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Exploring the Supernova – Supernova Remnant Connection

Late Time X-ray and Optical Observations of SN 1996cr

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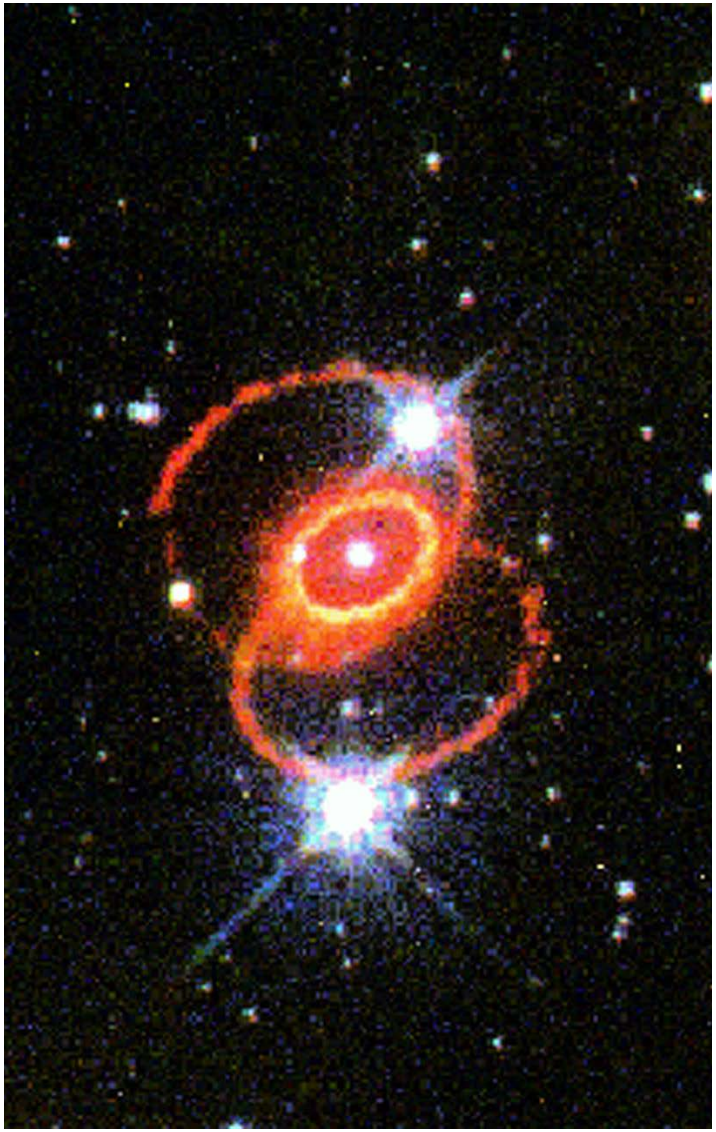
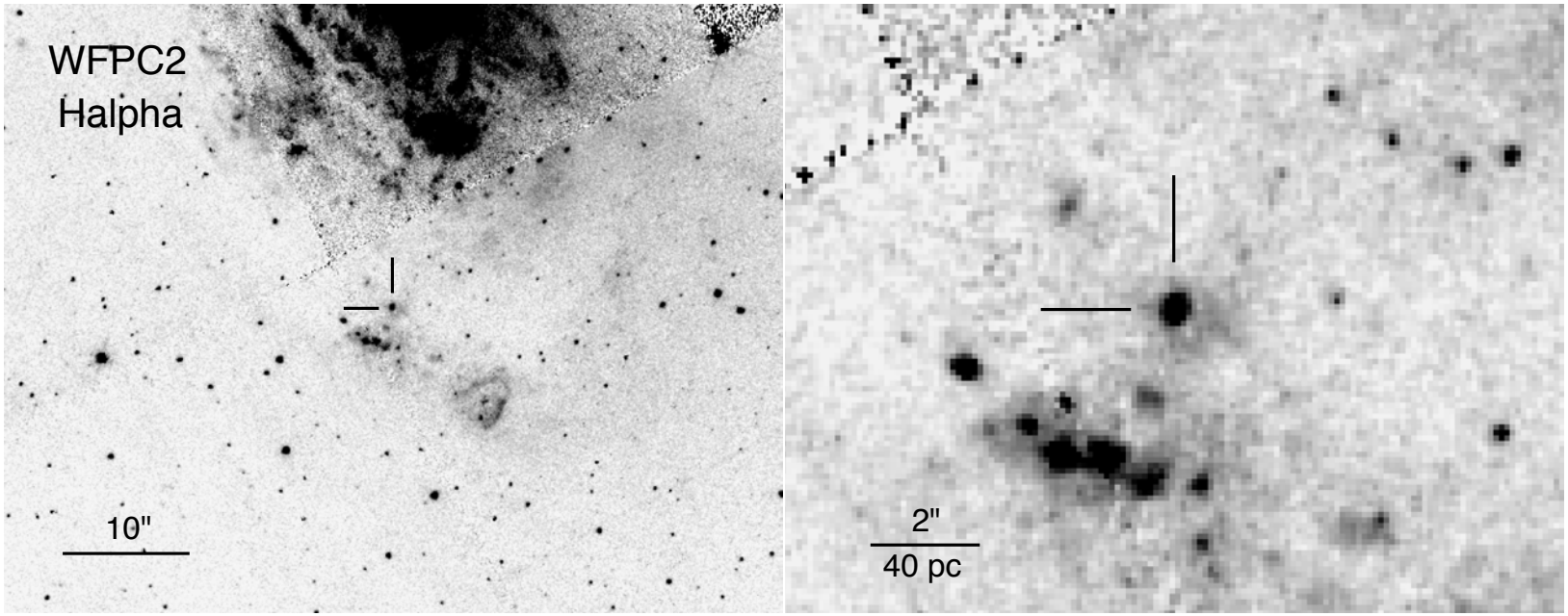
Motivation

