The Soft X-ray Diffuse Background and Hot Gas in and around the Galaxy

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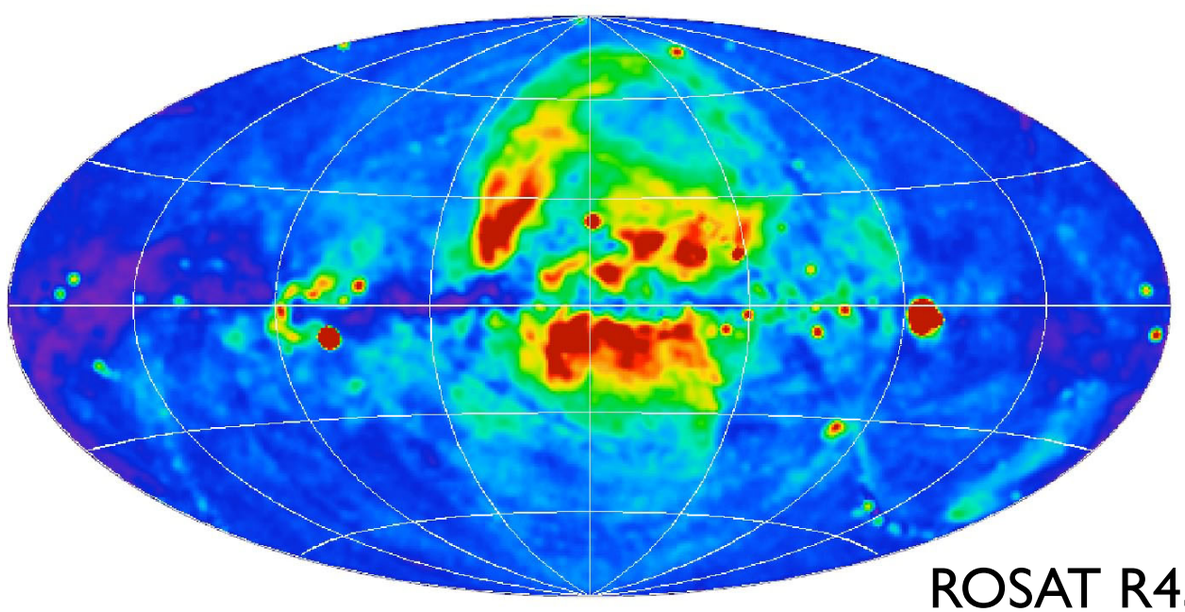
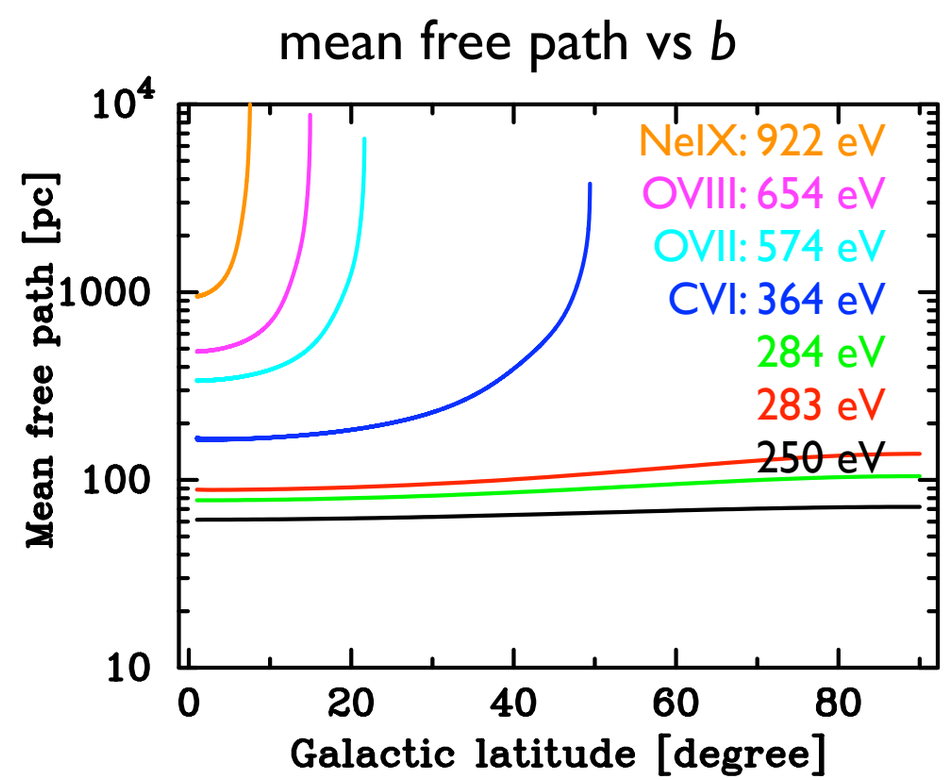
Yoshino et al. 2009, PASJ, 61, 805-823
Yao et al. 2009, ApJ. 690, 143-153
Hagihara et al. 2010, PASJ, in press

Hot ISM

- An important building block of chemical evolution and feedback in galaxies.
- Strong foreground emission; a big obstacle for the study of diffuse extragalactic soft X-ray emission, e.g. WHIM emission.



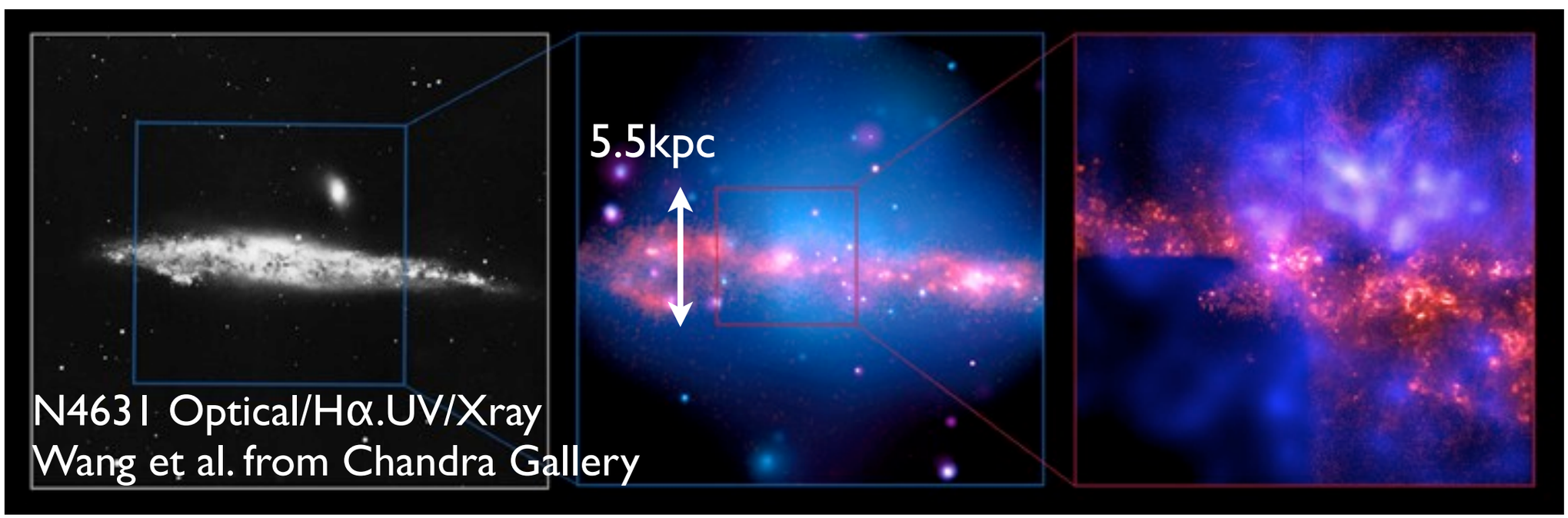
ROSAT R45 band
Snowden+(1997)



Objectives of this talk

To try to answer from *Suzaku* observations & combined analysis of *Suzaku* and *Chandra*

- What are the origins of the soft X-ray (0.5-1keV) diffuse background ?
- Is there hot halo associated with our Galaxy, like other spirals ?
  - If there is, what are the physical status (temperature, density) of the gas?

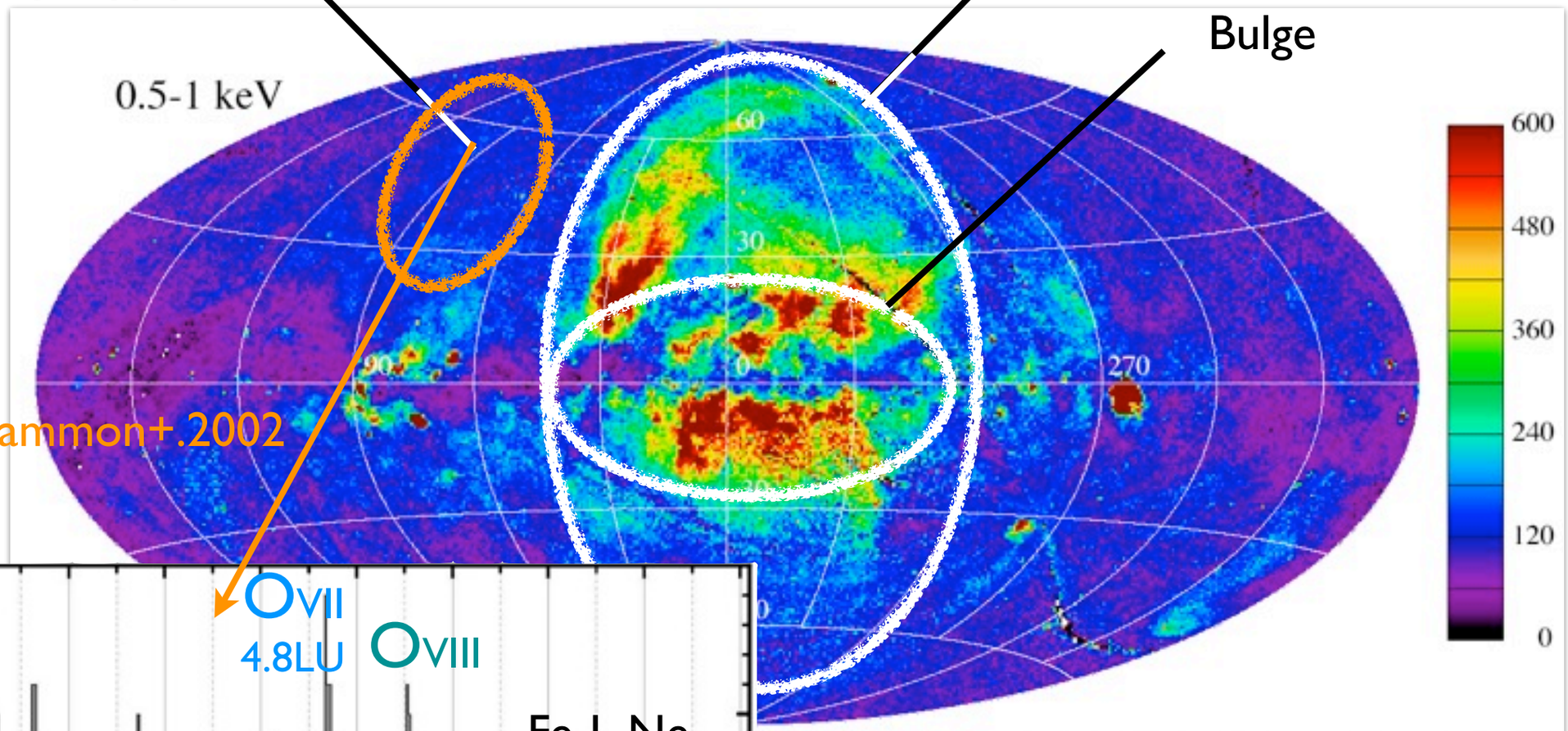


Soft X-ray Sky (0.5-1keV)

nearly uniform high latitude emission

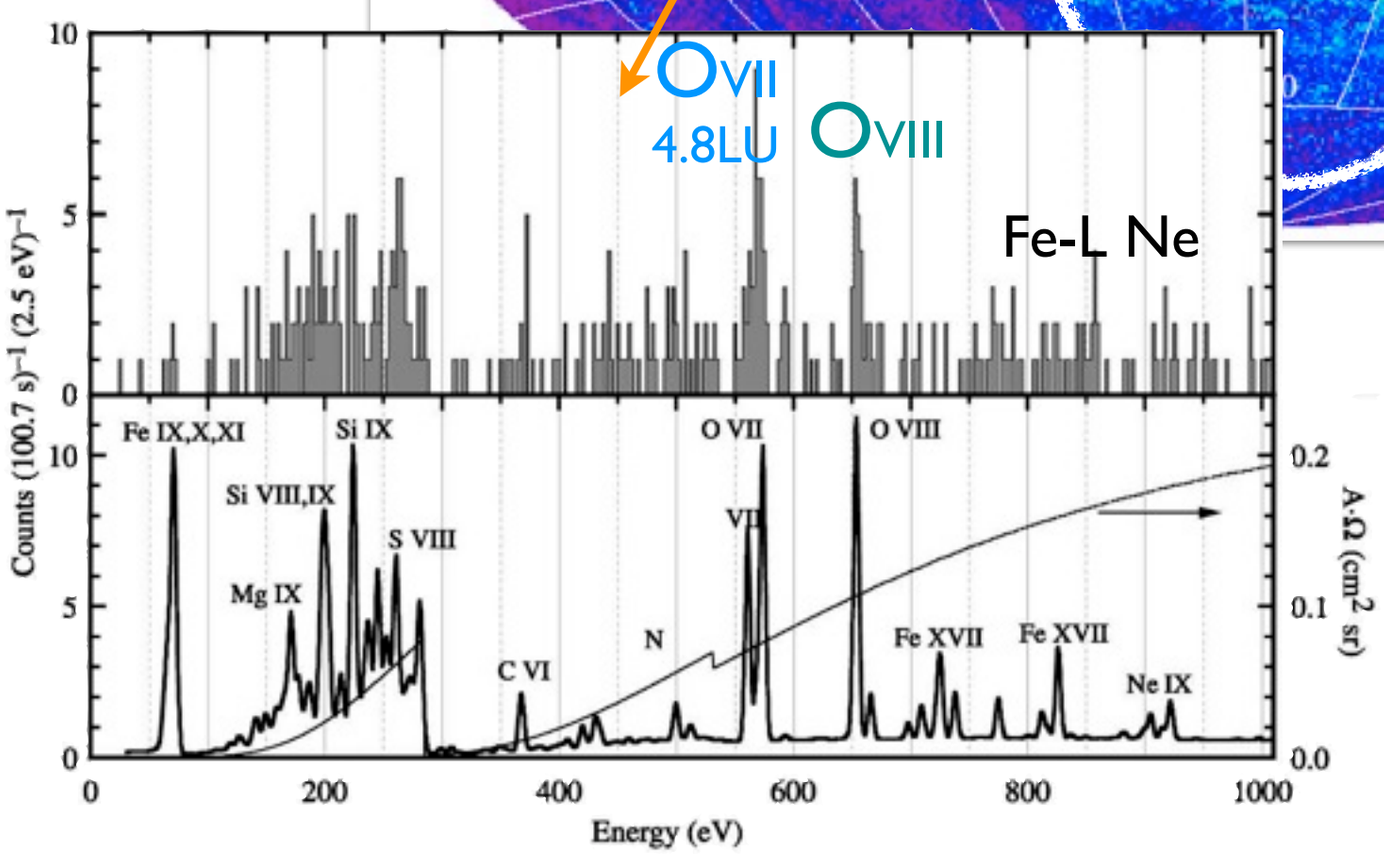
Loop I (NPS)

