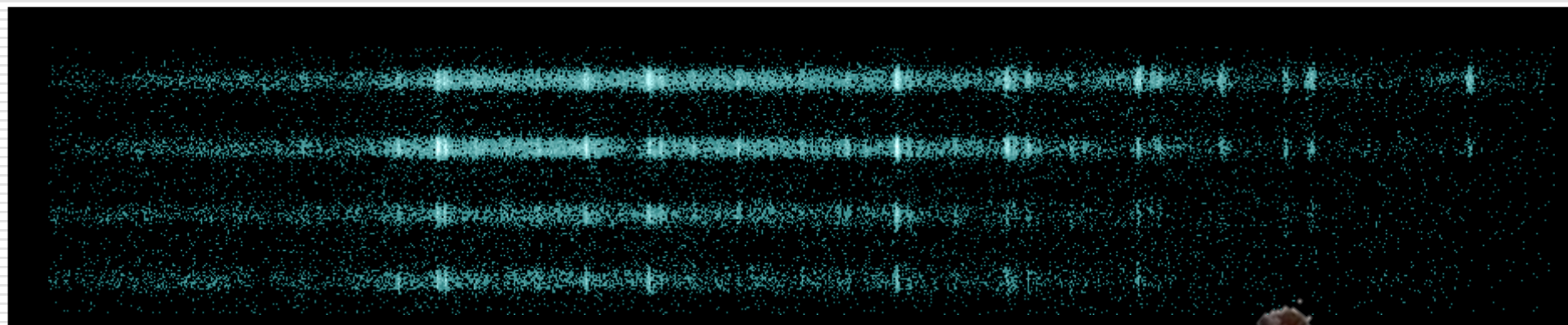


HETG Spectral-imaging of SN1987A



with

Svet Zhekov (SRI Sophia & U Colorado),

C.R. Canizares (MKI), R. McCray (U Colorado)

Eight Years of Science with Chandra, 23 October 2007



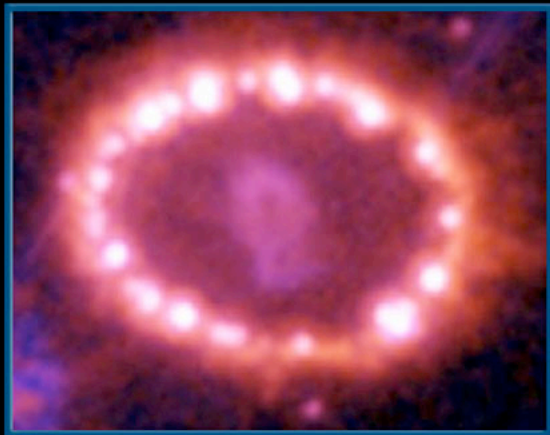
Overview

- Introduction to SN 1987A
- HETG Observations & Spectral results
- Spectral images: Modeling and velocities
- Future of SN 1987A

Introduction to SN 1987A

- Proceedings of Aspen conference:
"Supernova 1987A: 20 Years After:
Supernovae and Gamma-Ray Bursters"
AIP, New York, eds. S. Immler, K.W.
Weiler, and R. McCray
- Presentations on-line at:
<http://astrophysics.gsfc.nasa.gov/conferences/supernova1987a/>

