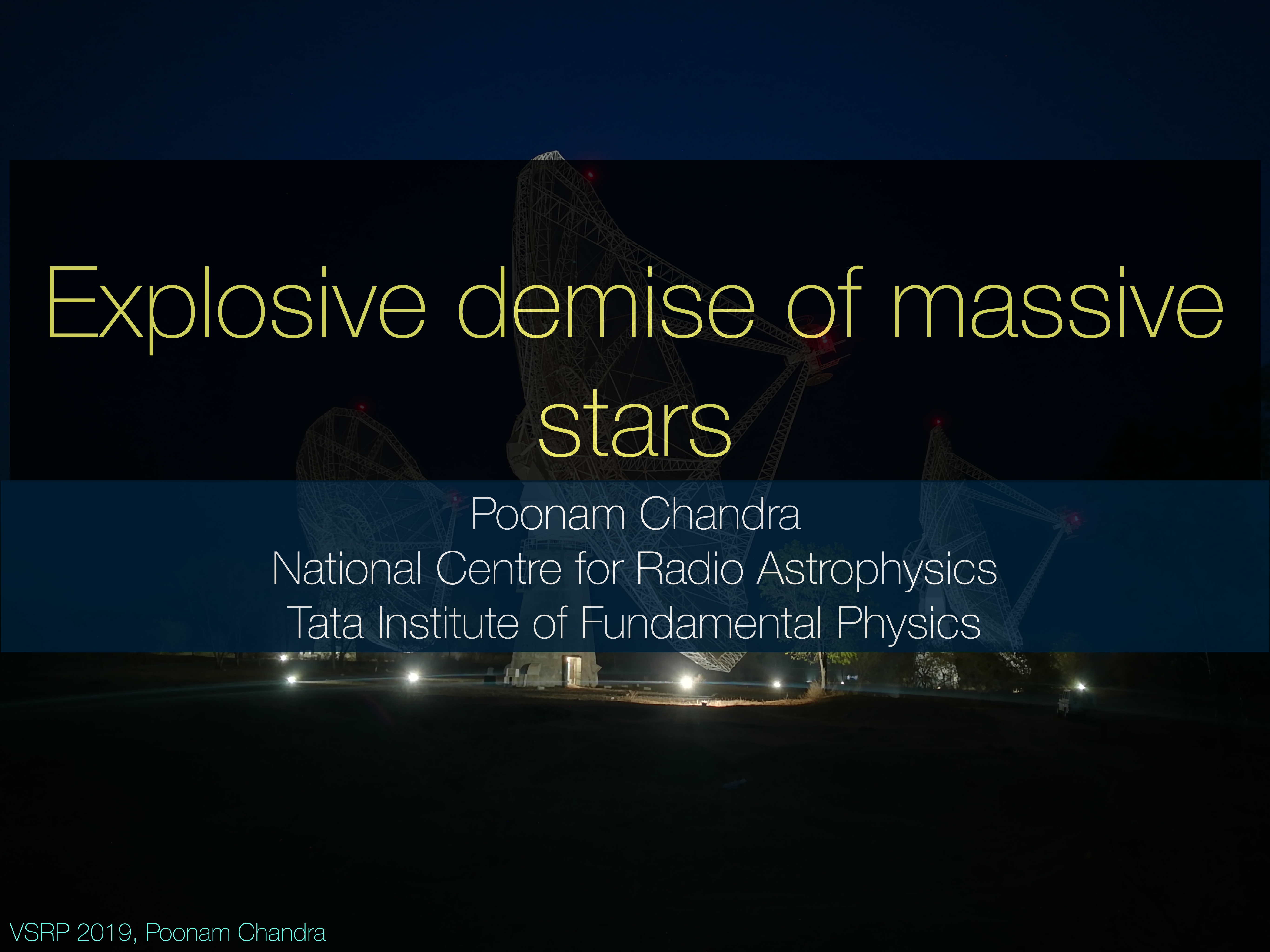
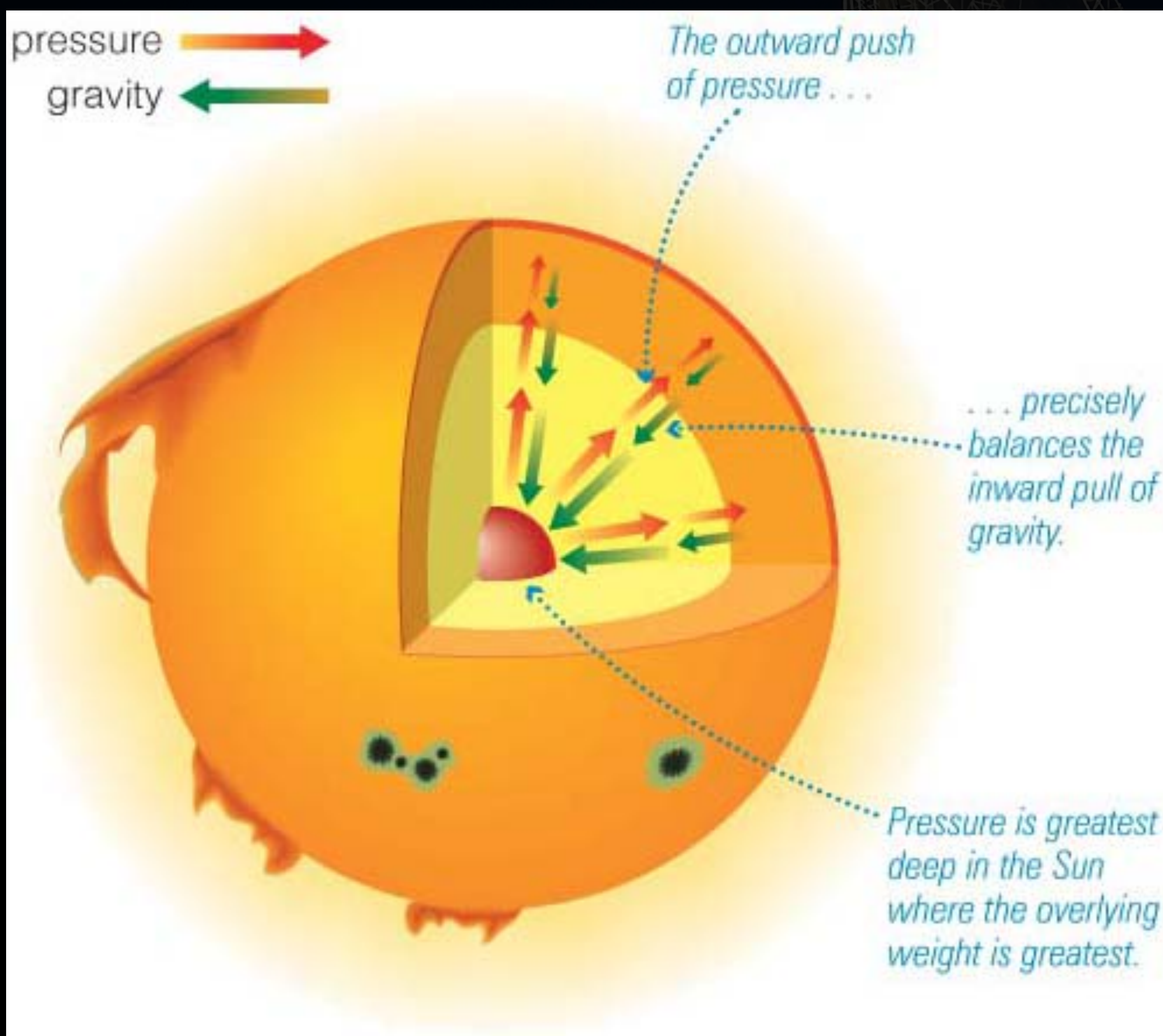
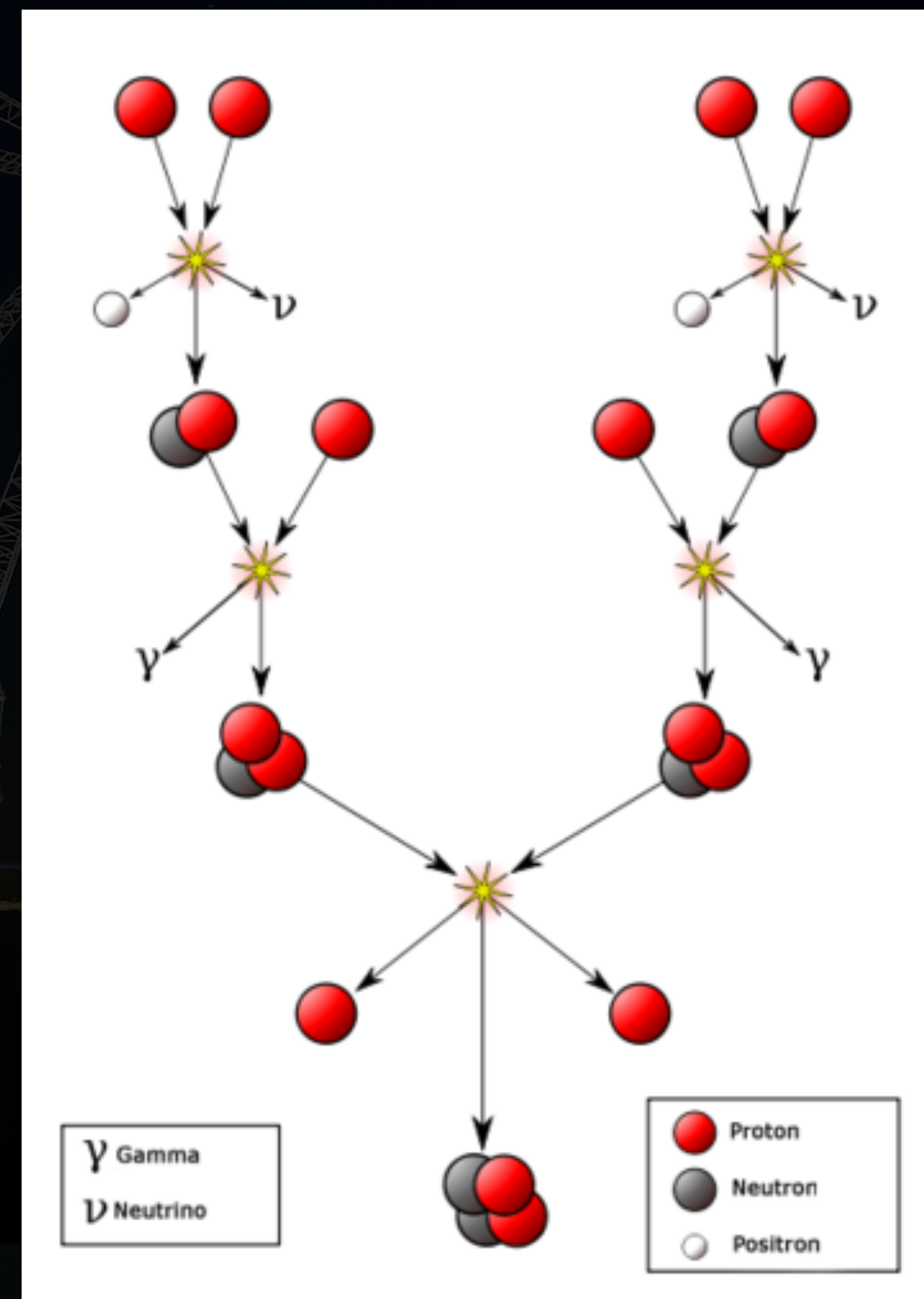


Explosive demise of massive stars

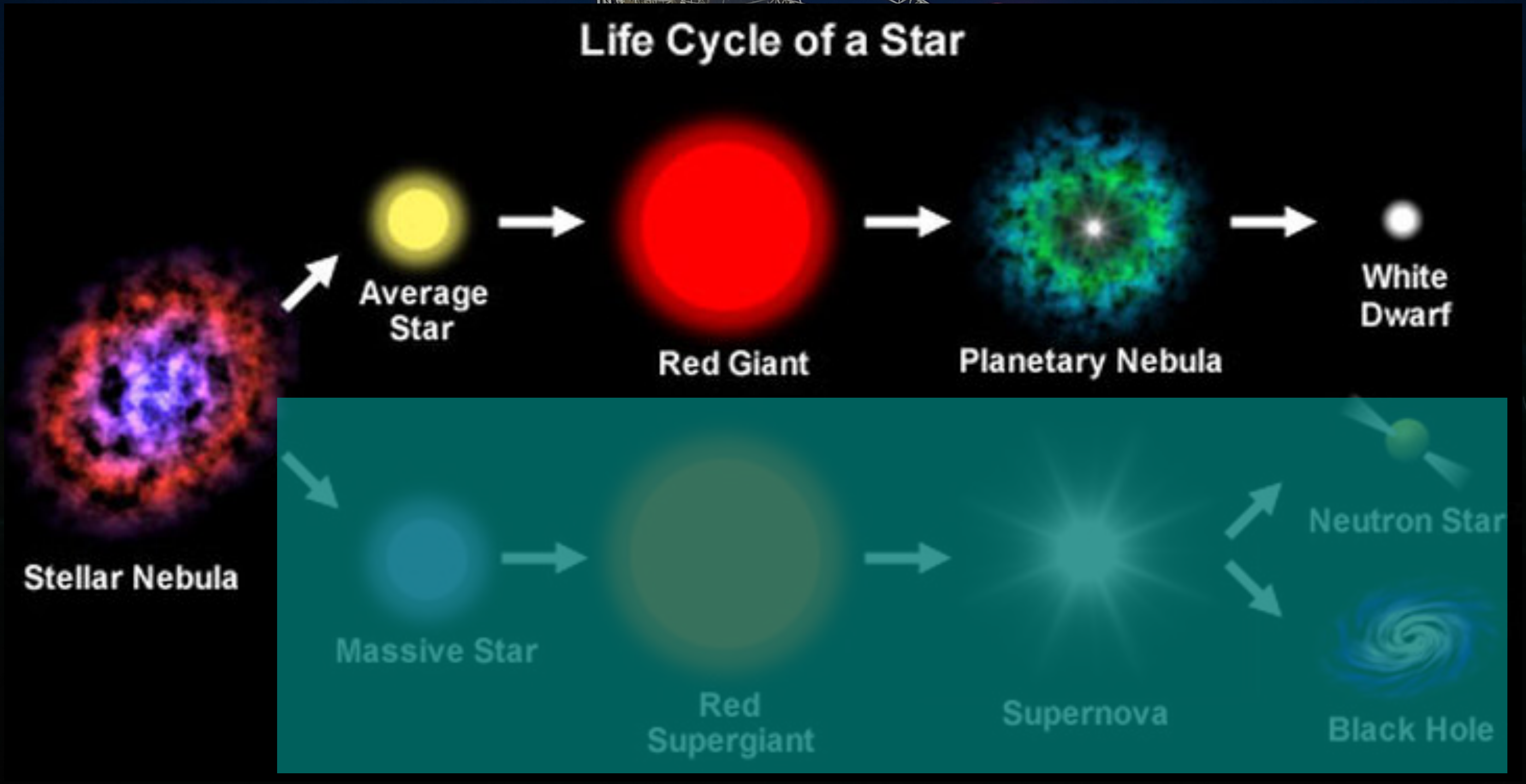
Poonam Chandra
National Centre for Radio Astrophysics
Tata Institute of Fundamental Physics

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.

