Charge Exchange X-ray emission in the heliosphere and beyond

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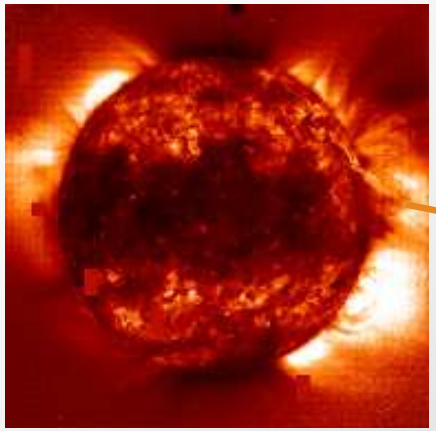
July 20, 2011

Charge Exchange mechanism

Highly charged ions (e.g., from the 1MK Solar Corona: Solar Wind Charge Exchange - SWCX)



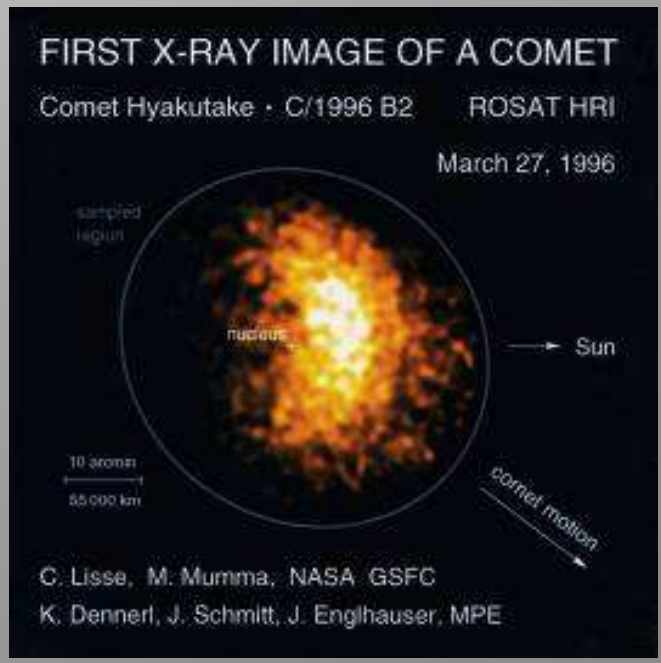
e.g. O^{+8} → O^{+7*} → O^{+7} + Radiative cascade

e^-

Atom or Molecule: (e.g., IS, cometary or exospheric)

e.g. H, He → H^+, He^+

Electronic capture

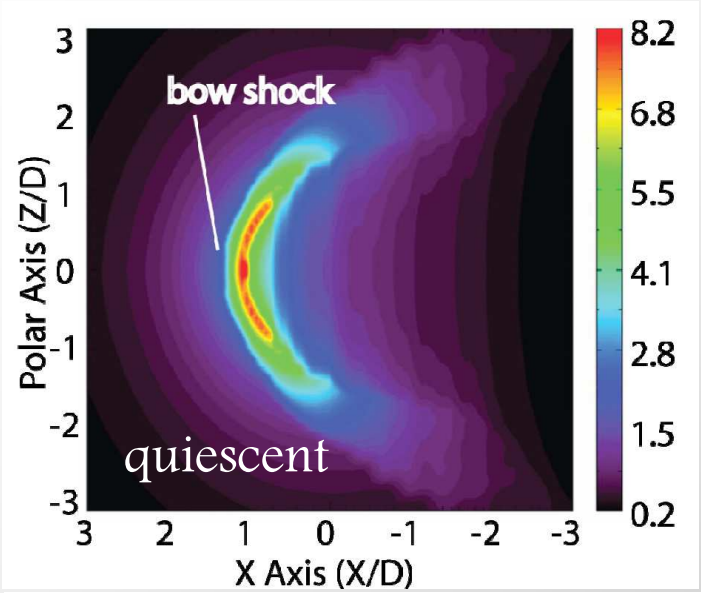


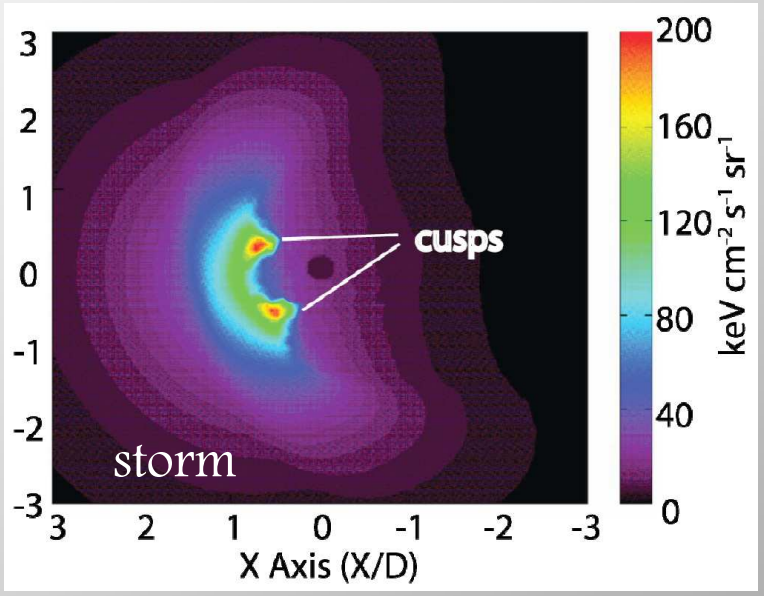
~CX mechanism important to plasma stability & diagnostics in nuclear fusion devices

~As an astrophysical phenomenon first discovered in comets (Lisse et al., 1996)

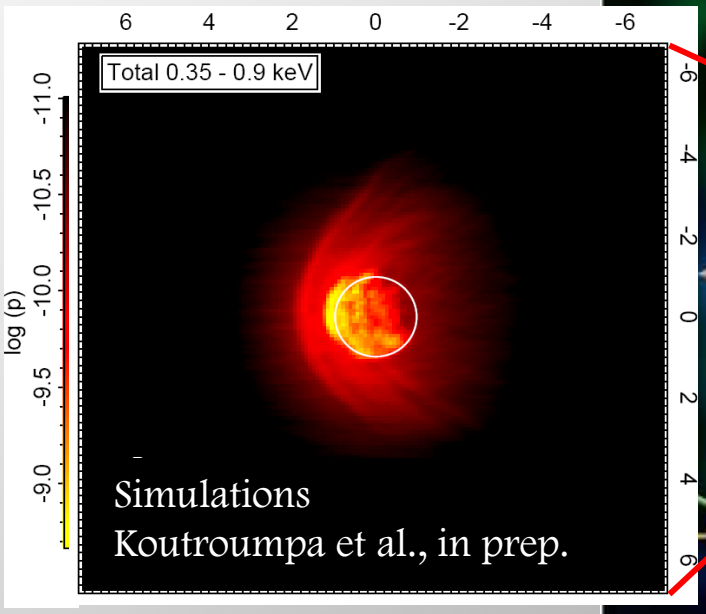
Solar Wind CX (SWCX) X-ray emission

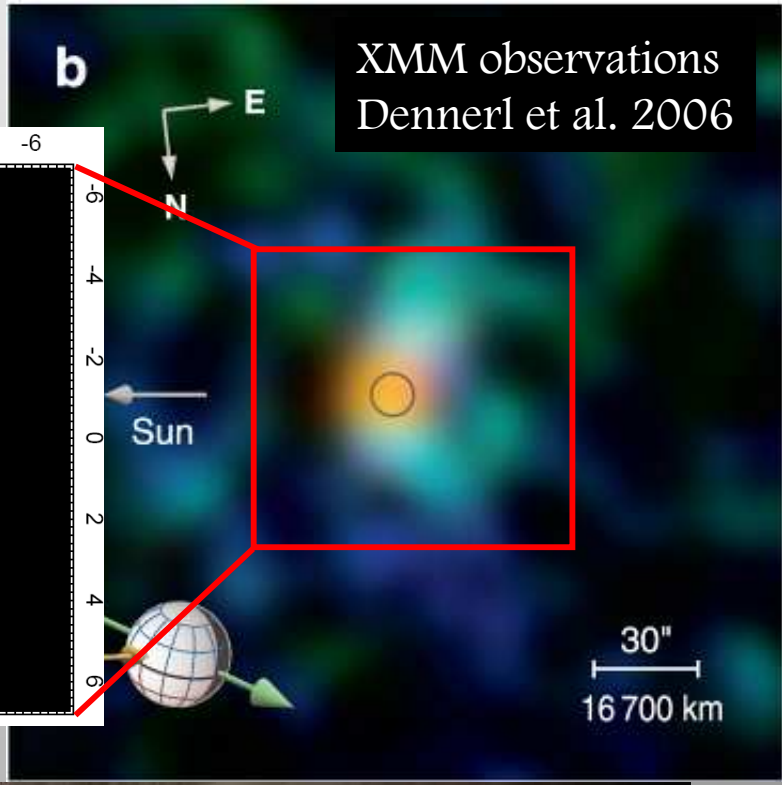
Earth's magnetosphere
(simulations Robertson et al. 2009)

