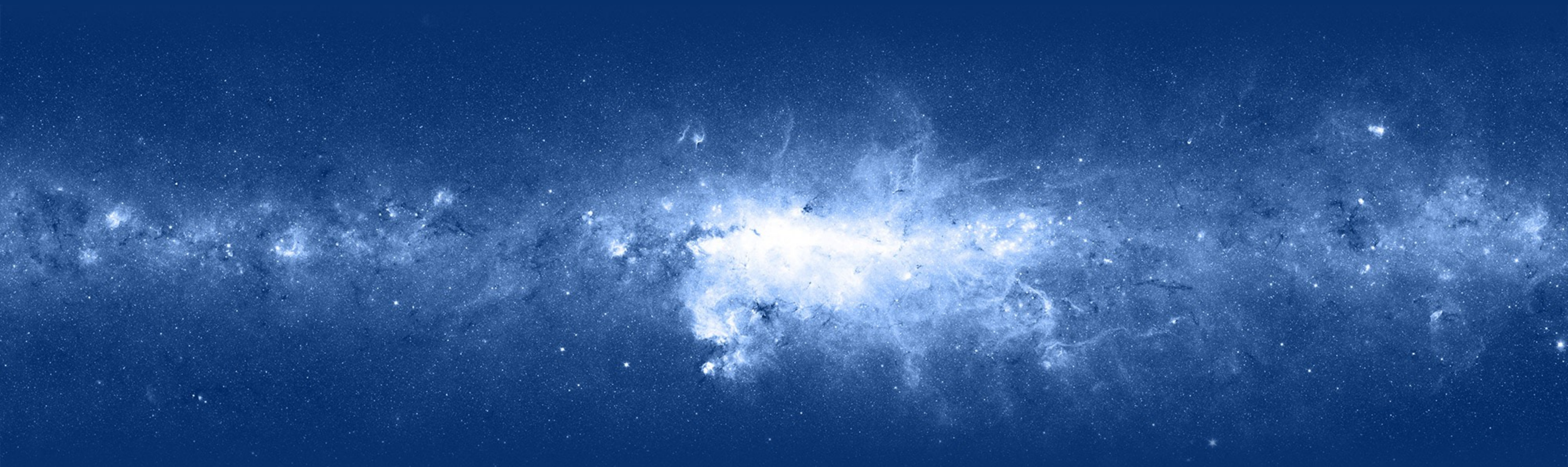
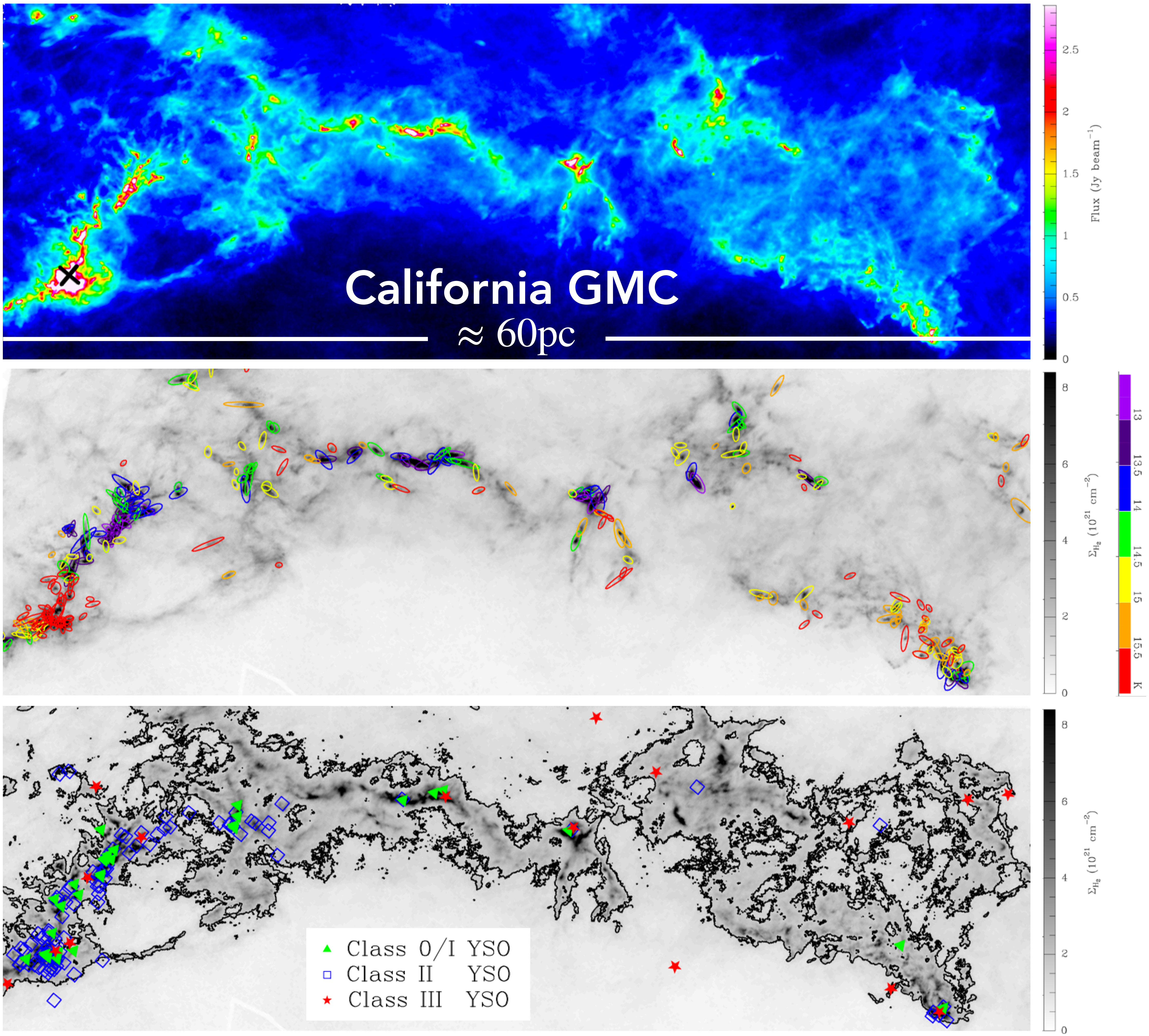
ASTR 670: Interstellar medium and gas dynamics

Prof. Benedikt Diemer



Chapter 9 • Star formation in a turbulent ISM

§9.1 • Free-fall collapse and the Jeans mass



Dust surface density

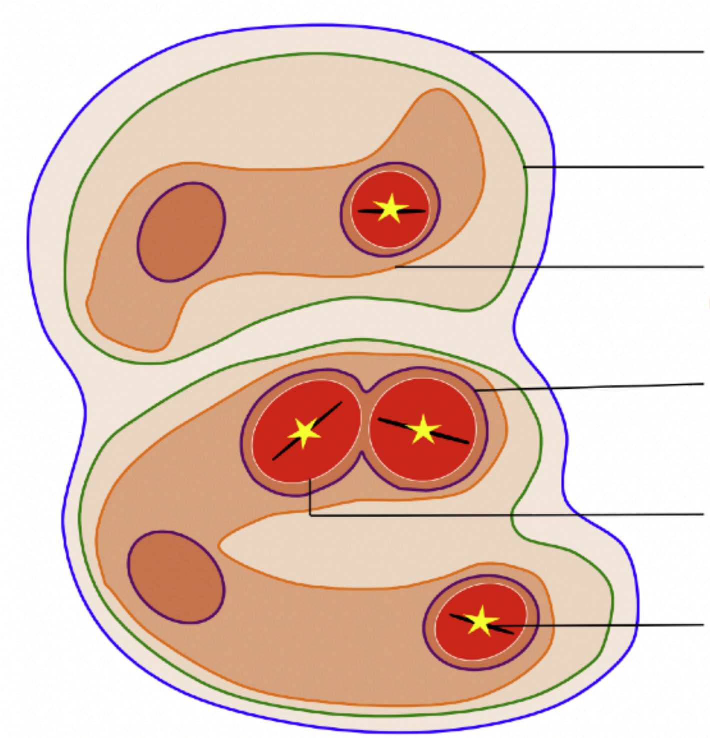
Cold molecular cores

Young stellar objects

Zhang et al. 2019

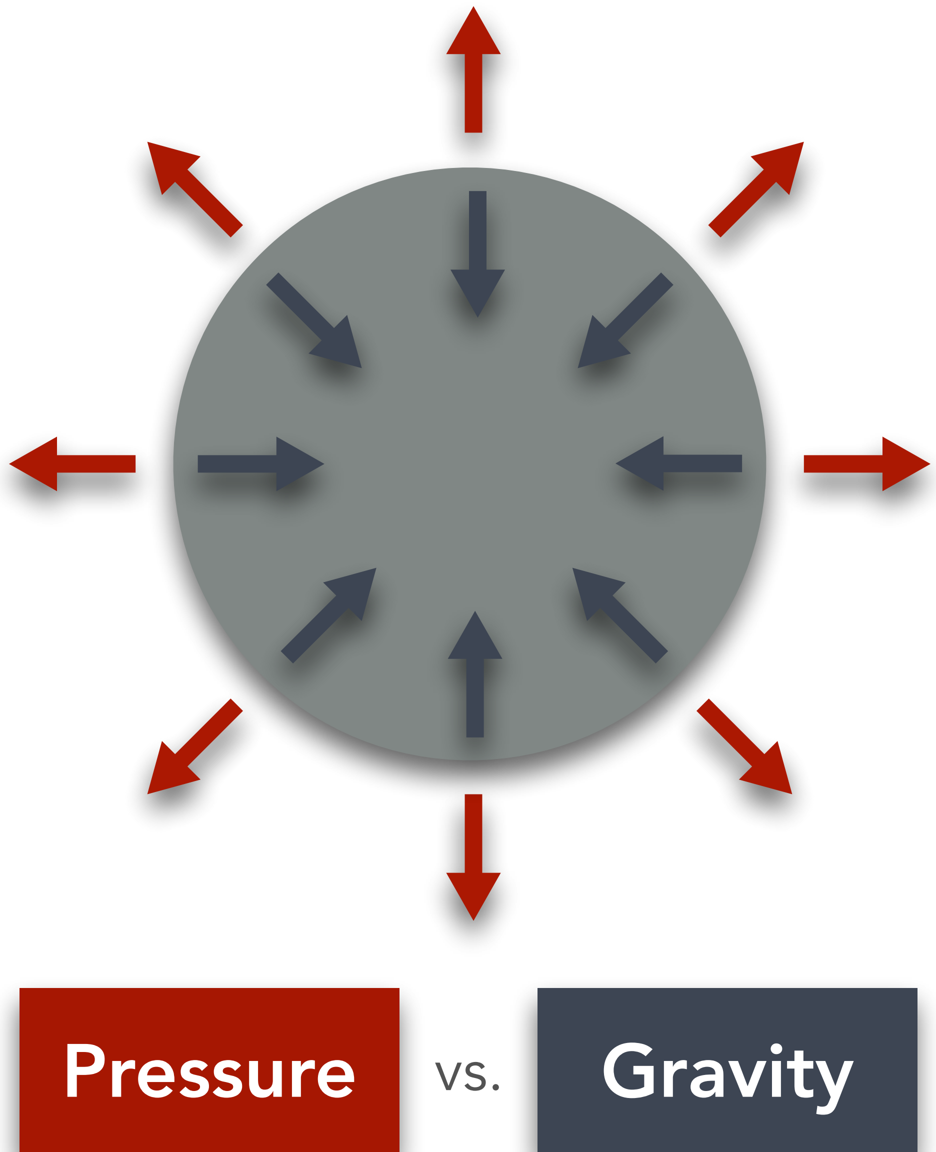
Clouds, clumps, and cores

	Clouds[a]	Clumps[b]	Cores[c]
Mass ($M_\odot$)	$10^3 - 10^4$	50–500	0.5–5
Size (pc)	2–15	0.3–3	0.03–0.2
Mean density (cm^{-3})	50–500	10^3–10^4	10^4–10^5
Velocity extent ($km\ s^{-1}$)	2–5	0.3–3	0.1–0.3
Crossing time (Myr)	2–4	≈1	0.5–1
Gas temperature (K)	≈10	10–20	8–12
Examples	Taurus, Oph, Musca	B213, L1709	L1544, L1498, B68



