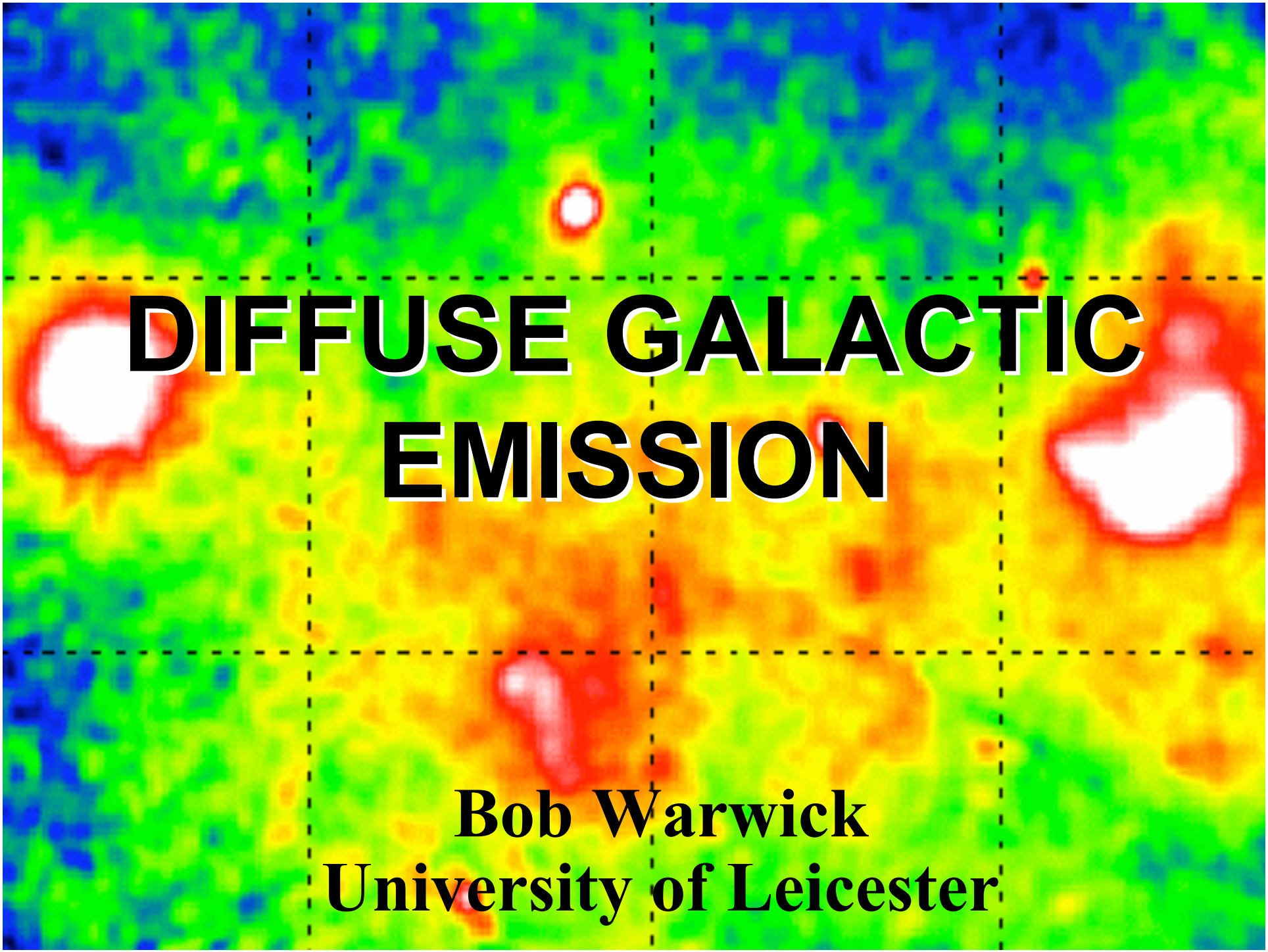
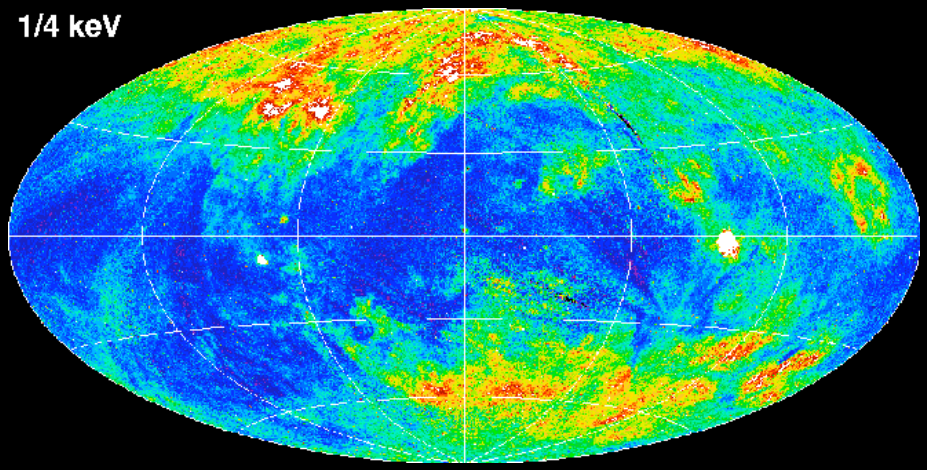
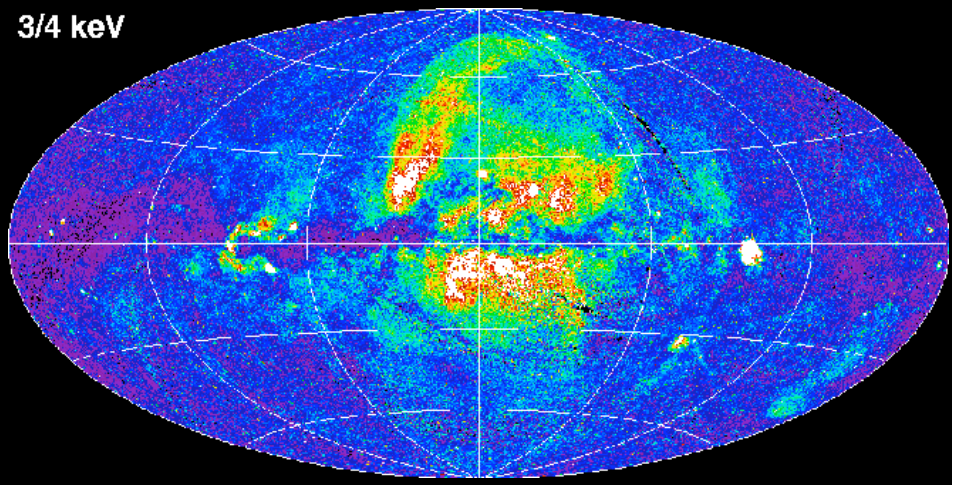


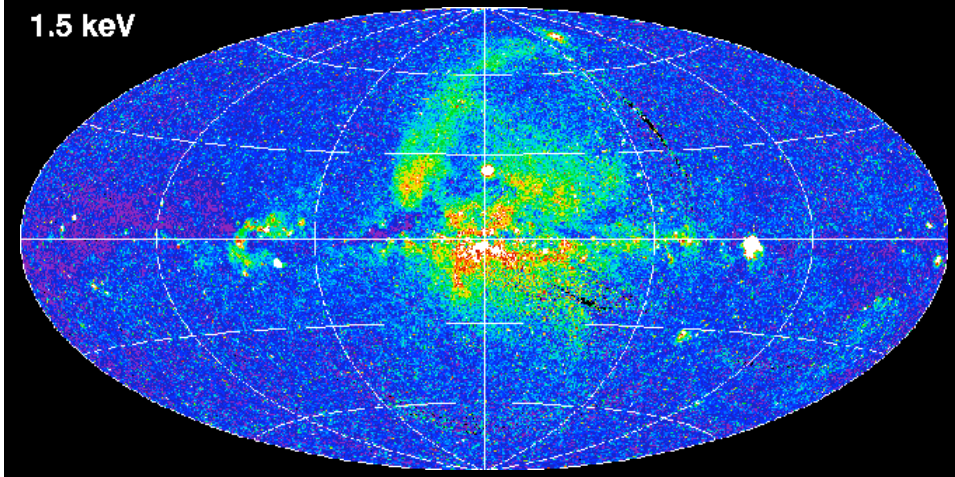
DIFFUSE GALACTIC EMISSION

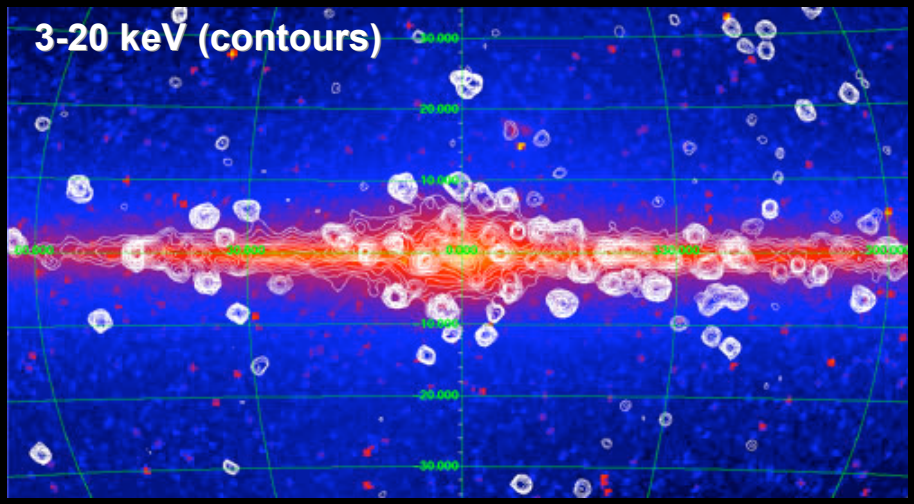
Bob Warwick
University of Leicester

THE X-RAY SKY









Snowden et al. 1997

Revnivtsev et al. 2006

Probing the Galaxy via X-rays

Direct thermal emission from the hottest phase of the ISM

$6 < \log T < 7.5$, $0.1 < kT < 3$ keV

in the disk, bulge and central region

extending into the halo and possible the IGM

Non-thermal emission produced near sites of cosmic ray particle acceleration (electron acceleration → TeV)

Absorption against bright background X-ray sources:

- **Corona Gas: $5.5 < \log T < 6.5$**
- **WIM, WNM: $\log T \sim 4$,**
- **HI, Molecular Clouds: $1 < \log T < 3$**

Fluorescence of dense clouds through X-ray or LECRe irradiation

Topics

- **Nearby Galaxies Perspective**
- The Constituent Parts of the SXRB
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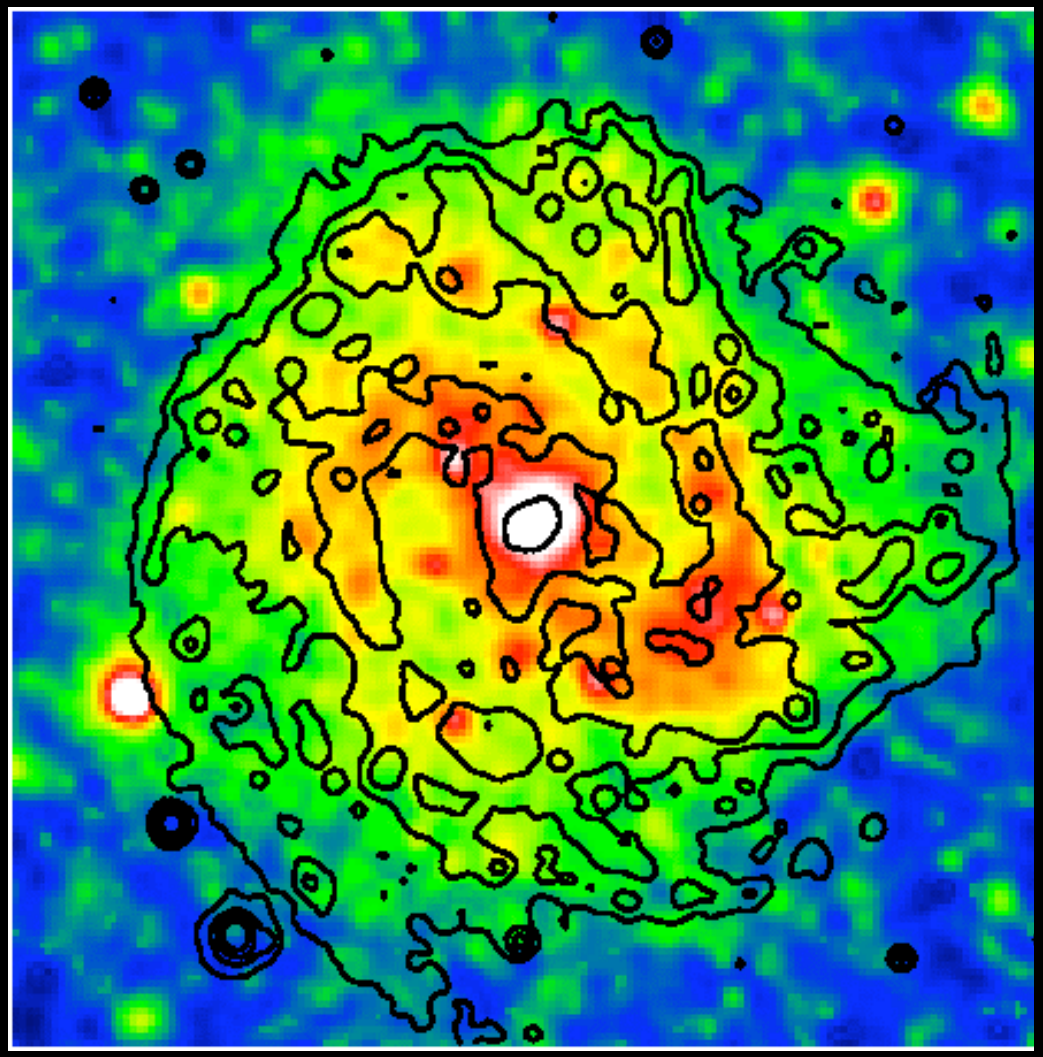
XMM-Newton Observations of the Nearby Spiral Galaxy – M83



