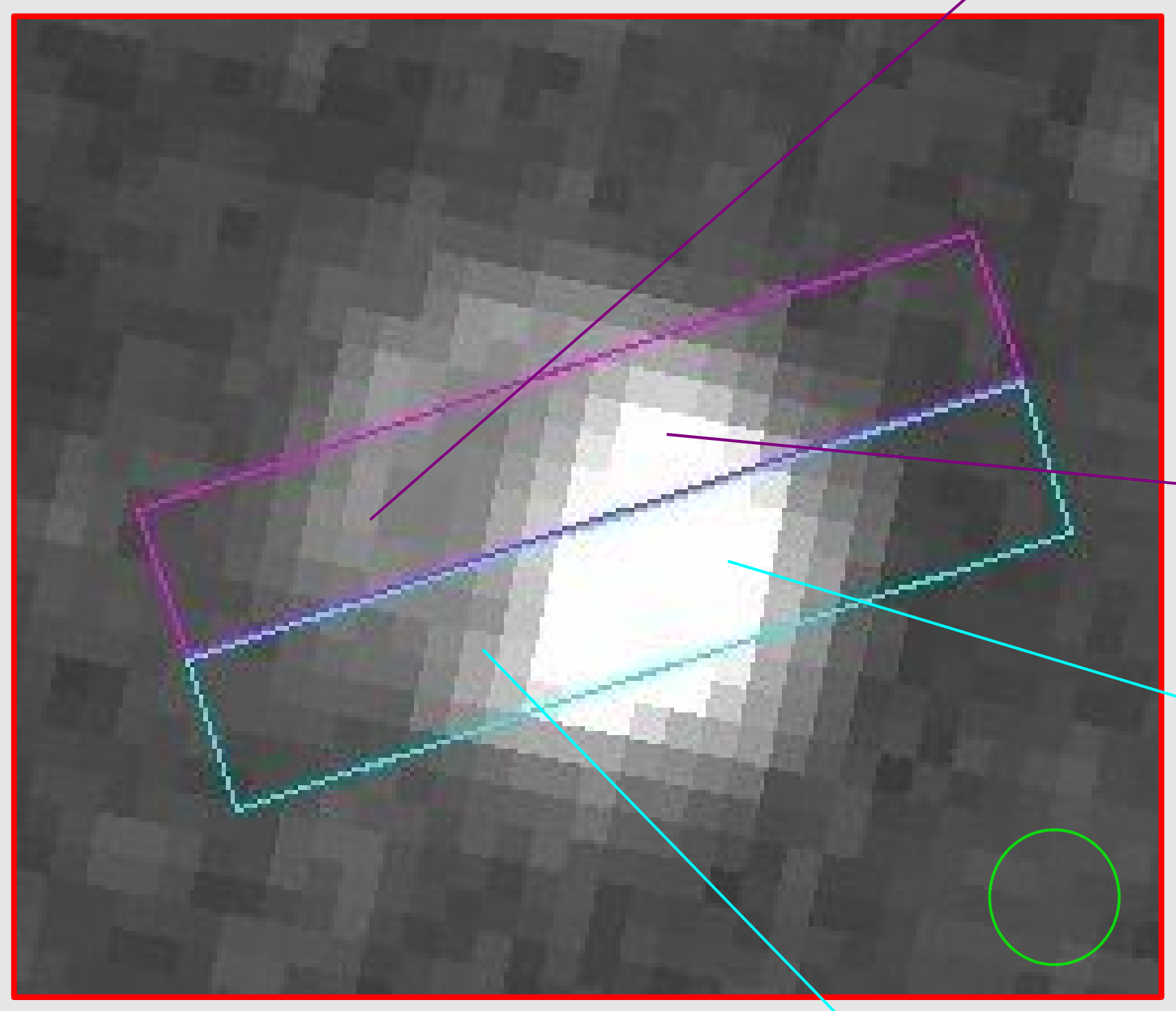
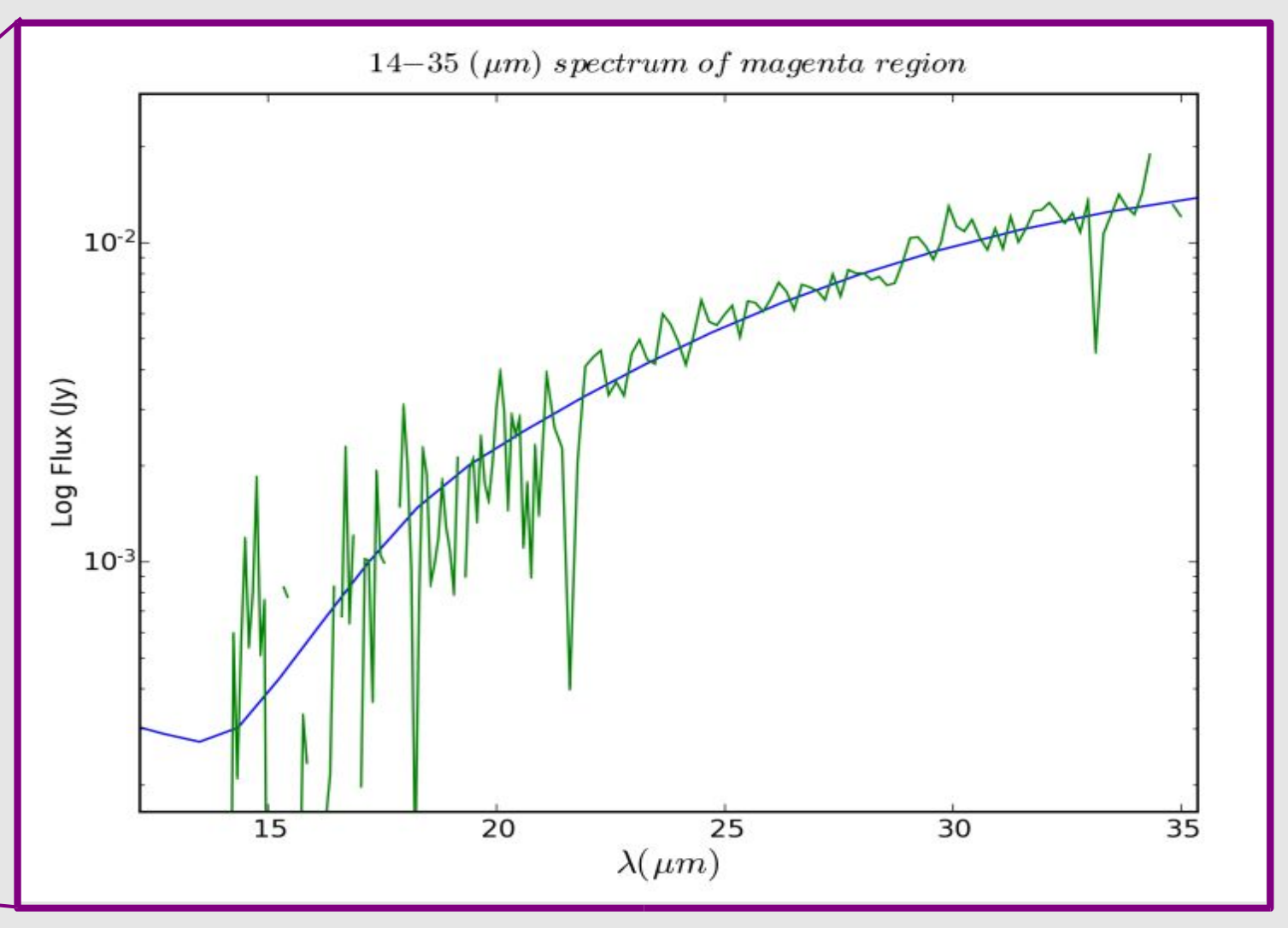
IR and X-Ray Observations of Two Young SNRs, 0509-67.5 and 0519-69.0

