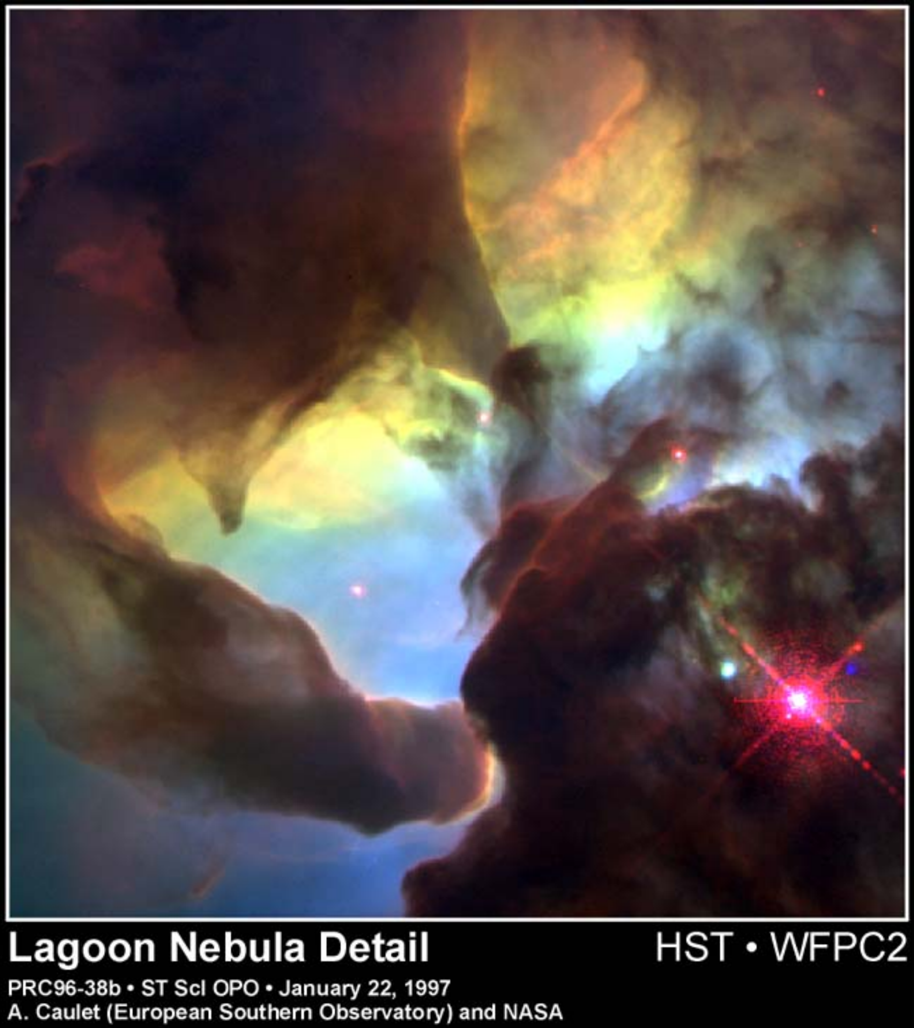
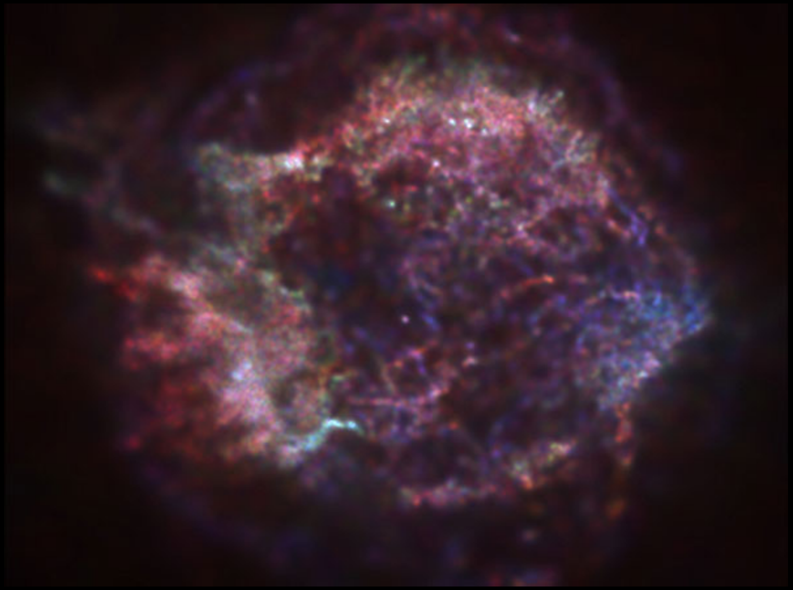
Stellar evolution-Birth to Death

Dr. Bob Benjamin—Physics Dept.—U. of Wisconsin-Madison





- **Chandra X-ray observatory of the Cas A supernova remnant.**
- **Note the dot right at the center!**

