Superluminous supernovae: fantastic bursts and where to find them

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European Research Council
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The Alan Turing Institute

Supernova!

A nova is a bright burst that happens when matter falls onto a white dwarf star

It can be as bright as 100,000 Suns

Name comes from the latin for "new"

A *supernova* is a much more powerful explosion that happens to some stars at the end of their lives

Supernovae can be brighter than *a billion Suns!*

Spot the supernova…

Credit: David Malin / Australian Astronomical Observatory.

Spot the supernova…

Credit: David Malin / Australian Astronomical Observatory.

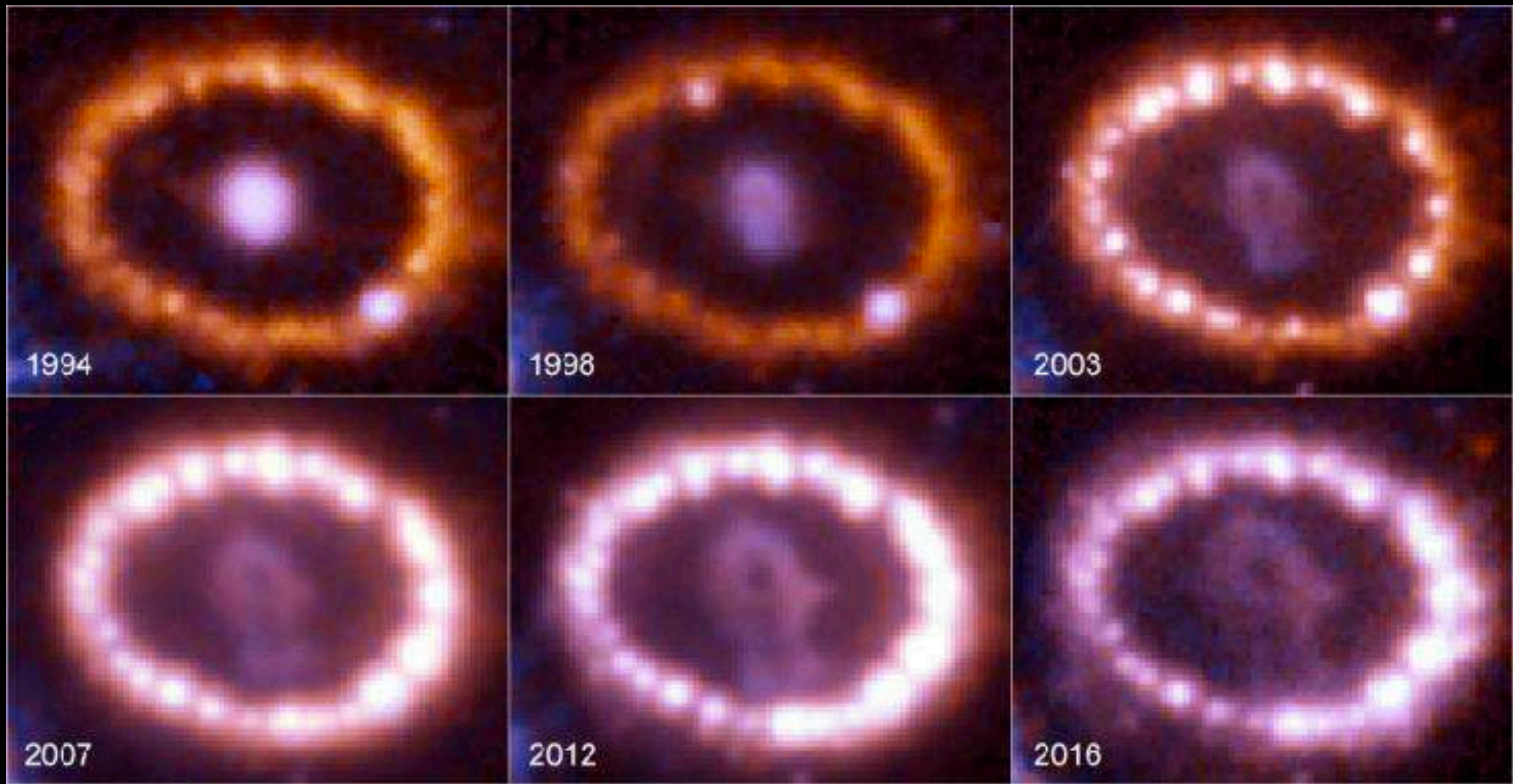
Supernova 1987A

It happened in the Large Magellanic Cloud (our closest neighbour) and was visible to the naked eye

Supernova 1987A

The star there before has now vanished!

This is how we know supernovae are the final explosions of an entire star



Credit: NASA, ESA and R. Kirshner

Discovering supernovae: the old way

Finding supernovae is one of the oldest branches of science

They happen throughout the Universe, but one close enough to see with the naked eye happens about once a century — nearly always in our own Galaxy

Many civilisations through history have recorded supernova sightings!

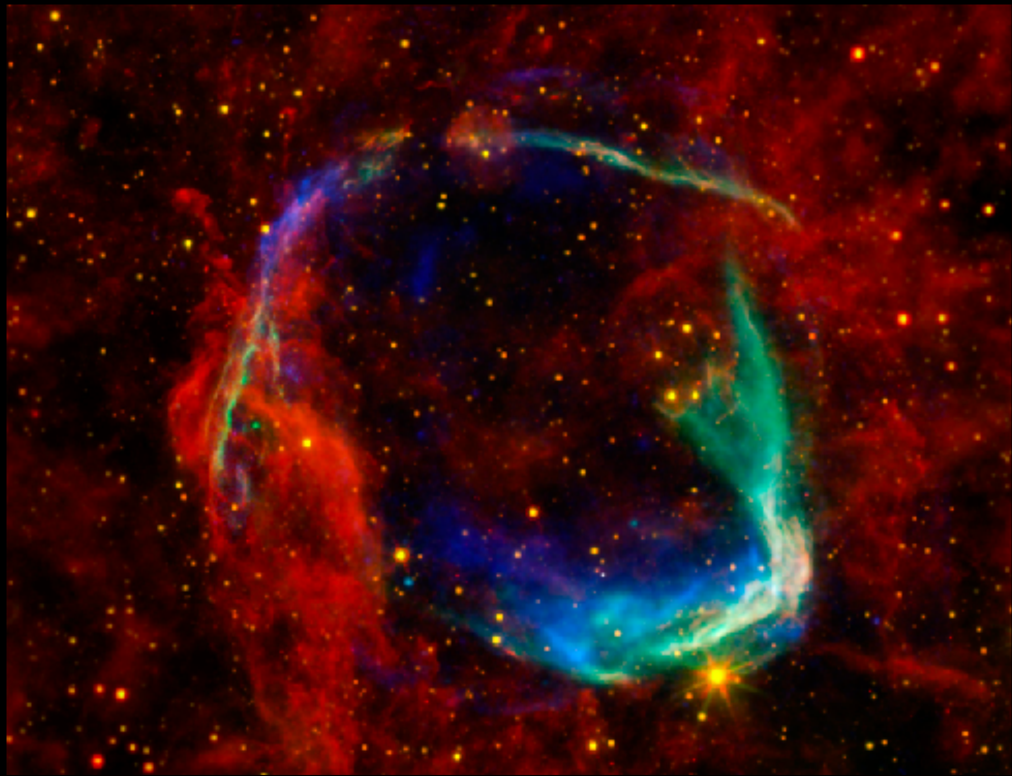
With modern telescopes, we can see the expanding clouds (nebulae) they leave behind…

SN 185

The oldest known supernova

Recorded by Chinese astronomers in 185 AD

SN 185 today —>



SN 1006

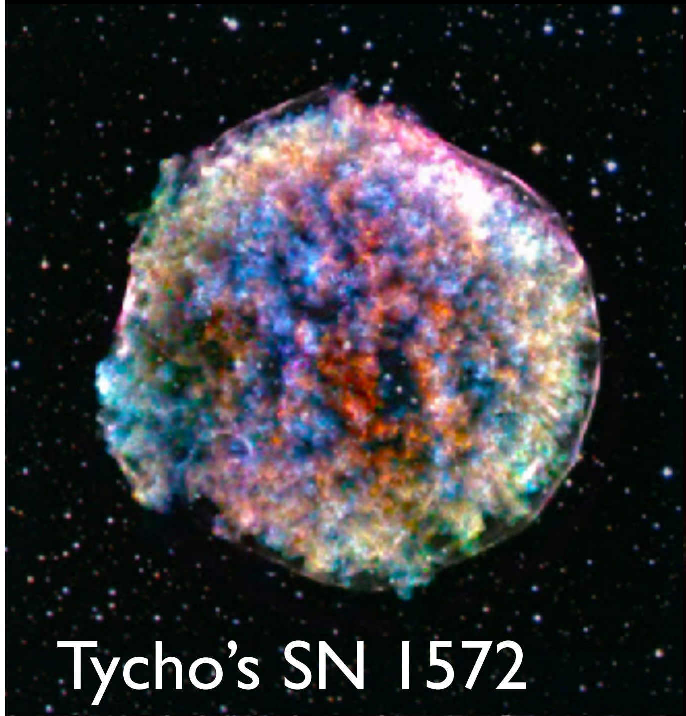
Probably the brightest stellar event in recorded history, with records from every continent

Appeared to be 10 times brighter than Venus as seen from Earth

SN 1006 today —>

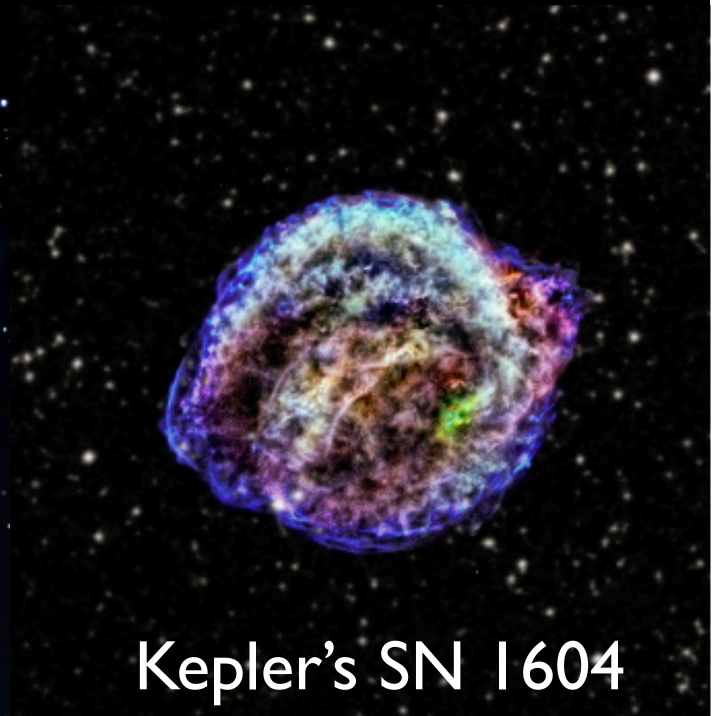
60 lightyears across!

