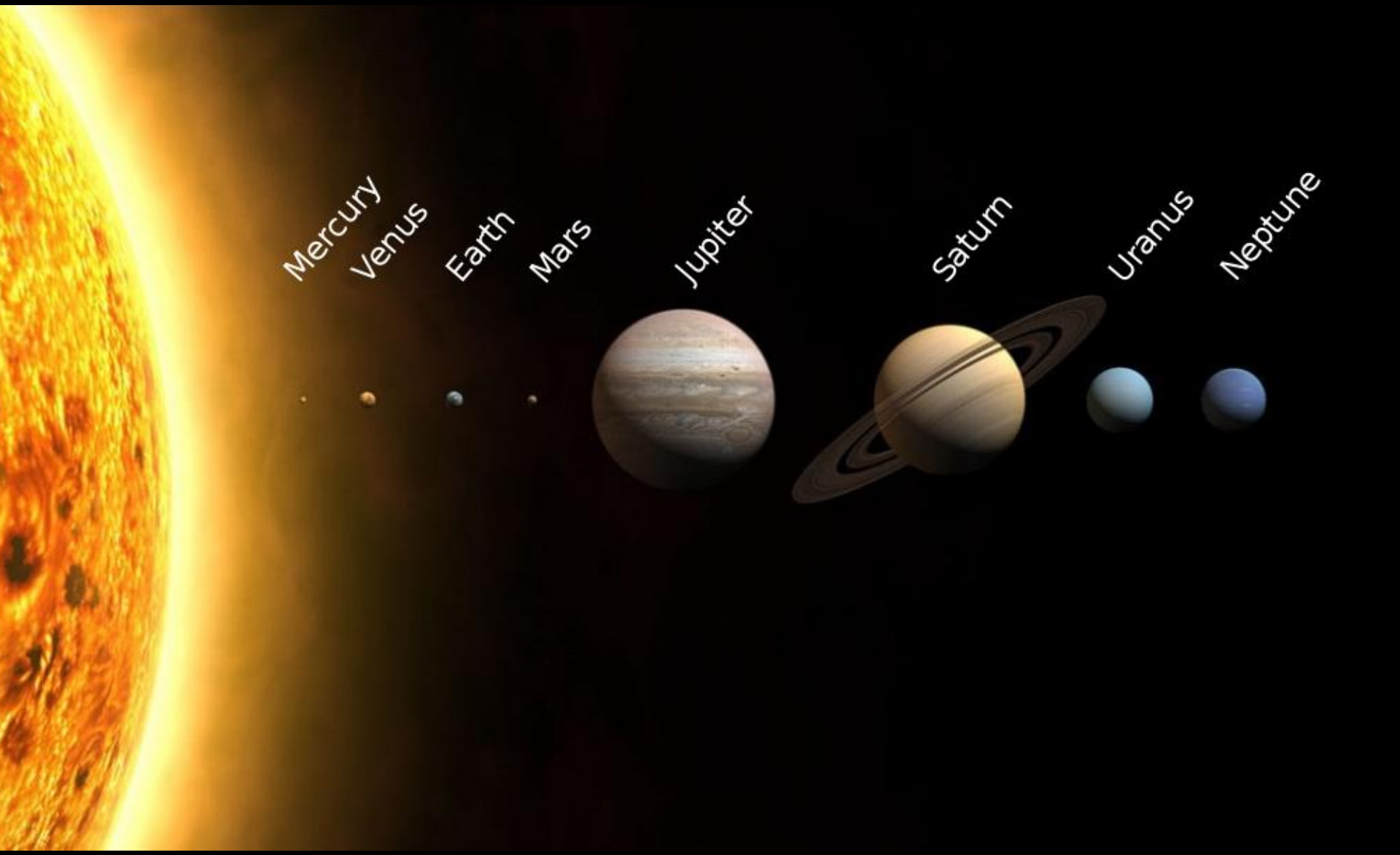
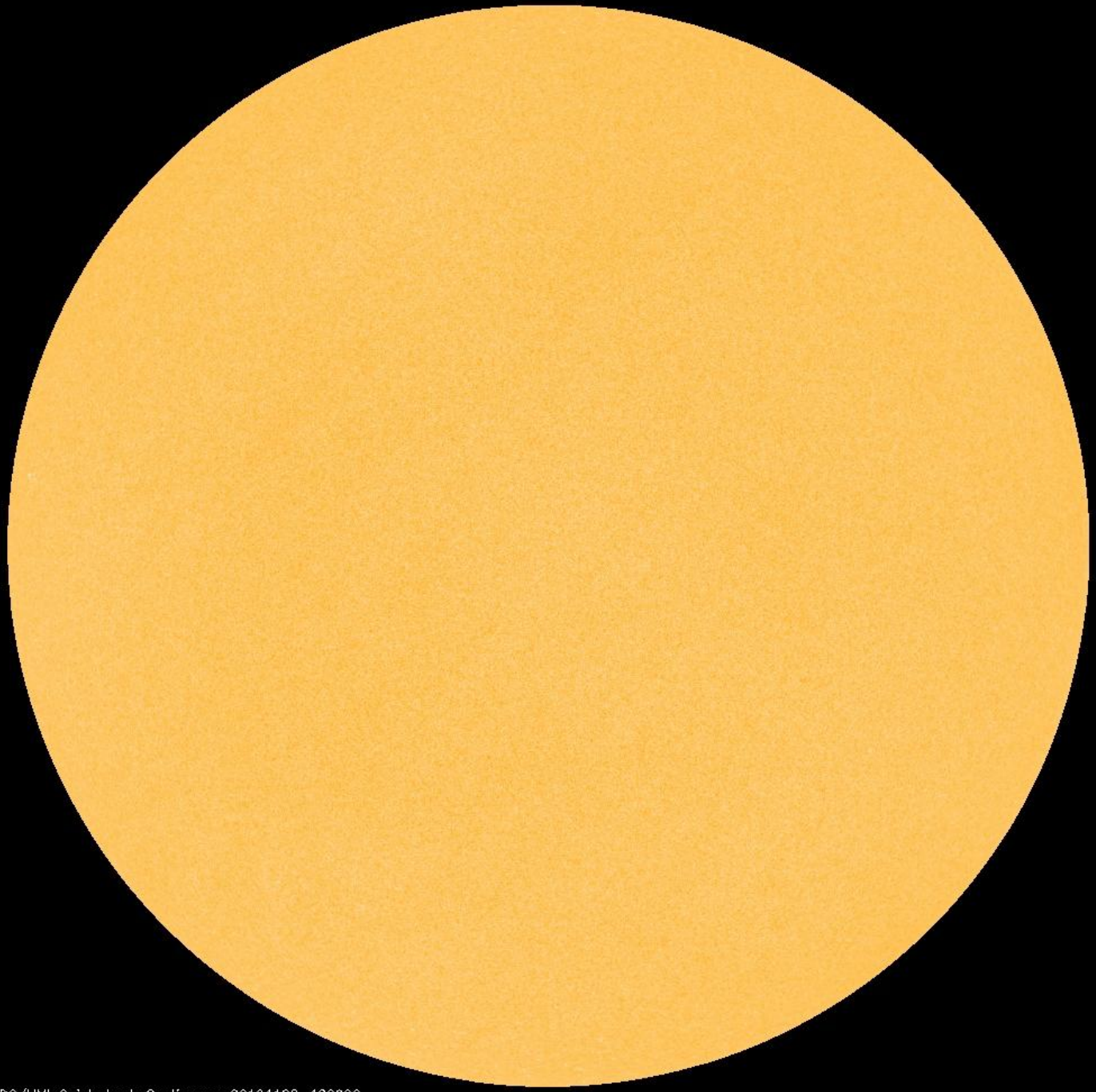
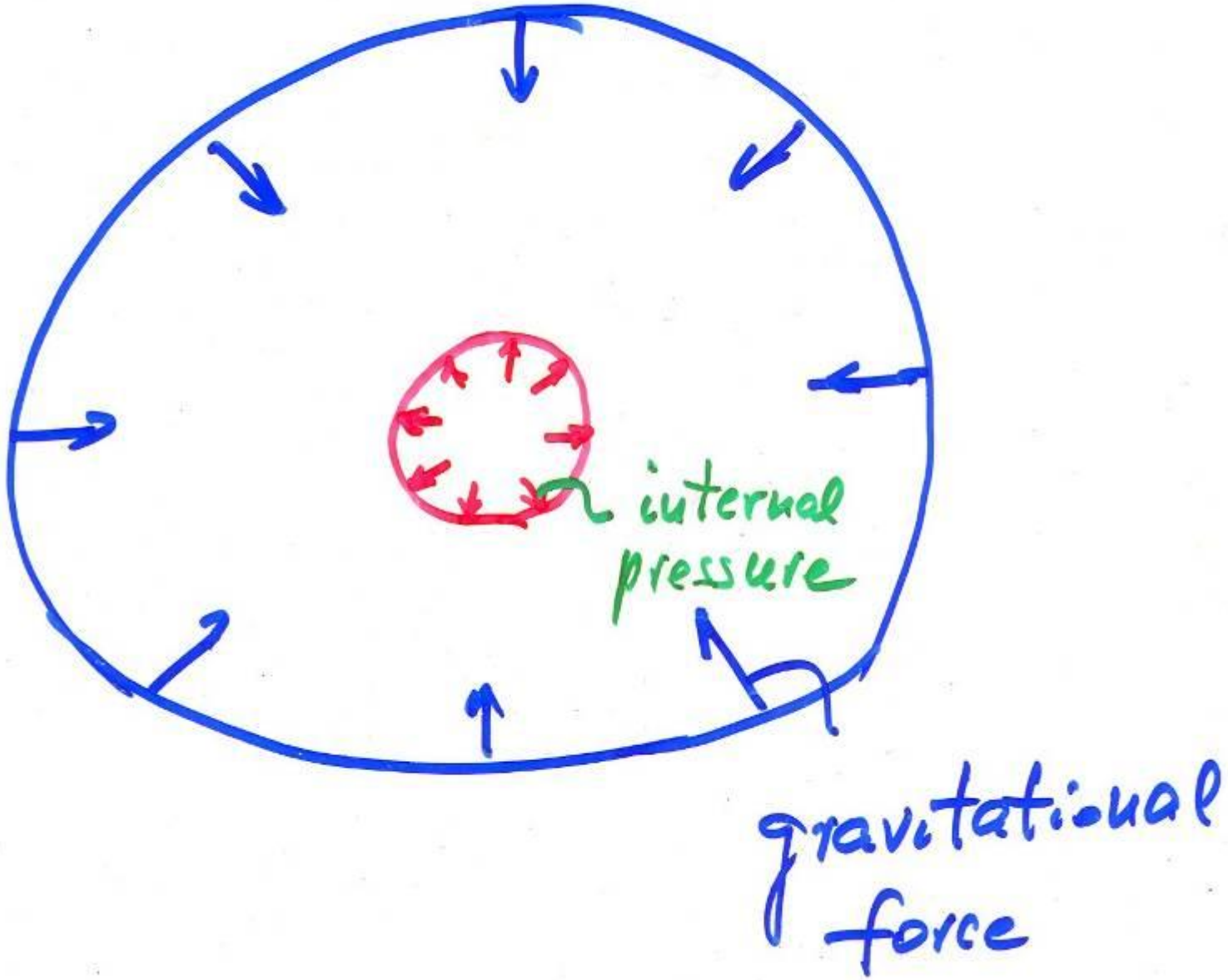
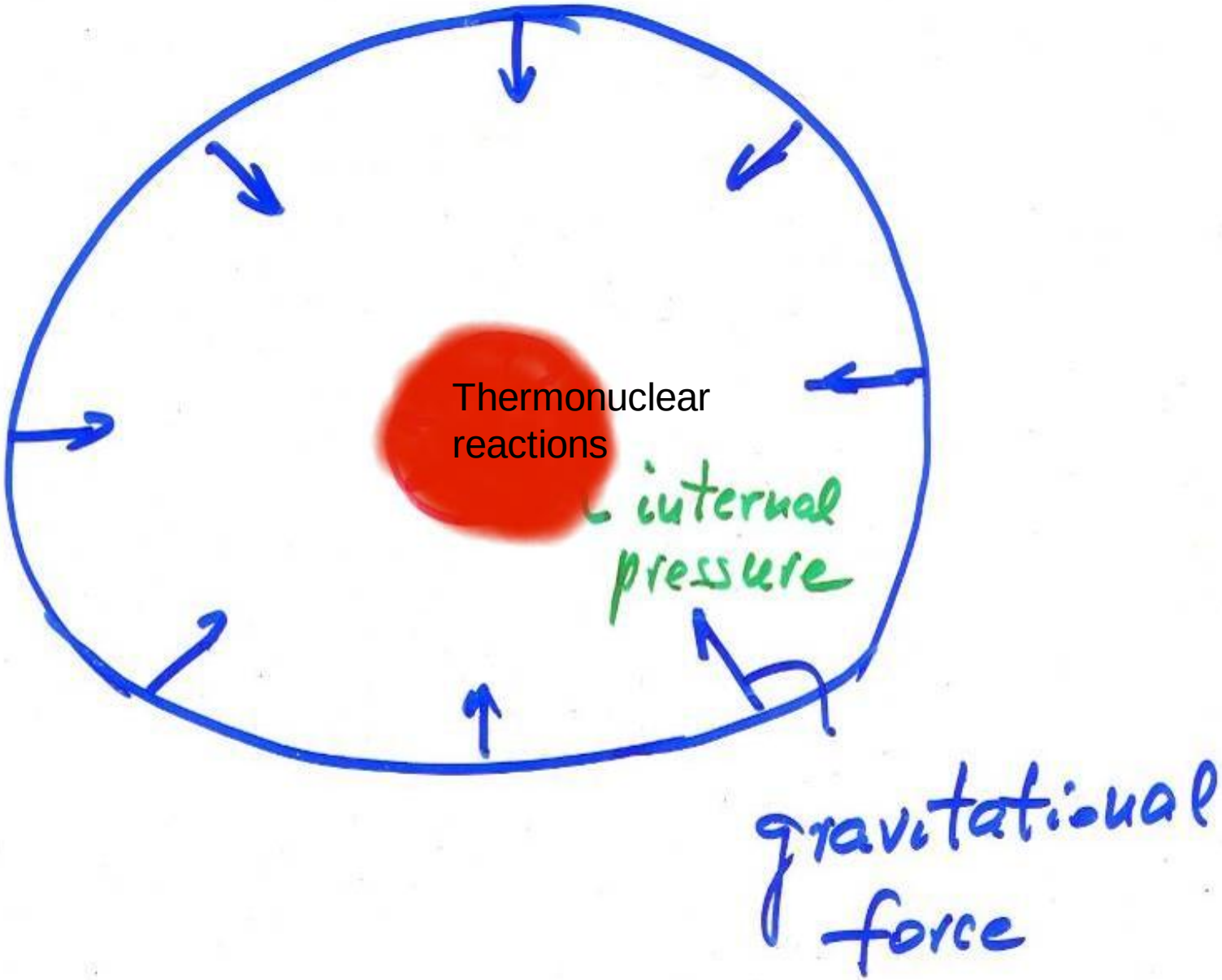
O przyszłości Wszechświata

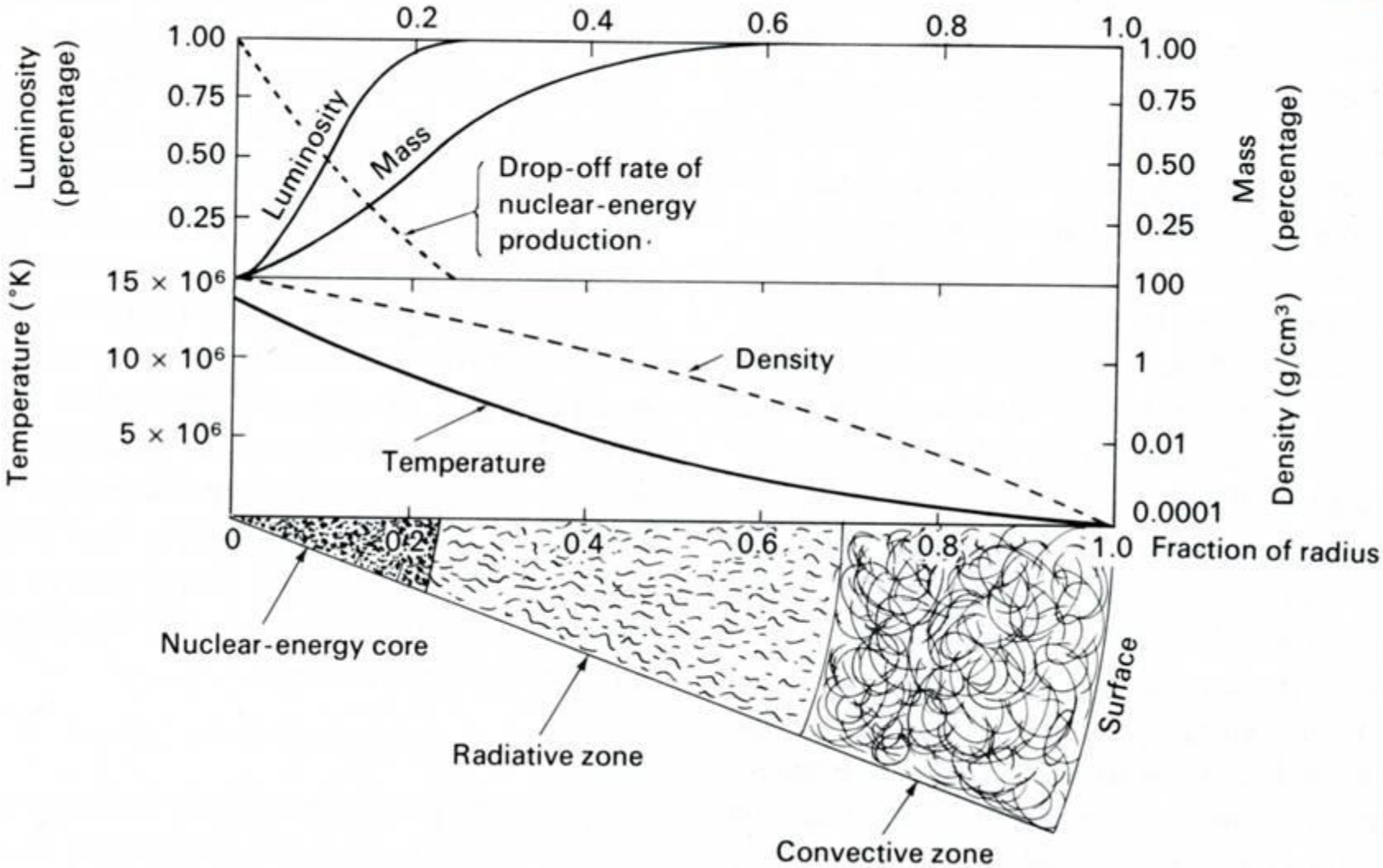
Marek Demiański
Instytut Fizyki Teoretycznej
Uniwersytet Warszawski


Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune


SDO/HMI Quick-Look Continuum: 20191128_120000

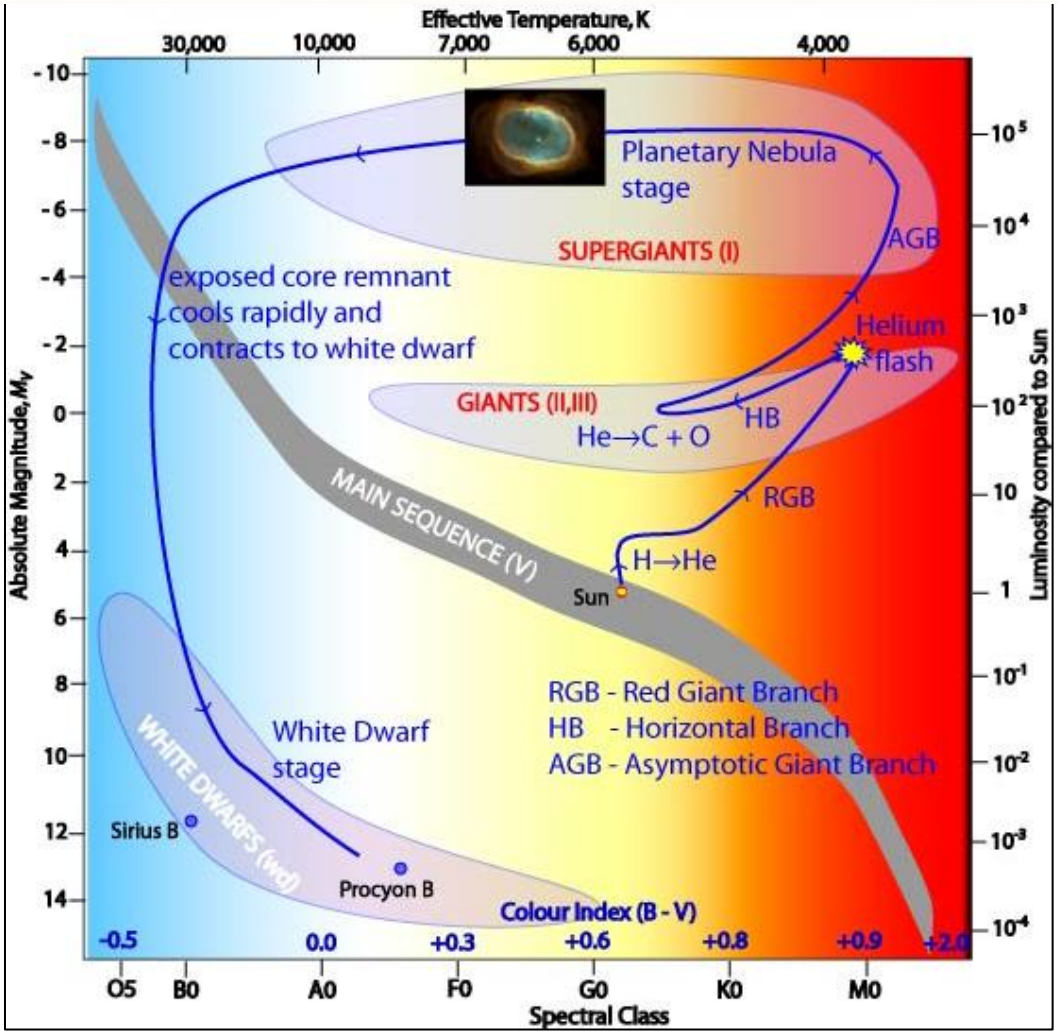

internal pressure
gravitational force


Thermonuclear reactions
internal pressure
gravitational force

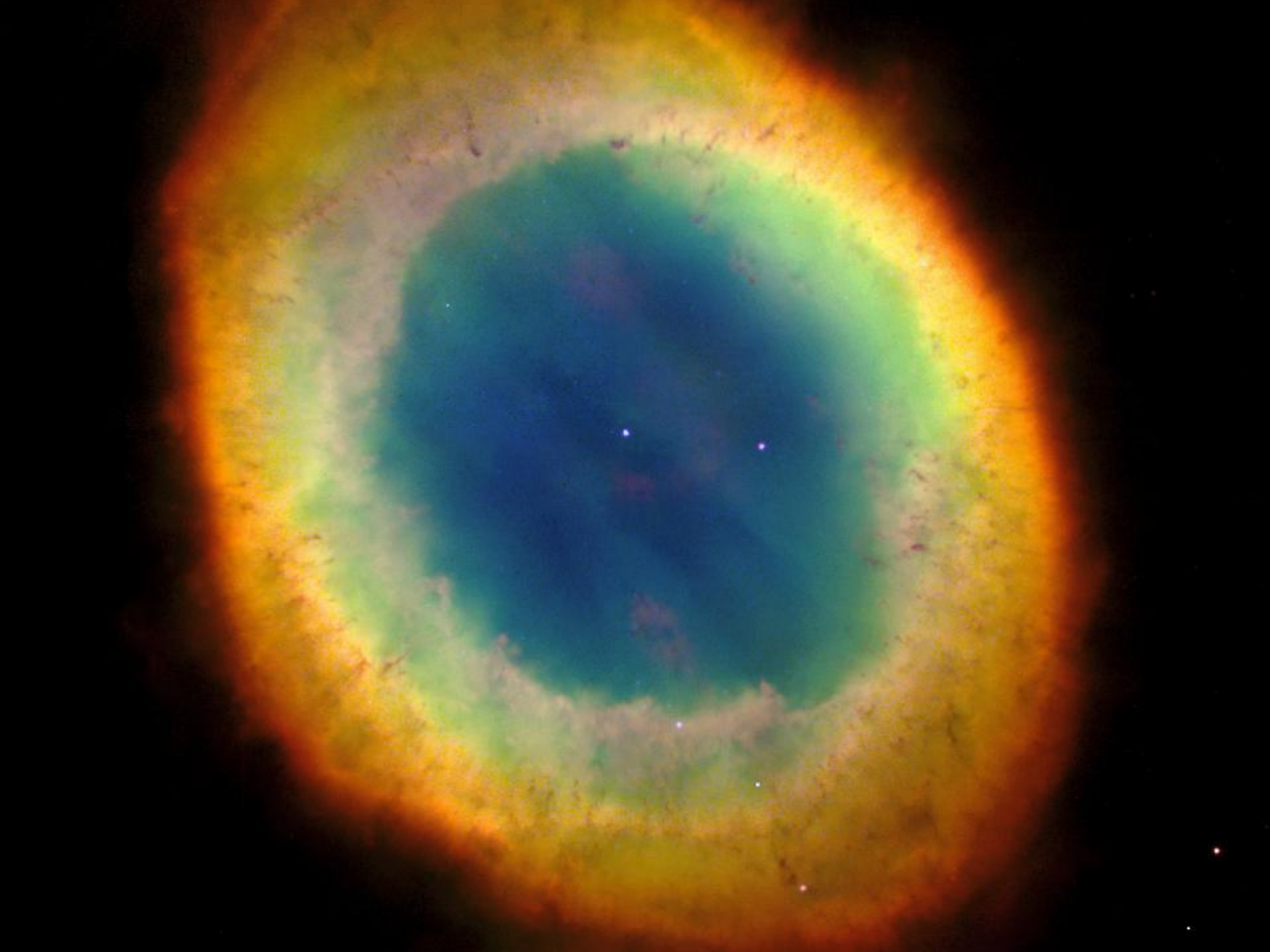

Luminosity (percentage)
Temperature (°K)
Mass (percentage)
Density (g/cm³)
Luminosity
Mass
Drop-off rate of nuclear-energy production
Density
Temperature
Fraction of radius
Nuclear-energy core
Radiative zone
Convective zone
Surface

