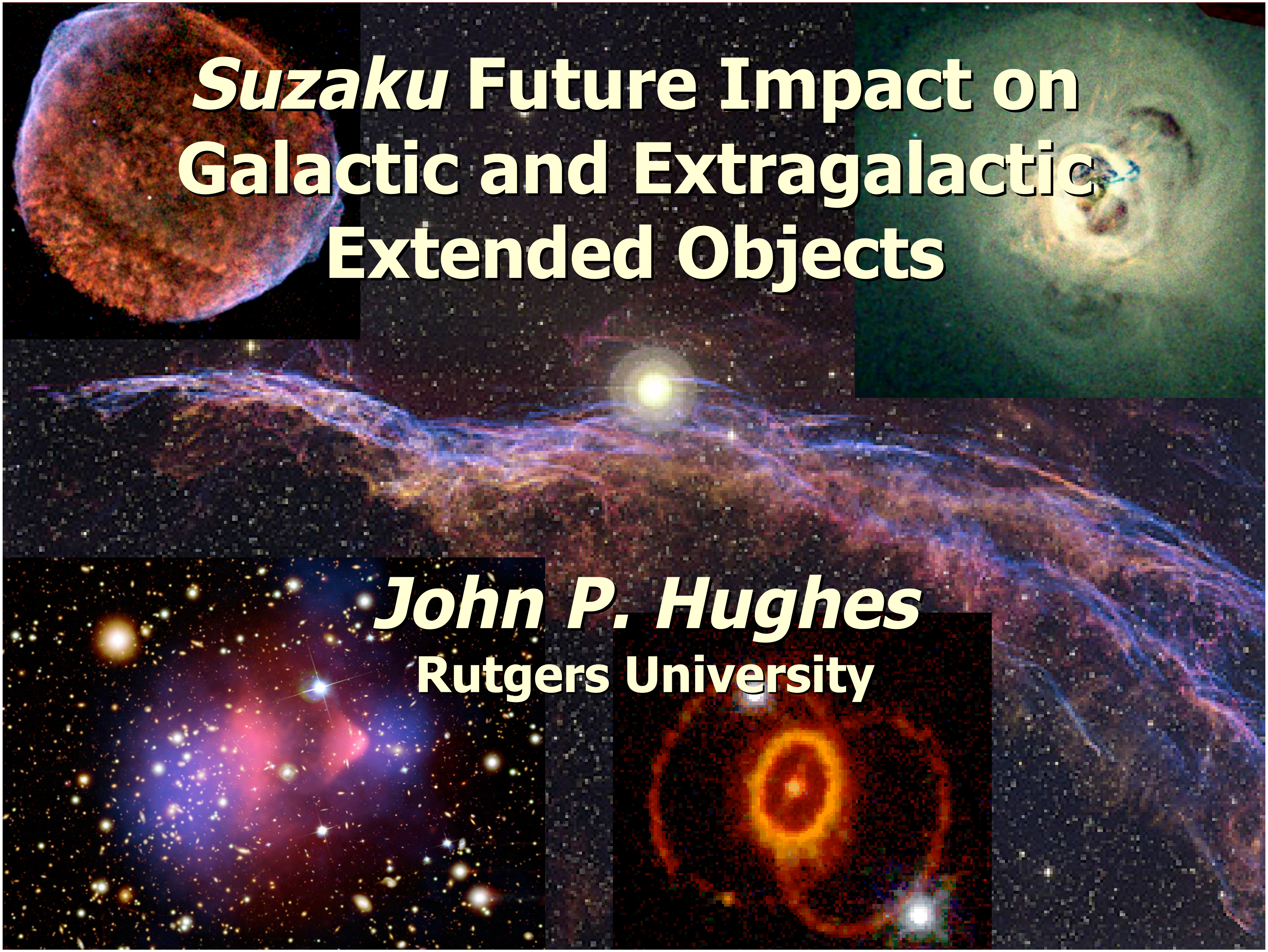


Suzaku Future Impact on Galactic and Extragalactic Extended Objects

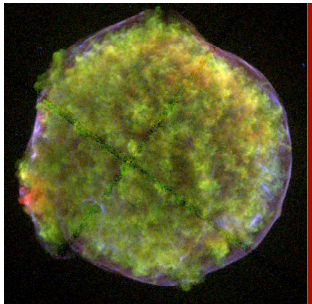
John P. Hughes

Rutgers University

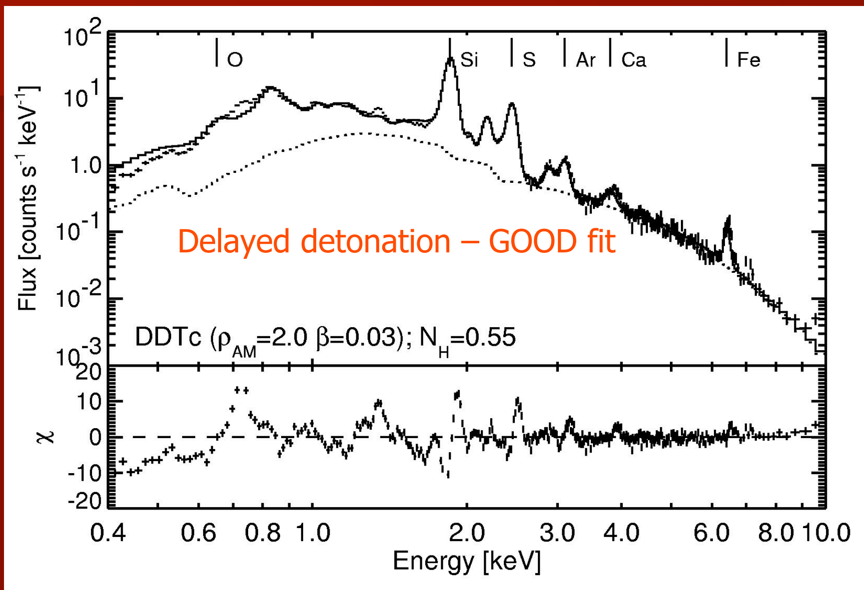
Galactic Extended Objects

- Solar wind charge exchange (Posters: Ezoe, 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

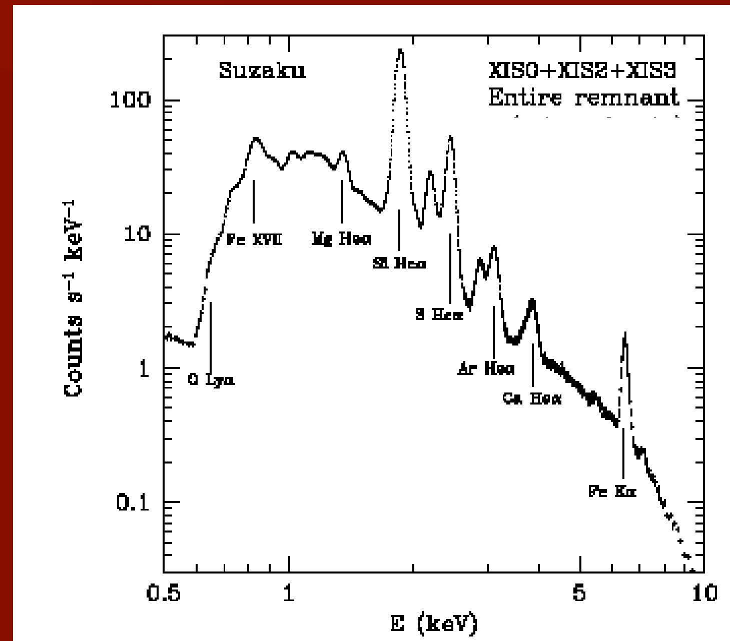


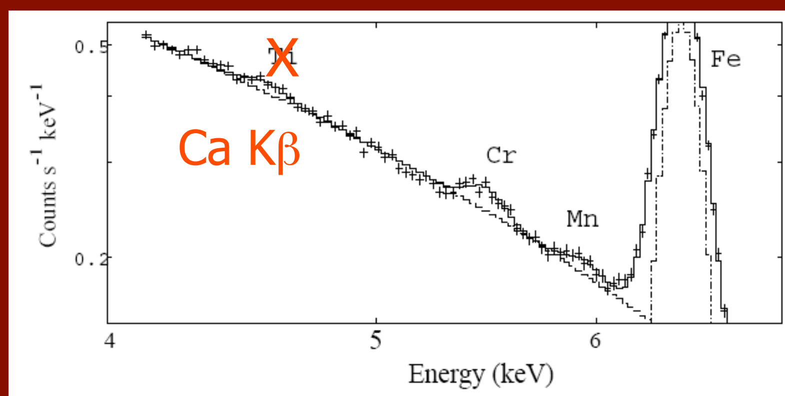
XMM-Newton (MOS)



