PENNSTATE

6 Years of Science with Chandra Symposium, Cambridge, Nov 2, 2005

Supernova Remnant 1987A at the Age of 18:

An On-Going Story by Chandra

Sangwook Park

David Burrows

Judith Racusin

Gordon Garmire (Penn State)

Dick McCray

Svetozar Zhekov (Colorado)

Kazimierz Borkowski (NC State)

SN/SNR 1987A *in Her Uniqueness*

- Brightest supernova observed by mankind since 1604 (J. Kepler)
- Distance: 50 kpc, in the LMC
- Age: 18 years and 5 months old as of July 2005

- Type II SN
- Progenitor: Blue supergiant (Sk -69 202, B3 I)
- Neutrino burst

  => Core-collapse explosion

- Most intensively studied SN of all time:
  - Optical/UV: HST and many ground-based
  - Radio: initial detection, turned on again in ~1990
  - X-ray: no initial detection, turned on in ~1990
  - Gamma-ray: detected decay lines from ^{56}Co → decay of ^{56}Ni, confirming explosive nucleosynthesis

  => ADS: 922 (~1/week) refereed papers (since 1987)

◆ Chandra monitoring since 1999:

– twice a year, separated by ~6 months

– as of 2005-07, 13 observations performed

SNR 1987A: Chandra Observations

Date (since SN)	Instruments	Exp. (ks)
1999-10-6 (4609)	ACIS-S+HETG	116
2000-1-17 (4711)	ACIS-S3	9
2000-12-7 (5038)	ACIS-S3	99
2001-4-25 (5176)	ACIS-S3	18
2001-12-12 (5407)	ACIS-S3	49
2002-5-15 (5561)	ACIS-S3	44
2002-12-31 (5791)	ACIS-S3	49
2003-7-8 (5980)	ACIS-S3	45
2004-1-2 (6157)	ACIS-S3	46
2004-7-22 (6359)	ACIS-S3	49
2004-8-26 (6393) ~ 2004-9-5 (6404)	ACIS-S+LETG	289
2005-1-9/13 (6533)	ACIS-S3	48
2005-7-11/16 (6716)	ACIS-S3	44
2005-12 (~6870)	*ACIS-S3*	*50*
2005-6 (~7050)	*ACIS-S3*	*40*

- Publications:

Burrows et al. 2000, ApJ, 543, L149 (Obs 1-2)

Park et al. 2002, ApJ, 567, 314 (Obs 1-4)

Michael et al. 2002, 574, 166 (Obs 1 & 3)

Park et al. 2004, AdSpR, 33, 386 (Obs 1-6)

Park et al. 2004, ApJ, 610, 275 (Obs 1-7)

Park et al. 2005, AdSpR, 35, 991 (Obs 1-9)

Zhekov et al. 2005, ApJ, 628, L127 (Obs 11)

Park et al. 2005, ApJL, in press (Obs 2-10, 12-13)

Racusin et al. 2005, in preparation

(X-ray radial expansion: Obs 1-13)

Zhekov et al. 2005, in preparation

(Obs 11: General results from LETG spectrum)

Park et al. 2005, in preparation

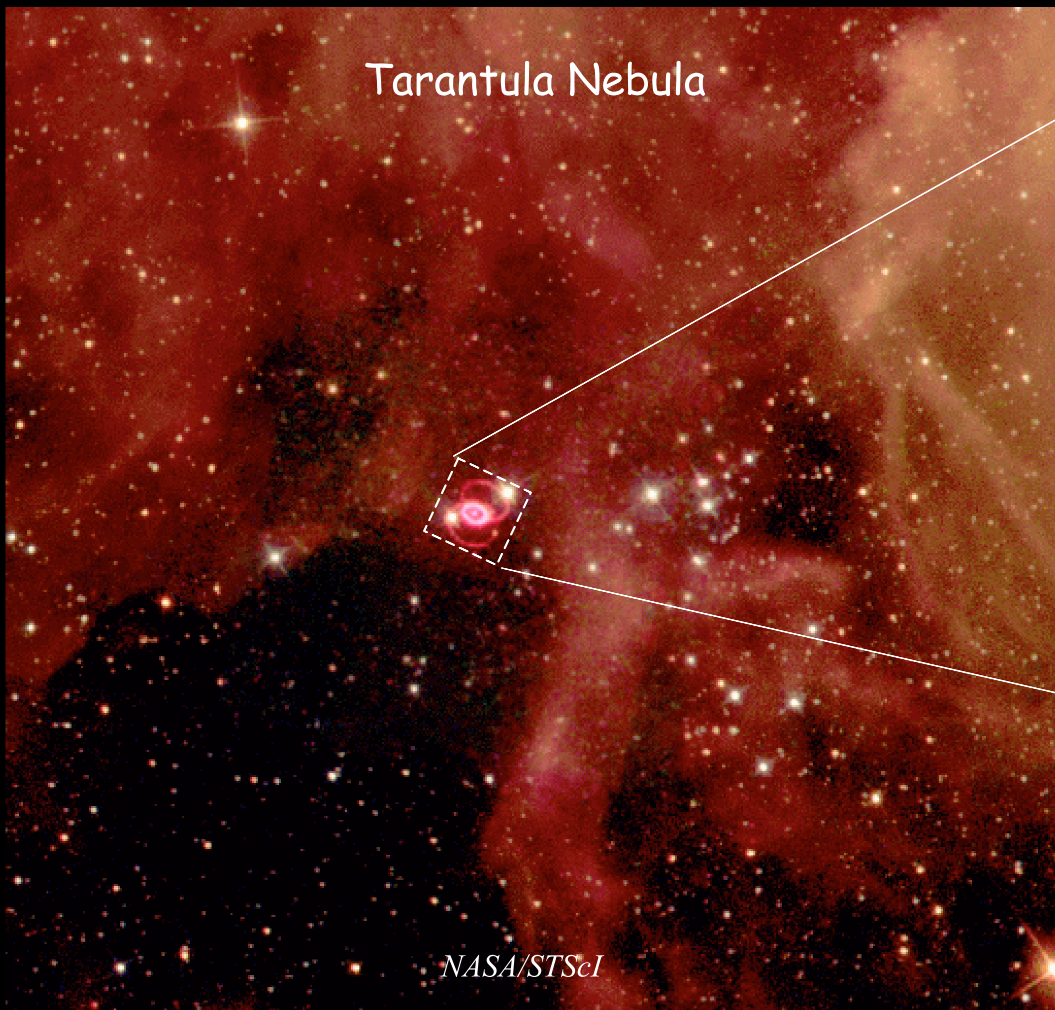
(Obs 10-13 ACIS images and spectral analysis)

Current presentation:

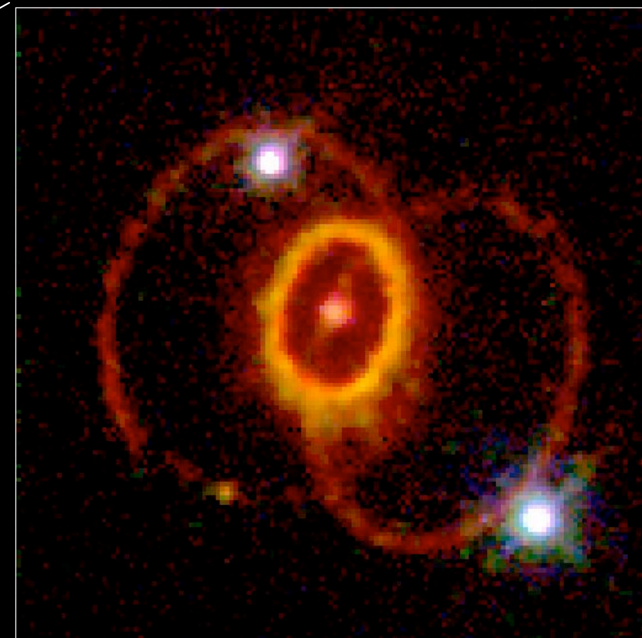
A review and the latest results.

SN 1987A: the Ring System (HST)

