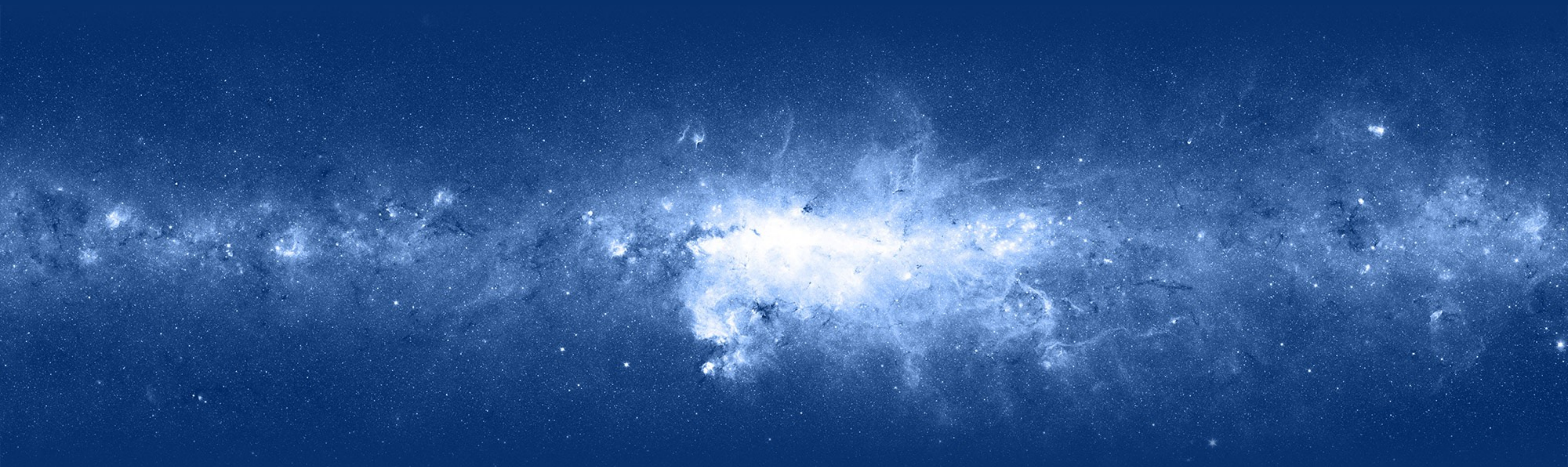
ASTR 670: Interstellar medium and gas dynamics

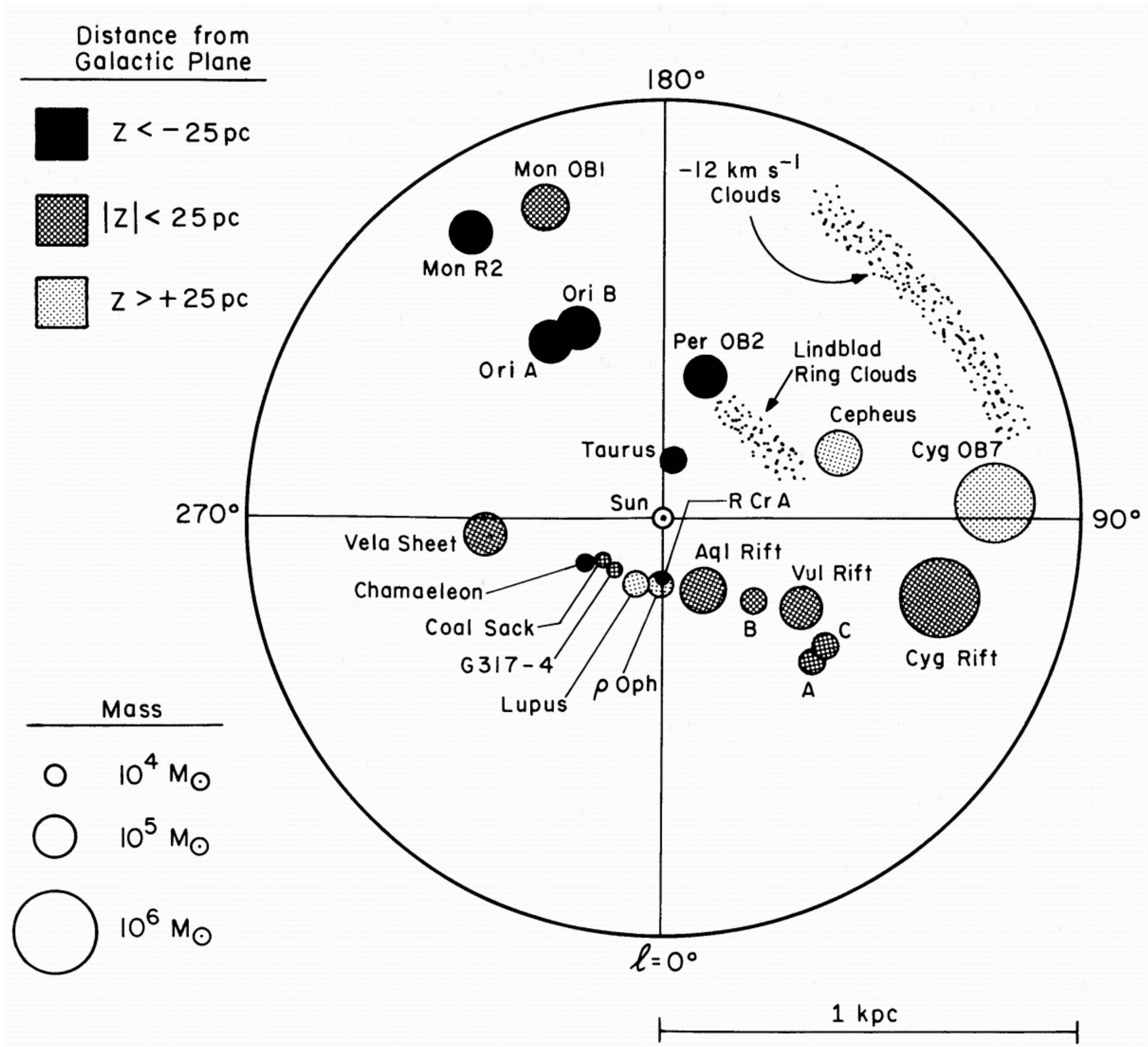
Prof. Benedikt Diemer



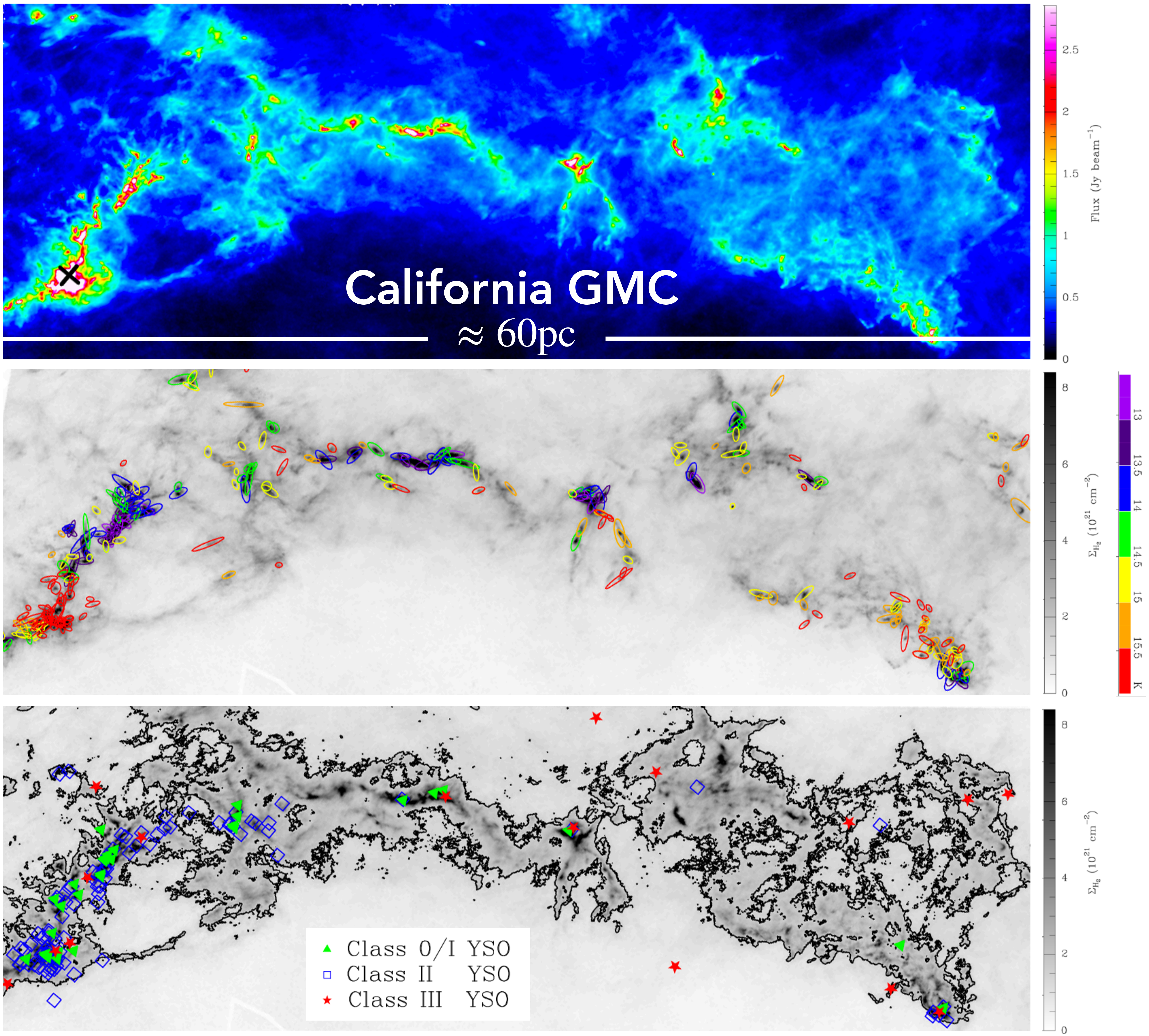
Chapter 8 • Molecular gas and giant molecular clouds

§8.1 • Properties of molecular clouds

Molecular clouds near the Sun



Dame et al. 1987



Dust surface density

Cold molecular cores

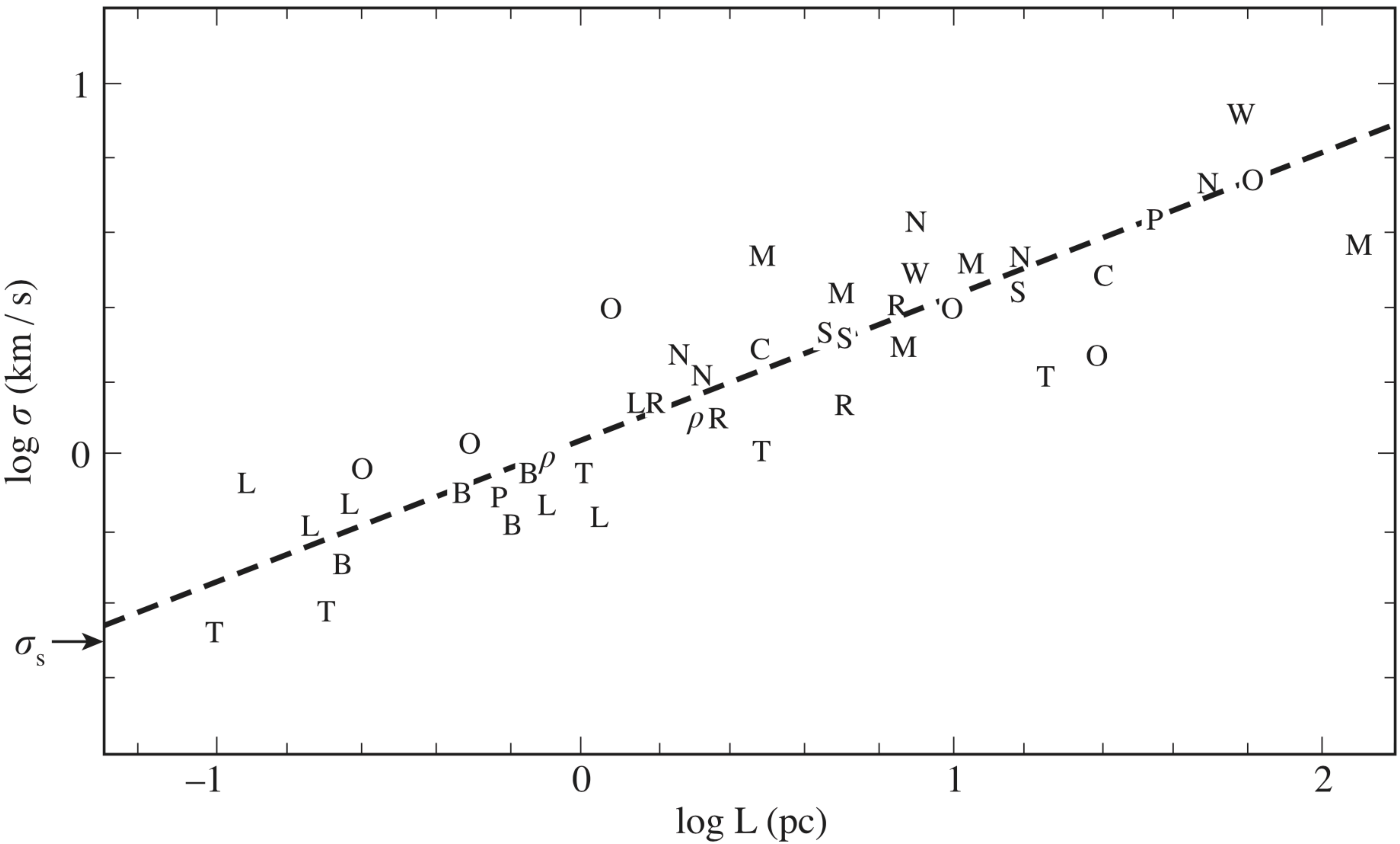
Young stellar objects

Zhang et al. 2019

Gas phases (in the Milky Way)

