Sternentstehung - Star Formation

Winter term 2022/2023

Henrik Beuther, Thomas Henning & Jonathan Henshaw

18.10 Today: Introduction & Overview (Beuther)
25.10 Physical processes I (Beuther)
08.11 Physcial processes II (Beuther)
15.11 Molecular clouds as birth places of stars (Henshaw)
22.11 Molecular clouds (cont.), Jeans Analysis (Henshaw)
29.11 Collapse models I (Beuther)
06.12 Collapse models II (Henning)
13.12 Protostellar evolution (Beuther)
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13.02 Examination week, no star formation lecture

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

More Information and the current lecture files: http://www.mpia.de/homes/beuther/lecture_ws2223.html

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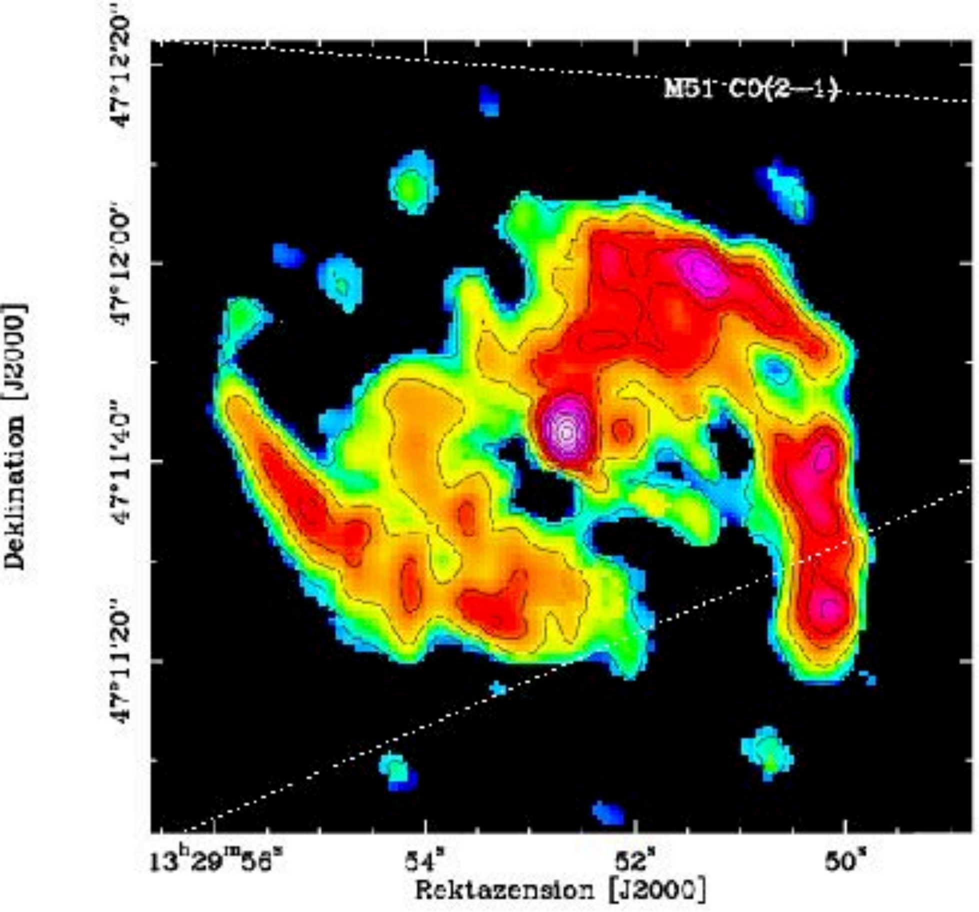
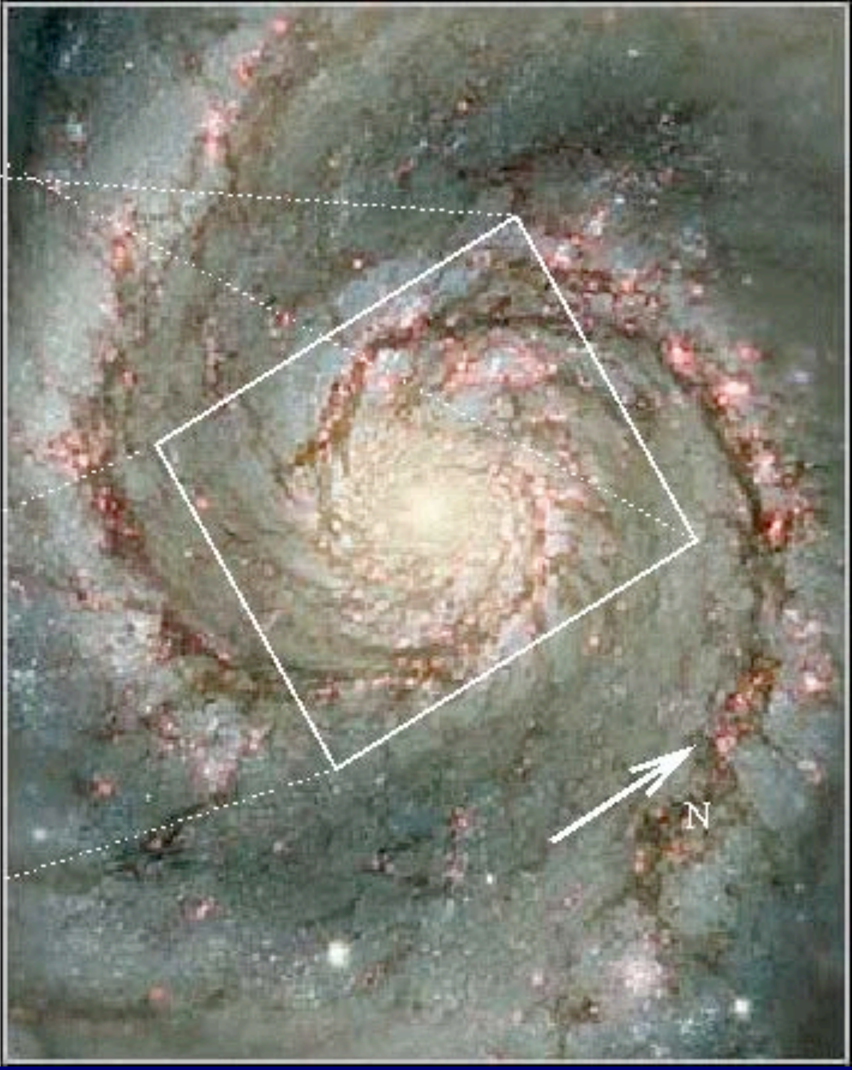
Topics today

