Sternentstehung - Star Formation

Winter term 2024/2025

Henrik Beuther, Thomas Henning & Caroline Gieser

15.10	**Today: Introduction & Overview**	**(Beuther)**
22.10	Physical processes I	(Beuther)
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05.11	Physcial processes II	(Beuther)
12.11	Molecular clouds as birth places of stars	(Beuther)
19.11	Molecular clouds (cont.), Jeans Analysis	(Henning)
26.11	Collapse models I	(Beuther)
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10.12	Protostellar evolution	(Gieser)
17.12	Pre-main sequence evolution & outflows/jets	(Henning)
07.01	Accretion disks I	(Henning)
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21.01	High-mass star formation, clusters and the IMF	(Gieser)
28.01	Extragalactic star formation	(Henning)
04.02	Planetarium@HdA, outlook, questions	
11.02	Examination week, no star formation lecture	(Beuther, Gieser, Henning)

Book: Stahler & Palla: The Formation of Stars, Wileys

More Information and the current lecture files: http://www.mpia.de/homes/beuther/lecture_ws2425.html

beuther@mpia.de, henning@mpia.de , gieser@mpia.de

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Webpage

Sternentstehung - Star Formation

Lecture in winter term 2024/2025, 2SWS

Henrik Beuther, Thomas Henning & Caroline Gieser

Tuesdays 9:15, *Start 15.10.2024*, **Philosophenweg 12, kleiner Hoersaal (kHS)**

The lecture will be given in English.

Registration: To register for the lecture, please either directly via heiCO, or send an email directly to "beuther at mpia.de", or simply come to the first lecture on October 15, 2024.

Required credit points can be obtained at the end of the term via oral examinations.

Literature: Steven Stahler & Francesco Palla: The Formation of Stars, Wiley-VCH 2004

Tentative Schedule:

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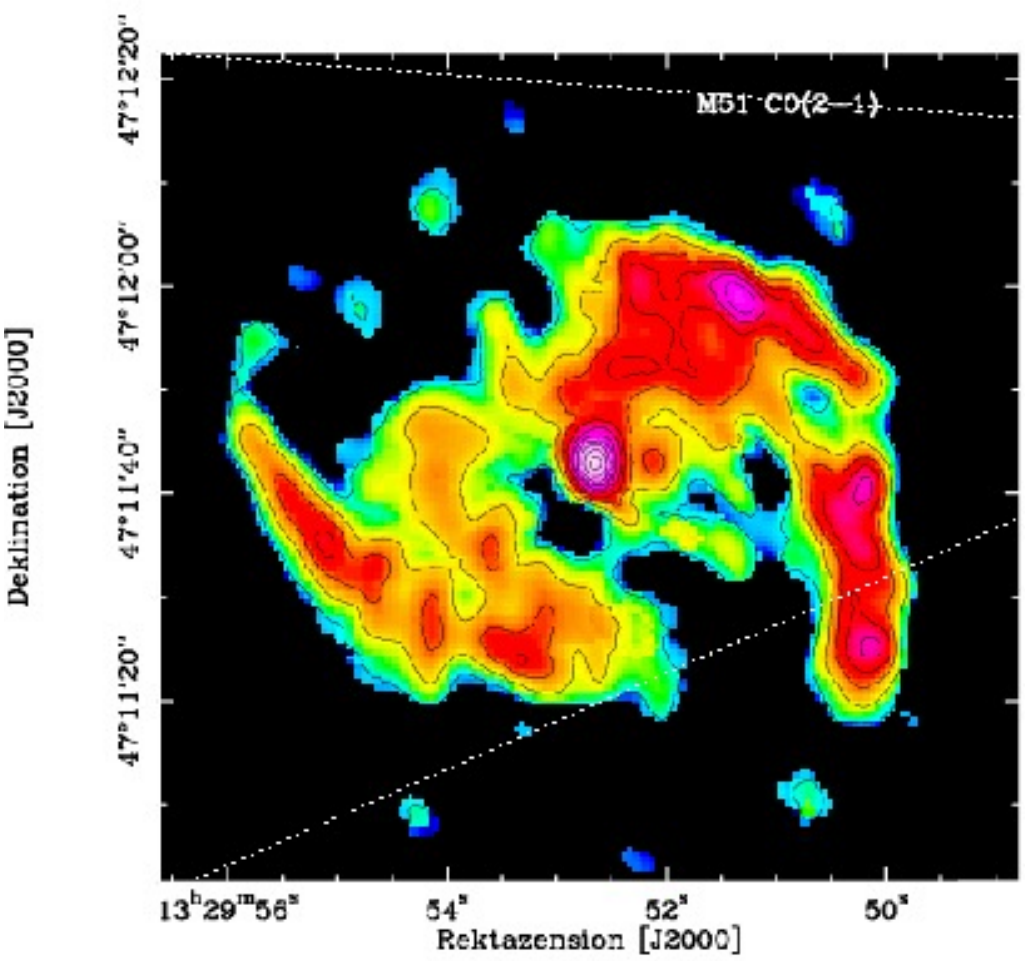
Slides will be provided here.

Topics today

- From large to small scales.
- Different wavelengths sample different physics.
- Stars.
- The Interstellar Medium.

