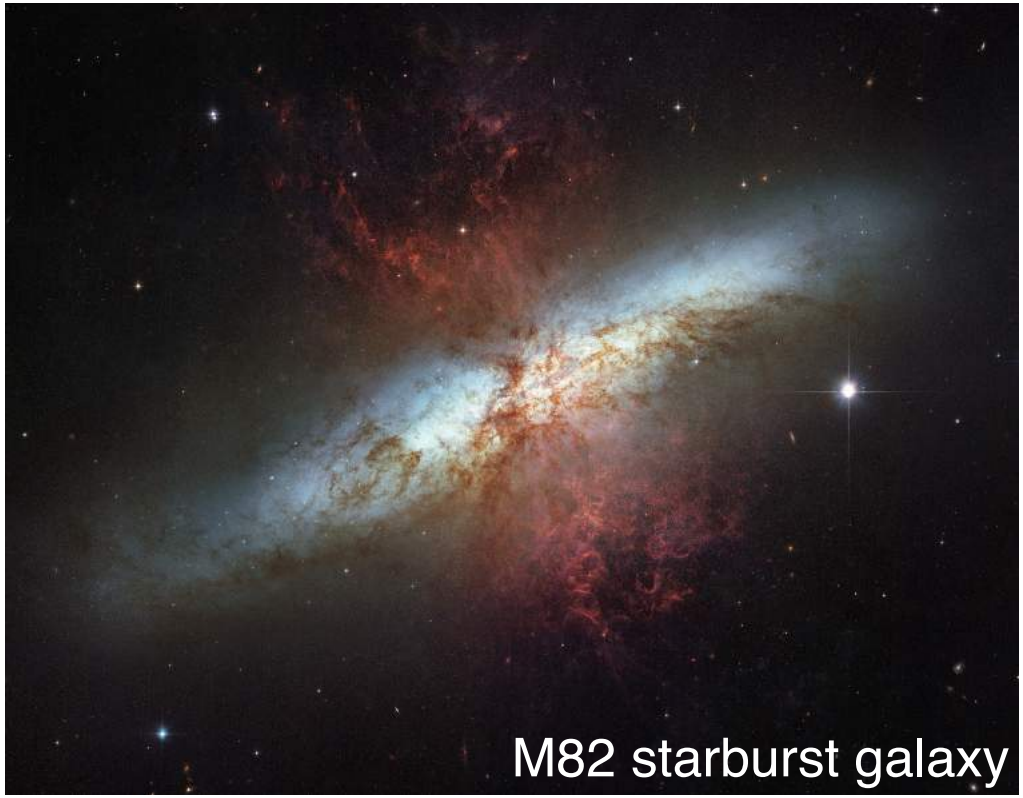
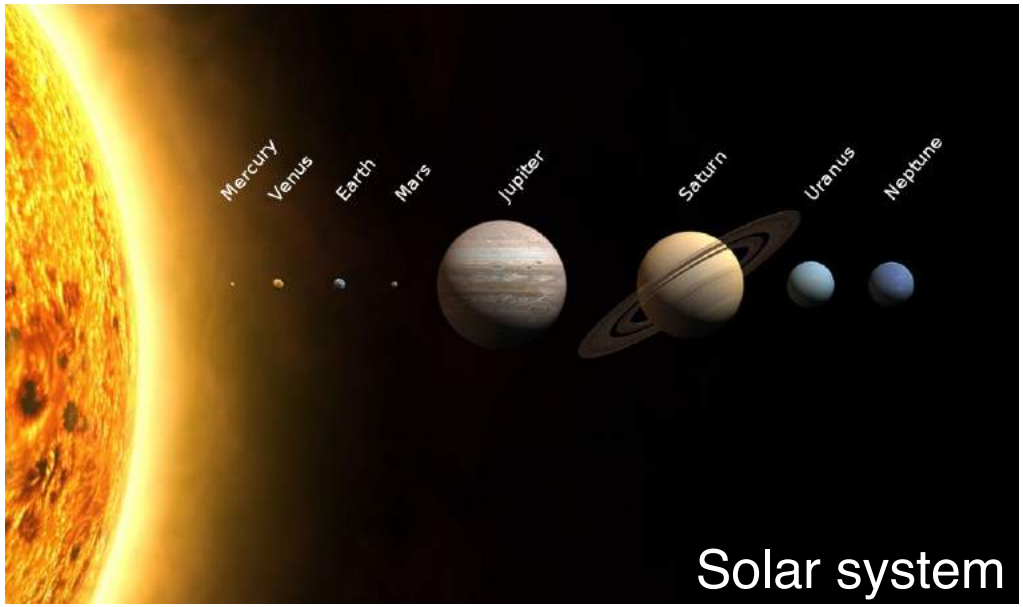
Why focus on stars?

- Central to many astrophysical phenomena
  - synthesize all heavy atoms
  - drive galaxy evolution
  - at the center of planetary systems
  - used to measure cosmological distances (Cepheids, Type Ia SNe)
  - remnants (WDs, NSs, BHs) are unique laboratories for extreme physics
  - …
- Many basic principles applicable to other systems
- Can go into reasonable depth in single quarter

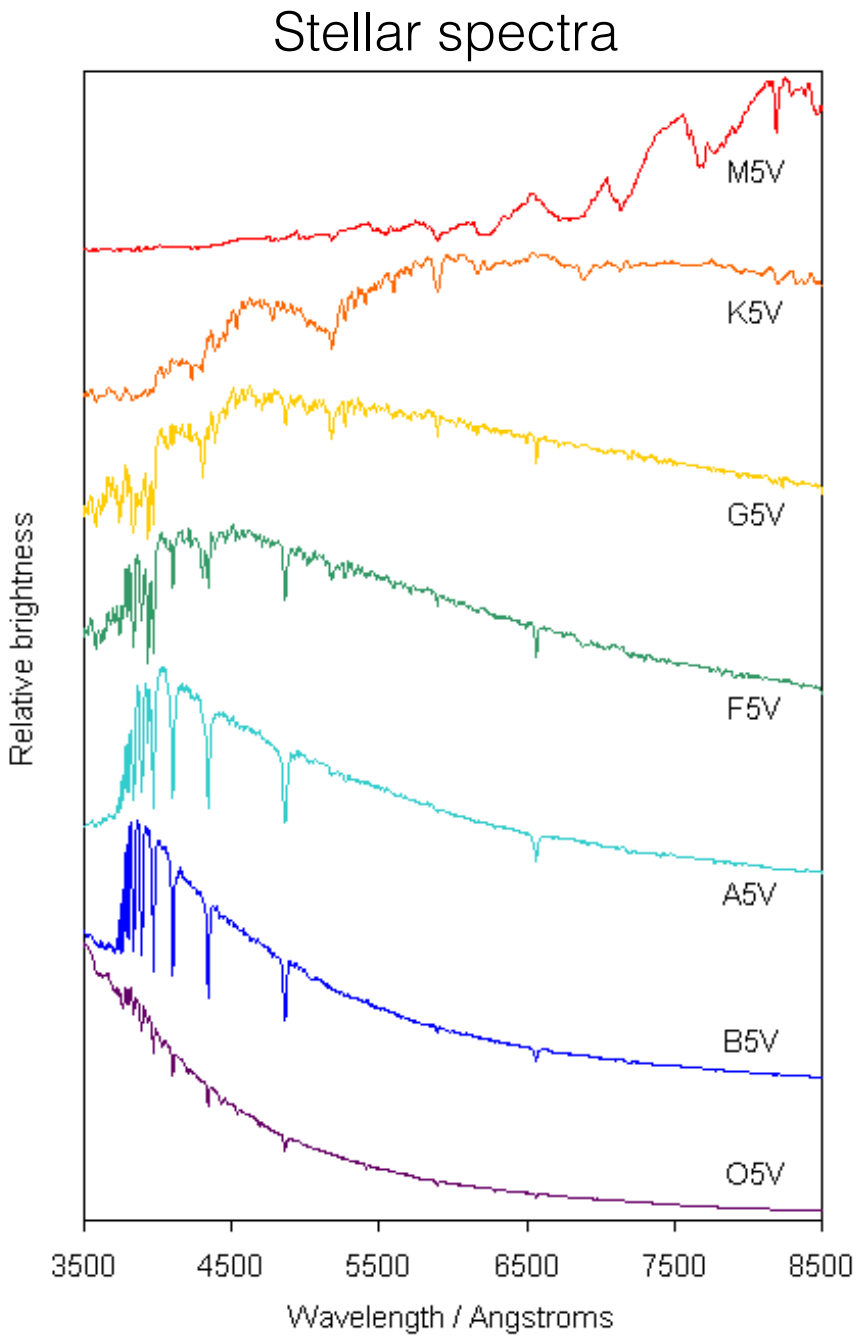

M82 starburst galaxy



Solar system

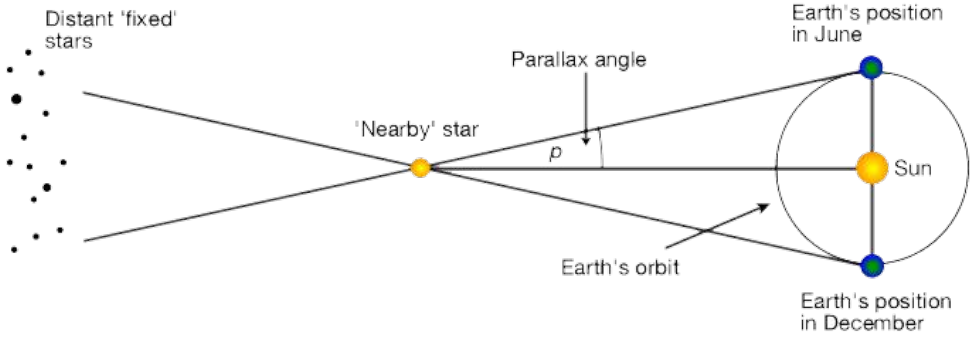
Overview of what we will cover in this course
Quantitative description of stars