And many more!



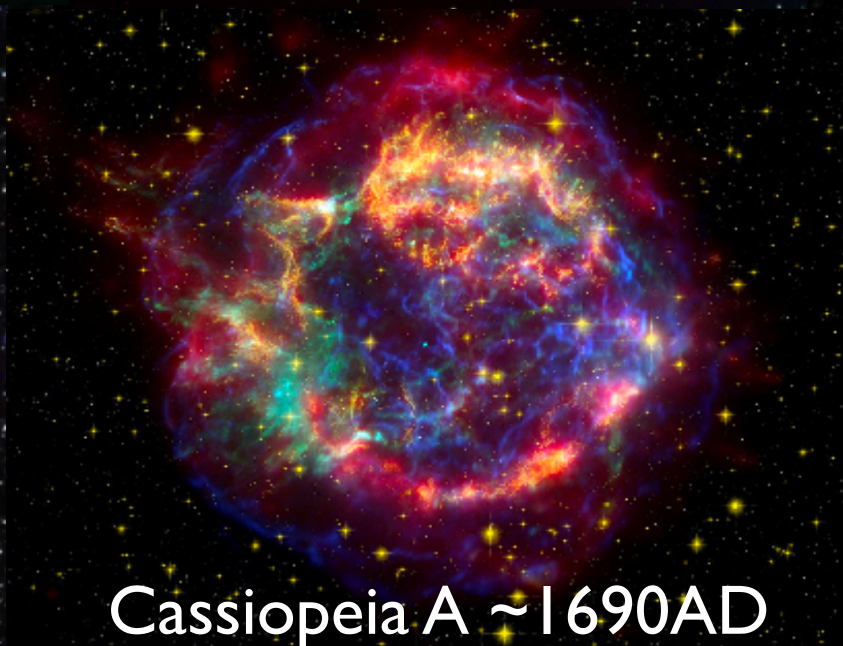
Tycho's SN 1572

Crab Nebula SN 1054



Kepler's SN 1604

G299 ~2500BC



Cassiopeia A ~1690AD

G292 ~600BC

Next?

The supernova revolution

Robotic telescopes around the world

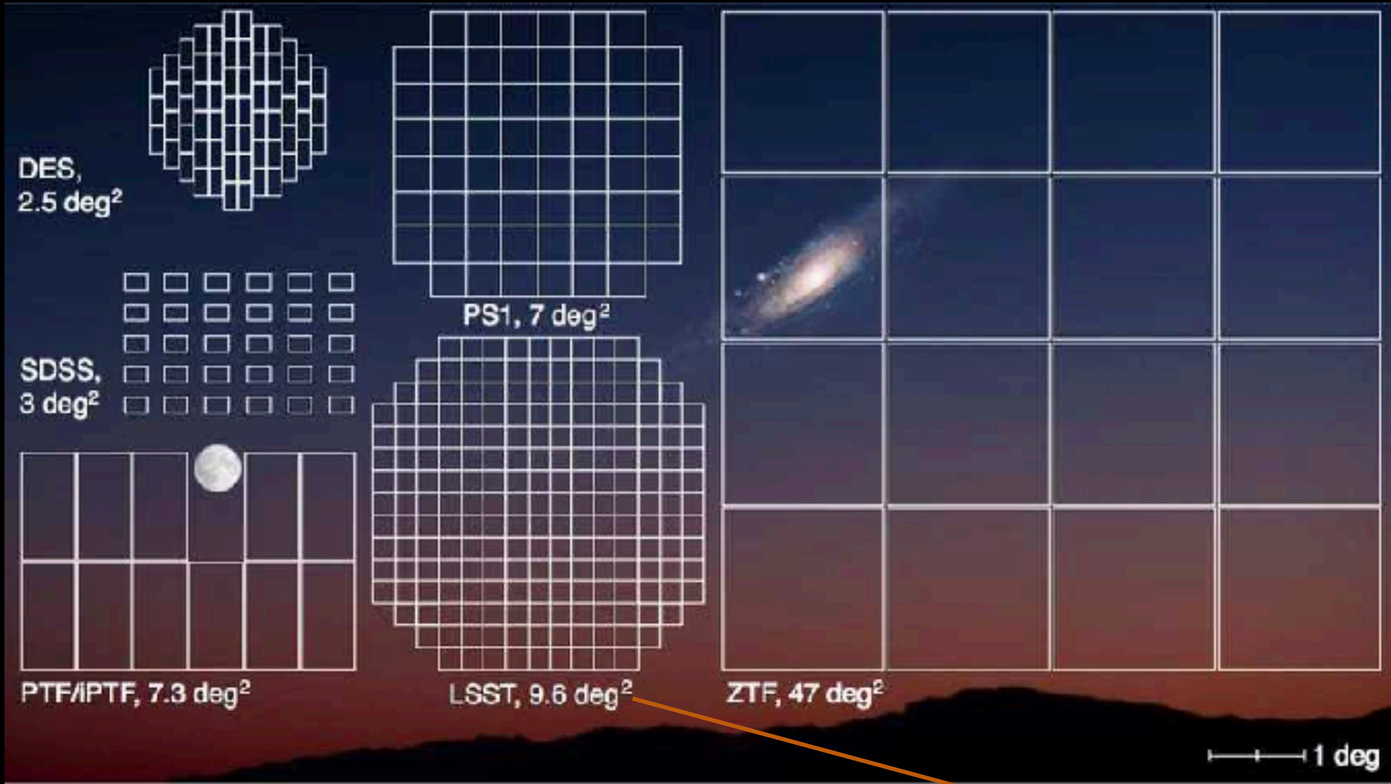
PanSTARRS, ATLAS
Hawaii

ZTF - California

ASASSN - Chile

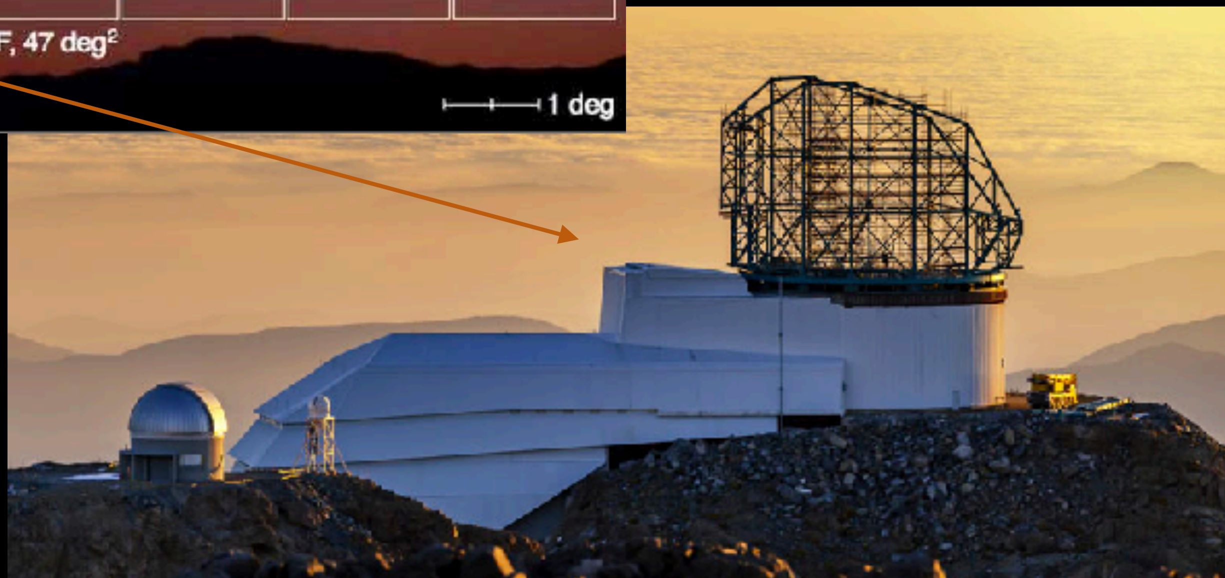
GOTO - Canary Islands

The supernova revolution



Vera Rubin Observatory will be the first telescope with a wide field of view *and* an 8m diameter mirror

— will search a larger volume of space than ever before!



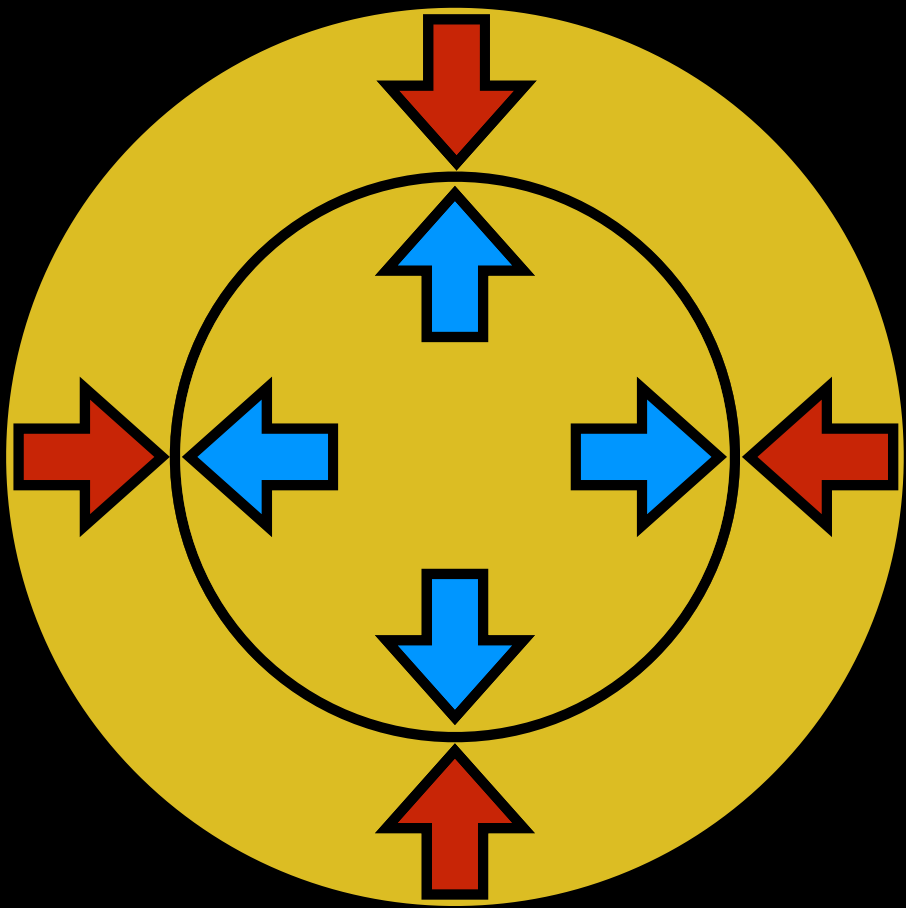
The supernova revolution

These robotic telescopes now find thousands of possible supernovae every night

These aren't nearby objects, but rather explode in distant galaxies throughout the Universe

