The supernova - supernova remnant connection through multi-dimensional (magneto)hydrodynamic modeling

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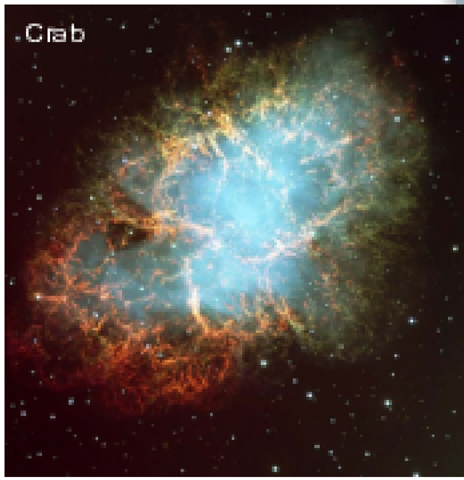
Supernova Remnants

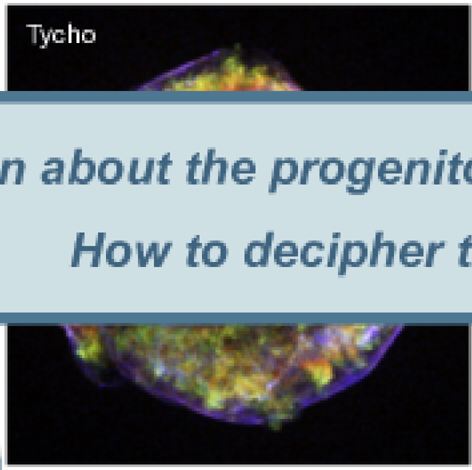
Supernova Remnants

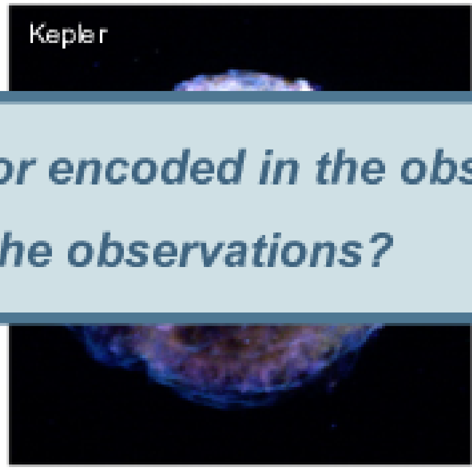
- complex morphology
- highly non-uniform distribution of ejecta

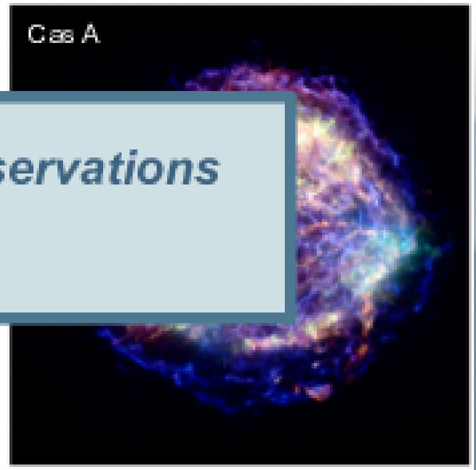
These properties may reflect

- pristine structures and features of progenitor SN explosion
- early interaction of SN blast with the inhomogeneous CSM









Information about the progenitor encoded in the observations

How to decipher the observations?

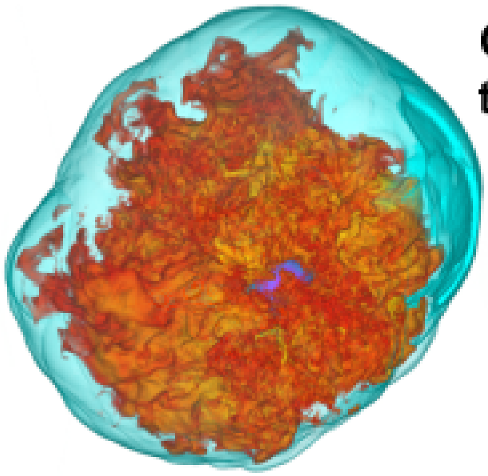
Supernova Remnants

SNRs offer the quite unique possibility

- to probe the physics of SN engines by providing insight into the asymmetries that occur during the SN explosion
- to investigate the final stages of stellar evolution by unveiling the structure of the medium immediately surrounding the progenitor star

