Week 10: ISM & Stellar Remnants

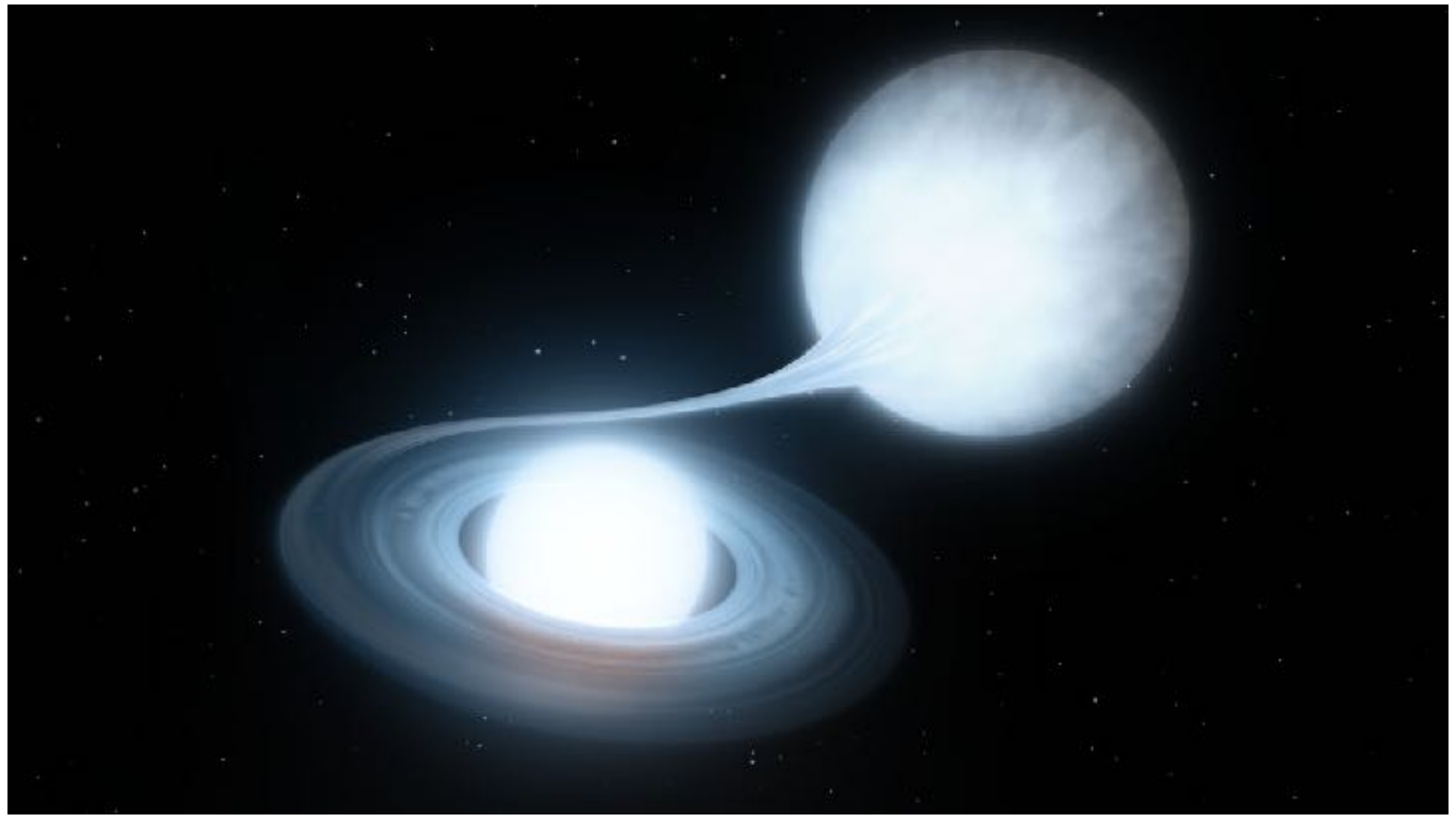
HW8 due now

HW9 online (last HW before Midterm 2 on Nov. 12th)

Read Ch. 19.1-3, 19.7 for next week

Can a White Dwarf have any mass?

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



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

$$\Delta v \sim c$$

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

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

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

Neutron Stars are supported by neutron degeneracy pressure


More massive than the Sun
R ~ 10 km

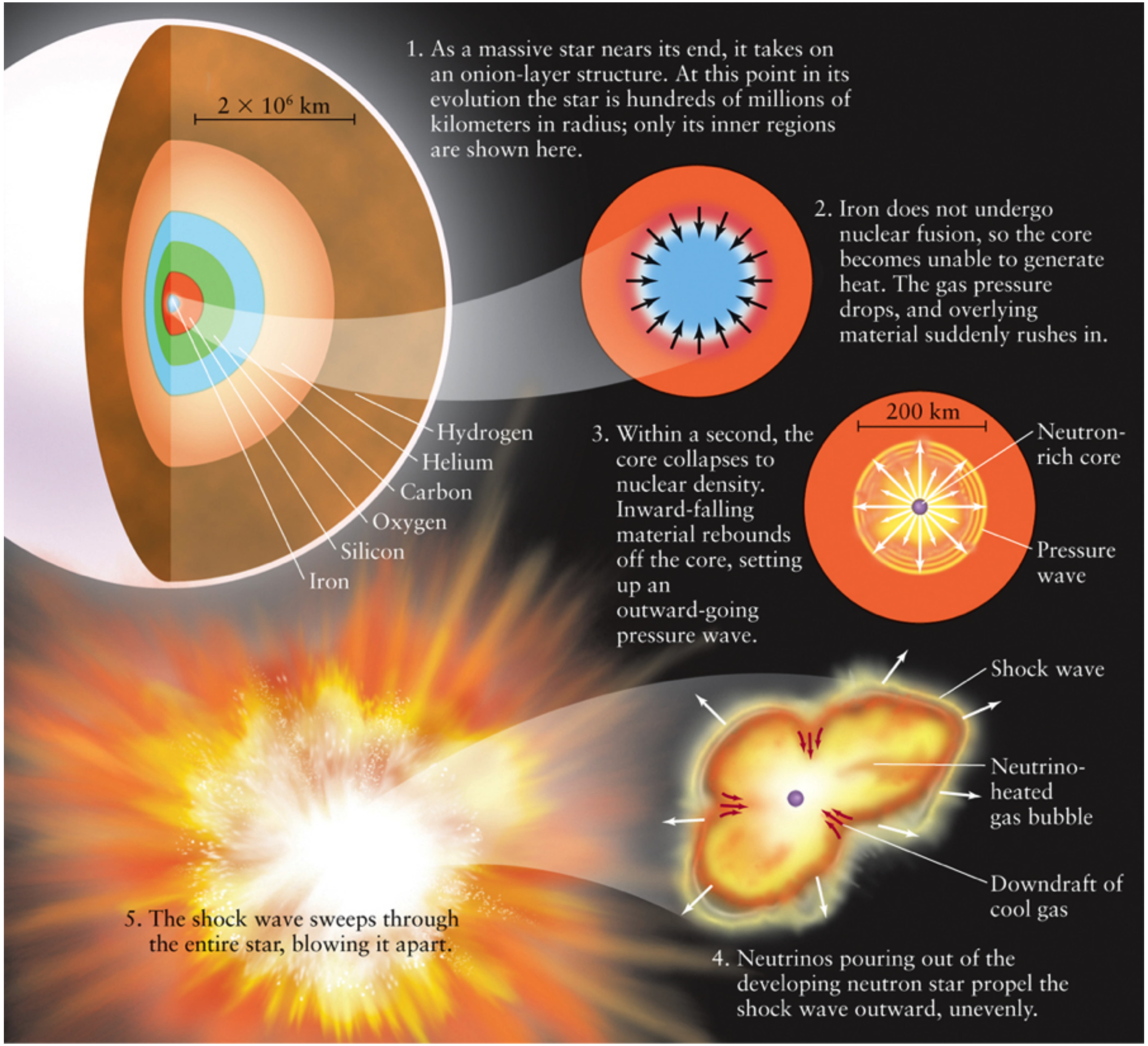
Supernovae!

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



1. As a massive star nears its end, it takes on an onion-layer structure. At this point in its evolution the star is hundreds of millions of kilometers in radius; only its inner regions are shown here.