Inner debris of the Supernova 1987A (SN 1987A) ring



Outer bipolar
outflow of
gas and
outer
ring

Inner bipolar
outflow
of debris

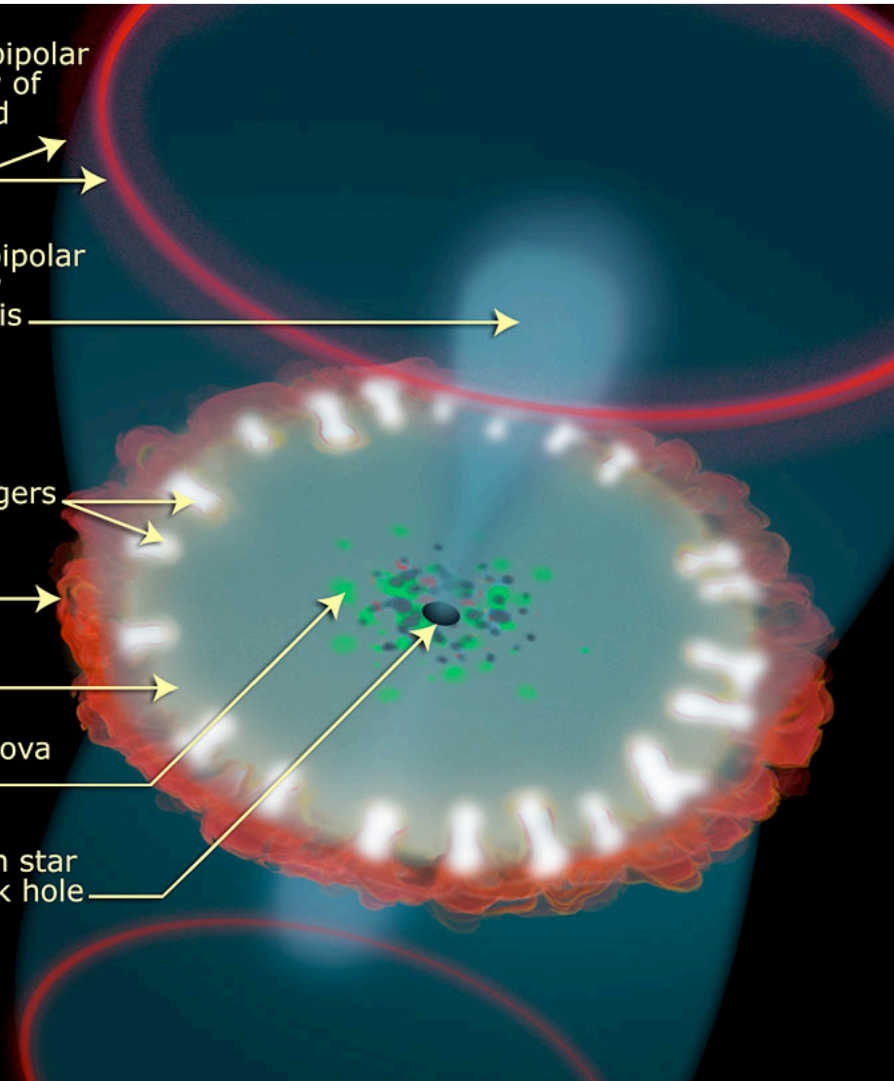
Hot fingers
of gas

Ring

Blast
wave

Supernova
debris

Hidden
neutron star
or black hole

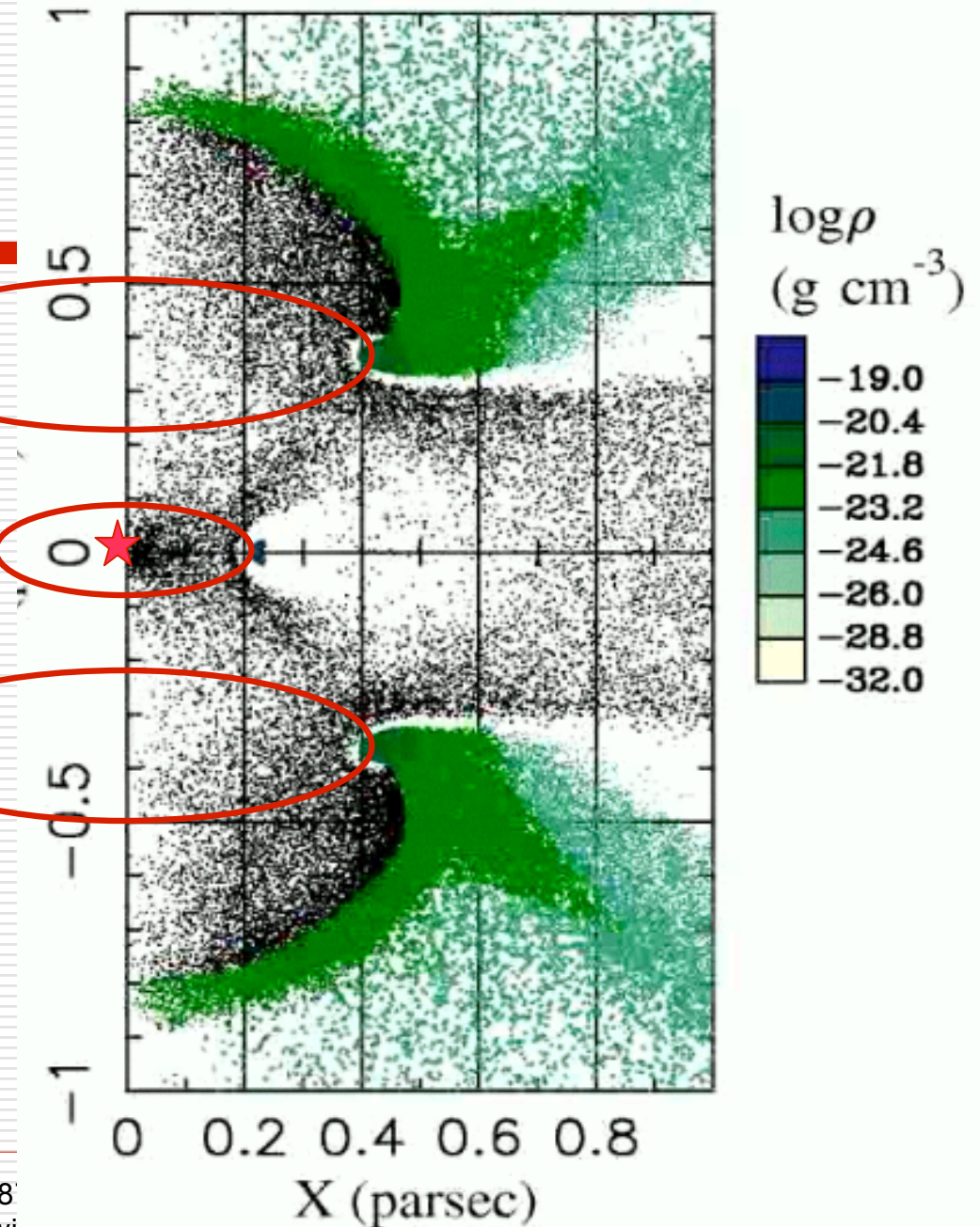


From ESA/Hubble: <http://www.spacetelescope.org/news/html/heic0704.html>

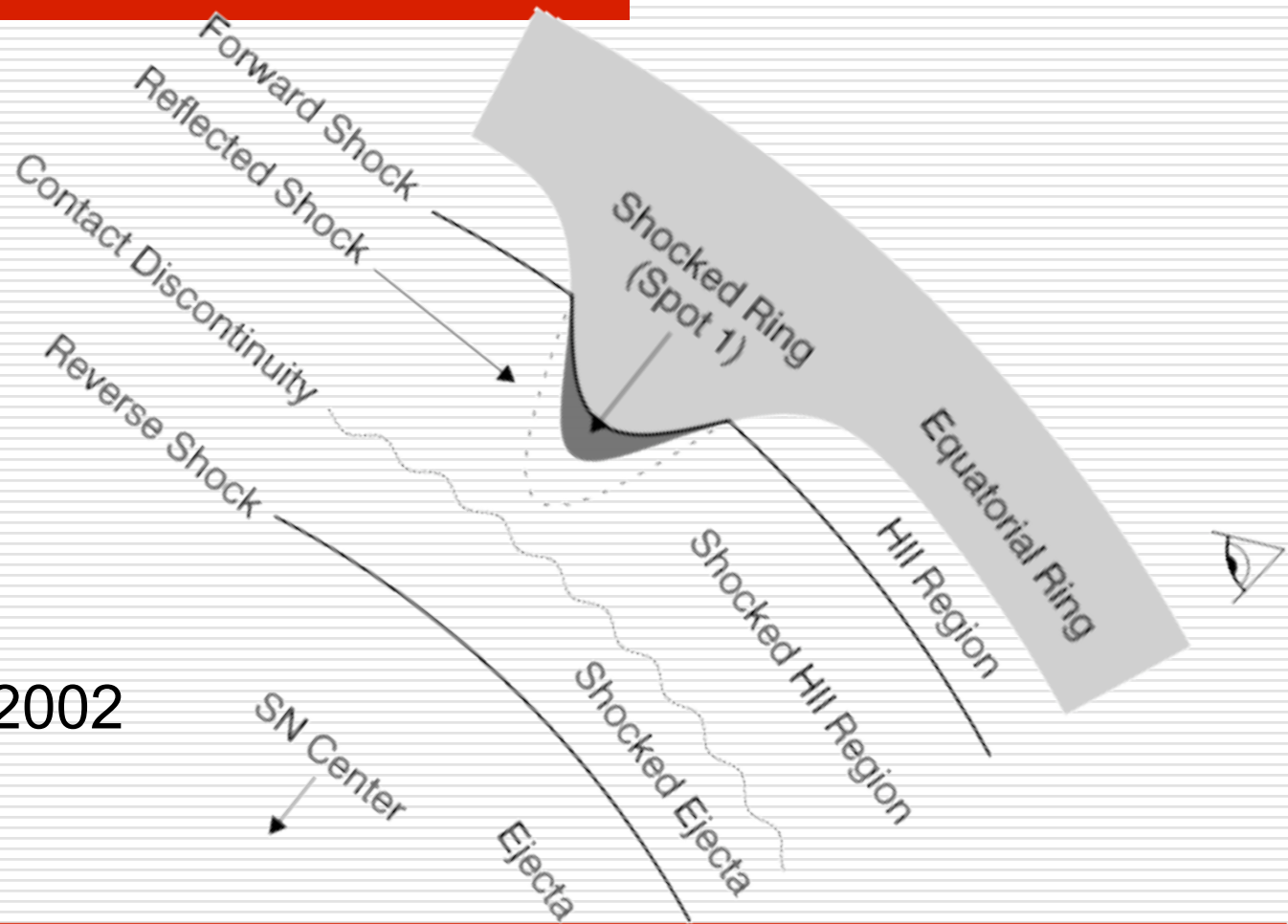
CSM from binary history

- Morris and Podsiadlowski 2007.
- Creation of the triple-ring system.