Badenes et al 2006

Suzaku



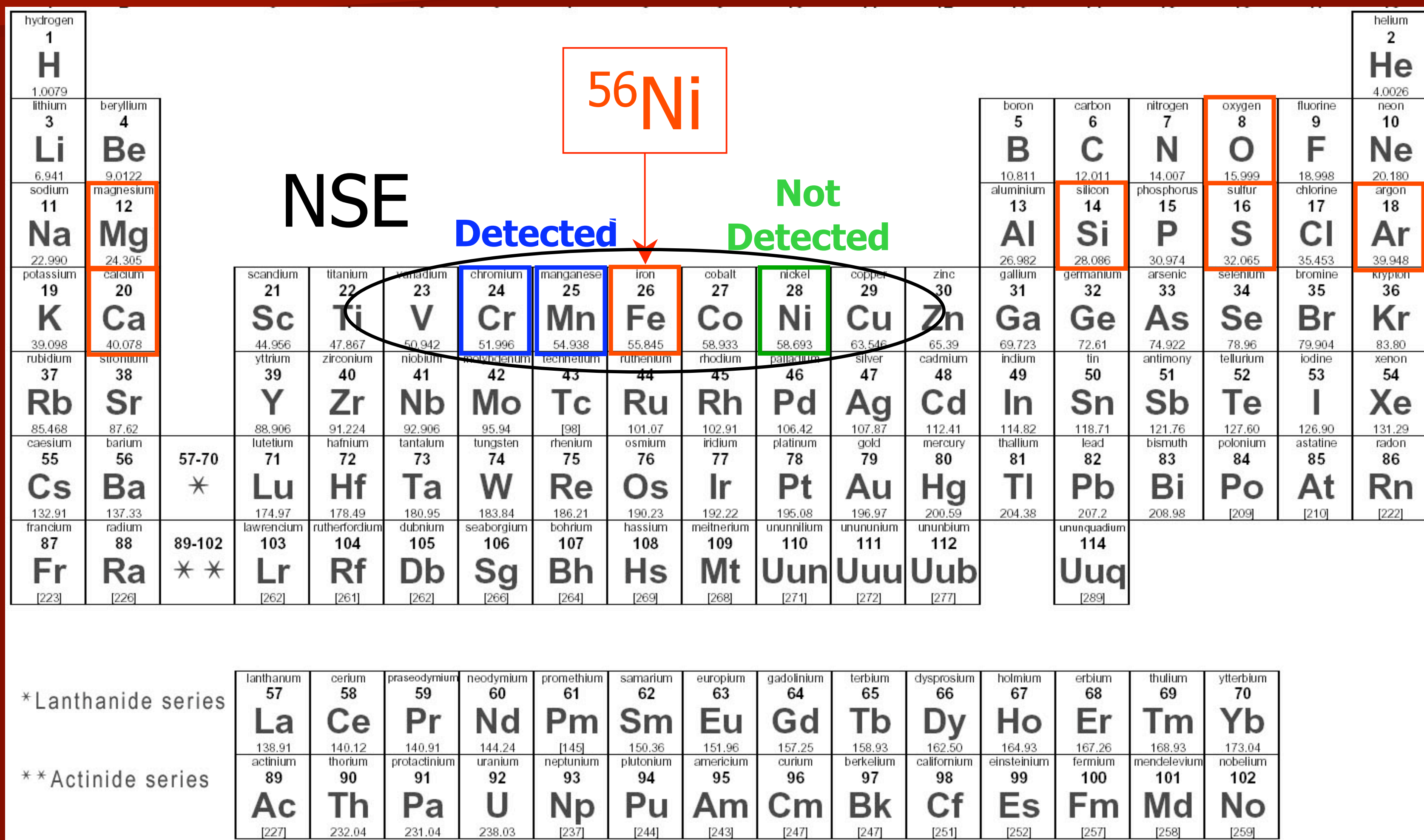


Tamagawa et al 2007

Hayato et al 2007

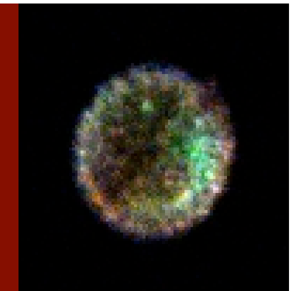
Fe-peak Elements in Tycho

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



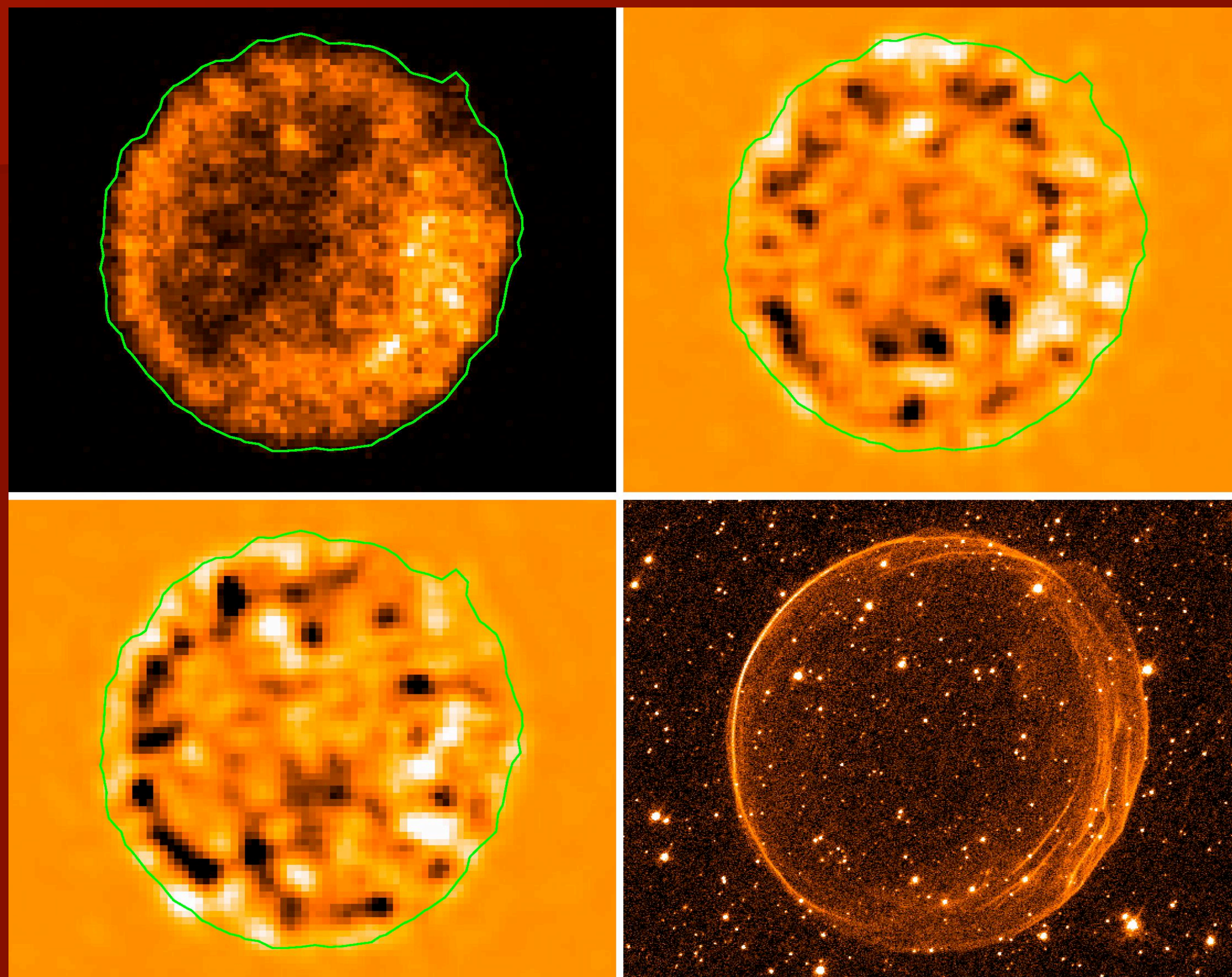
Bulk motion of SNR 0509-67.5

A Spectroscopically Confirmed SN Ia



Chandra

Chandra: Epoch2a – Epoch 1



Chandra: Epoch2b – Epoch 1

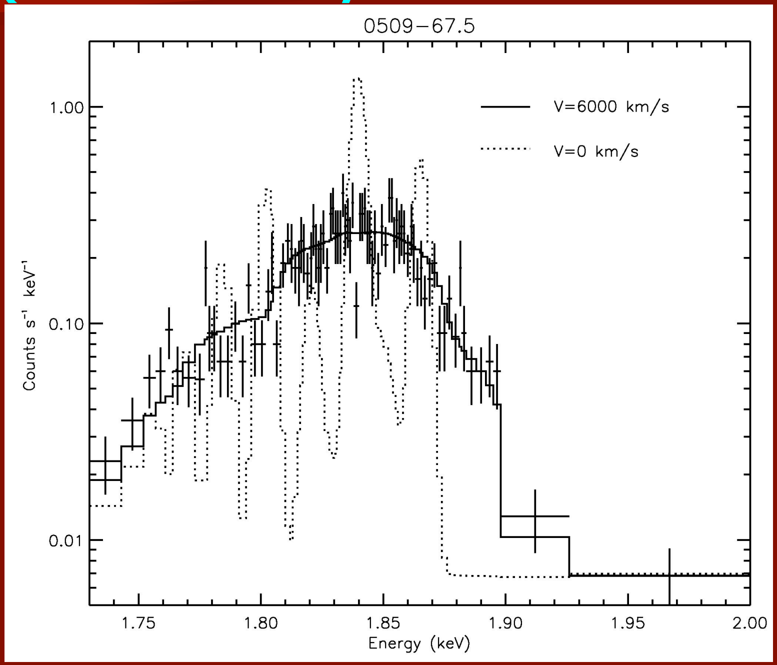
HST/ACS

Ejecta Expanding at ~6000 km/s

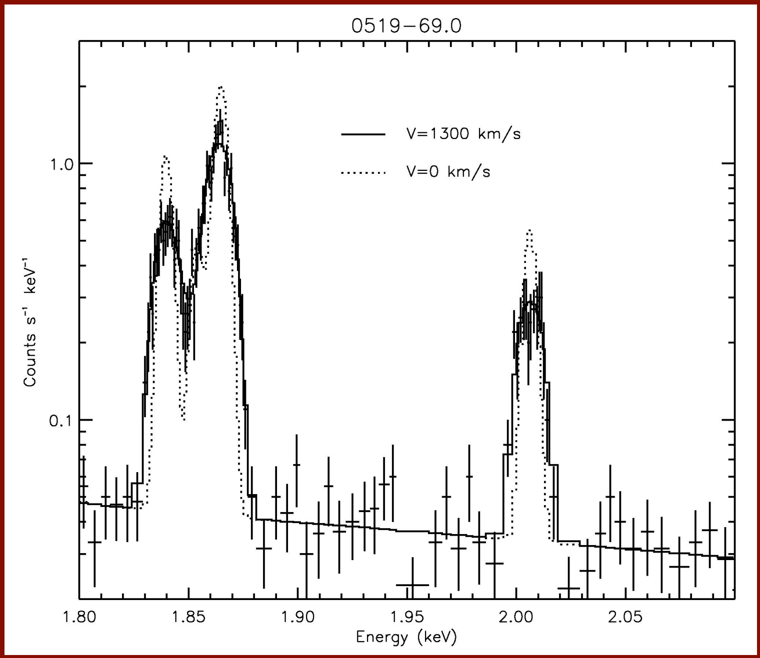
Hughes et al 2008, in prep

Implications for Suzaku

