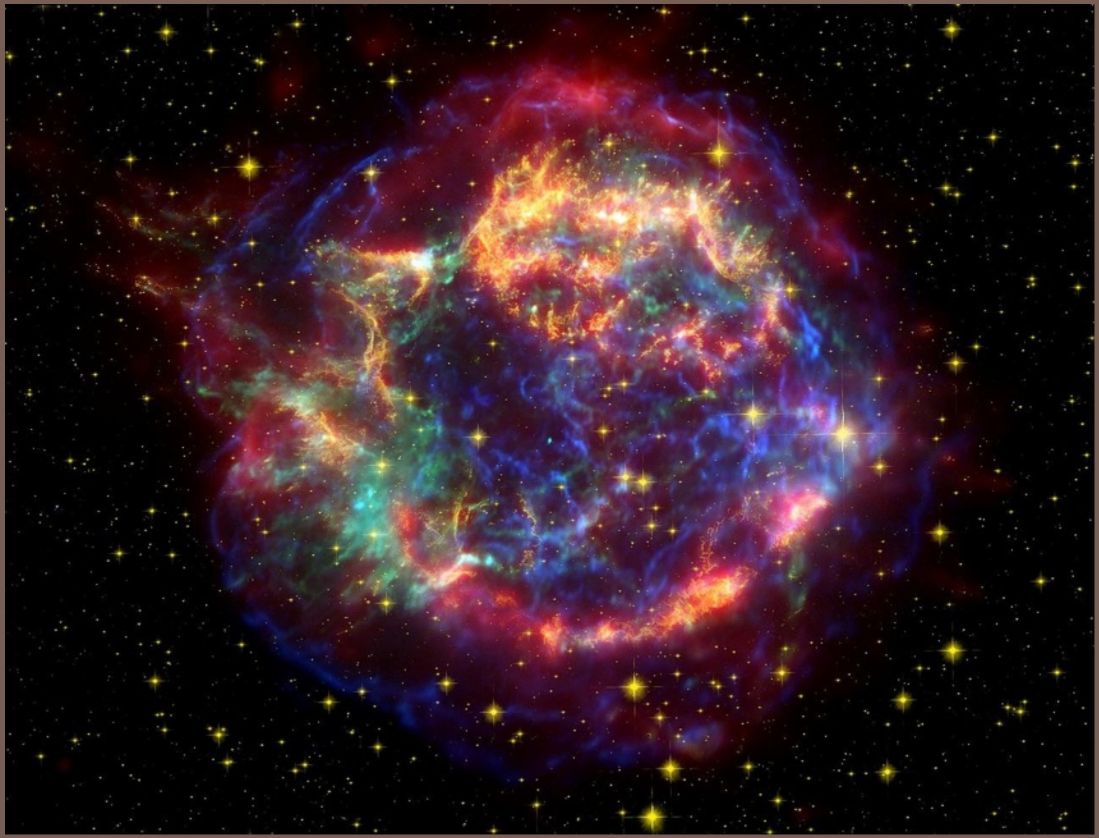


# STELLAR DEATH, AND OTHER THINGS THAT GO BOOM IN THE NIGHT

Kevin Moore - UCSB

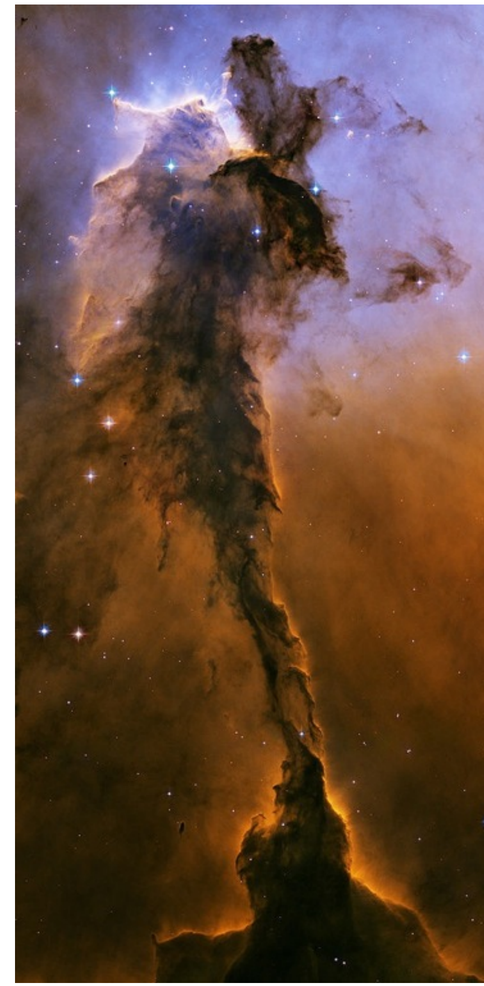
# Overview

- Stellar evolution basics
  - Fates of stars related to their mass
  - Mass transfer adds many possibilities

- Historical supernovae
- Current models of supernovae
- Connecting models to observations
  - What I work on!

