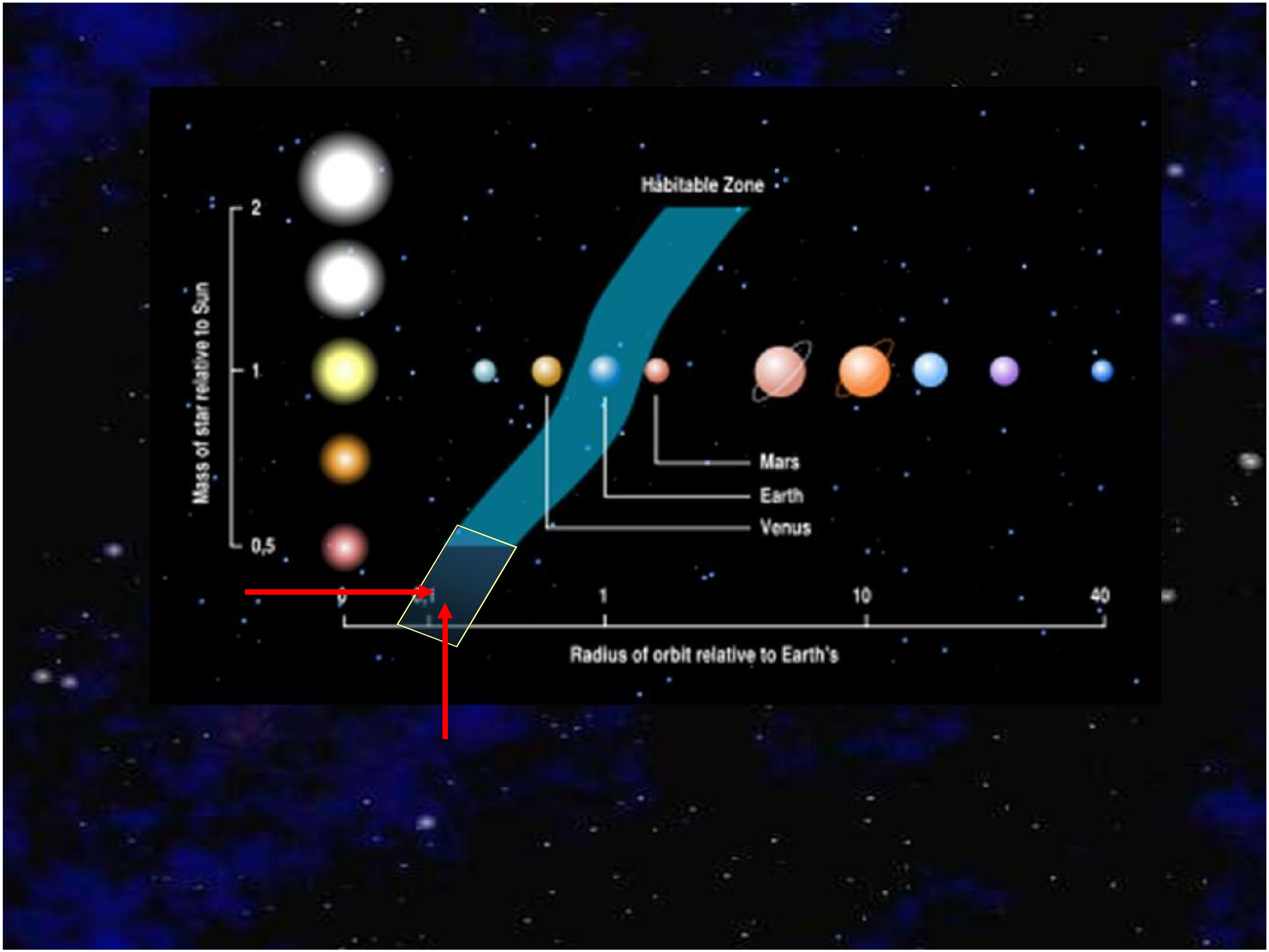
Scientists find most Earth-like planet yet

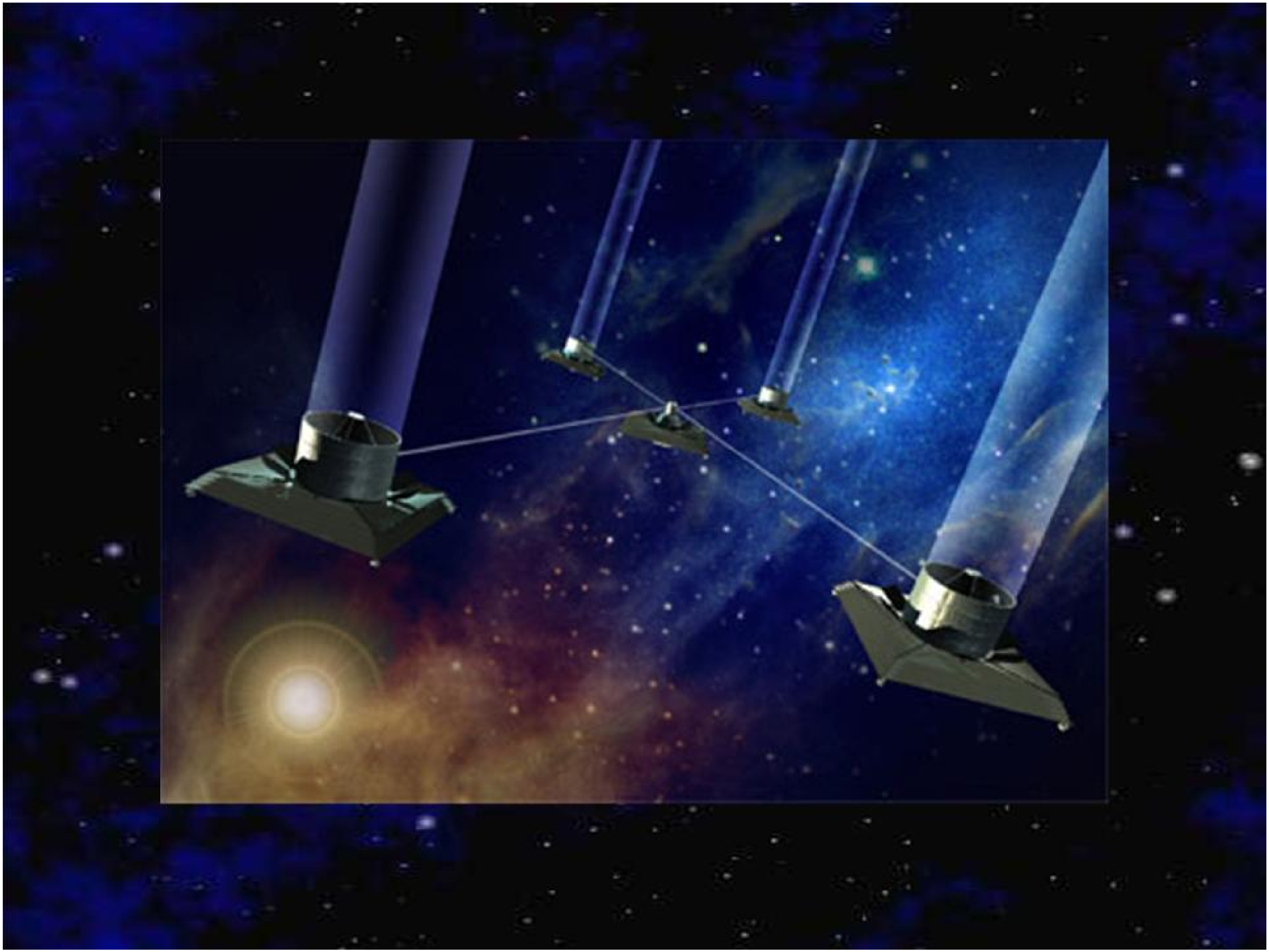
Models predict planet should be either rocky or covered with oceans

Gliese 581

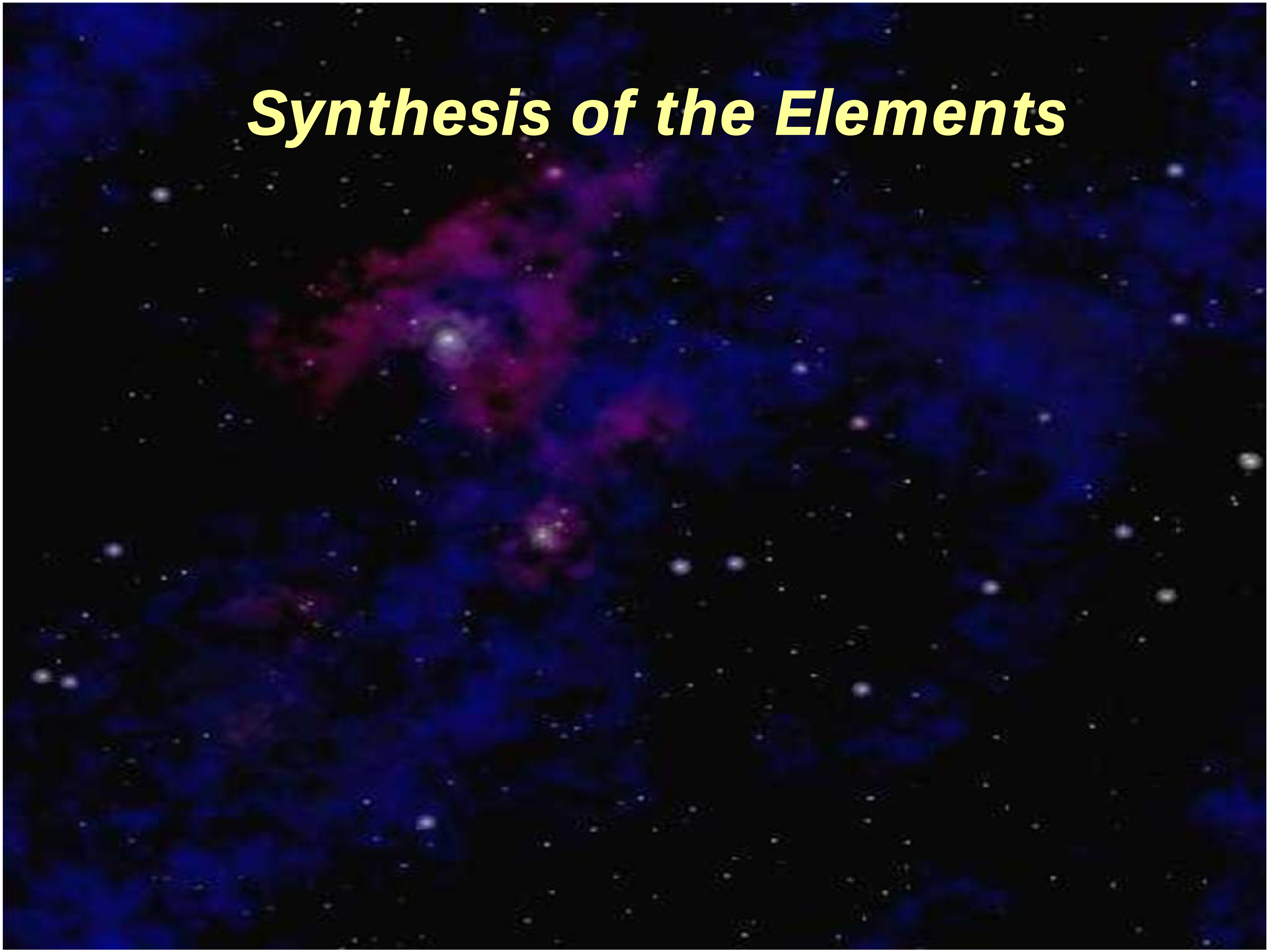
50% larger than earth, 5 times the mass
150 lb person would weight 333 lbs
Temperature: 32-104^{o}F

6,000,000 miles from M type star
13 days to complete orbit

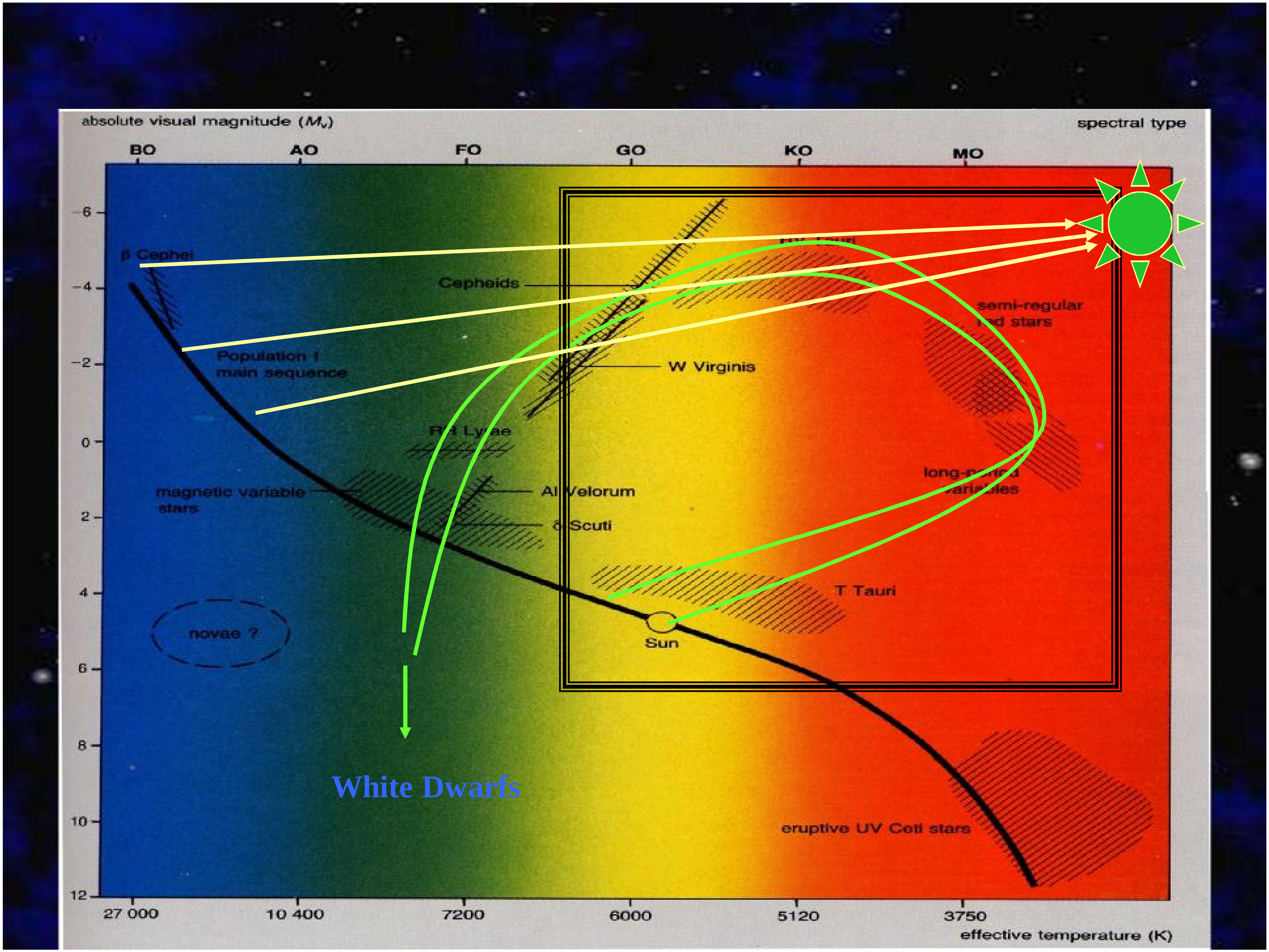

Habitable Zone
Mass of star relative to Sun
2
1
0,5
Mars
Earth
Venus
0
0,1
1
10
40
Radius of orbit relative to Earth's



Synthesis of the Elements



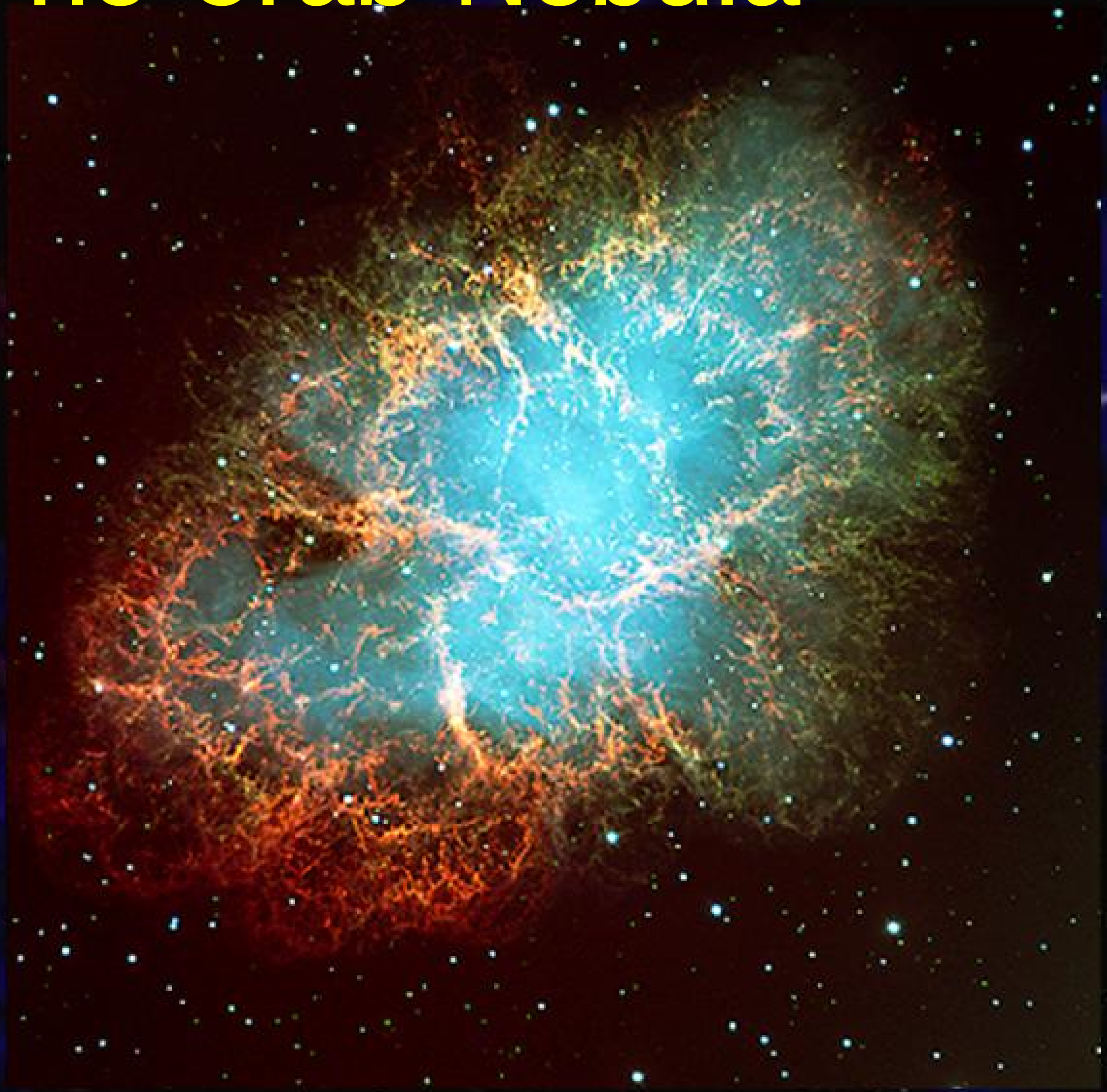
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H 1.008	2 IIA 2A											13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
		3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8	9 ------- VIII ------- ------- 8 -------	10	11 IB 1B	12 IIB 2B						
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.47	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La* 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 190.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.5	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (210)	85 At (210)	86 Rn (222)



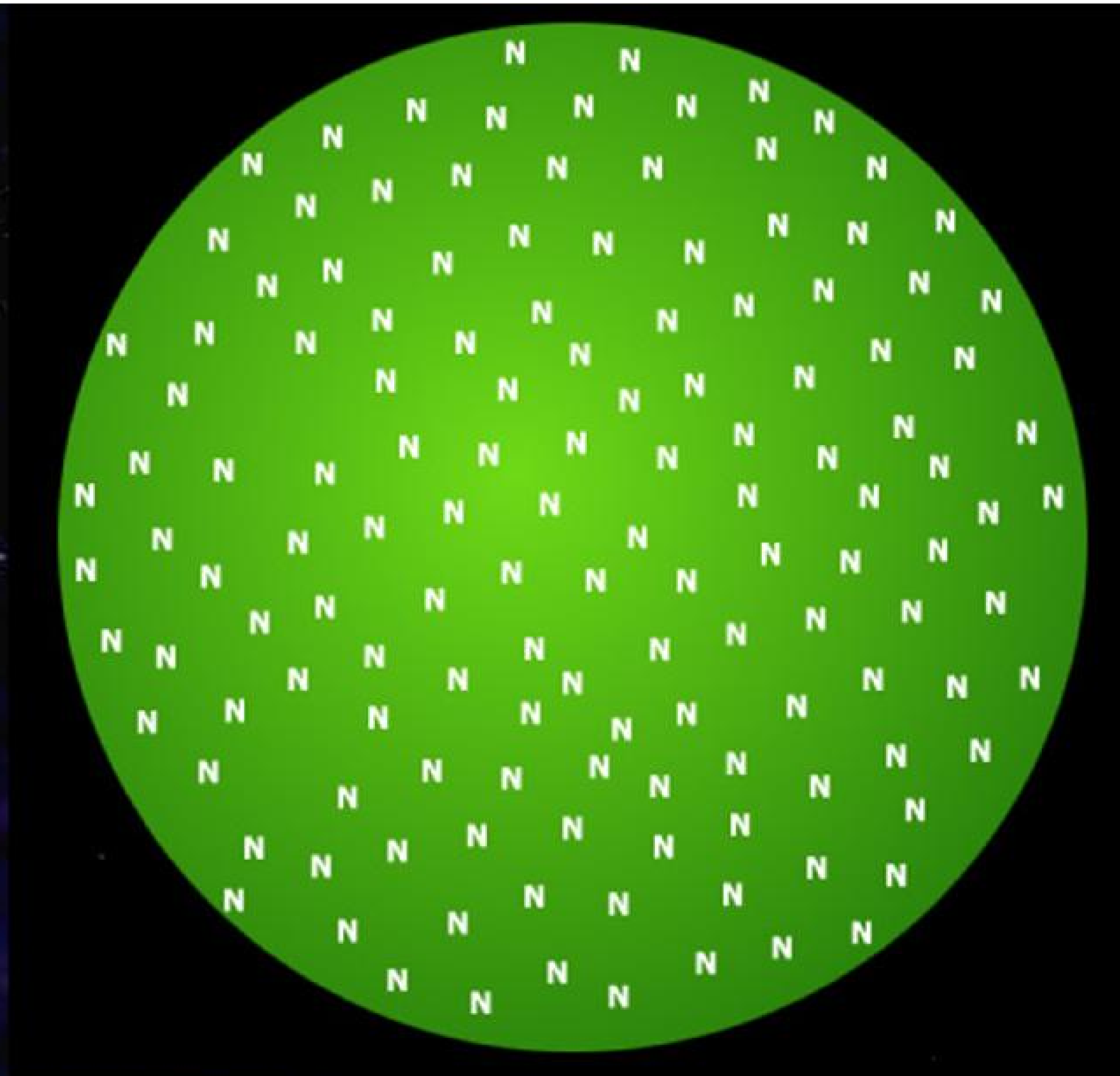
absolute visual magnitude (M_v)
spectral type
BO
AO
FO
GO
KO
MO
β Cephei
Cepheids
semi-regular
W Virginis
Population I
main sequence
RR Lyrae
magnetic variable
stars
AI Velorum
δ Scuti
T Tauri
Sun
novae ?
White Dwarfs
eruptive UV Ceti stars
27 000
10 400
7200
6000
5120
3750
effective temperature (K)

July, 1054 A.D.

