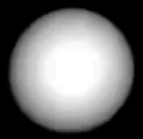
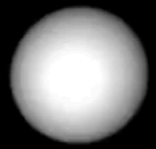
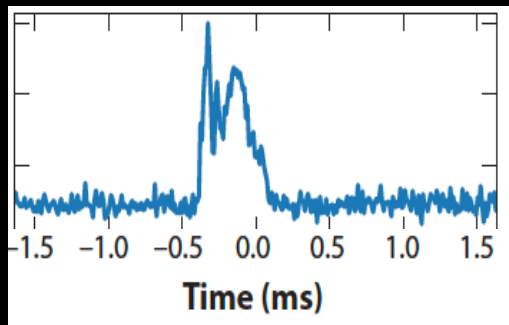
Cosmic Laboratories





Roger Blandford

KIPAC, Stanford



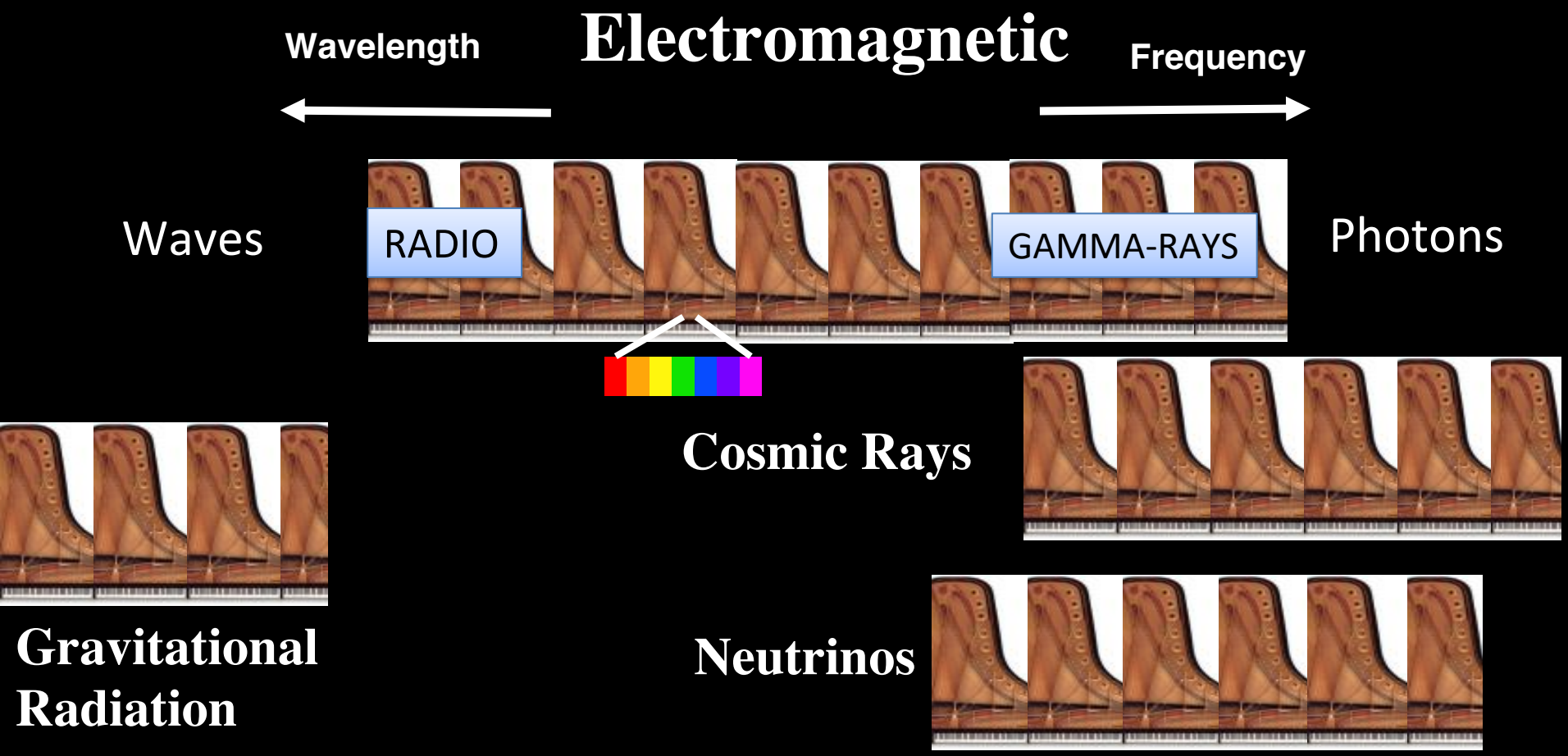
The Extremes of Astrophysics

Exploring extraordinary physical conditions unattainable on Earth

- Extreme Particle Energy – Cosmic Rays
- Extreme Gravity – Black Holes
- Extreme Luminosity – Gamma Ray Bursts
- Extreme Density – Neutron Stars
