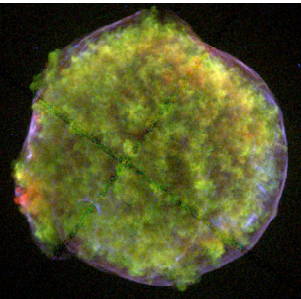


***Suzaku* Future Impact on
Galactic and Extragalactic
Extended Objects**

John P. Hughes
Rutgers University

Galactic Extended Objects

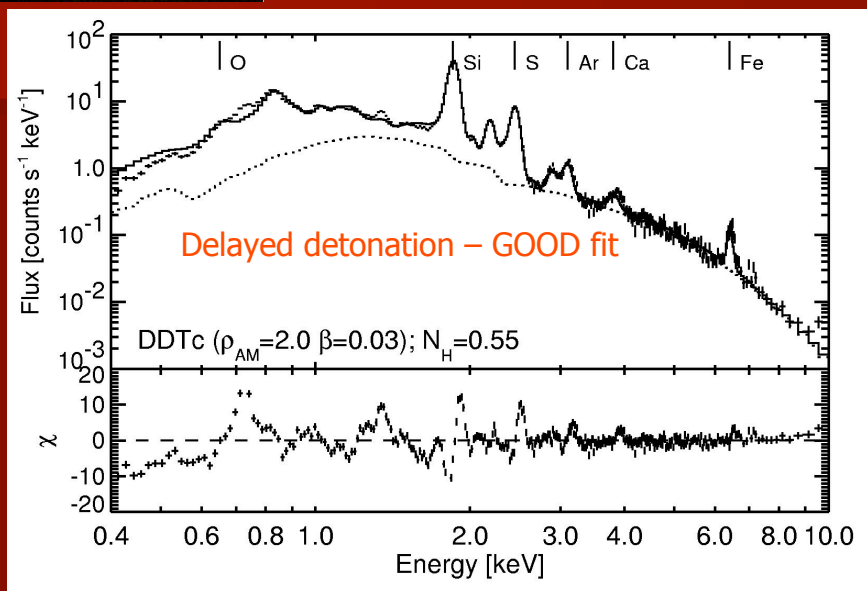
- Solar wind charge exchange (Posters: Ezoë, Hagihara, Henley)
- Comets (Brown talk)
- Hot diffuse ISM (Shelton talk)
- Supernova remnants
 - Thermal properties (Hwang talk)
 - Ejecta composition (Posters: Yamaguchi, Park, Nakajima, Tamagawa, Hayato)
 - Evolved SNRS, ISM shocks (Posters: Katsuda, Uchida, Ozawa, Stage)
 - Nonthermal shock properties (Bamba, Uchiyama talks)
 - Detailed studies of individual sources (Tanaka, Maddox talks, Posters: Allen, Nakamura)
 - HESS source follow-up (Matsumoto talk, Posters: Puehlhofer, Anada)
 - Pulsar wind nebulae (Poster: Mori)
- Large scale Galactic X-ray emission
 - Galactic Center (Koyama, Tsuru talks, Posters: Inui, Nobukawa, Takikawa); Galactic Bulge (Kokubun talk); Galactic Ridge (Posters: Laurent, Ebisawa, Yao)



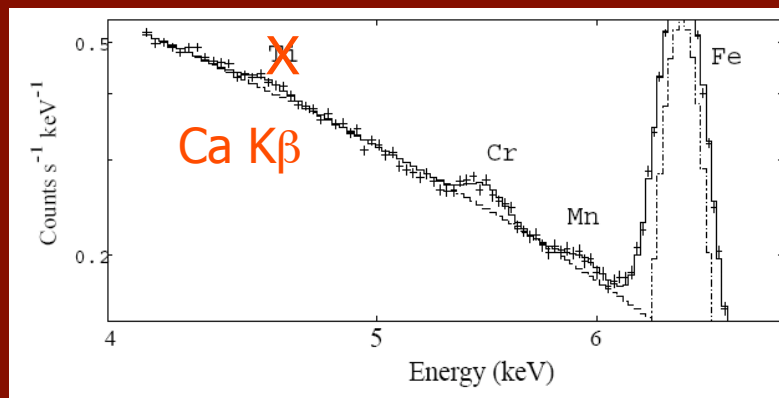
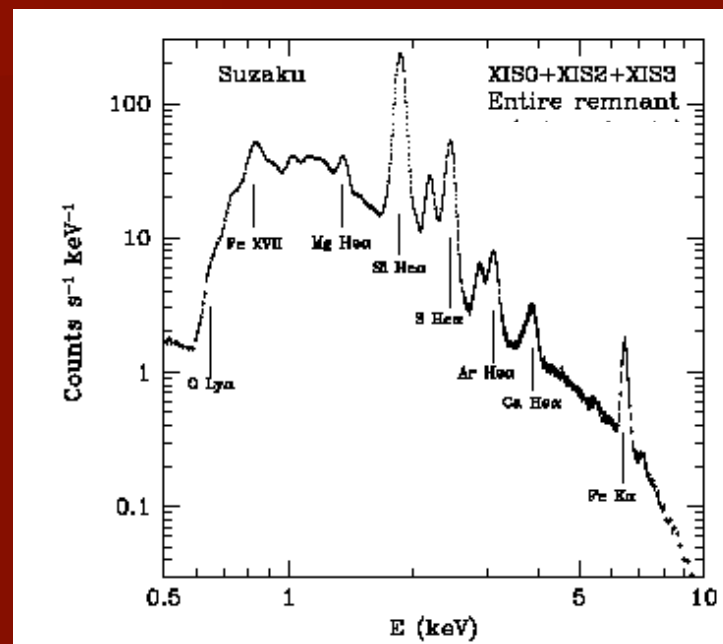
Tycho, a SN Ia Remnant

XMM-Newton (MOS)

Suzaku



Badenes et al 2006



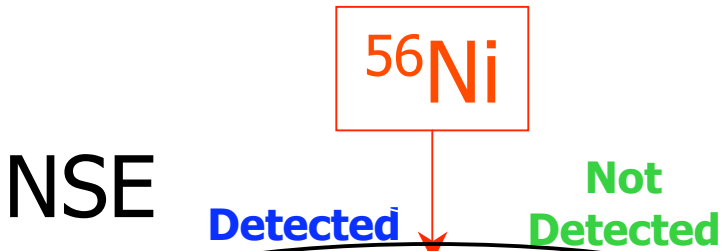
Tamagawa et al 2007

Hayato et al 2007

Fe-peak Elements in Tycho

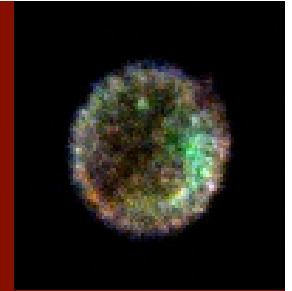
In SNe Ia nucleosynthesis is the explosion: C-O burns at high P and T to nuclear statistical equilibrium (NSE)

hydrogen 1 H 1.0079																			helium 2 He 4.0026									
lithium 3 Li 6.941	beryllium 4 Be 9.0122										boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180												
sodium 11 Na 22.990	magnesium 12 Mg 24.305										aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948												
potassium 19 K 39.098	calcium 20 Ca 40.078										scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	seletemium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80		
rubidium 37 Rb 85.468	strontium 38 Sr 87.62										yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	niobium 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	cadmium 46 Cd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29		
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *									lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]		
francium 87 Fr [223]	radium 88 Ra [226]	89-102 **									lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnium 110 Uun [271]	ununium 111 Uuu [272]	ununium 112 Uub [277]		ununquadium 114 Uuq [289]						
* Lanthanide series			lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04												
** Actinide series			actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]												

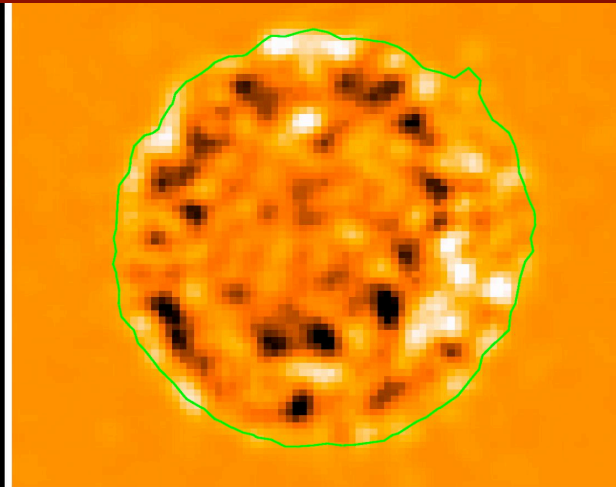
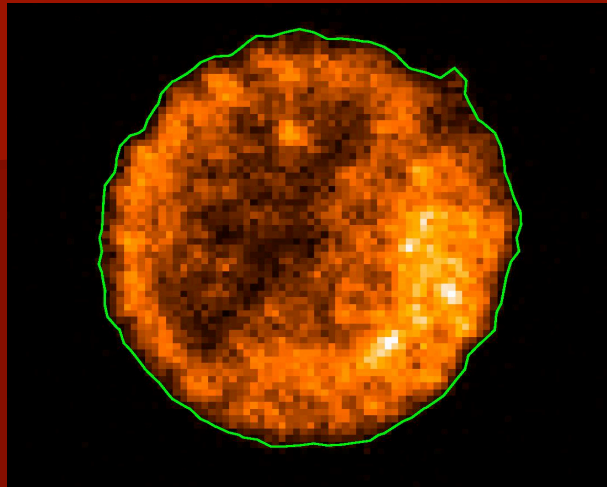