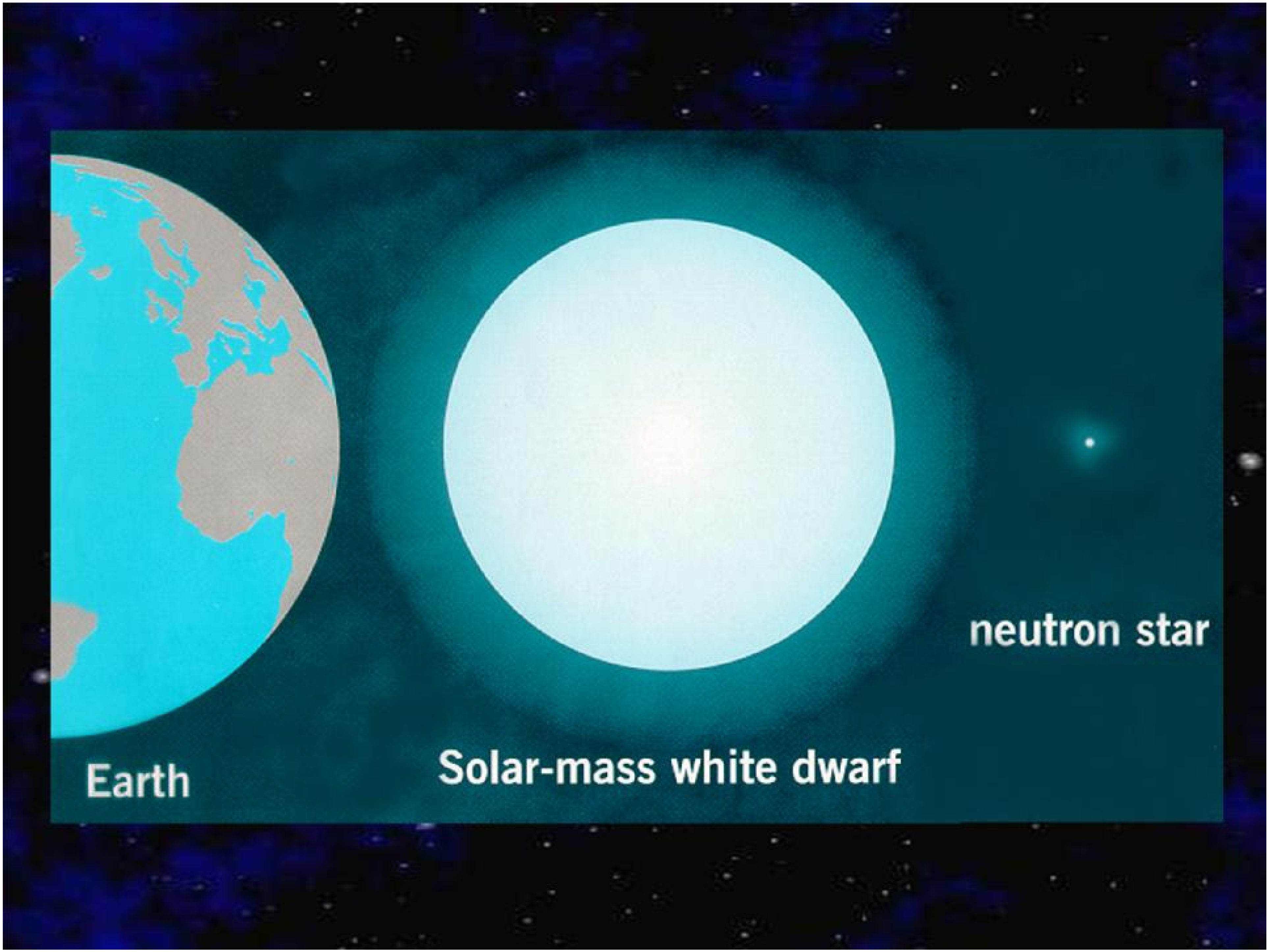
M1 - The Crab Nebula

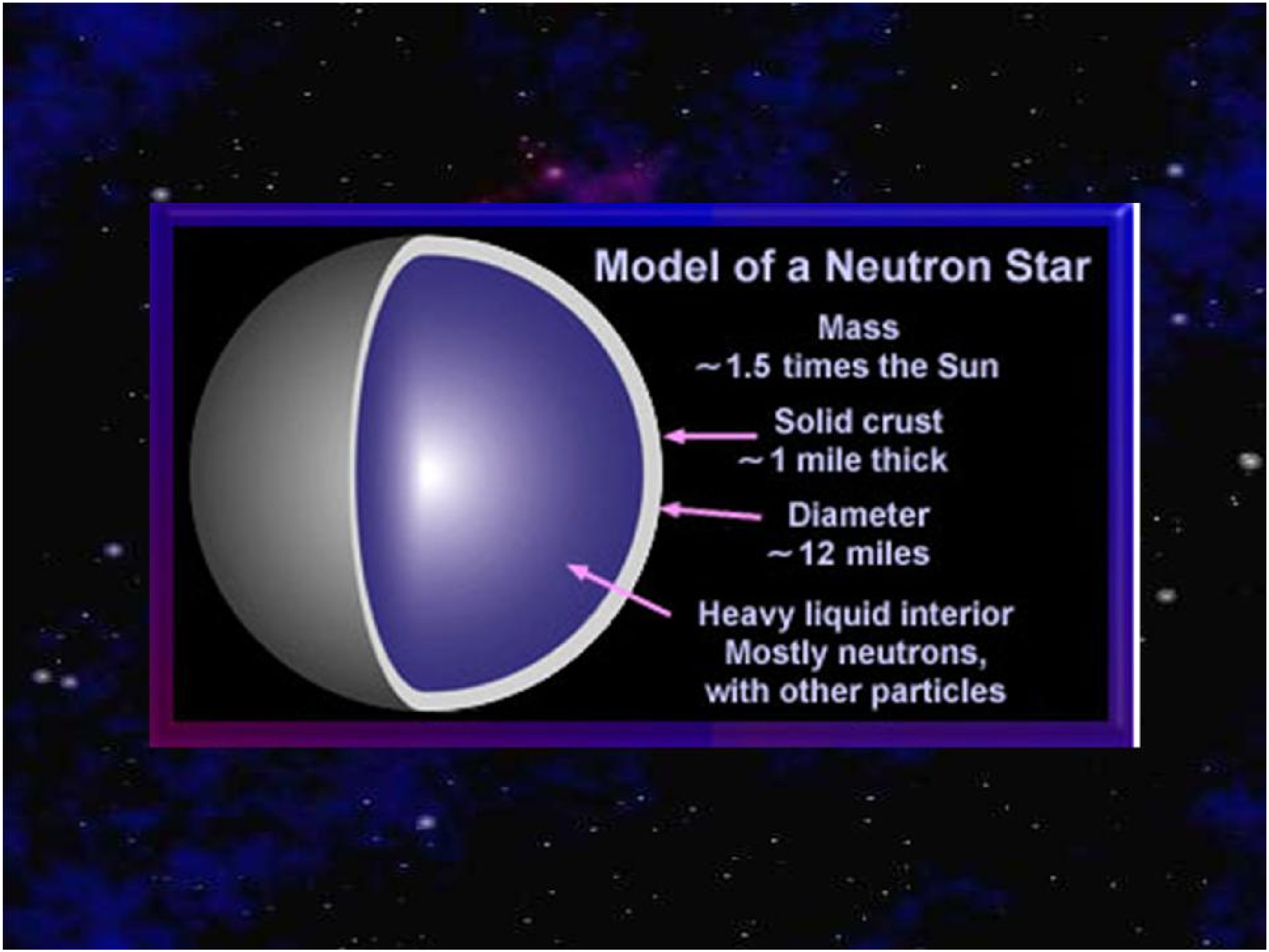


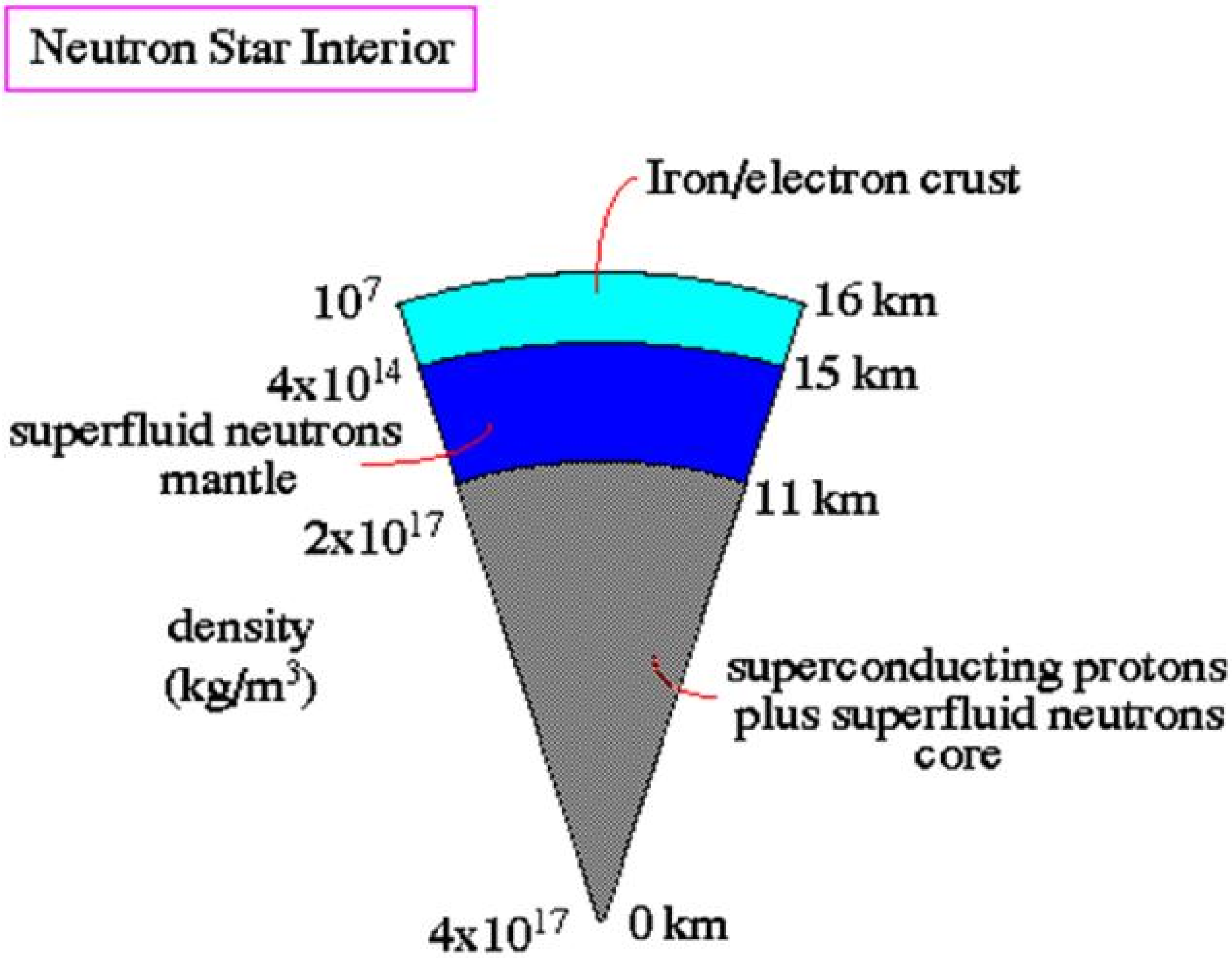
Crab Nebula



NEUTRON STAR


neutron star
Earth
Solar-mass white dwarf


Model of a Neutron Star
Mass
~1.5 times the Sun
Solid crust
~1 mile thick
Diameter
~12 miles
Heavy liquid interior
Mostly neutrons,
with other particles



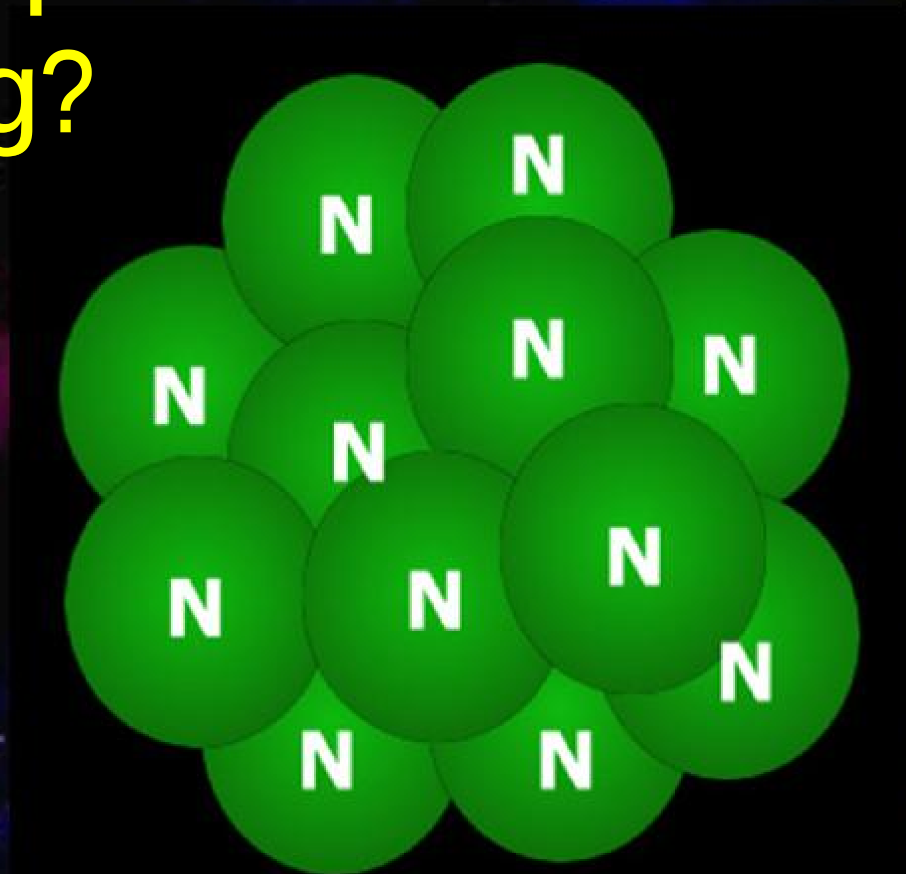
220,000,000 tons per cubic inch

Limit ~ 3 solar M

Spin up to 38000 rpm

Mag field: 10^{14} gauss

What keeps the neutron star from collapsing?



