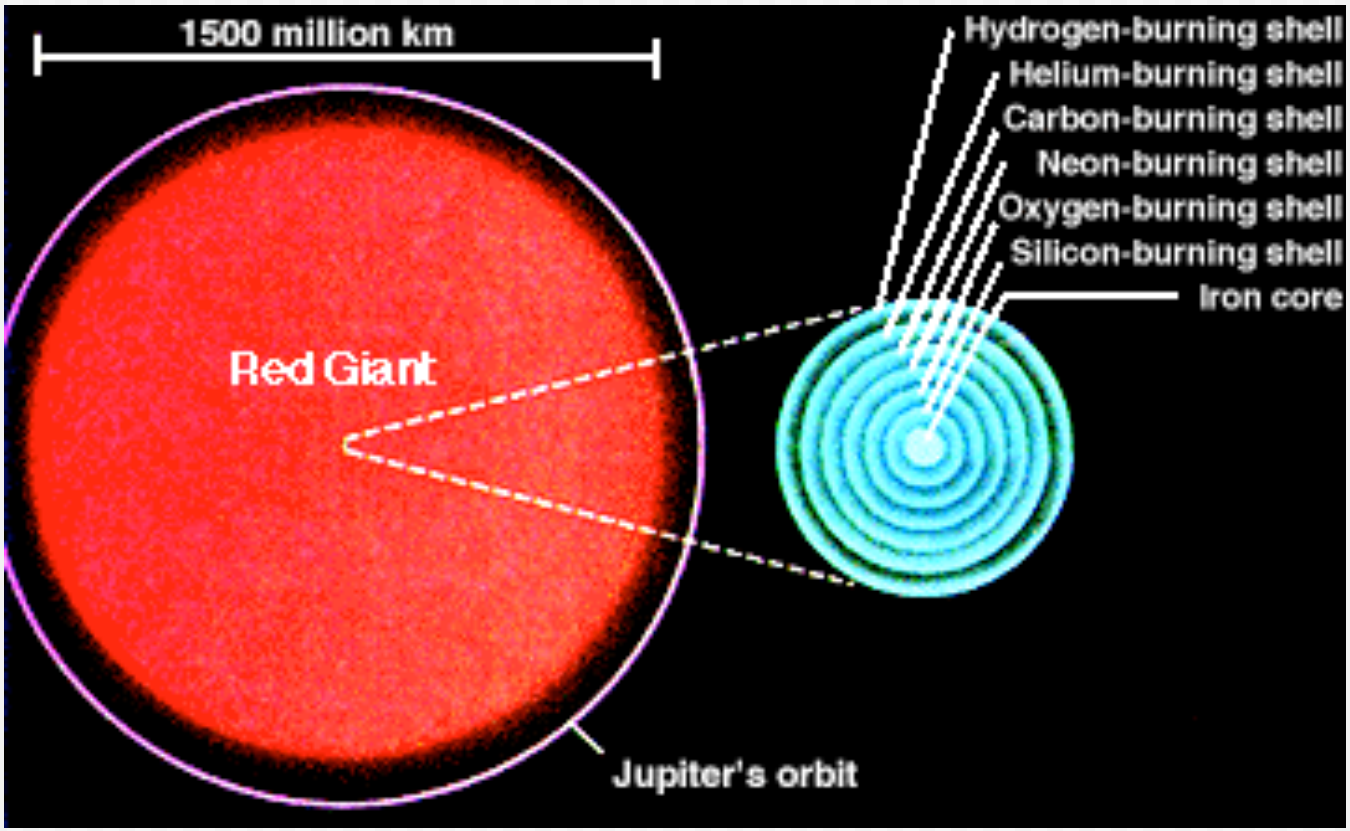
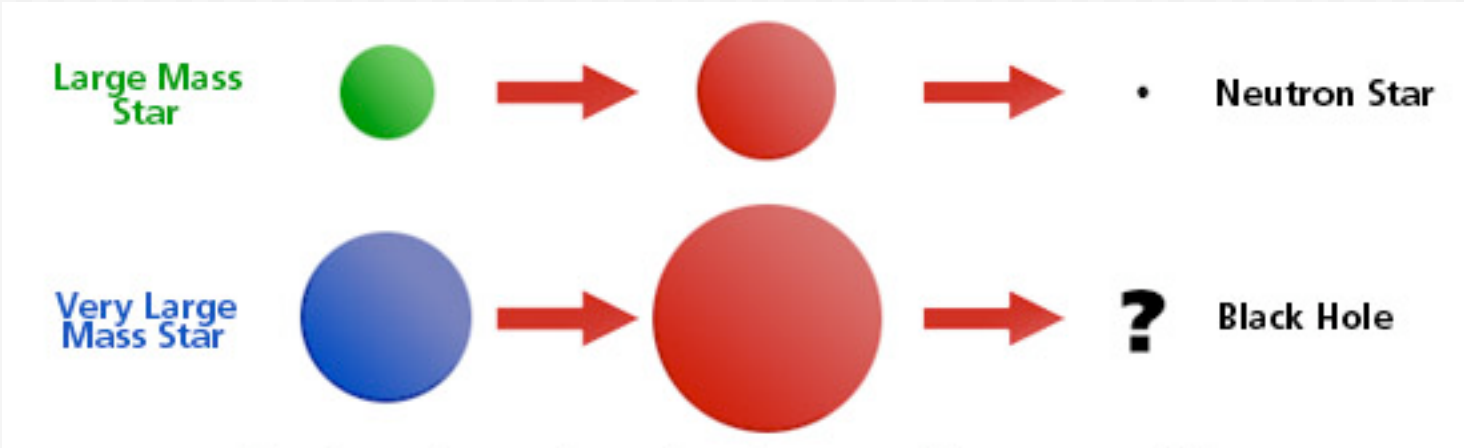
Very Massive Stars

