Understanding the violent Universe and the critical role of Women Scientists

Poonam Chandra
National Centre for Radio Astrophysics
Tata Institute of Fundamental Physics

United Nation's International Day of Women and Girls in Science - 11 February

In 2015, countries adopted the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals.

Goal 1: No Poverty

Goal 2: Zero Hunger

Goal 3: Good Health and Well-Being

Goal 4: Quality Education

Goal 5: Gender Equality

Goal 6: Clean Water and Sanitation

Goal 7: Affordable and Clean Energy

Goal 8: Decent Work and Economic Growth

Goal 9: Industry, Innovation and Infrastructure

Goal 10: Reduced Inequalities

Goal 11: Sustainable Cities and Communities

Goal 12: Responsible Production and Consumption

Goal 13: Climate Action

Goal 14: Life Below Water

Goal 15: Life On Land

Goal 16: Peace, Justice and Strong Institutions

Goal 17: Partnerships for the Goals

Stellar Classification

- Anne Jump Cannon (1863-1941)
- Pioneering work in stellar classification. First serious attempt to organize and classify stars based on their temperatures and spectral types.
- On May 9, 1922, the International Astronomical Union passed the resolution to formally adopt Cannon's stellar classification system; with only minor changes, it is still being used for classification today.
- She was nearly deaf throughout her career.

Stars are made of Hydrogen and Helium

- Cecilia Payne-Gaposchkin (May 10, 1900 – December 7, 1979)
- In 1925 she became the first person to earn a PhD in astronomy from Radcliffe College (now part of Harvard).
- Proposed stars made of Hydrogen and Helium (initially rejected because it contradicted the prevalent scientific consensus that the elemental composition of the Sun and the Earth were similar.)
- First woman to head a department at Harvard

Nucleosynthesis

- Margaret Burbidge (1919-).
- Studied chemical abundances in stars - a hypothesis that all chemical elements might be synthesized in stars by nuclear reaction.
- This theory has been the basis for a substantial field of research in astrophysics.
- The first woman president of the American Astronomy society.

Period luminosity relation

- Henrietta Swan Leavitt (1868-1921)
- A "computer", tasked with examining photographic plates in order to measure and catalog the brightness of stars.
- Relation between the luminosity and the period of Cepheid variables (Leavitt's relation)
- This discovery provided astronomers with the first "standard candle" with which to measure the distance to faraway galaxies.

Galaxy rotation curve - evidence of dark matter

- Vera Rubin (1928 - 2016)
- Pioneered work on galaxy rotation rates. Proved existence of dark matter.
- Rubin spent her life advocating for women in science and was known for her mentorship of aspiring women astronomers.

Galaxy Evolution & Universe Geometry

- Beatrice Muriel Hill Tinsley (1941-1981).
- Fundamental contributions to the astronomical understanding of how galaxies evolve, grow and die.
- Pioneering theoretical studies of how populations of stars age and affect the observable qualities of galaxies.
- Important contribution in investigating whether the universe is closed or open. Her galaxy models led to the first approximation of what protogalaxies should look like.

Radio Astronomy

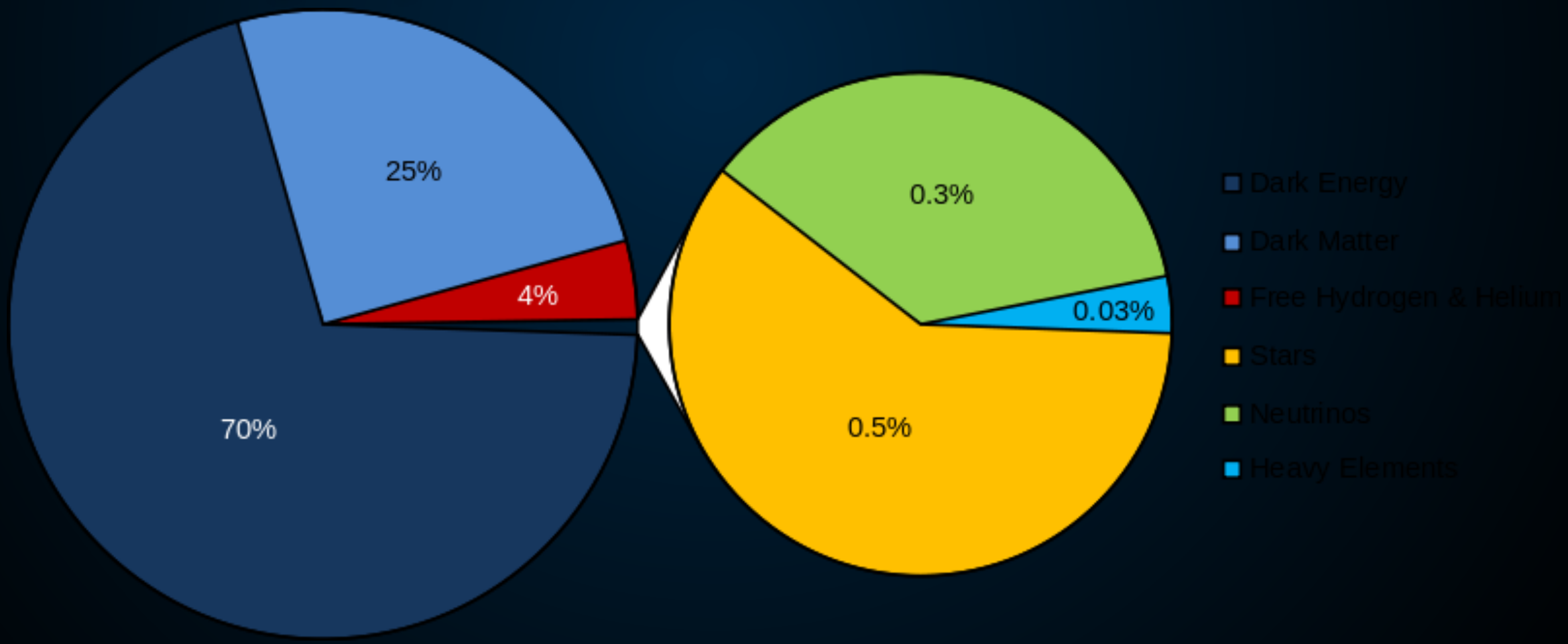
- Ruby Payne-Scott (1912-1981)
- First female radio Astronomer
- A connection between sunspots and increased radio emissions from the sun.
- First suggestion of Fourier synthesis in radio astronomy, an idea that hinted at the field's future of aperture synthesis.
- Short career, big achievements.

