



X-raying the local ISM

Efrain Gattuzz
(ESO)

Interstellar Medium in the Nearby Universe
Bamberg, Germany
26 March 2018



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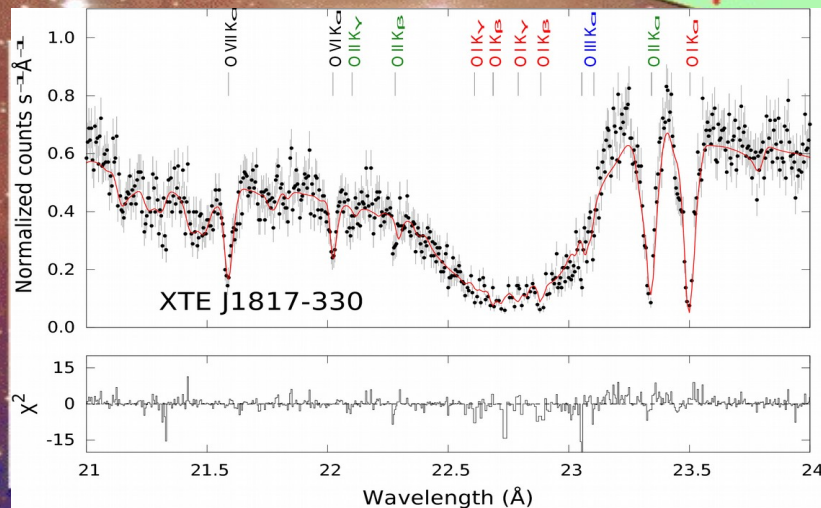
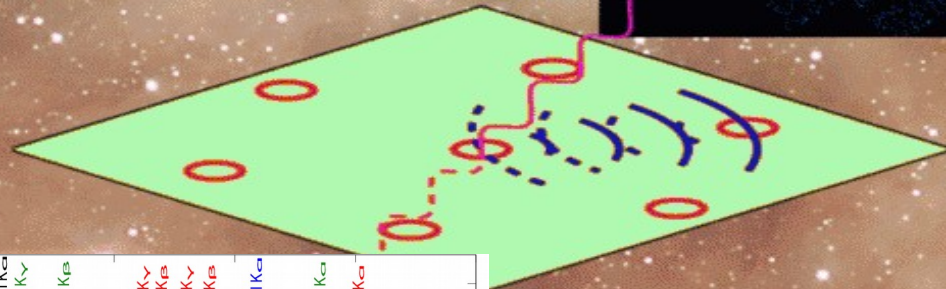
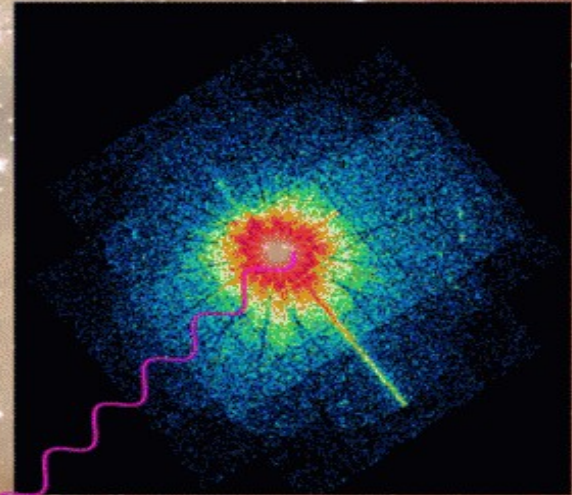
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Mirjam Oertel (Remeis-Observatory)

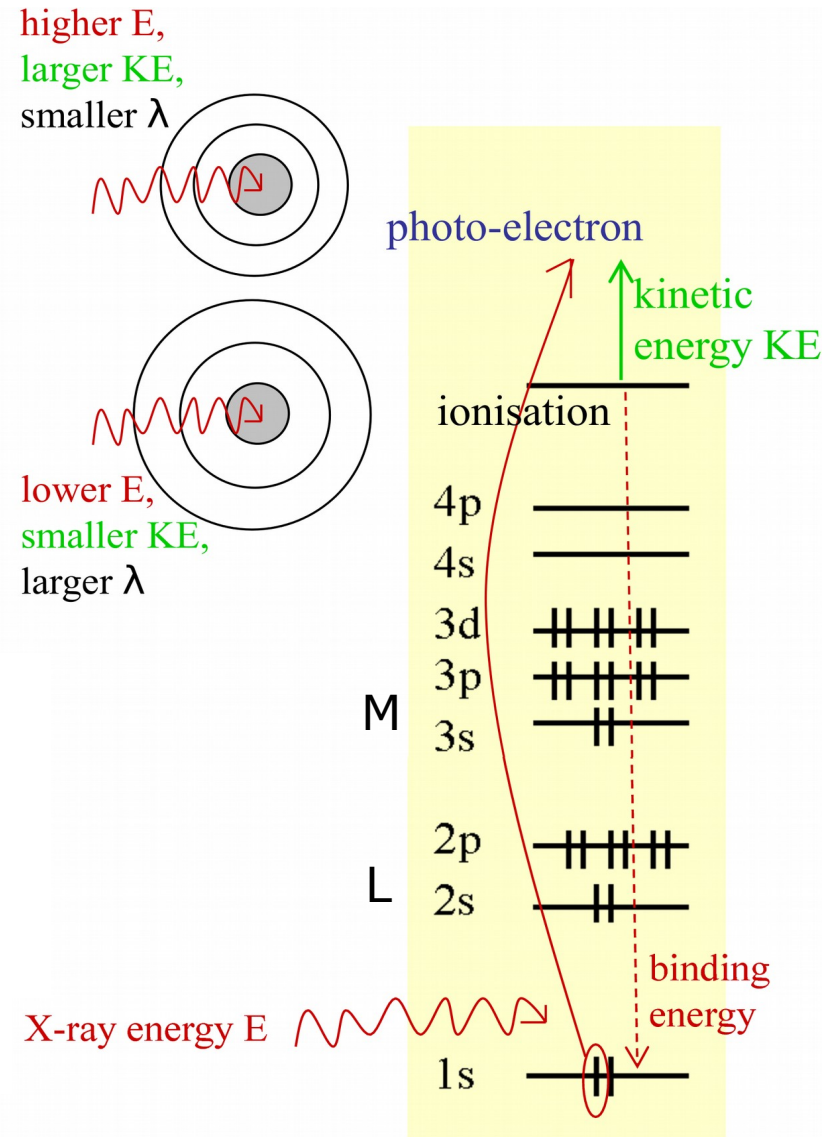
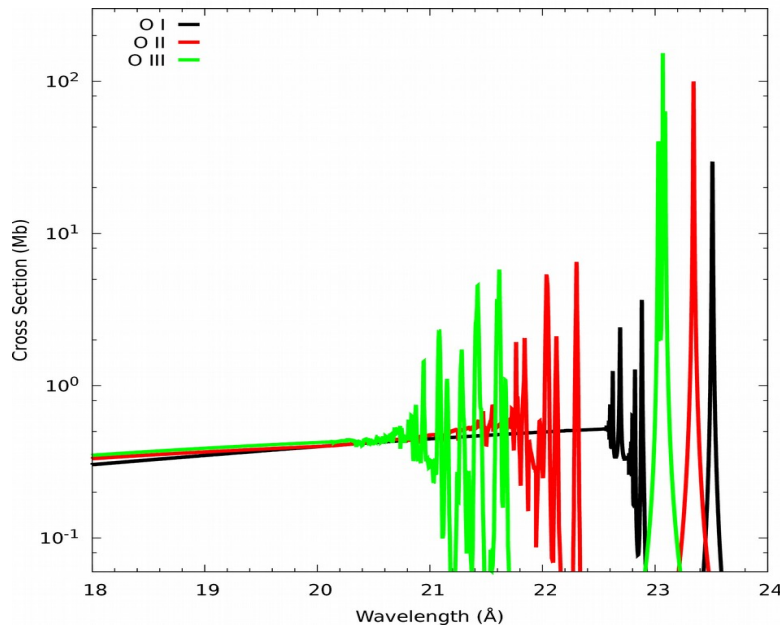
High-Resolution X-ray Spectroscopy



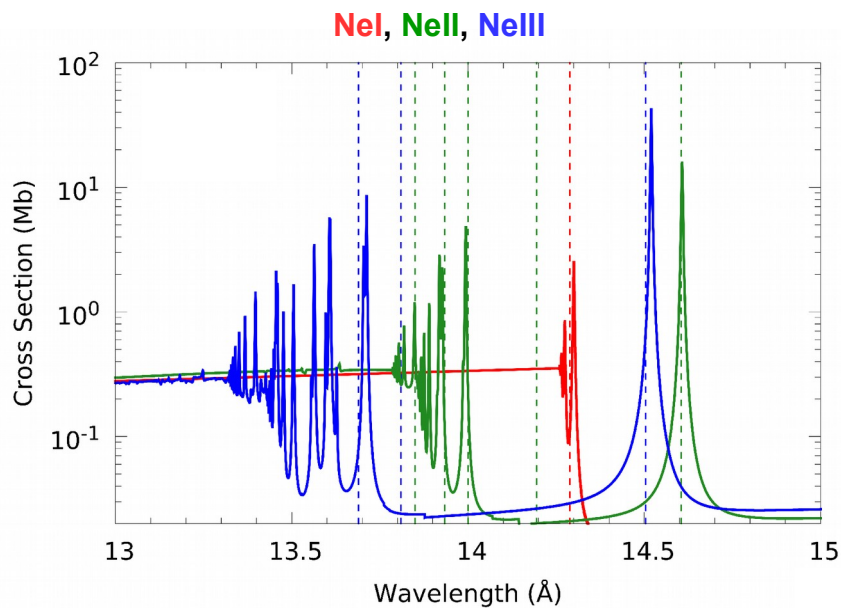
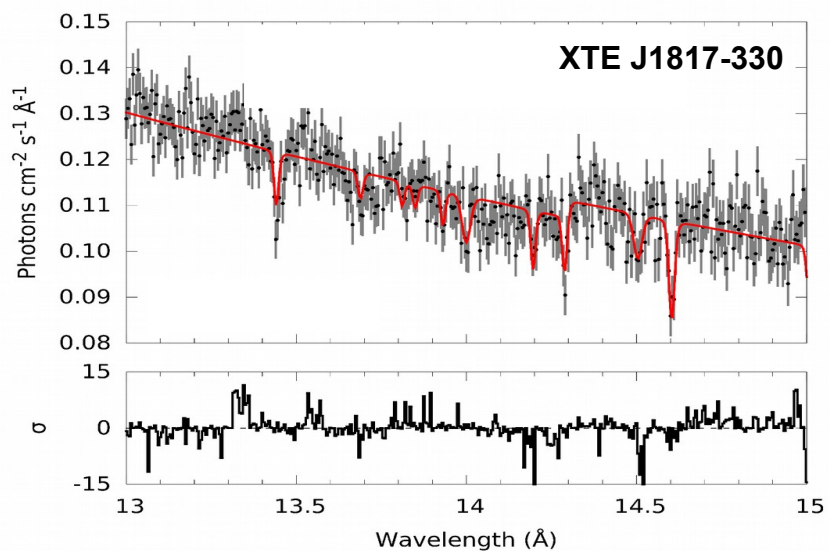
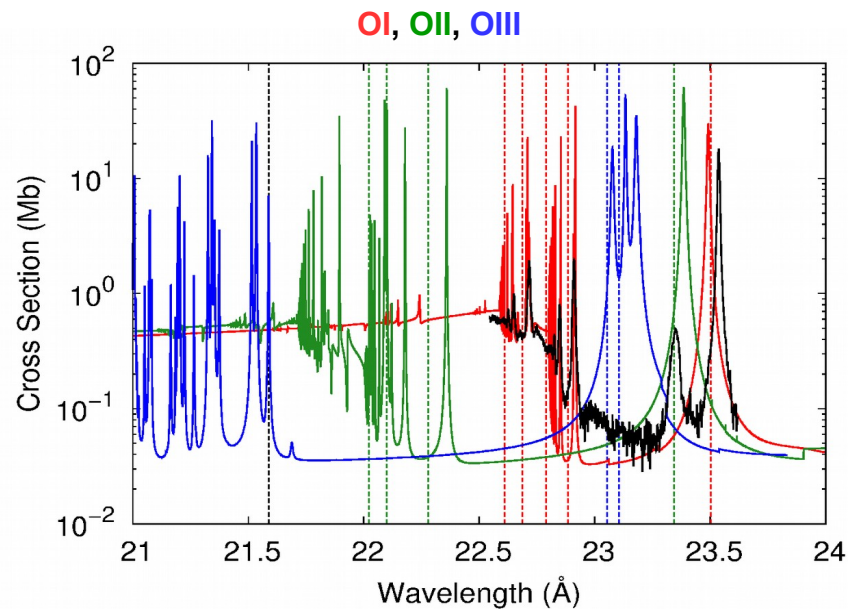
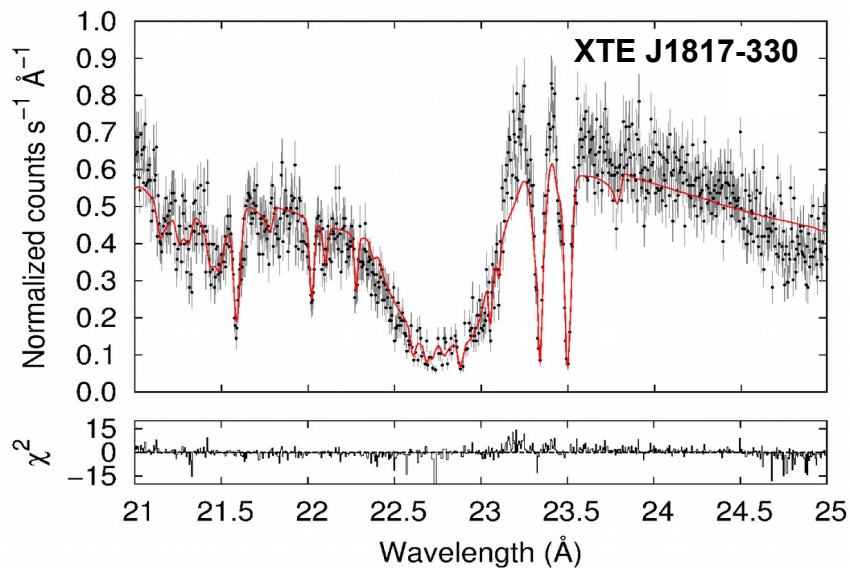
X-Ray Photoabsorption