- Extreme Magnetic Field – Magnetars

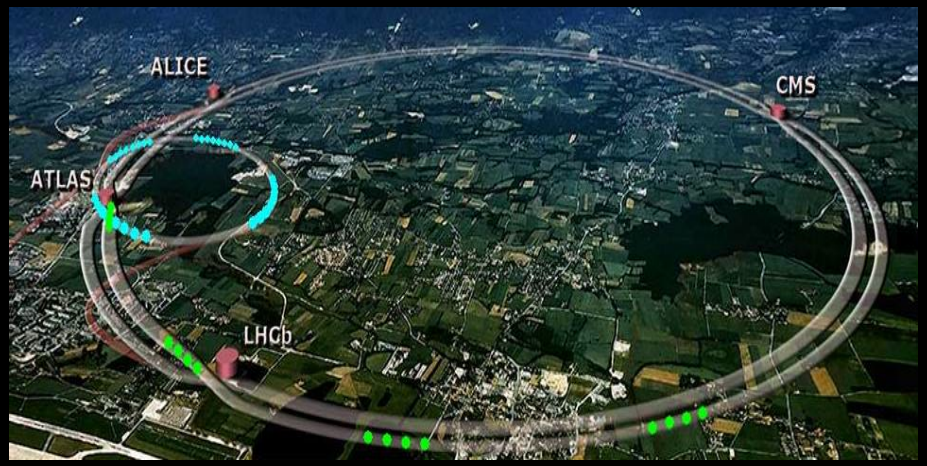
Aims:
- to test basic physics
- to reverse engineer the sources
- as tools for cosmology

Multi-Messenger Astronomy



140 Octaves to Explore

Extreme Particle Energy
Ultra High Energy Cosmic Rays



Large Hadron Collider
6.5 TeV Protons

Auger Observatory
100 Million TeV Nuclei

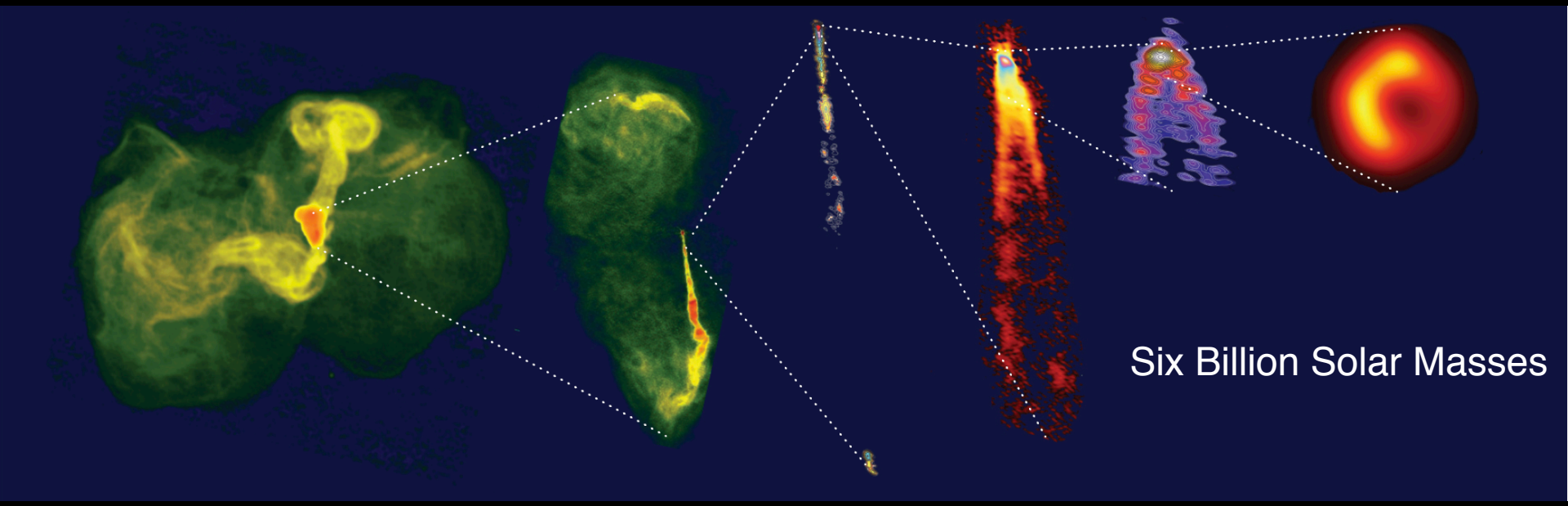
How are they Accelerated?
Ultra High Energy Particle Physics