Space Telescope Science Institute



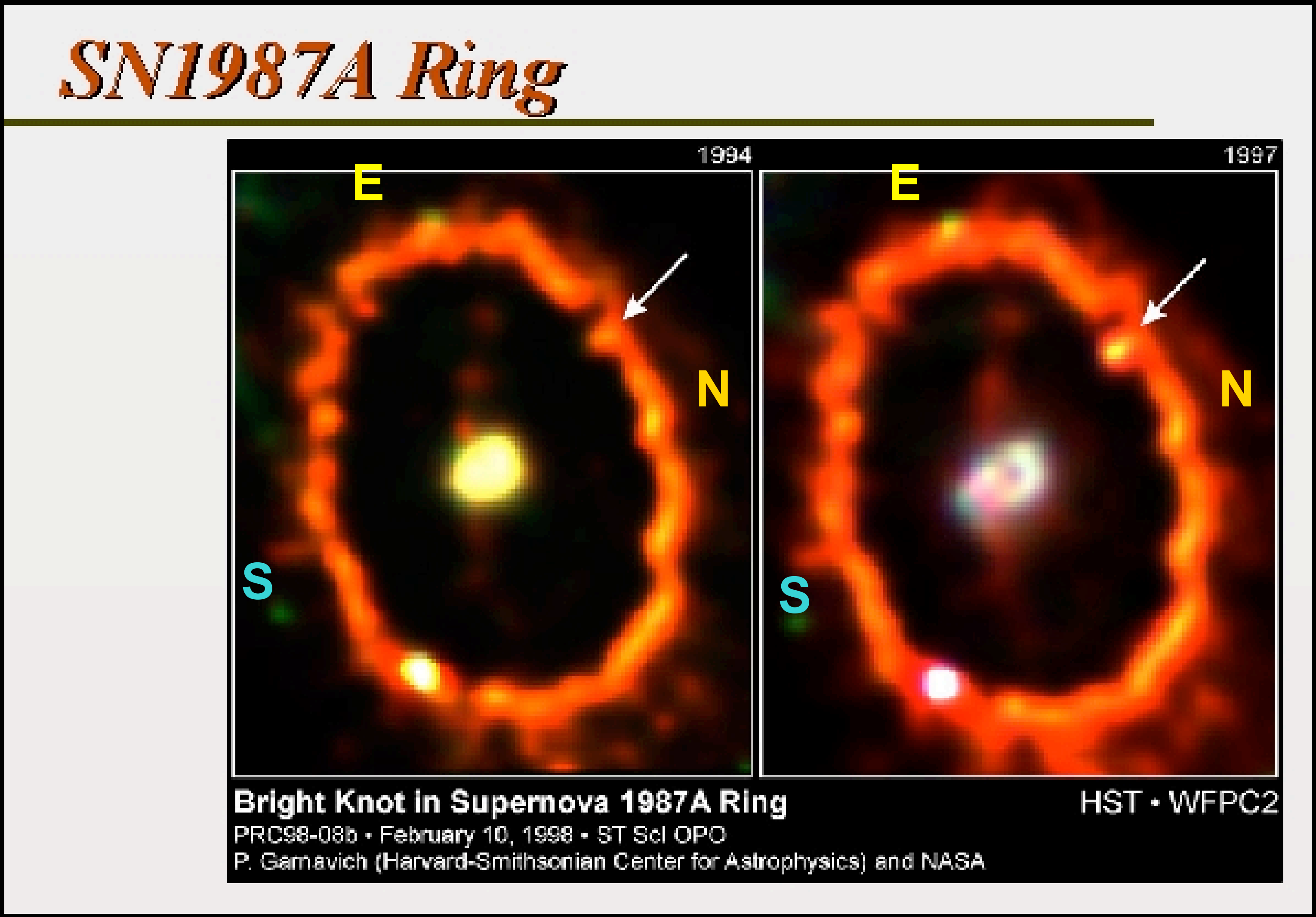
Supernova 1987A Rings



Hubble Space Telescope
Wide Field Planetary Camera 2

Inner ring is produced by fluorescence of gas in equatorial ring, ionized by initial UV flash of SN explosion.

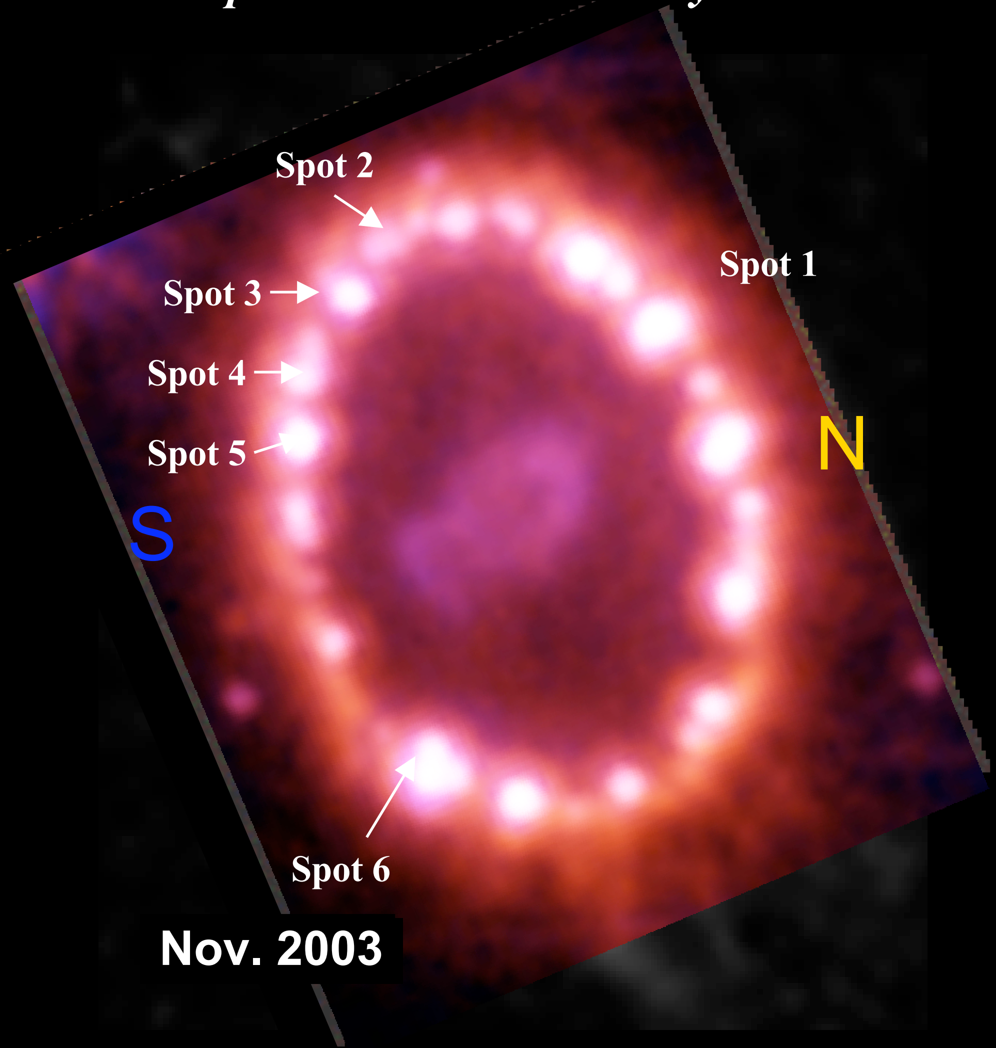
SN 1987A: Optical Spot in the Inner Ring



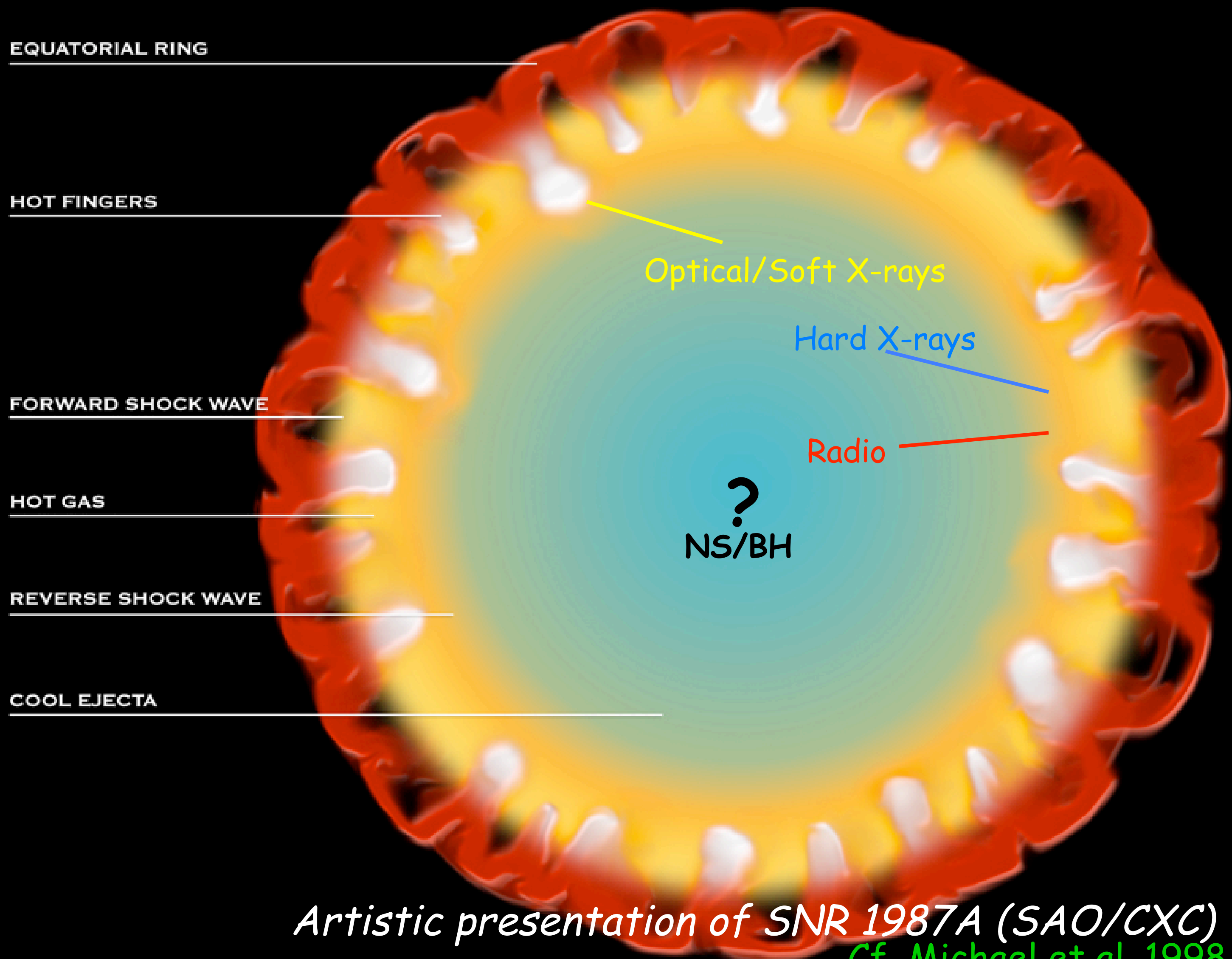
SNR 1987A: TIME-LAPSE MOVIE (HST)

SuperNova Intensive Study Collaboration

Time-lapse movie of the SN 1987A inner ring: Feb. 1998 - Nov. 2003. The optical spots are now all around the inner ring.



