Molecular clouds properties in galactic scale simulations

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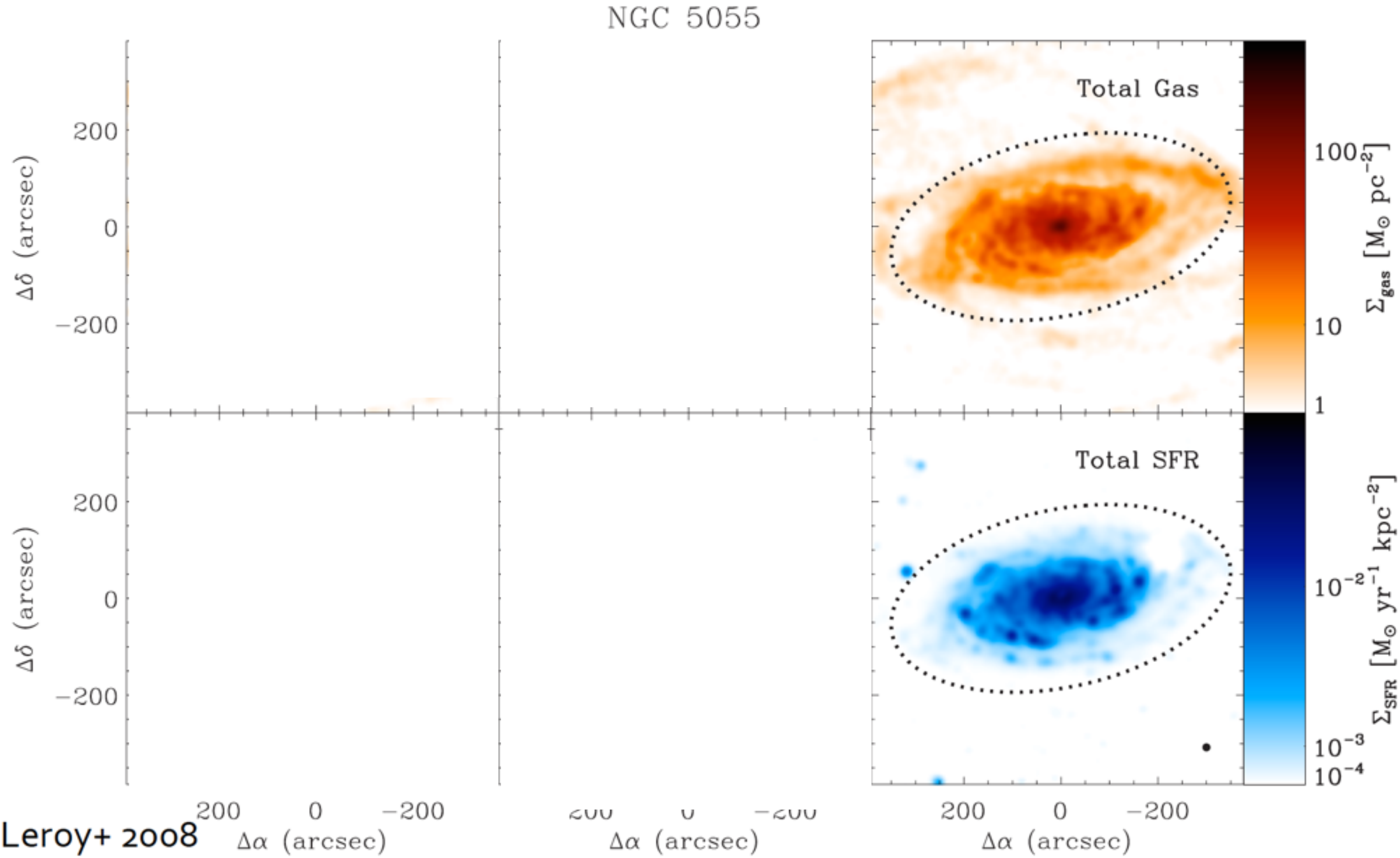
Star formation in galaxies

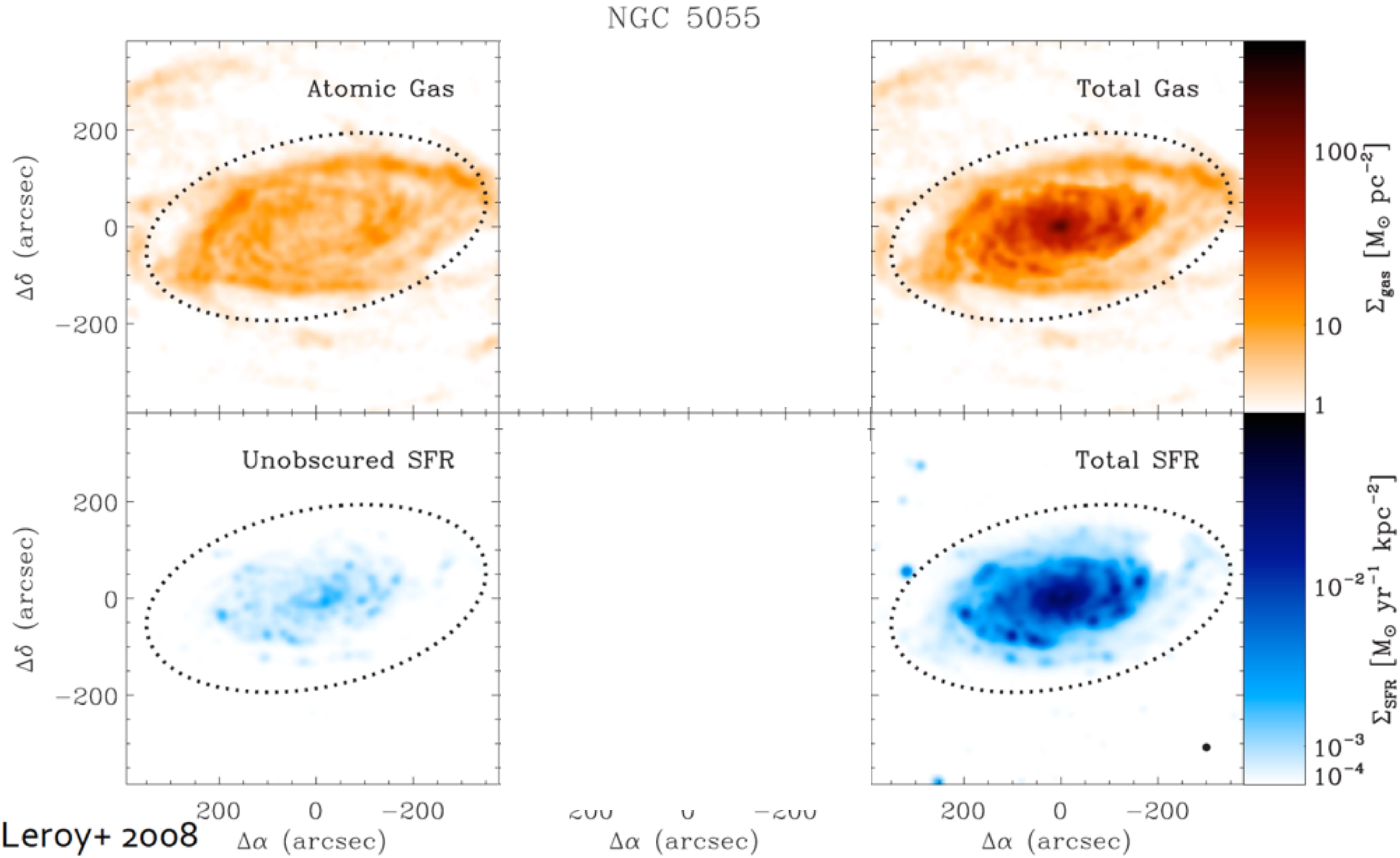
$$\mathrm{SFR} = \frac{\epsilon}{t_{\mathrm{SF}}} M_{\mathrm{gas}}$$

Galactic scale star formation



Leroy+ 2008

Galactic scale star formation



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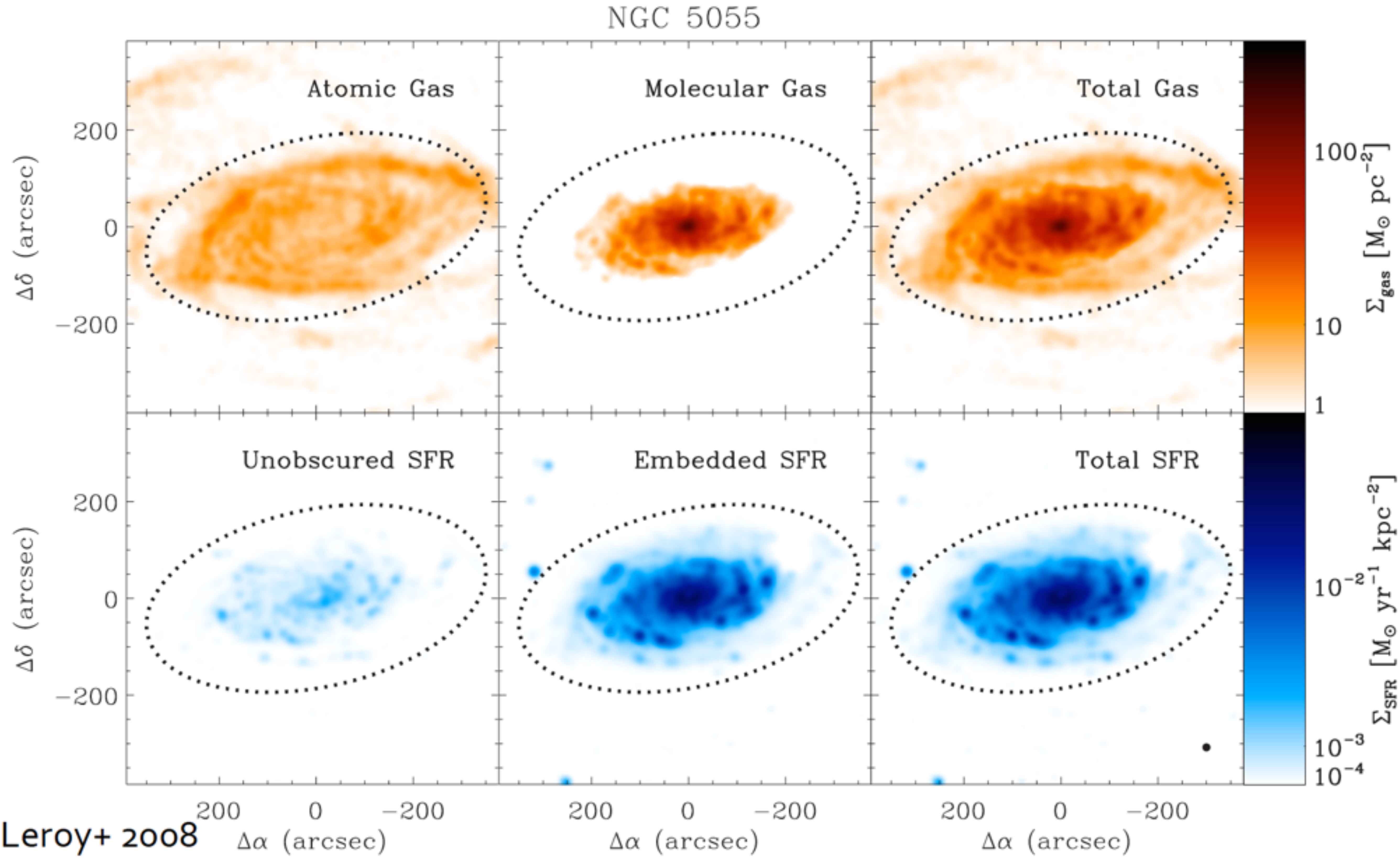

Leroy+ 2008

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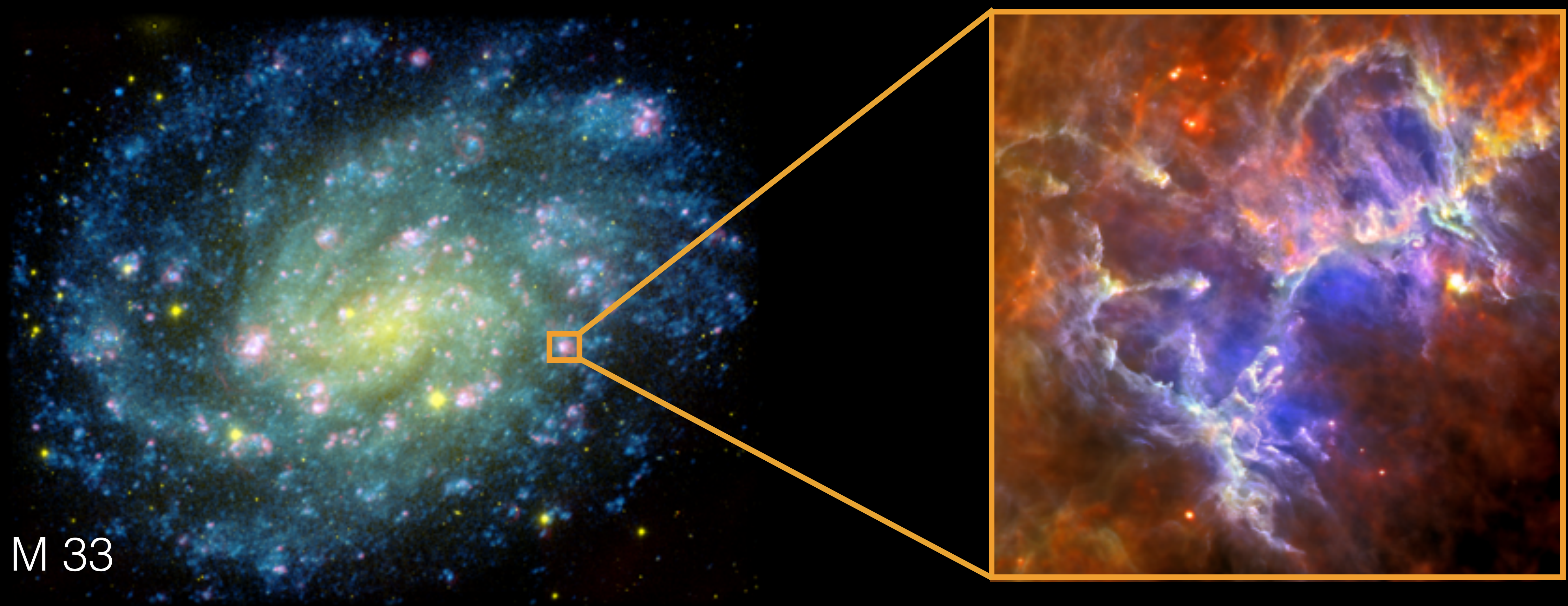

GMCs are the nurseries for
the majority of the stellar population

Clouds properties and evolution govern the galaxy's star formation rate.

Outline

I. Chemo-dynamical model of a galactic disk

II. GMCs molecular content: H_2, CO. Dark gas

III. SFR calculation: role of the cloud definition

IV. GMCs scaling relations

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Model

Isolated Milky Way size galaxies

- Multiphase gas-dynamics
(uniform grid, 5 pc spatial resolution)

- Non-equlibrium chemical kinetics
(20 species, including H_2, CO
≈50 chemical reactions, UMIST)

- N-body stellar population
(≈$2 \cdot 10^6$ particles)

- Stellar evolution
(STABURST'99)

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- Stellar evolution
(STABURST'99)

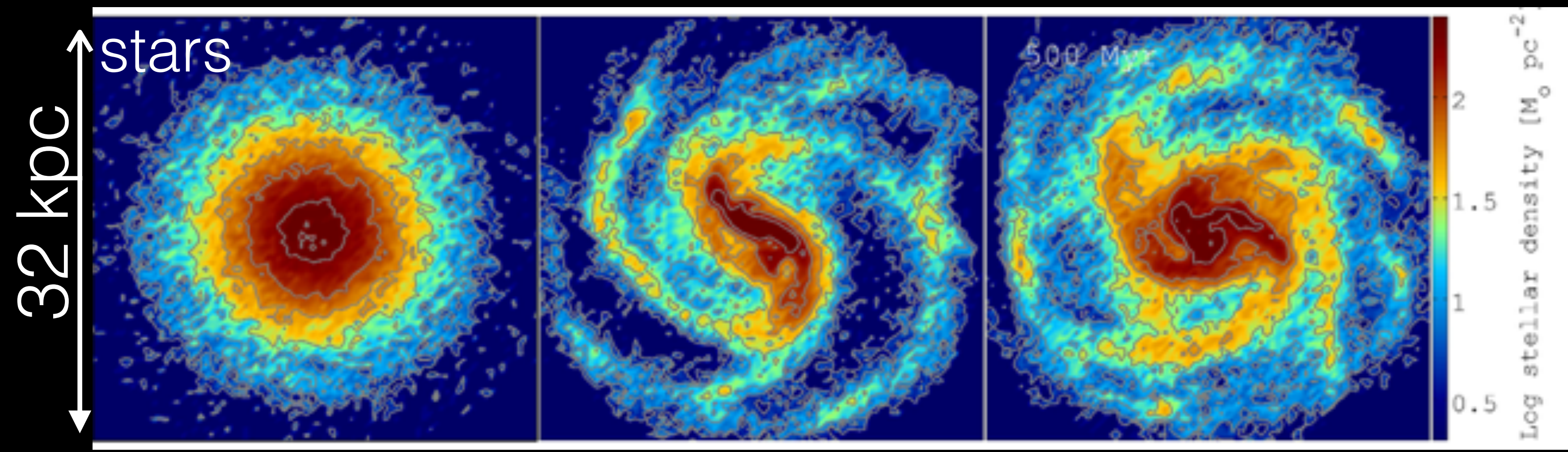
- Star formation
(based on the local Jeans instability criterion - NO SF threshold)

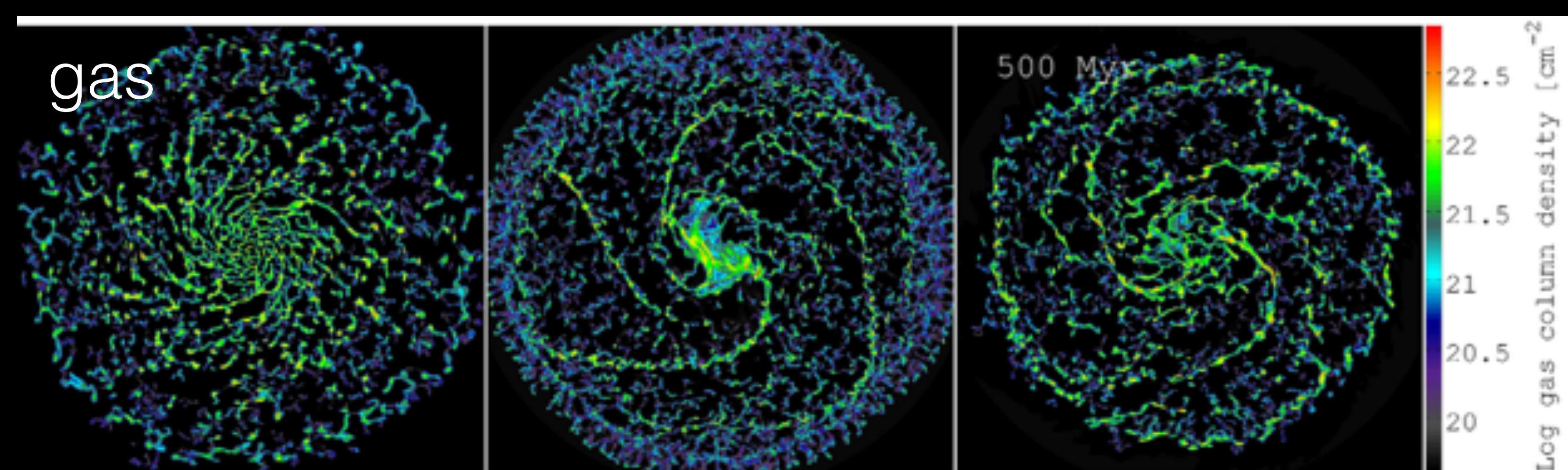
- Feedback
(SNe, stellar wind, mass loss according to STARBURST'99)

- Radiation transfer of UV flux from stellar population
(photodissociation of molecule)

Sample

- 8 MW-size galaxies
- Various morphology
- Spatially resolved clouds





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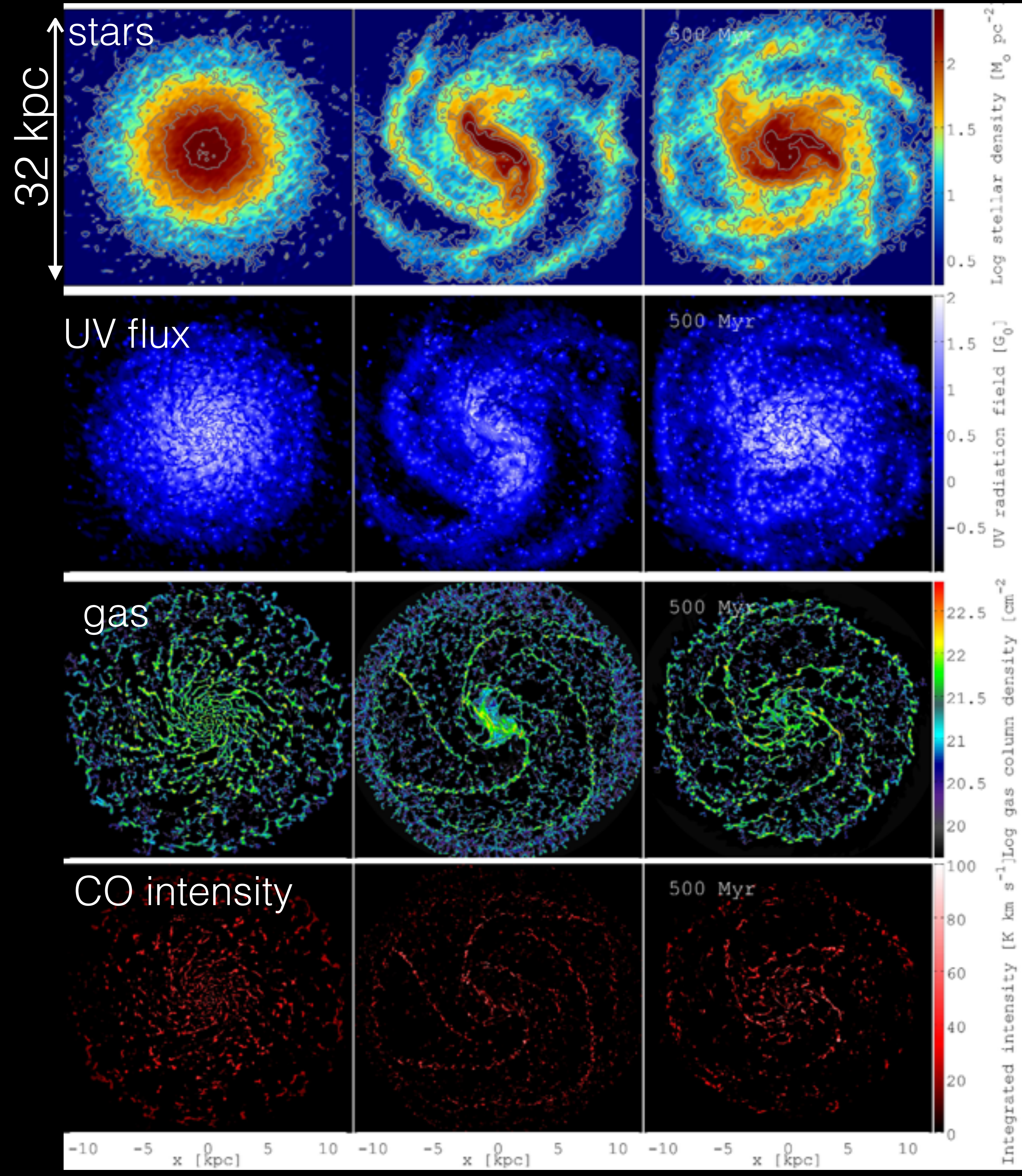

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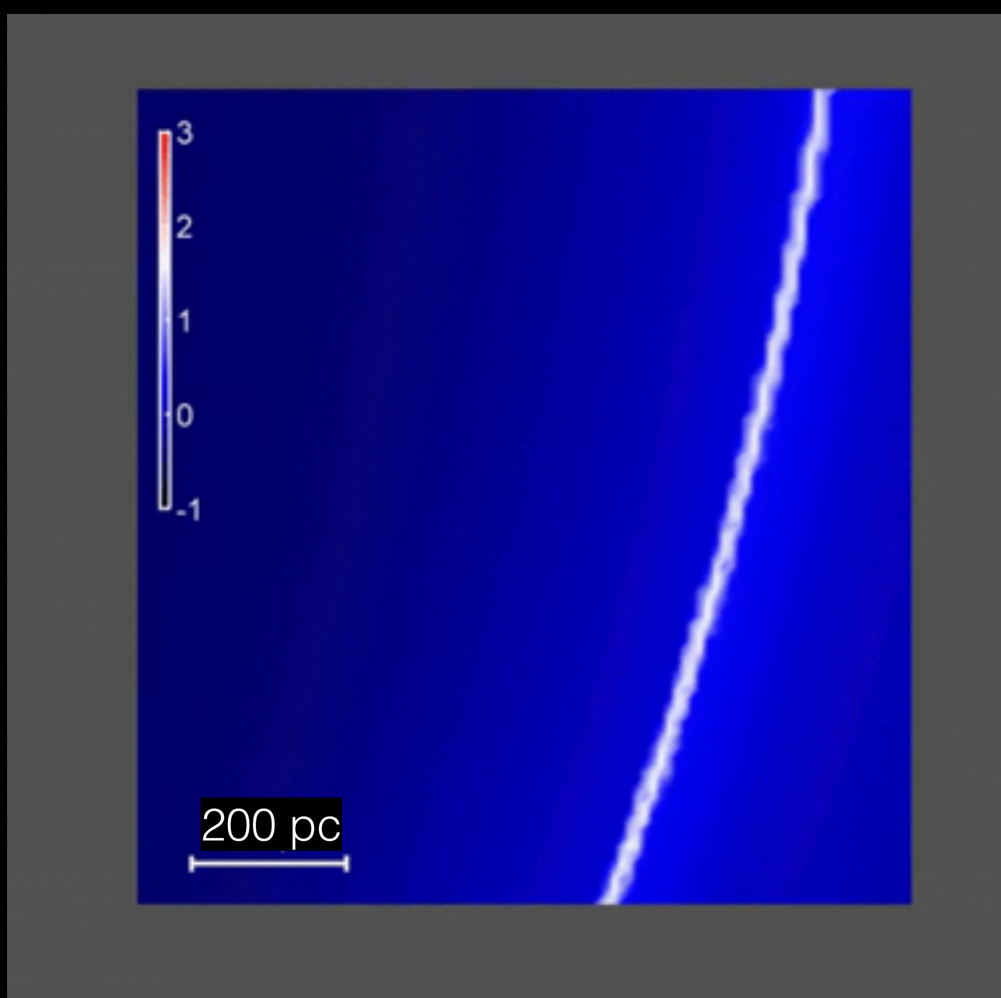

