X-raying the local ISM

Efrain Gatuzz

(ESO)

Interstellar Medium in the Nearby Universe

Bamberg, Germany

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COLLABORATORS

Javier García (CALTECH)

Timothy R Kallman (NASA/GSFC)

Sara Rezaei Kh. (MPIA)

Eugene Churazov (MPA)

Joern Wilms (Remeis-Observatory)

Thomas Gorczyca (WMU)

Muhammet Fatih Hasoglu (HKU)

Claudio Mendoza (WMU)

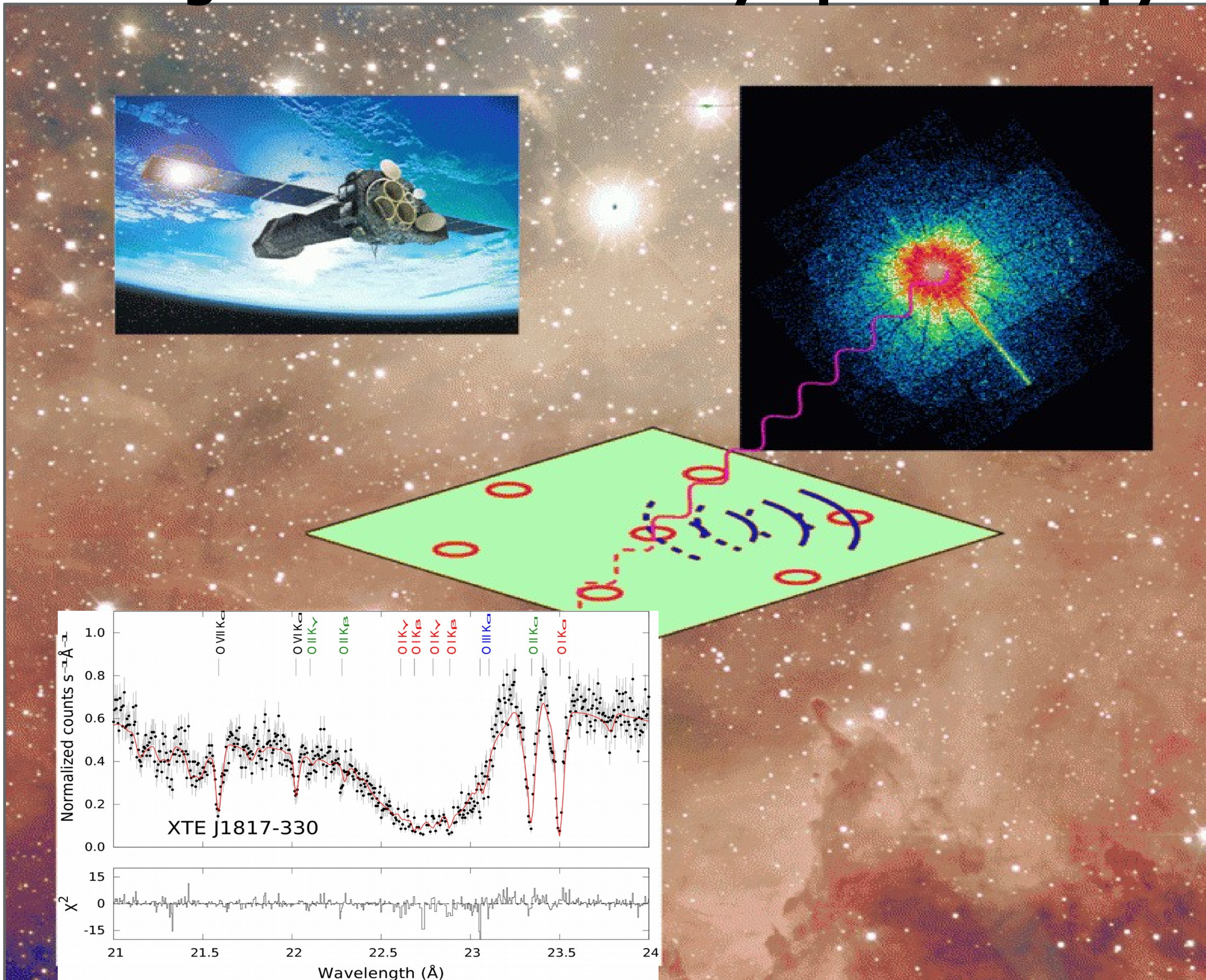
Katerine Joachimi (UCV)

Jan-Uwe Ness (ESAC)

Annika Kreikenbohm (Remeis-Observatory)

Mirjam Oertel (Remeis-Observatory)

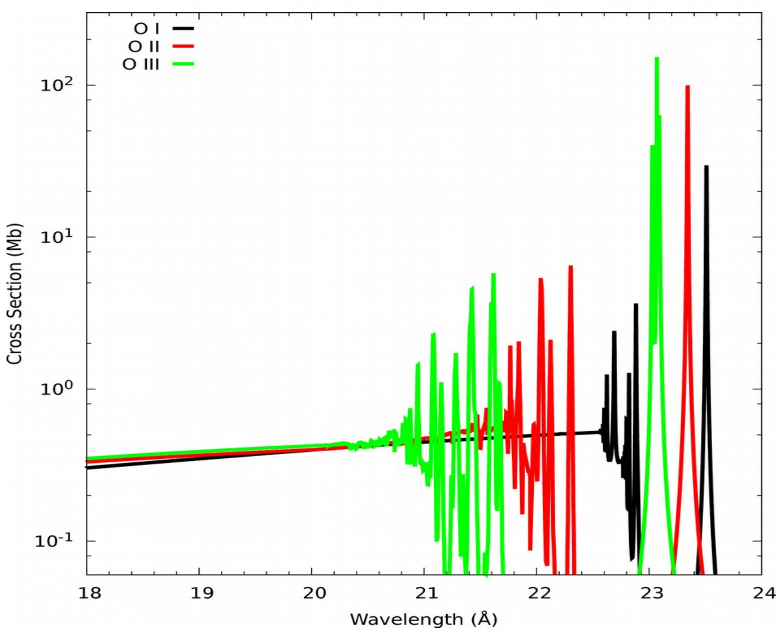
High-Resolution X-ray Spectroscopy

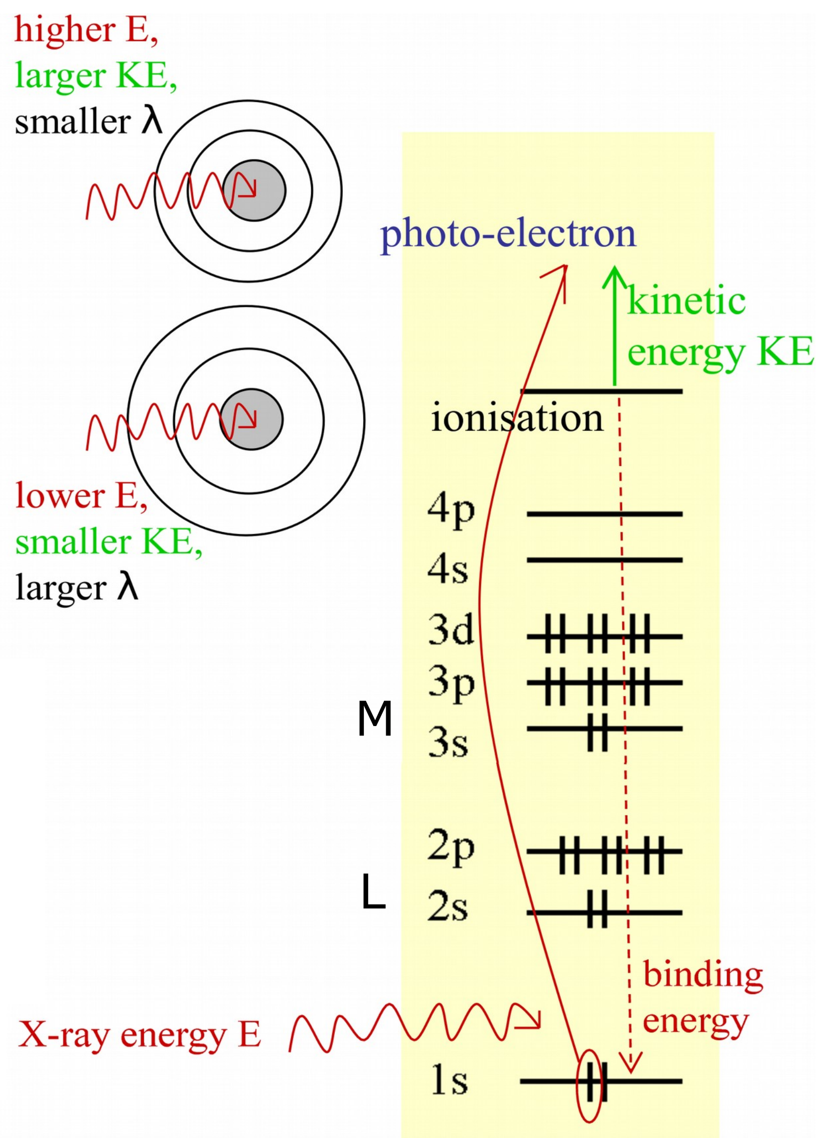


X-Ray Photoabsorption

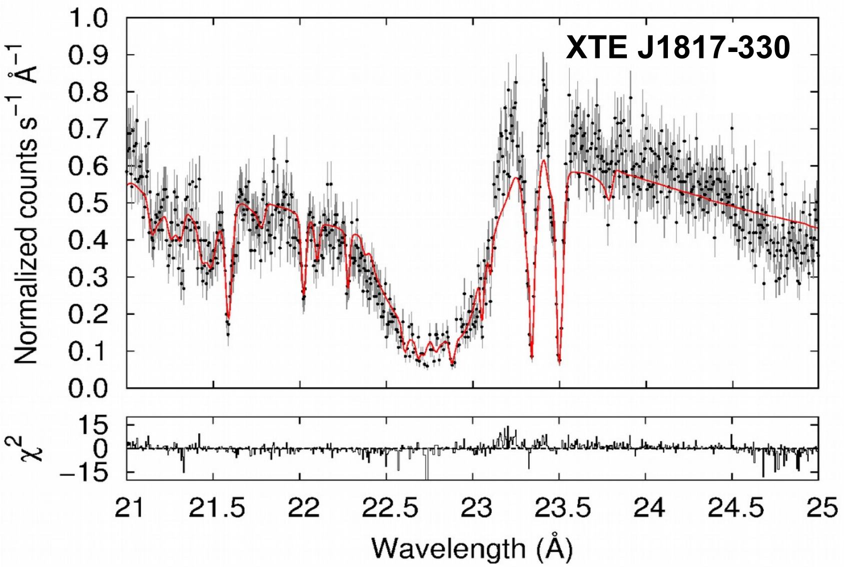
- The atom is excited by a photon.
- There is one **photoabsorption cross-section** for each ion.
- There are two decay processes:

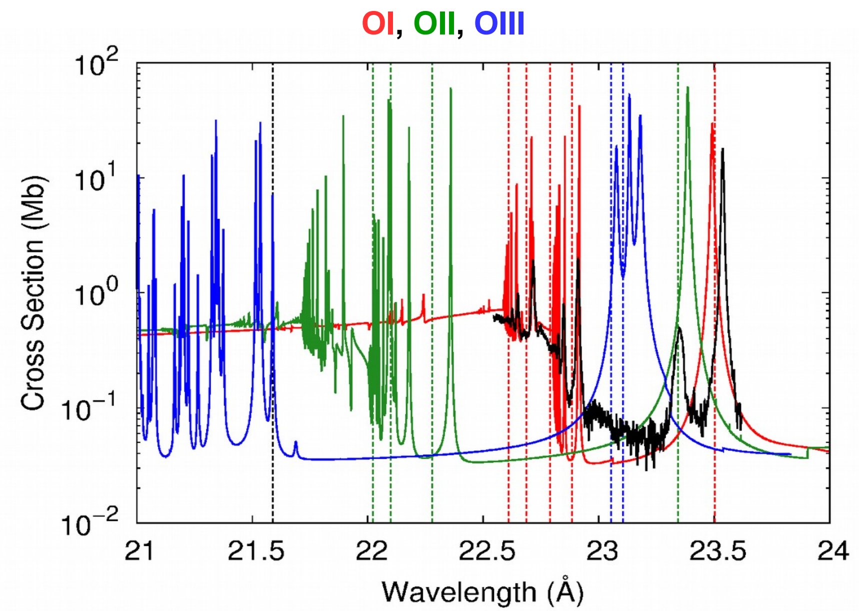
  X-ray fluorescence
  Auger effect.