Extreme Gravity
Black Holes

- Stellar Mass Black Holes
- Up to Ten Billion Solar Masses in Galactic Nuclei
- Size of Cambridge to Size of Solar System
- Event Horizon
- Gravitational and Rotational Energy

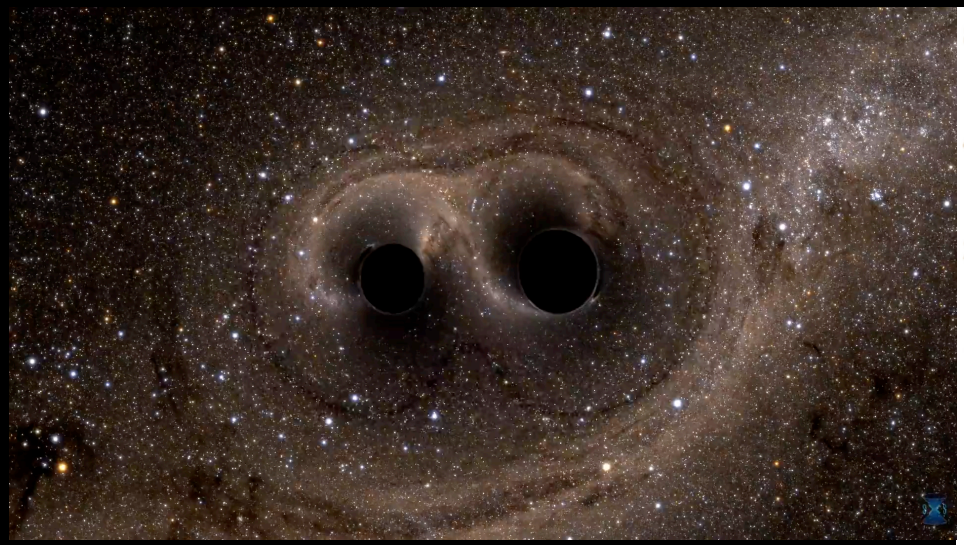
$$E = 0.1Mc^2$$

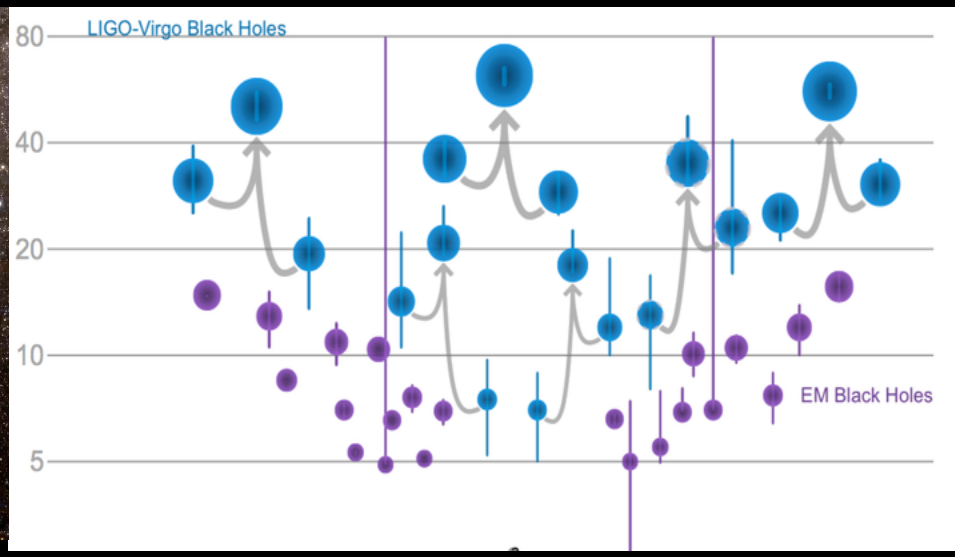
Black Hole “Shadow” in M87



- Black Hole Rotational Energy Powers Relativistic Jets
- Ten Million Trillion Volt Battery?
- May be Seeing Neutrinos from Other Jets
