Hot Science Cool Talks

UT Environmental Science Institute

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Exploding Stars in an Accelerating Universe

Dr. J. Craig Wheeler

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Exploding Stars in an Accelerating Universe

MCDONALD OBSERVATORY
AND
DEPARTMENT OF ASTRONOMY
BOARD OF VISITORS

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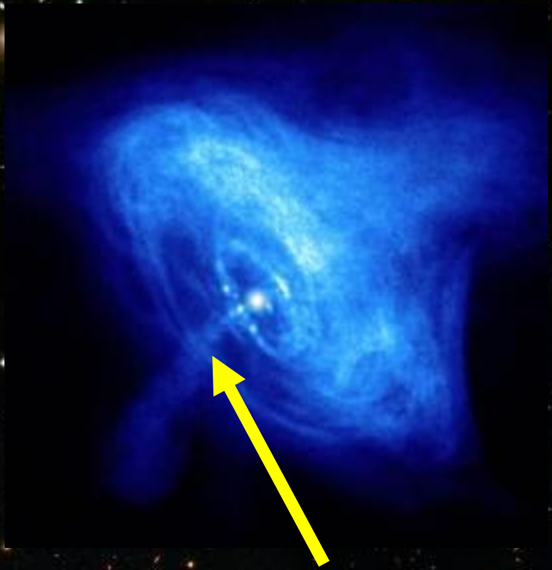
Supernovae

- Catastrophic explosions that end the lives of stars
- Provide the heavy elements on which planets and life as we know it depends
- Energize the interstellar gas to form new stars
- Produce exotic compact objects, neutron stars and black holes
- Provide yardsticks to measure the history and fate of the Universe

Crab Nebula

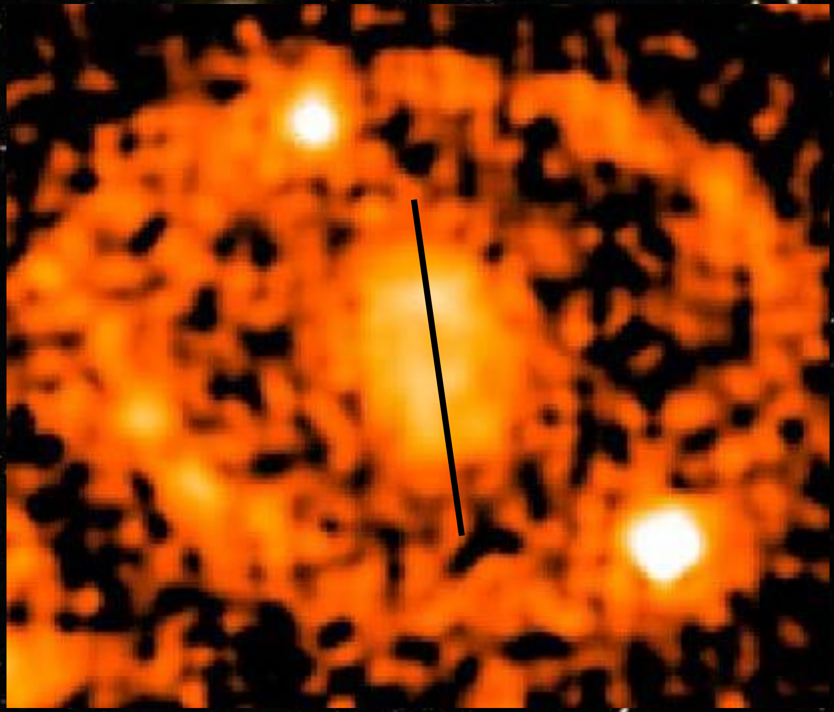
Chandra Optical Image

Chandra X-Ray Image

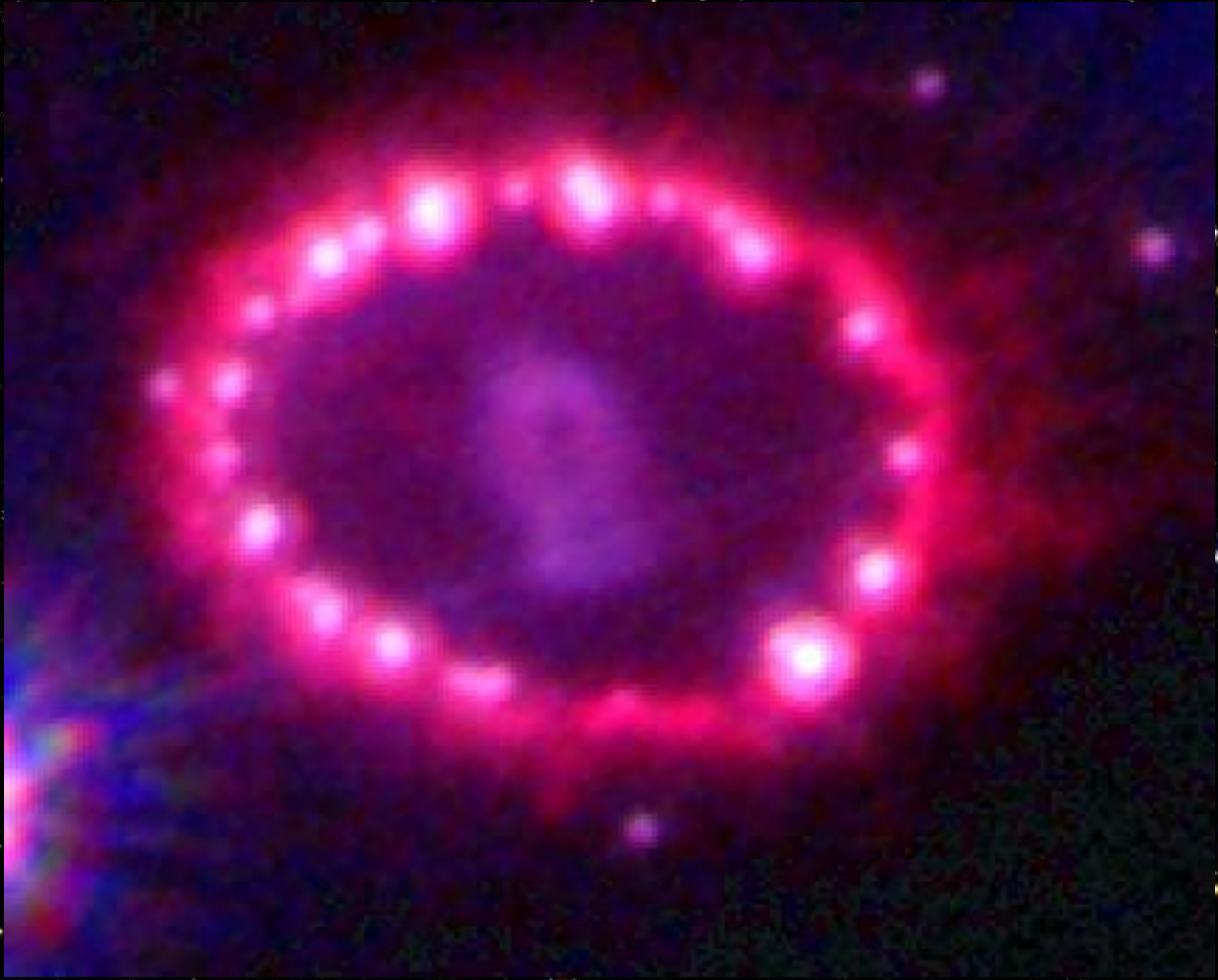


Supernova
(SN 1987A)

