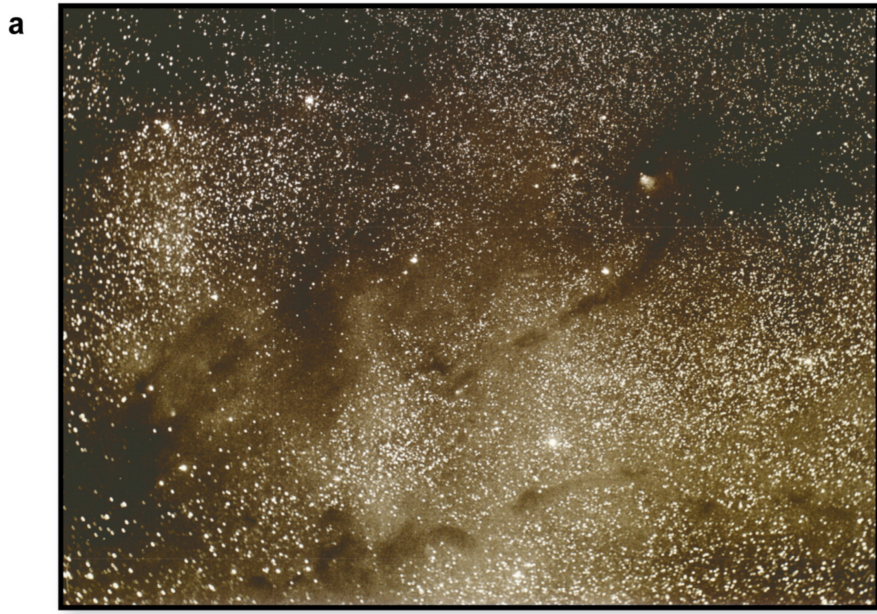
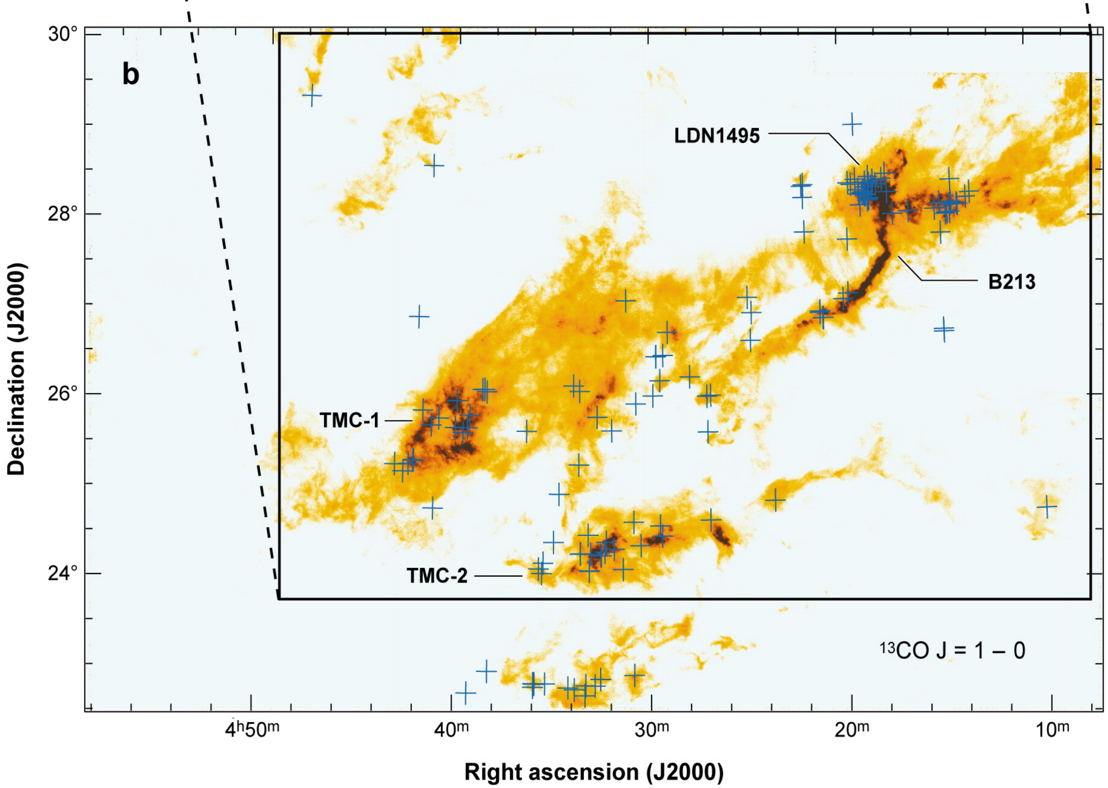

A step in the dark...
The initial conditions of
star formation in galaxies

Three fundamental questions on the formation of stars

- Where are the SF initial conditions set?
- What is their typical range?
- How do they affect the stellar Initial Mass Function (IMF)? (the mass spectrum of newly forme stars).



E.E. Barnard: Nebulous Region in Taurus (January 1907)



$$X_{\rm line}(n \geq n_\circ) = \frac{\int_{n_\circ}^{\infty} \left[\frac{dM(n)}{dn}\right] dn}{L_{\rm line}}$$