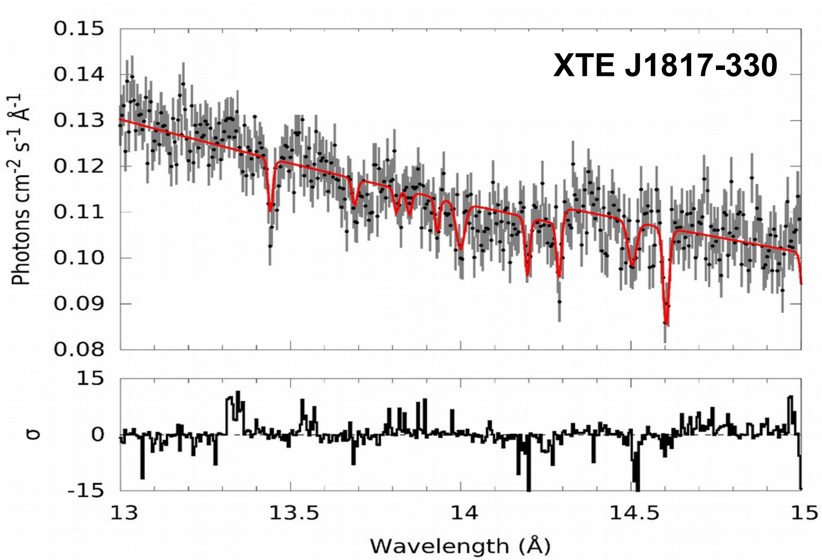


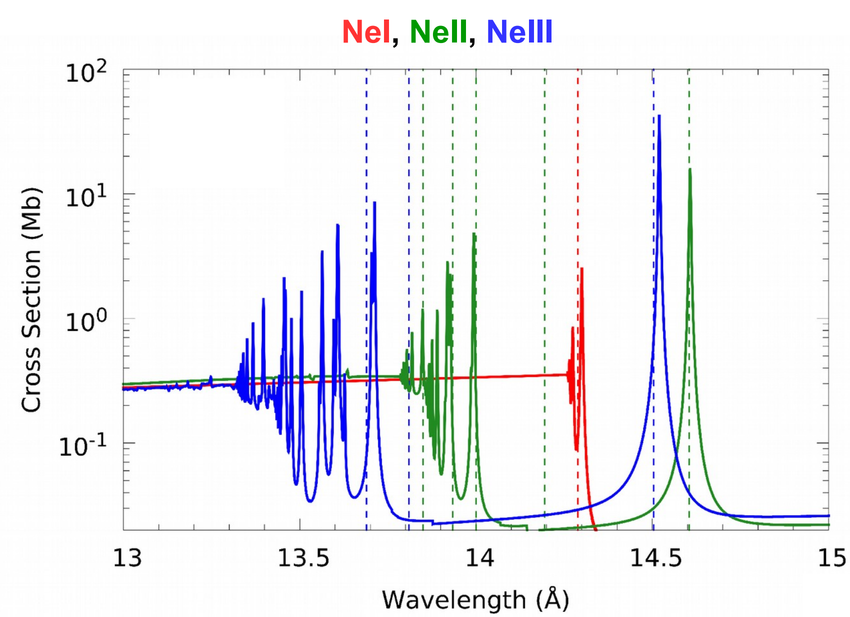


ISM ABSORPTION AFFECTS ALL X-RAY SPECTRA!