Bulk motion of SNR 0509-67.5

A Spectroscopically Confirmed SN Ia

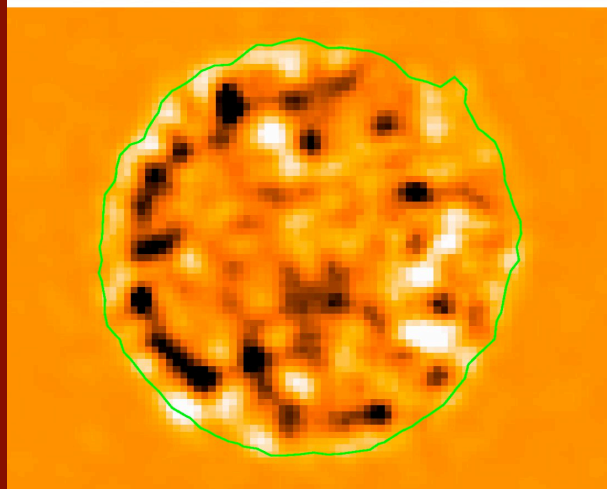


Chandra



Chandra:
Epoch2a –
Epoch 1

Chandra:
Epoch2b –
Epoch 1



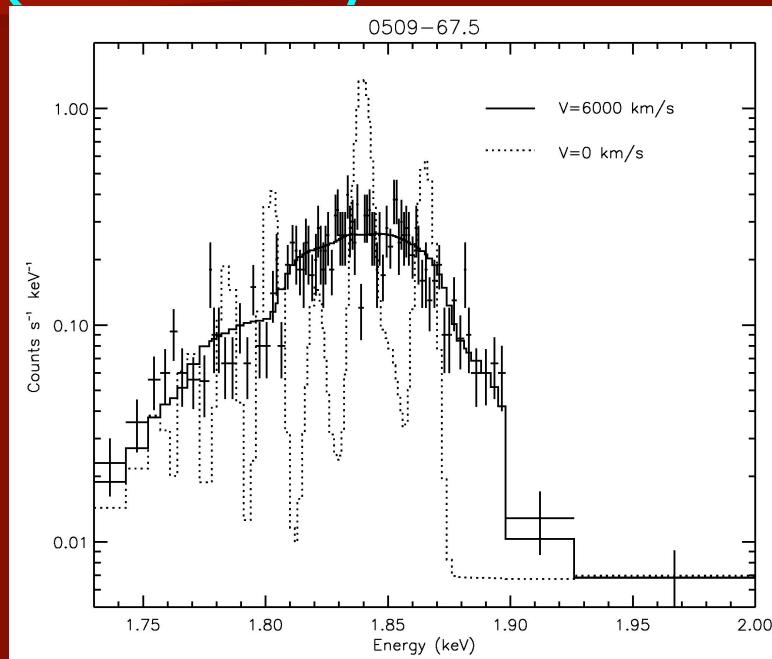
HST/ACS

Ejecta Expanding at ~ 6000 km/s

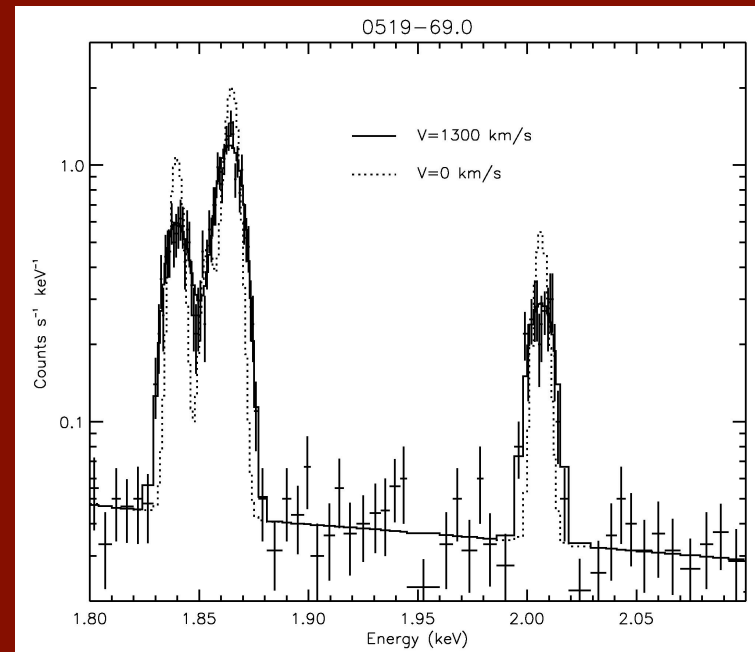
Hughes et al
2008, in prep

Implications for Suzaku

Significant line broadening in integrated spectra
(as seen by Suzaku: Nakajima et al 2007, poster)



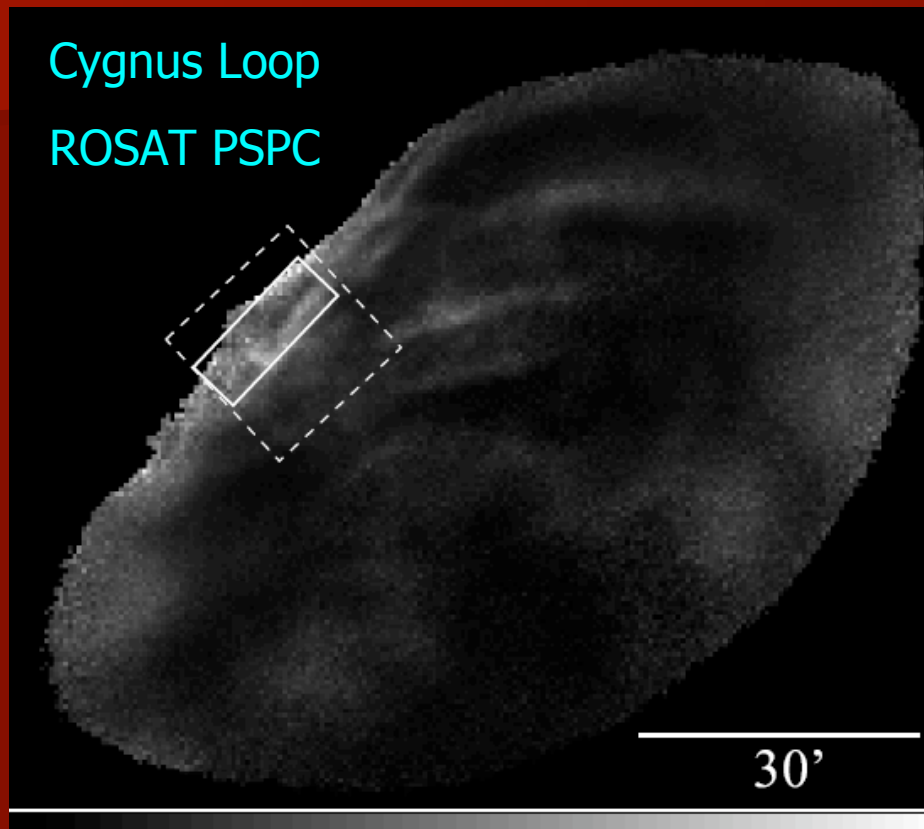
SNR 0509-67.5 6000 km/s



SNR 0519-69.0 1300 km/s

In resolved objects line broadening should vary with position; most relevant for SN1006 (shows some Si and S line broadening, Yamaguchi et al. 2007) and Tycho.

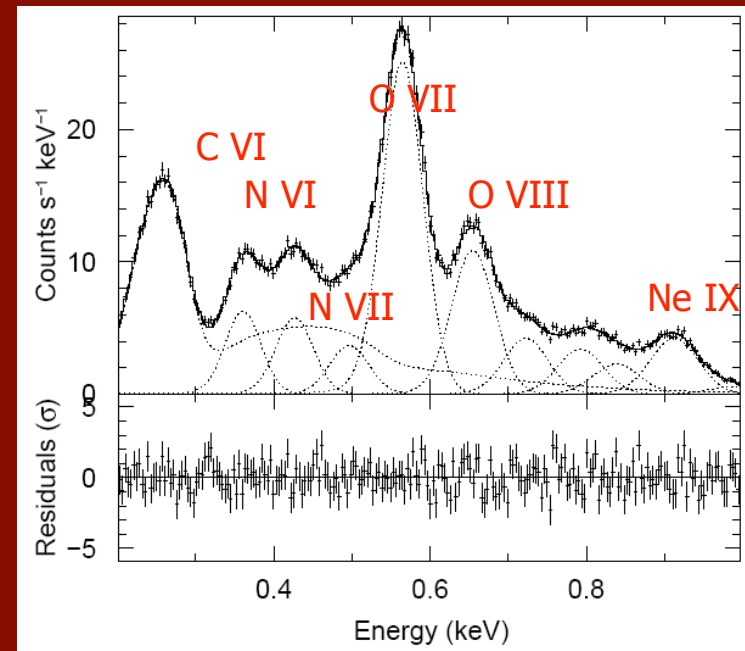
Resonance Line Scattering in SNRs



Band ratio map: $_ \text{ keV}$ to $_ \text{ keV}$

Miyata, Masai, & JPH 2008, in press

Extract Suzaku spectrum from softest region (solid white rectangle)



Resonance Line Scattering in SNRs

Suzaku

Cygnus Loop results

- 10%-40% of line photons are scattered from line-of-sight at rim
- More so for O than other species
- Possible explanation for low measured O abundance
- Affects temperature/net measurements
- Escape fraction varies across remnant

