Week 10: ISM & Stellar Remnants

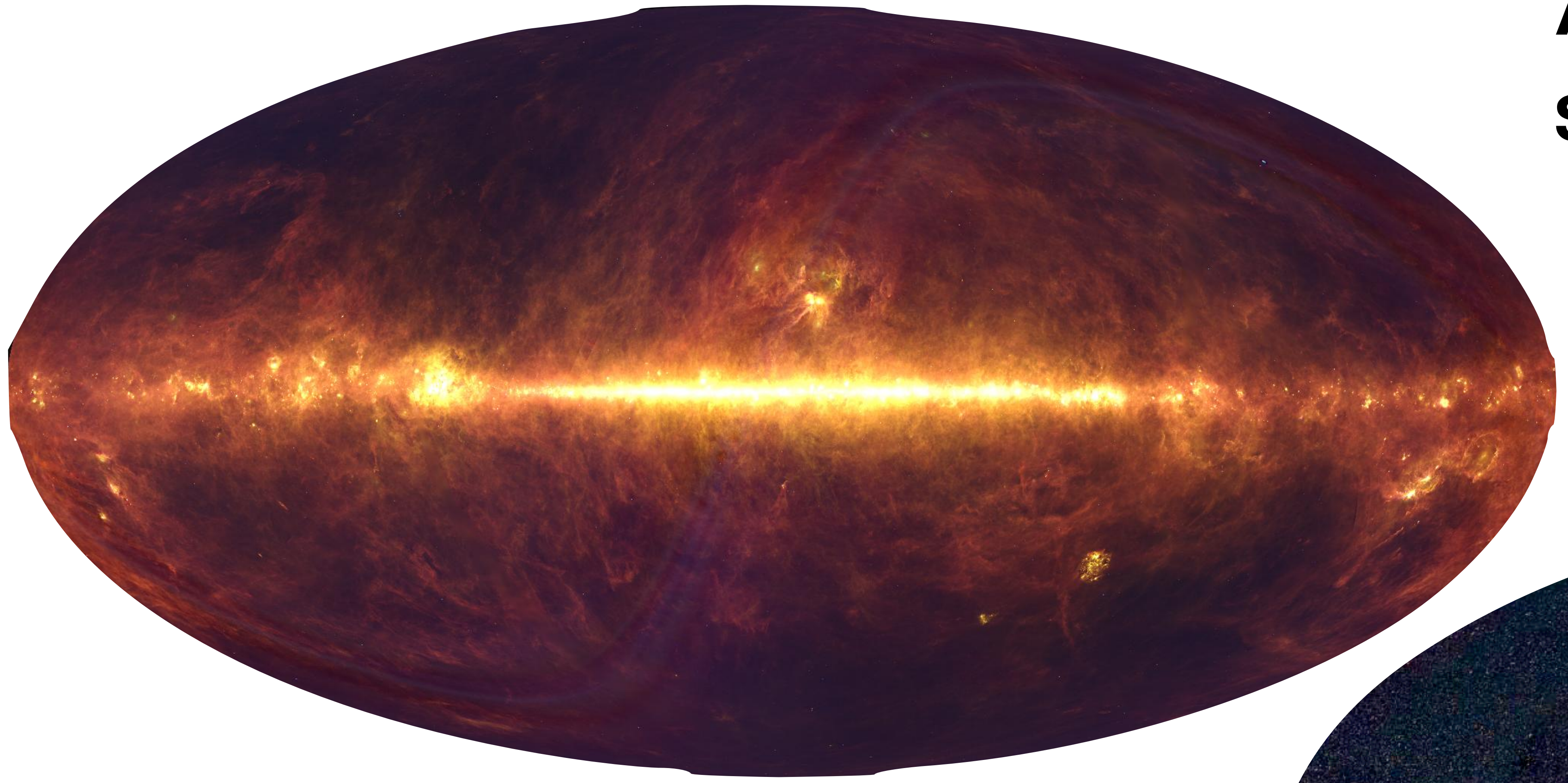
HW8 due Thursday

Read Ch. 16.1-2, 18

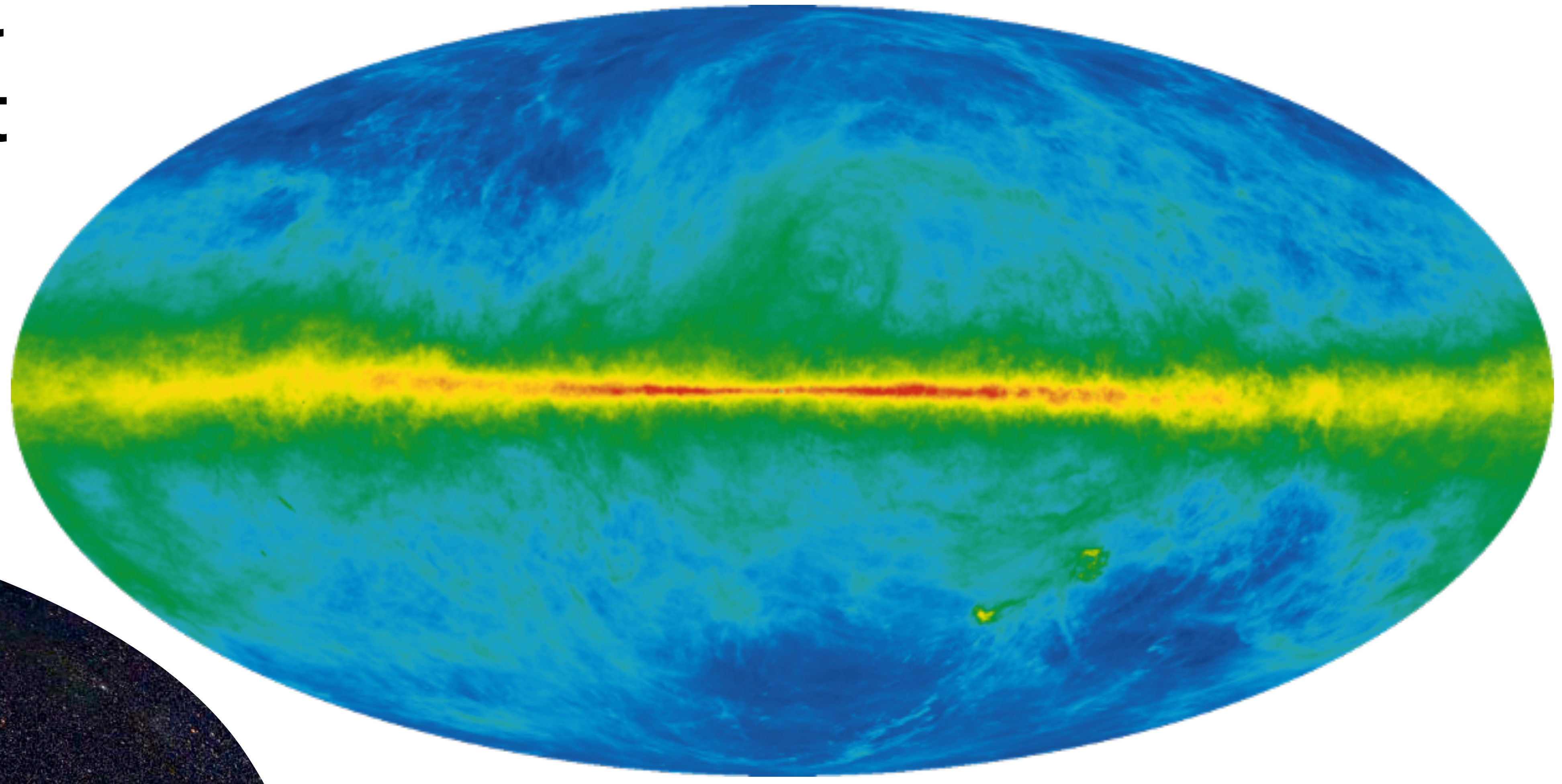
Interstellar Medium (ISM)

All the diffuse stuff in b/t stars and other compact objects in the MW

Hot Dust (far IR)

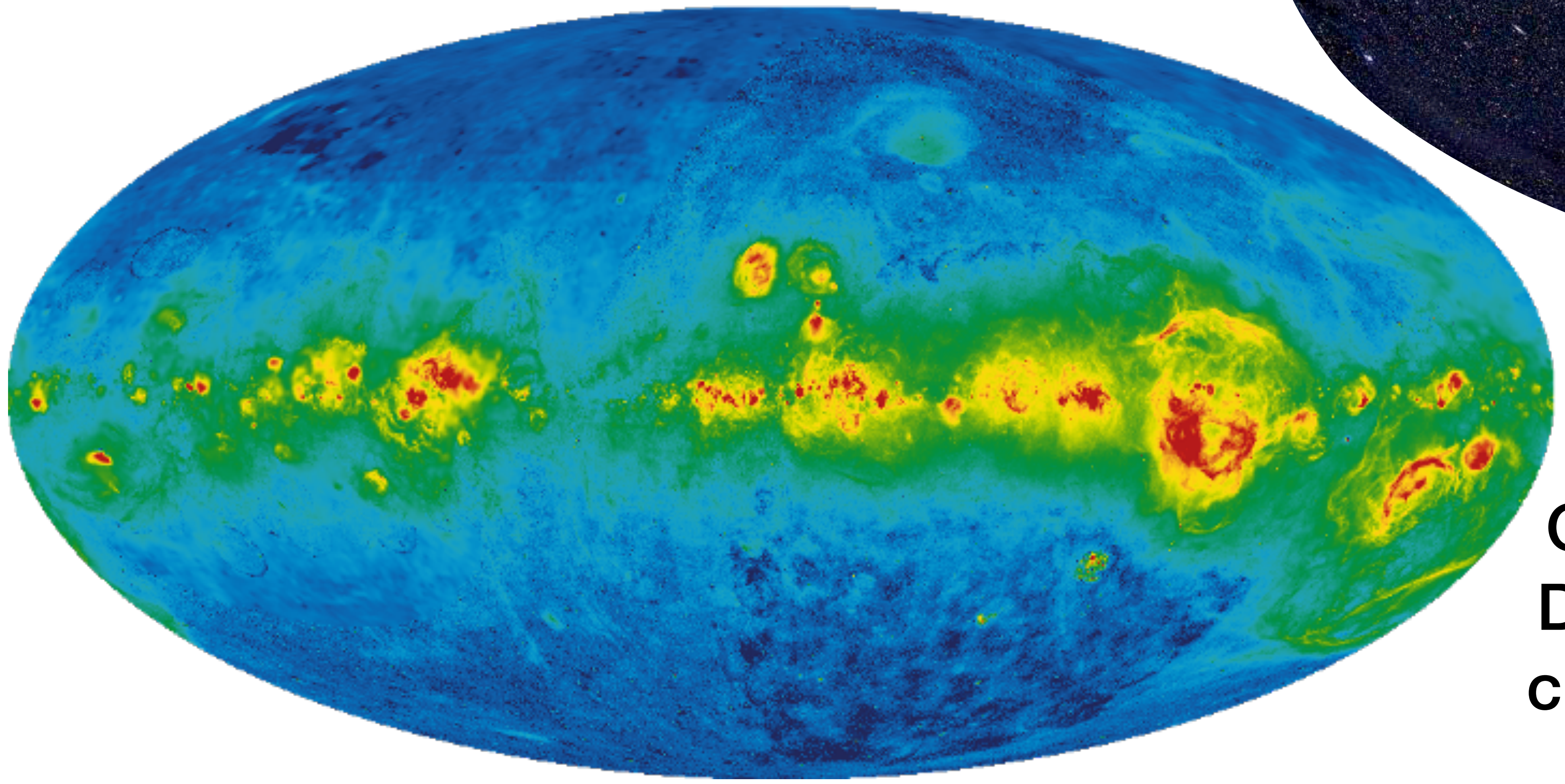


Neutral H (21cm; radio)

