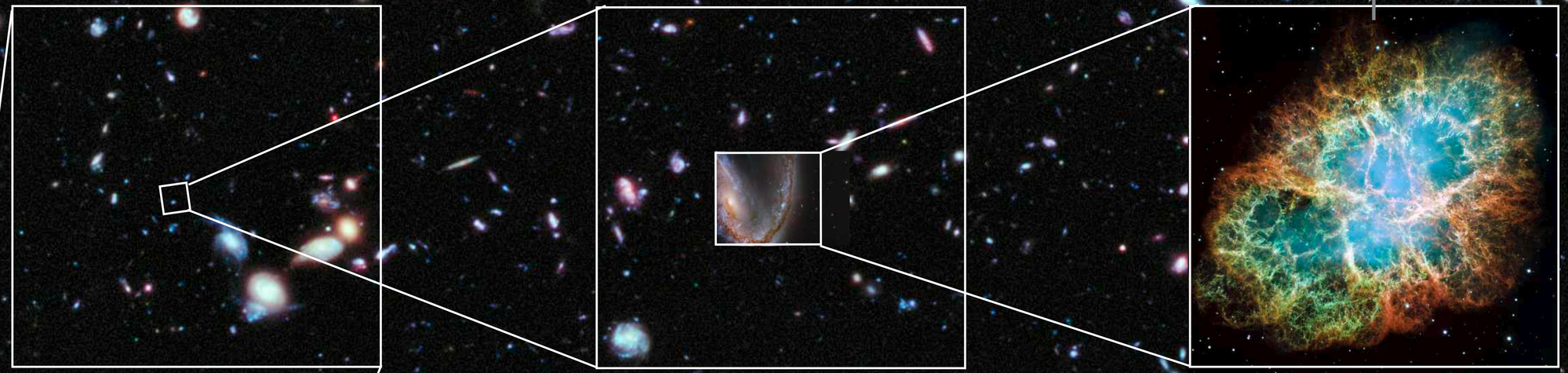


Tracing the Lives, Deaths, & Explosions Of Massive Stars

Sarafina Nance
Ph.D. Candidate
UC Berkeley / LBNL

(and Comet, my dog)

@starstrickenSF

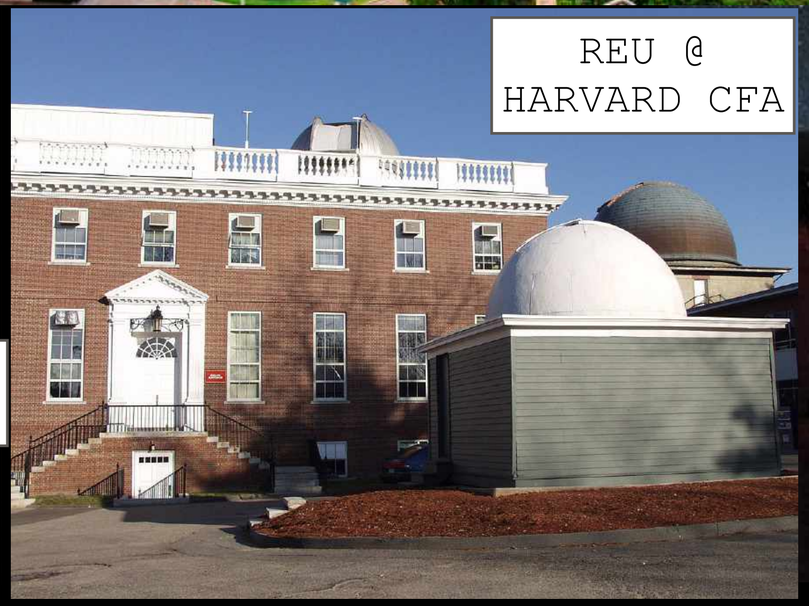
Royal Astronomical Society of Canada

PRE-GRAD SCHOOL

COLLEGE ADVISOR
J. CRAIG WHEELER

COLLEGE @
UT AUSTIN

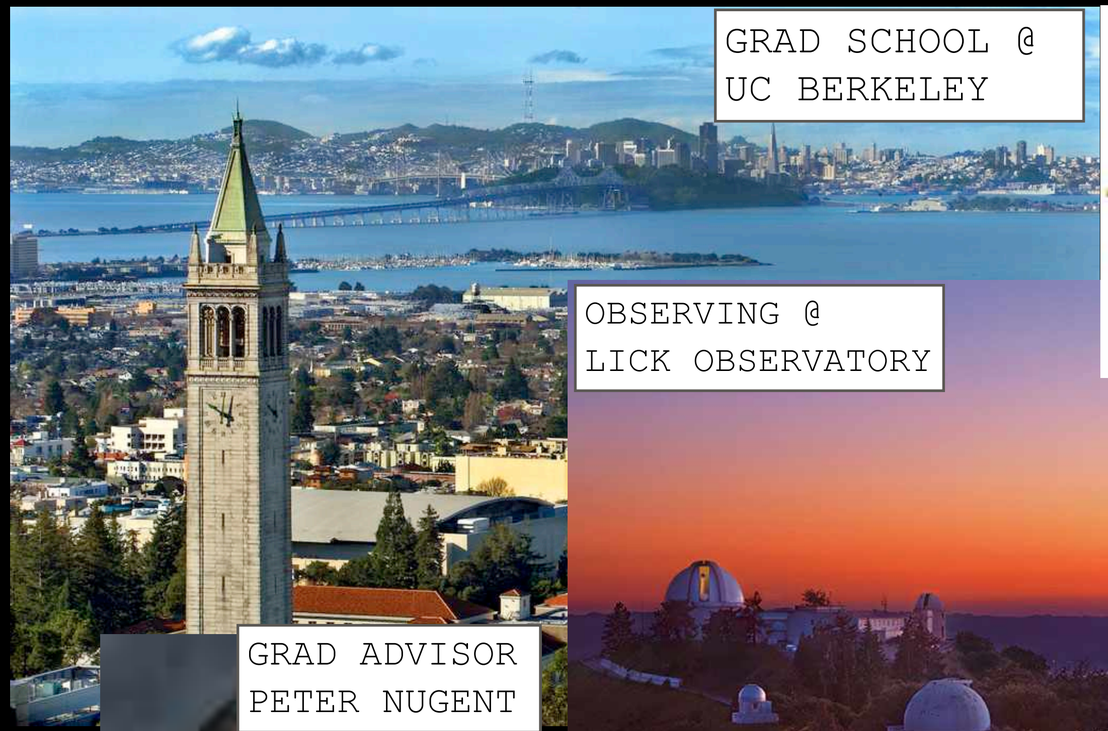
HIGH SCHOOL ADVISOR
FRANK MIKAN



REU @
HARVARD CFA

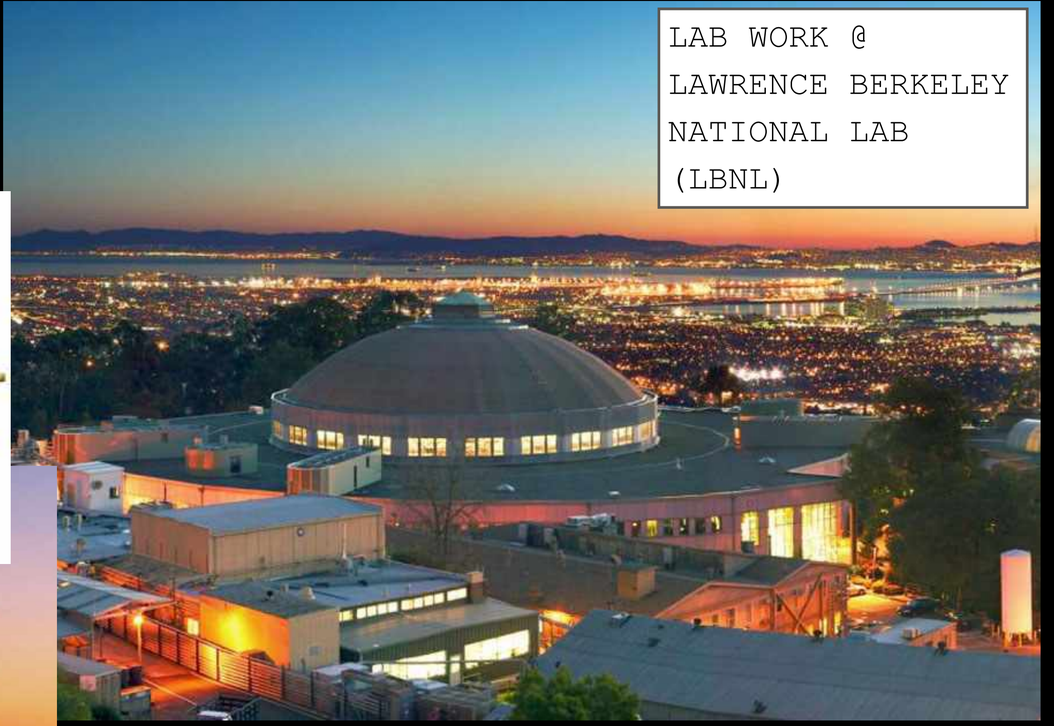
SUMMER INTERNSHIP @
MCDONALD OBSERVATORY

GRAD SCHOOL



GRAD SCHOOL @
UC BERKELEY

NSF



LAB WORK @
LAWRENCE BERKELEY
NATIONAL LAB
(LBNL)

OBSERVING @
LICK OBSERVATORY

GRAD ADVISOR
PETER NUGENT

CRD

COMPUTATIONAL COSMOLOGY CENTER

Home » Computational Cosmology Center

MEMBER OF C3

RUN JOBS ON
NERSC (CORI)
SUPERCOMPUTER

RESEARCH INTERESTS:

I like stars that explode (aka SUPERNOVAE).

I try to understand:

1. WHICH stars explode?
2. HOW do they explode?
3. What do they tell us about the FATE OF THE UNIVERSE?

@starstrickenSF

OUTLINE OF THIS TALK

- WHAT ARE SUPERNOVAE?

OUTLINE OF THIS TALK

- WHAT ARE SUPERNOVAE?
- BETELGEUSE:
  - The Great Dimming Event
  - When will it explode?

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  - The rate of the expansion of the Universe
  - The fates of the Universe

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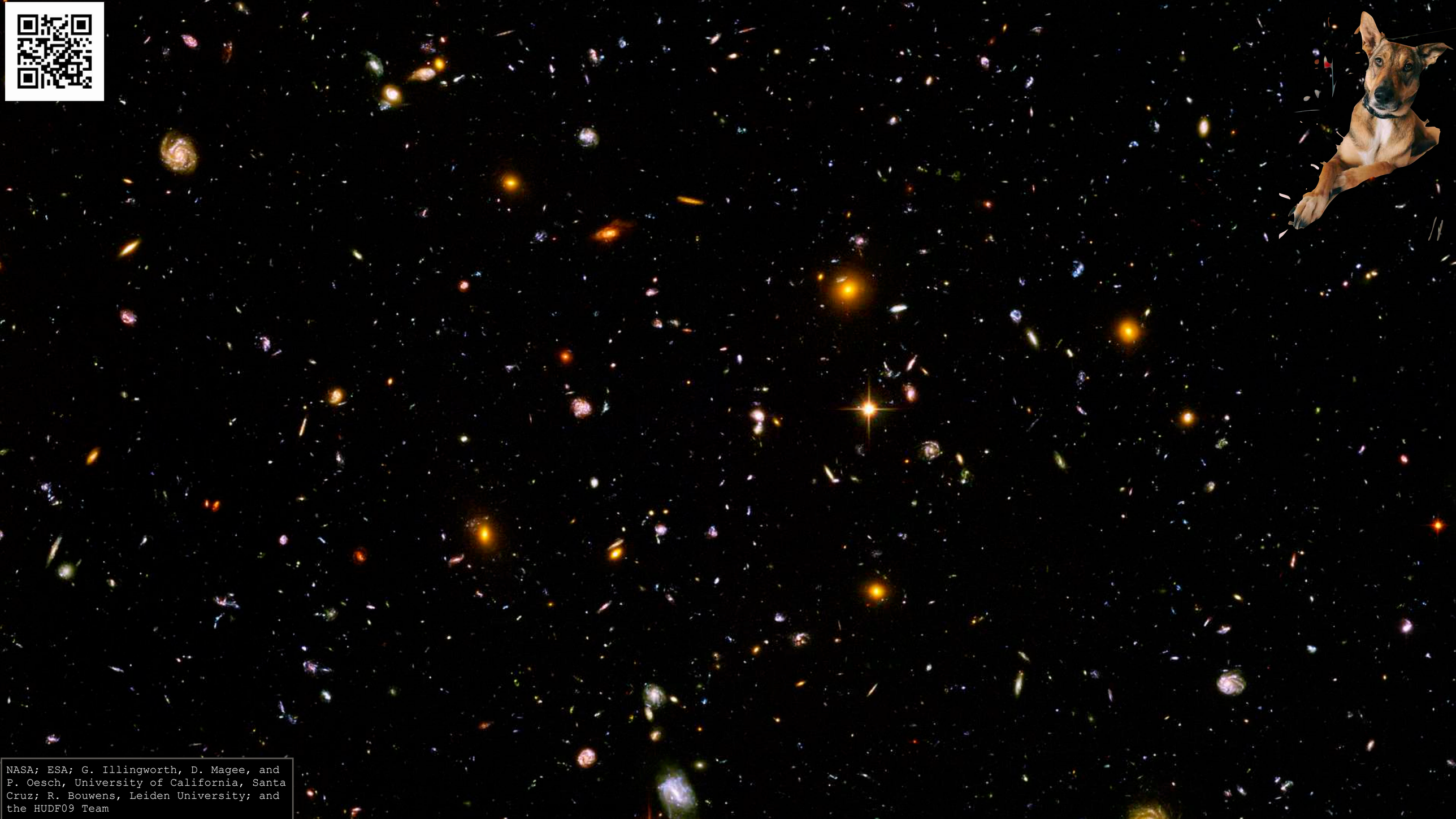
- THE ACCELERATING UNIVERSE:
  - Supernovae & the discovery of Dark Energy
  - The rate of the expansion of the Universe
  - The fates of the Universe
- HOW **YOU** CAN HELP US FIND SUPERNOVAE!



NASA; ESA; G. Illingworth, D. Magee, and P. Oesch, University of California, Santa Cruz; R. Bouwens, Leiden University; and the HUDF09 Team

OK, SO WHAT EVEN IS A SUPERNOVA? (PL: SUPERNOVAE)

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BRIGHT & POWERFUL
EXPLOSIVE DEATH
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*light = cosmic speed limit

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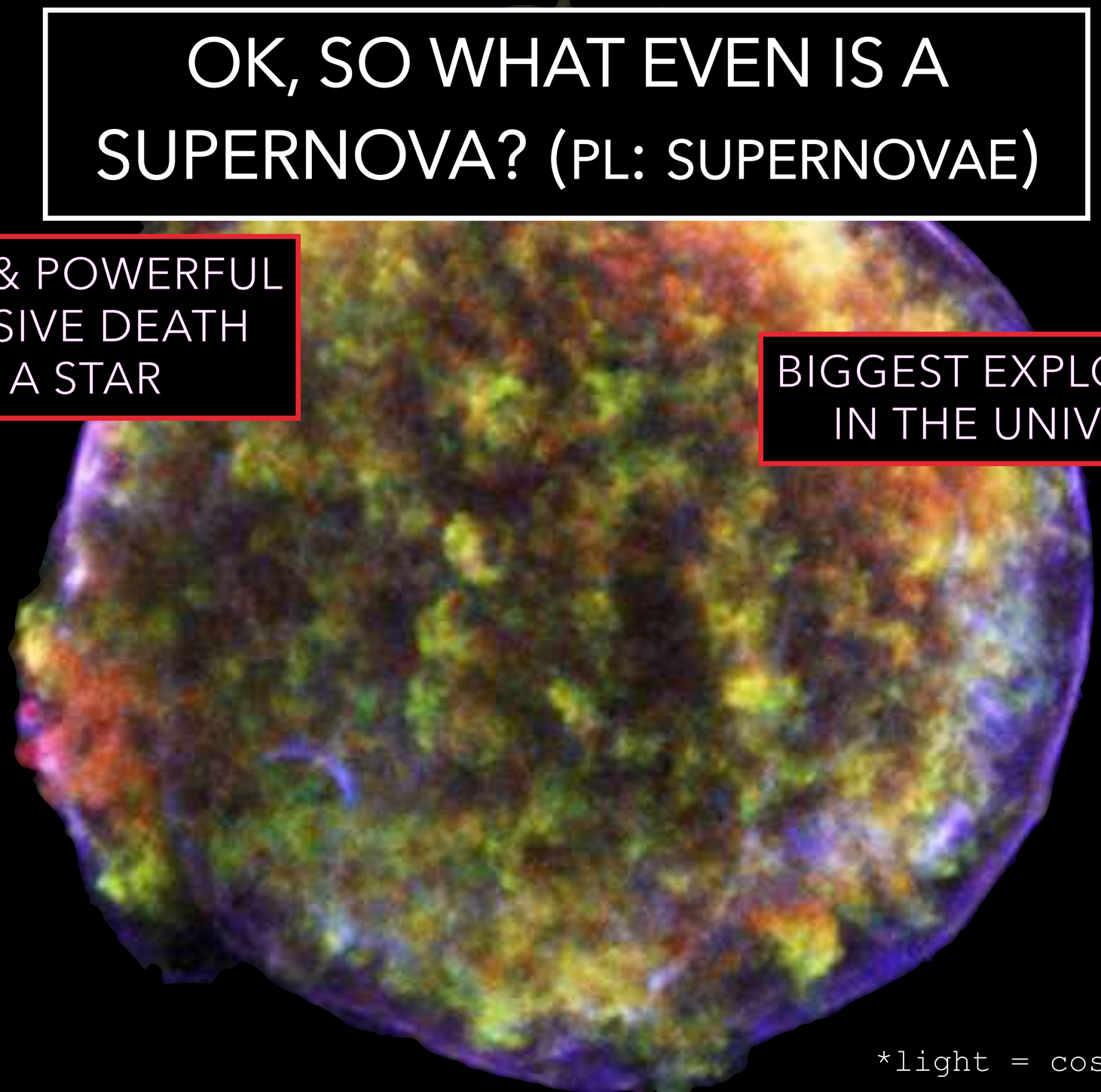

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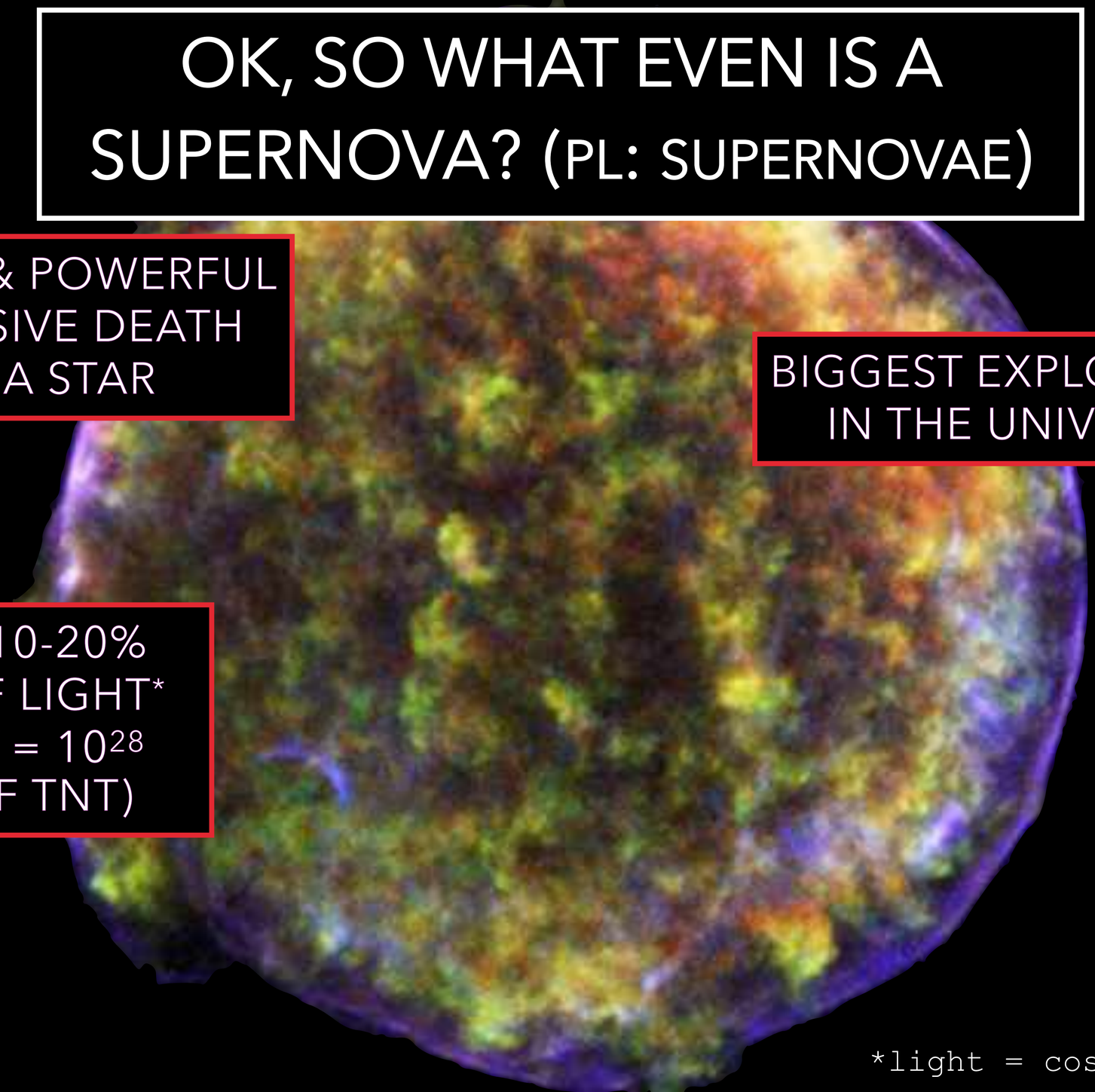
SPEEDS 10-20% SPEED OF LIGHT* (ENERGY = 10^{28} TONS OF TNT)



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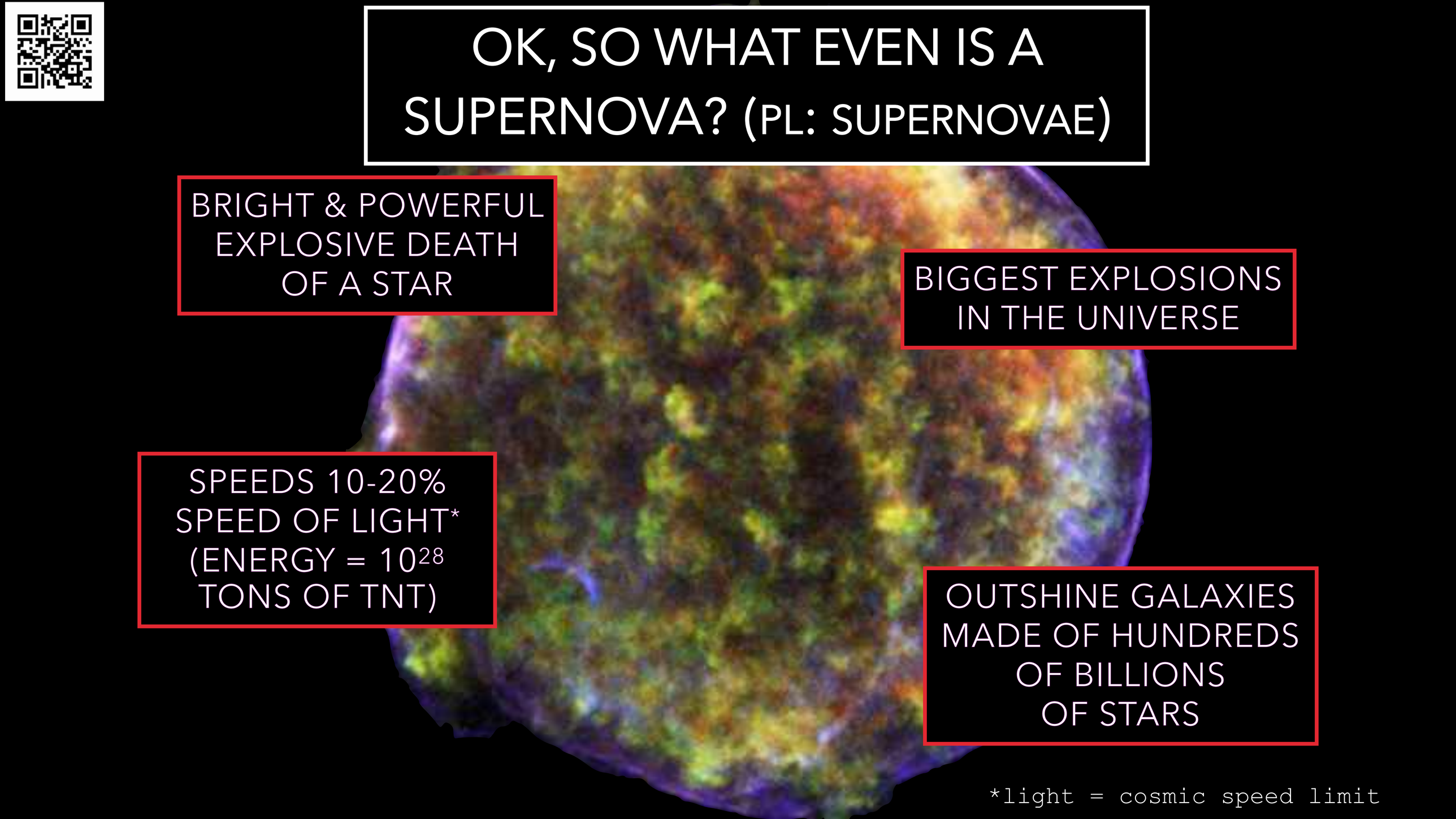