2D cylindrical slice
at time of SN explosion



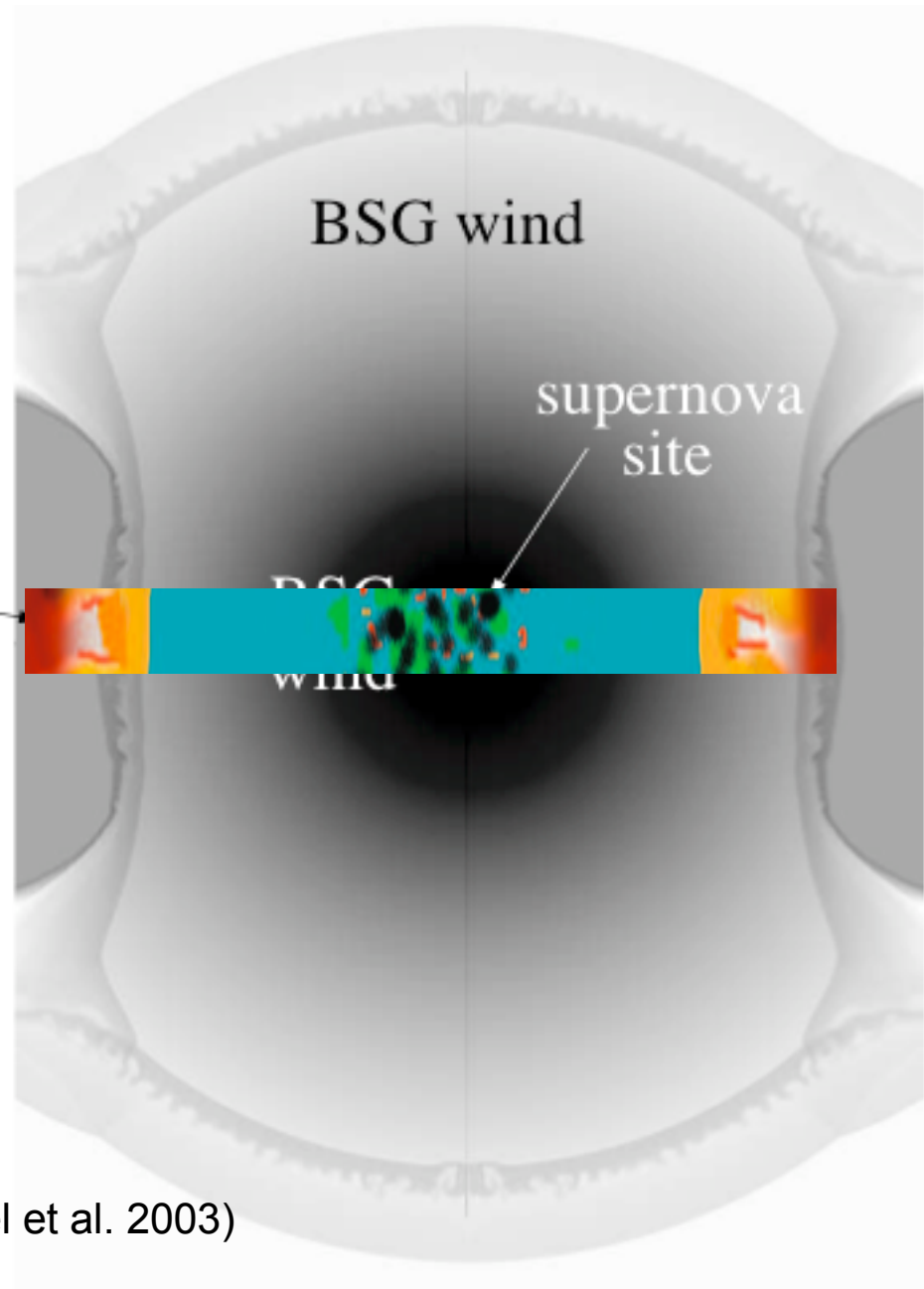
Shocks and Regions



From
Pun et al. 2002

Out-of-Plane structure

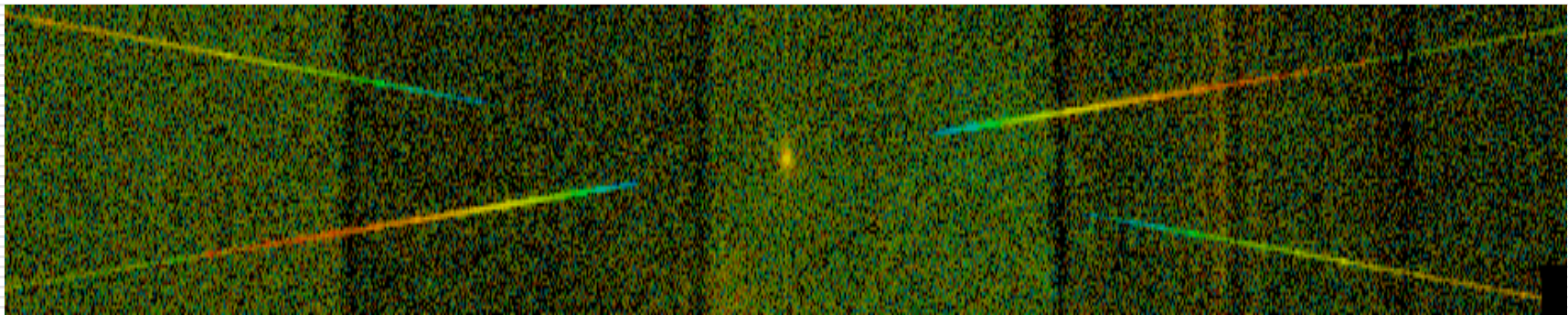
- Large, equatorial HII region swept-up by blast wave.
- Other structures along polar axis?



From Gaensler, Aspen'07 (based on Michael et al. 2003)

-- Recent HETG Obs.s --

- 360 ks of GTO time (Canizares PI)