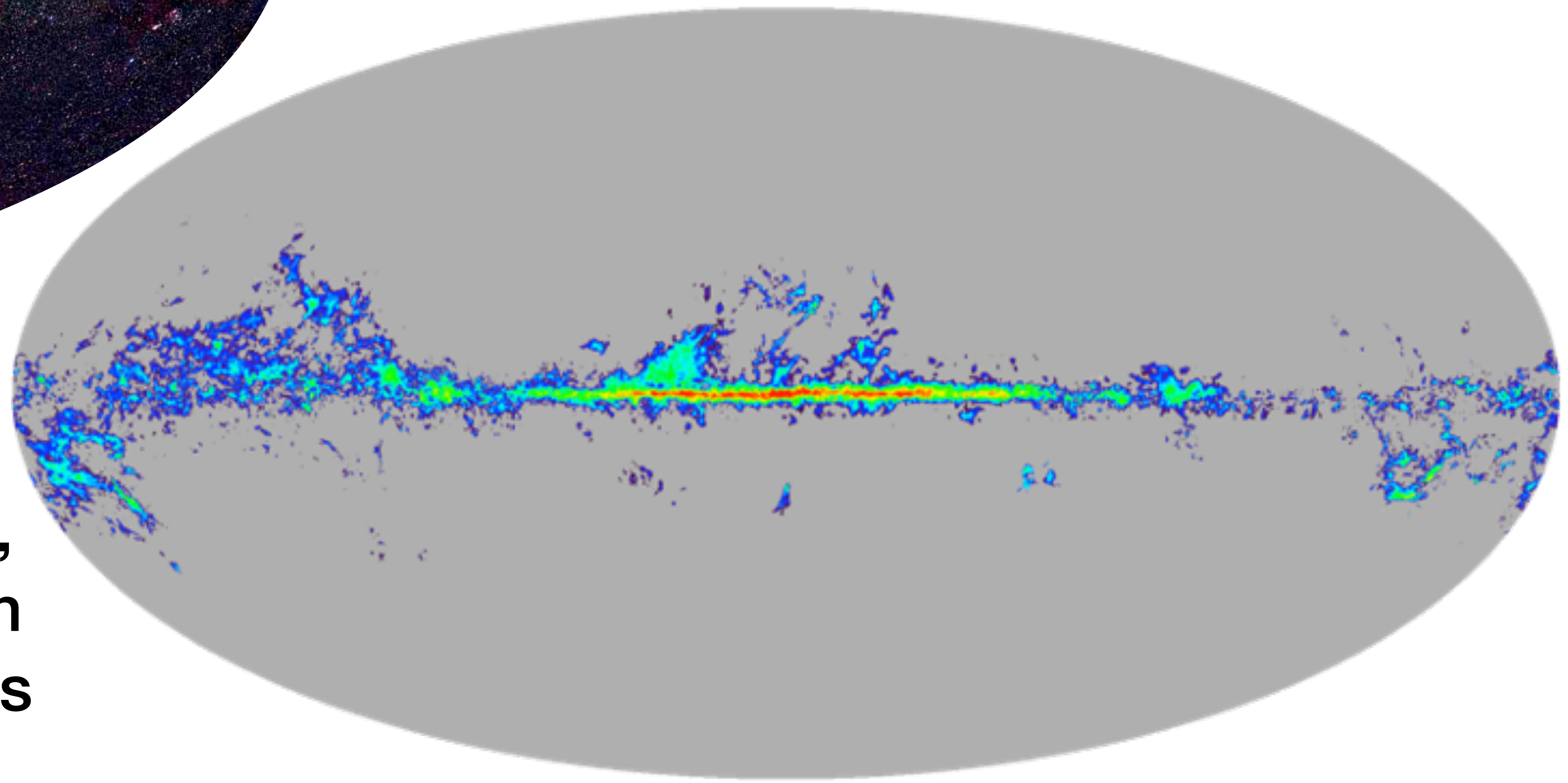


Stars (visible)

Balmer line n=3->2 (656.3 nm)



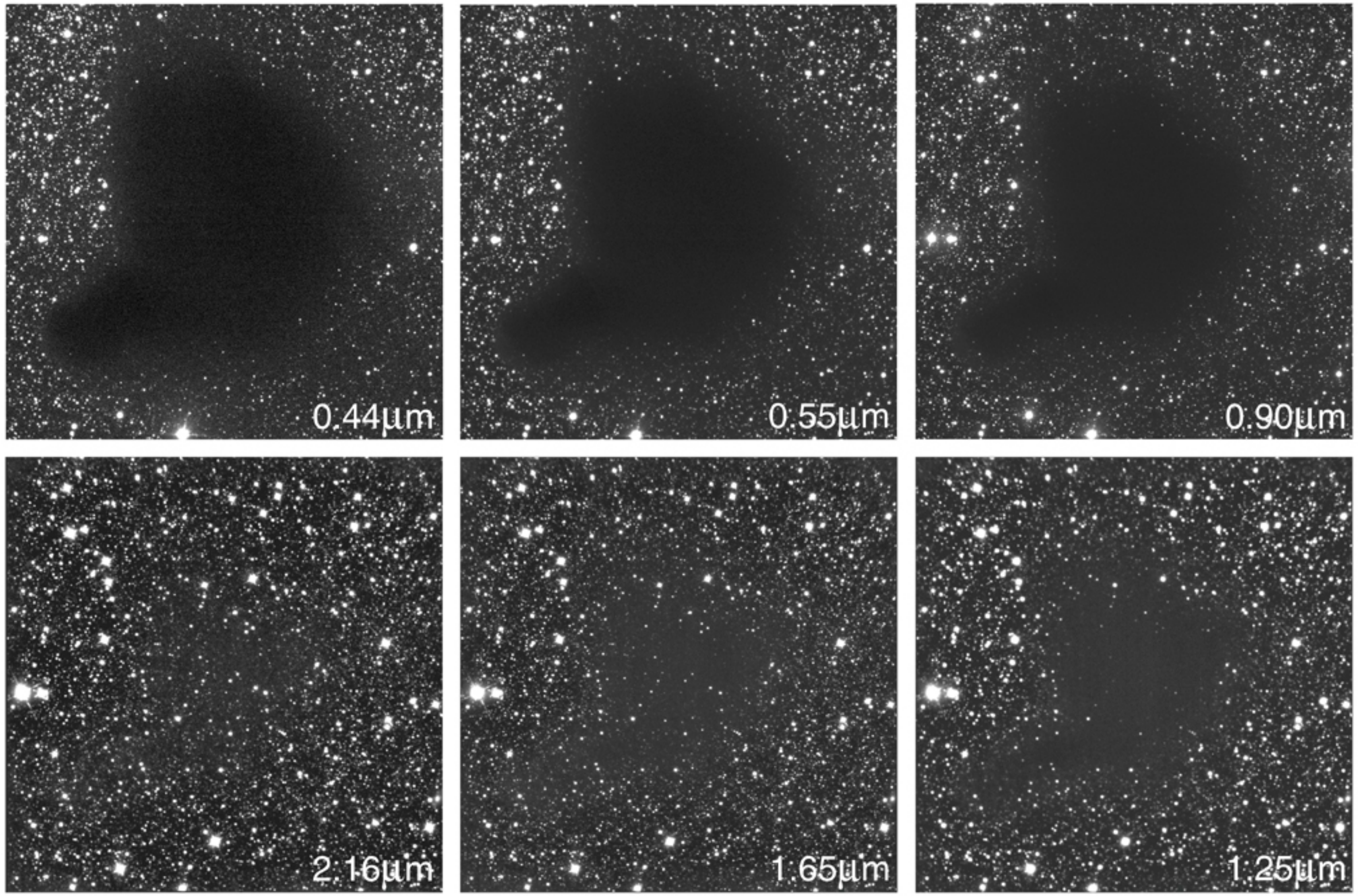
CO (2.6 mm; microwave)



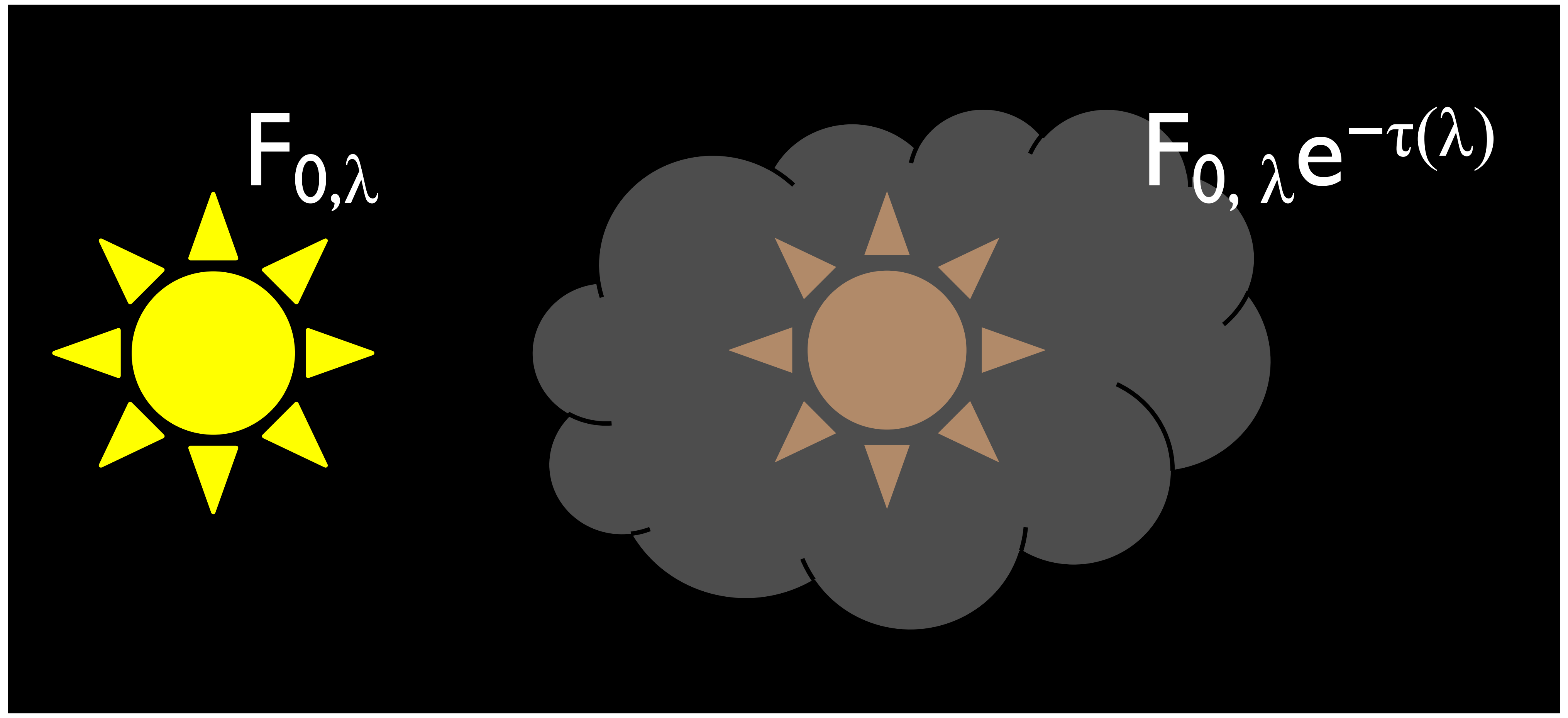
Gas (ionized, neutral, molecules), Dust (large molecules, singly or in clumps), & relativistic components (magnetic fields, cosmic rays)

Dust blocks starlight: Extinction

Barnard 68



Extinction messes up magnitudes AND colors



$$F_\lambda = F_{0,\lambda}e^{-\tau} = F_{0,\lambda}e^{-n\sigma r}$$

$$\begin{aligned} m_{\rm obs} &= C - 2.5\log(F) \\ &= C - 2.5\log(F_0) - 2.5\log(e^{-\tau}) \\ &= m_0 + 2.5\tau\log e \\ &= m_0 + 1.086\tau \end{aligned}$$

