Gamma-Ray Astronomy

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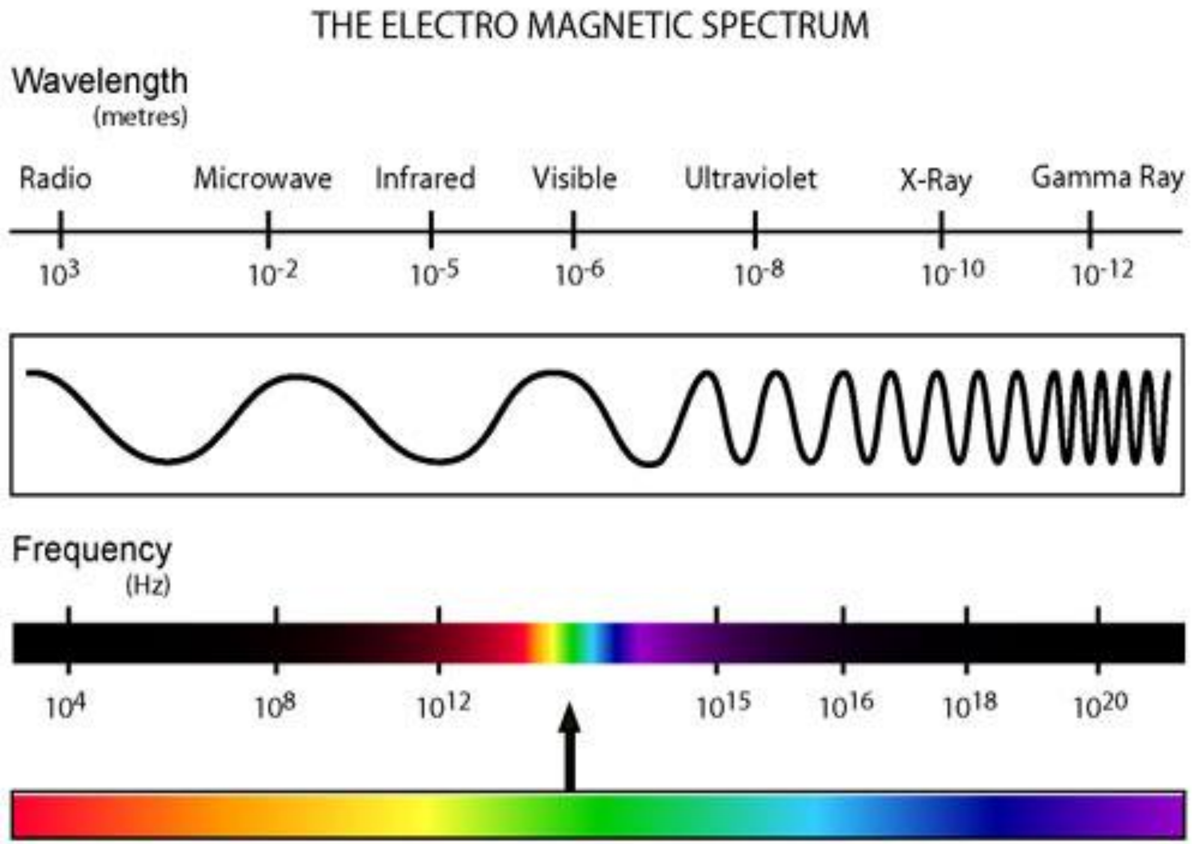
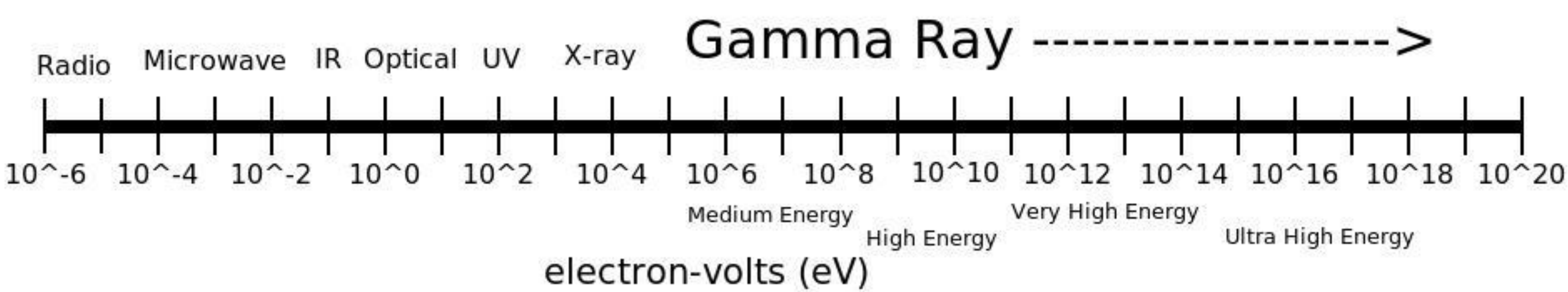
What do astronomers do?

