Physics 224
The Interstellar Medium

Lecture #2

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

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).

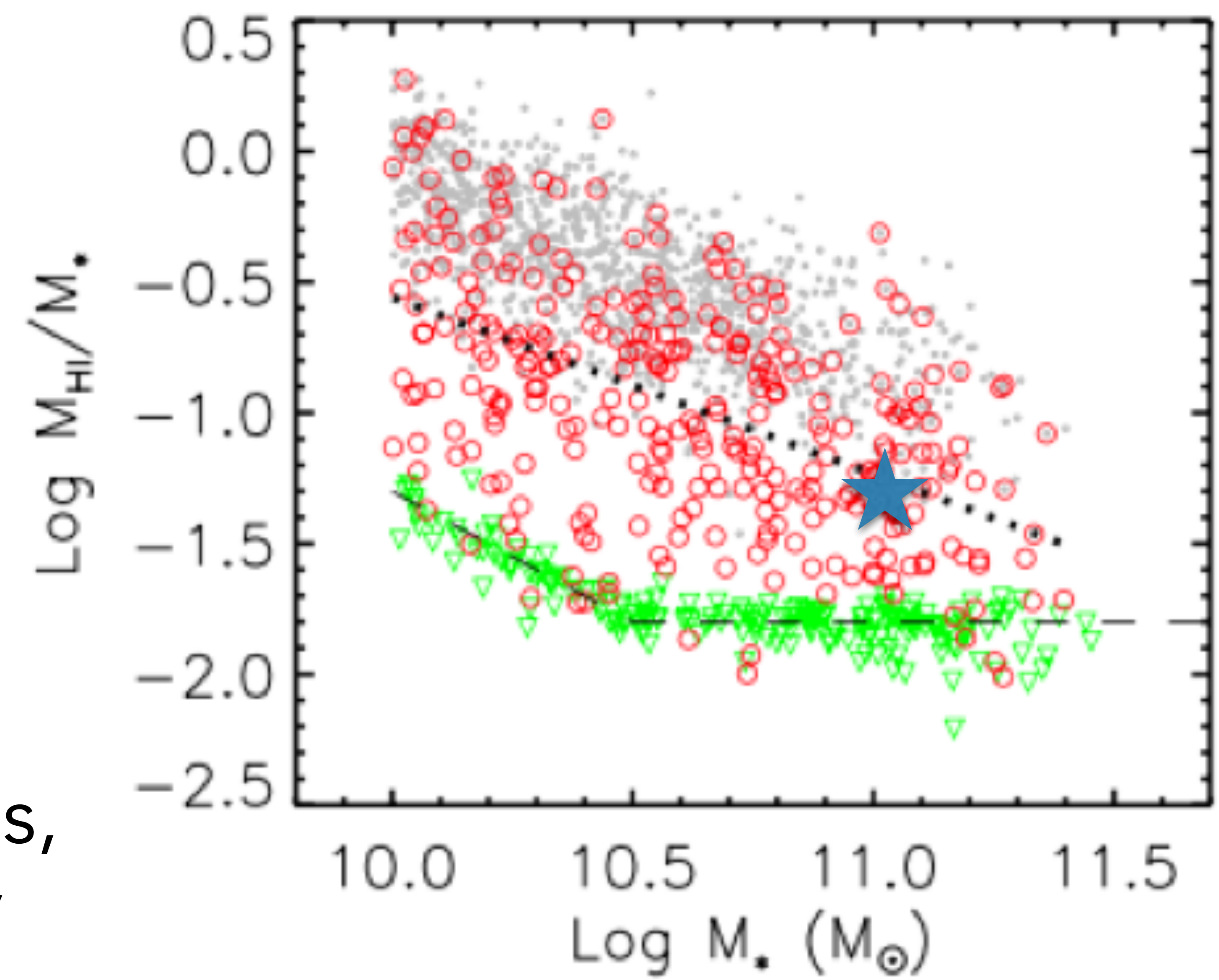
The Milky Way

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

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

ISM Mass: ~6×10^9 $M_\odot$

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



GASS Survey (Catinella et al. 2012)
gray = shallower ALFALFA survey
red = HI detected, green = not detected

ISM Gas

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

characterized by "phases"

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	*A*	M/M_H
C*	2×10^{-4}	12	0.00252
O*	1.5×10^{-4}	16	0.00246
Fe	3.5×10^{-5}	56	0.00196
Si	3.4×10^{-5}	28	0.00095
Mg	4×10^{-5}	24	0.00094
N,Al,S,Ca, Ni			0.00027
Total			**0.0091**