Bulge



ROSAT R45 band (≈ 0.5-1 keV)
Snowden+(1997)

XQC McCammon+.2002



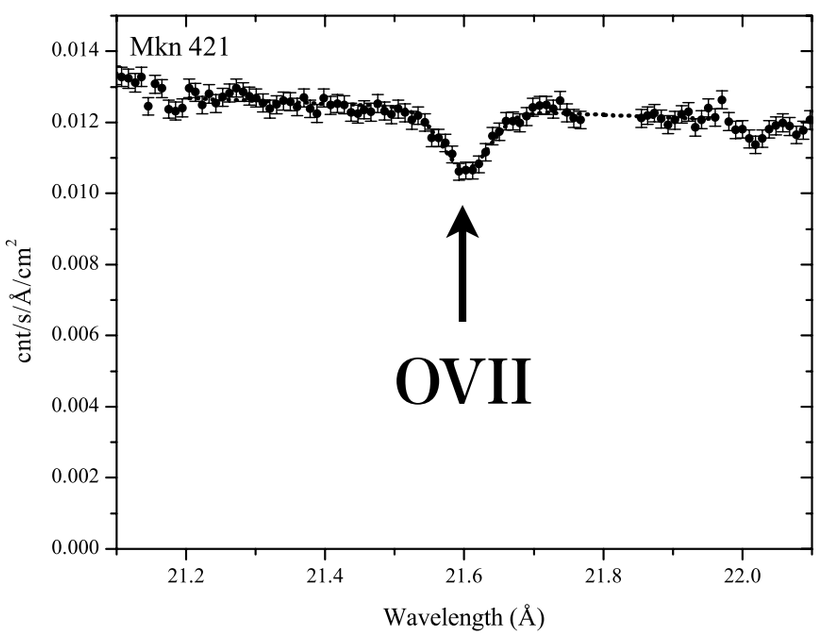
Line emission from highly-ionized ions dominates (~60%) the SXDB in 0.5-1keV

Shadow of the hot ISM

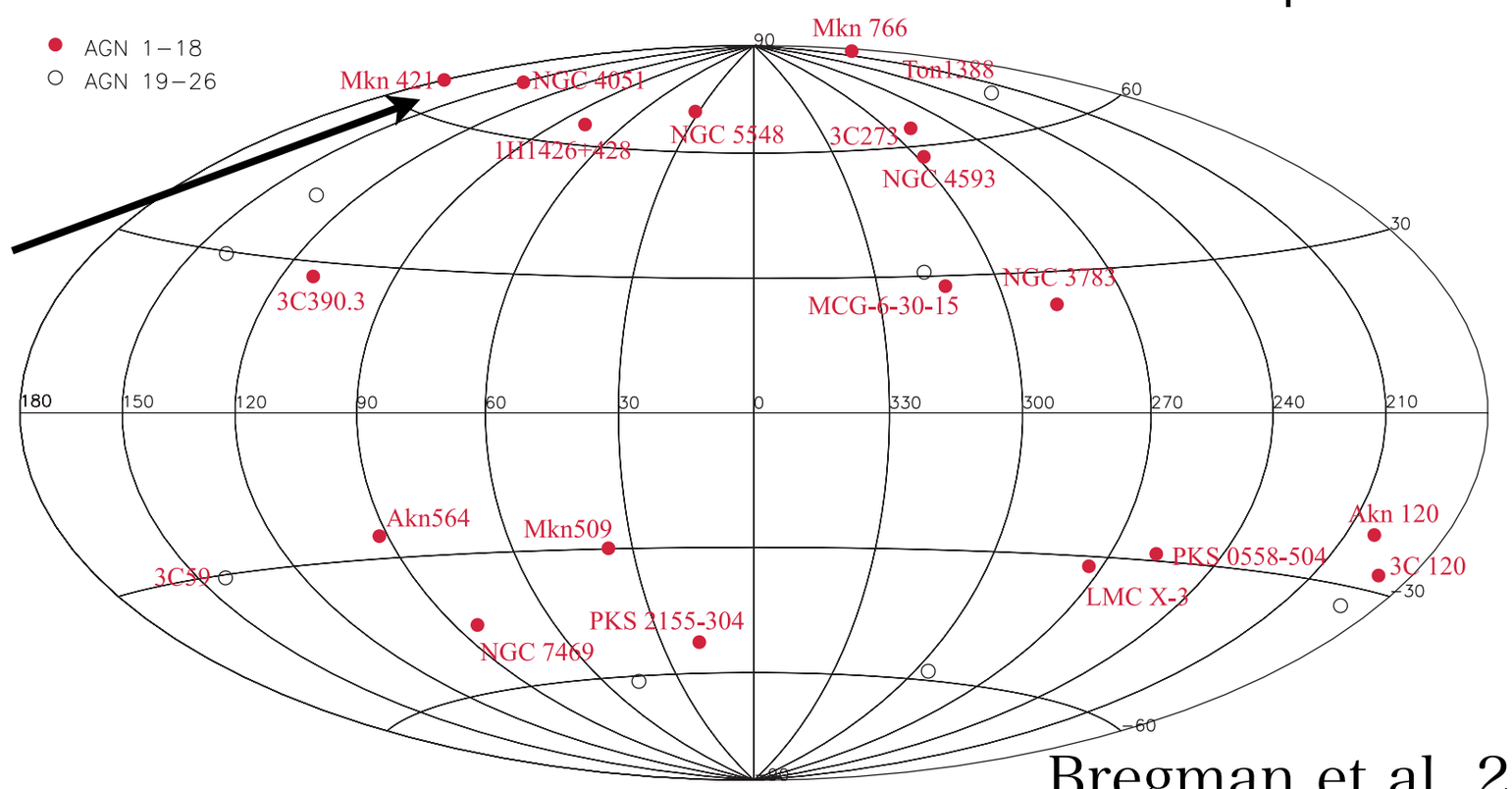
Several AGN exhibit highly ionized O (and Ne) absorption lines at z=0 (e.g. Bregman+ 2007, Fang+ 2006)

- Typical column density ~ 10^{16} (cm^{-2}), or NH of 10^{19} (cm^{-2}) with Solar abundances

Galactic sources also show highly ionized O and Ne absorption lines (e.g. Futamoto+ 2004, Yao and Wang 2005)

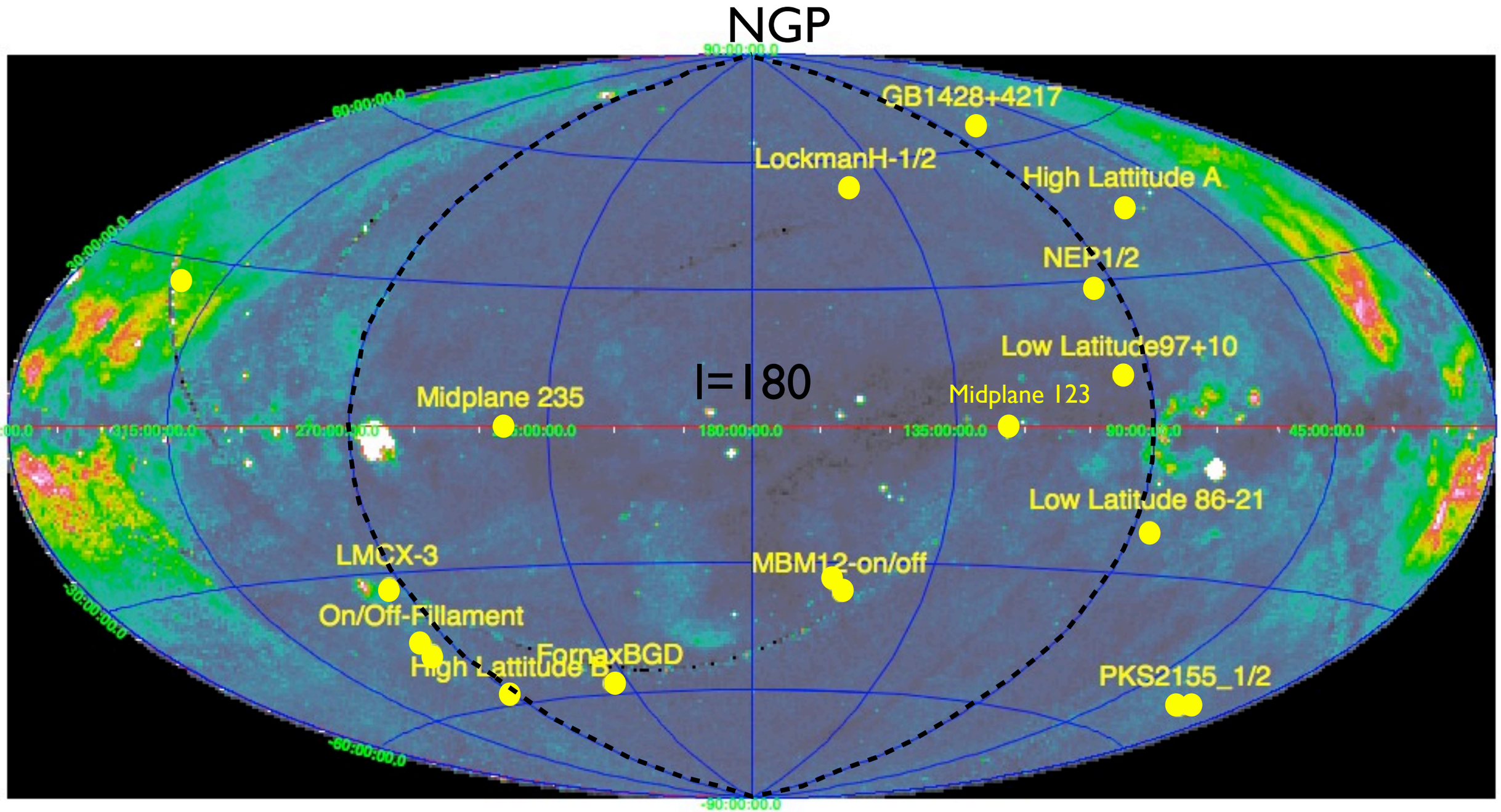


AGN with absorption structure ●



Bregman et al. 2007

Suzaku Observations of bland fields

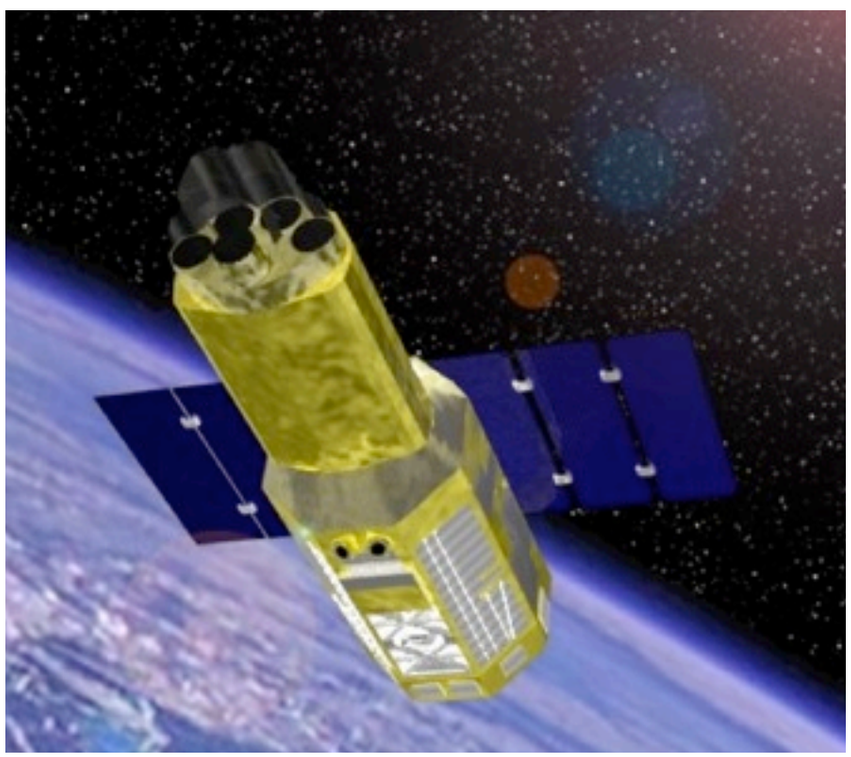


16 pointing observations of 15 fields,
well outside the local structures

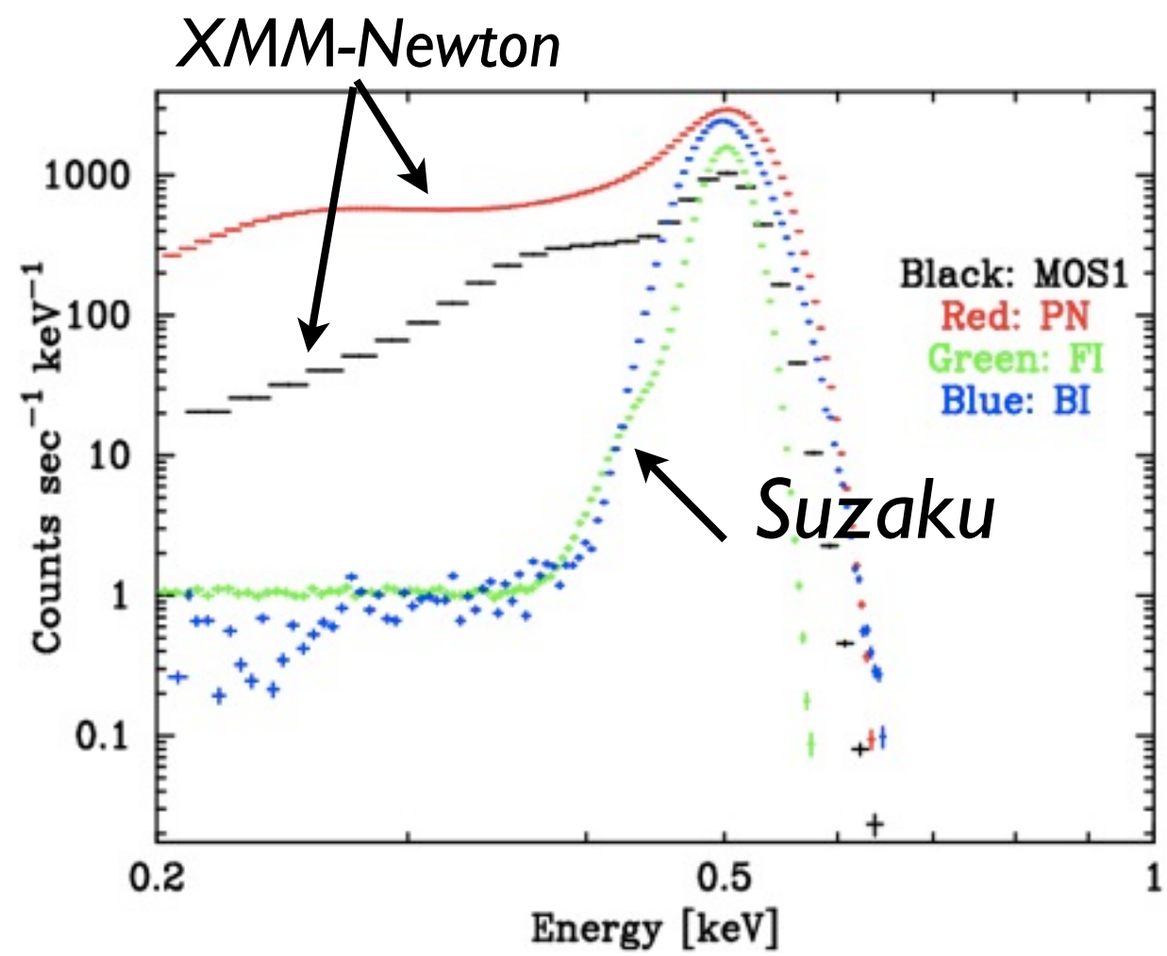
For detailed analysis, see Yoshino+ 2009, PASJ, 61, 805

Why *Suzaku*?