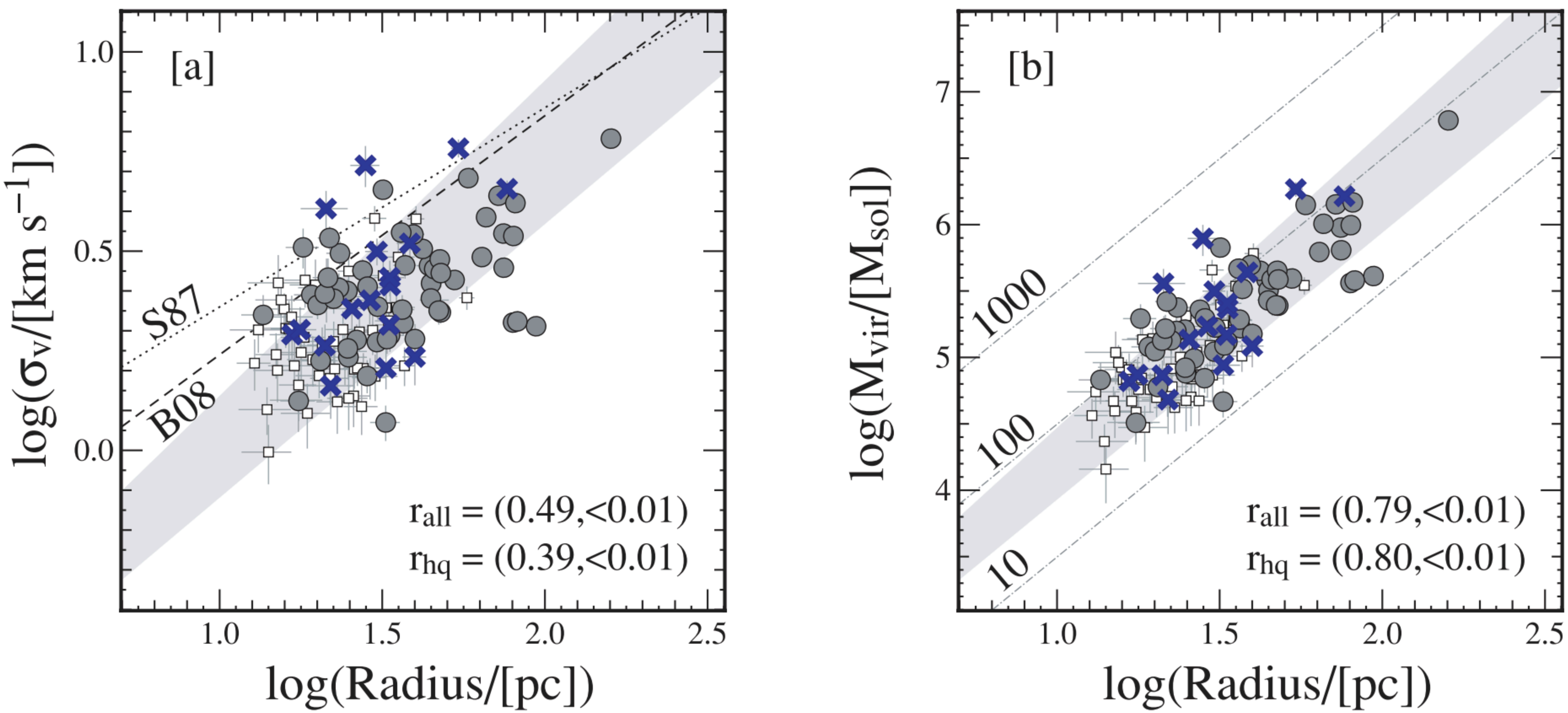
	Phase	T (K)	n_H (cm^{-3})	f_V -	P/k_B (K/cm^3)	Comments
H II 23%	Hot ionized medium (HIM)	$10^{5.7}$	0.004	0.5	4400	Collisionally ionized, shock-heated by supernovae and stellar winds
	H II regions	10000	$0.1-10^4$	0.01	varies	Photo-ionized nebulae around stars; density and pressure vary across these bubbles
	Warm ionized medium (WIM)	8000	0.2	0.1	4400	Diffuse photo-ionized gas, large scatter in temperature and density
H I 60%	Warm neutral medium (WNM)	8000	0.5	0.4	4400	About 60% of HI by mass; in pressure equilibrium witn CNM
	Cool neutral medium (CNM)	100	40	0.01	4400	Significant fraction of the mass despite small volume filling fraction
H_2 17%	Diffuse molecular gas	50	150	0.001	4400	Self-shielded against dissociation, but not dense enough to form stars
	Molecular clouds	10-50	10^3-10^6	0.0001	>10000	The site of star formation; more or less gravitationally bound

Size-linewidth relation



Larson 1981

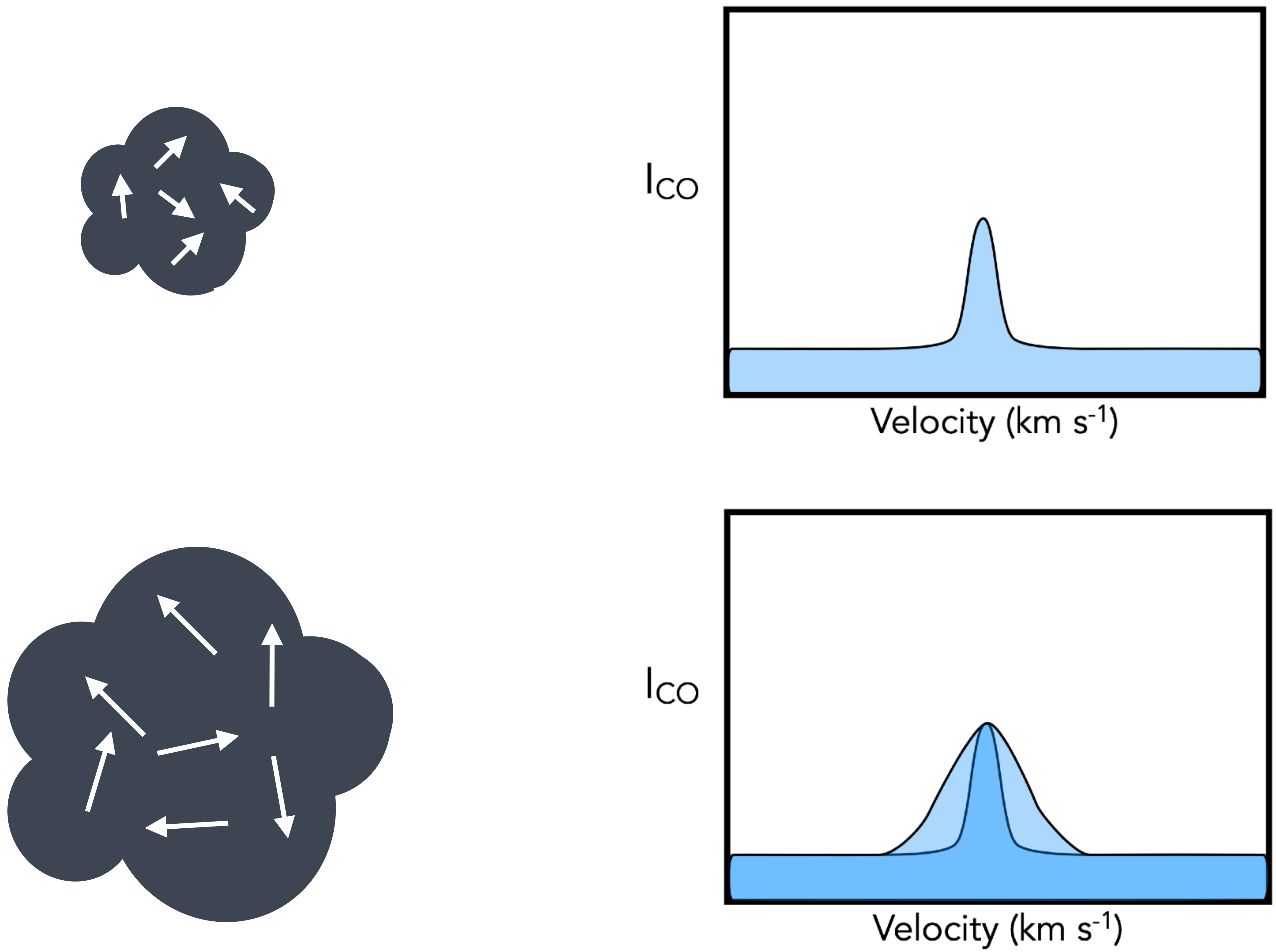
Molecular cloud scaling relations



Hughes et al. 2010

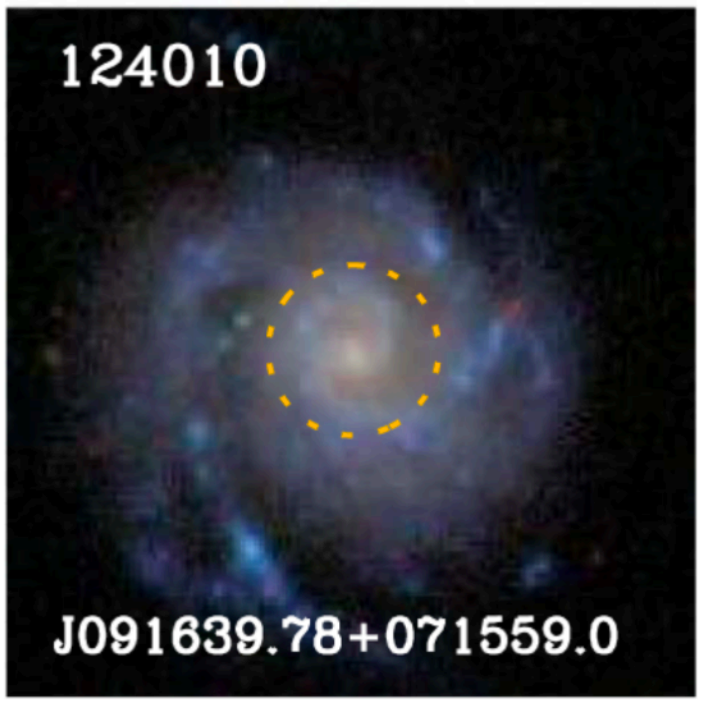
§8.2 • Observational tracers of molecular clouds