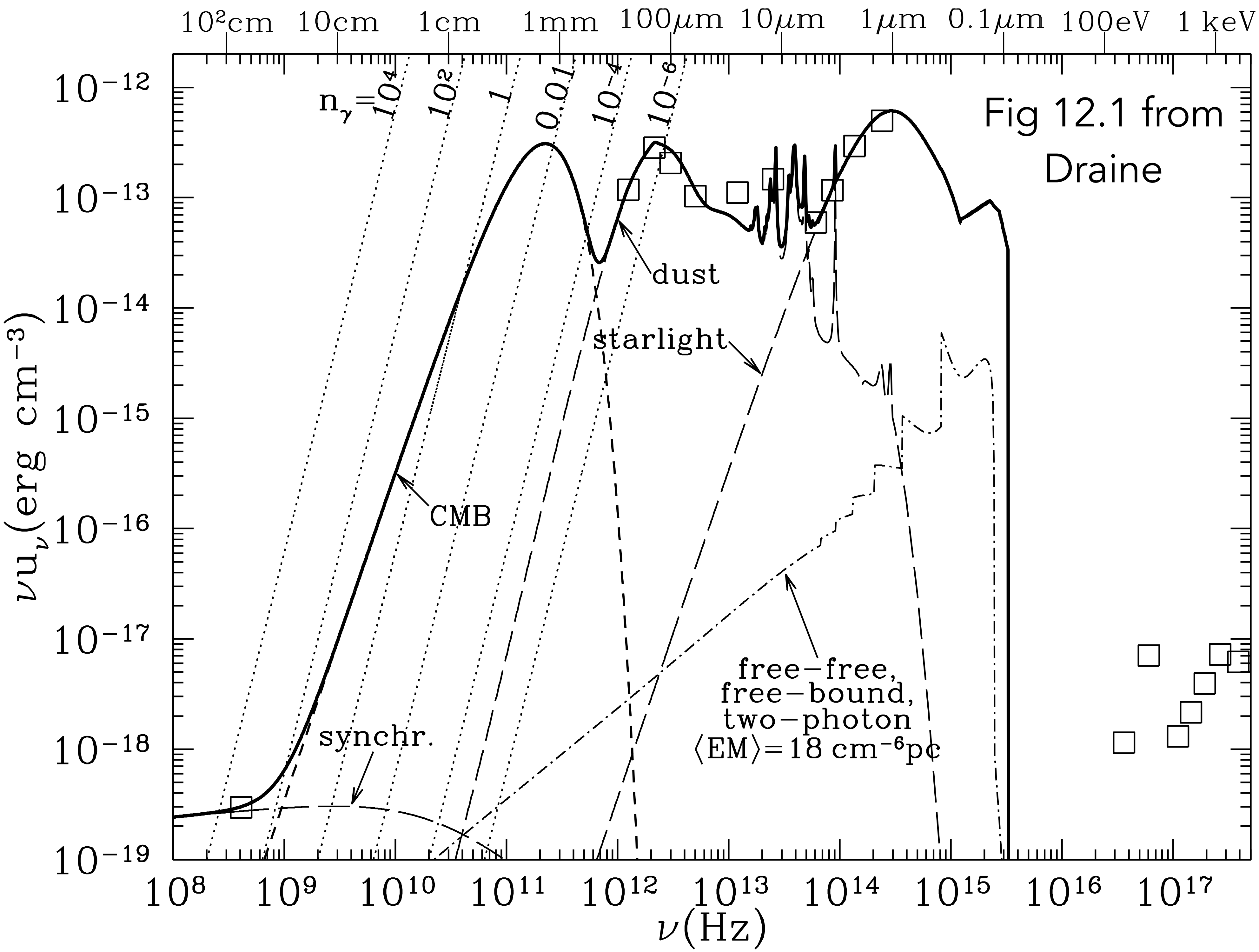
* uncertainty on oxygen depletion and carbon oscillator strength - see Draine