- Radiation concepts:
  - intensity
  - flux
  - luminosity
  - color

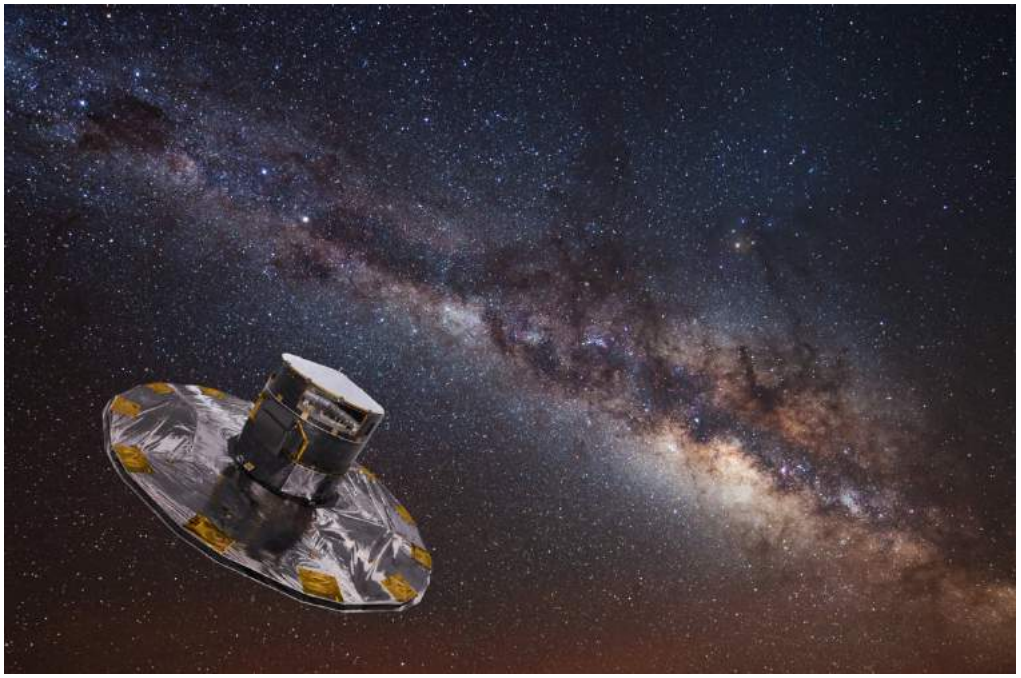


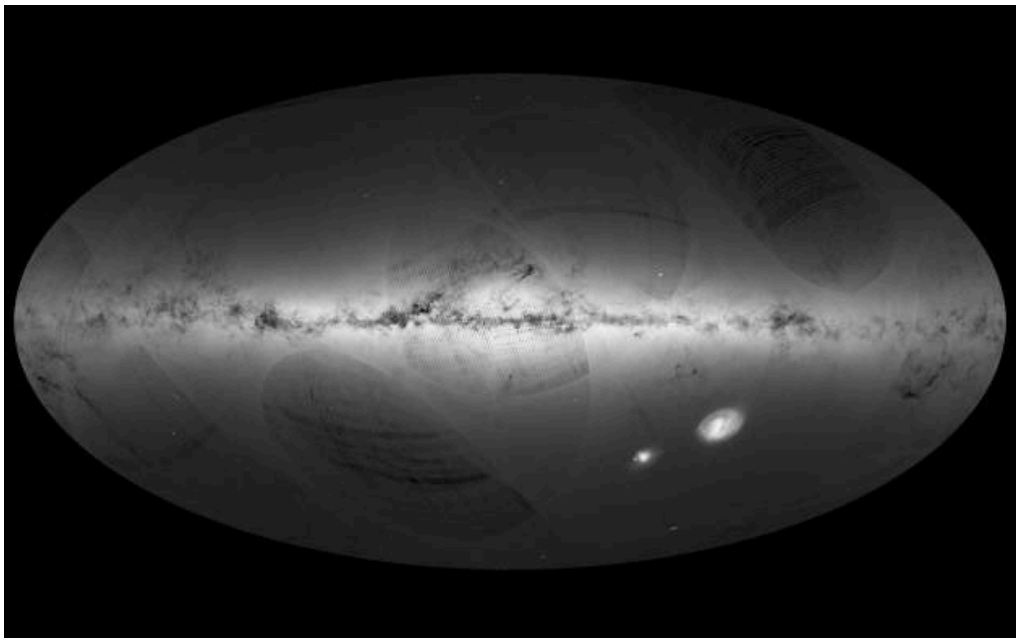
Measuring stellar parameters

- distances
- velocities
- masses

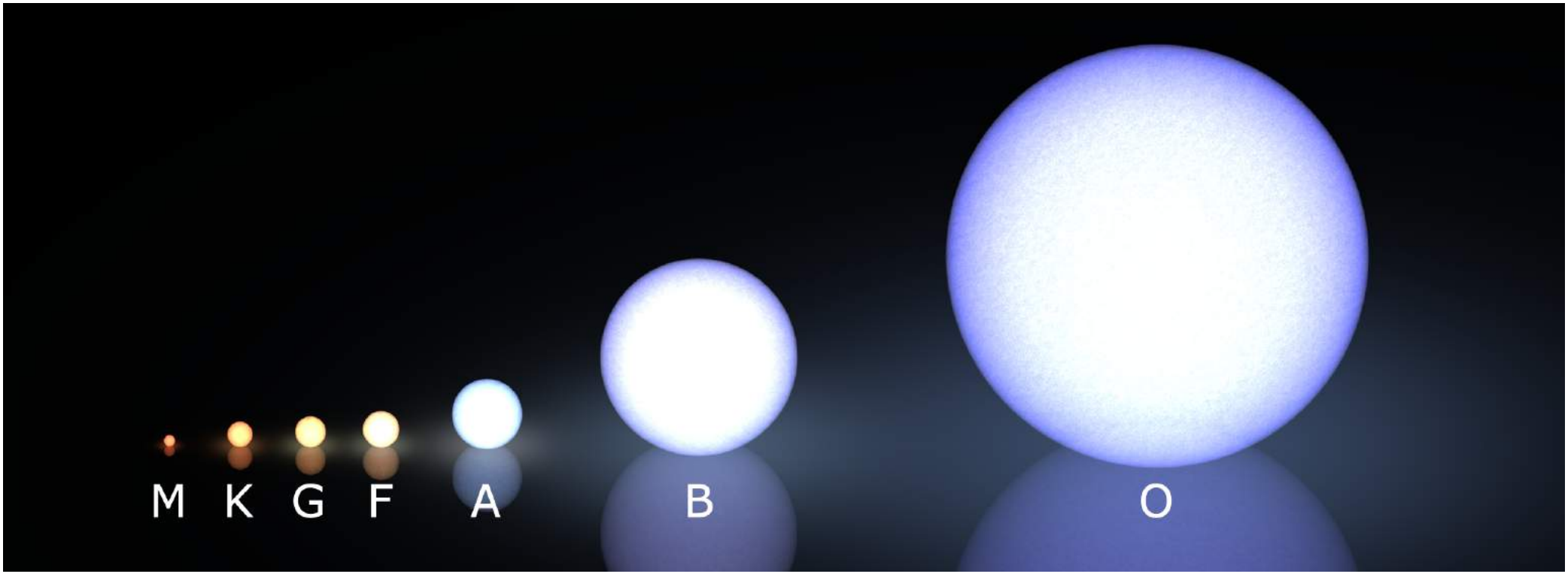


A billion stars measured by Gaia satellite





Classification and explanation of stellar types



- spectral types
- relationships between stellar mass, luminosity, and temperature