Brian J. Williams, for the Spitzer LMC SNRs Collaboration

We present Spitzer IRS and XMM-Newton RGS observations of two LMC type Ia SNRs, 0509-67.5 and 0519-69.0. Dust model fits to IRS data determine **post-shock density**, which we combine with emission measures from X-ray spectroscopy to determine amount of shocked gas in a remnant. Both SNRs show strong X-ray lines of Fe and Si, coming from ejecta, as well as O and Ne lines, which we model as arising from shocked ISM. Combining the emission measure obtained in this way with IRS determined post-shock densities, we can obtain swept-up gas masses and pre-shock densities for the remnant. In principle, this combined X-ray/IR approach yields independent measurements of the pre and post-shock density, and can determine the compression ratio, and constrain cosmic-ray modification of the shock front.

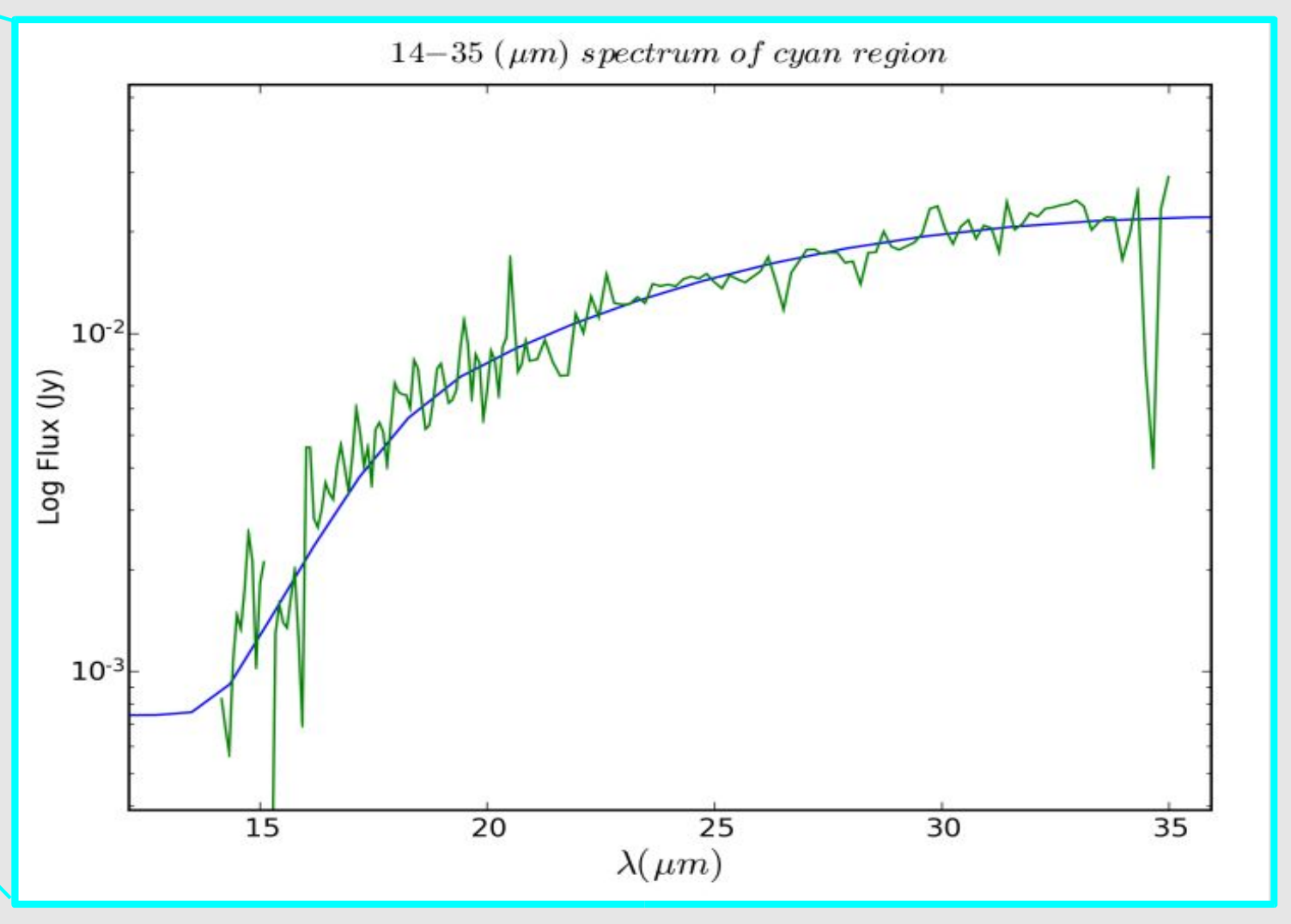
SNR 0509-67.5



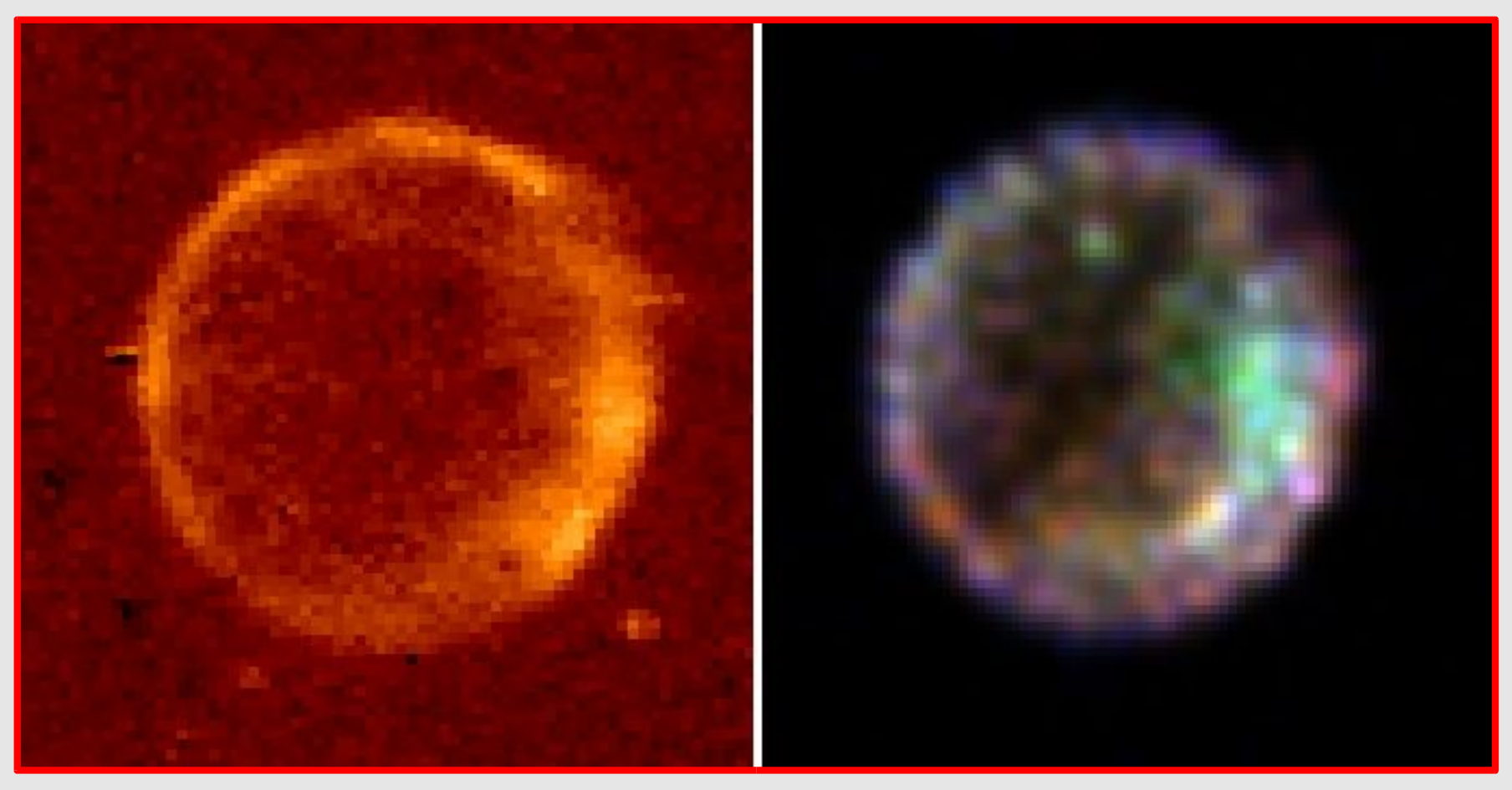


Green: Extracted Spectra from indicated regions, Blue: Model Fit

Dust hotter in brighter region due to higher density, ***we assume "faint" region indicative of whole of remnant***, see H-alpha image



Spitzer 24 micron image, overlaid with outline of two of the spectral extraction regions used for this remnant; remnant diameter is ~30", green circle is FWHM of MIPS 24 micron PSF.



Left: H-alpha (note brightness enhancement in SW), Right: 3-color Chandra X-ray image with Red: 0.3-0.7 keV, Green: 0.7-1.6 keV, Blue: 1.6-7 keV (image slightly smoothed)

Modeling dust

Dust grains in SNRs are both heated and destroyed (via sputtering) by collisions with ions and electrons in hot X-ray emitting plasmas. We model emission from collisionally heated grains that radiate in IR, using knowledge from X-ray and optical data. Grain temperature is sensitive to ion and electron temperatures, shock age, and most sensitively, post-shock density. We have recently constructed models that allow us to use an arbitrary grain composition, including porosity and mixing of various grain types. What remains is to choose a grain "recipe" to use to fit the data. Since there are few constraints from the ISM at this time, we have adopted here two possibilities, and report results from both: 1) Separate populations of compact (non-porous) silicate and graphite grains with appropriate size distributions for the LMC; 2) composite grains that are 50% vacuum, 42% silicate, and 8% graphite that make up 85% of the dust population by mass, and a small population of compact silicate grains below 10 nm containing 15% of dust mass. We do not consider here small PAH grains, as these are very likely destroyed immediately behind the shock. Proton temperature is important in grain heating for these remnants, for comparison's sake we show results for 0509 assuming $T_p = 10$ keV instead of 90, as has recently been claimed for RCW86 (Helder et al. 2009, *Science*, in press) via cosmic ray modified shocks.