NEUTRON DEGENERACY PRESSURE

Neutrons have a limit to how tightly they can be packed together

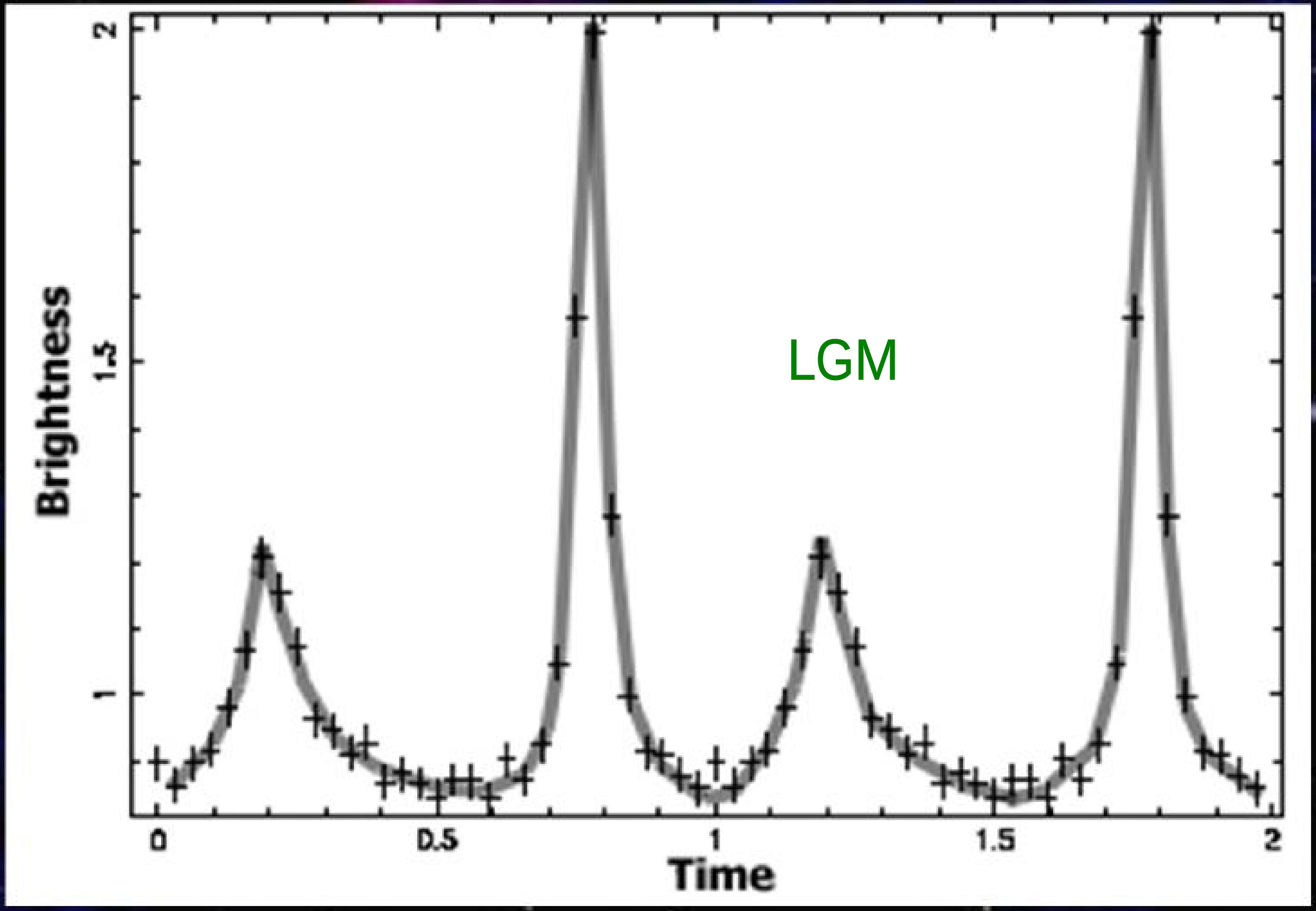
Chandrasekhar Limit for neutron stars

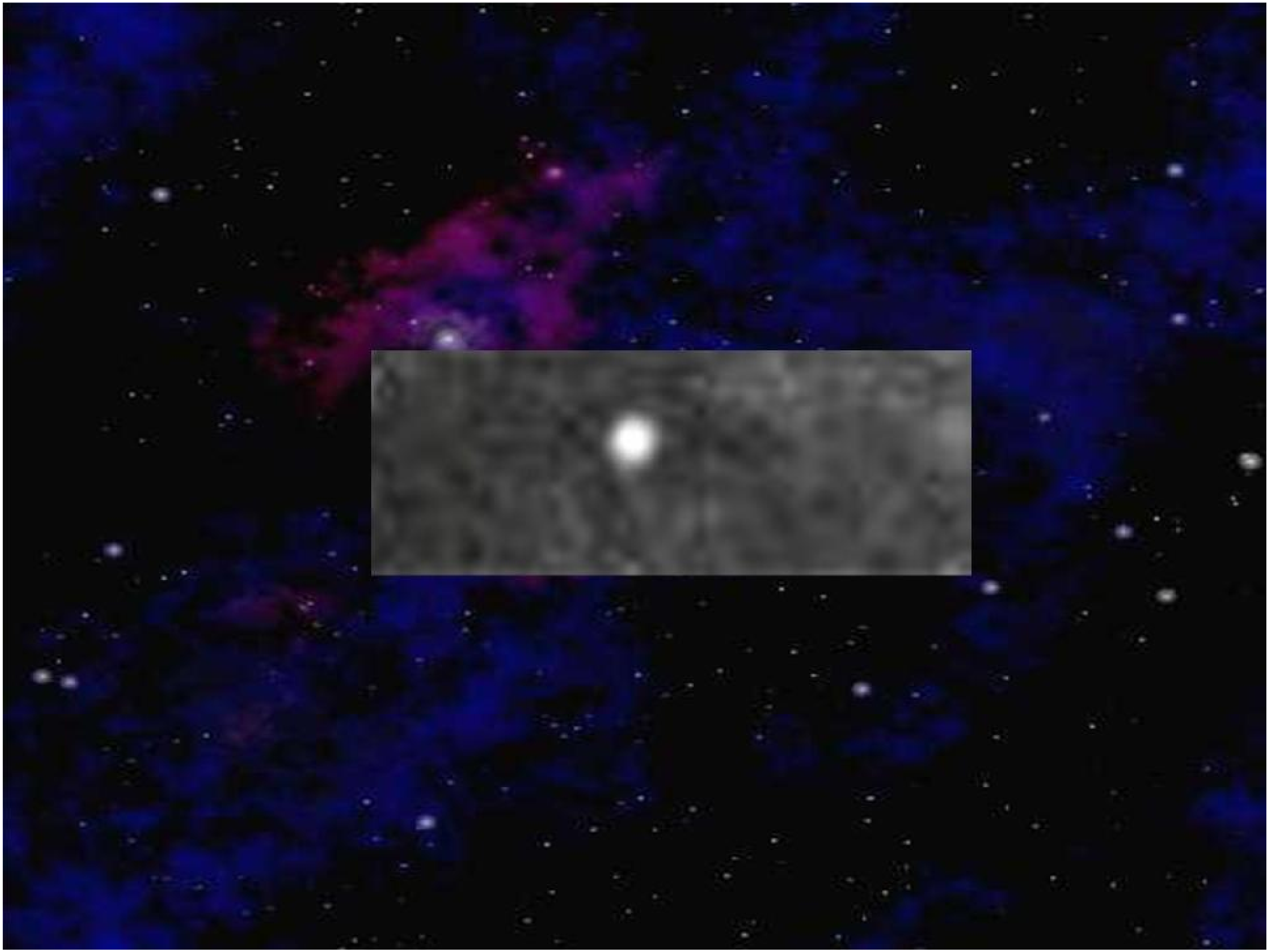
$$M < 3.0\ M_{\odot}$$

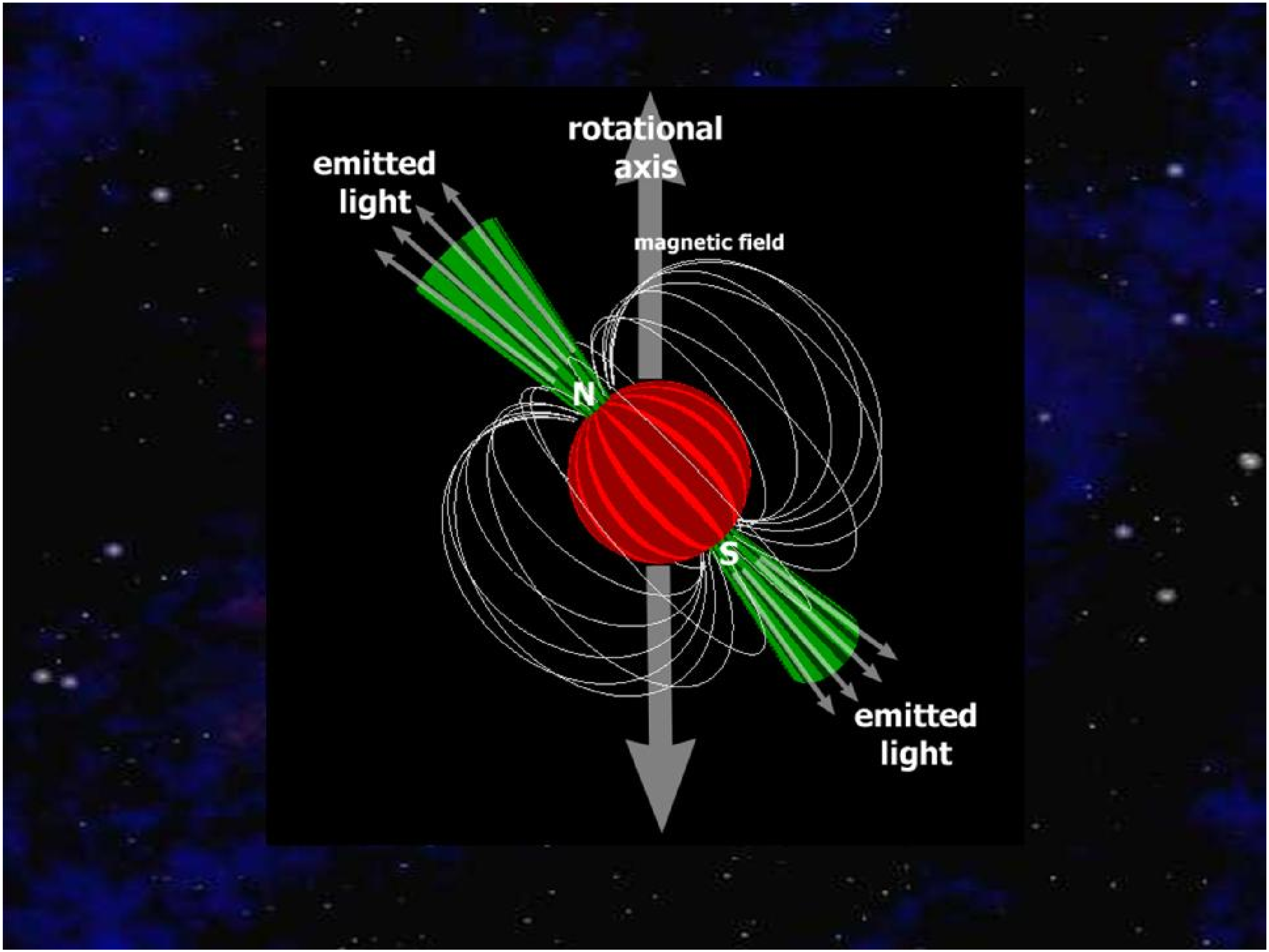
How do we know that neutron stars actually exist?

- First theorized in the 1930's
- First discovered in 1967

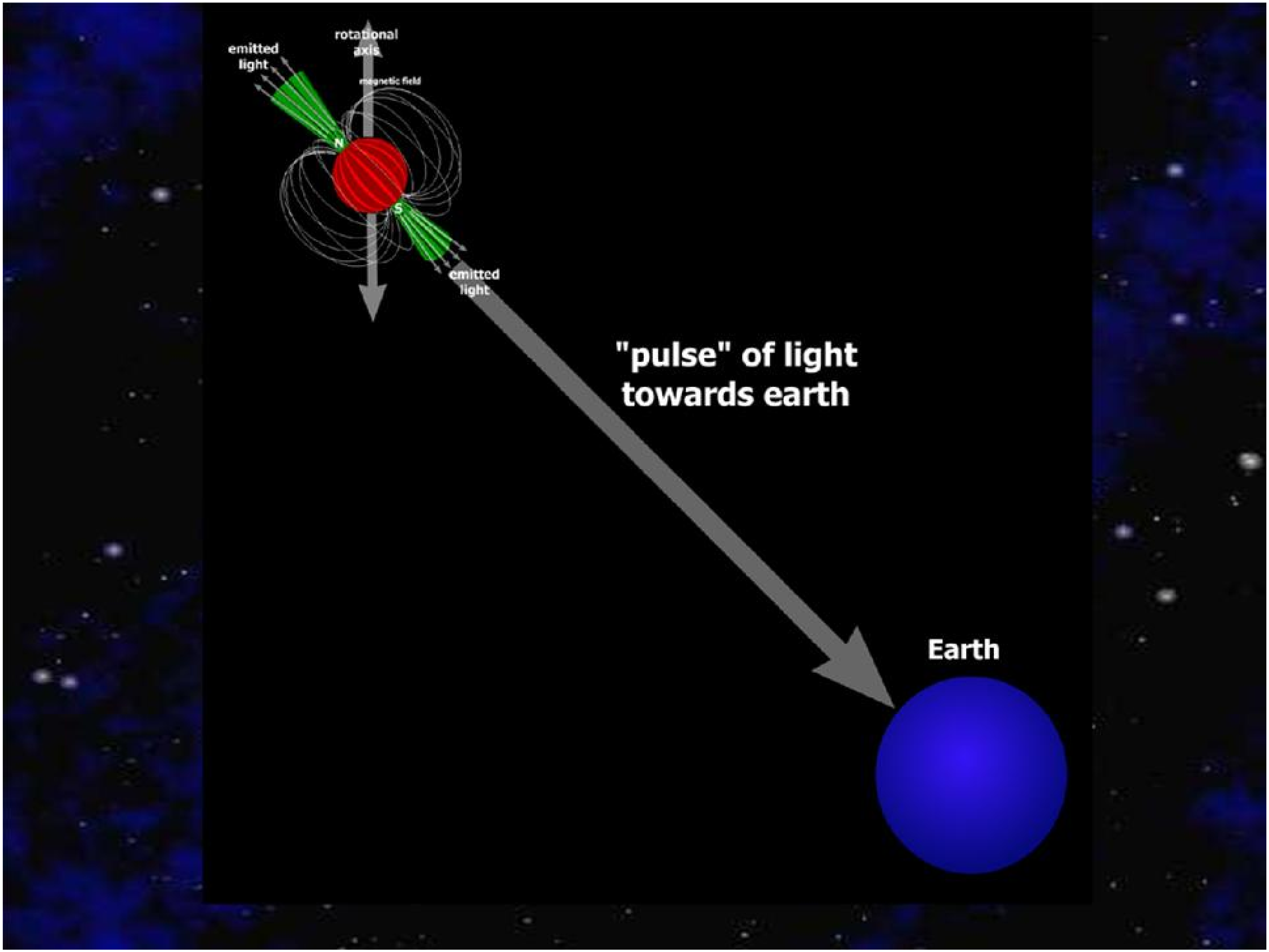
“pulsed” energy every 1.34 seconds

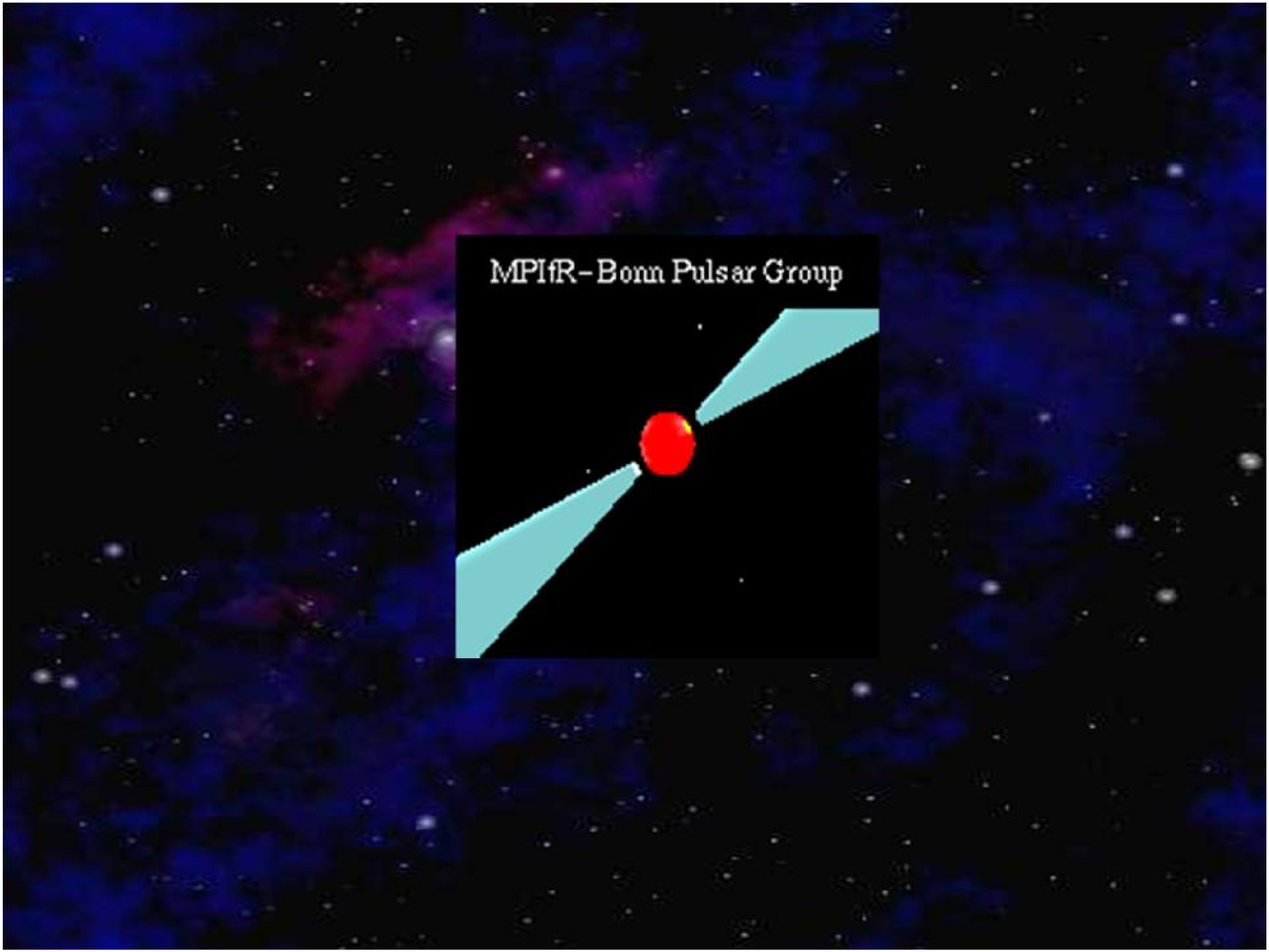





rotational axis
emitted light
magnetic field
N
S
emitted light

Conservation of Angular Momentum


rotational axis
emitted light
N
S
emitted light
"pulse" of light towards earth
Earth