BRIGHT & POWERFUL EXPLOSIVE DEATH OF A STAR

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SPEEDS 10-20% SPEED OF LIGHT* (ENERGY = 10^{28} TONS OF TNT)

OUTSHINE GALAXIES MADE OF HUNDREDS OF BILLIONS OF STARS

*light = cosmic speed limit

OK, SO WHAT EVEN IS A SUPERNOVA? (PL: SUPERNOVAE)

BRIGHT & POWERFUL EXPLOSIVE DEATH OF A STAR

BIGGEST EXPLOSIONS IN THE UNIVERSE

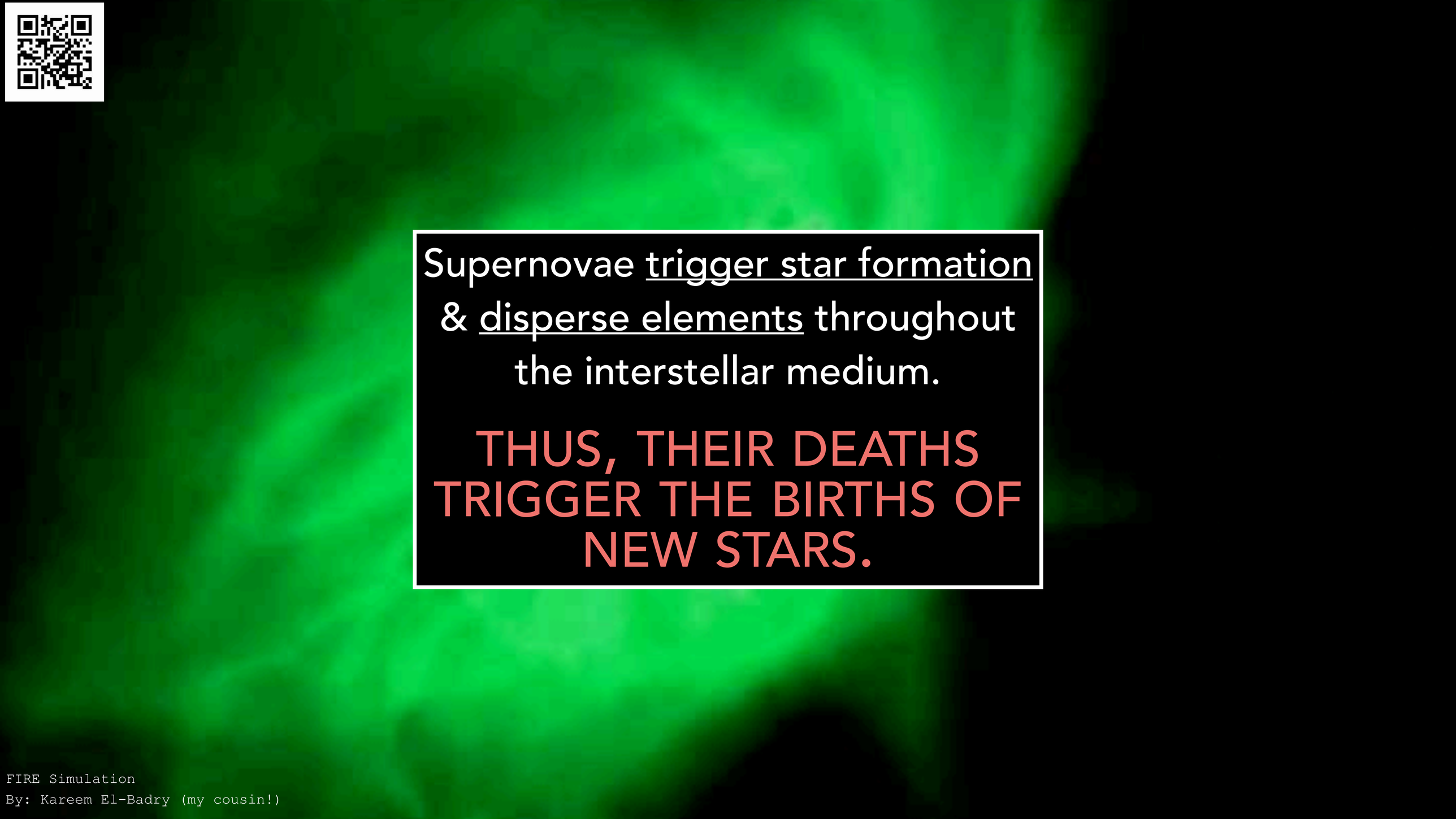
IN 1 MONTH,
EMITS AS MUCH ENERGY
AS THE SUN WILL ***EVER*** EMIT
OVER ITS
10 BILLION YEAR LIFETIME

SPEEDS 10-20%
SPEED OF LIGHT*
(ENERGY = 10^{28}
TONS OF TNT)

OUTSHINE GALAXIES
MADE OF HUNDREDS
OF BILLIONS
OF STARS

*light = cosmic speed limit

Why should we care about supernovae? Why are they cool?



FIRE Simulation
By: Kareem El-Badry (my cousin!)

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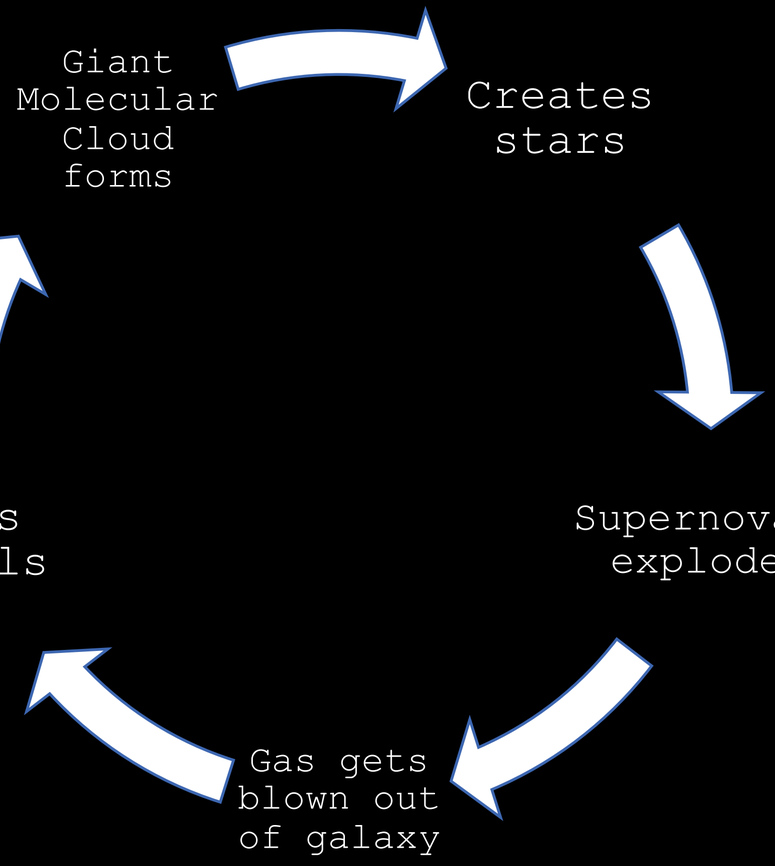
COSMOLOGICAL SIMULATION OF GALAXY EVOLUTION



Timescale ~3 Gigayears

Temperature color map.
Purple dots are cooler

FIRE Simulation
By: Kareem El-Badry (my cousin!)

Supernovae are the birthplace of heavy elements in the Universe.

Carl Sagan (my hero)

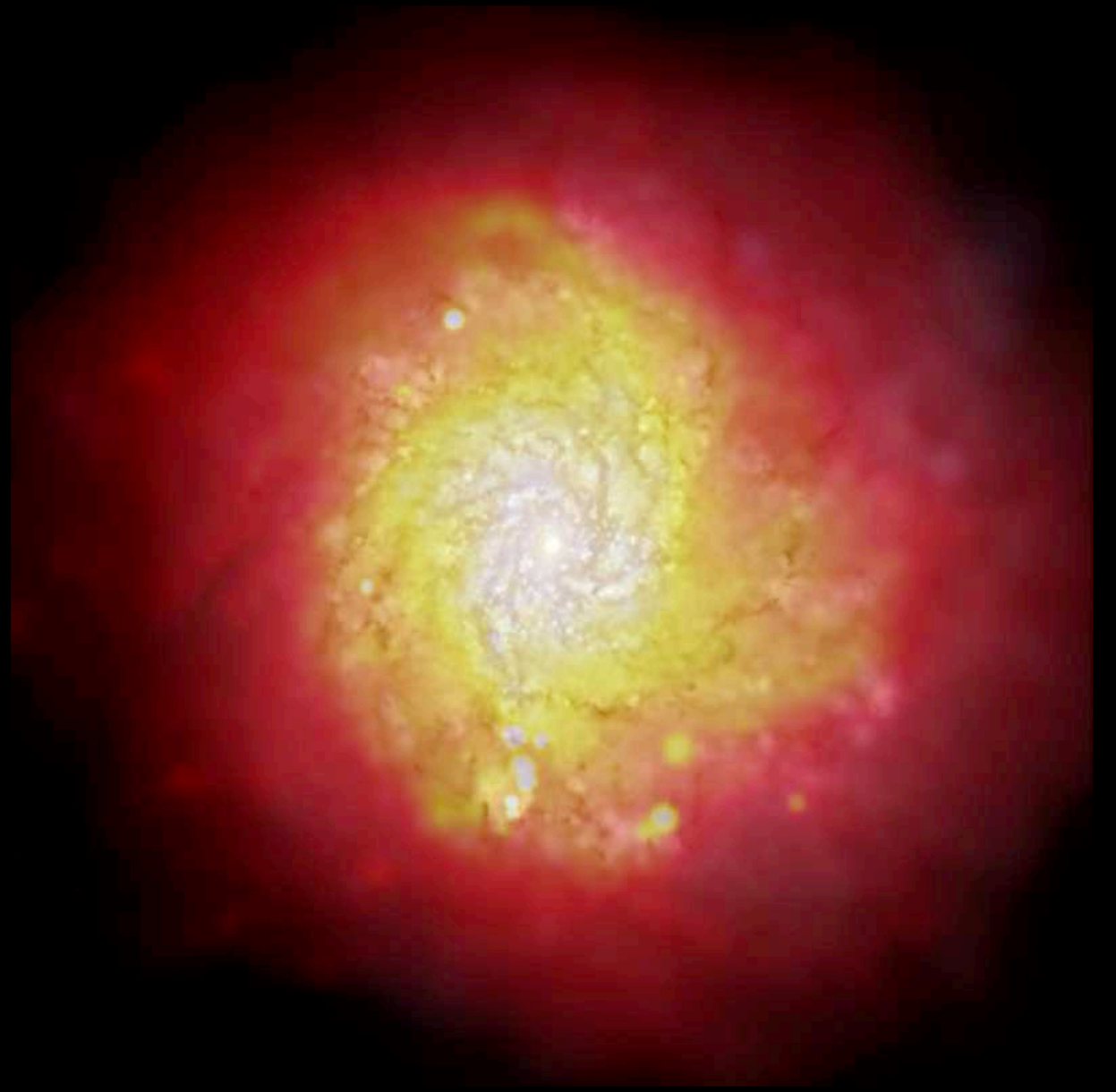
HOW COMMON ARE SUPERNOVAE?

1 supernova per second in the Universe

1-3 supernovae seen from Earth per day

1-2 supernovae per galaxy (like the Milky Way) per 100 years

FIRE Simulation:
Flying through a Milky-Way-like Galaxy
in the X-Ray

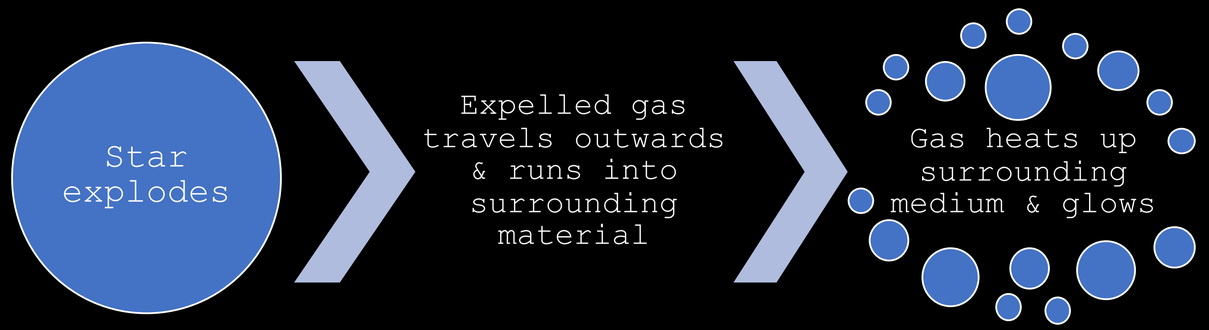


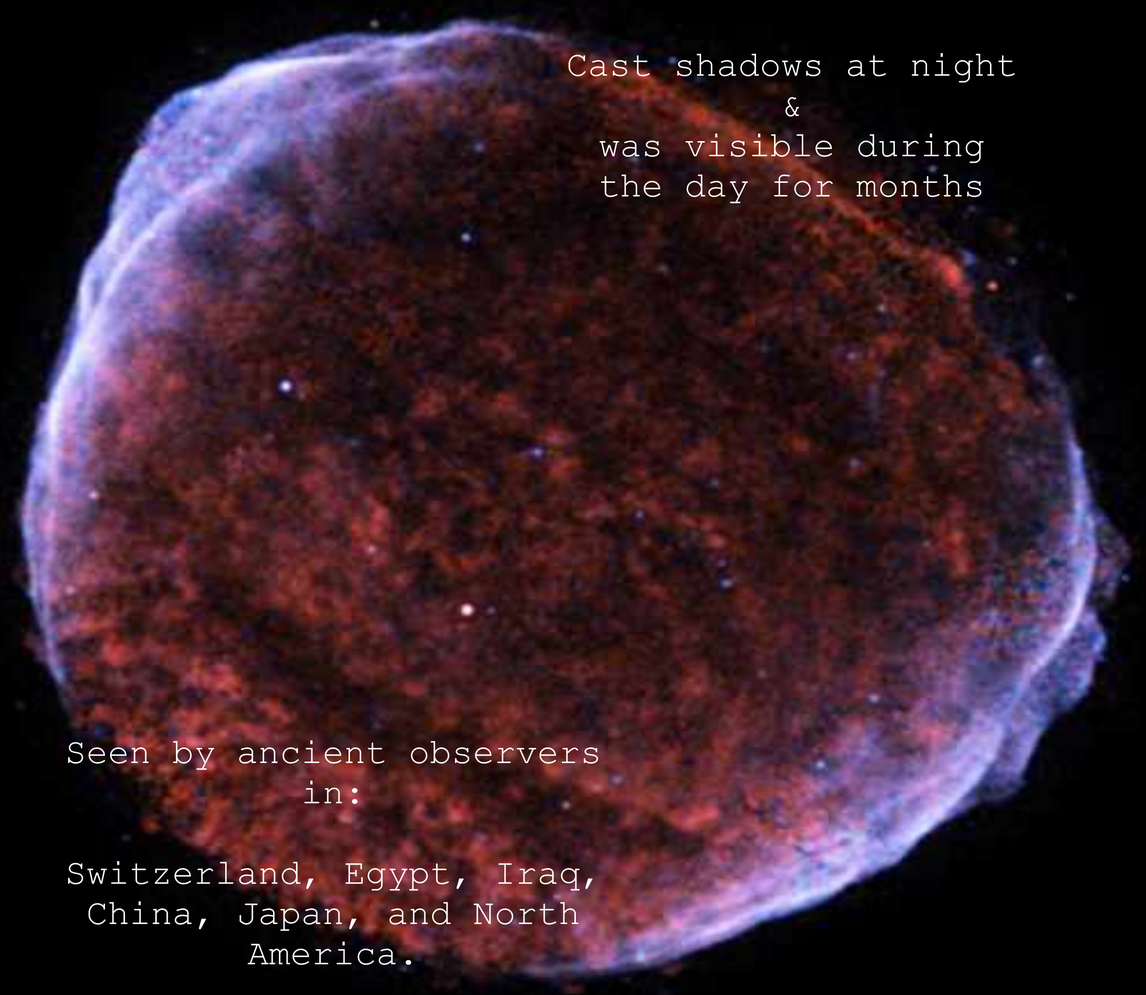
Phil Hopkins, Caltech 2015
FIRE Simulations

What do these supernovae actually look like from Earth?

HISTORICAL SUPERNOVAE

Formation of Supernova Remnants





Cast shadows at night
&
was visible during the day for months

Seen by ancient observers in:

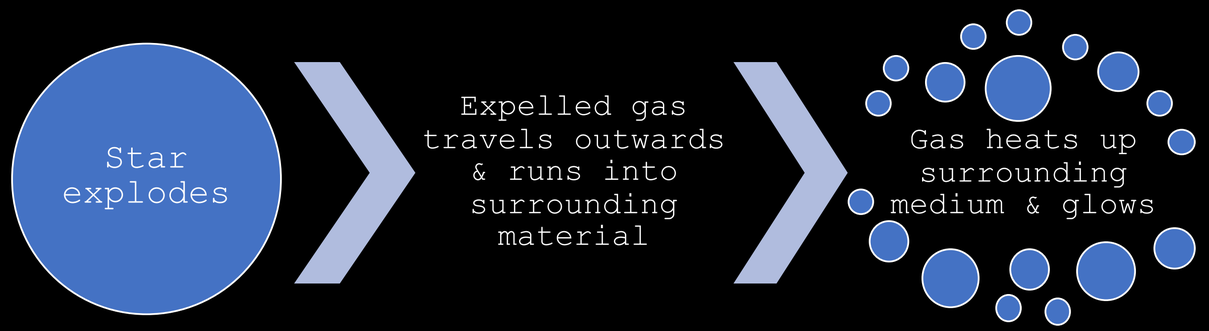
Switzerland, Egypt, Iraq, China, Japan, and North America.

SN 1006

Chanda X-Ray Satellite Telescope

HISTORICAL SUPERNOVAE

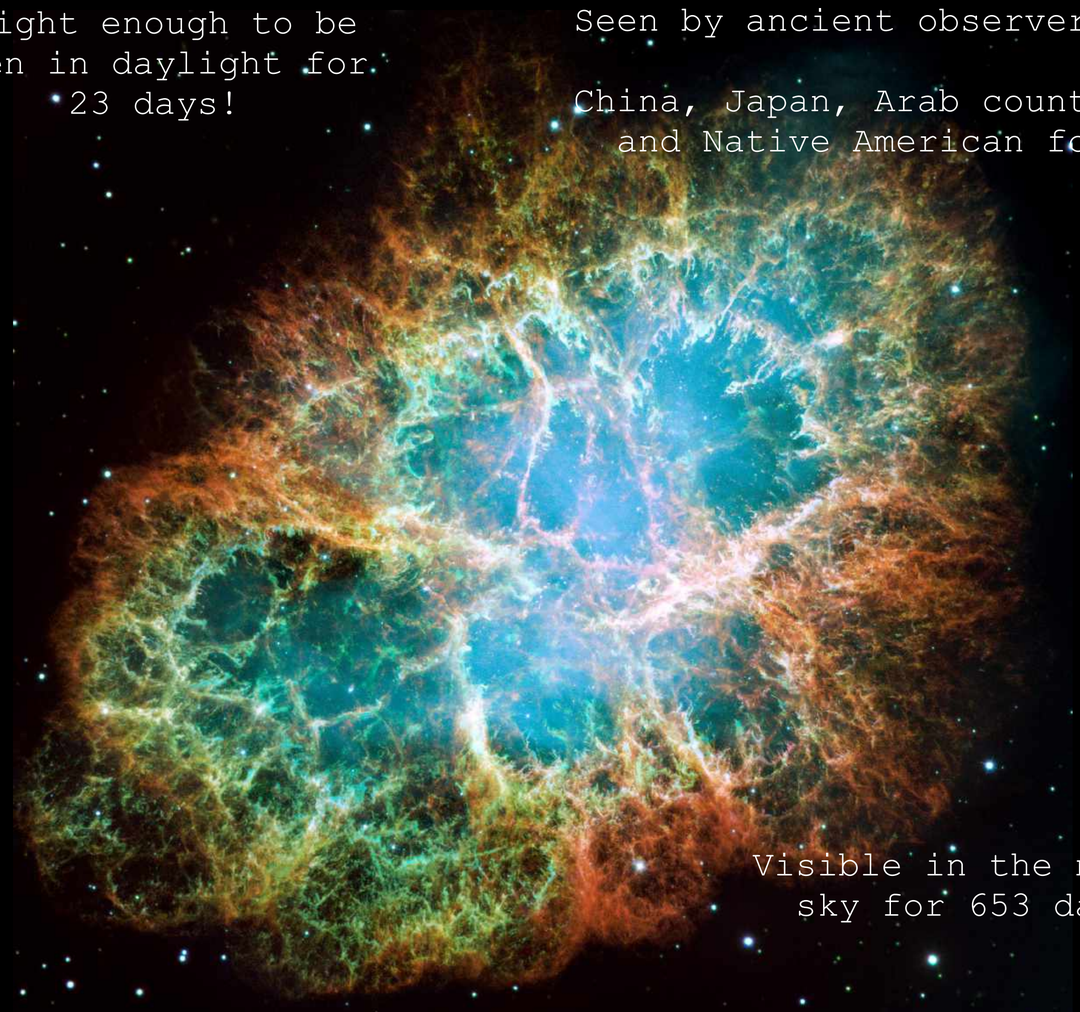
Formation of Supernova Remnants



Bright enough to be seen in daylight for 23 days!