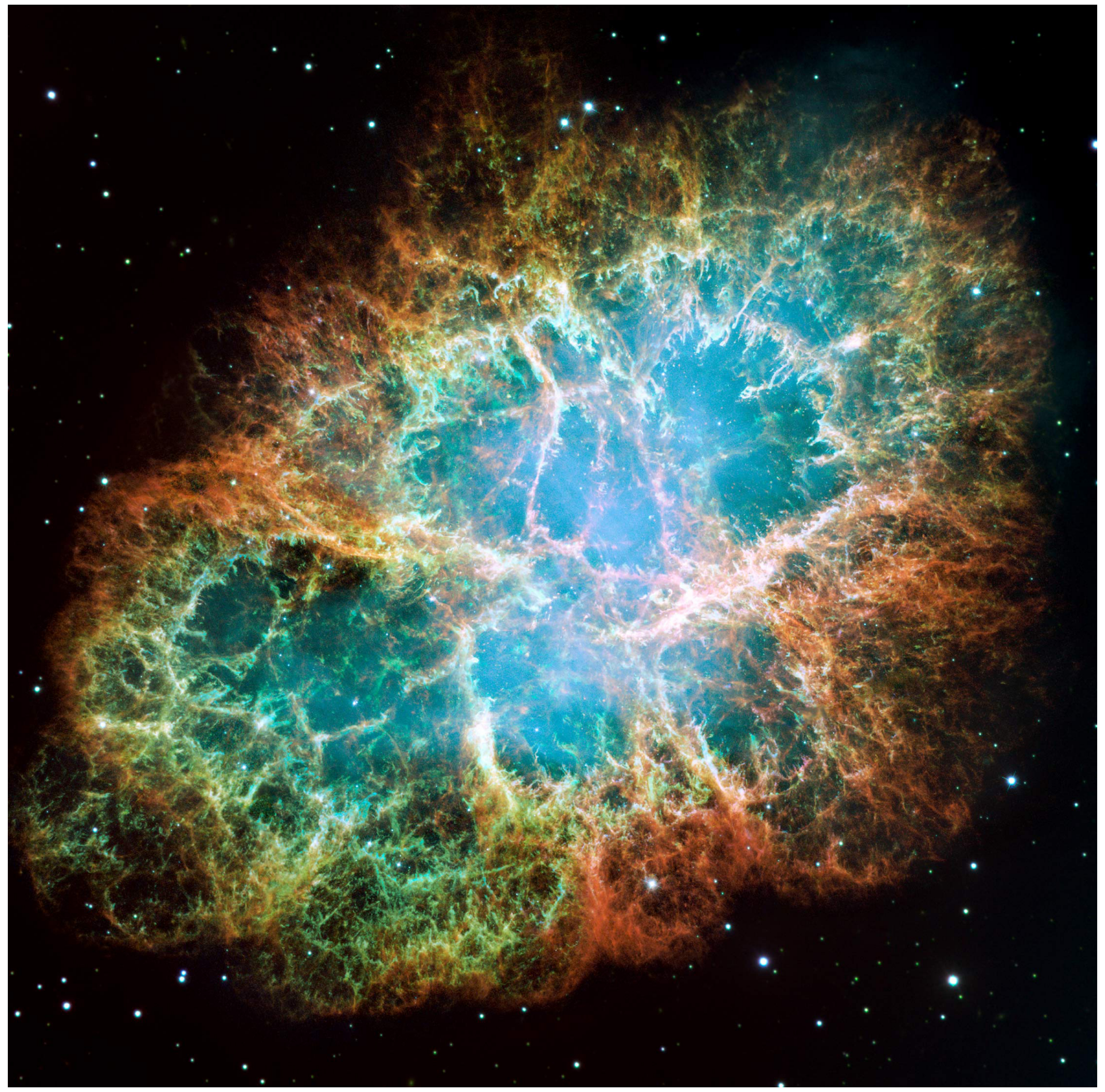
2. Iron does not undergo nuclear fusion, so the core becomes unable to generate heat. The gas pressure drops, and overlying material suddenly rushes in.

3. Within a second, the core collapses to nuclear density. Inward-falling material rebounds off the core, setting up an outward-going pressure wave.

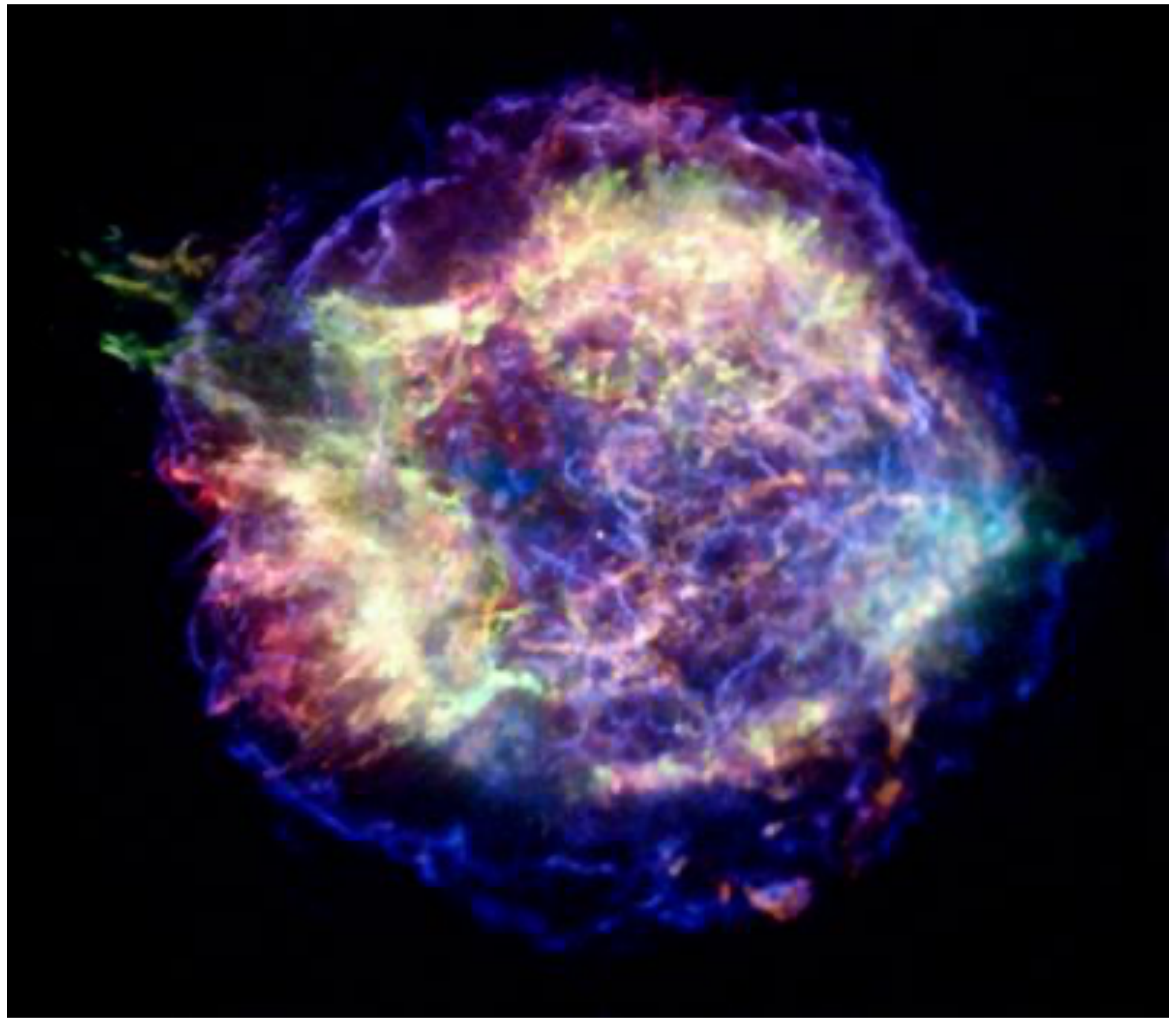
4. Neutrinos pouring out of the developing neutron star propel the shock wave outward, unevenly.

5. The shock wave sweeps through the entire star, blowing it apart.

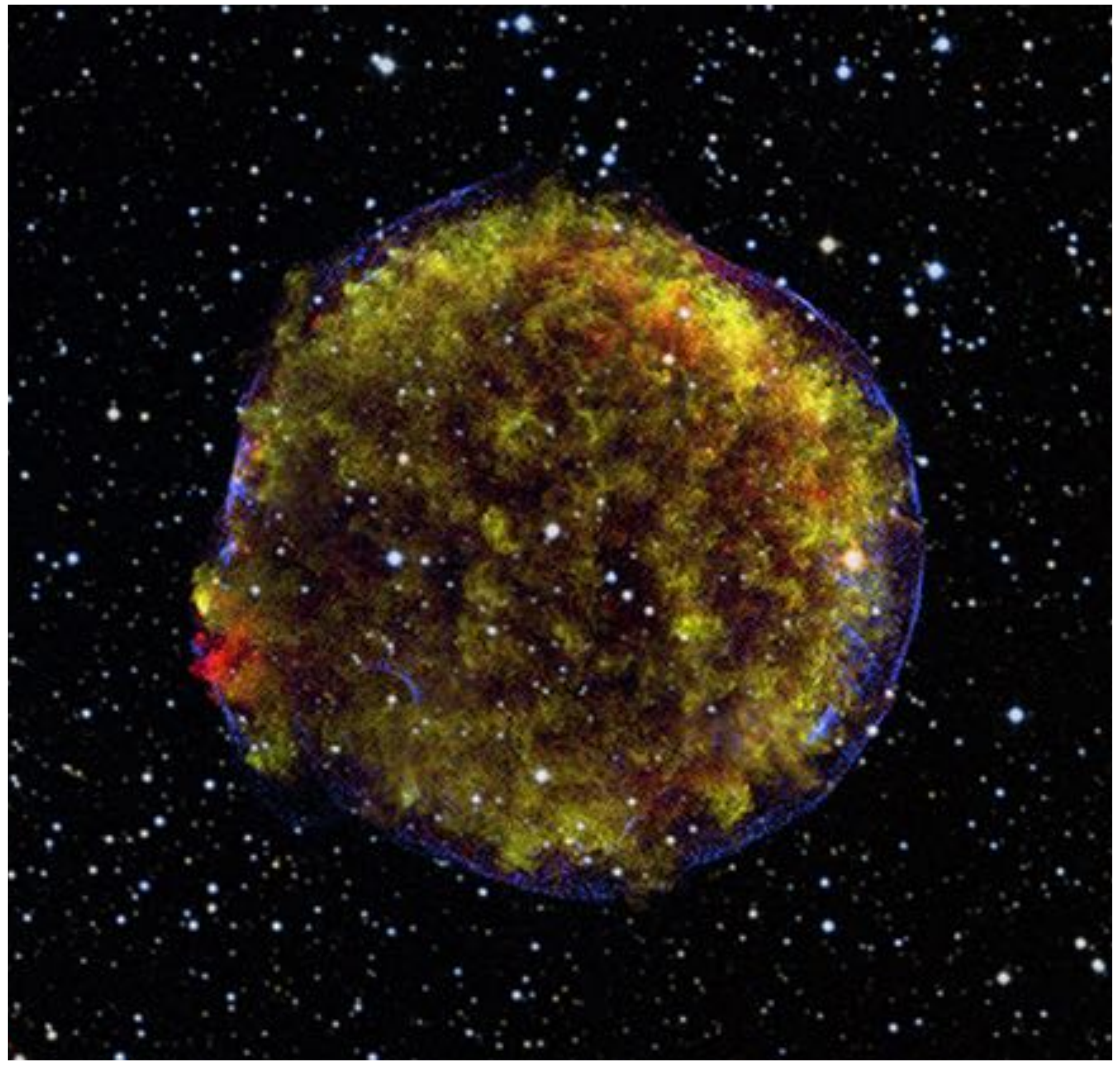
Historical SNe are now Supernova Remnants (SNRs)