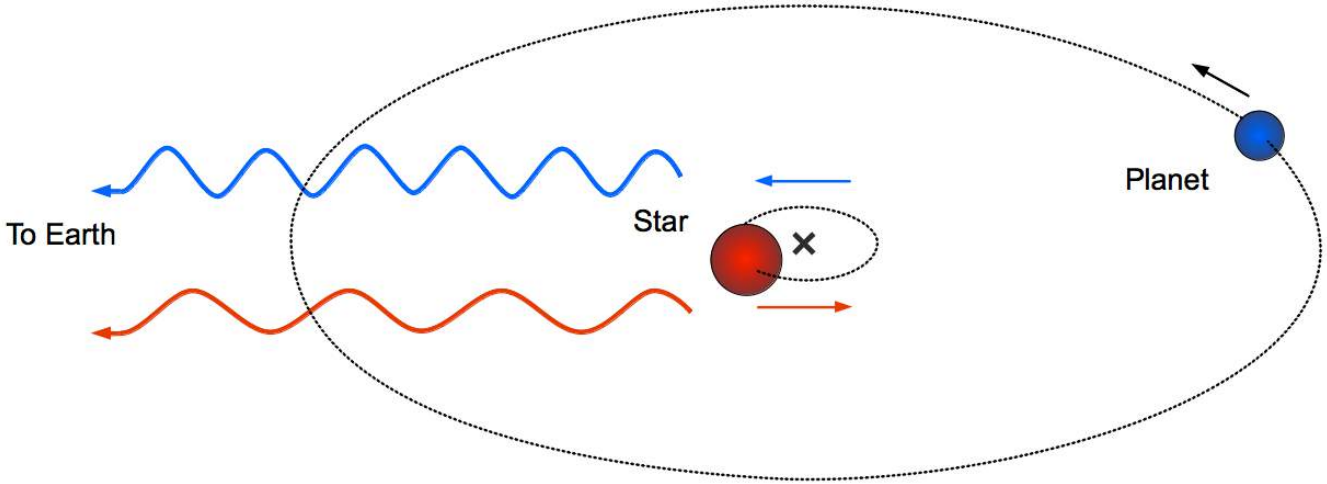
Binary stars and their applications

Visual binary

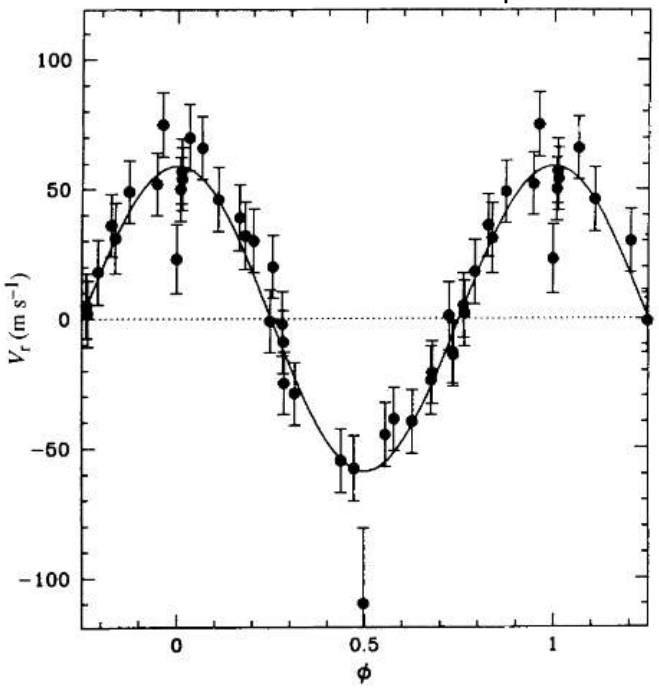
Eclipsing binary

- different types of binaries: visual, astrometric, spectroscopic, eclipsing
- measuring orbital parameters
- measuring stellar masses and radii

