A New Chandra View of SN 1987A

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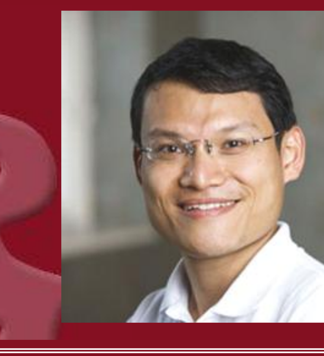
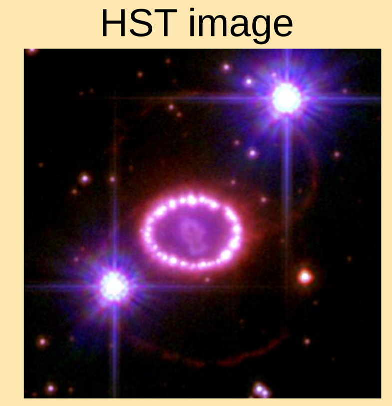


Abstract

We present the first HRC observation of SN 1987A, which provides the highest resolution images of the remnant, revealing its detailed structure and allowing us to constrain the flux of any possible central compact objects. Quantitative spatial modeling suggests that the remnant morphology can be well-described by a thin ring plus a thin spherical shell, with the outer boundary slightly larger than the radio emission, confirming the physical picture that the X-ray emission traces the forward shock while the radio emission originates near the reverse shock

HST image



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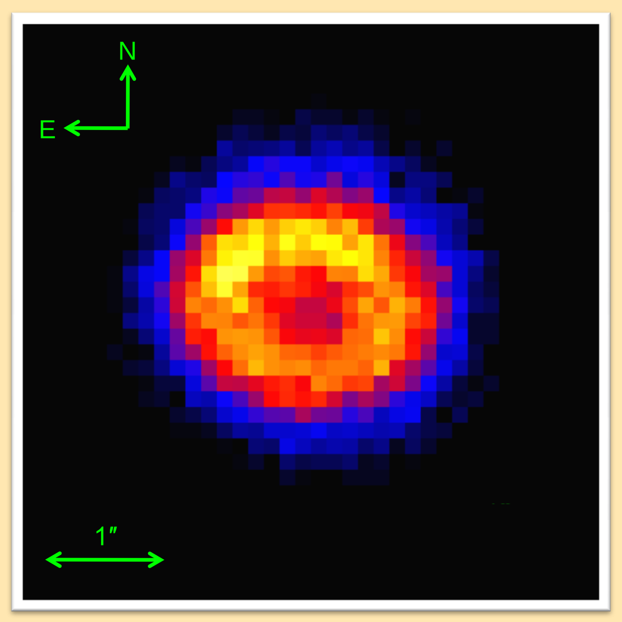
SN 1987A in X-rays

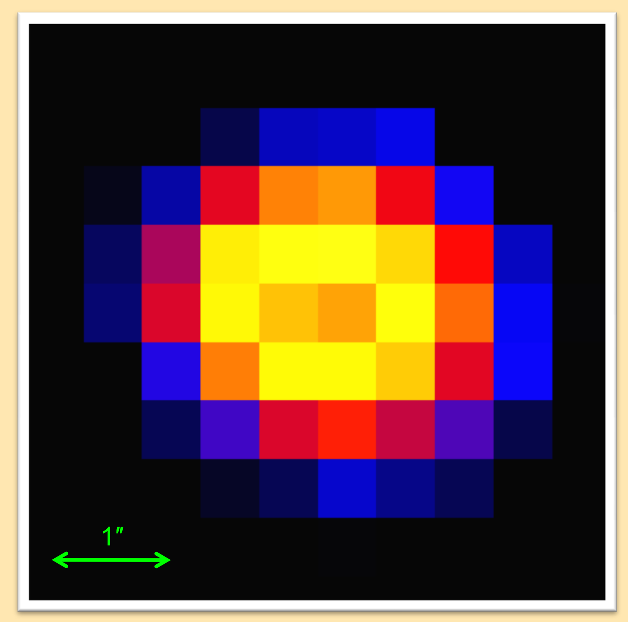
- Soft X-ray flux keeps increasing exponentially due to the encounter of blast wave with the dense circumstellar material (CSM), i.e. the optical inner ring (Park et al. 2007).
- The X-ray spectrum is well-described by a two-component shock model (kT~0.5 and 2 keV) (Zhekov et al. 2009).

