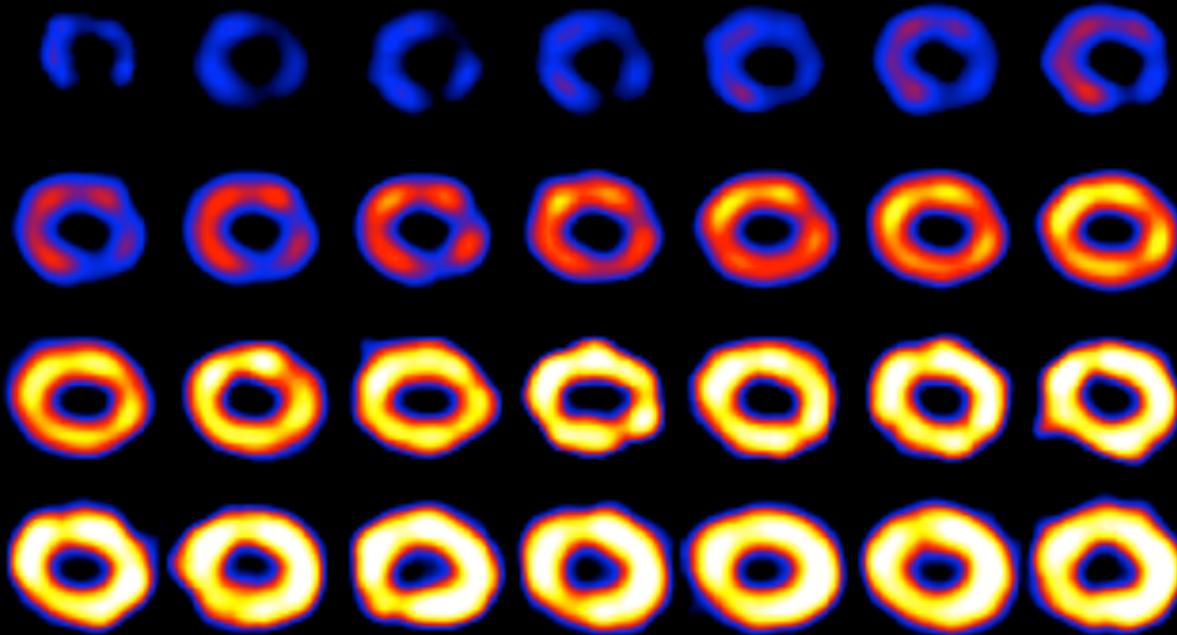


# The X-ray Evolution of SN1987A

(16 Years of SN 1987A with Chandra)



David Burrows and Kari A. Frank

# Built on the work of

PSU Chandra observations:

David Burrows

Sangwook Park

Judith Racusin

Eveline Helder

Kari Frank



and also:

Svetozar Zhekov

Michael Eli

Dan Dewey

Dick McCray

Vikram Dwarkadas

Eli Dwek

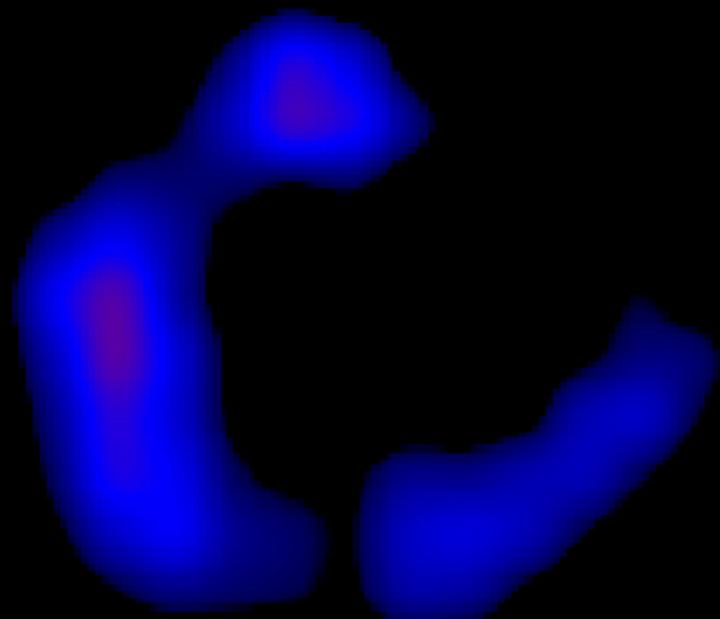
# Chandra Monitoring

- 1999 – Now  
(day 4600 – 10430)  
– > ½ of its lifetime!!
- ~6 month intervals
- 31 Epochs

Burrows+ (2000), Michael+ (2002),  
Park+ (2002,2004,2005,2006,2007,2011),  
Zhekov+ (2005,2006,2009),  
Racusin+ (2009), Dewey+ (2012),  
Helder+ (2013), Frank+ (2016)

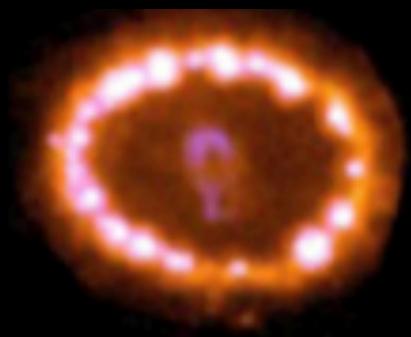
Date	Age	Grating
1999-10-06	4608	HETG
2000-01-17	4711	NONE
2000-12-07	5036	NONE
2001-04-25	5175	NONE
2001-12-12	5406	NONE
2002-05-15	5559	NONE
2002-12-31	5789	NONE
2003-07-08	5978	NONE
2004-01-02	6157	NONE
2004-07-22	6358	NONE
2005-01-09	6529	NONE
2005-07-11	6713	NONE
2006-01-28	6913	NONE
2006-07-27	7094	NONE
2007-01-19	7270	NONE
2007-07-13	7445	NONE
2008-01-09	7624	NONE
2008-07-01	7799	HETG
2009-01-18	8000	HETG
2009-07-06	8169	HETG
2010-03-28	8232	HETG
2010-09-28	8433	HETG
2011-03-25	8617	HETG
2011-09-21	8975	HETG
2012-03-28	9165	HETG
2013-03-21	9523	HETG
2013-09-28	9713	HETG
2014-03-19	9885	HETG
2014-09-20	10071	HETG
2015-03-14	10246	HRC/LETG
2015-09-17	10433	HETG

# Imaging: Morphological Evolution

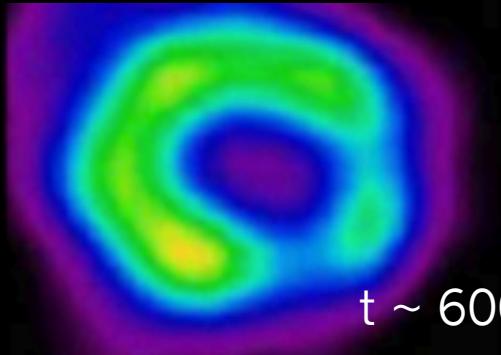


# Imaging: Multi- $\lambda$ Comparisons

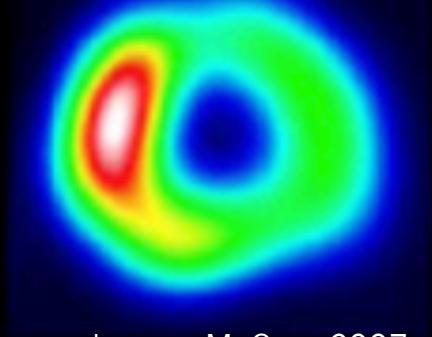
HST H $\alpha$  (2003)



Chandra (2003)



ATCA 9 GHz (2003)



$t \sim 6000$  days

Image: McCray 2007

HST H $\alpha$  (2011)

shocked ring

inner ejecta

Chandra (2012)

ATCA 6.8 mm (2011)