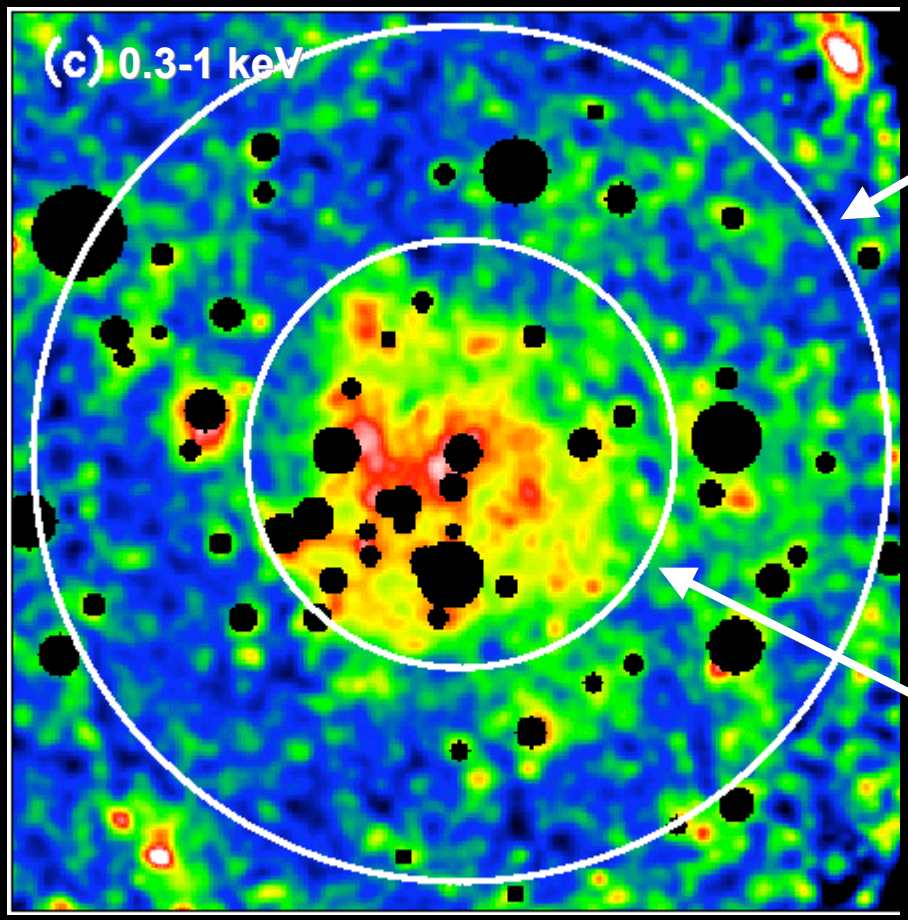
10’ = 10.8 kpc

Colours: 0.3 – 6 keV

Contours: UV

Owen et al 2007

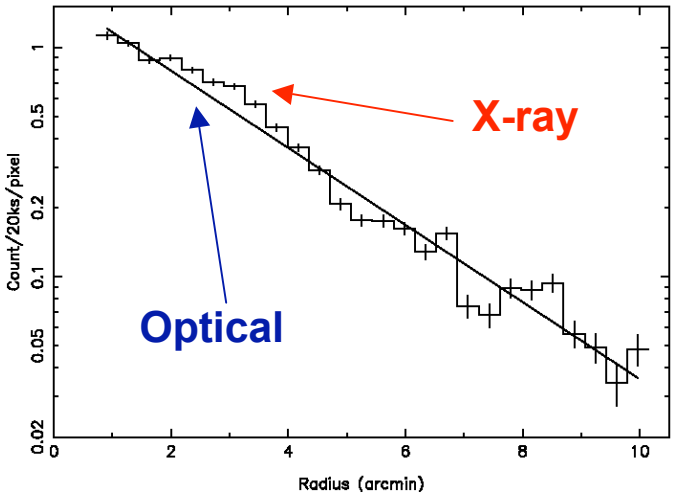
XMM-Newton Observations of M101



20’ = 42 kpc

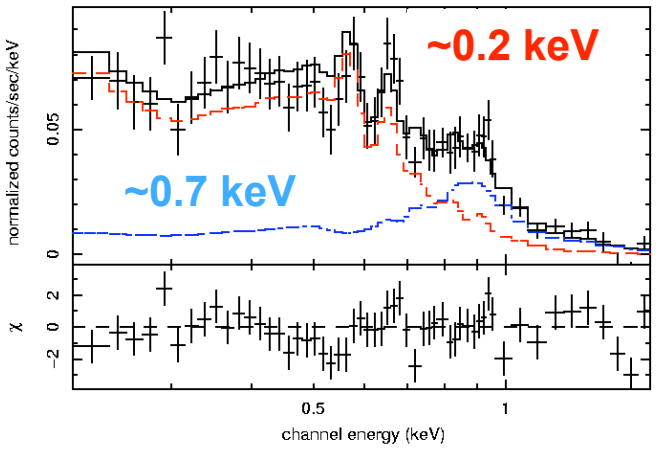
Warwick et al 2007

Radial Surface Brightness



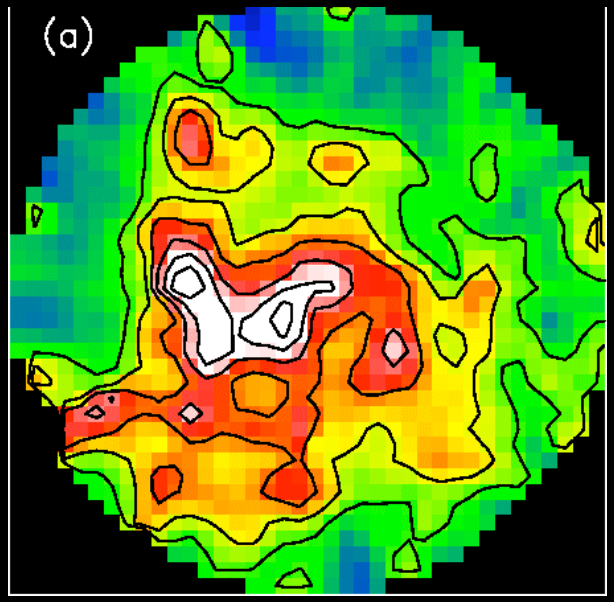
X-ray Spectrum

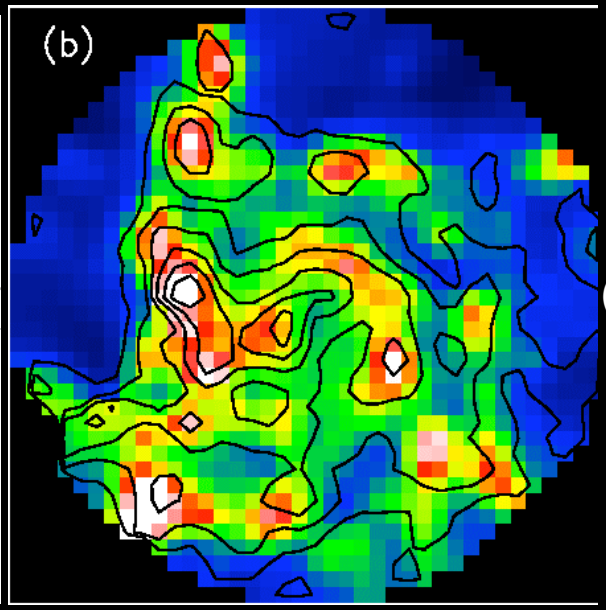
Lx ~ 2 x 10^{39} erg/s



M101: Soft X-ray, UV and Optical Light

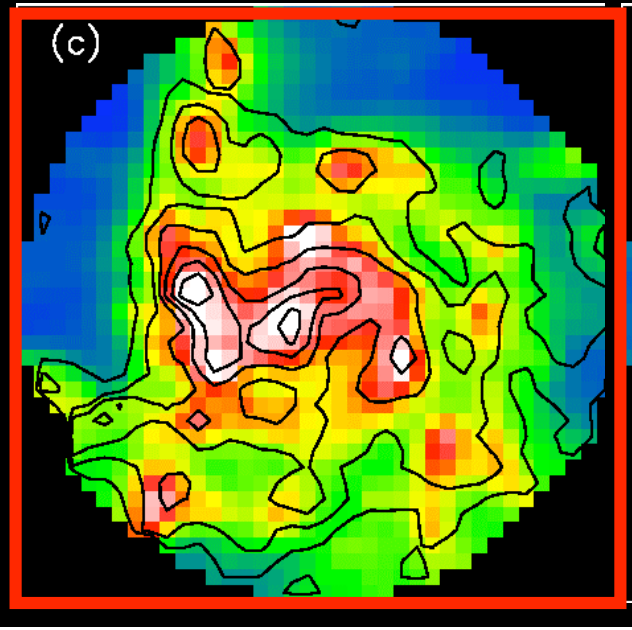
(a) 0.3-1 keV



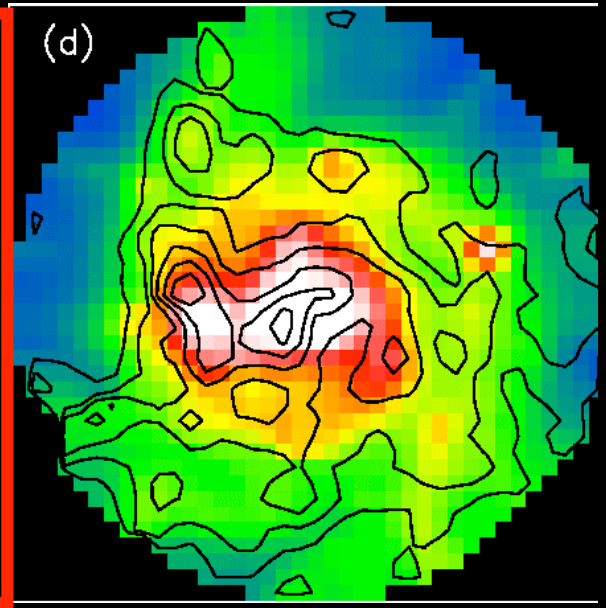


(b) GALEX NUV

Strongest Correlation

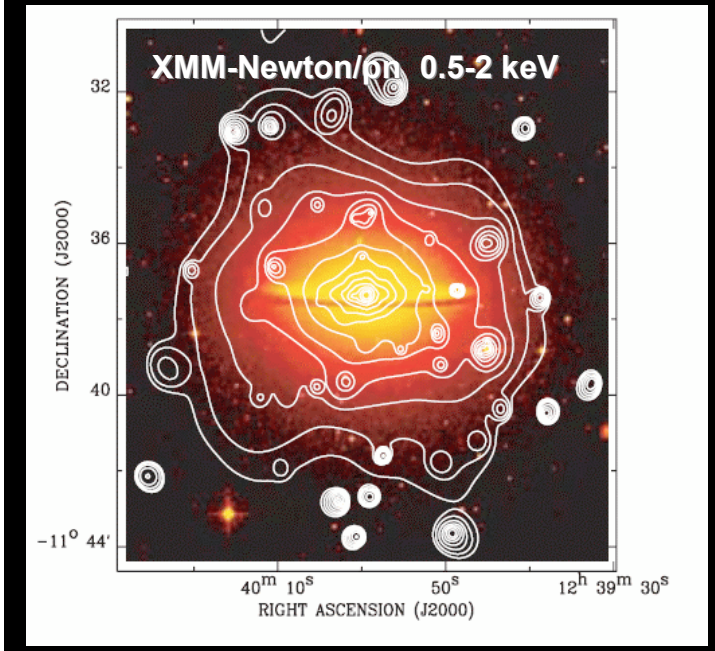


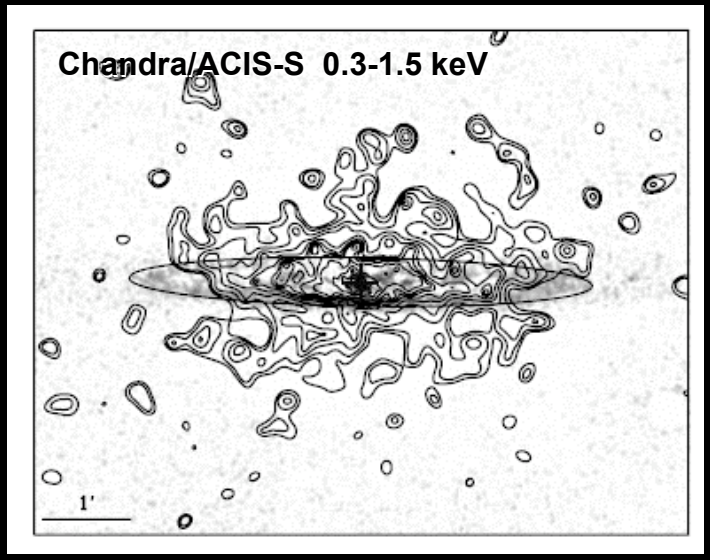
(c) OM U

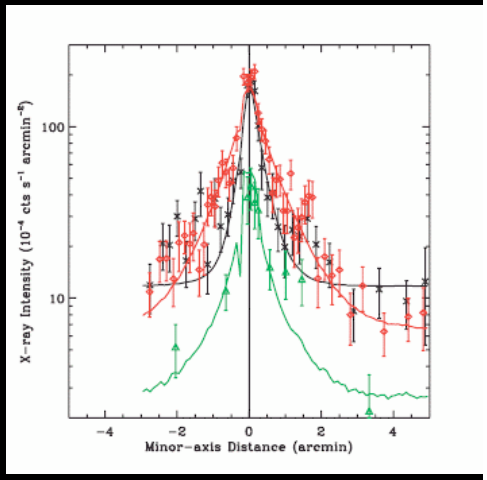


(d) OM V

Diffuse X-ray Emission in M104 (Sombero)







Z_0 ~ 1' (2.6 kpc)

- Edge-on Sa spiral with large-scale diffuse X-ray emission traceable out to ~20 kpc
- kT ~ 0.6--0.7 keV, Lx ~3 x 10^{39} erg/s
- Emission above disk is highly structured in inner region
- Energy required much less than mechanical input from SN
- No evidence for accretion from IGM

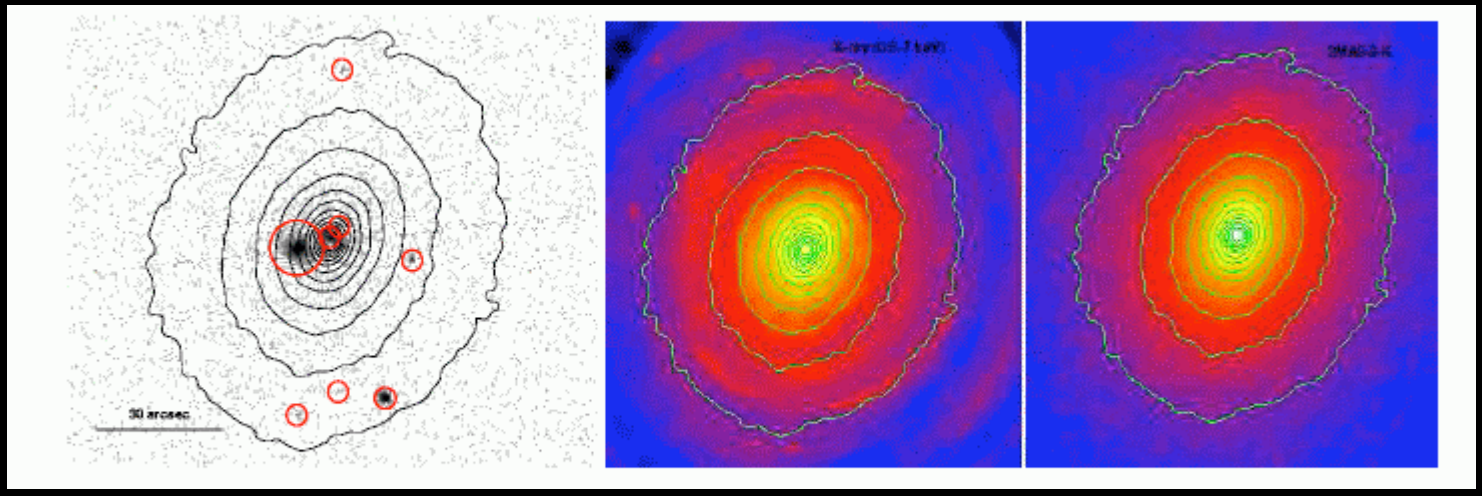
LI et al. 2007

Unresolved Hard X-ray Emission in M32

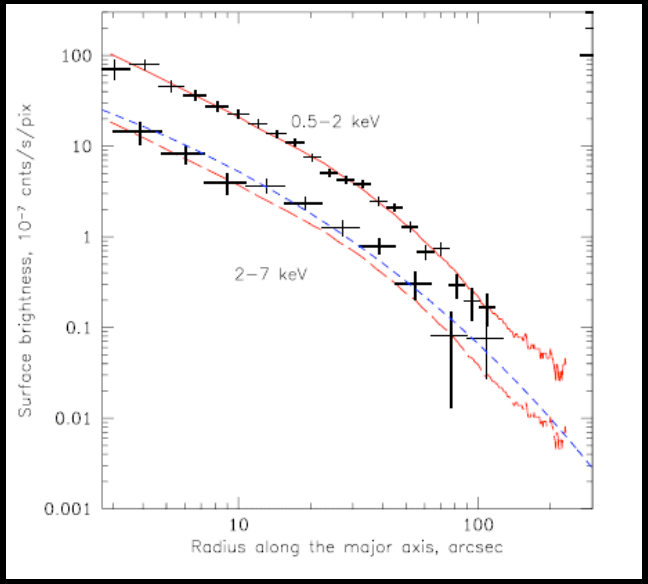
Chandra 0.3-7 keV

Smoothed source-subtracted

K-band



- M32 – nearby dwarf elliptical lacking HMXRB, signs of recent SF or hot gas
- excluding sources Lx > 10^{34} erg/s (ie all LMXRB) find the residual unresolved X-ray emission follows the optical light
- 2-10 keV emissivity ~ 4 x 10^{27} erg/s per solar mass

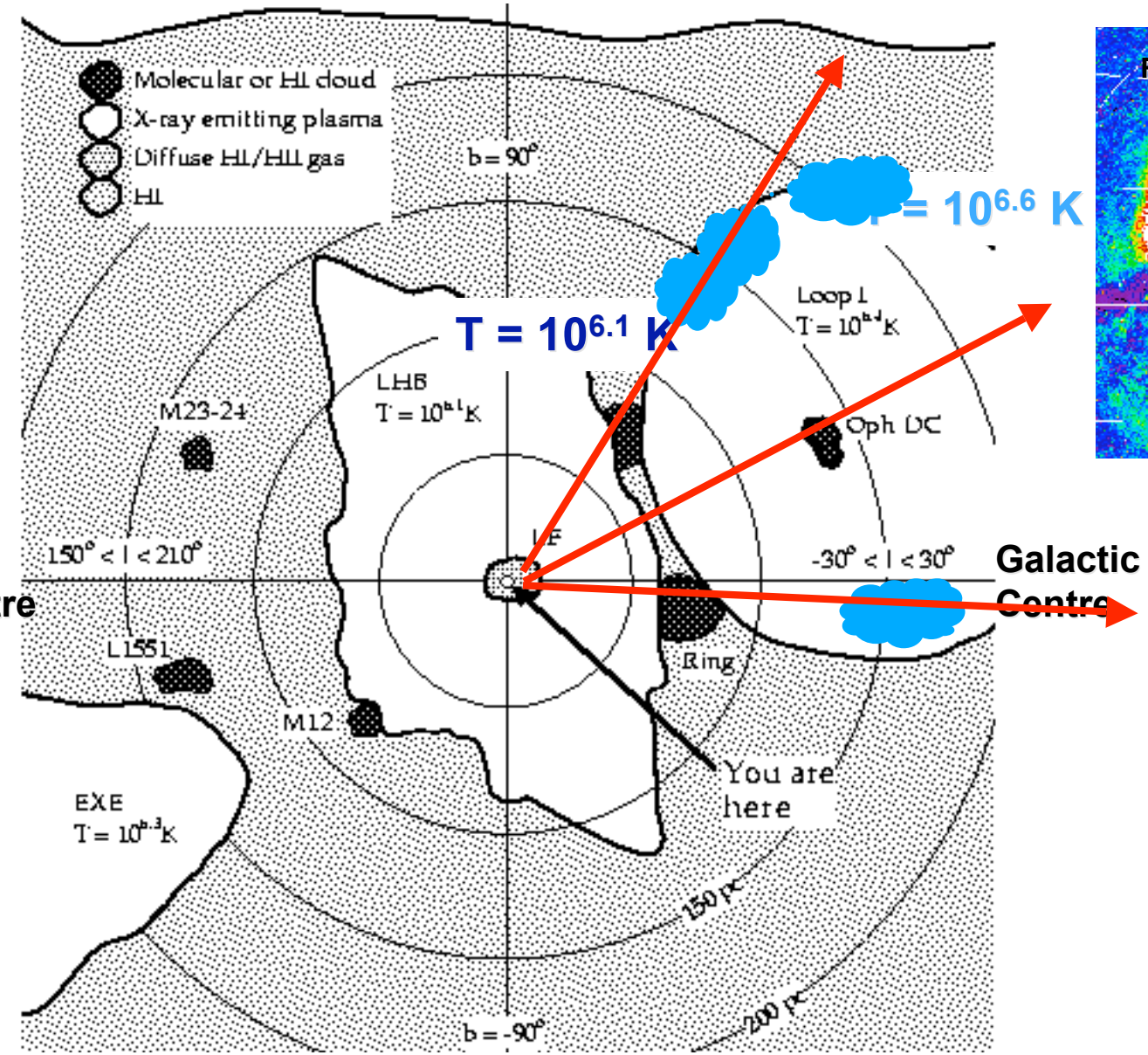


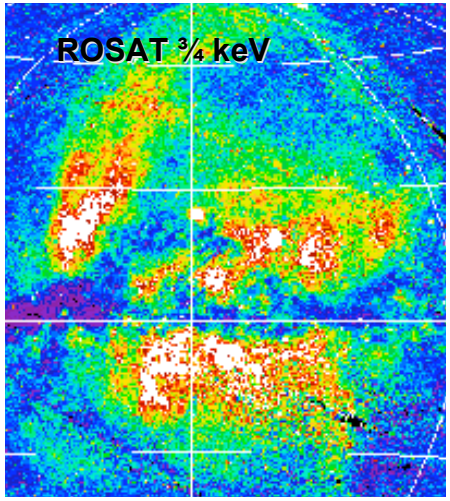
Revnivtsev et al. 2007

Topics

- Nearby Galaxies Perspective
- **The Constituent Parts of the SXRB**
- The Origin of the Galactic Ridge
- The Galactic Centre Laboratory
- XMM-Newton “Legacy” Programmes

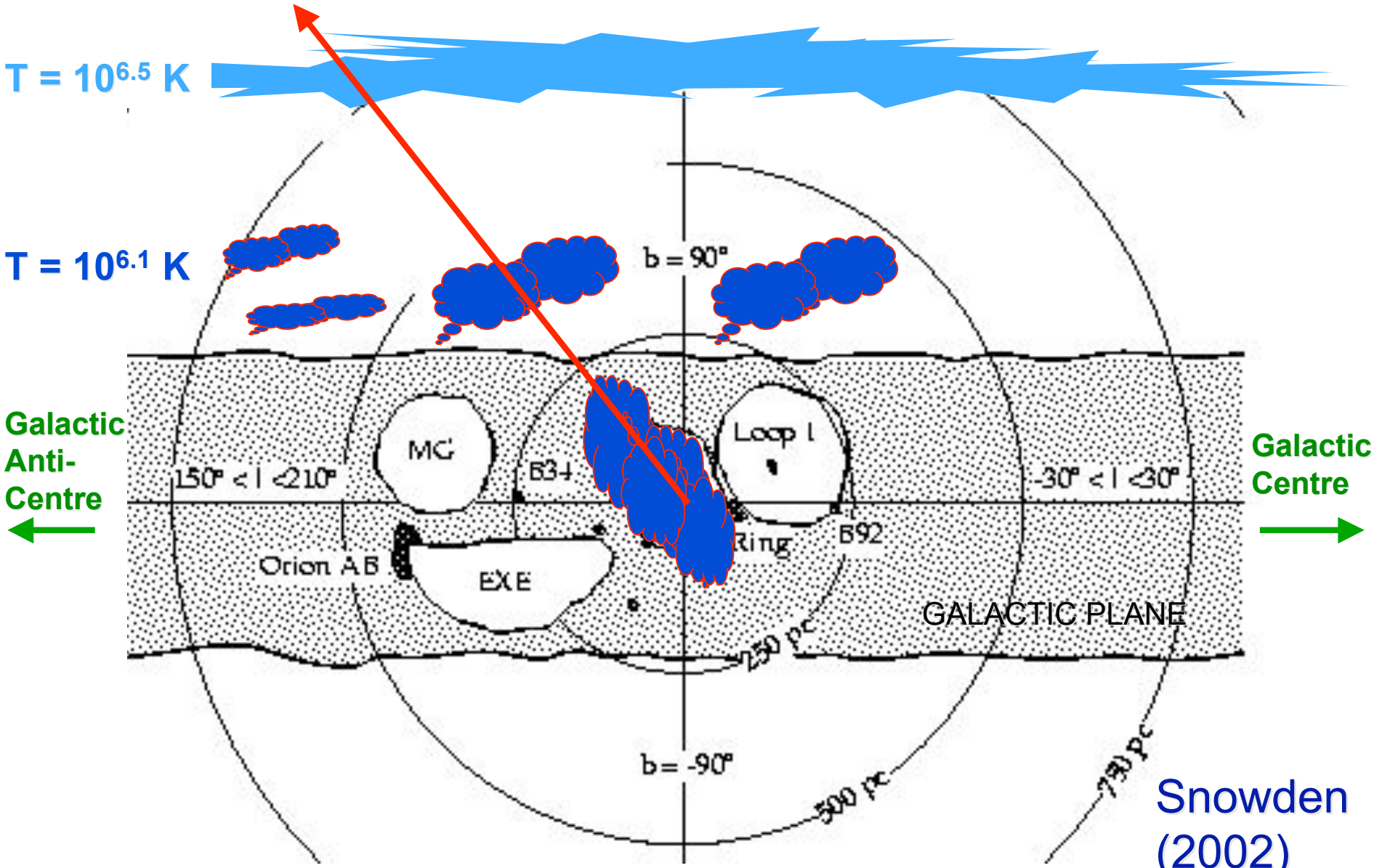
Distribution of ~ Hot Plasma in the Direction of Loop 1 and the Galactic Centre



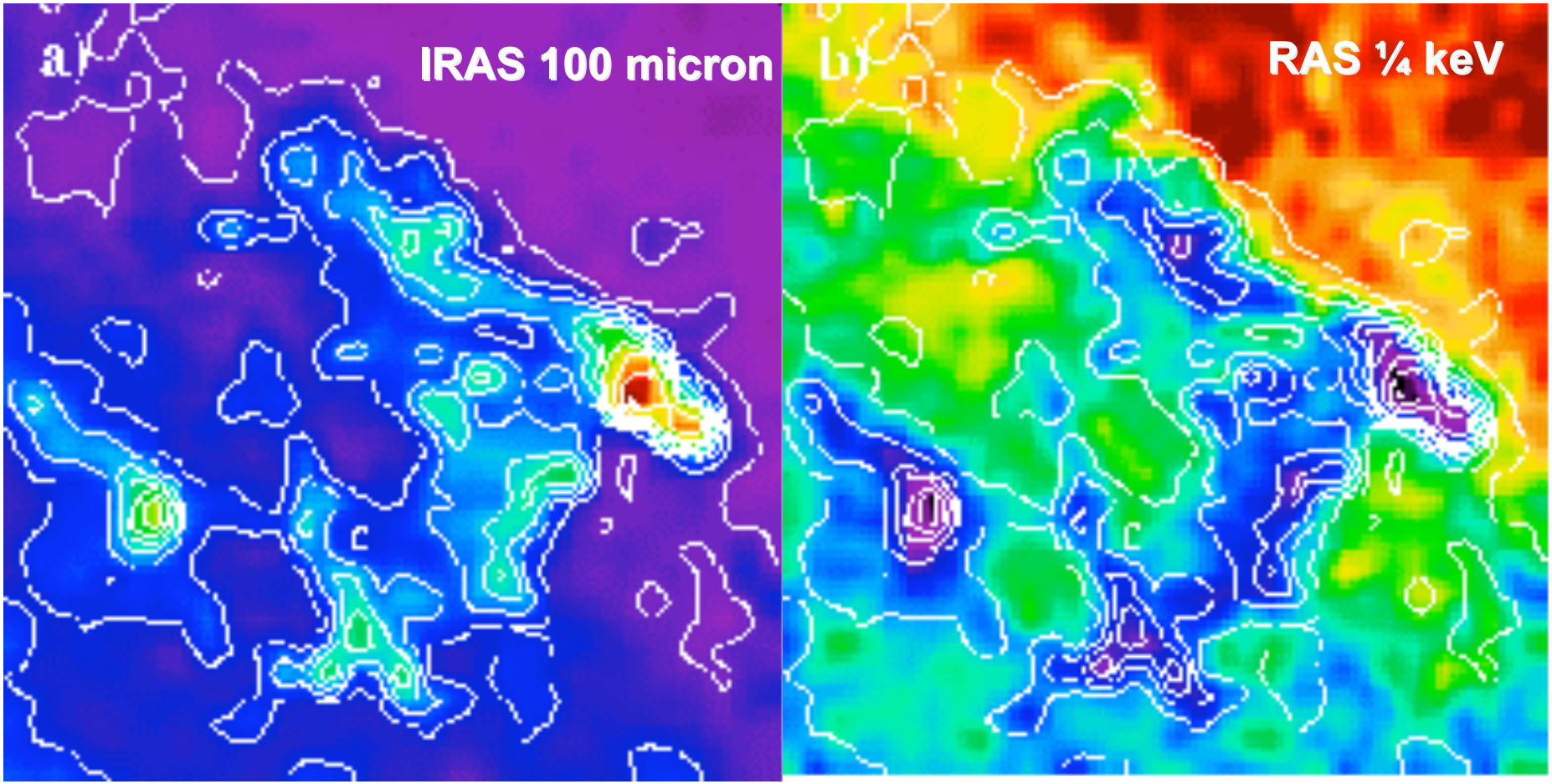


Snowden (2002)

