Introduction to Astronomy
AA 201
Fall Semester 2019

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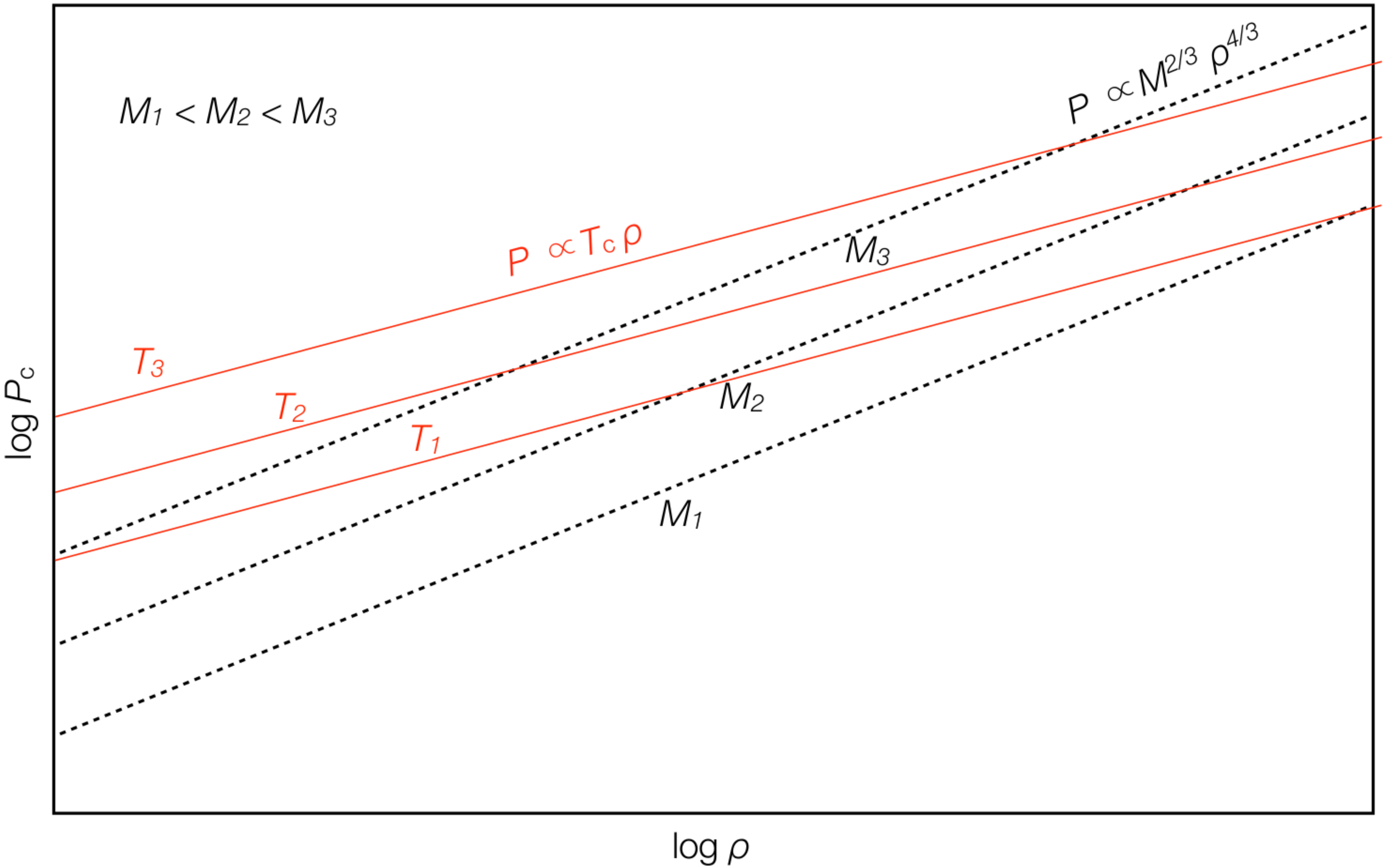
Extension: 839

Course webpage:

http://www.iiti.ac.in/people/~manoneeta/courses/AA201_2019/

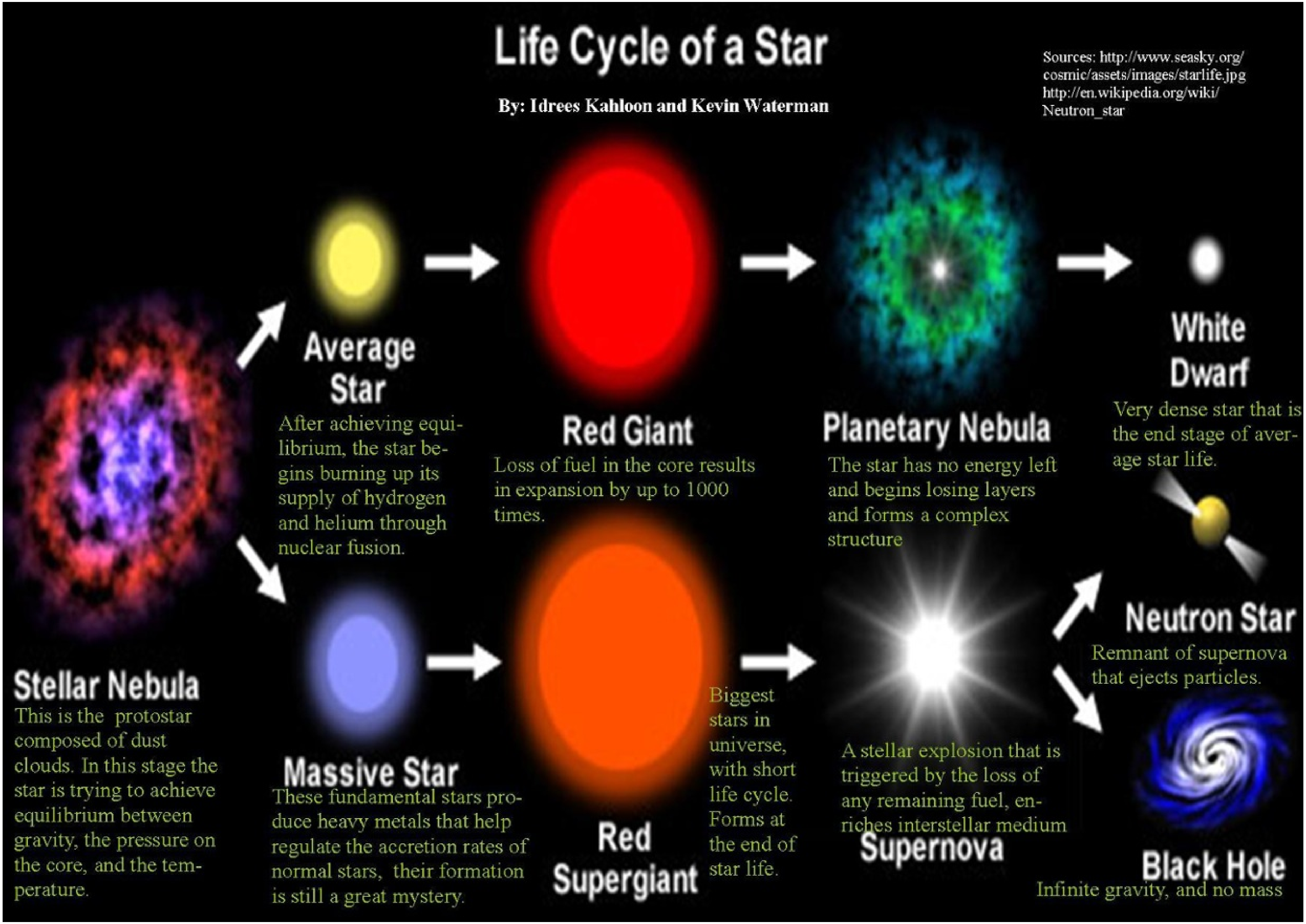


$M_1 < M_2 < M_3$
$P \propto M^{2/3} \rho^{4/3}$
$P \propto T_c \rho$
T_3
T_2
T_1
M_3
M_2
M_1
$\log P_c$
$\log \rho$

What happens after a star finishes of its fuel?

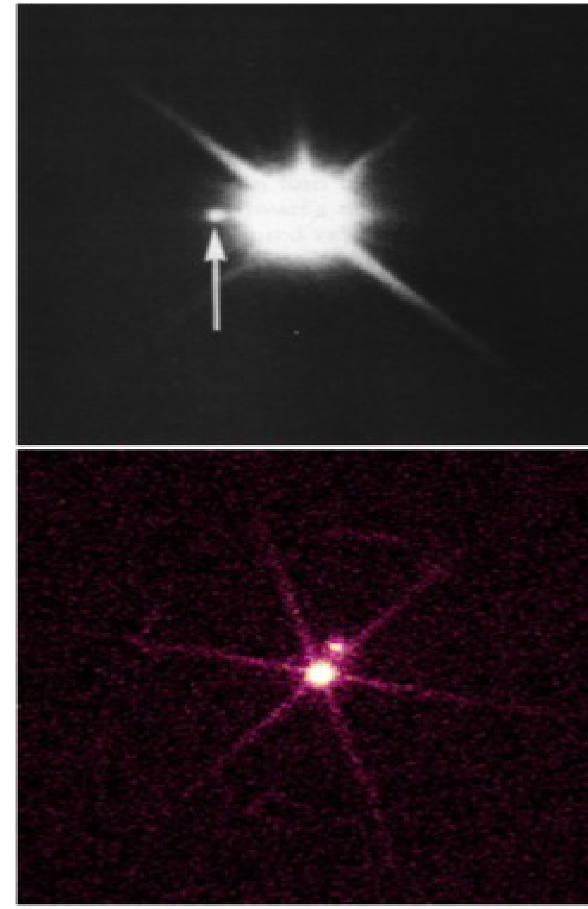
- As we have seen before, the (main-sequence) lifetime of a star depends on its mass.
- Subsequently, depending on the original mass, a number of outcomes are possible

Progenitor Mass	Outcome
$<0.5\ M_{solar}$	T_{ms} < age of universe
$0.5\ M_{solar} < M < 8\ M_{solar}$	WD + planetary nebula
$8\ M_{solar} < M < 20\ M_{solar}$	Core-collapse+SN Neutron star
$M > 20\ M_{solar}$	Core-collapse+SN Black hole