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



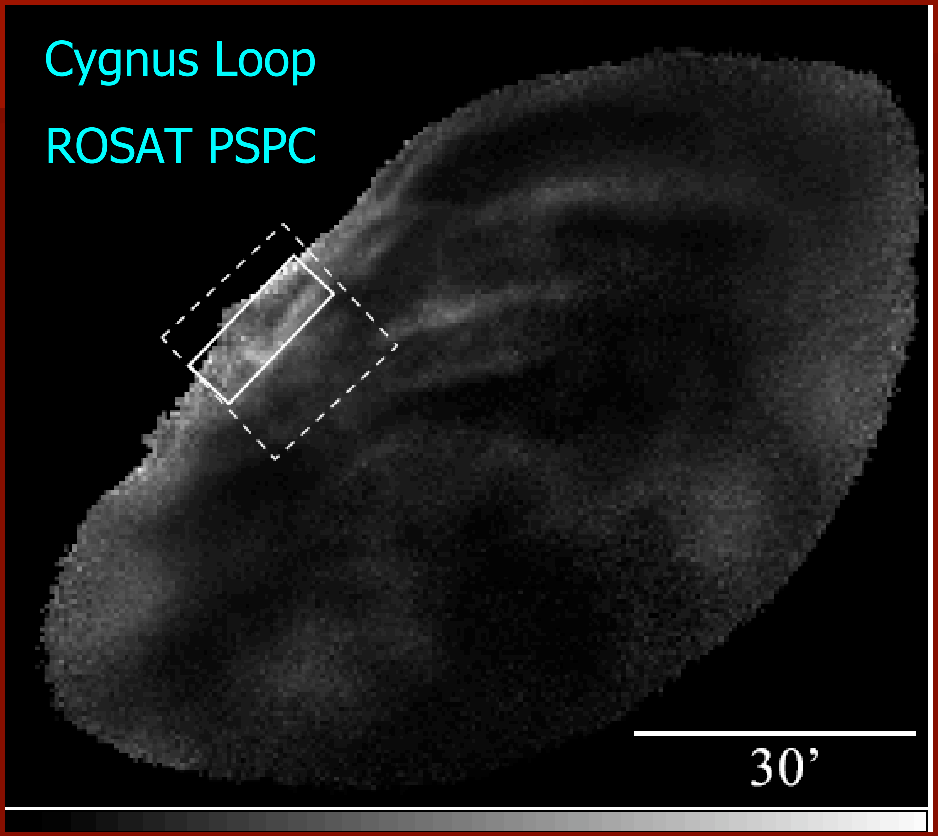
SNR 0509-67.5 6000 km/s



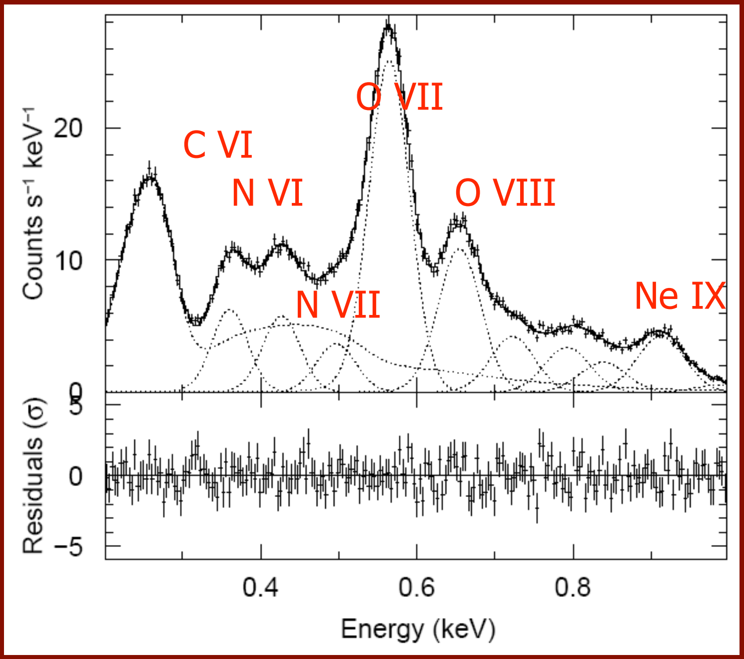
SNR 0519-69.0 1300 km/s

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



Extract Suzaku spectrum from softest region (solid white rectangle)



Band ratio map: _ keV to _ keV

Miyata, Masai, & JPH 2008, in press

Resonance Line Scattering in SNRs

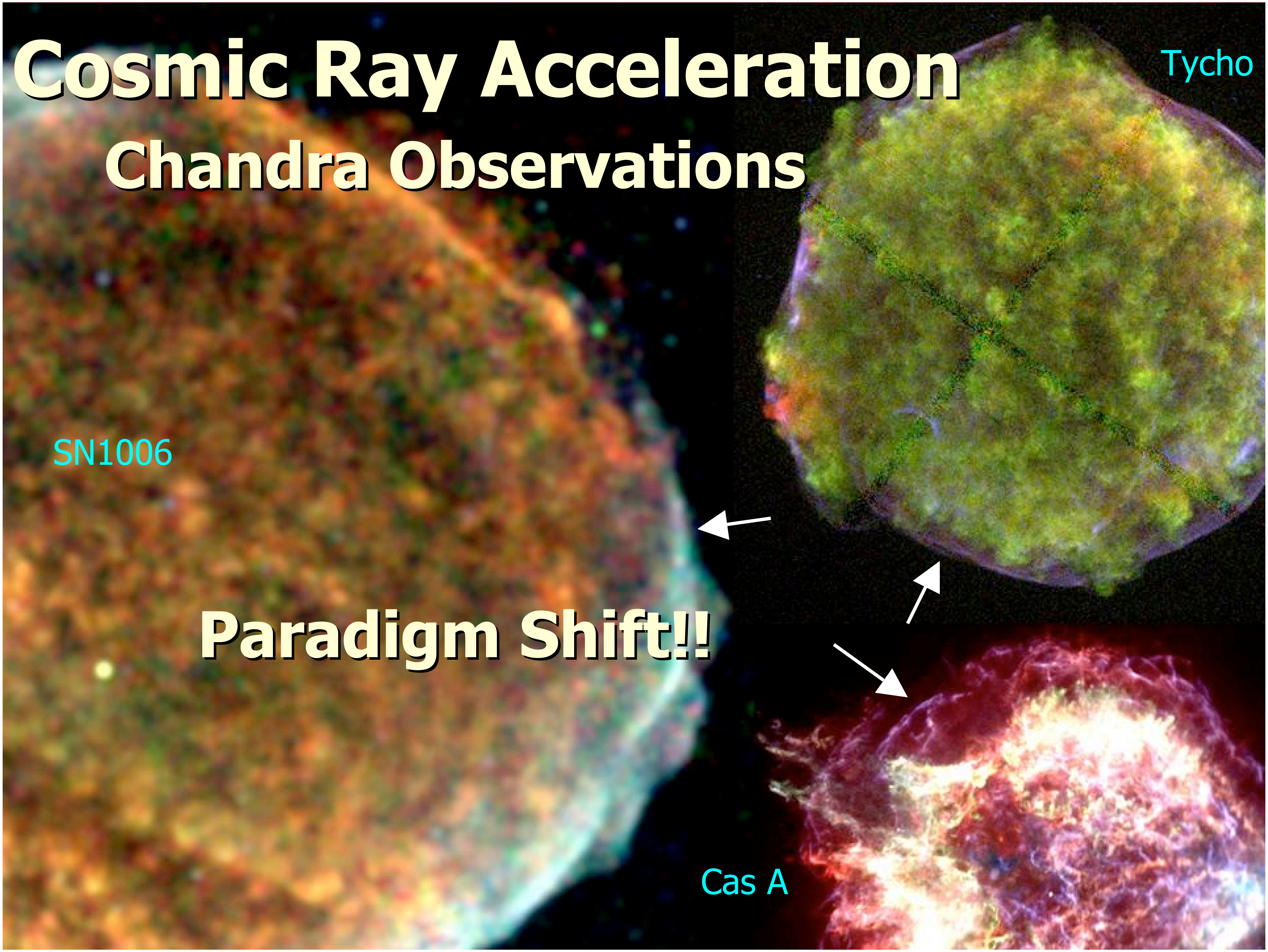
Suzaku
Cygnus Loop results

- 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 Kα	0.16	0.83
N VI Kα	0.11	0.87
O VII Kα	0.55	0.63
O VIII Lyα	0.20	0.80
Ne IX Kα	0.18	0.81