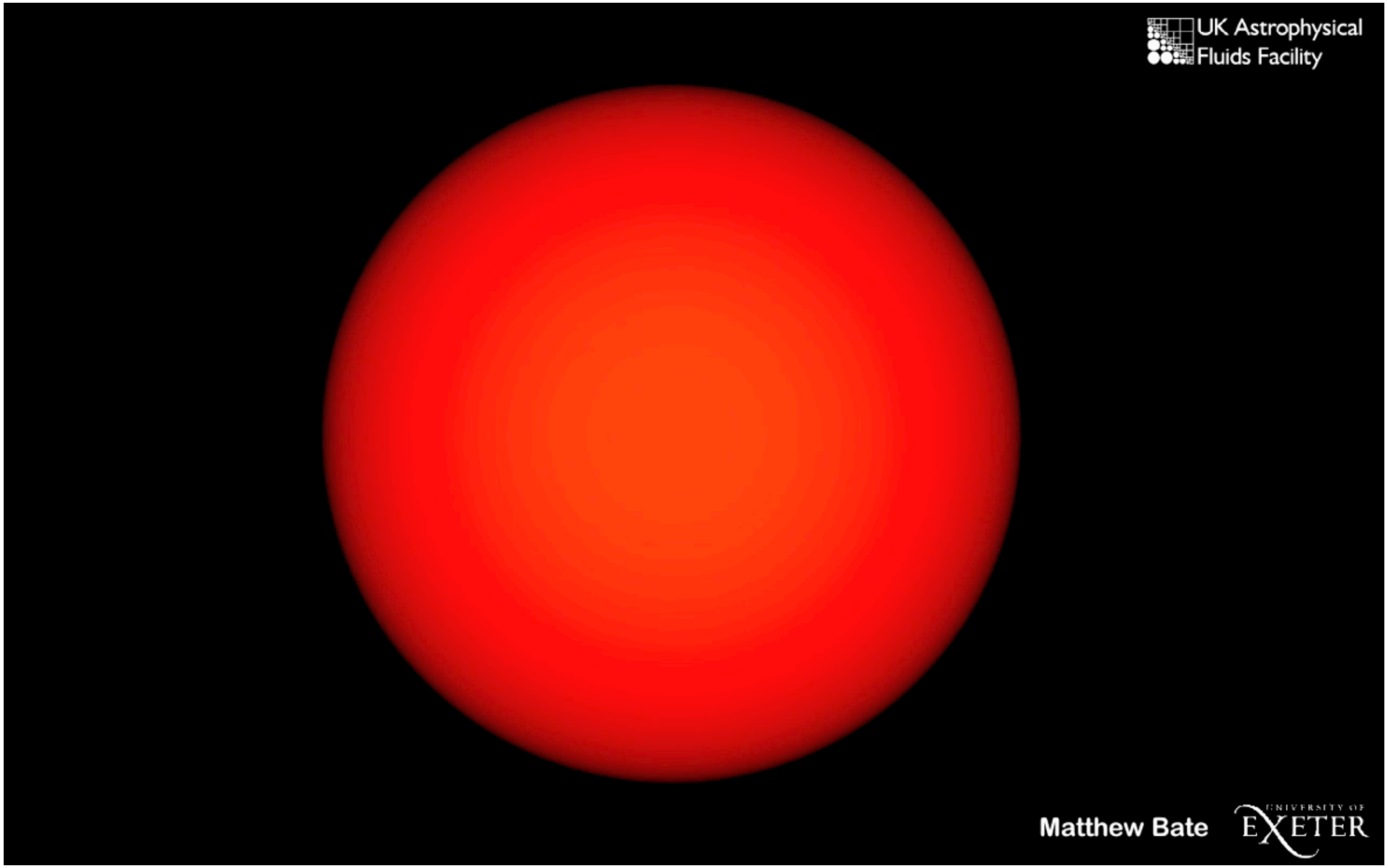
# Star formation

Star forming region S106



Eagle nebula

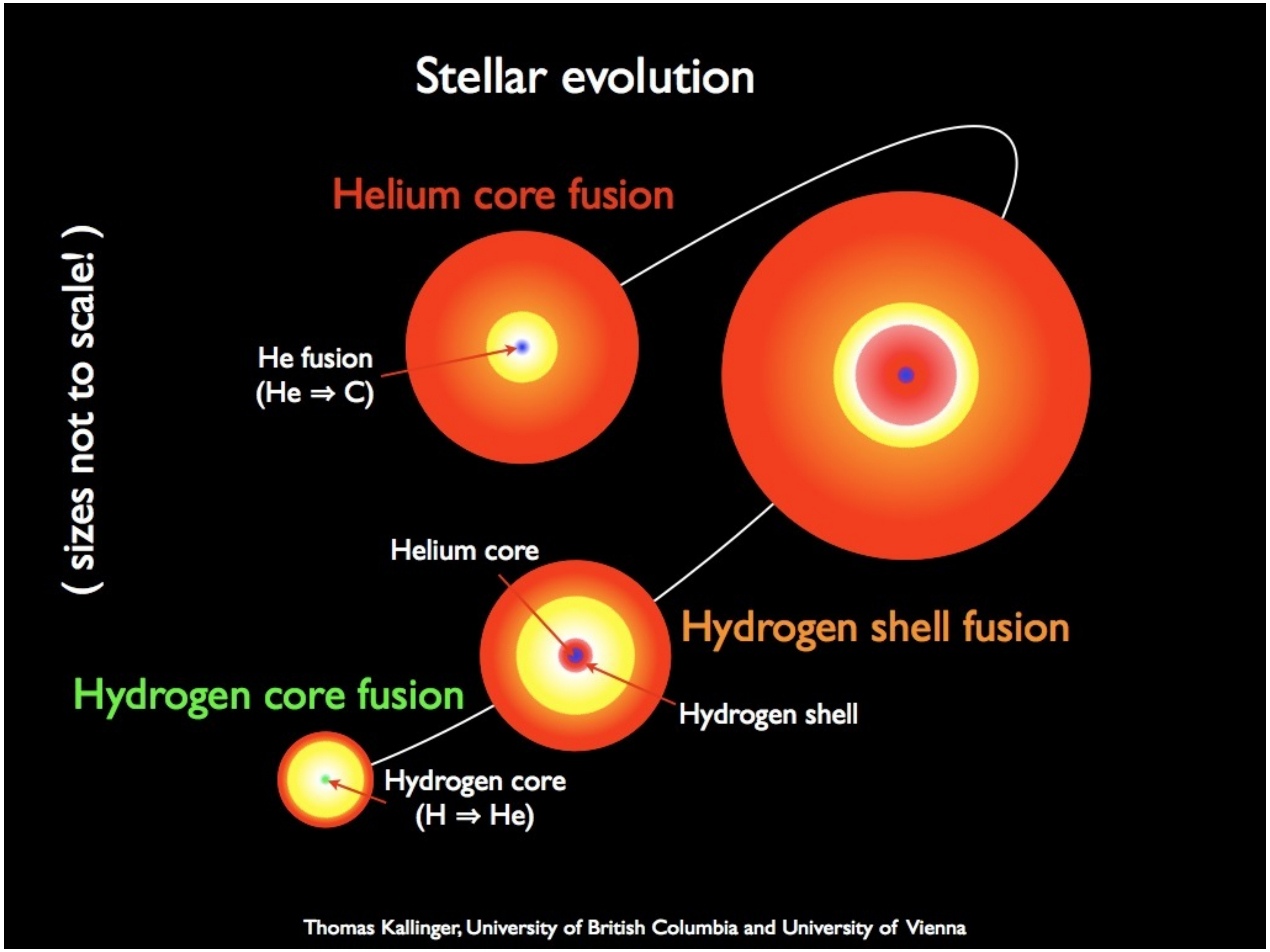
# Simulations of cluster formation



# Stellar evolution

In general, stars will burn heavier nuclei as they age

How far down the periodic table they can go depends on their mass



# White dwarfs – our future Sun!

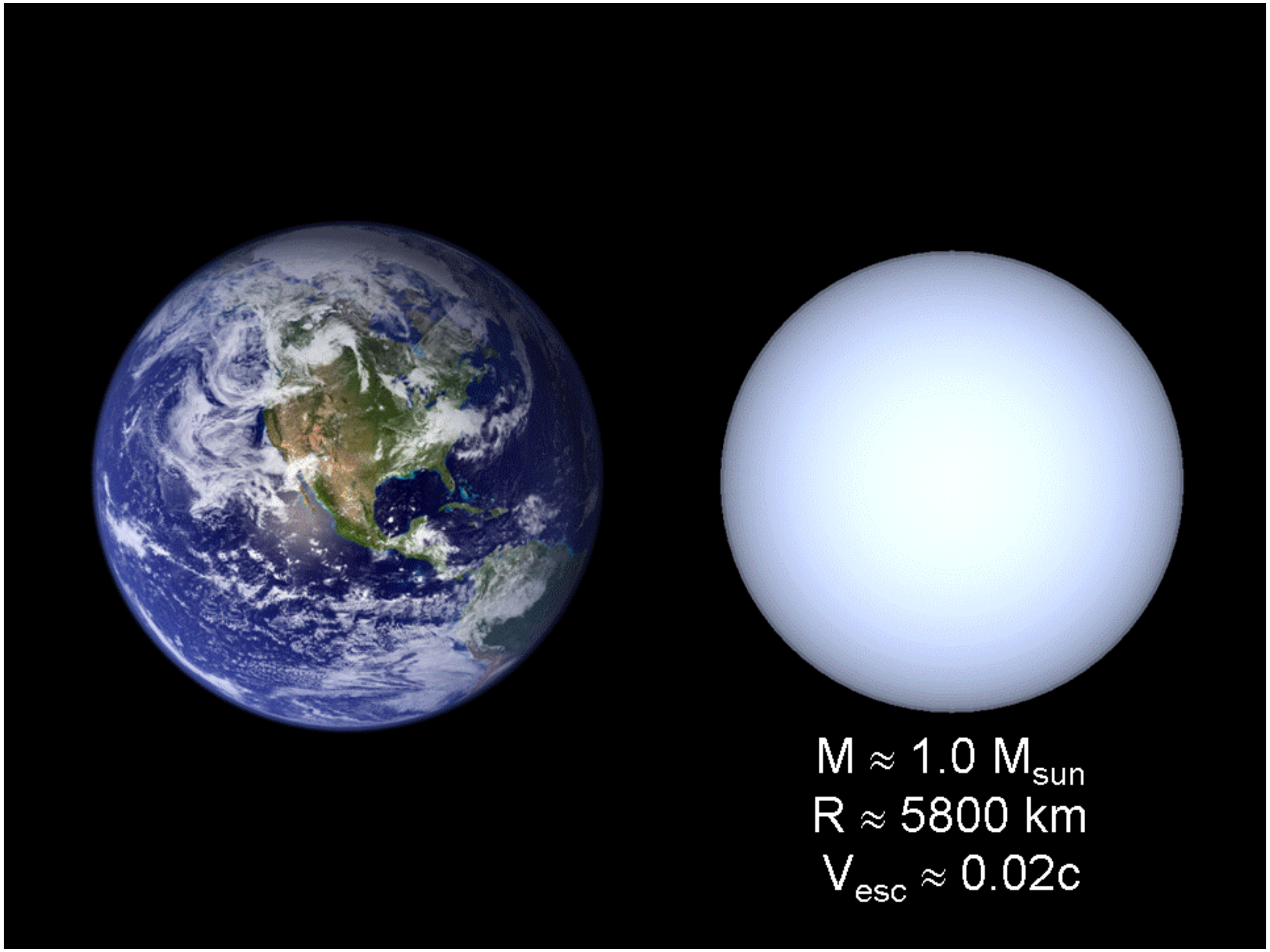


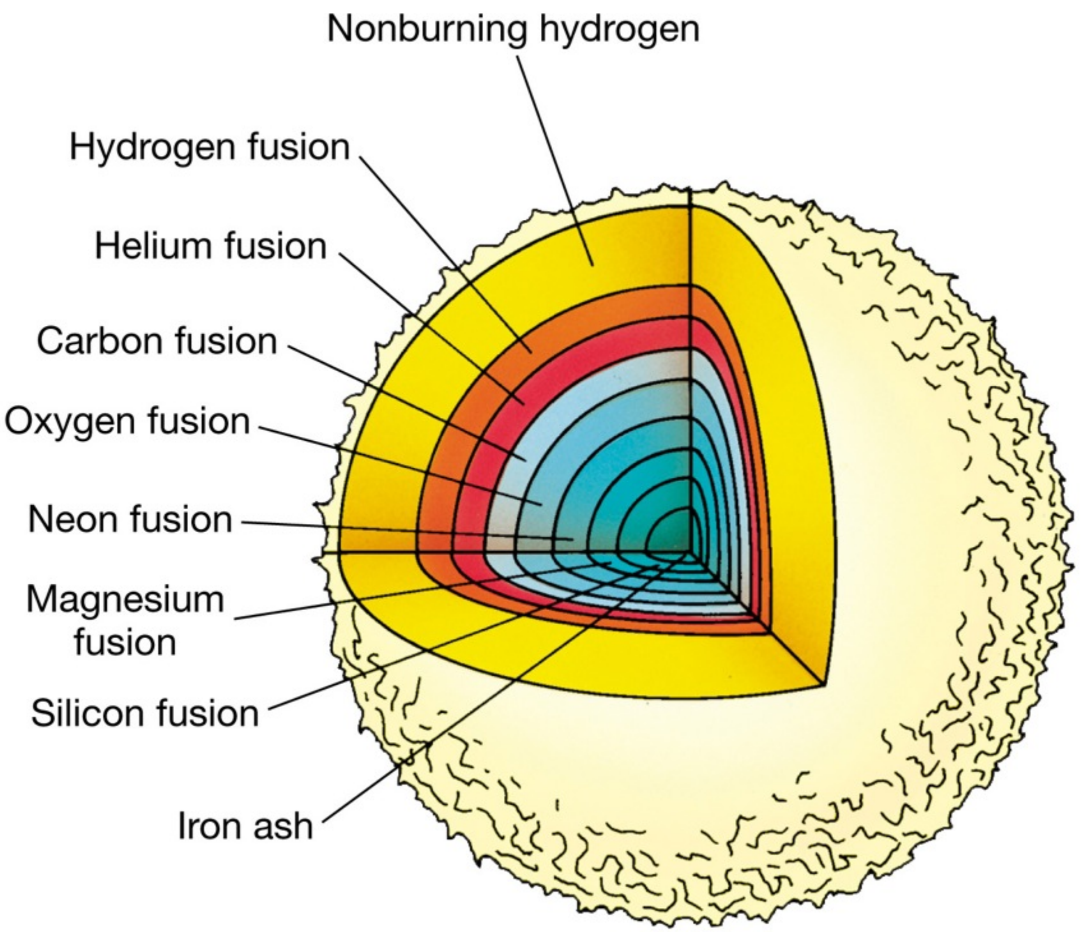

Image: Richard Pogge

# Stellar evolution

Massive stars (~6 solar masses and above) will build up an ‘onion skin’ of burning layers

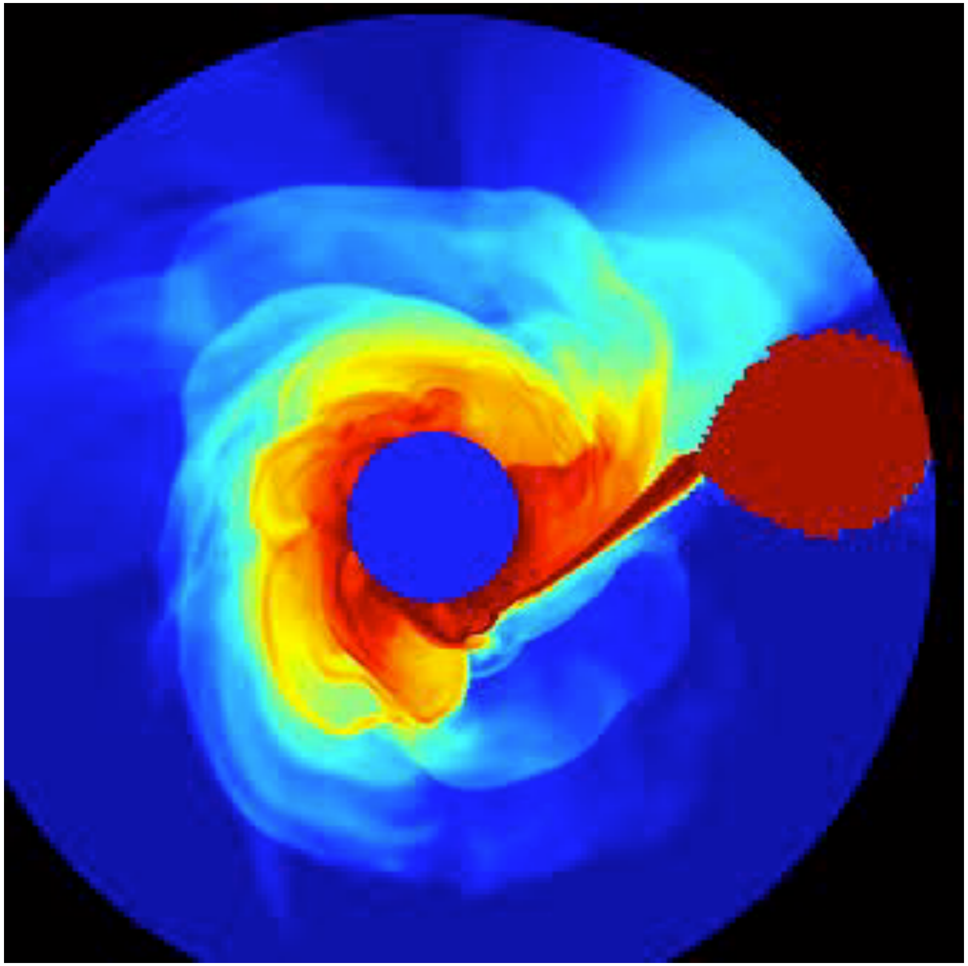
However, once you reach iron, you can no longer extract energy from fusion

Core collapse!