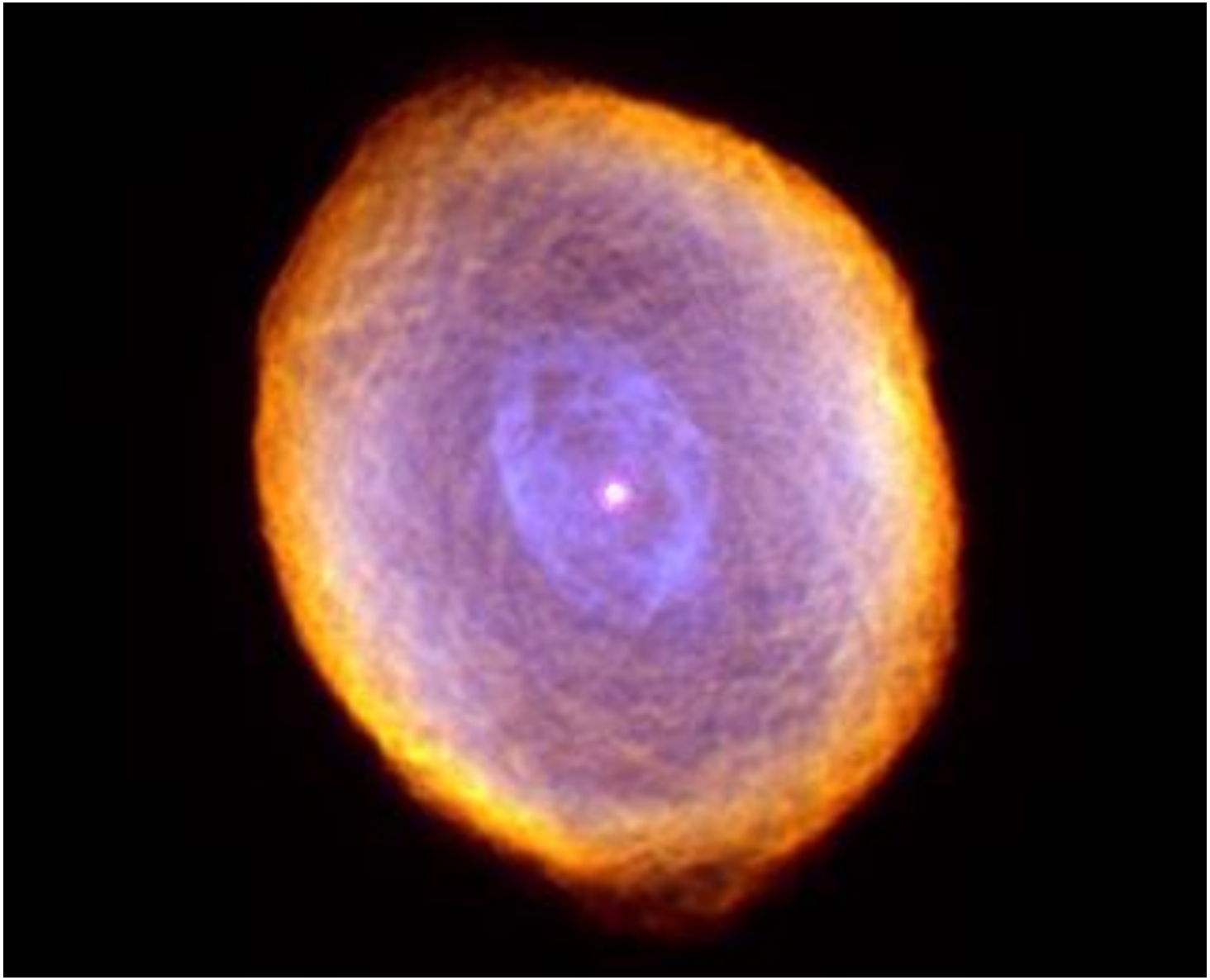
Summary: 1 $M_\odot$ Evolutionary Track

	~9 billion yrs	~1 billion yrs	~100 million yrs	~10,000 yrs	
Time spent as	Main sequence →	Red giant →	Yellow giant →	Planetary nebula →	White dwarf
Sun's age	4.5 billion yrs (now)	12.2 billion yrs	12.3 billion yrs	12.3305 billion yrs	12.3306 billion yrs



http://outreach.atnf.csiro.au/education/senior/astrophysics/images/stellarevolution/hrsunplannebwd.jpg

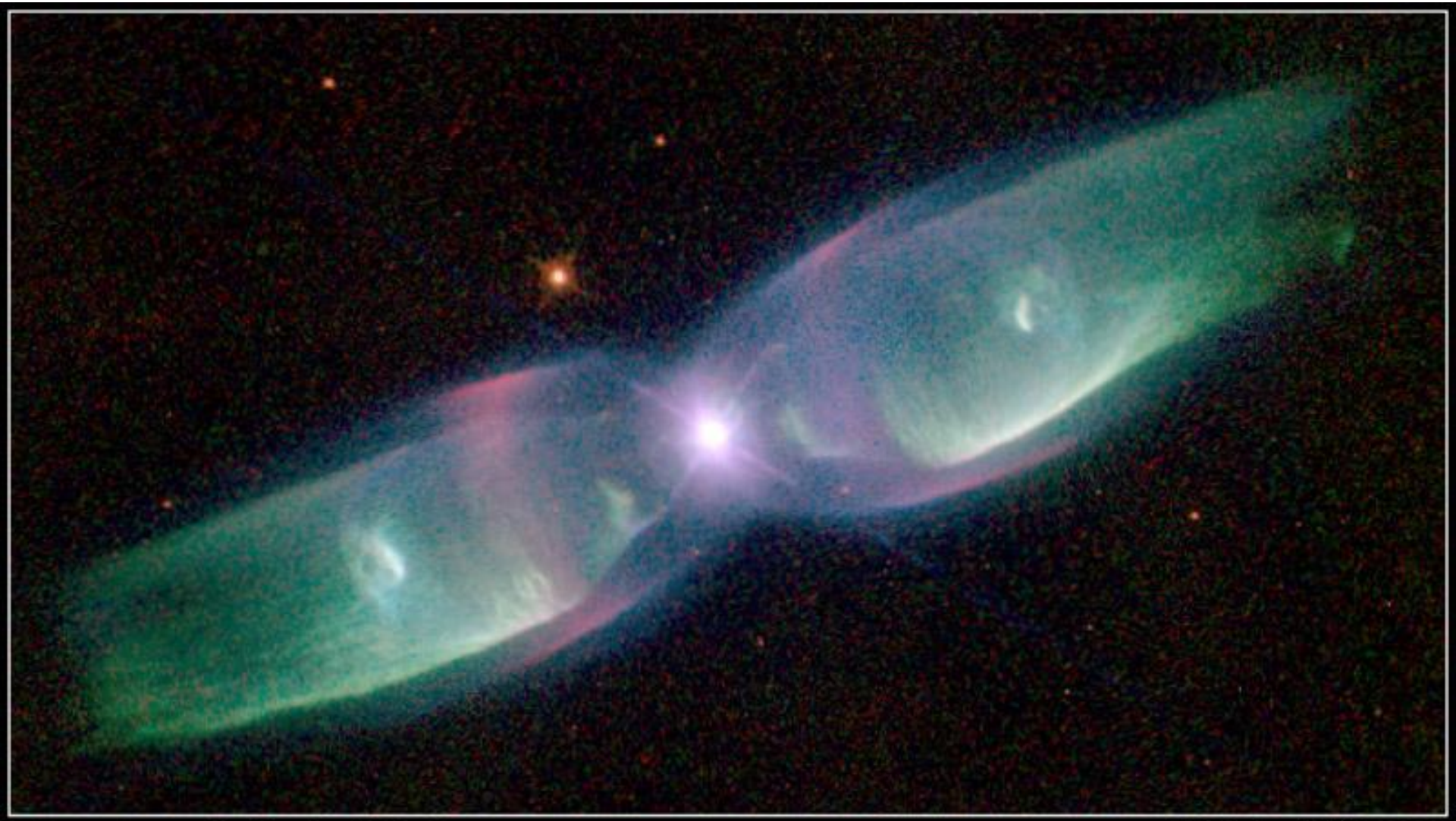




Henize 1357 • Stingray Nebula HST • WFPC2

PRC98-15 • ST ScI OPO • April 2, 1998

M. Bobrowsky (Orbital Sciences Corp.) and NASA

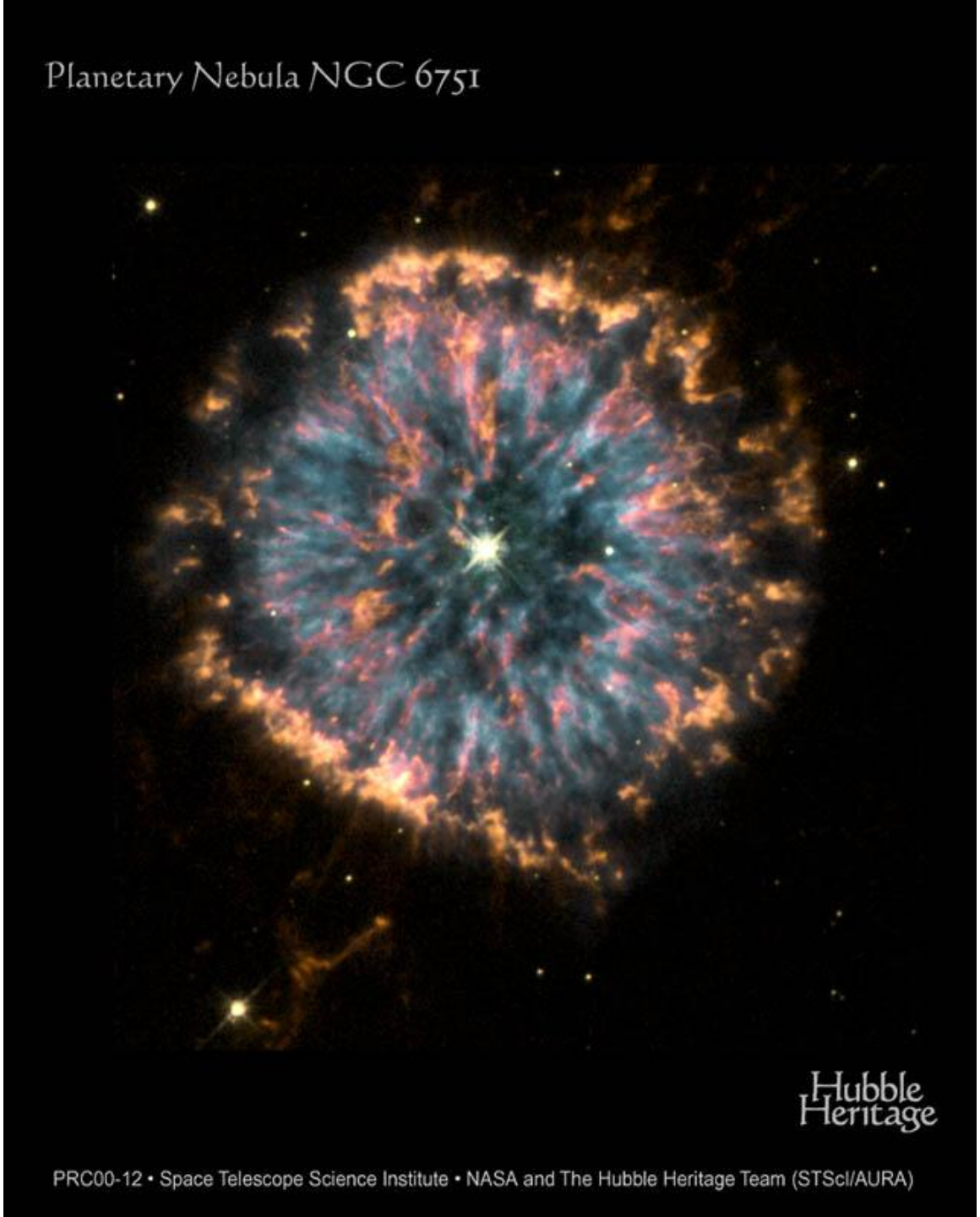


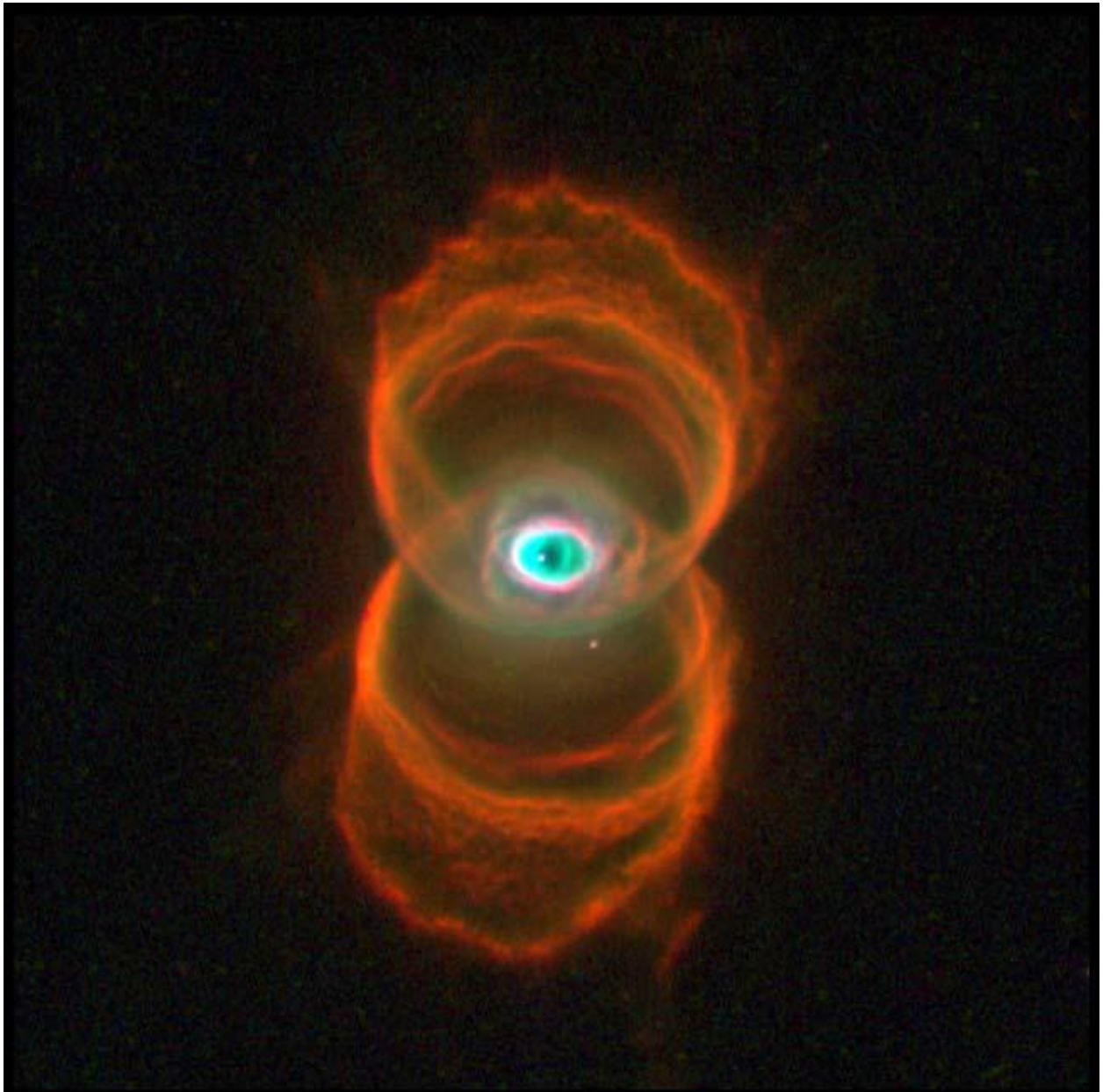
Planetary Nebula M2-9

HST • WFPC2

PRC97-38a • ST ScI OPO • December 17, 1997

B. Balick (University of Washington) and NASA

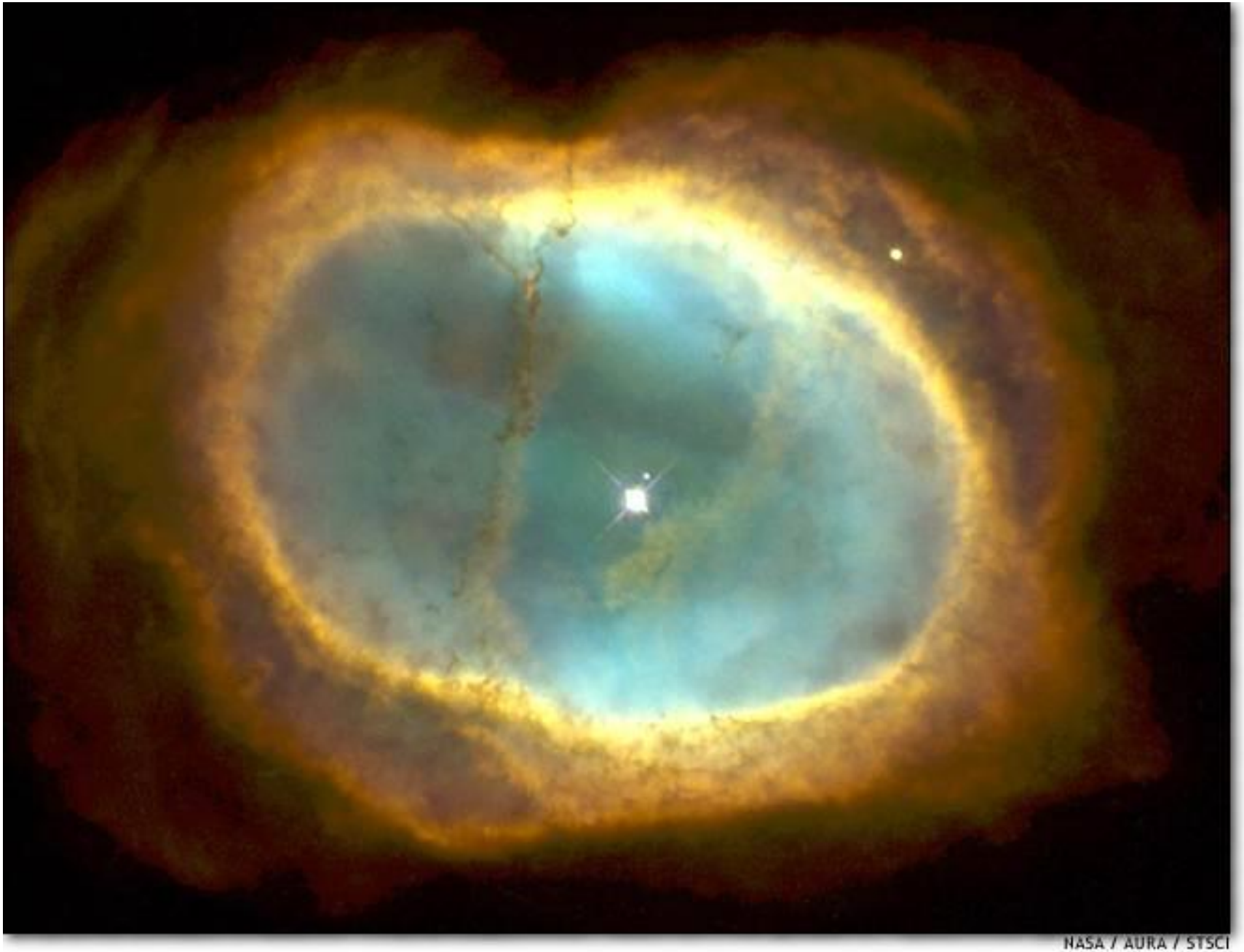

Planetary Nebula NGC 6751
Hubble Heritage
PRC00-12 • Space Telescope Science Institute • NASA and The Hubble Heritage Team (STScI/AURA)