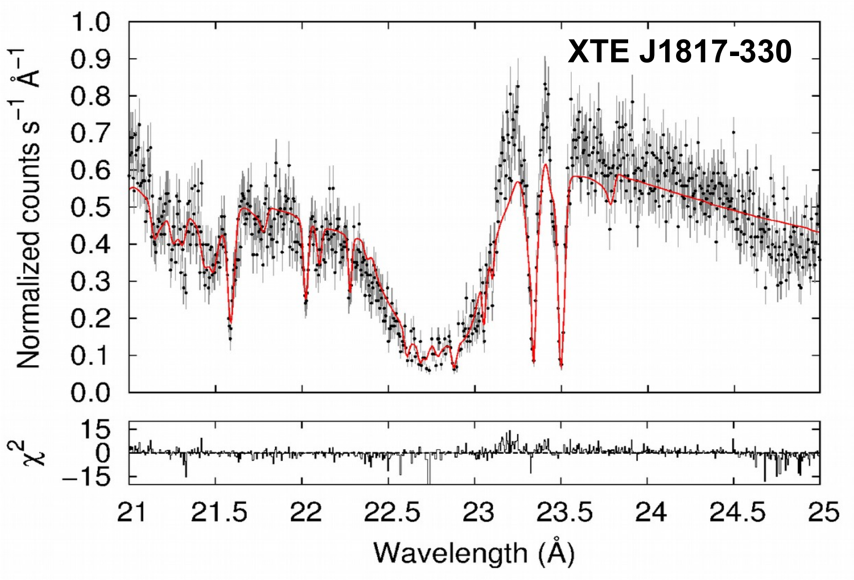


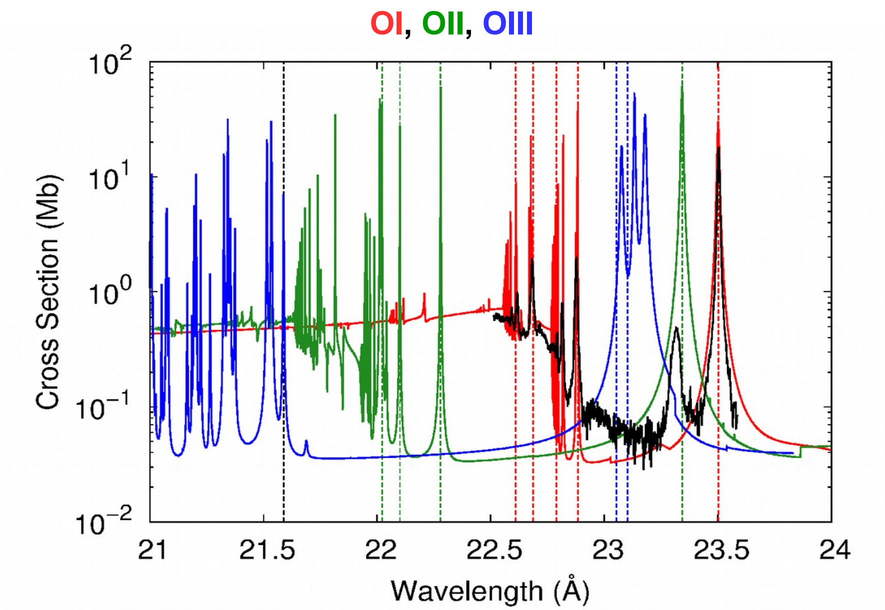


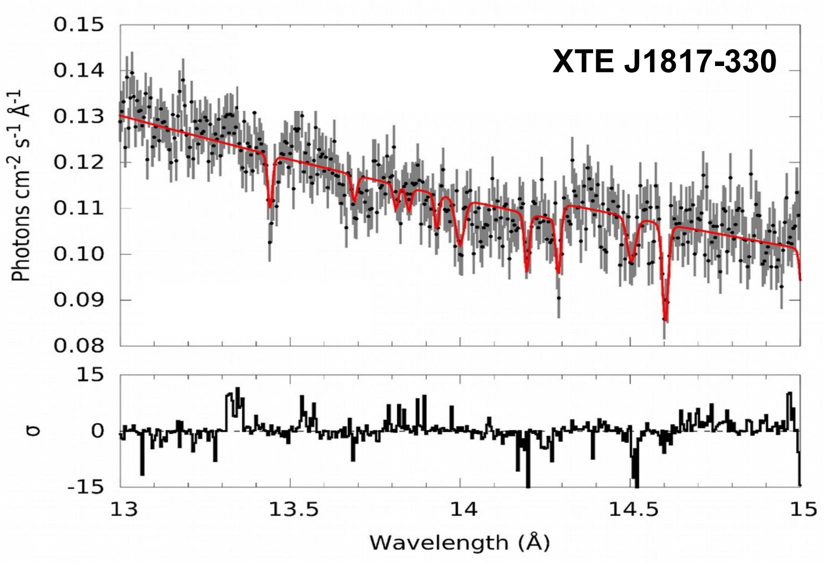


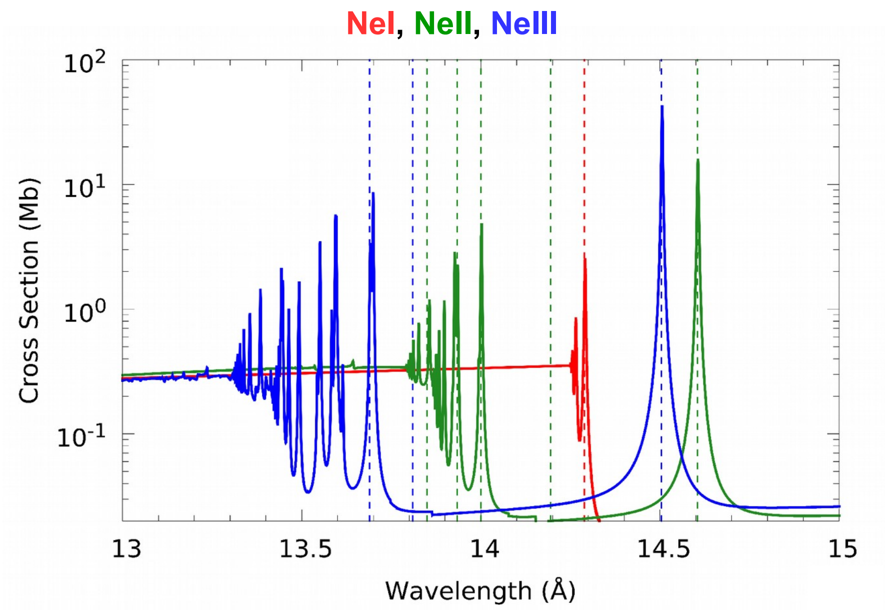


Gatuzz+13,+14,+15

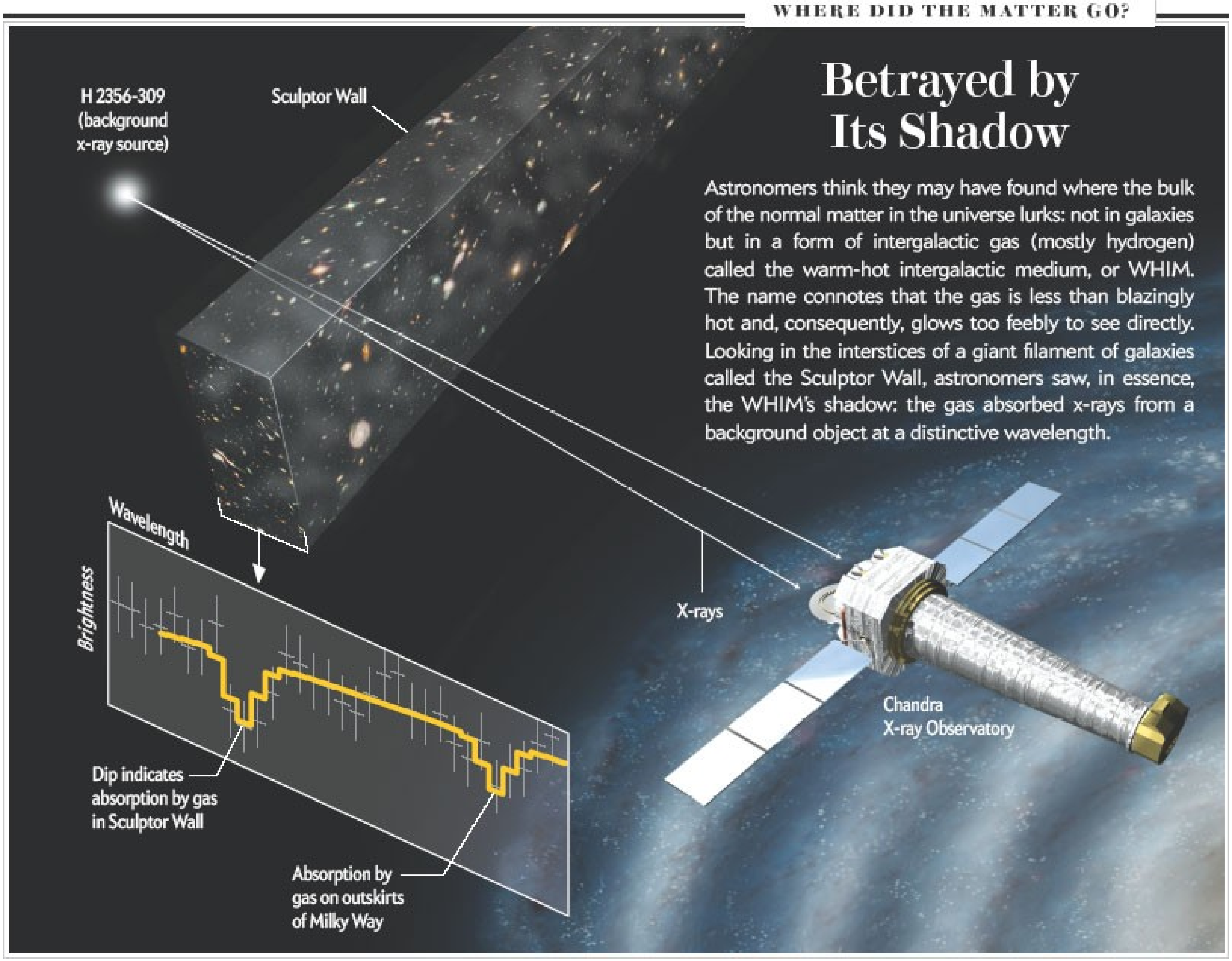






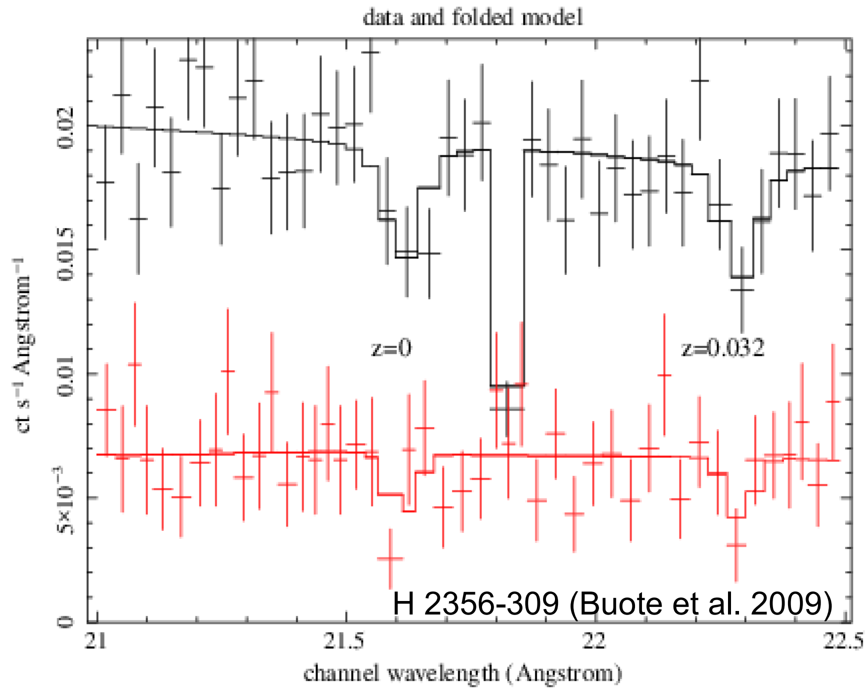


Gatuzz+13,+14,+15



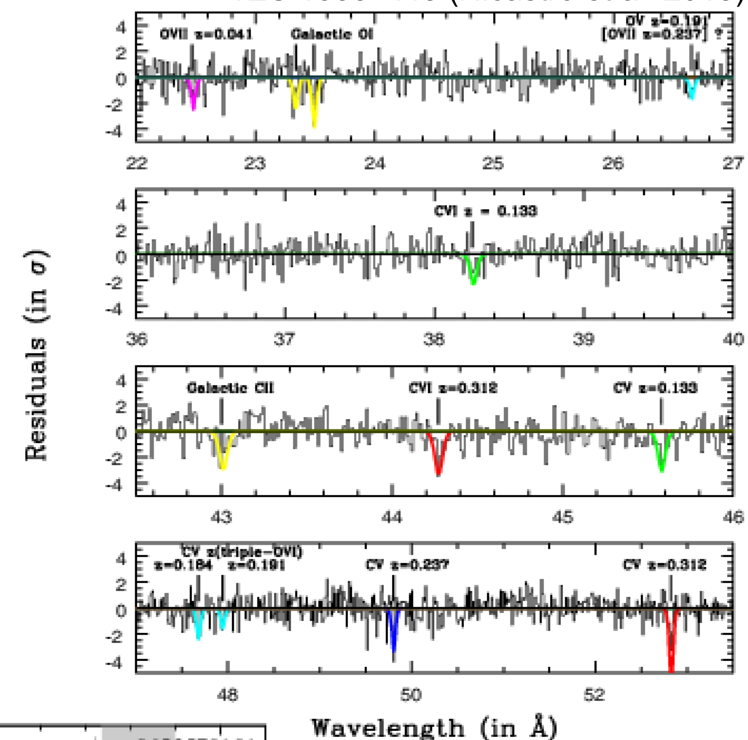
Buote+09, Fang+10, Zappacosta+10, Fang+11, Zappacosta+12

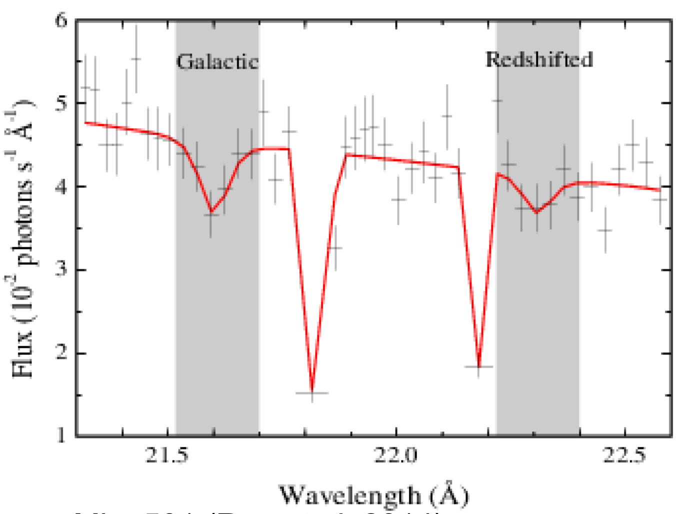
O VII Ka AT z≃0.03 FROM WHIM

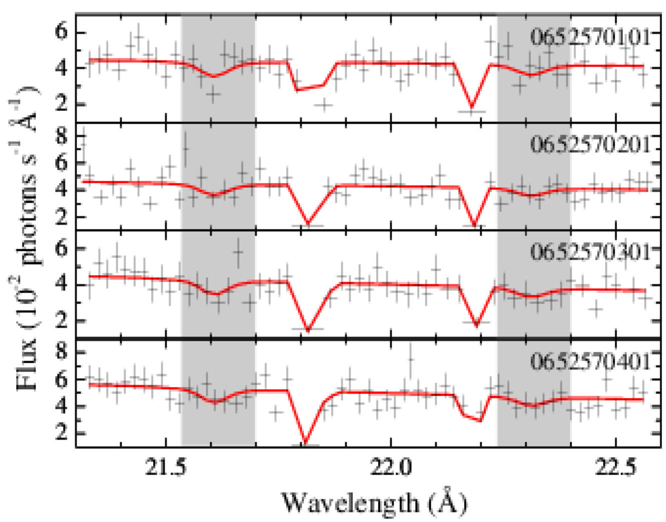


H 2356-309 (Buote et al. 2009)

1ES 1553+113 (Nicastro et al. 2013)







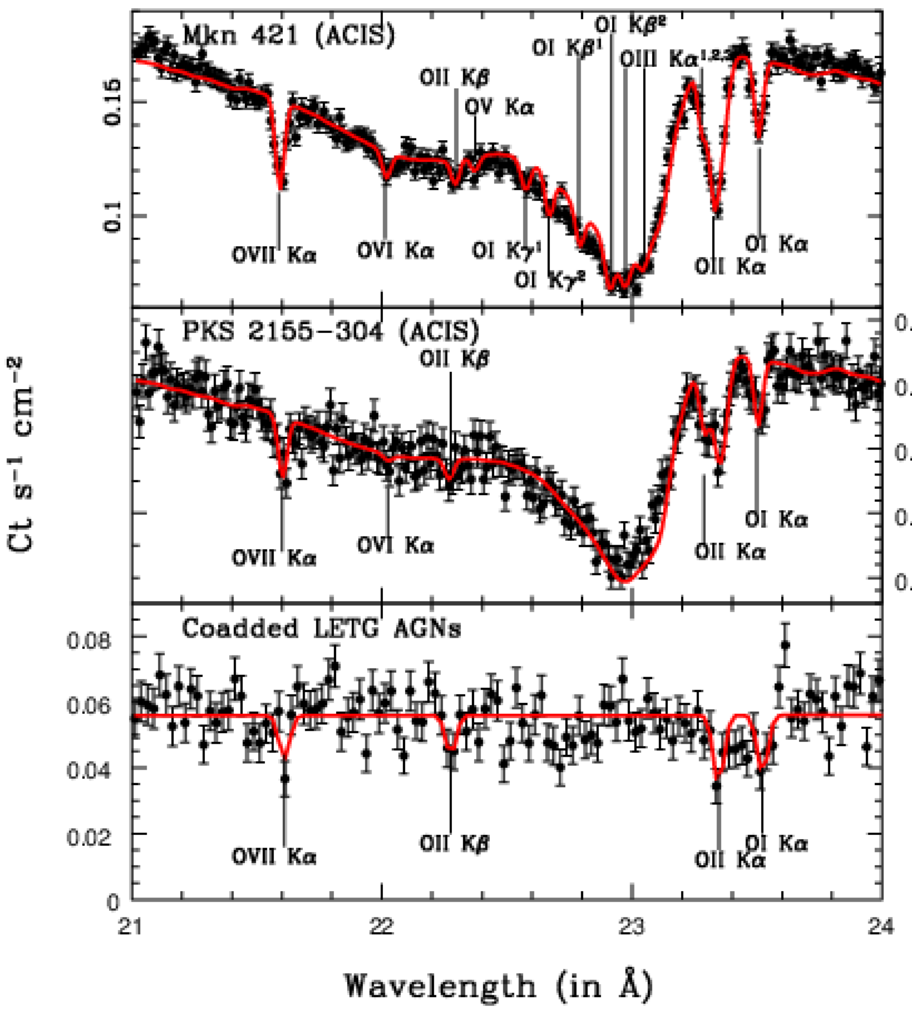
Mkn 501 (Ren et al. 2014)

ATOMIC DATA WARNING!