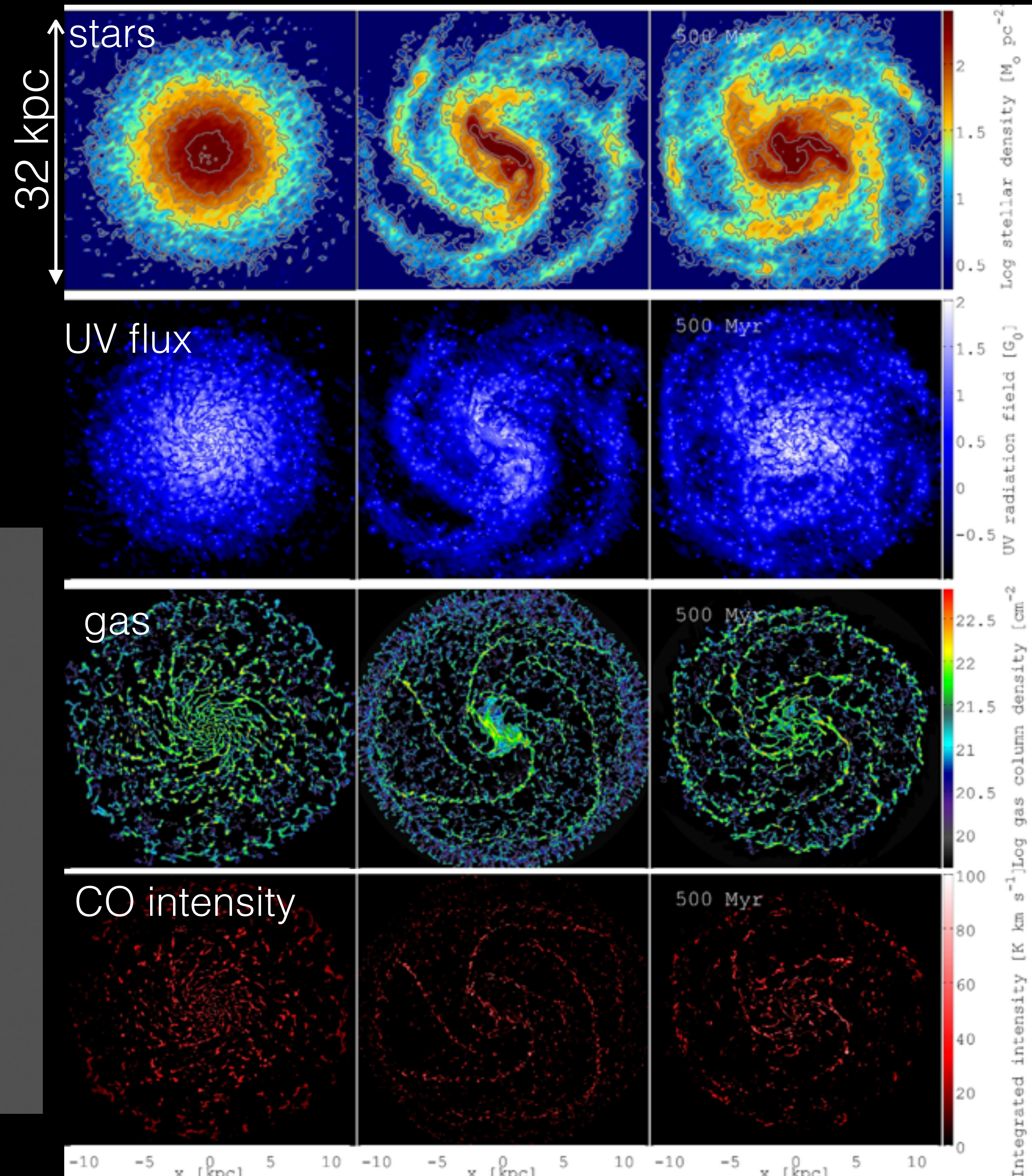

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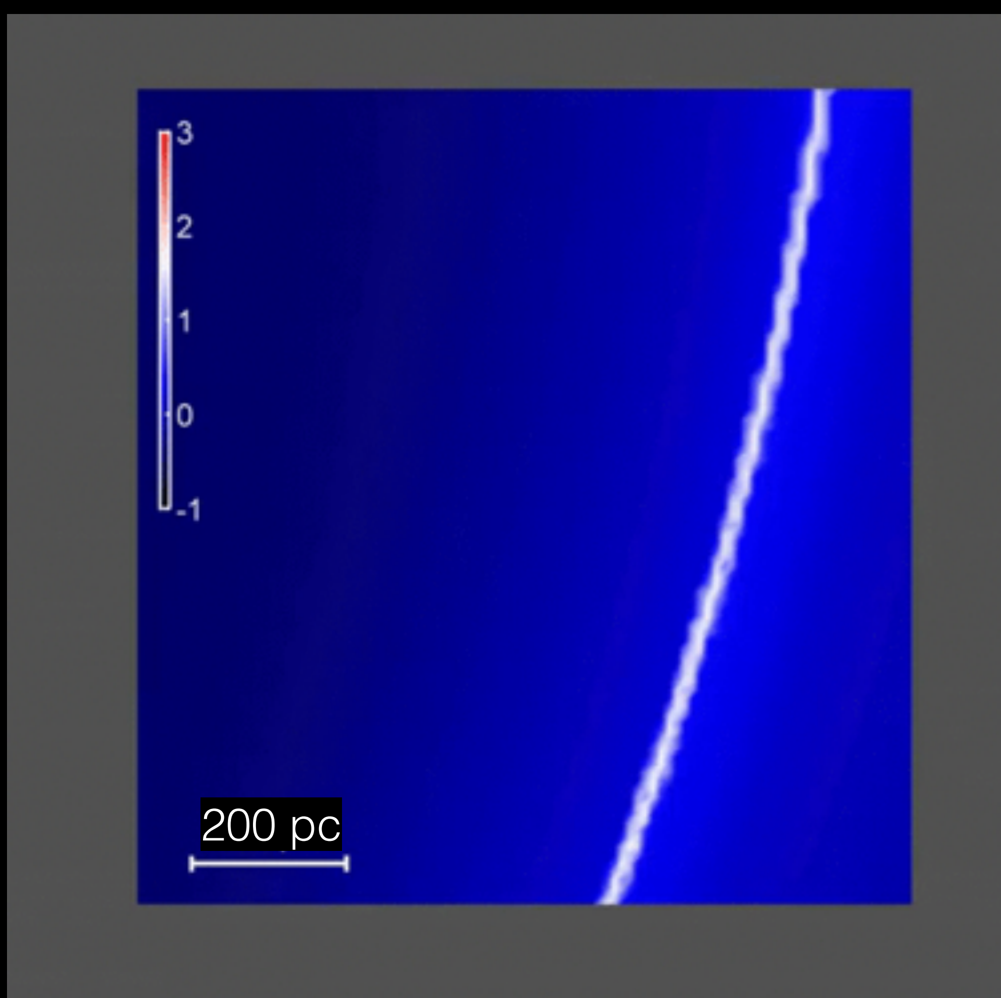
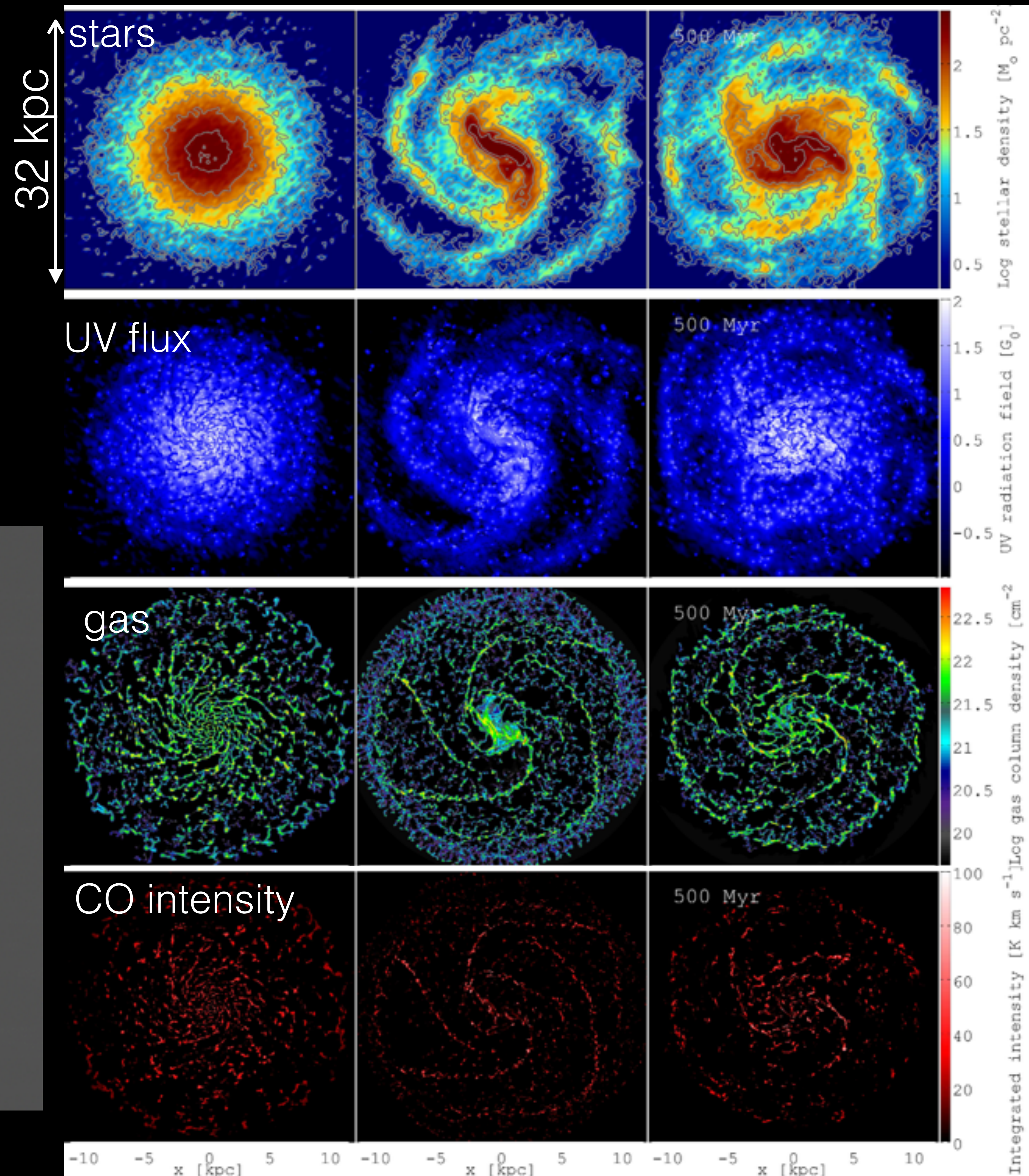
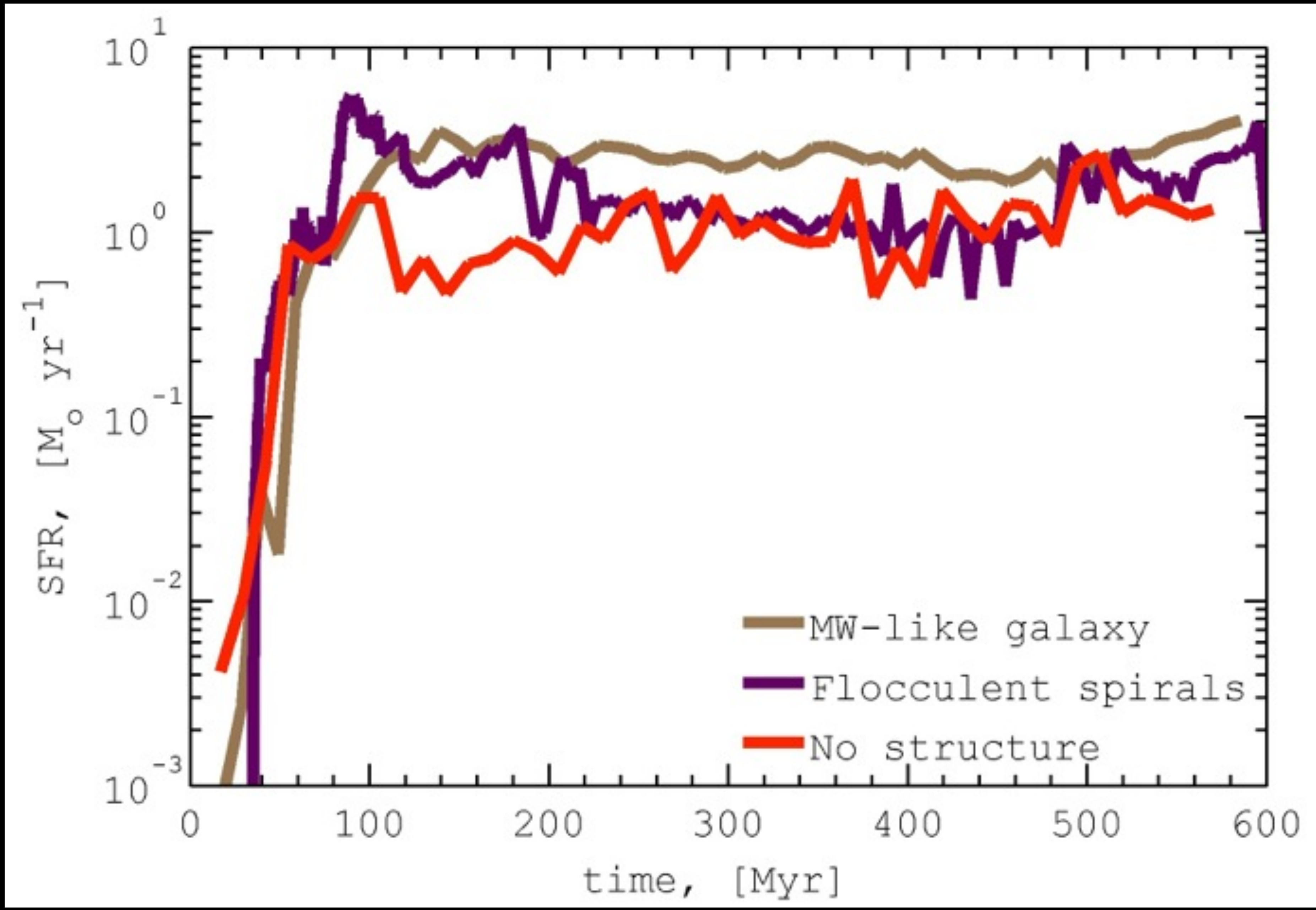




Star formation history



Star formation history

Initial fragmentation
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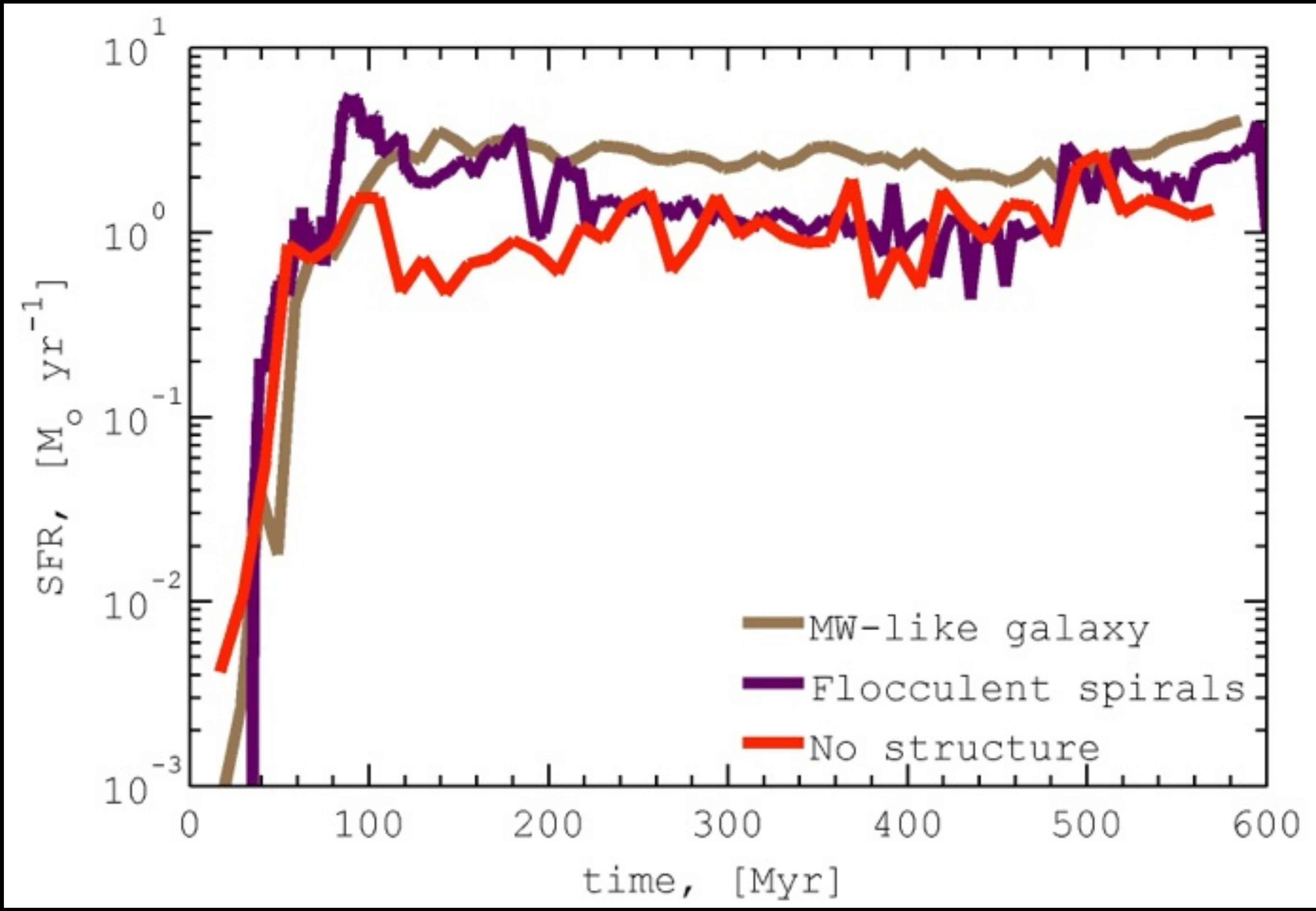
by stellar bar/spirals



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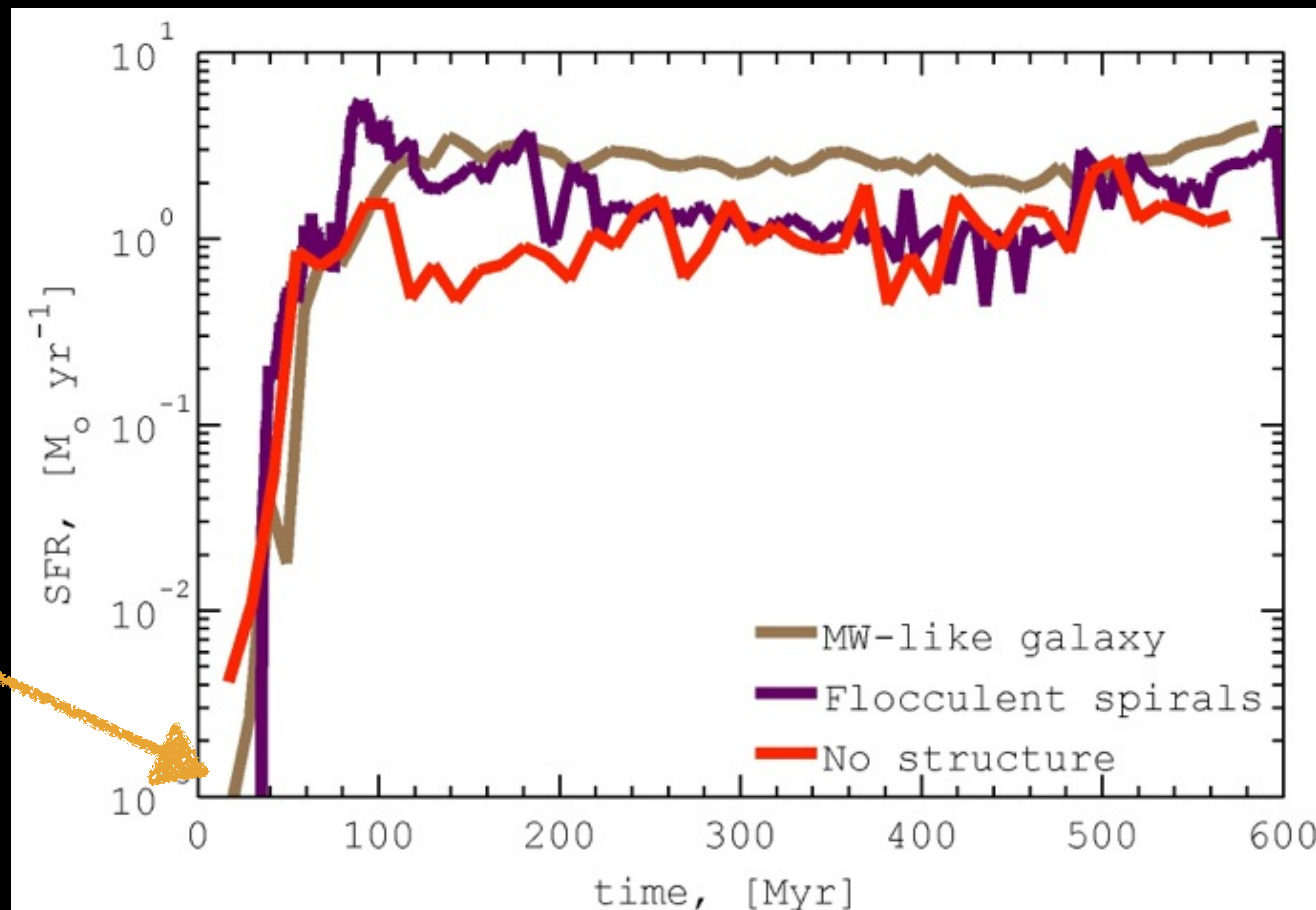
Molecules formation time scale
H->H_2
C,O->CO
…
≈ 10-20 Myr



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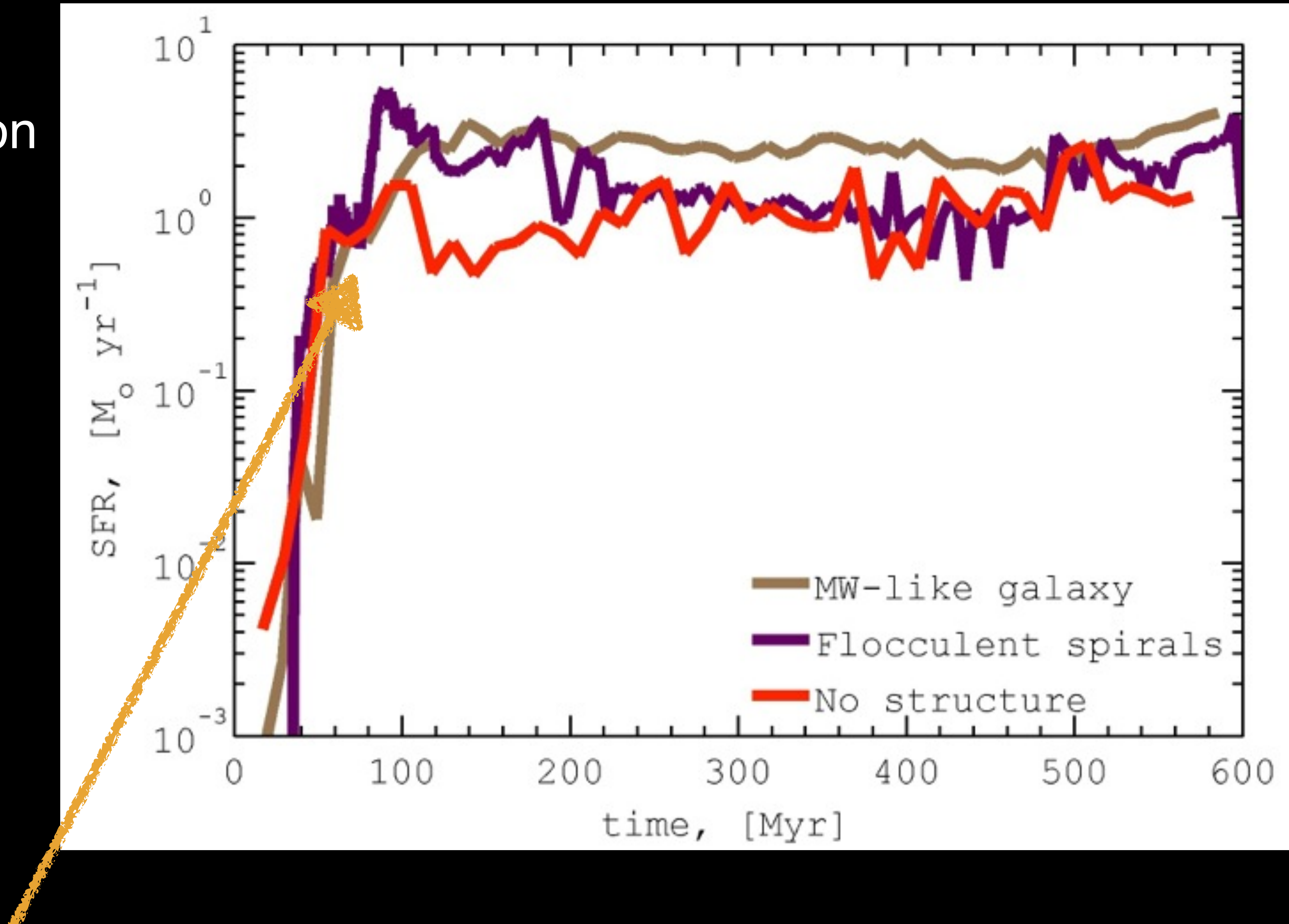