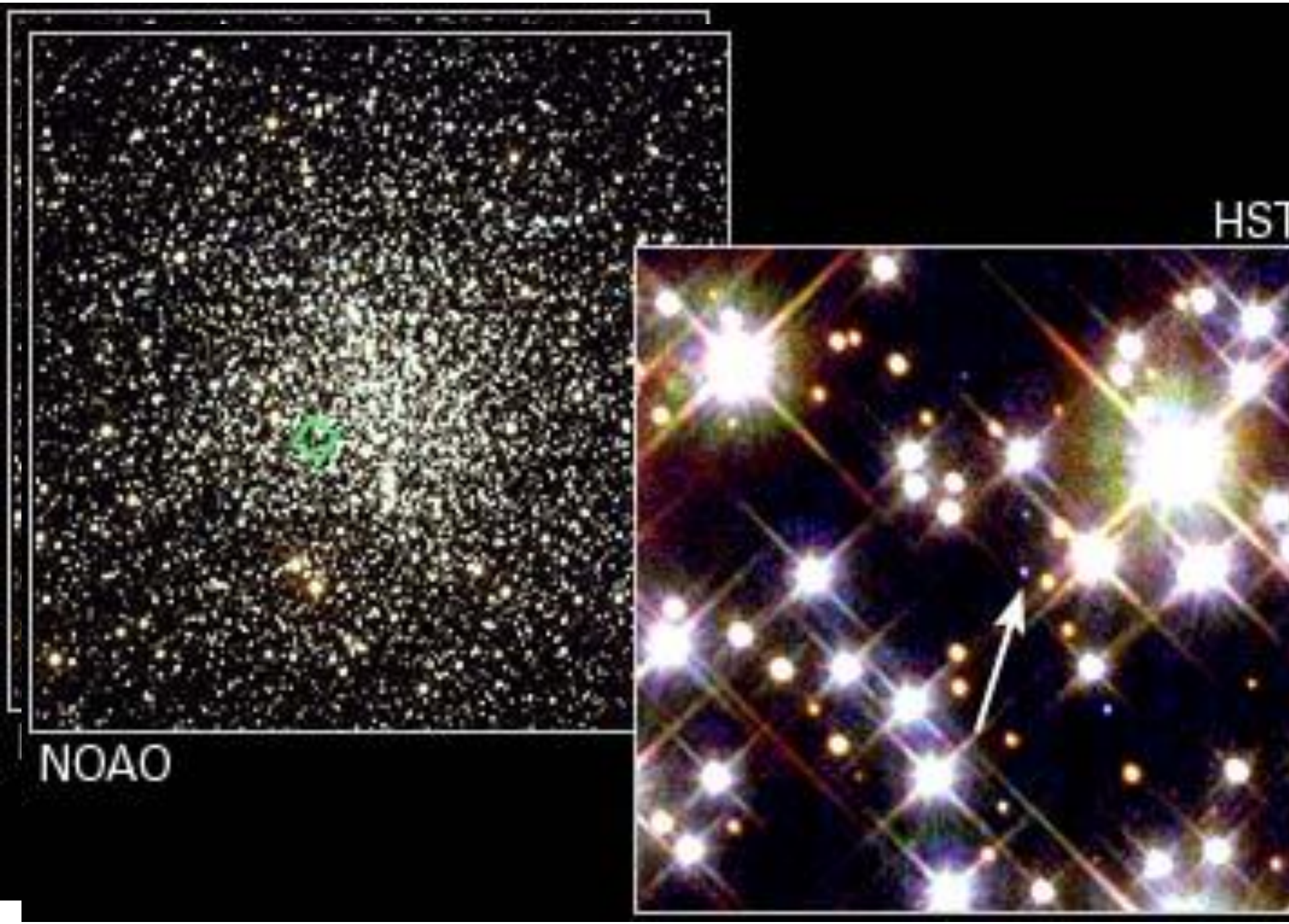


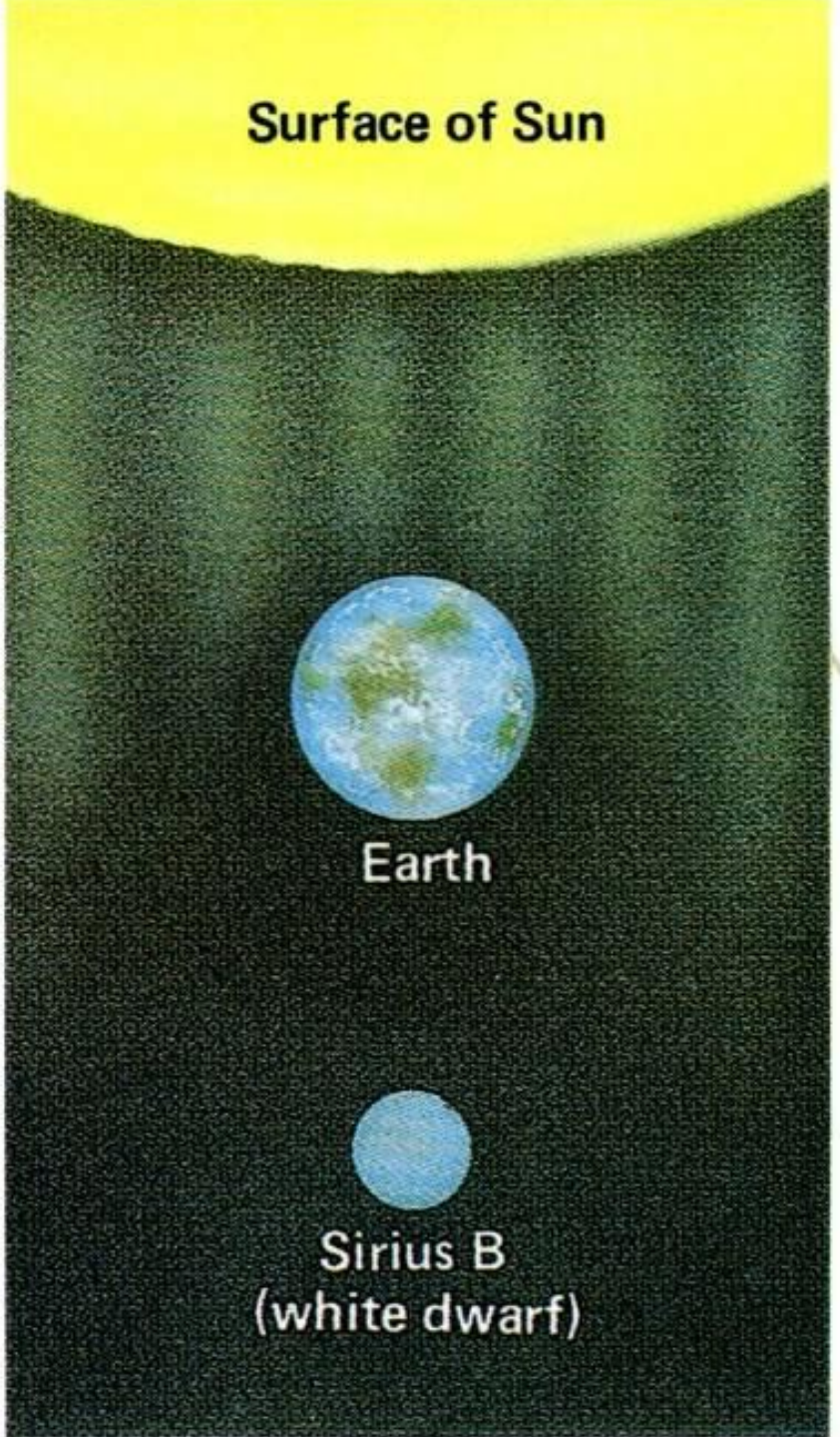
Hourglass Nebula · MyCn18 HST · WFPC2

PRC96-07 · ST ScI OPO · January 16, 1996

R. Sahai and J. Trauger (JPL), the WFPC2 Science Team and NASA


NASA / AURA / STSCI

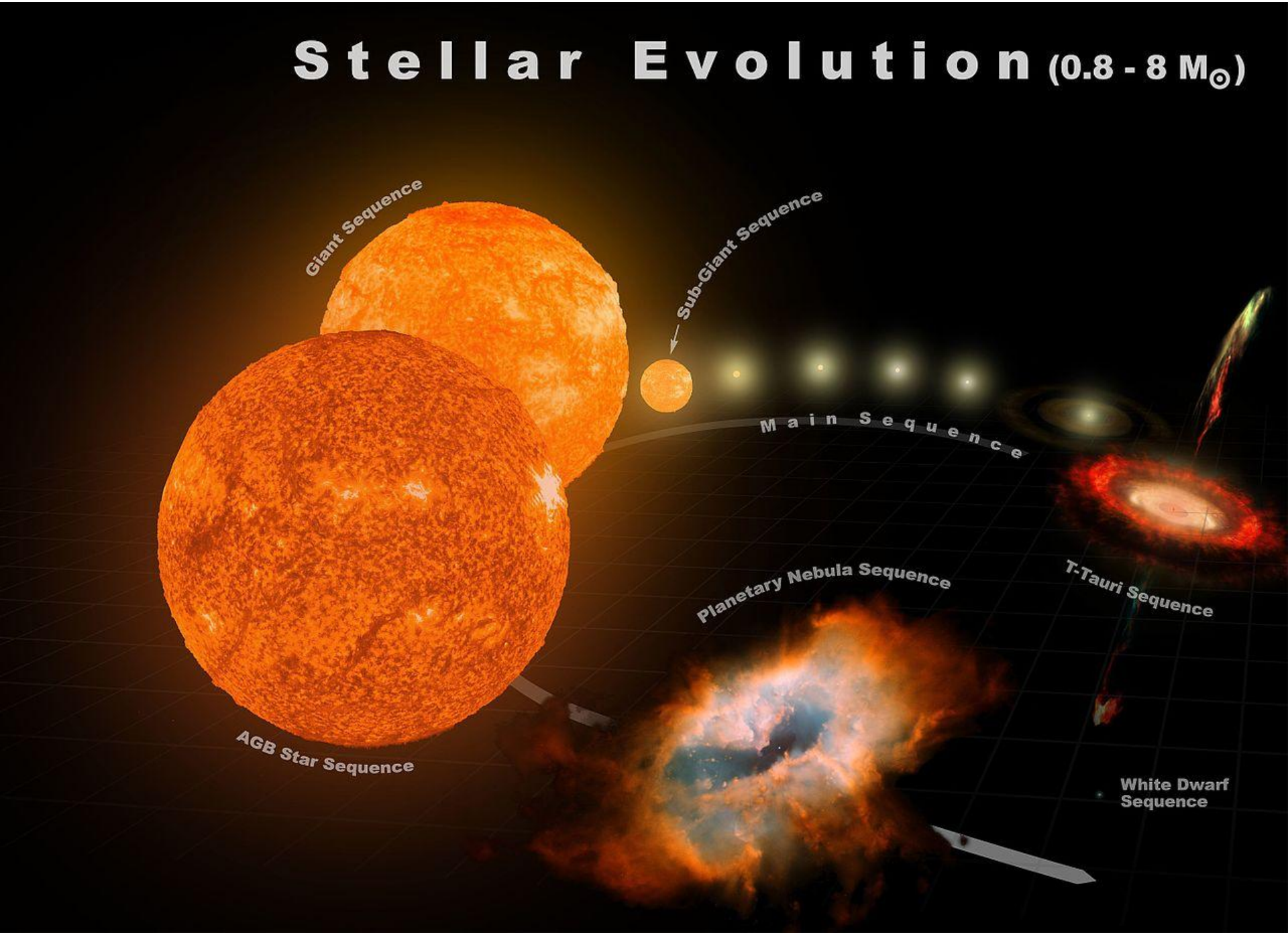

HST
NOAO


Surface of Sun
Earth
Sirius B
(white dwarf)

Białe karły

- Bardzo małe (R ~ 6000 km)
- Bardzo gorące (T ~10000 - 200000 K)
- Bardzo gęste ($\langle\rho\rangle \sim 10^9$ kg/m^3)
- Bez wewnętrznych źródeł energii !
- $M_{WD} \sim 0.6\ M_\odot$
- Skład He lub C,O
- $M_{max} \sim 1.4\ M_\odot$

Stellar Evolution (0.8 - 8 $M_\odot$)



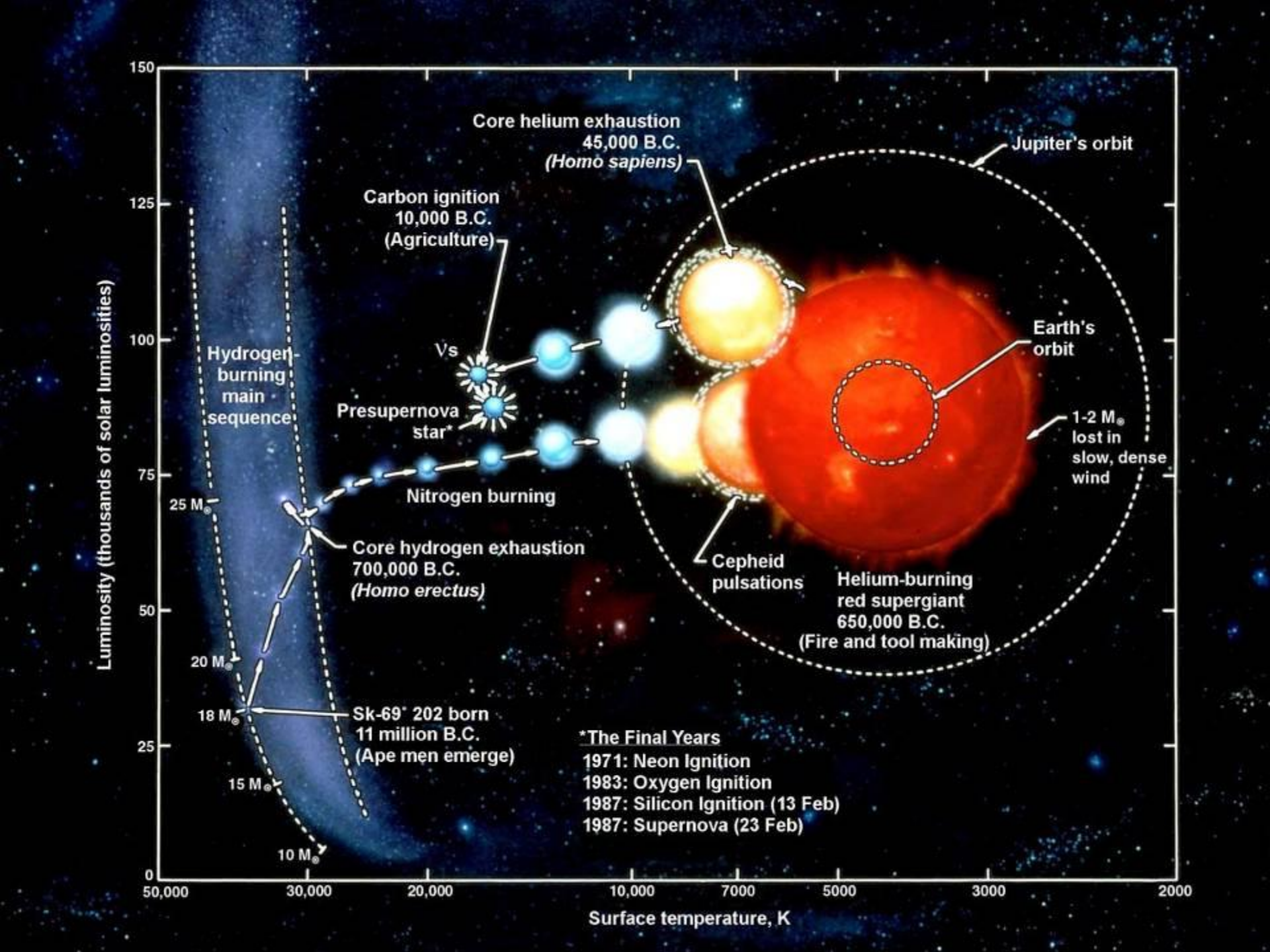

Core helium exhaustion
45,000 B.C.
(Homo sapiens)
Jupiter's orbit
Carbon ignition
10,000 B.C.
(Agriculture)
Vs
Earth's orbit
Hydrogen-burning main sequence
Presupernova star*
1-2 M⊙ lost in slow, dense wind
Nitrogen burning
25 M⊙
Core hydrogen exhaustion
700,000 B.C.
(Homo erectus)
Cepheid pulsations
Helium-burning red supergiant
650,000 B.C.
(Fire and tool making)
20 M⊙
18 M⊙
Sk-69° 202 born
11 million B.C.
(Ape men emerge)
15 M⊙
10 M⊙
*The Final Years
1971: Neon Ignition
1983: Oxygen Ignition
1987: Silicon Ignition (13 Feb)
1987: Supernova (23 Feb)
Luminosity (thousands of solar luminosities)
150
125
100
75
50
25
0
50,000
30,000
20,000
10,000
7000
5000
3000
2000
Surface temperature, K

Table 1.2
Properties of 3 Main Sequence Stars

Property	M8V	G2 V (sun)	O5V
Mass[1]	$M_\odot/10$	2.0×10^{30} kg	40 $M_\odot$
Radius[1]	$R_\odot/8$	7.0×10^{8} m	18 $R_\odot$
Luminosity[1]	$L_\odot 1300$	3.8×10^{26} W	5×10^{5} $L_\odot$
Lifetime on main sequence[2]	10^{13} y	10^{10} y	10^{6} y
Effective temperature T_{eff} (K)	2 700 K	5770 K	40 000 K
Absolute visual magnitude, M_V	+16	+4.83	–5.8
Absolute bolometric mag., M_{bol}[3]	~+12	+4.75	~–10
Apparent visual magnitude, m_V	–	–26.74	–
Color: frequency of peak power	IR	Yellow	UV
Color Index, $B–V \equiv m_B - m_V$	+1.8	+0.65	–0.35
Color Index, $U–B$	–	+0.13	–1.15

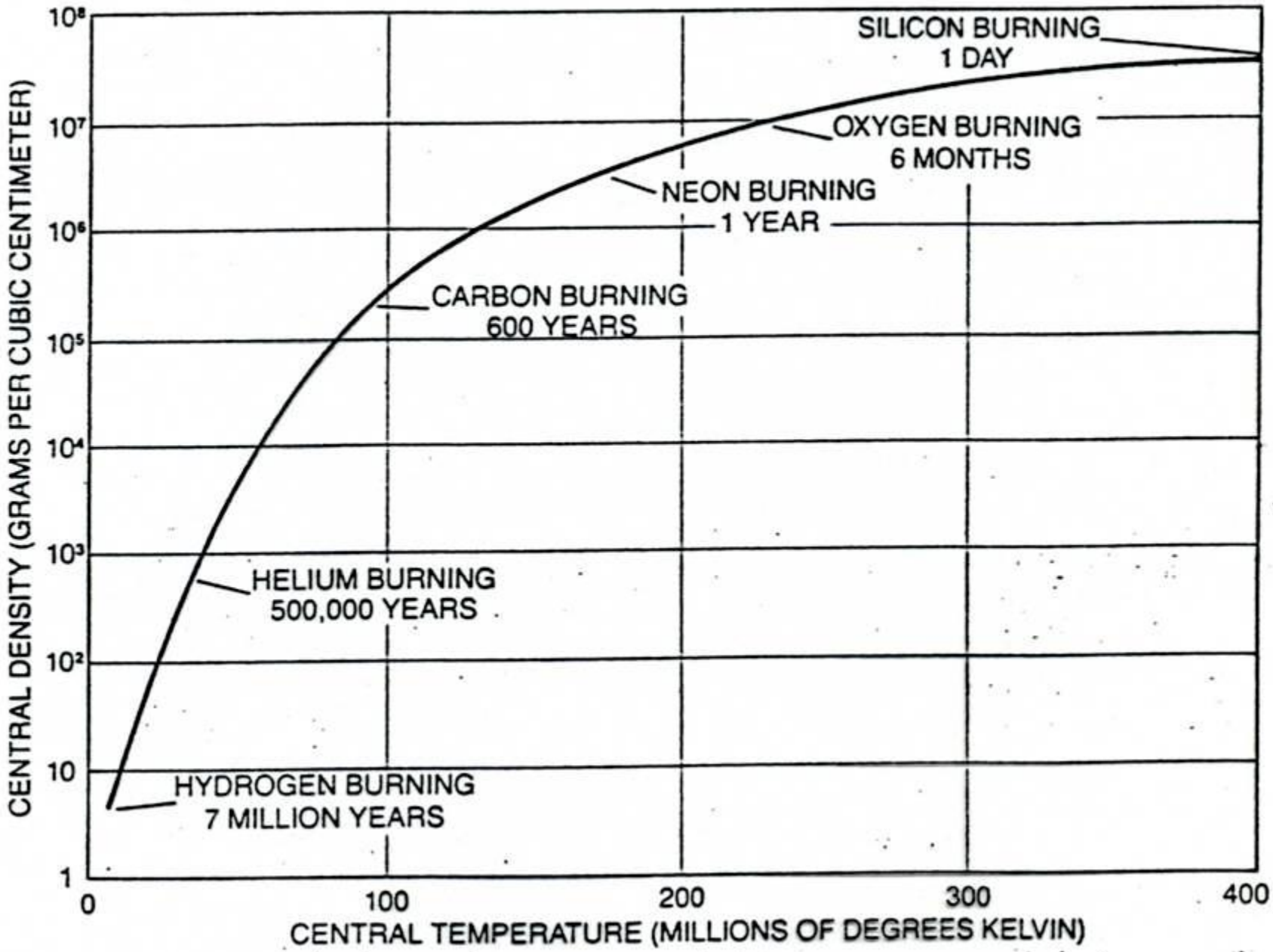
[1] The symbols $M_\odot$, $R_\odot$, and $L_\odot$ are the solar values.

[2] Time during the stable hydrogen-burning phase of the star's life.

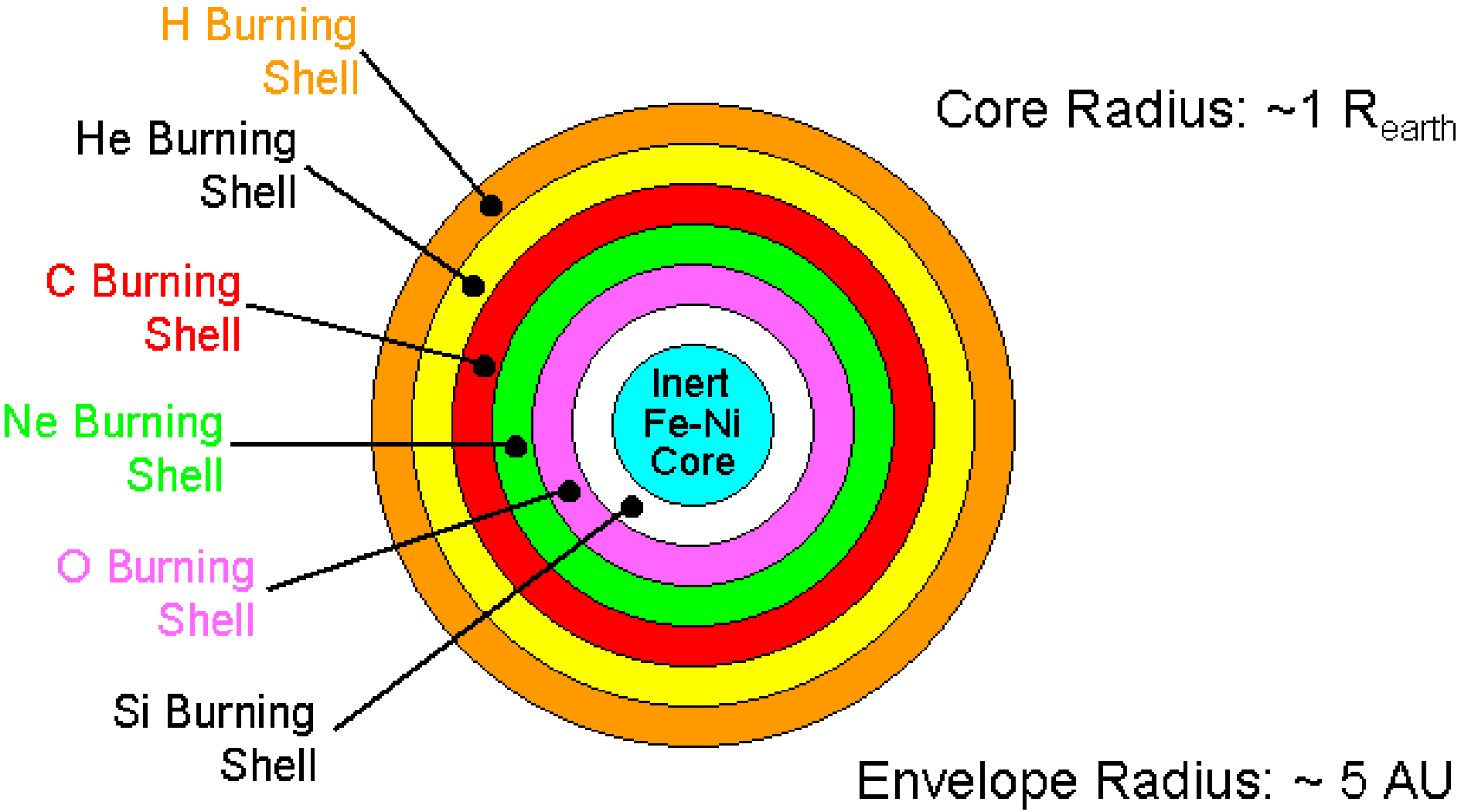
[3] The luminosity of a $M_{bol} = 0$ star is 3.0×10^{28} W.

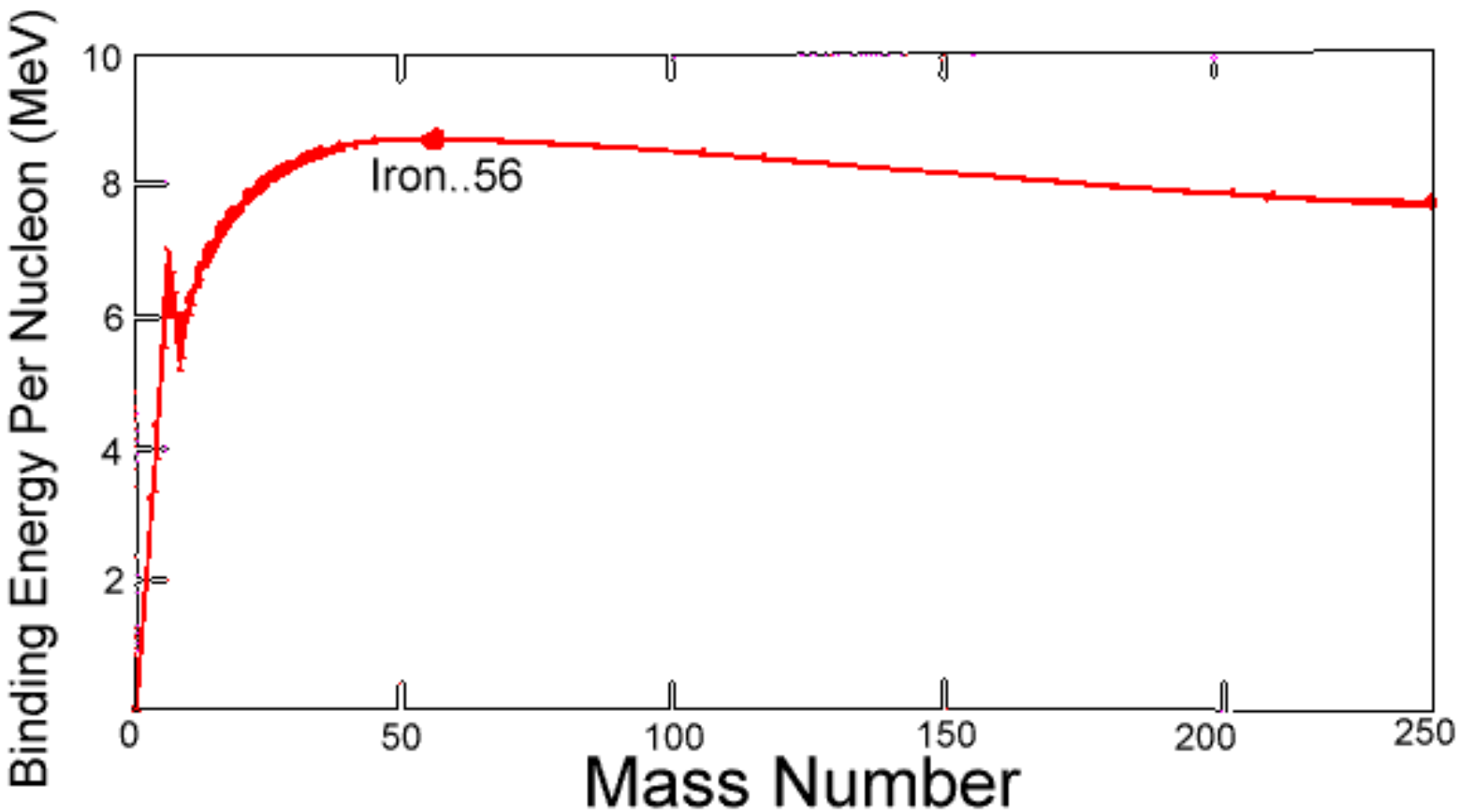
TABLE 16–3 ***Stages of Thermonuclear Energy Generation in Stars***

