



INTRODUCTION TO THE VIOLENT UNIVERSE

WHITE DWARFS, NEUTRON STARS AND BLACK HOLES

IL CIELO STELLATO NEL VISIBILE

- LE STELLE HANNO COLORE DIVERSO. QUESTO DIPENDE DALLA LORO TEMPERATURE ALLA SUPERFICIE INOLTRE HANNO LUMINOSITÀ DIVERSE A PARITÀ DI DISTANZA, LA DIFFERENTE LUMINOSITÀ INTRINSECA DIPENDE DALLA MASSA DELLA STELLA. PIÙ LA STELLA È MASSIVA PIÙ È LUMINOSA.



Maxwell's Equations

Differential form

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$$

$$\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \cdot \vec{B} = 0$$

$$\nabla \times \vec{B} = \mu_0 \vec{J} + \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$$

Maxwell's Equations

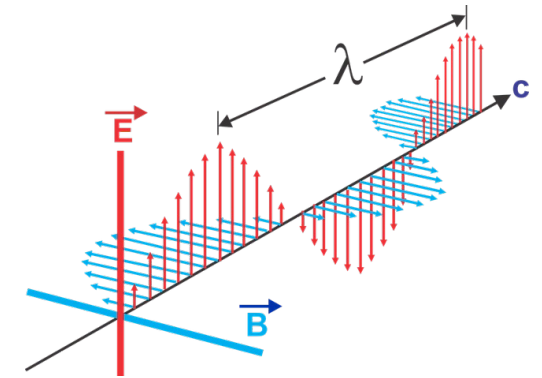
Integral form

$$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{enc}}{\epsilon_0}$$

$$\oint \vec{E} \cdot d\vec{l} = -\int \frac{\partial \vec{B}}{\partial t} \cdot d\vec{a}$$

$$\oint \vec{B} \cdot d\vec{a} = 0$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{enc} + \mu_0 \epsilon_0 \int \frac{\partial \vec{E}}{\partial t} \cdot d\vec{a}$$

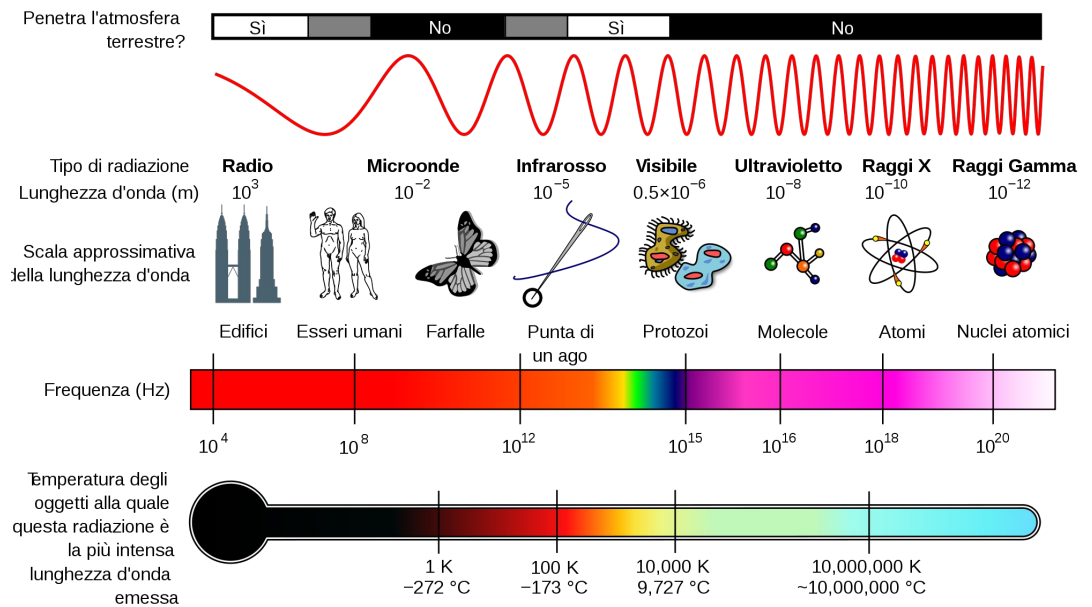


LE ONDE ELETTROMAGNETICHE

LA LUCE È UN'ONDA IN CUI IL CAMPO MAGNETICO E IL CAMPO ELETTRICO SONO TRA LORO ORTOGONALI E LA VELOCITÀ DI PROPAGAZIONE È ORTOGONALE AL PIANO CHE CONTIENE I DUE VETTORI \vec{E} E \vec{B} .

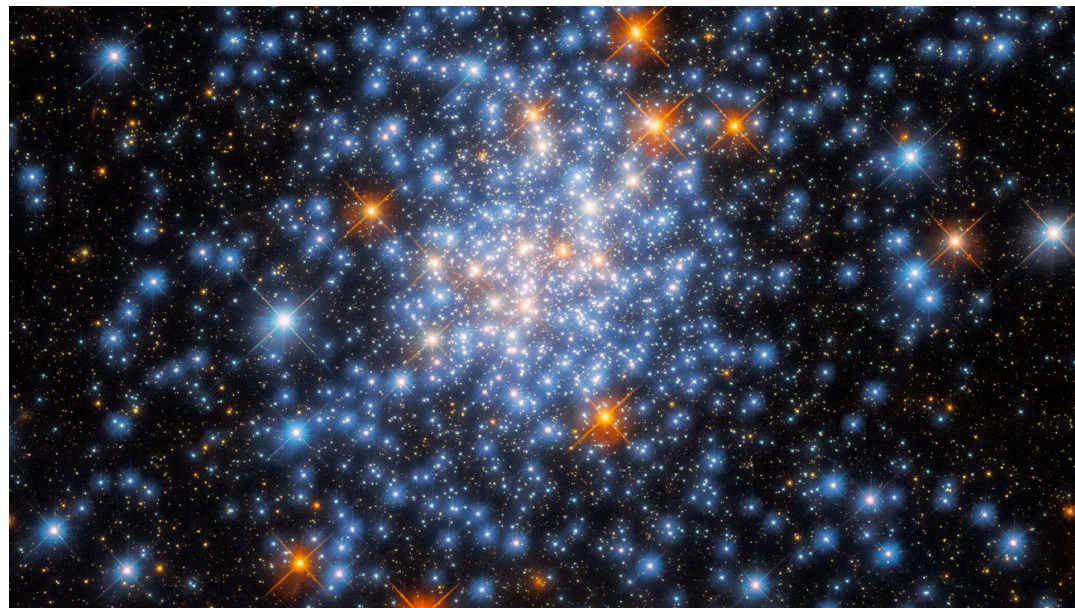
LO SPETTRO ELETTRO- MAGNETICO

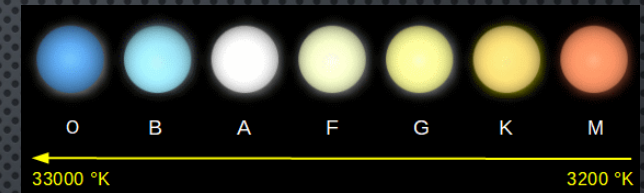
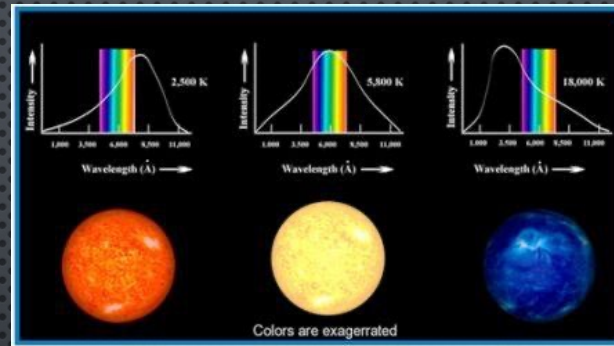
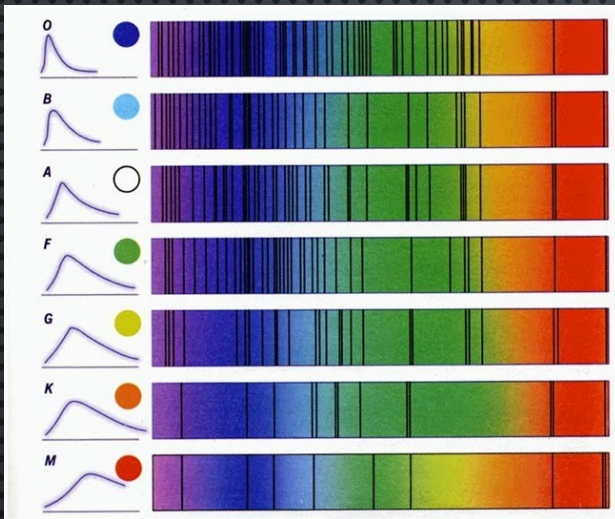
- LA BANDA ELETTROMAGNETICA CHE IL NOSTRO OCCHIO PERCEPISCE È QUELLA DEL VISIBILE, ED È UNA PICCOLISSIMA BANDA.