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SNe suppress the SF

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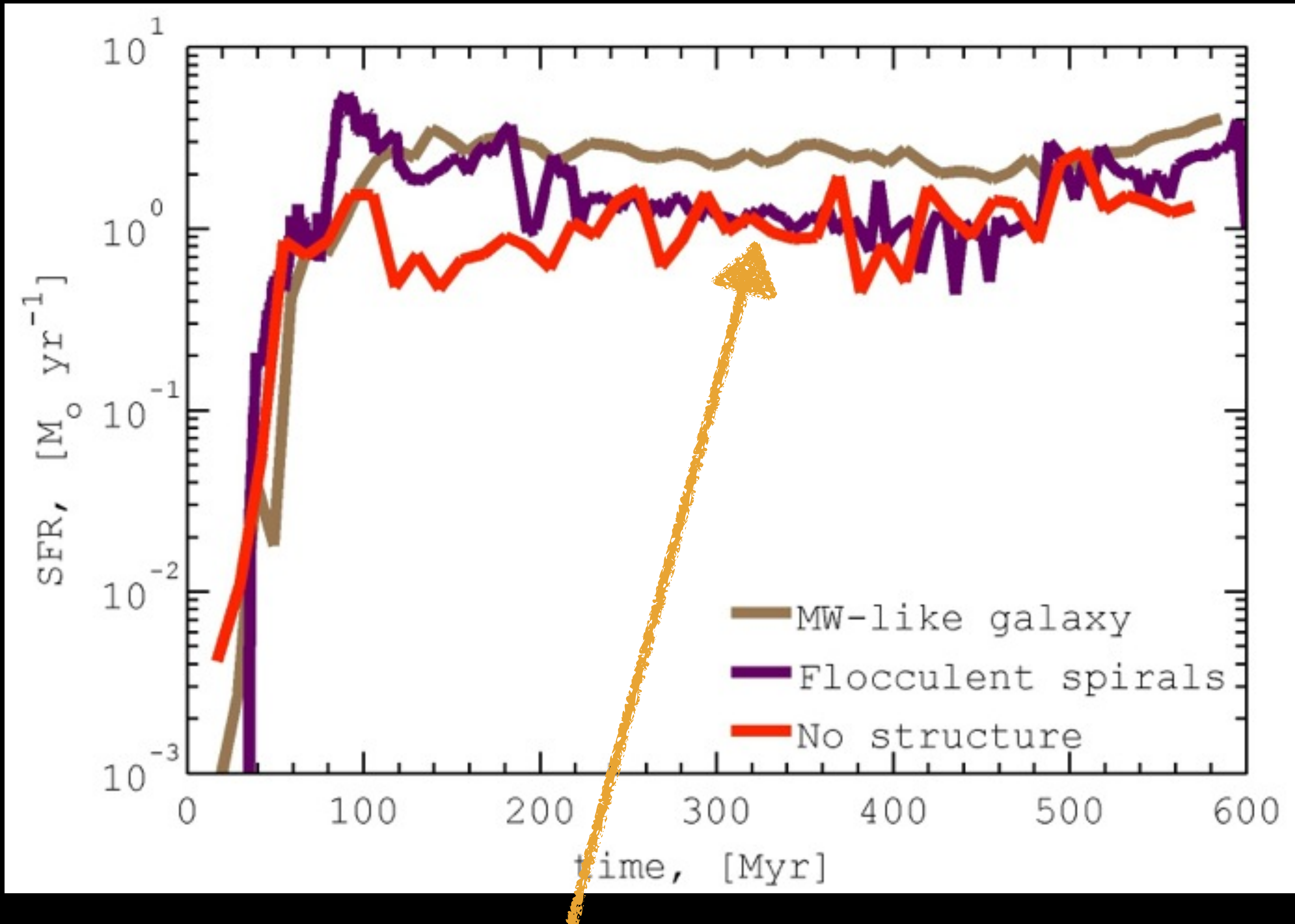
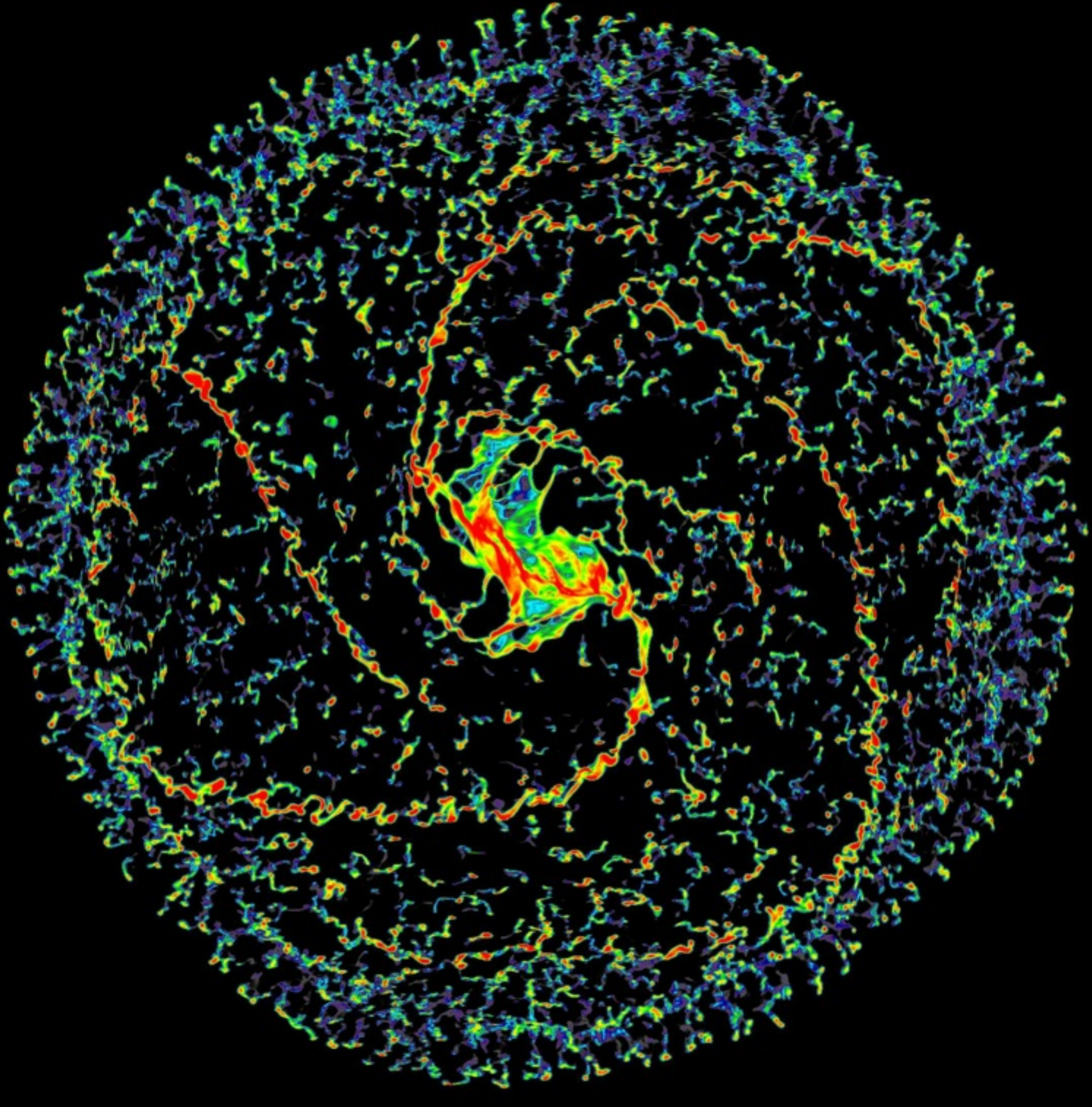


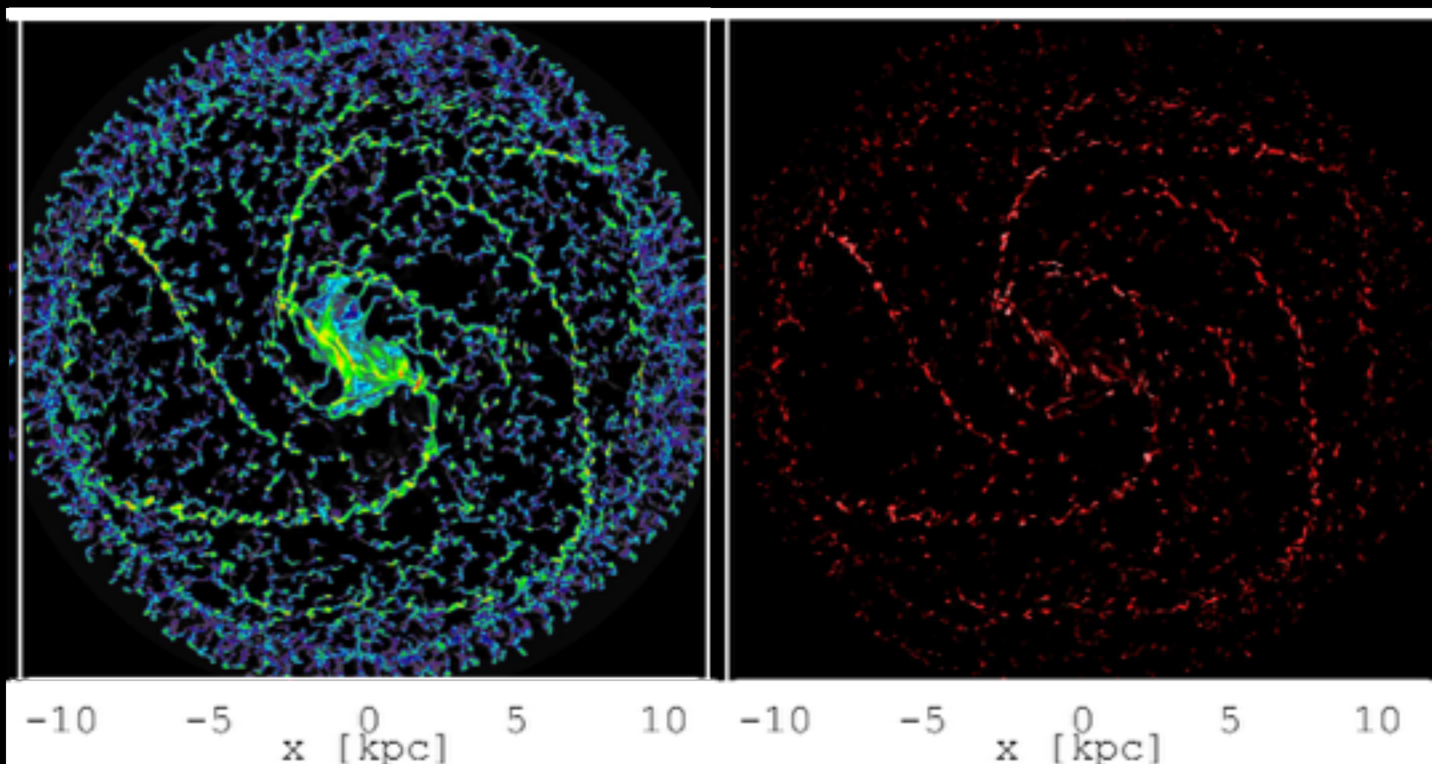
Constant SFR rate
because of the self-regulated SF



Extraction of clouds

column density threshold

CO integrated intensity threshold



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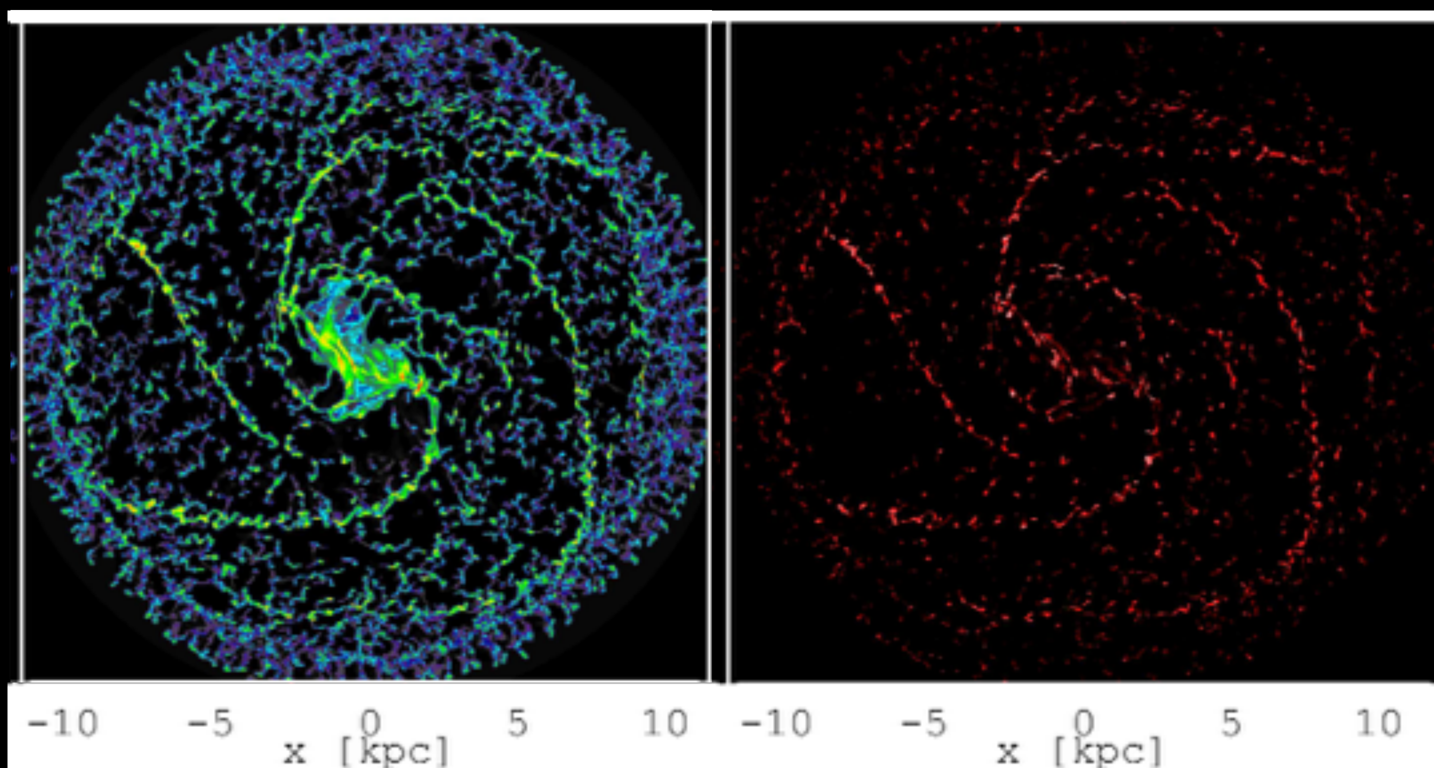

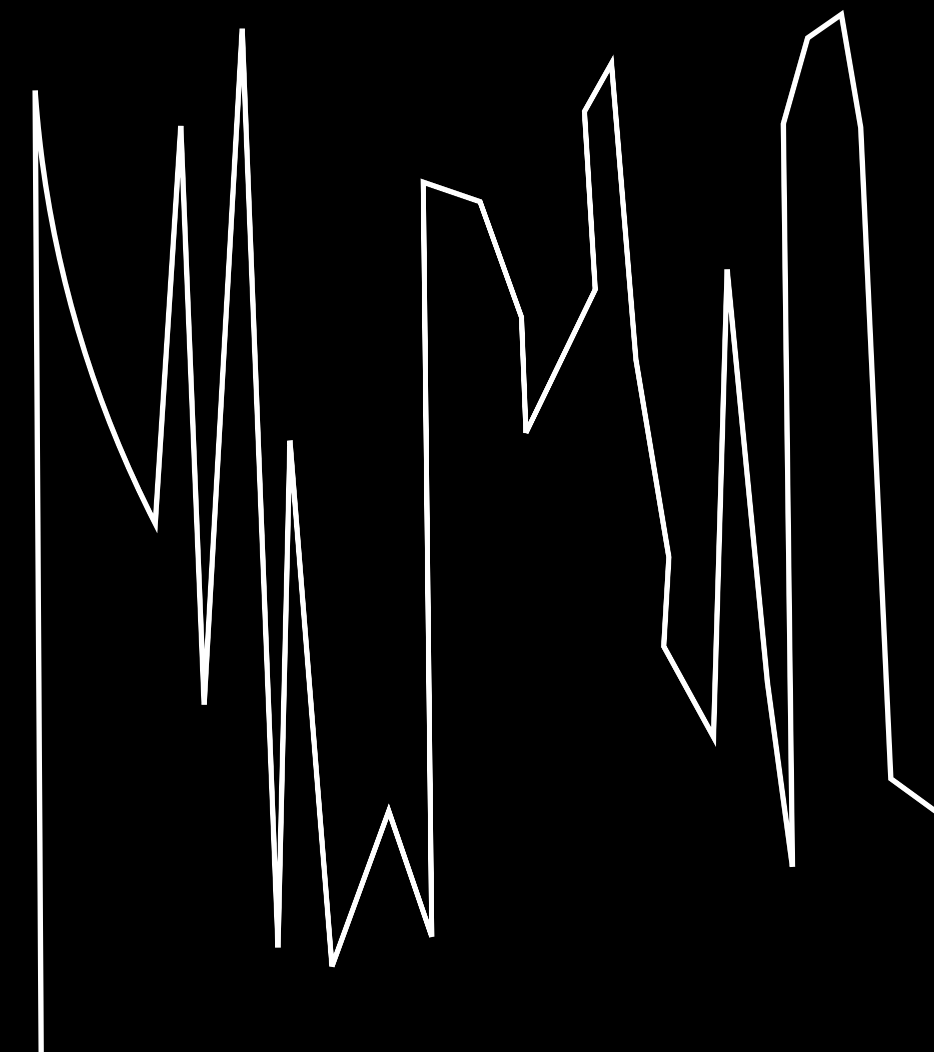

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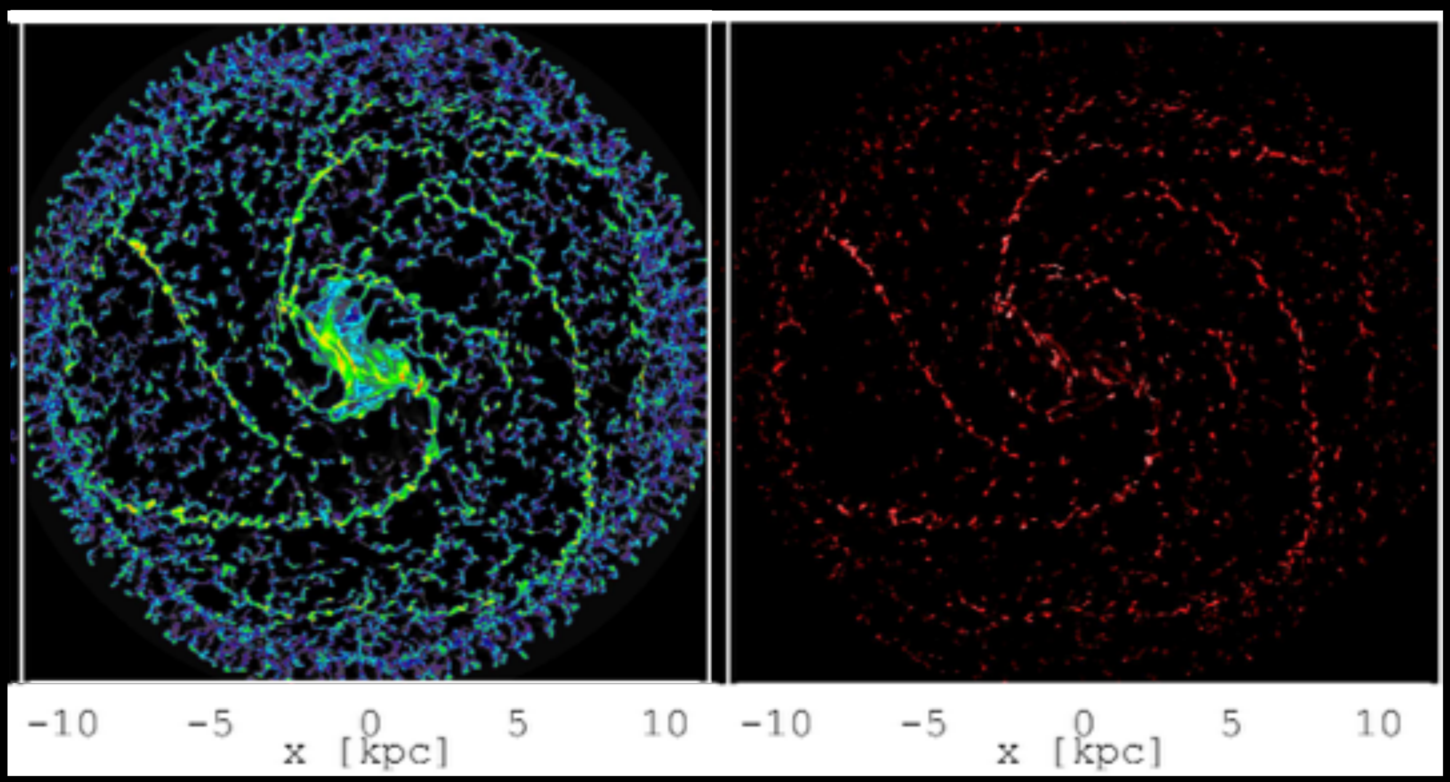
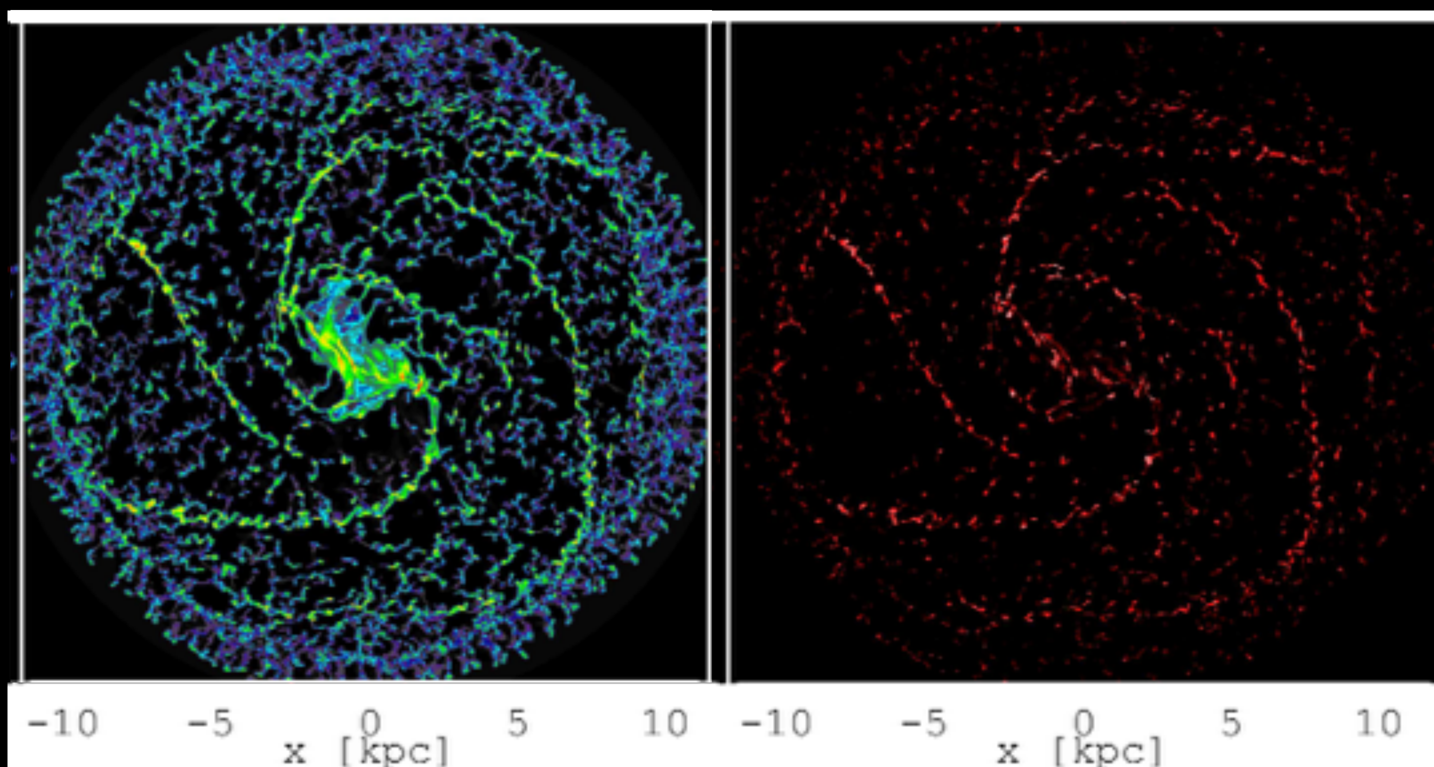


