

銀河面からのX線放射

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Contents

- X-ray emission from Galactic plane
 - 1980's to ASCA
- Our Chandra results
- Origin of the dimmest Galactic Point sources
 - Chandra and follow-up near-infrared results
- Discovery of discrete and extended sources
 - With ASCA and Chandra
- Origin of the Galactic diffuse X-ray emission

まとめ

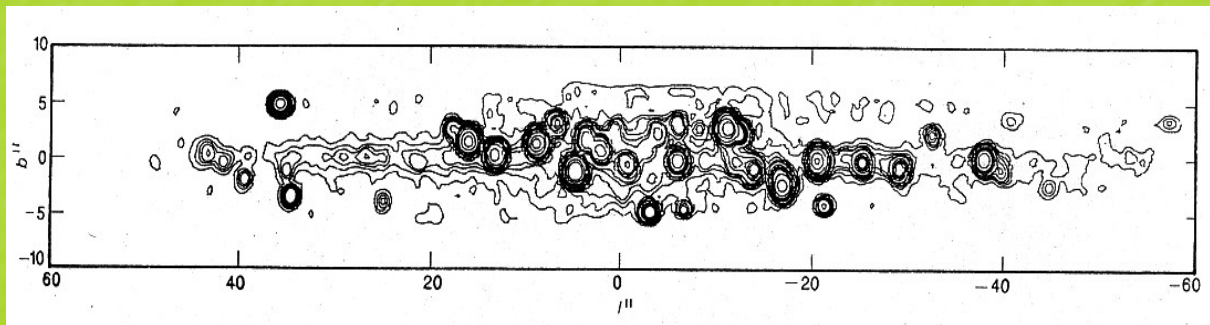
- 銀河面からのX線放射 (リッジ成分) は拡散成分
 - 点源の重ね合わせでは説明できない
 - 銀河円盤は高エネルギープラズマで満たされている
- 銀河面上のもっとも暗いX線点源の分類
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- リッジ成分の起源は謎
 - ガンマ線成分とスペクトルがほぼつながる
 - 熱的成分、非熱的成分の共存
 - X線による鉄ラインのプラズマ診断は非常に有用

Acknowledgments

- **Chandra Galactic plane observation**
 - Bamba, A., Hamaguchi, K., Kaneda, H., Maeda, Y., Paizis, A., Sato, G., Senda, A., Ueno, M. and Yamauchi, S.
- **ASCA Galactic survey**
 - Kaneda, H., Kinugasa, K., Kokubun, M., Koyama, K., Maeda, Y., Matsuzaki, K., Mitsuda, K., Murakami, H., Torii, K., Sakano, M. and Sugizaki, M.
- **ESO / NTT observation**
 - Tsujimoto, M., Nishihara, E., Beckman, V., Dubah, P. and Courvoisier, T.

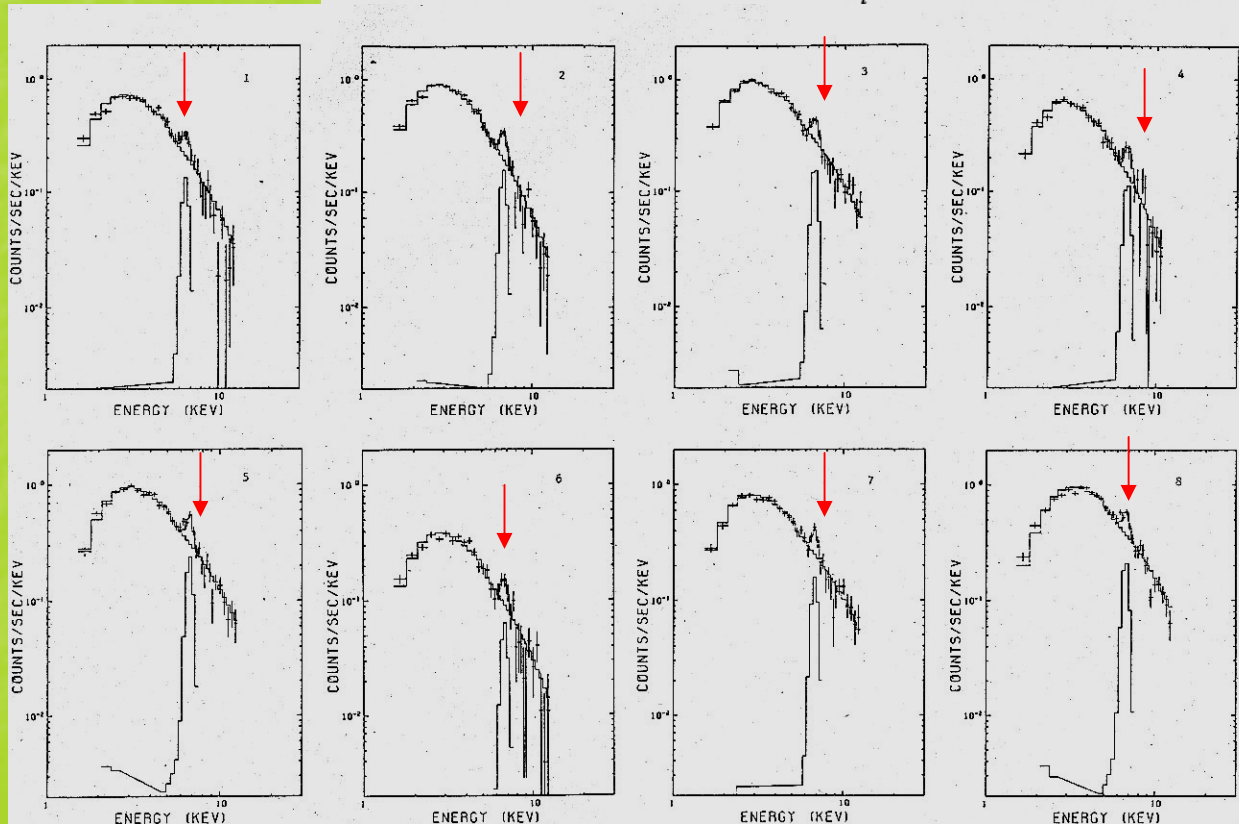
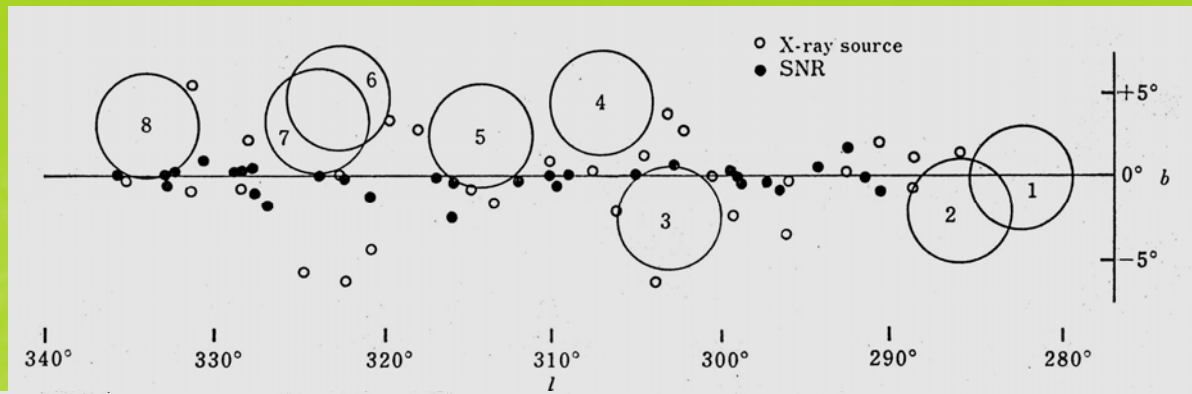
Galactic survey with non-imaging instruments

- **HEAO1 detection of the Galactic “Ridge” emission (Worrall et al. 1982)**
 - Total luminosity $\sim 1.4 \times 10^{38} \text{ erg s}^{-1}$
 - Energy spectrum “softer” than Cosmic X-ray BGD
- **EXOSAT Galactic plane scan (Warwick et al. 1985)**



Presence of the Galactic “Ridge” and “Bulge” emission

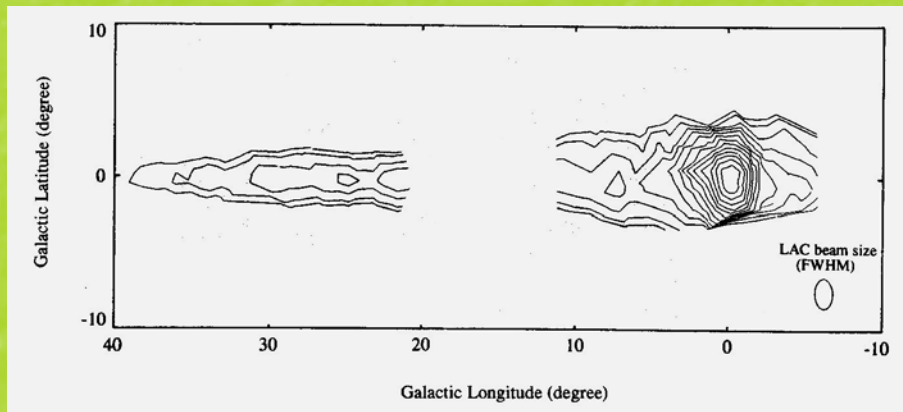
Tenma observation (Koyama et al. 1986)



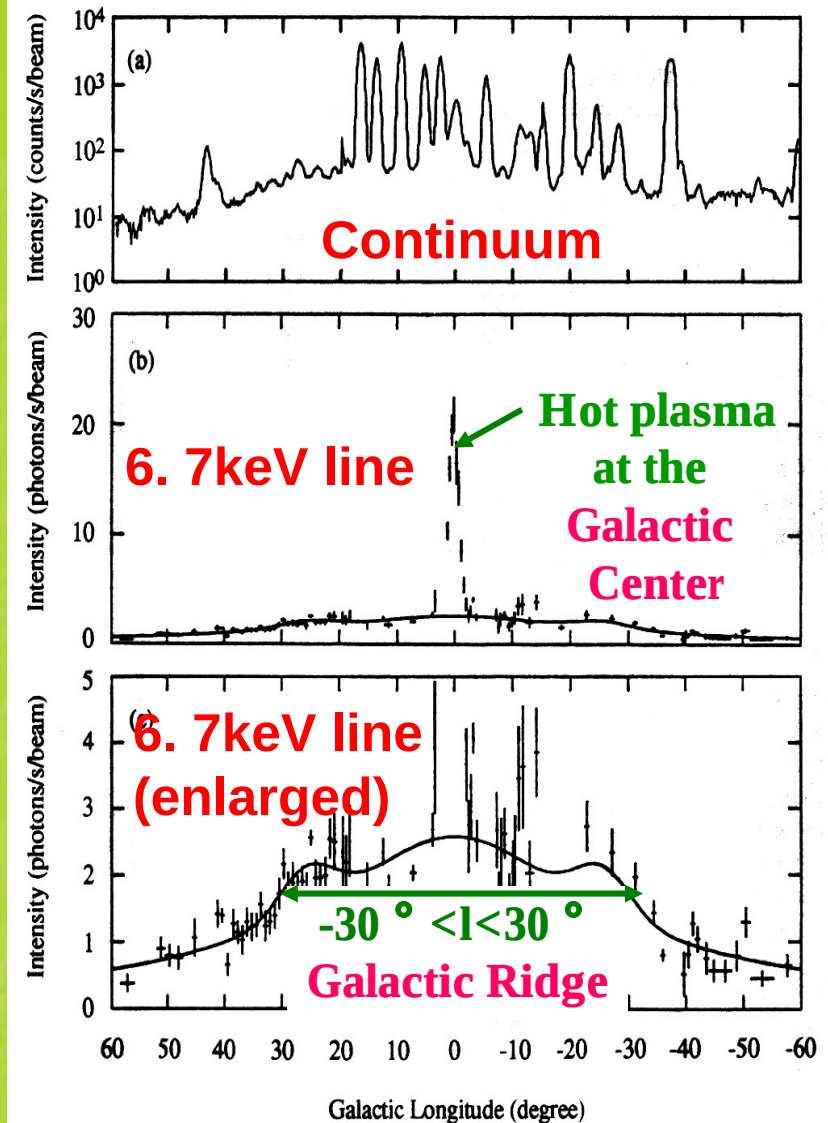
6.7 keV iron line emission → hot plasma emission
Temperature of the plasma $kT \sim 6 - 10$ keV

Ginga Galactic plane scan (Yamauchi and Koyama 1993)

6.7 keV Fe-line mapping

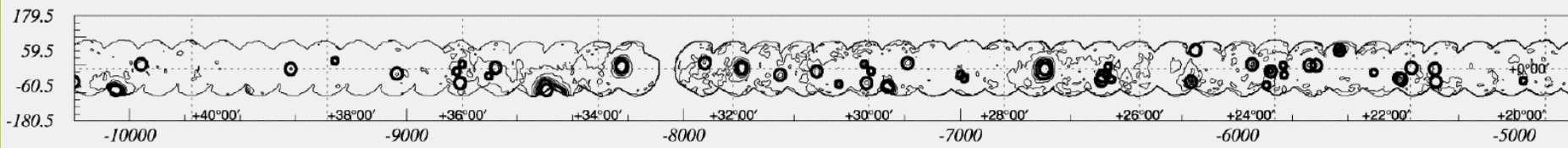


6.7 keV line is a good tracer
of thin hot plasma



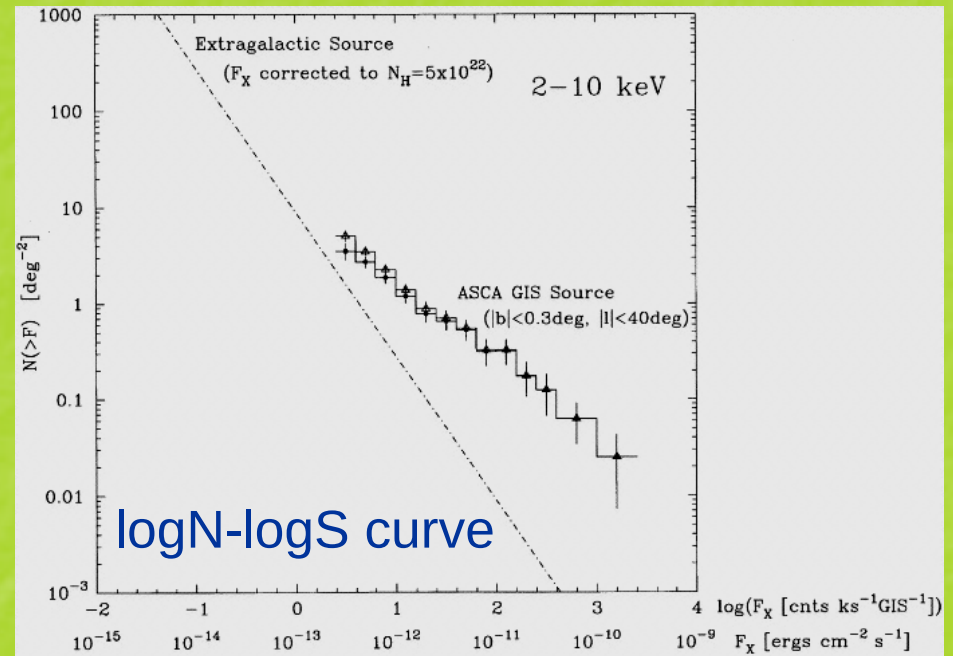
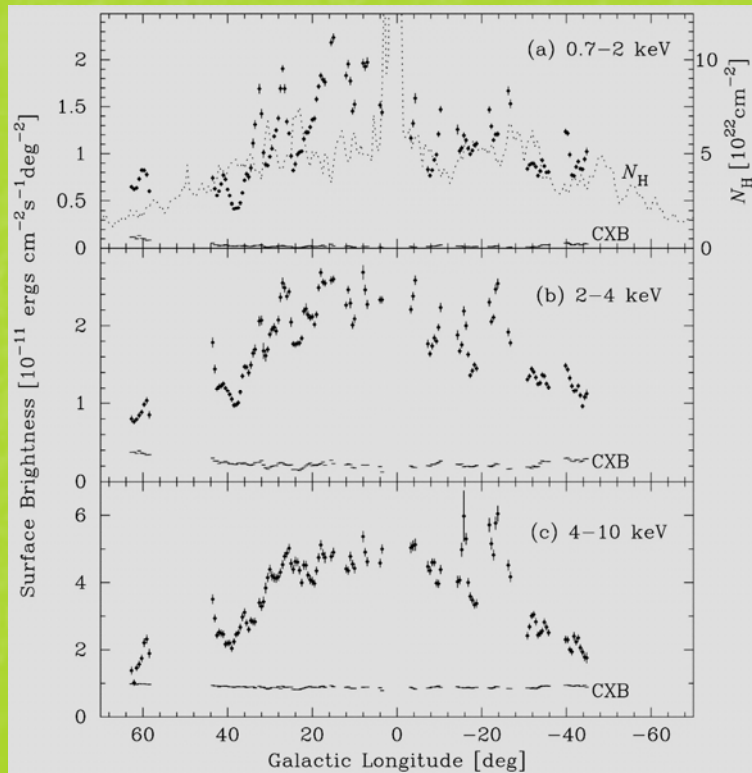
- **Hard X-ray plasma emission from the Milky way Galaxy (established in 1980's)**
 - Truly diffuse plasma?
 - Superposition of numerous point sources?
 - *A big question for a long time...*
- **Hard X-ray **imaging** observation is essential**
 - Separate hard X-ray point sources from diffuse emission
 - Penetrate the heavy Galactic absorption