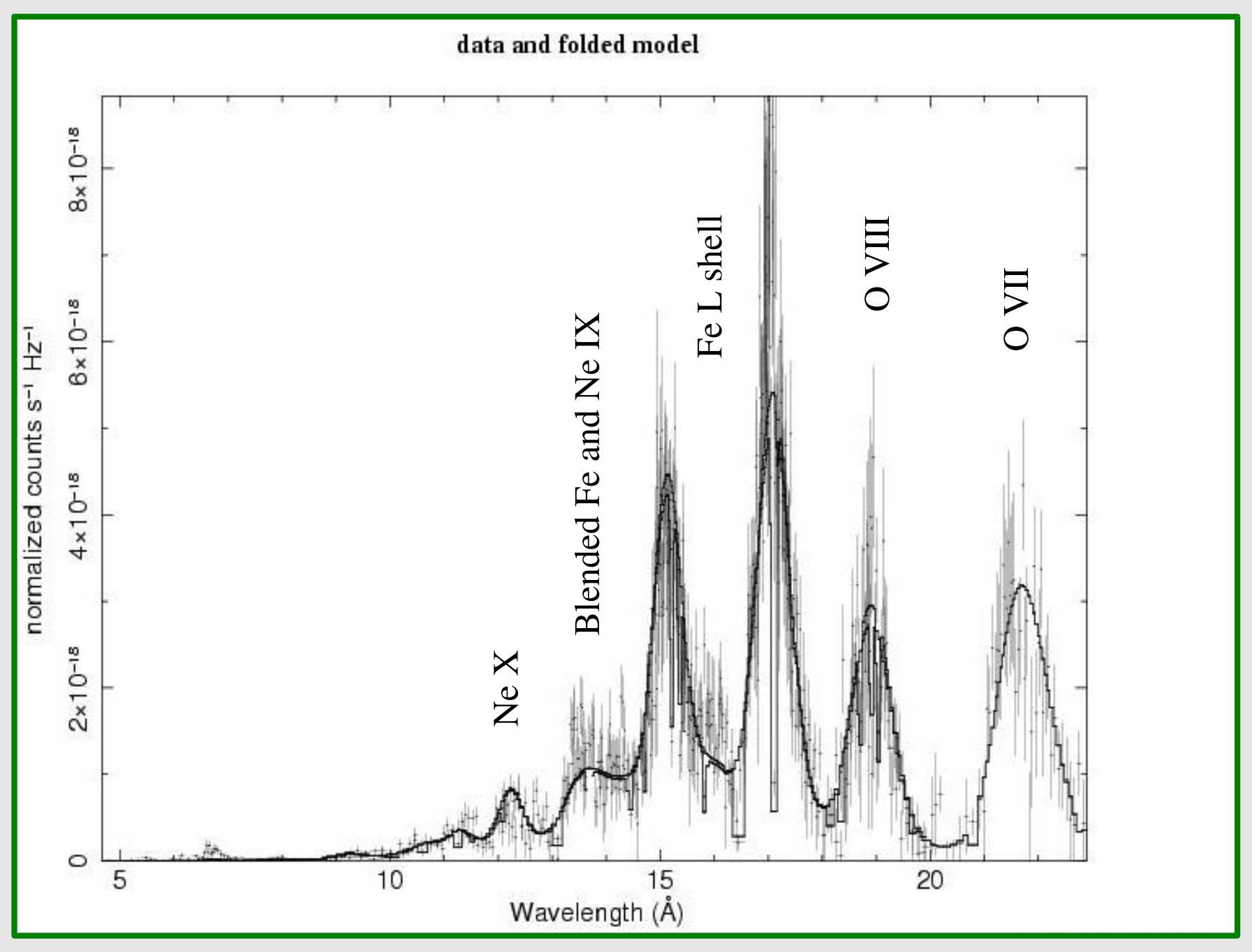
What is already known...

- Both very young remnants of type 1a SNe (~400 yrs for 0509, ~600 yrs for 0519; Rest et al. 2005, Nature, 438, 1132)
- Very high shock speeds; extremely high proton temperatures (**~90 keV for 0509**, **~30 keV for 0519**), low degree of ion-electron equilibration; Ghavamian et al. 2007, ApJ, 664, 304
- Warren & Hughes 2004 (ApJ, 608, 261) model Chandra spectra from 0509, find $n_0 = 1$ cm^{-3} if continuum is thermal in origin, $n_0 = 0.05$ if continuum is nonthermal
- Badenes et al. 2008 (ApJ, 680, 1149) modeled ejecta from 0509, also used 1-D model to find n_0 of 0.43 cm^{-3}
- Kosenko et al. 2008 (A&A, 490, 223) attempted to fit very weak nitrogen lines in RGS to determine EM of shocked ISM for 0509
- Both remnants could be sites for cosmic-ray modification of the shock, need to accurately determine compression ratio to know...

Description of RGS Modeling

We model emission seen in RGS spectra as coming from two sources, shocked ejecta and shocked ISM. For "ejecta" model, we fit data from 14-18 Å with a vpshock model consisting only of Fe. We then add another vpshock model, the "ISM" model, fixed at LMC abundances to account for data from 9-14 Å and 18-23 Å (we extended this range to 27 Å in the case of 0519, where the signal was better). We fix absorption and electron temperature to the best known values for both remnants.

XMM-Newton RGS Spectrum of 0509-67.5



RGS fits for "ISM" model* for 0509-67.5

Ionization timescale = 3.5 x 10^{10} cm^{-3} s (3.1, 4.0)
Emission measure = 2.0 x 10^{58} cm^{-3} (1.9, 2.2)
Line width (O lines) = 5250 km s^{-1} (4775, 5800)
Reduced chi^2 of 1.2 for 235 d.o.f.

