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Supernova Educator Guide

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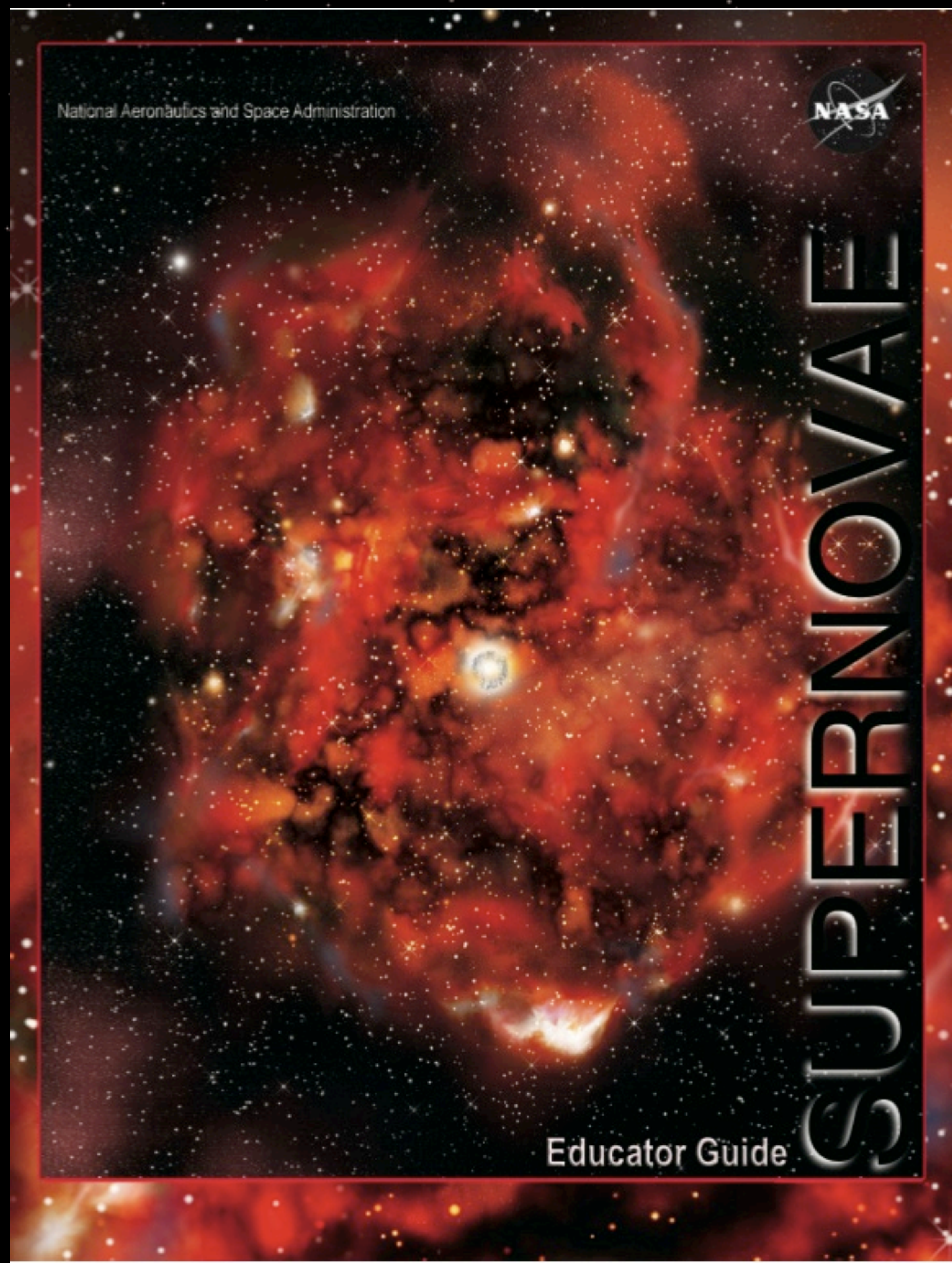
Saturday, November 1, 2008



NASA E/PO Group at SSU

~10 people working collaboratively to educate the public about current and future NASA high-energy missions.

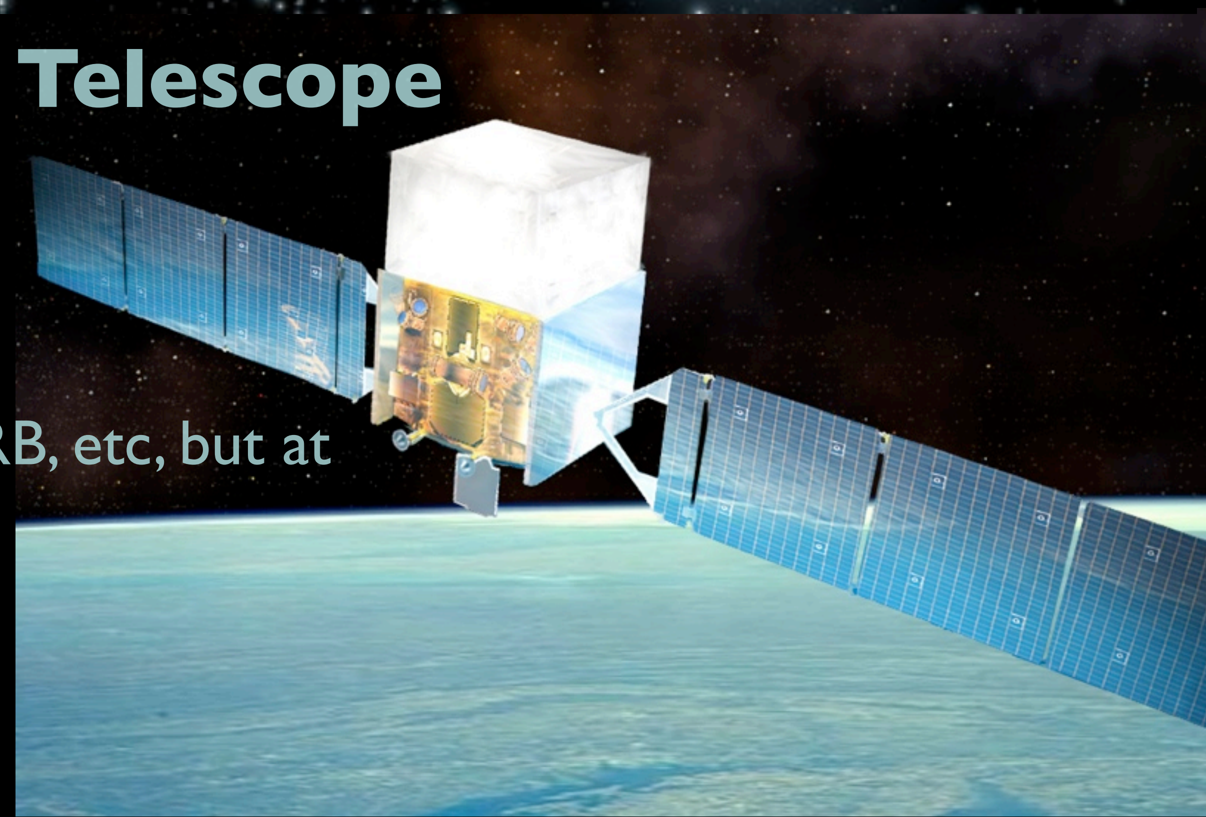
XMM-Newton

Fermi Gamma-ray Space Telescope

Led by Professor Lynn Cominsky

Fermi and XMM

- **XMM-Newton**
  - NASA/ESA X-ray telescope
  - Observes black holes, pulsars, AGN, etc
  - Launched December 20, 1999 (recently had some communication problems, but okay now).