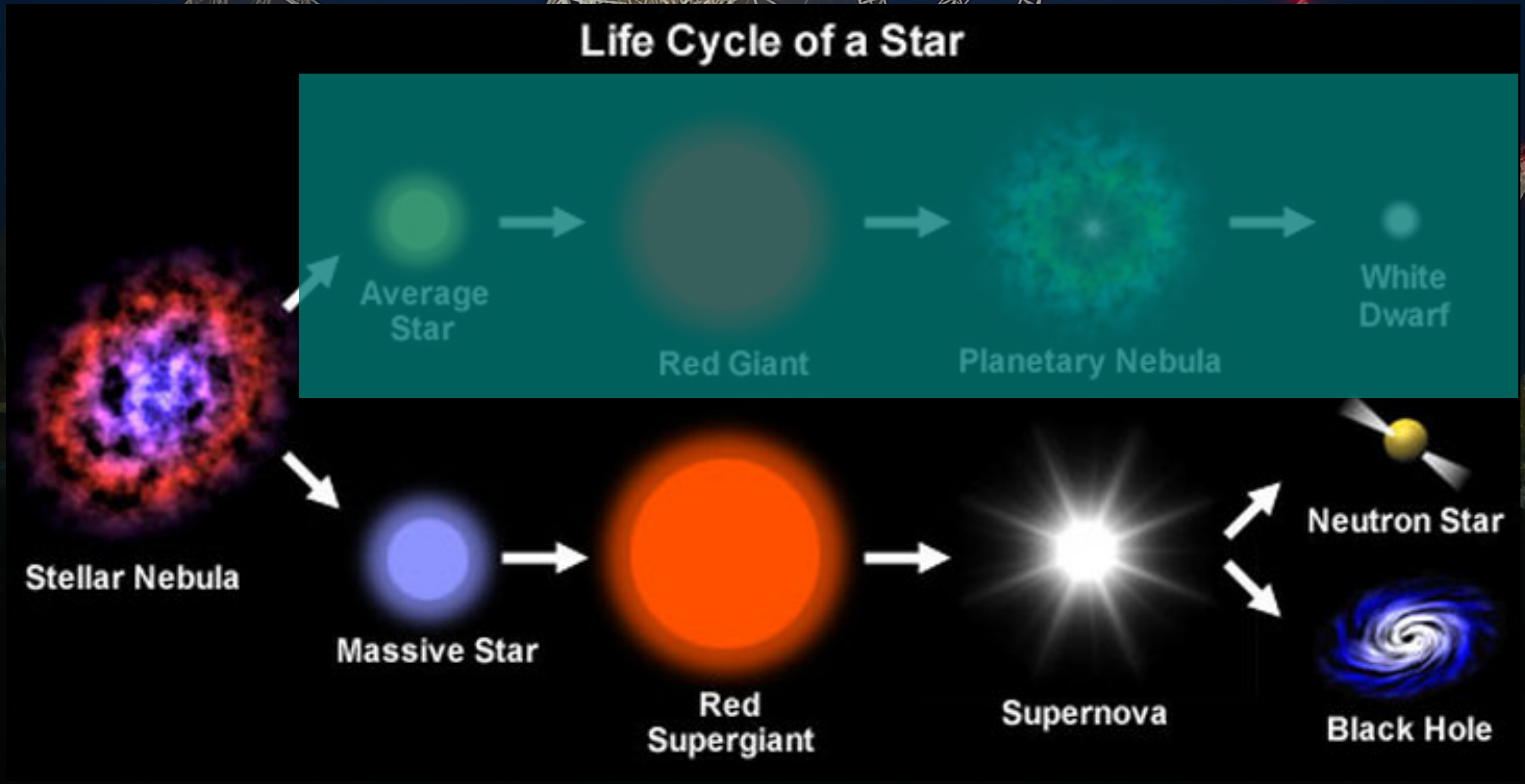

γ Gamma
ν Neutrino
Proton
Neutron
Positron

End of the Sun

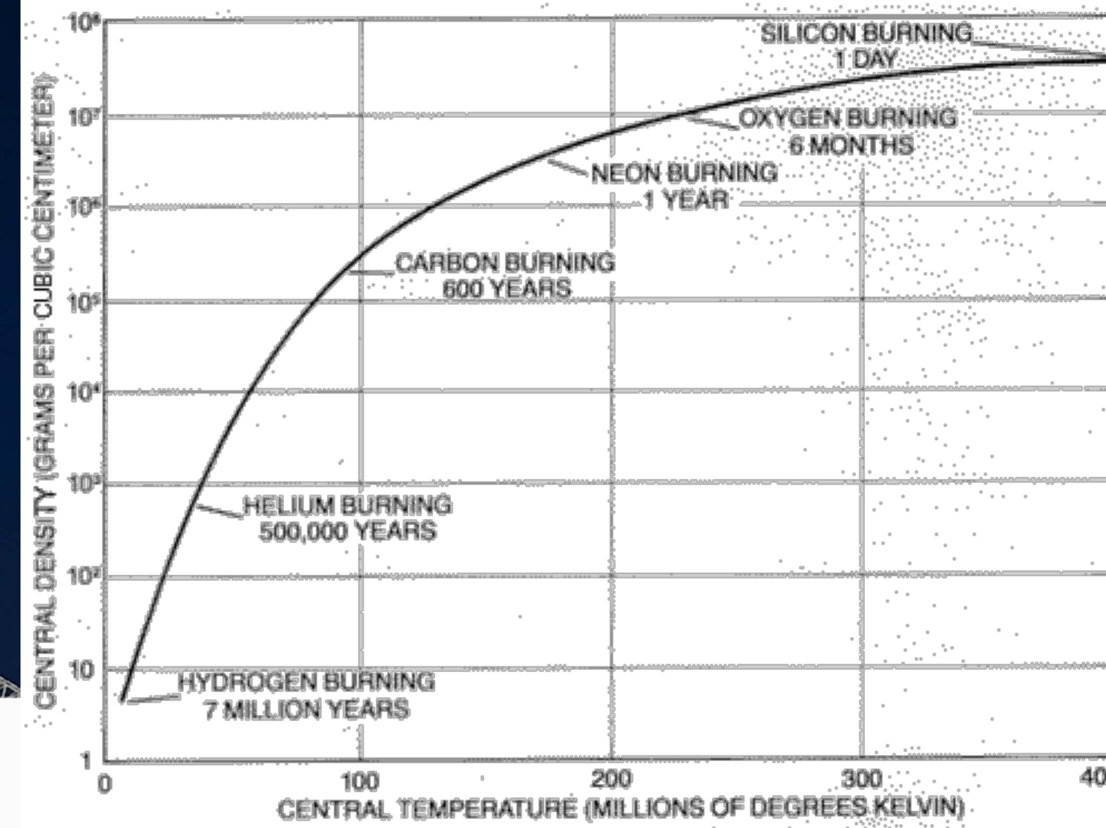


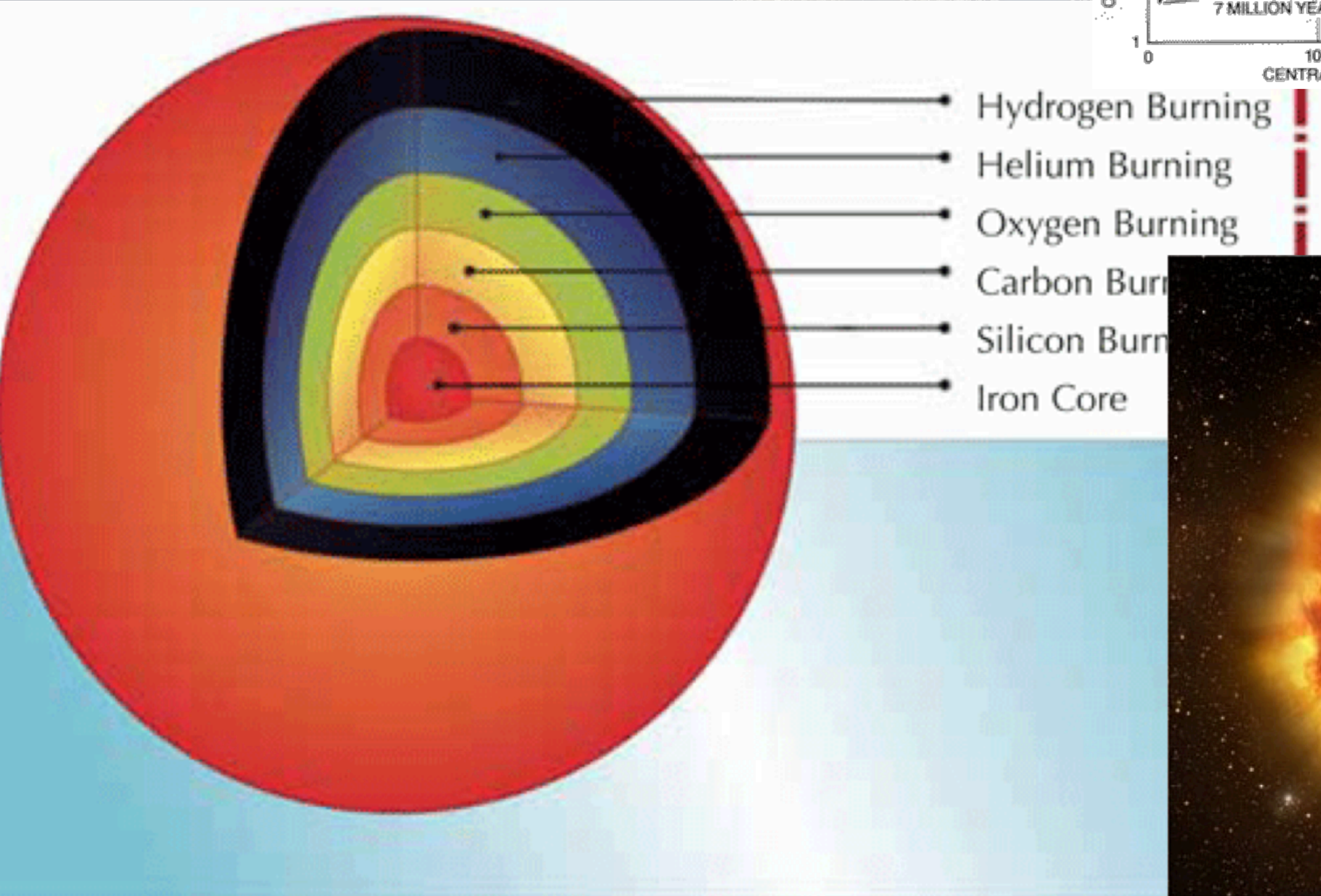
Massive Stars

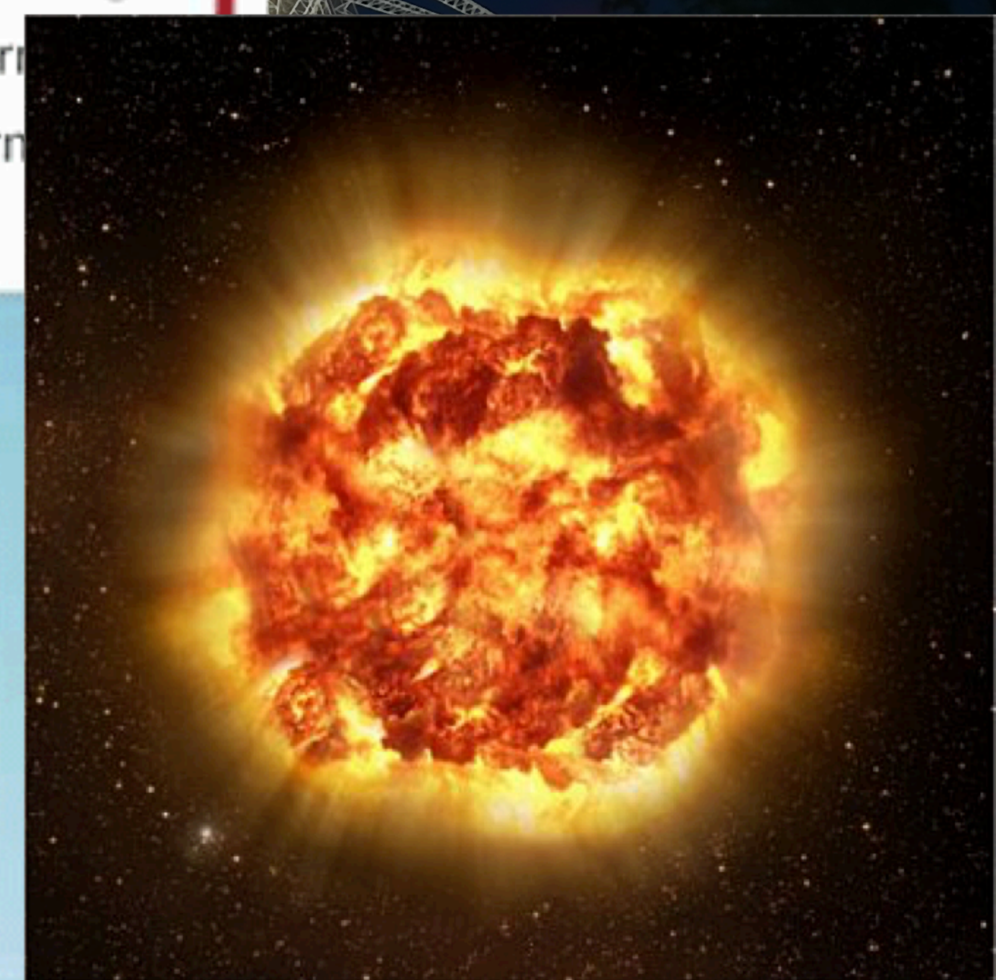
- Stars <0.4 $M_\odot$ to >100$M_\odot$.
- Massive star : evolution for millions of years - Nuclear fusion.
- Star collapses under its own gravity. Collapse turns into an explosion ejecting 1% (~10^{51} ergs) energy in electromagnetic radiation and 99% (~10^{53} ergs) in neutrinos.
- Violent explosion as supernovae or GRBs (>10^{44} Joules).