- if more massive, keep going
  - burn Carbon, then Neon, then Oxygen, then Sulfur
    - shorter and shorter intervals
  - Silicon burning to Iron in about 1 day



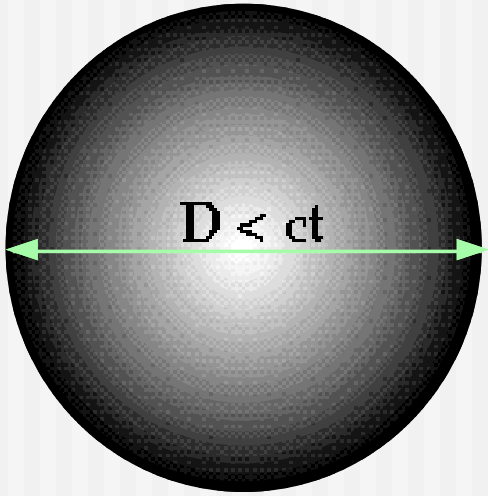
Type II Supernovae

- BIG PROBLEM: cannot release energy by burning Iron
  - just get hotter and hotter
  - in < 1 second core crashes in on itself
- detonate alot of unburnt fuel
  - blow away outer layers
  - can outshine a galaxy
  - elements heavier than Iron produced



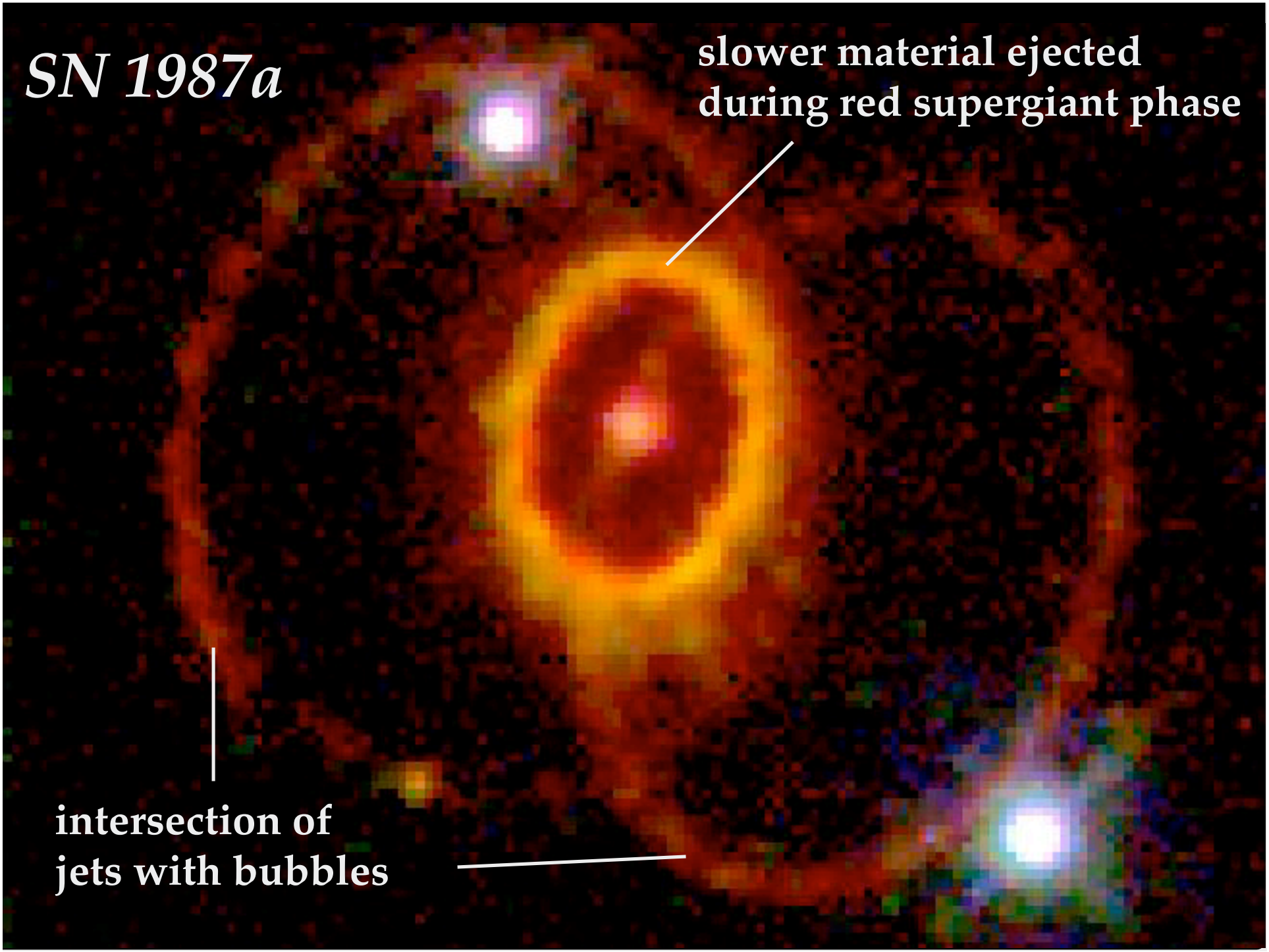
The Crab Pulsar

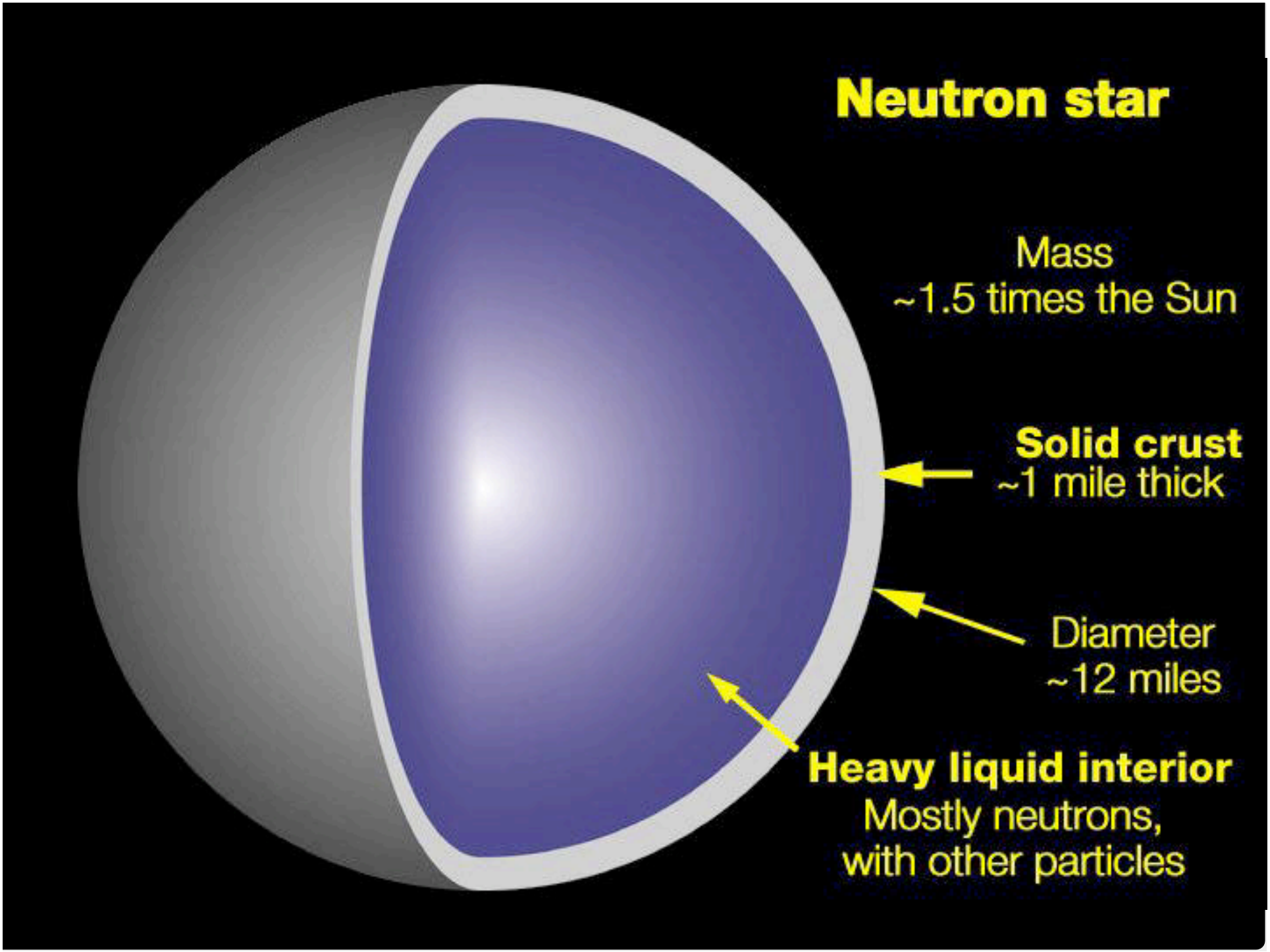
- accidentally found weak radio pulses, 1949
  - period 1/30 second



time scale, t, indicates maximum source size

- dim in optical, bright in other wavelengths
  - X-rays seen, 1964
  - visible in gamma-rays
  - synchrotron from fast electrons moving thru mag. field


SN 1987a
slower material ejected
during red supergiant phase
intersection of
jets with bubbles