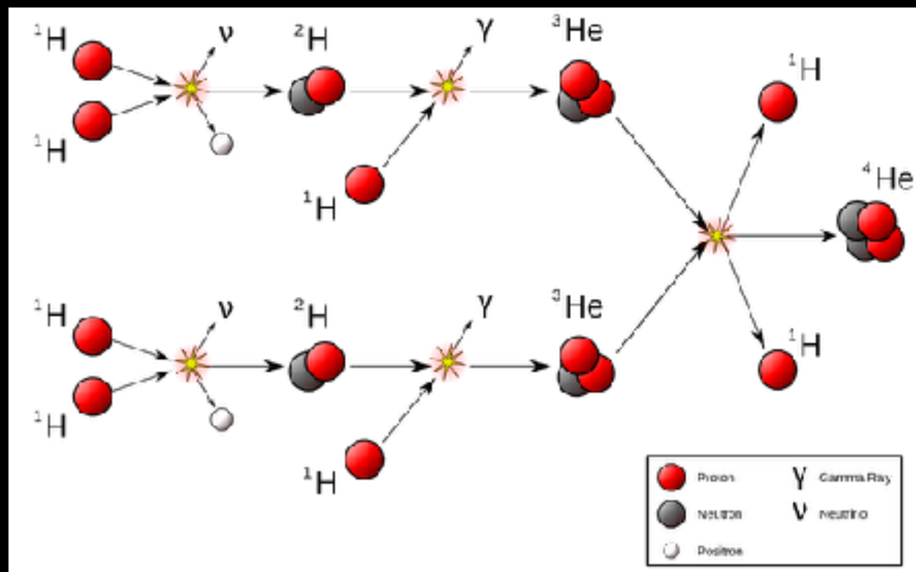
Our challenge is to sort through them, understand their properties, and figure out which ones need further investigation

Why does a star explode?



Nuclear reactions

Gravity



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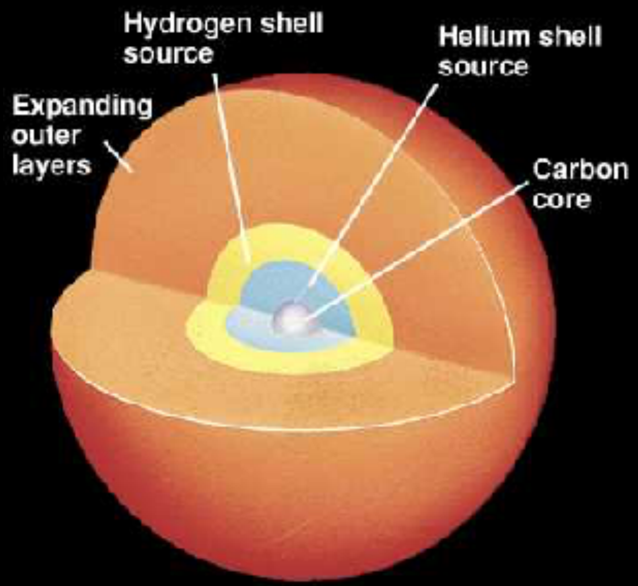
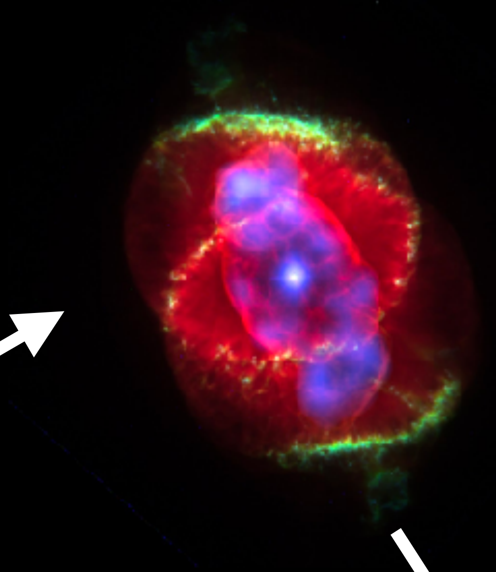
University of Birmingham

Why does a star explode? I.

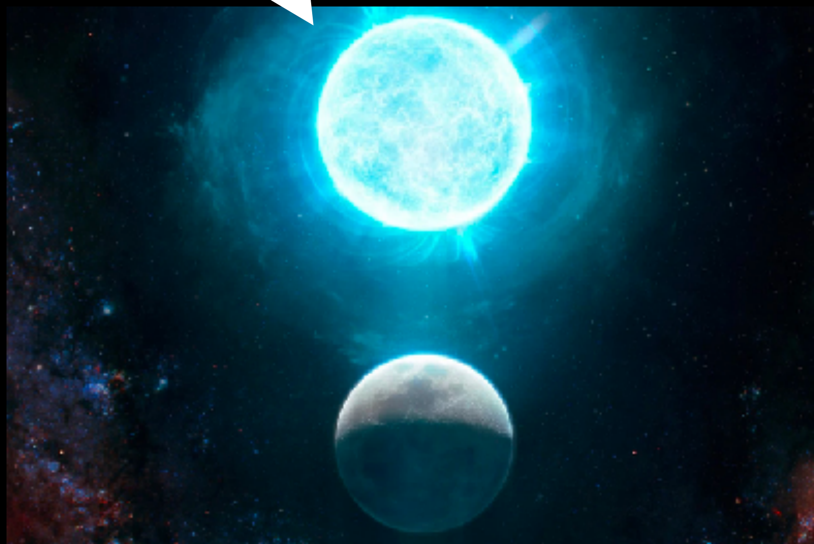
Stars *less* than 8 times the mass of the Sun



Becomes a red giant and then a "planetary nebula"



Leaves behind a white dwarf



Fusion reactions turn the core into carbon and oxygen

Too cold to make anything heavier

Why does a star explode? I.

The heaviest stable white dwarf weighs 1.4 times the mass of the Sun

If a white dwarf gains some mass and goes over the limit, it contracts and suddenly all the leftover nuclear material reacts at once!

This releases so much energy that it causes a huge explosion

We call this a Type Ia supernova

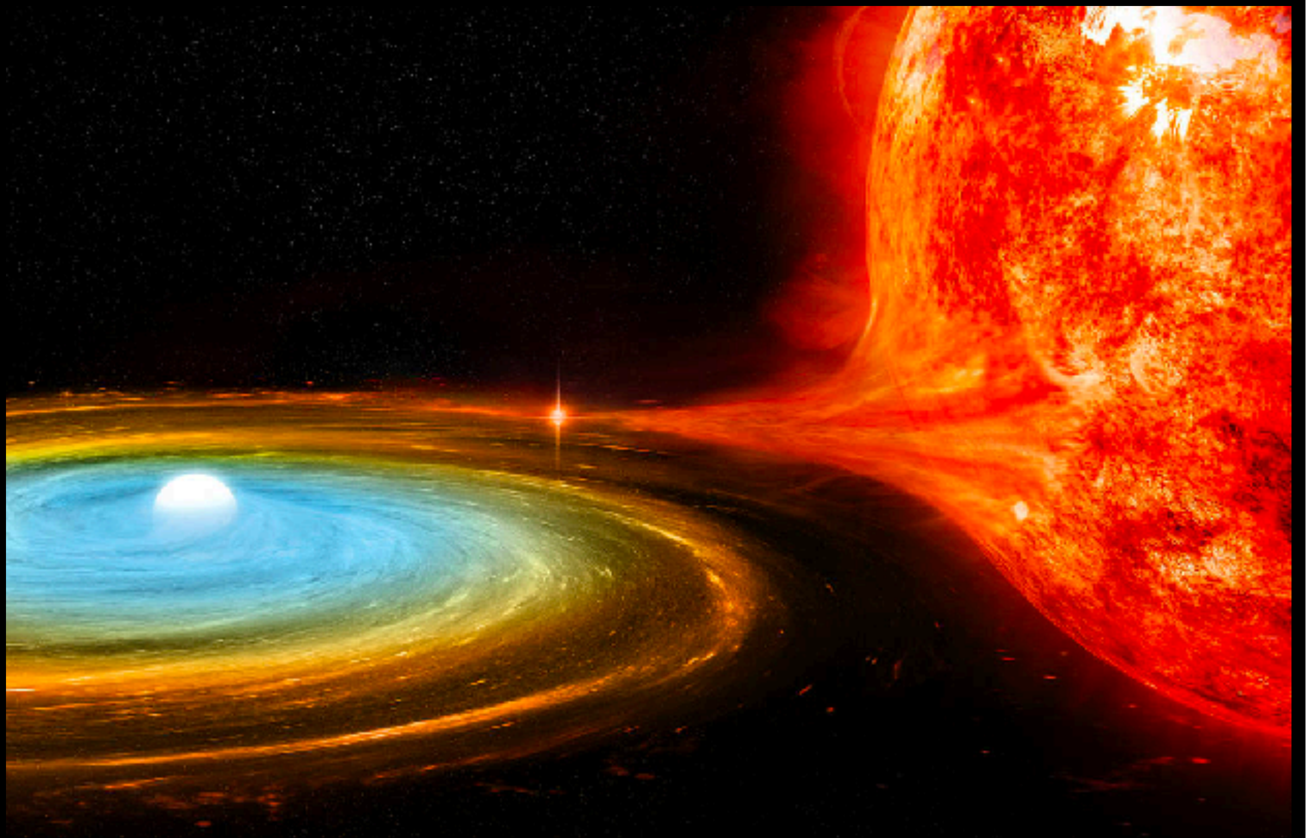
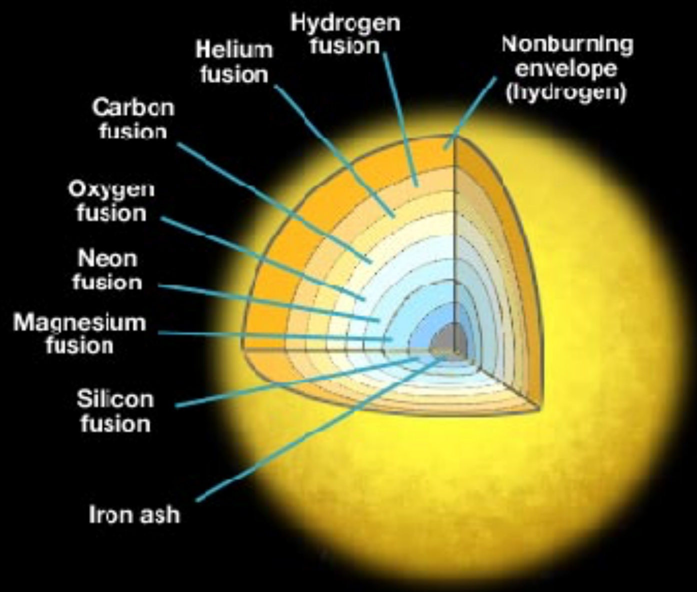