End of Massive Stars





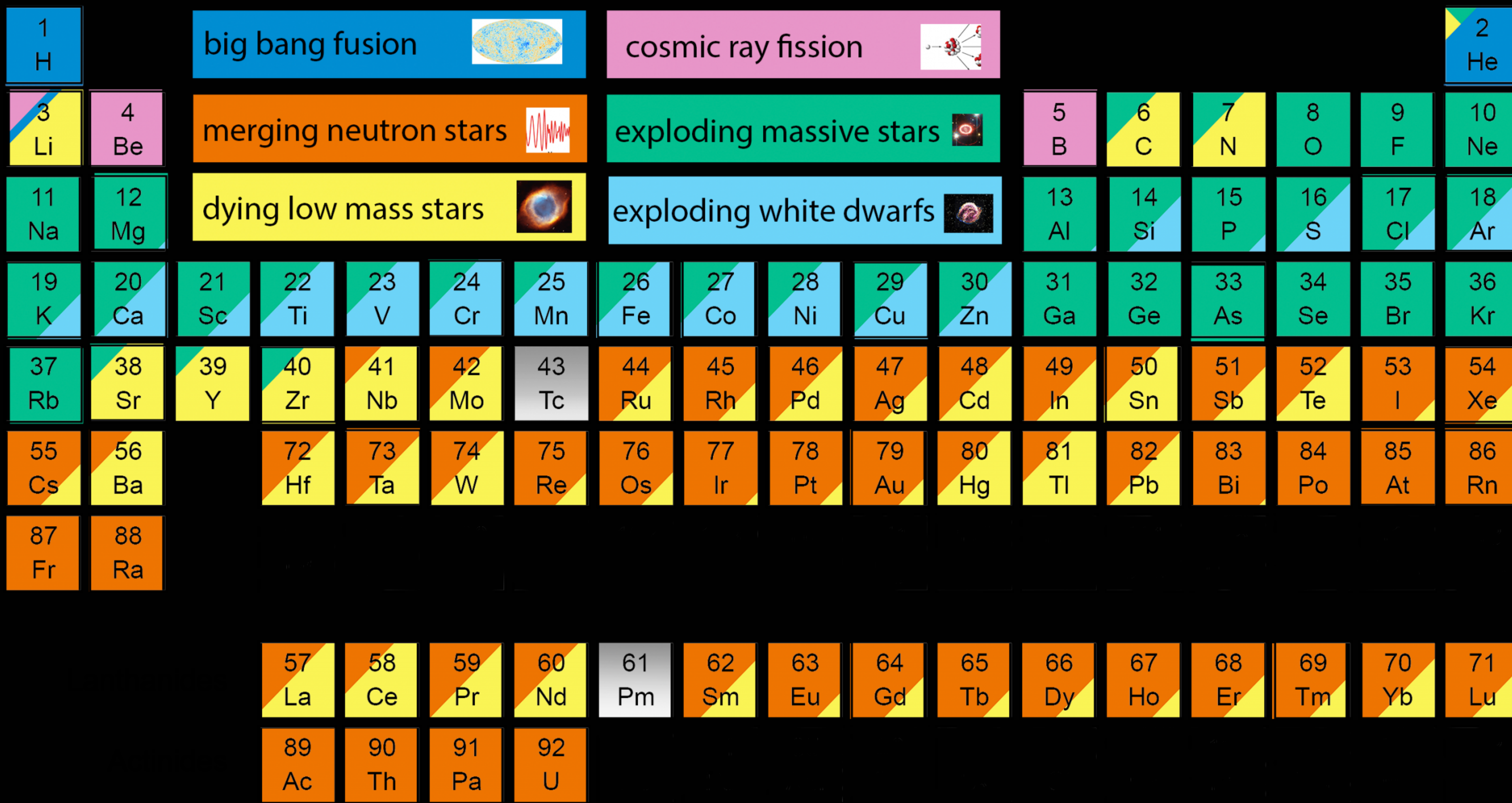


Periodic Table

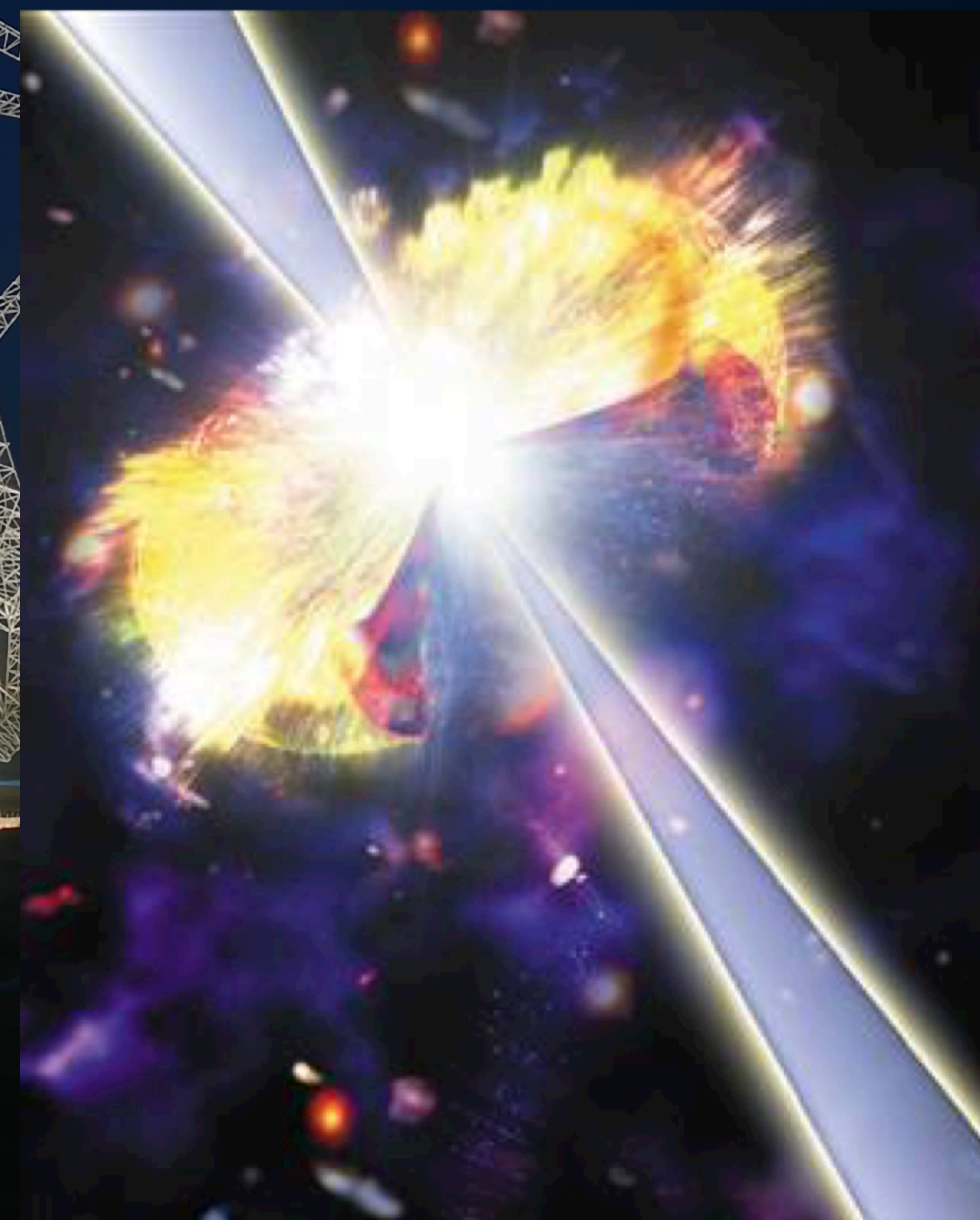
- big bang fusion
- cosmic ray fission
- merging neutron stars
- exploding massive stars
- dying low mass stars
- exploding white dwarfs

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																	

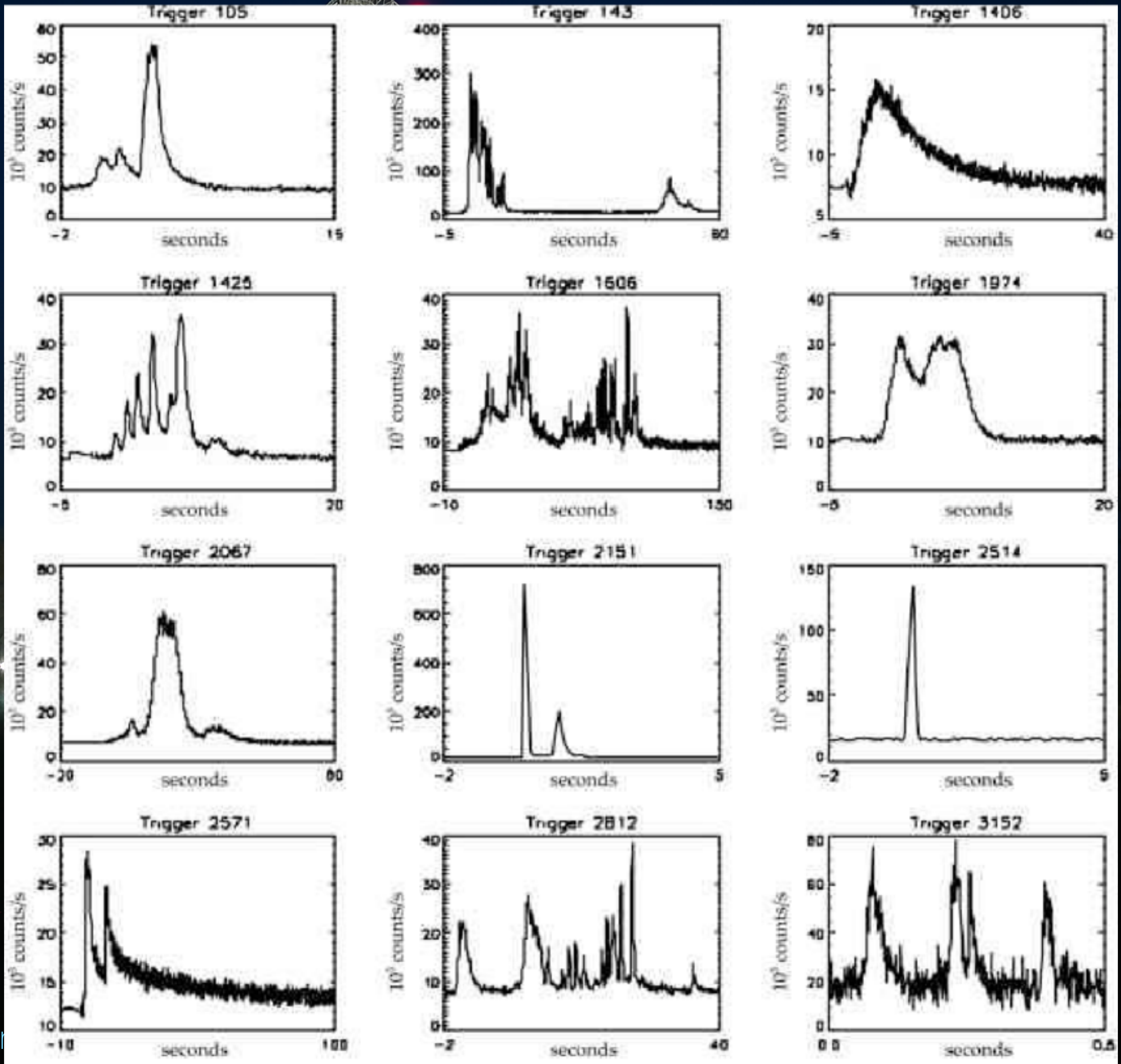
Periodic Table



Supernovae & gamma-ray bursts

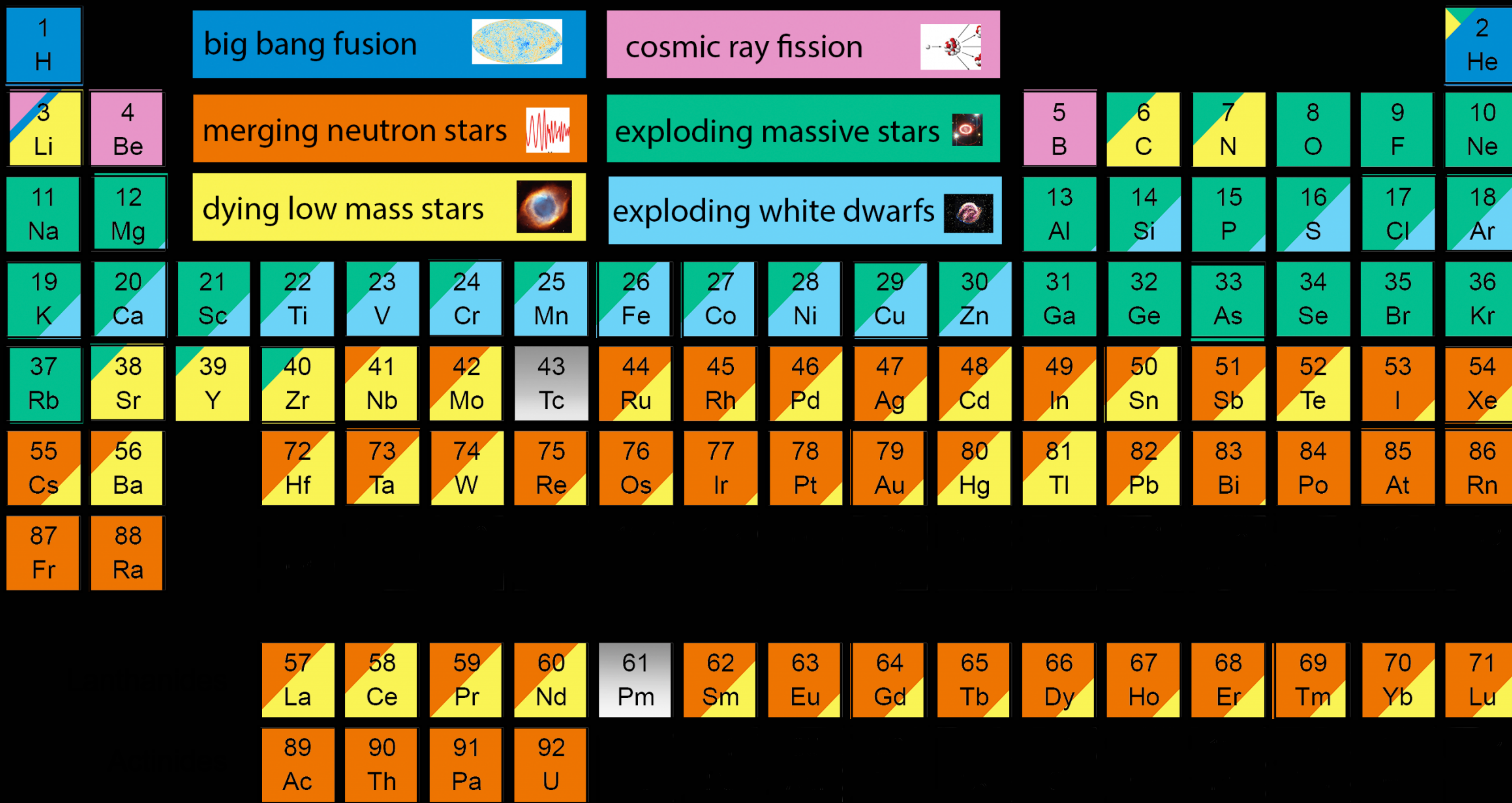


Every GRB has a unique fingerprint!

