

Physics 224

The Interstellar Medium

Lecture #2

- Part I: Overview of Milky Way's ISM
- Part II: Collisional Processes
- Part III: Statistical Mechanics

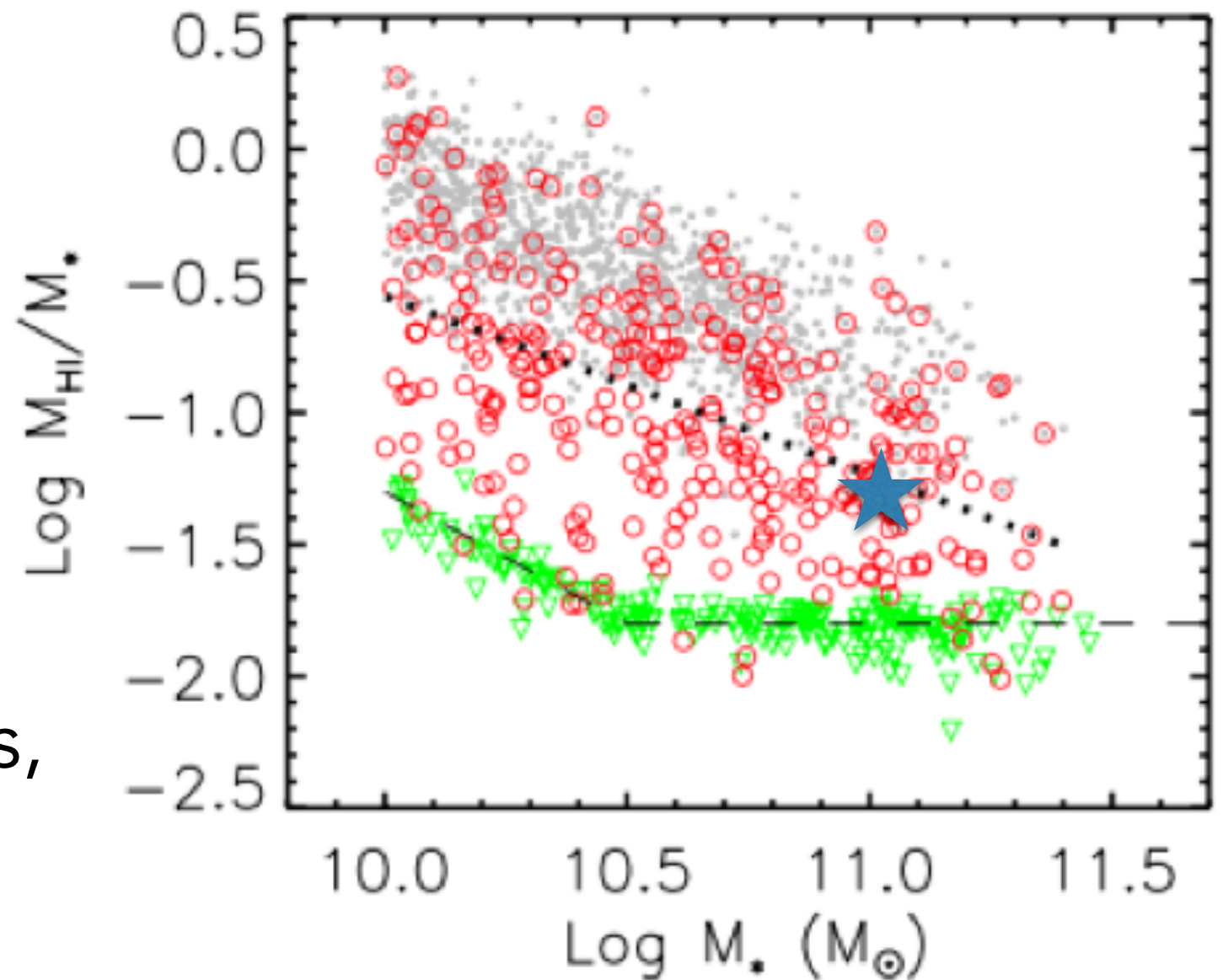
The Milky Way

Dark Matter: $\sim 10^{12} M_{\odot}$

Stellar Mass: $\sim 10^{11} M_{\odot}$

ISM Mass: $\sim 6 \times 10^9 M_{\odot}$

Not the same in all galaxies,
some have different ISM/
stellar mass ratios.