- Astronomers study light from objects in space
- Light as a wave
  - Wavelength (λ)
  - Frequency (f, v)
- Light as a particle
  - Energy (E)
- Can relate the two models: $E = (h*c) / \lambda$
  - $h = 6.626 \times 10^{-34}$ m^2kg/s (Planck's constant)
  - $c = 2.99 \times 10^8$ m/s (speed of light)
  - Units: works out to be Joules (J) ---> unit of Energy!

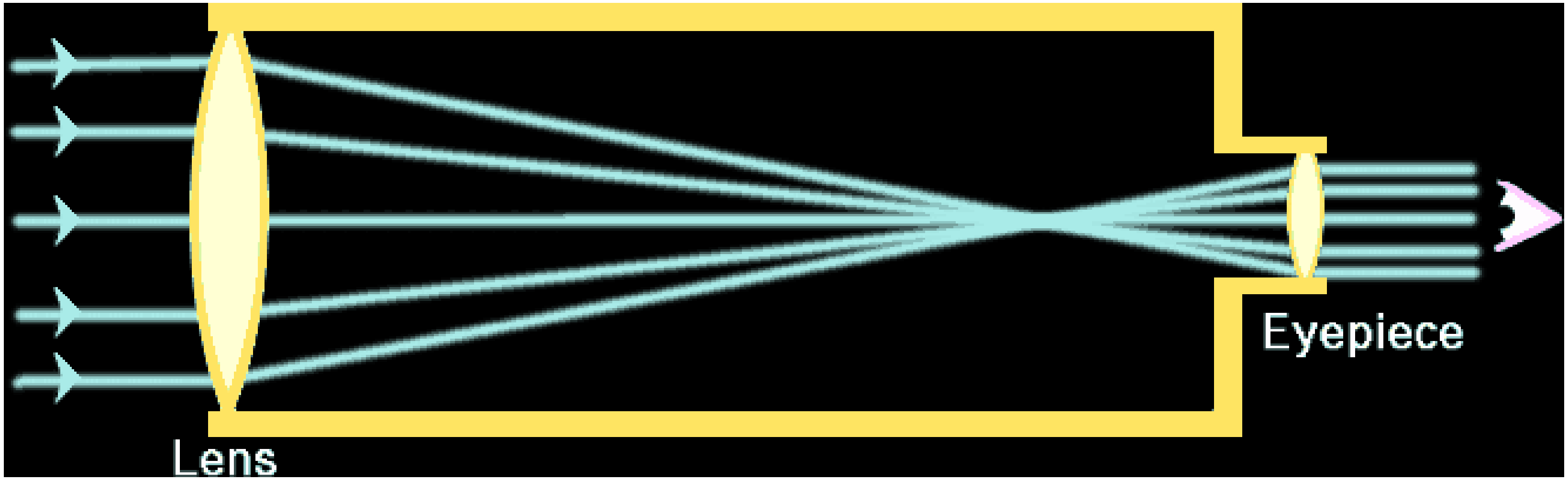


- Energy can also be measured in electron volts



Tools of the Trade

- A telescope’s main purpose is to collect and focus light from distant objects (NOT to magnify!)

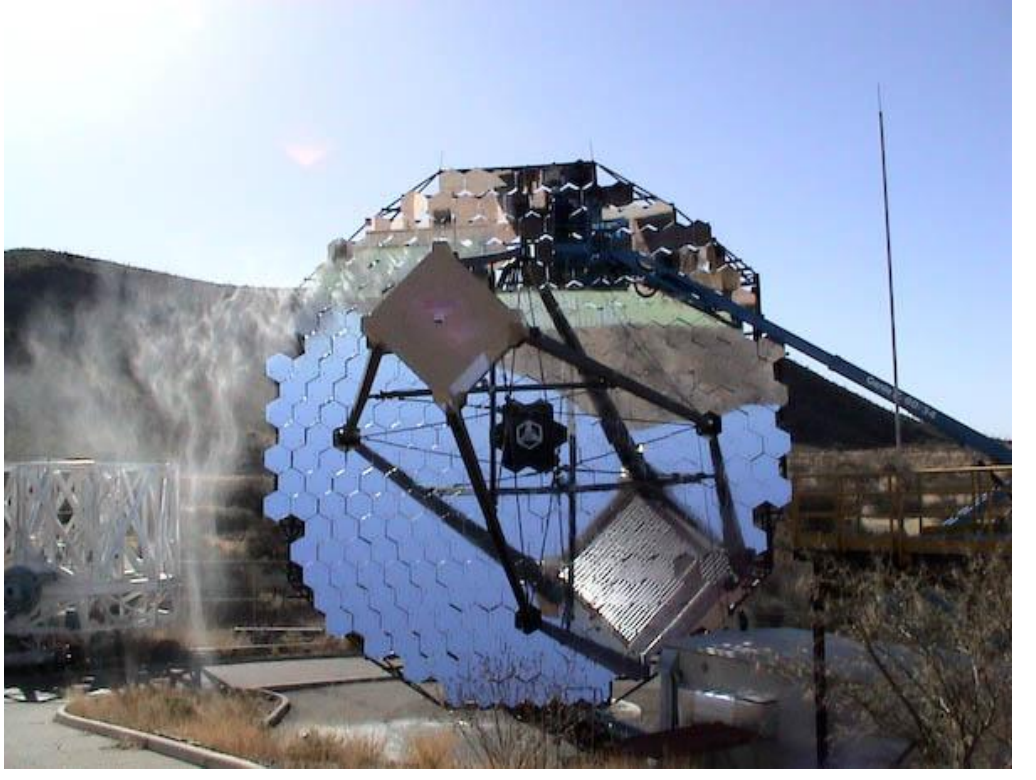


VERITAS

- **V**ery **E**nergetic **R**adiation **I**maging **T**elescope **A**rray **S**ystem
- Very high energy gamma ray (γ) observatory
- Array of 4 telescopes
- Located in southern Arizona