Species

 τ Escape
Fraction

C VI $K\alpha$	0.16	0.83
N VI $K\alpha$	0.11	0.87
O VII $K\alpha$	0.55	0.63
O VIII $Ly\alpha$	0.20	0.80
Ne IX $K\alpha$	0.18	0.81

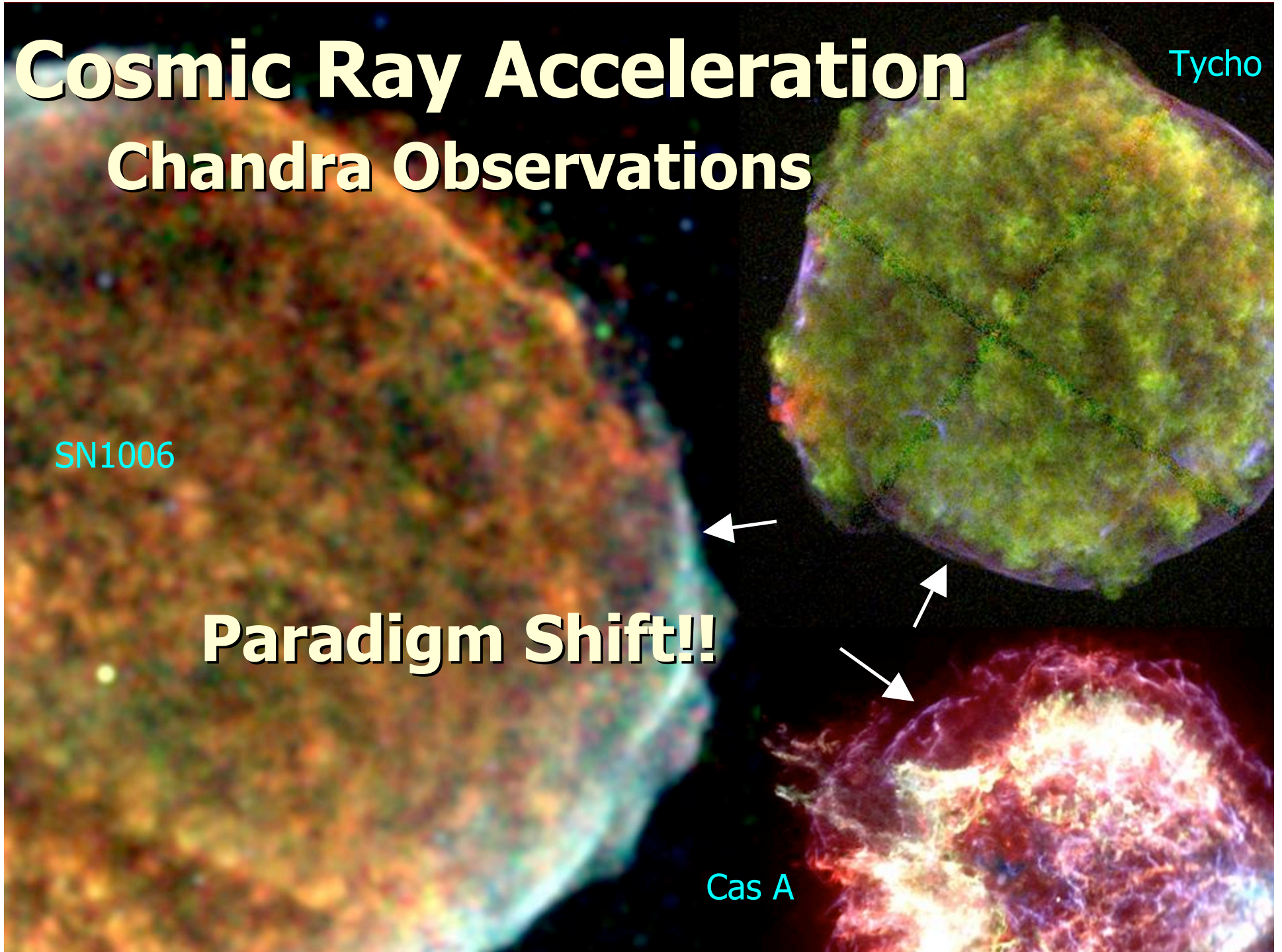
Cosmic Ray Acceleration Chandra Observations

Tycho

SN1006

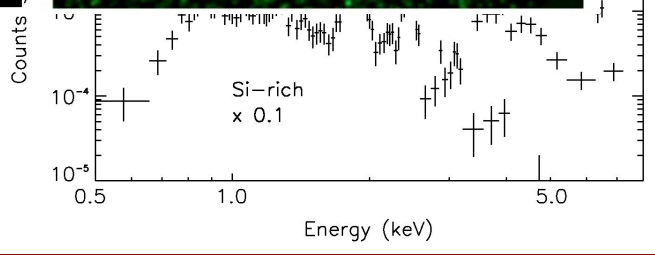
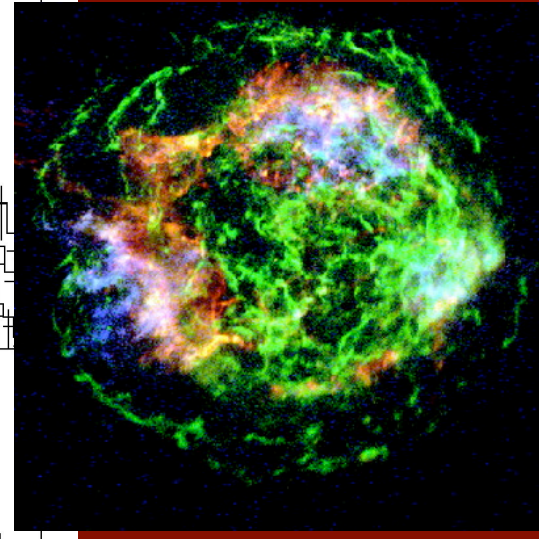
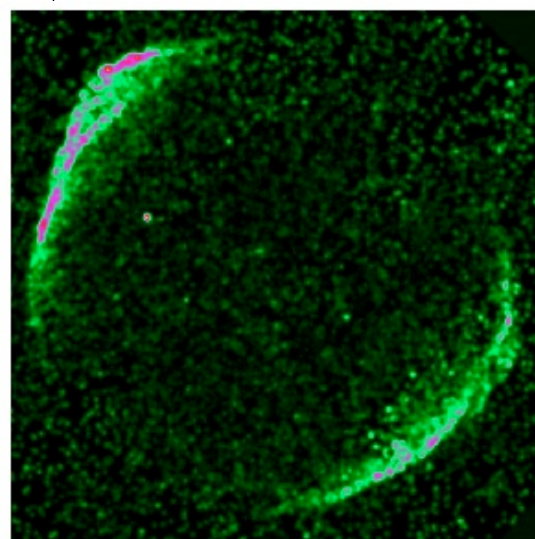
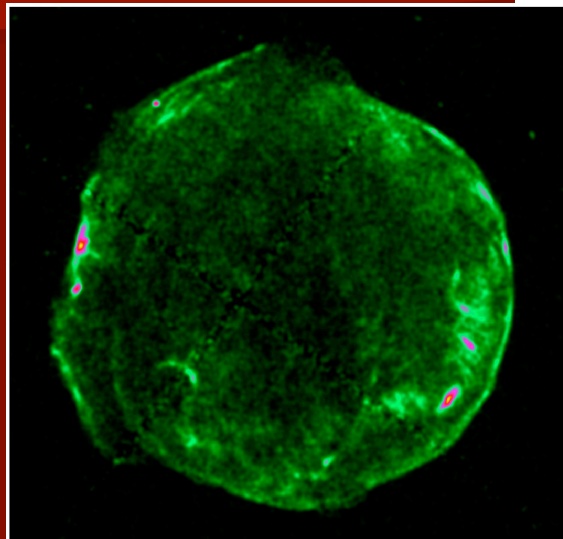
Paradigm Shift!!

Cas A



Chandra results on cosmic ray electrons

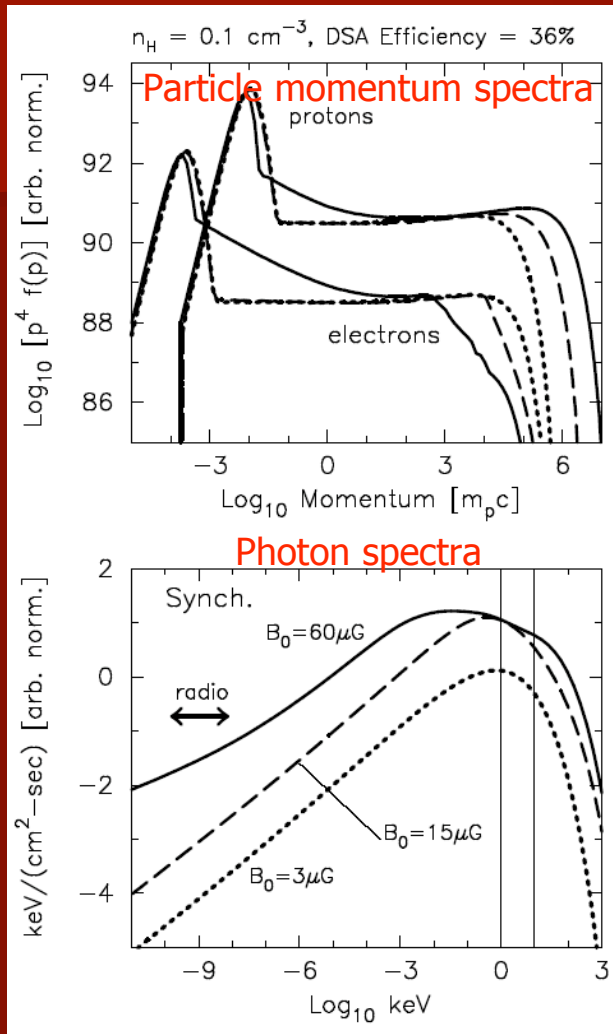
- Thin nonthermal
- many young SNRs



- Various morphologies, only partially understood (Cas A)
- Strong evidence for TeV energy electrons

and rim (Tycho), sets of filaments

Suzaku Impact



CR Acceleration Models

- *Top panel* - Model proton (top) and electron (bottom) spectra for $B_0 = 3 \mu\text{G}$ (dotted), $15 \mu\text{G}$ (dashed), and $60 \mu\text{G}$ (solid)
 - Synchrotron cooling distorts electron spectra at high momentum end
- *Bottom panel* - Photon spectra from radio frequencies to hard X-rays (1-10 keV band indicated)
 - Allows to constrain $p_{e,max}$, B_0 , η_{inj} , α_{cut}
 - In general solution not unique without additional information