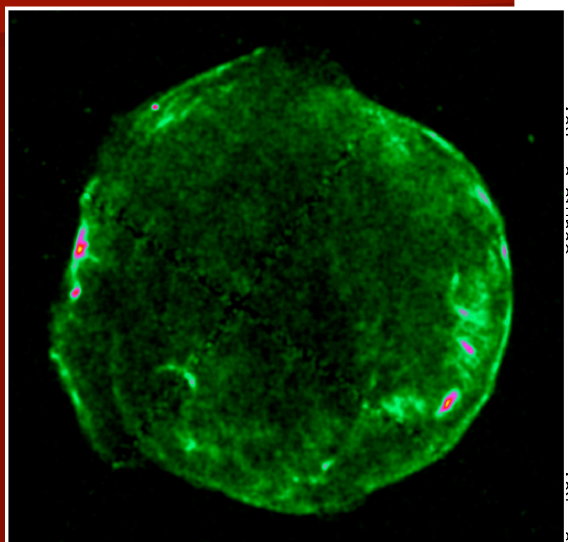
Cosmic Ray Acceleration

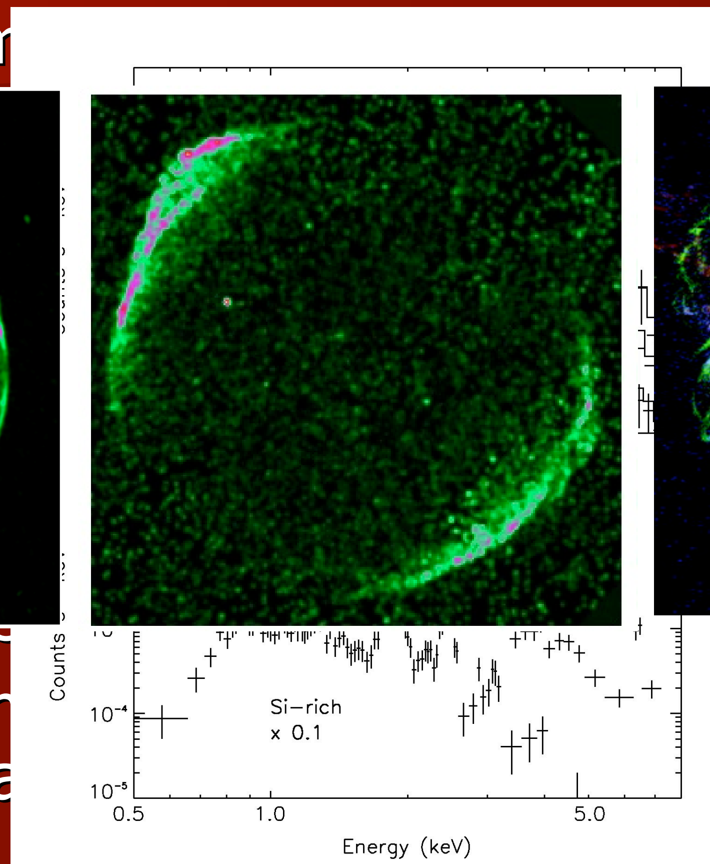
Chandra Observations

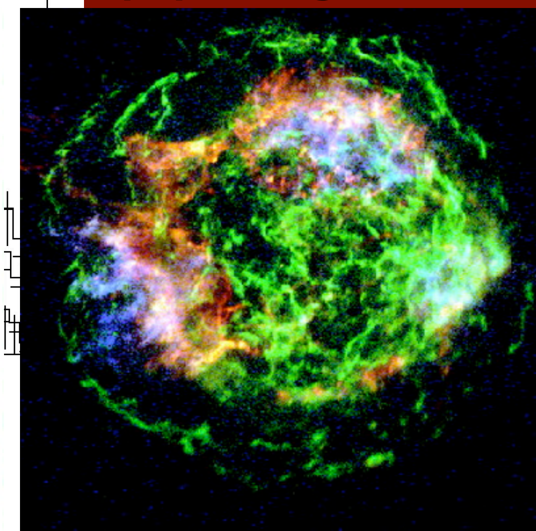


Chandra results on cosmic ray electrons

- Thin nontherm ny young SNRs







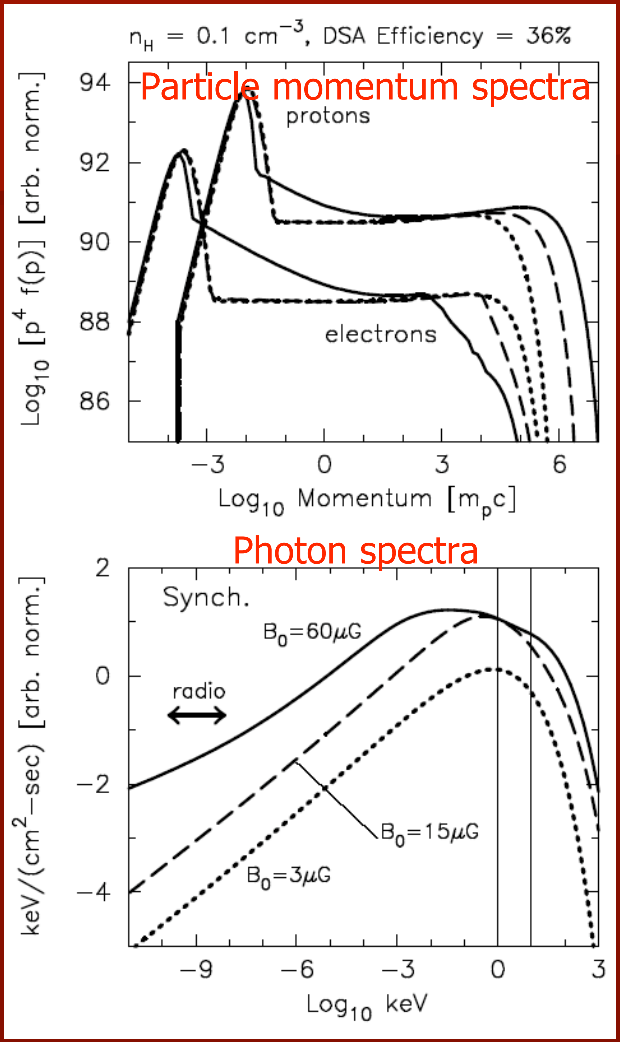
4

py

power law spe

- Various morph nd rim (Tycho), only partially a sets of filaments (Cas A)
- Strong evidence for TeV energy electrons

Suzaku Impact



Ellison et al. 2007

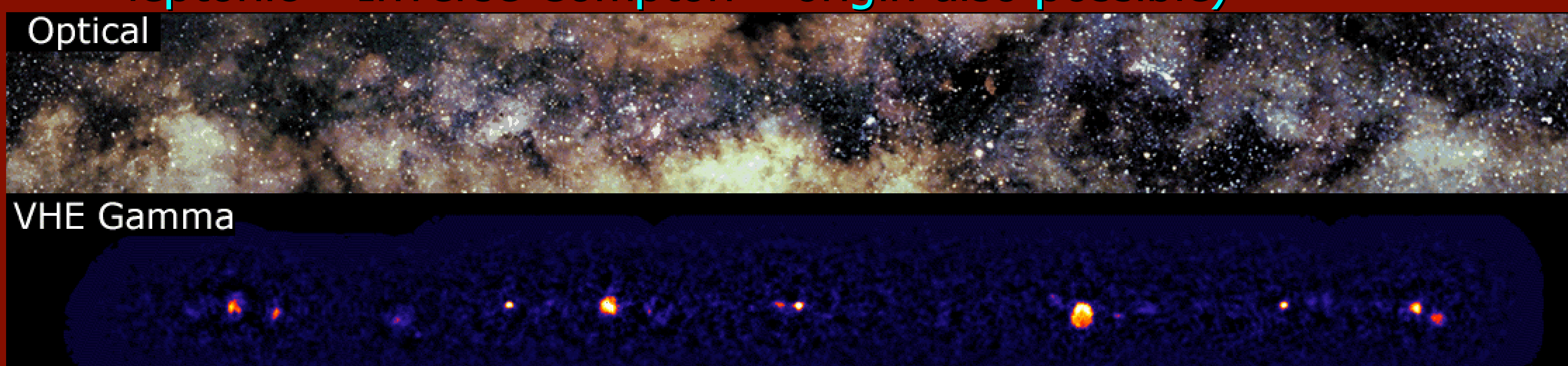
CR Acceleration Models

- *Top panel* - Model proton (top) and electron (bottom) spectra for B_0 = 3 μG (dotted), 15 μG (dashed), and 60 μG (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