ASCA: First imaging satellite above ~ 2 keV



Galactic Plane Survey project ($-45^\circ < l < 45^\circ$)

(Sugizaki et al. 2001)

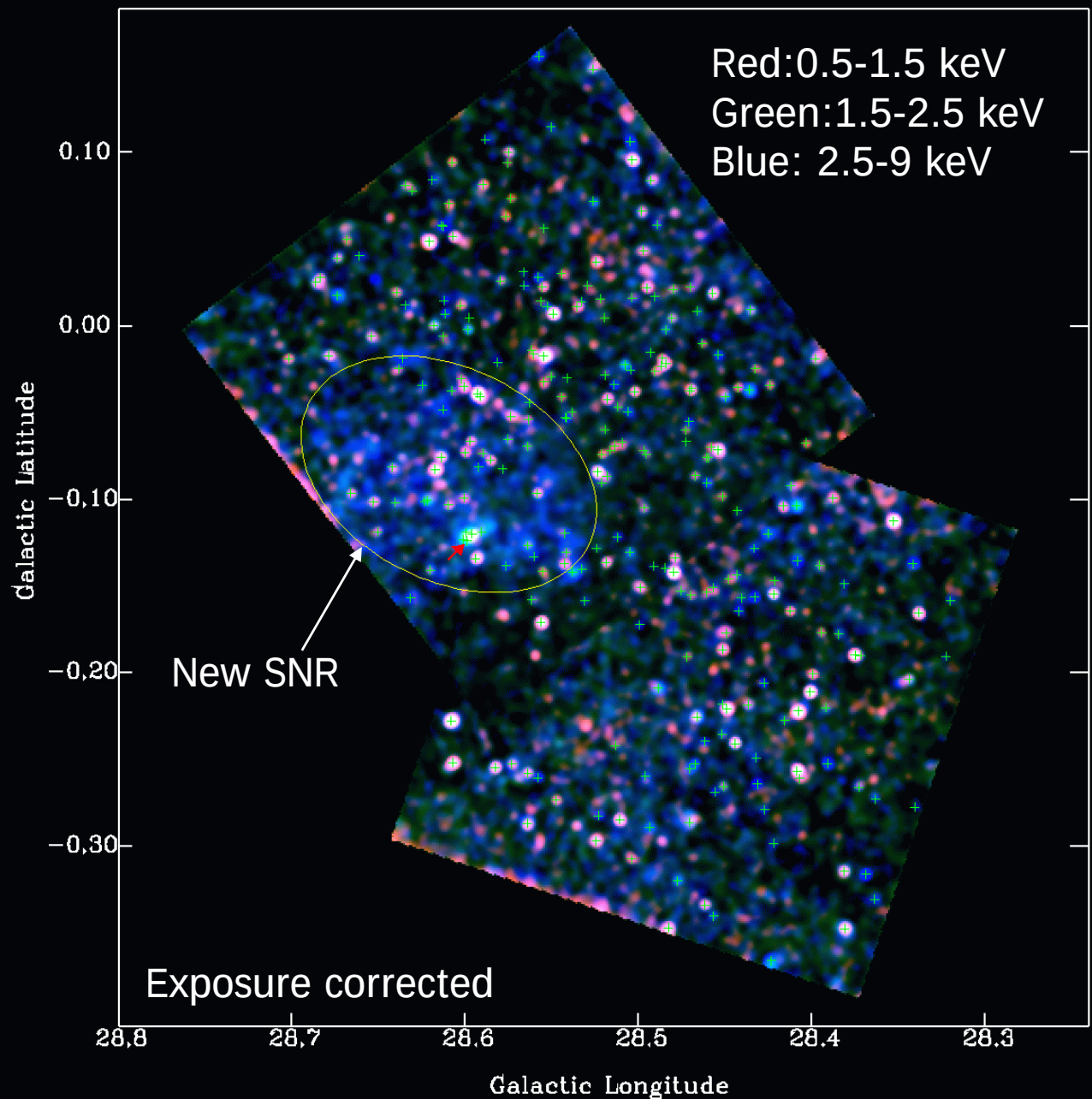


Spatial distribution of the Galactic ridge emission

Sensitivity $\sim 3 \times 10^{-13}$ erg s $^{-1}$ cm $^{-2}$ (2-10 keV)
Spatial resolution ~ 1 arcmin
Not able to resolve Galactic plane emission

Chandra observation

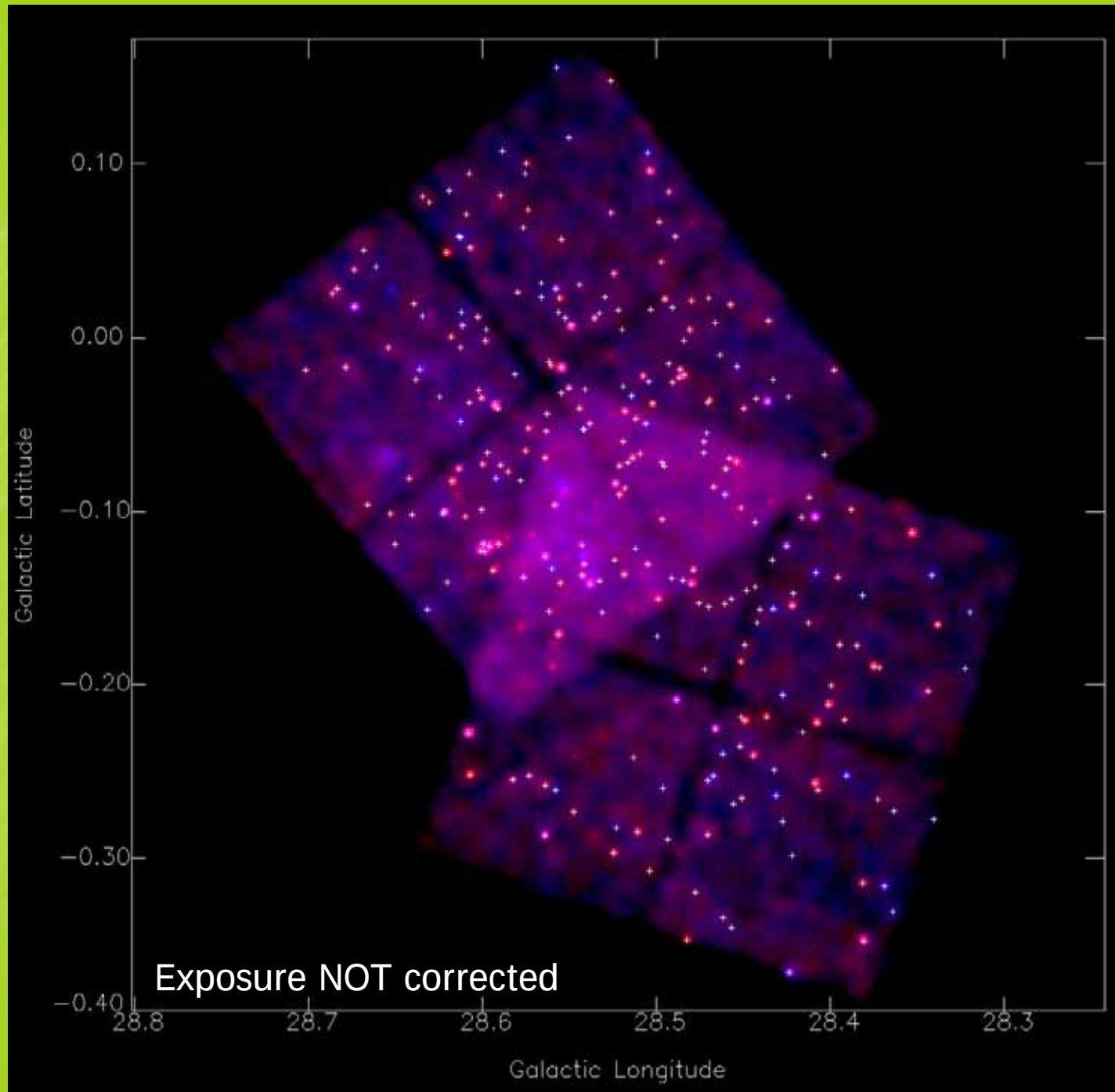
- AO1 100 ksec
+ AO2 100 ksec
- Deepest X-ray observation on a “blank” field on the Galactic plane
- Sensitivity: $\sim 3 \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$
($\sim 100 \text{ ksec}$; 2-10 keV)
- Many point sources and diffuse emission



Total 274
sources
(>4 sigma)

Source search
made in
0.5-3 keV,
3-8 keV and
0.5-8 keV

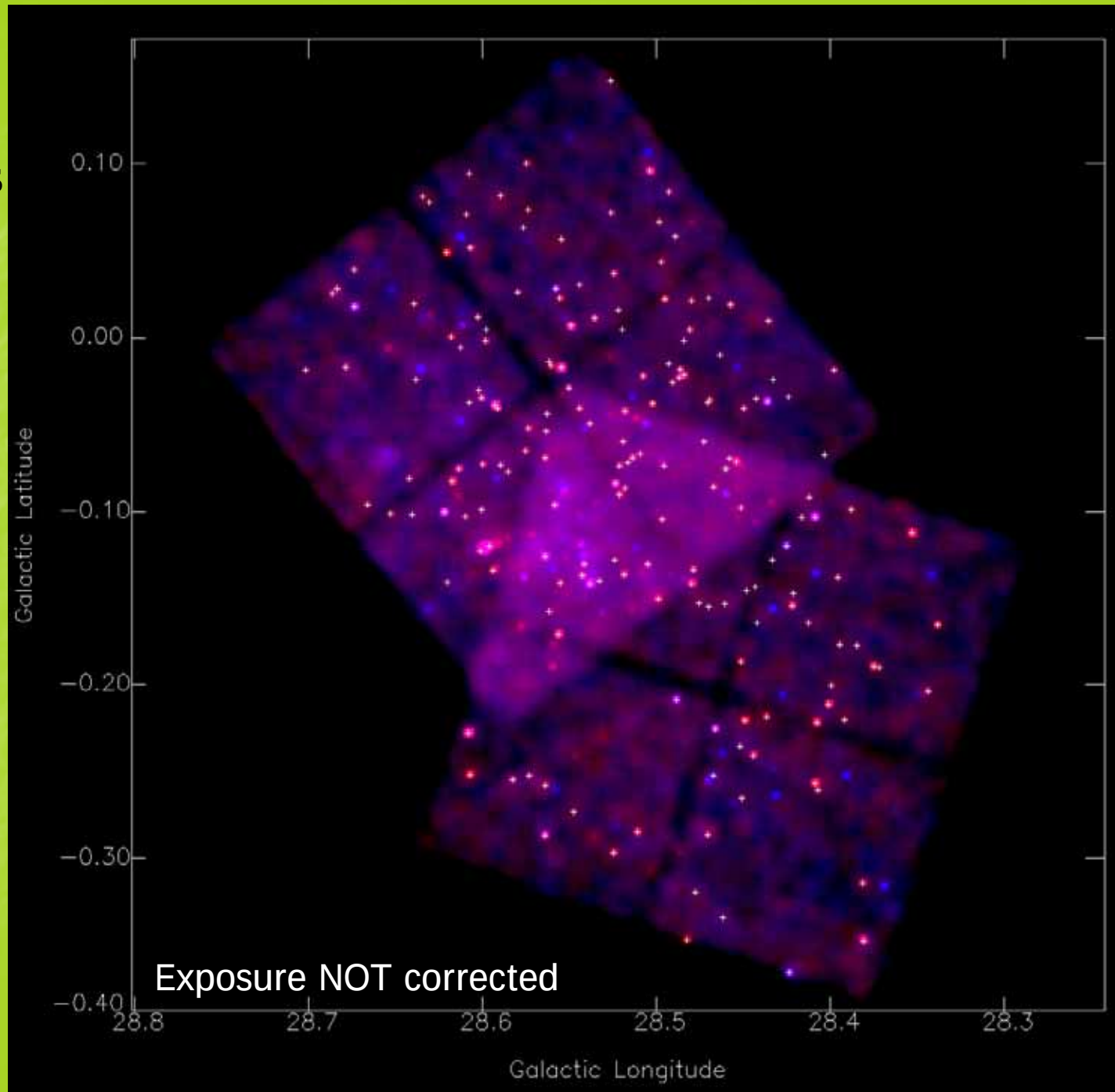
Red: 0.5-3 keV
Blue 3-8 keV



183 soft sources
(0.5 – 3 keV)