SNR 1987A: Physical Picture

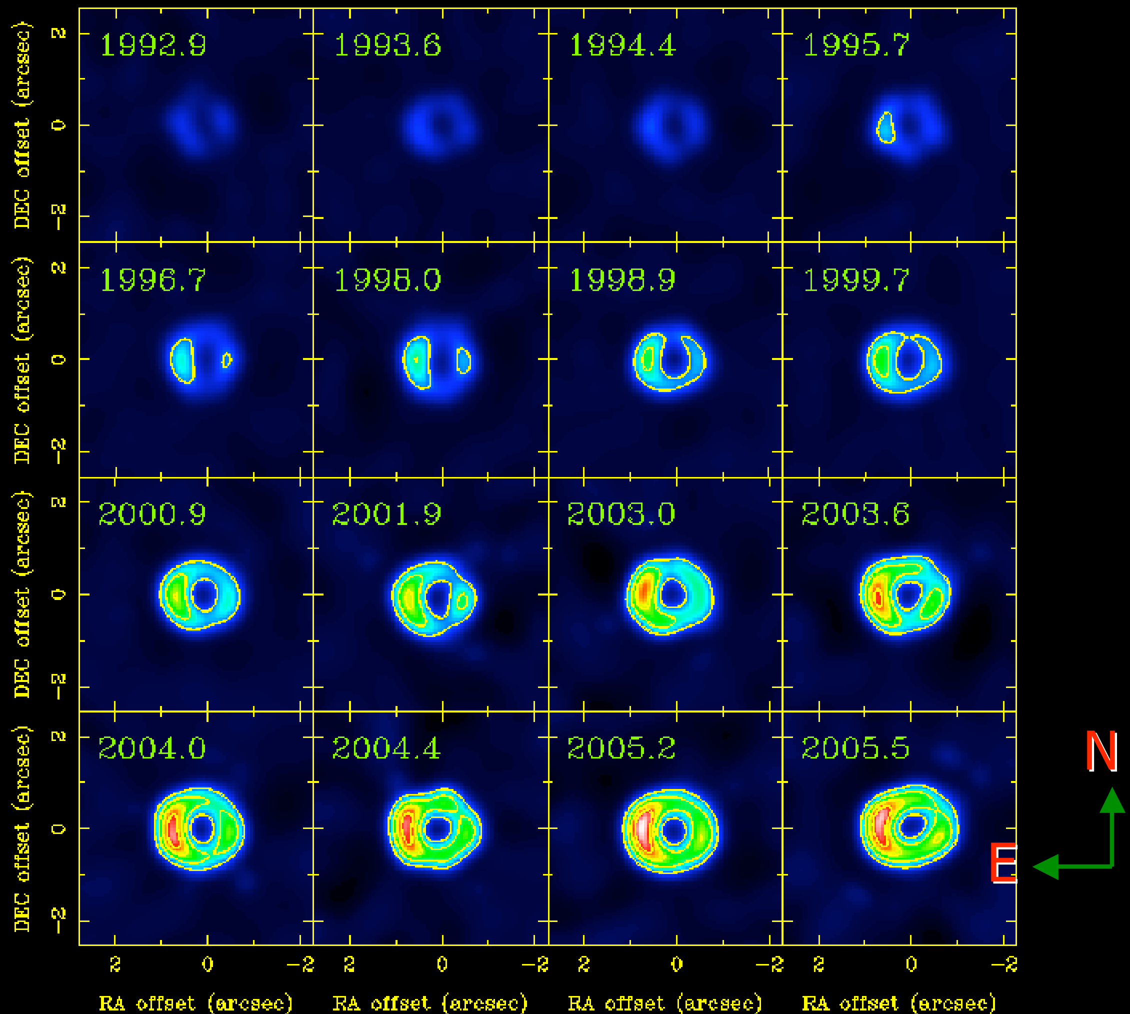


Artistic presentation of SNR 1987A (SAO/CXC)

Cf. Michael et al. 1998

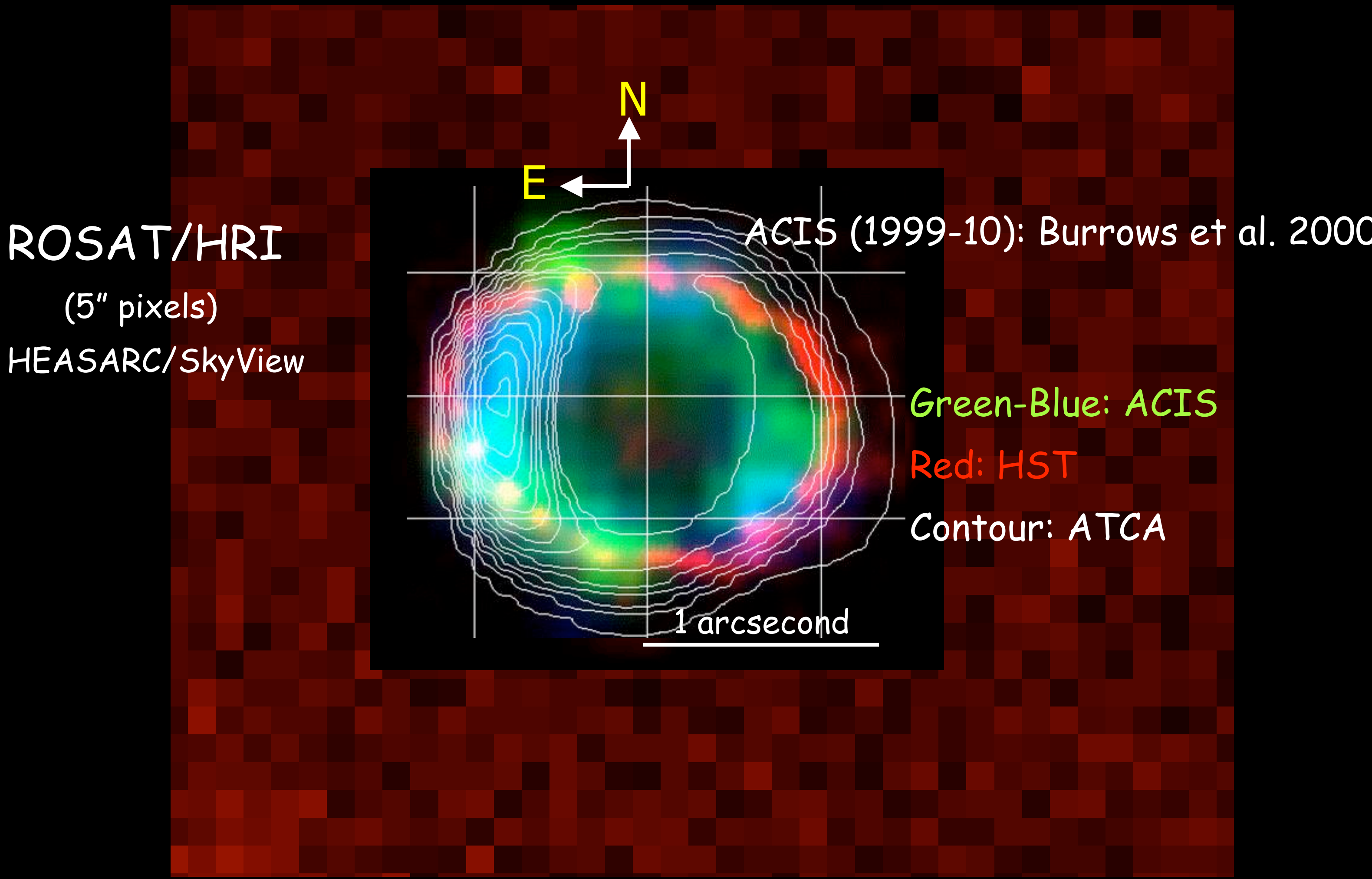
SNR 1987A: Radio Images (ATCA)