Distribution of ~ 10^6 K Plasma at High Galactic Latitude

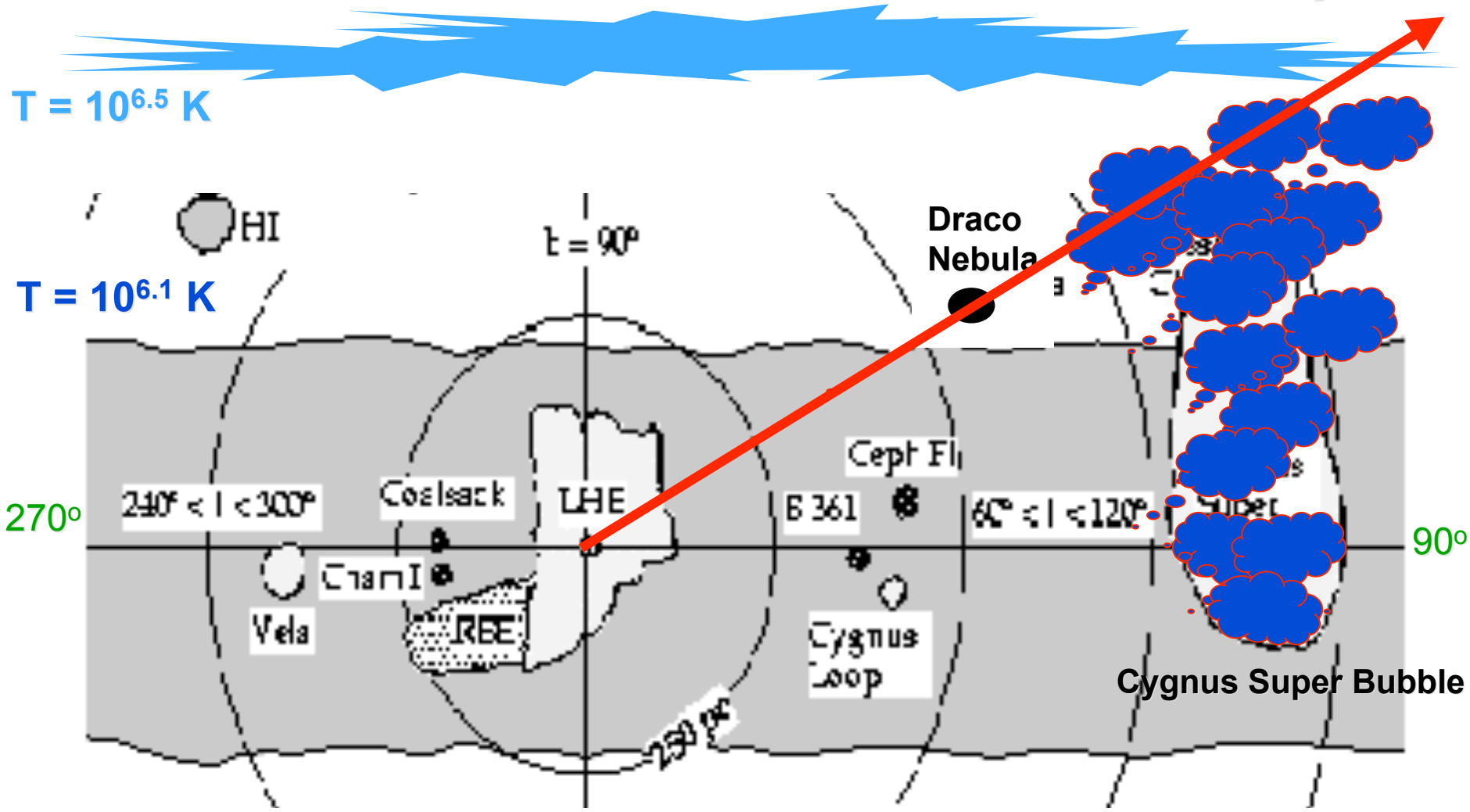


Shadowing of the ¼ keV SXRB in Draco



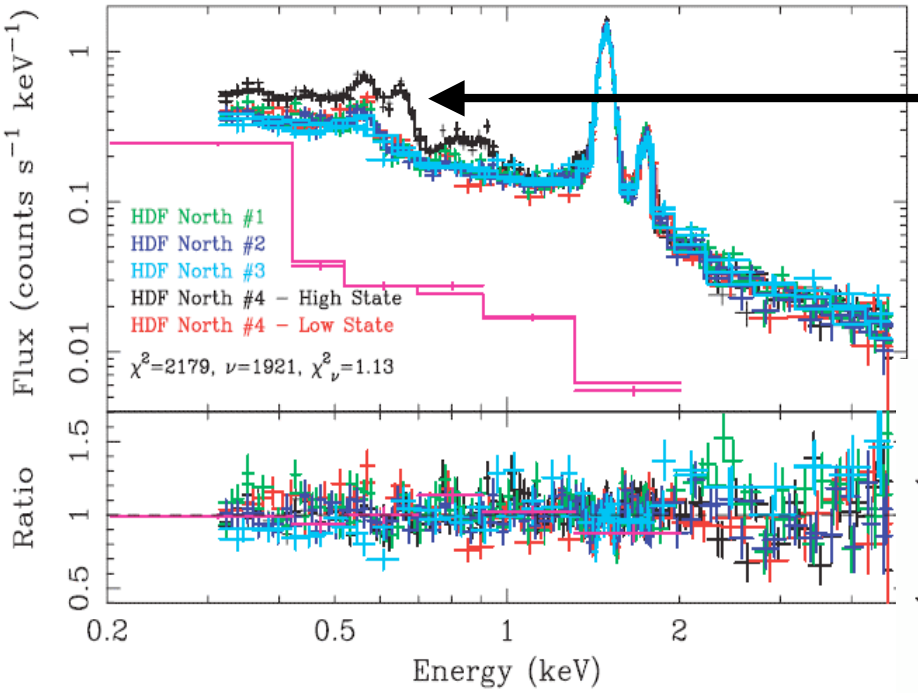
Burrows & Mendenhall 1991; Snowden et al. 1991

Distribution of ~ 10^6 K Plasma in the Local Galaxy

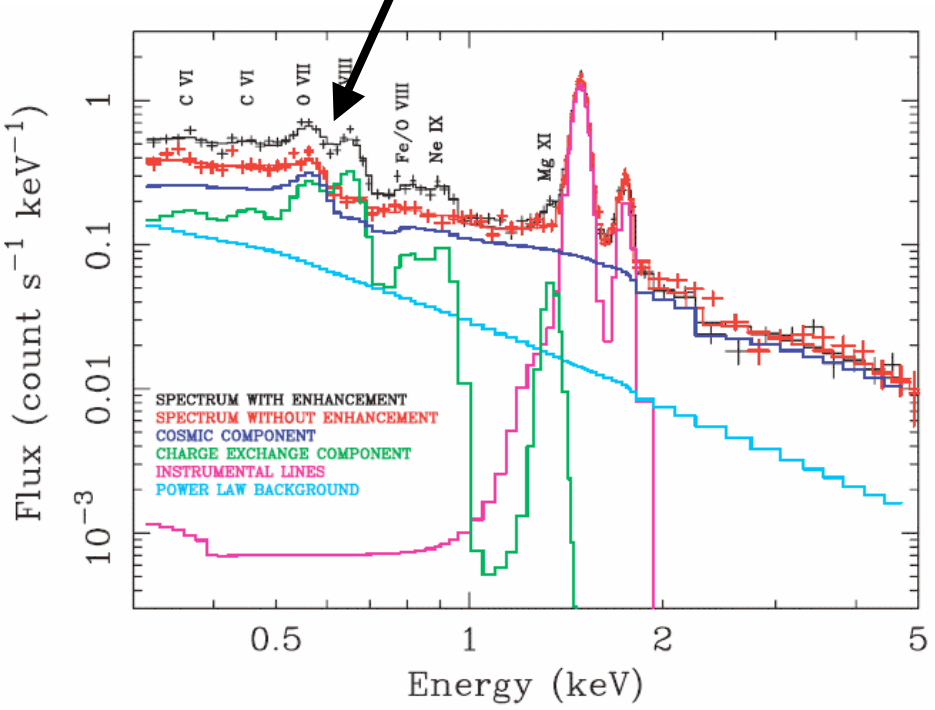


Snowden (2002)

Solar Wind Charge Exchange Emission from the Heliosphere and/or Earth's Exosphere

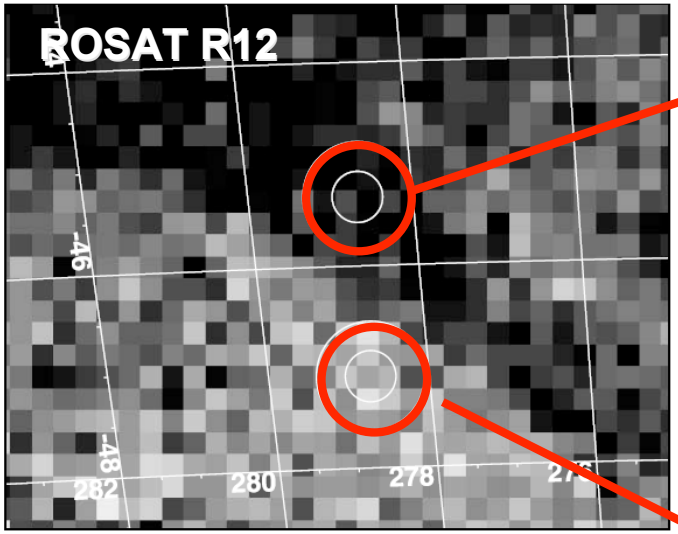


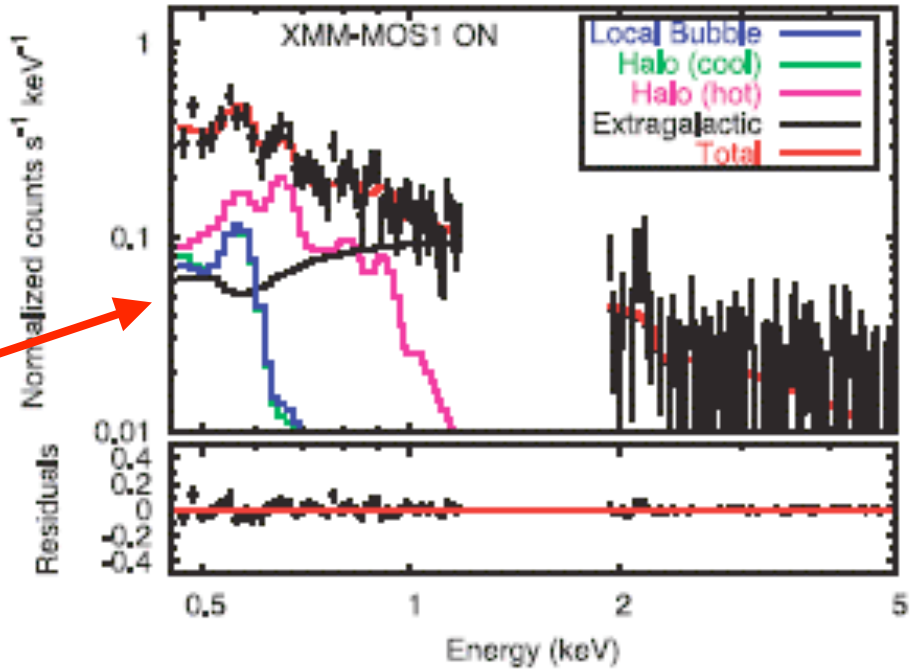
SWCX Component

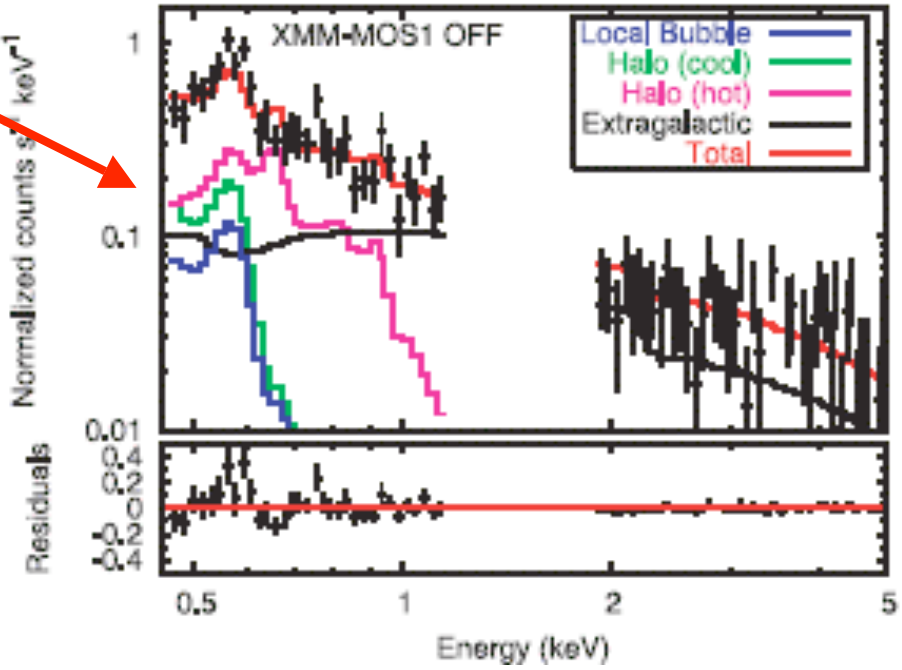


Snowden et al 2004

XMM-Newton Observations of an Absorbing Filament at b = -45°



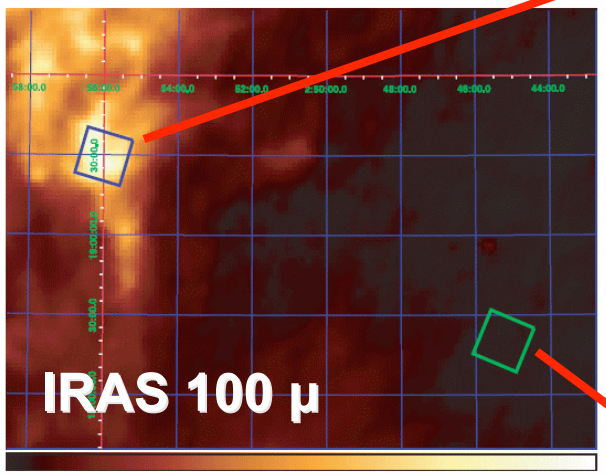


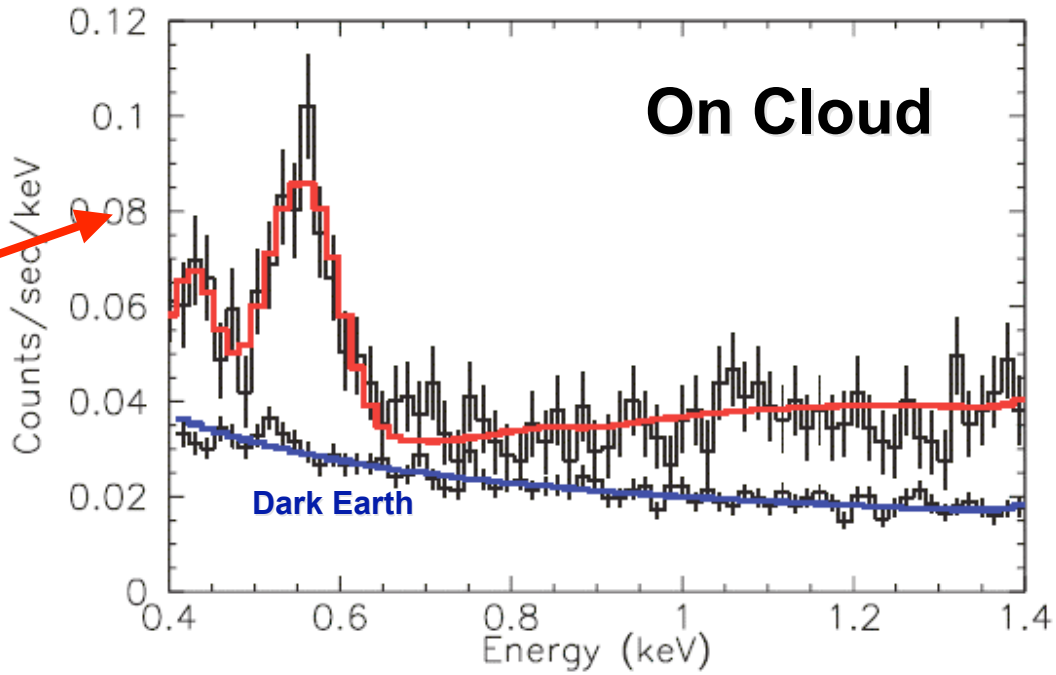


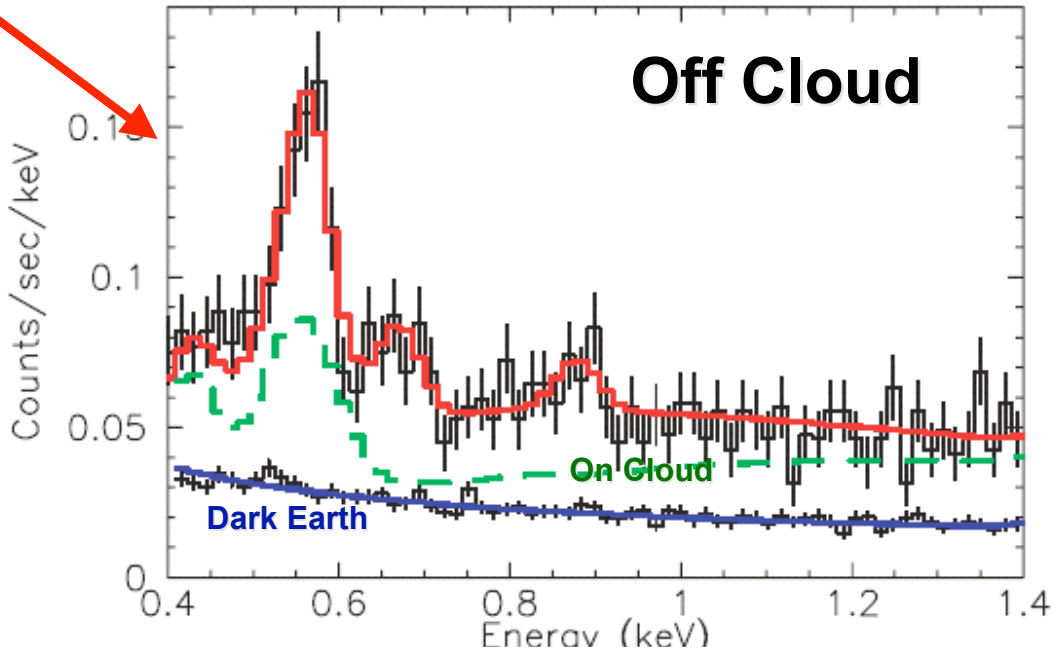
- LHB emission consistent with CIE plasma log T/K = 6.06
- Over-ionized plasma model implies implausibly young age for LHB (< 6 x 10^5 yr)

Henley et al 2007

Suzaku Observations of the Shadowing of the MBM 12 Cloud (b = -34°)



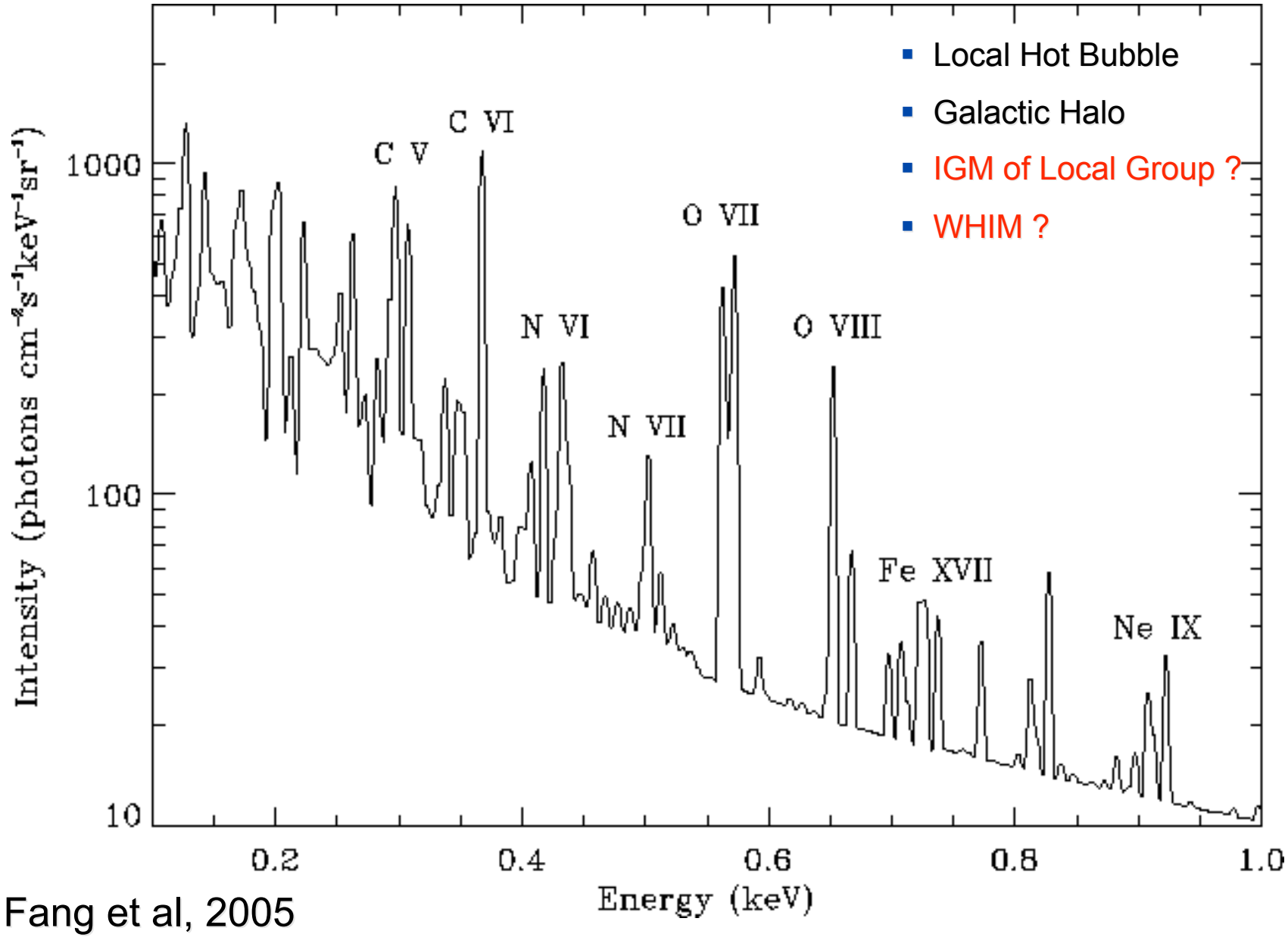




- OVII line consistent with T ~1.2 x 10^6 K; em ~0.0075 cm^{-6} pc (but then over-predicts ROSAT ¼ keV flux)
- OVII due to interplanetary SWCX?
- Is there a LHB at all?