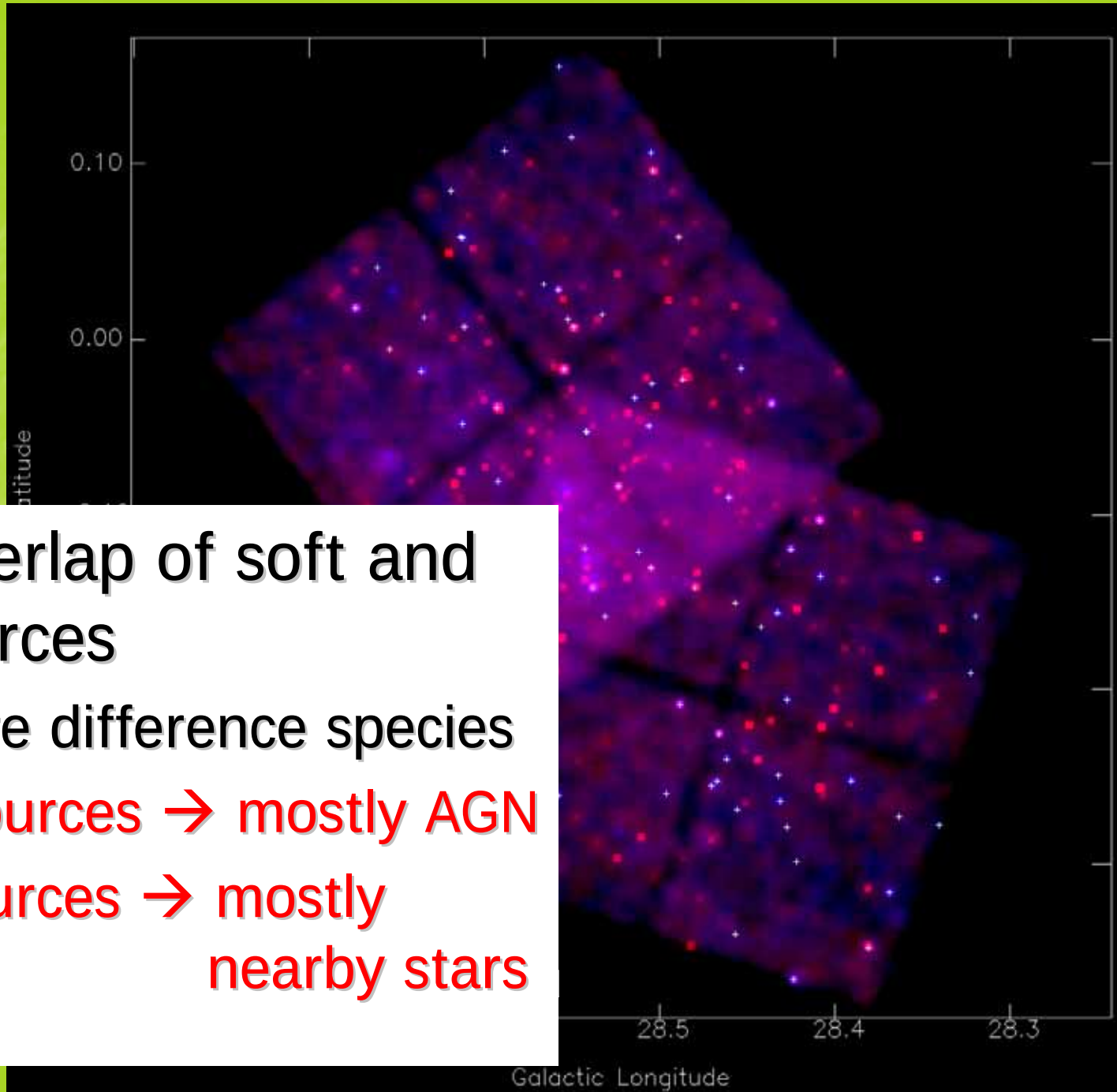
Red: 0.5-3 keV

Blue 3-8 keV



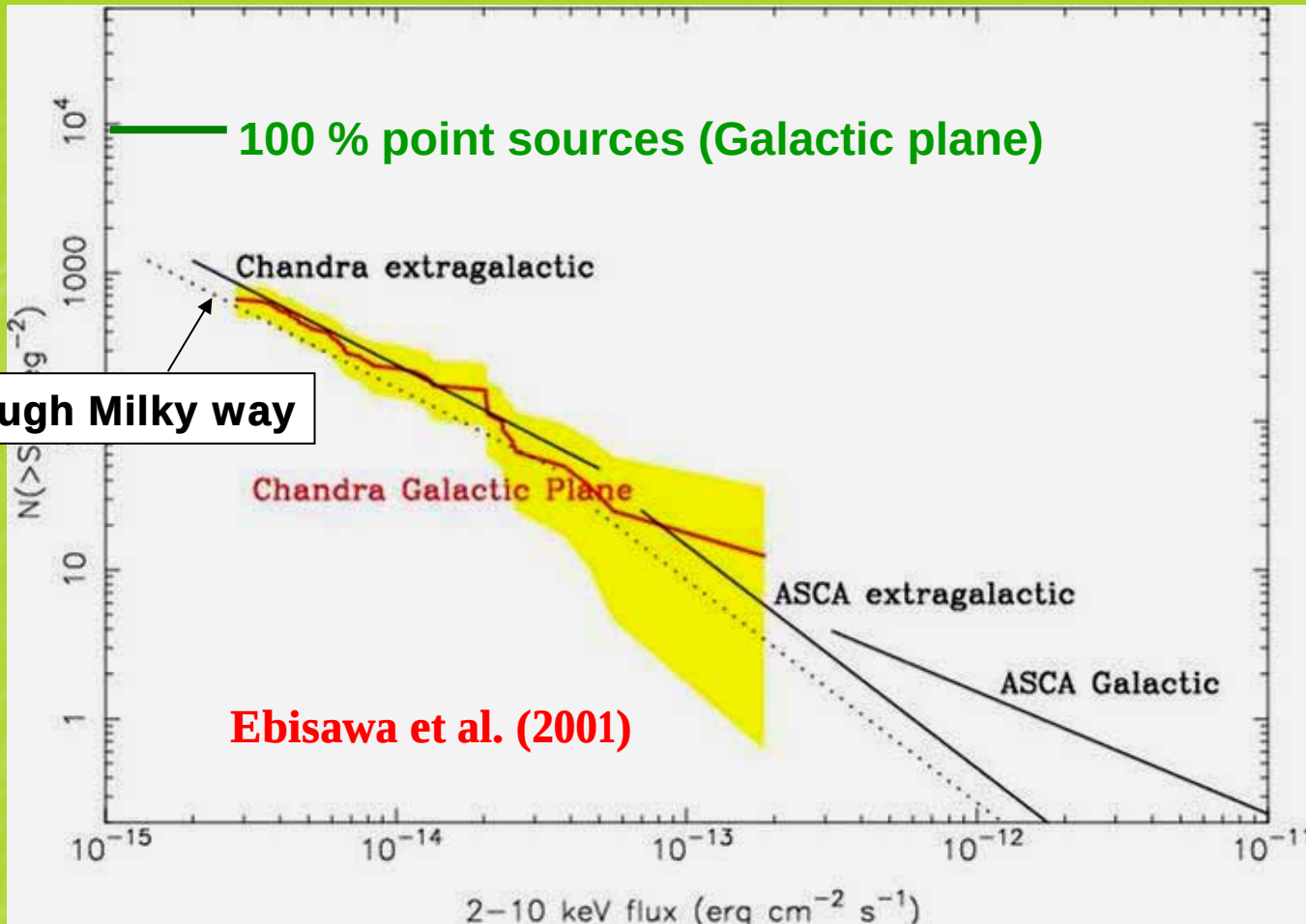
79 hard sources
(3- 8 keV)

Red: 0.5-3 keV
Blue 3-8 keV



- Small overlap of soft and hard sources
 - They are different species
 - Hard sources → mostly AGN
 - Soft sources → mostly nearby stars

2-10 keV band log N-log S

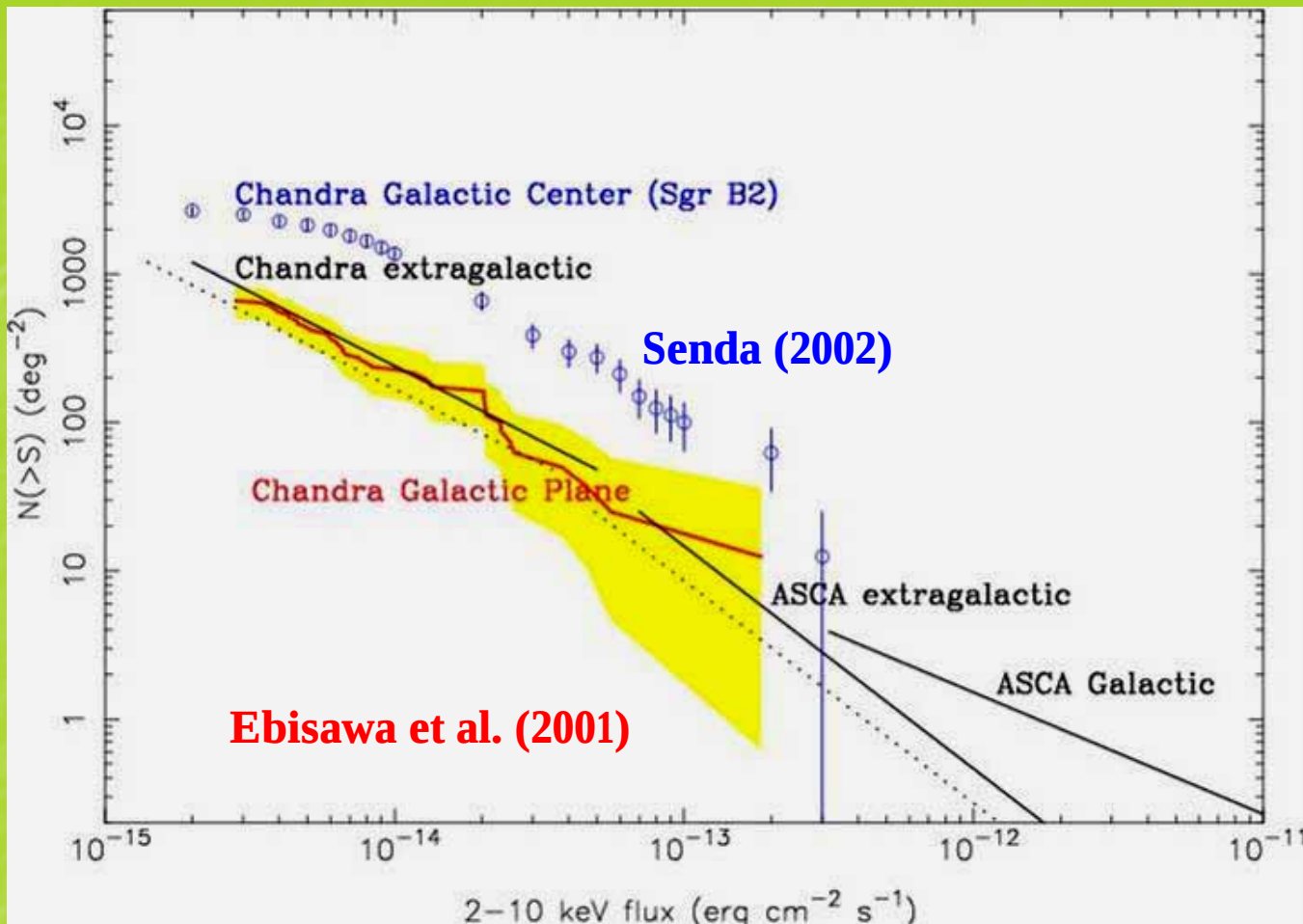


Point source contribution *only* ~10 % of the total emission in the FOV

Galactic ridge emission is truly diffuse

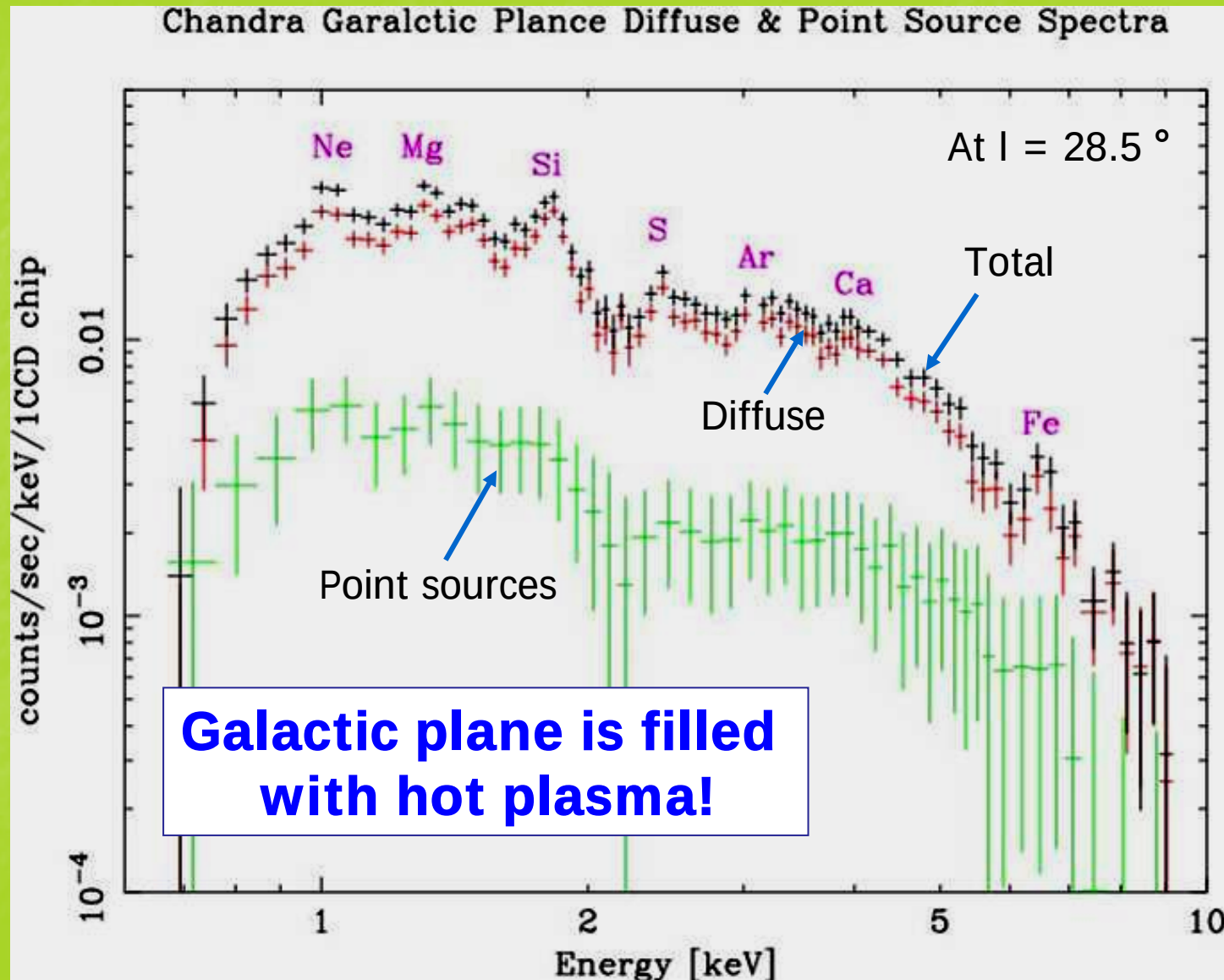
Most sources at $\sim 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$ are extragalactic

Comparison with Galactic Center



Much more **Galactic** hard point sources at GC region
Presumably white dwarf binaries
(quiescent dwarf novae)