Elongated debris

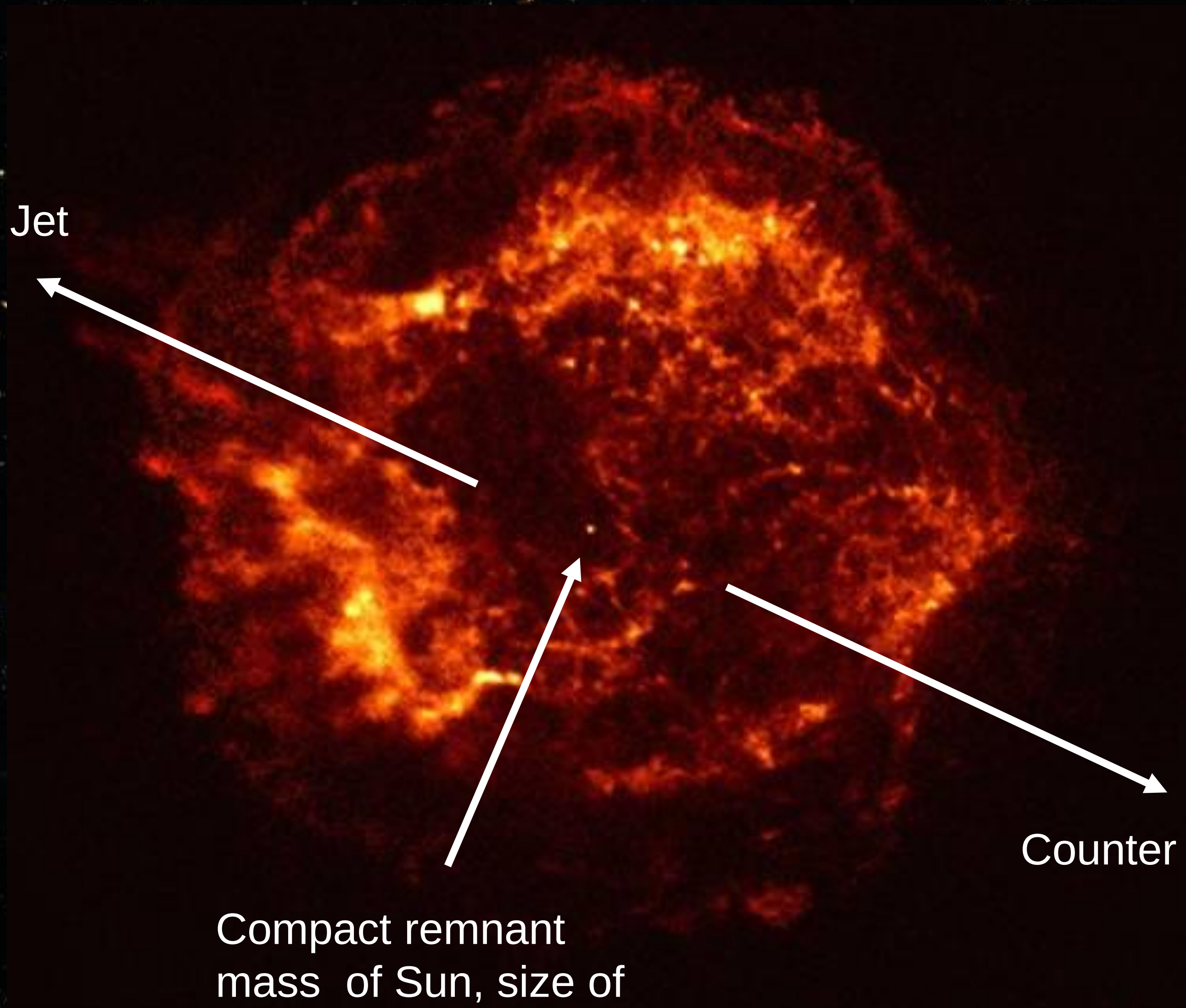


Bi-polar symmetry

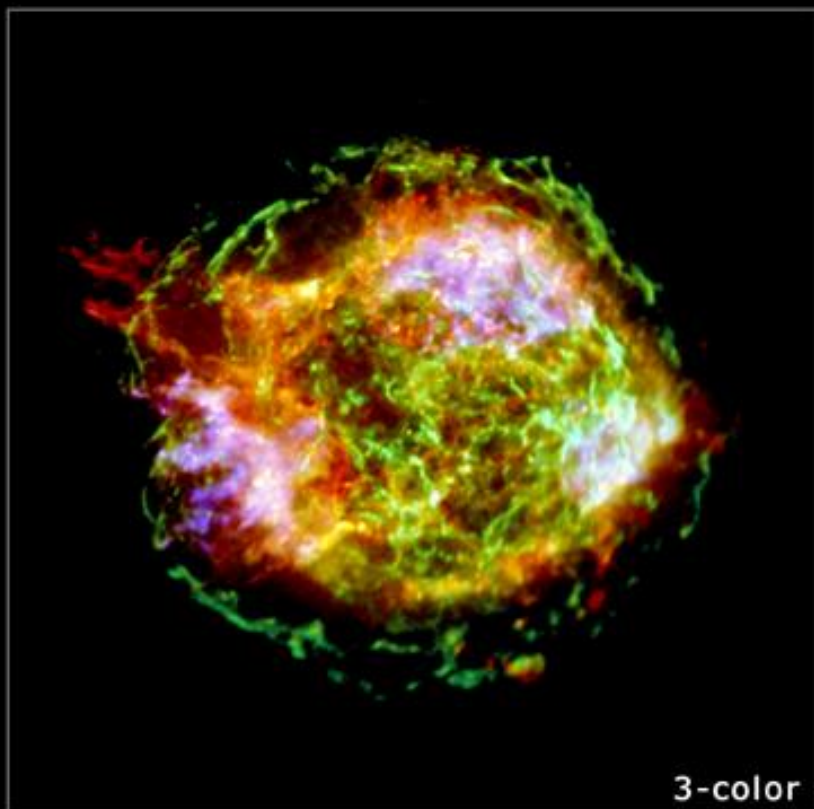


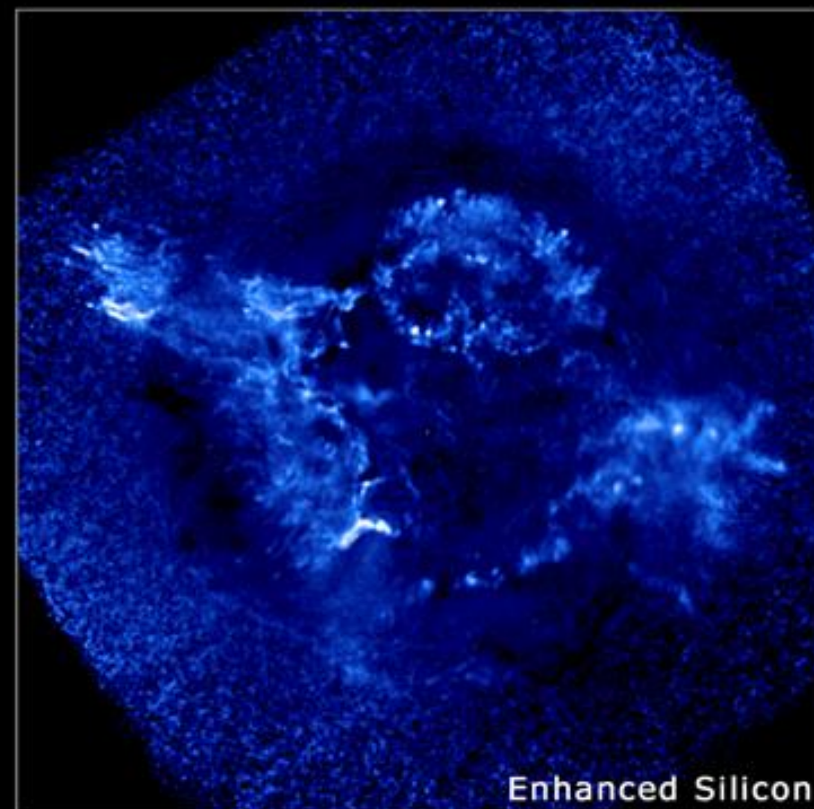
SN 1987A
SINS
Kirshner et al. 2003

Cassiopeia A by Chandra



Recent Chandra Observatory X-ray Image of Cassiopeia A



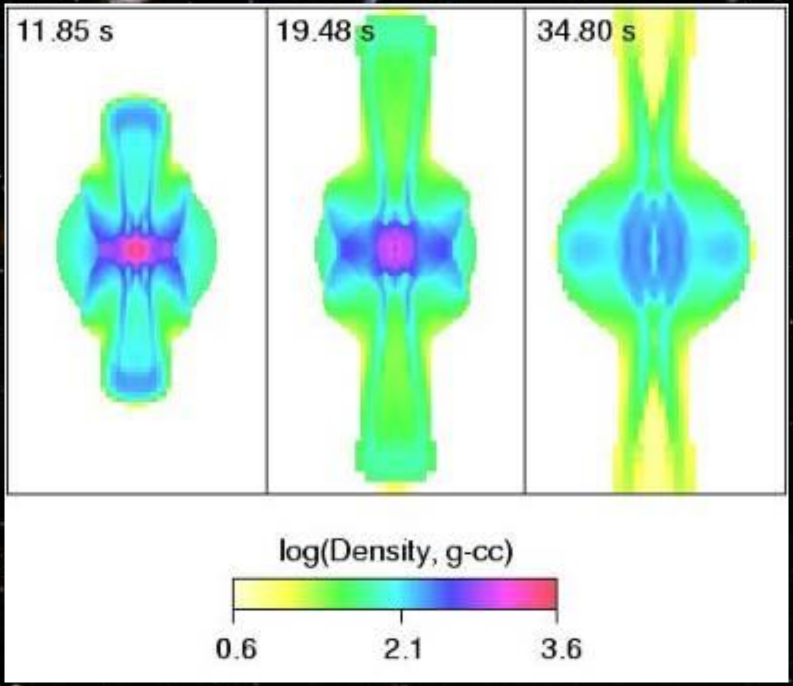


One type of supernova is powered by the collapse of the core of a massive star to produce