I COLORI DELLE STELLE

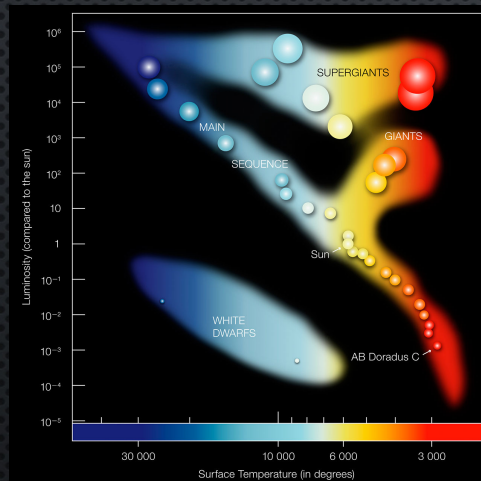
- ANCHE AD OCCHIO NUDO È POSSIBILE PERCEPIRE CHE LE STELLE HANNO DIFFERENTI COLORI.





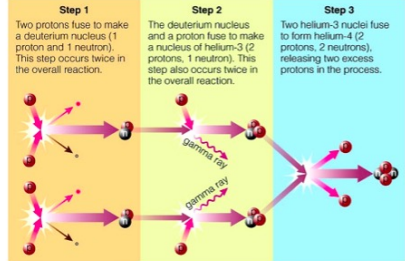
CLASSE SPETTRALE DELLE STELLE

THE MAIN SEQUENCE STARS : THE HYDROSTATIC EQUILIBRIUM



Hydrogen Fusion by the Proton-Proton Chain

Step 1	Step 2	Step 3
Two protons fuse to make a deuterium nucleus (1 proton and 1 neutron). This step occurs twice in the overall reaction.	The deuterium nucleus and a proton fuse to make a nucleus of helium-3 (2 protons, 1 neutron). This step also occurs twice in the overall reaction.	Two helium-3 nuclei fuse to form helium-4 (2 protons, 2 neutrons), releasing two excess protons in the process.

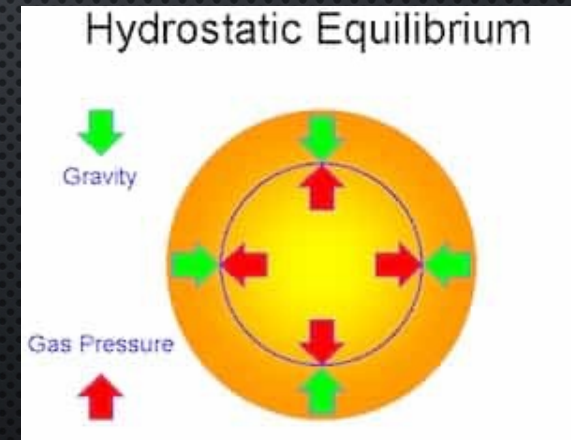


Key:

- neutron
- proton
- gamma ray
- neutrino
- positron

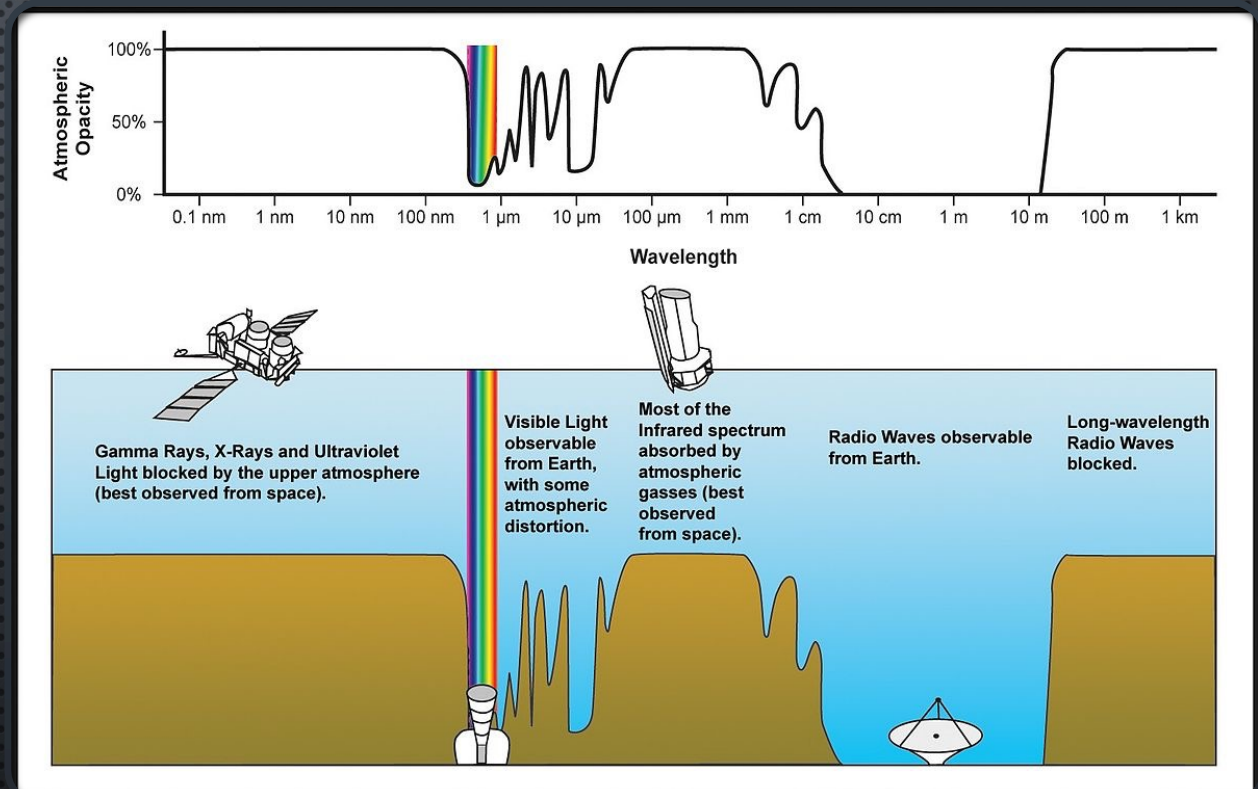
$$p + p \rightarrow {}^2\text{H} + e^+ + \nu_e \quad (\text{twice})$$

$$p + {}^2\text{H} \rightarrow {}^3\text{He} + \gamma \quad (\text{twice})$$

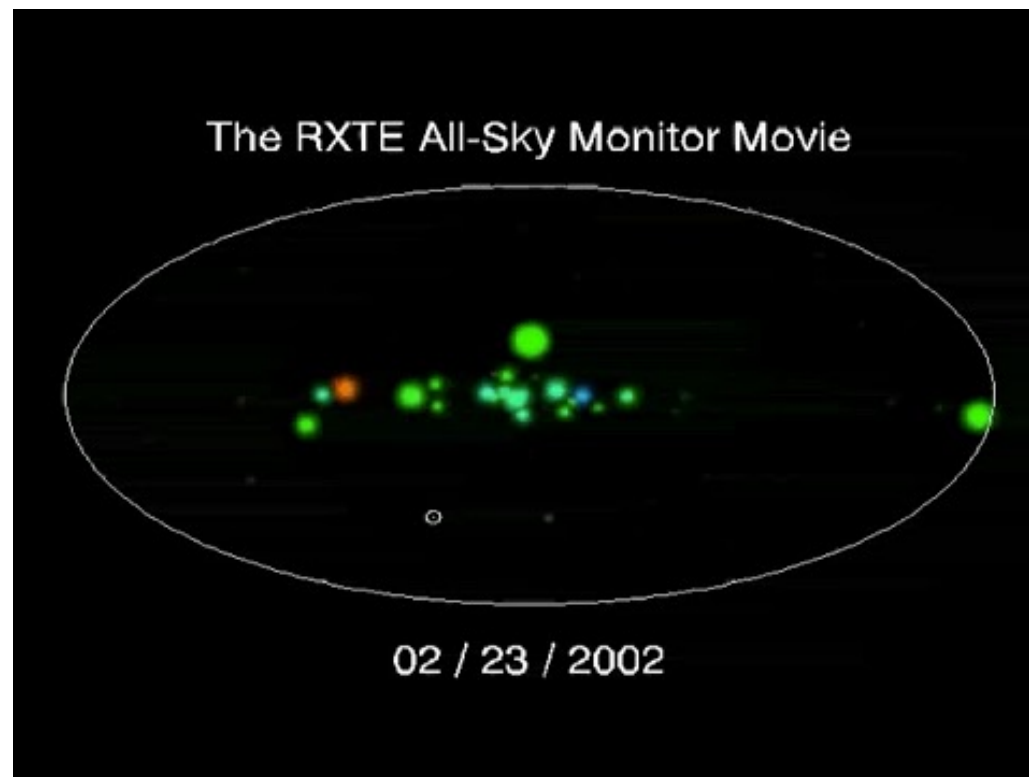
$${}^3\text{He} + {}^3\text{He} \rightarrow {}^4\text{He} + p + p$$


LA NOSTRA ATMOSFERA

- L'ATMOSFERA TERRESTRE PERMETTE IL PASSAGGIO DELLE ONDE RADIO E DELLE ONDE DEL VISIBILE.