- Good energy resolution, in particular < 1 keV, to separate emission lines from different ion species
- Low particle background = high sensitivity

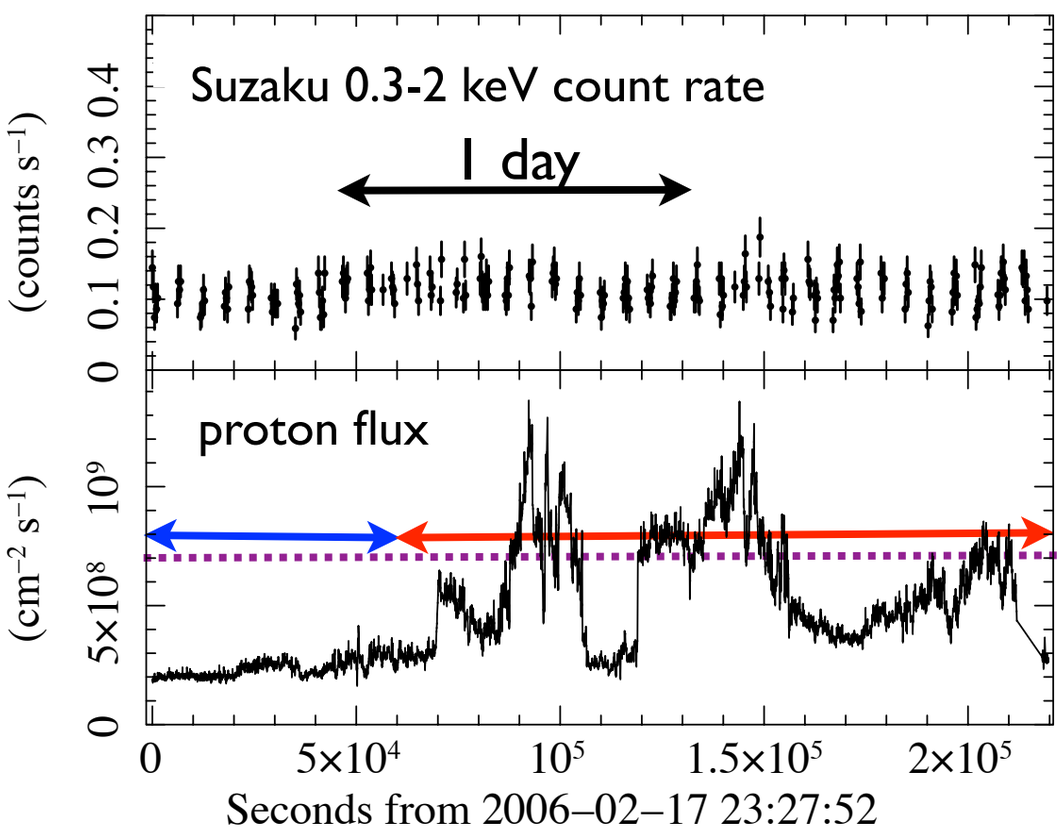


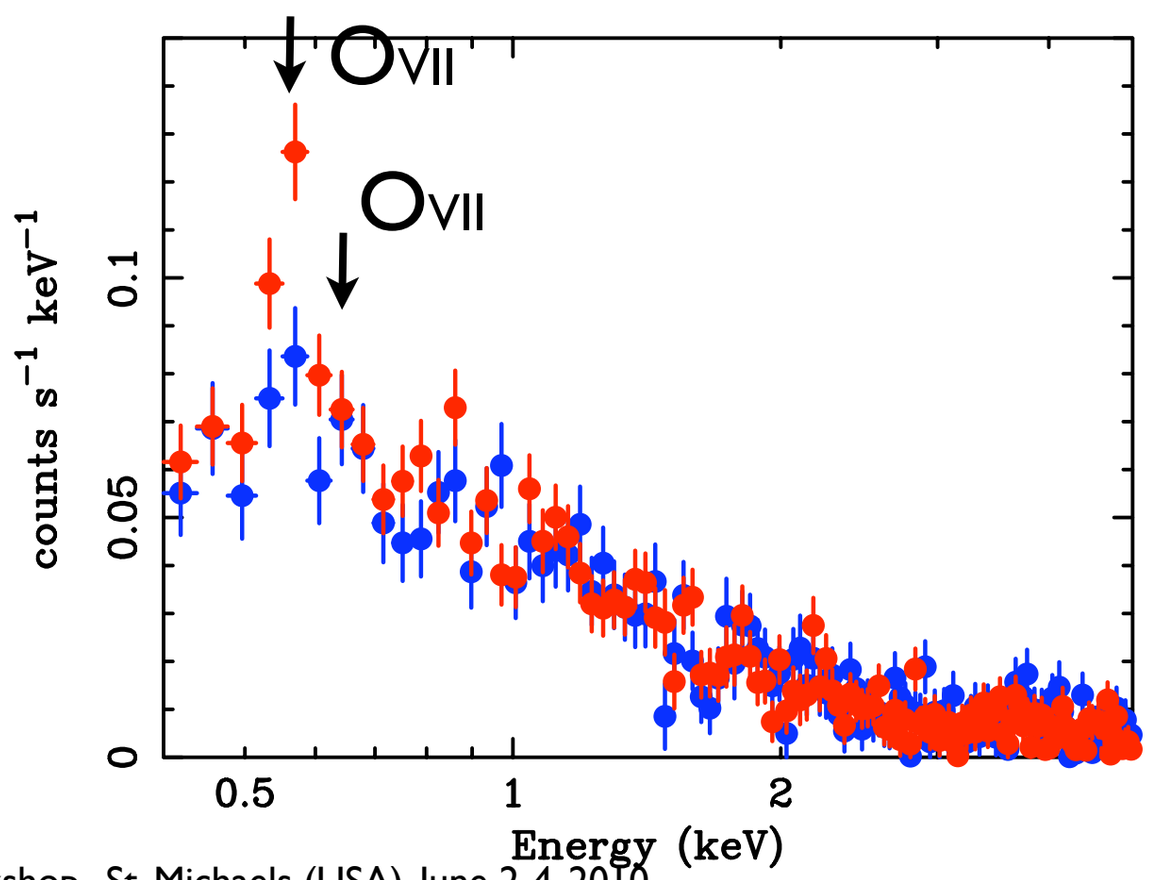
Energy spread function for 0.5 keV photons.



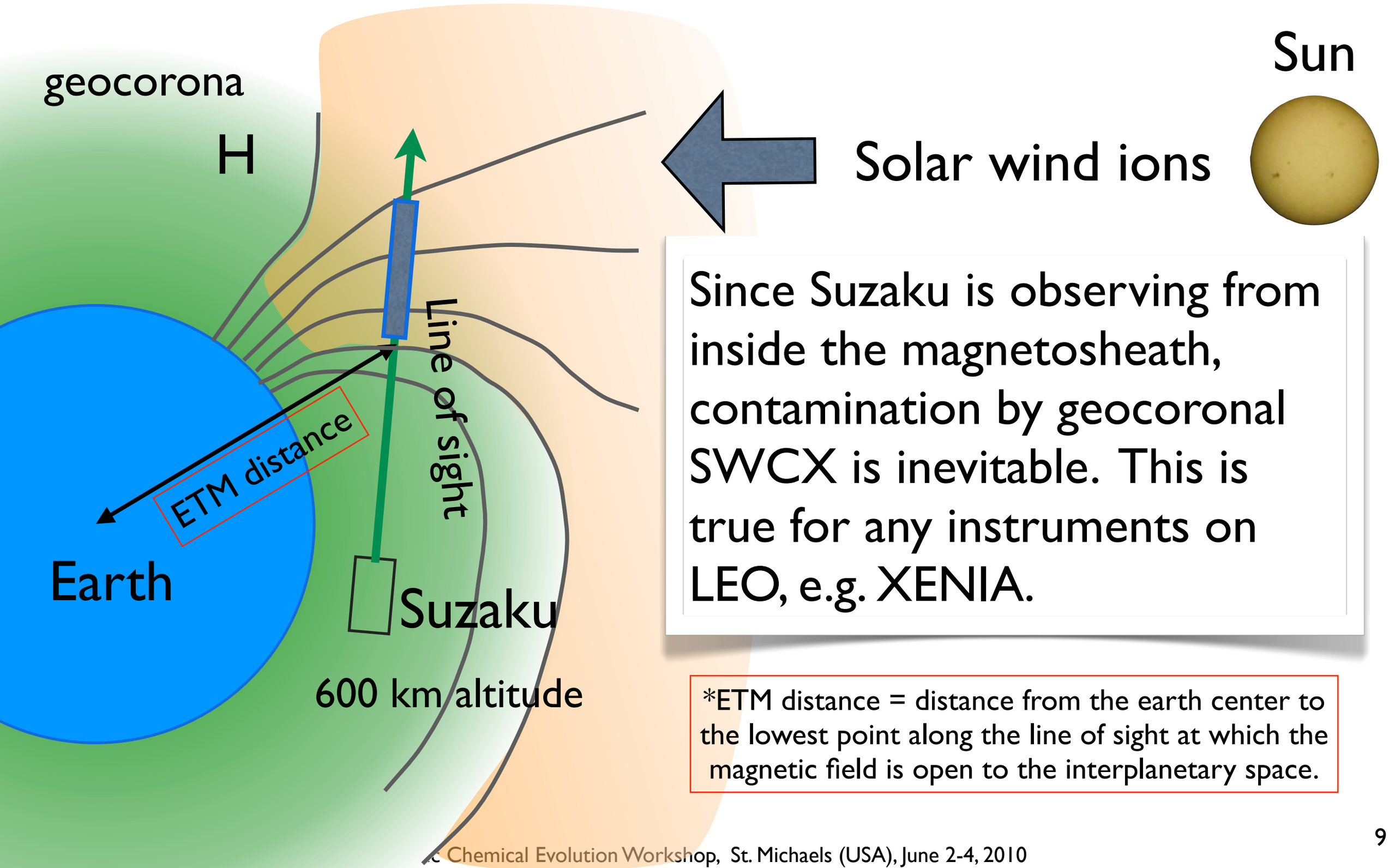
Note on analysis: Short-term (<1d) variations of SXDB

- Significant (>2σ) time variations were observed in OVII and/or OVIII emission intensities of 5 fields among the 15 fields analyzed by Yoshino +2009.
- Time variable emission is from the Earth vicinity, most likely by charge-exchange interaction of solar wind ions and H in geocorona (geocoronal SWCX).
- We removed time intervals with high emission intensity.
  - Intensity of variable emission depends on (1) solar wind flux, (2) ETM (Earth to Magnetopause) distance, (2) whether magnetic field is open to sun or anti-sun side.





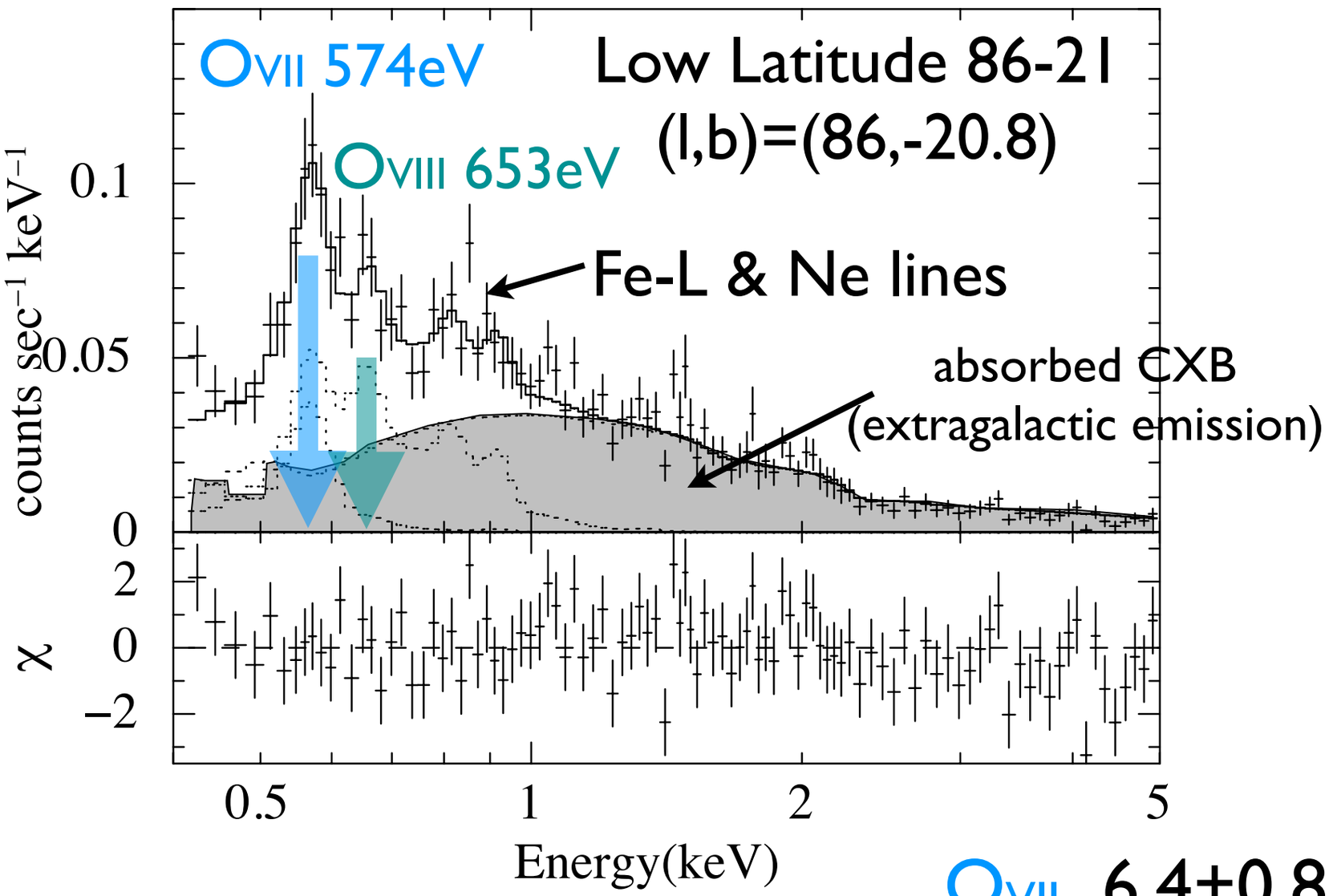
Geocoronal SWCX



Since Suzaku is observing from inside the magnetosheath, contamination by geocoronal SWCX is inevitable. This is true for any instruments on LEO, e.g. XENIA.