- While we currently observe 100s of supernovae/year, most are too far away and fade quickly
  - Early supernova emission is from stellar debris which is illuminated by radioactive byproducts of the explosion
- Supernova remnants are characterized by interactions with their surroundings
  - Most SNRs are old (100s-1000s yrs)
- It is rare to be able to watch a SN become a remnant in real time!



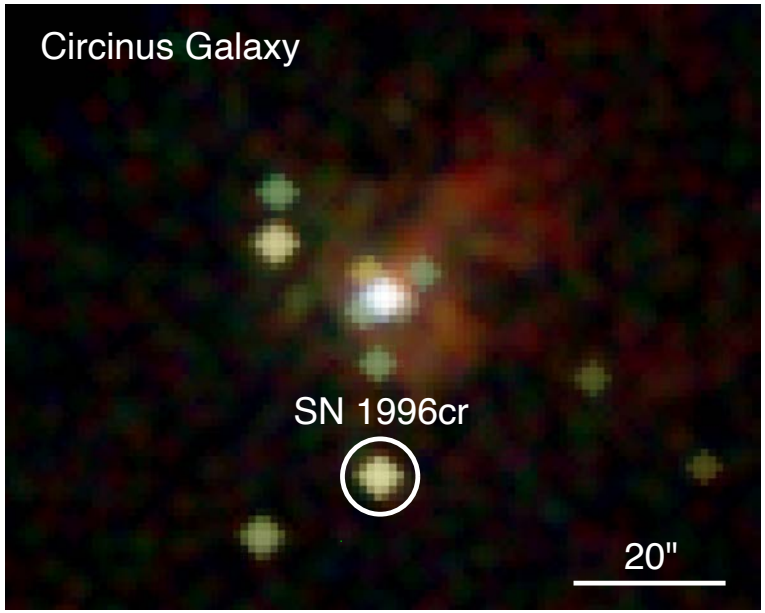
SN 1996cr

- Located in the nearby Circinus Galaxy (4.2 Mpc = 14 million ly)
- Discovered serendipitously with Chandra in 2000
- HST images reveal a bright point source surrounded by a fainter diffuse region, associated with a nearby cloud of hydrogen