Correcting Magnitudes

$$m_{\rm obs}(\lambda) = m_0(\lambda) + A(\lambda)$$

$$\text{e.g., } m_{V,\rm obs} = m_V + A_V$$
$$= V_0 + A_V$$

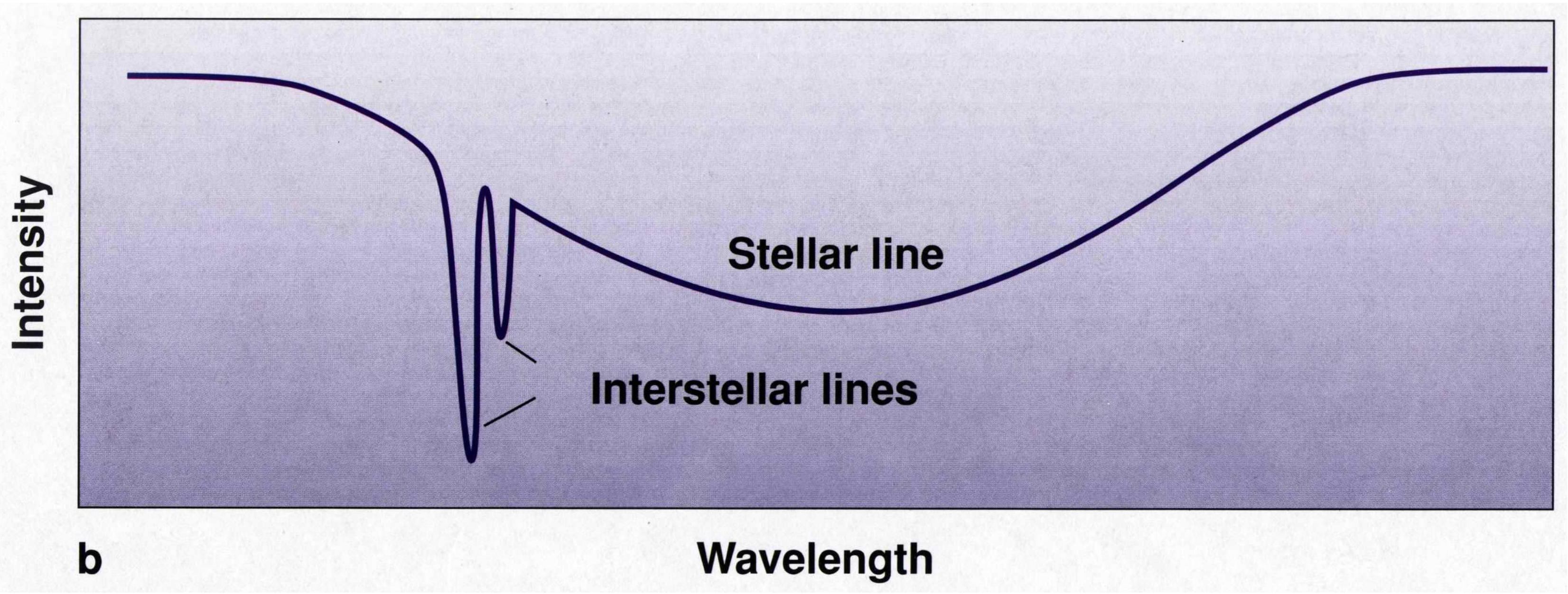
Correcting Colors

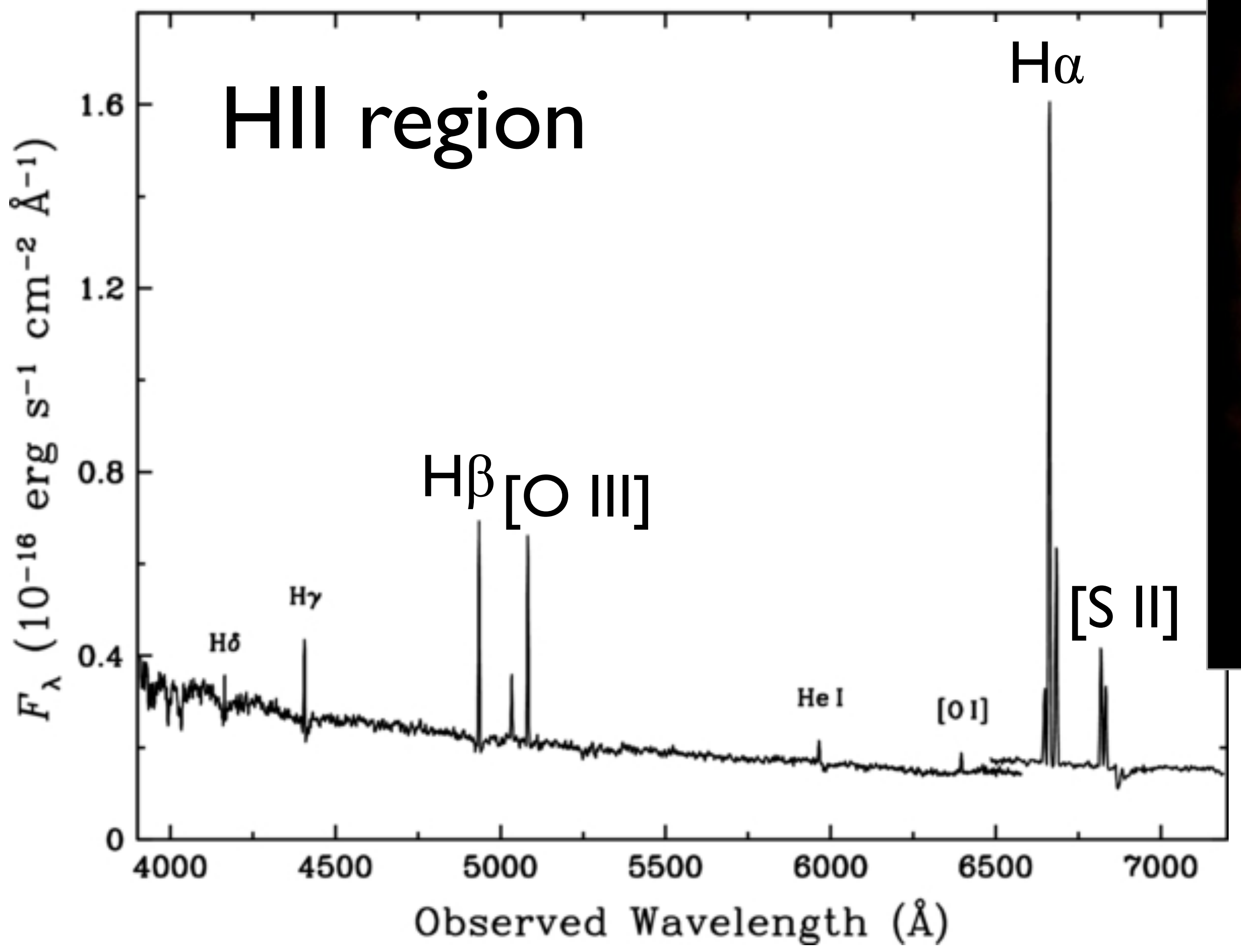
$$\begin{aligned} (B-V)_{\rm obs} &= (B-V)_0 + (A_B + A_V) \\ &= (B-V)_0 + E(B-V) \end{aligned}$$

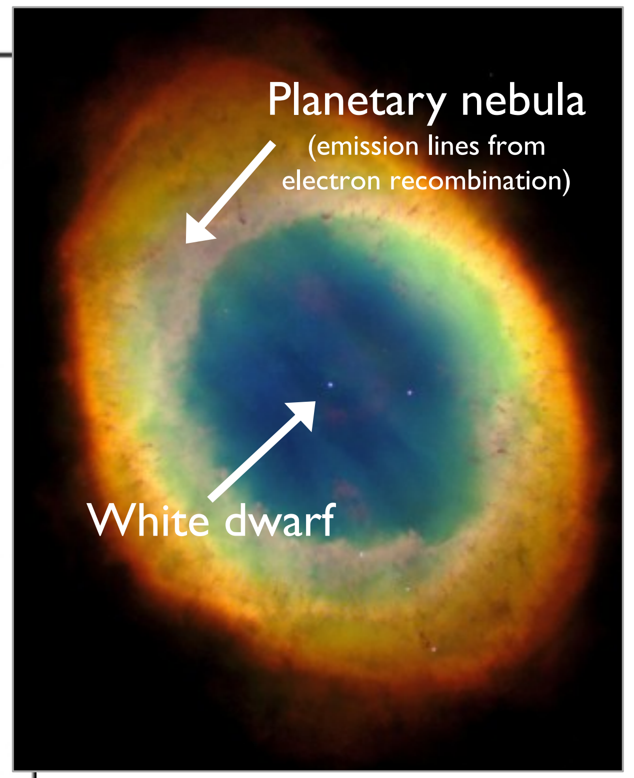
$$R \equiv \frac{A_V}{E(B-V)} \approx 3.1$$

Detection of gas is generally more direct

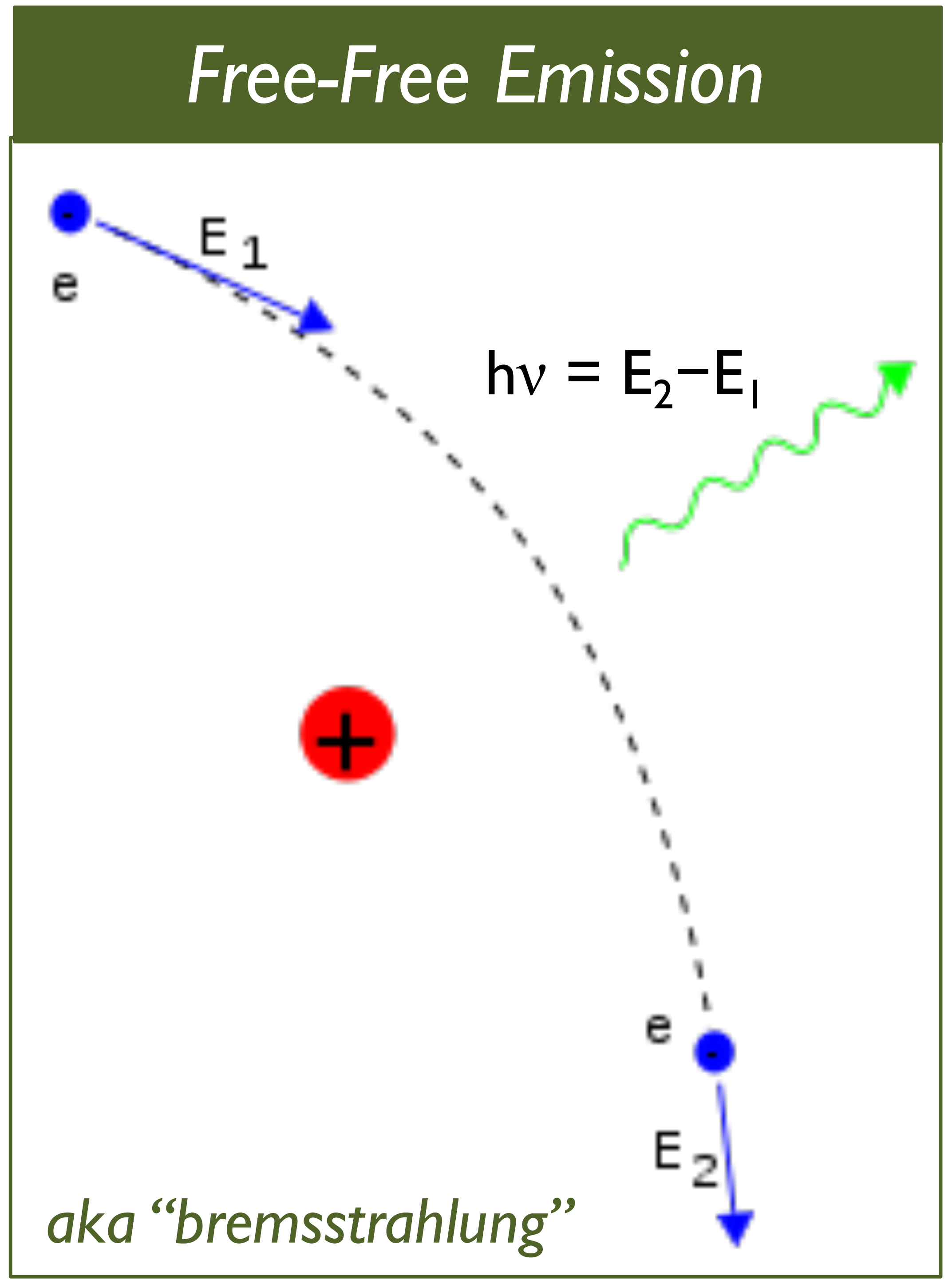
Absorption & Emission Lines (Kirchoff's laws)