GASS Survey
(Catinella et al. 2012)

The Contents of the ISM

- Gas
- Dust
- Photons
- Cosmic Rays
- Magnetic Fields

Note: ISM resides in the gravitational potential set by dark matter and stellar mass of a galaxy (sometimes gas mass matters too).

ISM Gas

in MW, approx. 23% ionized, 60% neutral, 17% molecular

Name	T (K)	Ionization	frac of volume	density (cm ⁻³)	P ~ nT (cm ⁻³ K)
hot ionized medium	10 ⁶	H ⁺	0.5(?)	0.004	4000
ionized gas (HII & WIM)	10 ⁴	H ⁺	0.1	0.2-10 ⁴	2000 - 10 ⁸
warm neutral medium	5000	H ⁰	0.4	0.6	3000
cold neutral medium	100	H ⁰	0.01	30	3000
diffuse molecular	50	H ₂	0.001	100	5000
dense molecular	10-50	H ₂	10 ⁻⁴	10 ³ -10 ⁶	10 ⁵ - 10 ⁷

ISM Dust

Gas & dust are well correlated in the disk of the Milky Way,
but gas/dust ratio can & does vary.

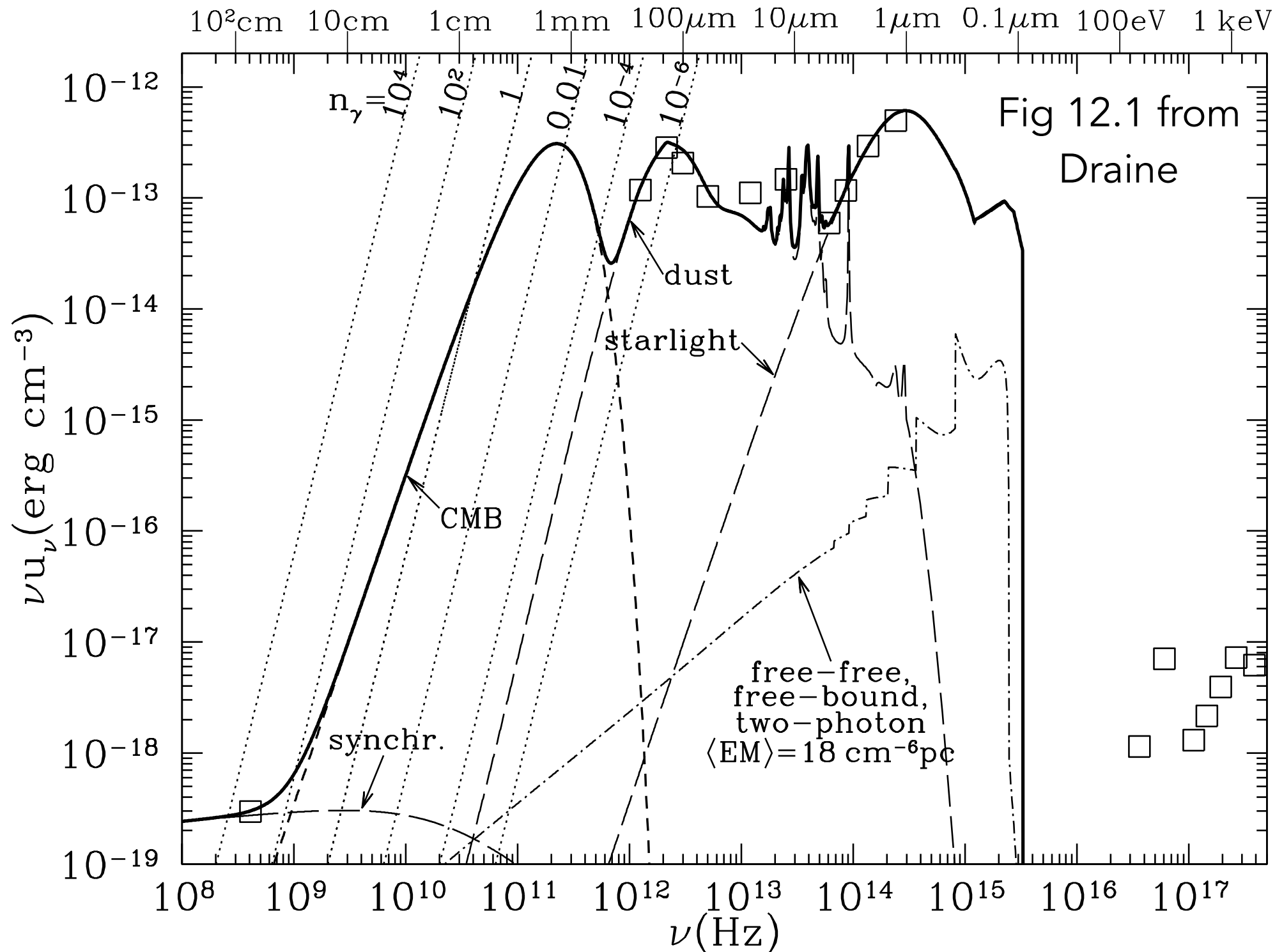
Element	Abundance	<i>A</i>	<i>M/M_H</i>
C	$0.6 \times 4.0 \times 10^{-4}$	12	0.0029
Mg	4.0×10^{-5}	24	0.0010
Fe	3.4×10^{-5}	56	0.0019
Si	3.8×10^{-5}	28	0.0011
O	$0.2 \times 8.0 \times 10^{-4}$	16	0.0022
Total			0.009