Triumph of 20th Century Physics

- **Mass conservation**

$$\frac{dM_r}{dr} = 4\pi\, r^2 \rho$$

- **Hydrostatic equilibrium**

$$\frac{dP}{dr} = -\frac{GM_r\rho}{r^2}$$

- **Thermal equilibrium**

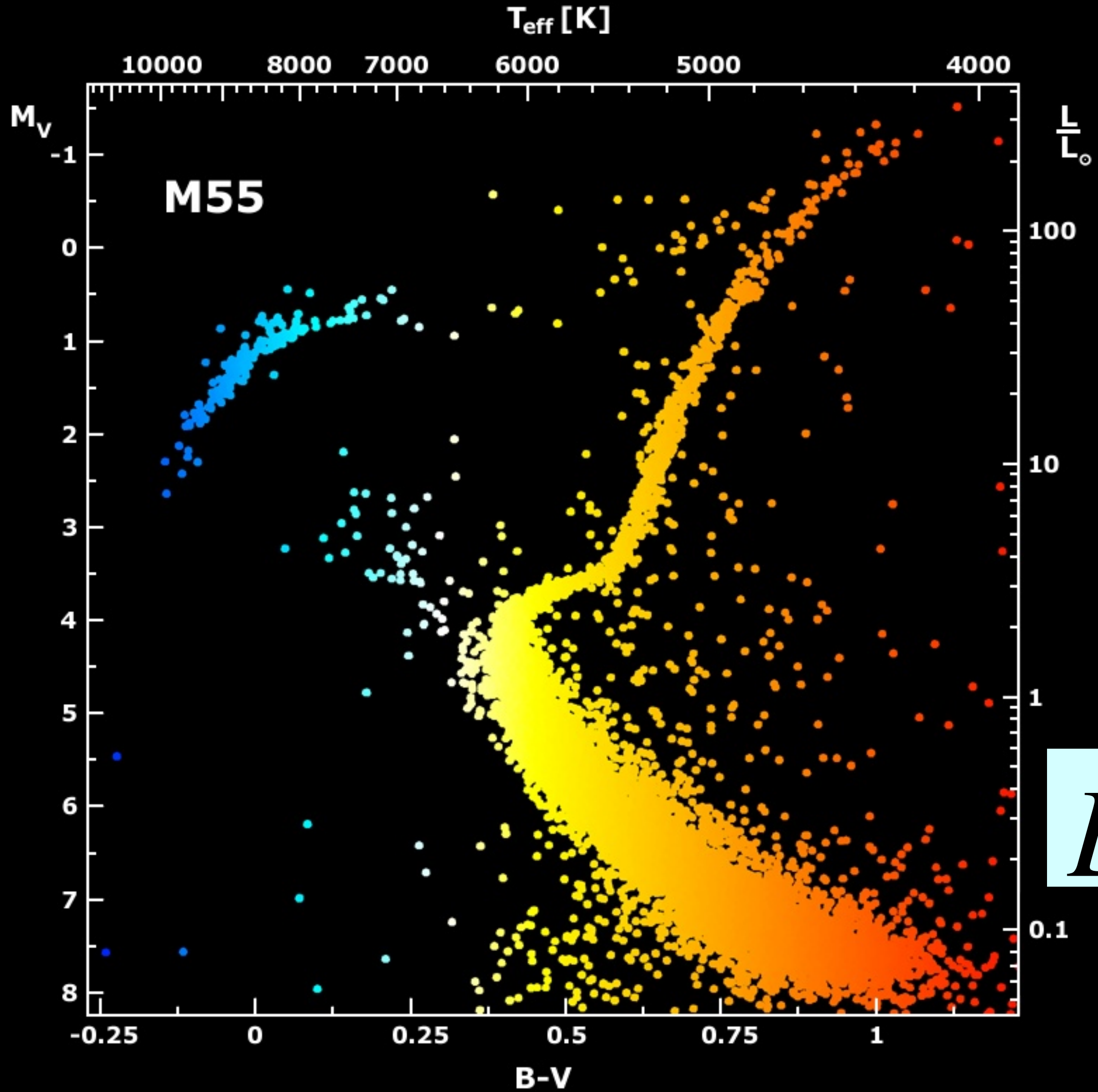
$$\frac{dL_r}{dr} = \varepsilon_{nuc} - \varepsilon_{neutrino}$$

- **Radiative diffusion**

$$L_r = -4\pi\, r^2 \frac{4ac}{3\rho\kappa} T^3 \frac{dT}{dr}$$

After three centuries of work, we have a reasonably complete picture for how stars evolve over time!