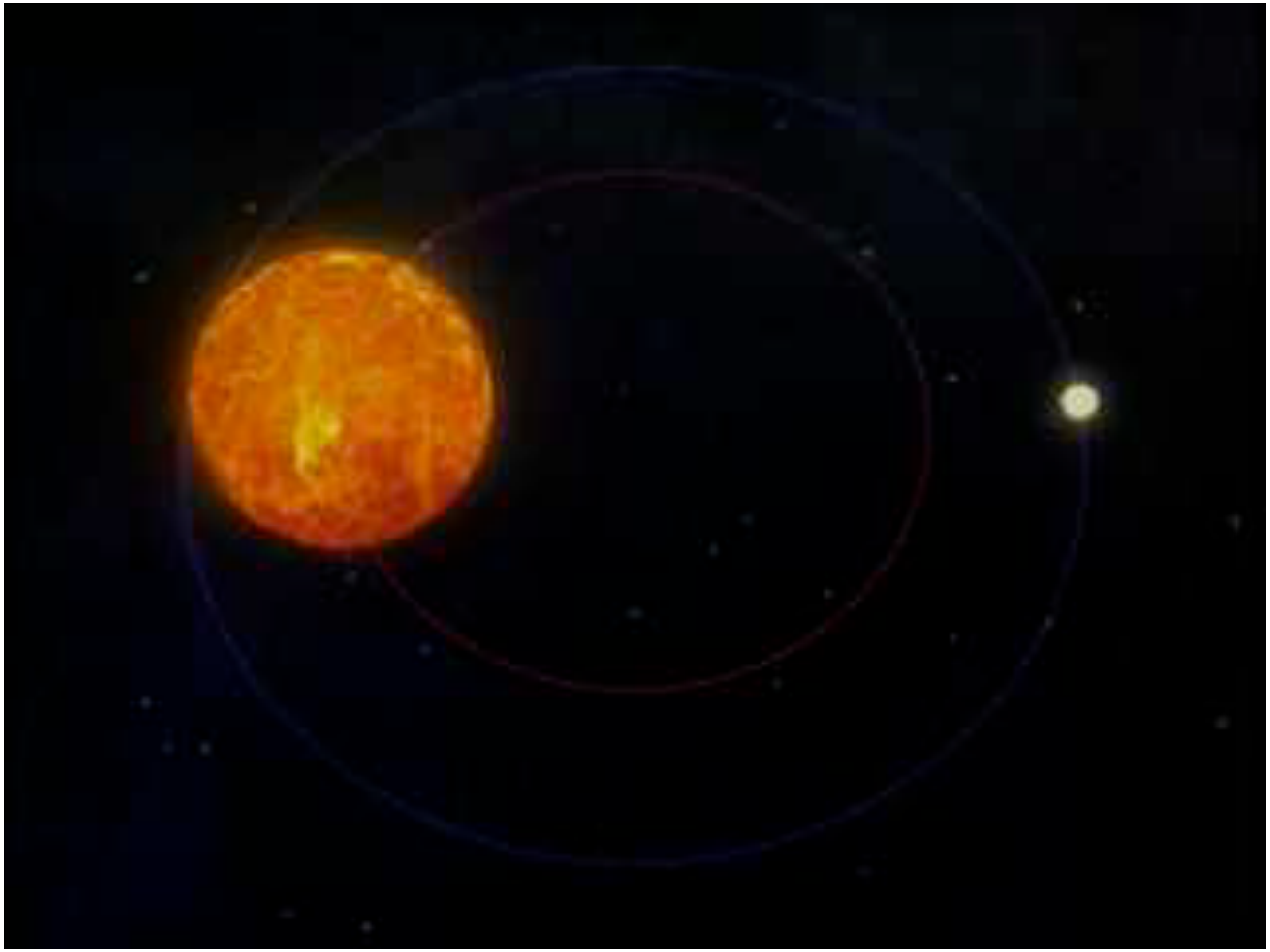
# Stellar evolution in binaries

Accretion (mass transfer from one star to another) can lead to all sorts of interesting additional outcomes!



**John M. Blondin, Marcedes T. Richards, Michael L. Malinowski (North Carolina State University)**

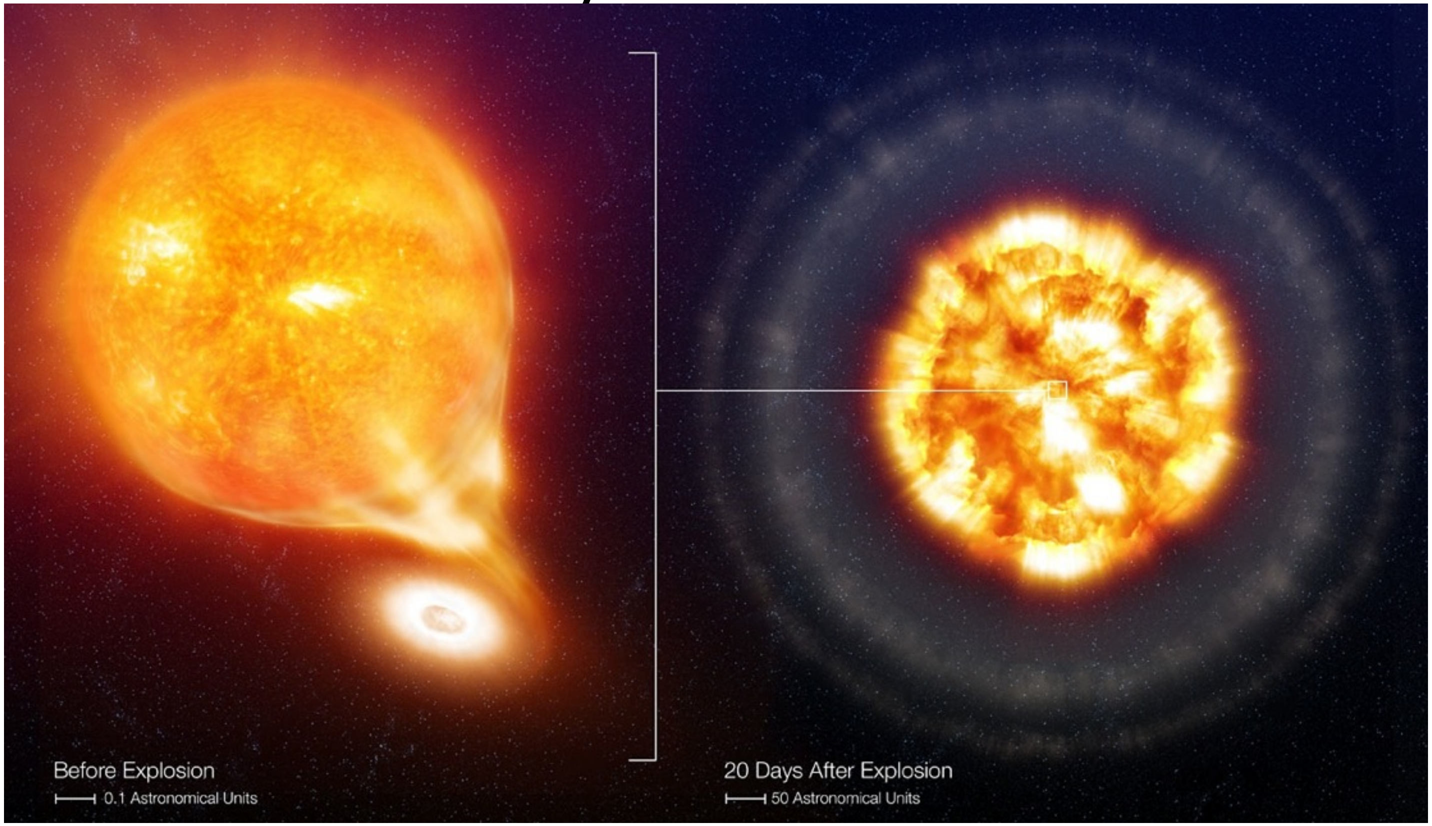
# White dwarfs in binaries



Space Telescope Science Institute

# Accretion onto white dwarfs

- Maximum mass of a white dwarf: ~1.4 $M_{\odot}$ (Chandrasekhar mass)




Artists' impression of a Type Ia Supernova explosion [Credit: ESO]

# Blowing up white dwarfs

Two different ways to bring a white dwarf above its maximum mass

We've never directly seen the progenitor of a Type Ia supernova before it happened

Currently a major unsolved problem in astrophysics!

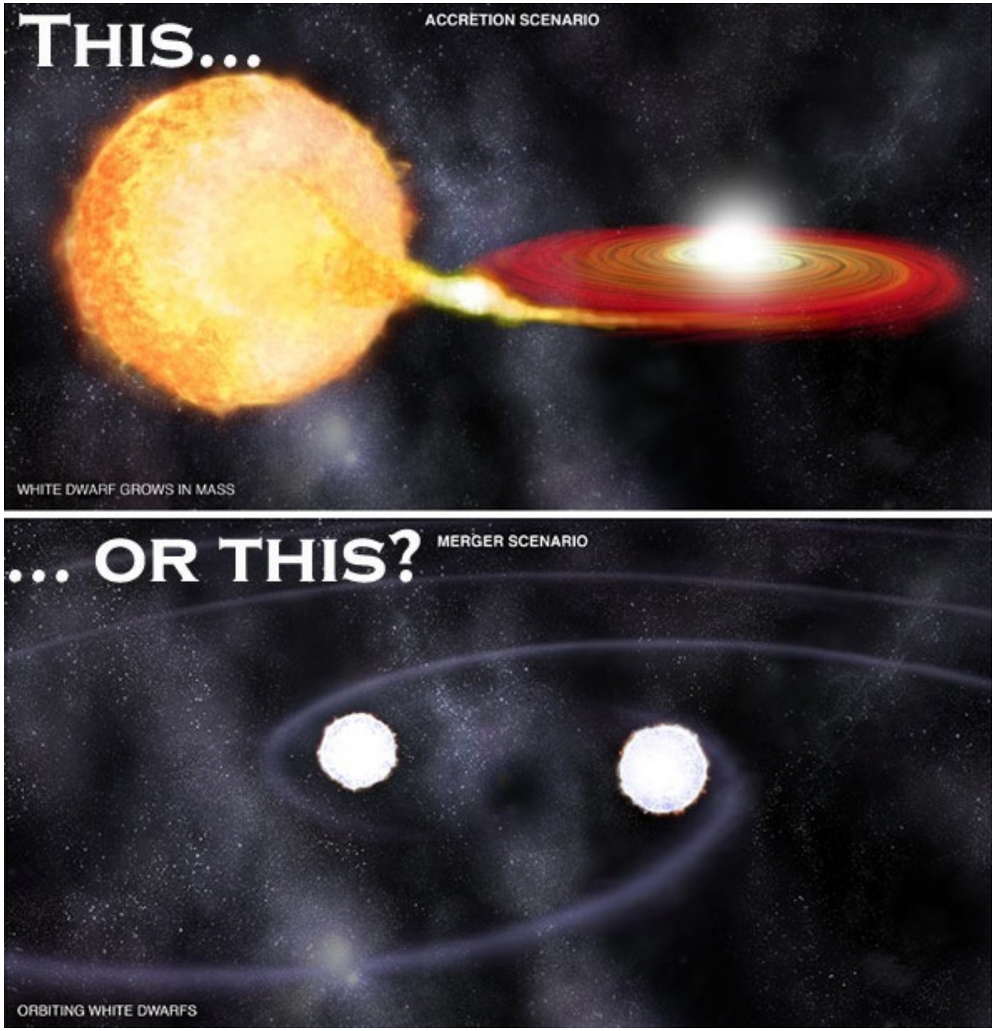



Illustration: NASA/CXC/M.Weiss (adapted a bit by The Bad Astronomer)