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

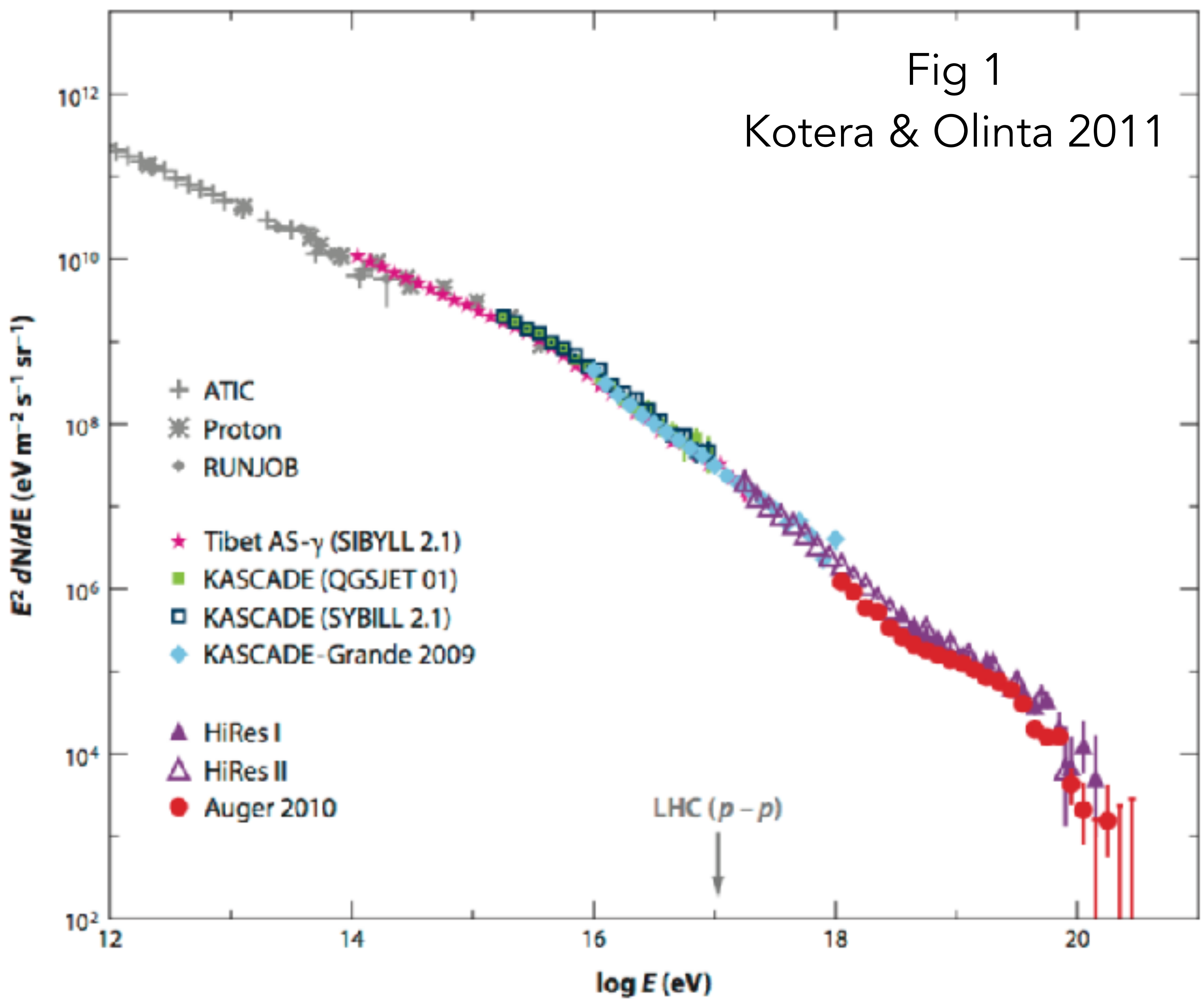
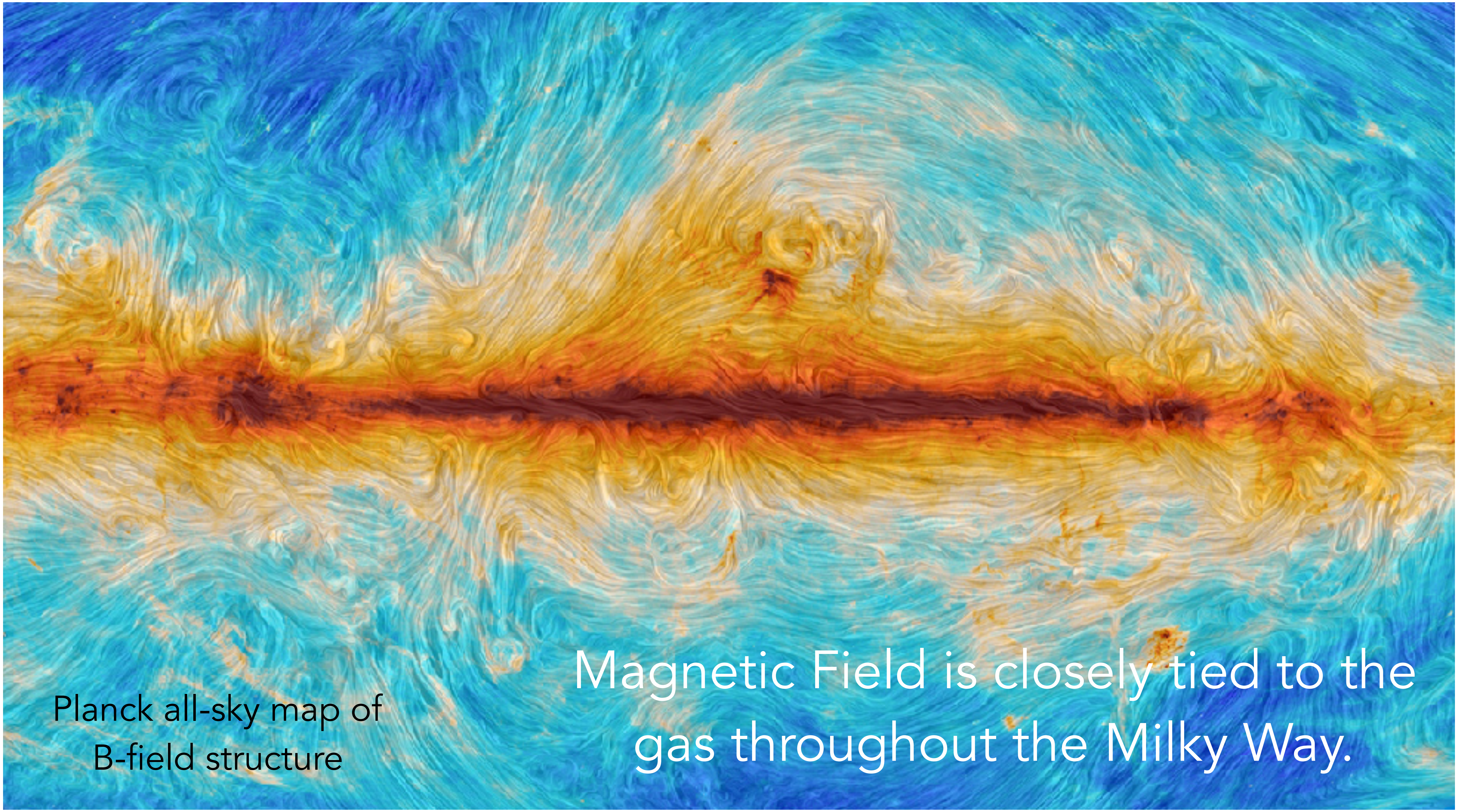


Fig 1
Kotera & Olinta 2011

Very energetic particles pervading the ISM.