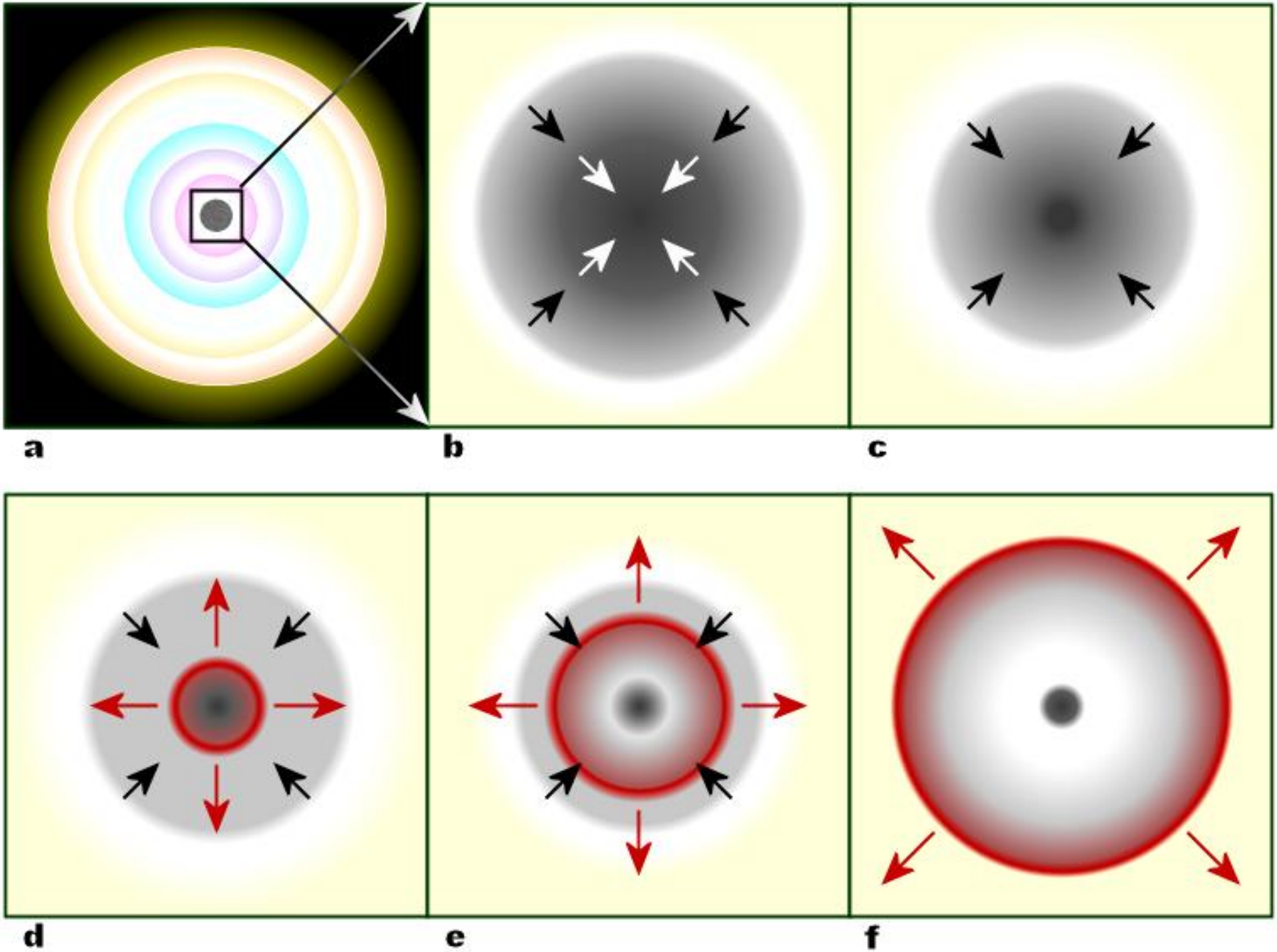
Process	Fuel	Major Products	Approximate Temperature (K)	Approximate Minimum Mass (solar masses)
Hydrogen burning	Hydrogen	Helium	$1–3 \times 10^7$	0.1
Helium burning	Helium	Carbon, Oxygen	2×10^8	1
Carbon burning	Carbon	Oxygen, Neon, Sodium, Magnesium	8×10^8	1.4
Neon burning	Neon	Oxygen, Magnesium	1.5×10^9	5
Oxygen burning	Oxygen	Magnesium to sulfur	2×10^9	10
Silicon burning	Magnesium to sulfur	Elements near iron	3×10^9	20

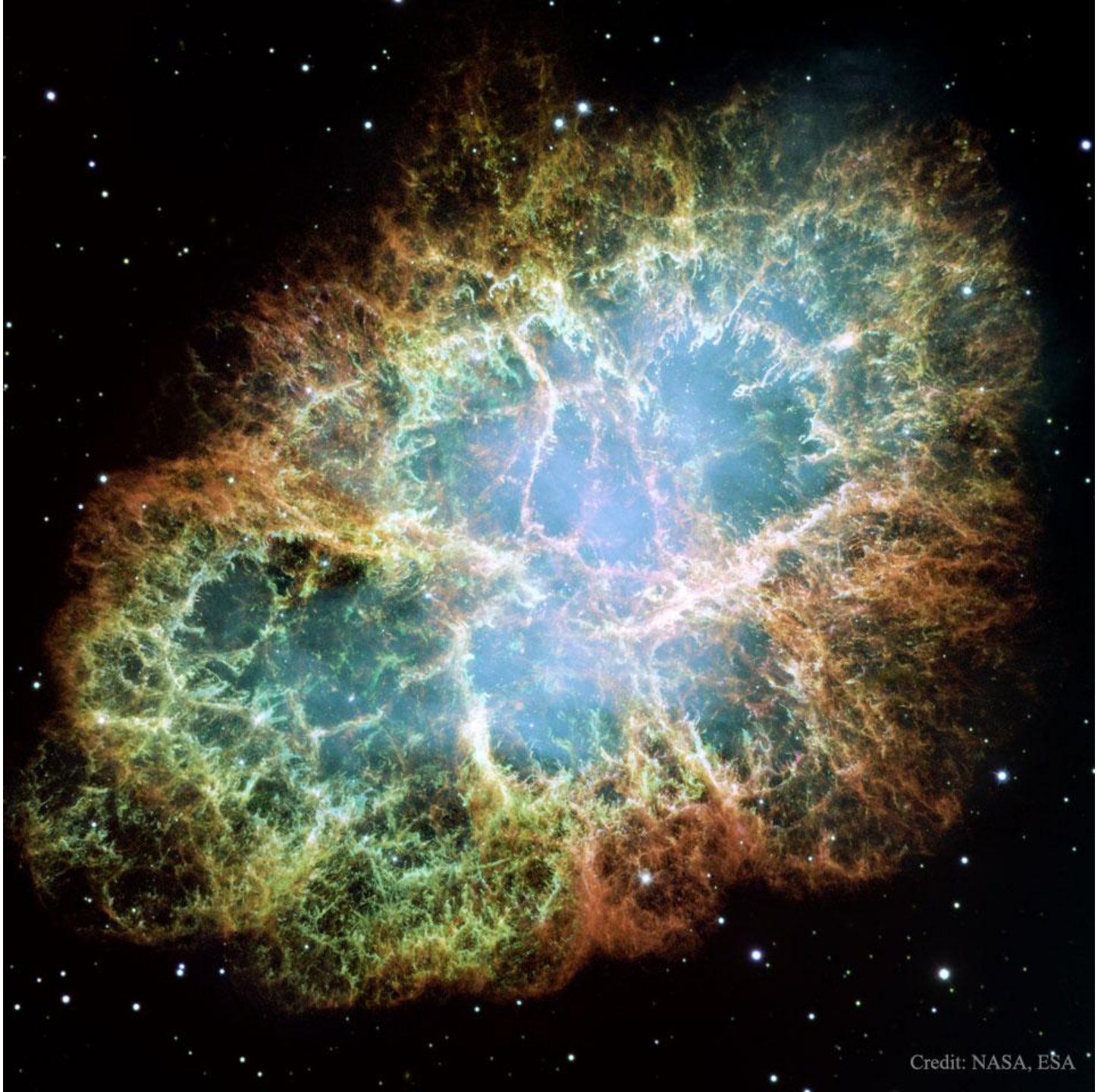


$M_{in} \sim 25\ M_{\odot}$


H Burning Shell
He Burning Shell
C Burning Shell
Ne Burning Shell
O Burning Shell
Si Burning Shell
Inert Fe-Ni Core
Core Radius: ~1 R_{earth}
Envelope Radius: ~ 5 AU

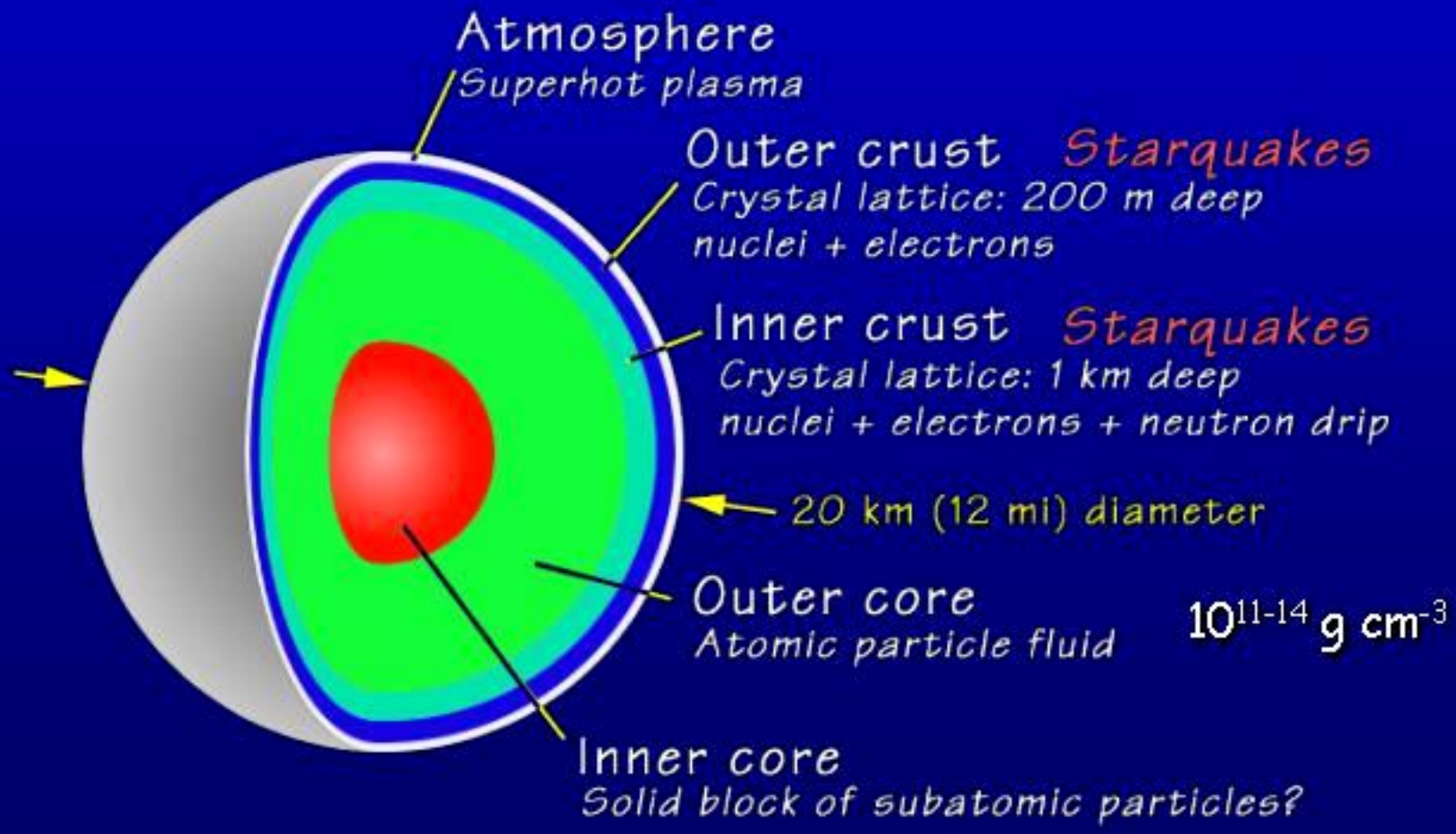

Binding Energy Per Nucleon (MeV)
10
8
6
4
2
Iron..56
0
50
100
150
200
250
Mass Number


a
b
c
d
e
f


Credit: NASA, ESA

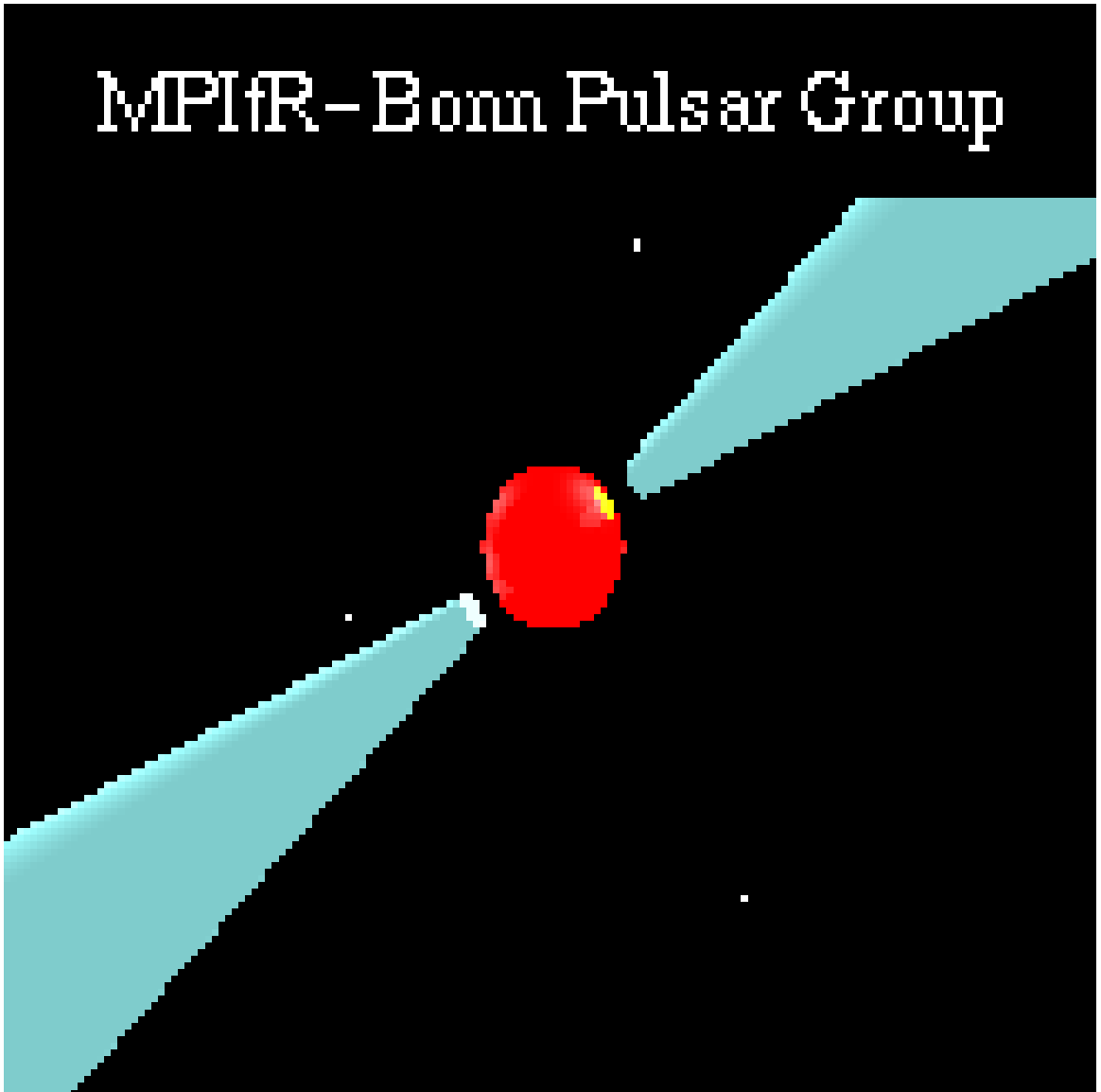
Size and Structure

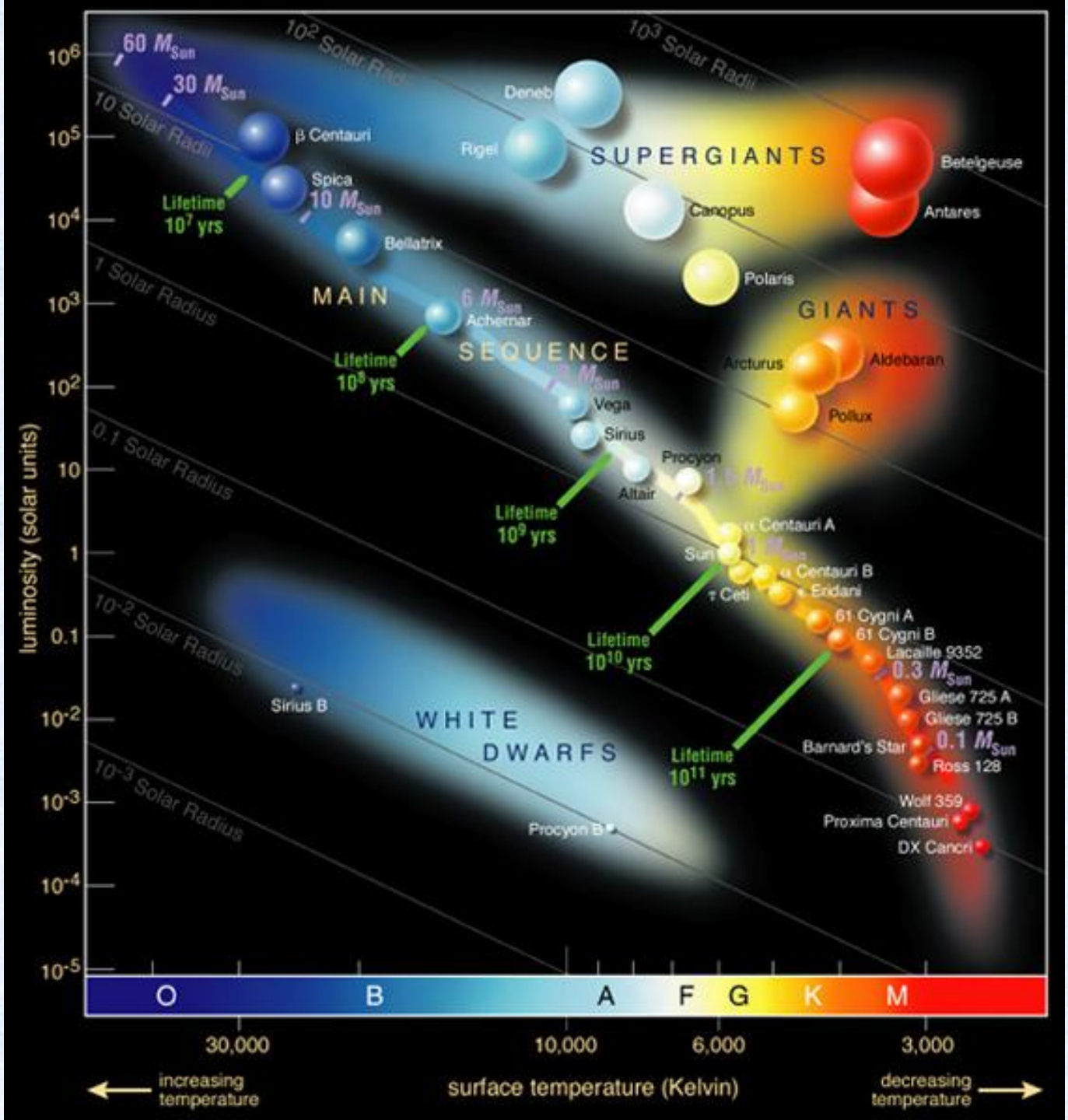
- Very dependent on Equation-of-State (EOS)!
- Current research suggests:

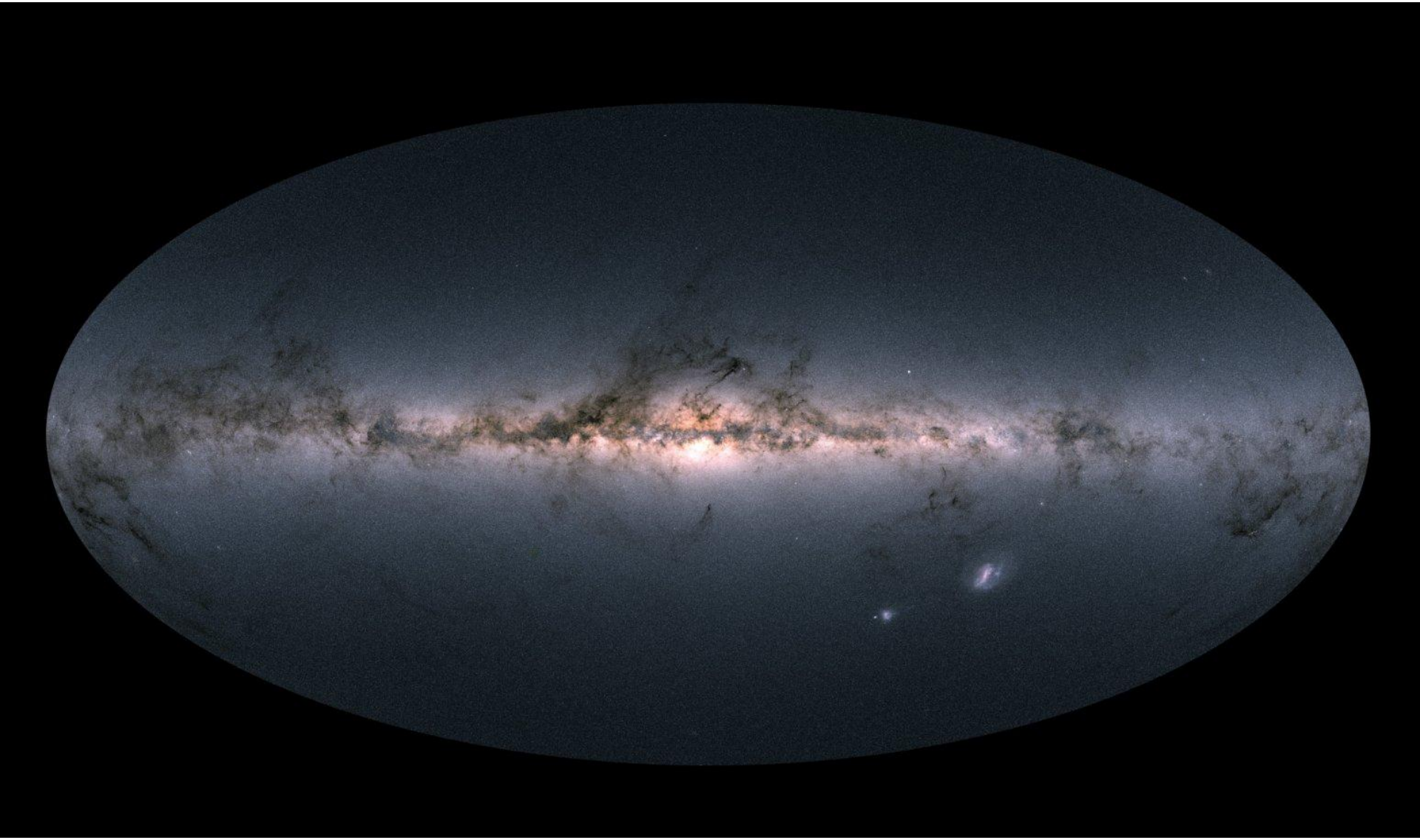


Silne pole magnetyczne

B ~ $10^{12}\ G$


MPIfR–Bonn Pulsar Group


luminosity (solar units)
surface temperature (Kelvin)
increasing temperature
decreasing temperature
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
SUPERGIANTS
GIANTS
MAIN
SEQUENCE
WHITE
DWARFS
10² Solar Radii
10³ Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10⁻² Solar Radius
10⁻³ Solar Radius
60 M_Sun
30 M_Sun
10 M_Sun
6 M_Sun
3 M_Sun
1.5 M_Sun
1 M_Sun
0.3 M_Sun
0.1 M_Sun
Lifetime 10⁷ yrs
Lifetime 10⁸ yrs
Lifetime 10⁹ yrs
Lifetime 10¹⁰ yrs
Lifetime 10¹¹ yrs
Deneb
Rigel
Canopus
Polaris
Betelgeuse
Antares
β Centauri
Spica
Bellatrix
Achernar
Arcturus
Aldebaran
Pollux
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B



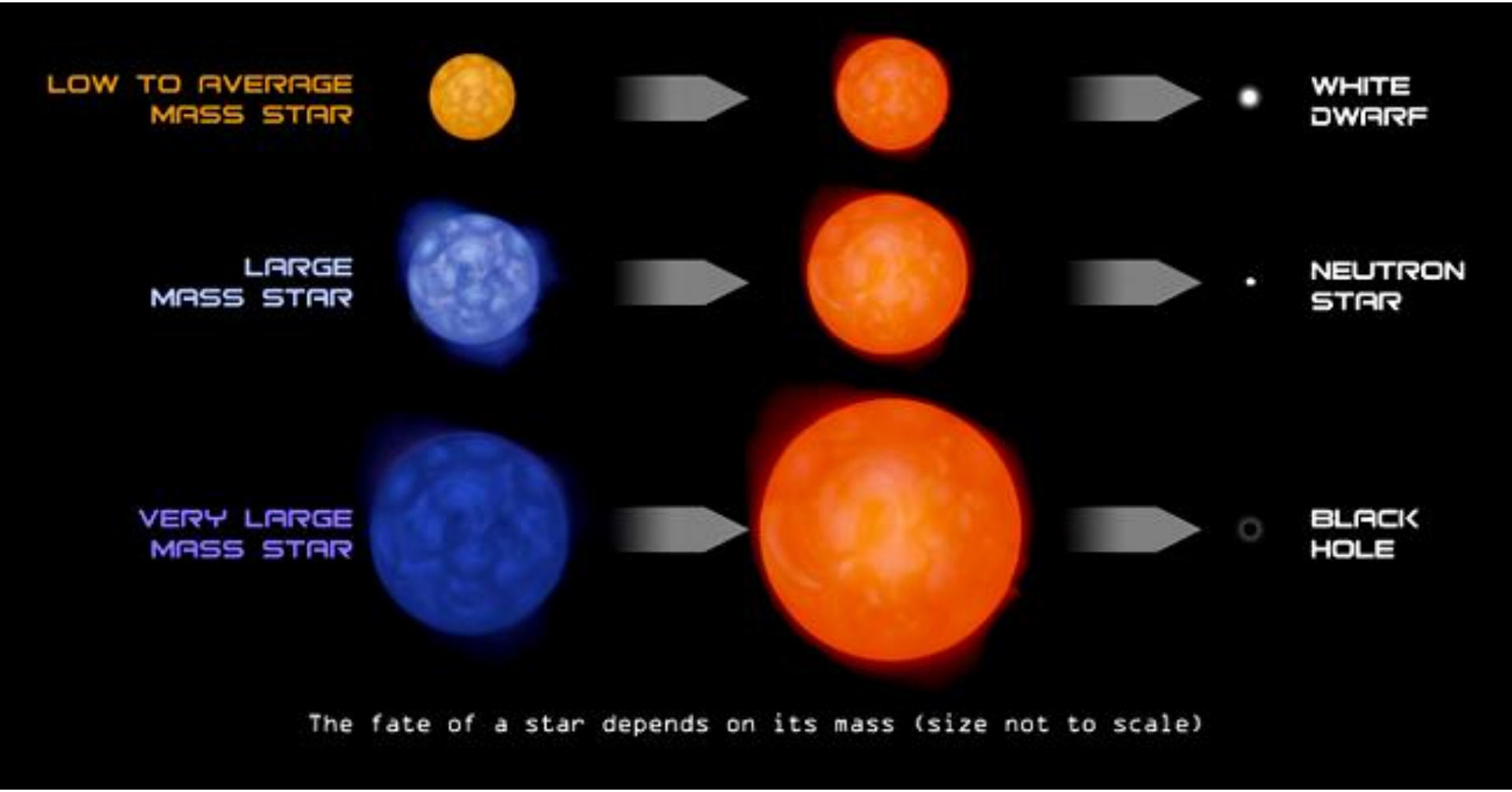
Ostatnie fazy ewolucji gwiazd
(i co po nich zostaje)