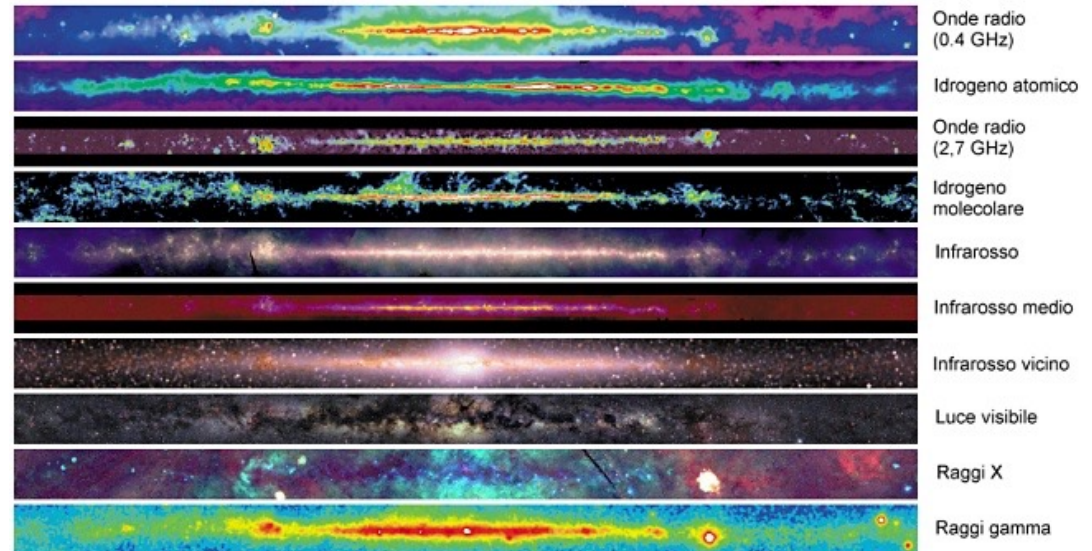


L'UNIVERSE VIOLENTO



COSA VEDIAMO DALLO SPAZIO

- COME VEDIAMO IL CENTRO GALATTICO A DIFFERENTI FREQUENZE (O LUNGHEZZE D'ONDA)



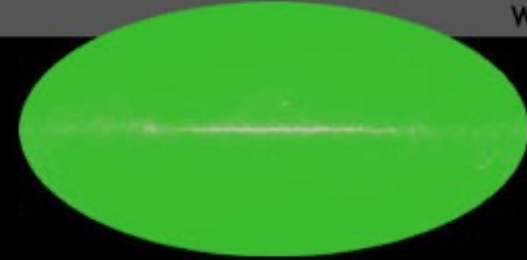
IL COSMIC MICROWAVE BACKGROUND

UNA LUCE DIFFUSA AD UNA
TEMPERATURA DI 2.7 K PERMEA IL
NOSTRO UNIVERSO. L'UNIVERSO NON È
ALLO ZERO ASSOLUTO!

1965



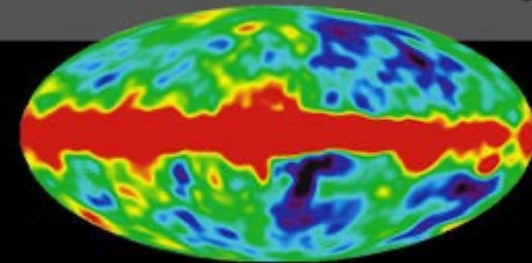
Penzias and
Wilson



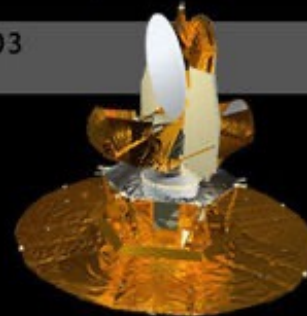
1992



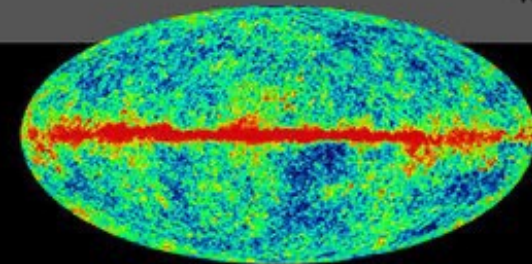
COBE



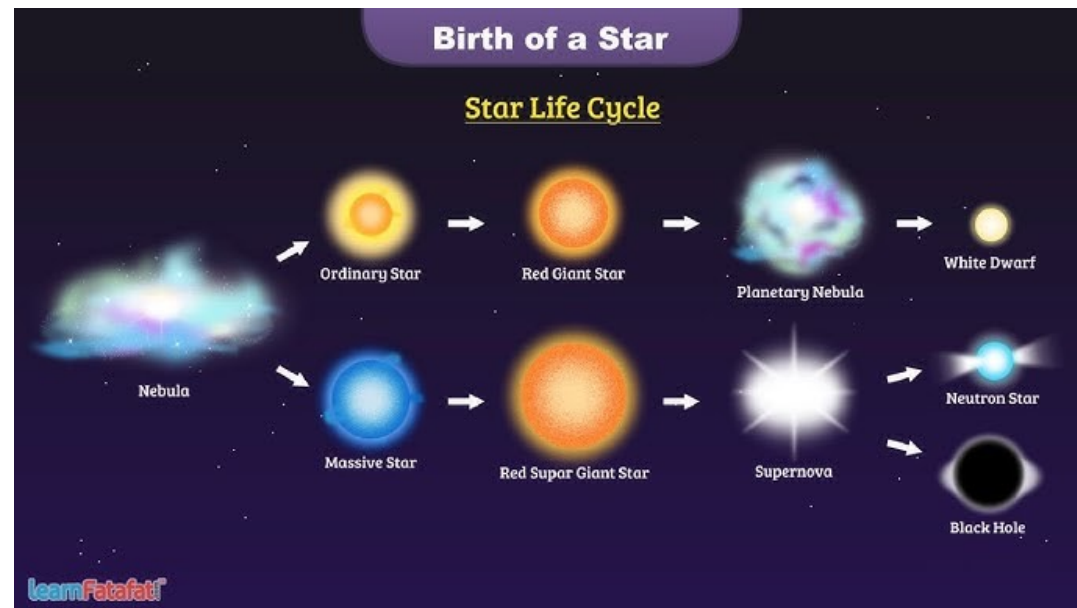
2003



WMAP

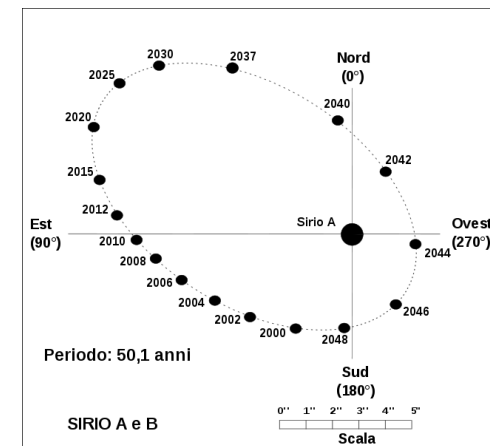
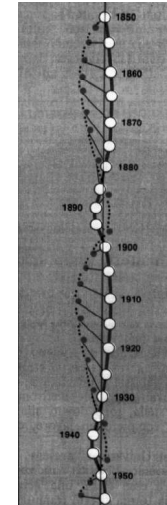


VITA DI UNA STELLA



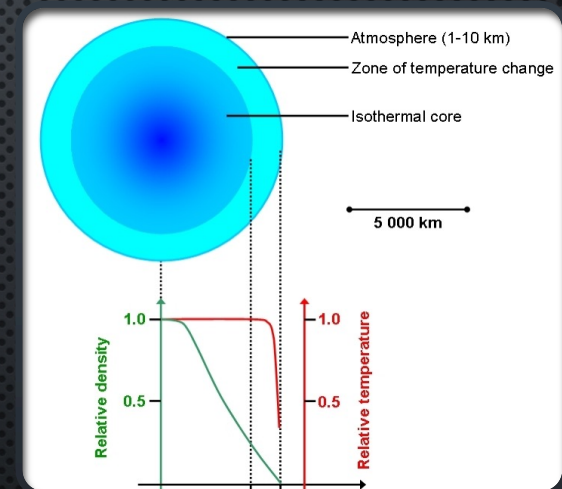
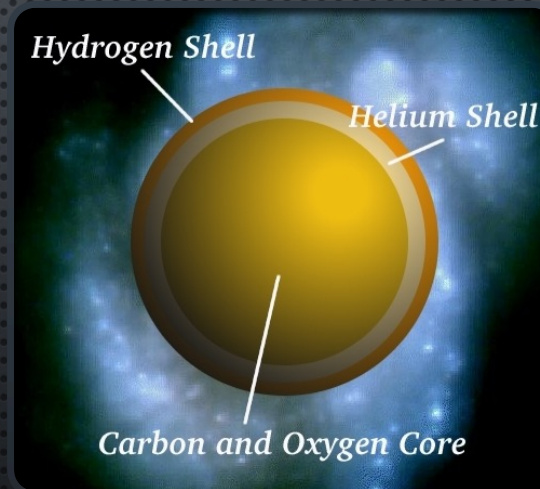
THE WHITE DWARF

- THE FIRST DISCOVERED WHITE DWARF WAS SIRIUS B IN 1844 ADOPTING THE PARALLAX METHOD.
- SIRIUS B WAS OBSERVED WITH A TELESCOPE IN 1862 THE FIRST TIME BY CLARK.
- ADAMS ARGUED THAT THE STAR WAS A WD IN 1925



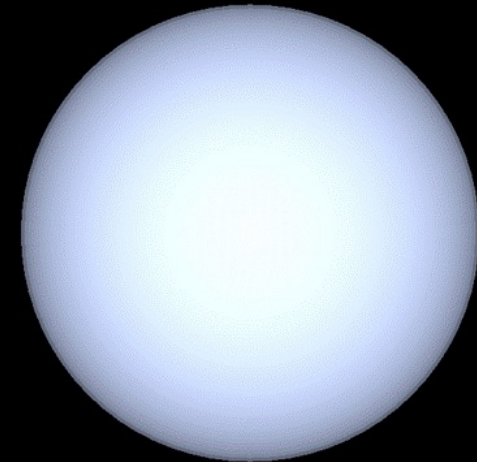
THE WHITE DWARF

- RADIUS 10,000 KM
- MAGNETIC FIELD UP TO 10^5 GAUSS



THE WHITE DWARF

- MAGNETIC FIELD UP TO 10^5 GAUSS
- MASS EARTH = $6 \cdot 10^{27}$ G
- $V_{\text{ESC}} = (2GM/R)^{1/2}$



$M \approx 1.0 M_{\text{sun}}$
 $R \approx 5800 \text{ km}$
 $V_{\text{esc}} \approx 0.02c$

THE WHITE DWARF

Mass < 1.4 solar masses
GRAVITY

White Dwarf
Electrons run out of room to move around. Electrons prevent further collapse. Protons & neutrons still free to move around.