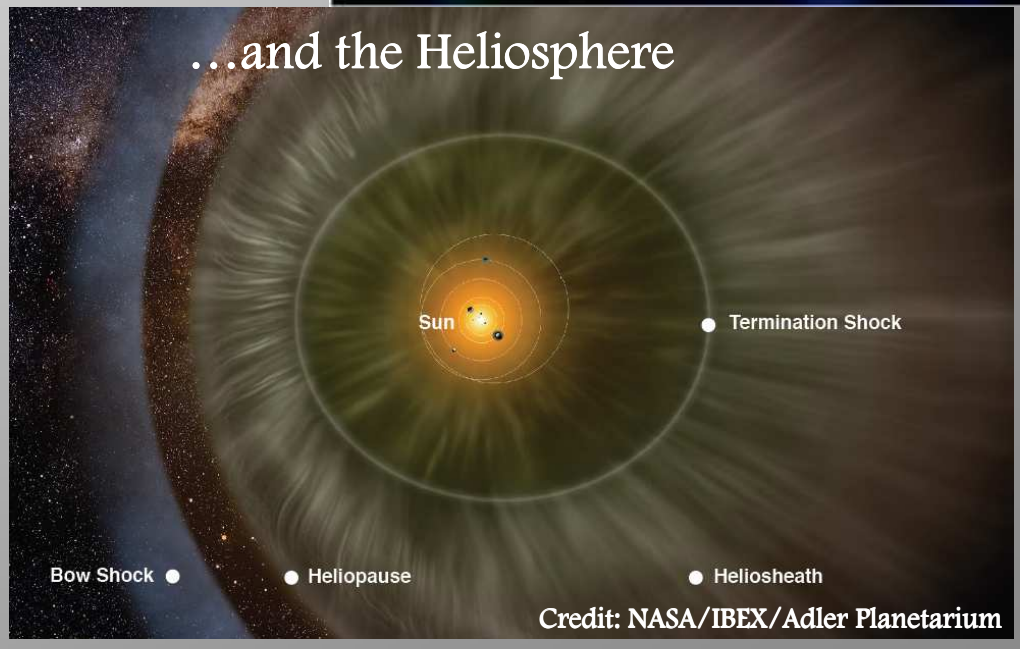




Mars exosphere

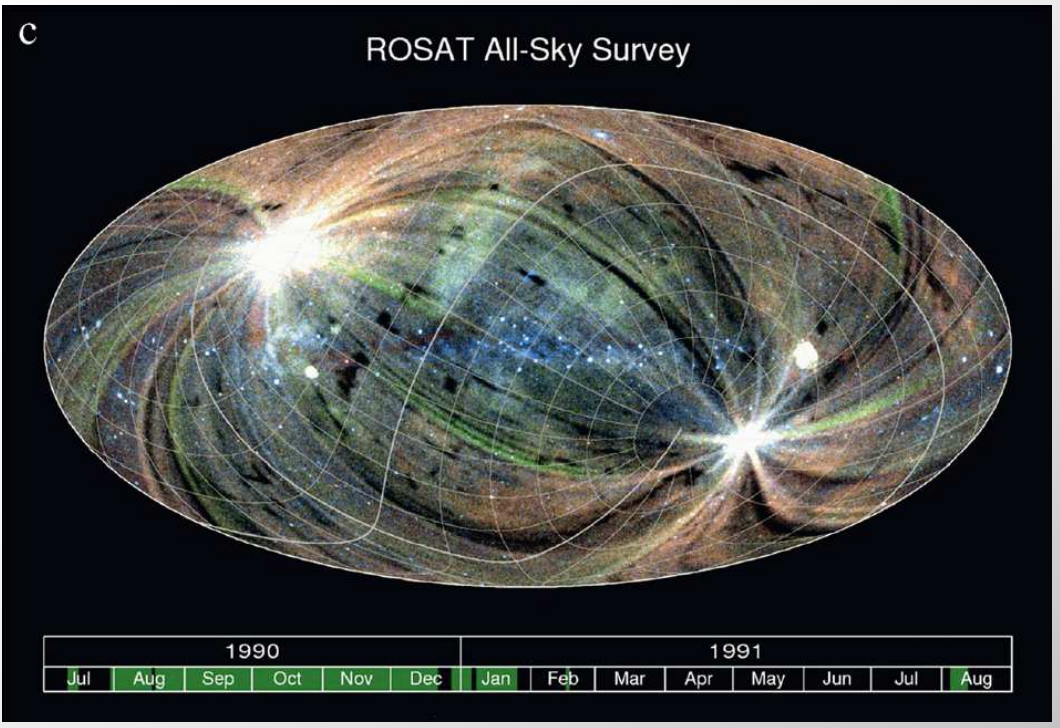






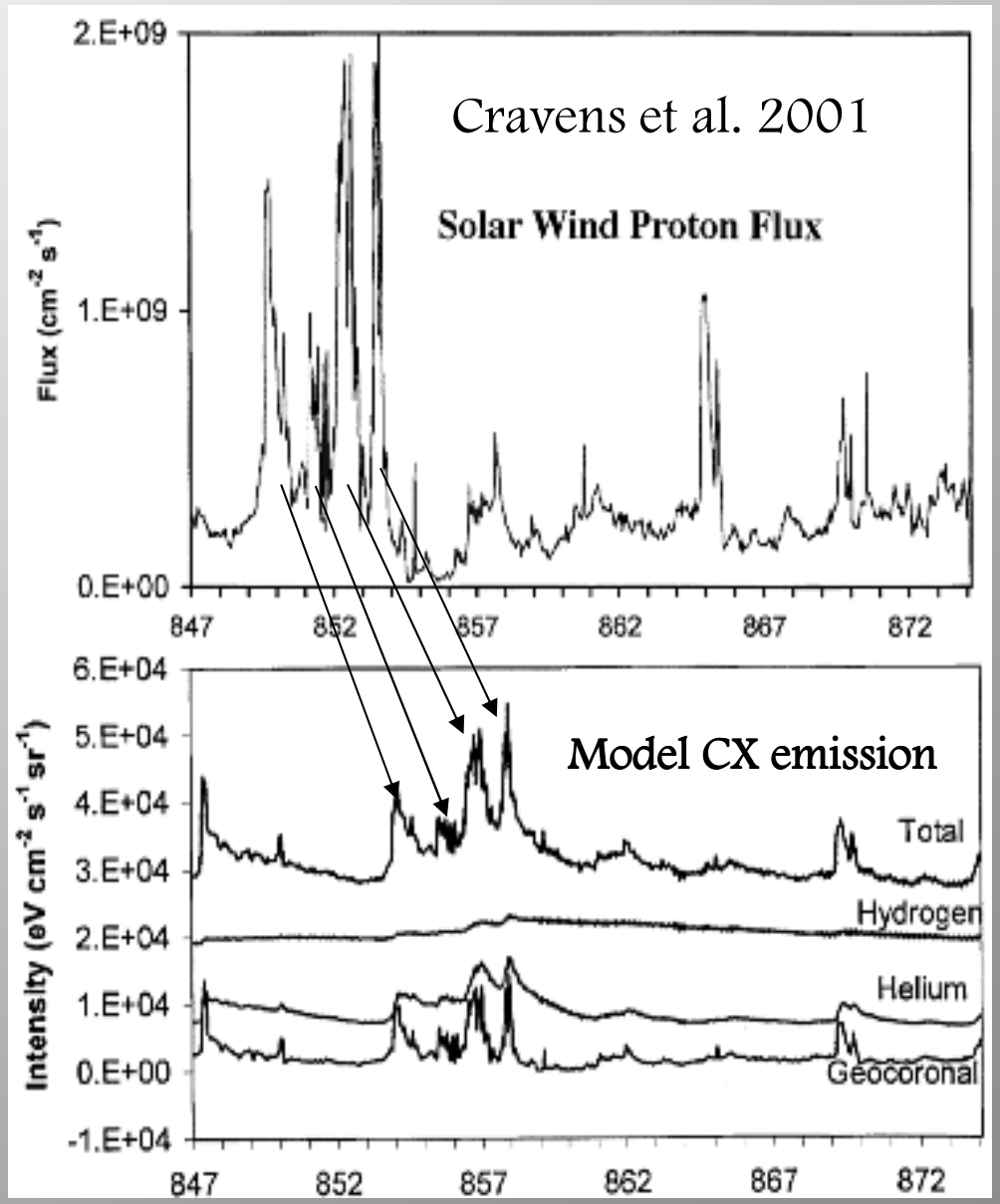
SWCX: variable foreground to all X-ray observations