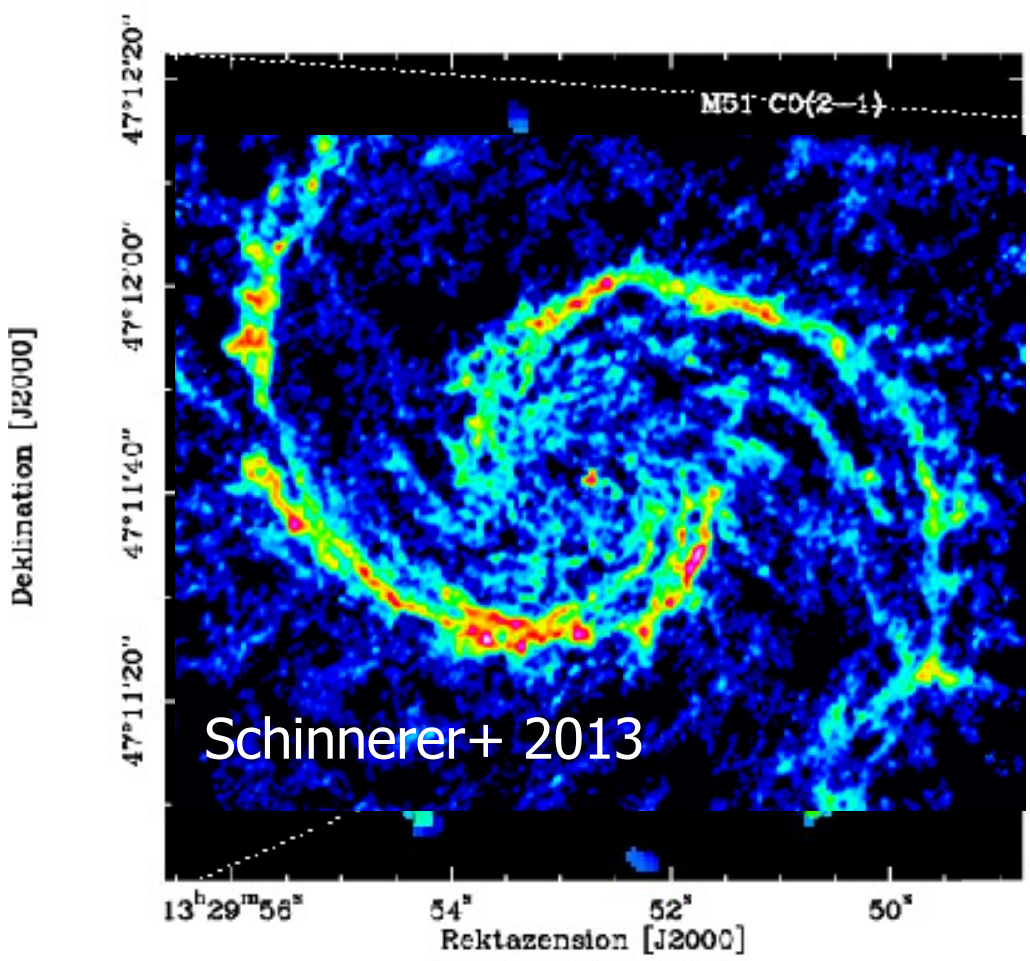
M51: The Whirlpool Galaxy



Schuster et al. 2007

Hubble Heritage Team

M51: The Whirlpool Galaxy



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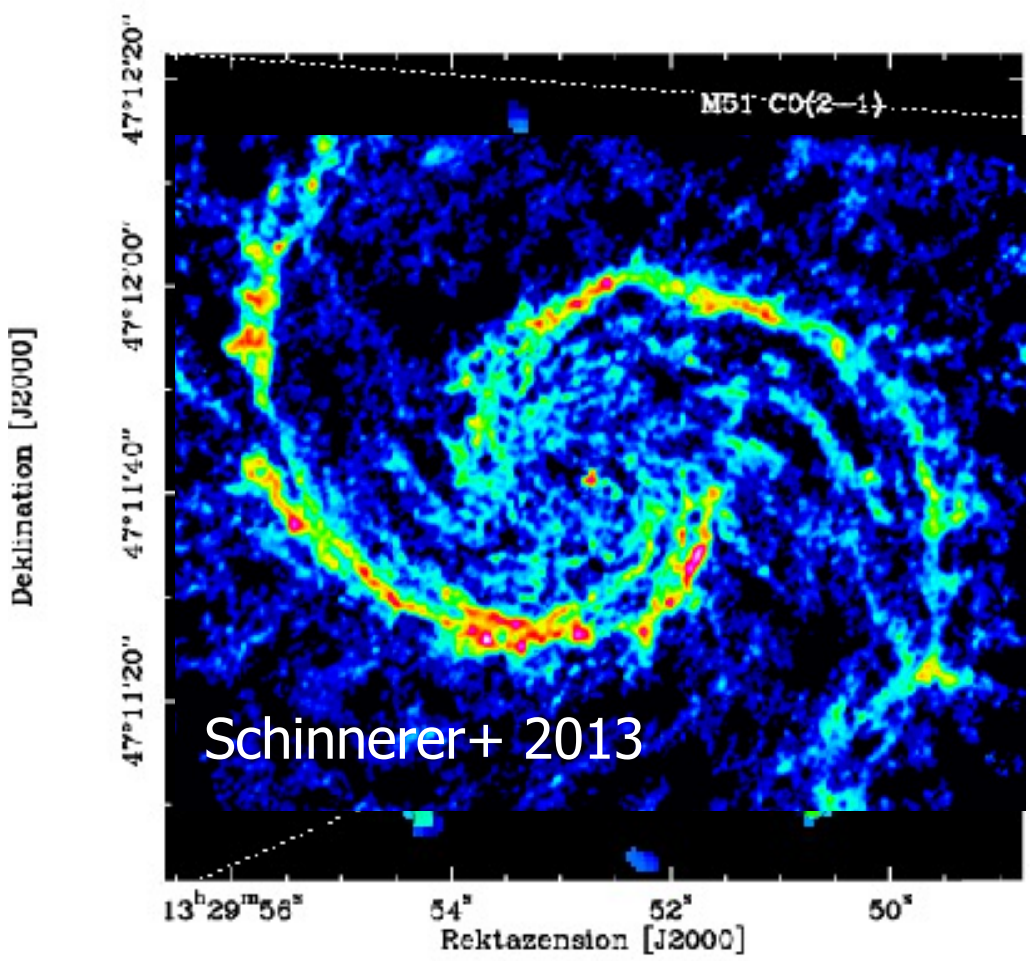
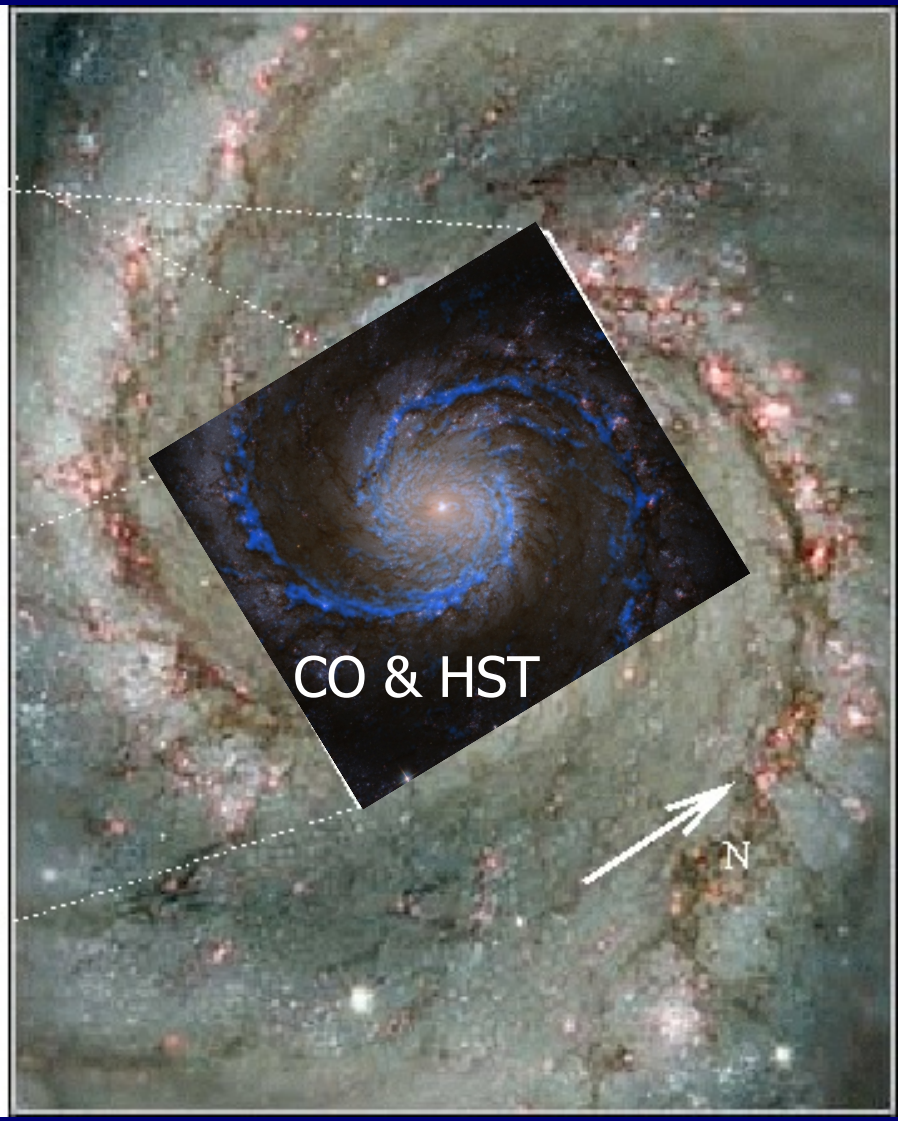
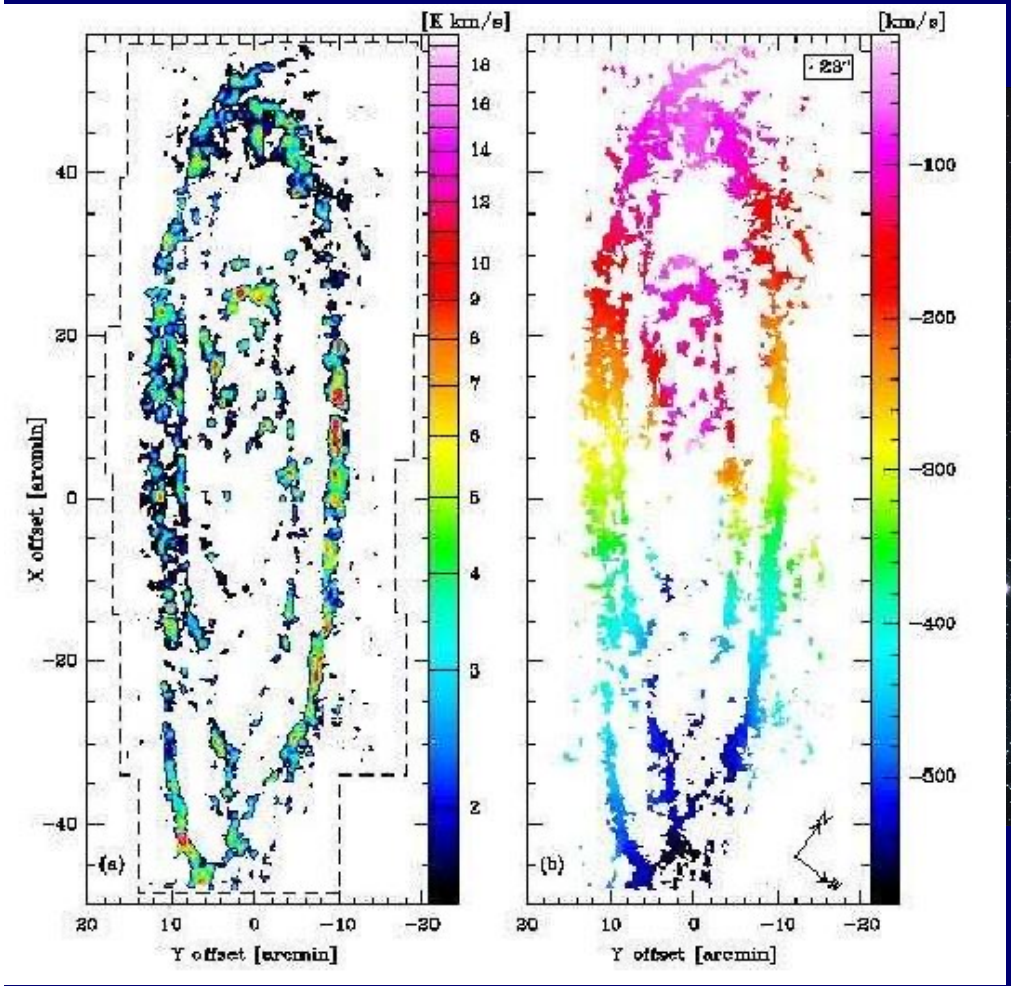