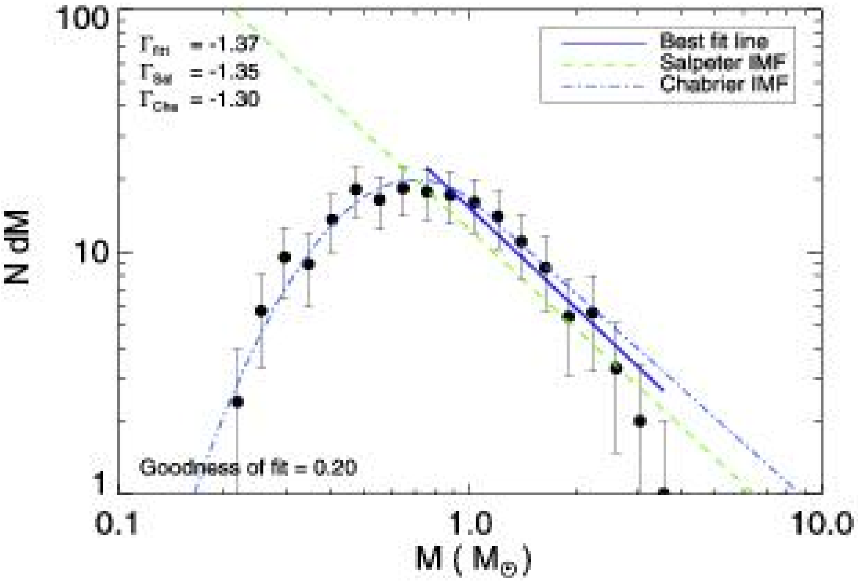
Total H_2 mass: CO J=1-0 ($n_\circ \sim 100\,\mathrm{cm}^{-3}$)

Dense H_2 mass: HCN J=1–0 ($n_\circ \sim 10^5\,\mathrm{cm}^{-3}$)

$$\tau_*(n_\circ) = \frac{M(n \geq n_\circ)}{\rm SFR}$$

Bergin EA, Tafalla M. 2007.
Annu. Rev. Astron. Astrophys. 45:339–96

The stellar Initial Mass Function (IMF)