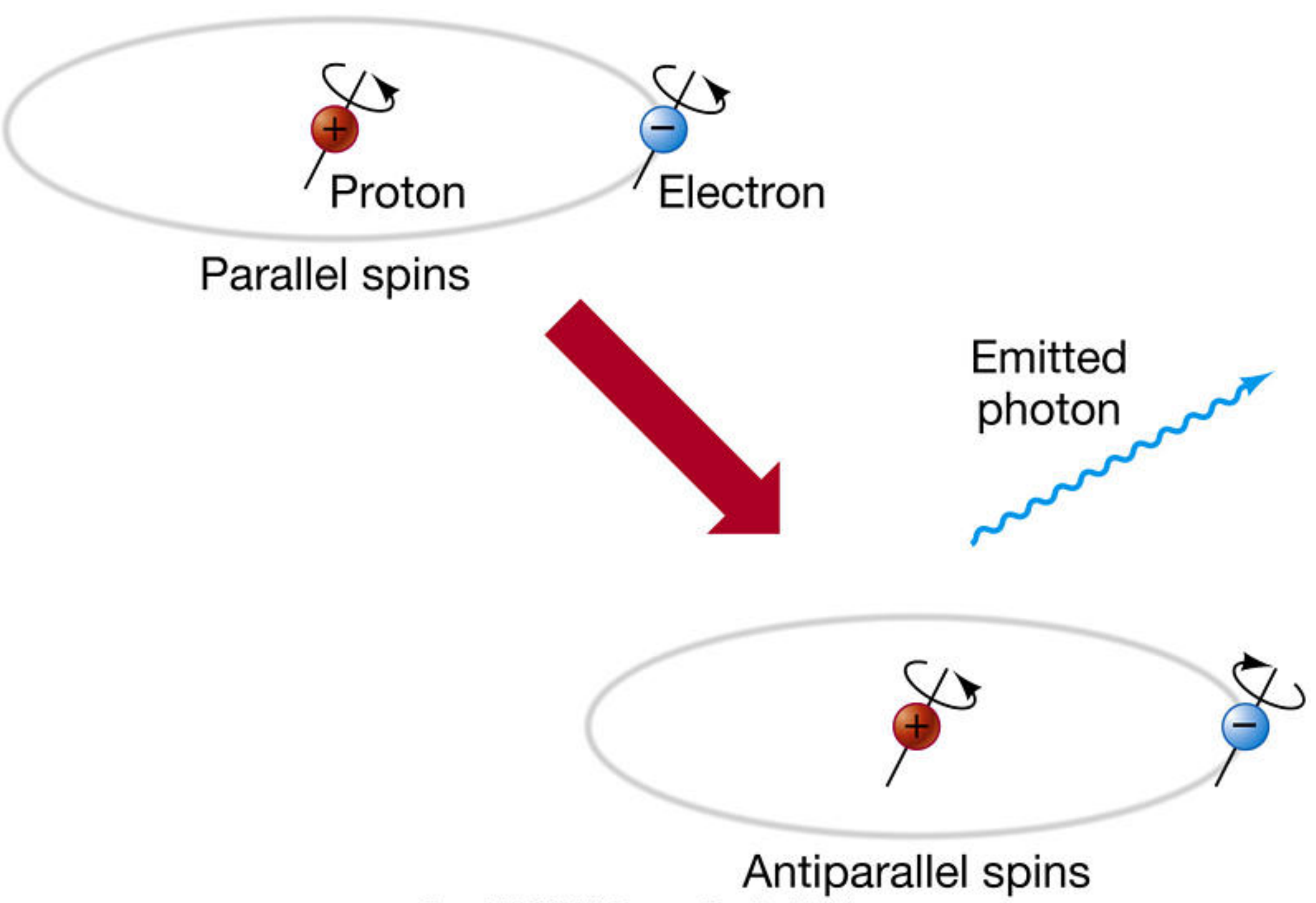




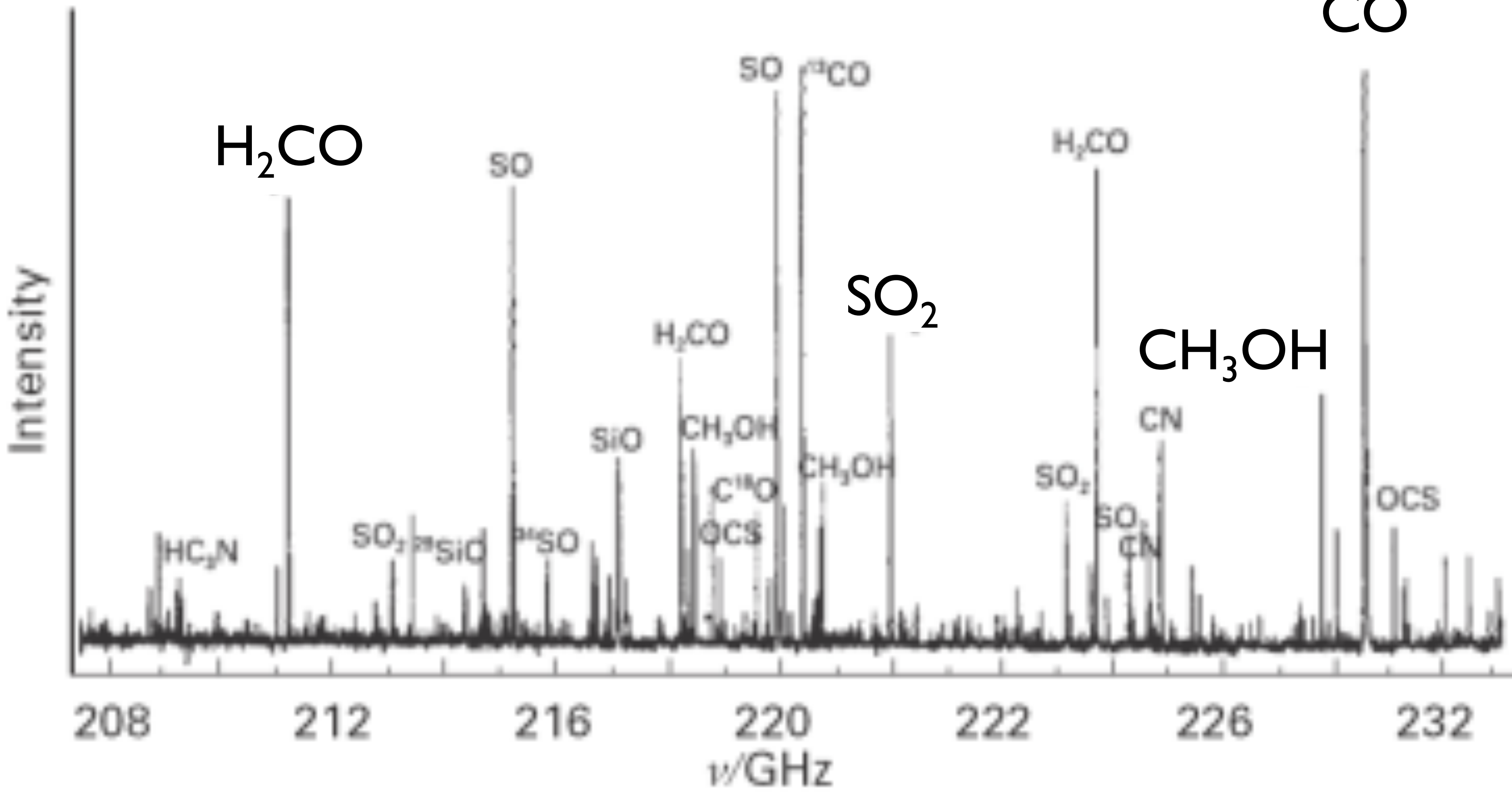
Radio continuum

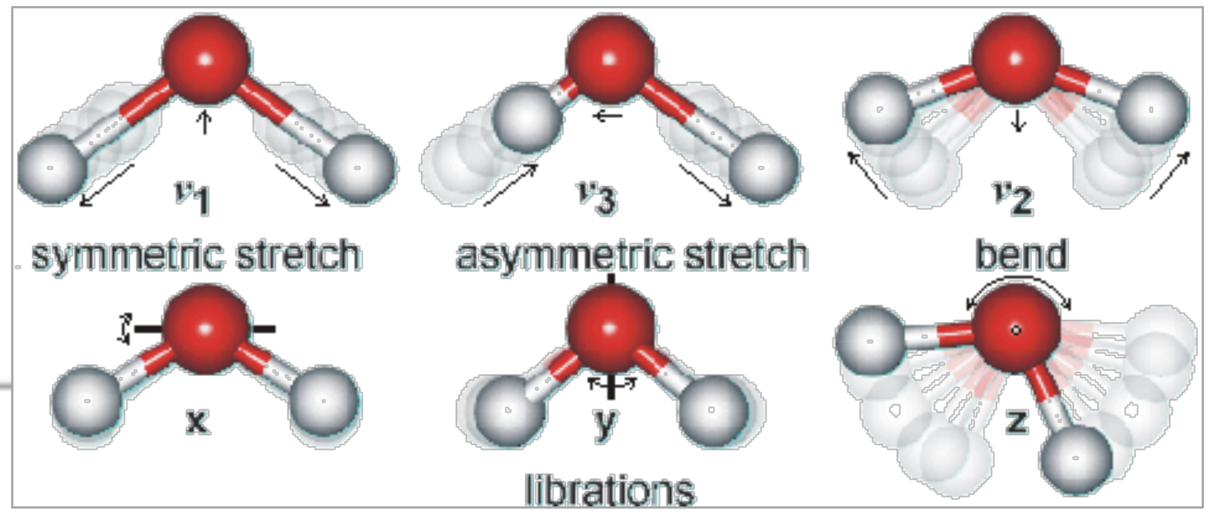


Neutral H "spin-flip": 21cm emission line



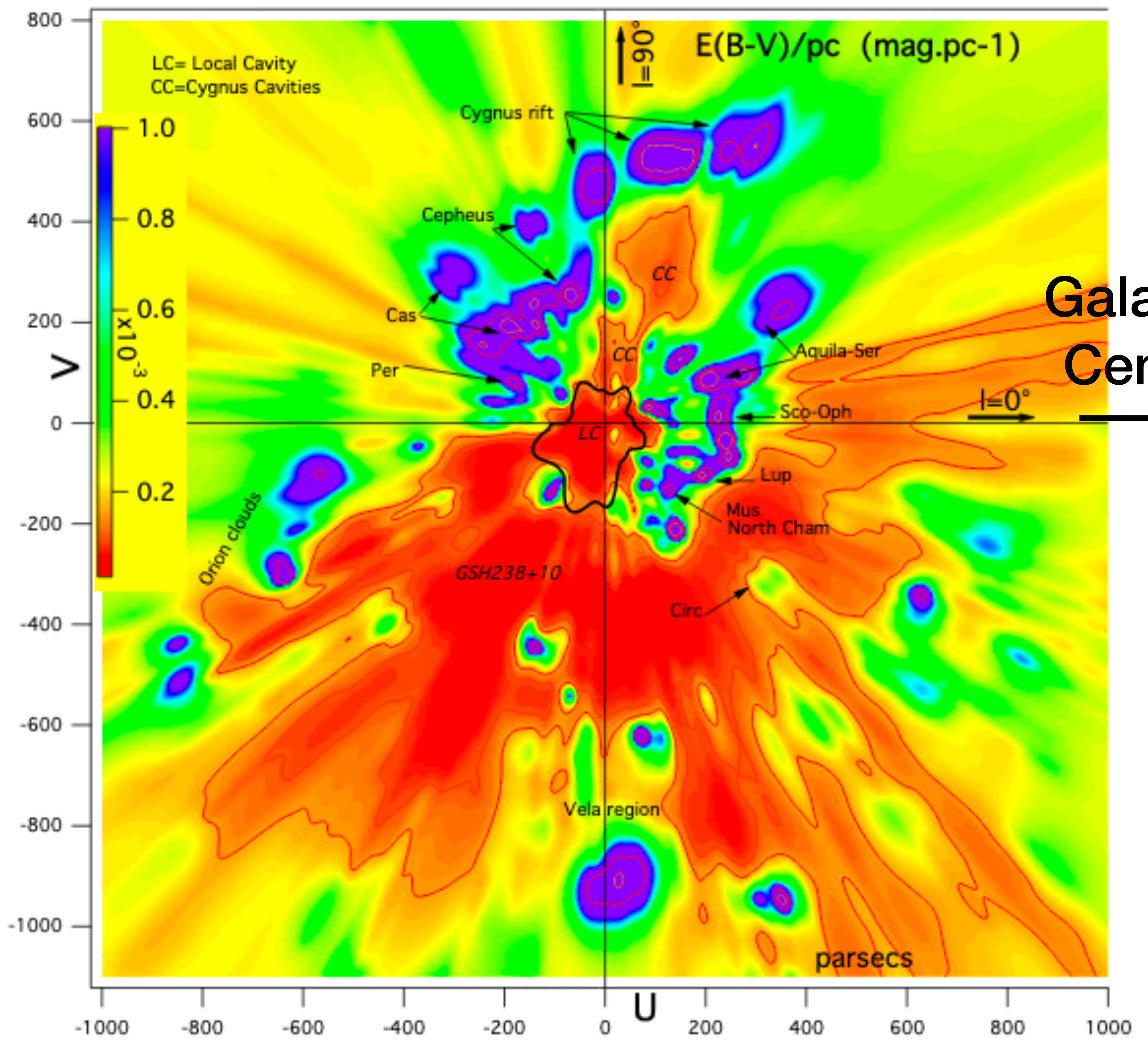
Molecule excitations (radio)





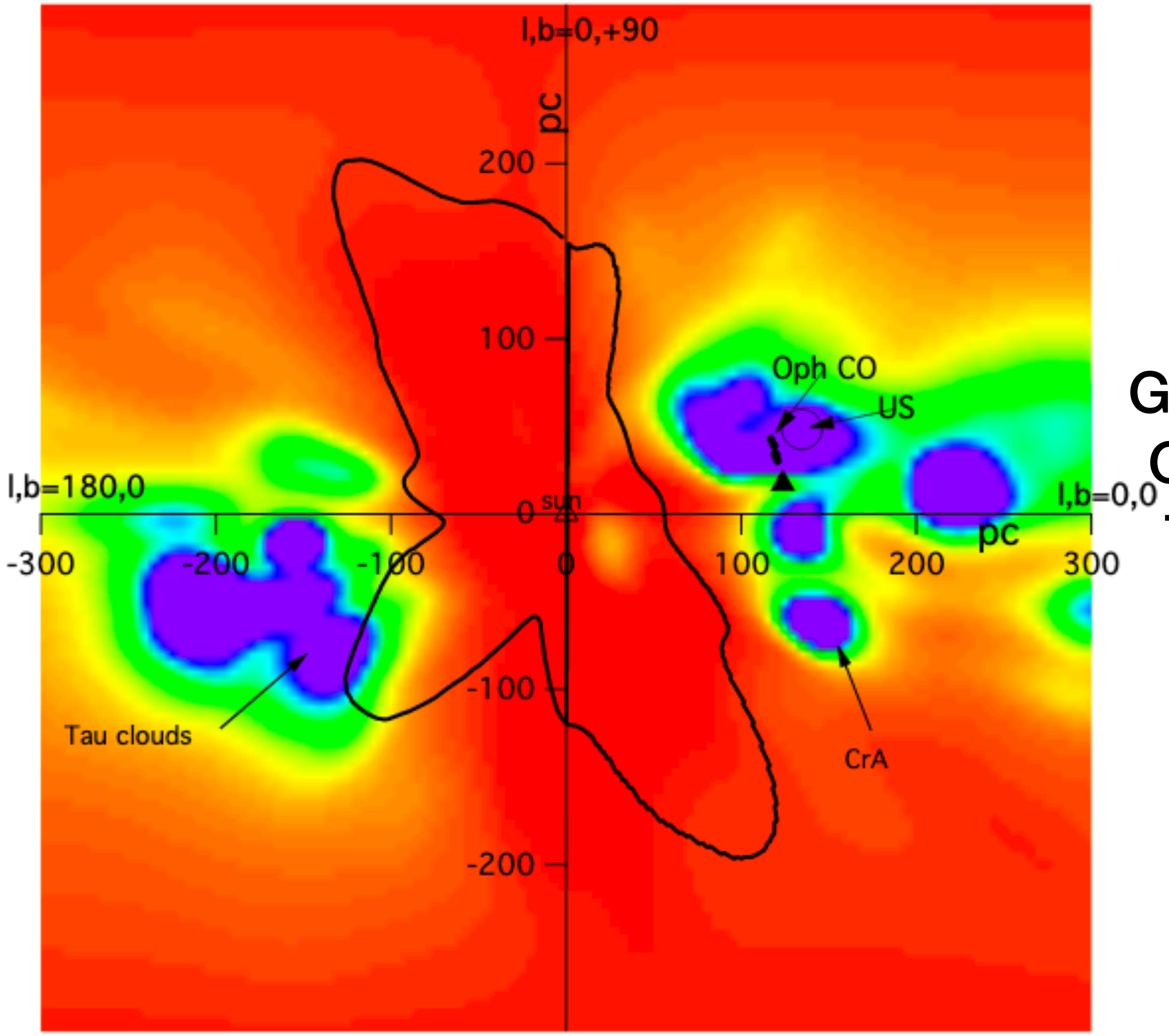
ISM also contains very hot gas heated by SNe