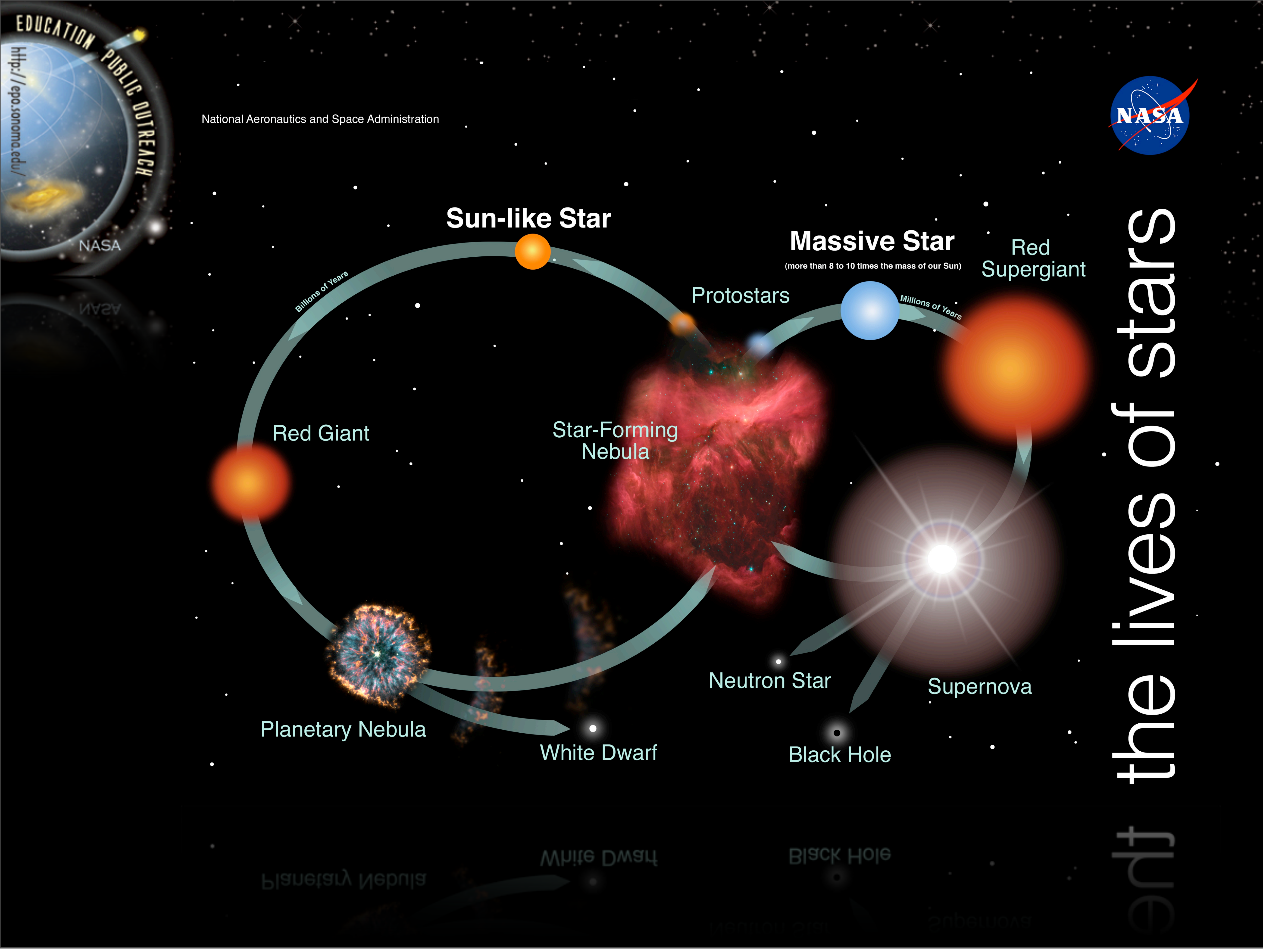


- **Fermi Gamma-ray Space Telescope**
  - First imaging gamma ray telescope
  - Observes black holes, pulsars, AGN, GRB, etc, but at higher energies than x-ray telescopes
  - Launched June 11, 2008

Image: R. Jay GeBany

Find the Supernova

The picture on the right shows SN 2005cs, a supernova that was discovered on June 28, 2005 in the galaxy M51. The supernova is the bright “star” just below the galaxy’s core, near the middle of the spiral arm.



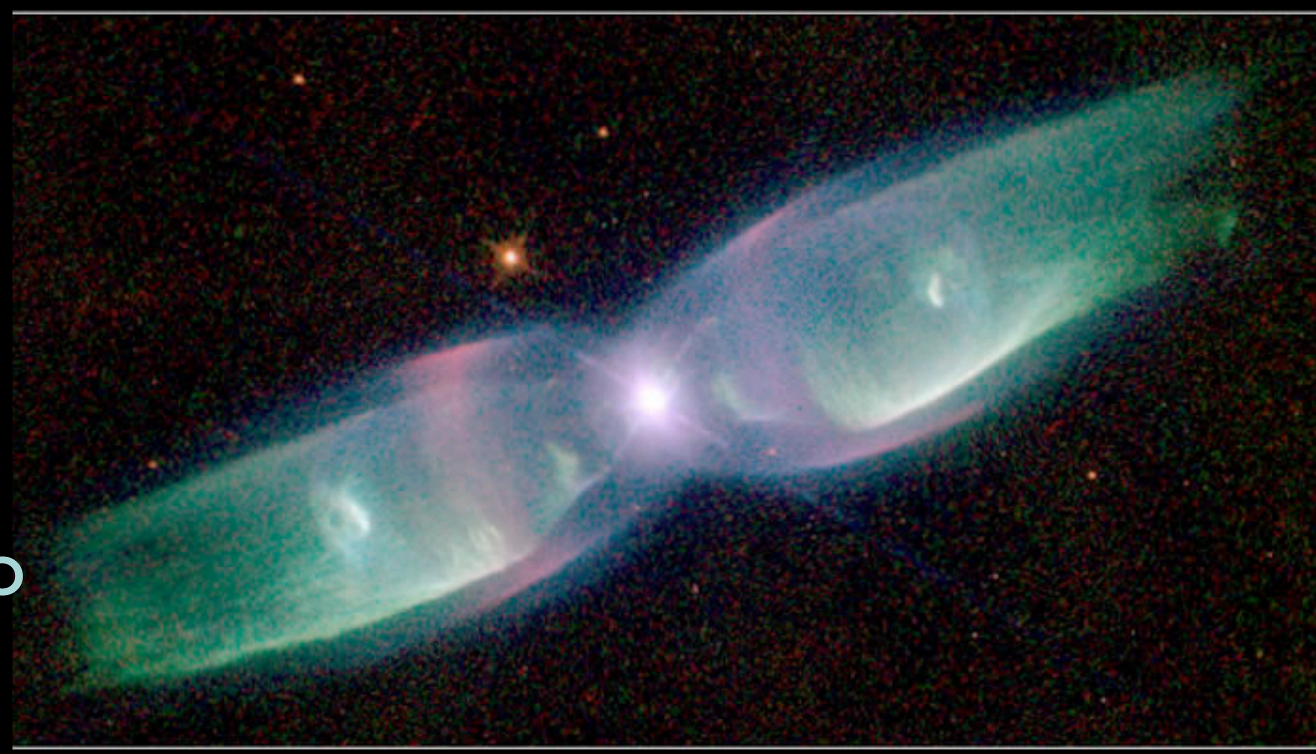
This figure is from a packet of materials on supernova that was developed for the Night Sky Network. It shows the star-gas cycle. On the left is a schematic of the life cycle for low mass stars (below a few times the mass of the Sun). They evolve through their hydrogen burning phase to become red giants (when they burn helium to carbon). When these stars run out of helium, they are done. They become planetary nebula and leave behind a white dwarf compact remnant. Stellar material blown off during the red giant and planetary nebula phases can be incorporated back into gas clouds, which can then form new stars. For low-mass stars the entire process from birth to white dwarf will require more than one billion years (the sun will require more than ten billion years).

On the right is shown the life cycle for high mass stars. These have masses about about 9 or 10 times the mass of the Sun. Just like low-mass stars, these stars start out burning hydrogen to helium. However, when they evolve beyond hydrogen burning, they are able to fuse elements beyond carbon. They can go all the way to iron, at which point, further fusion reactions become endothermic. Burning beyond iron causes the stellar core to collapse, which initiates a supernova explosion. What is left after a core collapse supernova is either a neutron star or a black hole, as well as an expanding cloud of gas called a supernova remnant. The supernova remnant is made up of the outer part of the star, perhaps 20 or 30 solar masses or more. The compact remnants (neutron star or black hole) contains only the central core of the star with a mass only a few times more than the Sun. The time required for massive stars to evolve into supernovae is less than a billion years, and only about one million years for the most massive stars (with 50 to 100 or more times the mass of the Sun).

Another kind of supernova, one resulting from an exploding white dwarf, is also possible. It leaves no compact remnant, only the expanding gas cloud supernova remnant.

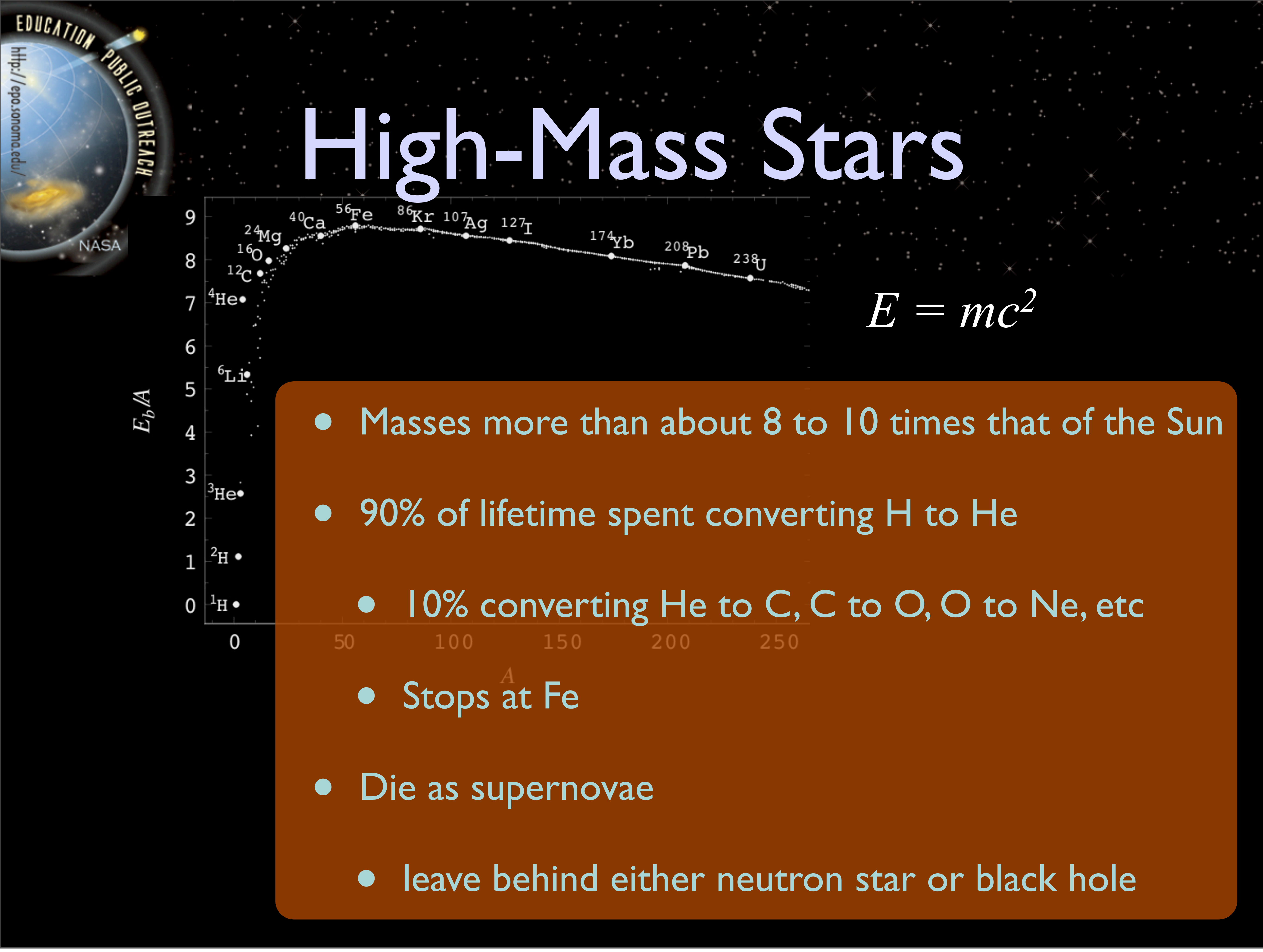
Low-Mass Stars

- Masses less than about twice that of the Sun
- 90% of lifetime spent converting H to He
  - 10% converting He to C
- Die as planetary nebula and white dwarf