Ellison et al. 2007

December 12, 2007

The Suzaku X-ray Universe

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HESS: High Energy Stereoscopic System



Imaging Atmospheric Cerenkov Telescope (Namibia, Africa)

- Sensitive to 100 GeV γ -rays
 - Spatially resolved images – Galactic plane survey – new sources
 - Potential to observe π^0 -decay signal from CR protons (but leptonic – Inverse Compton – origin also possible)

Optical

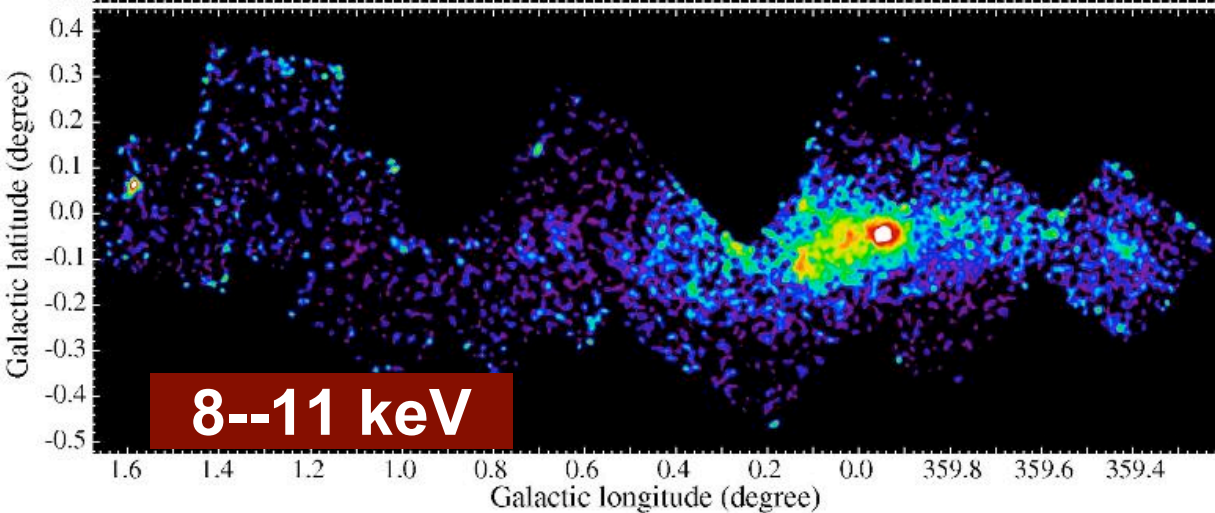
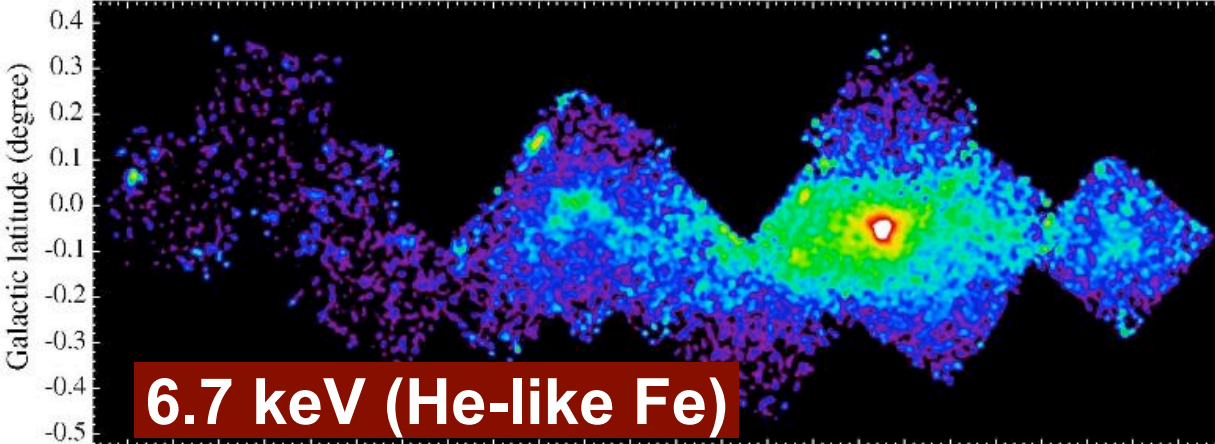
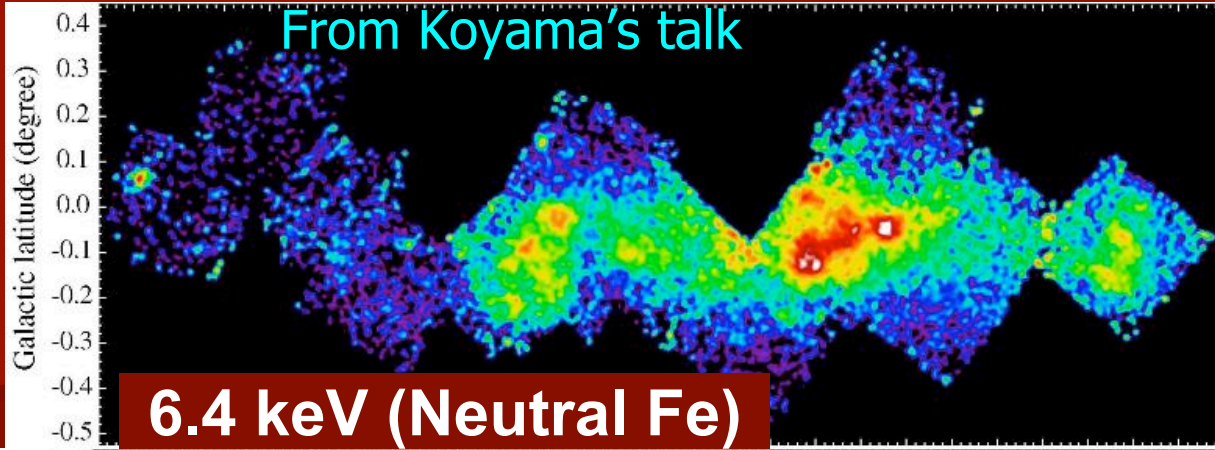


VHE Gamma

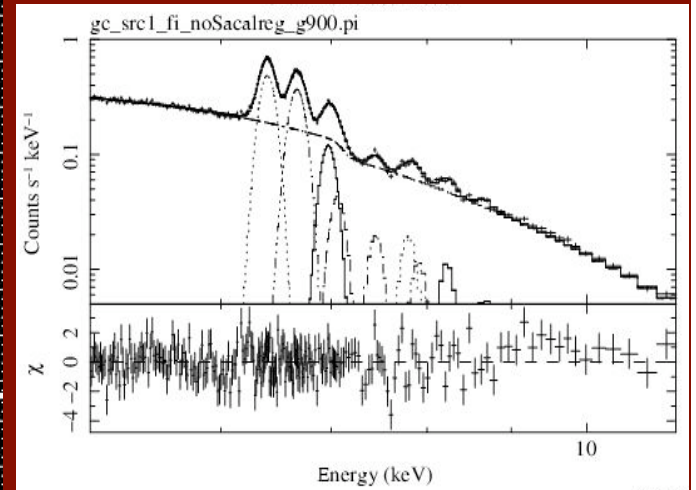


Understand the new population: Suzaku X-ray follow-up

From Koyama's talk



Suzaku X-ray Maps along the Galactic Center and Ridge (GC, GR)