Face-on disk view



Galactic Center

Edge-on disk view



Galactic Center

All these gas "phases" are in pressure equilibrium

Cold Molecular Clouds:
$T \sim 10$ K, $n \sim 10^9$ m^{-3}

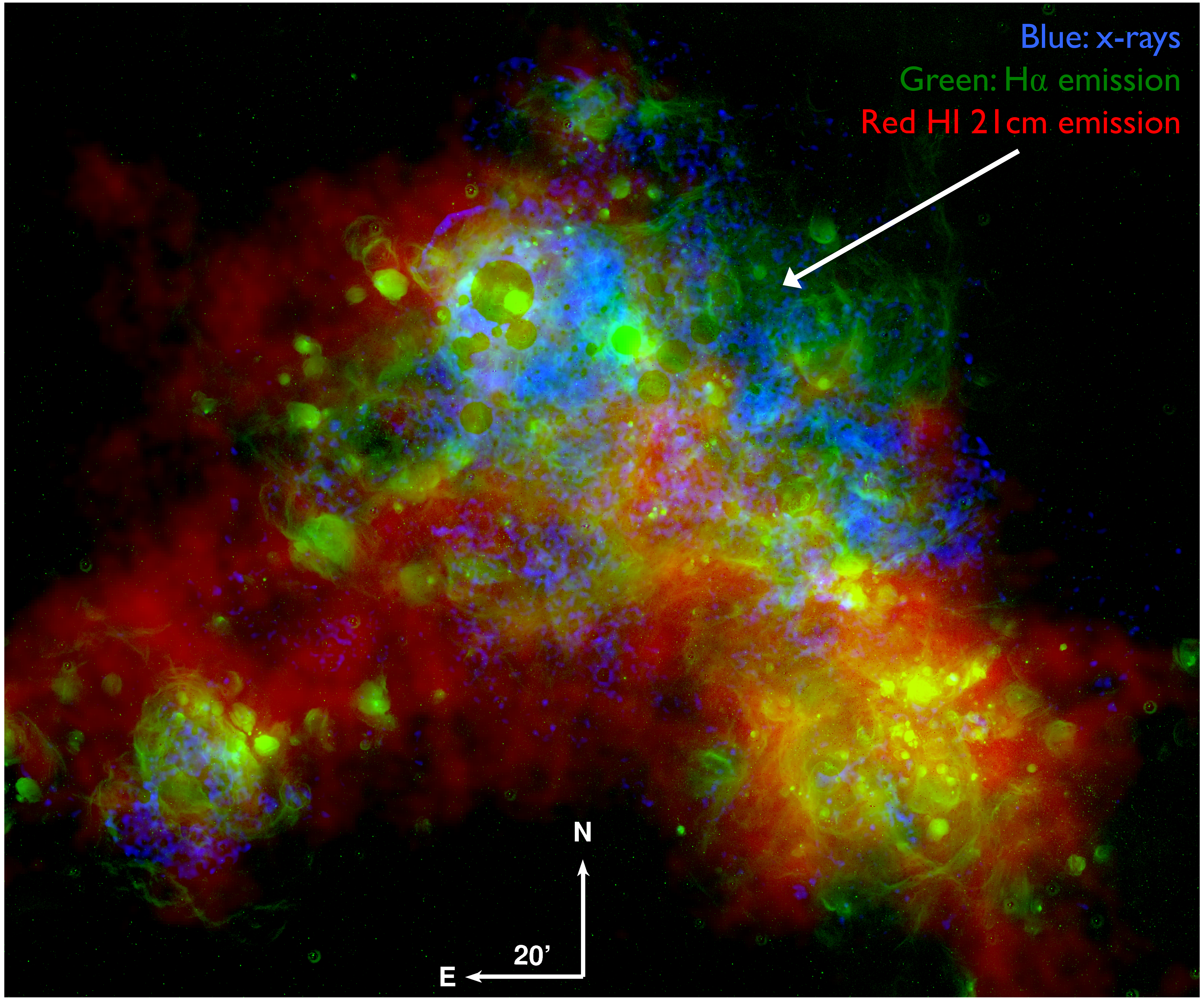
Cold Neutral Medium:
$T \sim 100$ K, $n \sim 10^8$ m^{-3}

Warm Neutral Medium:
$T \sim 7000$ K, $n \sim 10^5$ m^{-3}

Warm Ionized Medium:
$T \sim 10{,}000$ K, $n \sim 10^6$ m^{-3}

Hot Ionized Medium:
$T \sim 1{,}000{,}000$ K, $n \sim 10^4$ m^{-3}

$$P \sim nkT \sim \text{const.}$$



Stellar Remnants: White Dwarfs, Neutron Stars, & Black Holes

Degeneracy Pressure

As stellar evolution proceeds, cores are supported by “degeneracy pressure” when there is no fusion to provide the necessary pressure to support the core against gravitational collapse.

—> acts as a “pressure floor”

Source of this pressure come from the rules of QM — Pauli exclusion & uncertainty principles

$$\Delta x \Delta p \geq \hbar$$

Material getting maximally compressed, so electron momentum/velocity driven by that compression, NOT the temperature of the material!

$$P_{\rm th} = n_e kT \sim n_e m_e v_{\rm th}^2 \quad \text{b/c} \quad v_{\rm th} \approx \sqrt{\frac{kT}{m_e}}$$

$$v_{\rm th} \approx \frac{\Delta p}{m_e} \sim \frac{\hbar n_e^{1/3}}{m_e} \quad \text{b/c} \quad \Delta x \sim V^{1/3} \sim n_e^{-1/3}$$

$$\boxed{P_{\rm degen} \sim n_e m_e (\Delta v)^2 \sim \frac{\hbar^2 n_e^{5/3}}{m_e}}$$

White Dwarfs

Leftover C core of a low mass (M < 7ish M_{sun}) star

$$P_{\rm degen} \sim n_e m_e (\Delta v)^2 \sim \frac{\hbar^2 n_e^{5/3}}{m_e}$$ ⟵ Set these equal ⟶ $$P_{\rm c} \sim \frac{GM^2}{R^4}$$

$$n_e^{5/3} = \left(\frac{M}{m_p R^3}\right)^{5/3}$$ ↗ ↘

Solve for R

$$R \sim \frac{\hbar^2}{G m_e m_p^2}\left(\frac{M}{m_p}\right)^{-1/3} \approx 0.01 R_\odot \left(\frac{M}{0.7 M_\odot}\right)^{-1/3}$$

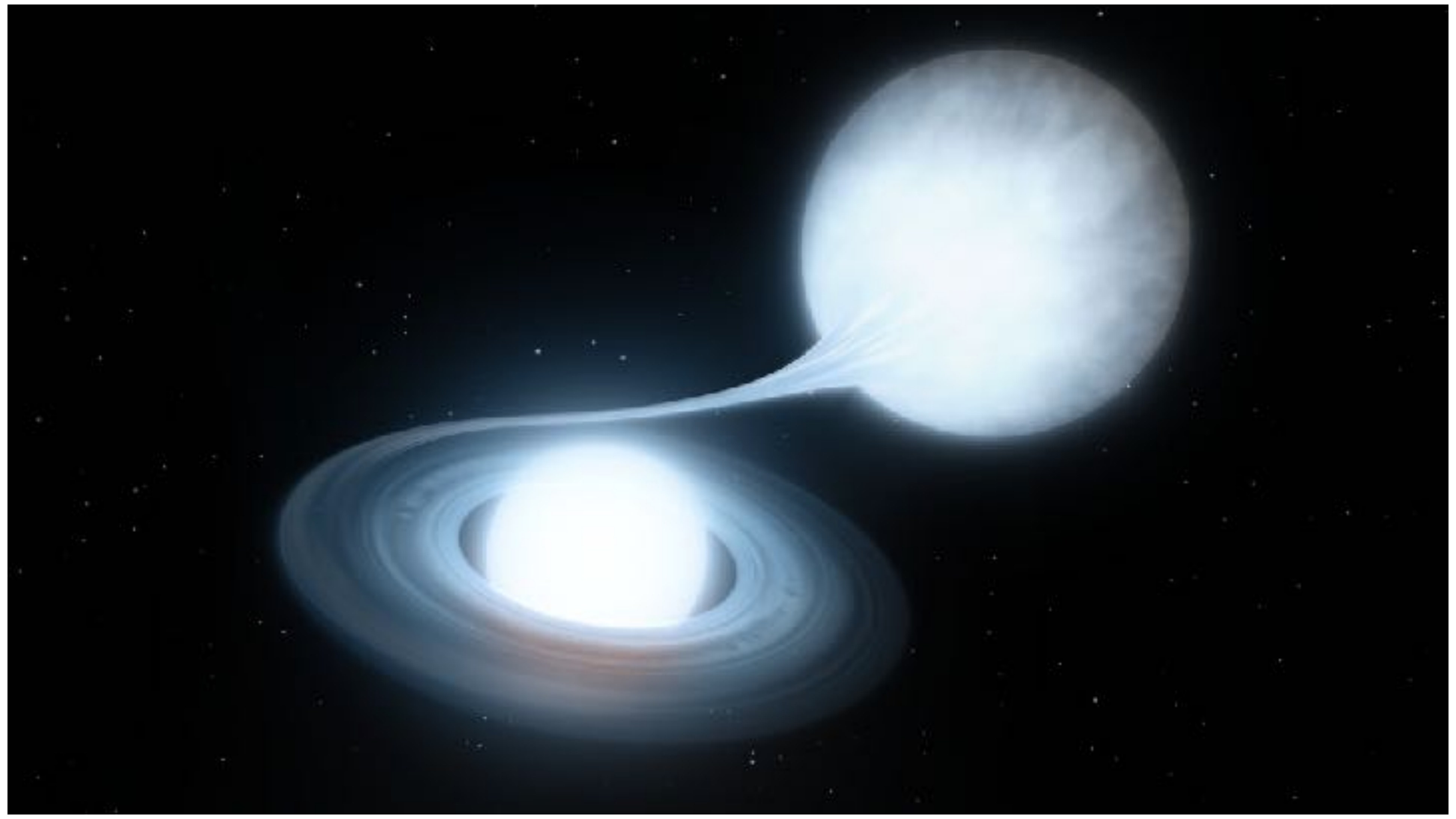
More massive WDs are smaller!

Why?

Also, because they have M~M_{sun} but are 100x smaller, their surface gravity is much stronger, producing strongly pressure-broadened absorption lines

Can a White Dwarf have any mass?

$$P_{\text{degen}} \sim n_e m_e (\Delta v)^2 \sim \frac{\hbar^2 n_e^{5/3}}{m_e}$$



As a WD becomes more massive, the pressure has to increase — what will cause the pressure to max out?

$$\Delta v \sim c$$

$$M_{\text{Ch}} \sim \left(\frac{\hbar^3 c^3}{G^3 m_p^4}\right)^{1/2} \sim 2M_\odot$$

Called the Chandrasekhar mass
Modern calculations give 1.4 M_{sun}

Initial mass of star	WD type
$M < 0.5 M_\odot$	He
$0.5 M_\odot < M < 5 M_\odot$	C/O
$5 M_\odot < M < 7 M_\odot$	Ne/Mg