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

M51: The Whirlpool Galaxy

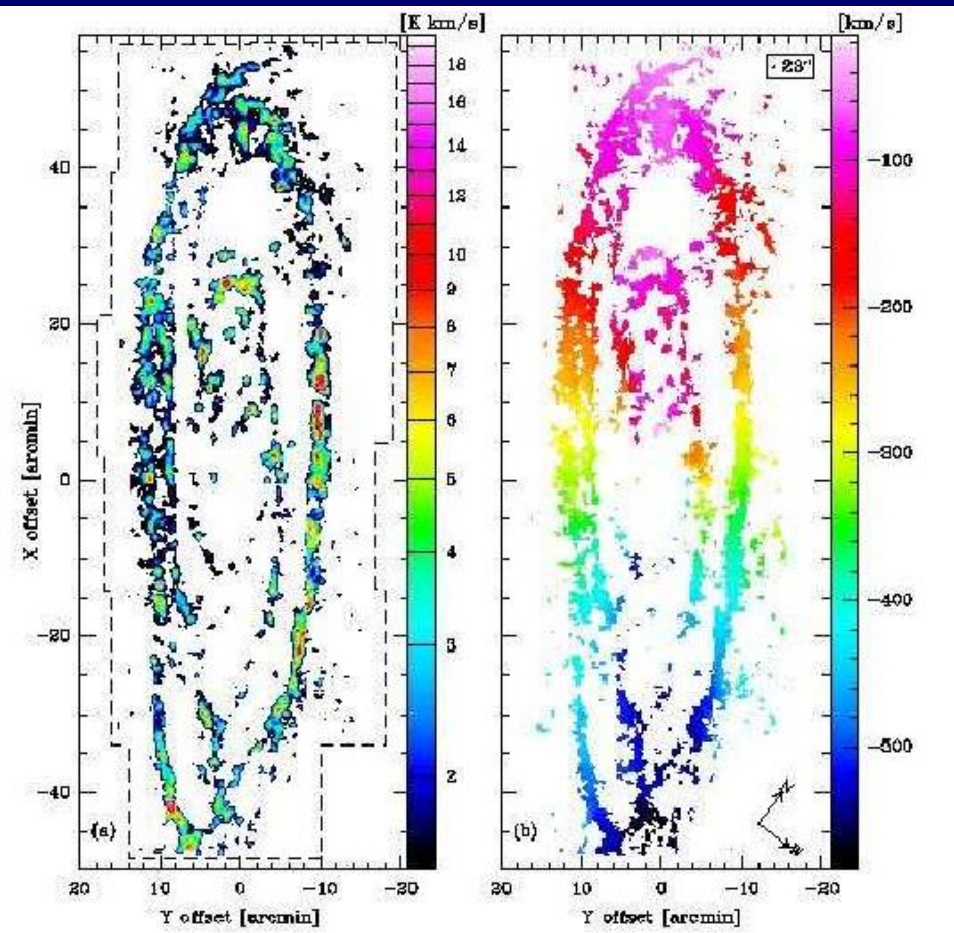




Schuster et al. 2007

Hubble Heritage Team

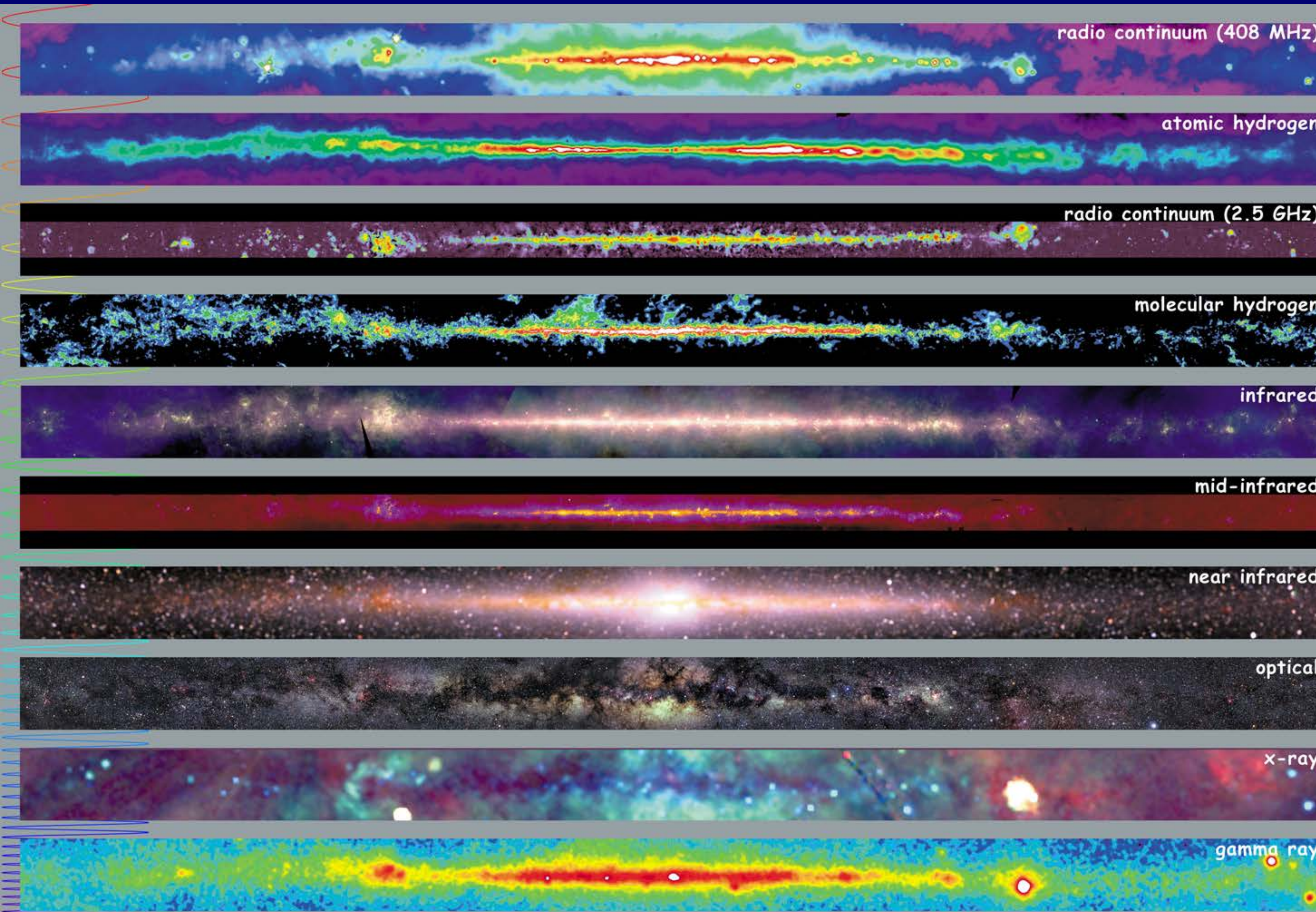
Andromeda



CO(2-1)