Image credit: NASA/CXC/M.Weiss

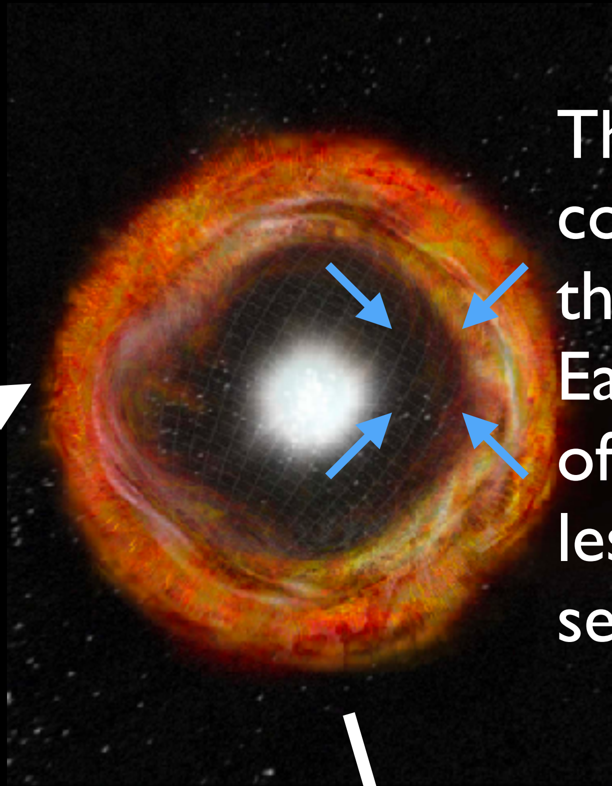
Why does a star explode? II.

Stars *more* than 8 times the mass of the Sun

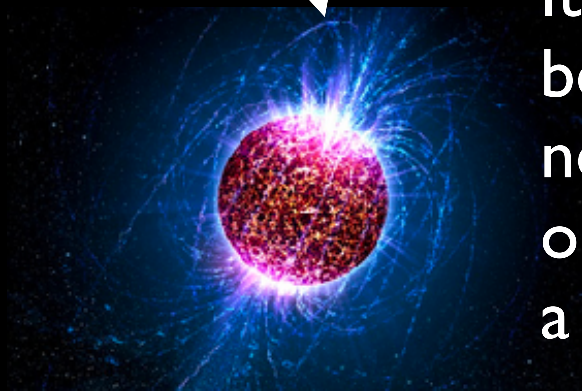


Fusion reactions very quickly turn the core into iron

This is the heaviest element that can be used in fusion



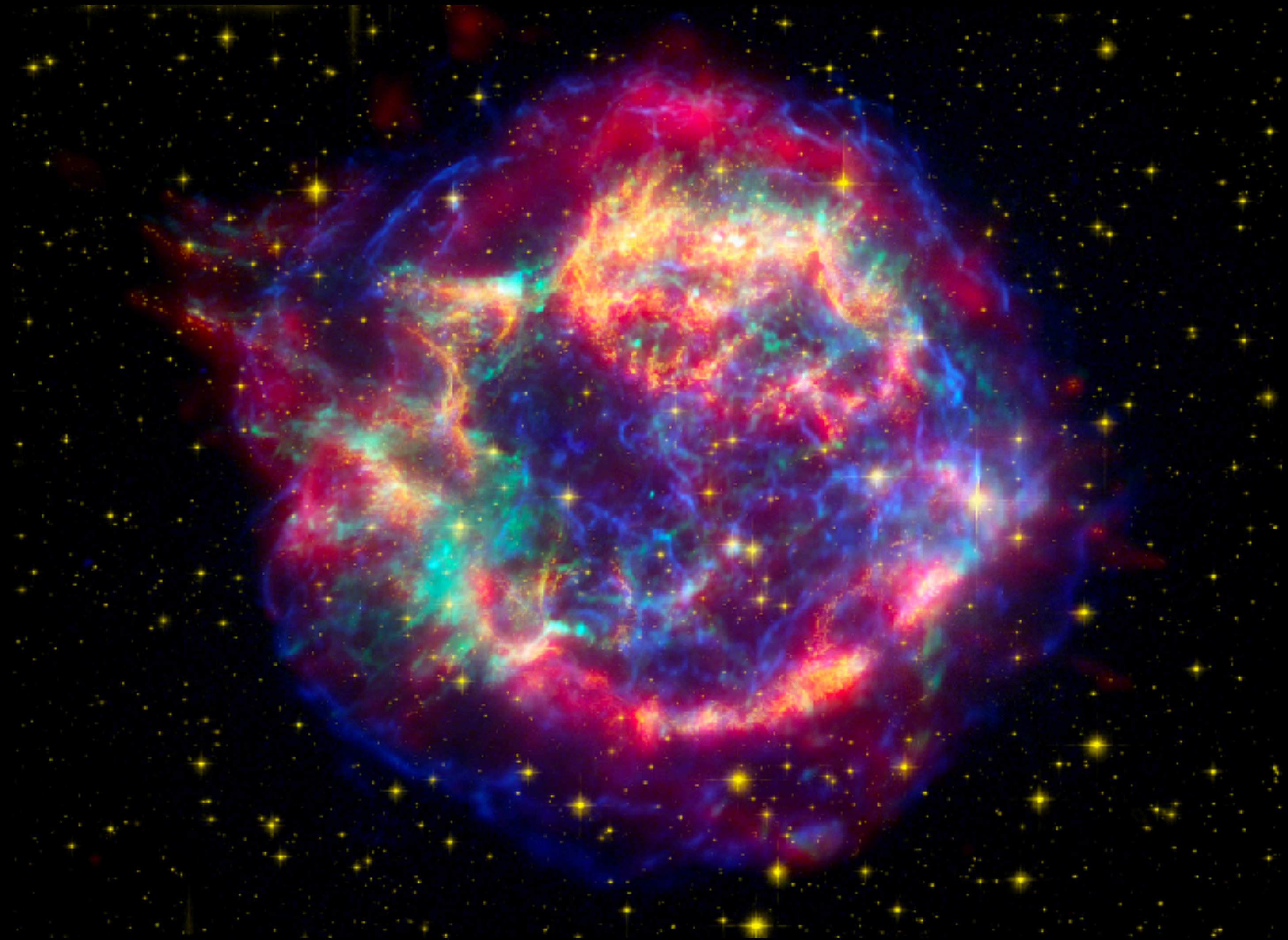
The core collapses from the size of the Earth to the size of Birmingham in less than a second!