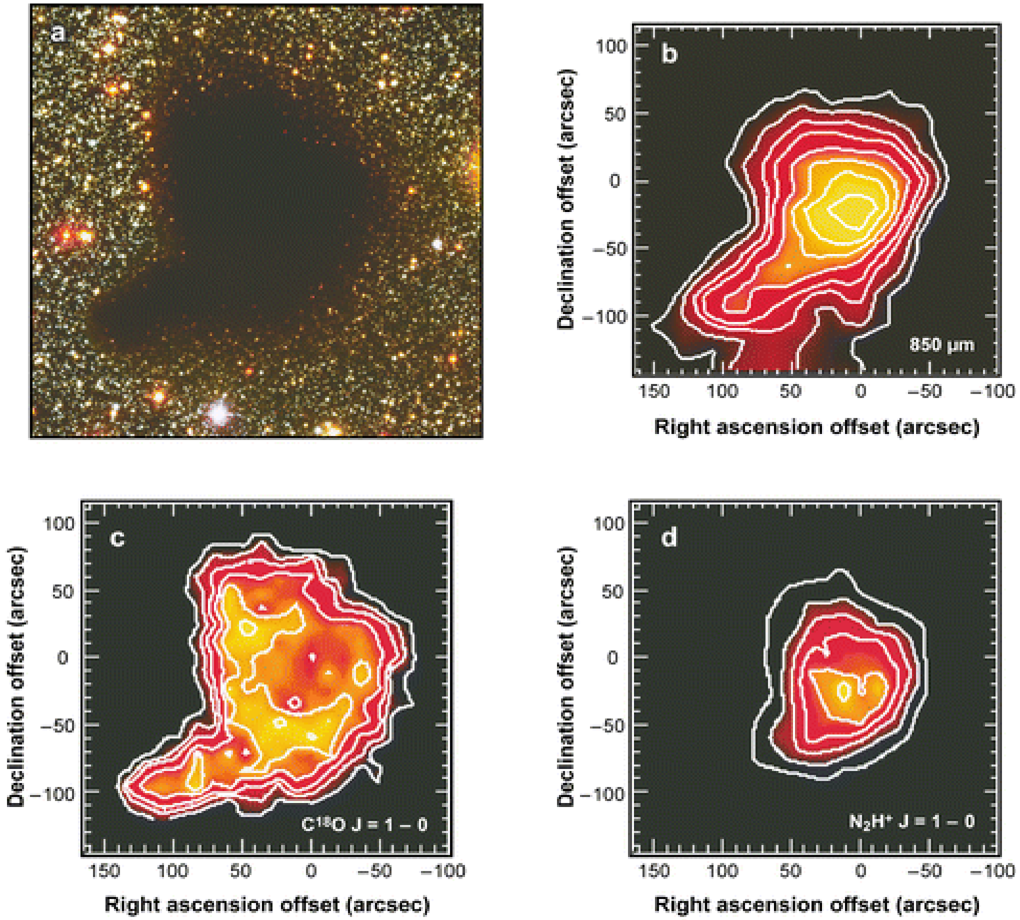


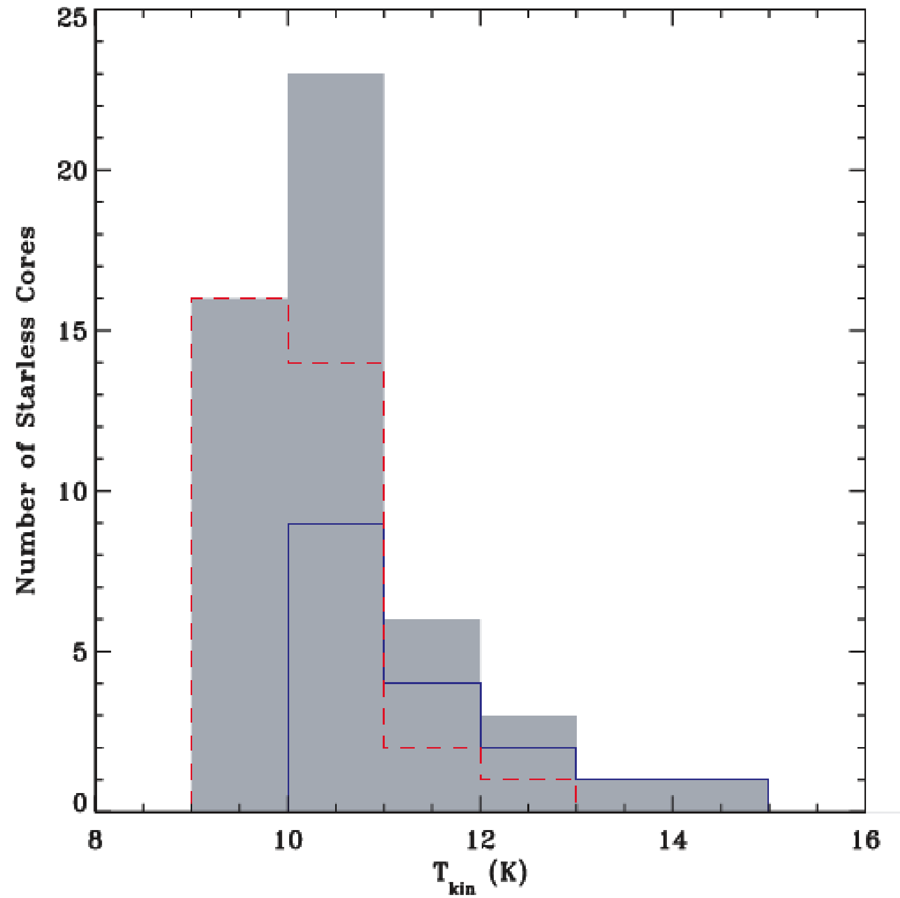
$$\psi(\mathrm{M}_*) = \frac{\mathrm{dn}(\mathrm{M}_*)}{\mathrm{dM}_*} \propto \mathrm{M}_*^{-x} \ \text{for}\,\mathrm{M} \gtrsim 1\,\mathrm{M}_\odot\,(x \approx 2.35)$$

$$\mathrm{SFR}_{\mathrm{obs}} = \mathrm{F}[\psi(\mathrm{M}_*), \mathrm{f}_{\mathrm{O,B\,stars}}(\lambda)] \times \mathrm{L}_\lambda$$

- is at the root of **<u>all</u>** astronomical observations used to obtain the star formation rate in galaxies.
- is a fundamental ingredient of **<u>all</u>** structure formation theories (....since they still have to make stars at the (very) end).

A universal stellar IMF(?)

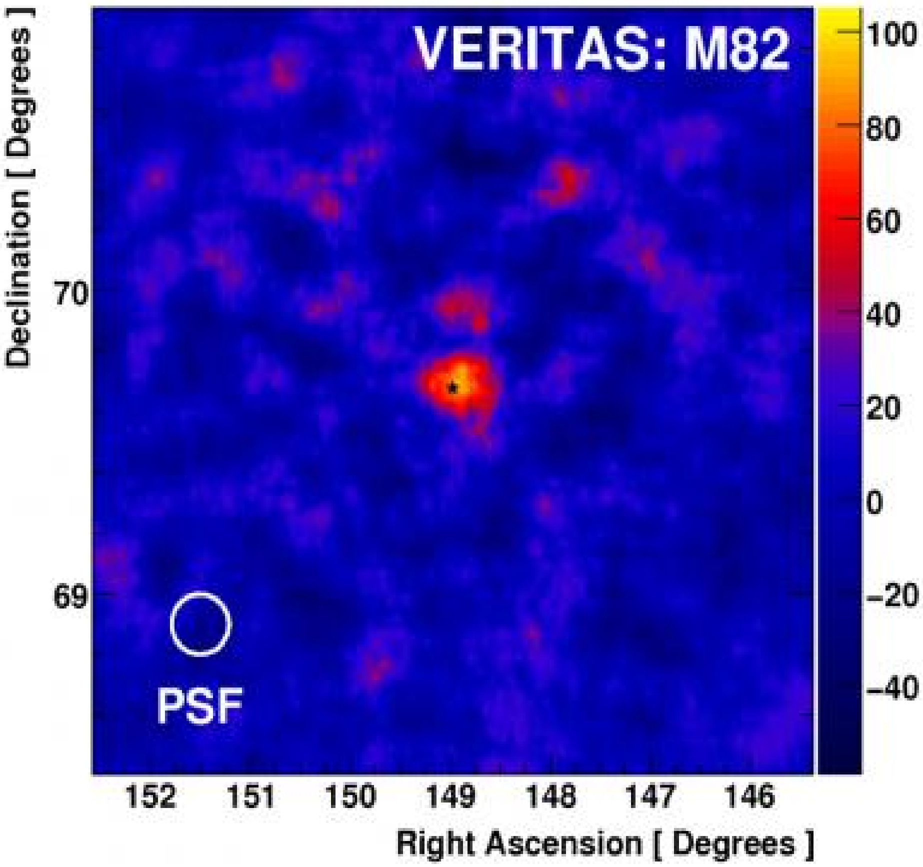




Initial conditions of star formation: **well-protected**...