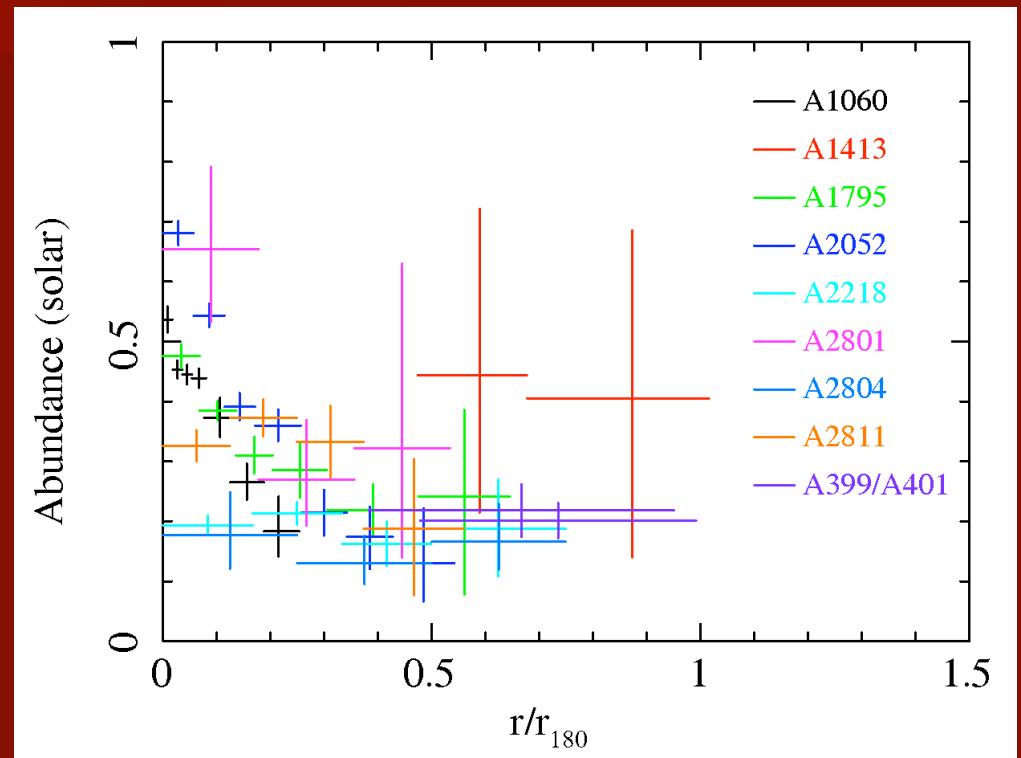
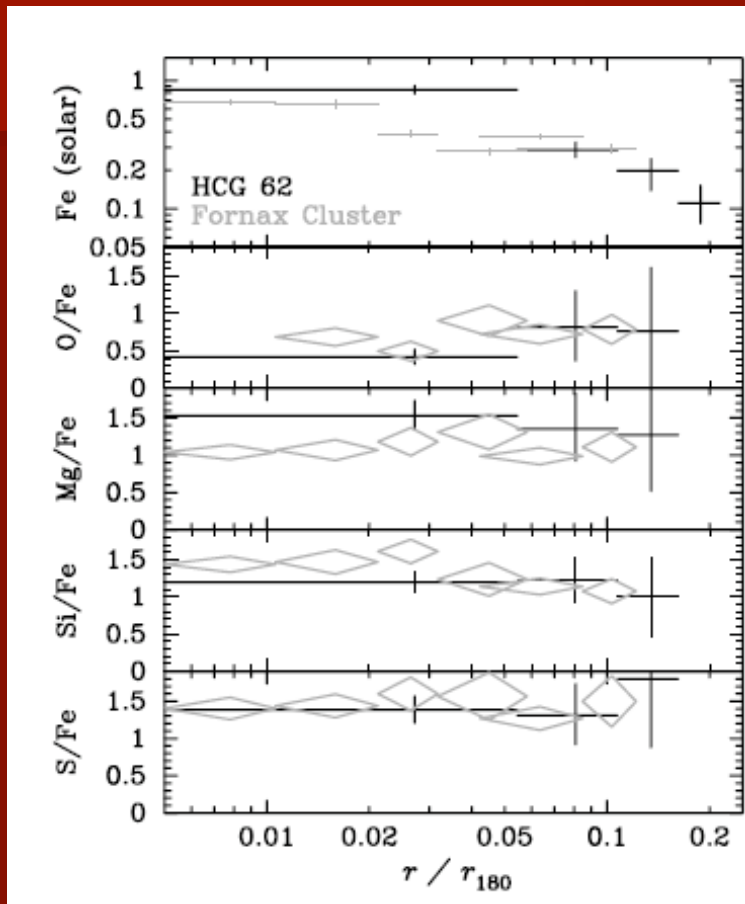
GC – hot thermal plasma –
confinement, heating
mechanism?

GR – likely point sources

Extragalactic Extended Objects

- Galaxy groups (Loewenstein talk, Poster: Miller)
- Cluster abundance measurements (Sato talk, Posters: Tawa, Tokoi)
- Mass measurements (Henry talk, Posters: Etori)
 - To the virial radius with Suzaku (Posters: Hoshino, Reiprich)
- Selected topics
 - Bulk flows (Henry talk, Posters: Hayashida)
 - Merging clusters (Posters: Tanaka, Madjeski)
 - Resonance line scattering (Poster: Furuzawa)
 - Soft excesses (Posters: Lieu, Werner, thesis talk: Bulbul)
- WHIM (Ohashi talk, Posters: Takei)
- Cluster Hard X-ray emission (Fukazawa, Sarazin talks, Posters: Kawaharada, Wilk, Nakazawa)

Abundance Profiles



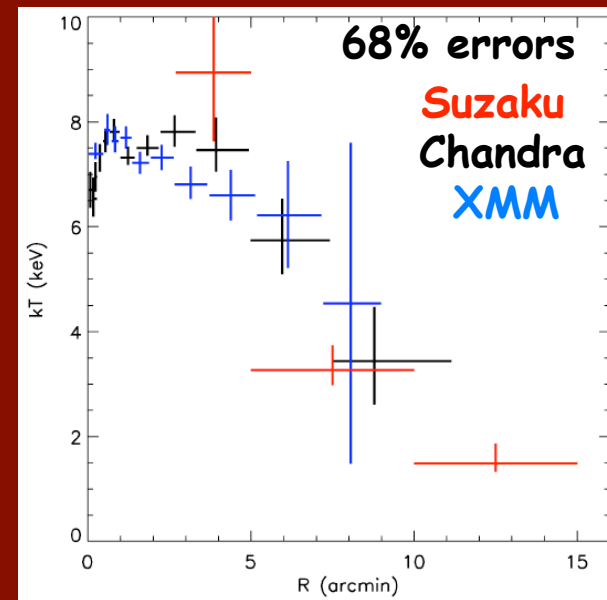
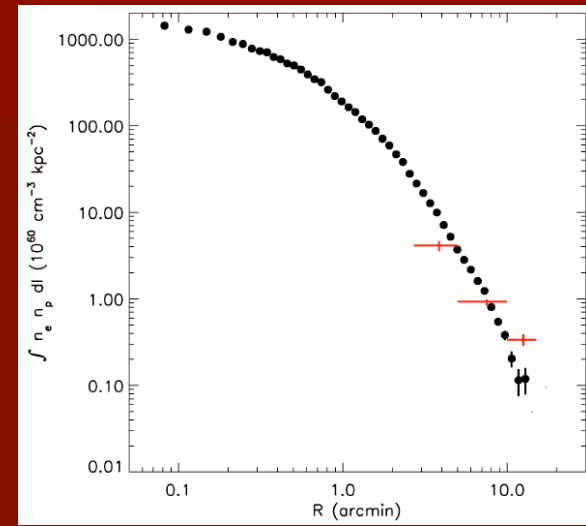
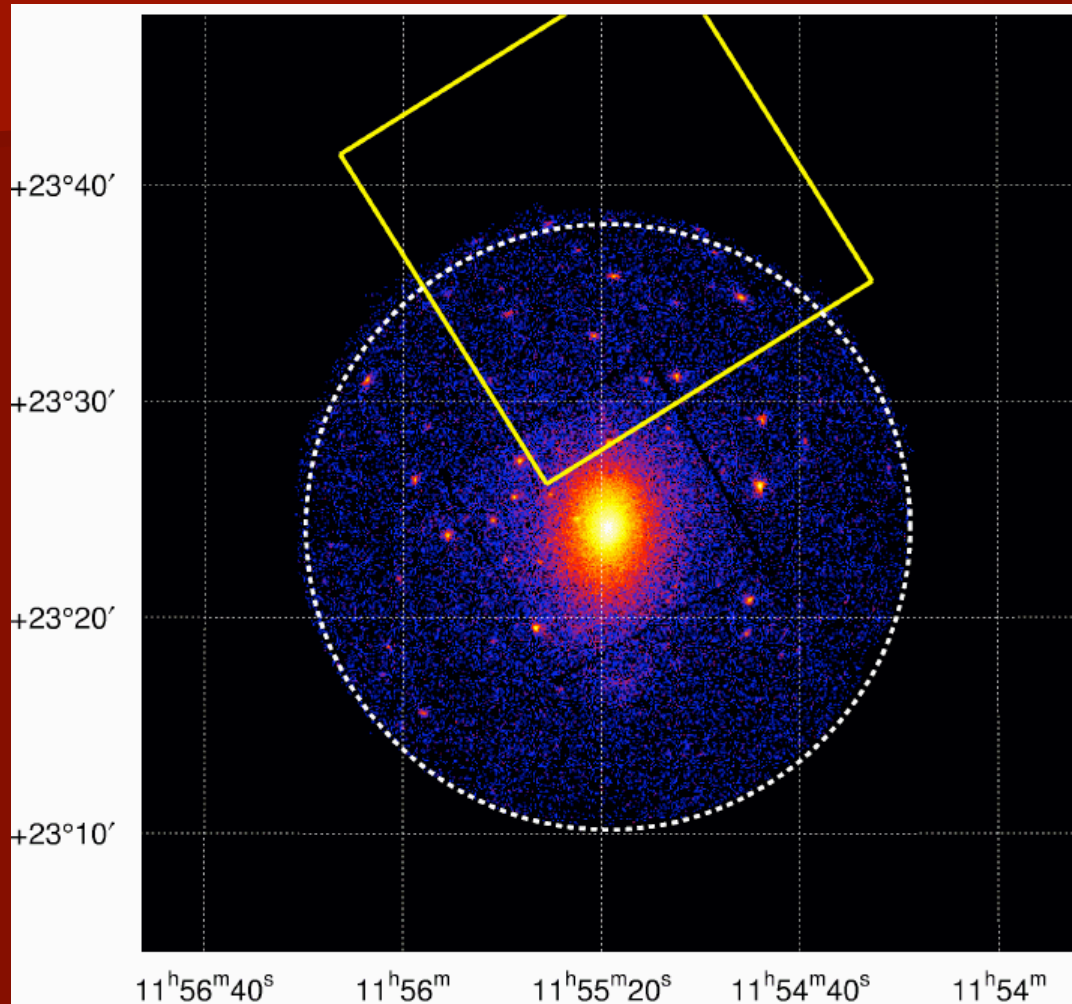
Tawa et al., in prep (From Henry's talk)