Seen by ancient observers in:

China, Japan, Arab countries, and Native American folks



Visible in the night sky for 653 days

Crab Nebula / SN 1054

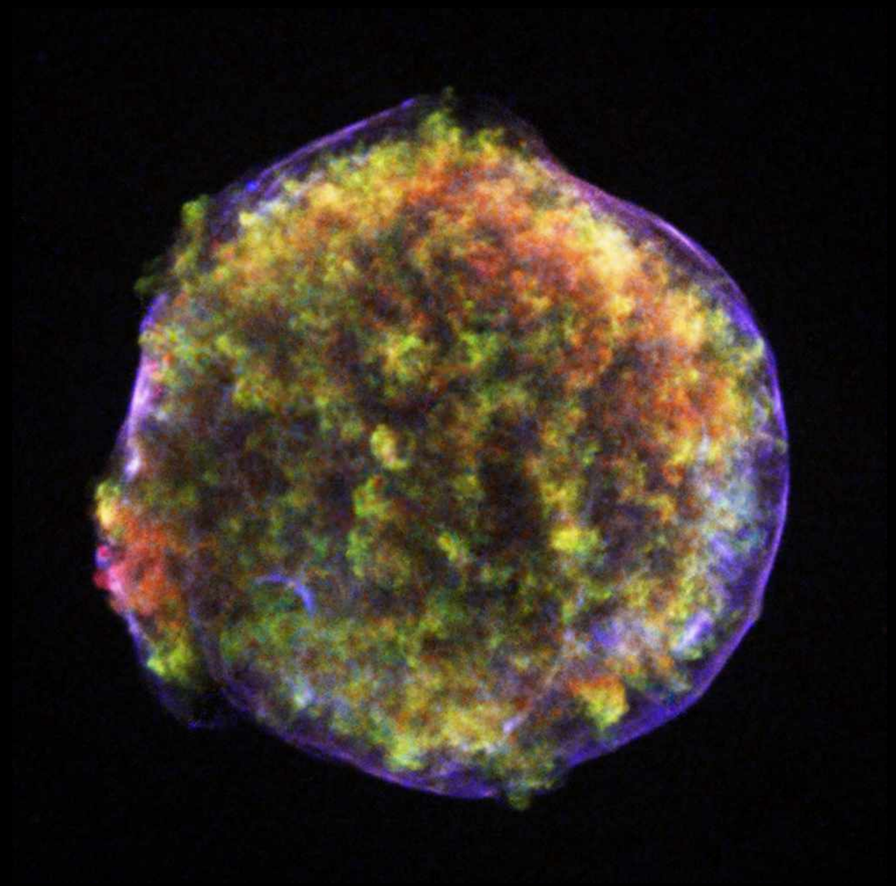
Hubble Space Telescope


Rendition of SN 1054 by Ancestral Puebloans (*Hisatsinom* in Hopi) in Peñasco Blanco - a Chacoan Ancestral Puebloan great house(Chaco Canyon)- in New Mexico, USA.
Petroglyph from 1054.
Hand shows relative size of sky objects
Crescent moon shows phase / position of moon relative to the supernova on July 4, 1054
Star = Supernova

B Cas/SN 1572

Tycho's SN Remnant

Tycho Brahe, discovered SN by eye 1572

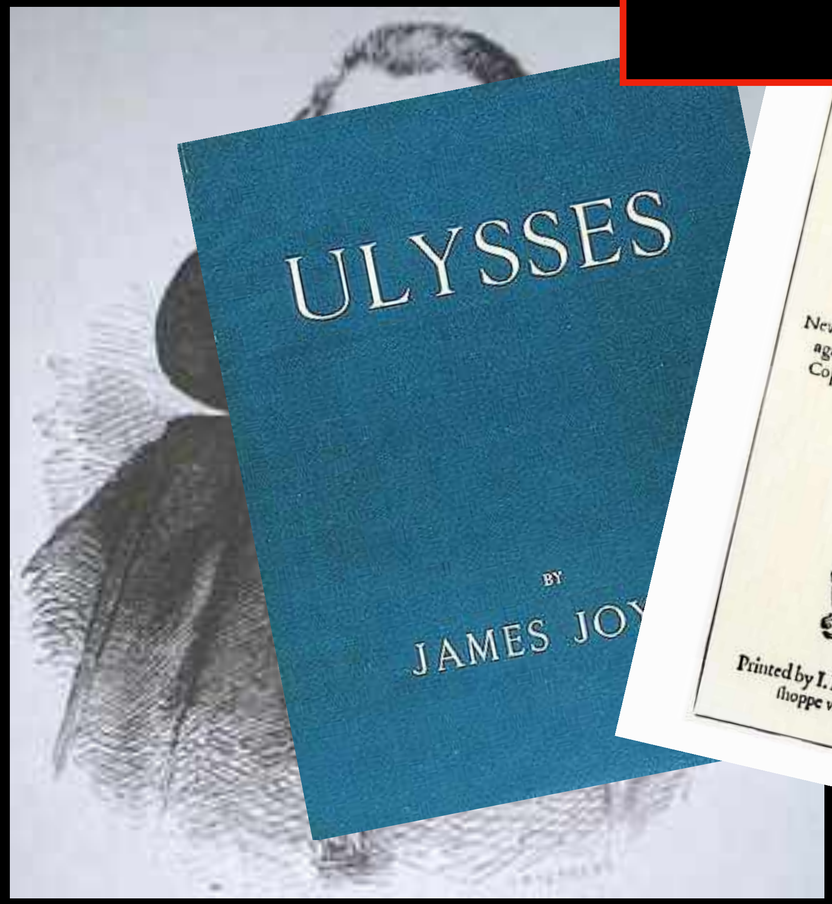


Chanda X-Ray Satellite Telescope

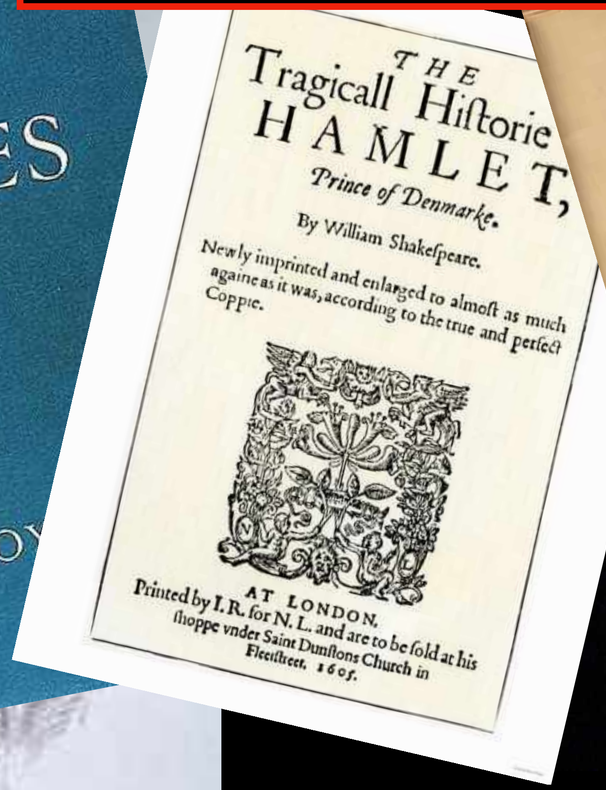
B Cas/SN 1572

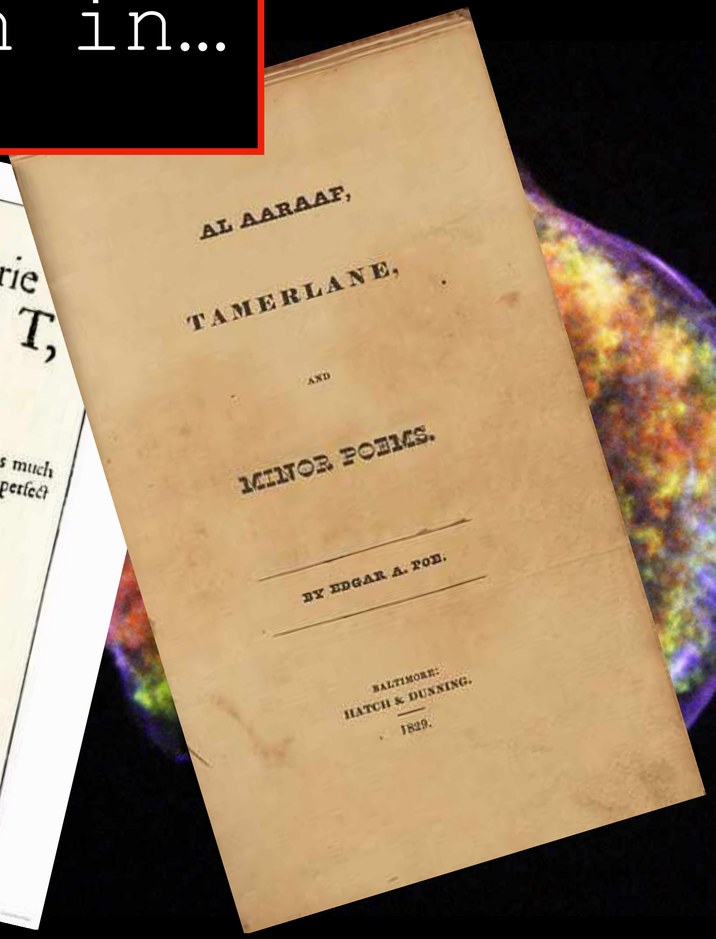
T *nt*

Also seen in…



Tycho Brahe, discovered SN by eye 1572

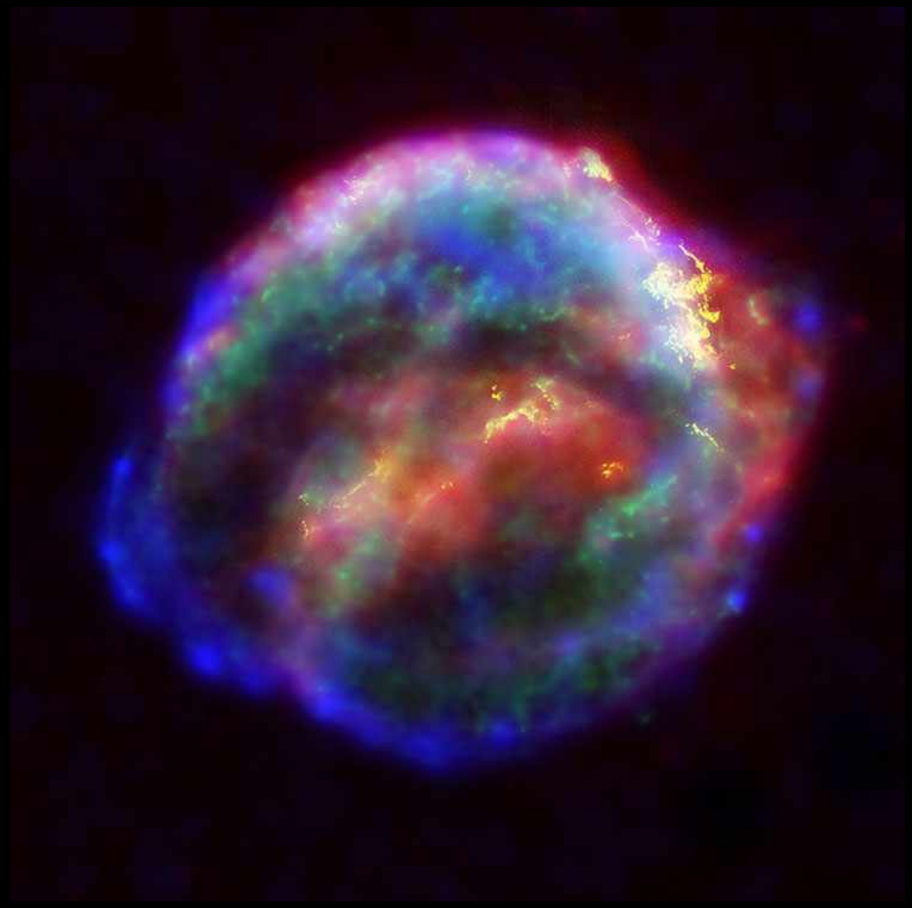




Chanda X-Ray Satellite Telescope

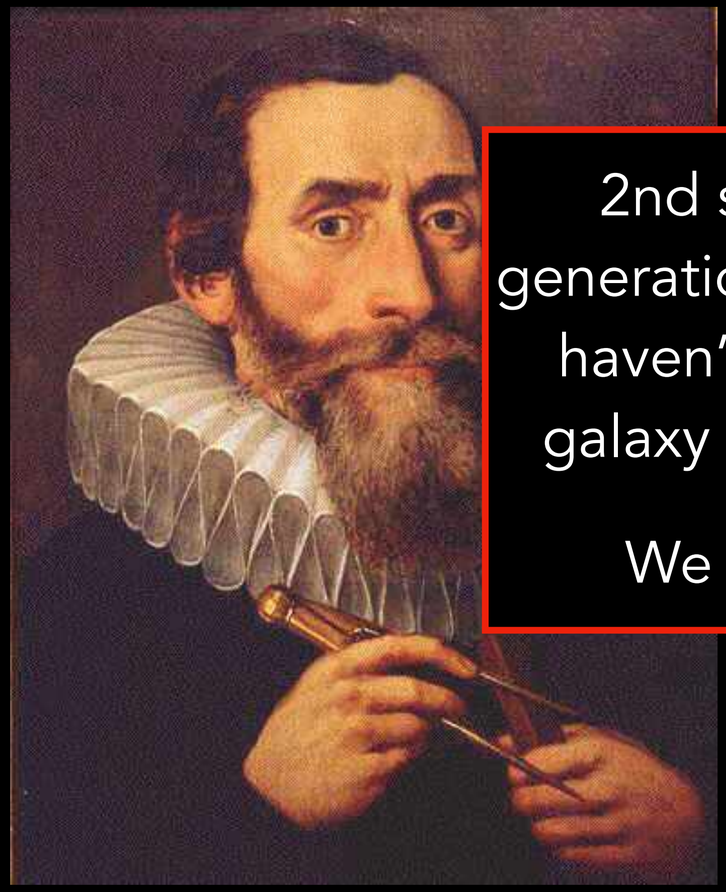
SN 1604
Kepler's Supernova

Johannes Kepler (Brahe's GRADUATE STUDENT), discovered SN by eye 1604



CXO/HST/Spitzer Space Telescope

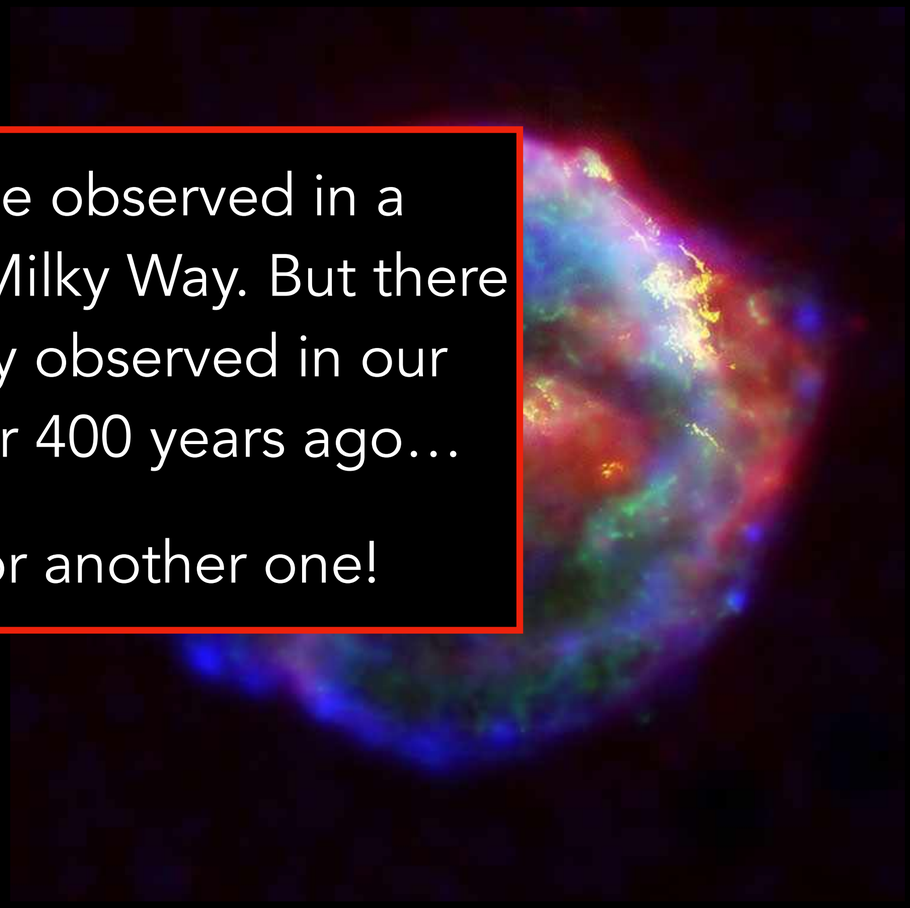
SN 1604
Kepler's Supernova



Johannes Kepler (Brahe's GRADUATE STUDENT), discovered SN by eye 1604

2nd supernovae observed in a generation in the Milky Way. But there haven't been any observed in our galaxy since, over 400 years ago…

We are due for another one!



CXO/HST/Spitzer Space Telescope

SN 1987A

On Feb 24, 1987, a star exploded in our cosmic backyard.

The Large Magellanic Cloud, just 170,000 lightyears away (10^{18} miles).

This was the first naked-eye supernova in the era of modern astronomy.

SN 1987A

Formation of Supernova Remnants

Here, the ejecta slams into the material released by the progenitor system ~20,000 years before the star exploded.

Tracing SN 1987A Across Cosmic Time

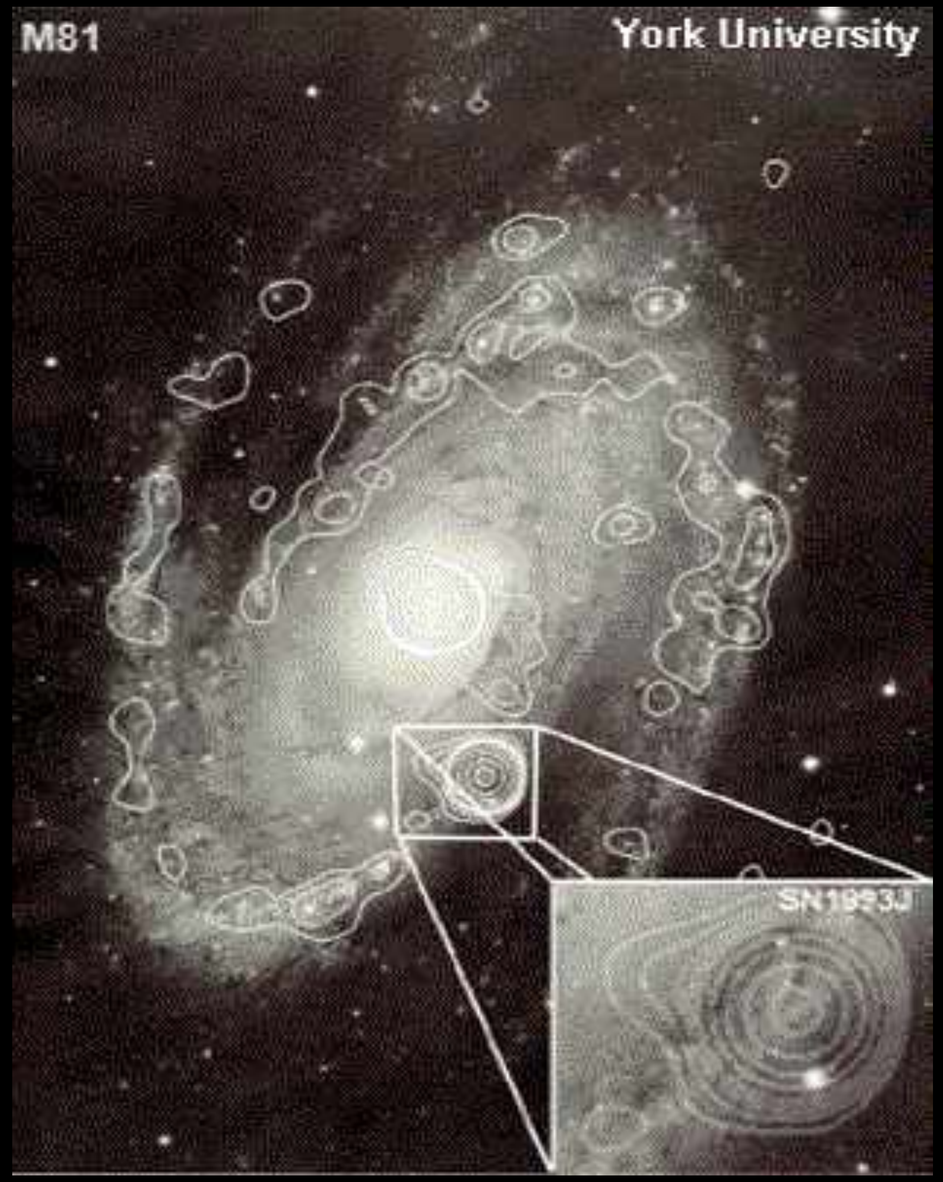
1994 – 2004

Hubble Space Telescope, NASA, ESA;
Video compilation: Mark McDonald

SN 1993J

Galaxy: M81

OTHER SUPERNOVAE VISIBLE FROM EARTH



Date: May 1993 – Feb 2000
Distance: 11 Megalightyears
Velocity of outflows:
10,000 mi/s –> 6,000 mi/s

Color scale: Brightness of radio emission (blue = faintest, red = brightest)

23 consecutive VLBI Images

SN 1994D

Galaxy: NGC 4526

OTHER SUPERNOVAE VISIBLE FROM EARTH

Date: May 1993 – Jeb 2000

Distance: 20 Megalightyears (~10^{20} miles)

Supernova as bright as the core of the galaxy (~100 billion stars)

Hubble Space Telescope

OTHER SUPERNOVAE VISIBLE FROM EARTH

SN 1998S

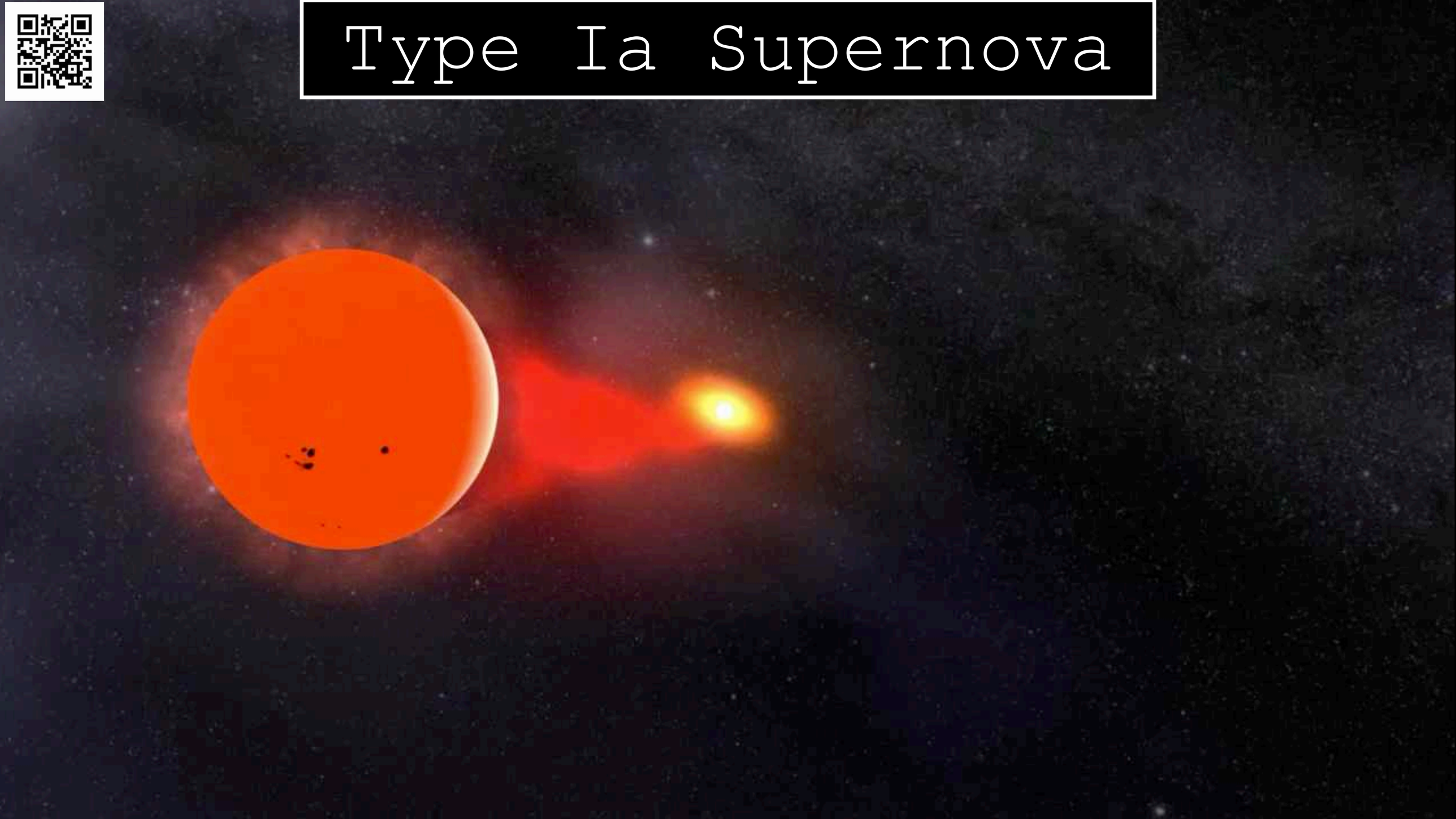
Galaxy: NGC 3877

Time: 3.5 months
Distance: 42 Megalightyears

Pedro Ré, Marine Biologist at
University of Lisbon / Portugal

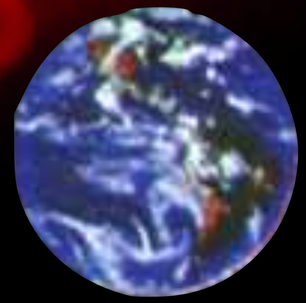
How are supernovae formed?