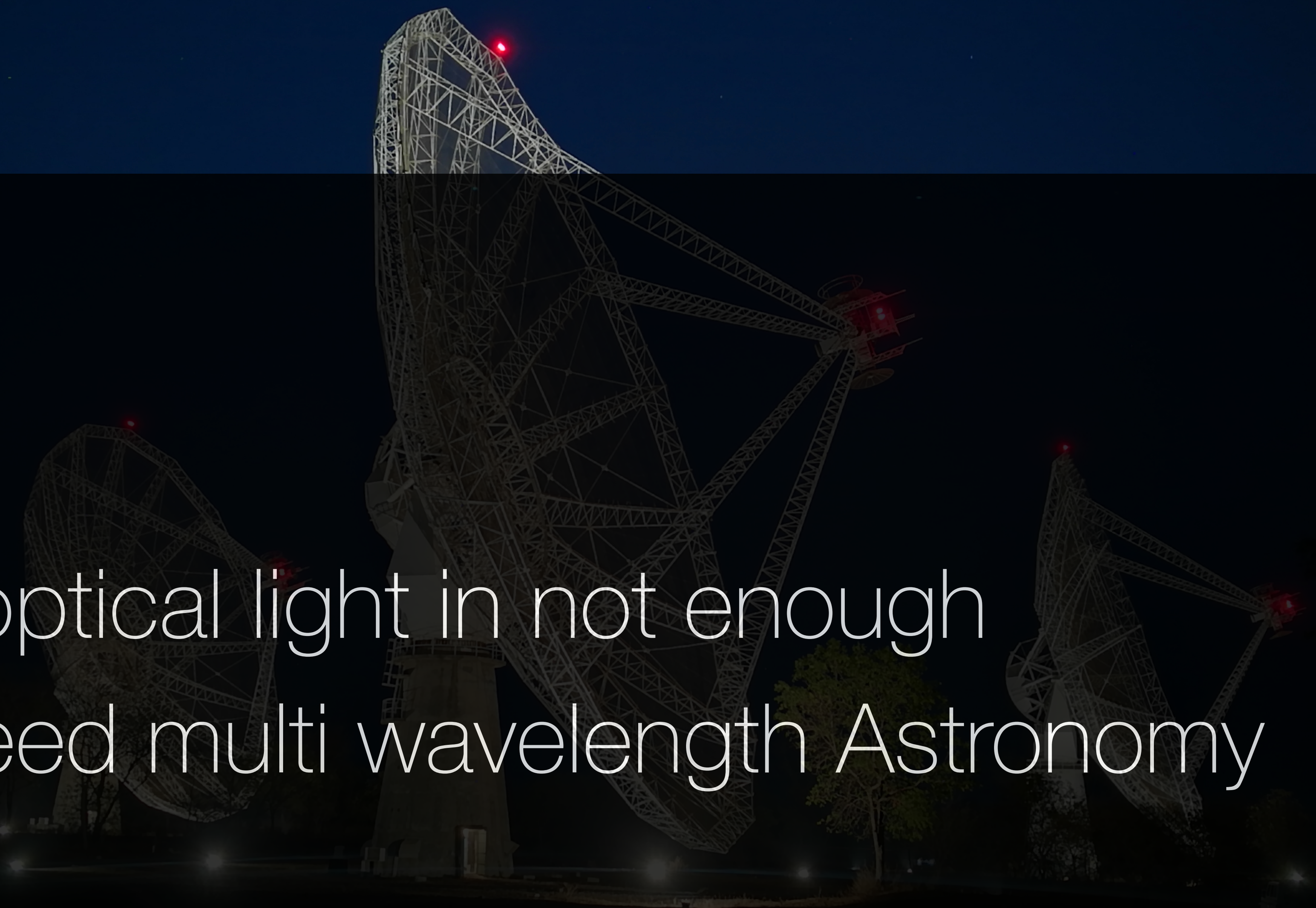


Sometimes one death is not enough!!!!!

Periodic Table



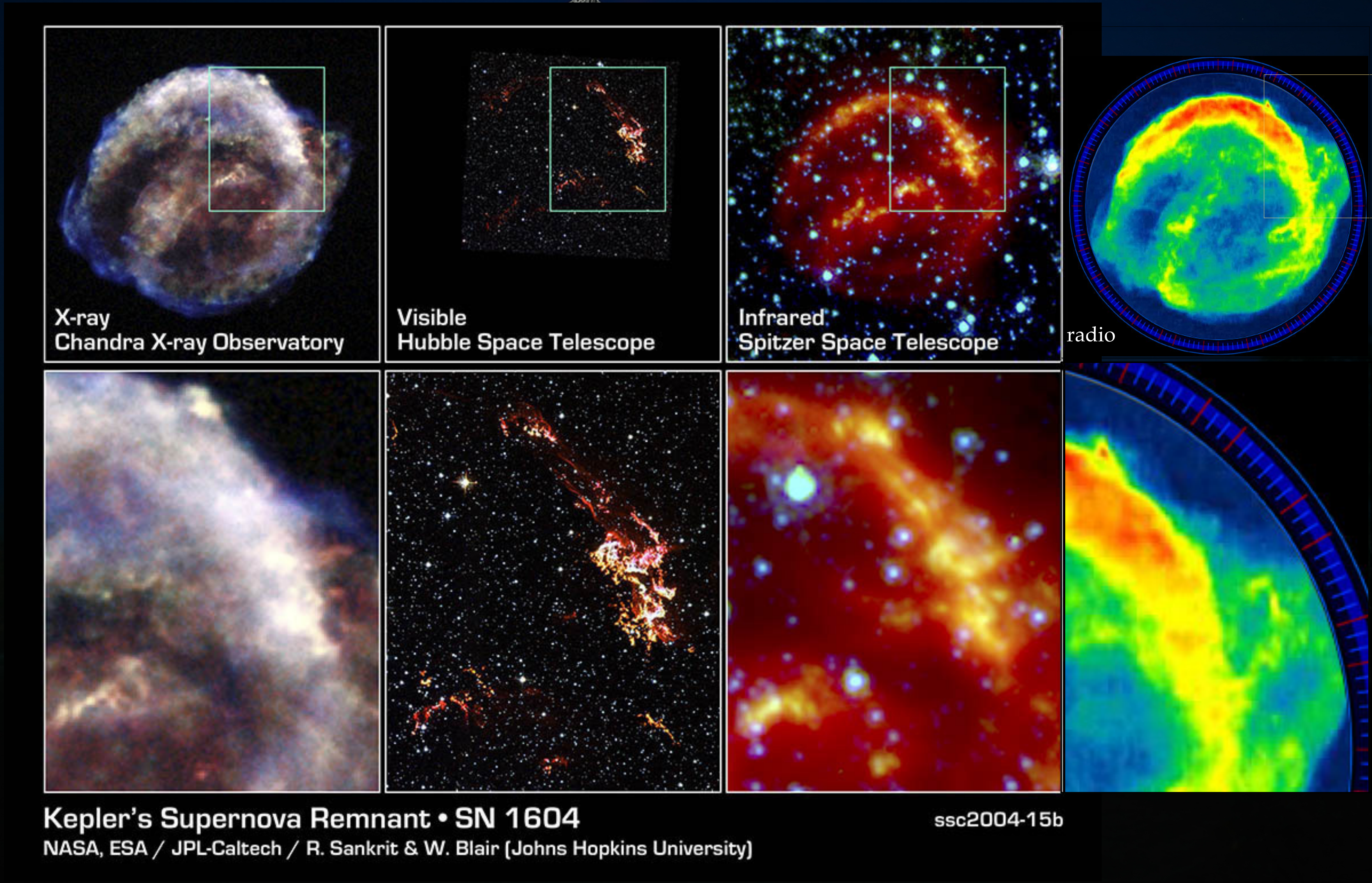
Multiwaveband view



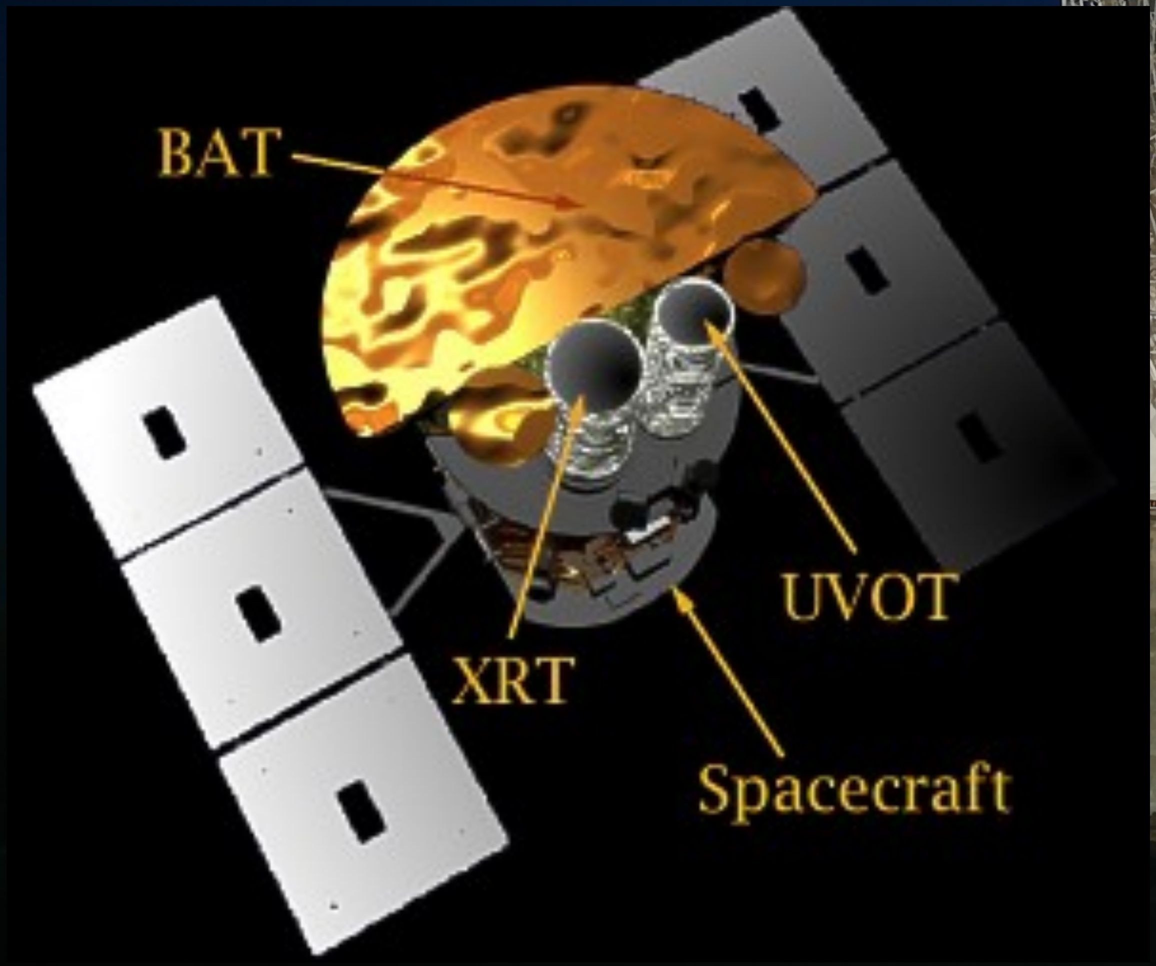
- Only optical light in not enough
- We need multi wavelength Astronomy