a neutron star, or perhaps a black hole

The mechanism of the explosion is still a mystery.

Observations begun at McDonald Observatory suggest that these explosions are powered by jets.

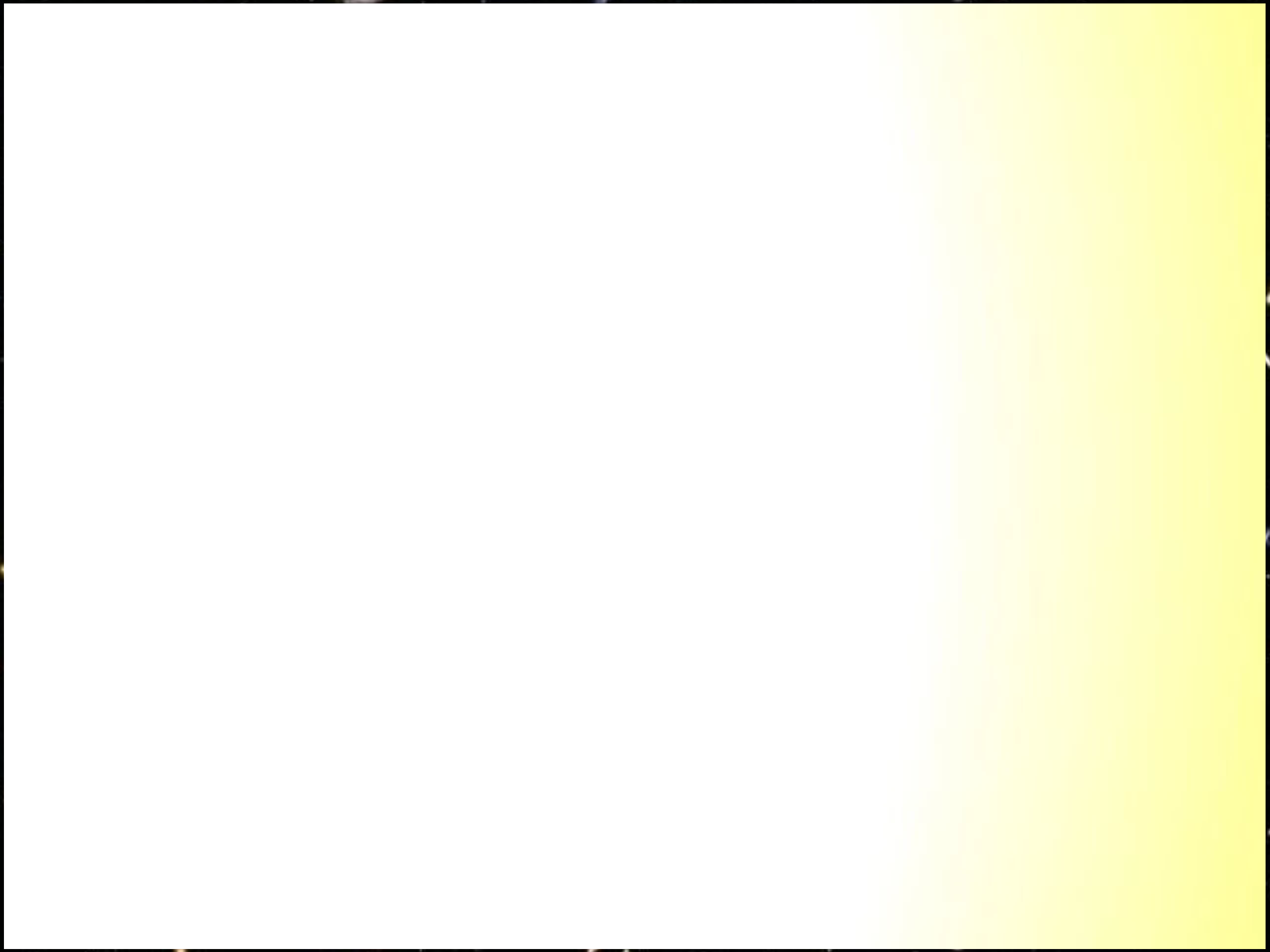


These supernovae may be related to gamma-ray bursts.

This is the first new idea to understand these supernovae in thirty years.

