Impact of ionization compression on star formation

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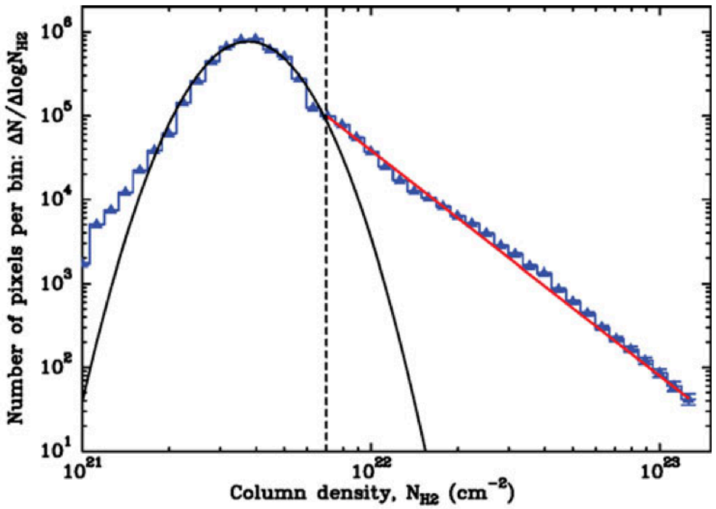
Age of OB associations in the Galaxy

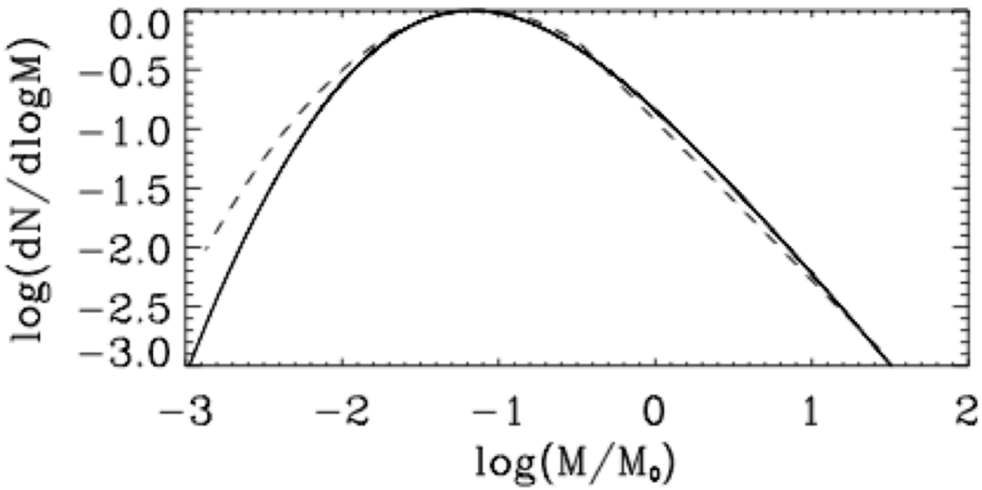
P. Tremblin, L.D. Anderson, P. Didelon, A. Raga et al.

A&A 2014 568A.4T

- Is feedback and ionization important to take it into account to understand the IMF?



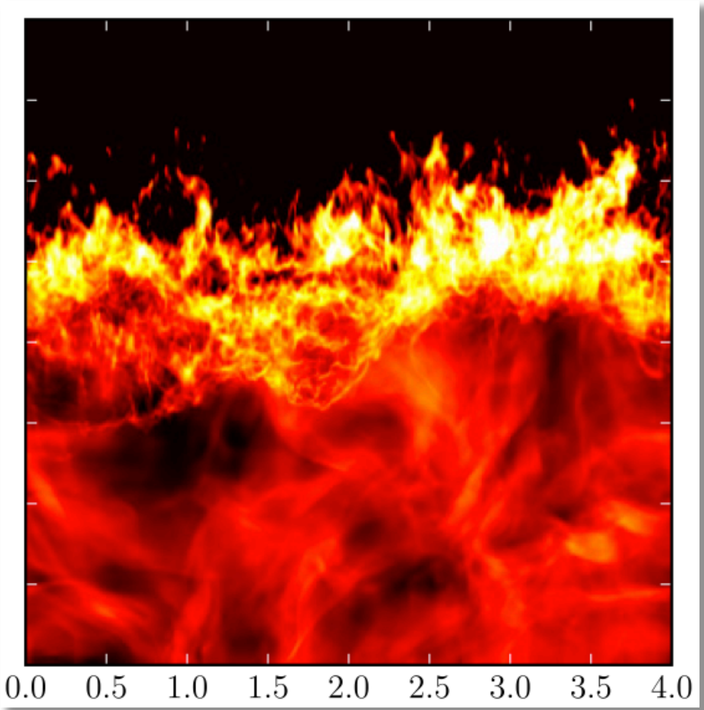
Observed PDF Aquila
André et al 2011



Modelled versus observed IMF
Padoan & Nordlund 2004
Hennebelle & Chabrier 2008

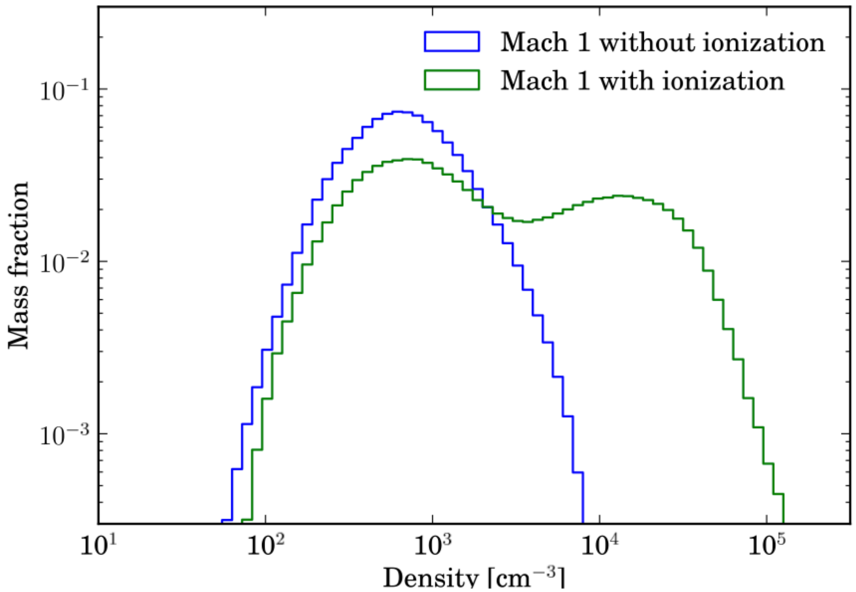
- What is ionization and compression from ionization ?