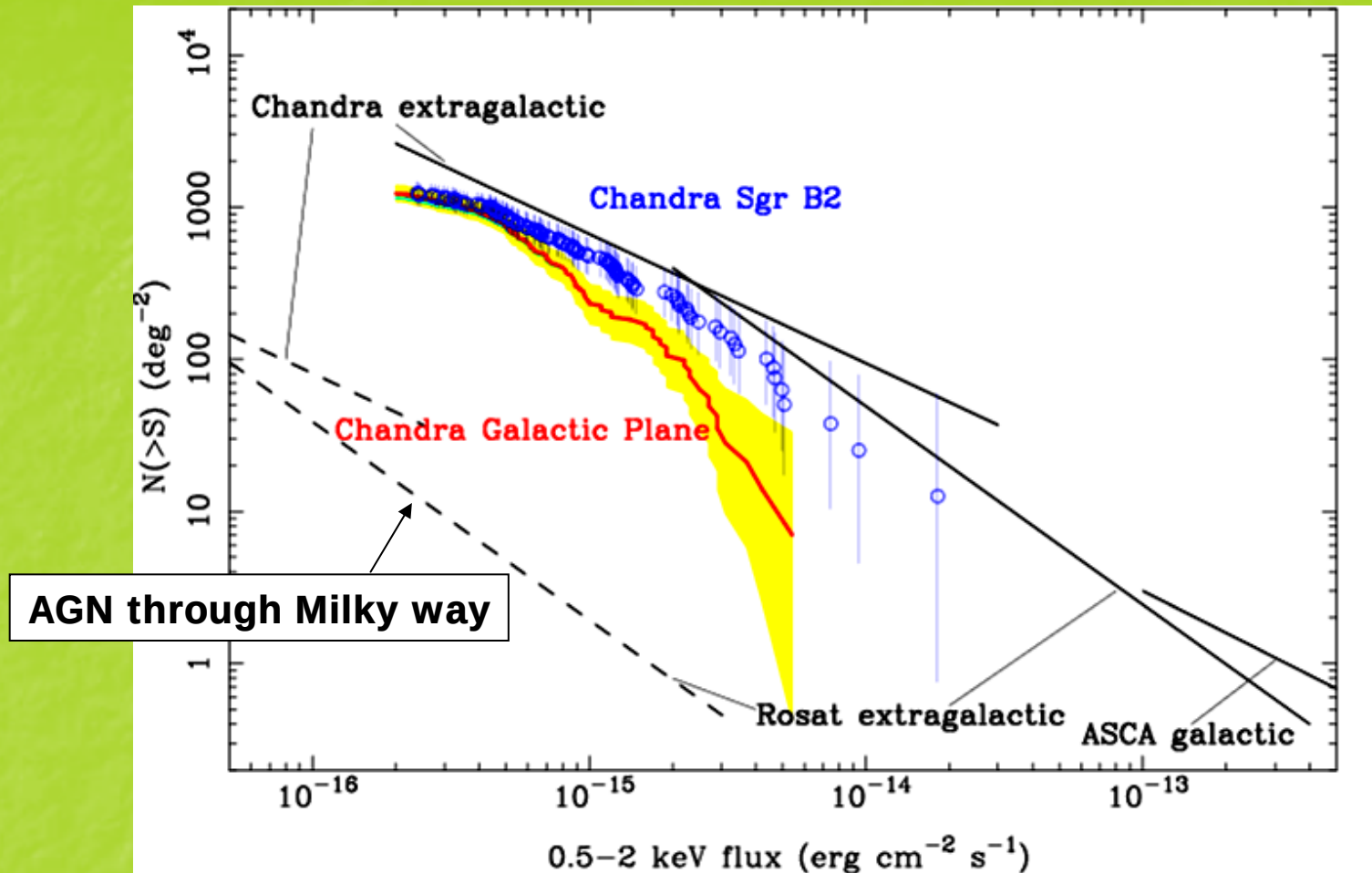
Diffuse Galactic ridge emission



まとめ

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0.5-2 keV band log N-log S

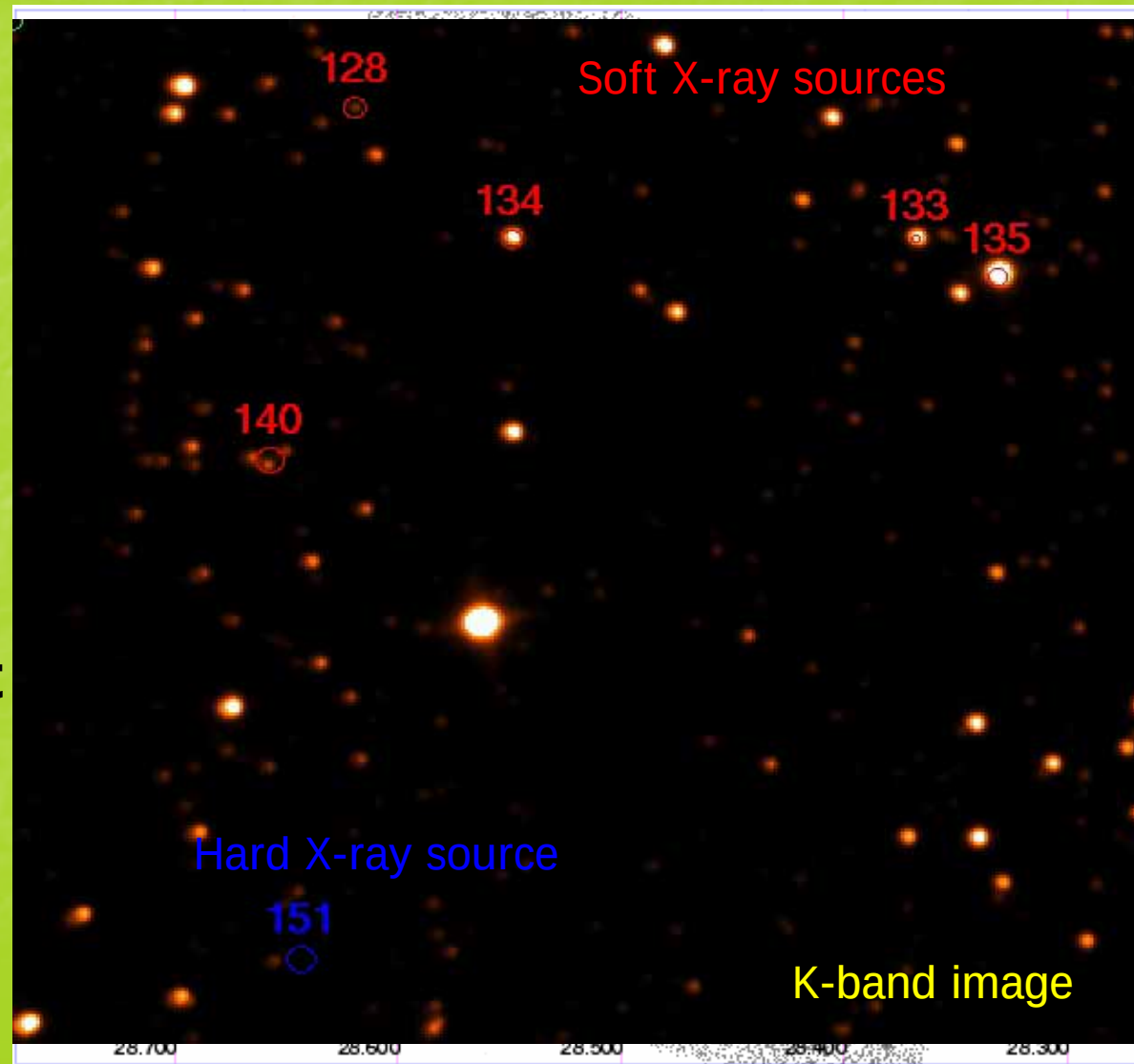


- There are many dim **Galactic** soft X-ray sources
 - Steep slope, new population of sources?
- Presumably **X-ray active stars**

Near-IR follow-up observation

- **ESO/NTT SOFI
near-IR
observation**

- 2002/07/29,30
- J, H, K_s
photometry
- Only central part
(~75 %) of the
Chandra field
covered

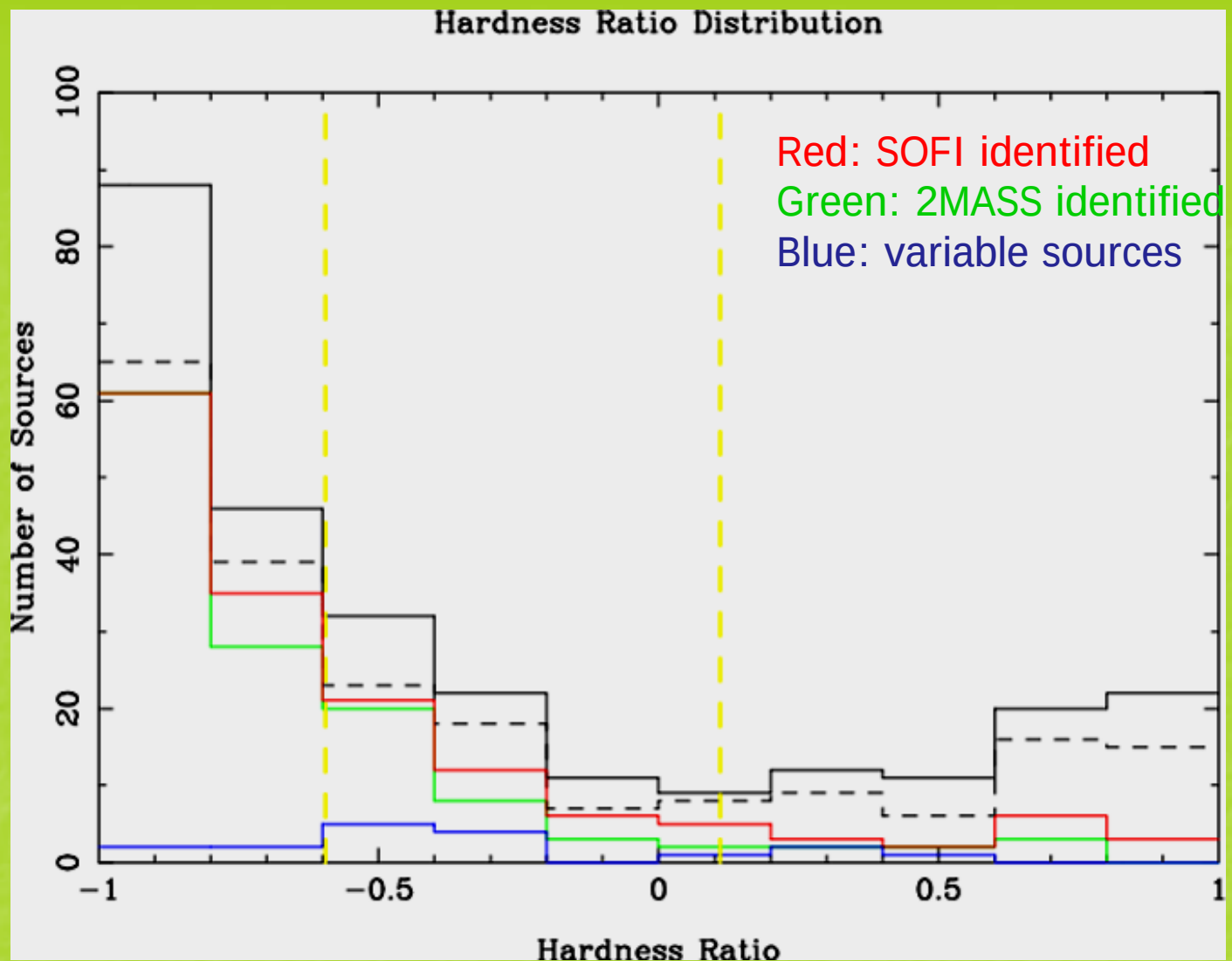


NIR identification of the X-ray sources

$HR = (H - S) / (H + S)$
 $H = 3-8 \text{ keV}$
 $S = 0.5-3 \text{ keV}$

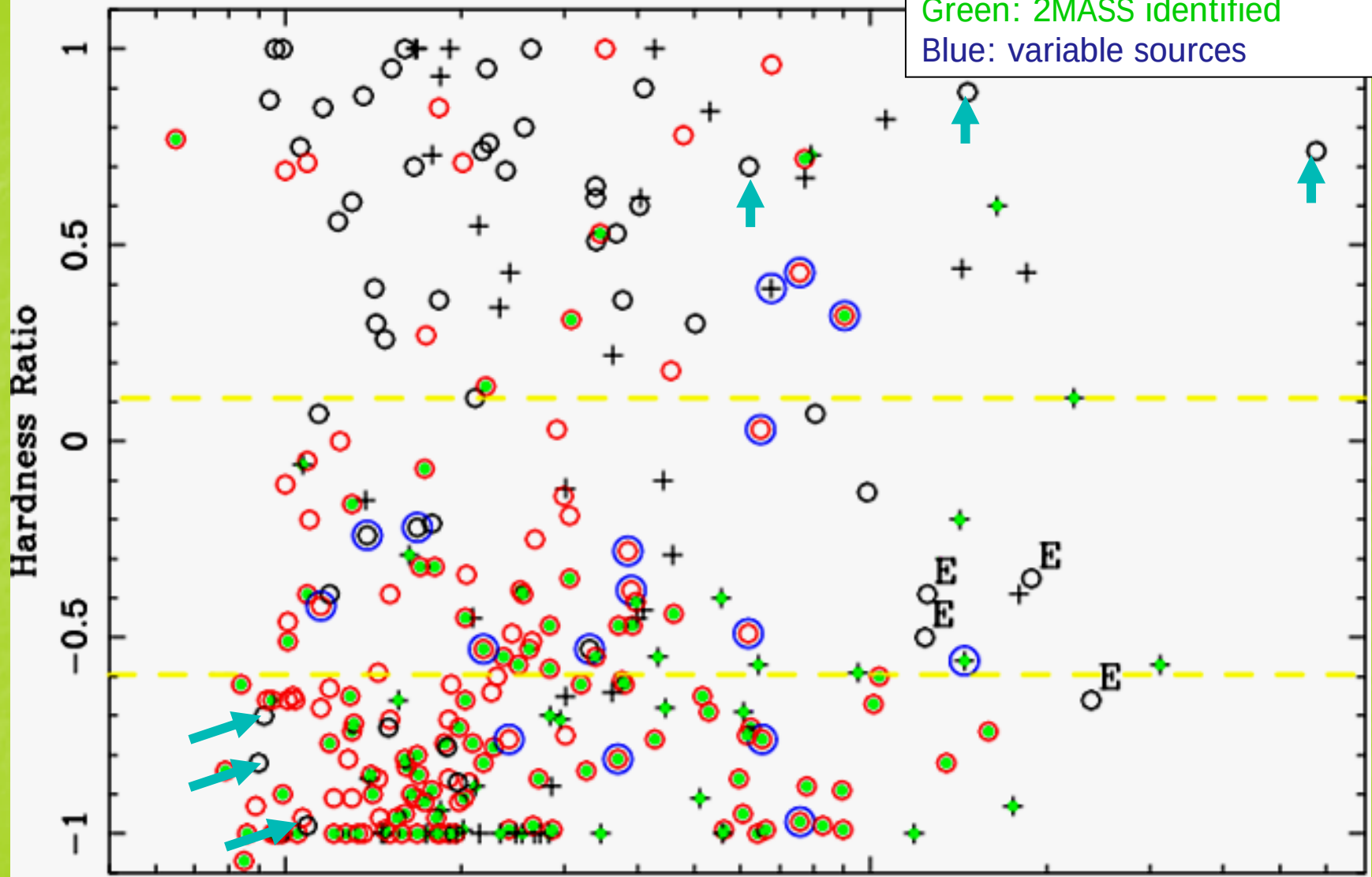
	Soft hardness ratio ≤ -0.60	Medium $-0.59 \text{ to } 0.1$	Hard ≥ 0.11	Total
All	137	68	69	274
Extended	1	3	0	4
Point Source	136	65	69	270
Time variation ^a	4 (3 %)	10 (15 %)	3 (4 %)	17 (6 %)
2MASS counterpart ^a	91 (70 %)	30 (46 %)	9 (13 %)	130 (48 %)
Covered by SOFI ^a	106 (78 %)	48 (74 %)	49 (71 %)	203 (75 %)
SOFI counterpart ^b	99 (93 %)	40 (83 %)	16 (33 %)	155 (76 %)
NIR counterpart ^c	119 (88 %)	49 (75 %)	19 (28 %)	187 (69 %)

93 % of the soft sources identified
Only 1/3 of the hard sources identified



- Two populations
 - Soft sources and Hard sources
- Soft sources tend to have near IR counterparts