Discovering and characterizing extrasolar planets with similar techniques

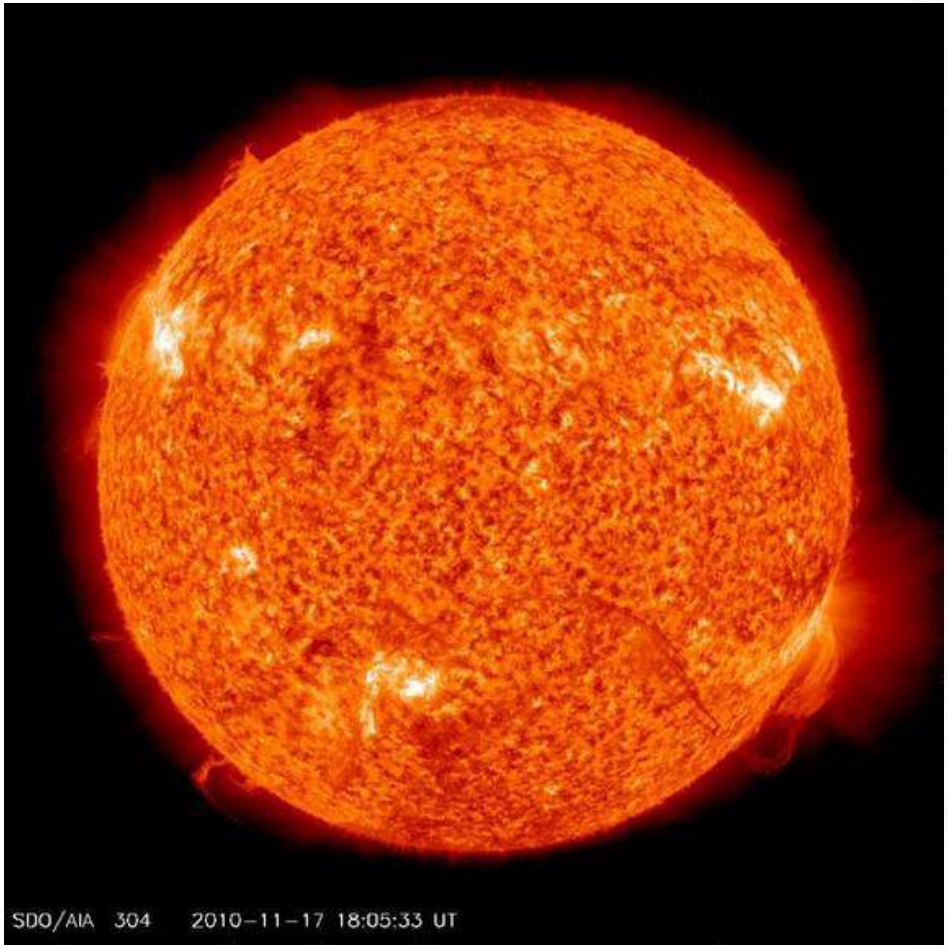


Radial velocity curve for 51 Peg b, the first extra solar planet

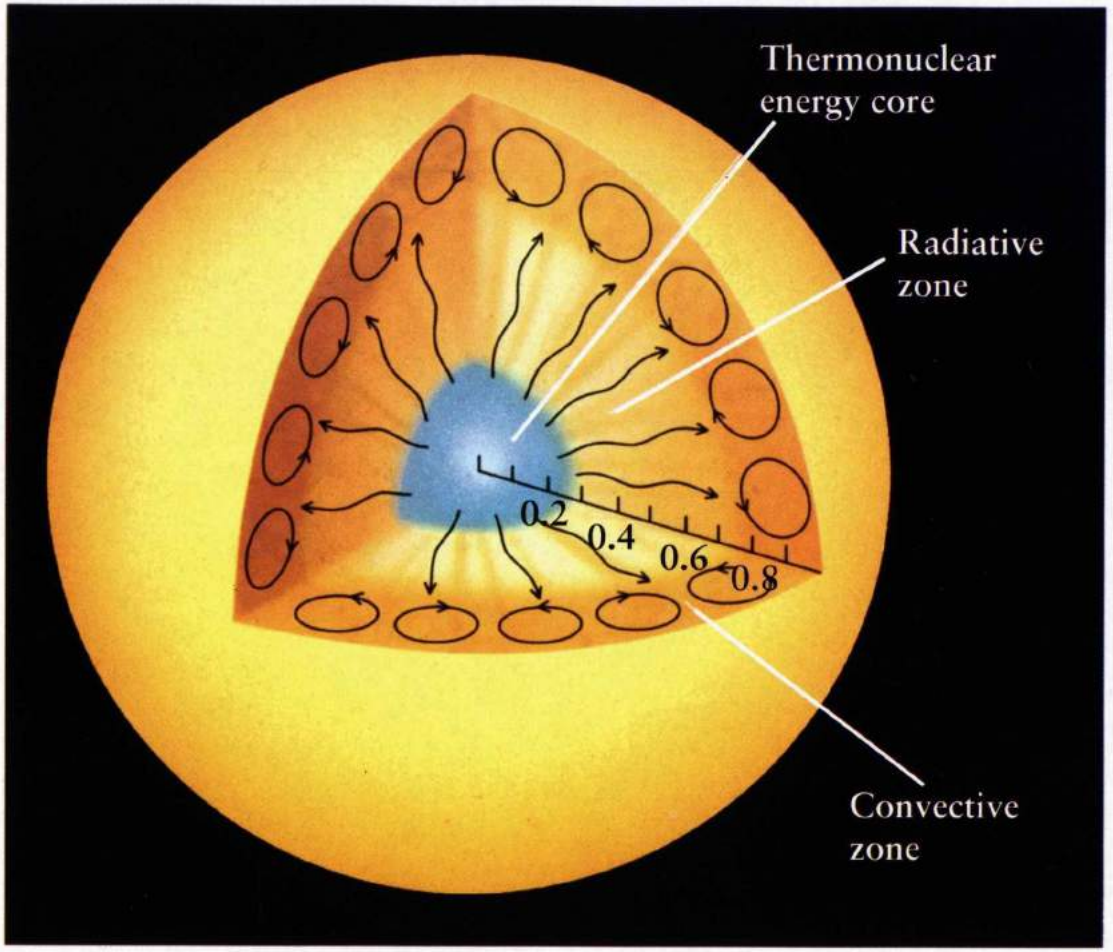


Modeling the equilibrium structure of stars of different types

Image of the Sun

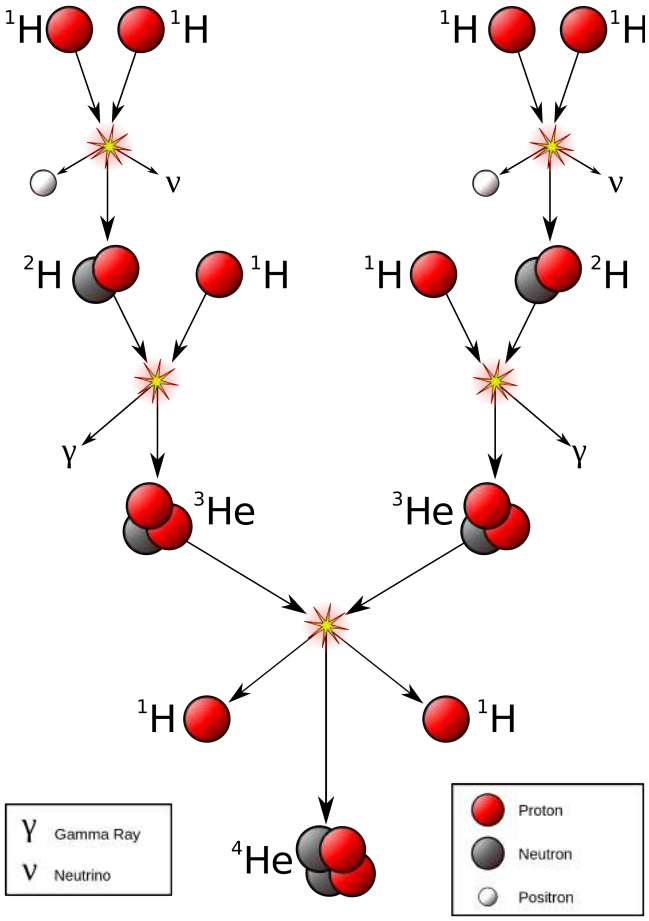


Model of Sun's interior

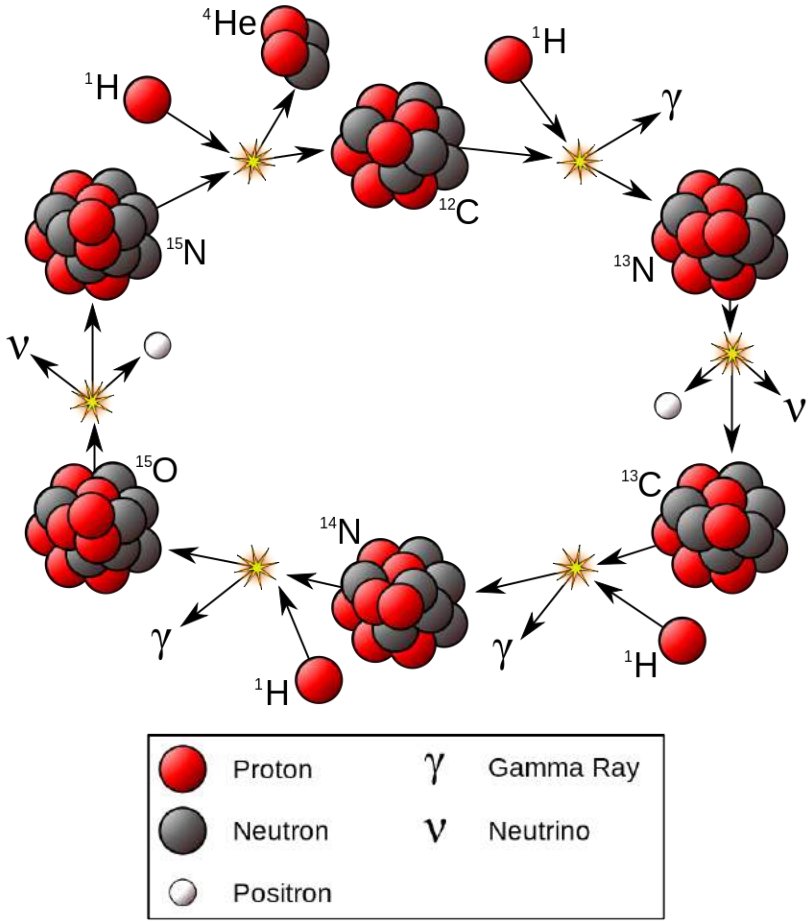


Nuclear energy generation in stars

pp chain

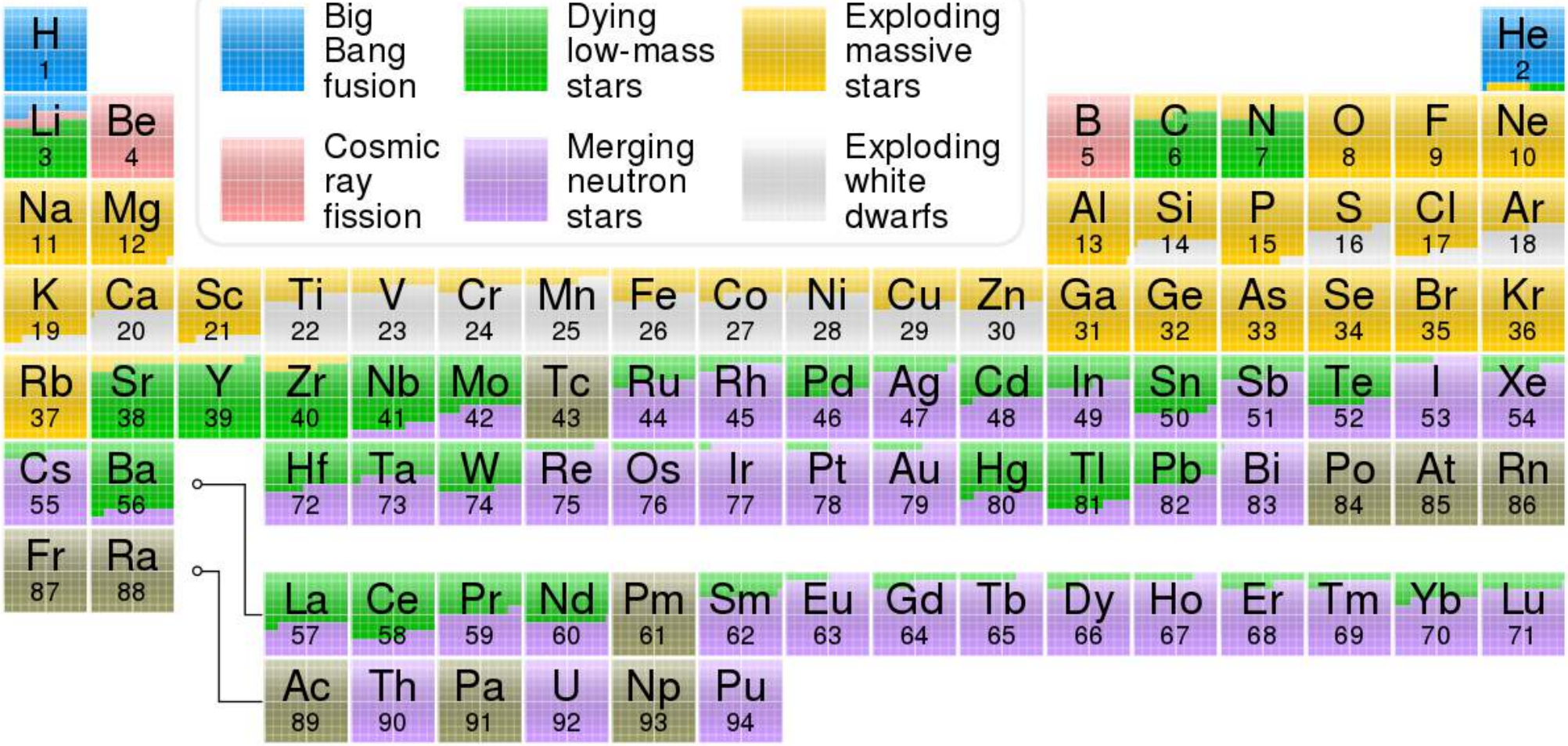


CNO cycle



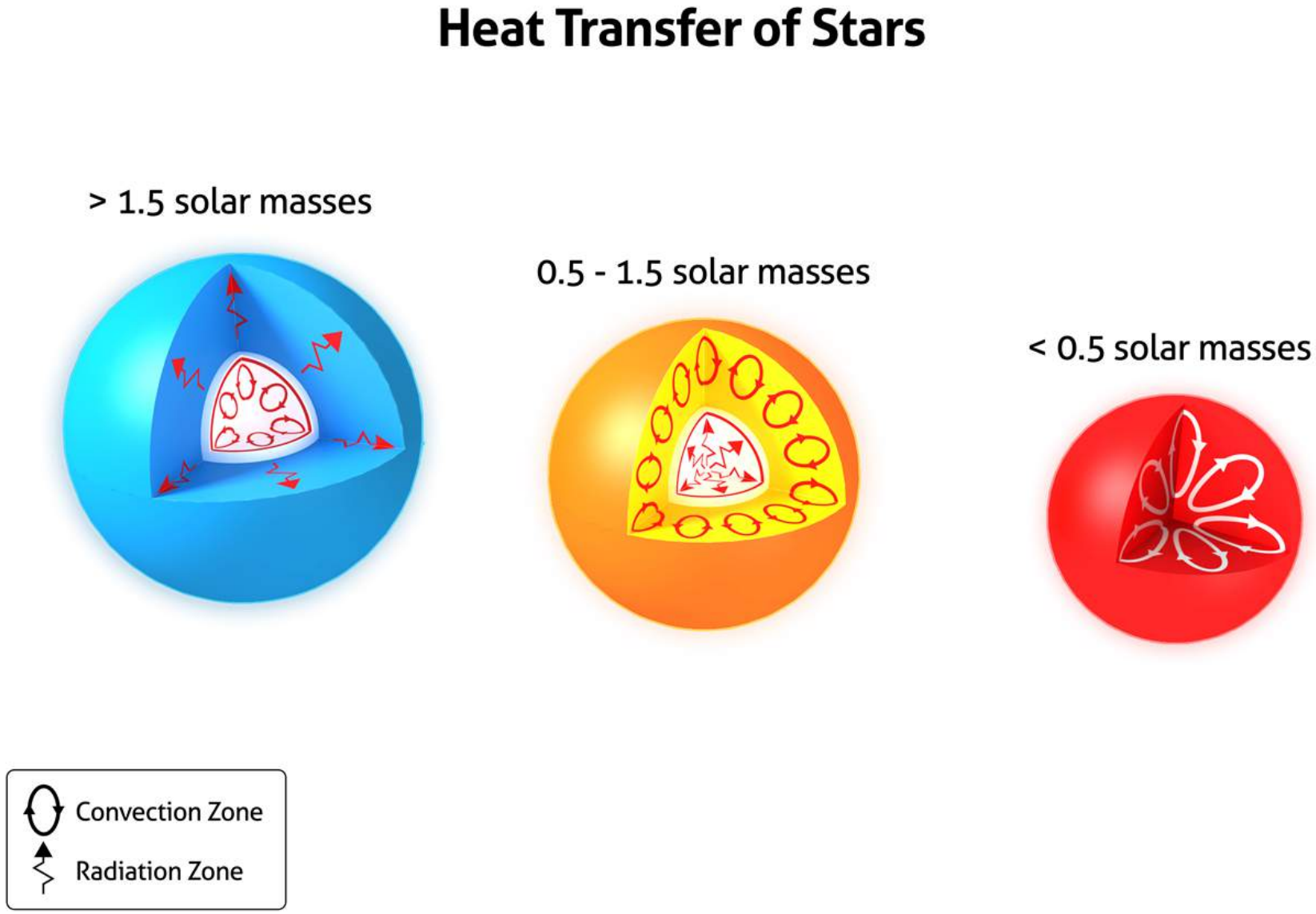
- understanding the rates of different nuclear reactions — the crucial role of quantum tunneling
- the products of different nuclear reactions: heavy elements, neutrinos, …

Where do different elements come from?