Raw ROSAT map



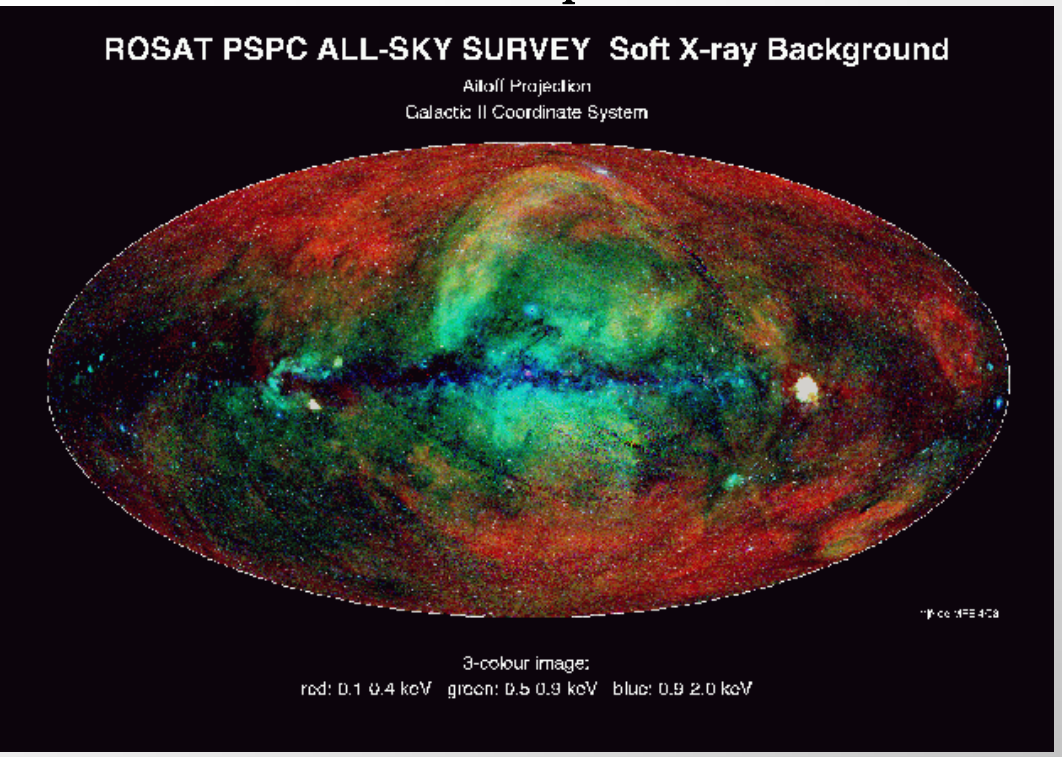
ROSAT Long Term Enhancements (LTEs):
'a mysterious X-ray background that varies on a timescale of ~1–2 days' (Snowden et al. 1994)

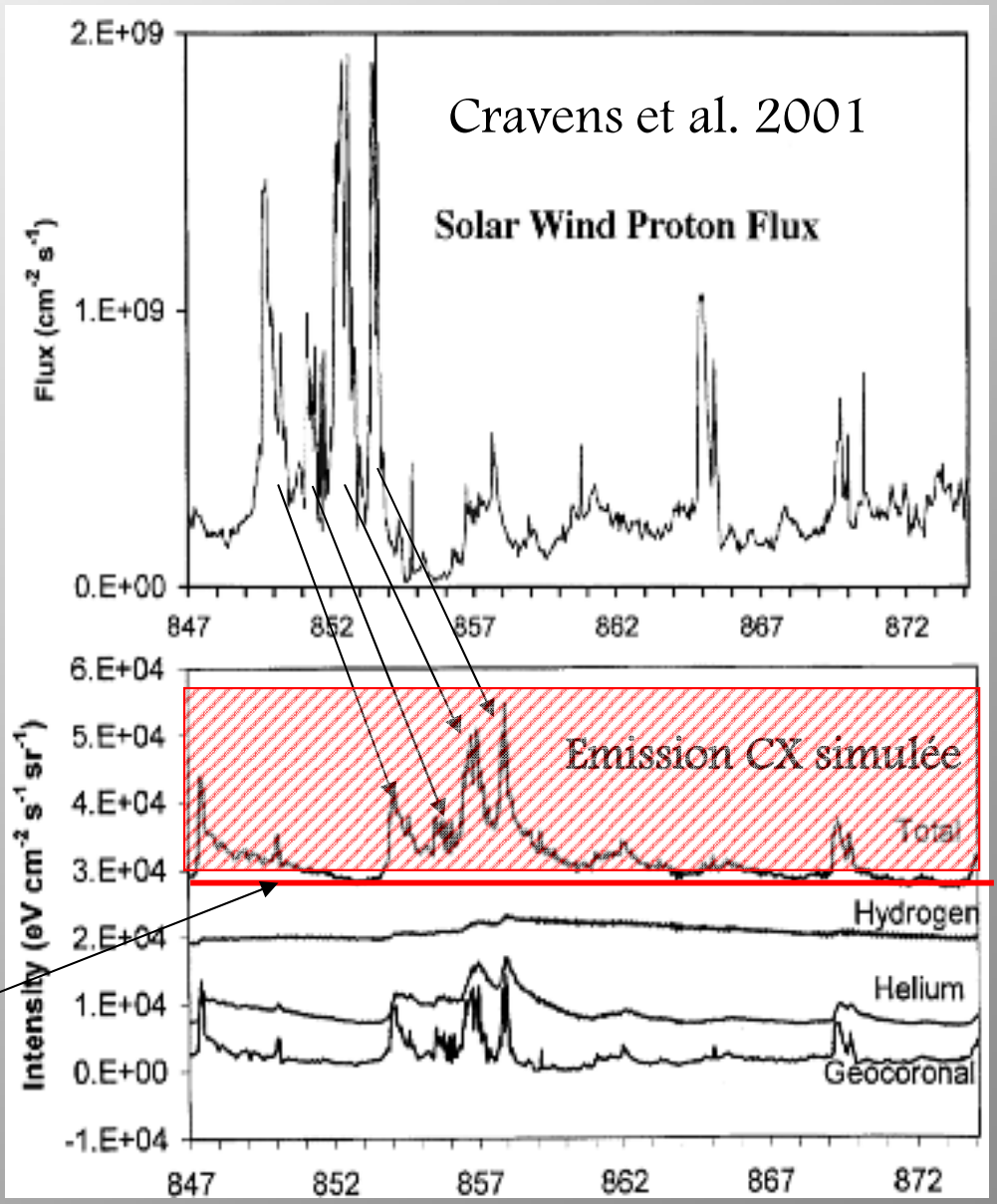
At the time:
-Source unknown
-No modeling



SWCX: variable foreground to all X-ray observations

Corrected (?) ROSAT map



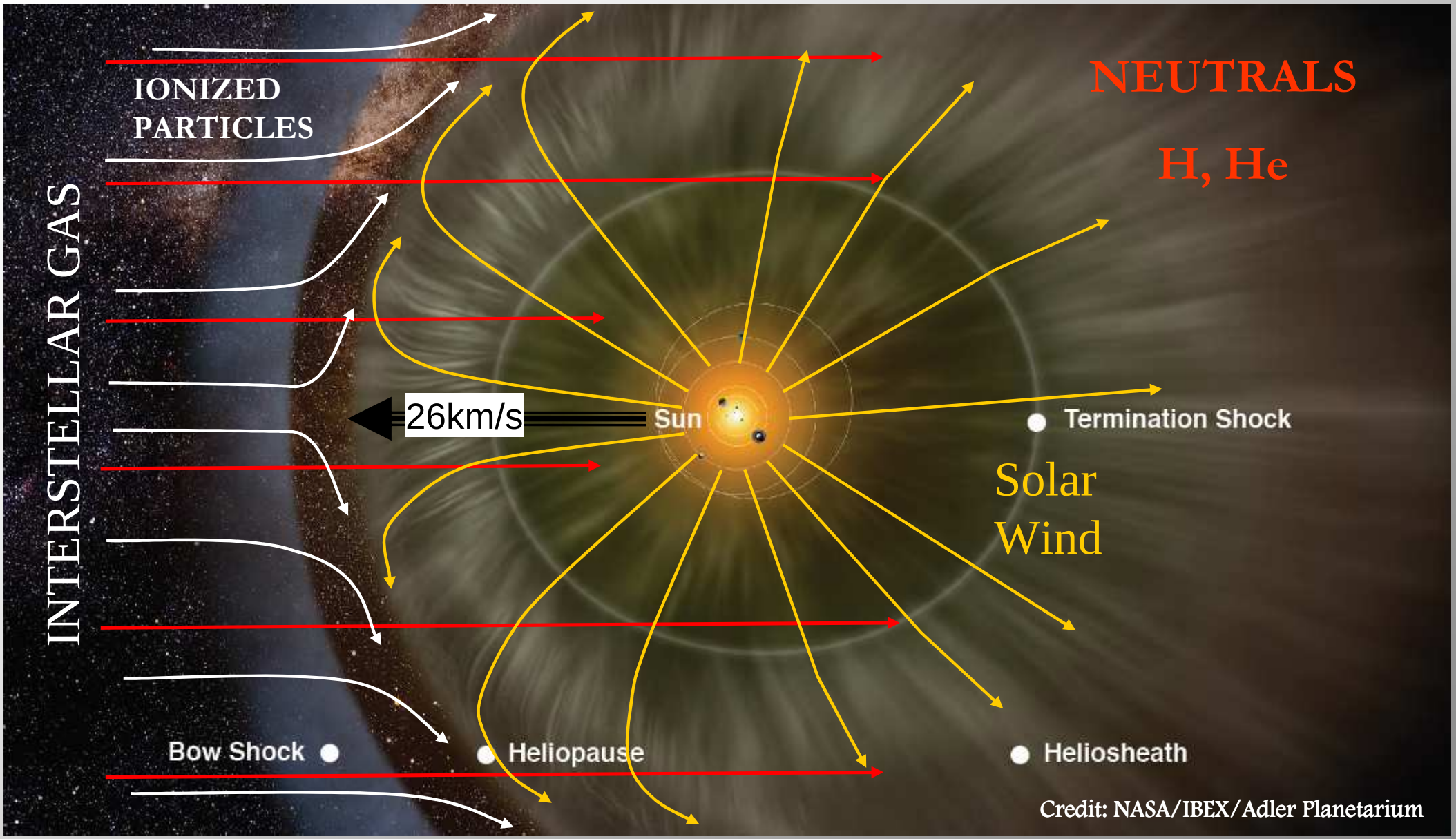


~ Empirical correction of the varying periods

~ Reveals the cosmic background features (non-varying)

~ But what about the non-varying solar system contribution???