O VII Ka at z≃0.03 from WHIM
(Buote et al. 2009, Fang et al. 2010, Ren et al. 2014)

OR

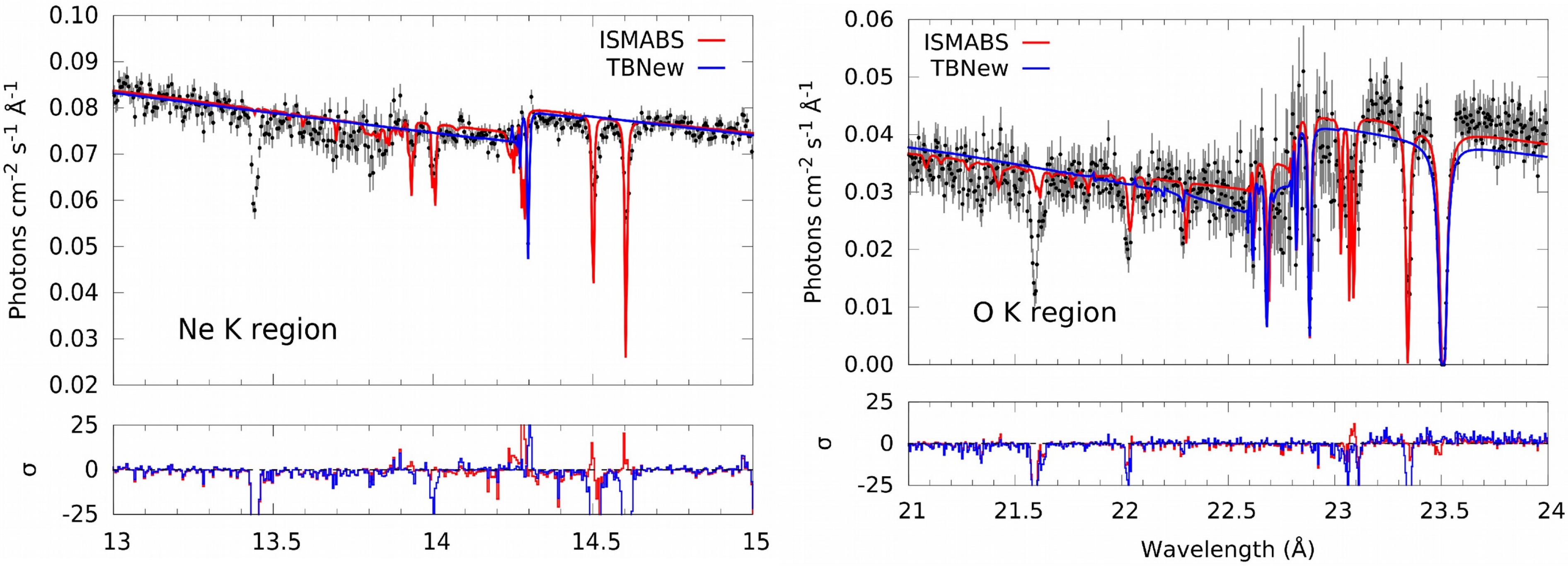
O II Kβ at z = 0 from ISM
(Nicastro et al. 2016)



ISMabs: ISM X-ray absorption model

$$I_{obs}(E) = e^{-\tau} I_{source}(E)$$

$$\tau = \sum_{i}^{k} \sigma_i \cdot N_i$$



Gatuzz+15

Ionization Equilibrium: *Ioneq*

$$I_{obs}(E) = e^{-\tau} I_{source}(E)$$

$$\tau = \sum_{k,j} \sigma_{k,j} \cdot N_h \cdot A_k \cdot n_{k,j}$$

$$\frac{dn_{k,j}}{dt} = (C_{k,j}) - (D_{k,j})$$

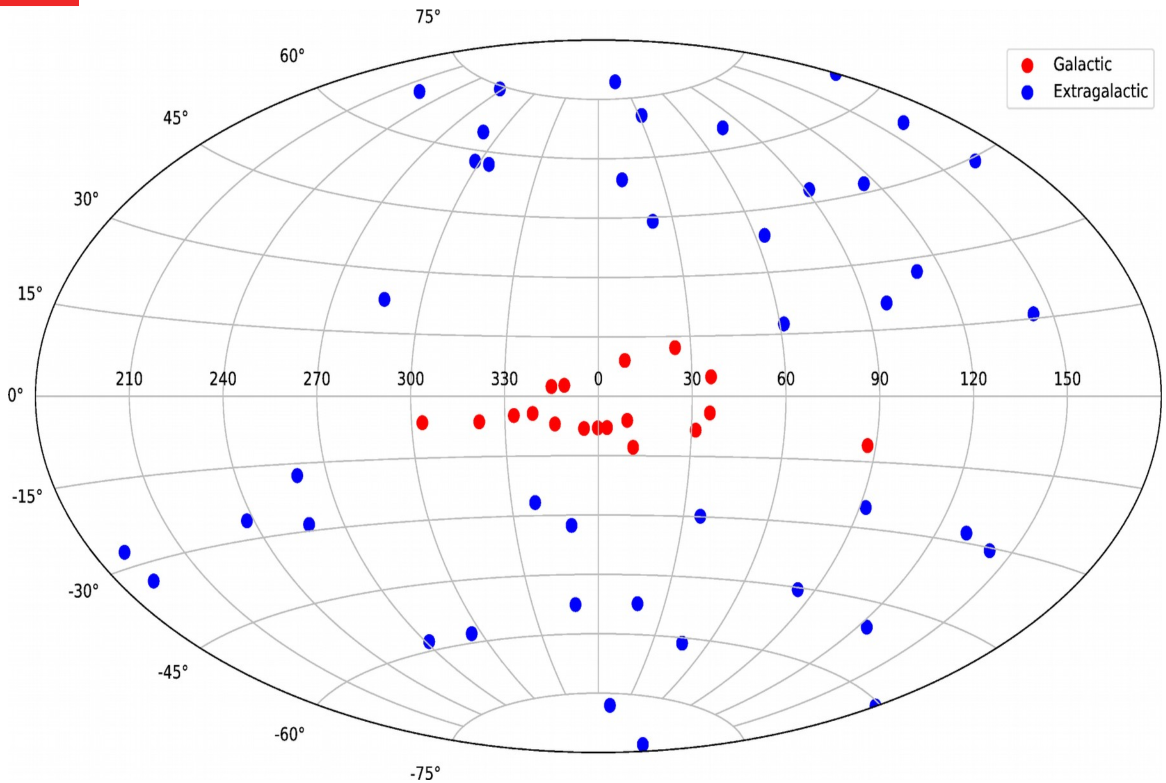
- Photoionization (Verner et al. 1996).
- Auger probabilities (Kaastra & Mewe 1993).
- Collisional ionization (Voronov 1997)
- Radiative recombination (Verner & Ferland 1996)
- Dielectronic recombination (Arnaud & Rothenflug 1985)

MODEL PARAMETERS:

- Temperature (Te)
- Ionization parameter (ξ)
- Hydrogen column density (N_h)
- Redshift (z)
- Turbulent broadening (υ_{turb})

Gatuzz+18a

DATA SAMPLE



Galactic Sources → LMXB
Extragalactic Sources → Blazars

> 1000 counts in the 21-24 A wavelength region

We did not impose additional constrains! (e.g. O VII Ka detection)

18 Galactic sources - 41 Extragalactic sources
165 observations from Chandra
257 observations from XMM-Newton

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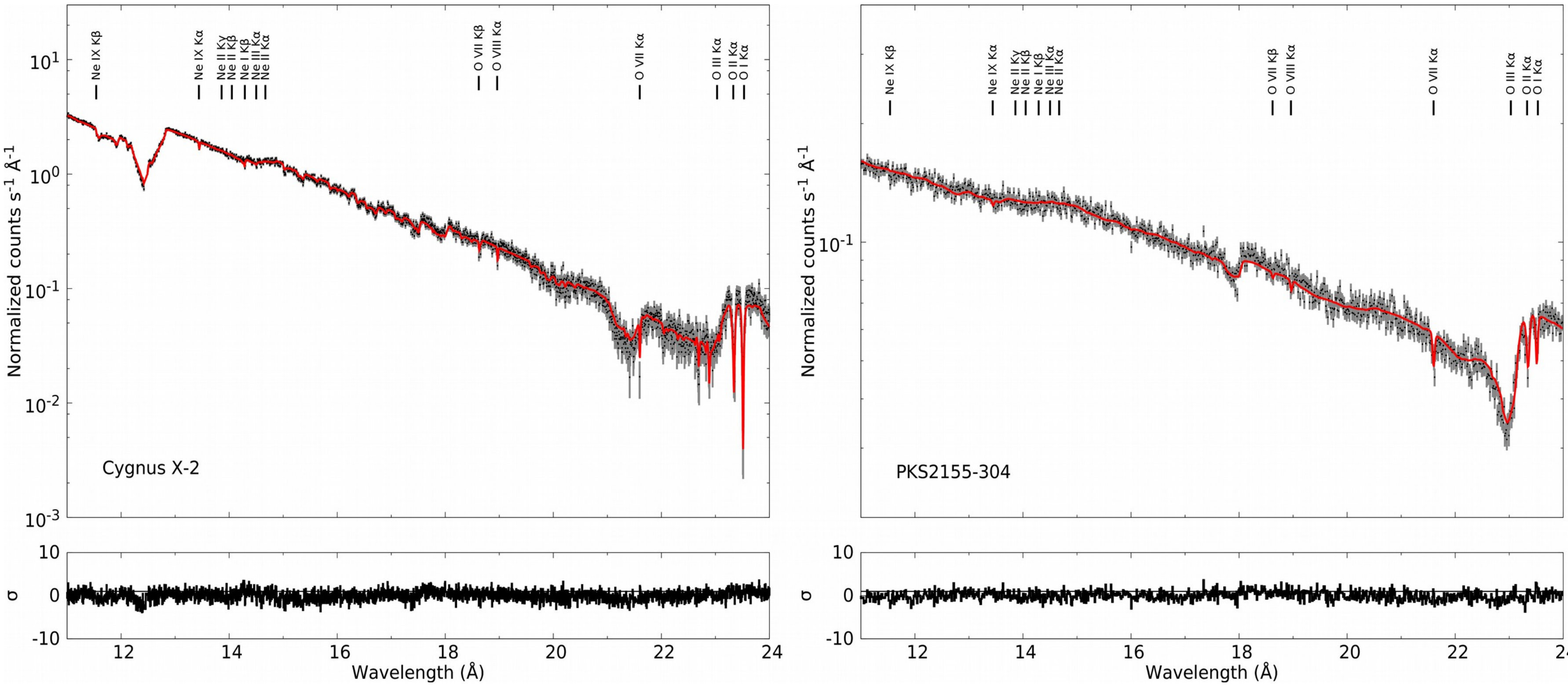
A detailed analysis of the ISM



COLD COMPONENT (Te ~ 10000 K): O I, Ne I, Fe I, Metallic Fe
WARM COMPONENT (Te ~ 51000 K): O II, O III, Ne II, Ne III
HOT COMPONENT (Te ~ 1.9 MK): Ne IX, O VII, O VIII

¡COLLISIONAL IONIZATION EQUILIBRIUM!

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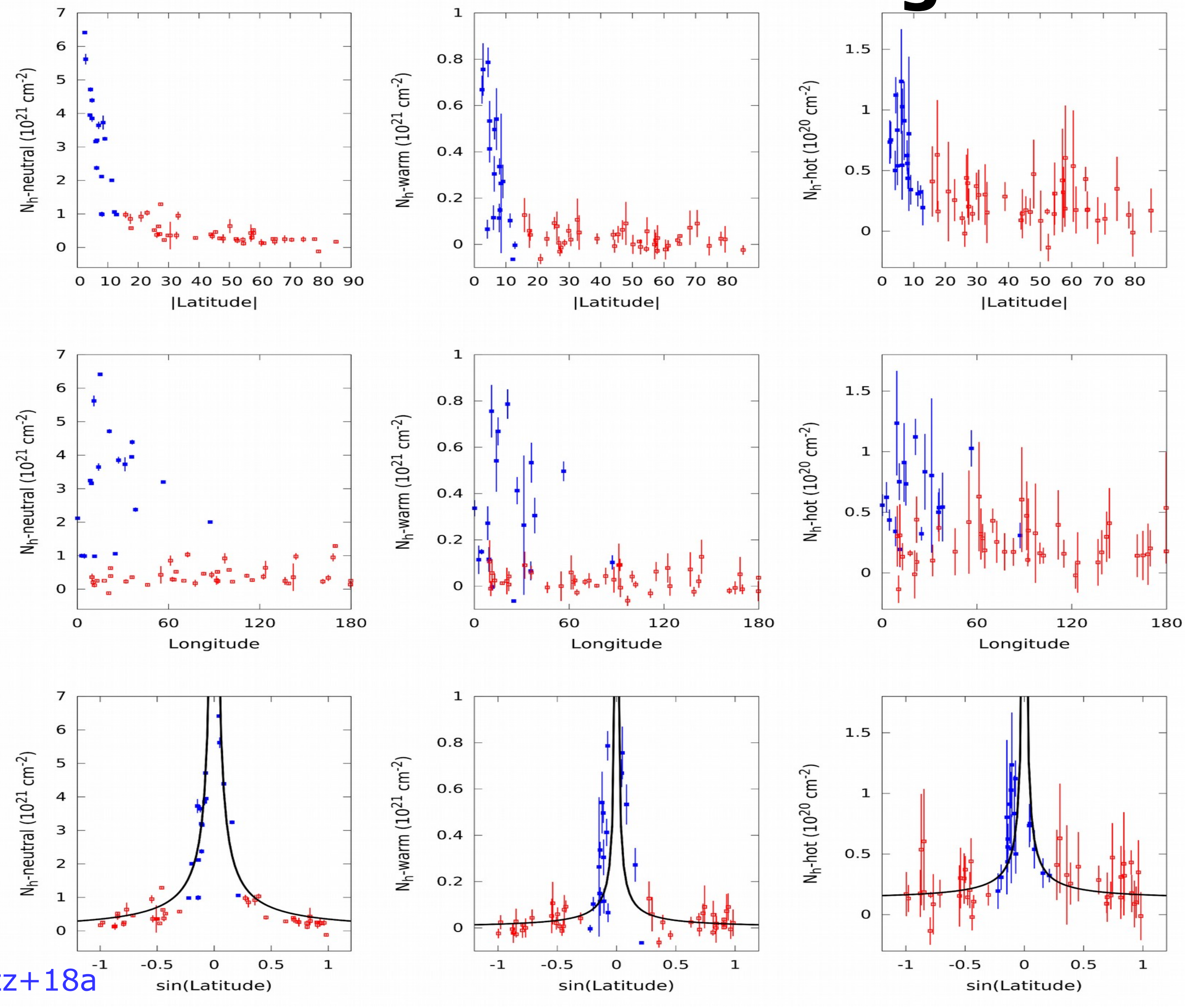
Distribution of the gas