$t \sim 9000$  days

Image: Indebetouw et al. 2014

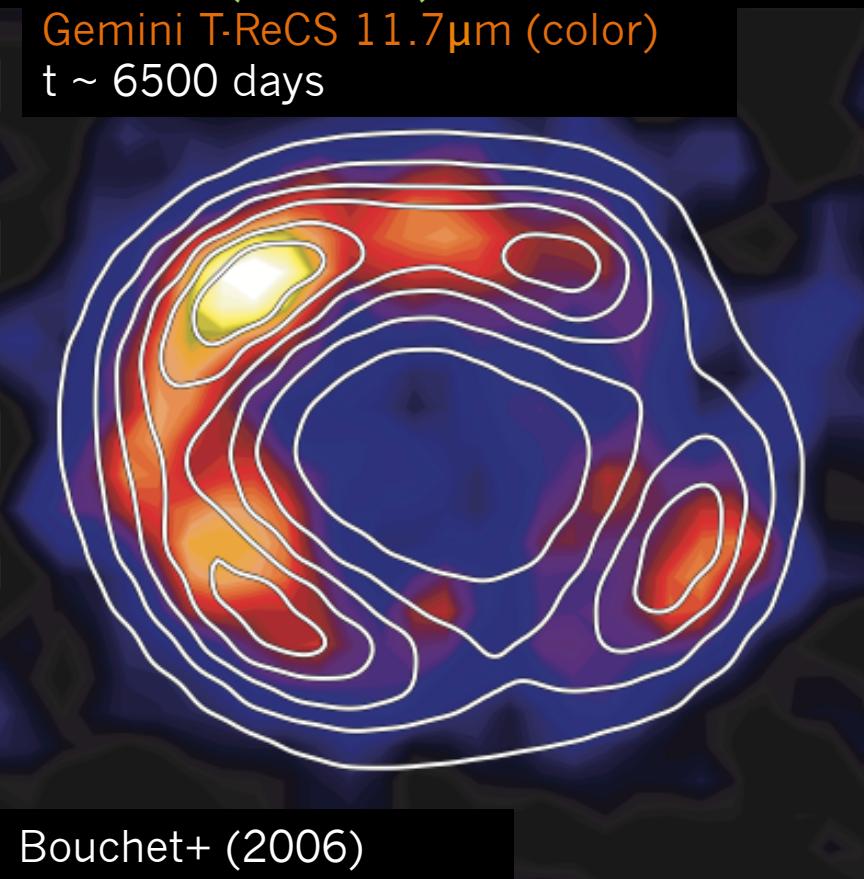
# Imaging: Multi- $\lambda$ Comparisons

*Collisional heating of ER dust*

Chandra (contours)

Gemini T-ReCS 11.7 $\mu$ m (color)

$t \sim 6500$  days

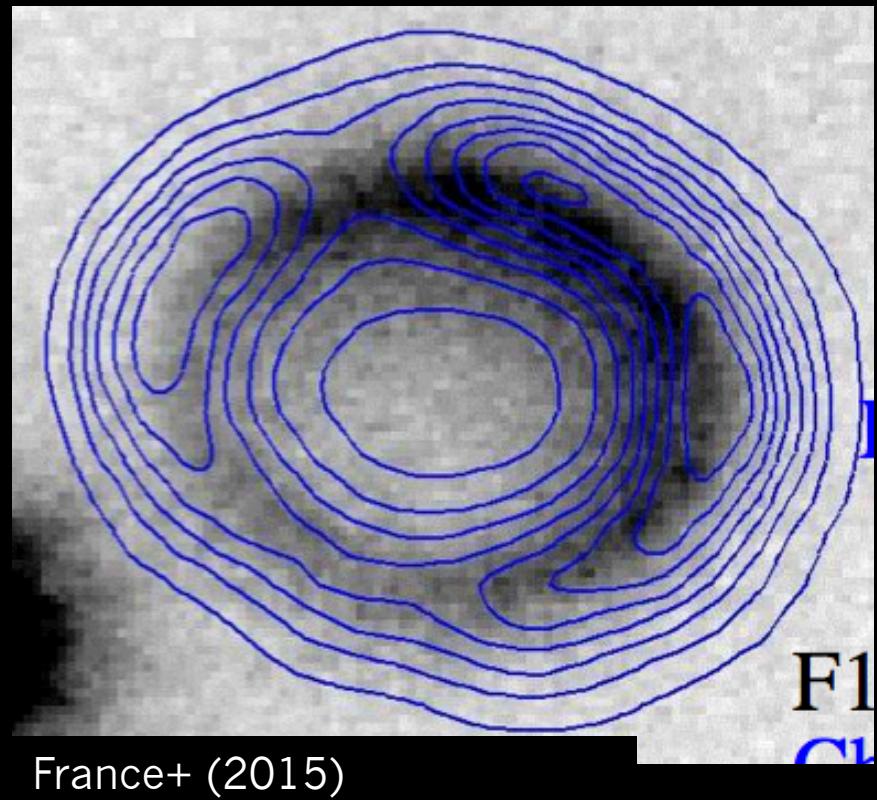


*Radiative heating of ejecta*

Chandra (contours)

HST Ly- $\alpha$  (grayscale)

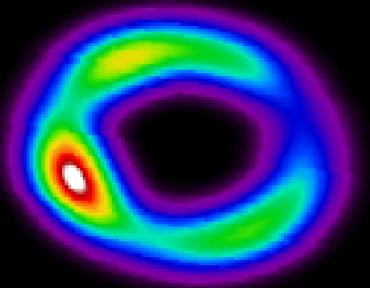
$t \sim 9900$  days



# Imaging: Blast Wave Location

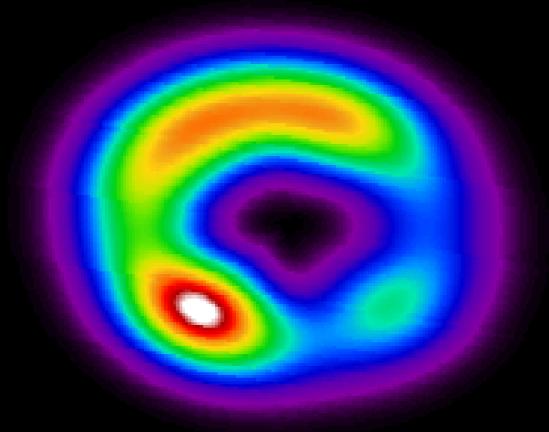
- Fit to inclined torus + 4 lobe model (Racusin+ 2009)