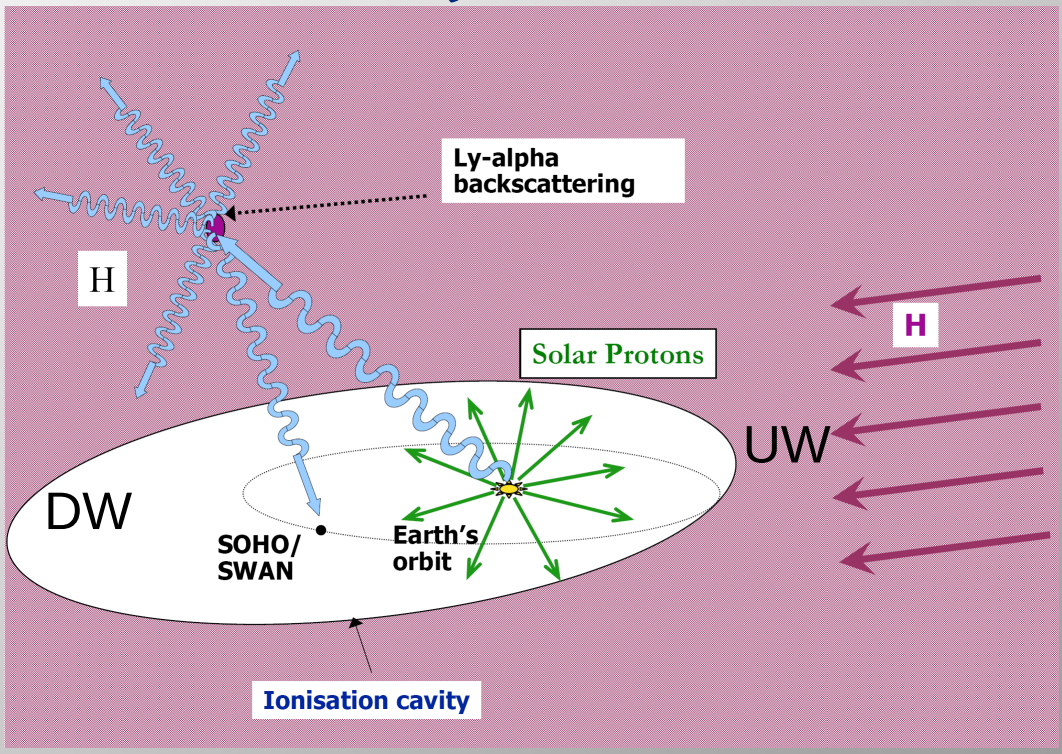
The heliospheric environment



Two species (H, He): different density distributions

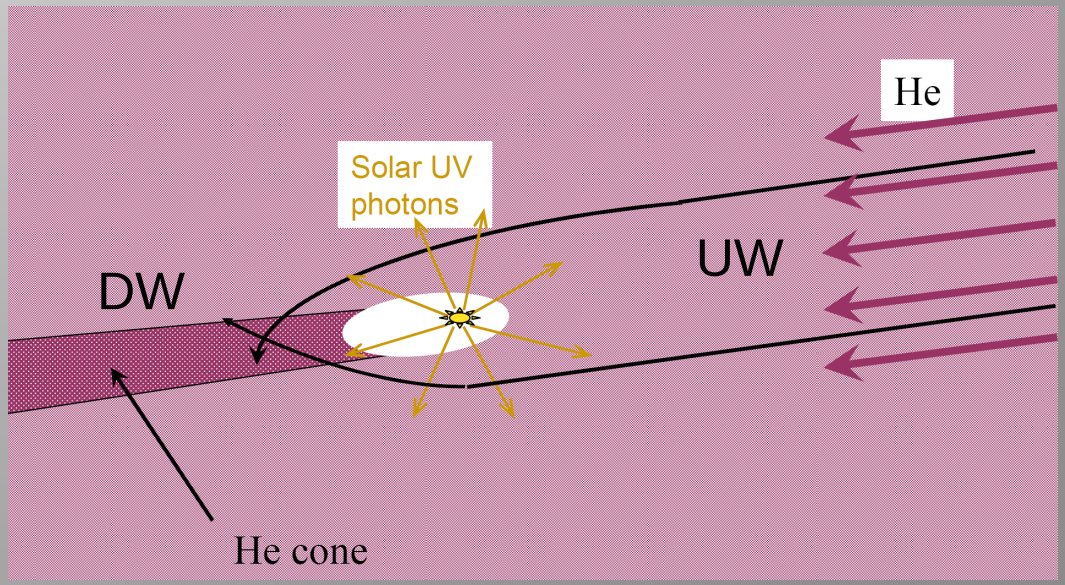
H atoms:
-Strong Ionization (CX with protons)
-Trajectories ruled by Radiation Pressure over Gravitation ratio

Observations:
-Ly-a, e.g. SWAN

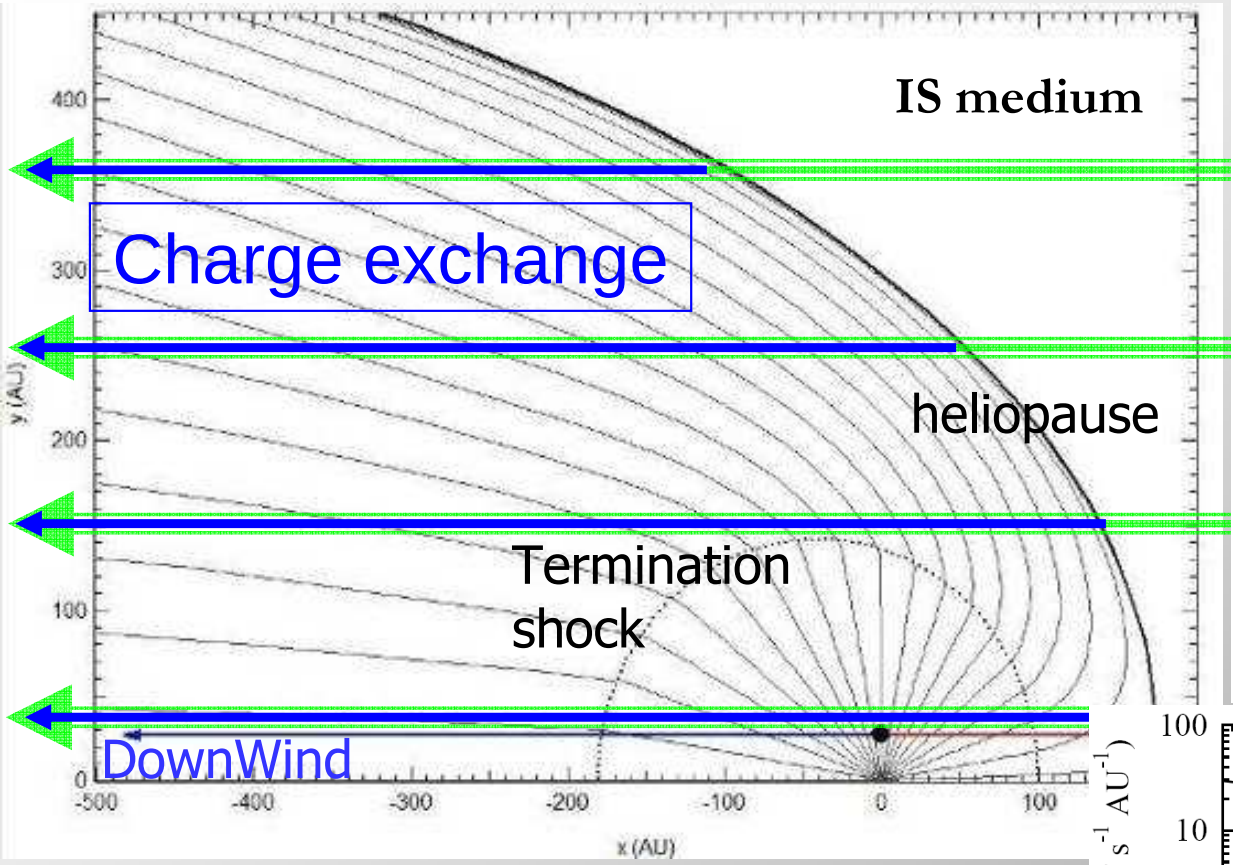


He atoms:
-Weak Ionization (UV photons, e^- impact)
-Strong gravitational focusing

Observations:
-58.4 nm, e.g. EUVE
-pick-up ions etc.