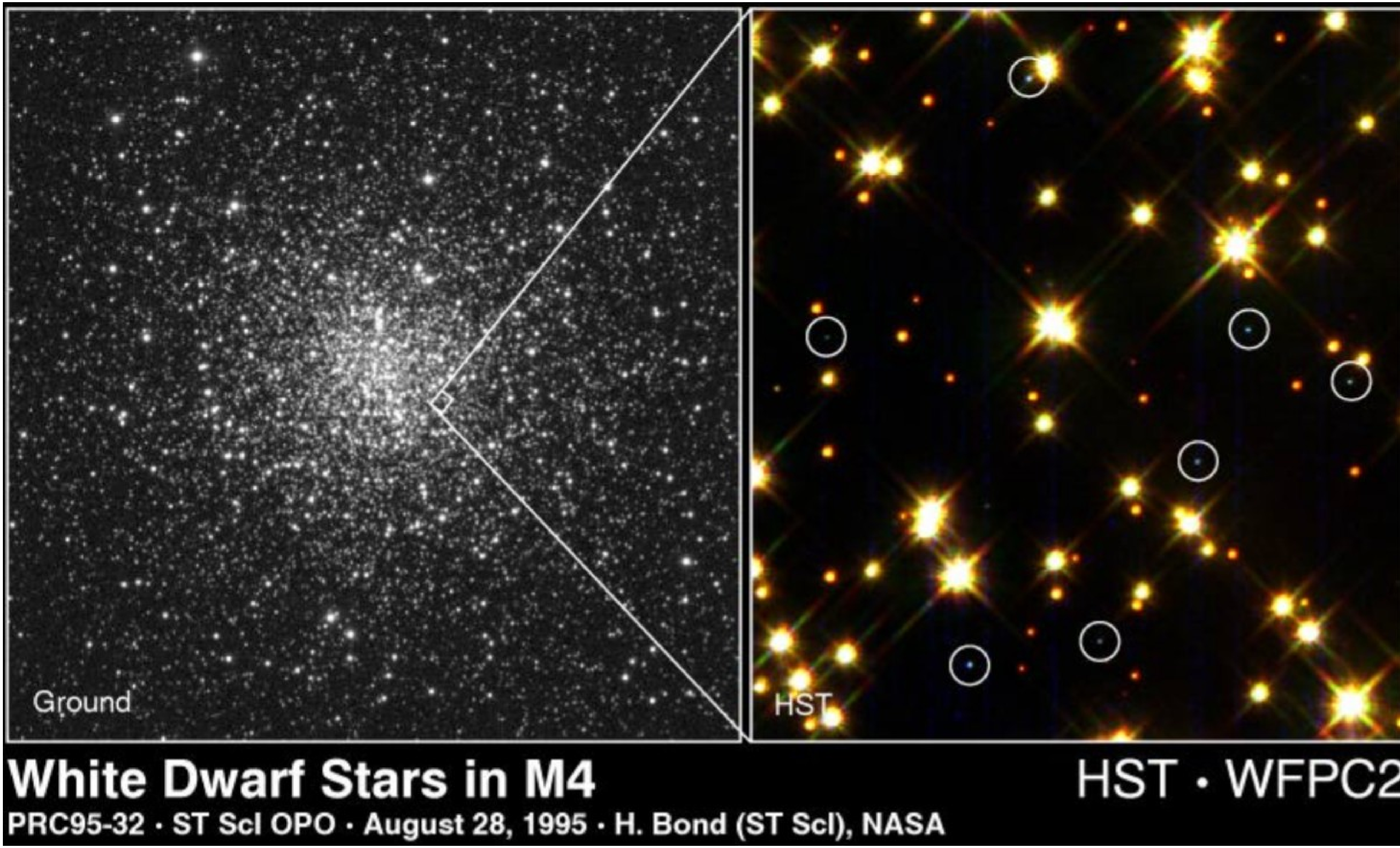

Life Cycle of a Star
By: Idrees Kahloon and Kevin Waterman
Sources: http://www.seasky.org/cosmic/assets/images/starlife.jpg http://en.wikipedia.org/wiki/Neutron_star
Average Star
After achieving equilibrium, the star begins burning up its supply of hydrogen and helium through nuclear fusion.
Red Giant
Loss of fuel in the core results in expansion by up to 1000 times.
Planetary Nebula
The star has no energy left and begins losing layers and forms a complex structure
White Dwarf
Very dense star that is the end stage of average star life.
Stellar Nebula
This is the protostar composed of dust clouds. In this stage the star is trying to achieve equilibrium between gravity, the pressure on the core, and the temperature.
Massive Star
These fundamental stars produce heavy metals that help regulate the accretion rates of normal stars, their formation is still a great mystery.
Red Supergiant
Biggest stars in universe, with short life cycle. Forms at the end of star life.
Supernova
A stellar explosion that is triggered by the loss of any remaining fuel, enriches interstellar medium
Neutron Star
Remnant of supernova that ejects particles.
Black Hole
Infinite gravity, and no mass

Sirius B: first evidence

- First white dwarf discovered
- Mass from orbital effect of Sirius A (brightest)
  - $M_B \sim 1.05\ M_{solar}$
- 1000 times fainter than Sirius A but hotter!
- $R \sim 5.5 \times 10^6$ m $= 0.008\ R_{solar}$
- Density $\sim 10^9$ kg/m^3
- Mixture of Carbon-Oxygen



Optical (top) and X-ray (bottom) images of Sirius A and B, which are an A-type star and a white dwarf. The optical image is dominated by the main sequence star, the X-ray image by the white dwarf.


Ground
HST
White Dwarf Stars in M4
HST • WFPC2
PRC95-32 • ST ScI OPO • August 28, 1995 • H. Bond (ST ScI), NASA

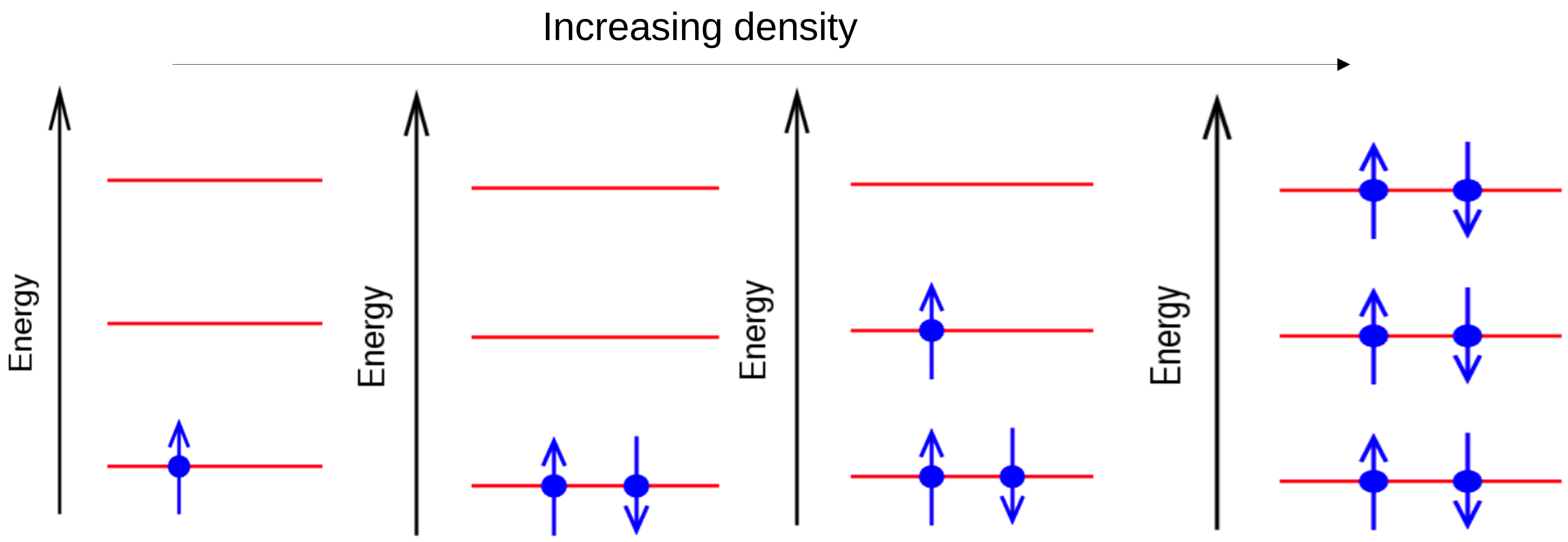
What powers these objects?