2 keV

1 keV

0.65 keV

MEG minus
plus

HEG minus
plus

2 Å

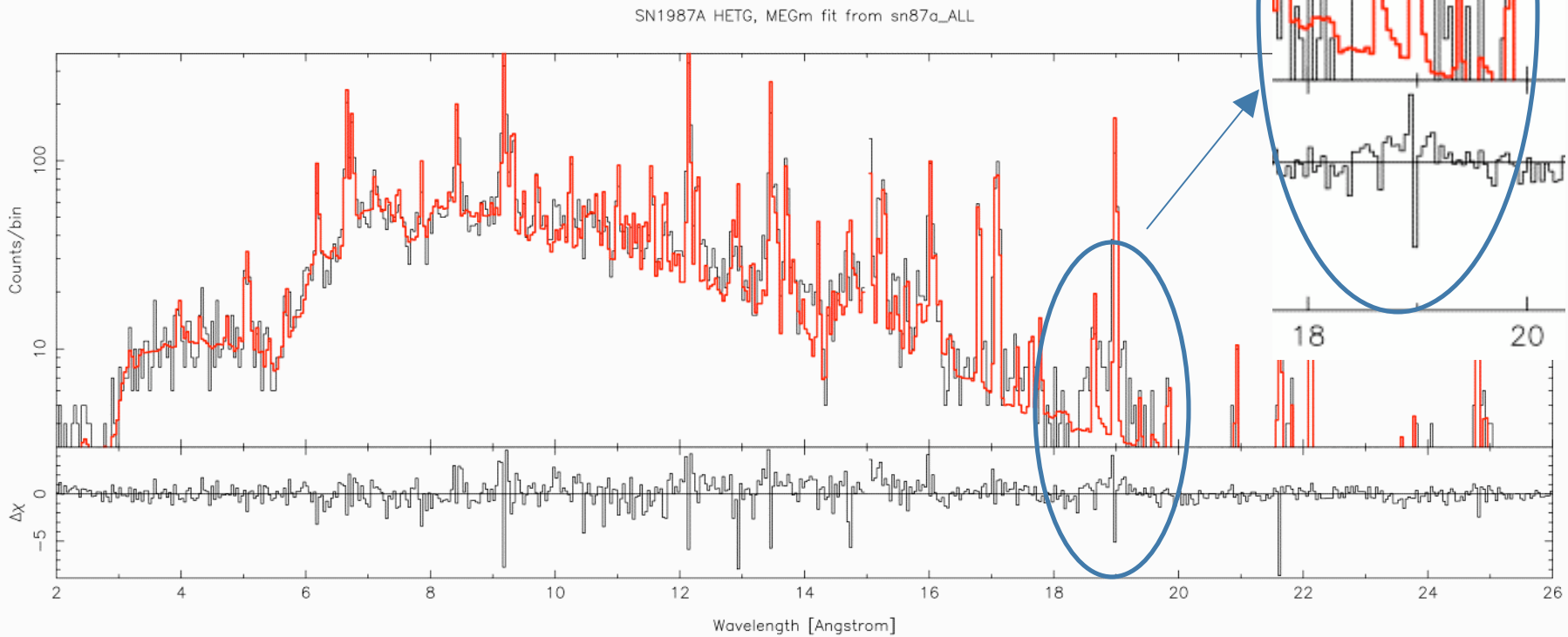
20 Å

Chandra & SN 19897A

- HETG (1999.8), Garmire/GTO - Michael et al.(2002)
- ACIS (2 per year), Burrows, Park et al.
- LETG (2004.7), McCray, Zhekov et al.
- HETG (2007.23), Canizares/GTO <---
- LETG (2007.7), McCray
- HRC-I (~ 2008.3), Murray/GTO

2-vpshock fit to data

- Good fit w/NEIVERS 2.0, Borkowski APEC
- Possible broad excess ?

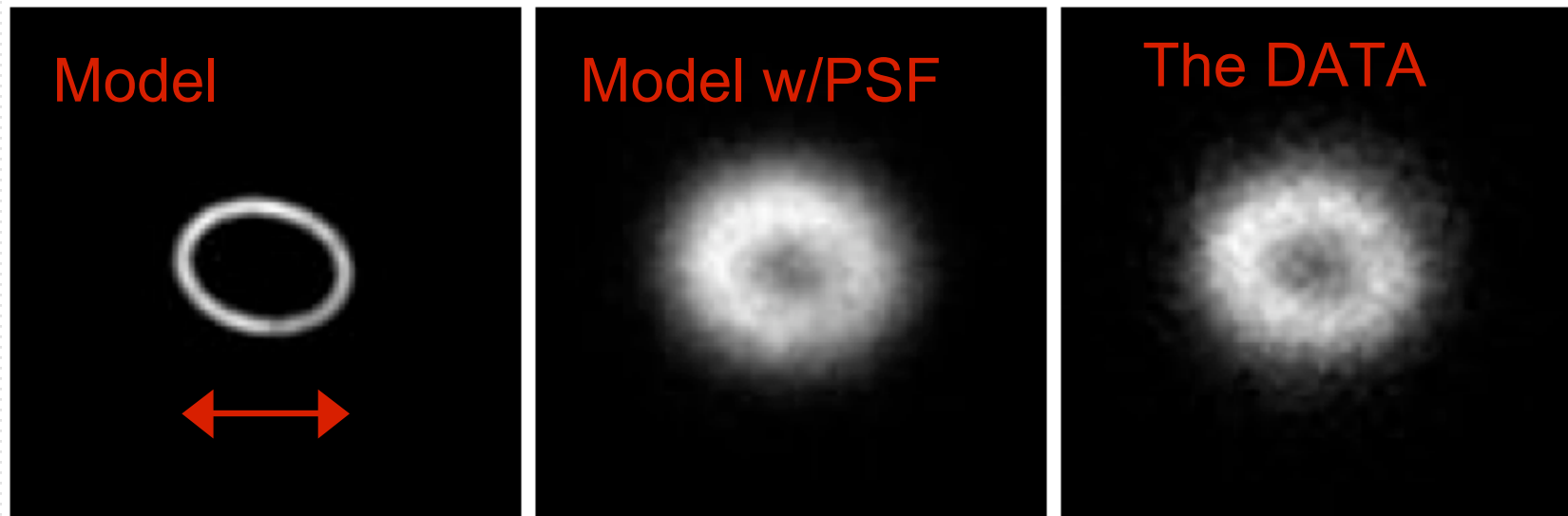


Summary of spectral results

- Flux increase ~ 20% per 6 months
 - Consistent with ACIS monitoring (Park)
- "Shock DEM": distribution 0.3 - 3 keV
- Abund.s, NH: similar to Zhekov 2006.
- 2 shock approx.: 0.55 and 2.11 keV
- Line centers: consistent with 286 km/s
- Broad component (?) ~ 9000 km/s.