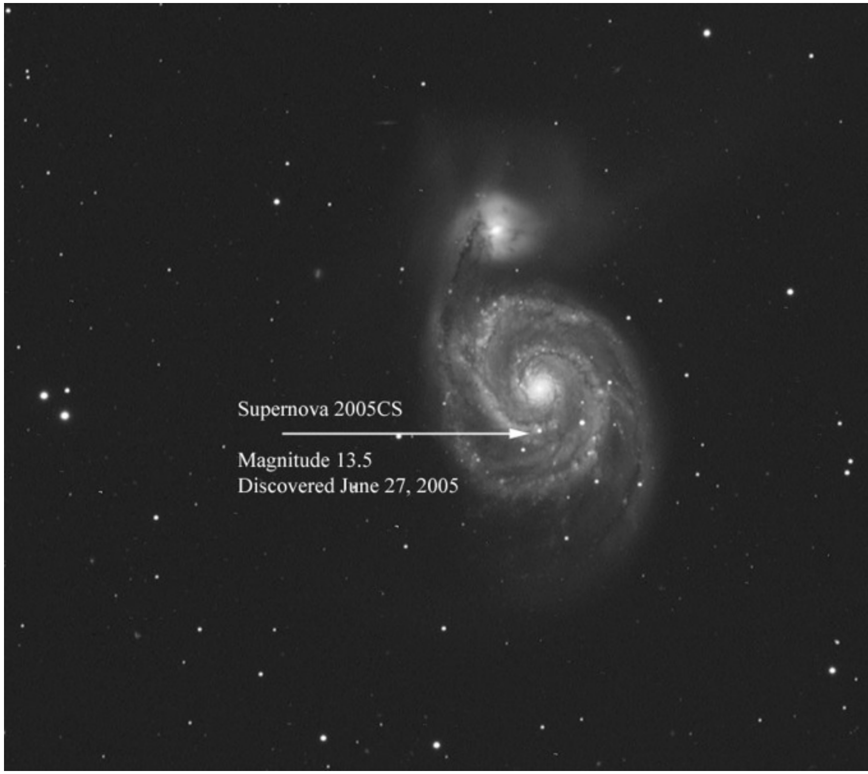
# Main classes of supernovae

- Thermonuclear (eg. Type Ia)
  - Get their energy from decay of radioactive isotopes formed during the explosion
    - Mostly nickel-56 decay (half-life ~6 days)
  - Do not leave behind compact objects
  - Roughly 2/3 of the iron in us was made in Type Ia's

SN 1994D

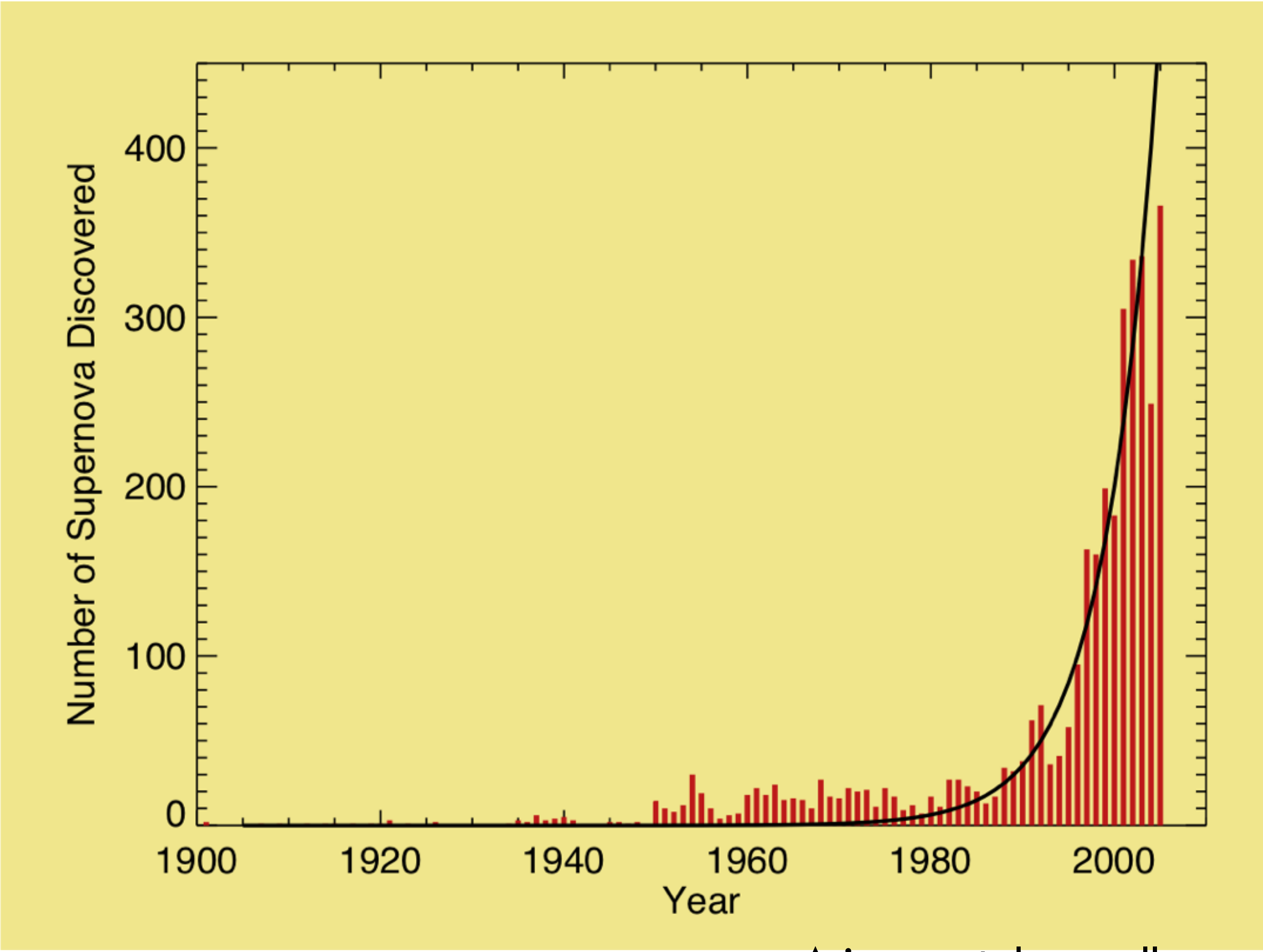
# Main classes of supernovae

- Core-collapse (eg. Type II)
  - Get their energy from gravitational collapse and release it through changes in ionization state
  - Leave behind neutron stars or black holes




SN 2005cs

# Supernova discoveries per year




Asiago catalog – all supernova types

# Historical supernovae

- Last one observed in our galaxy was in 1604 (Kepler's supernova, unknown type)
  - Average rate is one per century, but many are obscured by dust/gas

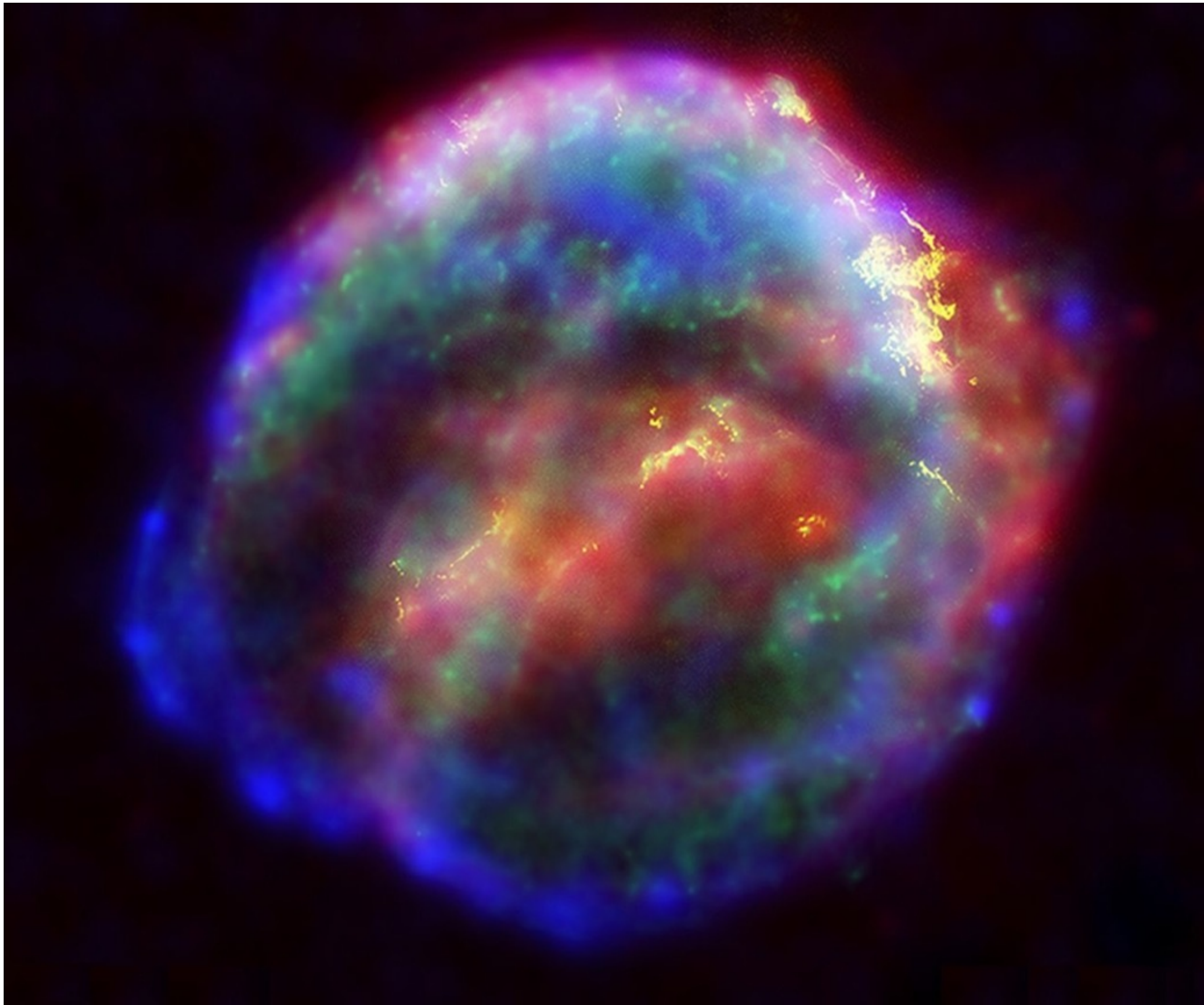
**Table 1.** Summary of the historical supernovae, and the source of their records