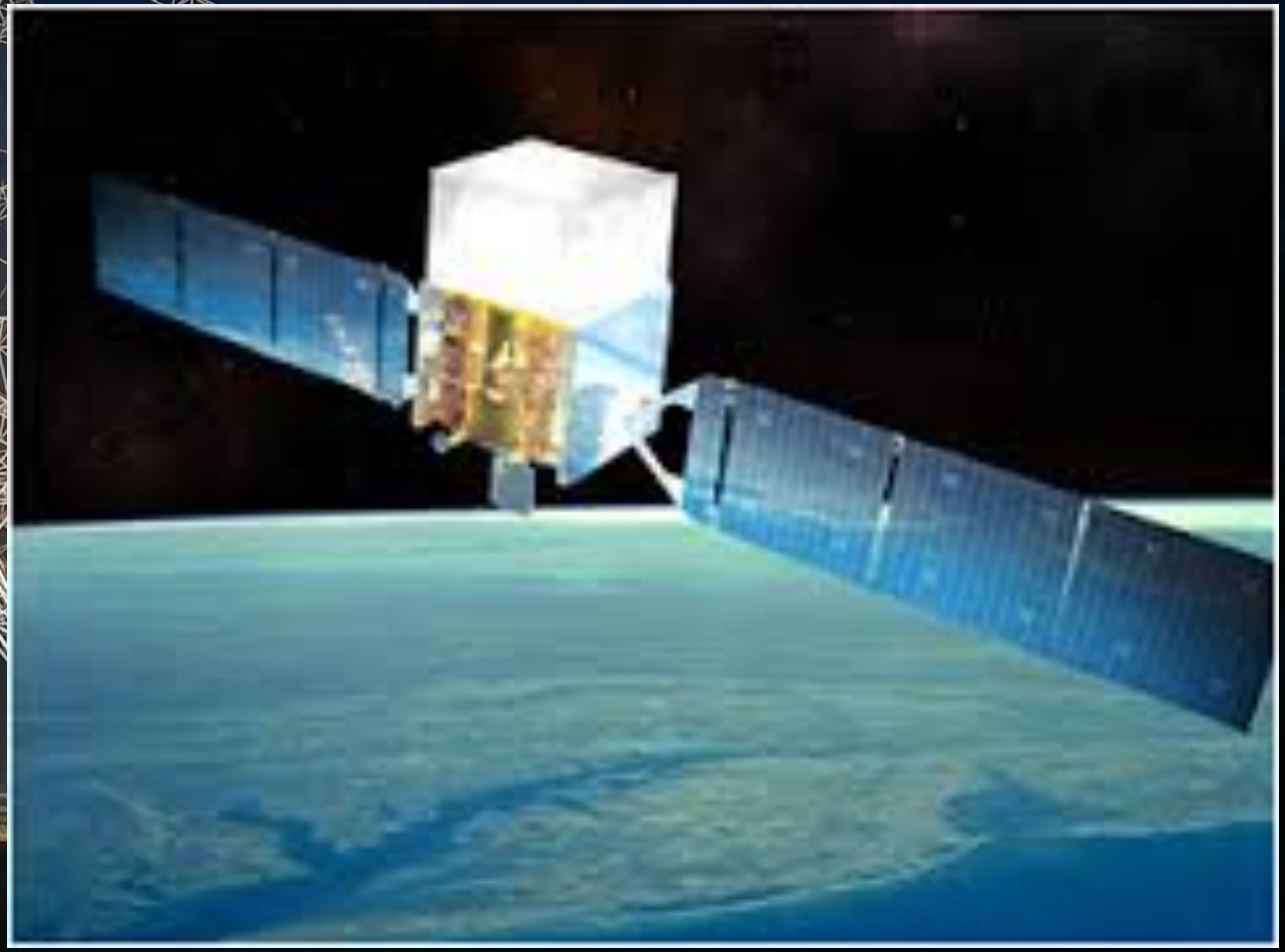
Complimentary view

Multiwavelength view

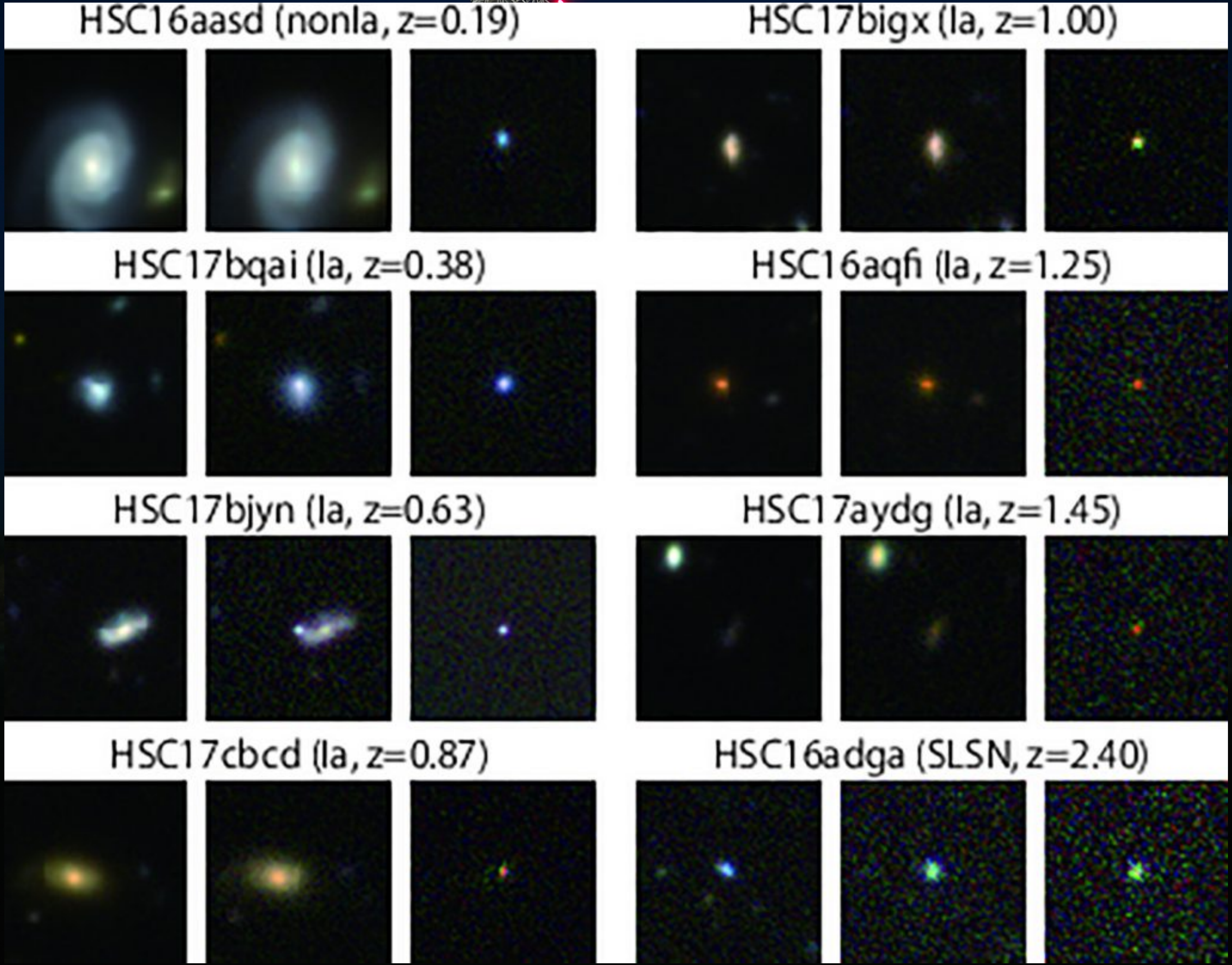


The Swift & Fermi





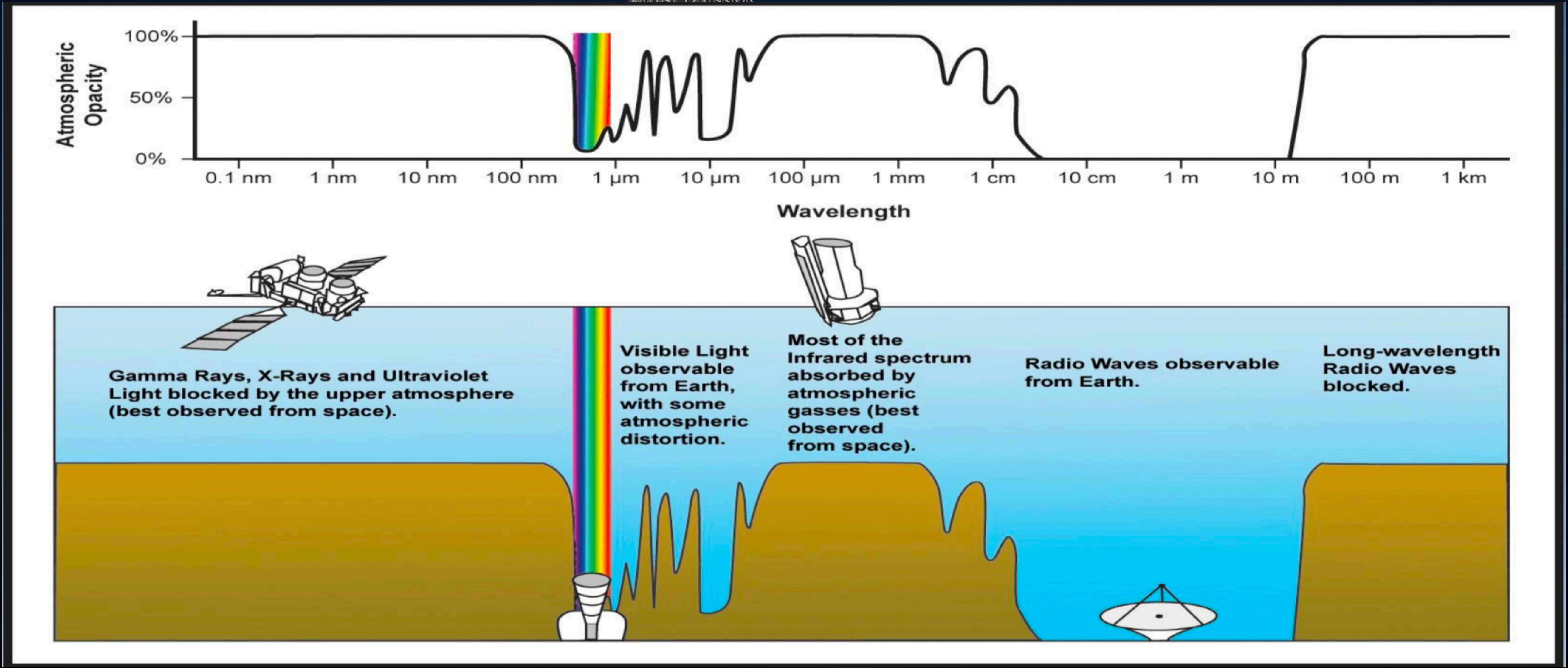
Supernovae Search



The AstroSAT

- Indian Satellite, Launched 28 Sep 2015
- Optical to hard X-ray, onboard instruments - UVIT, LAXPC, SXT, CZTI
- CZTI best for low latency follow ups - 36 deg^2 FOV
- For significant triggers in 100-1000 keV, CZTI would detect flash without repointing- open detector with 2 pi FOV.

Not so easy?

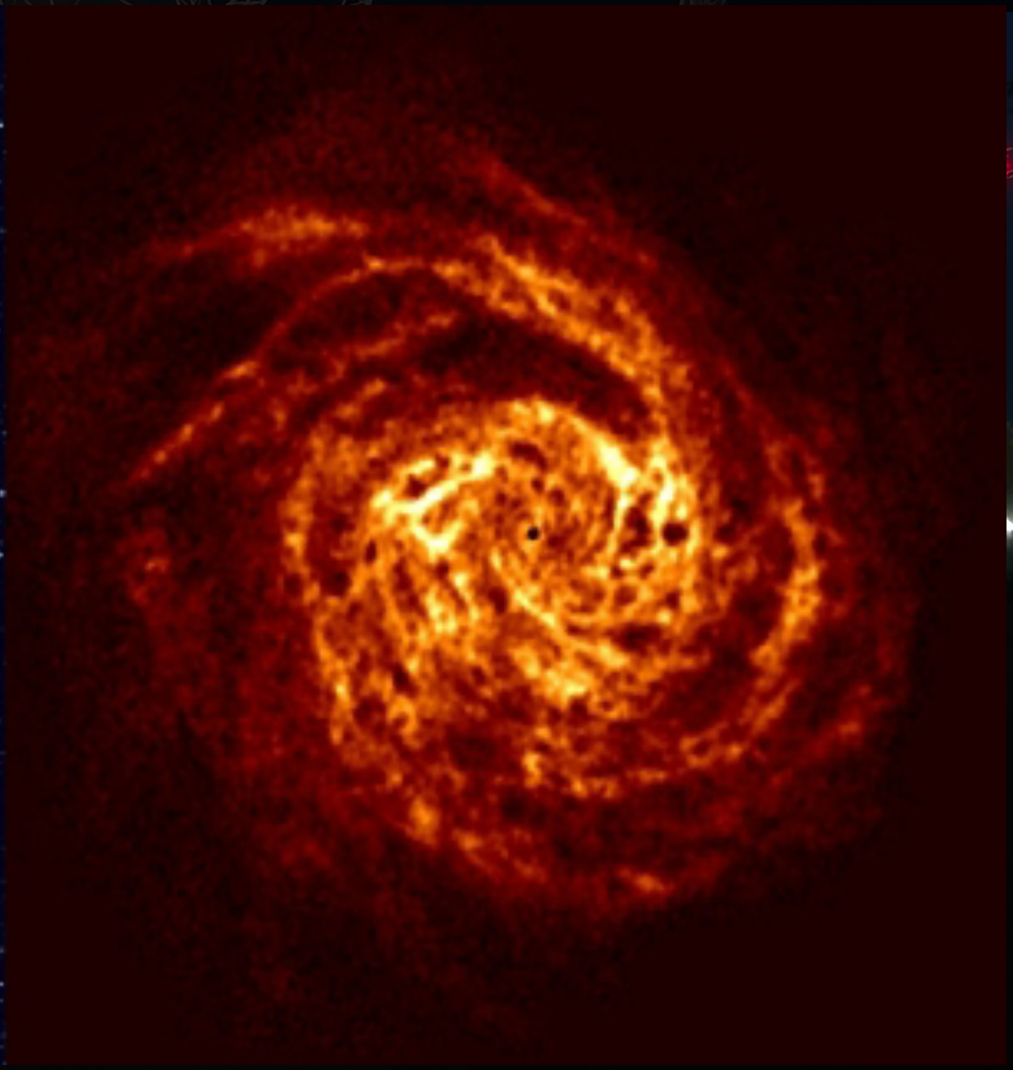

Atmospheric Opacity
100%
50%
0%
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).
Visible Light observable from Earth, with some atmospheric distortion.
Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio Waves observable from Earth.
Long-wavelength Radio Waves blocked.

Radio Astronomy?

- Second (transparent) window he atmosphere is transparent in the centimeter & meter bands

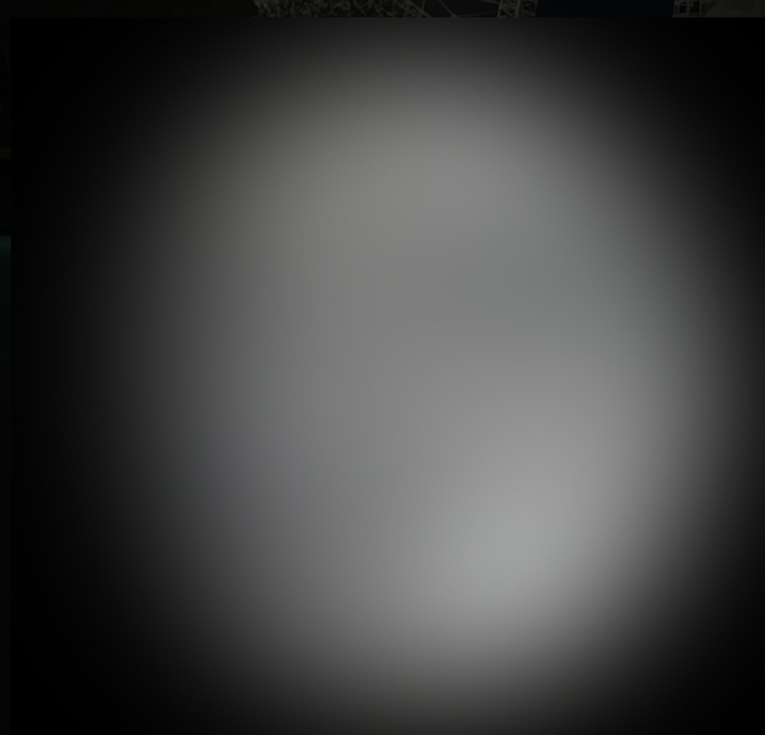
$\lambda < 5$ mm mostly absorbed by molecular bands