MPIfR-Bonn Pulsar Group

esa

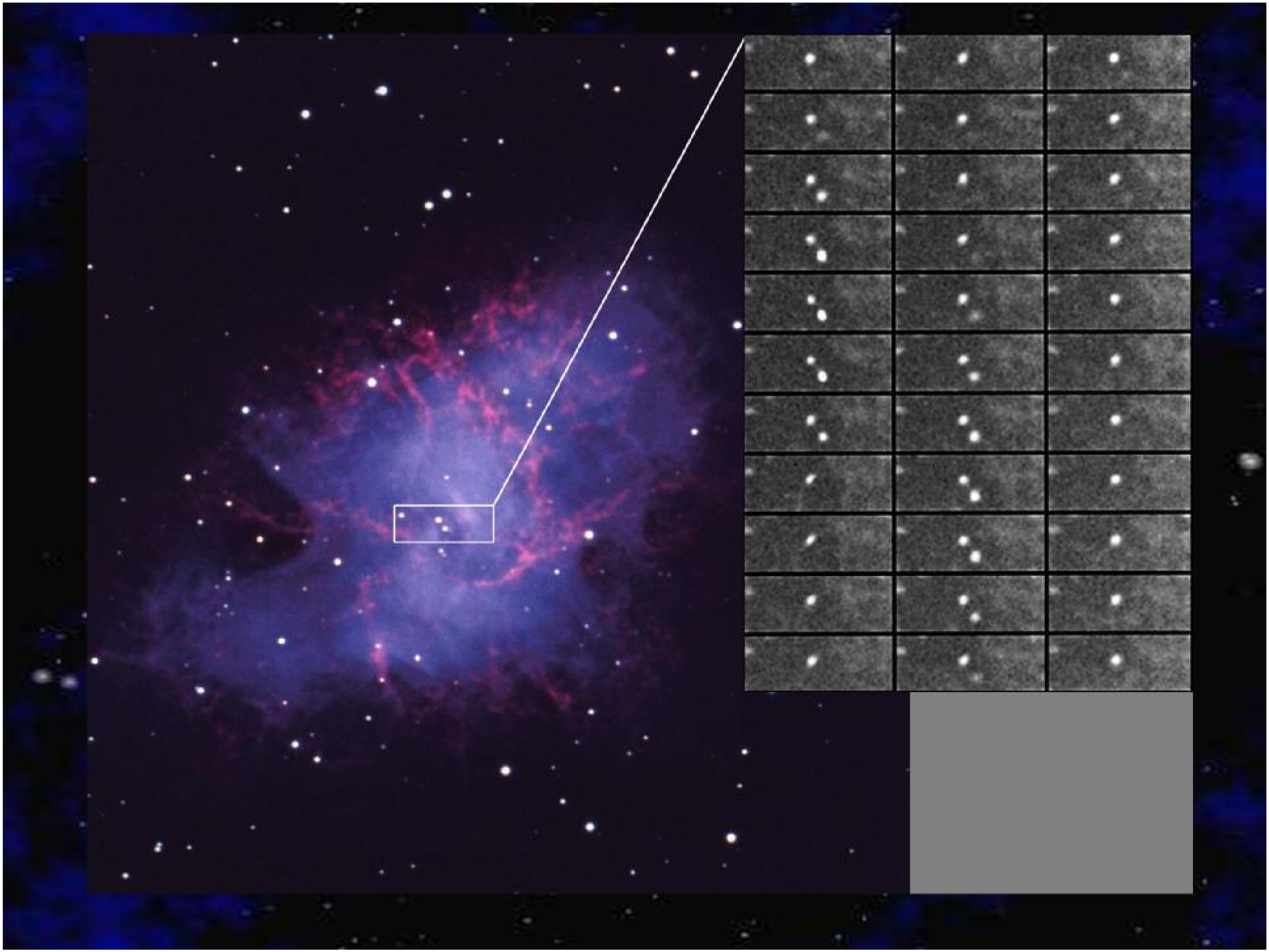
www.spacetelescope.org

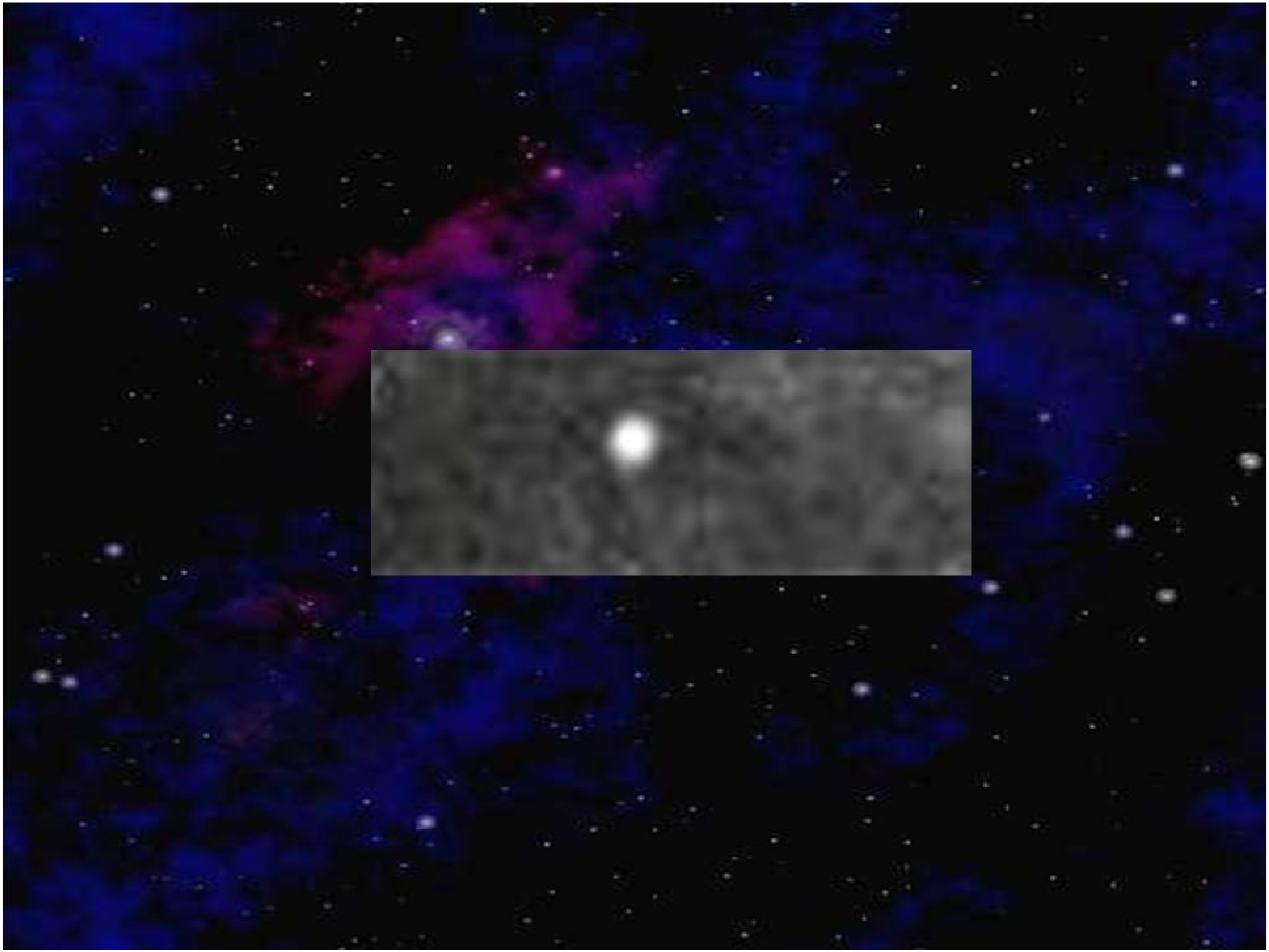
Rapidly rotating neutron star

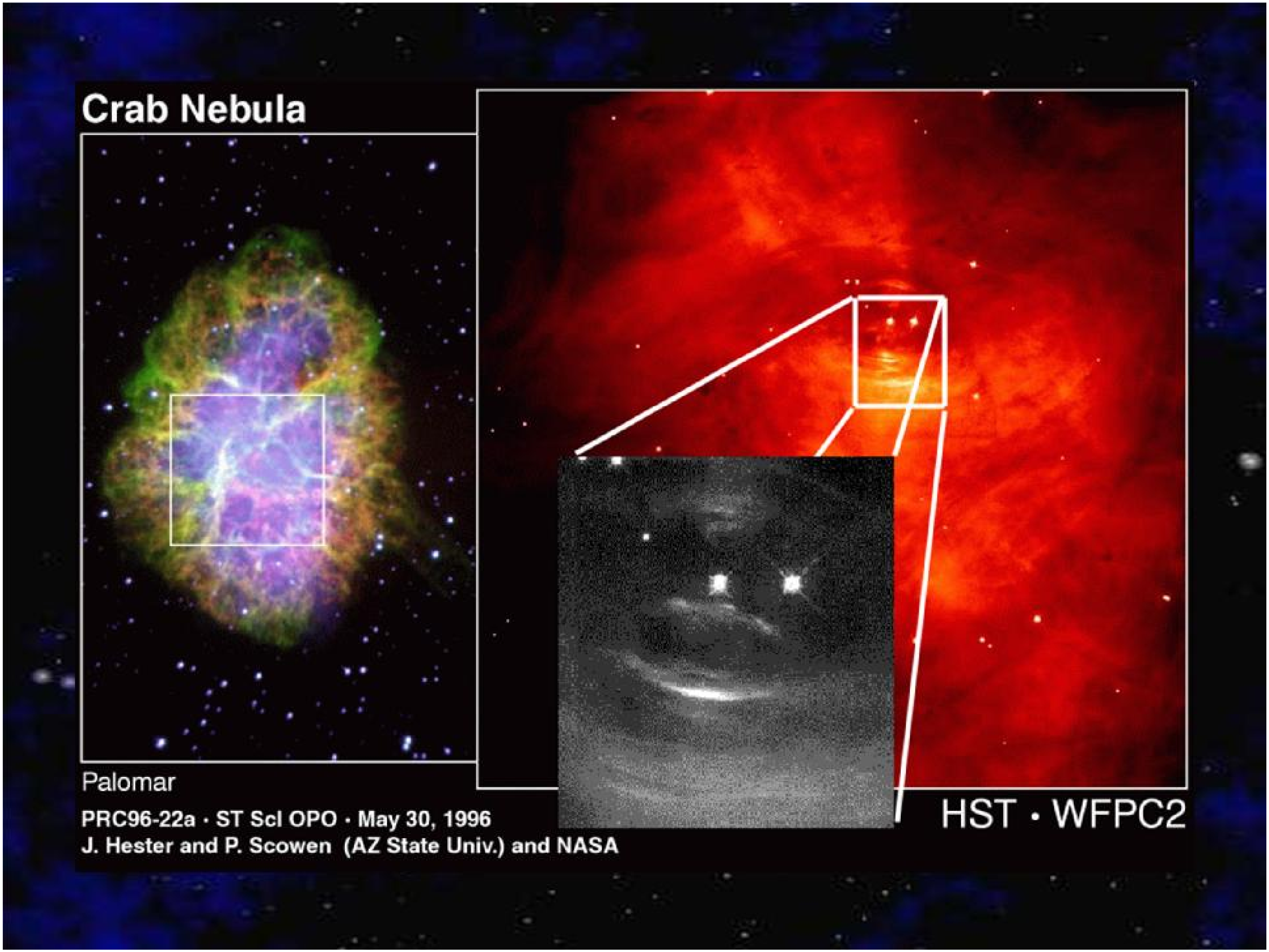
-or-

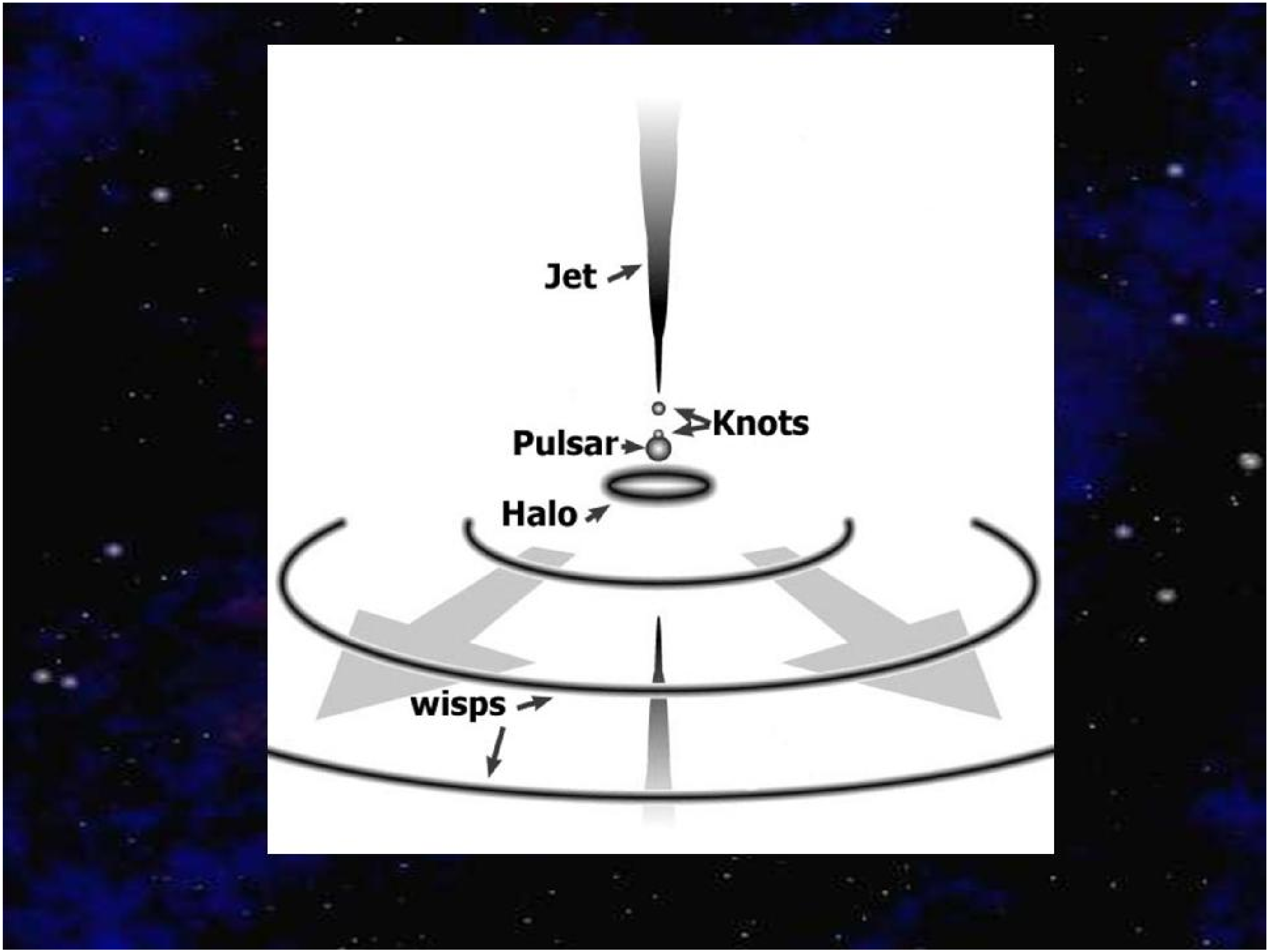
PULSAR

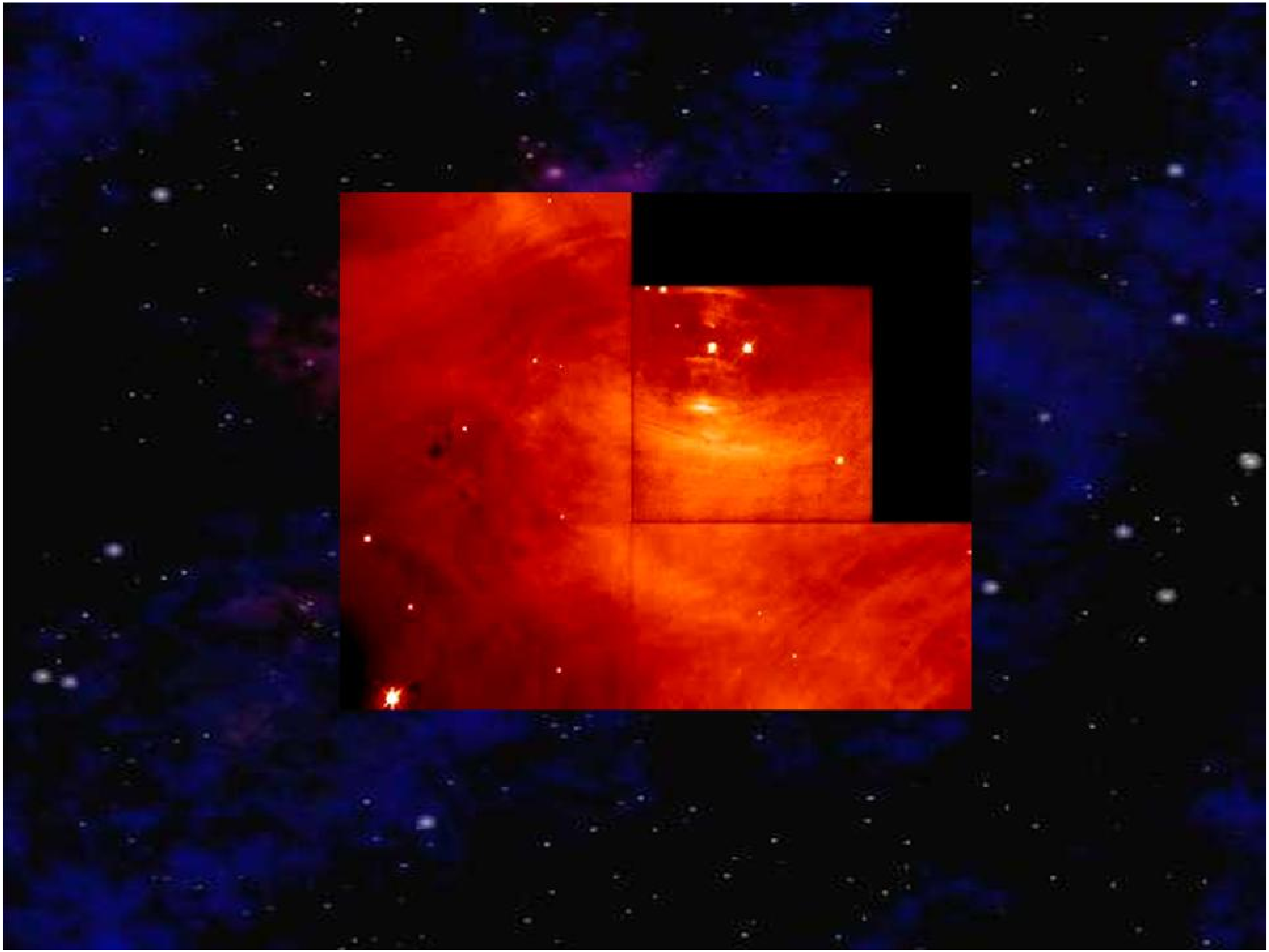
The Crab Nebula



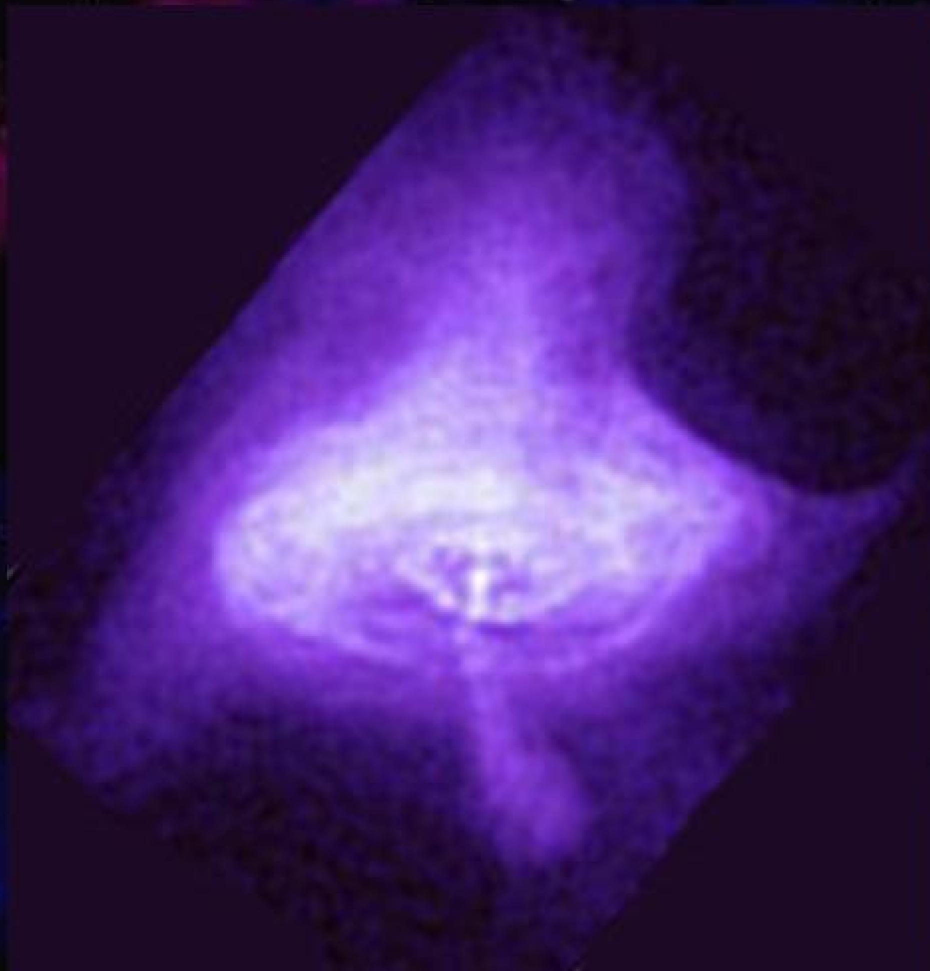



Crab Nebula
Palomar
PRC96-22a · ST ScI OPO · May 30, 1996
J. Hester and P. Scowen (AZ State Univ.) and NASA
HST · WFPC2