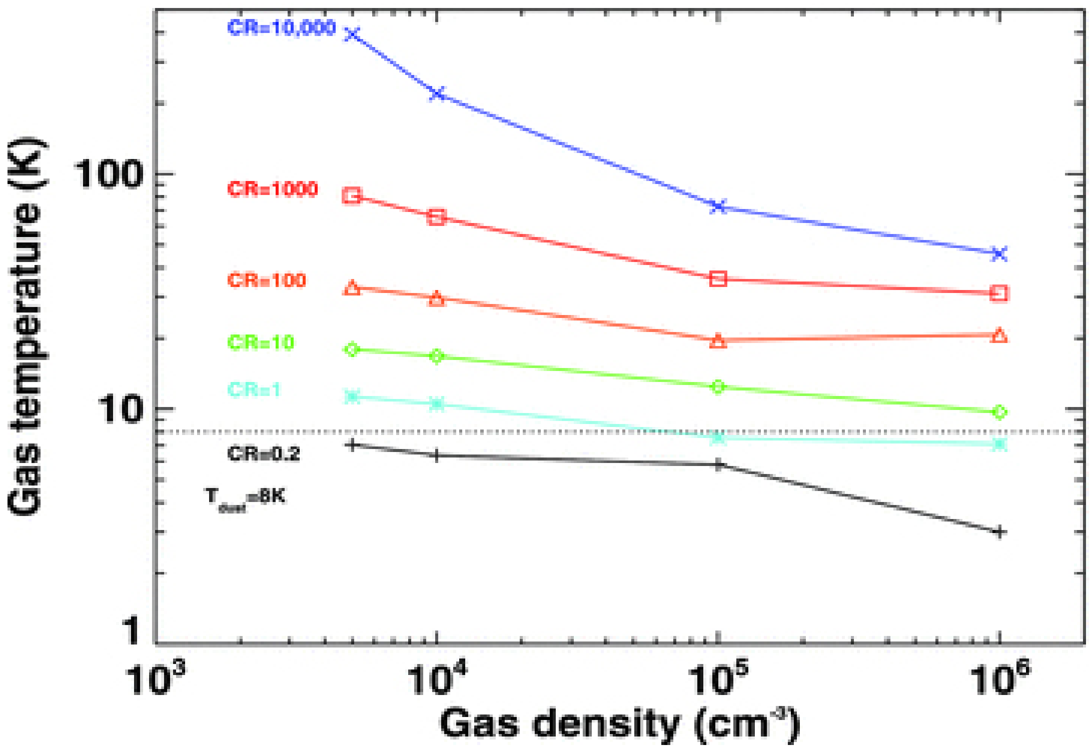
(.... it is quiet down there)

Cosmic rays not photons set the SF initial conditions in galaxies (Papadopoulos et al. 2010, 2011, 2013)

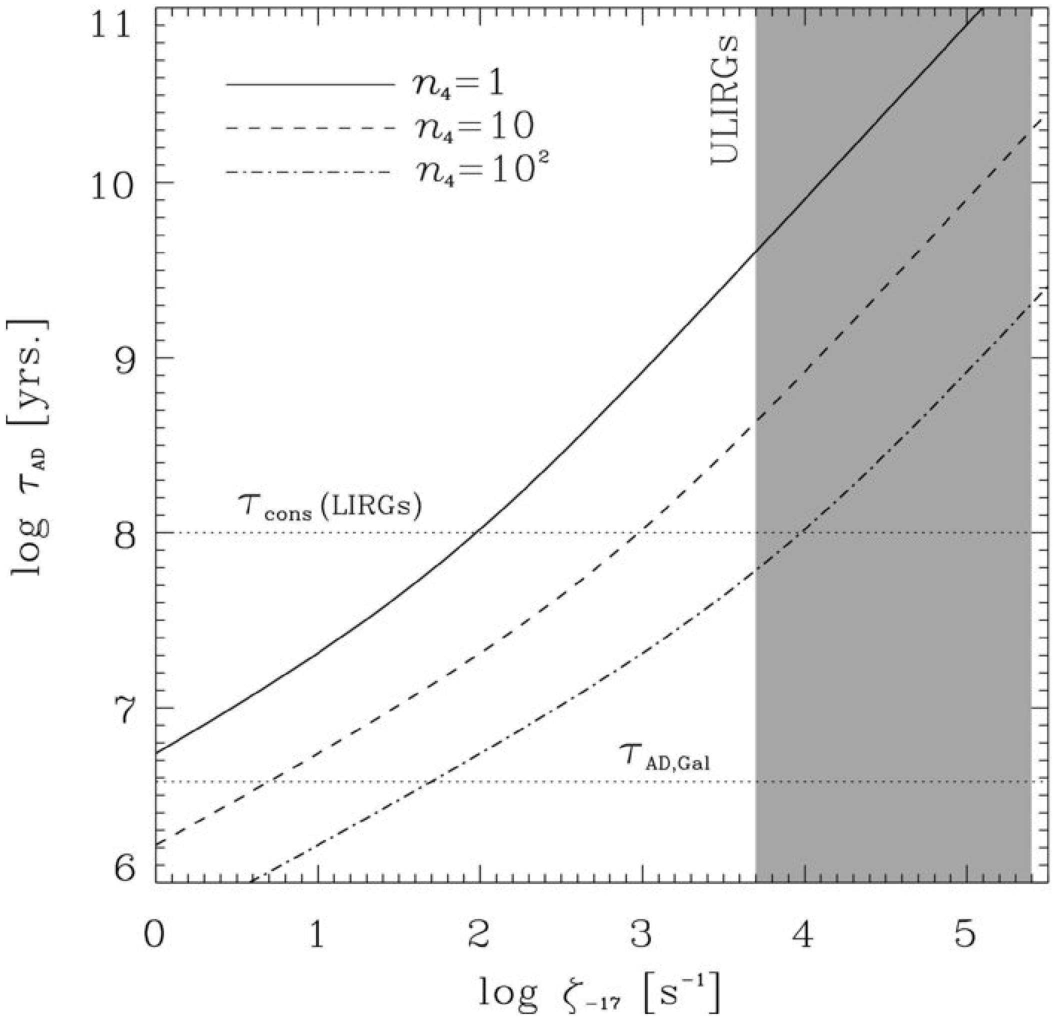


- Delineate the range of SF initial conditions in galaxies using molecular lines (observations).
- Insert them into numerical models to quantify the effects on the stellar IMF