Australian Telescope Compact Array



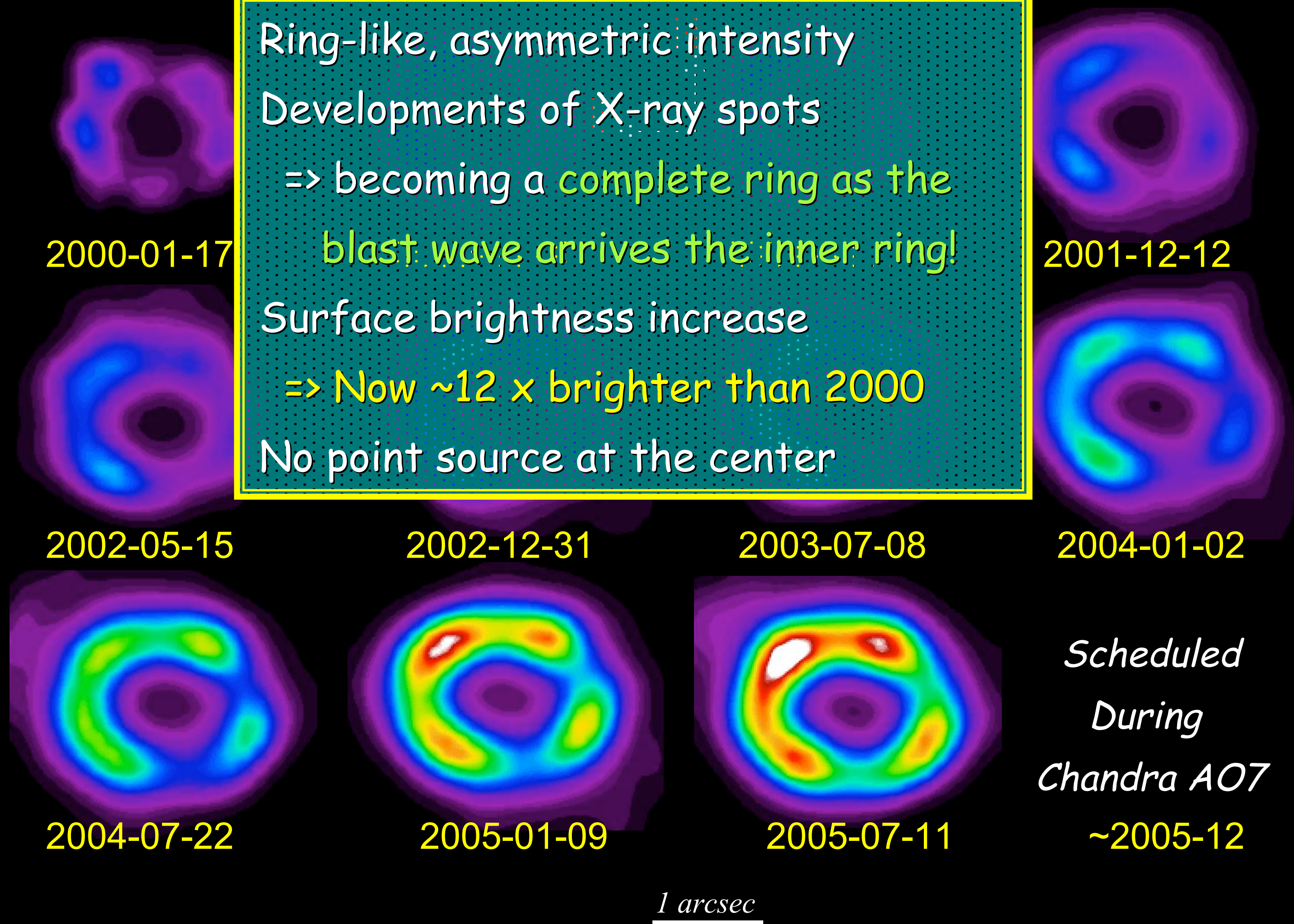
Courtesy of Bryan Gaensler & Lister Staveley-Smith

SNR 1987A: First X-ray Images

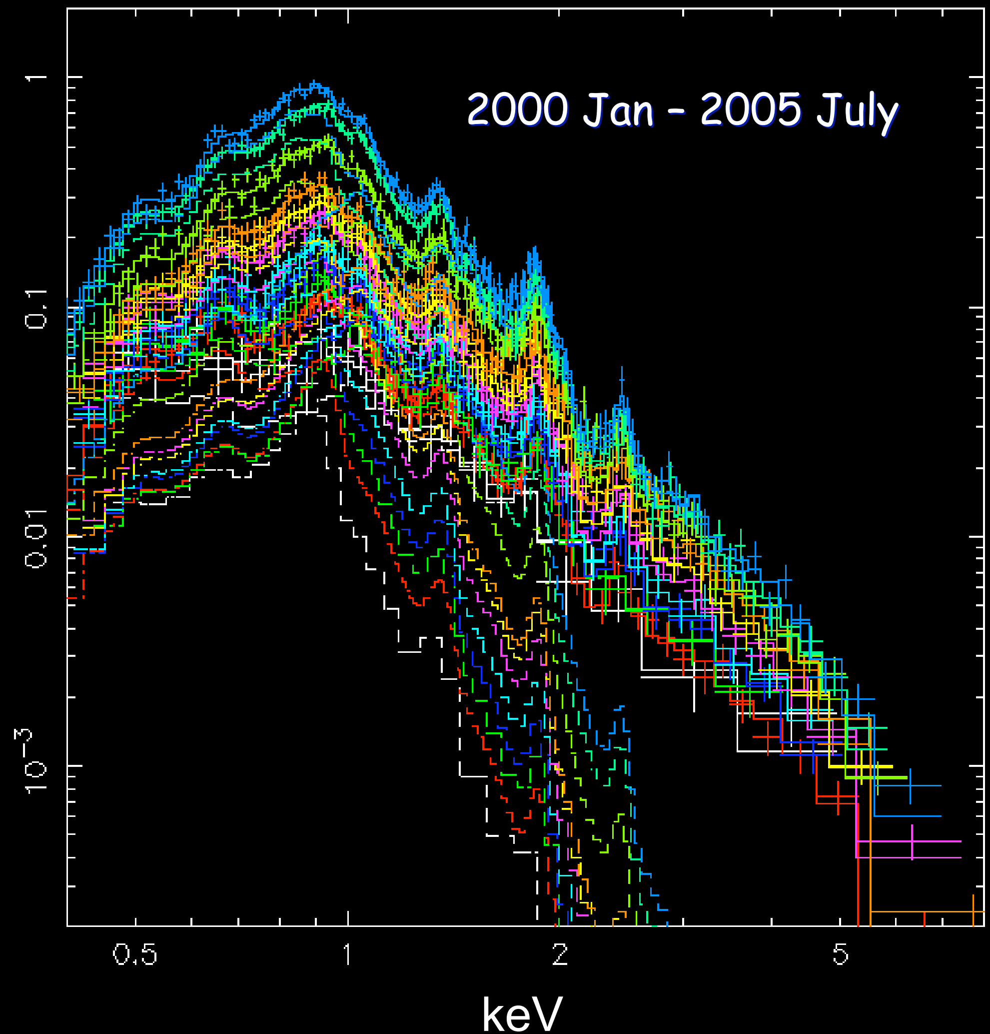


SNR 1987A: ACIS Images 2000–2005

- Ring-like, asymmetric intensity
- Developments of X-ray spots
  - => becoming a complete ring as the blast wave arrives the inner ring!
- Surface brightness increase
  - => Now ~12 x brighter than 2000
- No point source at the center



SNR 1987A: ACIS Spectrum ("2-shock" model)



$N_H = 2.35 \times 10^{21}\ cm^{-2}$

Soft component:

kT_s = 0.23 - 0.31 keV

$n_e\,t \sim 10^{13}\ cm^{-3}\ s$

Hard component:

kT_h = 2.2 - 3.2 keV

$n_e\,t \sim 2 \times 10^{11}\ cm^{-3}\ s$

Abundances fixed at values obtained from the LETG data:

N = 0.76 O = 0.09

Ne = 0. 29 Mg = 0.24

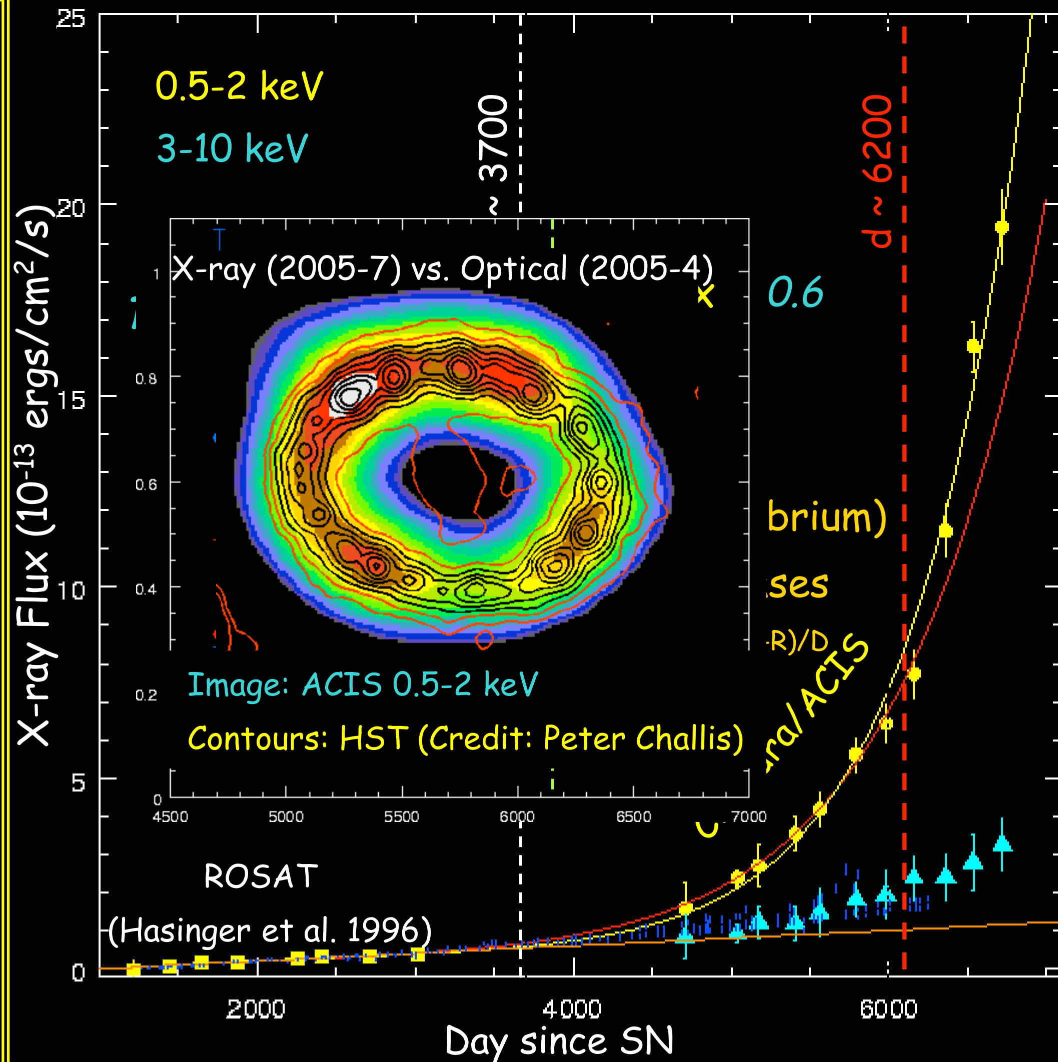
Si = 0.28 Si = 0.45

Fe = 0.16

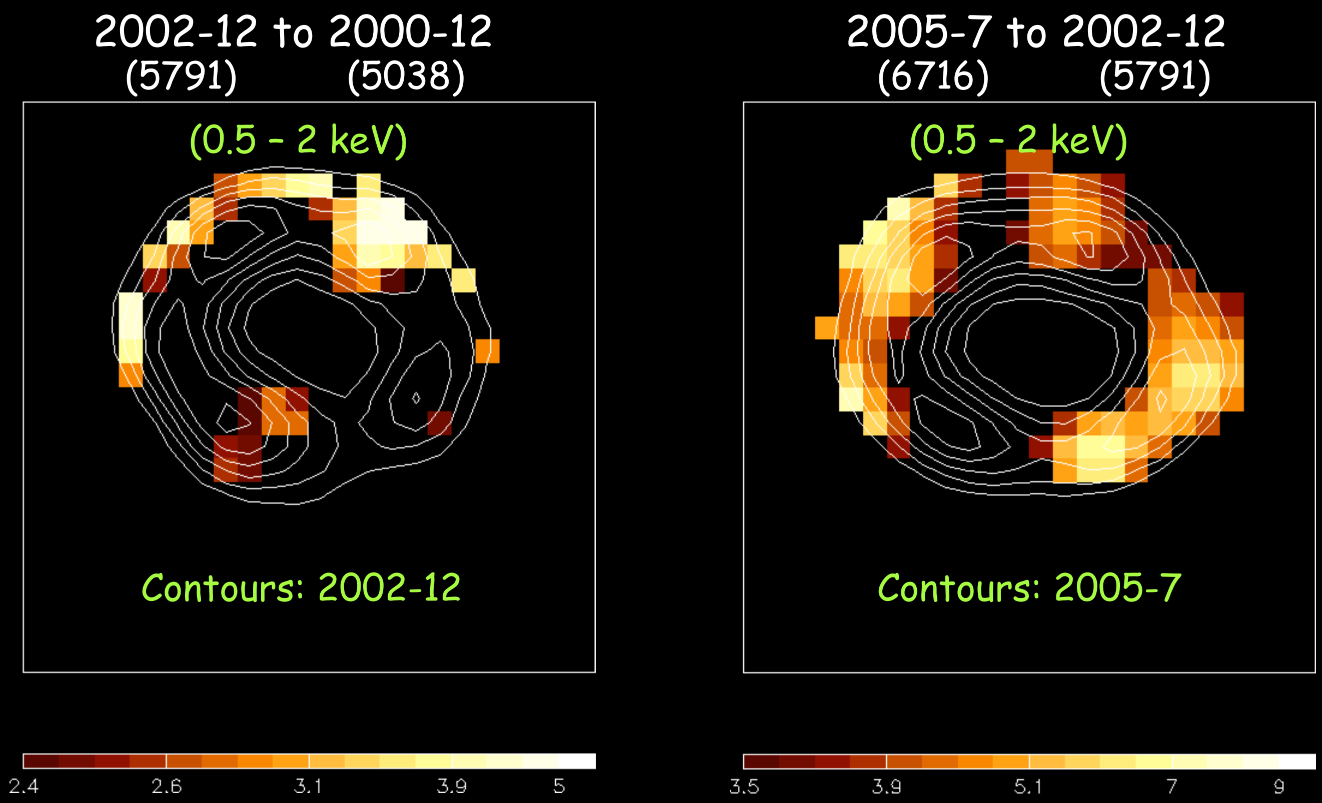
SNR 1987A: Soft X-Ray Light Curve

Linear increase of X-ray flux until day ~3000.
Rate jump in 1997 (day ~3700): coincident with emergence of optical spots.
An exponential radial density profile can fit the lightcurve over a decade.

An excess became evident since d ~ 6200.
Forward shock enters a “wall”?



SNR 1987A: Soft X-Ray Intensity Ratio



SNR 1987A: Hard X-Ray Emission

X-ray (2005-7) vs.

Radio (2005-6)

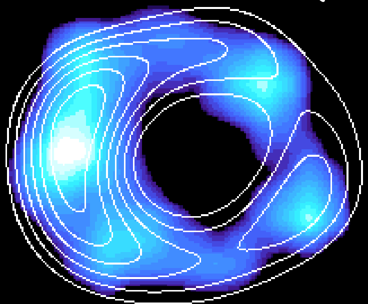


Image: ACIS 3-8 keV

Contours: ATCA 9 GHz

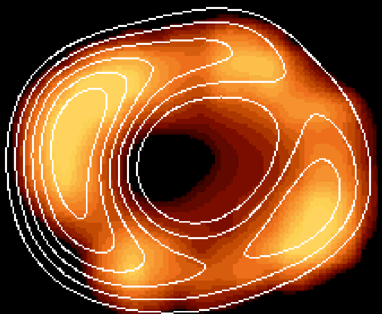
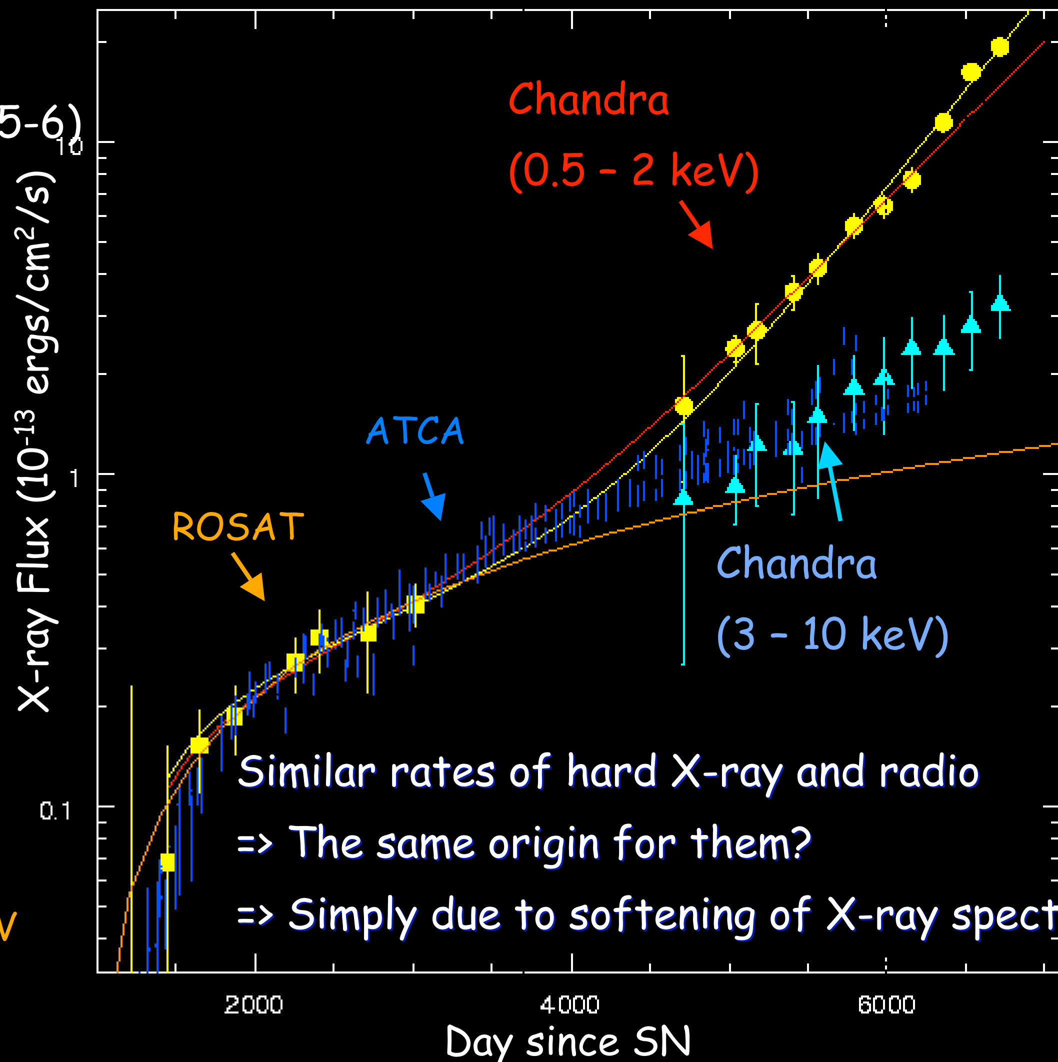


Image: ACIS 0.4-0.5 keV

Contours: ATCA 9 GHz



Similar rates of hard X-ray and radio

=> The same origin for them?