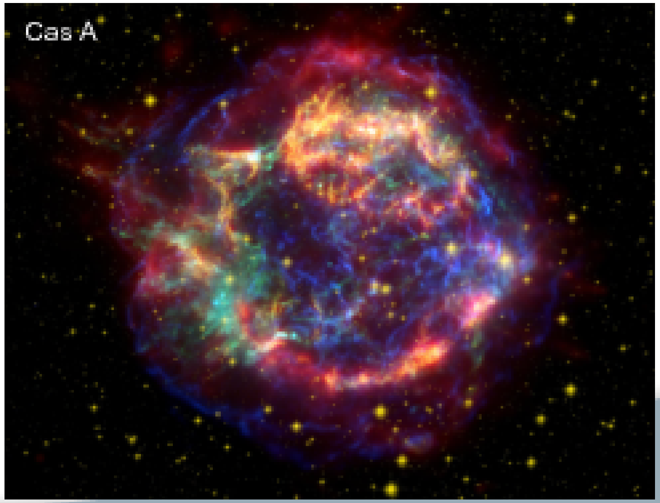
Very different time and space scales of SNe and SNRs make it difficult to study their connection in detail

~ 10^9 cm



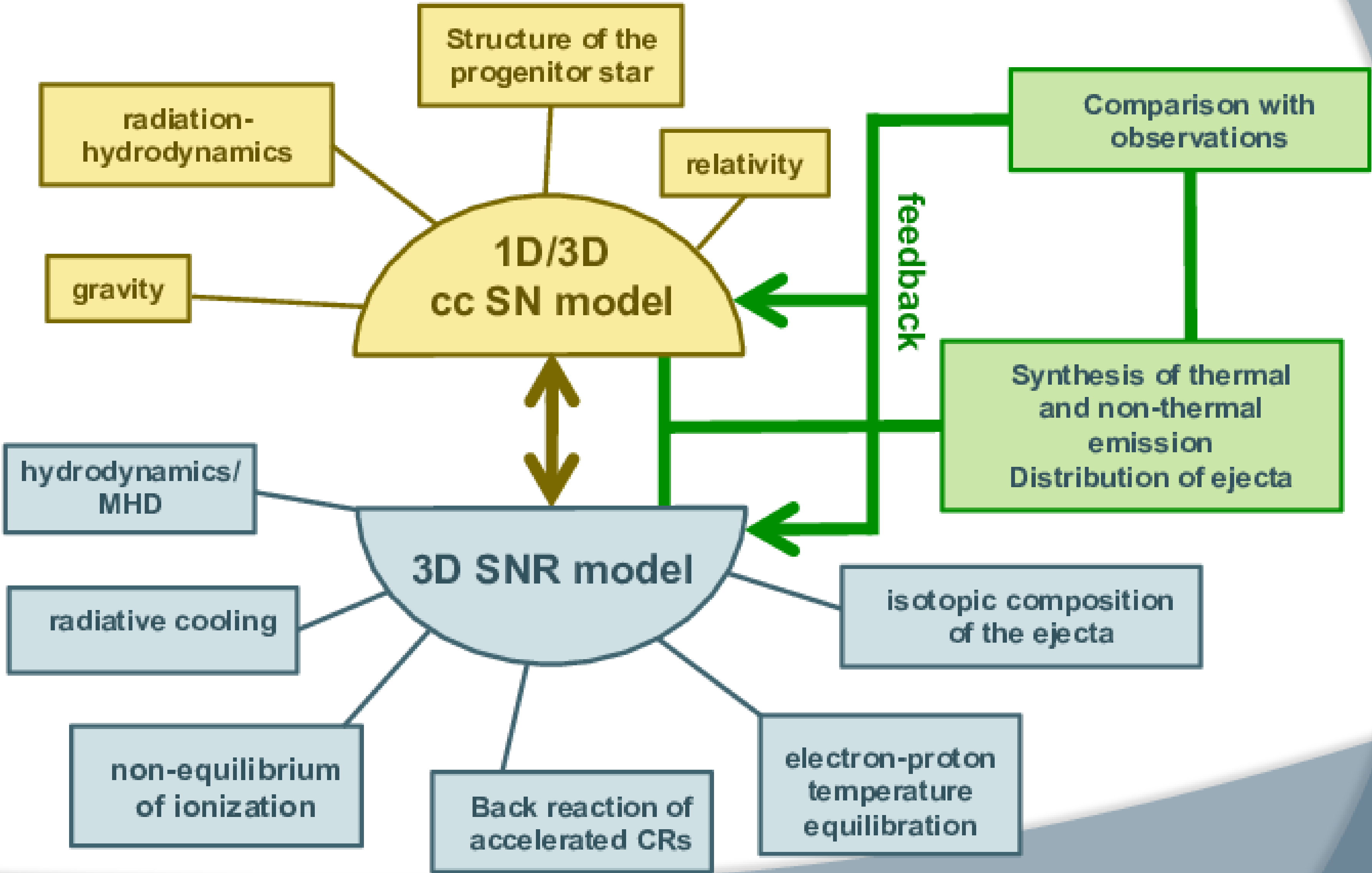
CC SN
t < 1 sec

~ 2.5 pc



SNR
t ~ 250 yr

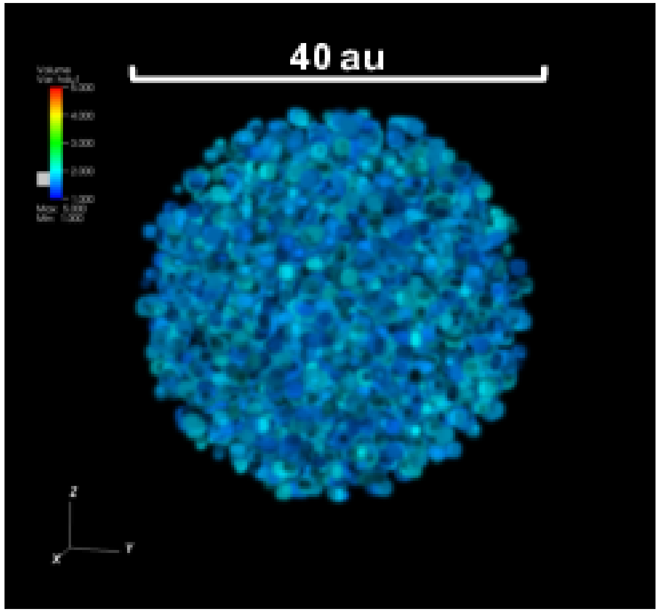
How to link SNe to SNRs ? The strategy



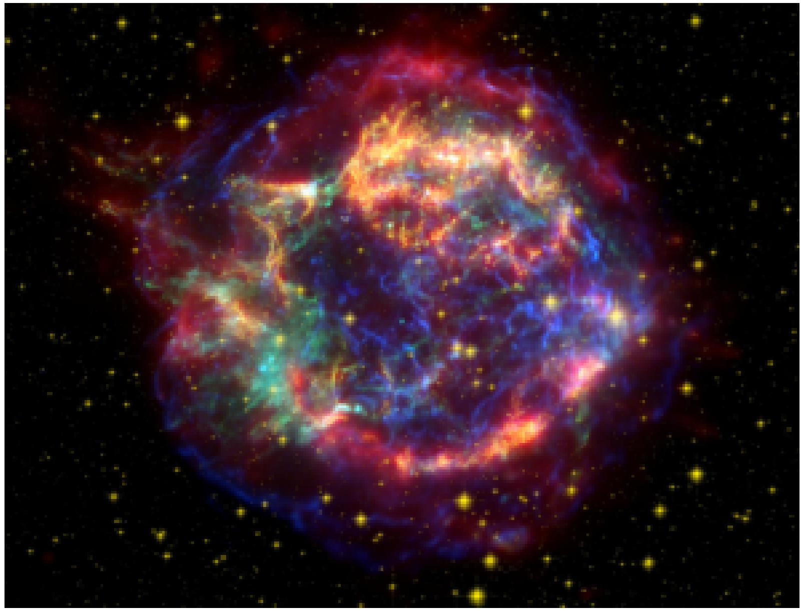
Modeling the SN-SNR evolution

A major challange is capturing the enormous range in spatial scales

Initial condition ~ 1 day after the SN event
Initial size ~ tens of AU