$0.085 \lesssim \frac{M_{in}}{M_\odot} \lesssim (8-12)$ $\longrightarrow$ biały karzeł
$M < 1.4 M_\odot$ granica Chandrasekhara

$\dashrightarrow$ mgławica planetarna

$(8-12) \lesssim \frac{M_{in}}{M_\odot} <\sim 20$ $\xrightarrow[\text{wybuch supernowej}]{}$ gwiazda neutronowa
$M \lesssim 3 M_\odot$

$\frac{M_{in}}{M_\odot} >\sim 20$ $\xrightarrow[\text{wybuch supernowej}]{}$ czarna dziura
$M > 3 M_\odot$

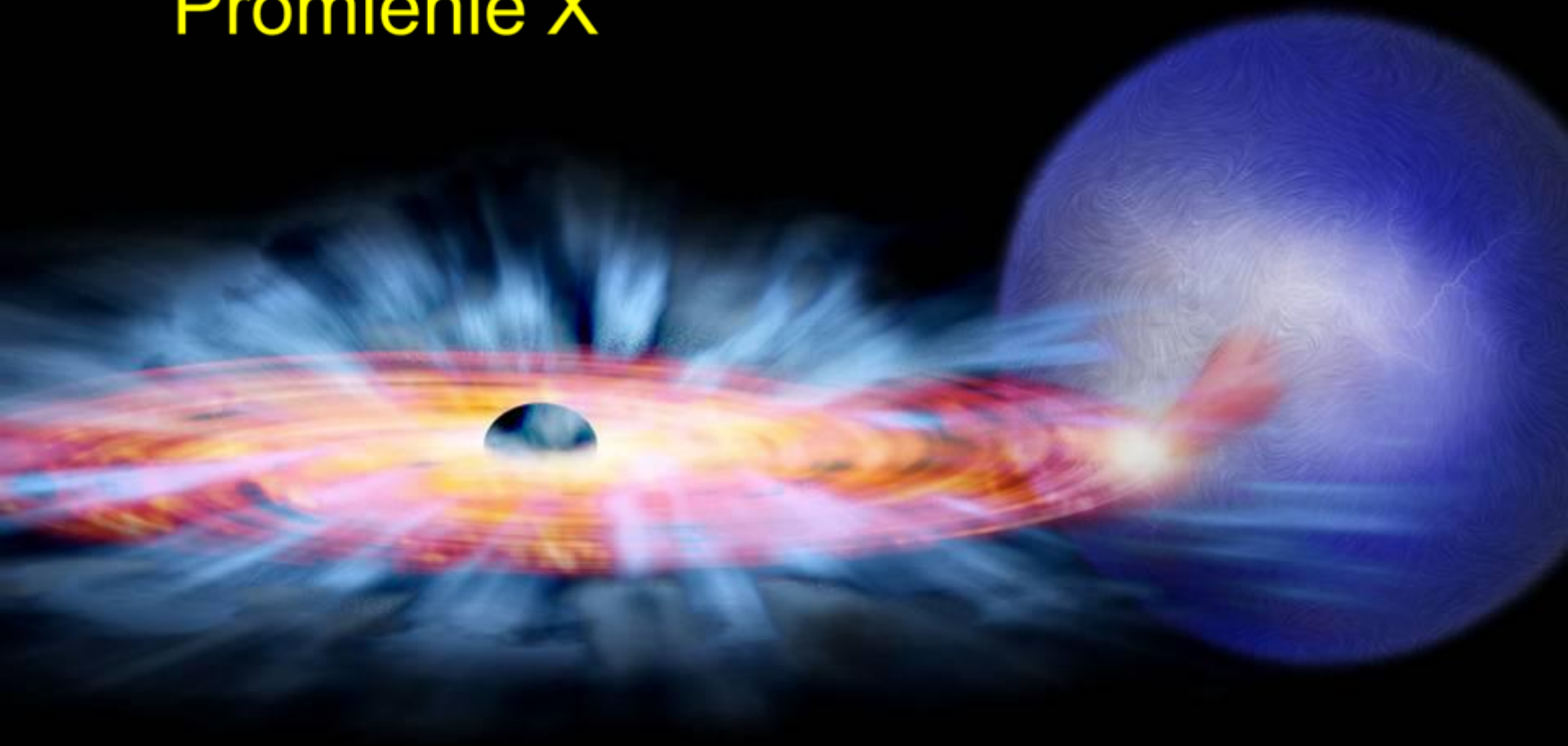

LOW TO AVERAGE MASS STAR
WHITE DWARF
LARGE MASS STAR
NEUTRON STAR
VERY LARGE MASS STAR
BLACK HOLE
The fate of a star depends on its mass (size not to scale)

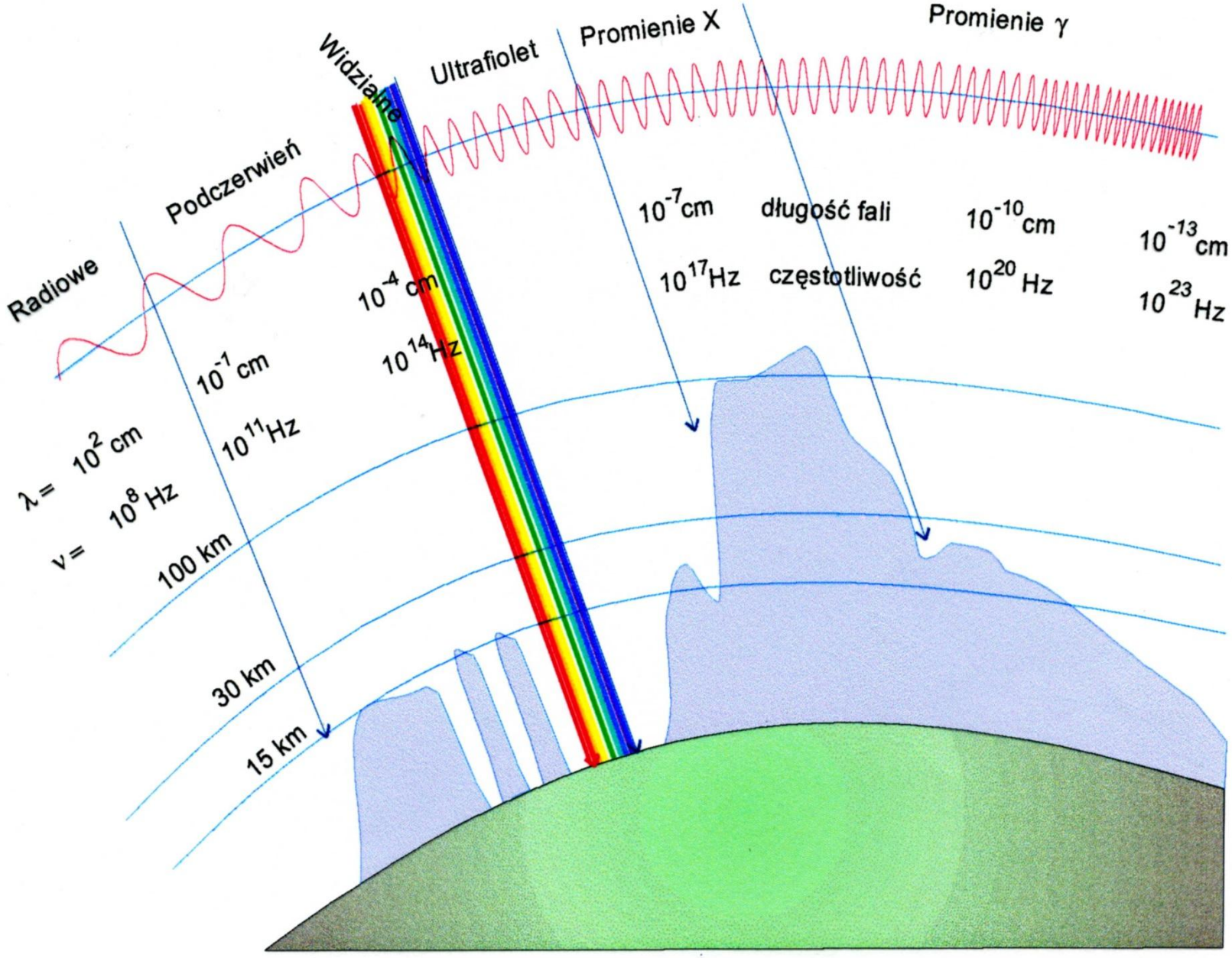
Czarne dziury

- Masa > 3 $M_\odot$
- Ładunek elektryczny ~ 0
- Okres rotacji < 0.001 s (?)
- Nie emitują promieniowania !
- Silne pole grawitacyjne

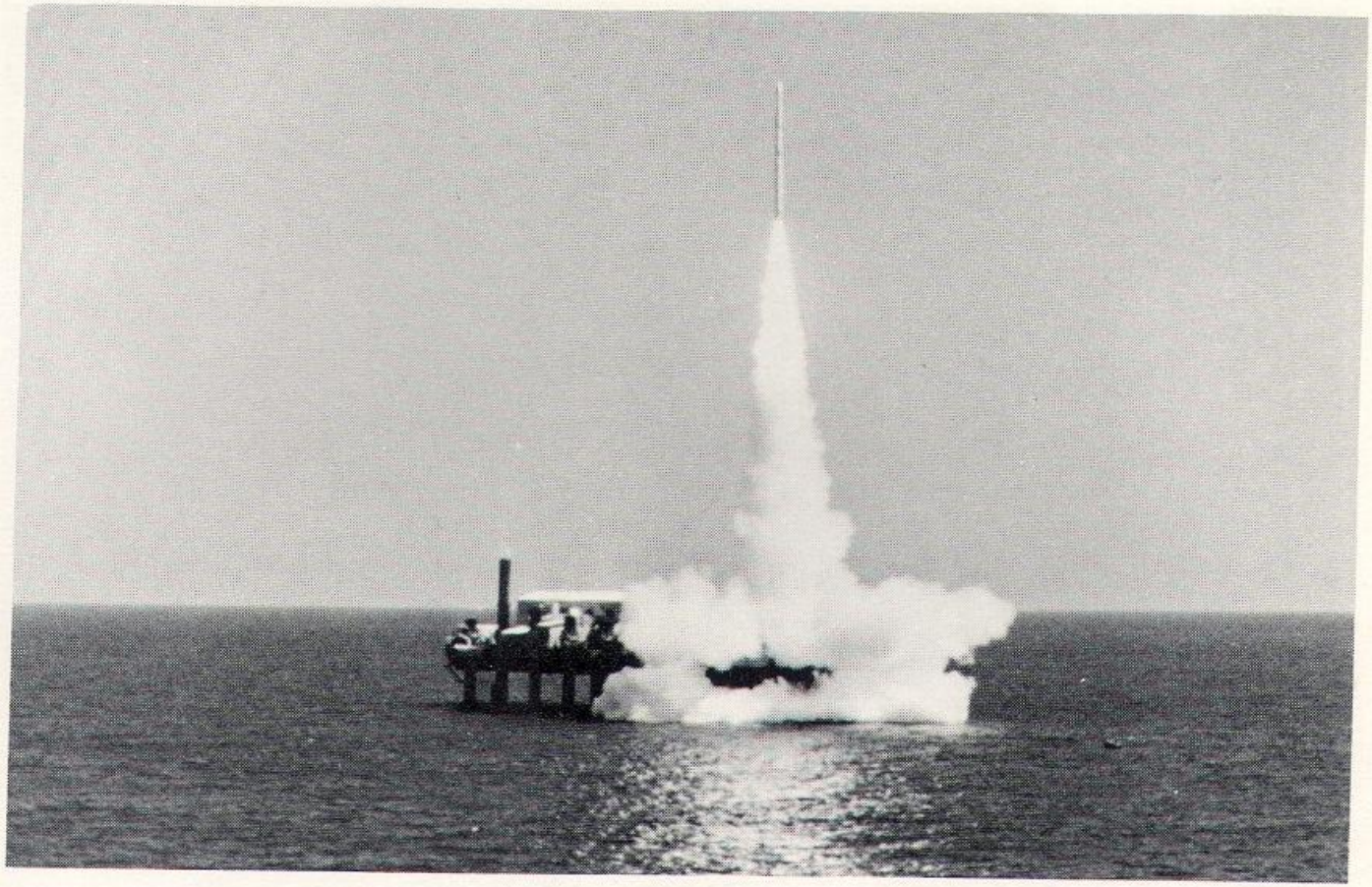
Jak je znaleźć ?

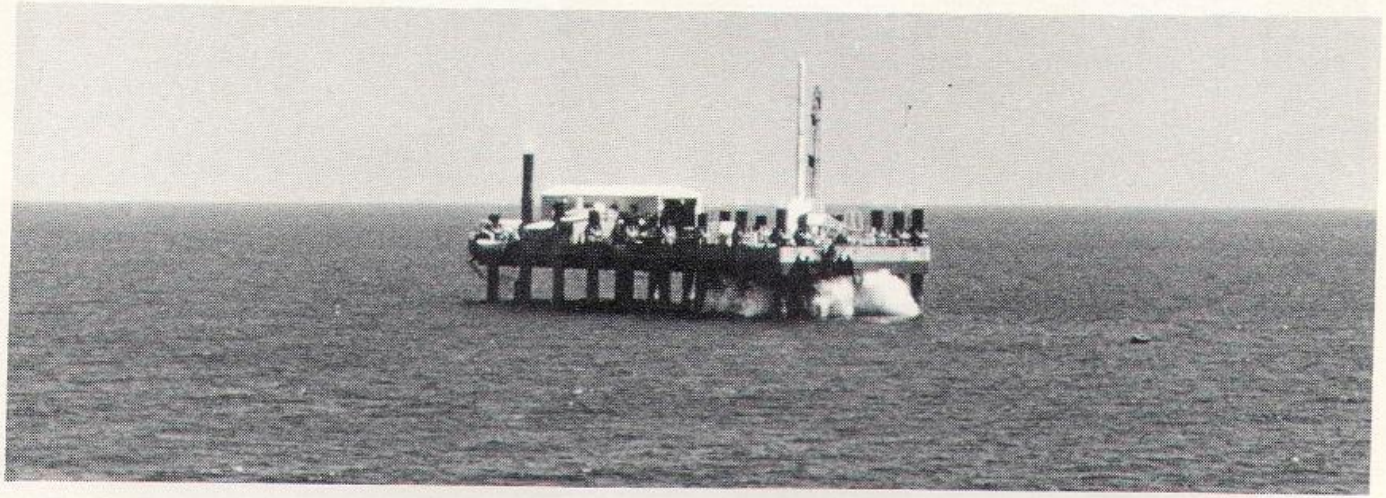
T ~ 10^6 K
Promienie X

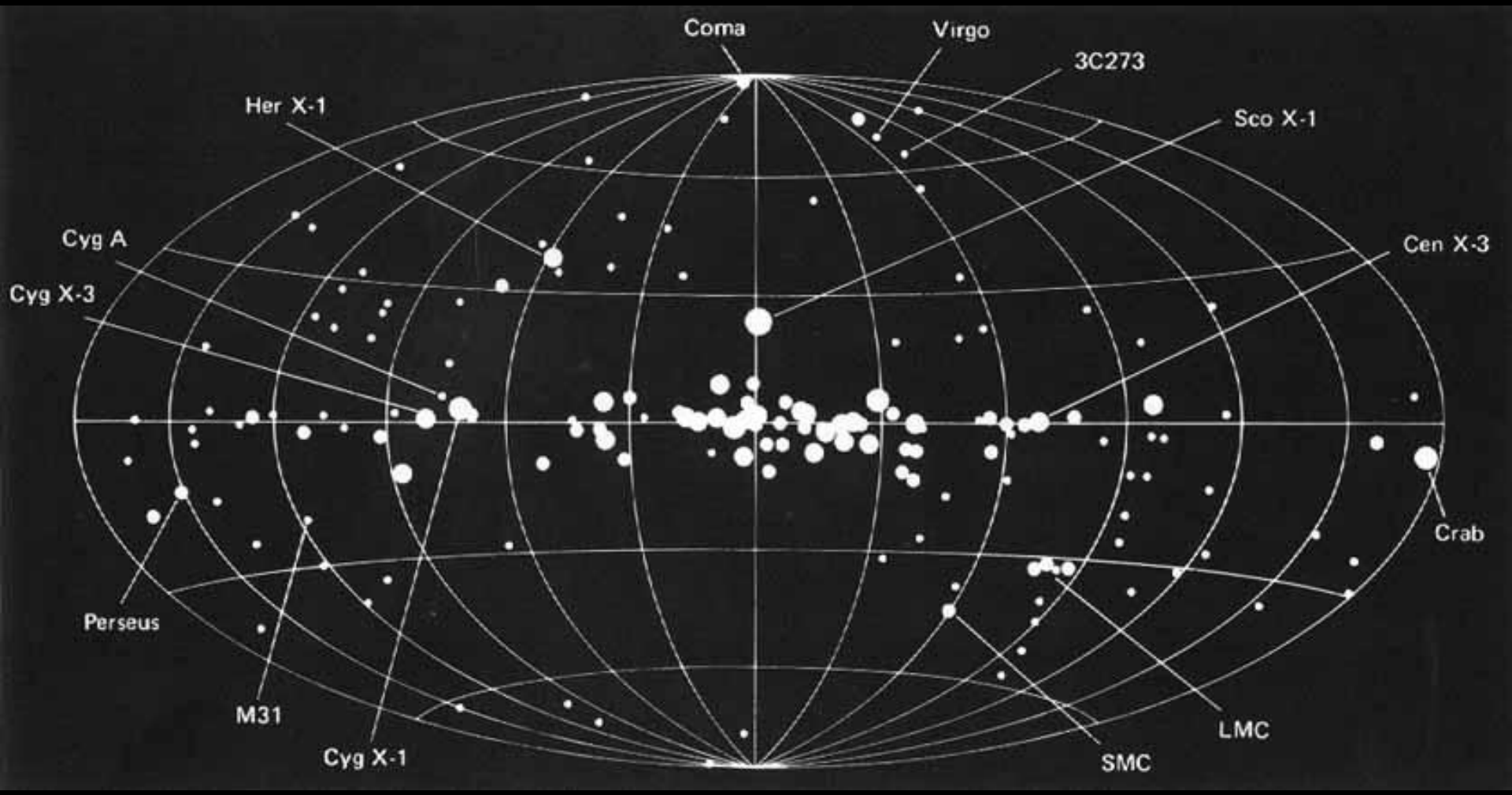


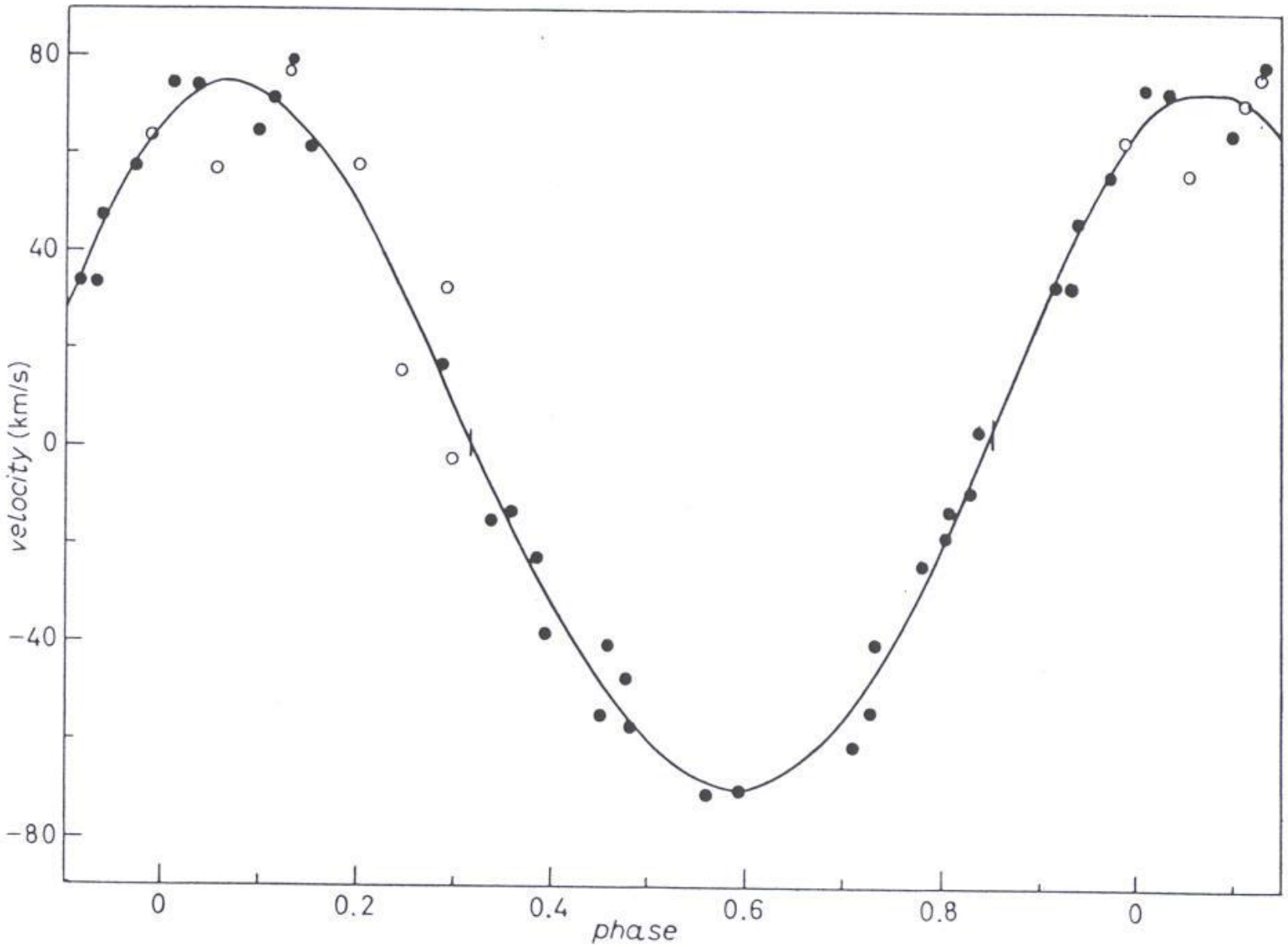


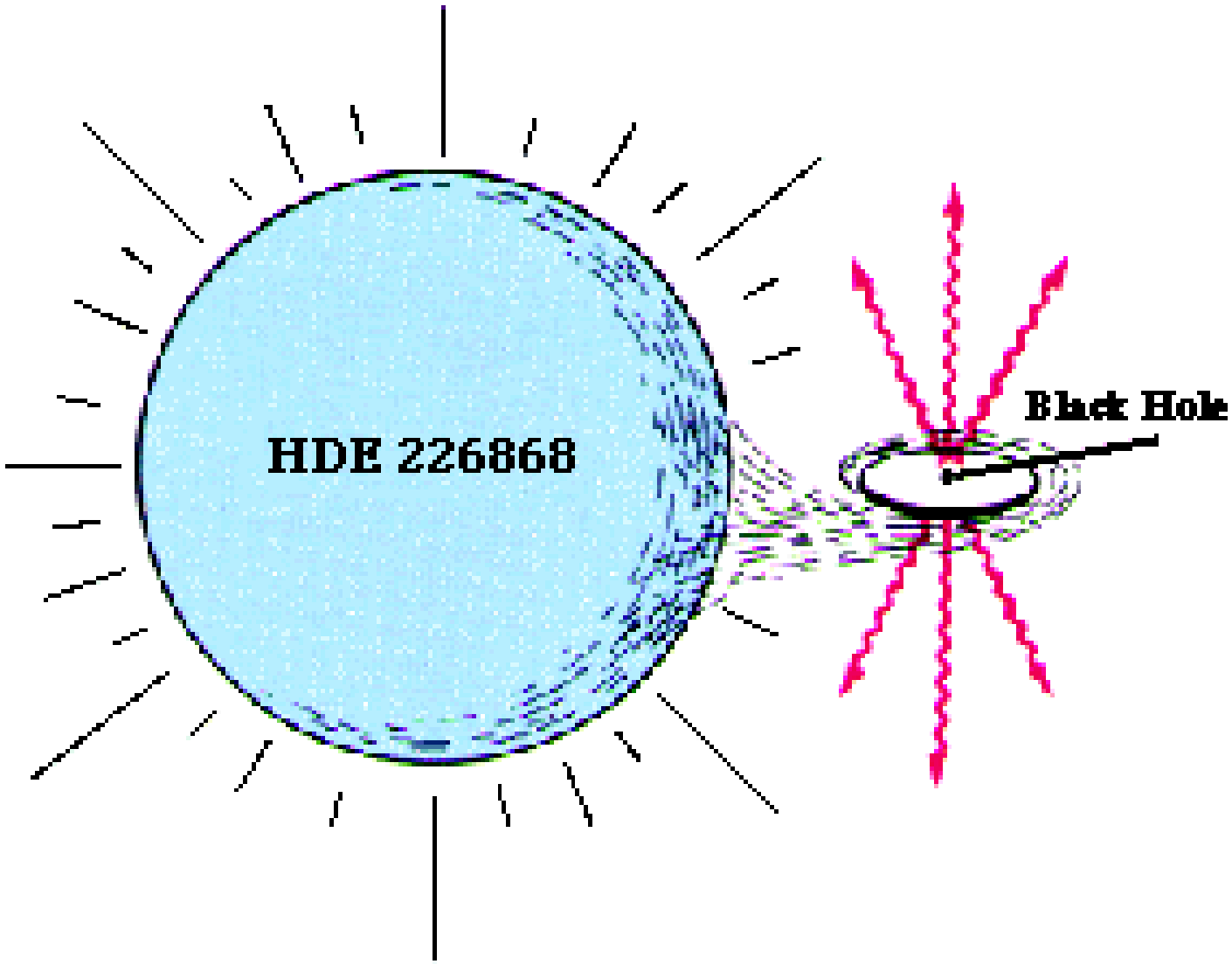
Fale elektromagnetyczne dochodzące z Kosmosu. Kolorem błękitnym zaznaczono obszary atmosfery, gdzie promieniowanie jest zatrzymywane na różnych wysokościach