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

Magnetic Fields



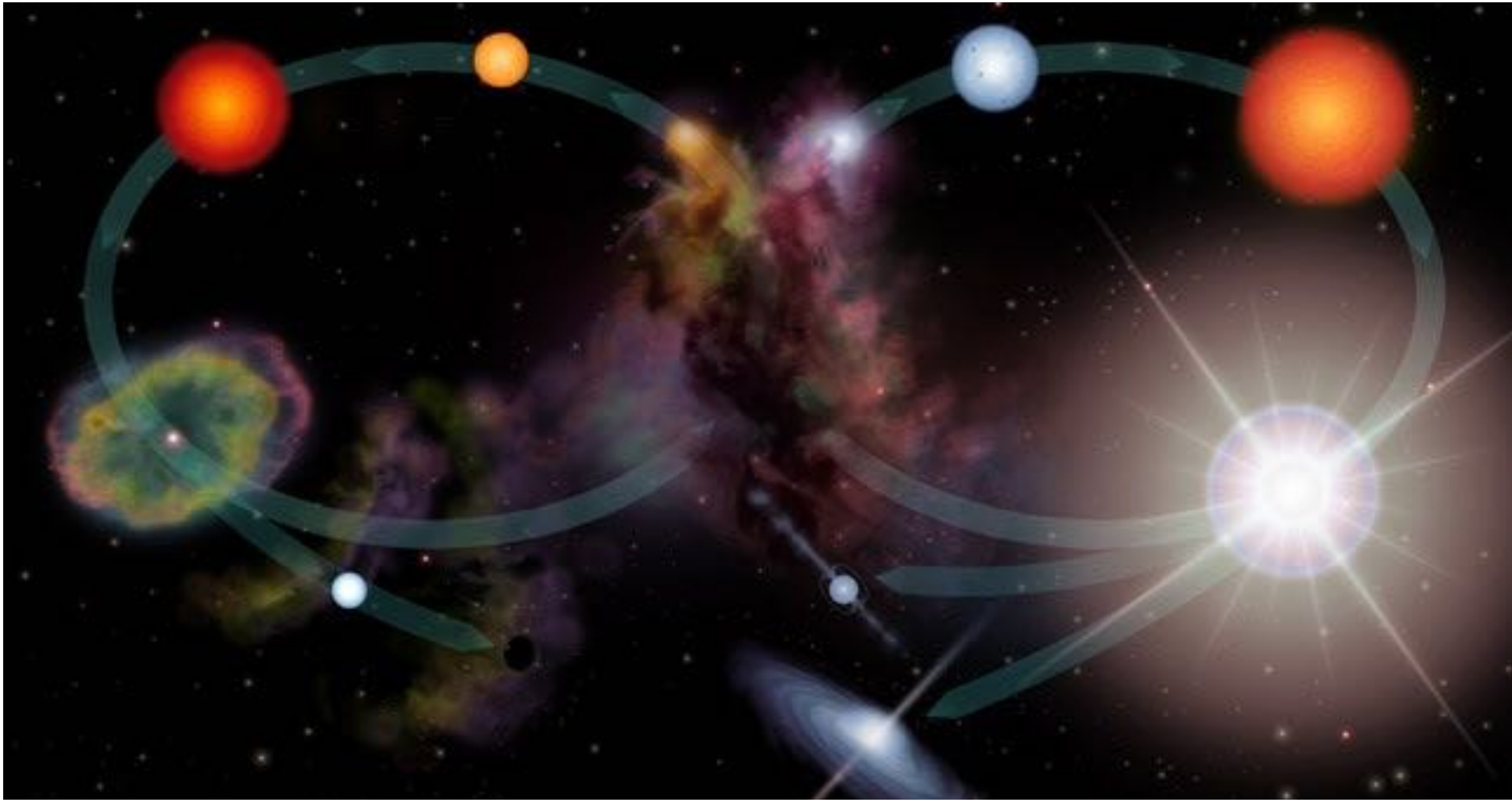
ISM Energy Density

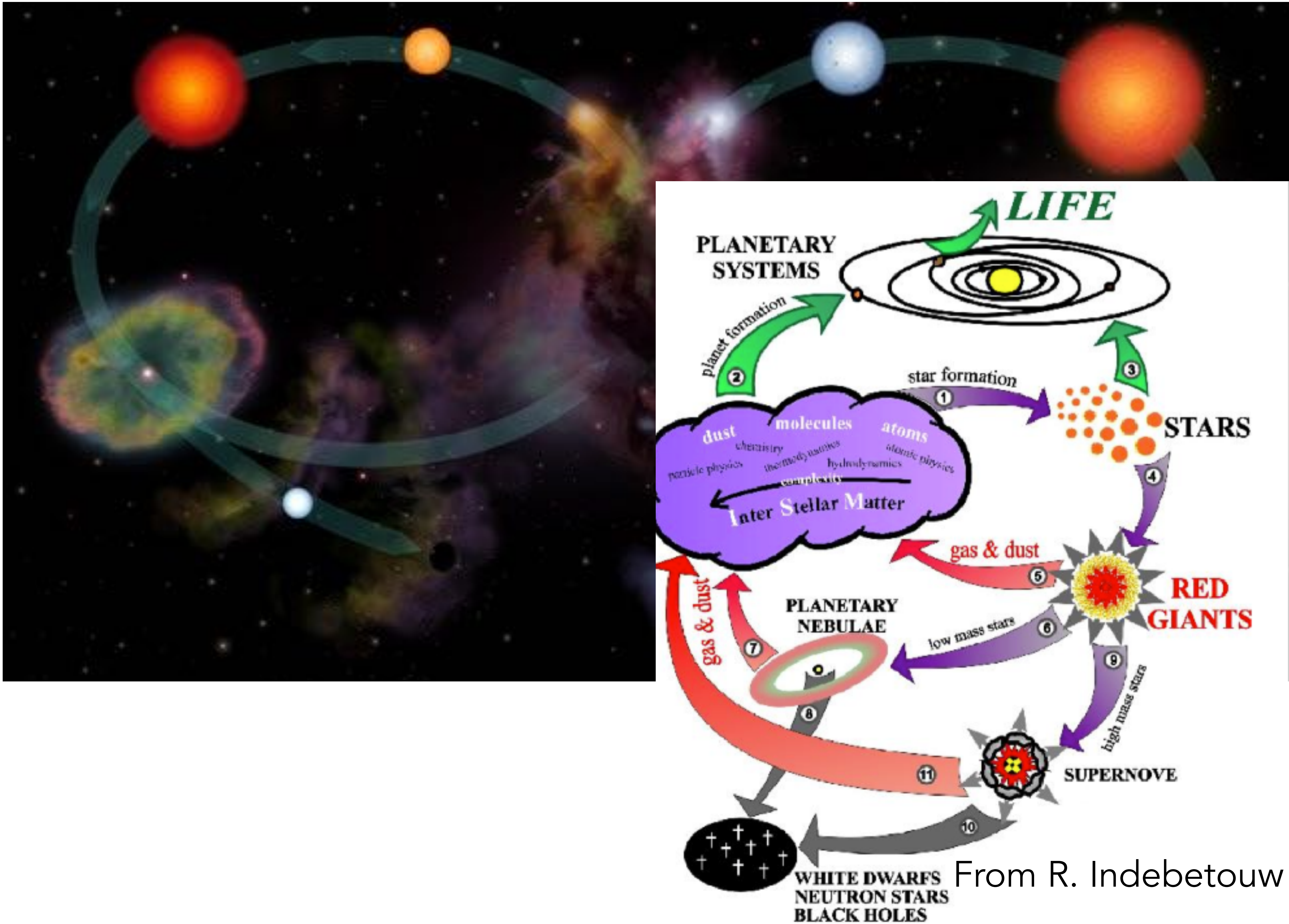
Component	***u* (eV cm^{-3})**
Cosmic Microwave Background	0.25 (T_{CMB} = 2.725 K)
Gas Thermal Energy	0.49 (for nT = 3800 cm^{-3} K)
Gas Turbulent Kinetic Energy	0.22 (for n = 1 cm^{-3}, v_{turb} = 1 km/s)
B-Field	0.89 (for 6 μGauss)
Cosmic Rays	1.39 (see Draine ch 13)
Starlight	0.54 (for hν < 13.6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

All the same order of magnitude! - Why?