- May Accelerate Ultra High Energy Cosmic Rays

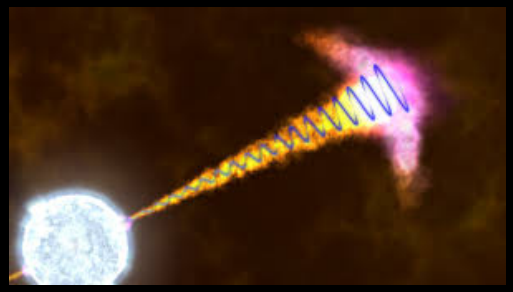
Gravitational Radiation





10+20* Black Hole Mergers Detected
Einstein's Theory of General Relativity Confirmed
Provenance of Black Hole Binaries

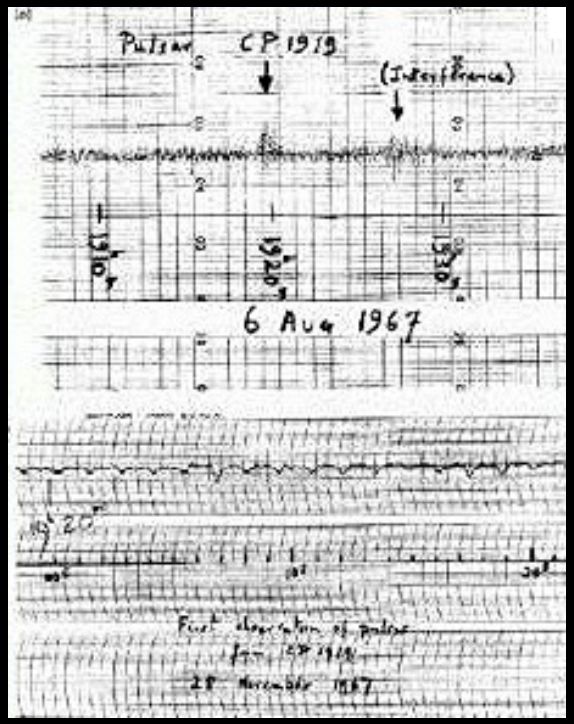
Extreme Luminosity
Gamma Ray Bursts



- Flashes Lasting Few Seconds
- Collapsing Massive Stars
- Relativistic Jets
- Apparent Luminosity of Ten Billion Galaxies
- Measure Distant Universe