=> Simply due to softening of X-ray spectrum?

SNR 1987A: Soft/Hard X-Ray Images

X-ray (2005-7) vs. Radio (2005-6)

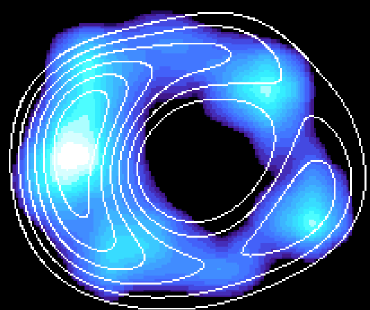


Image: ACIS 3-8 keV

Contours: ATCA 9 GHz

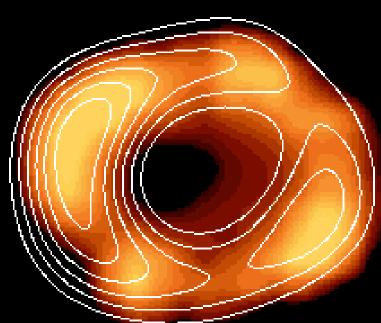


Image: ACIS 0.4-0.5 keV

Contours: ATCA 9 GHz

X-ray (2005-7) vs. Optical (2005-4)

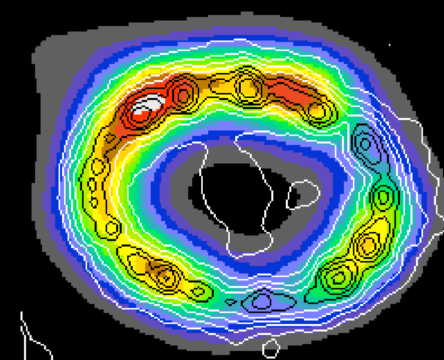


Image: ACIS 0.8-1.2 keV

Contours: HST Hα

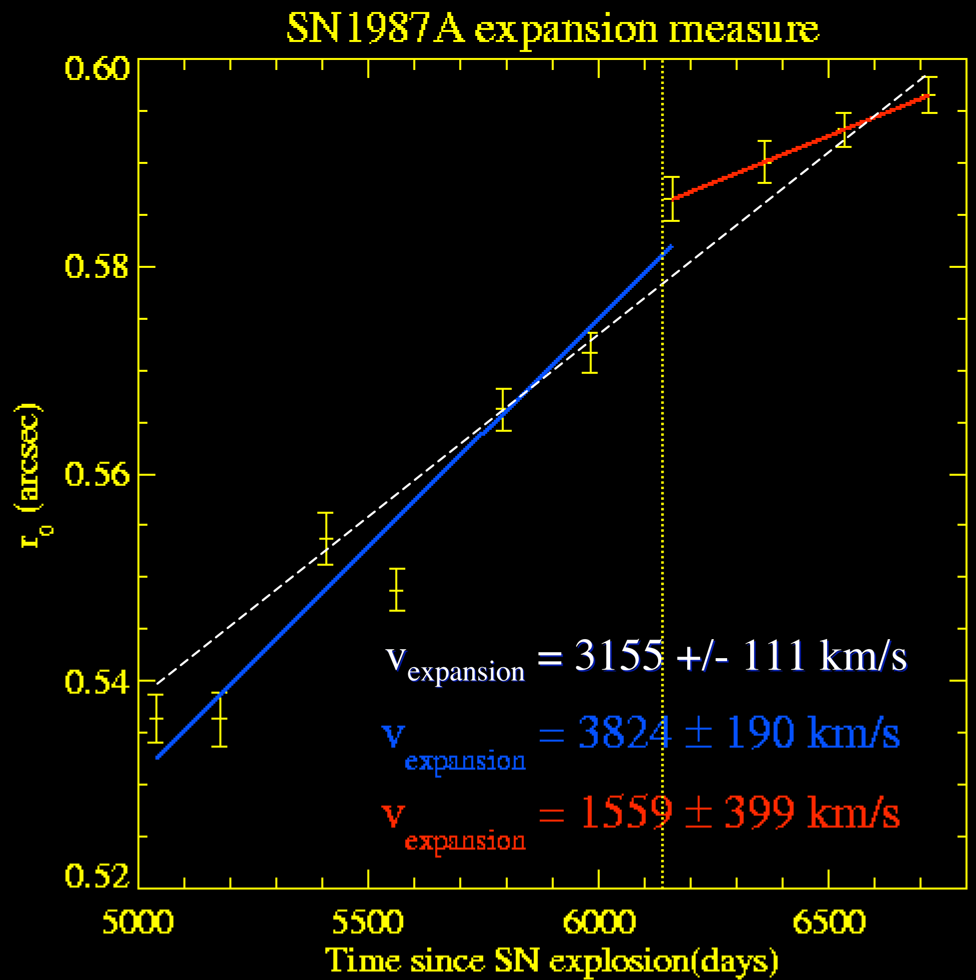
SNR 1987A: X-ray Expansion

Racusin et al. 2005 in preparation

X-ray radius vs time.

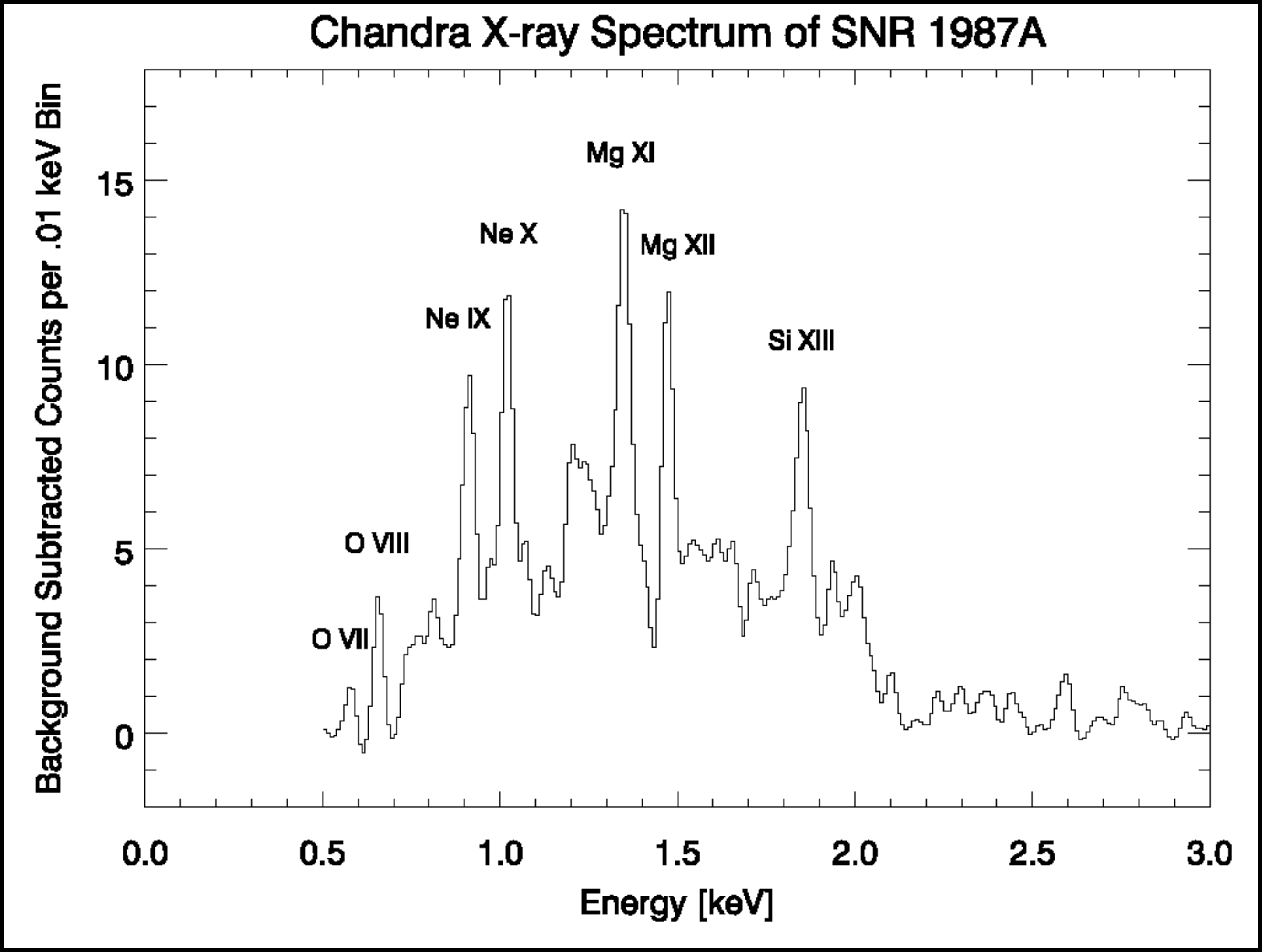
The broadband radial distribution for each observation is fitted to a Gaussian in order to estimate the radius of the SNR as a function of time.