Type Ia Supernova

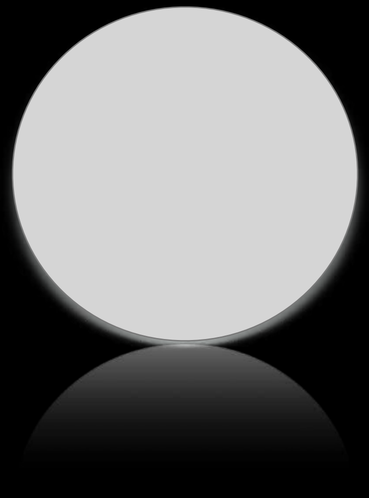


Sun

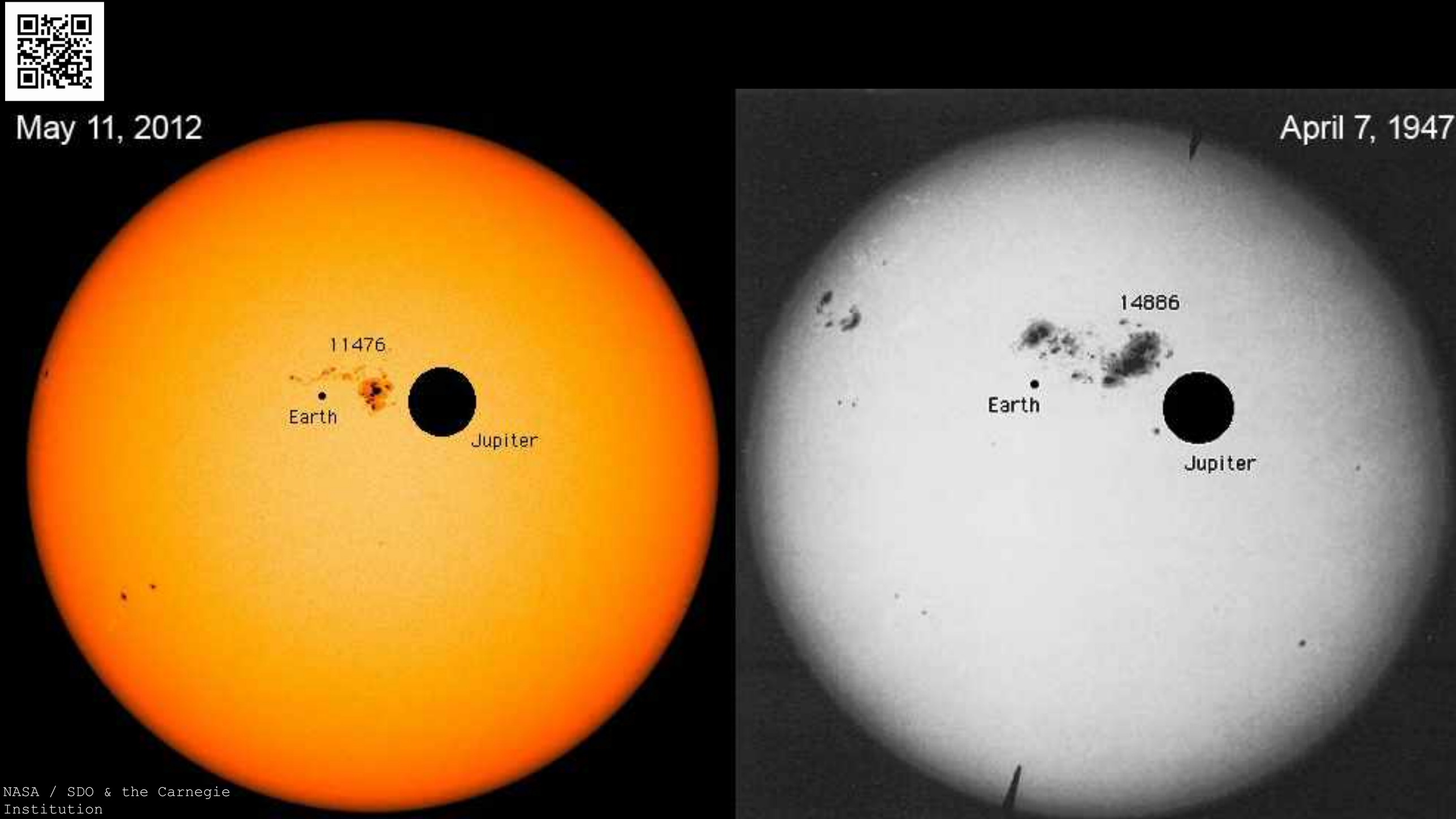
Earth



White Dwarf



NASA / SDO



NASA / SDO & the Carnegie Institution

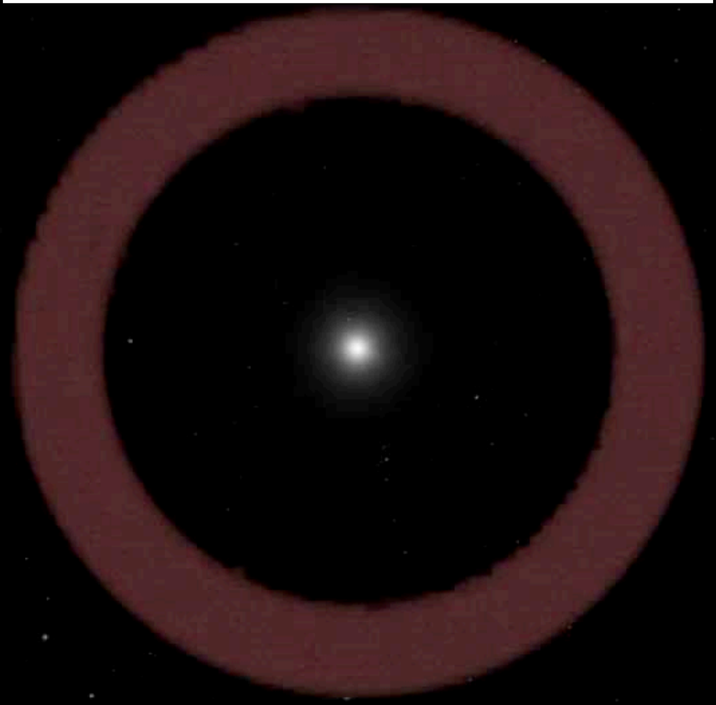
Type Ia Supernova

Occurs in a binary system, where the mass transfer triggers a *thermonuclear* supernova.

Core Collapse Supernovae

SN 1987A

Galaxy: Large Magellanic Cloud

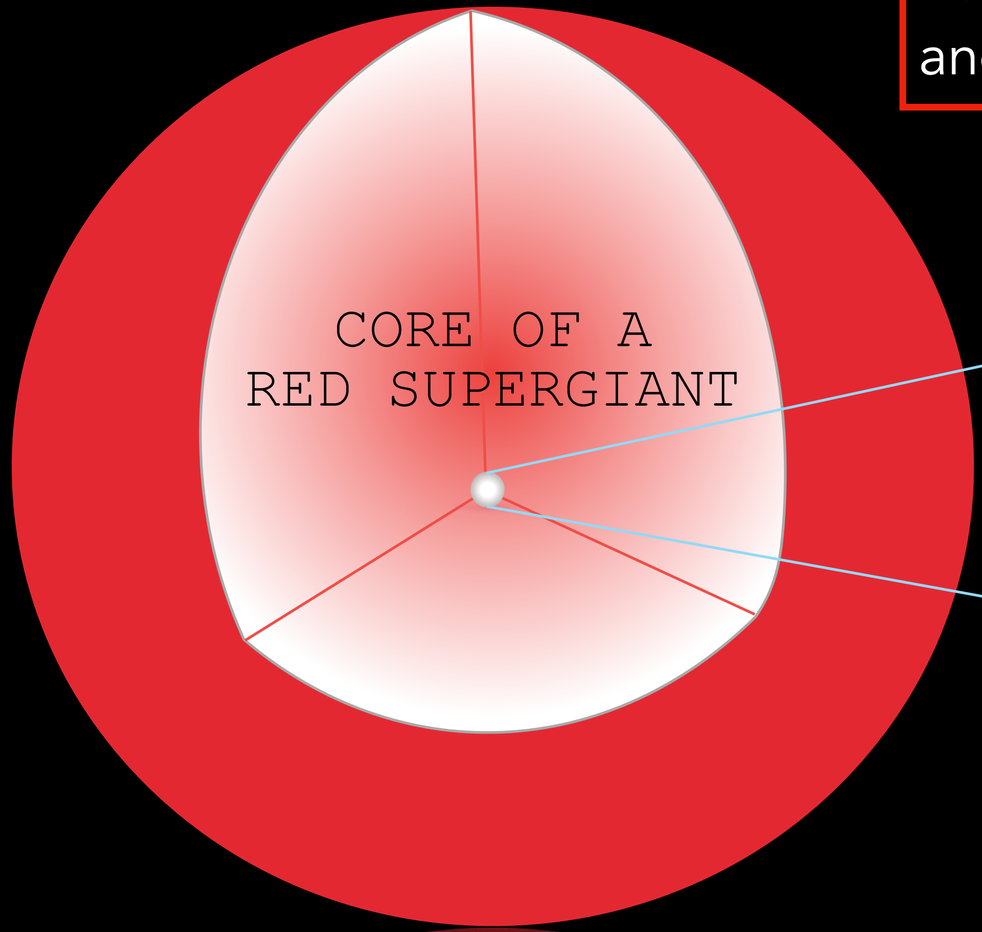


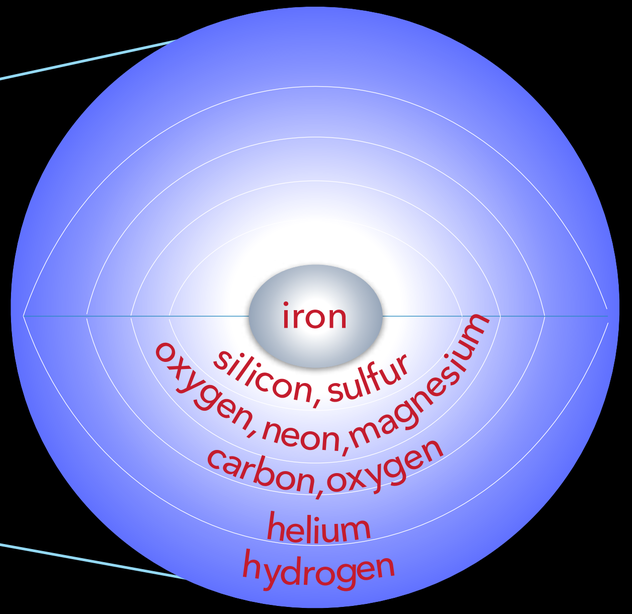
1987

NASA, ESA, and F. Summers and G. Bacon
STScI)
Simulation credit: S. Orlando
(INAF-Osservatorio Astronomico di Palermo)

Core Collapse Supernovae

Occurs at the end of a massive star's life. The star runs out of fuel, collapses, and subsequently explodes





Stellar core

$1M_\odot$ = 1 SOLAR MASS = THE MASS OF OUR SUN

DEATH OF MASSIVE STARS

WHITE $M < 8M_\odot$ DWARF

SUPERNOVA

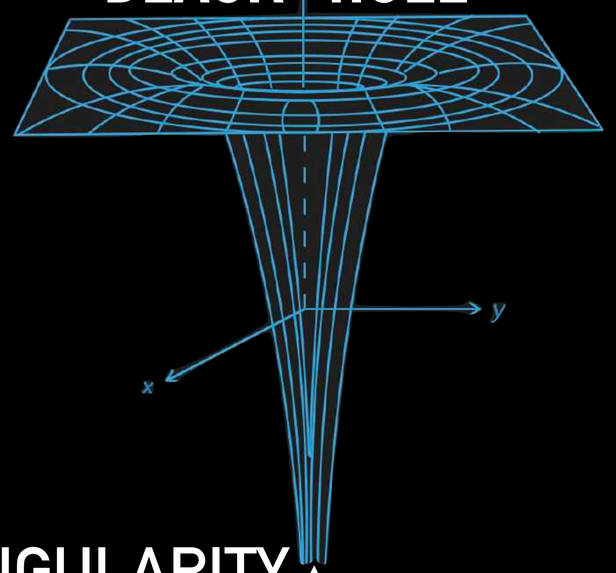
$M > 8M_\odot$

$M < 25M_\odot$

NEUTRON STAR

$M > 25M_\odot$

BLACK HOLE



SINGULARITY

$1M_\odot$ = 1 SOLAR MASS = THE MASS OF OUR SUN

DEATH OF STARS

WHITE $M < 8M_\odot$ DWARF

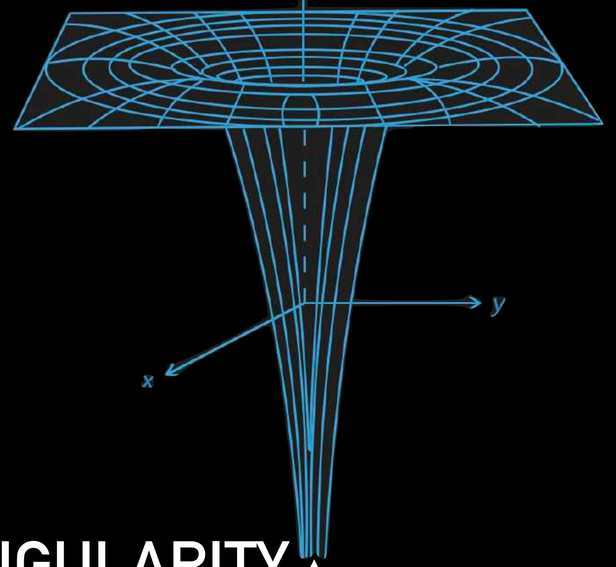
NEUTRON STAR

SUPERNOVA

Supernovae are powerful stellar explosions that push the boundaries of our physics knowledge.

$M > 25M_\odot$

BLACK HOLE



SINGULARITY

STELLAR GRAVEYARD

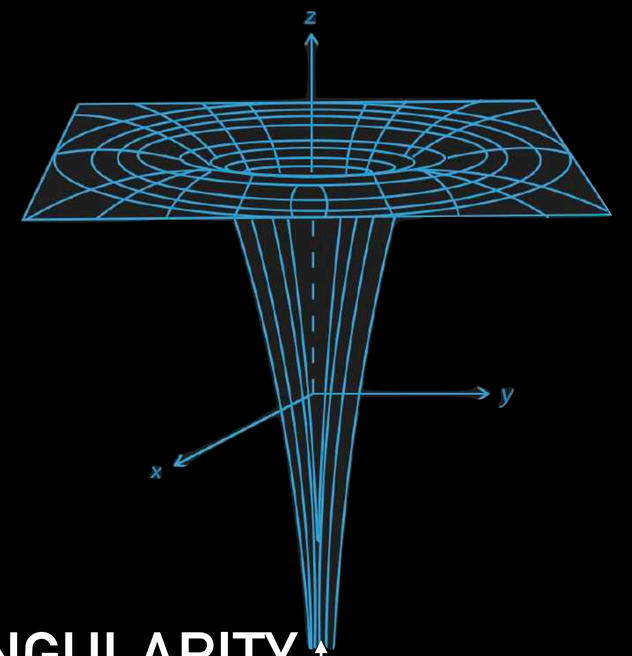
They form some of the most exotic phenomena in our Universe.

DWARF STARS

NEUTRON STAR

MAGNETAR

PULSAR



SINGULARITY

AND WHEN 2 OF THESE SPEEDY OBJECTS COLLIDE…

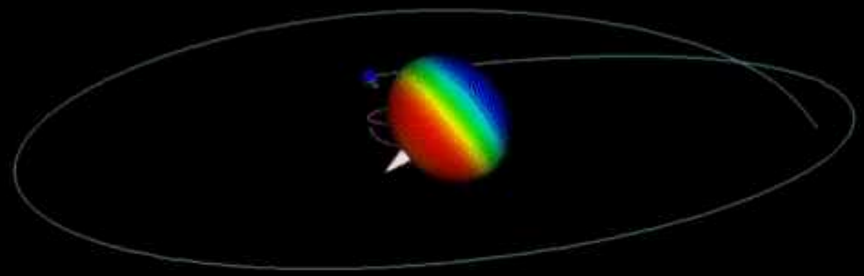
They create gravitational waves.

COMBINATIONS:

2 BLACK HOLES (BBH)

2 NEUTRON STARS (BNS)

1 NEUTRON STAR + 1 BLACK HOLE (NSBH)



Binary Black Holes (BBH)
Spins: 0.91 & 0.3
Mass Ratio: 6:1

by: Robert McGehee & Alex Streicher, SXS


Binary Black Holes (BBH)
Masses: ~30M⊙
Time: 1.3 billion years ago
By: Simulating eXtreme Spacetimes Project
www.black-holes.org

How do we find supernovae?

SEARCH FOR SUPERNOVAE

1 supernova per galaxy per 100 years

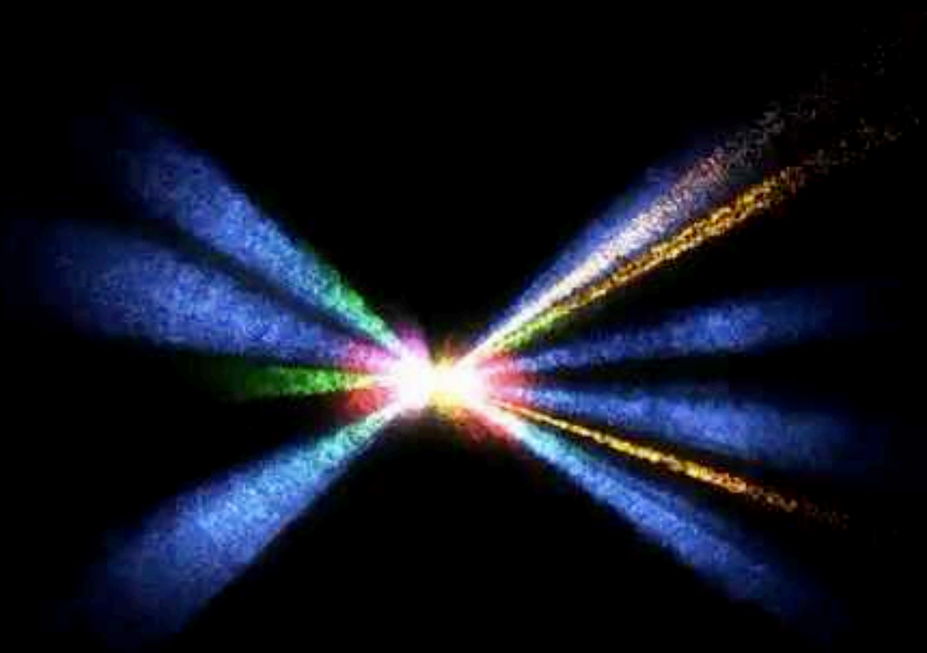
=

1 supernova per 100 galaxies per year

=

100 supernovae per 10,000 galaxies per year (if you monitor frequently enough)

3-D Visualization of
DES+OzDES, WiggleZ, GAMA, 2dF, 6dF, & SDSS Surveys



CENTER: US

DOTS: GALAXIES OBSERVED

Orange dots: DES + supernovae measured by OzDES.

Blue dots: WiggleZ Dark Energy Survey.

Green dots: Galaxy And Mass Assembly Survey (GAMA).

Red dots: 2dF Galaxy Redshift Survey.

Yellow dots: 6dF Galaxy Survey.

Purple dots: Sloan Digital Sky Survey (SDSS).

Animation by: Samuel Hinton

SEARCH FOR SUPERNOVAE

1 supernova per galaxy per 100 years

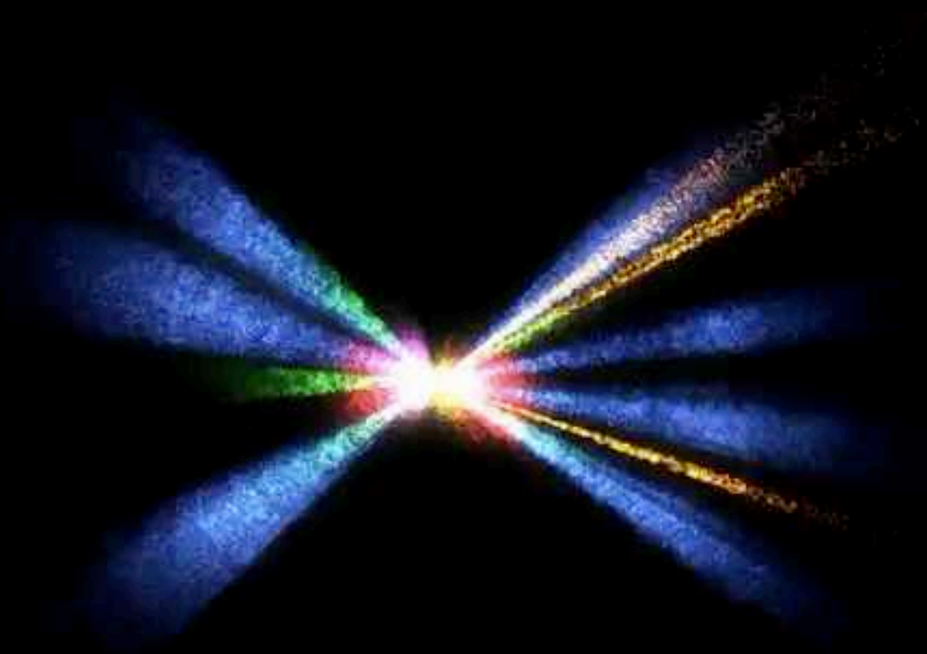
Thus, we need to look at a whole bunch of galaxies every single night!!!

er

100 supernovae per 10,000 galaxies per year (if you monitor frequently enough)

Animation by: Samuel Hinton

3-D Visualization of DES+OzDES, WiggleZ, GAMA, 2dF, 6dF, & SDSS Surveys



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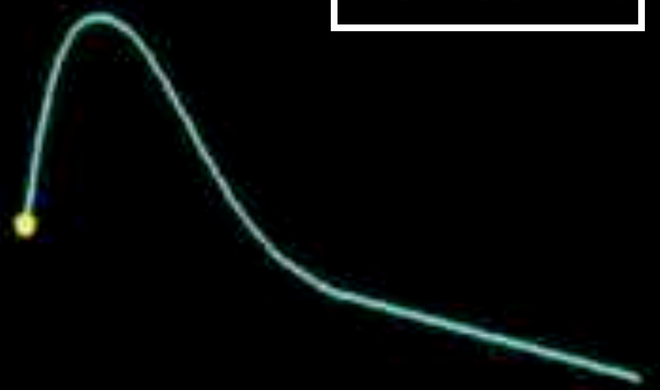
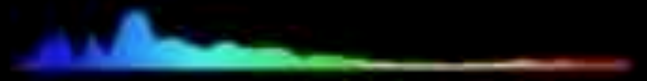
What kind of data do we get?

LIGHTCURVES



SPECTRA

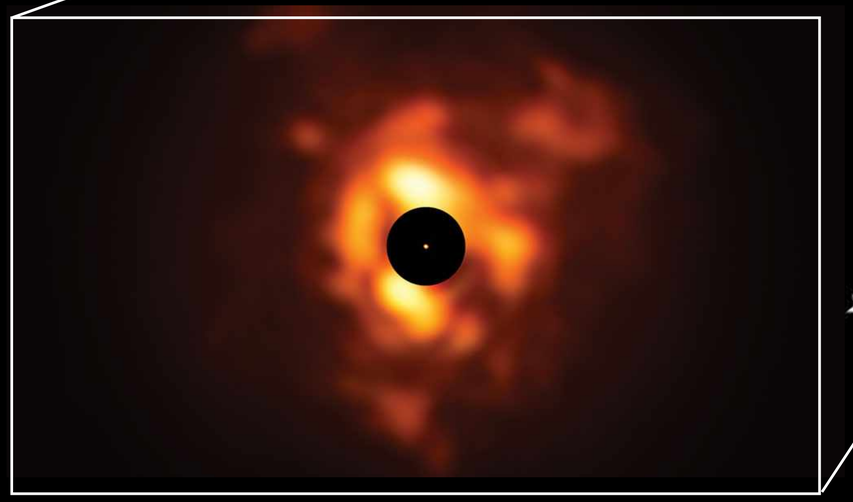


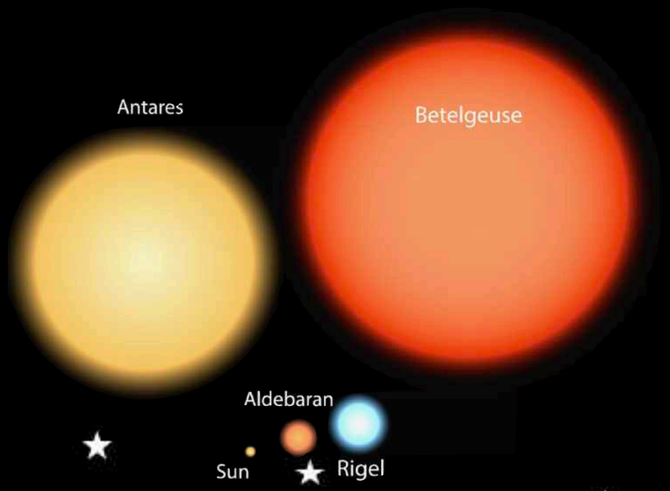
OUTLINE OF THIS TALK

- WHAT ARE SUPERNOVAE?
- BETELGEUSE:
  - The Great Dimming Event
  - When will it explode?
- THE ACCELERATING UNIVERSE:
  - Supernovae & the discovery of Dark Energy
  - The rate of the expansion of the Universe
  - The fates of the Universe
- HOW **YOU** CAN HELP US FIND SUPERNOVAE!