*ETM distance = distance from the earth center to the lowest point along the line of sight at which the magnetic field is open to the interplanetary space.

A Sample Spectrum with Suzaku

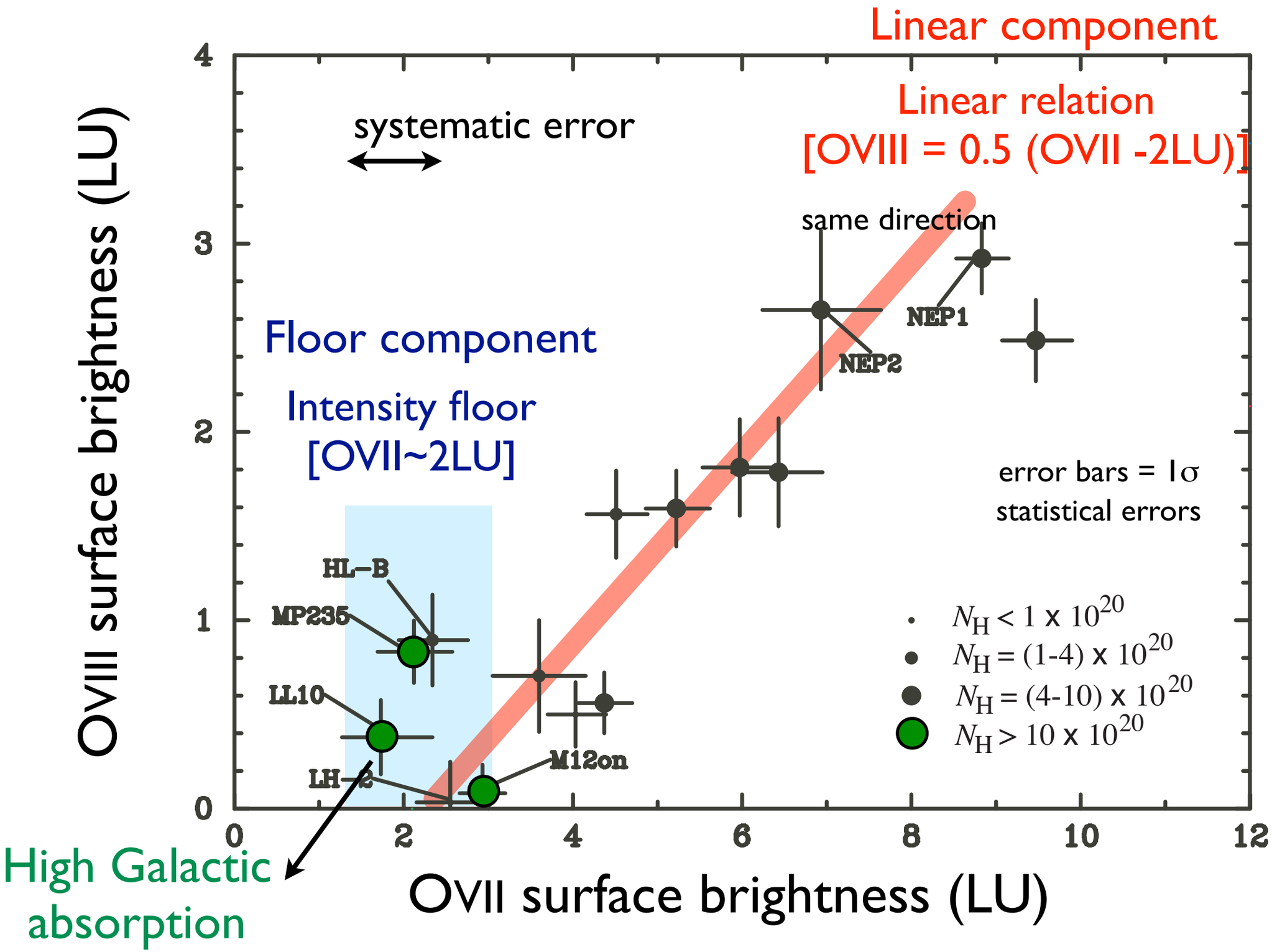


O_{VII} 6.4±0.8 LU

O_{VIII} 2.2±0.8 LU

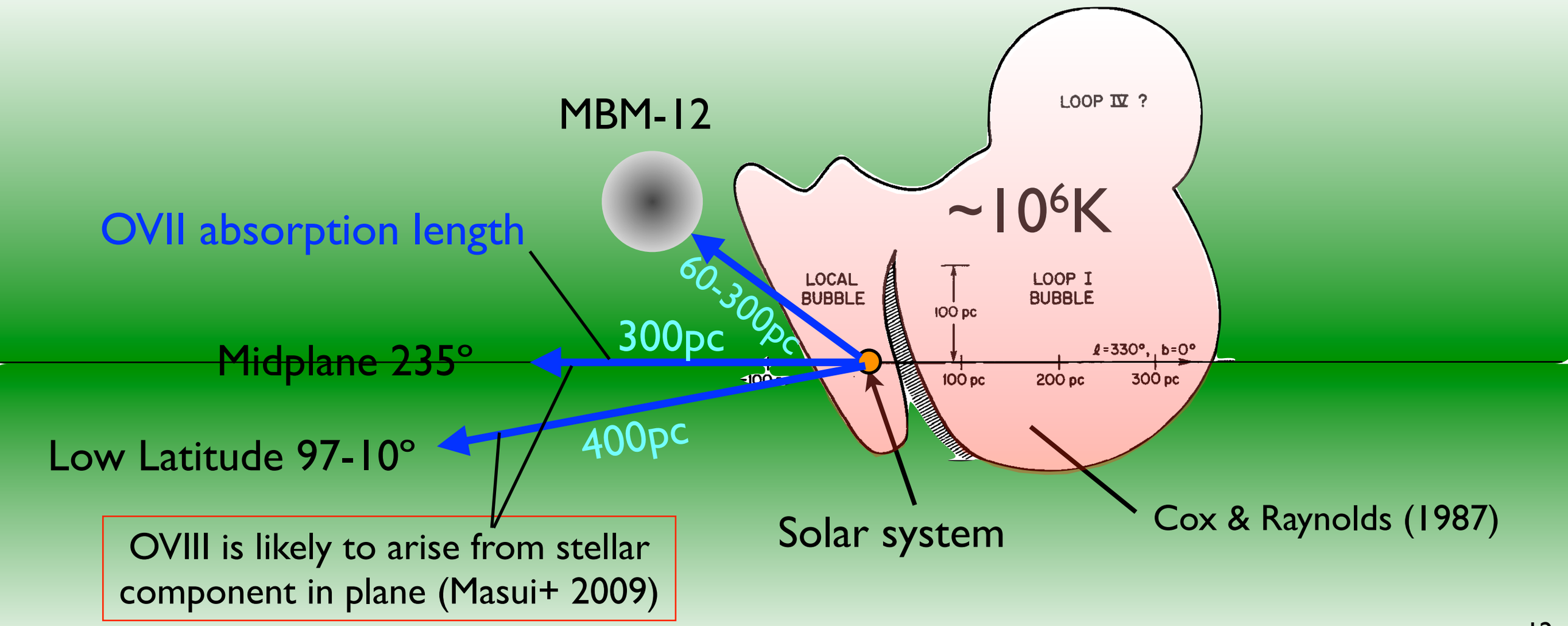
LU: photons/cm^2/sec/str

OVII - OVIII Correlation



Origin of "floor component"

- Three out of five fields on the OVII intensity floor have a large absorption.
  - OVII emission is arising within ~300 pc.
- Floor component is "local emission" (≲ 300 pc).



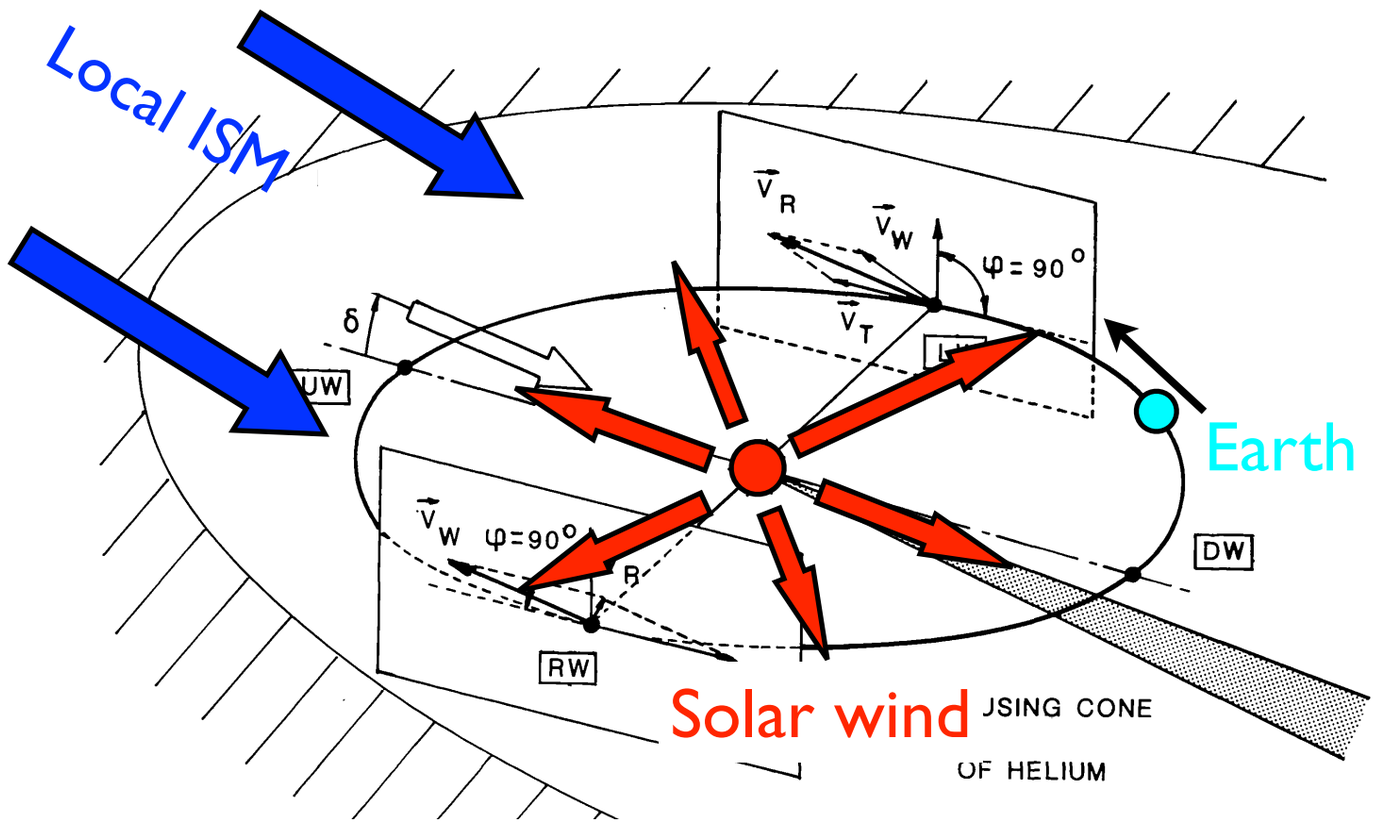
Is the "local" emission from the Local Bubble (LB)?

- Emission measure of 10^6K gas (Smith+ 2007)
  - If Suzaku OVII emission of MBM12 direction arises from hot gas:
    - MBM12 direction = 0.0077 cm^{-6} pc (OVII=3LU)
  - If All ROSAT R12 (0.15-0.28 keV) emission of MBM12 direction arises from hot gas
    (We know at least a part of R12 band emission must arise from LB)
    - MBM12 direction = 0.0024 cm^{-6} pc (Snowden+ 1993)
  - EUV Fe emission lines with CHIPS experiment
    - LB < 0.0004 cm^{-6} pc (90% upper limit, Hurwitz+ 2005)

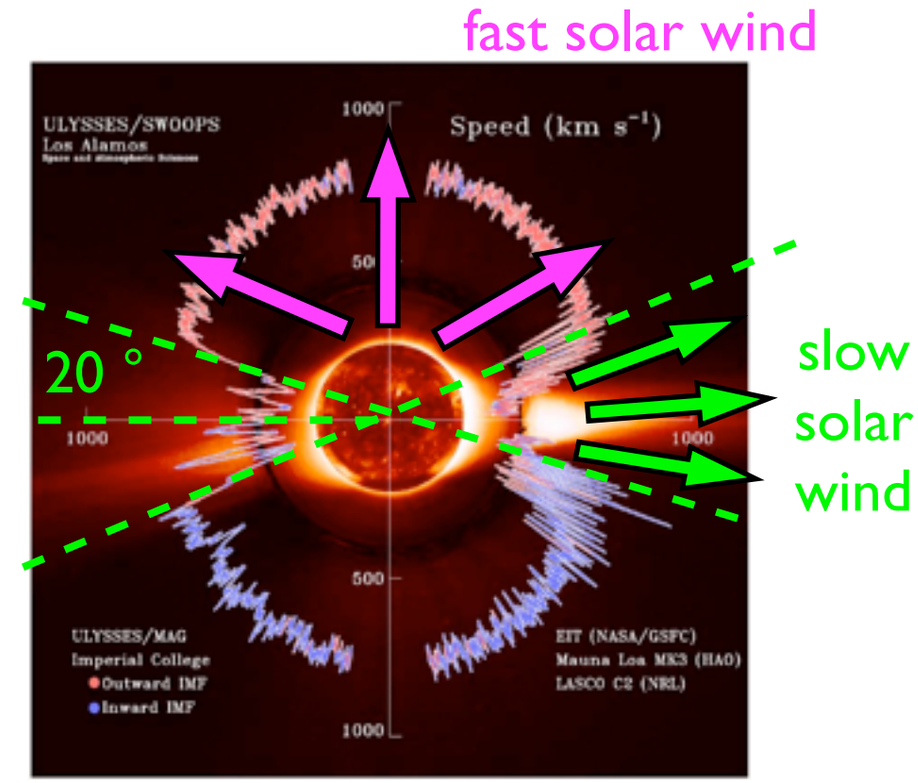
LB contributes only <1/3 or <1/20 of the local OVII emission

Floor component = Heliospheric SWCX

- The "local" emission (floor component) is most likely from the Heliospheric SWCX from interplanetary space.



