天文学正在发现

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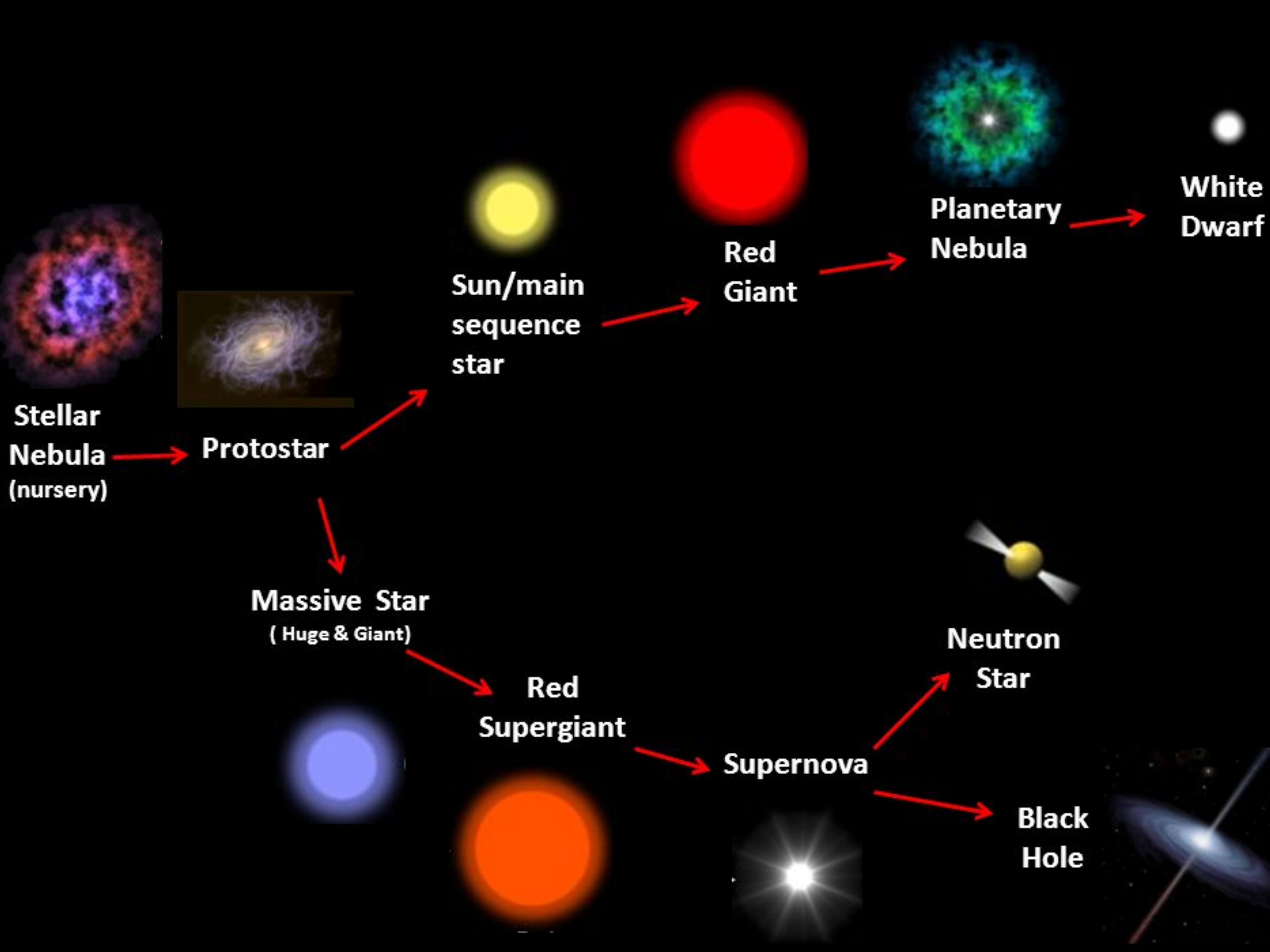
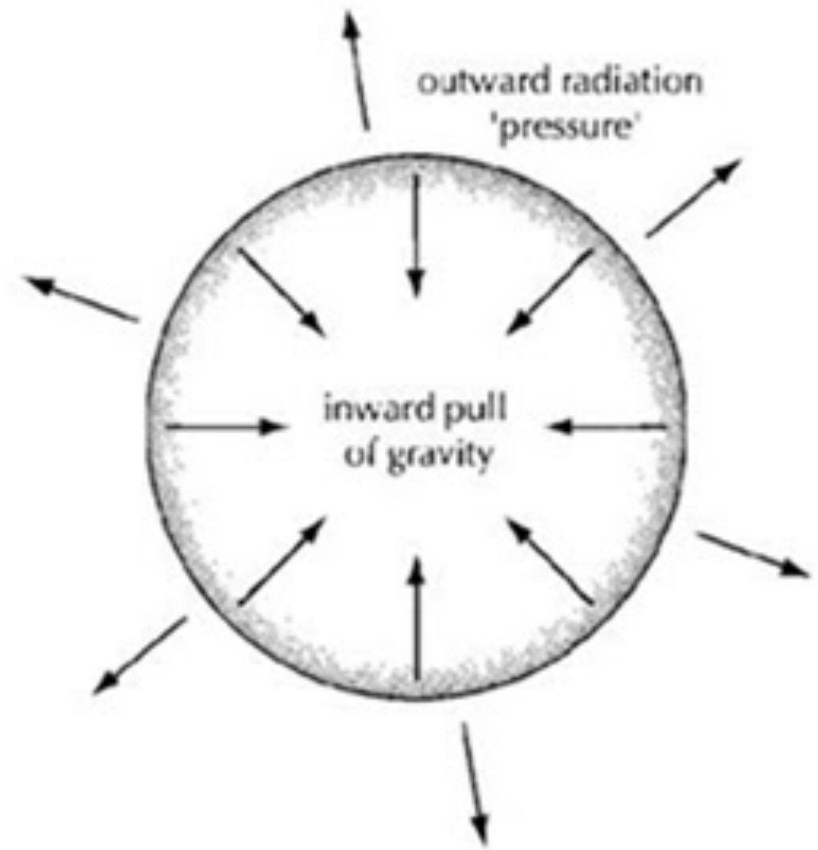
outline

1. 膨胀宇宙的发现
2. 暗物质的发现
3. 暗能量的发现
4. 宇宙微波背景辐射的发现
5. 中微子的发现
6. 引力波的发现
7. 脉冲星的发现
8. 宇宙第一缕曙光的“发现”

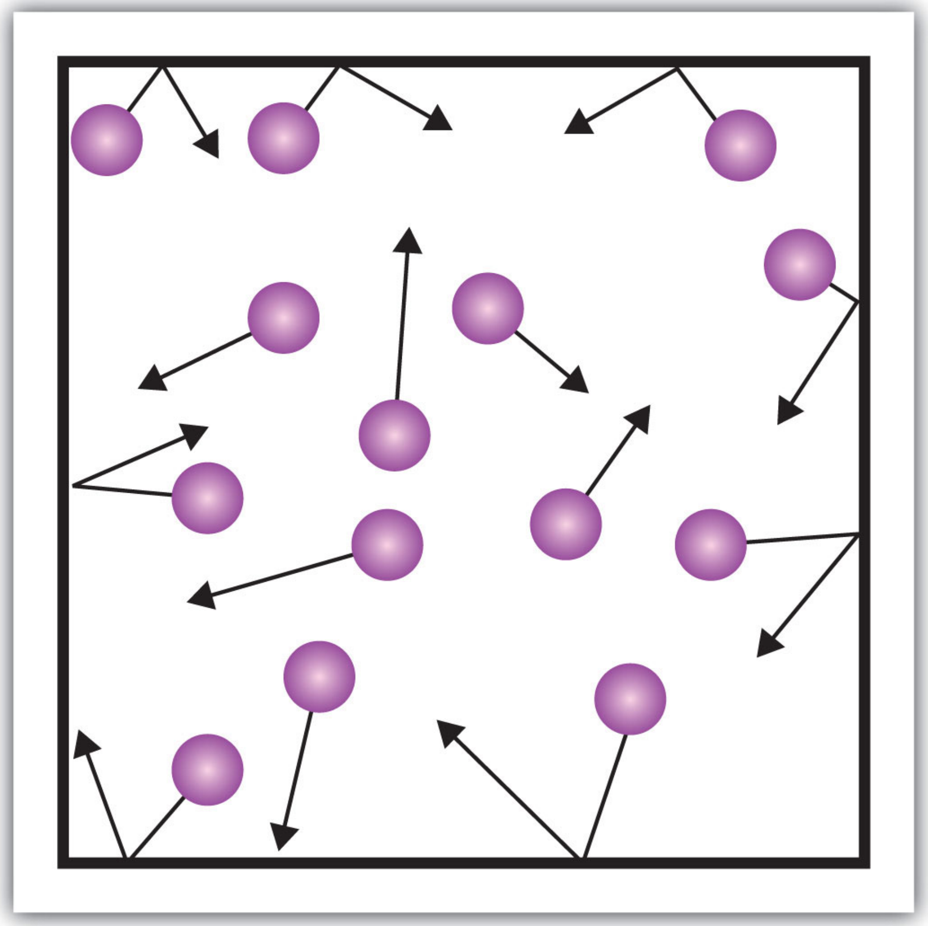

Stellar Nebula (nursery)
Protostar
Sun/main sequence star
Red Giant
Planetary Nebula
White Dwarf
Massive Star (Huge & Giant)
Red Supergiant
Supernova
Neutron Star
Black Hole

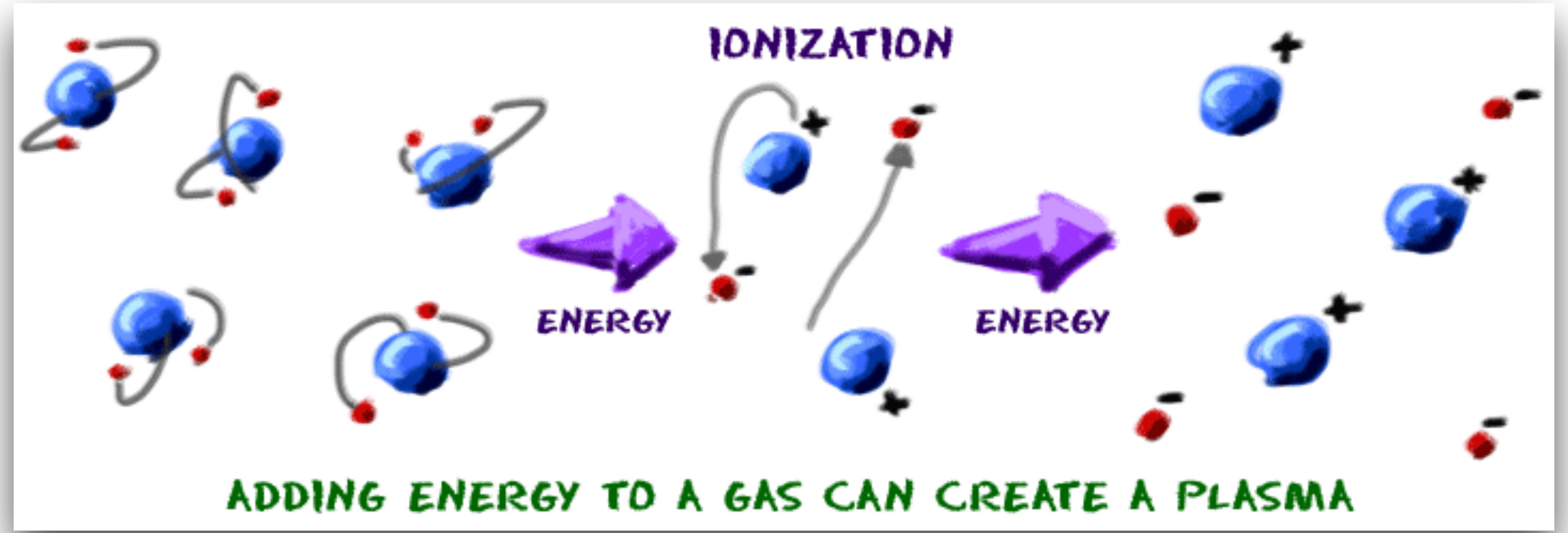
Stellar: gravity balanced with radiation pressure