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Distribution of the gas

$$N_i = \int_{observer}^{source} n_i(r)\,dr$$

COLD-WARM COMPONENTS (Robin et al. 2003)

$$n(r) = n_0\, e^{-\left(\frac{R}{R_c}\right)}\, e^{-\left(\frac{|z|}{z_c}\right)}$$

$$R^2 = r^2\cos^2 b - 2\,rR_{sun}\cos b\cos l + R_{sun}^2 \qquad z = r^2\sin^2(b)$$

HOT COMPONENT (Nicastro et al. 2016)

$$n(r) = n_{flat}(r) + n_{sph}(r)$$

$$n_{flat}(r) = \frac{n_{0,flat}}{\left[1+\left(\frac{R}{R_{c,flat}}\right)^2+\left(\frac{z}{z_{c,flat}}\right)^2\right]^{3\beta_{flat}/2}} \qquad n_{sph}(r) = \frac{n_{0,sph}}{\left[1+\left(\frac{r}{r_{c,sph}}\right)^2\right]^{3\beta_{sph}/2}}$$

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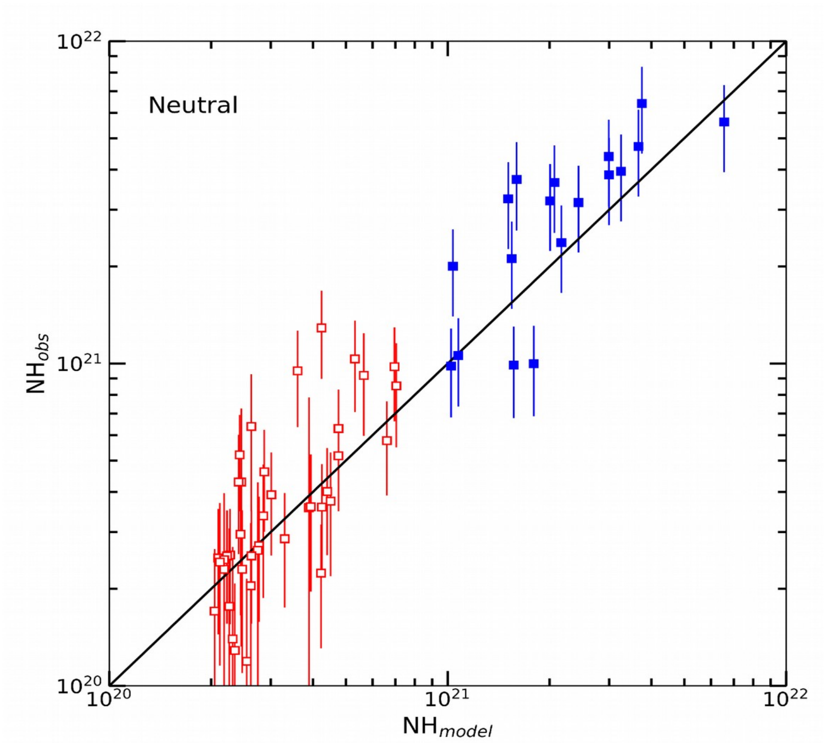
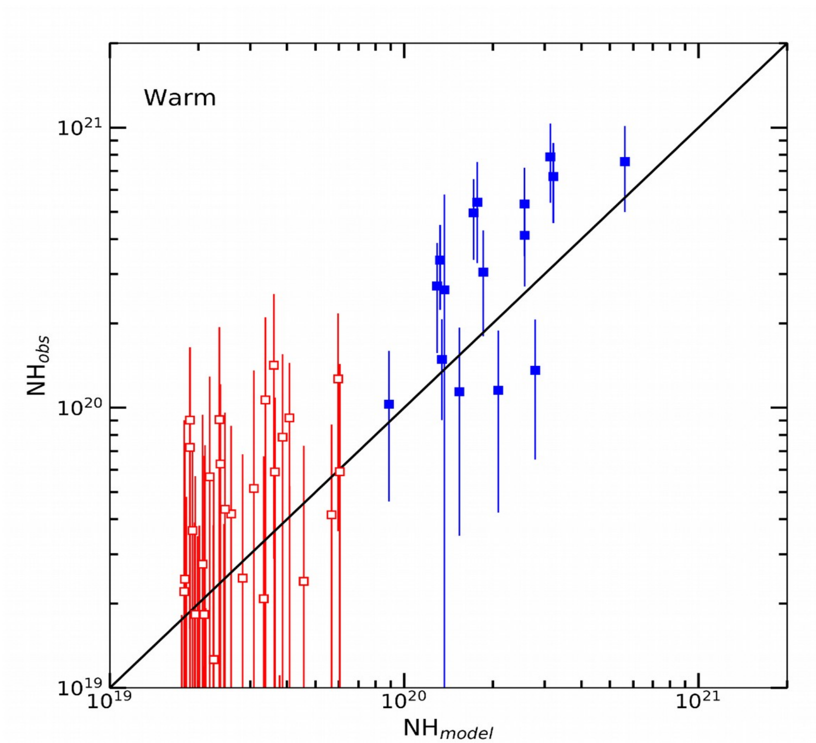
Density profiles





$$n_0 = (10.28 \pm 5.14)\, cm^{-3}$$
$$R_c = (4.46 \pm 2.23)\, kpc$$
$$z_c = (0.34 \pm 0.10)\, kpc$$
$$\chi / d.o.f = 67.2/56$$

$$n_0 = (1.25 \pm 1.14)\, cm^{-3}$$
$$R_c = (2.91 \pm 1.02)\, kpc$$
$$z_c = (0.10 \pm 0.01)\, kpc$$
$$\chi / d.o.f = 72.8/56$$

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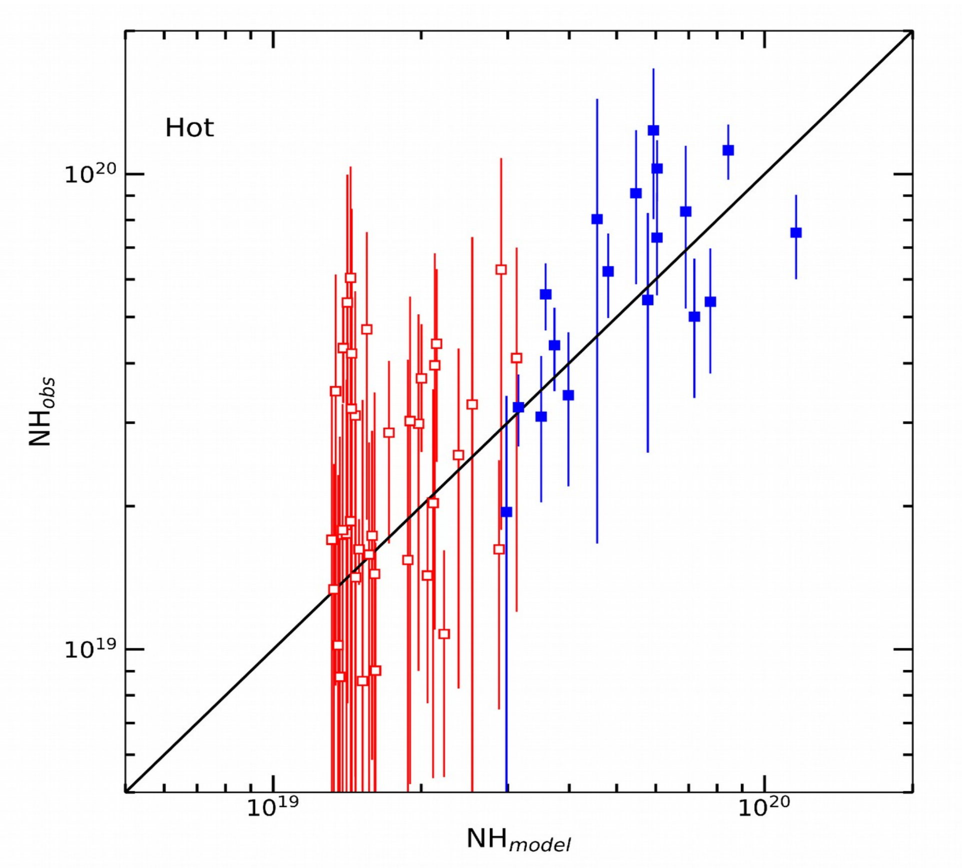
Density profiles