Dust is mainly composed
of C, Mg, Fe, Si, and O.

MW Dust-to-H Ratio
 ~ 0.009

Small sub- μm size grains
(can tell from reddening)

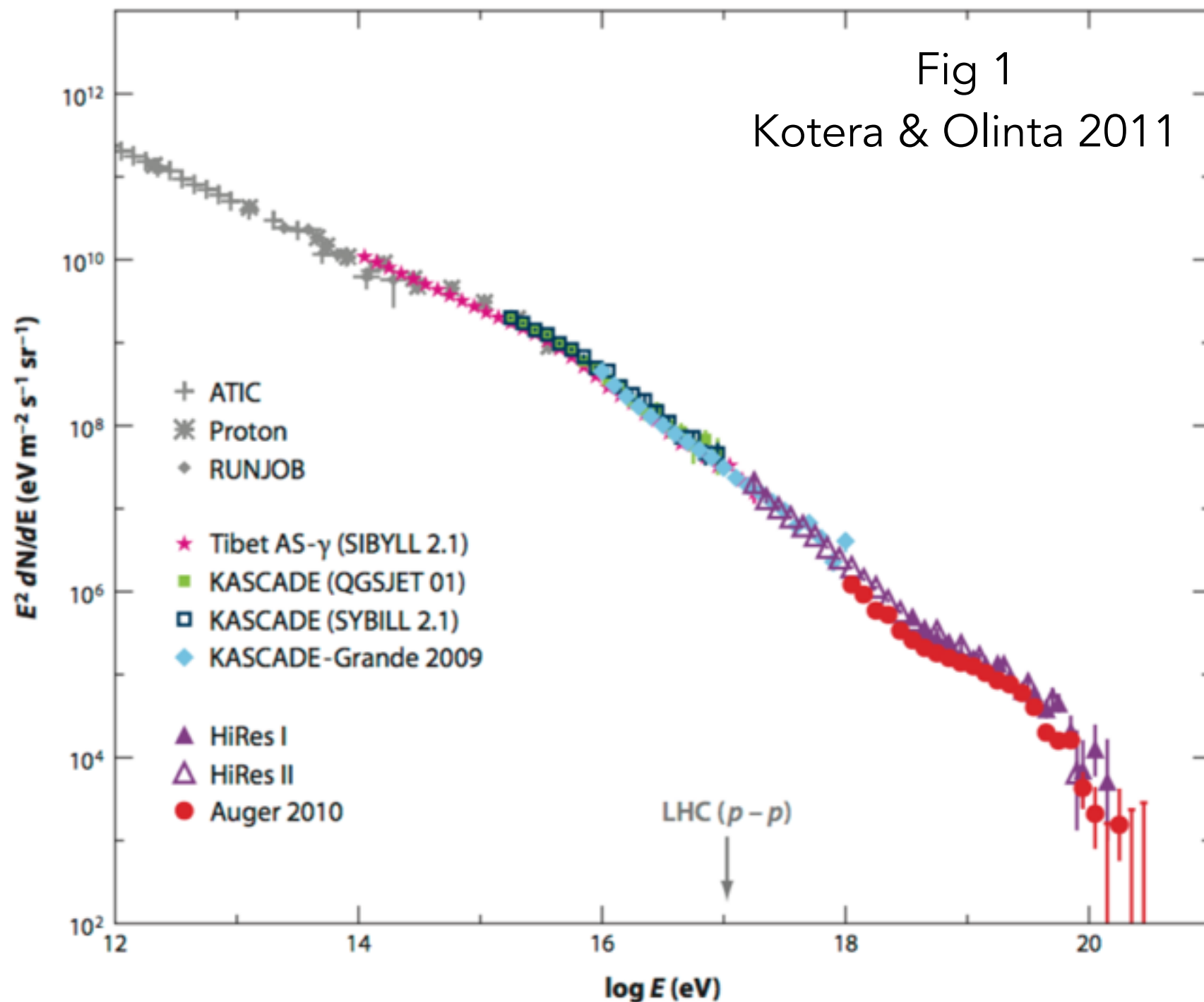
ISM Radiation Field



Average
Interstellar
Radiation