Matsushita et al 2007
Tokoi et al 2008

From Henry's talk

A1413: Mass to R_{vir}

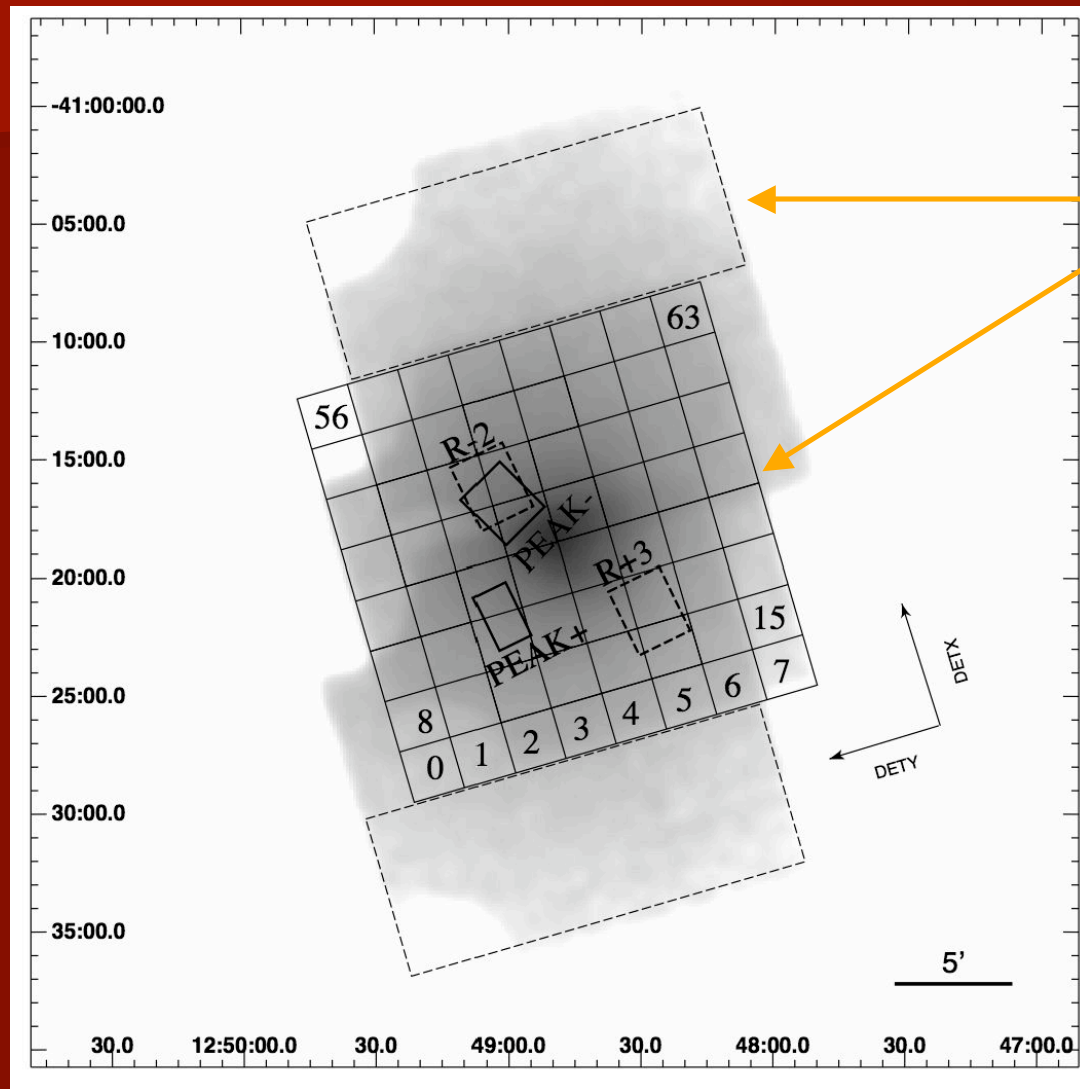
(Hoshino et al. in preparation)



From Henry's talk

Suzaku constraints on bulk flows

Centaurus Cluster Ota et al. PASJ 59, S351, 2007



$\Delta v < 1400 \text{ km s}^{-1}$
(90% confidence)
on scales of $135 h_{70}^{-1} \text{ kpc}$

Does not confirm Chandra

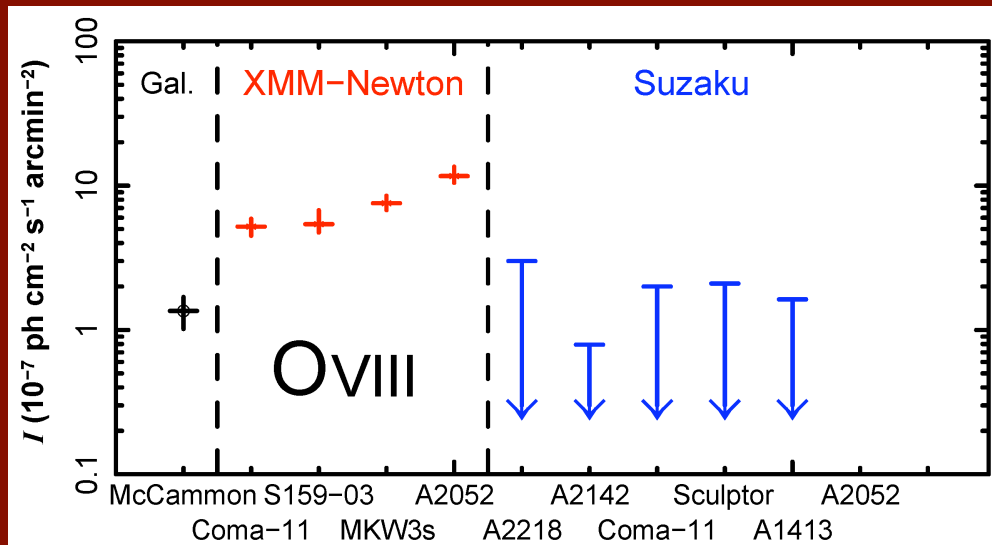
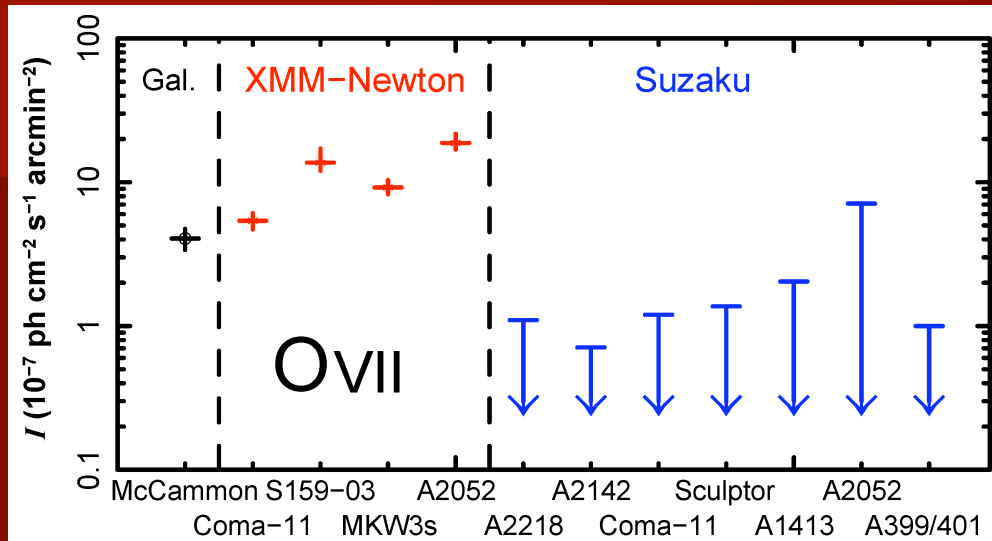
Region	Suzaku/XIS	Chandra/ACIS
	$\Delta v \text{ (km s}^{-1}\text{) }^*$	$\Delta v \text{ (km s}^{-1}\text{) }^\dagger$
PEAK-, PEAK+	$-660 \pm 390 \text{ (}\pm 660\text{)}$	2900 ± 700
R-2, R+3	$-540 \pm 360 \text{ (}\pm 660\text{)}$	2400 ± 1000

*The velocity difference derived from the XIS spectra. The 68% statistical errors and (the 68% systematic errors) are quoted.

†The velocity difference and the 1σ error derived from the Chandra ACIS spectra (Dupke, Bregman 2006).