| date | length of visibility | remnant | Historical Records: Chinese | Japanese | Korean | Arabic | European |
|---|---|---|---|---|---|---|---|
| AD1604 | 12 months | $G4{\cdot}5+6{\cdot}8$ | few | – | many | – | many |
| AD1572 | 18 months | $G120{\cdot}1+2{\cdot}1$ | few | – | two | – | many |
| AD1181 | 6 months | 3C58 | few | few | – | – | – |
| AD1054 | 21 months | Crab Nebula | many | few | – | one | – |
| AD1006 | 3 years | SNR327.6+14.6 | many | many | – | few | two |
| AD393 | 8 months | – | one | – | – | – | – |
| AD386? | 3 months | – | one | – | – | – | – |
| AD369? | 5 months | – | one | – | – | – | – |
| AD185 | 8 or 20 months | – | one | – | – | – | – |

Green & Stevenson, 2003

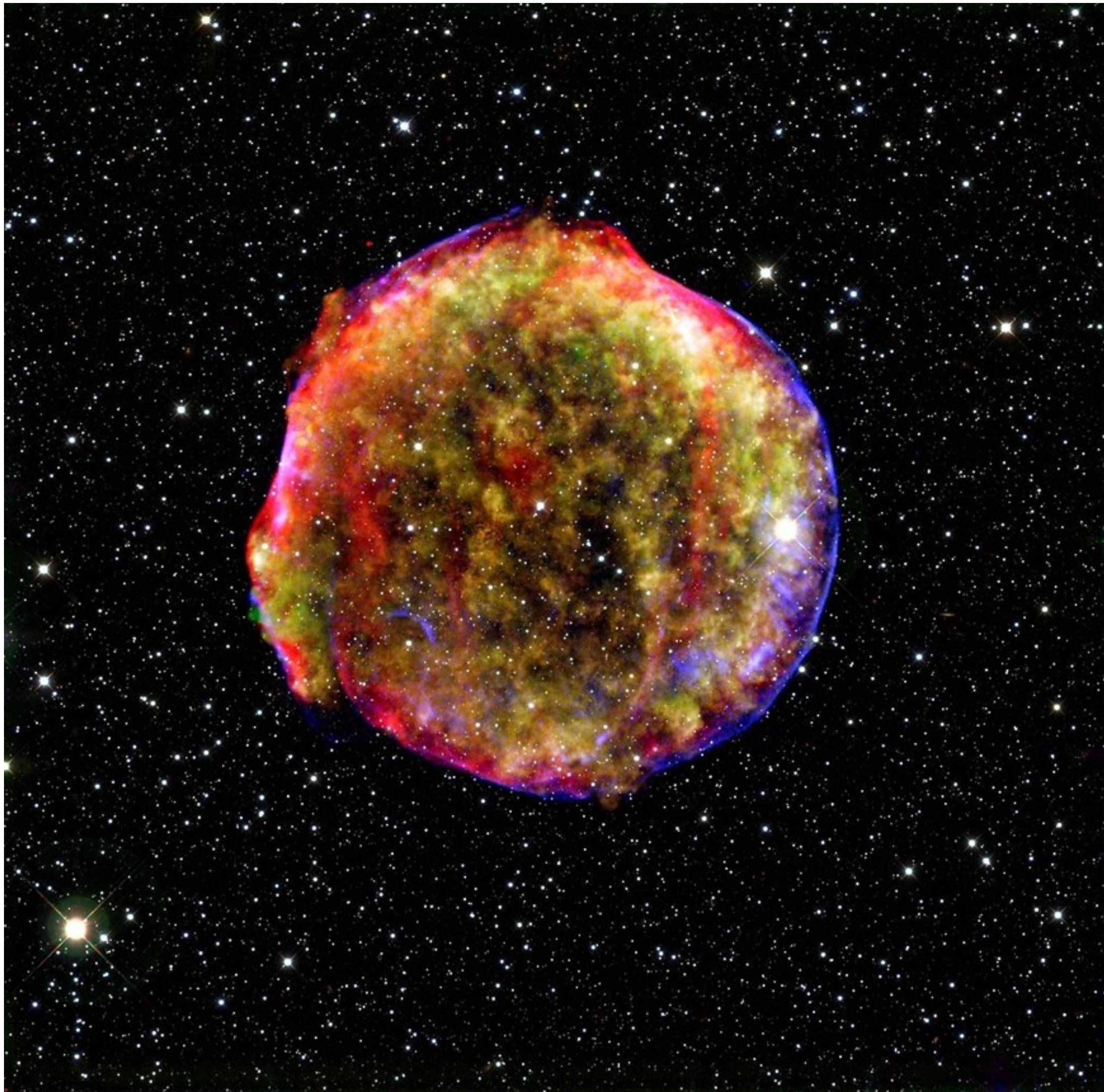
# Kepler's supernova

- ~20,000 ly away
- ~14 ly diameter
- observed in 1604 – type unknown
- At peak, was brighter than all the stars & planets except for Venus



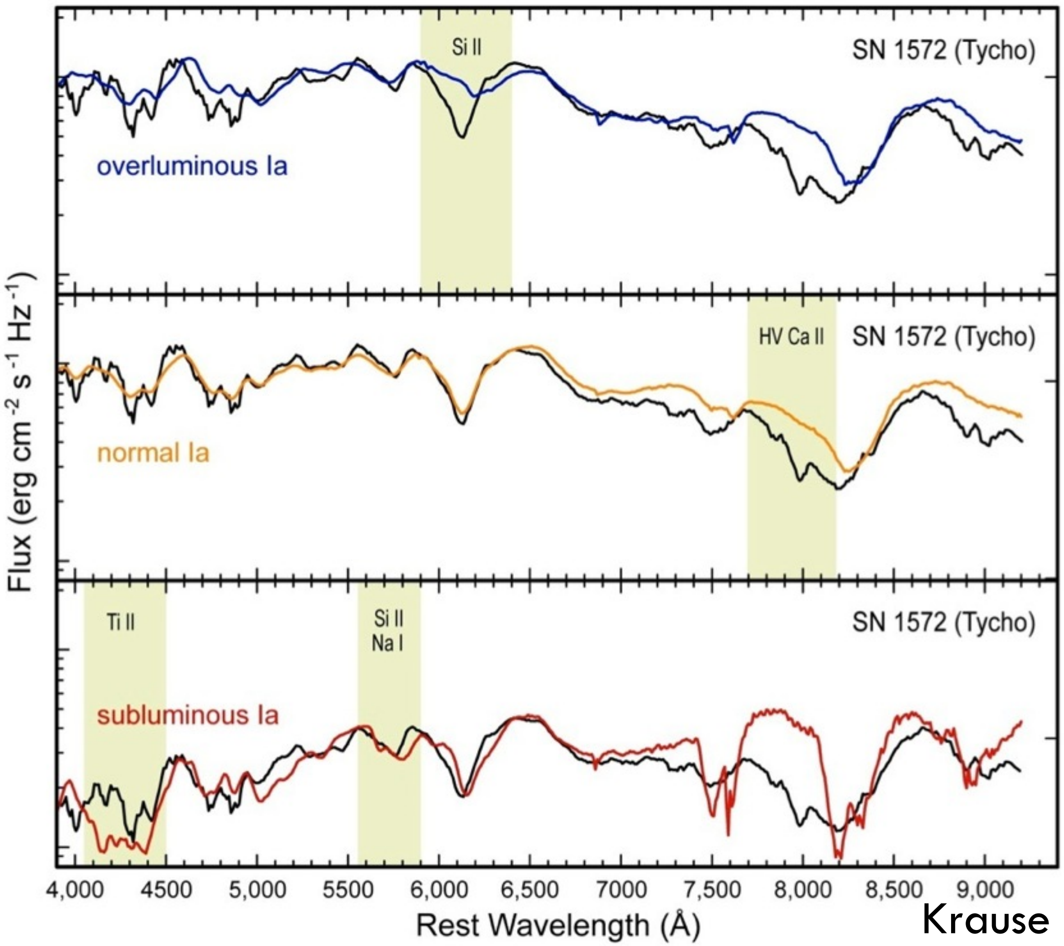
# Tycho’s supernova

- ~9000 ly away
- observed in 1572
- Type Ia supernova – exploding white dwarf
- Possible companion star identified, supporting single-degenerate channel