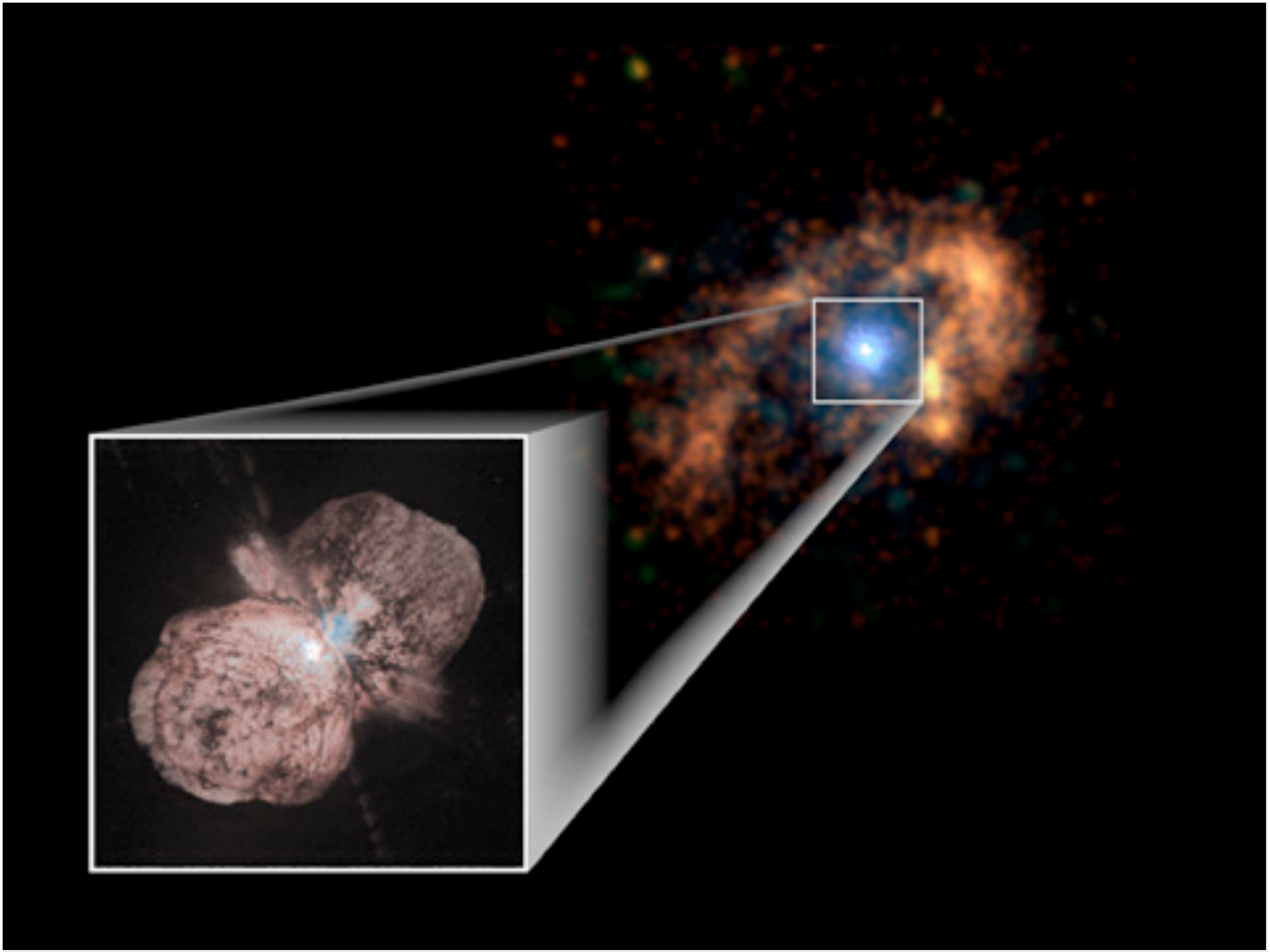

Neutron star
Mass
~1.5 times the Sun
Solid crust
~1 mile thick
Diameter
~12 miles
Heavy liquid interior
Mostly neutrons,
with other particles