Neutron Stars are supported by neutron degeneracy pressure

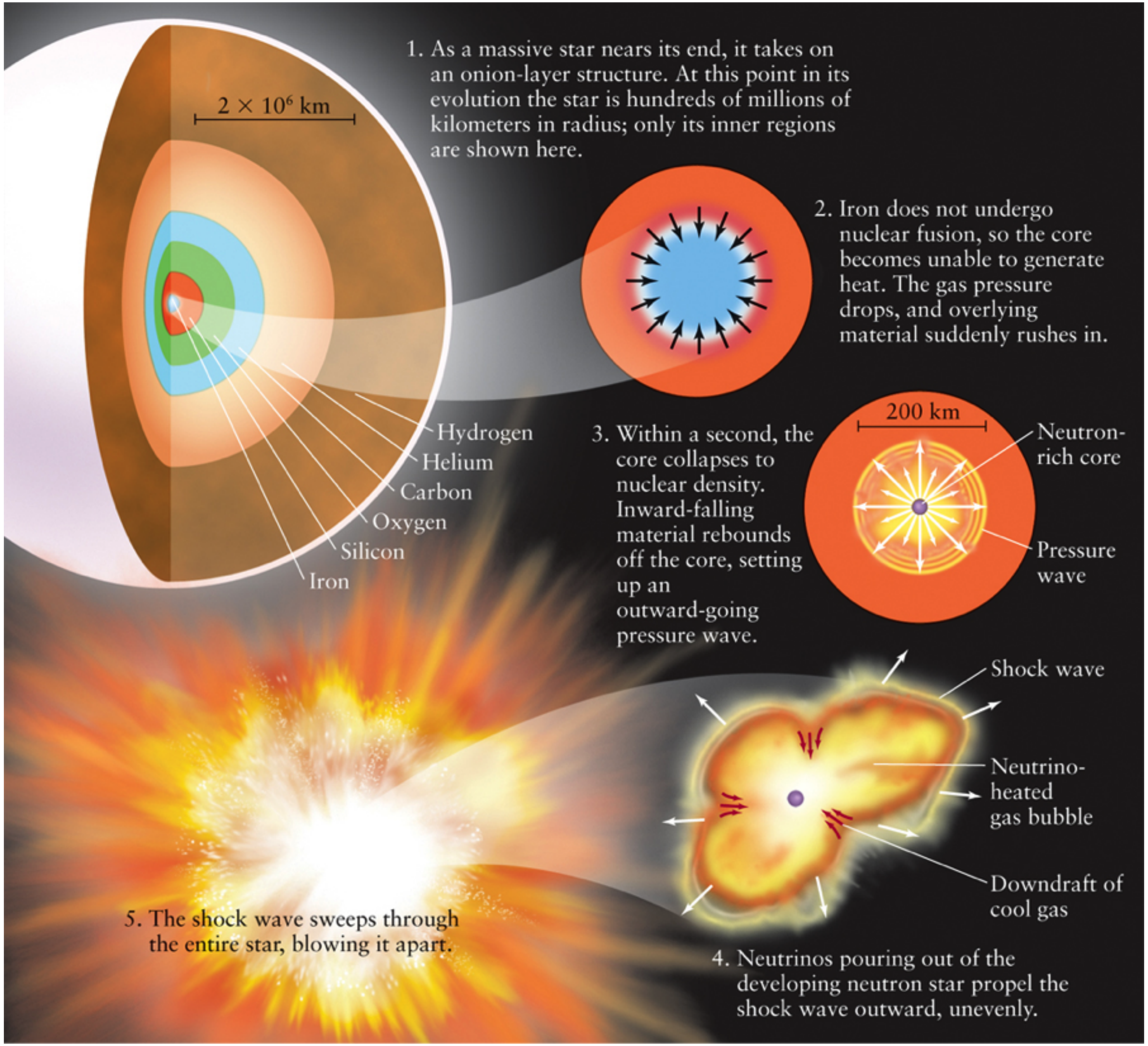
Supernovae!

Electron degeneracy pressure fails

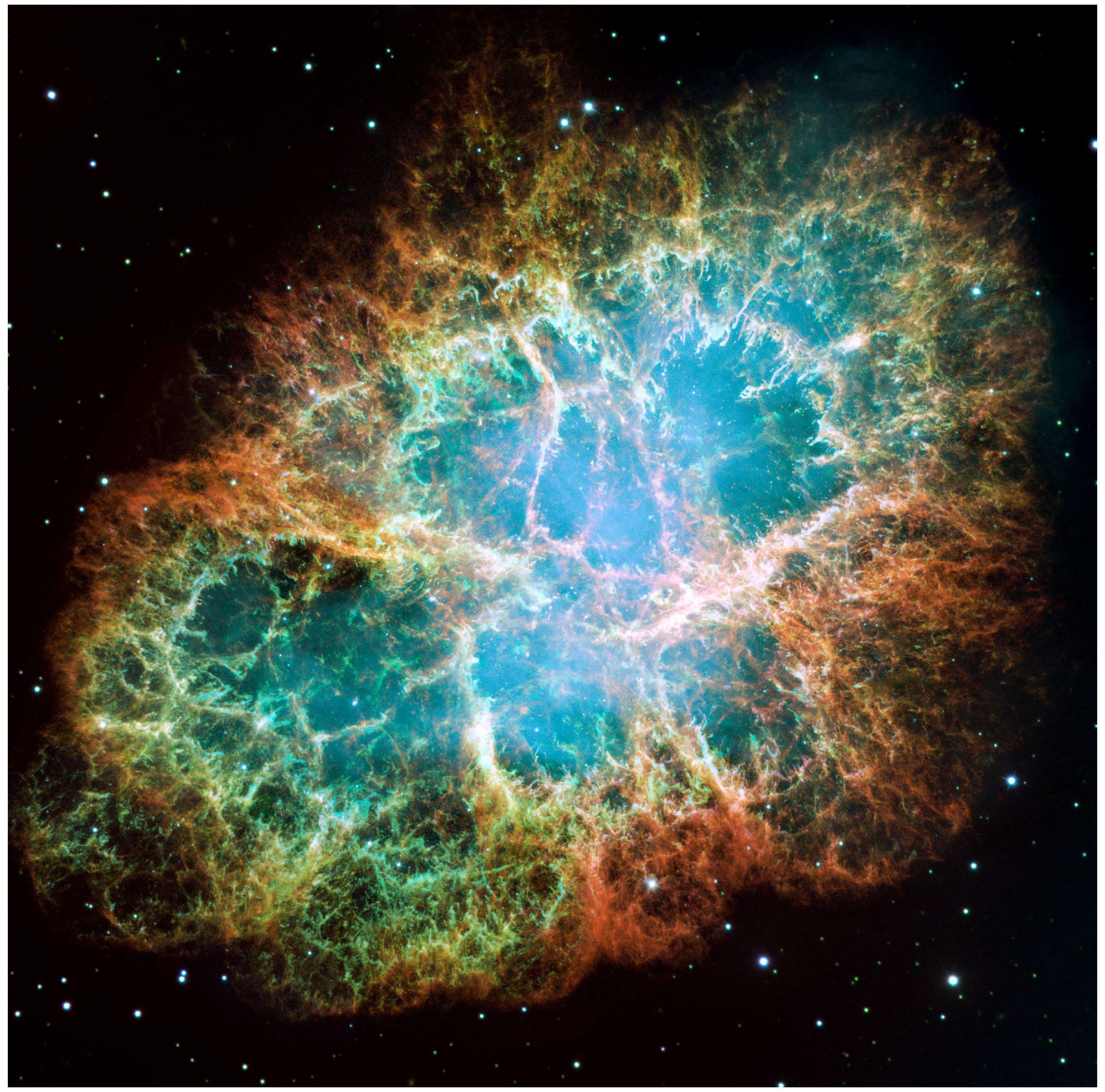
Electrons absorbed into protons in nuclei creating neutrons

$$p + e^{-} \rightarrow n + \nu_e$$

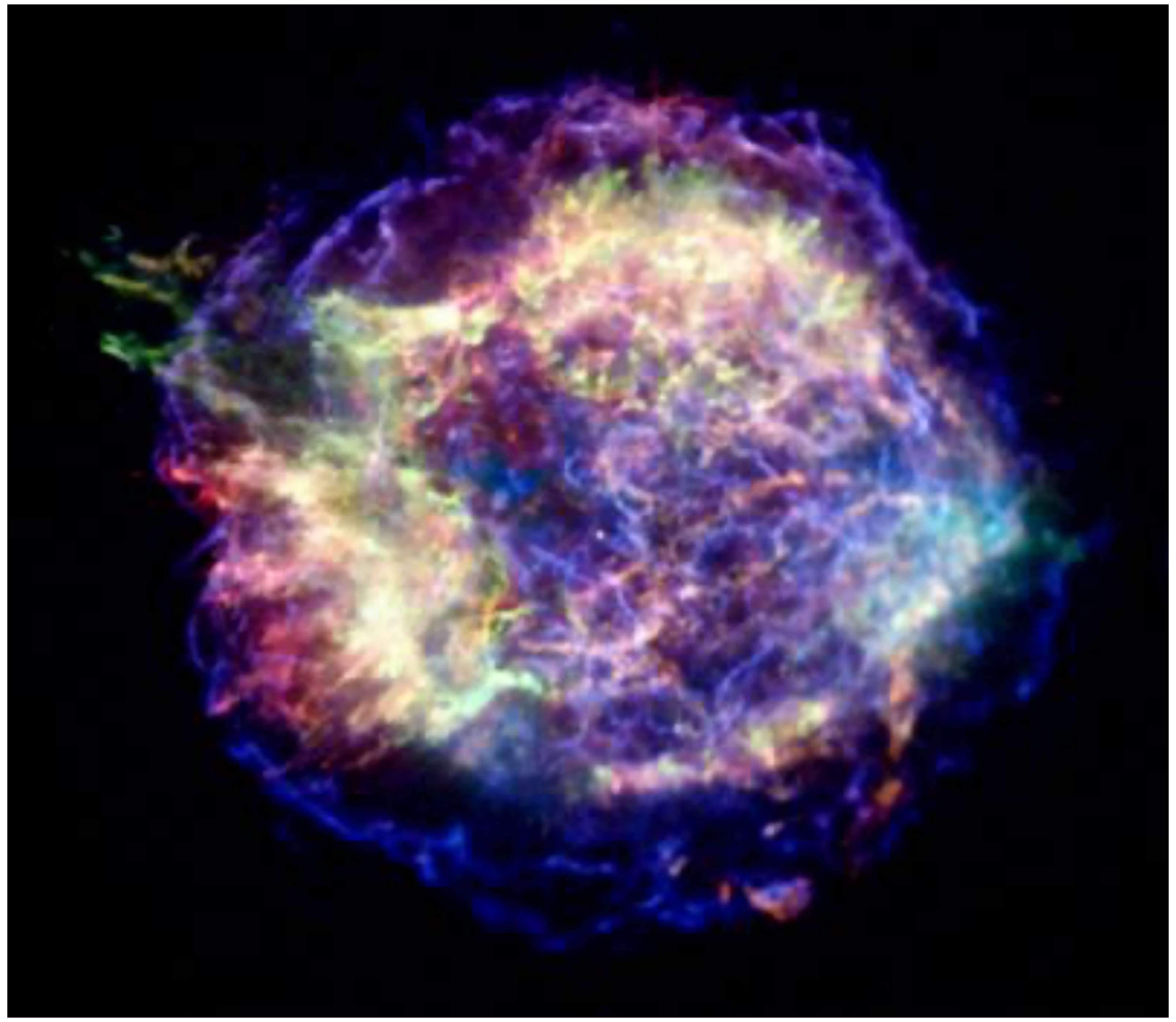
Outer layers bounce off of forming NS (or pressure wave), causing star to explode



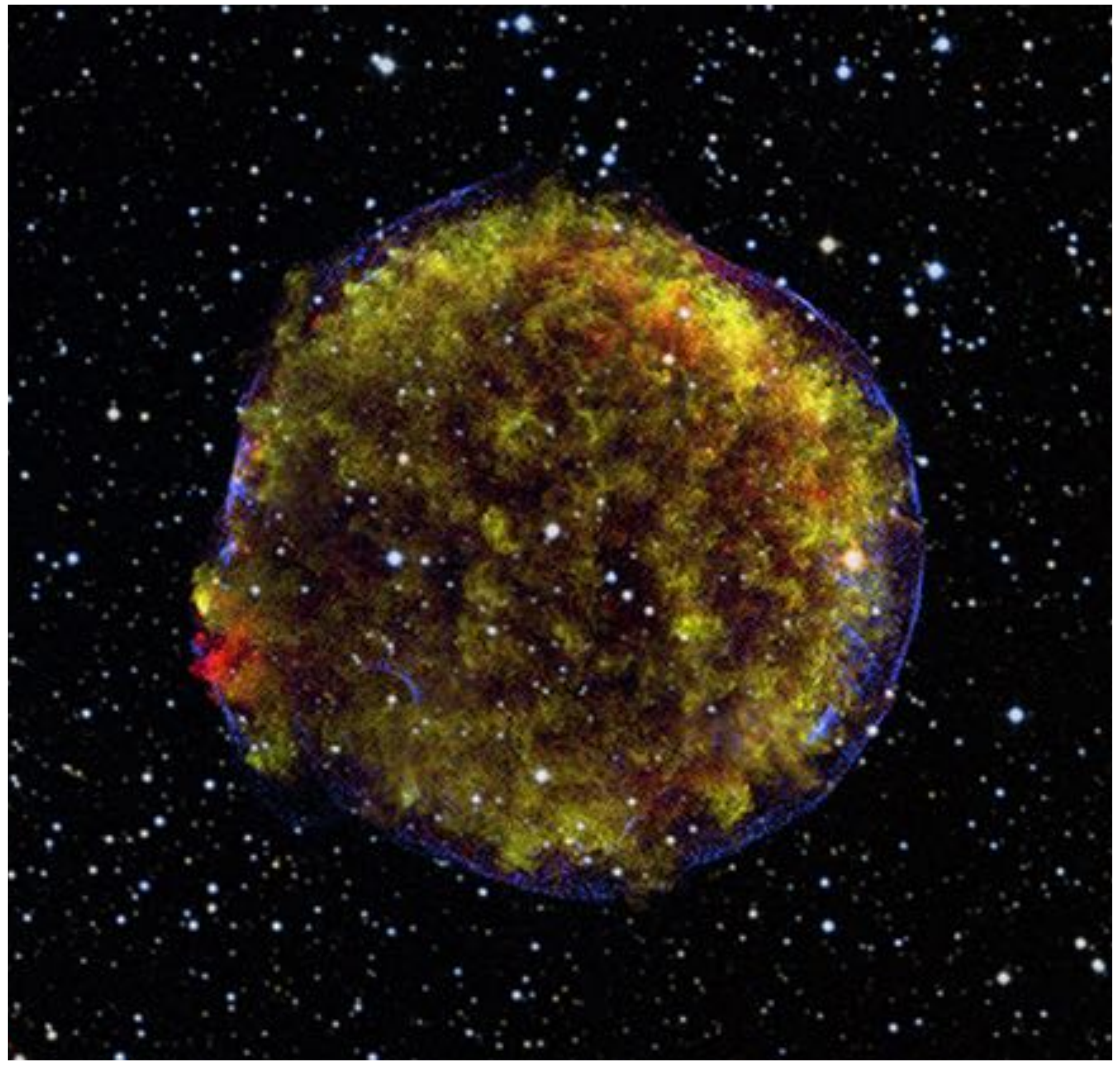
Historical SNe are now Supernova Remnants (SNRs)