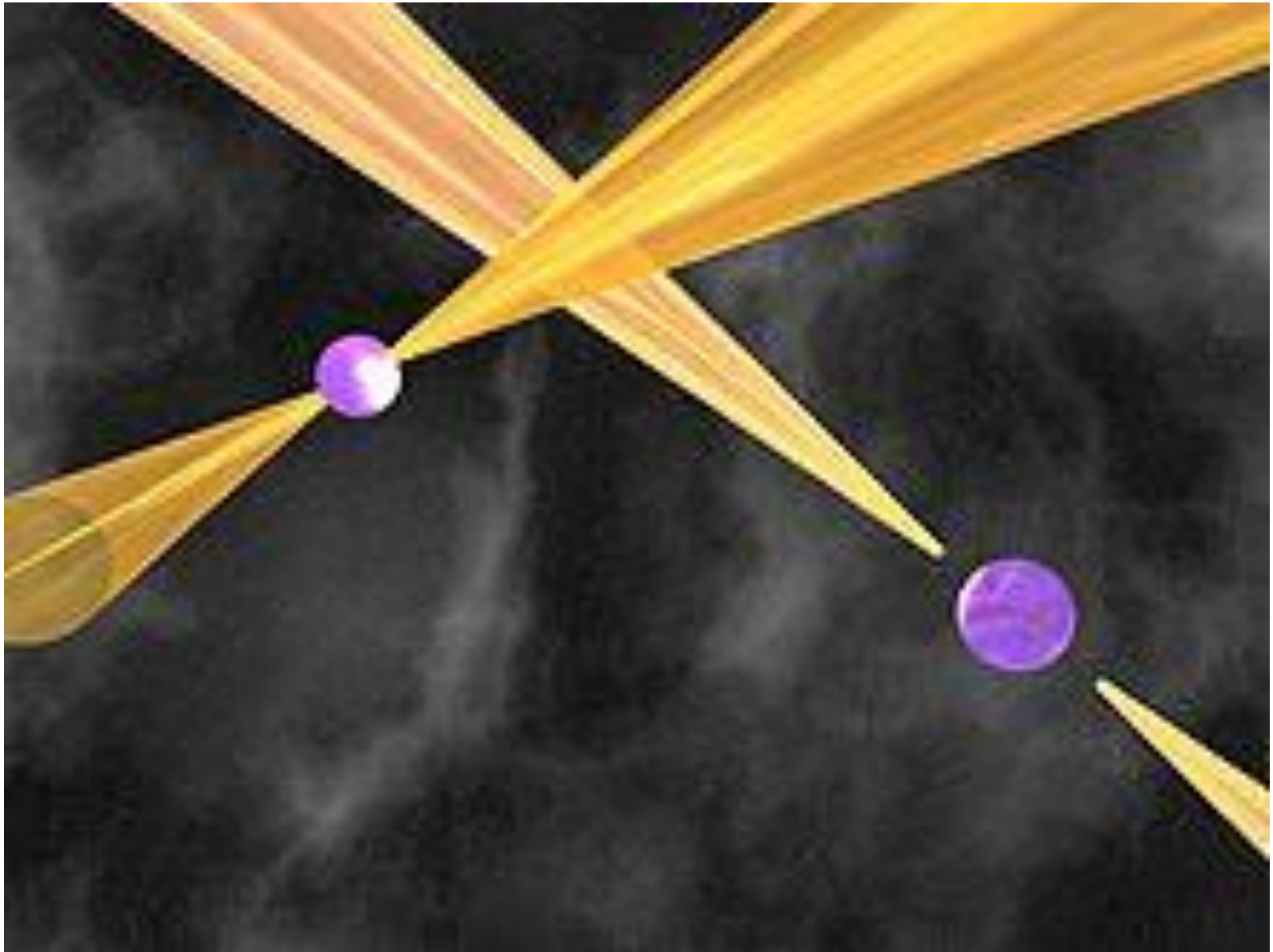


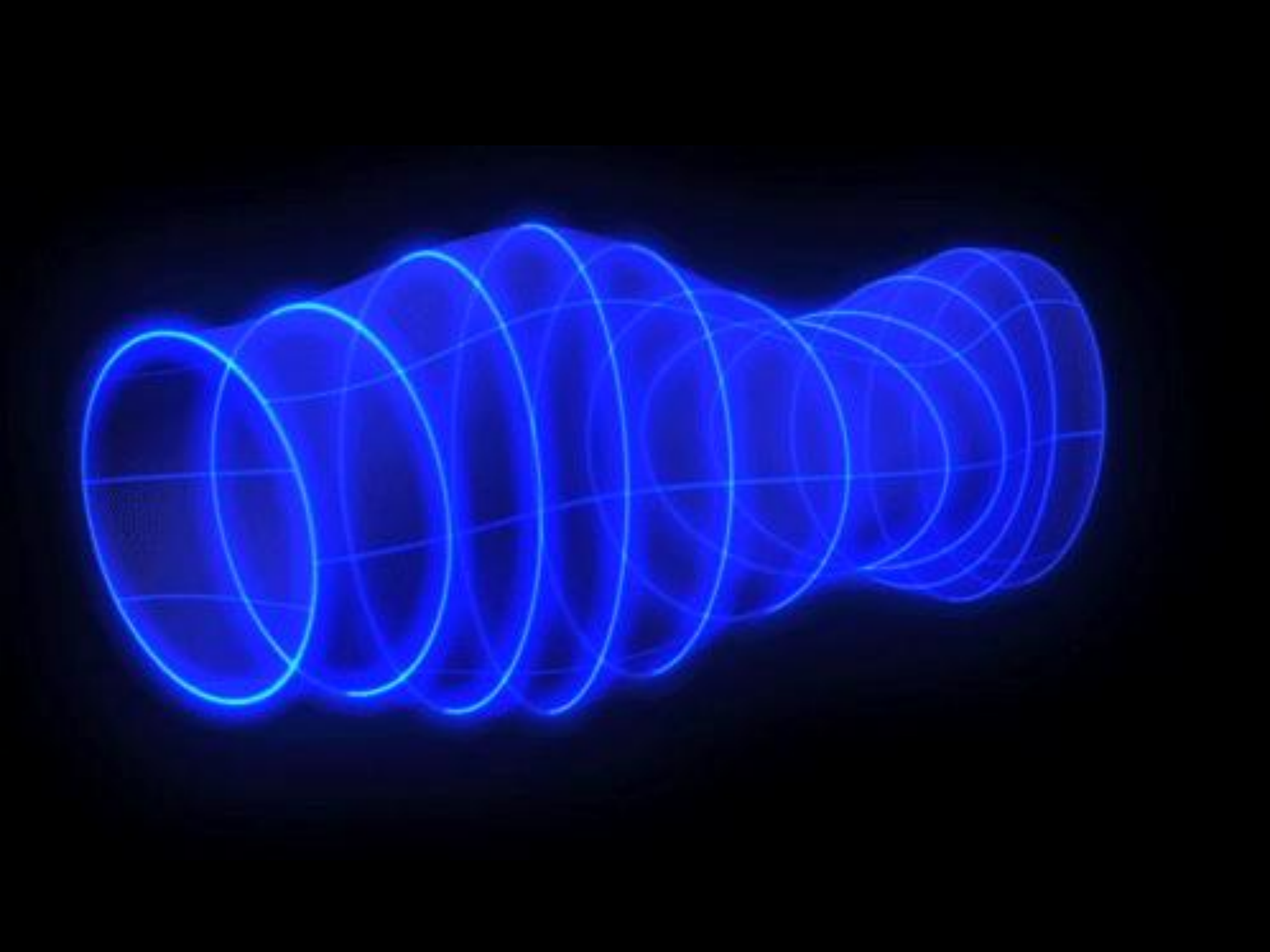

Coma
Virgo
3C273
Her X-1
Sco X-1
Cyg A
Cen X-3
Cyg X-3
Crab
Perseus
M31
Cyg X-1
LMC
SMC


80
40
0
-40
-80
velocity (km/s)
0
0.2
0.4
0.6
0.8
0
phase

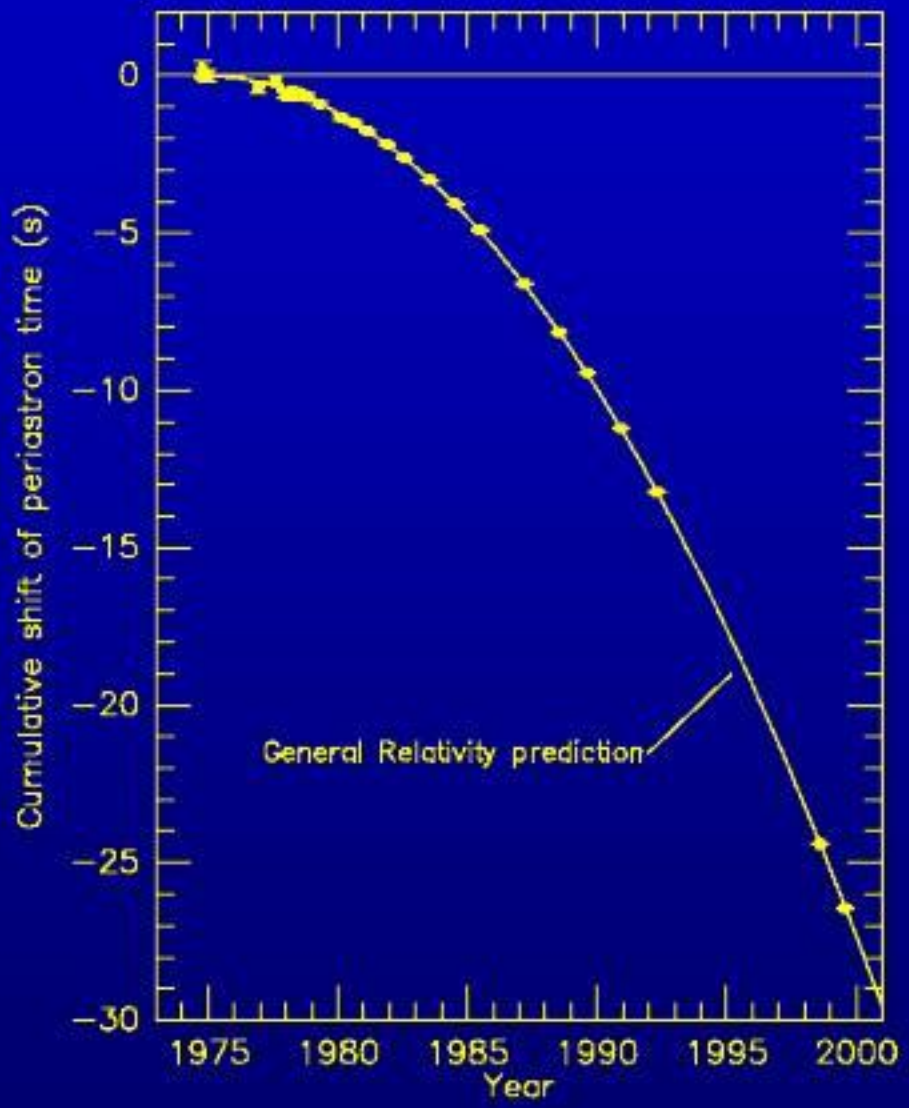

HDE 226868
Black Hole

Gravitational waves

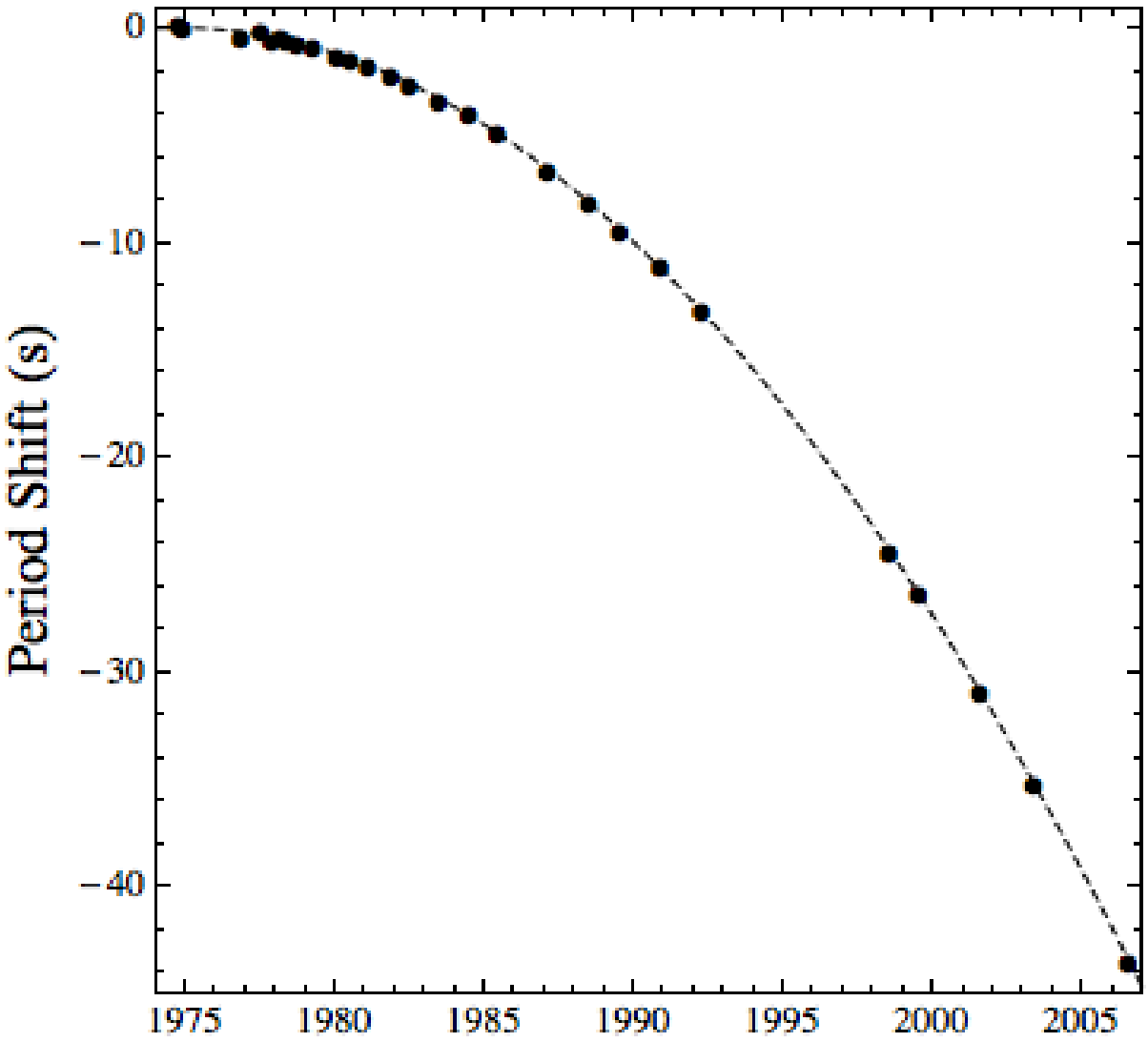




Theories of Gravity: Gravitational Waves

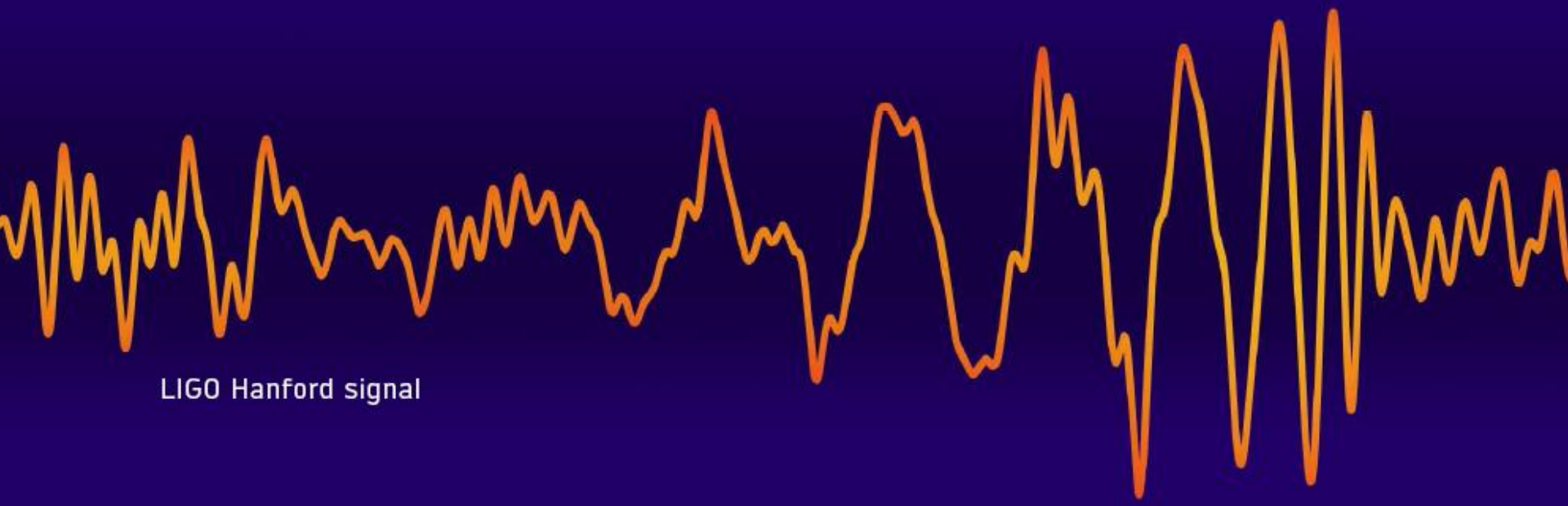


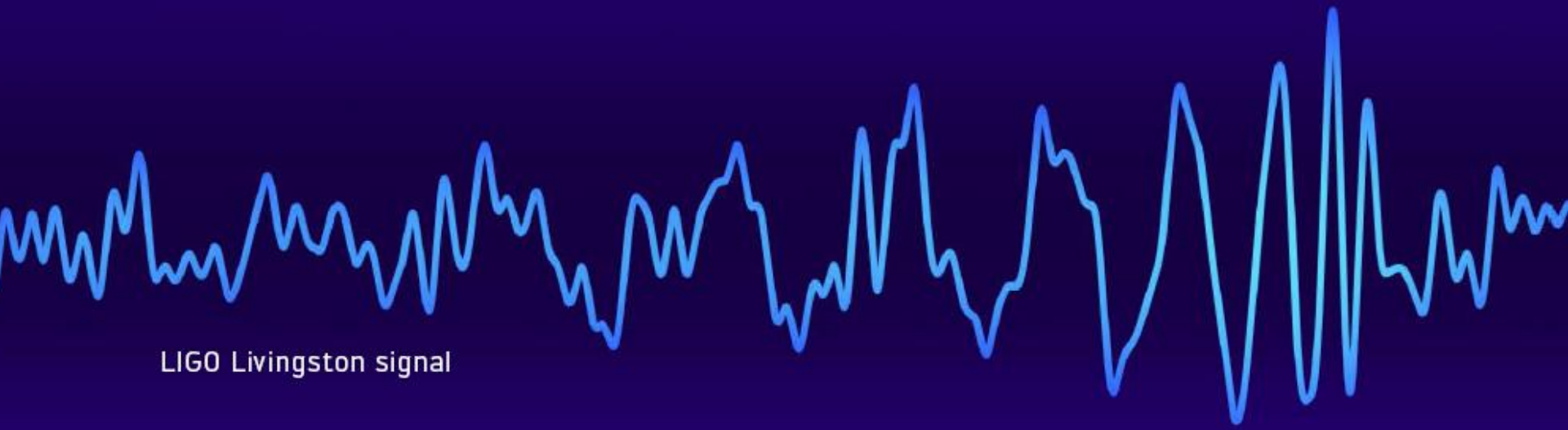
- **Orbit shrinks every day by 1cm!**

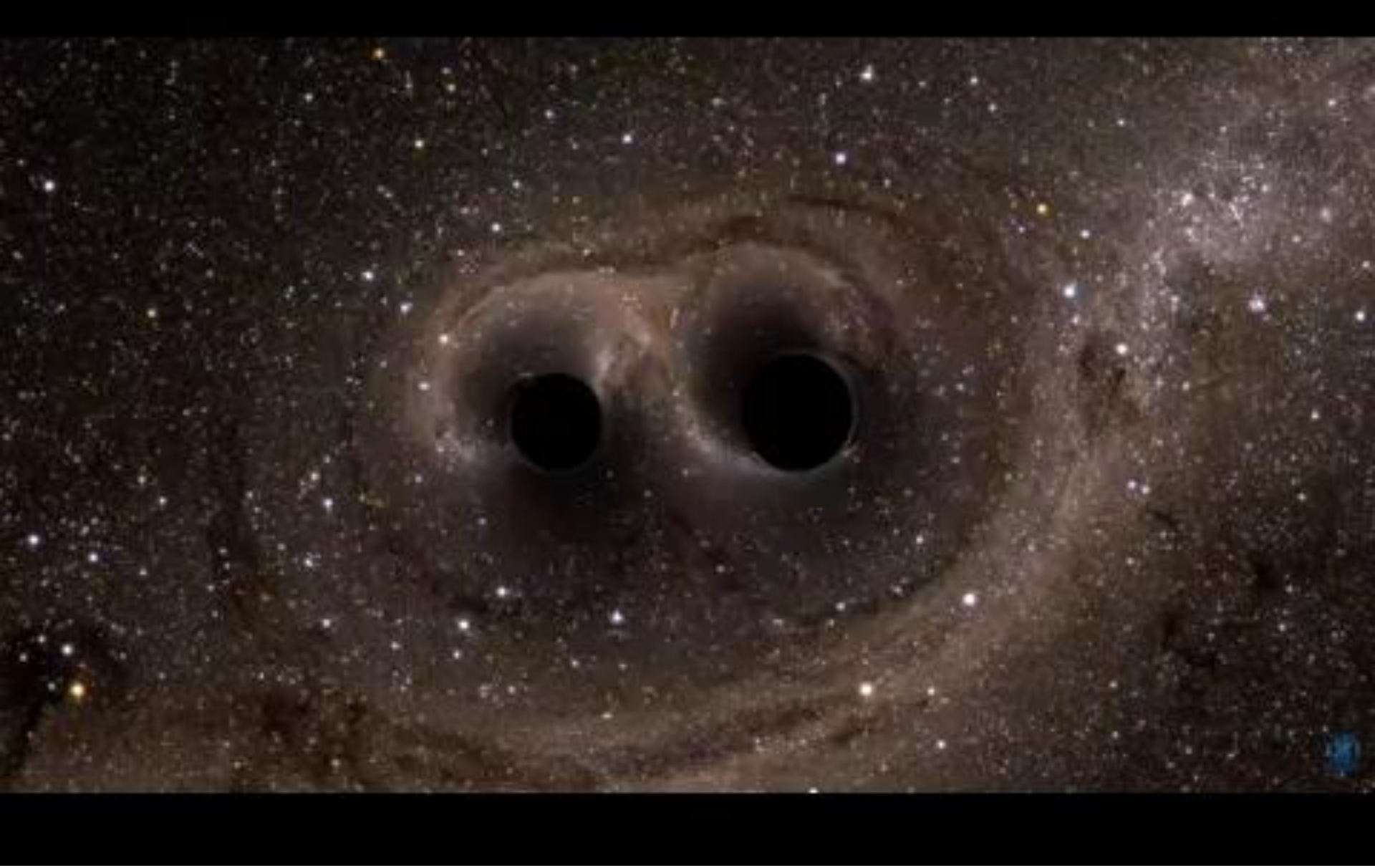

Period Shift (s)
0
−10
−20
−30
−40
1975
1980
1985
1990
1995
2000
2005

First detection!