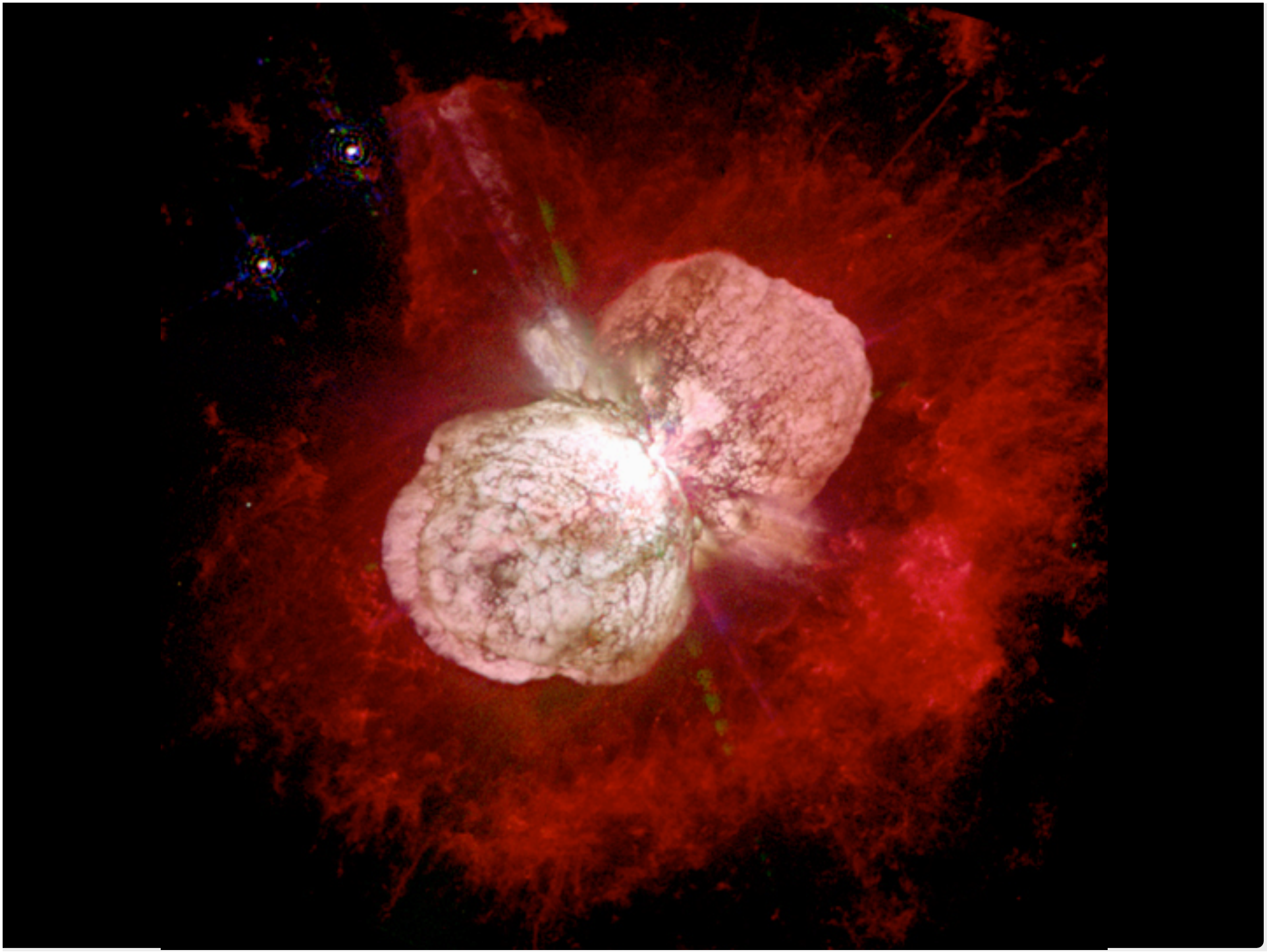
Eta Carinae

- one of most massive stars in Milky Way
  - 100 Suns
  - would be one of most luminous, but hidden in dust
- slowly brightened in last century
  - came to rival Sirius (brightest star) about 150 years ago
  - very irregular behavior
  - faded to dimness
- modern observations
  - reveal extended gas regions around star

Eta Carinae

- most massive, luminous star in Milky Way
  - beyond limit for star's mass
    - if star mass > 60 times the Sun, radiation pressure pushes it apart
  - mass about 120 times the Sun!
  - 5 million times solar luminosity!
- very unstable star
  - outer layers have been blown off multiple times
  - "Great Eruption" of 1800s
  - similar explosion about 1000 years ago
    - X-rays detected in large ring
- supernovae sized events
  - except didn't destroy the star!





"Will it awake, this sun of Argo, will it revive completely and project anew around its brightening sphere the radiation of light and heat which seemed to have departed from it forever? We may, we ought to hope for it."

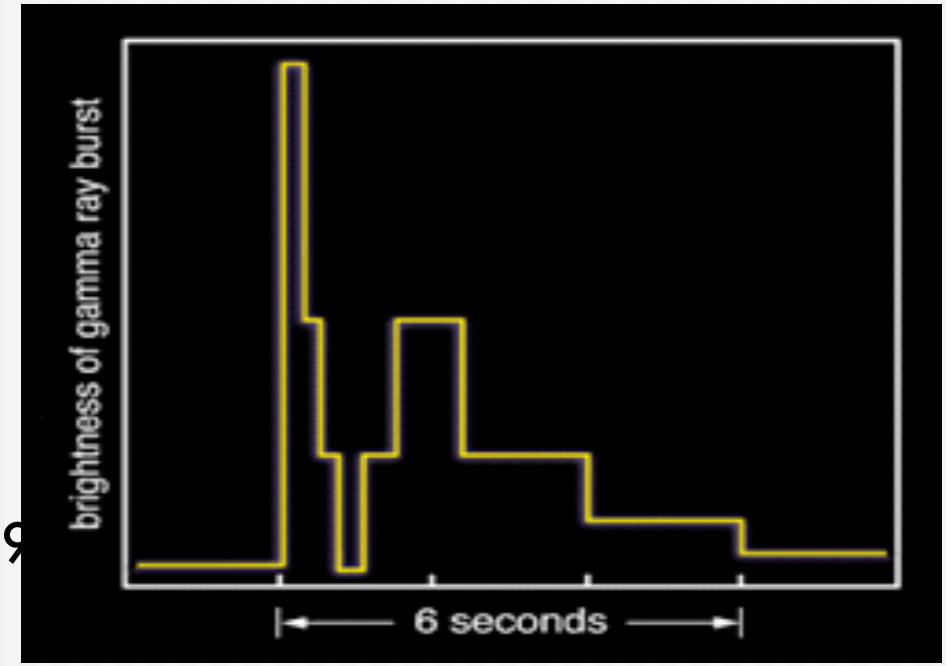
Camille Flammarion on η Car, 19th cent.