Crab Nebula
1054

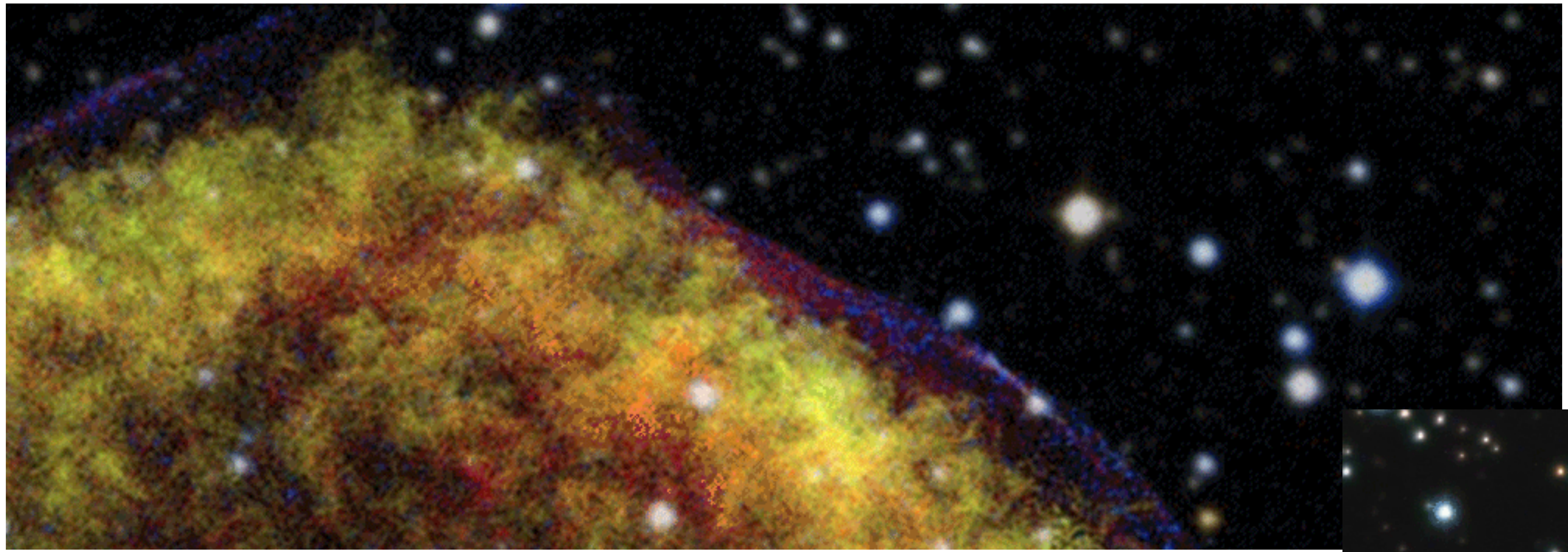


Cassiopeia A
~1680
(not clearly recorded)



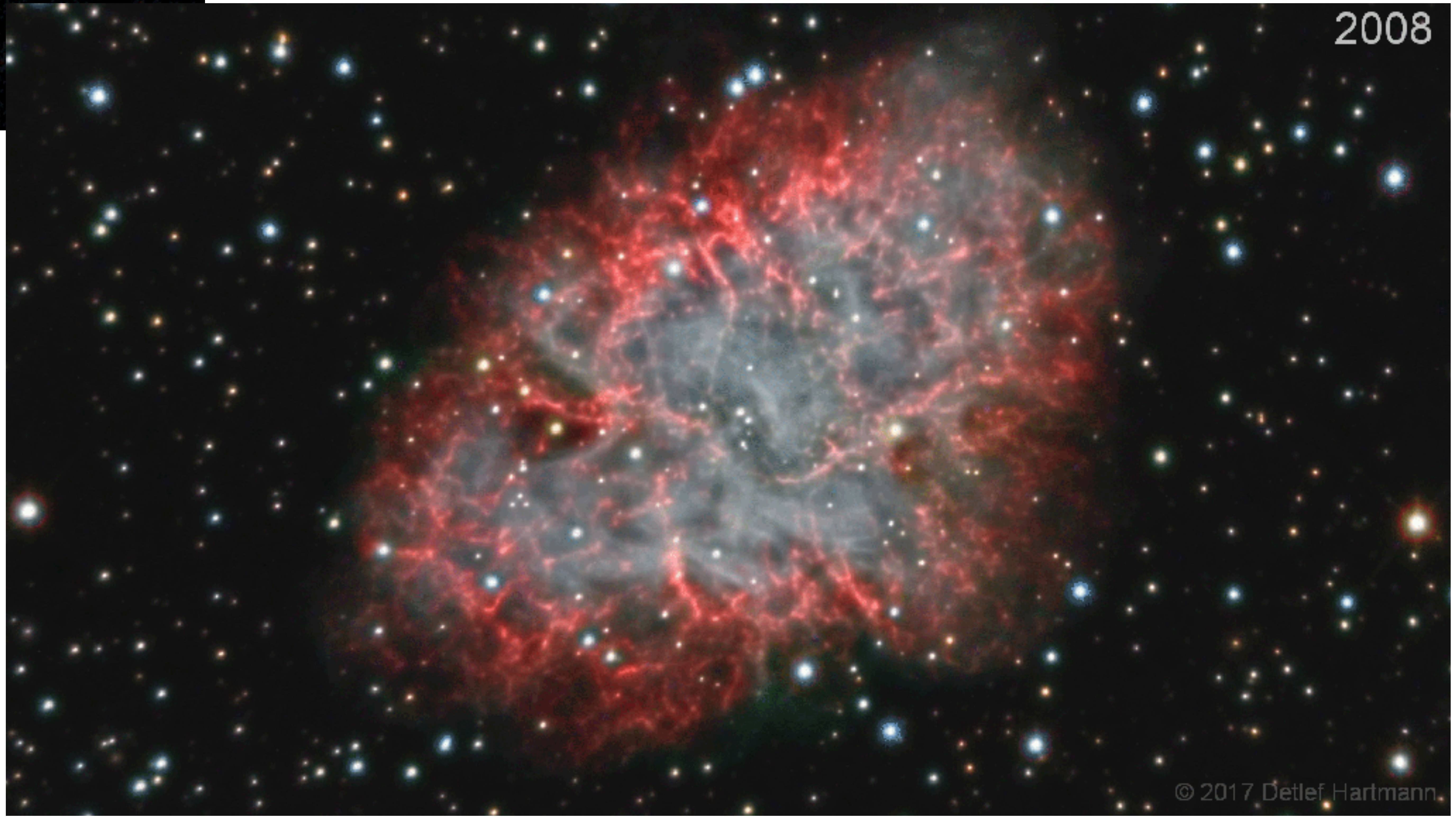
Tycho SNR
1572

Can watch them expand!