HESS: High Energy Stereoscopic System

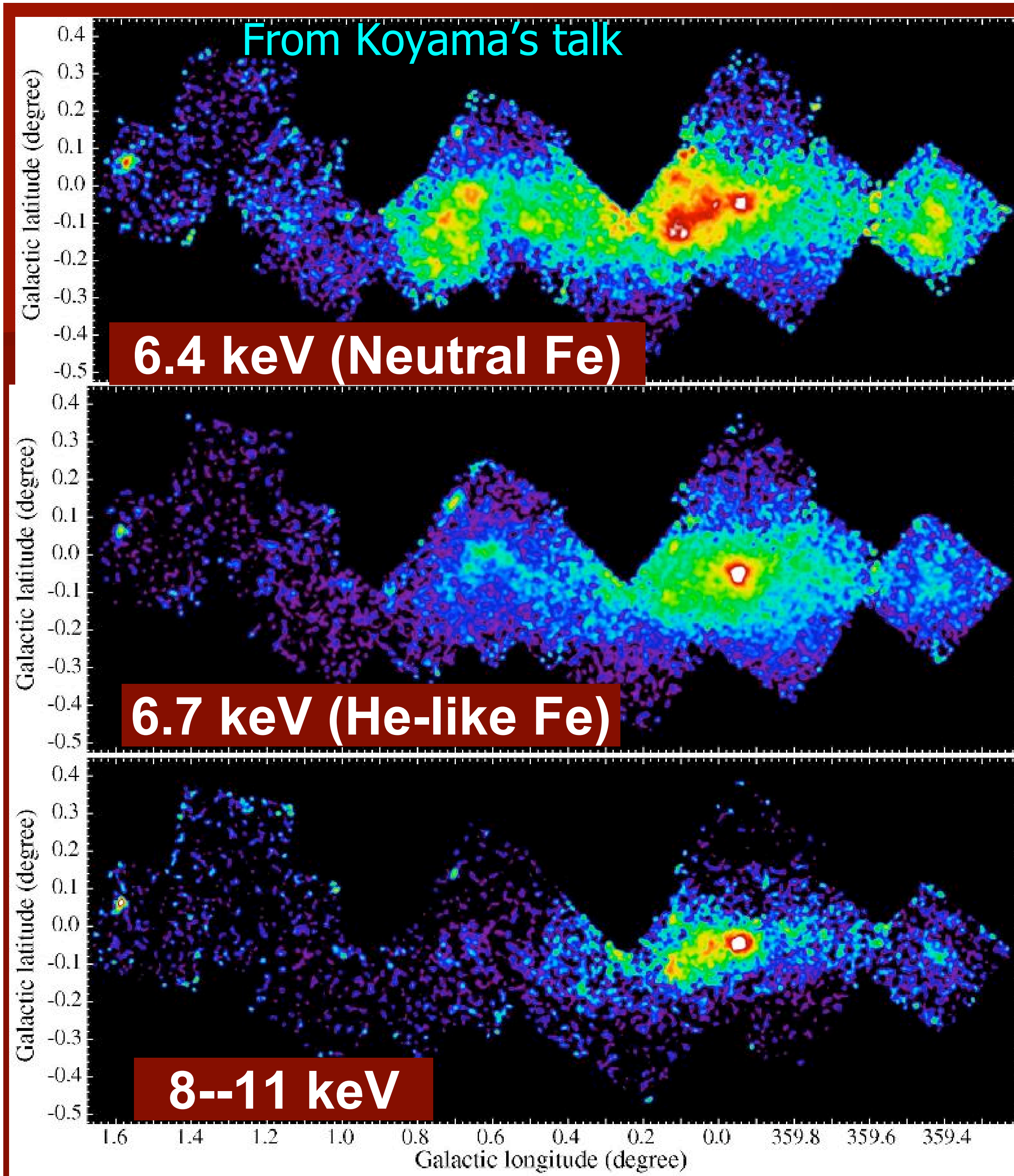
Imaging Atmospheric Cerenkov Telescope (Namibia, Africa)

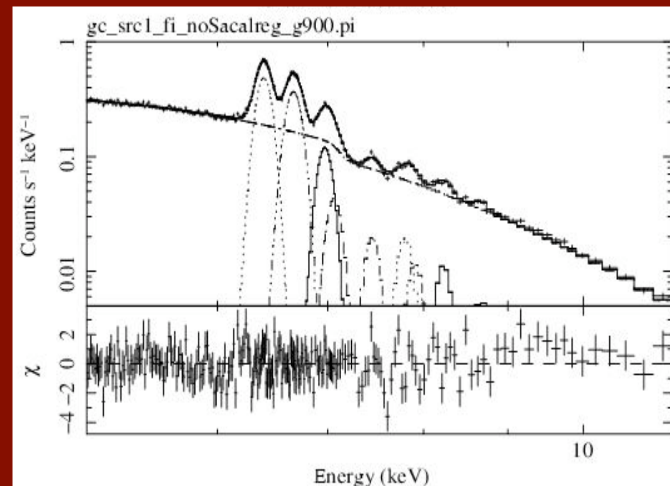
- Sensitive to 100 GeV γ-rays
  - Spatially resolved images – Galactic plane survey – new sources
  - Potential to observe π^0-decay signal from CR protons (but leptonic – Inverse Compton – origin also possible)



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

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





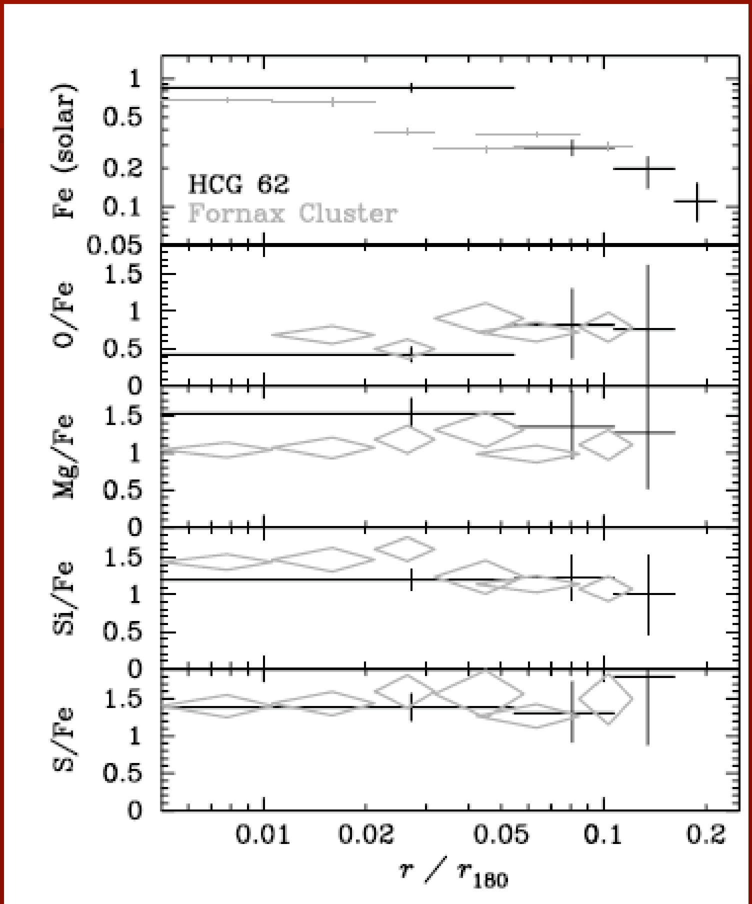
GC – hot thermal plasma – confinement, heating mechanism?

GR – likely point sources

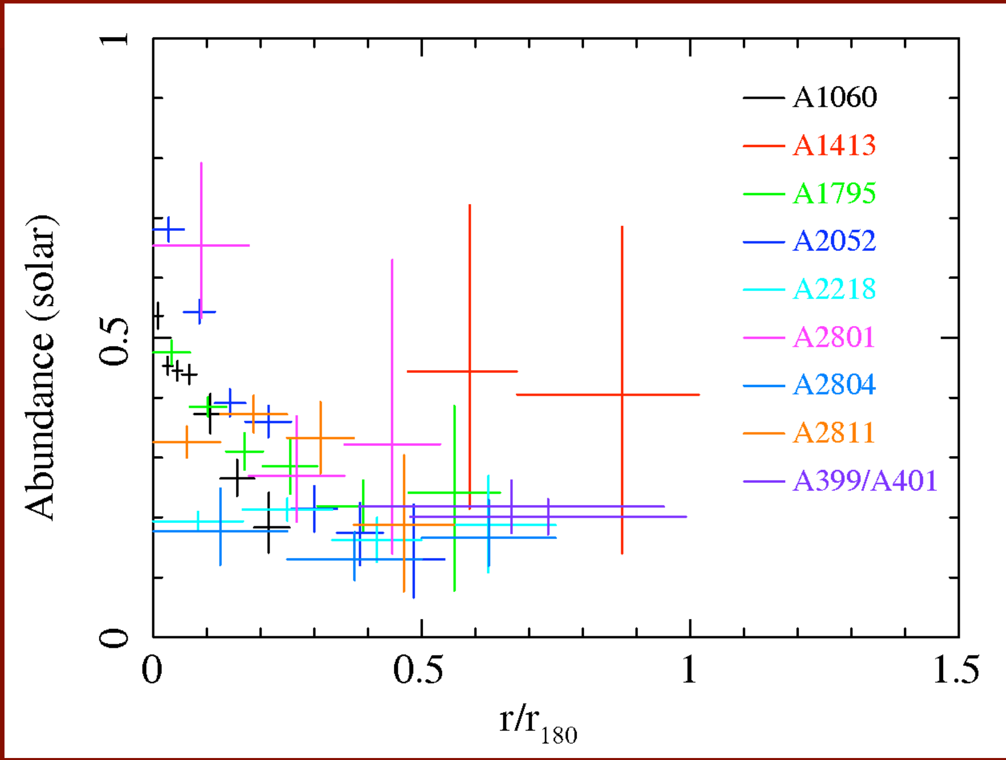
Extragalactic Extended Objects

- Galaxy groups (Loewenstein talk, Poster: Miller)
- Cluster abundance measurements (Sato talk, Posters: Tawa,Tokoi)
- Mass measurements (Henry talk, Posters: Ettori)
  - 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