Chandra HRC Observation

- 46ks, taken on 2008 Apr (day 7736)
- **Highest resolution** X-ray image of SN1987A.
- **First** direct image resolves the X-ray remnant, clearly showing the central 'hole'.
- Semi-major, semi-minor axes: 0.8″, 0.6″
  --Consistent with a circular ring tilted at 45°
- low (<2%) east-west asymmetry.



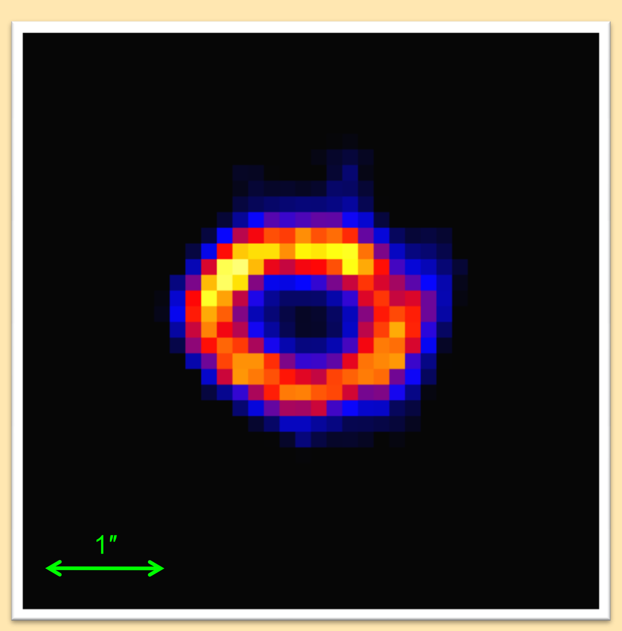
Raw HRC data



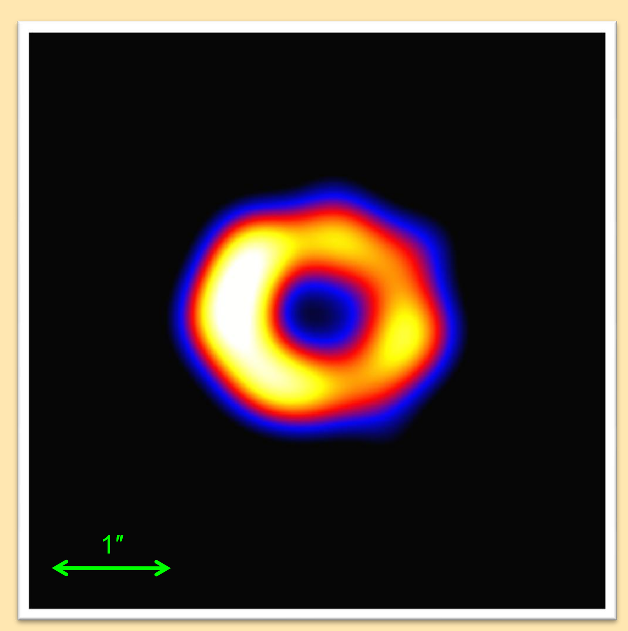
Raw ACIS data

Image Deconvolution

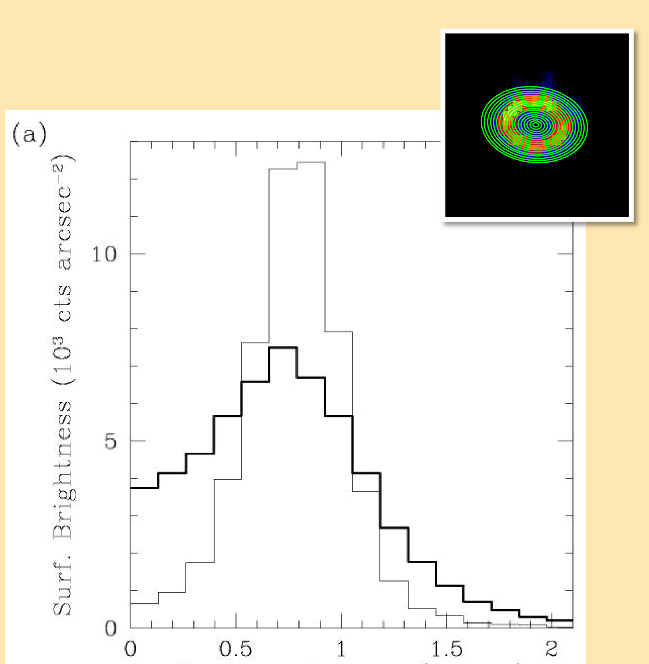
- 1keV PSF, 30 iterations
- Sharper ring
- Thickness ~0.6″
- No central source
- Better shows the hot spots