Discovery of Pulsars - first direct proof of neutron stars

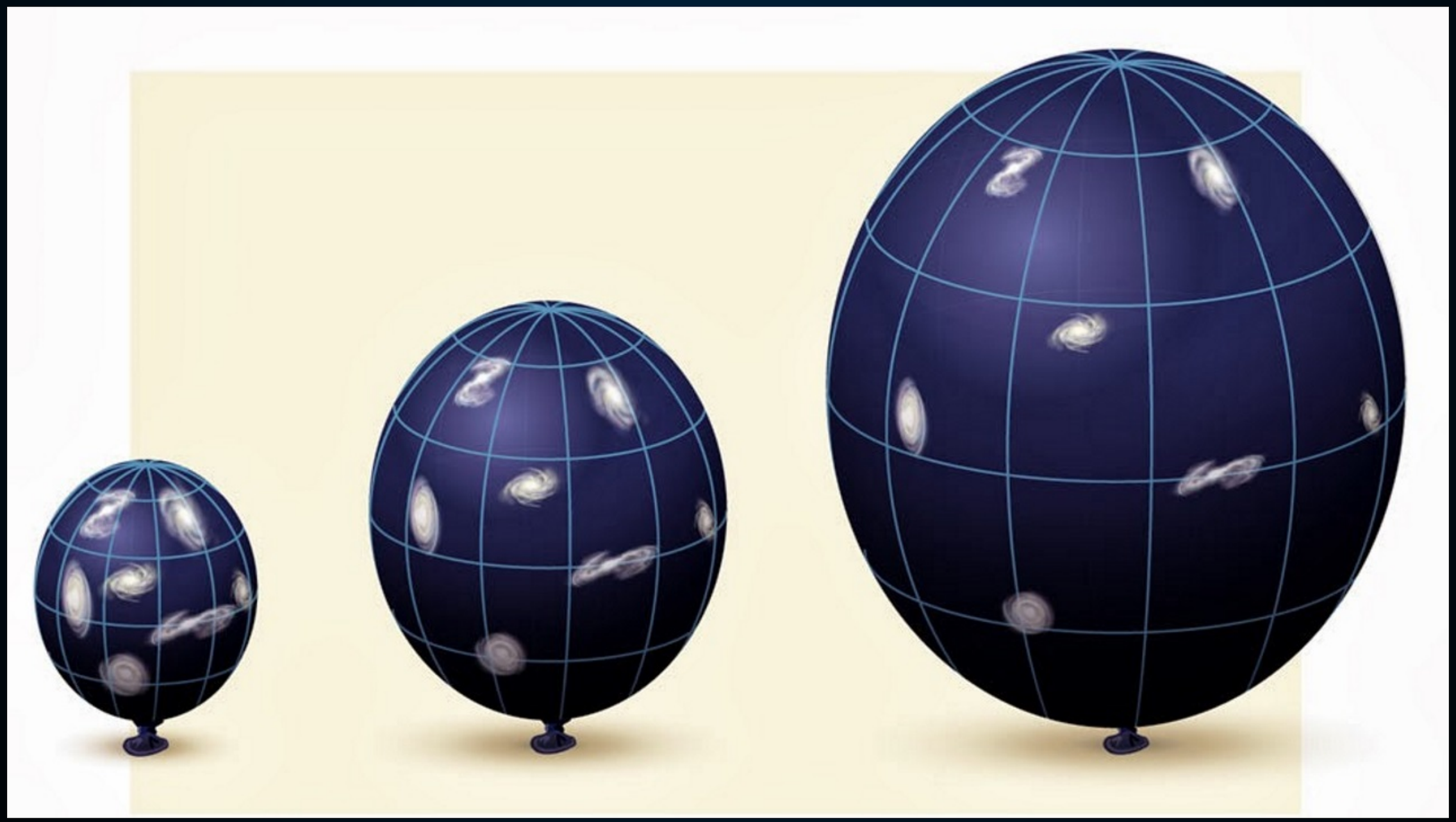
- Jocelyn Bell Burner (1943)
- Discovery of Pulsar - fast rotating neutron stars
- One of the most significant scientific achievements of the 20th century.
- In 2018, she was awarded the Special Breakthrough Prize in Fundamental Physics. She gave the whole of the £2.3m prize money to help women, ethnic minority, and refugee students become physics researchers.

Constitution of the Universe

- More than 100 billion galaxies.
- Each galaxy more than 100-200 billion stars



Expanding and accelerating Universe



Universe a violent place

Every second 8 stars die in Universe with an explosion so big as to outshine the whole Milky Way with 100 billion stars.

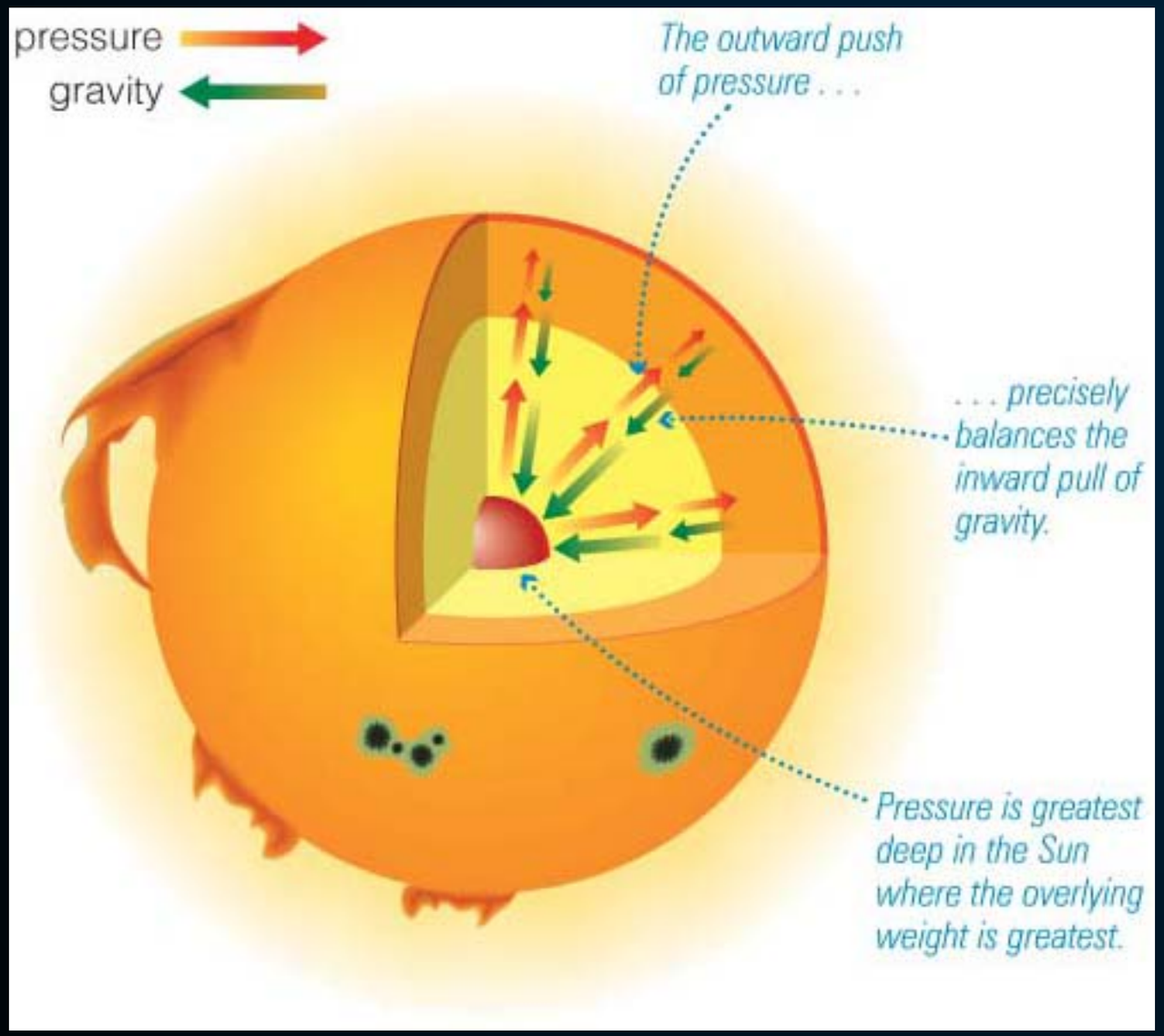
What about us?