Stronger gravity => more compact.

• WHY DOES THE WD NOT COLLAPSE IF NO MORE THERMONUCLEAR REACTIONS ARE PRESENT?

• PAULI EXCLUSION PRINCIPLE (FERMION GAS)

• HEISENBERG INDETERMINATION PRINCIPLE

THE WHITE DWARF

• WHY DOES THE WD NOT COLLAPSE IF NO MORE THERMONUCLEAR REACTIONS ARE PRESENT?

• PAULI EXCLUSION PRINCIPLE (FERMION GAS)

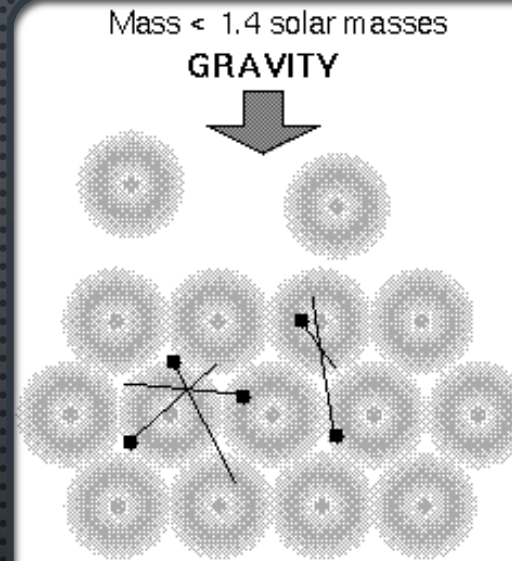
• HEISENBERG INDETERMINATION PRINCIPLE

$$\Delta x \Delta p \geq \hbar$$

• NOT RELATIVISTIC REGIME $P = K\rho^{5/3}$

• $R \propto M^{-1/3}$

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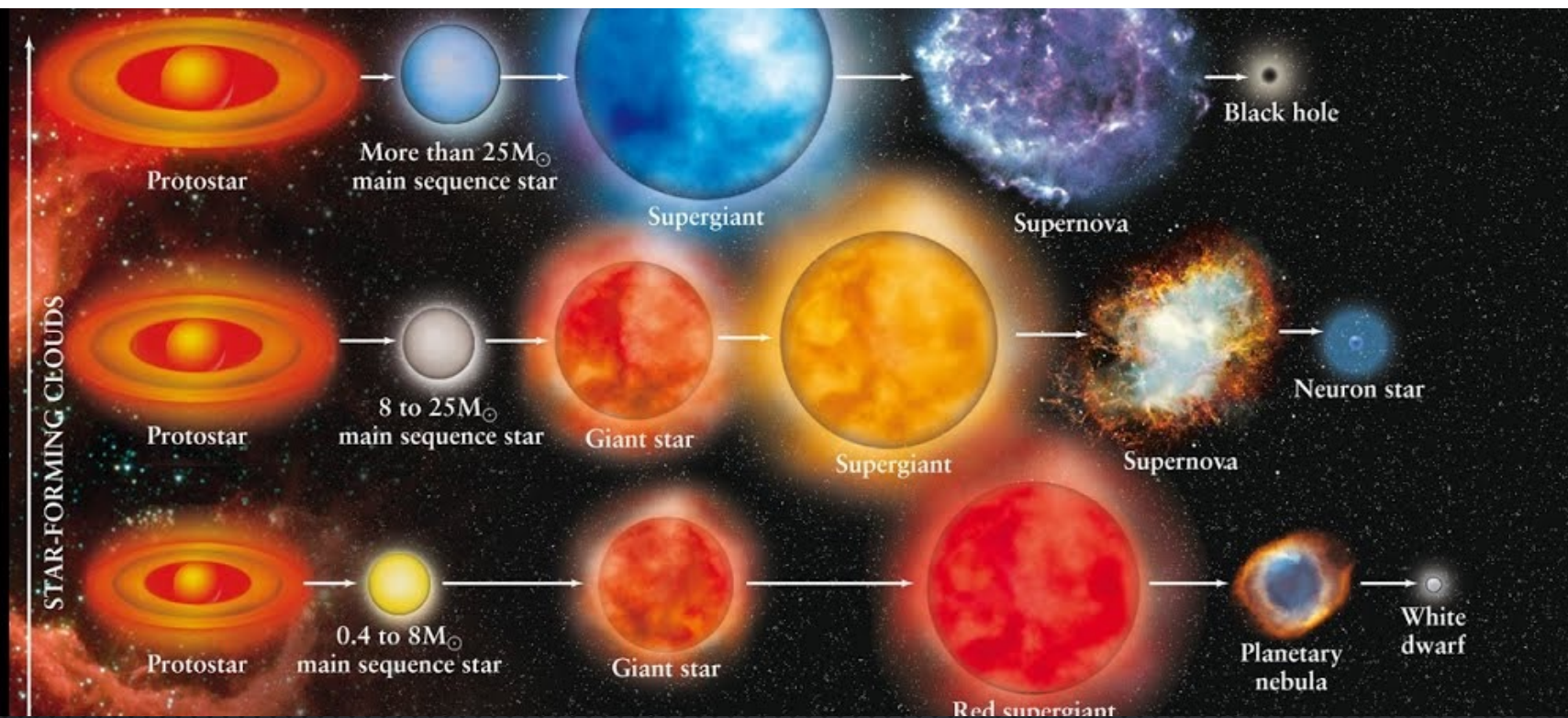


White Dwarf

Electrons run out of room to move around. Electrons prevent further collapse. Protons & neutrons still free to move around.

Stronger gravity => more compact.