- Reminder: Gravitational pressure balanced by thermal pressure of gas heated by fusion
- Here → Degeneracy pressure

- As star collapses →density increases → quantum mechanical effects becomes important

Degeneracy pressure

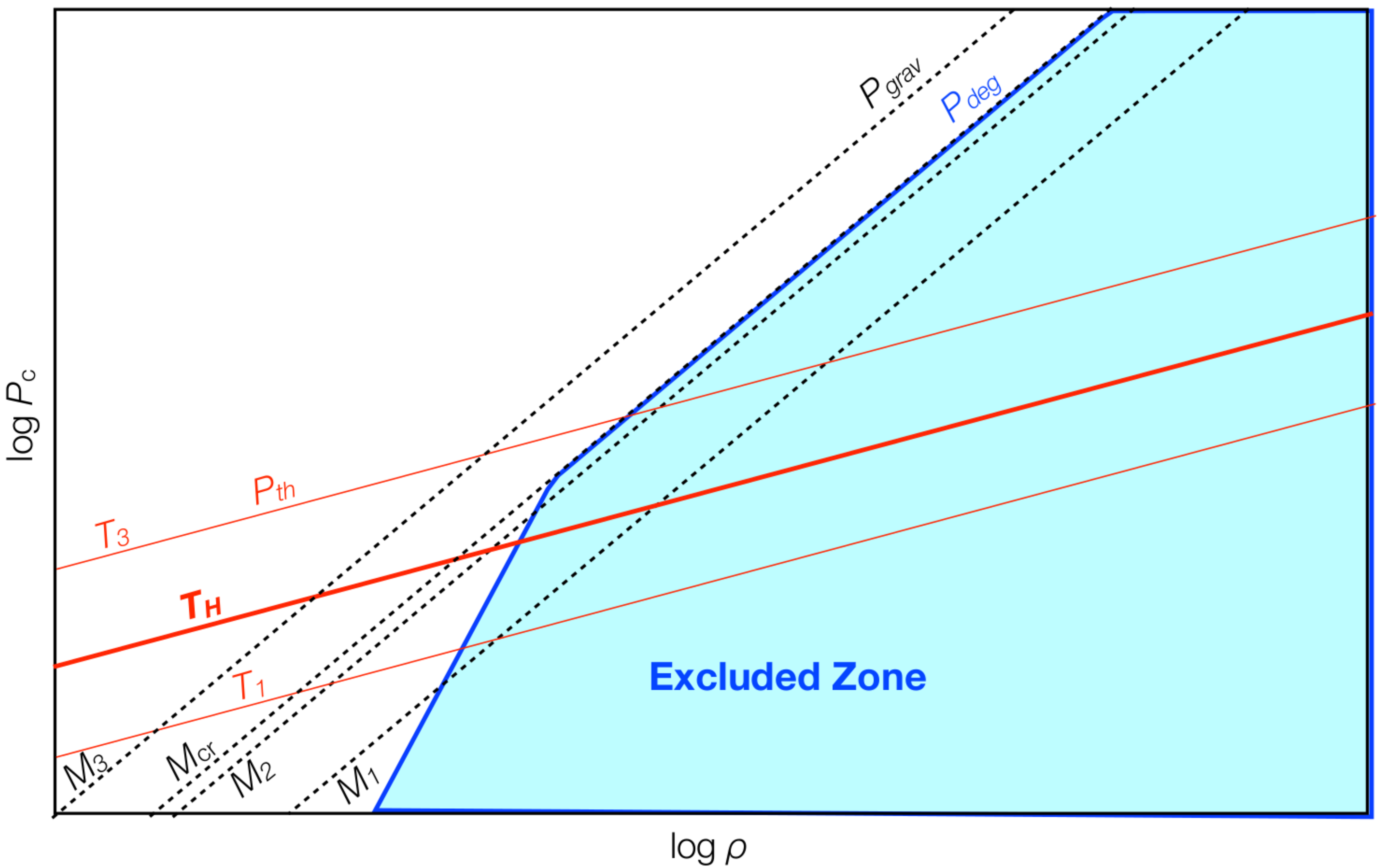
- Pauli exclusion principle
- For fermions, at least one quantum number must be different
- Quantum numbers: position, momentum, angular momentum, spin
- For normal gas density low, available phase space is large . But when density high → phase space low → exclusion principle becomes important



In degenarate electron gas, the electrons have much higher energy than thermal gas at the same temperature

White dwarfs

- Mass ~ 0.8 M_{solar}
- Radius ~ radius of earth
- Either He or C-O depending on progenitor
- Density ~ 10^6 g/cm^3 .
- Temperature interior ~ 10^7 K
- Maximum possible mass: 1.44 Msolar
  - Chandrasekhar limit!!
  - Relativistic degenarate gas behavior makes WD unstable
  - $P \sim \rho^{4/3}$



P grav
P deg
log P c
P th
T 3
T H
T 1
M 3
M cr
M 2
M 1
Excluded Zone
log ρ

Neutron Stars

- What happens when core crosses Chandrasekhar limit? → Collapse
- High densities favour
  - $p + e^- \rightarrow n + \nu_e$
- Gravity balanced by degenerate neutrons (similar to degenerate electrons for WD)
- Typical density ~ 10^{14} g/cm^3
- Mass ~ 1.4 – 3 M_{solar}
- Radius ~ 10 km
- Core material exotic displaying superconductivity and superfluidity at high temperatures → nautre not understood!