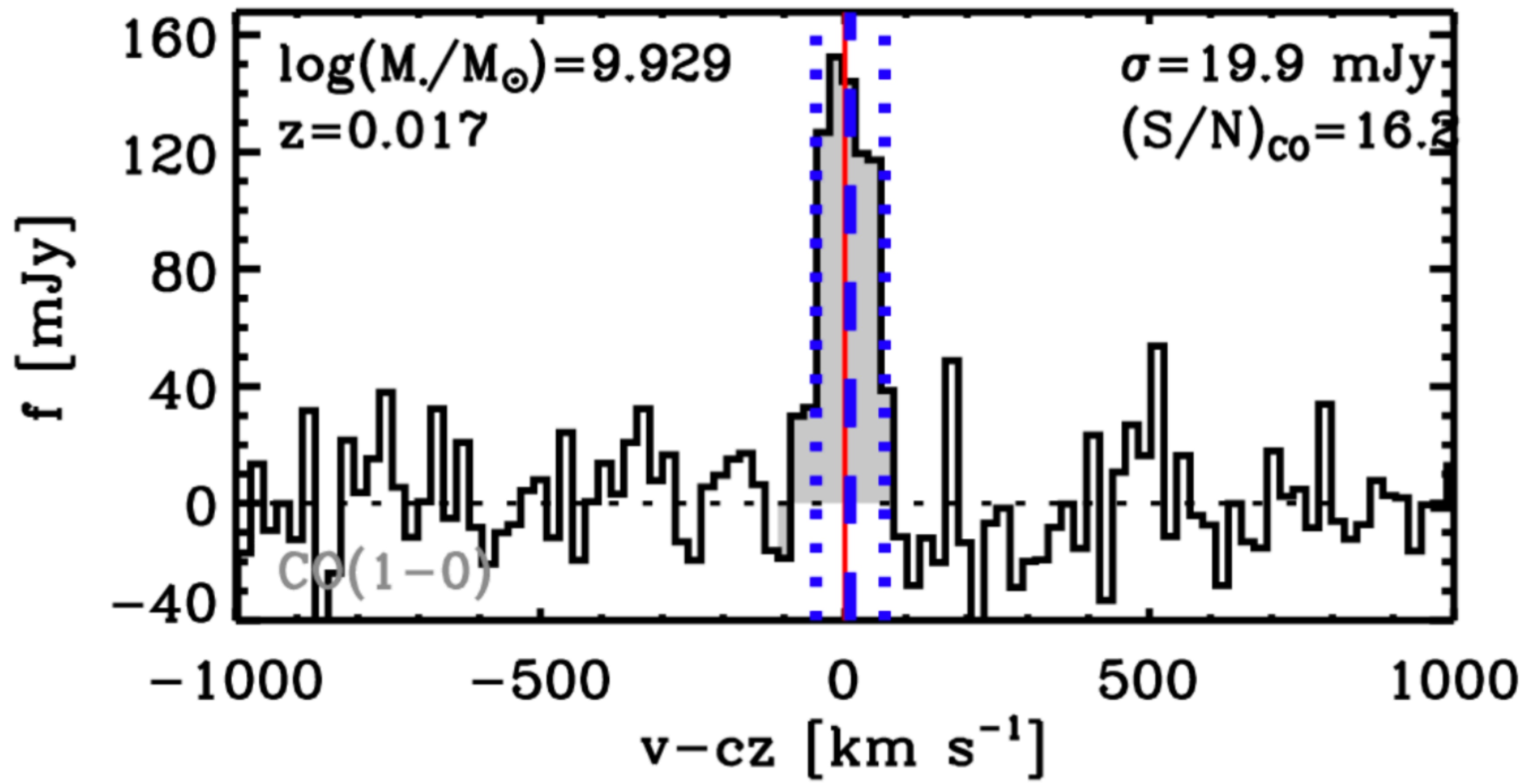
Integrated CO line



Images by Karin Sandstrom

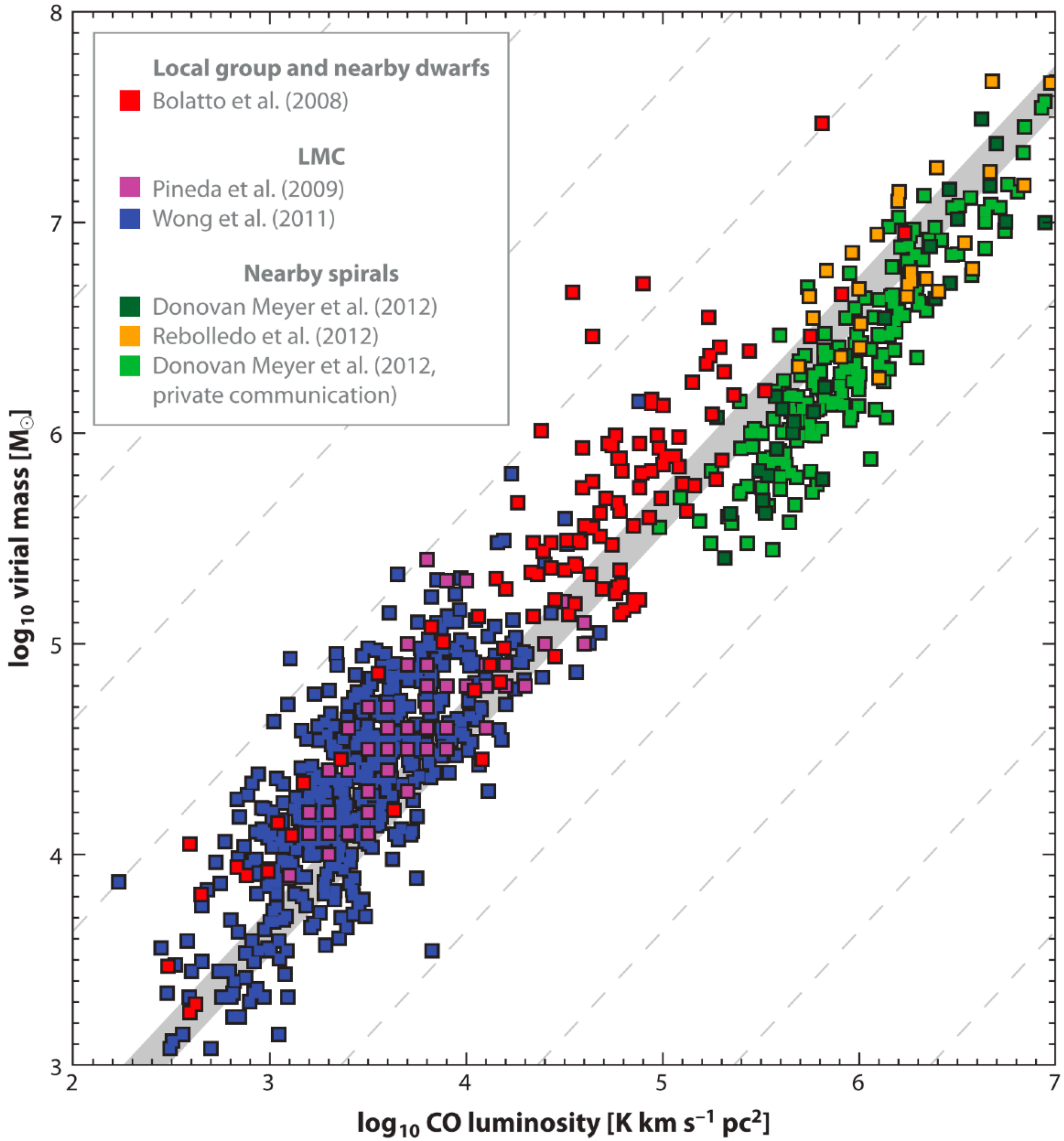
Integrated CO line





Saintonge et al. 2017

CO as a tracer for cloud mass



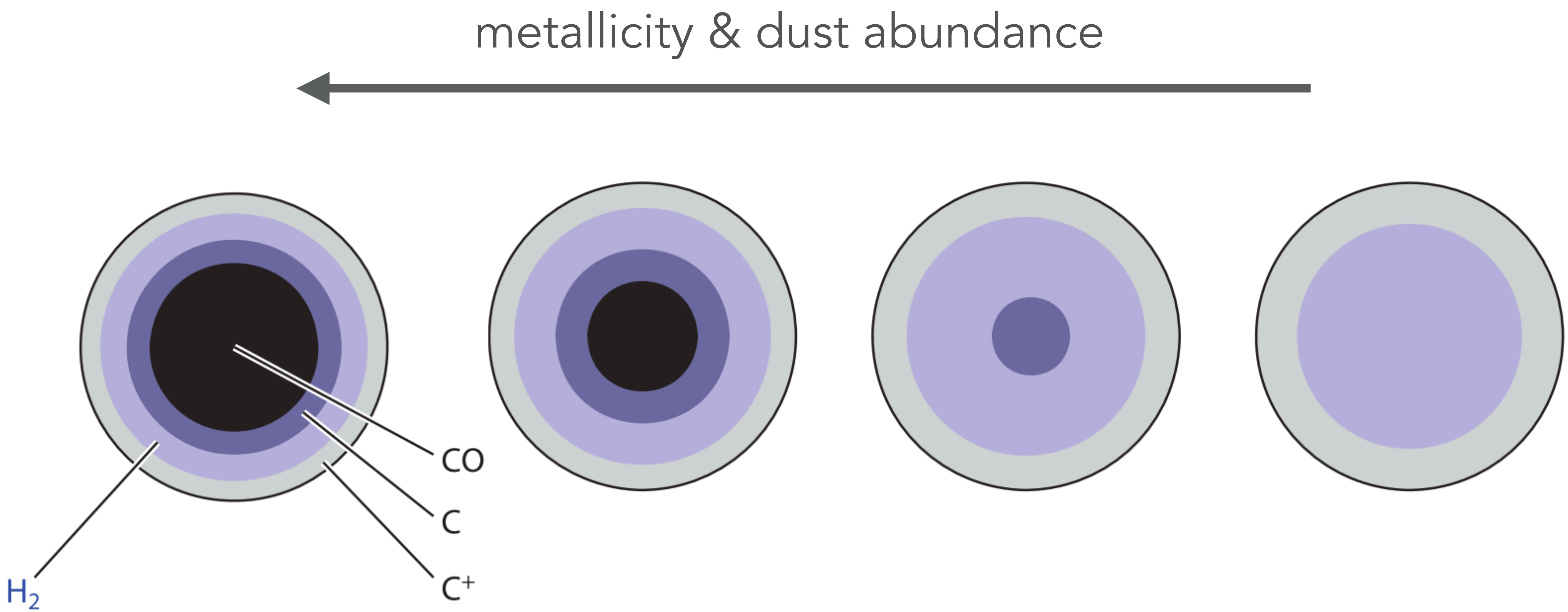
Bolatto et al. 2013

Disagreement about CO-H_2 conversion

Method	$X_{CO}/10^{20}\,cm^{-2}$ $(K\,km\,s^{-1})^{-1}$	References
Virial	2.1	Solomon et al. (1987)
	2.8	Scoville et al. (1987)
Isotopologues	1.8	Goldsmith et al. (2008)
Extinction	1.8	Frerking, Langer & Wilson (1982)
	2.9–4.2	Lombardi, Alves & Lada (2006)
	0.9–3.0	Pineda, Caselli & Goodman (2008)
	2.1	Pineda et al. (2010b)
	1.7–2.3	Paradis et al. (2012)
Dust emission	1.8	Dame, Hartmann & Thaddeus (2001)
	2.5	Planck Collaboration XIX et al. (2011)
γ-rays	1.9	Strong & Mattox (1996)
	1.7	Grenier, Casandjian & Terrier (2005)
	0.9–1.9[a]	Abdo et al. (2010c)
	1.9–2.1[a]	Ackermann et al. (2011, 2012c)
	0.7–1.0[a]	Ackermann et al. (2012a,b)

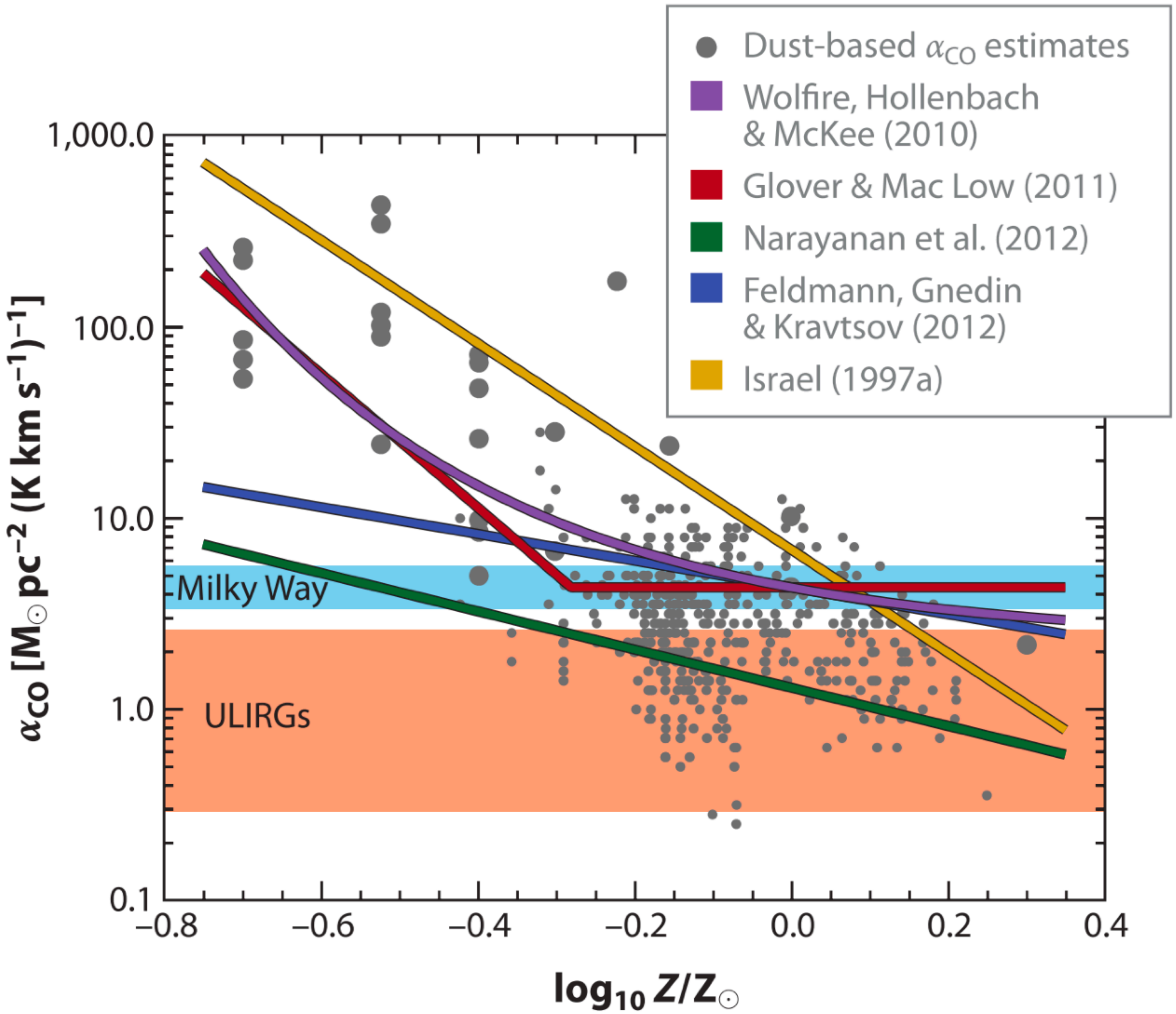
Bolatto et al. 2013

Metallicity-dependent CO-H_2 conversion?



Bolatto et al. 2013

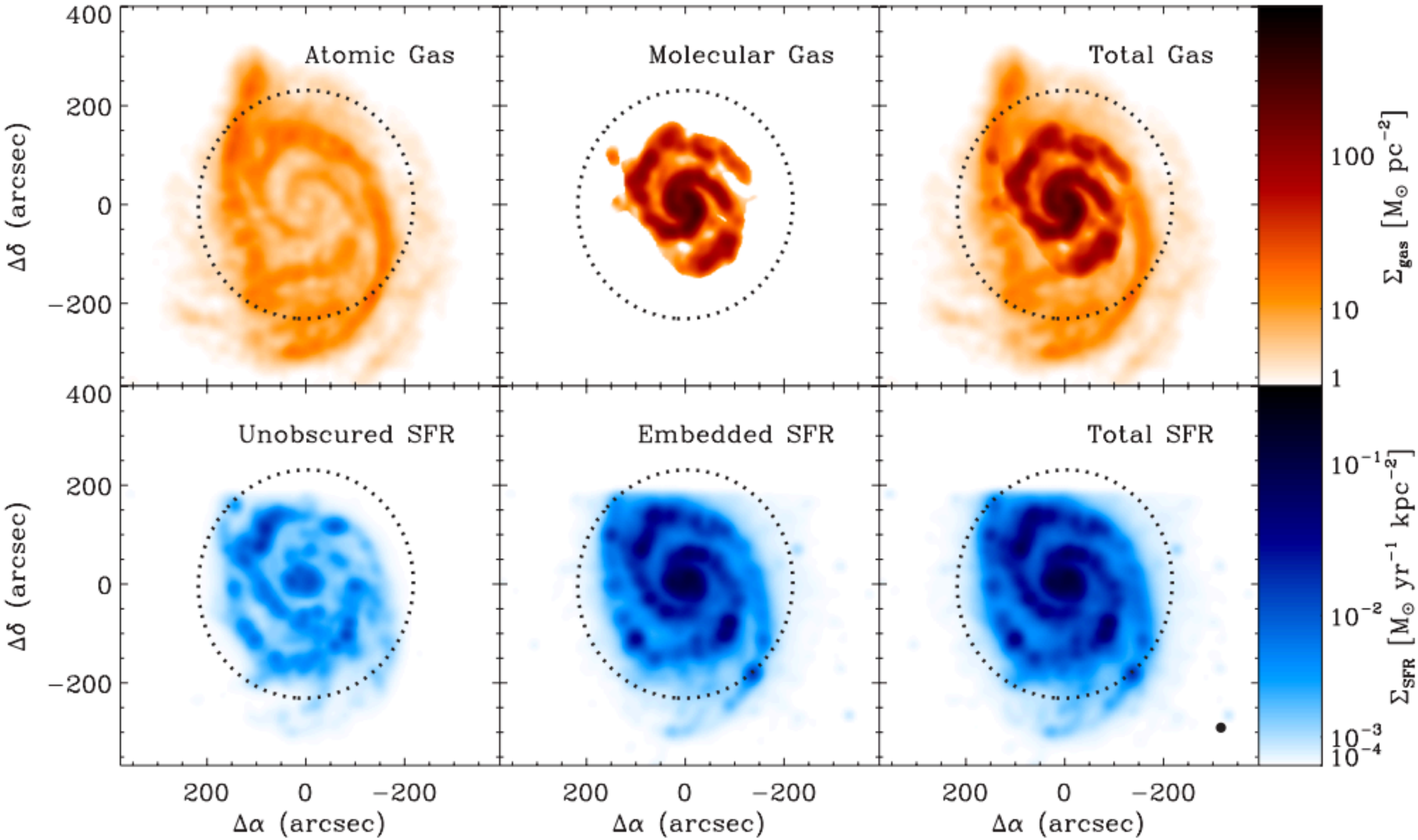
Metallicity-dependent CO-H_2 conversion?