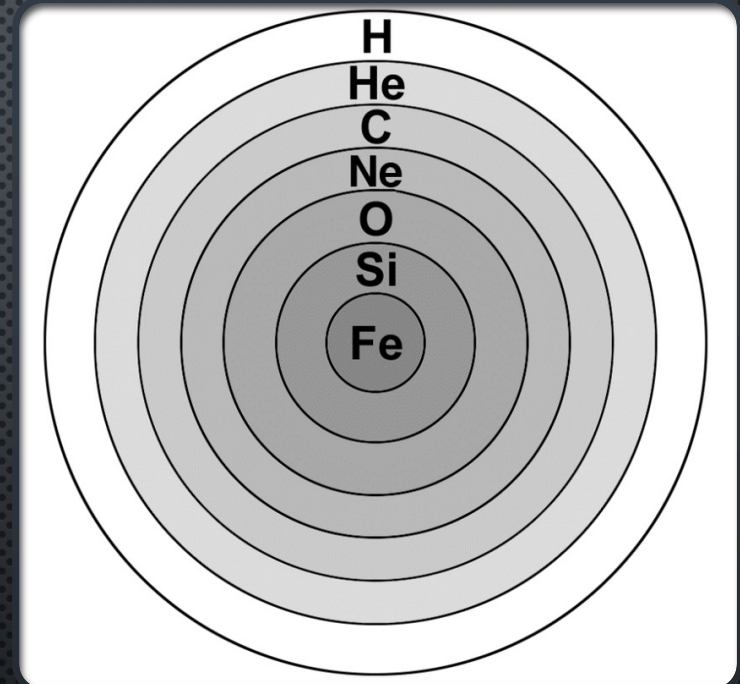
13 Dicembre 2023

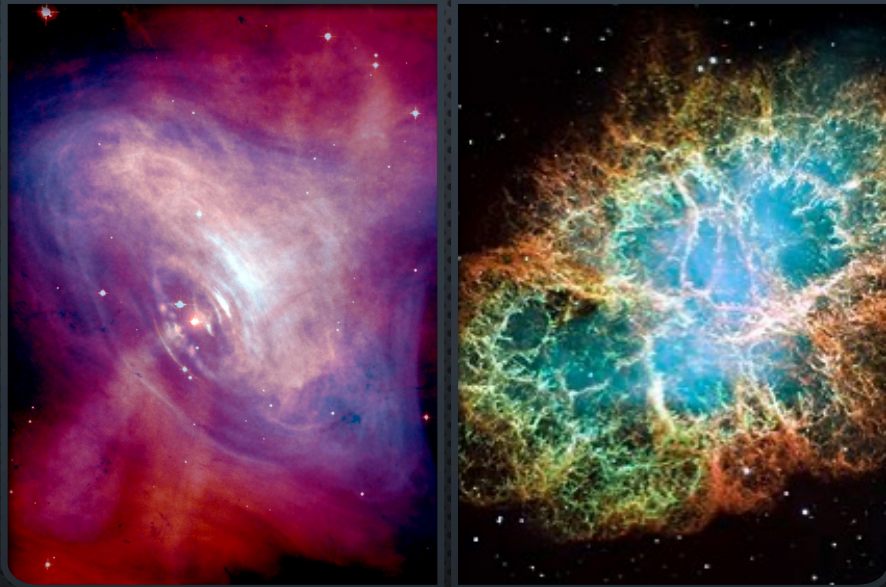


THE NEUTRON STARS

THE ONION STELLAR COMPOSITION BEFORE THE EXPLOSION AS TYPE-2 SUPERNOVA

- THE THERMONUCLEAR REACTIONS STOP AT Fe
- THE FUSION OF Fe IS AN ENDOENERGETIC PROCESS





THE CRAB NEBULA AND ITS NEUTRON STAR INSIDE

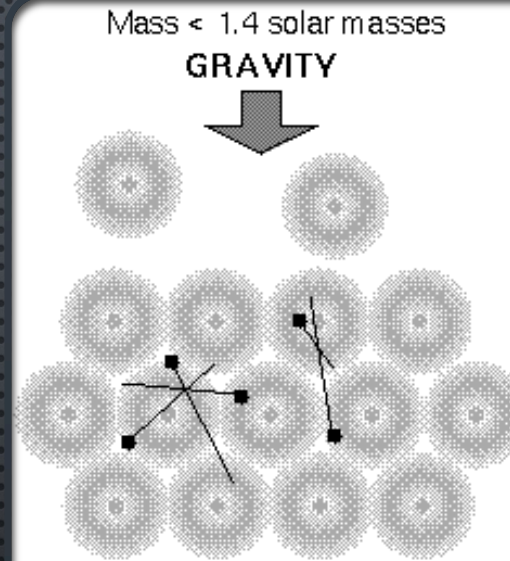
- MAGNETIC FIELD UP TO 10^{12} - 10^{14} GAUSS
- NS MASS = $1.4 - 2.5 M_{\text{SUN}}$

THE NEUTRON STAR

- DURING THE CORE COLLAPSE THE AVAILABLE VOLUME FOR THE ELECTRONS DECREASES
- PAULI EXCLUSION PRINCIPLE (FERMION GAS)
- HEISEMBERG INDETERMINATION PRINCIPLE

$\Delta x \Delta p \geq \hbar$, INCREASE THE ELECTRON VELOCITY

- THE PRESSURE TURNS TO A RELATIVISTIC REGIME $P = K\rho^{4/3}$

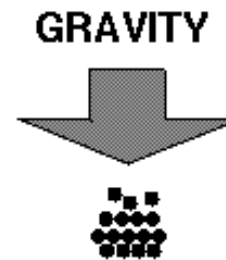


White Dwarf

Electrons run out of room to move around. Electrons prevent further collapse. Protons & neutrons still free to move around.

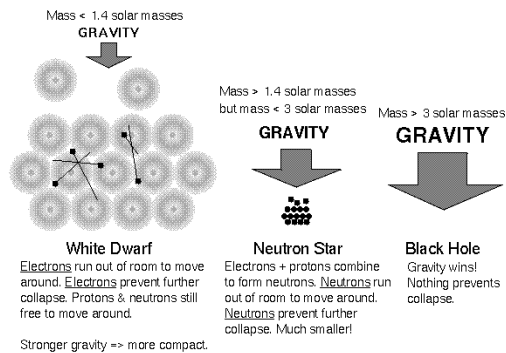
Stronger gravity => more compact.

Mass > 1.4 solar masses
but mass < 3 solar masses



Neutron Star

Electrons + protons combine to form neutrons. Neutrons run out of room to move around. Neutrons prevent further collapse. Much smaller!



THE NEUTRON STAR

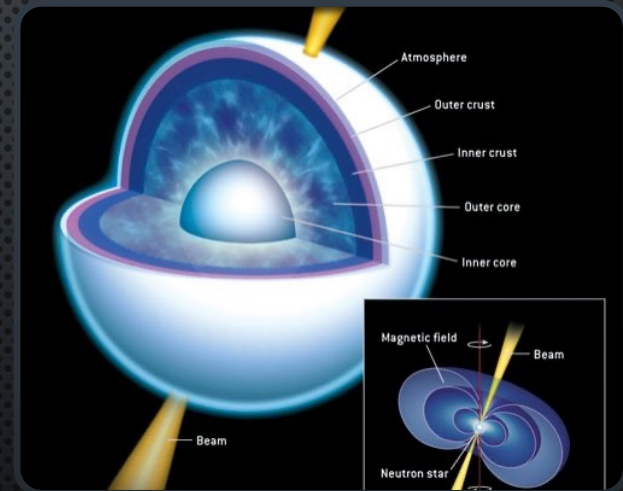
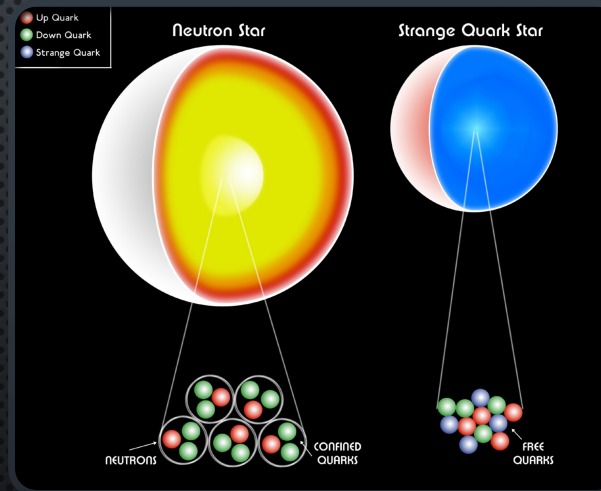
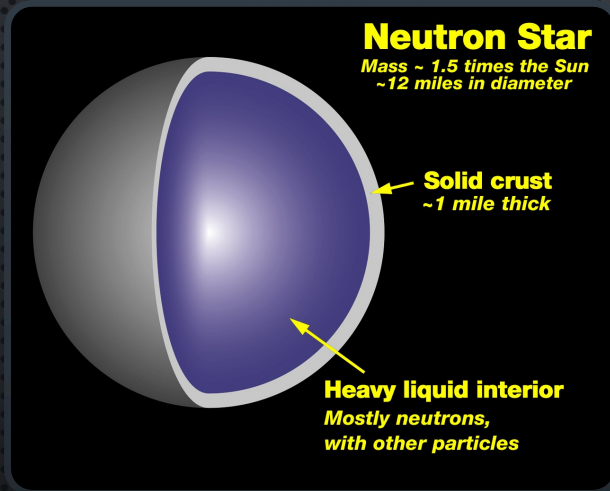
- THE GRAVITATIONAL PRESSURE DOMINATES OVER THE DEGENERATE PRESSURE
- PROTONS AND ELECTRONS FORM NEUTRONS (WHICH ARE FERMIONS)
- THE NEUTRONS HAVE A MASS 2000 TIMES LARGER THAN ELECTRONS, THE PRESSURE TURNS INTO A NON-RELATIVISTIC REGIME AGAIN.

• THE PRESSURE GOES FROM NON-RELATIVISTIC TO RELATIVISTIC $P = K\rho^{4/3}$

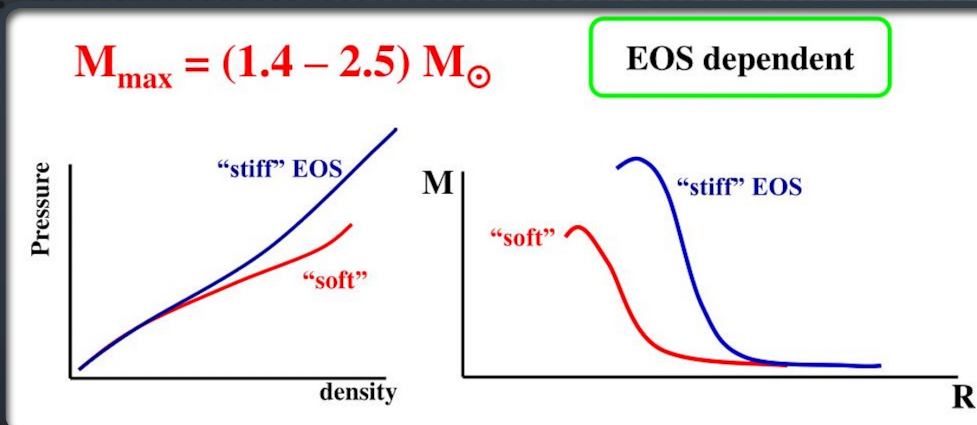
• $R \propto M^{-1/3}$

INTERIOR OF A NS, A PUZZLE TO BE RESOLVED

- MAGNETIC FIELD UP TO 10^{12} - 10^{14} GAUSS
- NS MASS = $1.4 - 2.5 M_{\text{SUN}}$
- RAGGIO = 10 KM

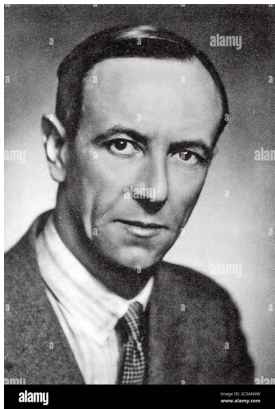


INTERIOR OF A NS, A PUZZLE TO BE RESOLVED



- WE DON'T KNOW THE EQUATION OF STATE (EOS) OF THE MATTER INSIDE THE NS; TWO CLASSES OF EOSs ARE PREDICTED BY THE NUCLEAR PHYSICISTS (THE STIFF EOS AND THE SOFT EOS)
- ACCORDING TO THESE EOSs THE NS MASS RANGES BETWEEN 1.4 AND 2.5 M_{SUN}
- THE LOWER LIMIT IS CALLED CHANDRASEKHAR LIMIT
- THE UPPER LIMIT IS CALLED OPPENHEIMER-VOLKOFF LIMIT

$$\frac{dM(r)}{dr} = 4\pi r^2 \rho(r), \quad \frac{dP(r)}{dr} = -\frac{G[\rho(r) + P(r)/c^2][4\pi r^3 P(r)/c^2 + M(r)]}{r^2[1 - 2GM(r)/(c^2 r)]}$$