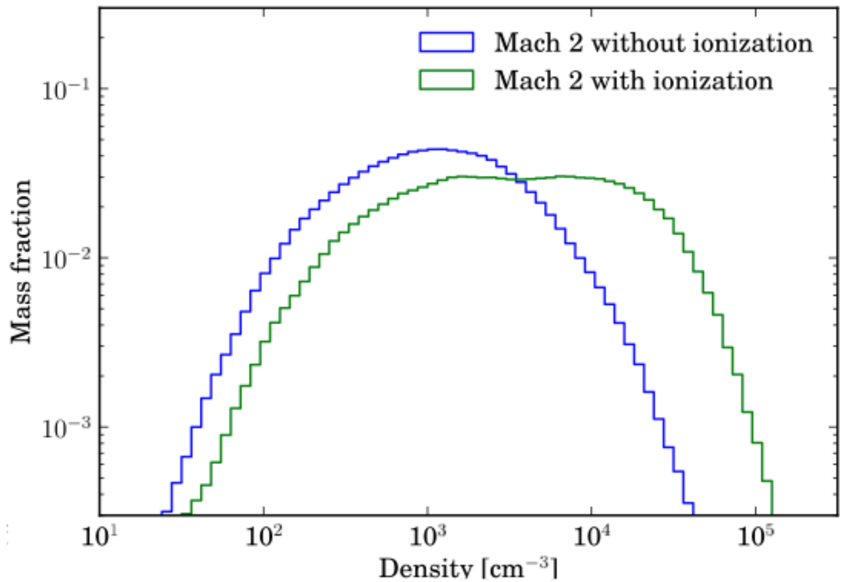
Eagle Nebula (Hill et al. 2012) HOBYS



Turbulent-ionized simulation (Tremblin et al. 2012)
HERACLES code

- How do we see the compression from ionization ?





Turbulent-ionized simulation (no gravity)
(Tremblin et al. 2012)

- Double-peaked or enlarged PDF of the gas

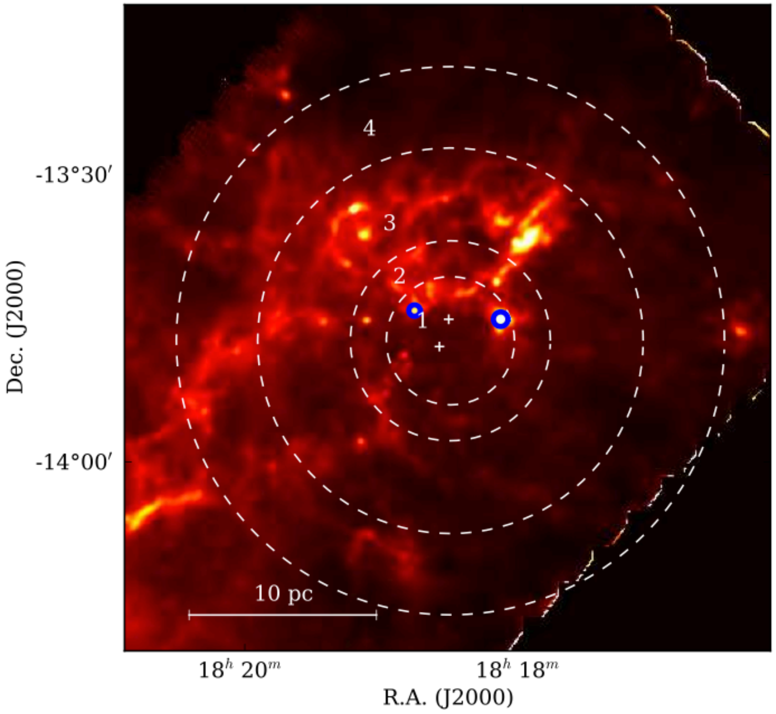
- What is the shape of the second component ?

  - If the turbulence is important in the compressed layer: lognormal shifted at higher densities by the square of the Mach number of the driven shock

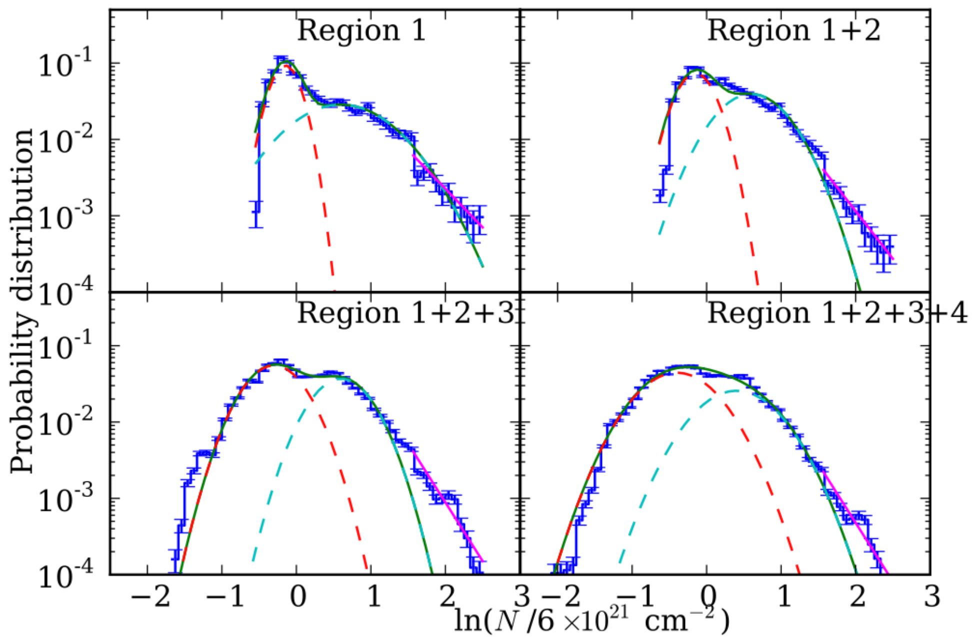
  - If the turbulence is low in the compressed layer: it is homogeneous and you expect a power-law profile in the PDF (similar to the power-law in a PDF of a spherical collapsing clump)

Unperturbed turbulent cloud	Compressed layer	Influence of gravity
Lognormal at low column densities	Lognormal (turbulent) or Power-law (homogeneous)	Power-law at highest column densities