Day 4608



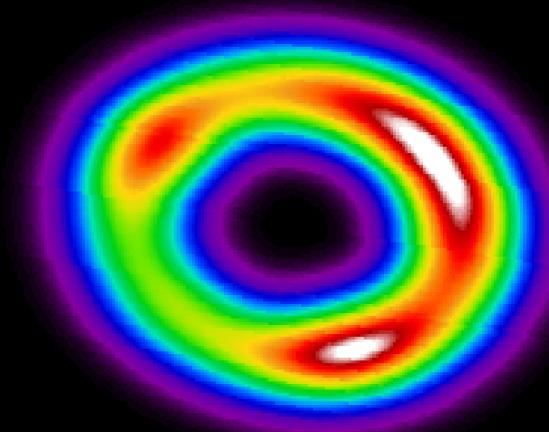
10/1999

Day 5789



12/2002

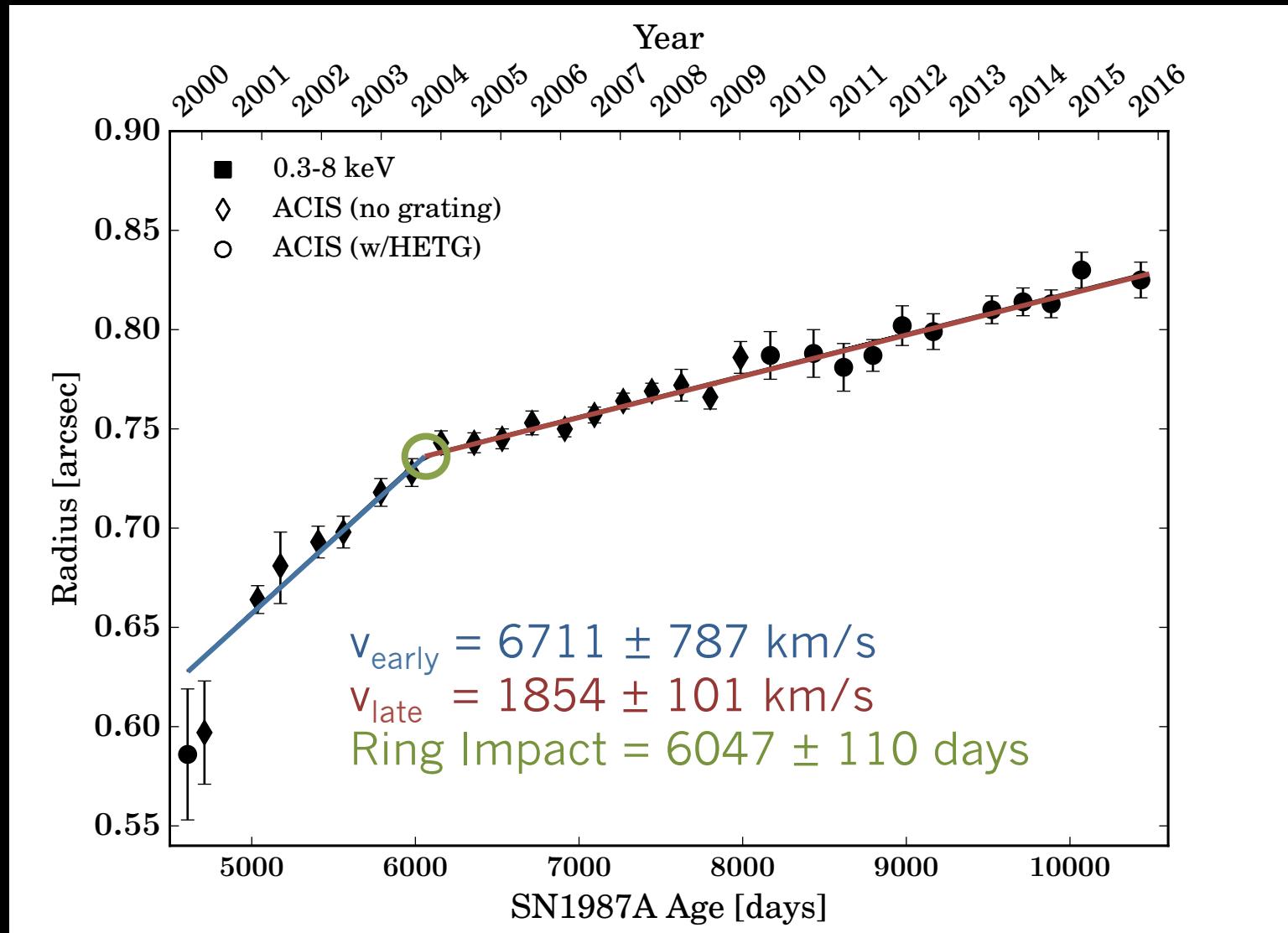
Day 10071



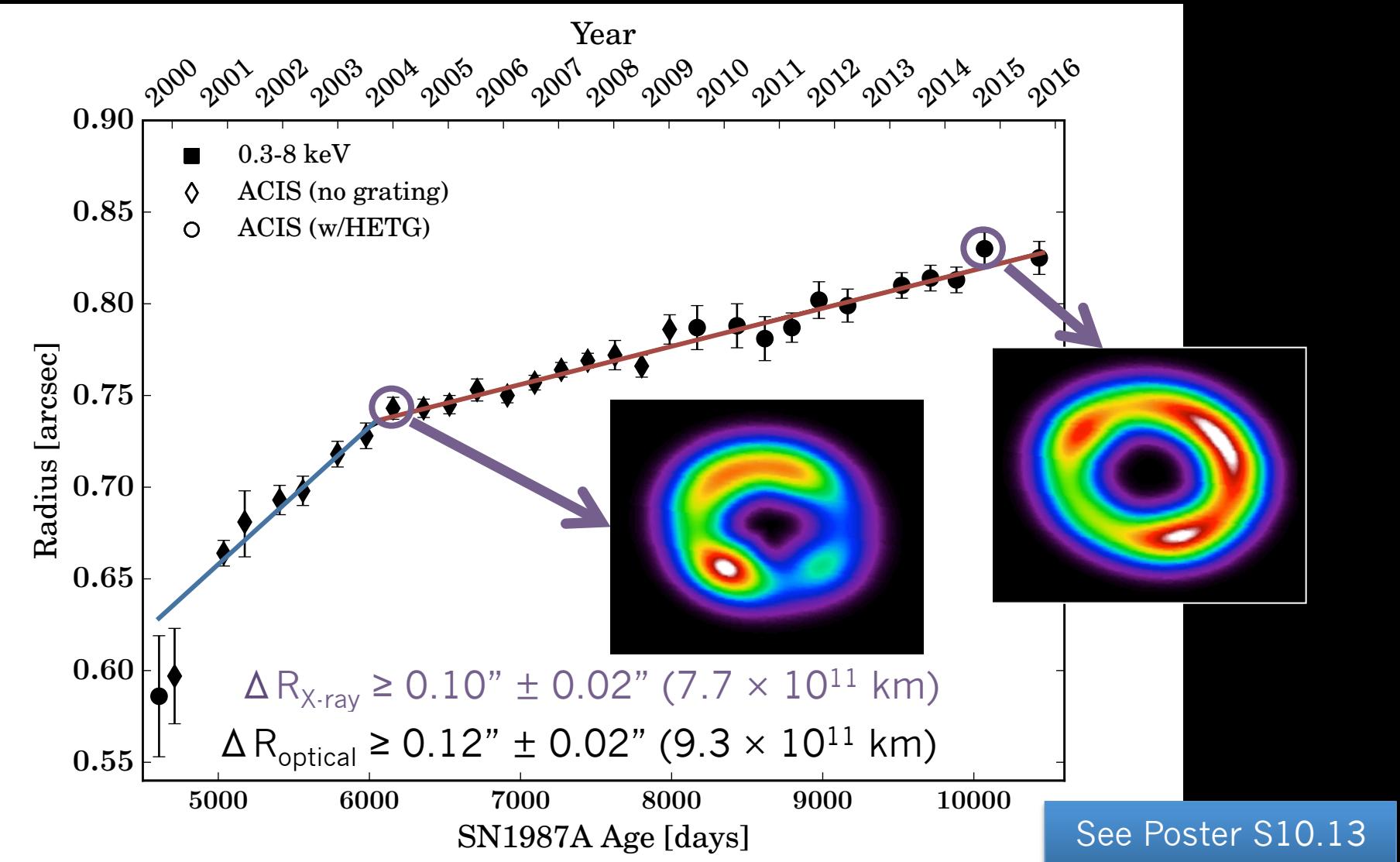
09/2014

Best-fit (deprojected) model images

# Imaging: Blast Wave Velocity

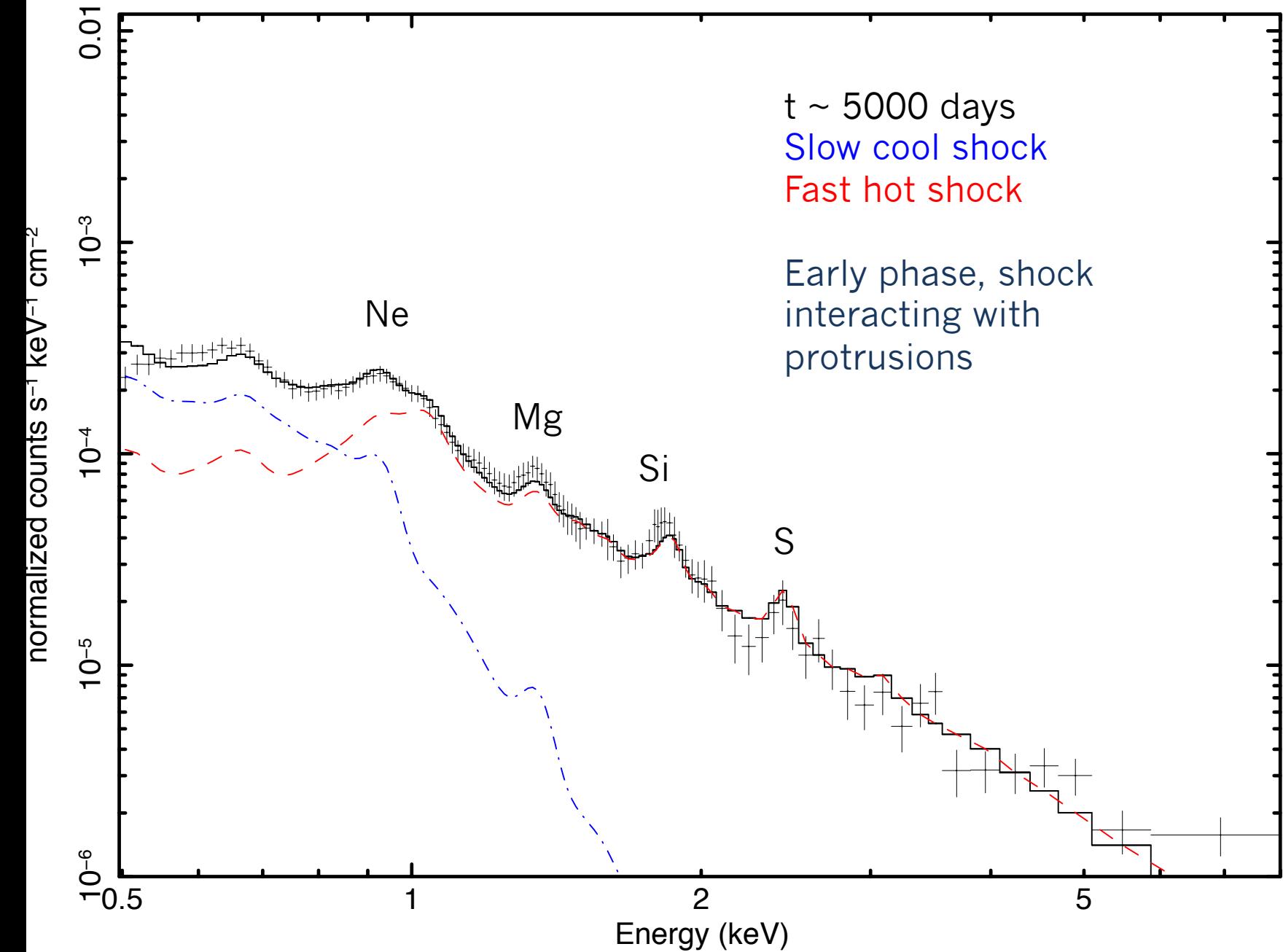