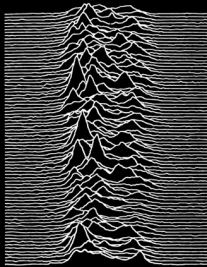
ABOUT THE NSs

- CHADWICK DISCOVERED THE NEUTRON IN 1932 (BOTTOM-LEFT)
- OPPHENHEIMER AND VOLKOFF SHOWED IN 1935 THAT CELESTIAL OBJECTS COMPOSED OF NEUTRONS COULD EXIST (TOP)
- JOCELYN BELL OBSERVED FOR THE FIRST TIME A PULSATING NEUTRON STAR (PULSAR) IN 1967 (BOTTOM-RIGHT)



ABOUT THE NSs

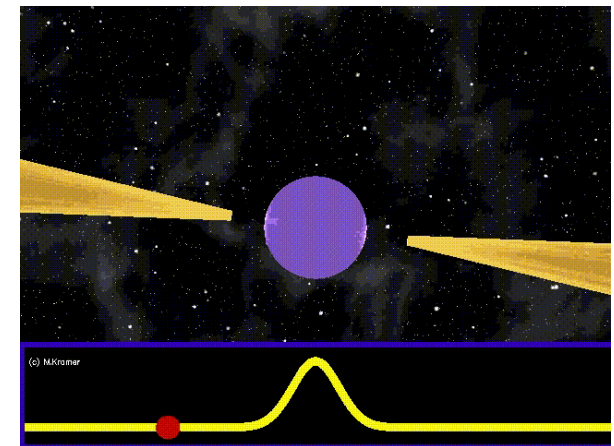
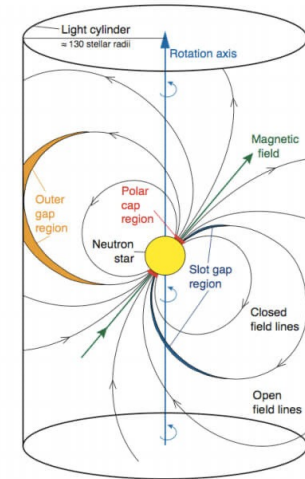
- JOCELYN BELL OBSERVED FOR THE FIRST TIME A PULSATING NEUTRON STAR (PULSAR) IN 1967 (BOTTOM-RIGHT)
- DISCOVERY AFFECTED WESTERN CUSTOM THAT IN 1979 THE RADIO EMISSION OF THE FIRST PULSAR BECAME THE FAMOUS COVER OF JOY DIVISION'S UNKNOWN PLEASURE ALBUM, A ROCK MILESTONE.



THE RADIO PULSARS THE LIGHTHOUSE EFFECT

- MAGNETIC FIELD UP TO 10^{12} - 10^{14} GAUSS
- ELECTRONS ARE STRIPPED OUT FROM THE NS SURFACE AND ARE ACCELERATED ALONG THE B-FIELD LINES BY SYNCHROTRON PROCESS
- THE ELECTRONS LEAVE THE NS AT THE LIGHT CYLINDER RADIUS
- THE ACCELERATED CHARGES EMIT PHOTONS

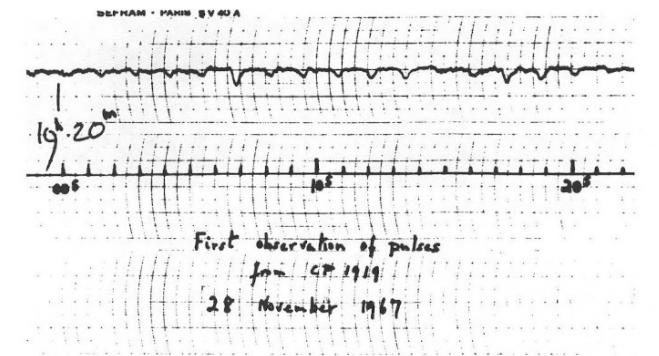
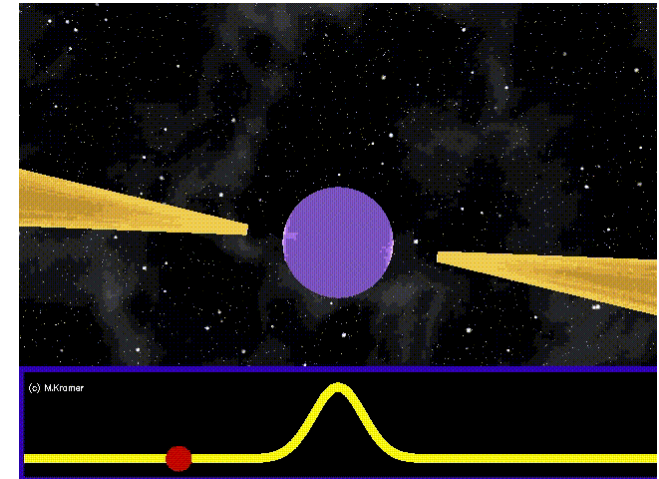
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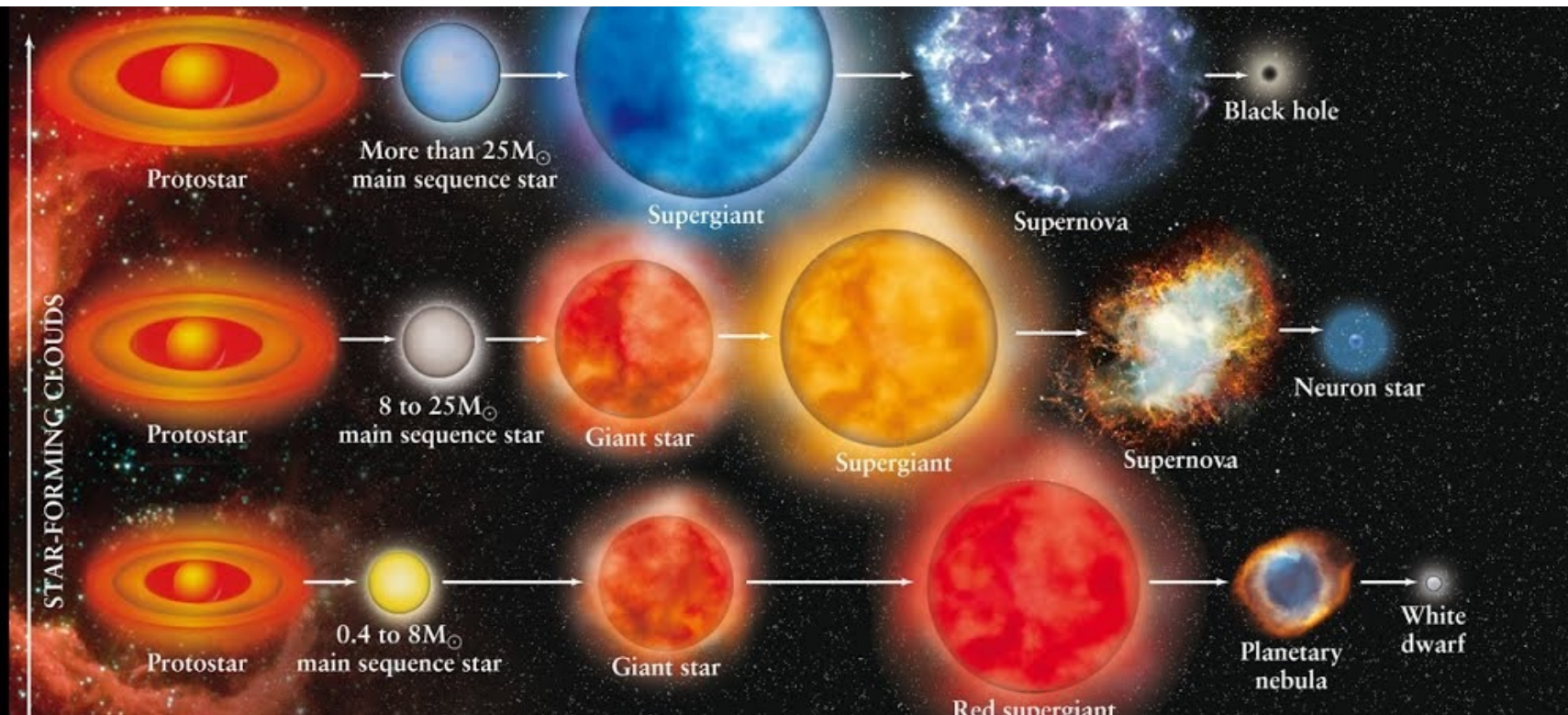