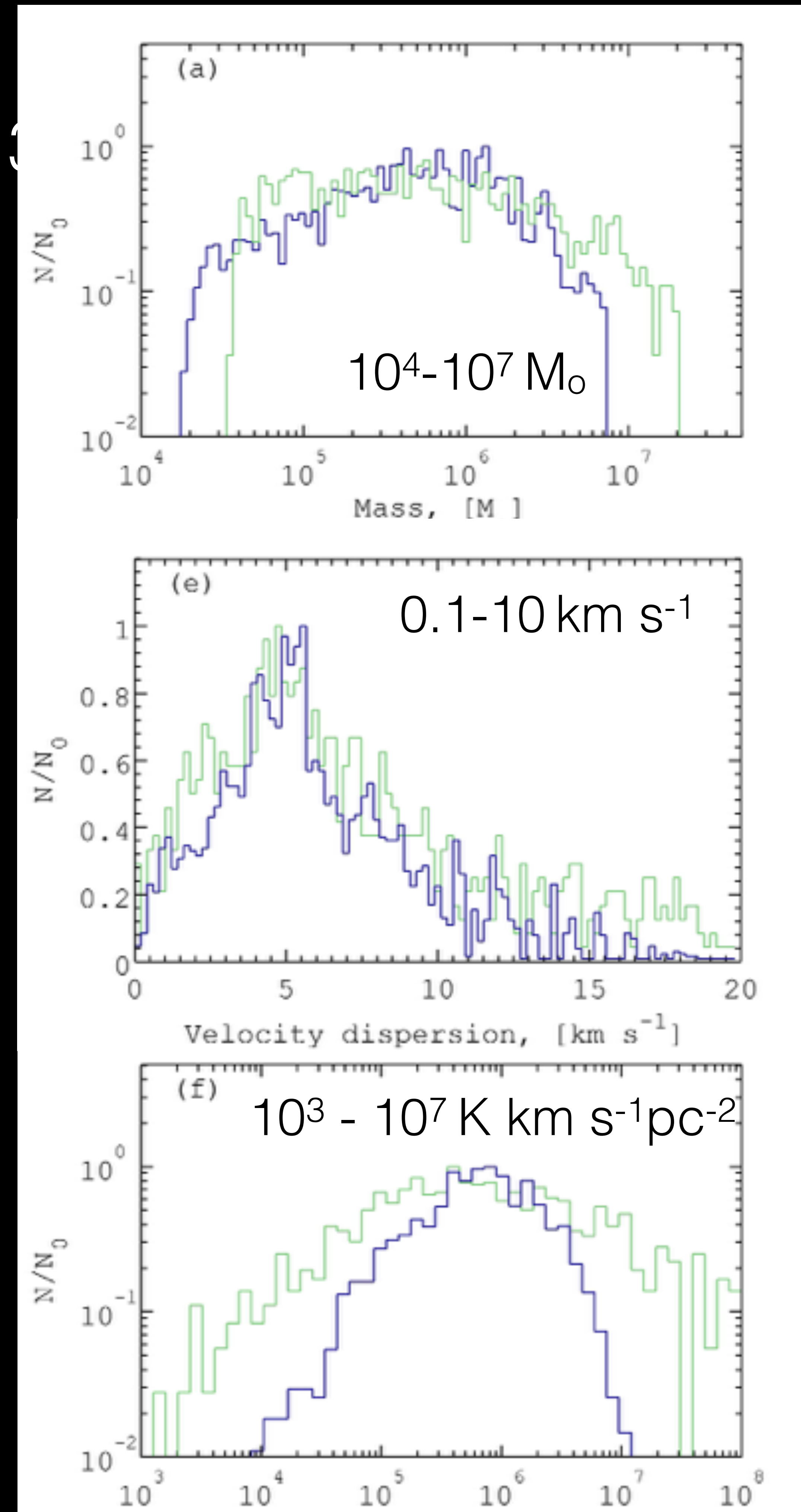
300-1000 clouds

Extraction of clouds

column density threshold

CO integrated intensity threshold





Temperature down to 5 K

Concentration up to 5 10^3 cm^{-3}

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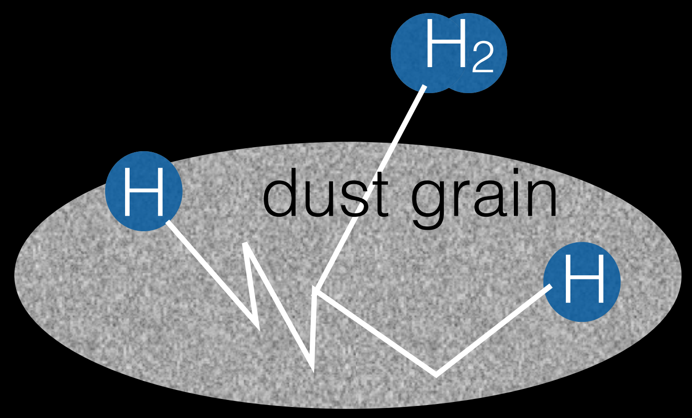
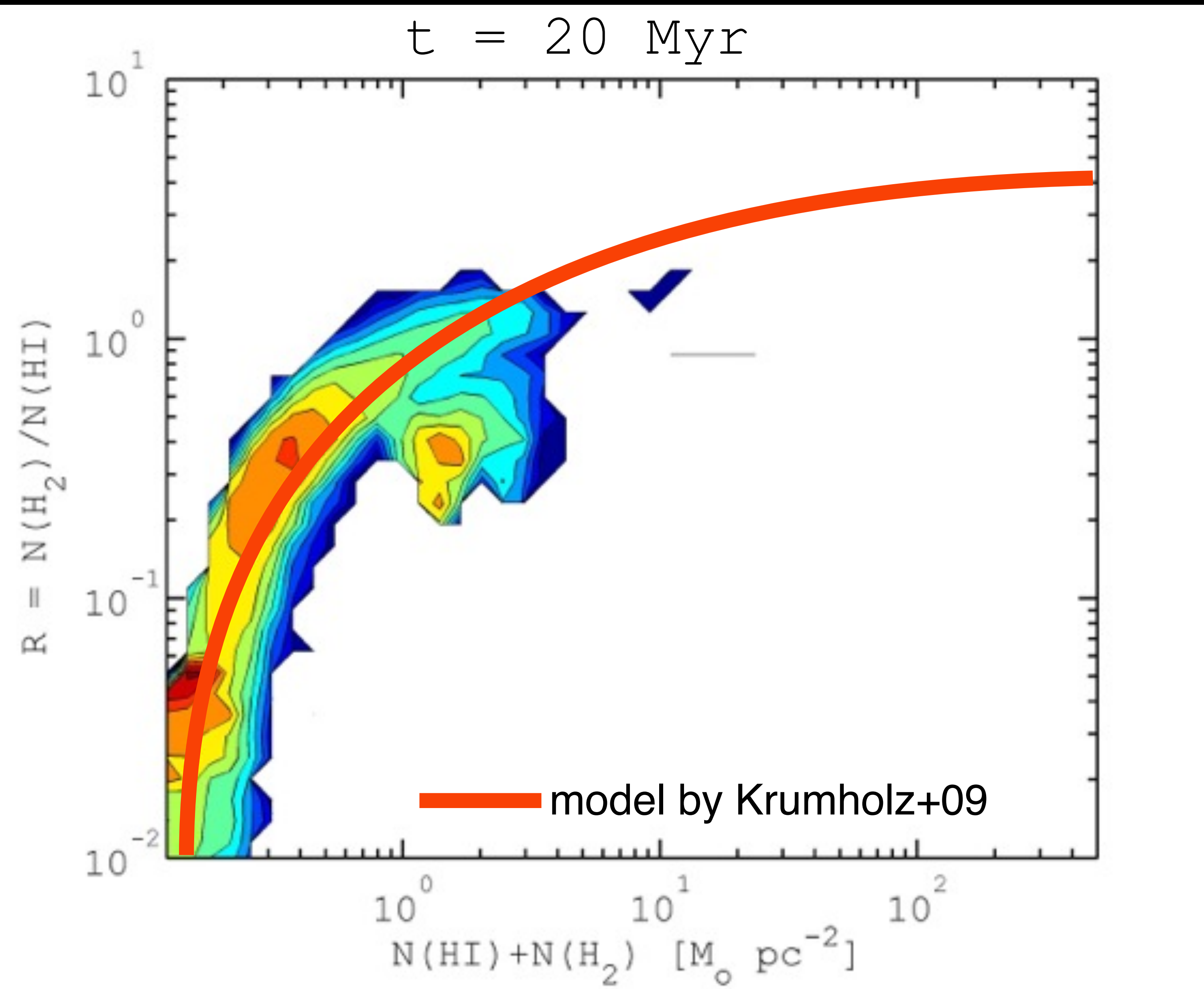
H_2 formation



Most of the mass in a molecular cloud is in the form of H_2

H_2 formation



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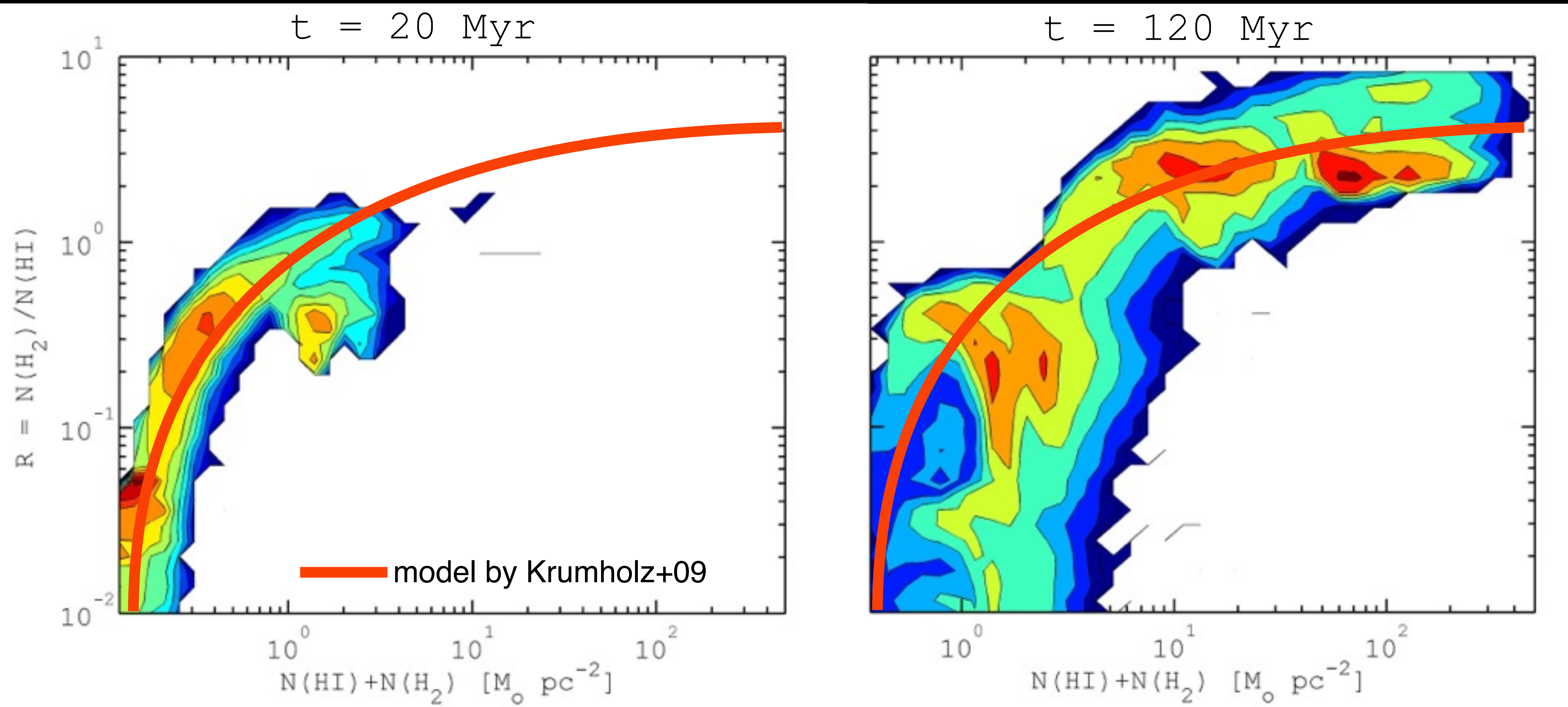

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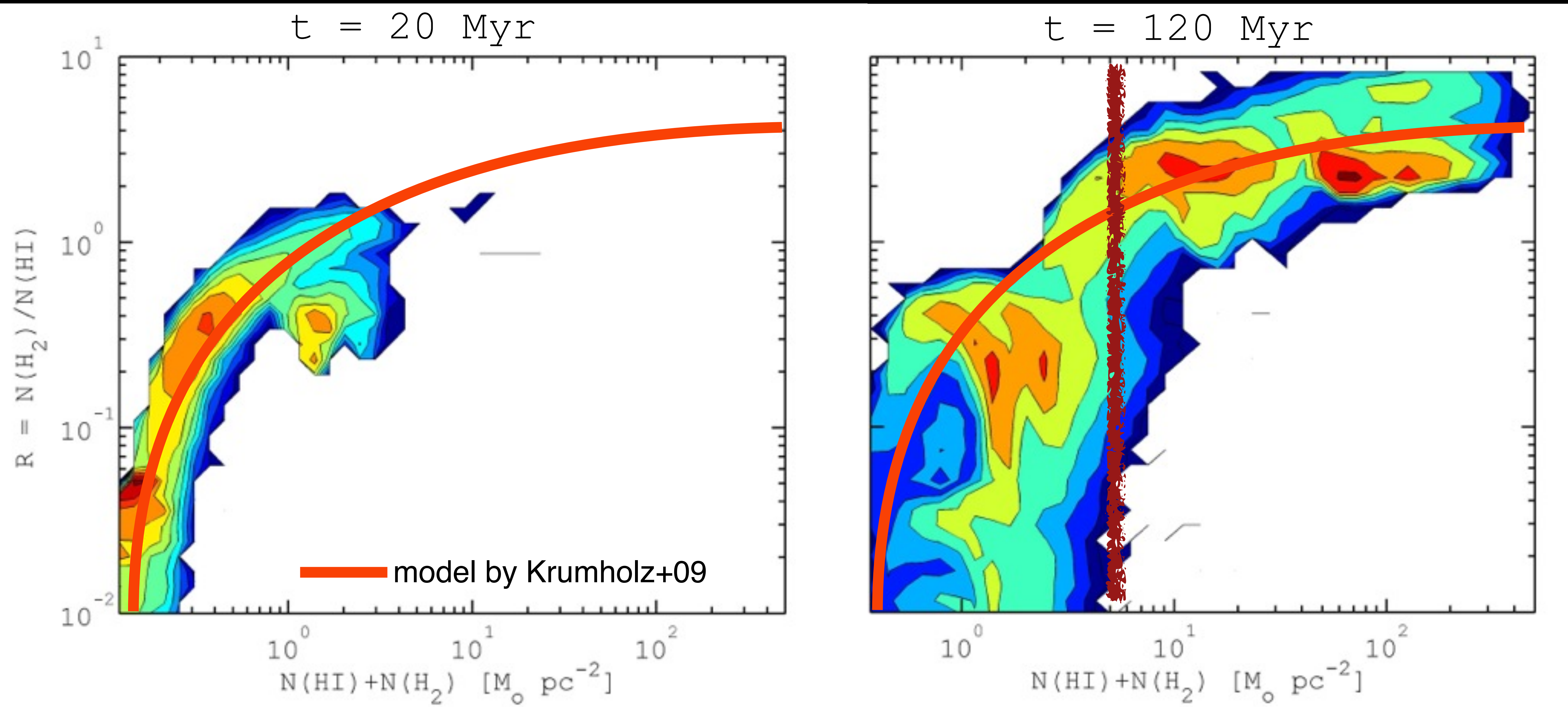


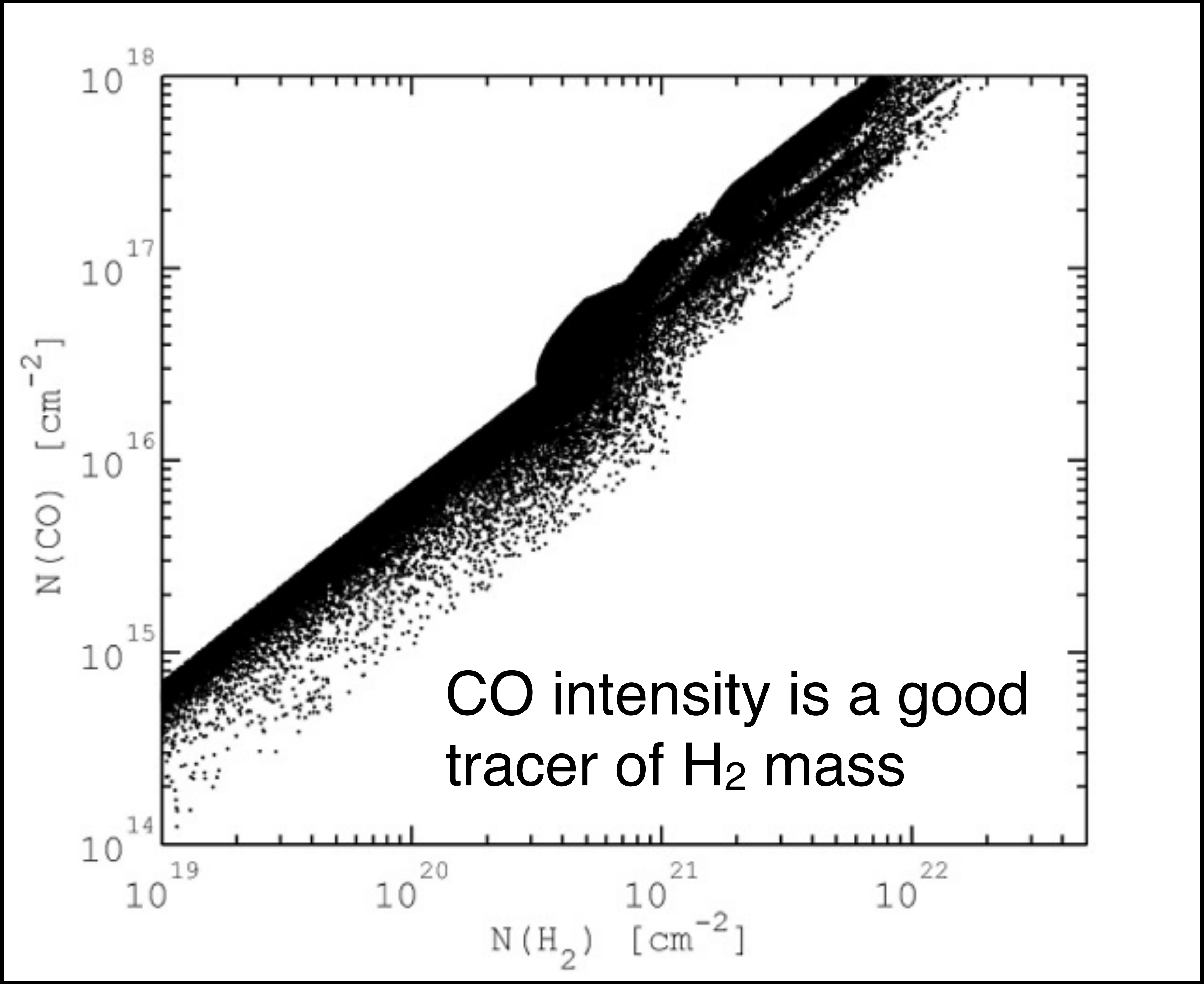
Most of the mass in a molecular cloud is in the form of H_2

Transition HI-> H2 at ~5-8 $M_o\,pc^{-2}$

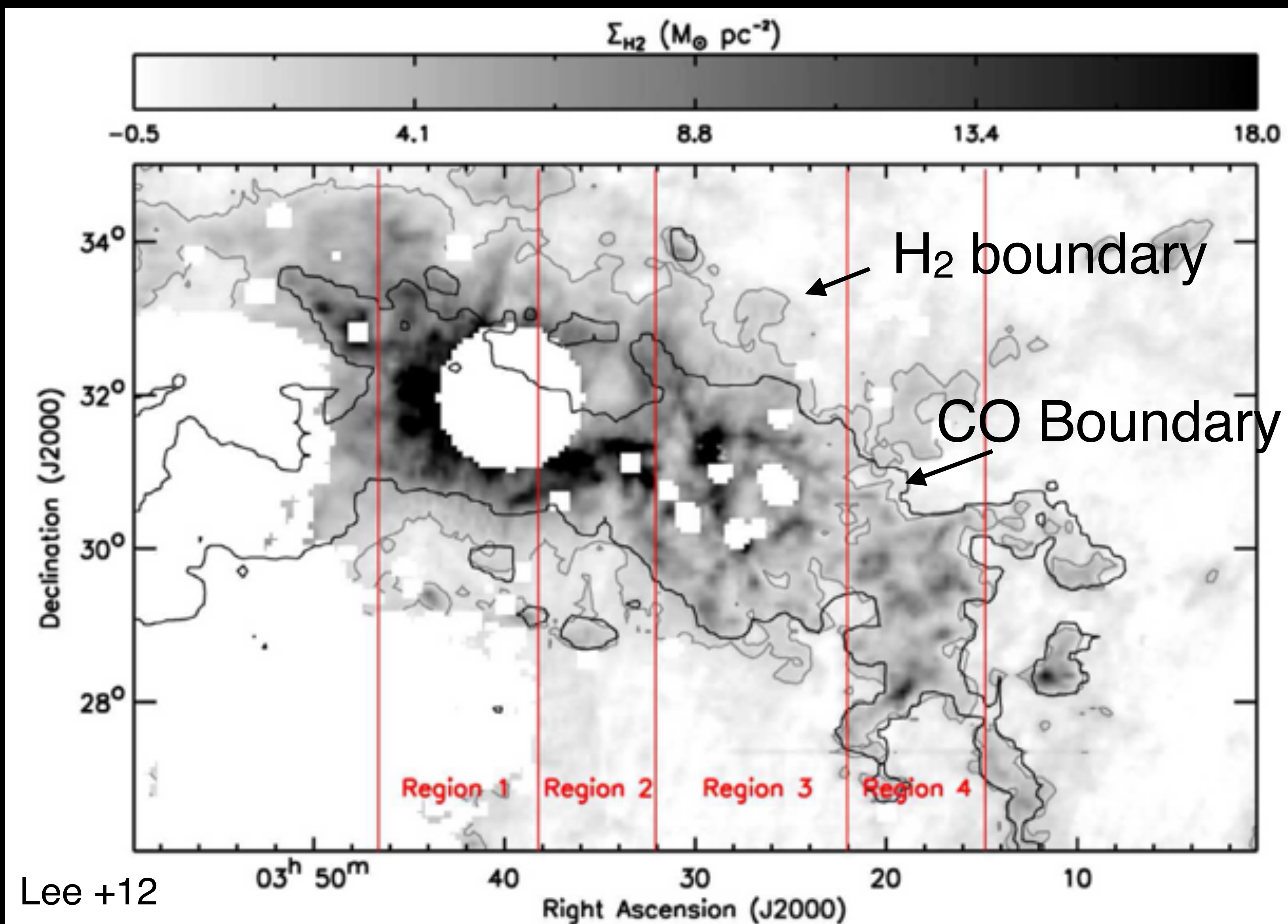
Constant shielding layer of HI -> H2 formation