Optical

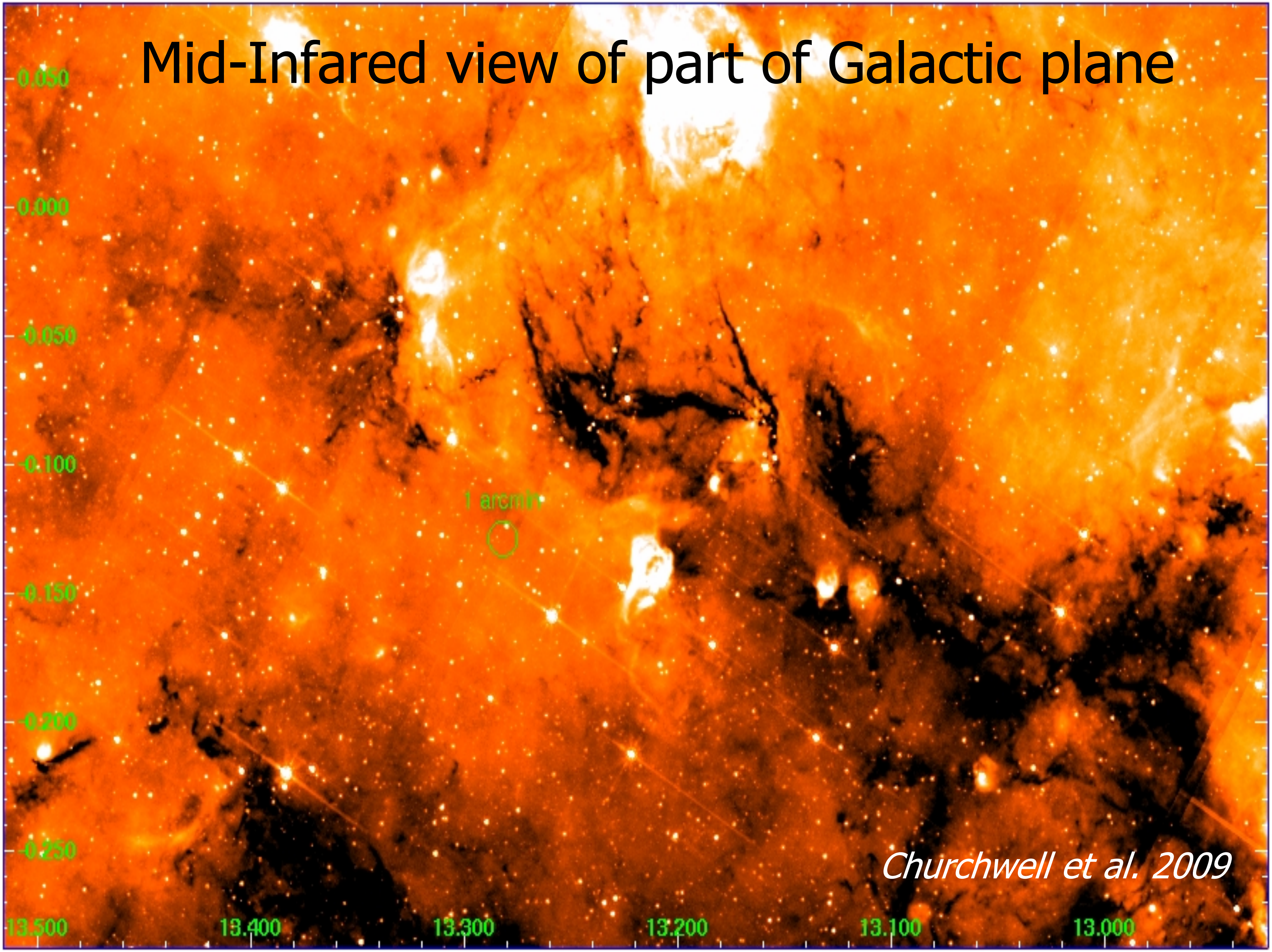
Nieten et al. 2006



http://adc.gsfc.nasa.gov/mw

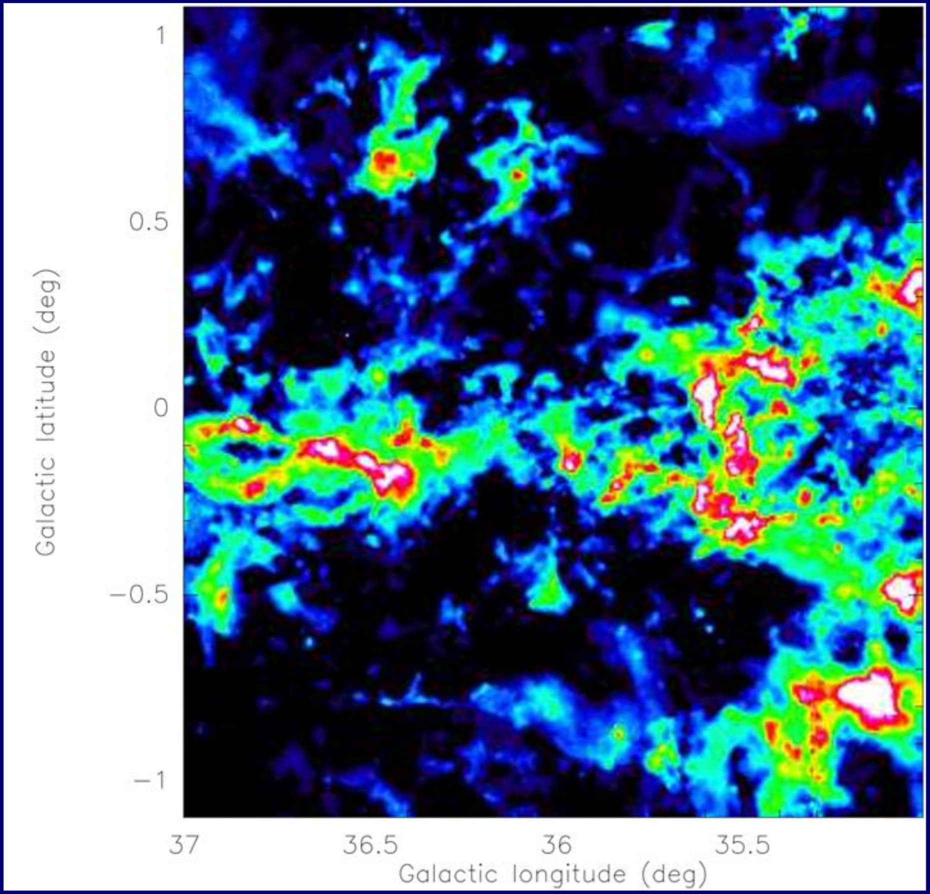
Multiwavelength Milky Way

Mid-Infared view of part of Galactic plane



Churchwell et al. 2009

Giant Molecular Clouds



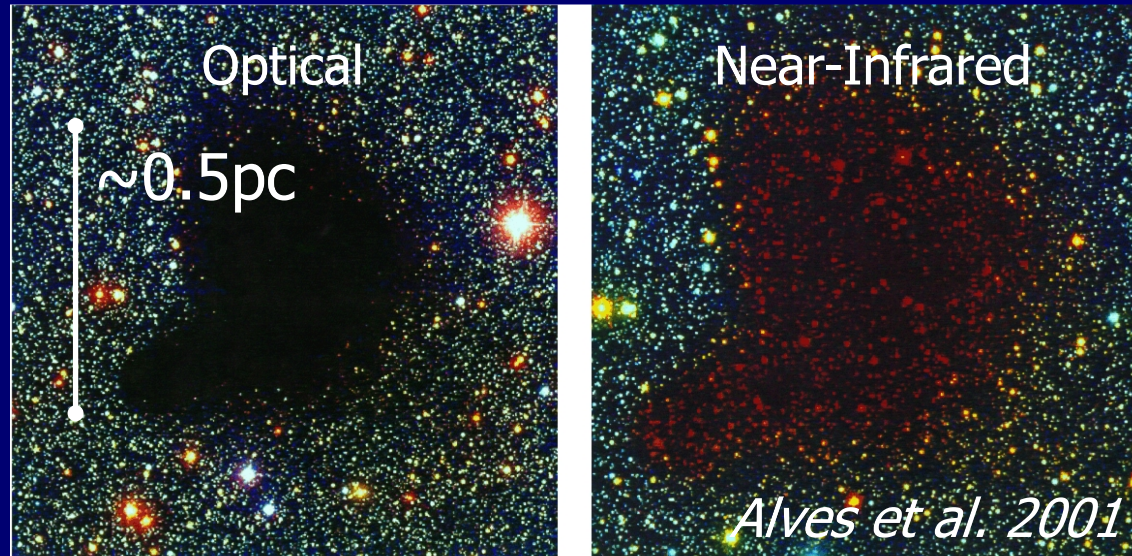
Galactic Ring survey
$^{13}CO(1\text{-}0)$
Jackson et al. 2006

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 ~$10^4 cm^{-3}$; Volume-averaged densities ~$10^2 cm^{-3}$
--> highly clumped material

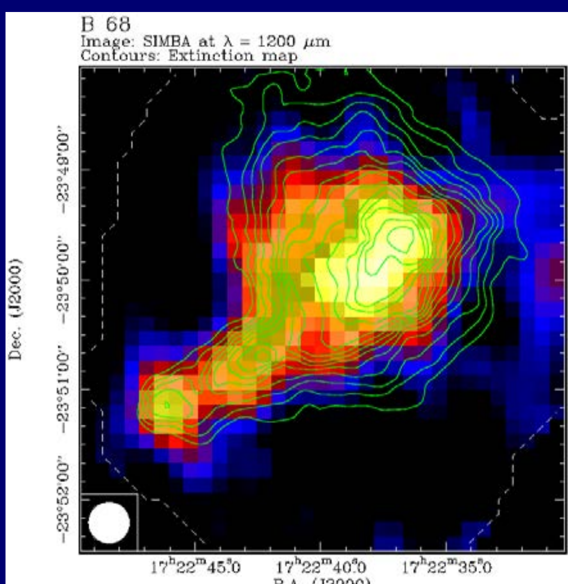
Sites of Star Formation

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

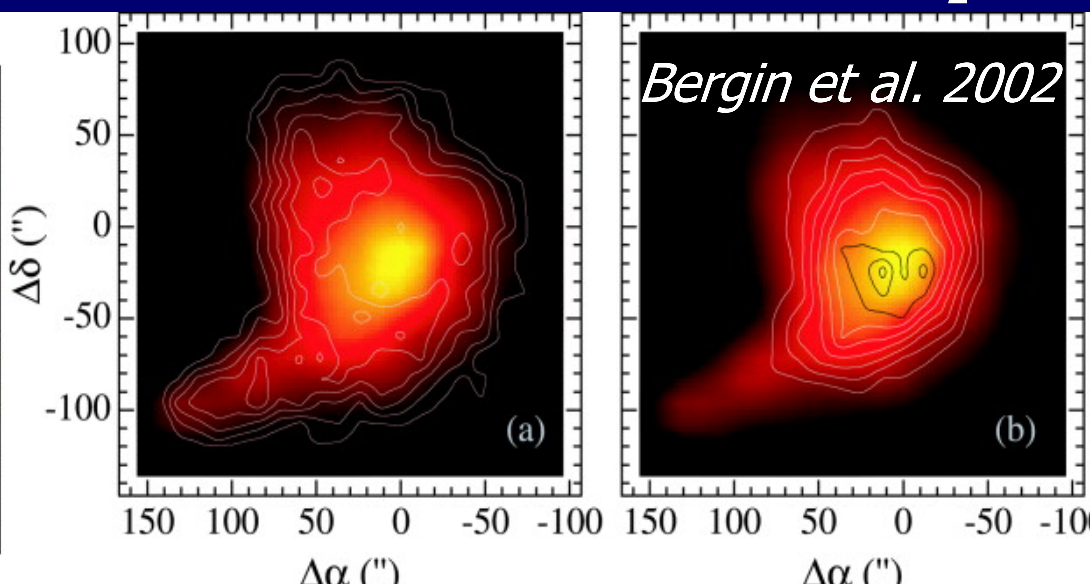
<u>Densities:</u>
Of the order $10^6 cm^{-3}$