Bolatto et al. 2013

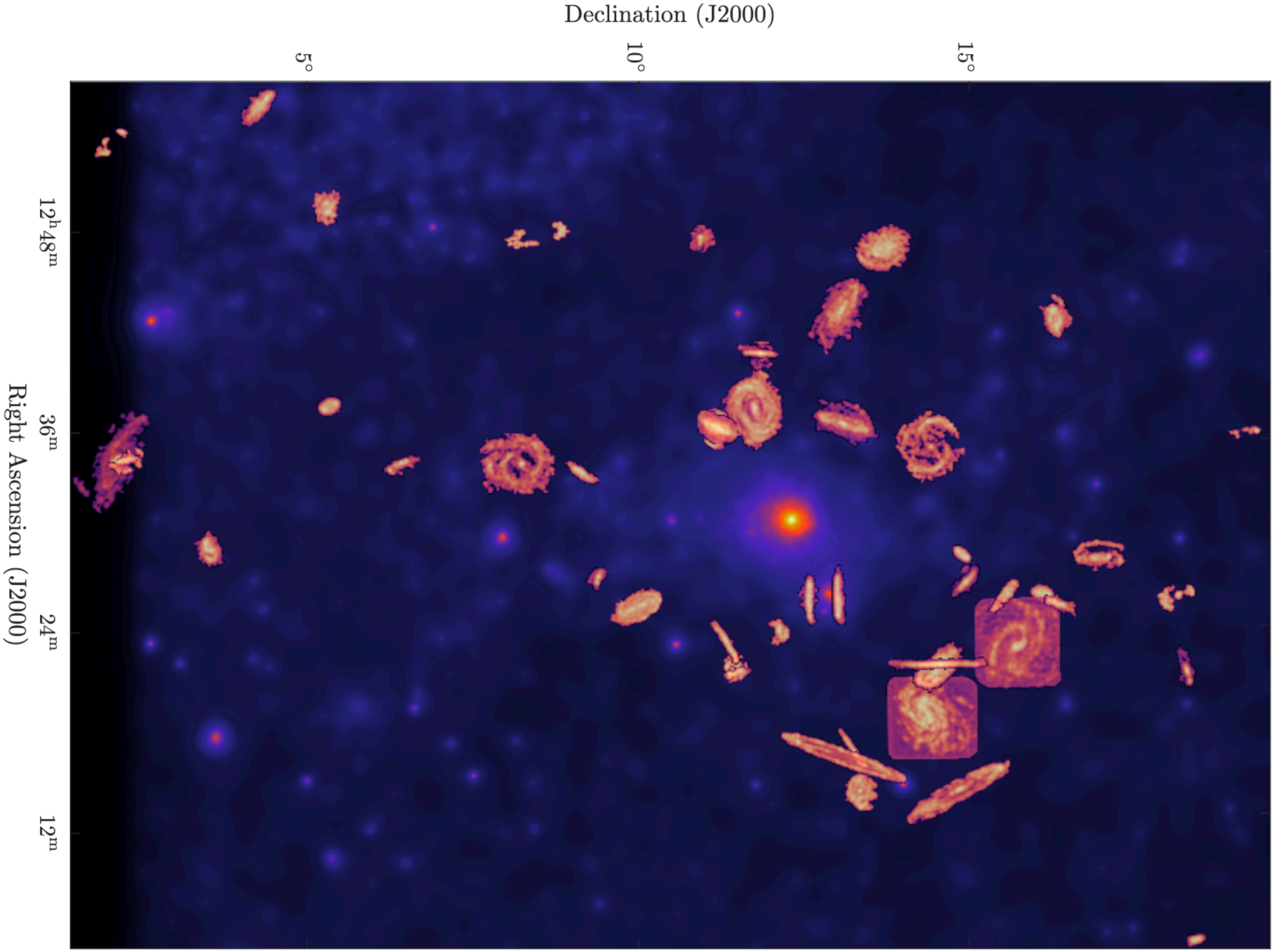
Extragalactic molecular gas

Resolved HI and CO observations



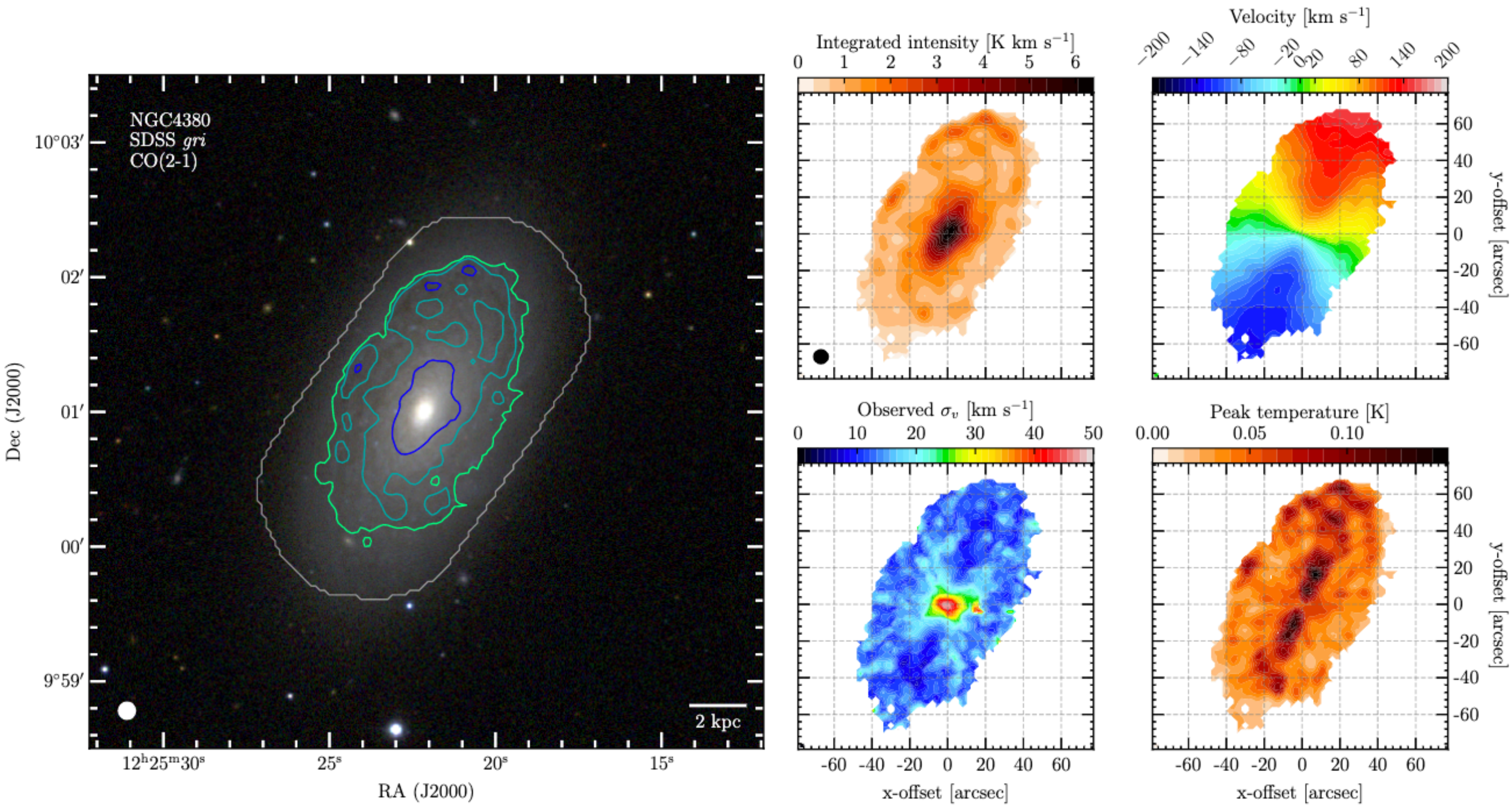
Leroy et al. 2008

VERTICO: Virgo Cluster in CO



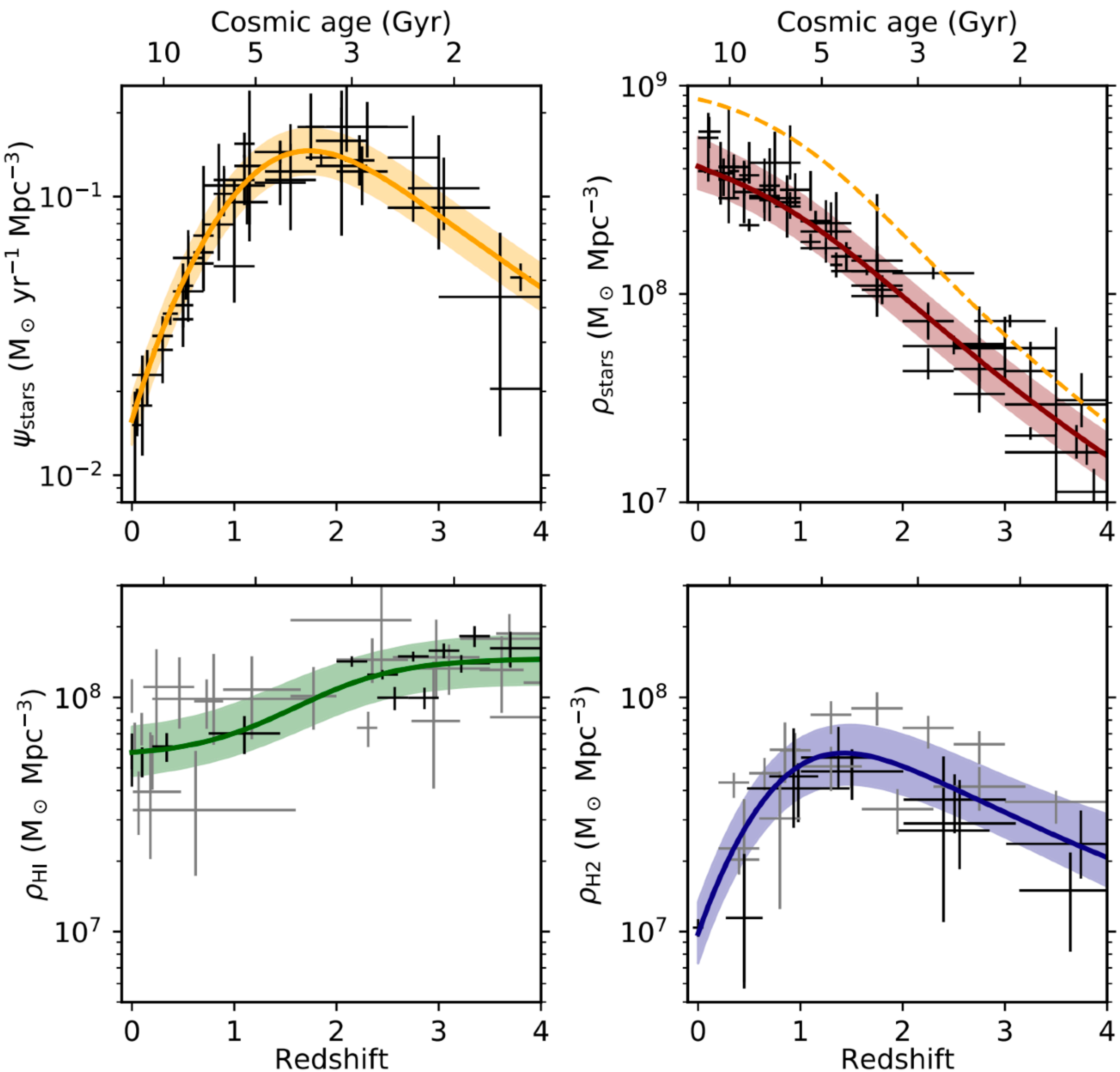
VERTICO survey • Brown et al. 2021

VERTICO: Virgo Cluster in CO

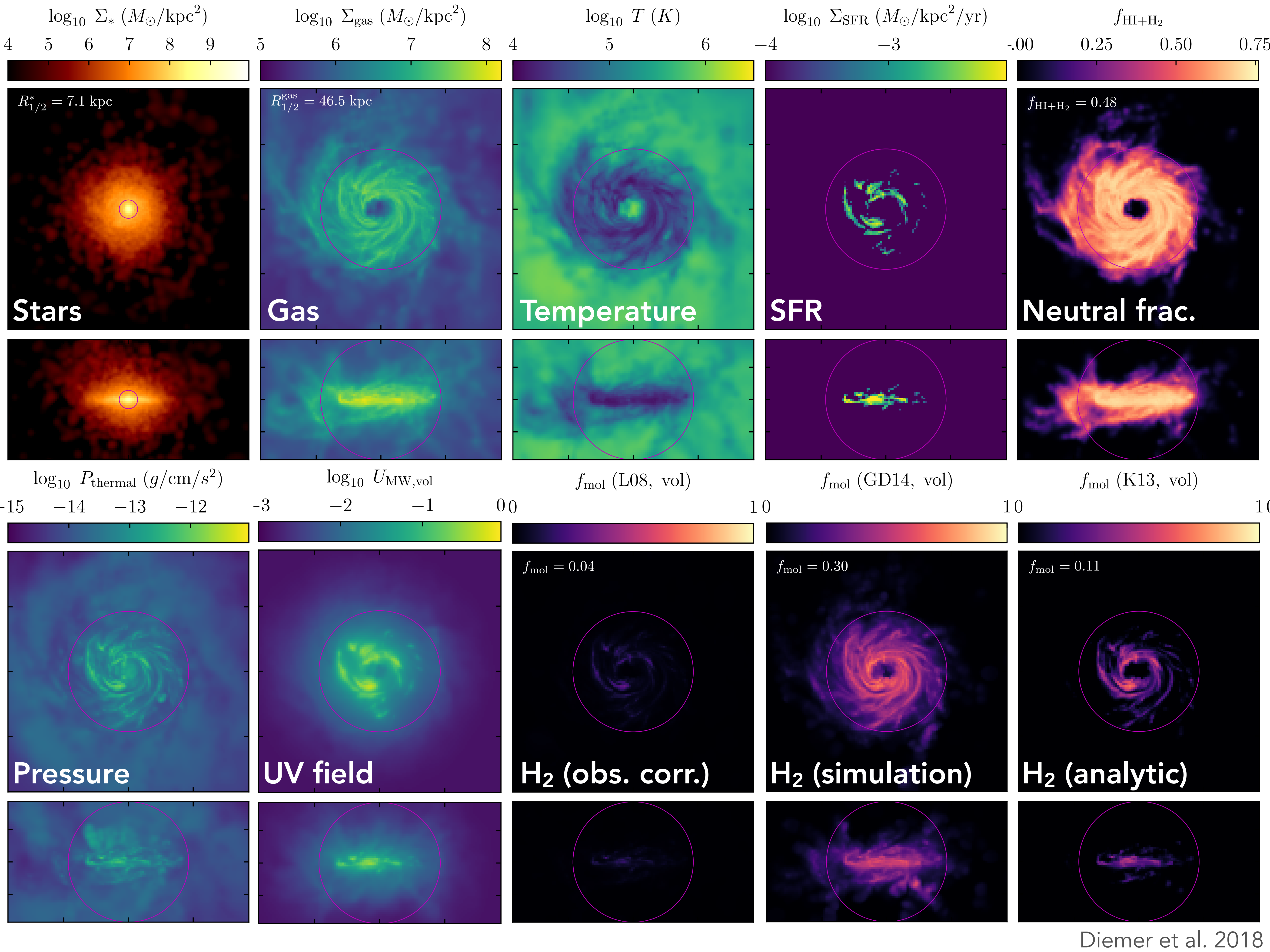


VERTICO survey • Brown et al. 2021

Evolution of gas abundance over cosmic time



Walter et al. 2020



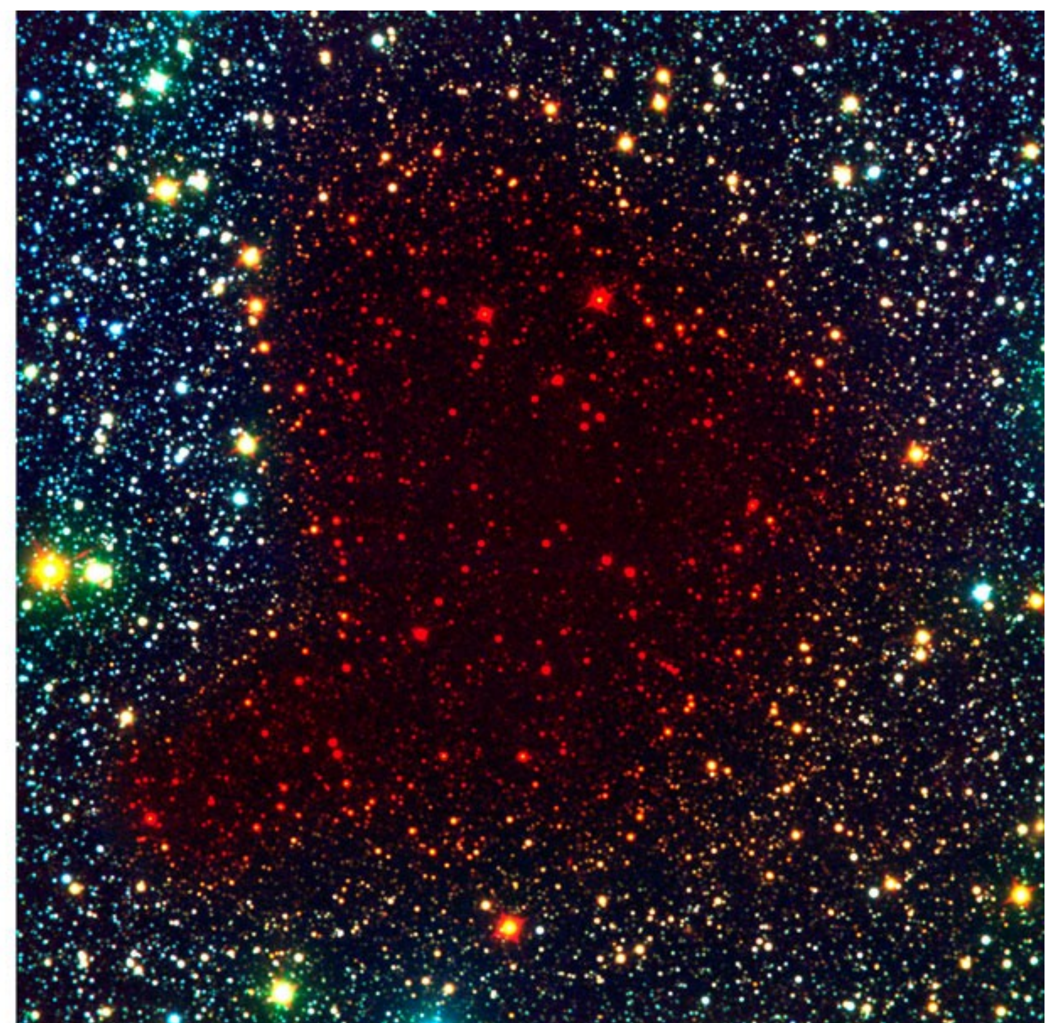
$\log_{10}\ \Sigma_* \ (M_\odot/\mathrm{kpc}^2)$
4 5 6 7 8 9
$\log_{10}\ \Sigma_{\rm gas}\ (M_\odot/\mathrm{kpc}^2)$
5 6 7 8
$\log_{10}\ T\ (K)$
4 5 6
$\log_{10}\ \Sigma_{\rm SFR}\ (M_\odot/\mathrm{kpc}^2/\mathrm{yr})$
−4 −3
$f_{\rm HI+H_2}$
-.00 0.25 0.50 0.75
$R^*_{1/2} = 7.1$ kpc
Stars
$R^{\rm gas}_{1/2} = 46.5$ kpc
Gas
Temperature
SFR
$f_{\rm HI+H_2} = 0.48$
Neutral frac.
$\log_{10}\ P_{\rm thermal}\ (g/\mathrm{cm}/s^2)$
-15 −14 −13 −12
$\log_{10}\ U_{\rm MW,vol}$
-3 −2 −1 0
$f_{\rm mol}$ (L08, vol)
0 1
$f_{\rm mol}$ (GD14, vol)
0 1
$f_{\rm mol}$ (K13, vol)