➢ Do we see it in observations ? Herschel column densities

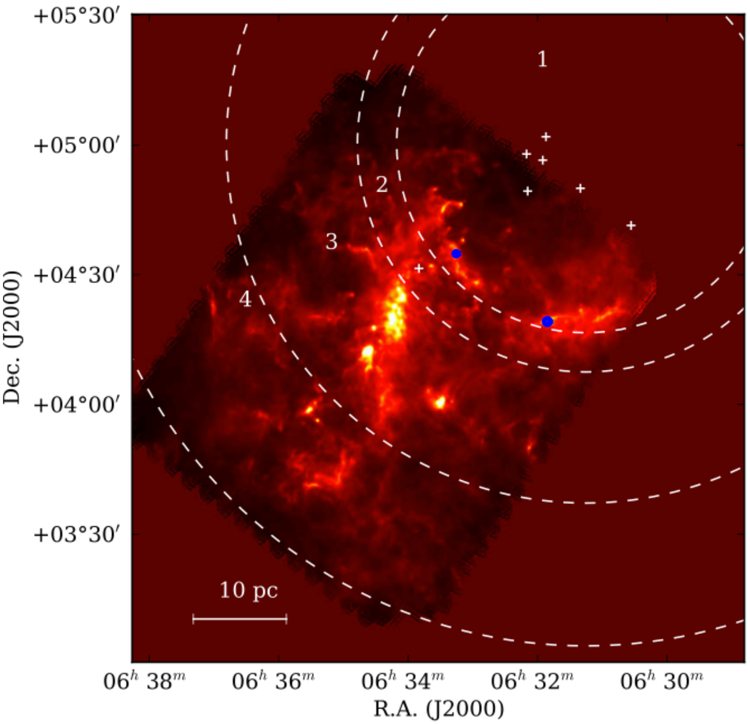


M16 column density map (Hill et al. 2012)

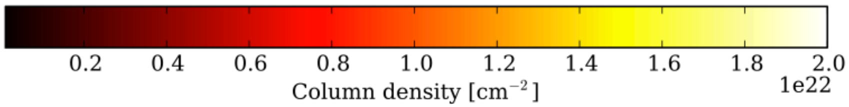


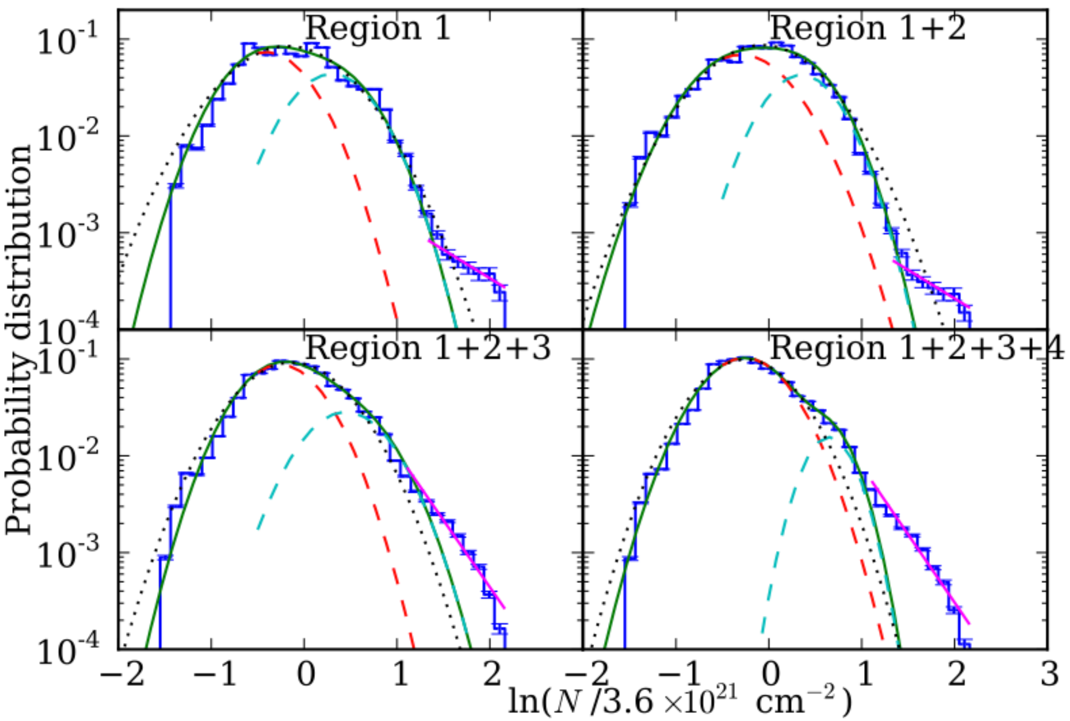
Tremblin et al. 2014

➤ Is a two-lognormal fit better than a single one for enlarged distribution ?



Rosette column density map (Schneider et al. 2012)