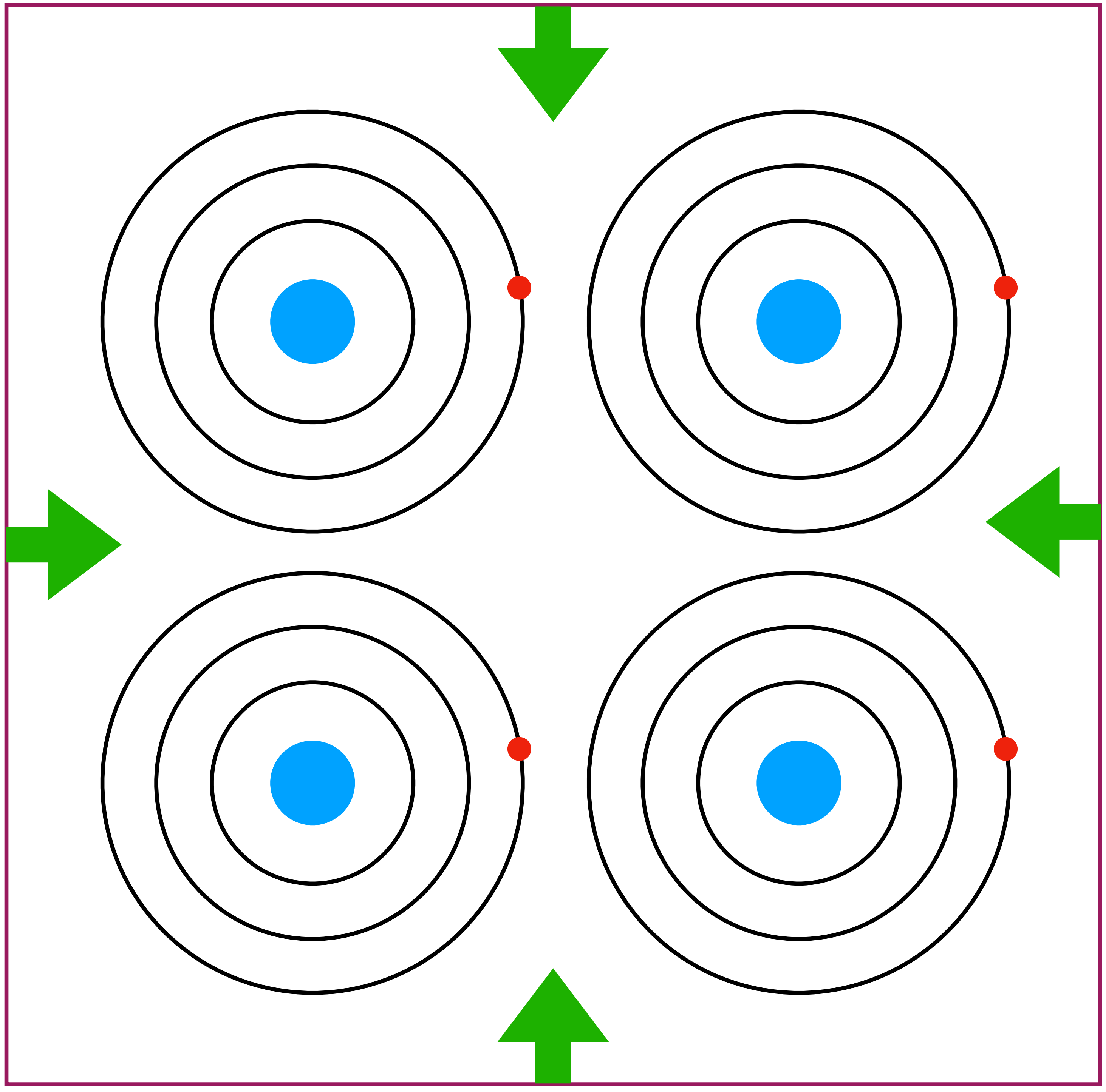


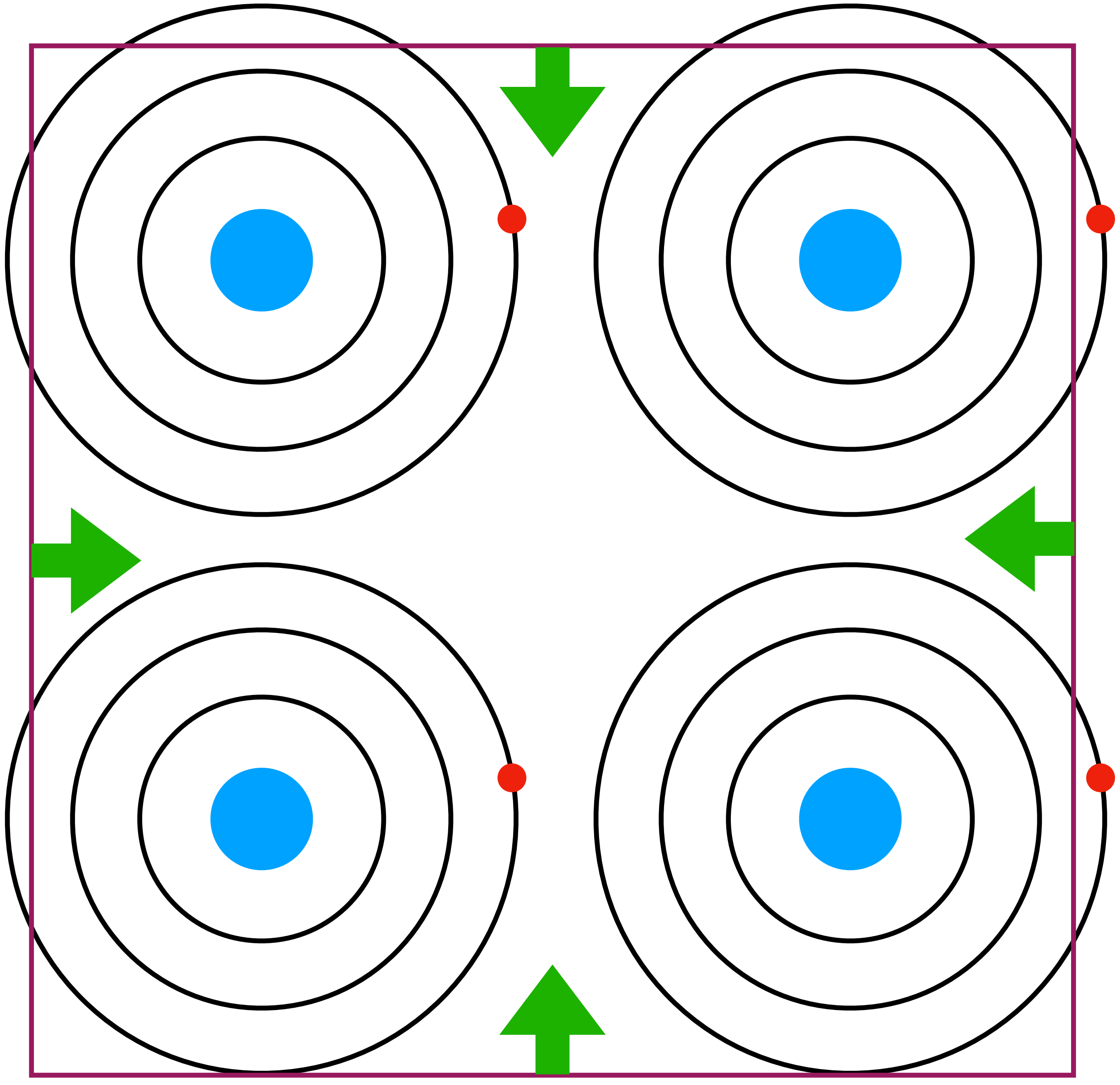
M ↗, gravity ↗

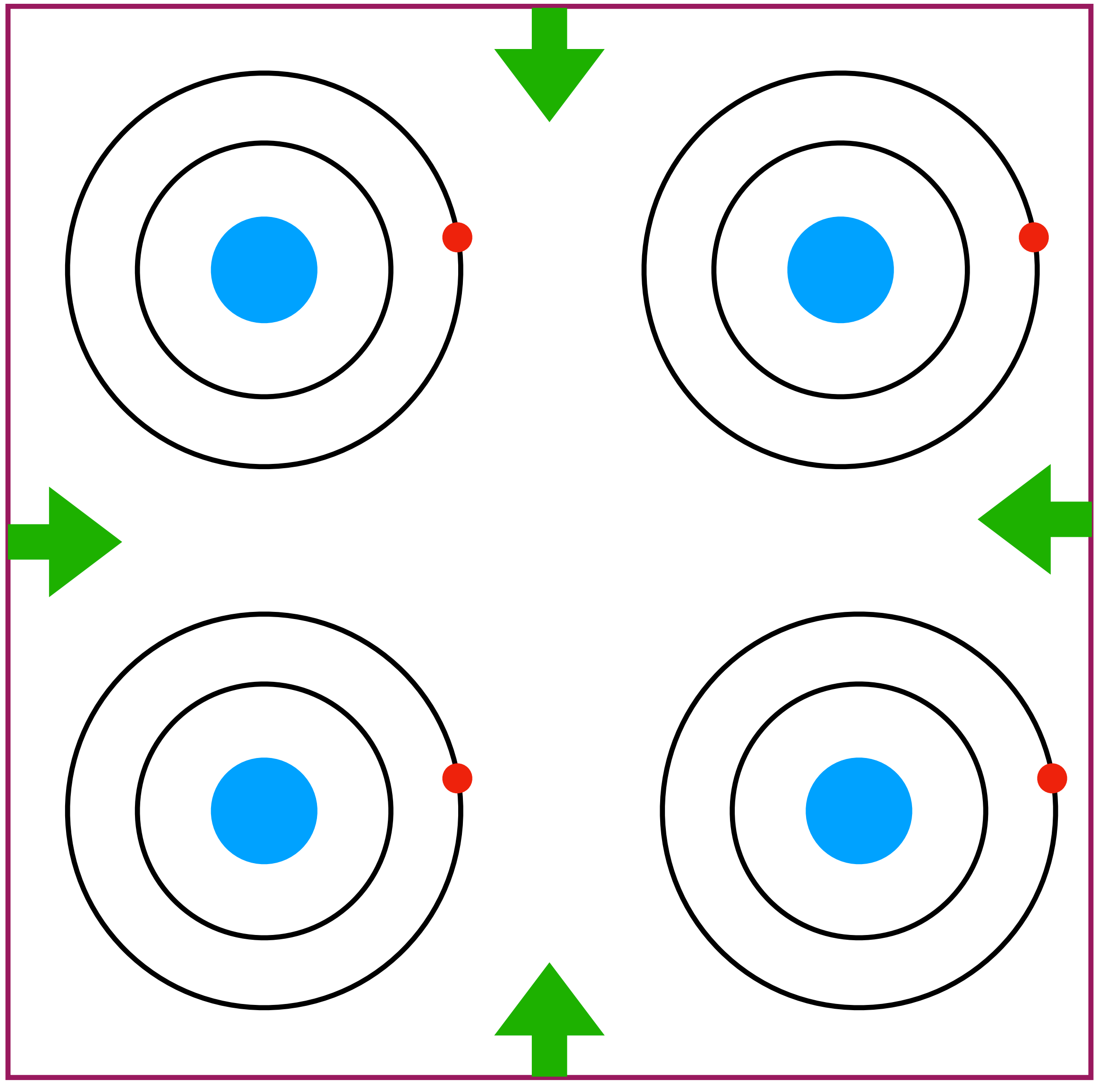
T ↗, pressure ↗

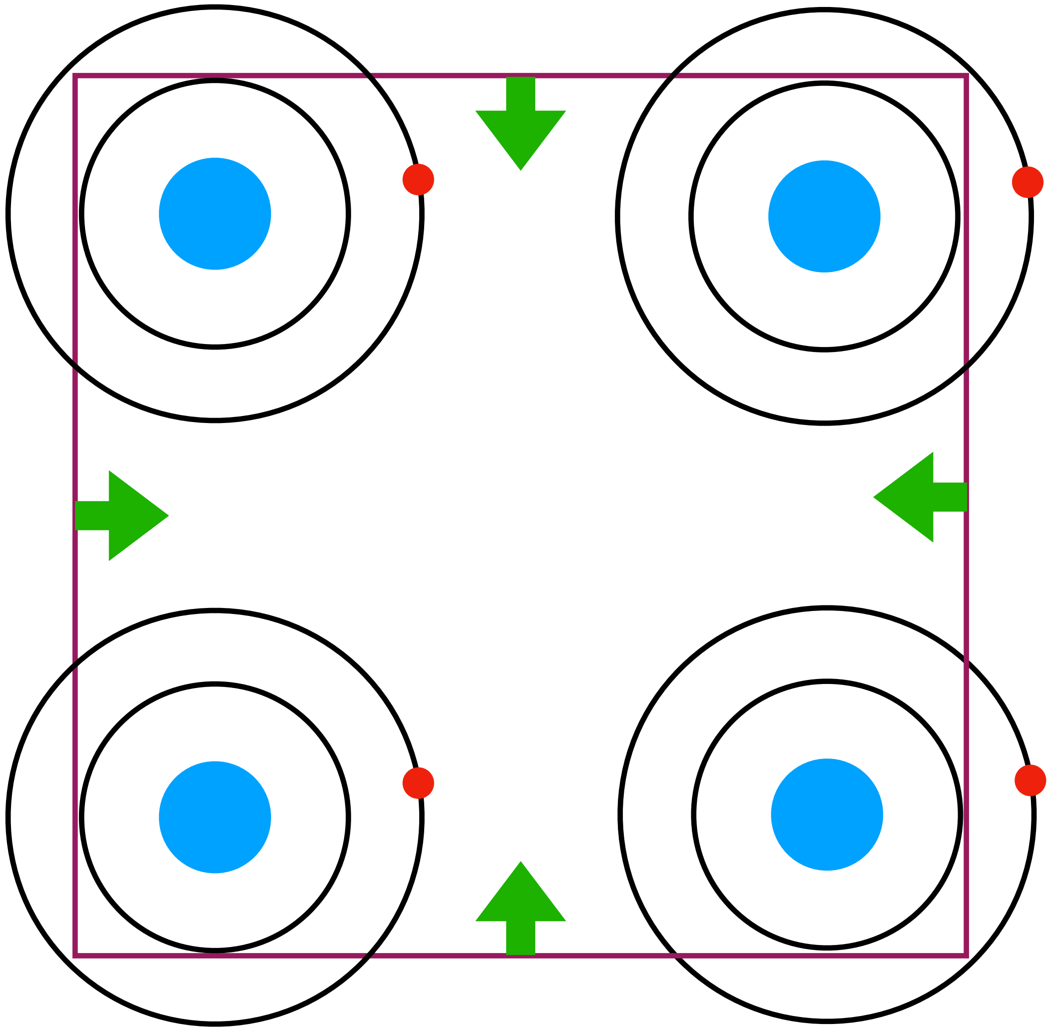




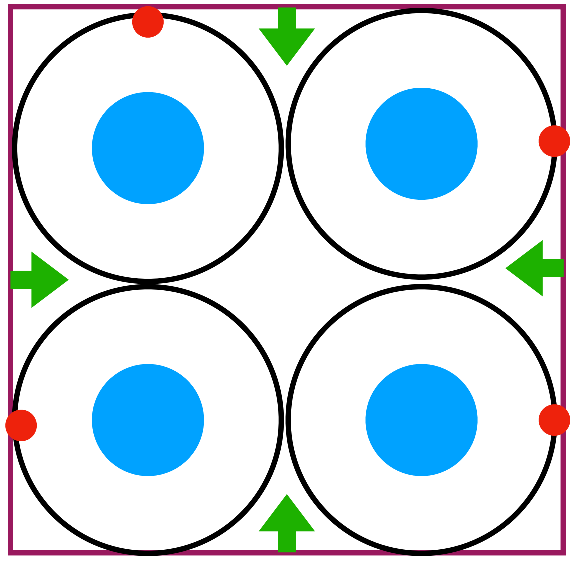