Estimated expansion velocity is ~3155 km/s. But, it is apparently decelerating since d ~ 6200.



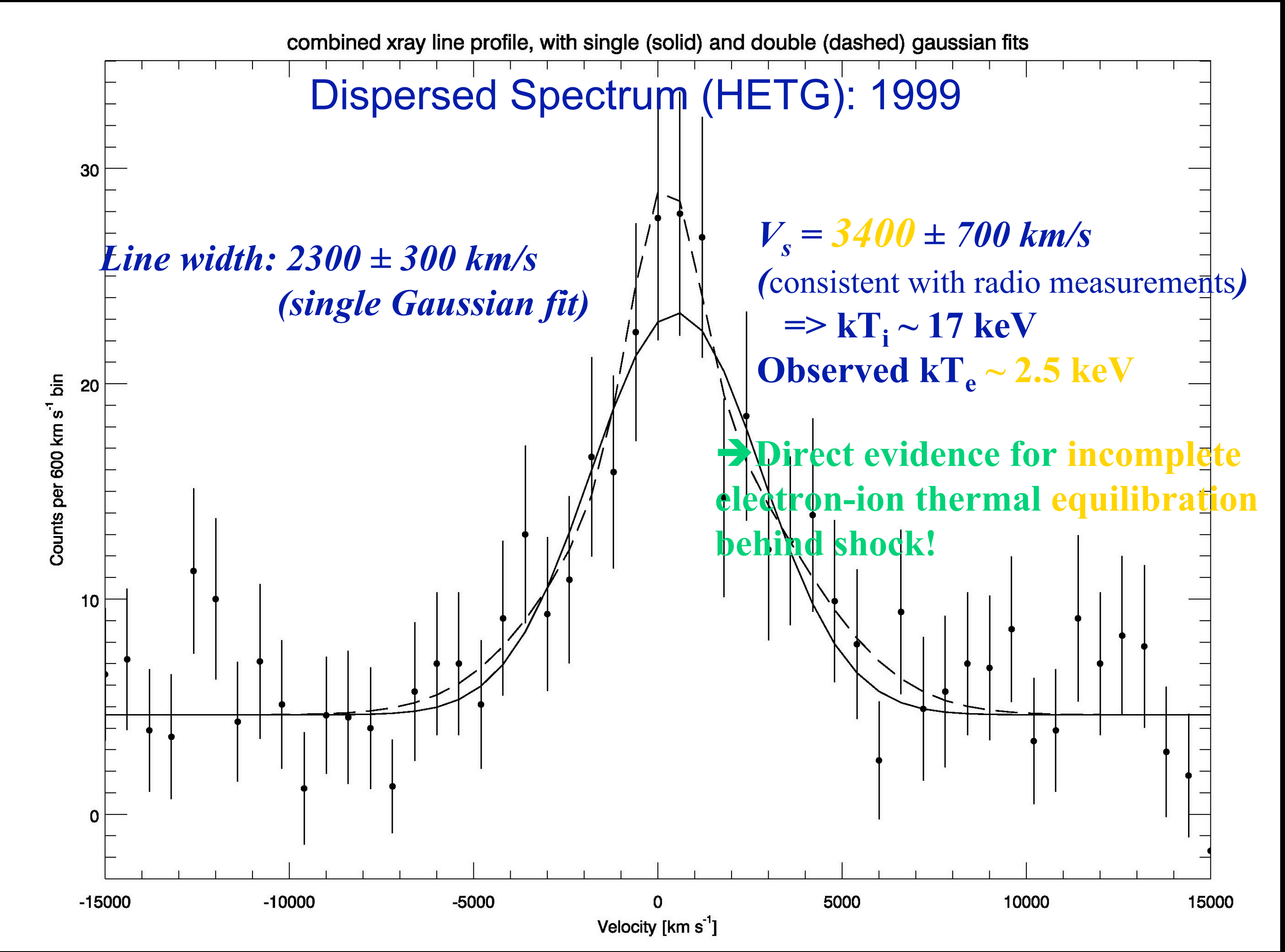
SNR 1987A: Dispersed Spectrum (1999)

Eli Michael / JILA



Combined Line Profile

Eli Michael / JILA



SNR 1987A: Dispersed Spectrum (2004)

Zhekov et al. 2005

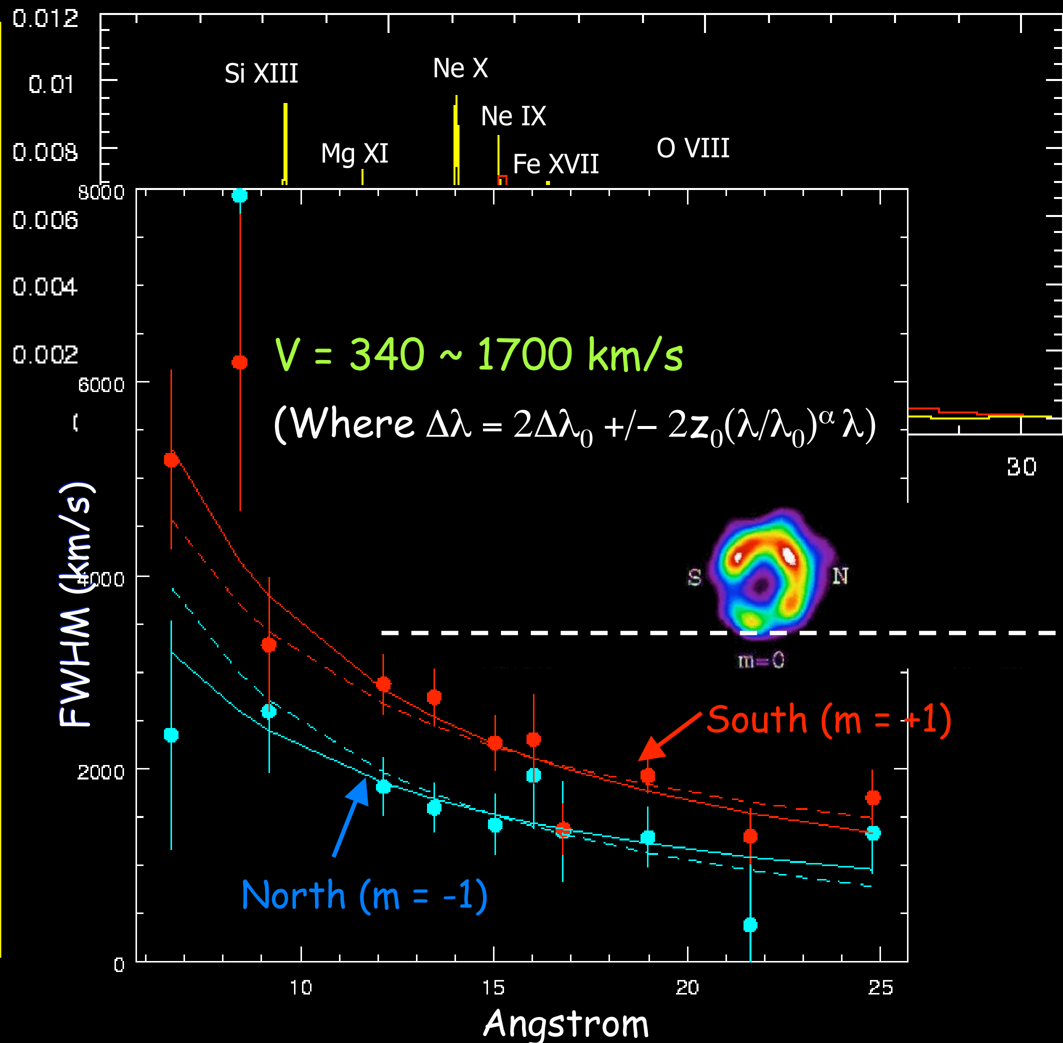
(Line Profiles & Kinematics)

LETG/ACIS-S
289 ks 2004-8/9

Detailed X-ray lines are resolved with good stats.

Individual line widths & doppler shifts are measures for the first time.

The most reliable abundance measurements.