*See "Description of RGS Modeling," errors quoted in () are 90% con. limts

Results for 0509-67.5

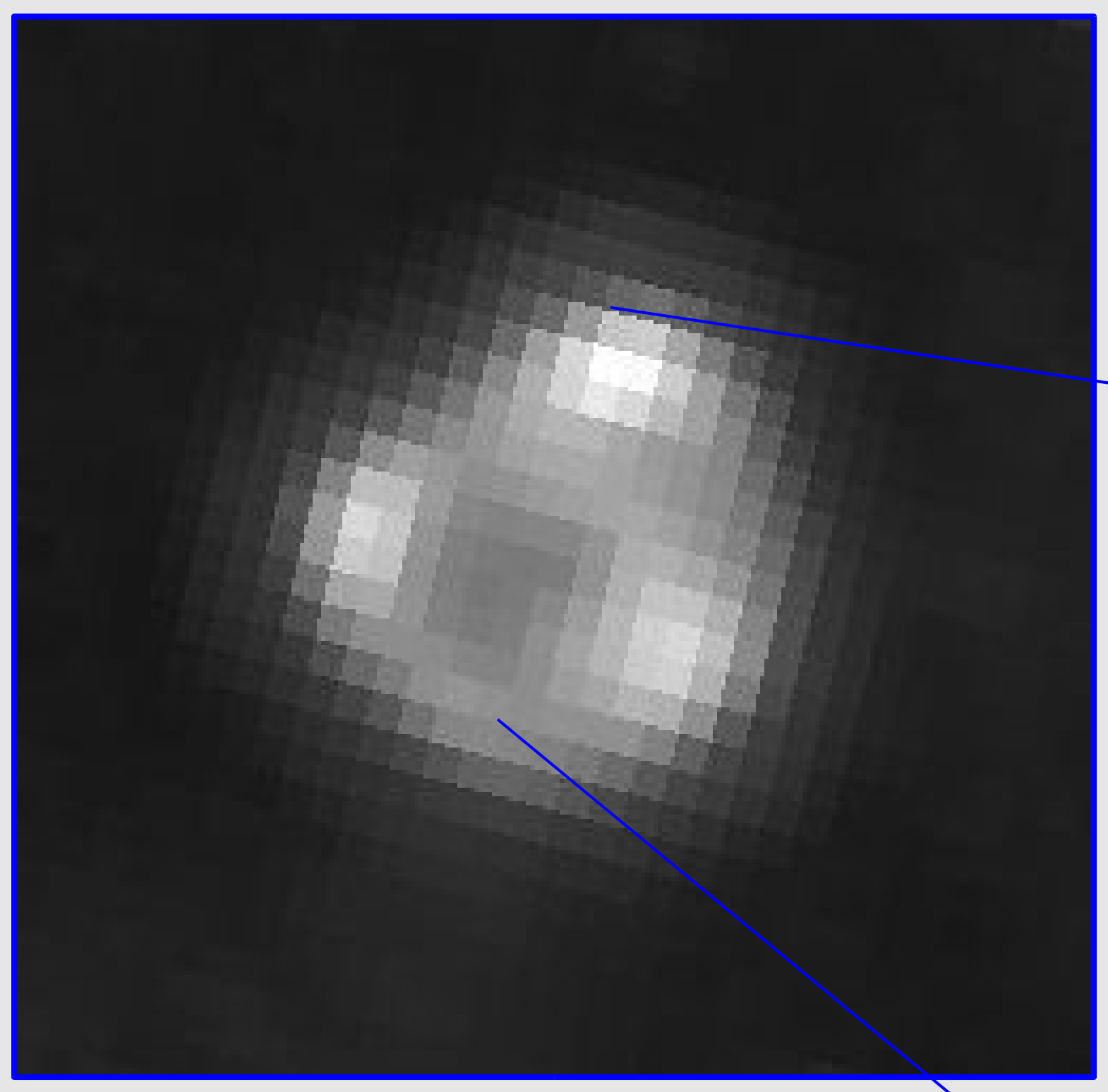
Compact Grains	**50% Porous Grains**	**Proton Temp 10 keV***
n_H: 1.0 cm^{-3}	n_H: 2.7 cm^{-3}	n_H: 2.0 cm^{-3}
n_e: 1.2 cm^{-3}	n_e: 3.24 cm^{-3}	n_e: 2.4 cm^{-3}
M_{gas} : ≤ 7 M_{sun}	M_{gas} : ≤ 2.6 M_{sun}	M_{gas} : ≤ 3.5 M_{sun}
n_0: ≤ 1.0 cm^{-3}	n_0: ≤ 0.38 cm^{-3}	n_0: ≤ 0.53 cm^{-3}
$M_{dust}/M_{gas} \geq 1 \times 10^{-4}$	$M_{dust}/M_{gas} \geq 2.2 \times 10^{-5}$	$M_{dust}/M_{gas} \geq 1.2 \times 10^{-4}$

*model included only to show effects of proton heating of grains, compact grains assumed