13 Dicembre 2023

THE FIRST OBSERVED RADIO PULSARS PSR B1919+21 (A.K.A. LGM-1)

- SPIN PERIOD 1.337302088331 s
- NS MASS = 1.4 – 2.5 M_{SUN}
- RAGGIO = 10 KM

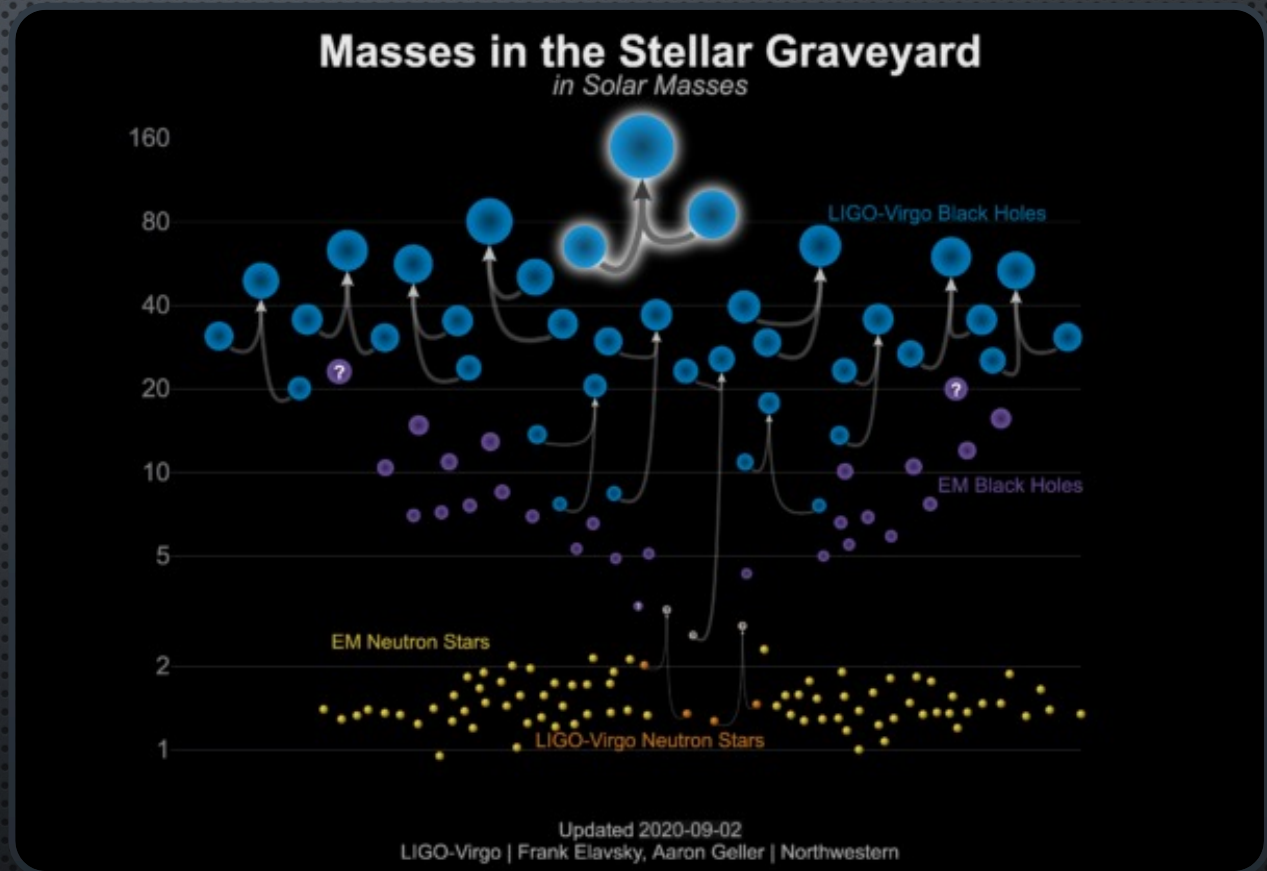




THE BLACK HOLES

THE MASS DISTRIBUTION OF NSs AND BHs

- ESTIMATED MASSES OF NSs AND BHs STUDYING THE ELECTROMAGNETIC SPECTRA AND THE GRAVITATIONAL WAVES

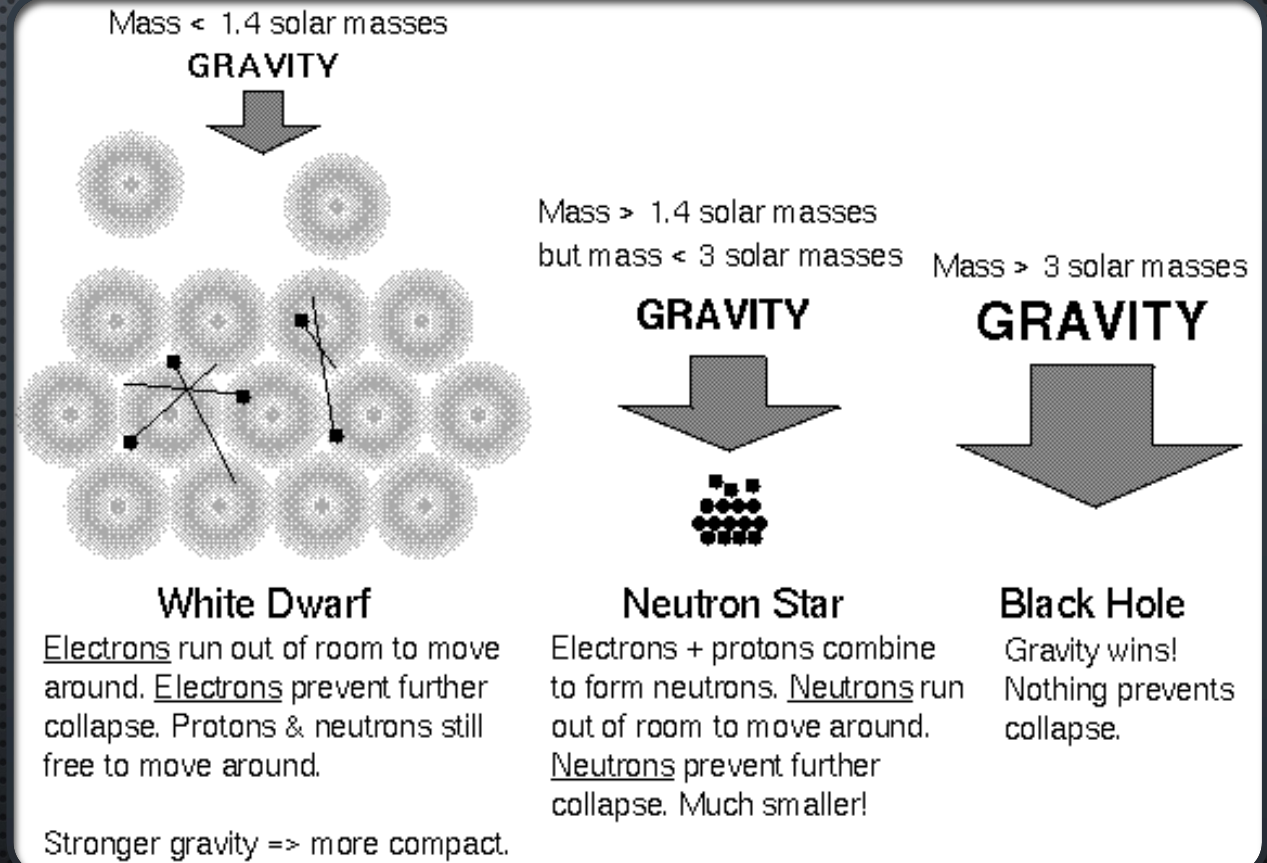


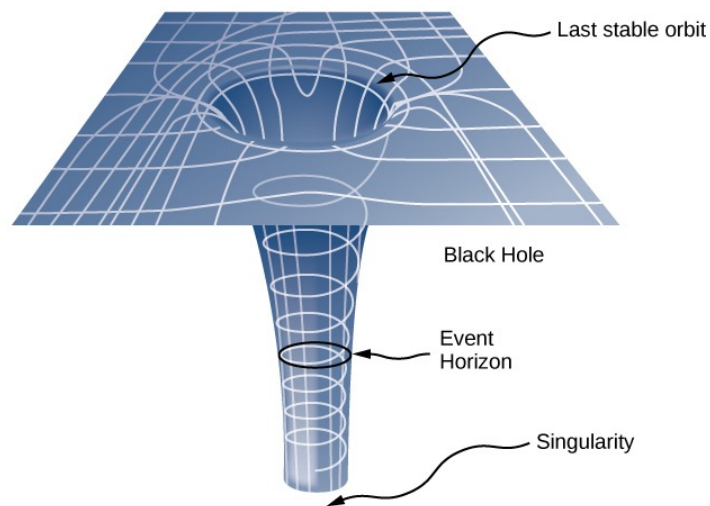
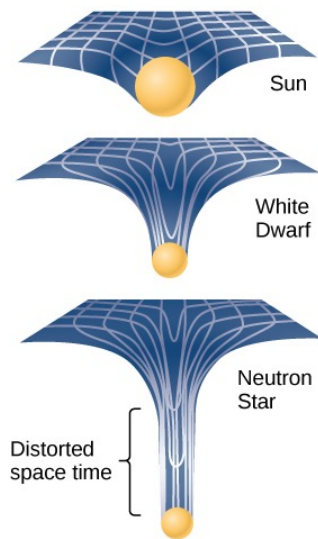
THE BLACK HOLE

- DURING THE CORE COLLAPSE THE AVAILABLE VOLUME FOR THE ELECTRONS DECREASES
- PAULI EXCLUSION PRINCIPLE (FERMION GAS)
- HEISENBERG INDETERMINATION PRINCIPLE

$\Delta x \Delta p \geq \hbar$, INCREASE THE ELECTRON VELOCITY

- GRAVITY WINS!