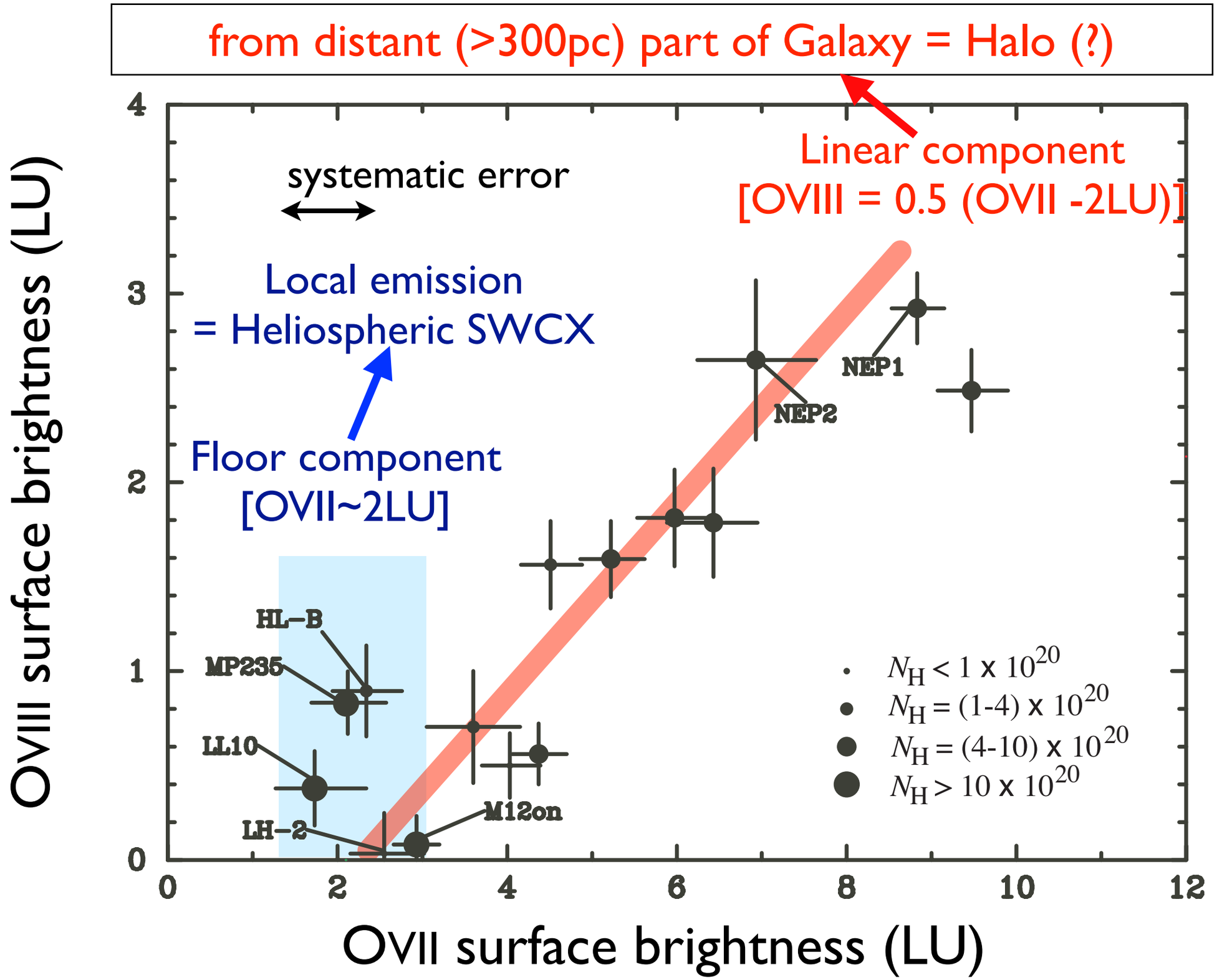
Solar wind near solar minimum



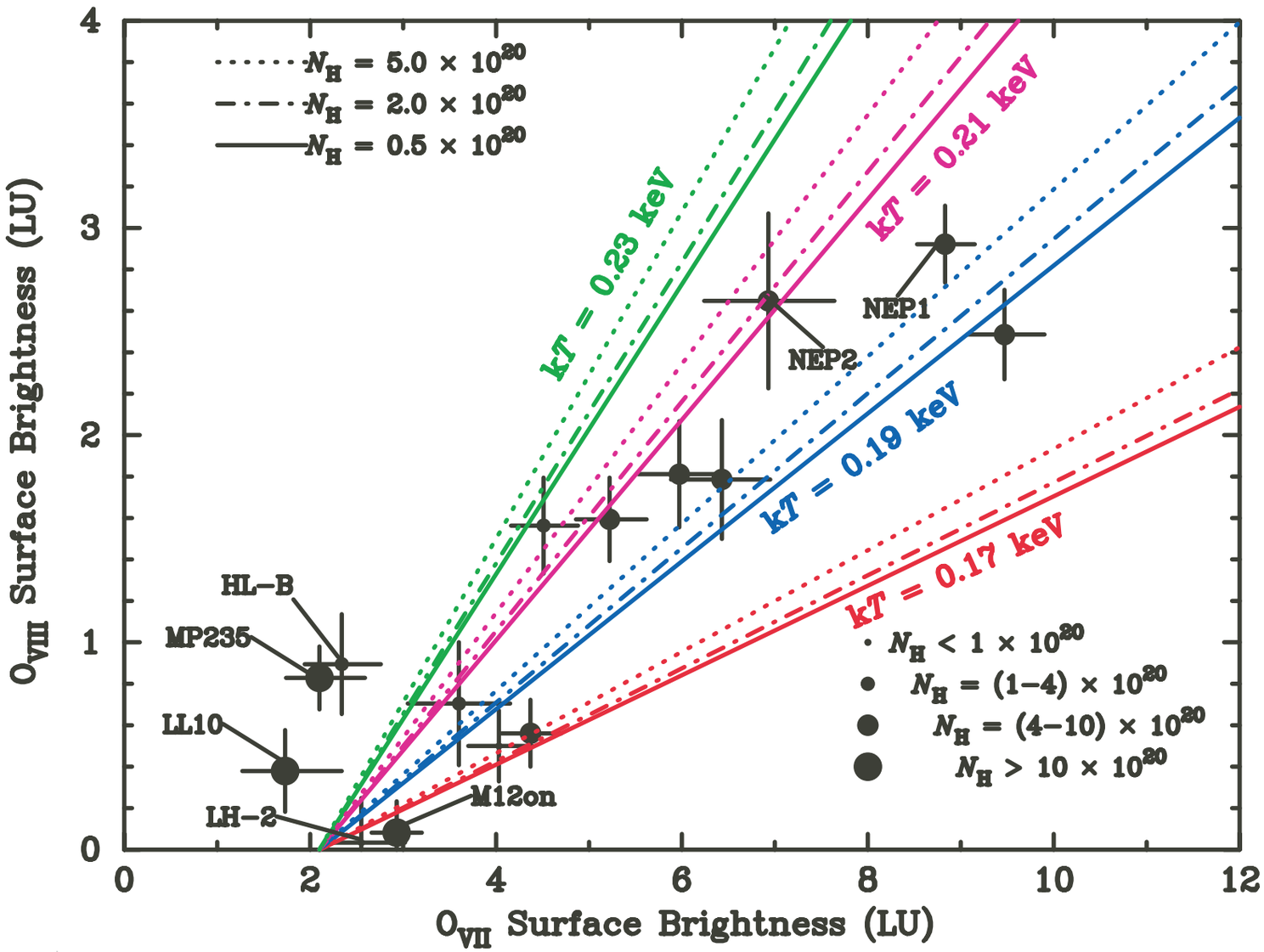
http://solarscience.msfc.nasa.gov/suess/SolarProbe/Page3.htm

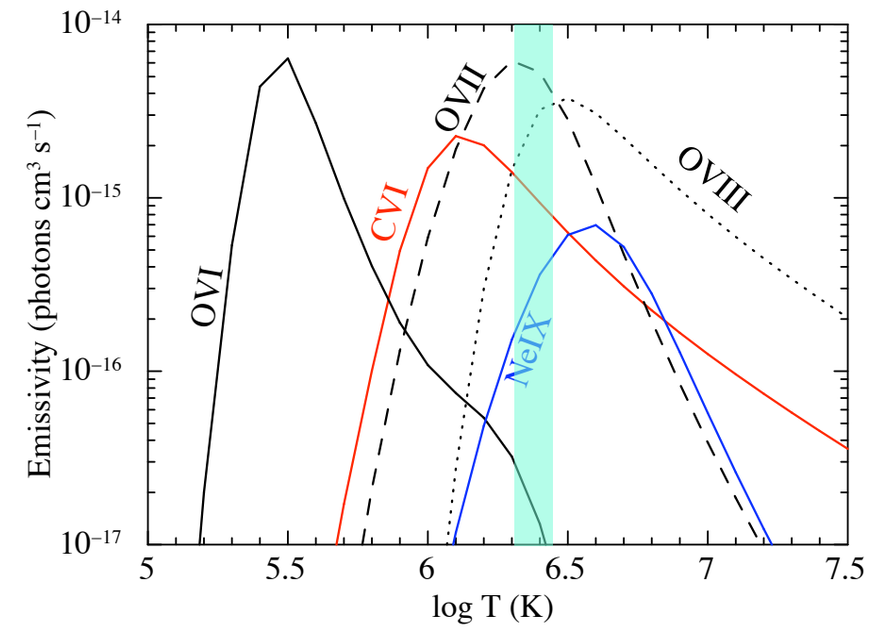
Intensity of Heliospheric SWCX is a complicated function of position of the earth, line of sight direction, and solar wind activity.
2 LU is roughly consistent with simulations (1.5-3 LU, Koutroumpa+ 2006)

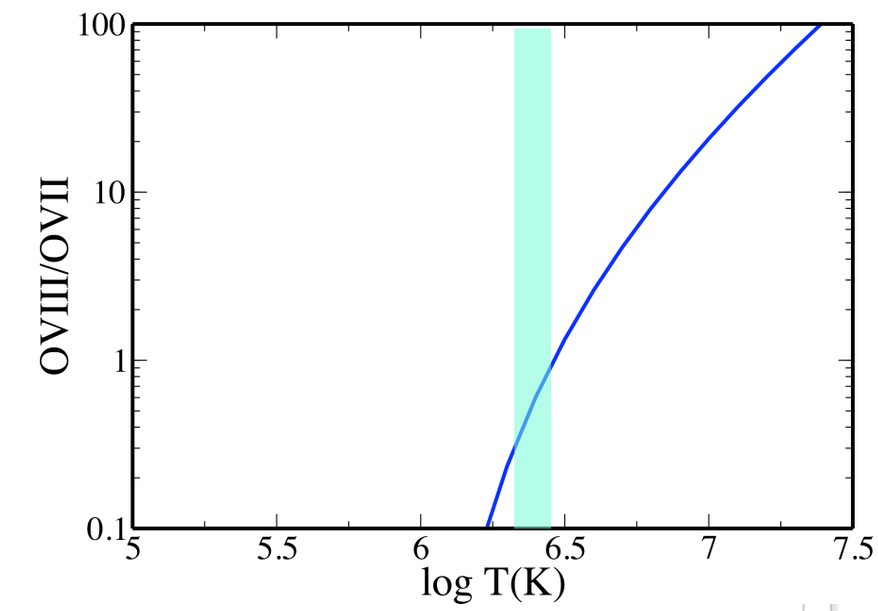
Linear component



Temperature of "halo" emission





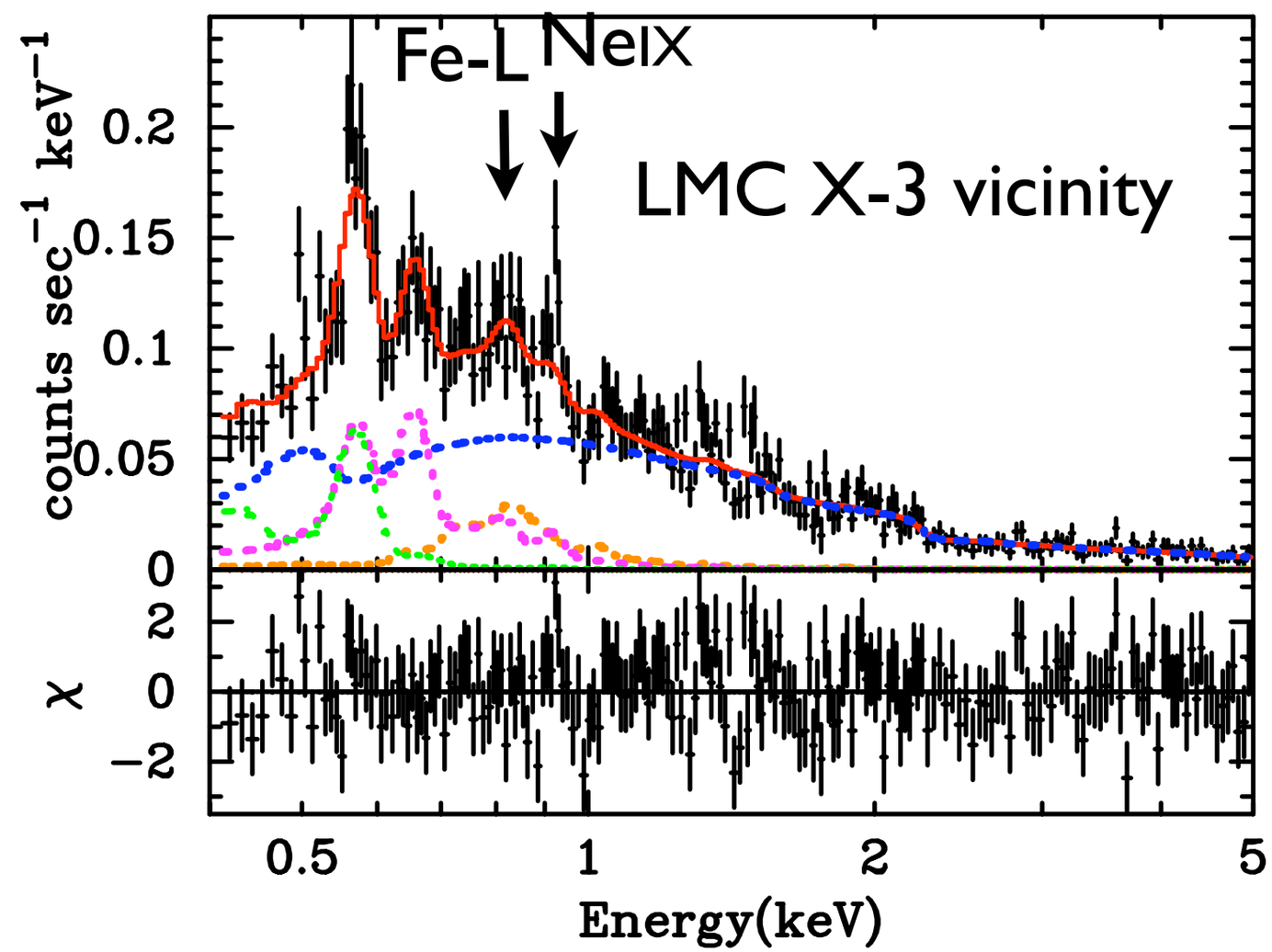


The temperature of halo determined from OVII/OVIII ratio is confined in a narrow range of kT = 0.19-0.23 keV