X-ray Intensity vs Hardness



Red: SOFI identified

Cross: not covered with SOFI

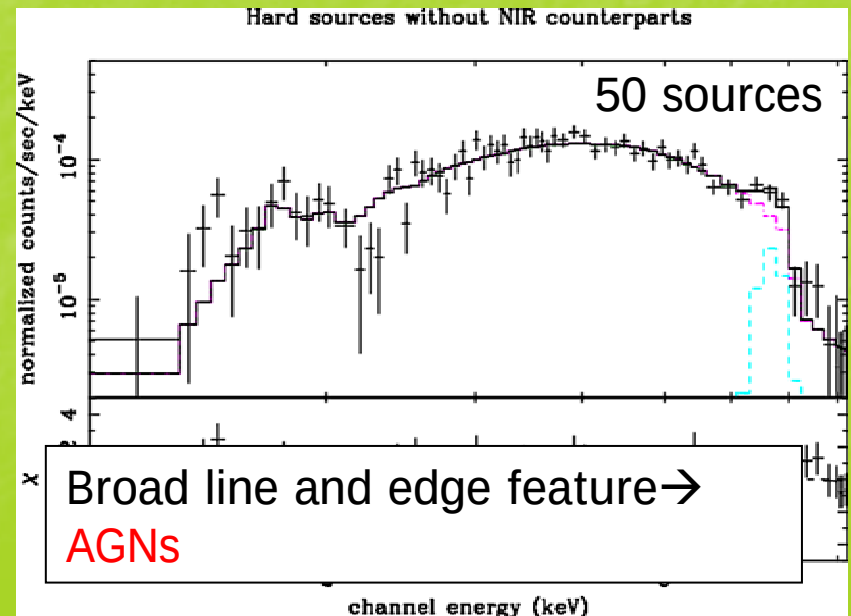
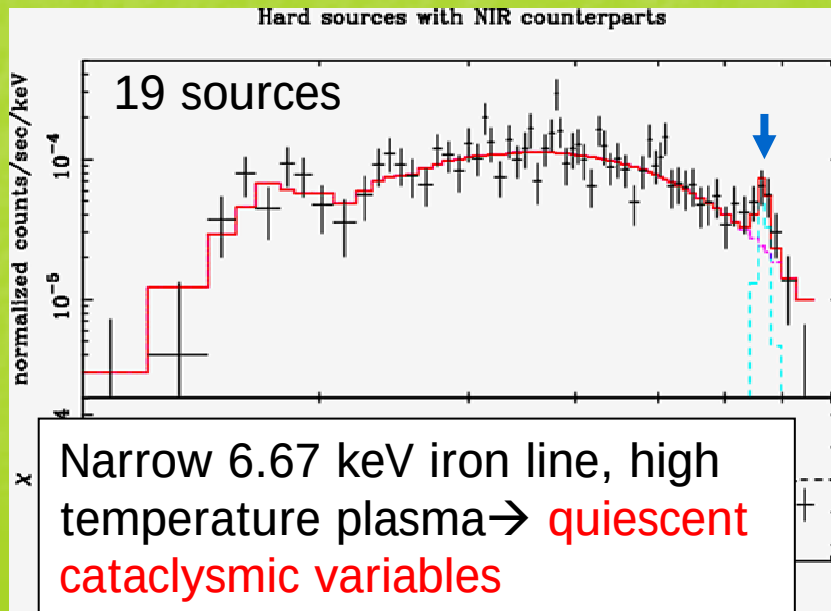
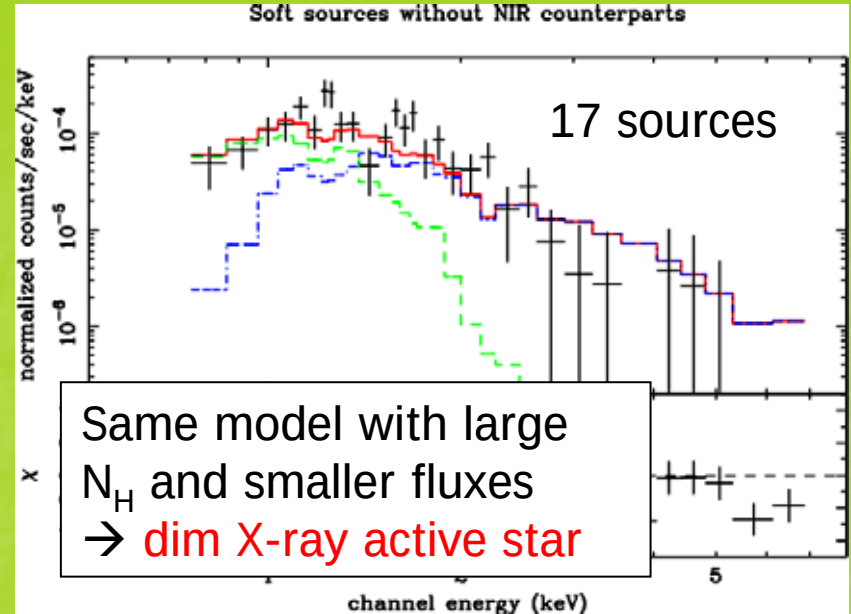
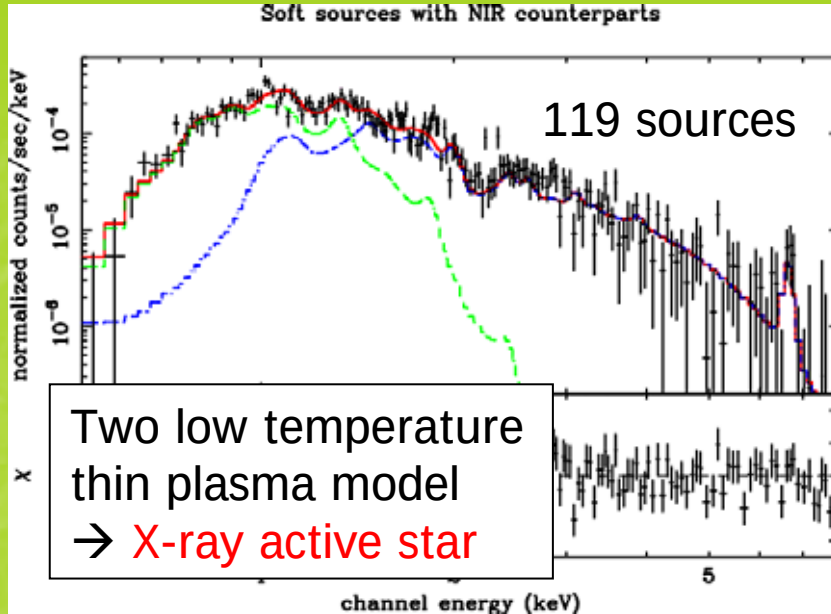
Green: 2MASS identified

Blue: variable sources

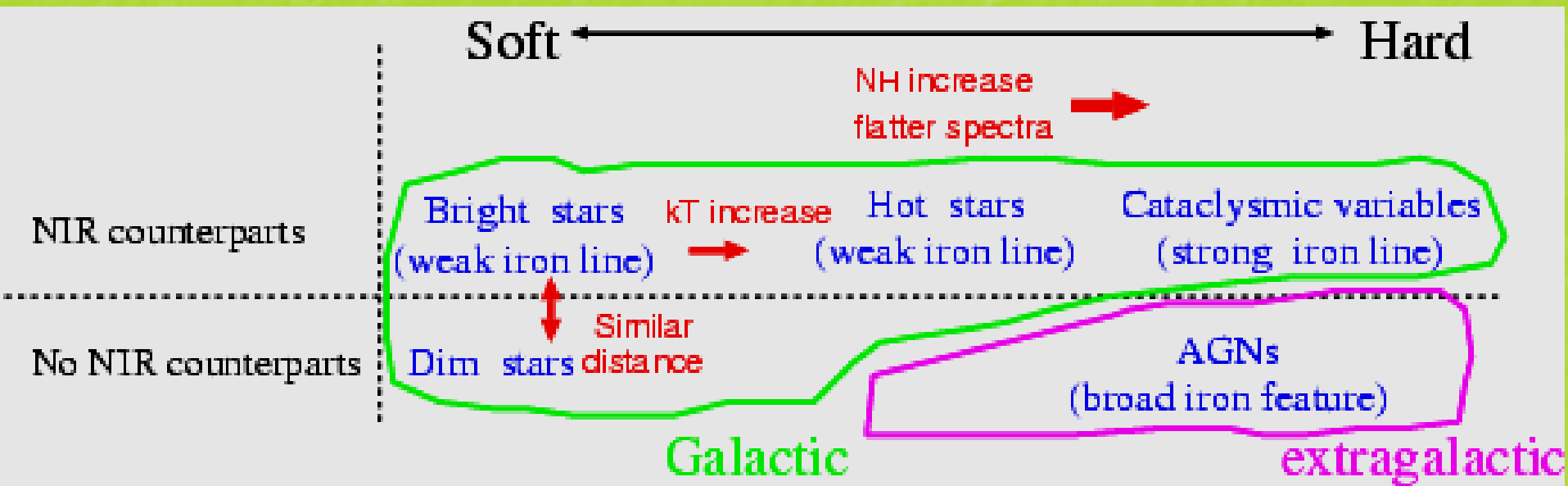
There are bright hard sources without NIR ID → AGN

Only a few dim soft sources are not identified in NIR → dim stars

Average source spectra



Classification of point X-ray sources



まとめ

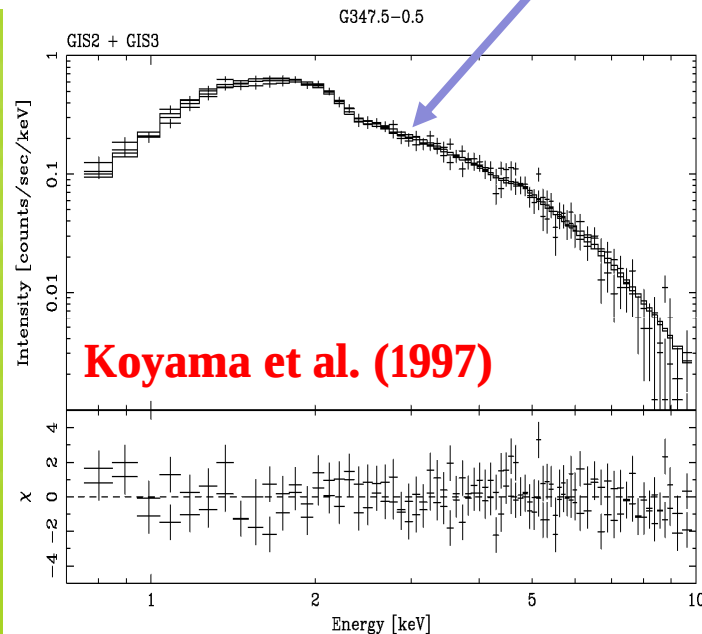
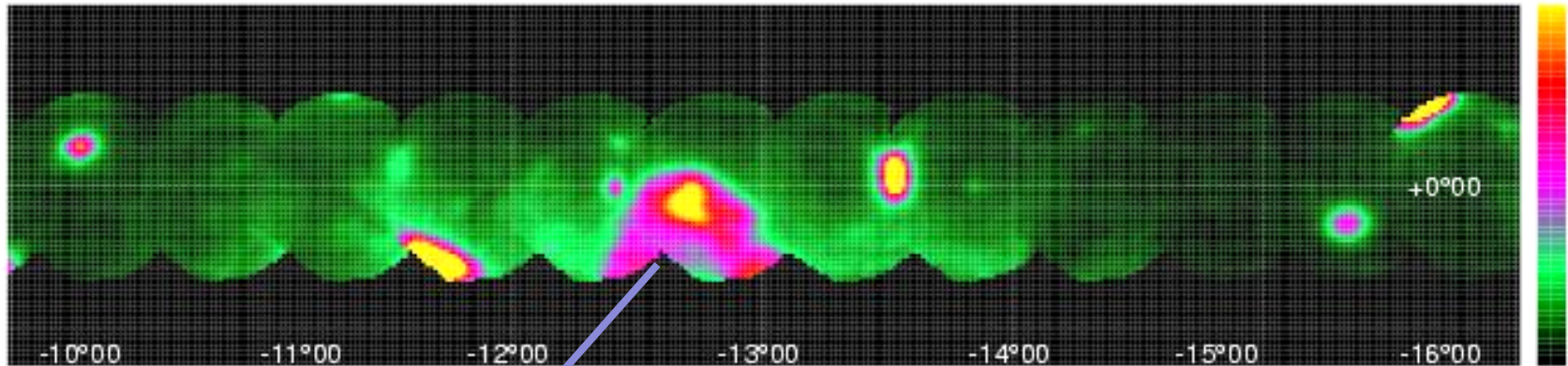
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Discovery of discrete and extended sources

- **ASCA and Chandra discovered numerous discrete and extended sources on the Galactic plane**

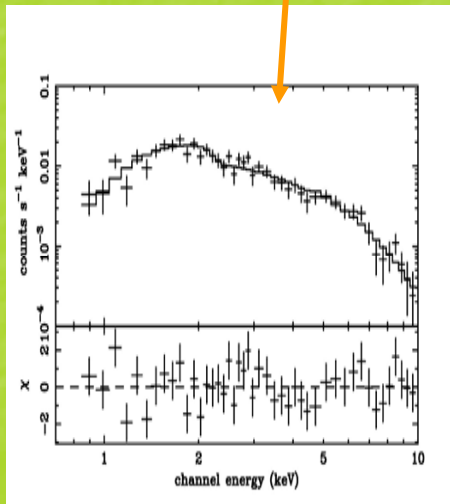
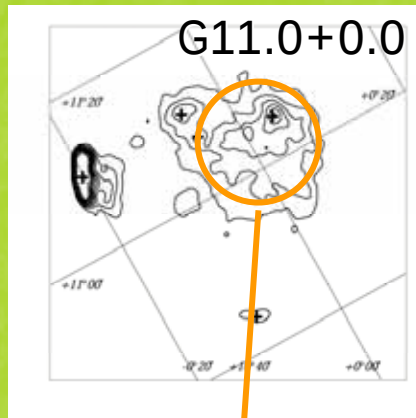
Non-thermal X-rays from the SNR Shell

Galactic Plane Survey 0.7-7keV

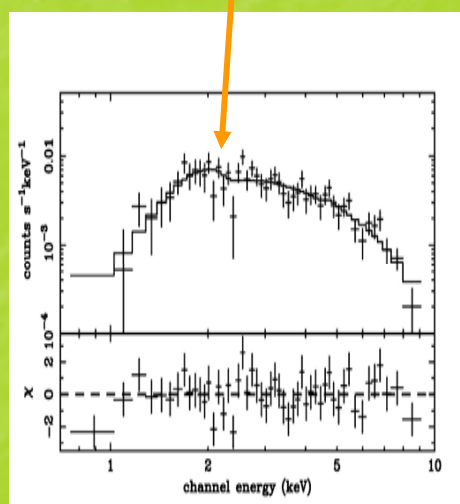
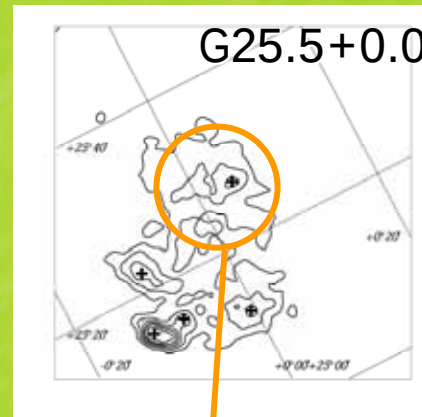


- **RXJ1713.7-3946**
 - **No emission lines**
 - **Photon index=2.4-2.5**
- **Northwest shell of G347.3-0.5**
- **TeV gamma-ray source (Enomoto et al. 2002)**
- **Particle acceleration site**

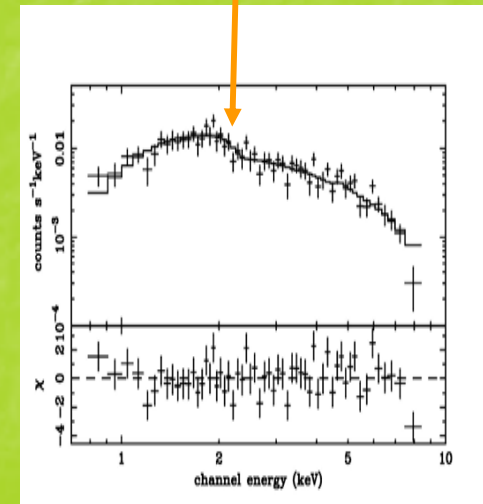
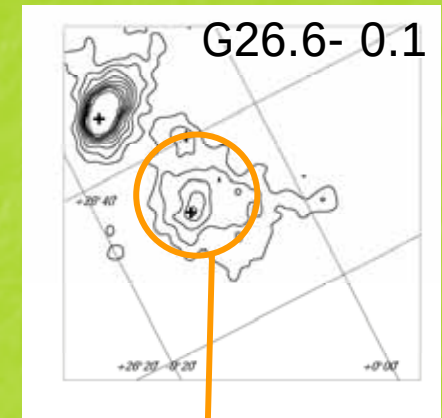
Unidentified Extended Sources: Non-thermal X-Ray SNR Candidates



Photon index=1.6



Photon index=1.8

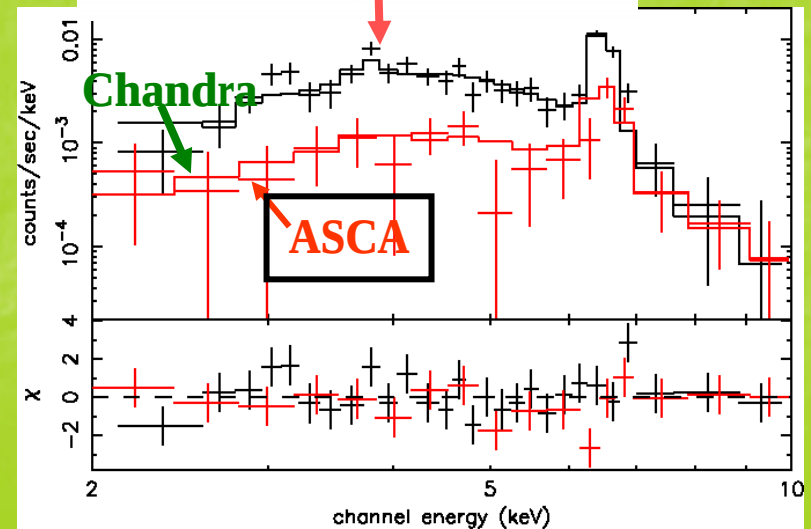
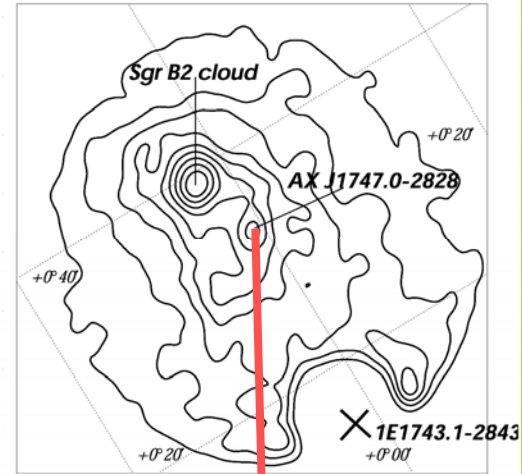
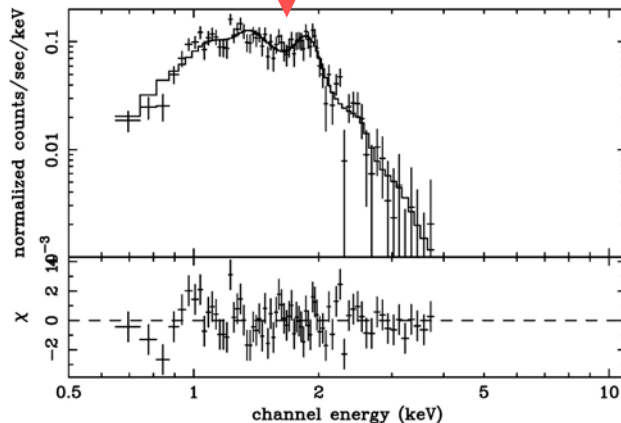
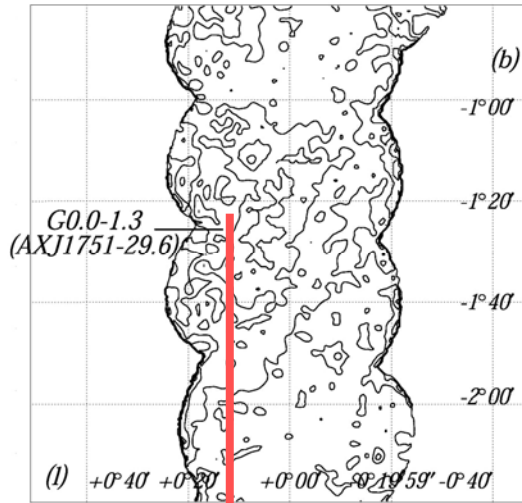