$$n_{0,flat} = (0.48 \pm 0.17)\, x\, 10^{-2}\, cm^{-3}$$

$$R_{c,flatt} = (50)\, kpc$$

$$z_{c,flat} = (0.41 \pm 0.12)\, kpc$$

$$\beta_{flat} = (0.96 \pm 0.47)$$

$$n_{0,sph} = (2.06 \pm 0.37)\, x\, 10^{-2}\, cm^{-3}$$

$$r_{c,sph} = (2)\, kpc$$

$$\beta_{sph} = (0.78 \pm 0.29)$$

$$\chi / d.o.f = 78.6/54$$

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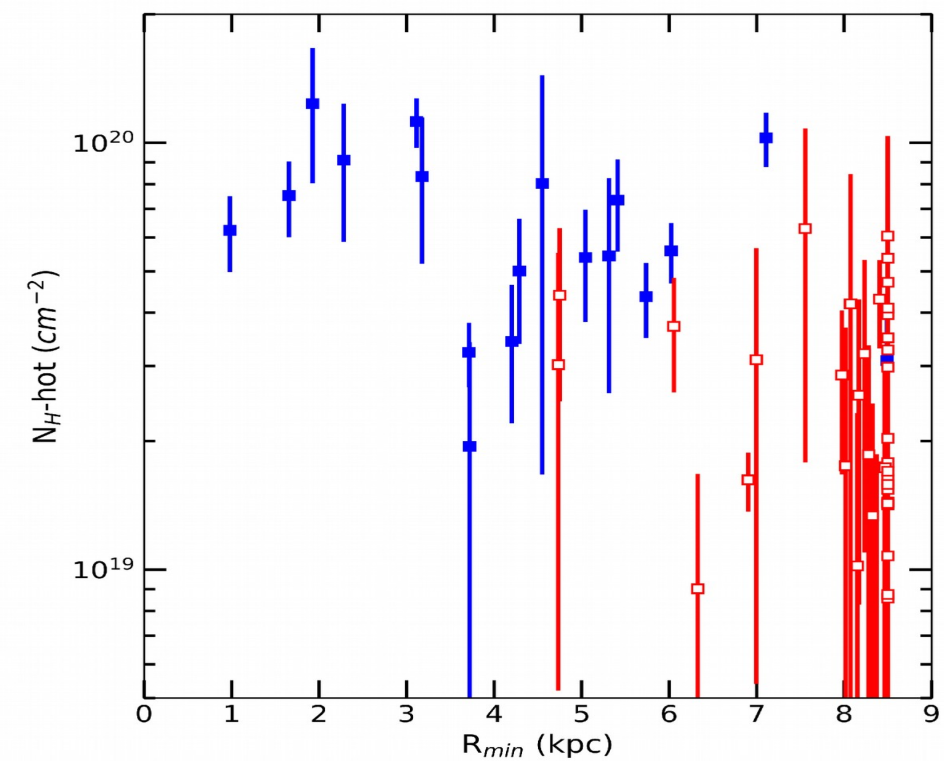
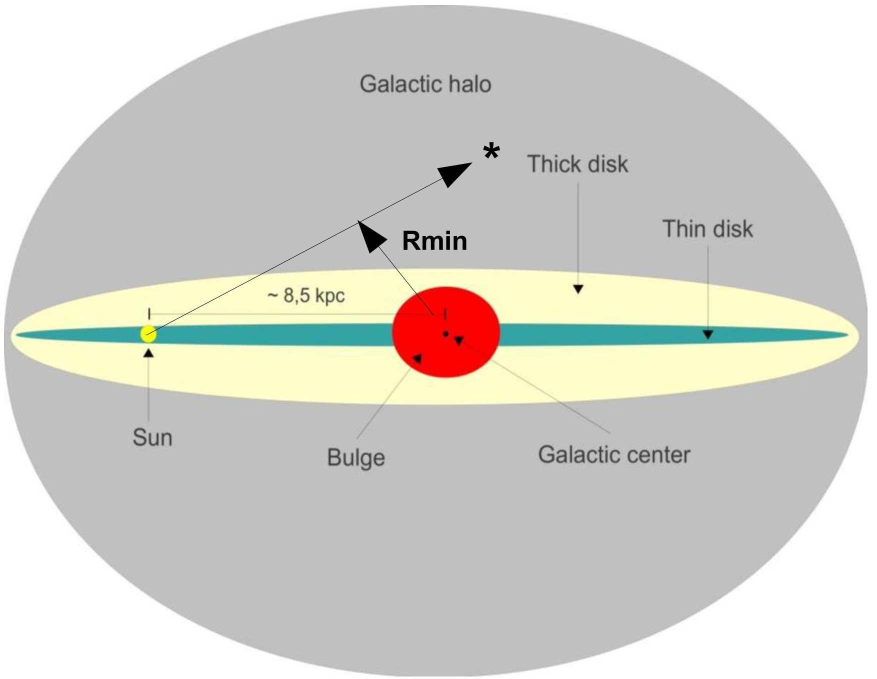
Galactic center properties

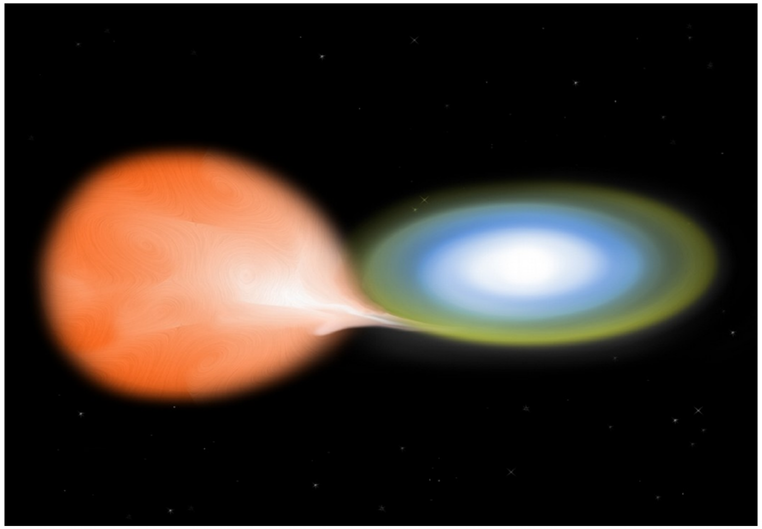




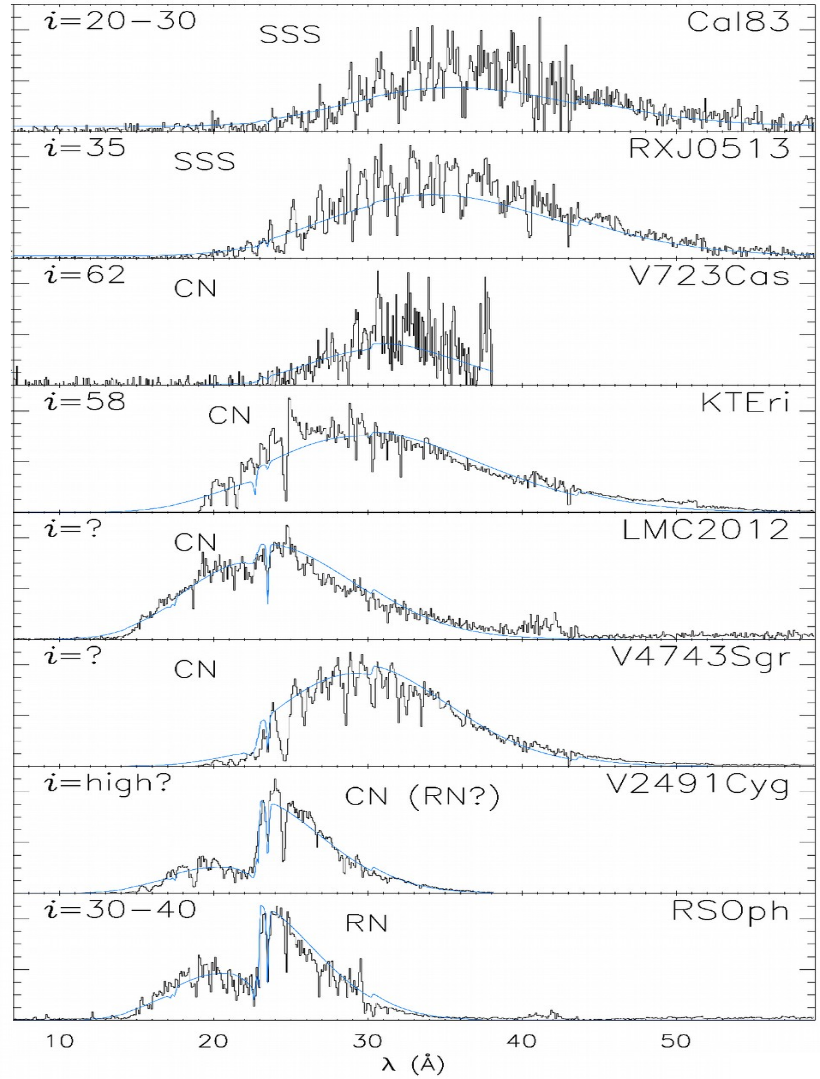
WE DO NOT HAVE ENOUGH INFORMATION IN ORDER TO CONSTRAIN THE GALACTIC CENTER PROPERTIES!