Bergin & Tafalla 2007 • Pokhrel et al. 2018

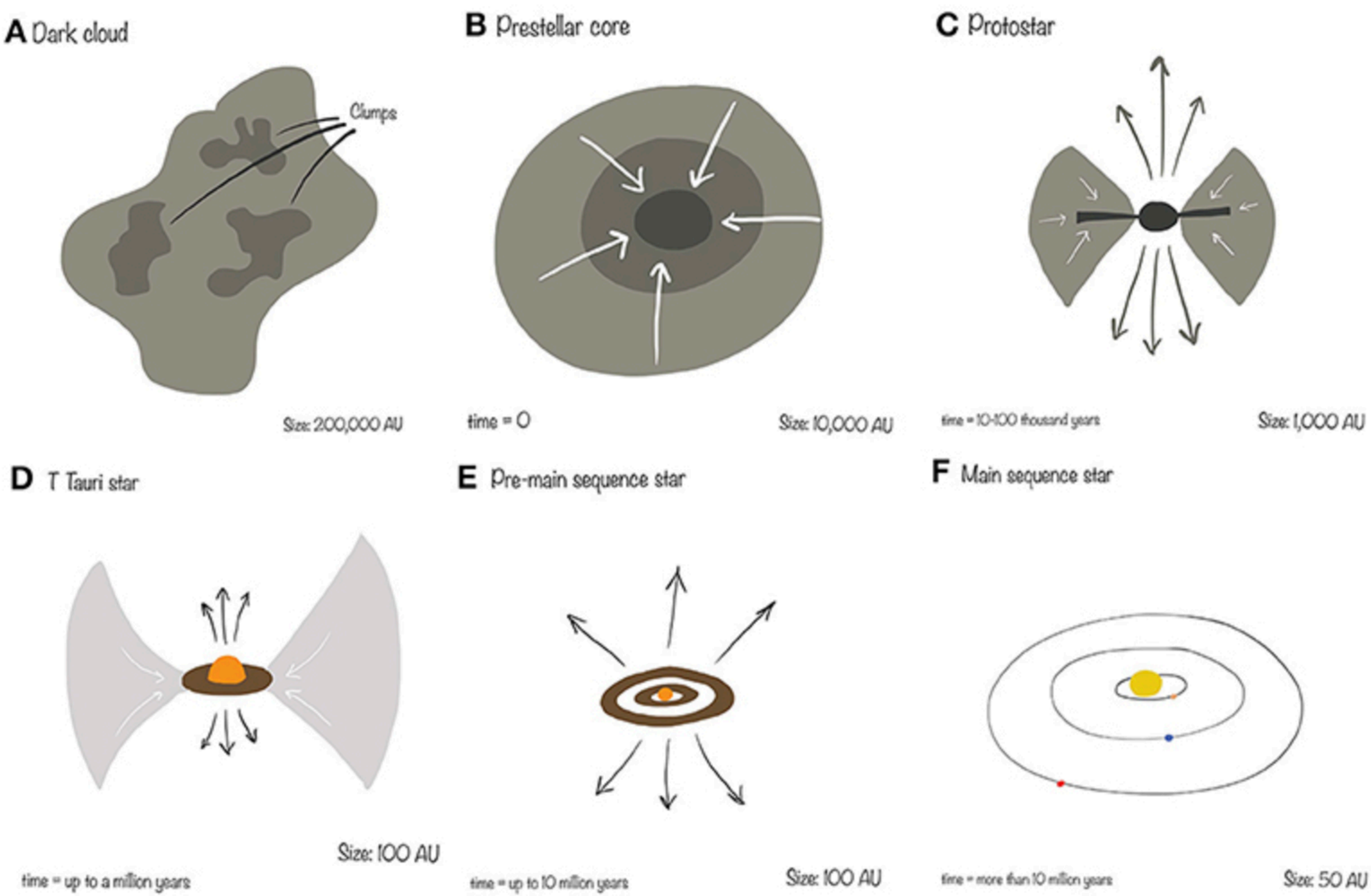
The Jeans Mass



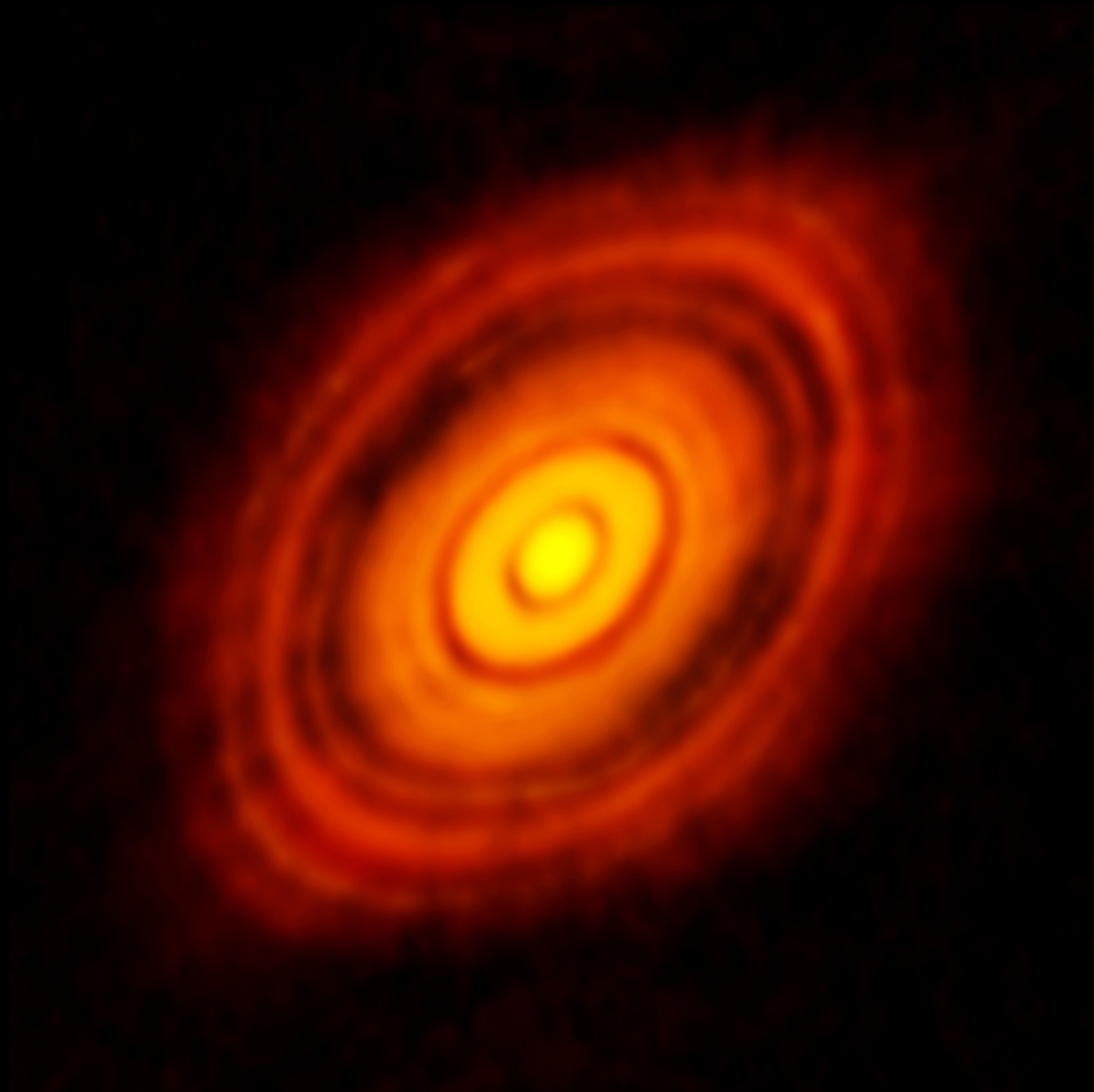
Sir James Hopwood Jeans

- Gravity tries to collapse gas
- Pressure resists collapse
- Gravity wins if cloud is larger than Jeans length, or has mass larger than Jeans mass
- In the Universe as a whole, we can work out the Jeans mass of gas right after recombination: $M_{\mathrm{J,recombination}} \approx 10^6 M_\odot$

Star formation

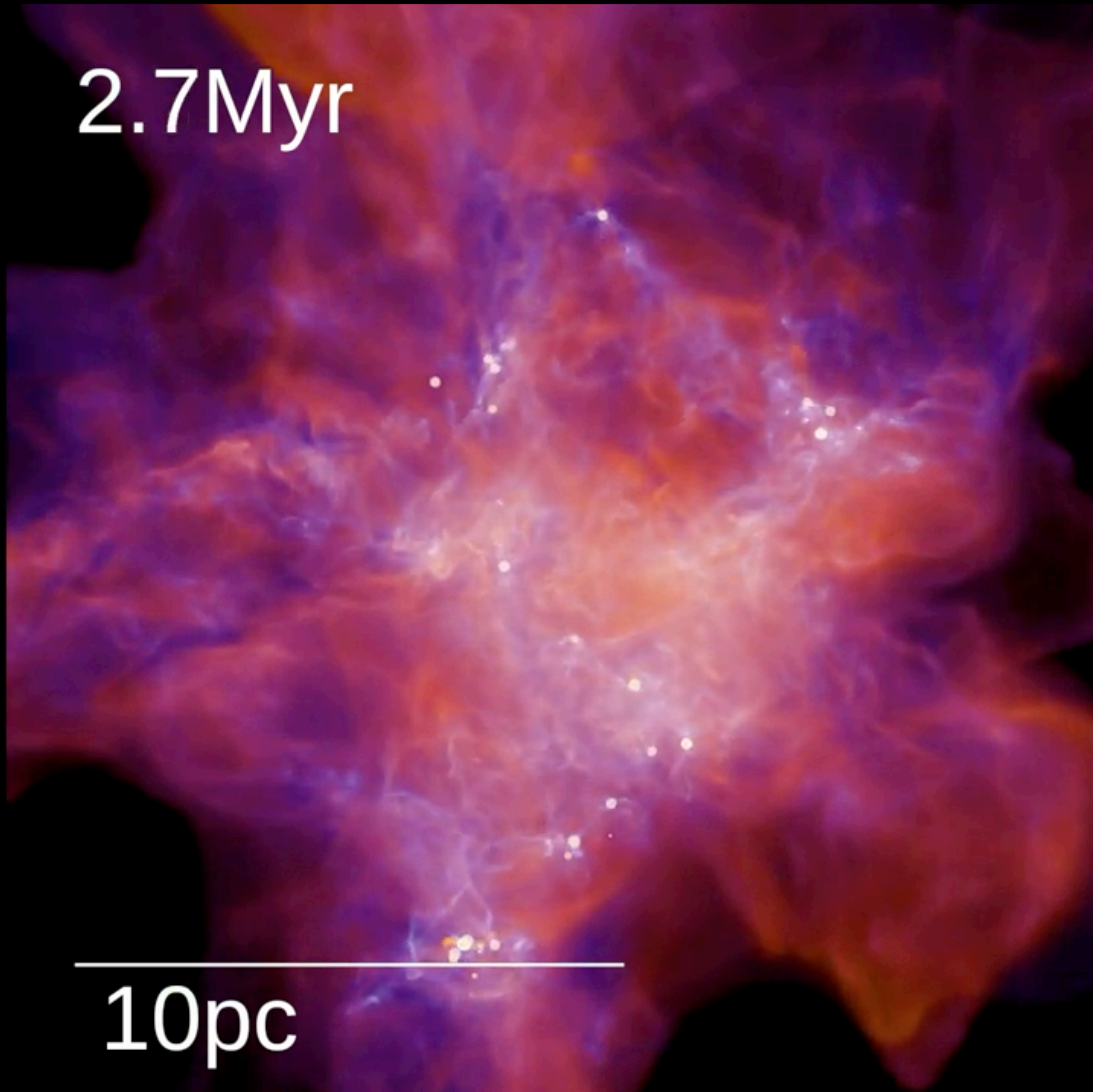


Protoplanetary disks



ALMA

Star formation



STARFORGE Collaboration (youtube)