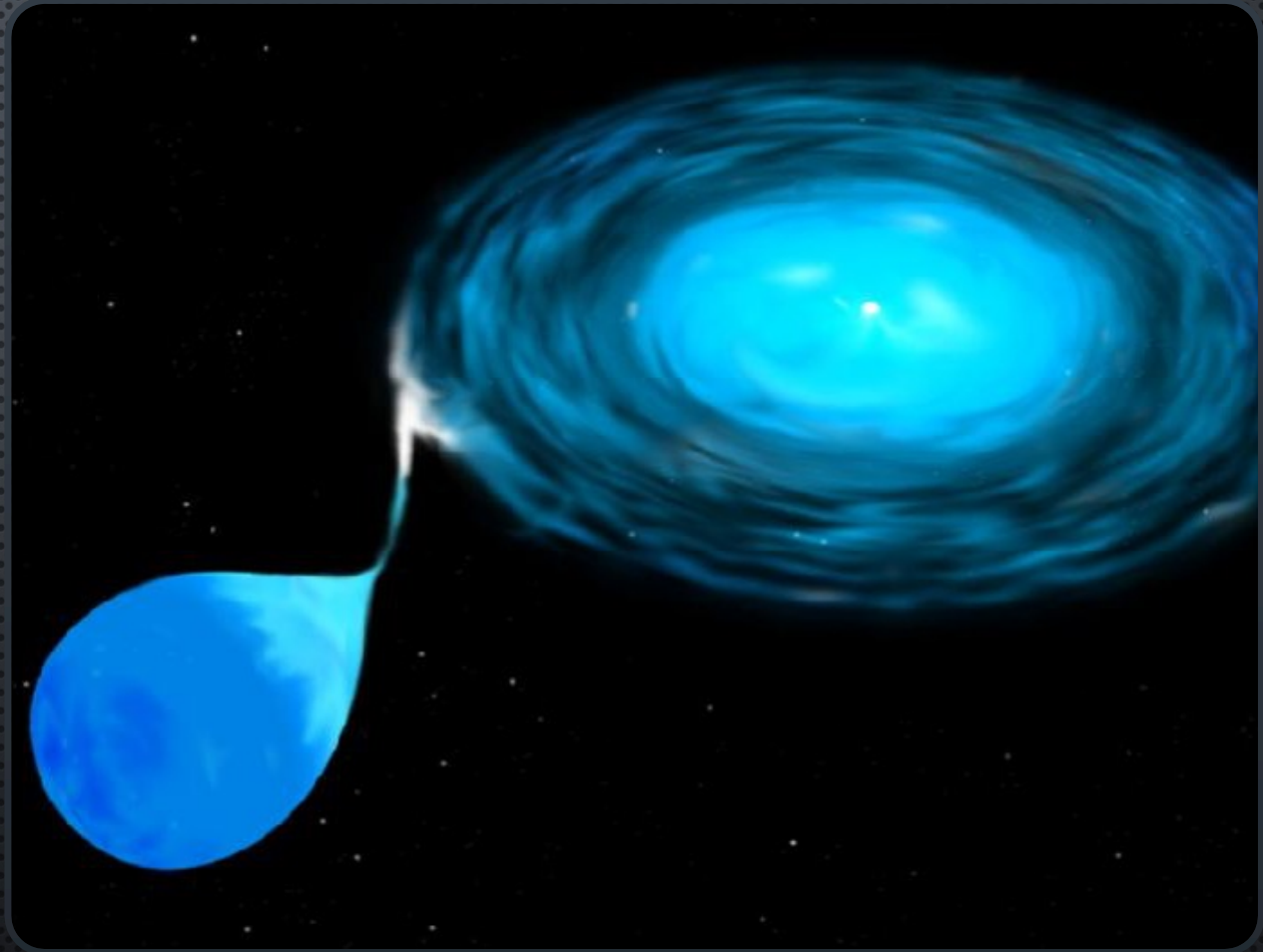


THE GRAVITATIONAL WELL

MORE THE OBJECT IS COMPACT AND MORE THE GRAVITATIONAL FIELD IS WARPED

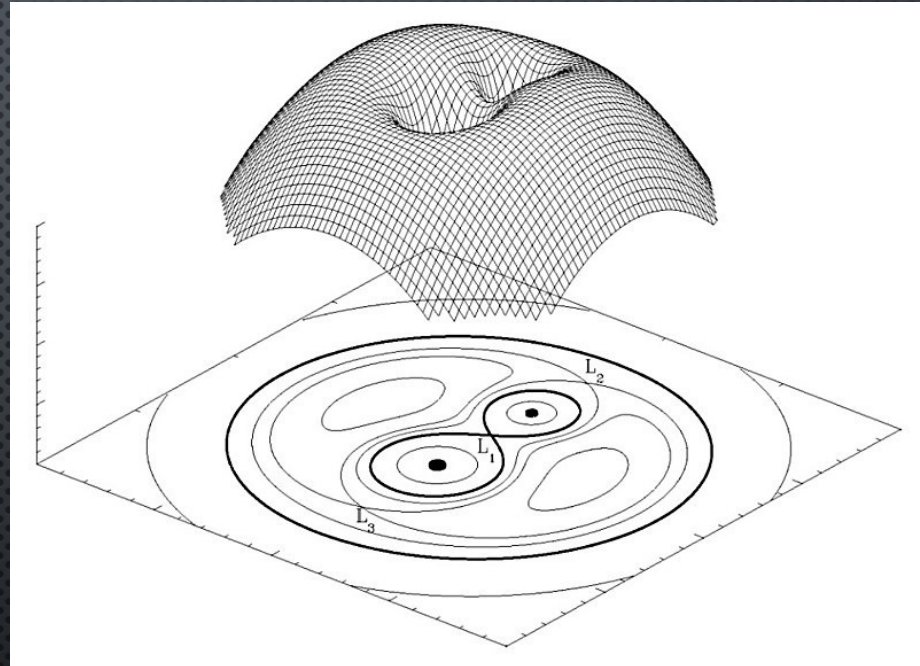
BINARY SYSTEM HOSTING A COMPACT OBJECT

- INNER LAGRANGIAN POINT
- ACCRETION DISK
- CONVERSION OF MECHANICAL ENERGY IN RADIATION

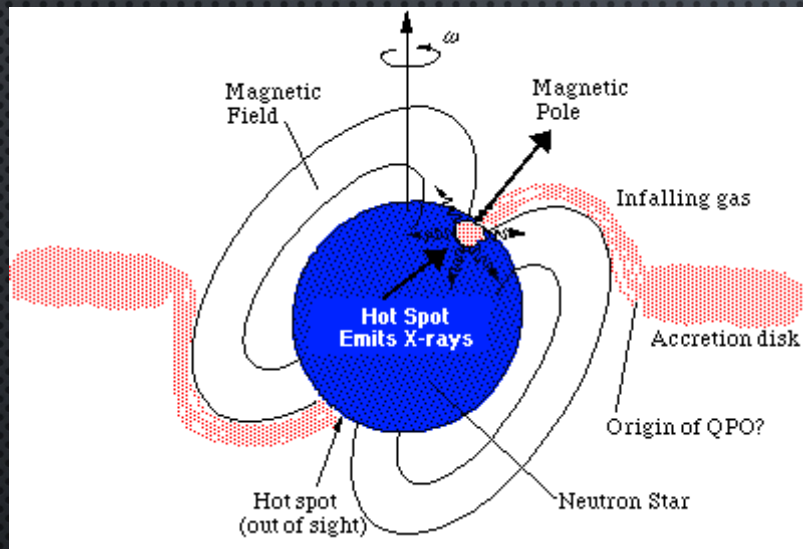


THE ROCHE LOBE

- INNER LAGRANGIAN POINT
- THE INTERNAL EQUIPOTENTIAL SURFACES ARE CALLED ROCHE-LOBES



MAGNETIZED NS IN BINARY SYSTEM



- AT THE MAGNETOSPHERIC RADIUS THE MAGNETIC FORCE DOMINATES OVER THE GRAVITATIONAL FORCE. THE MATTER MOVES ALONG THE B-FIELD LINES.
- THE MATTER FALLS ONTO THE MAGNETIC CAP
- THE LIGHTHOUSE EFFECT IN THE X-RAY BAND IS OBSERVED