The Main Sequence

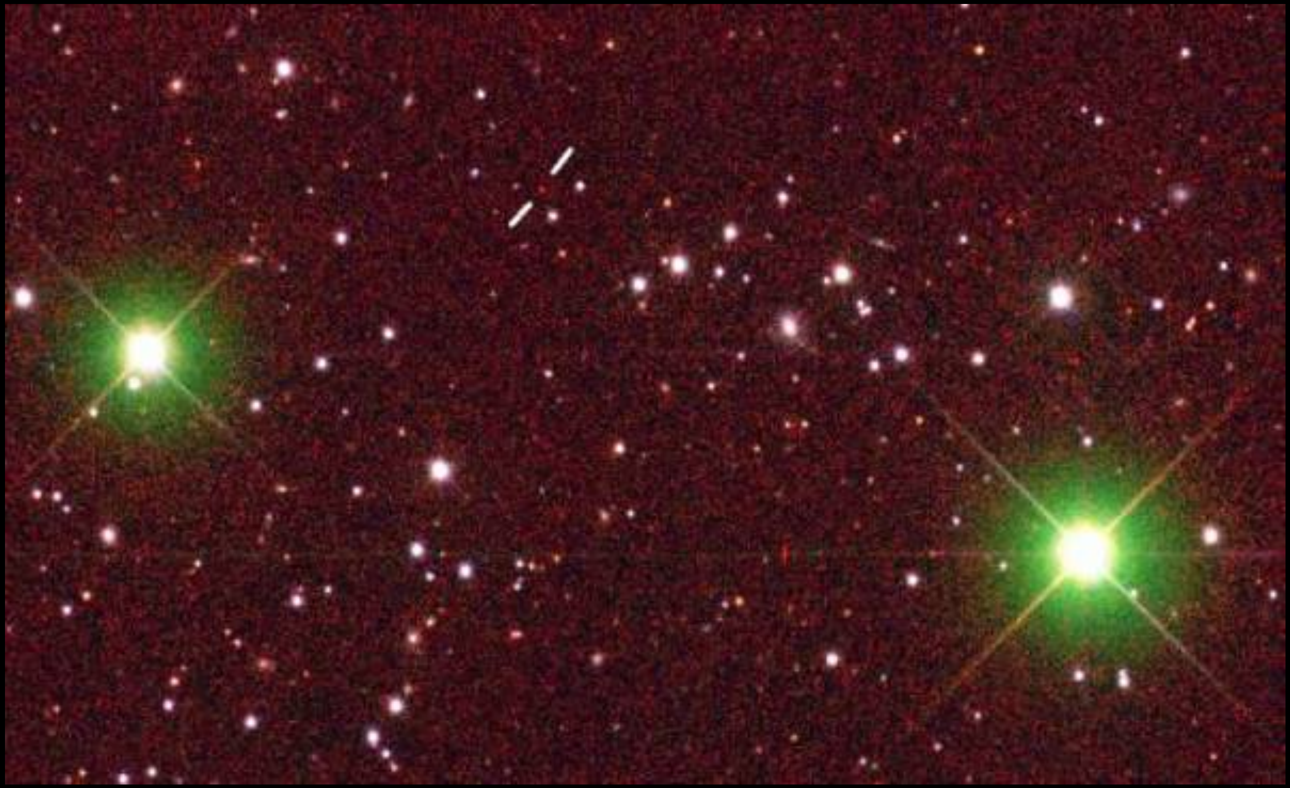


Color-Magnitude diagram
Of Globular Cluster M55

$$L = e\sigma 4\pi R^2 T^4$$

O B A F G K M…

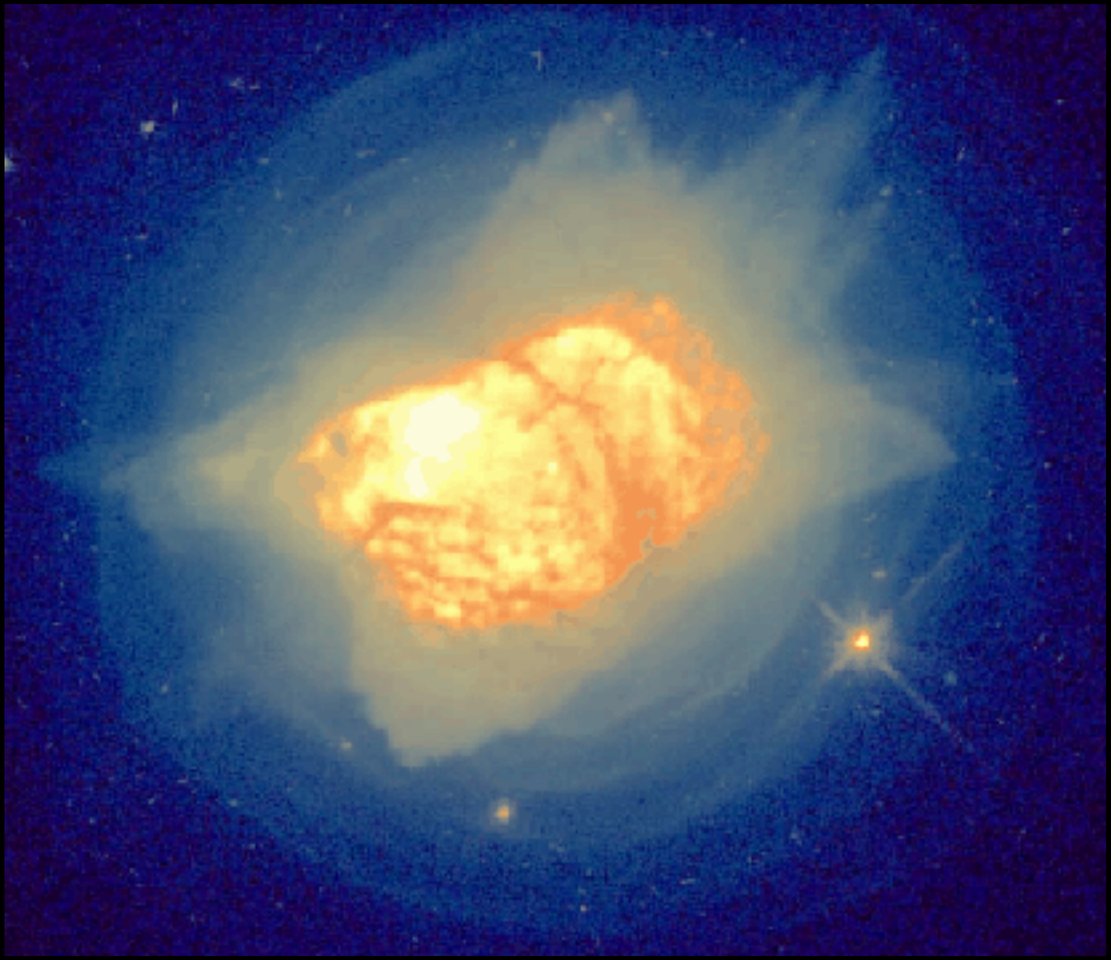
“New” Members of the Main Sequence