Betelgeuse

A Red Supergiant in the upper left shoulder of the constellation *Orion*





Betelgeuse photo: ESO, PIERRE KERVELLA, M. MONTARGÈS *ET AL*

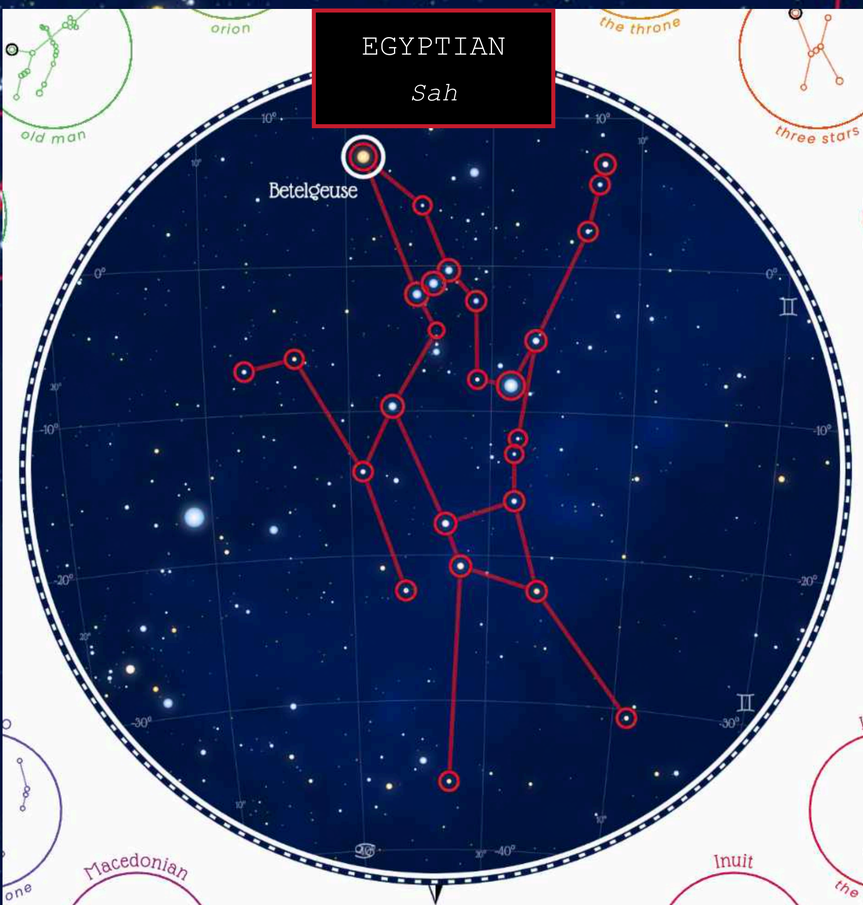
Betelgeuse:

IN CULTURES AROUND THE WORLD

Data viz from astronomer and data visualization lover: Nadieh Bremer

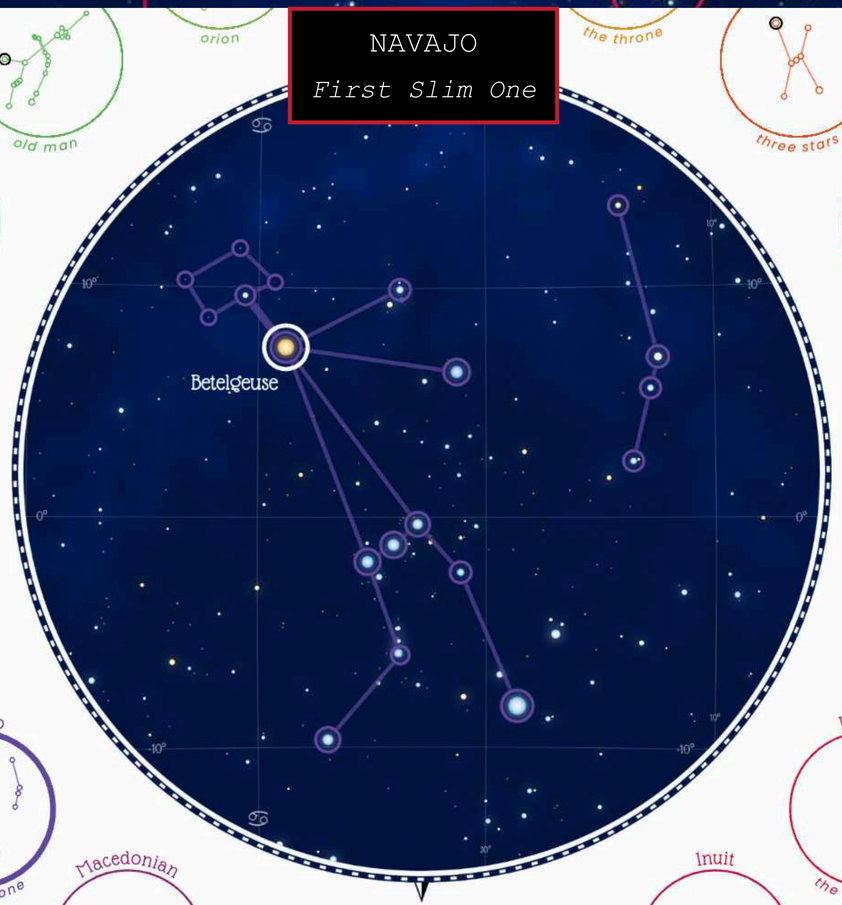
EGYPTIAN

Sah



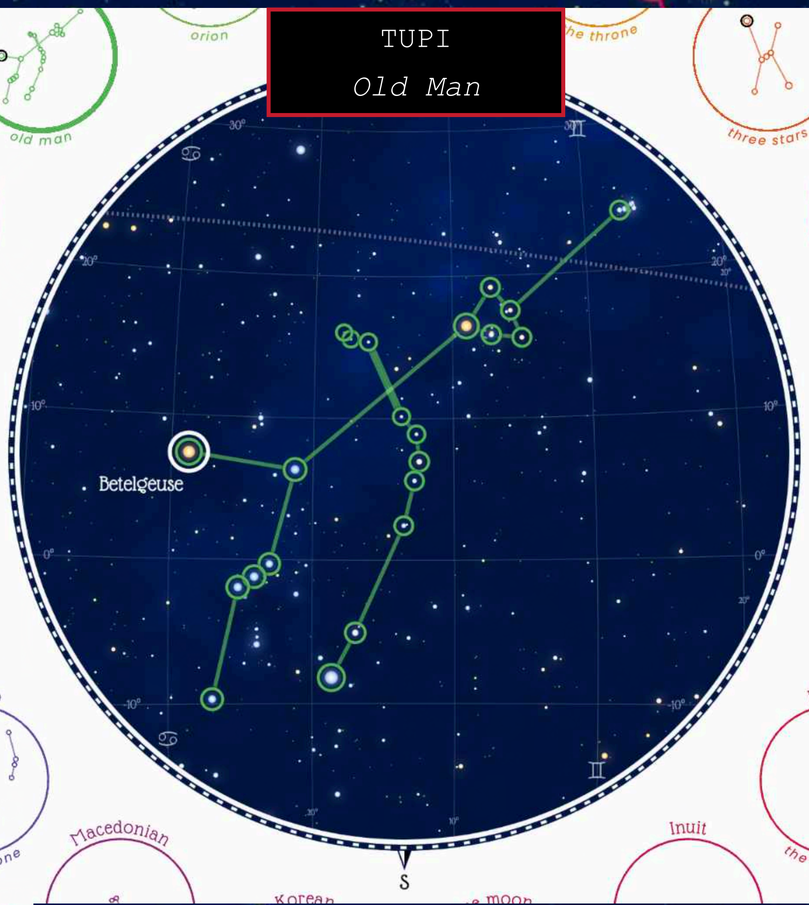
NAVAJO

First Slim One



TUPI

Old Man



Betelgeuse:

IN CULTURES AROUND THE WORLD

Data viz from astronomer and data visualization lover: Nadieh Bremer

ALL CULTURES LISTED

Arabic

Belarusian

Chinese

Dakota

Egyptian

Hawaiian Starlines

Indian

Inuit

Japanese Moon Stations

Korean

Macedonian

Navajo

Ojjbwe

Sardinian

Tukano

Tupi

Western

Is Betelgeuse going to explode soon?

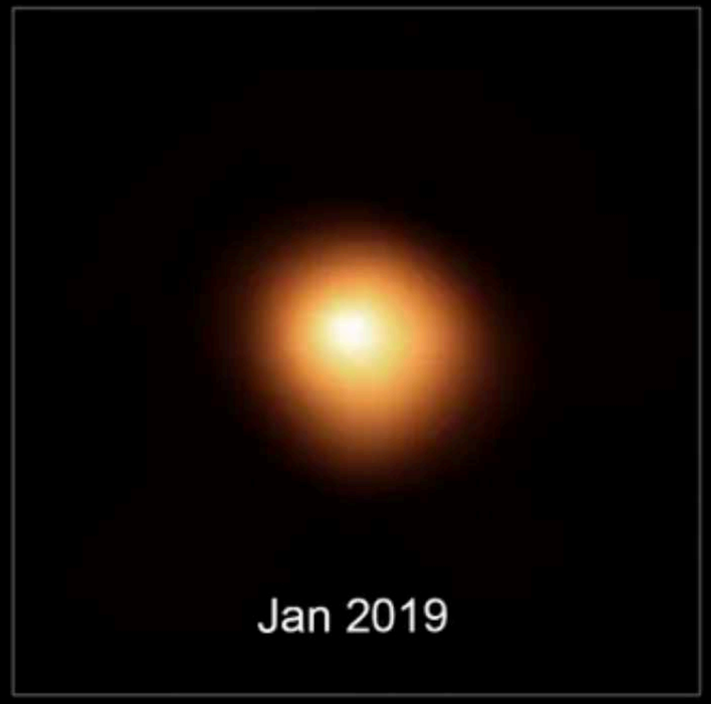
THE GREAT DIMMING EVENT

From 10/2019 - 2/2020, something really weird happened.

Betelgeuse dimmed. A lot.

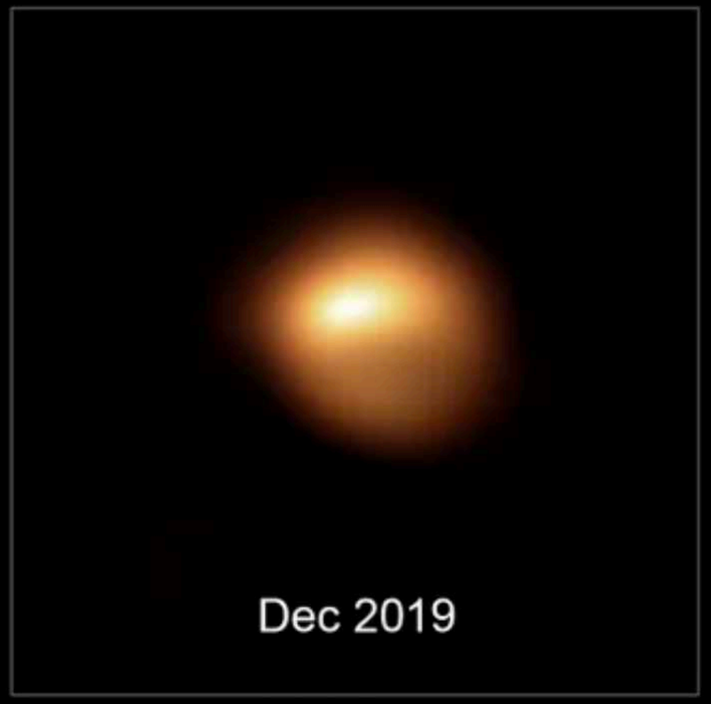
DOES THAT MEAN IT IS GOING TO EXPLODE SOON????

BEFORE DIMMING



Brightness: +0.2

AFTER DIMMING



Brightness: +1.12

SPHERE on ESO's VLT
ESO / M. Montarges et al.

THE GREAT DIMMING EVENT

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Home > Science news > Is the Betelgeuse star about to explode?

Is the Betelgeuse star about to explode?

2.26.2020 11:07 AM

SUPERNOVA WATCH

IS BETELGEUSE GOING TO EXPLODE? STAR'S BRIGHTENING TELLS A DIFFERENT STORY — FOR NOW

"Although the present dimming cycle seems over, it will be very important to see what happens next."

ience

Will Betelgeuse go supernova? Scientists uncover mystery of star's dimming brightness

Scientists were able to uncover the reason why the brightness of the Betelgeuse star has been dimming

By Carlo Inigo Monzon

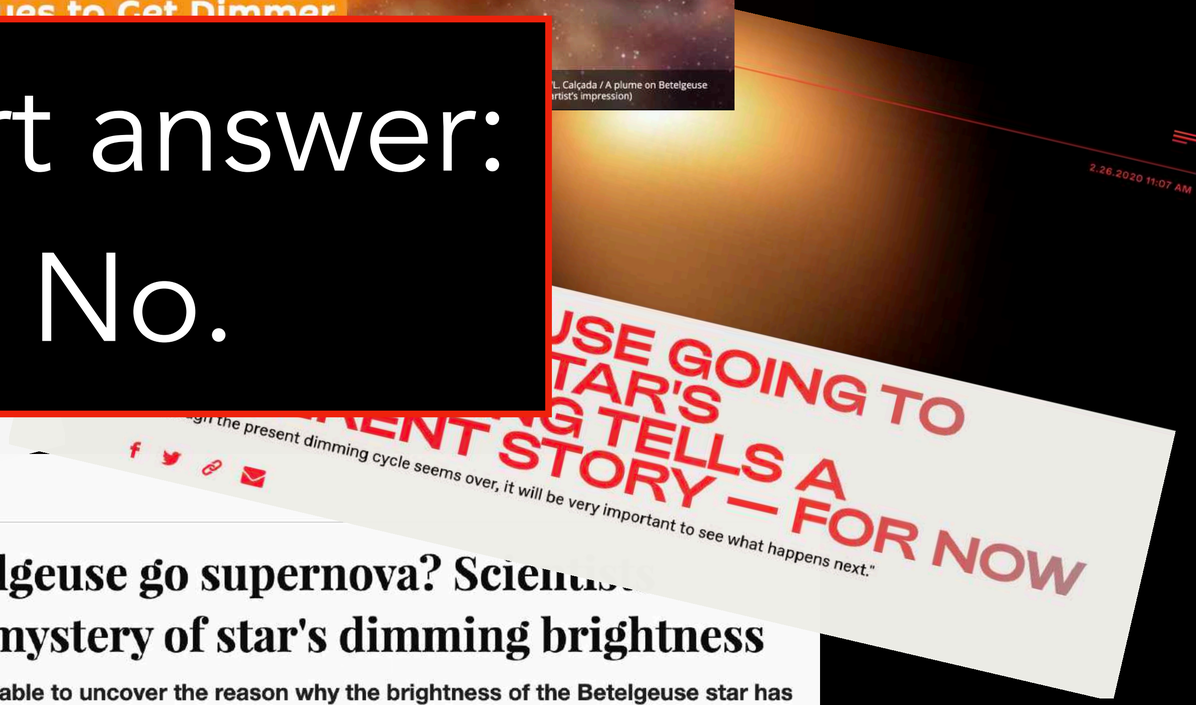
Updated March 10, 2020 15:00 +08

SPHERE on ESO's VLT
ESO / M. Montarges et al.

THE GREAT DIMMING EVENT

Short answer:

No.



SPHERE on ESO's VLT
ESO / M. Montarges et al.

THE GREAT DIMMING EVENT

Short answer:

No. :(

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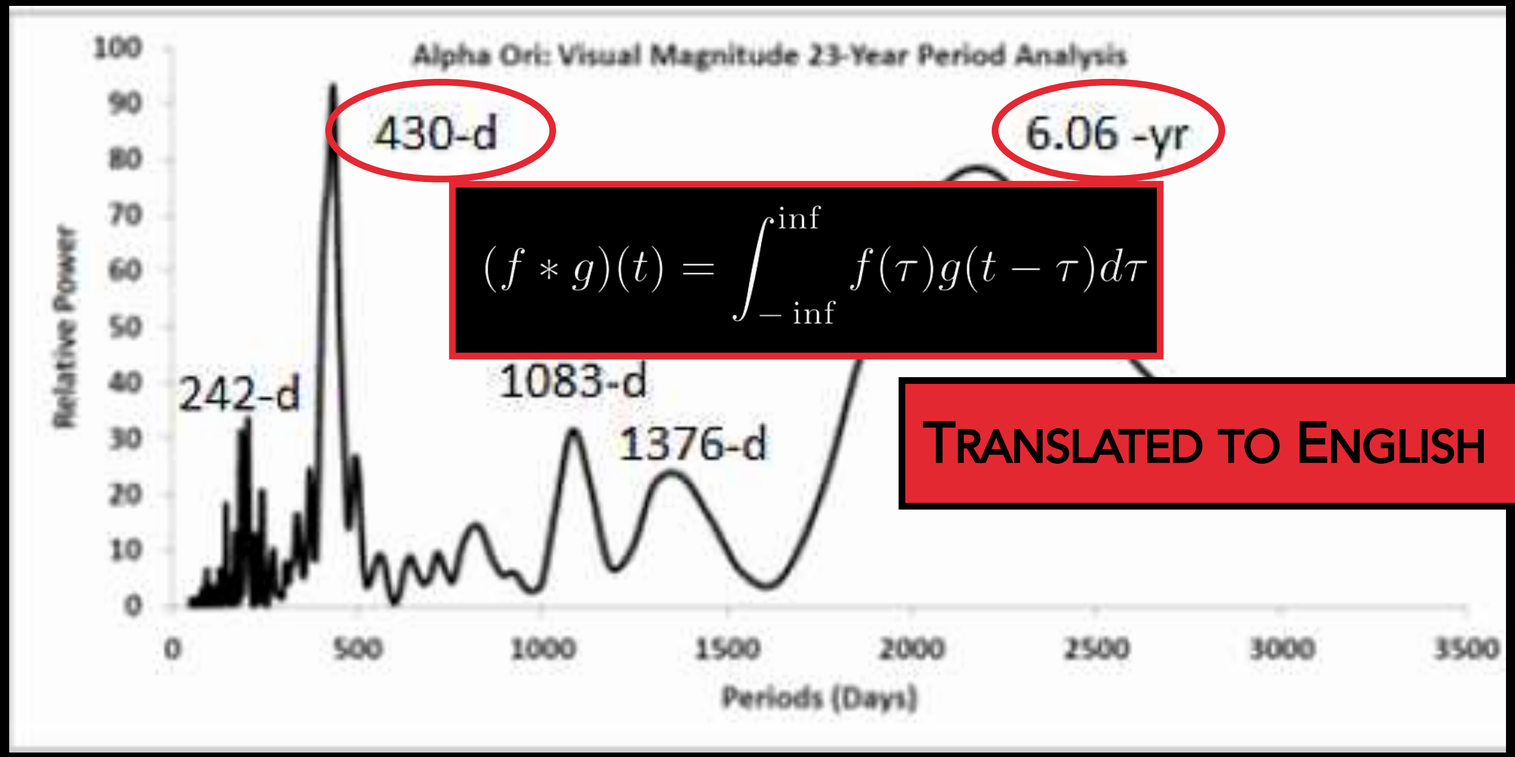
ESO / M. Montarges et al.

What does the data say?



$$(f * g)(t) = \int_{-\inf}^{\inf} f(\tau)g(t-\tau)d\tau$$

TRANSLATED TO ENGLISH

Betelgeuse has 2 distinct periods.

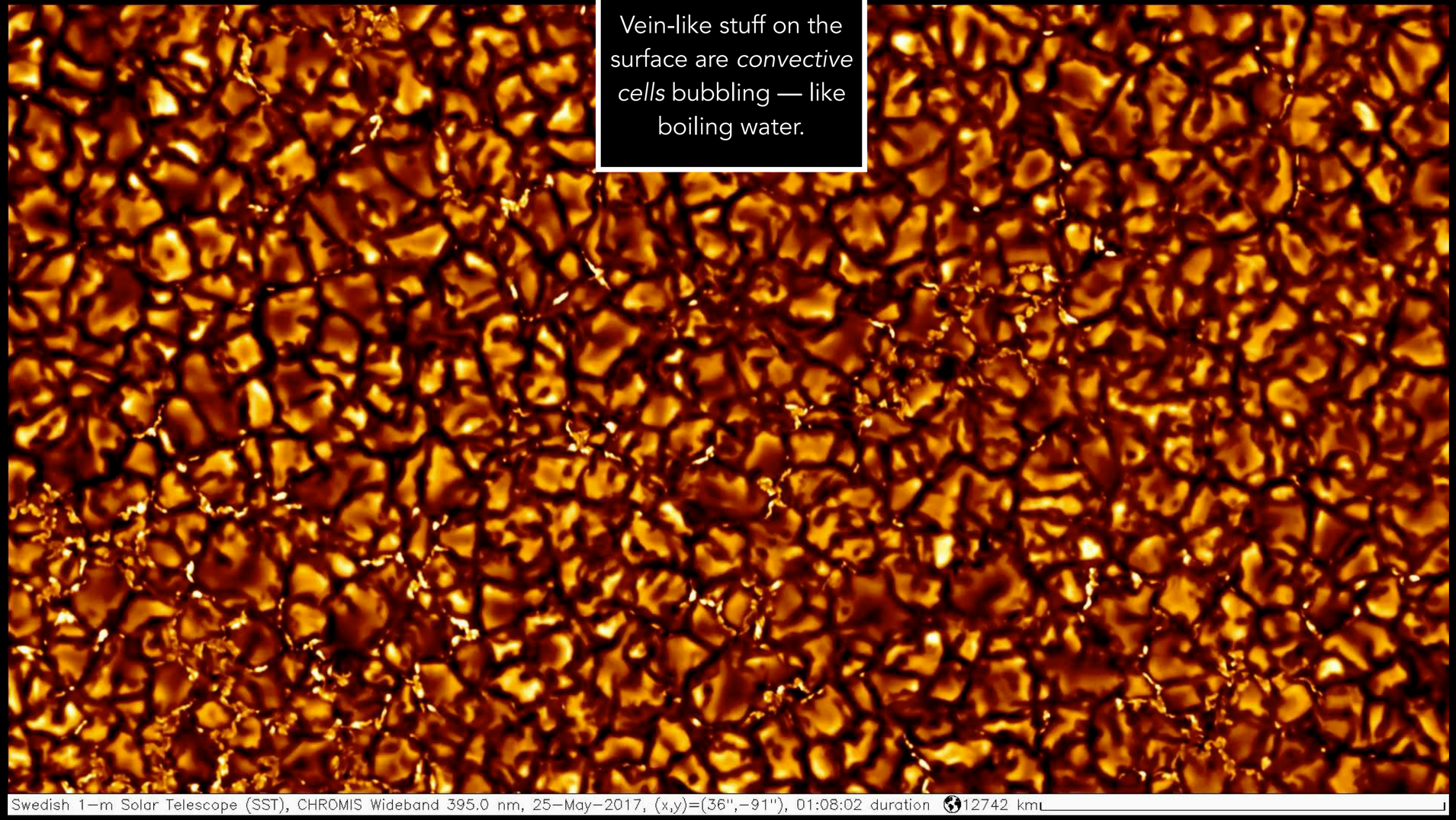
When combined, they create a periodic "beating" effect, which predicted the star would reach a minimum brightness between 2/14/20 & 2/28/20.