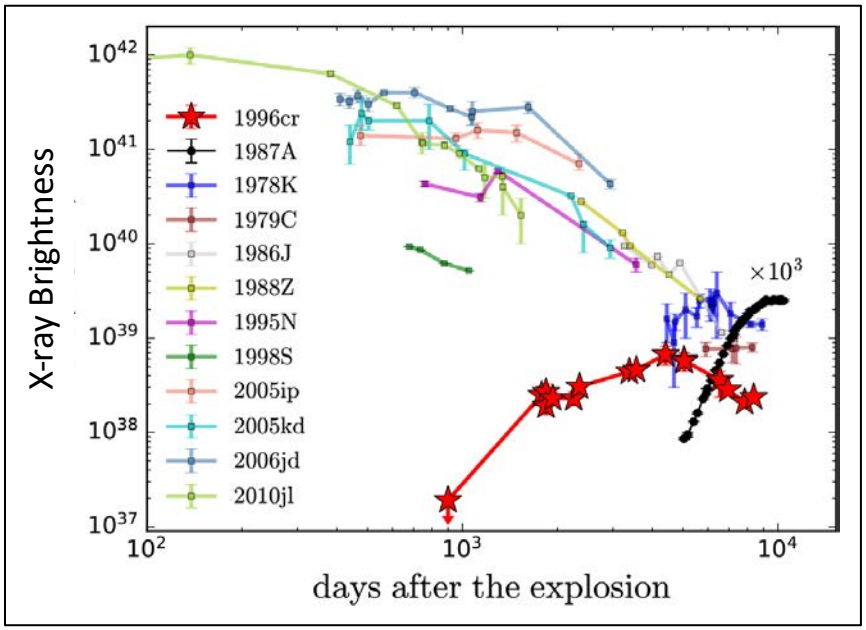


SN 1996cr in X-rays

- Viewed in X-rays, SN 1996cr is one of the most luminous sources in its host galaxy
- The X-ray light curve showed a dramatic rise and then a slow and steady decline



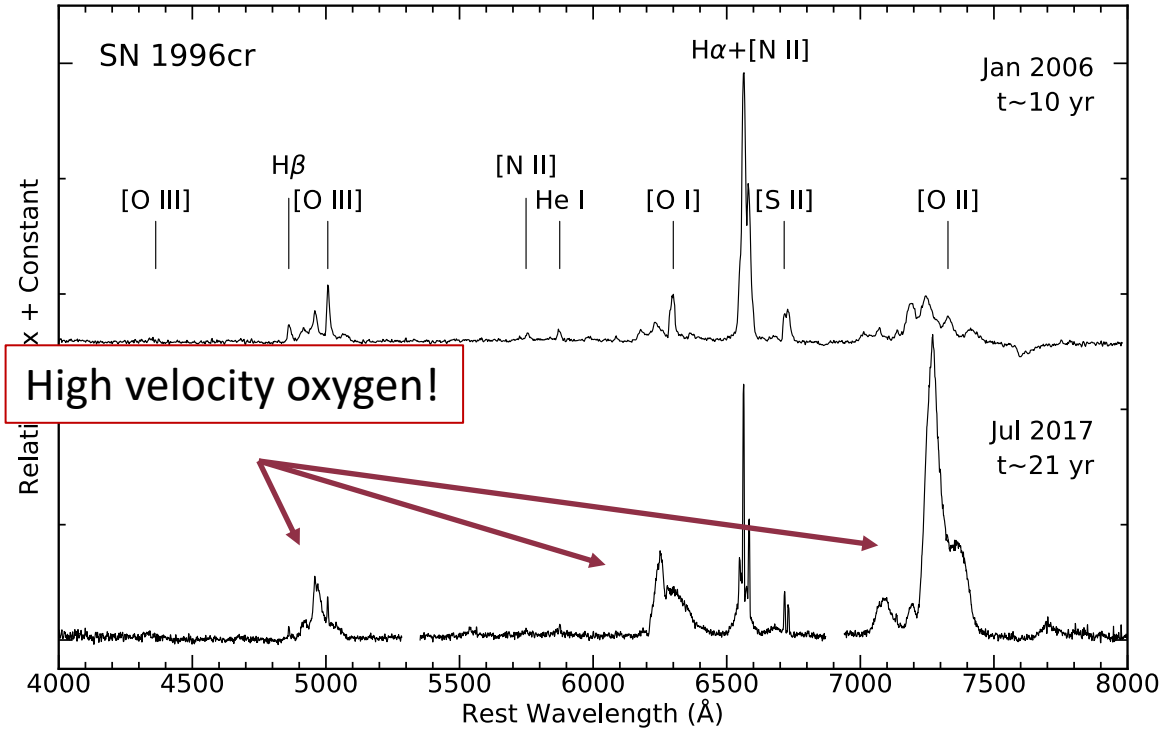
Chandra image of Circinus Galaxy and SN 1996cr