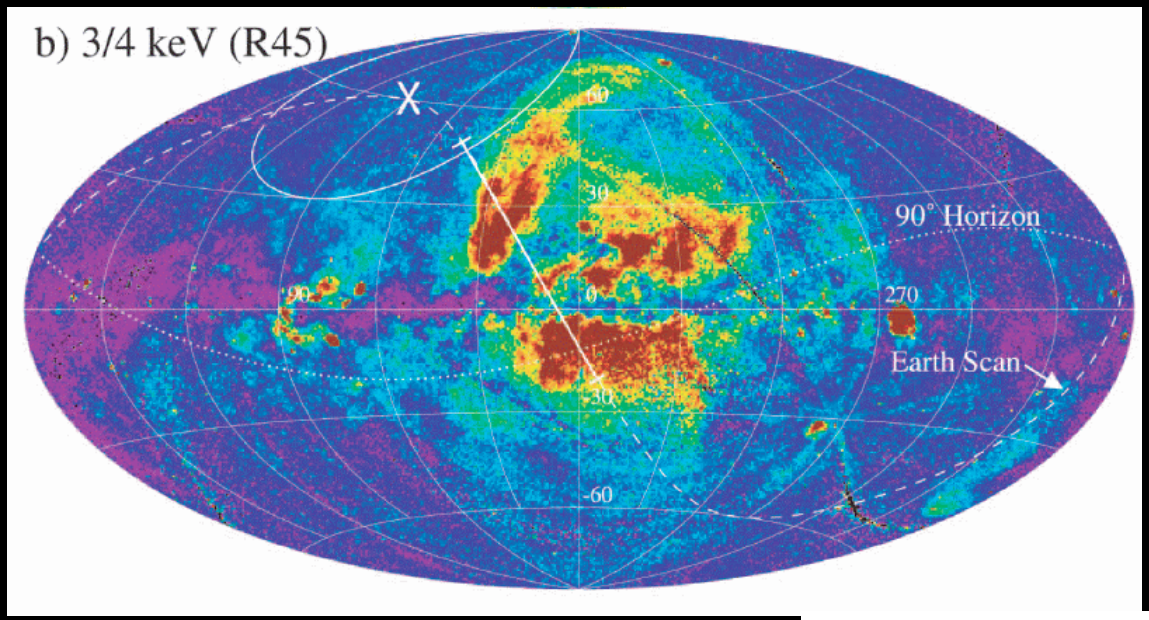
Smith et al. 2007

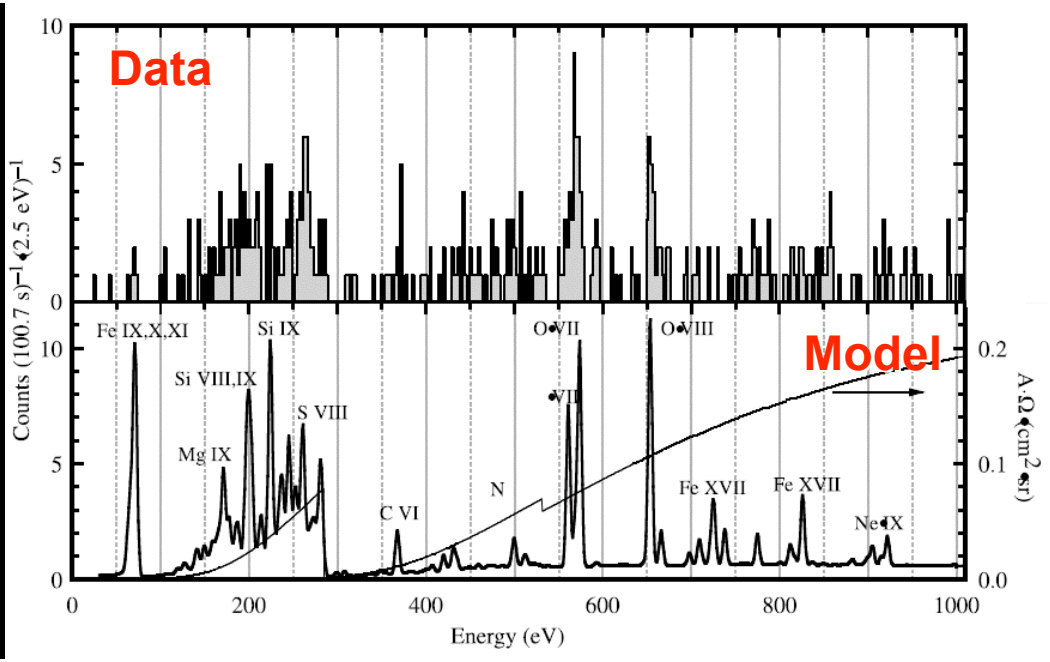
Simulated Spectrum of the SXRB at High Latitude



Fang et al, 2005

Measured Spectrum of the SXRB at High Latitude

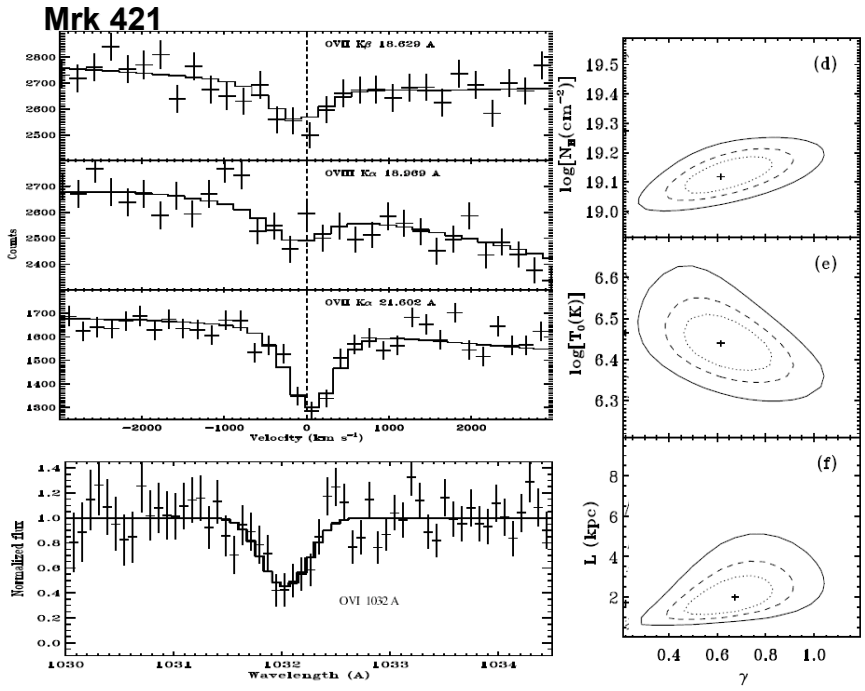




XQC Rocket Flight
McCammon et al 2002

Absorption Line Spectroscopy of Hot Gas in the Galaxy

- Gratings observations by Chandra and XMM-Newton predominantly of OVII, OVIII & Ne IX ions plus FUSE observations of OVI doublet (1031.9 & 1037.6 Å)
- Archive of ~20 AGN and ~10 Galactic LMXRB + LMX-3



Yao & Wang 2007

Line of sight to Mrk 421 (b = +65°)

- Gas temperature & density fall exponentially with height above plane
- Scale height ~ 1-2 kpc
- $T \sim 3 \times 10^6$ K, $n_e \sim 2.3 \times 10^{-4}$ cm^{-3} (mid-plane; high filling factor)
- consistent with results from nearby edge-on galaxies

Topics

- Nearby Galaxies Perspective
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- **The Origin of the Galactic Ridge**
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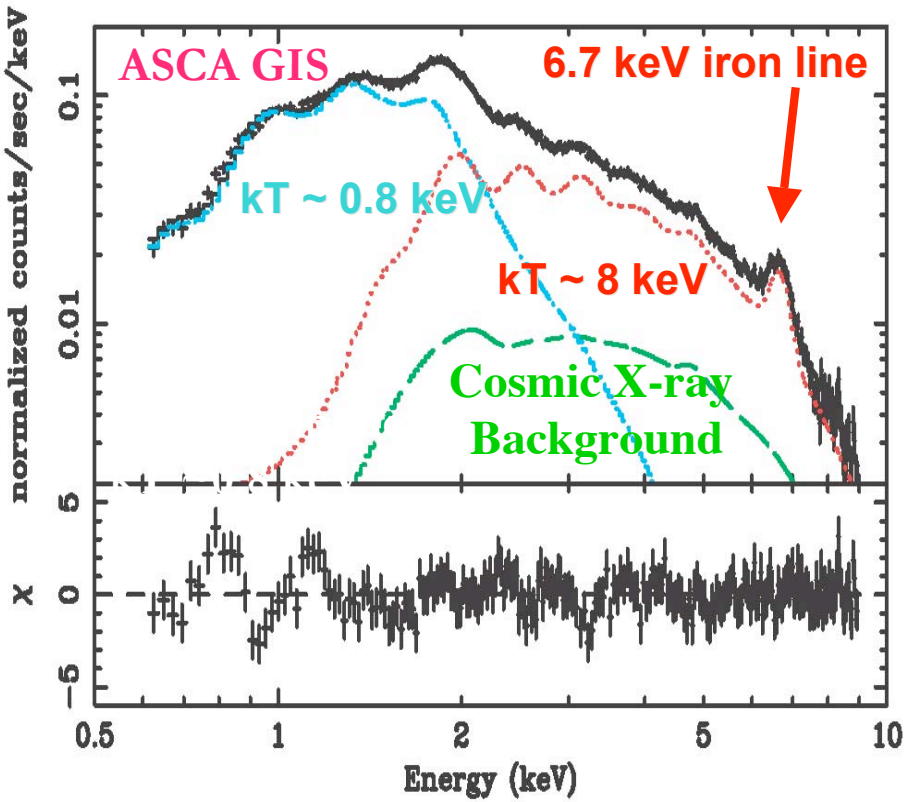
The Galactic X-ray Ridge Emission (GXRE)

- First evidence ~ early 1970's (Cooke et al 1970; Bleach et al. 1972)
- Identified as a significant Galactic feature by HEAO1 (Worrall et al. 1982)
- Narrow ridge evident in EXOSAT Galactic Plane Scan (Warwick et al. 1985)
- Extensively studied by Tenma, Ginga & ASCA (eg Yamauchi & Koyama 1993; Sugizaki et al 2001)

Spectrum of the Galactic Ridge

GXRE is characterised by a hard thermal continuum and 6.7 keV (+6.9 keV) iron Kα lines



Kaneda et al. (1997)

DIFFUSE ORIGIN FOR THE HARD COMPONENT?

- Luminosity of 1.4 x 10^38 erg/s
- Energy Density ~10 eV/cm^3
- Too hot to originate in SN activity
- Unbound to Galactic Disk & Bulge

Possible approaches to various aspects of the problem:

- Magnetic reconnection & confinement
- Quasi-thermal plasma
- LECRe – non-thermal contribution
- LECR ions & charge exchange

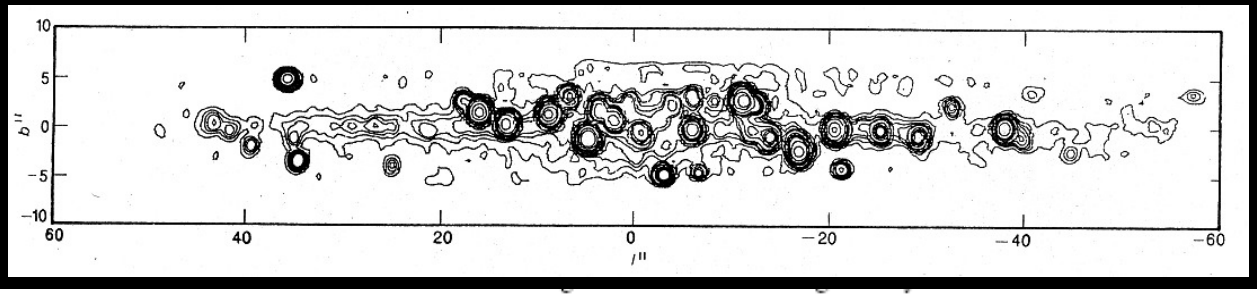
See Tanaka (2002)

POINT SOURCE ORIGIN?

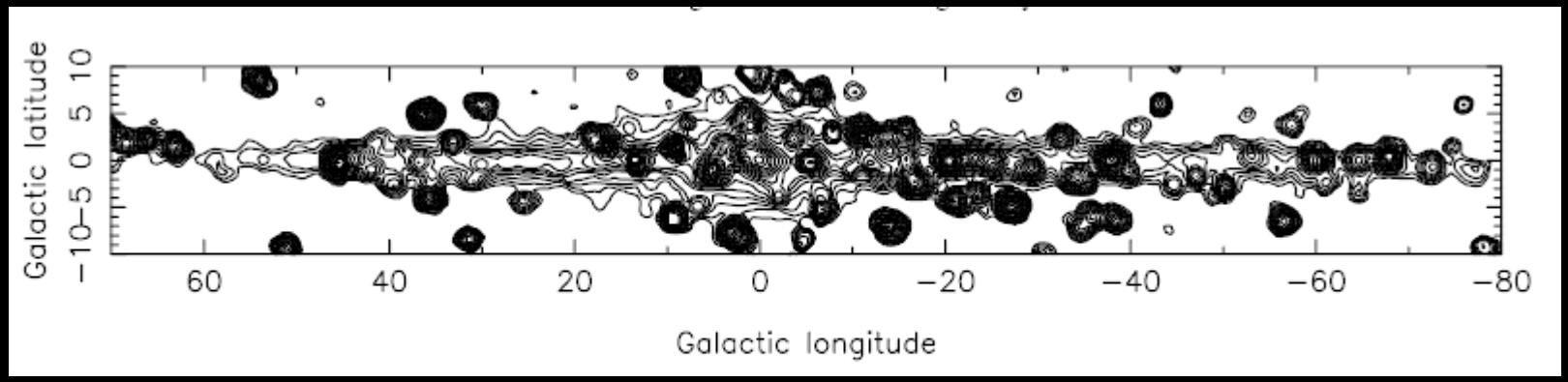
Unresolved discrete sources account for <20% of integrated flux

See Ebisawa et al. (2005); Hands et al. (2004)

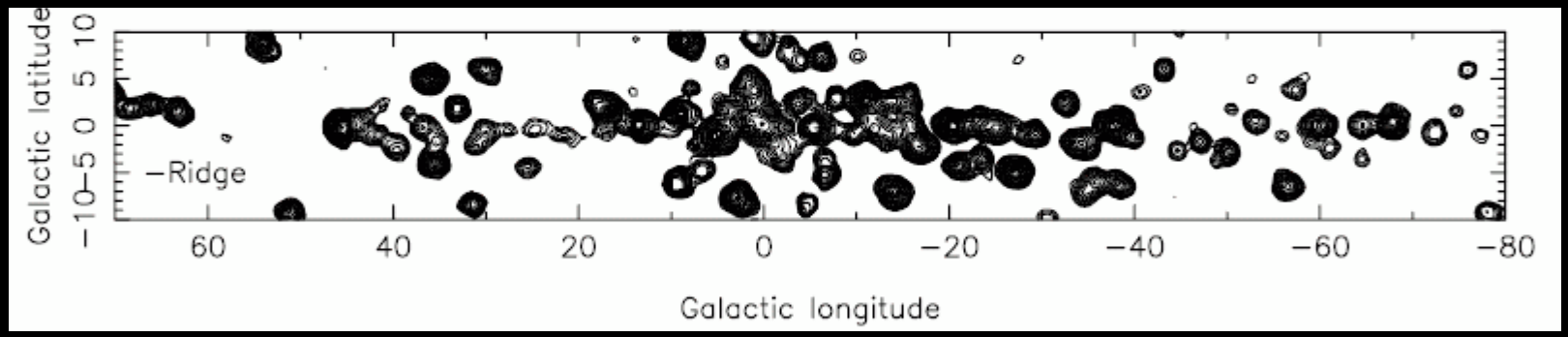
GXRE Emission Correlates With Near-Infrared Light



EXOSAT
(2-6 keV)



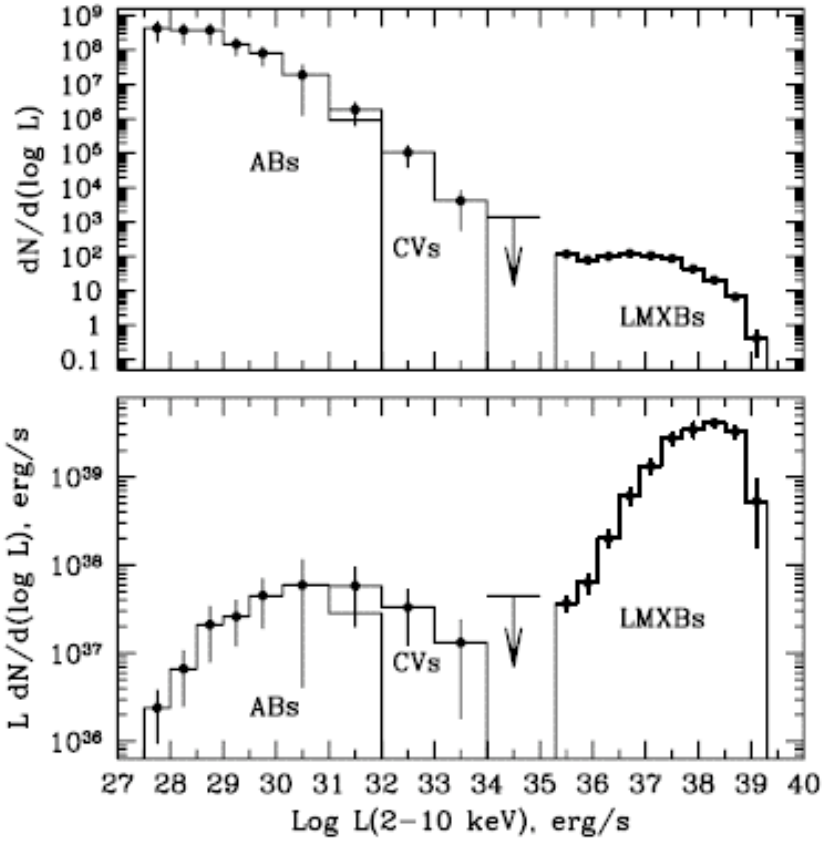
RXTE
(3-20 keV)

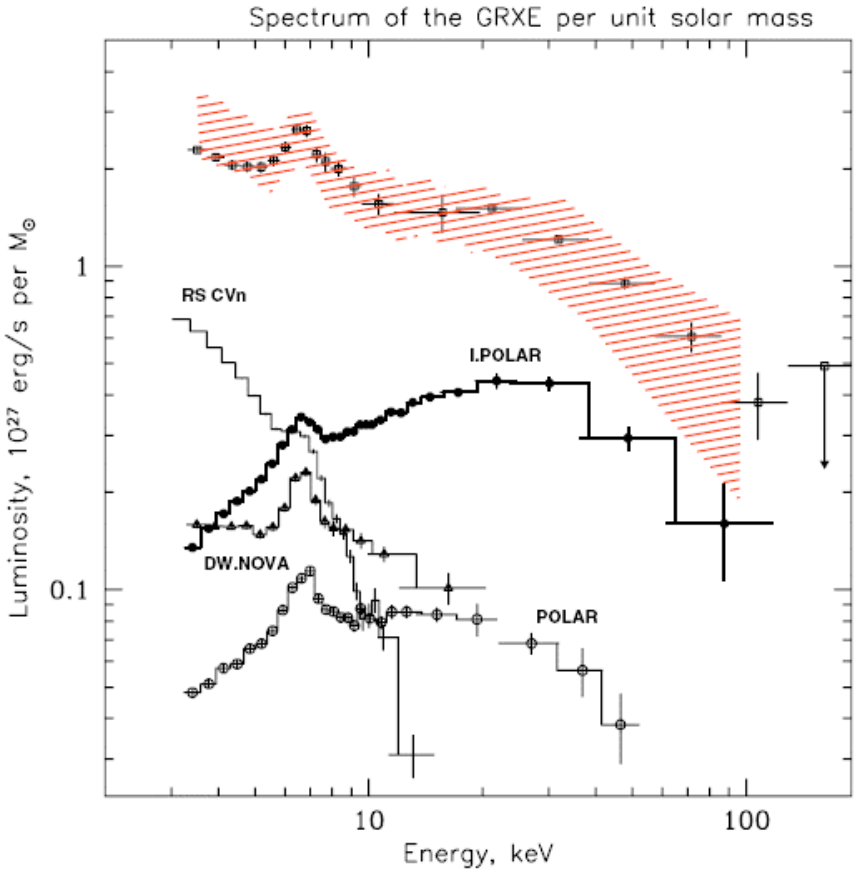


component proportional to near IR light subtracted

Revnivtsev et al 2006; Sazonov et al 2006

Luminosity Function and Spectrum of Discrete Sources Contributing to the GXRE

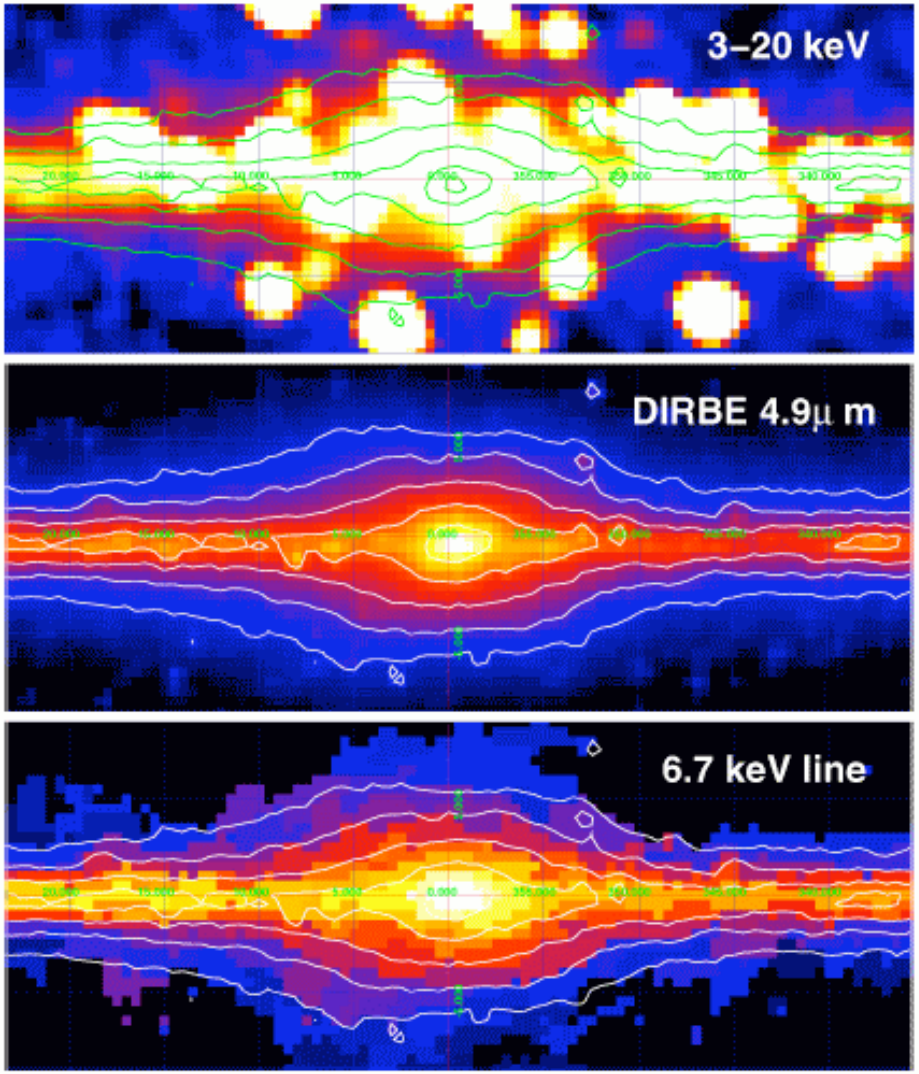


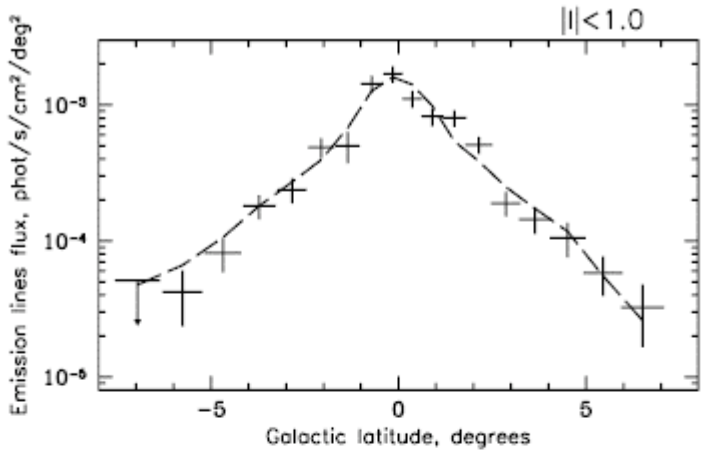


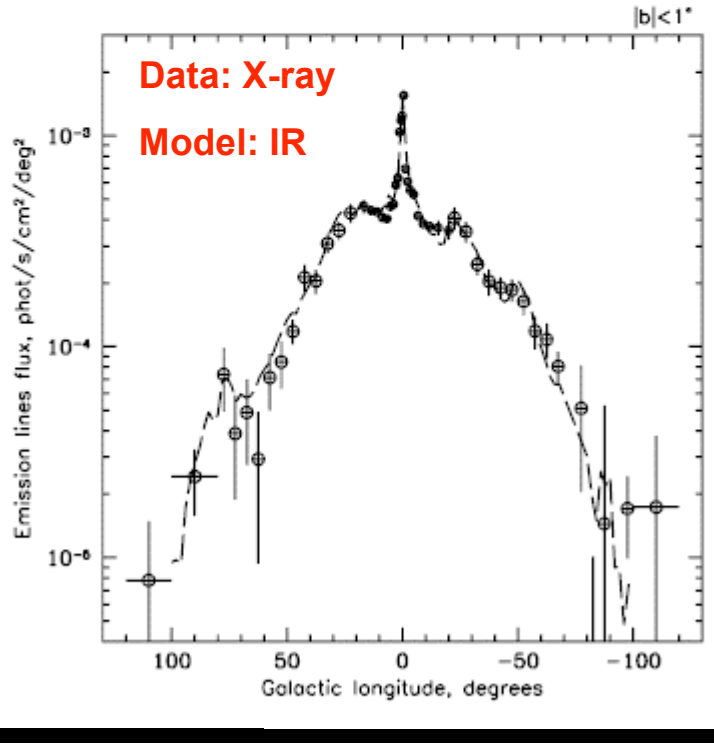
Locally $L_x/M = 4.5 \pm 0.9 \times 10^{27}$ erg/s per solar mass