Gamma-Ray Bursts

- accidentally detected in late 1960s
  - bursts of very high energy X-rays and gamma-rays
  - brighter than the rest of the gamma-ray sky when at peak
- last a few seconds
  - actually two subsets
    - those lasting about 10 seconds
    - those lasting less than 1 second
  - very broad range of durations
- very erratic behavior
  - variations as short as milliseconds observed
  - no two bursts have the same light-curve
- what are they? Stay Tuned!

Timeline

- accidental discovery 1967 by VELA spacecraft
  - celestial origin determined, 1973

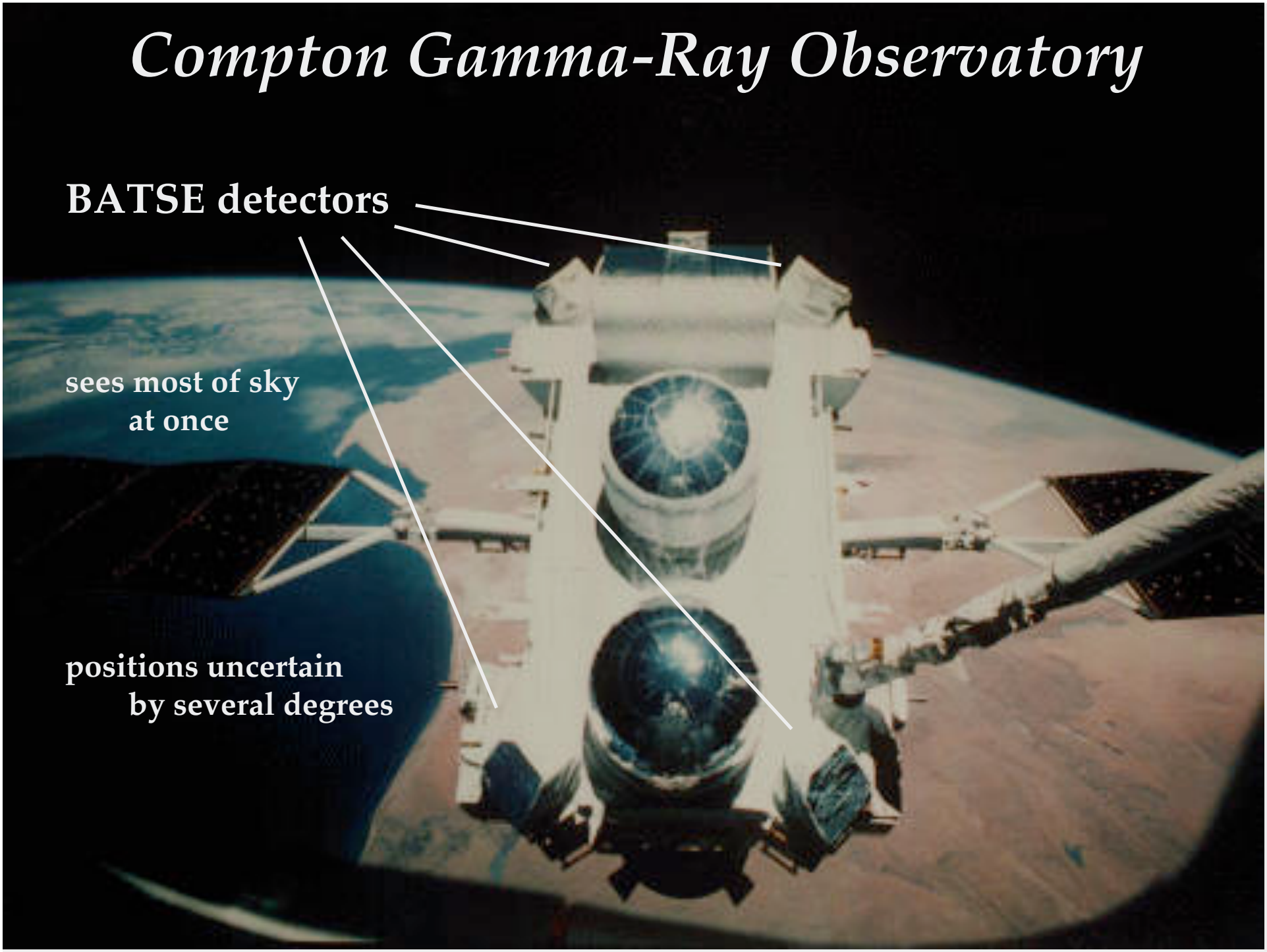


- 1973 - 19

What are Gamma-ray Bursts?

- brief, intense bursts of gamma-rays
  - often brighter than rest of gamma-ray sky
  - duration:
    - ~ 0.005 to 1000's of seconds
    - two groupings: 0.1 sec and 10 sec.
- occur about once/day
- complex and well-measured variation
  - extremely diverse
  - variations as short as 0.3 ms
    - places a limit on source size ($D < ct$) of < 100 km
- makes them very hard to explain/model