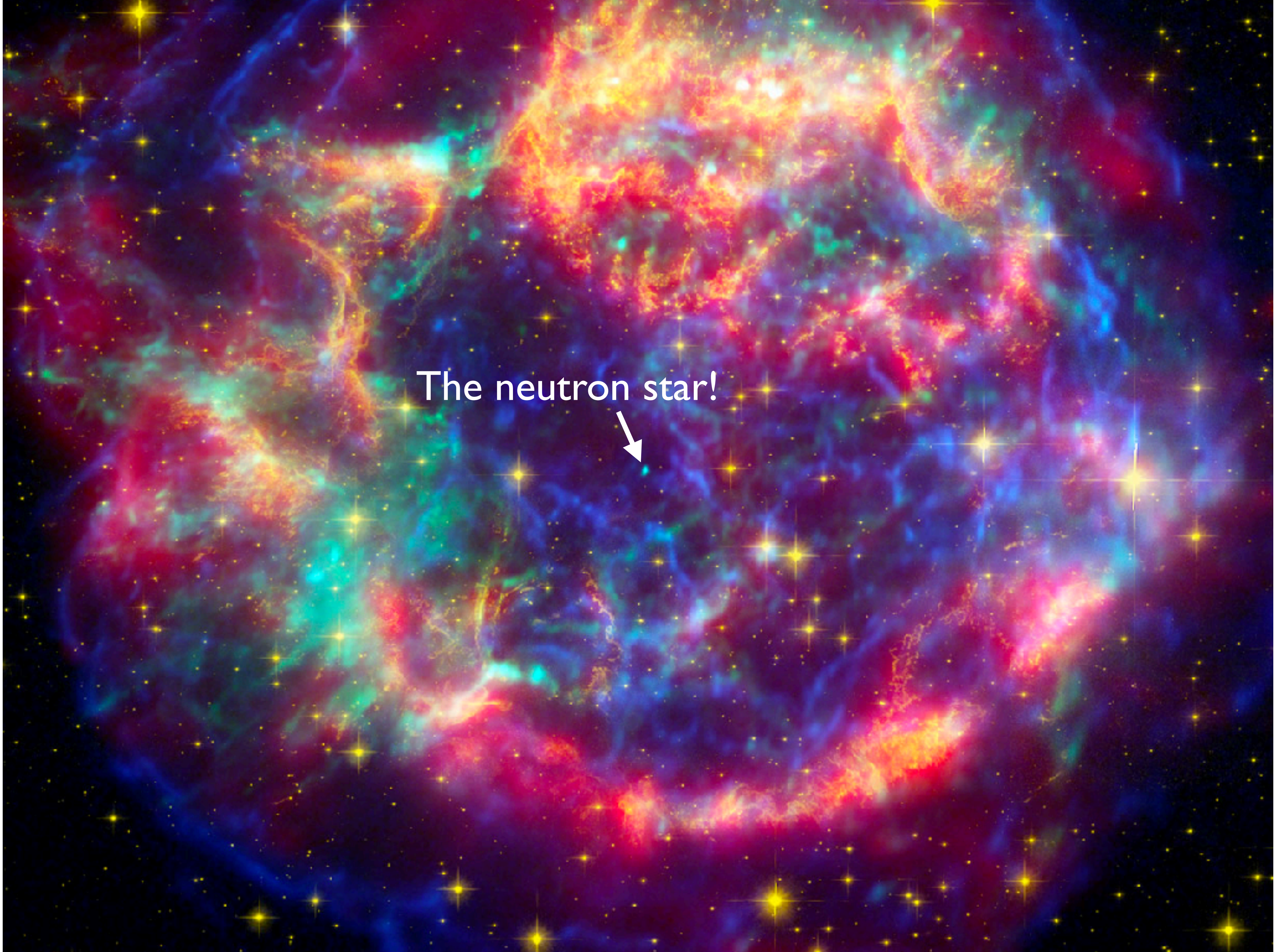


It leaves behind a neutron star or sometimes a black hole

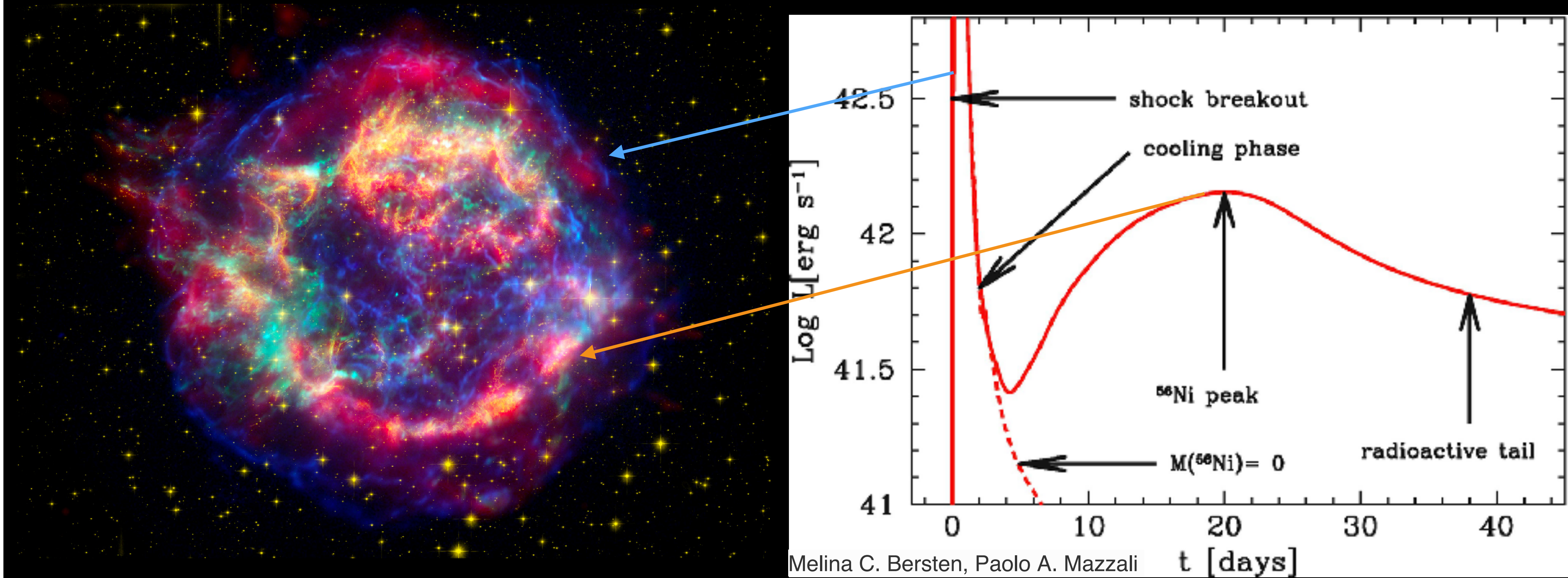
Why does a star explode? II.

The energy released by this collapse blows up the outer layers — we call this a Type II supernova




The neutron star!

Fantastic bursts…



First we see a bright flash when the blast escapes the surface of the star. This is only bright for a few days, but we can detect radio waves and X-rays for centuries as the blast continues out into space.

Most of the light we see comes from radioactive material produced deeper inside the explosion: mainly unstable Nickel decaying to Cobalt and then to stable Iron. This stays bright for a few weeks or months.

…and where to find them

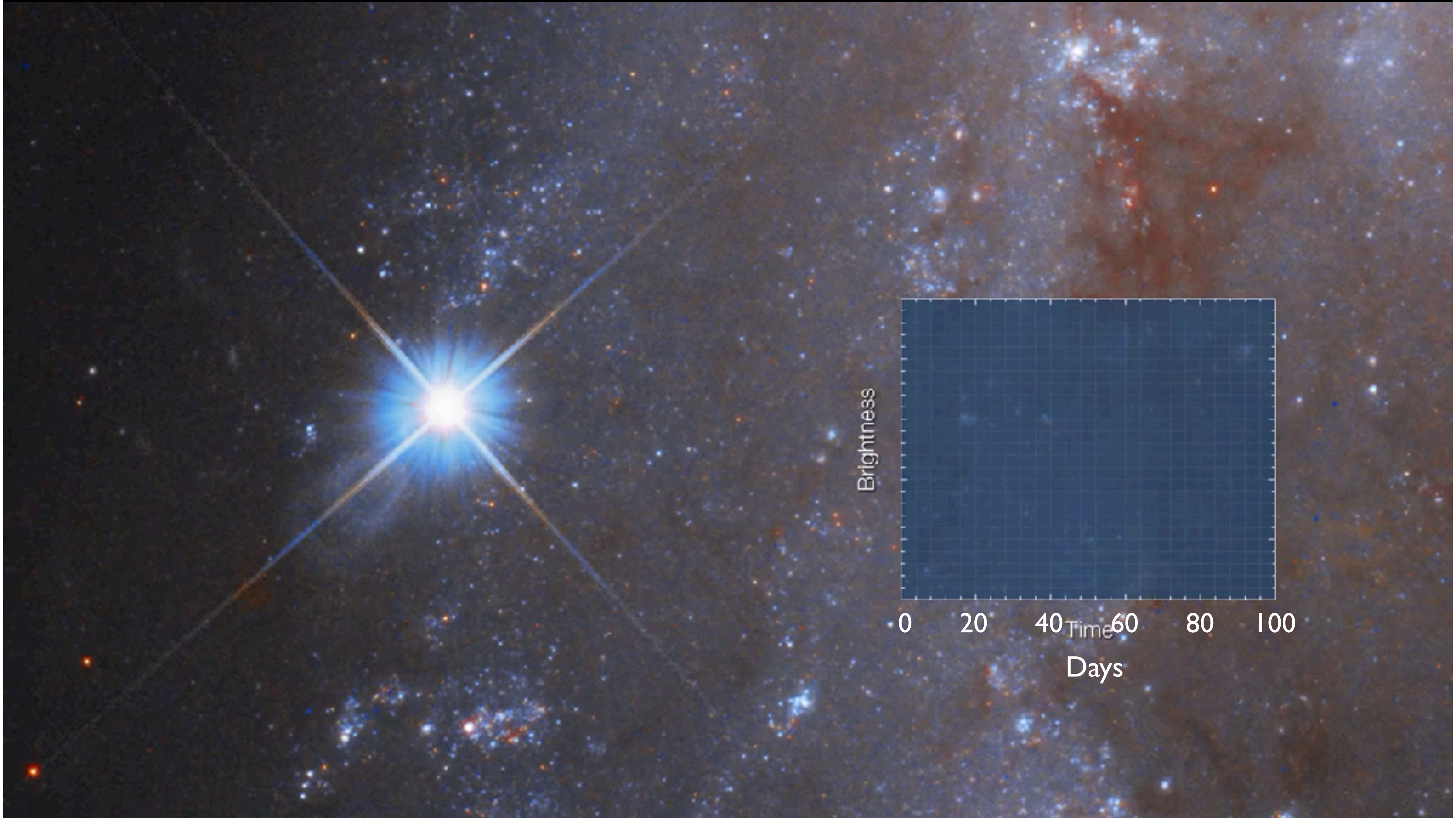
Massive galaxies
(lots of stars)

SN 1994D

Star-forming regions
(massive stars don't live for long)