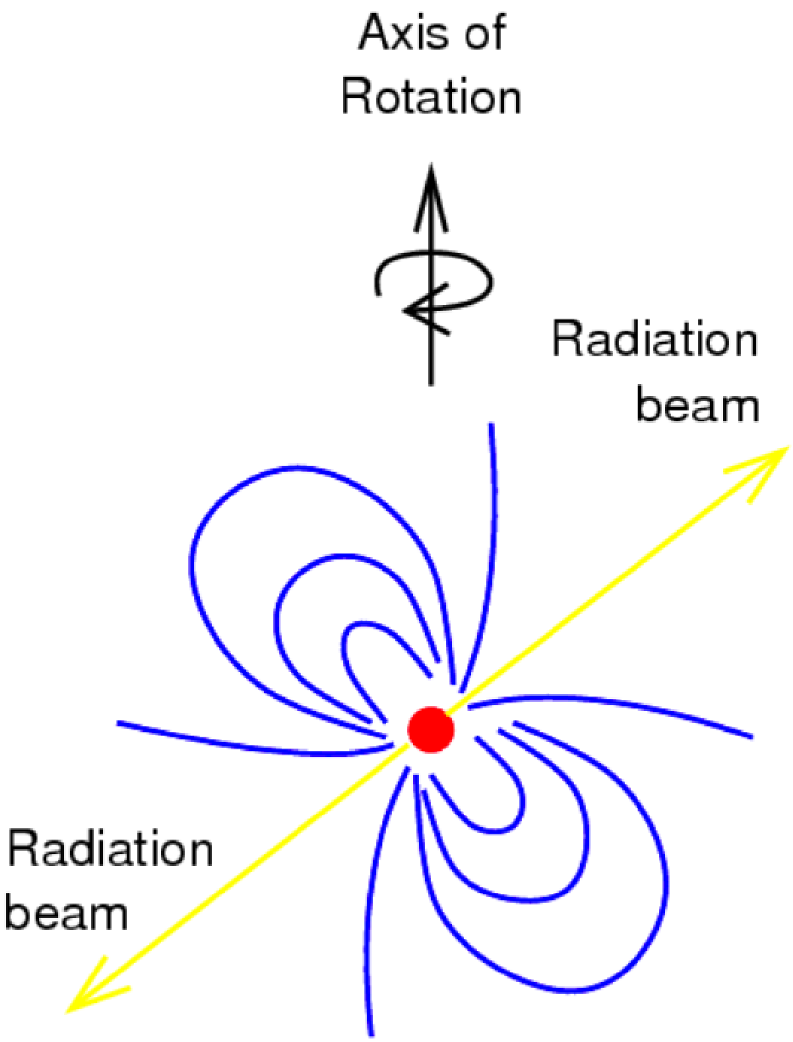
Neutron Stars

- Angular momentum conserved during collapse

- $MR^2 \Omega$ = constant
- $M_{NS} = M_{before} = M_{core}$
- $\Omega_{NS} = (R_{before}/R_{NS})^2 \, \Omega_{before}$

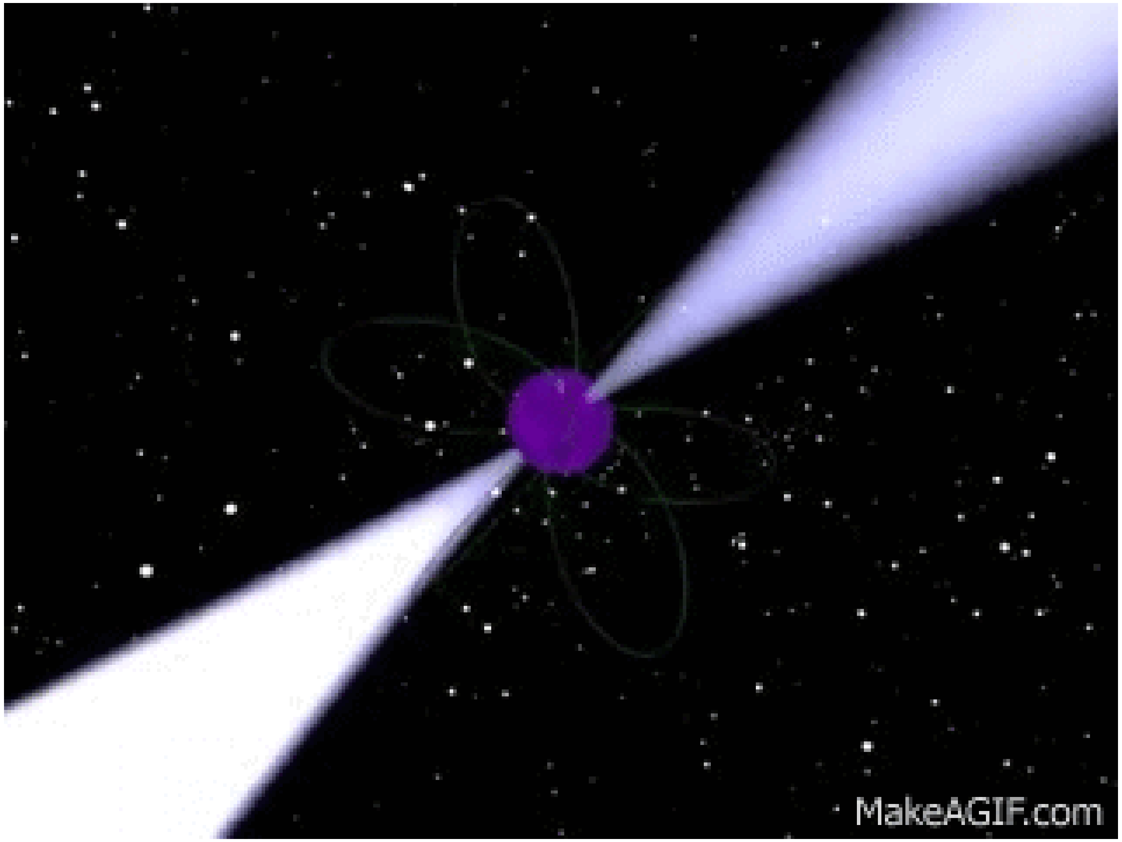
- Extremely Fast Rotators!!
- R_{before}=7X10^5 km ; R_{NS} = 10 km; P_{before} = 27 d; P_{NS} = 0.001s