Close-up of a Gamma Ray Telescope

- 345 small, hexagonal mirrors
  - total diameter of telescope is 12 m (39 ft.)
- All pointed to reflect light to the camera in the middle, made of 499 photo-multiplier tubes (PMT)

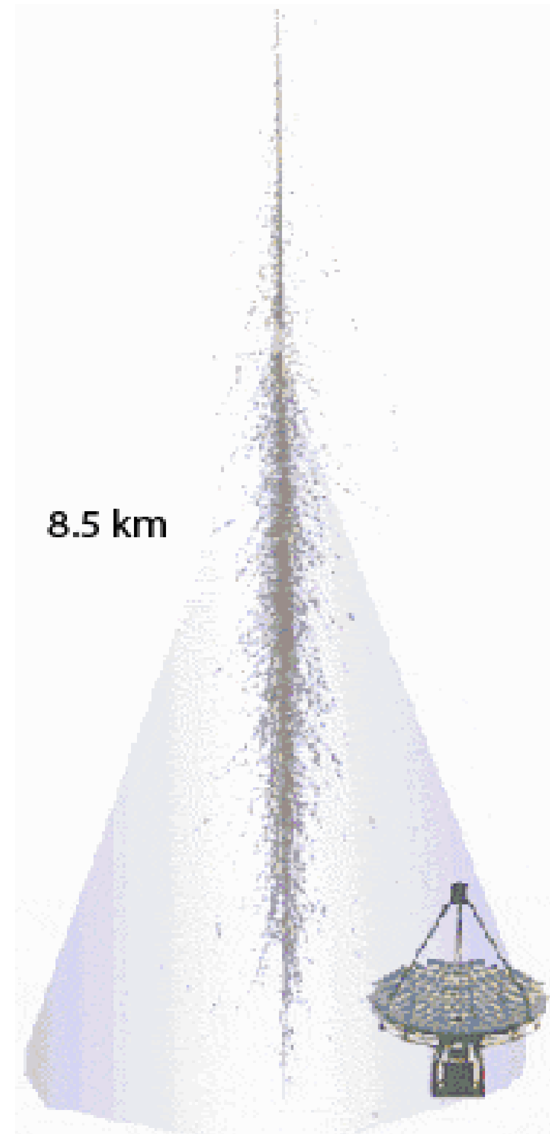


Guts of a Gamma-Ray Telescope

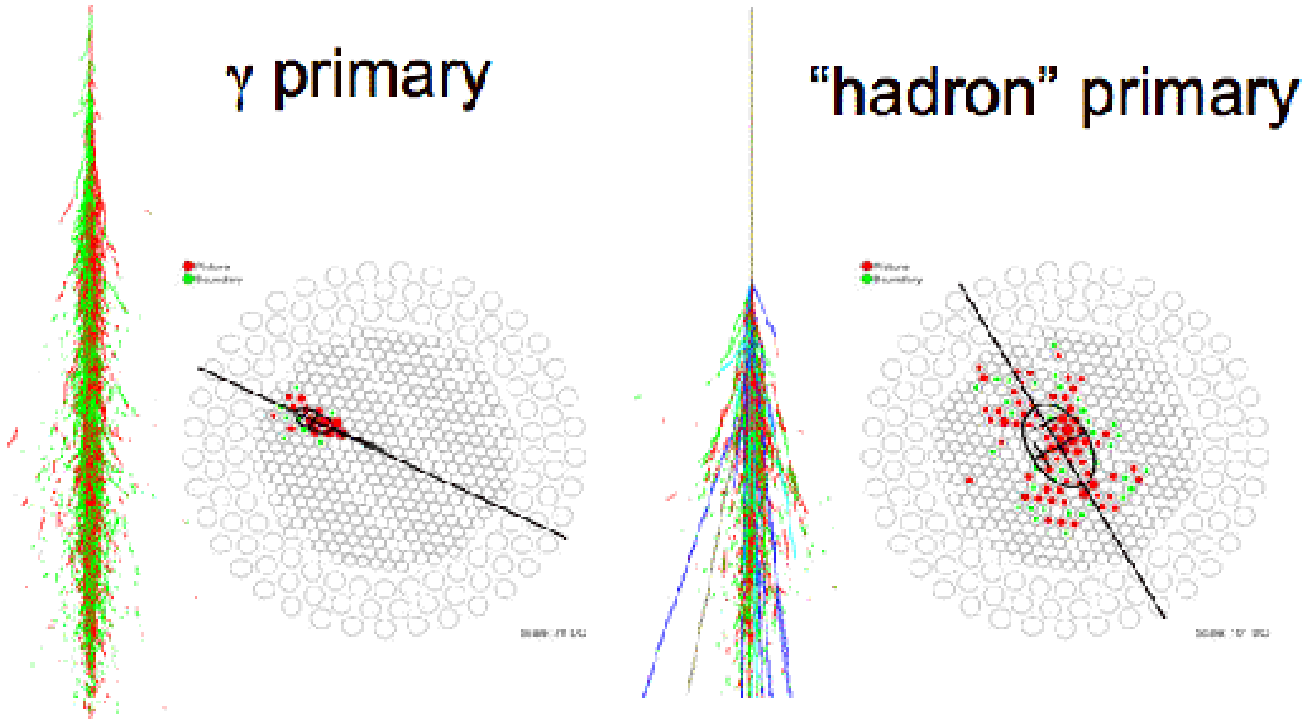
- Each telescope has a trailer to house the electronics that make it work
- Need wires both to send control signals to the telescopes and to transmit data from the PMTs
  - 20 minutes of observation produces ~5.5 GB of data (average 2 hour movie file is ~700 MB; 1GB = 1024 MB; 20 min. data = 6 movies!)