Field

varies from
place to place
depending on
local processes

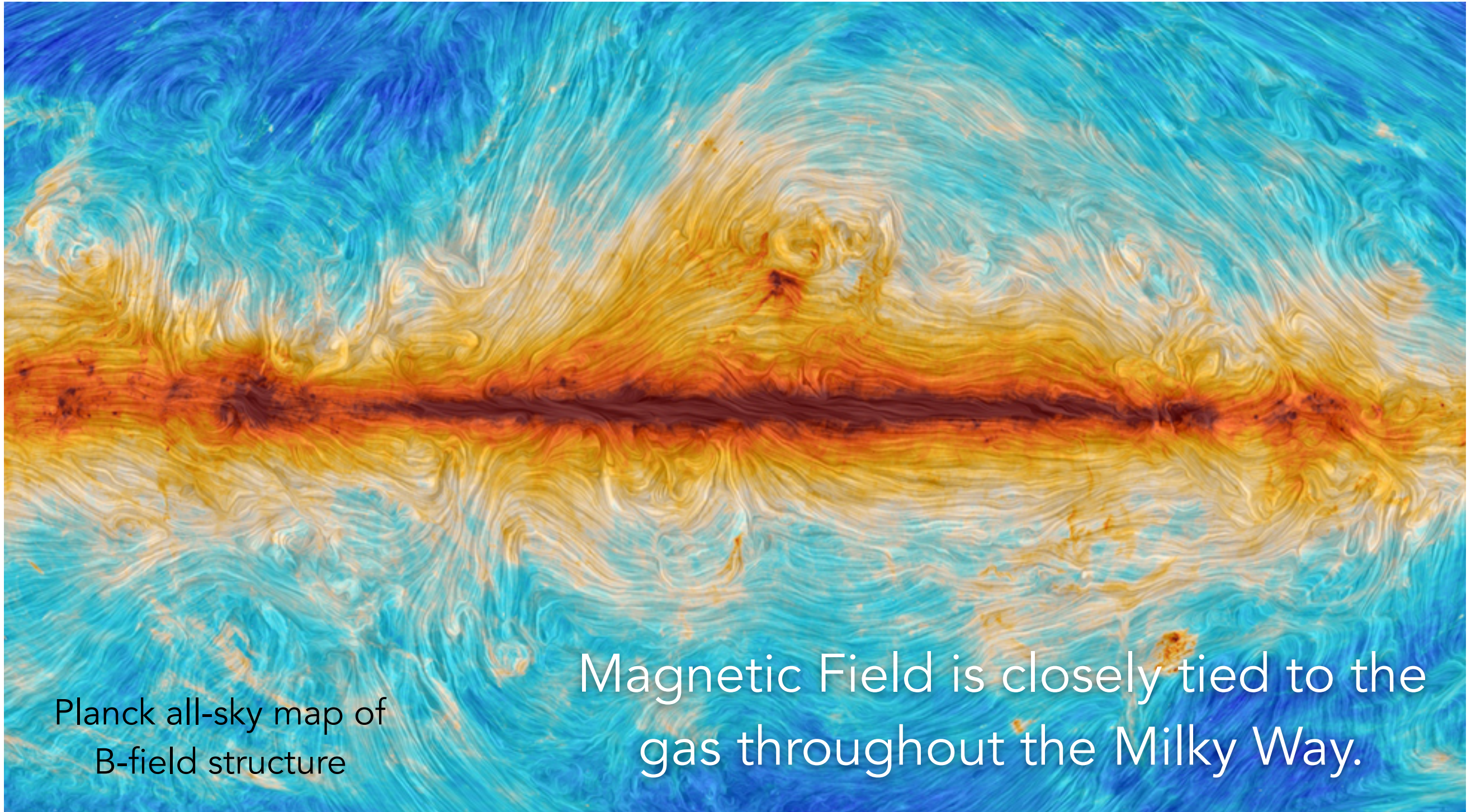
Cosmic Rays



Very energetic particles pervading the ISM.

Dominated by protons, but also includes other nuclei and e^- .