From Ohashi's talk

Summary of Suzaku constraints on the WHIM



- Suzaku upper limits on Oxygen lines are factor of 3 -5 lower than the XMM “detection”.
- Understanding the spectrum of Galactic emission is most important
- Detector background and solar wind process also cause significant effect on oxygen measurement

Henry's suggestion for large cluster cosmology

Mass - Observable Relation

Suzaku project

Observable	Scatter	Self Sim Shape?	Observable Cosmo Depend?
Richness	70%	?	N
Luminosity	40%	N	Y
Temp.	20%	Y	N
Gas mass	10%	N	Y
Y_x	10%	Y	Y

Choose Temperature

Low scatter

Self similar shape so simple physics

Independent of cosmology

Henry's suggestion for large cluster cosmology

Mass - Observable Relation

Suzaku project

Observable	Scatter	Self Sim Shape?	Observable Cosmo Depend?
Richness	70%	?	N
Luminosity	40%	N	Y
Temp.	20%	Y	N
Gas mass	10%	N	Y
Y_x	10%	Y	Y
Y_{SZ}	10%	Y	Y

Atacama Cosmology Telescope (ACT) and South Pole Telescope (SPT) are measuring Y_{SZ} in blind surveys of 100's to 1000's sq deg of sky - follow-up SZ clusters with Suzaku kT measurements?

Conclusions

To assure Suzaku's impact we must...

- Work on important problems
 - Ex.: composition of SN ejecta, explosion mechanism of SNe Ia, confinement/heating of Galactic Center hot gas, abundances in galaxy clusters, cluster masses, cosmology (and so on)
- Pursue pathfinder studies for future missions (NeXT, Con-X, XEUS)
 - Ex.: resonance line scattering, velocity measurements, etc.
- Make substantial links to other wavebands

To implement this we must...

- Make a serious commitment to large projects
 - Long observations of individual targets, focused study of a large sample of targets

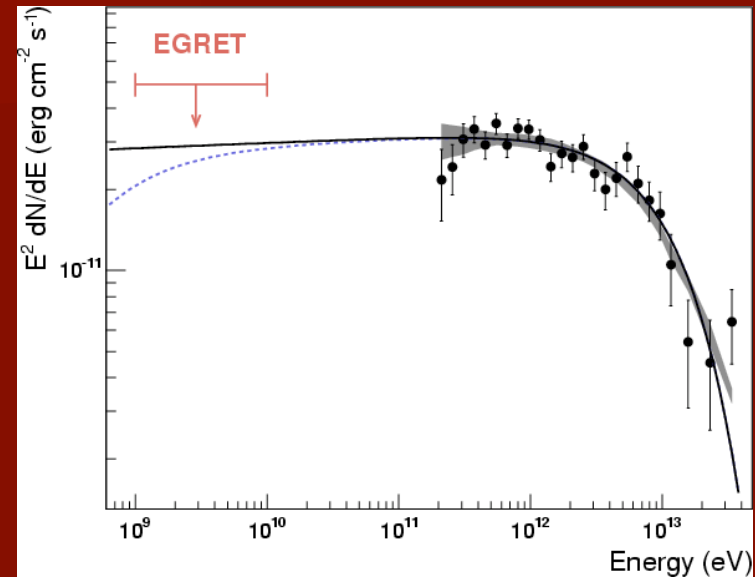
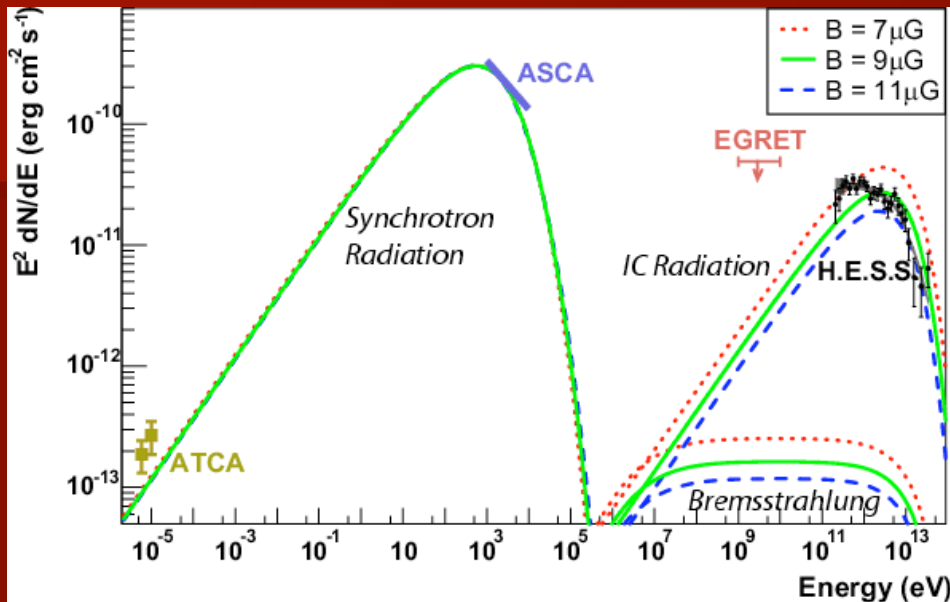
Very large (few 10^6 s), multi-year, key projects?

Galactic Extended Objects

- Composition: Yields from supernova explosions
 - Fate of SN ejecta – metals in the Universe
 - Star formation history in clusters
- Explosion mechanisms
 - Violent core collapse: jets, Fe/Si ejecta overturning in Cas A
 - How do SN Ia's explode?
- Sites of cosmic ray acceleration
 - Recall energy densities of CRs, starlight, & magnetic field in Galaxy comparable
 - Essential to the understanding of high-Mach collisionless shocks
 - Broader question: how do shocks partition their energy into bulk motion, thermal and nonthermal electrons and ions?
 - Energy removed from bulk motion & thermal gas – less available to stir the ISM

HESS Spectra of RX J1713

Aharonian et al (2006)



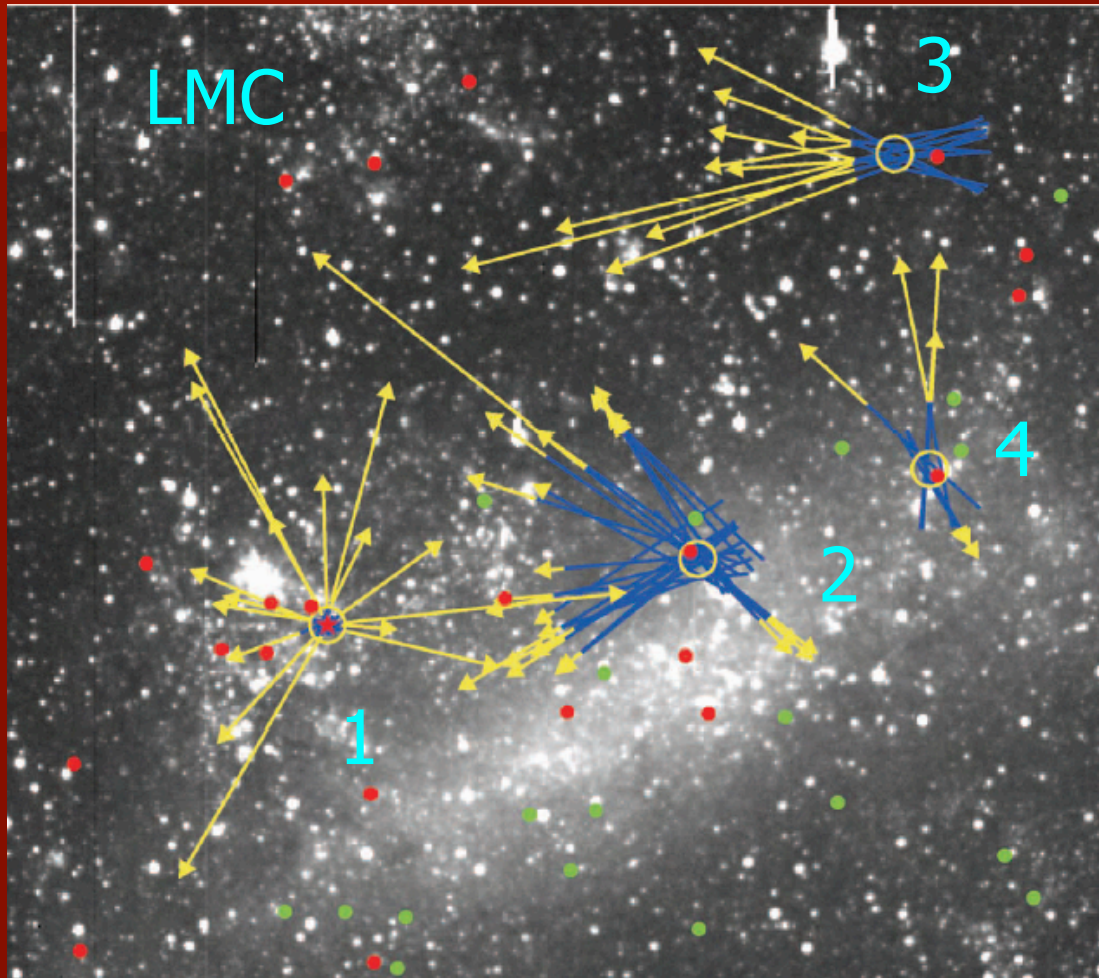
Inverse Compton Interpretation

- Links X-ray and γ -ray emission as suggested by similar morphology
- Requires low magnetic field