Schuster et al. 2007

Hubble Heritage Team

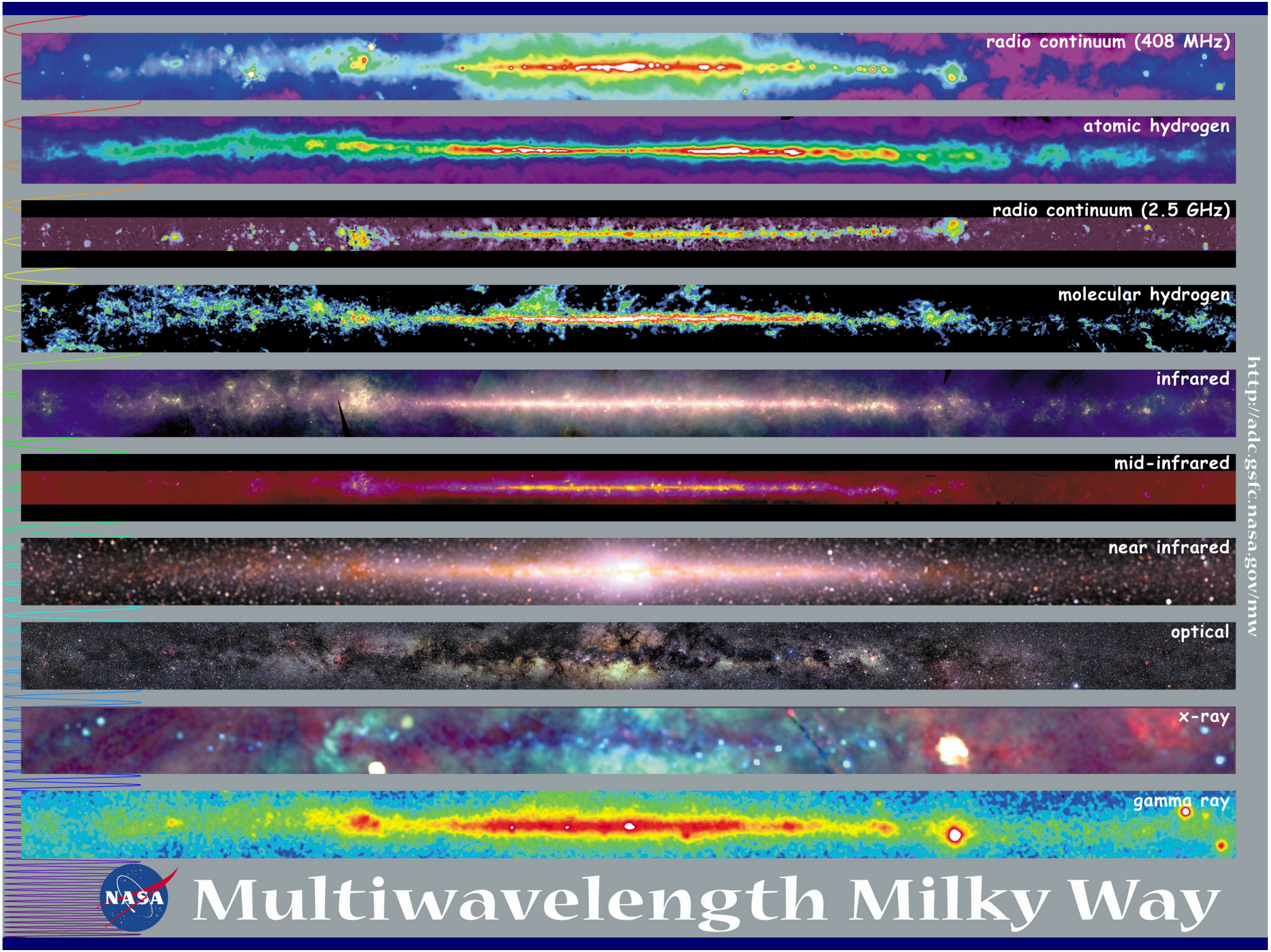
Andromeda



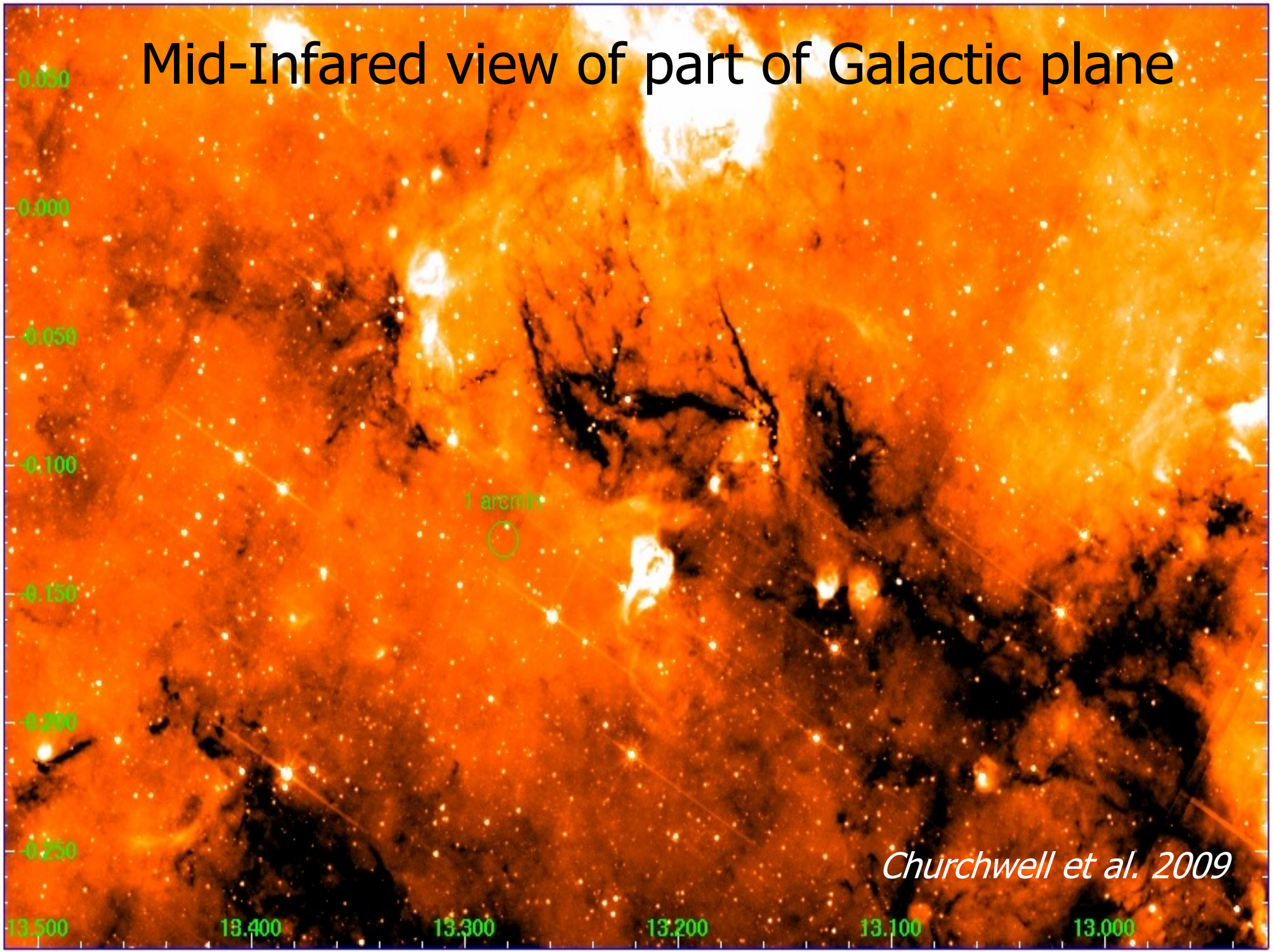
CO(2-1)

Optical

Nieten et al. 2006

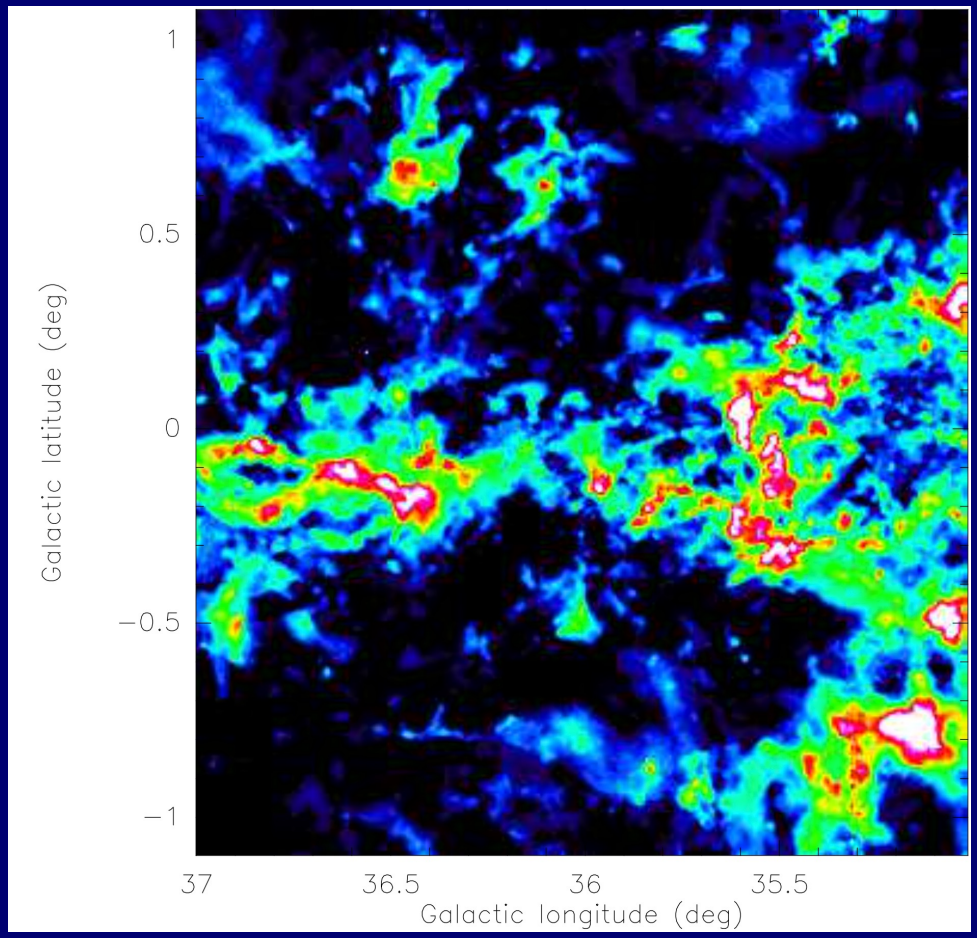

radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way

Mid-Infared view of part of Galactic plane



Churchwell et al. 2009

Giant Molecular Clouds



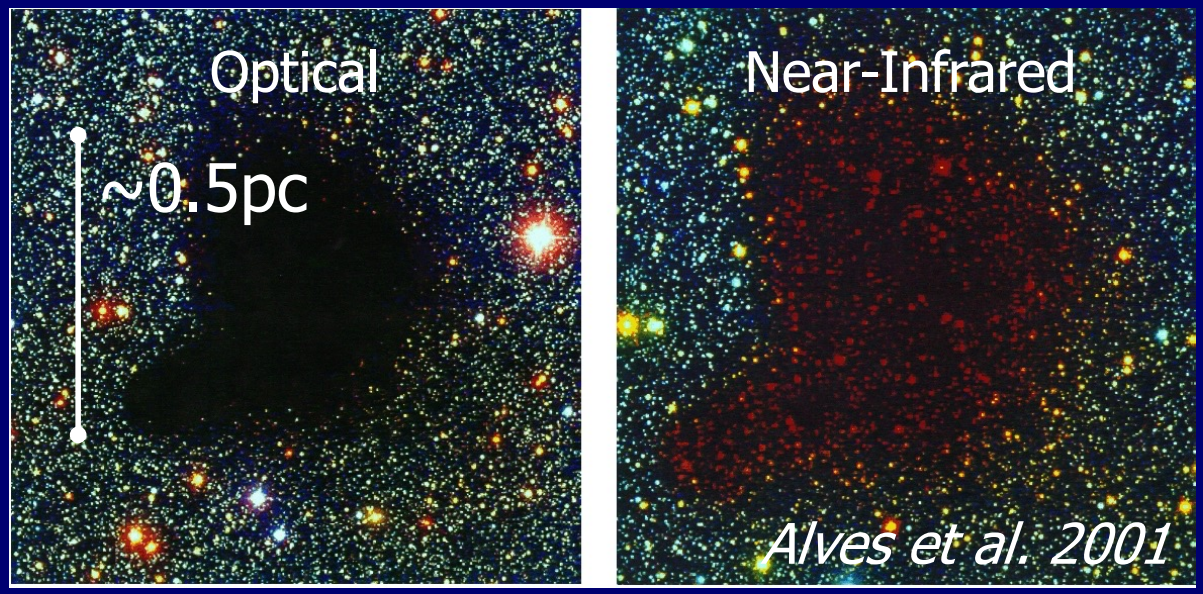
Galactic Ring survey
^{13}CO(1-0)
Jackson et al. 2006

Sizes: 20 to 100pc; Masses: 10^4 to 10^6 M_{sun}; Temperatures: 10 to 20K
Supersonic velocity dispersion ~2-3 km/s mainly due to turbulence
Magnetic field strengths on the order of 10μG
Average local densities ~10^4cm^{-3}; Volume-averaged densities ~10^2cm^{-3}
--> highly clumped material