§9.2 • Basic observations of star formation

Galaxies in different wavelengths

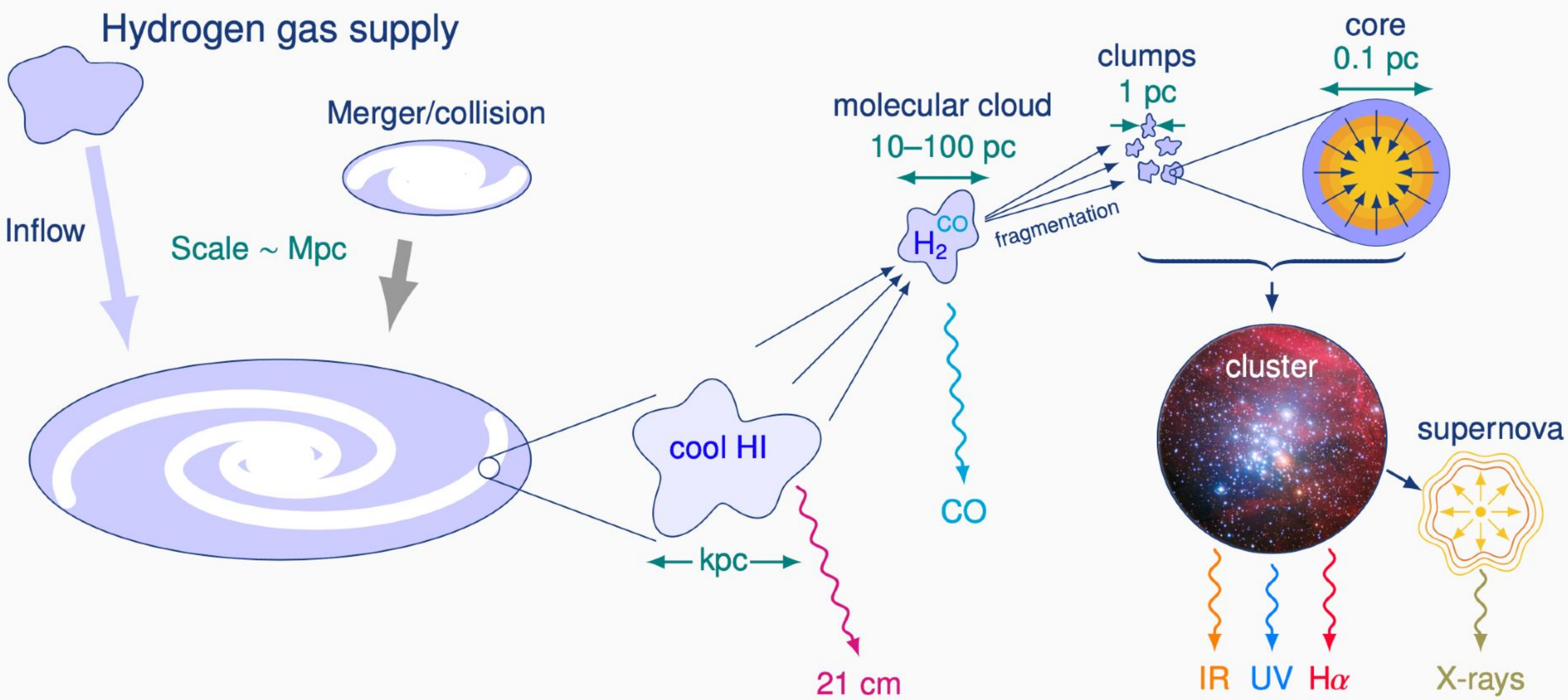


Image by Markus Pössel

SFR indicators

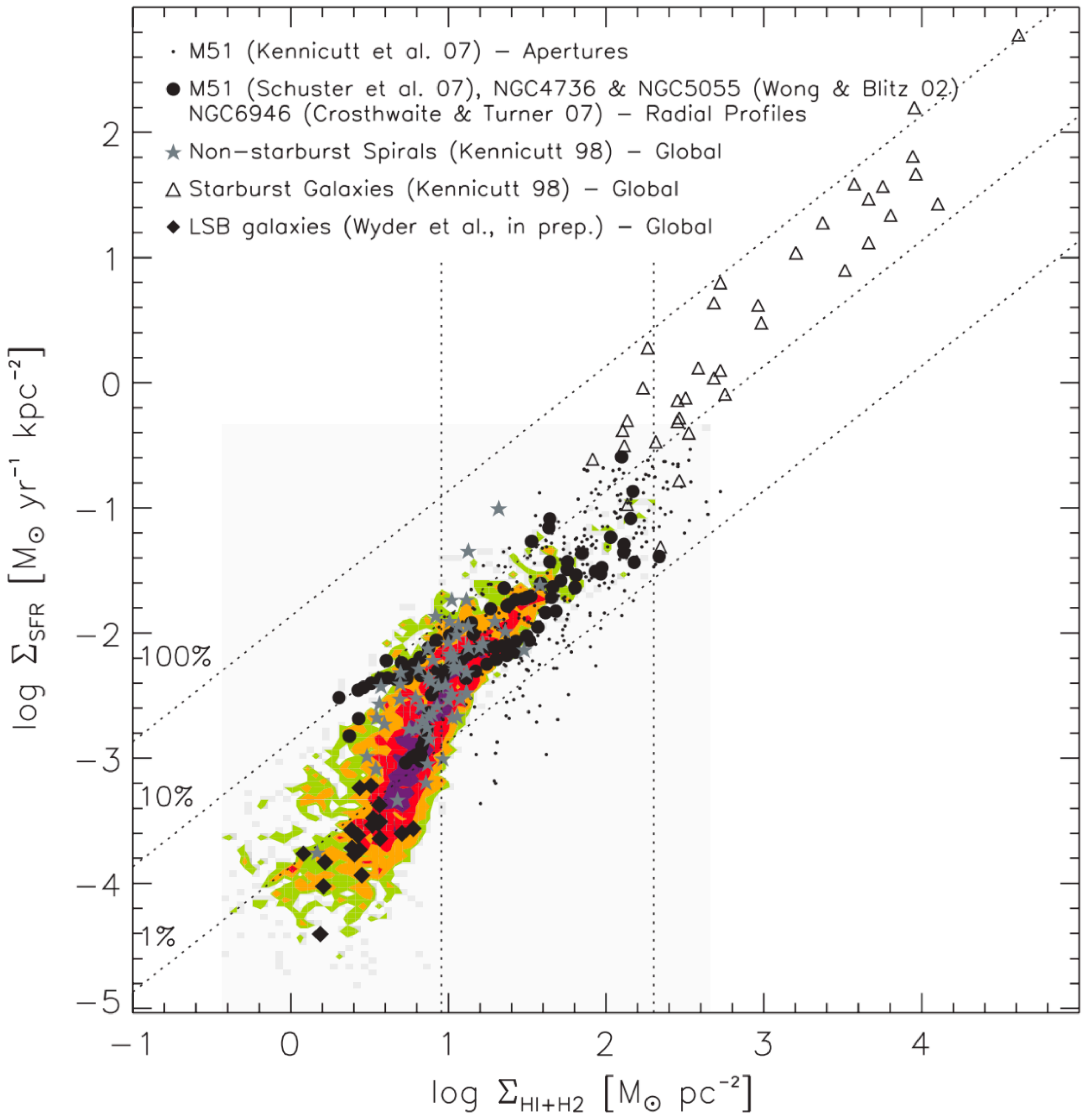
Band	Age range (Myr)[a]	L_x units	log C_x[b]	$\dot{M}_* / \dot{M}_*$(K98)[c]	Reference(s)
FUV	0-10-100	ergs s^{-1} (νL_ν)	43.35	0.63	Hao et al. (2011), Murphy et al. (2011)
NUV	0-10-200	ergs s^{-1} (νL_ν)	43.17	0.64	Hao et al. (2011), Murphy et al. (2011)
Hα	0-3-10	ergs s^{-1}	41.27	0.68	Hao et al. (2011), Murphy et al. (2011)
TIR	0-5-100[d]	ergs s^{-1} (3–1100 μm)	43.41	0.86	Hao et al. (2011), Murphy et al. (2011)
24 μm	0-5-100[d]	ergs s^{-1} (νL_ν)	42.69		Rieke et al. (2009)
70 μm	0-5-100[d]	ergs s^{-1} (νL_ν)	43.23		Calzetti et al. (2010b)
1.4 GHz	0-100	ergs s^{-1} Hz^{-1}	28.20		Murphy et al. (2011)
2–10 keV	0-100	ergs s^{-1}	39.77	0.86	Ranalli et al. (2003)

[a]Second number gives mean age of stellar population contributing to emission; third number gives age below which 90% of emission is contributed.