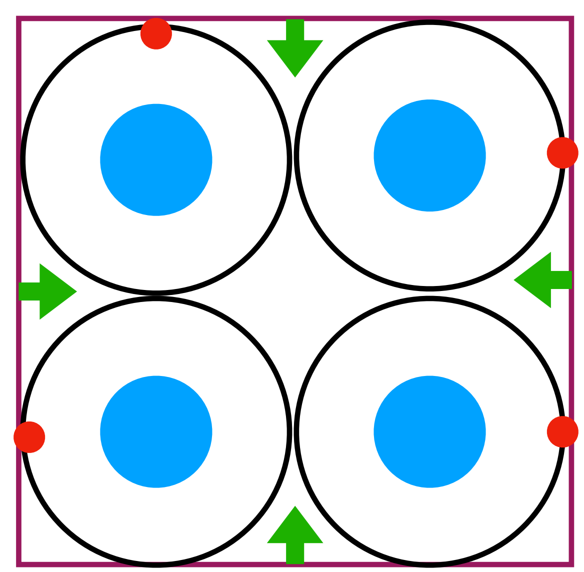




White Dwarf



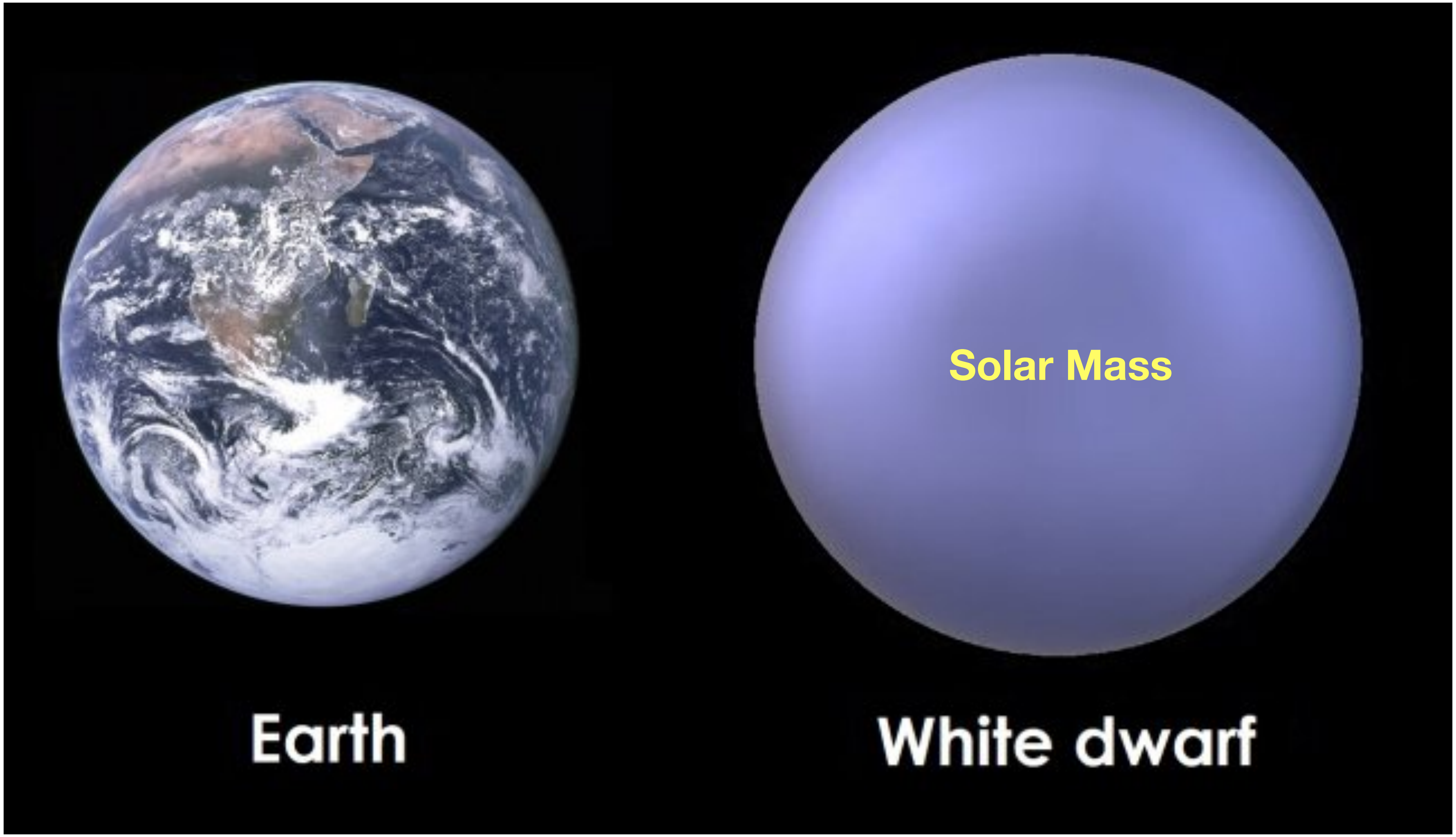
White Dwarf



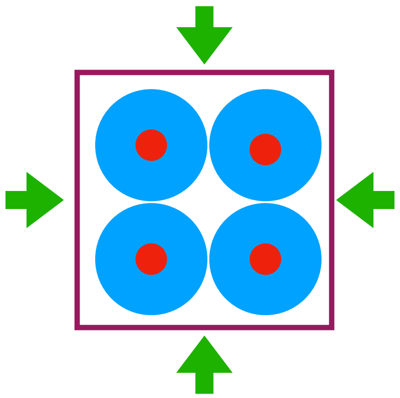
Pauli Exclusion Principle

electron degenerate pressure stop the collapse!