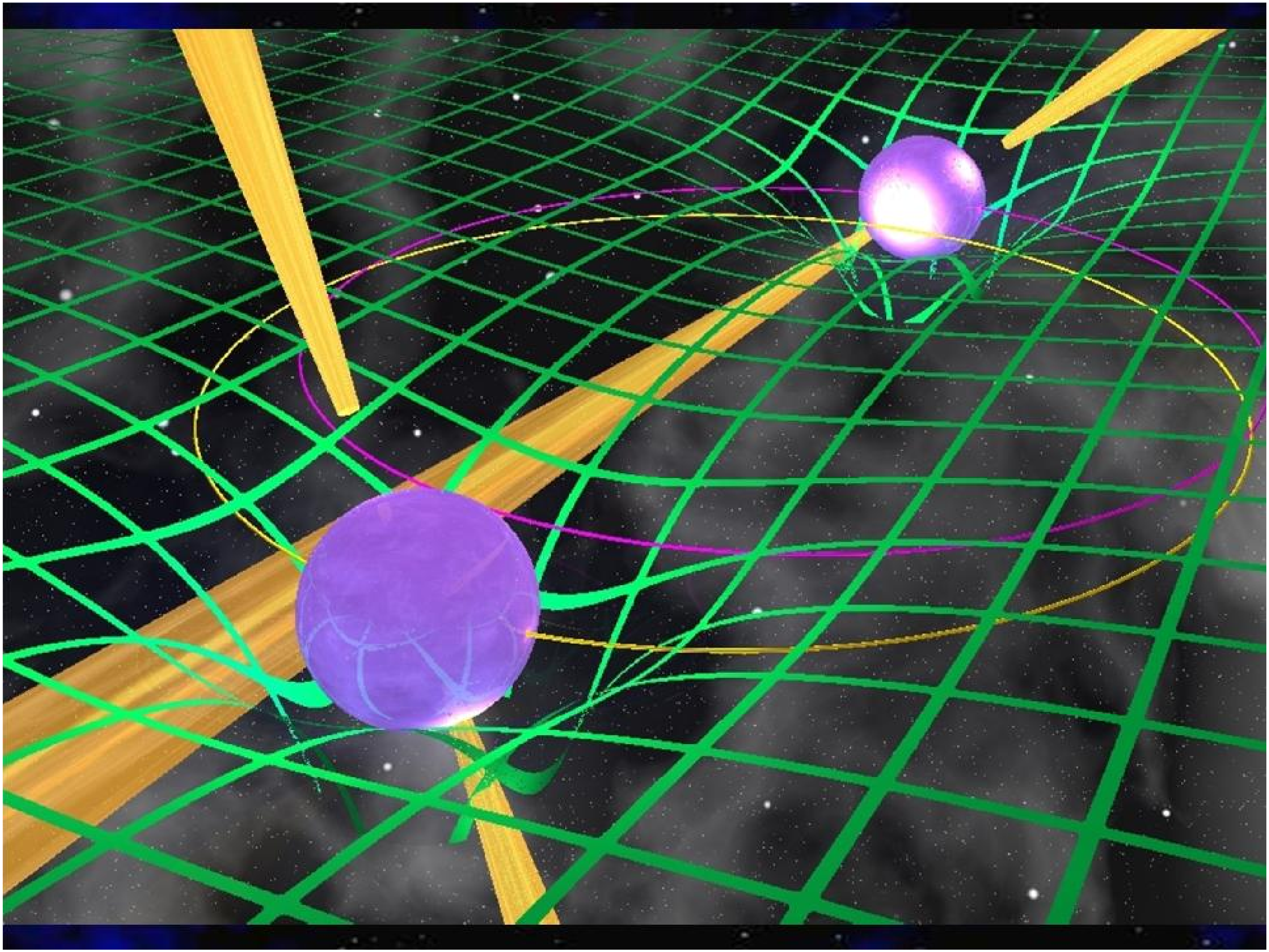

Jet
Knots
Pulsar
Halo
wisps

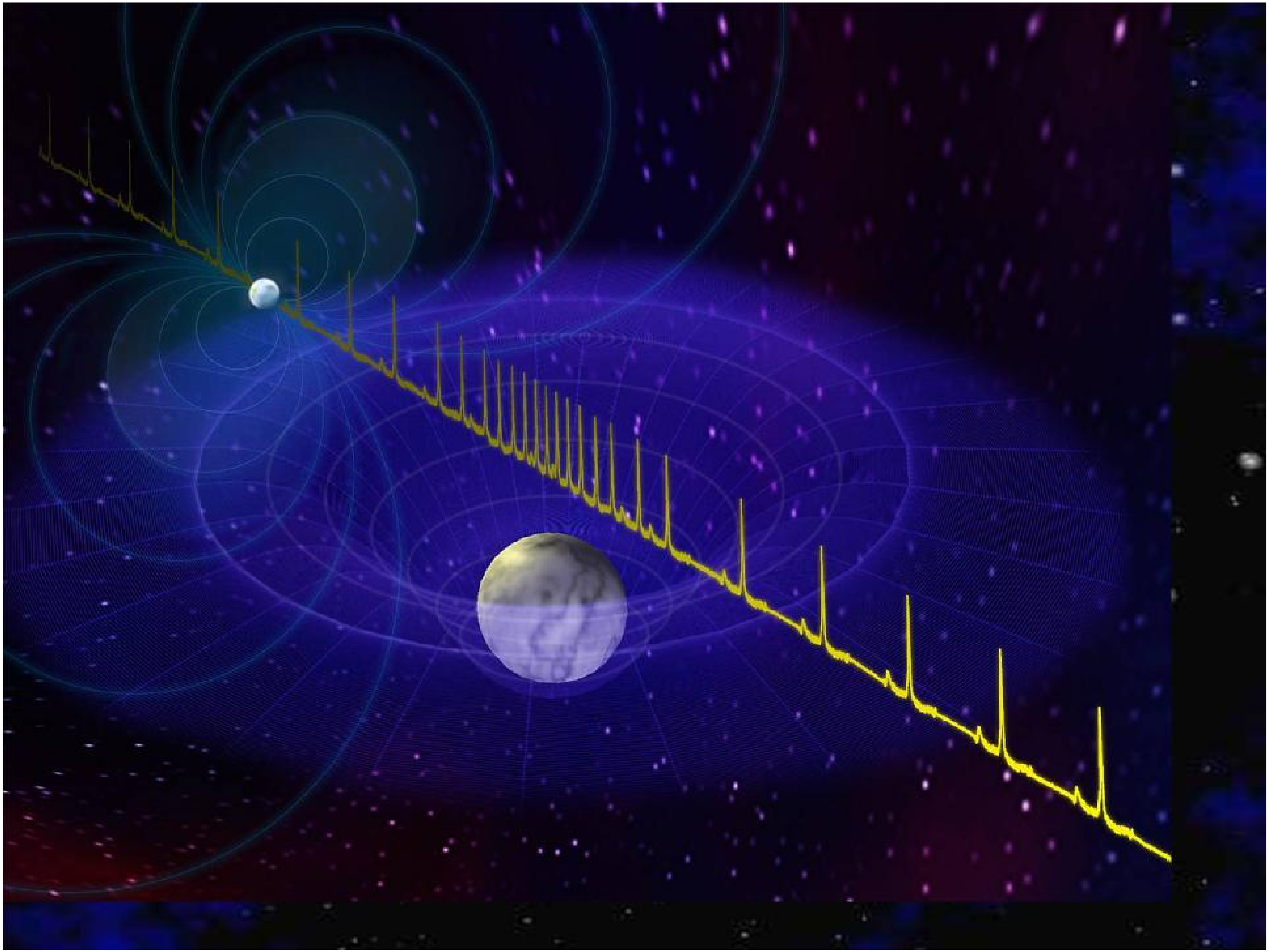


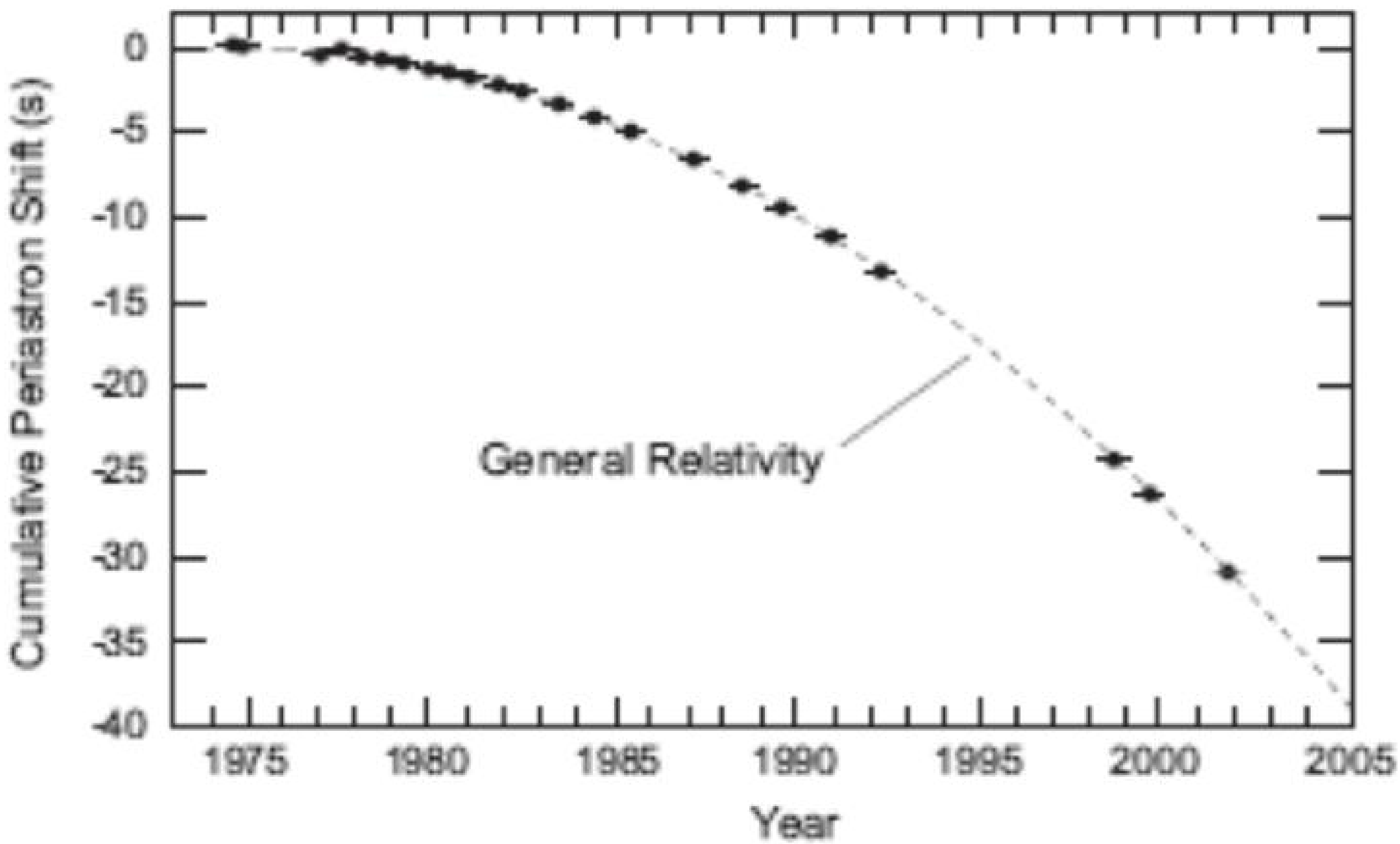
The Crab Pulsar – Xray image



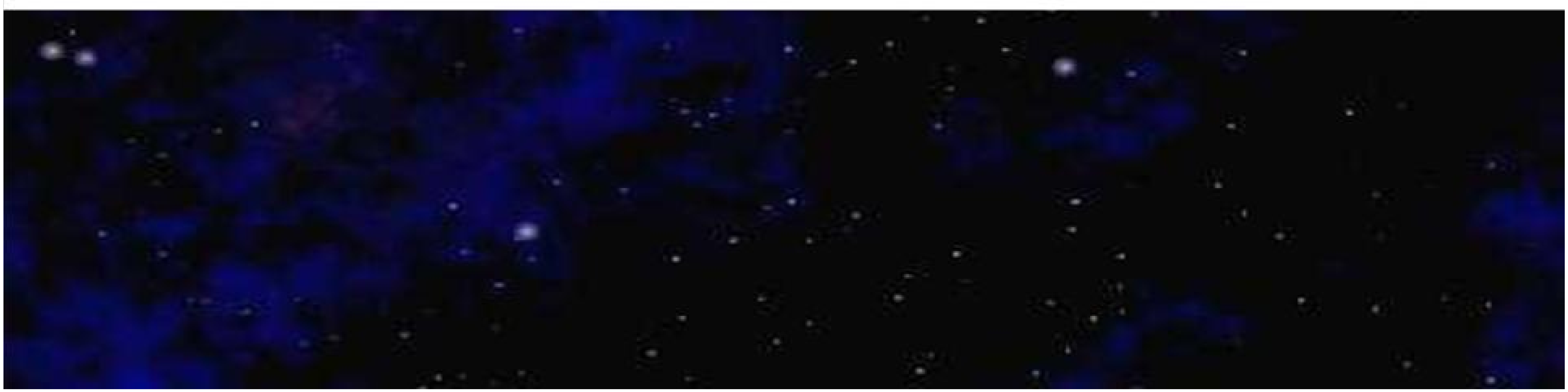
The Crab Pulsar





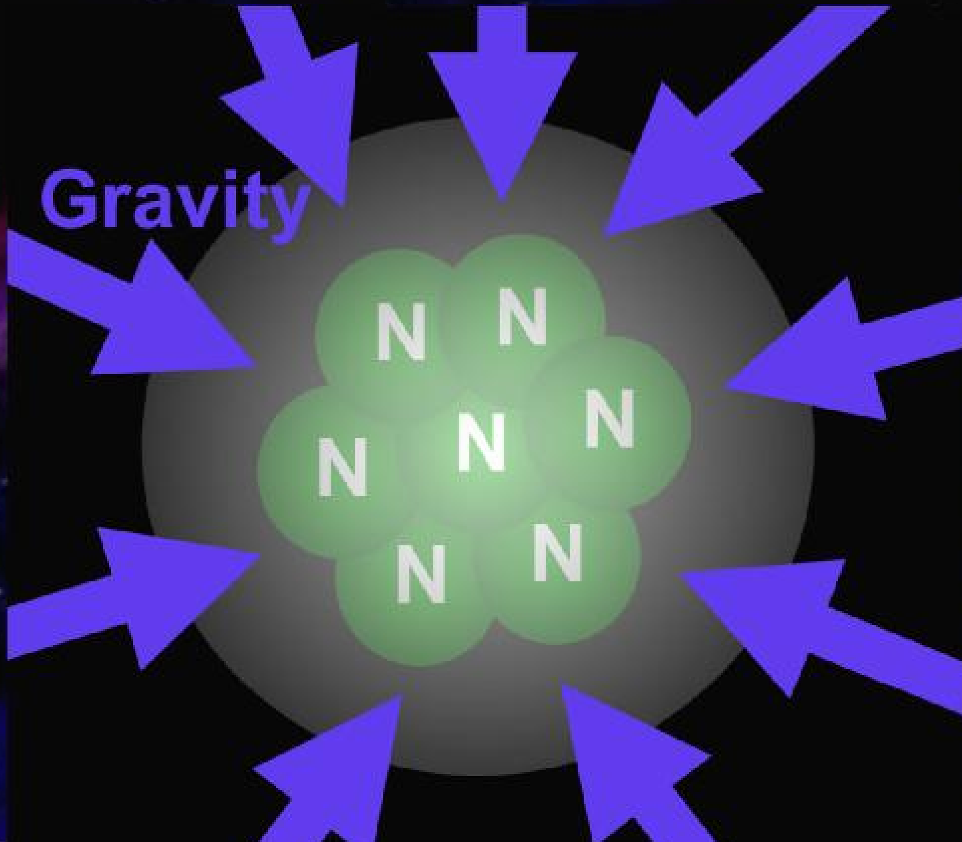


Cumulative Periastron Shift (s)
0
-5
-10
-15
-20
-25
-30
-35
-40
General Relativity
1975
1980
1985
1990
1995
2000
2005
Year



What if the core that survives the supernova blast is greater than 3.0 $M_{\odot}$?

What keeps the neutron star from collapsing?



Neutrons have a limit to how tightly they can be packed together

NEUTRON DEGENERACY PRESSURE

Chandrasekhar Limit for neutron stars

$$M < 3.0\ M_{\odot}$$

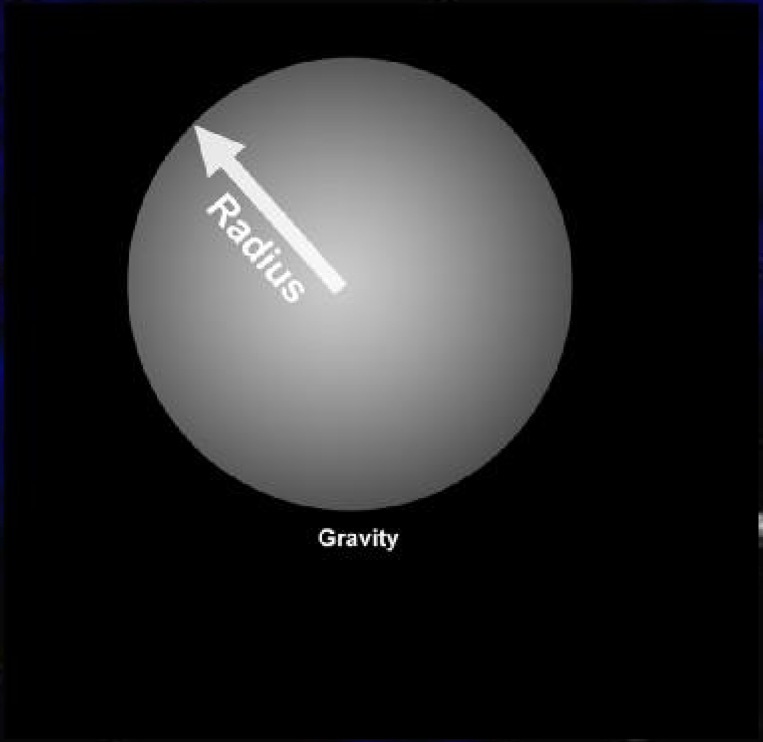
"It's black, and it looks like a hole. I'd say it's a black hole."

What if the iron core > $3.0M_{\odot}$

- Degeneracy pressure is overcome by gravity
- The core continues to shrink producing NO HEAT.
- No force in nature can stop the collapse

ESCAPE VELOCITY

$$V_{esc} = \sqrt{\frac{2GM}{R}}$$



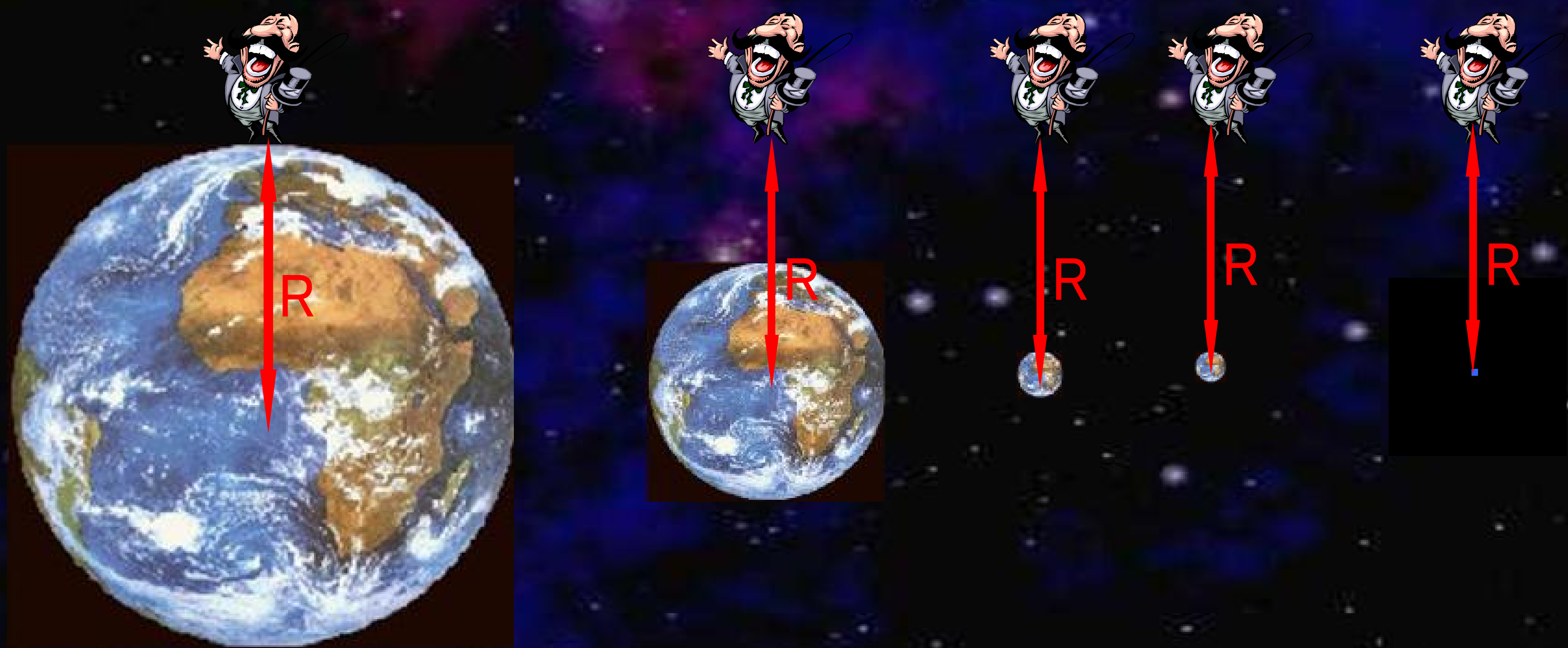
G = Universal Gravitational Constant

M = Mass of the gravitating body

R = Radius of the gravitating body

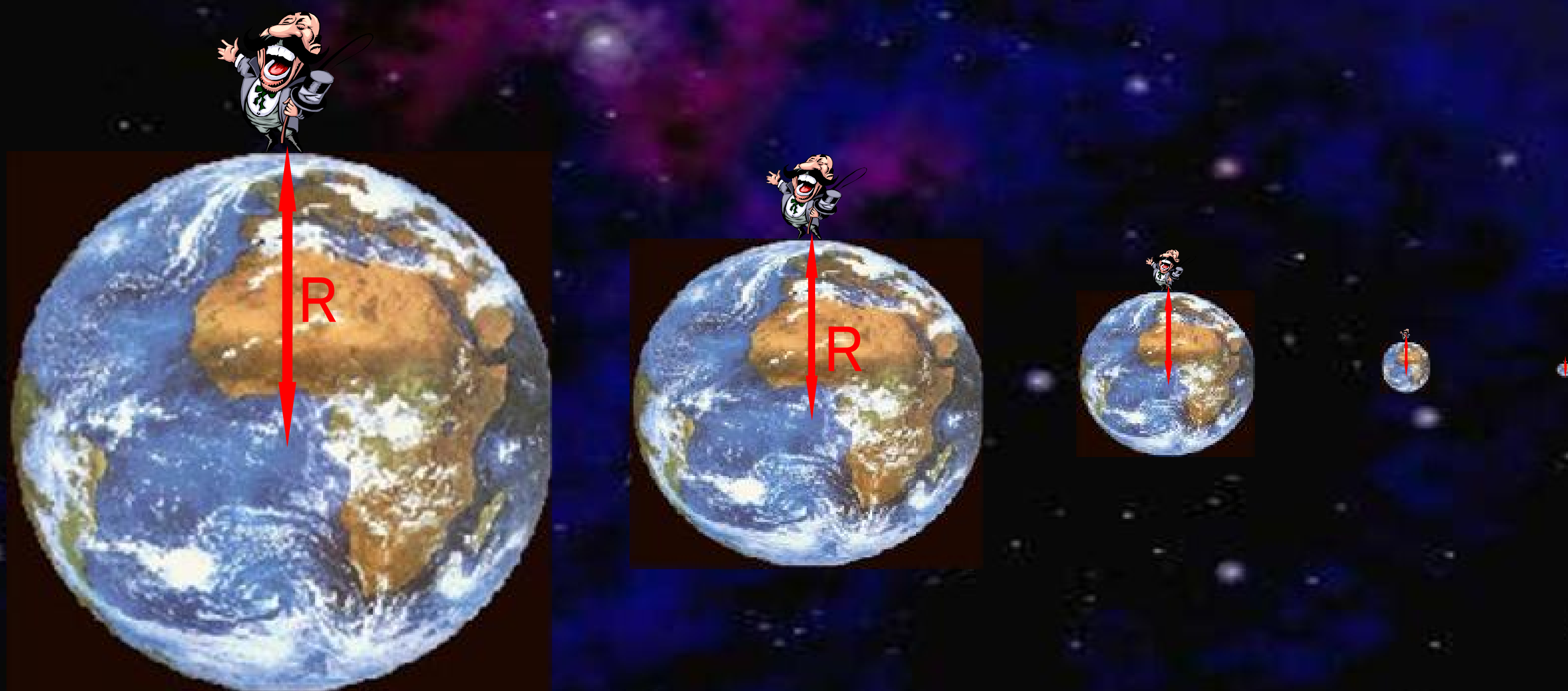
$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

$$F = \frac{Gm_1 m_2}{r^2}$$



$$V_{esc} = \sqrt{\frac{2GM}{R}}$$

$$F = \frac{Gm_1m_2}{r^2}$$

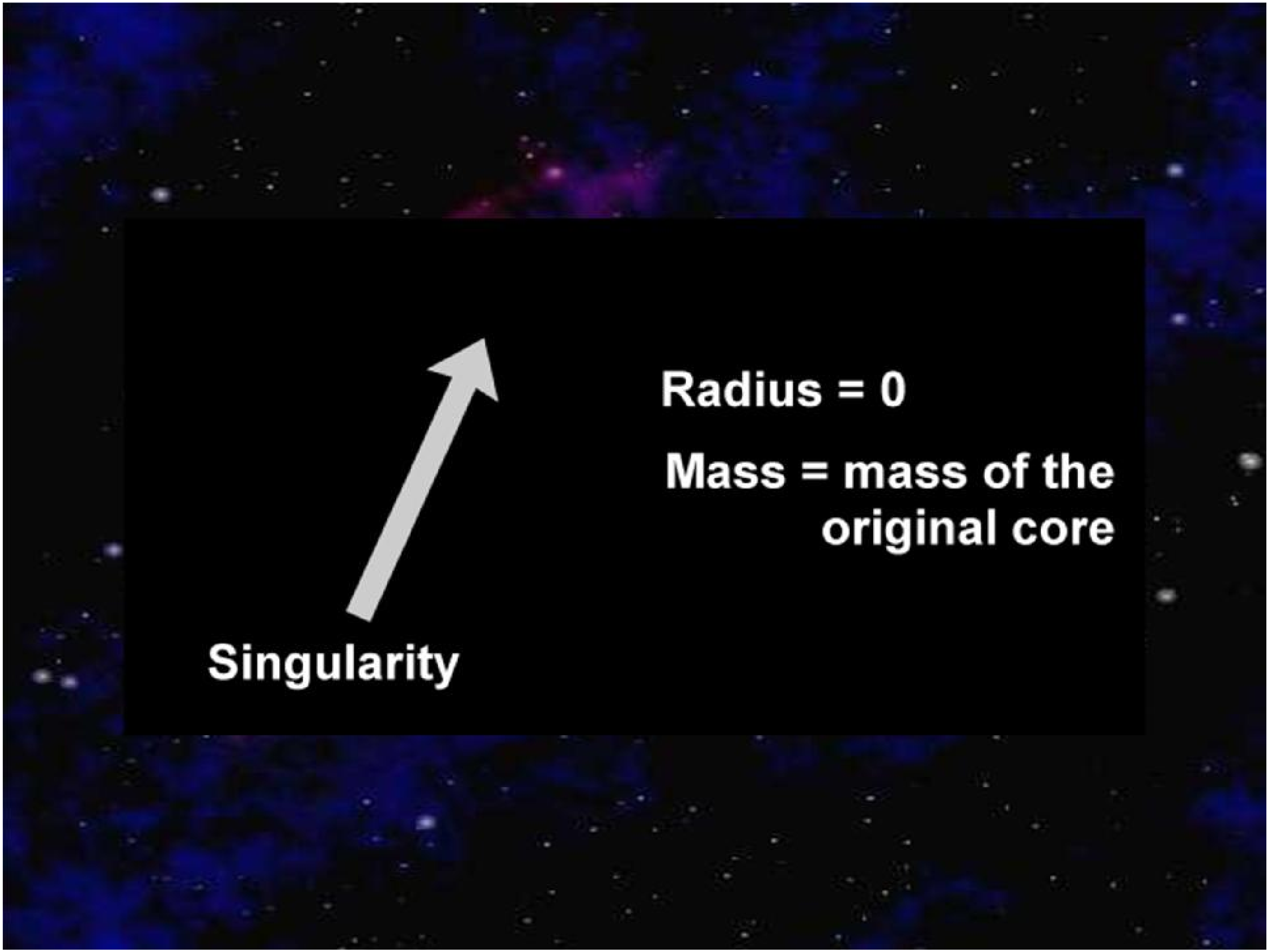


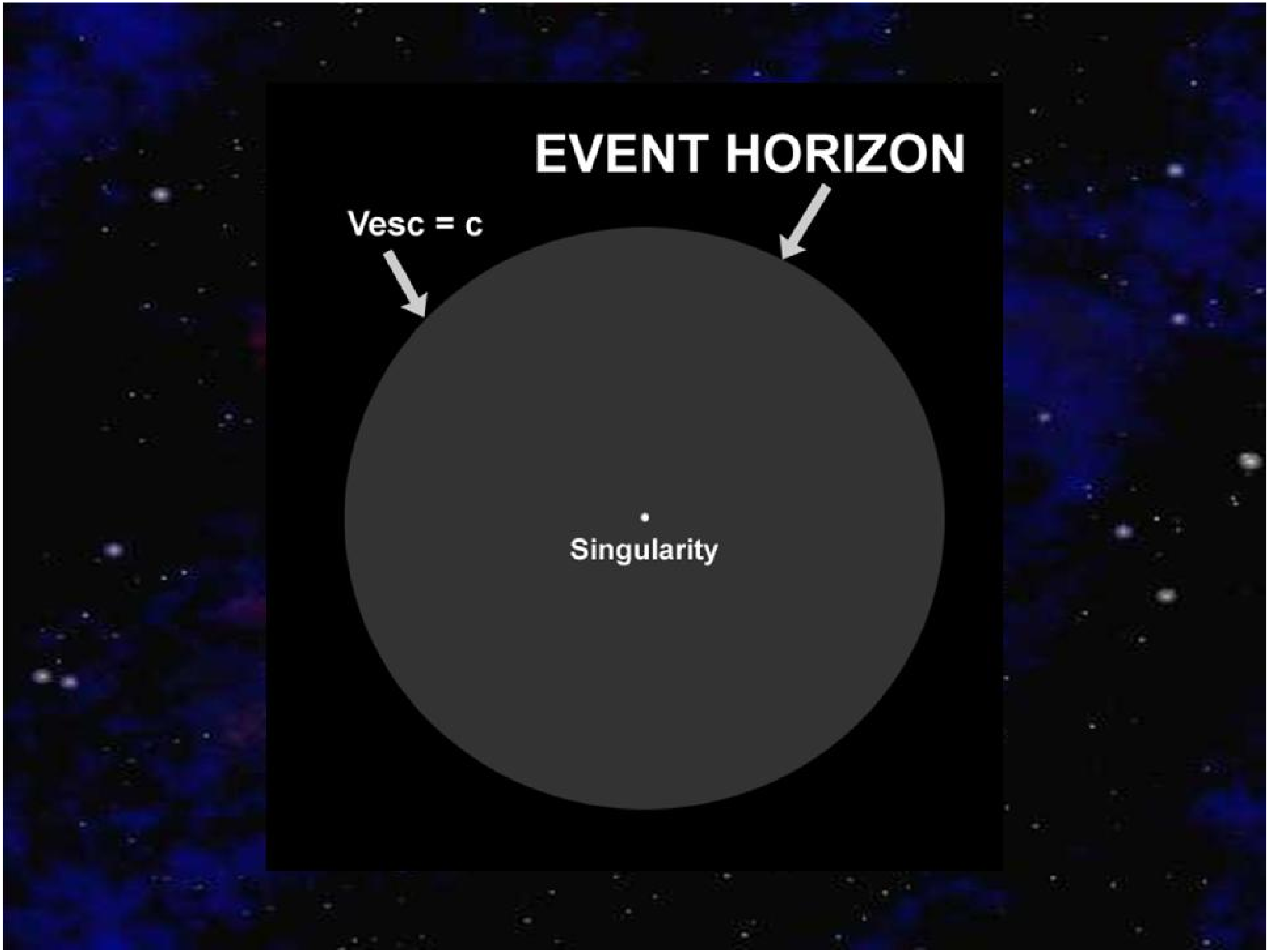
Soon the escape velocity is

greater than the speed of light!