Magnetic Fields



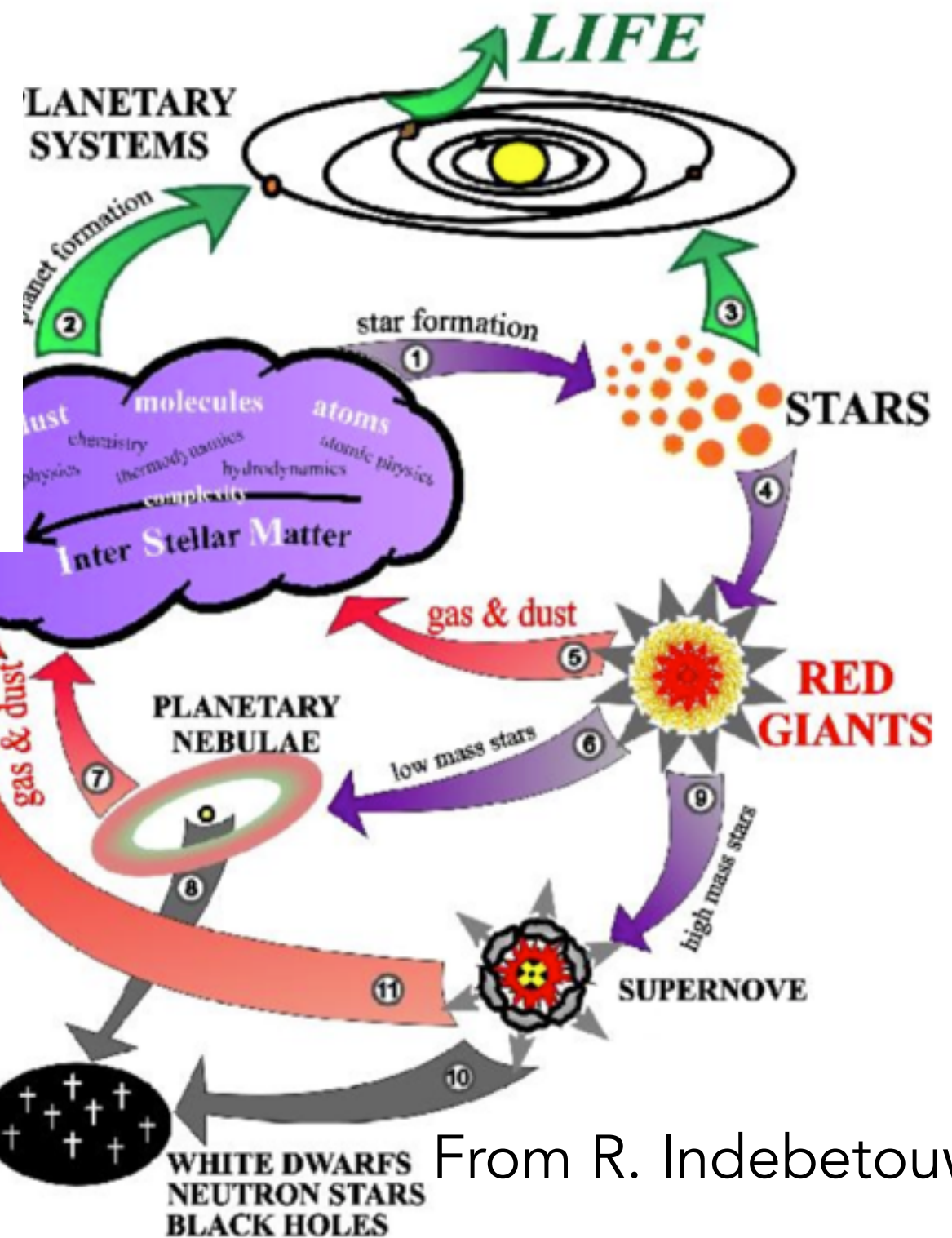