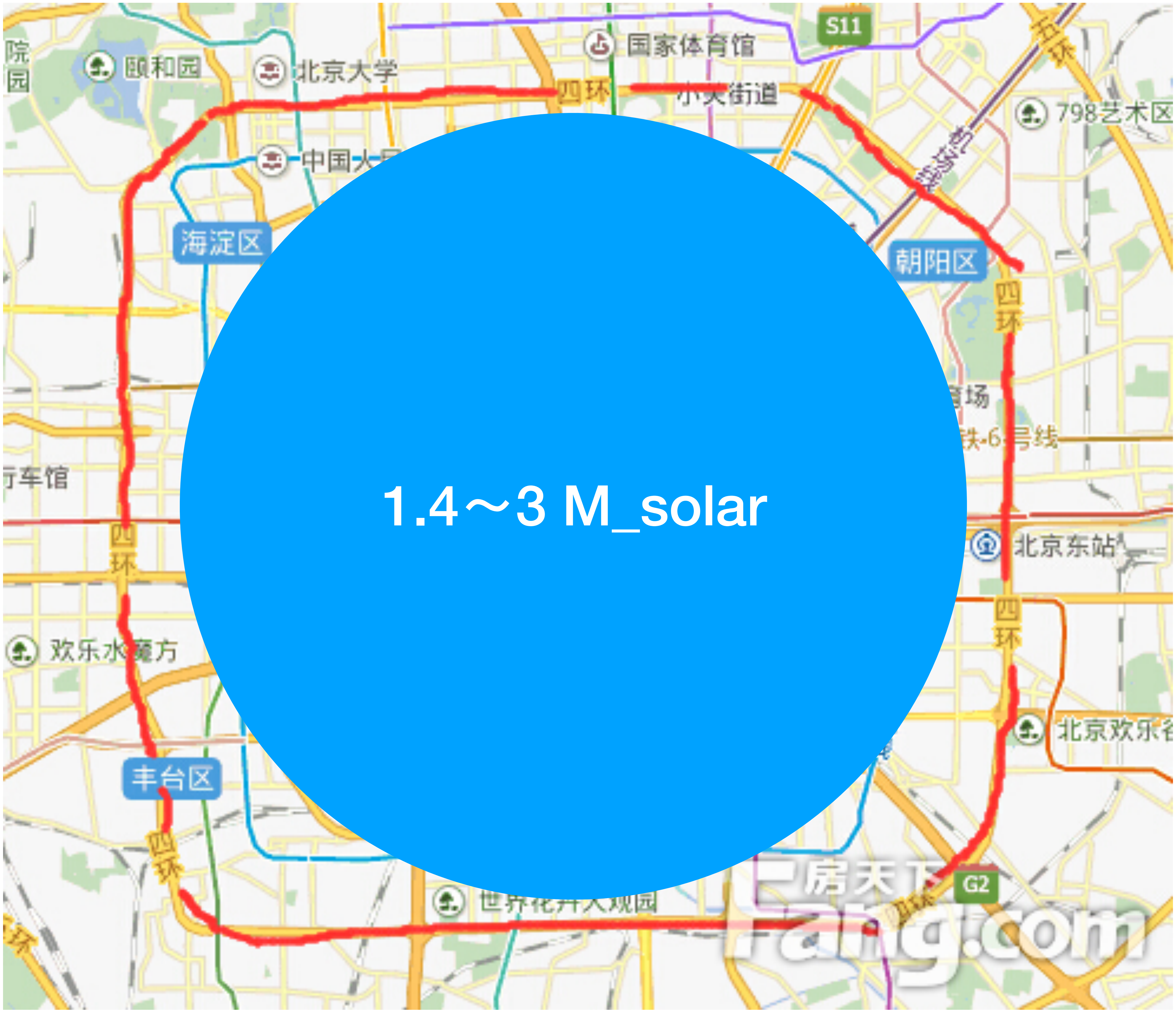
Ground state of electrons are FULLY occupied!


Solar Mass
Earth
White dwarf

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



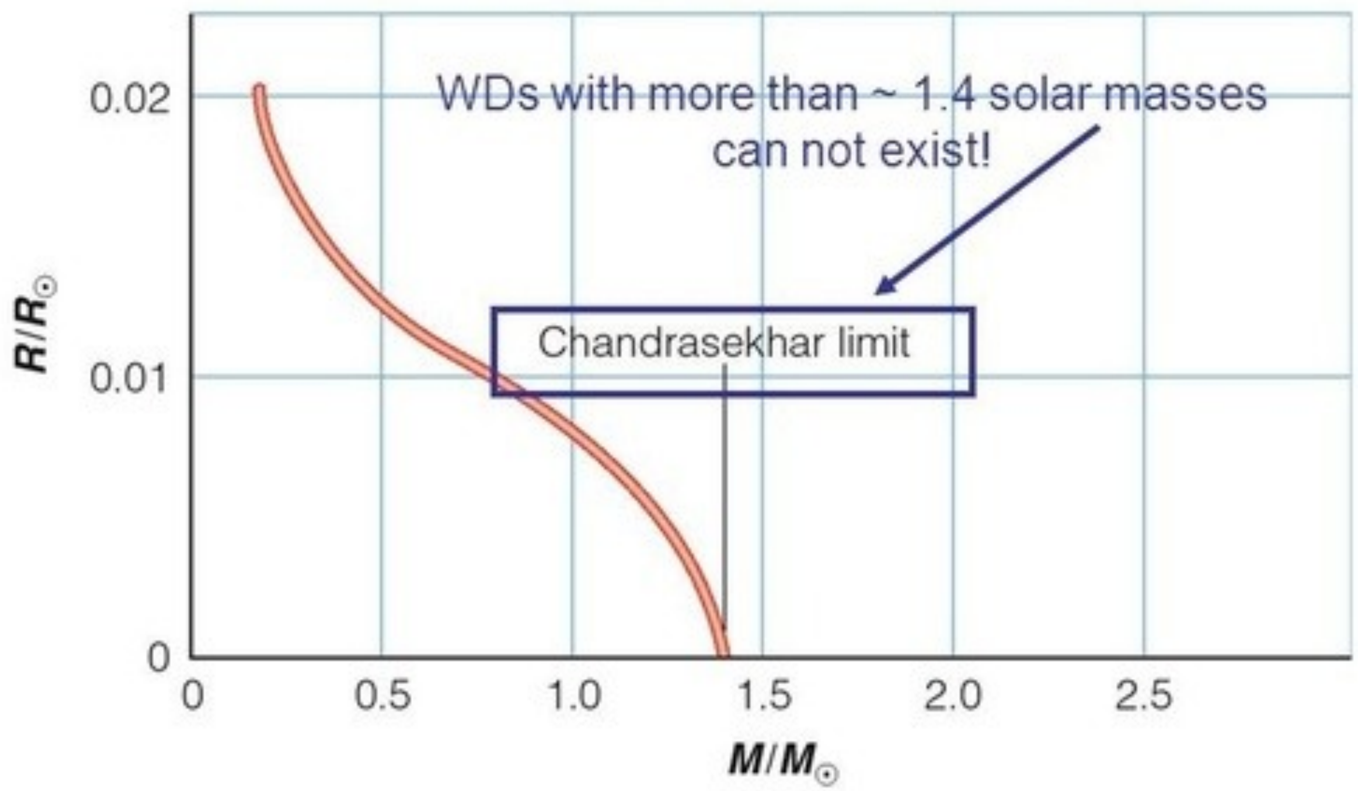
Neutron Star


1.4～3 M_solar
颐和园
北京大学
国家体育馆
S11
四环
小关街道
798艺术区
机场线
海淀区
朝阳区
北京东站
欢乐水魔方
丰台区
世界花卉大观园
G2
房天下
fang.com

The Chandrasekhar Limit

The more massive a white dwarf, the smaller it is.

→ Pressure becomes larger, until electron degeneracy pressure can no longer hold up against gravity.