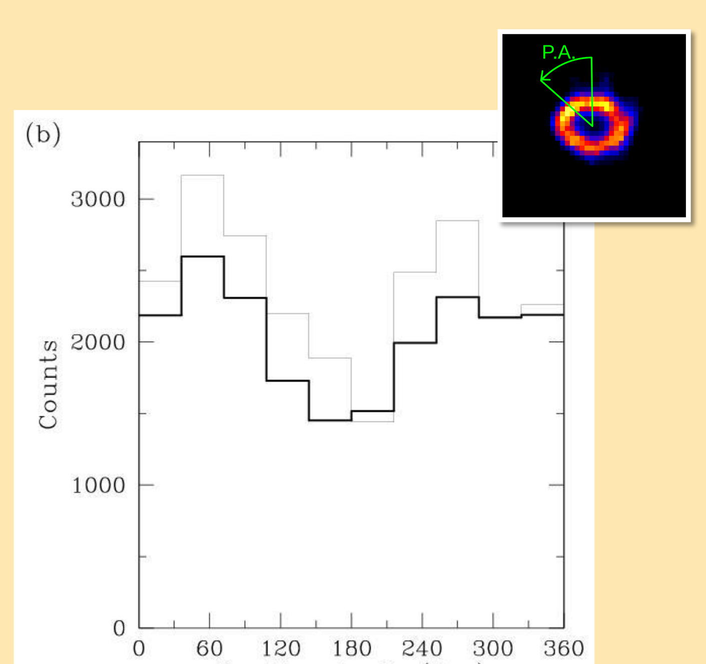
Deconvolved HRC image



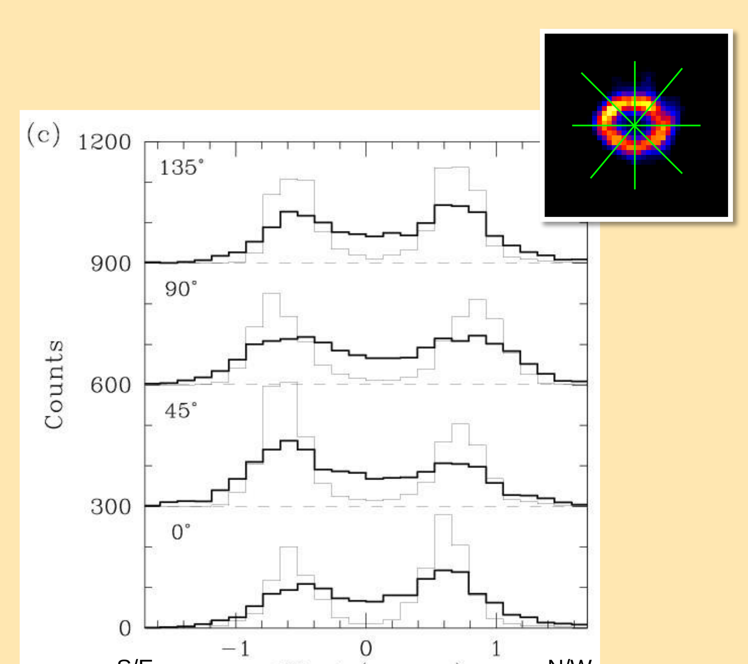
ATCA 3cm radio image



Radial profiles from elliptical annulus regions



Brightness around the ring



Slices through the remnant

Thick lines: raw HRC data; thin lines: deconvolved image.

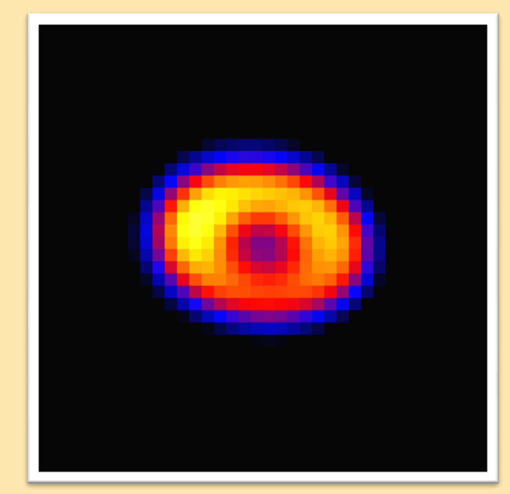
Spatial Modeling

- Simple models convolved with 1keV PSF.
- Fitting procedure from Ng & Romani (2008).