$$\log \dot{M}_*(\mathrm{M}_\odot\ \mathrm{year}^{-1}) = \log L_x - \log C_x$$

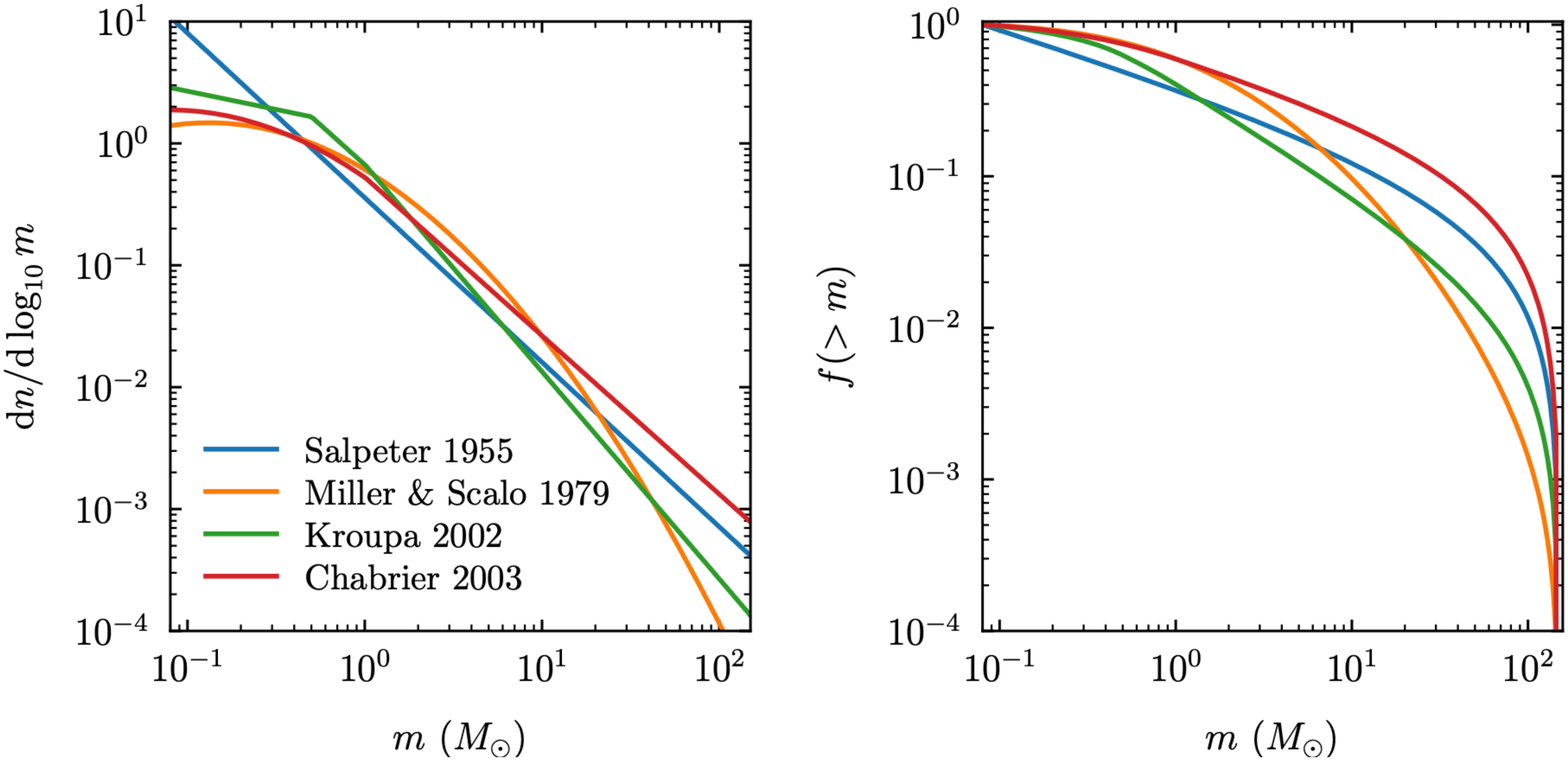
Kennicutt & Evans 2012

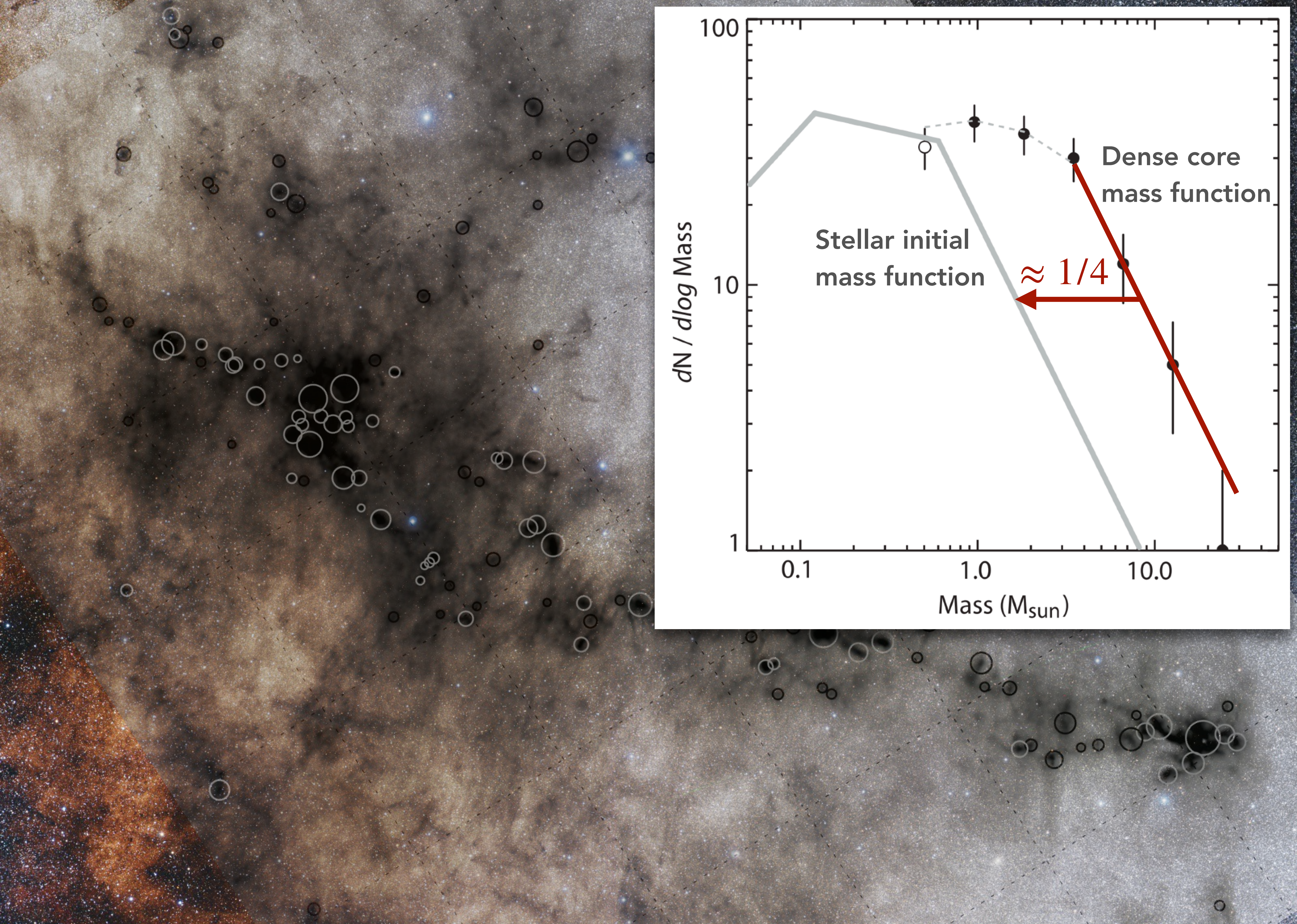
Kennicutt-Schmidt relation



Bigiel et al. 2008 • Kennicutt & Evans 2012

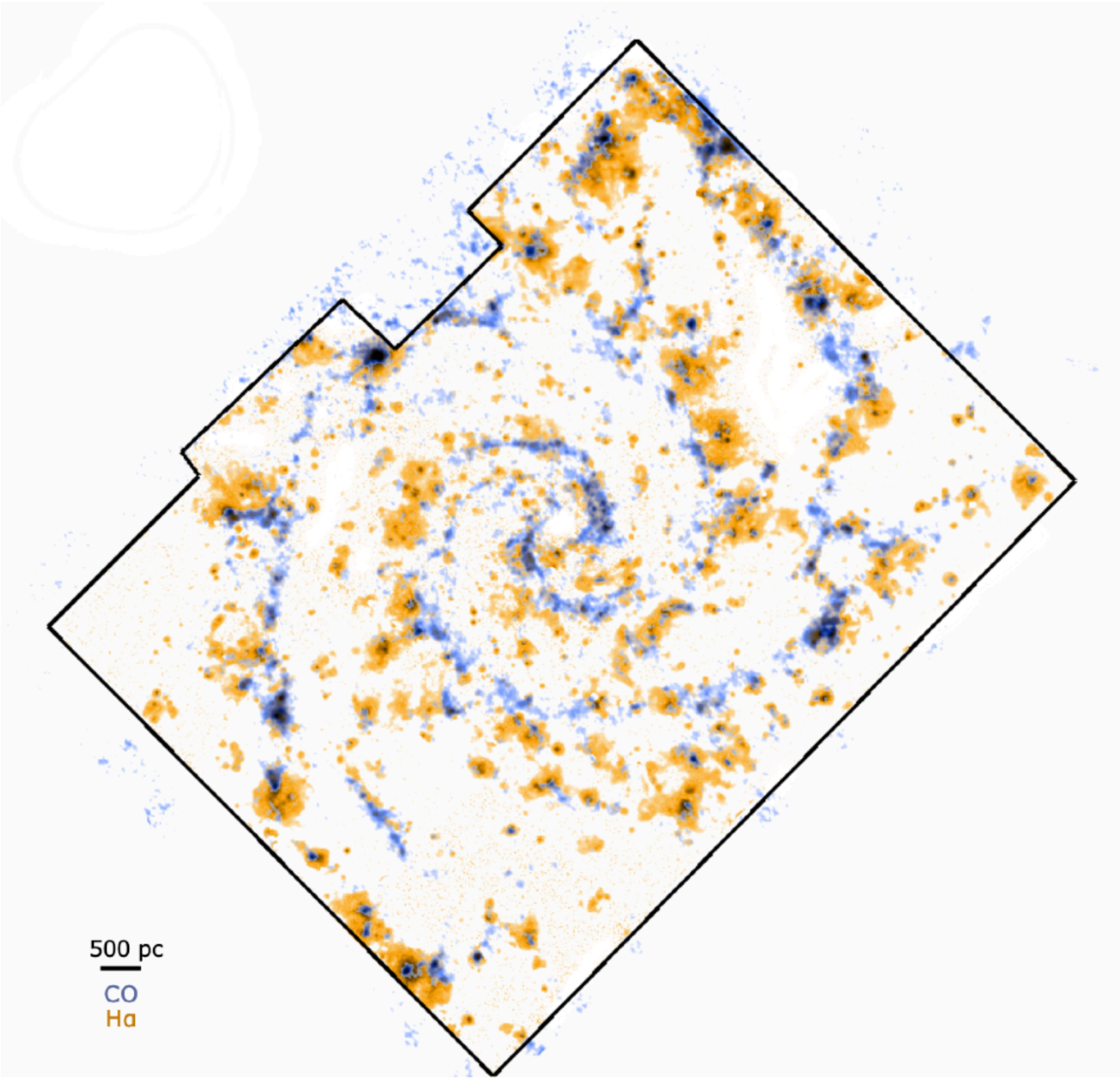
Stellar initial mass function (IMF)

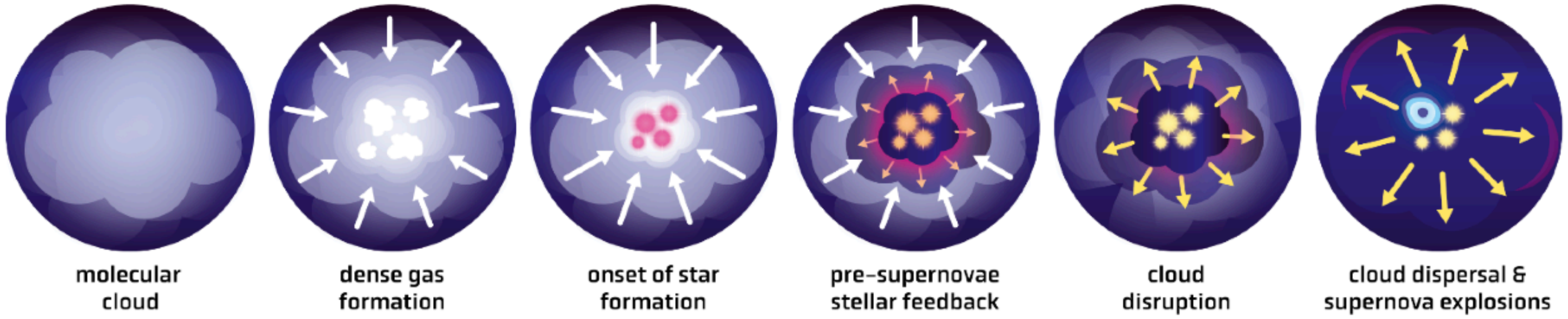




Pipe Nebula • Yuri Beletsky/Las Campanas • Alves et al. 2007 • Slide inspired by Karen Sandstrom