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Chandrasekhar 🇮🇳

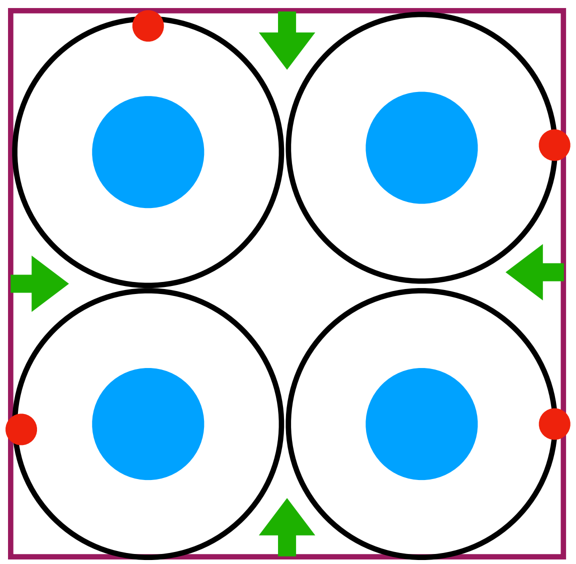
Age: 20

1.4 ~ 3 M_solar

non-rotating → 1.4

fast-rotating → 3

White Dwarf



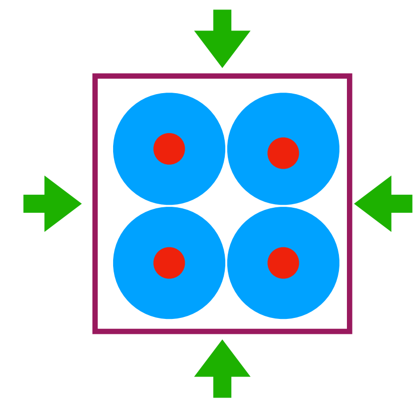
electron degenerate pressure

supported by the Weak force

砸烂弱相互

作用力的🐶

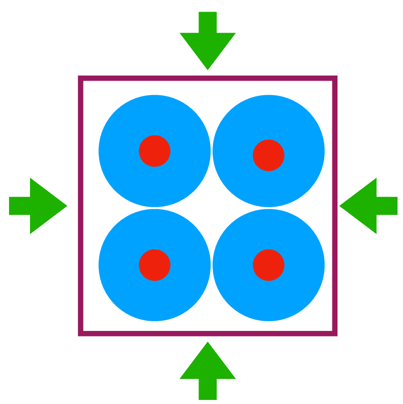
Neutron Star



neutron degenerate pressure

supported by the Strong force

Neutron Star

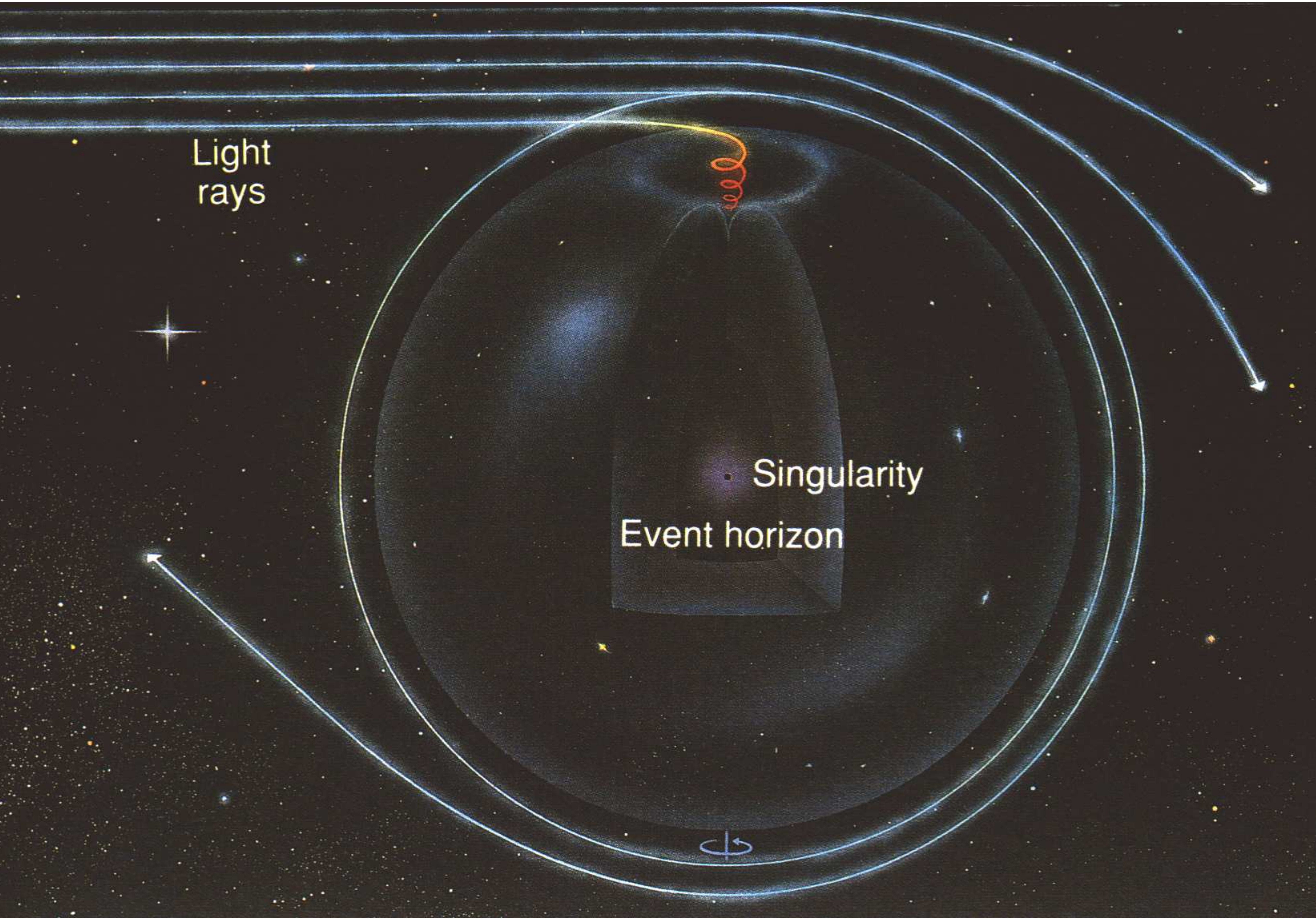


neutron degenerate pressure

supported by the Strong force

砸烂**强**相互作用力的🐶

?

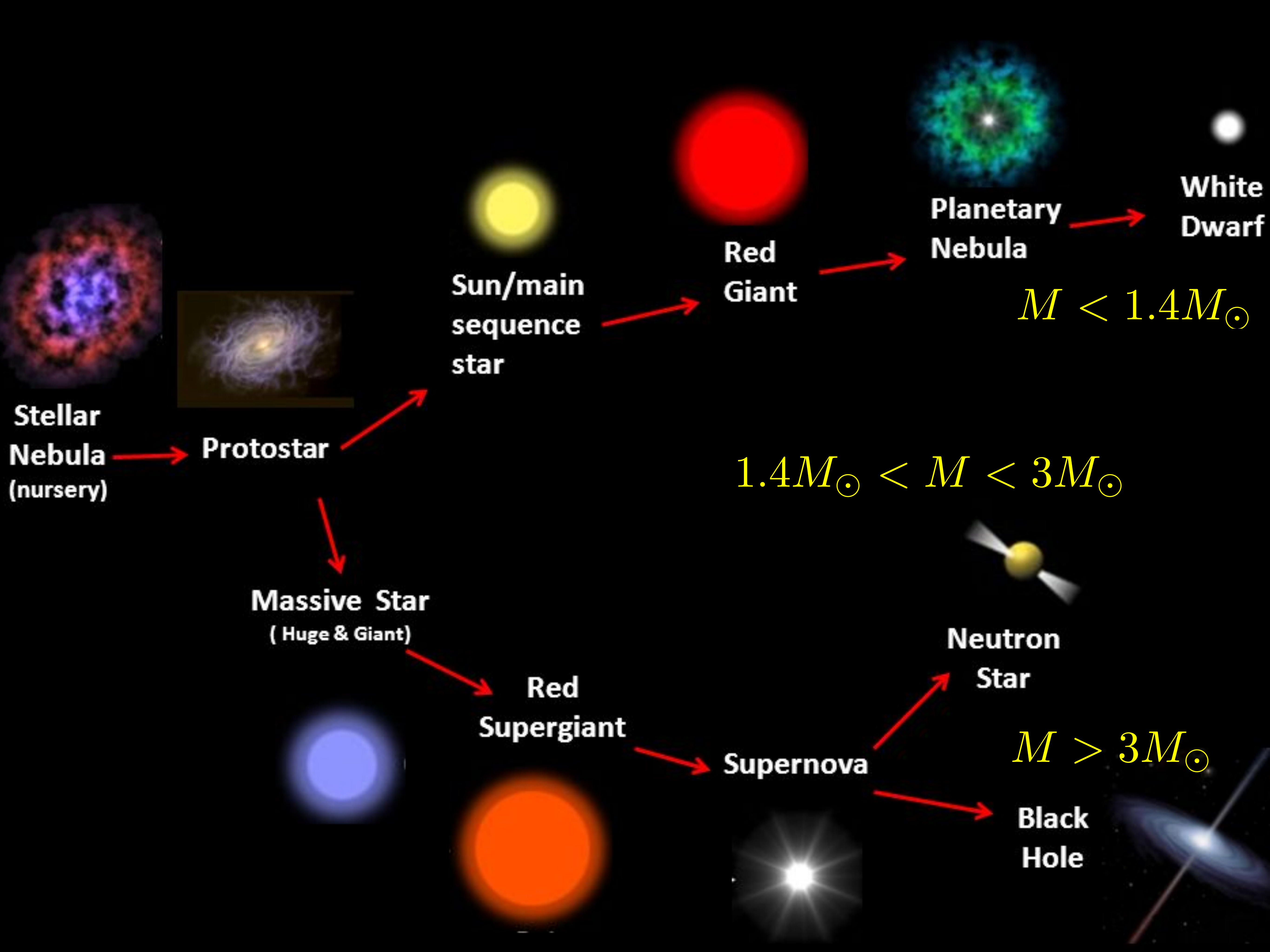

Light
rays
Singularity
Event horizon

TOV limit

Tolman–Oppenheimer–Volkoff

The electron degeneracy pressure is merely too weak to influence events once the Chandrasekhar limit is reached. Obviously once a star collapses to form a neutron star [or black hole, for that matter], electron degeneracy pressure is no longer in play. The TOV limit is the upper limit for neutron star mass. Beyond that, the neutron degeneracy pressure to too weak to prevent the star from further collapse - either a black hole or some intermediate state such as a quark star results. Given no quark stars have been positively identified to date, prevailing opinion is a black hole is the probable outcone of exceeding the TOV limit. We do not know the precise value of the TOV limit. The equation of state [EOS] for degenerate matter is poorly understood. When it was originally calculated, the TOV limit was predicted to be 0.7 solar masses - which is obviously too low. Based on the most massive known neutron star [1.97], current thinking is it is somewhere

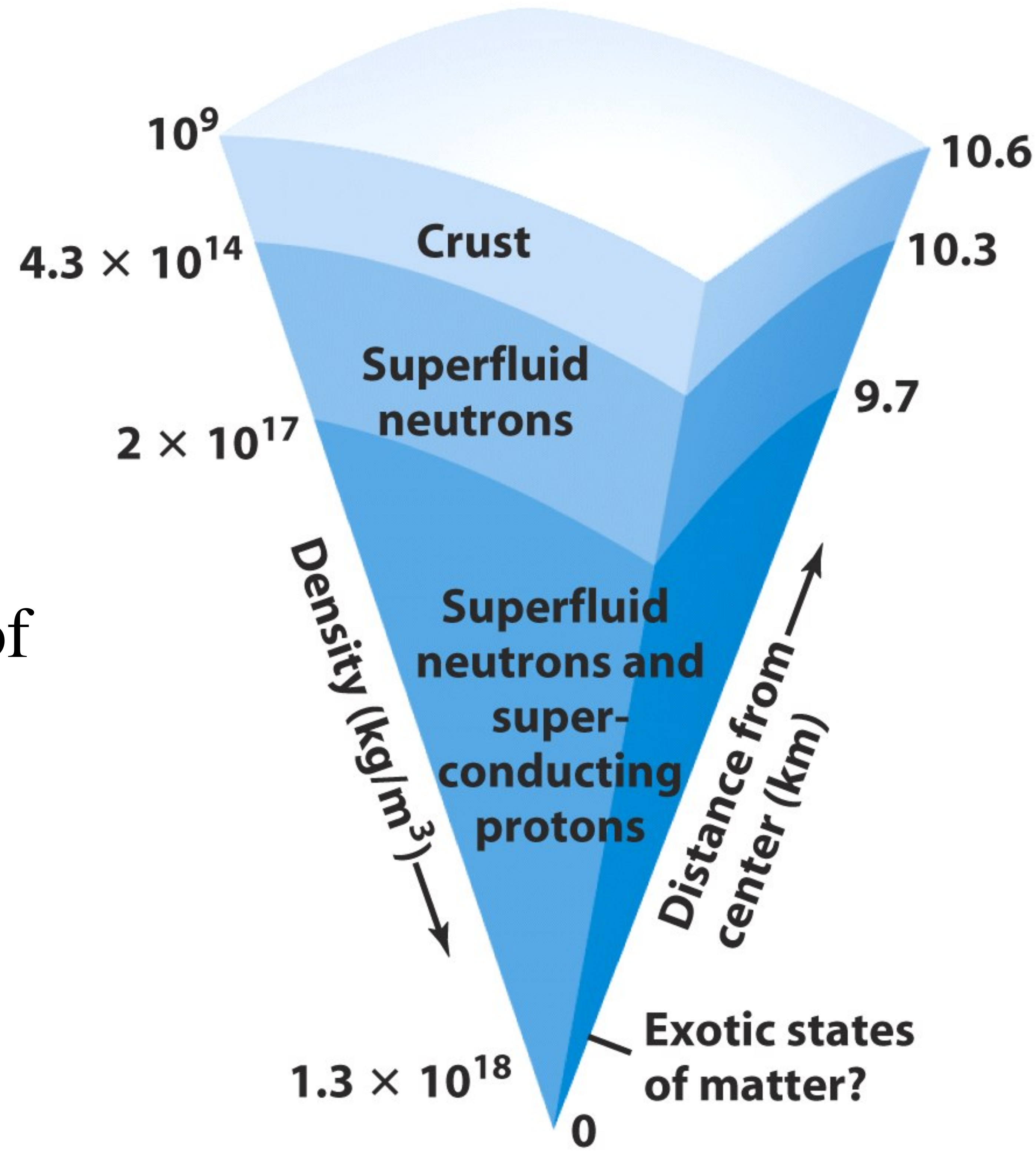
between 2 and 3 solar.