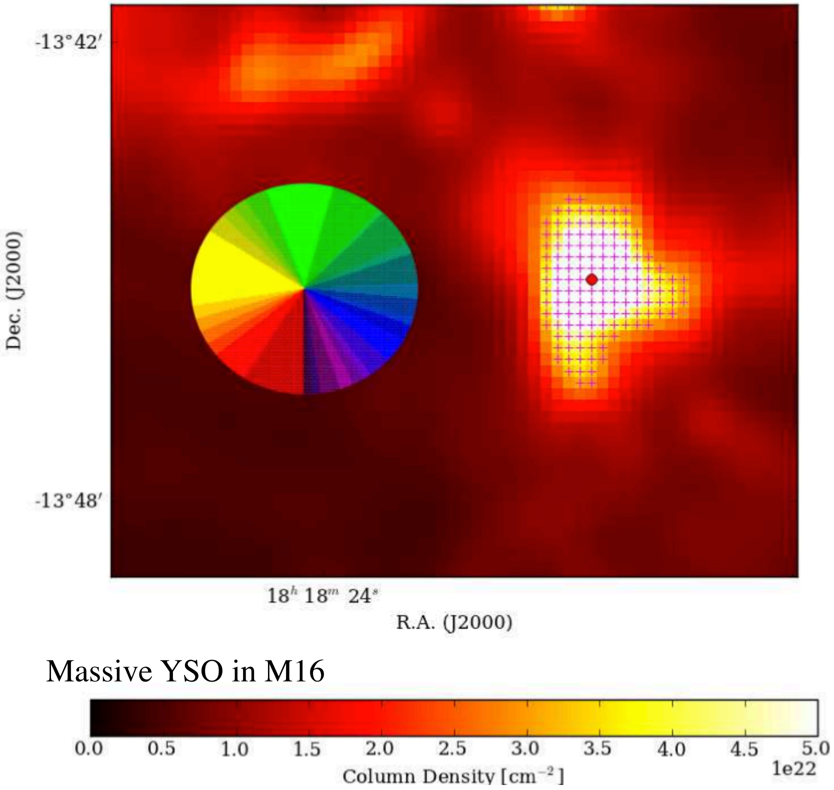




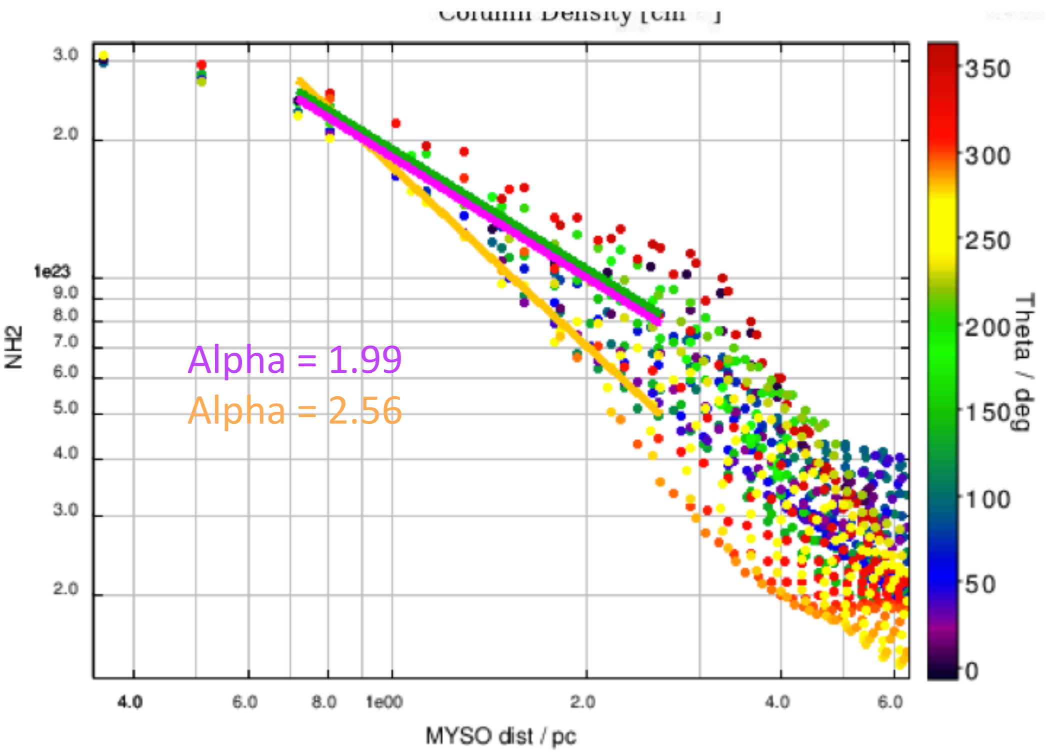
Tremblin et al. 2014

- Also small scale compression !

Steeper radial profile: distinguish between forced-fall and free-fall collapse

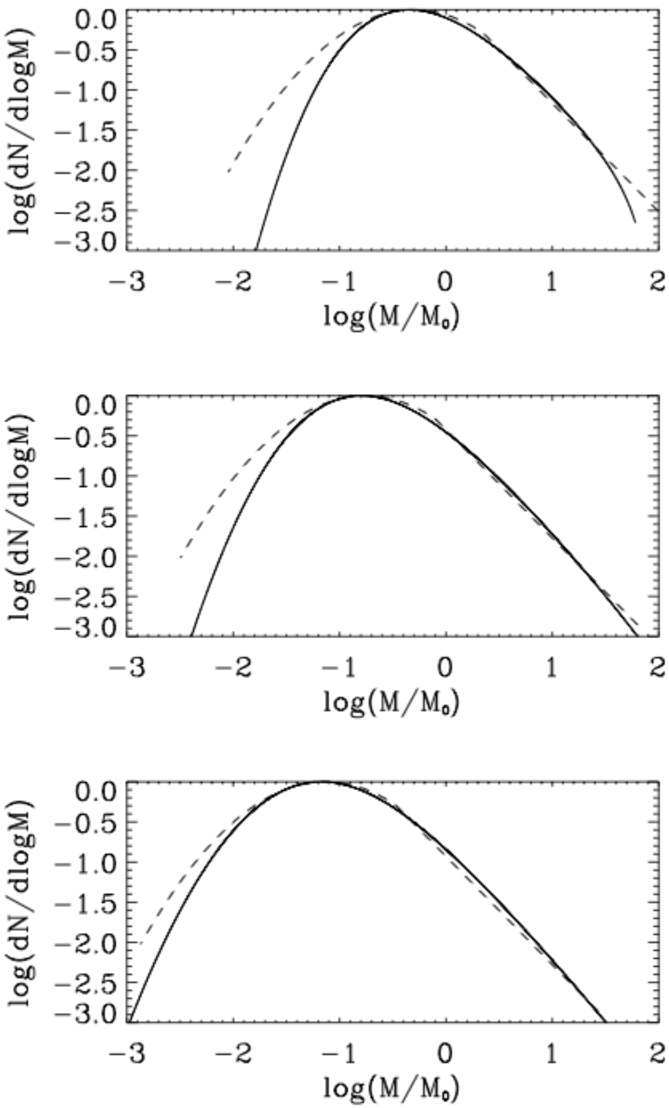


Massive YSO in M16



See also Russeil et al. 2013

- Important for the understanding of star formation and the IMF?



Mach 6

Mach 12

Mach 25

Hennebelle & Chabrier 2008

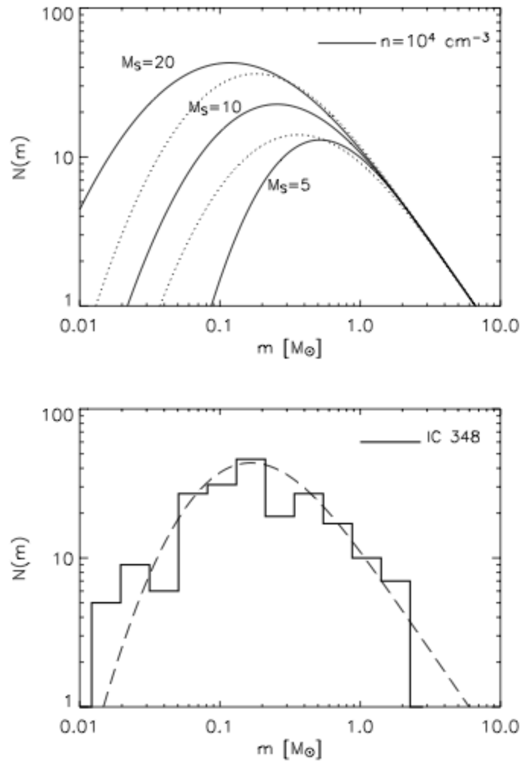
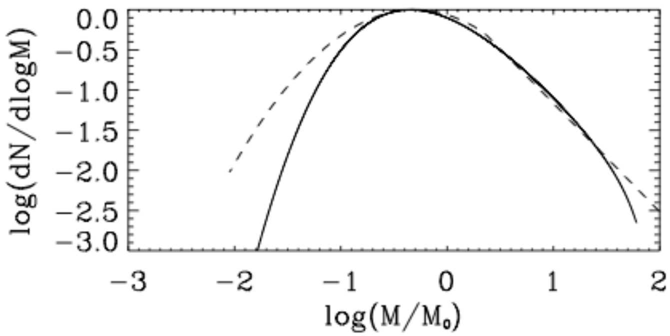
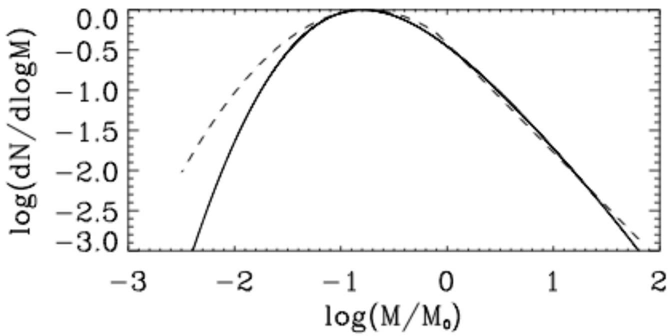