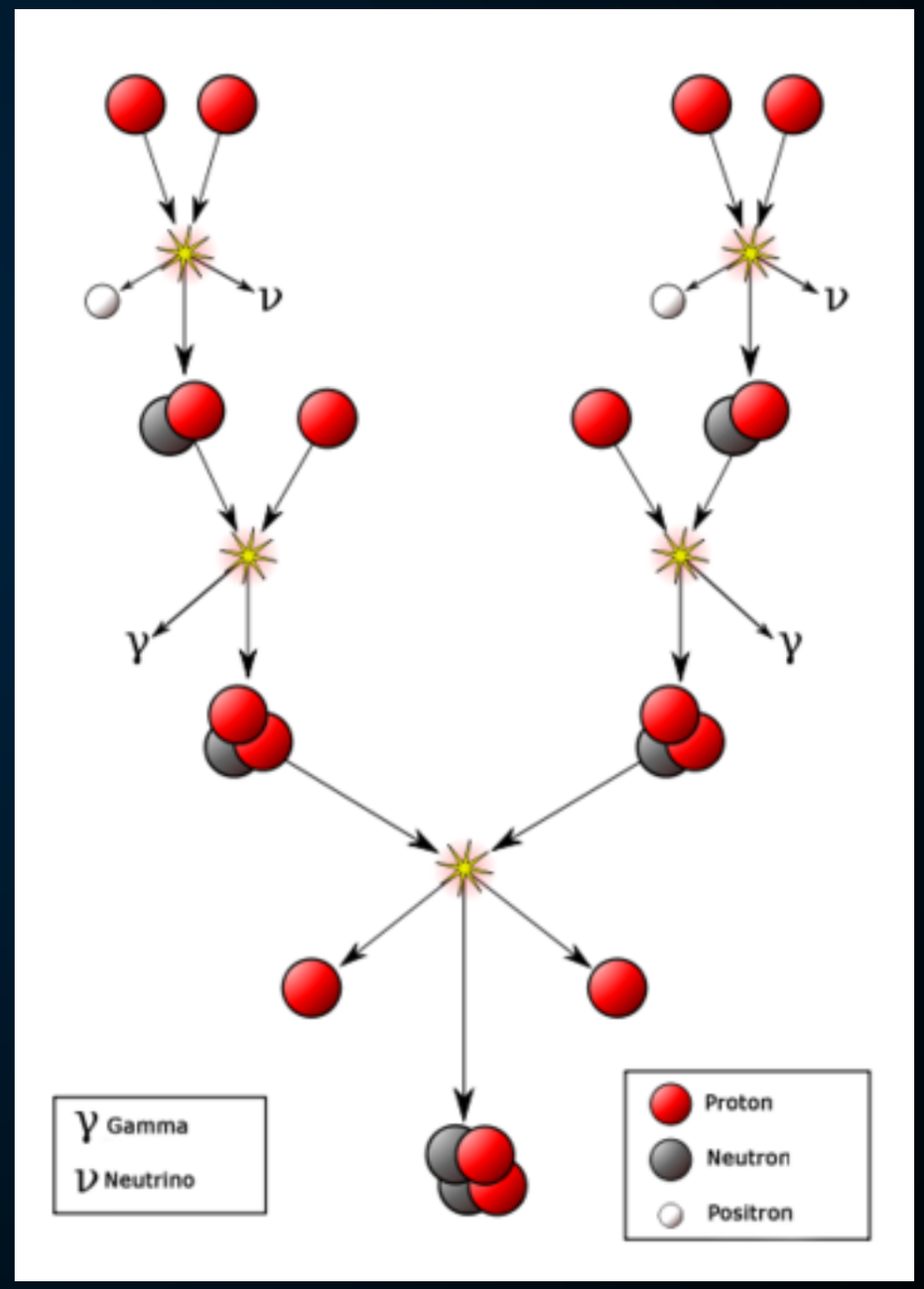
- Let's talk about our existence.

- After the origin of the Universe, Mostly Hydrogen (~74-75%), Helium (~24-25%), Lithium (~1%)?

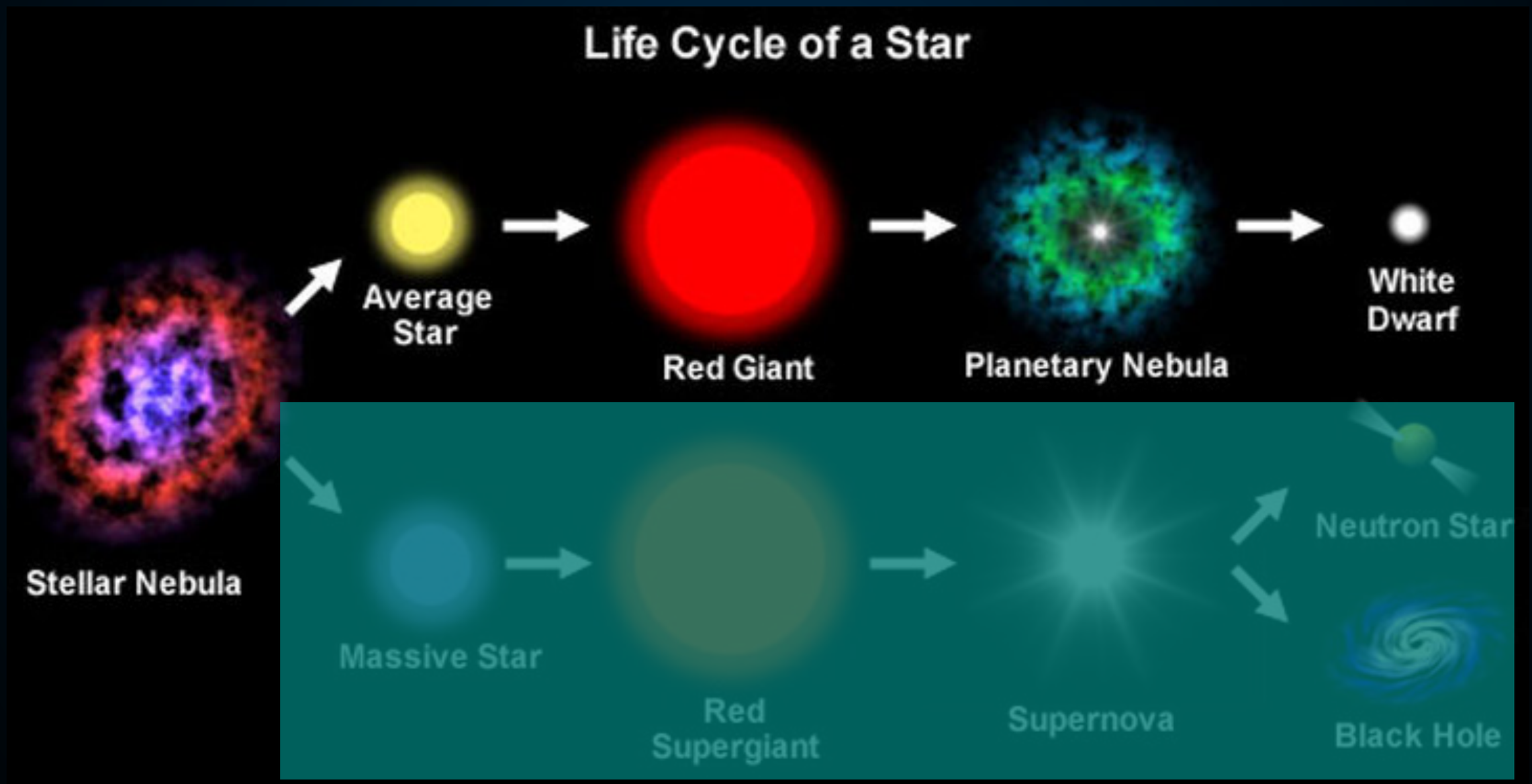
- How did the heavier elements produced?