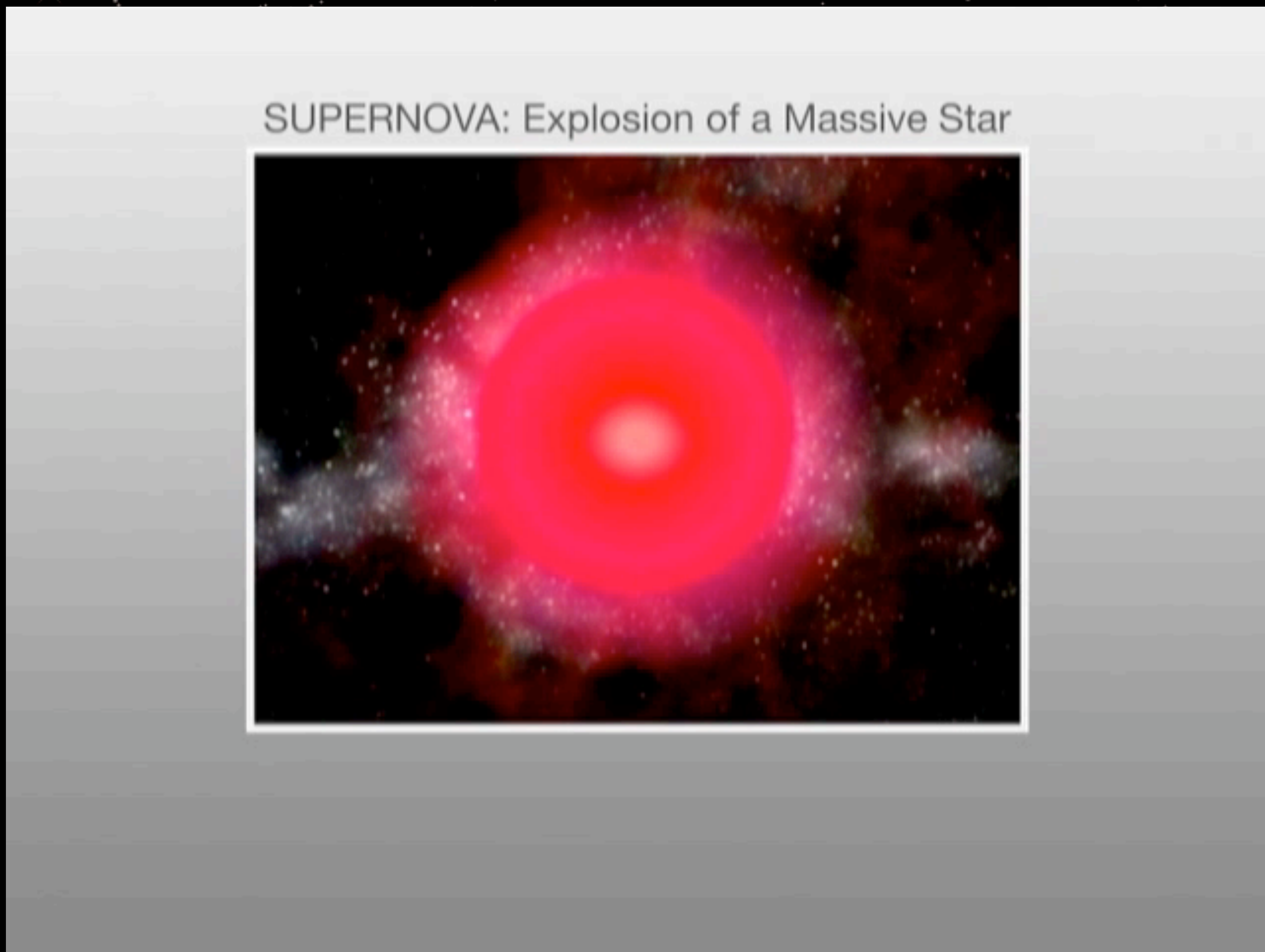
Planetary Nebula M2-9
Hubble Space Telescope • WFPC2

PRC97-38a • ST ScI OPO • December 17, 1997 • B. Balick (University of Washington) and NASA



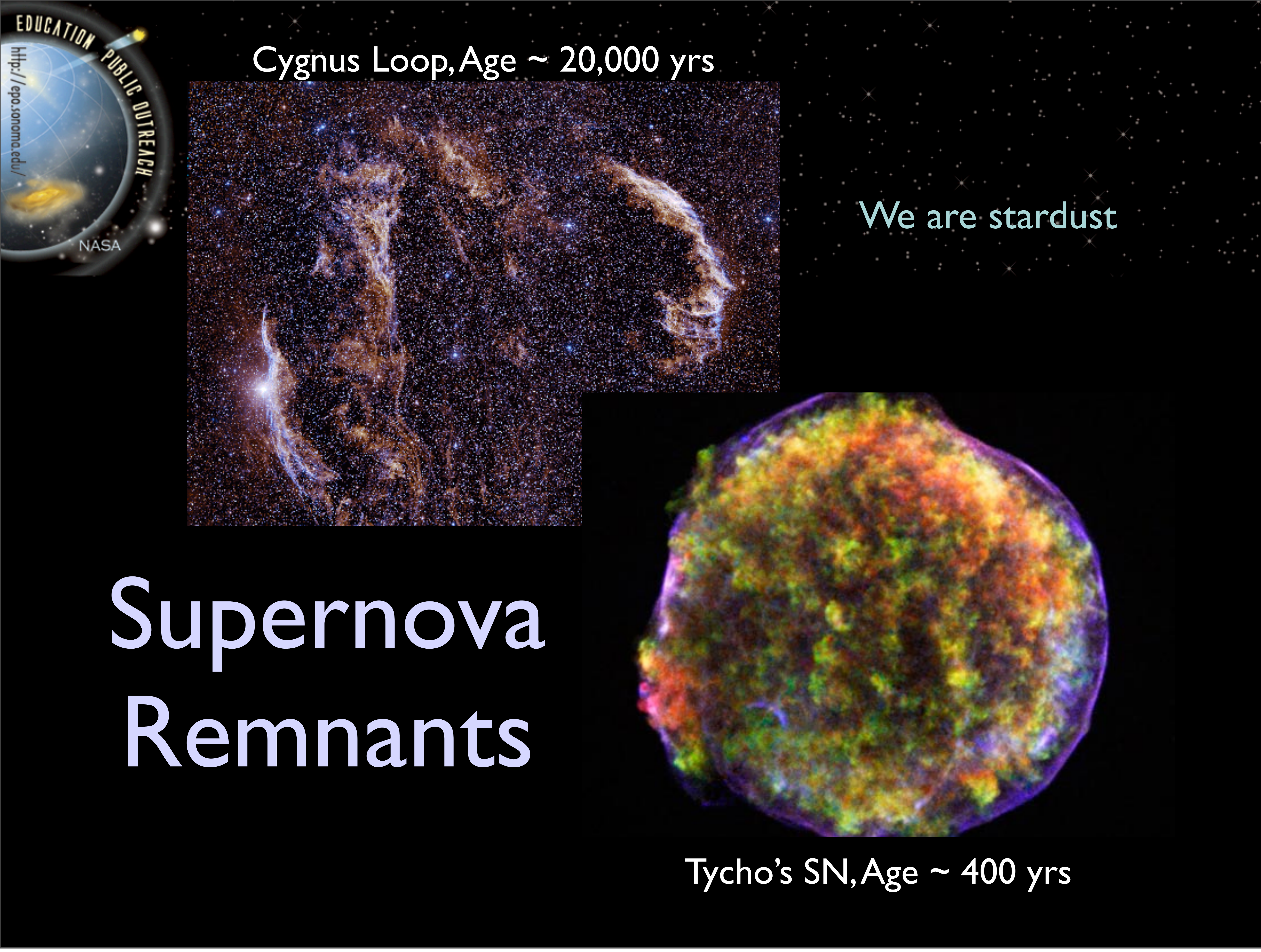
The slide shows the curve of binding energy. It is a plot of the binding energy per nucleon for each atomic nuclide. Stars maintain stability by converting light elements into heavier one, thereby releasing some of the binding energy (mass) and maintaining a high core temperature and pressure. When one type of element is exhausted in the core, the core contracts and heats up, and the next heavier element begins to burn (assuming the star has enough mass to raise temperatures high enough). This strategy can only work up to iron. Iron (Fe^{56}) has the highest binding energy per nucleon of any nucleus, so if Fe^{56} is burned, the core actually cools, leading to a catastrophic loss of thermal pressure and collapse.

Supernova!



This video depicts the inner structure of a red giant star. The outer parts are composed of hydrogen. Within the core, there will be an outer layer of hydrogen burning to helium, within that a layer of helium burning to carbon. Within that, a layer of carbon burning to oxygen, etc. As the center of the star is approached, heavier and heavier elements are fused as the temperature rises. In the most massive stars, beyond 8 to 10 solar masses, central core temperatures will be high enough to burn silicon into iron, and beyond, resulting in a supernova explosion.