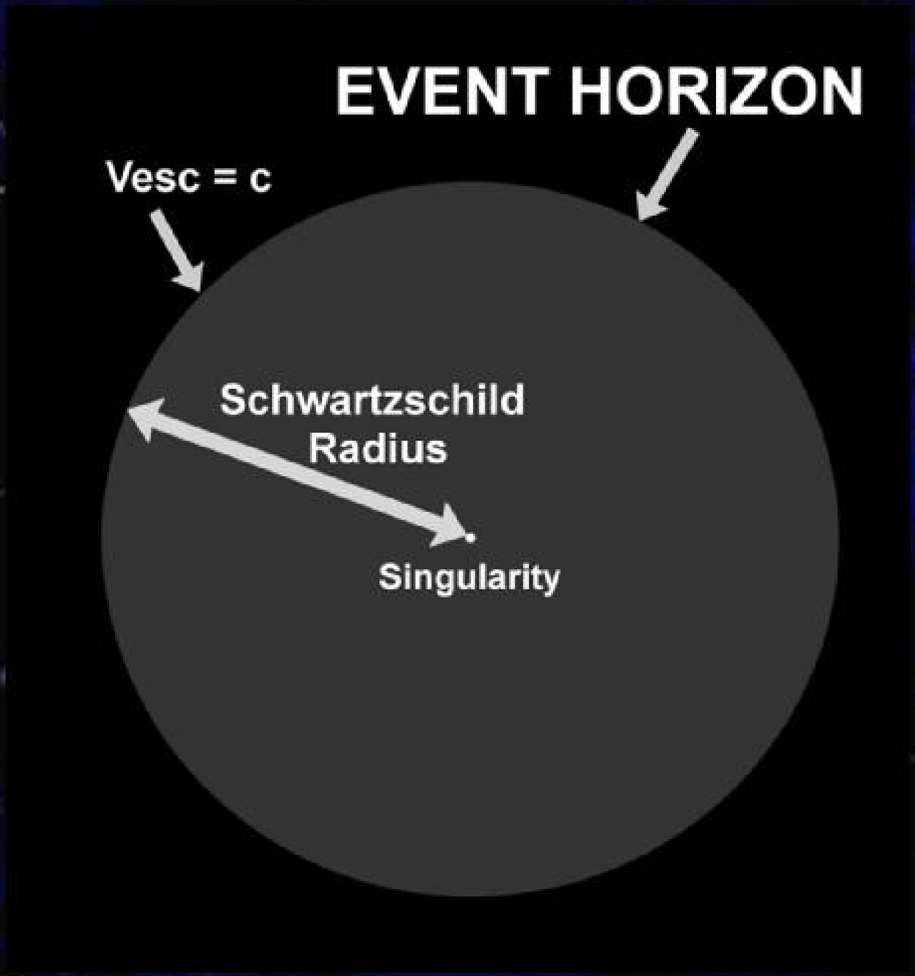
Ultimately, the gravity is so strong that NOT EVEN *LIGHT* CAN ESCAPE!

BLACK HOLE


Radius = 0
Mass = mass of the original core
Singularity


EVENT HORIZON
Vesc = c
Singularity

Physical Properties of Black Holes



$$R = \frac{2GM}{c^2}$$

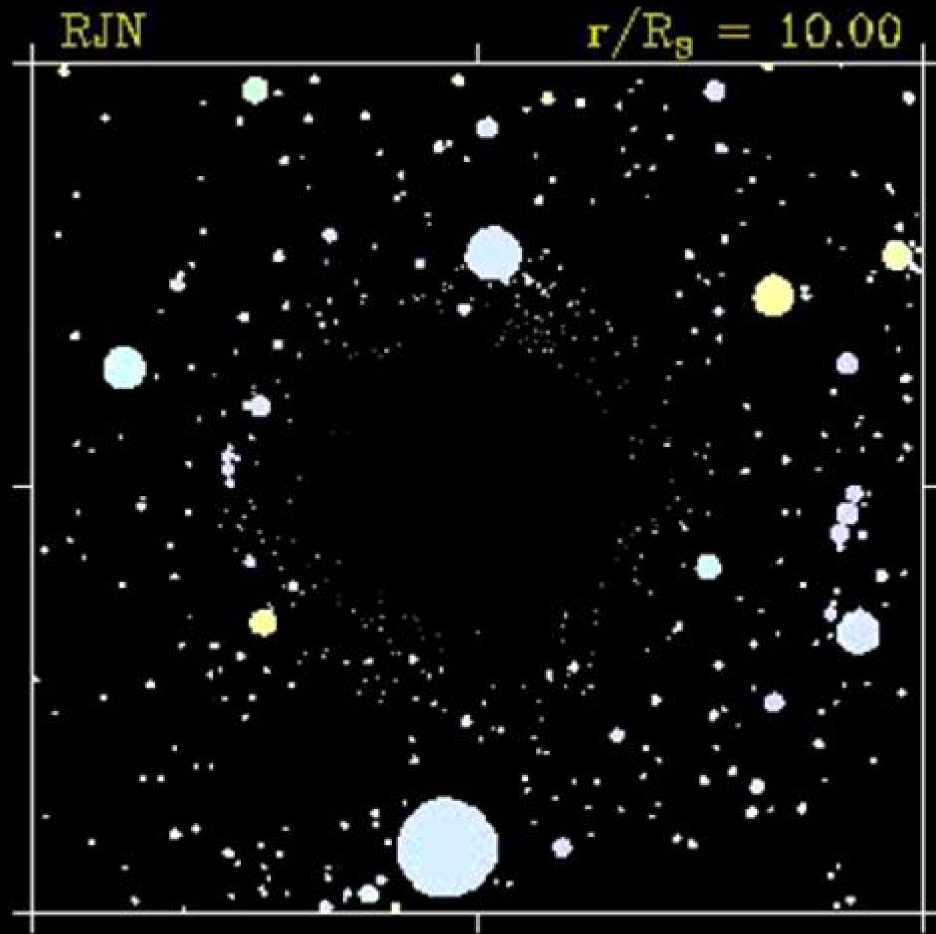
R = Schwartzschild Radius

Size of event horizon depends only on MASS

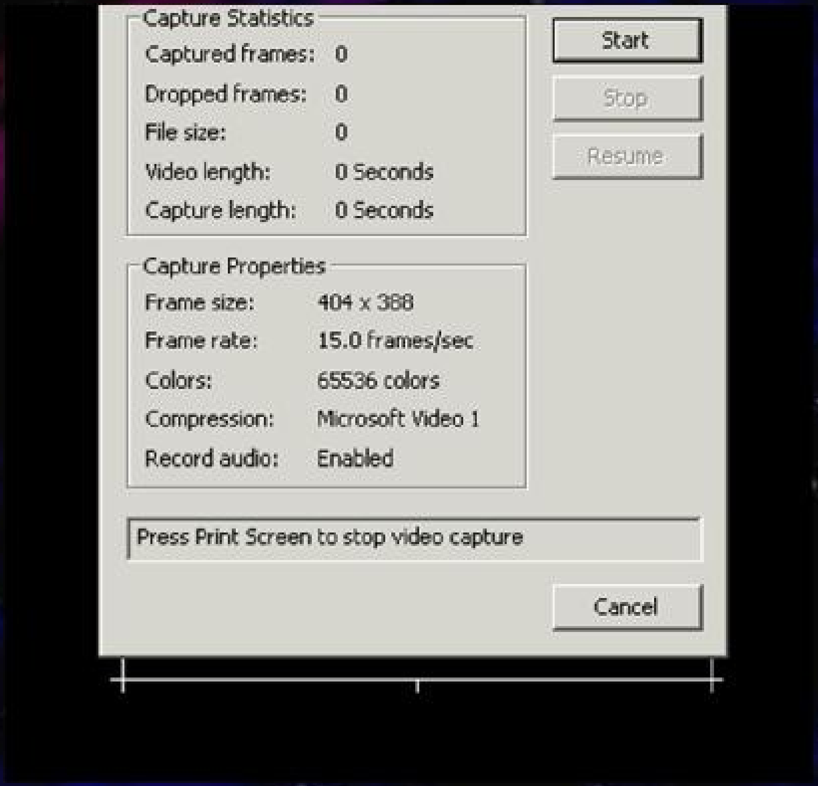
Mass bends space and time

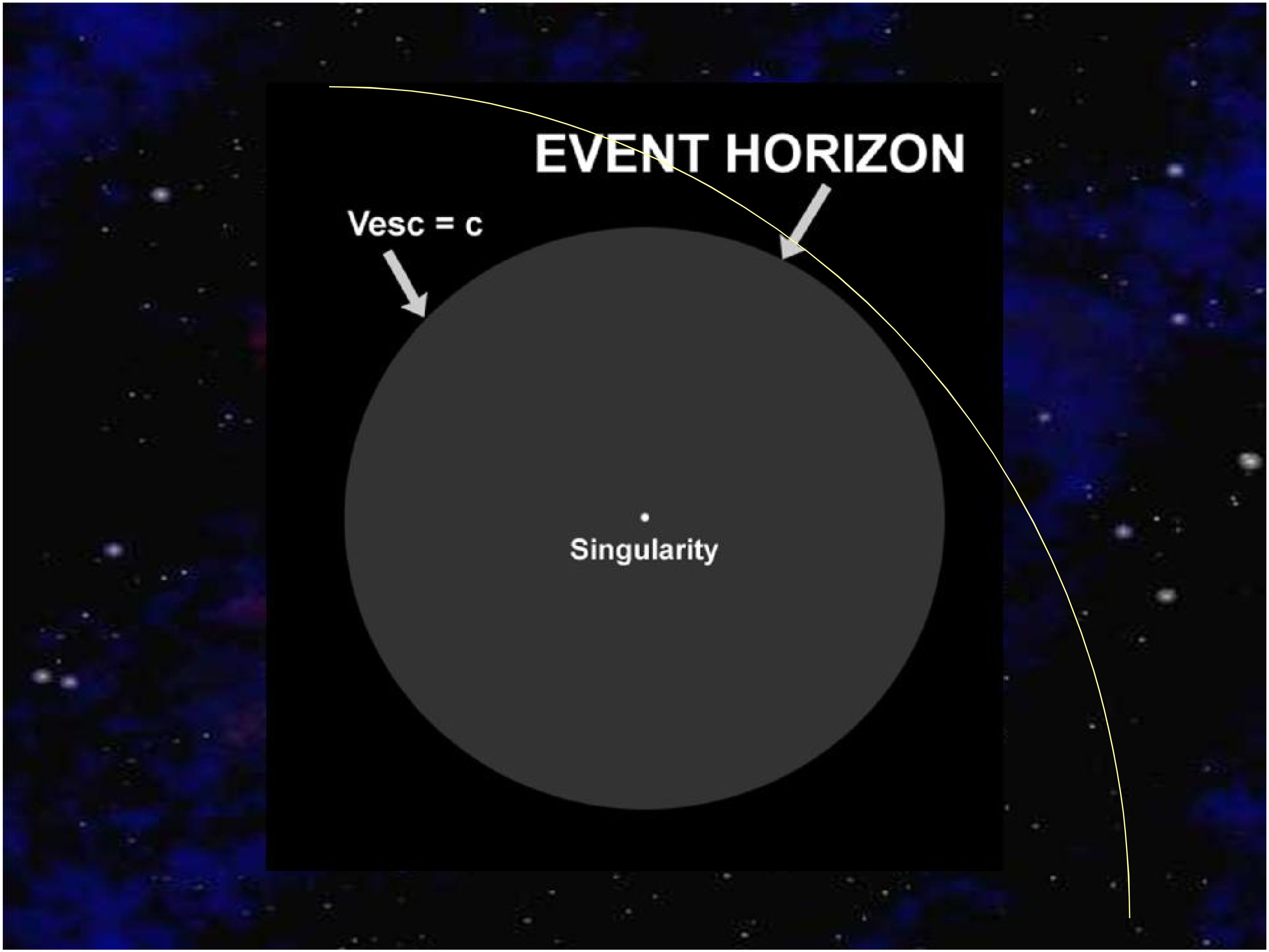
- very peculiar effects on time
- space becomes warped

In orbit around a Black Hole

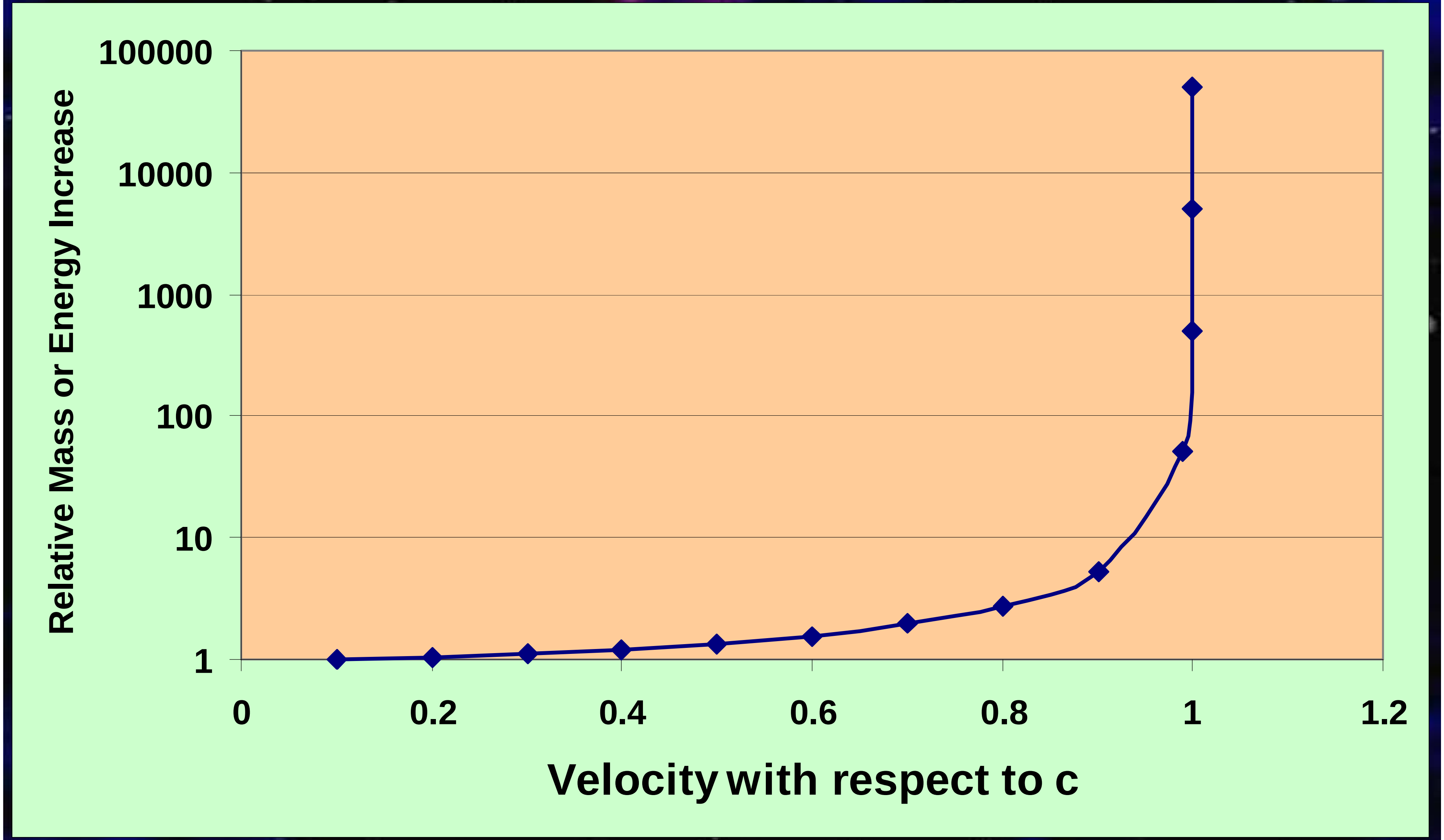


In orbit around a Black Hole at Event Horizon




EVENT HORIZON
Vesc = c
Singularity

Effect of increasing velocity on Mass and Energy Requirements



As velocity increases so does kinetic energy. If v=c then K goes to infinity.

$$K = \frac{mc^2}{\sqrt{1-\left(\frac{v}{c}\right)^2}} - mc^2$$

As velocity increases so does m_{moving}. If v=c then m_{moving} goes to infinity.

$$m_{moving} = \frac{m_{rest}}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

If object has mass of 1 kg, what is its mass at 80% c

$1-(.8/1)^2 = 0.36$ Sqrt 0.36 = 0.6 1kg/0.6 = 1.666kg

RESULTS:

***<u>Nothing</u>* with mass can travel AT the speed of light**

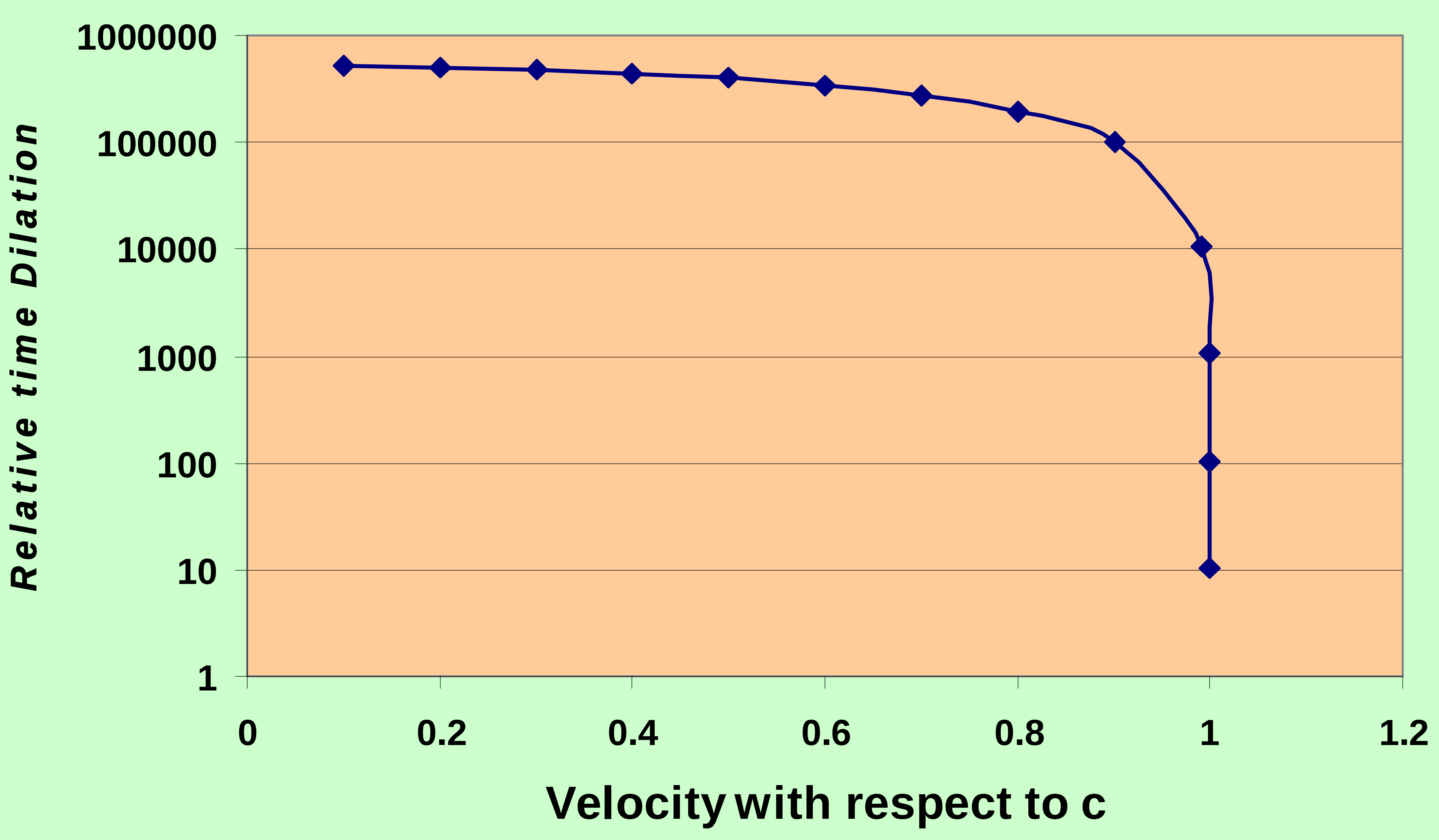
- However *<u>NEAR</u>* light speed is possible