# Why do we think Tycho's supernova was a Type Ia?

- Light echo spectrum

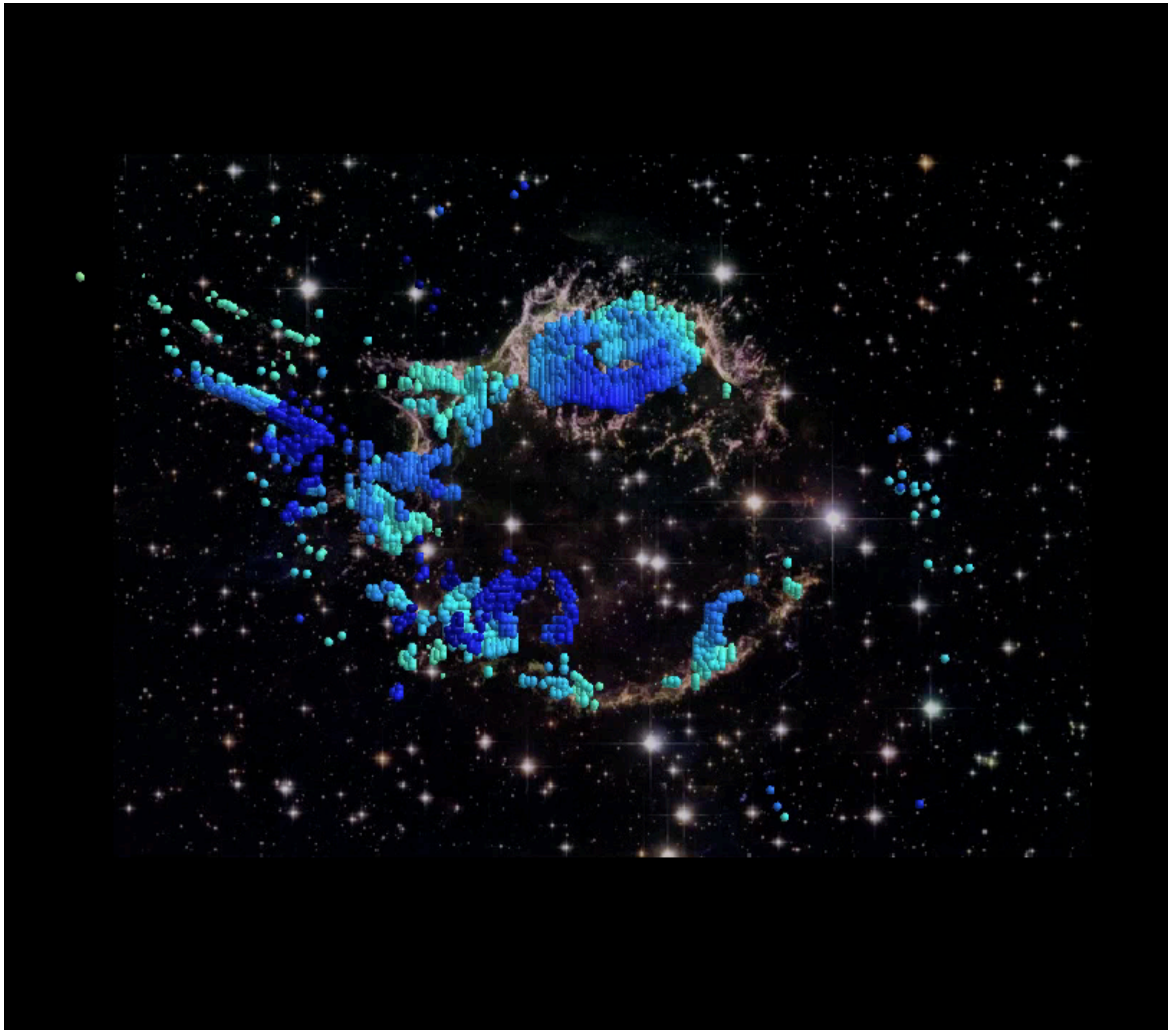



Krause et al., 2008

# Cassiopeia A

- A remnant of something we never saw explode
  - Estimated to be ~300 yrs old

# Cassiopeia A

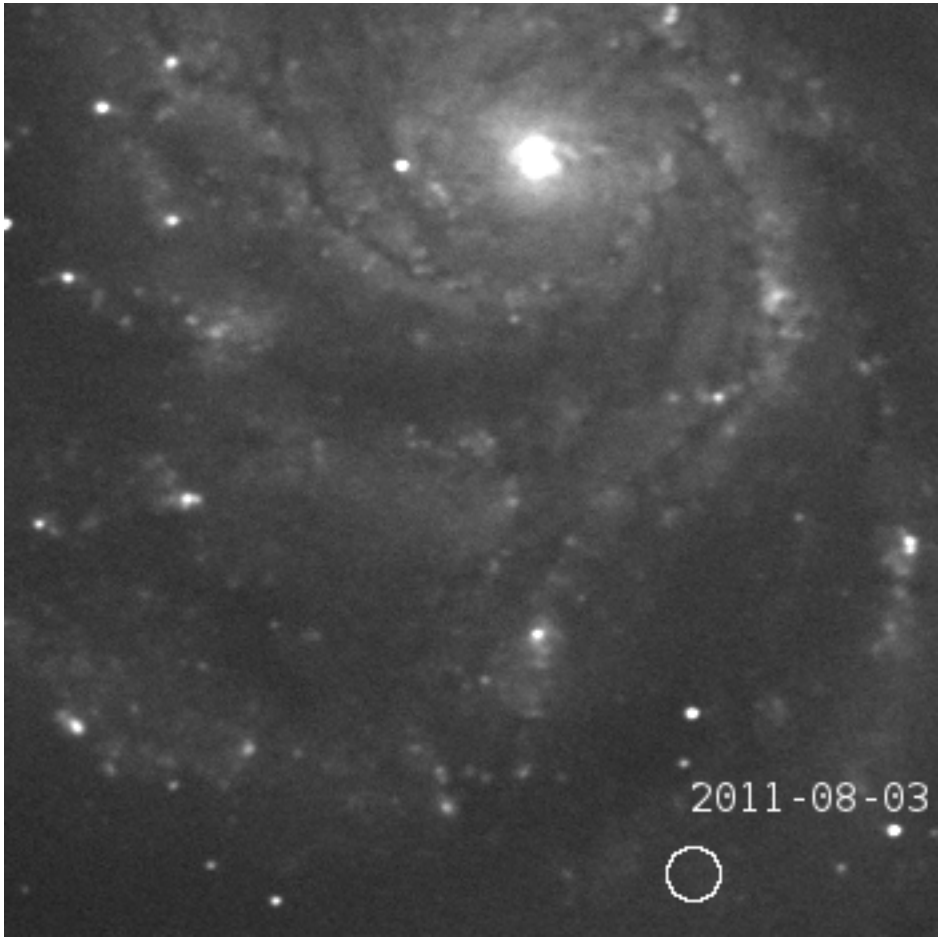


Cas A velocity reconstruction by Dan Milisavljevic

# Supernova of a generation

SN 2011fe happened right in our backyard! (Pinwheel galaxy – M101)

It was a normal Type Ia, and close enough that we could get upper limits on the size of its progenitor



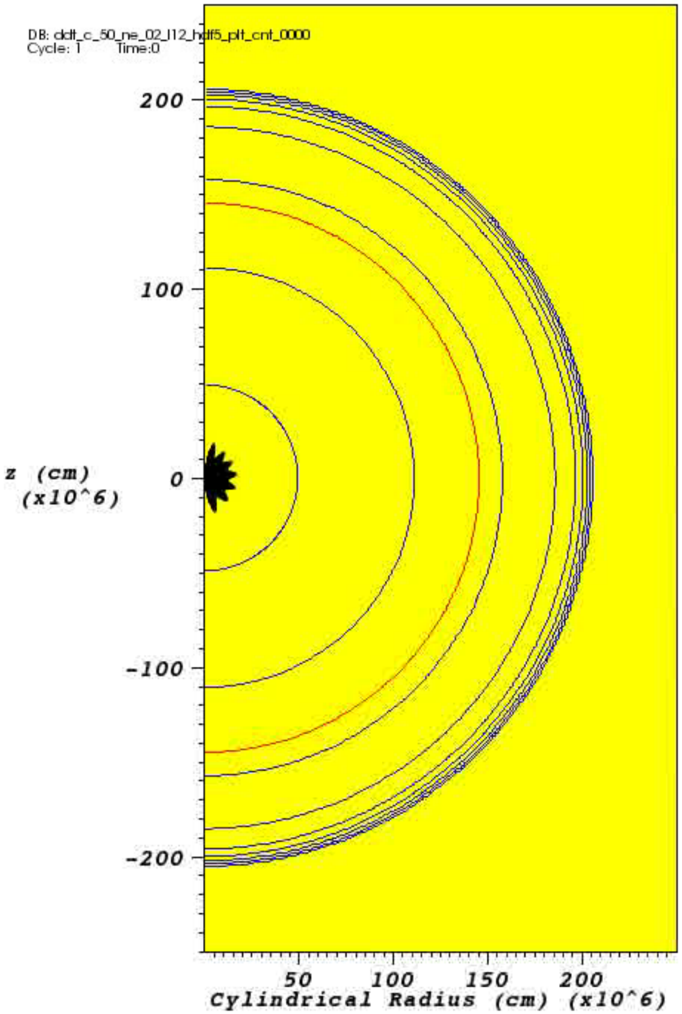

Movie courtesy of Branimir Sesar, Caltech

# Models of Type Ia supernovae

- Very hard for several reasons:
  - Need to be done in 3D – huge amounts of data & computation time (>1,000,000 cpu-hrs)
  - We don't know the type of burning (subsonic deflagration or supersonic detonation)
    - Both required for best fits to observations
  - We still don't have the progenitors pinned down!
    - SN 2011fe: strong evidence for double-degenerate scenario
    - Tycho's SN & interacting Ia's: strong evidence for single-degenerate scenario

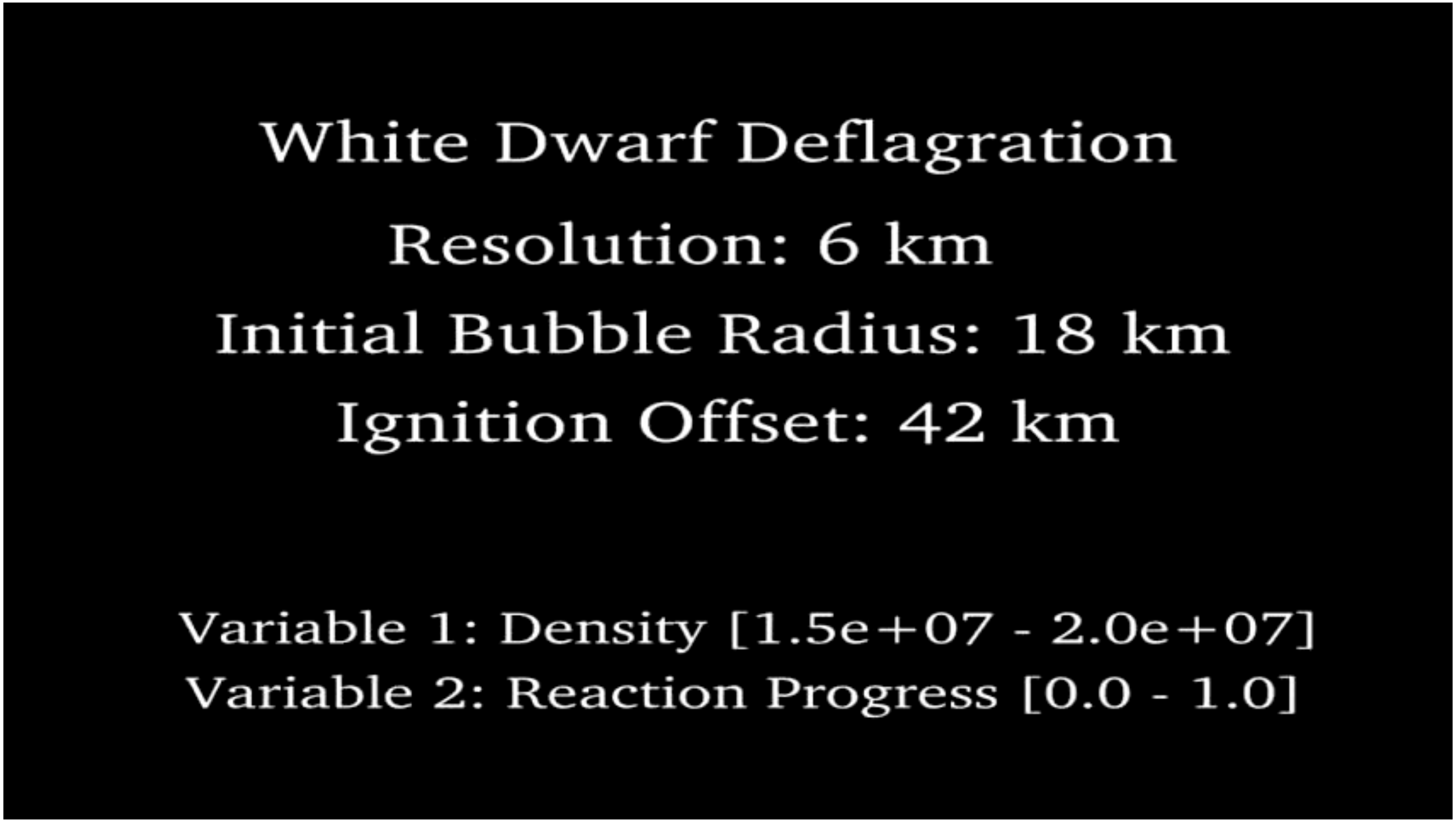
# Models of Type Ia supernovae

- 2D (axisymmetric) model of deflagration to detonation transition
- Colors indicate the elements synthesized (darker means heavier)