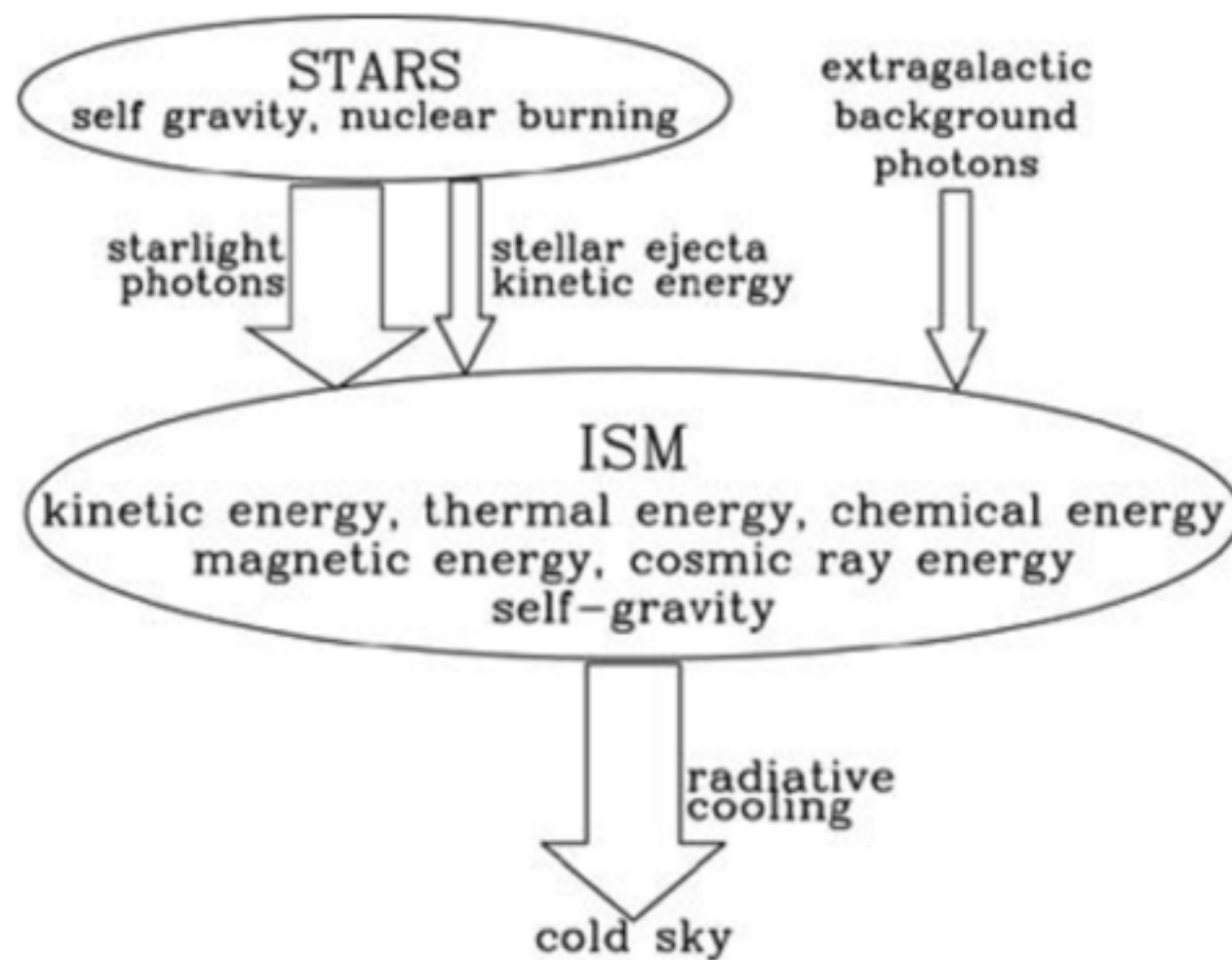
ISM Energy Density