0 1
Pressure
UV field
$f_{\rm mol} = 0.04$
H_2 (obs. corr.)
$f_{\rm mol} = 0.30$
H_2 (simulation)
$f_{\rm mol} = 0.11$
H_2 (analytic)
Diemer et al. 2018

§8.3 • Dust

Dust absorption

- **Struve 1847:** number of stars decreases in all directions
  - makes sense only if we are at center of spherical distribution
- **Barnard 1910s / 1920s:** catalog of dark clouds
  - Revisited Herschel's "holes in the sky"
  - Realized something seemed to absorb starlight

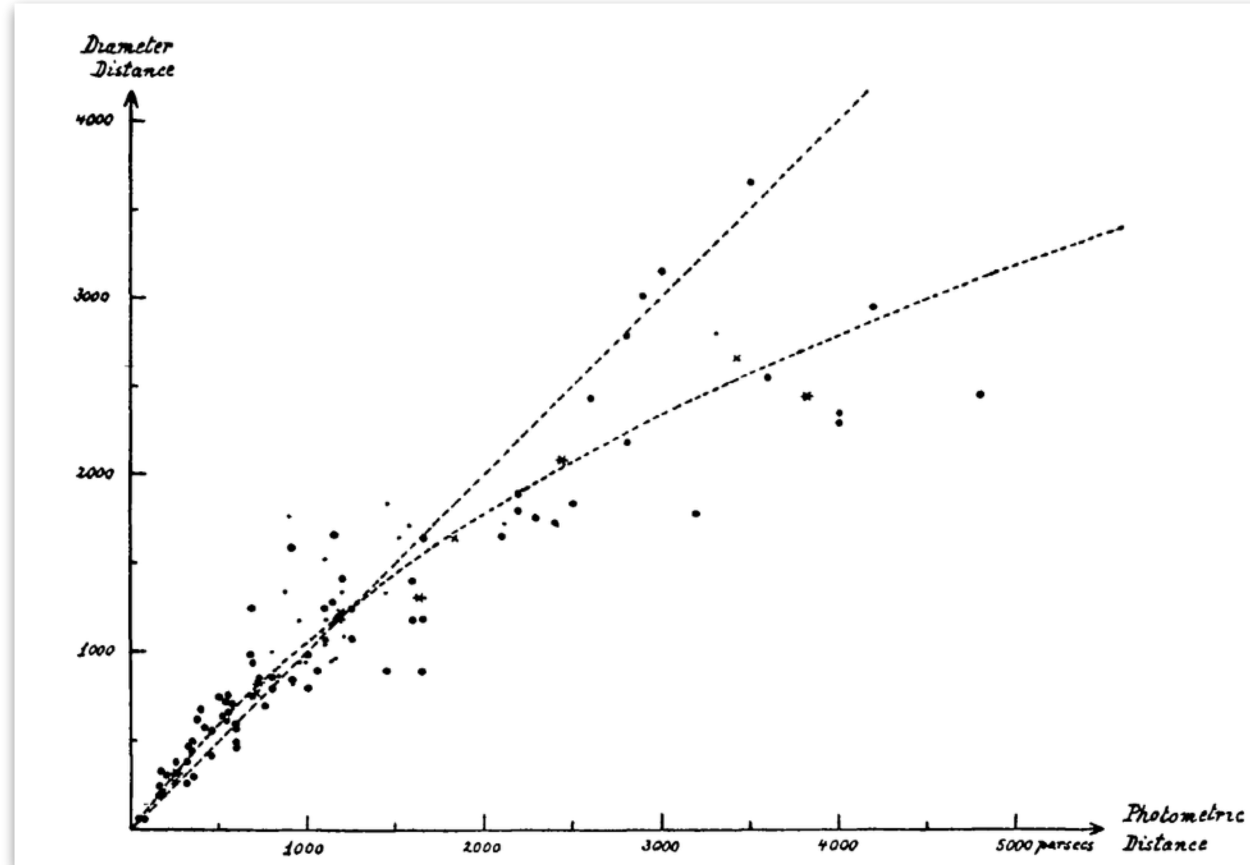
B, V, I

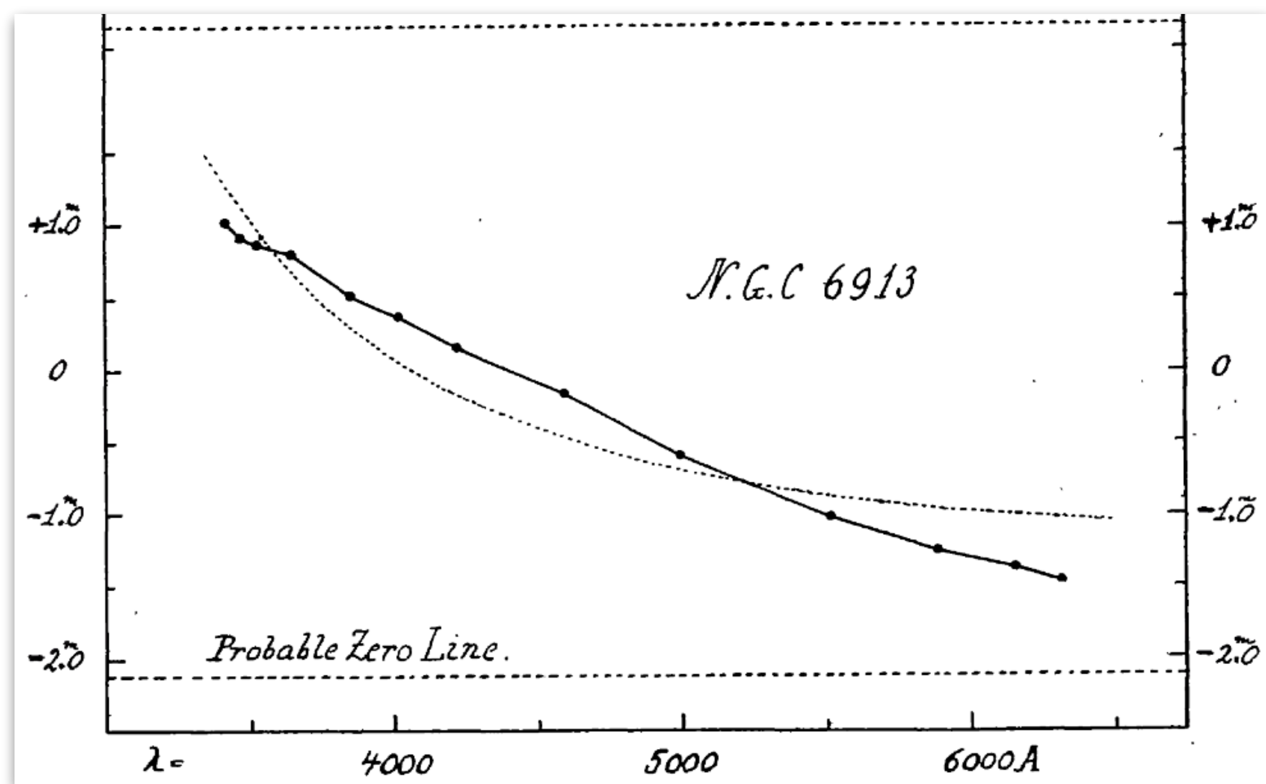


B, I, K

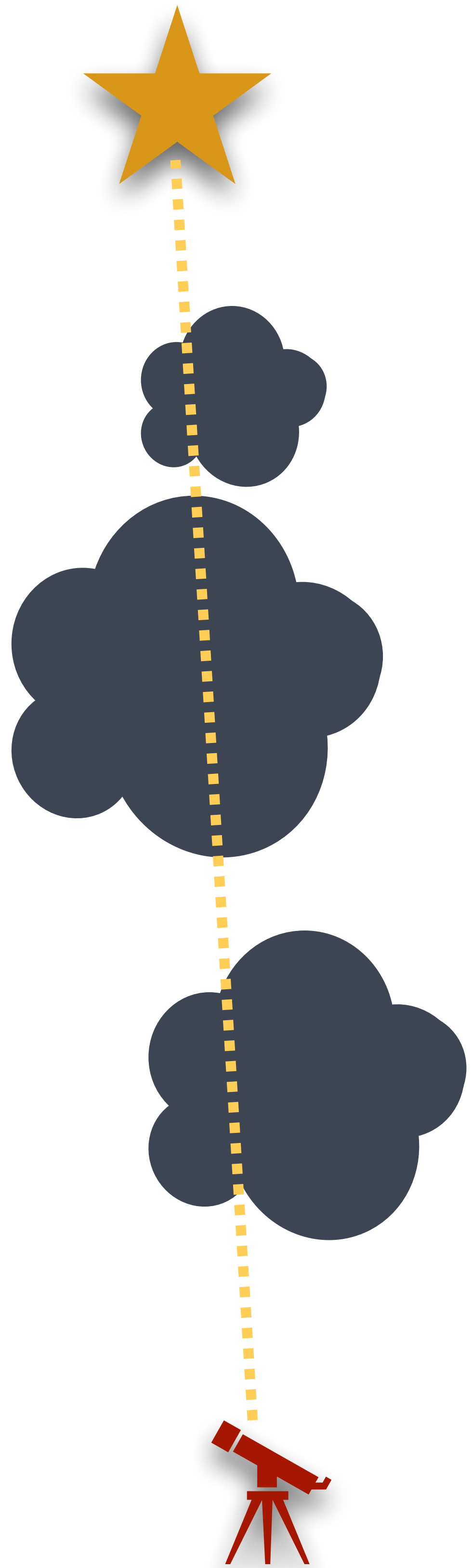
Dust absorption

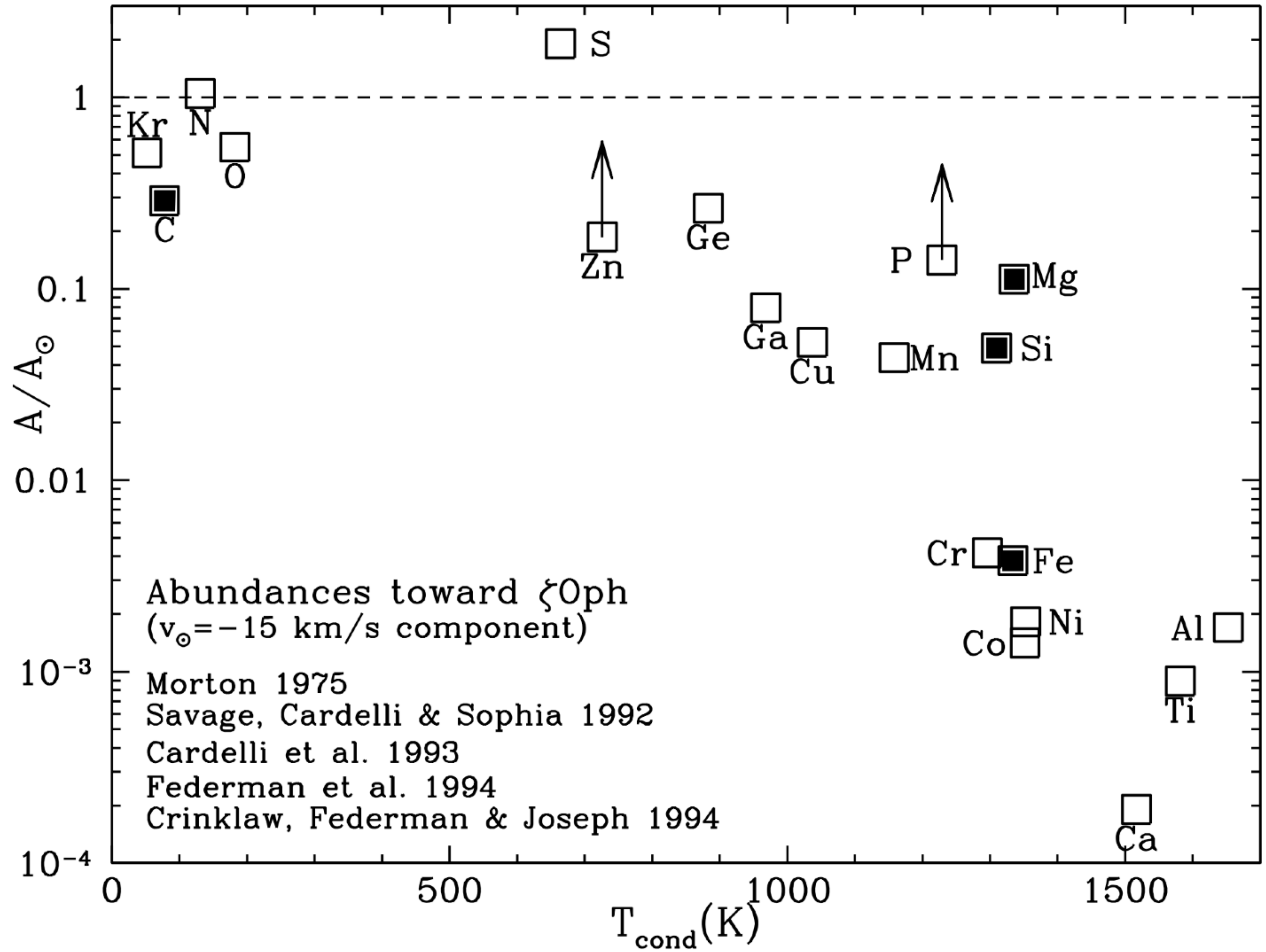
- **Trumpler 1930**
  - Measured distance to star clusters from their size and brightness
  - General dimming of stars with distance
  - Brightness falls off with distance!
  - Extinction depends on wavelength ("reddening")
  - "…interstellar light absorption may be a consequence of light scattering by small particles, fine cosmic dust, thinly spread through the vast spaces occupied by our Milky Way system."