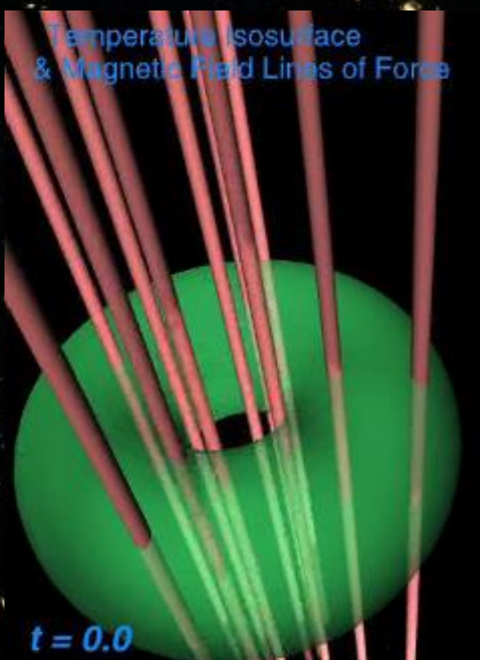
Khokhlov et al. 1999

Jet propagating through a Star

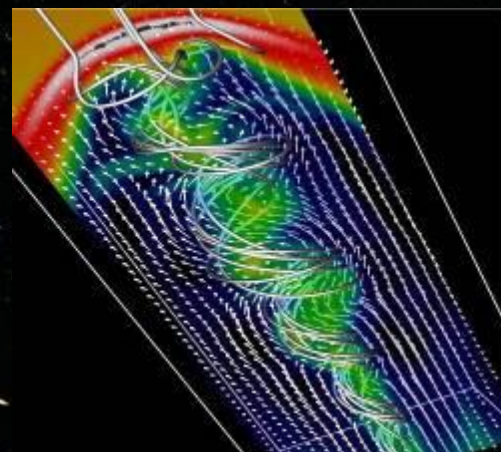


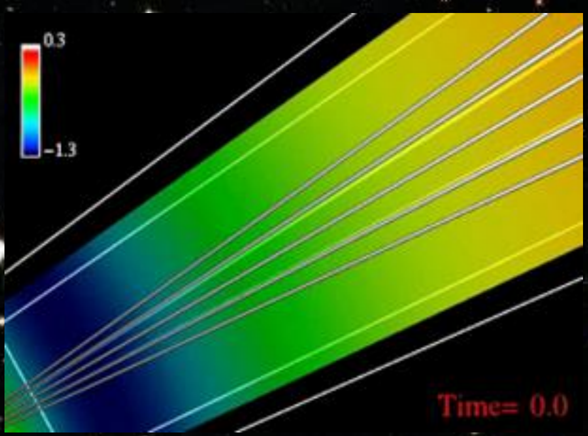
Weiqun Zhang & Stan Woosley, UC Santa Cruz

We are working on the theory of how to convert the rotation of the neutron star to coiled magnetic fields that launch the jet.



Uchida et al. 1999, Ap & SS, 264, 195-212





Nakamura et al. 2001, New Astronomy, 6, 61-78

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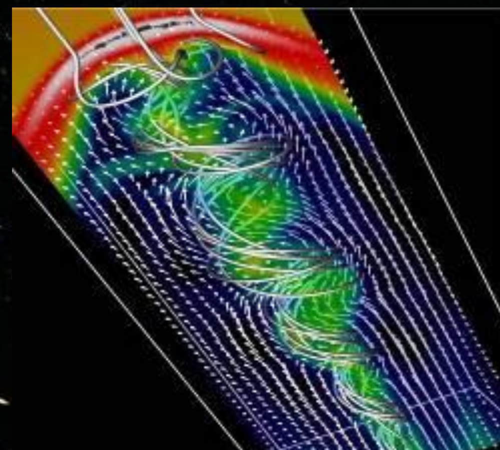

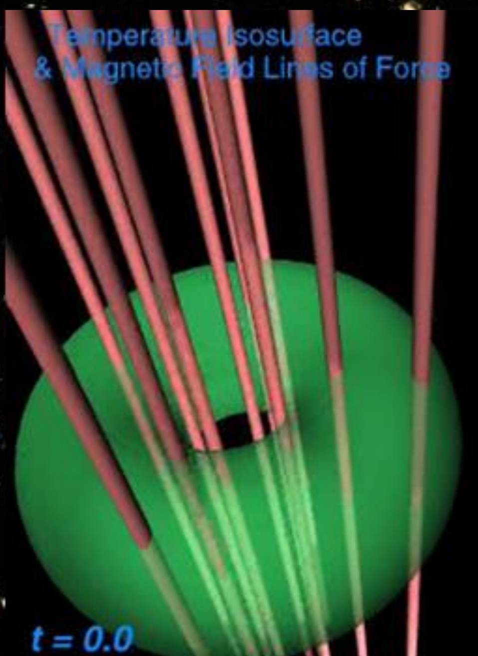

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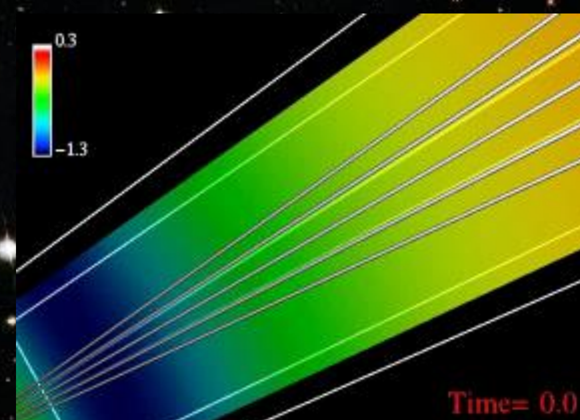

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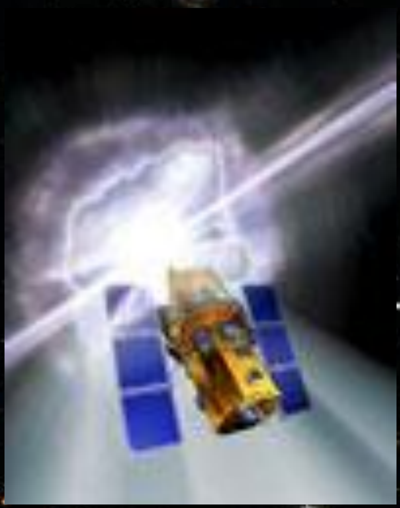
Jet Erupting Through Star

NASA

Gamma-Ray Bursts

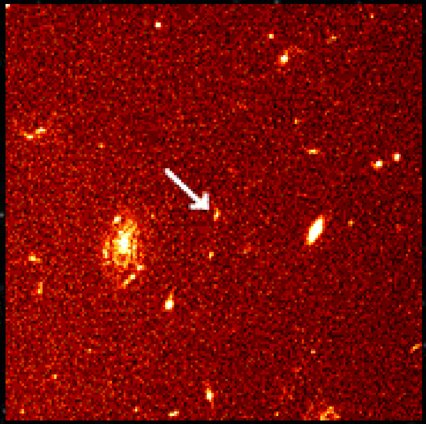
30-year Old Mystery



Swift Satellite

Cosmic explosions, flashes of gamma-rays lasting about 30 seconds, detected by satellites.

Seen across the Universe.