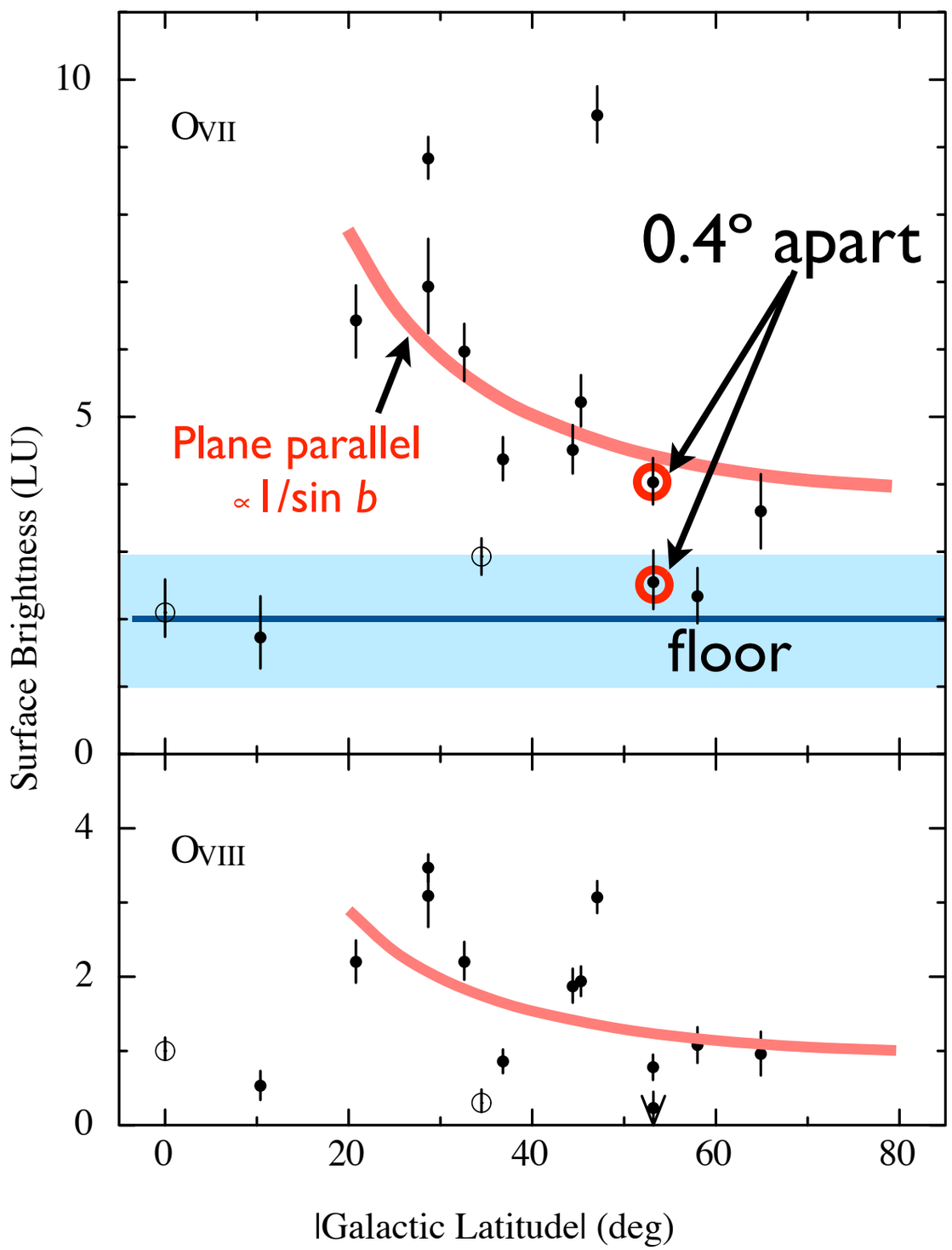
Blobs of hotter gas

- 4 out of 14 fields show strong Fe-L and Ne lines which cannot be emitted from solar abundance 0.2 keV hot gas.
- In order to fit O to Ne emission lines simultaneously, either overabundance ($(3-4)Z_\odot$ in Fe/O and Ne/O ratios), or a hotter component of *kT* =0.6 - 0.8 keV

Hot ISM in halo is likely to be multi-temperature and there are "blobs" of hot gas in some sight lines.



Spatial distribution of "halo" hot gas

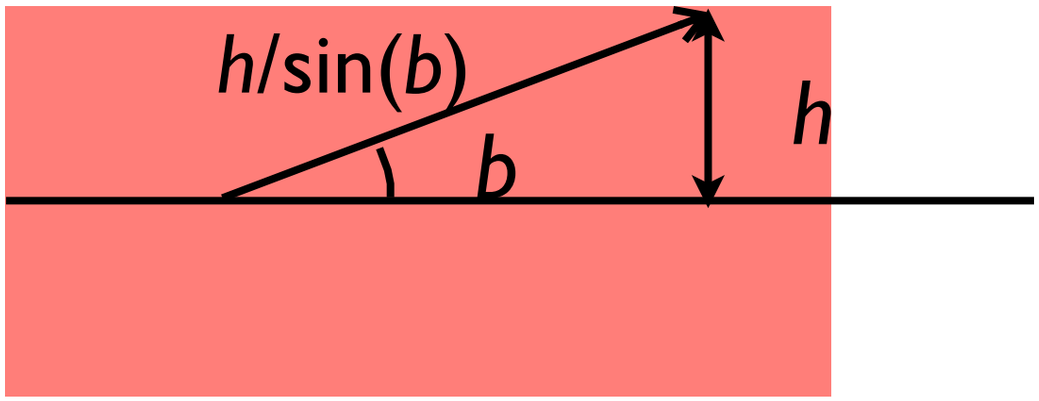


Overall latitude dependency is very roughly consistent with plane-parallel distribution.

However, there are

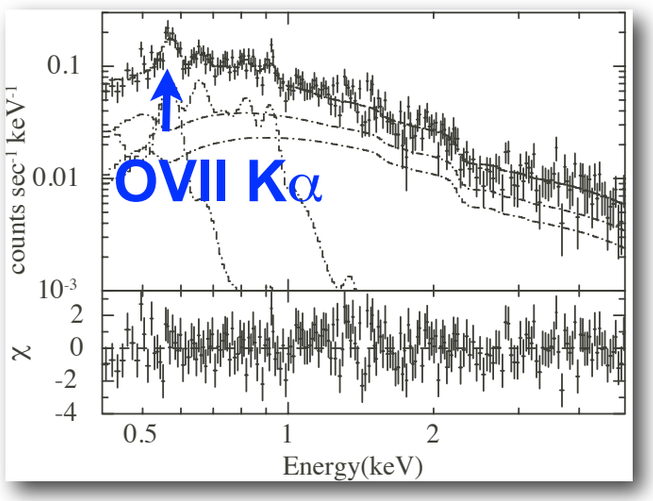
- systematic deviations,
- large outsiders,
- small scale fluctuations

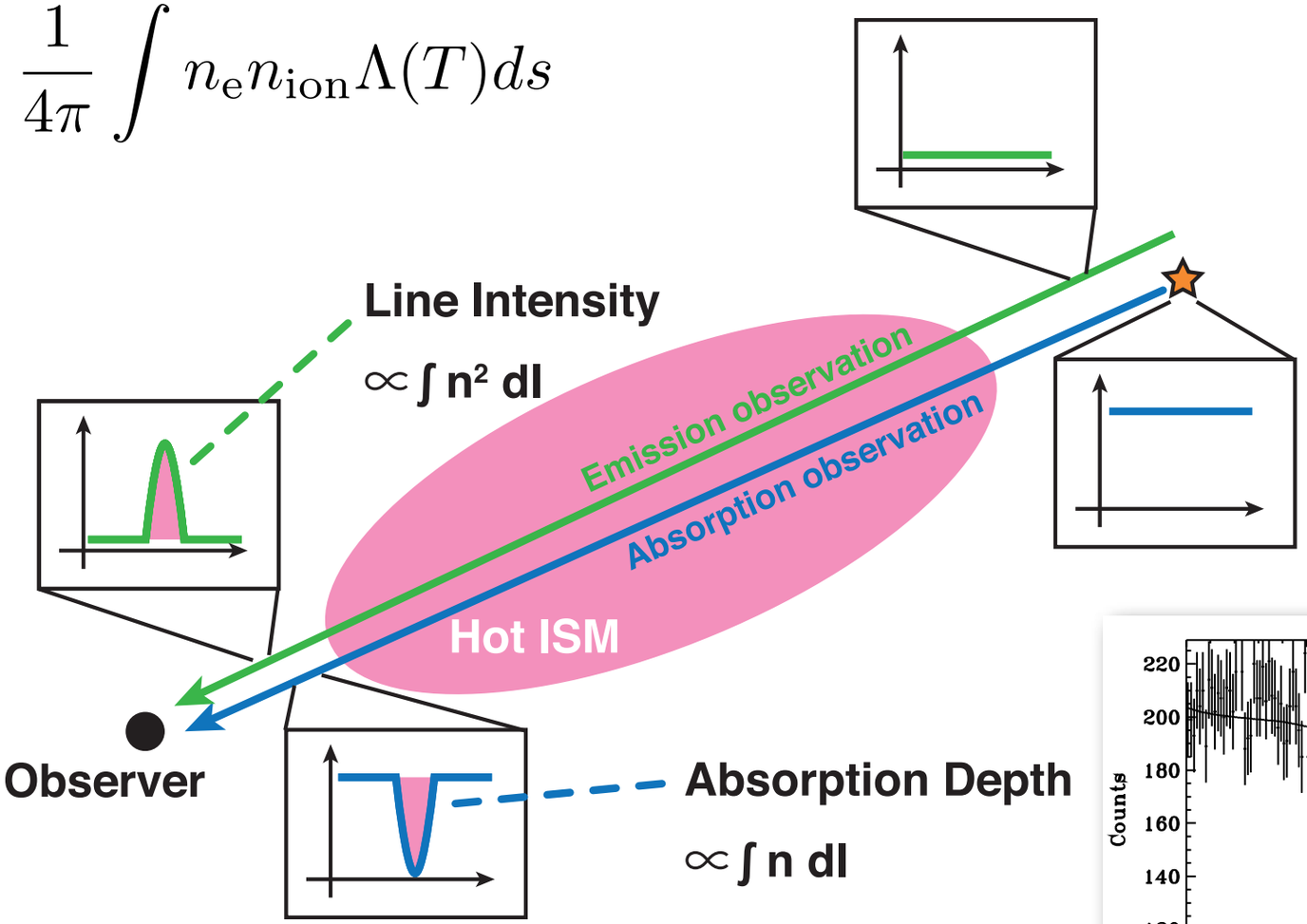
Hot gas in halo is likely patchy

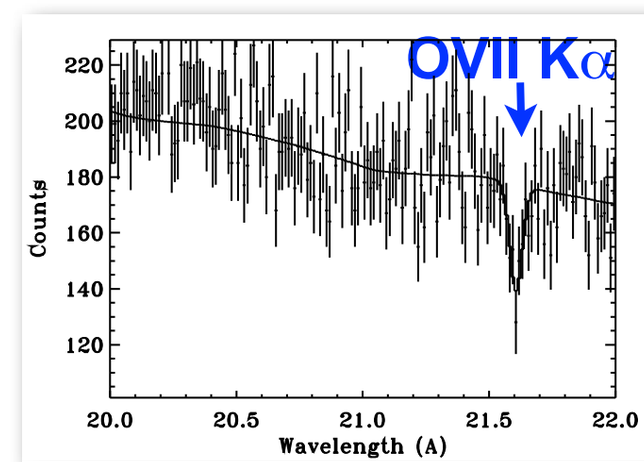


Combined analysis of absorption/emission spectra to constrain distribution along the sight line

Emission (Suzaku)
Surface brightness = $\frac{1}{4\pi}\int n_{\rm e} n_{\rm ion} \Lambda(T) ds$