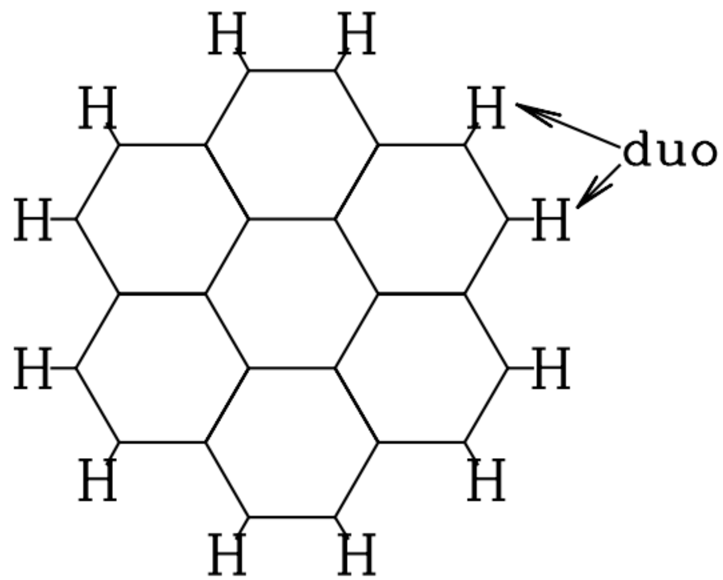
What is dust made of?



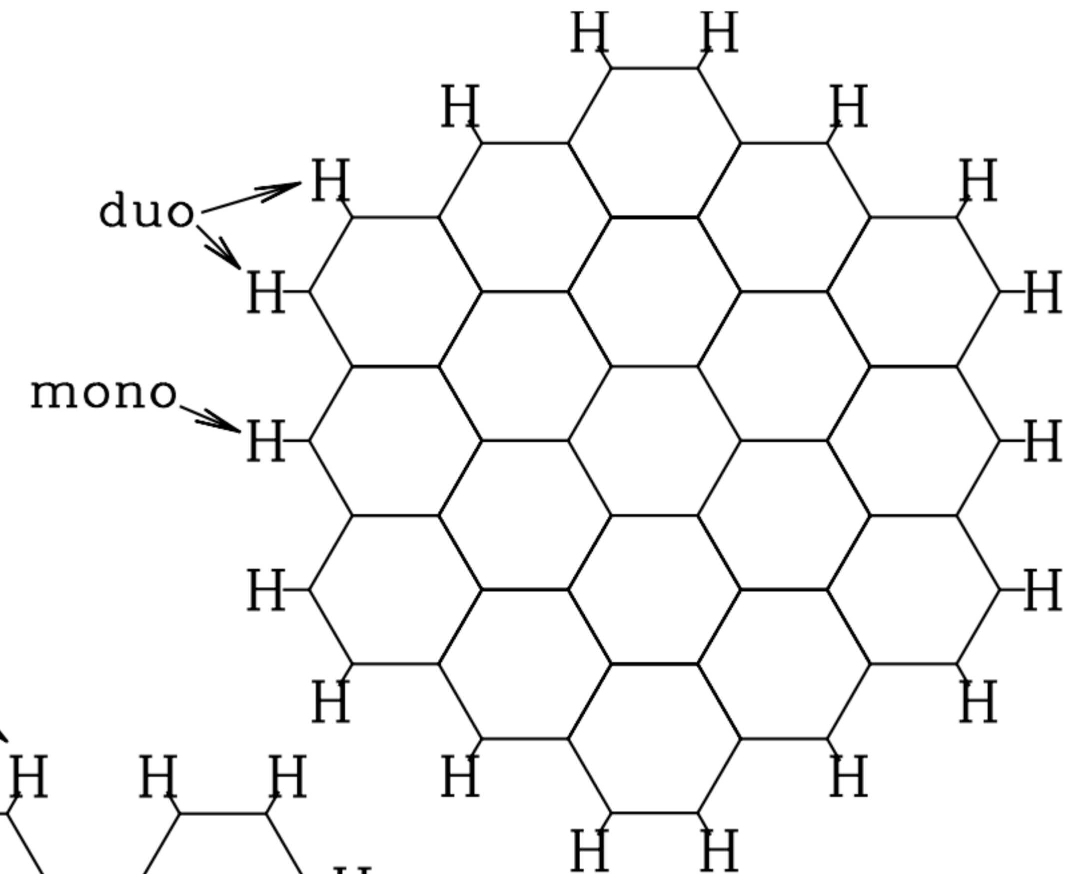


Draine §23.1

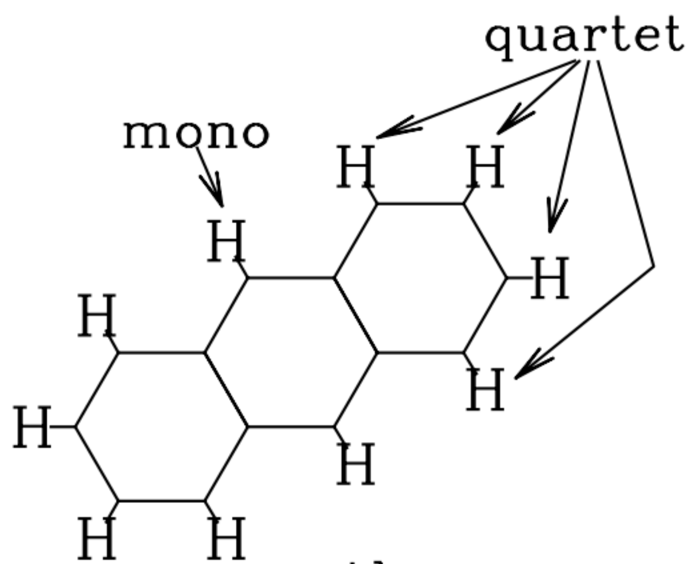
Polycyclic aromatic hydrocarbons (PAH)