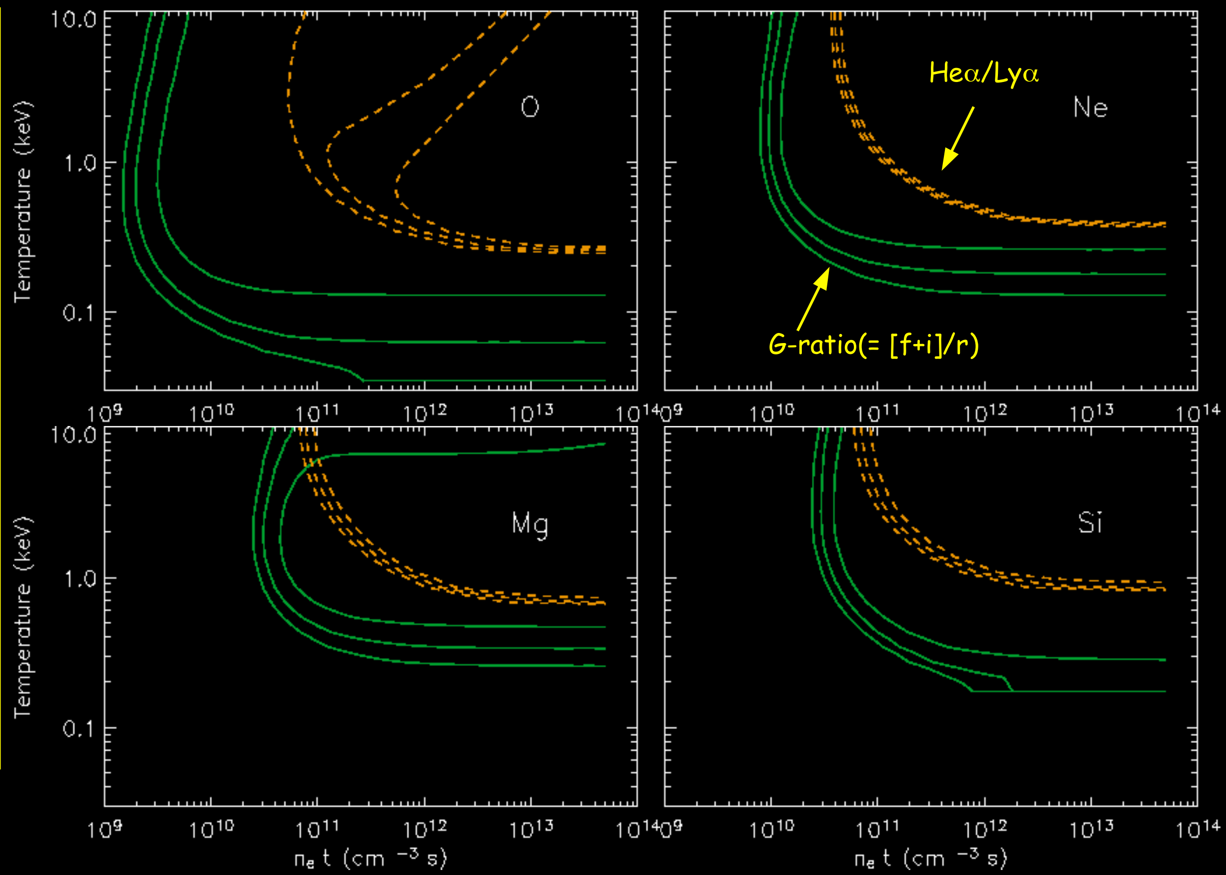


SNR 1987A: Dispersed X-Ray Spectrum

(Line Ratios)

Zhekov et al. 2005

Line ratios from individual species (Heα/Lyα & G-ratio of the He-like triplets) cannot be satisfied with a single kT-n_et state.
⇒ X-ray emitting plasma is in multi-kT,
Ionization states (e.g., kT = 0.1-2 keV)



SNR 1987A: Radial Expansion

- Evidence of shock wave expansion:
  - Development of optical spots: 1997 – present
  - Development of X-ray spots: 1999 - present
  - Predicted blast wave velocity from hydrodynamical models: ~4100 km/s (Borkowski et al. 1997)
  - Implied shock velocity from Doppler width of X-ray dispersed lines: ~3400 km/s (Michael et al. 2002)
  - Measured expansion rate of radio images: ~3000 km/s (Manchester et al. 2002)
- Measurement of the radial expansion rate of X-ray images: ~ 3500 km/s, as of 2004-7 .
- Since d ~ 6100, the expansion rate appears to be reduced to v ~ 1560 km/s (from ~3400 km/s).

SNR 1987A: Neutron Star?

Sangwook Park / PSU

No, NOT Detected Yet!

=> Stellar ejecta at the center of the SNR might still be optically thick in X-rays.

- Compare the observed 3-8 keV band images before and after adding simulated point sources (with various count rates) at the center of the SNR in order to determine upper limit (90 %) to point source contribution.
- Point source spectrum: Γ = 1.7 – 3.0, $N_H = 2 \times 10^{21} - 10^{24}$ cm^{-2} are assumed.
- Based on the image taken on 2004-7-22, a point source upper limit is Lx (3-10 keV) ~ 5×10^{33} - 3×10^{35} ergs s^{-1}

	$N_H = 2 \times 10^{21}$	$N_H = 1 \times 10^{23}$	$N_H = 1 \times 10^{24}$
Γ = 1.7	Lx = 7.7×10^{33}	Lx = 1.3×10^{34}	Lx = 2.5×10^{35}
Γ = 3.0	Lx = 5.2×10^{33}	Lx = 1.1×10^{34}	Lx = 3.0×10^{35}

SNR 1987A: Summary (as of 2005-7)

- Development of X-ray (and optical) spots: result of the blast wave encountering the dense CSM produced by progenitor's stellar winds.
- Soft X-ray flux increase rate may be described by emission from shock-heated ISM with an exponential radial distribution.
- X-ray spectral variations suggest that the fast shock front is now entering the main body of the inner ring at day ~ 6000.
- A point source upper limit: L_x (3-10 keV) = 5×10^{33}–3×10^{35} ergs s^{-1} .

⇒ A dramatic flux increase (by ~3 orders of magnitudes) has begun.

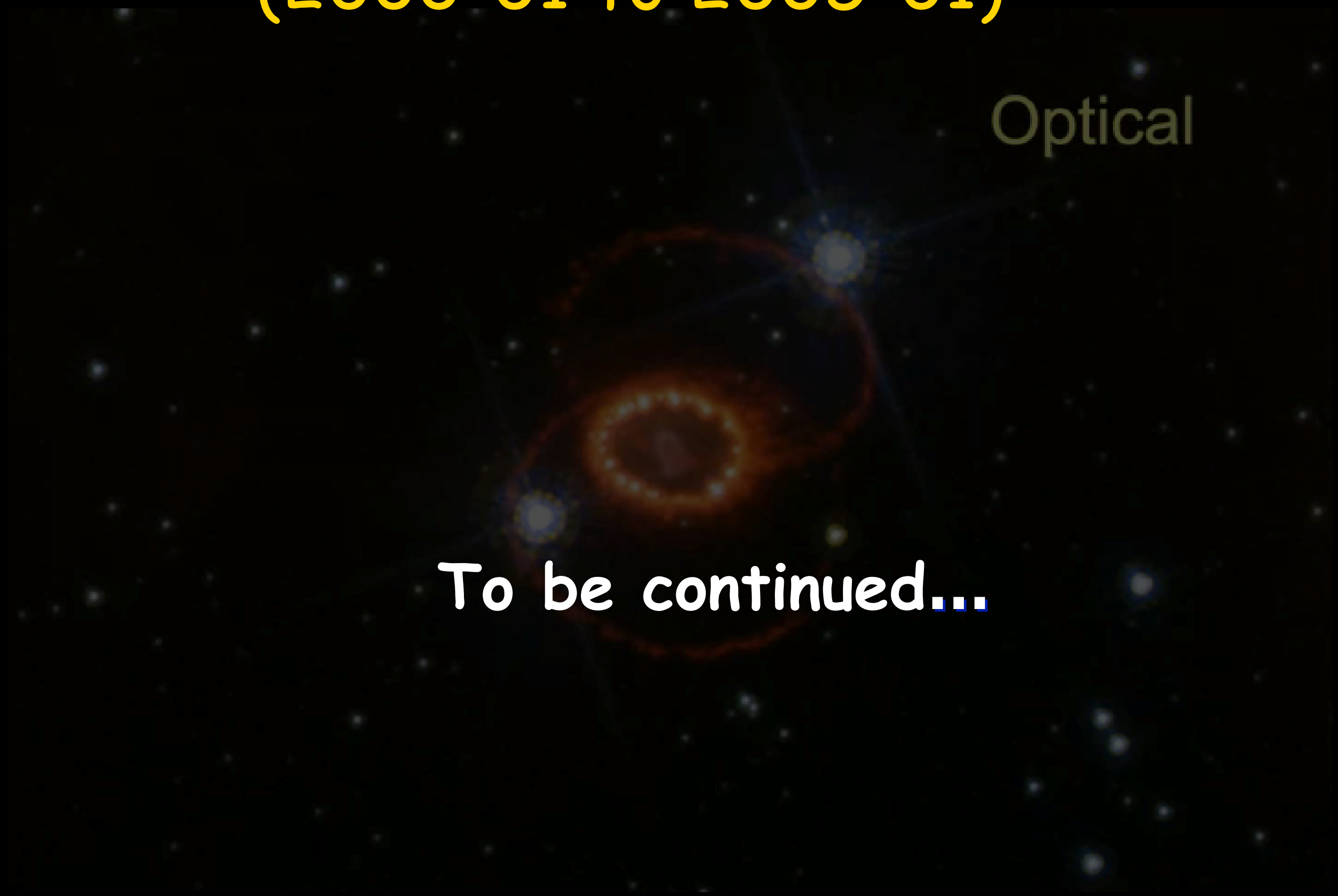
⇒ Spectral & morphological changes should be watched.

⇒ First-ever Observation of "Birth of a Supernova Remnant & a Neutron Star!!

- Deep grating (LETG) observations (Aug 26 – Sep 5, 2004) confirms X-ray emission originating from the inner ring.
- The next monitoring observations has been approved during AO8!!

=> continue to watch shock evolution, flux increase, nonthermal synchrotron emission, and neutron star.

SNR 1987A Time-Lapse Movie:
(2000-01 to 2005-01)



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