Science!

- Gamma rays themselves cannot survive a trip through Earth's atmosphere
- 10-20 km (6-12 miles) above ground, a gamma ray photon will collide with a proton or neutron and create a shower of secondary particles (mostly electrons and positrons)
- We detect light created by these secondary particles, and trace their path back to find out where in the sky the gamma ray came from

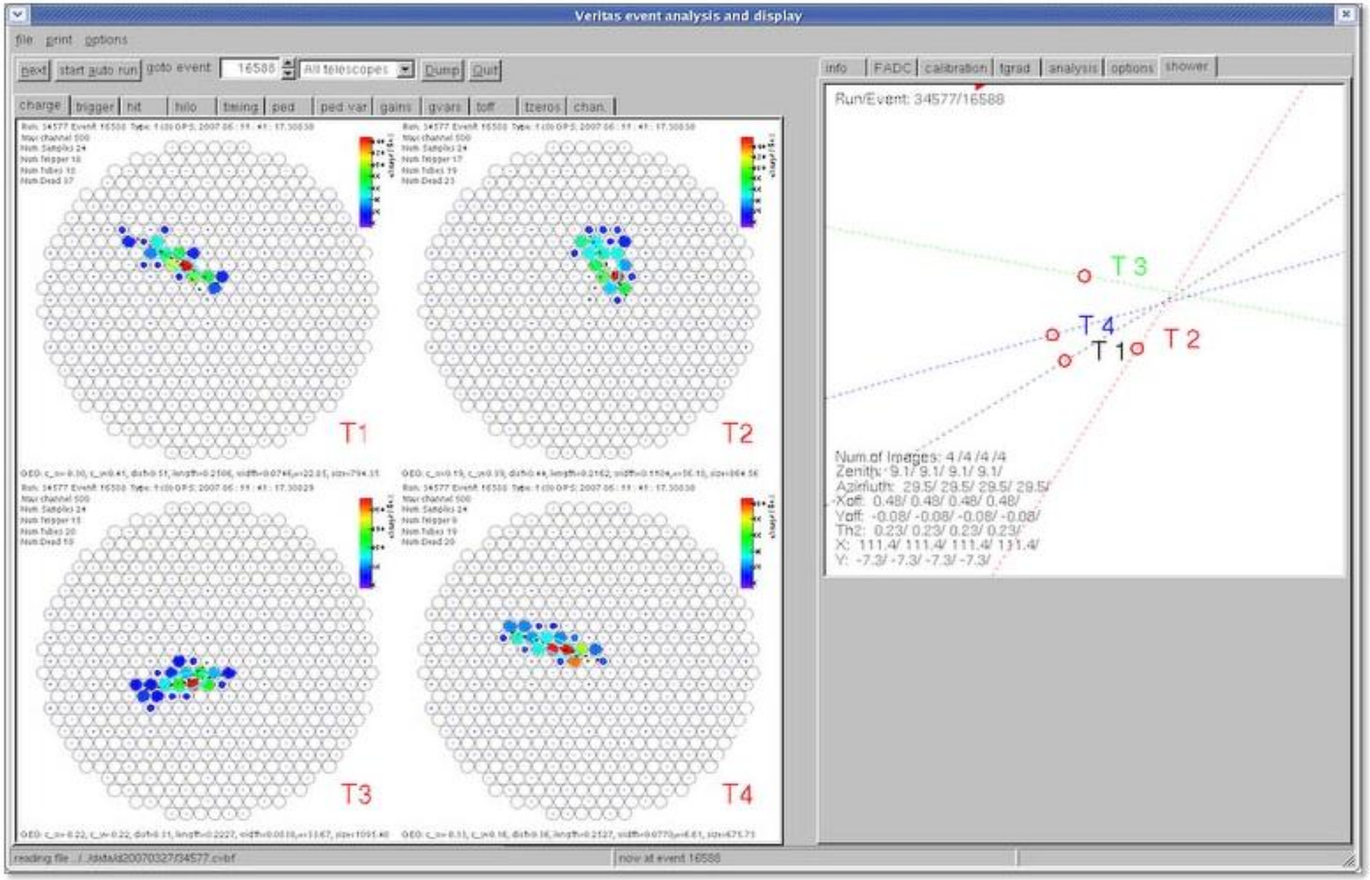


Data Analysis



- Gamma rays are not the only particles that cause these particle showers
- Data analysis techniques must separate gamma-ray showers from cosmic-ray showers
  - Cosmic rays are “stray” protons that are found throughout the universe