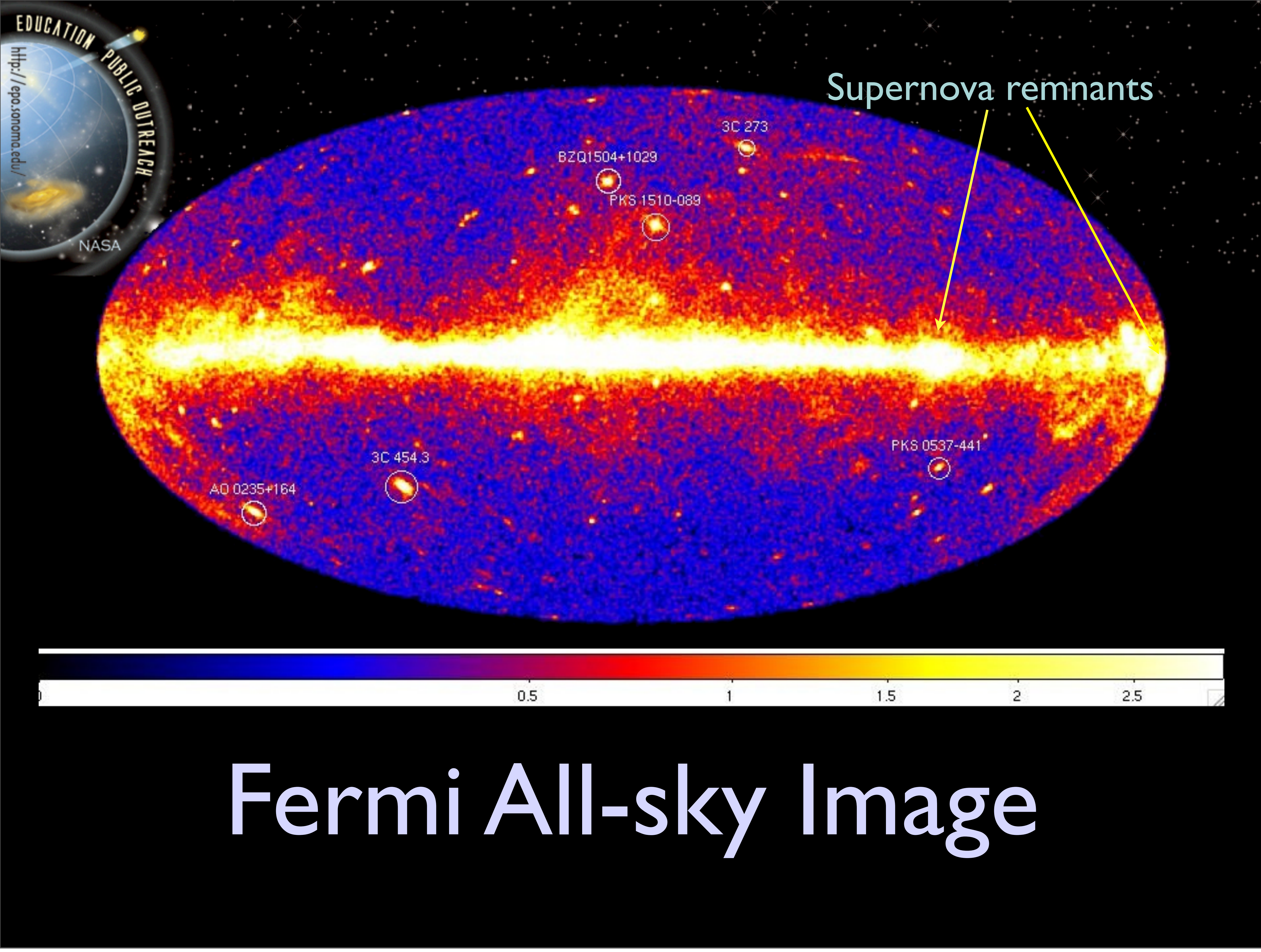
Though the total lifetime of these stars will be measured in millions of years, the time required for a star to convert its core silicon to iron and then collapse is only two or three days.



The top image shows the Cygnus loop in optical light. This is an old supernova remnant. An x-ray image of the remnant would show a bubble of hot gas inside the shocked gas visible in this image.

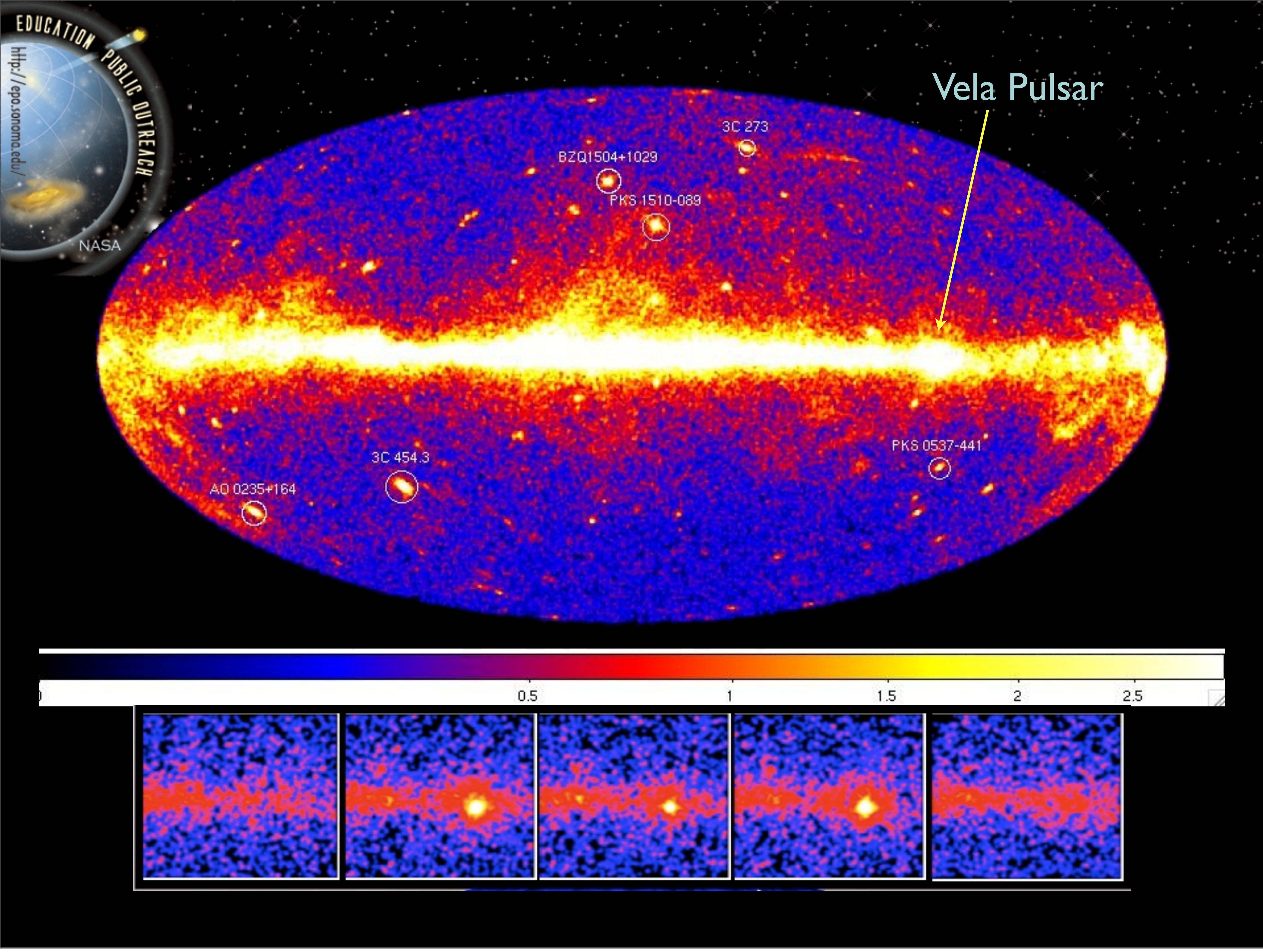
The lower image is an x-ray image made by the Chandra X-ray Observatory. It is Tycho's supernova, which was observed by Tycho Brahe near the end of the 16th century (1572). An optical image does not show the remnant at all because of intervening dust clouds that block visible light.

Both images illustrate how the heavy-element rich stellar interior is blasted out into surrounding space after a supernova. This is how elements such as silicon, oxygen, nitrogen, etc are made available to be incorporated into subsequent star (and planet) formation.



This slide shows the gamma ray sky as seen by the Fermi Gamma-ray Space Telescope. The bright horizontal band is the plane of the Milky Way. The labeled objects off of the Galactic plane are active galactic nuclei. The arrows show two supernova remnants within our galaxy.

After clicking, the slide will show the Vela Pulsar, a rapidly spinning, strongly magnetic neutron star that was formed when the star that formed the Vela supernova remnant collapsed. Also indicated is the Crab Nebula. The following slide highlights the Crab pulsar.