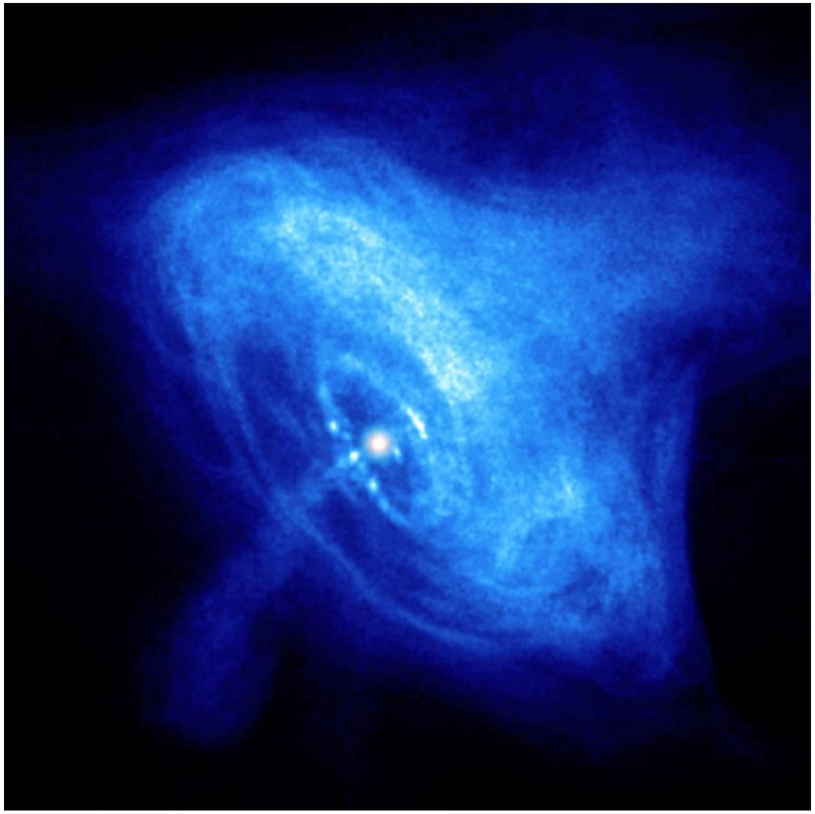
Pulsars



"Lighthouse model" for pulsars

- Fast rotating neutron star with strong magnetic fields
- Lighthouse effect
- B ~ 10^{12} -10^{13} G (10^{13} times geomagnetic field)
- Spin ~ ms – 10 s
- Magnetic flux is conserved
  - BR^2 = constant


MakeAGIF.com



Black Holes

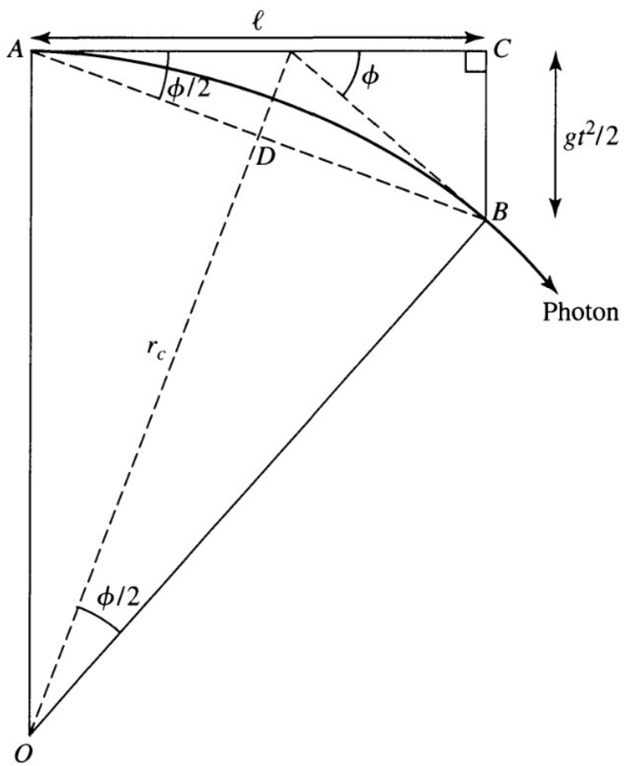
- Core > 3 M_{solar} => Gravity wins

- Light emitted cannot escape gravitational attraction

- Escape velocity = velocity of light

  → Schwarzschild radius

Near the blackhole



Light Bending

$$\boxed{\frac{\nu_\infty}{\nu_0} = \left(1 - \frac{2GM}{r_0 c^2}\right)^{1/2}.}$$

$$z = \frac{\lambda_\infty - \lambda_0}{\lambda_0} = \frac{\nu_0}{\nu_\infty} - 1$$