Proton/ π^0 -decay Interpretation

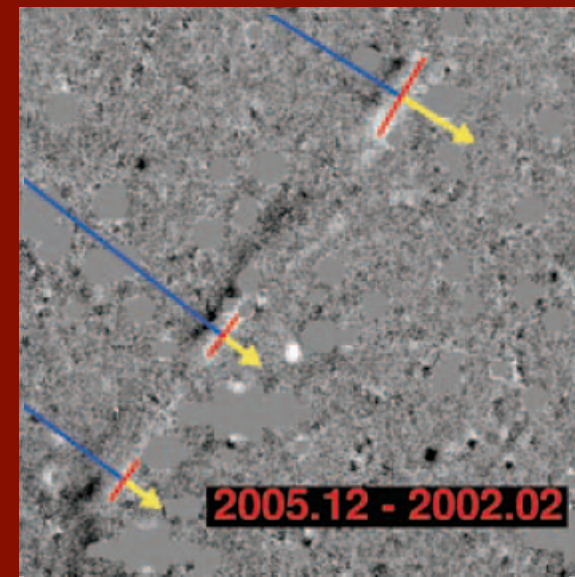
- Fits spectral shape
- Requires high ambient density, inconsistent with XMM results

SNR 0509-67.5: A Spectroscopically Confirmed SN Ia



Light Echoes from Old or Ancient LMC SNe

- 1) SN1987A 15 yrs
- 2) 0519-69.0 600 yrs
- 3) 0509-67.5 400 yrs
- 4) N103B 900 yrs



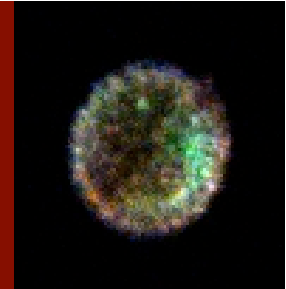
Rest et al 2005

December 12, 2007

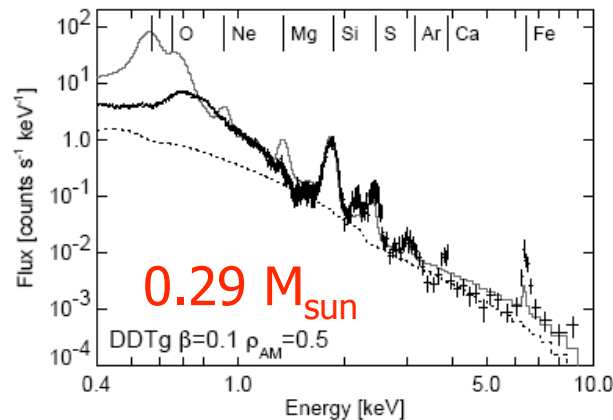
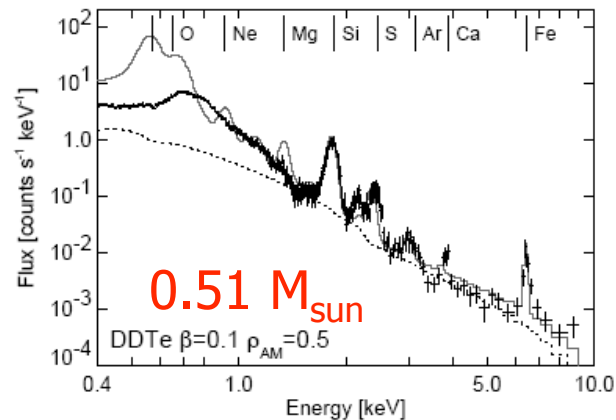
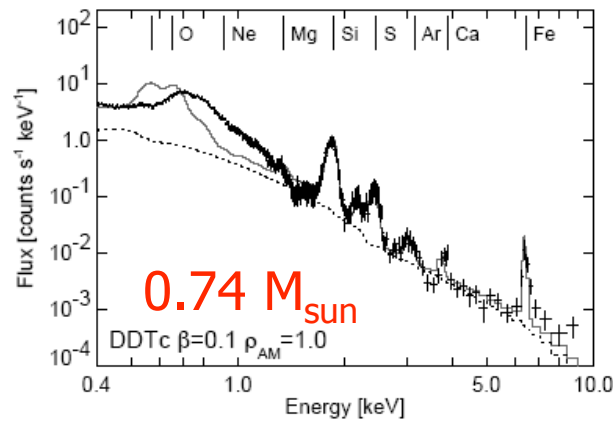
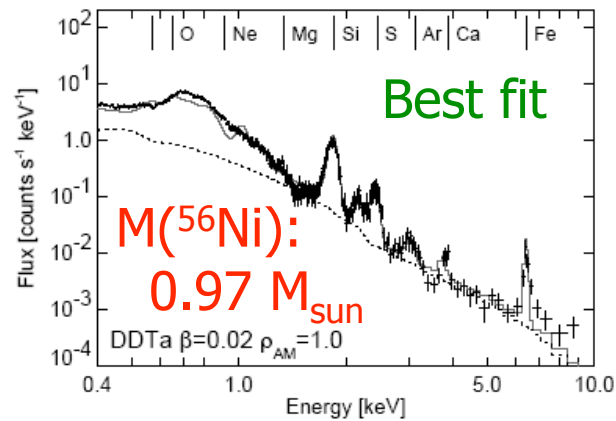
The Suzaku X-ray Universe

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SNR 0509-67.5: X-ray Spectrum



XMM-Newton (PN)



Constraints

Line Centroids

- Si $K\alpha$
- S $K\alpha$
- Fe $K\alpha$

Flux Ratios

- O $K\alpha$ /Si $K\alpha$
- Fe L/Si $K\alpha$
- Fe $K\alpha$ /Si $K\alpha$

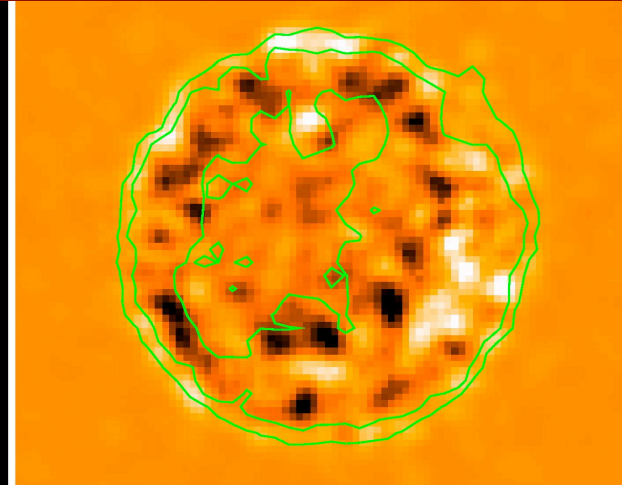
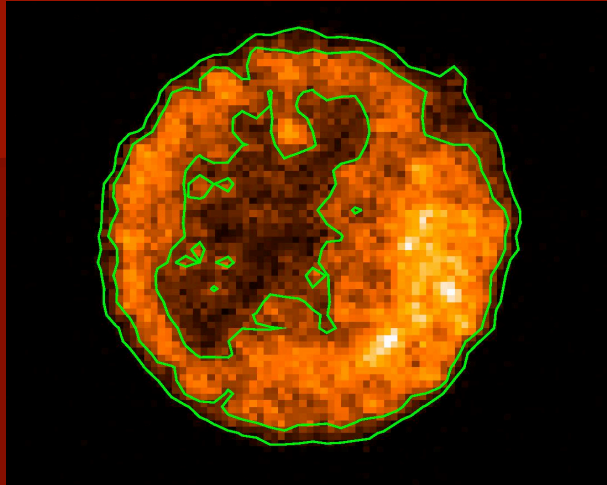
SNR 0509-67.5
is SN1991T-like

Badenes, JPH, et al 2007, ApJ, in press

Recall 1 parameter variation of SNe Ia:
Luminous-to-faint SNe correspond to high-to-low Ni mass

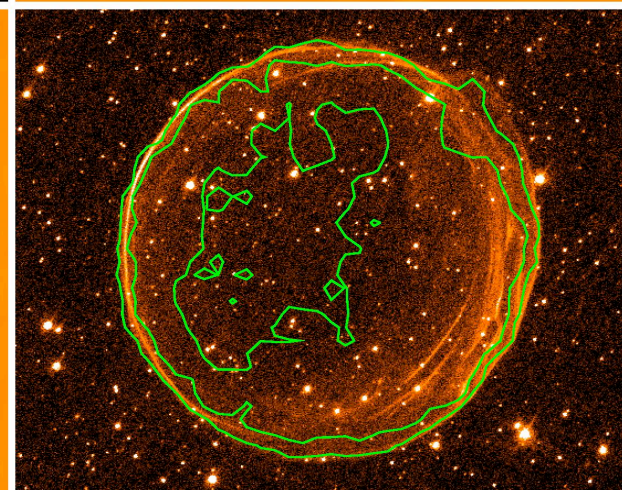
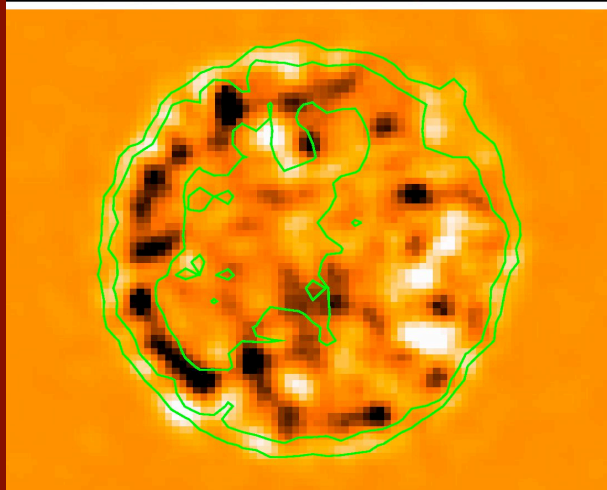
Proper motion of SNR 0509-67.5

Chandra



Chandra:
Epoch2a –
Epoch 1

Chandra:
Epoch2b –
Epoch 1



HST/ACS

Ejecta Expanding at ~ 6000 km/s

Hughes et al
2008, in prep