What I Do



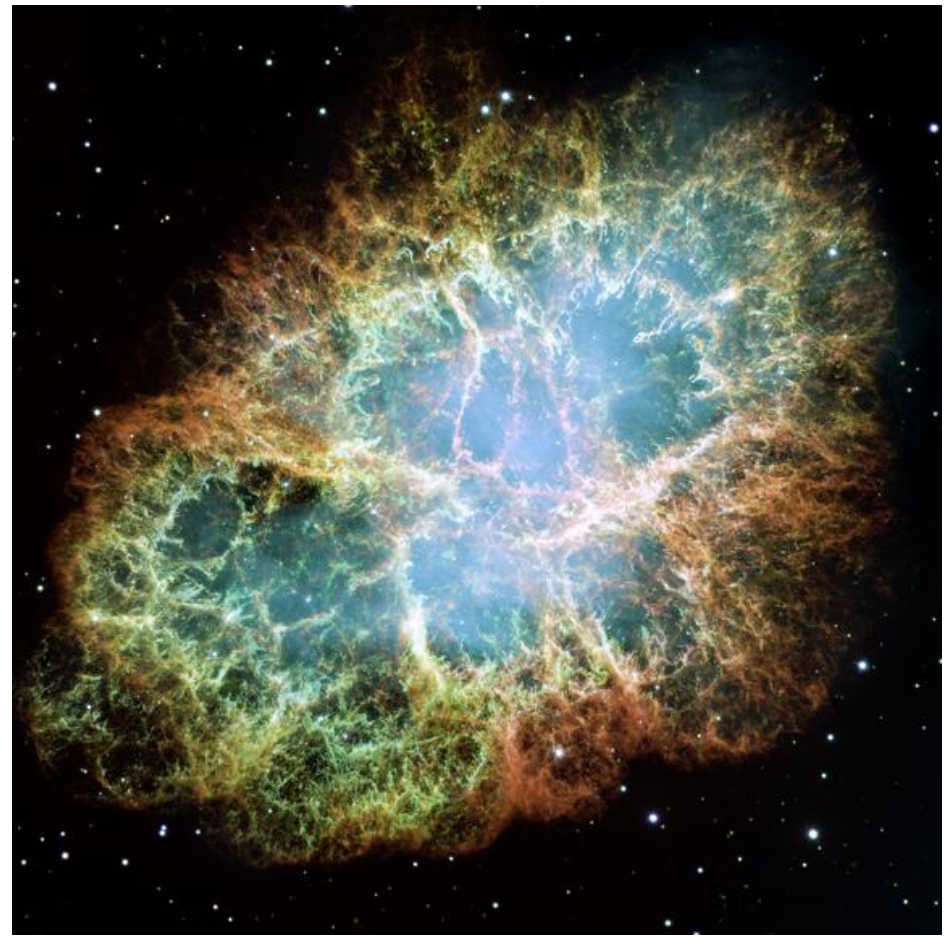
- Operate the telescope and take data
- Analyze data using software written by other scientists
- Write programs to further study data and try to improve our analysis techniques

What does this data tell us?

- Since gamma rays are so energetic, it takes extreme conditions to create them
  - only systems with a lot of energy are capable of producing gamma rays
- What kinds of systems have this much energy?
  - Supernovae
  - Pulsars
  - Black holes