Quirola-Vásquez et al. (2019)

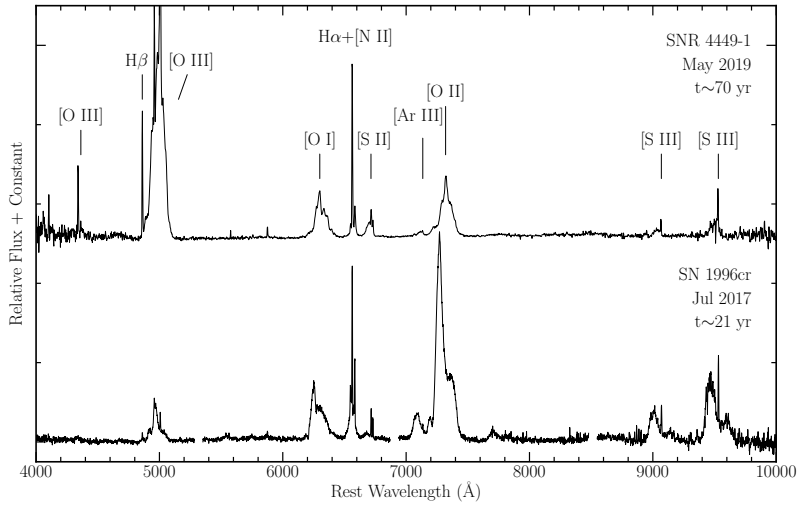
Optical Evolution of 96cr

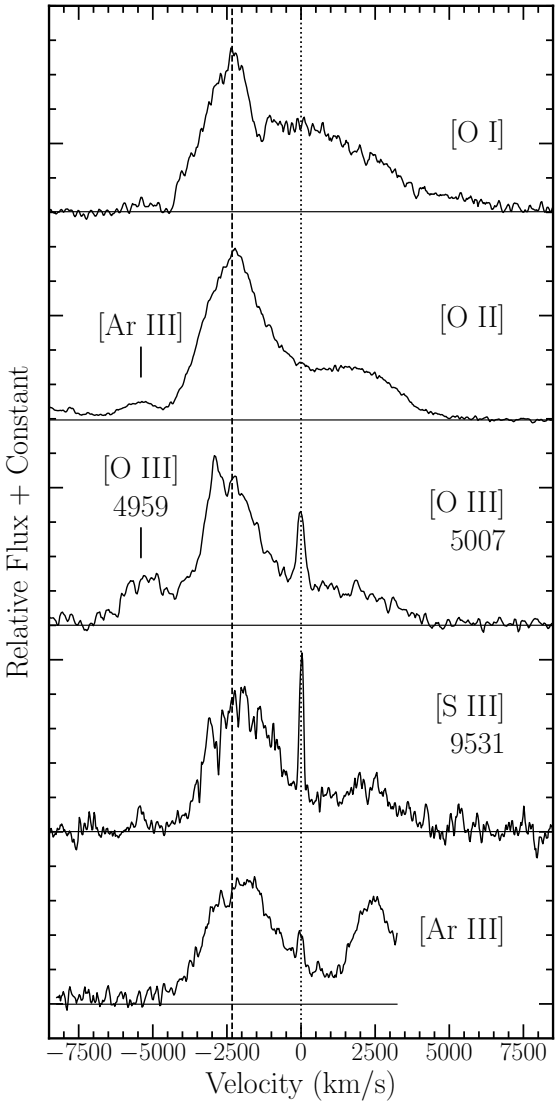
- A comparison of optical spectra taken in 2006 and 2017 reveals large changes in the spectrum over ~ 10 years, namely the emergence of very bright and broad oxygen line emission