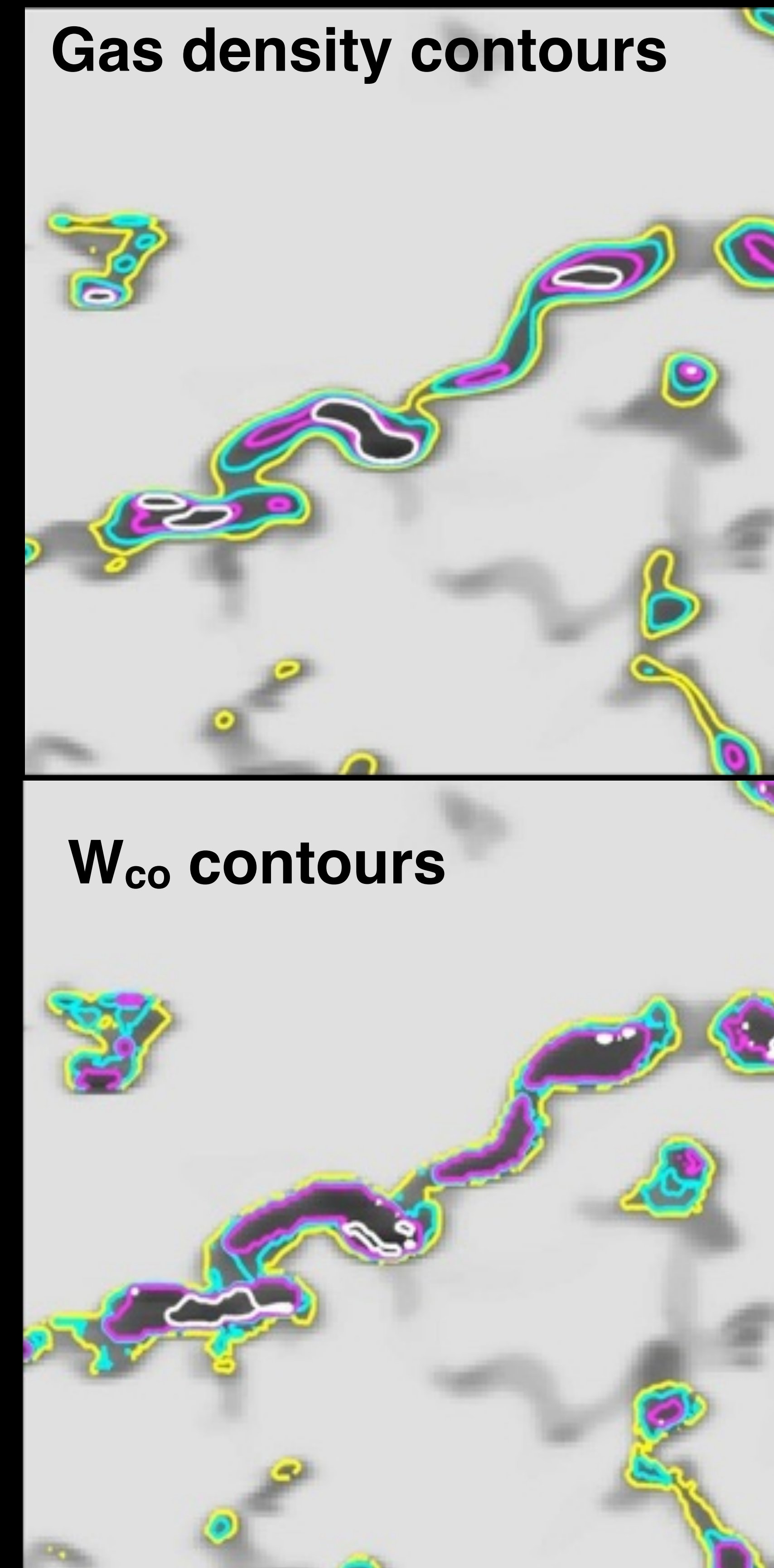
CO

$N(H_2)[cm^{-2}] = X_{co}\ W_{co}\ [K\ km\ s^{-1}]$



H_2 / CO clouds structure





Conversion factor

$N(H_2)[cm^{-2}] = X_{co}\ W_{co}\ [K\ km\ s^{-1}]$ Dickman et al. 1986

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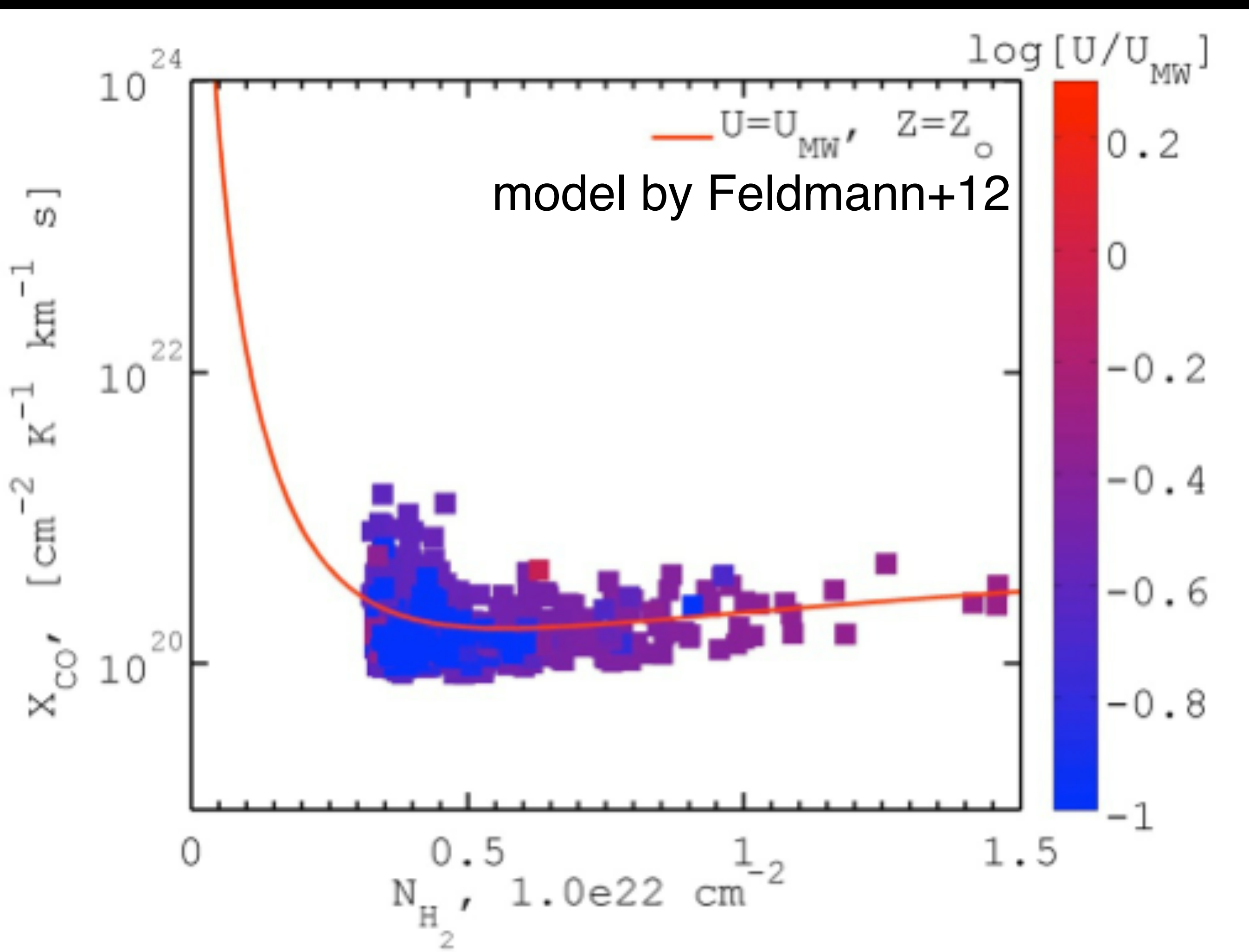
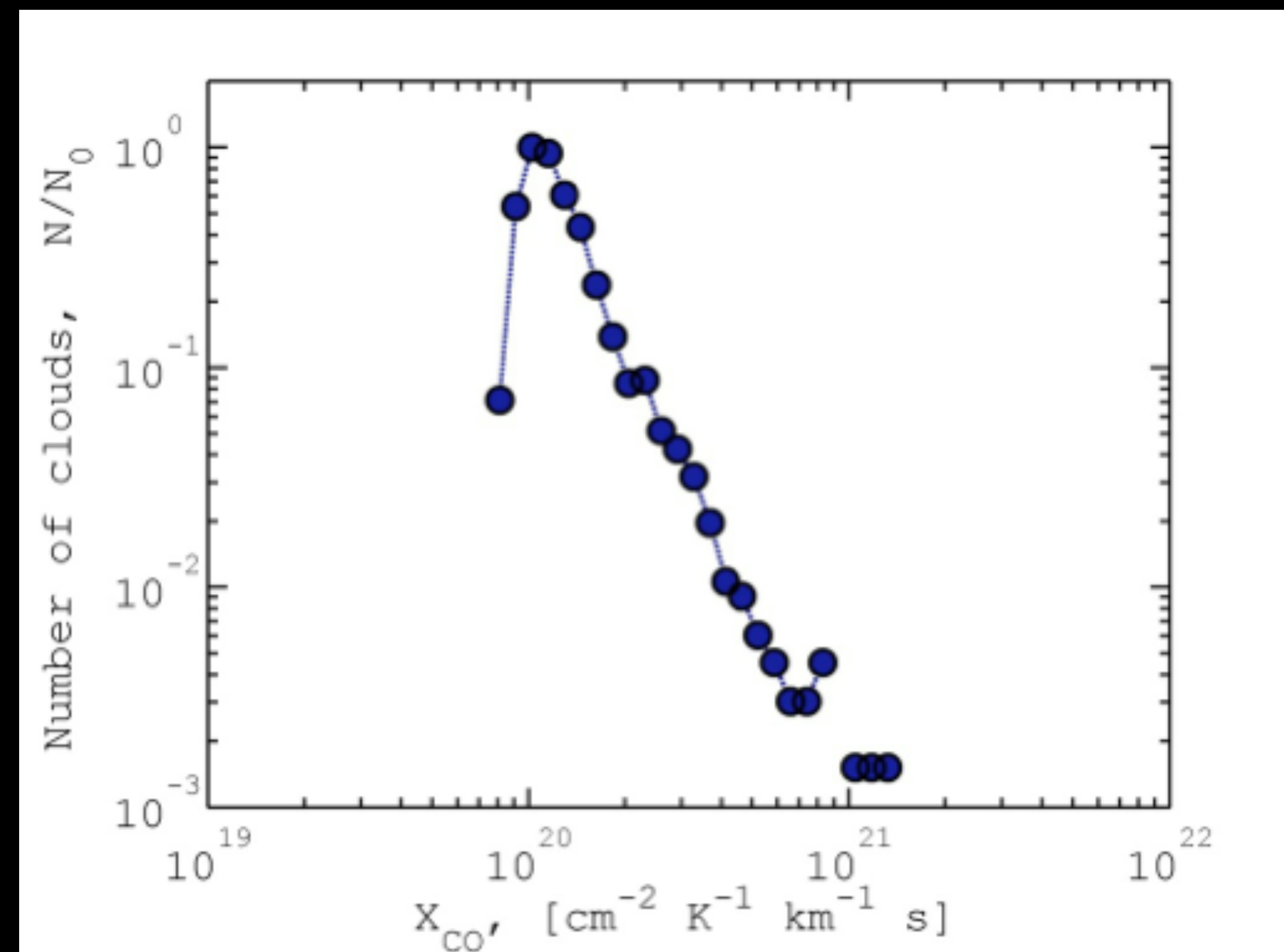
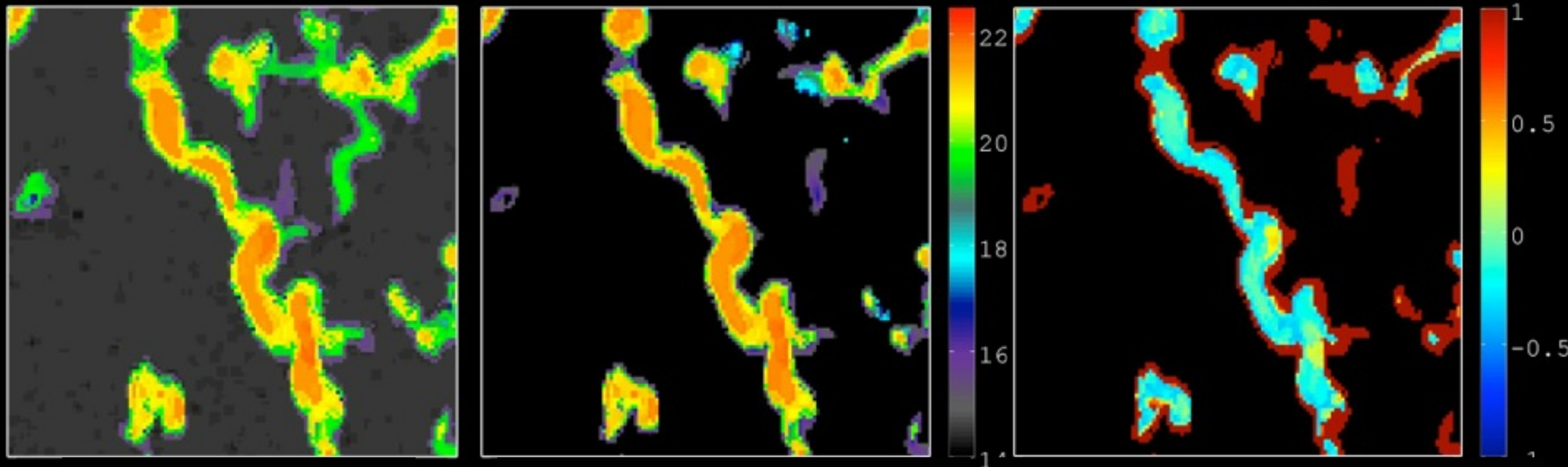




Dark gas amount

For standard X_{CO}: $N_{H2}^* = 2\times10^{20}\ W_{CO}$



Simulated N_{H2} Reconstructed N_{H2}^* Residual $(N_{H2}-N_{H2}^*)/N_{H2}$

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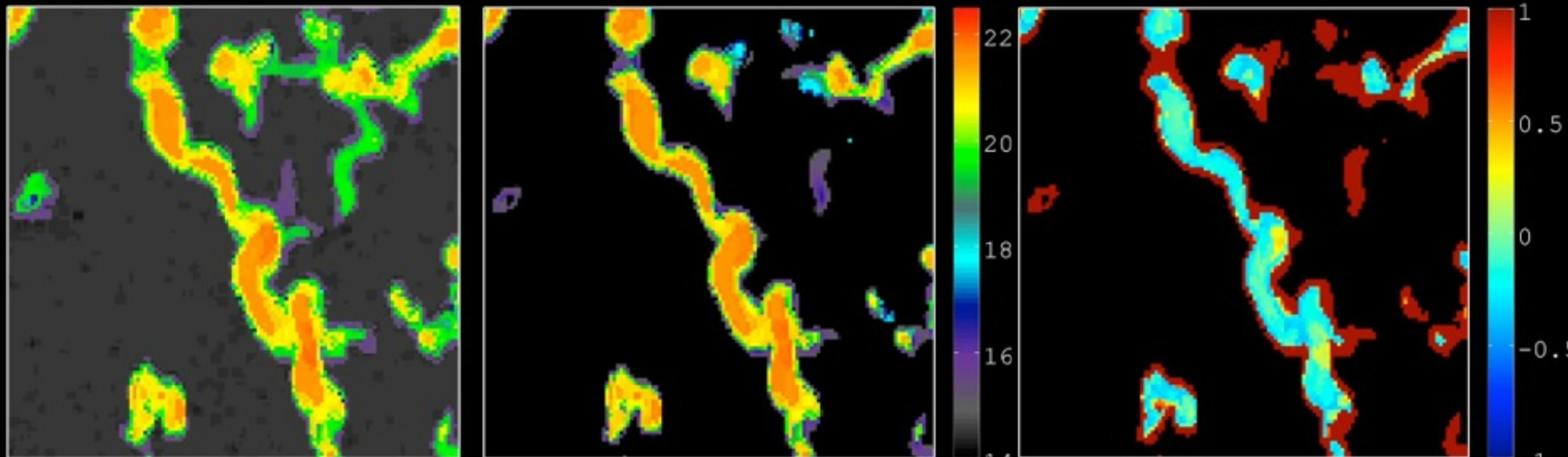

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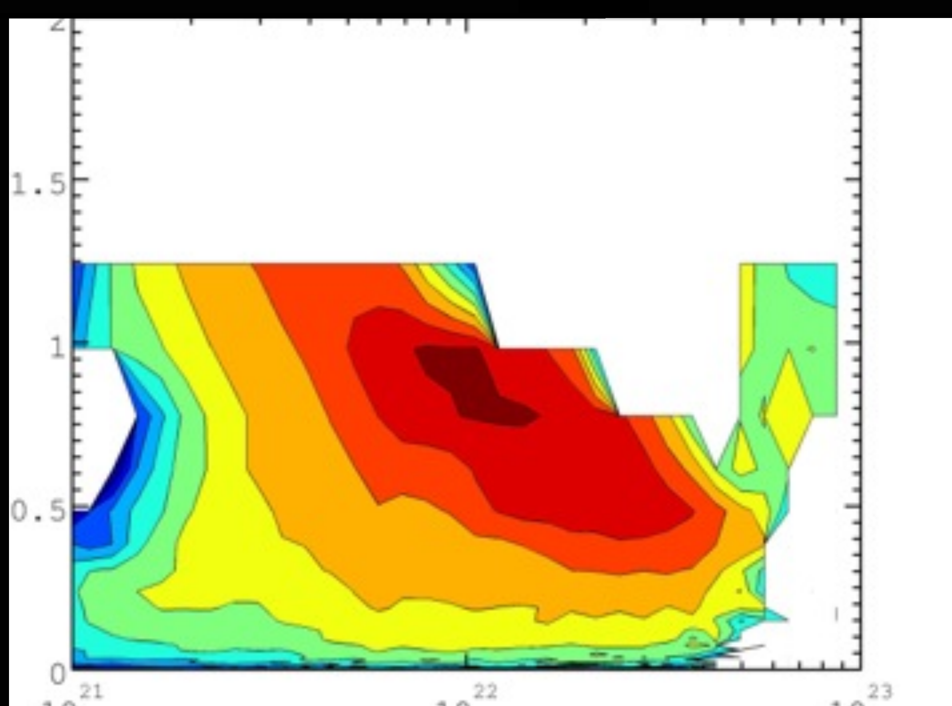

Residual $(N_{H2}-N_{H2}^*)/N_{H2}$

N_{total}

Dark gas amount

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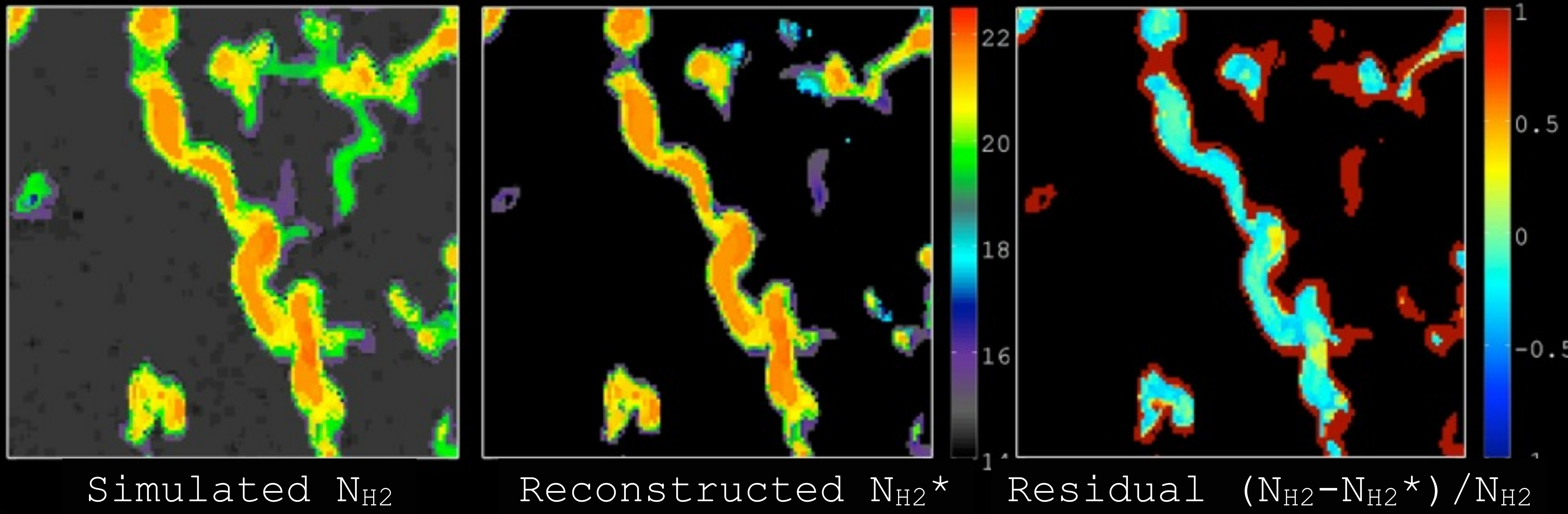
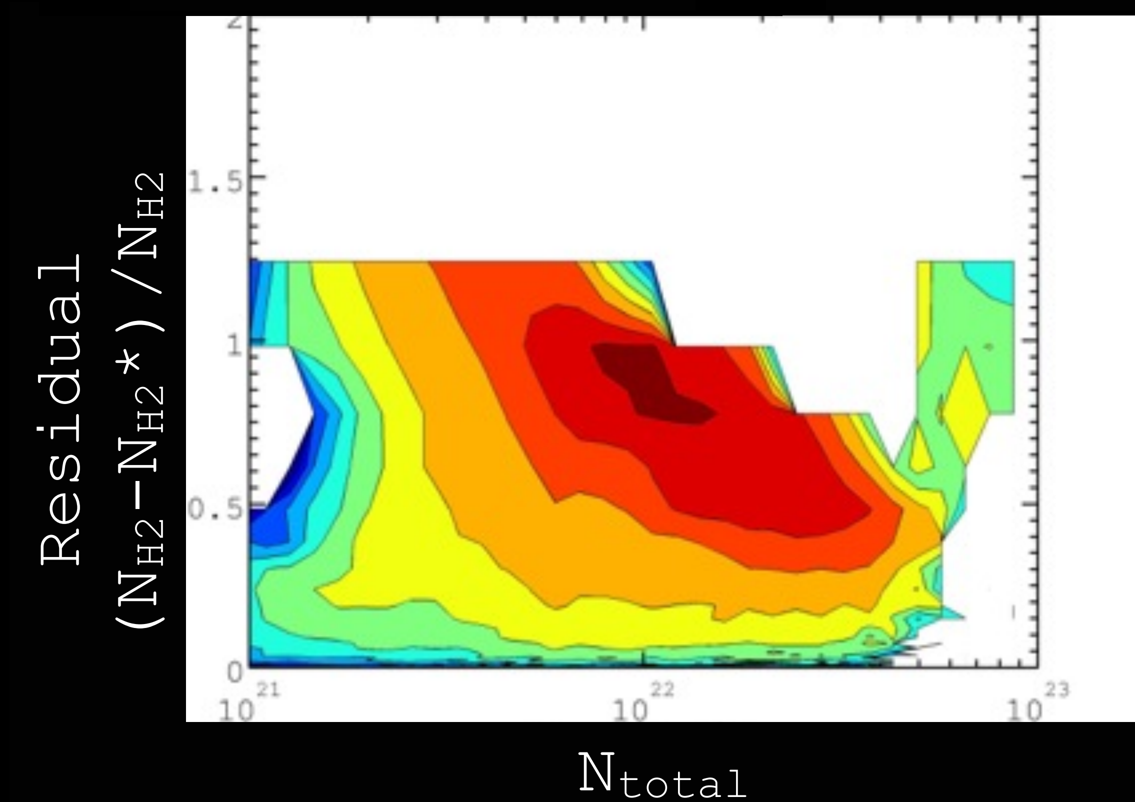
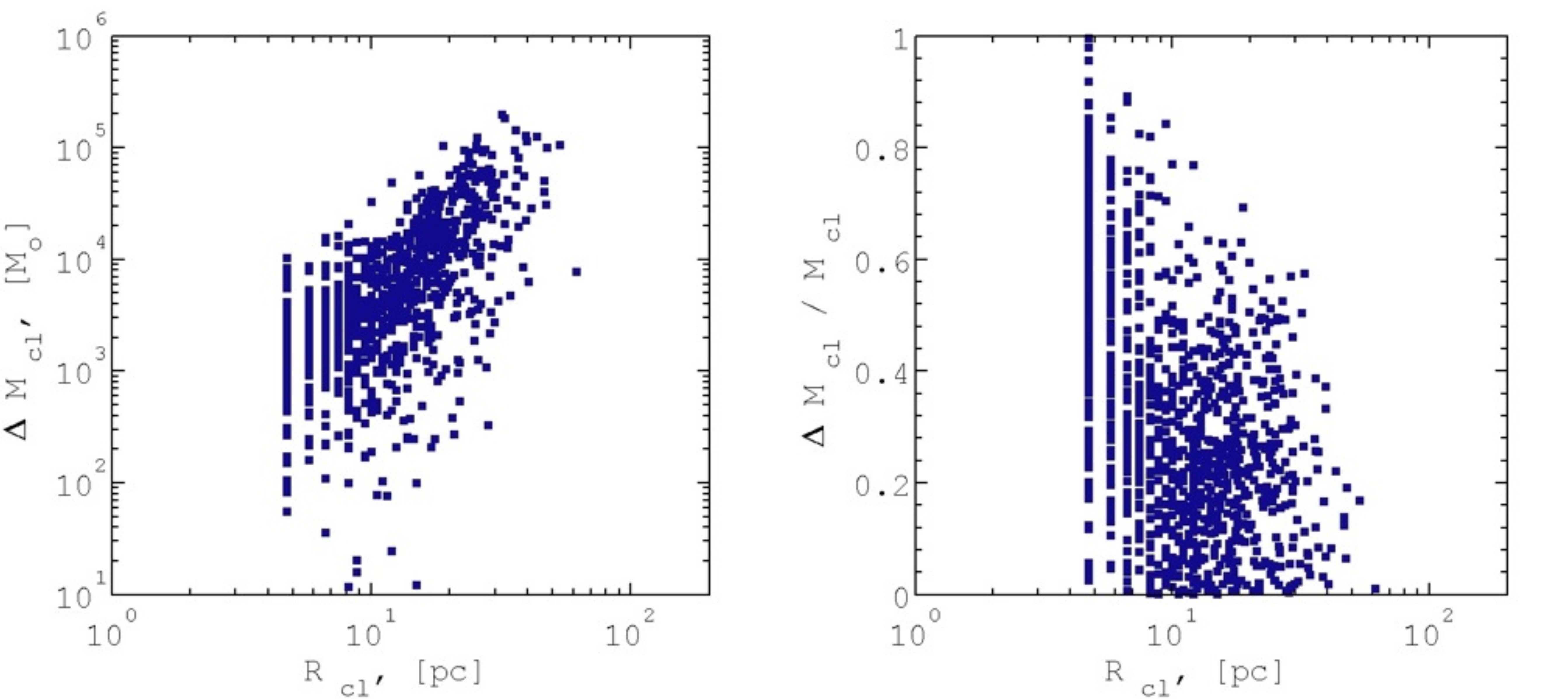




Limited density range
of the clouds description by L_{CO}

Dark gas amount in GMCs



Constant X_{CO}: up to 15% of gas is missed in the entire disc

Outline

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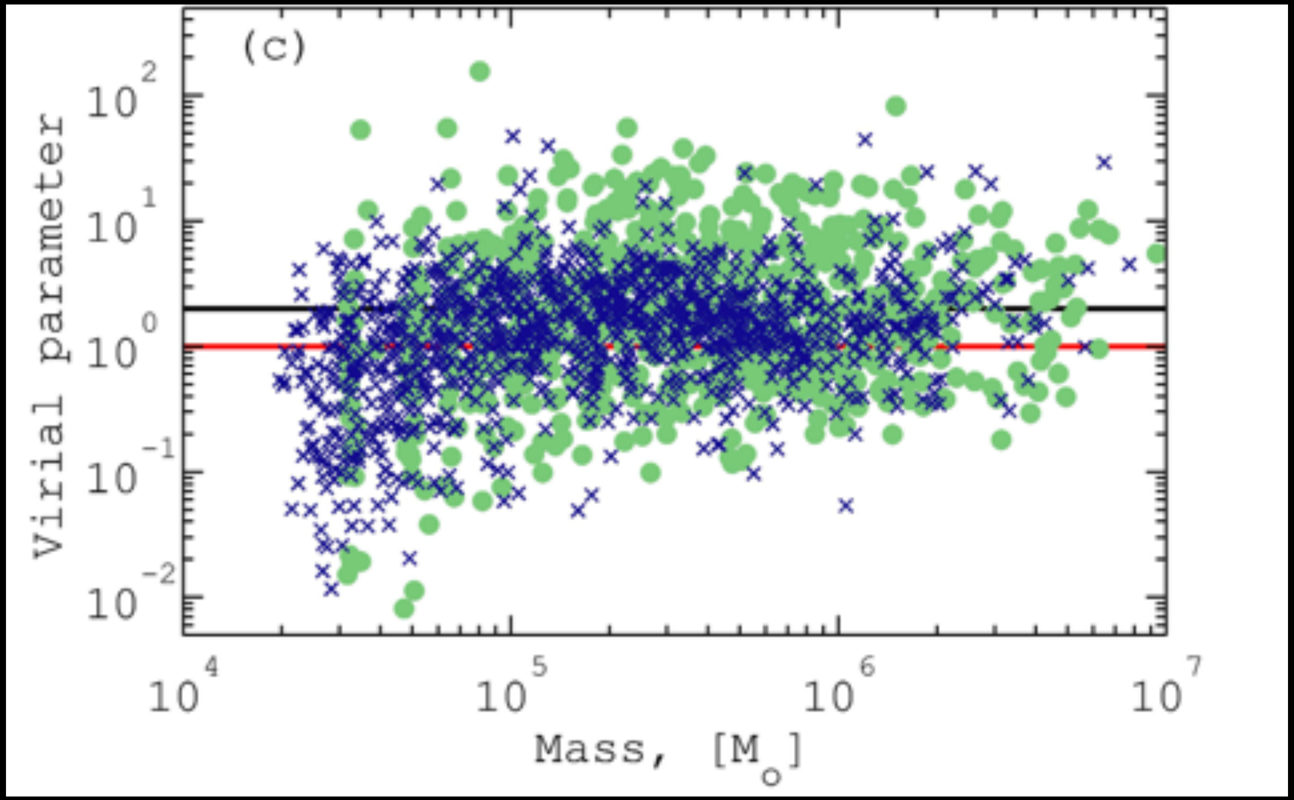
Clouds state

Virial parameter $\alpha = 5\sigma^2 R/ (G M)$

$\alpha \ll 1$	$\alpha \sim 1$	$\alpha = 2$	$\alpha \gg 1$
collapsing or must be supported by something more than internal turn	gravitationally bound and stabilized by internal thermal	threshold between gravitationally bound and unbound objects	externally bound or transient features



Spatial distribution of (un)bound clouds

Virial parameter

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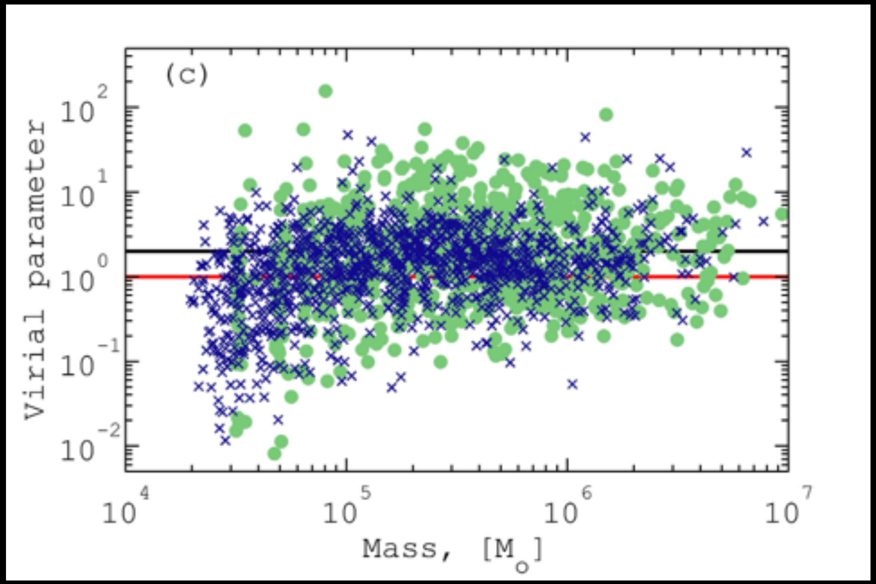

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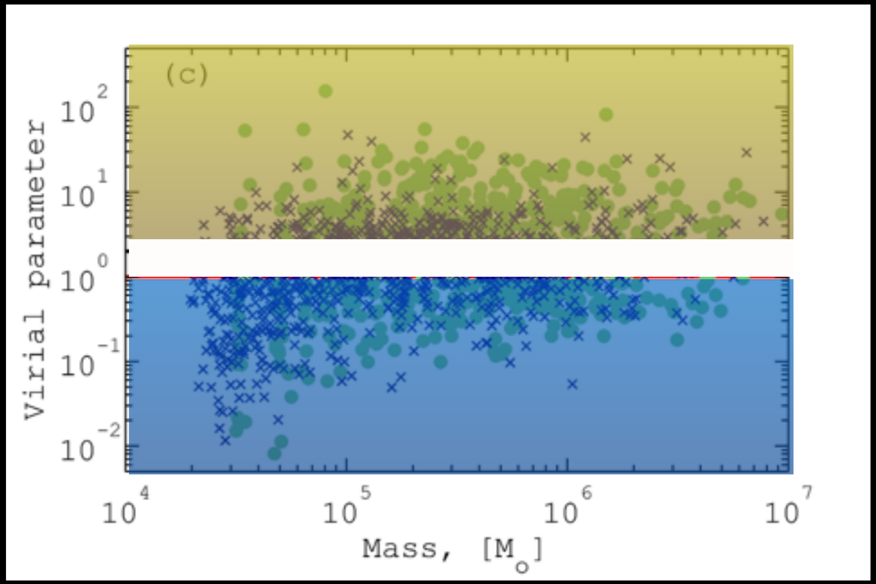