Guess what? It did just that.

After that, it re-brightened… right on schedule!!!

Theory #1

Vein-like stuff on the surface are *convective cells* bubbling — like boiling water.



Observer: Vasco Henriques
Data reductions : Vasco Henriques / Luc Rouppe van der Voort
Date: 25 May 2017
Wavelength: 3950 Å, near Ca II H and K

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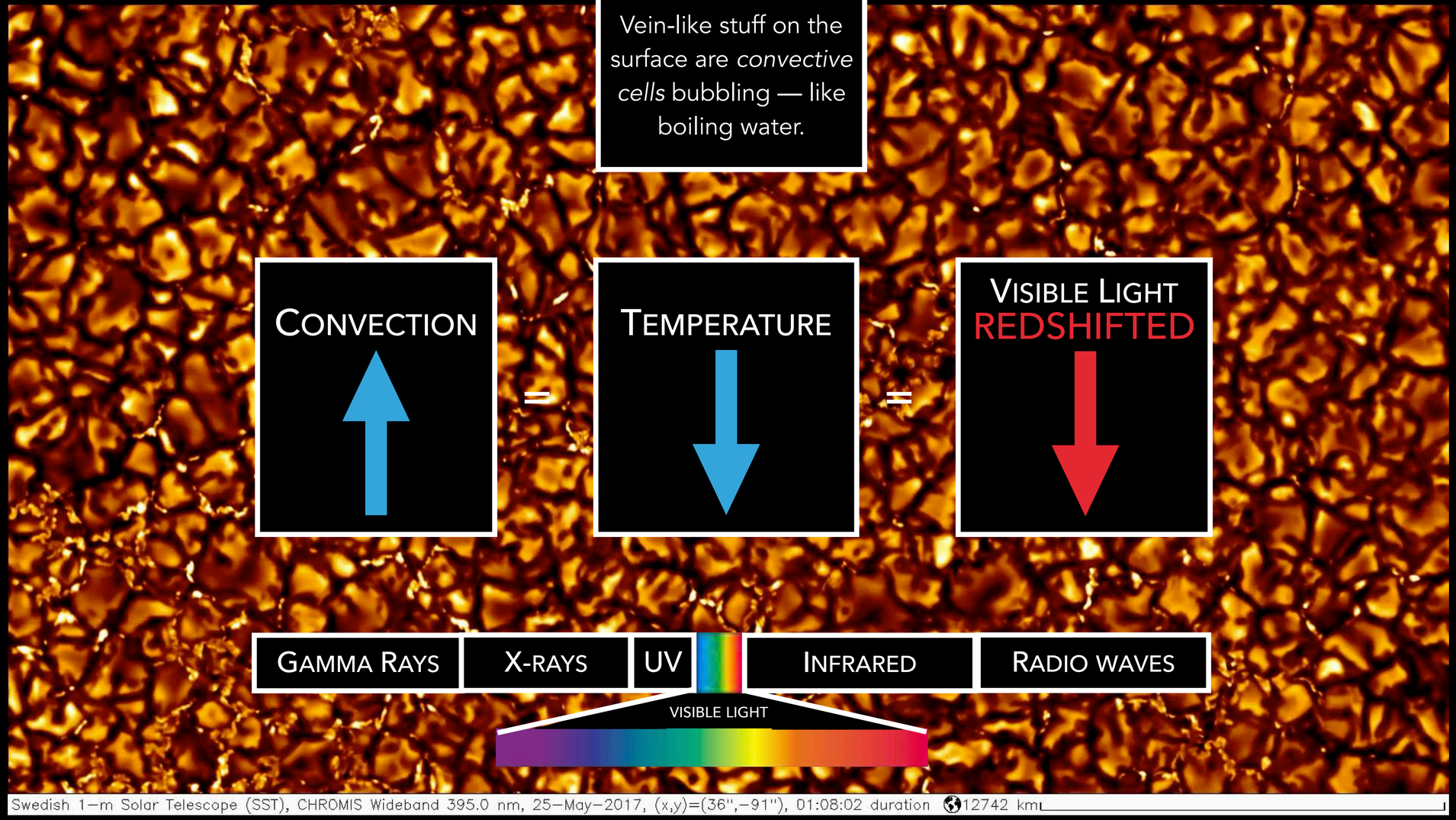

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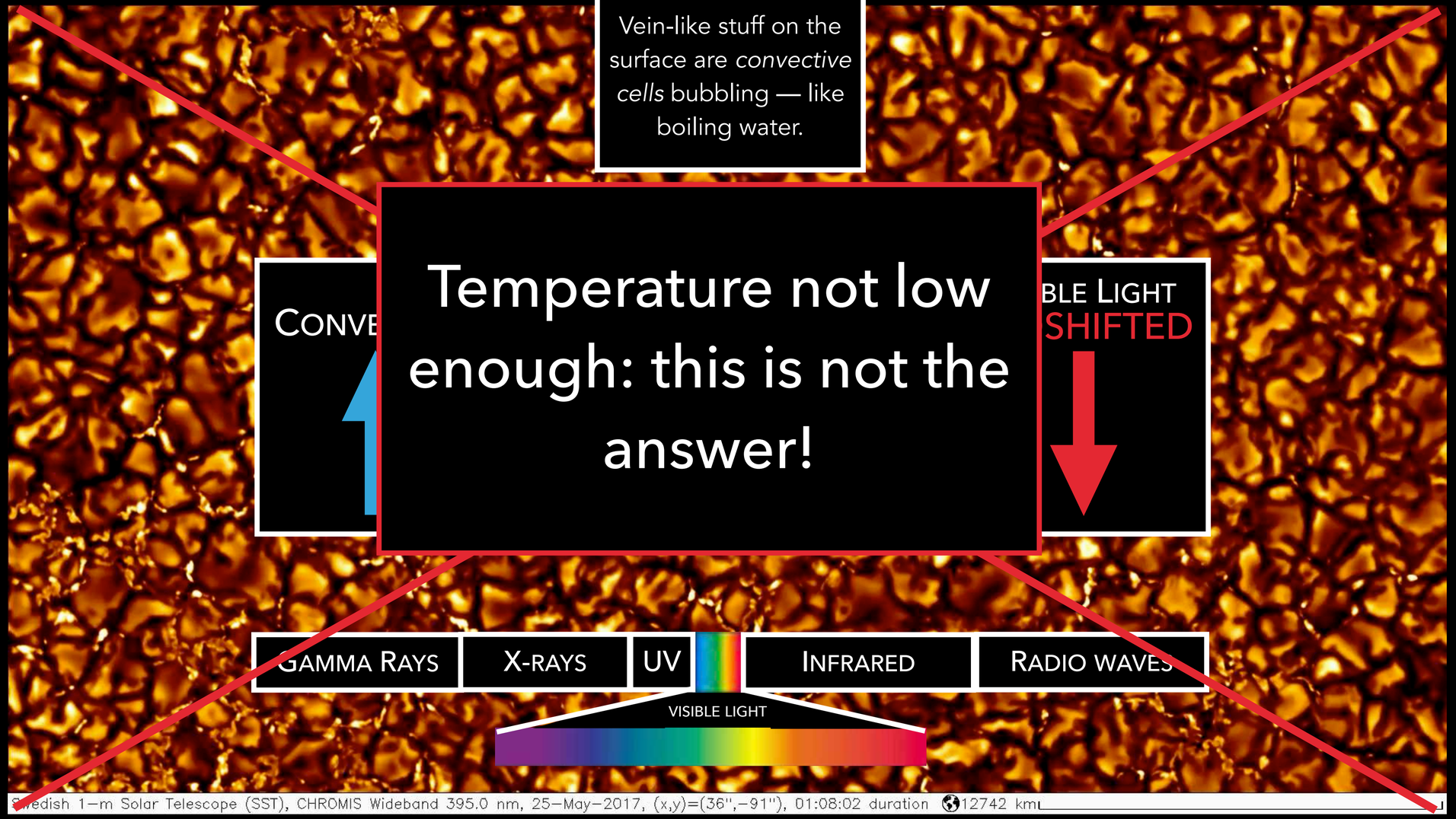

Observer: Vasco Henriques
Data reductions : Vasco Henriques / Luc Rouppe van der Voort
Date: 25 May 2017
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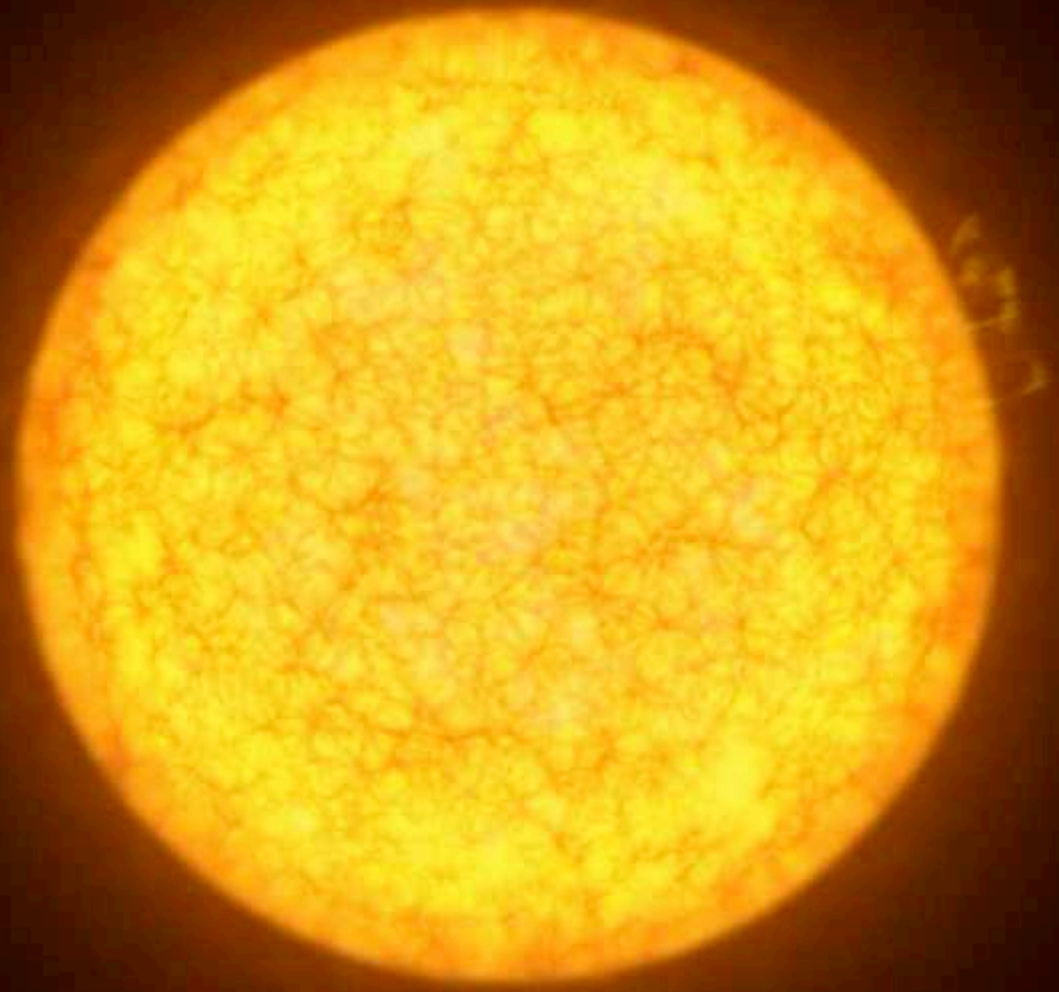
Theory #2



Betelgeuse burped out a shell of material that obscured the star, making it appear dimmer.

Notice the star

EXPANDING & SHRINKING,

thus growing

BRIGHTER & DIMMER

NASA, ESA, M. Kornmesser

Theory #2

Betelgeuse burped out a shell of material that obscured the star, making it appear dimmer.

We see evidence of "gray" dust around Betelgeuse – this seems to be the right answer!

Notice the star

EXPANDING & SHRINKING,

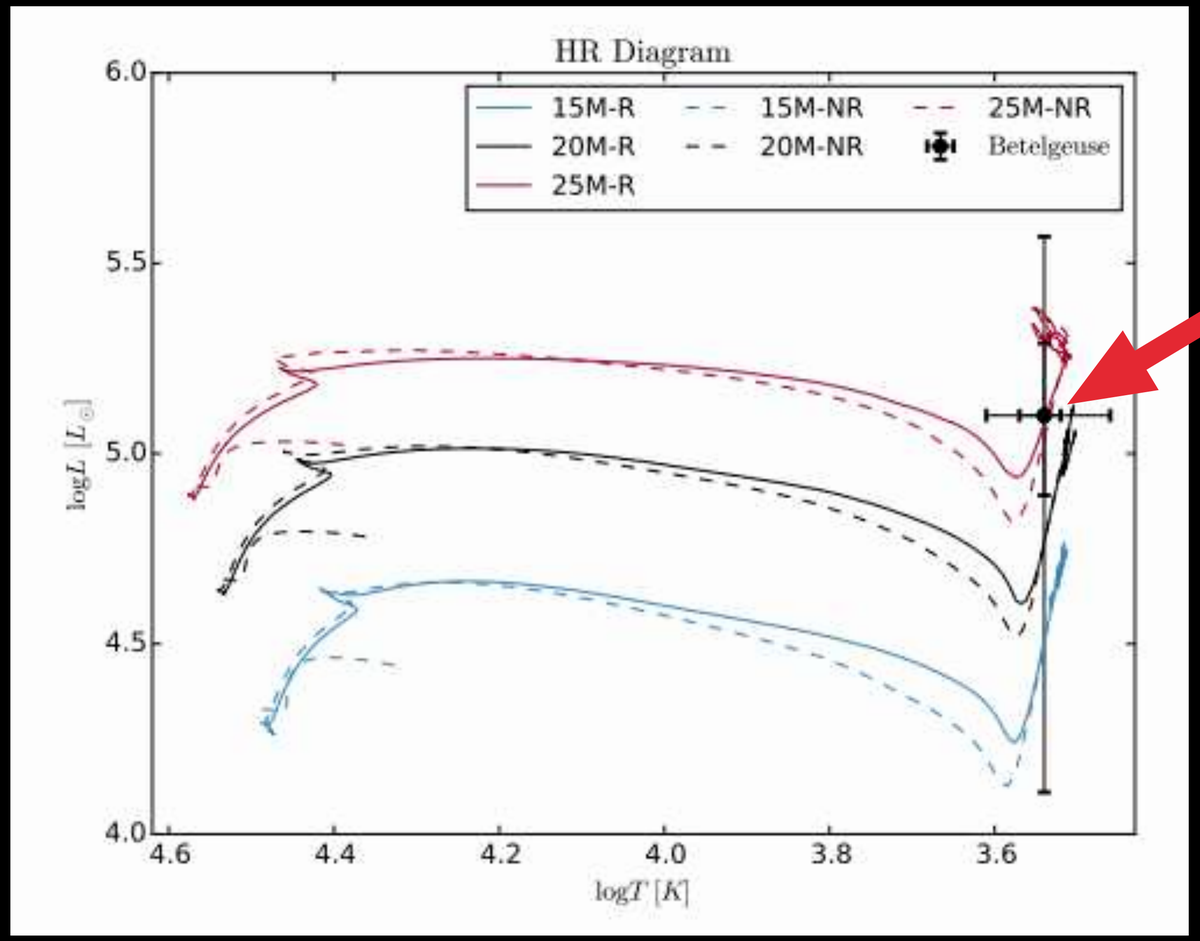
thus growing

BRIGHTER & DIMMER

NASA, ESA, M. Kornmesser

If Betelgeuse is NOT going to explode soon, then when WILL it explode?

Compare observations with simulations



Simulations comparing Betelgeuse's *observed characteristics* with its *simulated characteristics* place Betelgeuse at the base of the *Red Giant Branch*

AKA not exploding for another **~100,000 years** (or so)

Wheeler, Nance, et al. 2016

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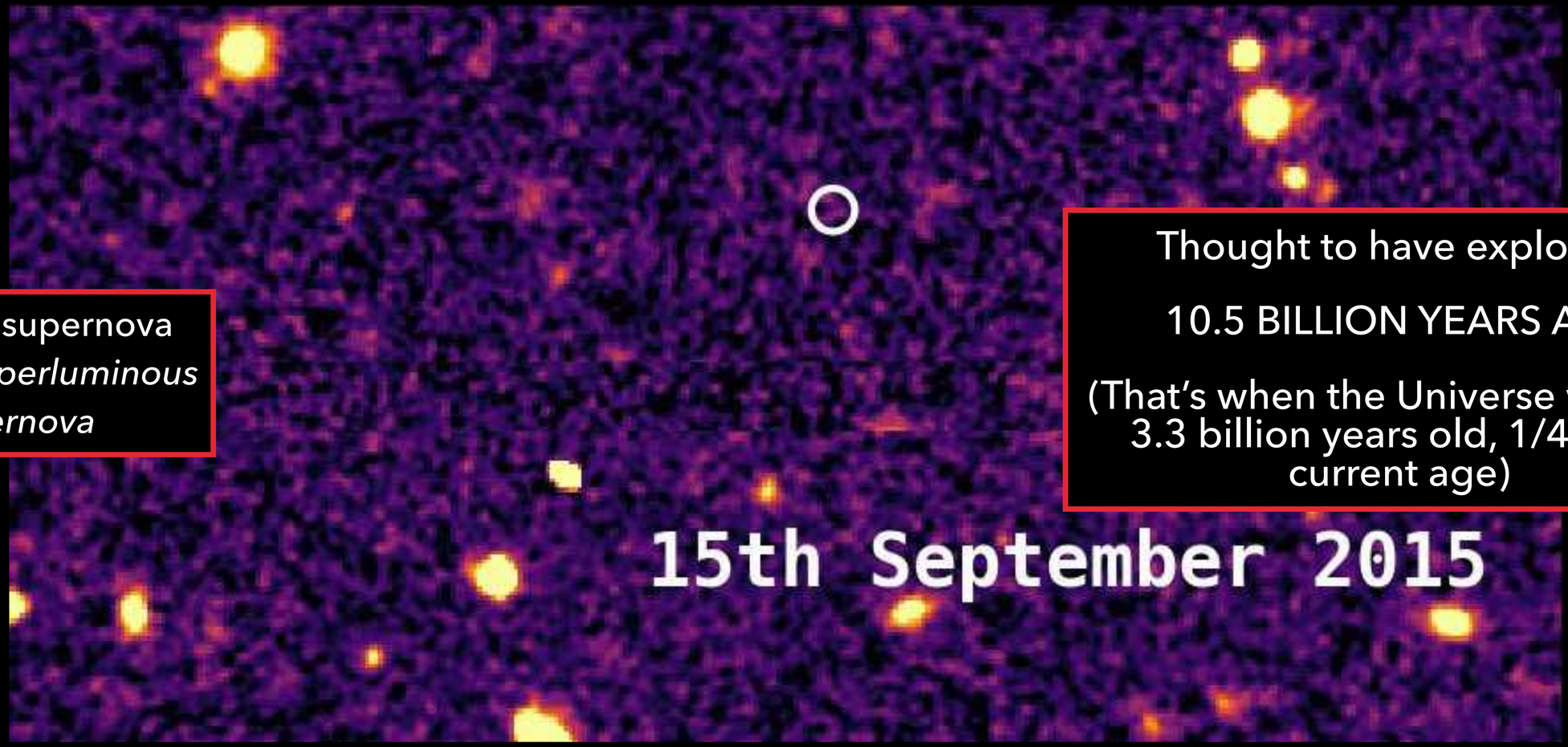
Searching the Cosmos with the

Hubble Space Telescope

Most Distant Supernova Ever

DES16C2nm



A type of supernova called a *Superluminous Supernova*

Thought to have exploded

10.5 BILLION YEARS AGO

(That's when the Universe was just 3.3 billion years old, 1/4 of its current age)

Mat Smith & DES Collaboration

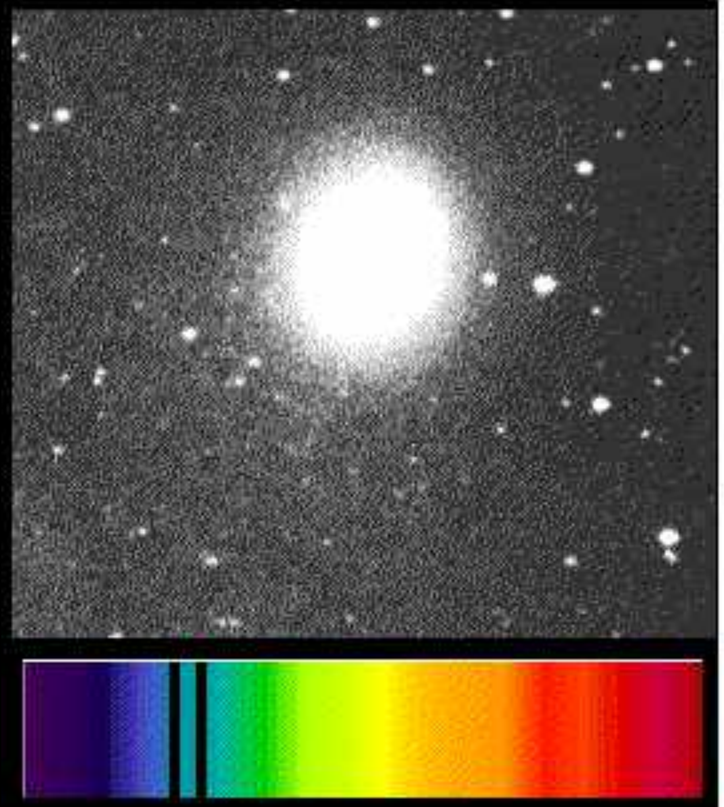
The Expanding Universe

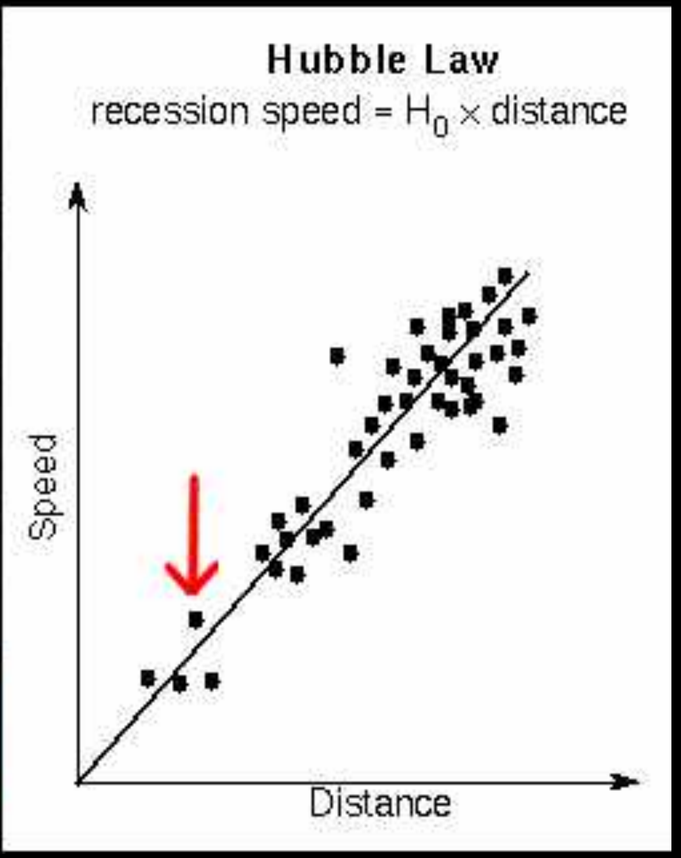
All galaxies move away from each other.

All galaxies have mass (stars, planets, etc.) which means they gravitationally pull on each other.

All this pulling ***should*** slow down the Hubble Expansion, forcing distant galaxies to slow down.

Visualization of Hubble's Law (1929)





The Expanding Universe

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Way better visualization of Hubble's Law (1929) that includes bread

The Expanding Universe

All galaxies move away from each other.

All galaxies have mass (stars, planets, etc.) which means they gravitationally pull on each other.

All this pulling ***should*** slow down the Hubble Expansion, forcing distant galaxies to slow down.

But that's not what we see!!!!!