Our Sun


pressure
gravity
The outward push of pressure . . .
. . . precisely balances the inward pull of gravity.
Pressure is greatest deep in the Sun where the overlying weight is greatest.


ν
ν
γ
γ
γ Gamma
ν Neutrino
Proton
Neutron
Positron

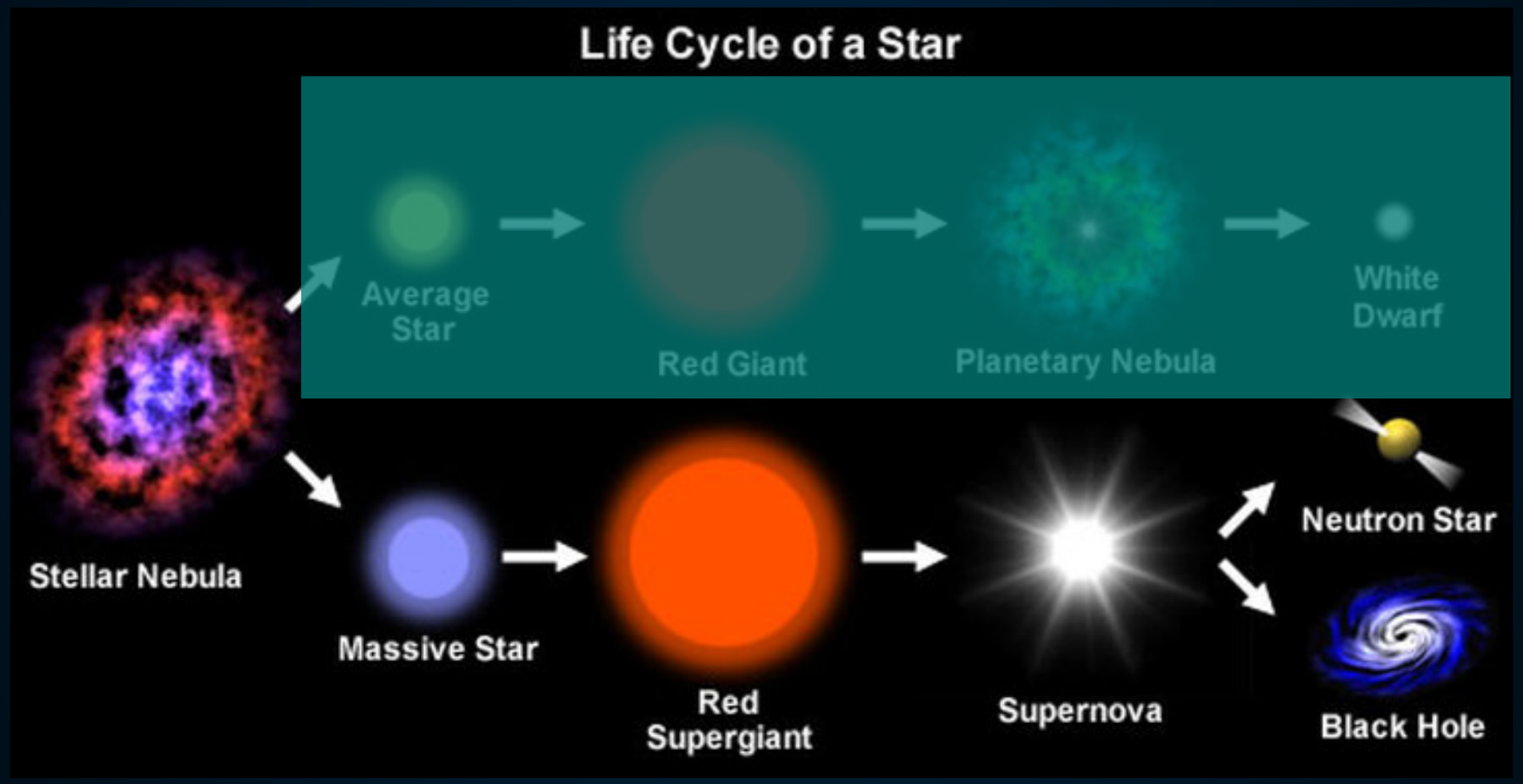
Our Sun


Life Cycle of a Star
Stellar Nebula
Average Star
Red Giant
Planetary Nebula
White Dwarf
Massive Star
Red Supergiant
Supernova
Neutron Star
Black Hole

Story of massive stars

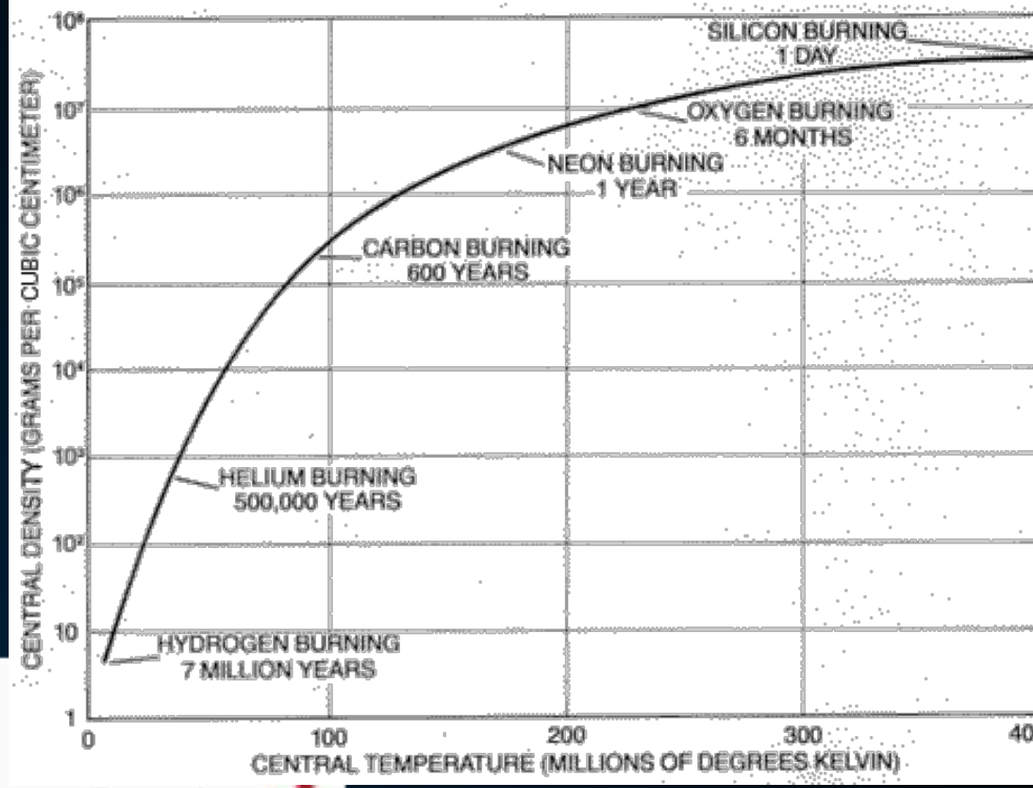
- Stars <0.4 $M_\odot$ to >100$M_\odot$.
- Massive star : evolution for millions of years - Nuclear fusion.
- Runs out of nuclear fuel, collapses under own gravity in less than a second - violent explosion as supernovae or GRBs (>10^{44} Joules).