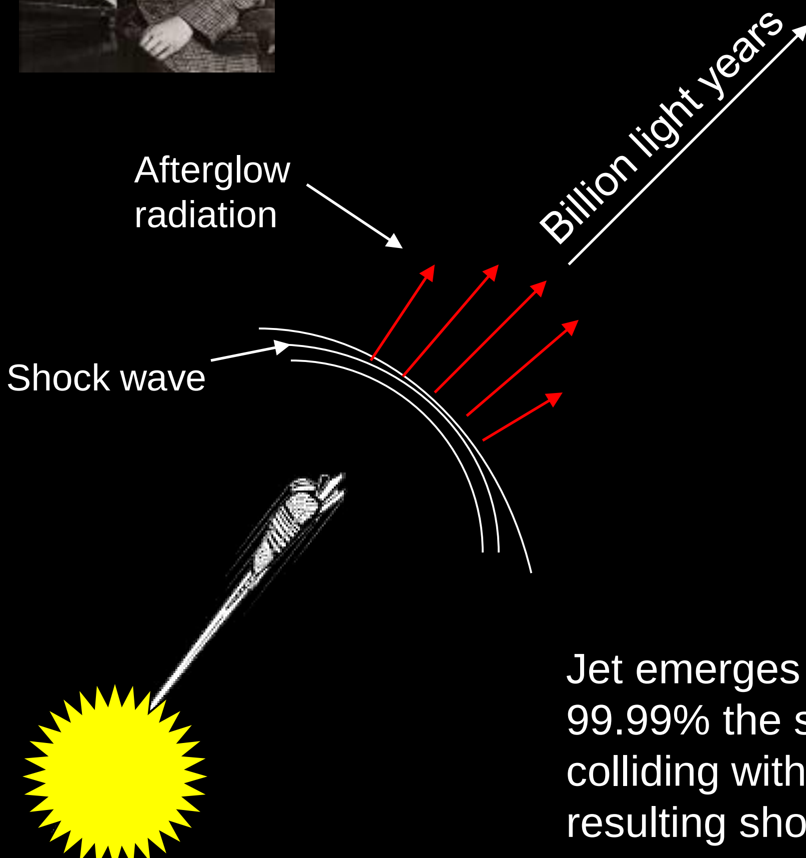


Energy is expelled in narrow jets.
Energy comparable to that of supernovae, but all in gamma-rays, with later afterglow in X-ray, radio and optical radiation.
Birth of a black hole?

Burst and Afterglow

Einstein's Special Relativity in Action

Deceleration takes months, but because shock chases its own light, we perceive a rapid speed-up of the process playing out in days through our telescopes.



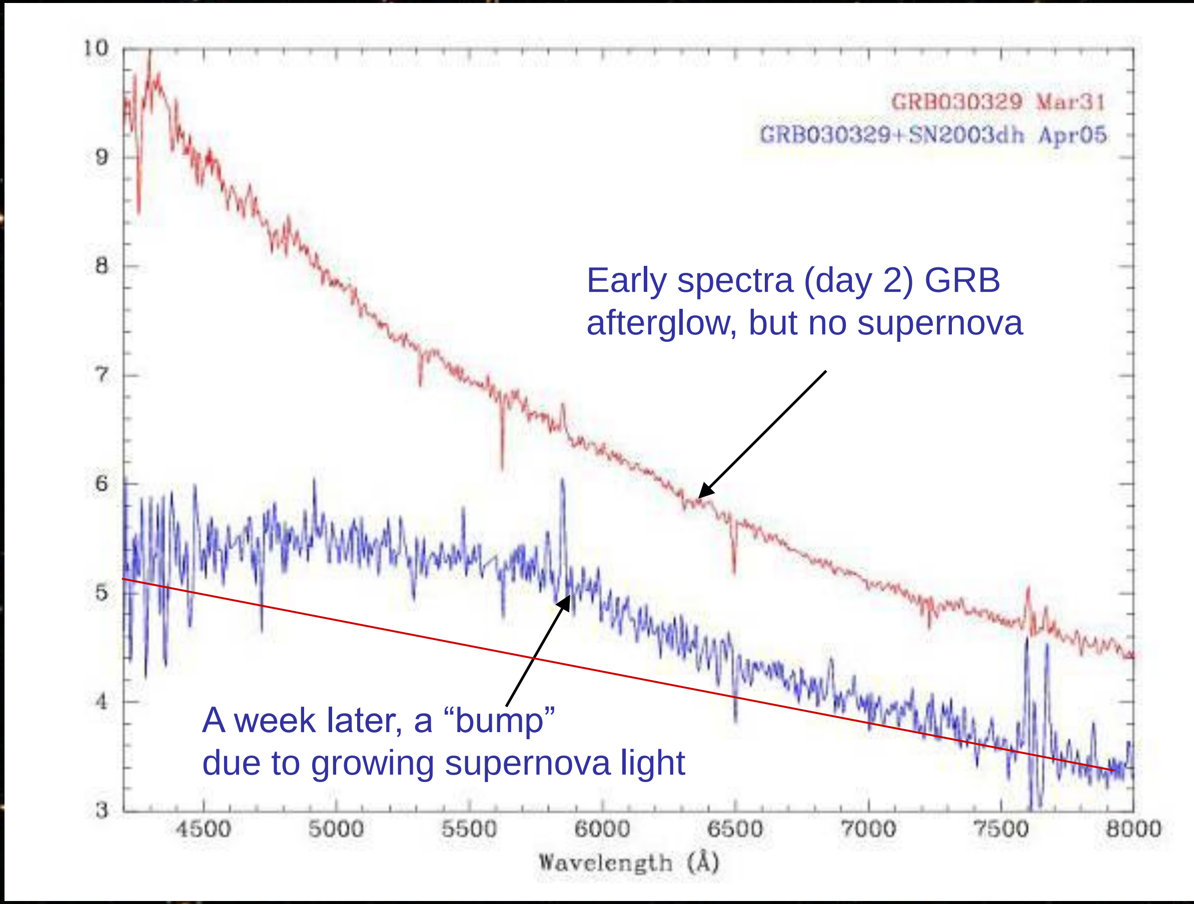
Jet emerges from exploding star at more than 99.99% the speed of light, decelerates by colliding with the interstellar medium. The resulting shock wave radiates the *afterglow.*

The raging issue: are gamma-ray bursts produced in some form of core collapse supernova? Circumstantial evidence...

THEN PROOF!