SN 1987A is resolved

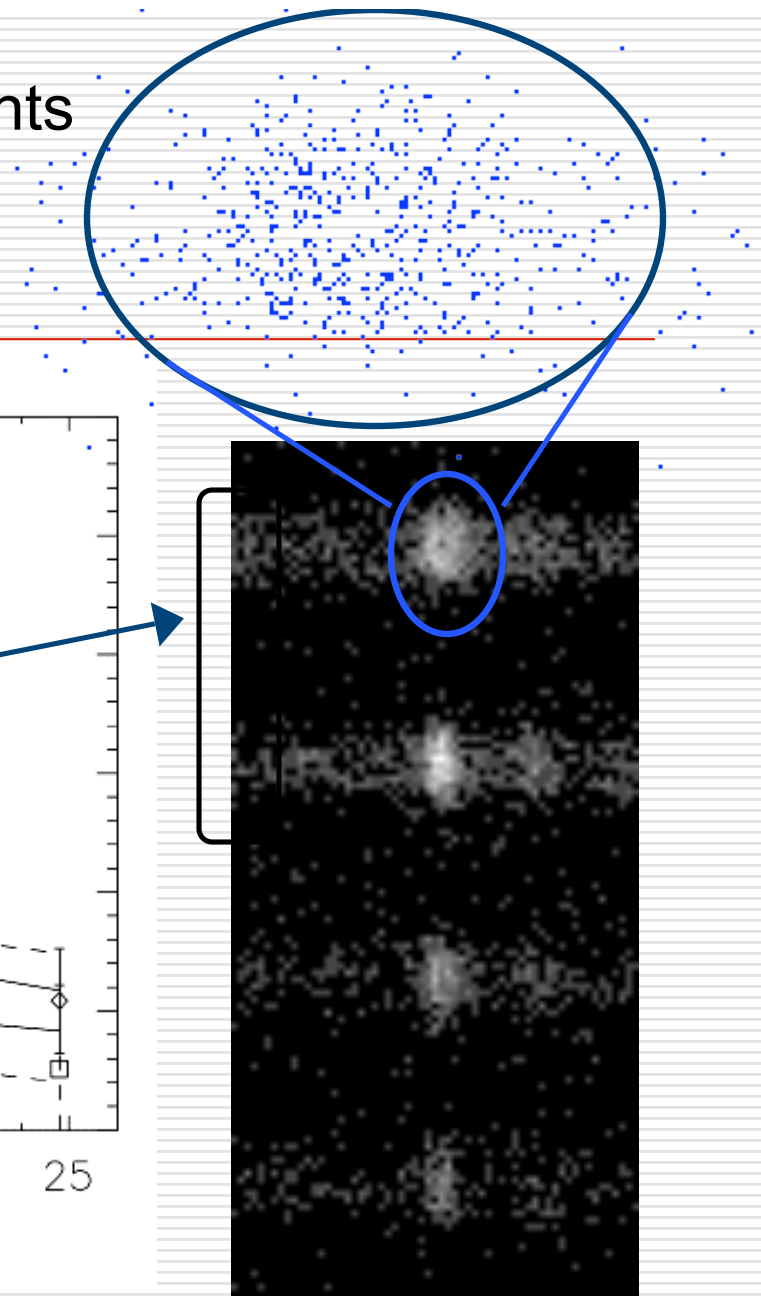
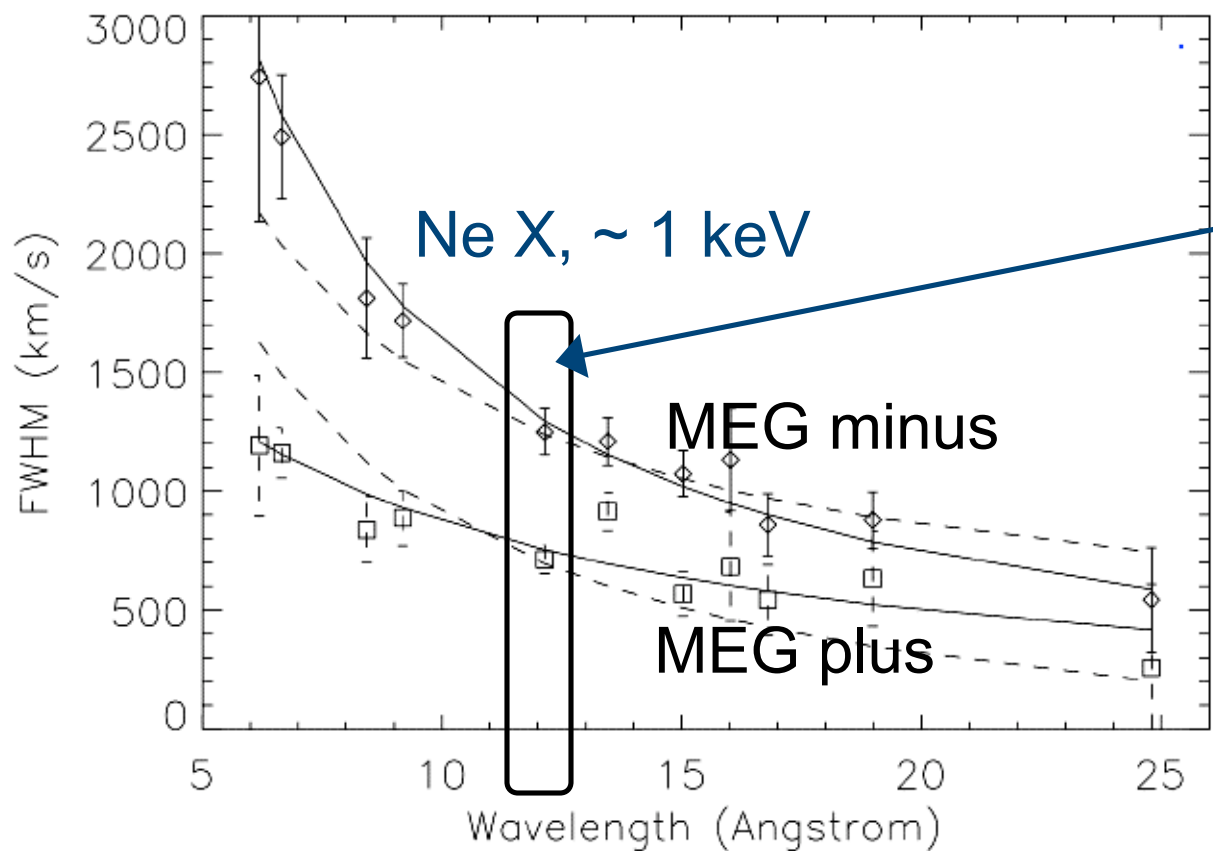
- ❑ Tilted, thin ring models the zeroth-order
- ❑ Intensity varies with ring azimuth



1.7" diameter ring

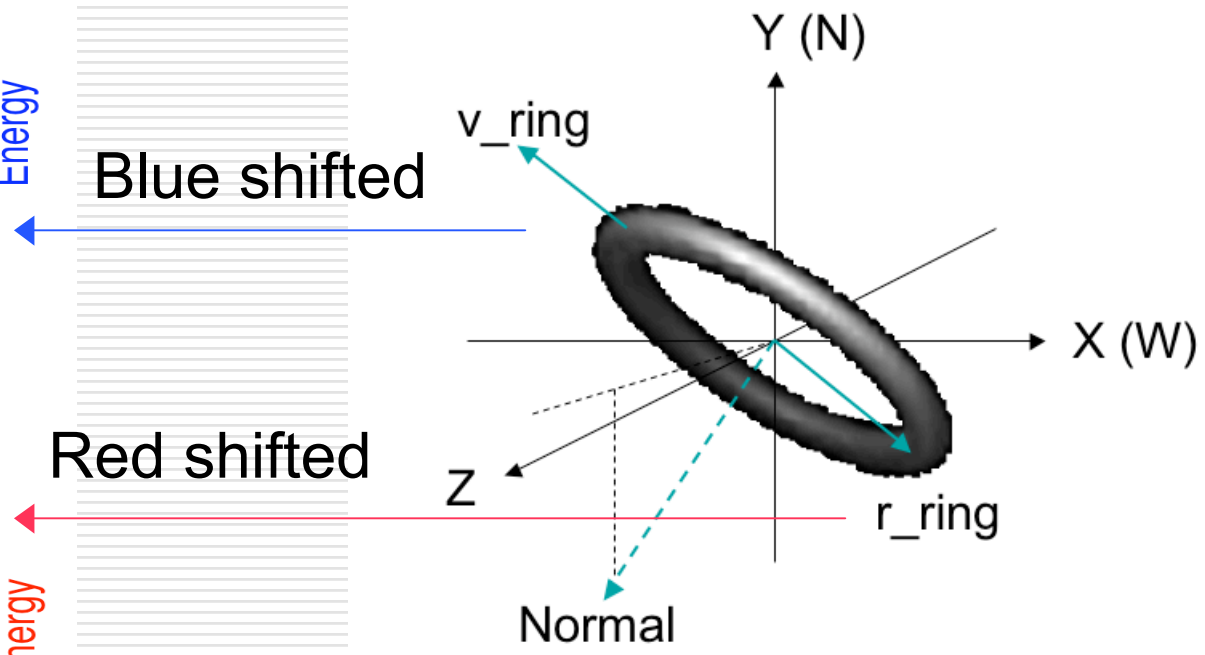
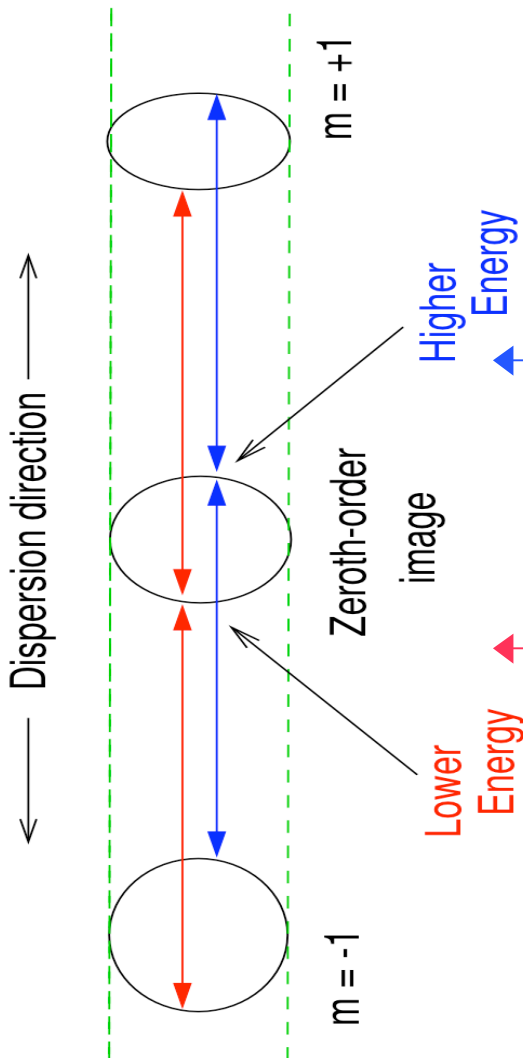
Spectral images, FWHM in orders