Photon index=1.3

Unidentified Extended Sources: SNR Candidates with Thermal Emission

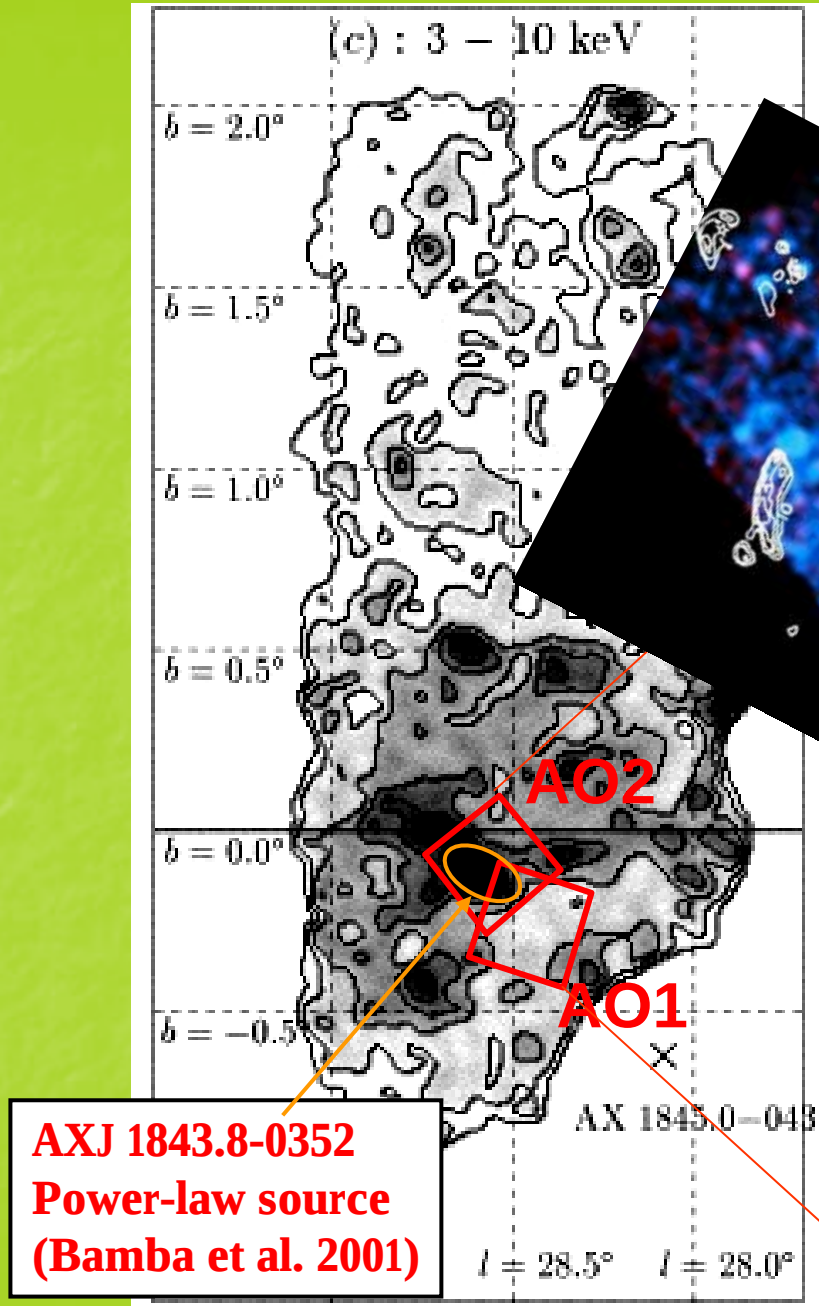
G0.0-1.3 (AXJ1751-29.6)

G0.56-0.01 (AXJ1747.0-2828)

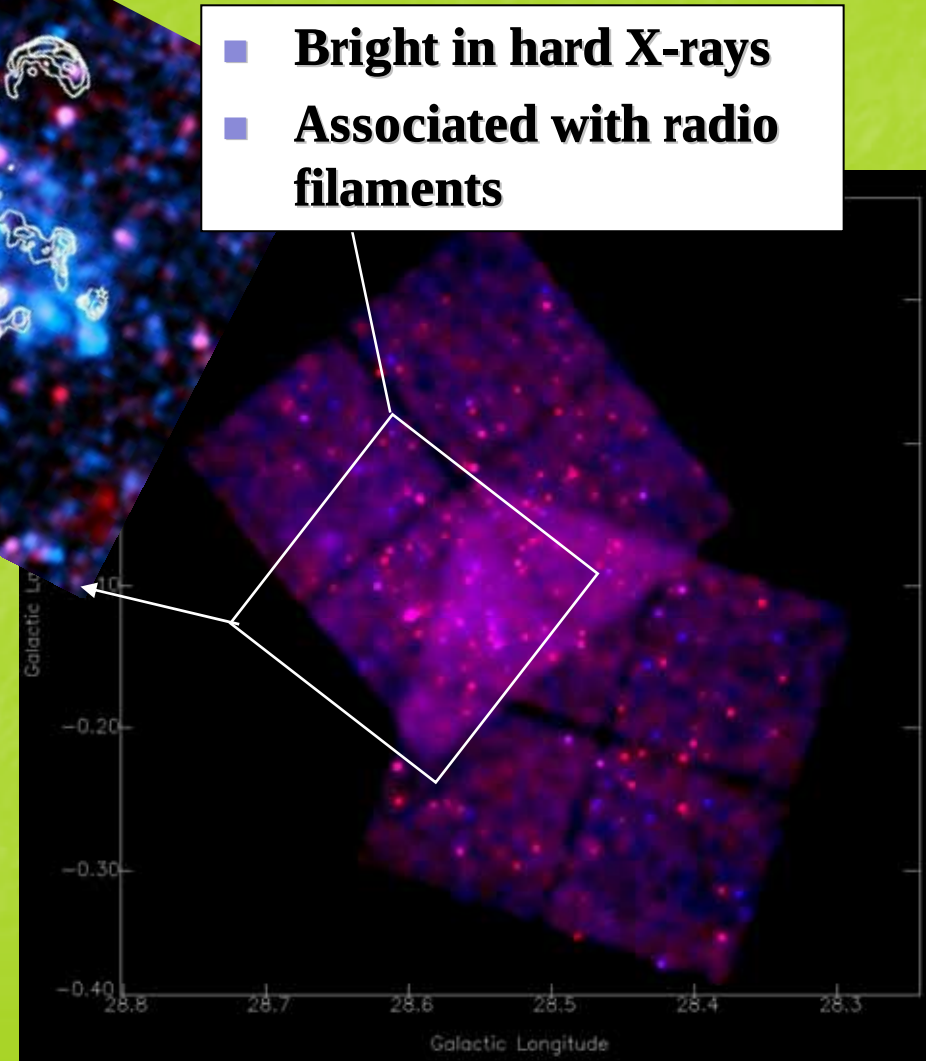


Sakano (2000), Sakano et al. (2002), Senda et al. (2002)

Diffuse feature at the Scutum region
 region $(l,b)=(28.5,-0.1)$

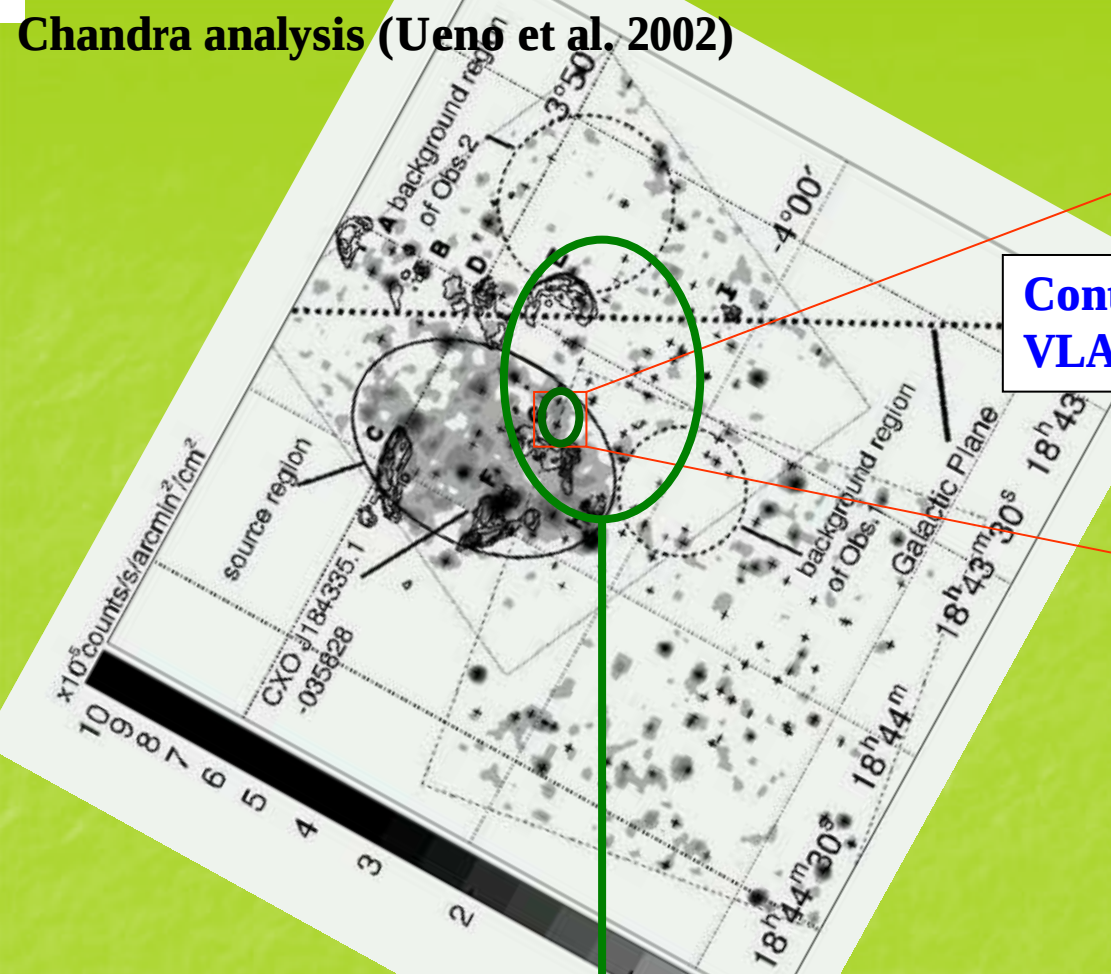


(Kaneda et al. 1997)



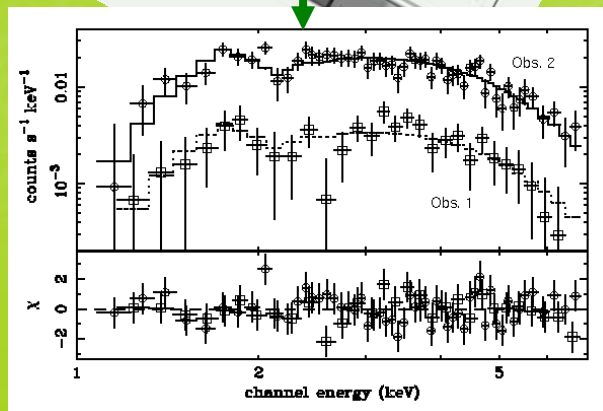
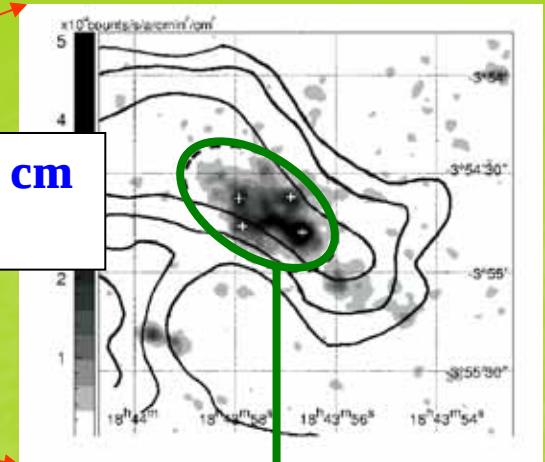
Ebisawa et al. (2001, 2002)

Chandra analysis (Ueno et al. 2002)



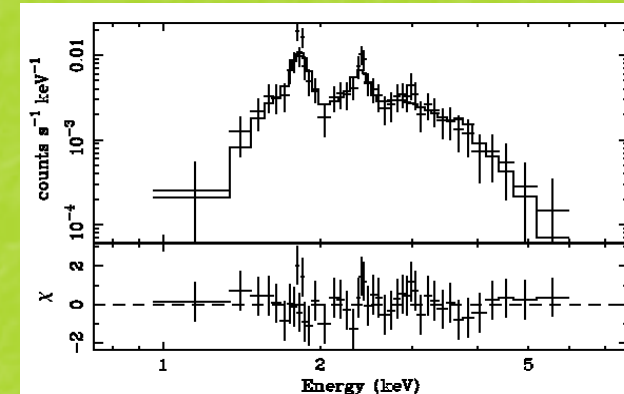
CXO J184335.1-035828

**Contour: 20 cm
VLA map**



AXJ 1843.8-0352

**Non-thermal
spectrum
($\alpha=2.1$)**



Thermal spectrum

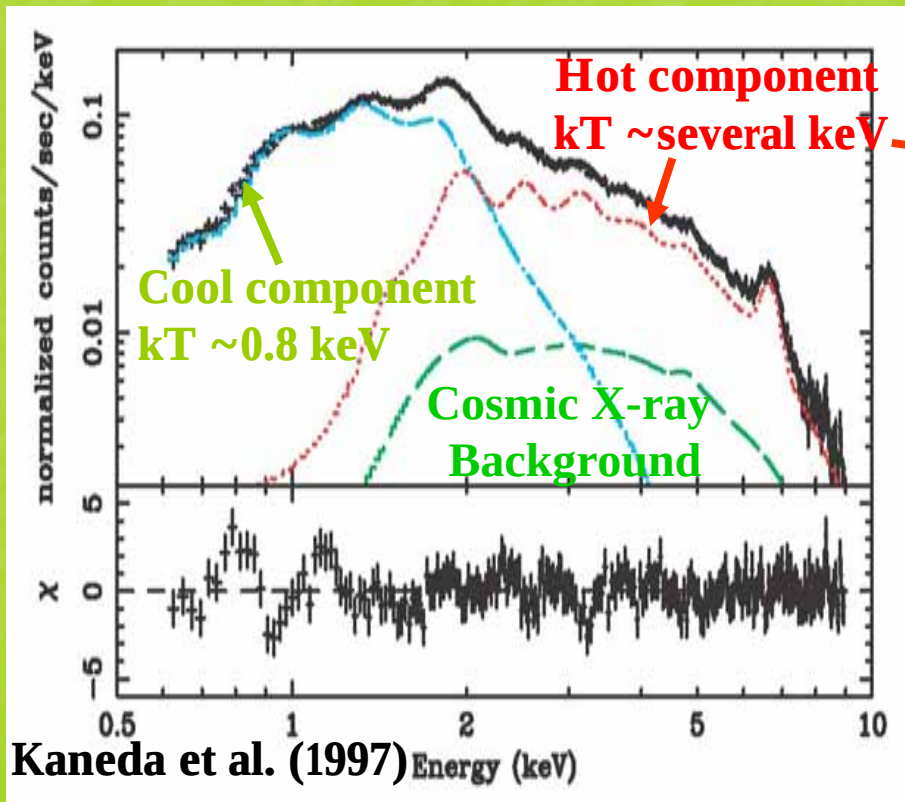
**Co-existence of thermal and
non-thermal spectral components**