Animation courtesy of Dean Townsley

# Models of Type Ia supernovae

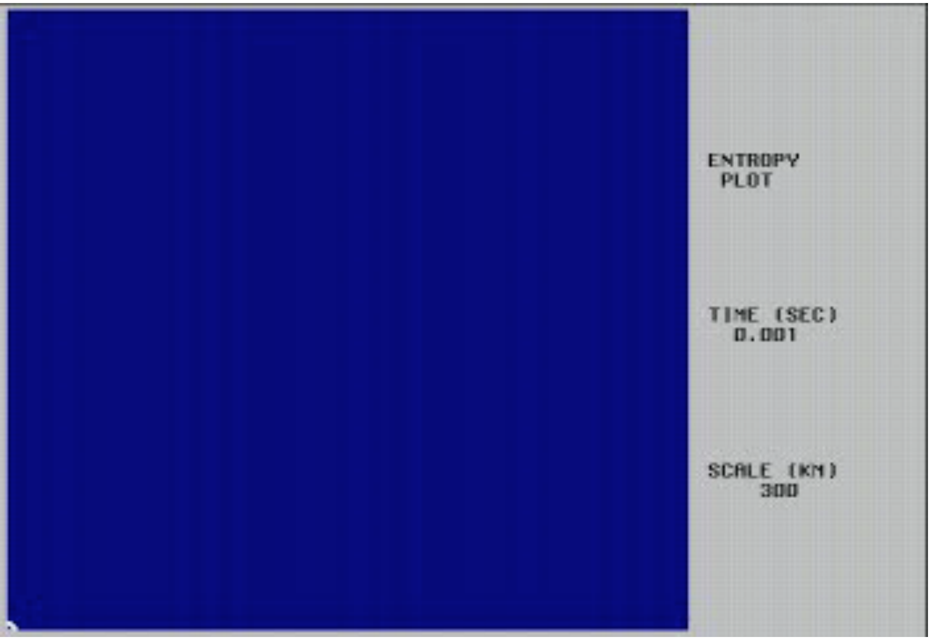


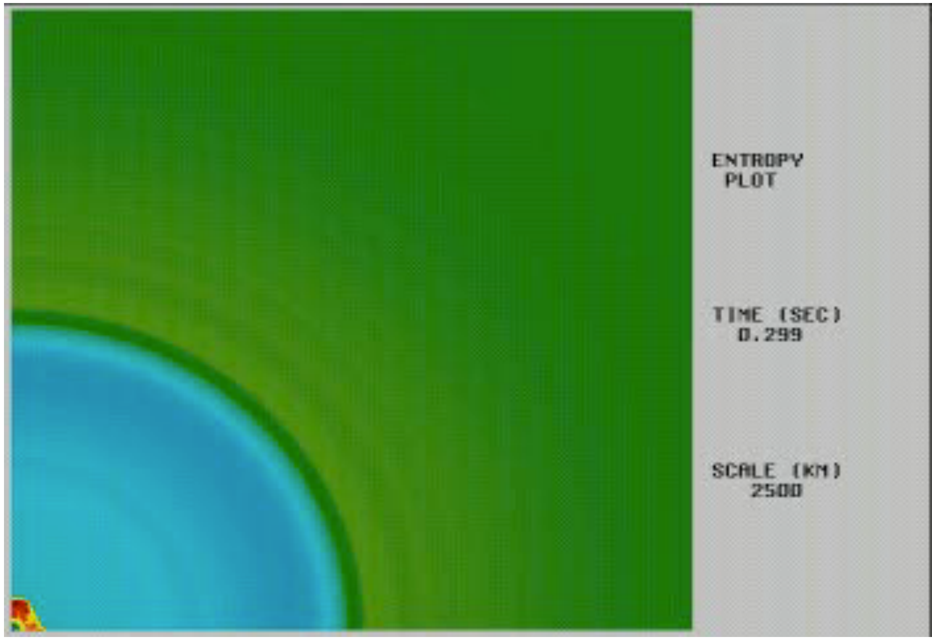

Animation courtesy of FLASH group

# Models of core-collapse supernovae

- Also very difficult:
  - Neutrino interactions are important in reviving the shockwave that blows the star apart –hard to model since neutrino type is important
  - Including general relativity is necessary
  - Huge nuclear network required & rapid flows
    - Photodisintegration – photons destroying nuclei
    - Neutronization – protons and electrons forming neutrons