FIG. 2.—*Top*: Analytical mass distributions computed for $\langle n \rangle = 10^4$ cm^{-3}, $T = 10$ K, and for three values of the sonic rms Mach number, $M_S = 5$, 10, and 20 (*solid lines*). The dotted lines show the mass distribution for $T = 10$ K, $M_S = 10$, and $\langle n \rangle = 5\times10^3$ cm^{-3} (*lower curve*) and $\langle n \rangle = 2\times10^4$ cm^{-3} (*upper curve*). *Bottom*: IMF of the cluster IC 348 in Perseus obtained by Luhman et al. (2003) (*solid line histogram*) and theoretical IMF computed for $\langle n \rangle = 5\times10^4$ cm^{-3}, $T = 10$ K, and $M_S = 7$ (*dashed line*). The histogram of the IC 348 mass function in Luhman et al. (2003) is computed with 9 bins, while the histogram shown here is computed with 12 bins.

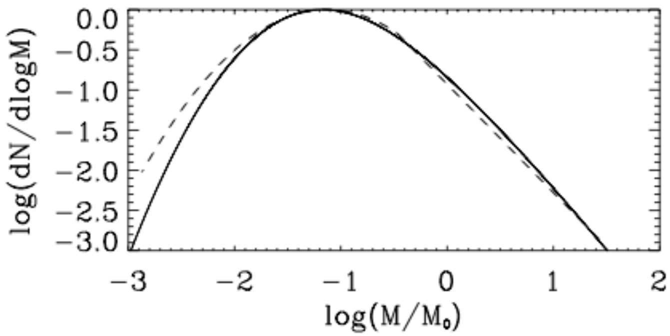
Padoan & Nordlund 2004



Mach 6



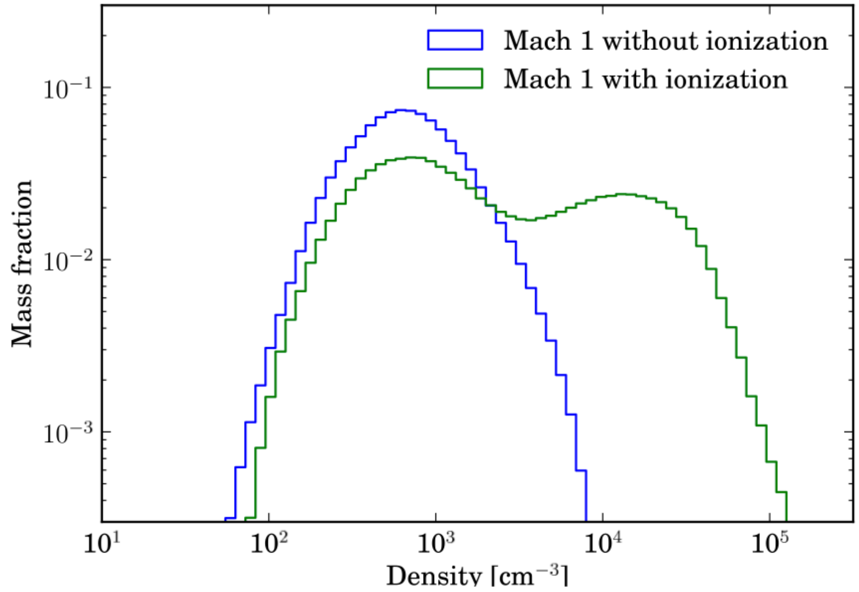
Mach 12



Mach 25

Hennebelle & Chabrier 2008

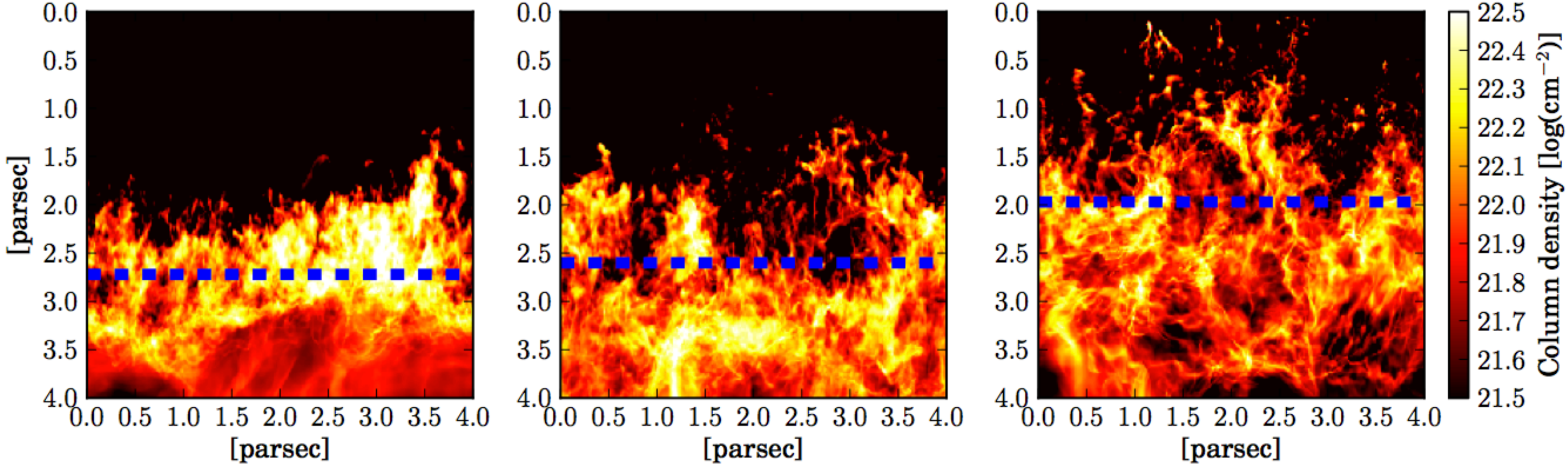
- ➢ Important for the understanding of star formation and the IMF?