Matsushita et al 2007
Tokoi et al 2008

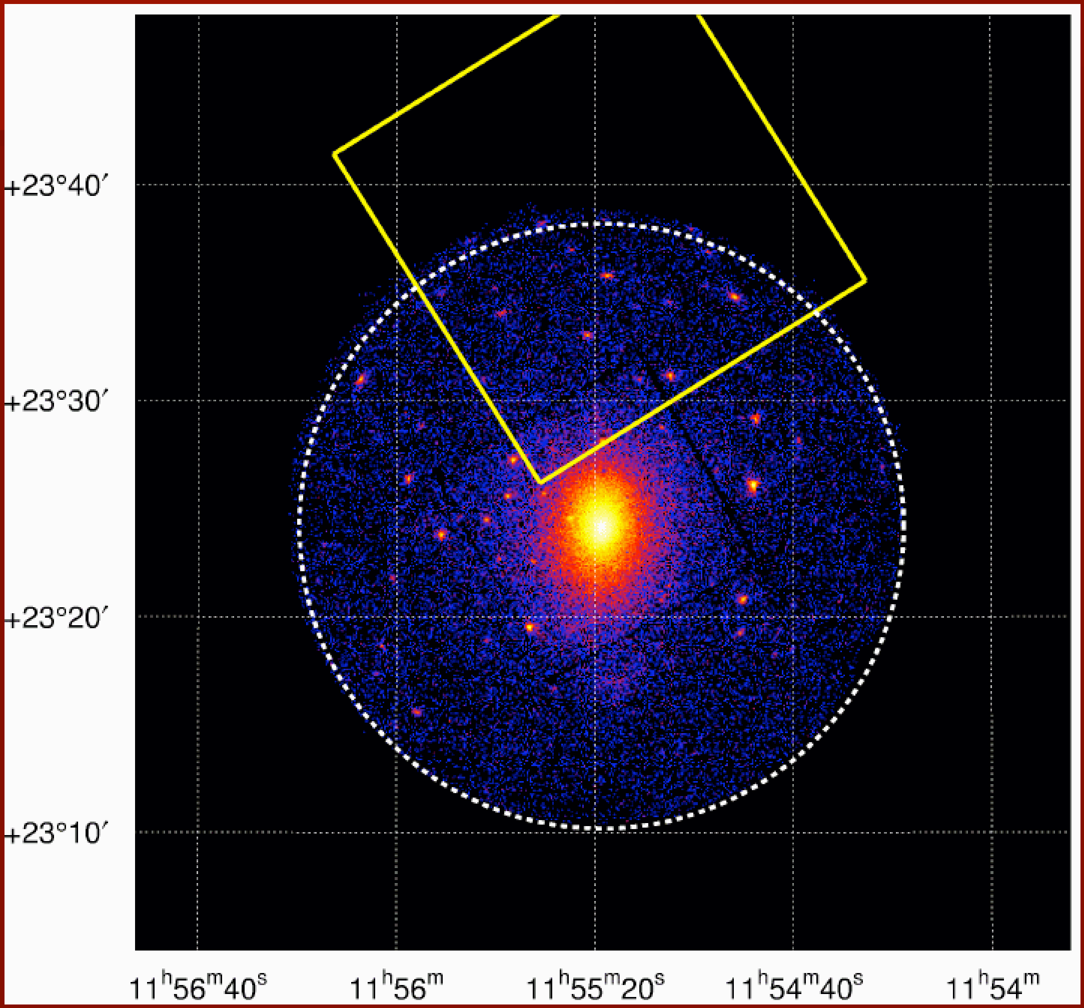


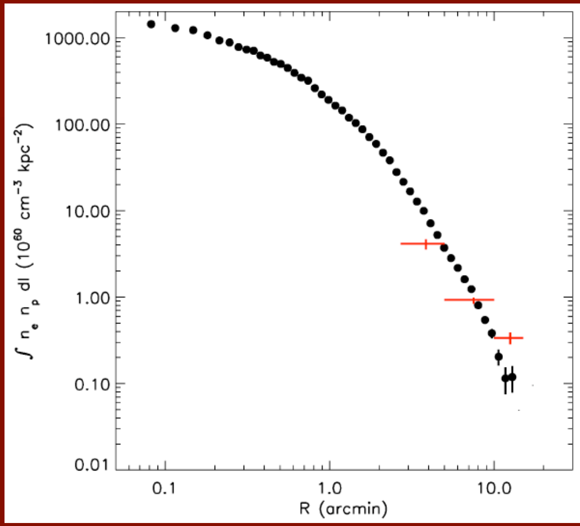
Tawa et al., in prep (From Henry's talk)

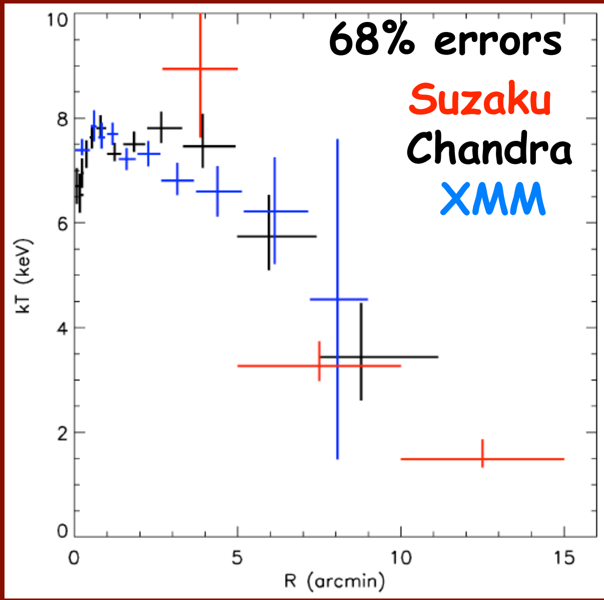
From Henry's talk

A1413: Mass to R_{vir}

(Hoshino et al. in preparation)