Supernovae

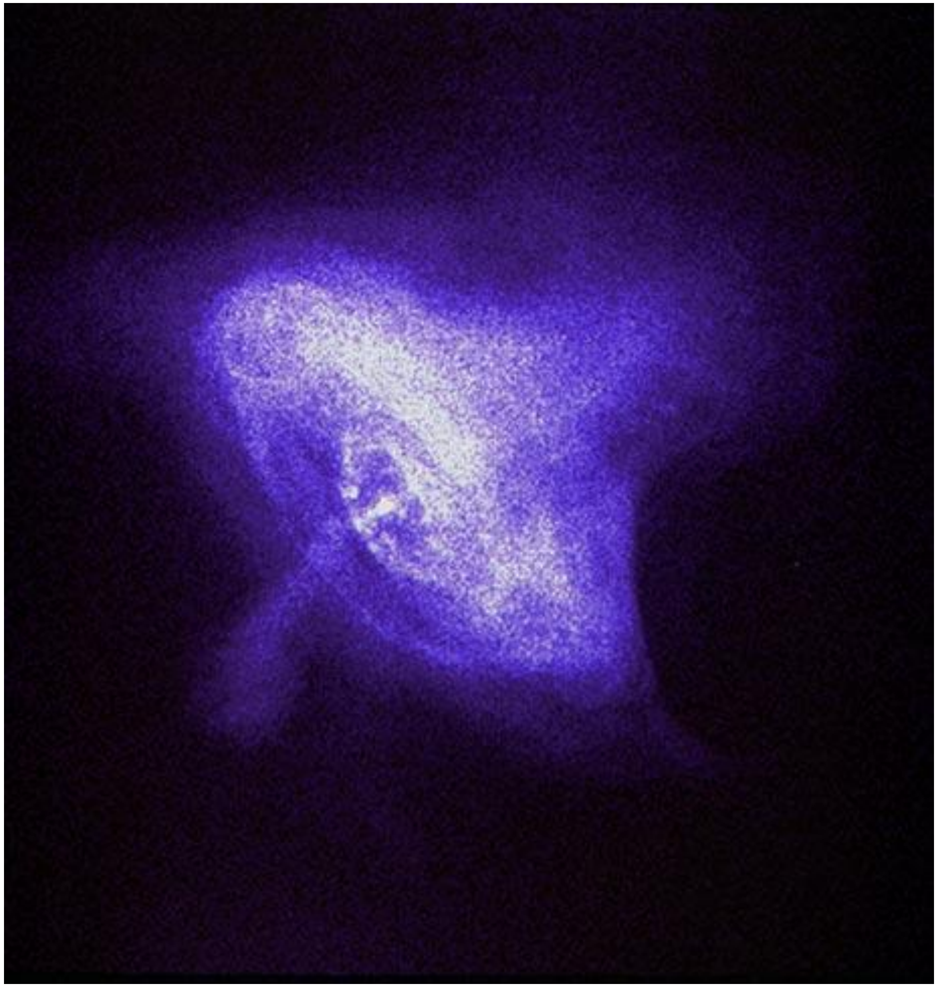
- Massive stars die in huge explosions, leaving clouds of stellar material behind (and possibly neutron stars or black holes)
- Shock waves from the explosion move so fast and get so hot, they have enough energy to emit gamma rays



Crab Nebula – Hubble Space Telescope (visible light)