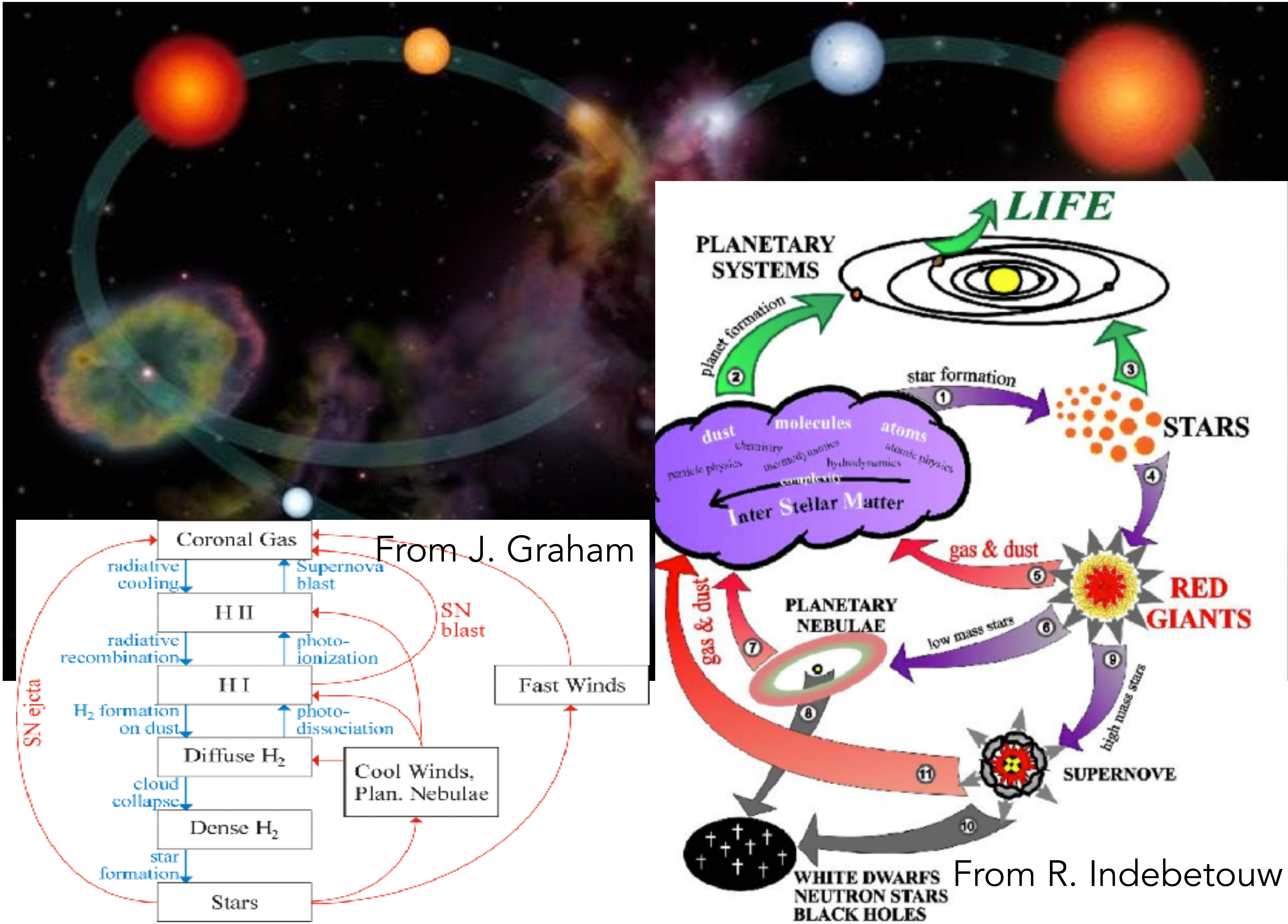
The ISM is Complex

- 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 R. Indebetouw



From J. Graham

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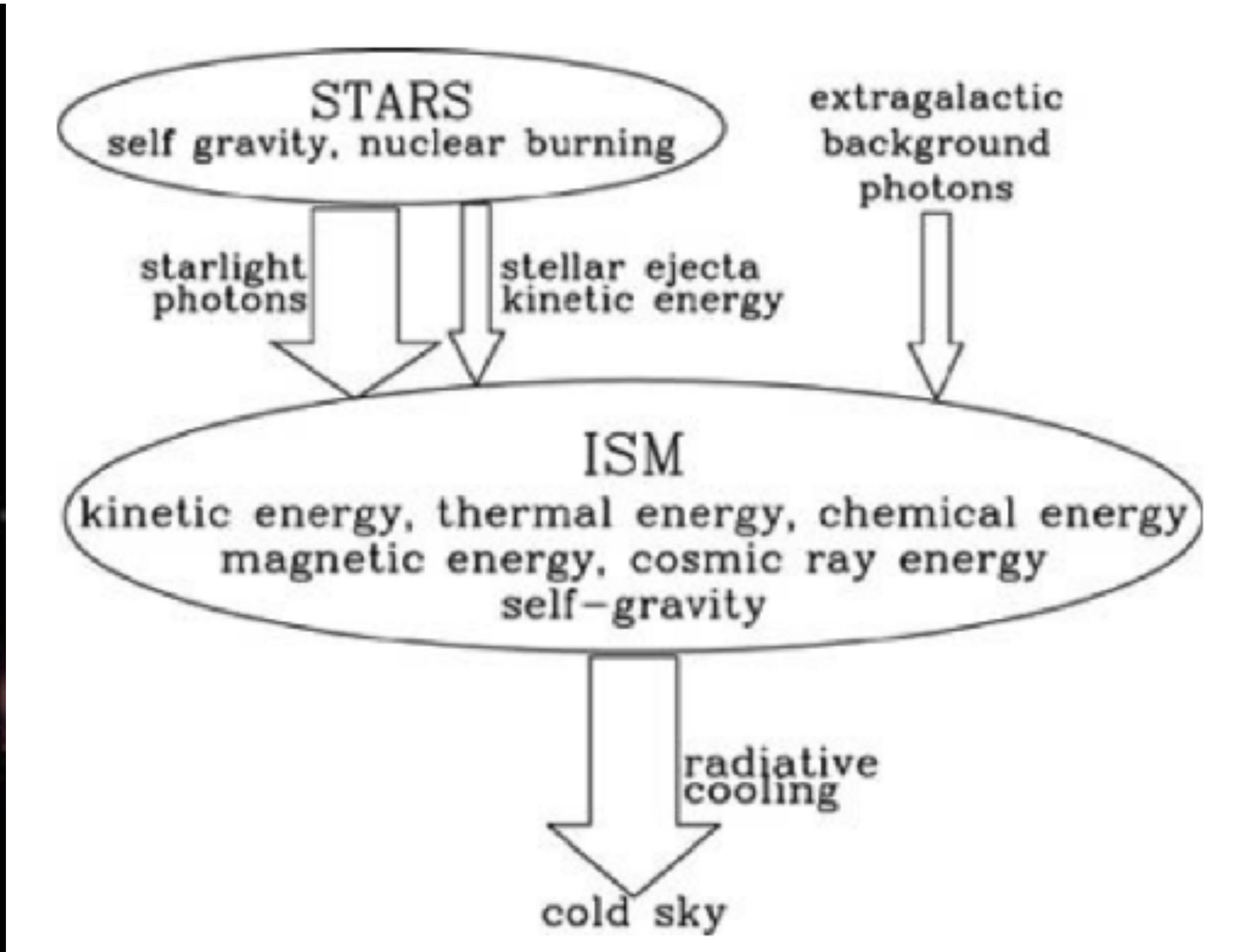