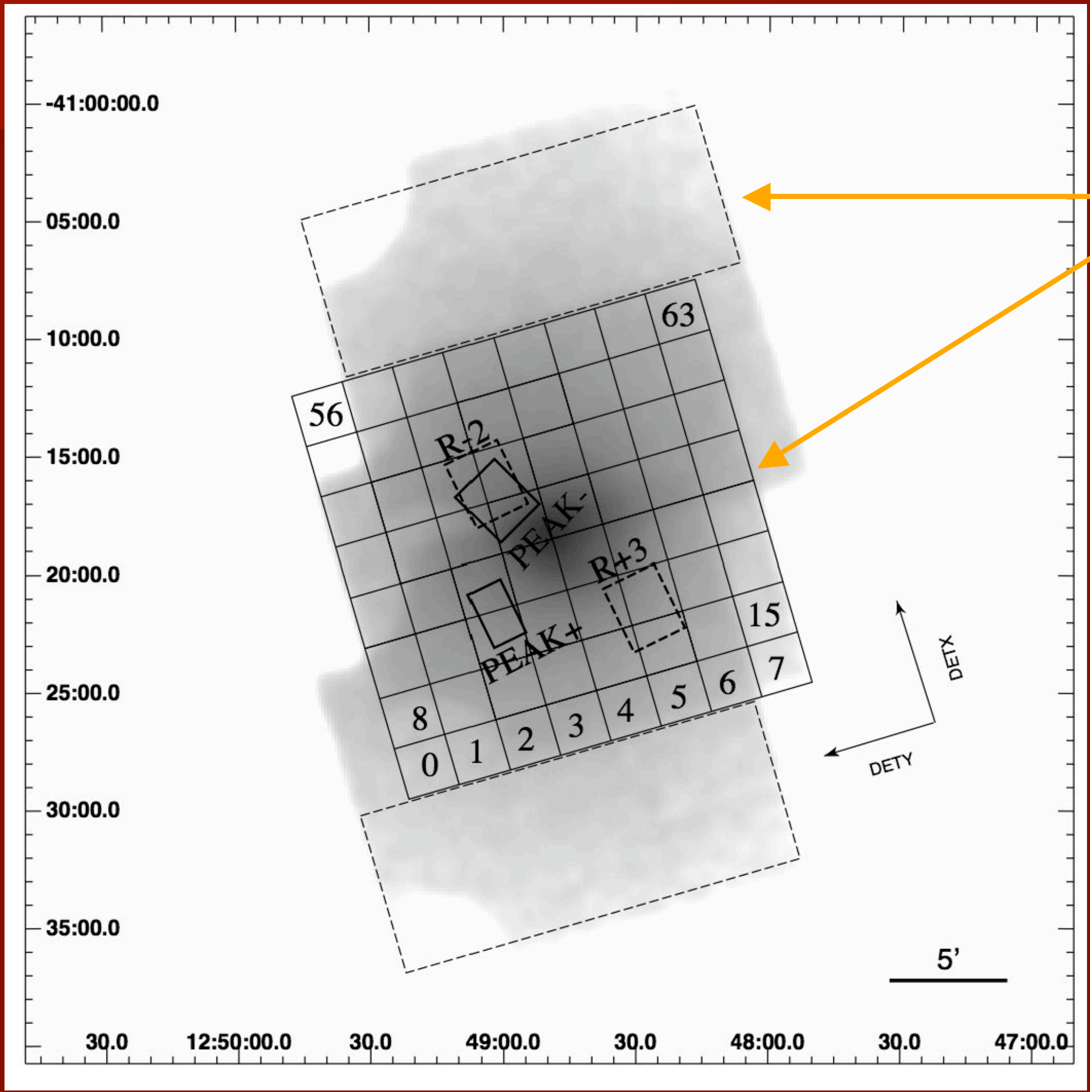




From Henry's talk

Suzaku constraints on bulk flows

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



Δv < 1400 km s^{-1} (90% confidence) on scales of 135 h_{70}^{-1} kpc

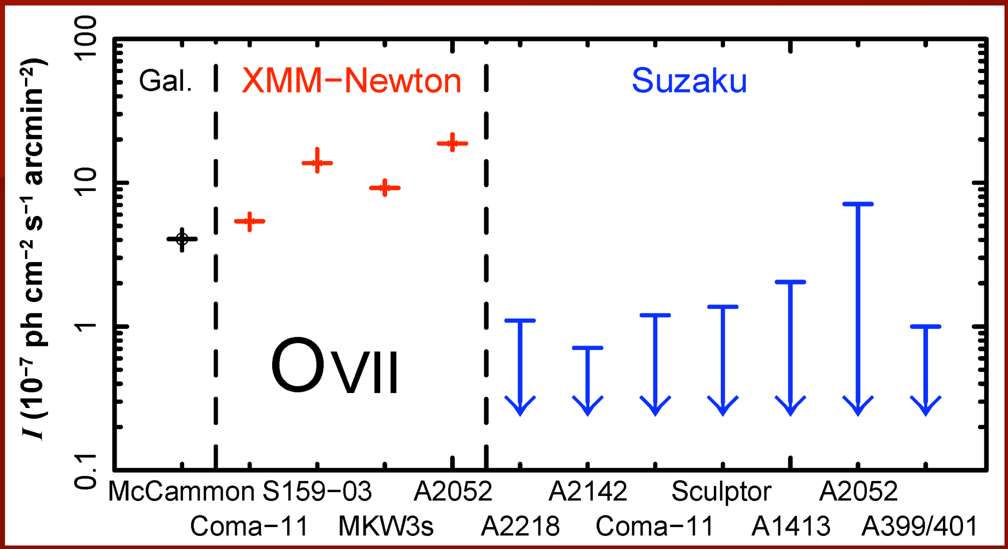
Does not confirm Chandra

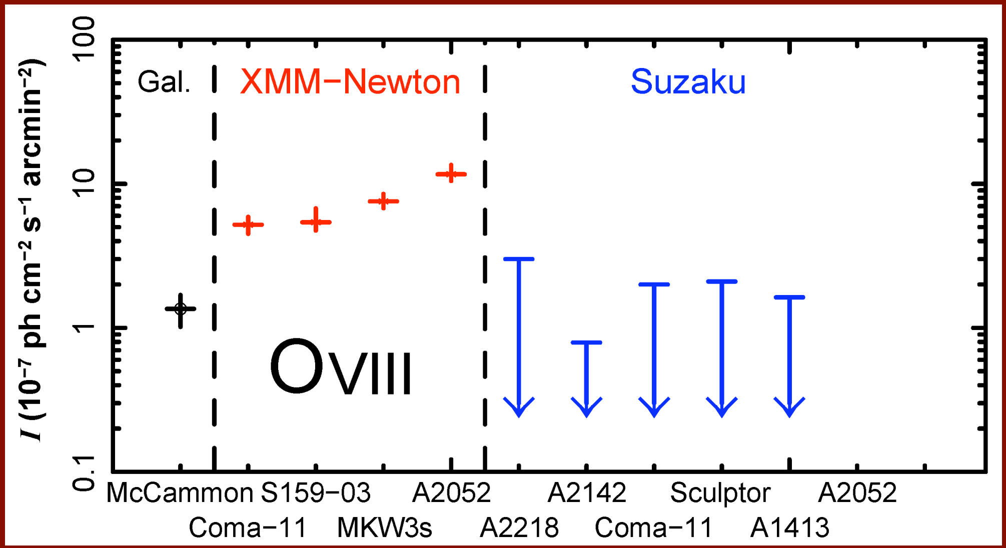
Region	Suzaku/XIS	Chandra/ACIS
	Δv (km s^{-1}) *	Δv (km s^{-1}) †
PEAK−, PEAK+	-660 ± 390 (± 660)	2900 ± 700
R−2, R+3	-540 ± 360 (± 660)	2400 ± 1000

*The velocity difference derived from the XIS spectra. The 68% statistical errors and (the 68% systematic errors) are quoted.
†The velocity difference and the 1 σ 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

Suzaku can not measure Y_x due to spatial resolution

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

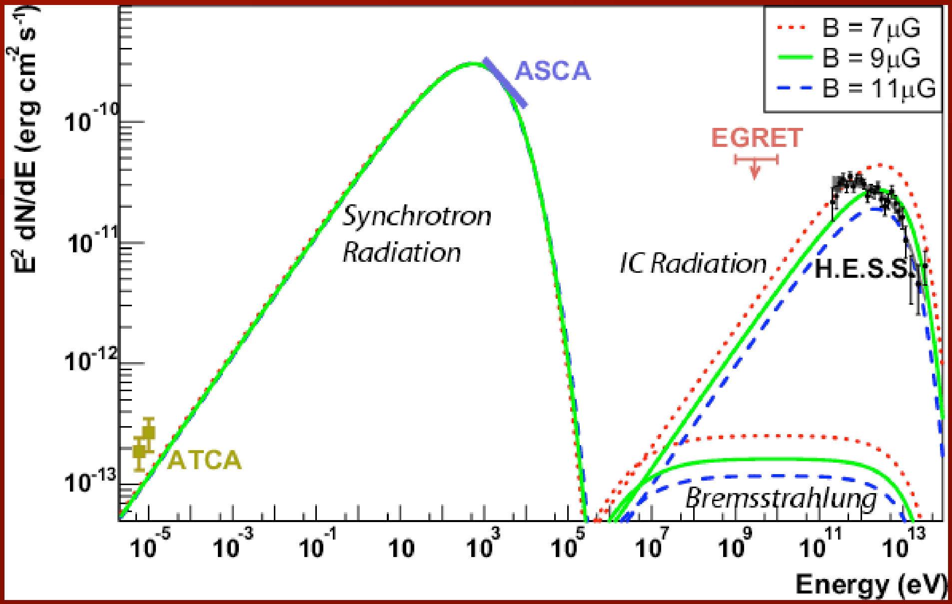
Very large (few 10^6 s), multi-year, key projects?

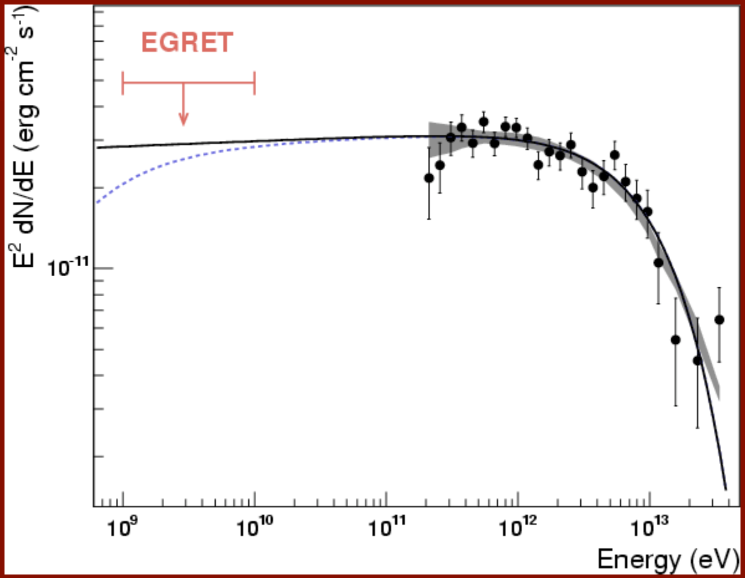
Galactic Extended Objects

- 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)





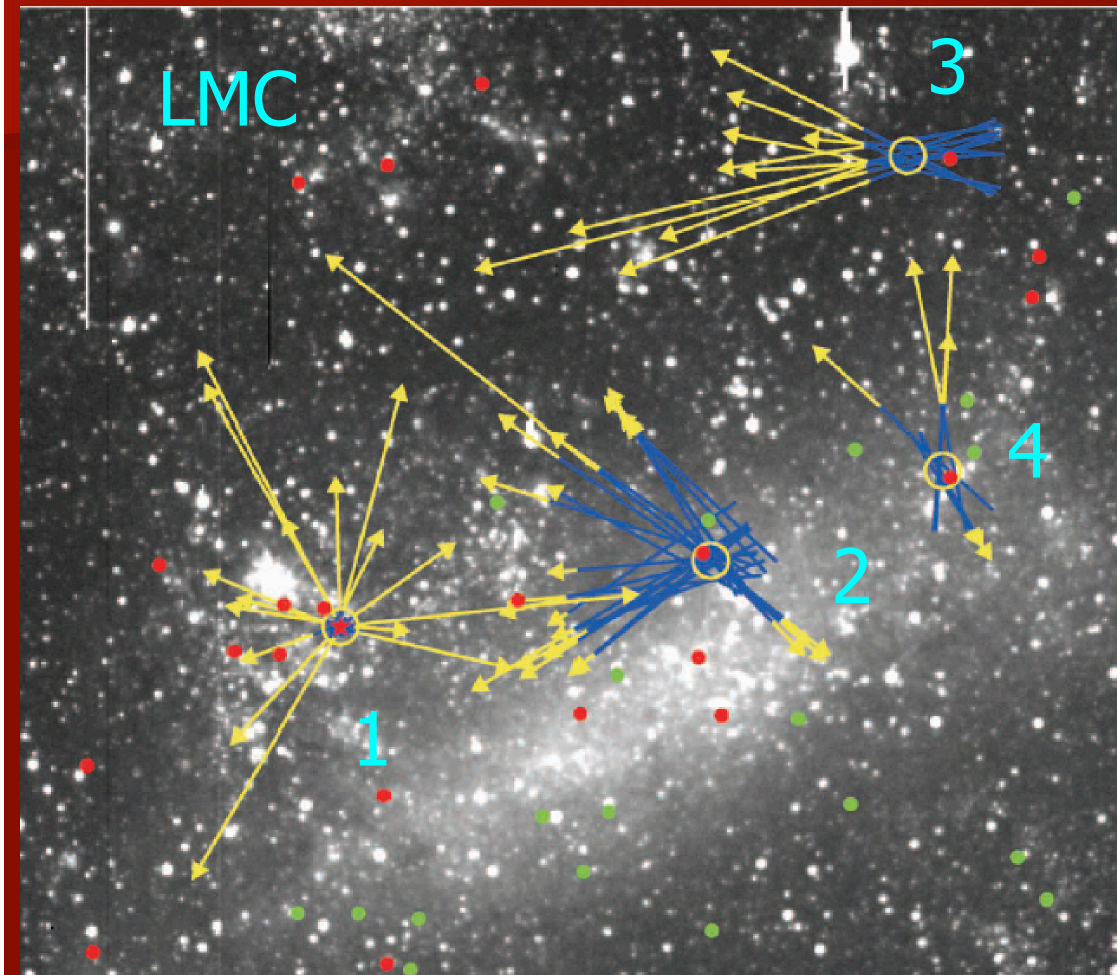
Inverse Compton Interpretation

- 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

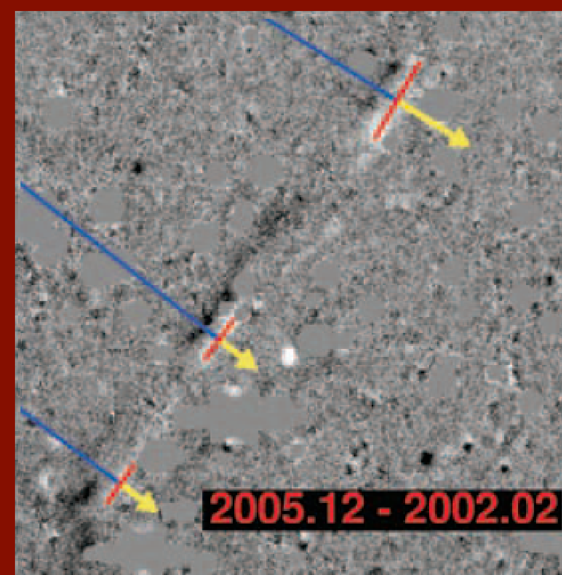
SNR 0509-67.5: A Spectroscopically Confirmed SN Ia