$\lambda > 15$ m or so, absorbed or reflected by the ionosphere

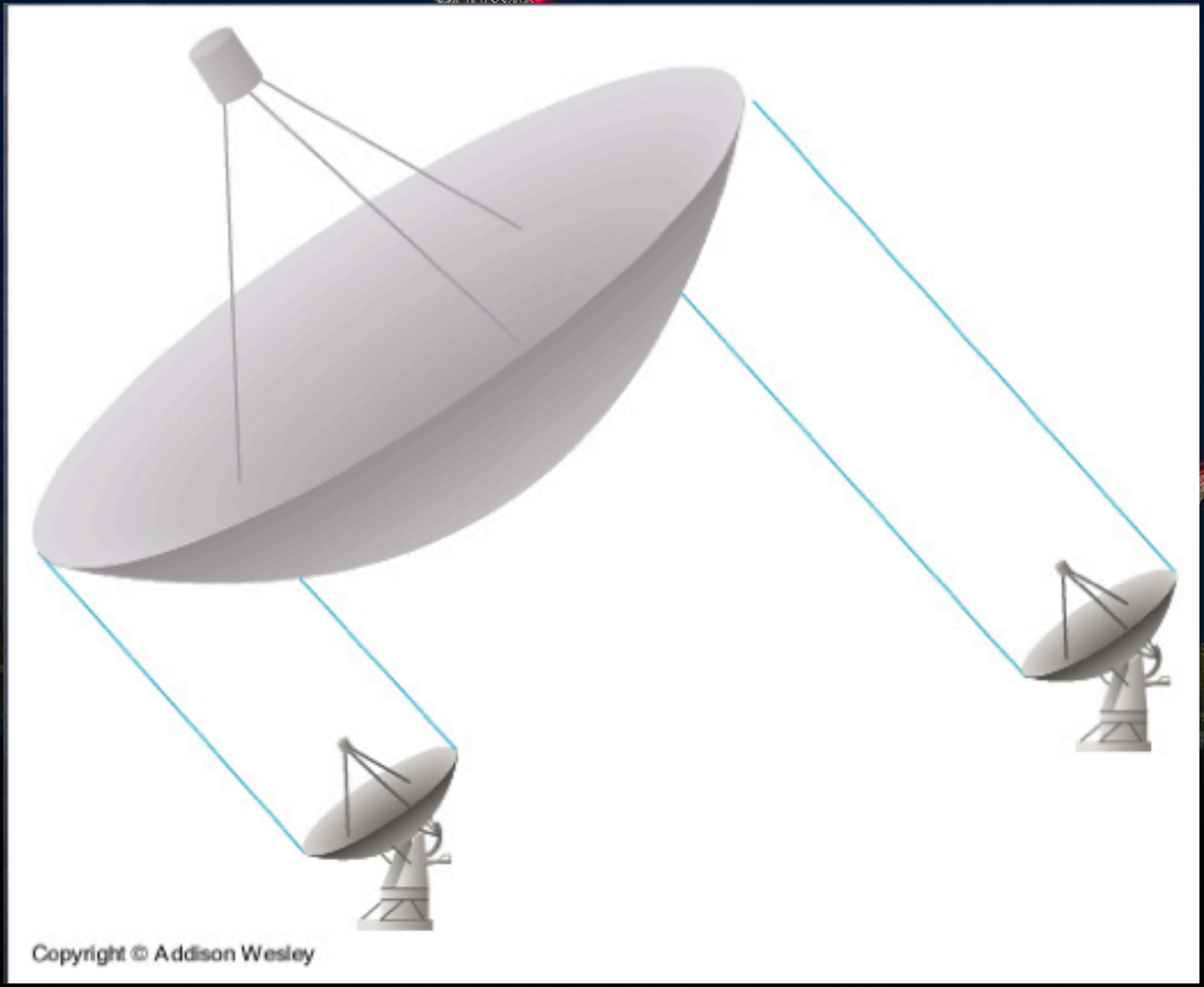


Resolution and Radio Telescopes

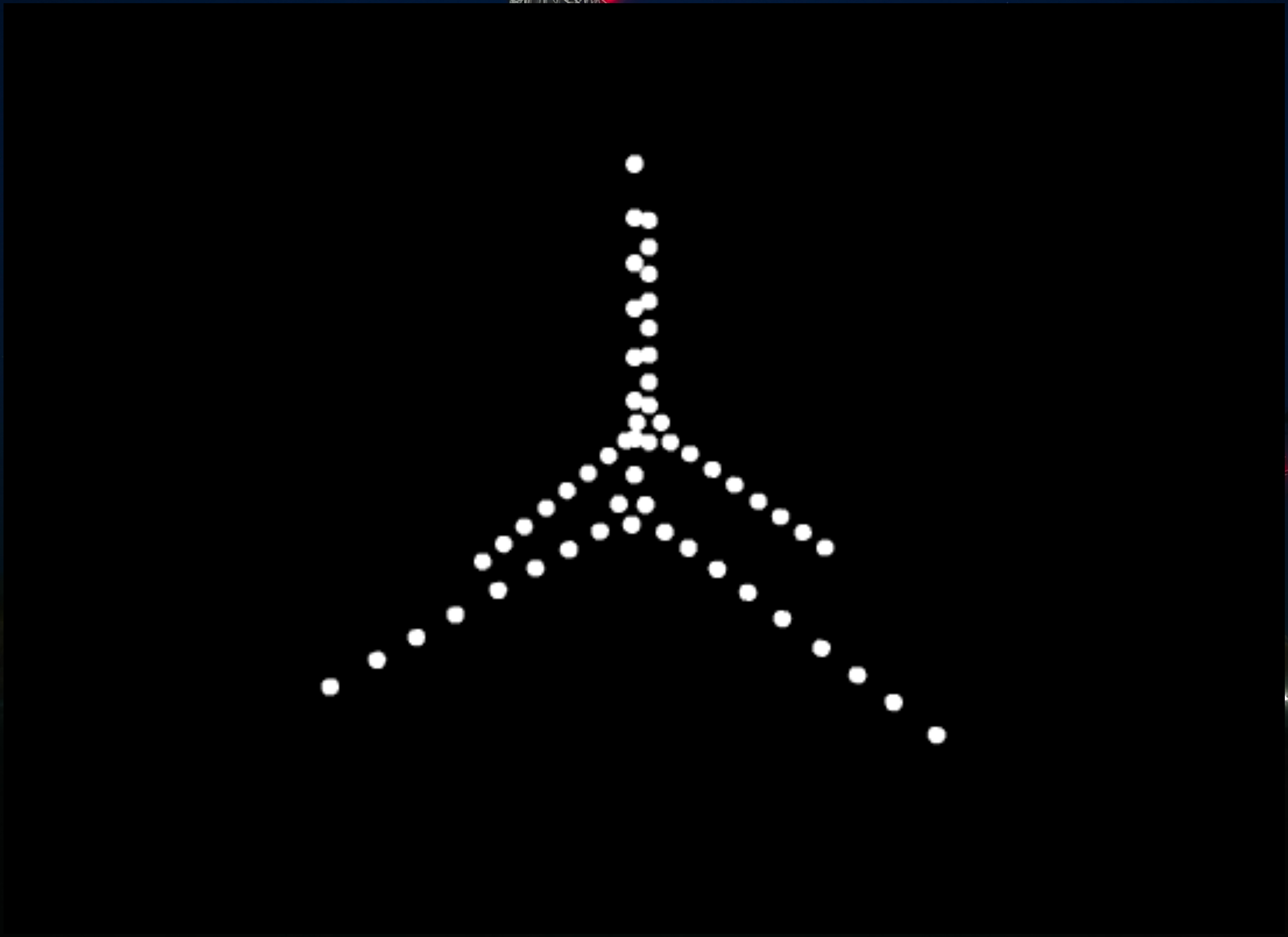
- A 10cm optical telescope has a resolution $\lambda/D \approx 1$ arcsec
- The worlds largest radio telescope (300m) has a resolution ≈ 10 arcmin.