Crab Nebula
1054

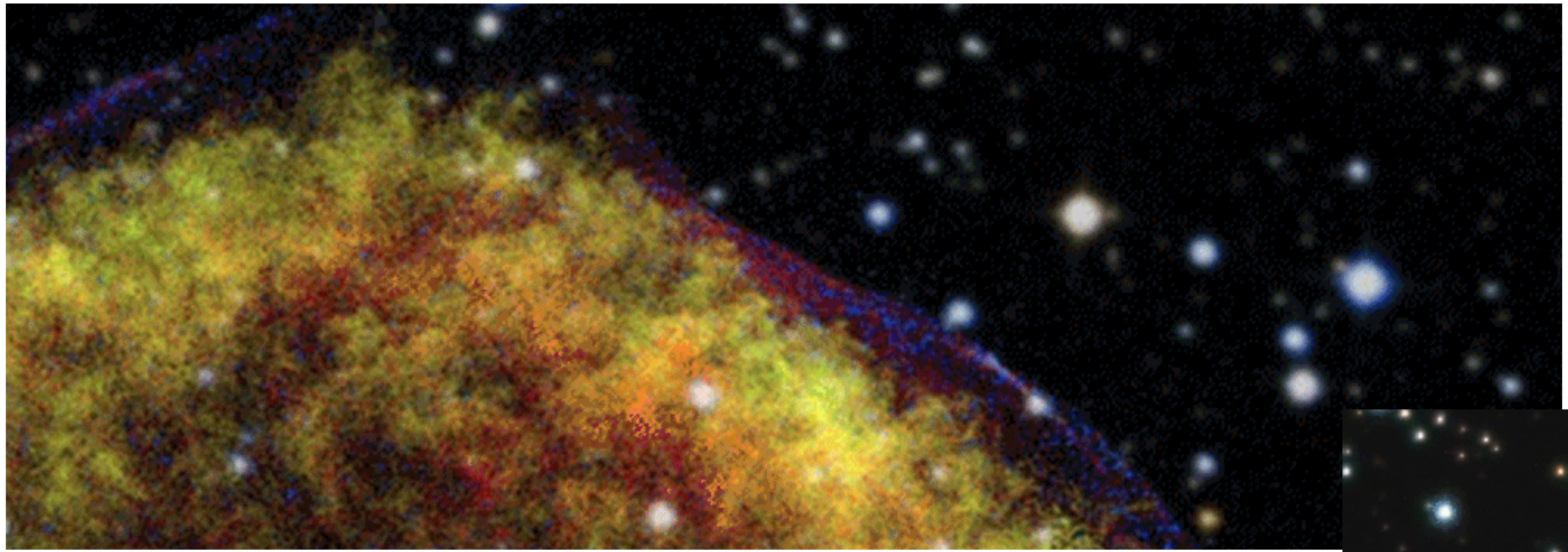


Cassiopeia A
~1680
(not clearly recorded)



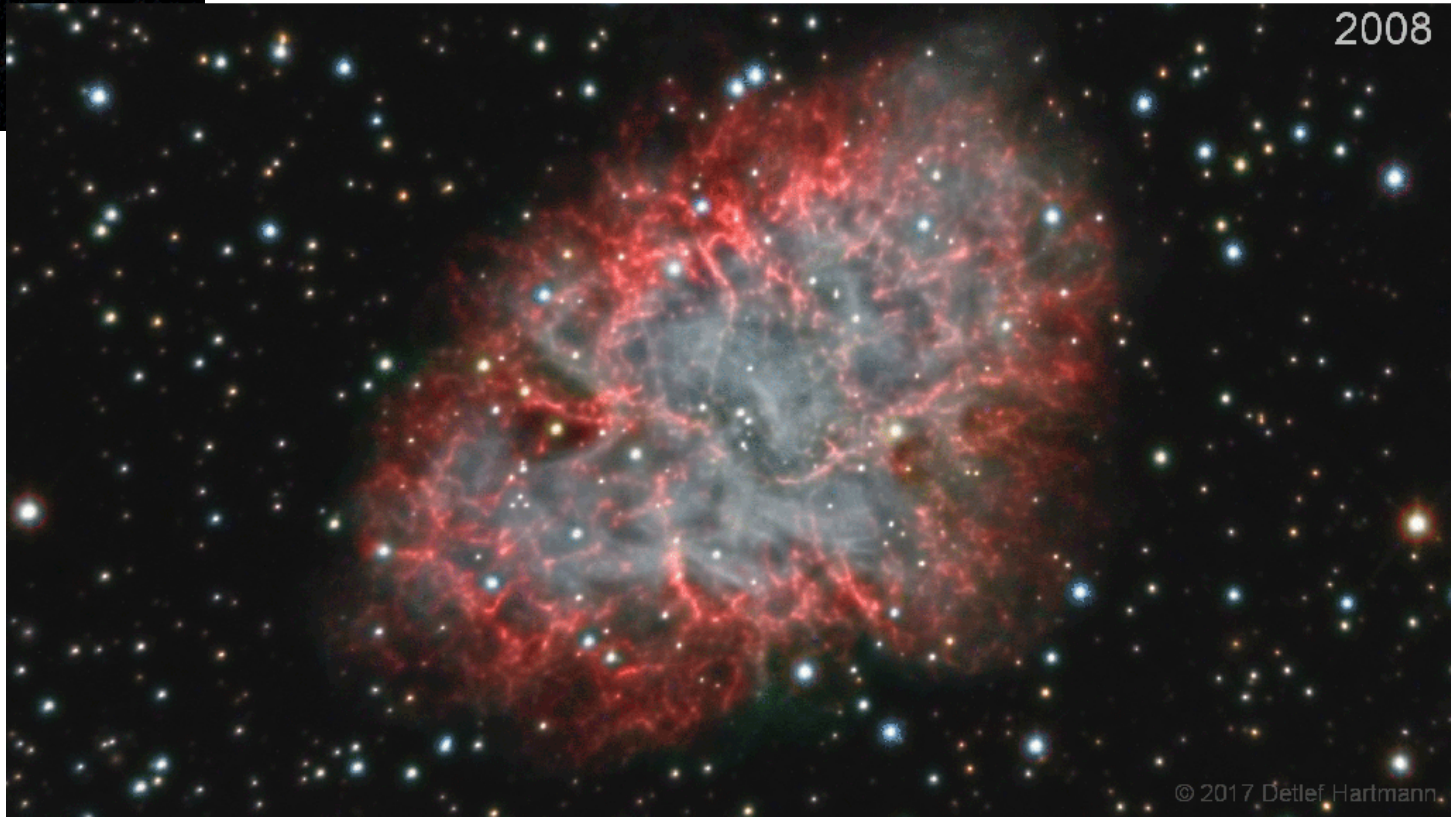
Tycho SNR
1572

Can watch them expand!