Final time ~ hundeds of yr (current age)
Final size several pc



18/20 nested levels of adaptive mesh refinement
→ effective resolution ~ 0.2 AU (3e12 cm)

> 100 cells per remnant radius during the whole evolution

Two study cases
- Cas A
- SN 1987A

Effects of SN anisotropies

The case of SNR Cassiopeia A

SNR Cassiopeia A

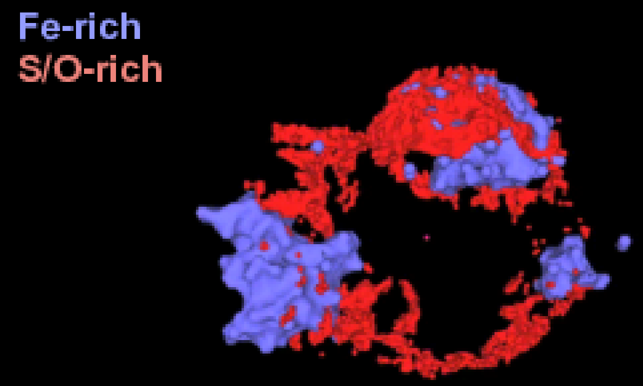
Observations suggest that its morphology and expansion rate are consistent with a remnant expanding through the wind of the progenitor red supergiant (e.g. Lee+ 2014)