まとめ

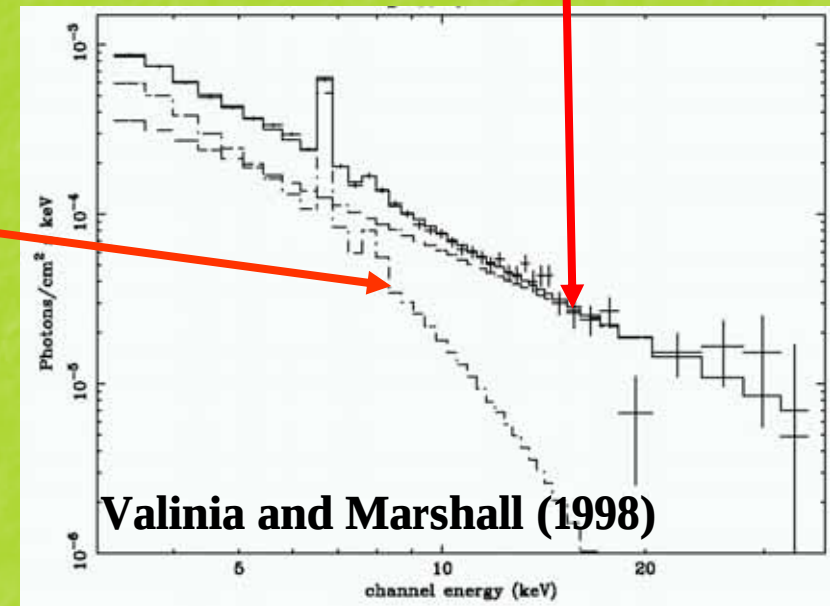
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Energy spectra of the Galactic Ridge X-ray emission

- Emission lines from highly ionized Si, S, and Fe
 - Explained with **thermal** plasma model



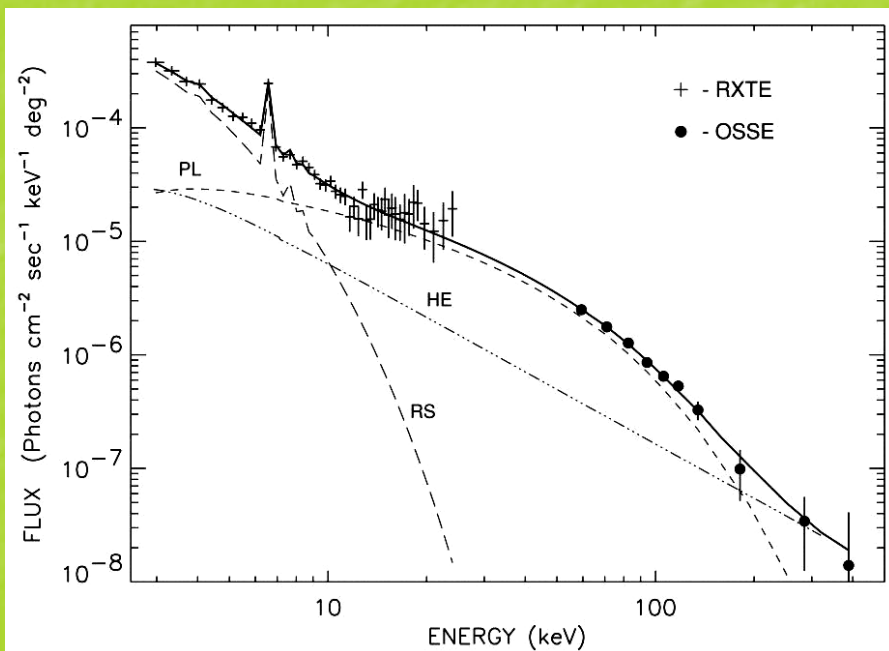
- **Non-thermal** (power-law) component above ~ 10 keV



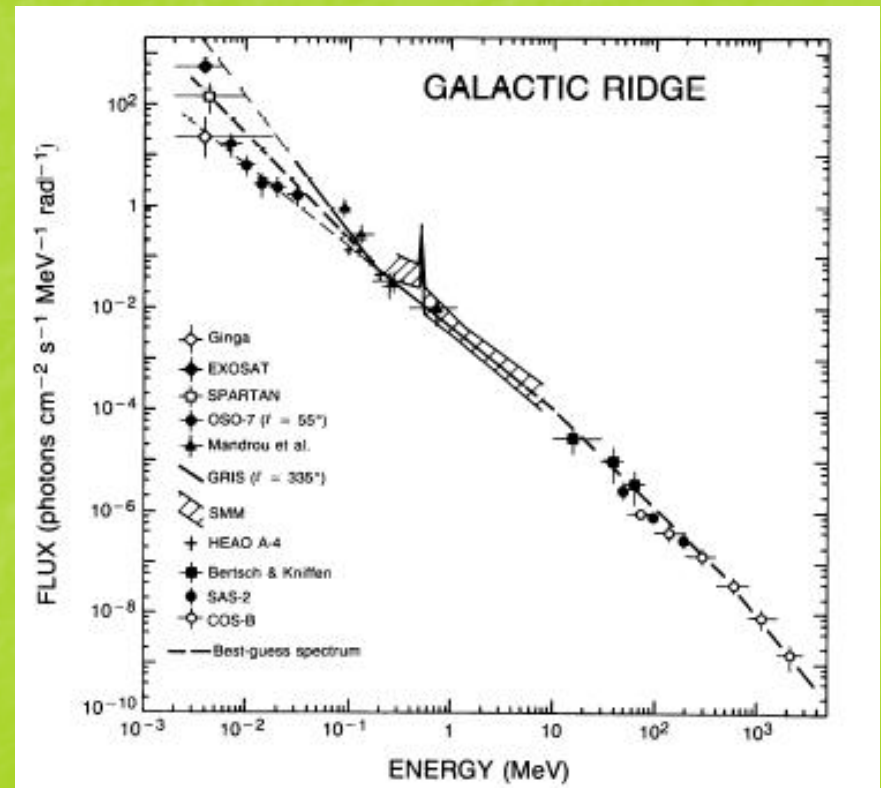
Omnipresence of thermal and non-thermal plasma in the Galaxy

Galactic diffuse X-ray and gamma-ray emission

Hard X-ray smoothly connects gamma-rays up to ~ 1 GeV



Valinia et al. (2000)



Gehrels and Tueller (1993)

Problem of the Galactic Ridge X-ray emission (GRXE)

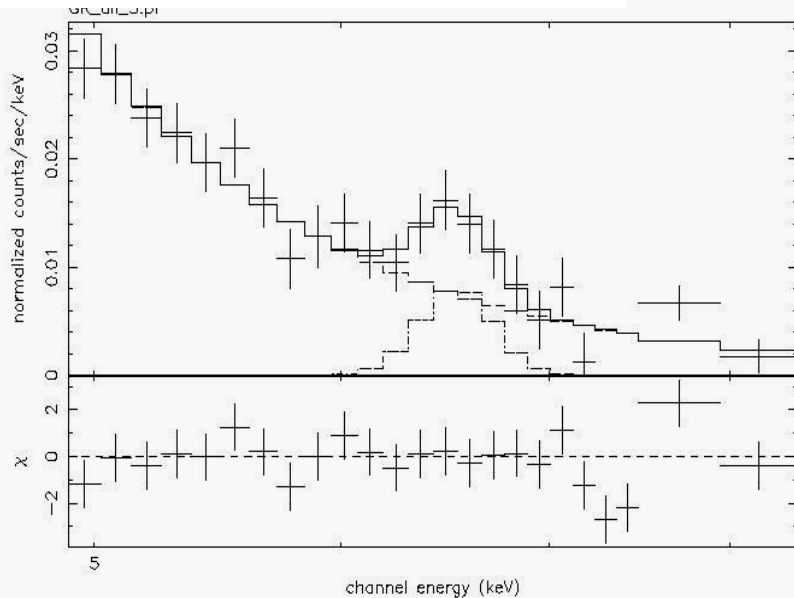
- **Purely thermal model impossible** (Warwick et al. 1985; Koyama et al. 1986)
 - $p/k = 2nT \sim 10^5 \text{ K cm}^{-3} \sim 10 \text{ eV cm}^{-3}$
 - Too high pressure/energy density!
 - Thermal velocity exceeds the escape velocity
 - Not able to confine in the Galactic disk
- Thermal + Non-thermal model?
- What is the origin of thermal/non-thermal energy source?

Models for GRXE

- Non-thermal bremsstrahlung for hard X-ray tail (Yamasaki et al. 1997)
- Interaction of low energy cosmic-ray electrons and ISM (Valinia et al. 2000)
- Magnetic reconnection of interstellar magnetic fields (Tanuma et al. 1999, 2001)
- Charge exchange of cosmic-ray heavy nuclei (Tanaka 2002)
- In-situ acceleration of electrons (Dogiel et al. 2002; Masai et al. 2002)

Precise iron K-line spectroscopy is crucial

**Diffuse iron line from
Chandra ACIS-I Scutum field**

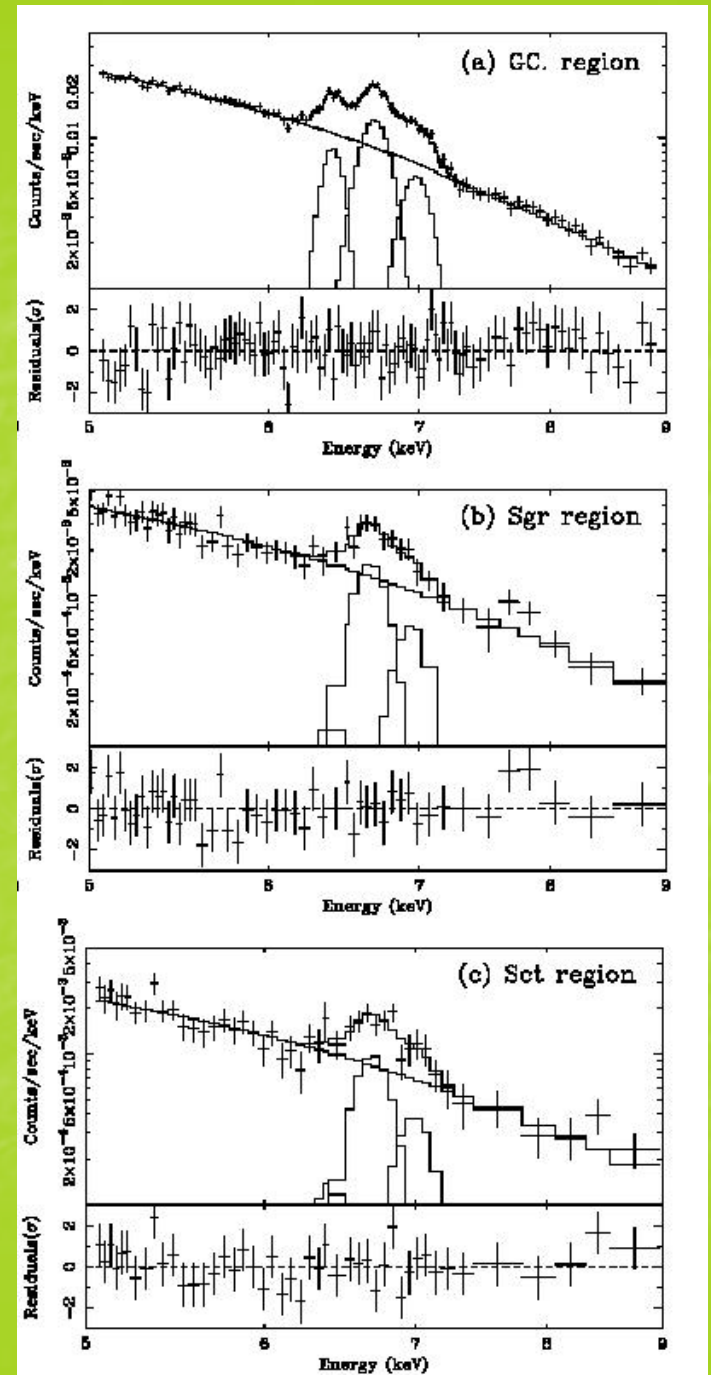


- **Iron line central energy 6.56 ± 0.01 keV**
- **Significantly less than 6.67 keV (He-like iron)**

- **Contamination of 6.4 keV fluorescence line?**
- **Non-ionization equilibrium?**
- **Presence of 6.97 keV hydrogenic line? (claimed by Tanaka 2002)**

Origin of the Galactic ridge emission

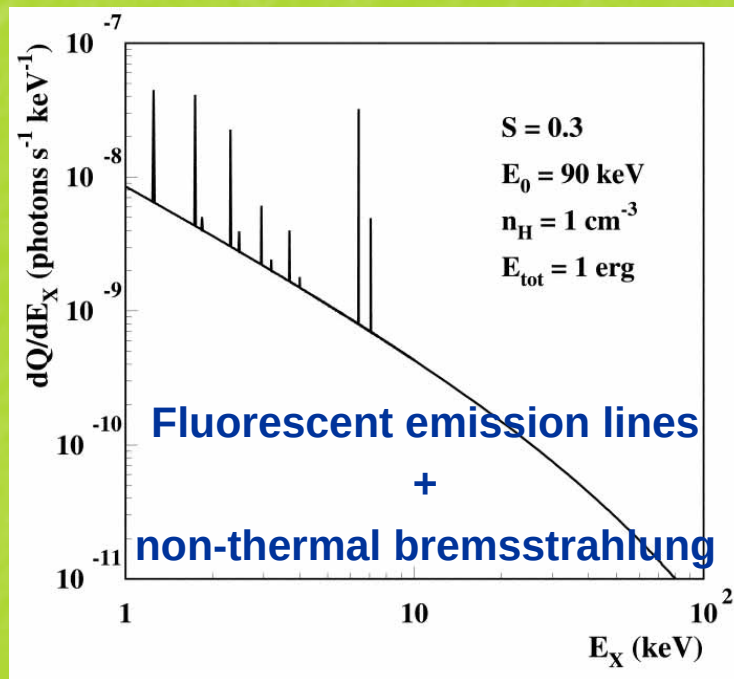
- Cosmic-ray Fe ion, charge exchange model (Tanaka 2002)
 - 6.97 keV hydrogenic line expected
 - Observed from GC and ridge by ASCA
 - Technically difficult analysis