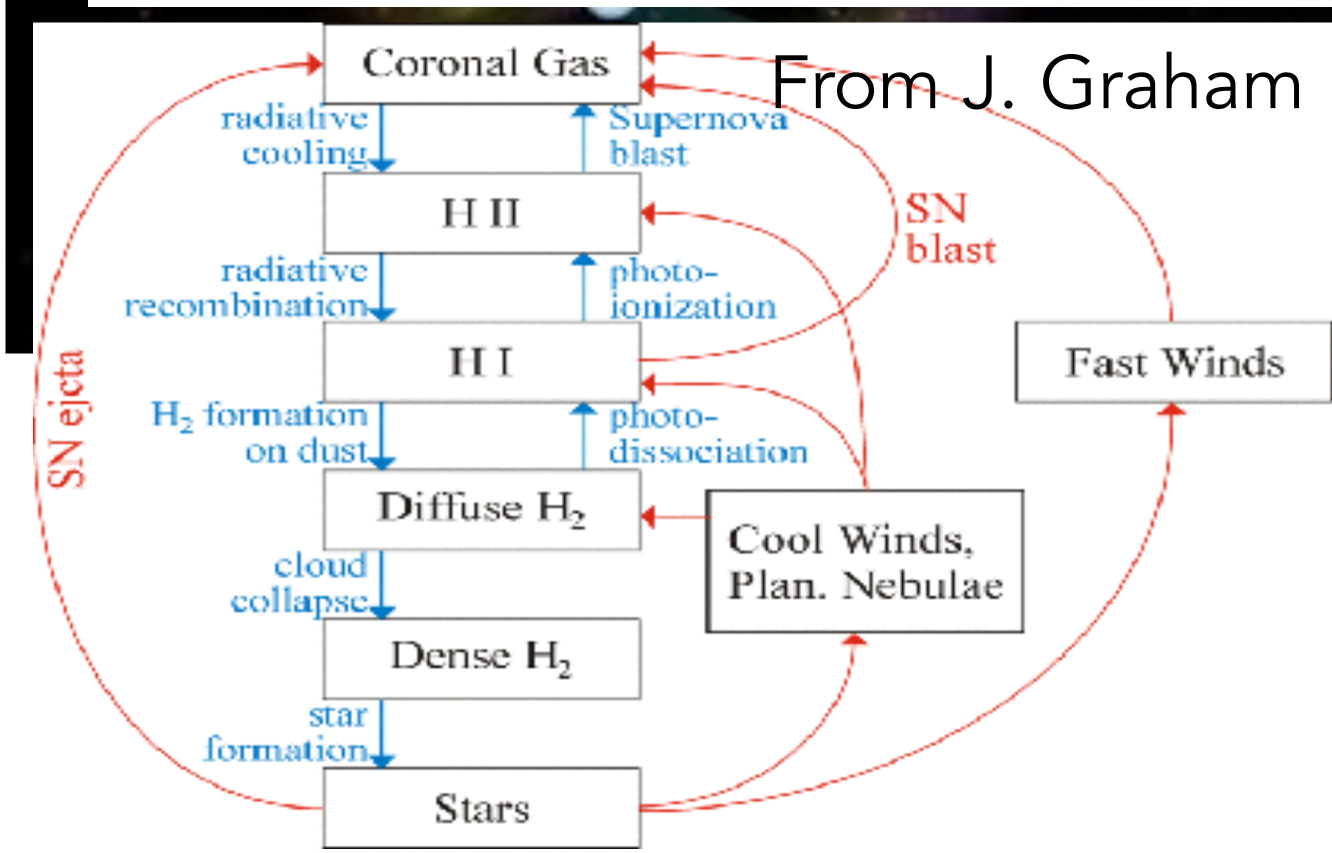

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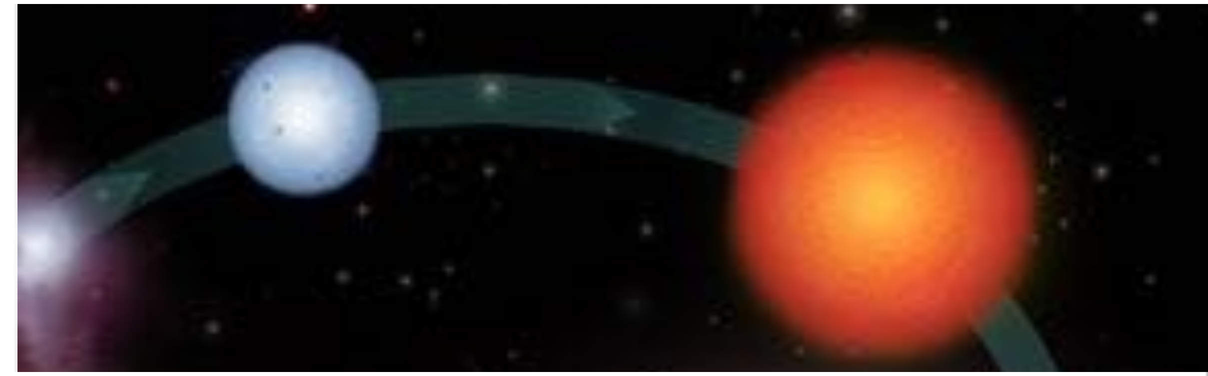