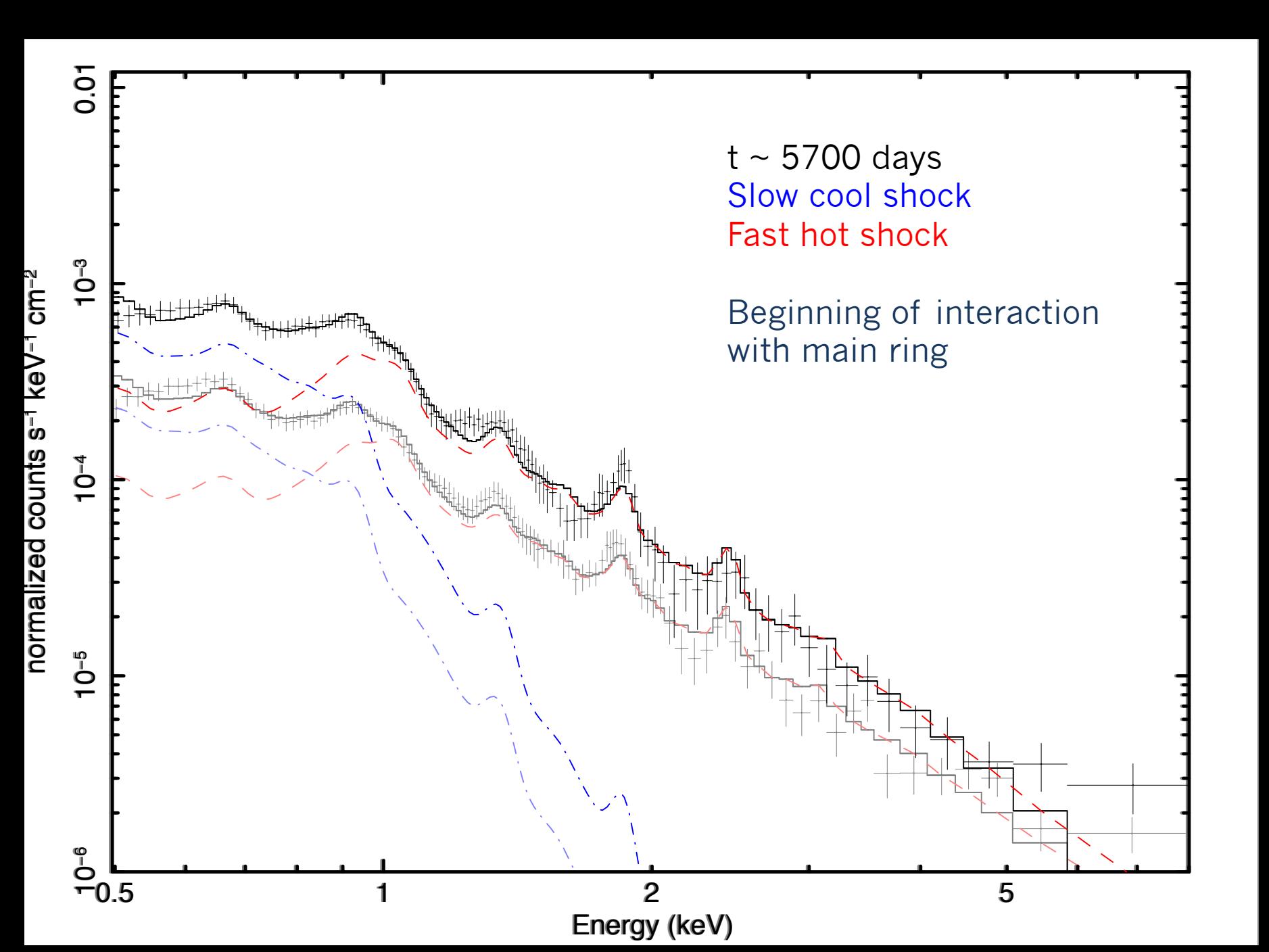
# Imaging: Blast Wave Progression

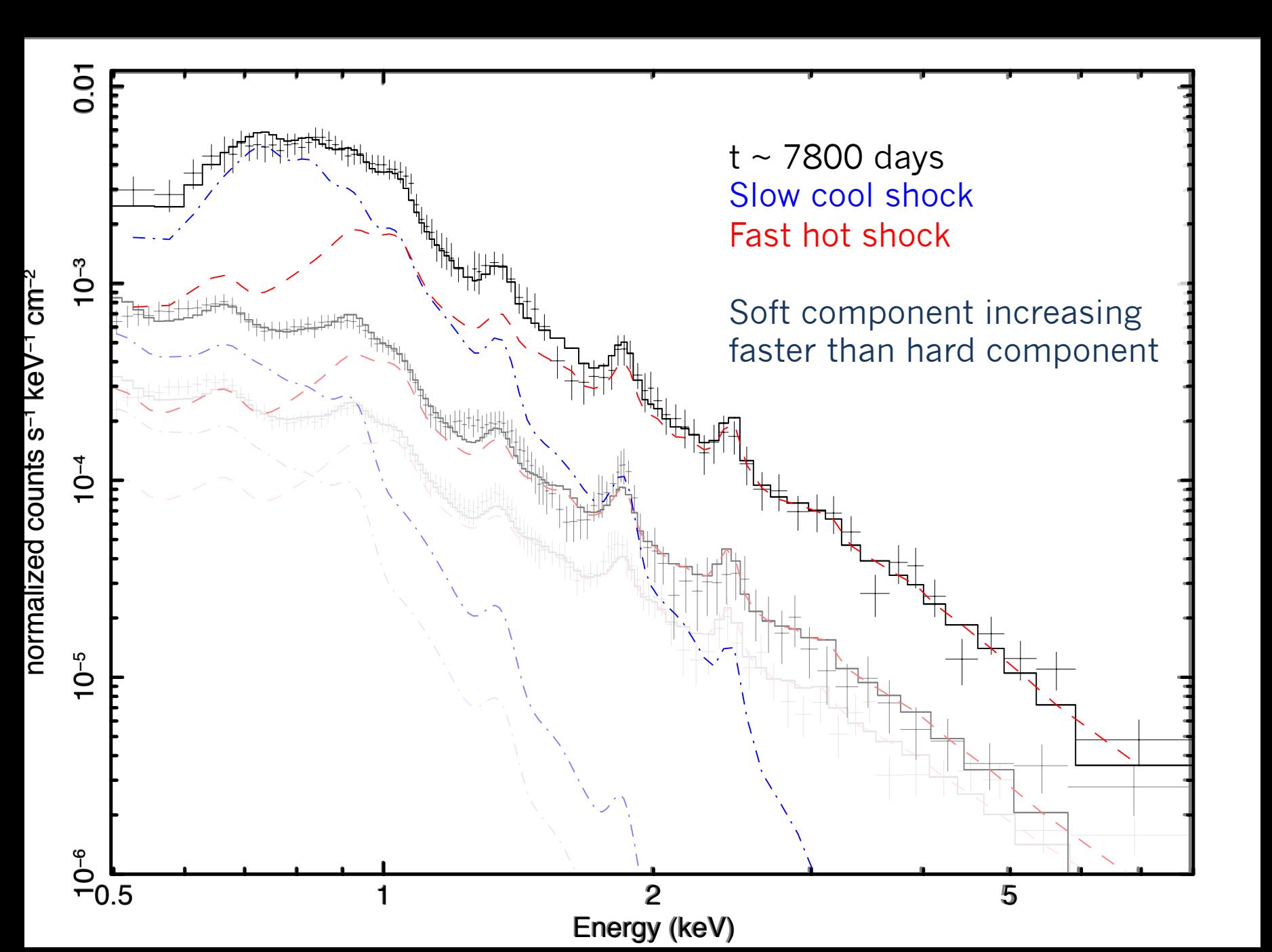


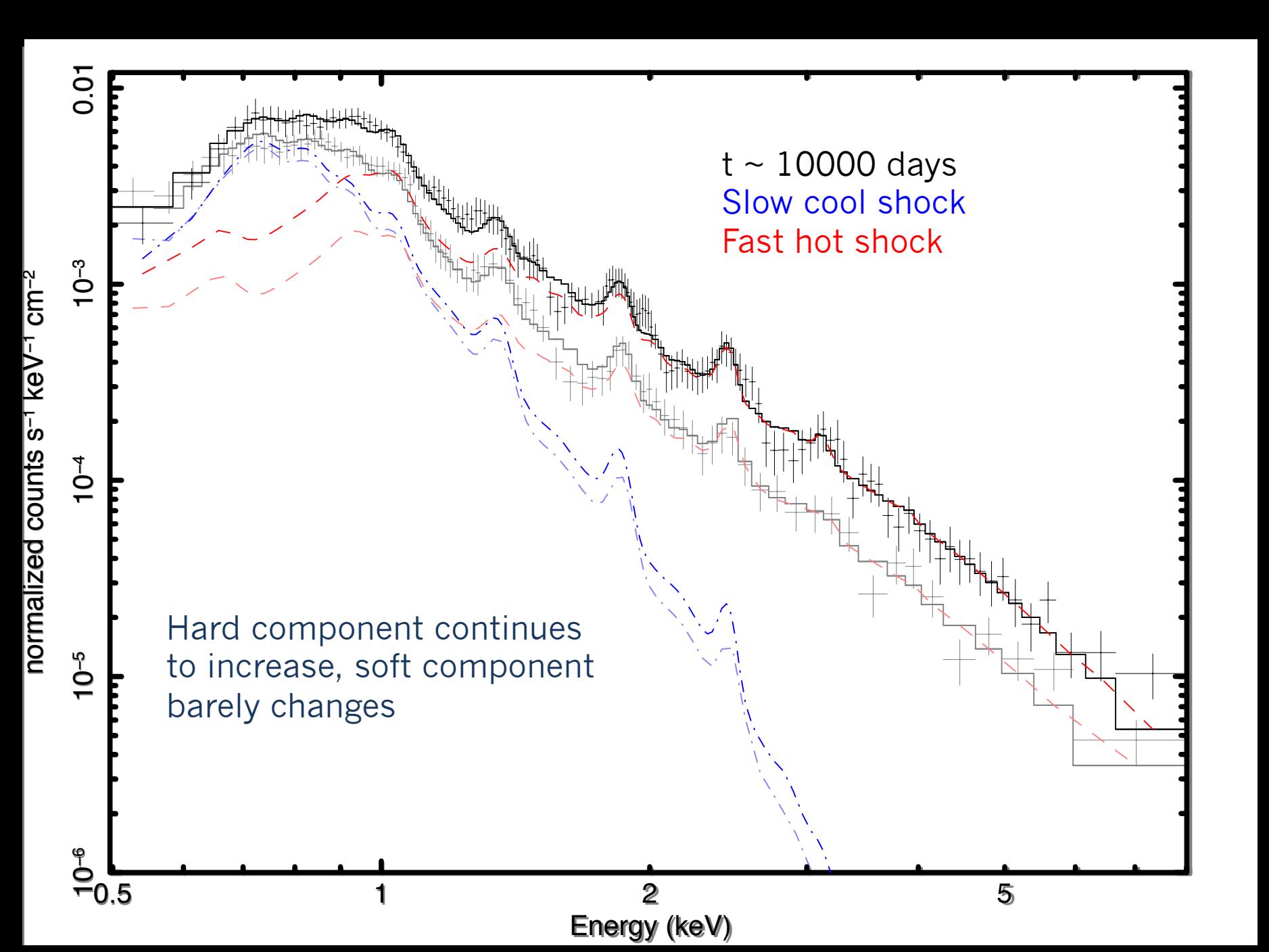
# CCD Spectroscopy

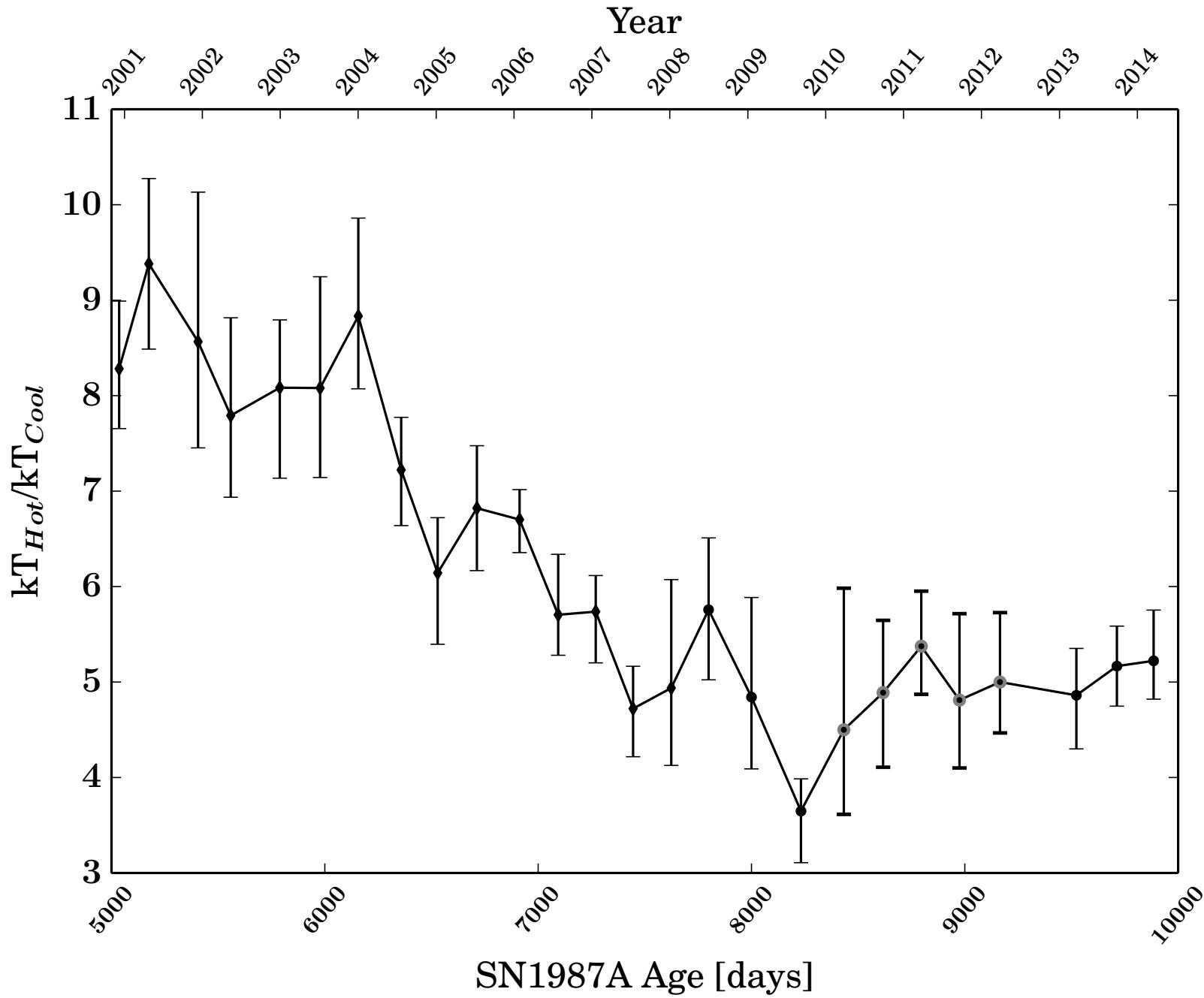
- 1- or 2-component NEI thermal shock model
  - Soft component:
    - $kT \sim 0.3 \text{ keV}$
    - $n_e t > 10^{12} \text{ s/cm}^3 (\sim \text{CIE})$
  - Hard component:
    - $kT \sim 1 - 3 \text{ keV}$
    - $n_e t = 2 - 3 \times 10^{11} \text{ s/cm}^3$
- Simplification of very complex, multi-shock system