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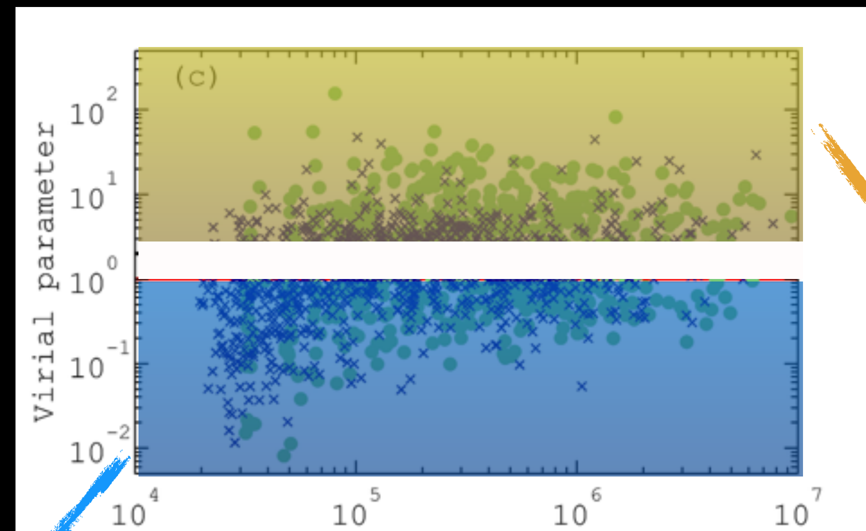

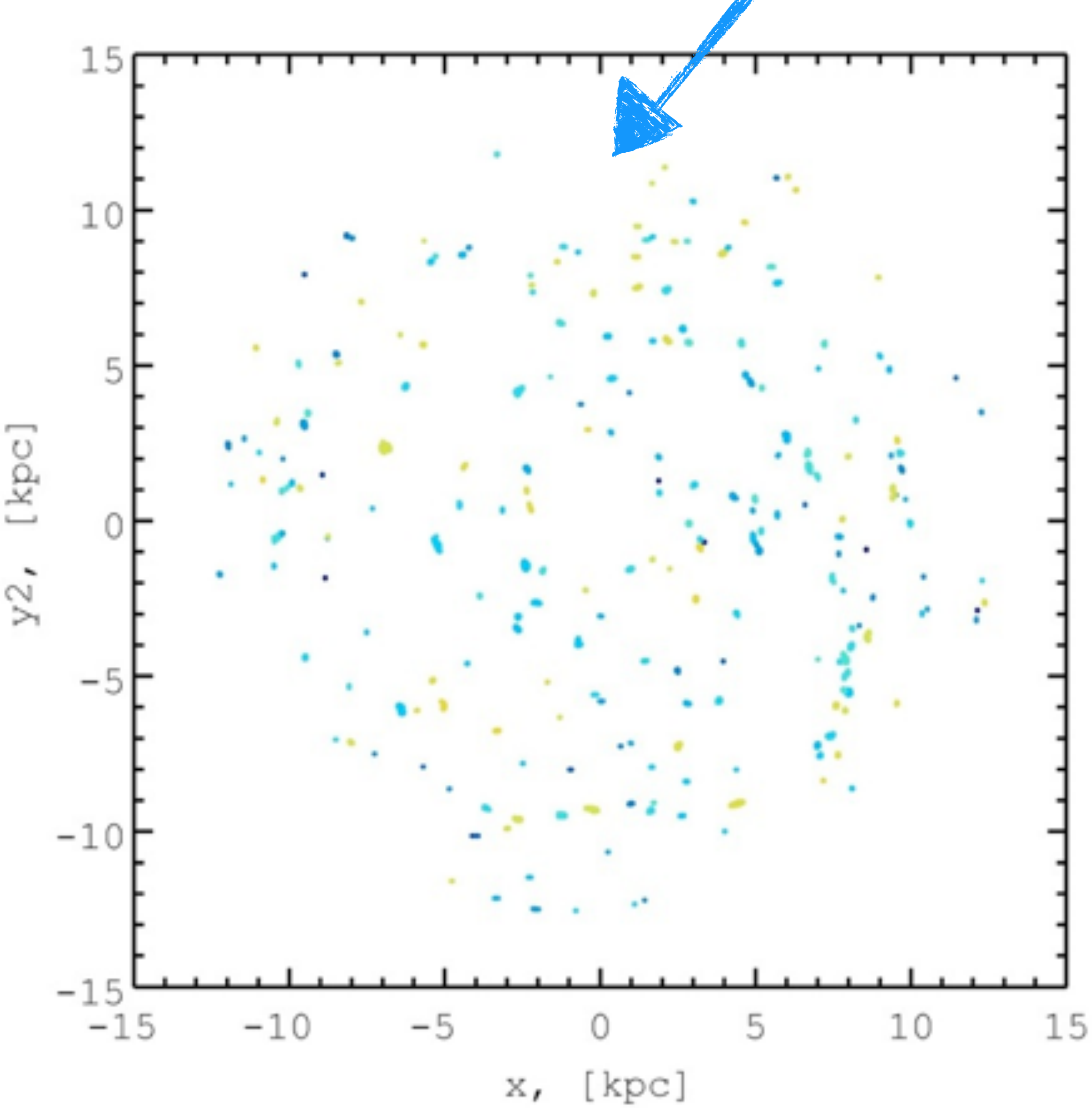

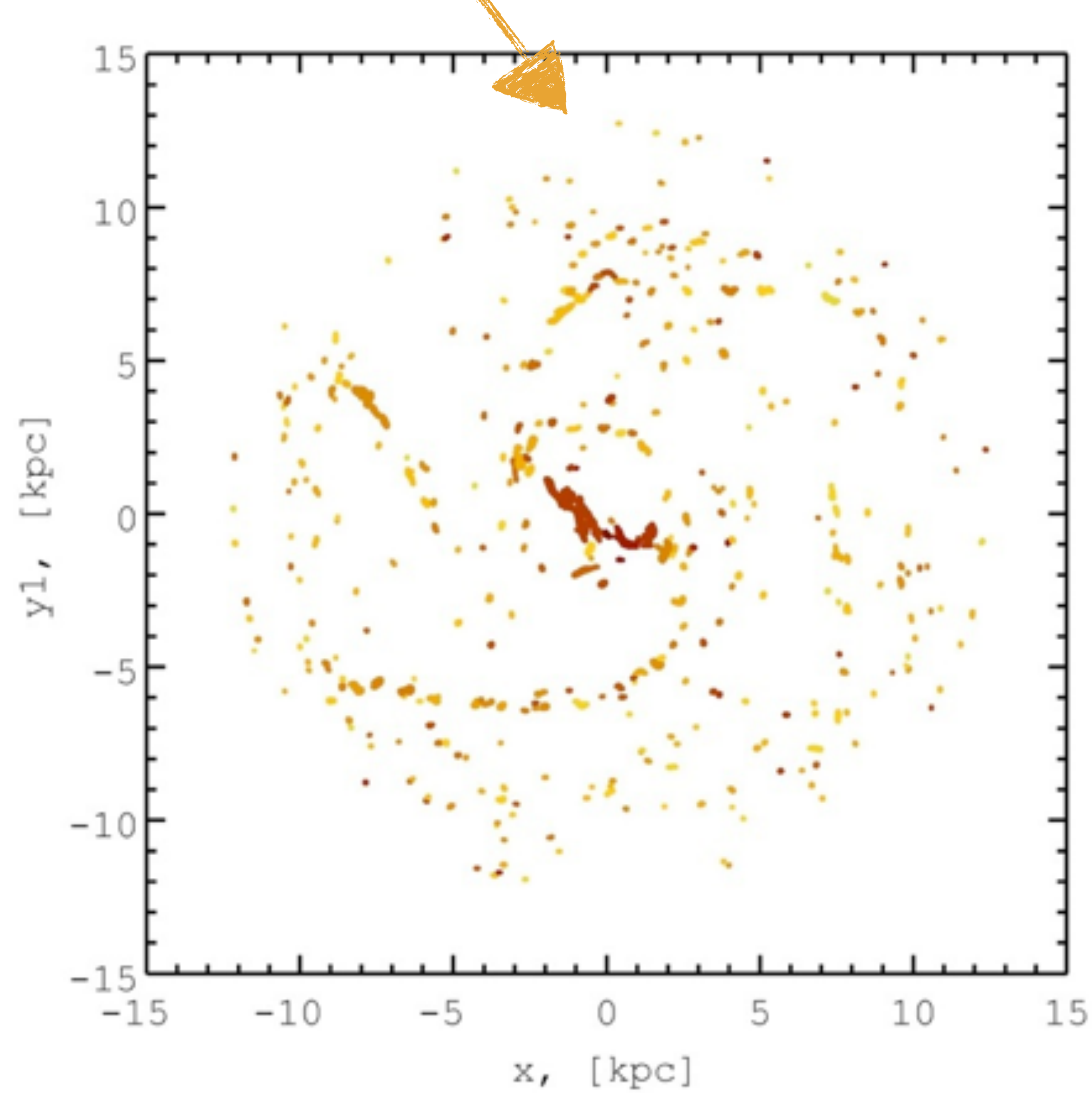

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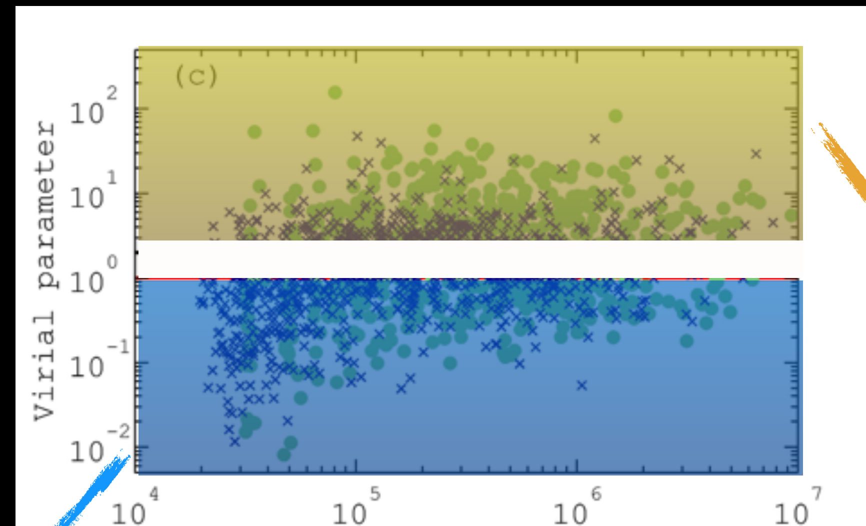
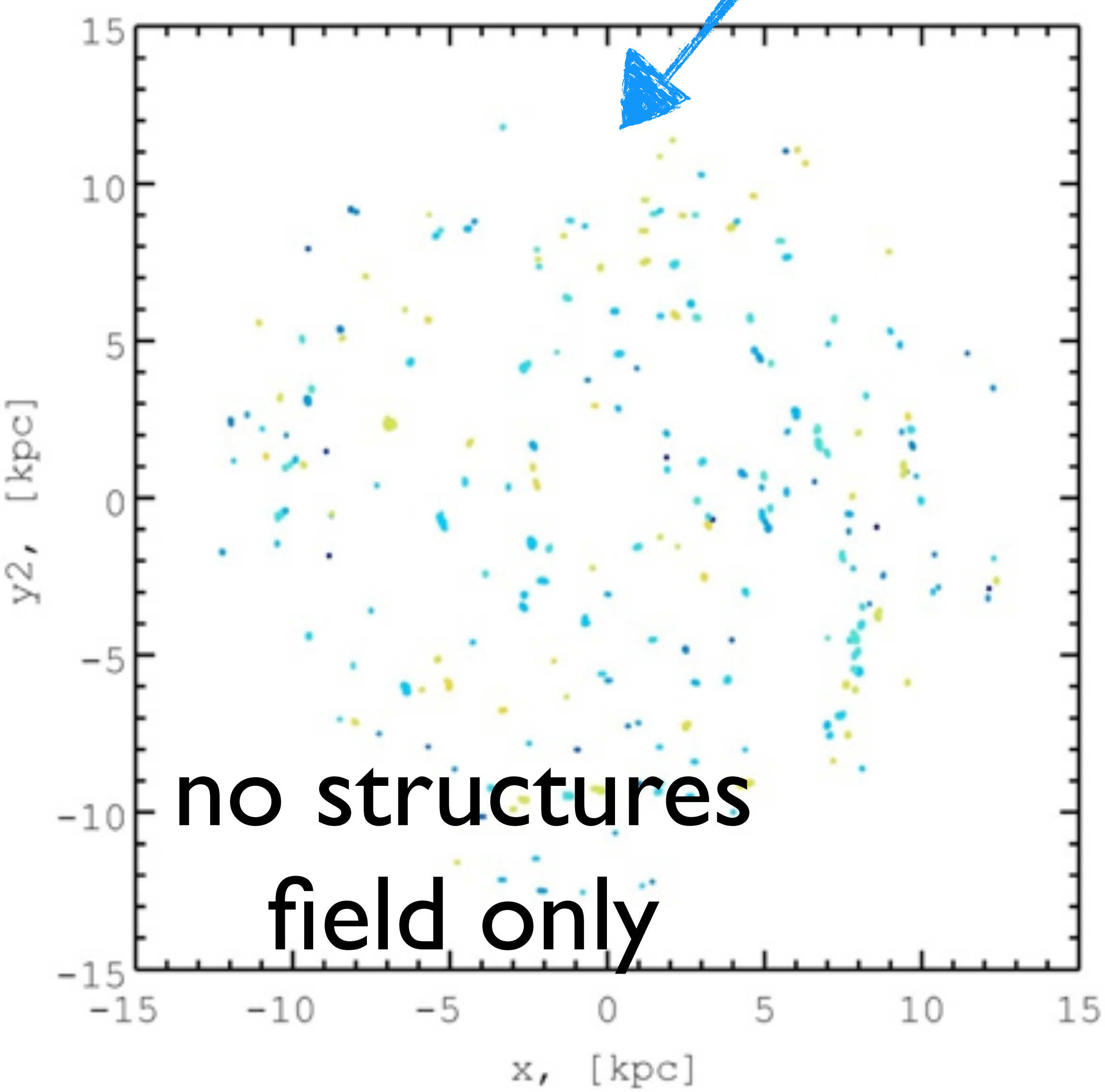
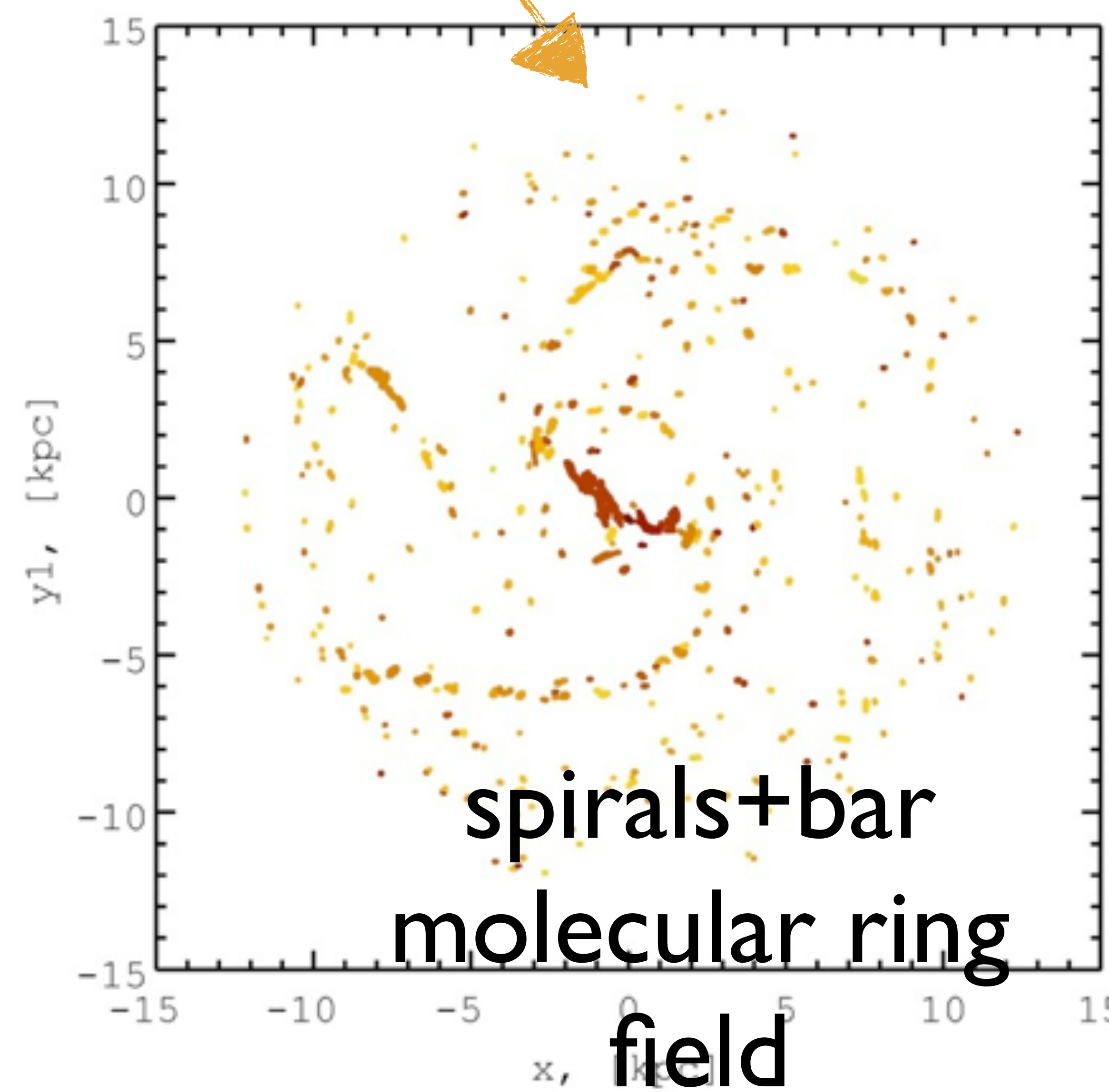
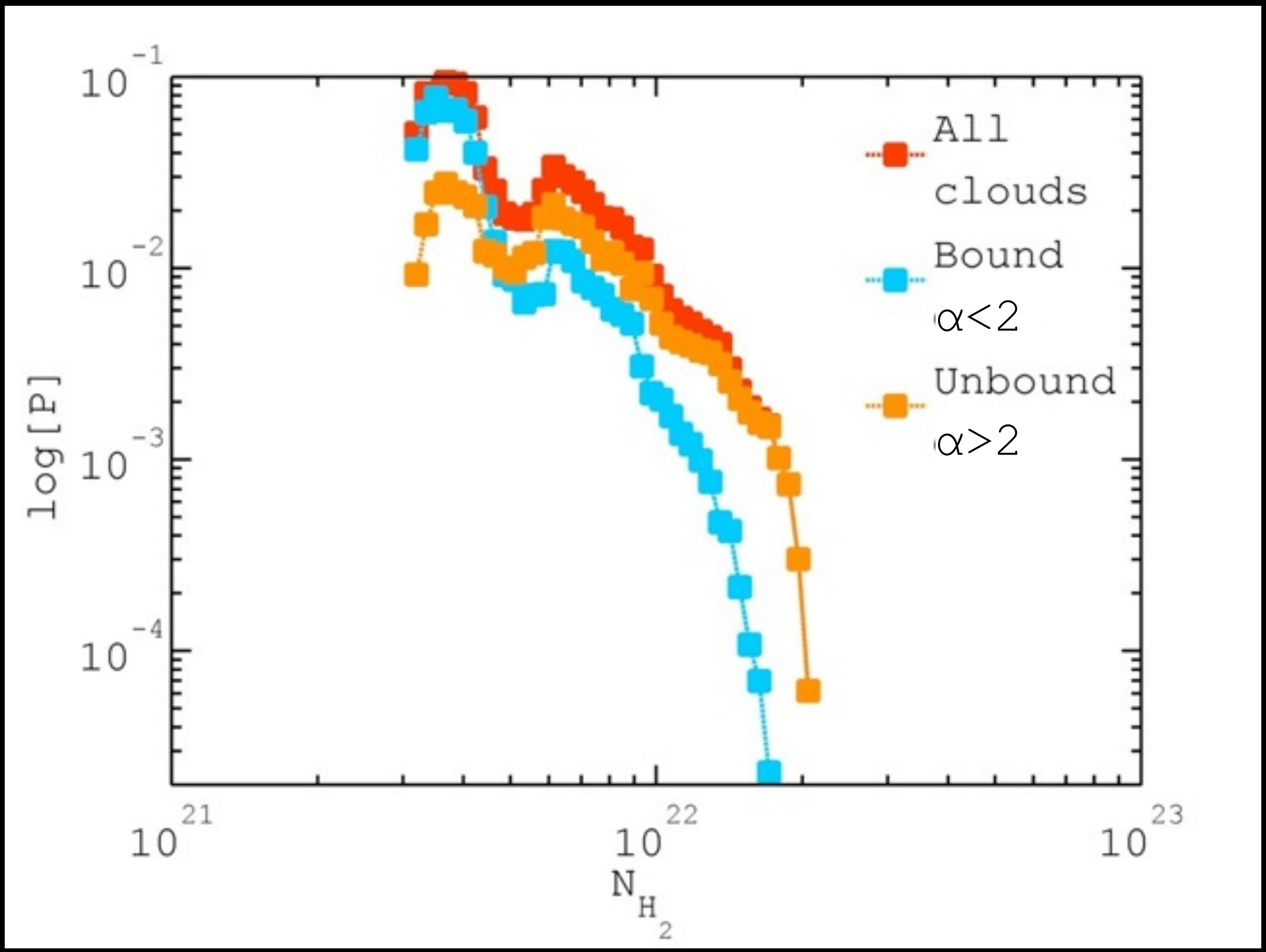




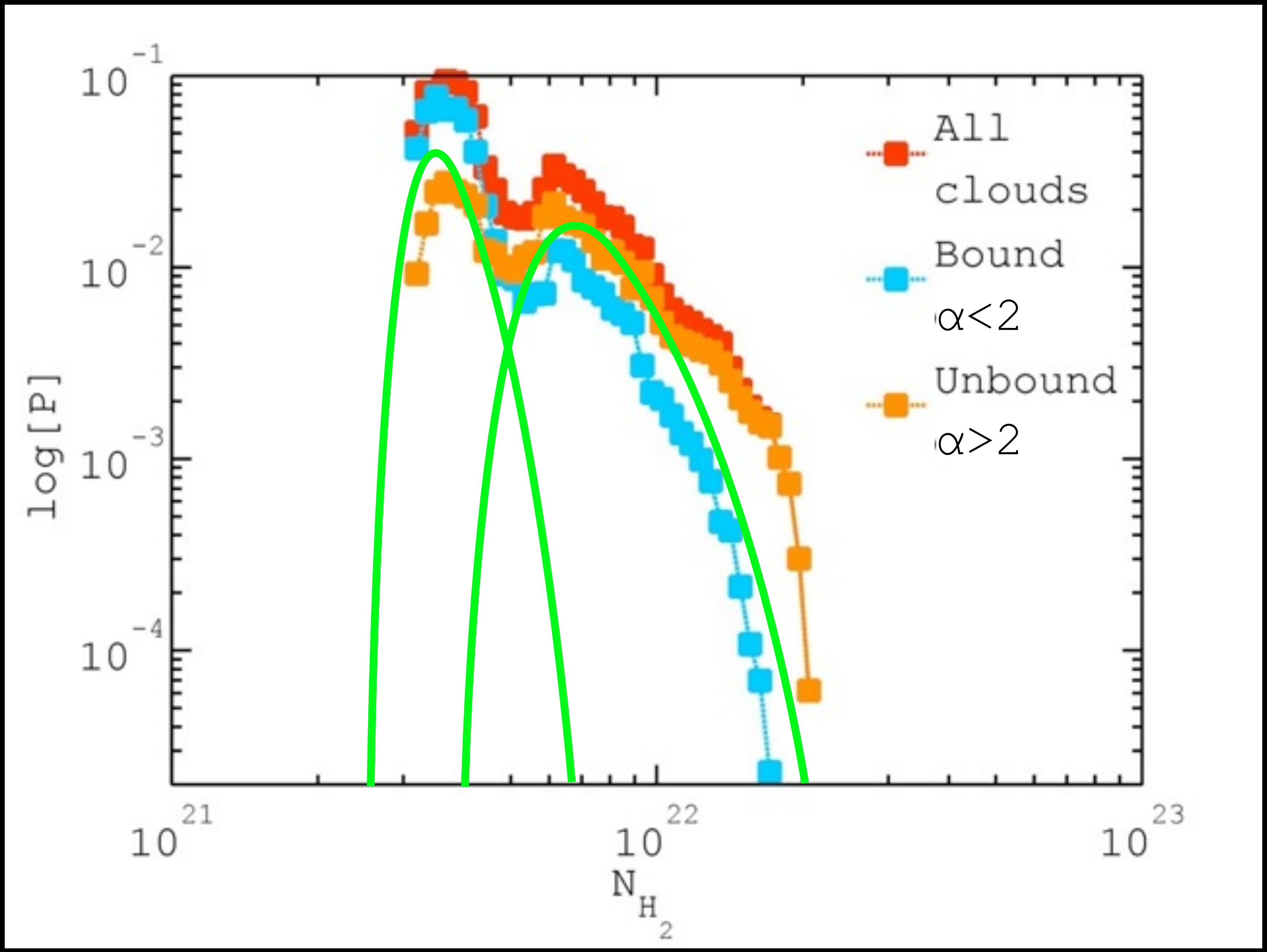


Clouds PDF



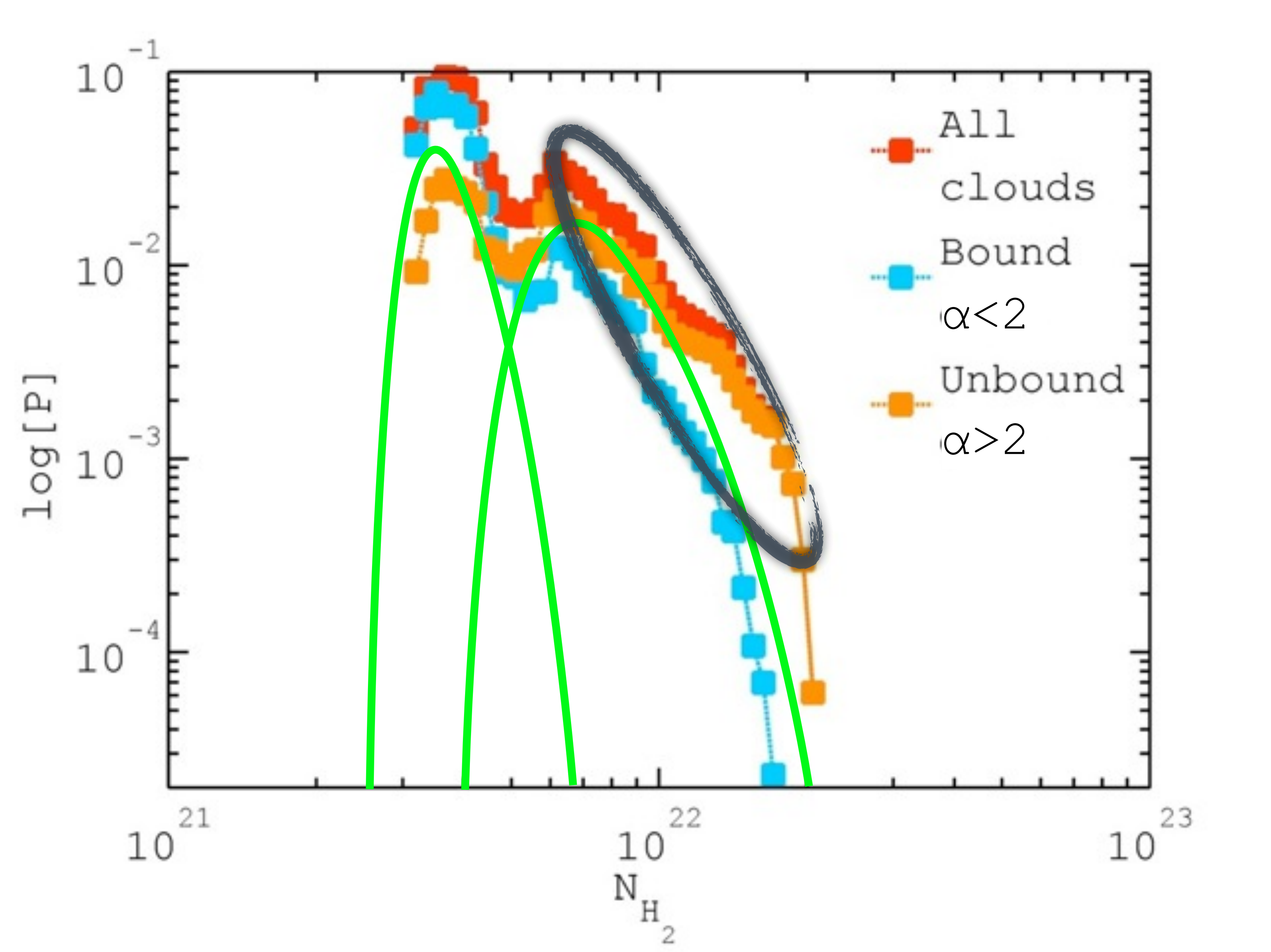
All clouds
Bound α<2
Unbound α>2
log[P]
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{21}
10^{22}
10^{23}
N_{H_2}

Clouds PDF



PDF(H_2) of all clouds is a superposition of two PDFs?