The SWCX heliospheric model



Three main ingredients:

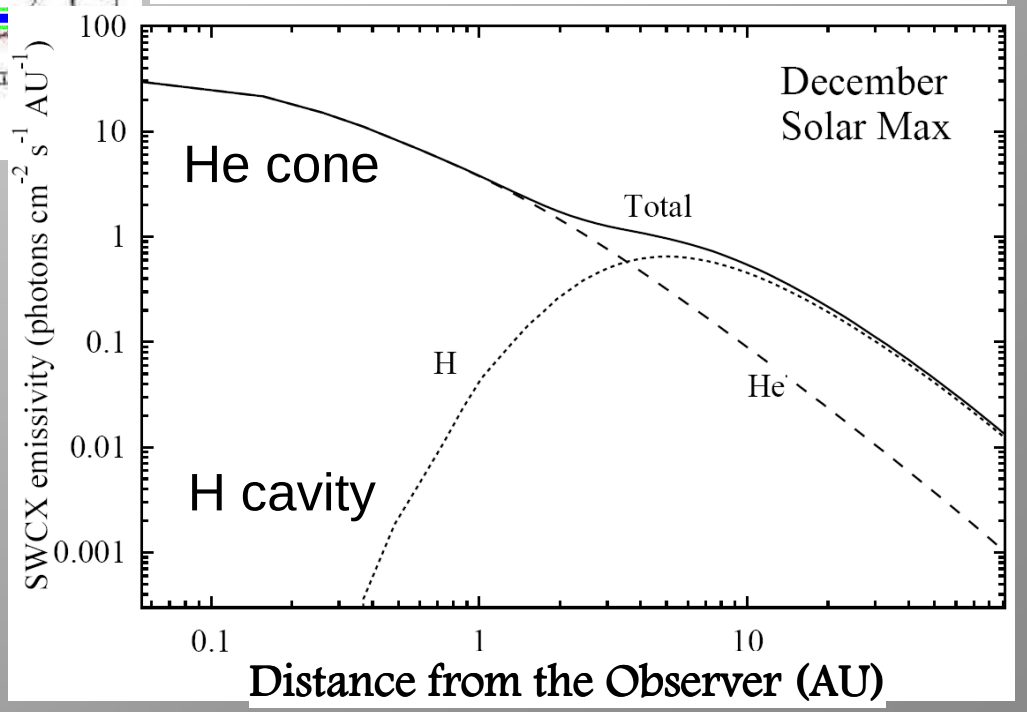
1. Neutral distributions
(e.g. IS H, He)

2. Ion distributions
(e.g. SW $O^{+7,8}$)

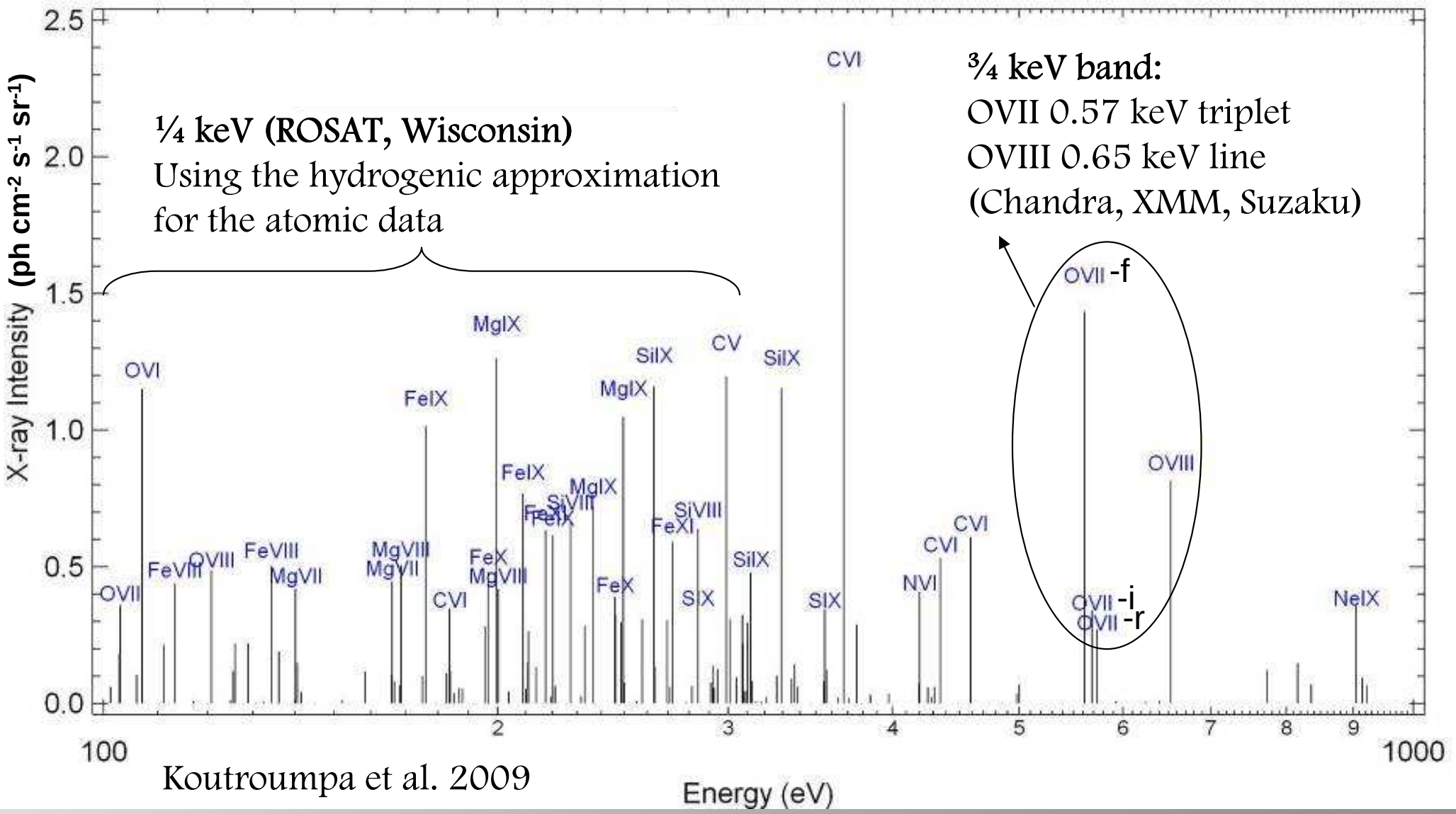
3. Atomic data:
   - CX collision cross sections σ
   - transition probabilities P(hv)

$$I(CX) \propto n_n \cdot n_i \cdot V \cdot \sigma \cdot P(hv)$$

- Surrounds Earth-bound observatories
- CX production up to the heliopause
- Emissivity drops very quickly



SWCX spectrum 0.1-1.0 keV



Koutroumpa et al. 2009

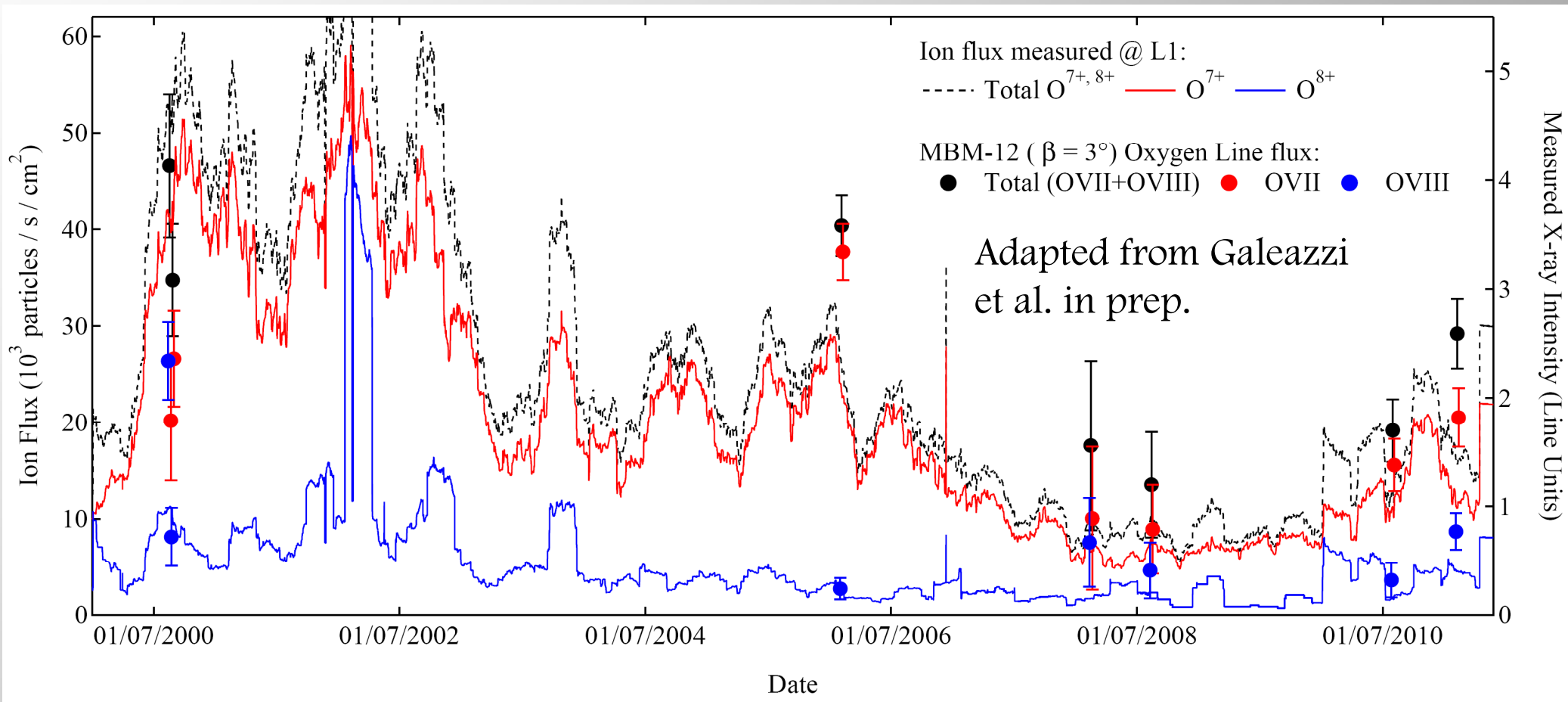
Same spectral lines (same ions) as a 10^6 K equilibrium plasma (APEC, MEKAL), but no continuum, and different line ratios (e.g., He-like triplets O VII, Ne IX)