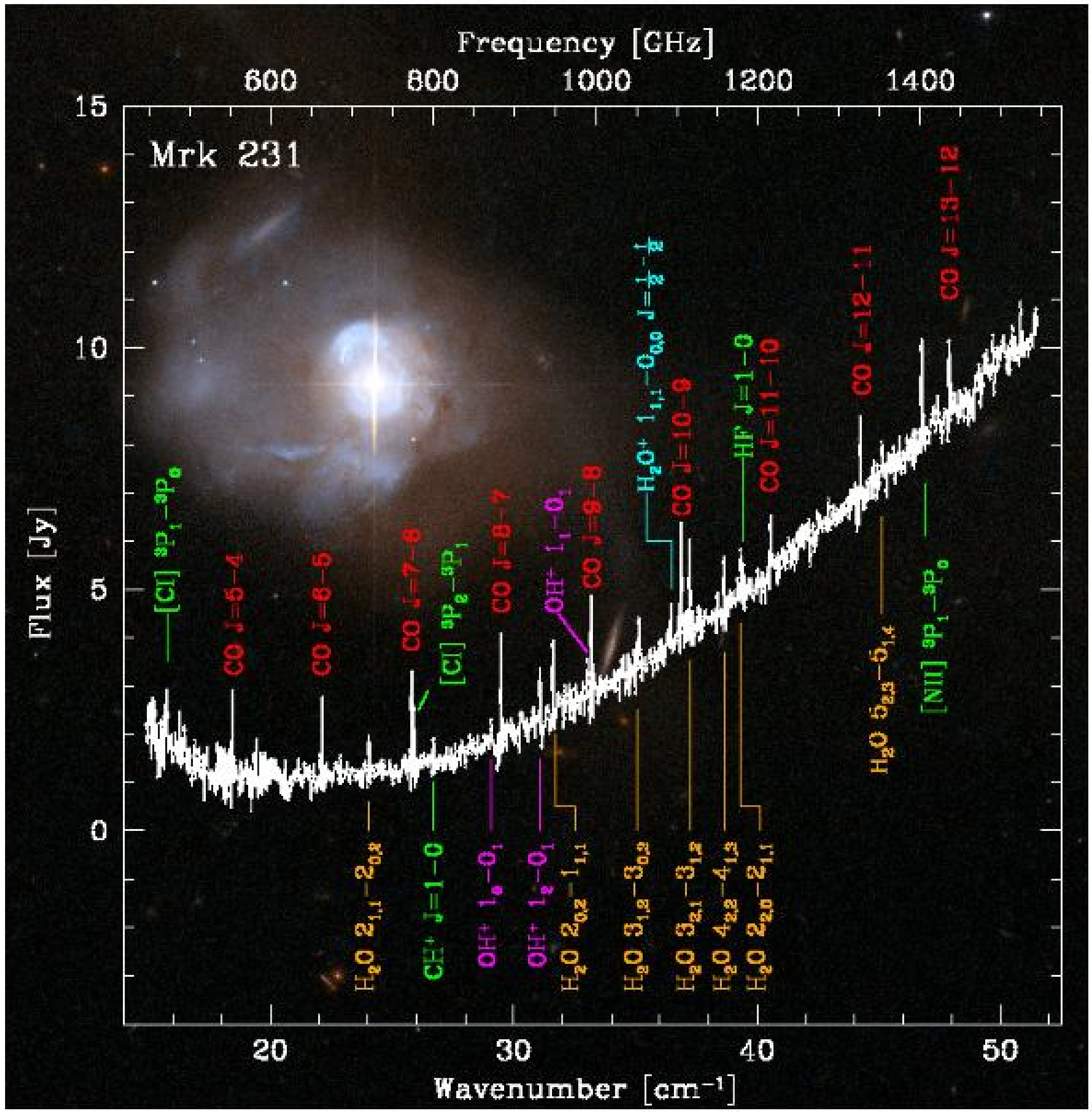
Cosmic rays: the most penetrative heating source of the gas in galaxies



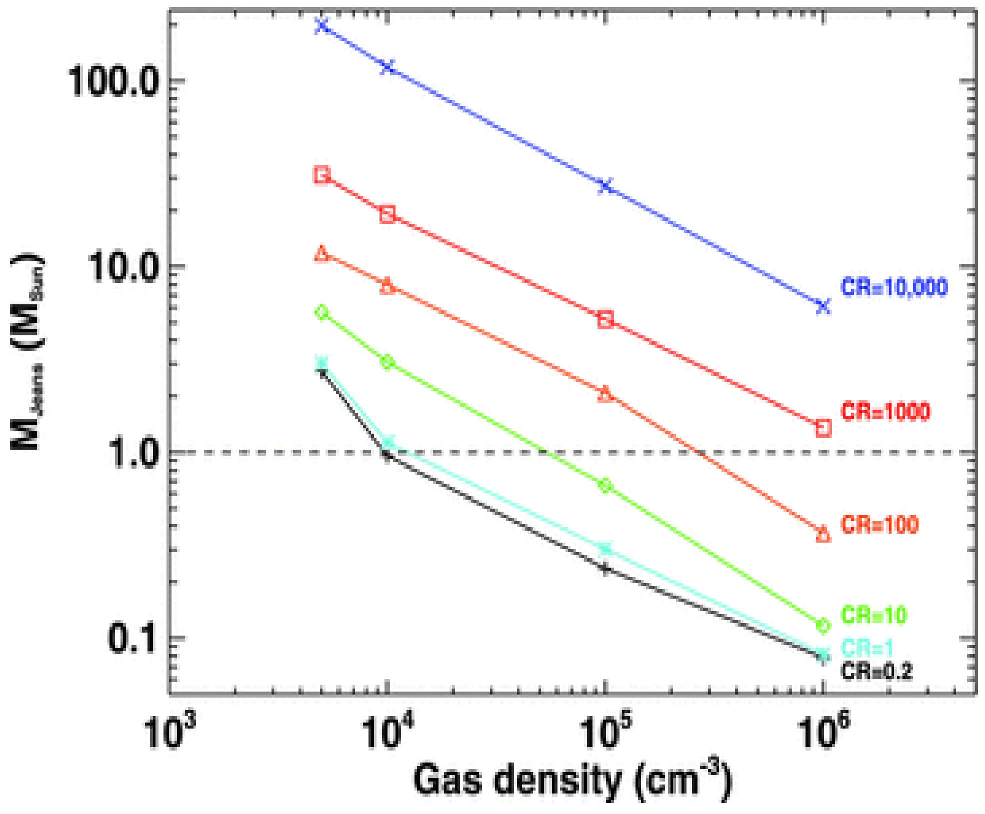
...and the most penetrative ionizing source as well (giving a hold to B)