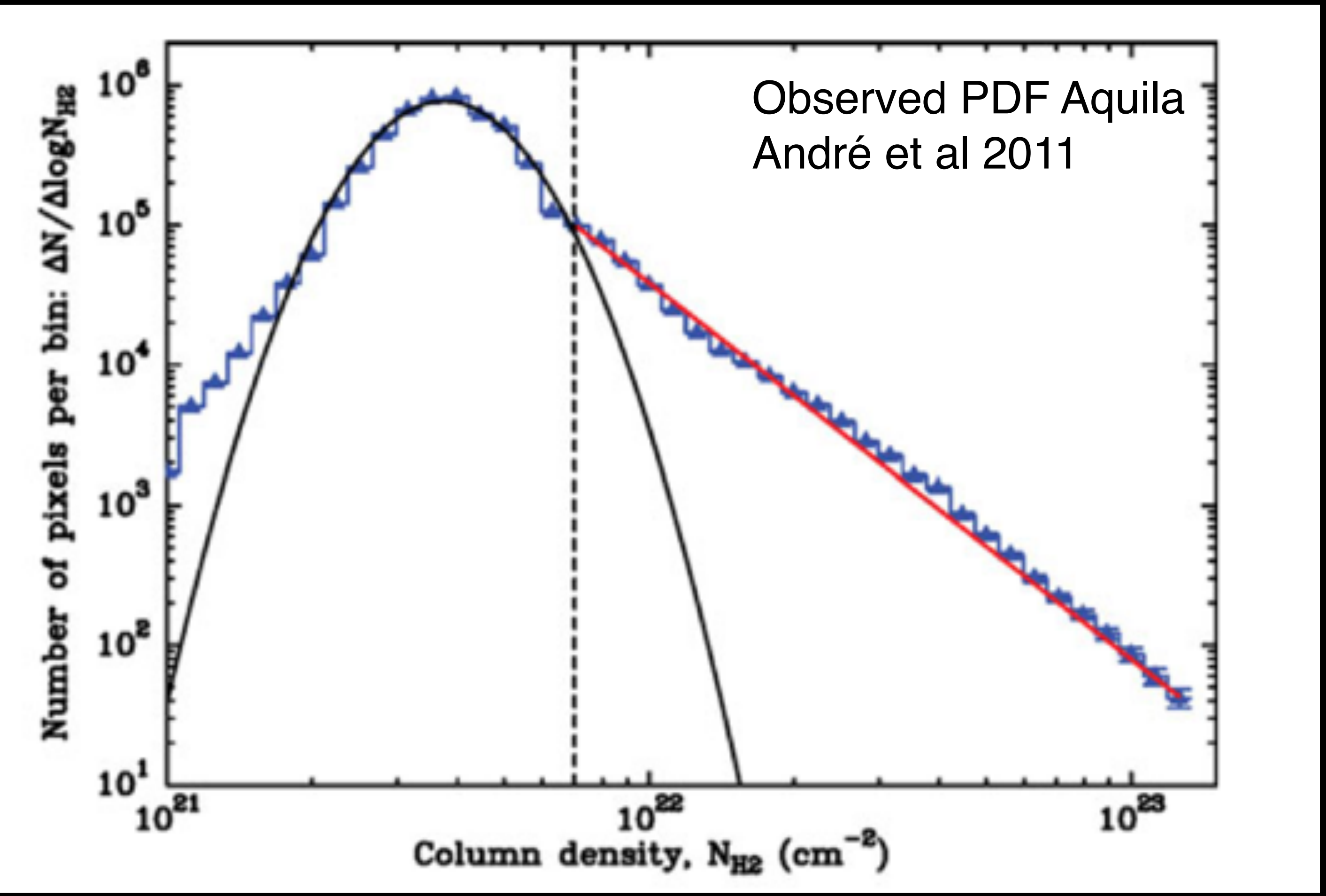
Clouds PDF



Unbound clouds tend to have higher H_2 abundance

PDF(H_2) of all clouds is a superposition of two PDFs?

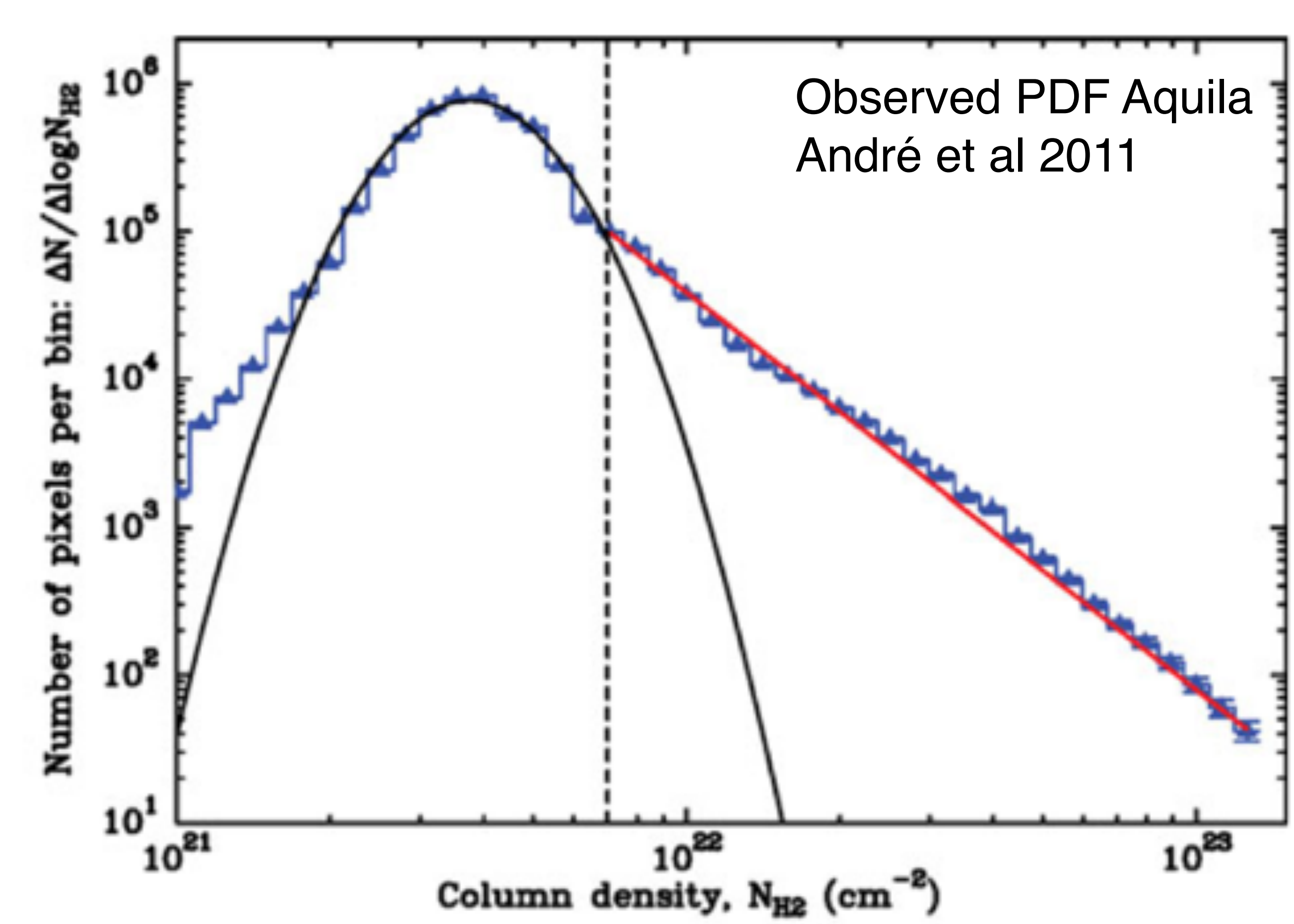
GMCs PDF

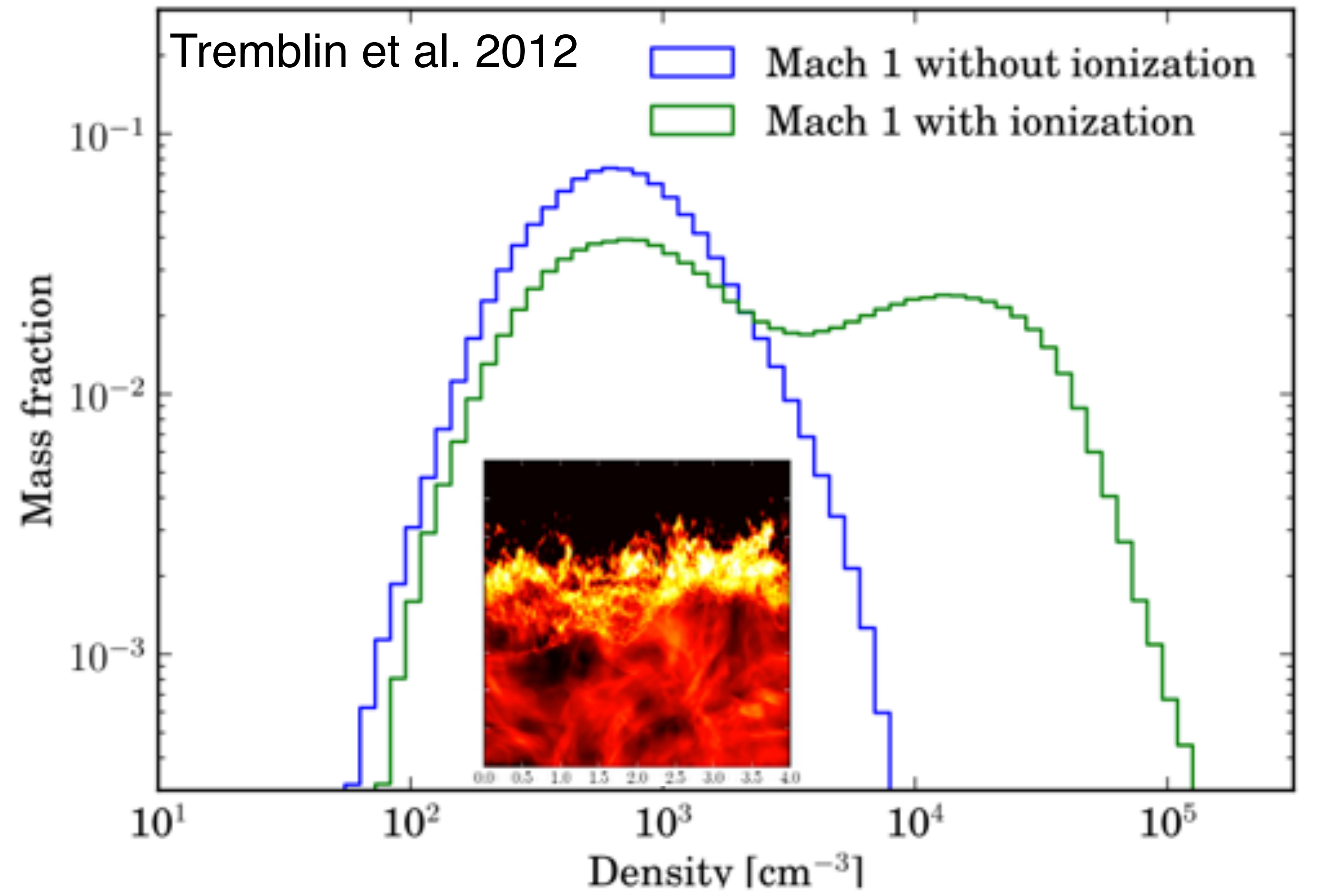


Turbulent cloud -> Lognormal at low column densities

Influence of gravity -> Power-law at highest column densities

GMCs PDF





Turbulent cloud -> Lognormal at low column densities

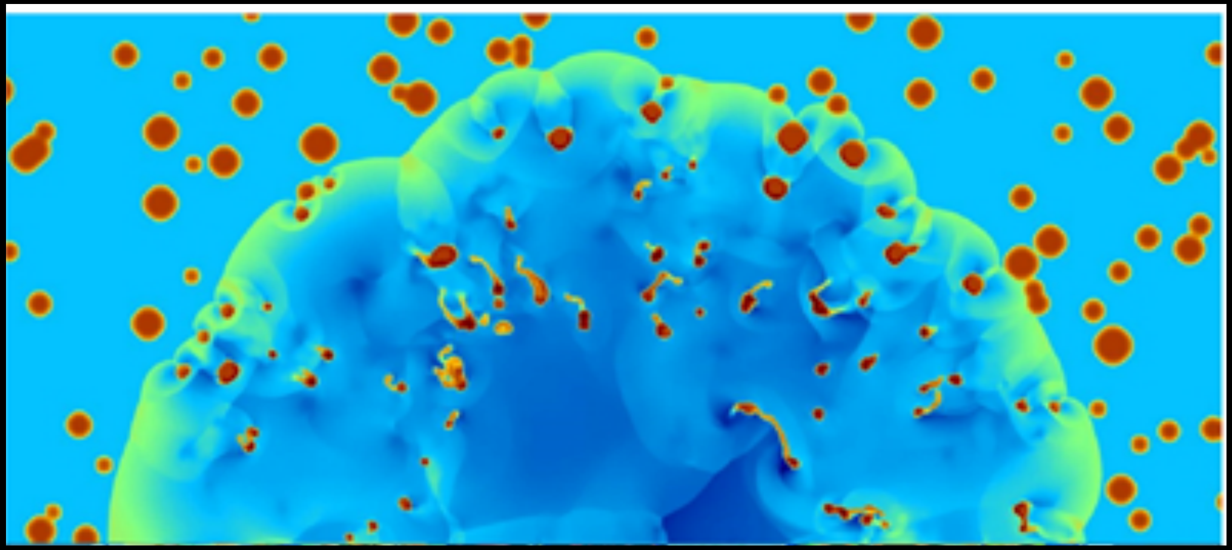
Influence of gravity -> Power-law at highest column densities

Feedback and ionisation

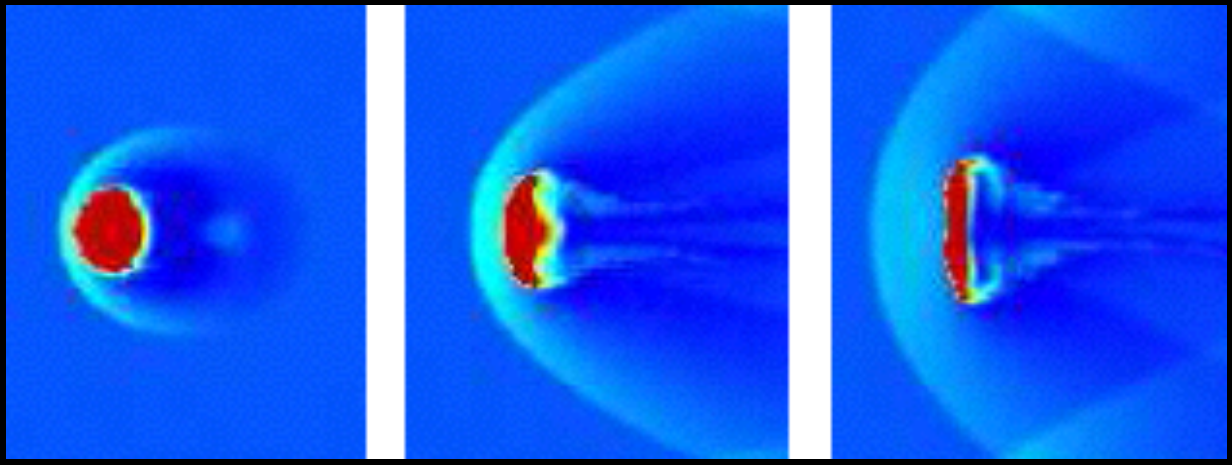
Compressed layer -> Lognormal (turbulent) or Power-law (homogeneous)

- Stellar feedback makes clouds *unbound* in terms of the *virial parameter*

$$\alpha = 5\sigma^2 R/ (G\ M)$$



- Clouds can be compressed due to motion through the potential well (spirals, bar)



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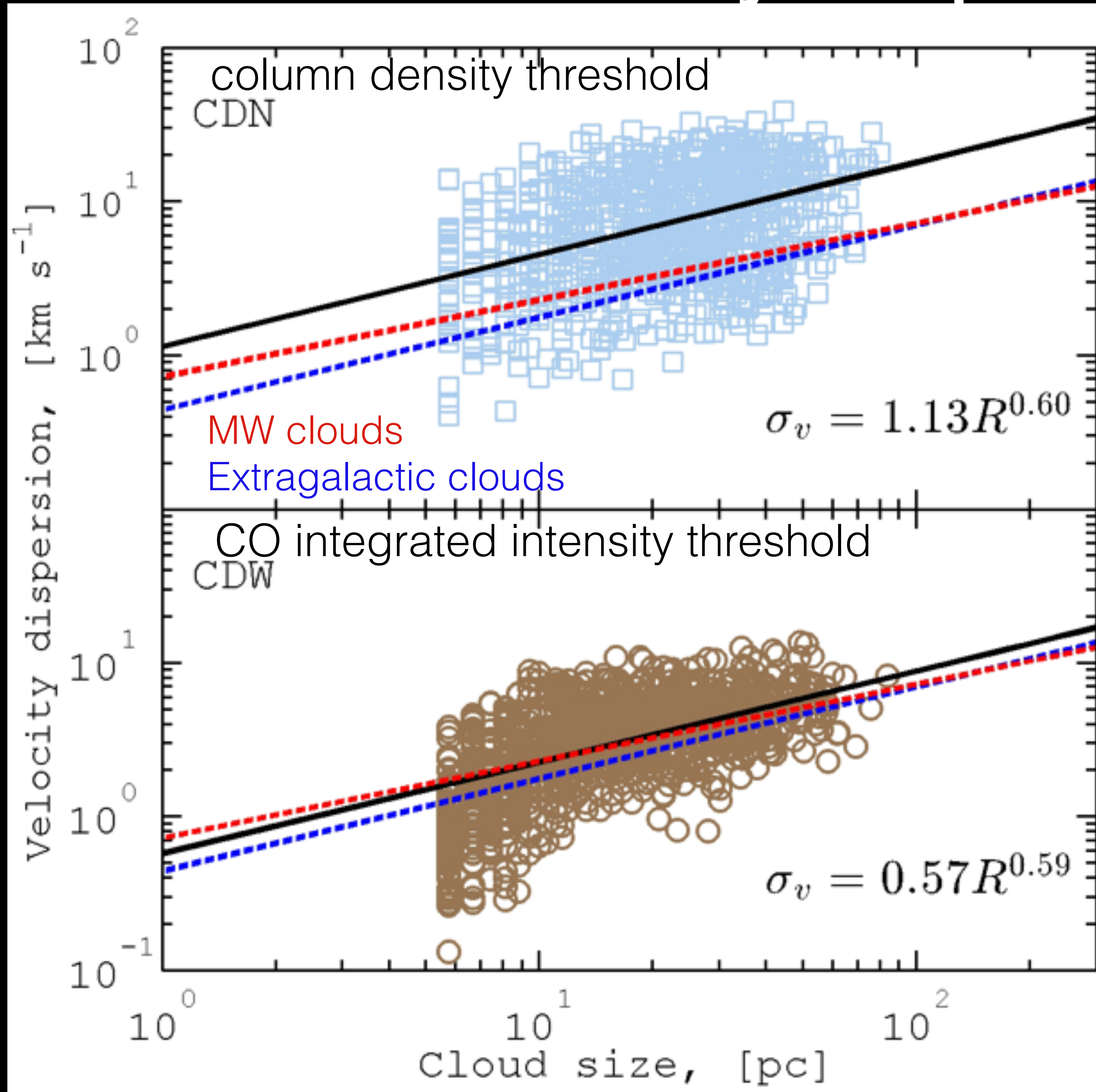
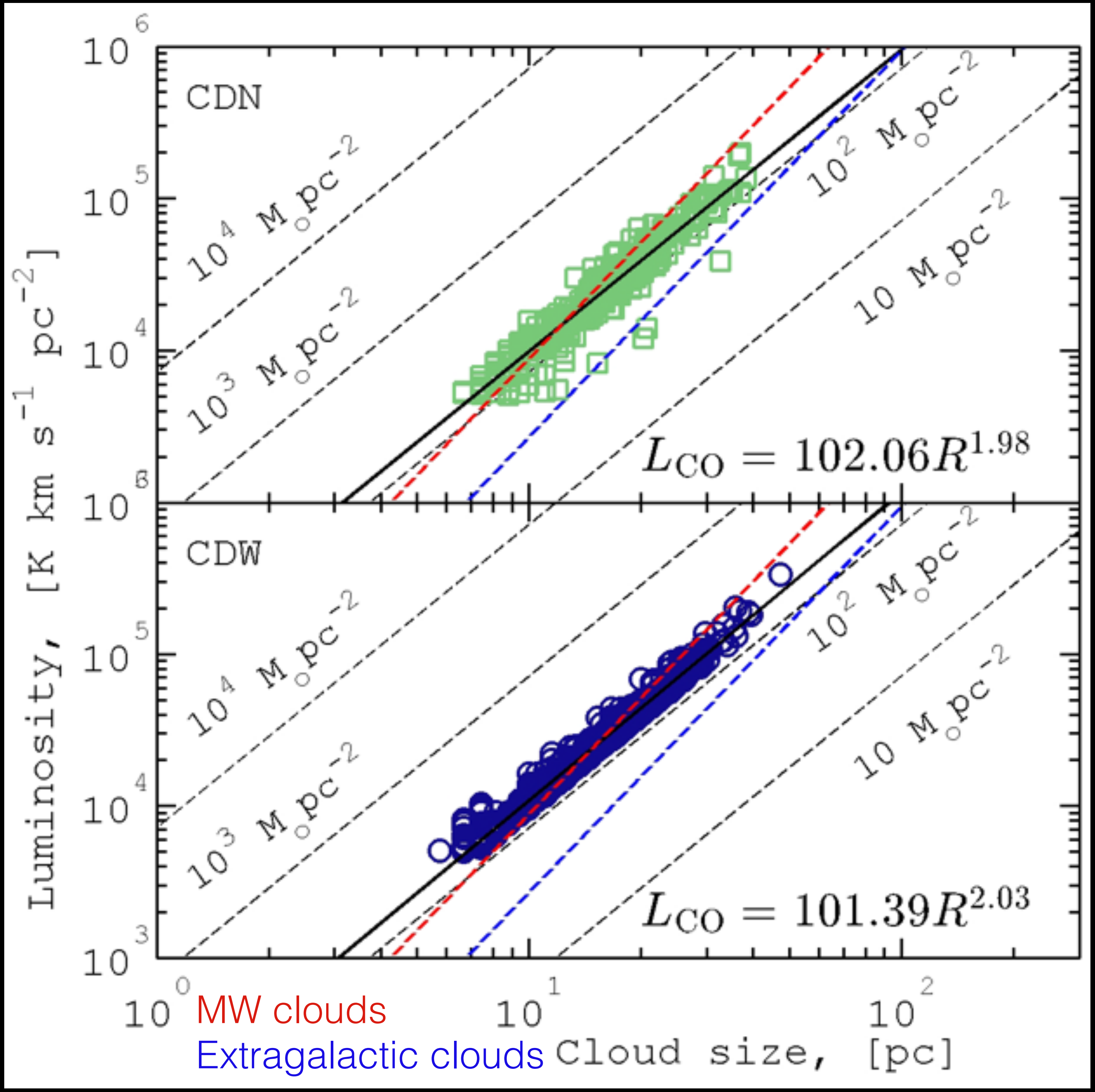
Cloud size - los velocity dispersion

$\sigma_v \sim R^{1/3}$

Kolmogorov (1941) cascade of the turbulent energy



Luminosity - size relation



Summary

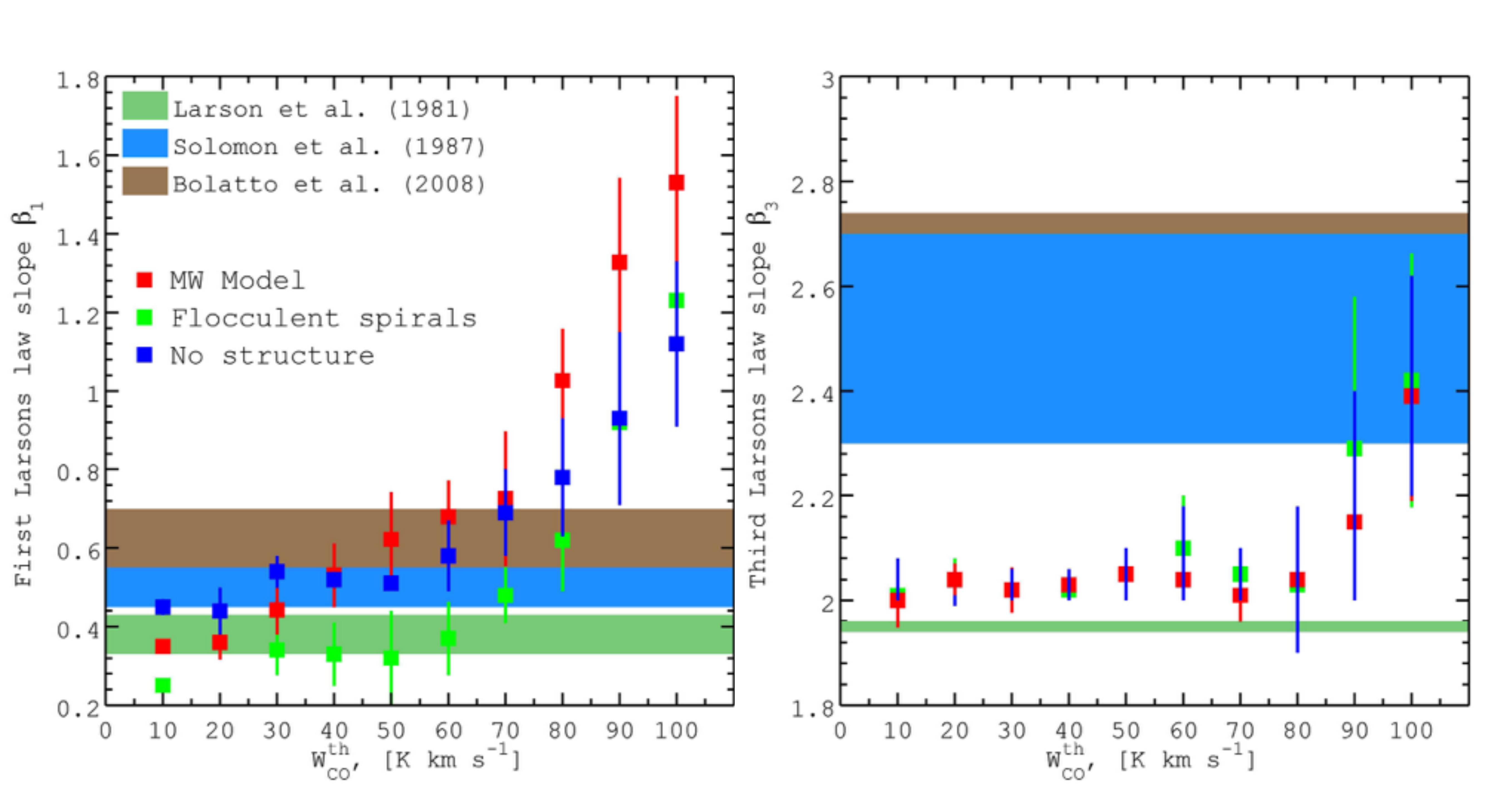
Despite some variations of GMCs physical parameters, the scaling relations (Larson's relations) are rather robust towards to the cloud definition method.