Tycho

Crab



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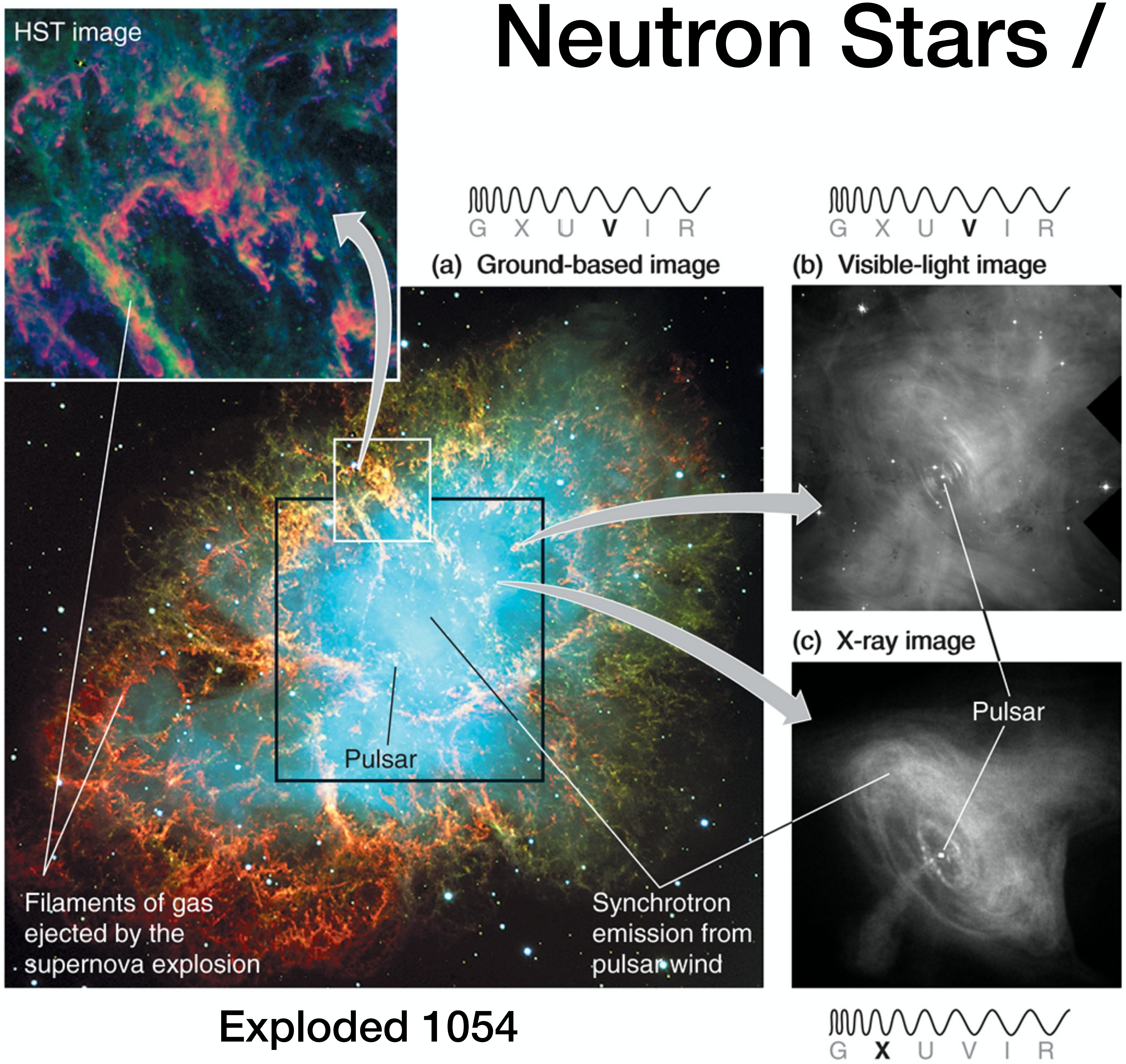
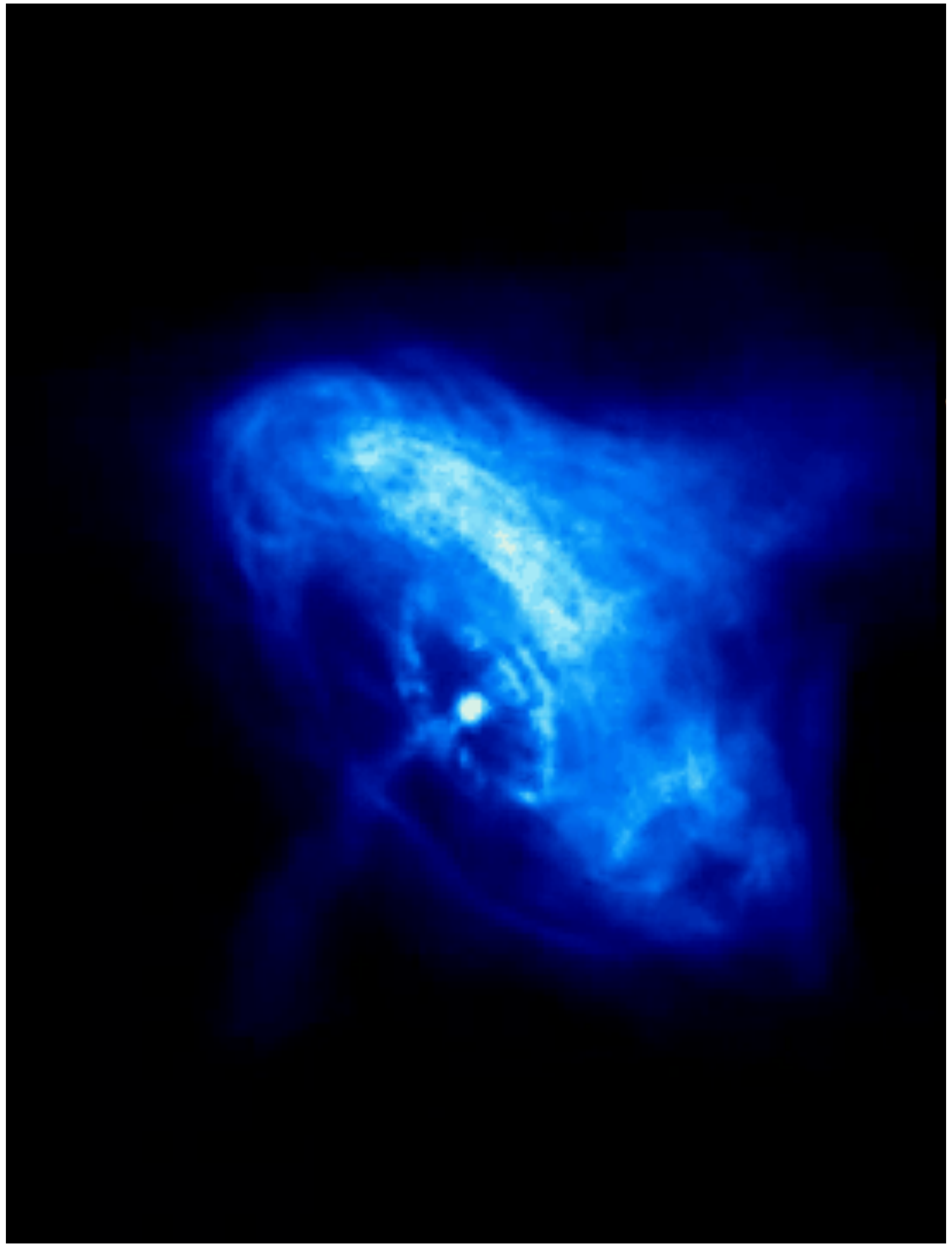
Neutron Stars / Pulsars