Stellar
Nebula
(nursery)
Protostar
Sun/main
sequence
star
Red
Giant
Planetary
Nebula
White
Dwarf
$M < 1.4 M_\odot$
$1.4 M_\odot < M < 3 M_\odot$
Massive Star
(Huge & Giant)
Red
Supergiant
Supernova
Neutron
Star
$M > 3 M_\odot$
Black
Hole

The Structure of Neutron Stars

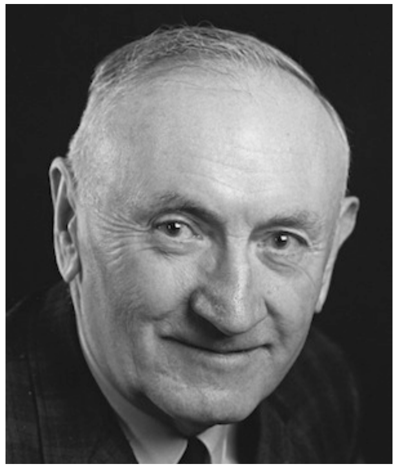
Not quite one gigantic atomic nucleus, but sort of a macroscopic quantum object

A neutron star consists of a *neutron superfluid*, superconducting core surrounded by a superfluid mantle and a thin, brittle crust



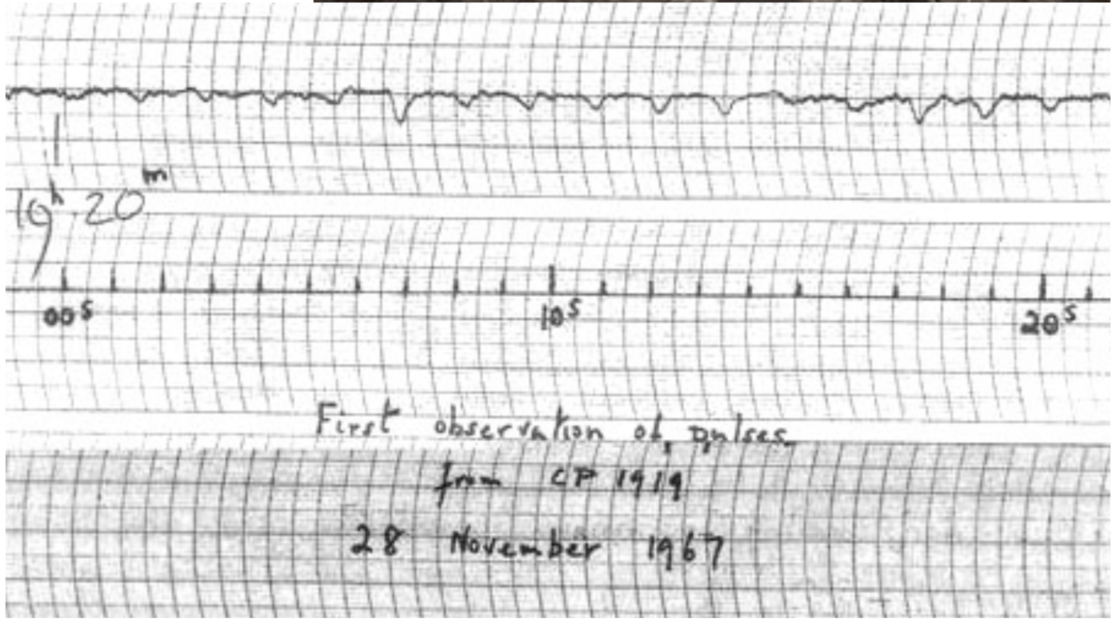
Prediction and Discovery of Neutron Stars

- The neutron was discovered in 1932. Already in 1934 Walter Baade and Fritz Zwicky suggested that supernovae involve a collapse of a massive star, resulting in a neutron star



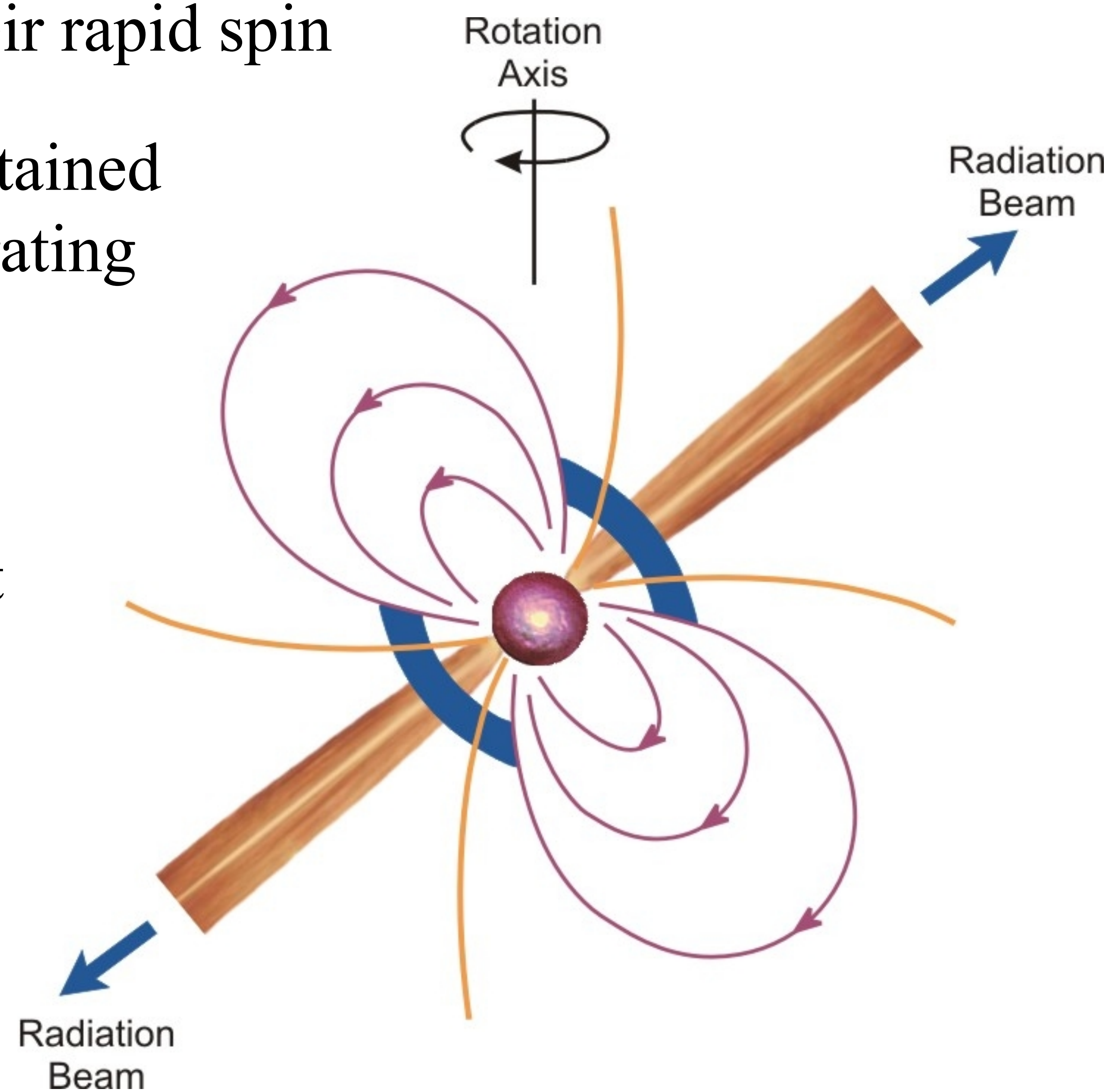
- In 1967 Jocelyn Bell and Antony Hewish discovered pulsars in the radio (Hewish shared a Nobel prize in 1974)

- Fast periods (~ tens of ms) and narrow pulses (~ ms) implied the sizes of the sources of less than a few hundred km (since $R < c\,\Delta t$). That excluded white dwarfs as sources



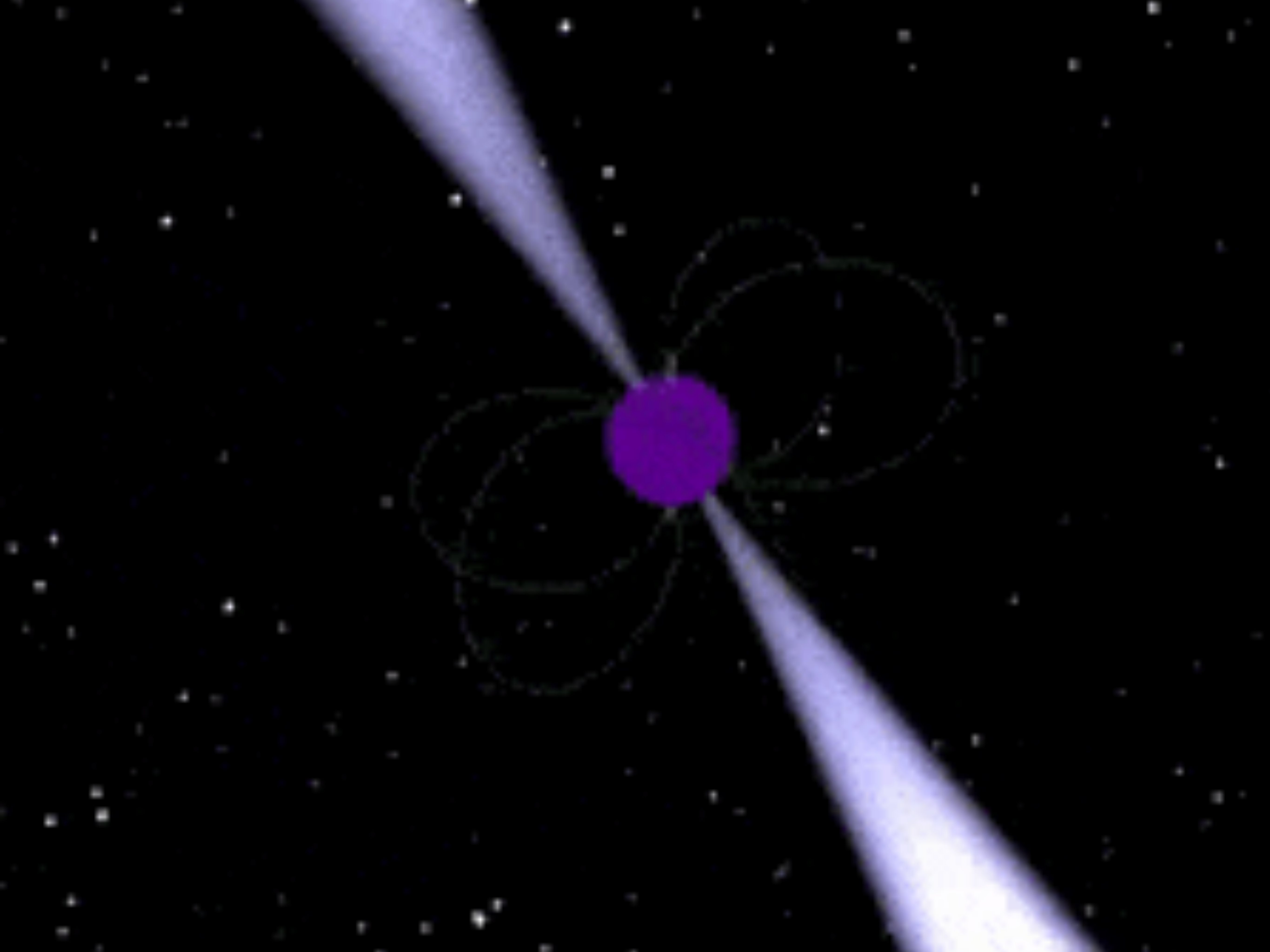
Pulsar: Cosmic Lighthouses

- As a stellar core collapses, in conserves its angular momentum. This gives the pulsar their rapid spin