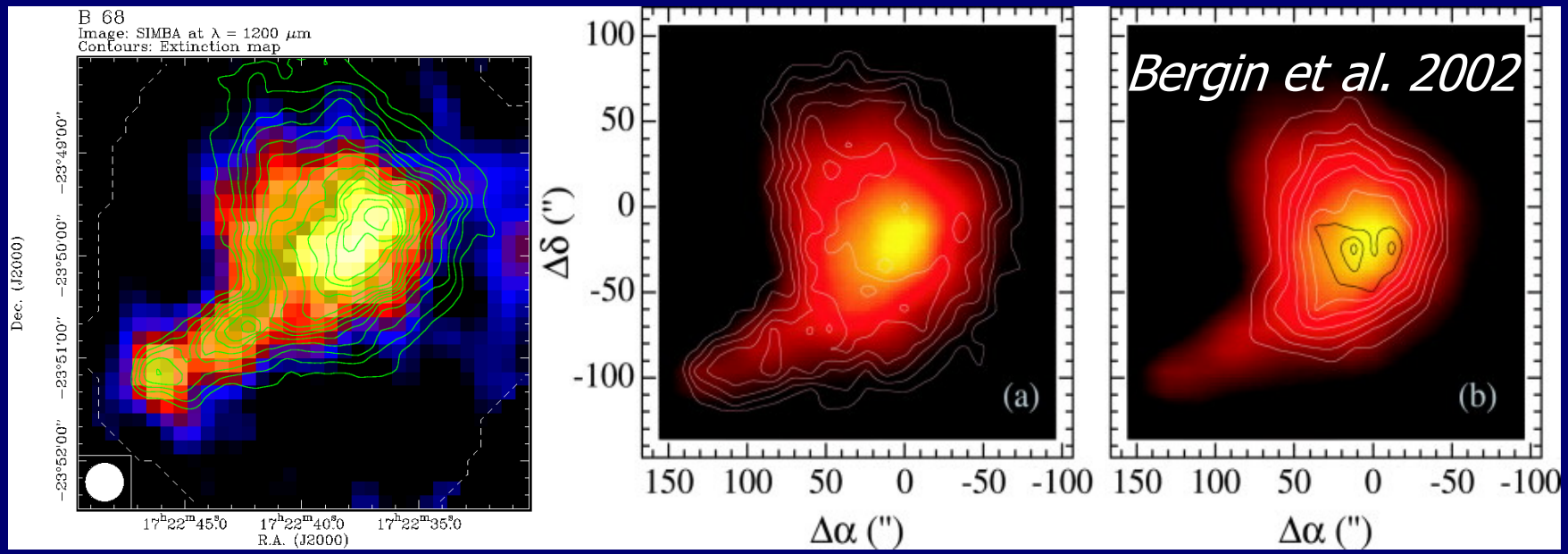
Sites of Star Formation

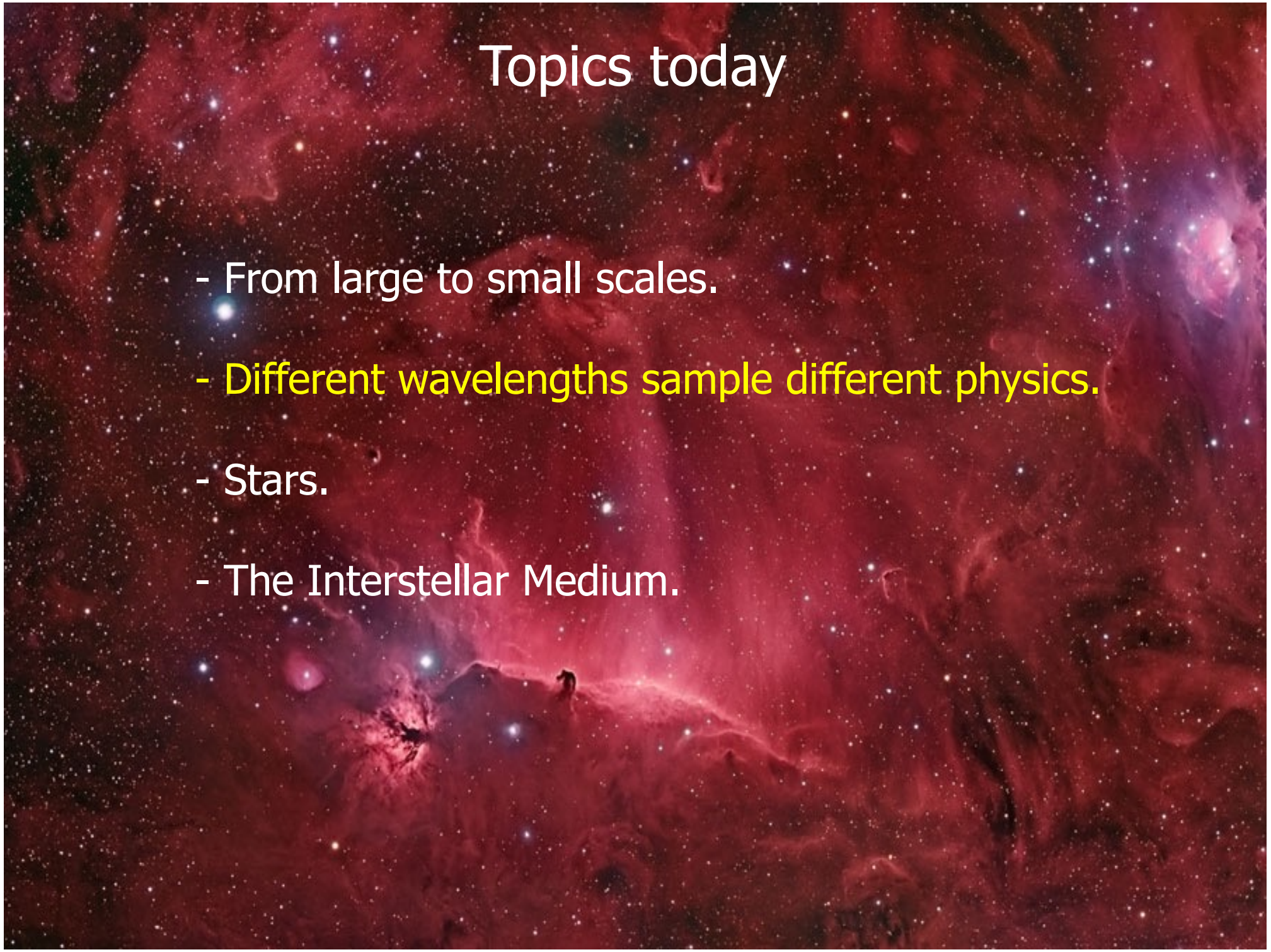
<u>Masses:</u>
Between fractions and a few 100 solar masses

<u>Densities:</u>
Of the order $10^6 cm^{-3}$



1.2 mm Dust Continuum $C^{18}O$ N_2H^+

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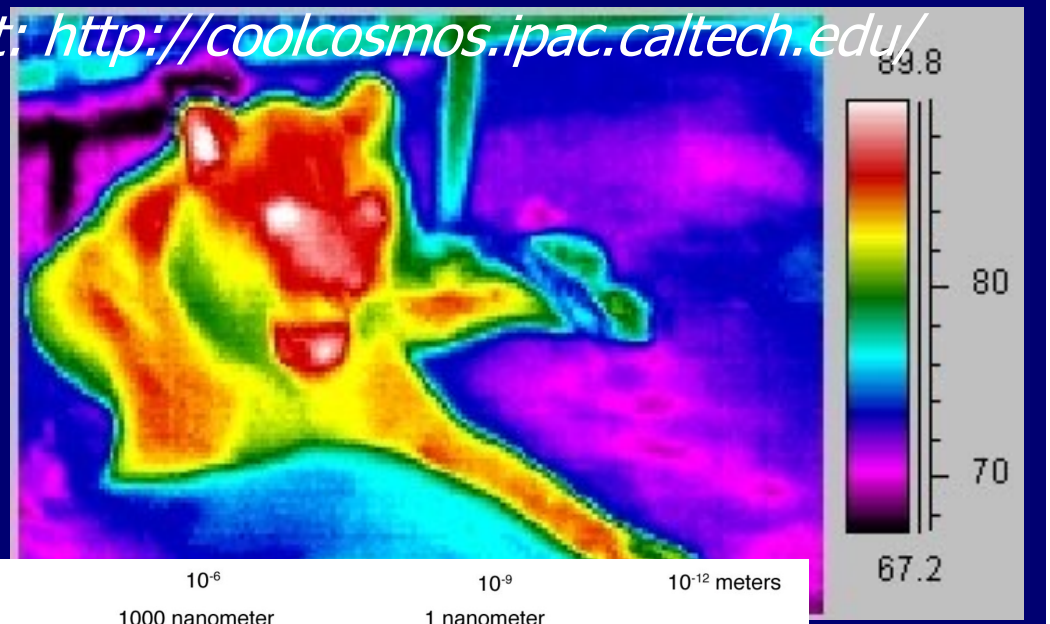
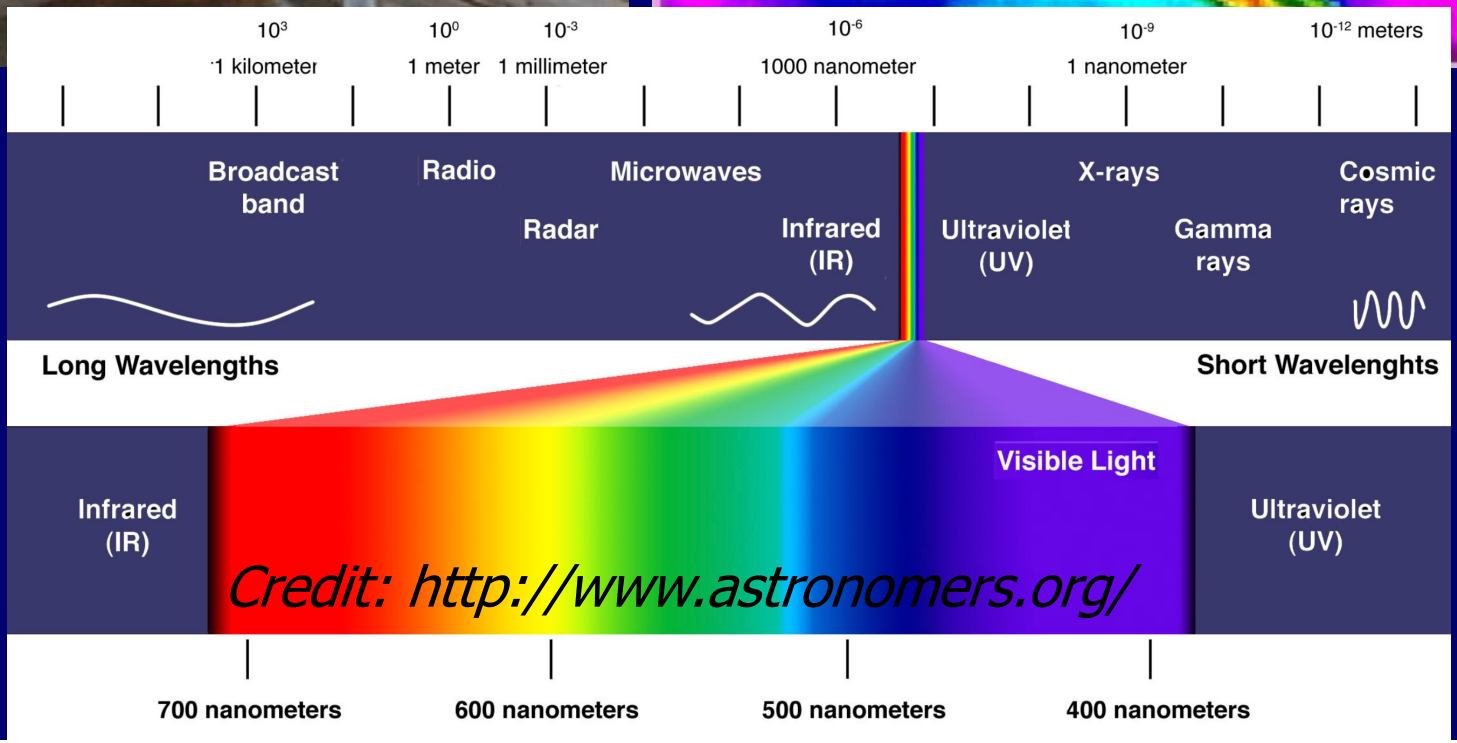
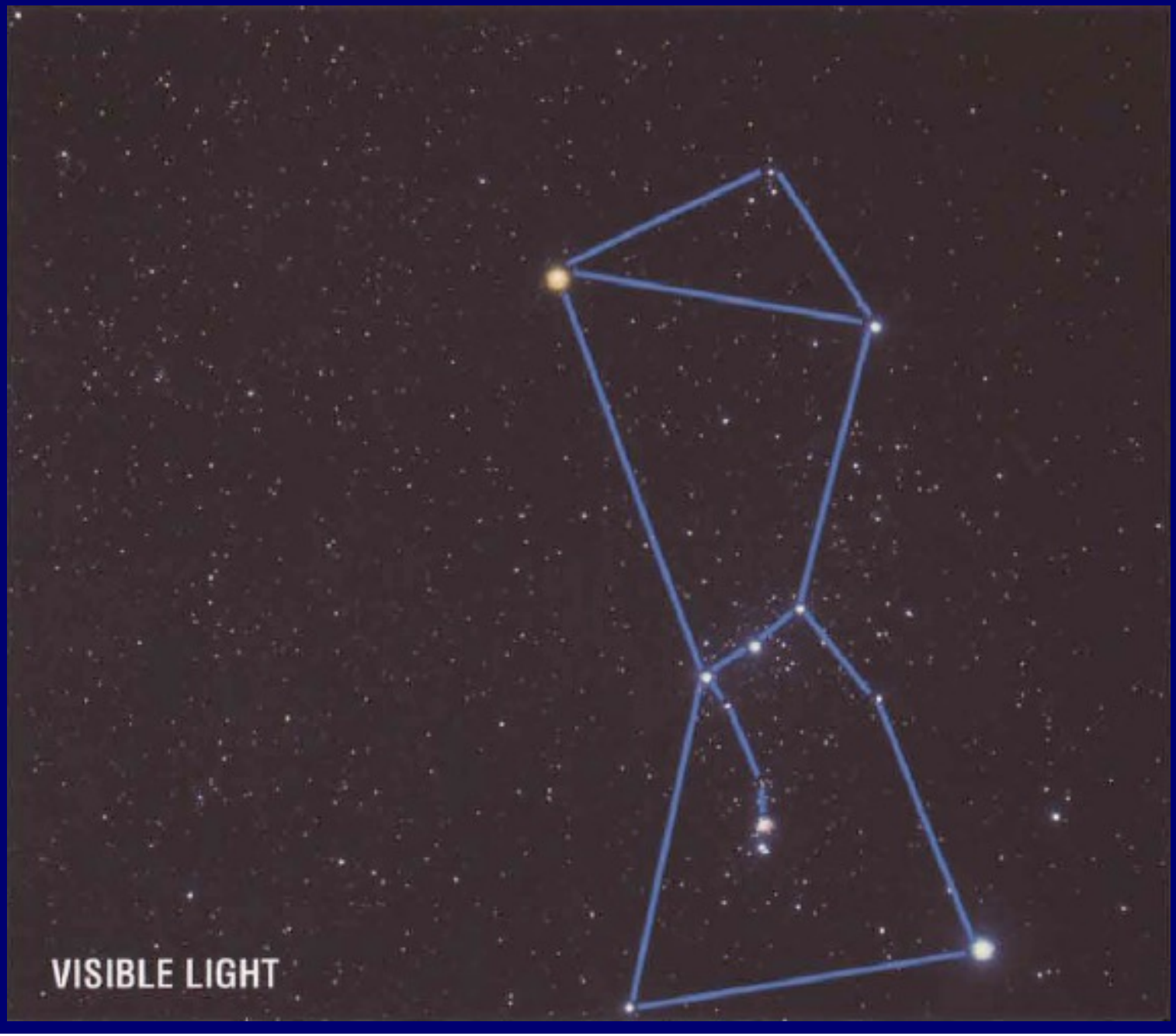
- The Interstellar Medium.