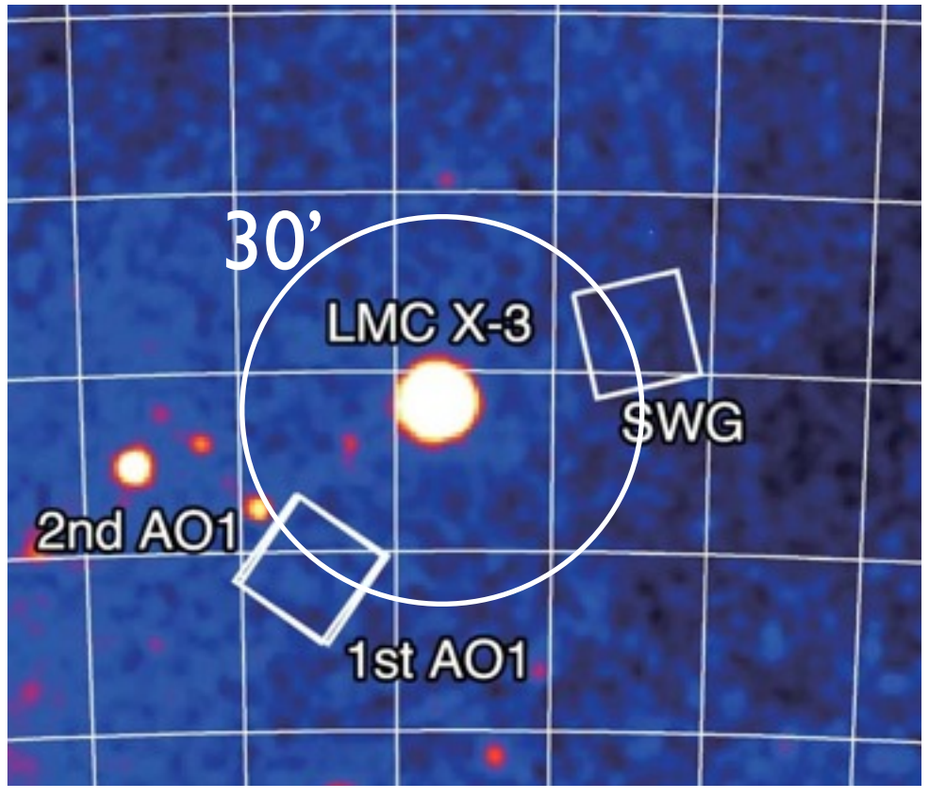


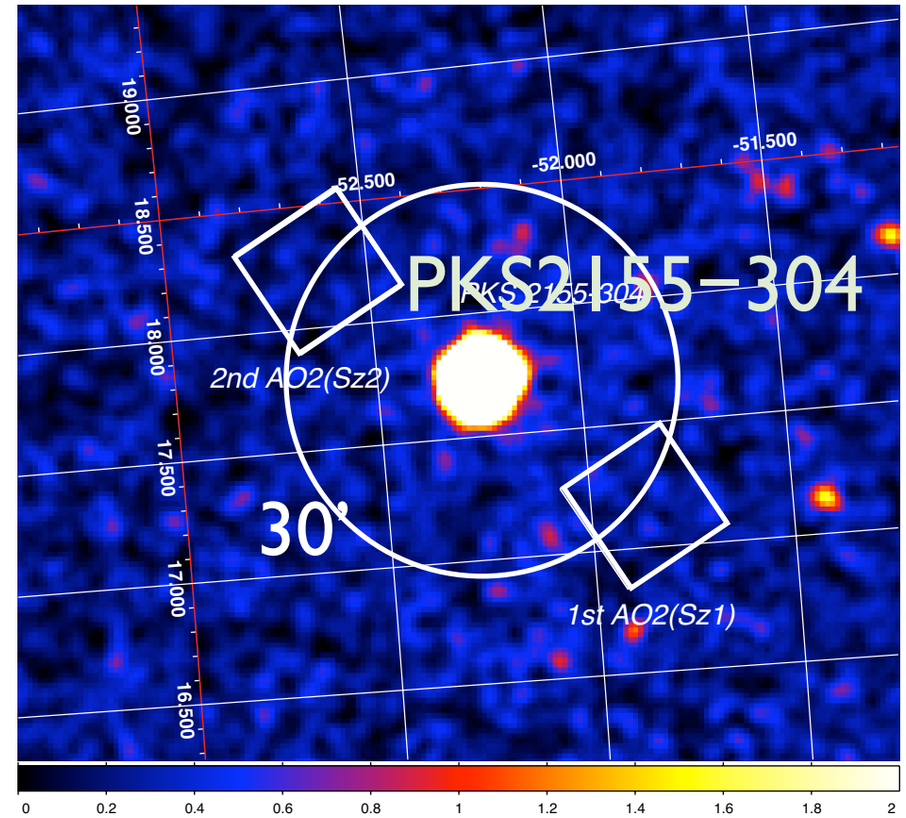
⇒combination analysis can separate density and thickness along the line of sight

Absorption (Chandra)
column density = $\int n_{\rm ion} ds$

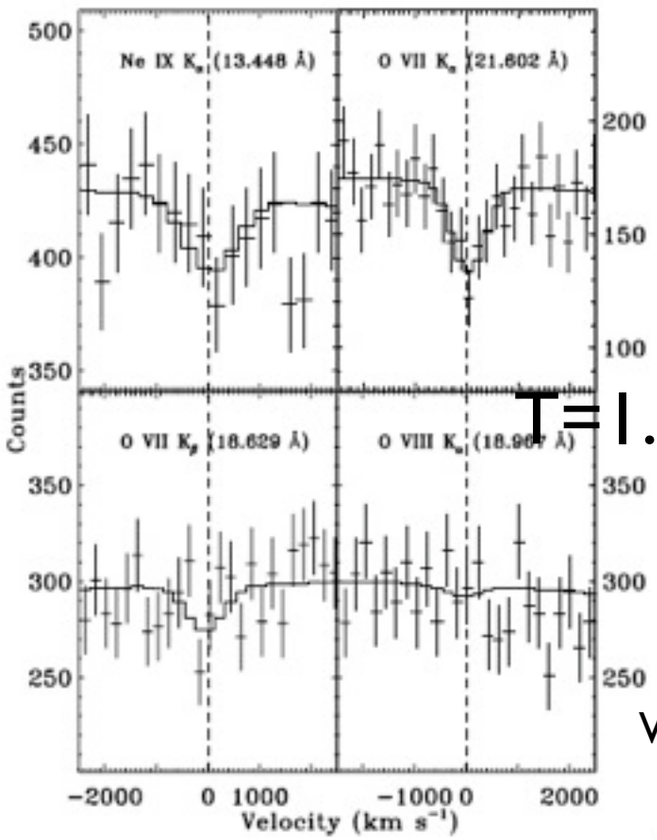
Observations: 2 Lines of Sight

	Distance	Absorption	Emission
LMC X-3 (Wang et al. 2005, Yao et al. 2009)	~50 kpc	Chandra LETG-HRC:100ks Fuse: 120ksec	Suzaku:3 obs(~30' away, 120 ks in total)
PKS2155-304 (Hagihara et al. submitted)	470 Mpc (z=0.116)	Chandra Calibration 46 obs:1Ms	Suzku: 2 obs(~30' away, 107 ks in total)