SN Ejecta

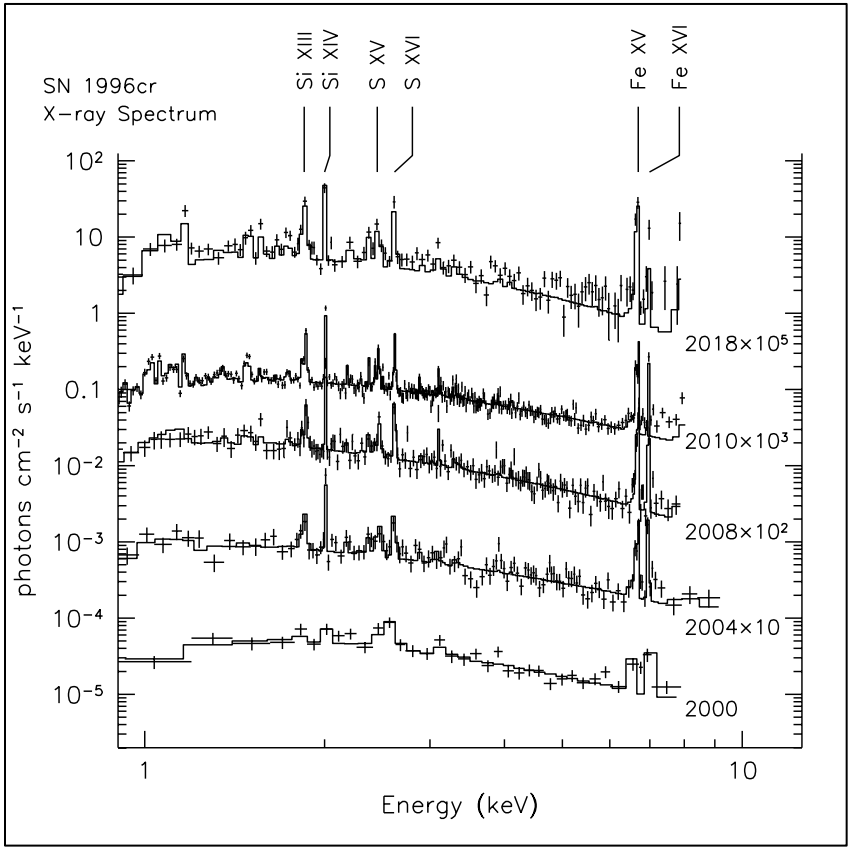
- 2006 observations detected oxygen with velocities > 3000 km/s
- 2017 observations detect oxygen to 2300 km/s and O-burning products (S, Ar) at 2000 km/s
- New observation suggests emission is from a deeper layer of ejecta than what was observed i