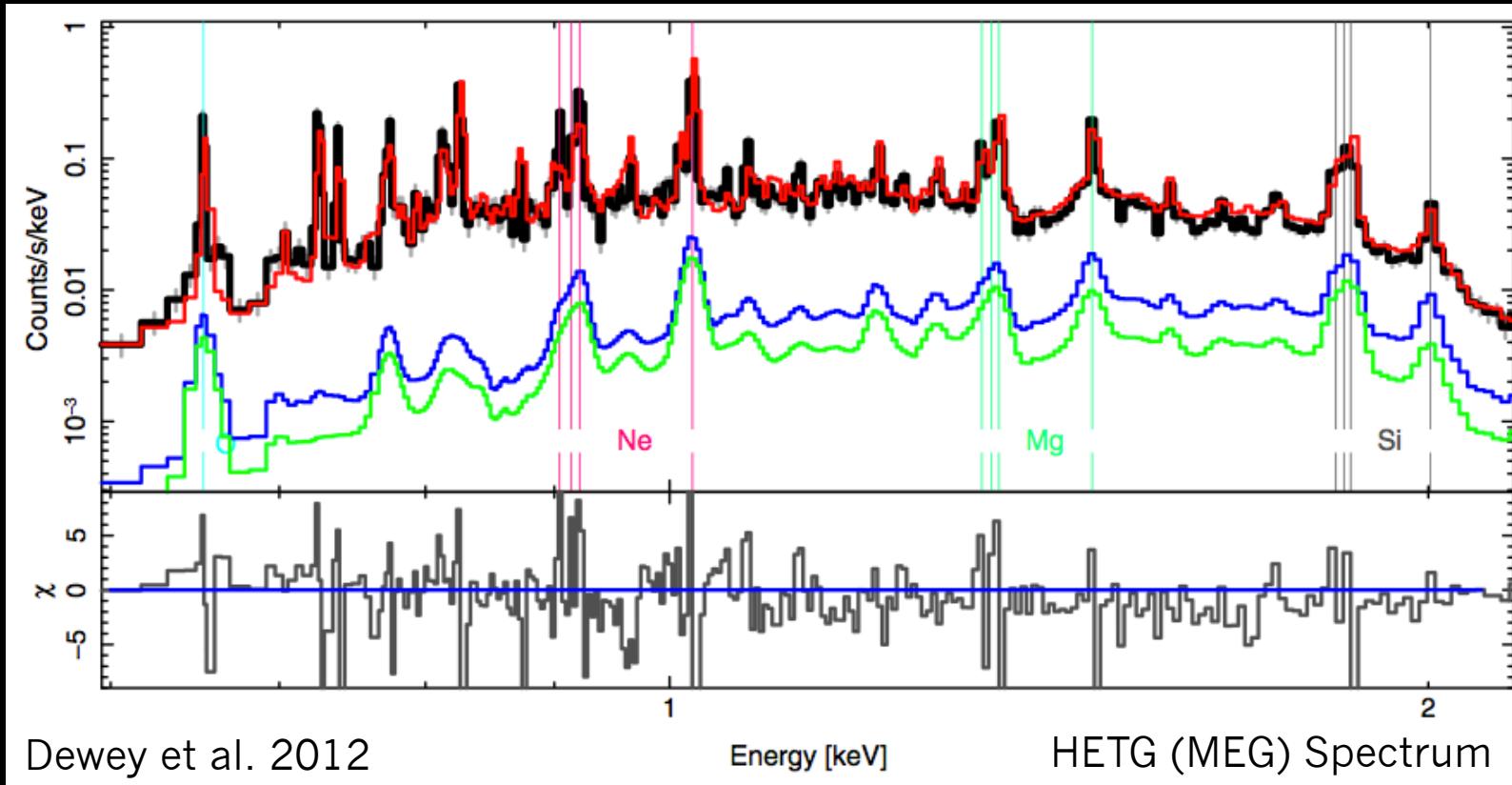








# Grating Spectroscopy: Abundances

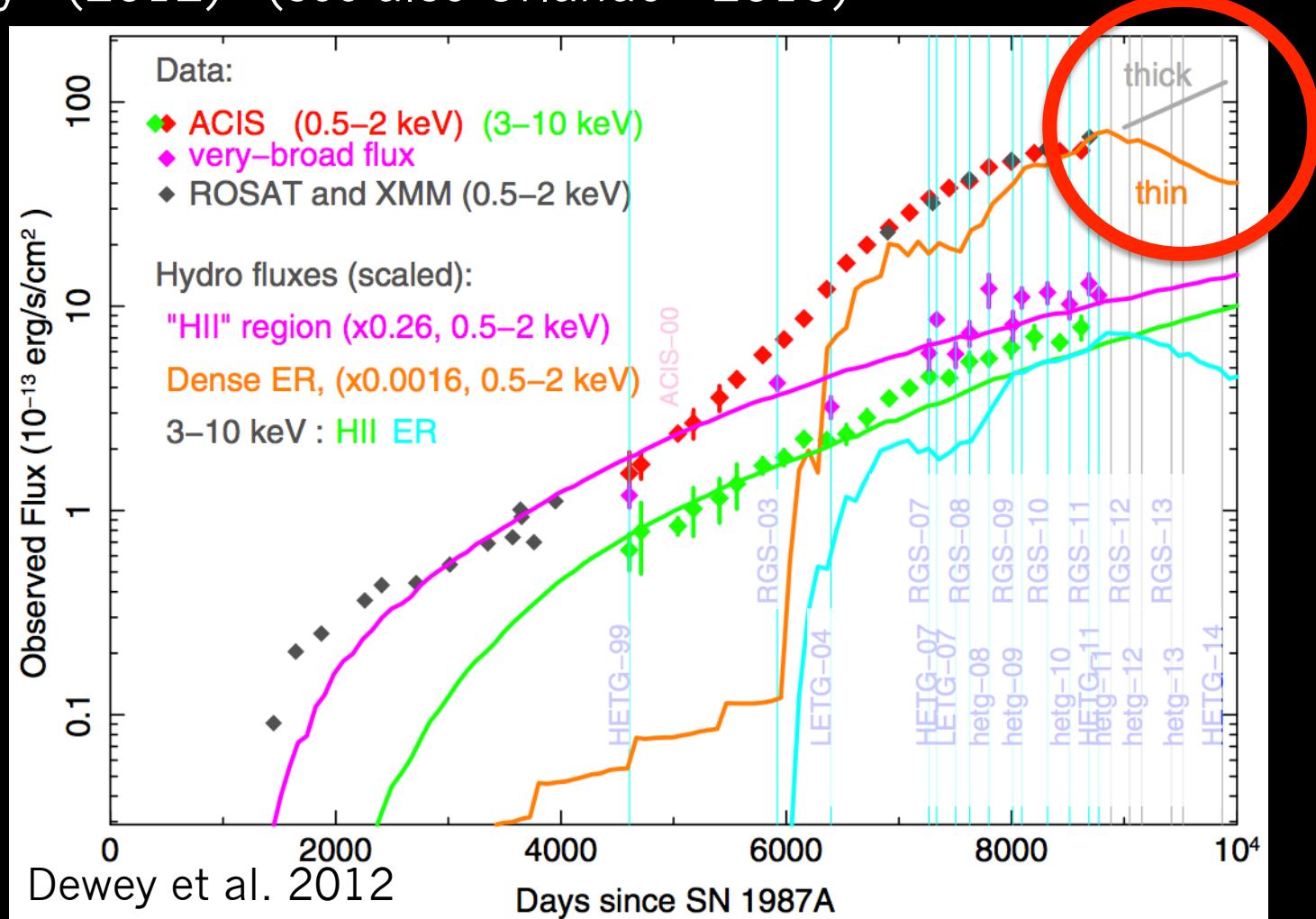


From LETG spectrum:  
(Zhekov+ 2006)

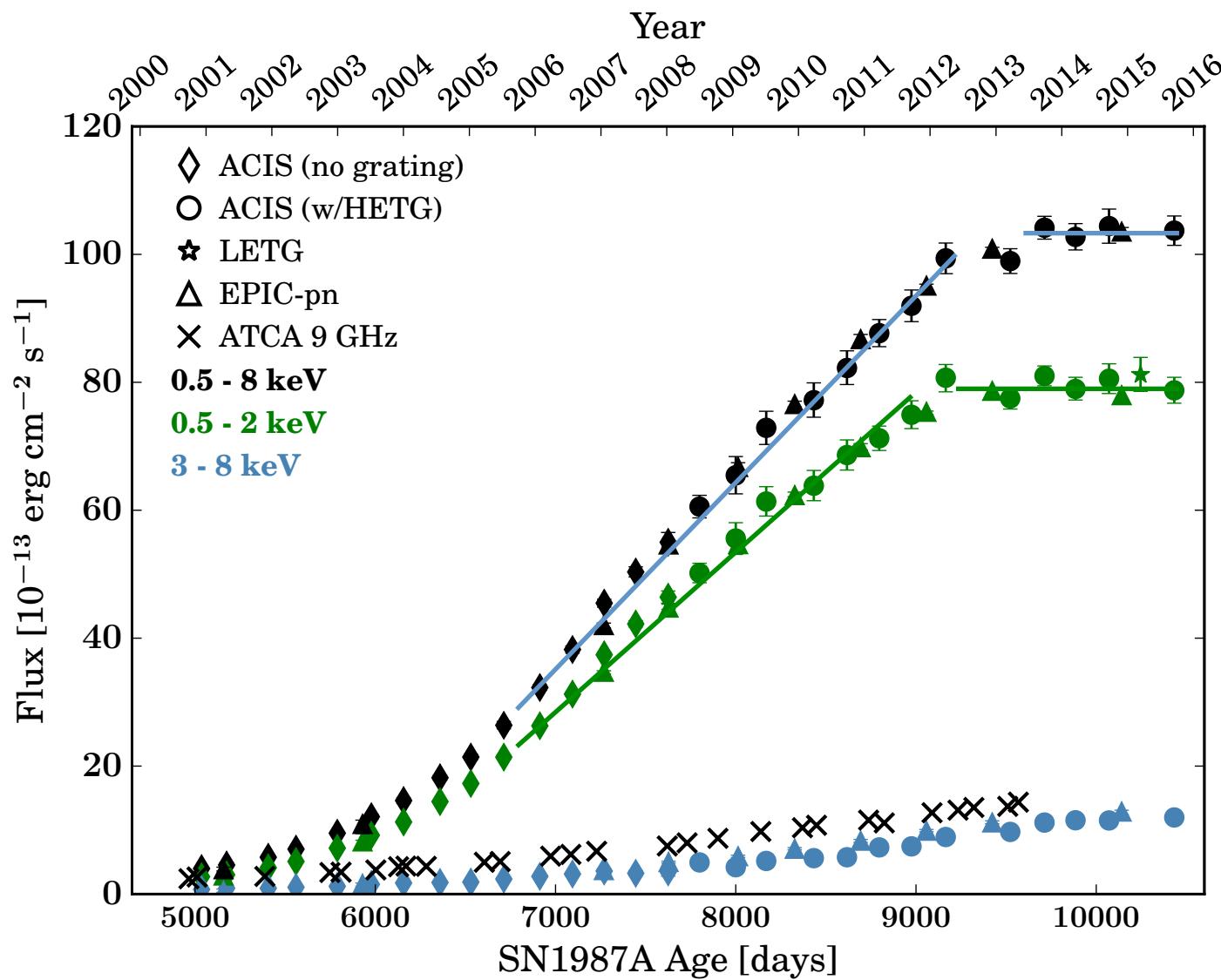
$$\begin{array}{ll} N = 0.76 & \text{Si} = 0.28 \\ \text{Ne} = 0.29 & \text{S} = 0.45 \\ \text{Mg} = 0.24 & \text{Fe} = 0.16 \end{array}$$