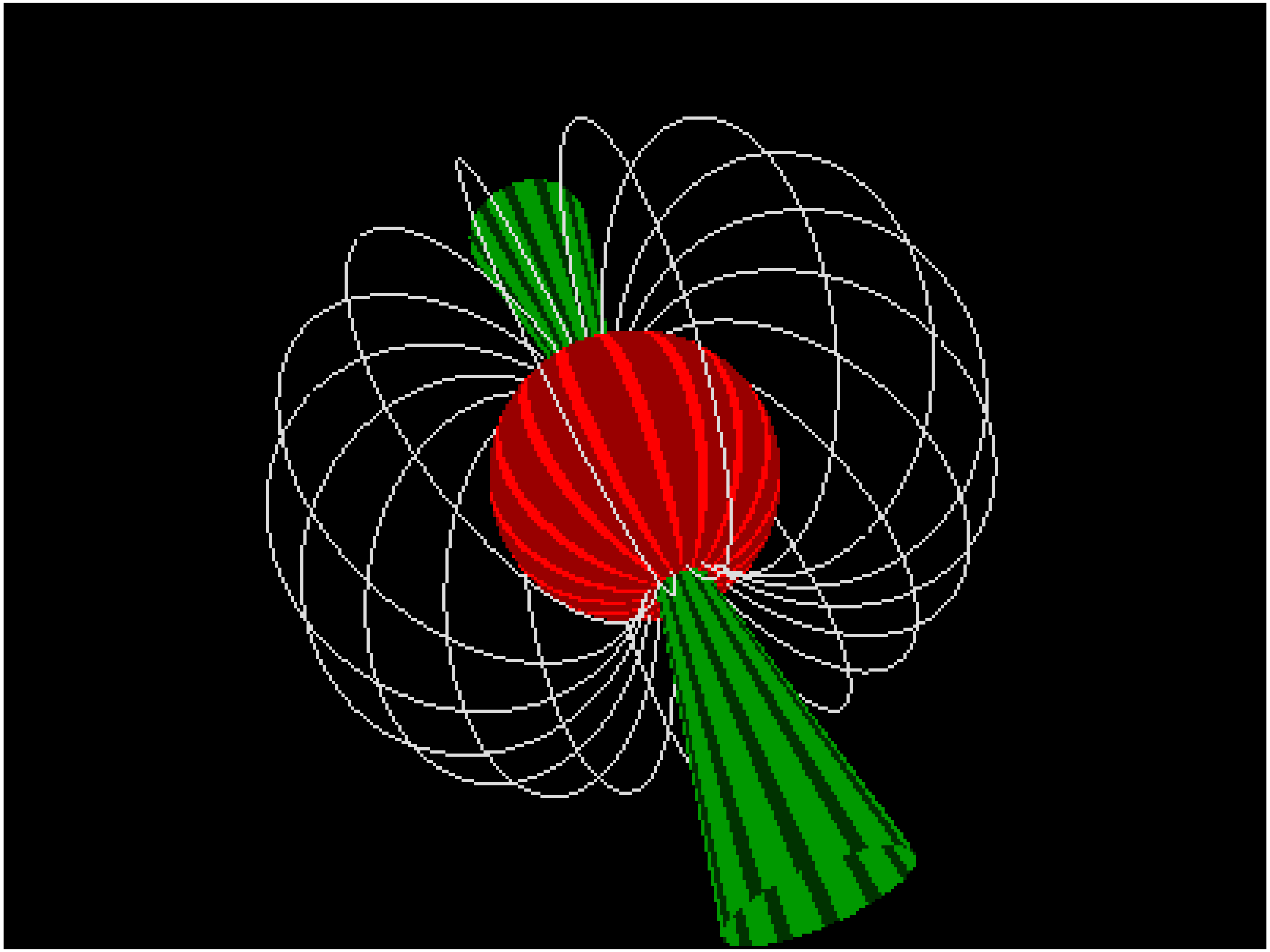
Pulsars

- Rapidly rotating neutron stars
- Particles get caught in the strong magnetic field and are quickly accelerated outward at the magnetic poles, forming relativistic jets (very, very fast, so very energetic!)



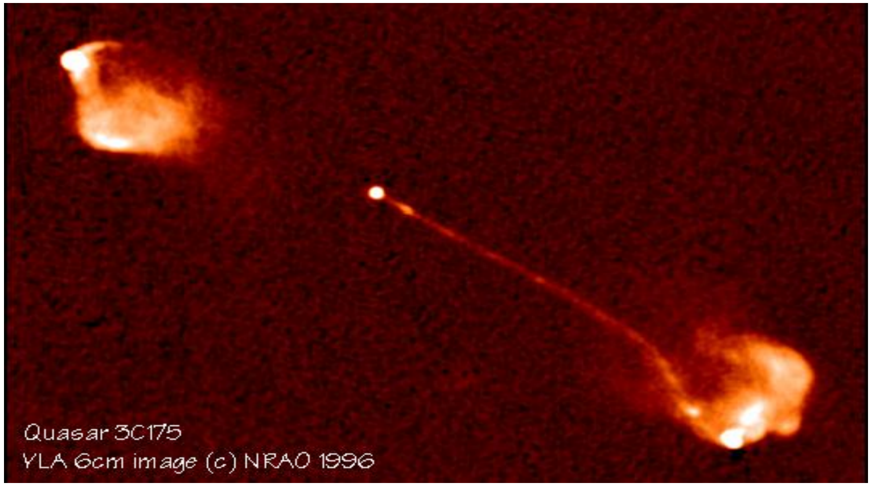
Crab Pulsar – Chandra X-Ray Telescope

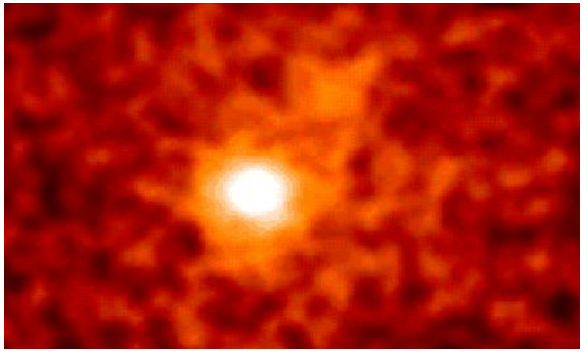
Pulsar – Magnetic field lines and jets



Black Holes

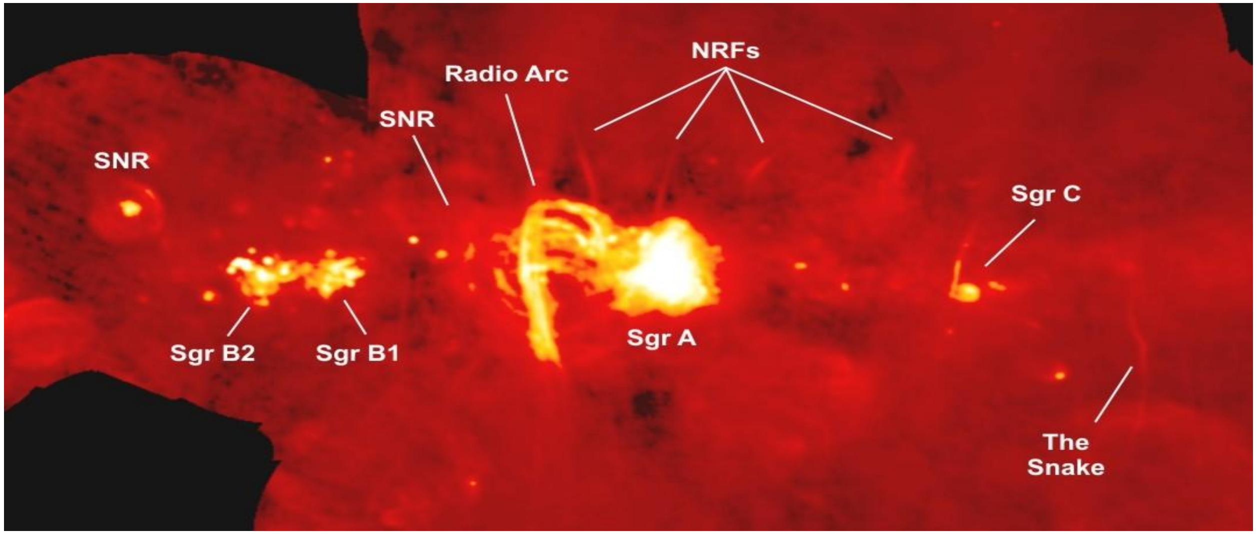
- As material is attracted to black holes, it interacts with the black holes' magnetic fields, forming relativistic jets similar to those of pulsars
- These jets are associated with black holes of all size ranges, from a few solar masses to millions of solar masses