Radio Interferrometry

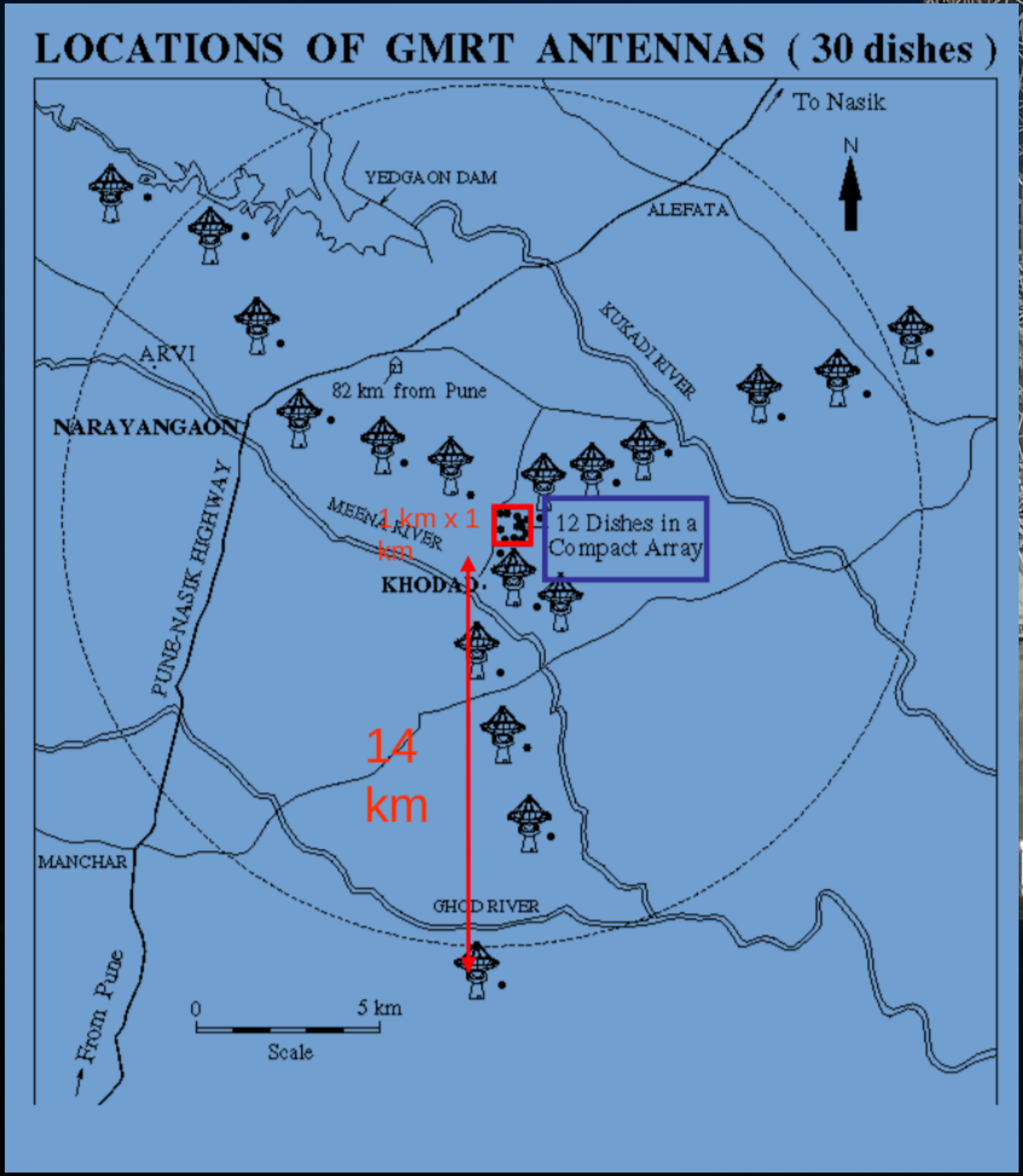


Aperture synthesis

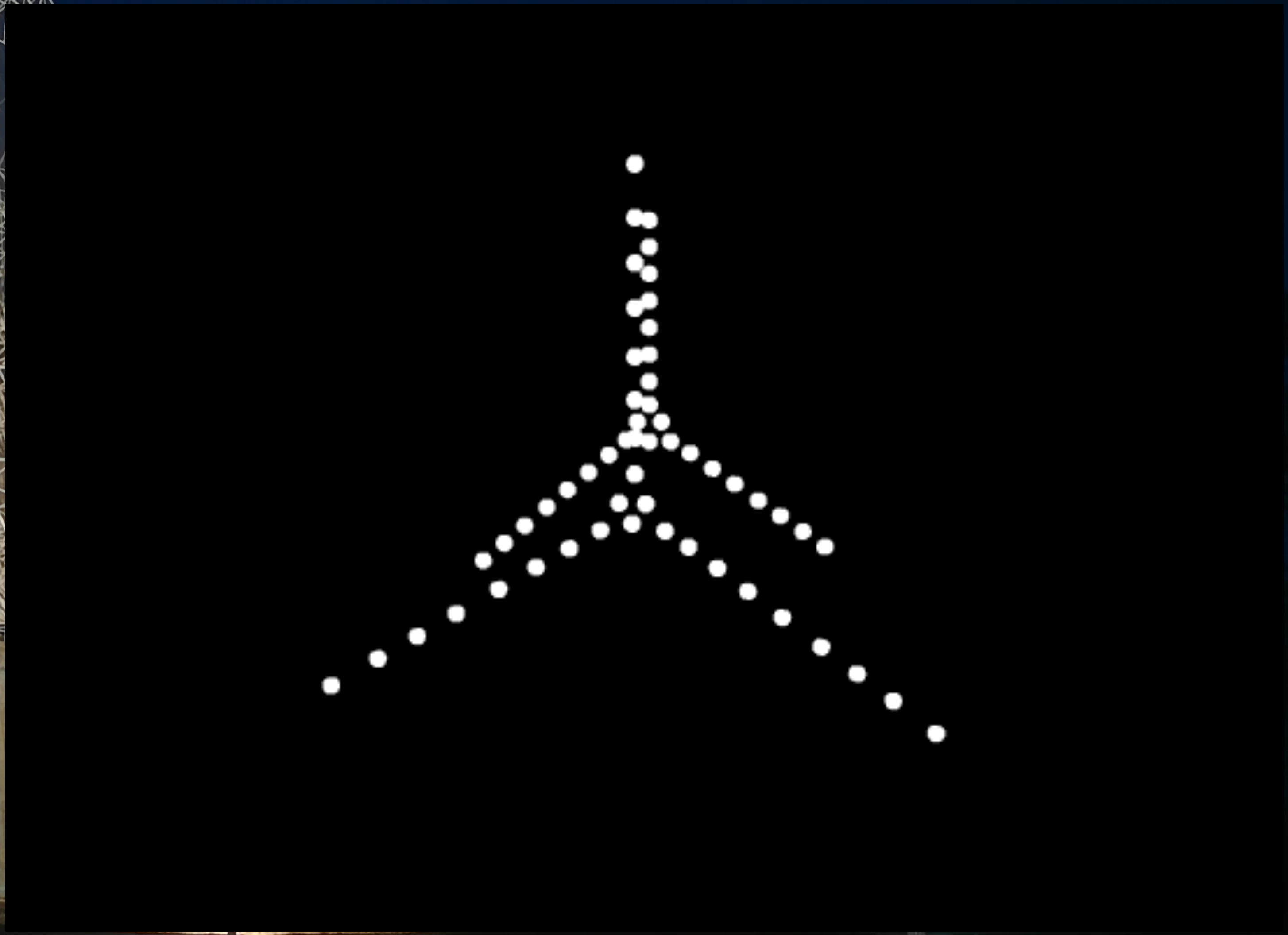


The Very large Array

The GMRT



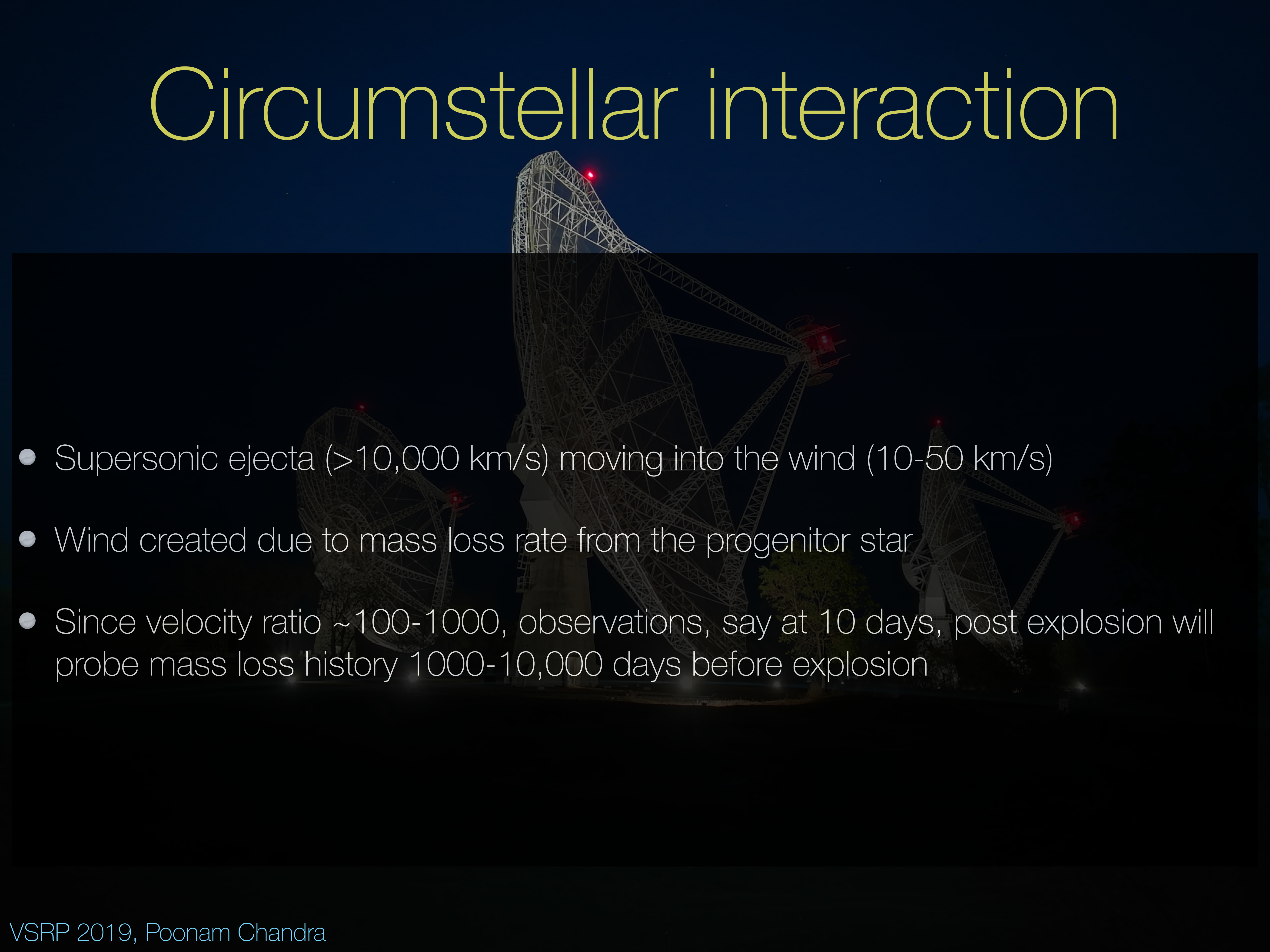
LOCATIONS OF GMRT ANTENNAS (30 dishes)
To Nasik
N
YEDGAON DAM
ALEFATA
KUKADI RIVER
ARVI
82 km from Pune
NARAYANGAON
PUNE-NASIK HIGHWAY
MEENA RIVER
1 km x 1 km
12 Dishes in a Compact Array
KHODAD
14 km
MANCHAR
GHOD RIVER
From Pune
0
5 km
Scale



The GMRT

Why look through radio Lens?

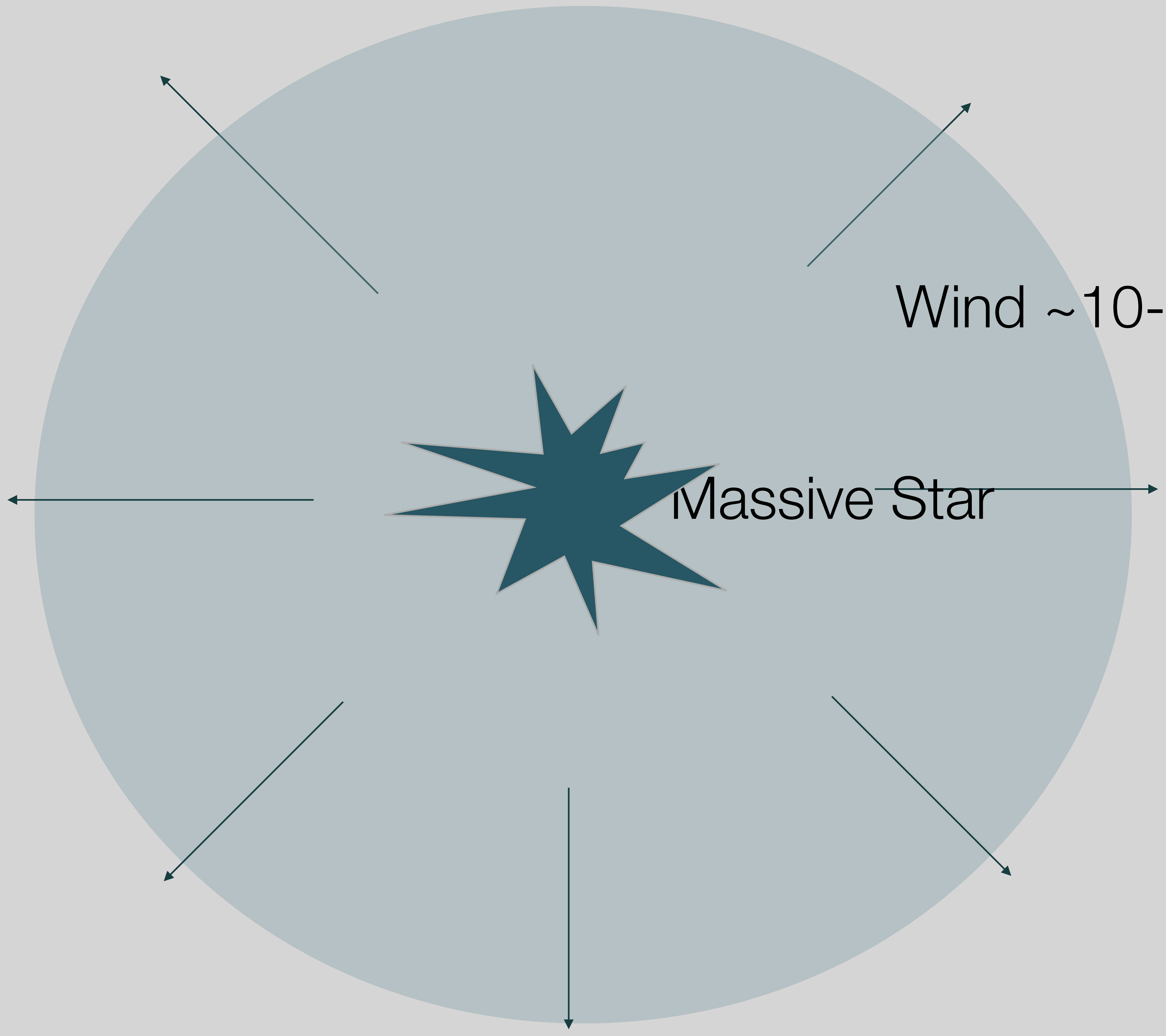
- One cannot recreate in the lab. Computer simulations?
- Sensitive to 2D, 3D models, Complex neutrino physics, Role of rotation, magnetic field, General relativistic, magneto hydrodynamics, Limited by computing power, Progress is slow.
- Stellar evolution models leading to end stages of explosions are not well known.
- Very expensive



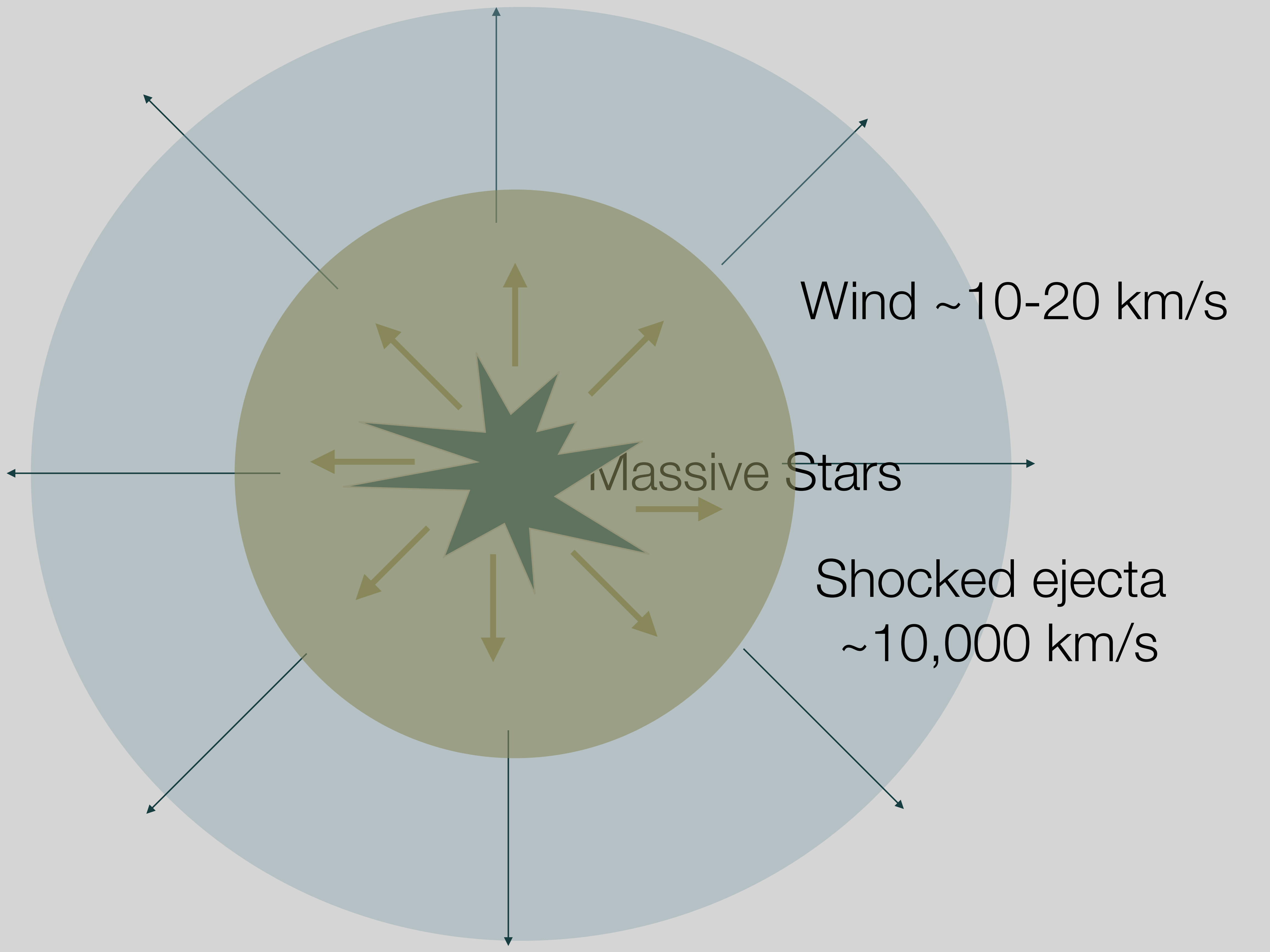
Circumstellar interaction

- Supersonic ejecta (>10,000 km/s) moving into the wind (10-50 km/s)
- Wind created due to mass loss rate from the progenitor star
- Since velocity ratio ~100-1000, observations, say at 10 days, post explosion will probe mass loss history 1000-10,000 days before explosion