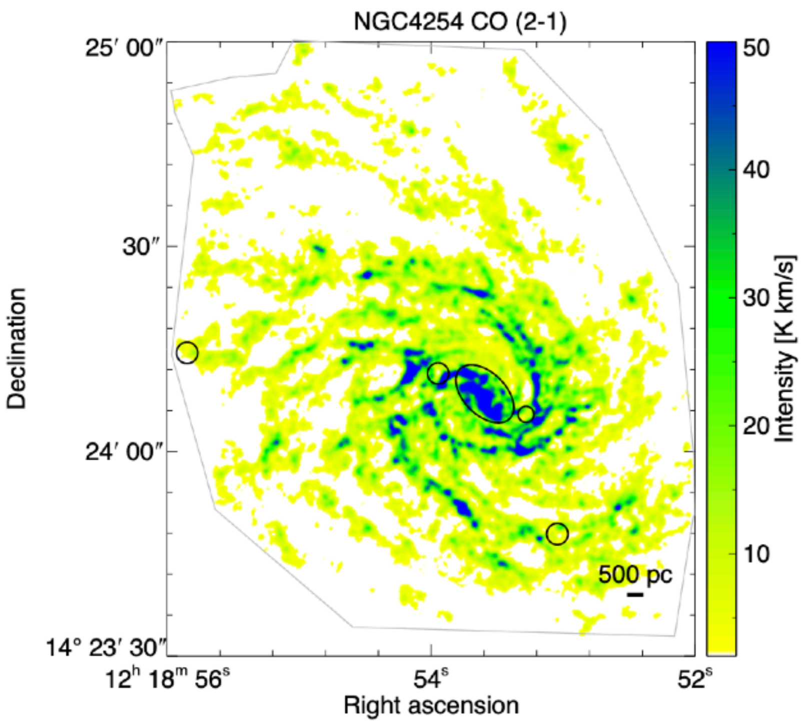
The cloud lifecycle

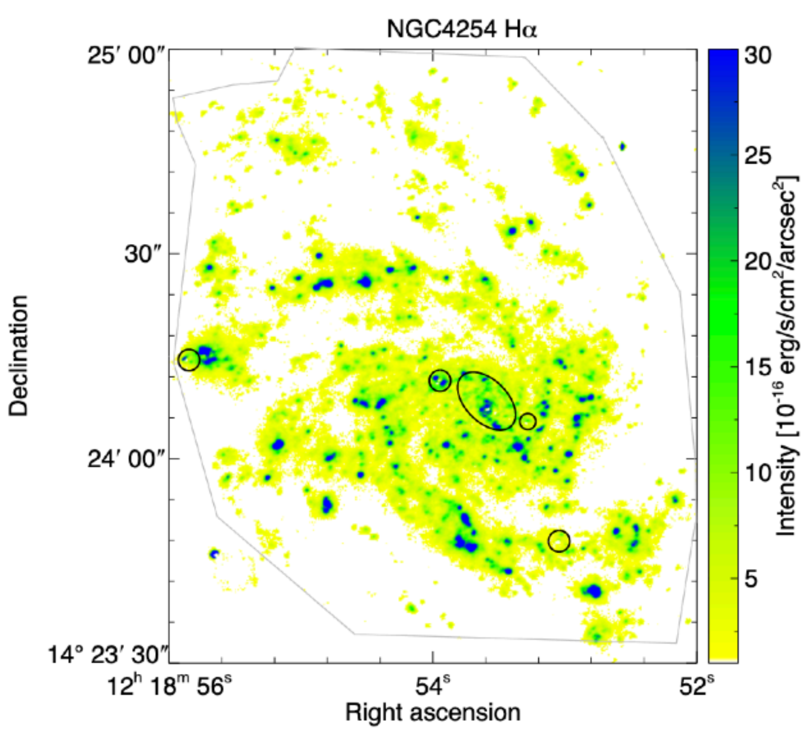


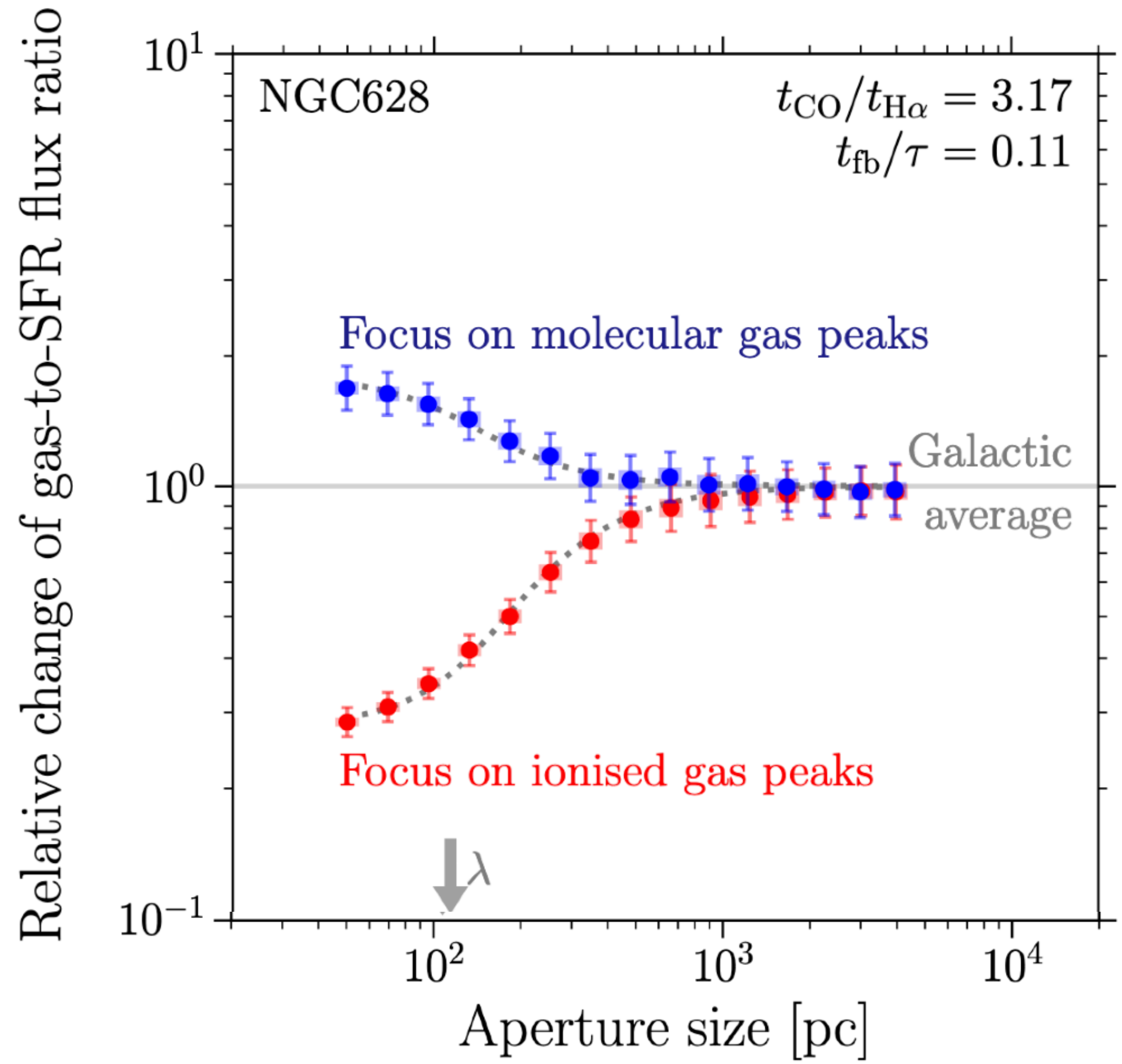


Schinnerer & Leroy 2024

The cloud lifecycle



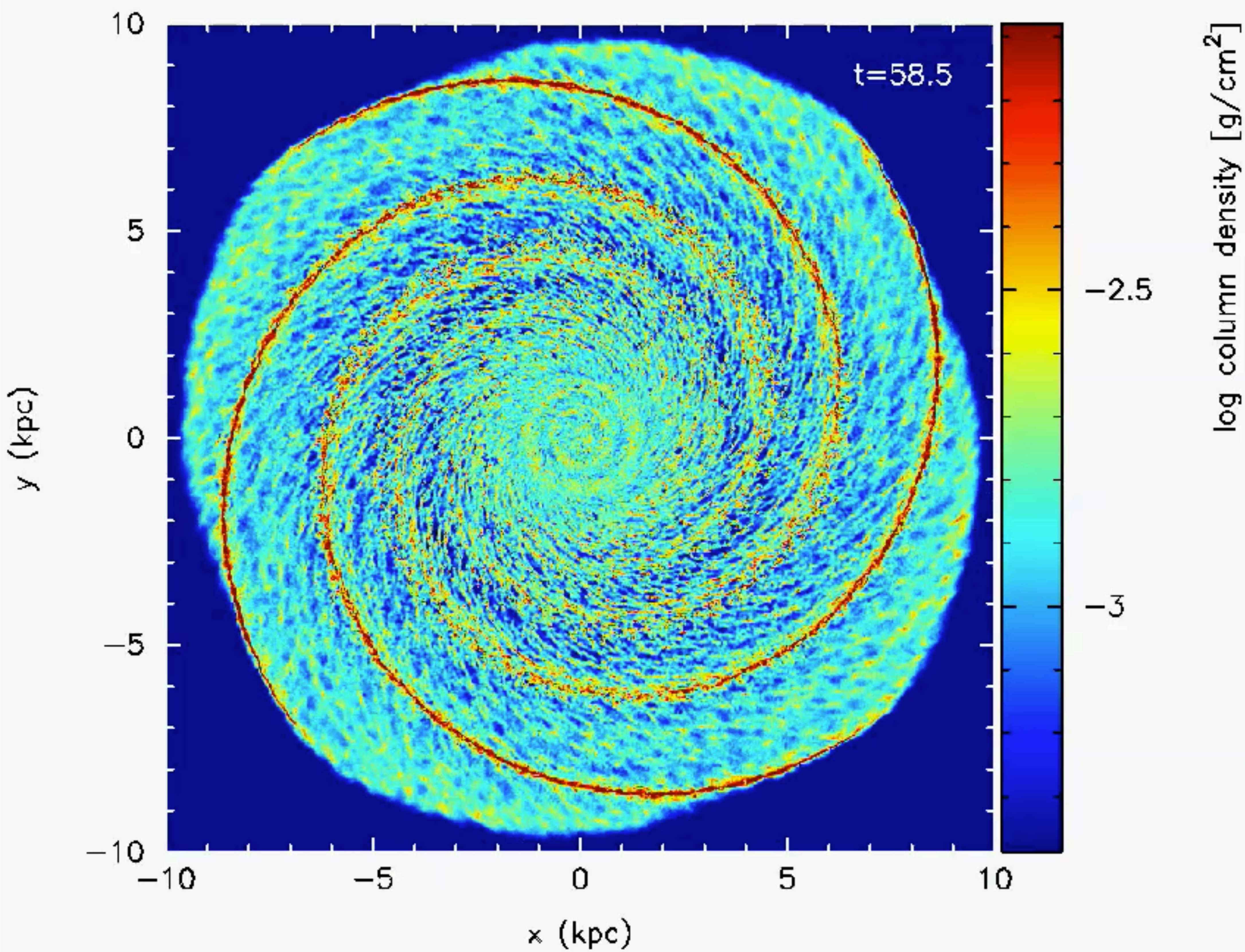




Chevance et al. 2019

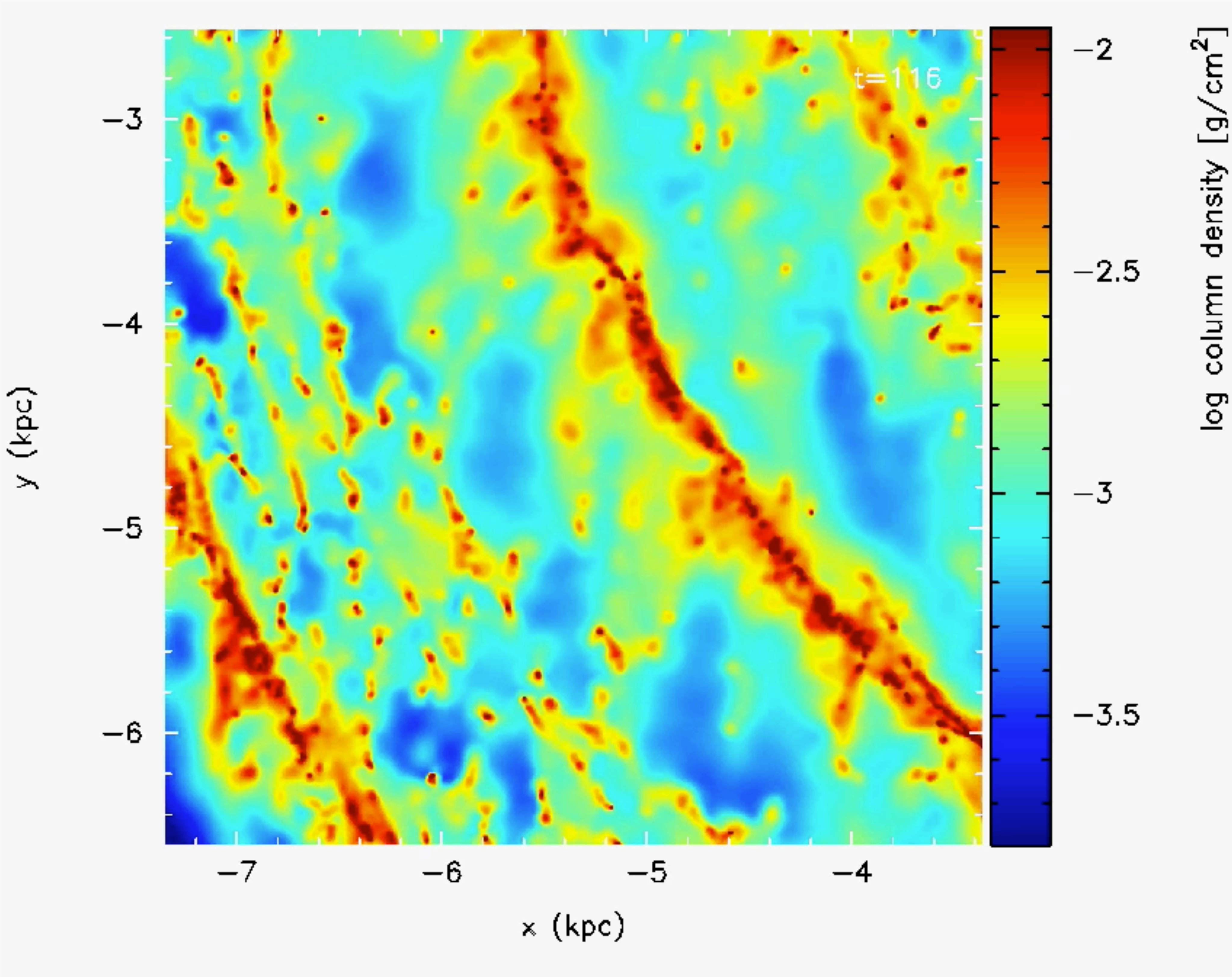
§9.3 • The role of turbulence

Are GMCs gravitationally bound?

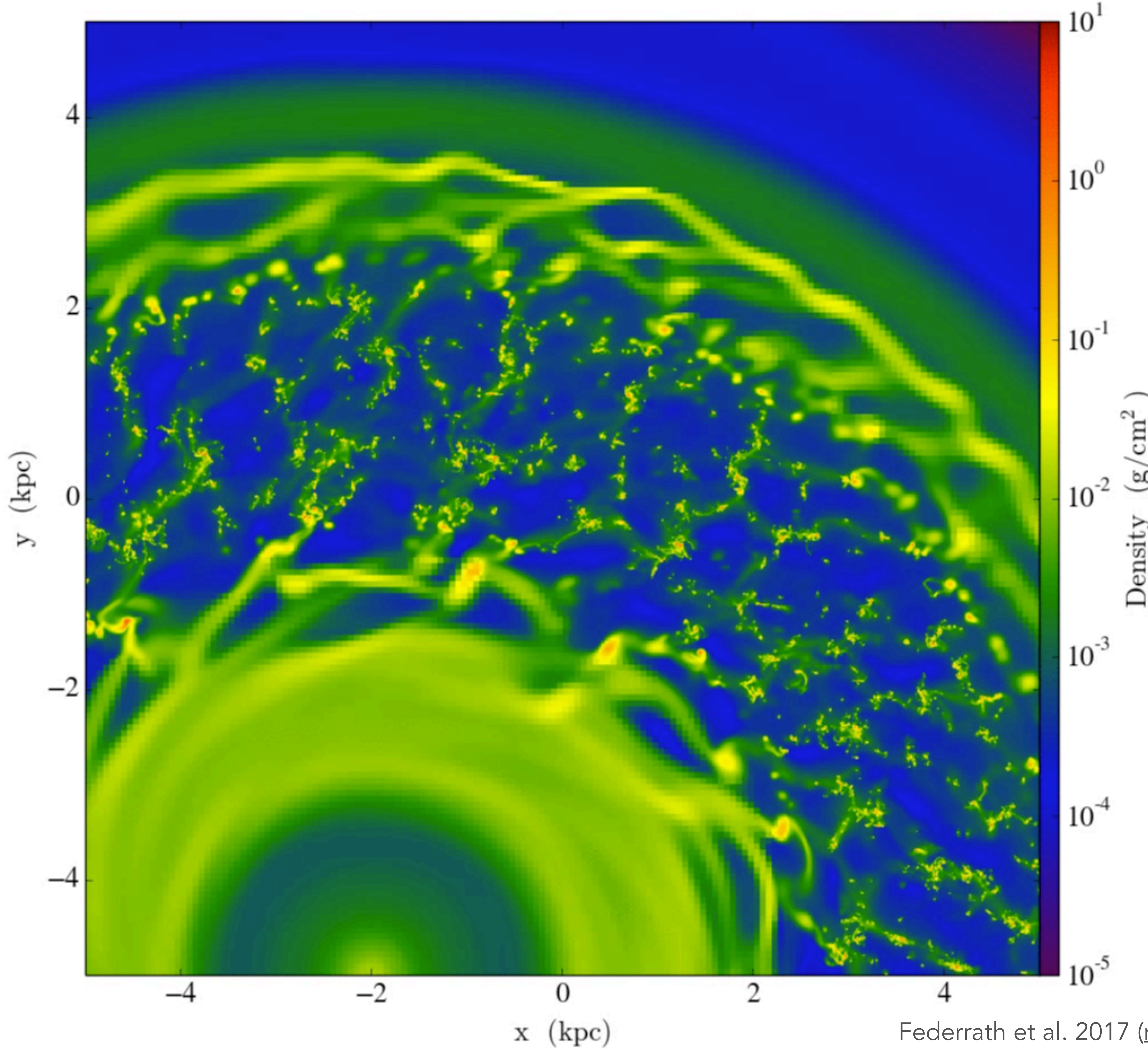


Dobbs et al. (movie page)

Are GMCs graviationally bound?