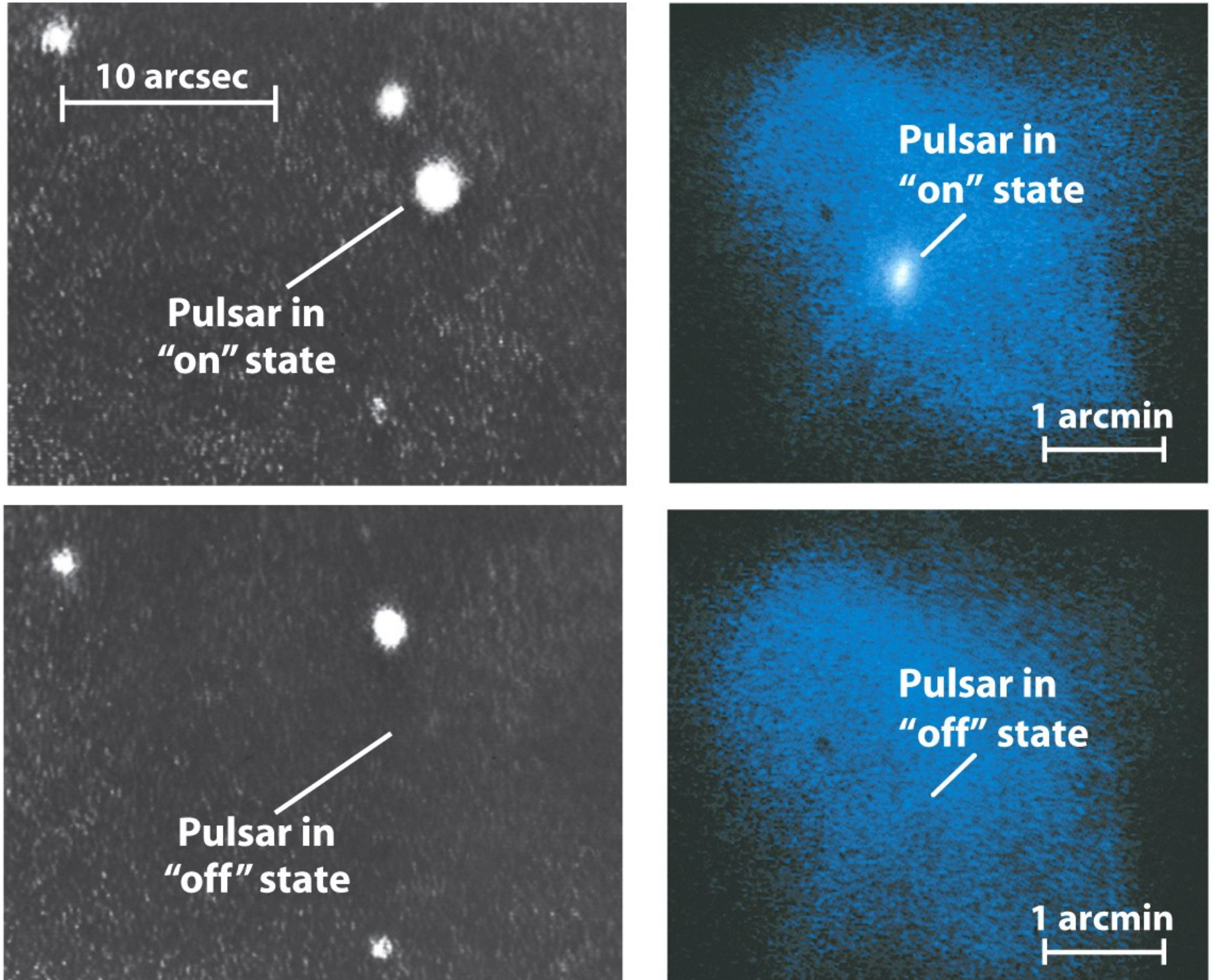
- Magnetic field is also retained and compressed, accelerating electrons, which emit synchrotron radiation

- Magnetic poles need not be aligned with the rotation axis. Thus, the beams of radiation sweep around as a lighthouse beam



孩子问：**妈妈，飞机为什么不会撞到天上的星星啊?**

妈妈：因为星星会闪啊！



The Crab pulsar in visible light

The Crab pulsar in X rays

世界上最精准的时钟之一!

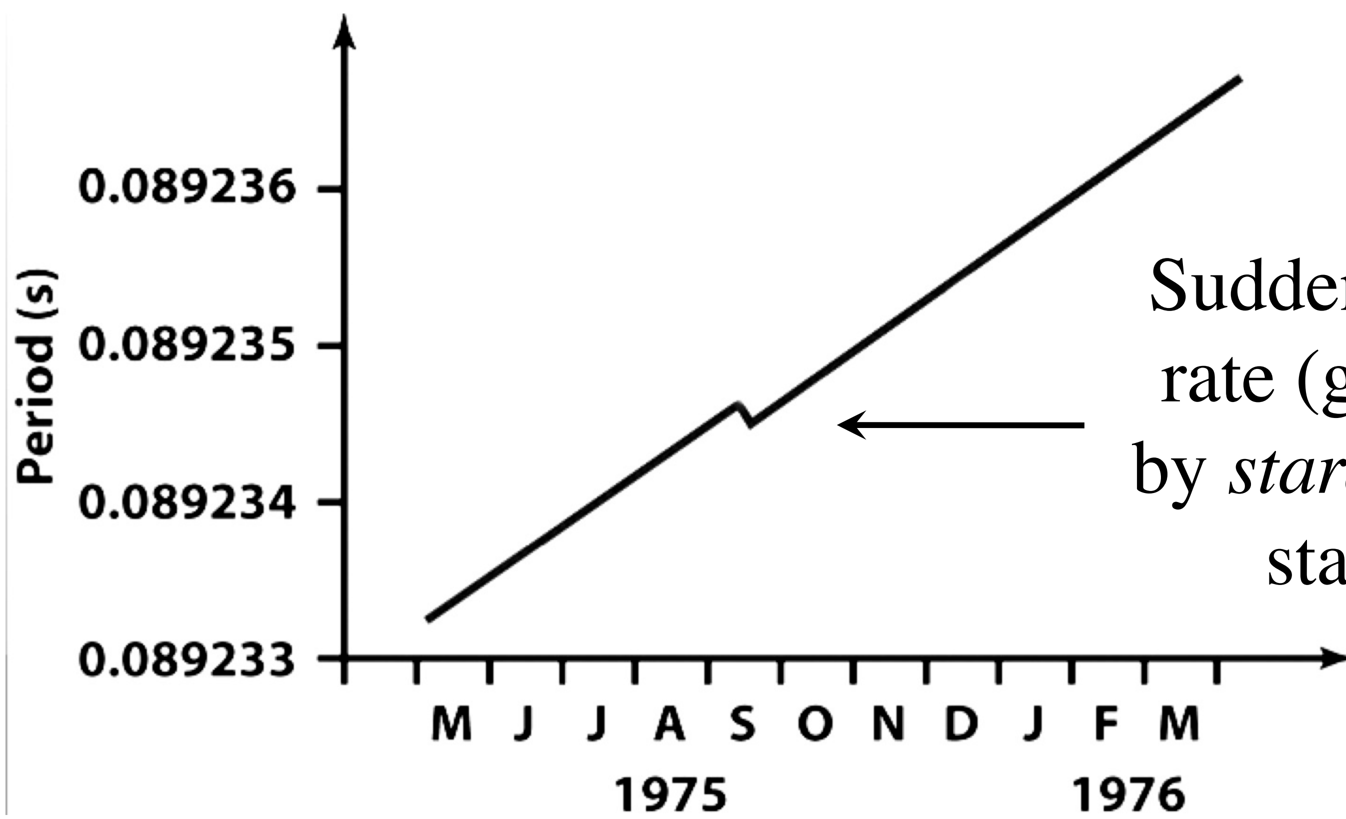
Pulsar Timing and Slowdown

- Because of their huge moments of inertia, most pulsars are *extremely stable*, as steady as (or better than) atomic clocks
- However, the energy they radiate comes at the expense of the rotational kinetic energy, resulting in a gradual slowdown

$$E_{rot} = \tfrac{1}{2} I \omega^2 = 2\pi^2 I P^{-2} \qquad L = dE/dt = 4\pi^2 I P^{-3} \dot{P}$$

(I = moment of inertia, P = period)