• A “methane” or T dwarf discovered two years ago located only 30 light years from Earth!

... L T

Evolution and Lifetimes



Stellar Lifetimes

= Nuclear Fuel / Luminosity

= M / M^4

= M^{-3}

Hot stars burn bright, and burn out.

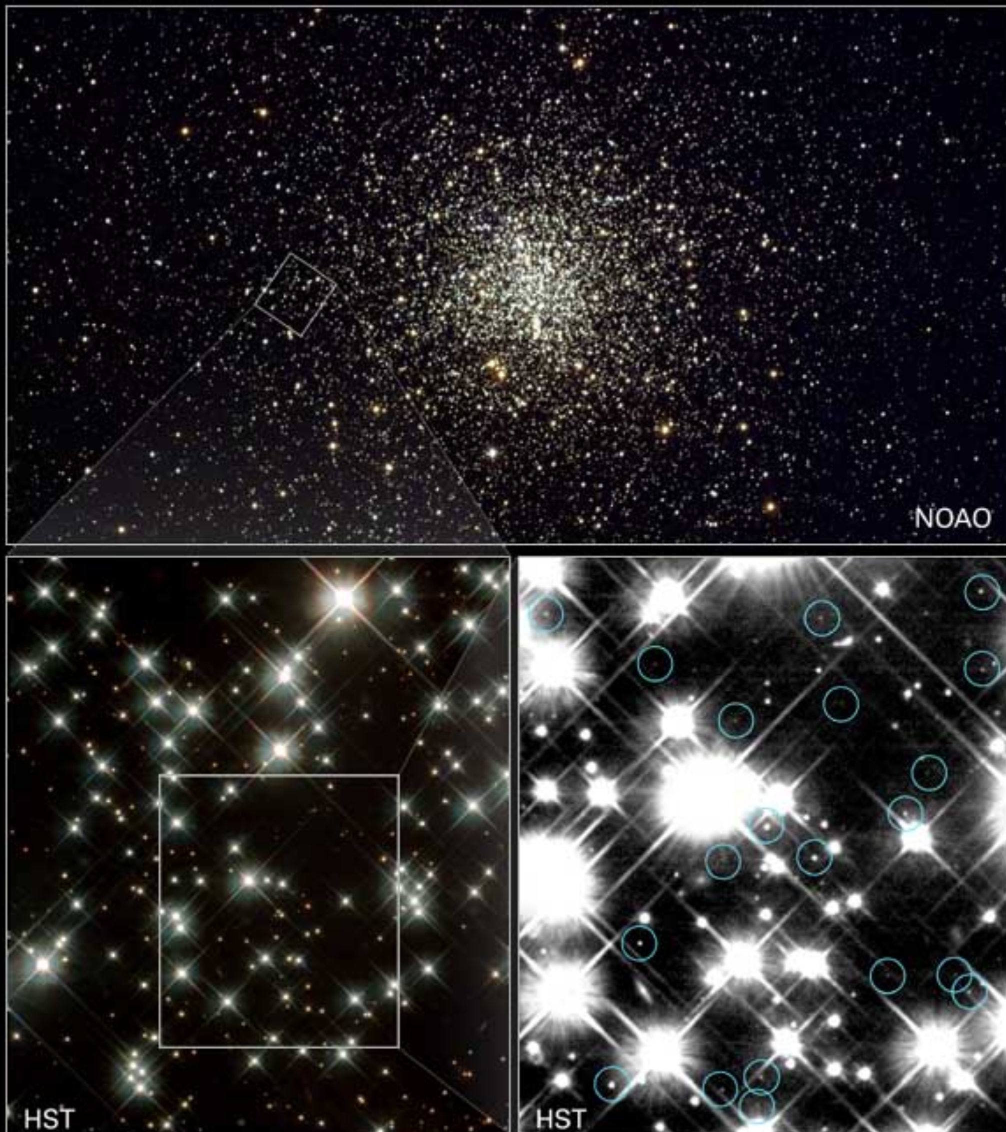
Cools stars conserve fuel, last longer.