Component	u (eV cm ⁻³)
Cosmic Microwave Background	0.25 ($T_{\text{CMB}} = 2.725$ K)
Gas Thermal Energy	0.49 (for $nT = 3800$ cm ⁻³ K)
Gas Turbulent Kinetic Energy	0.22 (for $n = 1$ cm ⁻³ , $v_{\text{turb}} = 1$ km/s)
B-Field	0.89 (for 6 μ Gauss)
Cosmic Rays	1.39 (see Draine ch 13)
Starlight	0.54 (for $h\nu < 13.6$ eV)

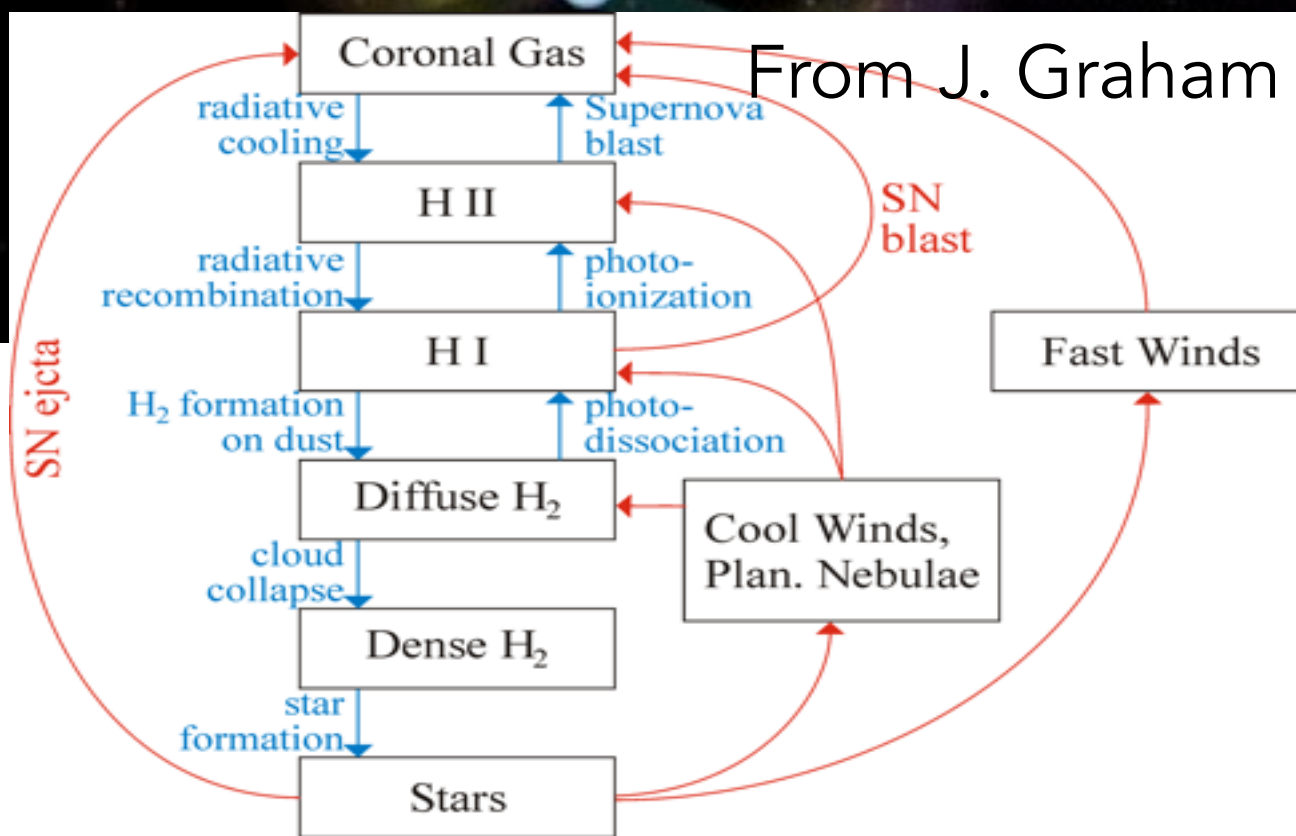
All the same order of magnitude!