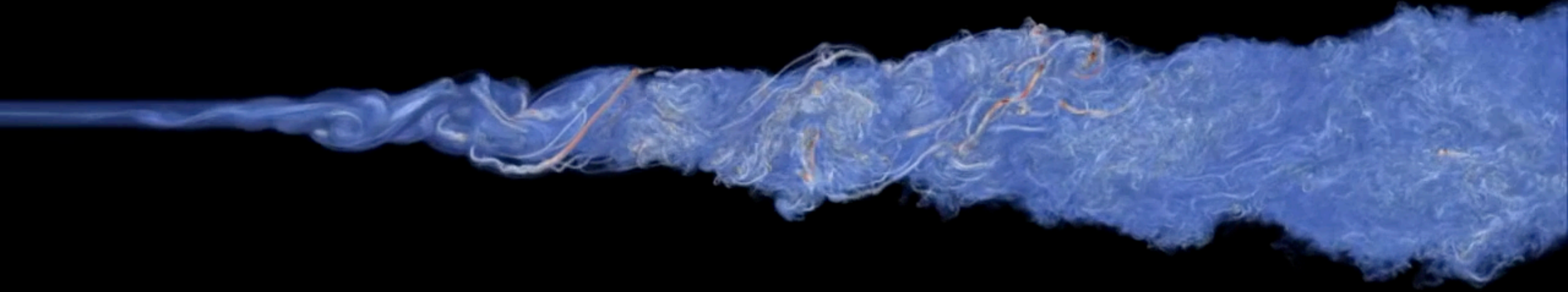
Dobbs et al. (movie page)



Federrath et al. 2017 (movie page)

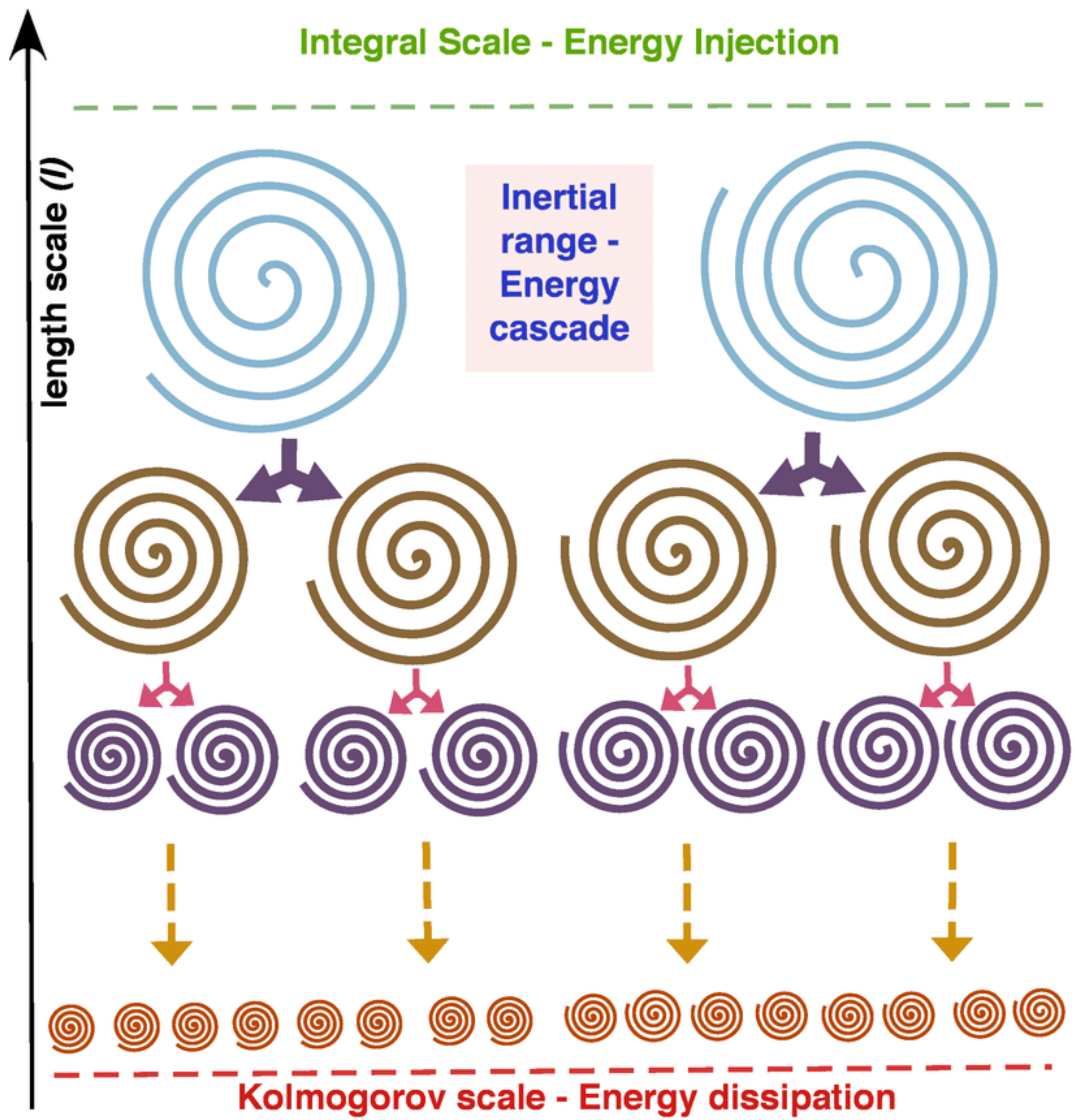
Turbulence

van Dyke 1982



Caprace et al. (youtube)

Turbulent cascade



Banerjee et al. 2014

Turbulence

Atmospheric Diffusion shown on a Distance-Neighbour Graph.

By LEWIS F. RICHARDSON.

(Communicated by Sir Gilbert Walker, F.R.S.—Received November 7, 1925.)

§ 1. THE NEED FOR A NEW METHOD.

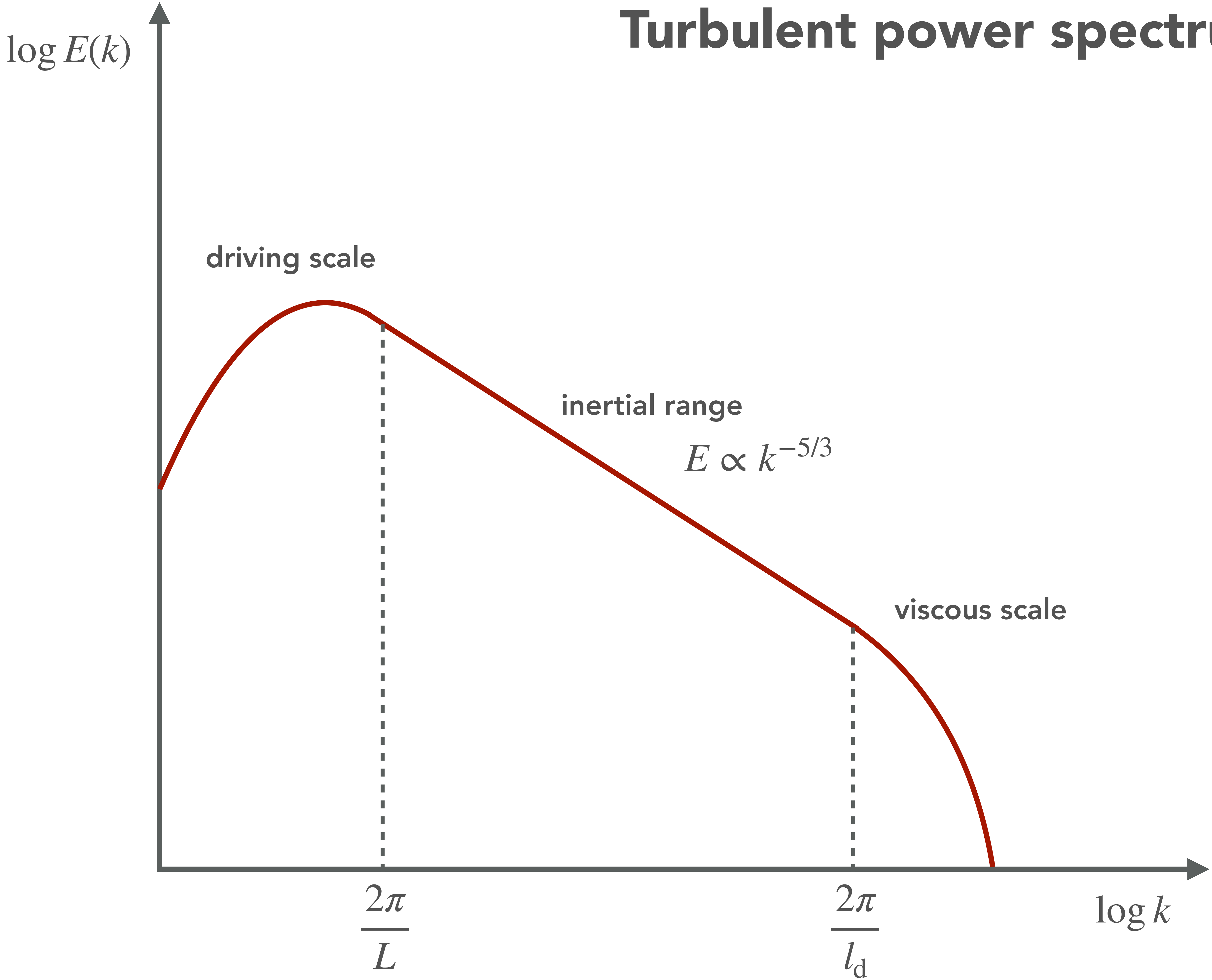
§ 1.2. *Does the Wind possess a Velocity ?*

This question, at first sight foolish, improves on acquaintance. A velocity is defined, for example, in Lamb's 'Dynamics' to this effect : Let Δx be the distance in the x direction passed over in a time Δt, then the x-component of velocity is the limit of $\Delta x / \Delta t$ as $\Delta t \to 0$. But for an air particle it is not obvious that $\Delta x / \Delta t$ attains a limit as $\Delta t \to 0$.

Big whirls have little whirls that feed on their velocity,
and little whirls have lesser whirls and so on to viscosity.