Cassiopeia A is an attractive laboratory to bridge the gap between SNe and their remnants

This remnant is one of the best studied and its 3D structure has been characterized in good detail

(e.g. DeLaney+ 2010, Milisavljevic & Fesen 2013, 2015)

- 3 Fe-rich regions
- 2 Si-rich jets
- Rings circling Fe-rich regions



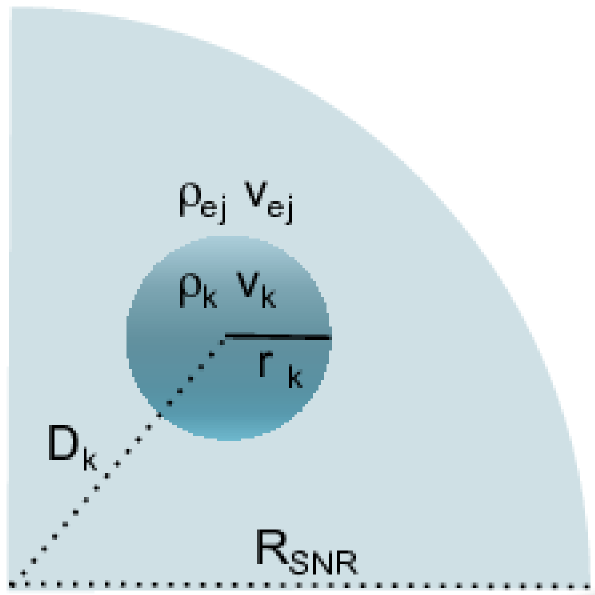
(Milisavljevic & Fesen 2013)

Initial conditions and parameter space

The post-explosion structure of the ejecta is described by small-scale clumping of material and larger-scale anisotropies

(e.g. Kifonidis+ 2006; Wang & Wheeler 2008; Gawryszczak+ 2010)

- Small-scale clumping as in Orlando+ (2012)
- Large-scale anisotropies as overdense spherical knots



Parameters of large-scale anisotropies

(Kifonidis+ 2003; Ellinger+ 2012)