- ➢ Feedback compression can enlarge PDF while keeping a realistic turbulent level for the cloud

➢ Dating of OB associations
from their associated Hii regions

➢ The development of the Hii region is slowed down by the turbulence



- Dynamics of the ionization front (Raga et al 2012):

$$\frac{1}{c_{II}}\frac{dr}{dt} = \left(\frac{r_s}{r}\right)^{\beta} - \frac{c_0^2}{c_{II}^2}\left(\frac{r}{r_s}\right)^{\beta}$$

- Spitzer 1978, Dyson 1980

$$\begin{aligned} r_s &= (3S_*/4\pi n_0^2\alpha)^{1/3} \\ c_{II}t/r_s &= 4/7 \times ((r/r_s)^{7/4} - 1) \\ P_{II} &= n_0(r_s/r)^{3/2}k_bT_{II} \end{aligned}$$

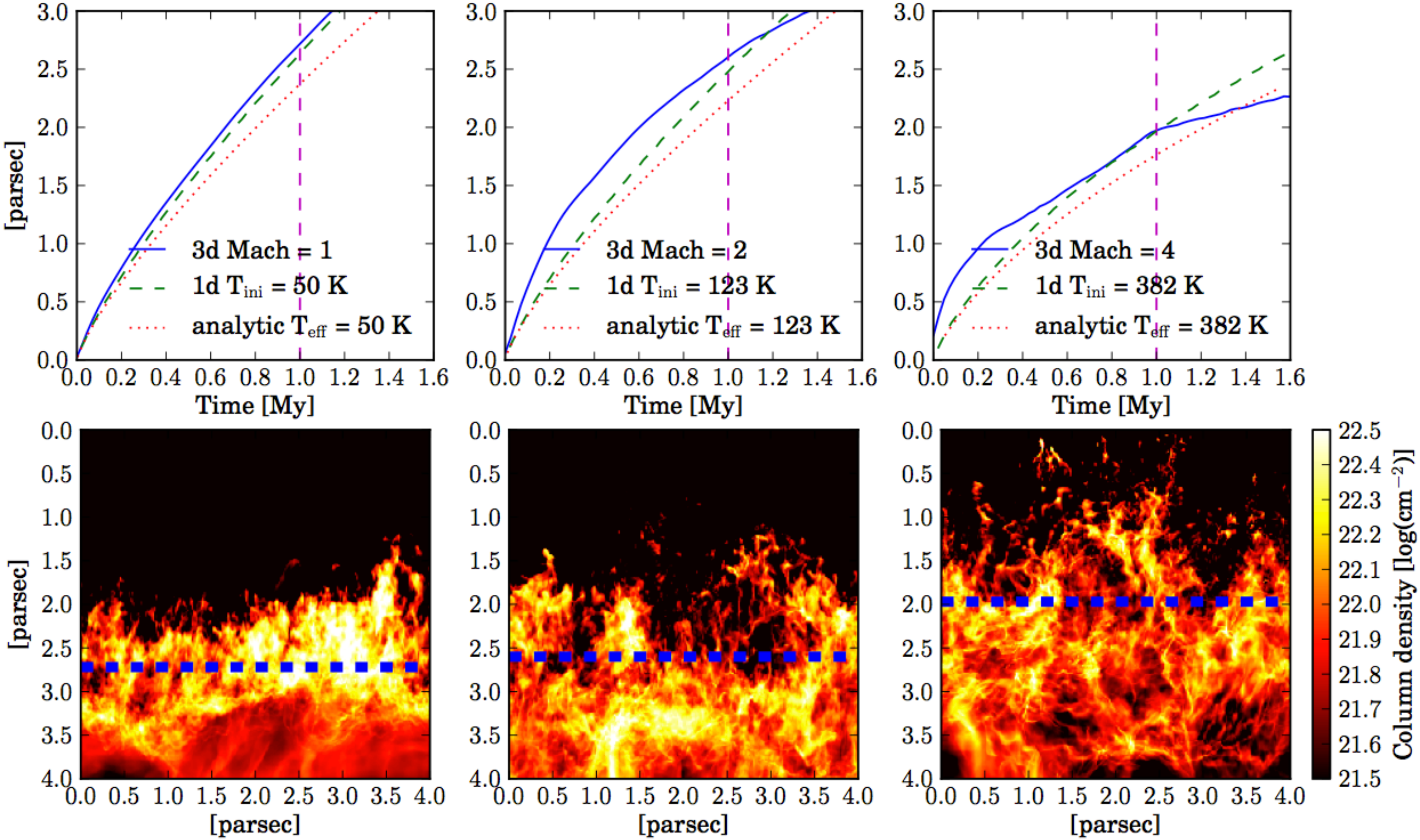
- Raga et al 2012, Tremblin et al 2014

$$c_{II}t/r_s = f(r/r_s, c_0^2/c_{II}^2) - f(1, c_0^2/c_{II}^2)$$

$$r_{eq} = r_s(c_{II}/c_0)^{4/3}$$

- $P_{II} > P_0$

➢ Dating of OB associations from their associated Hii regions



➢ Dating of OB associations from their associated Hii regions

➢ 1D generic spherical models with HERACLES in Larson's law "profiles" :