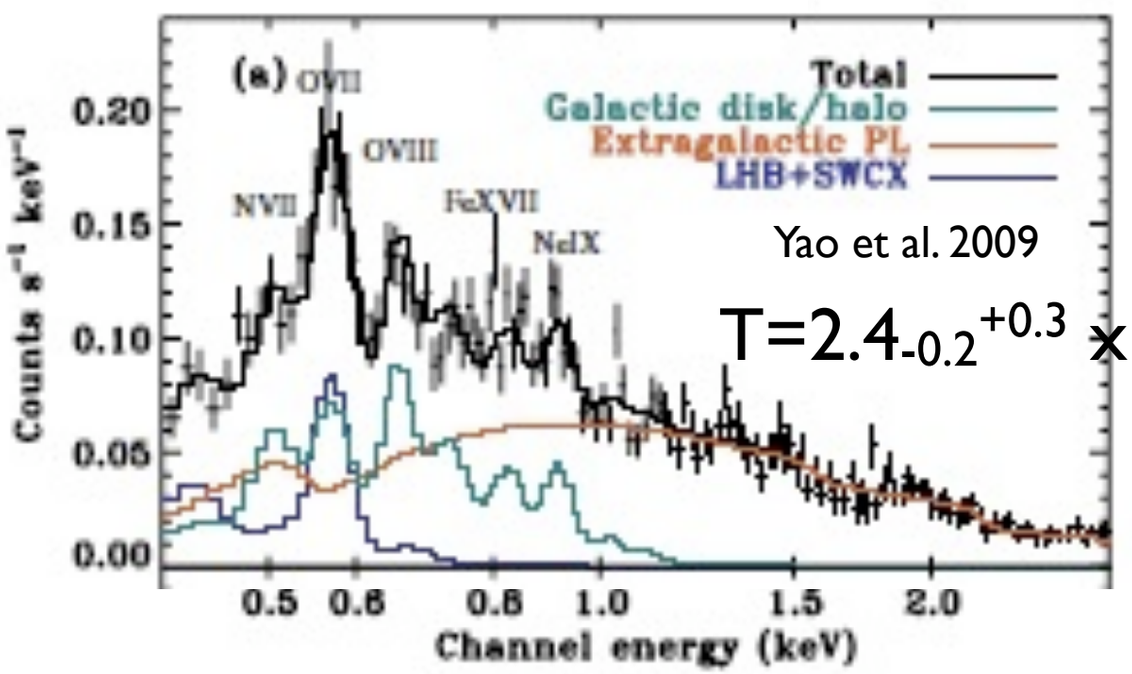


LMC X-3



$T=1.3_{-0.5}^{+0.7}\times10^6$ K

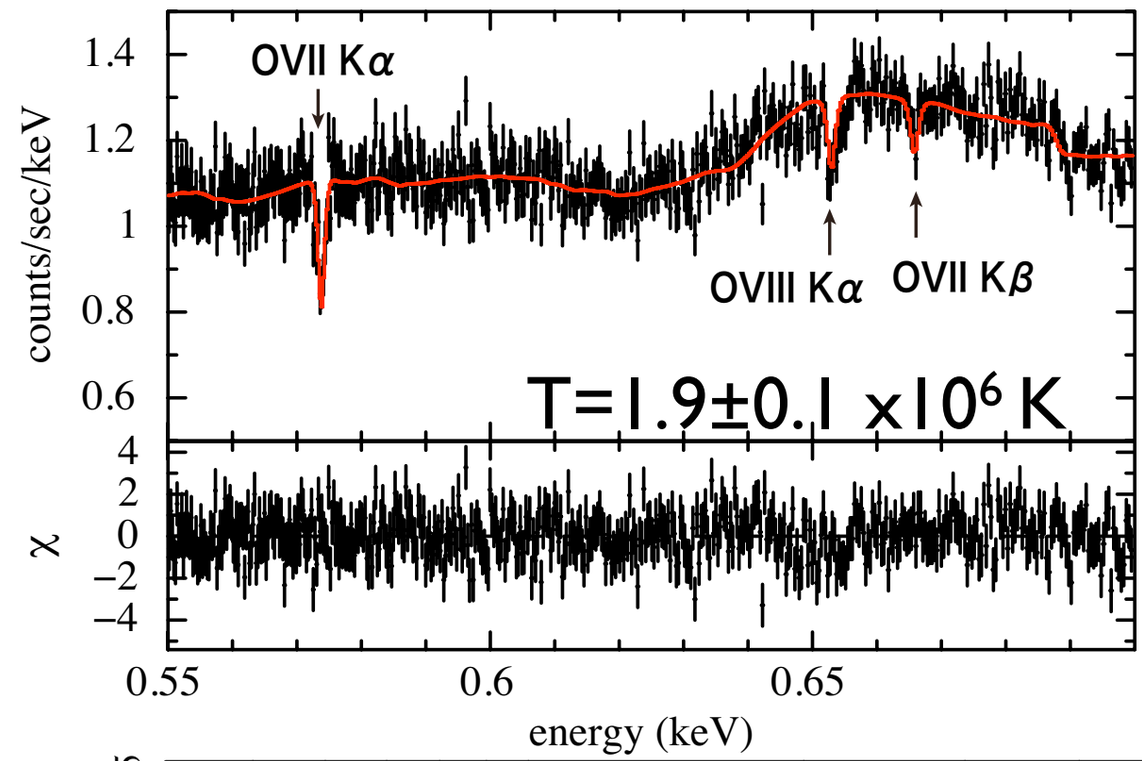
Wang et al. 2005



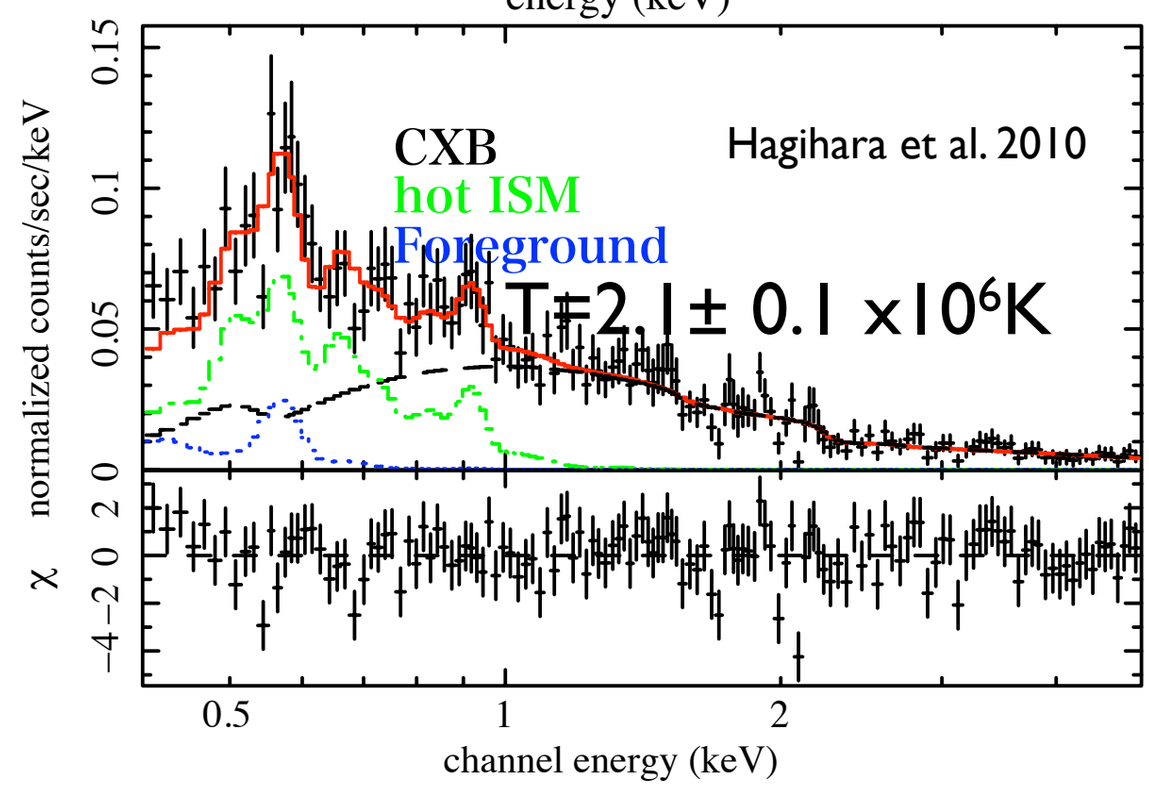
Yao et al. 2009

$T=2.4_{-0.2}^{+0.3}\times10^6$K

PKS2155-304



$T=1.9\pm0.1\times10^6$ K

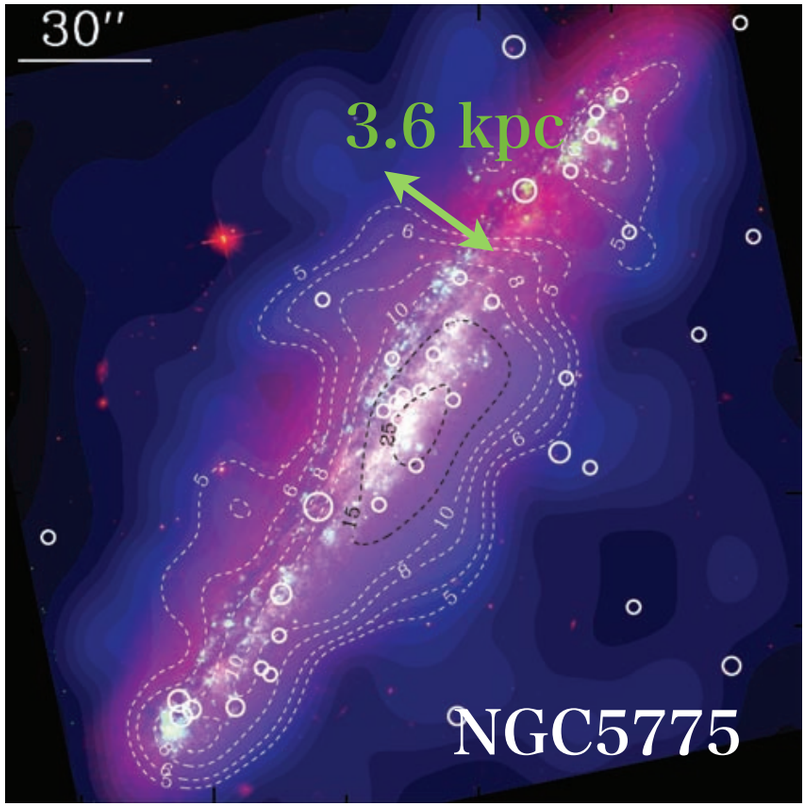


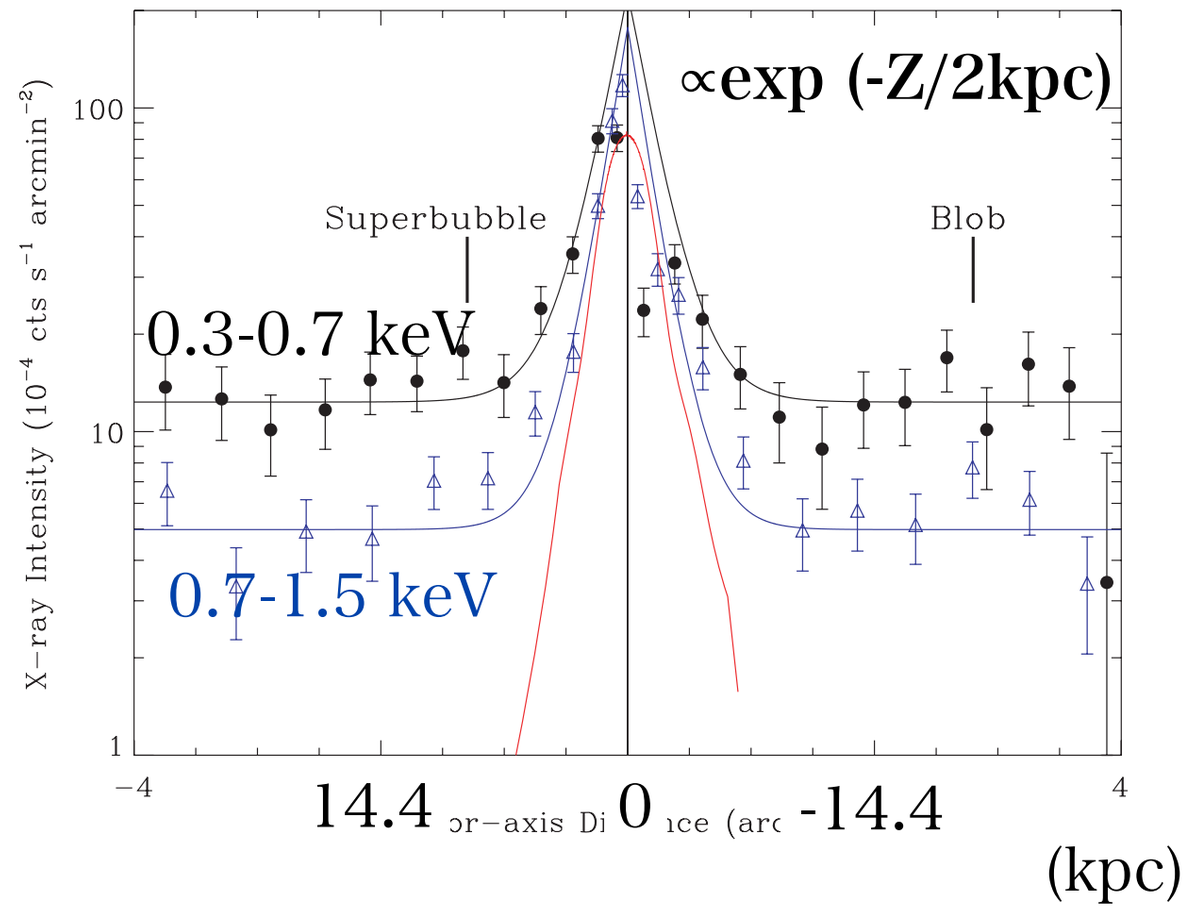
Hagihara et al. 2010

$T=2.1\pm0.1\times10^6$K

In both cases, simple uniform plasma can not explain the absorption/ emission simulaneously

Exponential thick hot disk model





We assumed an exponential disk model for the hot gas responsible for absorption and emission. (Yao and Wang 2007, Yao et al. 2009)

$$n_{\rm e} = n_0 e^{-z/h_n}$$

$$T = T_0 e^{-z/h_T}$$

$$\Rightarrow \quad \frac{dEM}{dT} \propto \gamma \left(\frac{T}{T_0}\right)^{2\gamma-1} \quad \text{where} \quad \gamma \equiv \frac{h_T}{h_n}$$

Results: Exponential thick hot disk parameters

	Temperature		Density	
	on-Plane val. (10^6 K)	Scale hight (kpc)	on-Plane val. (10^{-3} cm^{-3})	Scale hight (kpc)
PKS 2155-304	$3.2^{+0.7}_{-0.6}$	$2.2^{+13}_{-2.1}$	$1.3^{+9.7}_{-0.7}$	$5.1^{+3.9}_{-4.7}$
LMC X-3	$3.6^{+1.1}_{-0.7}$	$1.4^{+3.8}_{-1.2}$	$1.4^{+2.0}_{-1.1}$	$2.8^{+3.6}_{-1.8}$

- Exponential disk model can explain the absorption/emission spectra
- Parameters of two lines of sight are consistent within 90%
  - T_0~3MK, n_0~10^{-3} cm^{-3}, scale ~a few kpc

The consistency of two line of sight suggest that there is Galactic scale hot ISM like a halo.
We need observations of more lines of sights to further constrain the geometry.

Hot gas in halo

- OVII/OVIII intensity ratio ~ 2 , indicating line of sight averaged O temperature of kT = 0.21±0.02 keV
- Patchy and blobs of hot (kT~0.7 keV) gas exist
- Extending a few kpc scales, at least for two lines of sights.
  - Midplane density ~ 1×10^{-3} cm^{-3} if we assume exponential geometry.

➡ Total mass $M \sim 10^8 M_\odot$

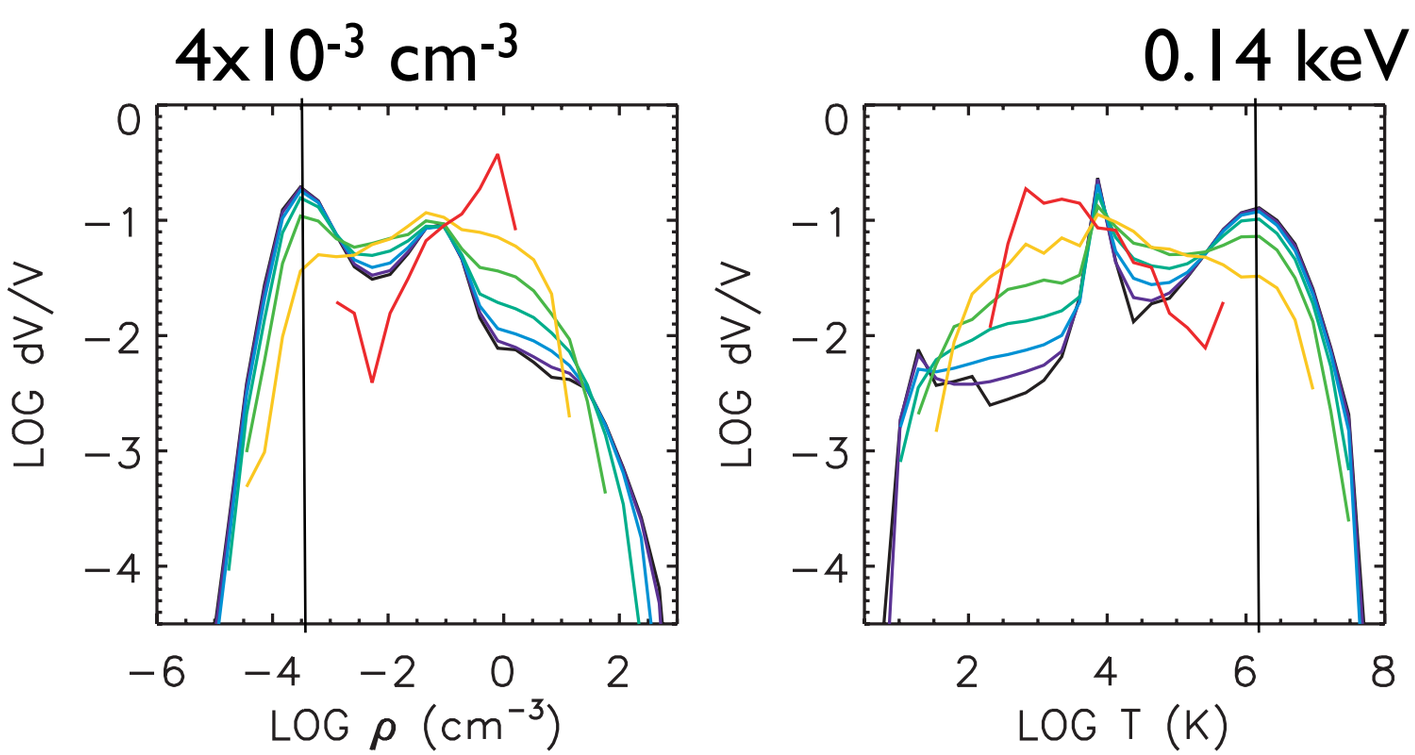
Total luminosity $L \sim 10^{39} \mathrm{erg\ s^{-1}}$

(assuming a 15kpc radius cylindrical structure and a 1.4 kpc vertical scale height)

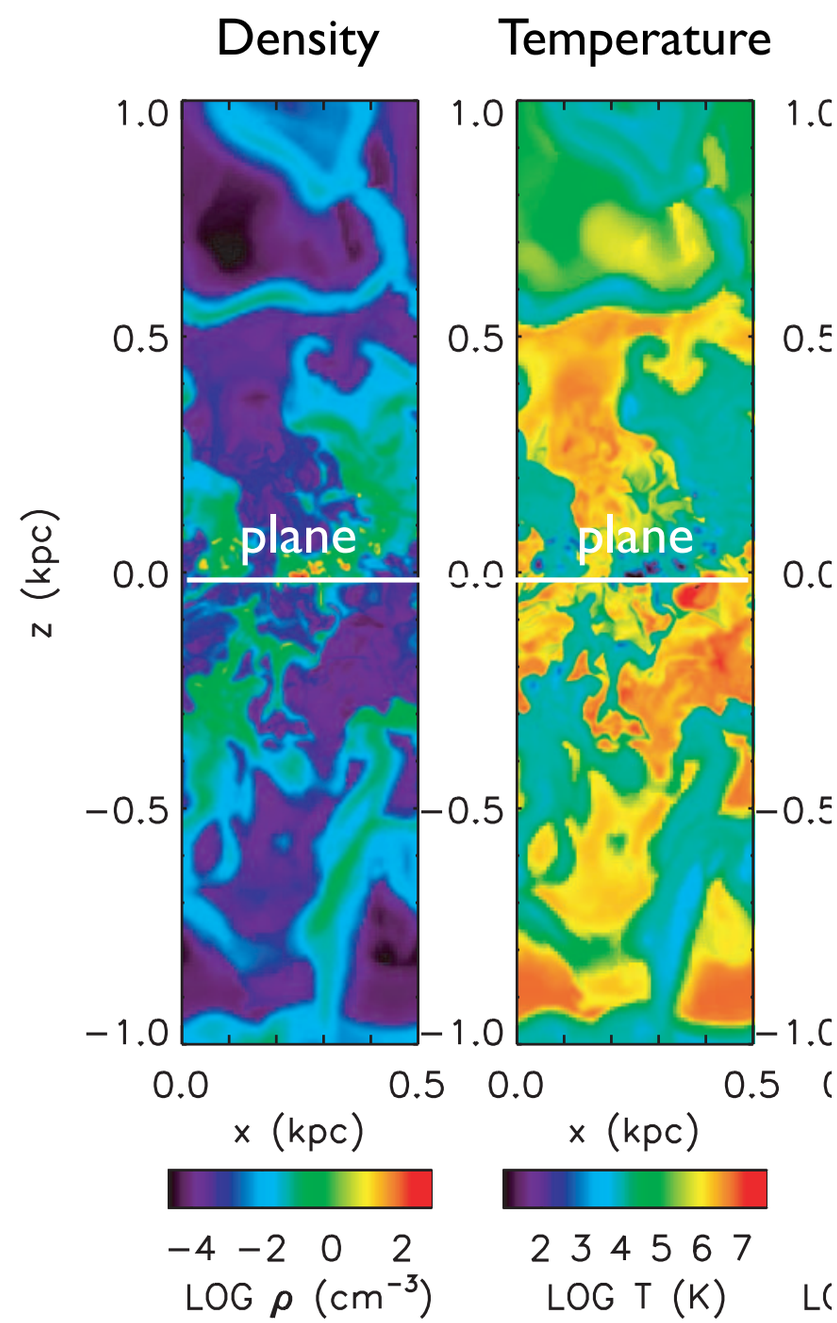
- Almost consistent with other spirals (e.g. NGC 4631, Yamasaki + 2009).
- Mass and energy can be supplied by SNe and stellar wind from Galactic disk (e.g. Norman & Ikeuchi 1989).

SN-driven ISM model

- Hot gas may have been supplied by SNe in Galactic disk SNe through chimney or fountain.
- Simulations shown here predicts multi-temperature, blobby hot gas.
  - Somewhat resemble to the observations



Numerical simulations by Joung & Mac Low (2006)

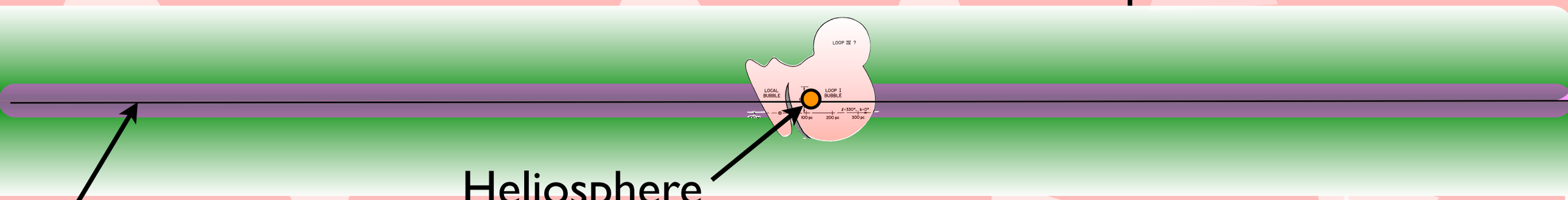


Future works

- Combined absorption/emission analysis of more lines of sights
  - Mkn 421, NGC 4051,...
  - Scale height and its radial dependence
- More blank fields observations
  - Spatial distribution, fluctuations, filling factor...
- Comparison with simulations
- We would like to know:
  - Interaction with ISMs and physical process
  - Pressure balance ?
  - What process determine the temperatures ?
  - Origins and life cycle of the halo
  - The velocity of the halo gas :escaping or not?

Hot blobs
(kT=0.6-0.8 keV)

a few kpc scale height
kT = 0.2 keV
"patchy"
O_{VII} = 0-8 LU



Heliosphere

Stellar emission

Solar Wind Charge Exchange (OVII ~ 2LU)