Richardson 1926

Turbulent power spectrum

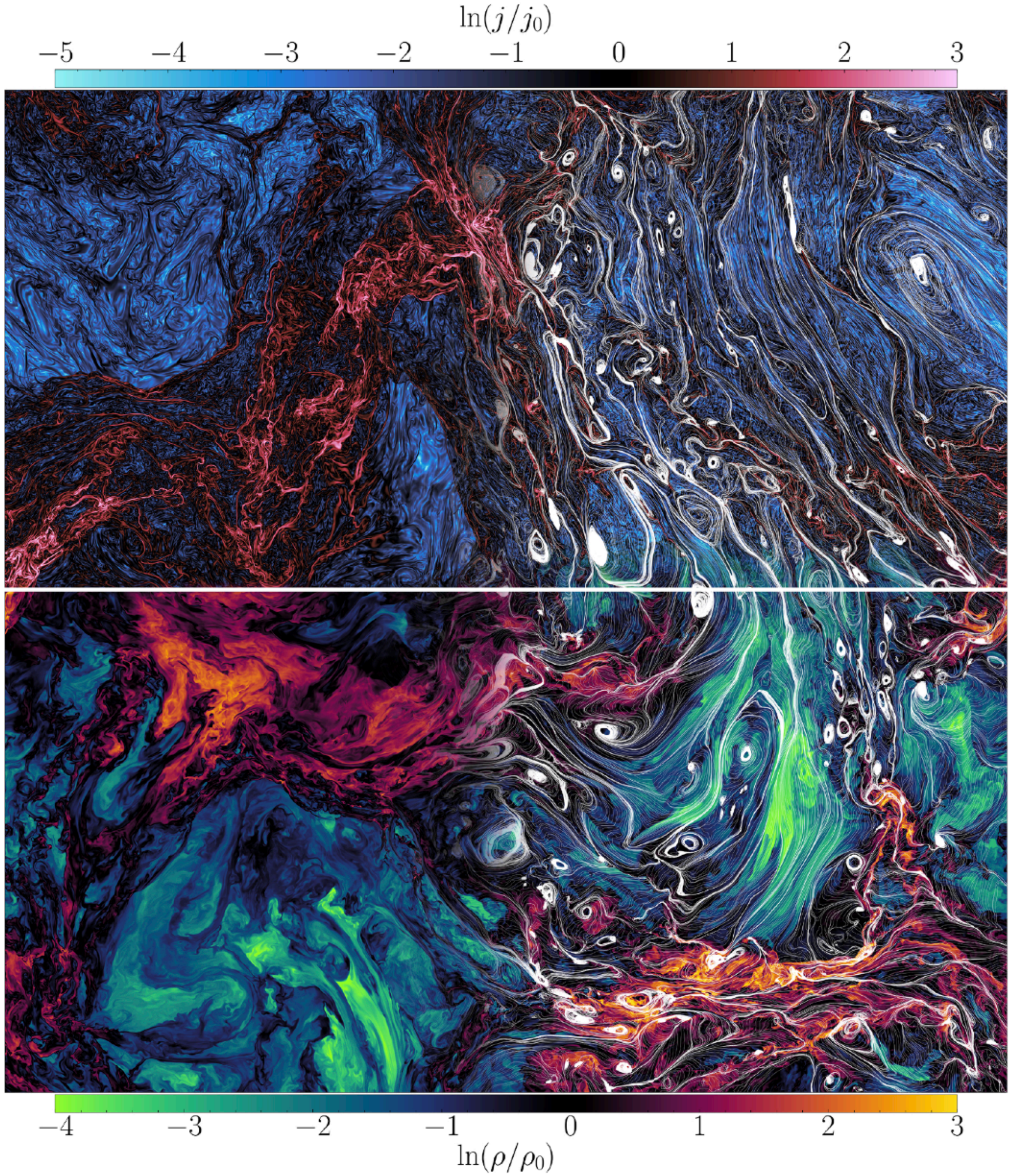


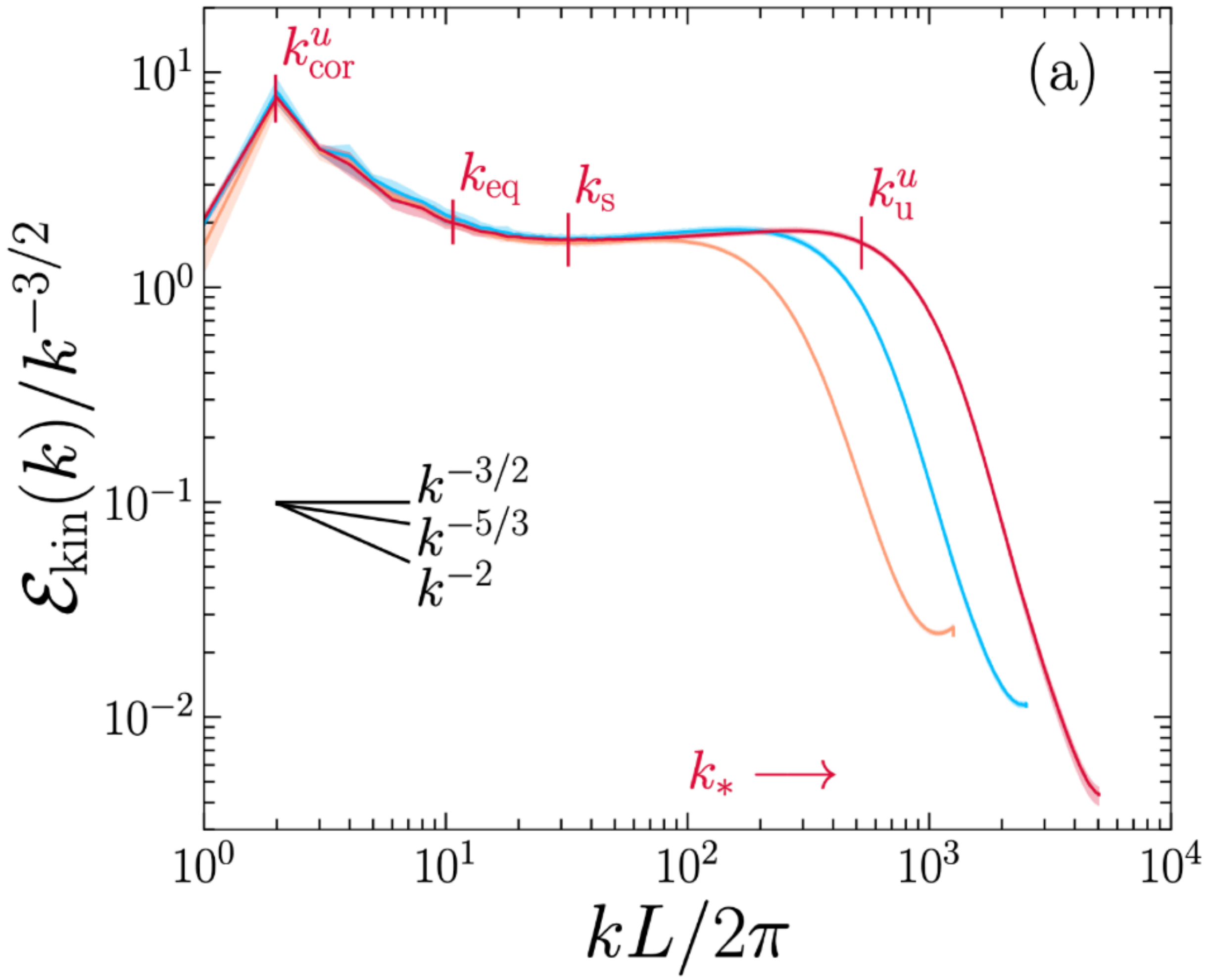
Turbulent parameters in the ISM

Quantity	Unit	cold atomic medium	molecular clouds	dense molecular cores
$\langle n \rangle$	$\mathrm{cm^{-3}}$	30	200	10^4
T_K	K	100	40	10
B	μG	10	20	100
l	pc	10	3	0.1
σ_l	$\mathrm{km\ s^{-1}}$	≈ 3.5	1	0.1
$\lambda = 1/\langle n \rangle \sigma$	AU	2	0.03	6×10^{-4}
$c_S = \sqrt{kT_K/\mu \mathrm{m_H}}$	$\mathrm{km\ s^{-1}}$	0.8	0.5	0.2
$v_A = B/\sqrt{4\pi\rho}$	$\mathrm{km\ s^{-1}}$	3.4	2.0	1.4
$\nu = \frac{1}{3}\lambda v_{th}$	$\mathrm{cm^2\ s^{-1}}$	2.8×10^{17}	1.8×10^{17}	9×10^{16}
$P_{th} = \langle n \rangle k T_K$	$\mathrm{erg\ cm^{-3}}$	4×10^{-13}	10^{-12}	10^{-11}
$Re = l v_l/\nu$		5.7×10^7	8.1×10^6	5.4×10^4
$\frac{1}{2}\rho\langle v_l \rangle^3/l$	$\mathrm{erg\ cm^{-3}\ s^{-1}}$	2×10^{-25}	1.7×10^{-25}	2.5×10^{-25}
Λ	$\mathrm{erg\ cm^{-3}\ s^{-1}}$	5×10^{-24}	4×10^{-24}	3.5×10^{-24}
$\epsilon = \frac{1}{2}\langle v_l \rangle^3/l$	$\mathrm{L_\odot/M_\odot}$	1.5×10^{-3}	1.1×10^{-4}	3.2×10^{-6}
l_d	AU	2.9	4.0	5.7
$\lambda_T = l_d^{1/3} L^{2/3}$	pc	0.34	0.38	0.42
$\nu_t = l\langle v_l \rangle$	$\mathrm{cm^2\ s^{-1}}$	2×10^{25}	5×10^{23}	5×10^{21}
$P_t = \frac{1}{3}\langle \rho v_l^2 \rangle$	$\mathrm{erg\ cm^{-3}}$	3×10^{-11}	2×10^{-11}	10^{-11}

Lequeux §13.3

Turbulent power spectrum





Beattie et al. 2025

SILCC: **SI**mulating the **L**ife**C**ycle of molecular **C**louds

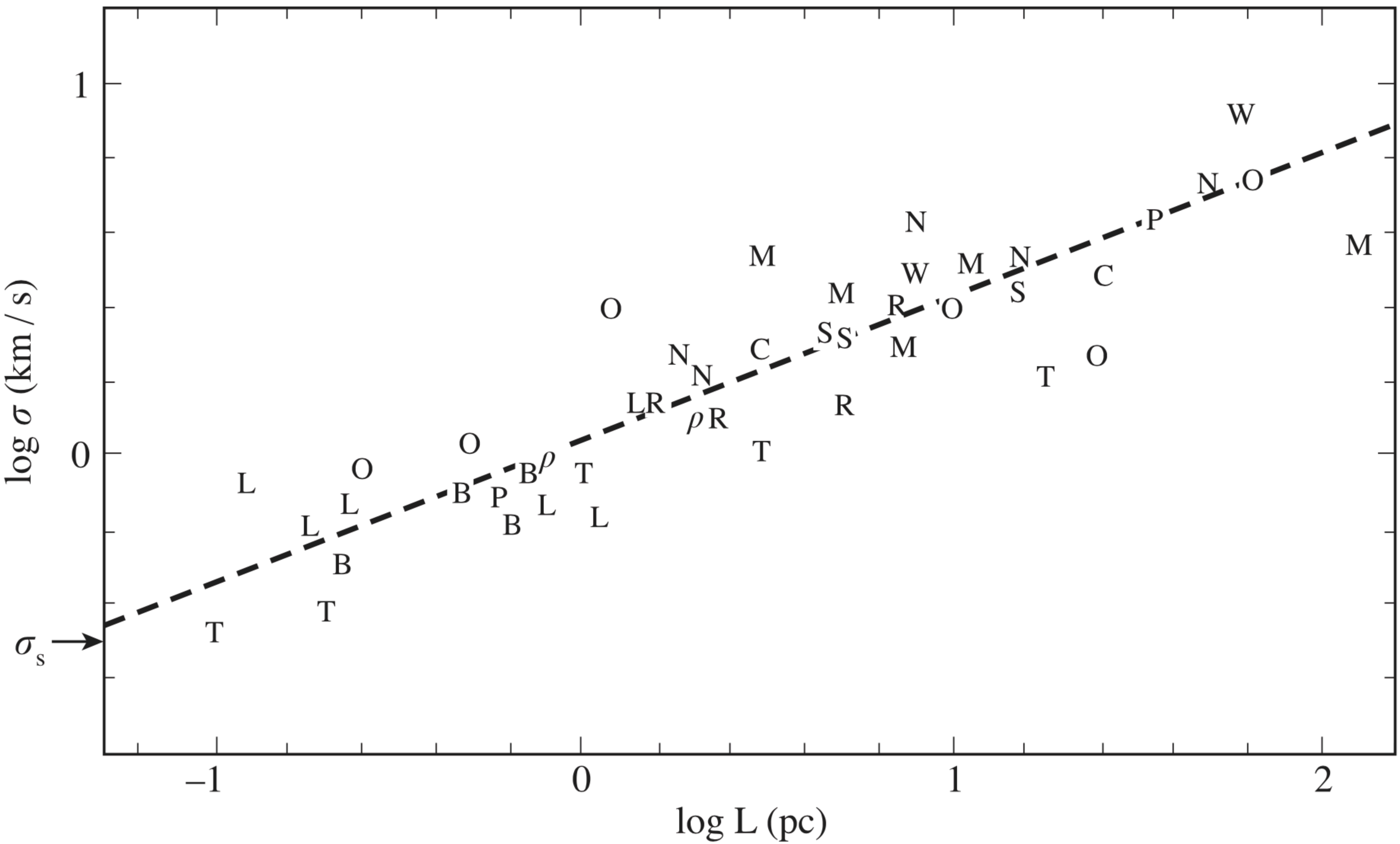
Stefanie Walch
Philipp Girichidis
Thorsten Naab
Andrea Gatto
Simon C. O. Glover
Richard Wünsch
Ralf S. Klessen
Paul C. Clark
Thomas Peters
Dominik Derigs
Christian Baczynski