(atomic database in collaboration with V. Kharchenko)

Large scale variations: solar cycle

-Influence on neutral distributions (e.g. ionization processes)
-Changes in SW ion flux/composition

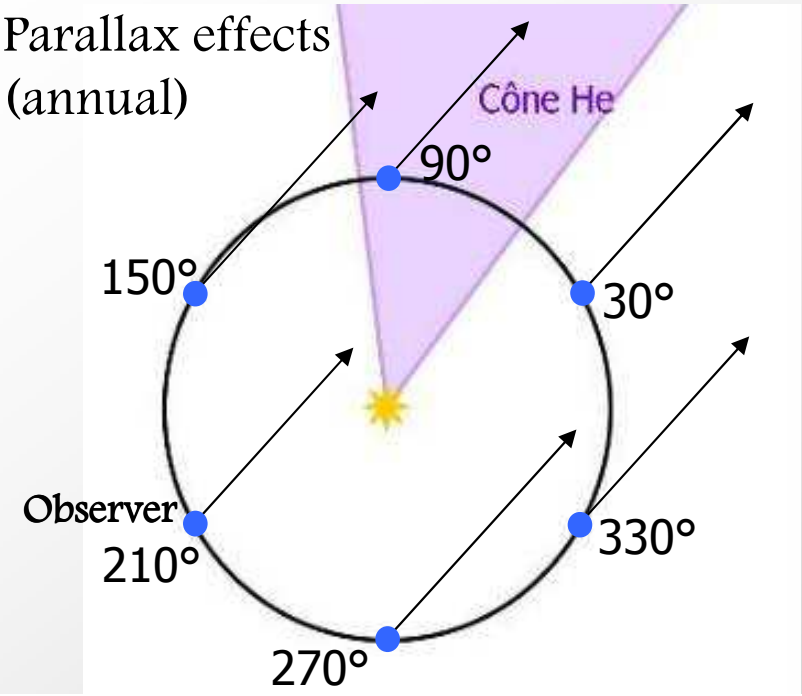
Oxygen (O^{7+} & O^{8+}) flux measured @ L1 with ACE/SWICS, averaged over 3 solar rotations (81 days)



(Not accounting for time-of-flight from L1 to the most emissive part of the LOS)

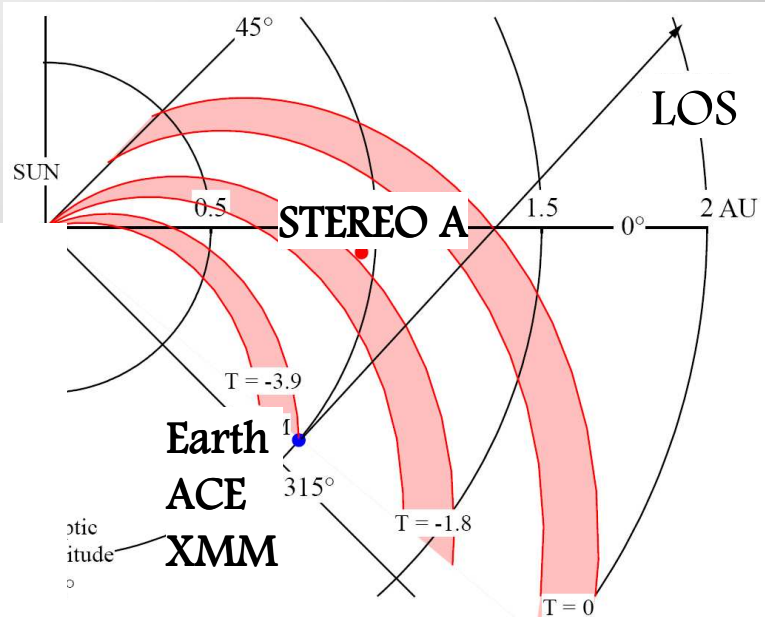
Short scale variations

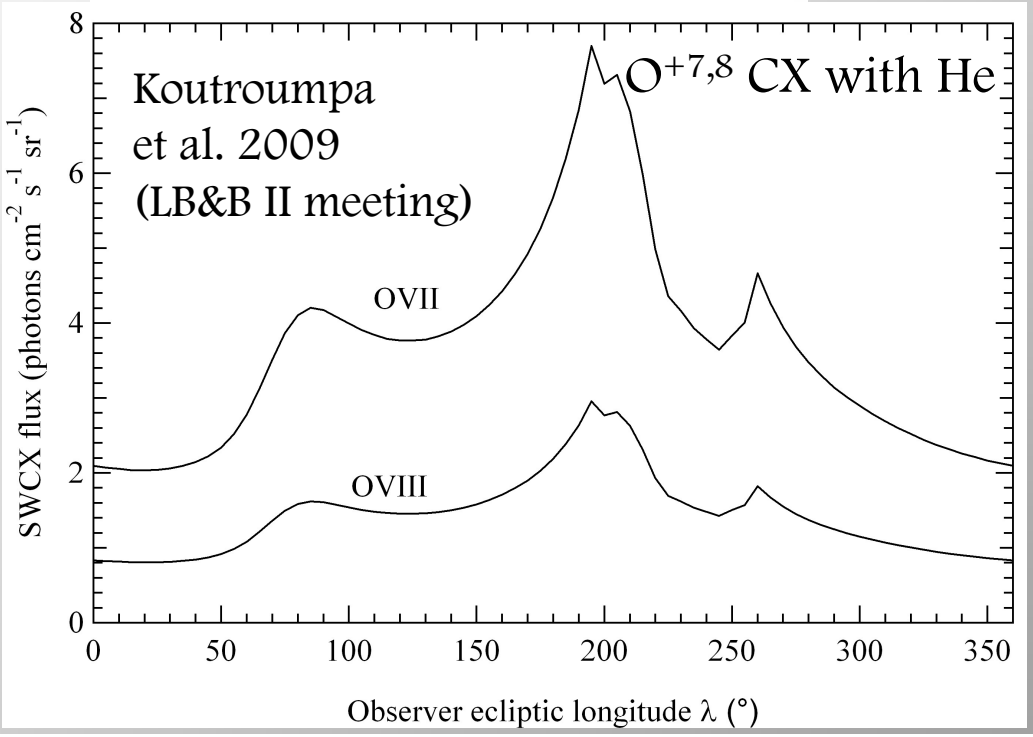
Parallax effects (annual)