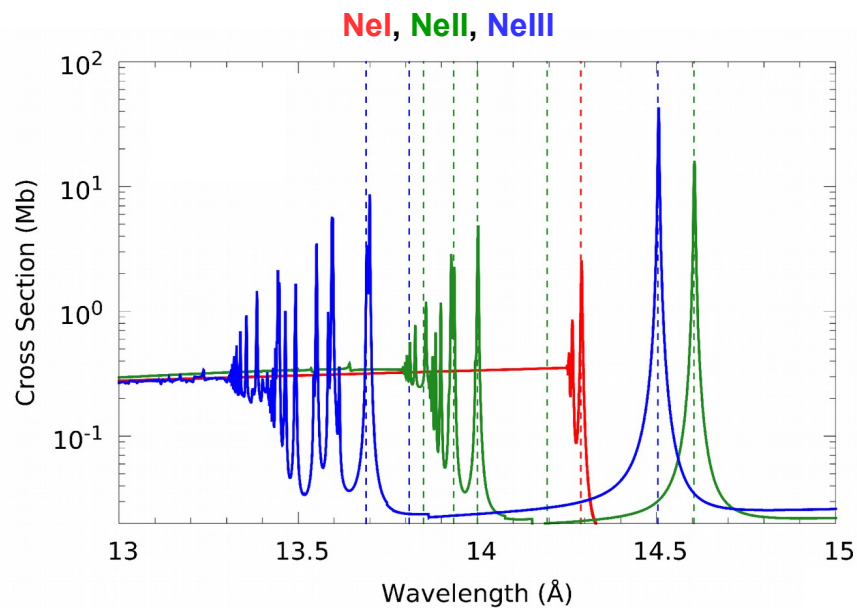
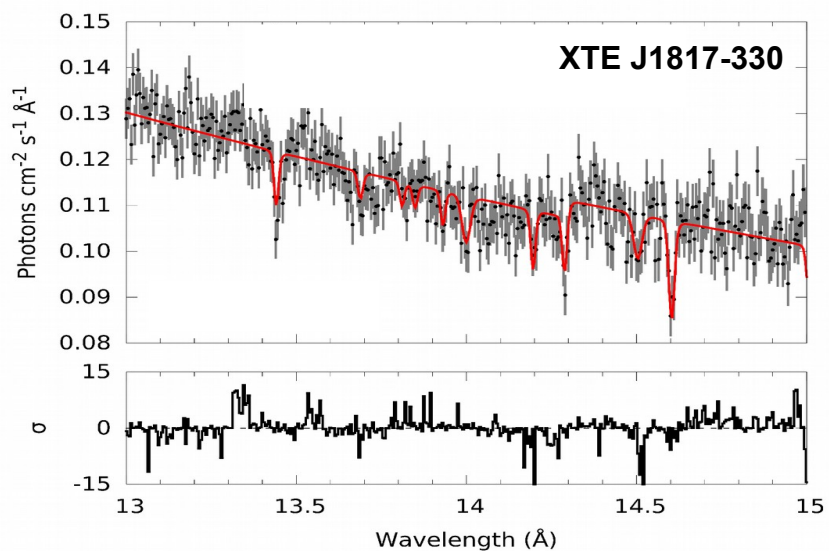
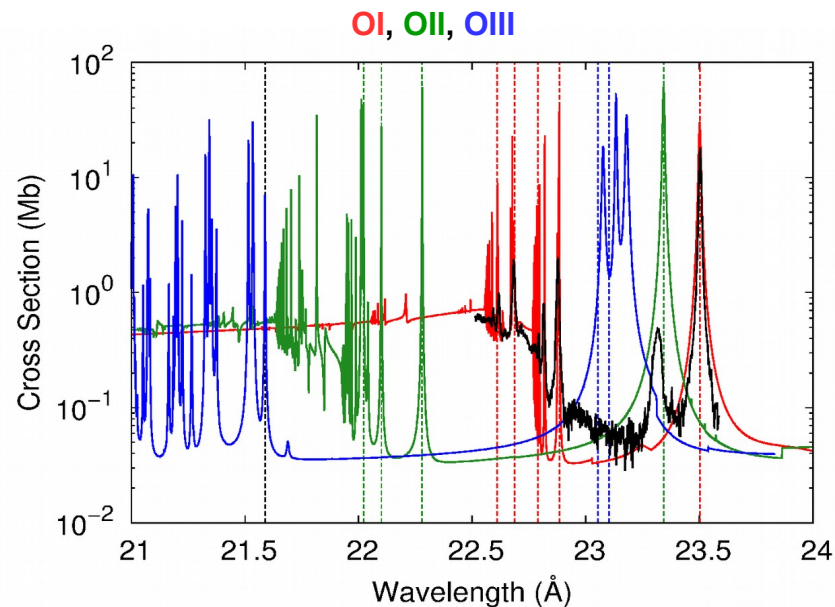
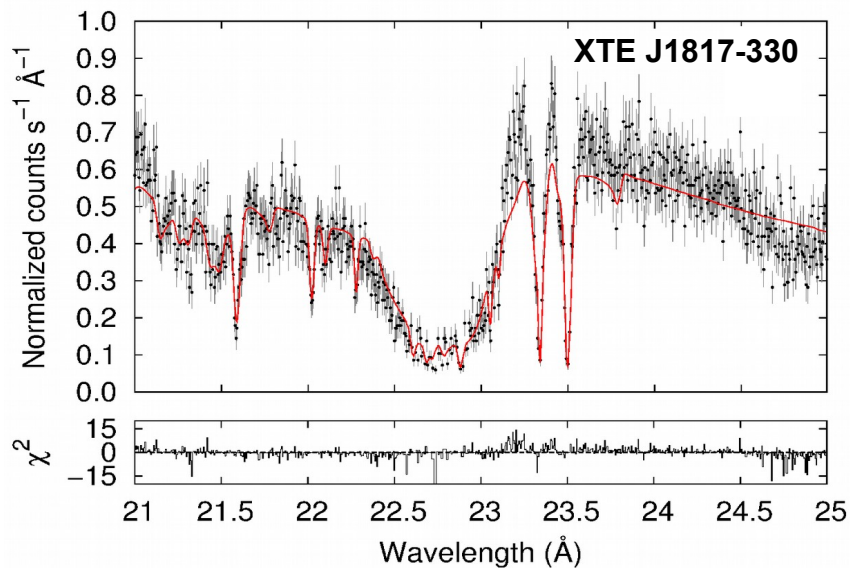
- The atom is excited by a photon.
- There is one **photoabsorption cross-section** for each ion.
- There are two decay processes:

X-ray fluorescence
Auger effect.



ISM ABSORPTION AFFECTS ALL X-RAY SPECTRA!



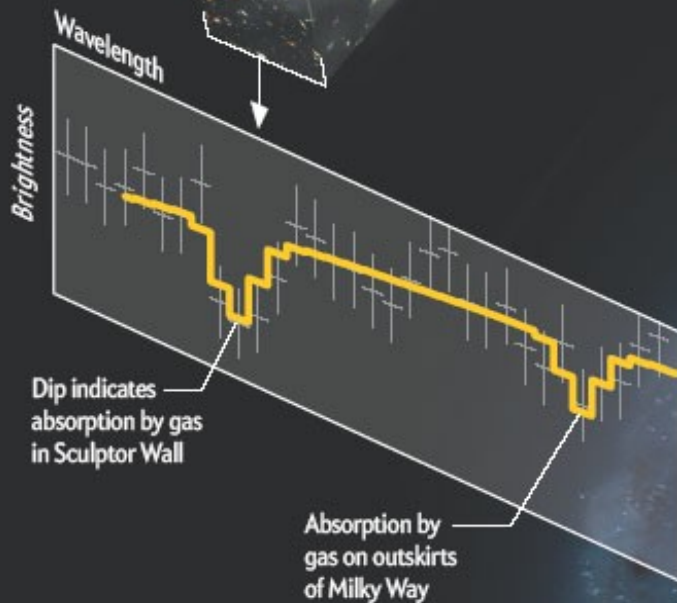


Betrayed by Its Shadow

Astronomers think they may have found where the bulk of the normal matter in the universe lurks: not in galaxies but in a form of intergalactic gas (mostly hydrogen) called the warm-hot intergalactic medium, or WHIM. The name connotes that the gas is less than blazingly hot and, consequently, glows too feebly to see directly. Looking in the interstices of a giant filament of galaxies called the Sculptor Wall, astronomers saw, in essence, the WHIM's shadow: the gas absorbed x-rays from a background object at a distinctive wavelength.