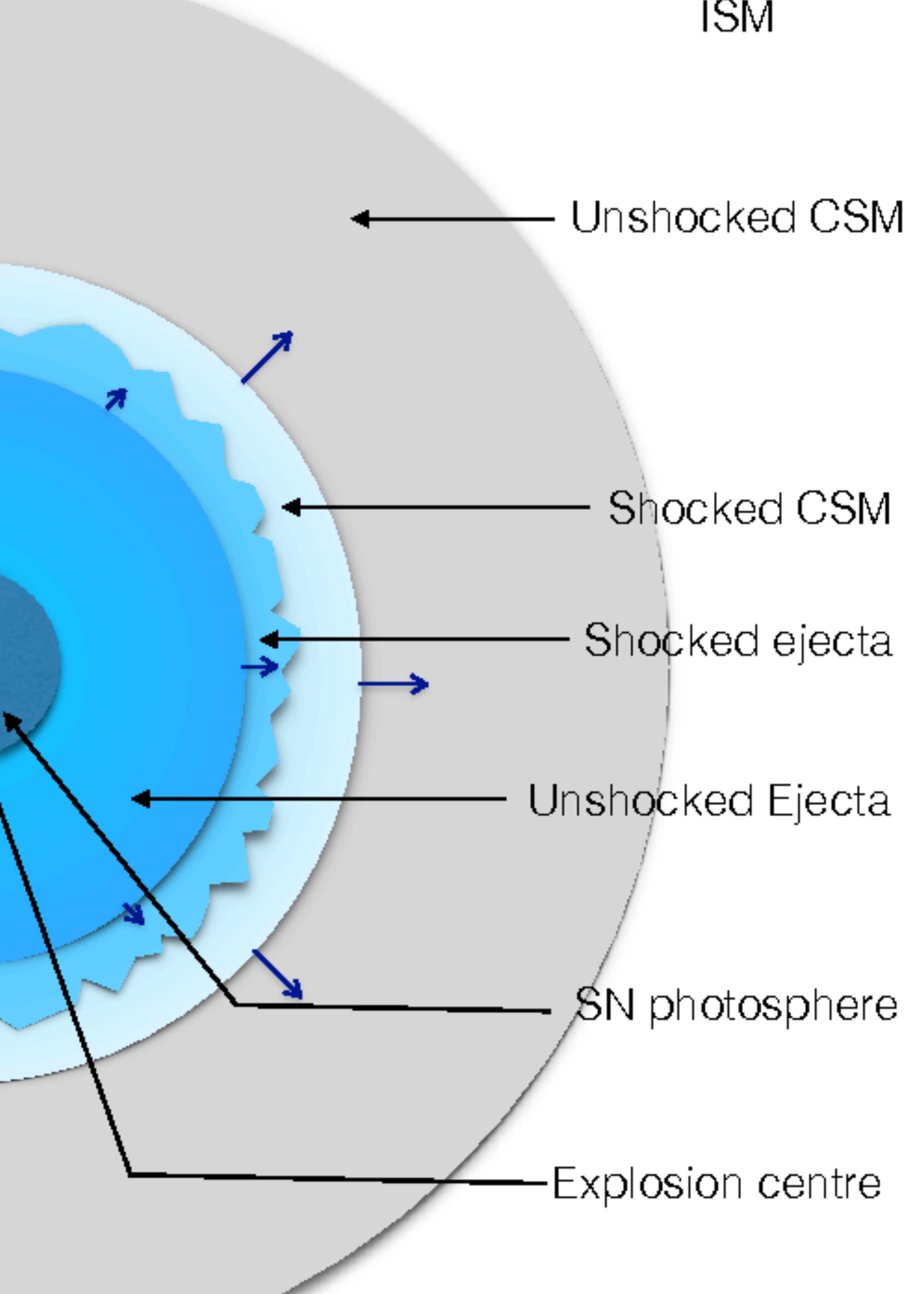
Circumstellar interaction



Circumstellar interaction



Circumstellar interaction



Circumstellar Interaction

- n forward shock electrons reach relativistic energies
- Enhanced magnetic field near contact discontinuity
- Synchrotron emission
- In Radio frequencies

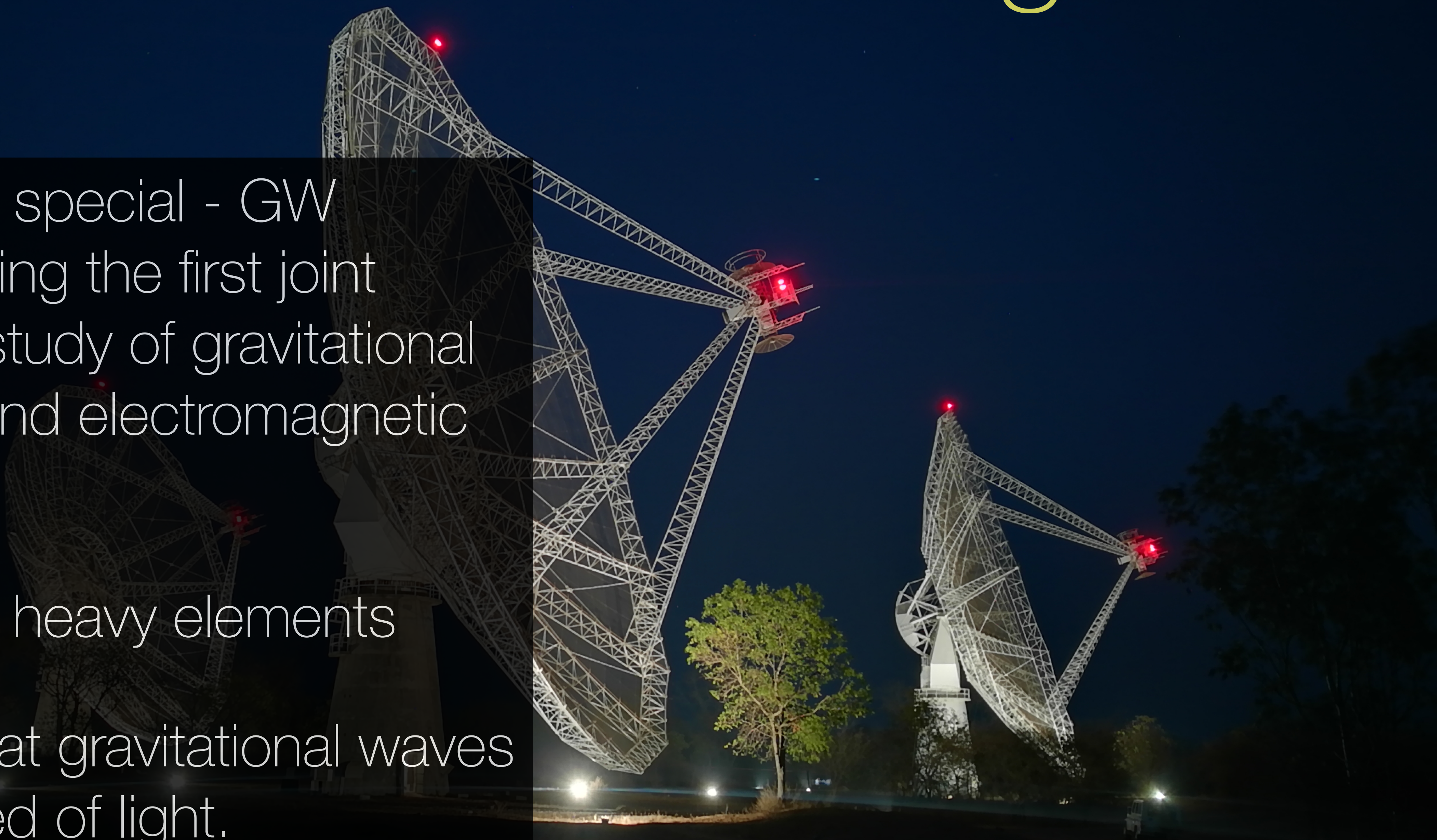
How do we know so much?

- Only light in not enough
- We need multi wavelength Astronomy
- We need multi-messenger Astronomy
- Sometimes listening to songs not enough, need to watch the video too!!!

Gravitational Waves

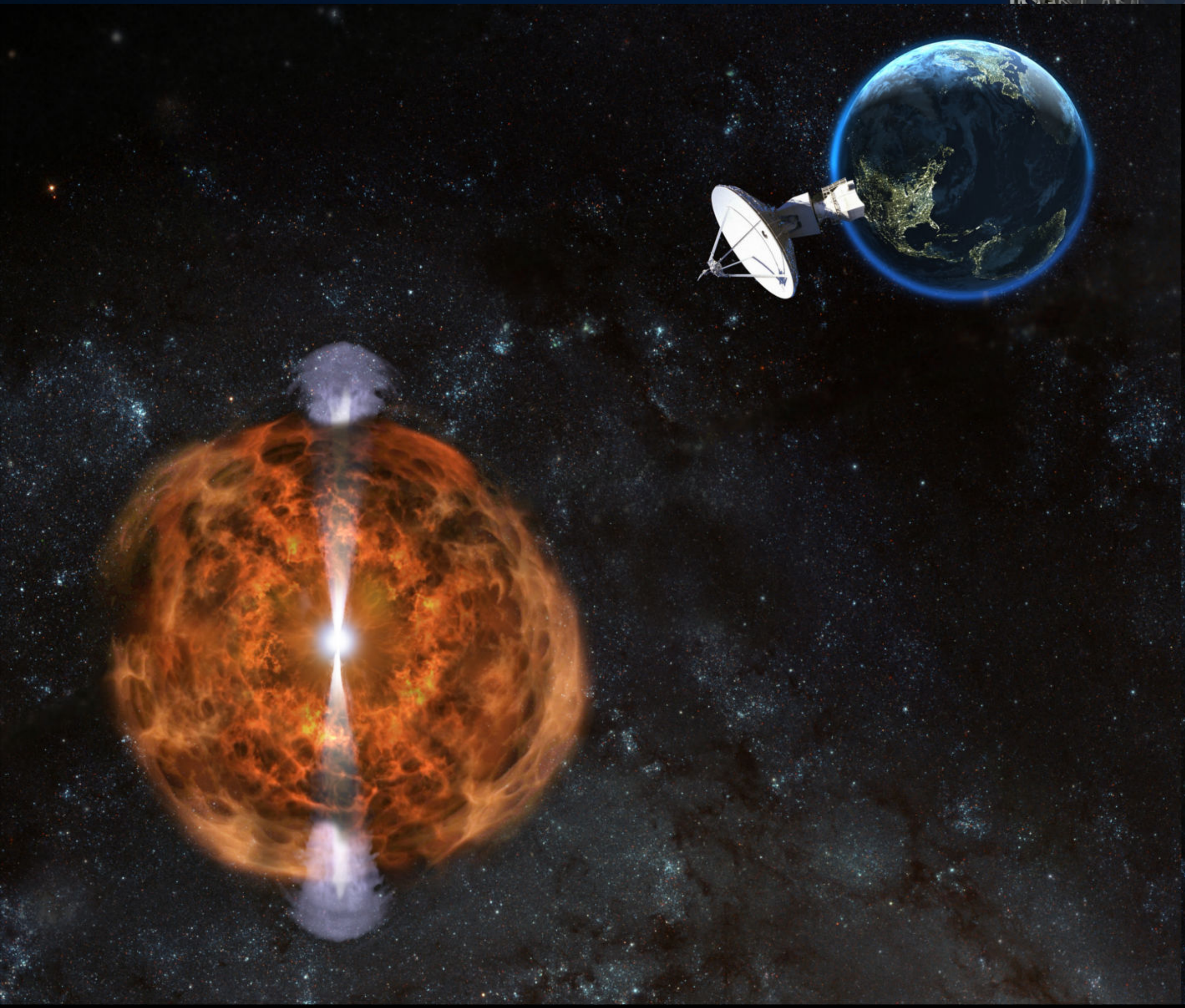
- 100 year old prediction by Einstein.
- Detection on 14 Sep 2015, GW 140915 by Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO).
- Merging of two ~30 solar mass black holes. Energy released equivalent to 3.
- Confirmation of General Theory of Relativity
- Existence of binary stellar-mass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

The GW event on 17 Aug 2017

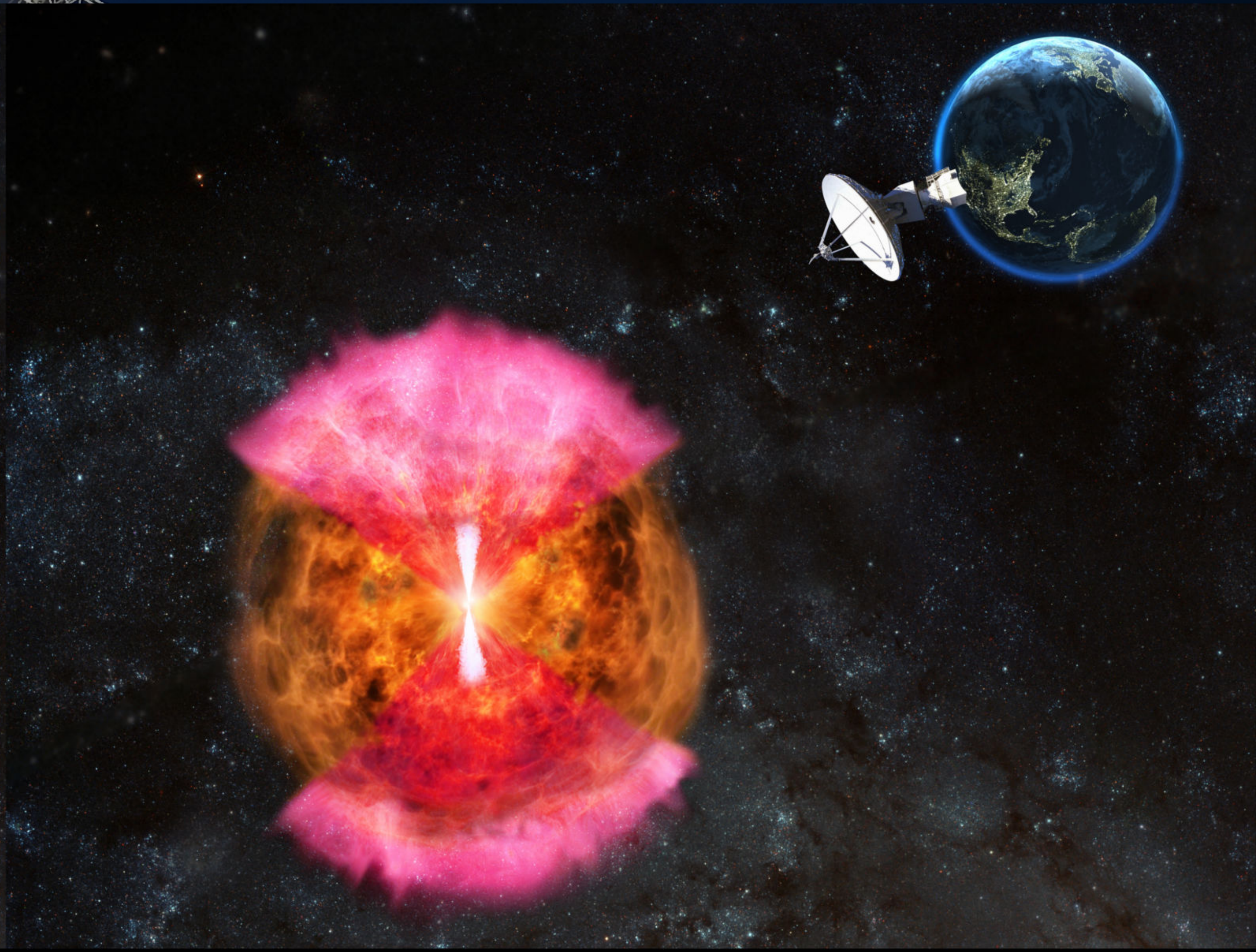


- One event was special - GW 170817 - marking the first joint detection and study of gravitational waves (GWs) and electromagnetic radiation (EM).
- Confirmation of heavy elements
- Confirmation that gravitational waves travel with speed of light.
- Confirmation that two neutron stars make gamma ray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

GW 170817



Off-Axis Jet SGRB



Choked Jet Cocoon

LIGO (in India too)