D_k = [0.15 – 0.35] R_{SNR}

r_k = [3% - 10%] R_{SNR}

ρ_k = [10 – 100] ρ_{ej}

v_k = [1 – 10] v_{ej}

Spatial Distribution of the Cas A ejecta

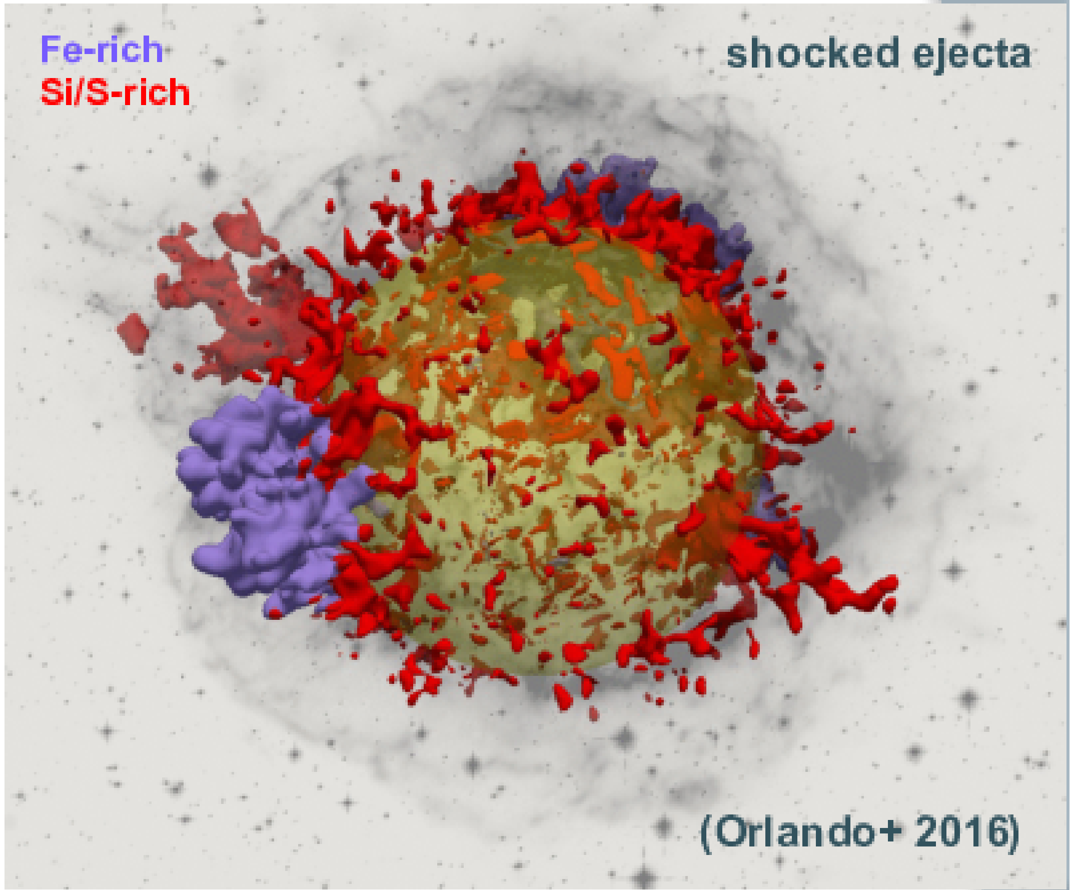
Shocked ejecta

Post-explosion anisotropies (pistons) reproduce the observed distributions and masses of Fe and Si/S if

- mass of $\approx 0.25\ M_{sun}$ (5% of the tot.)
- kinetic energy of $\approx 1.5 \times 10^{50}$ erg (7% of the total)

The pistons produce a spatial inversion of ejecta layers at the epoch of Cas A, leading to the Si/S-rich ejecta physically interior to the Fe-rich ejecta

The pistons are also responsible for the development of rings of Si/S-rich material which form at the intersection between the reverse shock and the material accumulated around the pistons during their propagation