Walch et al., MNRAS 454, 238 (2015)
Girichidis et al., arXiv:1508.06646

KS SN rate, random driving

SILCC project (website) • Walch et al. 2015

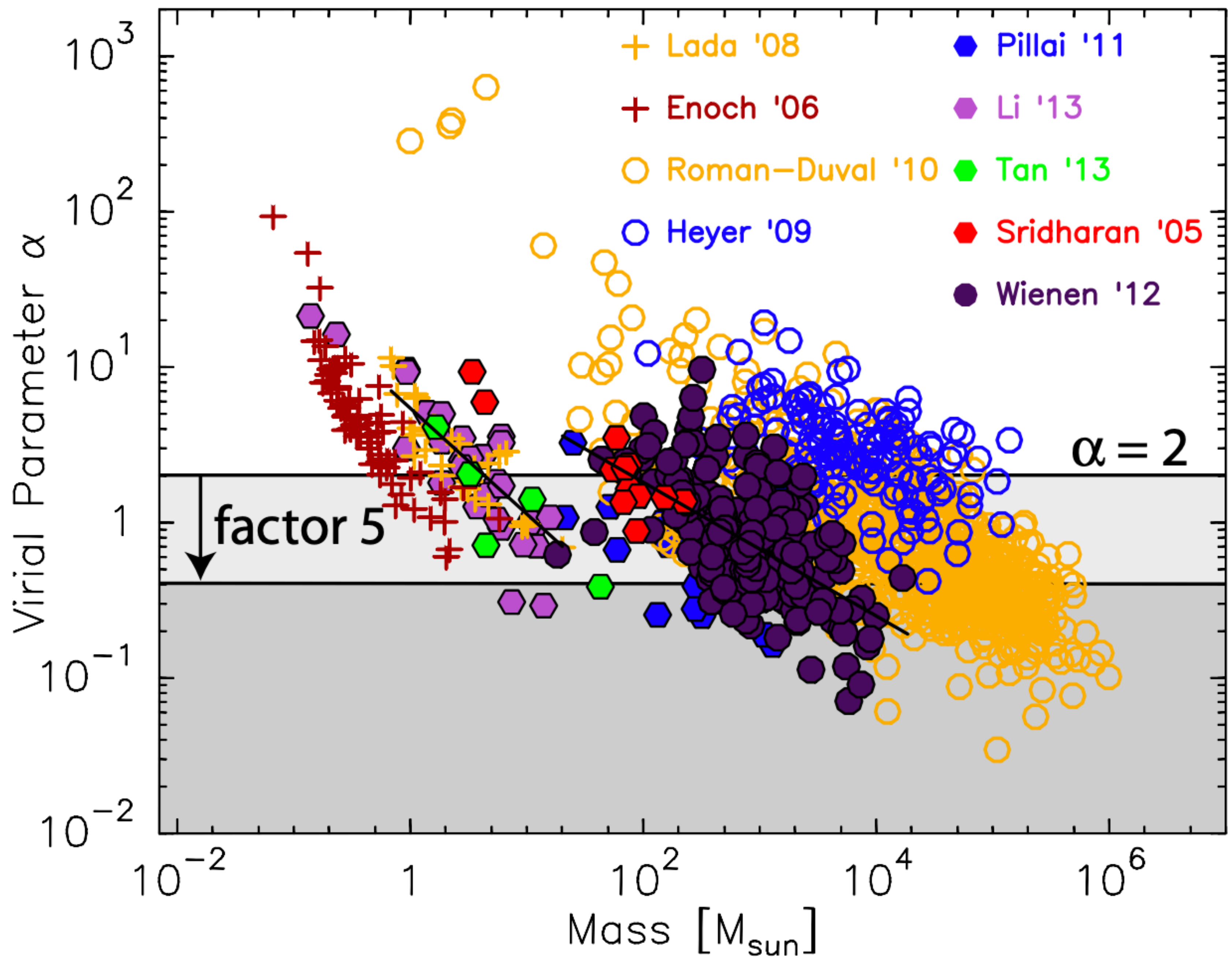
Size-linewidth relation



Larson 1981

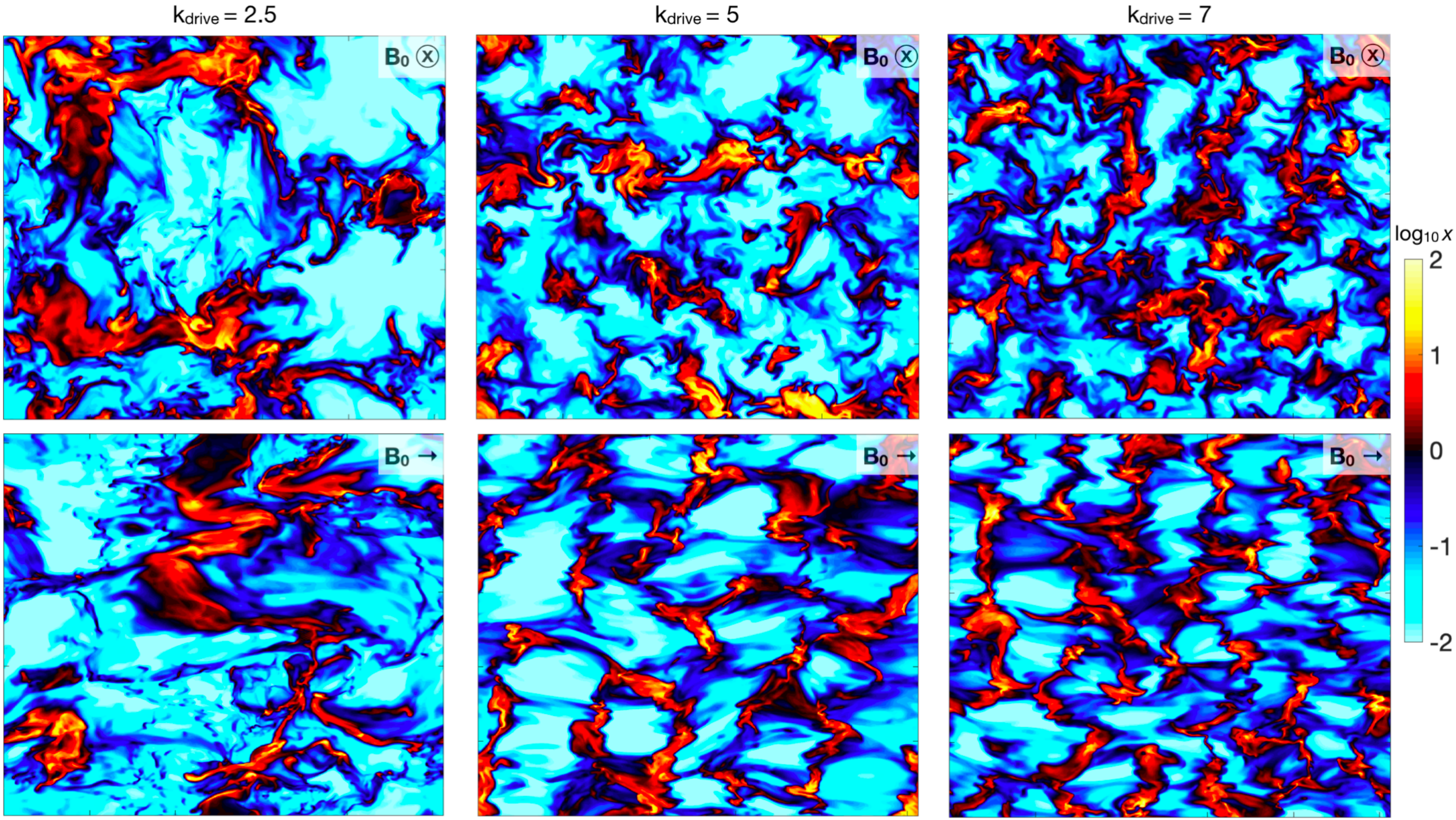
Are GMCs graviationally bound?

$$\alpha \equiv \frac{5\sigma_u^2 R}{GM}$$



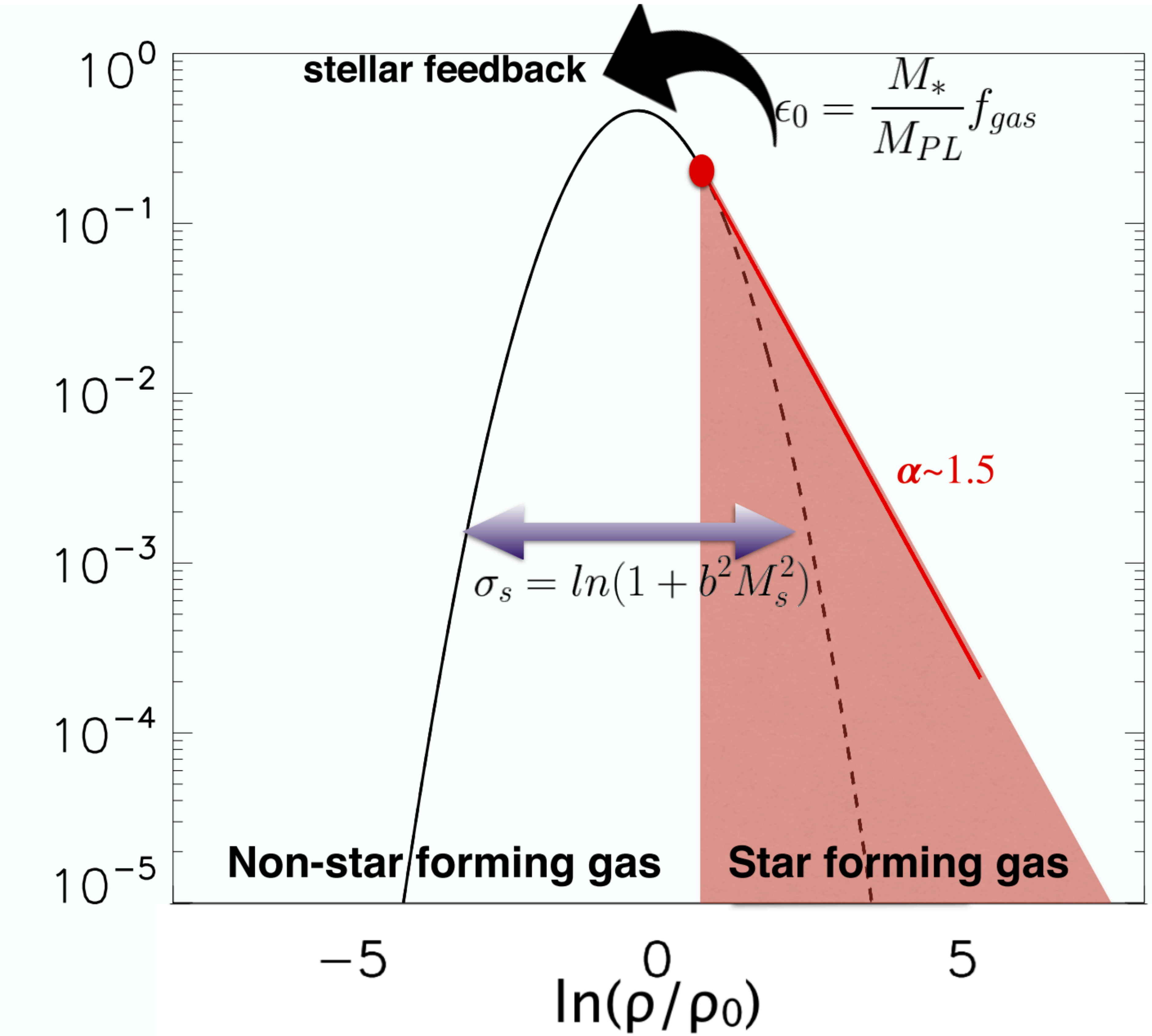
Kauffmann et al. 2013

Turbulent parameters in the ISM



Bialy & Burkhart 2020

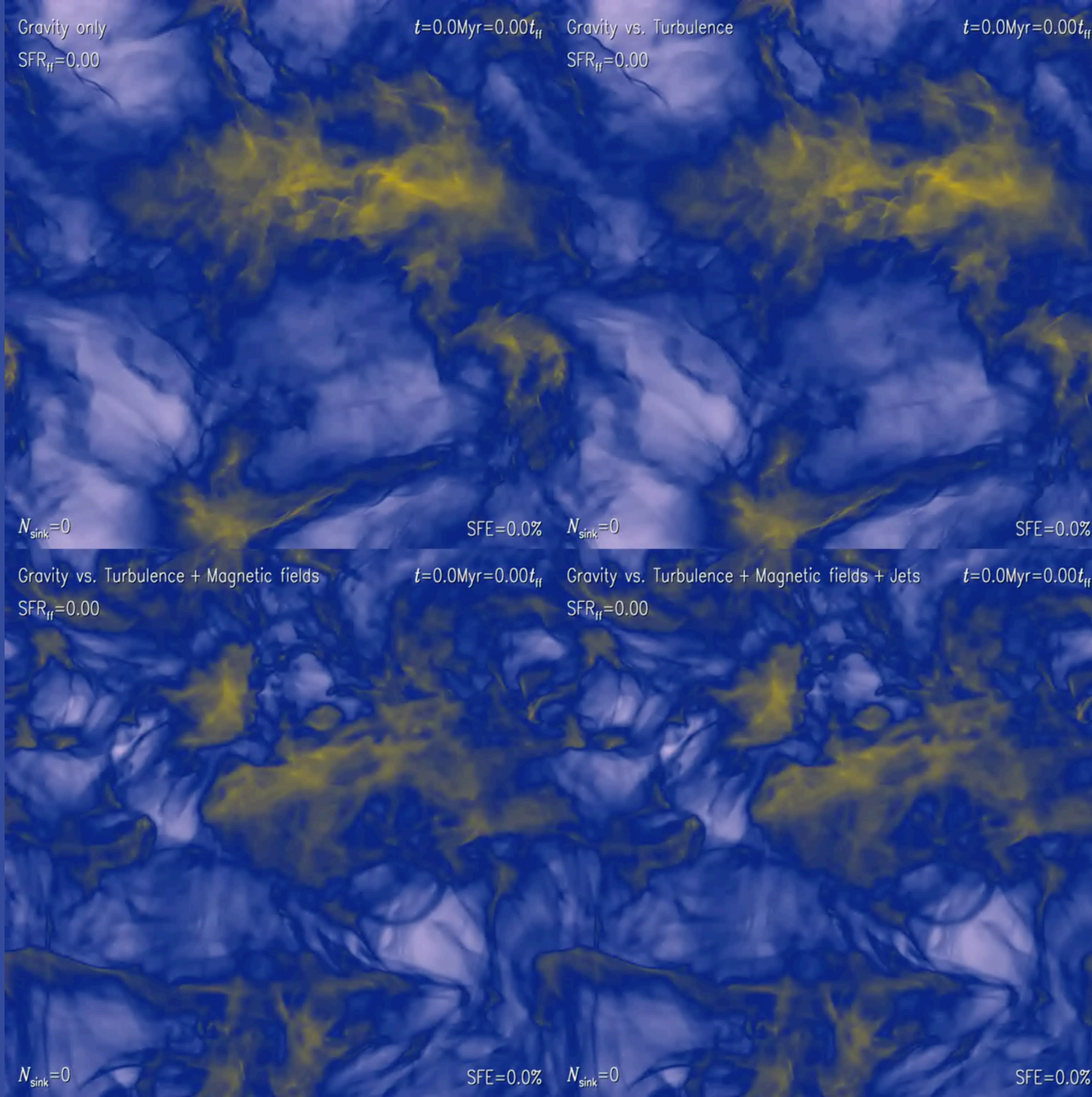
Density PDF



Burkhart & Mocz 2018

Gravity only

Gravity + turbulence



Gravity + turbulence + B

Gravity + turb. + B + jets

Federrath et al. 2015 (movie page)

Reading

Draine

- §41.1
- §42.3-5