1.2 mm Dust Continuum



$C^{18}O$ N_2H^+



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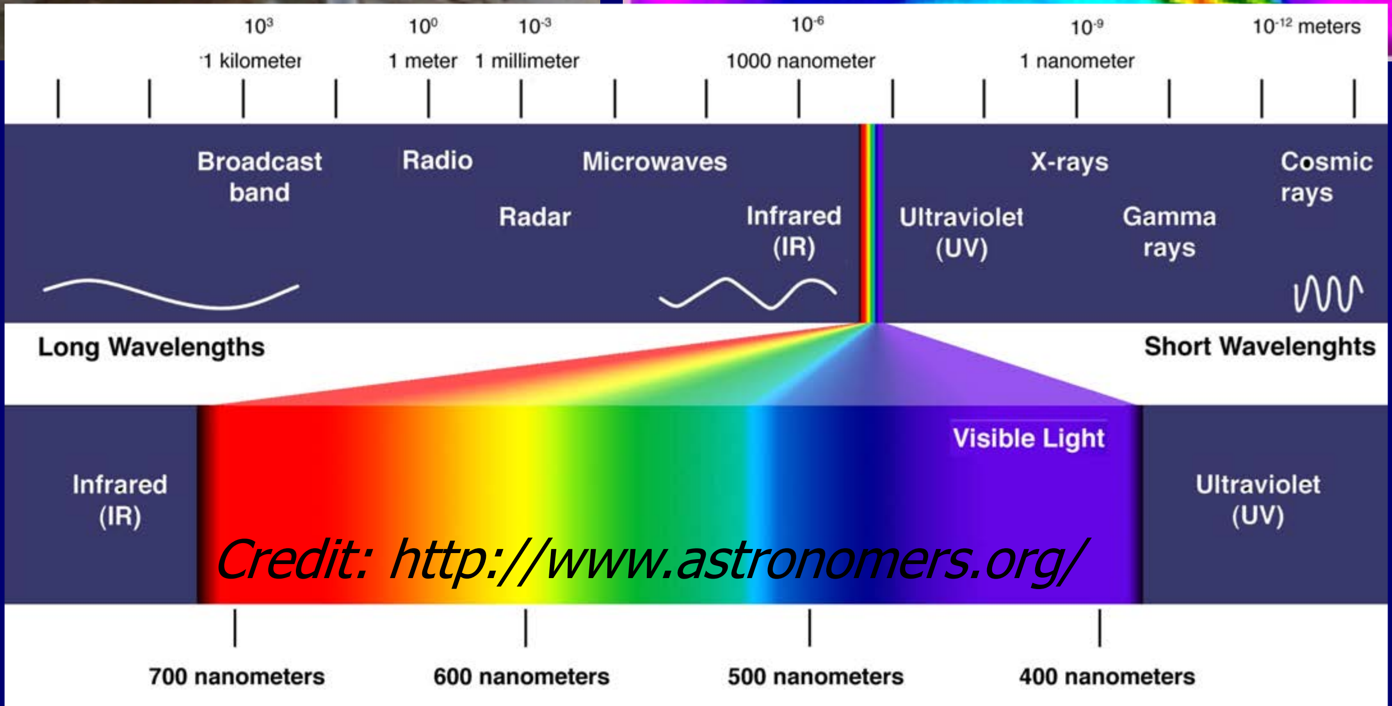
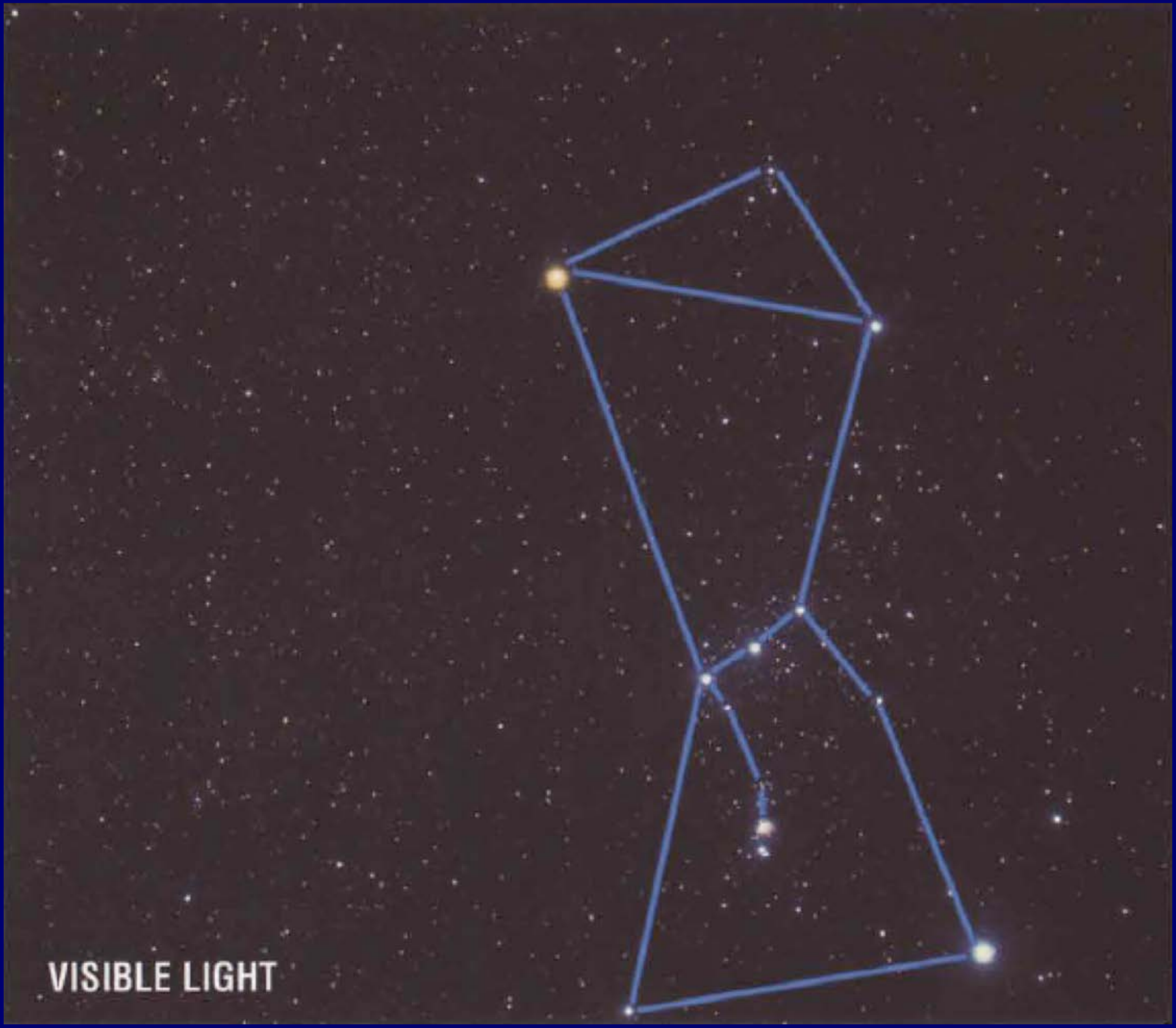
The electromagnetic spektrum