Revnivtsev et al 2006; Sazonov et al 2006

The Correlation of the GRXE 6.7 keV line emission with infrared light

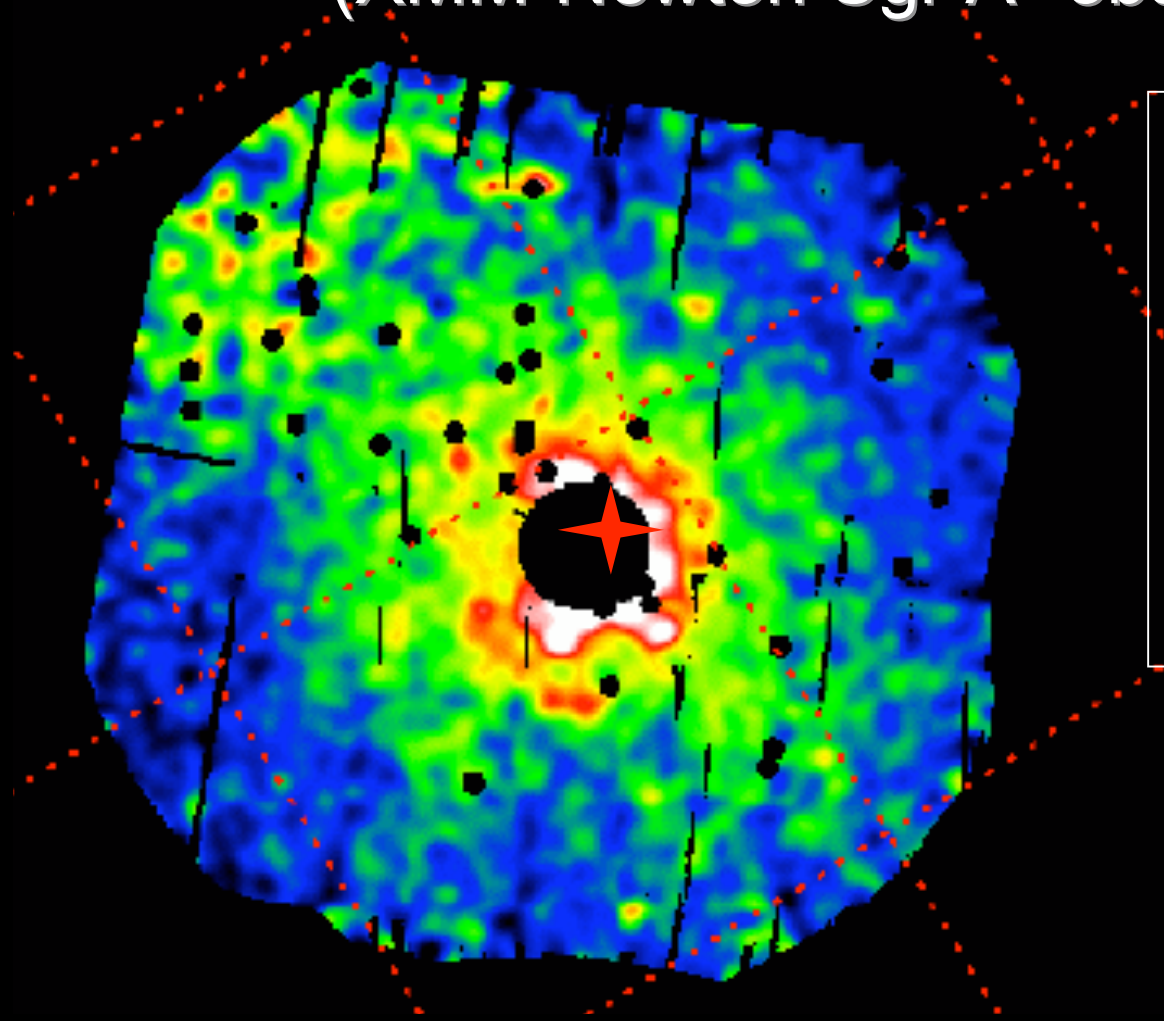






Revnivtsev et al 2006

The 6.7 keV line as a tracer of the hard GXRE component in the Galactic Centre (XMM-Newton Sgr A* observations)



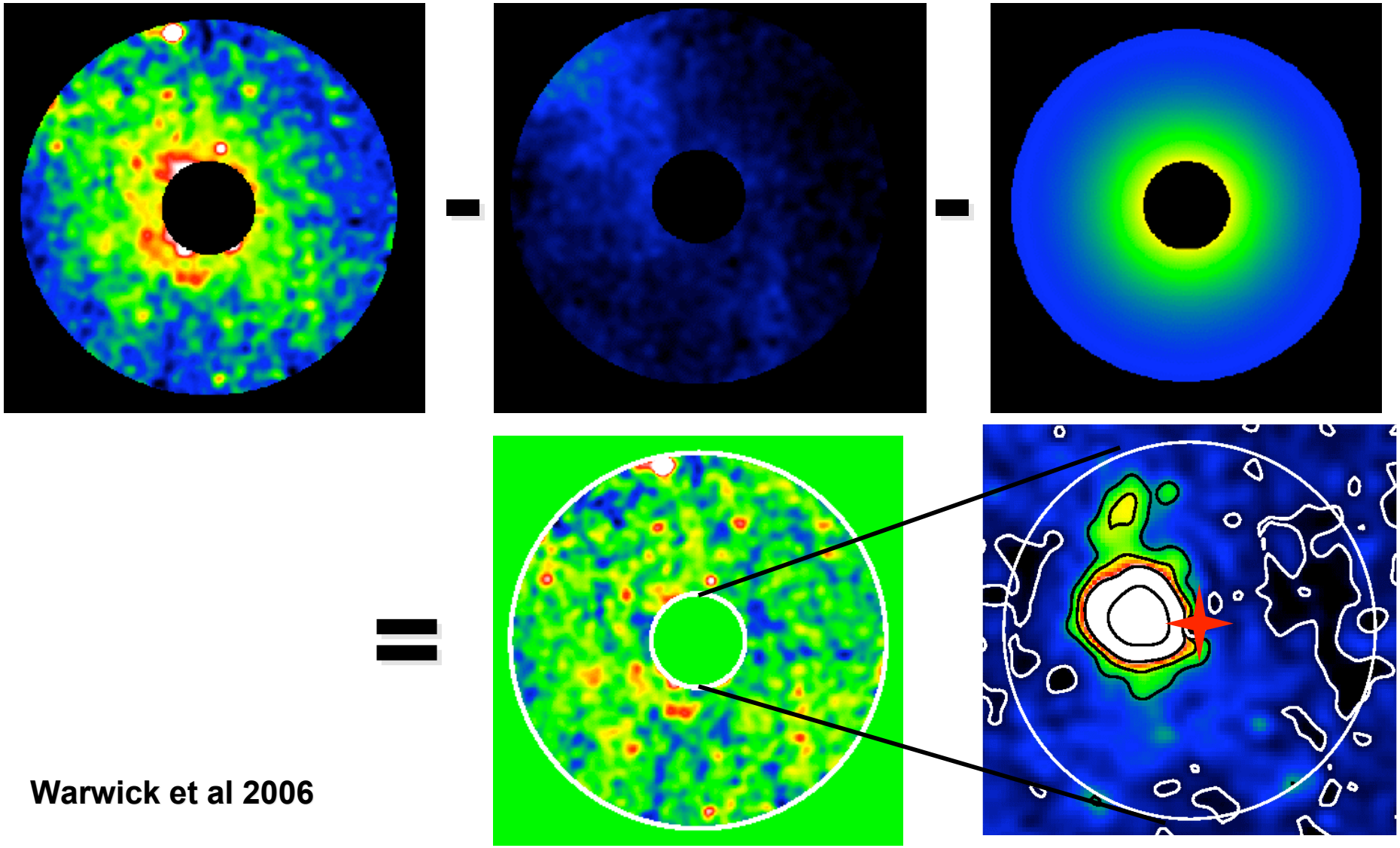
60 pc @ 8 kpc

→ Spectral characteristics match those of a hot kT ~ 8.0 keV plasma in ionization equilibrium

→ Implied rate of energy input if diffuse and unbounded ~10^{40} erg s^{-1}

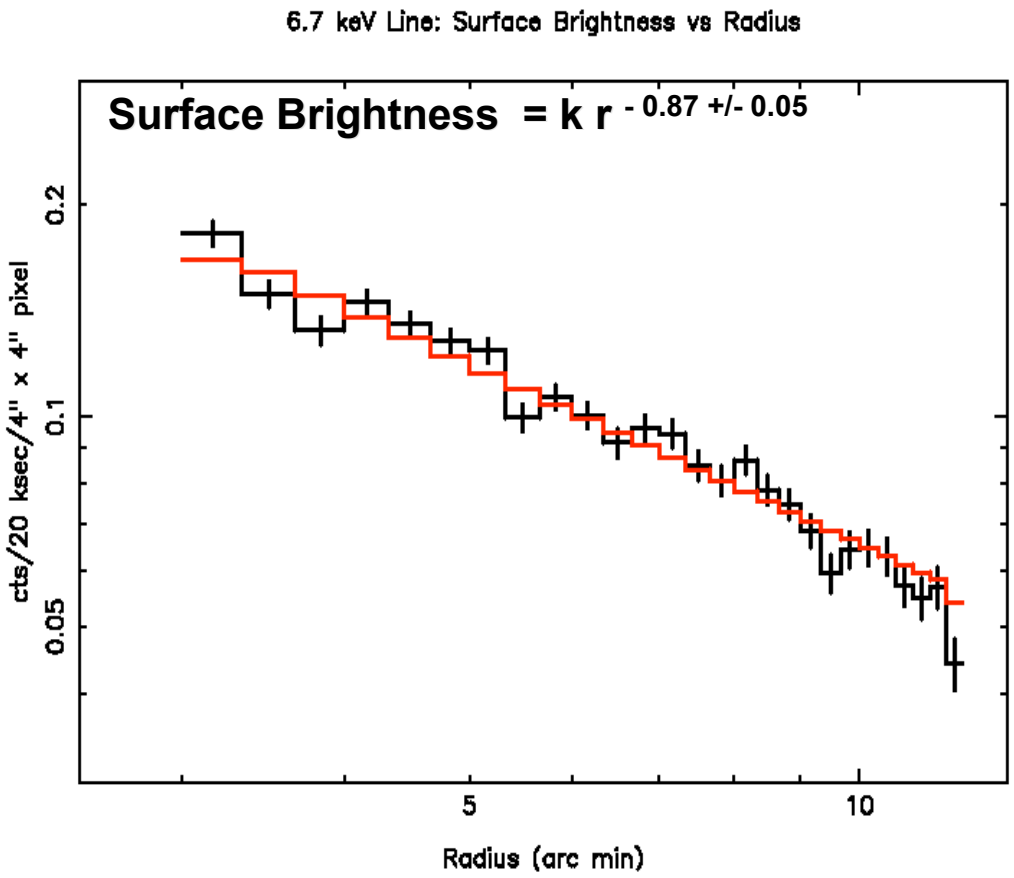
= Sgr A*

Modelling the Spatial Distribution of the 6.7 keV He-like iron line



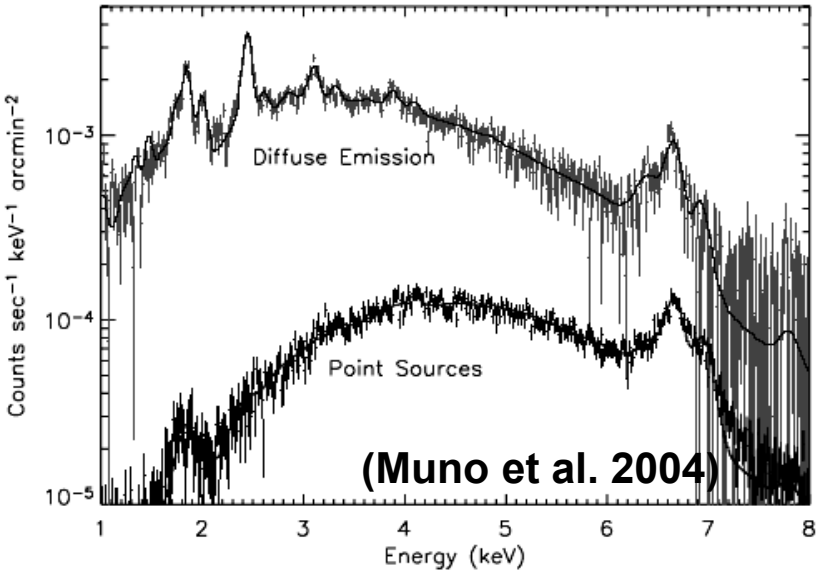
Warwick et al 2006

Radial Distribution of the GXRE Component in the Galactic Centre



- The observed radial surface brightness distribution is very similar to that of resolved Chandra point sources (Muno et al 2004)
- Consistent with an association with the extended r^{-2} stellar cusp (eg Serabyn & Morris 1996; Launhardt et al 2002)

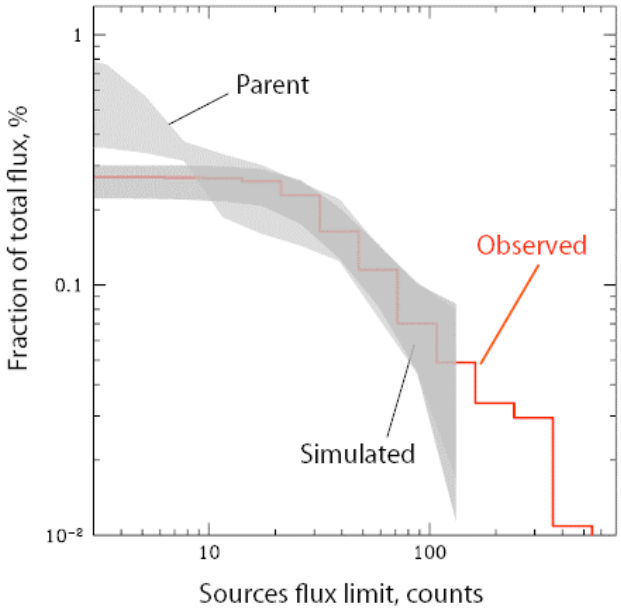
The Point Source Population Near the Galactic Centre



- Integrated spectra of resolved sources rather similar to that of the diffuse emission
- Resolved sources account for about ~10% of the observed hard component

- **A recent estimate puts the resolved fraction of the 4-8 keV flux at ≥ 40% for sources with Lx > 10^{31} erg/s**
- **The unresolved (~60%) of the hard flux is most likely produced by CVs and coronally active stars with Lx in range $10^{28\text{-}31}$ erg/s**

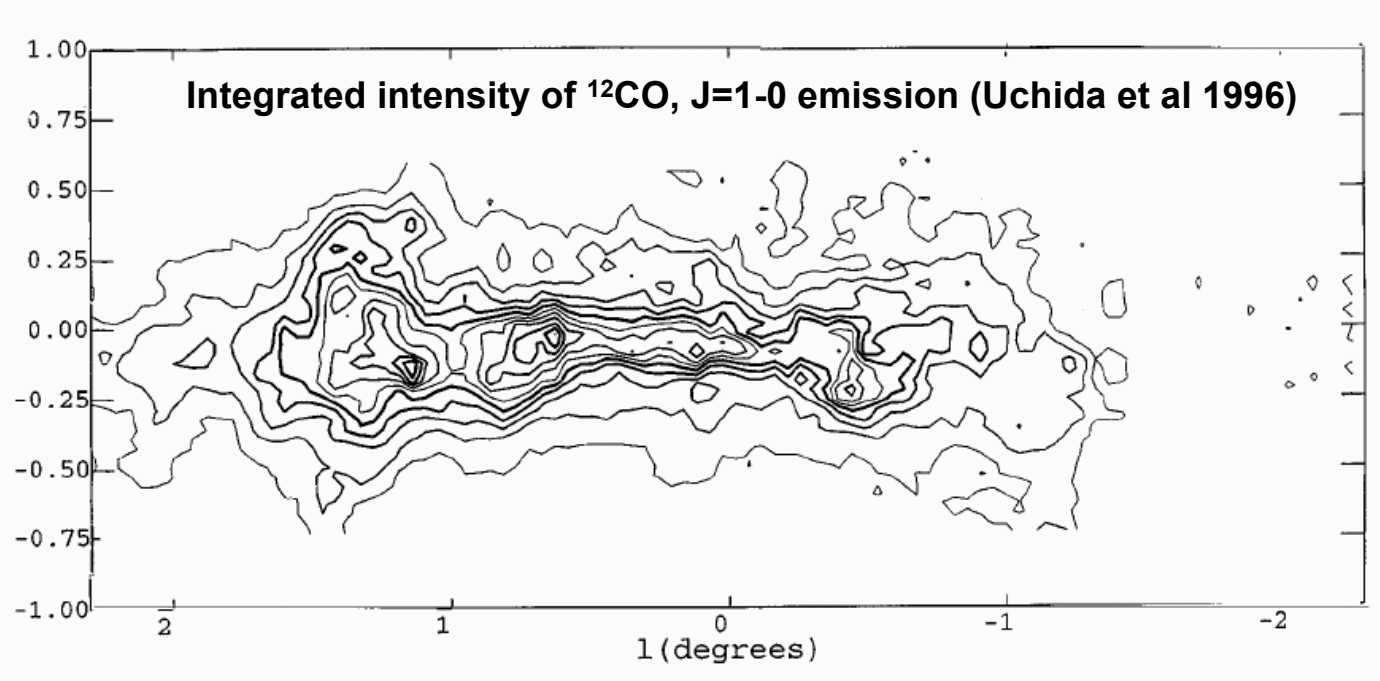
Revnivtsev et al 2007



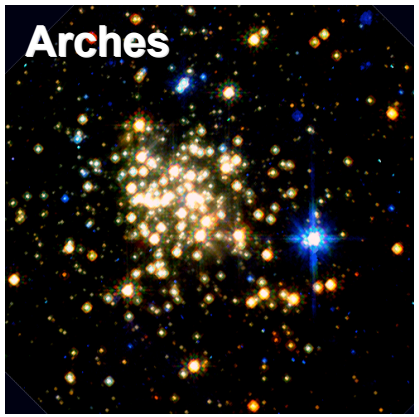
Topics

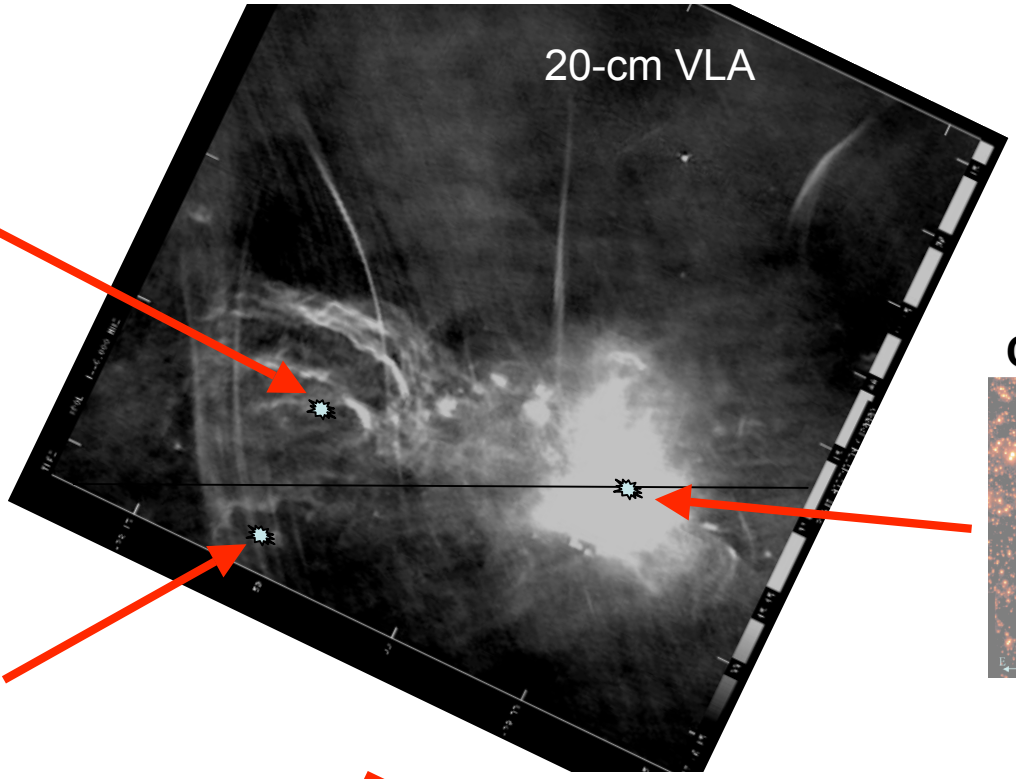
- Nearby Galaxies Perspective
- The Constituent Parts of the SXRB
- The Origin of the Galactic Ridge
- **The Galactic Centre Laboratory**
- XMM-Newton “Legacy” Programmes

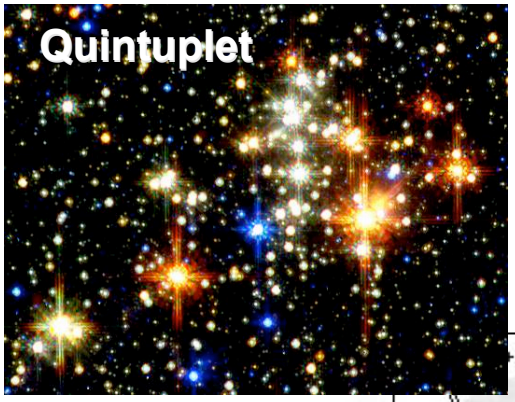
The Central Molecular Zone (CMZ) of the Galaxy



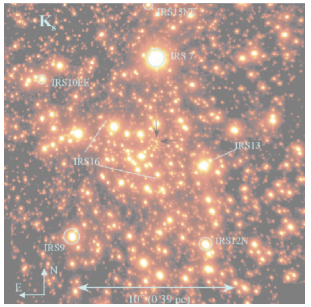
- The region within ± 1.5° (± 200 pc) of the GC contains largely molecular gas of high density (n >10^4 cm^{-3}) and high volume filling factor (f > 0.1) in a disk "population" of clouds.
- This is an active region with pockets of on-going star-formation and massive star clusters. Colliding winds, SNe, supernova remnants, pulsars, X-ray binaries and Sgr A* serve as heat sources and potential sources of high energy particles.