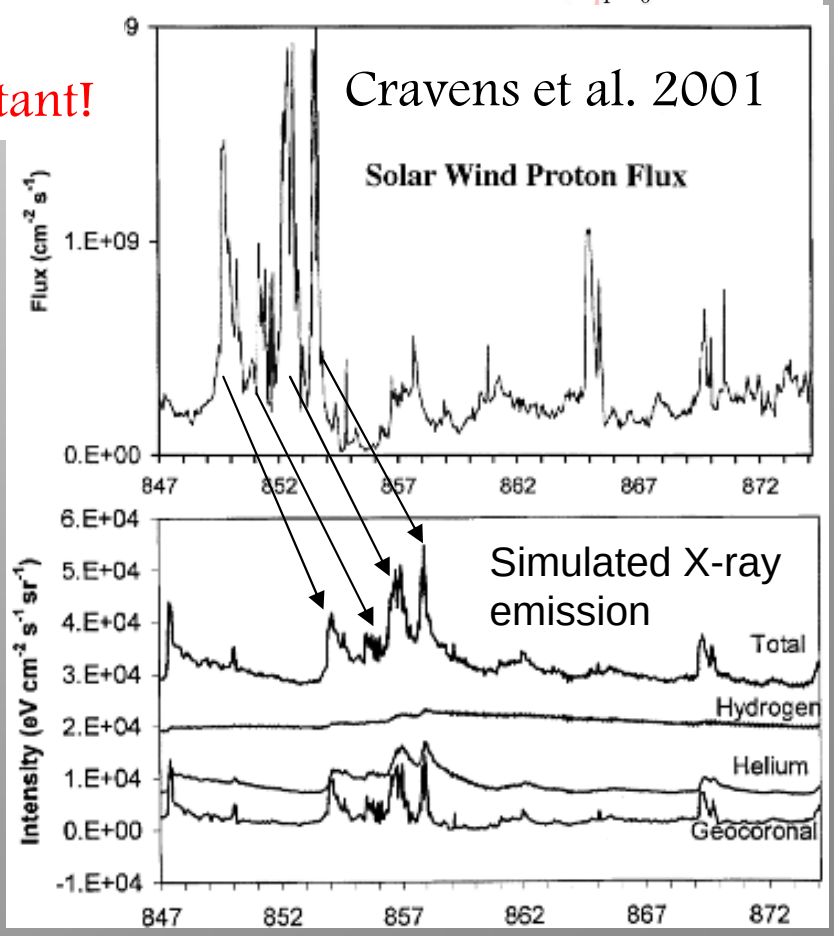


CME, CIR Enhancements (hours to days) Koutroumpa et al. '07, '09a, '11

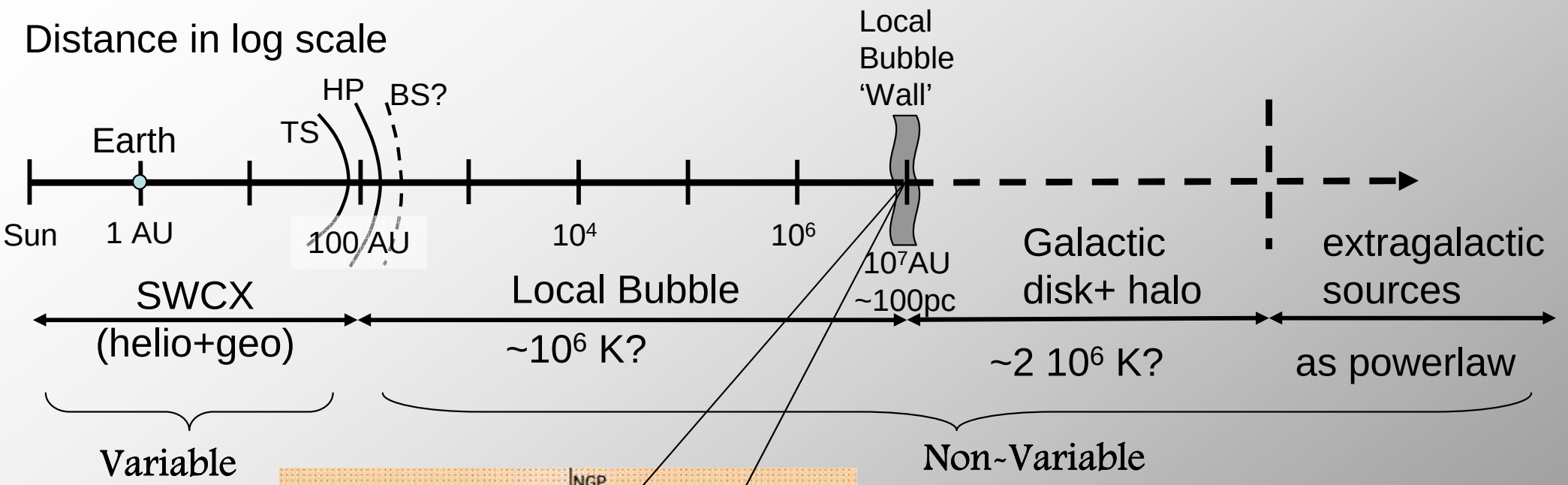
Observation geometry important!

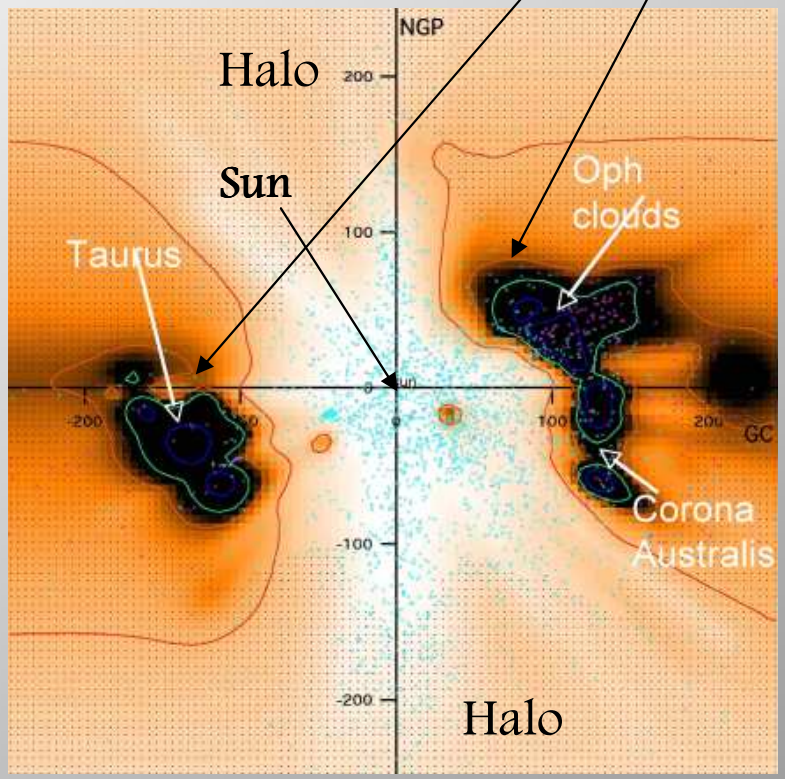






The diffuse soft X-ray background

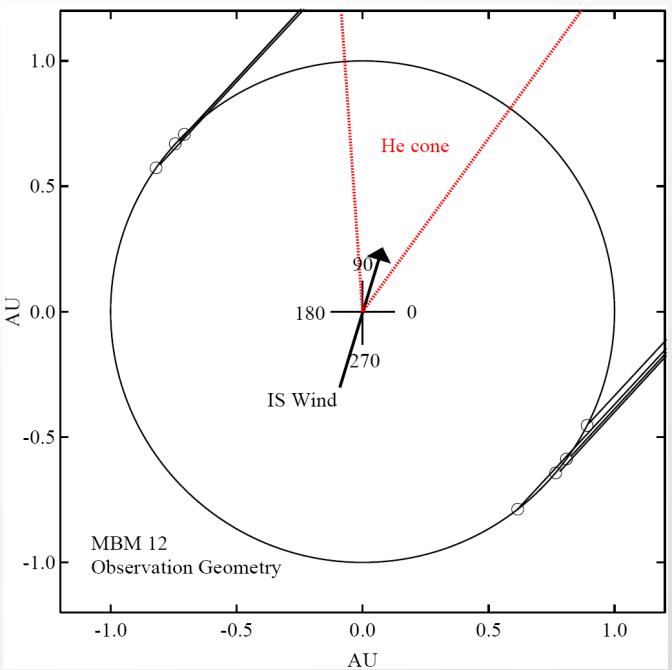




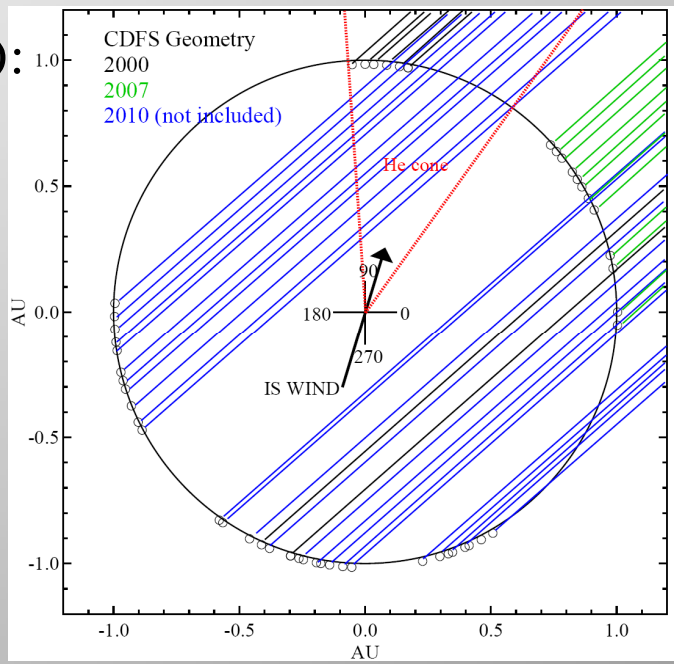
~Suzaku, XMM-Newton & Chandra observations over the last solar cycle (2000-2011)

~Using SWCX temporal + spatial variations to deduce the invariable cosmic background at different column densities N_H

Observation geometries/periods

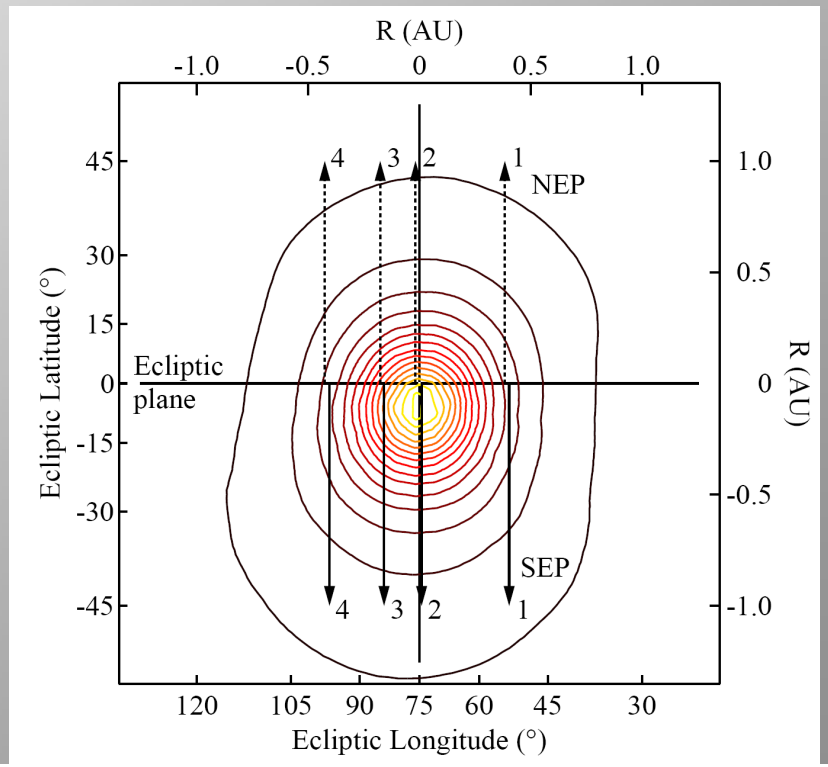


CDFS (N_H~10^{20} at./cm^2):
~Chandra campaign
~2000 ~ 2010 period
~LOS @ β=– 46°