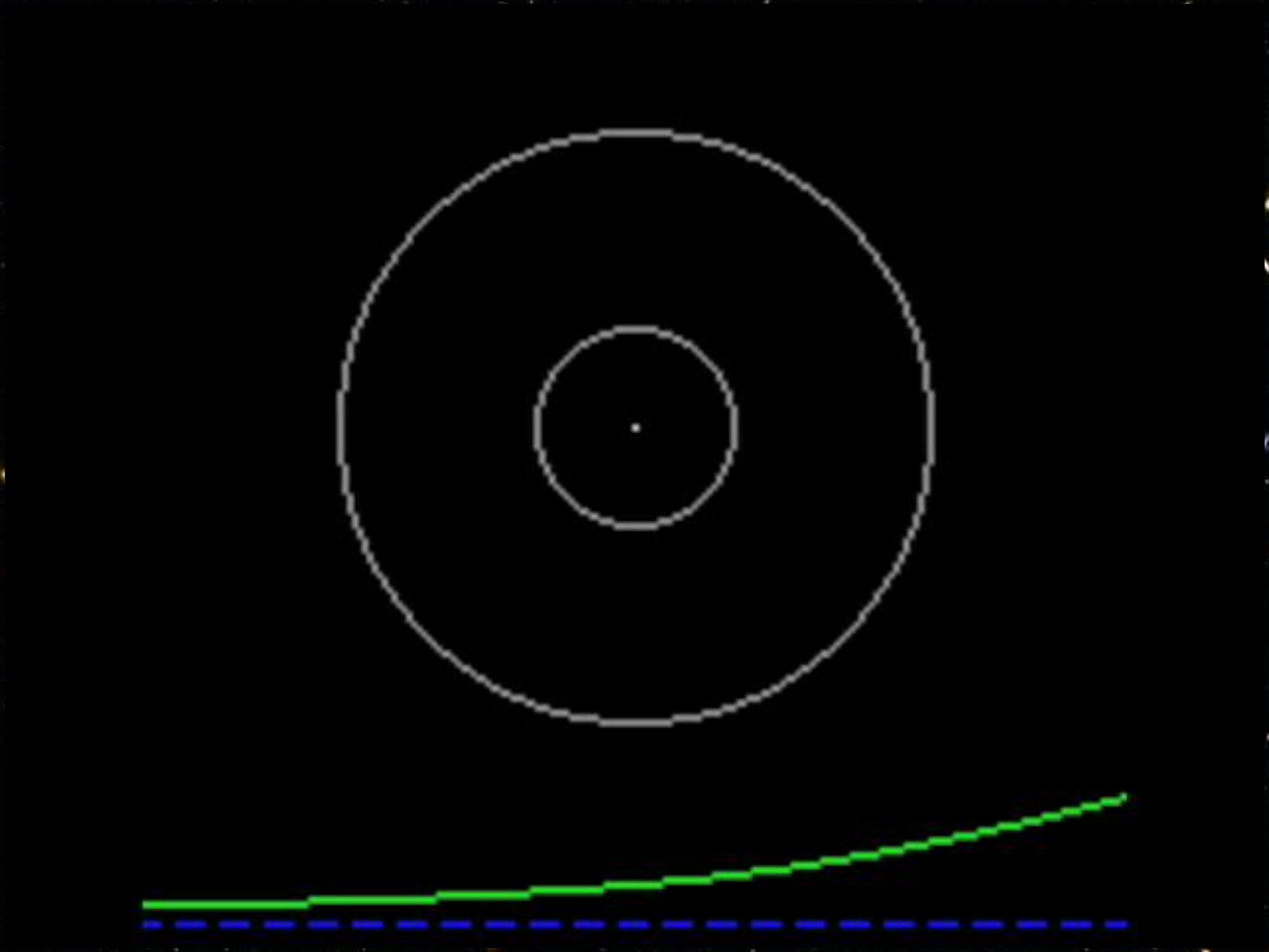
GRB 030329
was nearby,
only 3 BILLION
light years away!
relatively bright.

SN2003dh was
discovered a week
later!

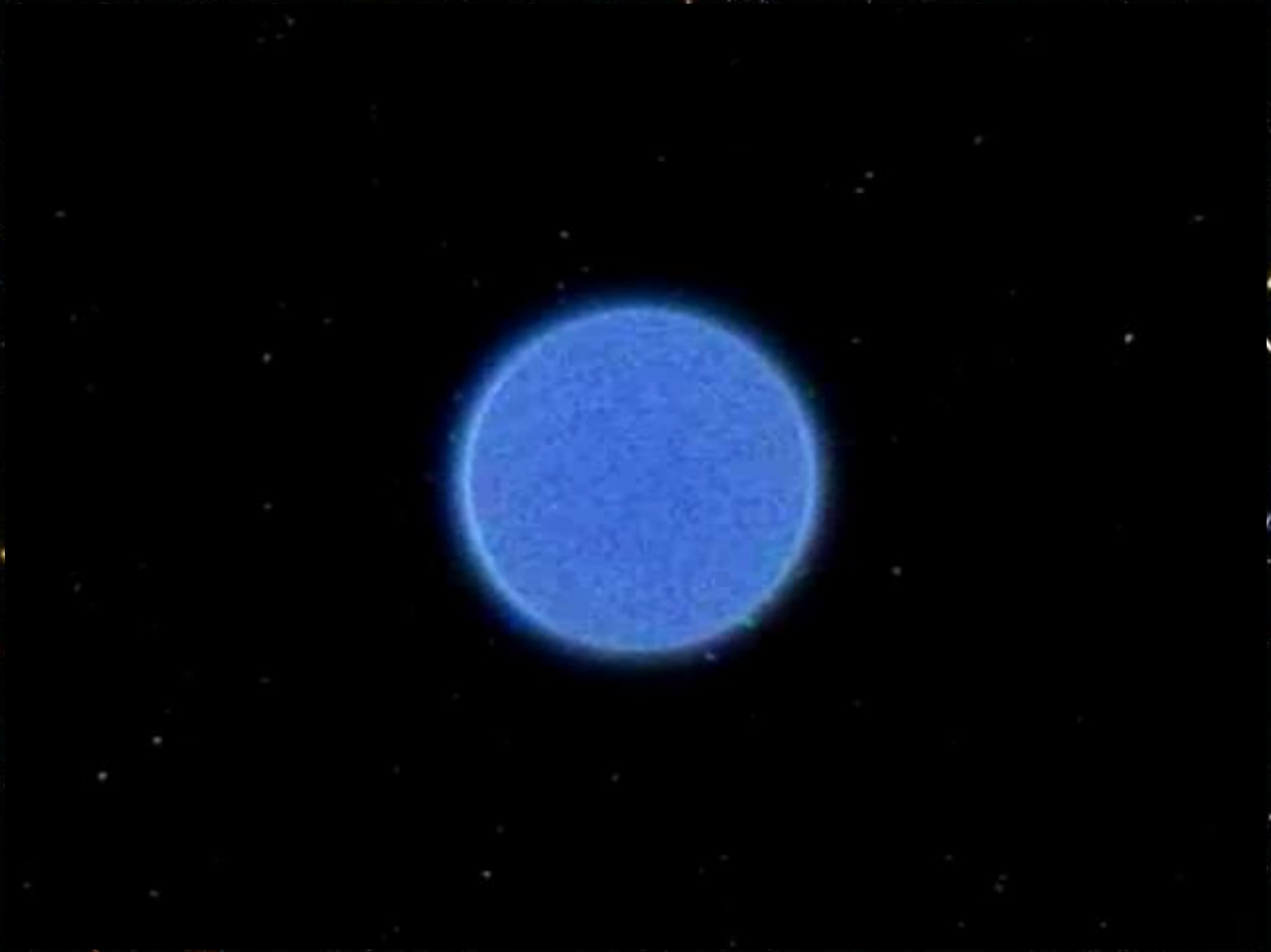


Black Holes - the quintessential legacy of Einstein

The path of light swallowed by a black hole



We have identified stellar-mass black holes in binary star systems and supermassive black holes in the centers of galaxies.



They are typically associated with jets.

Black Hole Forming in Star, producing jet and Gamma-Ray Burst

Every burst, twice a day somewhere in the Universe - the birth of a black hole?

NASA

Robotic Transient Source Experiment (ROTSE)

- We have joined the U. of Michigan Robotic Transient Source Experiment (ROTSE) collaboration.
- Four ROTSE telescopes around the world. Texas, Australia, Namibia and Turkey.
- 18 inch mirrors, 1.85 degree squared field of view.

ROTSE

ROTSE can point and shoot within 6 secs of electronic satellite notification, take automatic snapshots every 1, 5, 20, 60 secs.

***ROTSE* has:**

- Discovered the optical transient during the 30 second gamma-ray burst
- Followed the light in unprecedented detail
- Relayed the discovery and coordinates to the Hobby-Eberly Telescope for spectroscopic follow up

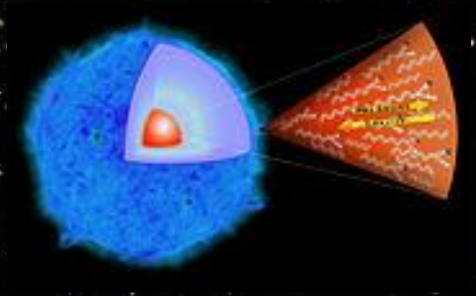
A New Type of Supernova

Texas graduate student, now Postdoctoral Fellow, Robert Quimby used ROTSE to conduct the *Texas Supernova Search*, covering unprecedented large volumes of space.