Exploded 1054

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

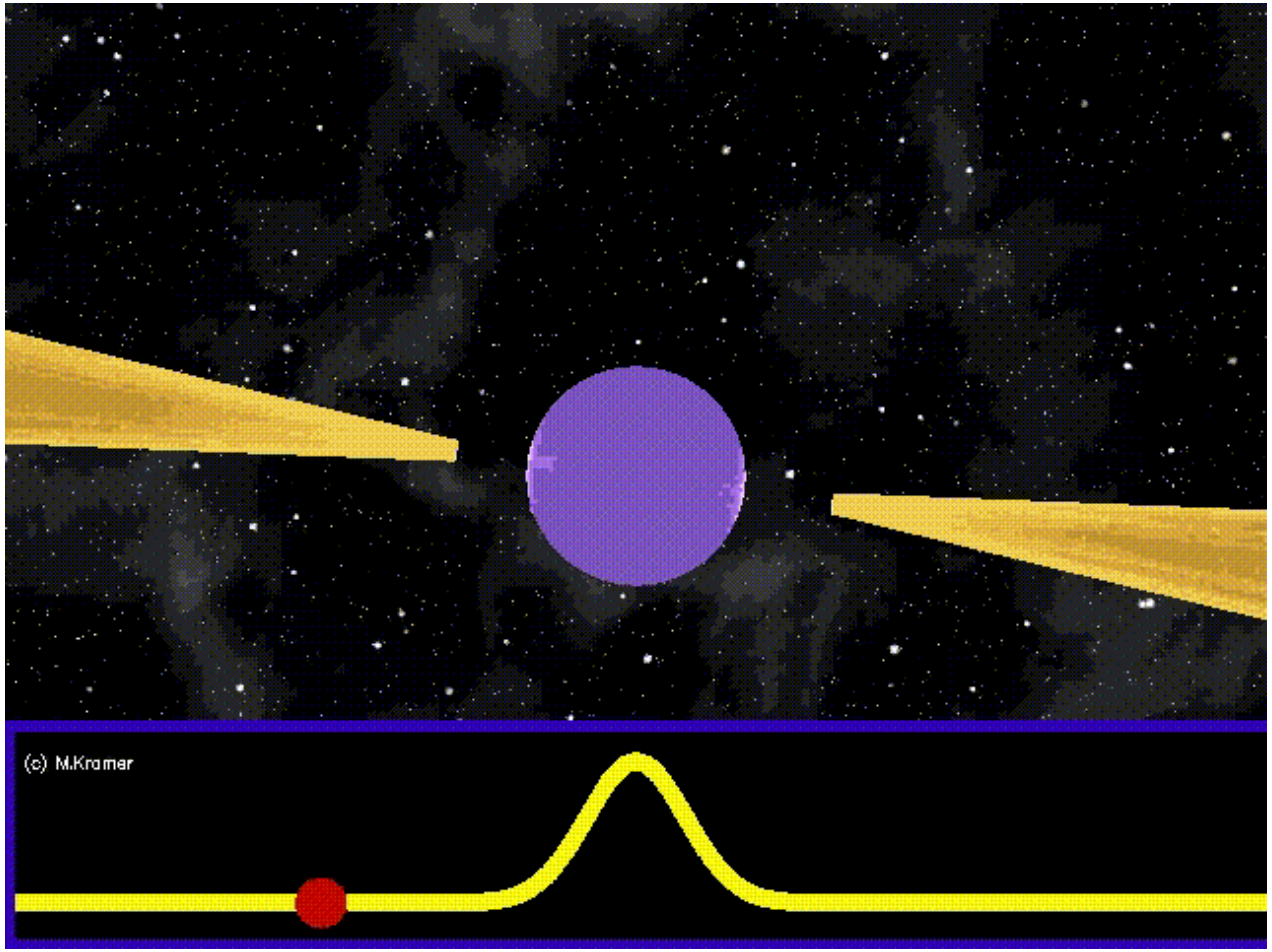
Jocelyn Bell Burnell

Discovered radio pulsars as a grad student in 1967 (but her PhD advisor won the Nobel Prize, not her)

In the radio, the pulses are very short and recur with periods of milliseconds to seconds

Pulsars emit pulses at all wavelengths

When formed, rotates with a period of ~ 10-100 ms



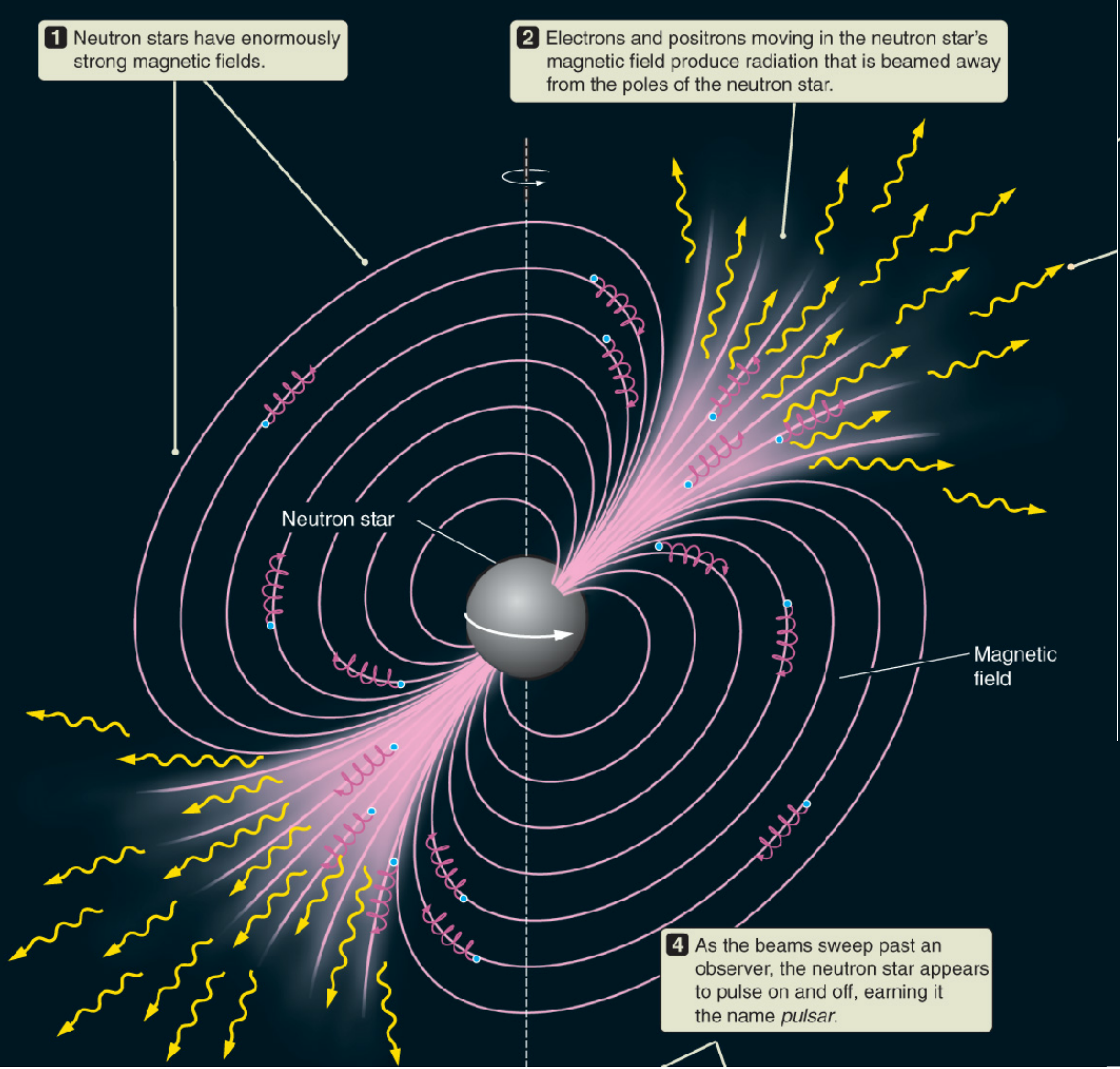
Realistic simulation of the magnetic field of a pulsar:

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

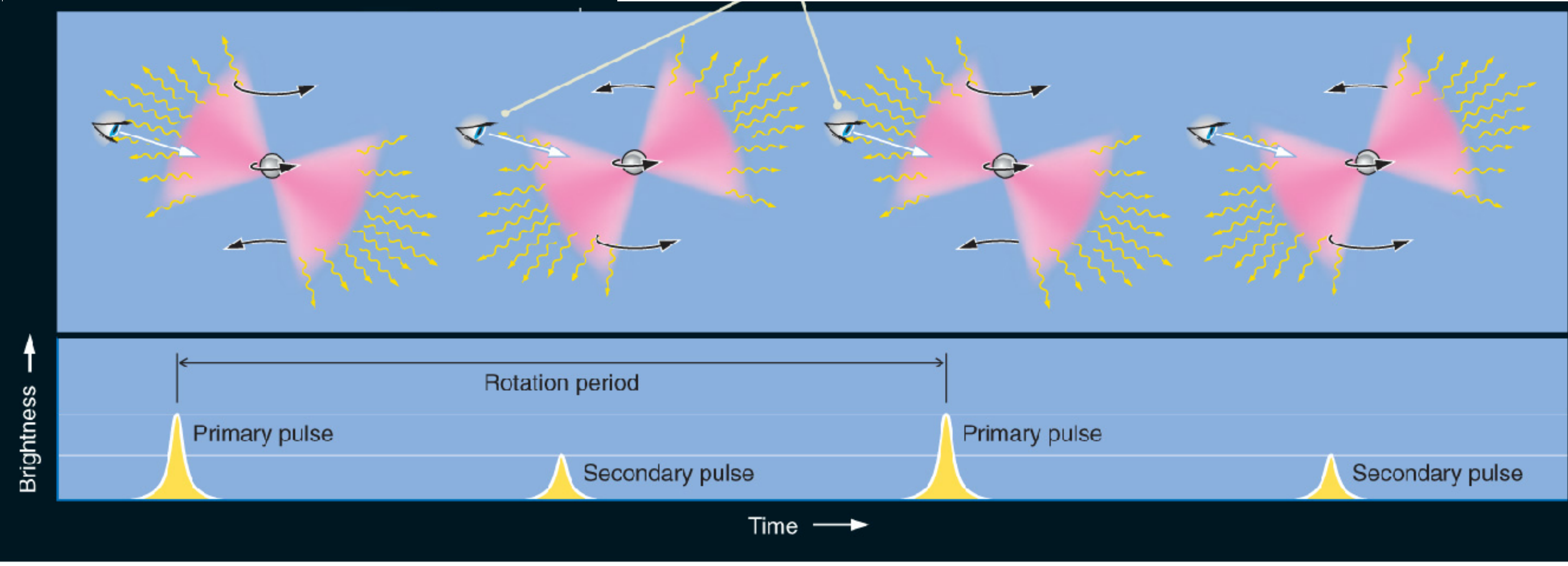


1 Neutron stars have enormously strong magnetic fields.

2 Electrons and positrons moving in the neutron star's magnetic field produce radiation that is beamed away from the poles of the neutron star.