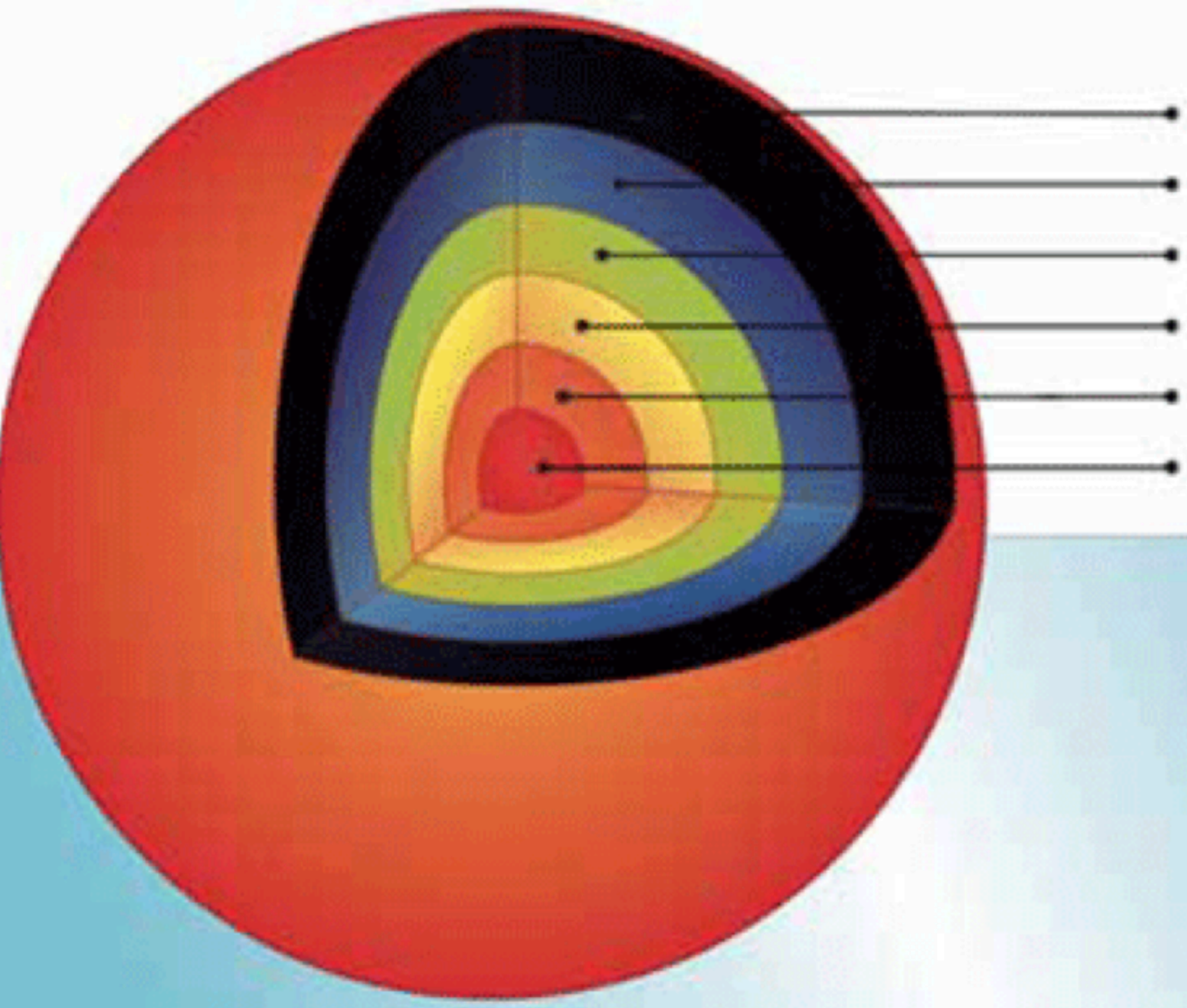
Evolution of massive stars



- Star collapses under its own gravity. Collapse turns into an explosion ejecting 1% (~10^{51} ergs) energy in electromagnetic radiation and 99% (~10^{53} ergs) in neutrinos.

End of massive stars

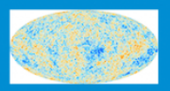


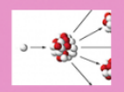


Brown & Bethe 1992

Periodic Table

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											

big bang fusion 

cosmic ray fission 

merging neutron stars 

exploding massive stars 

dying low mass stars 

exploding white dwarfs 

Supernovae and Gamma Ray Bursts

Gravitational Waves

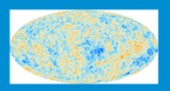
- 100 year old prediction by Einstein.
- Detection on 14 Sep 2015, GW 140915 by Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO).
- Merging of two ~30 solar mass black holes. Energy released equivalent to 3.
- Confirmation of General Theory of Relativity
- Existence of binary stellar-mass black hole system - such mergers do happen within the current life time of the universe.

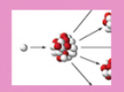
Gravitational Wave GW170817

- One event was special - GW 170817 - marking the first joint detection and study of gravitational waves (GWs) and electromagnetic radiation (EM).
- Confirmation of heavy elements
- Confirmation that gravitational waves travel with speed of light.
- Confirmation that two neutron stars make gamma ray bursts.