Credit: http://coolcosmos.ipac.caltech.edu/



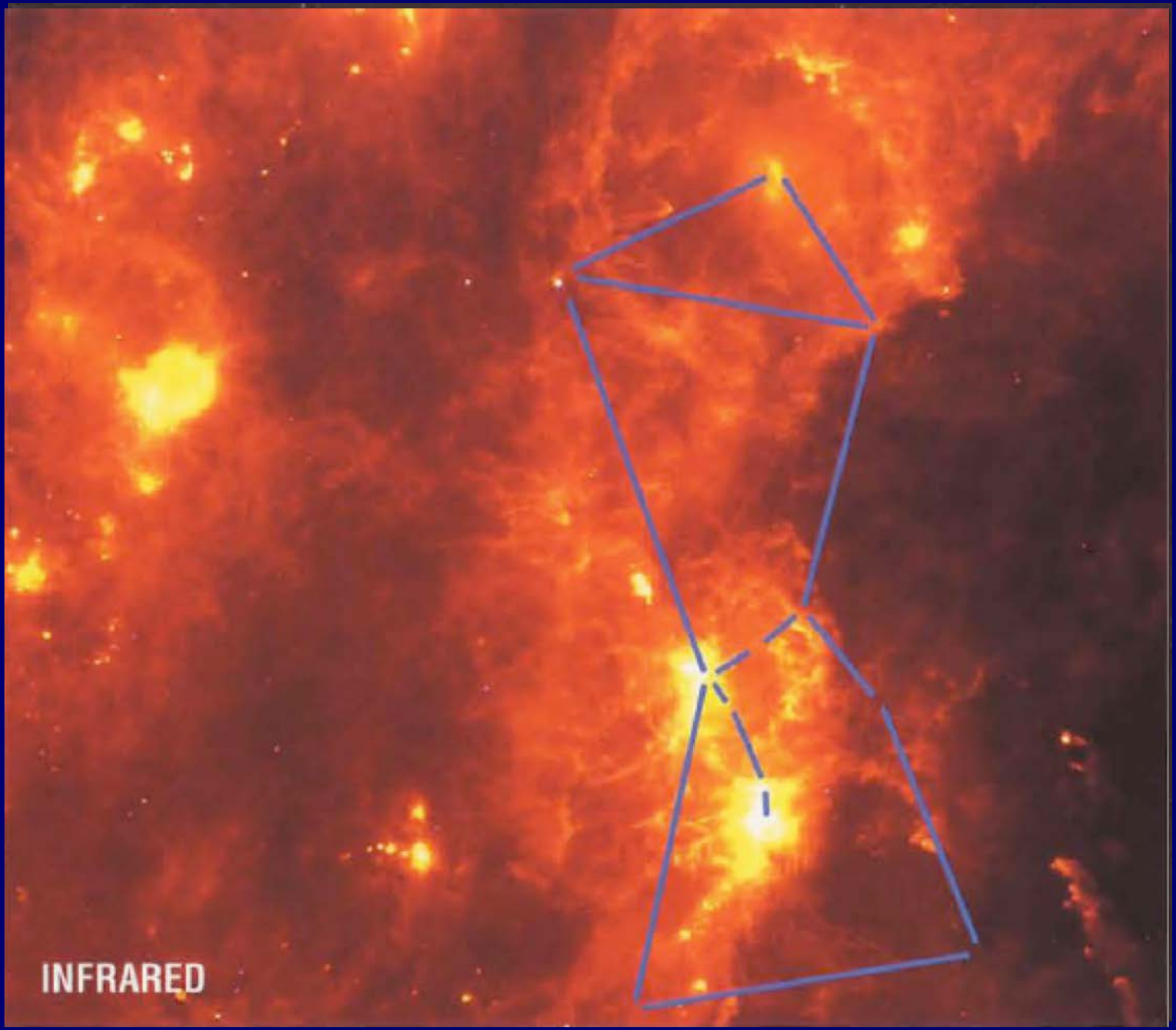
Credit: http://www.astronomers.org/

Orion



Credit:
IPAC
Caltech

Orion



Credit:
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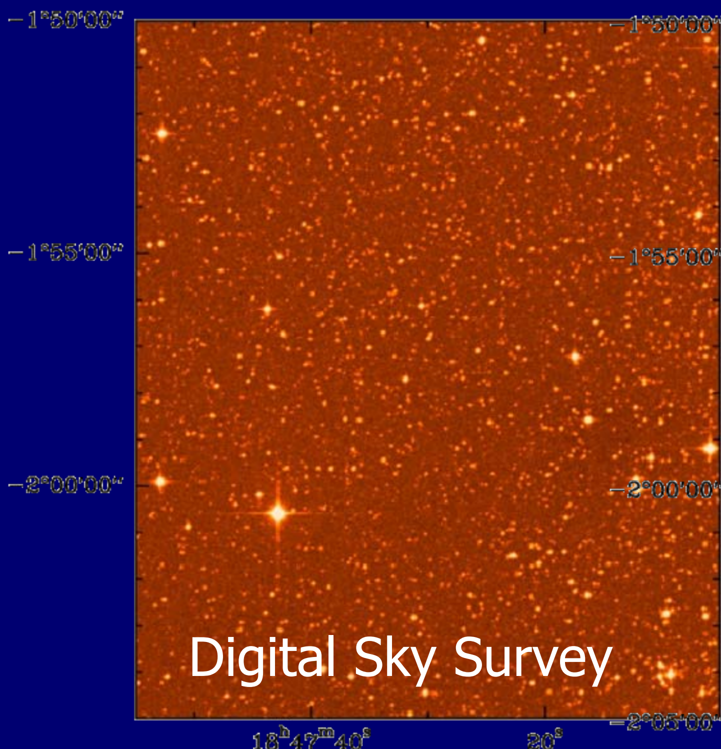
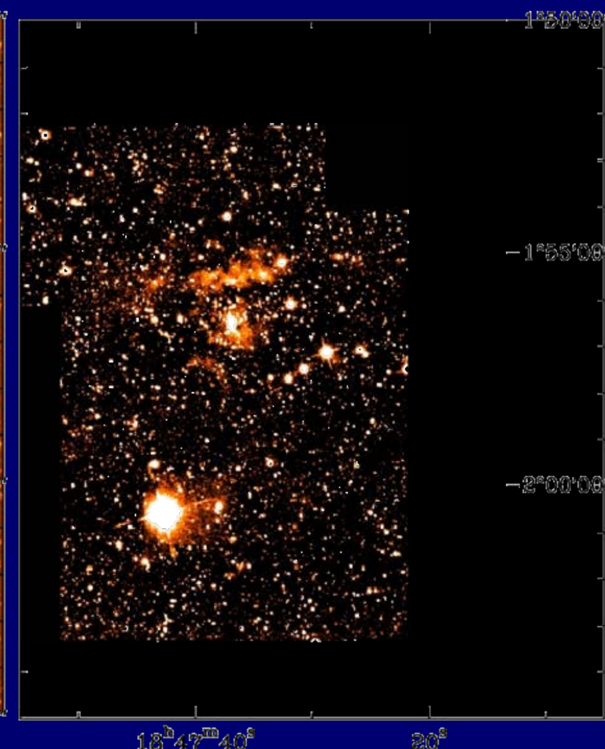
The Star-Forming Region W43

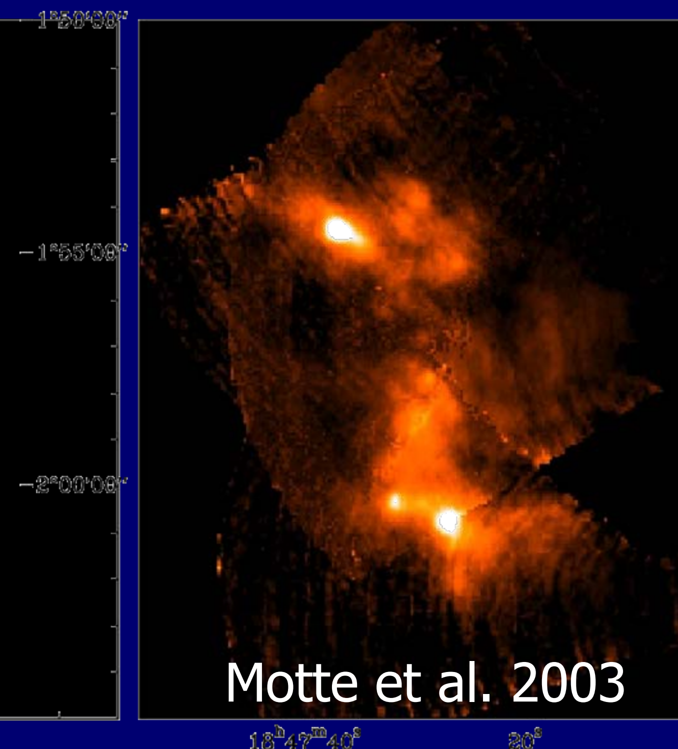
Optical



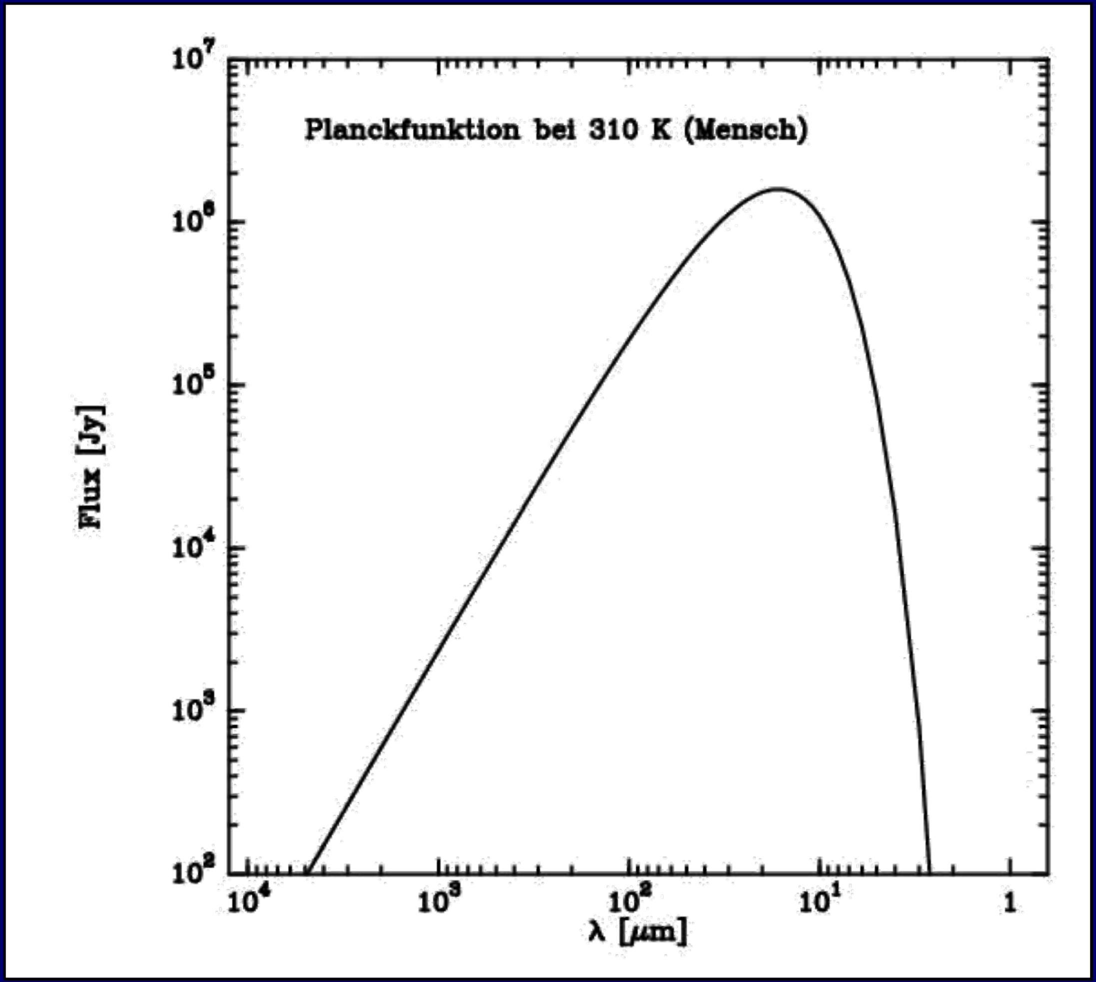
Near-Infrared



1.2mm dust cont.