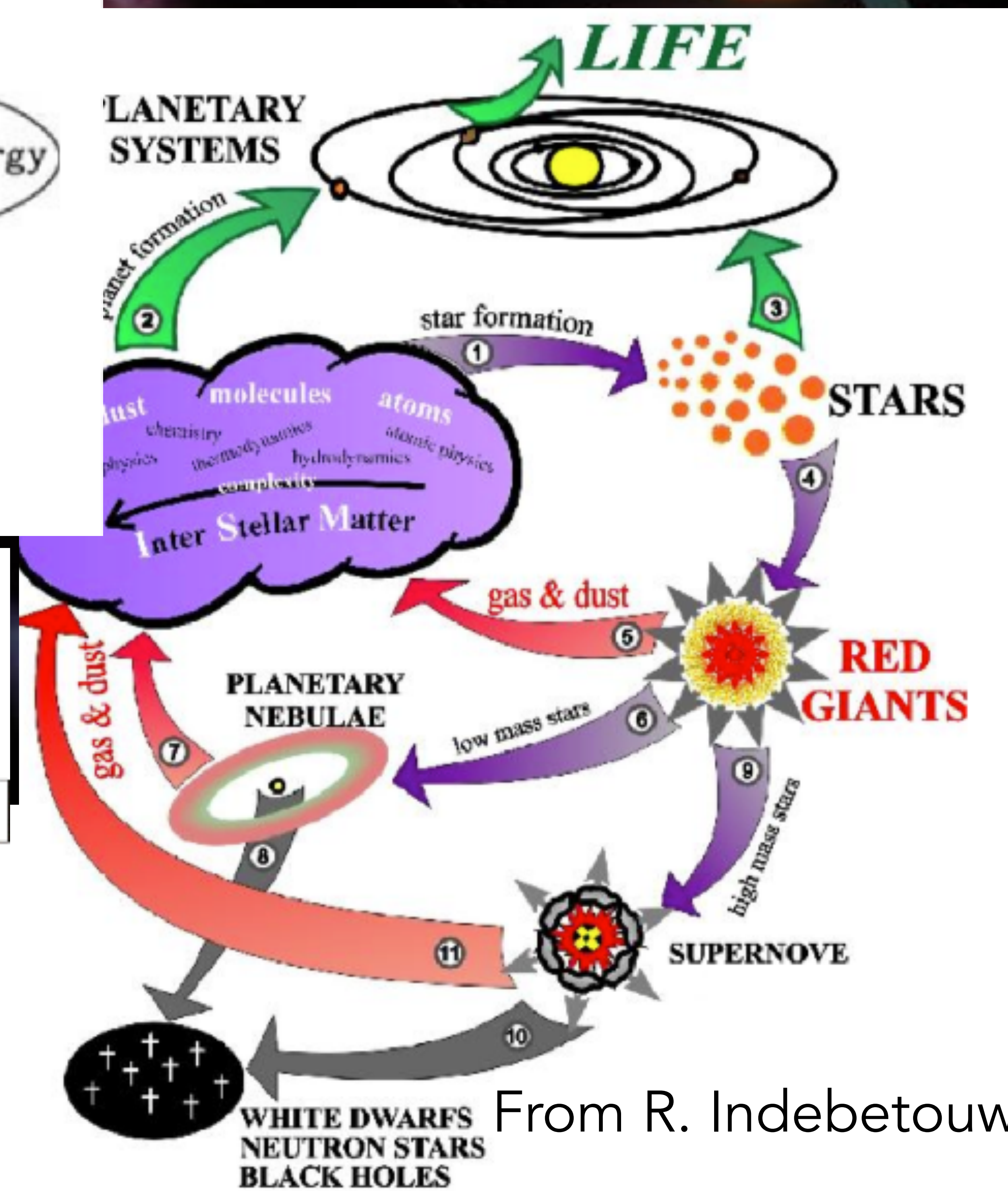

From R. Indebetouw

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 (H_2 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