Periodic Table

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											

big bang fusion 

cosmic ray fission 

merging neutron stars 

exploding massive stars 

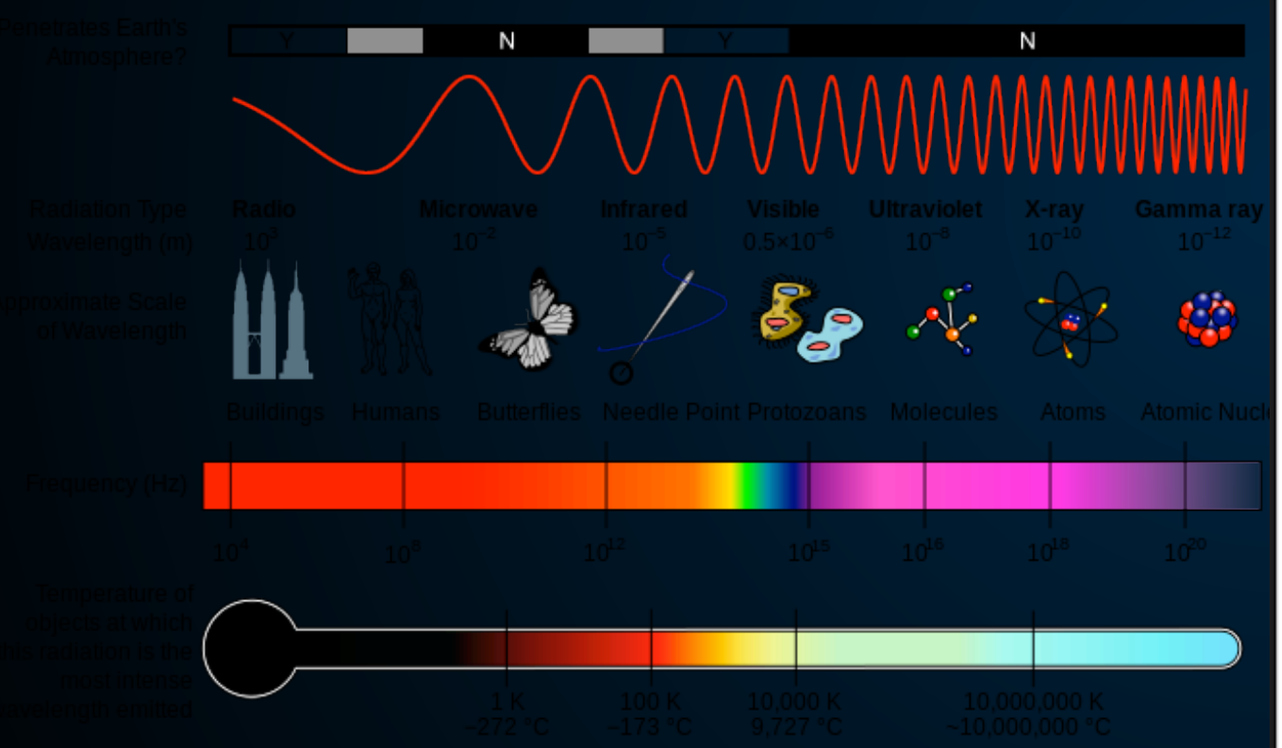
dying low mass stars 

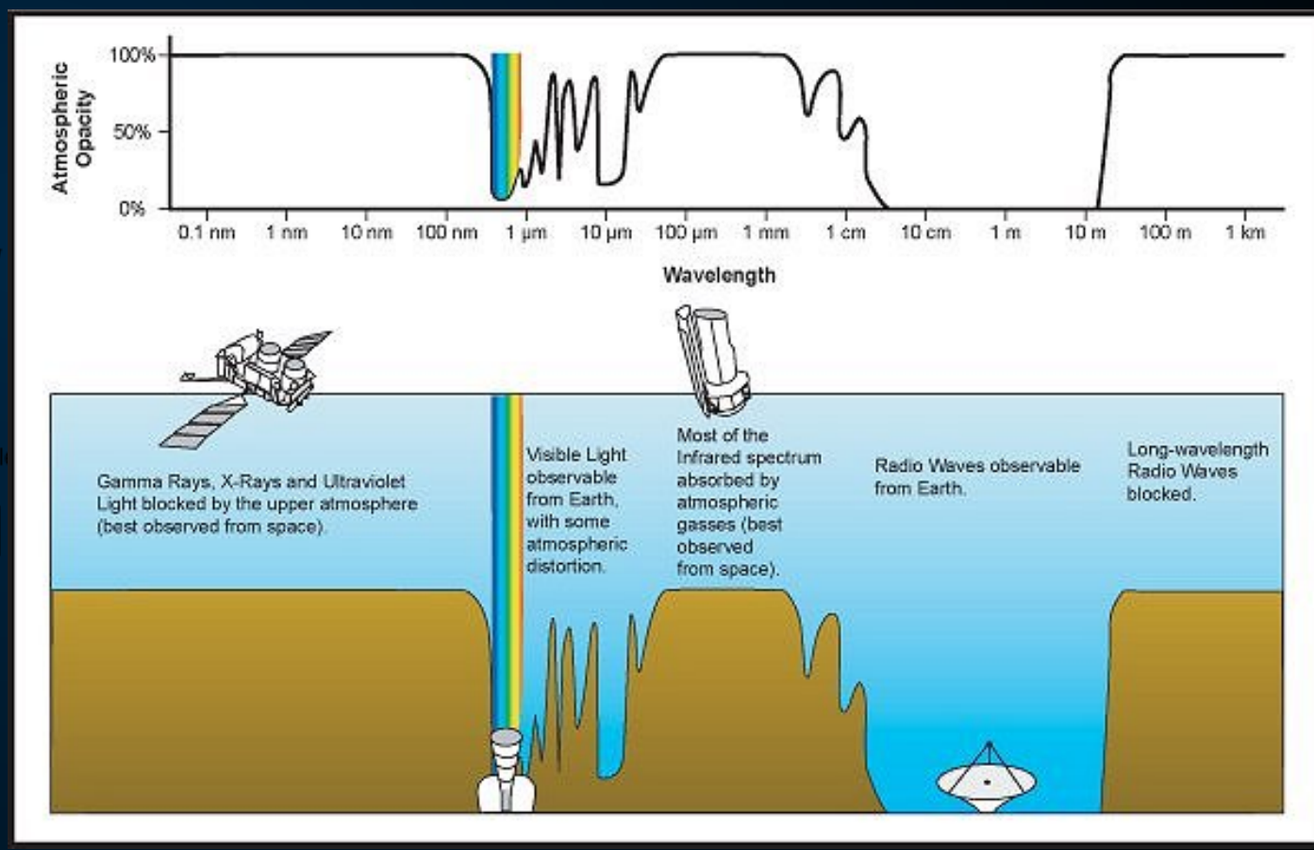
exploding white dwarfs 

Blast from the past!

And how to study them?

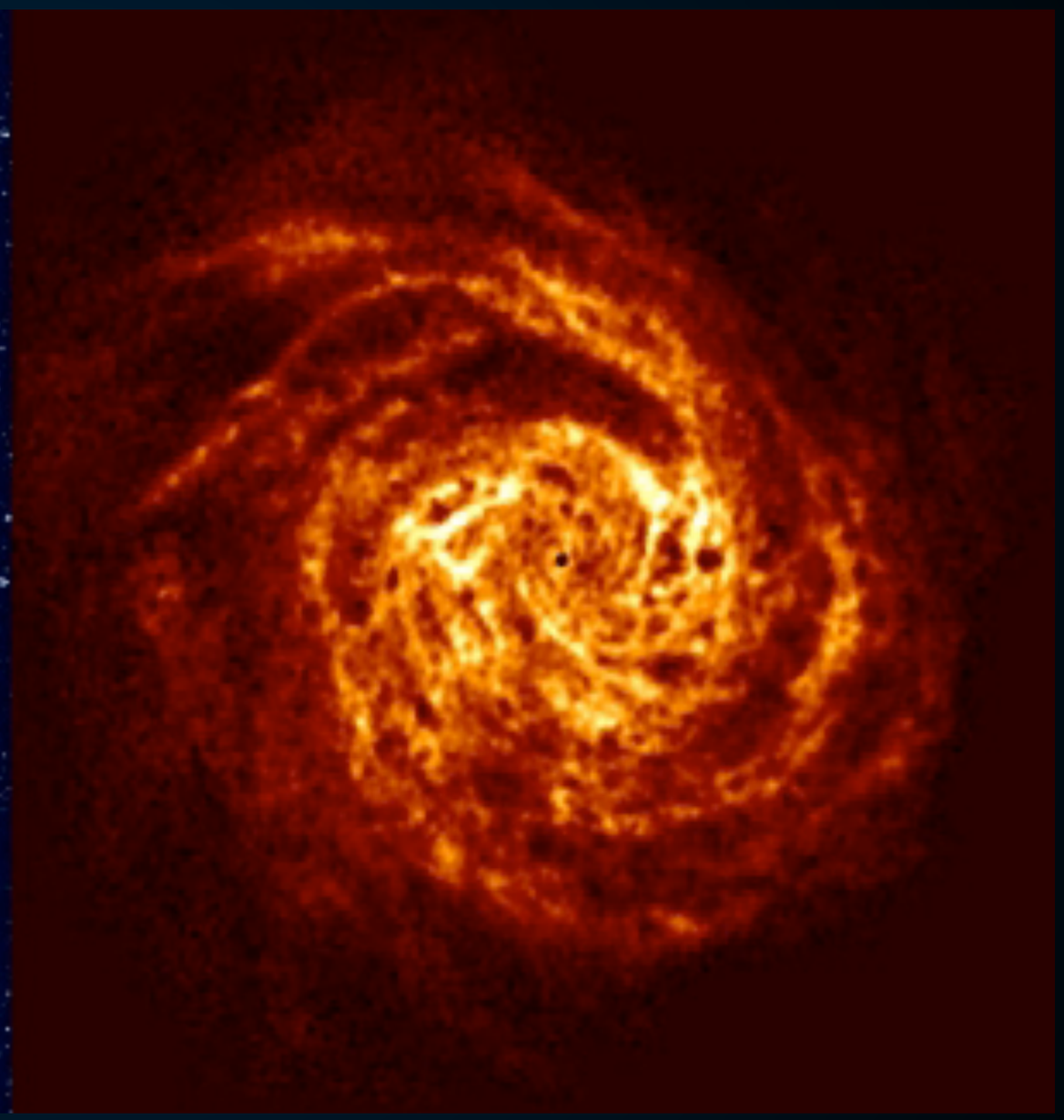
Electromagnetic Spectrum - and transparent window on earth