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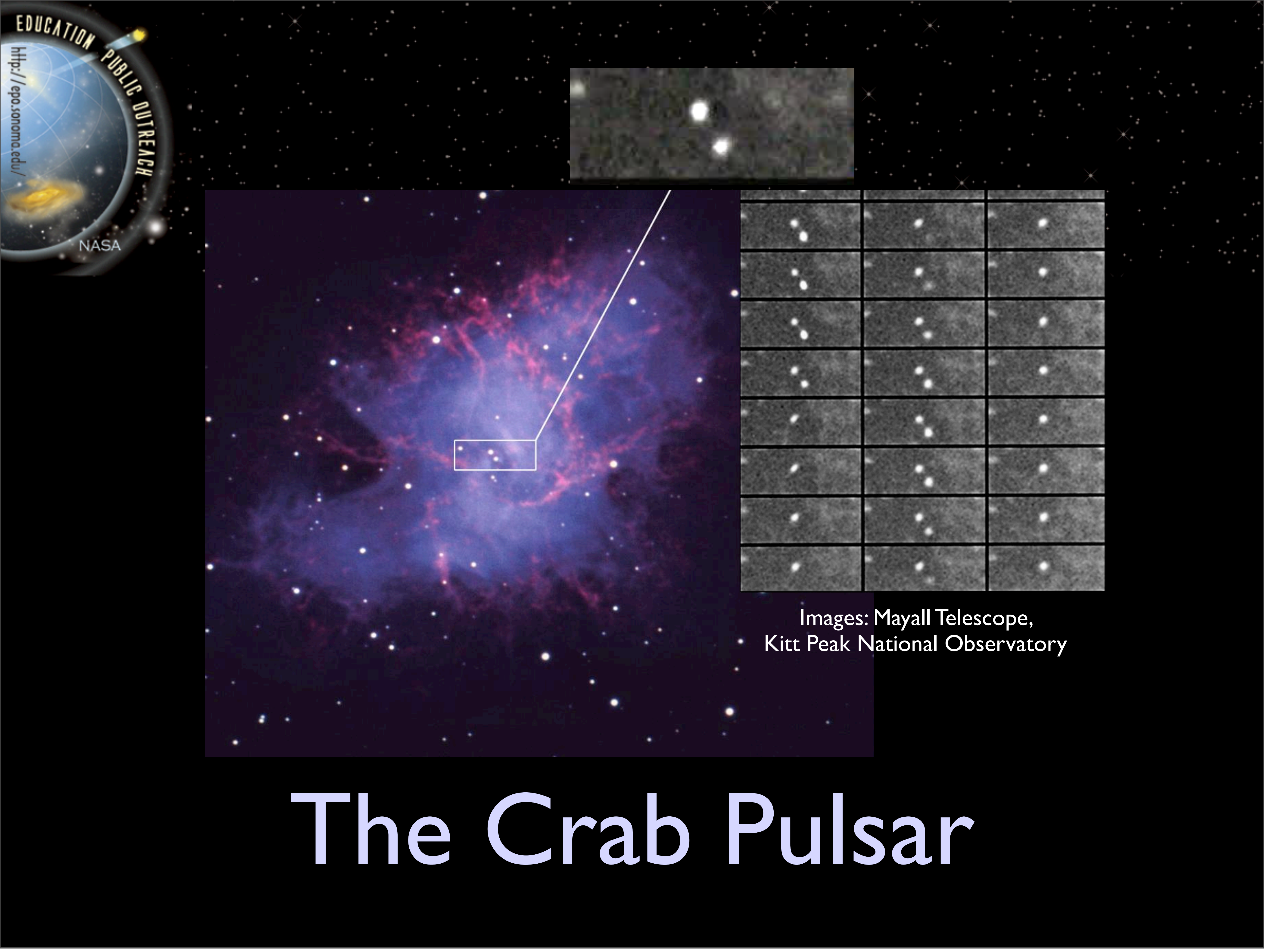
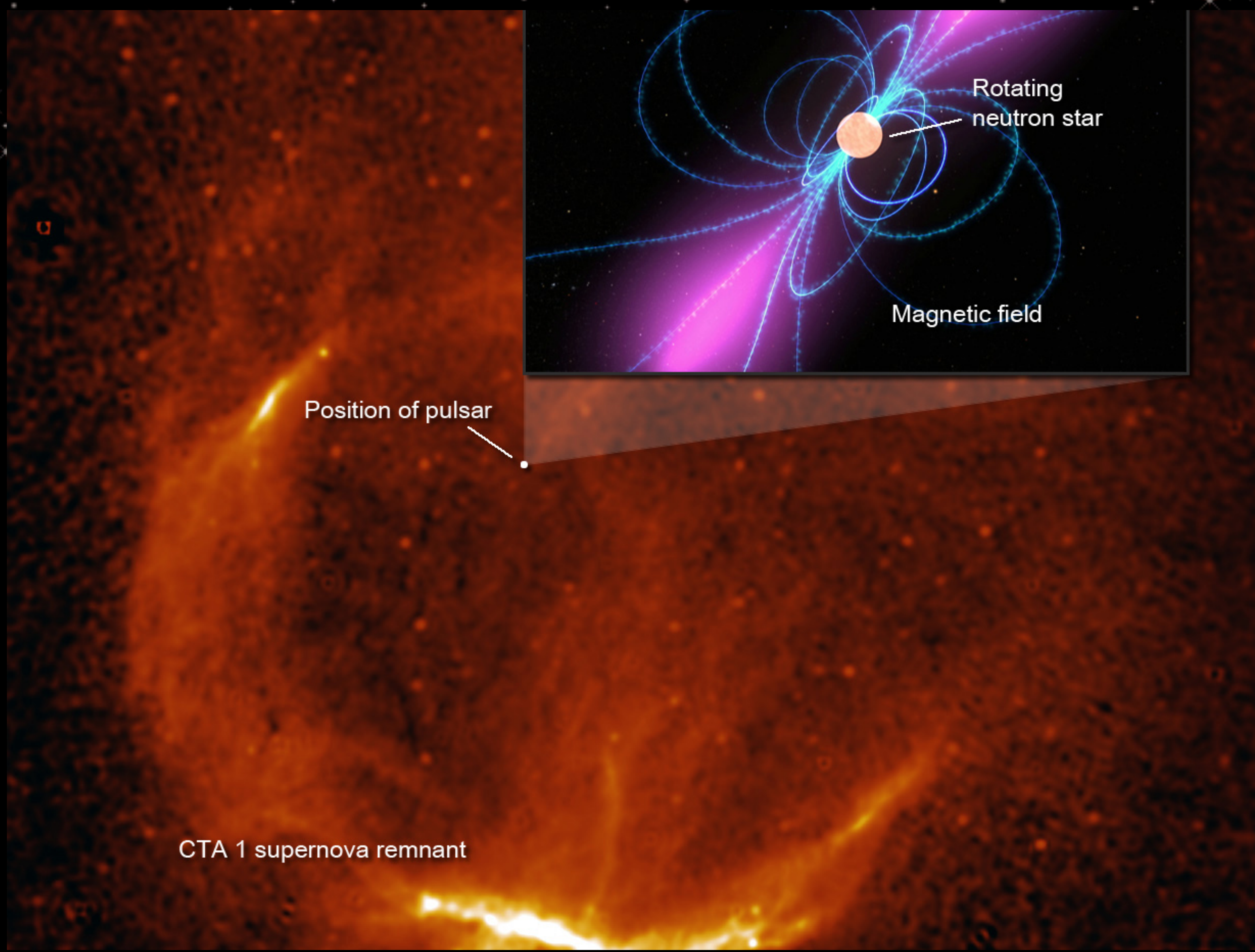


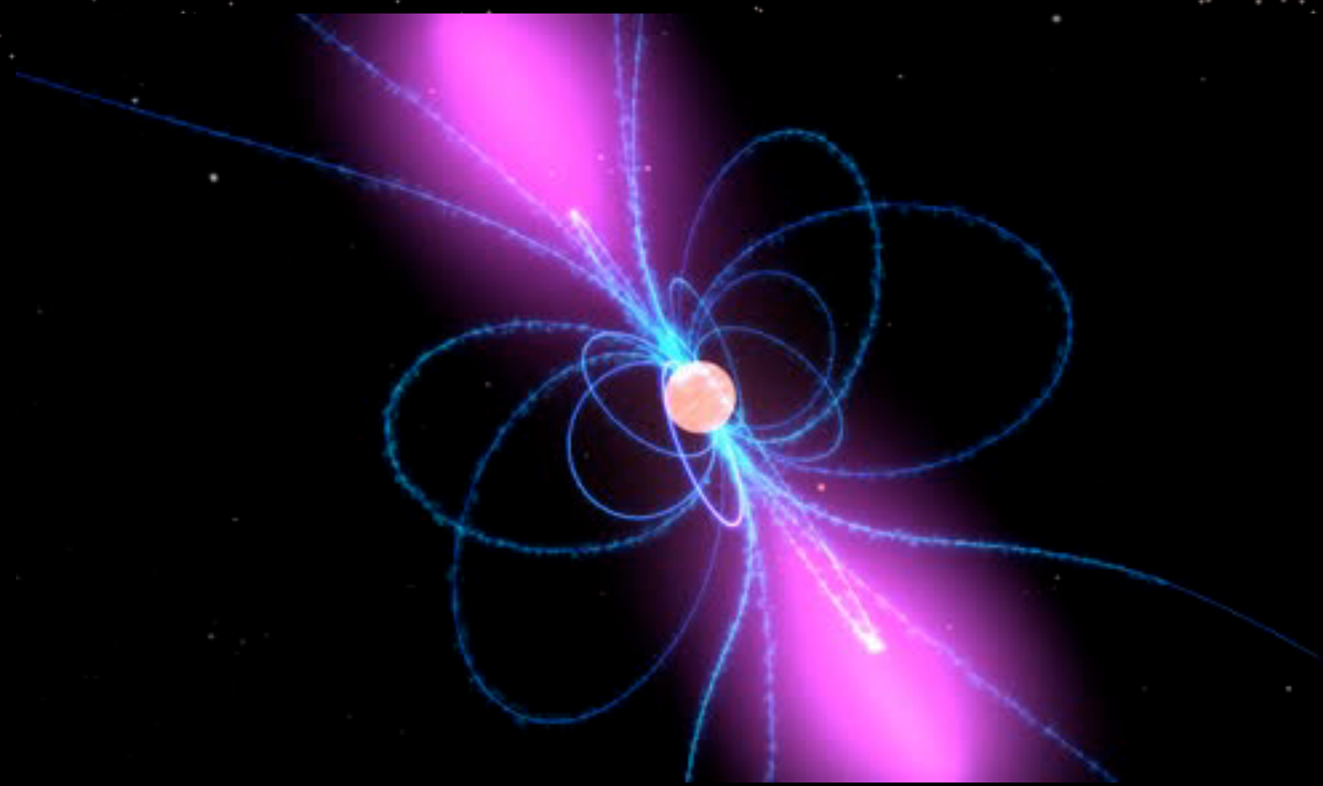
This slide shows the Crab nebula and pulsar. These are remnants of a historical supernova that is the subject of one of the activities in this Supernova Educator Guide. The panels to the right of the nebula show the pulsar blinking on and off. The same panels have been compiled into an animation that plays near the top of the slide. The panels are separated by roughly 1 millisecond intervals.