Comparison of SFR(UV) vs SFR(clouds) lets to investigate evolutionary stages of clouds or its lifetime.

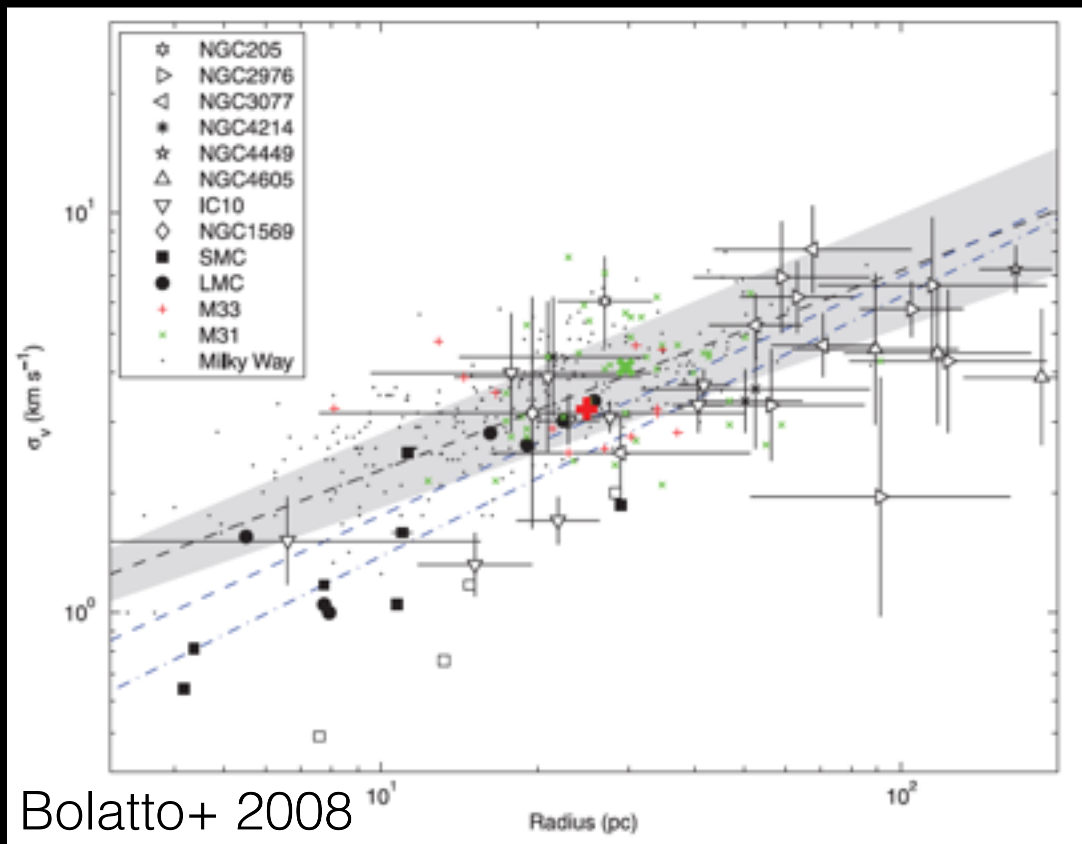
Dark gas amount can reaches up to 15% of the GMCs mass in the entire galactic disc. Thus it can affect on the estimated SF rate.


Thanks!

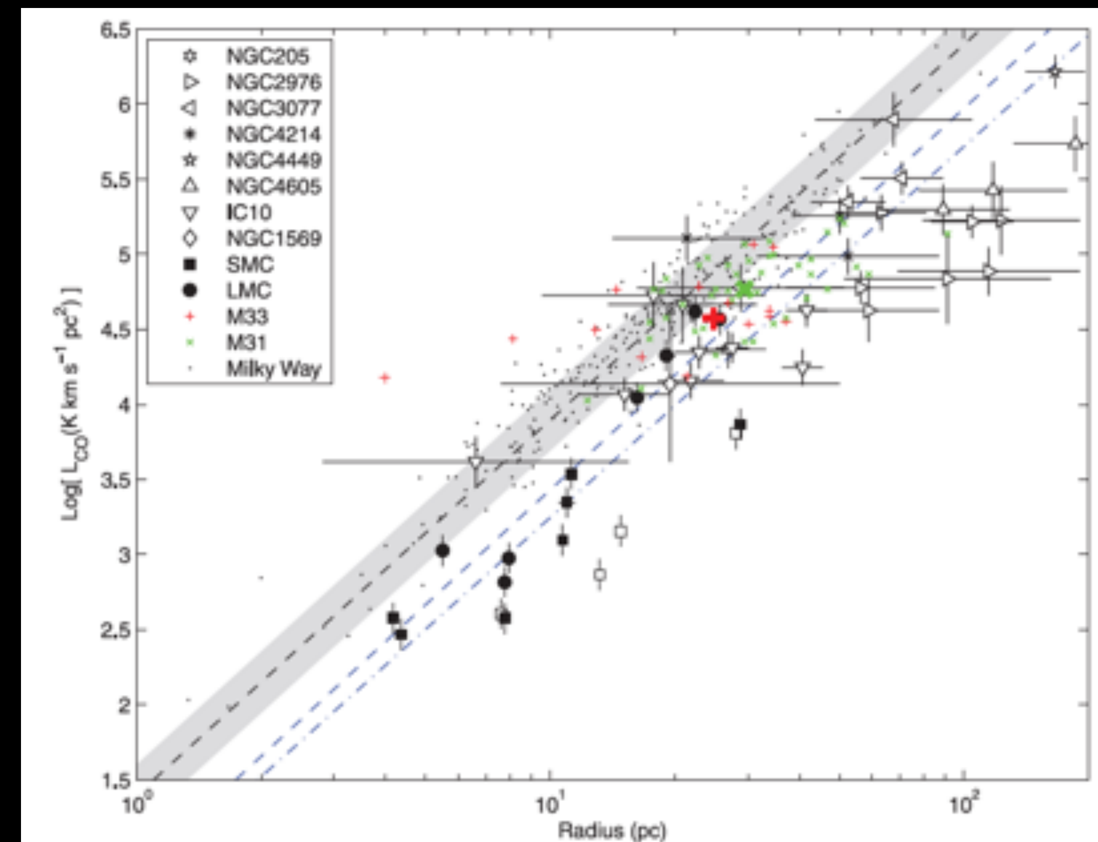
Scaling relations as function of intensity threshold

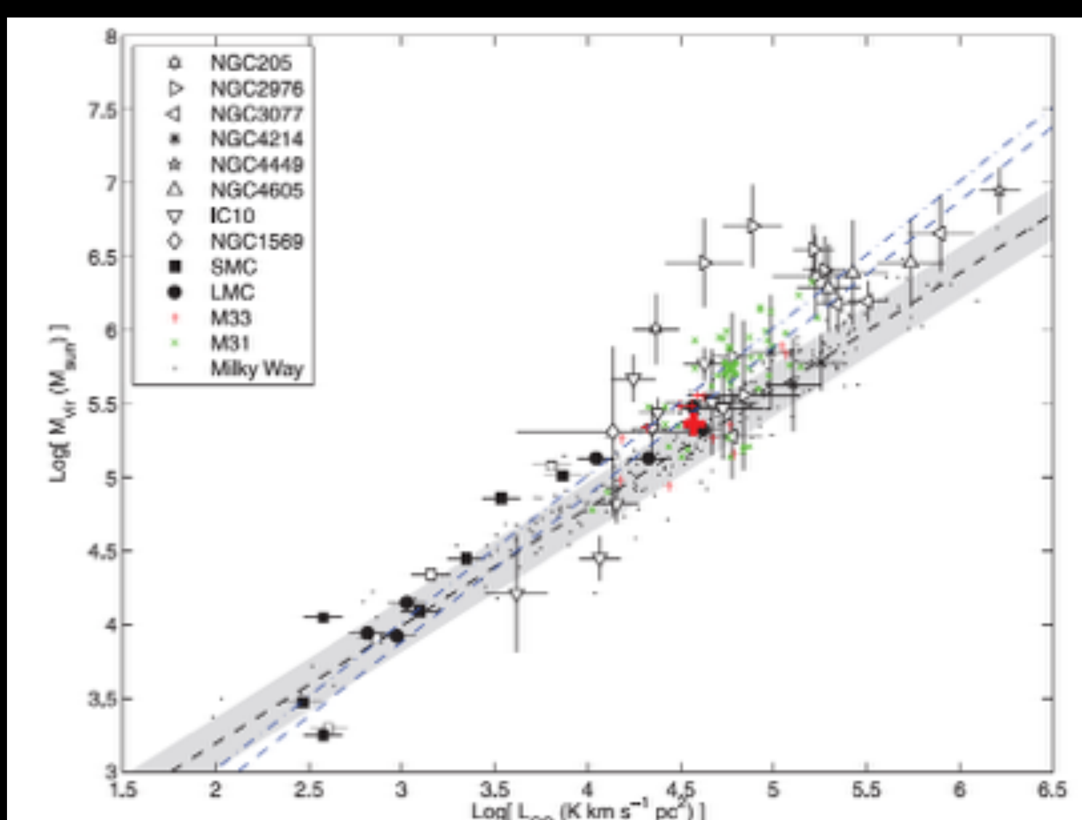


GMCs scaling relations (Larson's laws)

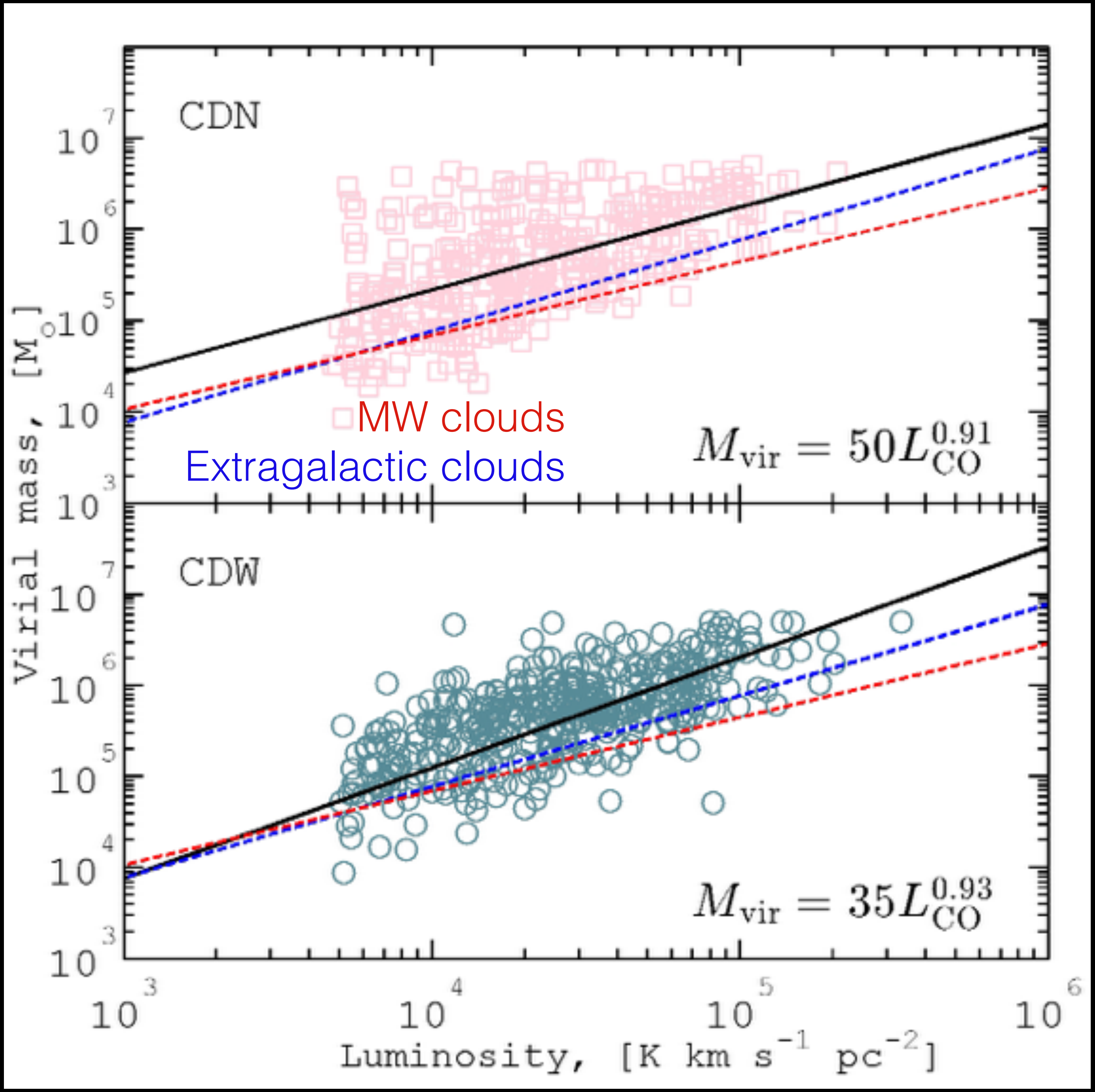


Bolatto+ 2008

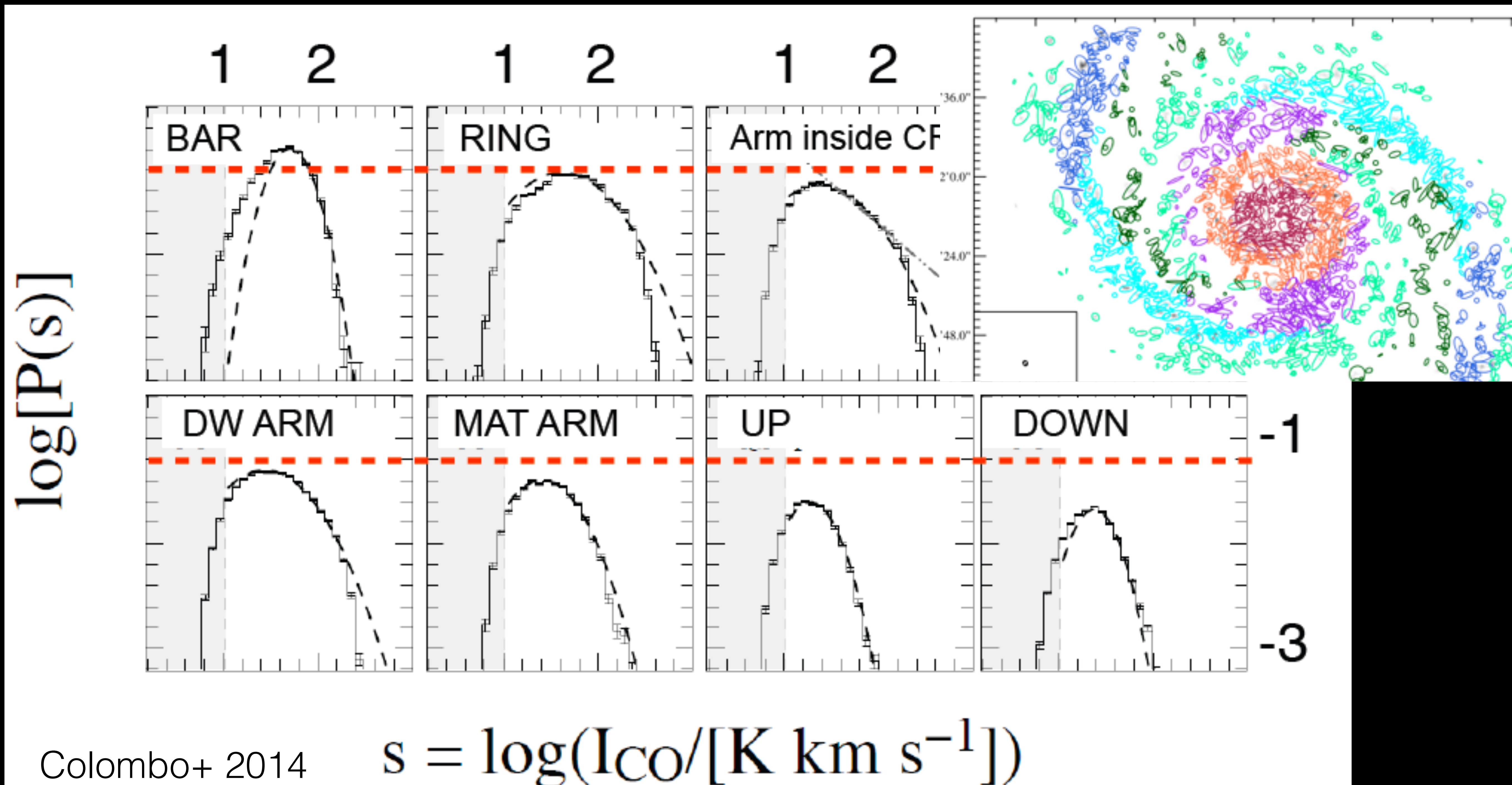




Virial mass - luminosity relation



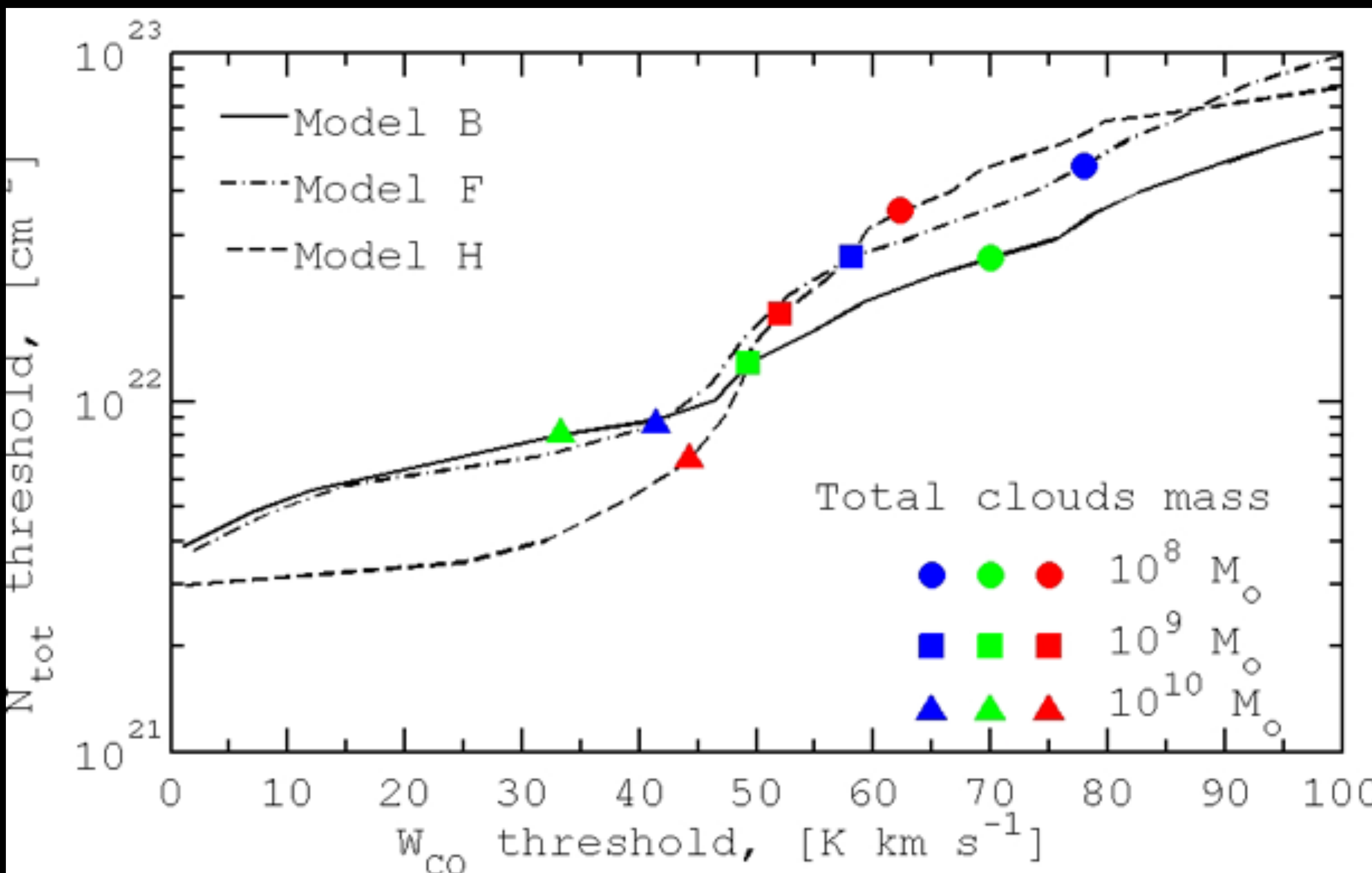
GMCs PDF in M51



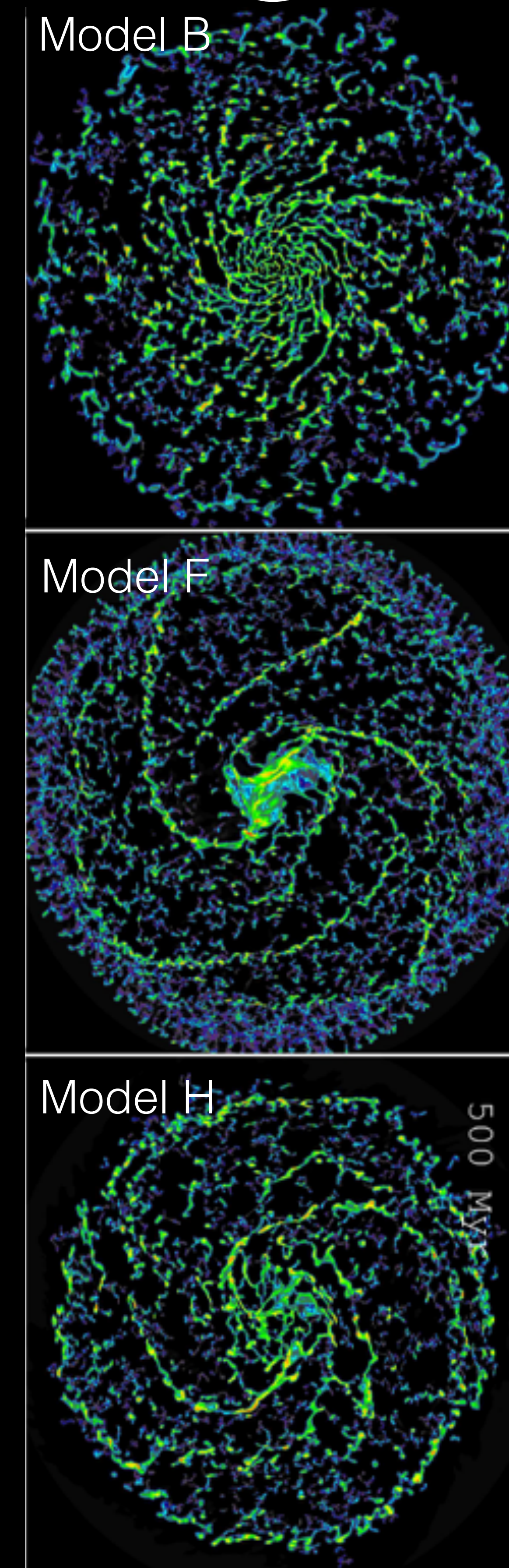
Thresholds matching

Parametric curve $N^{th}_{tot}(W^{th}_{CO})$

column density threshold N^{th}_{tot}



CO integrated intensity threshold W^{th}_{CO}



Chemical kinetics

$$\frac{\partial n_i}{\partial t} + \frac{1}{a}\nabla \cdot (n_i \mathbf{v}) = \sum_j k_{ij}(T)\, n_i n_j + \sum_j \Gamma_j^{\mathrm{ph}} n_j$$

two-body reactions Photoreactions

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No	r1	r2	r3	p1	p2	p3
2	H	C		CH	$h\nu$	
8	H	O		OH	$h\nu$	
594	H_2^+	H_2		H_3^+	H	
640	H_3^+	C		CH^+	H2	
641	H_3^+	O		OH^+	H2	
665	H_3^+	CO		HCO^+	H2	
791	He^+	H2		H^+	H	He
835	He^+	CO		C^+	O	He
1073	C^+	H_2		CH^+	H	
3202	H^+	e		H	$h\nu$	
3204	H_3^+	e		H_2	H	
3206	He^+	e		He	$h\nu$	
3208	C^+	e		C	$h\nu$	
3209	CH^+	e		C	H	
3223	OH^+	e		O	H	
3255	HCO^+	e		CO	H	
3635	H	$h\nu_{CR}$		H^+	e	
3636	He	$h\nu_{CR}$		He^+	e	
3642	H_2	$h\nu_{CR}$		H_2^+	e	
3643	H_2	$h\nu_{CR}$		H	H	
3646	C	$h\nu$		C+	e	
3663	H_2	$h\nu$		H	H	
3701	CO	$h\nu$		C	O	
10000	C^+	CH		HCO^+	$h\nu$	
10001	O	CH		CO	H	
10002	C	OH		CO	H	
10003	Me^+	e		Me	$h\nu$	
10004	H_3^+	Me		Me^+	e	H_2
10005	CH	$h\nu$		C	H	
10006	OH	$h\nu$		O	H	
10007	Me	$h\nu$		Me+	e	
10008	HCO^+	$h\nu$		CO	H	
10009	H	DUST		H2	$h\nu$	
10010	H	e		H^+	e	e