$$\langle\sigma\rangle = 1.1\text{km/s}\left(\frac{r}{\text{pc}}\right)^{0.38}$$

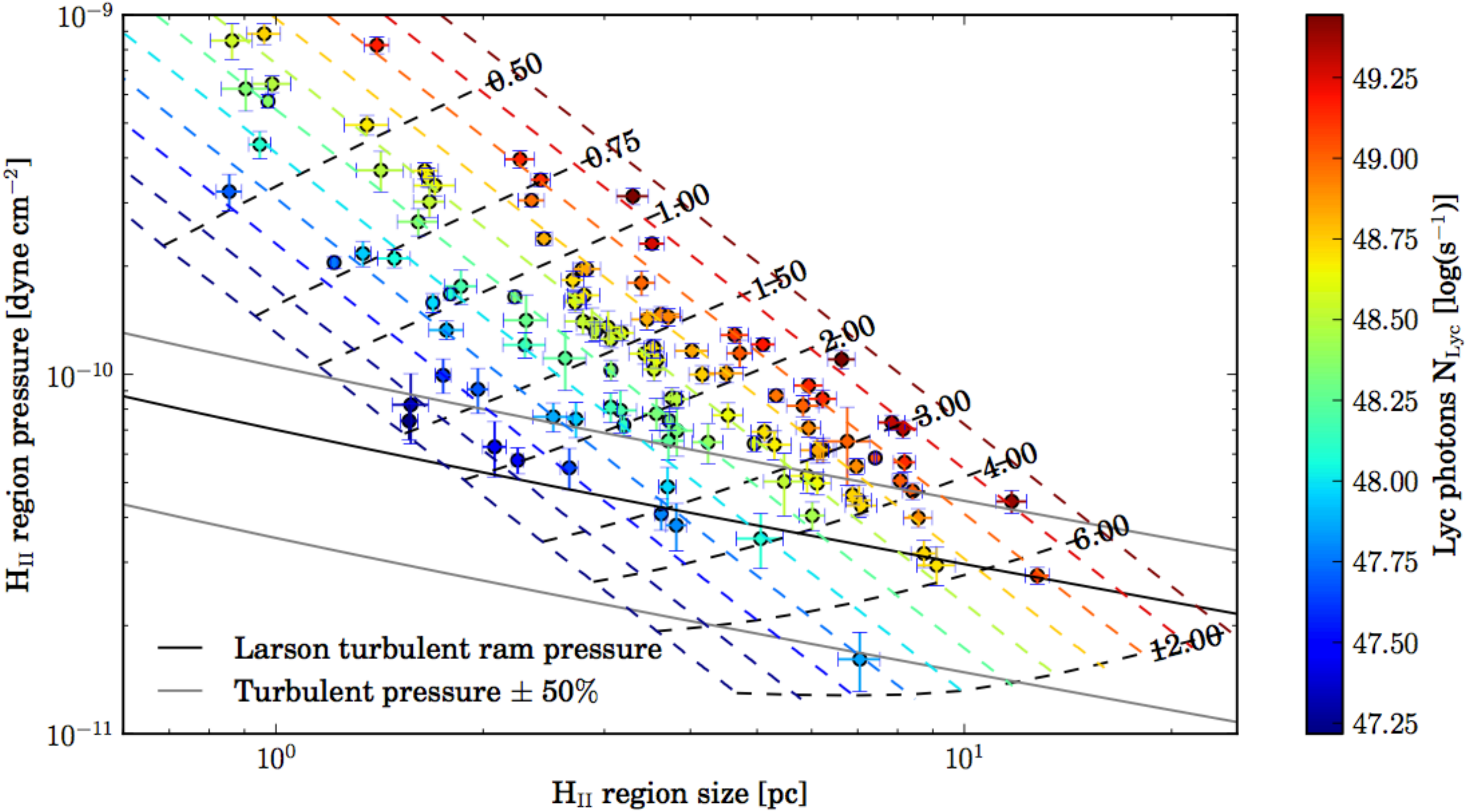
$$\langle n\rangle = 3400\text{cm}^{-3}\left(\frac{r}{\text{pc}}\right)^{-1.1}$$

$$P_{\text{turb}} \approx \langle\rho\rangle(c_0^2 + \langle\sigma\rangle^2/3)$$

➢ These simulations can be used to get an estimation of the age of the OB association:

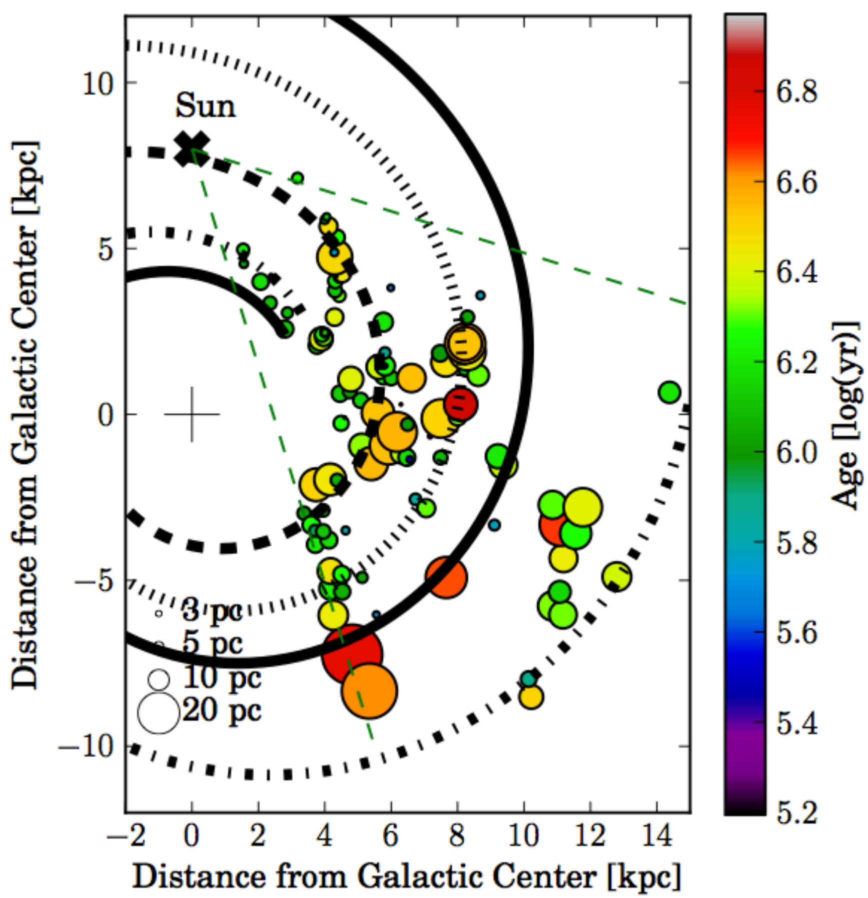
Cloud (D) [kpc]	Radius [pc]	$S_\nu(\nu)$ [Jy](GHz)	Phot. Age [Myr]	Dyn. Age [Myr]
Rosette (1.6[a])	18.7±1.2[b]	350(4.75)[b]	≤ 5[c]	5.0±0.4
M16 (1.75[d])	7.2±0.7[e]	117(5)[e]	2-3[f]	1.9±0.2
RCW79 (4.3[g])	7.1±0.3[h]	19.5(0.84)[h]	2-2.5[i]	2.2±0.1
RCW36 (0.7[j])	1.1±0.07[e]	30(5)[e]	1.1±0.6[k]	0.4±0.03