4 As the beams sweep past an observer, the neutron star appears to pulse on and off, earning it the name *pulsar*.

3 As the neutron star rotates, these beams sweep around like the beam of a lighthouse.

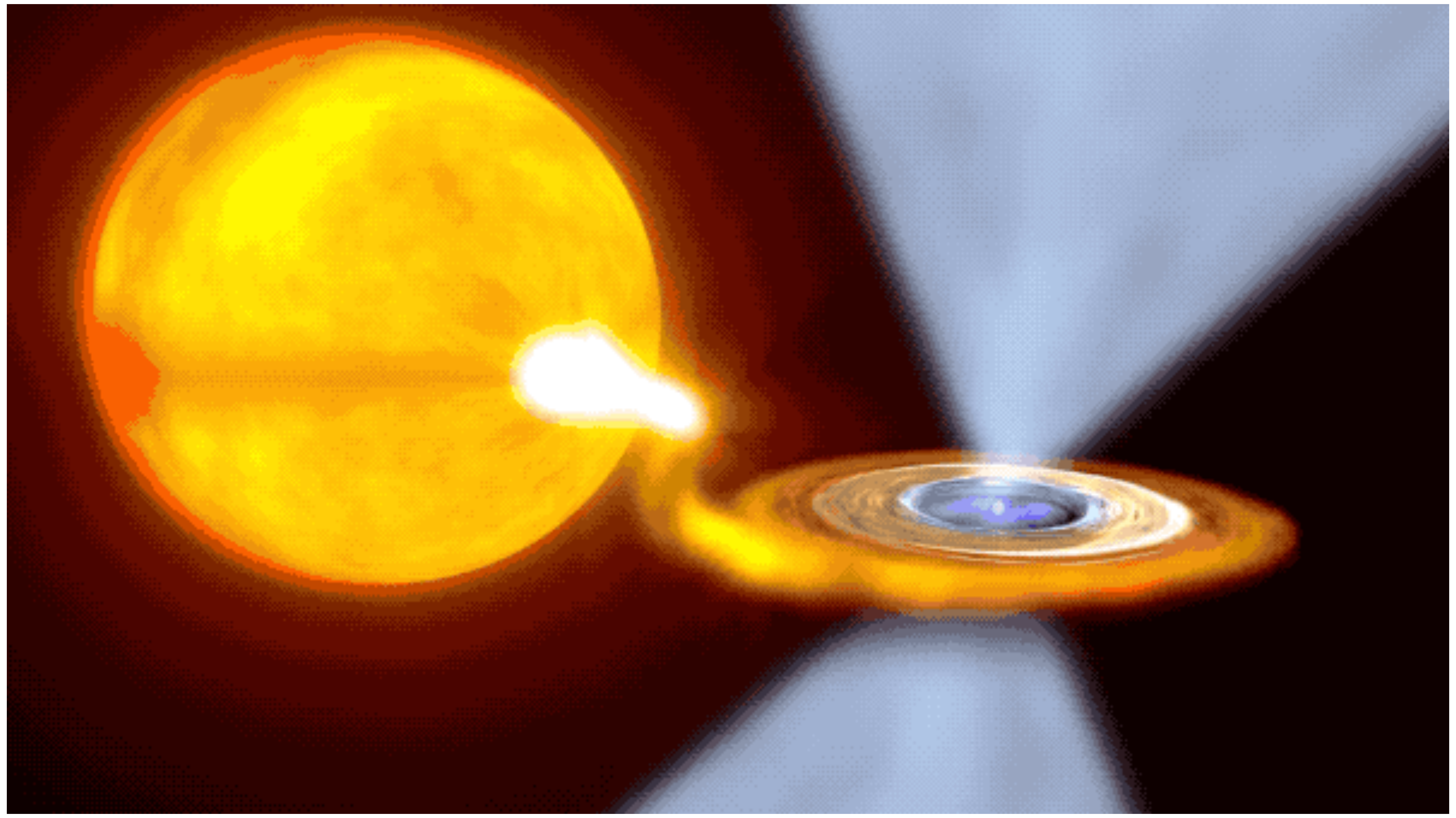


Neutron Stars are born with strong magnetic fields (get stronger as the core collapses)

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

Can a Neutron Star have any mass?



Neutron degeneracy pressure will also eventually fail

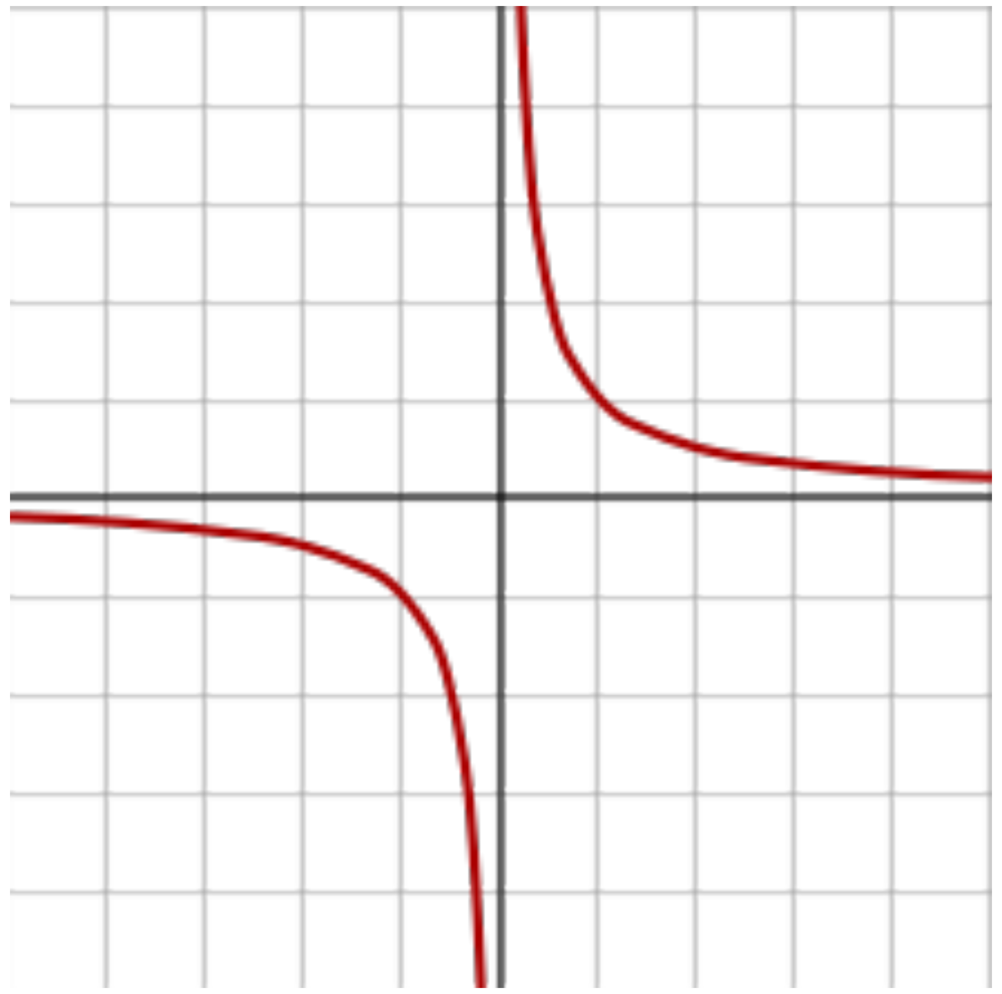
$$M_{\mathrm{max,NS}} \approx 3M_{\odot}$$

Once a NS reaches the critical mass, its collapse can no longer bed stopped. All of its mass will end up (as far as we know) in a single point at the center of the black hole, called the singularity.

Why is it called a singularity?

Roger Penrose won the Nobel Prize this year for mathematically proving that black holes must have singularities at their centers, *IF* general relativity is the correct theory of gravity.

$$f(x) = \frac{1}{x}$$



Black Holes

If the Sun suddenly collapsed and formed a black hole, what would happen to the Earth?

For a spherically symmetric object, its gravitational force (outside the object) is identical to that of an object with the same mass all at *r* = 0 —> exactly the case of a black hole!

The escape speed for a BH is the same as usual then, but b/c we can get much closer to them, the escape speed can get really high

$$v_{\rm esc} = \left(\frac{2GM}{r}\right)^{1/2}$$

Set $v_{\rm esc} = c$ (speed of light)