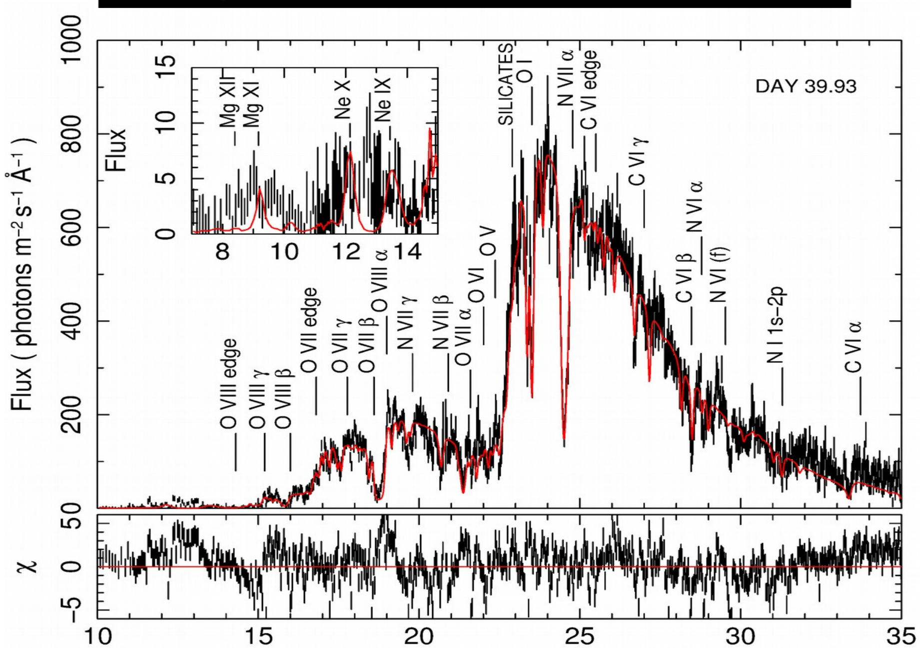
Gatuzz+18a

X-RAY NOVAE: ISM FINGERPRINTS



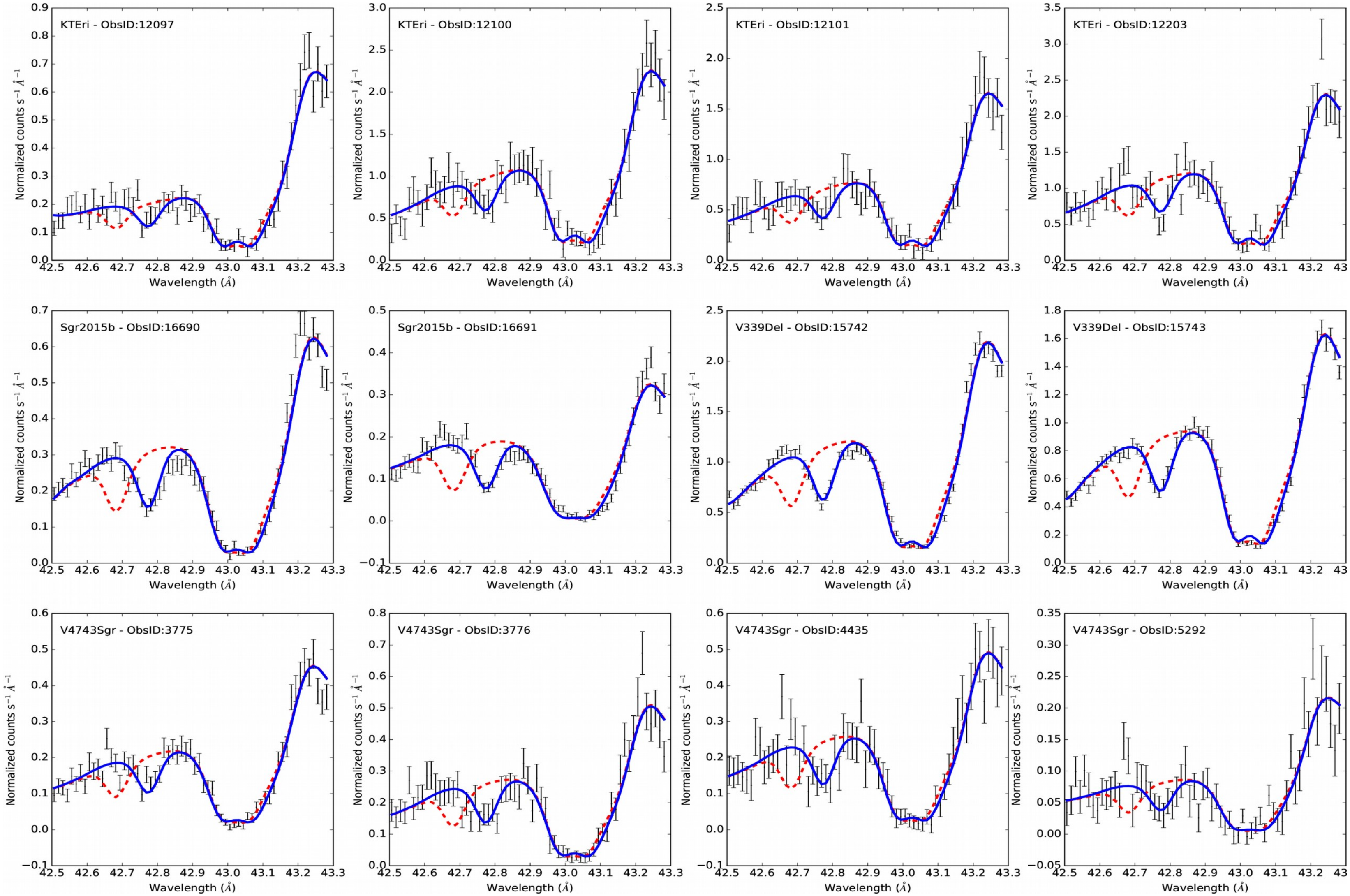
Ness+13





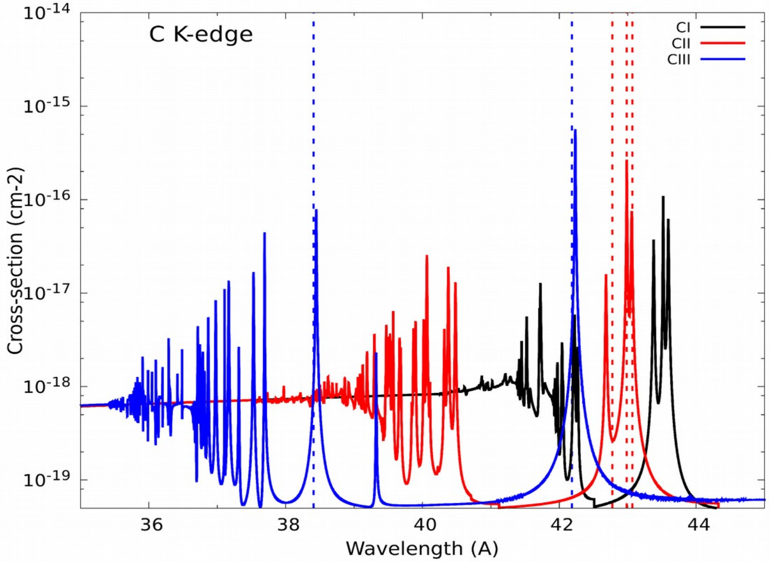
Pinto+12

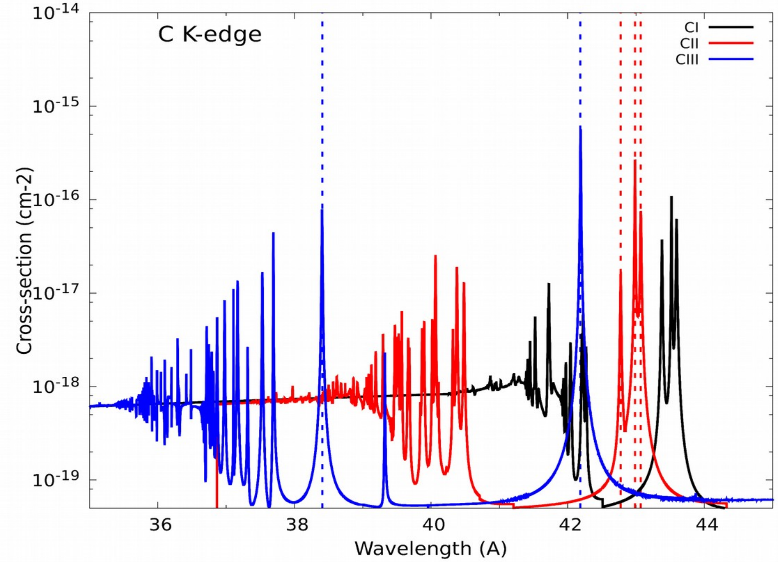
X-RAY NOVAE: ISM FINGERPRINTS

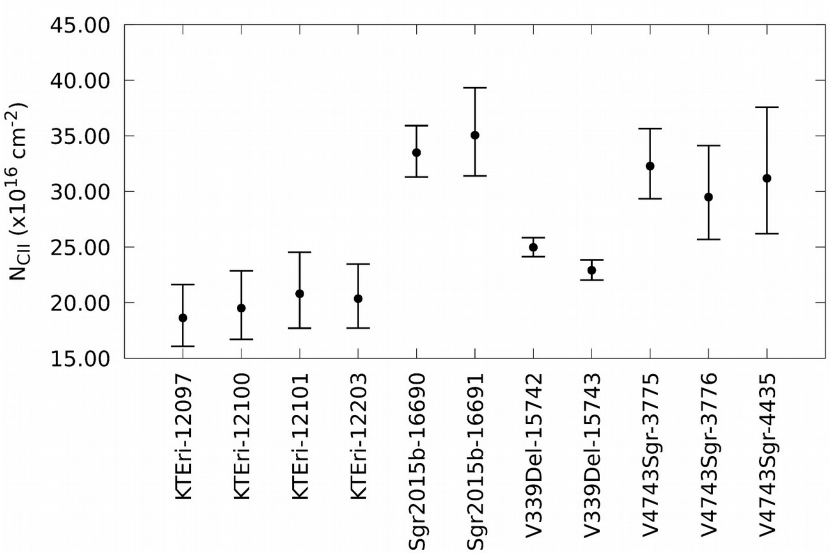


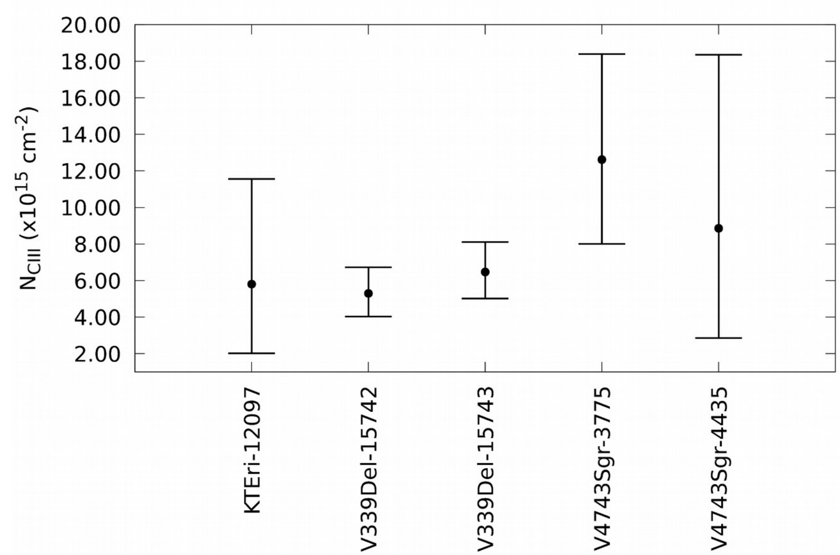
Gatuzz+18b (submitted)

X-RAY NOVAE: ISM FINGERPRINTS









Gatuzz+18b (submitted)

Exploring the X-ray Transient and Variable Sky (ExTRAS)

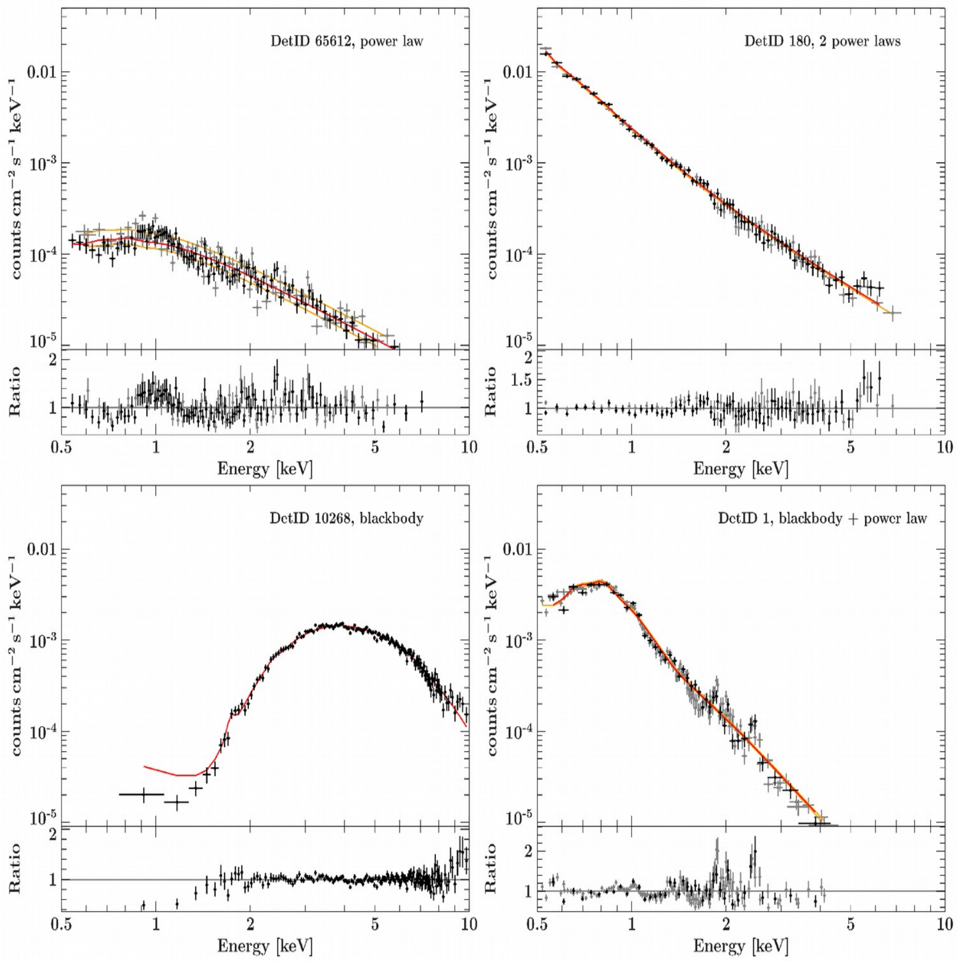
"Characterise as well as possible the variability of XMM sources in public archives, by providing tools and a catalogue to the community"

3XMM-DR6 catalogue (137212 sources)

Six phenomenological models:

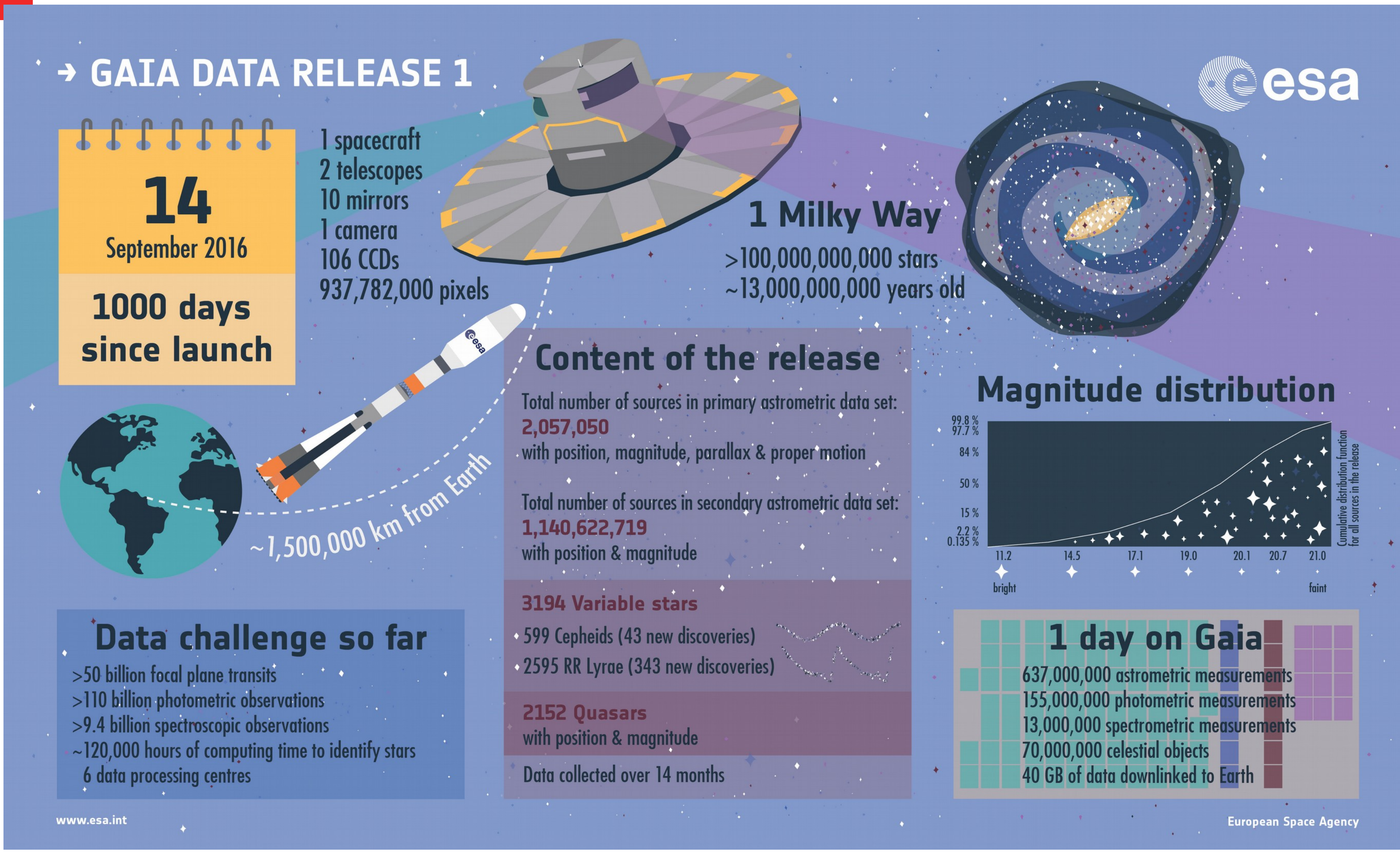
- An absorbed power-law model
- An absorbed thermal model
- An absorbed black-body model
- An absorbed emission spectrum from collisionally-ionized diffuse gas plus power-law model
- An absorbed double power-law model
- An absorbed black-body plus power-law model