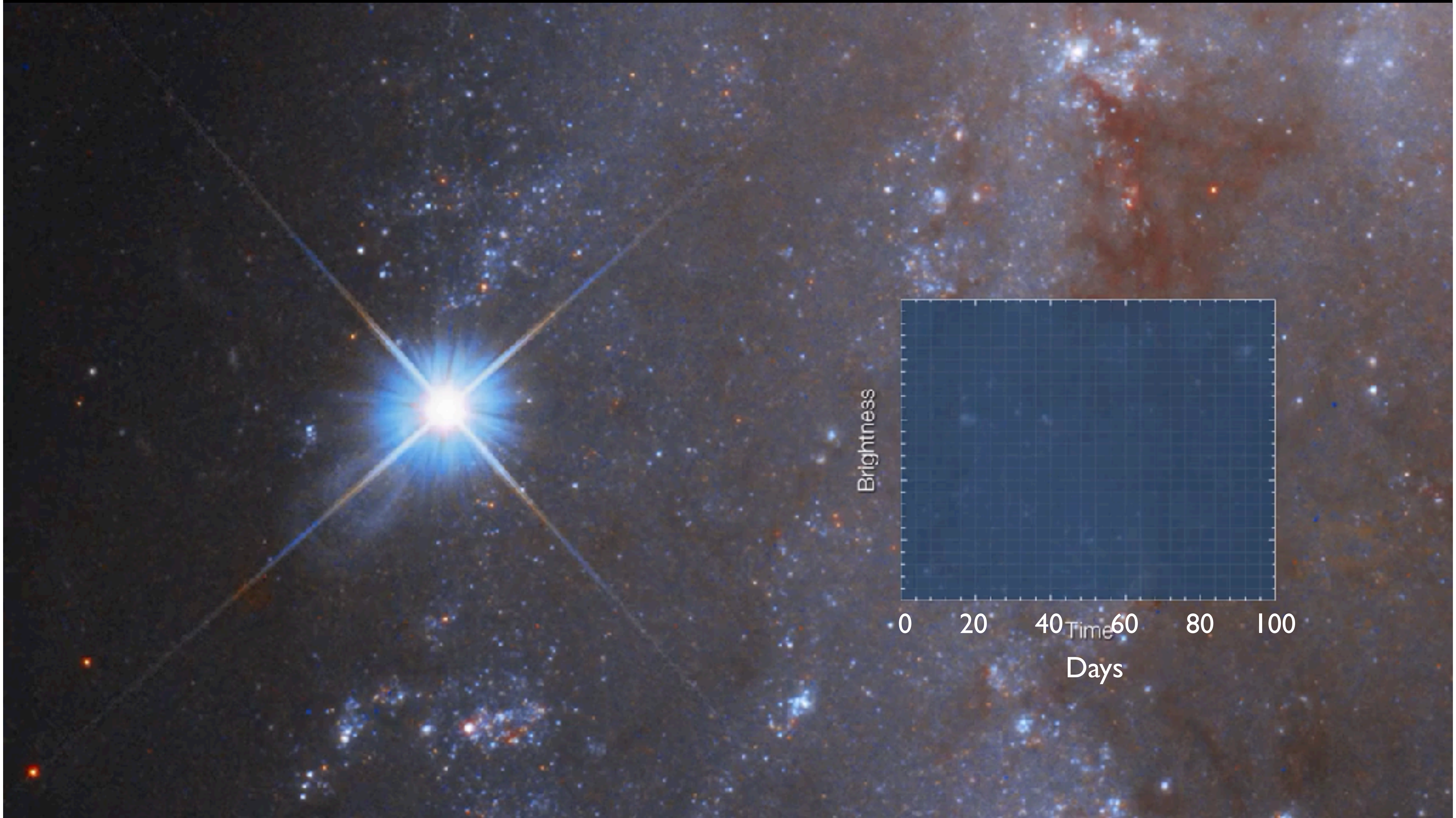
SN 2018gv

Typical supernova in a spiral galaxy



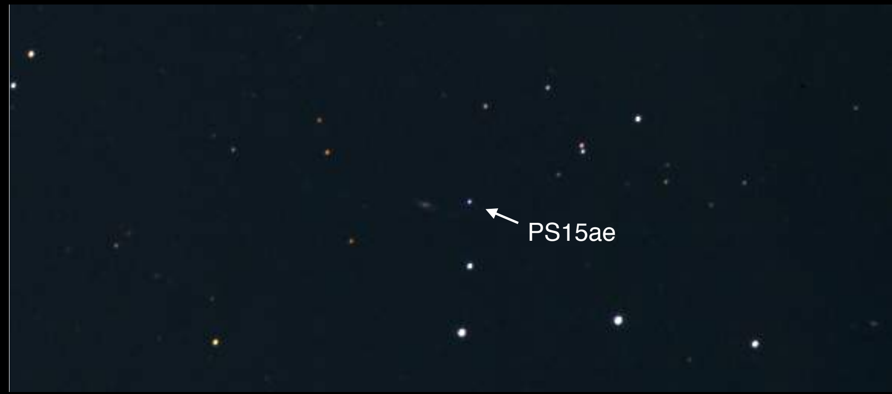
Credit: ESA/Hubble & NASA, A. Riess and the SH0ES team, Acknowledgment: Mahdi Zamani

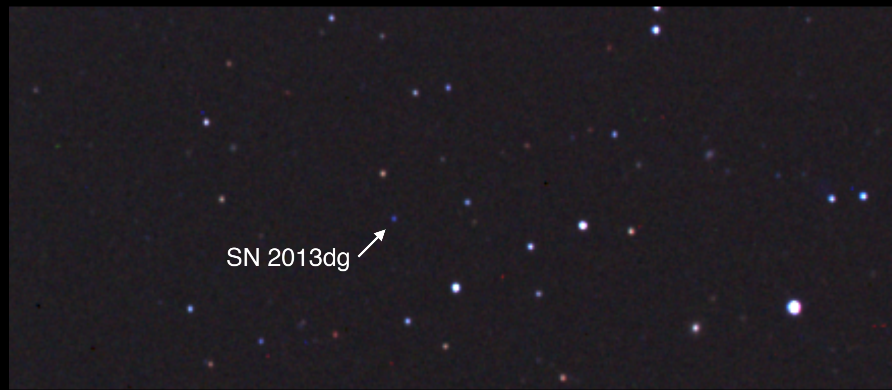
Typical supernova in a spiral galaxy

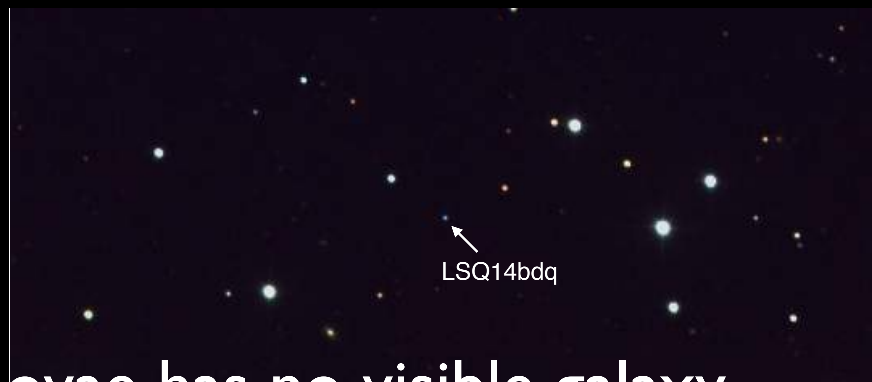


Credit: ESA/Hubble & NASA, A. Riess and the SH0ES team, Acknowledgment: Mahdi Zamani

But wait!