Black Hole Birth Cries

Extreme Density Neutron Stars

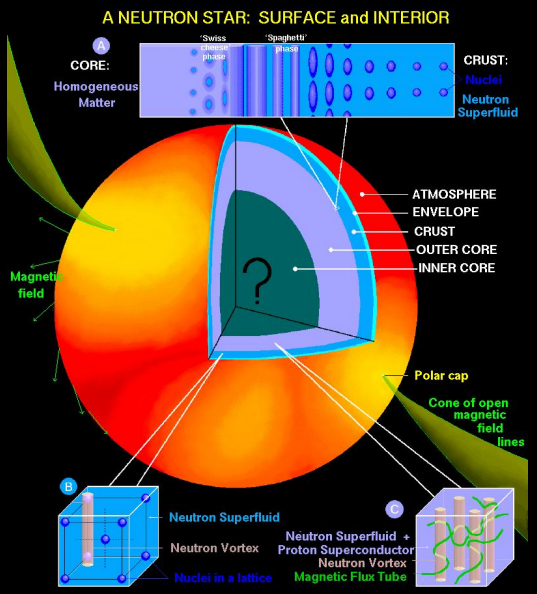


Discovered as Radio Pulsars 1967 in Cambridge

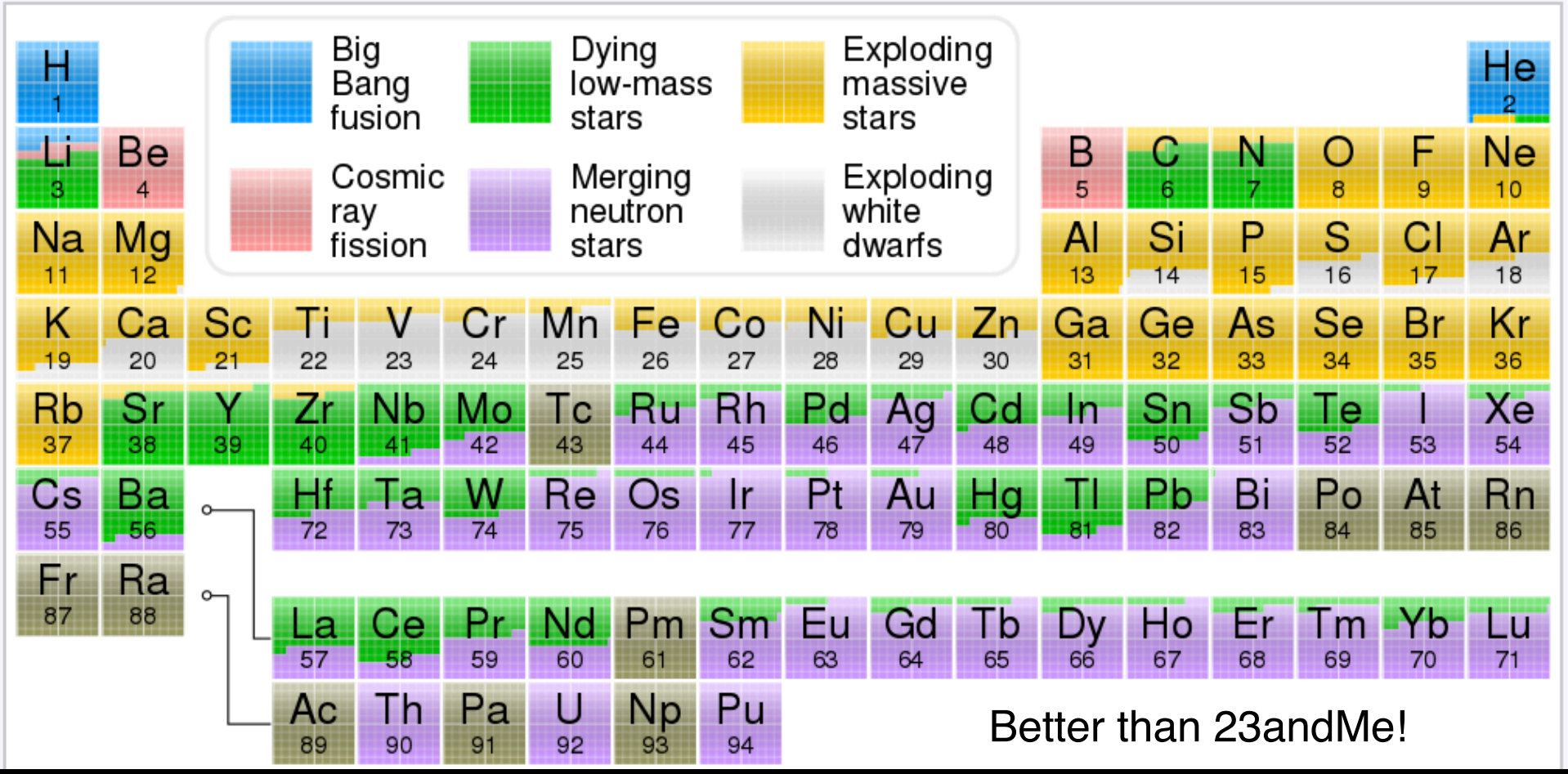
Extreme Density
Neutron Stars

- 1.5 Solar Mass Star
- 10 km Radius
- 1,000,000,000,000,000 x Water
- 1,000,000,000,000 x Earth Field

Confirm General Relativity
Strength of Nuclear Matter?
Measure Size of Universe?