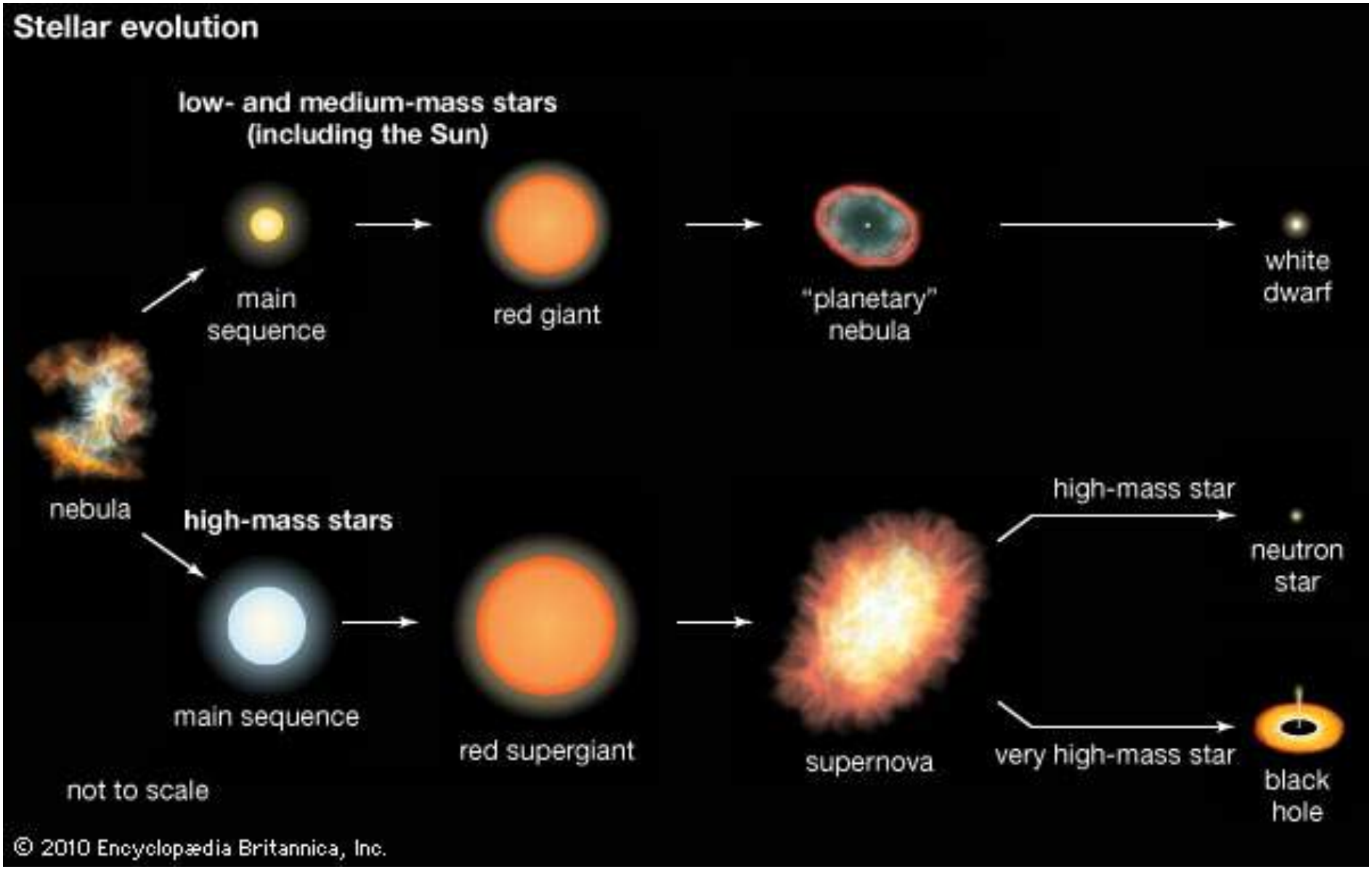
- understanding which elements are produced in the Big Bang, inside stars, in stellar explosions, …

Different mechanisms of energy transport inside stars



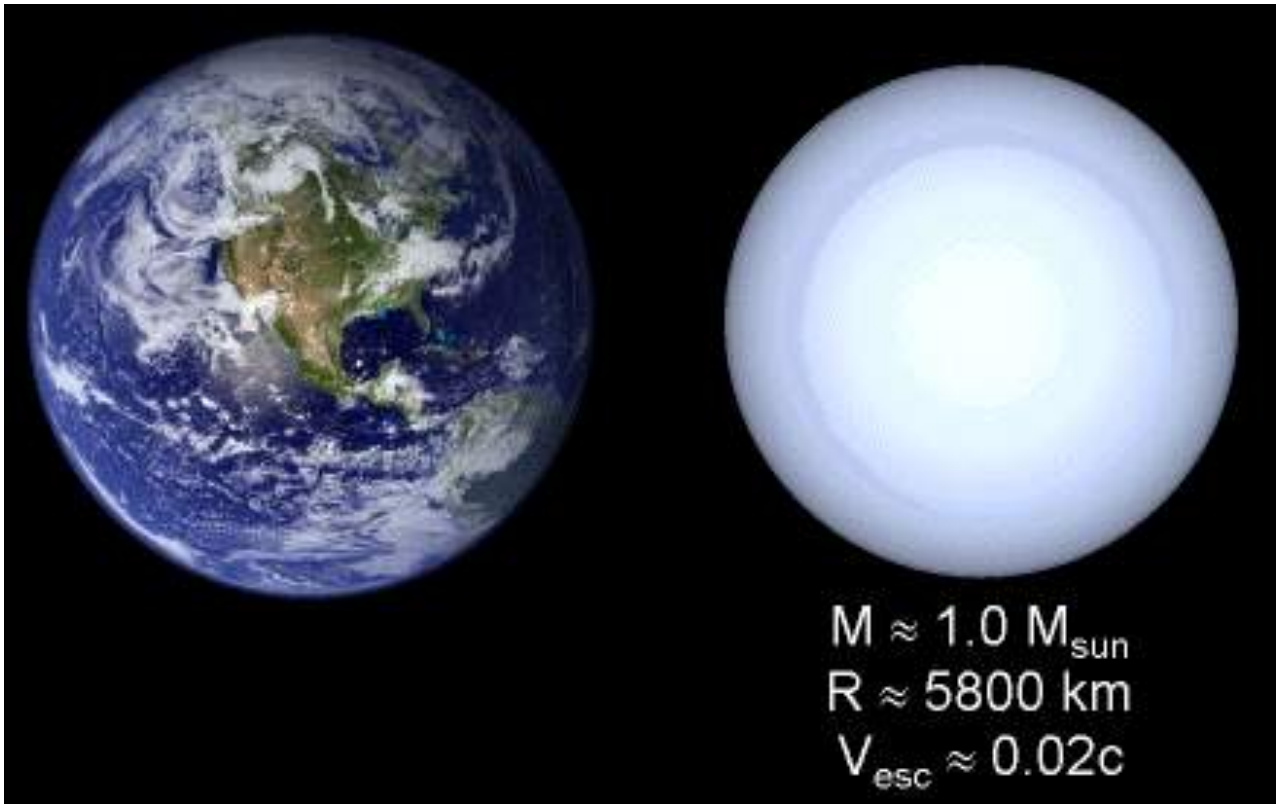
- how is energy transported from the nuclear burning core to the surface?

The end points of stellar evolution



- what happens when stars run out of nuclear fuel?