$$= \left(1 - \frac{2GM}{r_0 c^2}\right)^{-1/2} - 1$$

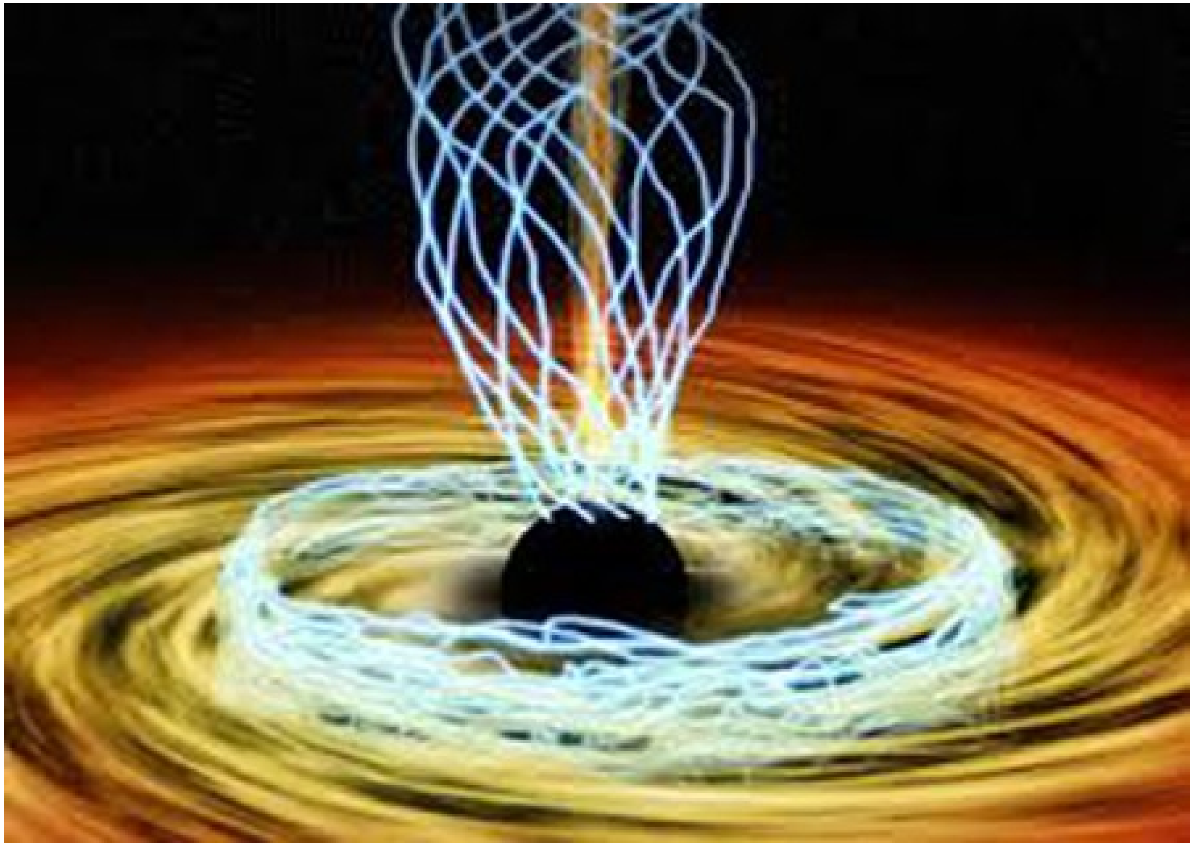
$$\simeq \frac{GM}{r_0 c^2},$$

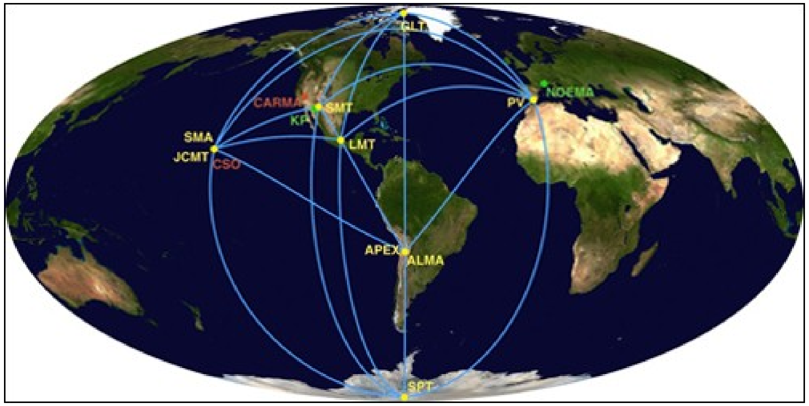
Gravitaional reshift

$$\boxed{\frac{\Delta t_0}{\Delta t_\infty} = \frac{\nu_\infty}{\nu_0} = \left(1 - \frac{2GM}{r_0 c^2}\right)^{1/2}.}$$

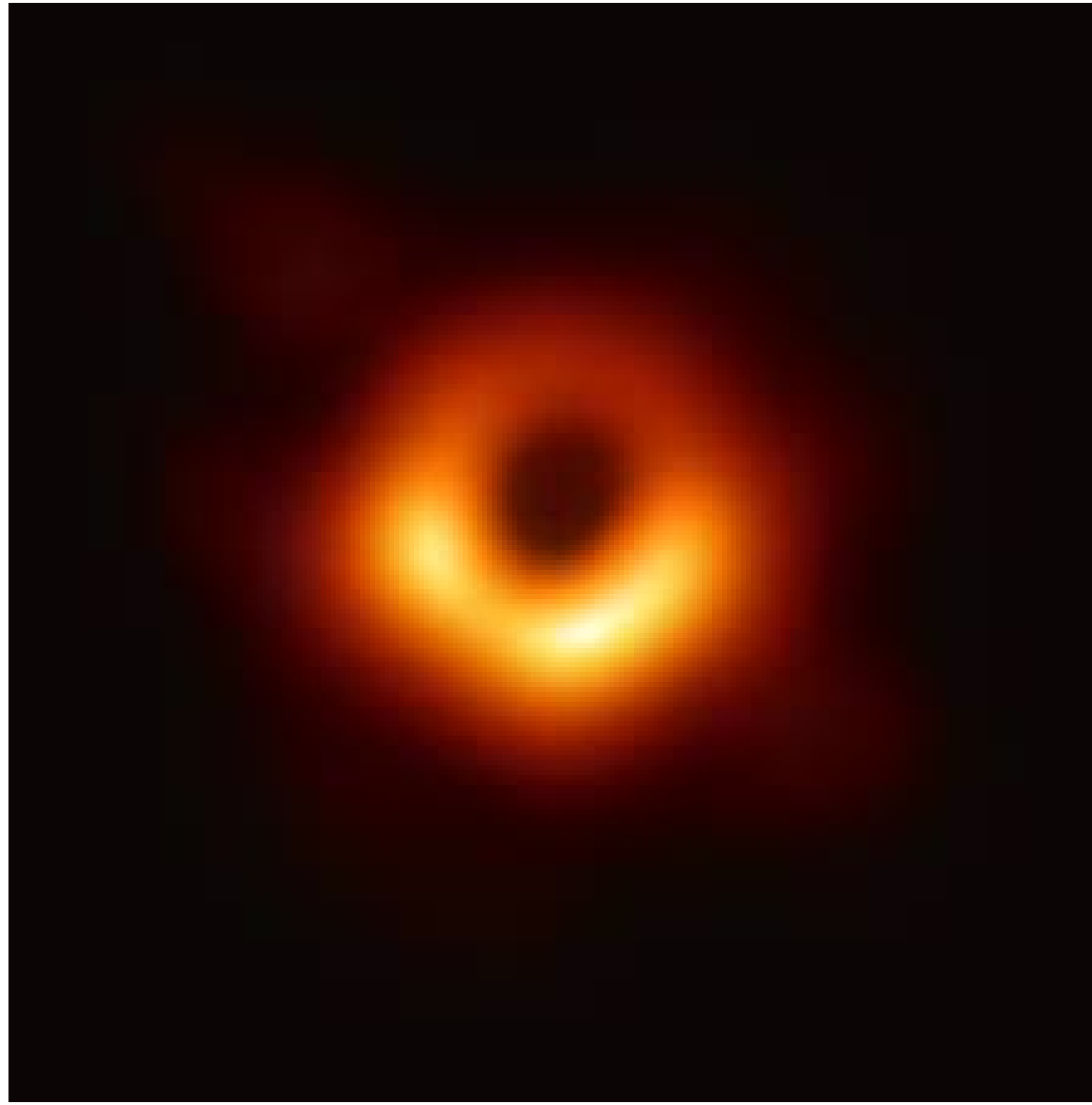
Times slows down!