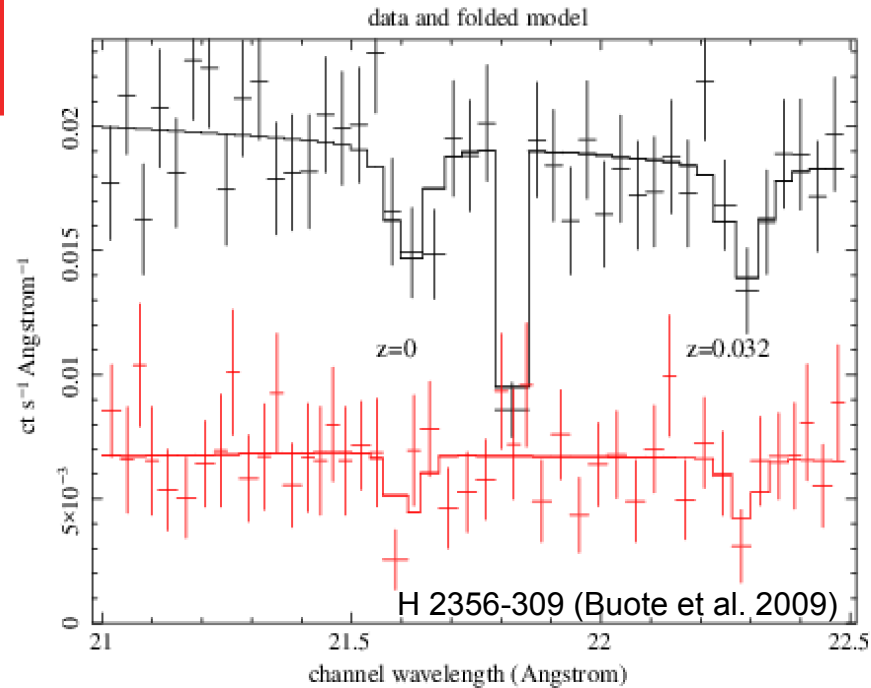
H 2356-309
(background
x-ray source)

Sculptor Wall

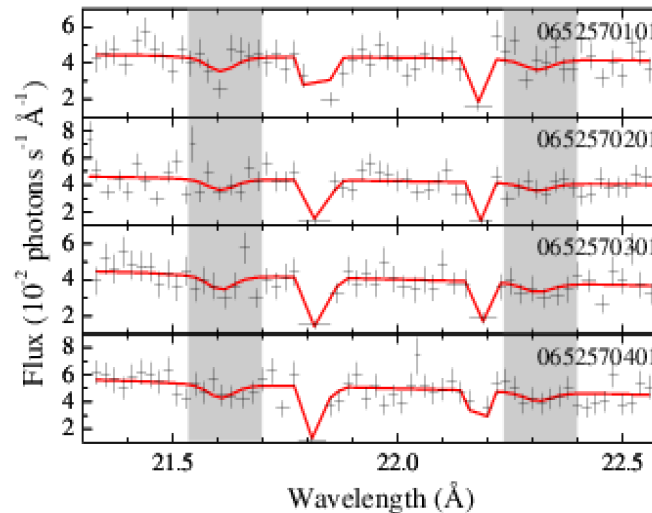
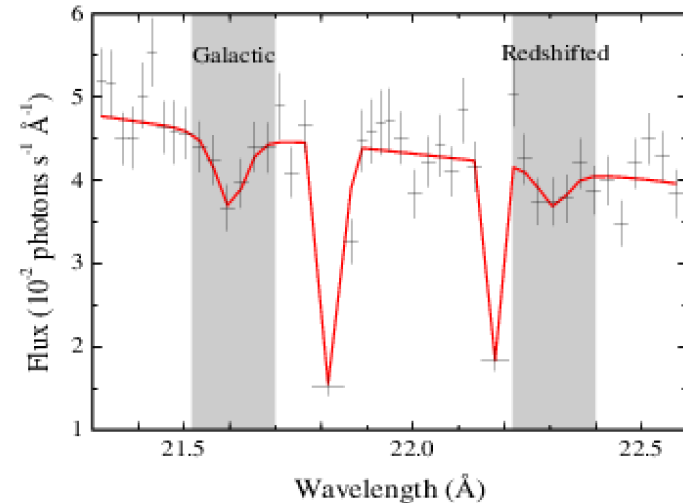
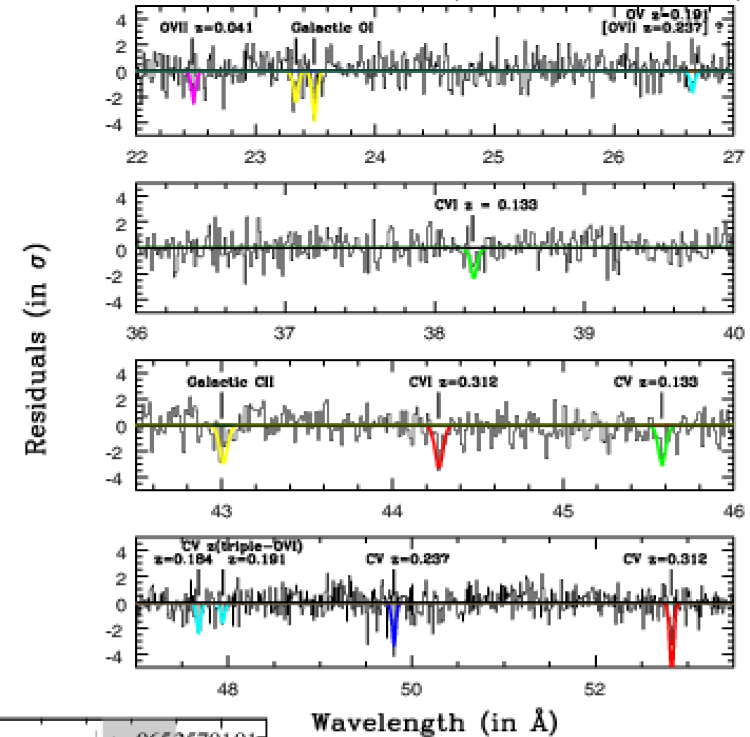


Buote+09, Fang+10, Zappacosta+10, Fang+11, Zappacosta+12

O VII Ka AT $z \approx 0.03$ FROM WHIM



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

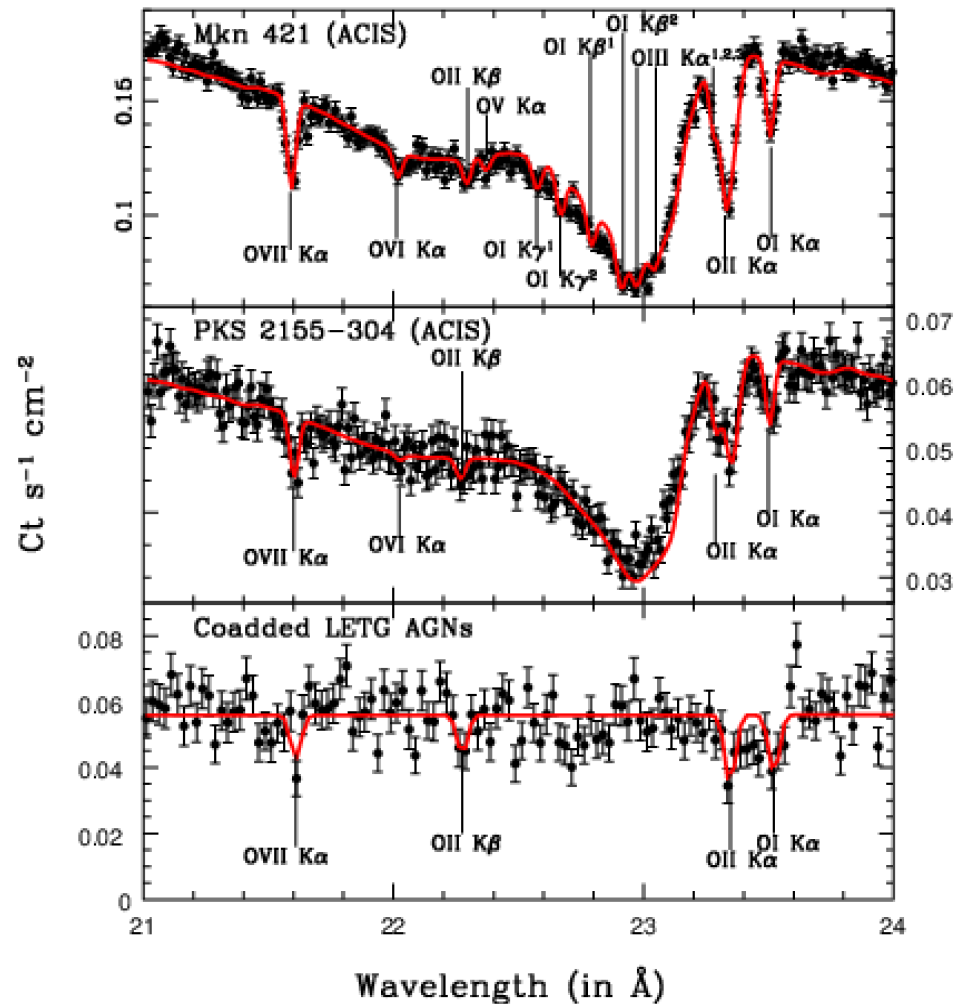


ATOMIC DATA WARNING!

O VII $K\alpha$ at $z \approx 0.03$ from WHIM
(Buote et al. 2009, Fang et al. 2010, Ren et al. 2014)

OR

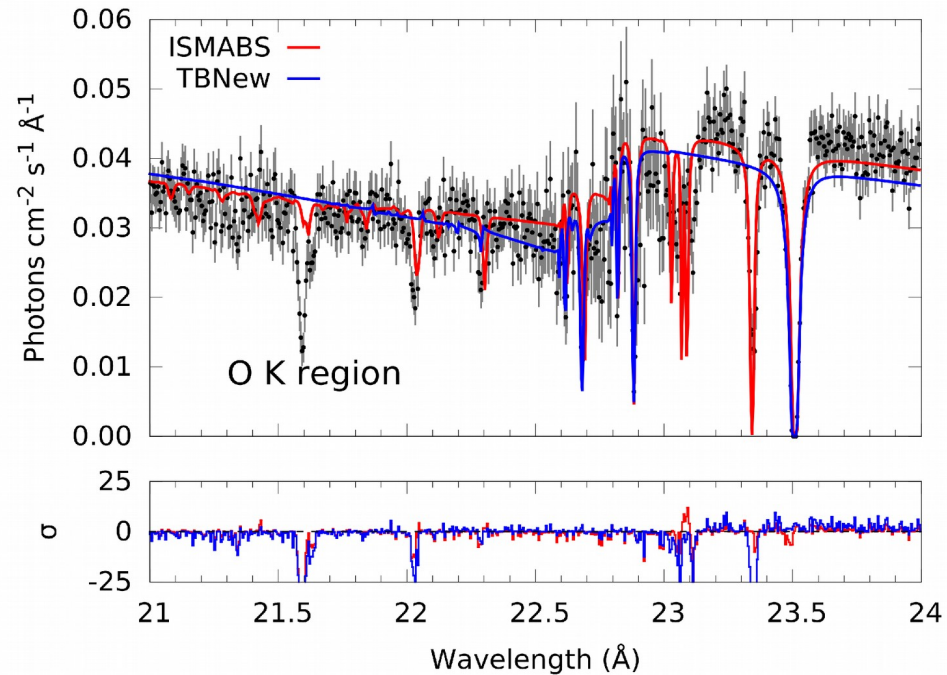
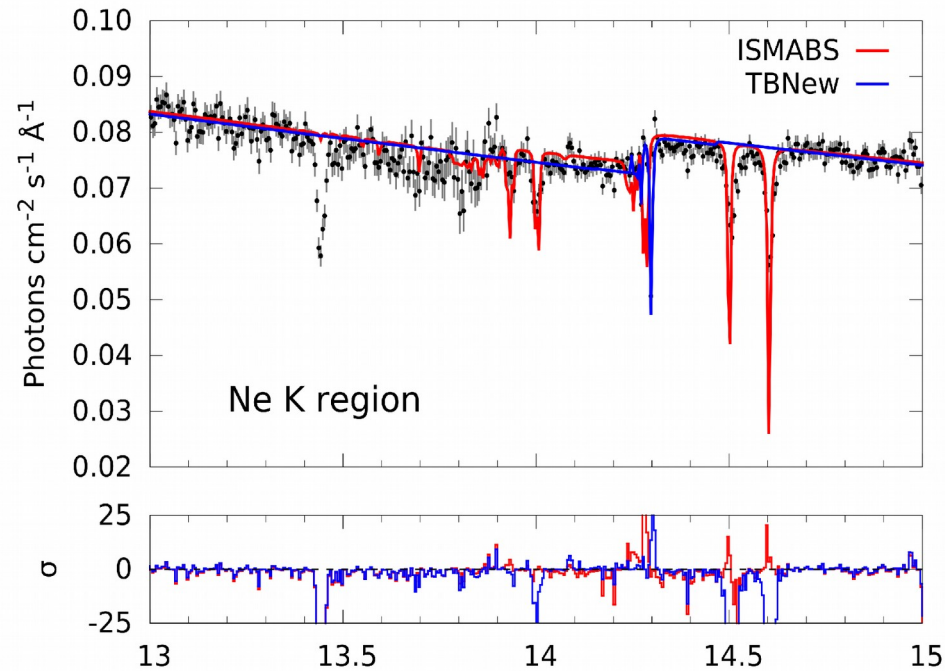
O II $K\beta$ at $z = 0$ from ISM
(Nicastro et al. 2016)