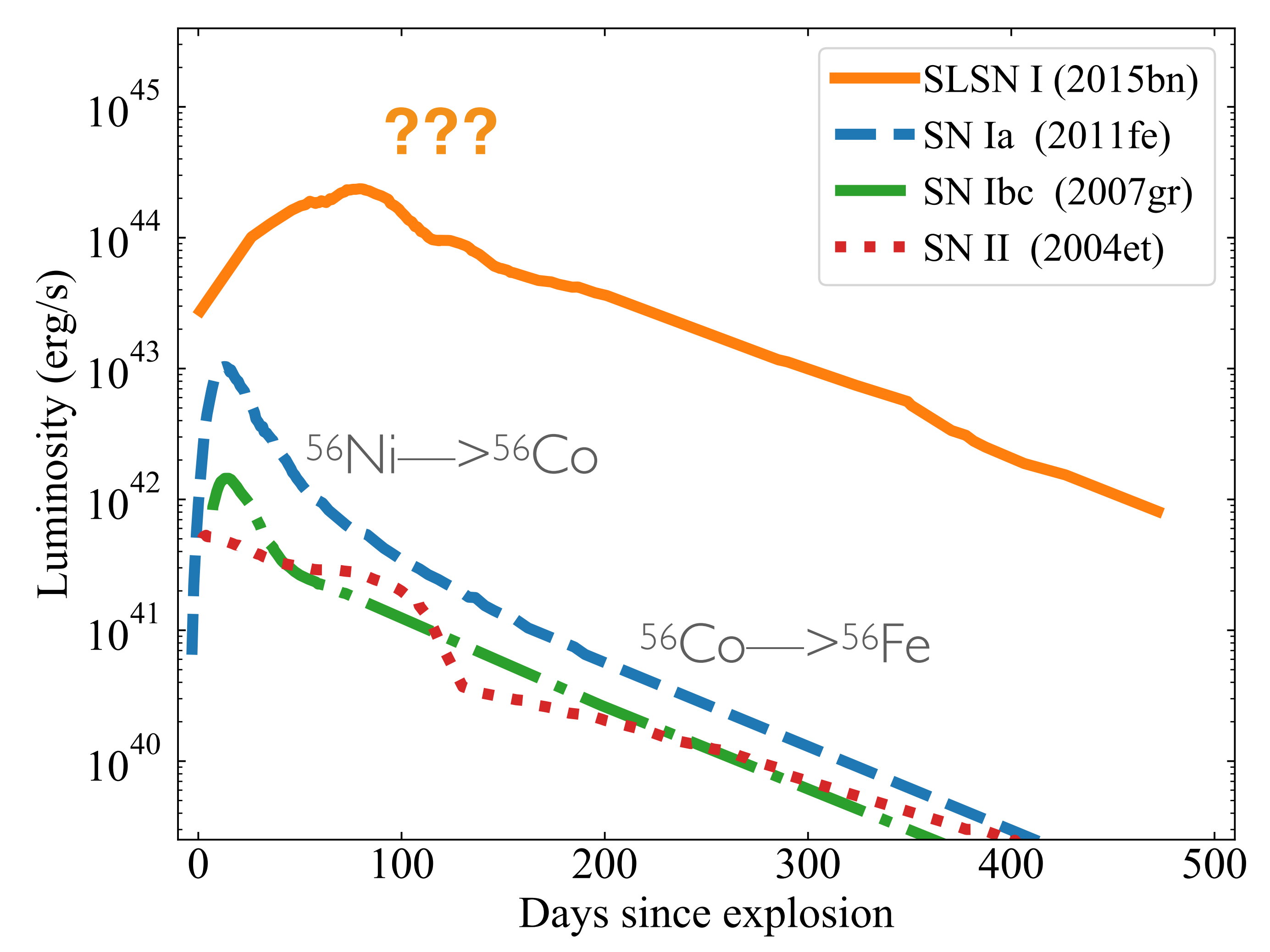




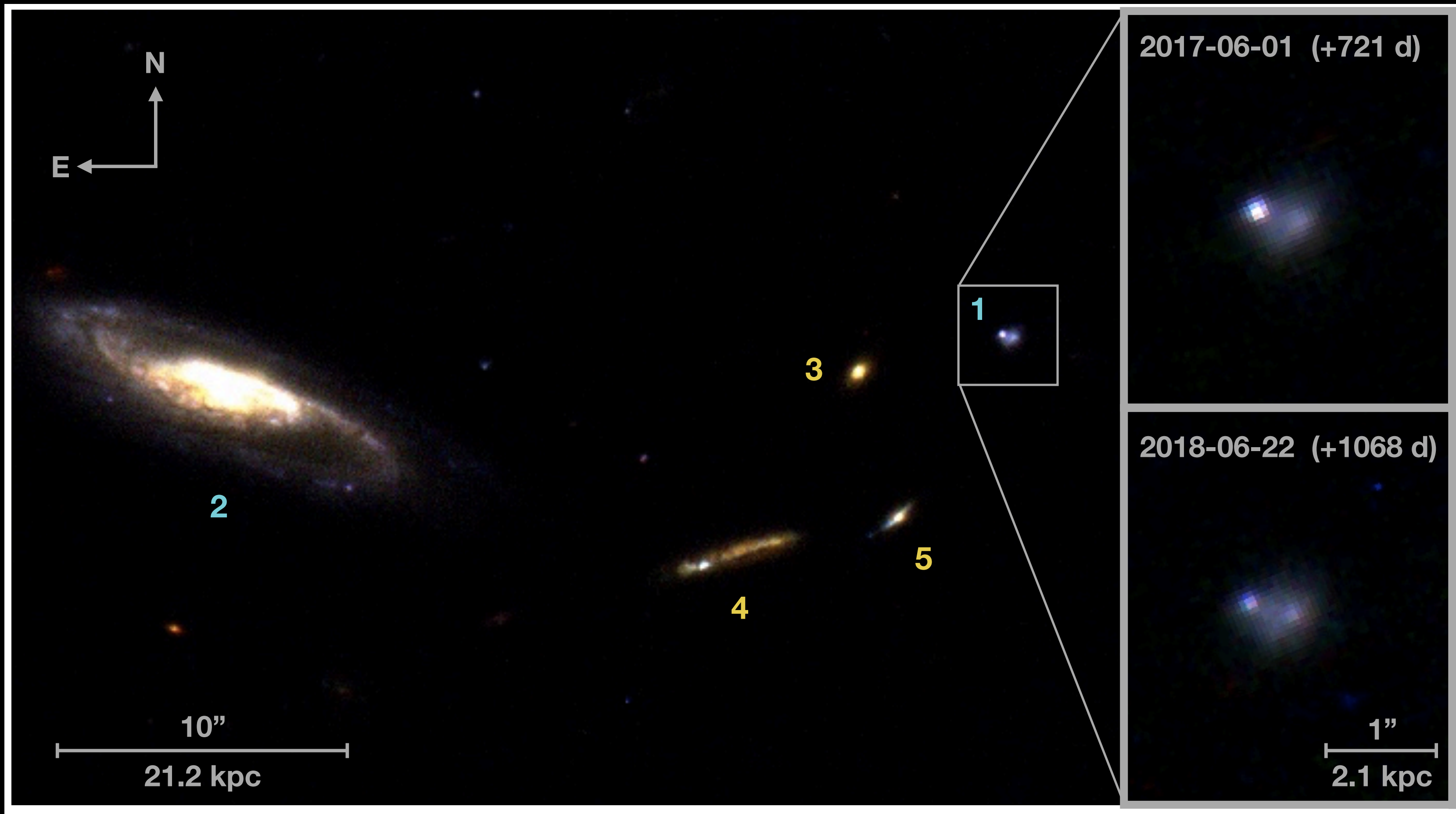


1 out of every 1000 supernovae has no visible galaxy

Superluminous supernovae

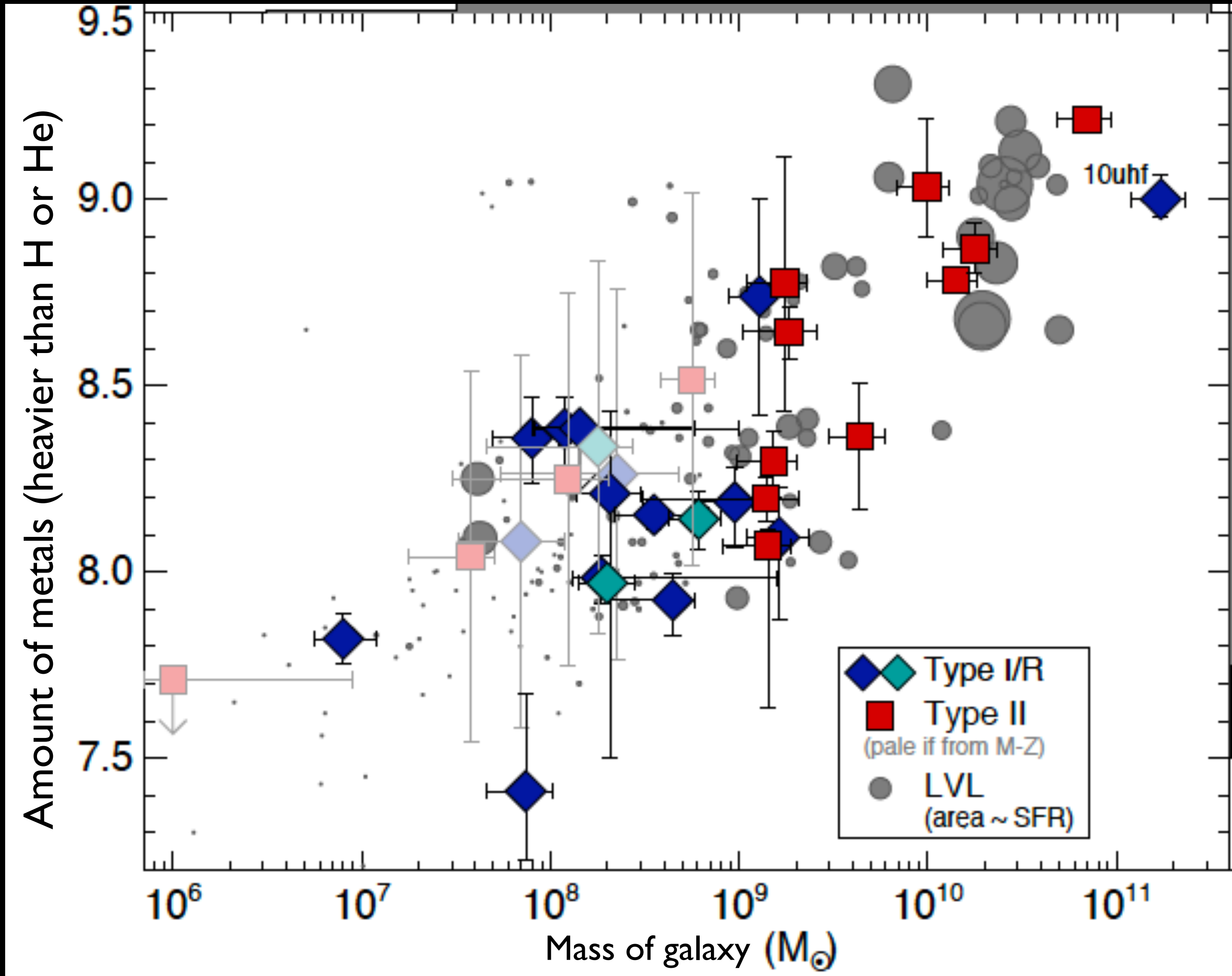


Are they really host-less?



Nicholl et al 2018

Why dwarf galaxies?



Perley et al 2016

Why so bright?

Makes more radioactive nickel?

100x brighter could mean 100x more radioactive Ni

This can only be made by a star ~100 times heavier, called a "pair-instability supernova"

The explosion of such a massive star would give a supernova that brightens and fades too slowly

BUT we think these massive supernovae should be out there somewhere!

Why so bright?

Large nickel mass

Why so bright?

If the supernova collides with some dense gas, it can turn more of its energy into light

This gas could be material lost by the star during its life before the explosion

This could explain some superluminous supernovae where we do see evidence for slow-moving material

Why so bright?

Collision with slow, dense gas ?

Large nickel mass

Why so bright?

Maybe the answer is hidden inside…

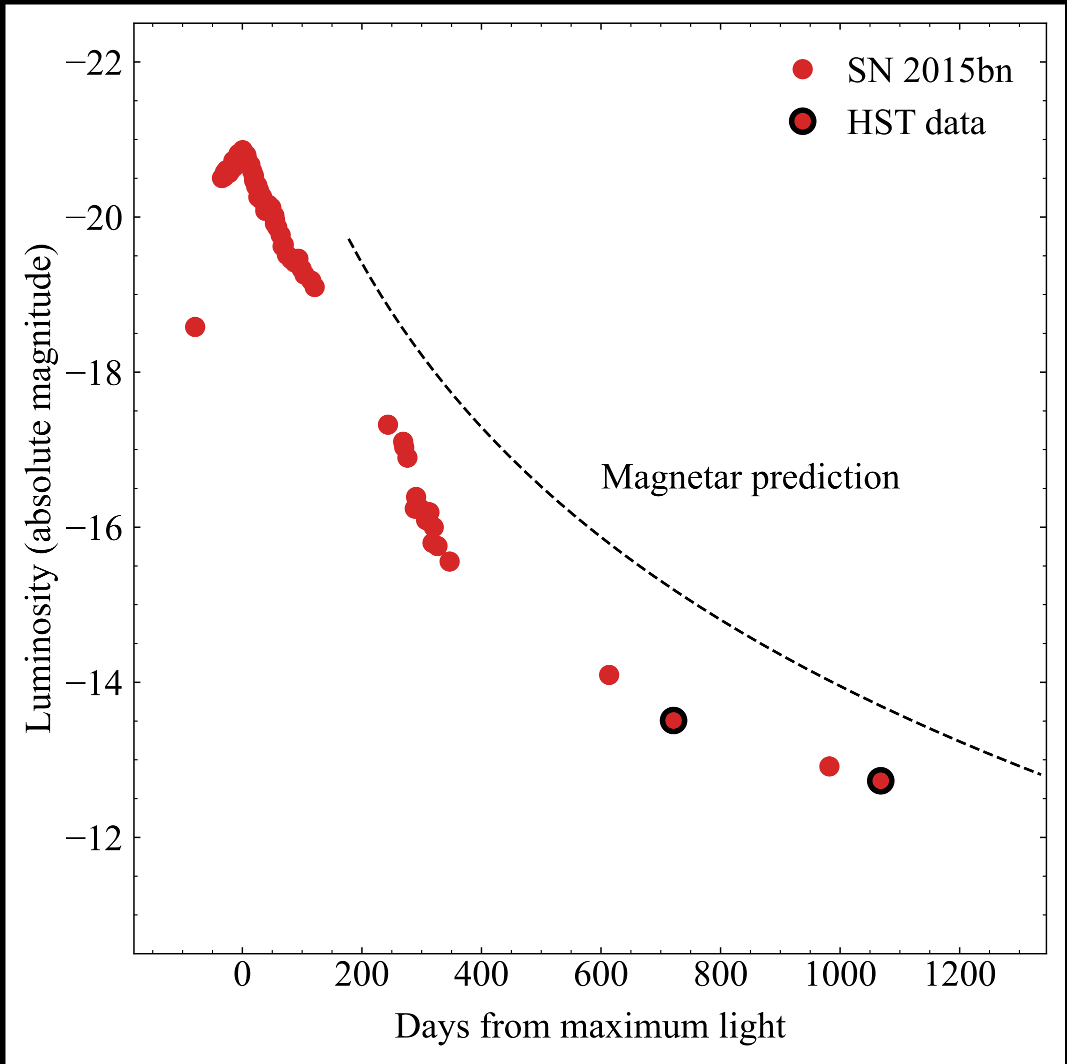
Some observed neutron stars rotate very quickly, giving them a large energy

Others are among the most magnetic objects in the Universe

If a neutron star is both fast-spinning and magnetic, it can give most of its energy to power the supernova!

This is called a magnetar

Why so bright?