Fermi Discovery



Gamma-ray Pulsar

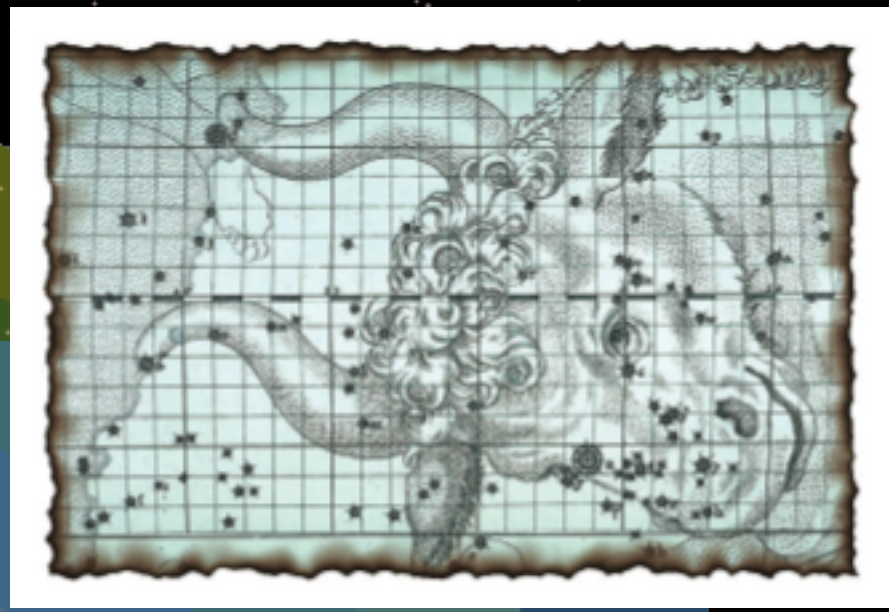
This image is a Fermi Gamma-ray Space Telescope image of a previously known supernova remnant. What makes it interesting is the presence of the pulsar within the remnant. This pulsar was unknown until Fermi imaged the region. It is the first pulsar found that pulses only in gamma rays. Other pulsars are known to pulse only in x-rays, and most pulse across the EM spectrum from radio to x- and gamma-rays (the crab is an example of the latter).



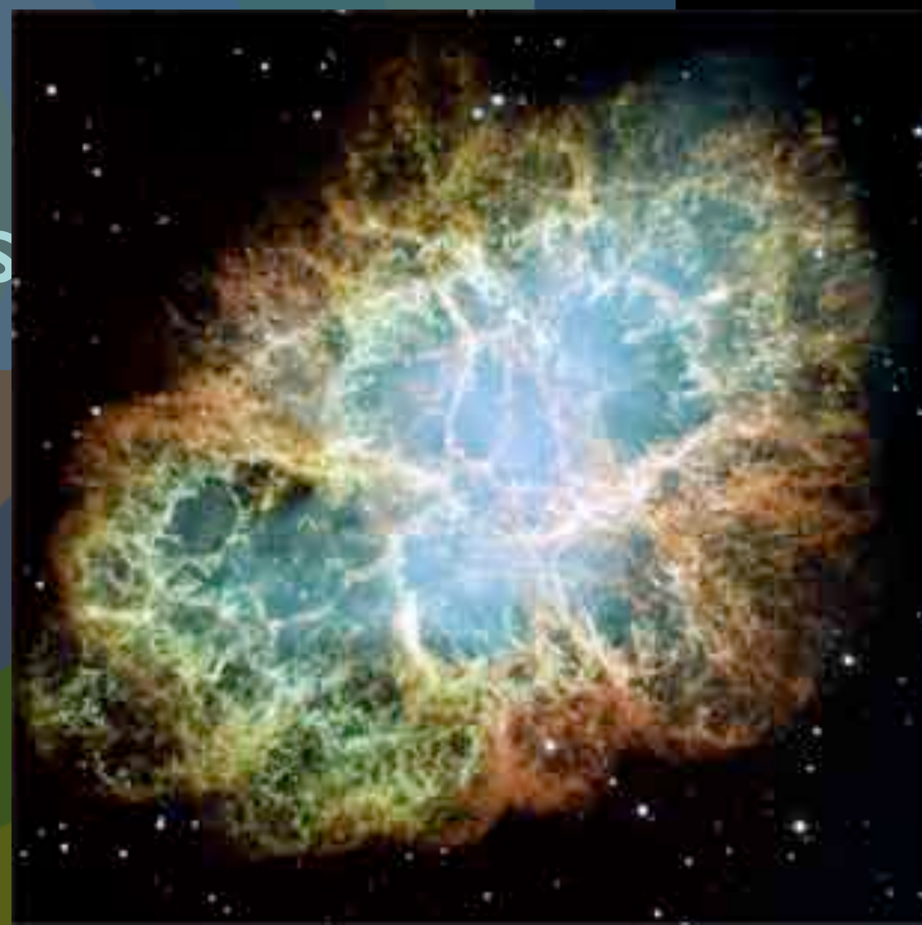
Lighthouse Model

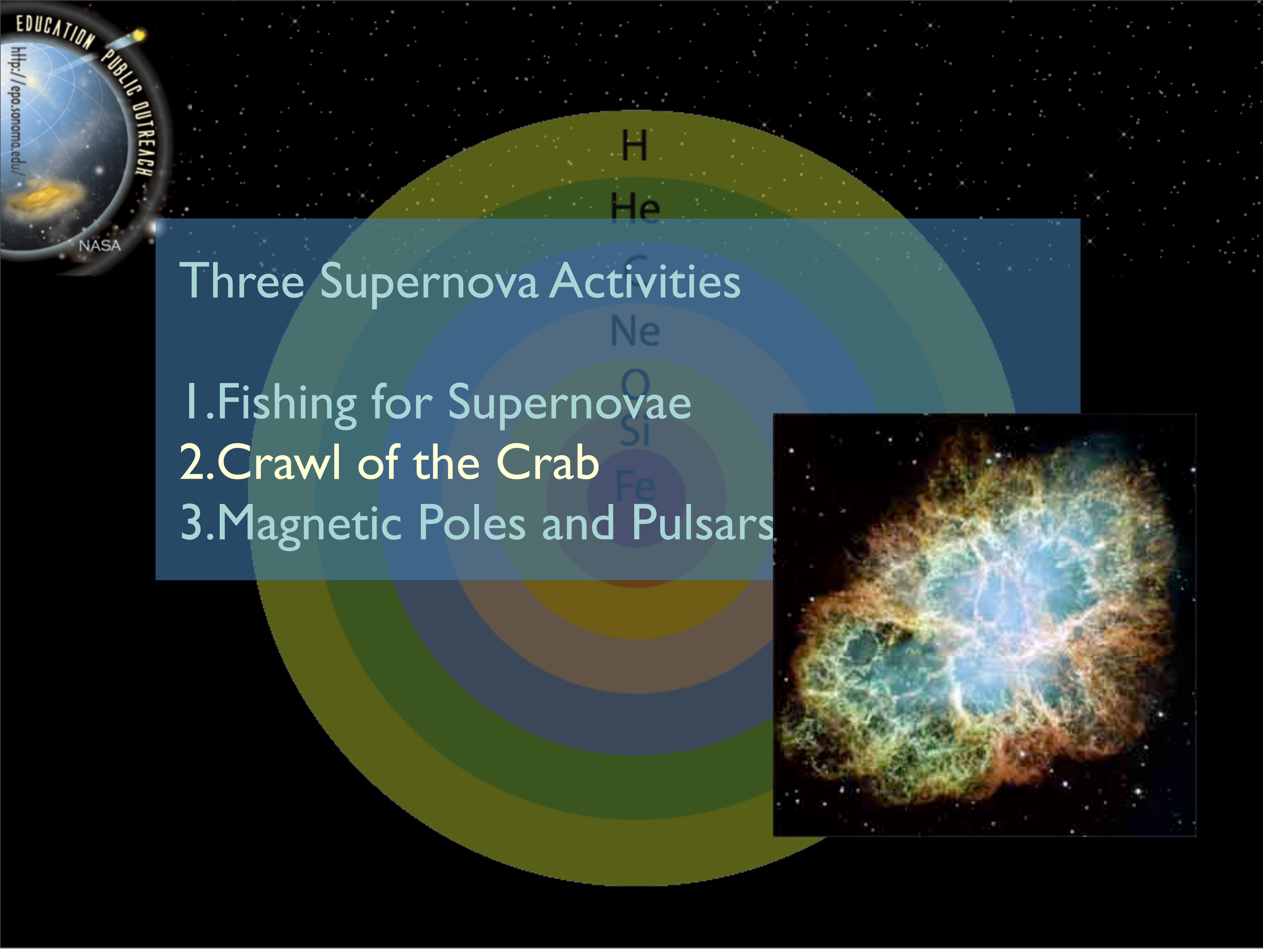
This animation illustrates the light-house model of pulsar emission. It is the model that explains how most pulsars produce pulses of radiation across the EM spectrum. However, it is not a good model for the gamm-ray only pulsar discovered by Fermi.