Origin of the Elements



Complements Cosmological, Supernova Element Production

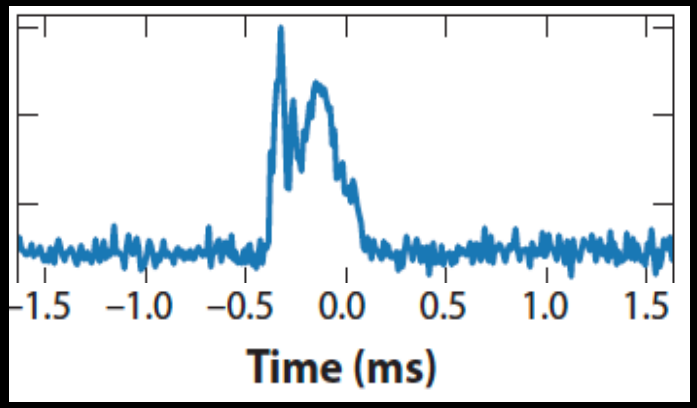
Extreme Magnetic Field Magnetars

- Neutron Stars
- Magnetic Field Thousand Times Larger
- Million Billion Times Earth

Magnetars push Quantum Electrodynamics into New Territory

Fast Radio Bursts

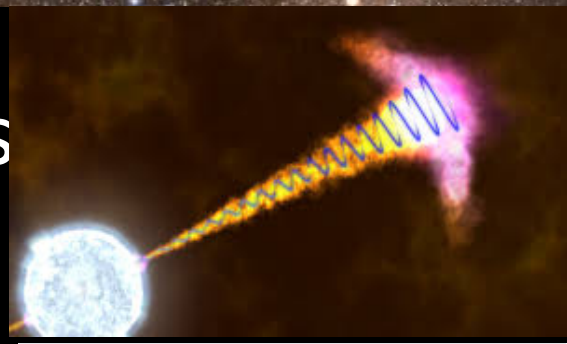
- Short, Intense Bursts of Radio Waves
- Millisecond Duration
- Roughly One per Minute
- Great Tools for Cosmology

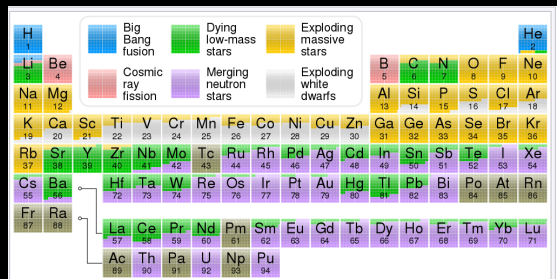


Most Popular Explanations Involve Magnetars

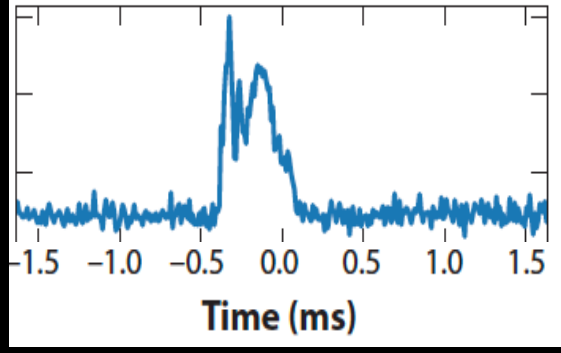
Exciting Discoveries

- Black Holes
  - Black Hole Shadow
  - Gravitational Radiation
- Neutron Star Merger(s)
  - Nature of Gamma Ray Bursts
  - Heavy Elements





The Future



- Improved and New Telescopes
- Surveys to Find Sources and Issue Alerts
- Data Handling and Simulation
- Some Immediate Challenges
  - Provenance of Binary Black Holes
  - Reverse Engineer Relativistic Jets
  - Physics of Nuclear Matter
  - Origin of Ultra High Energy Cosmic Rays
  - Nature of Fast Radio Bursts
- Scientific Discovery is “Logically Unscripted”