***ISMabs*: ISM X-ray absorption model**

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

$$\tau = \sum_i^k \sigma_i \cdot N_i$$



Ionization Equilibrium: *Ioneq*

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

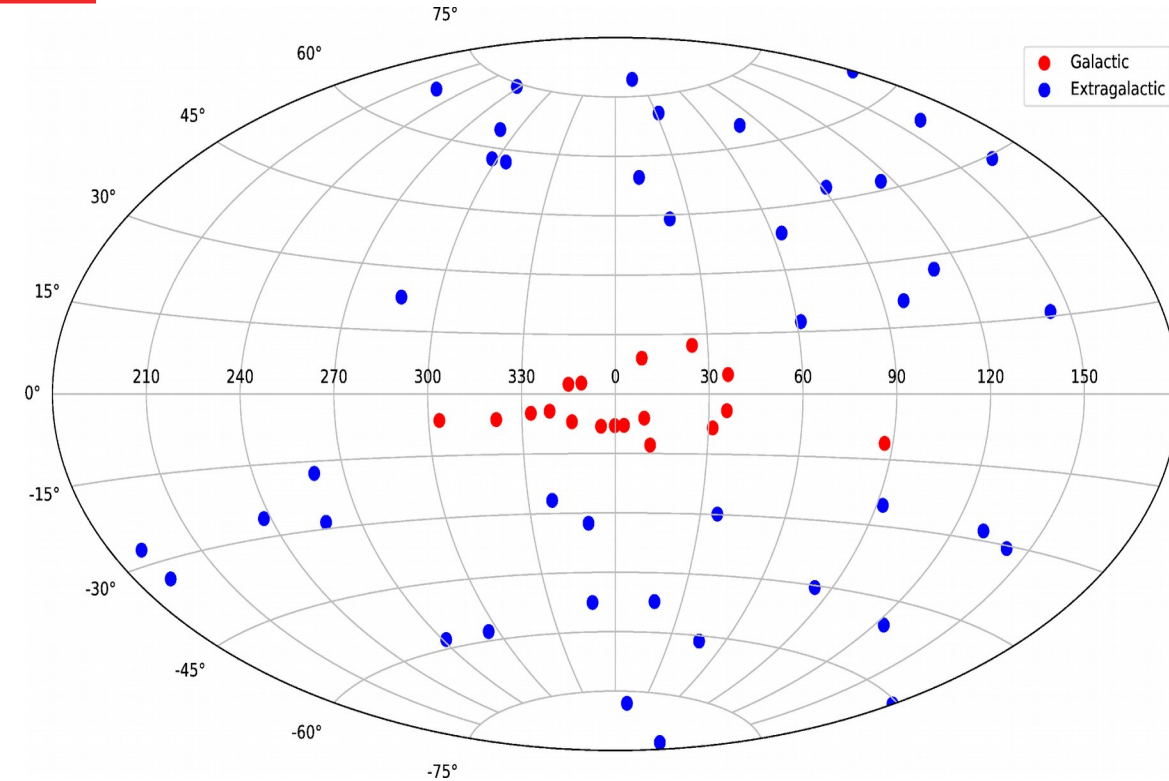
$$\tau = \sum_{k,j} \sigma_{k,j} \cdot N_h \cdot A_k \cdot n_{k,j}$$

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

MODEL PARAMETERS:

- Photoionization ([Verner et al. 1996](#)).
- Auger probabilities ([Kaastra & Mewe 1993](#)).
- Collisional ionization ([Voronov 1997](#))
- Radiative recombination ([Verner & Ferland 1996](#))
- Dielectronic recombination ([Arnaud & Rothenflug 1985](#))
- Temperature (T_e)
- Ionization parameter (ξ)
- Hydrogen column density (N_h)
- Redshift (z)
- Turbulent broadening (v_{turb})

DATA SAMPLE



Galactic Sources → LMXB
Extragalactic Sources → Blazars

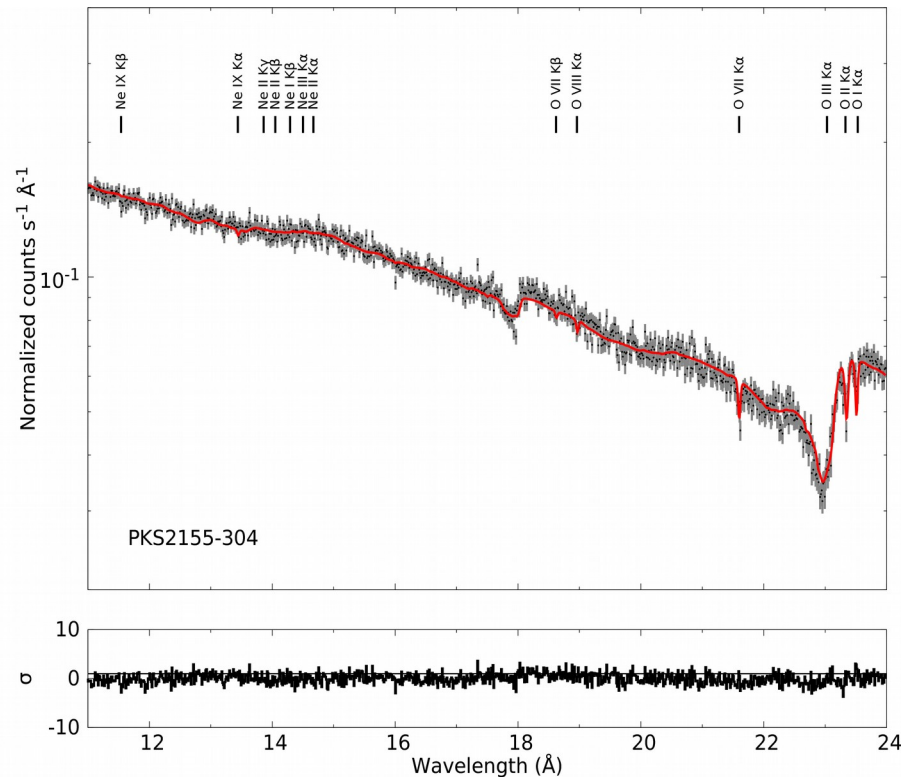
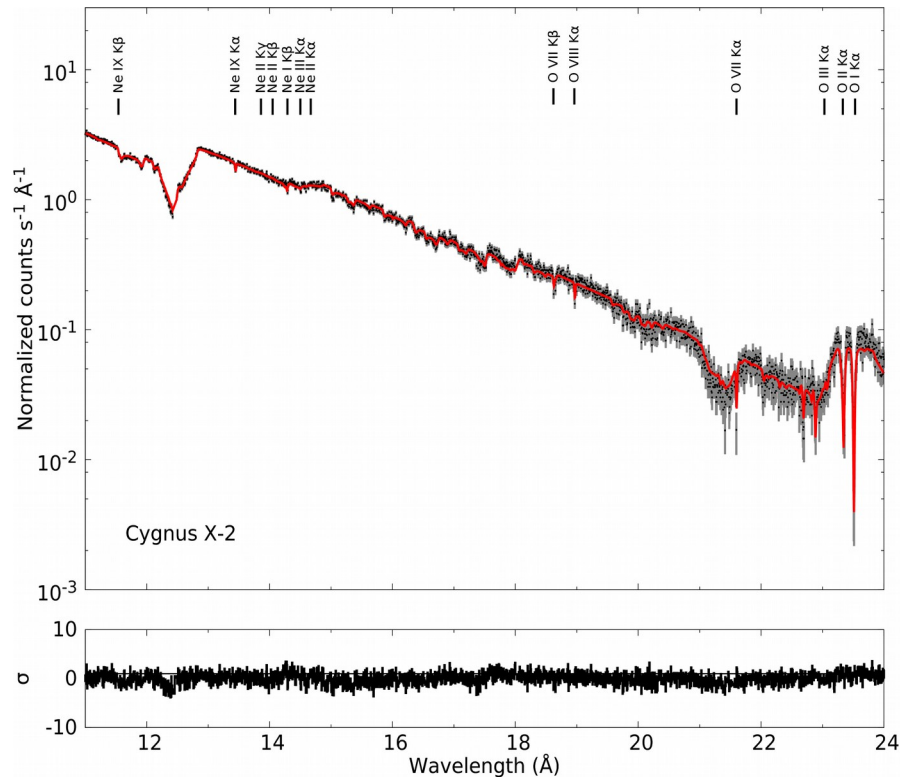
> 1000 counts in the 21-24 Å wavelength region