Advantages of NEAR light speed travel: Relativistic Time Dilation

- The measurement of the passage of time is relative to the frame of reference
- The passage of time for someone moving at high speeds appears slower as seen by an observer at rest

$$\Delta t_{rest} = \frac{\Delta t_{moving}}{\sqrt{1-\left(v/c\right)^2}}$$

Time Dilation as velocity increases, 1year = 525600 minutes



50% light speed

At 50% c

- 1.15 seconds on earth pass for every 1 second measured by a traveler
- A 10 lightyear journey would take 20 earth years
- Travelers would experience a 17 .4 year journey

75% light speed

- 1.5 seconds on earth pass for every 1 second measured by a traveler
- A 10 lightyear journey would take 13 earth years
- Travelers would experience a 8.7 year journey

99% light speed

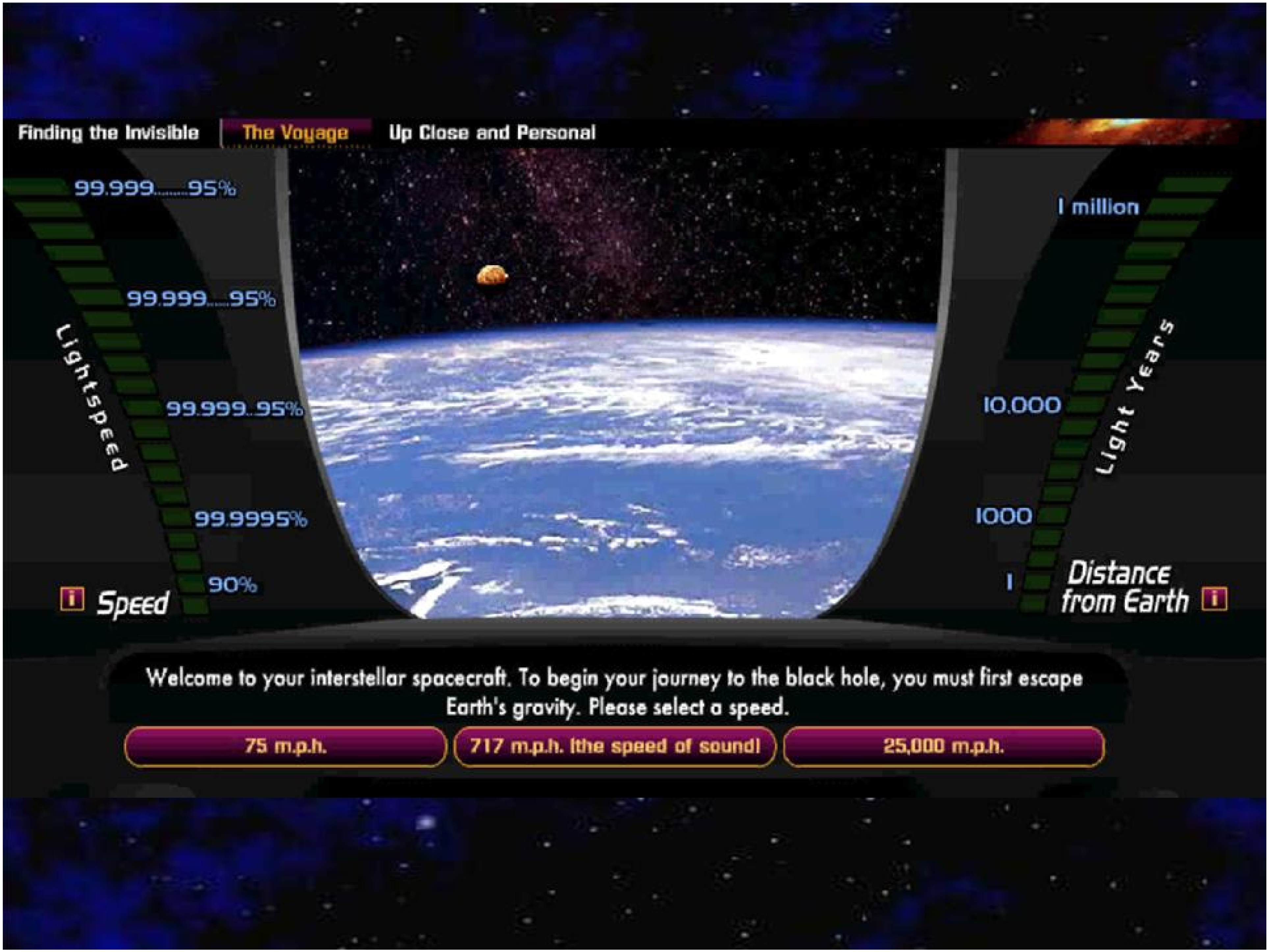
At 99% c

- 7 seconds on earth pass for every 1 second measured by a traveler
- A 10 lightyear journey would take 10.1 earth years
- Travelers would experience a 1 year 5 month journey

99.99% light speed

At 99.99% c

- 71 seconds on earth pass for every 1 second measured by a traveler
- A 10 lightyear journey would take 10 earth years
- Travelers would experience a 1 month 2 week journey


Finding the Invisible
The Voyage
Up Close and Personal
99.999........95%
99.999.....95%
99.999..95%
99.9995%
90%
Lightspeed
Speed
1 million
10,000
1000
1
Light Years
Distance from Earth
Welcome to your interstellar spacecraft. To begin your journey to the black hole, you must first escape Earth's gravity. Please select a speed.
75 m.p.h.
717 m.p.h. (the speed of sound)
25,000 m.p.h.

Examples

$M = 3\ M_\odot$ $R_S = 9\text{km}\ (5.4\ \text{mi})$

$M = 1\ M_\odot$ $R_S = 3\text{km}\ (1.8\ \text{mi})$

$M = 1\ M_{earth}$ $R_S \sim 1\ \text{cm}$

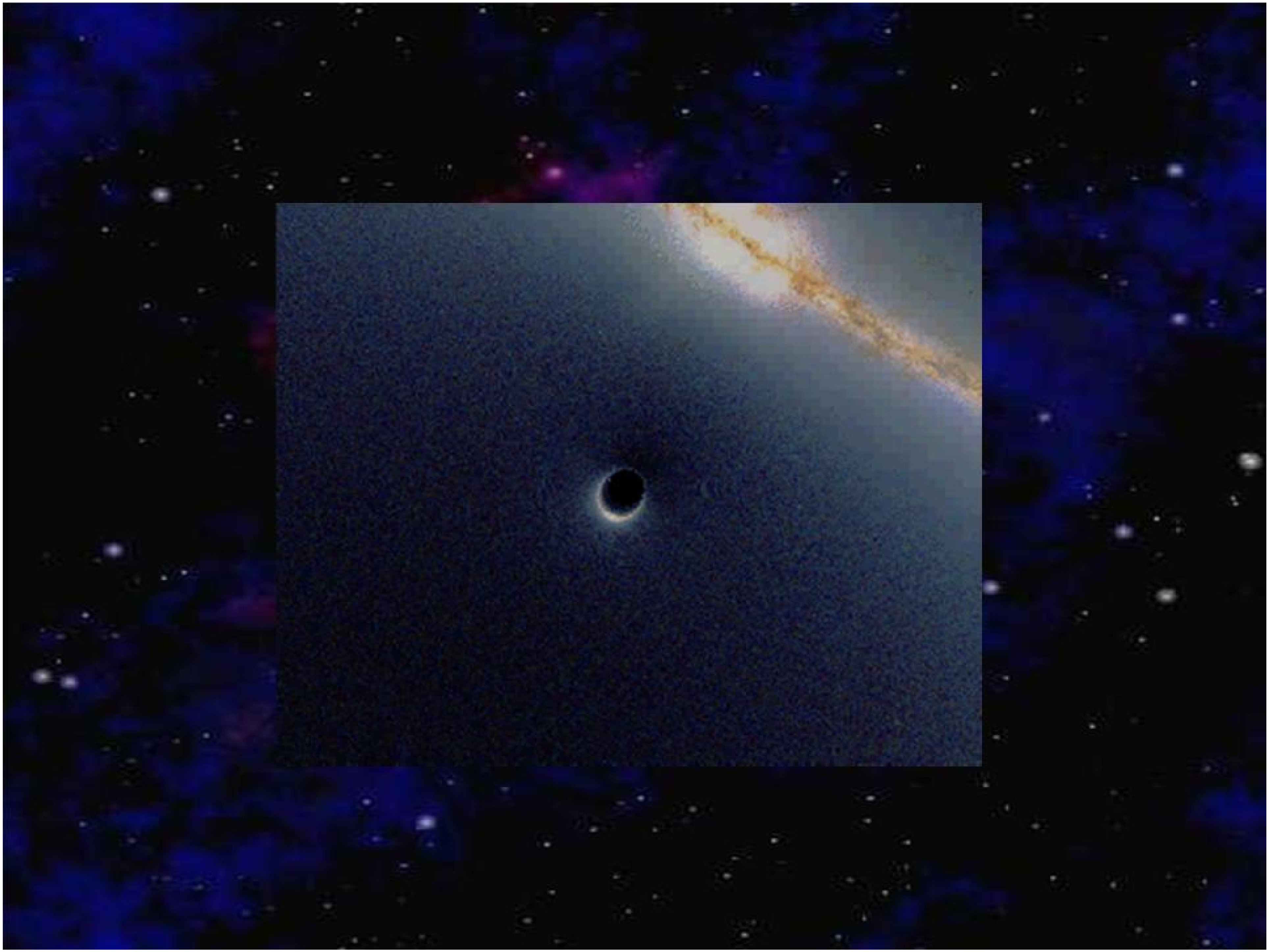
If we can’t see ‘em, how do we find ‘em?