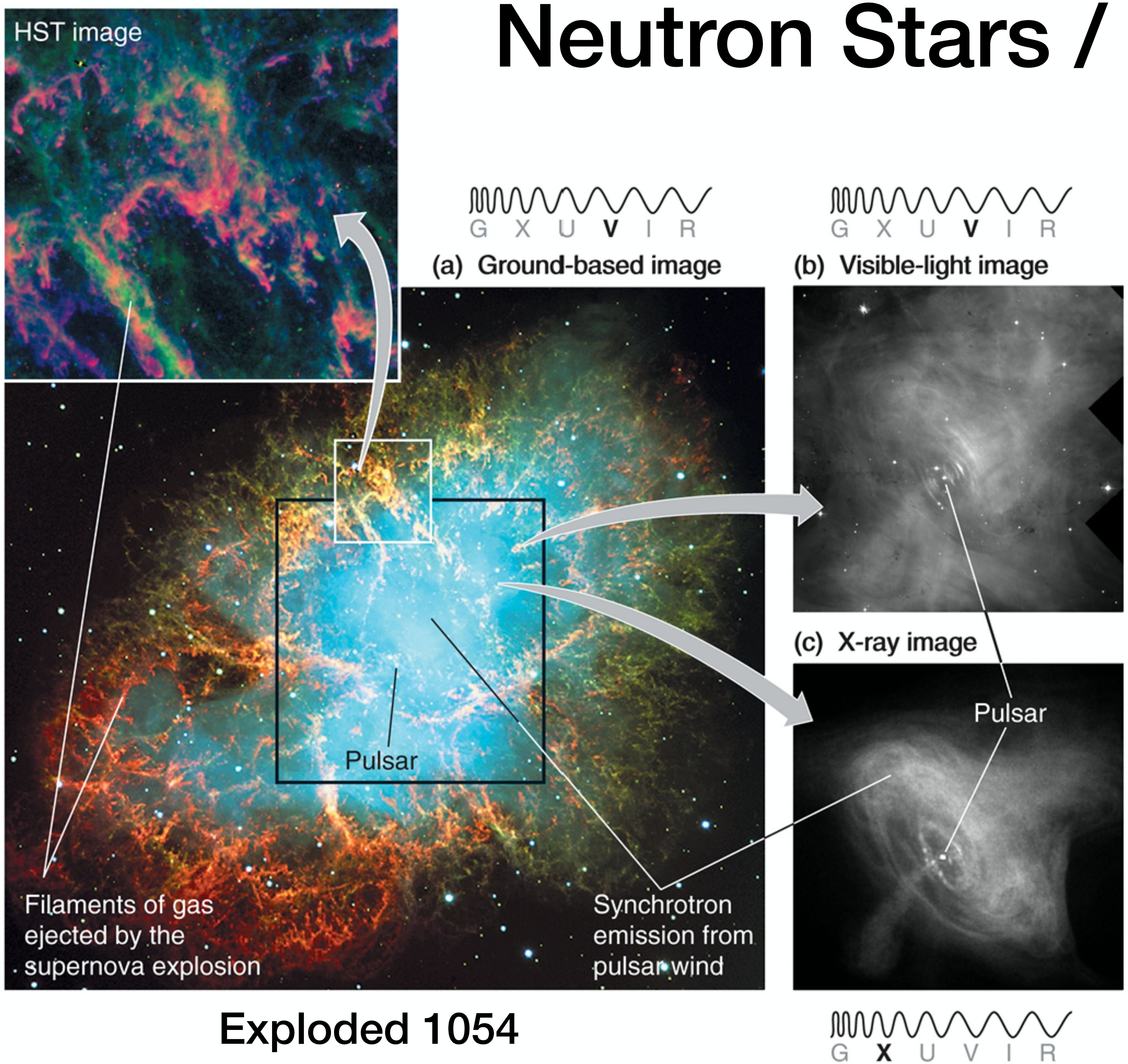


Tycho

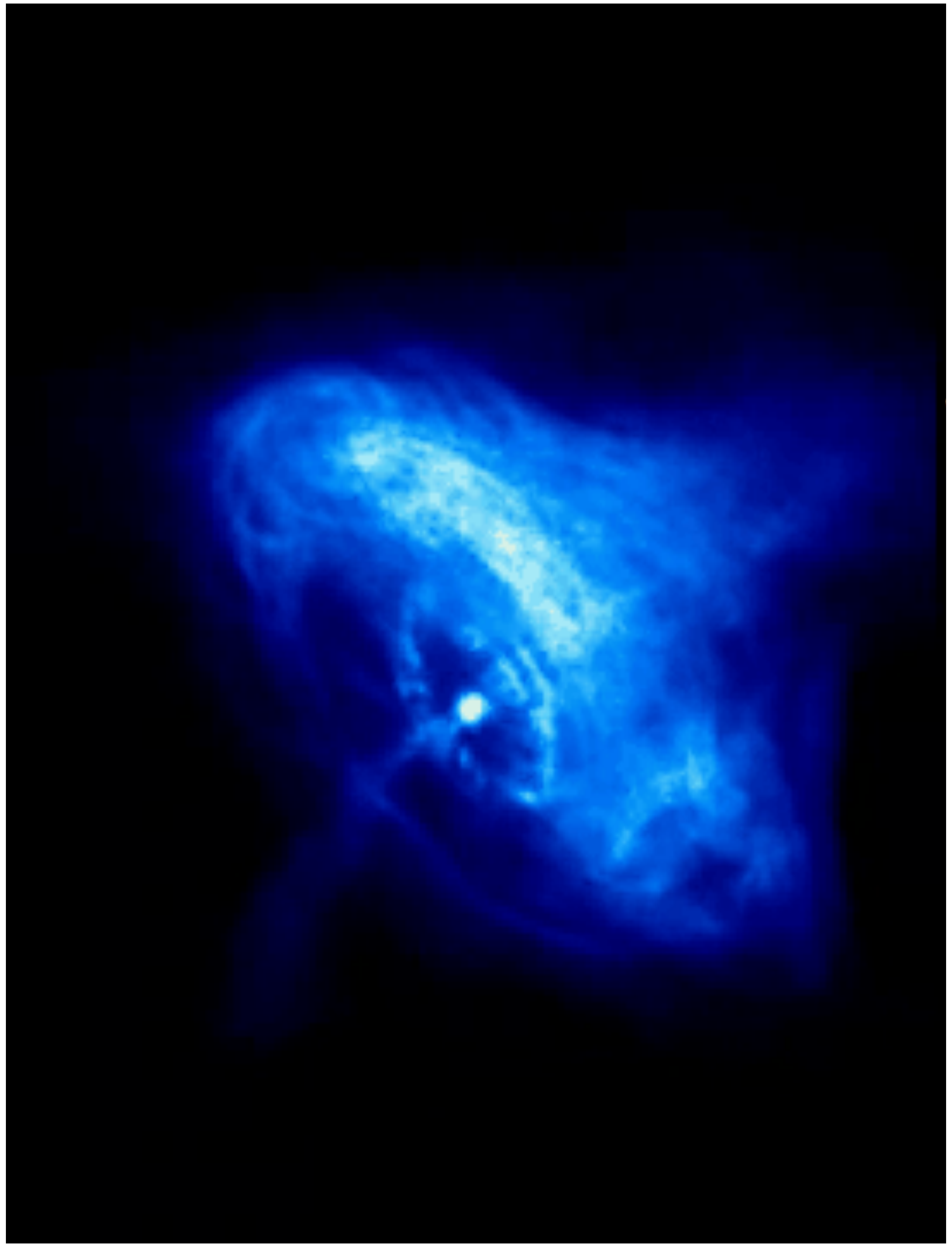
Crab



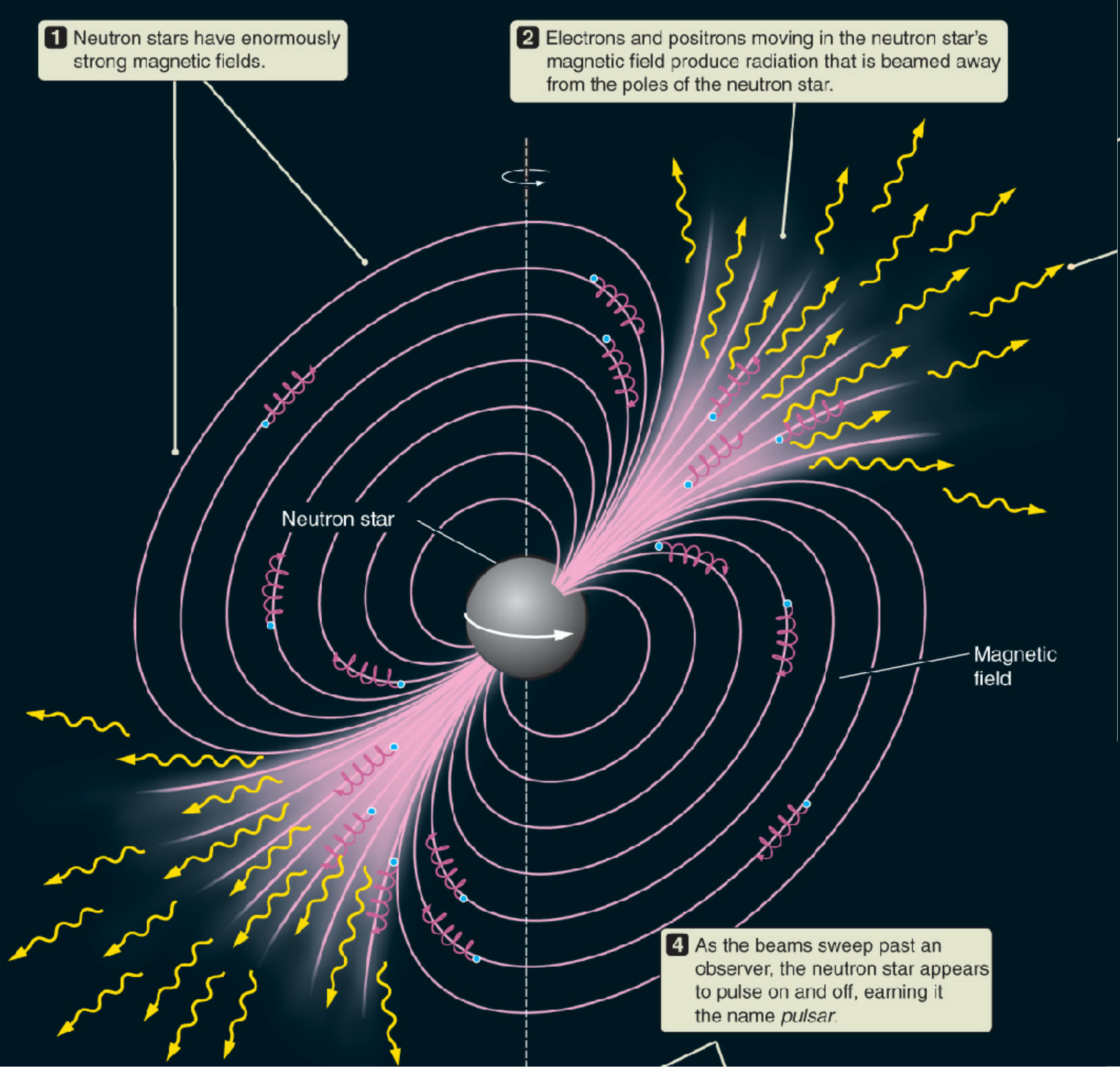
Neutron Stars / Pulsars



Exploded 1054



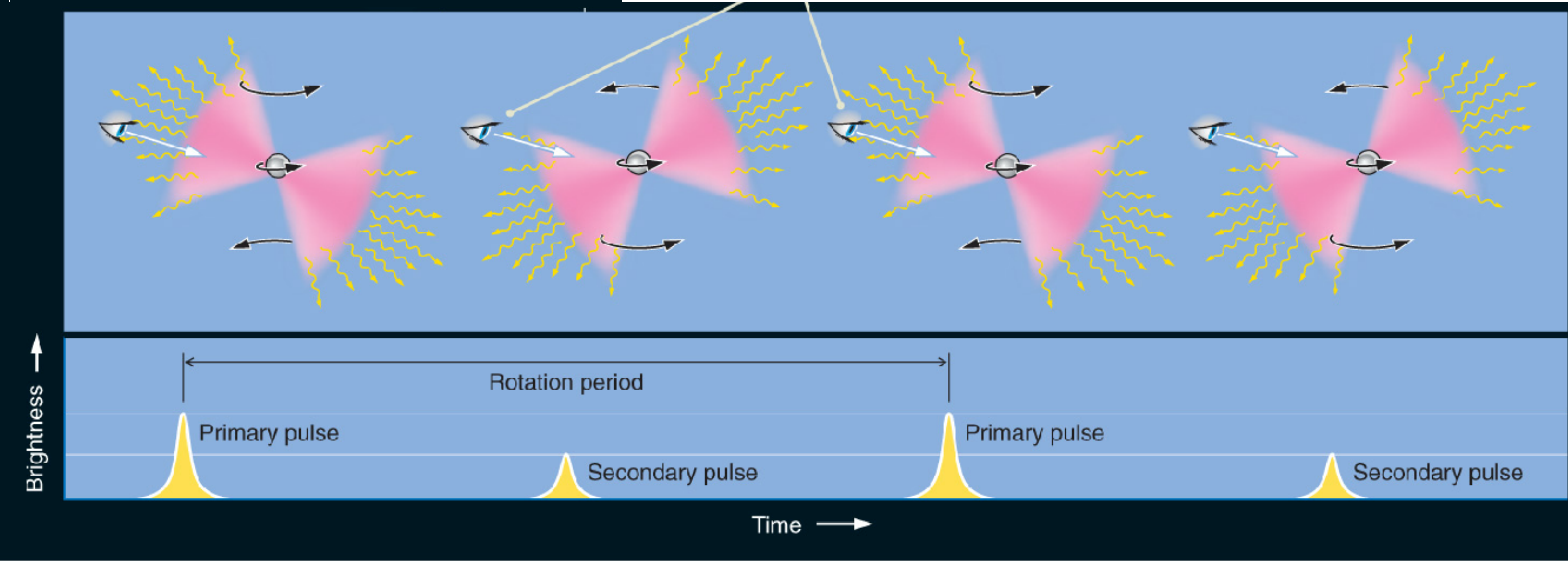
www.youtube.com/watch?v=t5uA1RJsDhw&feature=related



Neutron Stars are born with strong magnetic fields (get stronger as the core collapses)

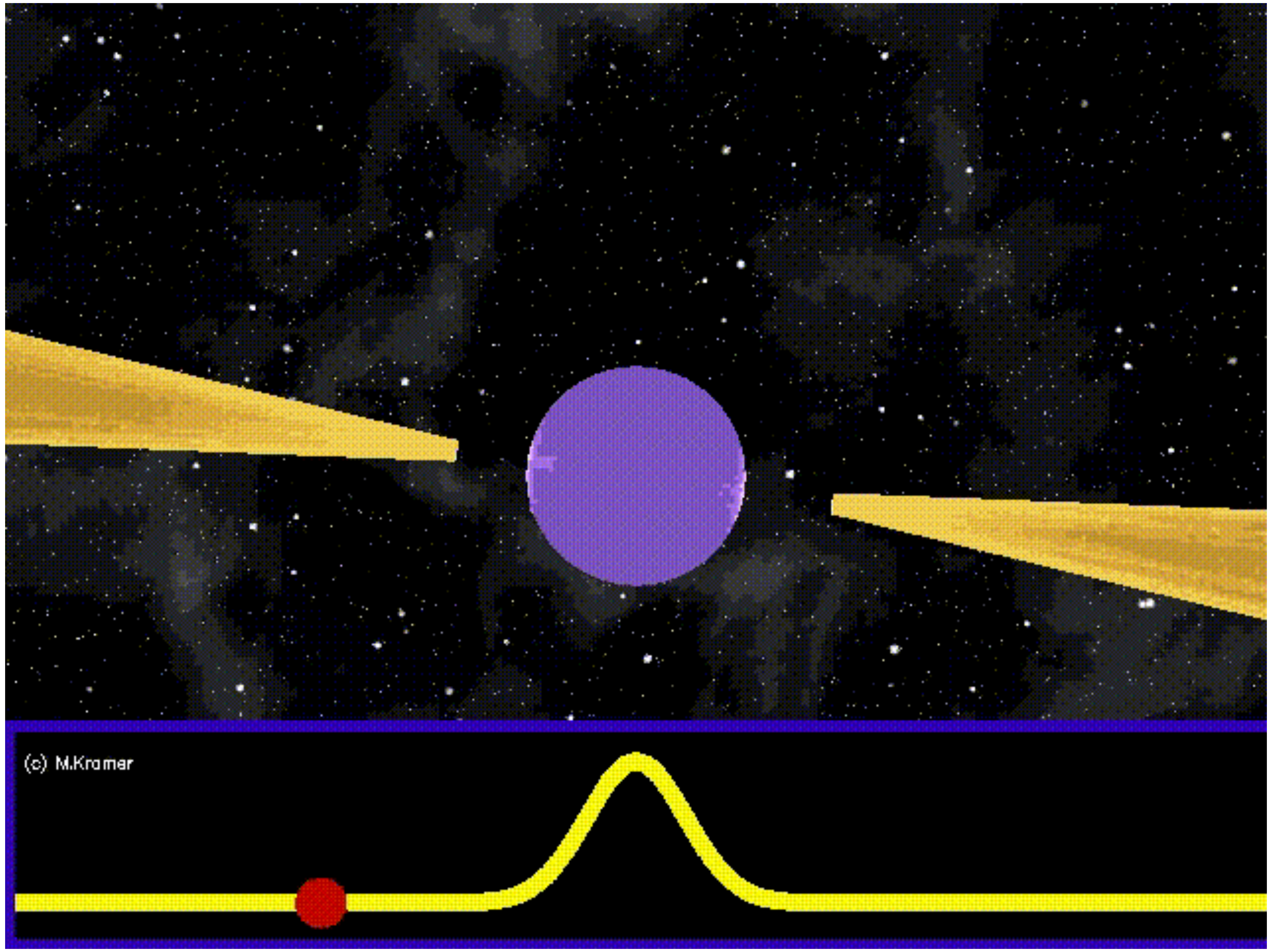
Field accelerates electrons and positrons, which causes them to emit radiation across the spectrum

We see the beam once or twice each time the star rotates



Pulsars emit pulses at all wavelengths

When formed, rotates with a period of ~1s



Realistic simulation of the magnetic field of a pulsar:

https://www.youtube.com/watch?v=jwC6_oWwbSE

Millisecond Pulsar:
https://www.youtube.com/watch?v=MPpDTvYL5ik

Black Widow Pulsar:

https://www.youtube.com/watch?v=-SoZ1xvCpMw