# Grating Spectroscopy: Detailed Modeling

Dewey+ (2012) (see also Orlando+ 2015)



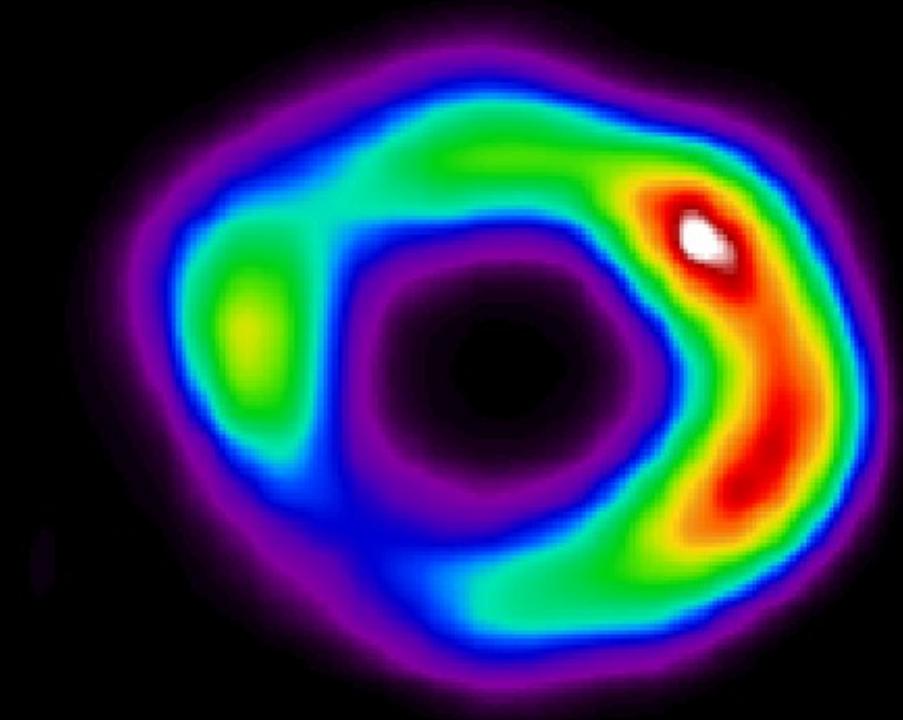
# X-ray Light Curve



# Central Source?

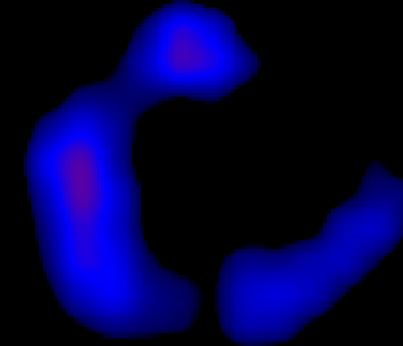
- We know that a NS was formed
- Search for central X-ray point source unsuccessful so far
- Background increased as SNR brightened