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

18 Galactic sources - 41 Extragalactic sources

165 observations from Chandra
257 observations from XMM-Newton

A detailed analysis of the ISM



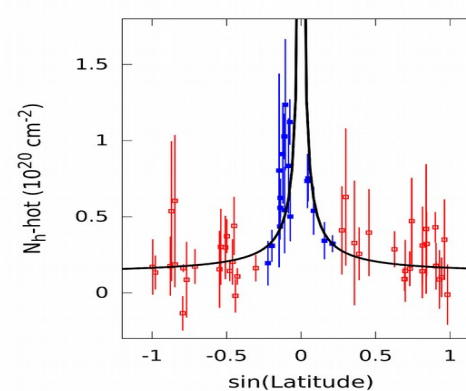
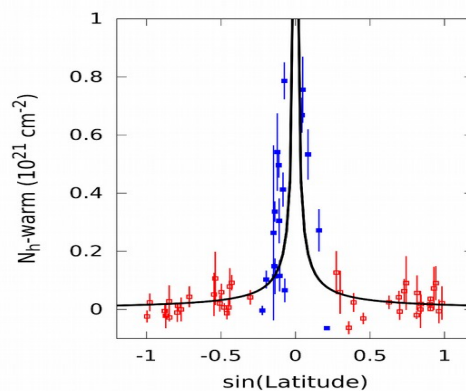
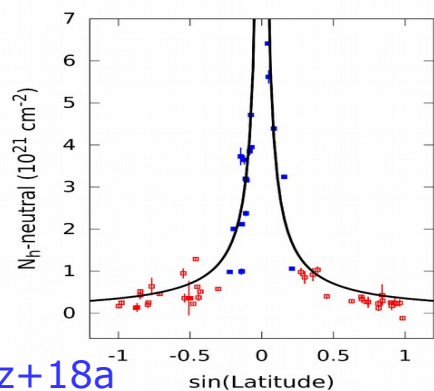
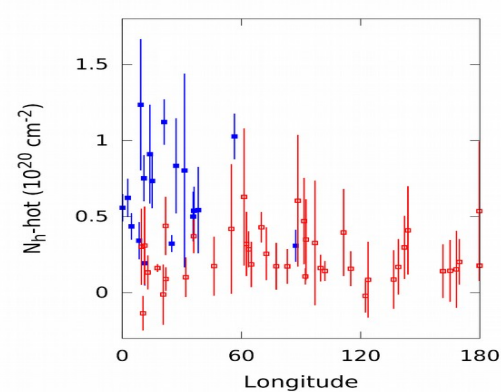
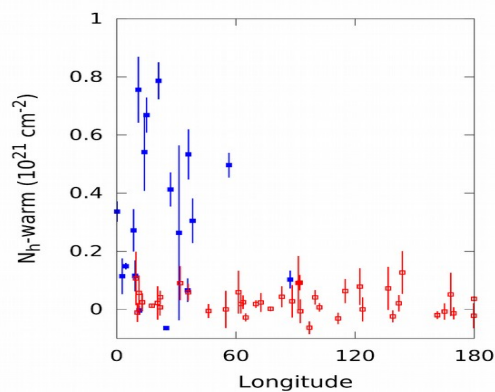
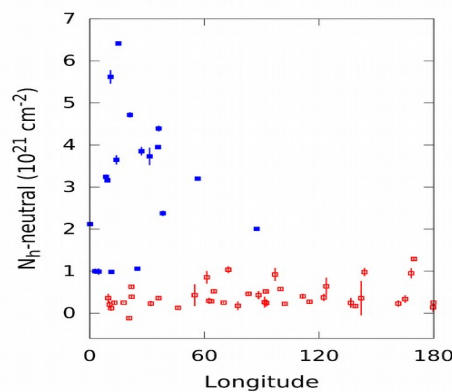
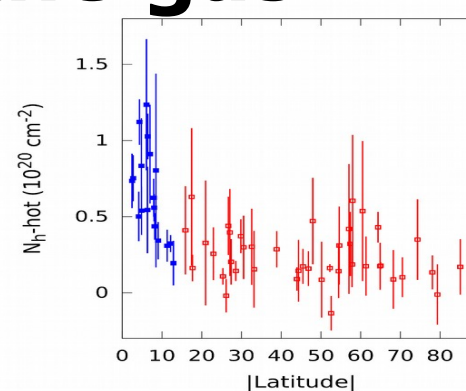
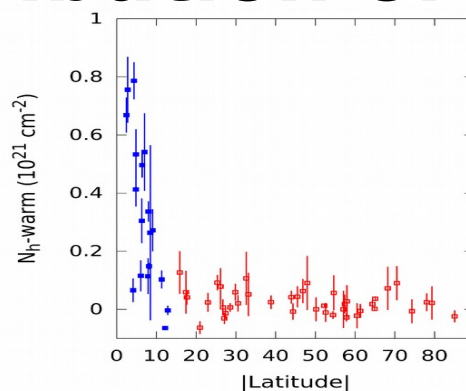
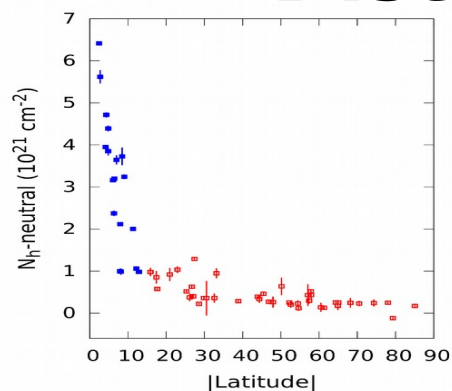
COLD COMPONENT ($T_e \sim 10000 \text{ K}$): O I, Ne I, Fe I, Metallic Fe

WARM COMPONENT ($T_e \sim 51000 \text{ K}$): O II, O III, Ne II, Ne III

HOT COMPONENT ($T_e \sim 1.9 \text{ MK}$): Ne IX, O VII, O VIII

¡COLLISIONAL IONIZATION EQUILIBRIUM!

Distribution of the gas



Distribution of the gas

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

COLD-WARM COMPONENTS ([Robin et al. 2003](#))

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

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

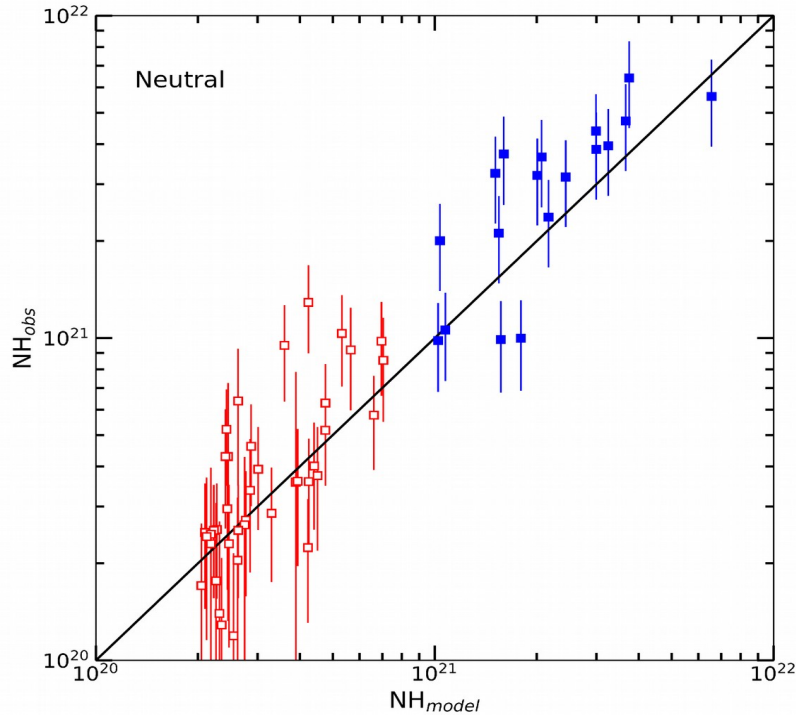
HOT COMPONENT ([Nicastro et al. 2016](#))

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

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

$$n_{\text{sph}}(r) = \frac{n_{0,\text{sph}}}{\left[1 + \left(\frac{r}{r_{c,\text{sph}}} \right)^2 \right]^{3\beta_{\text{sph}}/2}}$$

Density profiles

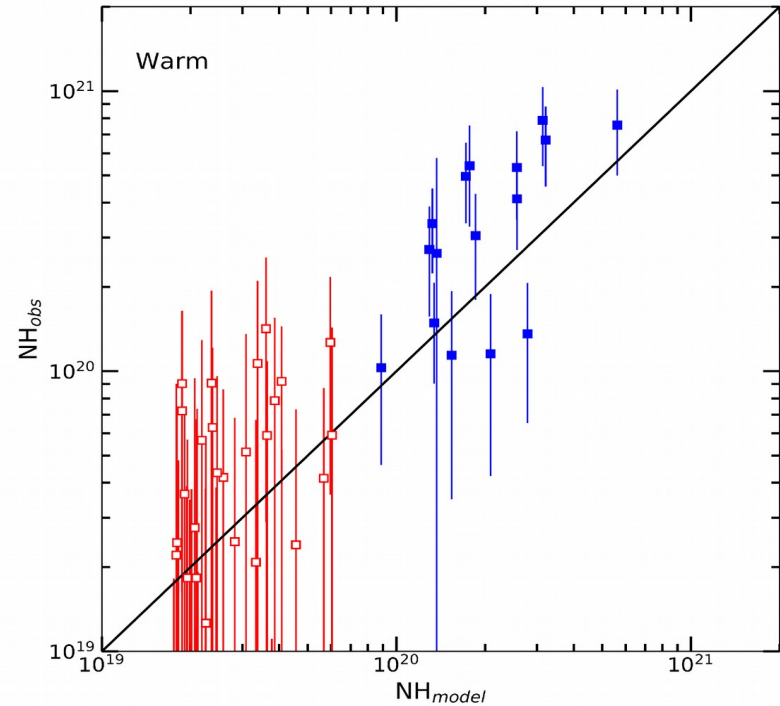


$$n_0 = (10.28 \pm 5.14) \text{ cm}^{-3}$$

$$R_c = (4.46 \pm 2.23) \text{ kpc}$$

$$z_c = (0.34 \pm 0.10) \text{ kpc}$$

$$\chi/d.o.f = 67.2/56$$



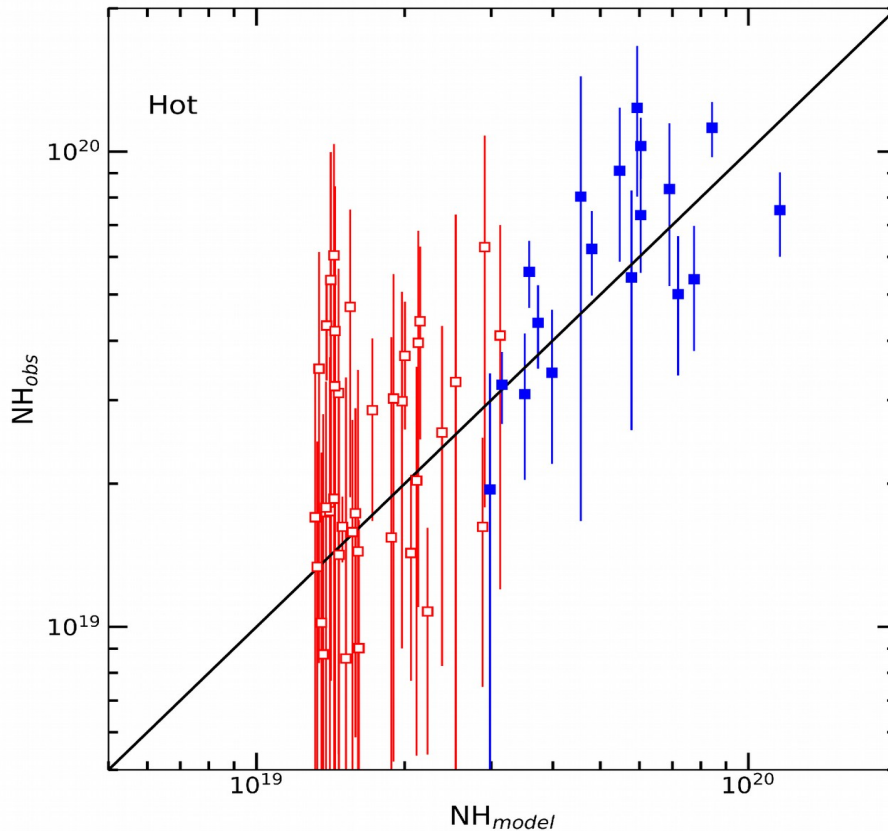
$$n_0 = (1.25 \pm 1.14) \text{ cm}^{-3}$$