The X-ray Evolution of SN 1996cr

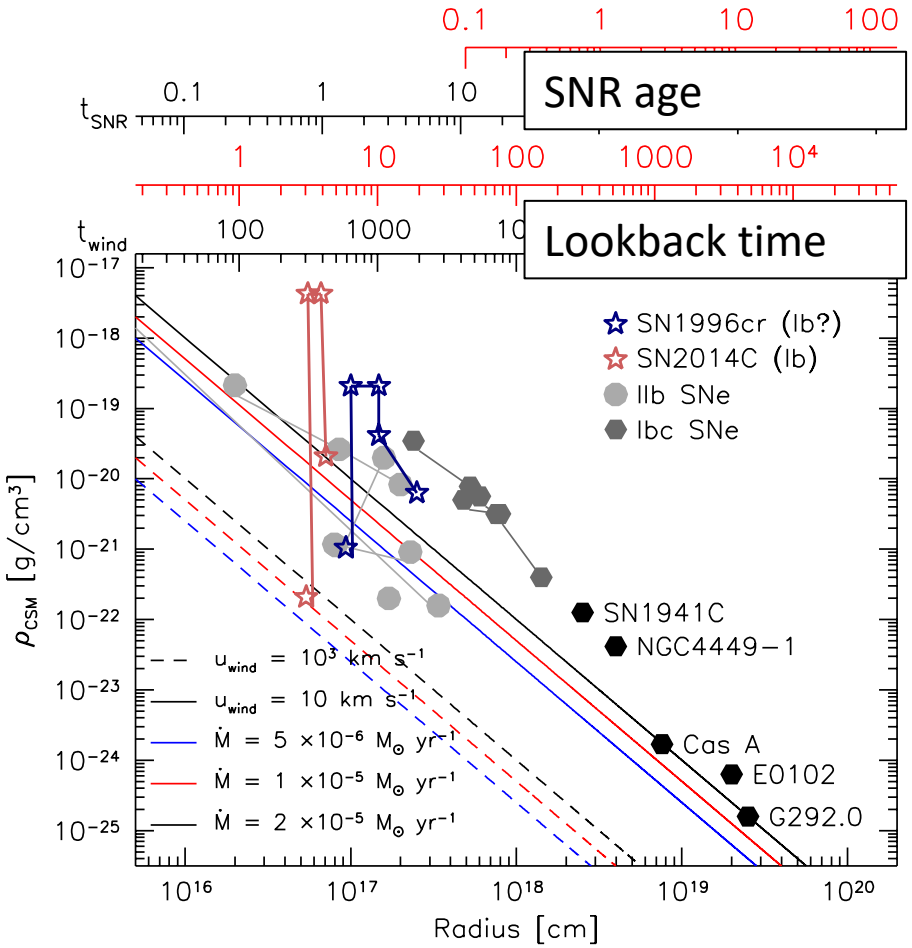
- Early X-ray observations showed a fast shock interacting with a large amount of material expelled from the progenitor
- Subsequent observations reveal increased line emission from elements such as silicon and sulfur
- Latest Chandra observation (late 2018) shows an X-ray spectrum more akin to a supernova remnant, with bright emission lines from elements that are formed during the explosion



Evolution of the X-ray spectrum of SN 1996cr as recorded by Chandra

The CSM Environments Around Massive Stars

- Evolved supernovae provide a bridge between supernova remnants and their progenitors
  - Every year of supernova evolution looks back at ~ 1000 years of evolution of the progenitor star
  - Supernova shocks are “time machines” which allow us to reconstruct the evolution of the star before it exploded



Circumstellar environments around several supernovae and supernova remnants, for a host of mass loss parameters.

Summary

- Recently obtained optical spectra of SN 1996cr reveal dramatic changes in the properties of the emitting material
  - Our new observations allow us to probe the energetics and composition of the deeper layers of ejecta
- SN 1996cr now bears a strong resemblance to young SNR such as the extremely luminous SNR in NGC 4449 and Cas A in our own Galaxy
- The X-ray evolution paints a picture of an object which is evolving into a supernova remnant rich in line emission from the products of the explosion
- Changes in the X-ray emission allow us to reconstruct the mass loss history of the progenitor, placing it in context to other, “like-” supernovae and supernova remnants

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