The electromagnetic spektrum



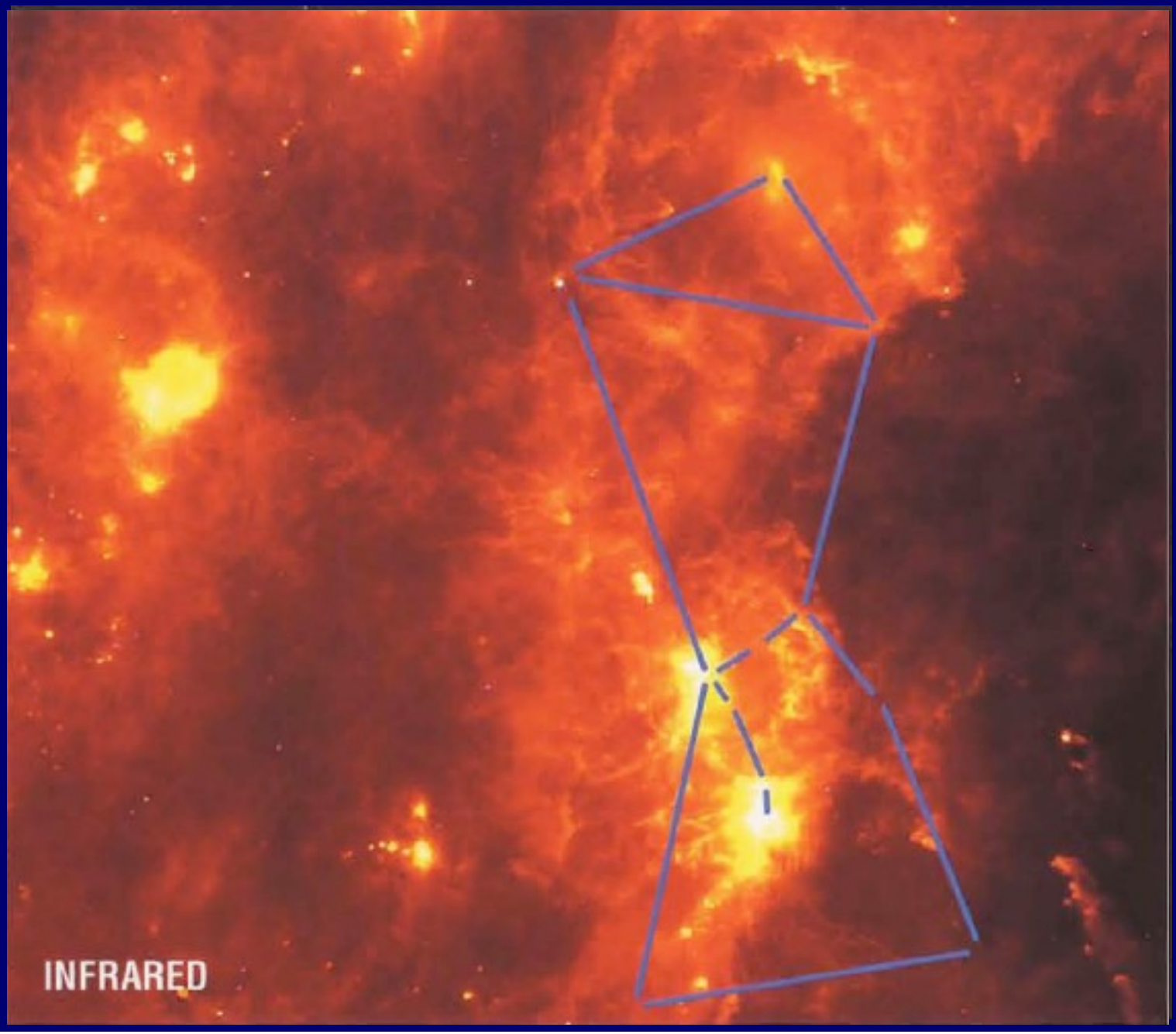


Orion



Credit:
IPAC
Caltech

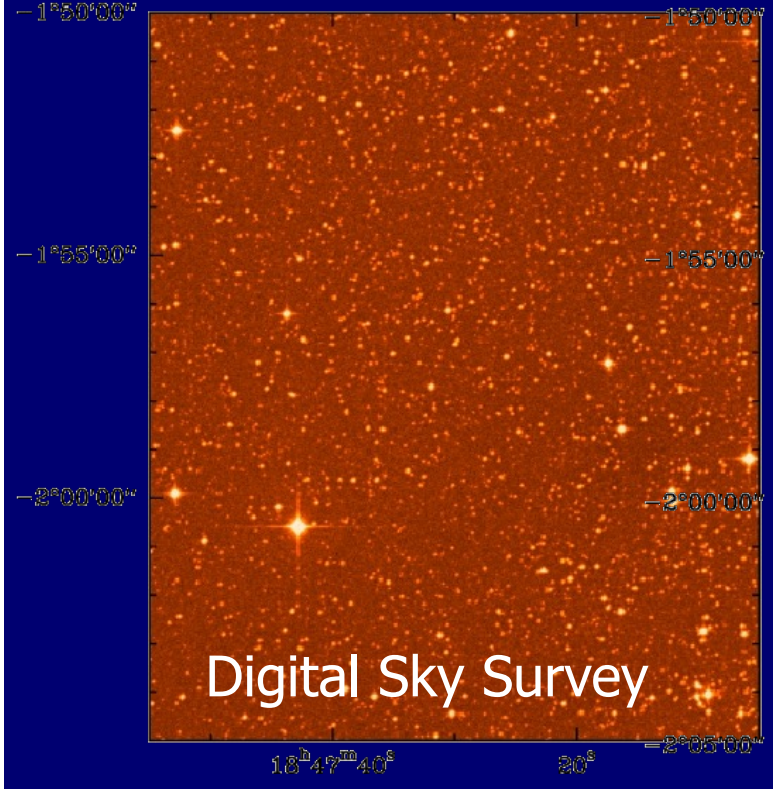
Orion



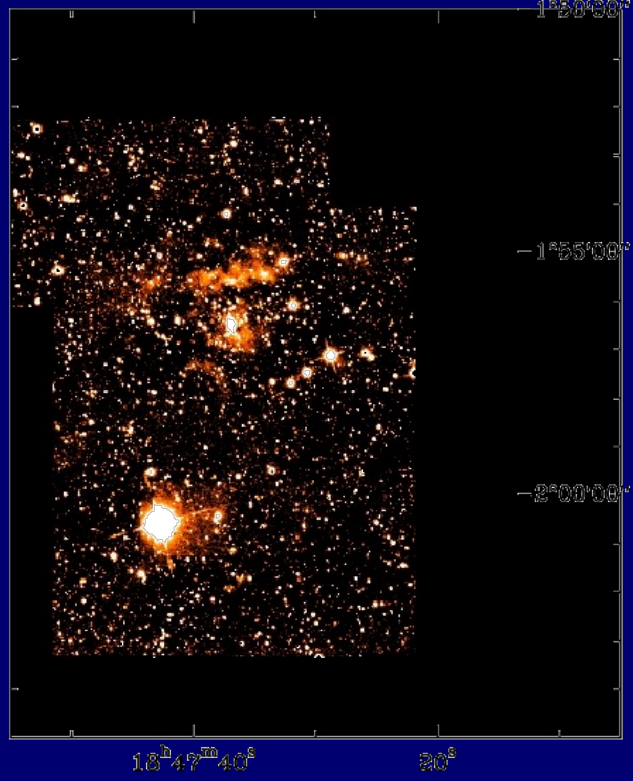
Credit:
IPAC
Caltech

The Star-Forming Region W43

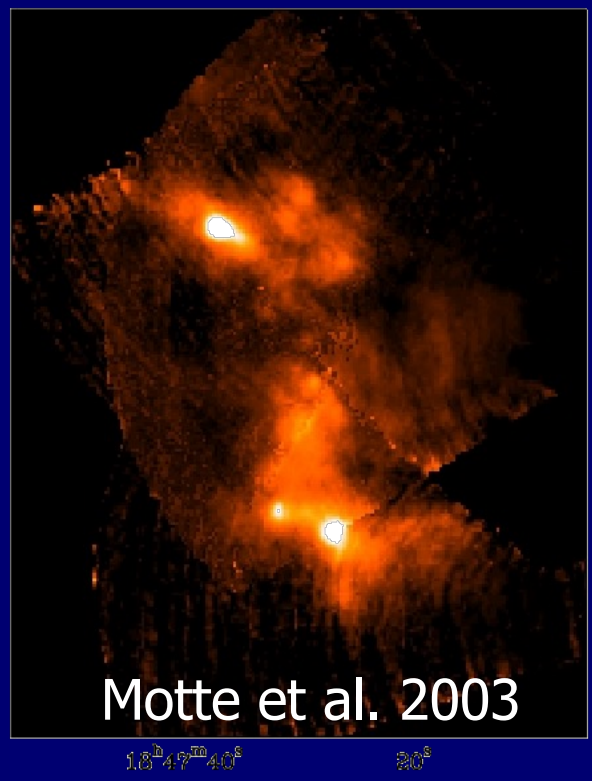
Optical



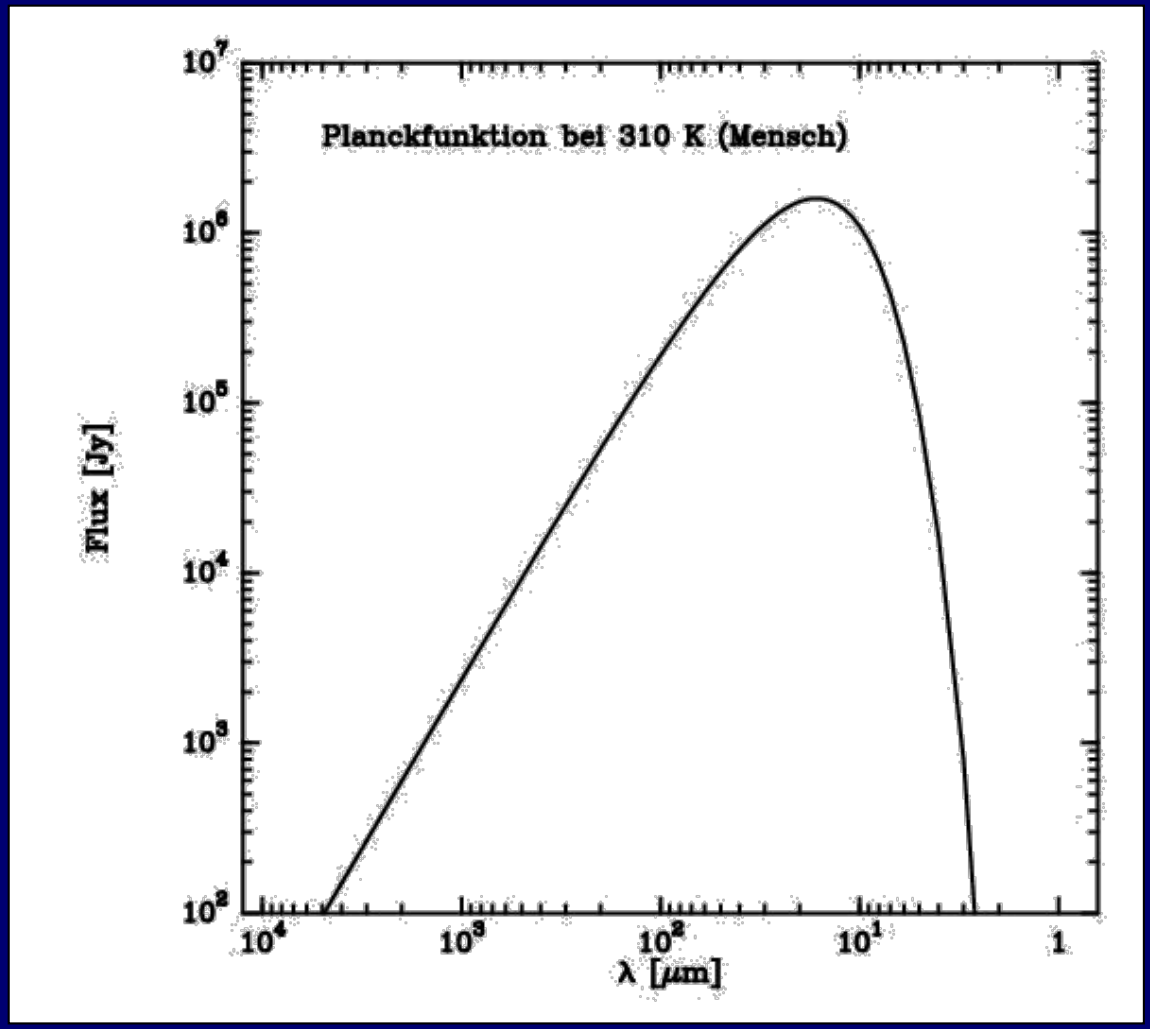