$$R_c = (2.91 \pm 1.02) \text{ kpc}$$

$$z_c = (0.10 \pm 0.01) \text{ kpc}$$

$$\chi/d.o.f = 72.8/56$$

Density profiles



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

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

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

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

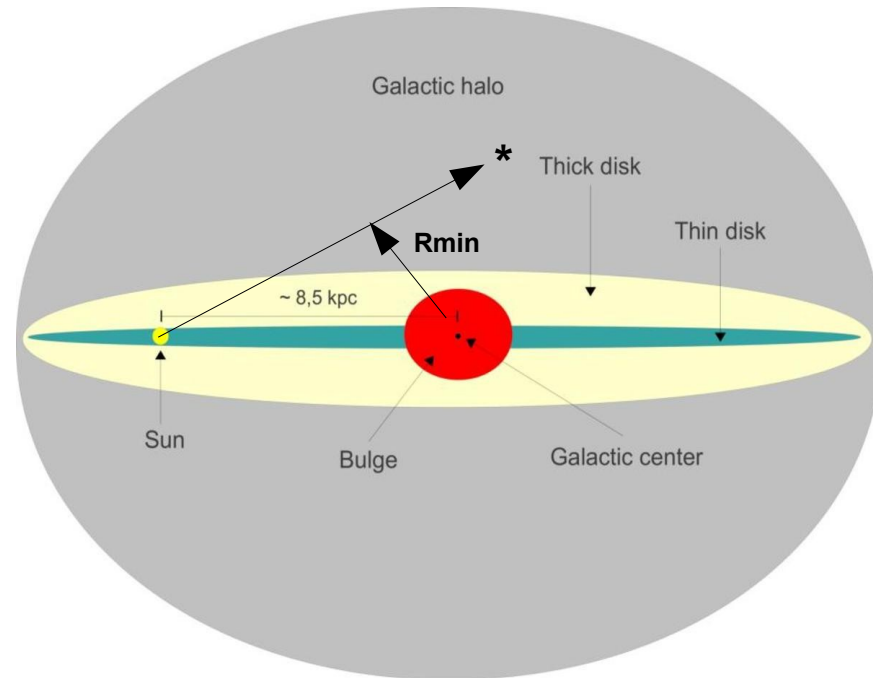
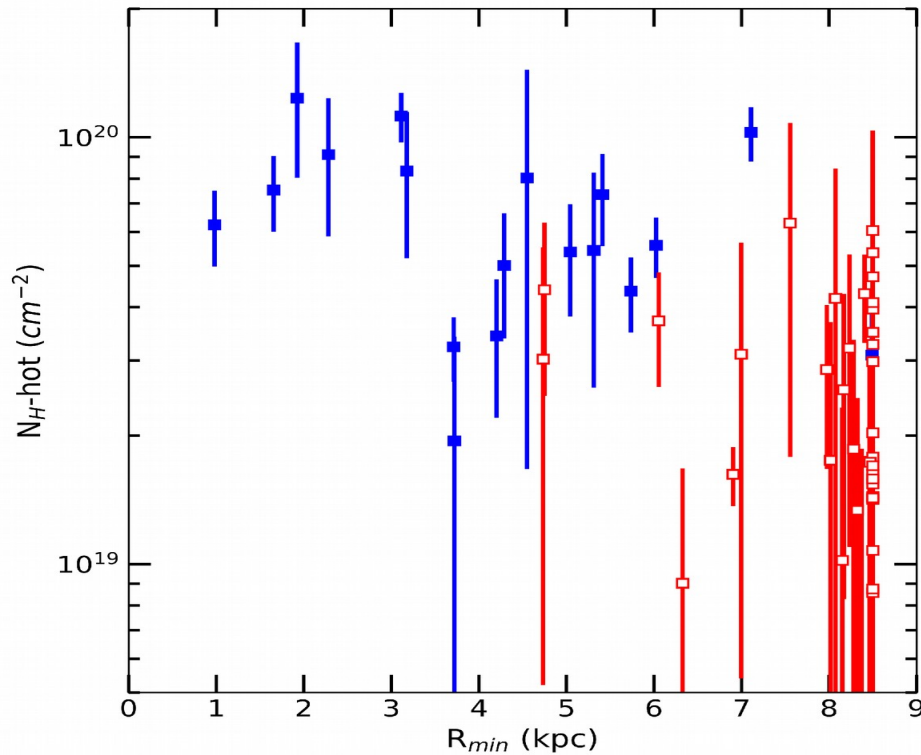
$$n_{0,sph} = (2.06 \pm 0.37) \times 10^{-2} \text{ cm}^{-3}$$

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

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

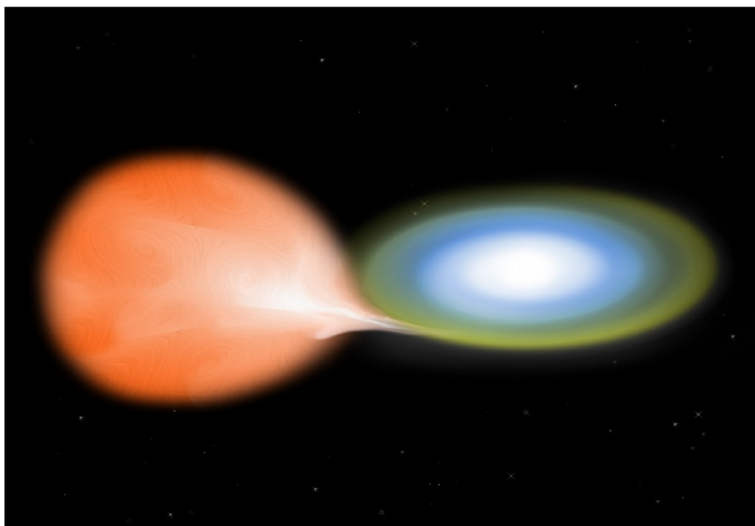
$$\chi/d.o.f = 78.6/54$$

Galactic center properties

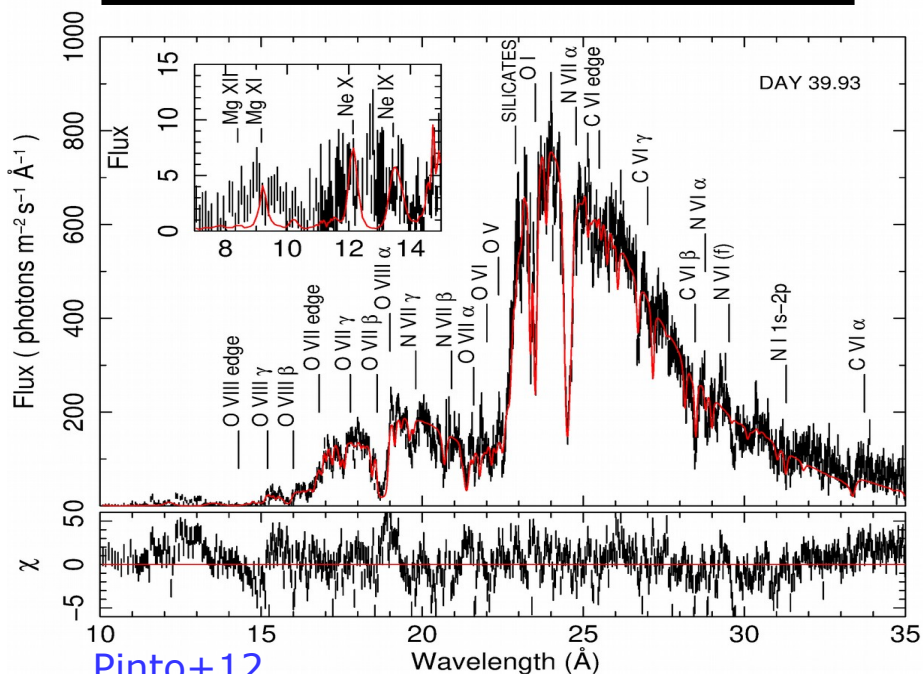
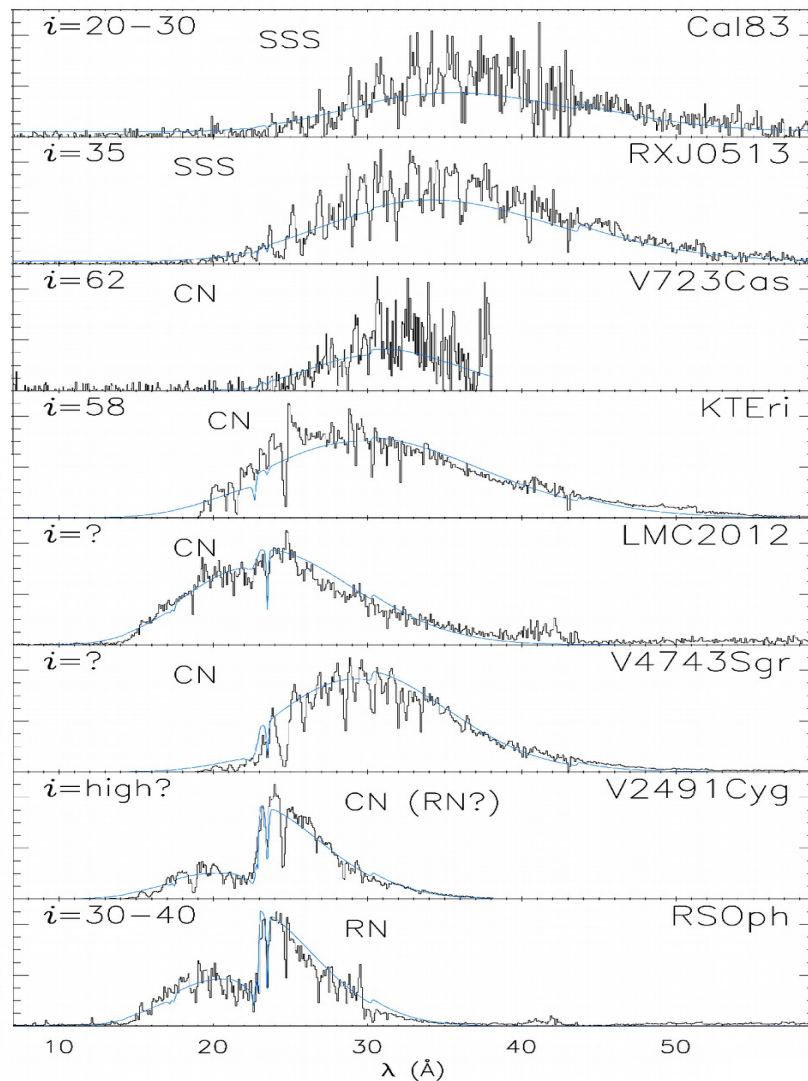