The ISM is Complex


- Huge dynamic ranges in density, temperature.
- Very dense regions of the ISM are “ultra-high” vacuum
 - ISM conditions are tough to reproduce in a lab.
- Most processes are not in thermodynamic equilibrium
 - low density means long equilibrium timescales.
- Processes are interconnected in feedback loops.



From J. Graham



From R. Indebetouw

How does THIS affect THIS 	Gravitational Potential	Gas	Dust	Radiation Field	Cosmic Rays	Magnetic Fields	Stars
Gravitational Potential	————	hydrostatic pressure, dynamics, spiral arms, large scale gas stability	2nd order	2nd order	pressure confinement, dynamical influence (e.g. spiral arms)	gas dynamics, pressure arrange B-field	sets stellar mass distribution, 2nd order hydrostatic pressure -> SF
Gas	self-gravity in dense gas clouds	gas dynamics, collisional excitation, self gravity	dust growth in dense gas, collisional heating/cooling, charging, dust destruction in shocks	alters radiation field (H2 shielding, ionizing photons absorbed)	creation (shocks accelerate), collisions (CR + p+ -> γ ray), confinement (B-field)	dynamically, MHD turbulence, dynamos create/ amplify B-field	star formation
Dust	2nd order	heating/cooling gas, shielding, chemistry, metal abundance (grain sputtering)	grain-grain collisions, shielding small grains from UV	extinction (absorption & scattering)	2nd order	ionization of grains and gas, keeps B-field tied to gas	key role in SF
Radiation Field	2nd order	heating of gas, ionization, photoelectric effect	heating dust, charging grains (PE effect), destruction of small grains	————	2nd order	ionization of gas, keeps B-field tied to gas	key role in SF
Cosmic Rays	2nd order	ionization in dense gas, connection to B-field	2nd order	2nd order	————	tied closely to B-field, equipartition?	heats dense gas that forms stars
Magnetic Fields	2nd order	dynamically, MHD turbulence	grain alignment, charged grains coupled to B-field	2nd order	tied closely to B-field, equipartition?	? reconnection & dissipation	dynamically important in collapse -> SF
Stars	large part of the overall mass that sets the grav potential	SNe/winds - dynamics, nucleosynthesis (metals), radiation field generation	create & destroy dust, generate radiation field that heats dust	directly produce it	SNe shocks -> CR	2nd order	feedback shuts off SF

Collisions govern many key ISM processes

- Distribute energy among particles in the gas (ie from e- ejected from dust by the photoelectric effect or photoionization)
- Collisional Ionization
- Recombination
- Collisional Excitation (can lead to radiative deexcitation and loss of energy from gas)
- Chemical reactions
- Gas-dust grain collisions, grain-grain collisions.
- Etc, etc, etc