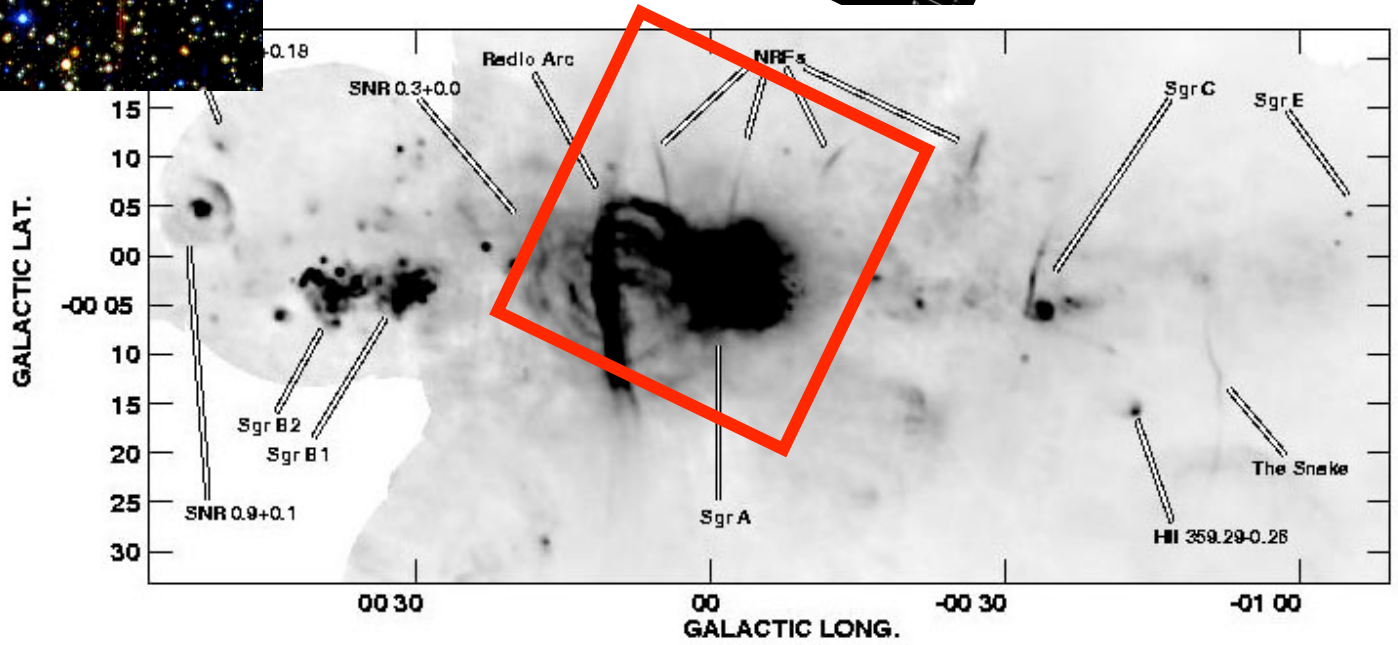

Arches


20-cm VLA

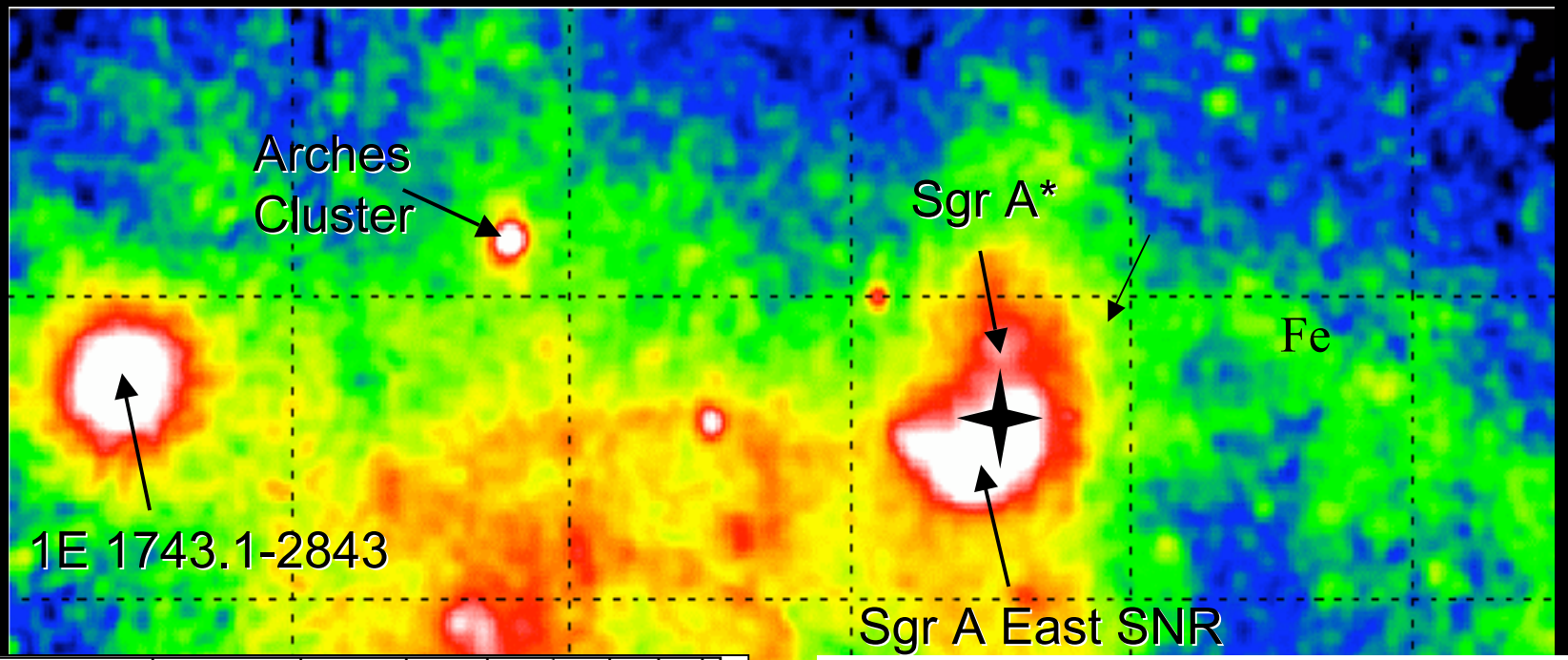

Quintuplet

Central



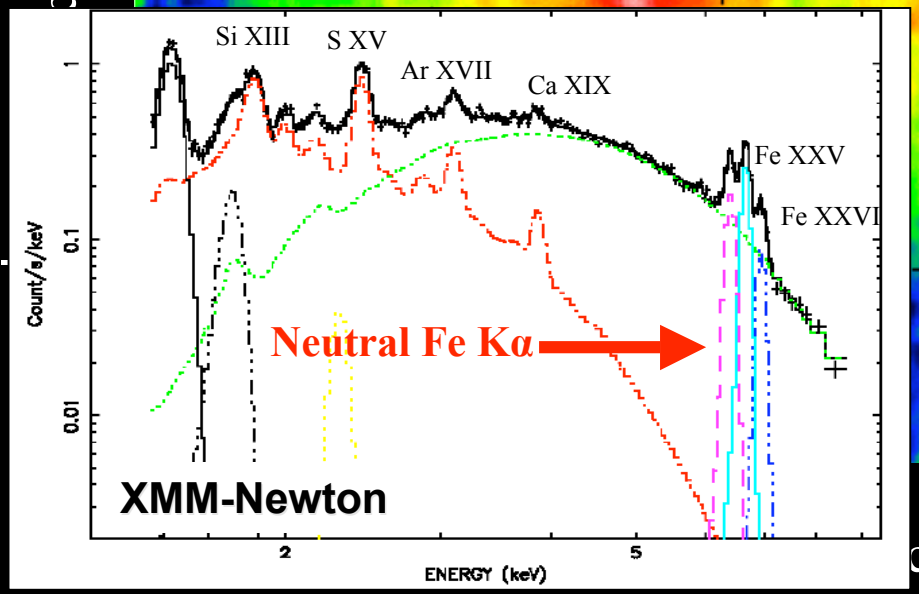

Radio Arc
NRFs
SNR 0.3+0.0
Sgr C
Sgr E
Sgr B2
Sgr B1
SNR 0.9+0.1
Sgr A
The Snake
HII 359.29-0.26
GALACTIC LAT.
GALACTIC LONG.
15
10
05
00
-00 05
10
15
20
25
30
00 30
00
-00 30
-01 00

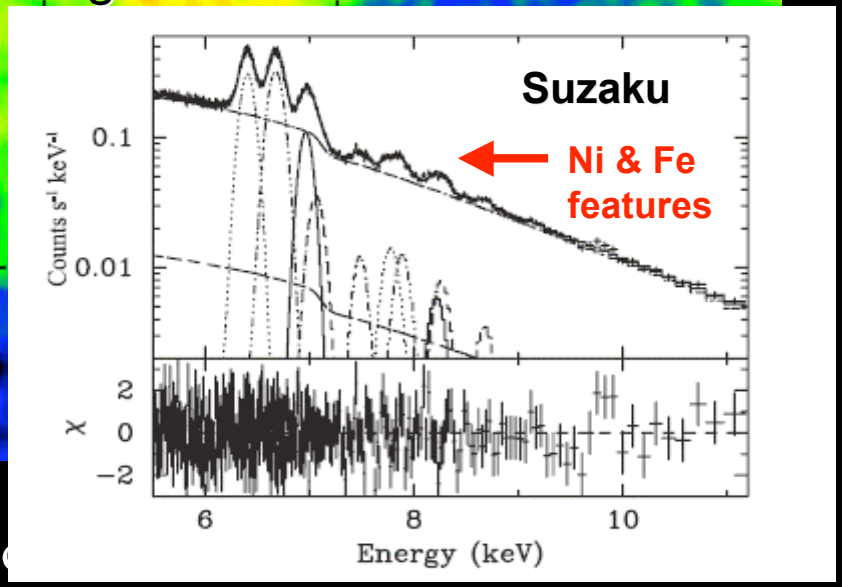
Sgr A - Radio Arc Region 2-4.5 keV X-ray



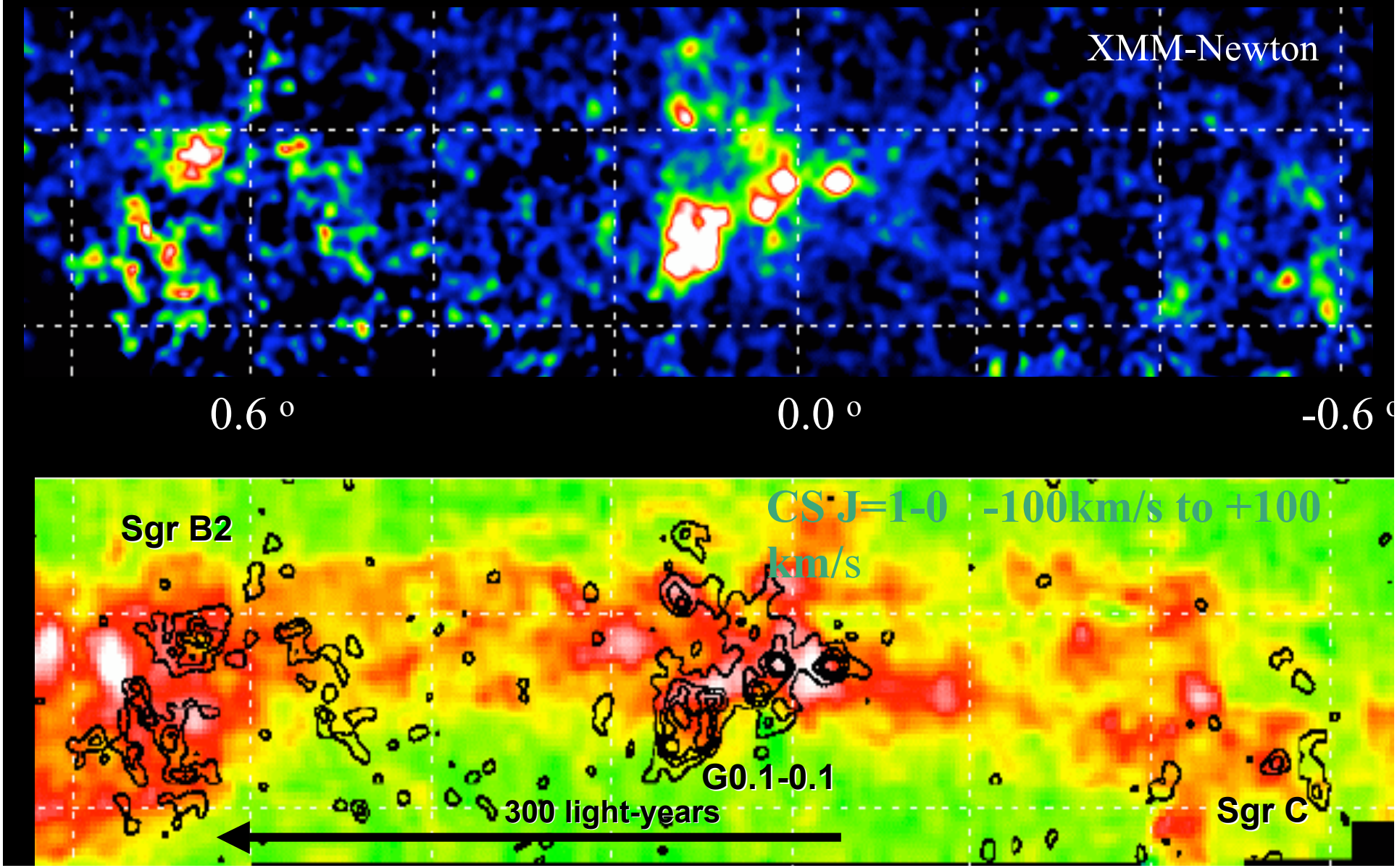
0.0°

ctic Latitude



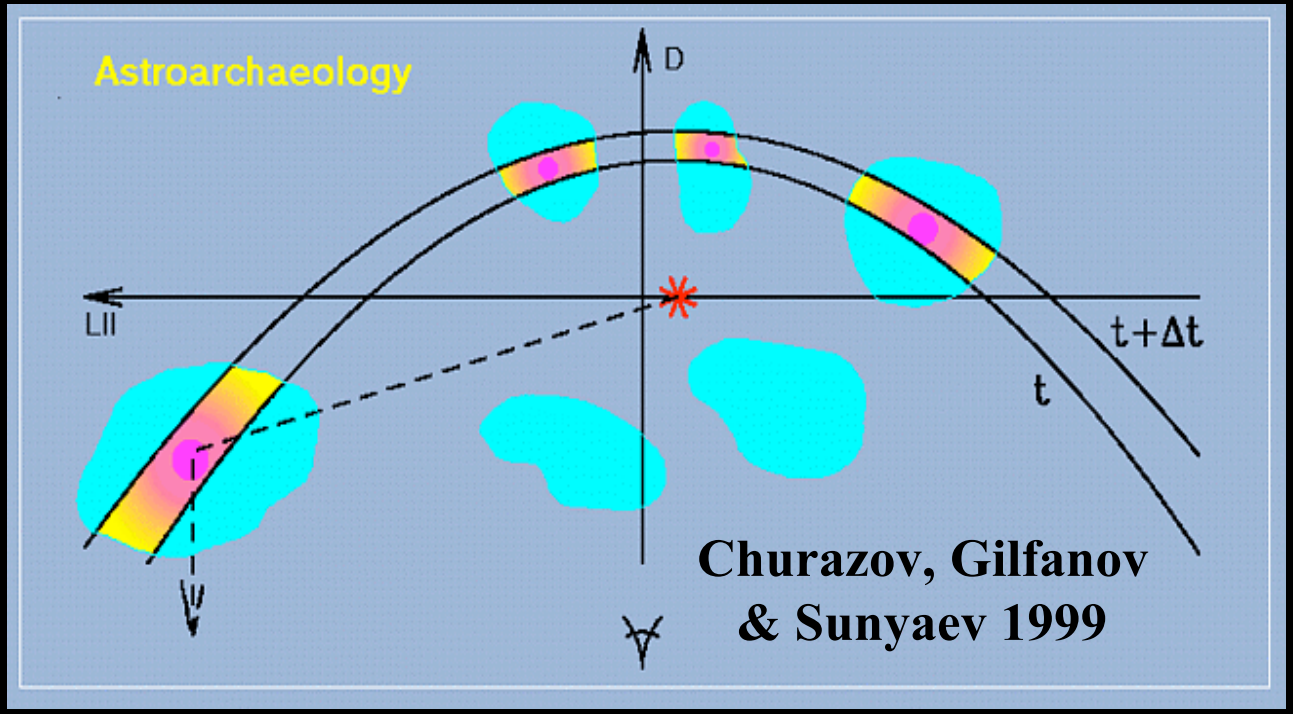


Distribution of Iron 6.4 keV Line Emission



X-RAY REFLECTION NEBULAE

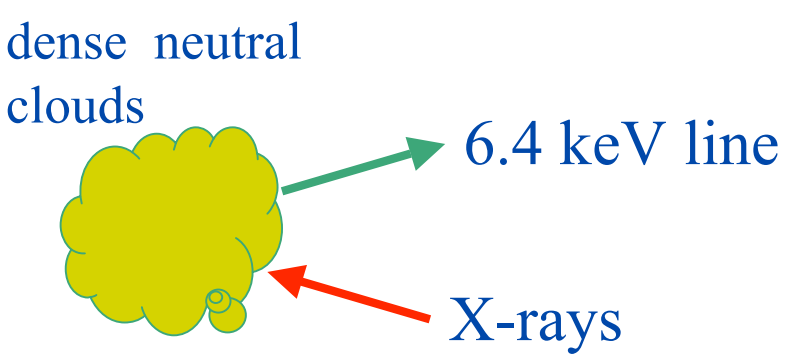
An X-ray echo of the past activity of Sgr A* ?



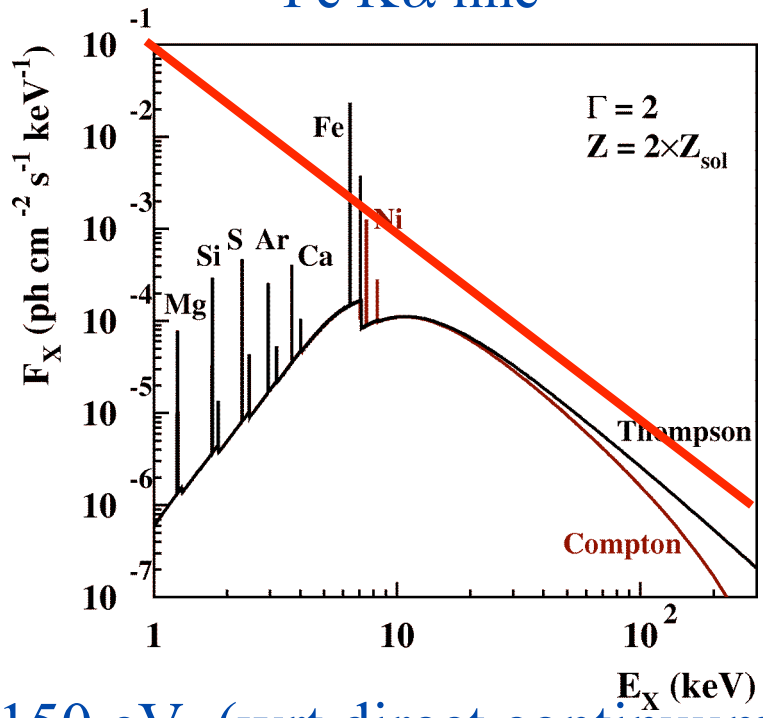
Fluorescence of the Sgr B2 molecular cloud is the result of a flare on Sgr A* producing $L_X \sim 10^{39}$ erg/s, for $\Delta t > \sim 10$ yrs, ~300 yrs ago.

(Sunyaev et al. 1993, Koyama et al. 1996, Murakami et al. 2001, Revnivtsev et al.2004..

X-ray Reflection From Cold Near-Neutral Matter



Fe Kα line



Reflection models predict:

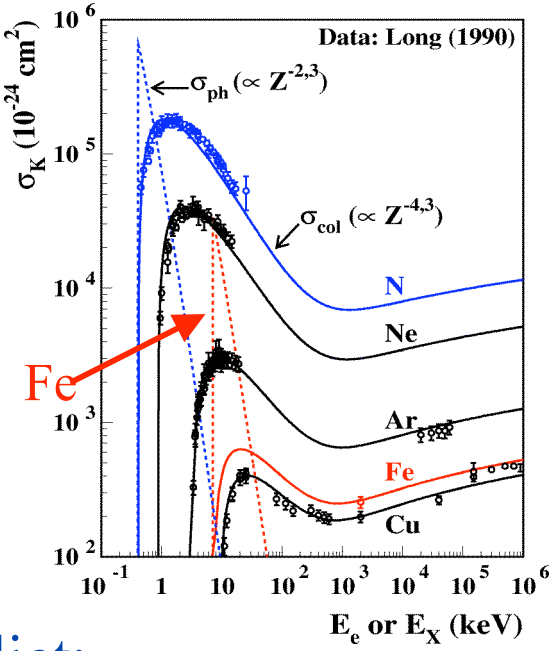
Neutral Fe K_{alpha} Line Eq. Width ~ 150 eV (wrt direct continuum)

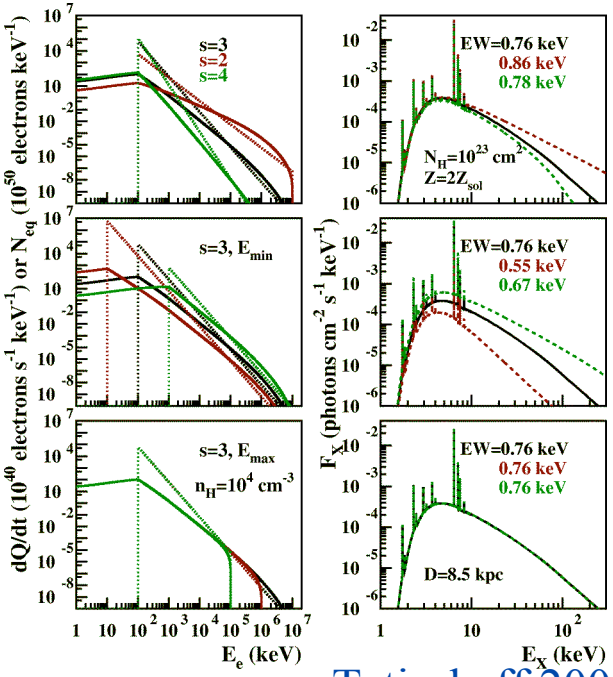
Neutral Fe K_{alpha} Line Eq. Width > 1 keV (Z = 1) (wrt reflected continuum)

Significant iron-K edge on reflected continuum, $N_{Fe} \sim 2 \times 10^{19}$ Fe cm^{-3}

Alternative Model: Excitation by Cosmic-ray Electrons

- Cosmic-ray electrons E ~ 10 keV – 1 GeV have significant cross-section for interaction with K-shell electrons (Valinia et al. 2000; Yusef-Zadeh et al. 2002)
- Such cosmic rays maybe produced in young, massive stellar clusters (Yusef-Zadeh 2003)
- Radio data establish a large population of GeV electrons in the inner 300 pc.