Origin of the Galactic ridge emission

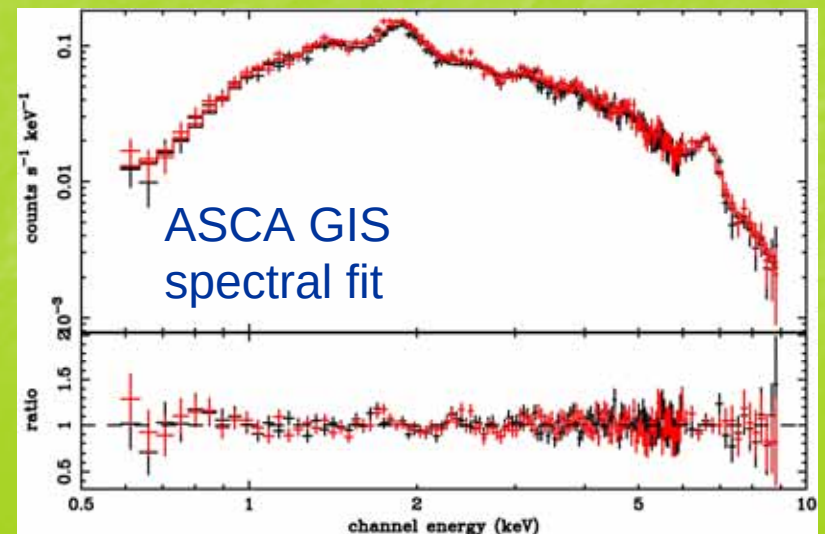
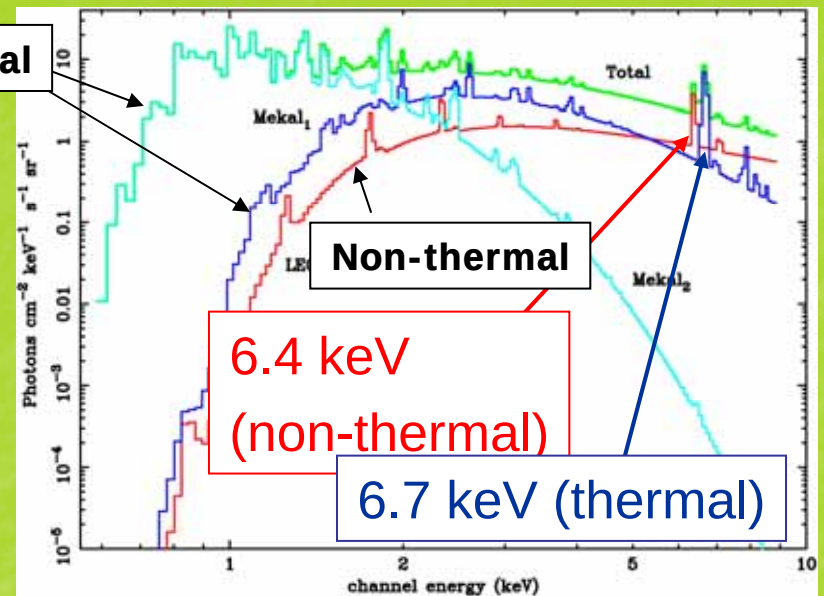
Valinia et al. (2000)

Low Energy Cosmic Ray
electron model



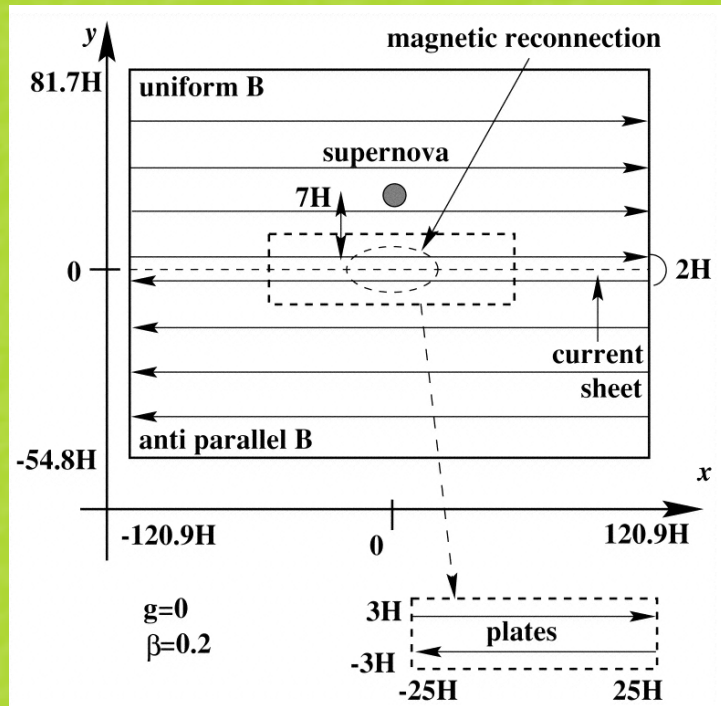
6.4 keV + 6.67 keV iron line feature
explained!

Thermal

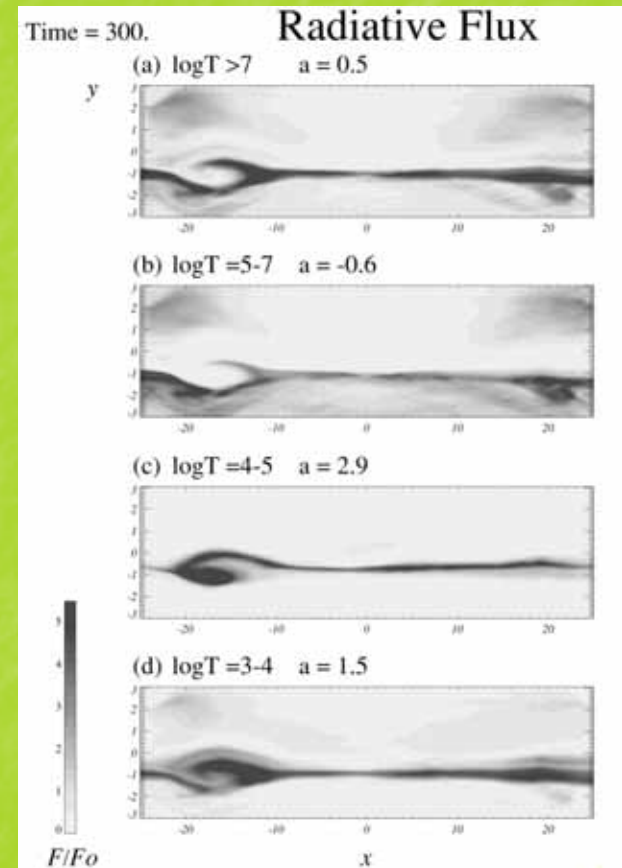


Origin of the diffuse hard X-ray emission

■ MHD simulation (Tanuma et al. 1999; 2001)



Supernova triggers magnetic reconnection
(similar to solar flare)

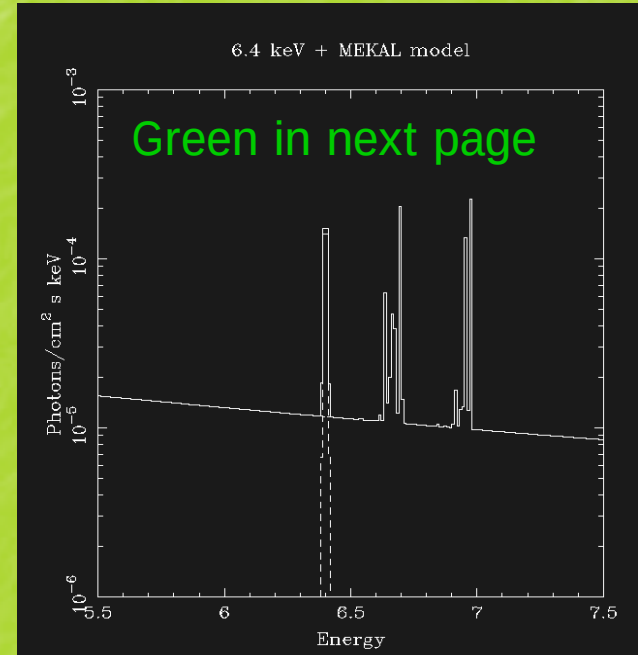
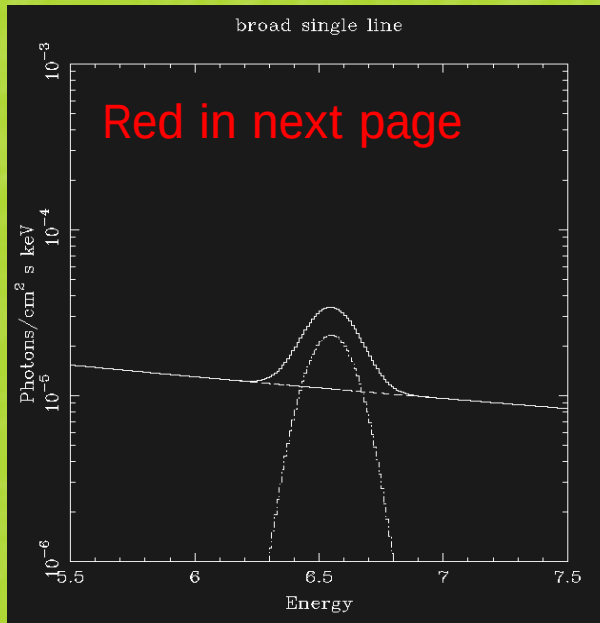
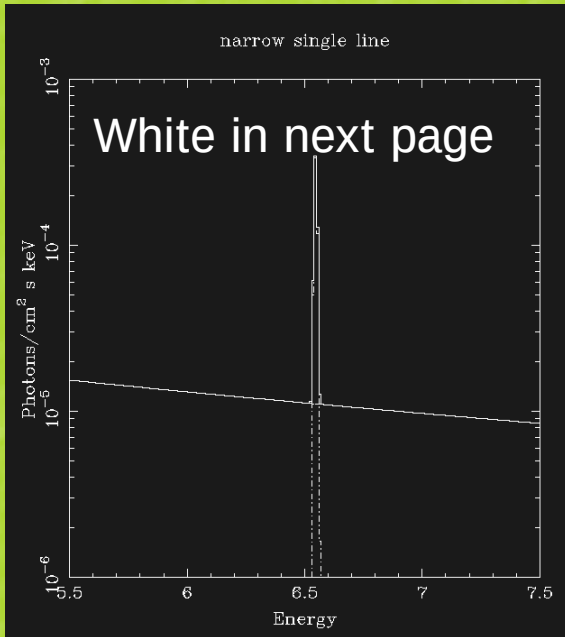


Hot, non-ionization equilibrium plasma (6.60 keV line expected)

Iron line diagnostics of GRXE

- Iron line spectroscopy is crucial to study origin of GRXE
 - Line center energy? Presence of 6.97 keV line?
 - Line width
 - Narrow?
 - Broad due to cosmic ray motion?
- ASTRO-E2 simulation
 - **XRS – X-ray micro-calorimeter ($\Delta E \sim 8$ eV)**
 - XIS – CCD camera ($\Delta E \sim 120$ eV)
- Diffuse flux is proportional to the detector FOV
 - Small FOV of XRS (2.8×2.8 arcmin²)
 - Large FOV of XIS ($18 \times 18 \times 4$ arcmin²)
 - **XRS is ~ 200 times less sensitive to diffuse iron line emission than XIS!**

Models to fit the Chandra spectrum



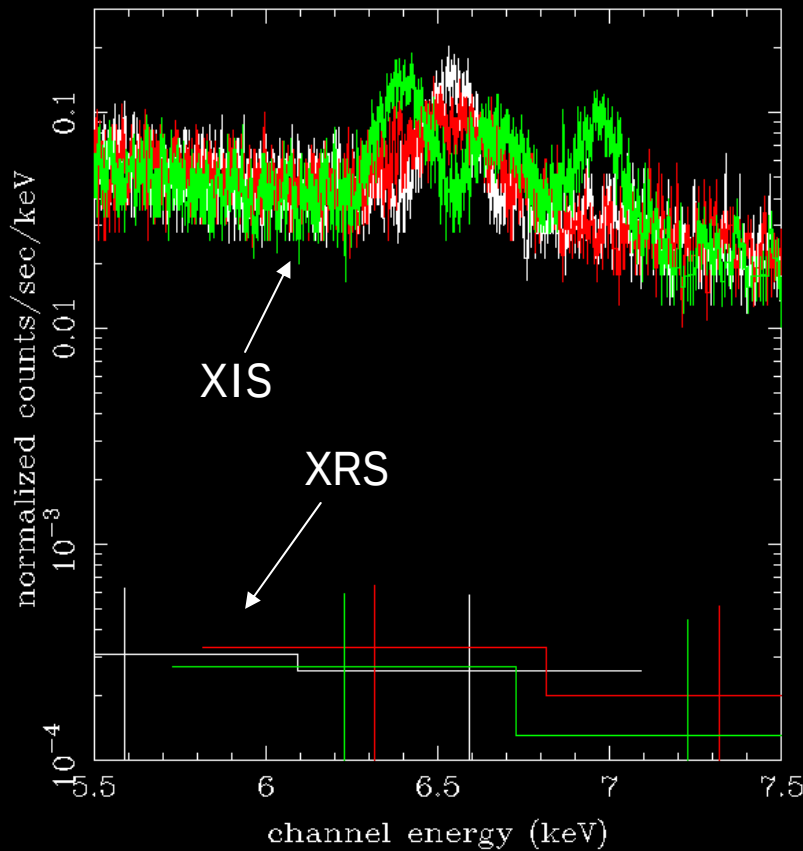
Narrow 6.55 keV line

Broad 6.55 keV line

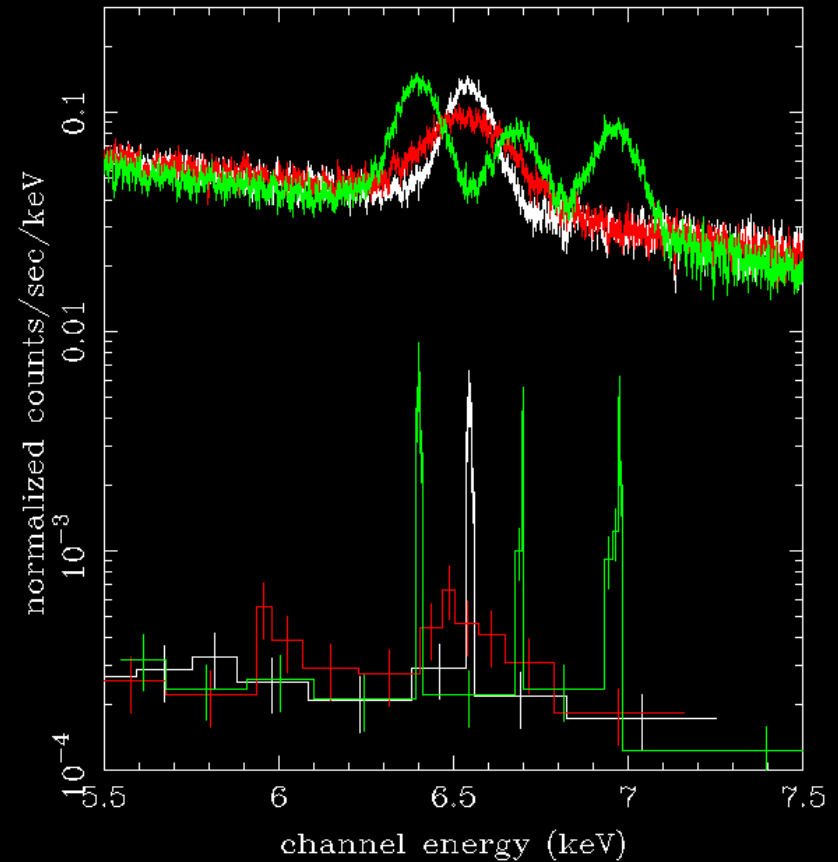
6.4 keV + thermal
spectrum (6.7 + 7.0
keV)

Simulation (XRS+4XIS)

XRS + XIS 100 ksec 100 ksec



XIS + XRS 1Msec exposure 1 Msec



X-ray calorimeter unambiguously resolves the iron emission line!
But 1 Msec observation with ASTRO-E2 XRS not feasible...
Task for future calorimeter mission (NEXT, Constellation-X?)

Origin of the diffuse emission

■ Galactic diffuse emission (Galactic center, bulge and ridge)

- Thermal and non-thermal components
- **Very high energy density ($\sim 10 \text{ eV/cm}^3$)** , compare to cosmic rays, interstellar magnetic fields ($\sim 1 \text{ eV/cm}^3$)

■ Discrete diffuse sources (SNR like)

- Sources with thermal spectra
- Sources with non-thermal spectra
- Co-existence of thermal and non-thermal components

How are they related?

まとめ

- 銀河面からのX線放射 (リッジ成分) は拡散成分
 - 点源の重ね合わせでは説明できない
 - 銀河円盤は高エネルギープラズマで満たされている
- 銀河面上のもっとも暗いX線点源の分類
 - 硬X線源の多くは活動的銀河中心核
 - 少し激変星の静状態 (白色矮星連星) が混じっている
 - 軟X線源の多くは活動的な主系列星
- 銀河面上に、非熱的および熱的な、広がったX線源がみついている
 - 電波では見つかっていない超新星残骸の候補
 - 一つの超新星残骸中に熱的成分と非熱的成分が混在している
- リッジ成分の起源は謎
 - ガンマ線成分とスペクトルがほぼつながる
 - 熱的成分、非熱的成分の共存
 - X線による鉄ラインのプラズマ診断は非常に有用

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