~ 600 events



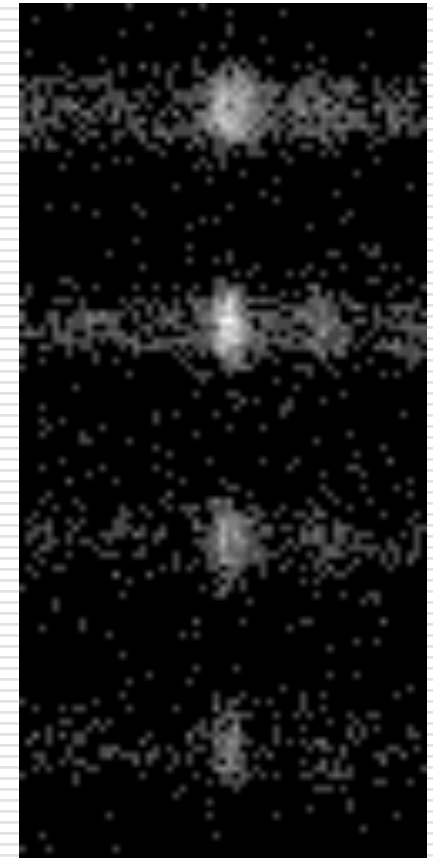
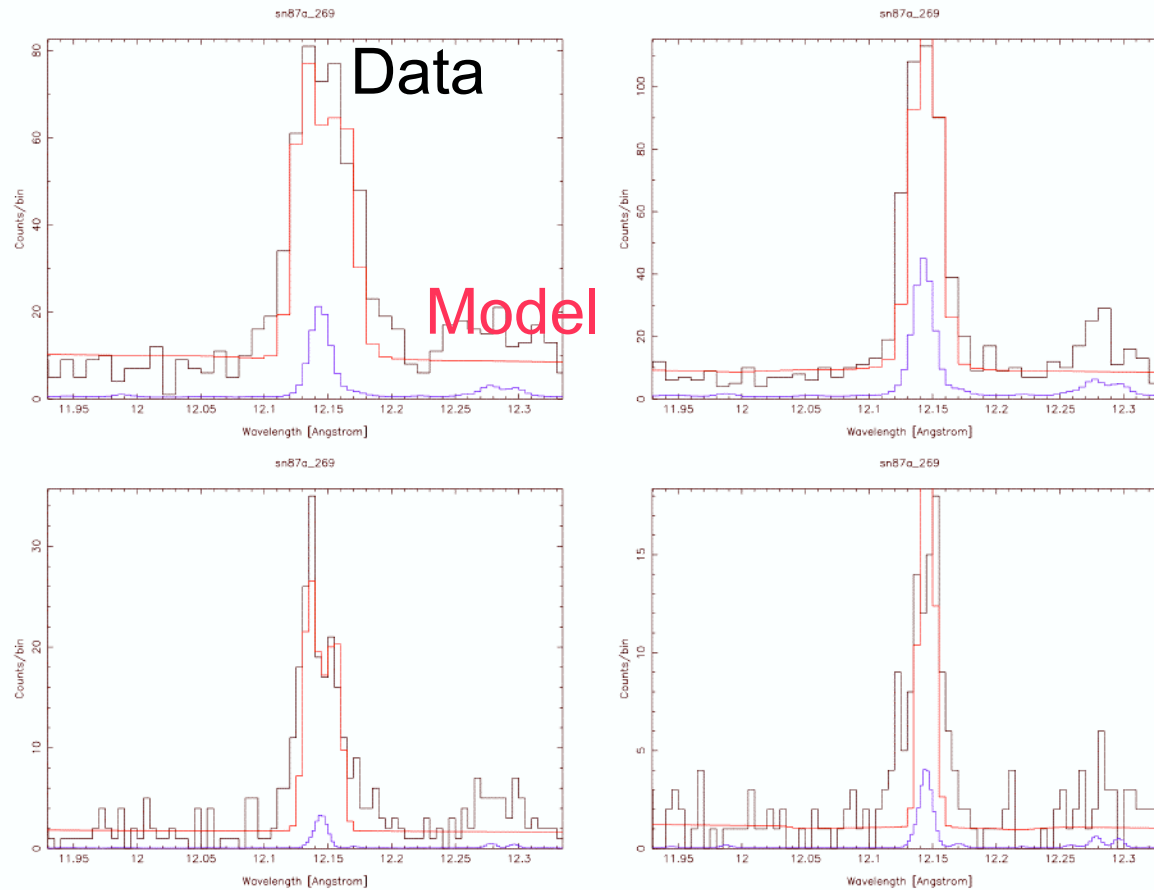
Ring Doppler effect