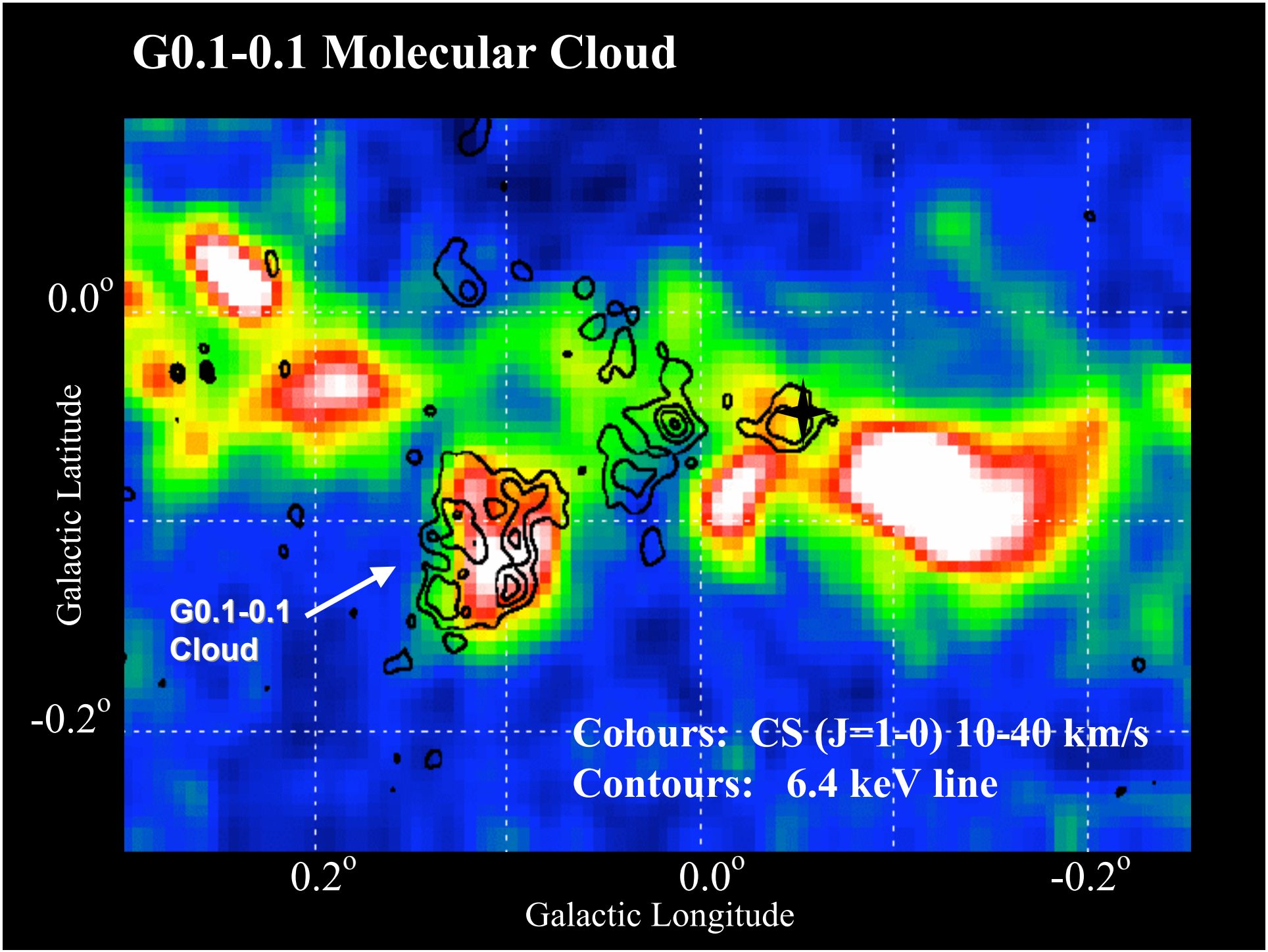
Tatischeff 2005

Models predict:

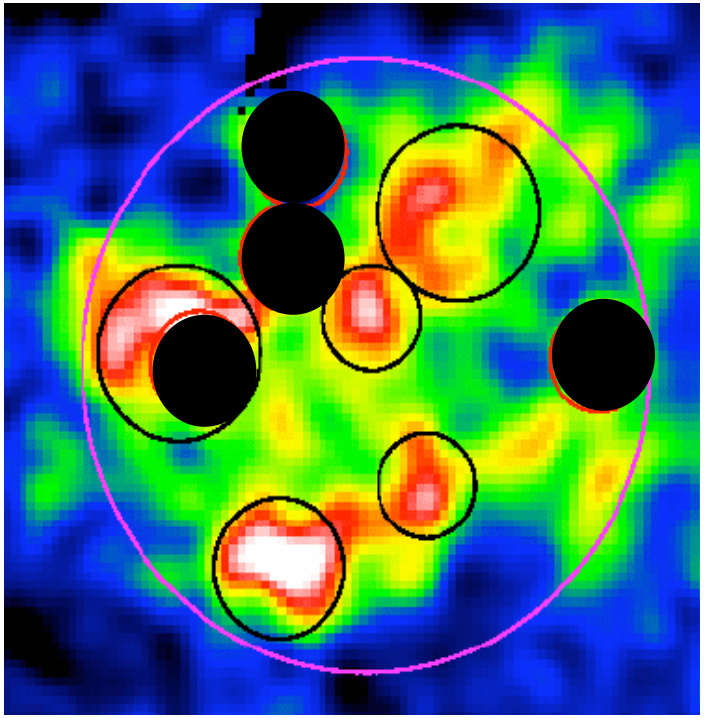
Neutral Fe K_{alpha} Line Eq. Width ~0.55-0.85 keV (Z = 1)

Significantly smaller iron-K edge on non-thermal bremsstrahlung cont.

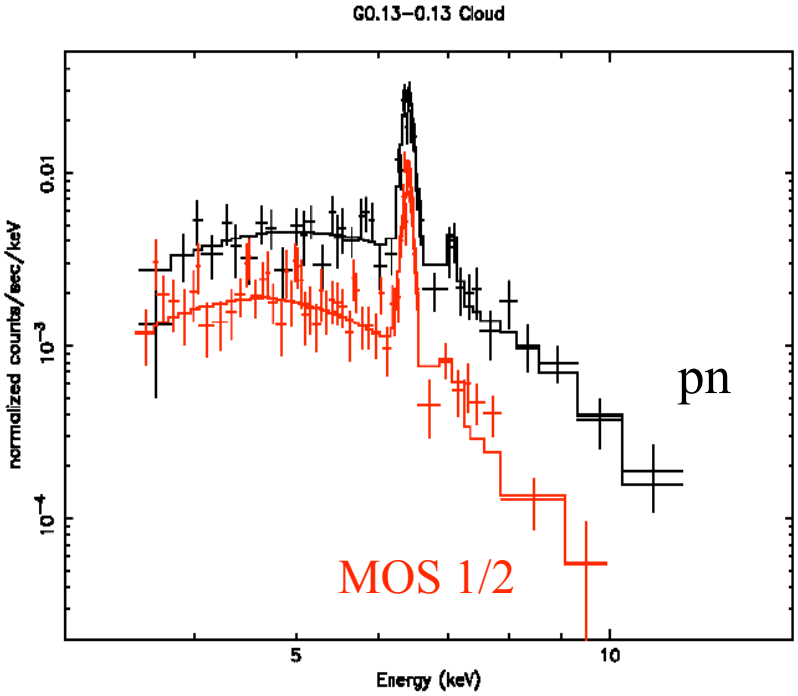
G0.1-0.1 Molecular Cloud



X-ray Spectrum of G0.1-0.1 Cloud



On-Cloud Regions ◯



Power-Law + Gaussian Line Model:

Photon Index ~ 1.9

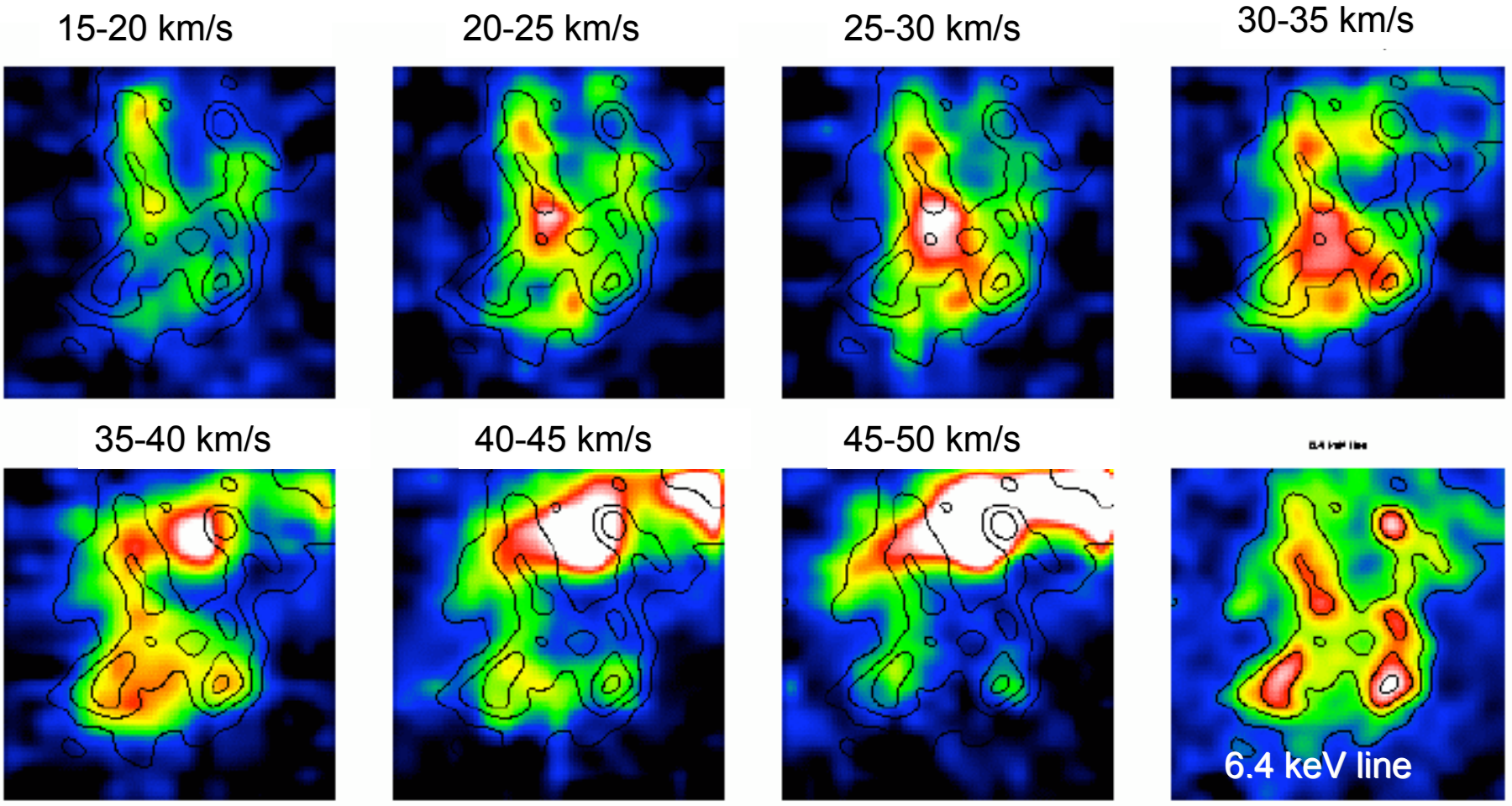
NH = 2.3 x 10^{23} H cm^{-2}

F_{line} = 2.4 x 10^{-5} photon/cm^2/s

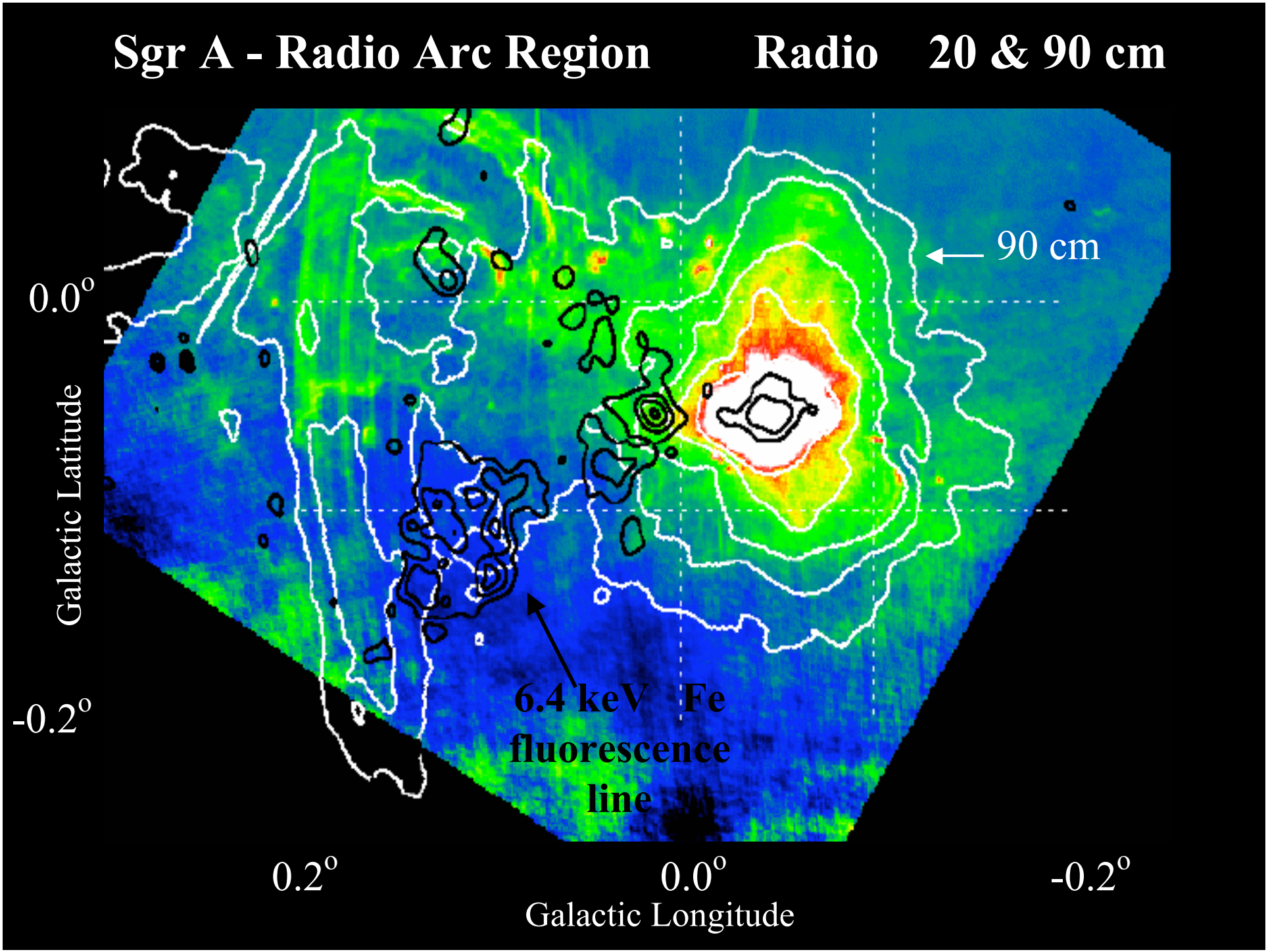
E.W. = 1.45 keV (implies Z ~ 3)

N_{Fe} < 1 x 10^{19} Fe cm^{-2}

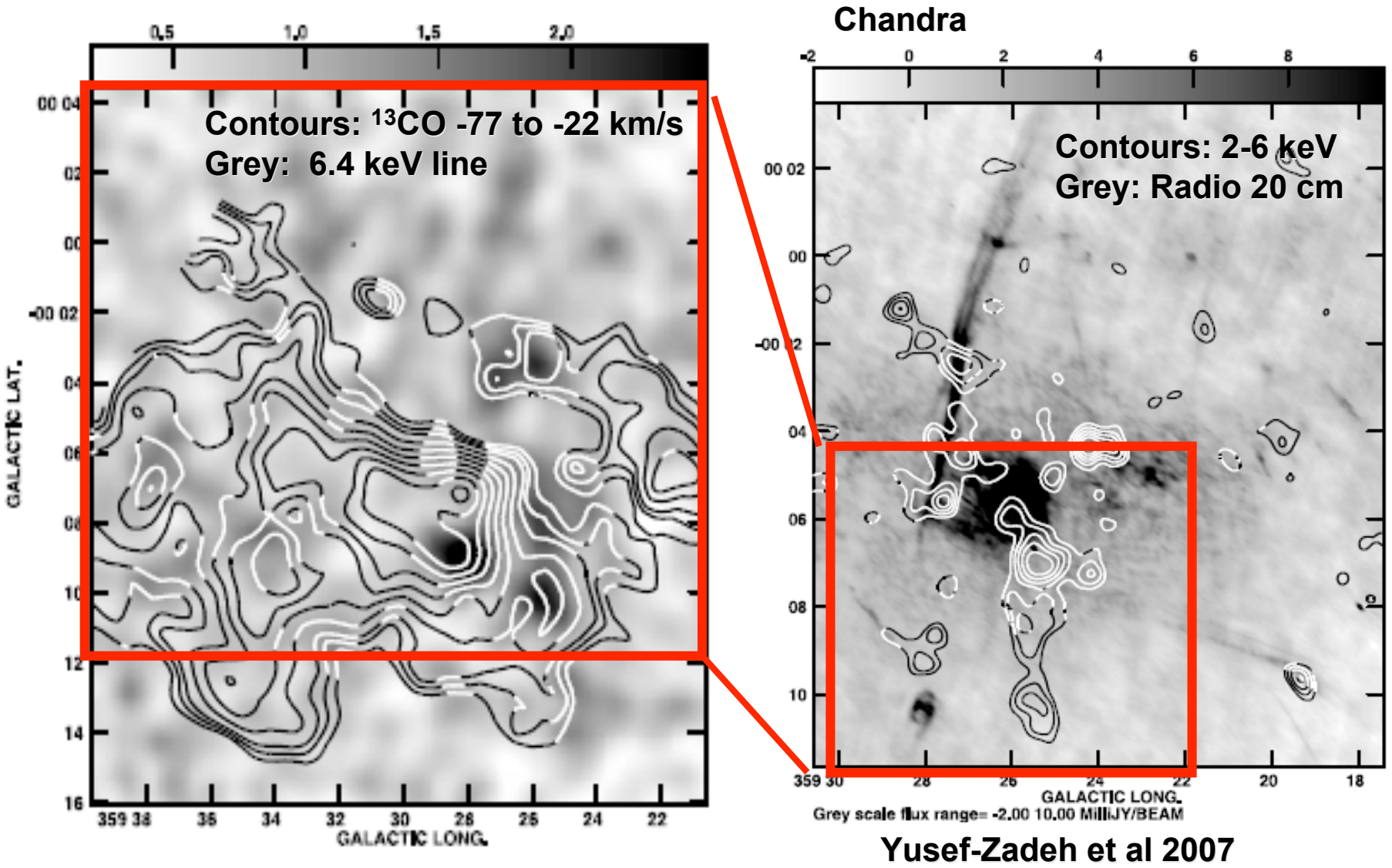
Correspondence of X-ray 6.4 keV line with Molecular Gas measured in SiO J = 1-0



Handa et al. (2005)


Sgr A - Radio Arc Region
Radio 20 & 90 cm
90 cm
0.0°
-0.2°
Galactic Latitude
6.4 keV Fe
fluorescence
line
0.2°
0.0°
-0.2°
Galactic Longitude

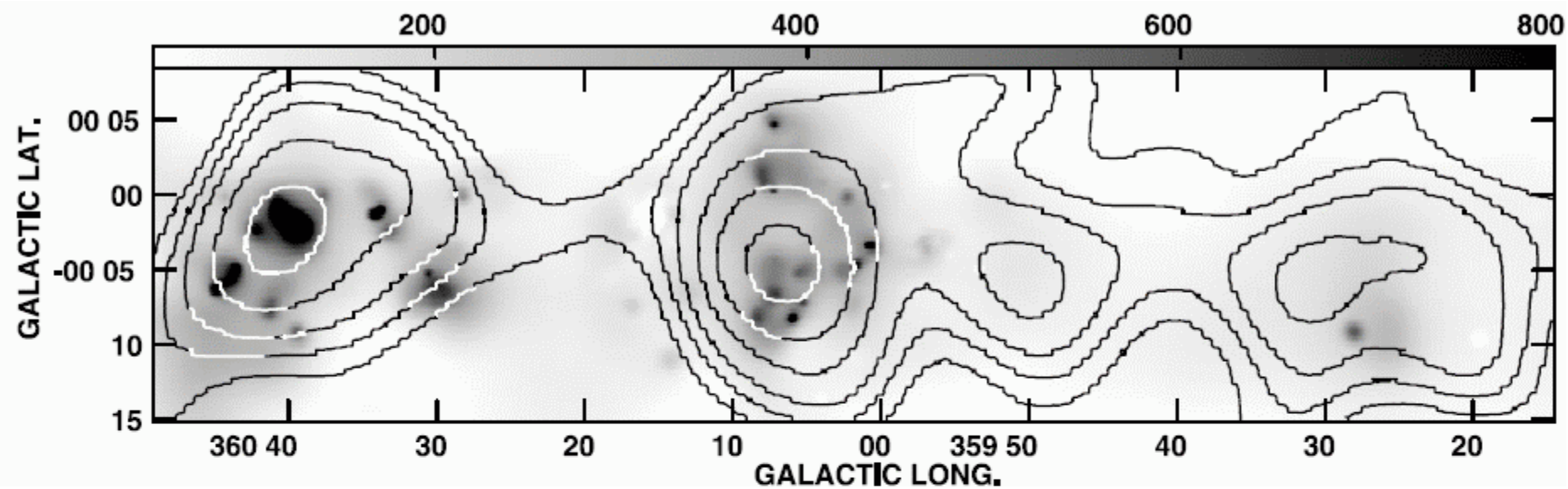
X-ray Reflection Nebulosity in Sgr C Region