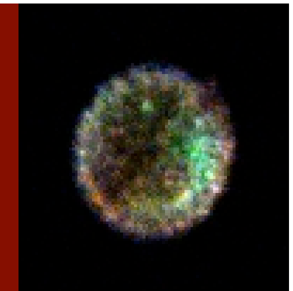
Rest et al 2005

Light Echoes from Old or Ancient LMC SNe

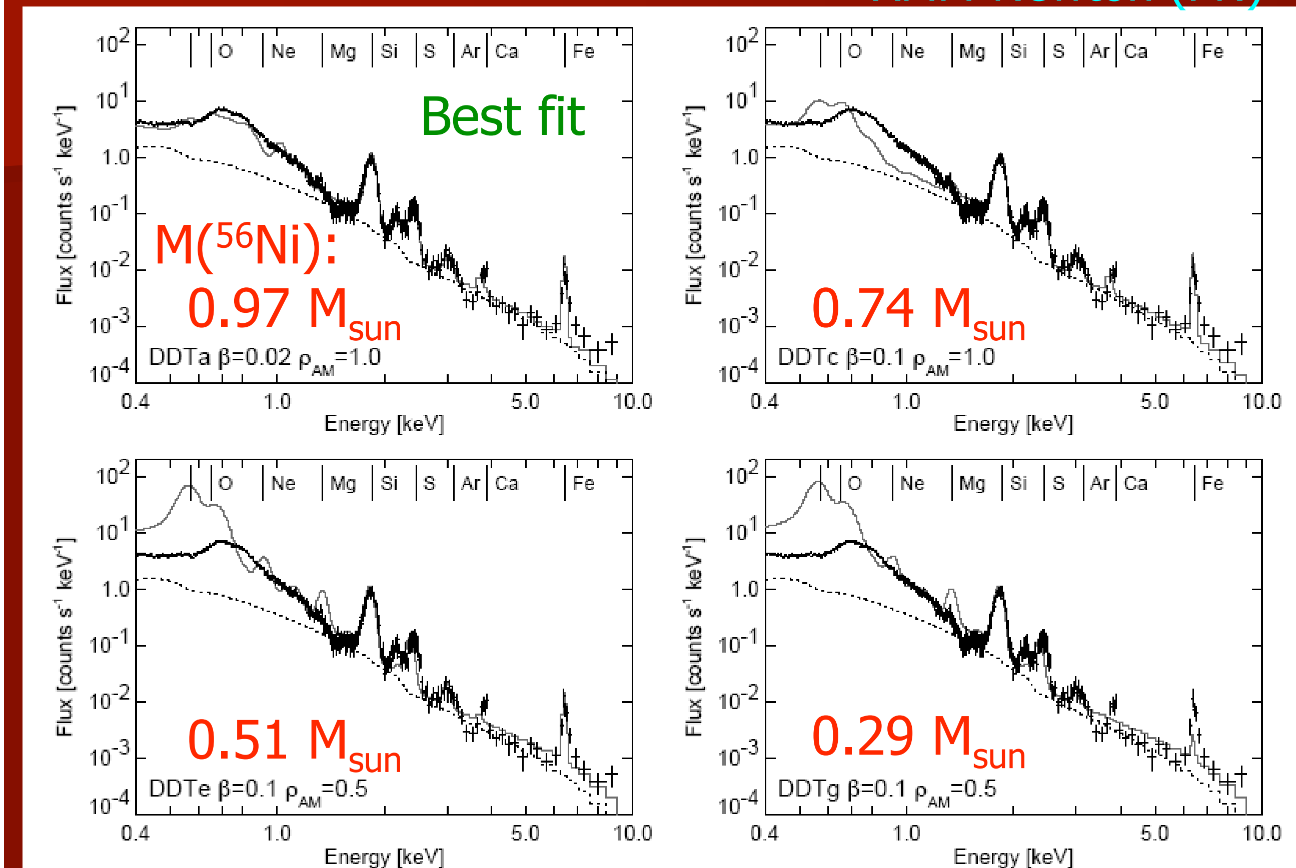
- 1) SN1987A 15 yrs
- 2) 0519-69.0 600 yrs
- 3) 0509-67.5 400 yrs
- 4) N103B 900 yrs



SNR 0509-67.5: X-ray Spectrum



XMM-Newton (PN)



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

Constraints

- Line Centroids
  - Si Kα
  - S Kα
  - Fe Kα
- Flux Ratios
  - O Kα/Si Kα
  - Fe L/Si Kα
  - Fe Kα/Si Kα

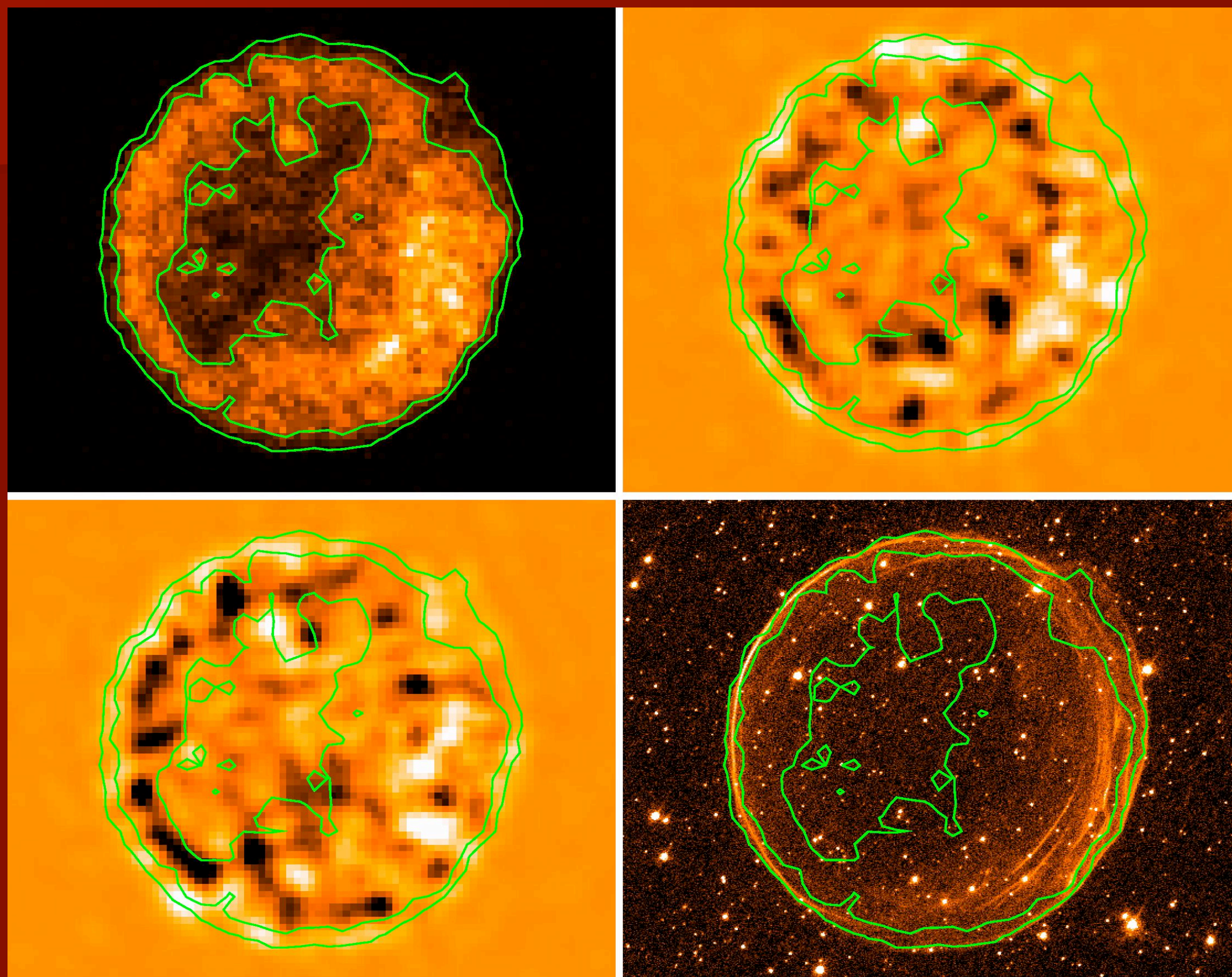
SNR 0509-67.5 is SN1991T-like

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

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Hughes et al
2008, in prep