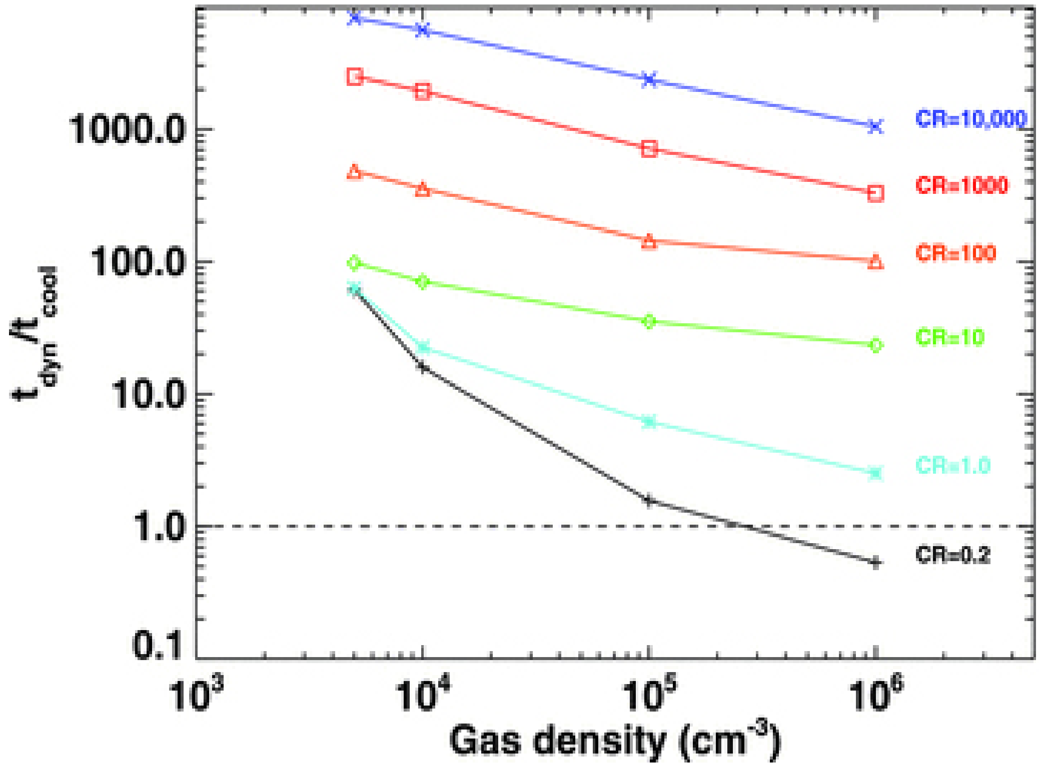


ESA's Herschel Space Observatory: a new view to the warm and dense H_2 gas

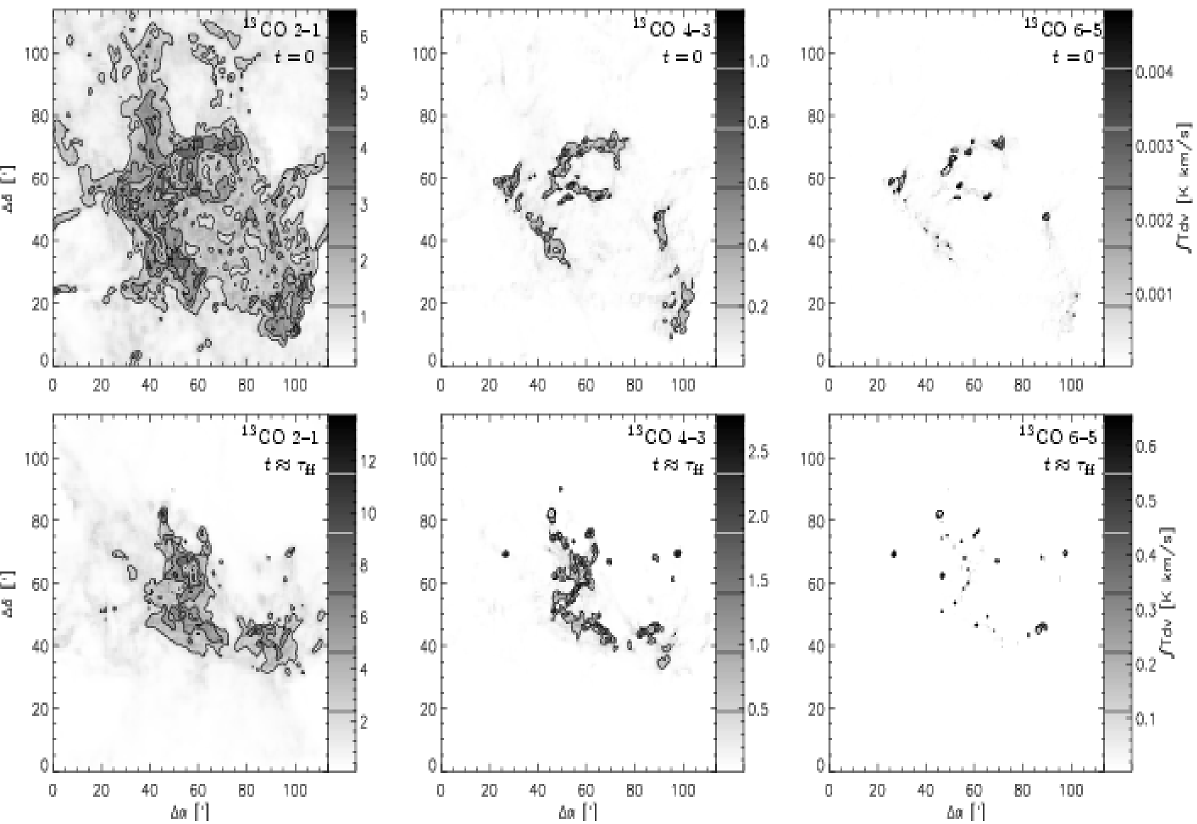


New initial conditions for star formation in starbursts





Two new methods of estimating H_2 gas mass in the Universe



- Using the two lines of atomic carbon (Herschel, ALMA).
- Using key molecular lines to ´fix´ the dM(n)/dn of the turbulence-induced probability density function of H_2 clouds