Hubble Space Telescope Image of Planetary Nebula NGC 7027

The Death of the Sun

- Sun will run out of fuel in about 4-5 billion years.
- Core heats up, outer layers expand to about orbit of Mars.
- Outskirts of red giant star detach from sun, blown outward.
- Center cools to a white dwarf.
- Details depend on rotation, magnetic fields, and companions.

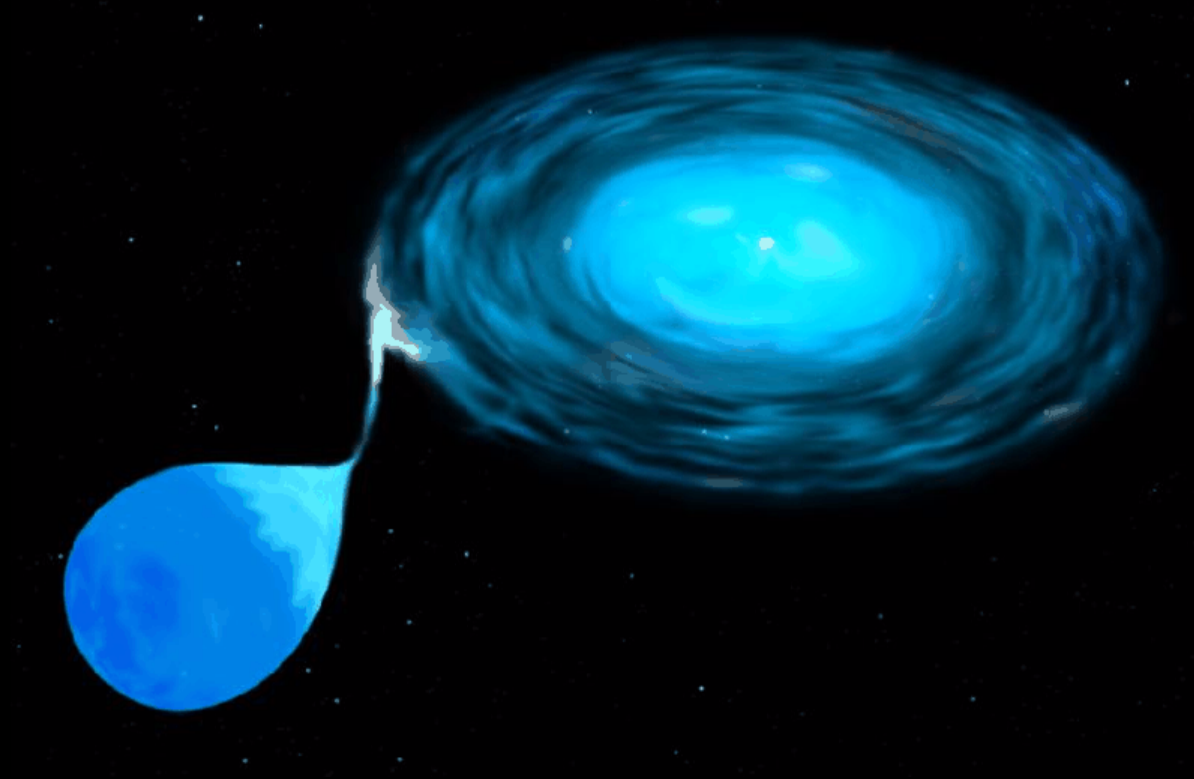
White Dwarf Stars



White Dwarf Stars in Globular Cluster M4 HST WFPC2
NASA and H Richer (University of British Columbia) STScI-PRC02-10

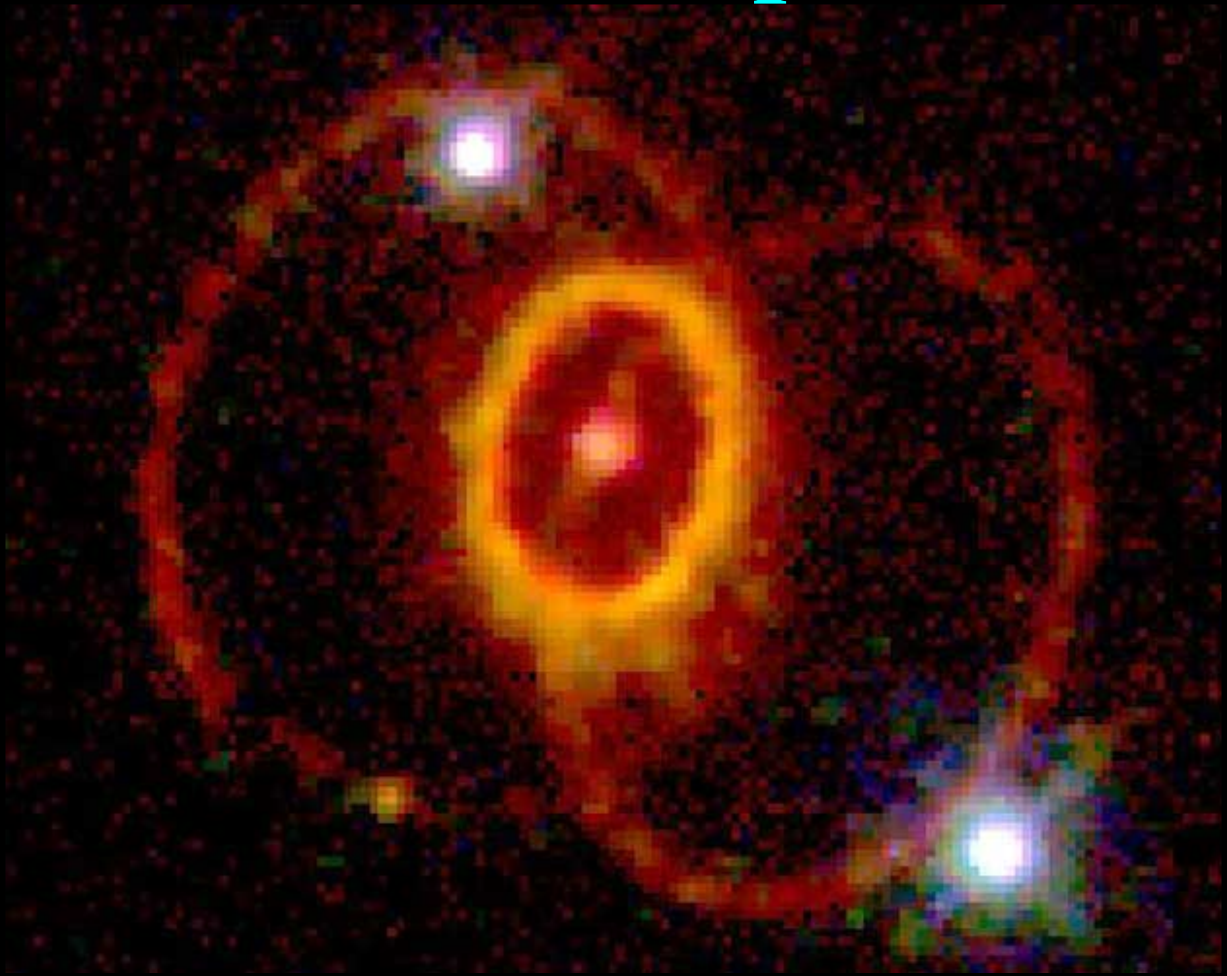
- Held up by "degeneracy pressure. Electrons resist being squeezed together.
- Density $=10^6$ gm/cm^3
- About the size of the Earth, mass of 0.6-1.4 M_{sun}
- Cool like bricks. By looking at temperature, we can estimate the age.
- Picture shows a region of 1 light year across, 8 hours of HST time.
- Age of white dwarfs in the globular cluster M4 =12-13 billion years old.