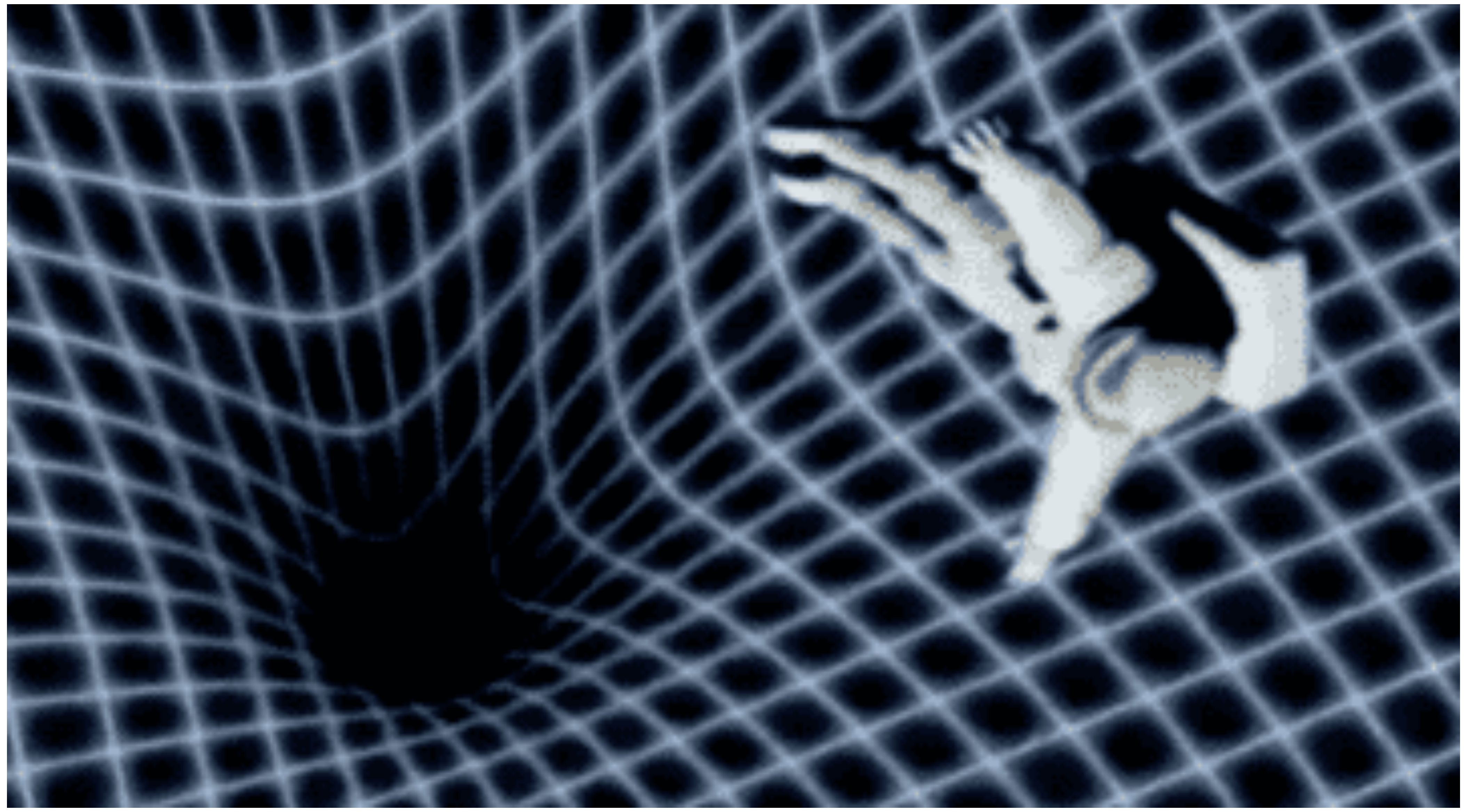
$$r_{\rm Sch} = \frac{2GM}{c^2}$$

<u>Schwarzschild radius</u>

The spherical surface defined by this radius is called the <u>event horizon</u>

Black Holes

Spaghettification



F_g changes so quickly with radius that gravitational tidal forces (the difference in F_g between your head and your feet) become strong enough to rip you apart as you fall towards a BH's singularity

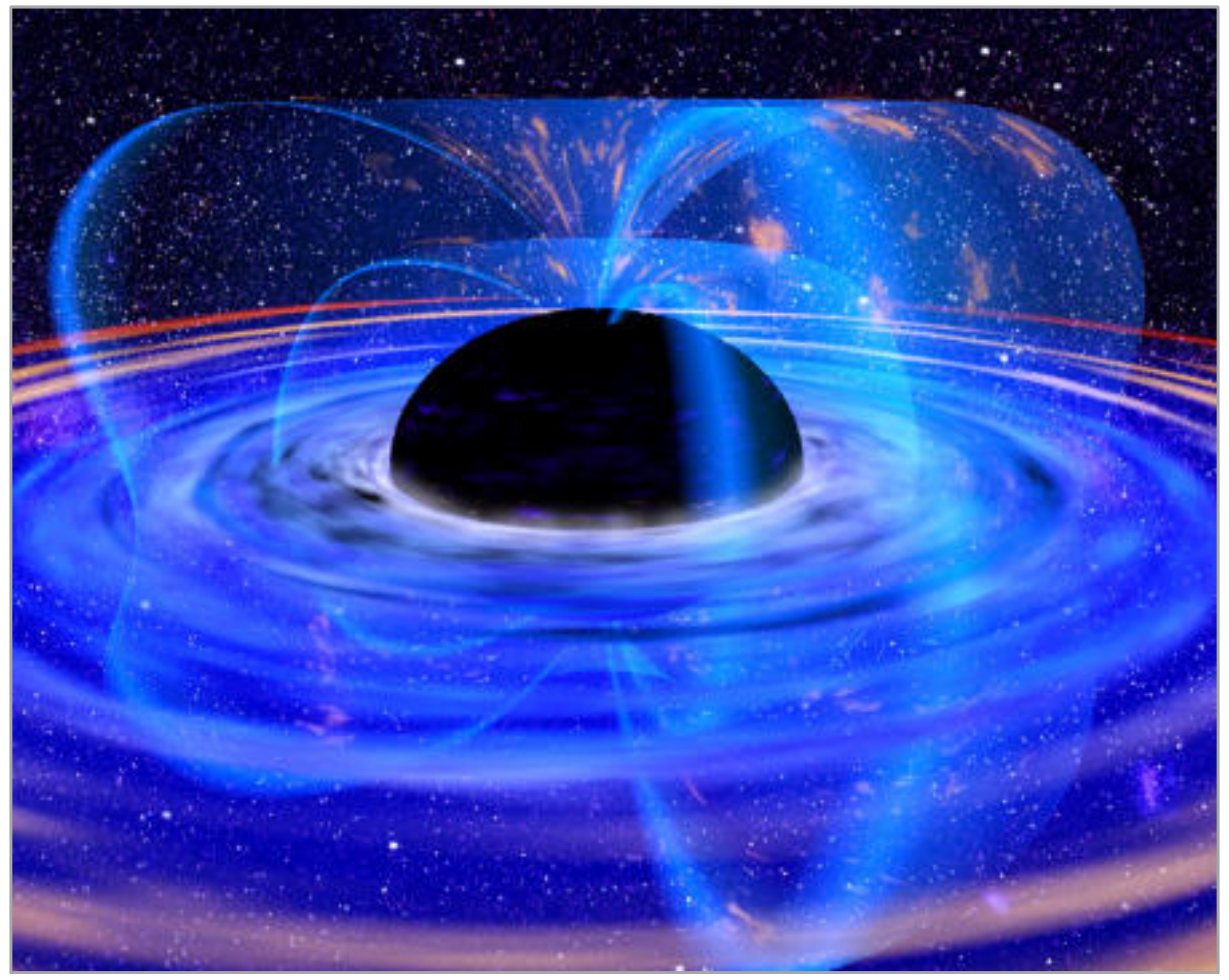
$$\Delta F \approx \frac{GMm}{r^3}\ell$$

Your mass

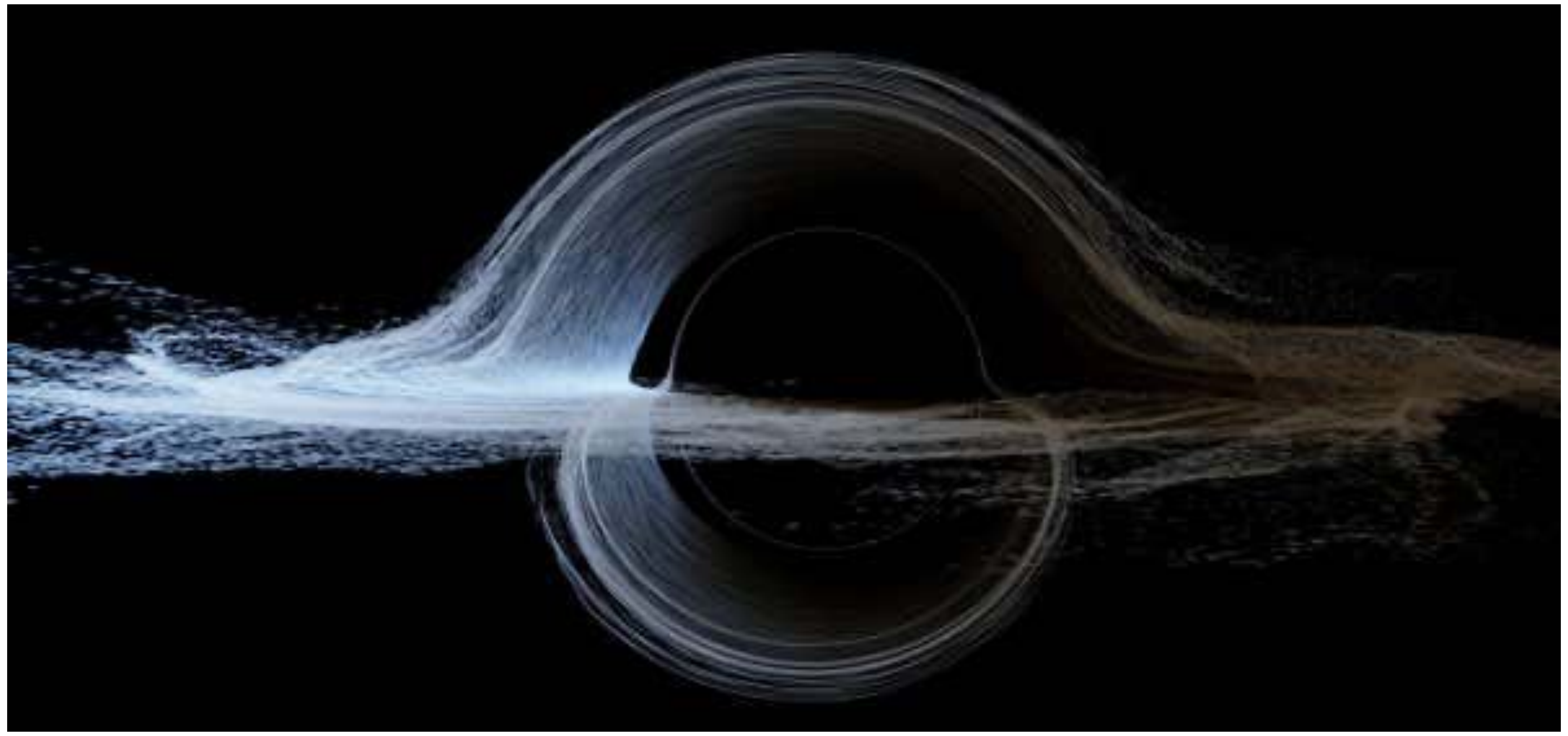
Your height

Other effects (e.g., explaining *Interstellar*)