**WE DO NOT HAVE ENOUGH INFORMATION IN ORDER TO
CONSTRAIN THE GALACTIC CENTER PROPERTIES!**

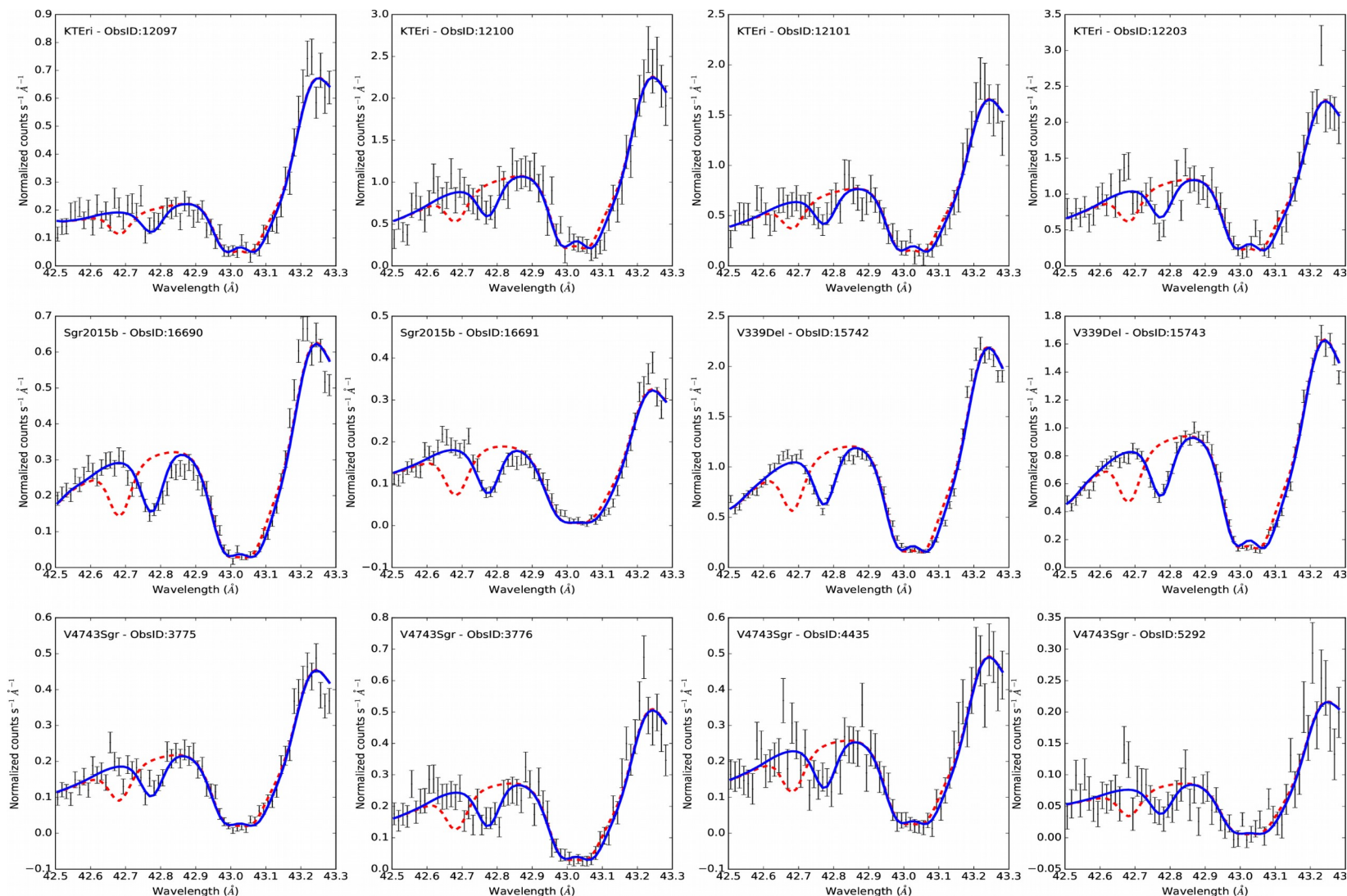
X-RAY NOVAE: ISM FINGERPRINTS



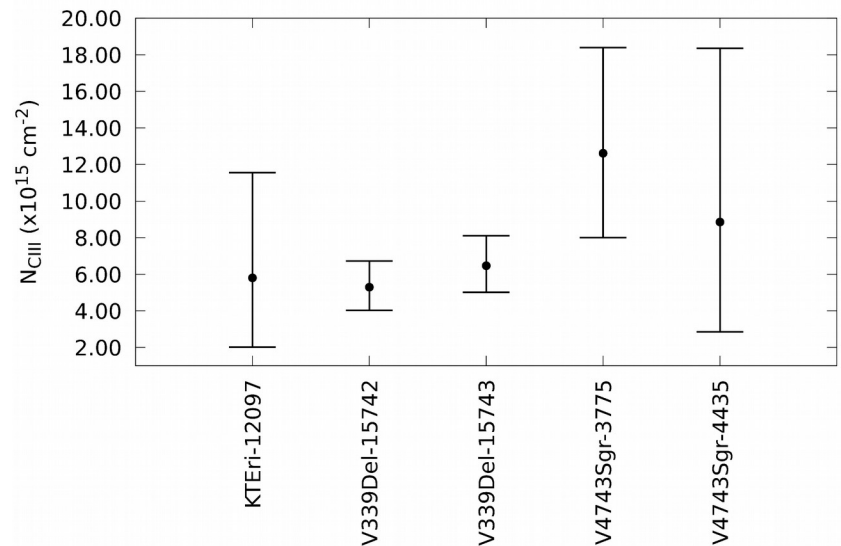
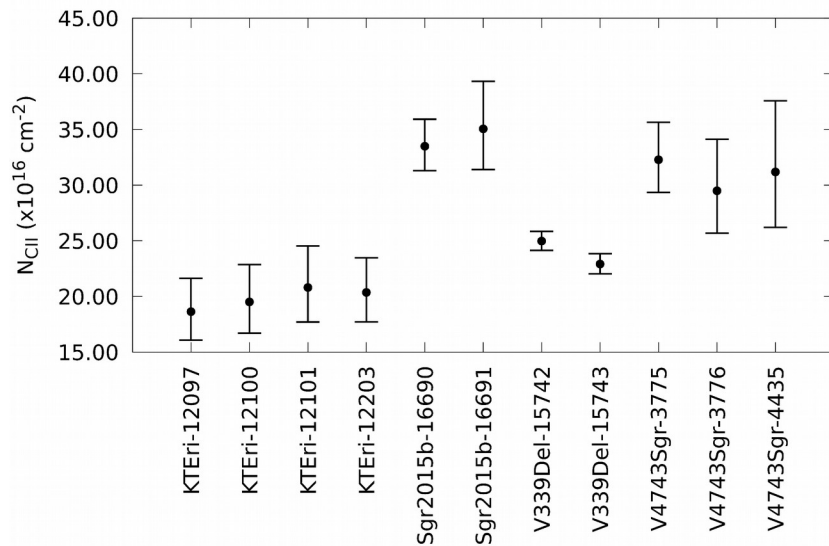
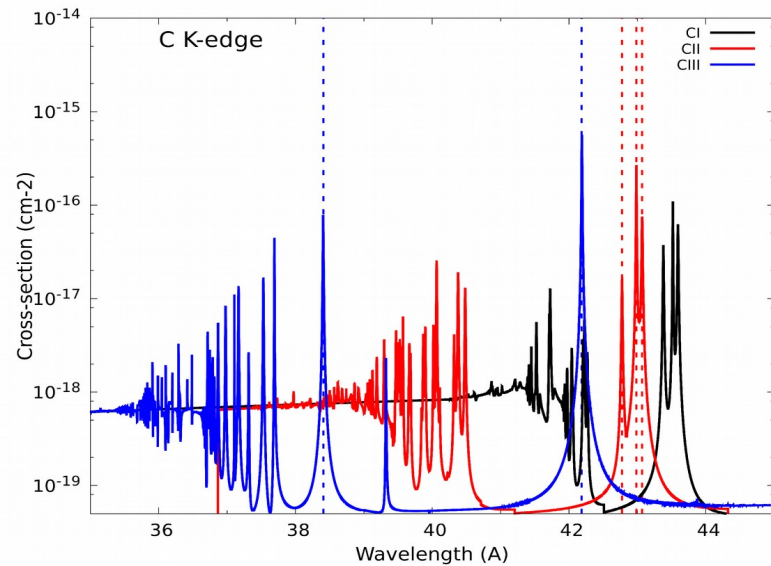
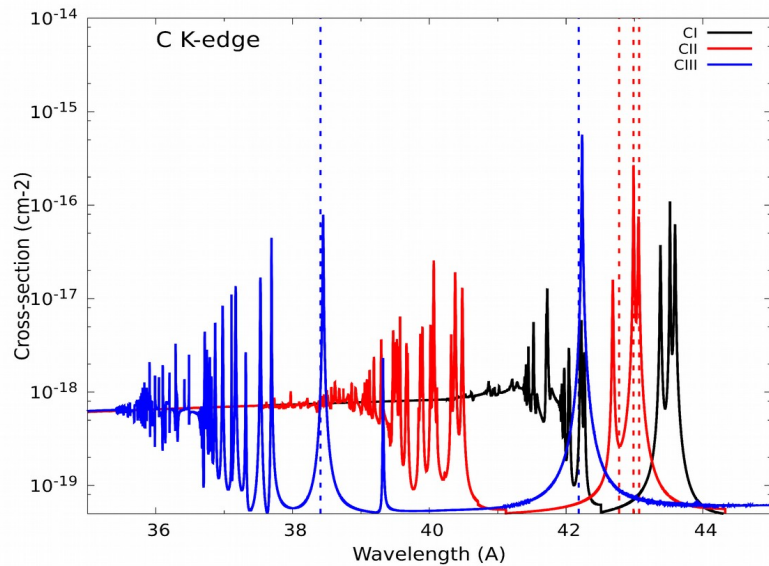
Ness+13



X-RAY NOVAE: ISM FINGERPRINTS



X-RAY NOVAE: ISM FINGERPRINTS



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

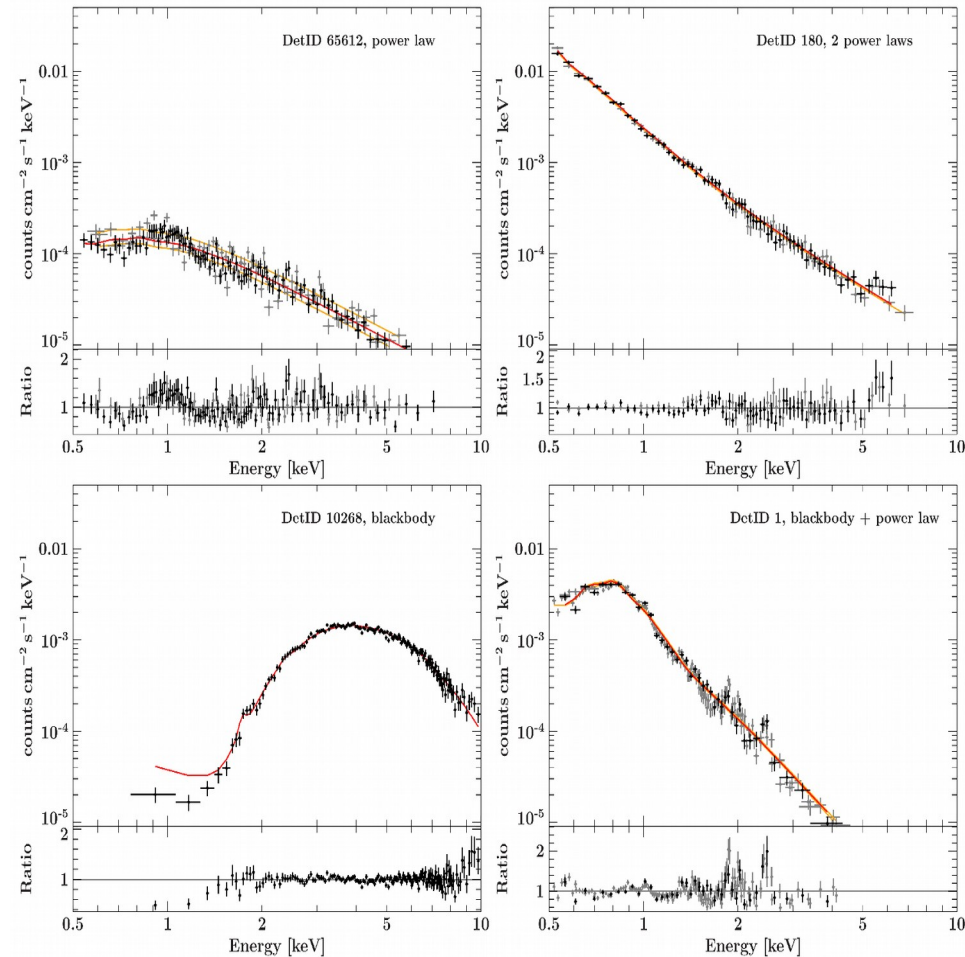
"Characterise as well as possible the variability of XMM sources in public archives, by providing tools and a catalogue to the community"

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



GAIA DATA RELEASE 1

→ GAIA DATA RELEASE 1

14

September 2016

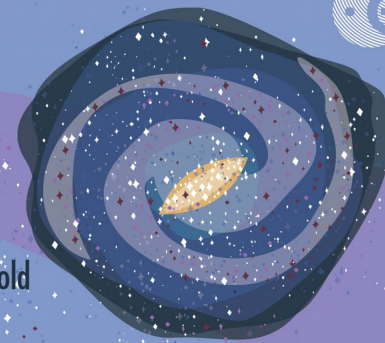
1000 days
since launch

1 spacecraft
2 telescopes
10 mirrors
1 camera
106 CCDs
937,782,000 pixels



1 Milky Way

>100,000,000,000 stars
~13,000,000,000 years old



~1,500,000 km from Earth

Content of the release

Total number of sources in primary astrometric data set:
2,057,050
with position, magnitude, parallax & proper motion

Total number of sources in secondary astrometric data set:
1,140,622,719
with position & magnitude

3194 Variable stars

- 599 Cepheids (43 new discoveries)
- 2595 RR Lyrae (343 new discoveries)



2152 Quasars

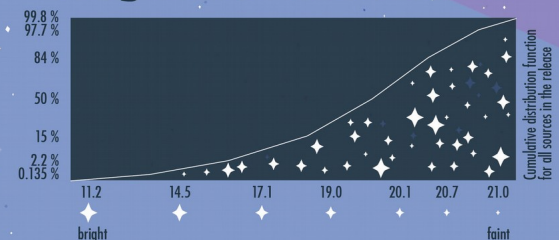
with position & magnitude

Data collected over 14 months

Data challenge so far

- >50 billion focal plane transits
- >110 billion photometric observations
- >9.4 billion spectroscopic observations
- ~120,000 hours of computing time to identify stars
- 6 data processing centres