09/2015  
(10433 days)

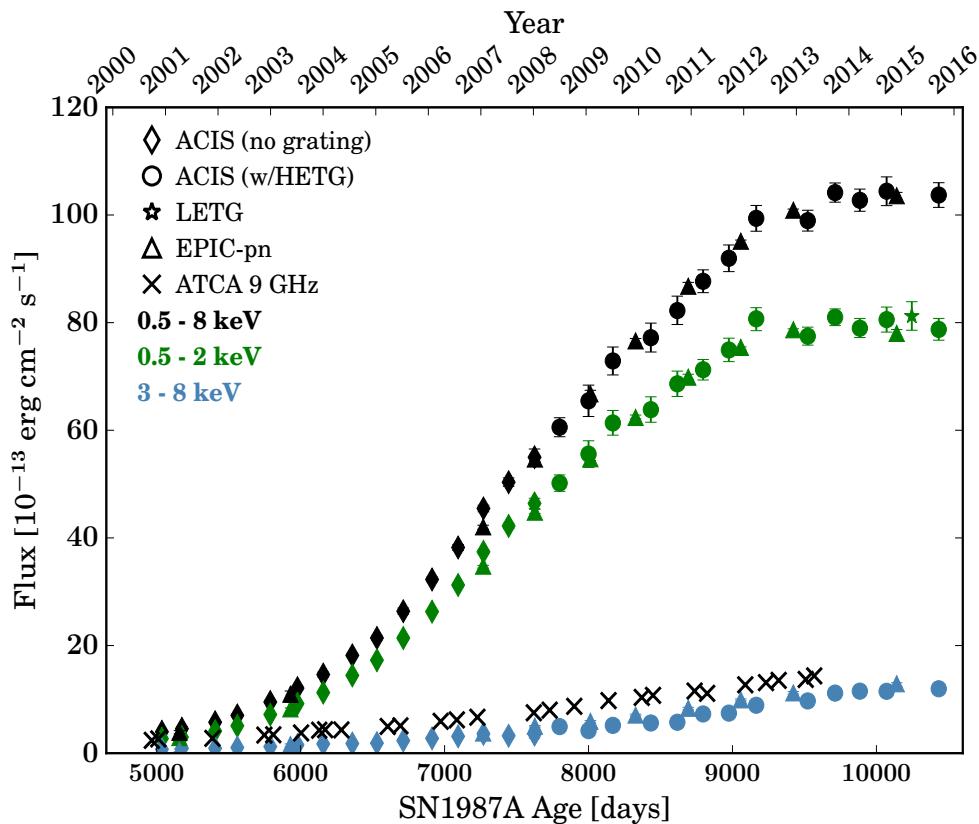
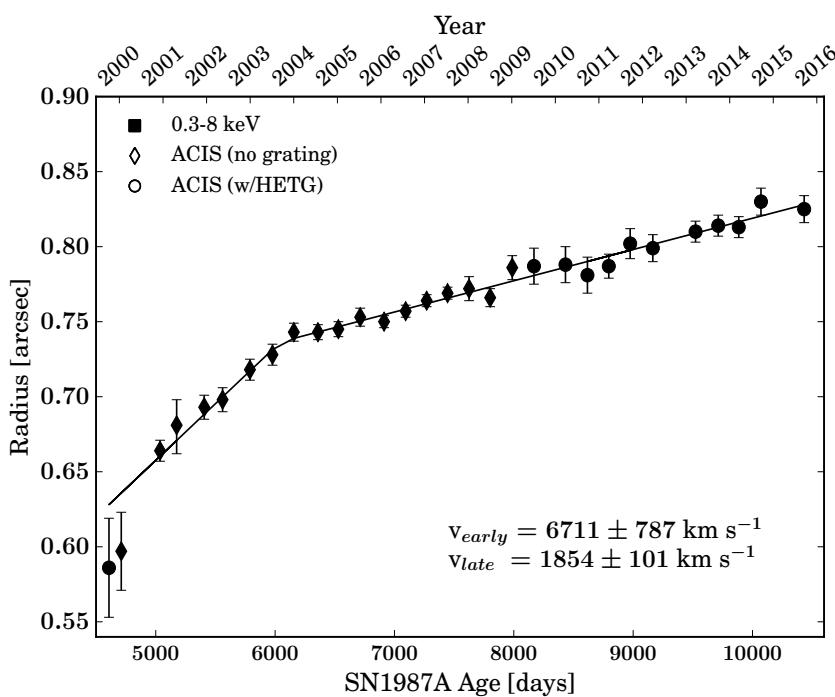


# Conclusions

- Chandra imaging and spectroscopy provides tool for understanding the physical evolution of SN 1987A
- Blast wave leaving known ring?



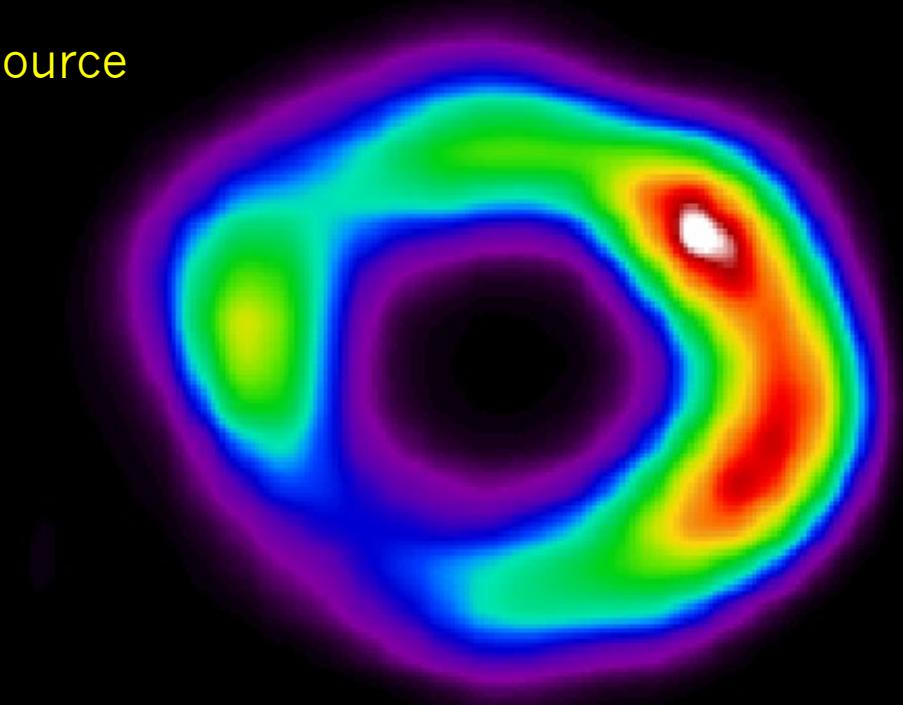
$$\Delta R_{X\text{-ray}} \geq 0.10'' \pm 0.02'' (7.7 \times 10^{11} \text{ km})$$



# Conclusions

- Chandra imaging and spectroscopy provides tool for understanding the physical evolution of SN 1987A
- Blast wave leaving known ring?
- Stay tuned for future exploration!
- Still no evidence for X-ray central source

09/2015  
(10433 days)



# Phase 6+: The future

- Central point source?
  - Possible radio detection, offset (Zanardo+ 2014)
  - Still no X-ray detection
- Destruction of the ER
- Detection of shock-heated ejecta (see poster S10.14)
- Beyond the ER???
  - CSM
  - Interaction with outer rings
    - Possibly as early as 20 years from now (Tziampzis+ 2011)
  - Soft X-ray observations with ~arcsecond resolution will be critical!