the bulk of asymmetries observed in Cas A are intrinsic to the explosion

Effects of inhomogeneous CSM

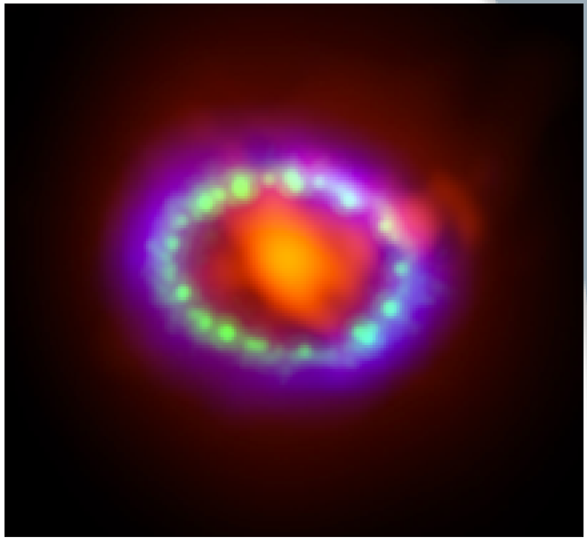
The case of SN 1987A

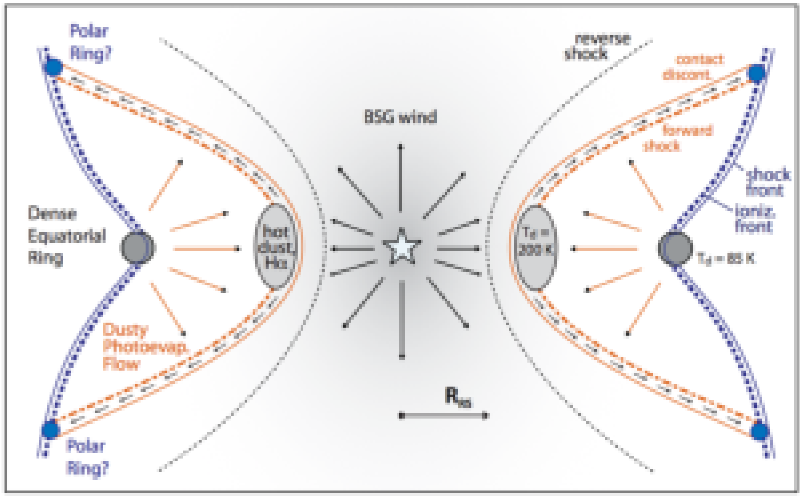
Effects of inhomogeneous CSM: SN 1987A

Origin of the CSM

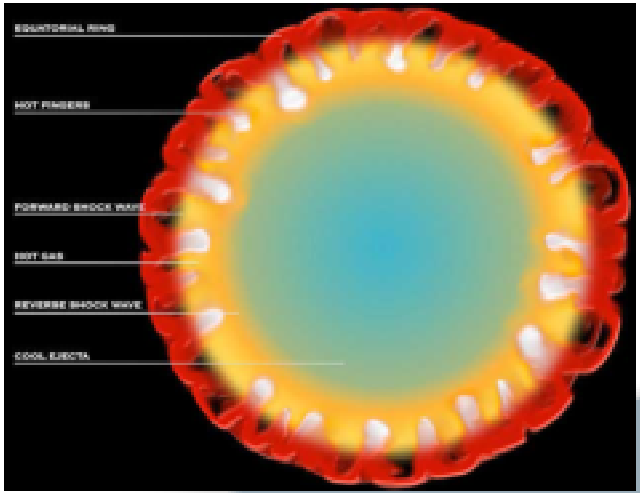
interaction of a slow wind from the red supergiant phase with the faster wind from the blue supergiant phase
(e.g.Morris & Podsiadlowski 2007)

Currently, the explosion is sweeping up the inner equatorial ring that was formed by the late stages of the star's evolution.