From the Chandra POG



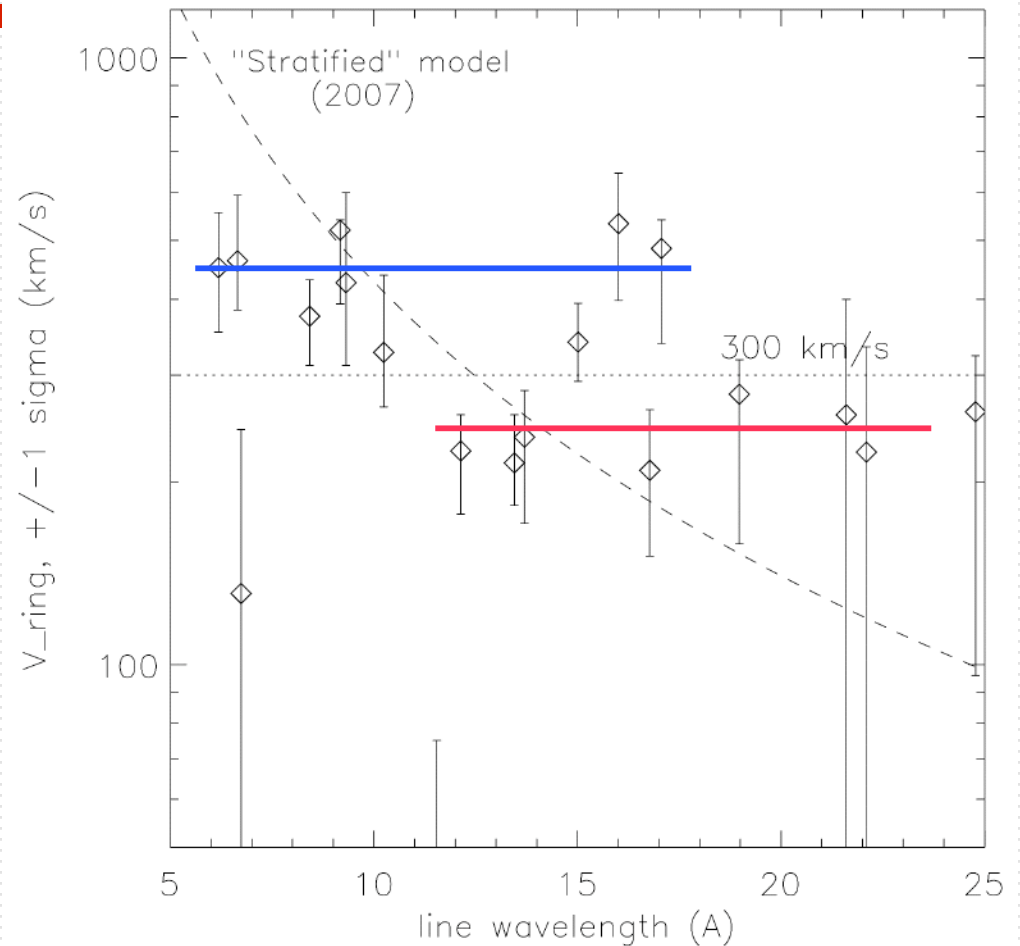
Fitting 1D projections

isis - 3D



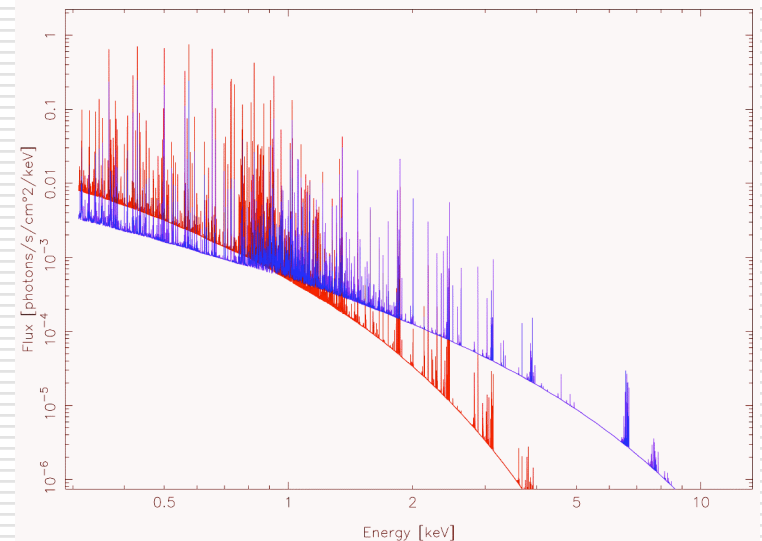
V_Ring for the lines

- Continuous distribution ?
- Discrete velocities by component ?



Modeling the Spectral-Images

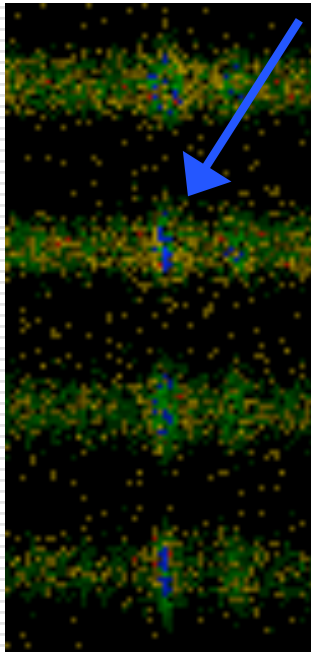
- Simple tilted ring
- Azimuthal intensity variation
- Two spectral components **2.11** & **0.55 keV**
- Ring velocity for each component, **470 km/s** and **240 km/s**
- ... and ...



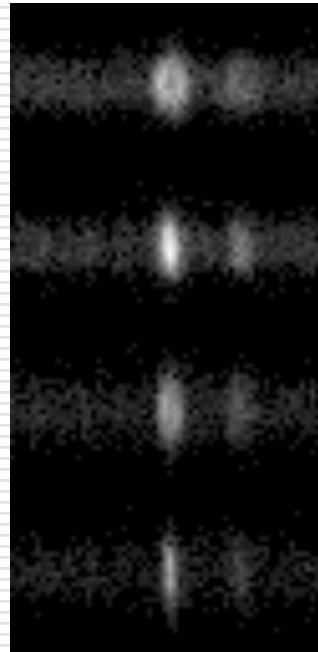
Adding "V_Turbulence"