Three Supernova Activities



1. Fishing for Supernovae
2. Crawl of the Crab
3. Magnetic Poles and Pulsars

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Three Supernova Activities
1.Fishing for Supernovae
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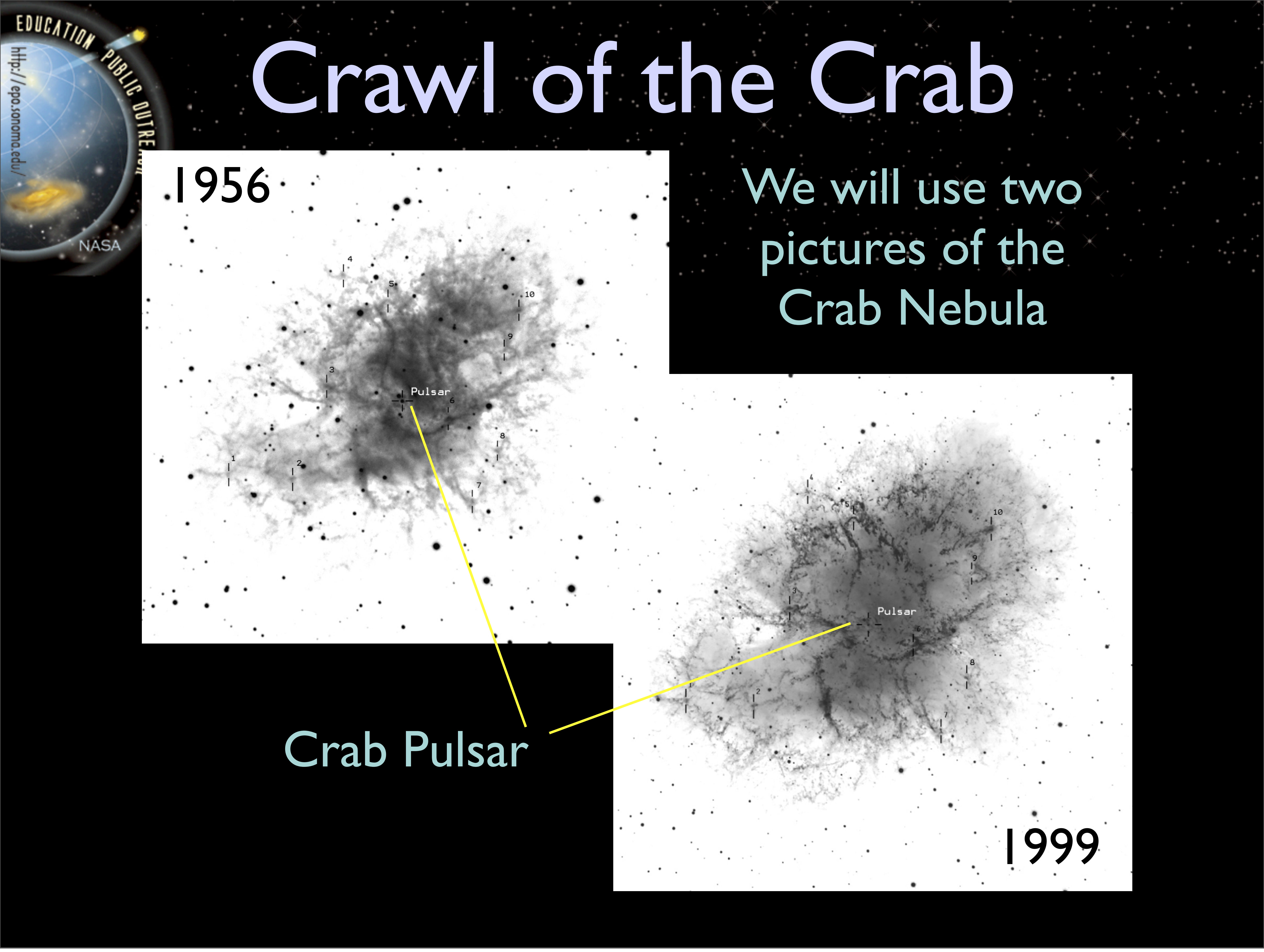
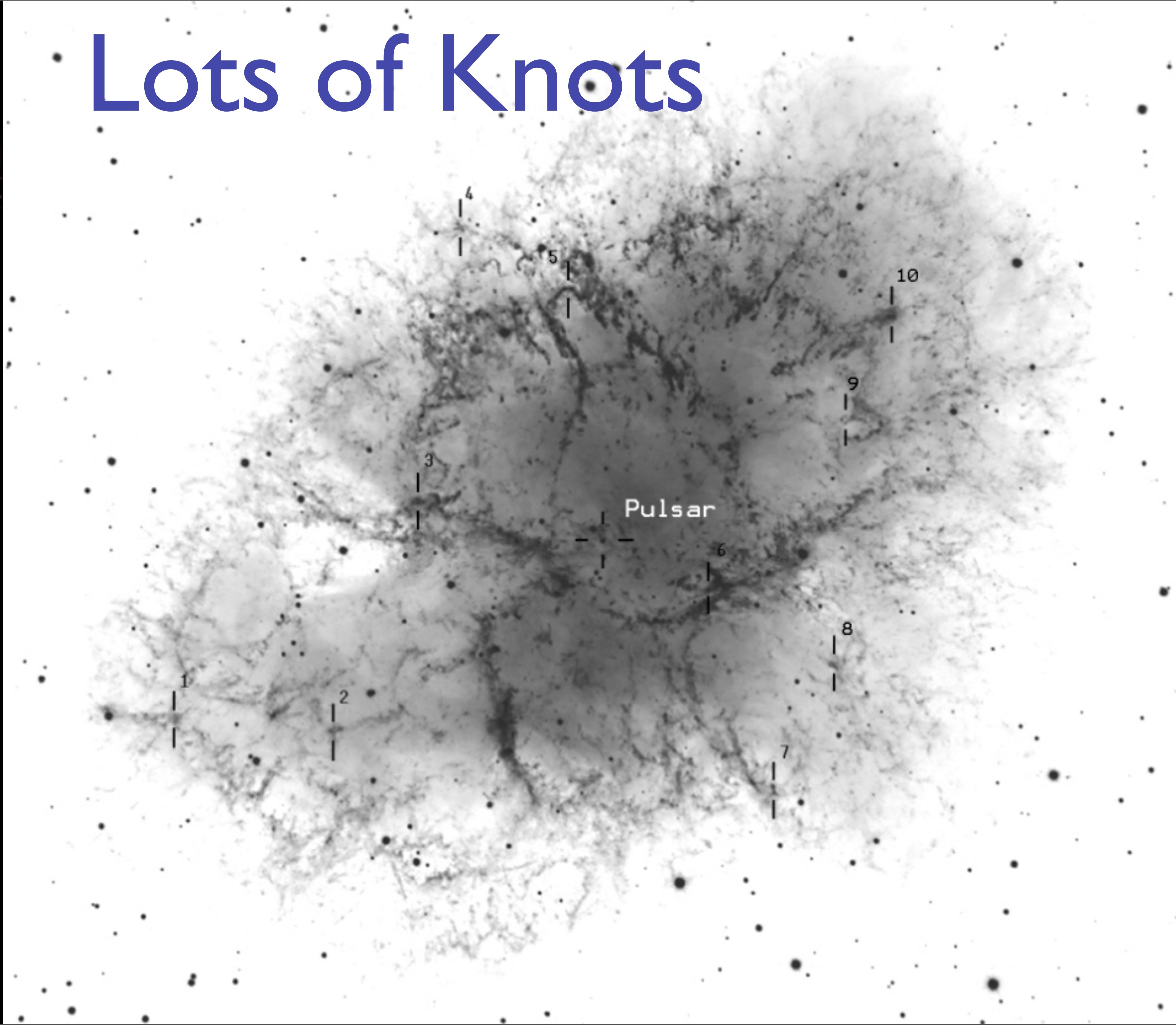
3.Magnetic Poles and Pulsars
H
He
C
Ne
O
Si
Fe



These two images, taken several decades apart, show the expansion of the crab nebula. They are included in the exercise to be completed by students.

Lots of Knots



The labeled knots are common to both images. They should be used to measure the amount of expansion between the two images.

Measuring Expansion Gives Age

1. Assume pulsar remains at center of nebula
2. Assume the knots move over time at constant speed
3. Using both images we can measure the rate of expansion
4. Compare rate to size, we have the age

$$v = \frac{d}{t}$$

So let's get started!

Representative Answers

- The answer you get will depend somewhat upon how you measure the knots
  - There is no single right answer (within reason)
- When I do the exercise I get an age of about 833 years, so an explosion date of 1999 - 833 = 1166
  - The actual explosion was seen in 1054

The numbers given here were obtained by SSU personnel using the online version of the Crawl of the Crab exercise. Different people will get slightly different answers because they will have small differences in the way they measure the position of the knots. There is no single correct answer here, but an age around 900 years should be obtainable if the measurements are done carefully.

Related Science Standards

	Activity I, Grades 7 - 8 Fishing for Supernovae	Activity 2, Grades 9 - 12 The Crawl of the Crab	Activity 3, Grades 9 - 12 Magnetic Poles and Pulsars	Activity 4, Grades 8 - 12 Neutron Stars in the News
Science as Inquiry		•Abilities of technological design •Understanding about scientific inquiry	•Abilities of technological design •Understanding about scientific inquiry	•Abilities necessary to do science •Understanding about scientific inquiry
Physical Science	•Properties/Changes in properties of matter	•Conservation of energy and increase in disorder	•Motion and forces •Interaction of energy and matter	
Earth/Space Science		•Origin and evolution of the universe	•Origin and evolution of the universe	
Science/ Technology	•Understanding about science and technology		•Abilities of technological design •Understanding about scientific inquiry	
History/Nature of Science	•Science as a human endeavor •Nature of science knowledge	•Science as a human endeavor •Nature of science knowledge	•Science as a human endeavor •Nature of science knowledge	•Science as a human endeavor •Nature of science knowledge