Pulsar 3C279 – Egret Gamma Ray Telescope

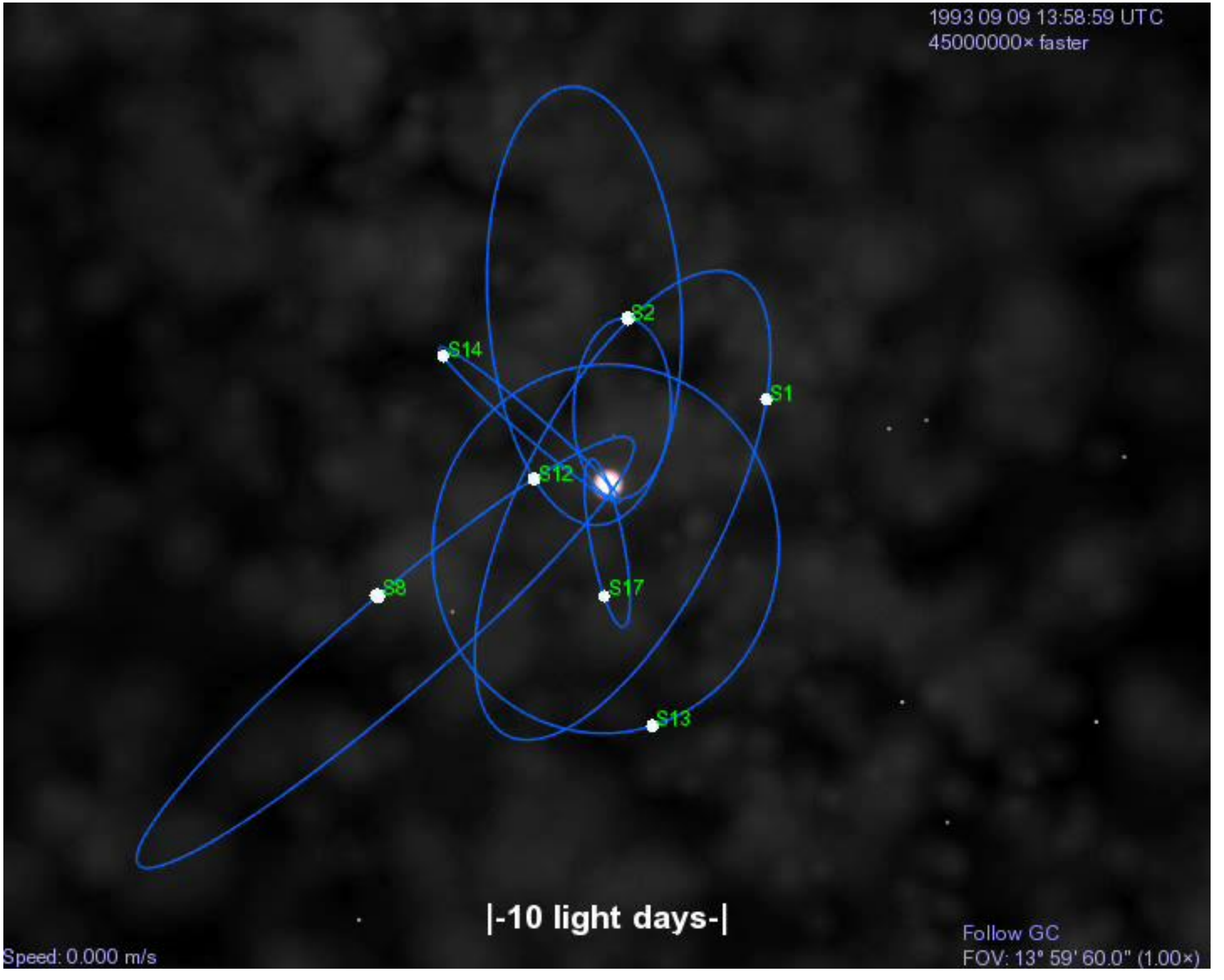
The Milky Way's Central Black Hole



Sgr A* -- combined data from VLA and Green Bank (radio telescopes)

- Sagittarius A* (Sgr A*)
- ~4 million solar masses
- Radius of event horizon less than 100 AU (Pluto's orbit is an average of 39.5 AU)
- Astronomers now think that most galaxies have black holes at their centers, but most are not active
  - Sgr A* is not active, so does not emit gamma rays

Simulation of Sgr A*



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