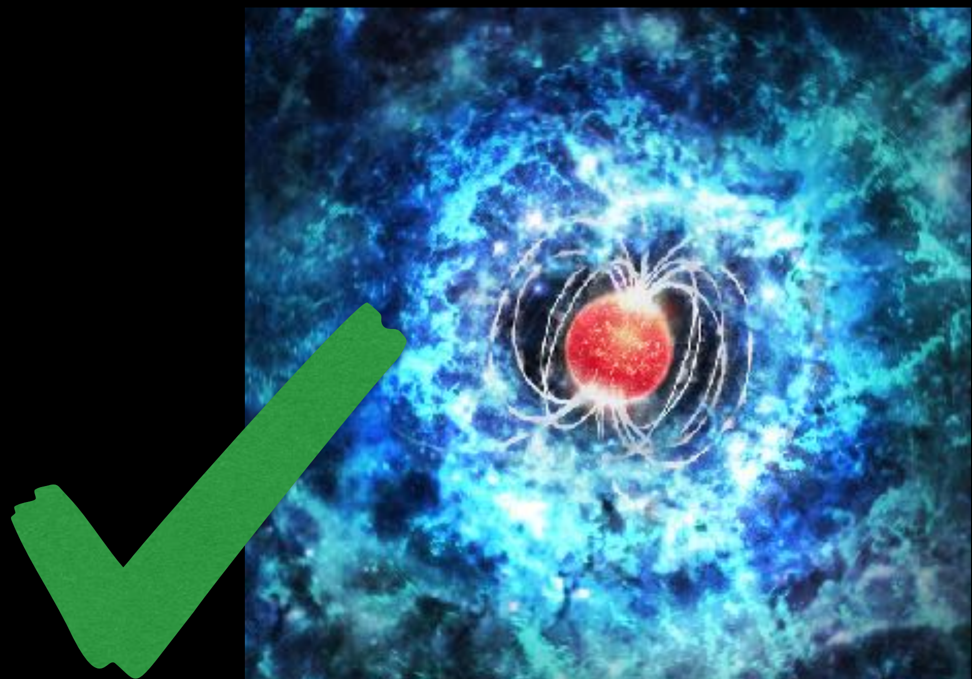


By observing super-luminous supernova for a long time, sometimes we can see the effect of the magnetar more directly!

Why so bright?

Collision with slow, dense gas

Large nickel mass



Fast-spinning magnetar

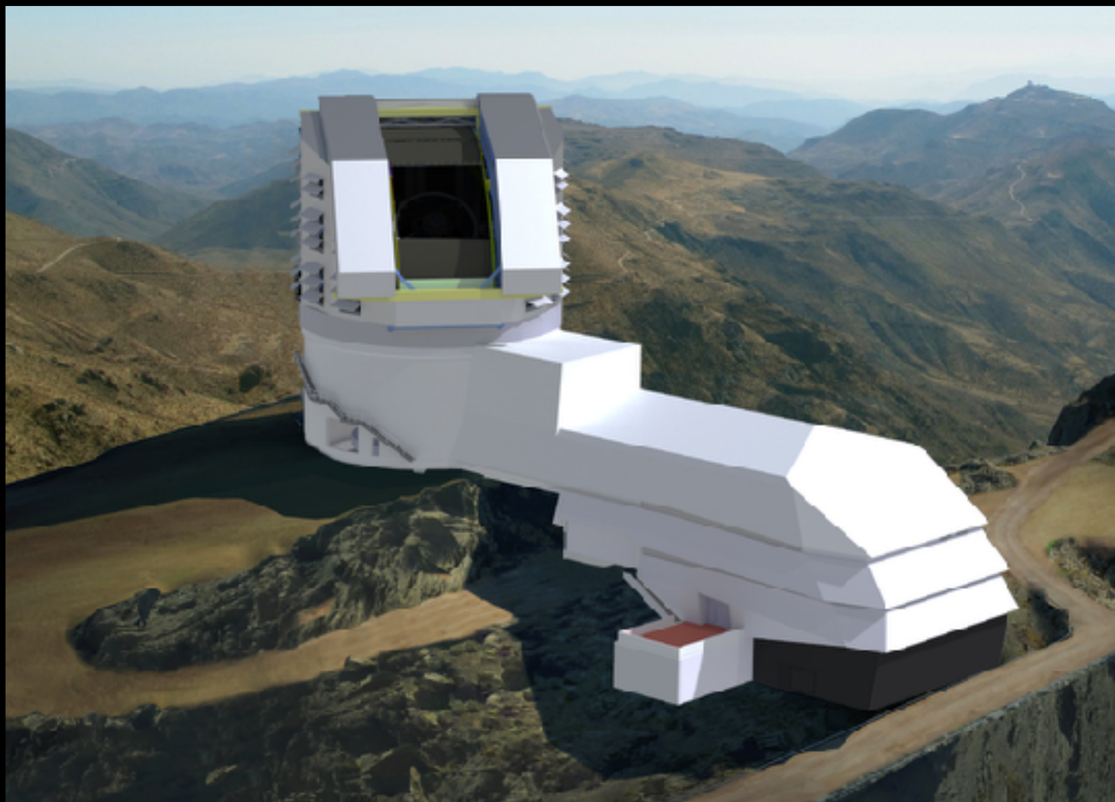
Open questions

Many scientists now agree that a magnetar powers most superluminous supernovae

- Why do they only form in metal-poor galaxies?
- How do these stars lose their envelopes, and why do we only catch up with it sometimes?
- Does the star need a binary companion to keep it spinning rapidly?
- Do some superluminous supernovae come from the most massive stars in the Universe?

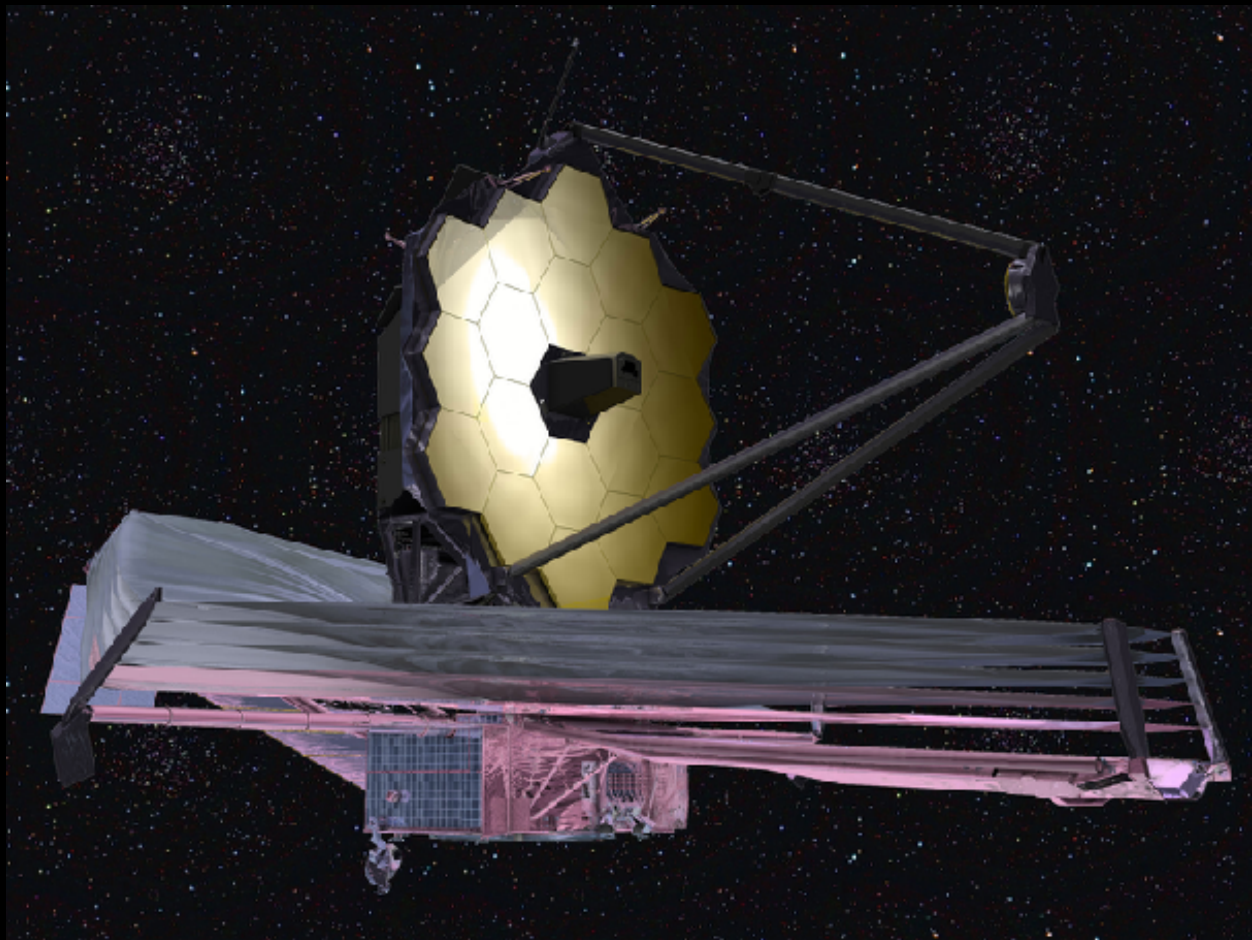
The future is superluminous!
i. Vera C. Rubin Observatory

The Legacy Survey of Space and Time



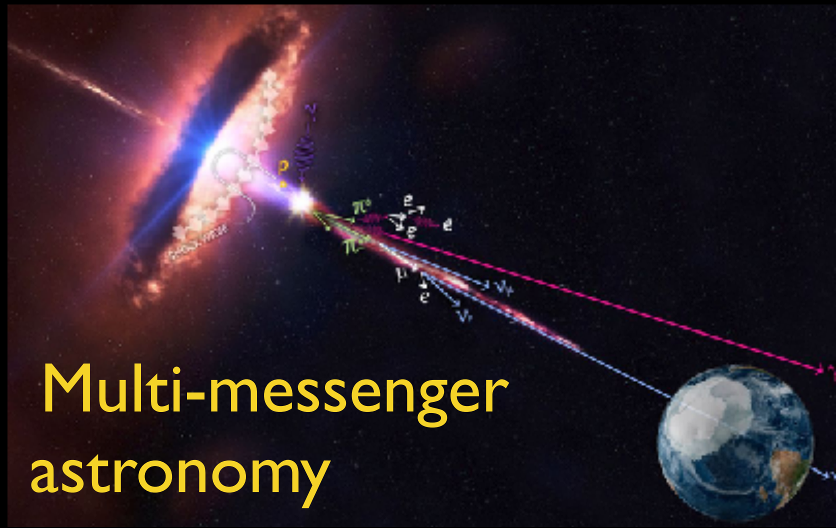
1000 SLSNe per year (currently 100 total)

The future is superluminous!
ii. James Webb Space Telescope



JWST can see SLSNe from the first billion years after Big Bang

The future is superluminous!
iii. The golden age of transients



Thanks!