9:50:45 UTC, 14 September 2015

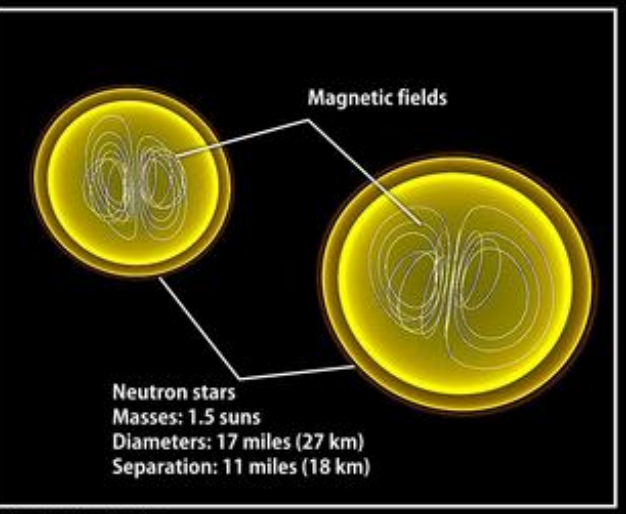




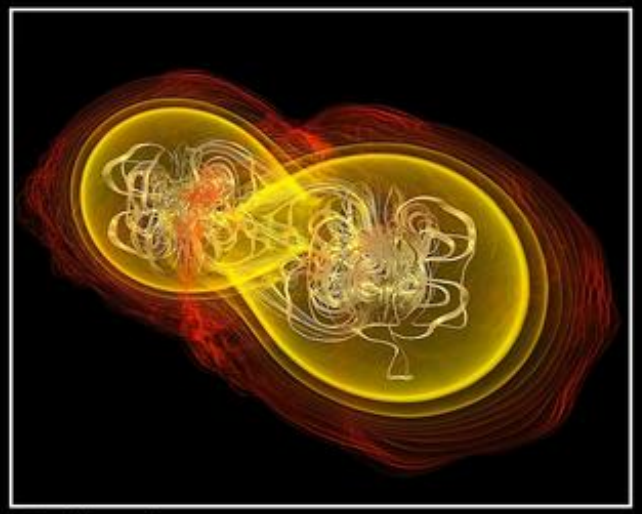


$M_1 = 36M_\odot$, $M_2 = 29M_\odot$, $M_f = 62M_\odot$, $\Delta M = 3M_\odot$

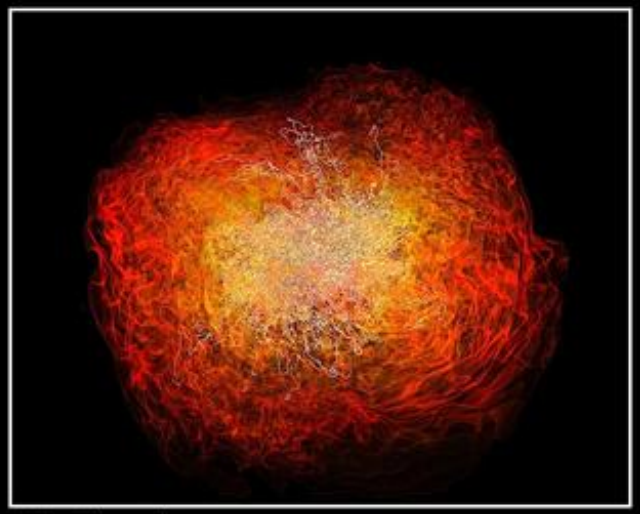
Crashing neutron stars can make gamma-ray burst jets



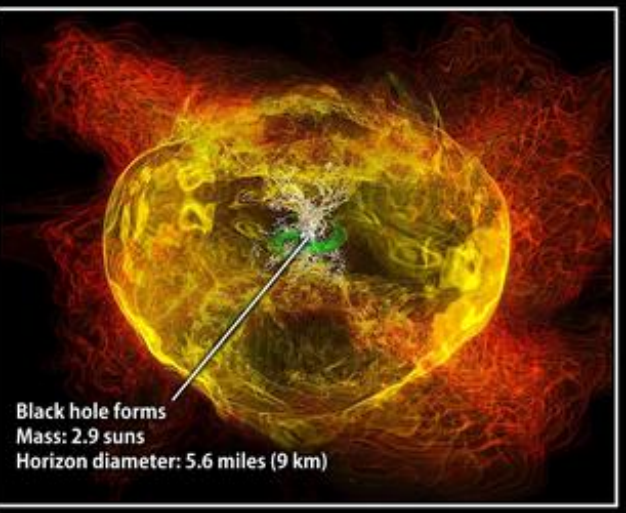
Simulation begins



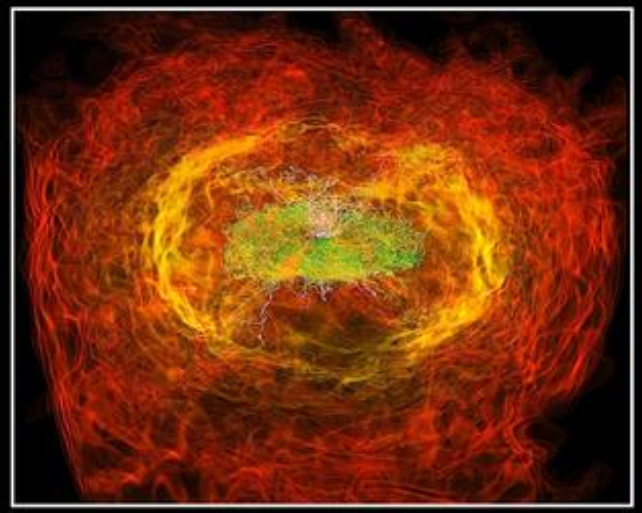
7.4 milliseconds



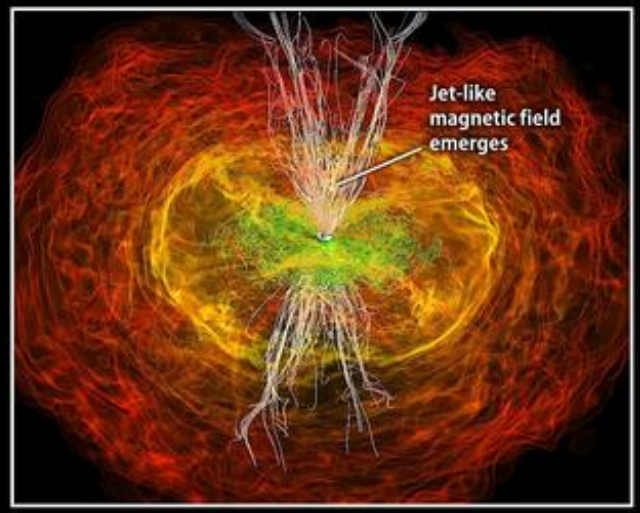
13.8 milliseconds



15.3 milliseconds



21.2 milliseconds

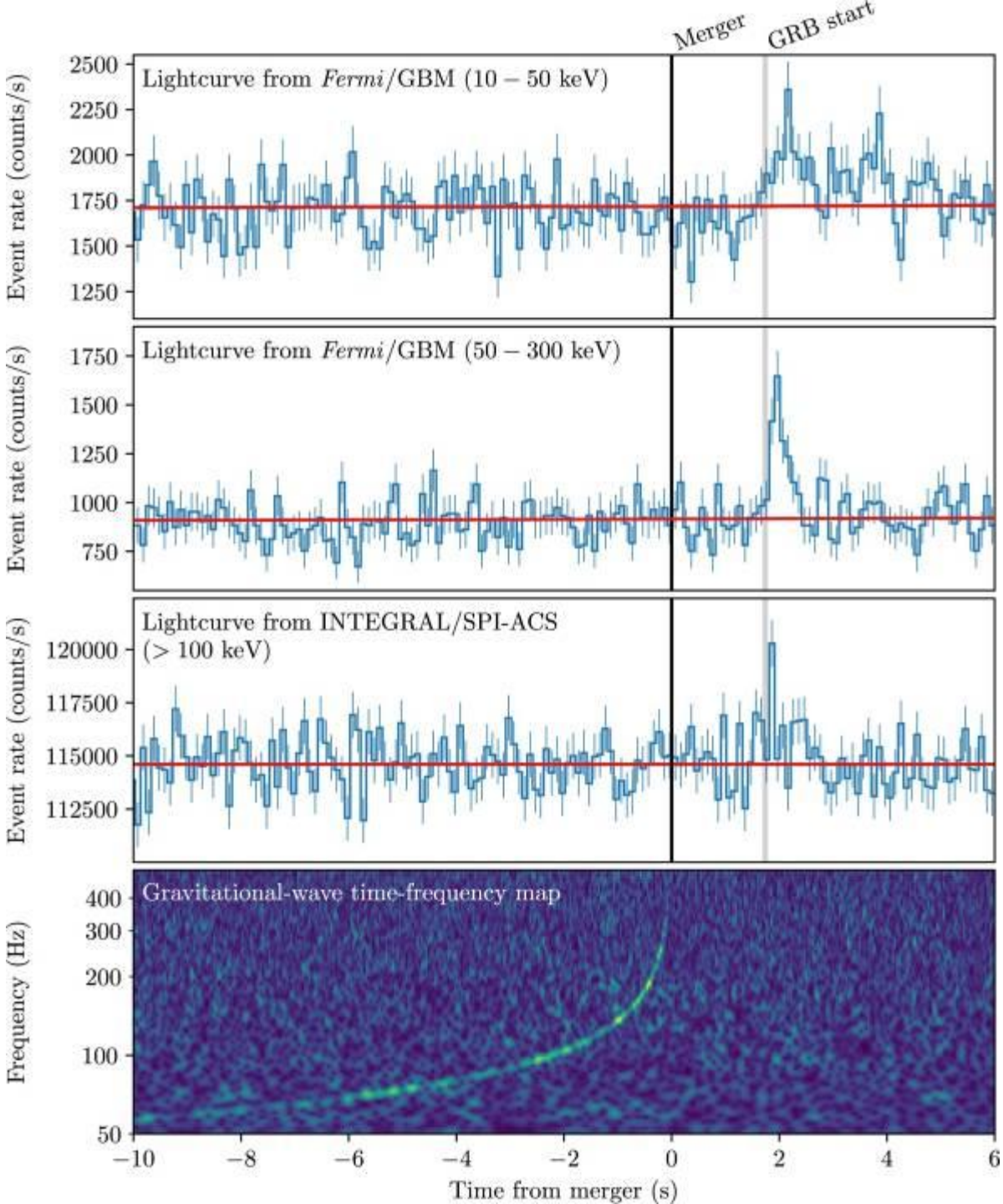


26.5 milliseconds

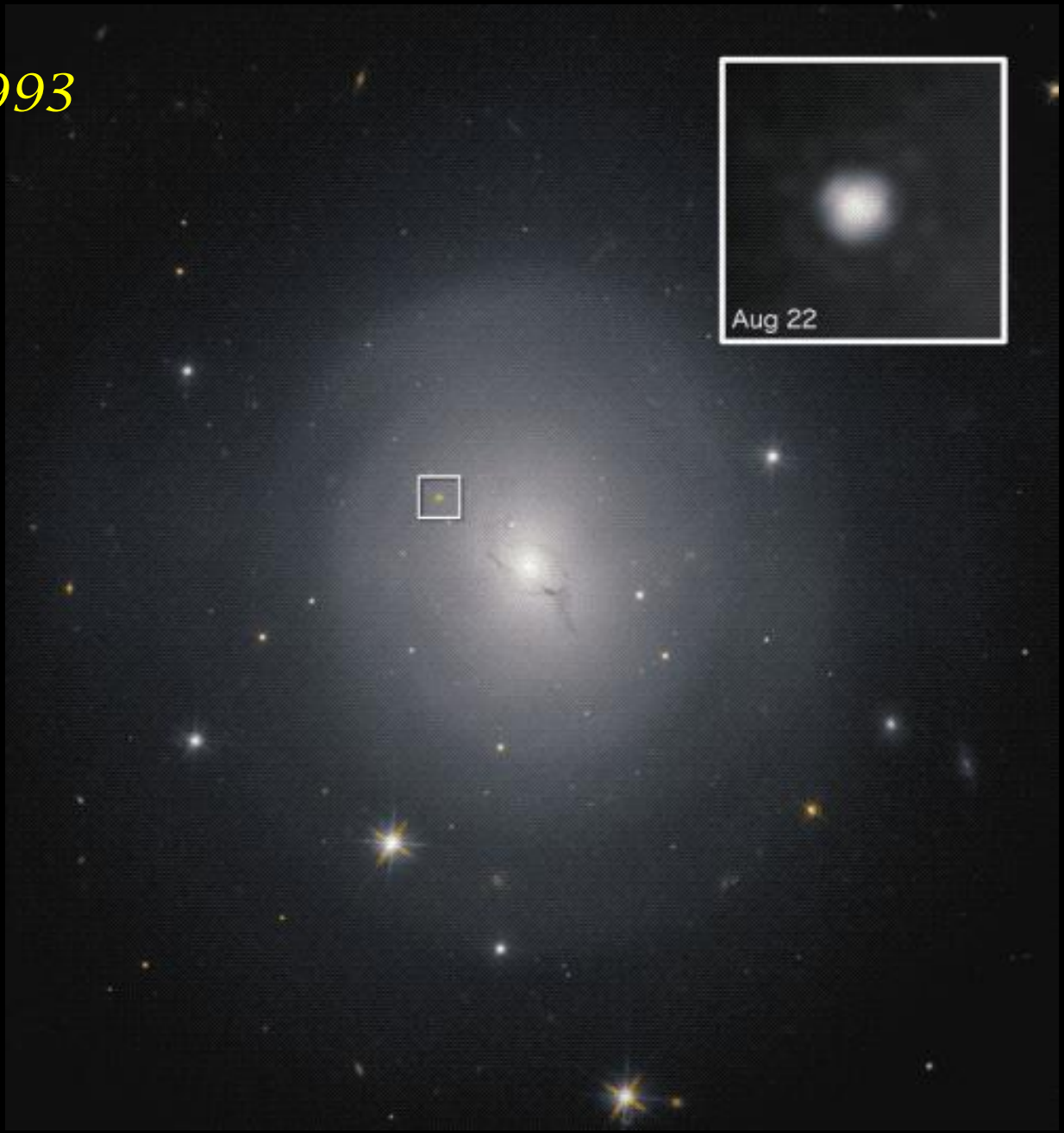
Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla

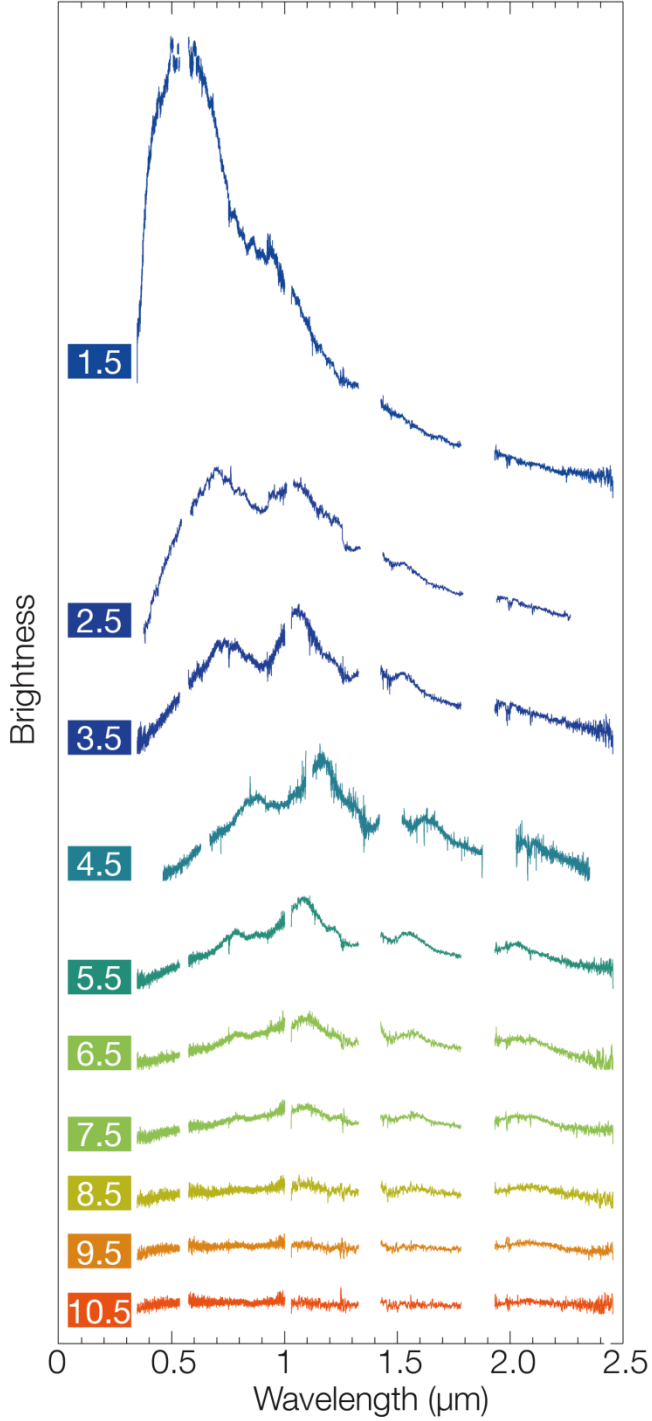
Swift Neutron Star Collision v. 2

Animation: Dana Berry
310-441-1735
Produced by Erica Drezek


Merger
GRB start
Lightcurve from *Fermi*/GBM (10 – 50 keV)
Event rate (counts/s)
2500
2250
2000
1750
1500
1250
Lightcurve from *Fermi*/GBM (50 – 300 keV)
Event rate (counts/s)
1750
1500
1250
1000
750
Lightcurve from INTEGRAL/SPI-ACS
(> 100 keV)
Event rate (counts/s)
120000
117500
115000
112500
Gravitational-wave time-frequency map
Frequency (Hz)
400
300
200
100
50
−10
−8
−6
−4
−2
0
2
4
6
Time from merger (s)

NGC 4993




1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
10.5
Brightness
0
0.5
1
1.5
2.0
2.5
Wavelength (μm)

