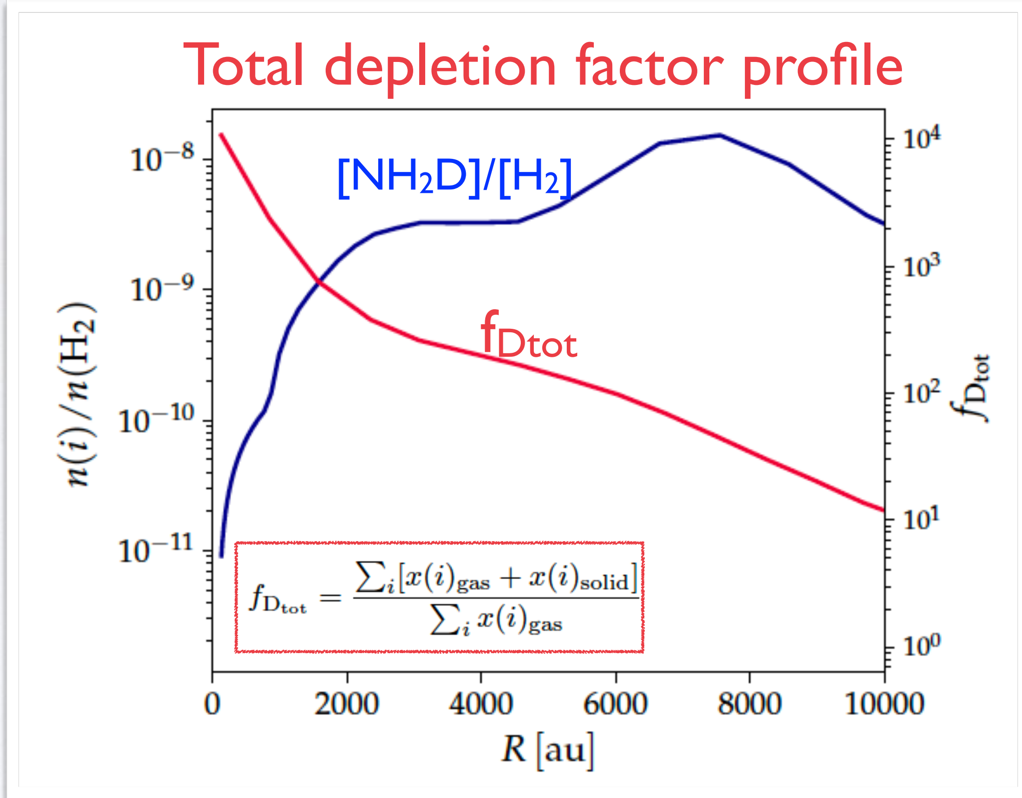
Caselli, Pineda, Sipilä+2021, in prep.

99.99% of all species heavier than He are frozen in the central 1000 au of a pre-stellar core





L1544 **ALMA**-Band 3 observations + comparison with gas-grain chemical/RT model: *NH_2D abundance sharply drops in the central 2000 au.*



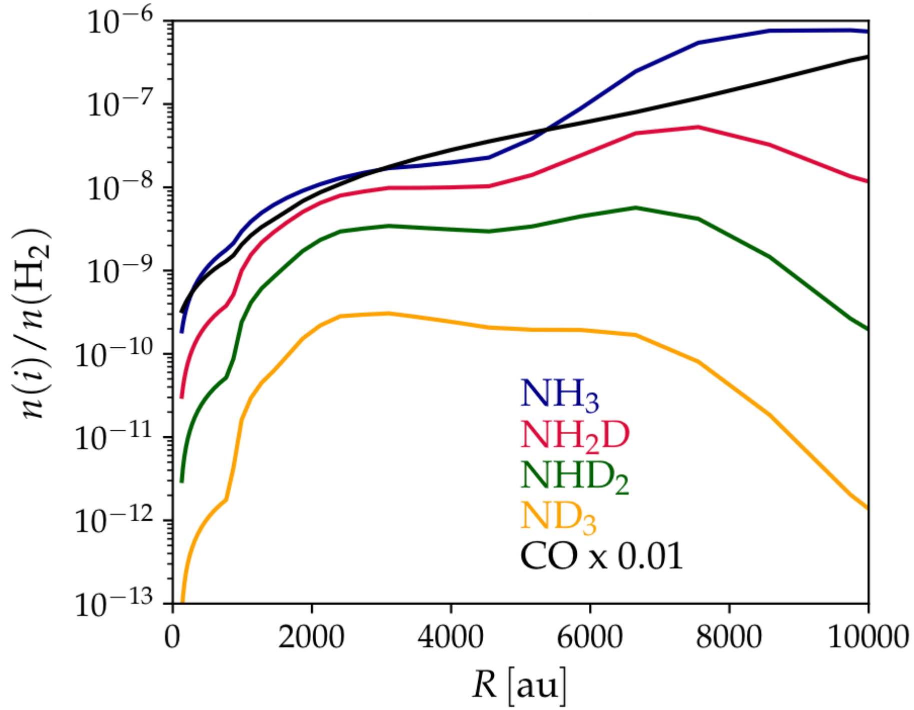
$$f_{\mathrm{D_{tot}}} = \frac{\sum_i [x(i)_{\mathrm{gas}} + x(i)_{\mathrm{solid}}]}{\sum_i x(i)_{\mathrm{gas}}}$$