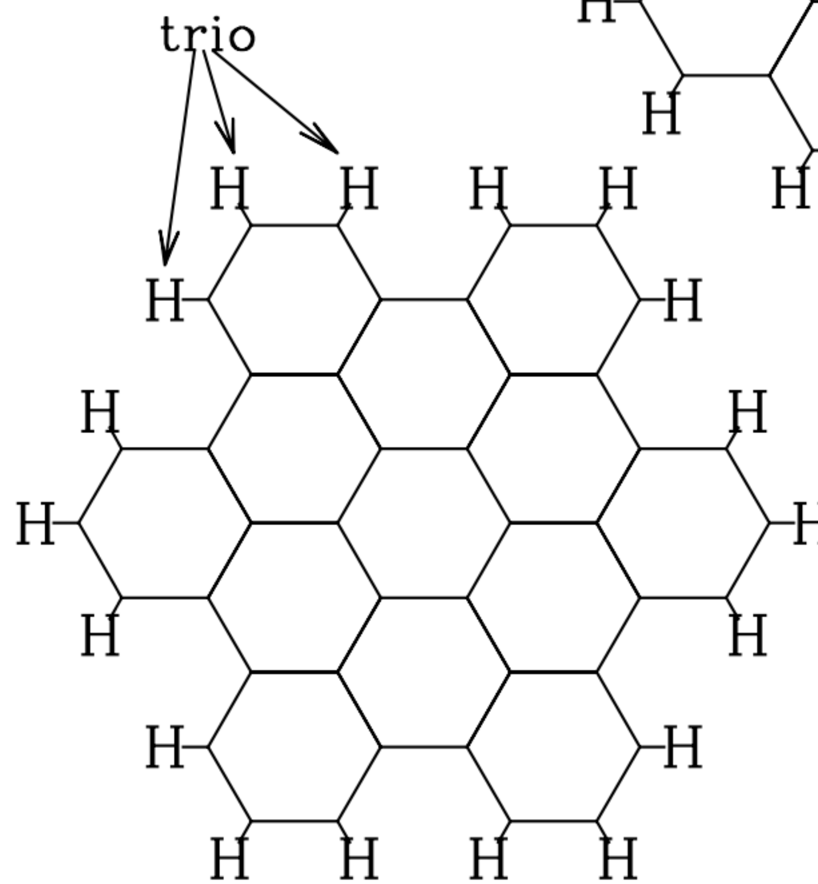
coronene
$C_{24}H_{12}$



circumcoronene
$C_{54}H_{18}$

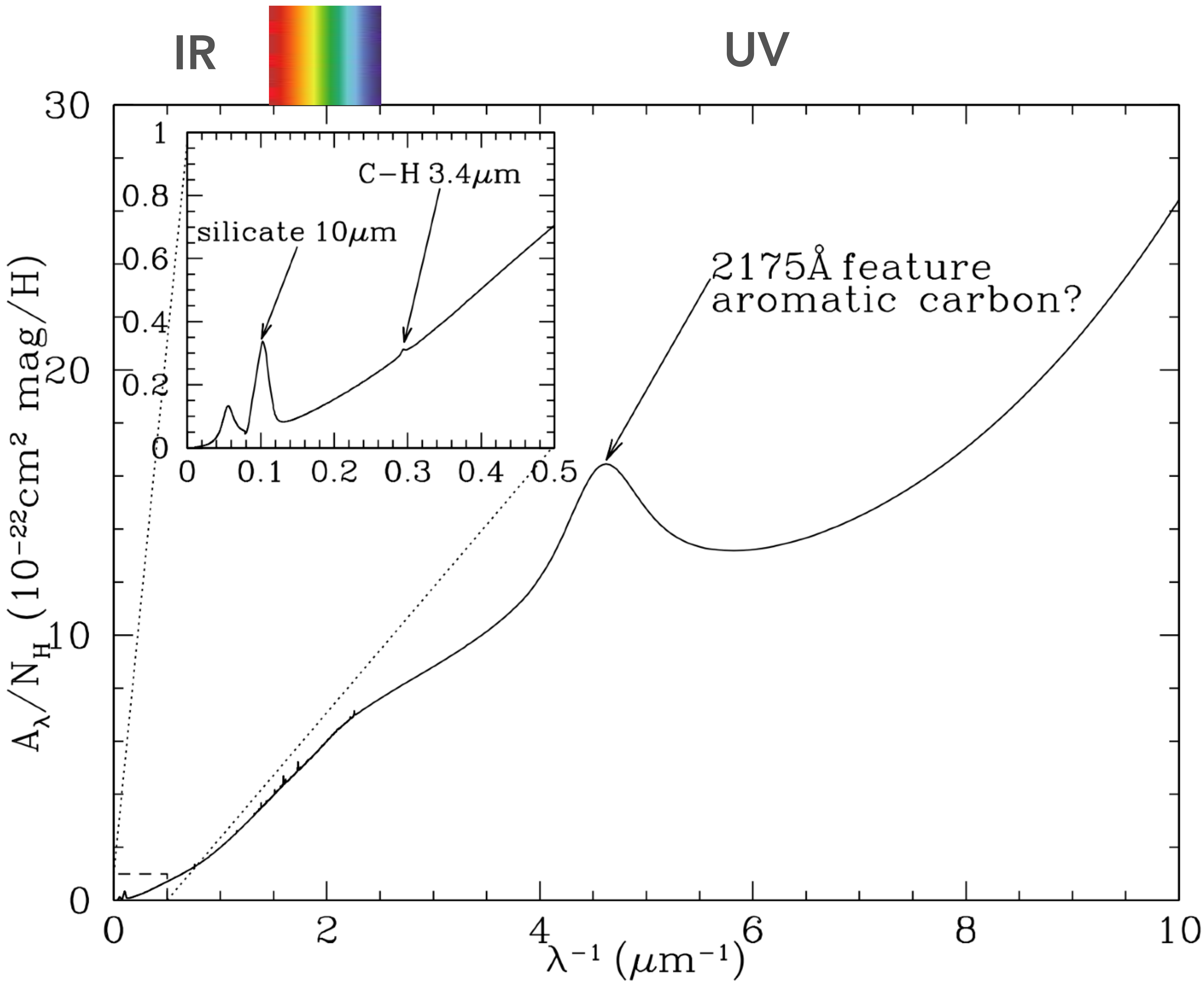


anthracene
$C_{14}H_{10}$



hexabenzocoronene
$C_{42}H_{18}$

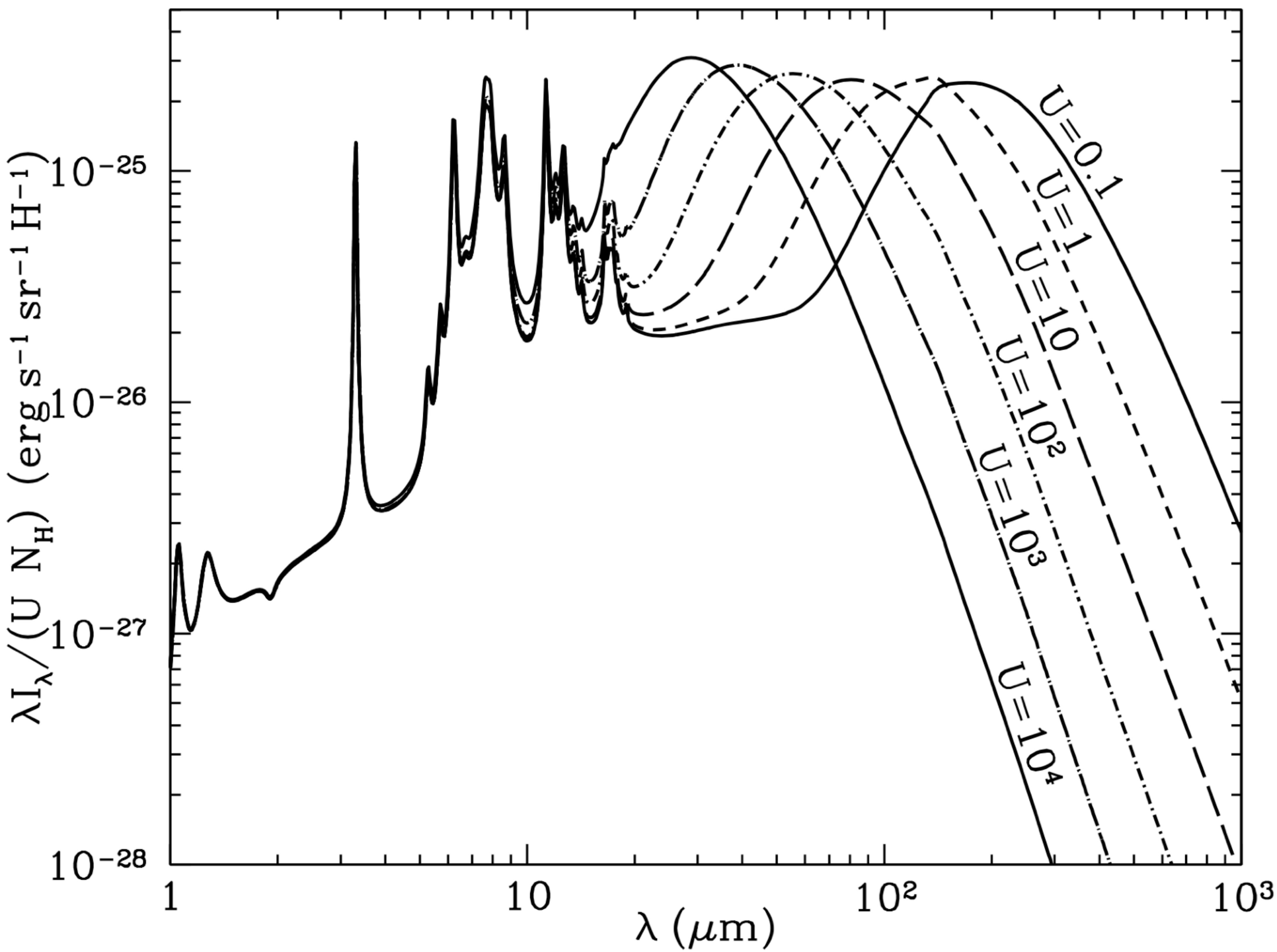
Dust extinction



Inverse wavelength!

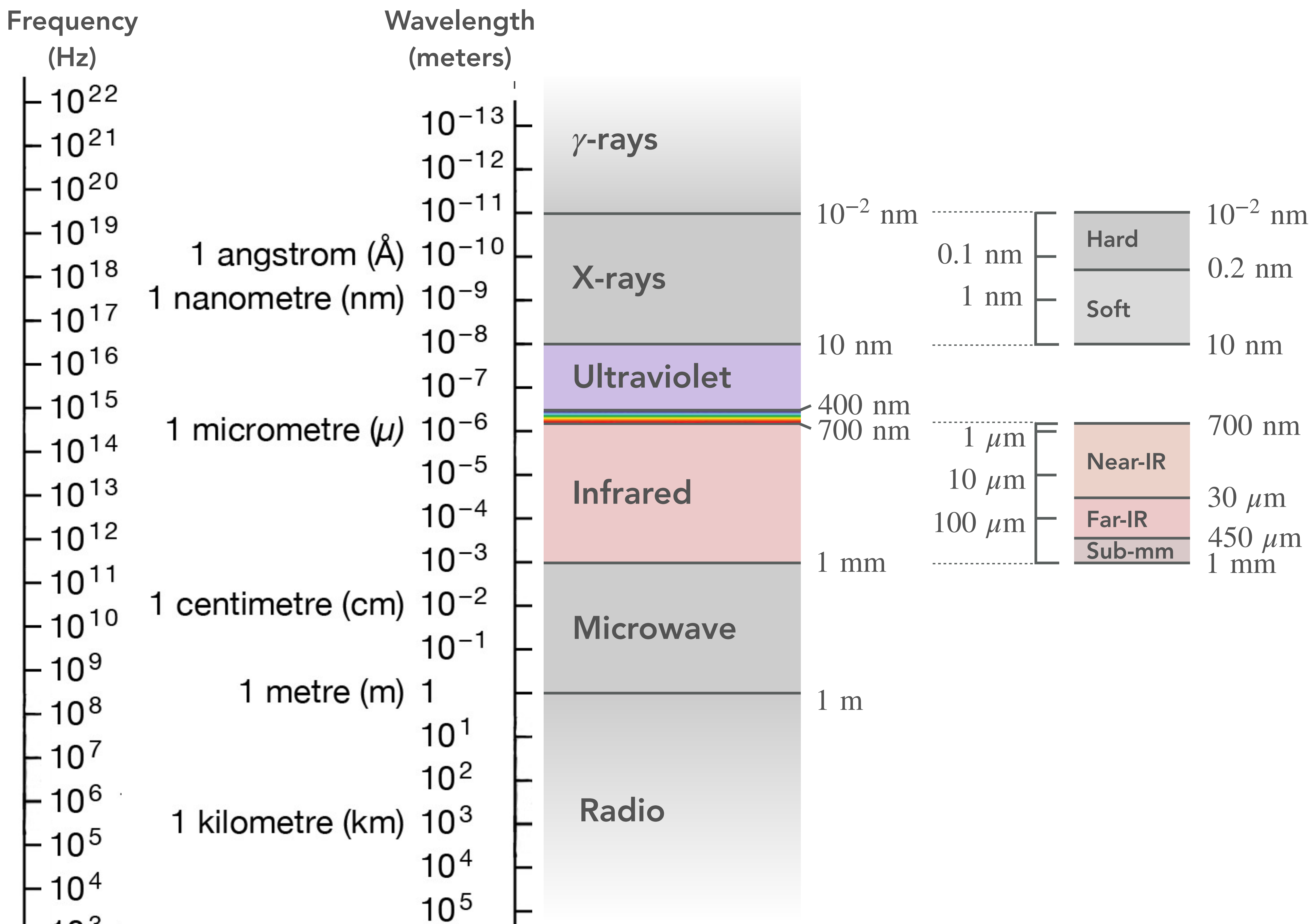
Draine §22.1

Emission spectrum

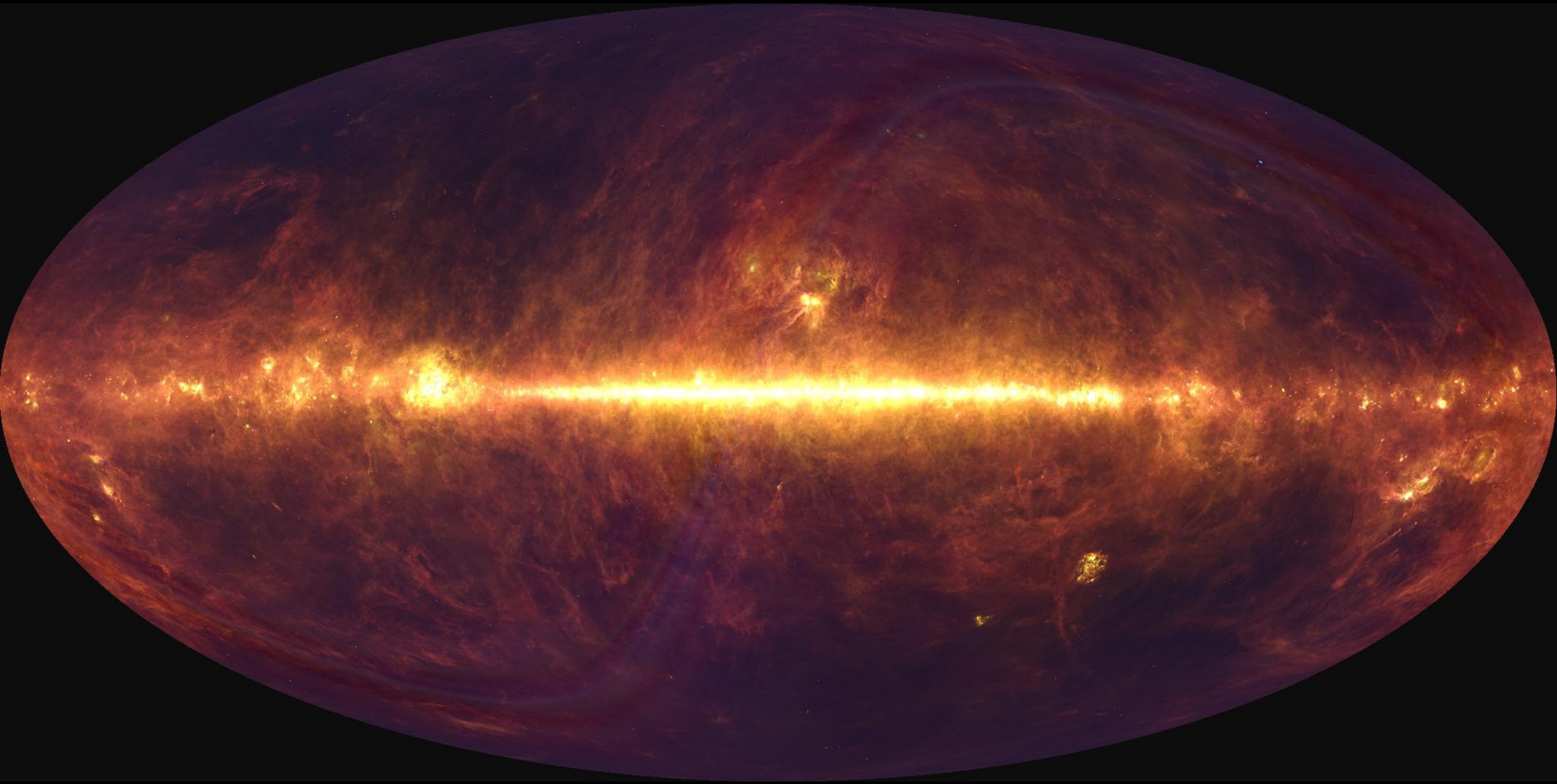


Draine §24.3

EM spectrum in astronomy

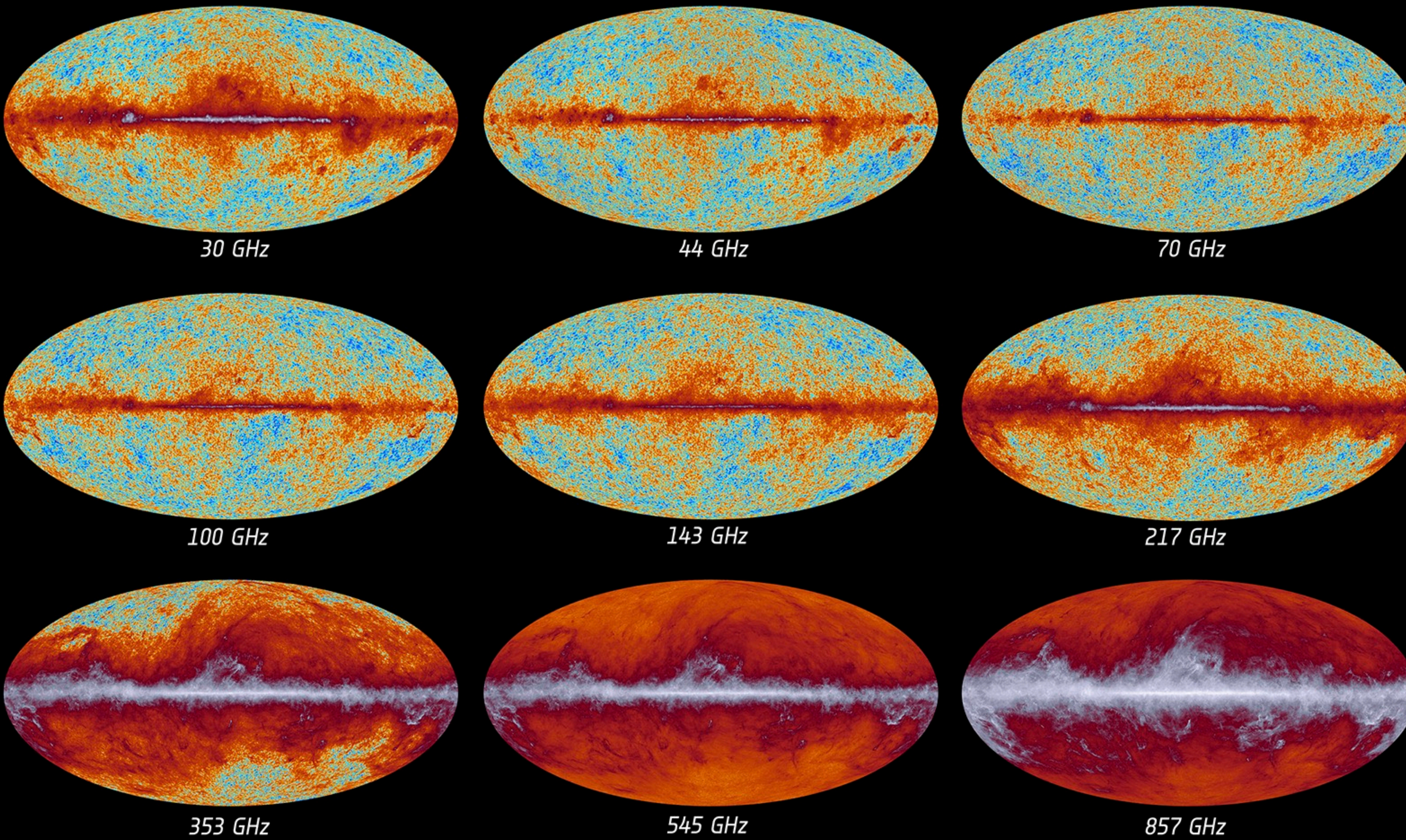


IRAS (infrared)