Principle of equivalence




GLT
NOEMA
PV
CARMA
SMT
KP
SMA
JCMT
CSO
LMT
APEX
ALMA
SPT

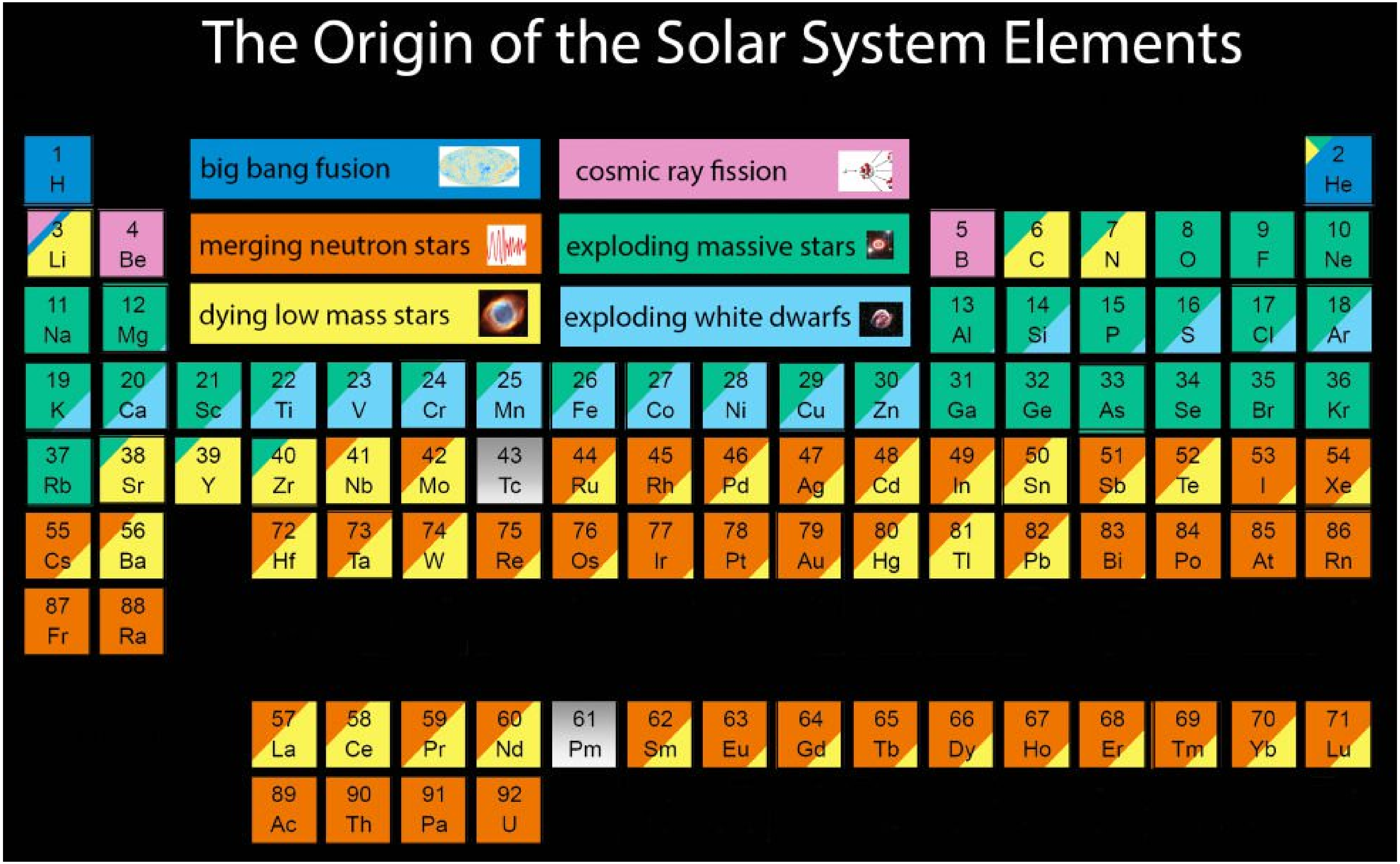

NOEMA
Northern Extended
Millimeter Array
CARMA
Combined Array for Research in
Millimeter-wave Astronomy
BOSTON
IRAM
30-meter telescope
CSO
Caltech Submillimeter
Observatory
LMT
Large Millimeter Telescope
JCMT
James Clerk Maxwell Telescope
SMA
Submillimeter Array
APEX
Atacama Pathfinder Experiment
ASTE
Atacama Submillimeter
Telescope Experiment
ARO/SMT
Arizona Radio Observatory/
Submillimeter-wave Astronomy
ALMA
Atacama Large Millimeter/
Submillimeter Array
SPT
South Pole Telescope



Summarising

- Most of the matter orbits a BH before slowly inspiralling in
- After falling loses history
- No hair theorem → all you need is M, S, Q
- Mass → 2 distinct classes (missing link?)
- Tidal effects will distort any rigid body before falling
- Light bending
- Time dilation
- Strong source of gravity and high energy radiation
- Every galaxy has BH at centre

- More exotic Stuff
  - Fate of a black hole
  - Wormholes


The Origin of the Solar System Elements
big bang fusion
cosmic ray fission
merging neutron stars
exploding massive stars
dying low mass stars
exploding white dwarfs
1 H
2 He
3 Li
4 Be
5 B
6 C
7 N
8 O
9 F
10 Ne
11 Na
12 Mg
13 Al
14 Si
15 P
16 S
17 Cl
18 Ar
19 K
20 Ca
21 Sc
22 Ti
23 V
24 Cr
25 Mn
26 Fe
27 Co
28 Ni
29 Cu
30 Zn
31 Ga
32 Ge
33 As
34 Se
35 Br
36 Kr
37 Rb
38 Sr
39 Y
40 Zr
41 Nb
42 Mo
43 Tc
44 Ru
45 Rh
46 Pd
47 Ag
48 Cd
49 In
50 Sn
51 Sb
52 Te
53 I
54 Xe
55 Cs
56 Ba
72 Hf
73 Ta
74 W
75 Re
76 Os
77 Ir
78 Pt
79 Au
80 Hg
81 Tl
82 Pb
83 Bi
84 Po
85 At
86 Rn
87 Fr
88 Ra
57 La
58 Ce
59 Pr
60 Nd
61 Pm
62 Sm
63 Eu
64 Gd
65 Tb
66 Dy
67 Ho
68 Er
69 Tm
70 Yb
71 Lu
89 Ac
90 Th
91 Pa
92 U