They look messy, but there is beautiful order in their pdfs (log-normals with $\sigma[\ln(n)]=f(M_s)$)

...two important advantages

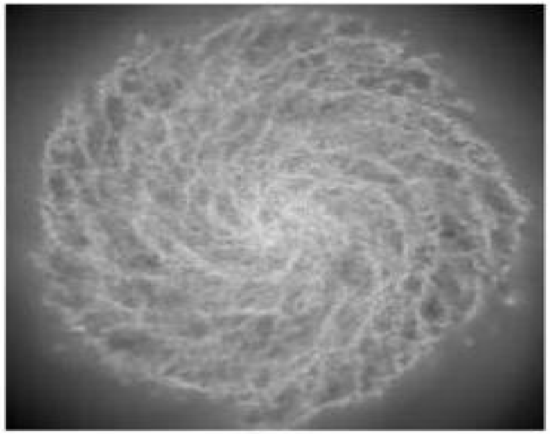
- The two C lines are observable over immense cosmic distances (look-back times), and **excellent** tracer of galactic dynamical mass (Papadopoulos et al. 2004).

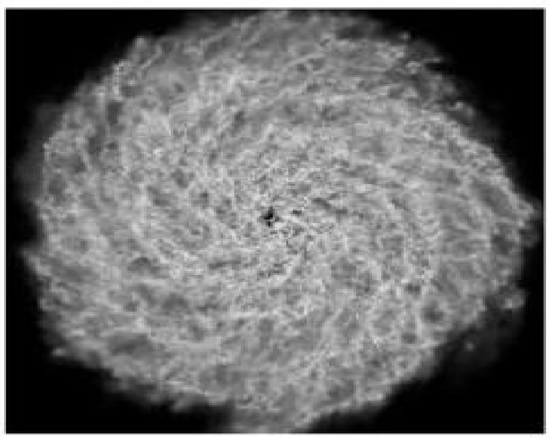
- The pdf-method is much more comprehensive than any (single line)-X_{line} method with:

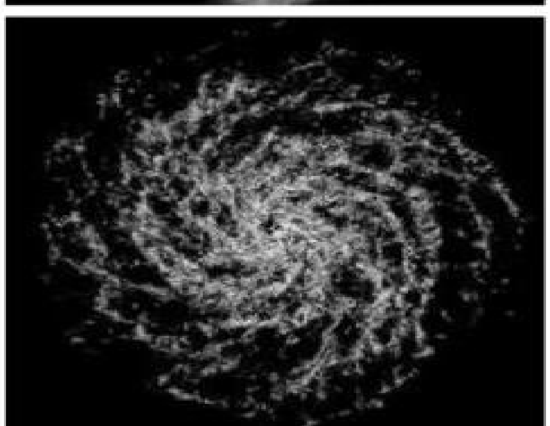
  a) dynamic range over all H_2 gas states,

  b) $f_{dense}=M(n\geq n_{\circ})/M_{total}(H_2)$ also obtained!

Inserting the new micro-physics into the larger picture (Pelupessy & Papadopoulos 2009)