White dwarfs

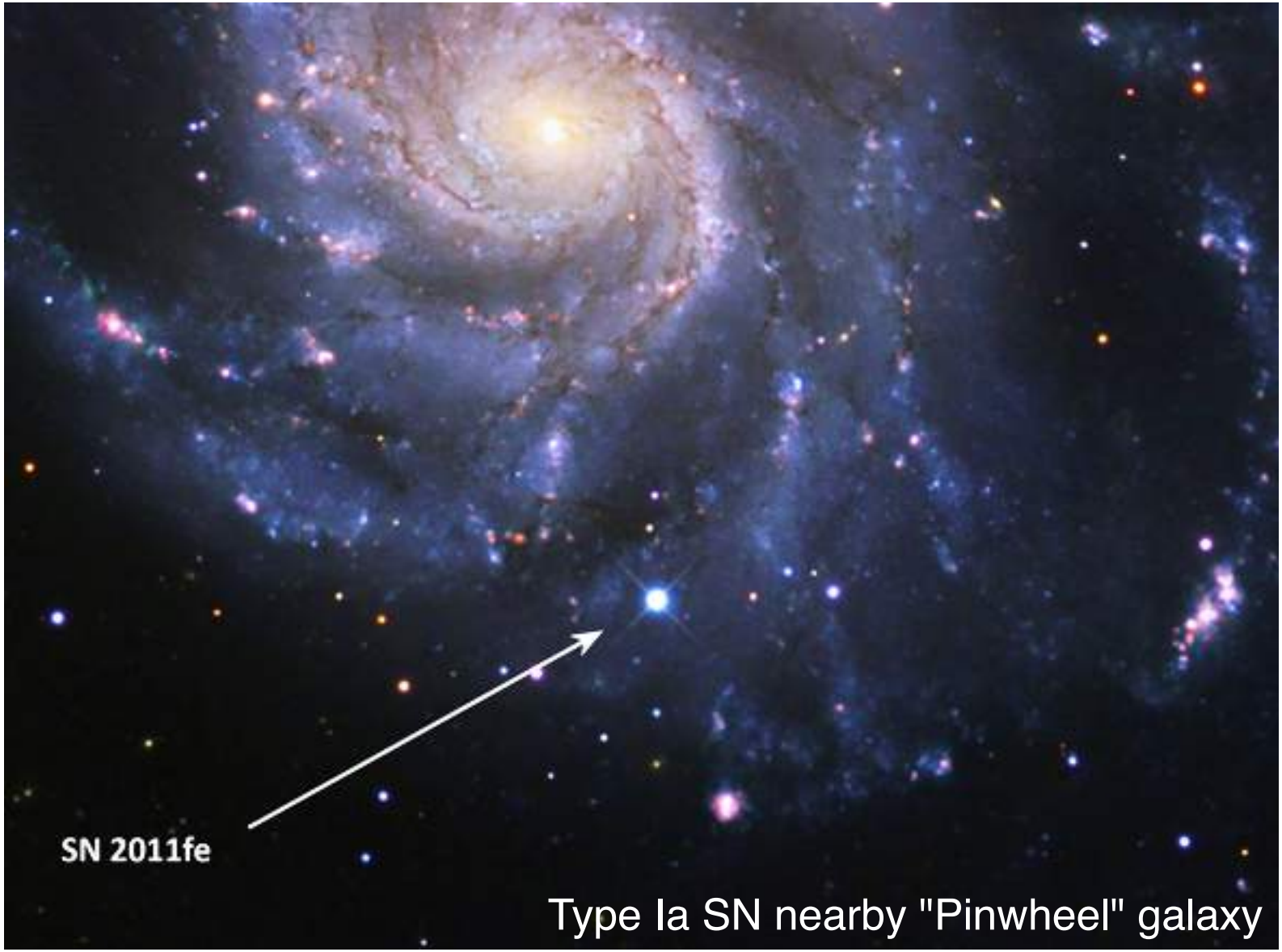


- what supports stars against gravitational collapse when they can no longer produce nuclear energy? quantum degeneracy pressure

- maximum (Chandrasekhar) mass for WDs ~1.4 M$_{sun}$

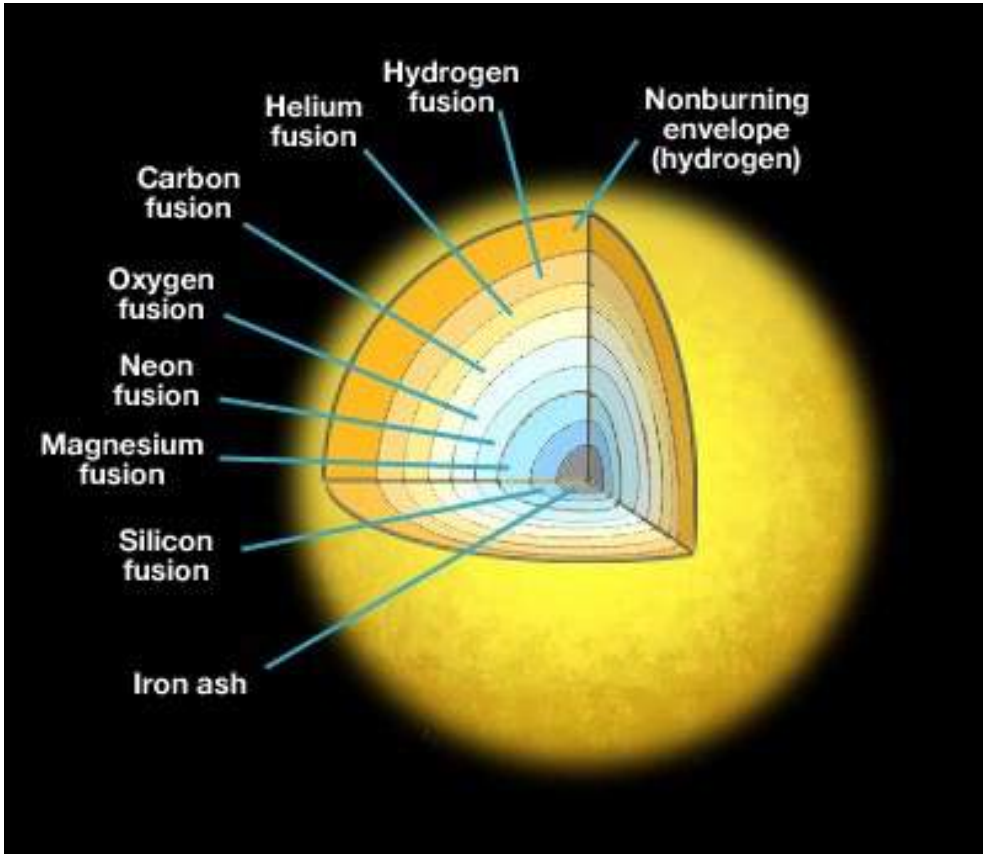
What happens when a WD exceeds the Chandrasekhar mass? Type Ia SNe

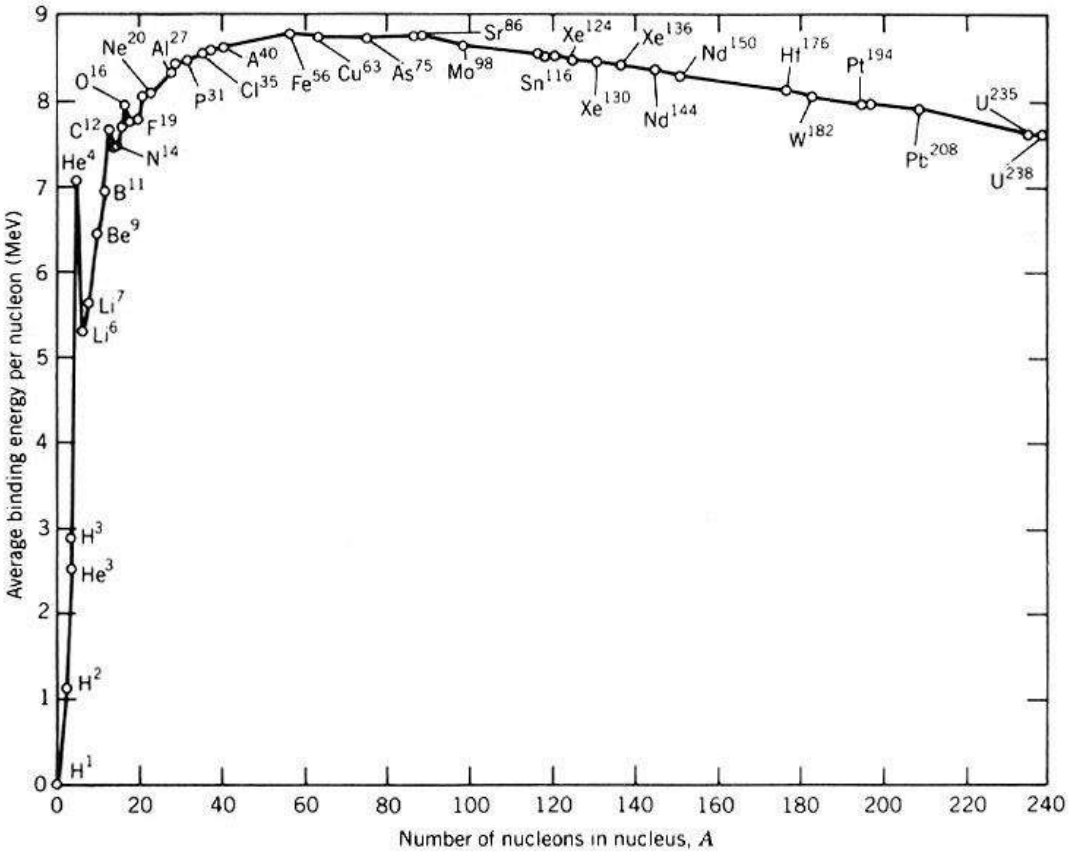
Measuring cosmological distances with exploding stars



- standard(izable) candles: use to measure large cosmic distances
- mapping the expansion of the Universe — discovery of dark energy