- Additional velocity blur of 200 km/s RMS

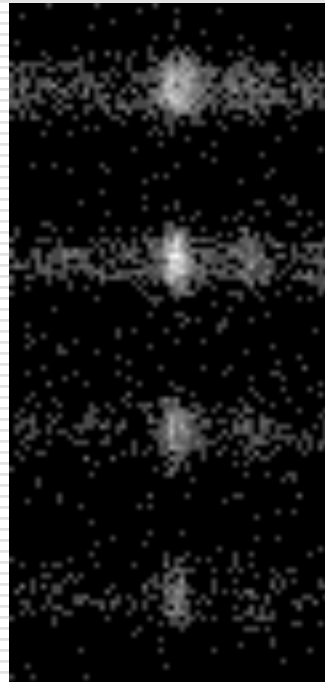
No blur: "blue" excess



Residual

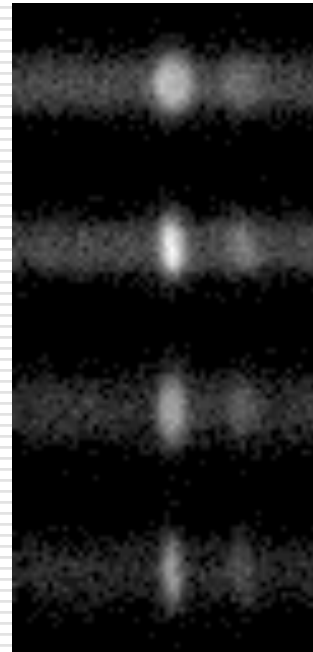


Model

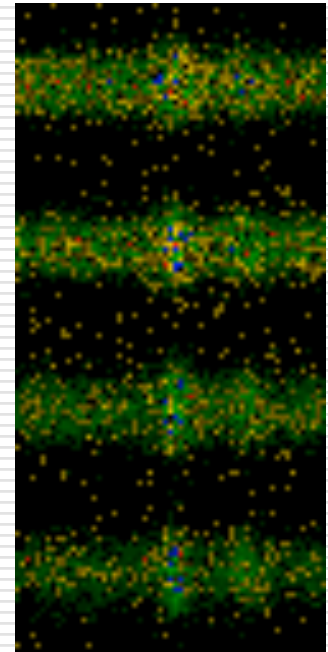


The DATA

With blur: better fit



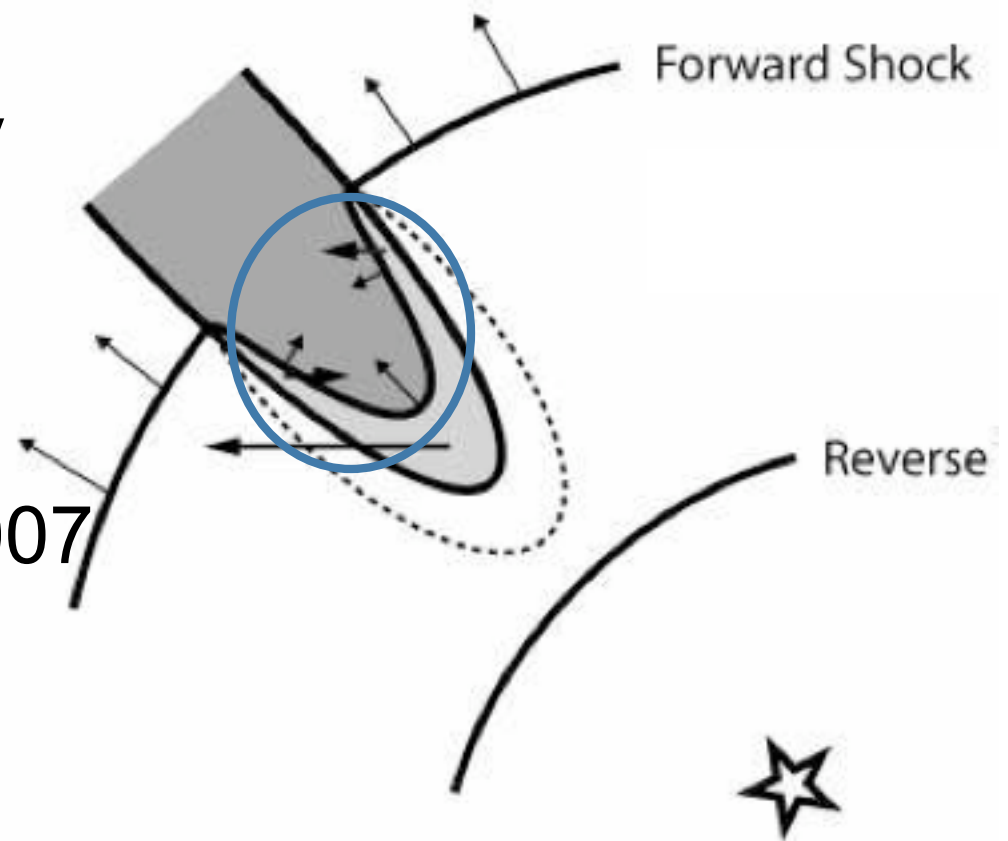
Model



Residual

Interpreting the additional blur

- Turbulent velocity
 - Ion thermal velocity
 - Oblique shocks give range of directions.
- Smith & McCray 2007



Shock Temp and Velocities

- Strong, adiabatic shock model has:
 $V_{\text{bulk}} \sim 3/4 V_{\text{shock}}$
- Post-shock temp and shock velocity:
 $kT_e \sim 1.4 \text{ keV} (V_{\text{shock}}/1000 \text{ km/s})^2$
- $kT_e \sim 0.55 \text{ keV} \rightarrow V_{\text{bulk}} \sim 470 \text{ km/s}$
- $kT_e \sim 2.11 \text{ keV} \rightarrow V_{\text{bulk}} \sim 920 \text{ km/s}$

- In reality, complexity reduces V_{bulk} ?

Summary of Spectral-Imaging

- ❑ Bulk radial motion of X-ray emitting plasma is ~ 200 -- 600 km/s.
- ❑ Additional "turbulent" velocity range of ~ 200 km/s RMS is indicated.
- ❑ No need for emission out-of-the-equatorial-plane, beyond ± 25 deg.
- ❑ Broad component (?) with FWHM ~ 9000 km/s -- geometry undetermined.

Future Missions and '87A...

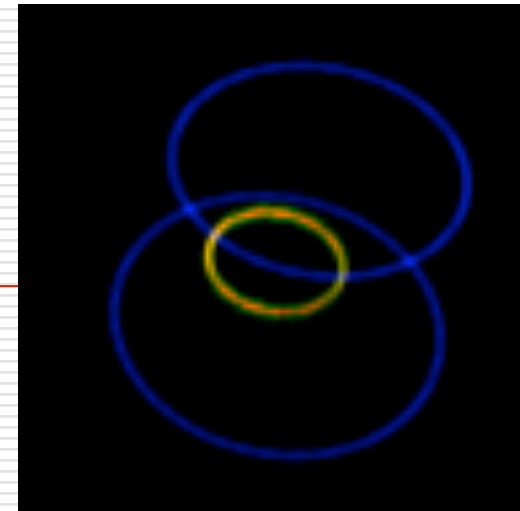


- ❑ Three words: Chandra, Chandra, Chandra
- ❑ What future Instrument do you want ?
- ❑ "What are you rebelling against?"
"What have ya got?"
--> Better instruments
are always welcome.
- ❑ Long-slit [X-ray] Grating Spectrometers are very useful (FUSE, STIS, IRS.)

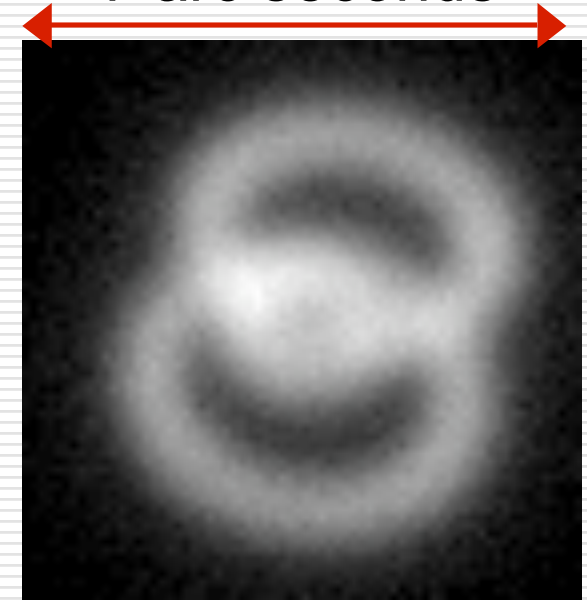


SN 1987A in the future

- ❑ Blastwave continues, reaching Outer Rings
- ❑ Other CSM interactions
- ❑ Detailed CSM knowledge, Sugerman et al. 2005
- ❑ "To astrophysicists in the year 2987."
-E. Michael, thesis dedication.



7 arc seconds



The End

Thank you