Solitary stellar mass black hole

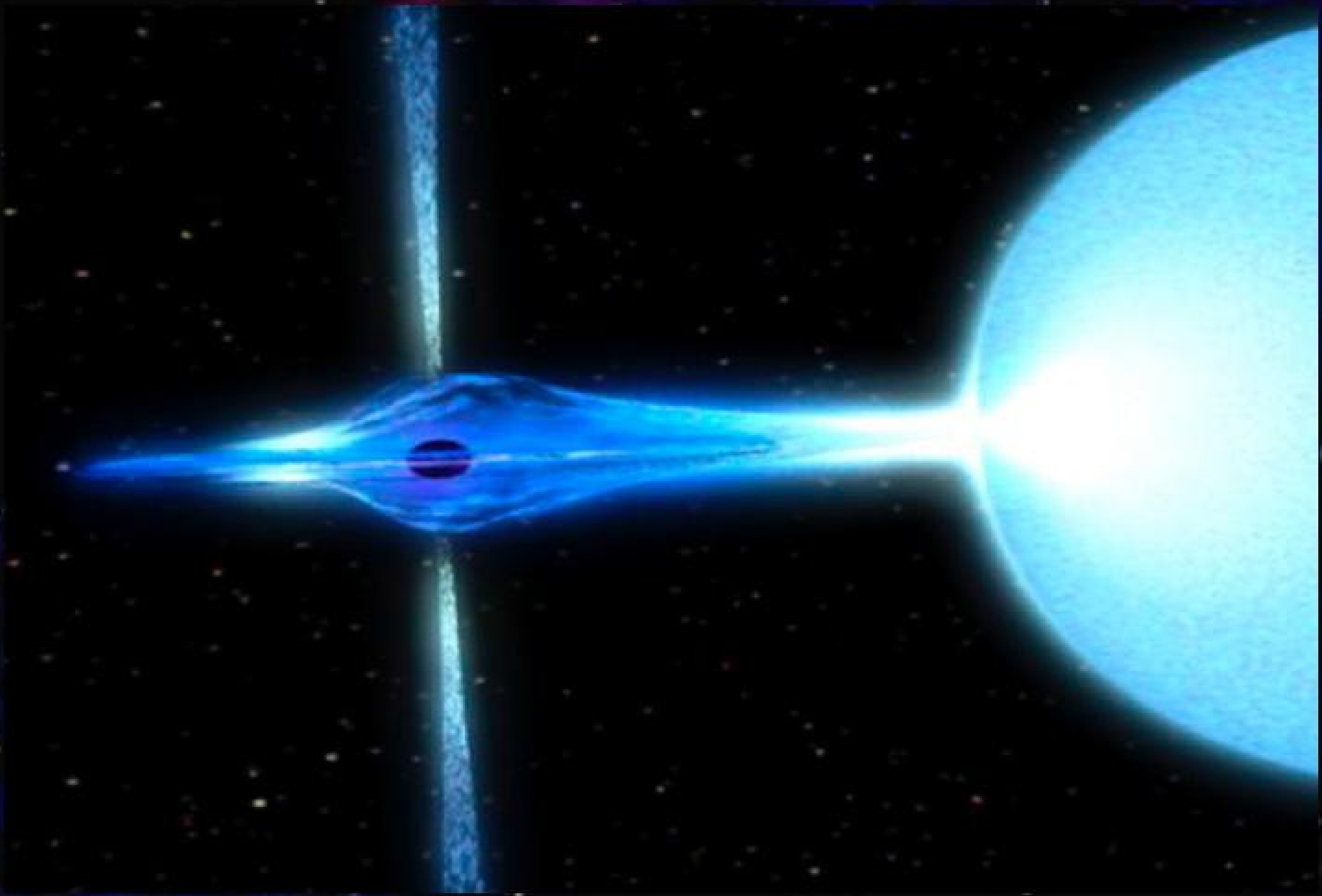

esa
www.spacetelescope.org

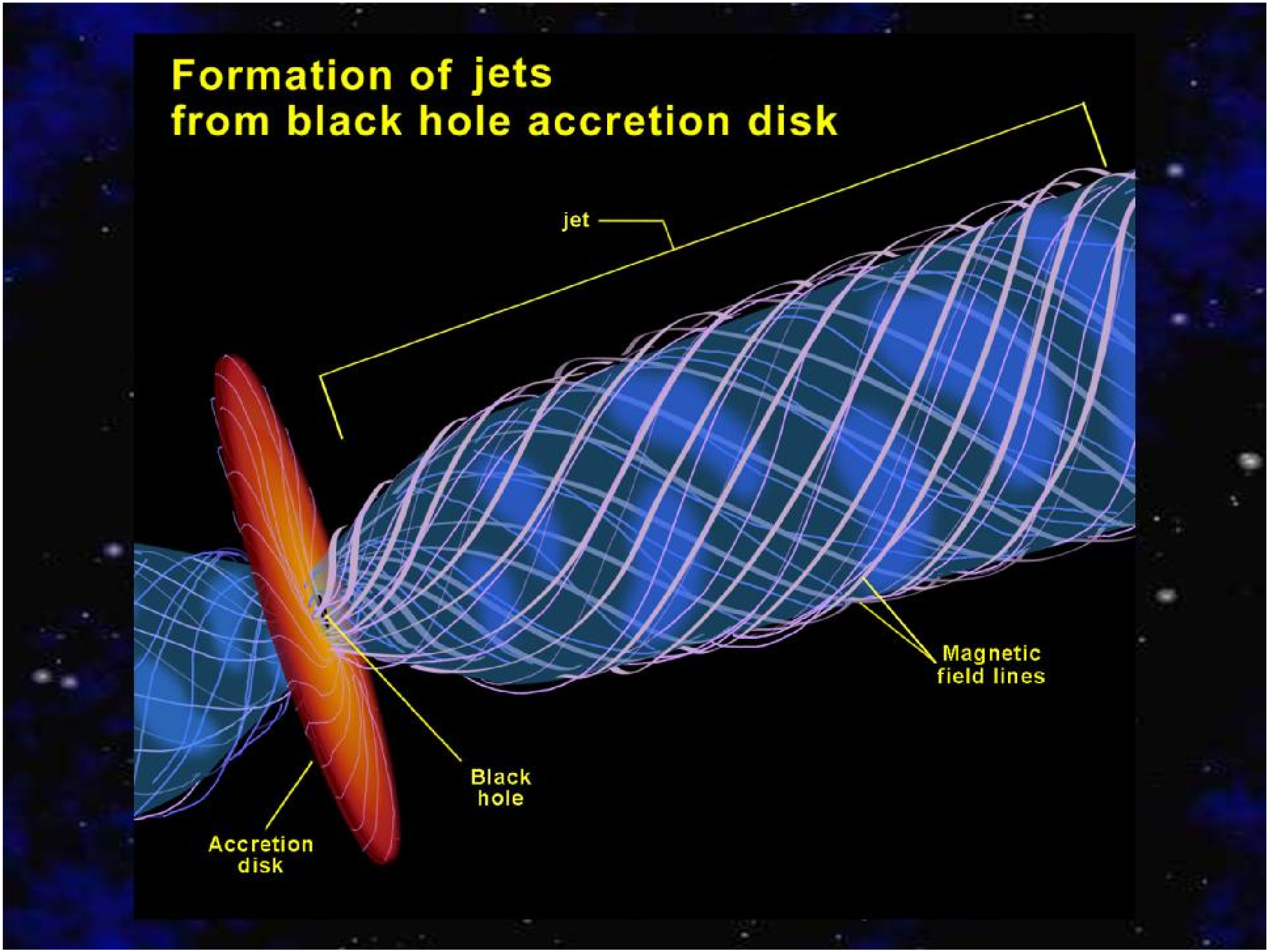
www.spacetelescope.org

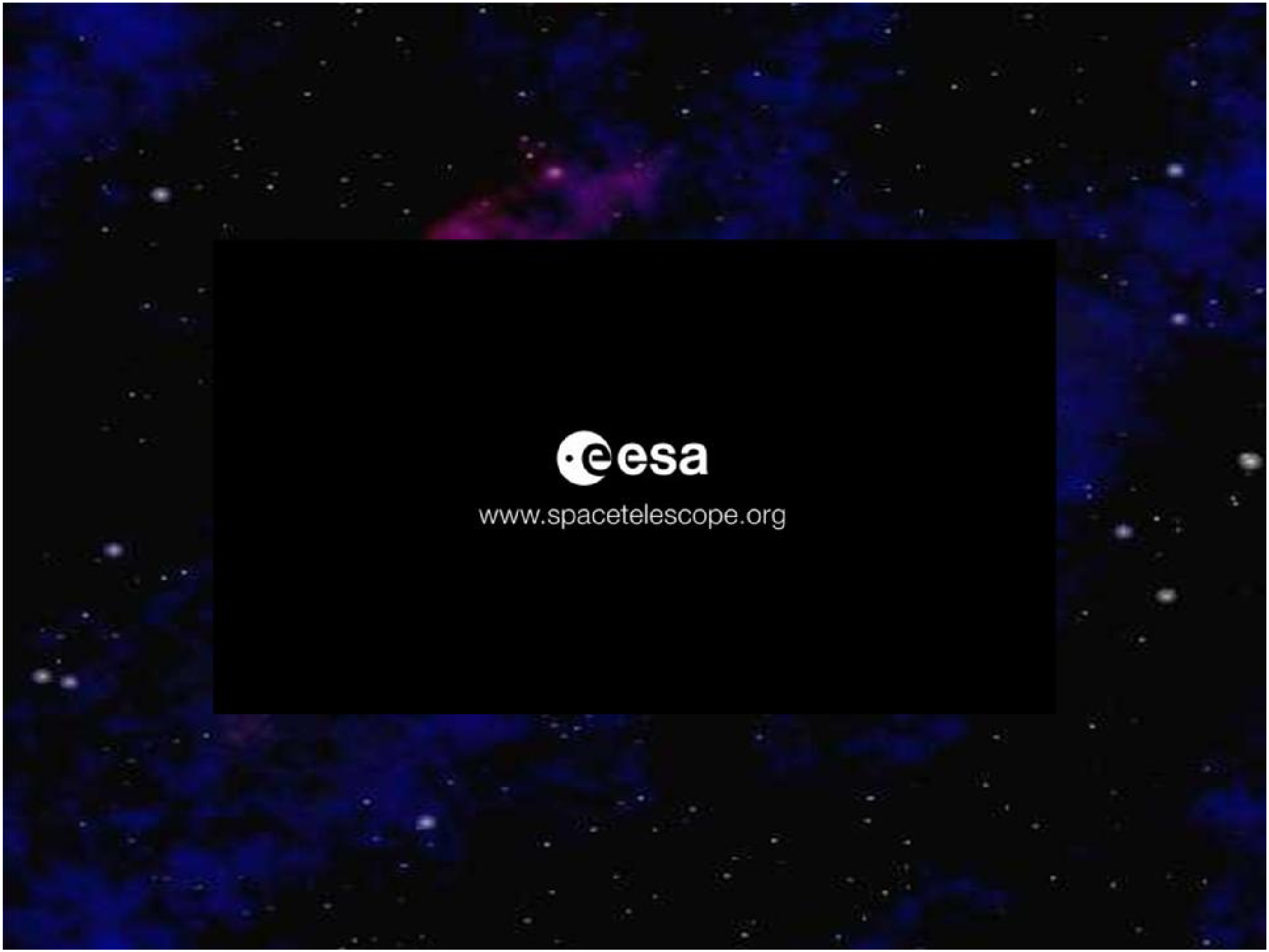
Solitary stellar mass black hole

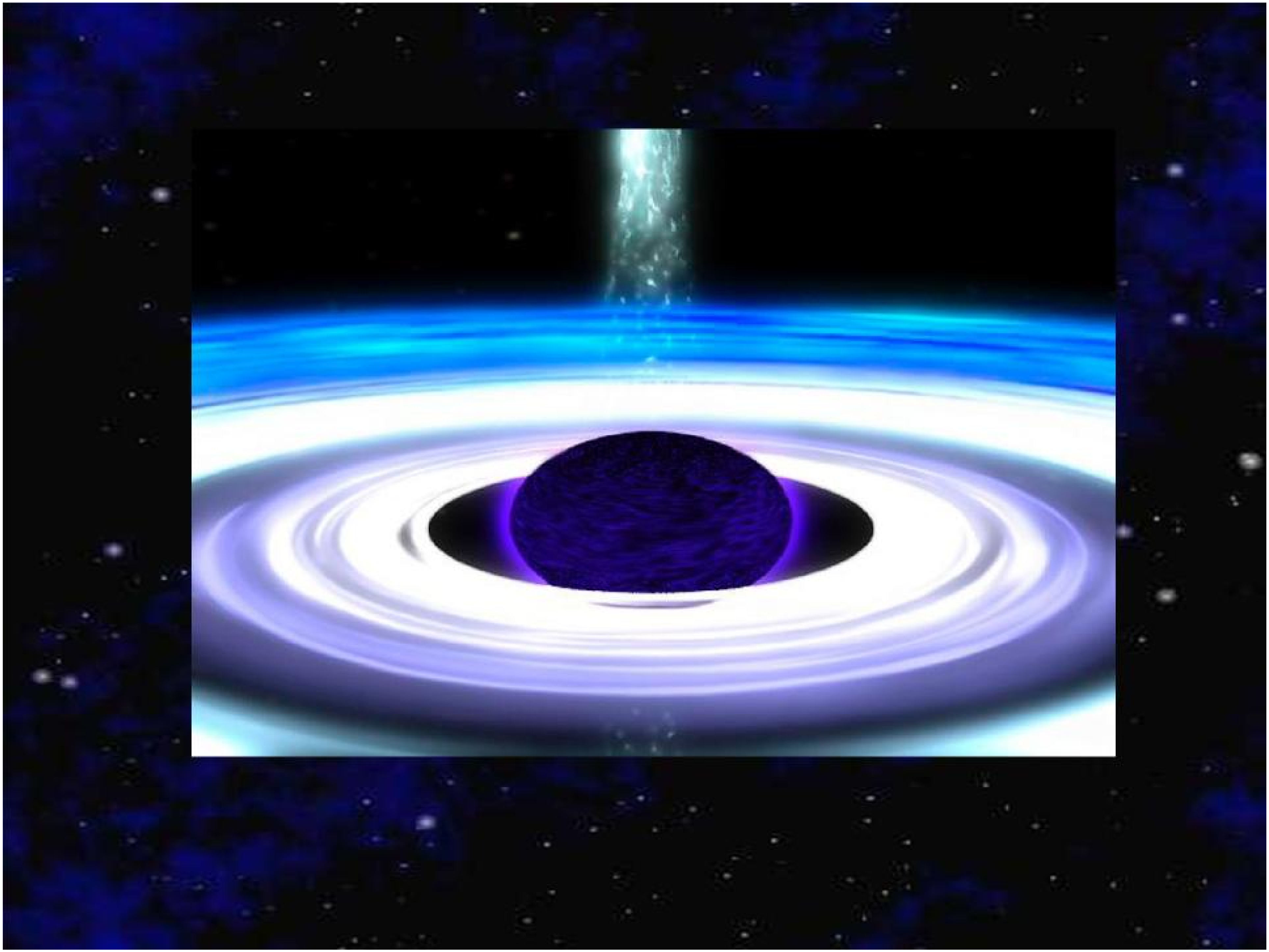


Black hole in a binary system

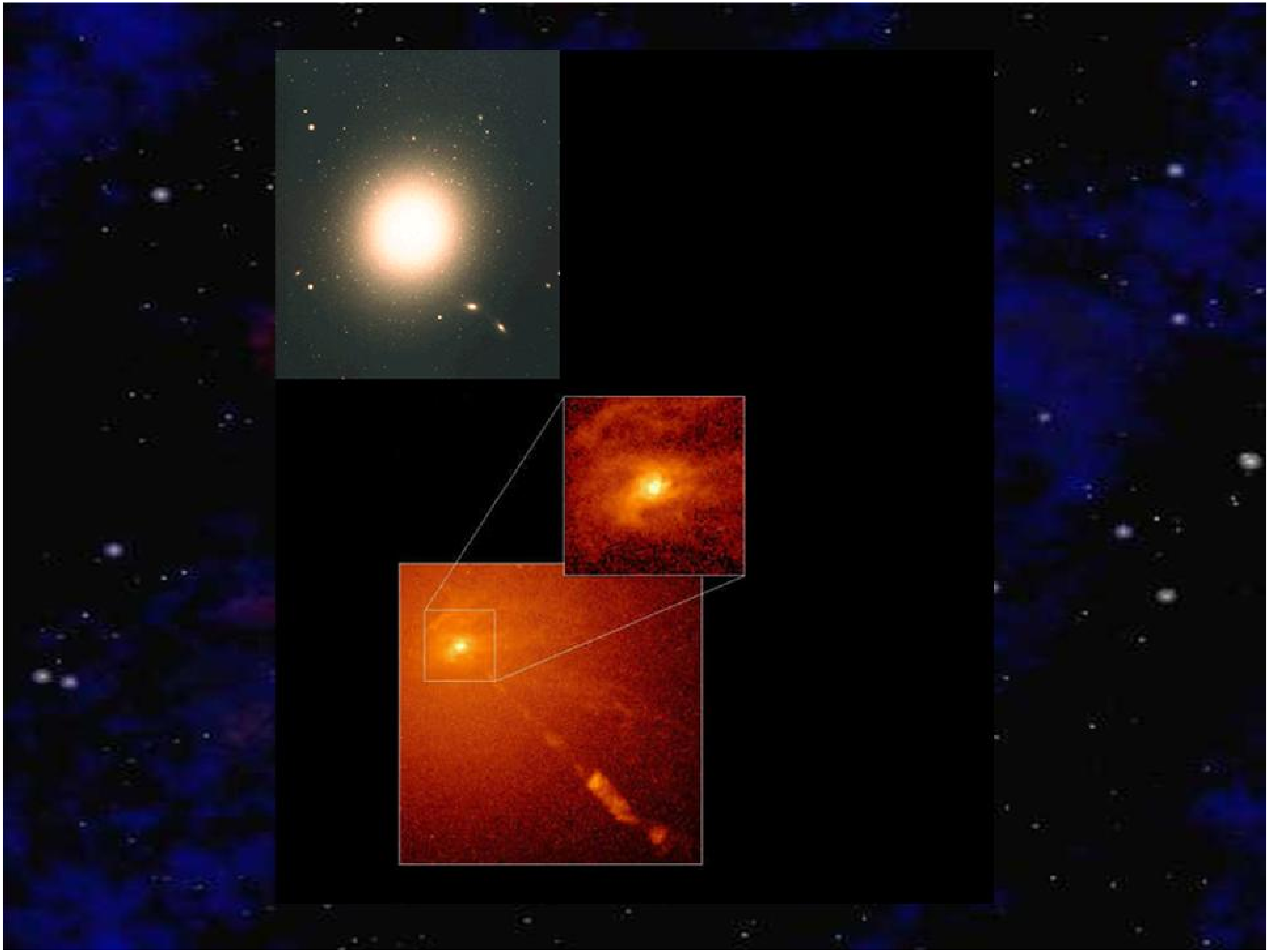


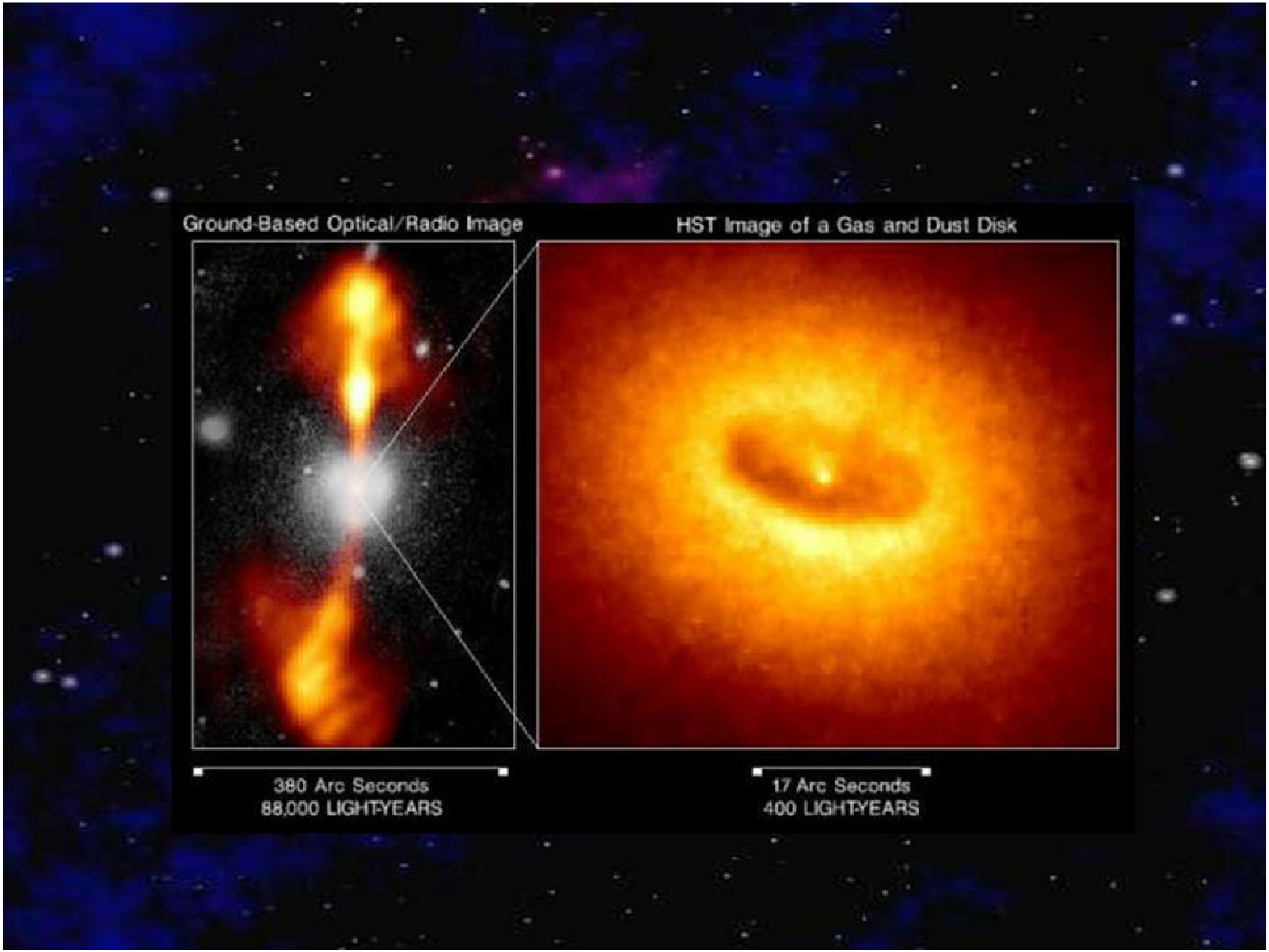

Formation of jets
from black hole accretion disk
jet
Magnetic
field lines
Black
hole
Accretion
disk

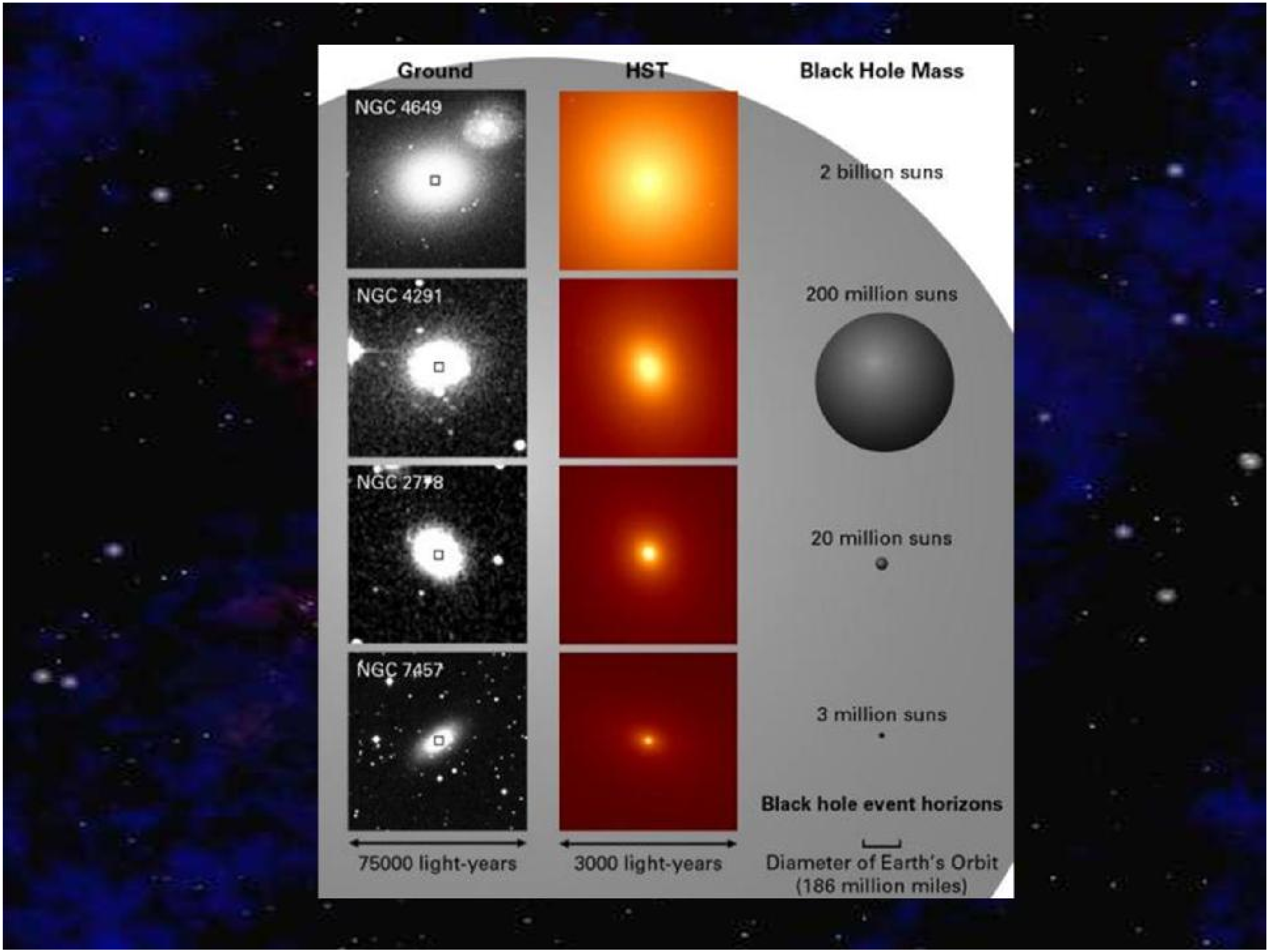

esa
www.spacetelescope.org



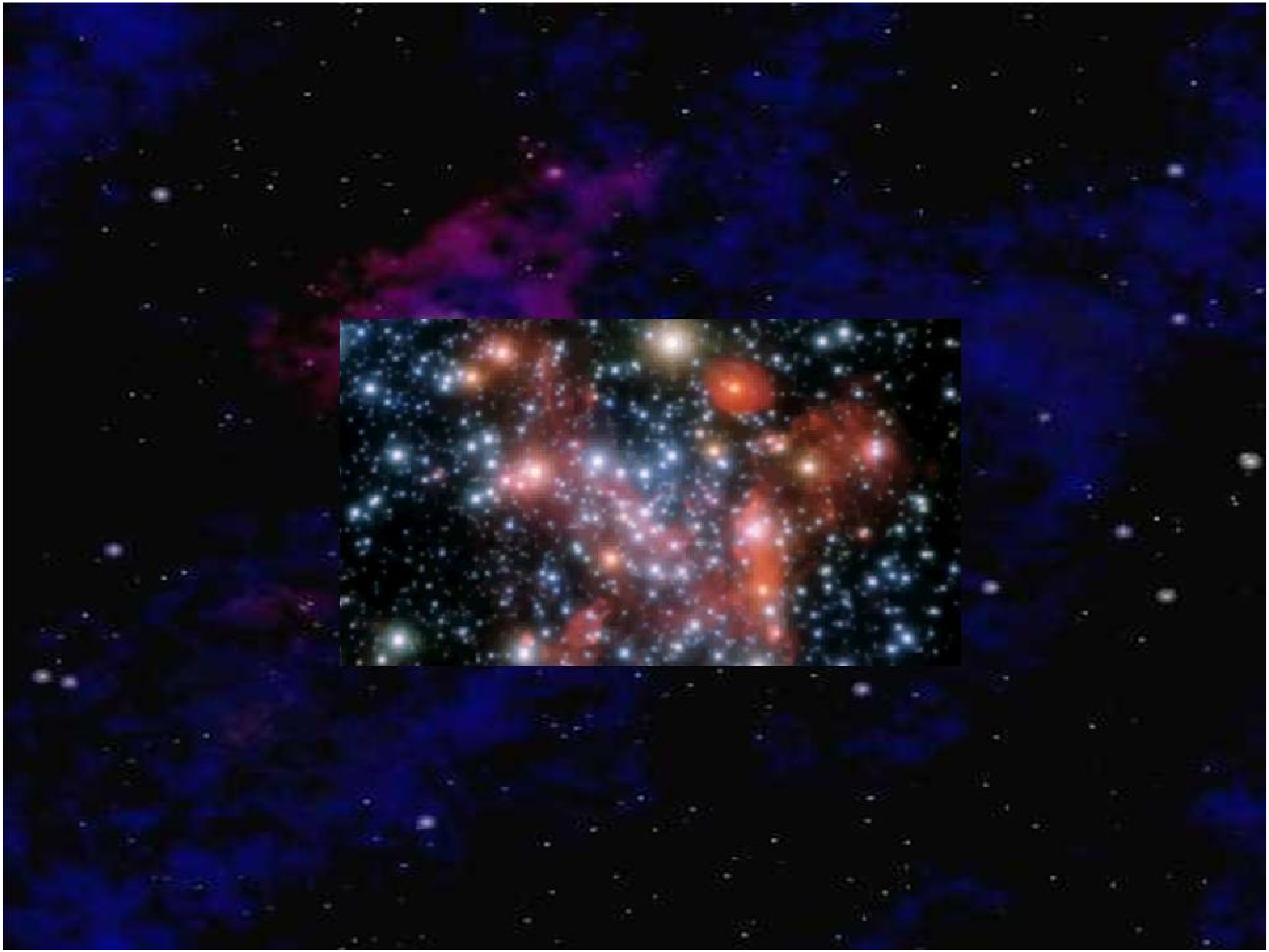
Super-massive black holes in galaxies




Ground-Based Optical/Radio Image
HST Image of a Gas and Dust Disk
380 Arc Seconds
88,000 LIGHT-YEARS
17 Arc Seconds
400 LIGHT-YEARS


Ground
HST
Black Hole Mass
NGC 4649
2 billion suns
NGC 4291
200 million suns
NGC 2778
20 million suns
NGC 7457
3 million suns
Black hole event horizons
75000 light-years
3000 light-years
Diameter of Earth's Orbit
(186 million miles)

Probing the Galactic Center

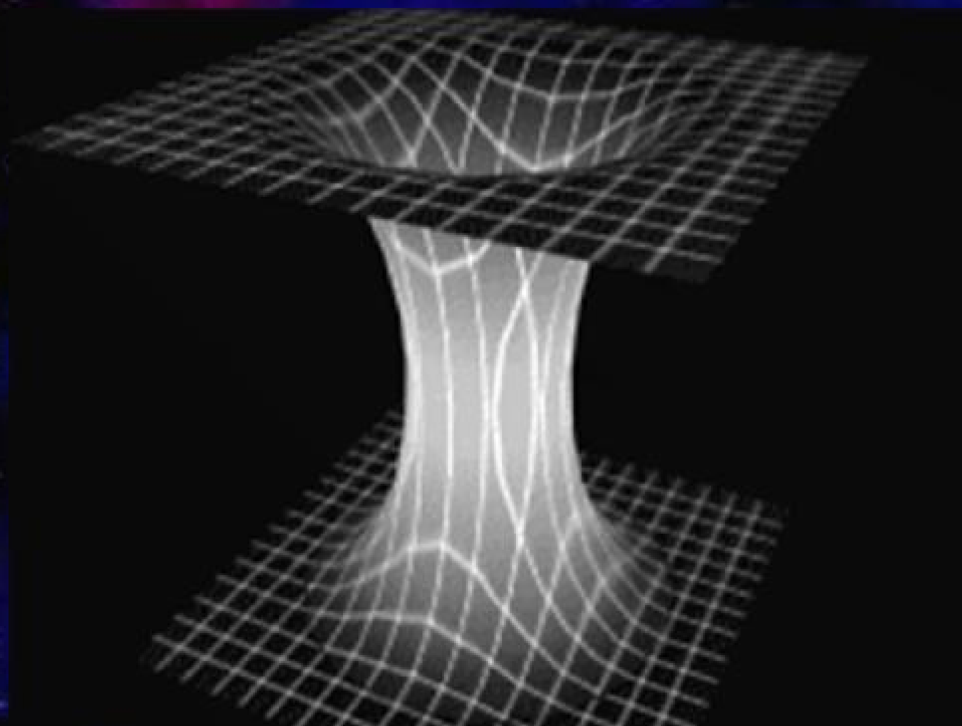


Common misconceptions about black holes:

- Not “vacuum cleaners”
- Not normally made from just anything

Common misconceptions about black holes:

- No "worm holes"



Common misconceptions about black holes:

- Enter at your own risk!