Core collapse at the end of a massive star's life

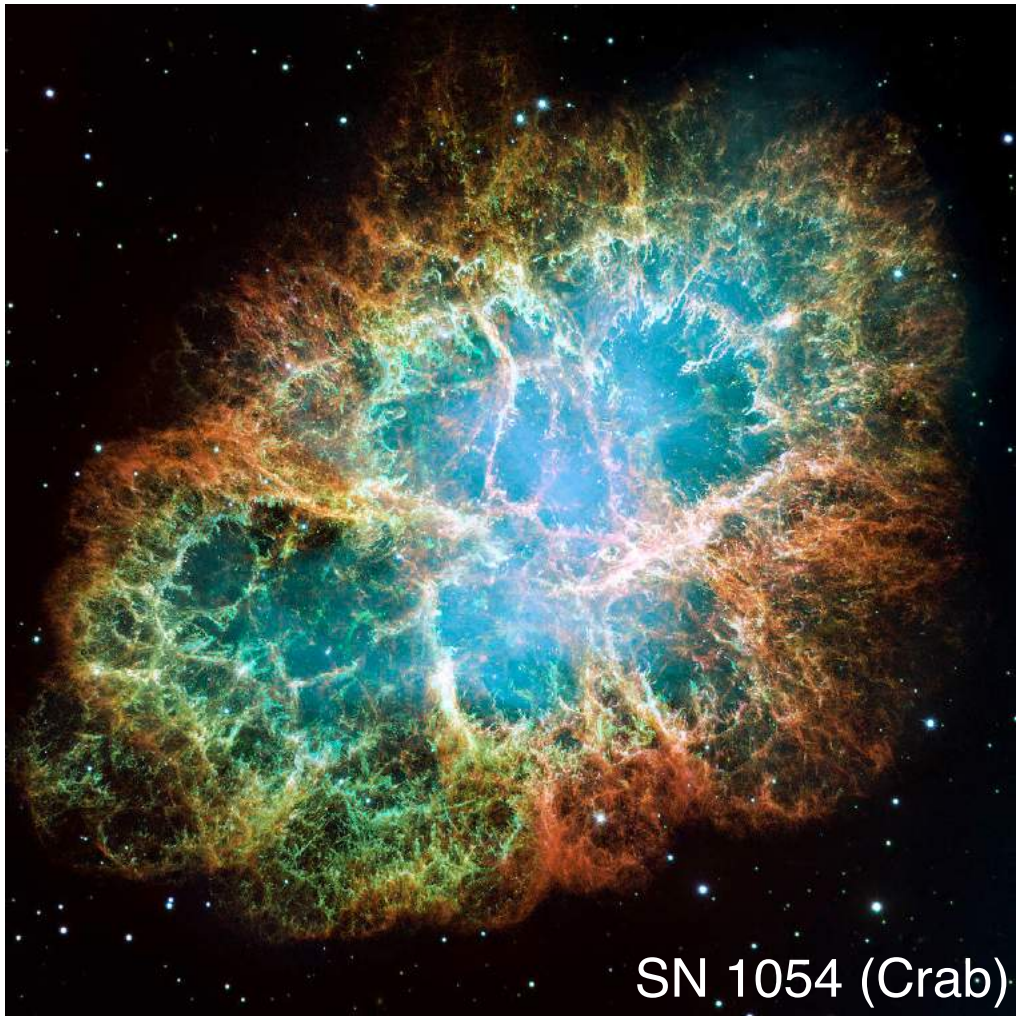




- massive stars burn and synthesize several heavy elements
- when they reach iron, nuclear fusion no longer produces energy: core collapse

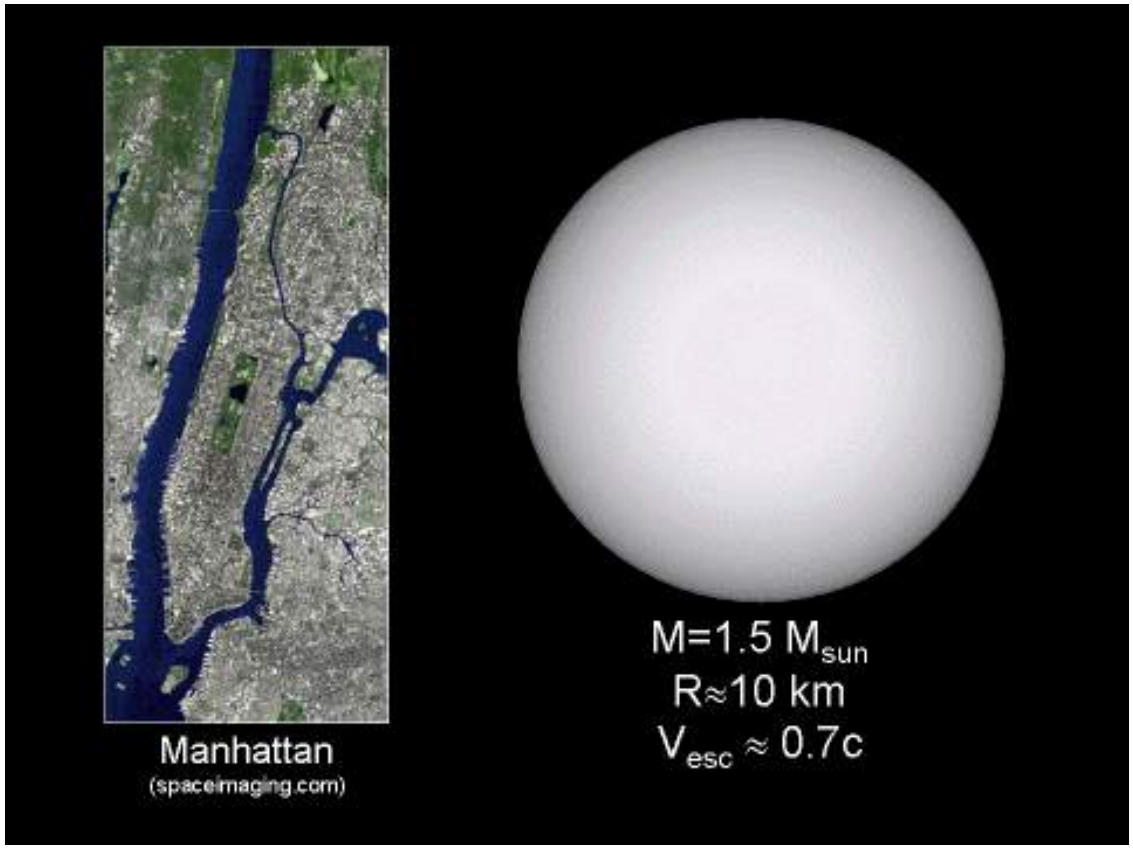
Core collapse supernovae and their remnants


SN 1987a in Large Magellanic Cloud


SN 1054 (Crab)

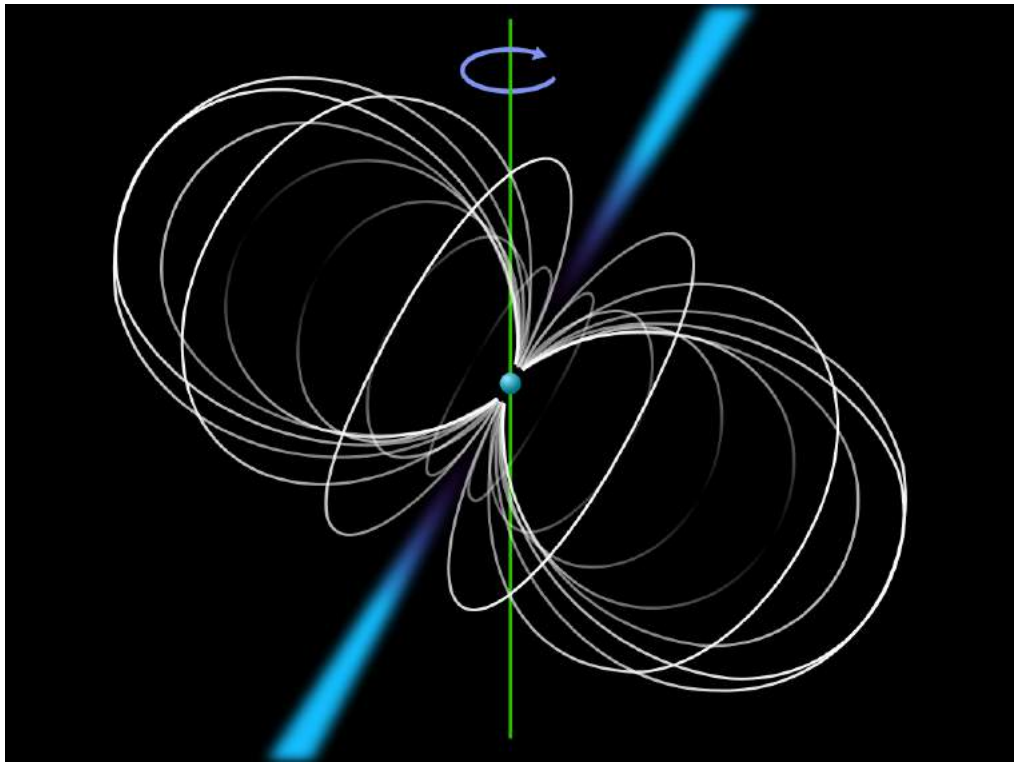
- core collapse produces another kind of SN explosions (Type II, Type Ibc)