Yusef-Zadeh et al 2007

Correlation with TeV Sources

Grey: 6.4 keV line emission Contours: HESS TeV Emission

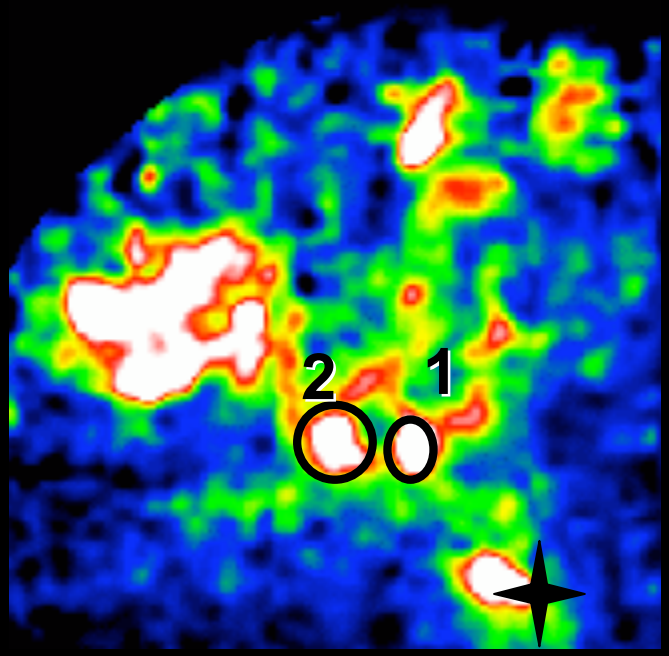


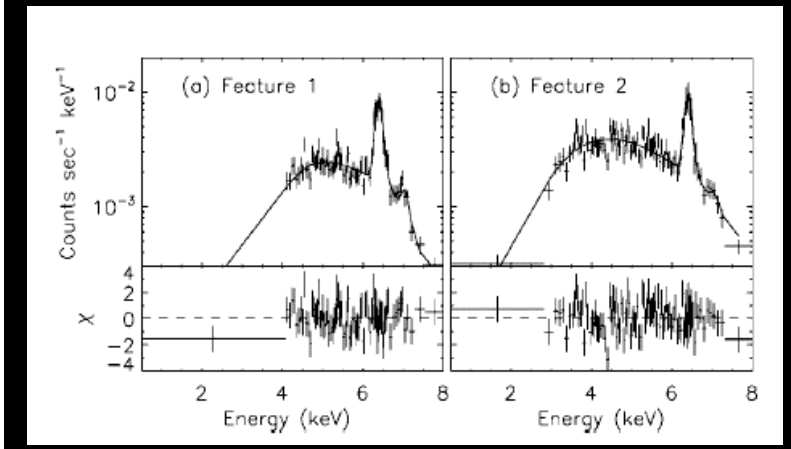
From Yusef-Zadeh et al 2007

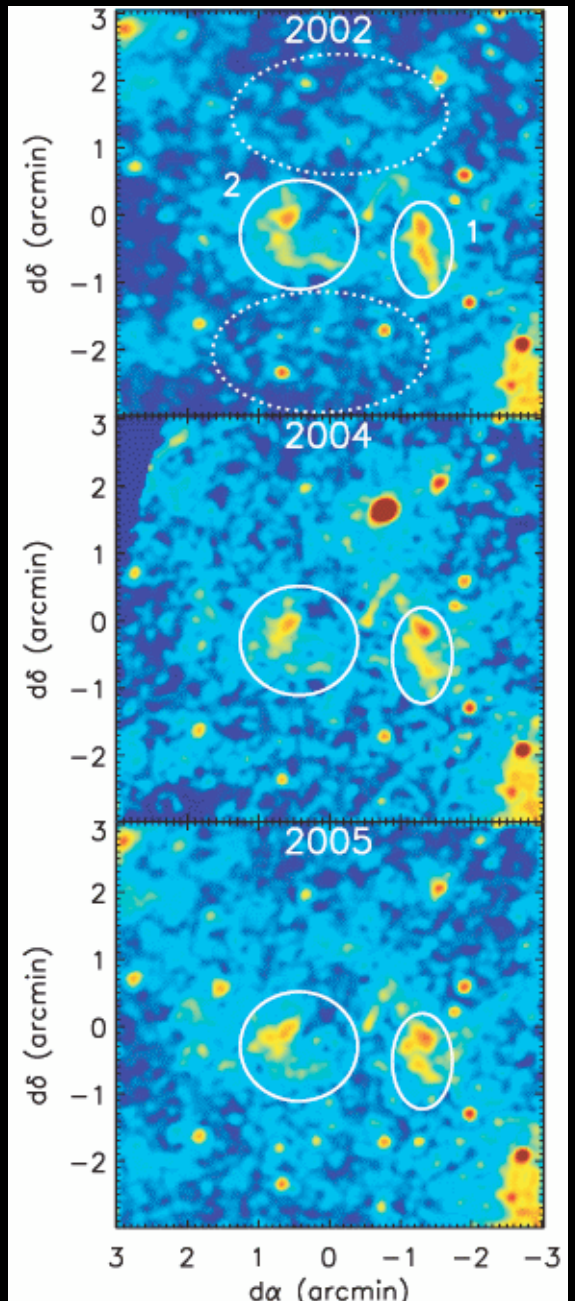
Implications of LECRe Models

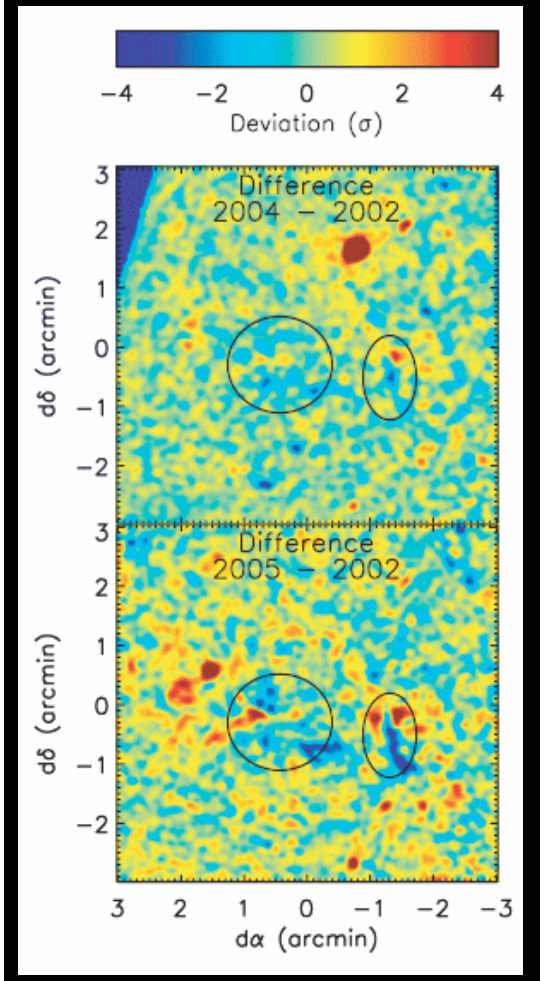
- There is a significant population of low-energy (10 keV – 1 MeV) cosmic ray electrons in the GC
- Implied high energy density ~10-1000 eV/cm^3
- Acceleration may occur at the interaction sites between molecular clouds and non-thermal filaments. Other possible sites: winds from massive star clusters and nebulae of young pulsars.
- Very important source of heat into molecular clouds (might explain elevation cloud temperatures in GC)

Variability of 6.4 keV features seen by Chandra









Muno et al 2007

Topics

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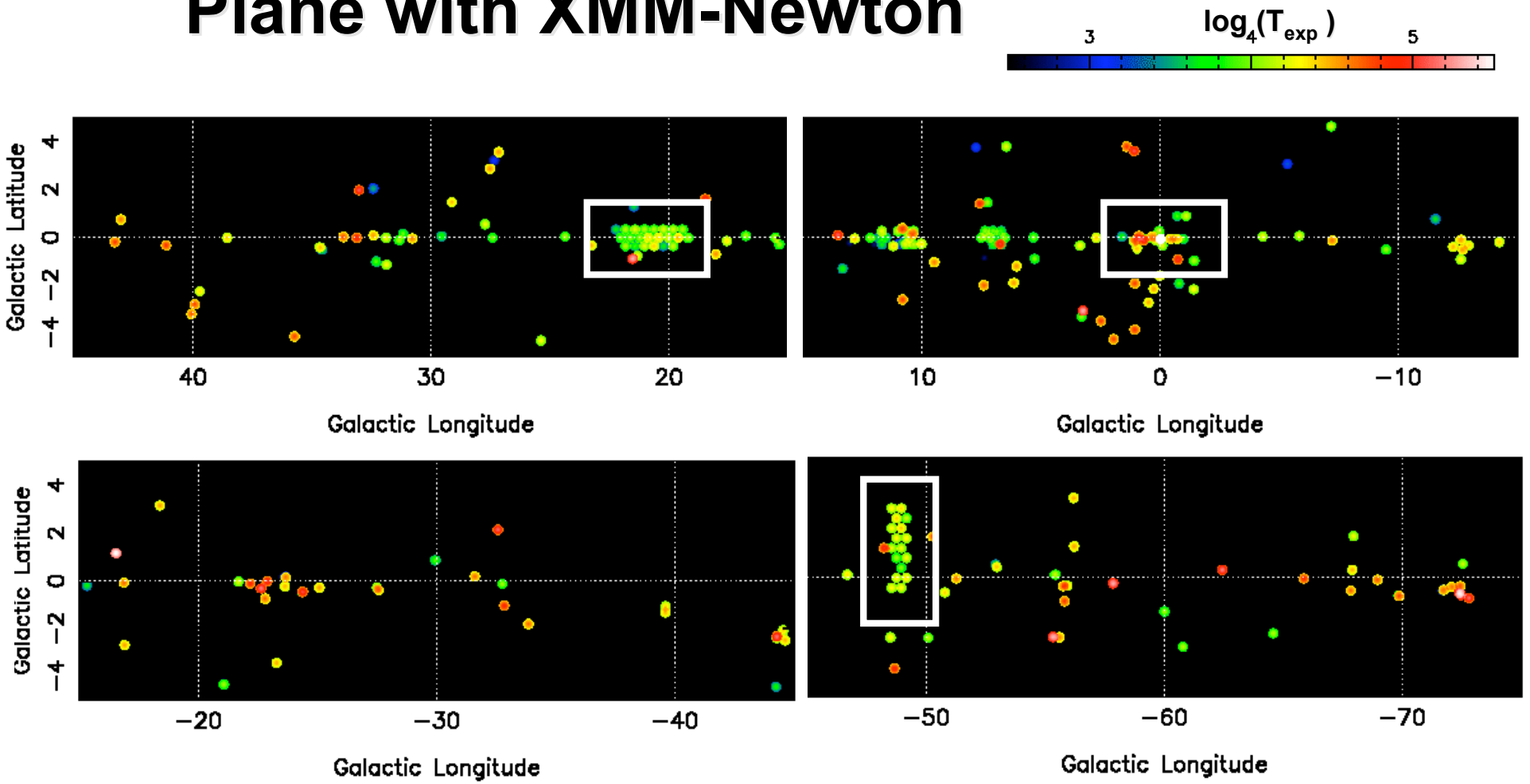
Observations of the Inner Galactic Plane with XMM-Newton

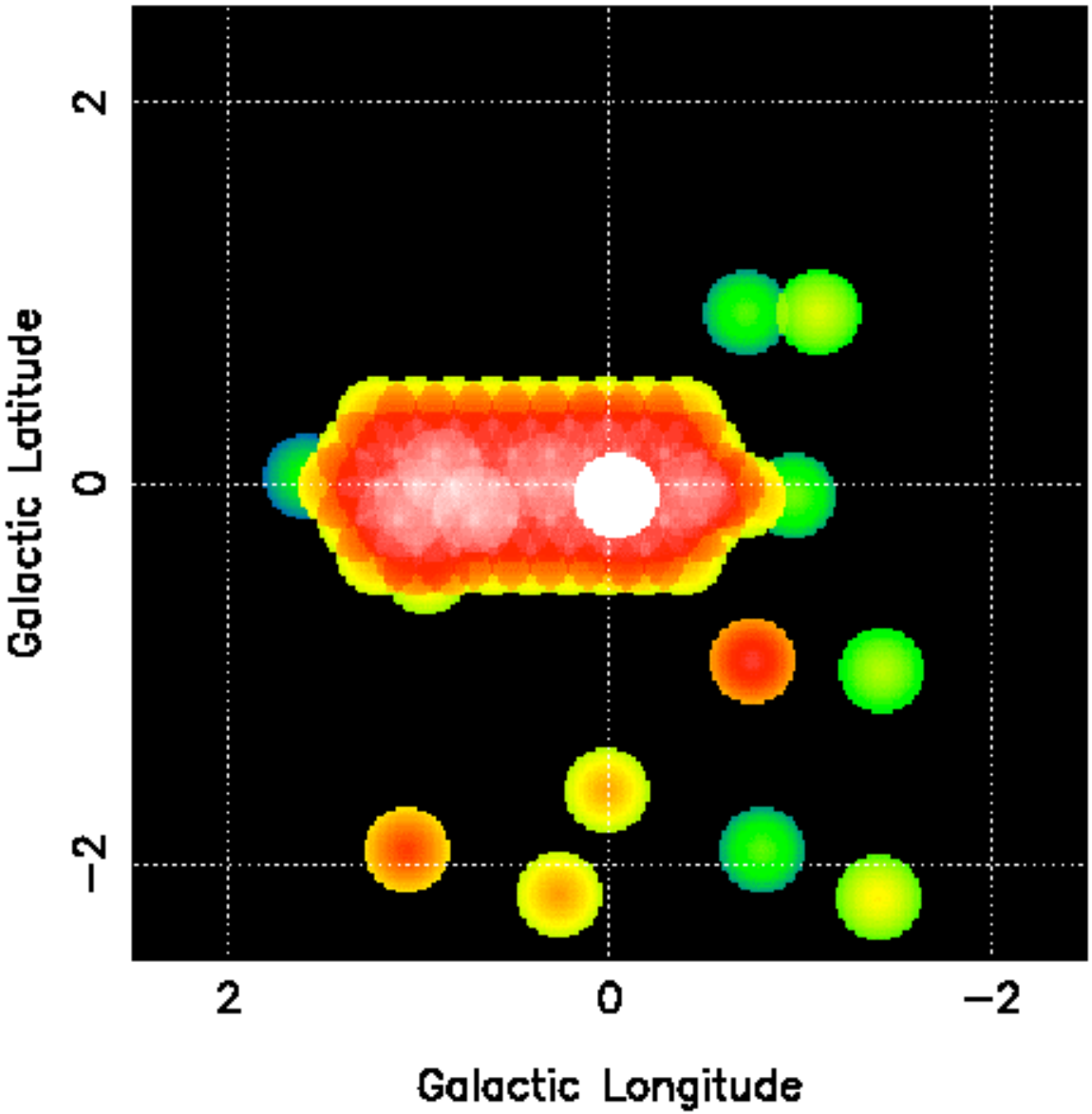


Total GP exposure (|b| < 5°); pn = 5.6 Ms; MOS = 9.5 Ms

We need COVERAGE, COVERAGE, COVERAGE !

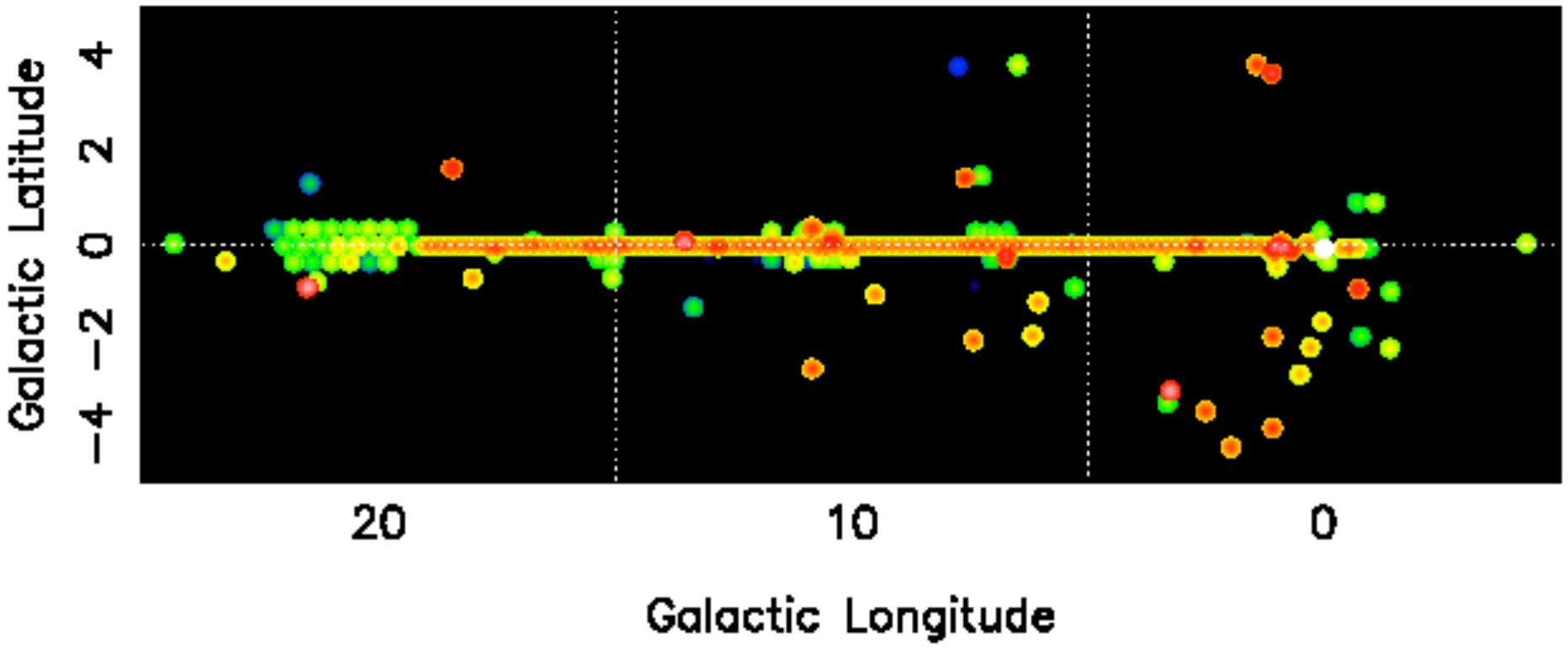
LEGACY PROGRAMME I

EXTENDED GALACTIC CENTRE SURVEY



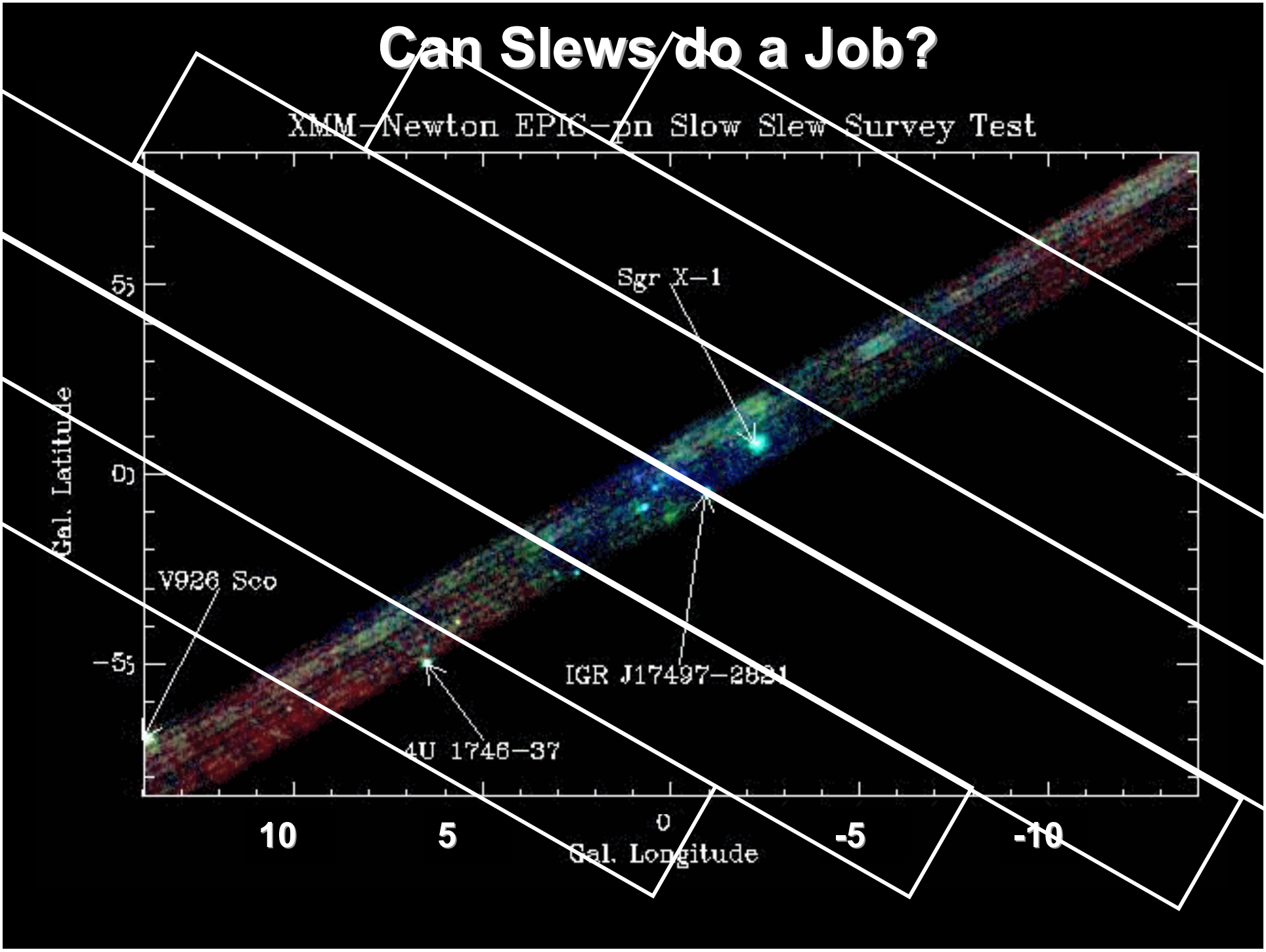
49 x 20 ks
= 1Ms

LEGACY PROGRAMME II
EXTENDED GALACTIC PLANE SURVEY



90 x 15 ks = 1.35 Ms

Can Slews do a Job?



Some Interesting Questions Relating to Diffuse Galactic X-ray Emission

- **What is the physical state, extent and origin of the hot gas that resides within the local cavity?**

- **What is the physical state, extent and origin of the hot gas at high z-height? Can we find direct evidence for a (smooth) Galactic corona and/or a Galactic wind? Does the Galactic halo extend into the IGM of the Local Group and beyond?**

- **Does the integrated emission of faint sources explain *all* of the hard (~ 8 keV) thermal features seen in the Galactic Plane and Bulge?**

- **What role do high energy particles play in exciting X-ray fluorescence and non-thermal X-ray continuum emission in the Galactic Centre?**