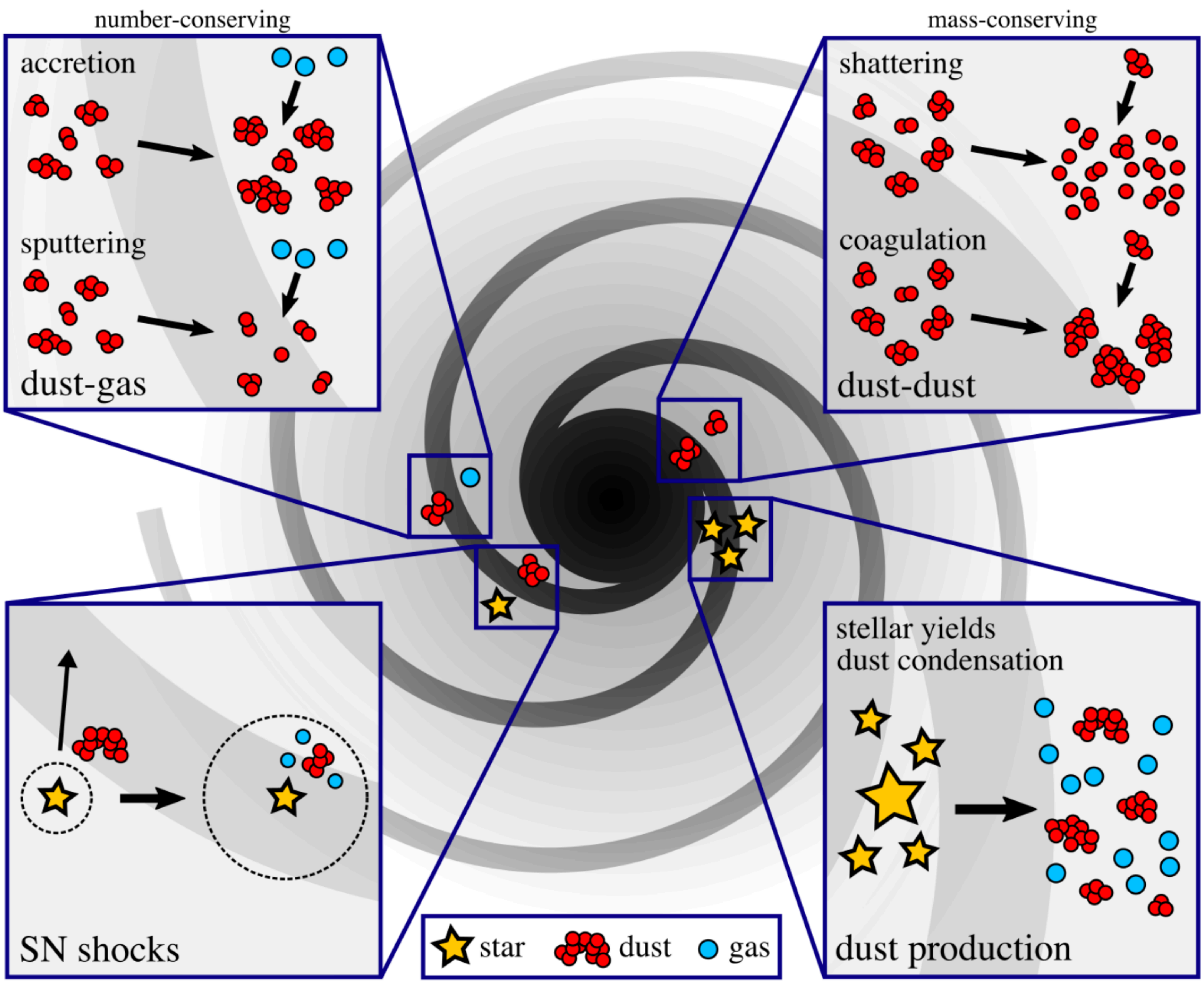


IRAS satellite

Planck (microwave, 3.5 - 100 mm)



Planck collaboration

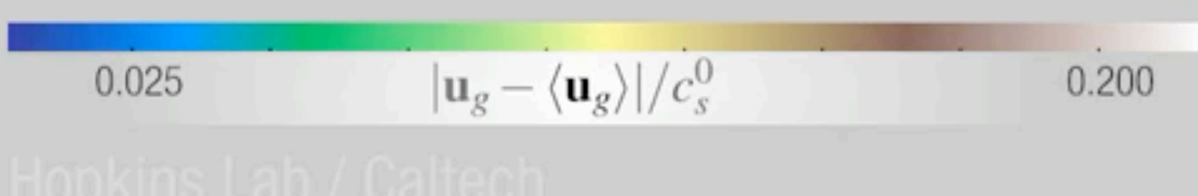


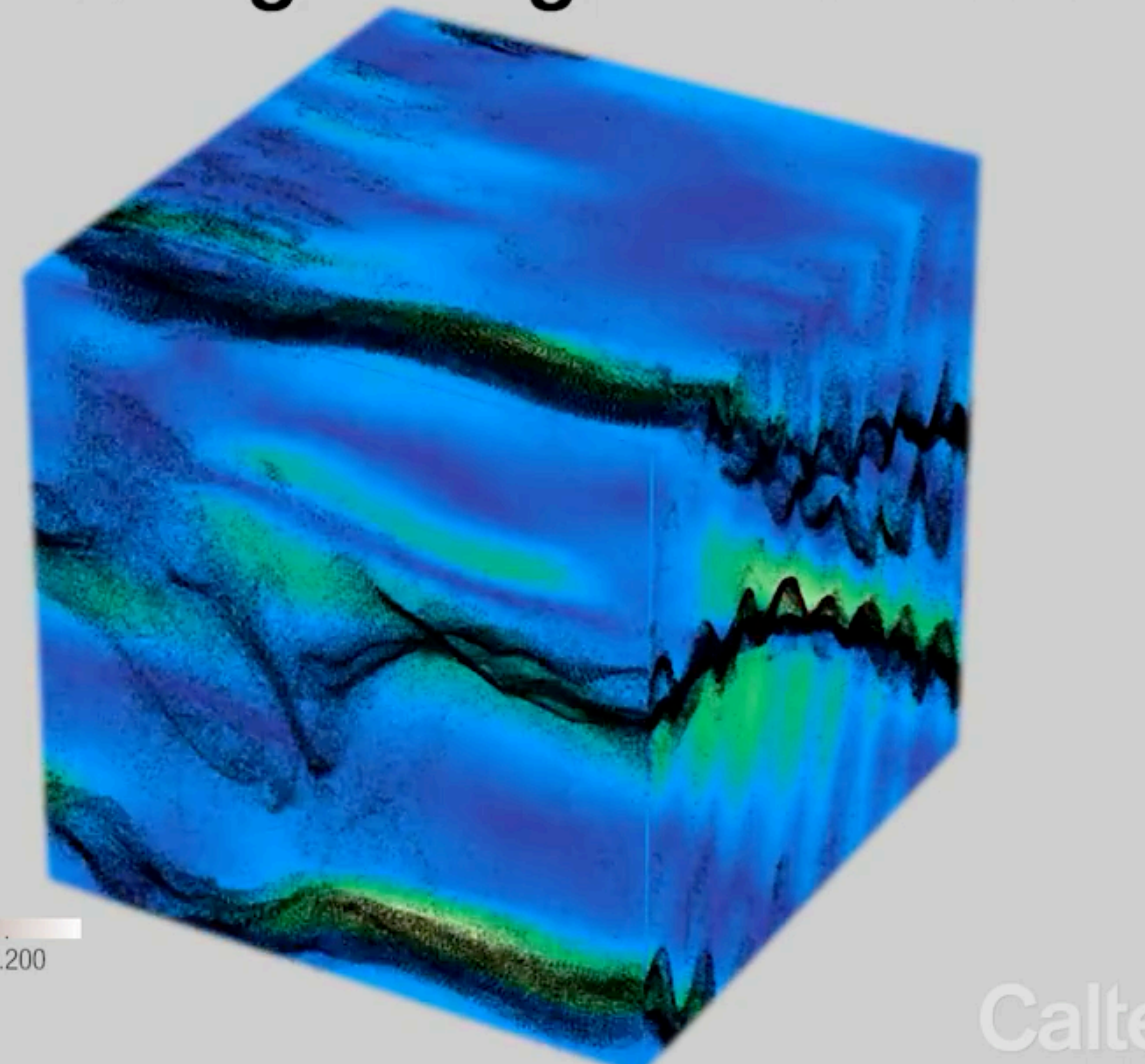
McKinnon et al. 2018

Dust Moving Through Magnetized Gas

BLACK DOTS
represent dust grains

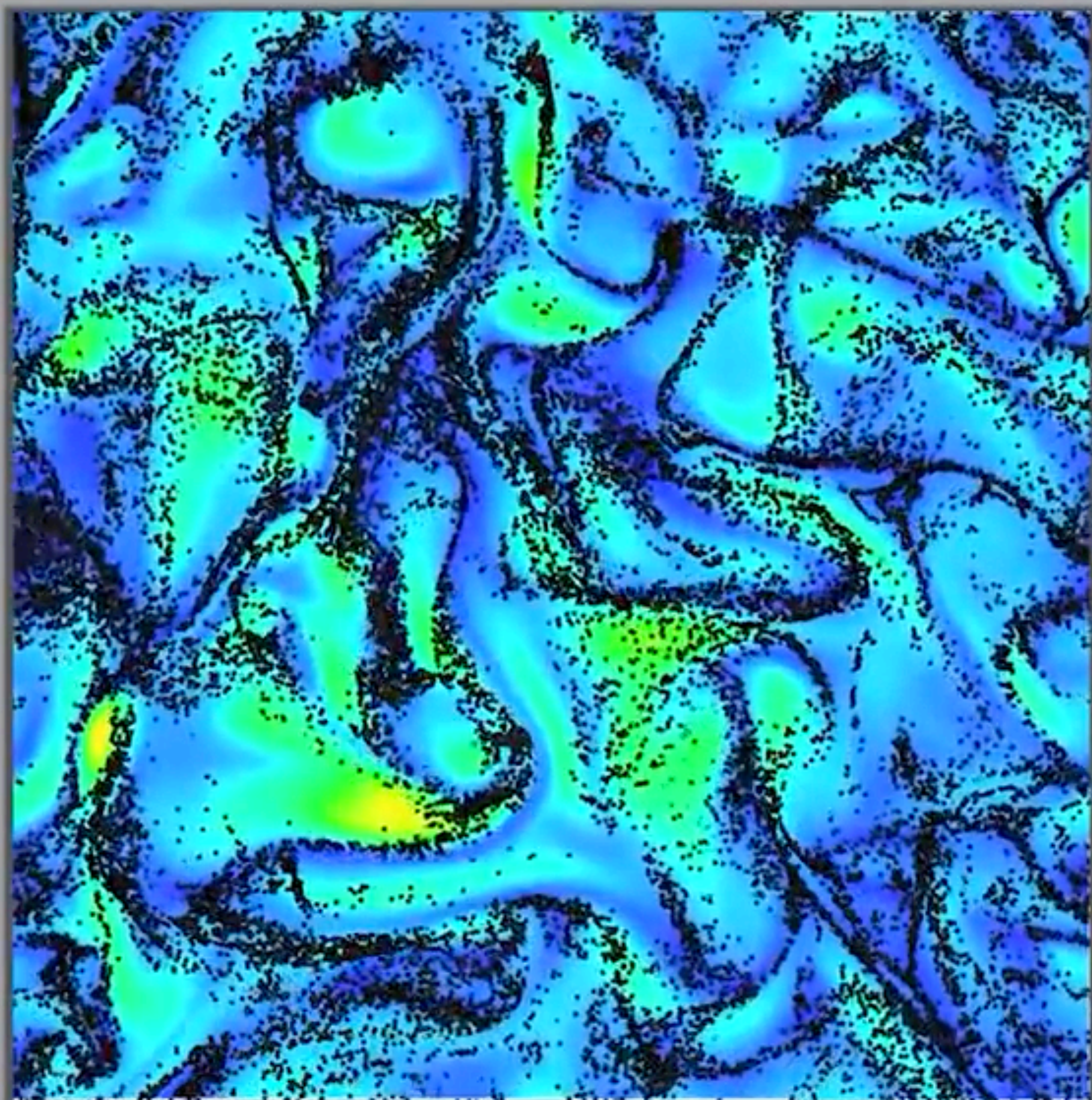
COLORS
show gas velocity
relative to mean





Hopkins Group / CalTech (video page)

Dust in Turbulence



BLACK DOTS
represent dust grains

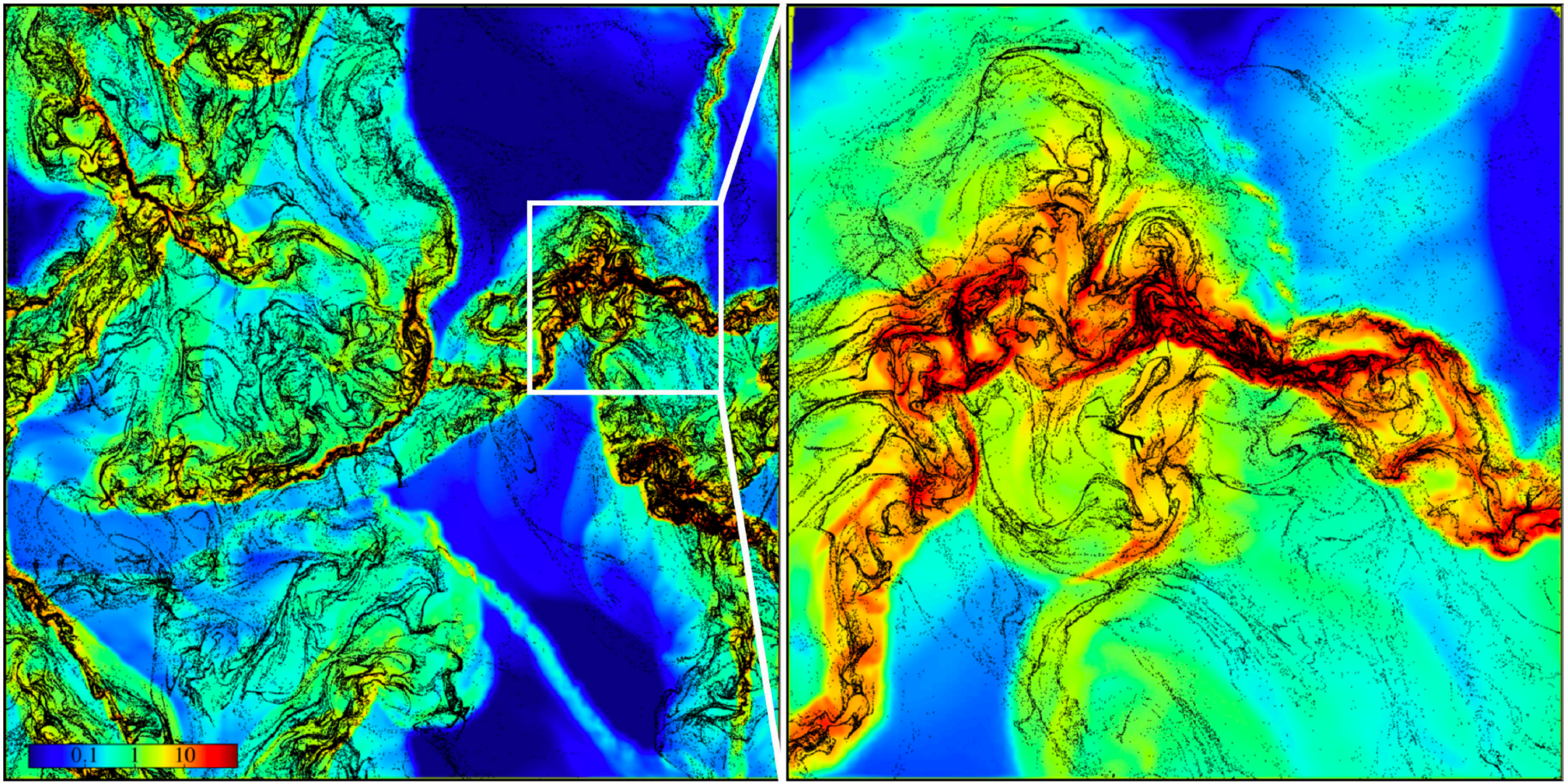
COLORS
show gas vorticity
(*spinning* or *stretching*)
yellow - higher vorticity
blue - lower vorticity

altech

Caltech

Hopkins Group / CalTech (video page)

Dust dynamics



Hopkins & Lee 2015

Reading

Draine

- §19.1-3
- §21.1
- §23.1
- §32.1, §32.9