Quimby discovered the intrinsically brightest supernova ever seen! (at the time, Fall 2006)

I proposed that it was yet a different kind of explosion, proposed theoretically 40 years ago, hypothesized to occur among the first stars ever formed in the Universe, but never seen.

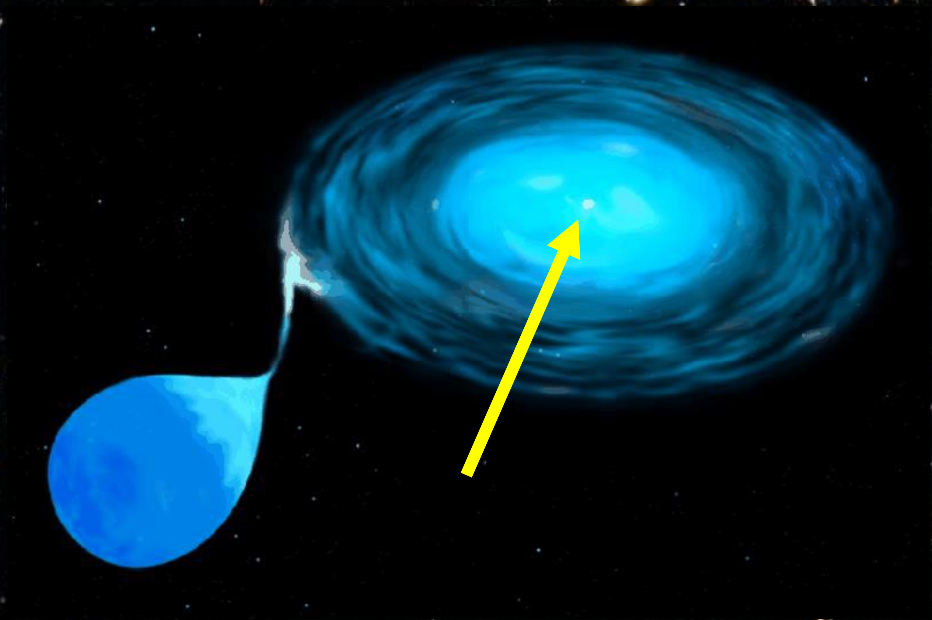
A very massive star, more than 100 times that of the Sun, gets so hot that its radiation, gamma-rays, convert some energy to matter and anti-matter, specifically pairs of ***electrons*** and anti-electrons, otherwise known as ***positrons***. This process makes the pressure decline, the oxygen core contracts, heats, undergoes thermonuclear explosion, totally disrupting the star: a ***pair-formation supernova.***



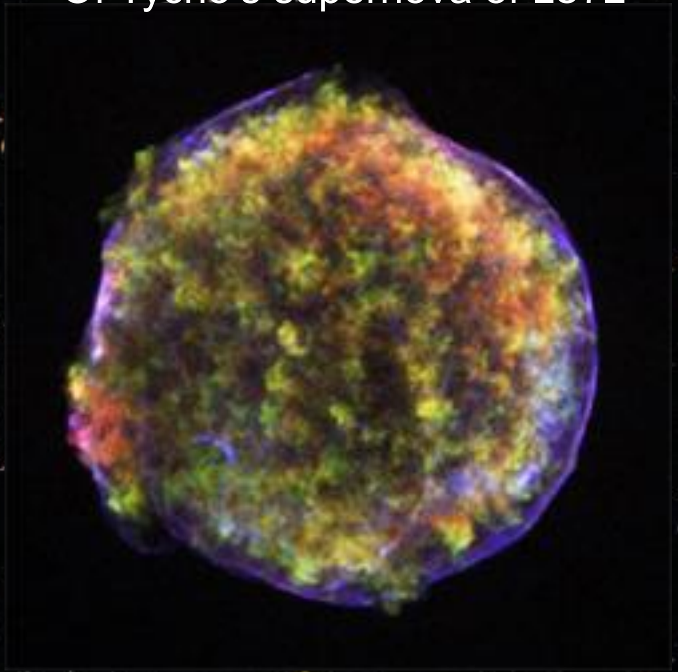
One hypothesis: The progenitor resembled Eta Carina

Quimby has since found an even brighter supernova!

The other principal type of supernovae (Type Ia) is thought to come from a white dwarf that grows to an explosive condition in a binary system.



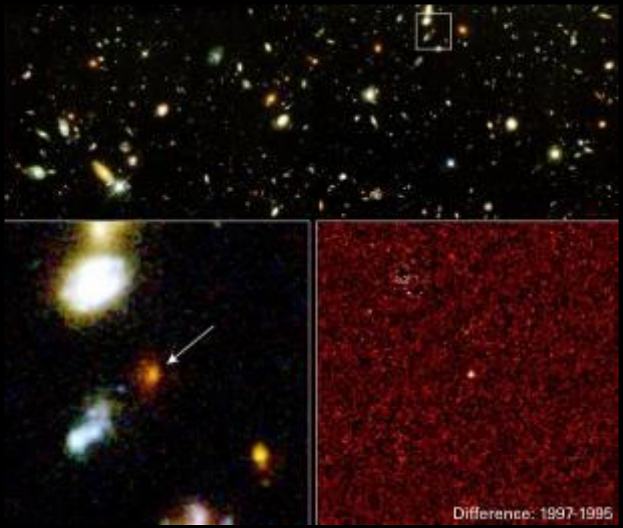
Chandra X-ray Observatory image
Of Tycho's supernova of 1572



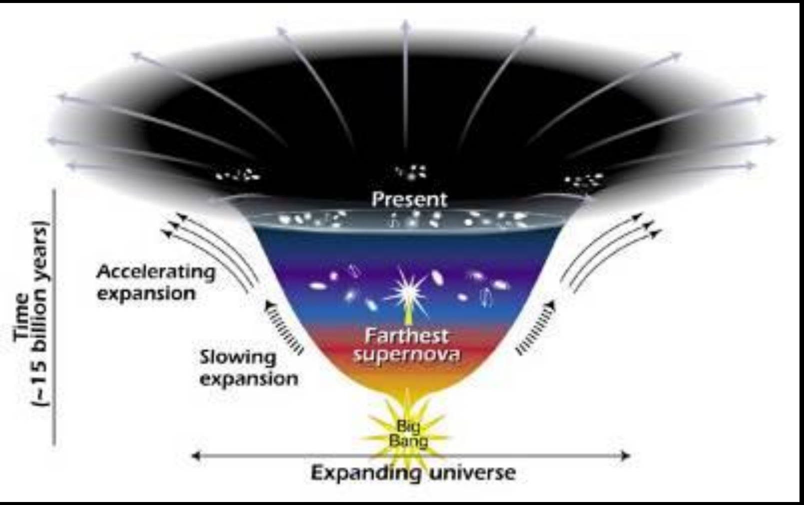
These explode completely, like a stick of dynamite, and leave no compact object (neutron star or black hole) behind.

This type of supernovae is generally the brightest and can be seen at cosmological distances.