Mathematics Standards

	Activity 2: The Crawl of the Crab Grades 9 -12	Activity 3 Magnetic Poles and Pulsars Grades 9 - 12
Algebra	•Understand patterns, relations, functions •Represent and analyze mathematical situations and structures •Use mathematical models to represent and understand quantitative relationships	
Geometry	•Specify locations and describe spatial relationships using coordinate geometry and other representational systems •Use visualization, spatial reasoning and geometric modeling to solve problems	•Specify locations and describe spatial relationships using coordinate geometry and other representational systems •Use visualization, spatial reasoning and geometric modeling to solve problems
Measurement	•Understand measurable attribute of objects and the unites, systems and processes of measurement •Apply appropriate techniques, tools and formulas to determine measurements	•Understand measurable attribute of objects and the unites, systems and processes of measurement •Apply appropriate techniques, tools and formulas to determine measurements
Data Analysis and Probability	•Formulate questions that can be addressed with data and collect, organize and display relevant data to answer them •Select and use appropriate statistical methods to analyze data •Develop and evaluate inferences and predictions that are based on data	•Develop and evaluate inferences and predictions that are based on data
Communication	•Organize and consolidate their mathematical thinking through communication •Communicate their mathematical thinking coherently and clearly to peers, teachers and others	•Organize and consolidate their mathematical thinking through communication •Communicate their mathematical thinking coherently and clearly to peers, teachers and others
Connections	•Recognize and use connections among mathematical ideas •Recognize and apply mathematics in contexts outside of mathematics	•Recognize and use connections among mathematical ideas •Recognize and apply mathematics in contexts outside of mathematics
Representation	•Create and use representations to organize, record and communicate mathematical ideas •Select, apply and translate among mathematical representations to solve problems •Use representations to model and interpret physical, cocial and mathematical phenomena	•Create and use representations to organize, record and communicate mathematical ideas •Select, apply and translate among mathematical representations to solve problems •Use representations to model and interpret physical, cocial and mathematical phenomena

Resources

XMM-Newton Websites:

http://xmm.sonoma.edu

Fermi Websites:

http://fermi.sonoma.edu/

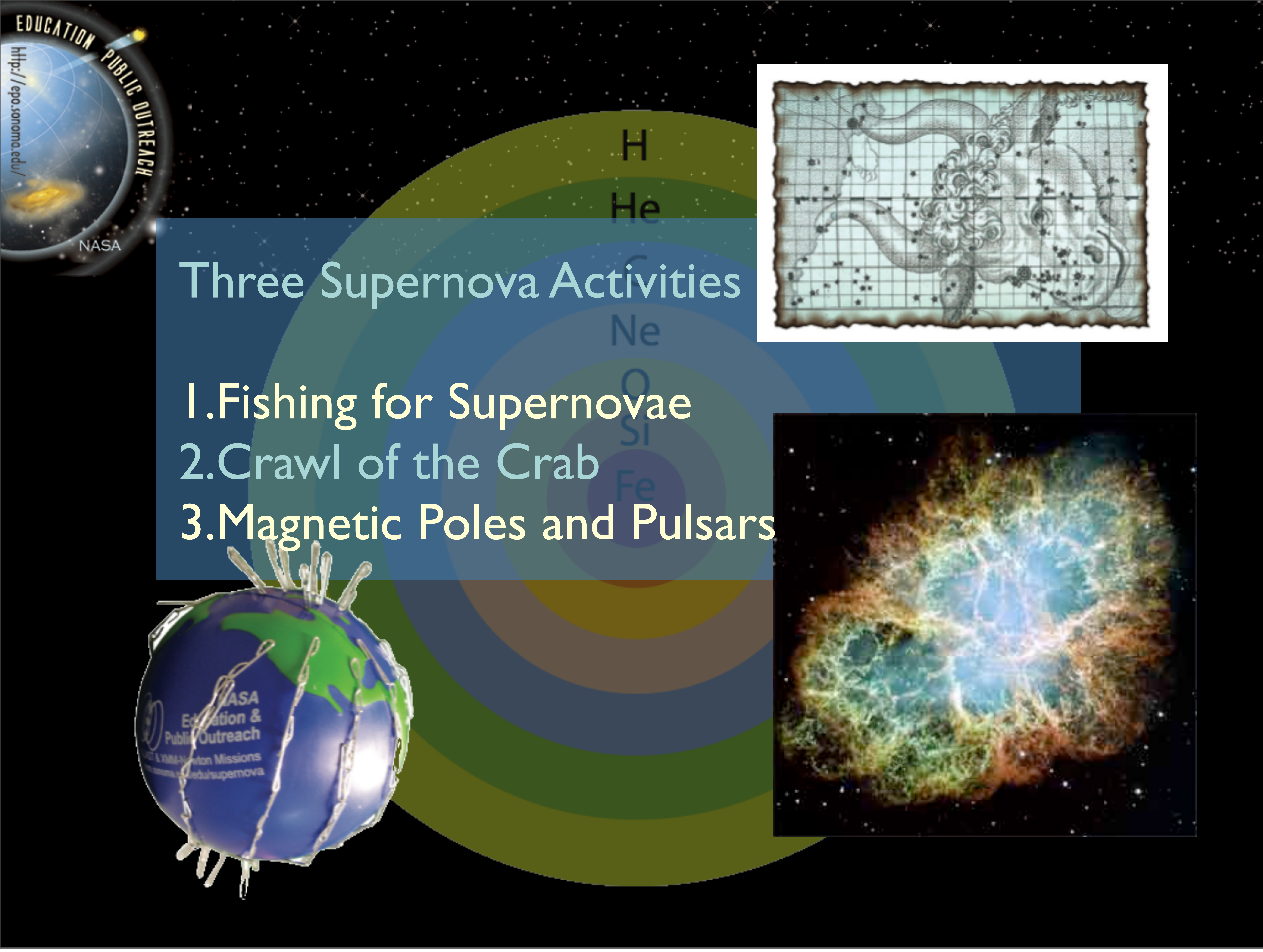
http://nasa.gov/fermi

Supernova Website:

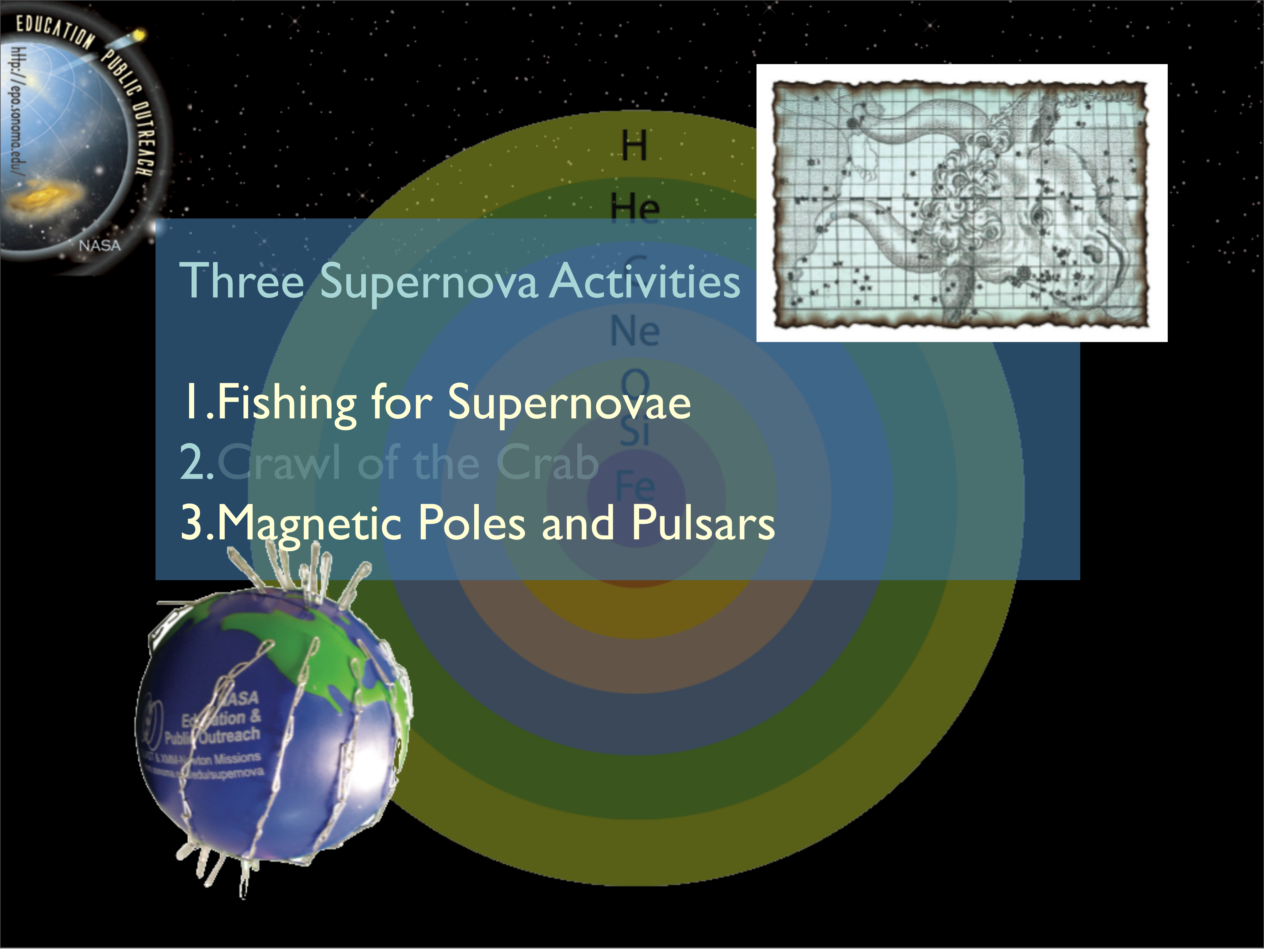
http://imagine.gsfc.nasa.gov/docs/science/know_l2/supernovae.html

http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/snovcn.html

These are links to additional resources. The top two contain materials on XMM-Newton and Fermi, as well as additional educational products sponsored by these missions. The bottom two links will allow you to learn more general information about supernovae.



In addition to Crawl of the Crab, the Supernova Educator Guide contains three additional activities. The two shown here are Fishing for Supernovae, a card game for elementary level students that allows them to collect "books" of supernova images taken in different kinds of light (x-ray, visible, radio, etc). The other, Magnetic Poles and Pulsars, is an exploration of magnetism in household objects and in stars and planets. A fourth activity, not shown here, is a science reading/literacy exercise. Students read a news article about a discovery made by the XMM-Newton telescope and answer questions about the discovery.



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The Next Supernova?

The images show the sky toward the constellation Orion. Orion is an area of active star formation. It therefore contains many massive stars. The Orion Nebula and the Belt in particular have very massive stars. The region is likely to produce many supernovae in the next million years or so... maybe even tomorrow, so look up!

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Please fill out your assessment forms now.

Thank You!