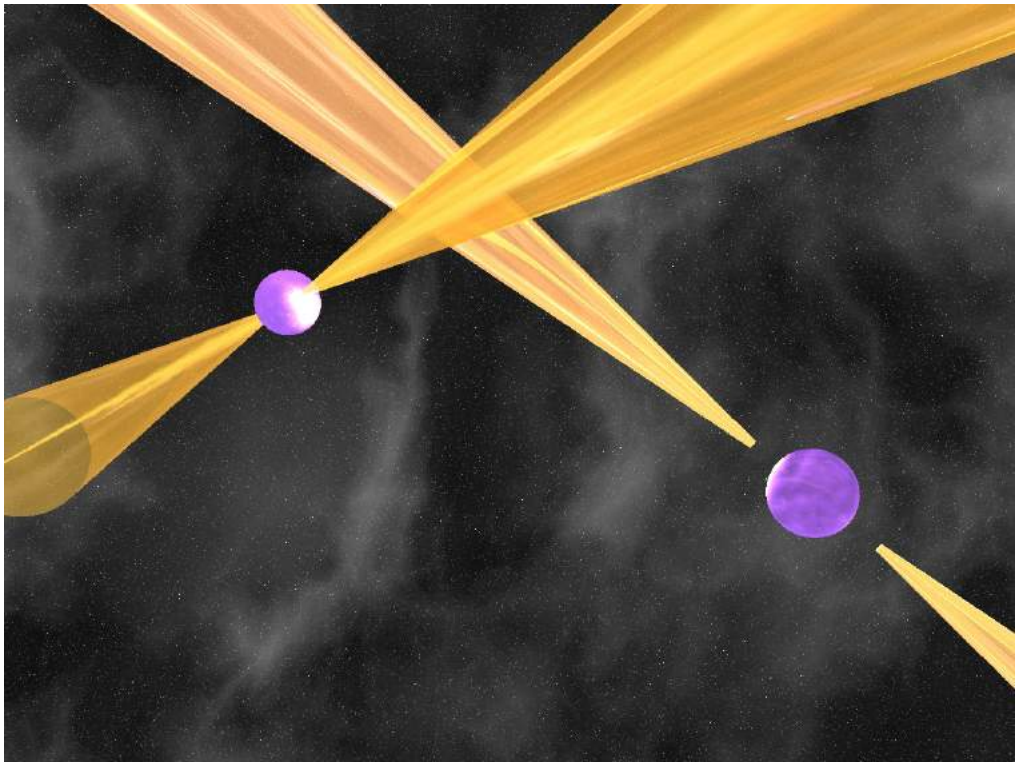
Neutron stars



- the equation of state of nuclear-density matter
- the Chandrasekhar limit for NSs (neutron degeneracy pressure) ~2-3 M_{sun}

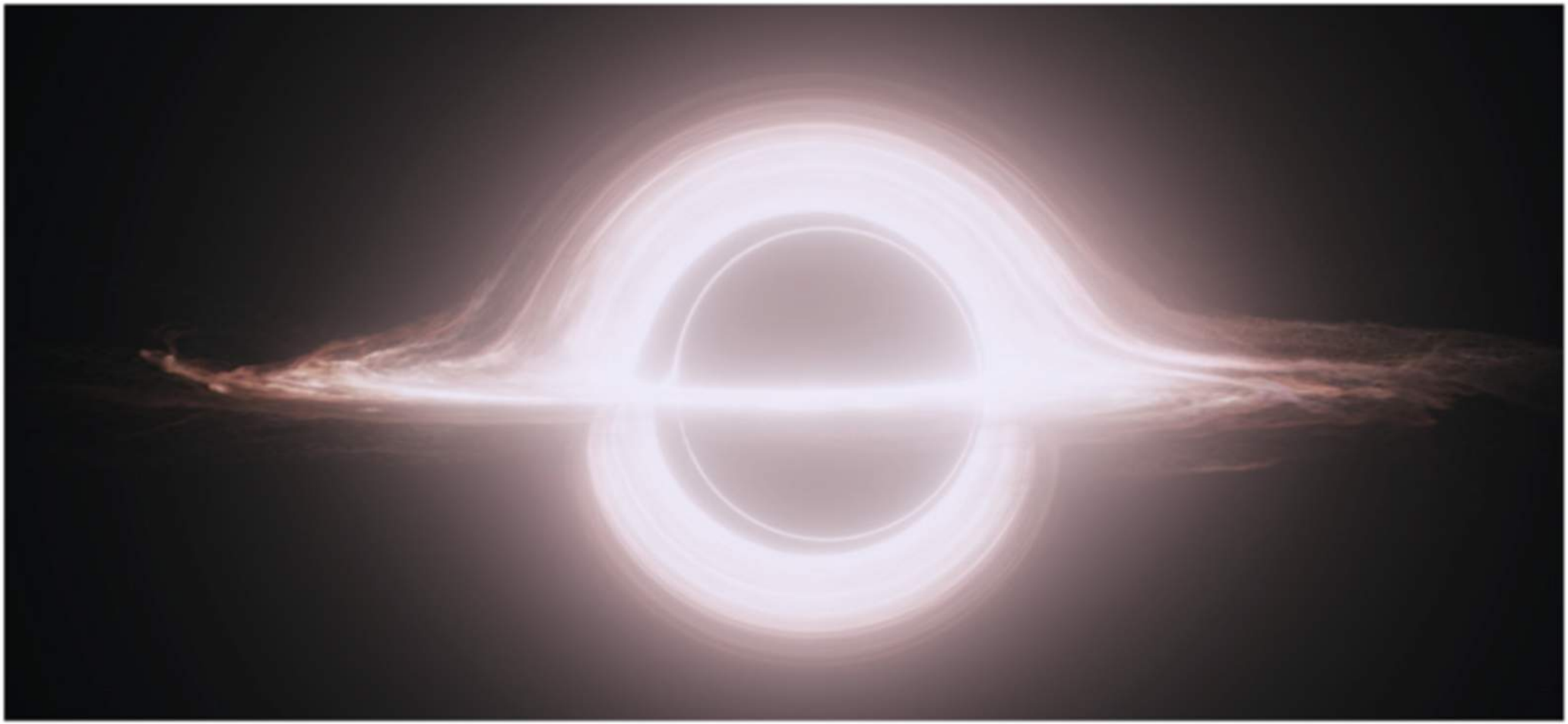
Pulsars





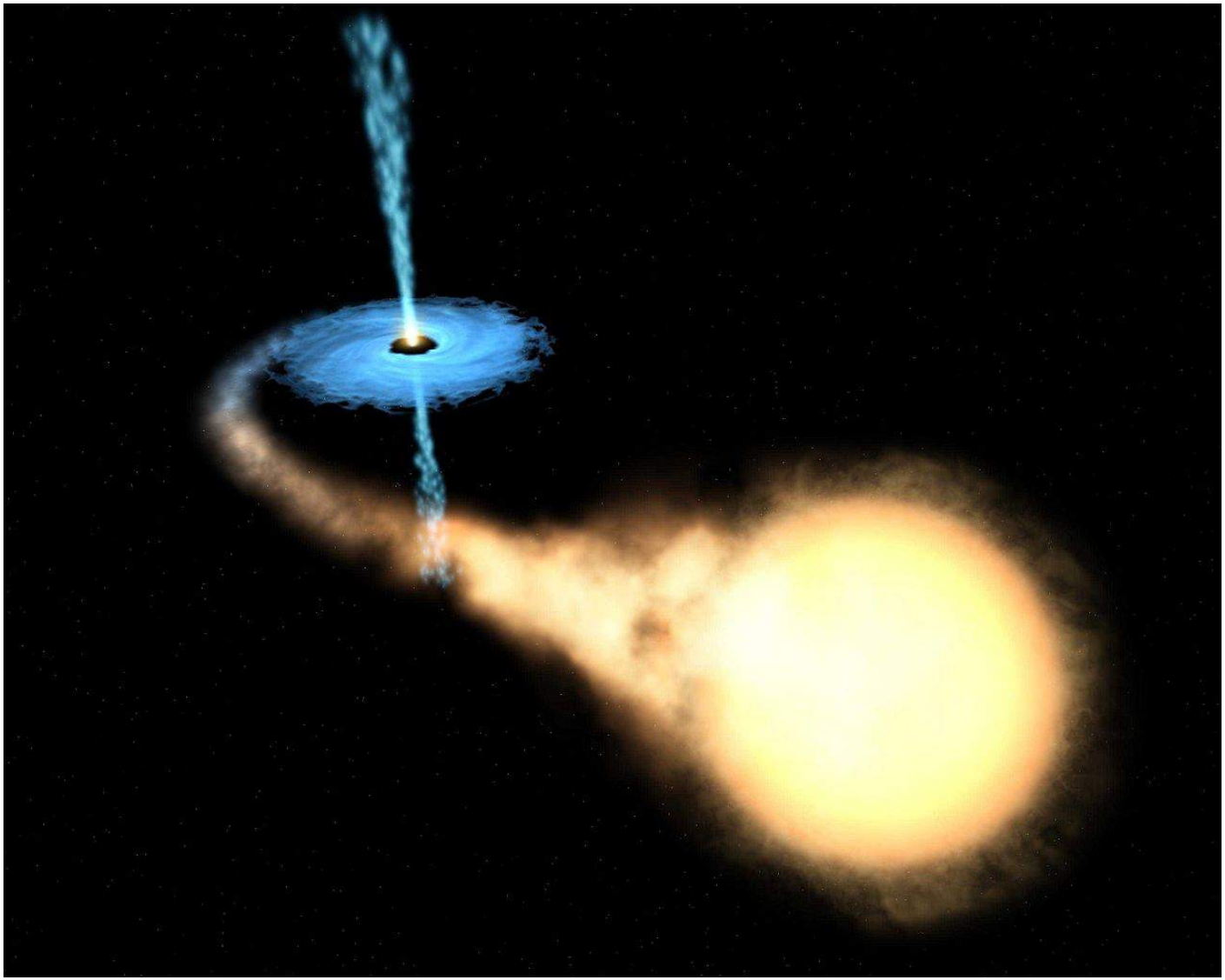
- ultra-dense, highly magnetized, rapidly rotating ($P \sim 10^{-3}$–10 s) neutron stars
- usually observed in the radio or x-rays
- tests of Einstein's relativity using binary pulsars

Black holes



- what happens when NSs become too massive to be supported against collapse?
- the properties and observational manifestations of black holes

High-energy manifestations of accreting black holes



- accretion disks
- accretion disk winds and relativistic jets

Gravitational waves from merging black holes

Sept 14, 2015 binary BH signal