Compton Gamma-Ray Observatory

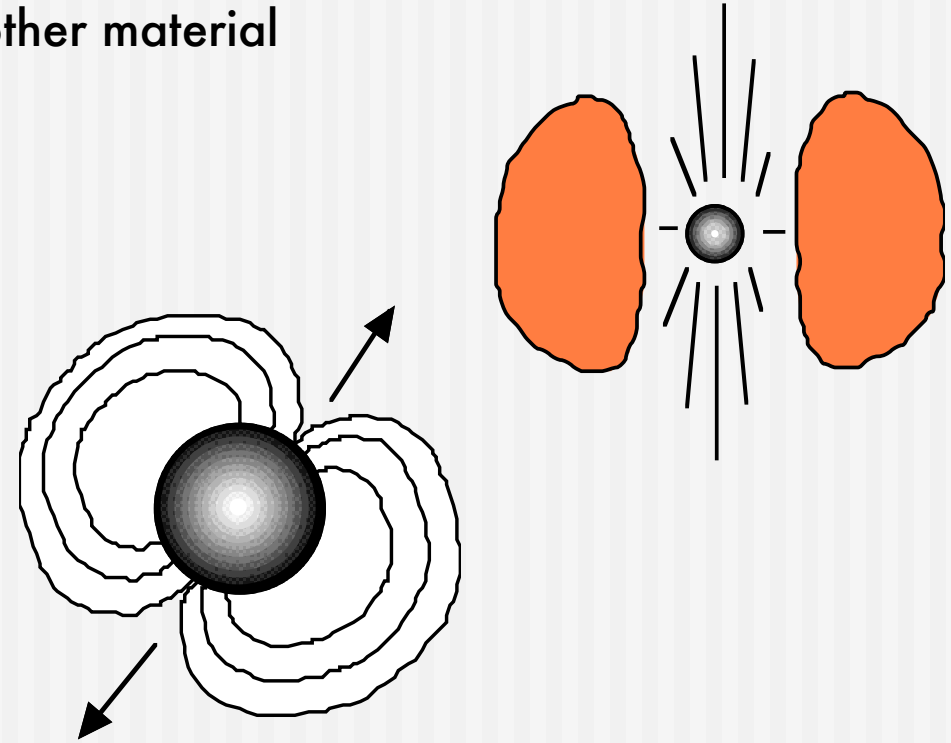


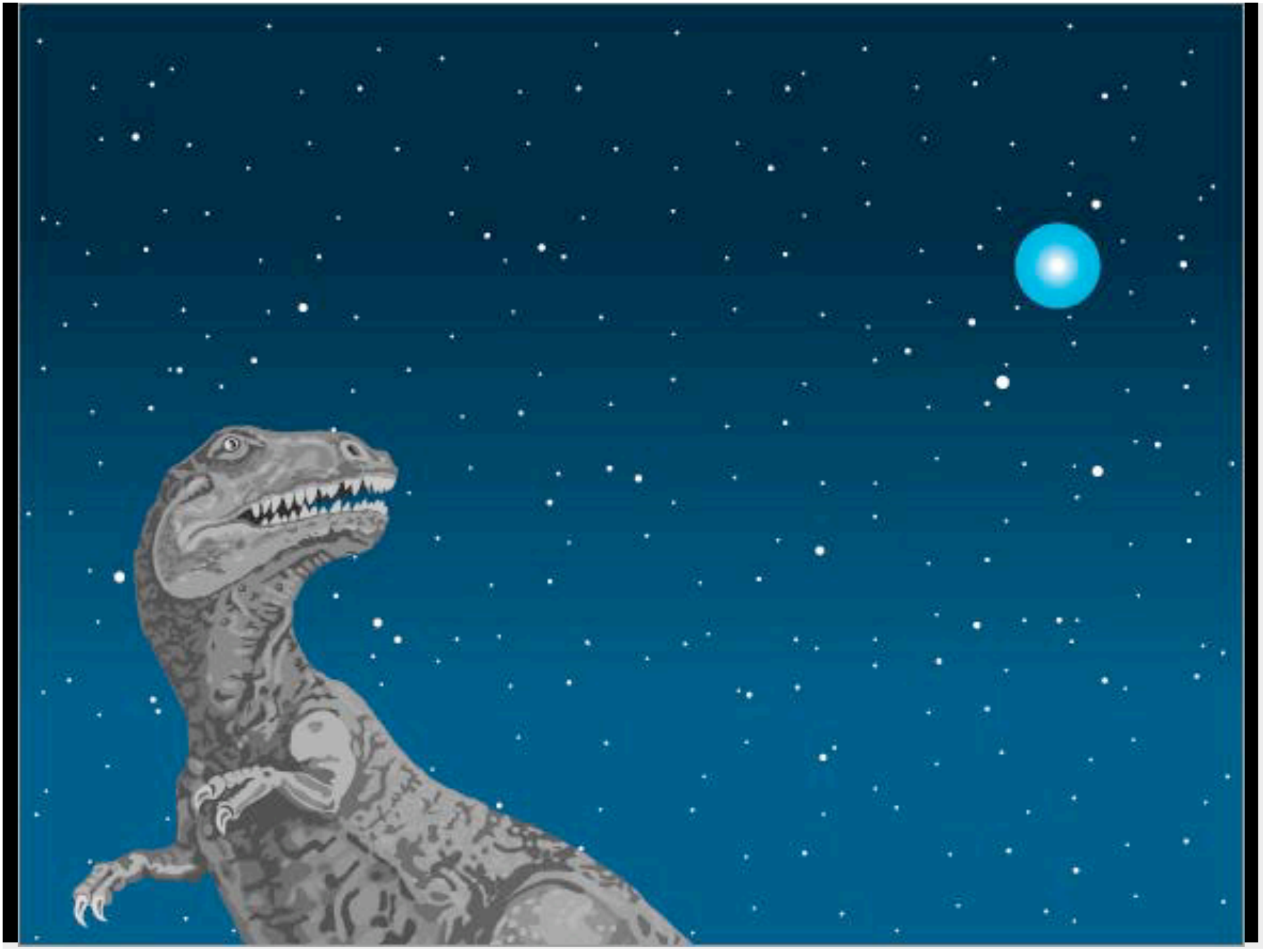
Multi-Wavelength Observation

- counterparts
  - bursting simultaneous with gamma-rays
  - fading afterglow tells only about expanding fireball
- rapid coordinates available starting in 1993
  - takes about 4.5 seconds
- no optical counterparts to 8th magnitude within 30 minutes of a burst
- first afterglow detected 1997
  - only some bursts have them
  - may be visible for weeks
  - most fade smoothly
  - after a few hours, objects are faint (> 18th mag.)

Energy Crisis

- energy output
  - large fraction of a star's mass turned into pure energy
  - current models can only produce about 1% of this
- perhaps energy output directed in jets
  - allows for smaller total energy production
  - restriction by other material
  - magnetic fields



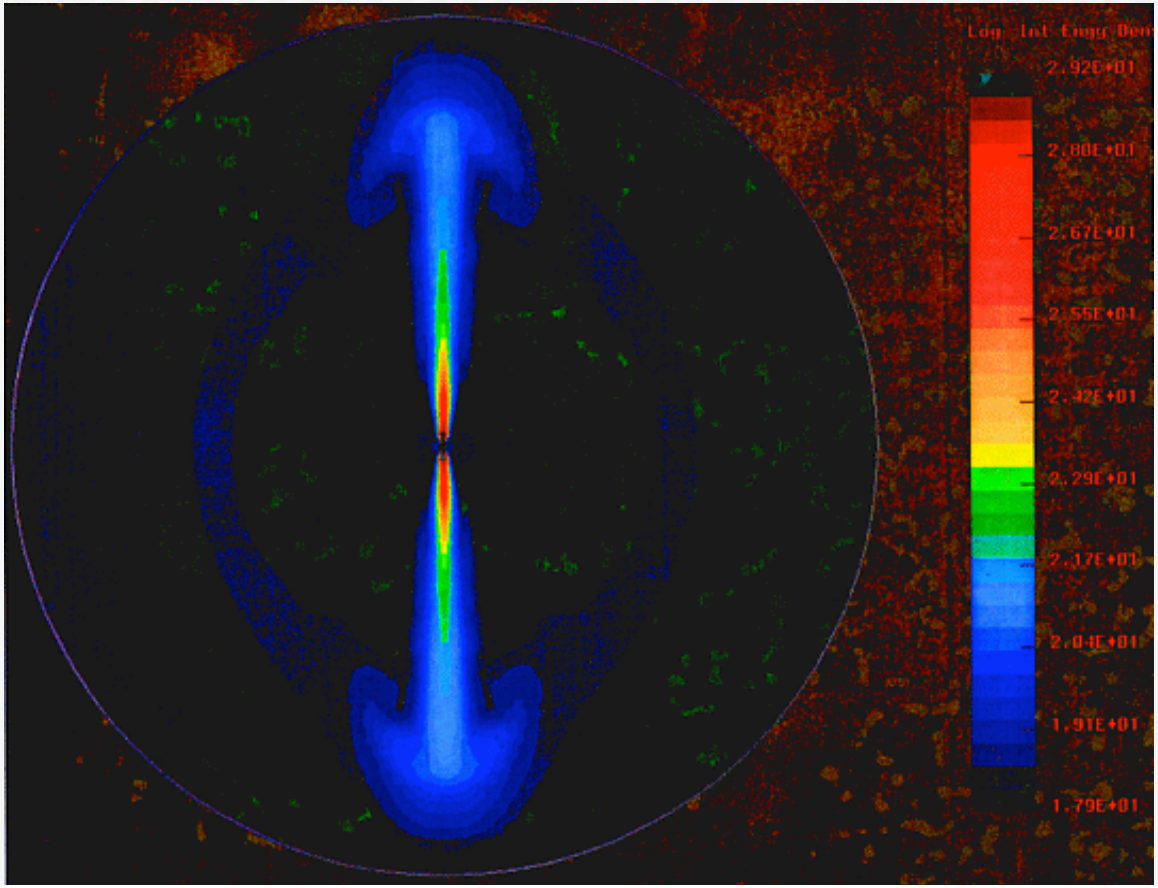


Implications

- some GRBs, at least, have optical bursts
  - this optical burst very apparently bright
  - as violent in optical as in gamma-rays
- energy output in optical:
  - as bright as 2 million galaxies
  - brightest object ever seen
- energy output in gamma-rays
  - > 1000 supernovae
  - > 1 solar rest mass
- largest known explosion since Big Bang

Hypernova?

- very massive star (eg. eta Carinae)
  - doesn't live long enough to leave birth area
  - should reside in starformaing regions



Where Are We?

- at least some gamma-ray bursts
  - at cosmological distances
  - show signature of afterglow from a fireball
  - possess optical counterparts
  - exhibit very violent optical bursts coincident with gamma-rays
- this indicates (if all GRBs same!)
  - enormous energy release
  - free of optically absorbing material near the explosion
- remaining questions
  - what is the central engine?
  - short vs. long?