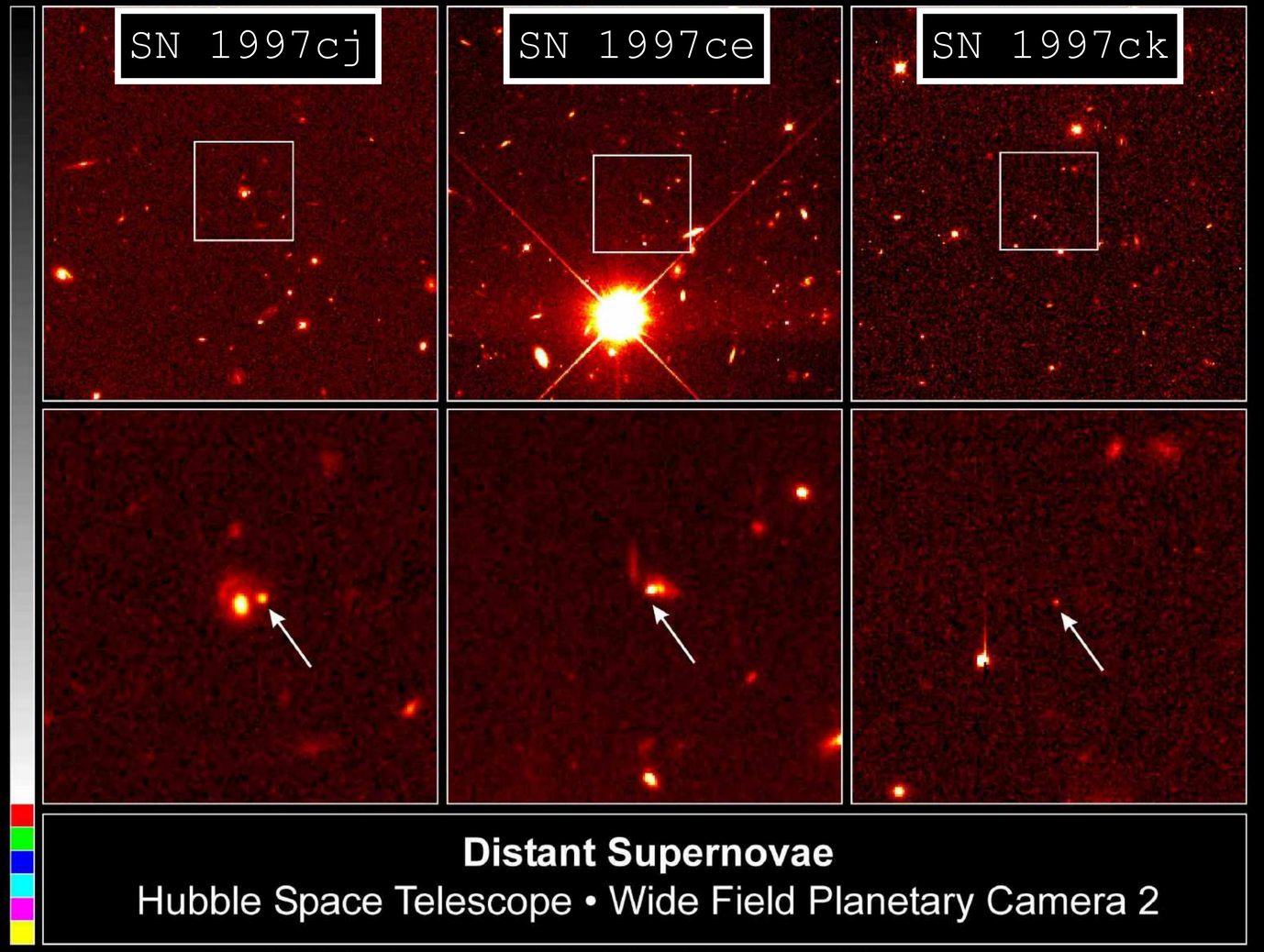
Way better visualization of Hubble's Law (1929) that includes bread

The Expanding Universe

Instead, in 1997, astronomers found something very weird.

Distant supernovae appeared fainter than expected.

Thus, they must be farther away than we thought.



Peter Garnavich, Harvard-Smithsonian Center for Astrophysics, the High-z Supernova Search Team, and NASA/ESA

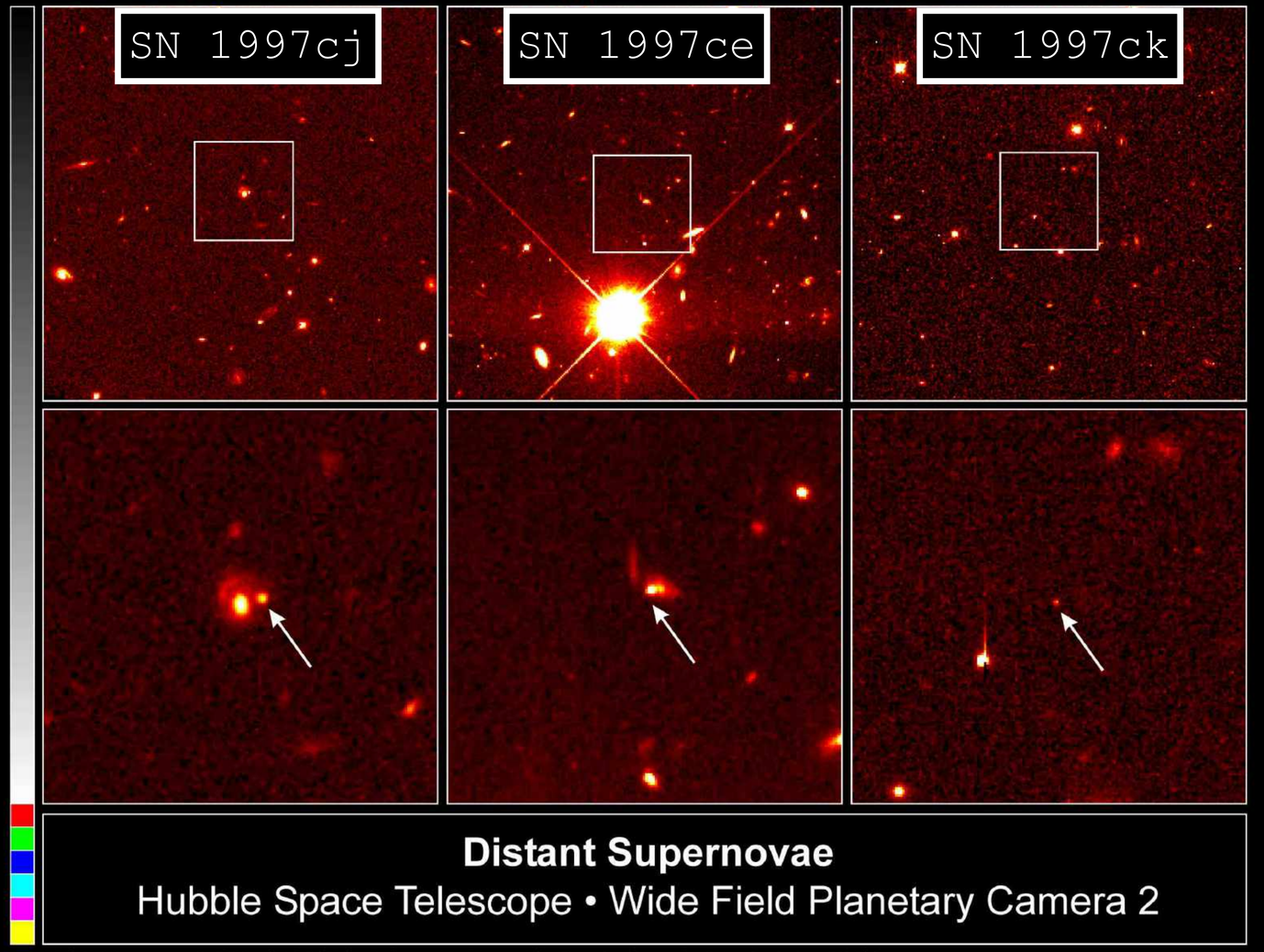
The Expanding Universe

Instead, in 1997, astronomers found something very weird.

Distant supernovae appeared <u>fainter</u> than expected.

Thus, they must be <u>farther away</u> than we thought.

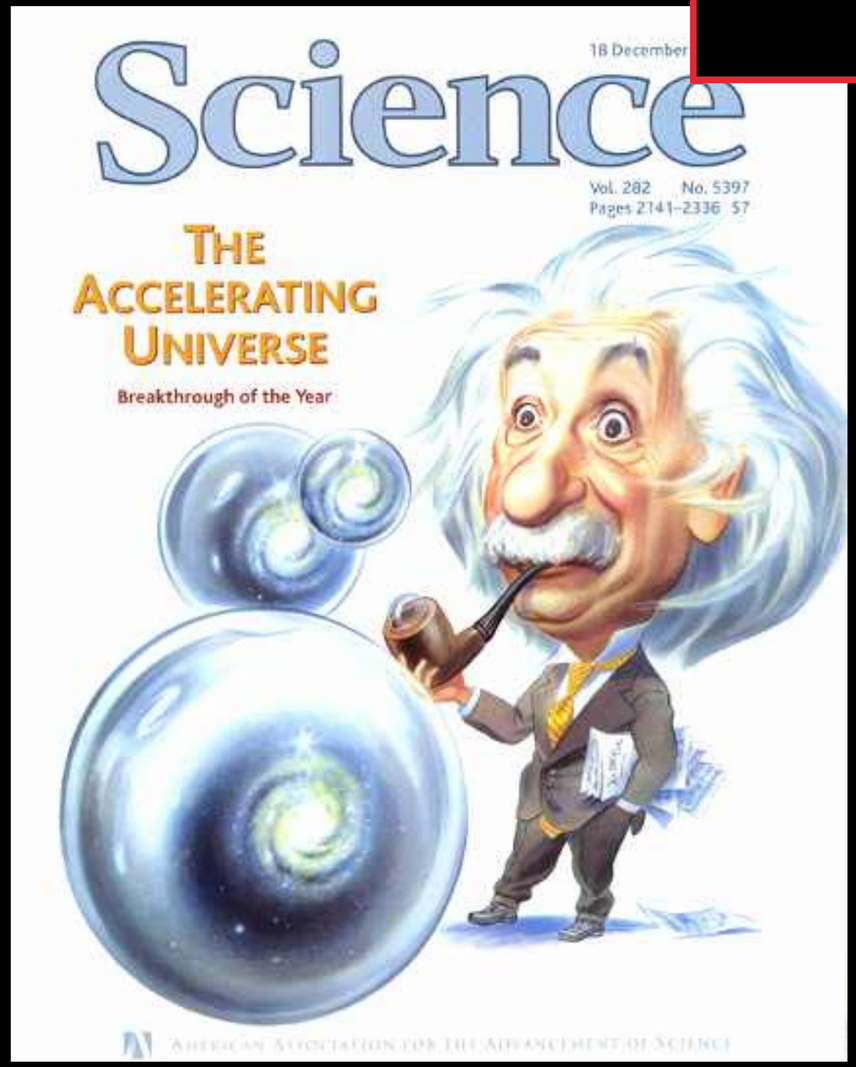
Something must be forcing the Universe to expand faster and faster to explain the dim supernovae, *not* slowing down as expected. But what?

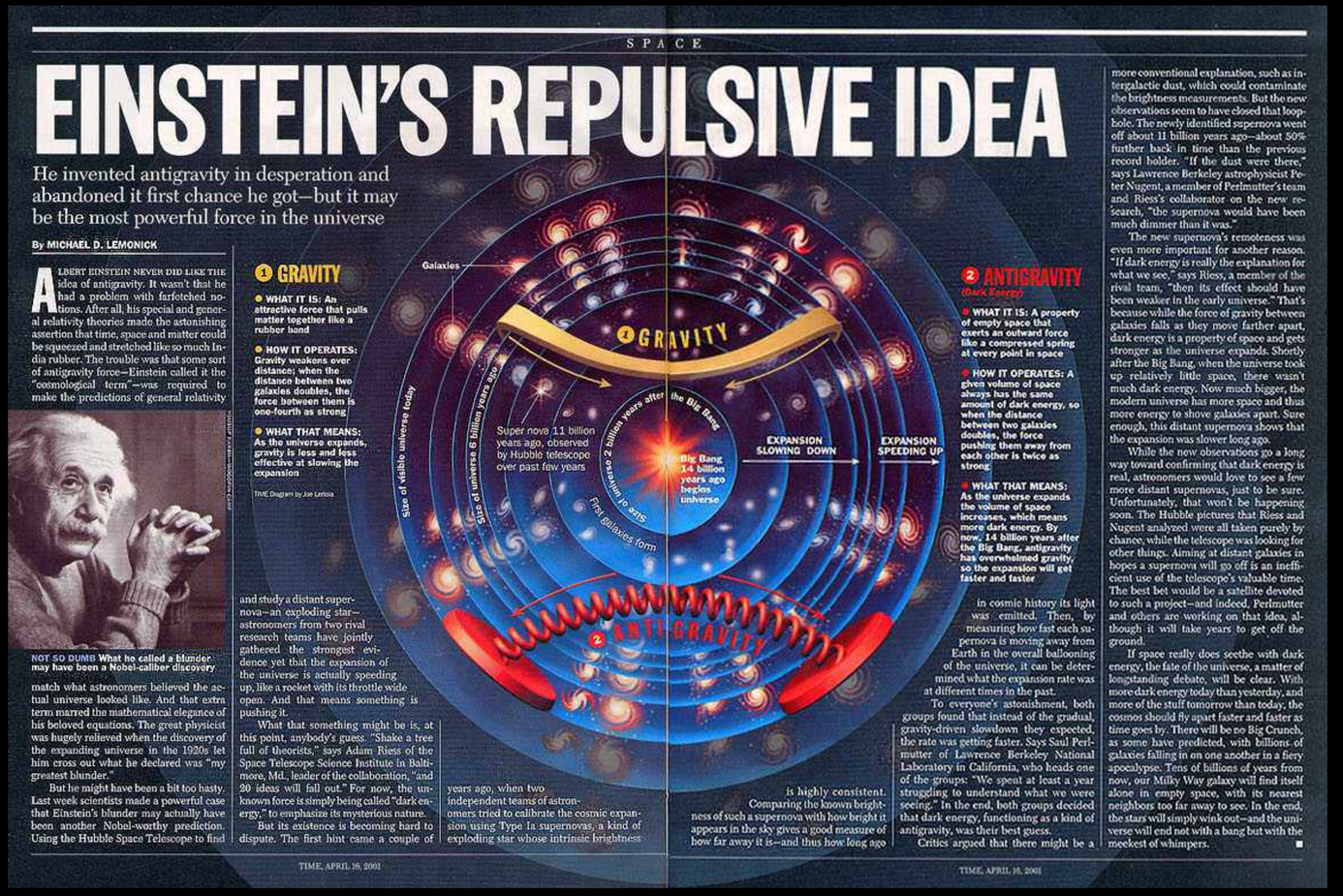


Peter Garnavich, Harvard-Smithsonian Center for Astrophysics, the High-z Supernova Search Team, and NASA/ESA

The ~~Expanding~~ Accelerating Universe

1998 Scientific Breakthrough of the Year





SPACE

EINSTEIN'S REPULSIVE IDEA

He invented antigravity in desperation and abandoned it first chance he got—but it may be the most powerful force in the universe

By MICHAEL D. LEMONICK

ALBERT EINSTEIN NEVER DID LIKE THE idea of antigravity. It wasn't that he had a problem with farfetched notions. After all, his special and general relativity theories made the astonishing assertion that time, space and matter could be squeezed and stretched like so much India rubber. The trouble was that some sort of antigravity force—Einstein called it the "cosmological term"—was required to make the predictions of general relativity match what astronomers believed the actual universe looked like. And that extra term marred the mathematical elegance of his beloved equations. The great physicist was hugely relieved when the discovery of the expanding universe in the 1920s let him cross out what he declared was "my greatest blunder."

But he might have been a bit too hasty. Last week scientists made a powerful case that Einstein's blunder may actually have been another Nobel-worthy prediction. Using the Hubble Space Telescope to find and study a distant supernova—an exploding star—astronomers from two rival research teams have jointly gathered the strongest evidence yet that the expansion of the universe is actually speeding up, like a rocket with its throttle wide open. And that means something is pushing it.

What that something might be is, at this point, anybody's guess. "Shake a tree full of theorists," says Adam Riess of the Space Telescope Science Institute in Baltimore, Md., leader of the collaboration, "and 20 ideas will fall out." For now, the unknown force is simply being called "dark energy," to emphasize its mysterious nature.

But its existence is becoming hard to dispute. The first hint came a couple of years ago, when two independent teams of astronomers tried to calibrate the cosmic expansion using Type Ia supernovas, a kind of exploding star whose intrinsic brightness is highly consistent. Comparing the known brightness of such a supernova with how bright it appears in the sky gives a good measure of how far away it is—and thus how long ago in cosmic history its light was emitted. Then, by measuring how fast each supernova is moving away from Earth in the overall ballooning of the universe, it can be determined what the expansion rate was at different times in the past.

To everyone's astonishment, both groups found that instead of the gradual, gravity-driven slowdown they expected, the rate was getting faster. Says Saul Perlmutter of Lawrence Berkeley National Laboratory in California, who heads one of the groups: "We spent at least a year struggling to understand what we were seeing." In the end, both groups decided that dark energy, functioning as a kind of antigravity, was their best guess.

Critics argued that there might be a more conventional explanation, such as intergalactic dust, which could contaminate the brightness measurements. But the new observations seems to have closed that loophole. The newly identified supernova went off about 11 billion years ago—about 50% further back in time than the previous record holder. "If the dust were there," says Lawrence Berkeley astrophysicist Peter Nugent, a member of Perlmutter's team and Riess's collaborator on the new research, "the supernova would have been much dimmer than it was."

The new supernova's remoteness was even more important for another reason. "If dark energy is really the explanation for what we see," says Riess, a member of the rival team, "then its effect should have been weaker in the early universe." That's because while the force of gravity between galaxies falls as they move farther apart, dark energy is a property of space and gets stronger as the universe expands. Shortly after the Big Bang, when the universe took up relatively little space, there wasn't much dark energy. Now much bigger, the modern universe has more space and thus more energy to shove galaxies apart. Sure enough, this distant supernova shows that the expansion was slower long ago.

While the new observations go a long way toward confirming that dark energy is real, astronomers would love to see a few more distant supernovas, just to be sure. Unfortunately, that won't be happening soon. The Hubble pictures that Riess and Nugent analyzed were all taken purely by chance, while the telescope was looking for other things. Aiming at distant galaxies in hopes a supernova will go off is an inefficient use of the telescope's valuable time. The best bet would be a satellite devoted to such a project—and indeed, Perlmutter and others are working on that idea, although it will take years to get off the ground.

If space really does seethe with dark energy, the fate of the universe, a matter of longstanding debate, will be clear. With more dark energy today than yesterday, and more of the stuff tomorrow than today, the cosmos should fly apart faster and faster as time goes by. There will be no Big Crunch, as some have predicted, with billions of galaxies falling in on one another in a fiery apocalypse. Tens of billions of years from now, our Milky Way galaxy will find itself alone in empty space, with its nearest neighbors too far away to see. In the end, the stars will simply wink out—and the universe will end not with a bang but with the meekest of whimpers. ■

NOT SO DUMB What he called a blunder may have been a Nobel-caliber discovery

1 GRAVITY

- WHAT IT IS: An attractive force that pulls matter together like a rubber band
- HOW IT OPERATES: Gravity weakens over distance; when the distance between two galaxies doubles, the force between them is one-fourth as strong
- WHAT THAT MEANS: As the universe expands, gravity is less and less effective at slowing the expansion

TIME Diagram by Joe Lertola

2 ANTIGRAVITY (Dark Energy)

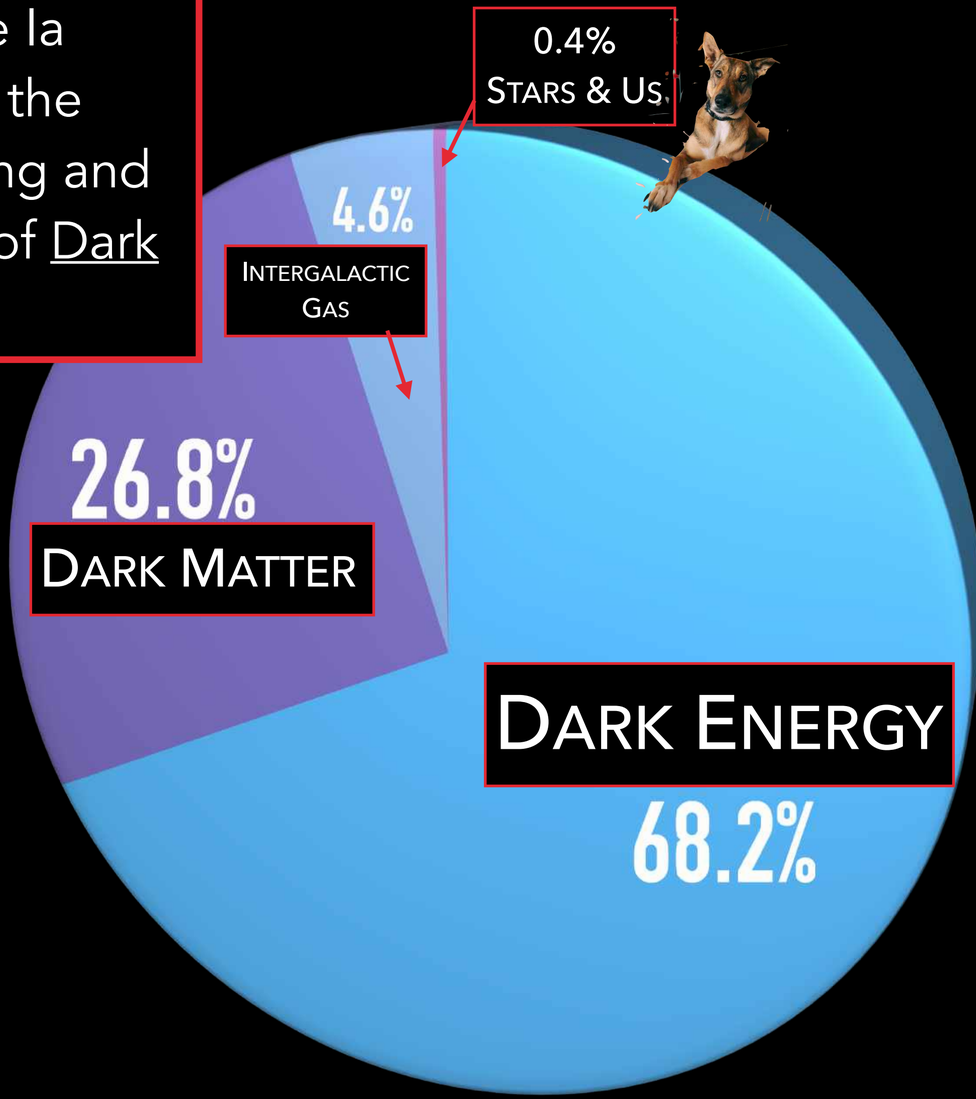
- WHAT IT IS: A property of empty space that exerts an outward force like a compressed spring at every point in space
- HOW IT OPERATES: A given volume of space always has the same amount of dark energy, so when the distance between two galaxies doubles, the force pushing them away from each other is twice as strong
- WHAT THAT MEANS: As the universe expands the volume of space increases, which means more dark energy. By now, 14 billion years after the Big Bang, antigravity has overwhelmed gravity, so the expansion will get faster and faster

TIME, APRIL 16, 2001

The ~~Expanding~~ Accelerating Universe

Observations of distant Type Ia supernovae have shown that the Universe is "currently accelerating and that over 2/3 of it is in the form of Dark Energy."