Binary Systems and Novae



• Novae are runaway nuclear surface flashes of
on the surface of a white dwarf in binary systems.
• These flashes occur every ten to thousand years.
• Not clear whether mass builds up or blows off over time.

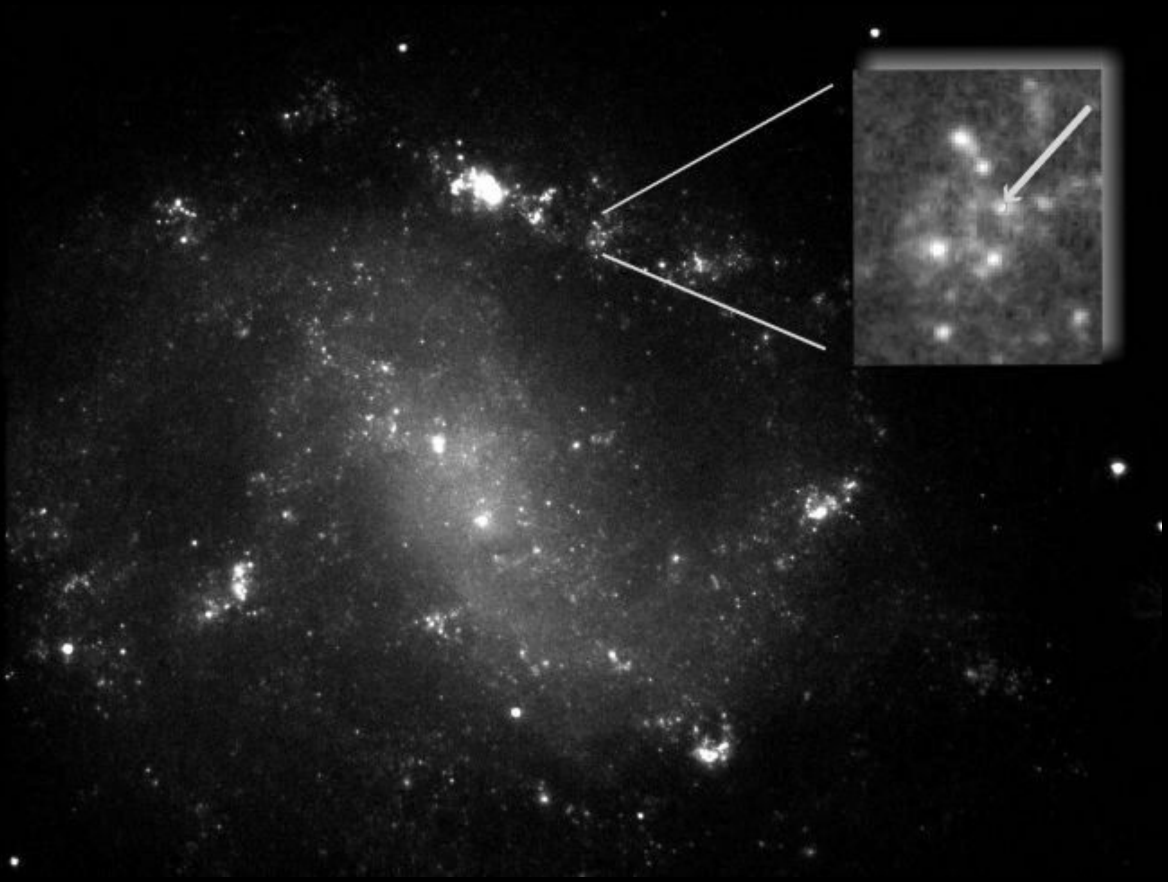
Supernovae



HST image of SN 1987 A in the Large Magellanic Clouds

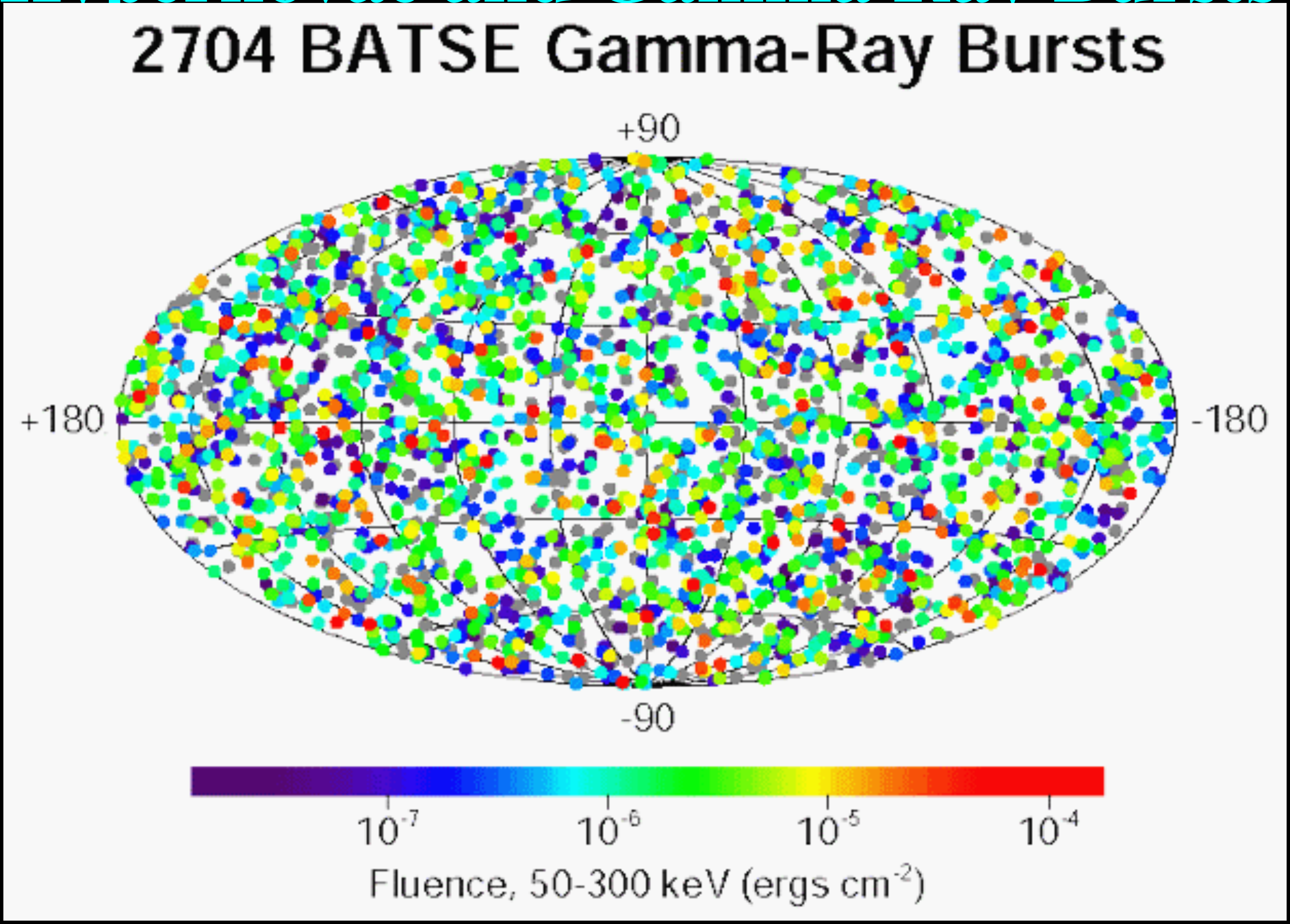
- Stars more massive than ~8 x Sun cannot be supported by electron degeneracy pressure when they run out of nuclear fuel.
- Core collapse!
- Huge release of nuclear energy.
- Formation of all elements heavier than iron.
- End product? (Nothing?), neutron star, (quark star?), black hole.

Supernovae in the Universe



<u>ESO 184-G82</u>
100 million light years away.
Inset : expanded view of star-forming region, 300 light-years across.
Supernova light reached earth April 25, 1998.
A source of a gamma-ray burst?

Hypernovae and Gamma Ray Bursts



Gamma-ray burst may be particular powerful supernova explosion, the coalescence of two neutron stars, or something unthought of.

Supernova Remnants


The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

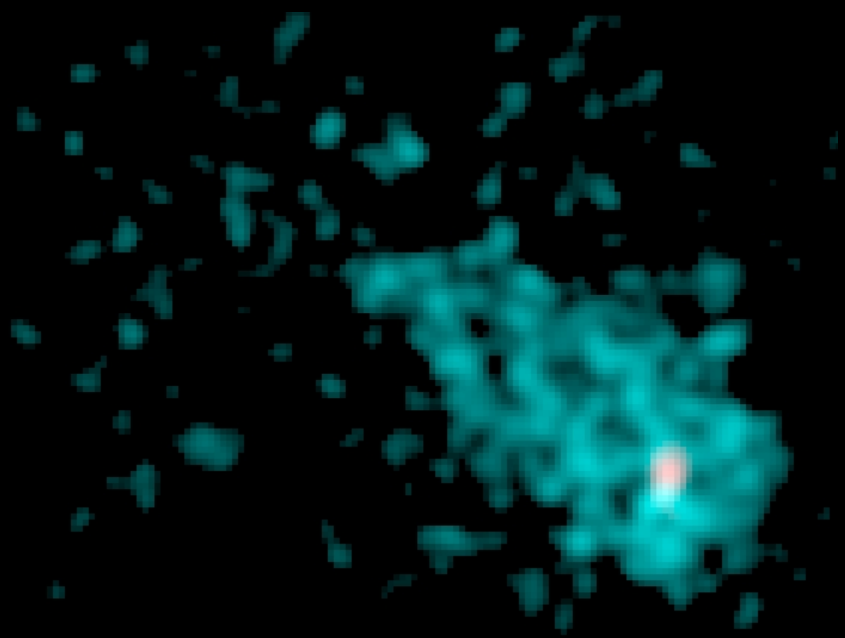
ESO PR Photo 40f/99 (17 November 1999)

Supernova explosion produces vast regions of hot gas, which last for 100,000 years before dissipating into the general interstellar medium.