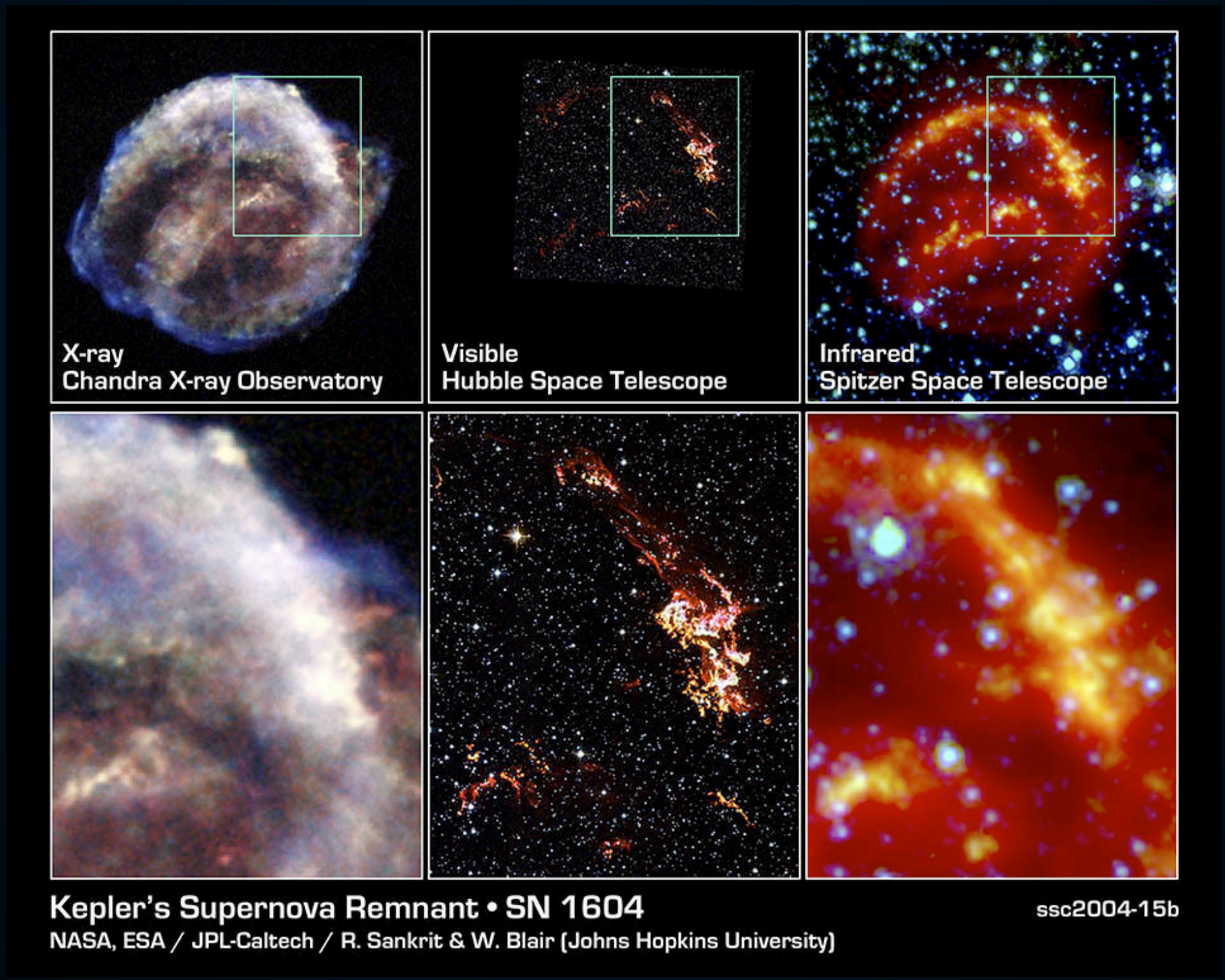
Looking through different lenses

NGC 6946 - Optical & Radio



- Stars and warm gas emit visible light but cold gas glows at radio wavelengths

Kepler Supernova Remnant



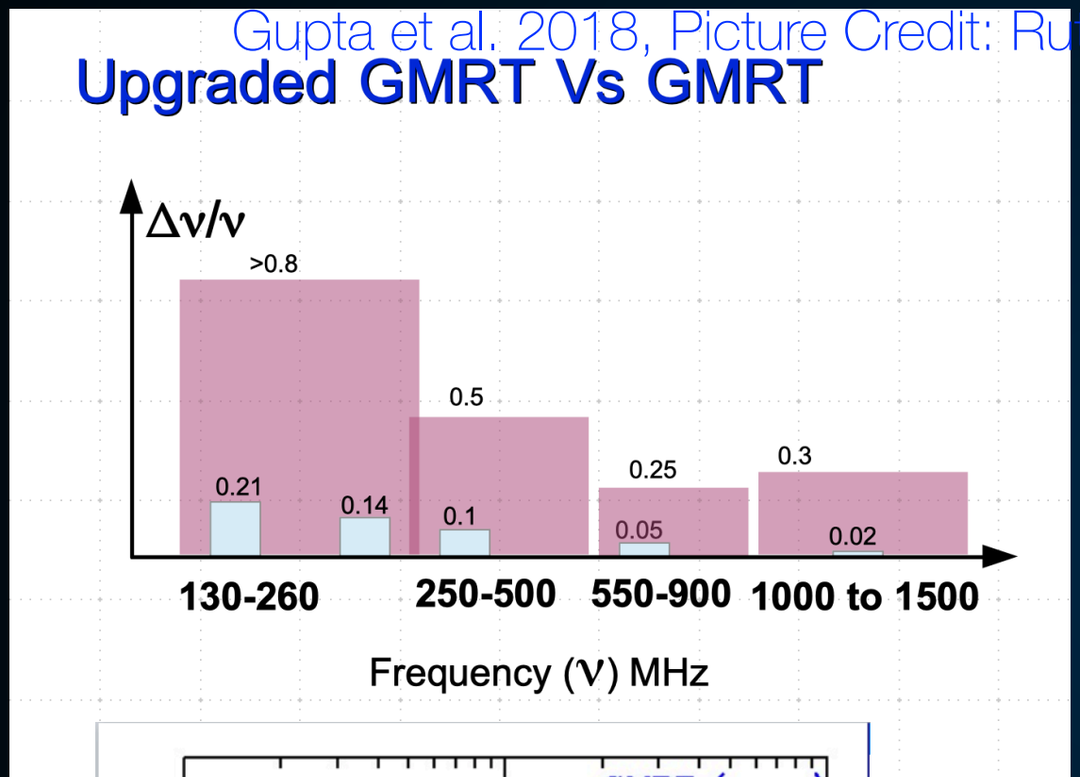
Some notable Indian Observatories

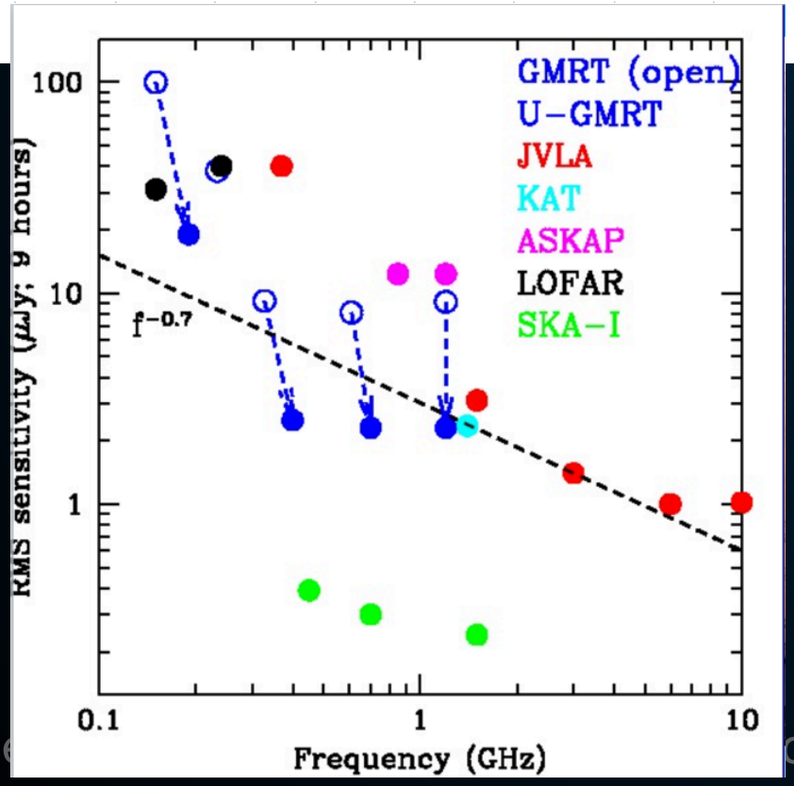
The Giant Metrewave Radio Telescope (GMRT)

- 30 antennas, each antenna 45 m in diameter, spread over 25 km.
- 80 km from Pune in Narayan Gaon
- The most sensitive radio telescope in the World at low frequencies, i.e. 1420 MHz (λ=20cm), 610 MHz (λ=50cm), 325 MHz (λ=90cm), 150 MHz (λ=200cm).
- Now Upgraded GMRT with 3 times higher sensitivity

The upgraded GMRT

Gupta et al. 2018, Picture Credit: Ruta Kale





The AstroSAT

- Indian Satellite. Launched 28 Sep 2015
- Optical to hard X-ray
- Onboard instruments - UVIT, LAXPC, SXT, CZTI
- All wavelengths from UV to X-rays.
- CZTI best for low latency follow ups - 36 deg^2 FOV

Square Kilometre Arra

- The Square Kilometre Array (SKA), the next generation radio telescope, construction starting sometime this year.
  - In South Africa & Australia.
  - India is one of the member countries in the SKA Organisation and hence involved in the design and operation of SKA-I.