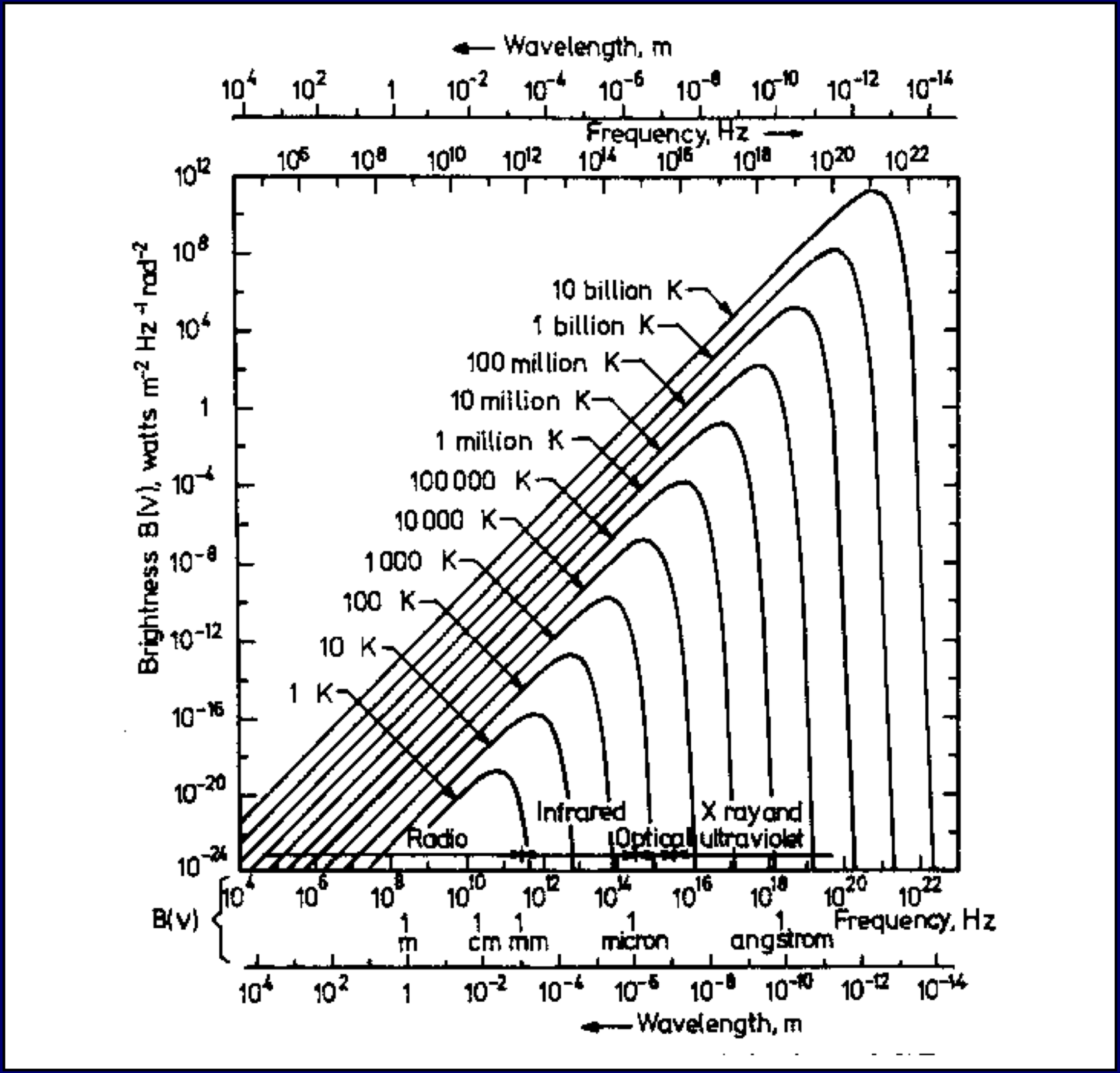


Planck's Black Body



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

Planck's Black Body



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

Wien's Law

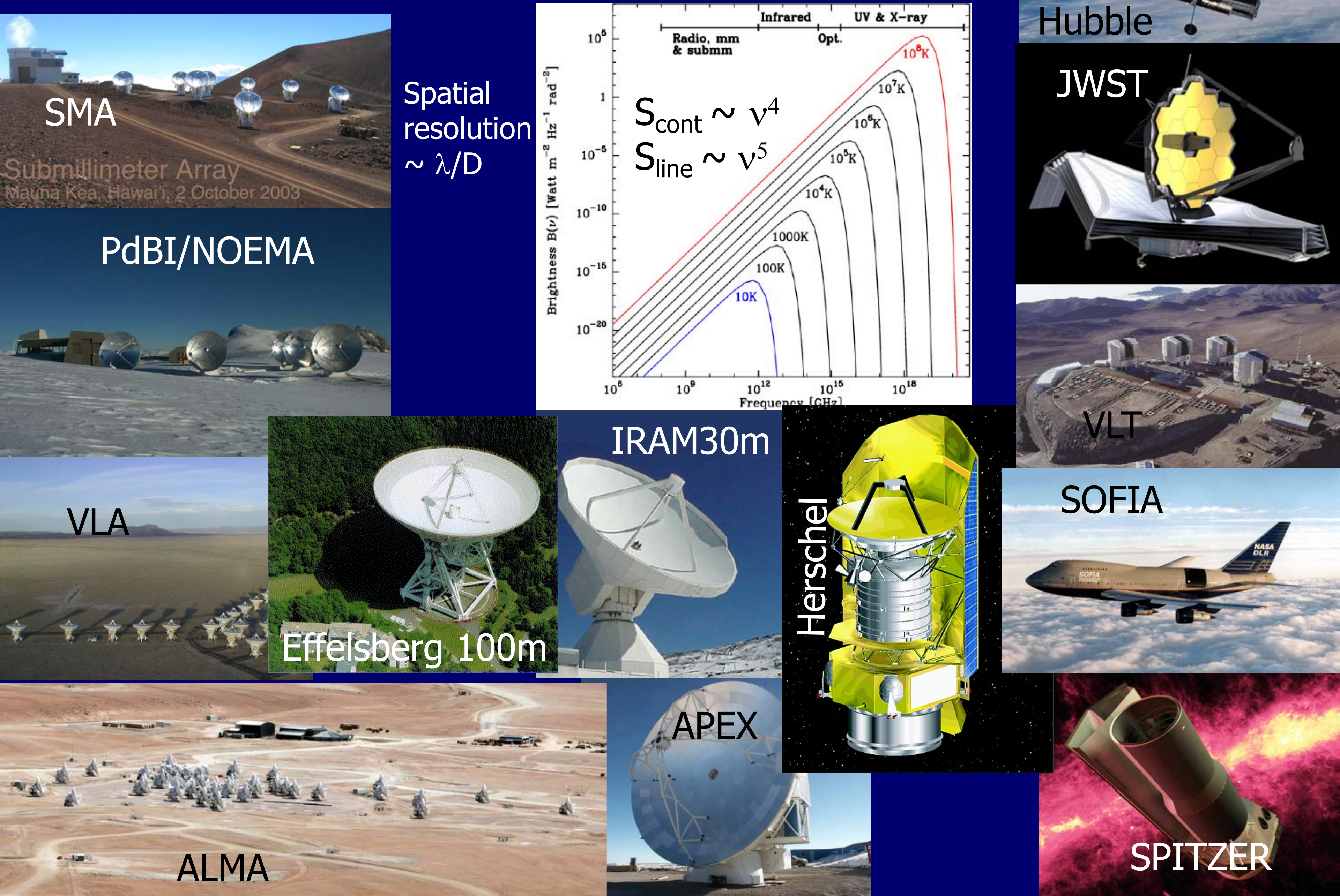
$$\lambda_{max} = 2.9/T \text{ [mm]}$$

Examples:

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

Observatories

Spatial resolution $\sim \lambda/D$



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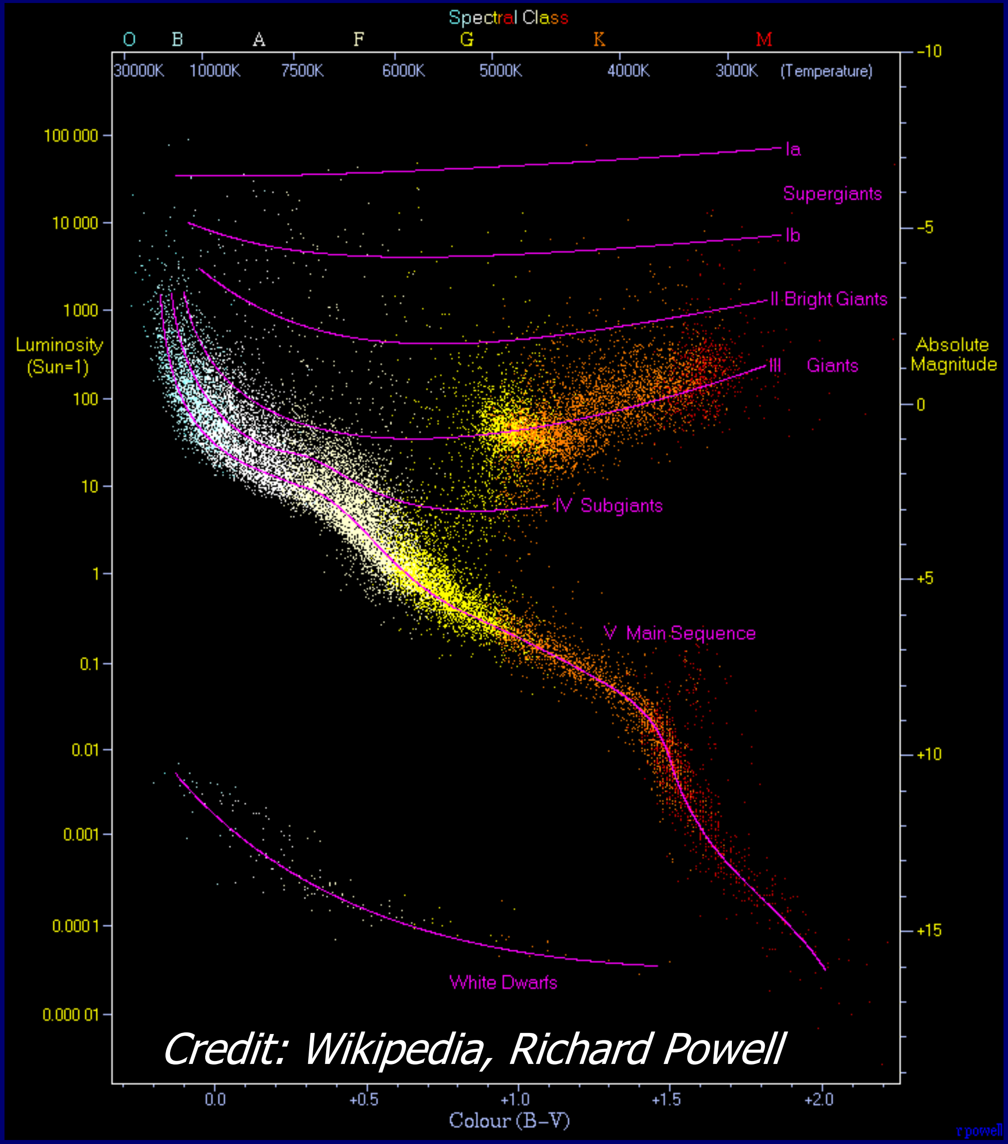
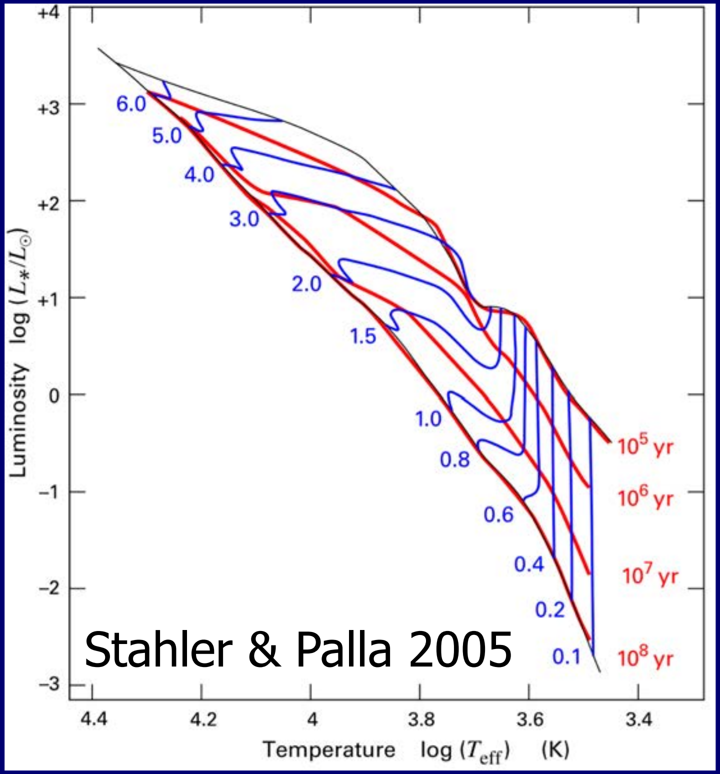
Hertzsprung-Russel diagram