BH with accretion disk (no gravitational lensing)



What it would actually look like



Gravitational Lensing

Light follows shortest path b/t 2 points, but space-time curved, so light rays are curved

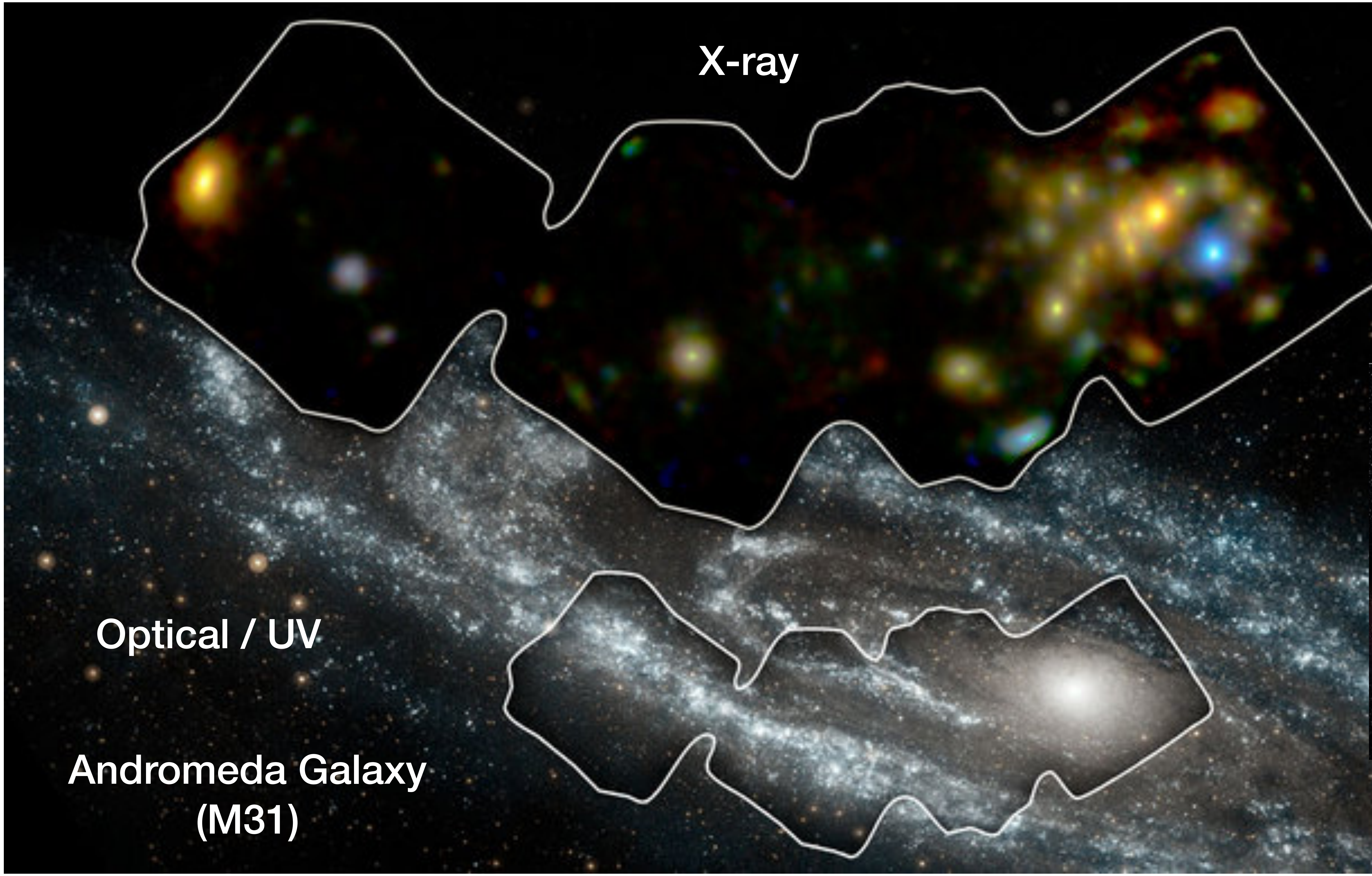
Time Dilation

Time passes slower the closer you are to a massive object (GPS satellite clocks "have more ticks" than our clocks in a given interval of time)

Gravitational Redshift

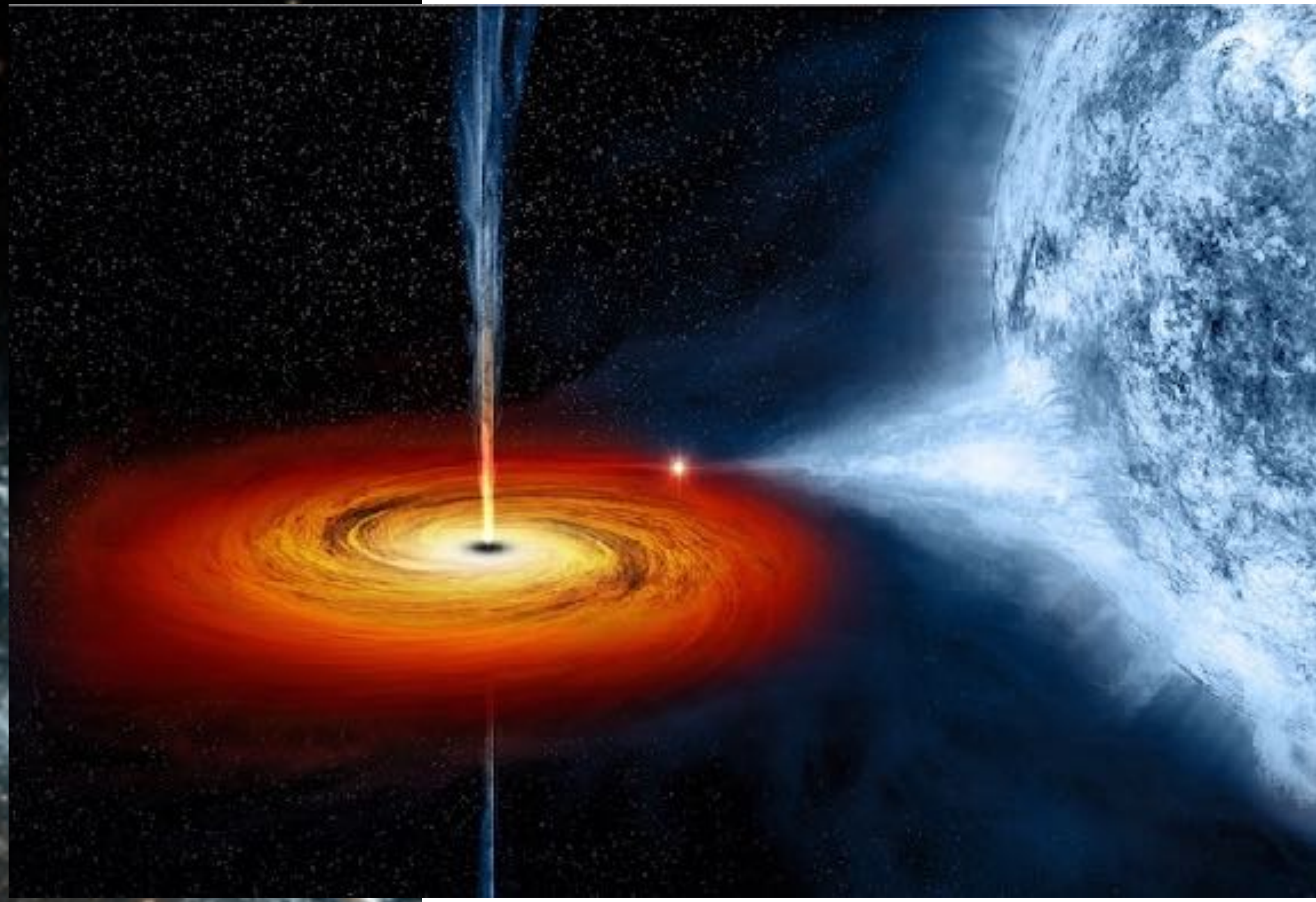
Light has to "climb out" of a gravitational potential well, losing energy — light with less energy has a longer wavelength (just outside the event horizon, light is nearly infinitely redshifted)

Observing real NSs and BHs



X-ray Binaries

Close binary stars where 1 star has exploded and is now accreting matter from its companion



Star's life determined mostly by its initial mass

White Dwarf:

$$M < 7M_\odot$$

Neutron Star:

$$7M_\odot < M < 18M_\odot$$

Black Hole:

$$M > 18M_\odot$$