Element Origins

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											

Merging Neutron Stars

Exploding Massive Stars

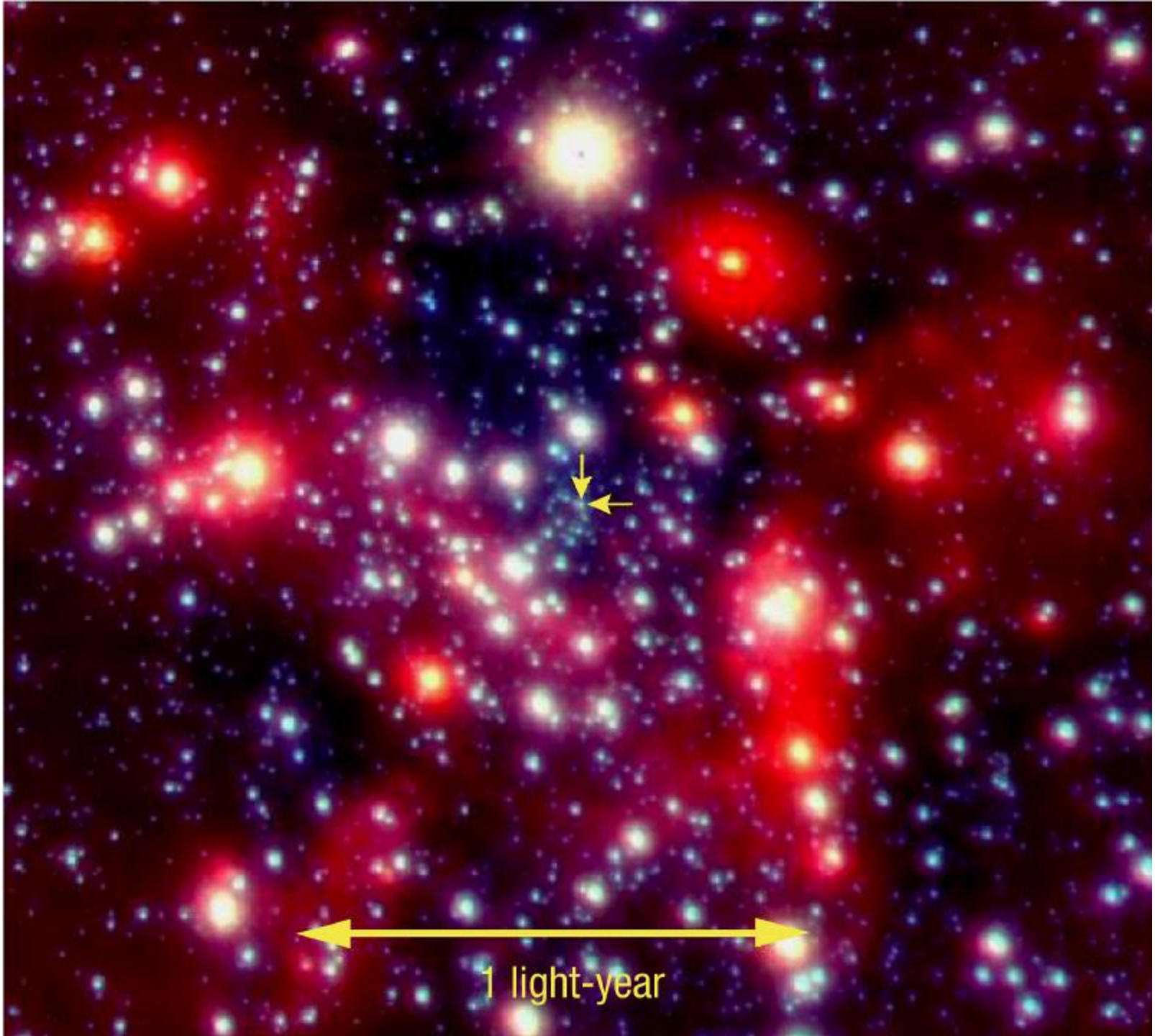
Big Bang

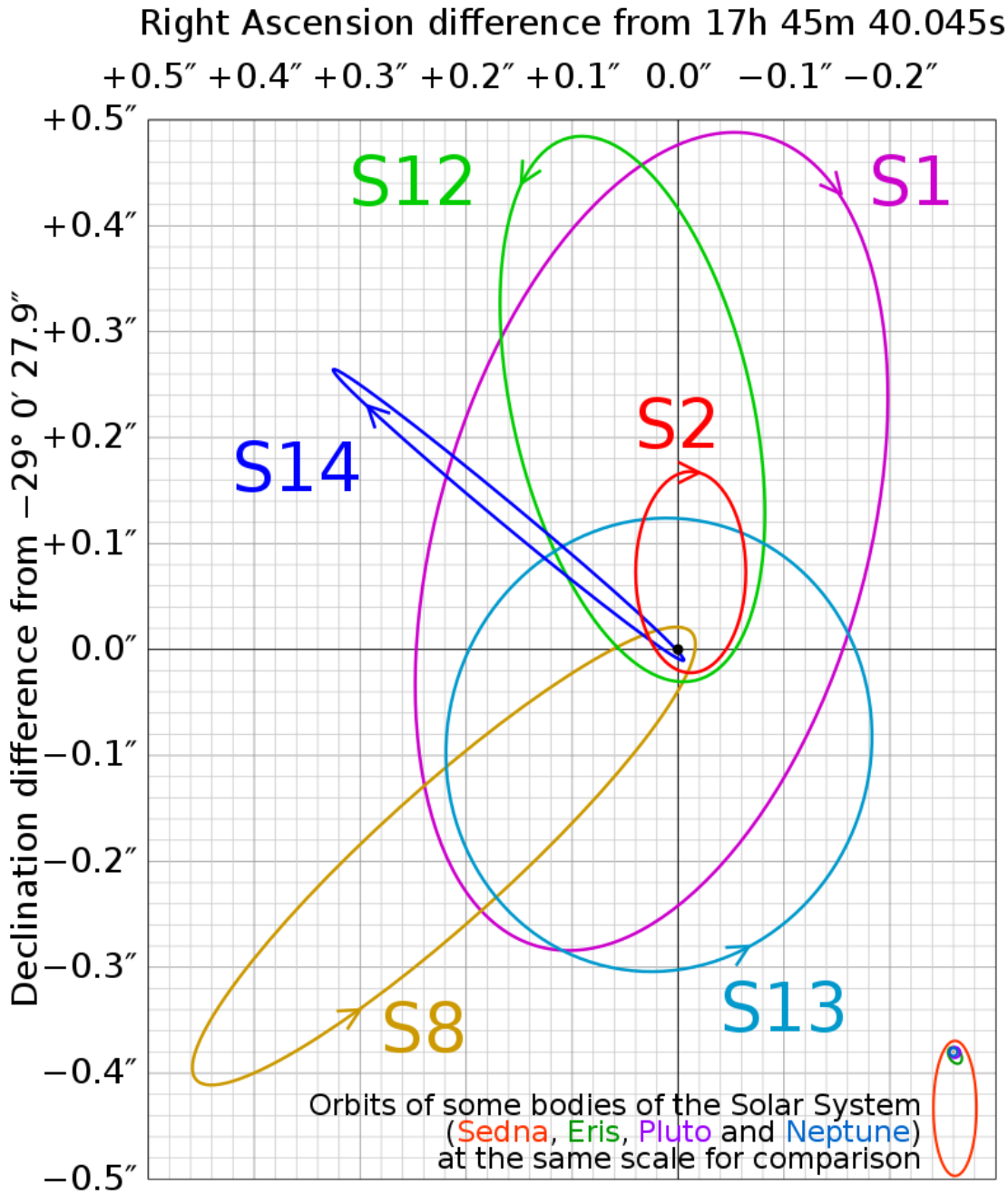
Dying Low Mass Stars

Exploding White Dwarfs

Cosmic Ray Fission

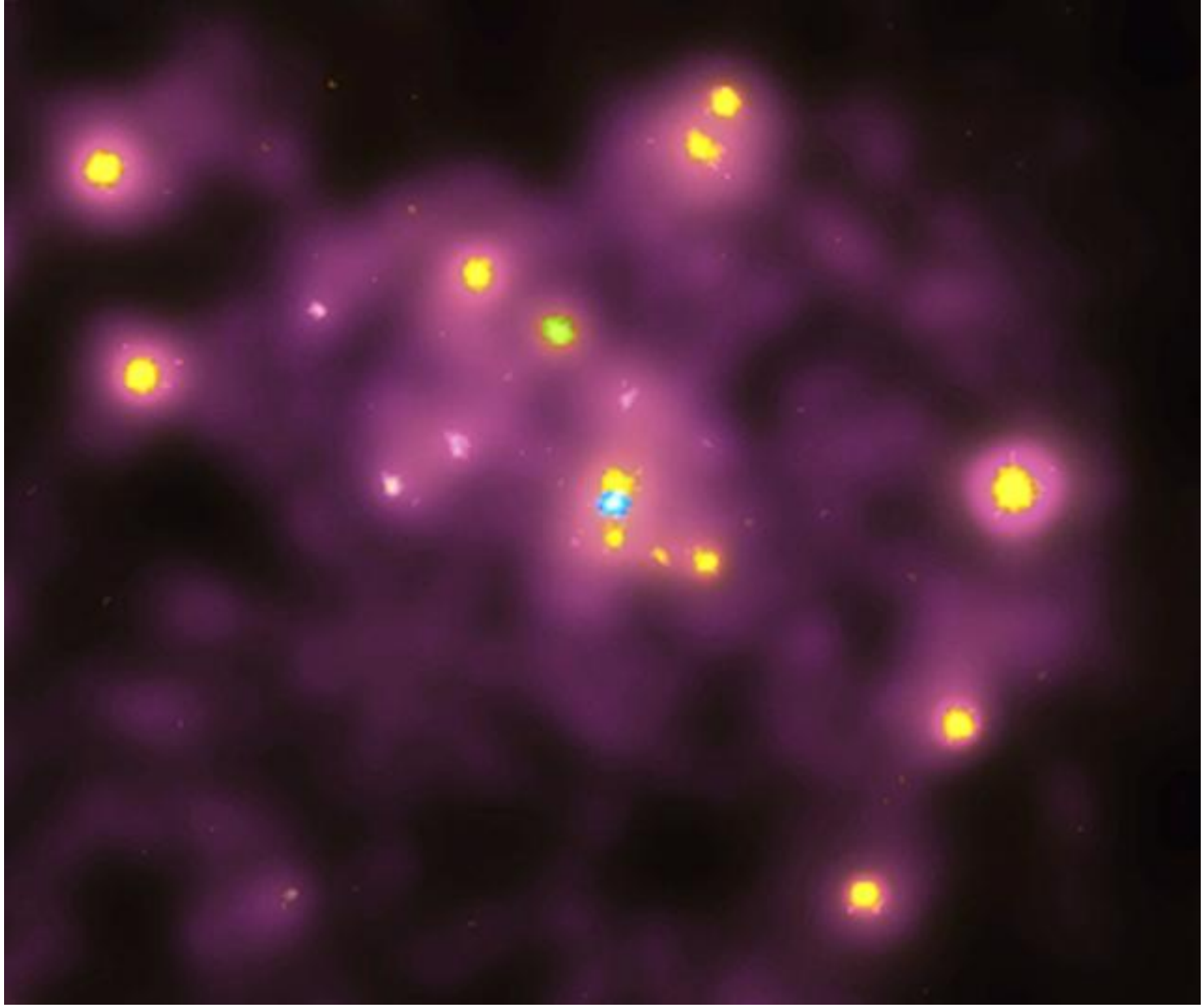
Based on graphic created by Jen


1 light-year



$M_{BH} \sim 3.6\ 10^6\ M_\odot$

Czarna dziura w centrum Andromedy

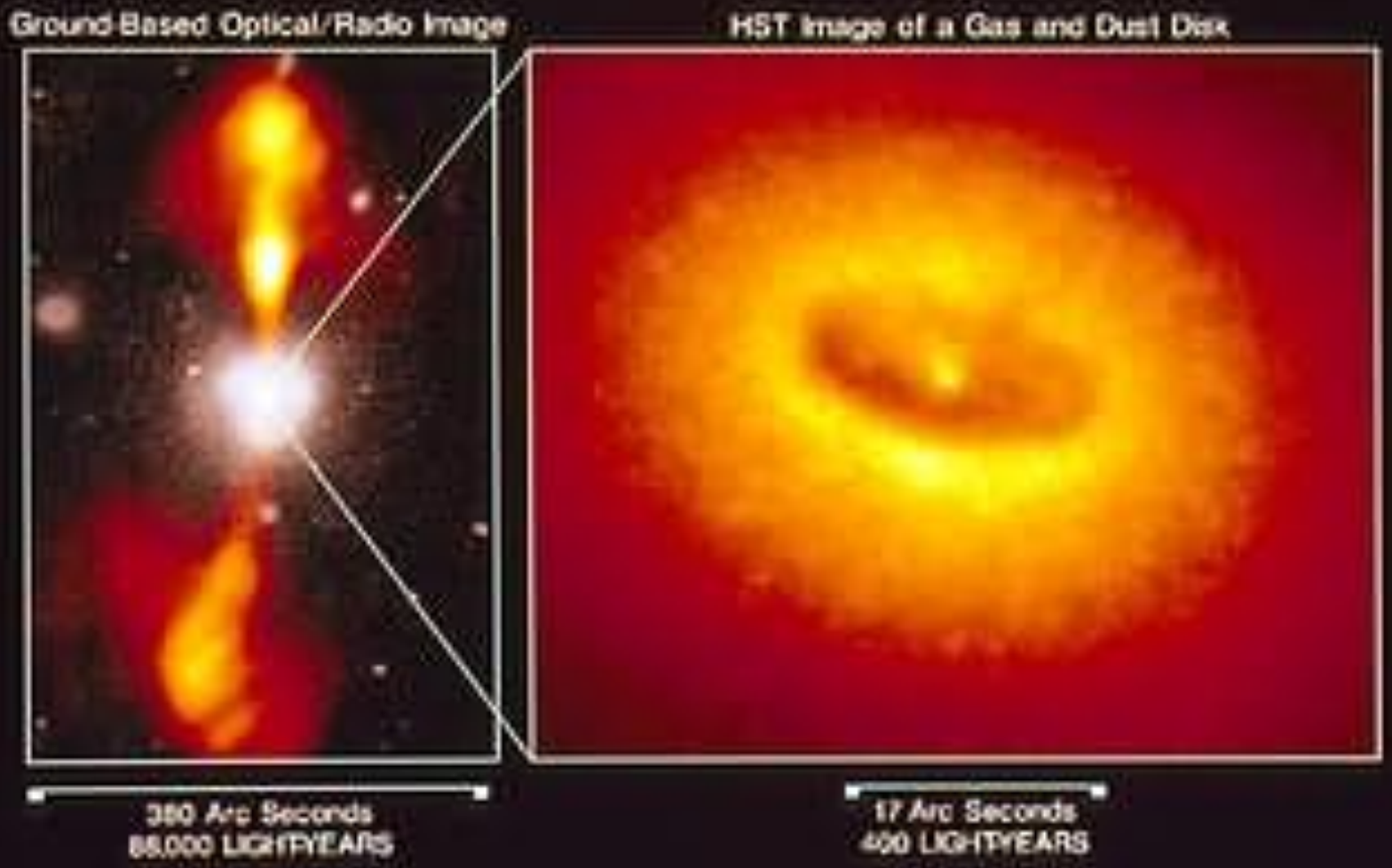


$$M_{BH} \sim (1-2)\, 10^8\, M_\odot$$

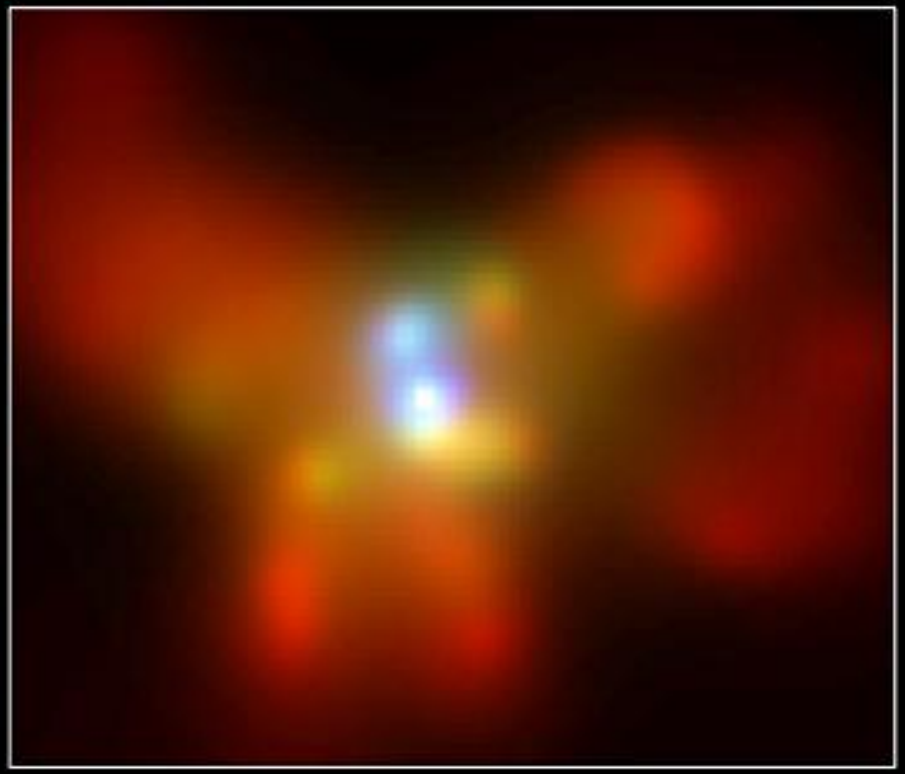
Core of Galaxy NGC 4261

Hubble Space Telescope

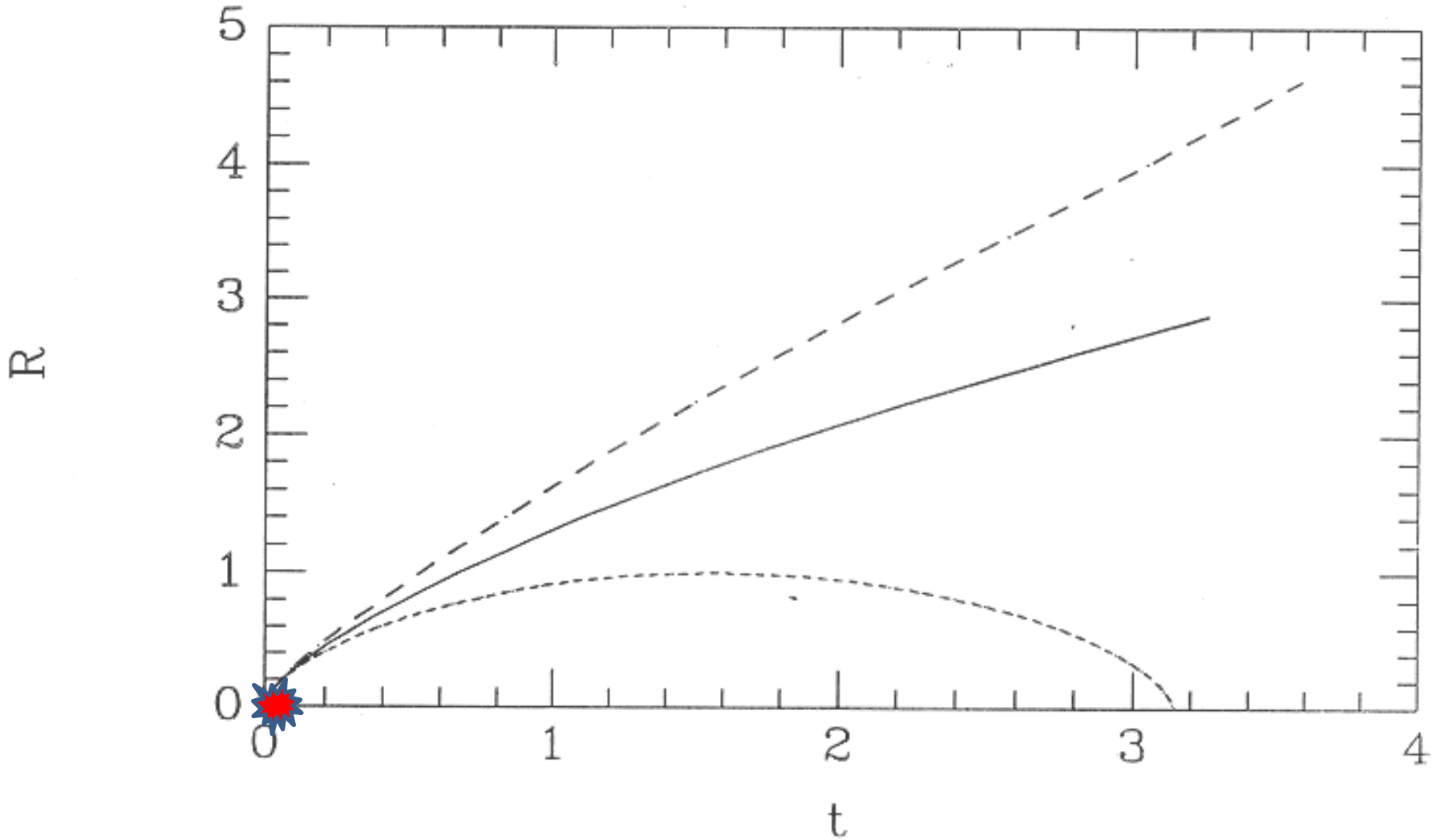
Wide Field / Planetary Camera



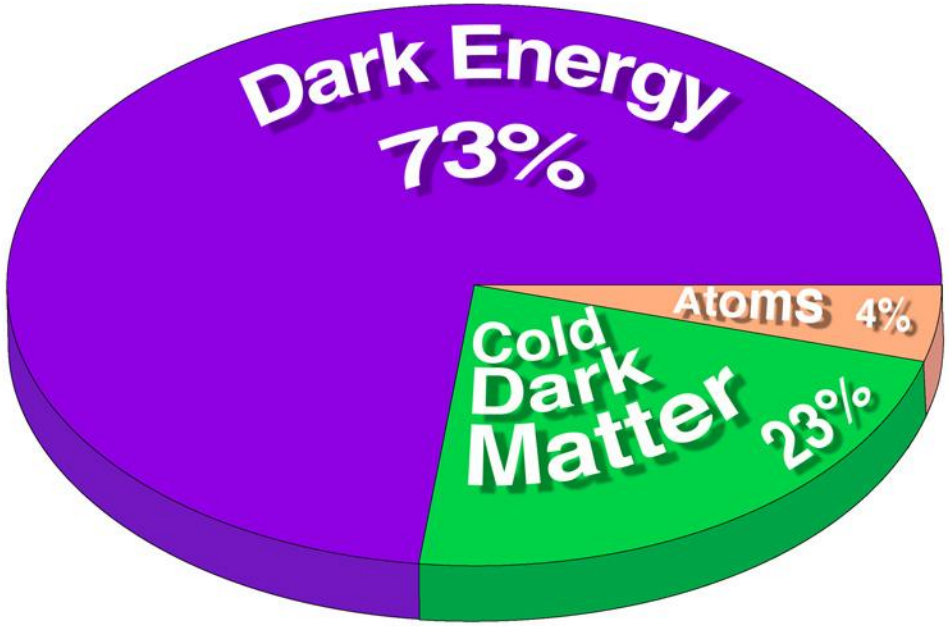
Hubble Optical



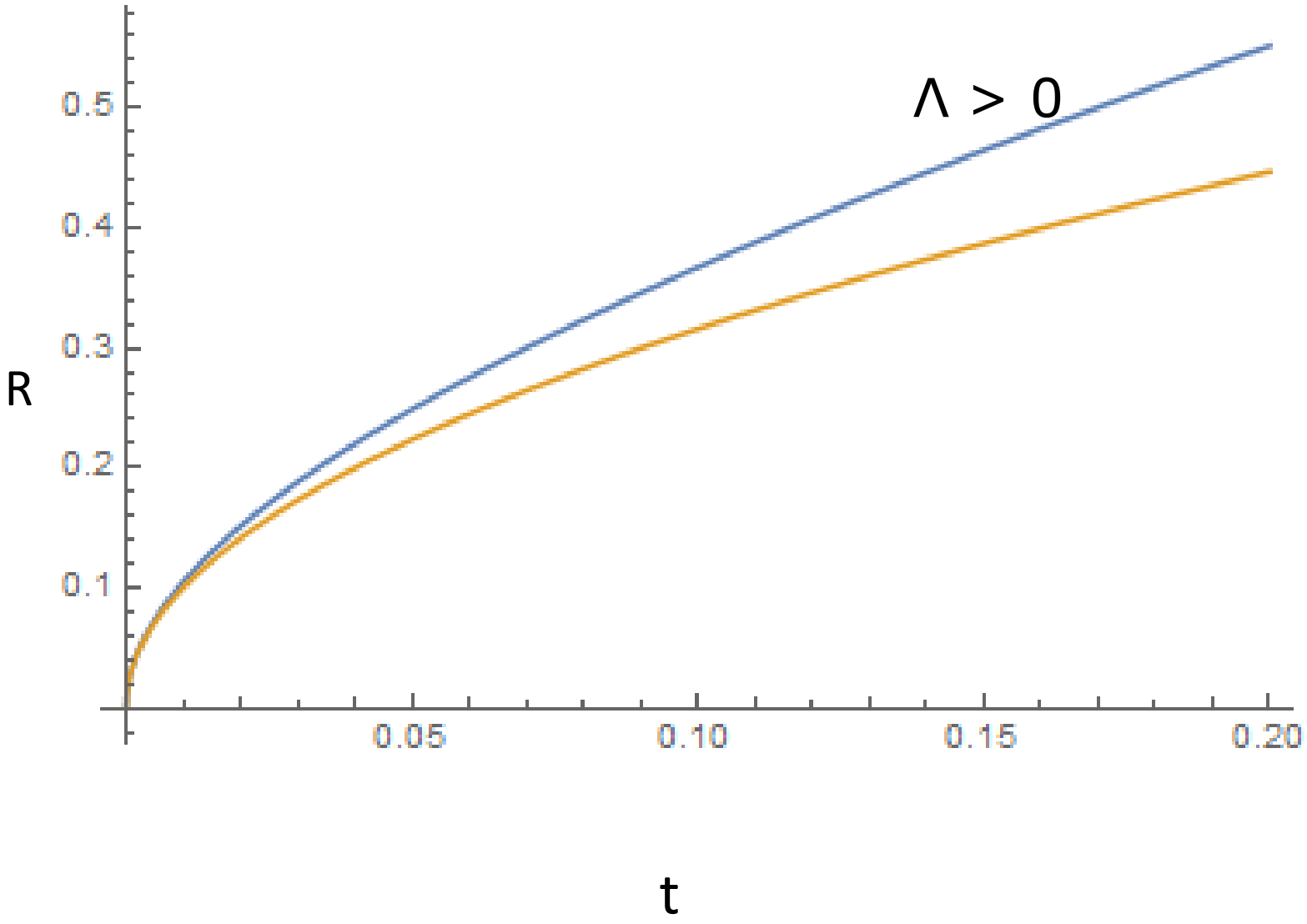
Chandra X-ray


R
t
0
1
2
3
4
5
0
1
2
3
4

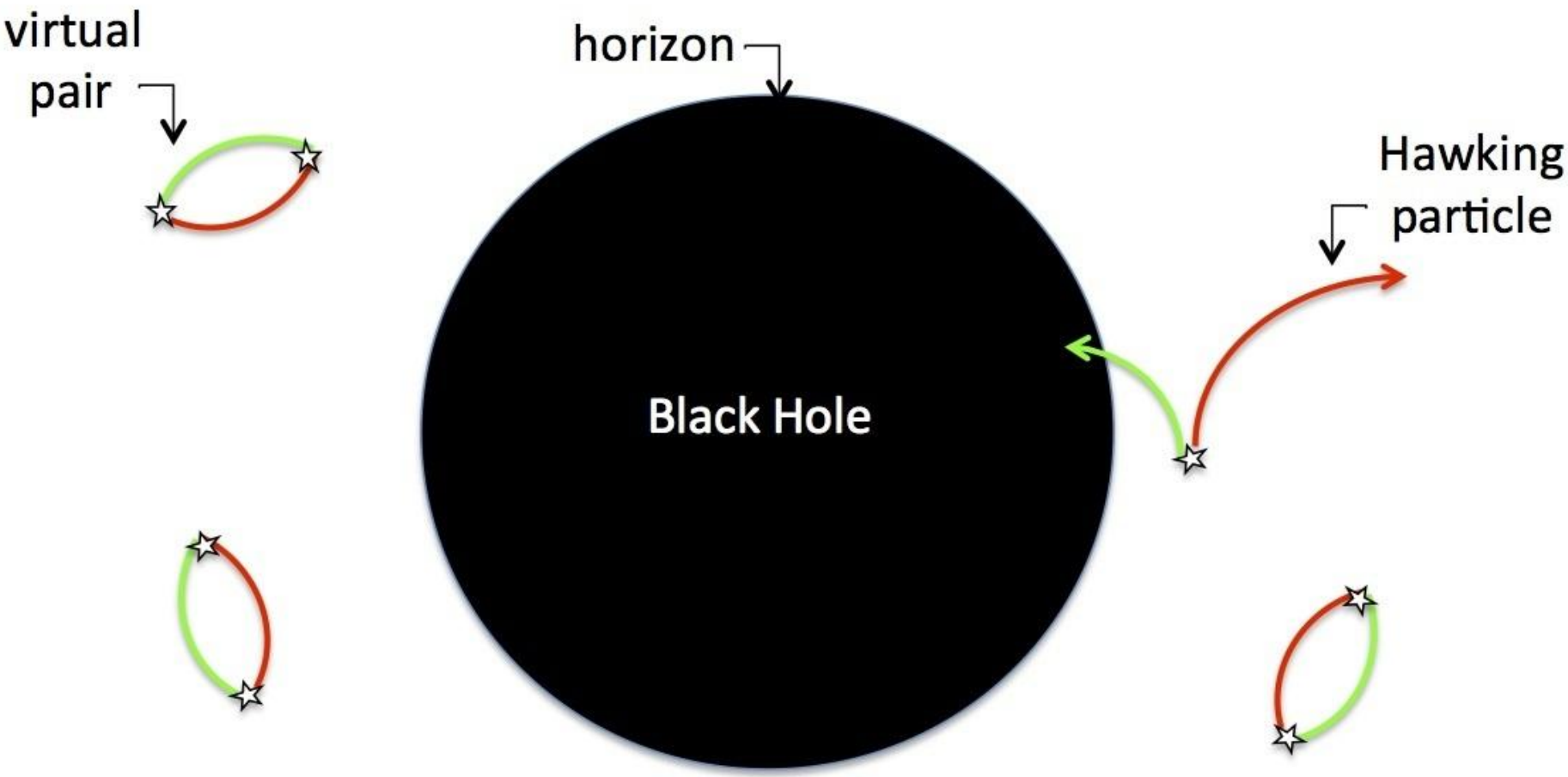
Podstawowe składniki Wszechświata

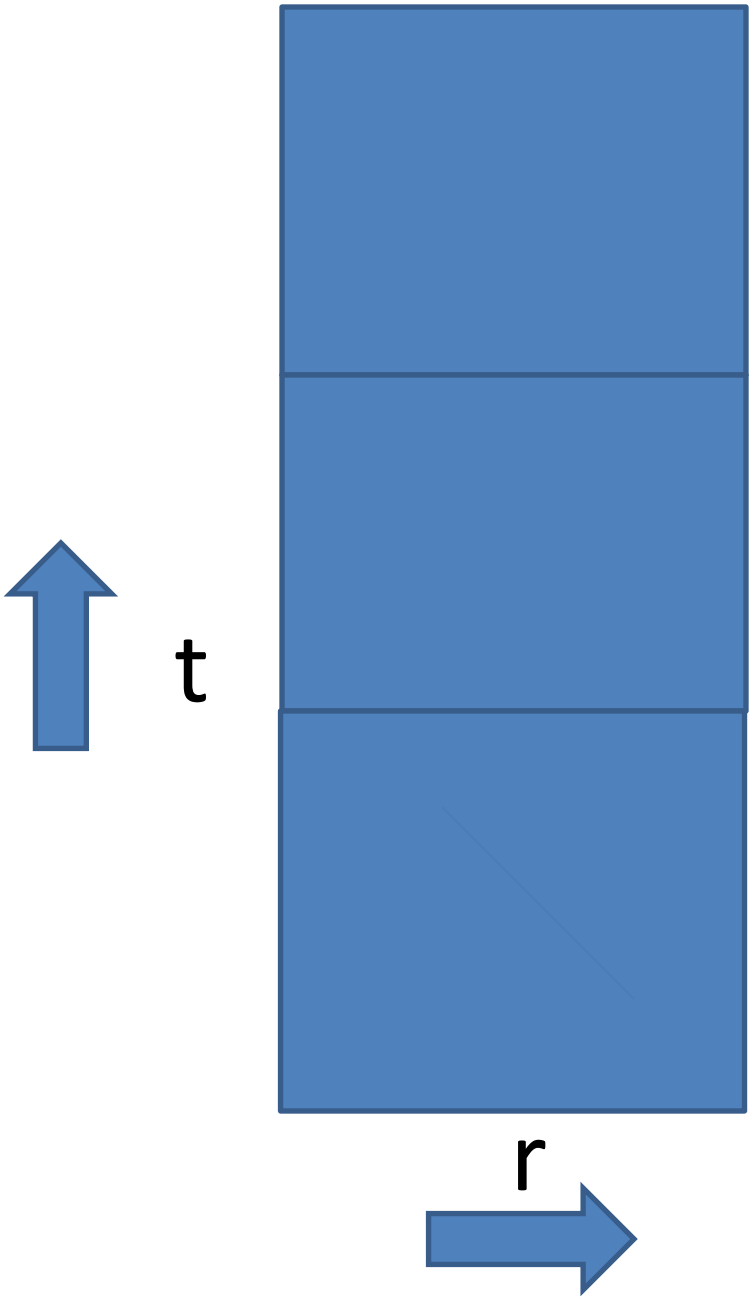


Λ – stała kosmologiczna



Promieniowanie Hawkinga





Cykliczny Wszechświat Penrose'a