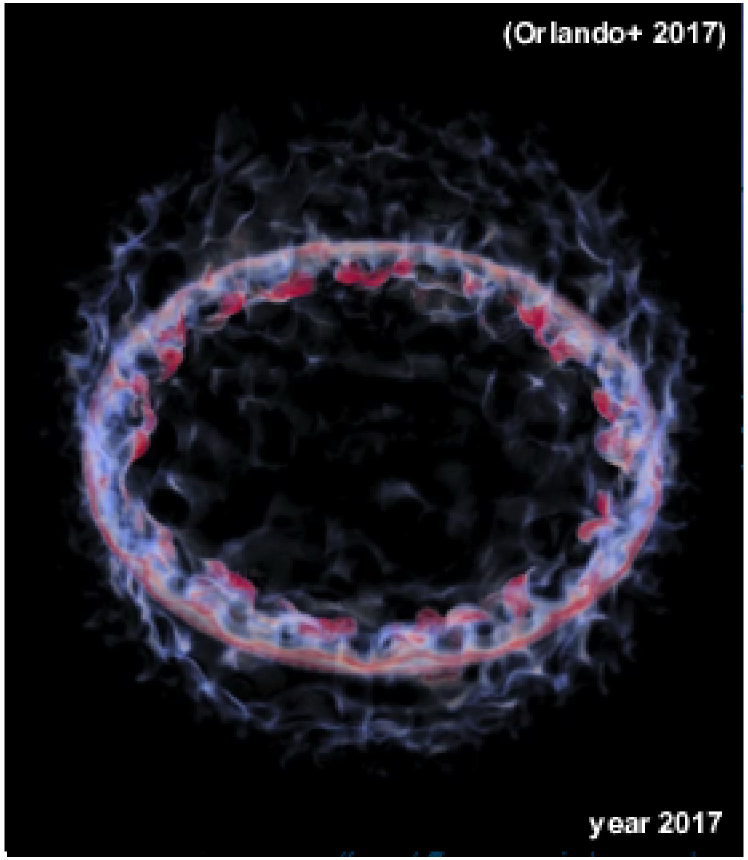


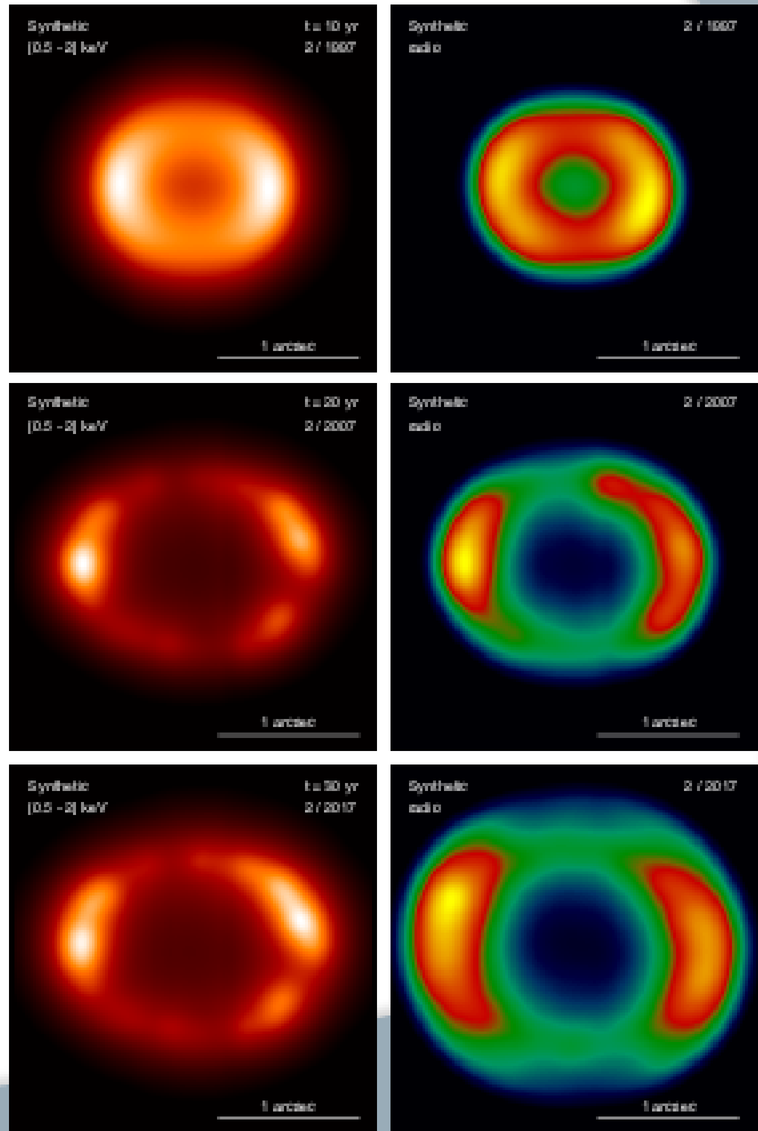


(Smith+ 2013)



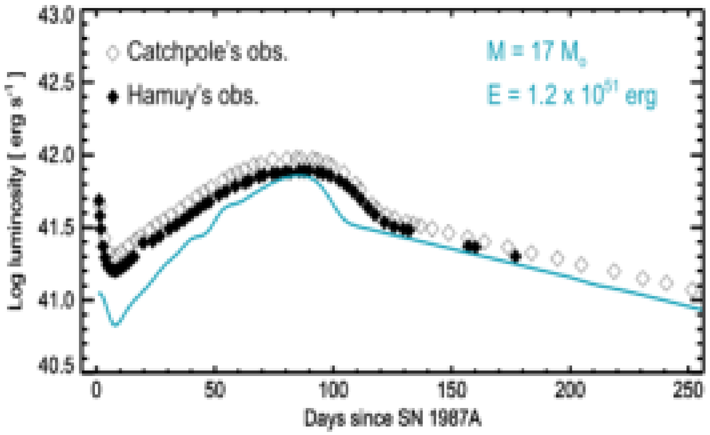
SN 1987A: MHD evolution and radio emission





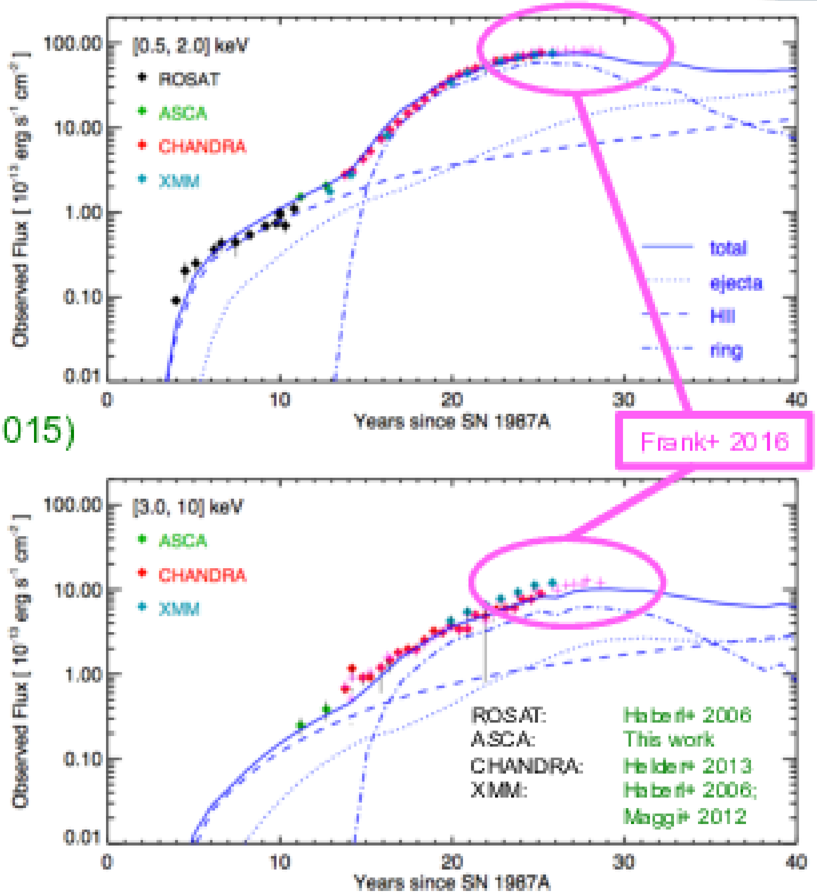
- 3D MHD simulations performed with *PLUTO* (Mignone+ 2007, 2012)
- Synthesis or radio emission performed with *REMLIGHT* (Orlando+ 2007, 2011)