Crab Nebula

- **Explosion observed in 1054 AD**

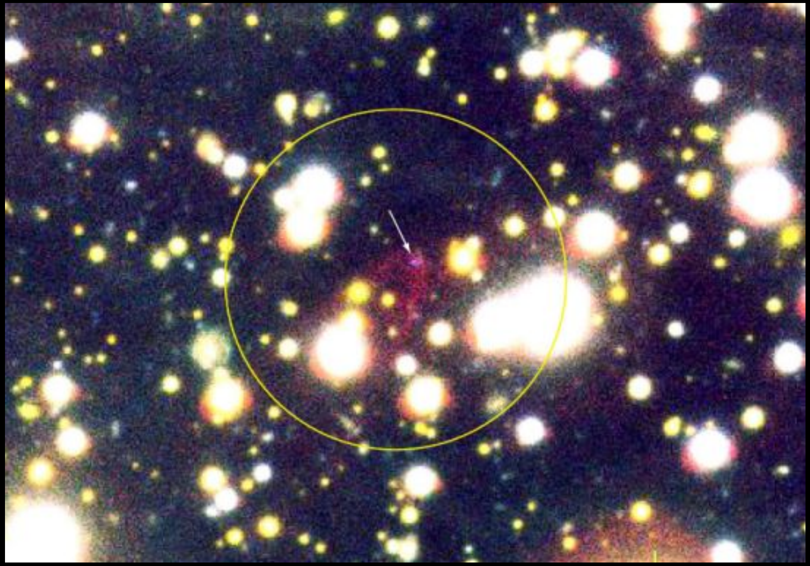
Neutron Stars



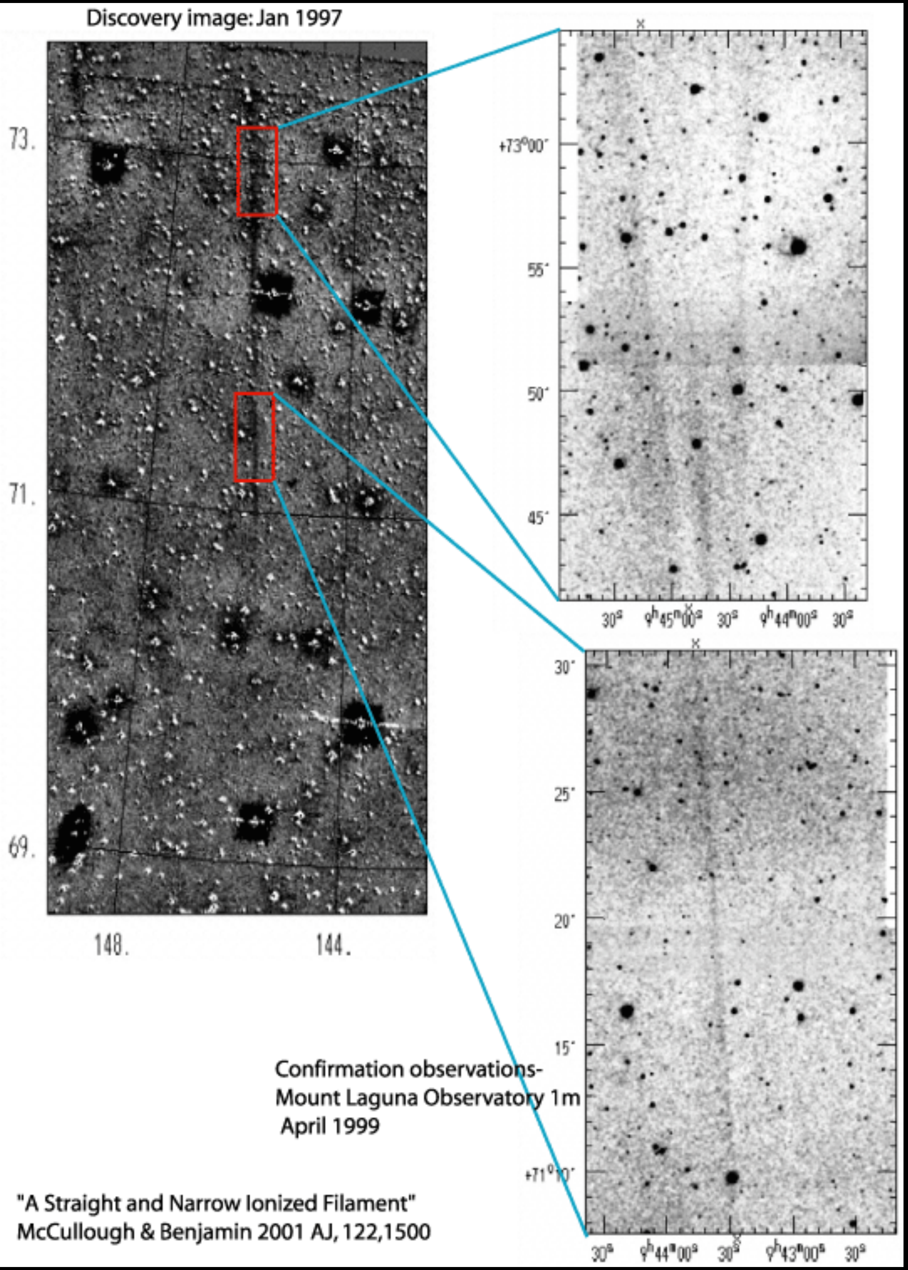
Discovery of a neutron star in the supernova remnant IC 443 using Chandra X-ray Obs.

- Size of New York City (10 km).
- Density of ~4 x 10^{14} gm/cm^3
- 1 cm^3 of N.S.=mass of humanity
- Supported by neutron degeneracy pressure.
- Exact physics of nuclear matter not as well understood.
- Mostly detected as radio pulsars from spinning cone of radio emission?
- Can also detect via X-ray emission from hot surface (but faint!!)

Neutron Stars in the Interstellar Medium

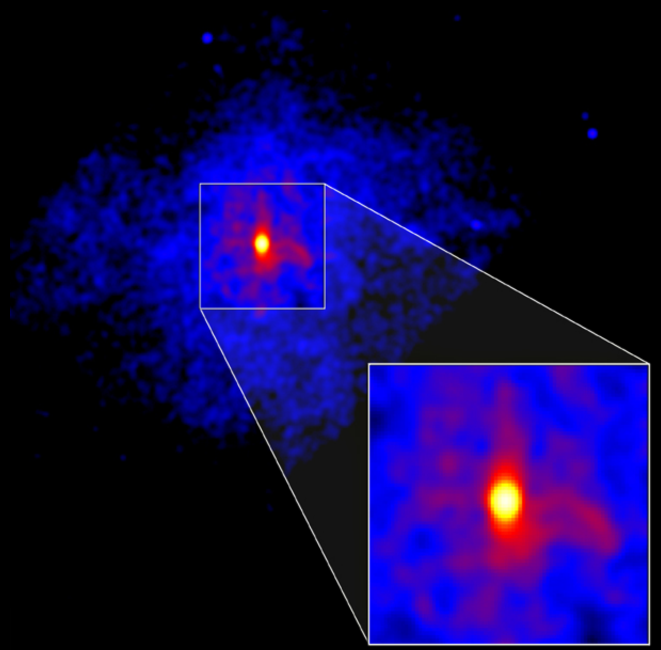


Bow shock around a runaway neutron star RX J1856.5-3754 (seen in emission from ionized gas)



Possible Stellar Contrail?

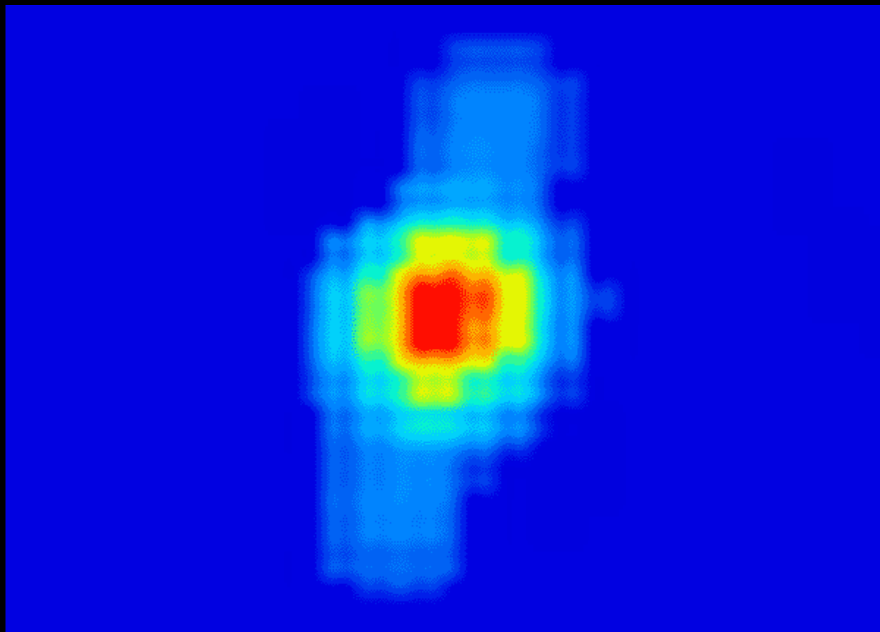
Quark Stars?