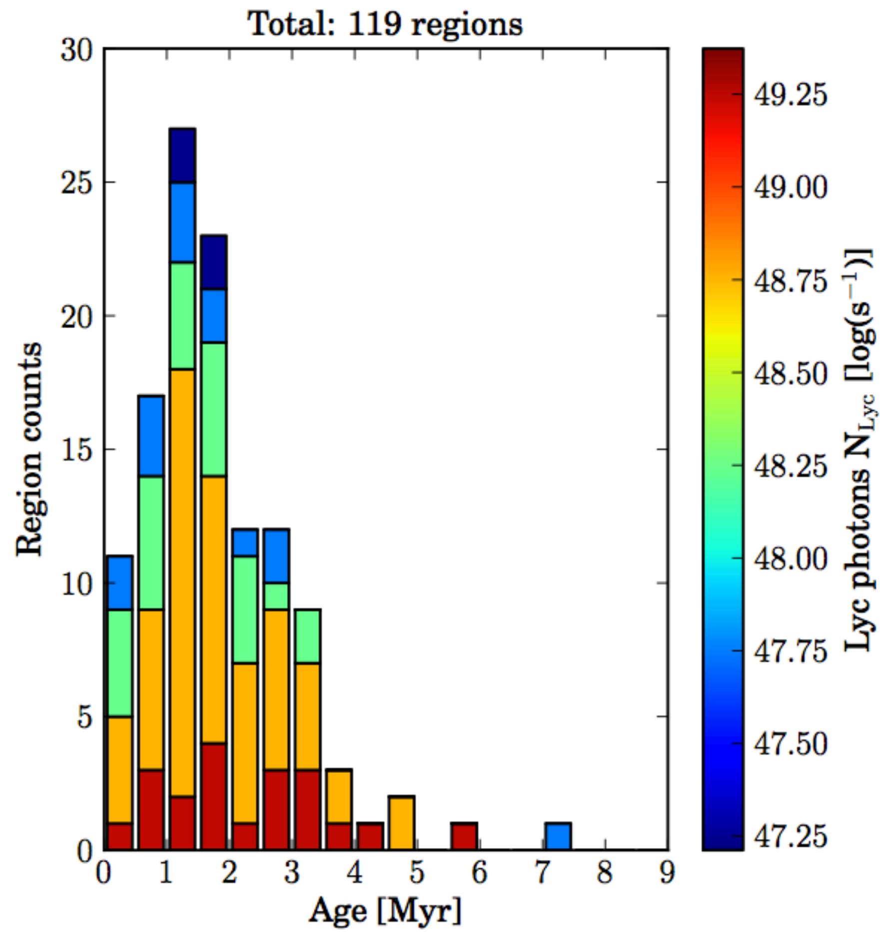
➢ Dating of OB associations
from their associated Hii regions



➢ Observations from the HRDS survey (Anderson et al 2011)

➢ Dating of OB associations from their associated Hii regions





- Summary

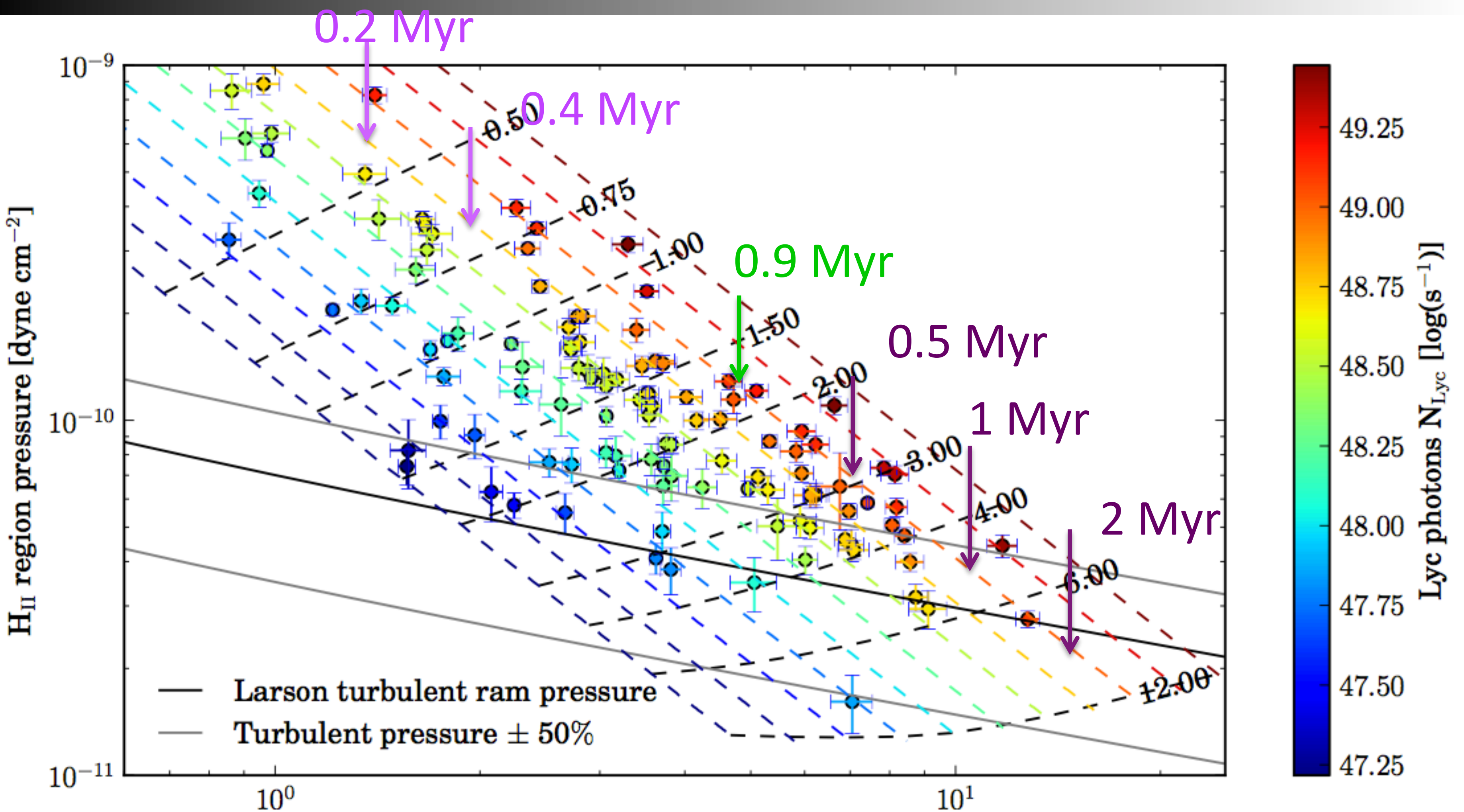
- Ionization compresses molecular clouds and can be identified in PDFs as a second lognormal (or power-law if homogeneous compressed layer) or enlarged distribution (if the initial turbulence is high).

- Compression is also seen on radial profiles of clumps allowing to distinguish free-fall collapse and forced-fall collapse:

  steep radial profile $r^{-\text{alpha}}$ with alpha > 2 (around 2.5)

- While the bubble expands and halt star formation in the ionized regions it forms a second generation of stars in a compressed layer. This second generation could be of importance to get a correct IMF with realistic Mach numbers in gravo-turbulent theories.

➢ Dating of OB associations from their associated Hii regions



➢ Comparison with simulations Arthur et al 2011, Dale et al 2014 (run UQ), Walch et al 2013

All <n> ~ 1000 cm-3 (Arthur no gravity, Walch ionization at start, Dale ionization after 3 free fall time, unbound cloud, explain the difference ??)

Does ionization after several free fall times match observations (RCW79 and M16 would be 3x bigger) ?