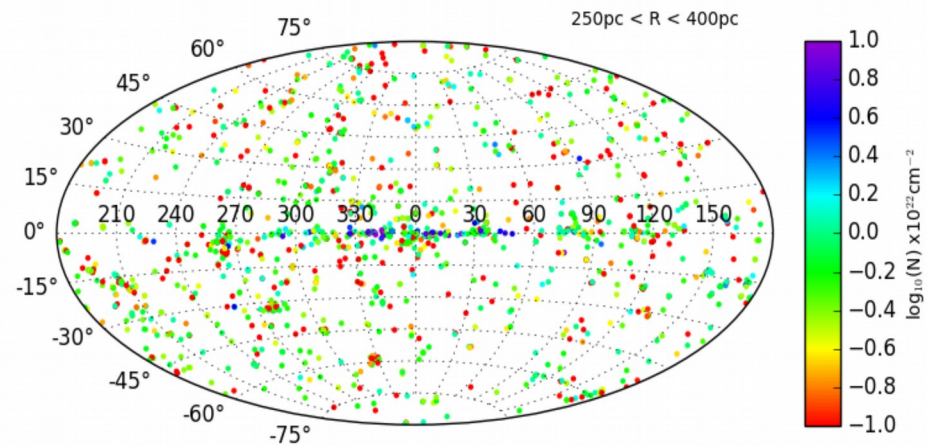
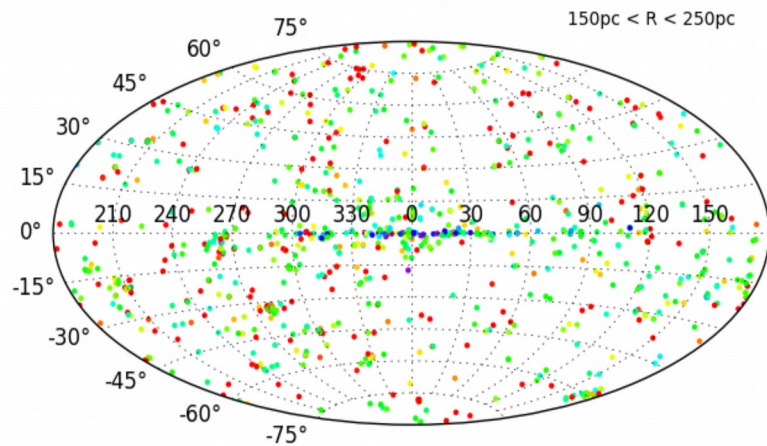
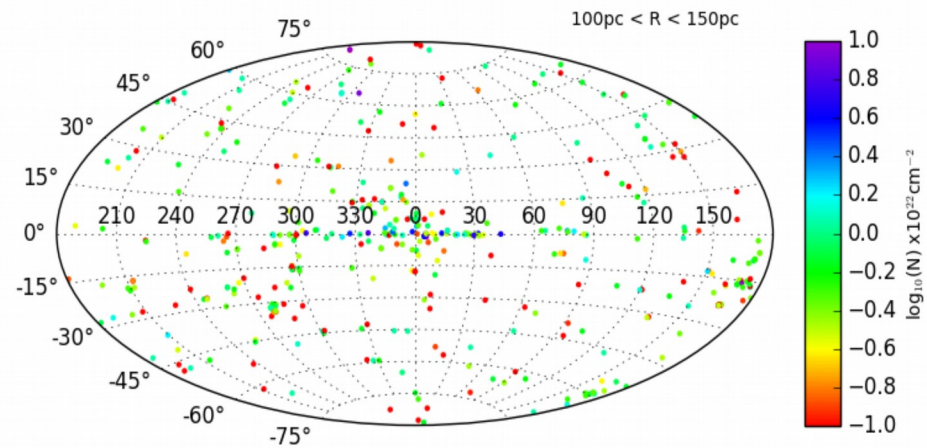
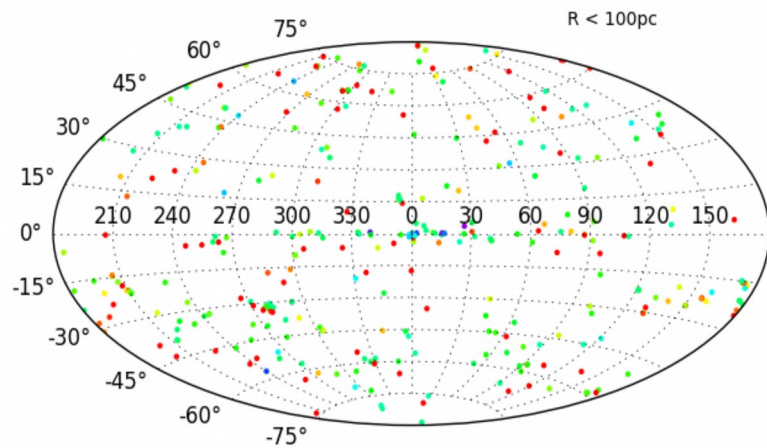
Magnitude distribution



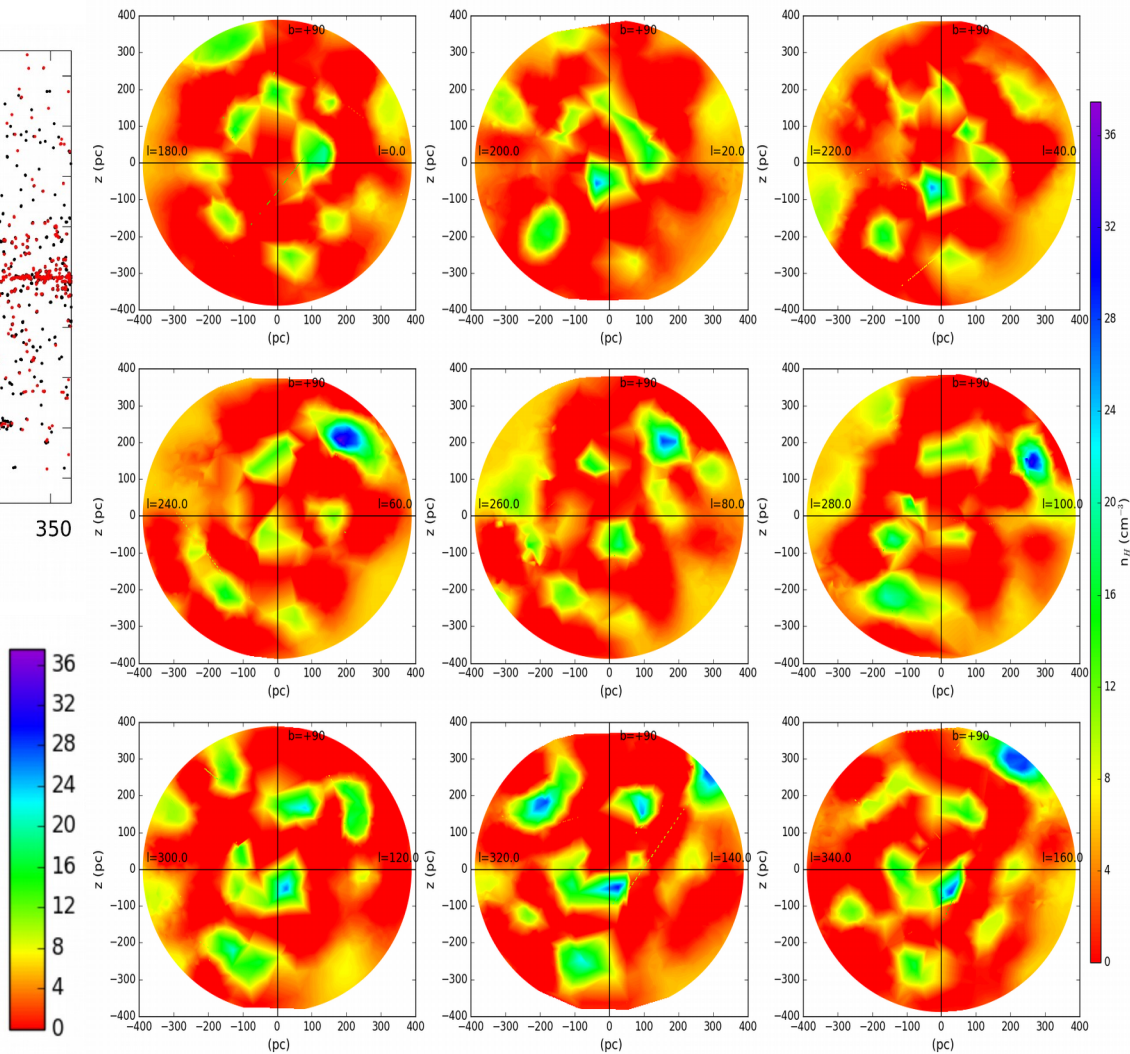
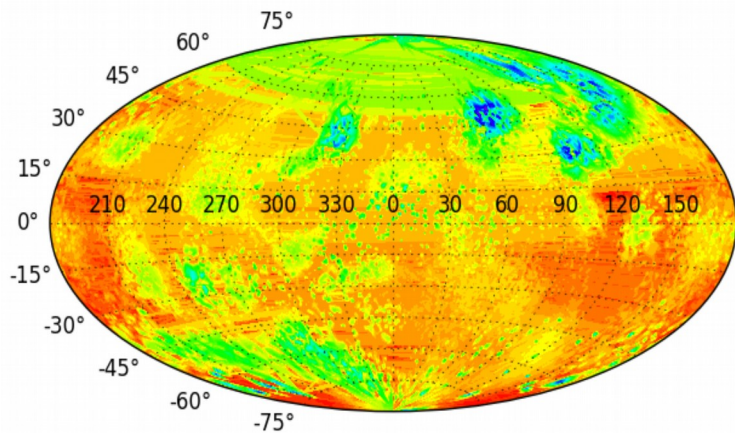
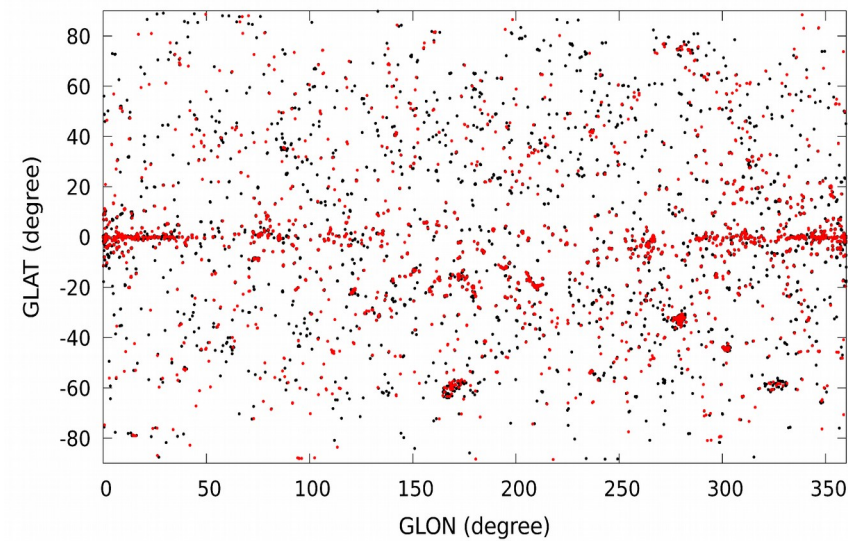
1 day on Gaia

637,000,000 astrometric measurements
155,000,000 photometric measurements
13,000,000 spectrometric measurements
70,000,000 celestial objects
40 GB of data downlinked to Earth

ISM 3D MAP



ISM 3D MAP



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!