Caselli, Pineda, Sipilä+2021, in prep.

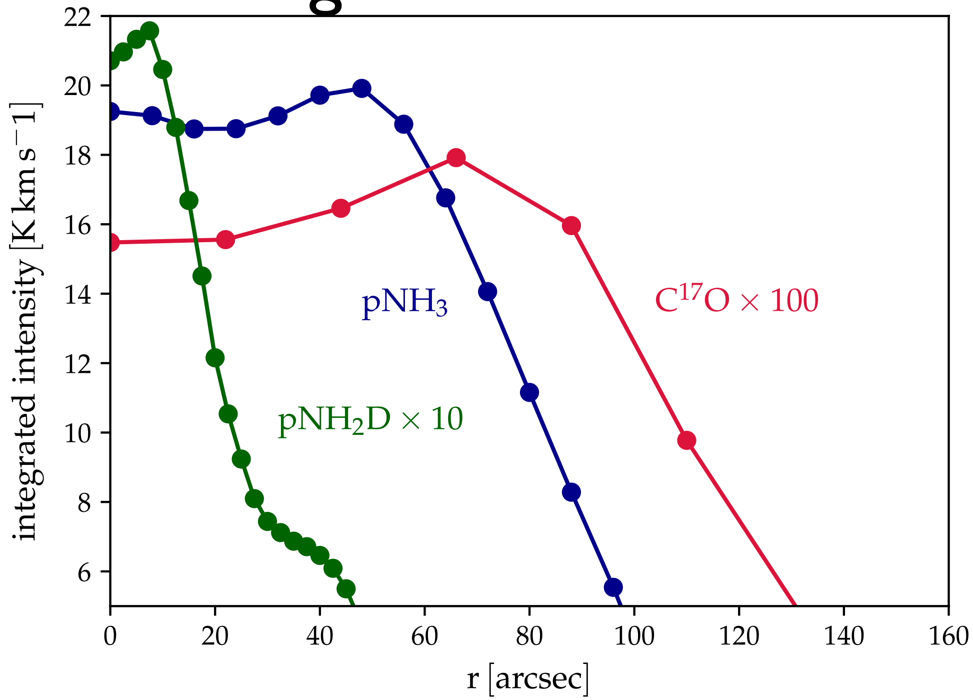
Do we really understand molecular emission?

Yes, if we have a good understanding of the physical structure + high angular and spectral resolution observations

Predicted Abundances

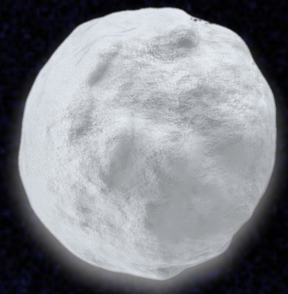


Integrated Intensities



Important to take into account excitation conditions !

Just before stellar birth, almost all (99.99%) species heavier than He reside on dust grain surfaces in the central 2000 au of a pre-stellar core.



Dust grains are covered with thick icy mantles, promoting dust coagulation and possibly preserving pre-stellar chemistry into the next stages of planet formation.

Image credit: Alves+(2001)

Q1: Does catastrophic freeze-out affect the structure of the future protoplanetary disk?

Q2: How does the core environment affect the structure and evolution of PSCs?

Q3: What is stopping material accretion from filament to core and from core to disk?

Q4: Can asymmetric accretion be at the origin of fragmentation during contraction?