Nh from best fit model



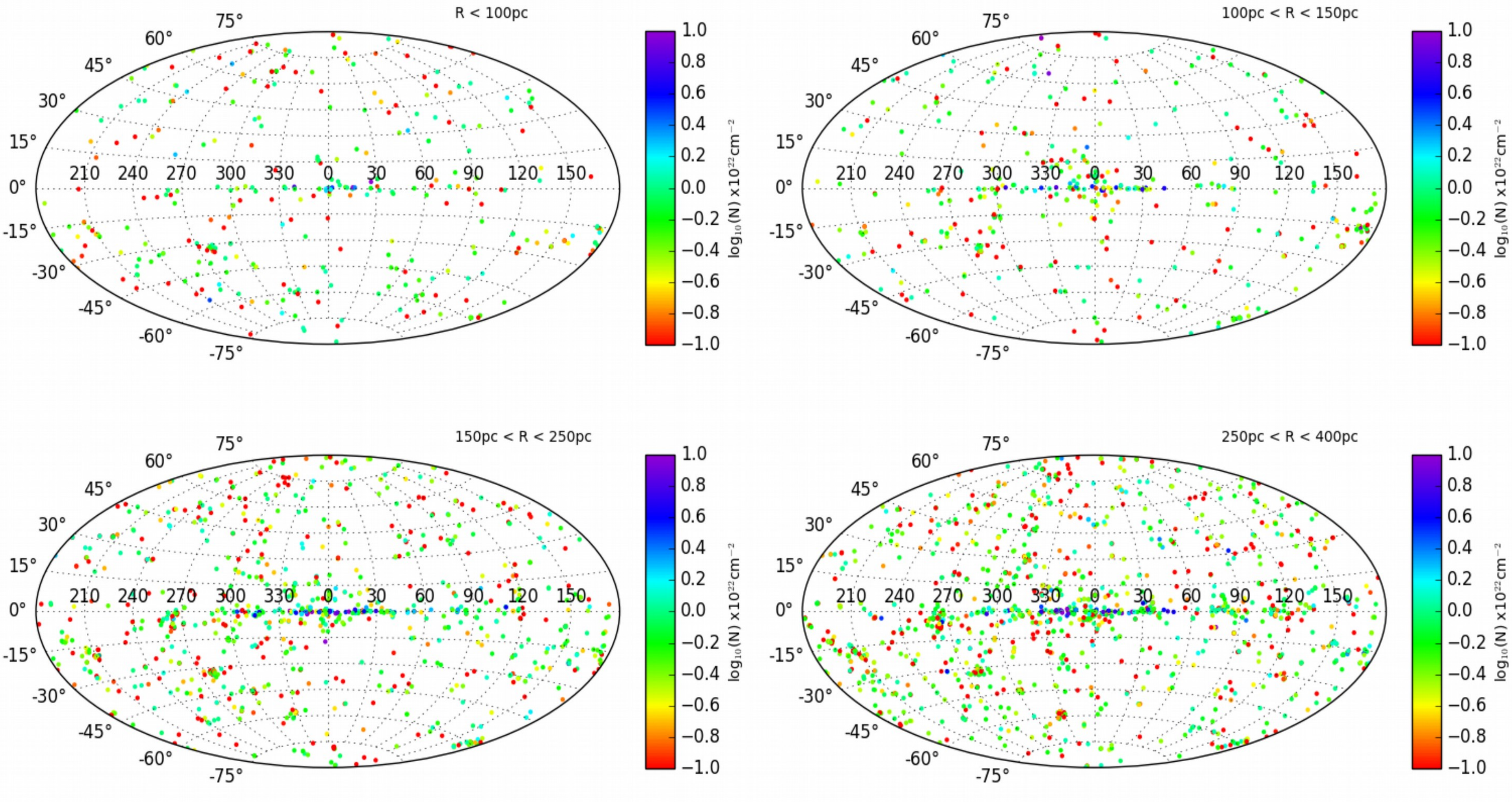
Gatuzz+18c (submitted)

GAIA DATA RELEASE 1



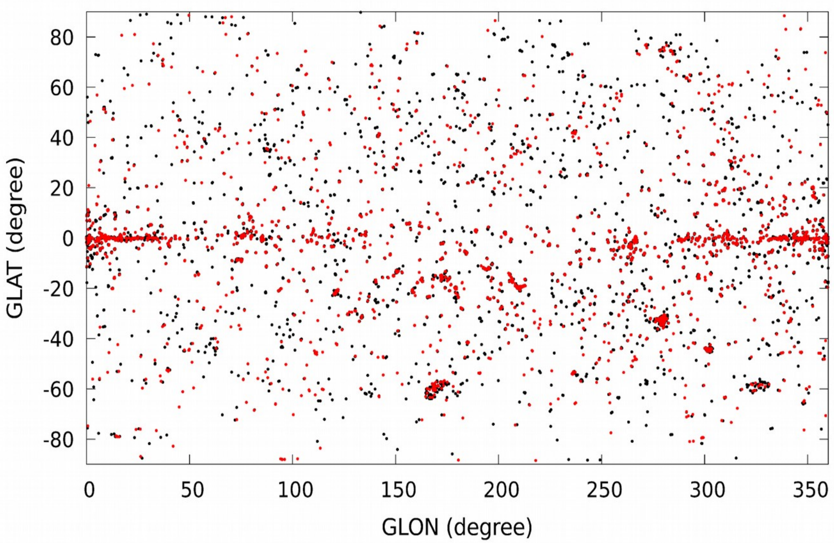
Gatuzz+18c (submitted)

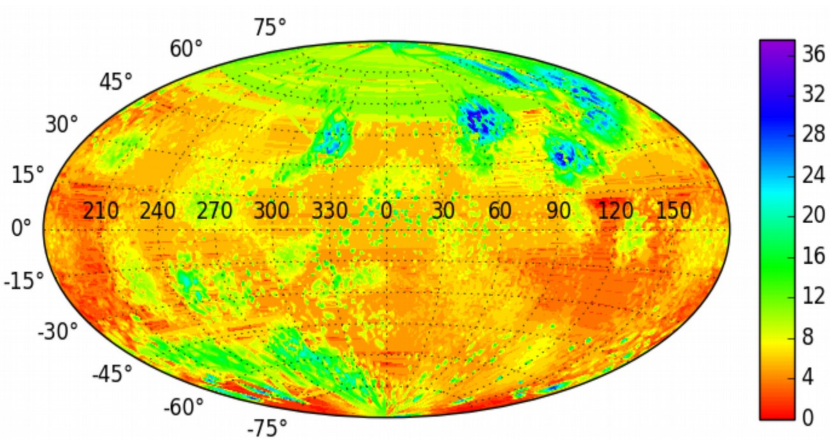
ISM 3D MAP

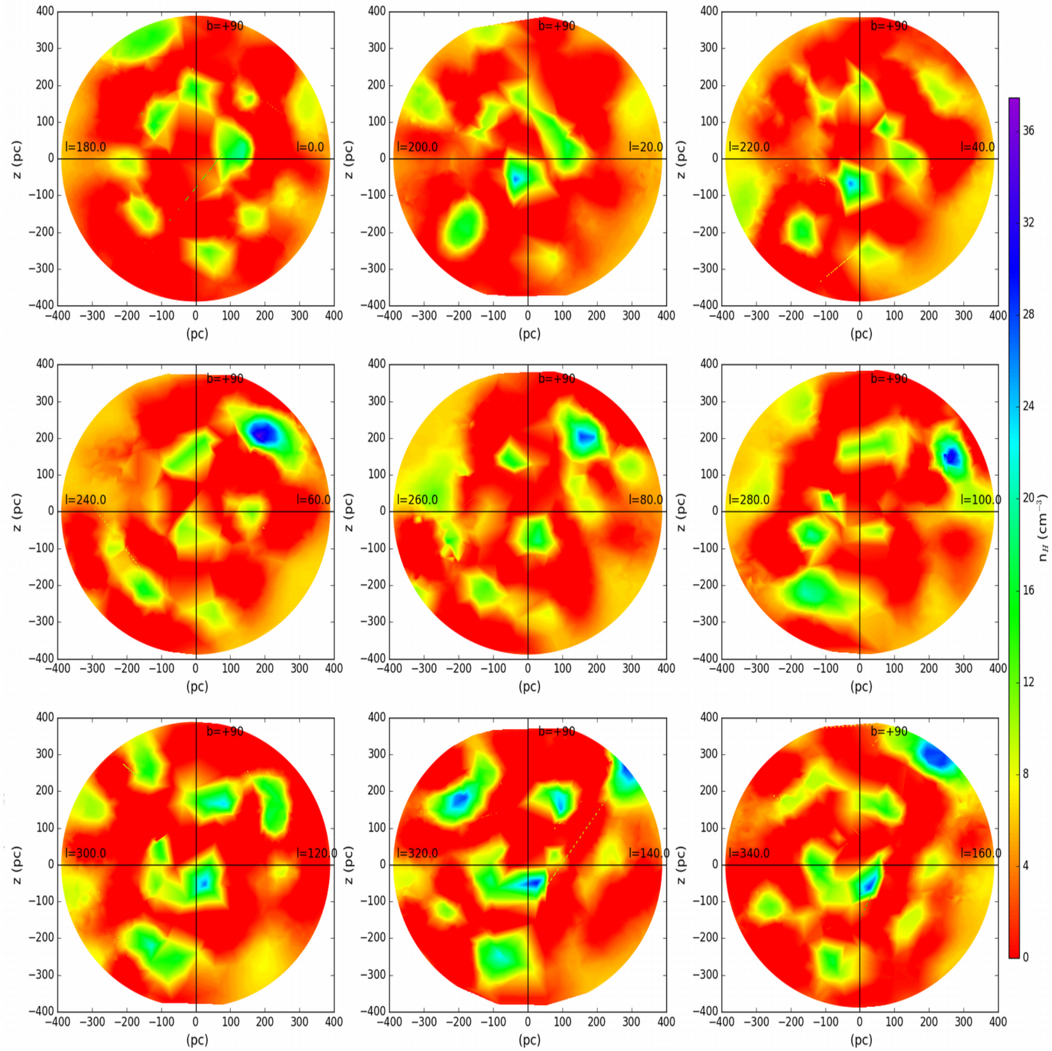


Gatuzz+18c (submitted)

ISM 3D MAP







Gatuzz+18c (submitted)

Conclusions

- ISM absorption affects all X-ray spectra.
- The atomic data is important.
- We have developed accurate tools to model the ISM X-ray absorption (**ISMabs** and **IONeq**).
- We have estimated the density distribution of the neutral, warm and hot gas components in the Milky Way.
- We have modeled carbon ISM absorption features in X-ray novae spectra.
- Using results from the **ExTRAS** project, in combination with **GAIA** distances, we are developing 3D maps of the ISM gas distribution as seen on X-ray.

THANK YOU!