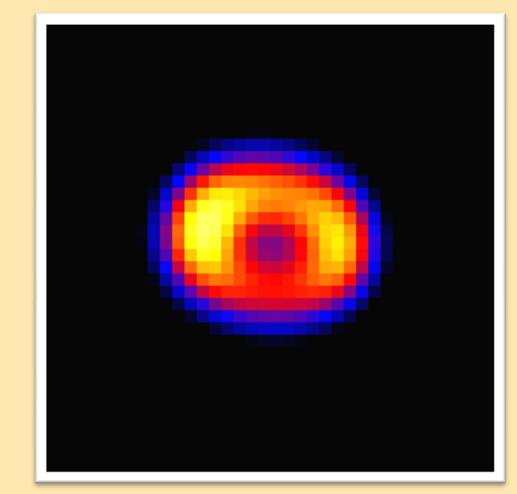
Shell component => high latitude emission from fast shocks? Need more observations to confirm.

Model	Ring Radius (″)	Shell Radius (″)	Thickness (″)	χ^2 / dof
Thin Ring	0.83±0.01	—	0.04 (fixed)	1218 / 4090
Thick Ring	0.75±0.02	—	0.56±0.08	942 / 4089
Torus	—	0.82±0.02	0.39±0.02	884 / 4088
Ring+shell	0.82±0.03	0.94±0.05	0.05 (fixed)	709 / 4088

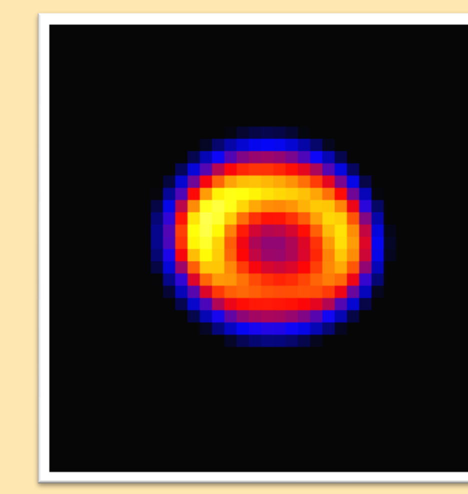
Best-fit Models



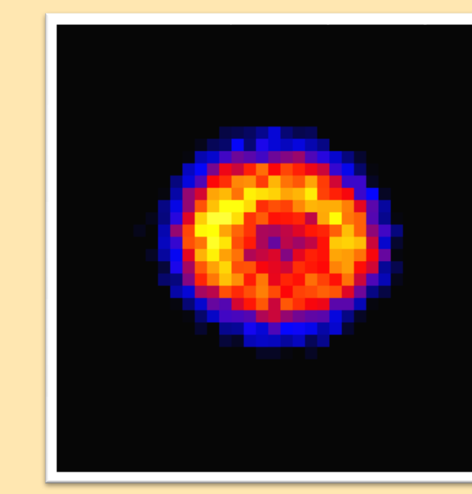
Thick ring



Torus (used by Ng et al. 2008 to describe the radio shell)



Shell+ring



Poisson simulation for the shell+ring model

Flux Limit on a Central Source

- 0.007 cts/s (3σ confidence level)
  - T_∞=2.2MK, for a R_∞=13km blackbody at 51kpc
  - or $L_{2\text{-}10keV}$ = 4.8×10^{34} erg/s, for powerlaw with Γ=1.5
- Rule out bare ordinary NS, magnetar and bright PWNe (e.g. the Crab Nebula).
- but NS/CCO with fast cooling, obscured NS or black hole are still possible.

X-ray vs. Radio

- No direct correlation between X-ray hot spots and radio lobes.
  - could imply different origins of the emissions.
- Similar sizes for the outer edge:
  - X-ray: 0.96″±0.05″±0.03″ (statistical & systematic errors)
  - Radio: 0.92″±0.06″ (Potter et al. 2009)
  - Consistent with the picture that X-rays trace the forward shock, while the radio emission originates near the reverse shock.

Conclusions

- The X-ray shell has similar size as the optical inner ring
  => the blast wave has encountered the dense CSM all around the ring.
- The remnant morphology is best-described by a ring+shell model. If confirmed, the shell component may correspond to high latitude emission from fast shocks.
- X-ray and radio shells have comparable sizes.
- No central source detected, but the flux limit can rule out a bare NS without fast cooling mechanisms.

References

Ng et al. 2008, ApJ, 684, 481
Ng & Romani 2008, ApJ, 673, 411
Park et al. 2007, AIPC, 937, 43
Potter et al. 2009, ApJ, Submitted
Zhekov et al. 2009, ApJ, 692, 1190