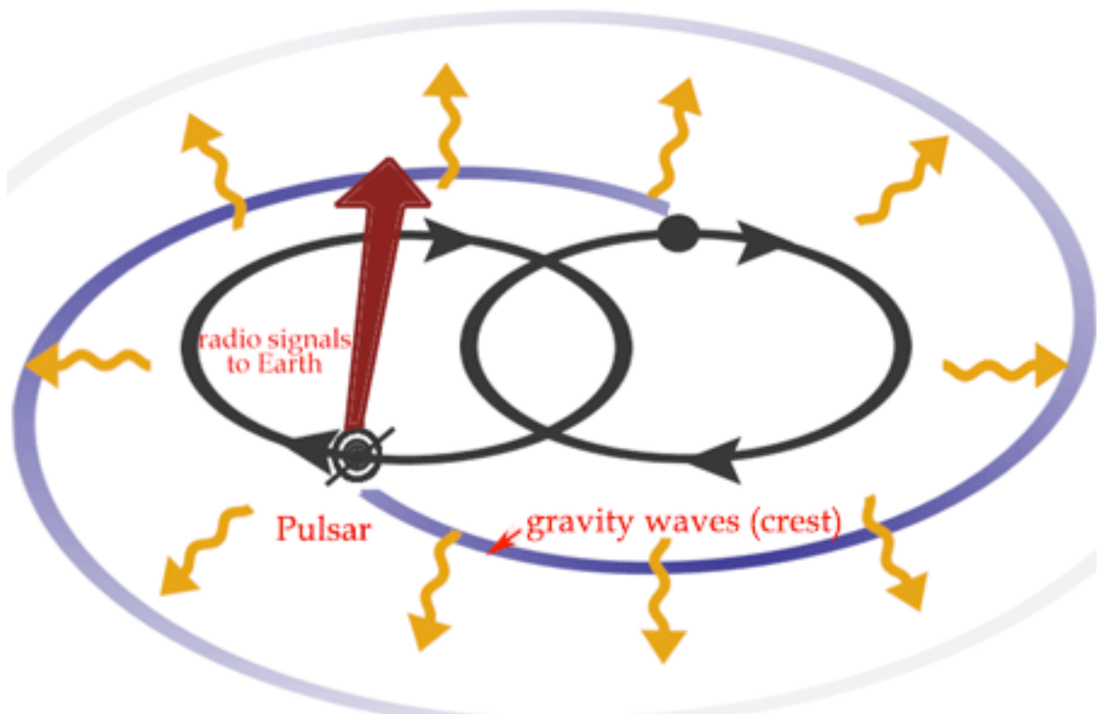
Period derivative

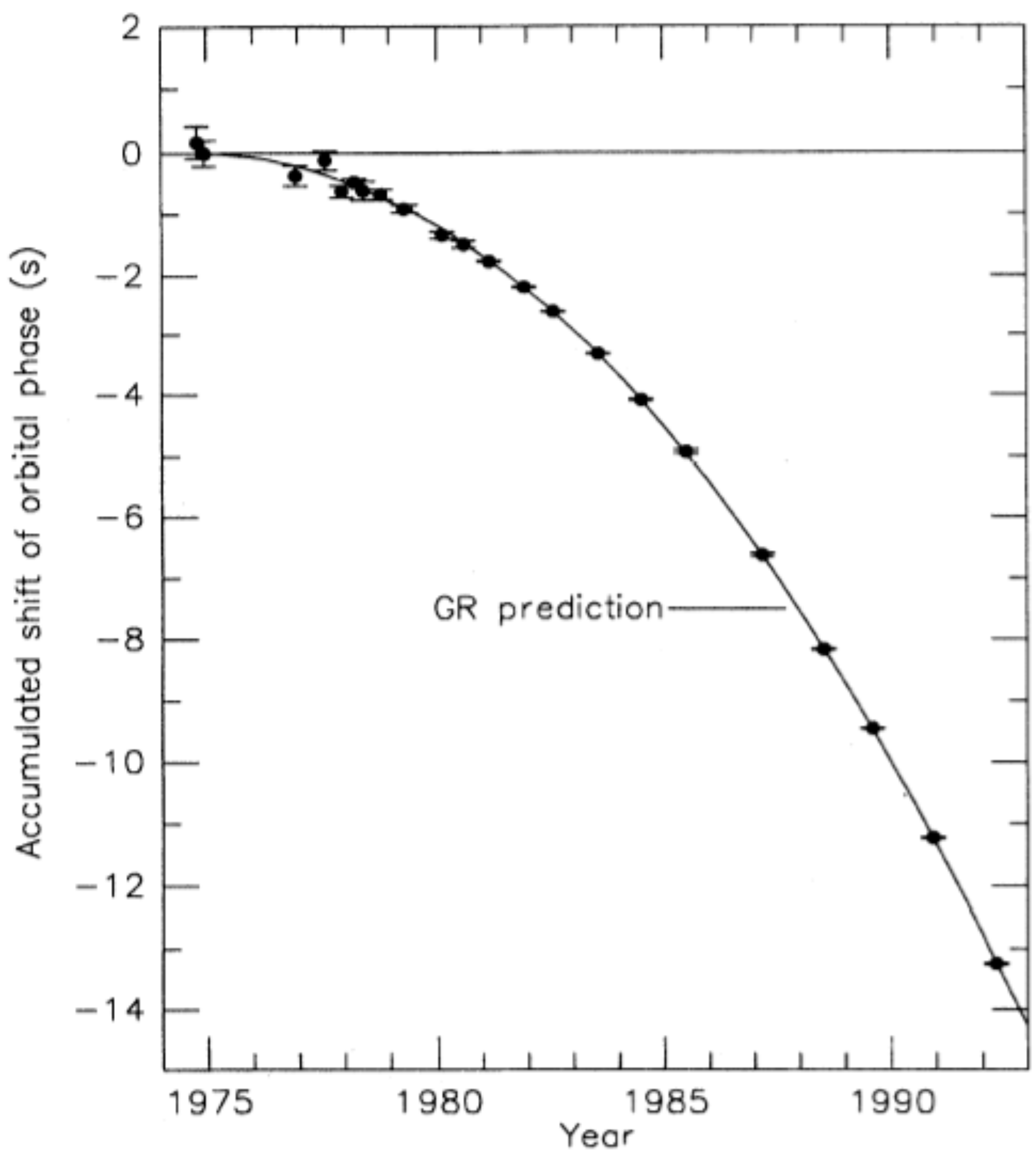


Sudden speedups of the pulse rate (glitches) may be caused by *starquakes* – settling of the star to a lower moment of inertia

Binary Pulsars

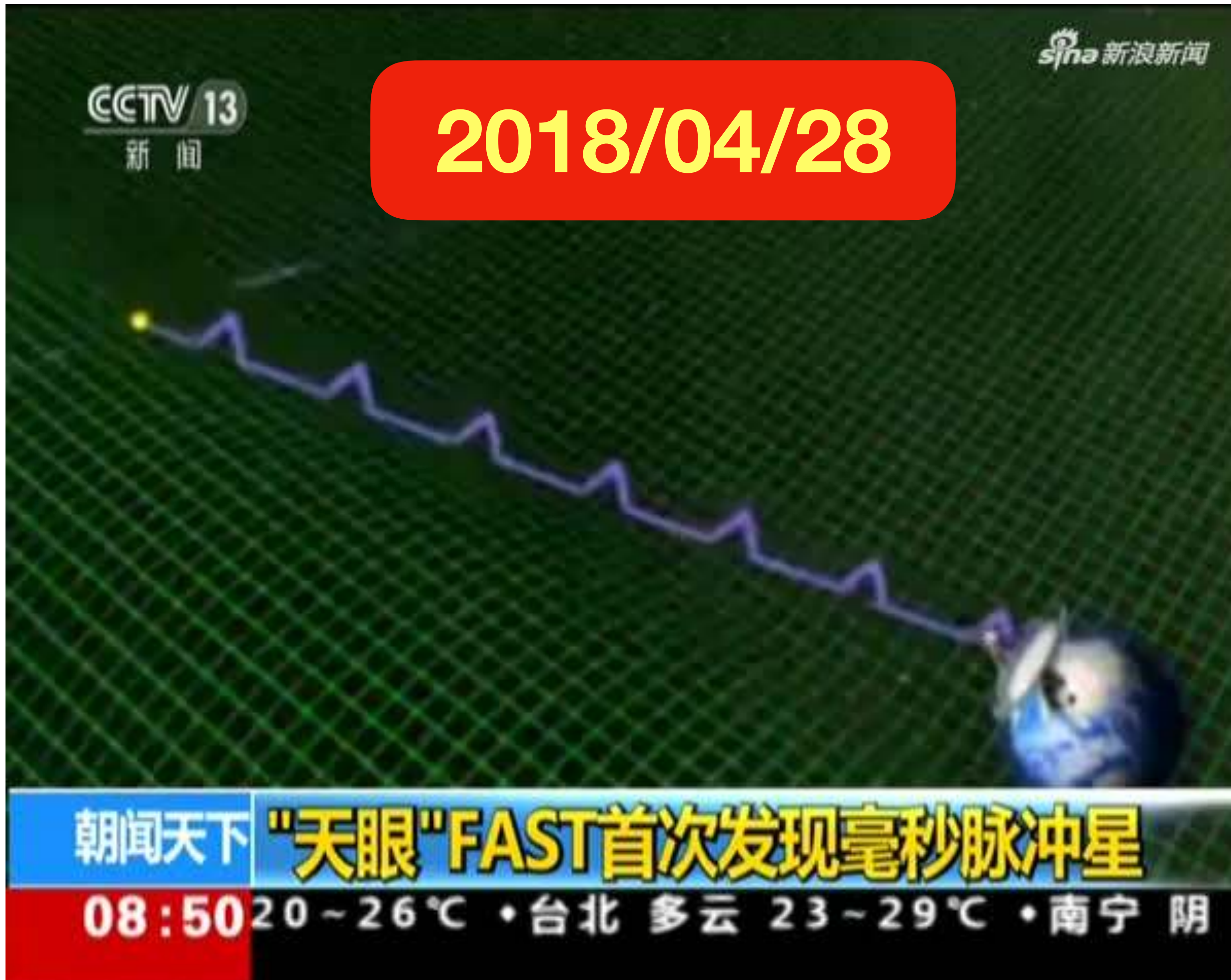
- First one discovered in 1974 by Joseph Taylor & Russell Hulse
- This is a *relativistic binary*, and some of the orbital kinetic energy is being radiated away as *gravitational waves*

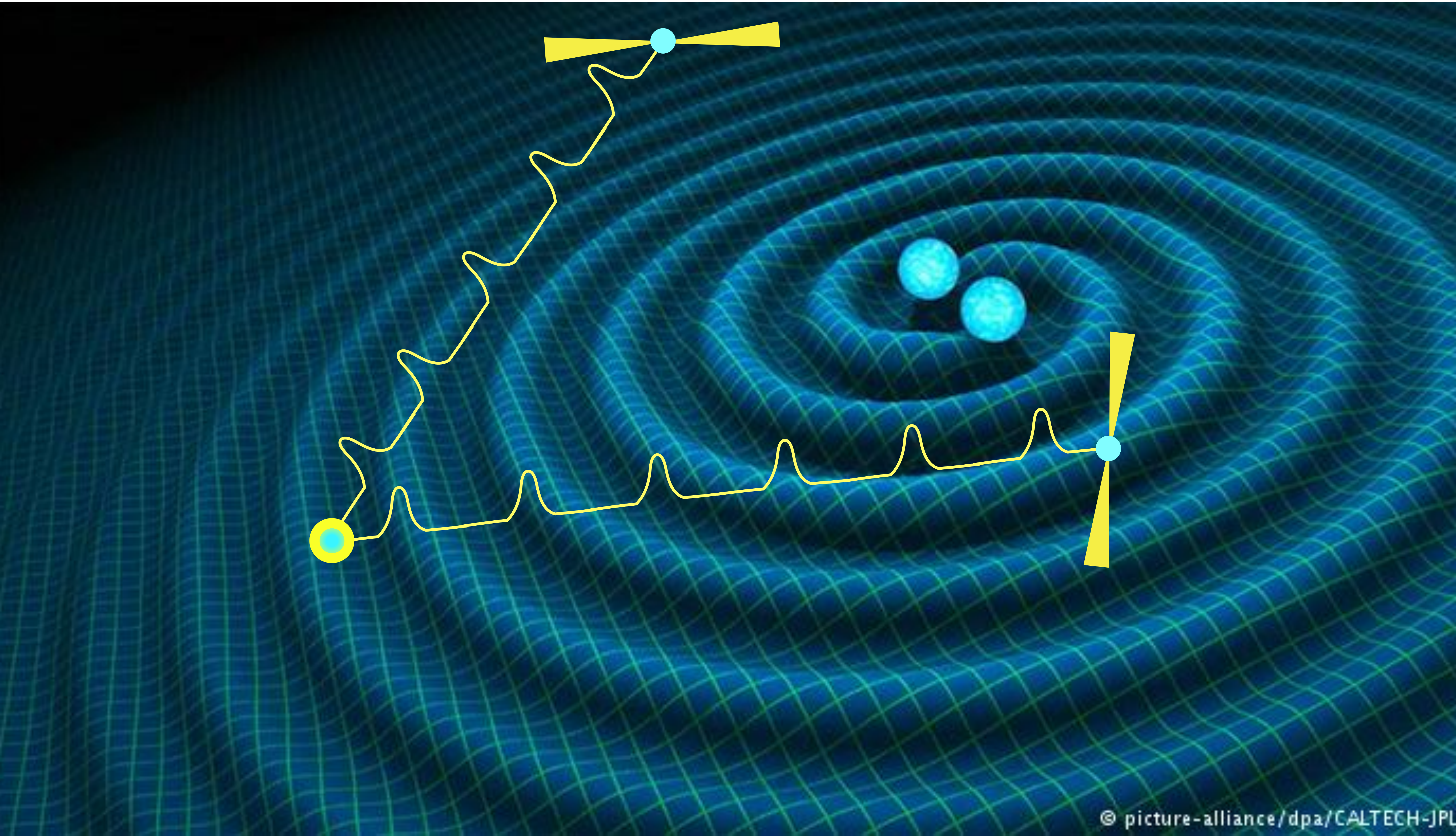




- The observed rate of energy loss is exactly what the General Relativity predicts!
- Won the Nobel Prize in 1993

Problem-12: 综述一下FAST项目中与脉冲星相关的部分，如：科学目标，实验方案，仪器，等

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