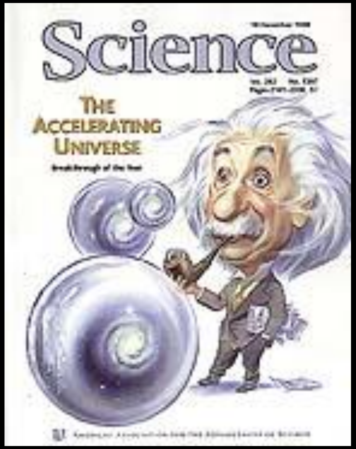
They were used as cosmological probes...



to discover the acceleration of the Universe...



the Science Magazine scientific Breakthrough of the Year in 1998



The Accelerating Universe

From a National Academy of Science Report:

“The resulting acceleration of universal expansion is a new development in physics, possibly as important as the landmark discoveries of quantum mechanics and general relativity near the beginning of the 20th century.”

Dark Energy

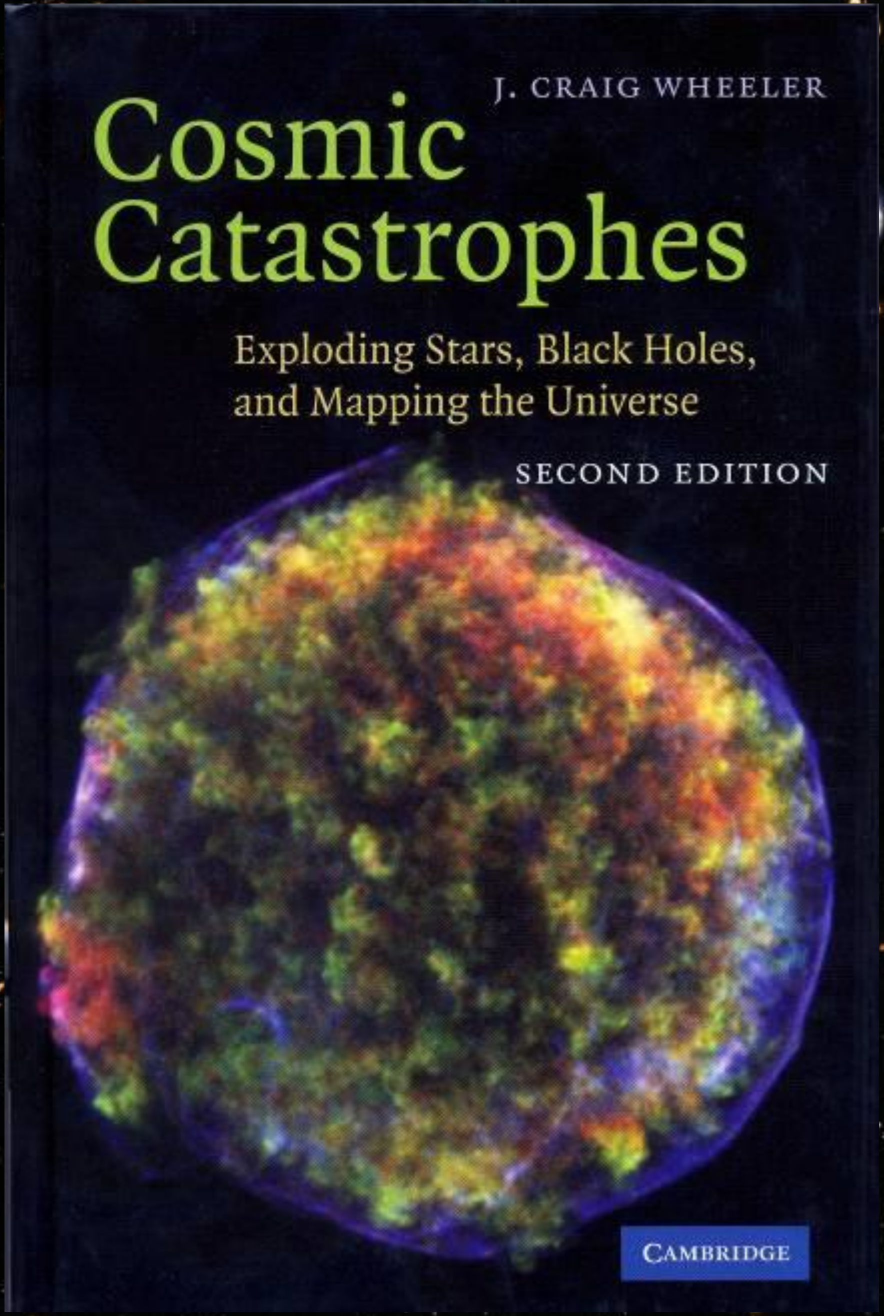
- One of the greatest challenges to astrophysics now is to understand the nature of the Dark Energy that drives the acceleration.
- The dark energy is probably a field (like a magnetic field, but different), but it is 120 orders of magnitude smaller than physicists would expect. No current theory of physics accounts for it.
- If it stays constant, the Universe will expand to a Dark Oblivion. If it reverses, the Universe could slam shut in a Big Crunch (in more than 10 billion years).
- To test the behavior of the dark energy in space and time, supernovae remain a key tool of choice for precision measurements.

Dynamic Behavior of Dark Energy

Conclusions

The Ragged Edge of Research

- All core collapse explosions are asymmetric, maybe produced by magnetic jets. How can this be proved?
- Gamma-ray bursts are caused by jets of material moving at nearly the speed of light. Do they mark the birth of black holes?
- At least some gamma-ray bursts (and maybe all) arise in supernova explosions. How does this work?
- Have we discovered pair-formation supernovae?
- Type Ia helped to discover the Dark Energy, but they must be studied and understood in unprecedented detail to learn what the Dark Energy is - *the biggest problem facing physics today*.



- Cosmic Catastrophes: Exploding Stars, Black Holes, and Mapping the Universe
- Written for course of same title
- Covers all the topics of the lecture, and more

Film - scientific premise related to tonights topics.

Available at:

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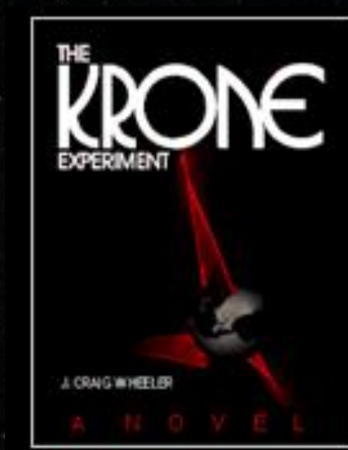

Dr. J. Craig Wheeler

J. Craig Wheeler is the Samuel T. and Fern Yanagisawa Regents Professor of Astronomy at the University of Texas at Austin, where he was chair of the department from 1986 to 1990. He was a Research Fellow at Caltech working in Nobel Laureate Willy Fowler's group from 1969 to 1971. From 1971 to 1974,he was an Assistant Professor of Astronomy at Harvard. In 1974, he moved to Texas as an Associate Professor of Astronomy. He specializes in the astrophysics of violent events: supernovae, neutron stars, black holes, gamma-ray bursts and the relation of these events to astrobiology. He was elected to the Academy of Distinguished Teachers in 2002. He is serving as President of the American Astronomical Society from 2006 to 2008. He has published about 200papers in refereed journals and conference proceedings, has edited books on supernovae and accretion disks. He published a novel, "The Krone Experiment," co-authored the screenplay, and played a role in the independent film made in Austin. He has also written a popular astronomy book, "Cosmic Catastrophes: Supernovae, Gamma-Ray Bursts and Adventures in Hyperspace" the second edition of which was released in December 2006.