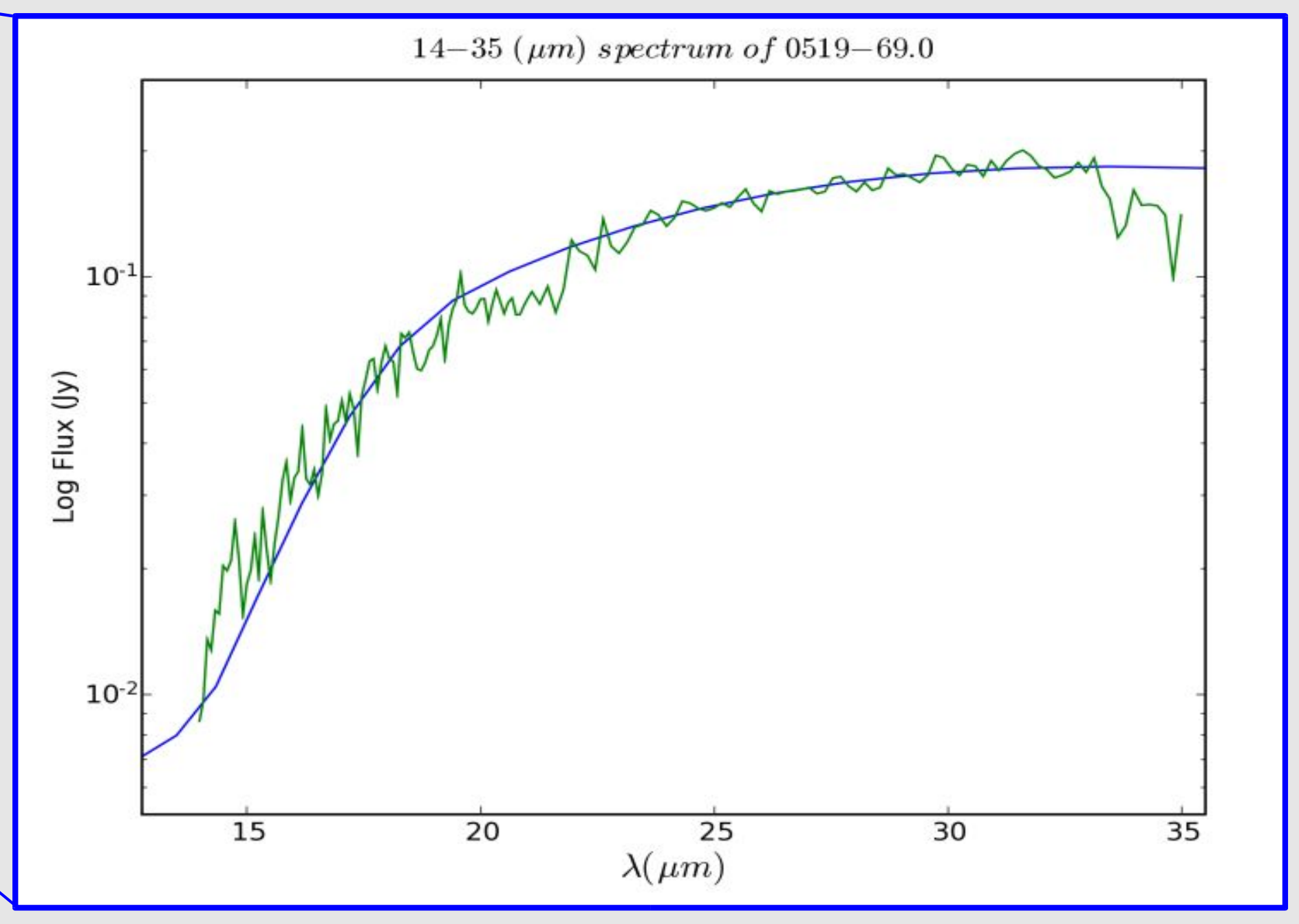
*** Bright Region of 0509-67.5 ***

We consider the "bright" cyan region of 0509 to be a dense region in an otherwise uniform remnant. To model this, we subtract the "faint" spectrum at left from the "bright," and model the residual spectrum. Dust modeling here gives a density ~10 times higher than results above. Dust mass there is ~10 times lower than rest of remnant, consistent with the idea that this region is a "perturbation." Enhancement in brightness in SW of H-alpha image indicative of extent of region. FUSE detection of broad Ly-ß may be coming from this region (Ghavamian et al. 2007, ApJ, 664, 304).