Near-Infrared



1.2mm dust cont.

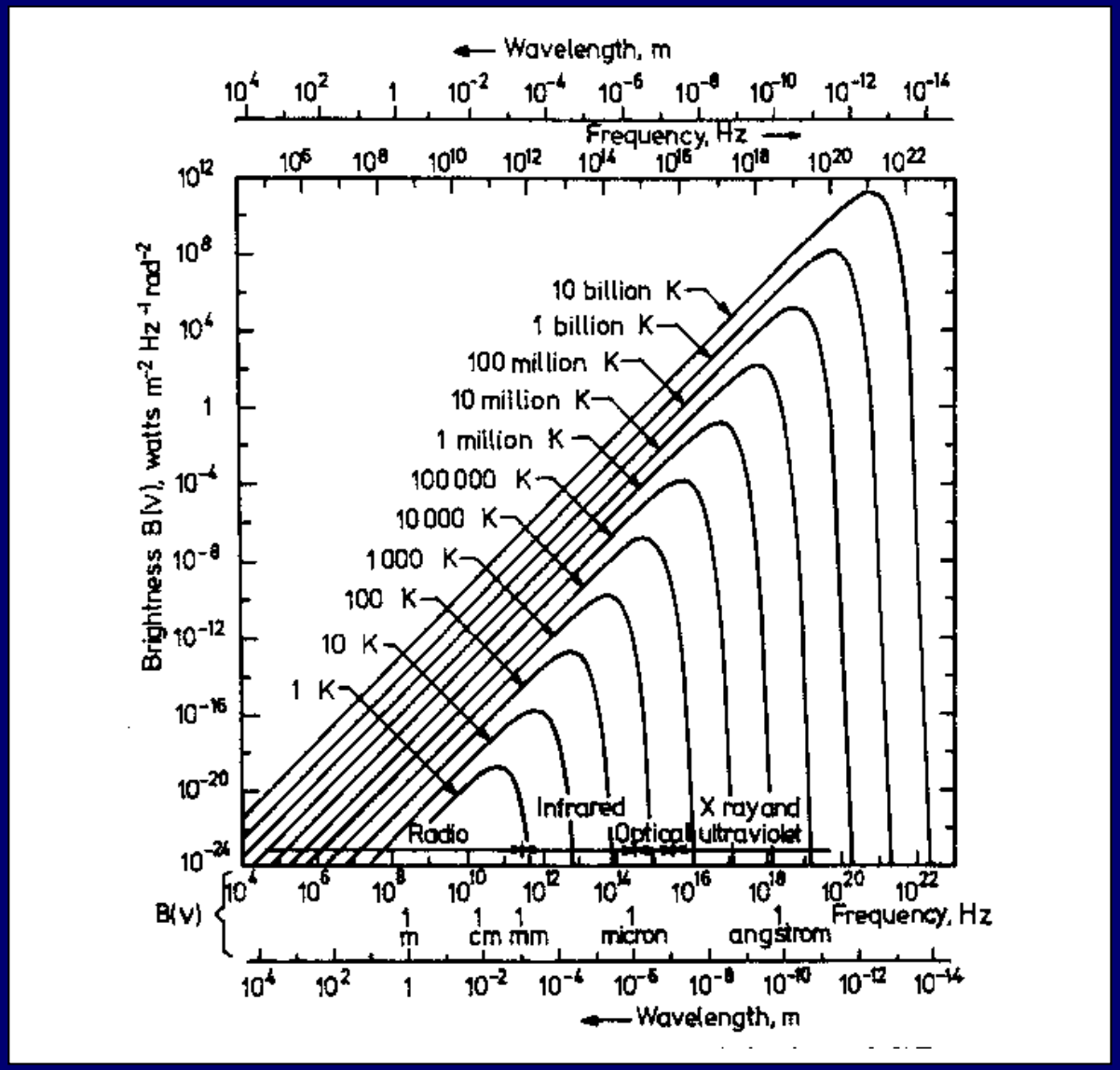


Planck's Black Body



$B_\nu(T) = 2h\nu^3/c^2 * 1/(\exp(h\nu/kT)-1)$

Planck's Black Body



$$B_\nu(T) = 2h\nu^3/c^2 * 1/(\exp(h\nu/kT)-1)$$

Wien's Law

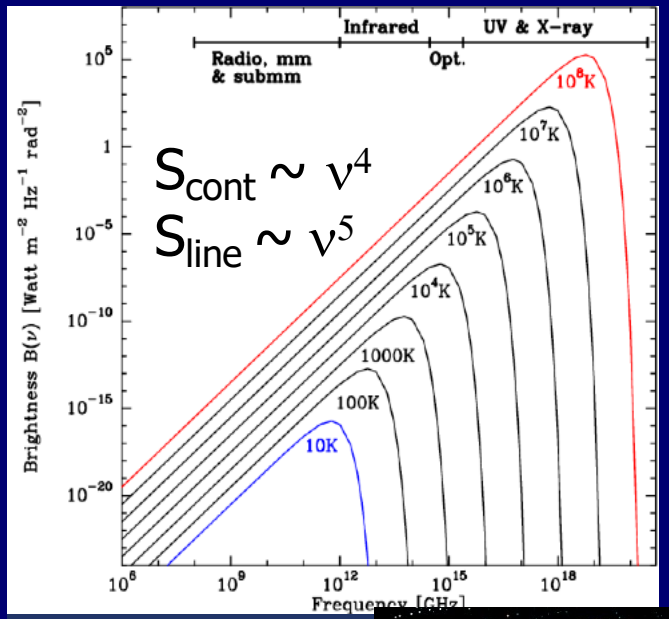
$\lambda_{max} = 2.9/T$ [mm]