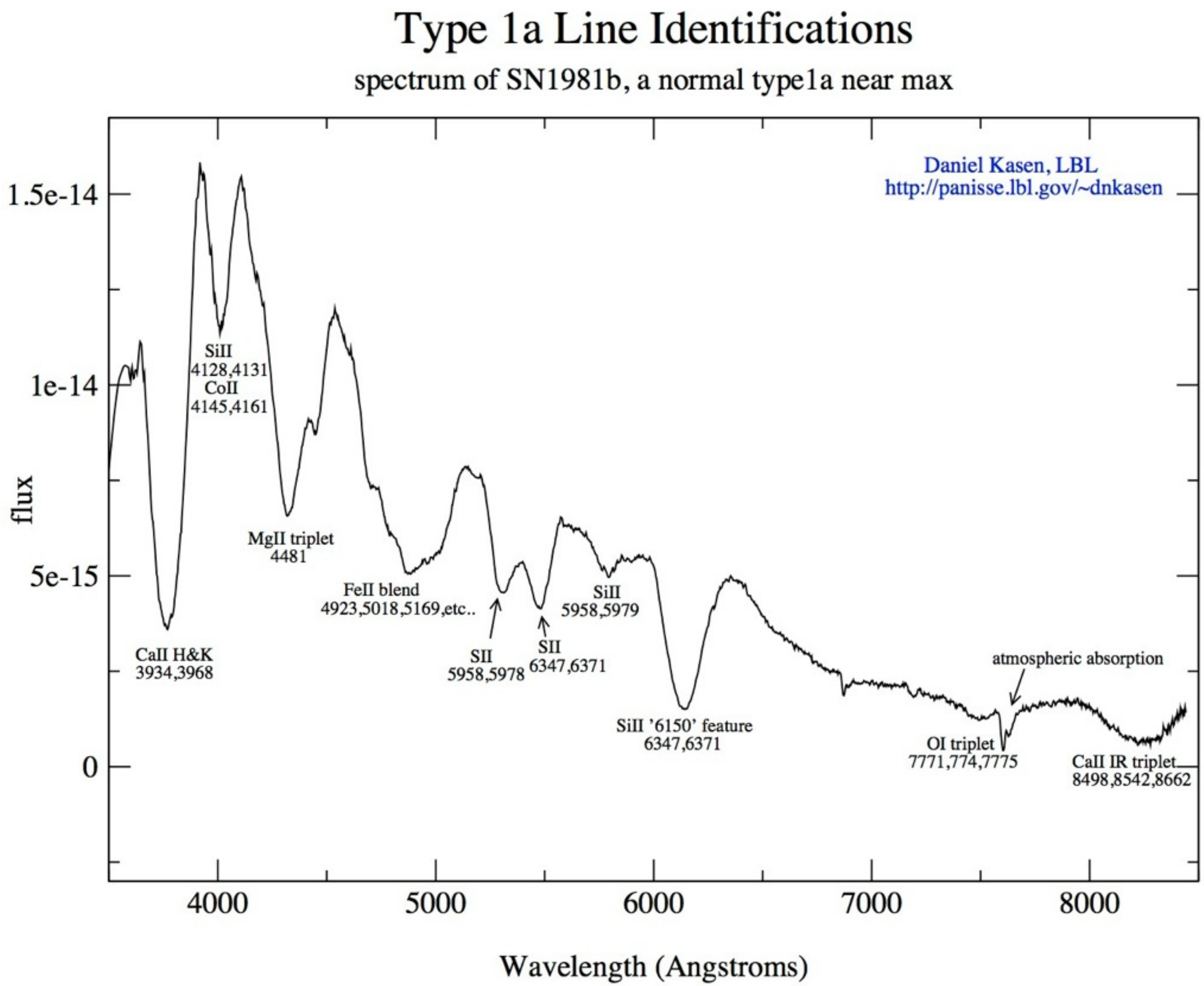
# Models of core-collapse supernovae



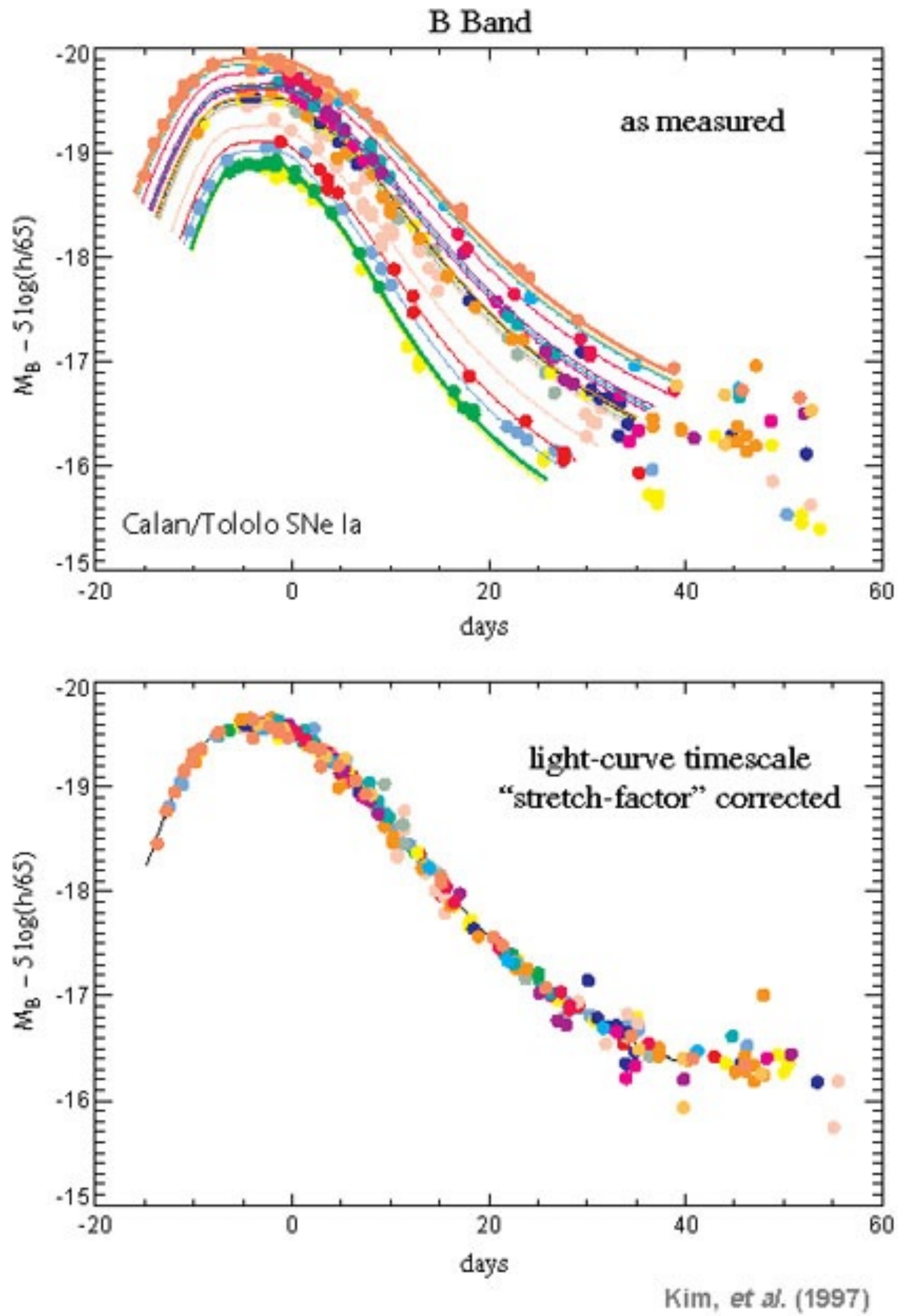

Burrows et al., 1995

# Connecting models to observations



# Applications of supernovae

- Decay timescale and intrinsic brightness of Type Ia's are related
  - Measure distances!
  - Universe is accelerating! (2011 Nobel Prize)



# Applications of supernovae

- May have heard about the ‘superluminal’ neutrino measurements reported last fall from Gran Sasso

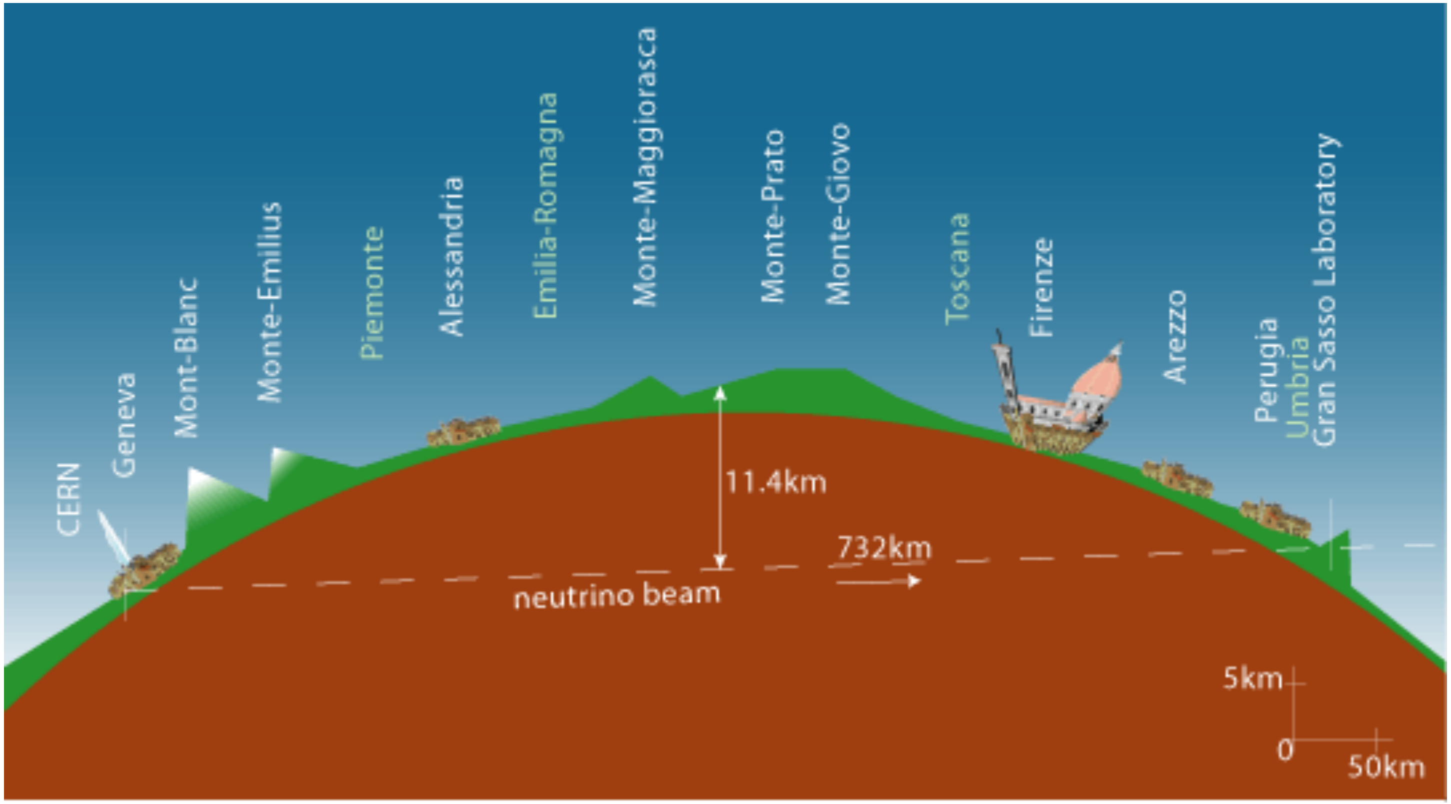



Image: CERN

# Applications of supernovae

- We saw neutrinos from a core-collapse supernova once: SN 1987A
  - Neutrinos arrived ~3 hrs before photons did
    - As expected – they scatter much less than photons
  - However, if superluminal neutrino measurements were correct, we should have seen the neutrinos almost 4 years before the photons!

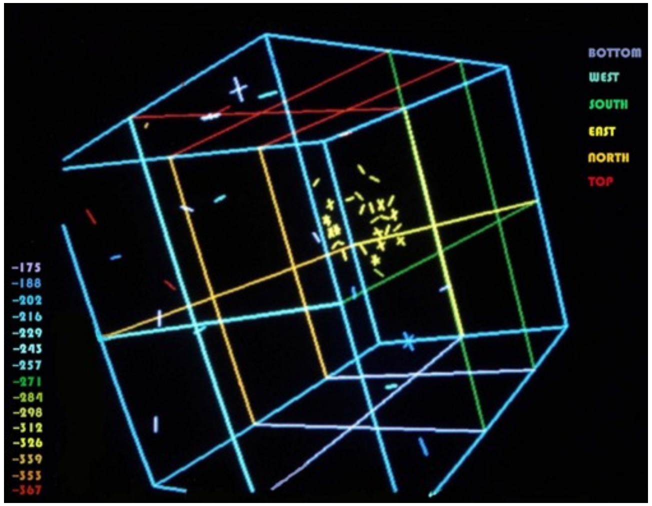



Image: Kamiokande

# Summary

- Stars' fates are largely determined by their mass
  - Accretion opens up many new possibilities

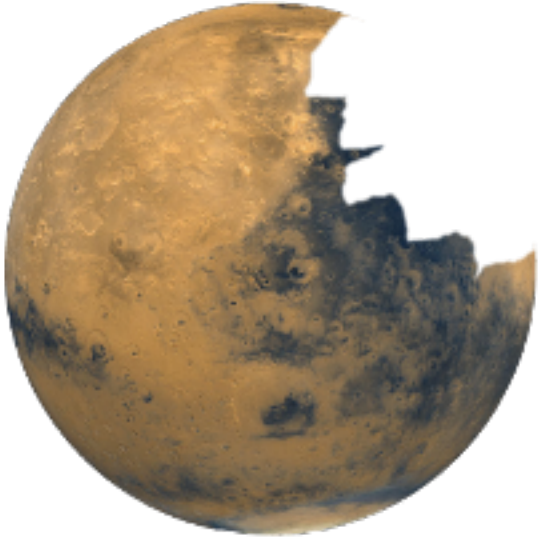
- There are two typical ways for a star to blow up
  - Core collapse – end of the line for massive stars
    - Shock revival? Black holes/neutron stars?
  - Type Ia – white dwarf
    - Accretion? Merger? Double detonation?

- Still very hard to model these events in detail

# Closing plug – astrobites.com

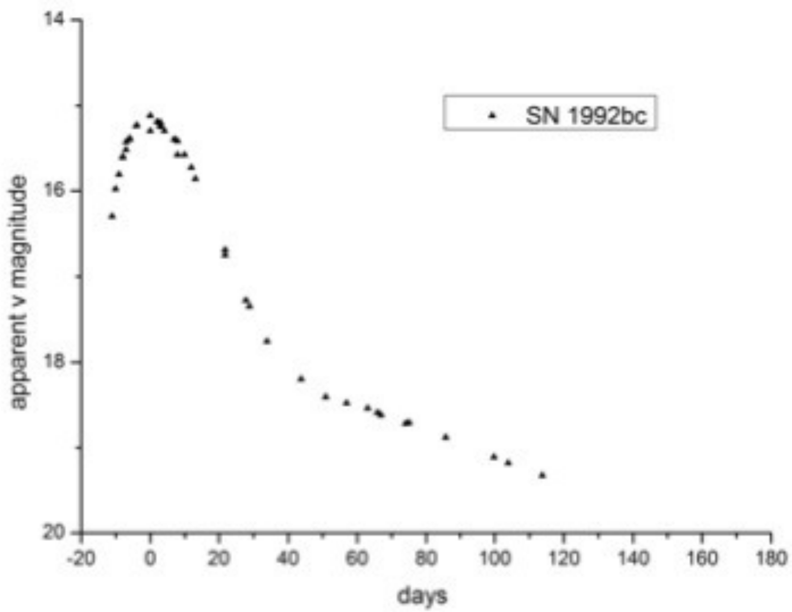
- Website with summaries of astronomy papers
  - Targeted to undergrads – minimal jargon

- Great way to keep up to date with what scientists are working on



# Connecting models to observations

- Light curve – luminosity as a function of time
  - Tells us about the overall energy of the supernova, assuming we have the distance (eg. from host redshift)
  - Lets us infer the mass of the ejecta (in general, more mass = more opaque and thus slower decay)



# Connecting models to observations

- Spectra – luminosity as a function of wavelength
  - Tells us about the composition and ionization state of the ejecta (ions absorb and emit photons and specific frequencies)
  - Very complicated to model in detail since there could be hundreds of ionic species and millions of ionization states
  - Provides information useful in modeling the light curve
    - Composition influences opacity