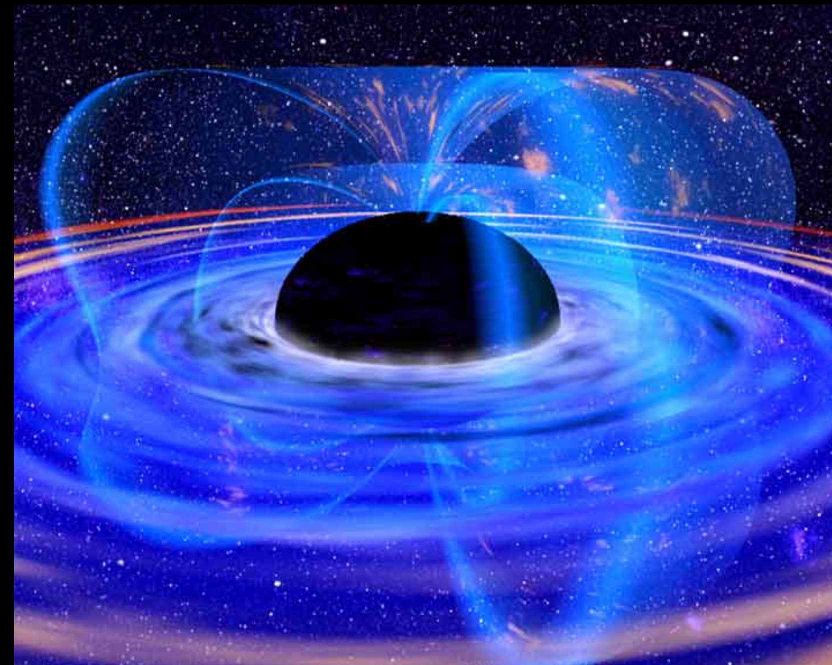


RX J1856.5-3754
Dr. Jeremy Drake
• T=700,000 K implies D=5.65 km
Too small for a neutron star?

3C58 (SN 1181)
Dr. Patrick Slane
SNR age=821 years
T< 100,000 K
Too cold for a neutron star?

Black Holes("Frozen Stars")





Black holes: The reality

V4641 Sgr- Radio emission from the closest black hole candidate (d=1500 light-years)

Black holes: The artist's imagination

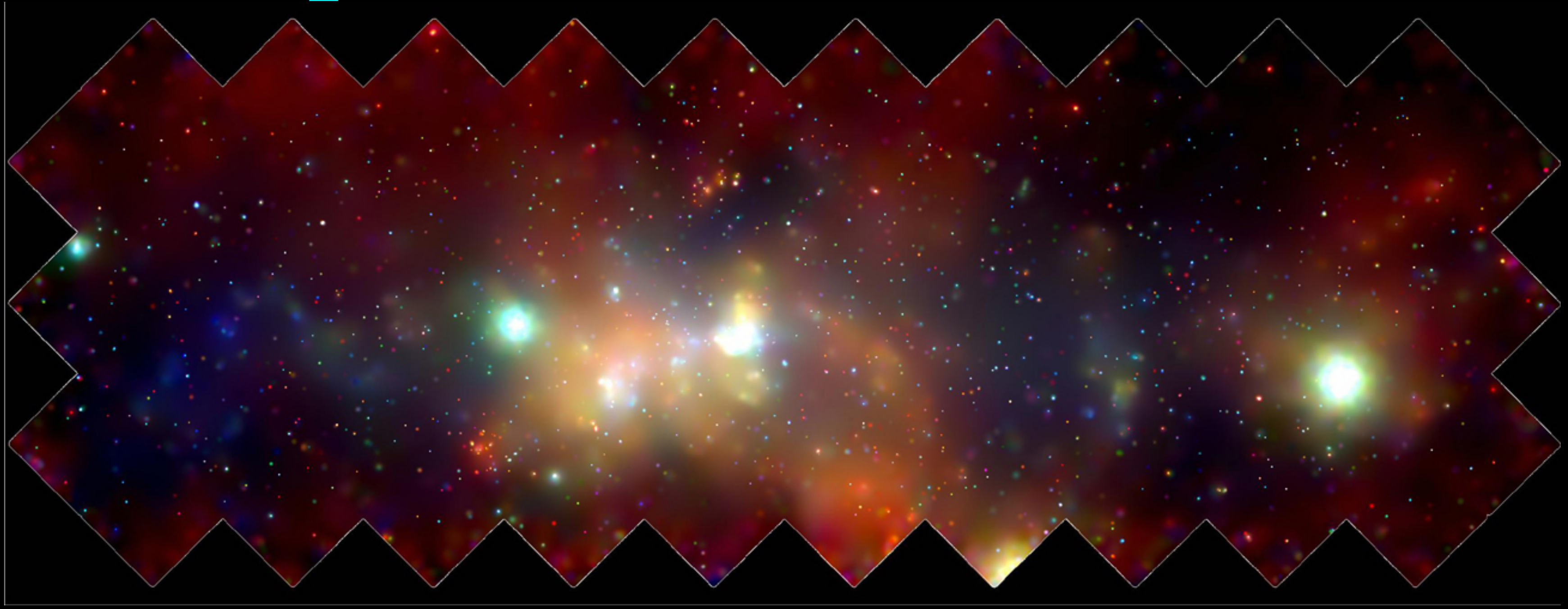
X-ray emission powered by magnetic and gravitational heating as material falls into a black hole.

$$R_{Sch} = \frac{2GM}{c^2}$$

Event horizon: Distance where even light cannot escape.

- Requires general relativity to work out physical properties of black holes.

Supermassive Black Holes



Panoramic View of the Center of the Milky Way

Q. D. Wang-Chandra X-ray Observatory

- **There is evidence for supermassive (> 10^6 M_{sun}) black holes in the center of many galaxies. We don't know why they are there.**

- **Galaxies are the challenge for the 21st century…**

References

The images used here were taken from several web sites including

- The Chandra X-ray Observatory

http://www.chandra.harvard.edu

- The Hubble Space Telescope

http://www.stsci.edu

- Astronomy Picture of the Day

http://antwrp.gsfc.nasa.gov/apod/

- Bob Benjamin's home page

http://wisp.physics.wisc.edu/~benjamin