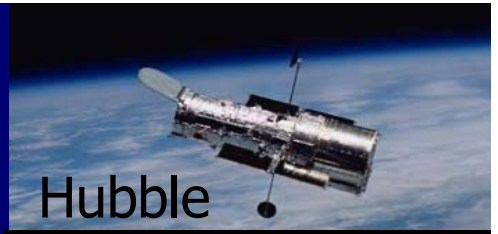
Examples:

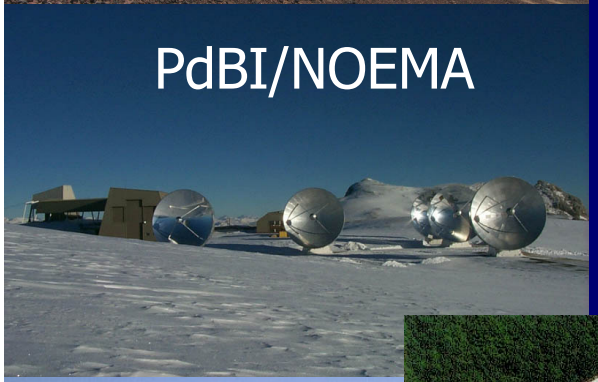
The Sun	T ~ 6000 K	$\Rightarrow \lambda_{max}$ = 480 nm (optical)
Humans	T ~ 310 K	$\Rightarrow \lambda_{max}$ = 9.4 μm (MIR)
Molecular Clouds	T ~ 20 K	$\Rightarrow \lambda_{max}$ = 145 μm (FIR/submm)
Cosmic Background	T ~ 2.7 K	$\Rightarrow \lambda_{max}$ = 1.1 mm (mm)

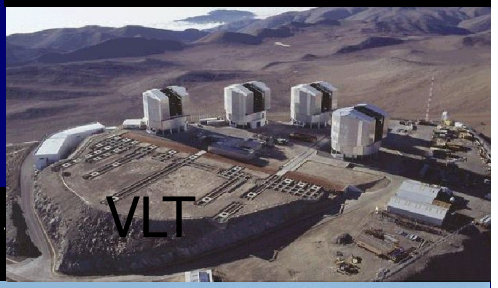
Observatories

Spatial resolution ~ λ/D









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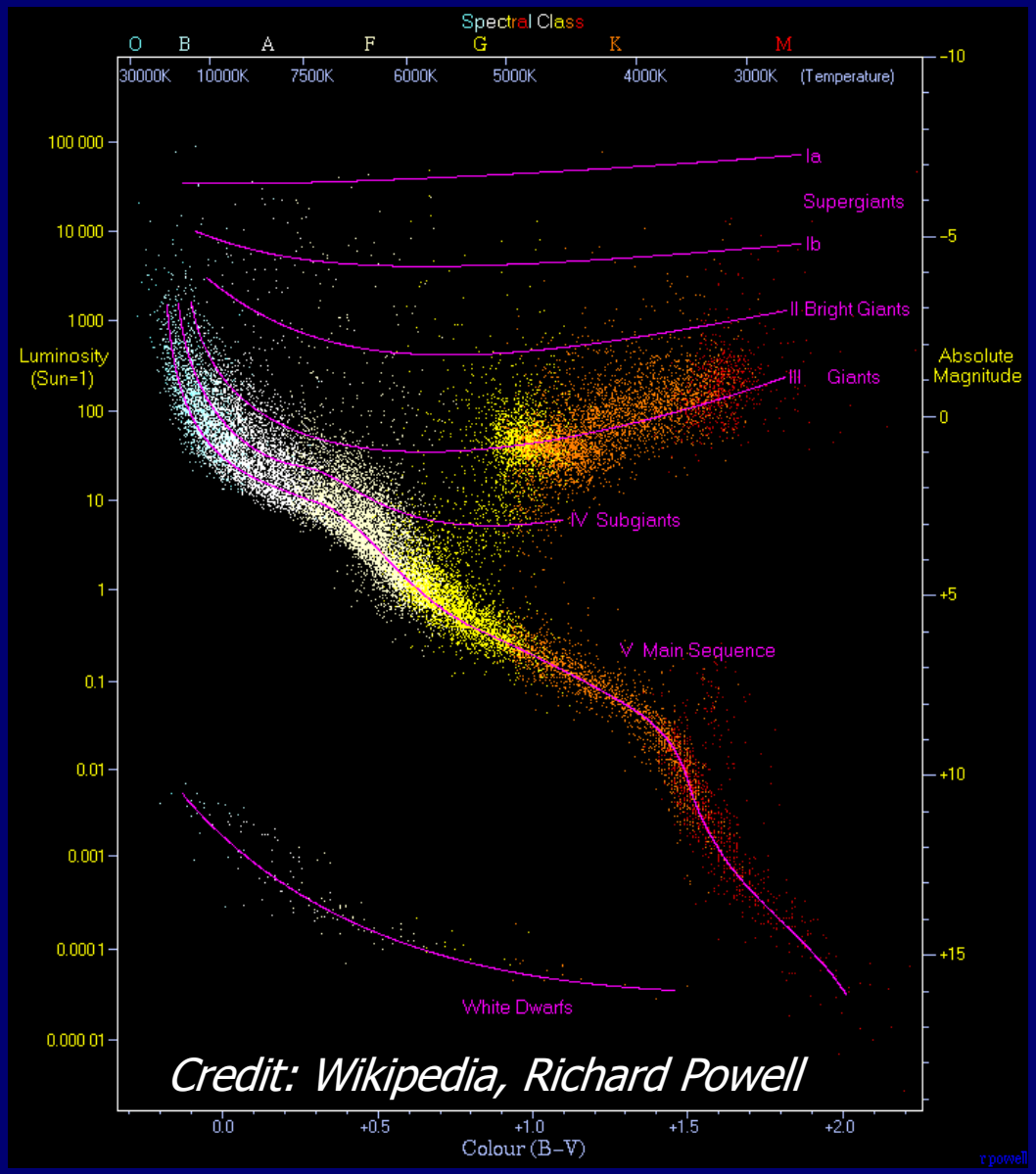
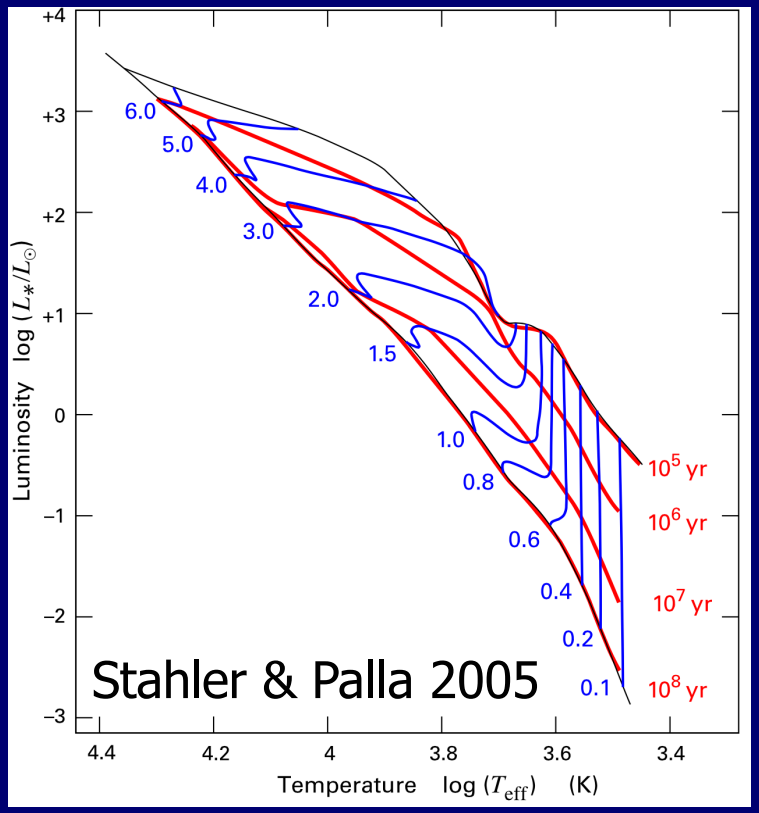
Hertzsprung-Russel diagram



Main sequence: $L=4\pi R^2\sigma_b T^4$ Stefan-Boltzmann law

Hertzsprung-Russel diagram



Time-scales:

Free-fall time scale: Virial theorem → $t_{ff} = (R^3/GM)^{1/2}$ $\rho=10^5 cm^{-3}$ ------> $t_{ff} \sim 10^5$ yr

Contraction of protostar under gravity releasing energy as radiation:

Virial theorem: $E_{pot} + 2E_{kin} = 0$ --> $E_{kin} = 0.5E_{pot} \sim GM^2/R$

---> Kelvin-Helmhotz time scale: $t_{KH} = E_{kin}/L = GM^2/(RL)$

$\sim 10^7$ yr for the sun

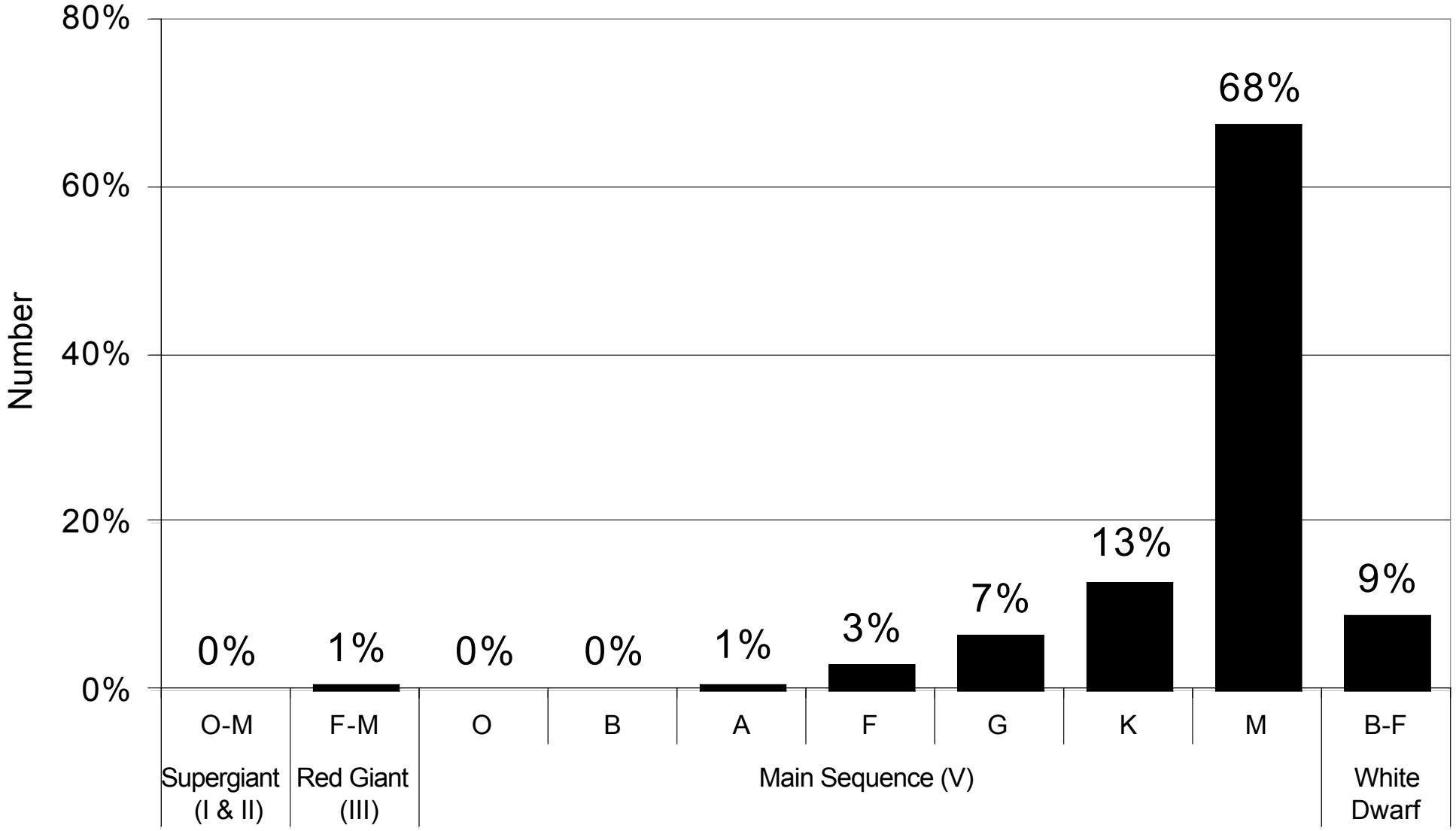
Properties of Main Sequence Stars

Mass [M_{sun}]	Sp. Type	Lum [$\log(L_{sun})$]	T_{eff} [log(K)]	t_{MS} [yr]
60	O5	5.90	4.65	3.4×10^6
40	O6	5.62	4.61	4.3×10^6
20	O9	4.99	4.52	8.1×10^6
10	B2	3.76	4.34	2.6×10^7
4	B8	2.26	4.08	1.6×10^8
2	A5	1.15	3.91	1.1×10^9
1	G2	0.04	3.77	1.0×10^{10}
0.8	K0	-0.55	3.66	2.5×10^{10}
0.2	M5	-2.05	3.52	$>10^{11}$

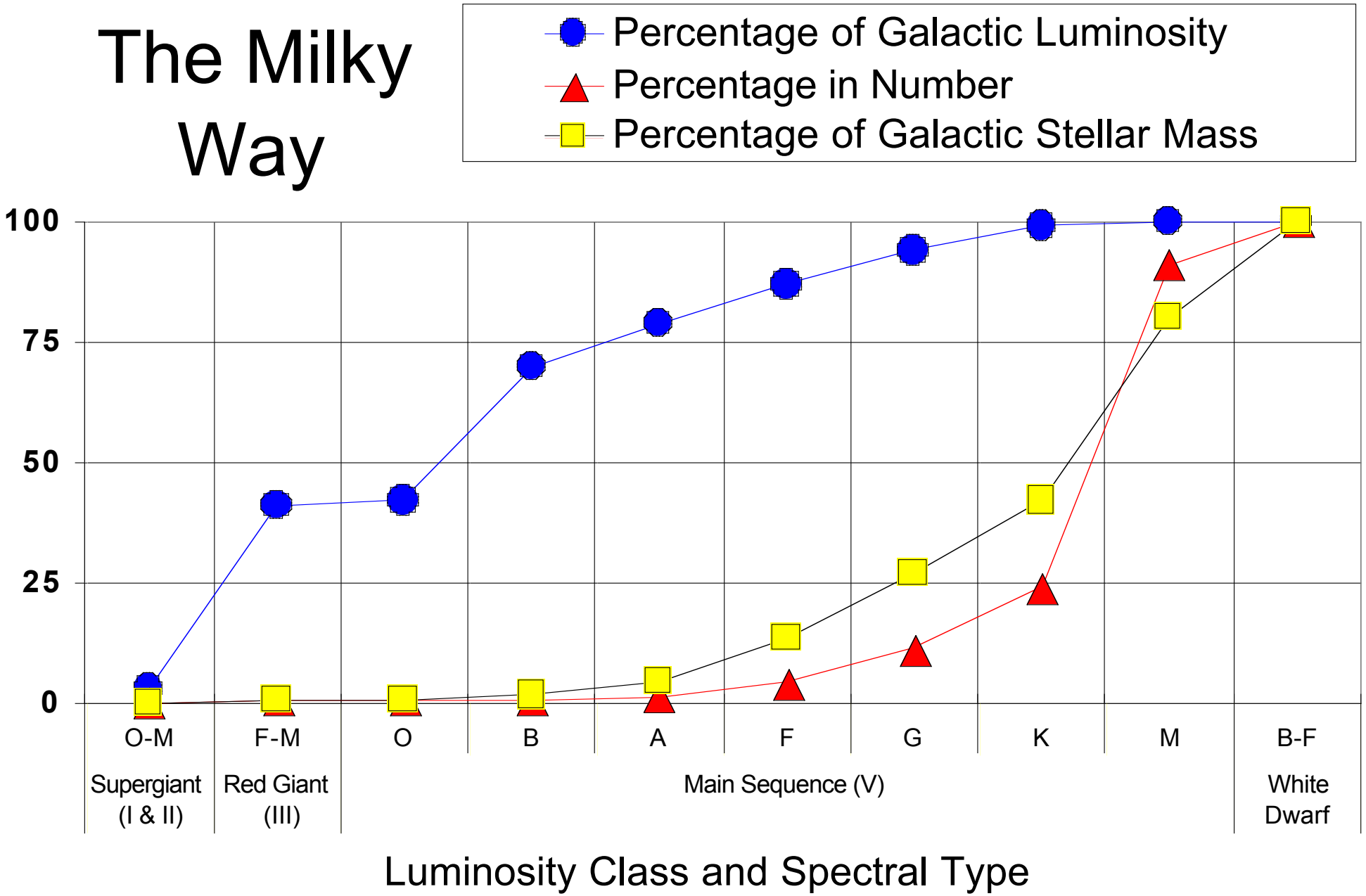
} greater than age of universe

$t_{MS} \sim 5 \times 10^{-4}\, Mc^2/L = 1 \times 10^{10}\, (M[M_{sun}])/(L[L_{sun}])$ yr

Number of Stellar Types in the Milky Way



The Milky Way



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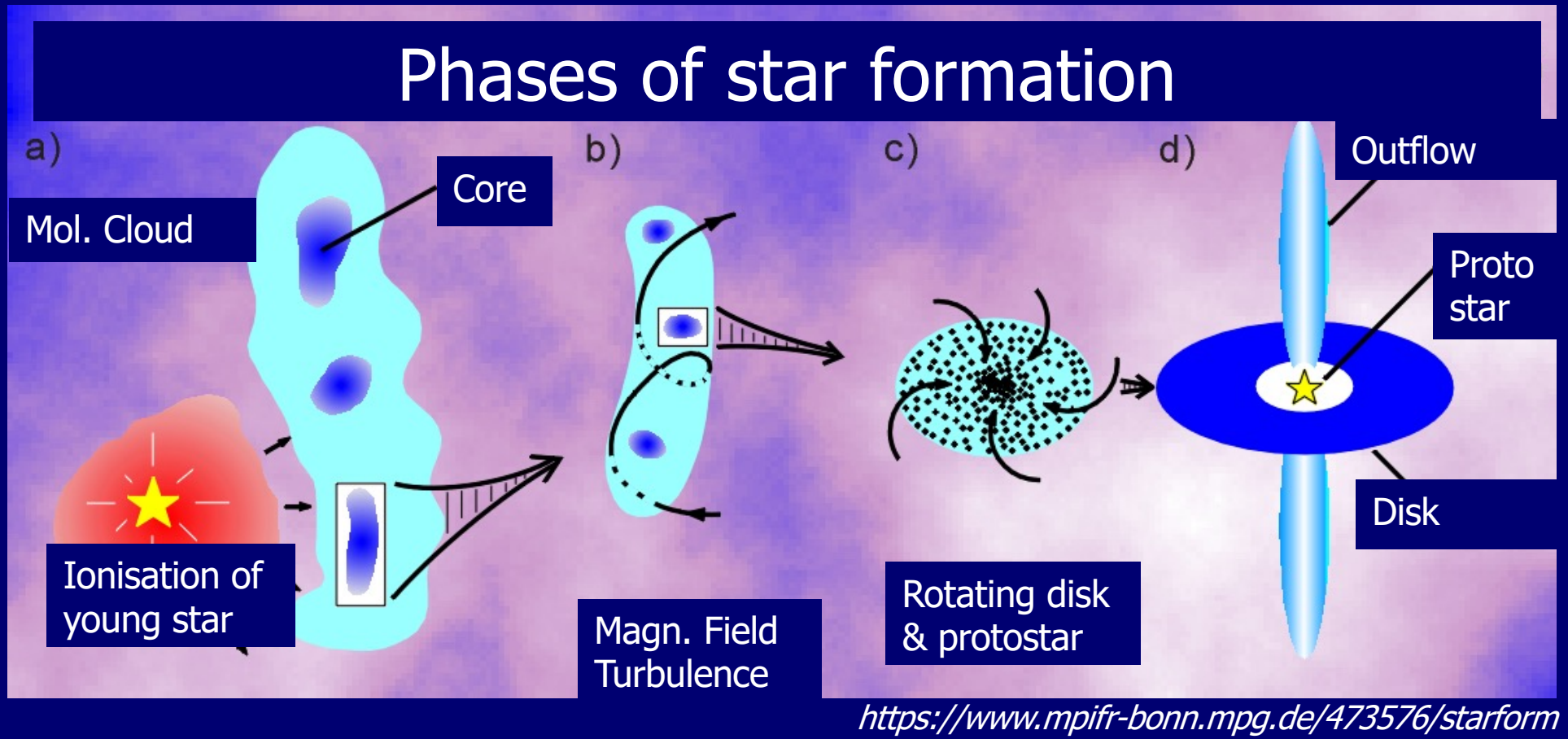
ISM next week

Star formation paradigm



Time-scales: Main accretion ~ 500 000 years
Pre-main sequence evolution ~ 2 Million years

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