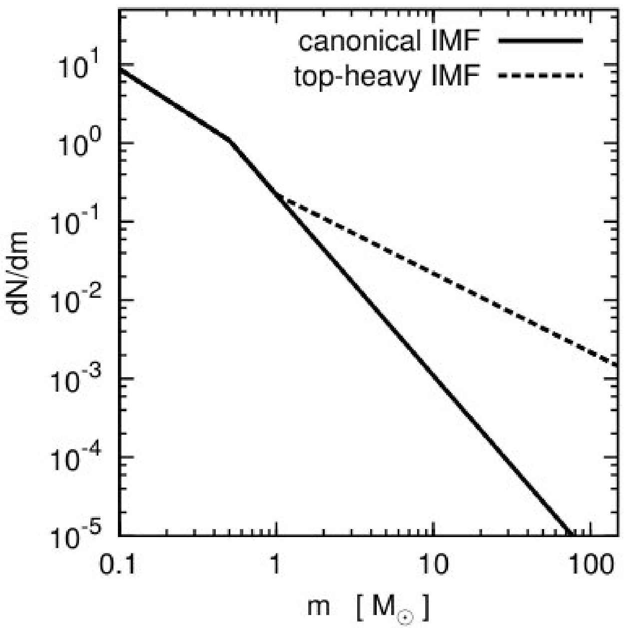


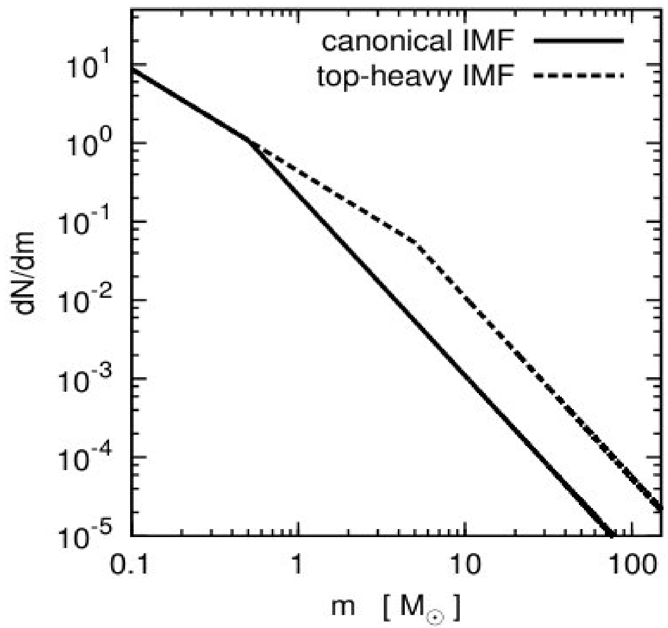


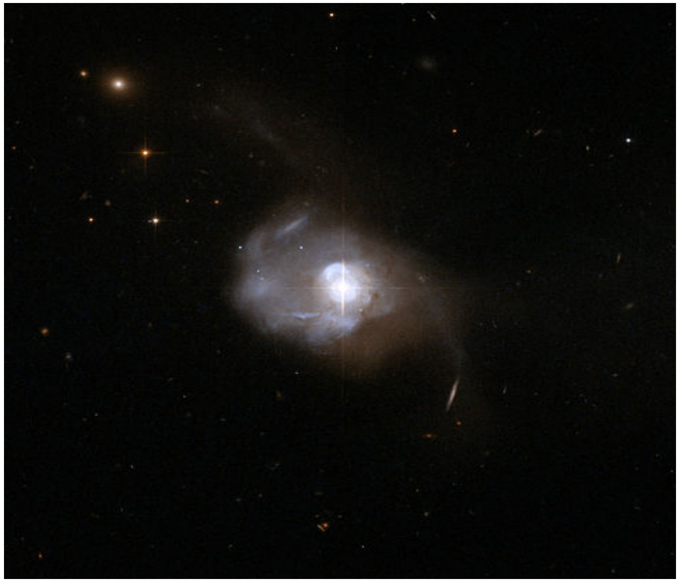


- Include molecules (H_2, CO, HCN), and atoms (C, C^+) in galaxy evolution modes for the first time!
- Make stars out of H_2 gas (as nature really does it....)
- Insert physical stellar IMFs
- Interface the models with molecular and atomic line imaging observations (ALMA and EVLA) across cosmic epoch.

The stellar IMF of distant galaxies forever out of reach? (...the next best thing)





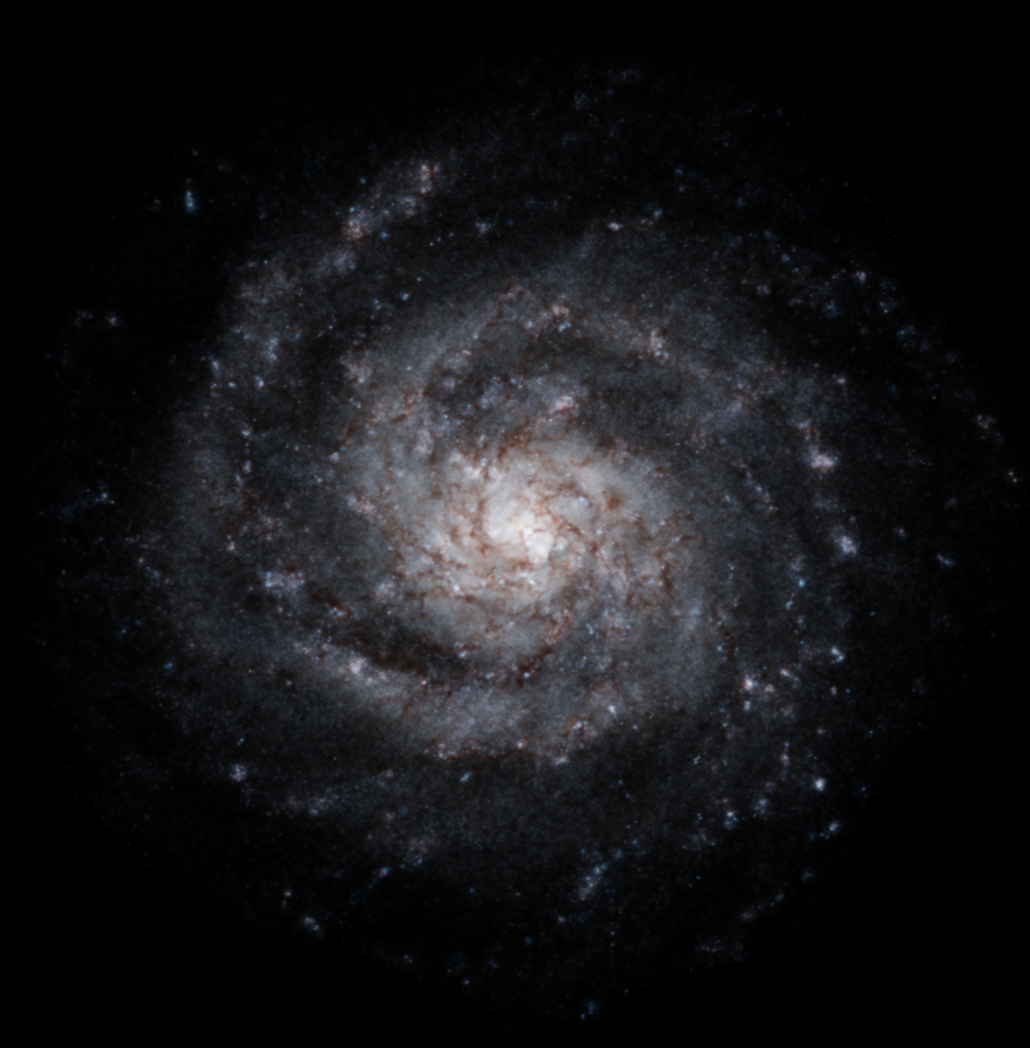


1) The initial conditions of star formation in galaxies across cosmic epoch.

2) The stellar initial mass function of the stars formed.

3) Two new methods of tracing the ´fuel´ of star formation: H_2 gas

4) Integrate the new ISM physics into galaxy formation, taking full advantage of ALMA and JVLA.



The JVLA in the Plains of St. Augustin

ALMA at Llano Chajnantor