SNR 0519-69.0



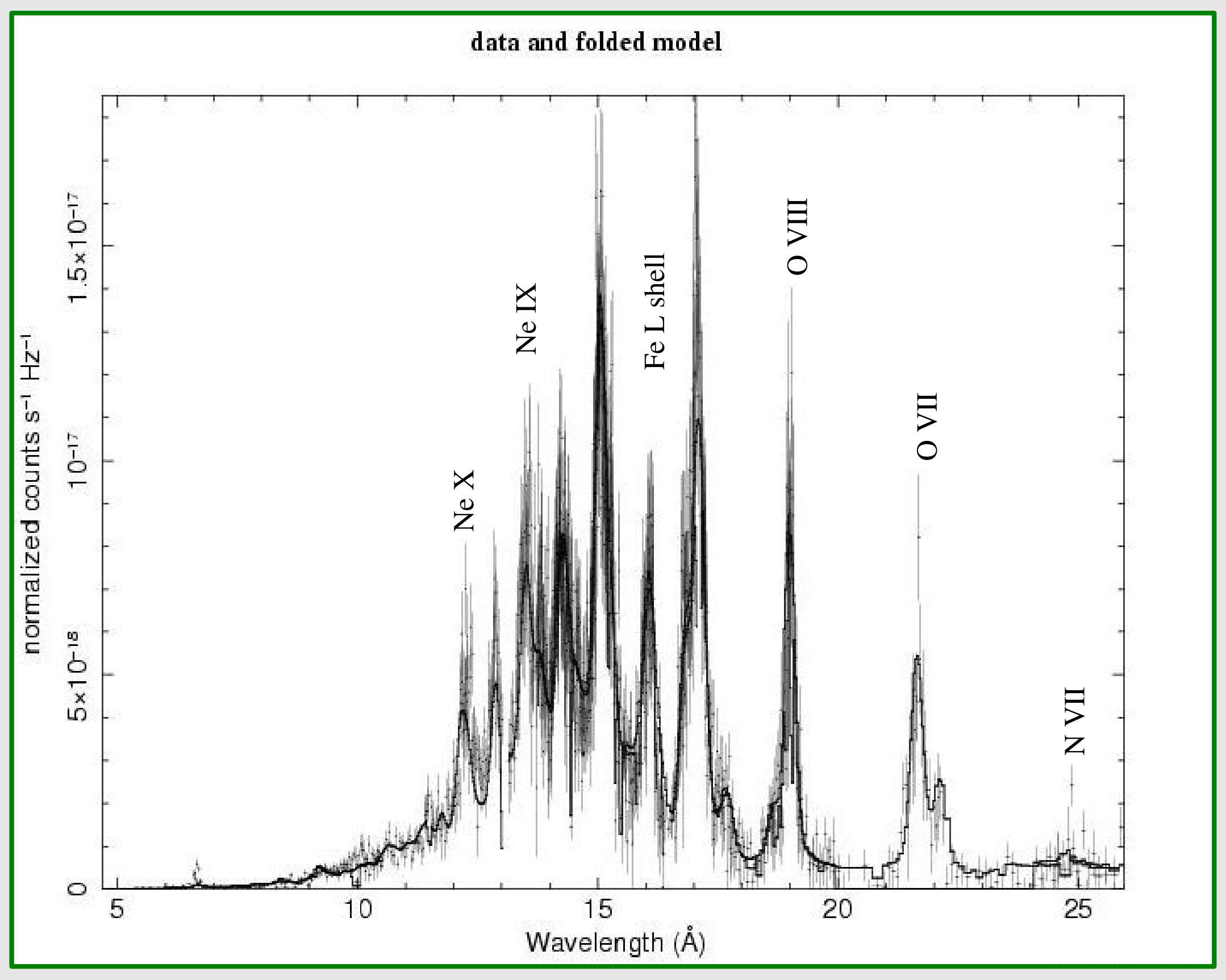
Left: *Spitzer* 24 micron image, Below: integrated IRS spectrum with model fit to dust continuum



Results for 0519-69.0

Compact Grains	**50% Porous Grains**
n_H: 11.5 cm^{-3}	n_0: 22 cm^{-3}
n_e: 13.8 cm^{-3}	n_e: 26.4 cm^{-3}
M_{gas} : ≤ 10.7 M_{sun}	M_{gas} : ≤ 5.6 M_{sun}
n_0: ≤ 1.6 cm^{-3}	n_0: ≤ 0.84 cm^{-3}
$M_{dust}/M_{gas} \geq 1.3 \times 10^{-4}$	$M_{dust}/M_{gas} \geq 5.9 \times 10^{-6}$

XMM-Newton RGS Spectrum of 0519-69.0



RGS fits for "ISM" model* for 0519-69.0

Ionization timescale = 2.9 x 10^{11} cm^{-3} s (2.3, 3.2)
Emission measure = 1.75 x 10^{59} cm^{-3} (1.66, 1.81)
Line width (O lines) = 1475 km s^{-1} (1350, 1700)
Reduced chi^2 of 1.55 for 235 d.o.f.

*See "Description of RGS Modeling," errors quoted in () are 90% con. limts

Discussion on Ejecta Contribution to O and Ne lines

Type Ia explosion models of Badenes et al. (2003, ApJ, 593, 358) contain unburned O and C as ejecta products. However, recent near-IR observations of type Ia SNe (Marion et al. 2009, AJ) suggest that the entire progenitor is burned in the explosion and that O and Ne are byproducts of carbon burning. Since any ejecta contribution to O and Ne lines would lower X-ray EM, we report M_{gas} and n_0 as upper limits.

Collaborators on the *Spitzer* LMC SNRs project: **K.J. Borkowski, S.P. Reynolds, W.P. Blair, P. Ghavamian, K.S. Long, J.C. Raymond, R. Sankrit, S. Hendrick, P.F. Winkler, R.C. Smith, & S. Points.**

Summary

1. We use IR spectra of SNRs to directly measure post-shock density, and combine this with X-ray EM to infer pre-shock density of ISM.
2. Results for 0509-67.5 are consistent with Badenes 2008 value of $n_0 = 0.43$ cm^{-3}
3. Bright region in 0509 due to region of much higher density
4. Proton heating of dust grains is important at these temperatures
5. Compact grain model seems to fit better for 0519-69.0, while porous grain model seems to fit better for 0509-67.5
6. In all models, we find lower than "typical" dust-to-gas mass ratio of 2.5 x 10^{-3}, expected for LMC
7. **Subject to uncertainties, this technique can provide a handle on both pre and post-shock densities, and can constrain compression ratio; cosmic-ray modification**

NC State Astrophysics