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

Hertzsprung-Russel diagram



<u>Time-scales:</u>

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

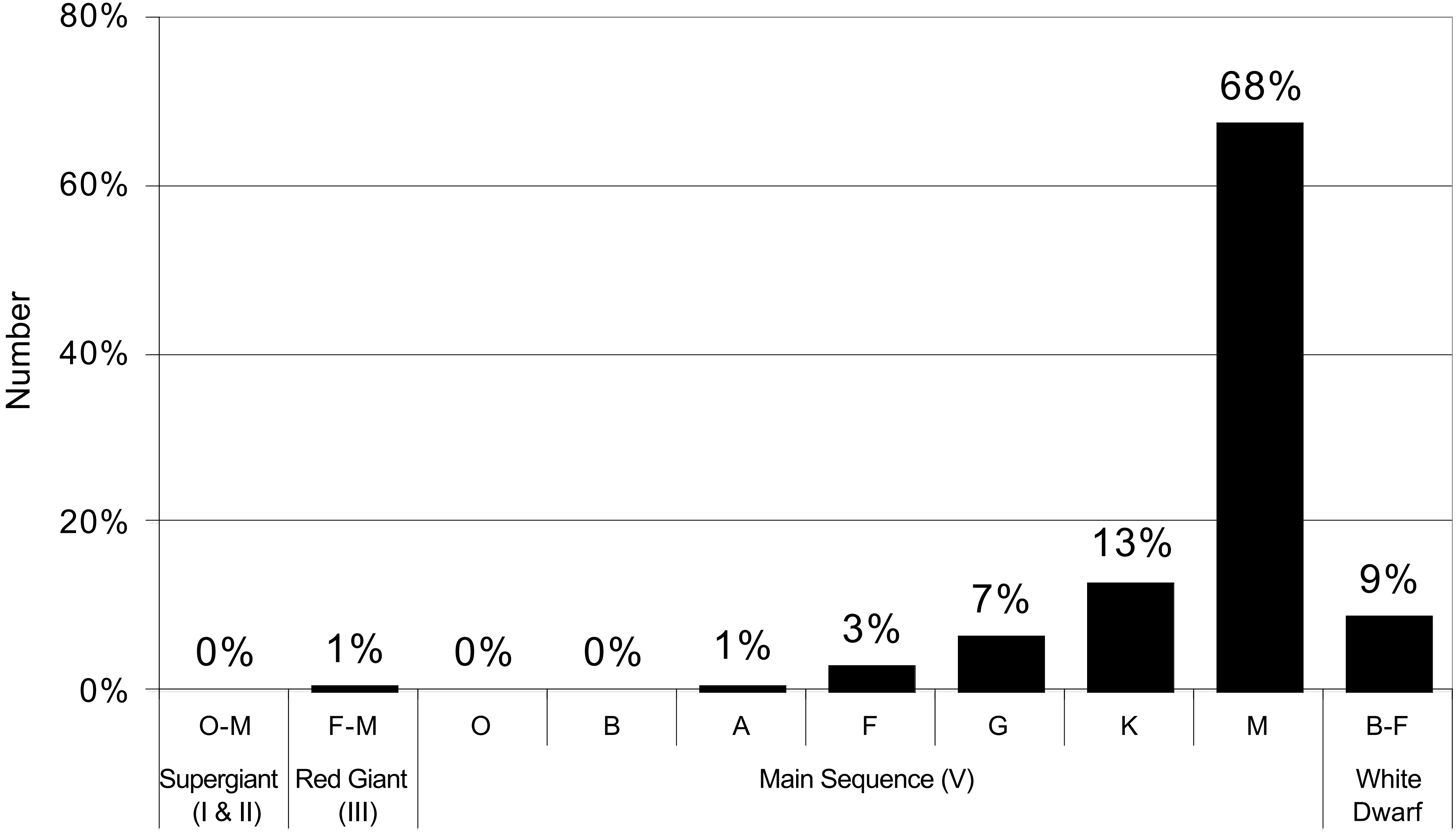
Properties of Main Sequence Stars

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	$>10^{11}$

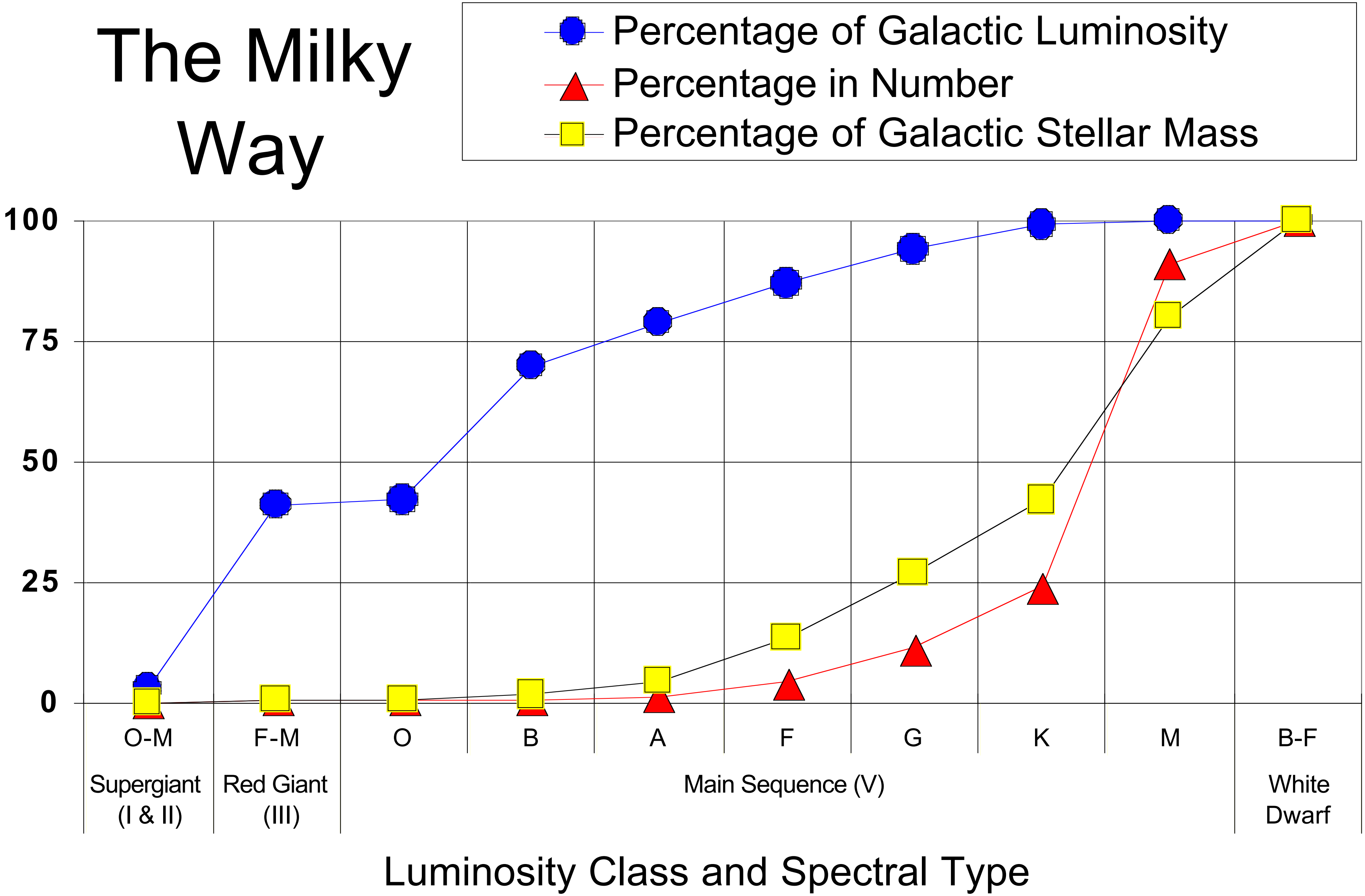
} greater than age of universe

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

Number of Stellar Types in the Milky Way



The Milky Way



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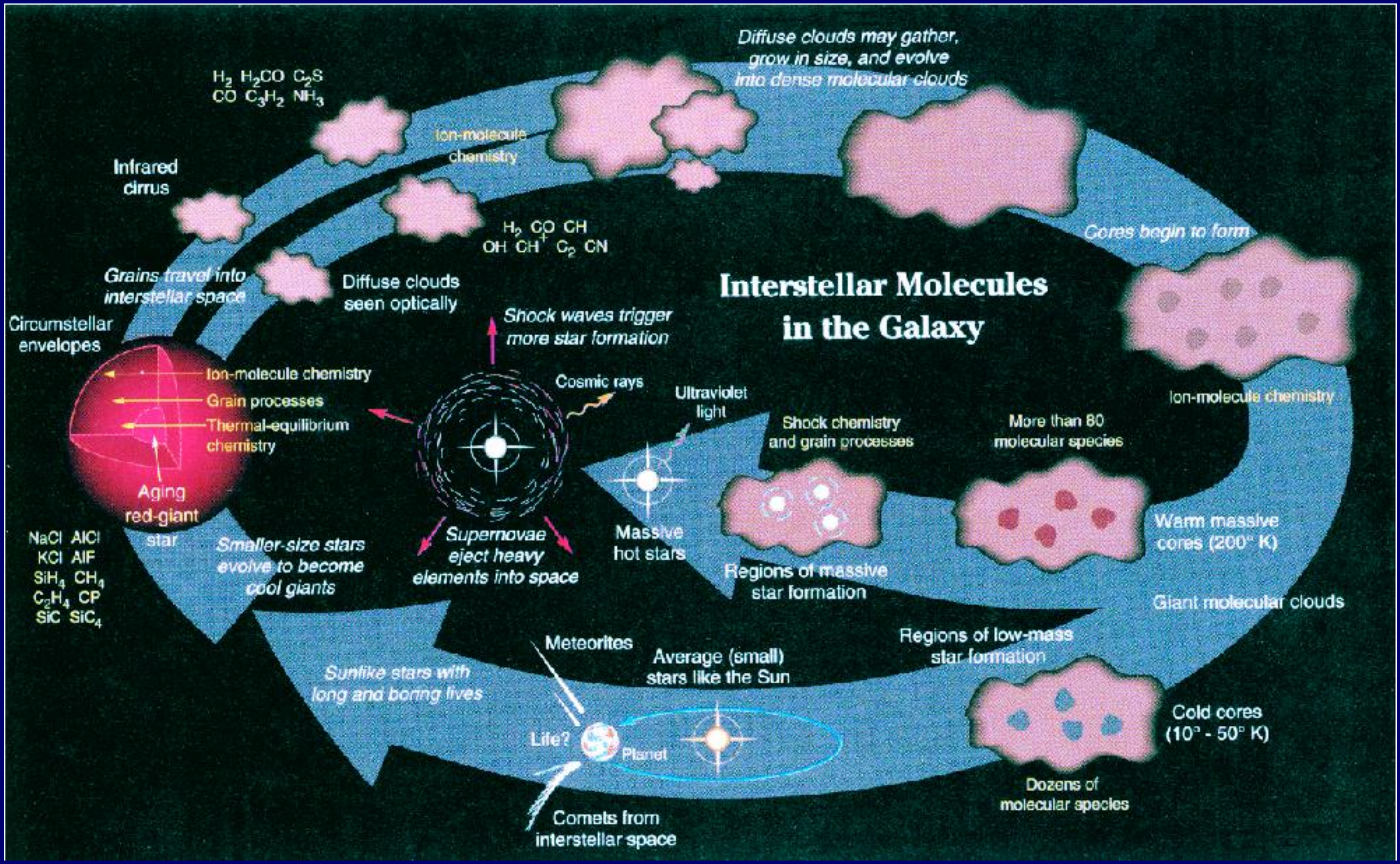
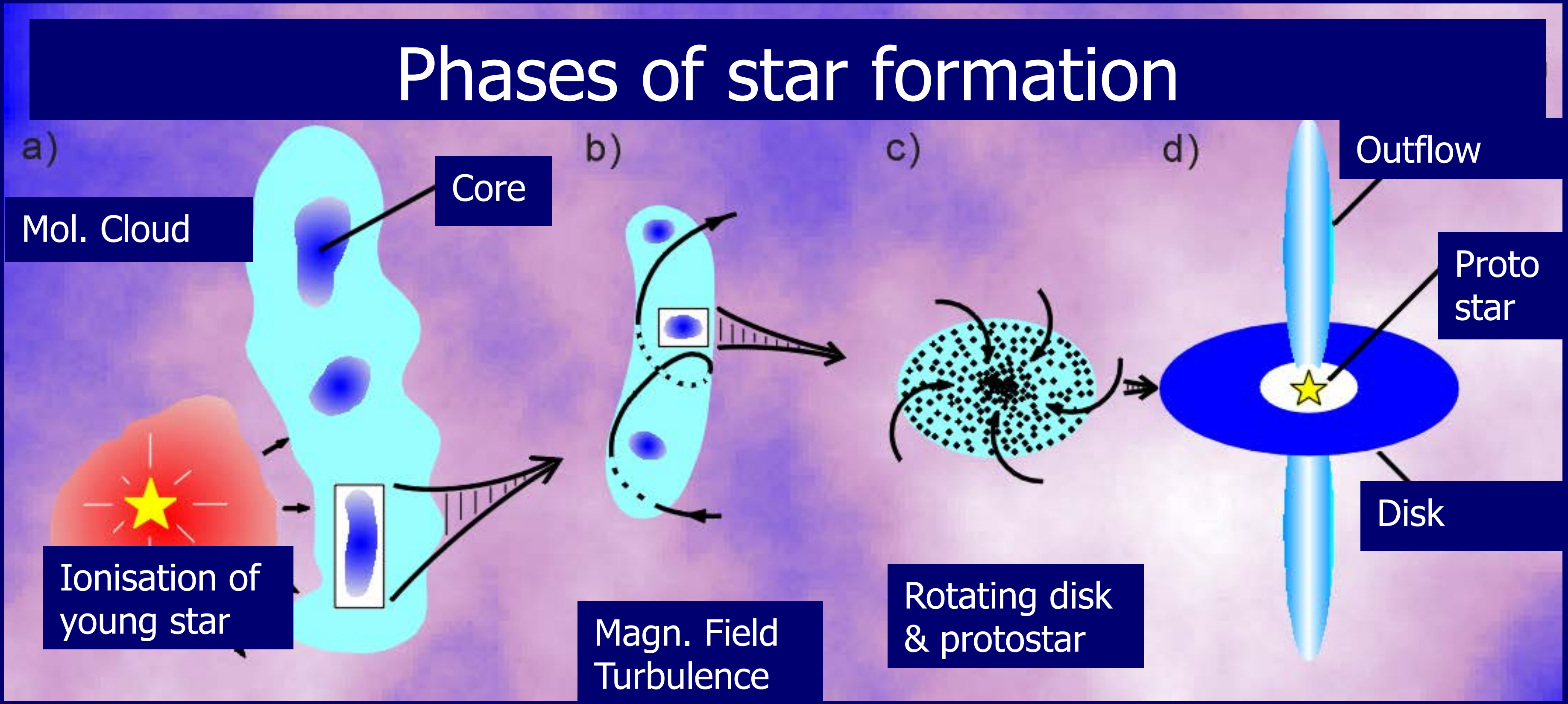
The cosmic cycle



http://www.astro.uni-koeln.de

Star formation paradigm



https://www.mpifr-bonn.mpg.de/473576/starform

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

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