The Thirty Meter Telescope (TMT)

- The TMT is an international project being funded by scientific organisations of Canada, China, India, Japan and USA - in Hawaii.

- The Thirty Meter Telescope (TMT) project is the joint responsibility of the Department of Science & Technology (DST) and the Department of Atomic Energy (DAE) from India.

- TMT will enable scientists to study fainter objects far away from us in the Universe, which gives information about early stages of evolution of the Universe.

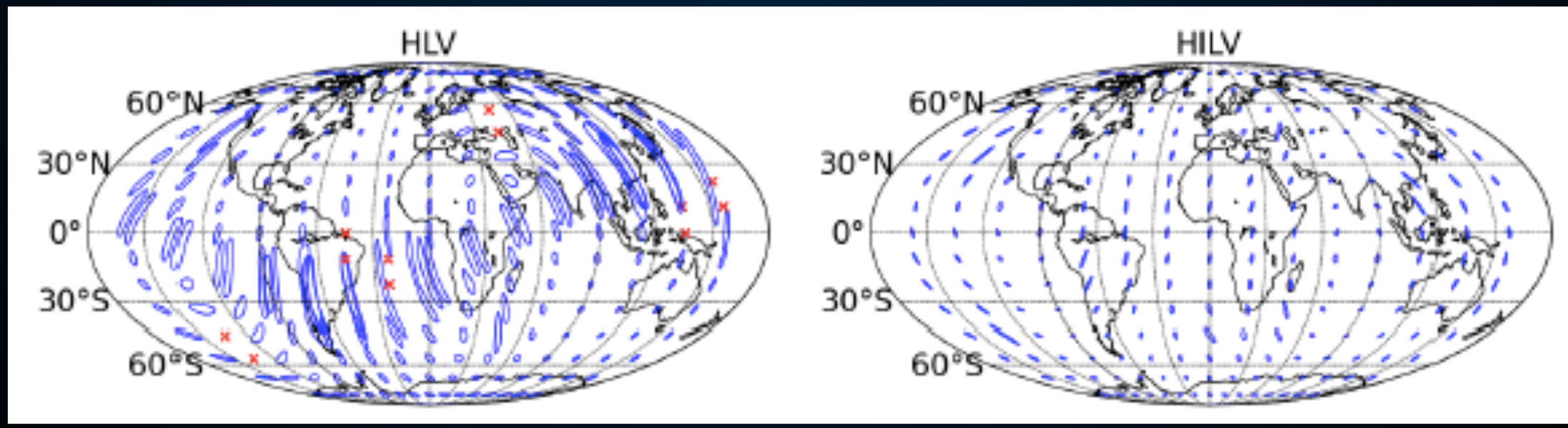
- India major participant in the project.

Multimessenger Astronomy - LIGO India

LIGO India

- Addition of a LIGO-I with increase detection fraction of mergers by 30%
- Reduce localization error by a factor of 2.

- Median localization area at merger time, for 40-s latency time



Take Home Message

- One of the best time to do Astronomy
- uGMRT - World's largest radio telescope and pathfinder of Square Kilometre Array
- LIGO- India - breakthrough in gravitational waves
- TMT 30m telescope - India's significant participation
- AstroSAT - a very sensitive high frequency Indian satellite telescope