Nobel Prize Ceremony, 2011

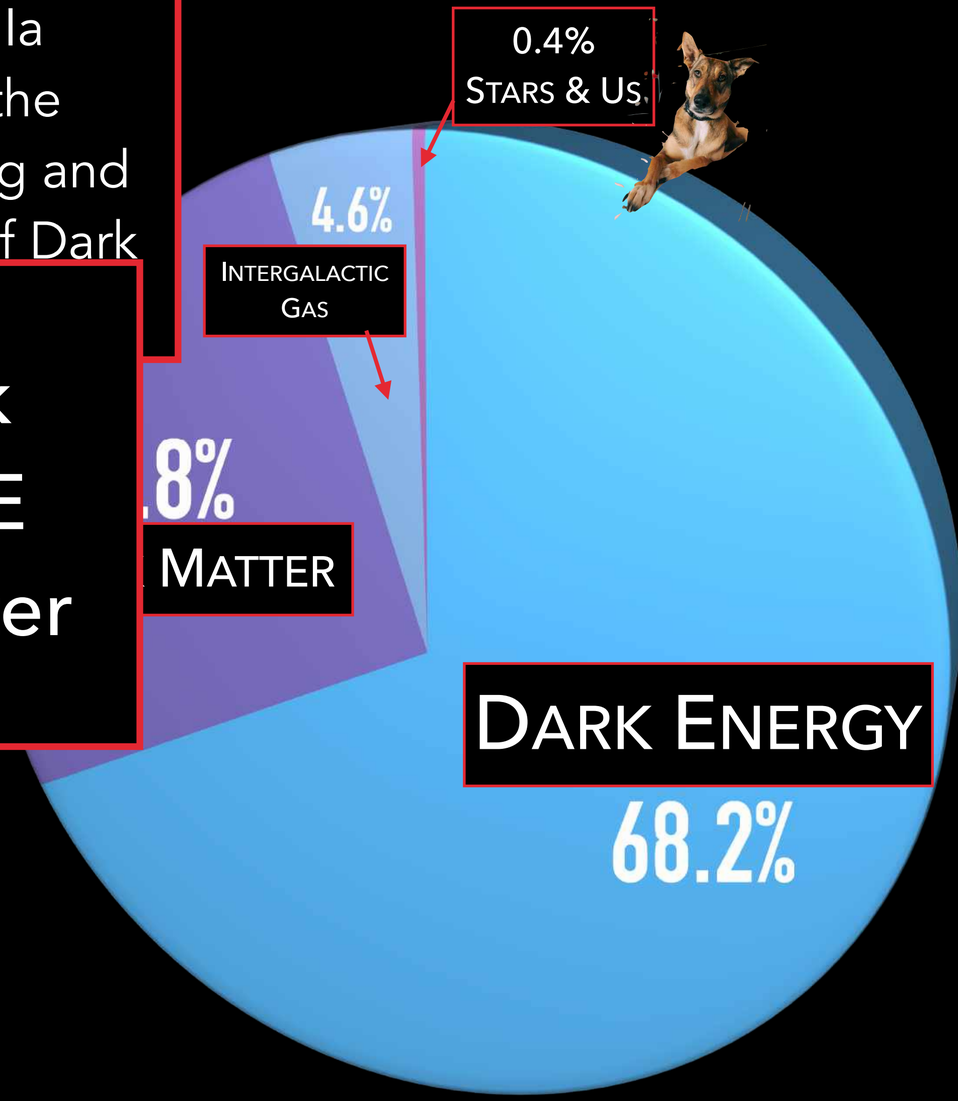


The ~~Expanding~~ Accelerating Universe

Observations of distant Type Ia supernovae have shown that the Universe is "currently accelerating and that over 2/3 of it is in the form of Dark

IMPORTANT: Dark Energy IS NOT THE SAME AS Dark Matter

Nobel Prize Ceremony, 2011



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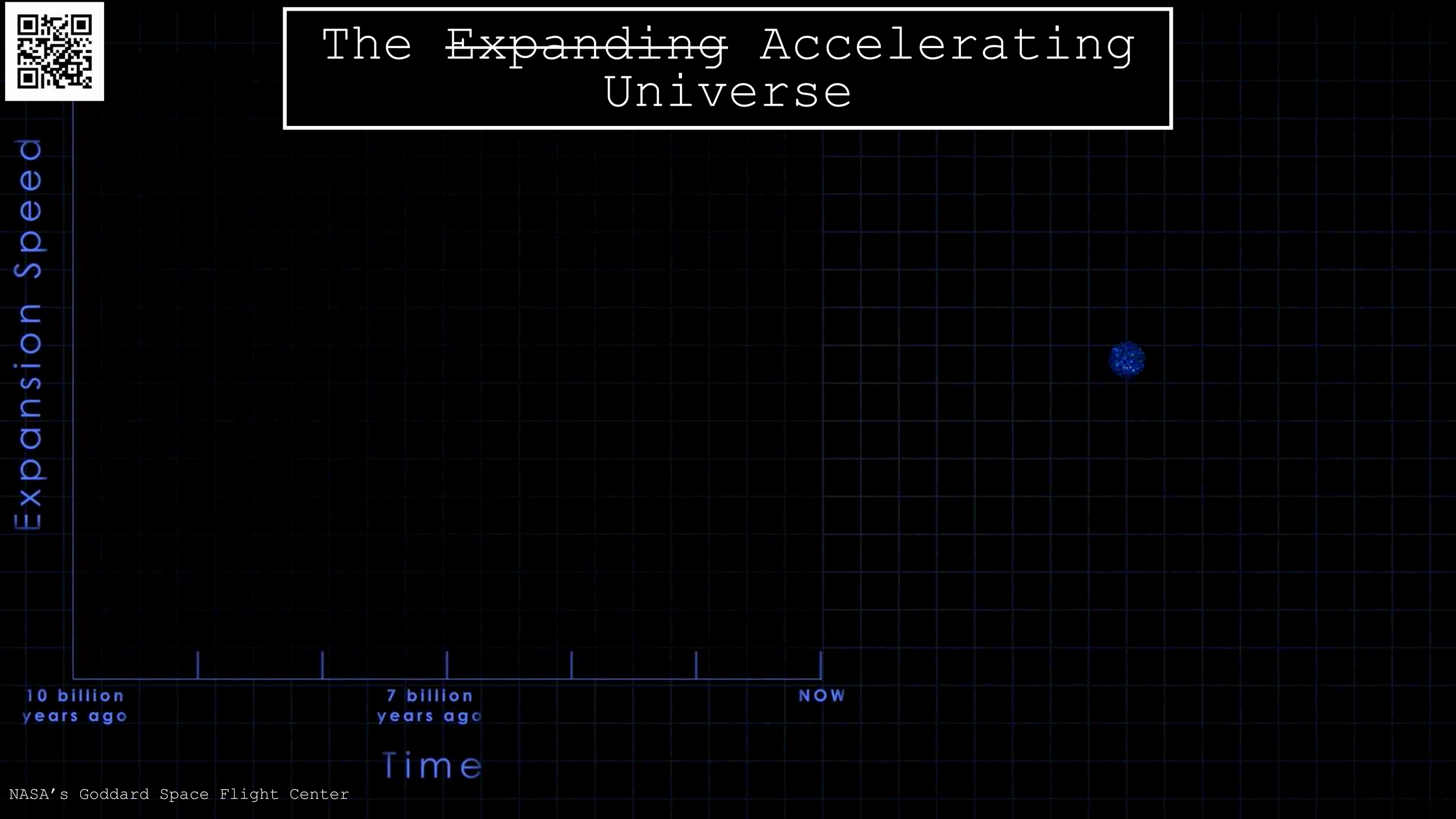


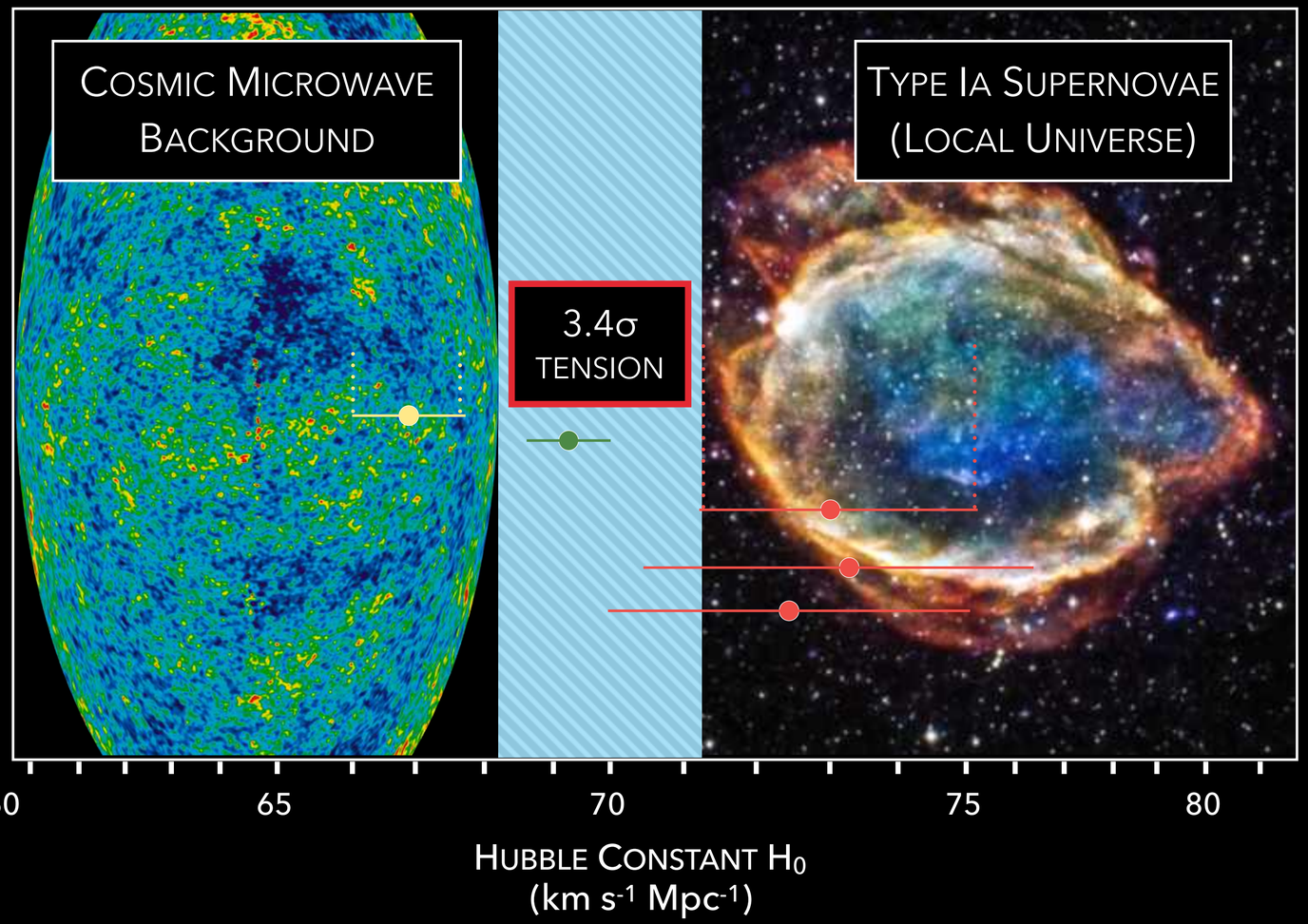
NASA’s Goddard Space Flight Center

The ~~Expanding~~ Accelerating Universe

NASA/STScI/G. Bacon

But this expansion rate is actually not well-constrained

Early Universe observations give a 'low' value

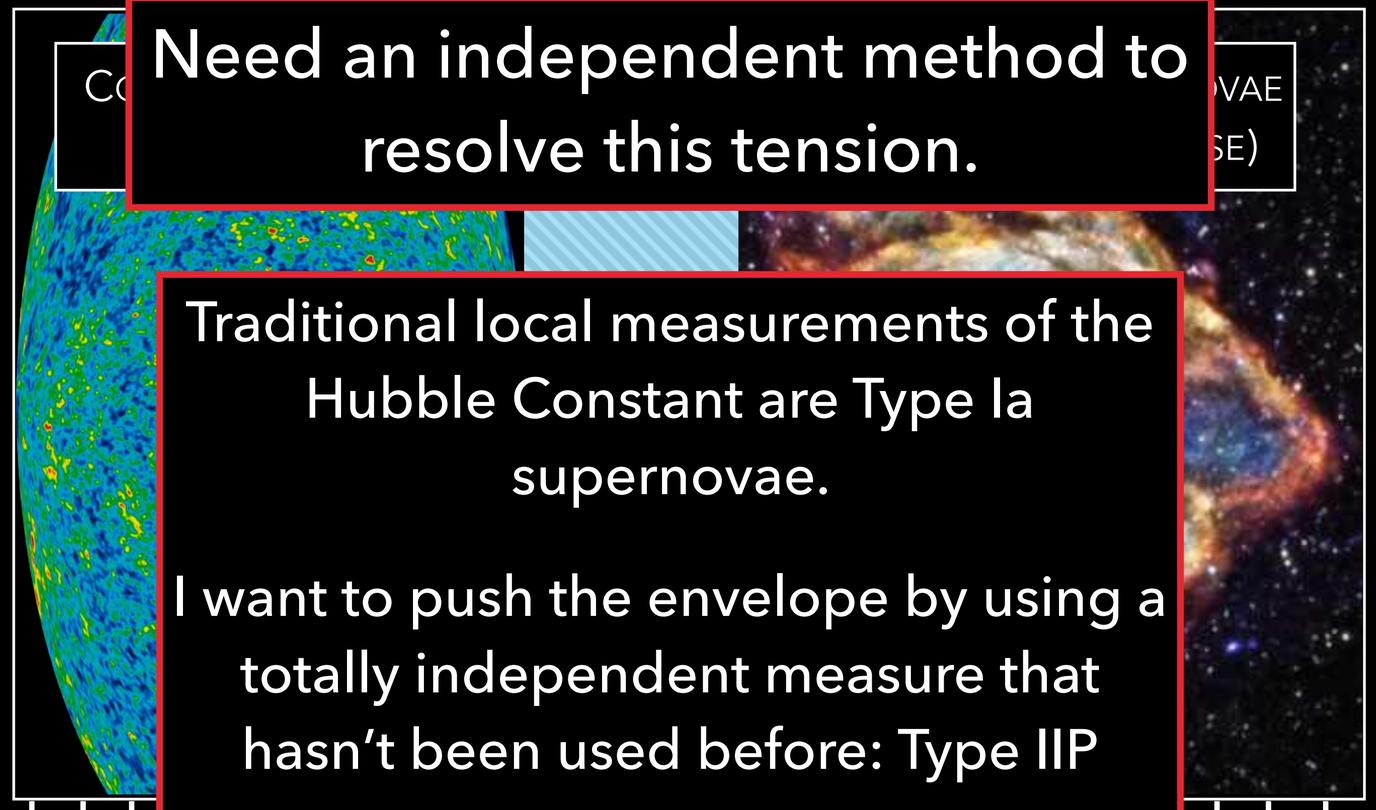


Local Universe (present-day) observations give a 'high' value

But this expansion rate is actually not well-constrained

Need an independent method to resolve this tension.

EARLY UNIVERSE observations give a 'low' value



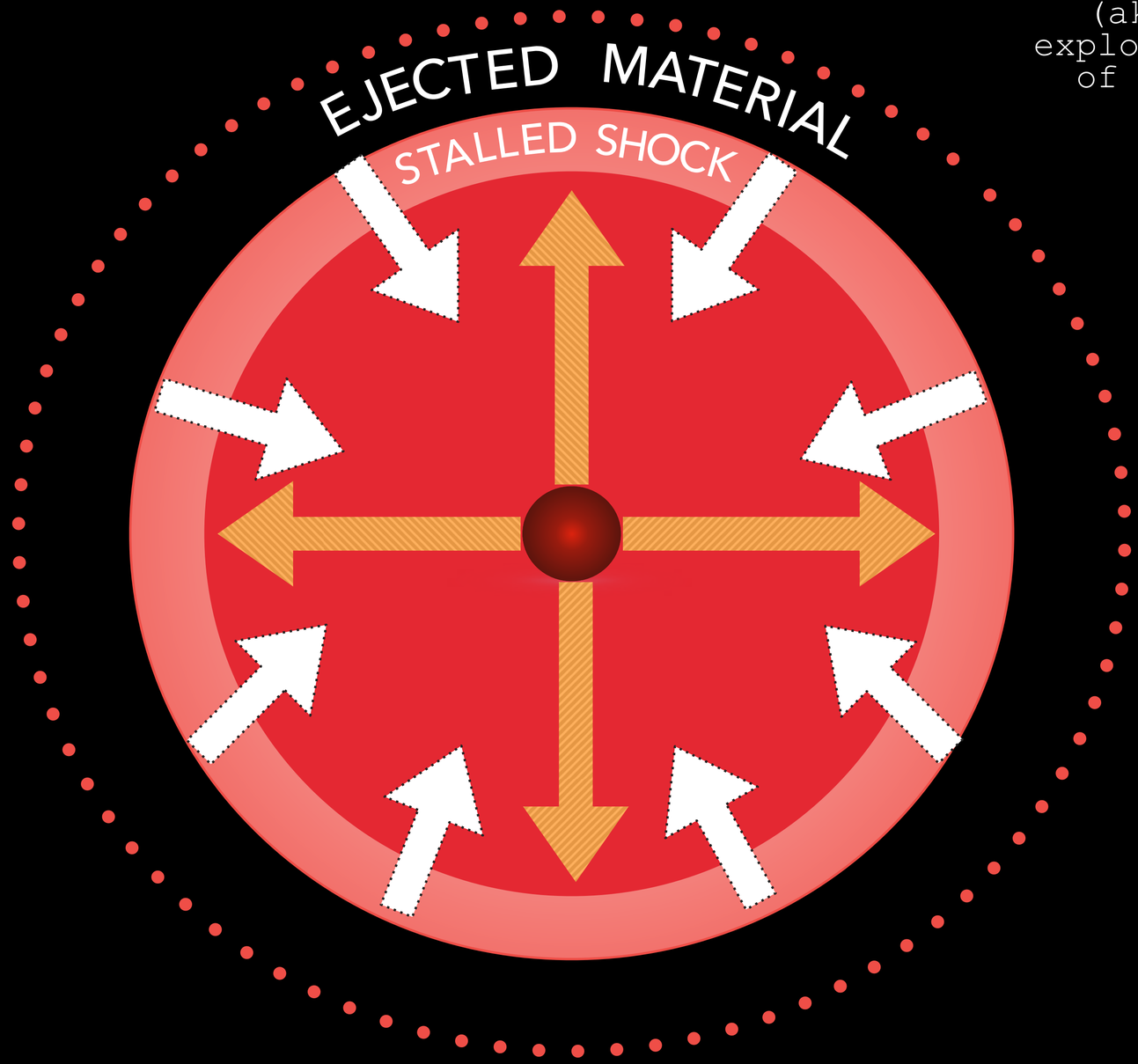
Traditional local measurements of the Hubble Constant are Type Ia supernovae.

I want to push the envelope by using a totally independent measure that hasn't been used before: Type IIP supernovae.

LOCAL UNIVERSE (present-day) observations give a 'high' value

Remember Type II Supernovae?

(aka big stars that explode without the help of a companion star)



Pressure from *neutrinos* that drives the expansion & subsequent explosion

Proto-Neutron Star

In-falling material driven by gravity

I use these babies (specifically Type IIP) to try to measure the rate of the expansion of the Universe!

The expansion rate tells us something about the Fate of the Universe

NASA/STScI/G. Bacon

The expansion rate tells us something about the Fate of the Universe

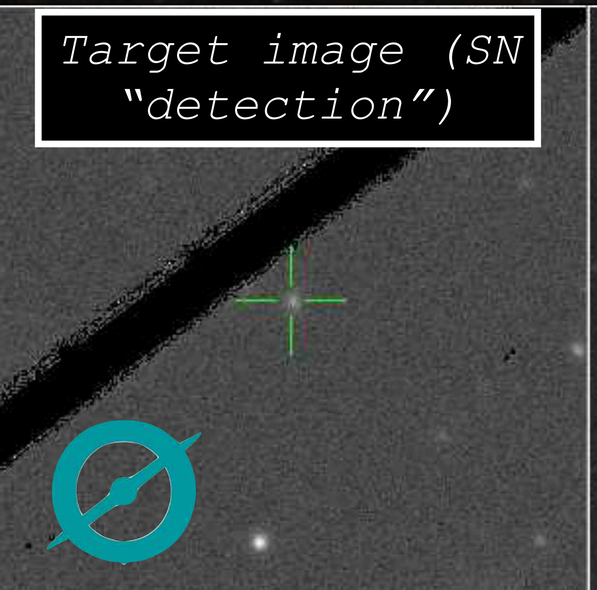
NASA/STScI/G. Bacon

We need your help finding supernovae!

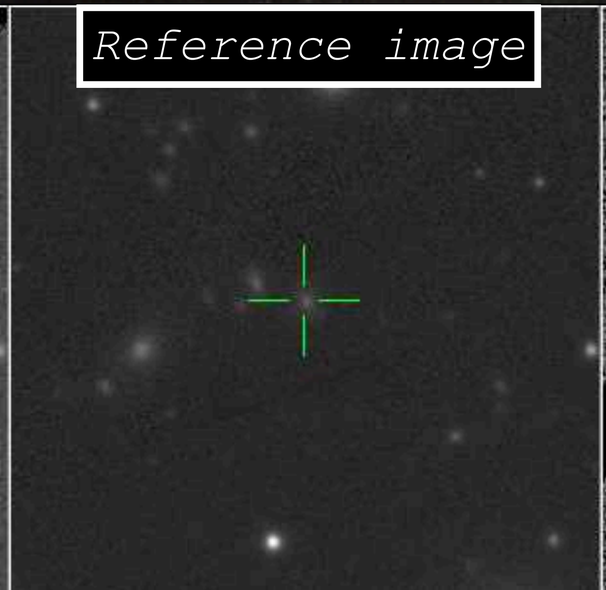
Help discover supernovae from Pan-STARRS1.

http://supernova.galaxyzoo.org

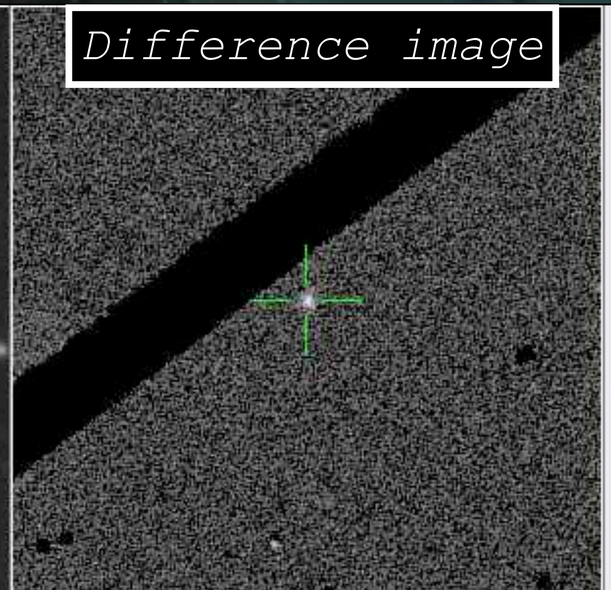
Target image (SN "detection")

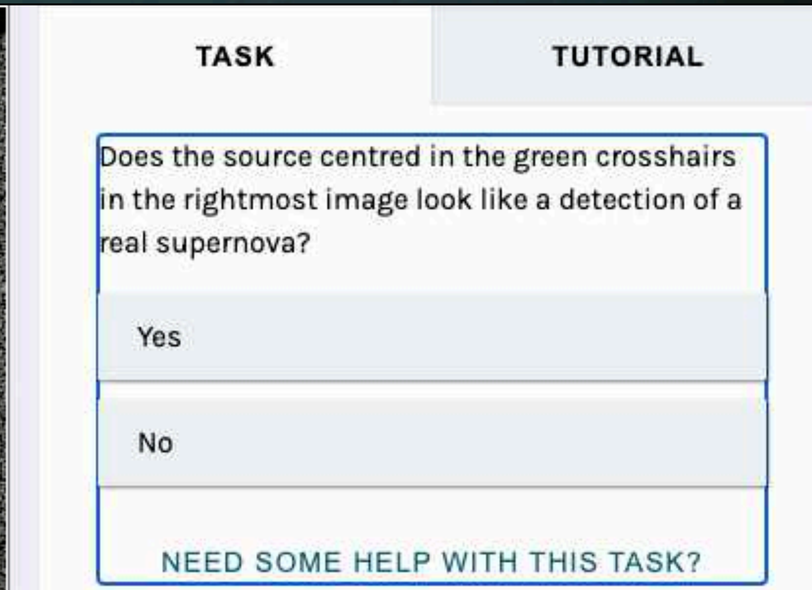


Reference image



Difference image





Explore the cosmos with me in my new show *CONSTELLATIONS*

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SUPERNOVAE ARE EXPLODING STARS. THEY CAN BE 2-STAR OR 1-STAR SYSTEMS.

BETELGEUSE IS (PROBABLY NOT) GOING TO EXPLODE ANYTIME SOON.

THE UNIVERSE IS EXPANDING. THAT EXPANSION IS ACCELERATING THANKS TO DARK ENERGY. WE FOUND THAT OUT BY STUDYING SUPERNOVAE.

YOU CAN HELP US FIND SUPERNOVAE!

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