Lightcurves



(Orlando+ 2015)

Bolometric lightcurve of the SN model compared to that observed



the physical model reproducing the observables of the supernova (the cause) is able to reproduce also the observables of the subsequent expanding remnant (the effect)

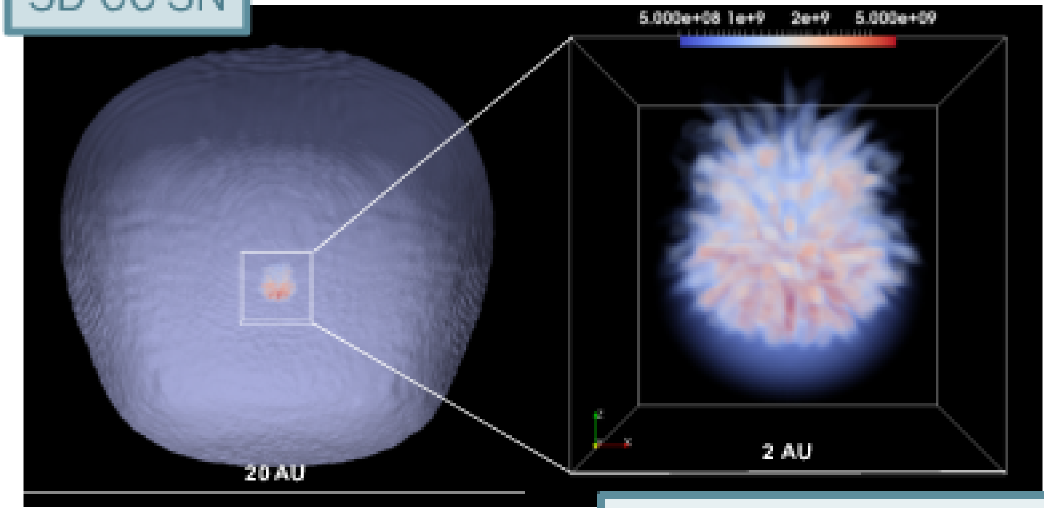
Abundances from Zhekov+ (2009)

ISM Absorption: 2.35e21 cm^{-2} (Park+ 2006)

Distance: 51.4 kpc (Panagia 1999)

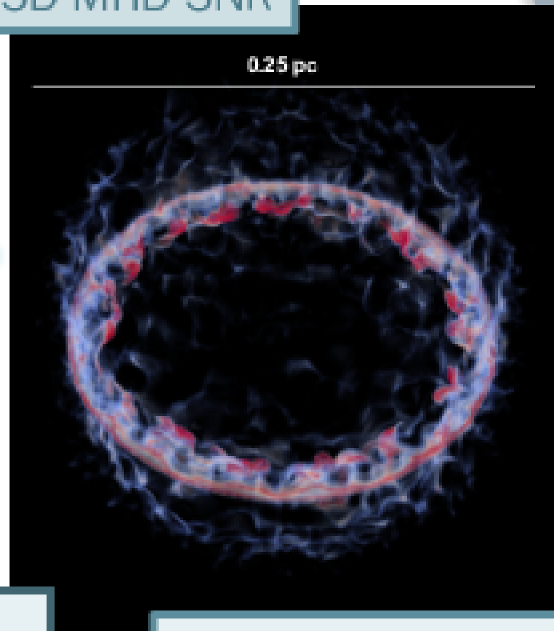
Evolving 3D SN 1987A explosion to 3D SNR

3D CC SN



~ 25 hours since the SN event

3D MHD SNR



30 years since the SN event

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Conclusions

FACTS

- SNRs morphology and properties reflect the physical and chemical properties of the progenitor SNe and the environment in which blast waves travel
- Multi-wavelenght/multi-messenger observations of SNRs encode information about the physical and chemical properties of both stellar debris and surrounding CSM
  - anisotropies, dynamics and energetics of the SN explosions
  - clues on the final stages of stellar evolution

> Linking SNe to SNRs has breakthrough potential
> to open new exploring windows on SN and SNR issues

TASKS

Deciphering observations might depend critically on models

- Models should connect stellar progenitor → SN → SNR
- Observational facts as a guidance for models (account for dynamics, energetics, and spectral properties of SNe and SNRs)
- Strongly improve the synergy and comunication among communities (progenitors, SNe, SNRs)

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