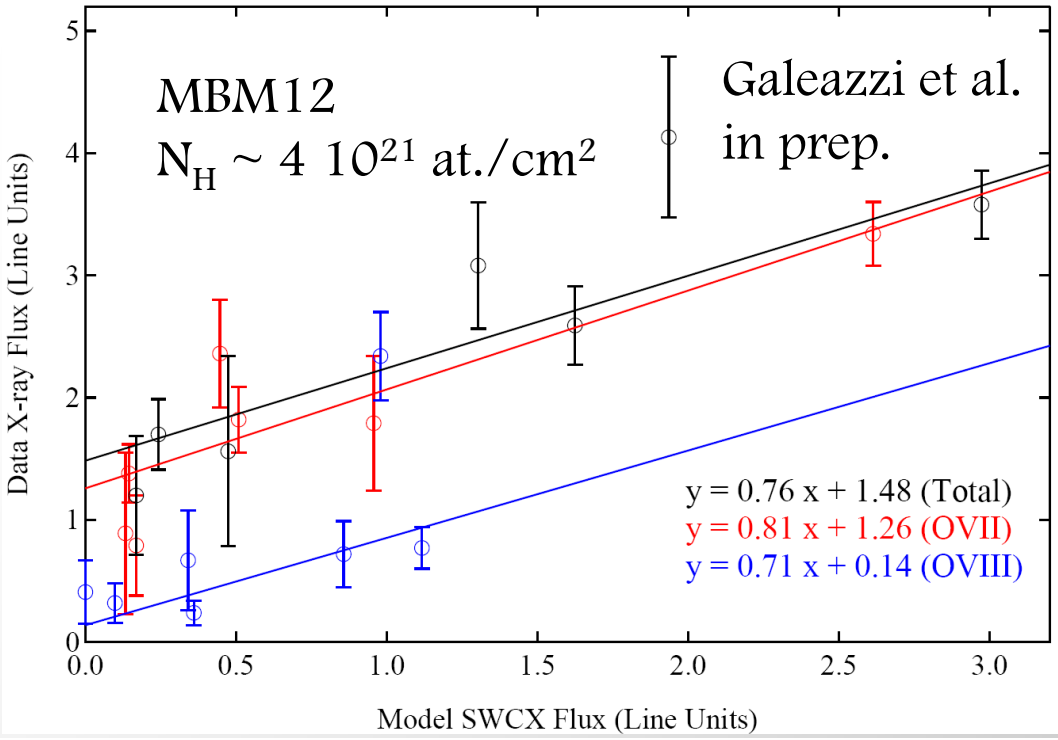
MBM-12 (N_H~4 10^{21}at./cm^2):
~3 instruments
(Chandra, XMM, Suzaku)
~2000 ~ 2011 period
~LOS ~ in the ecliptic

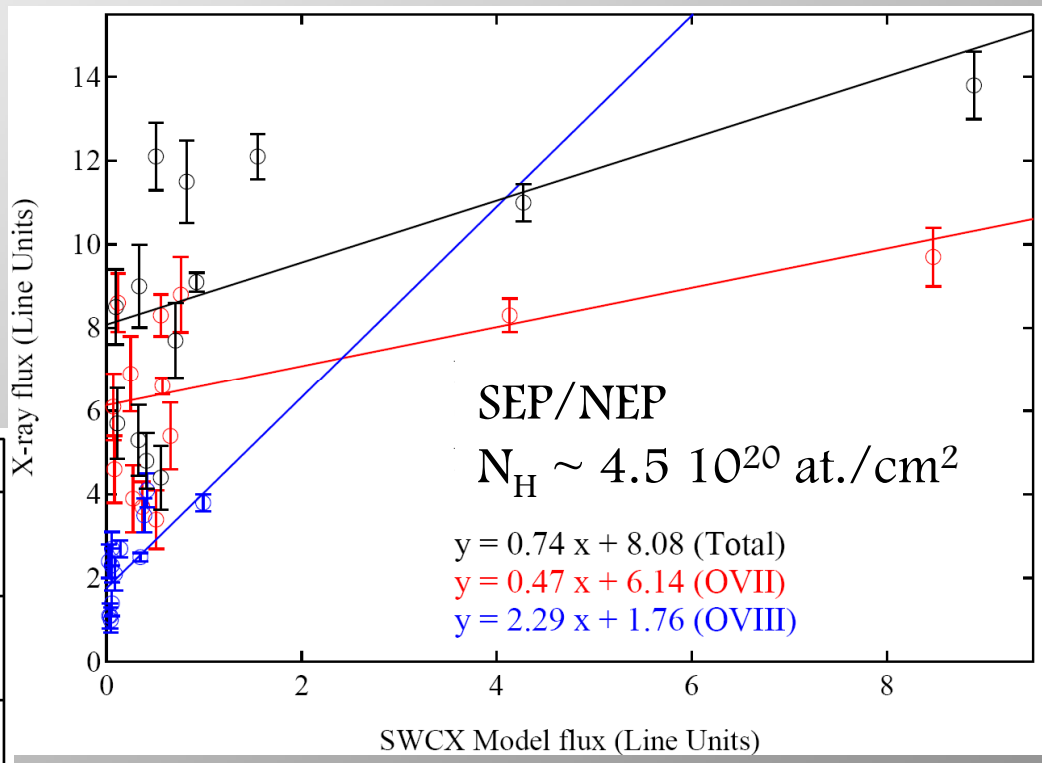
South/North Ecliptic Poles:
(N_H ~ 4.5 10^{20} at./cm^2)
~SWCX dedicated campaign
~Positions through the He cone
~XMM, Suzaku
~2003 ~ 2009
~LOS @ β = ± 90°

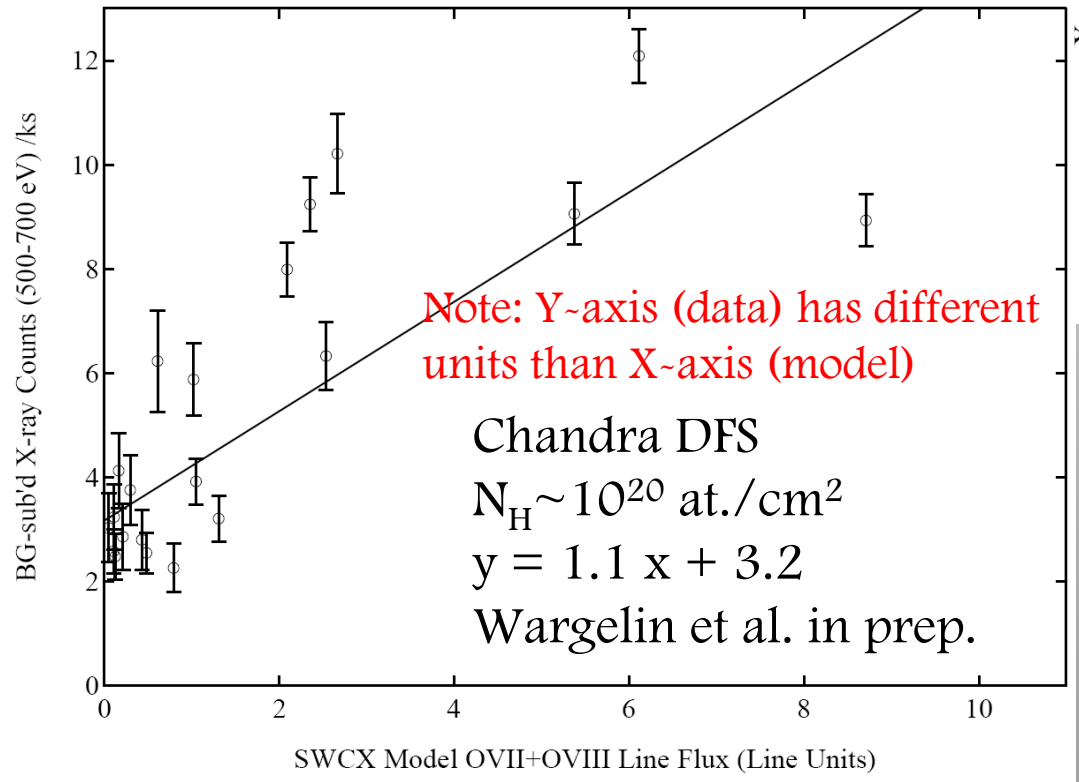


Data-Model preliminary fit results

Koutroumpa et al. in prep.



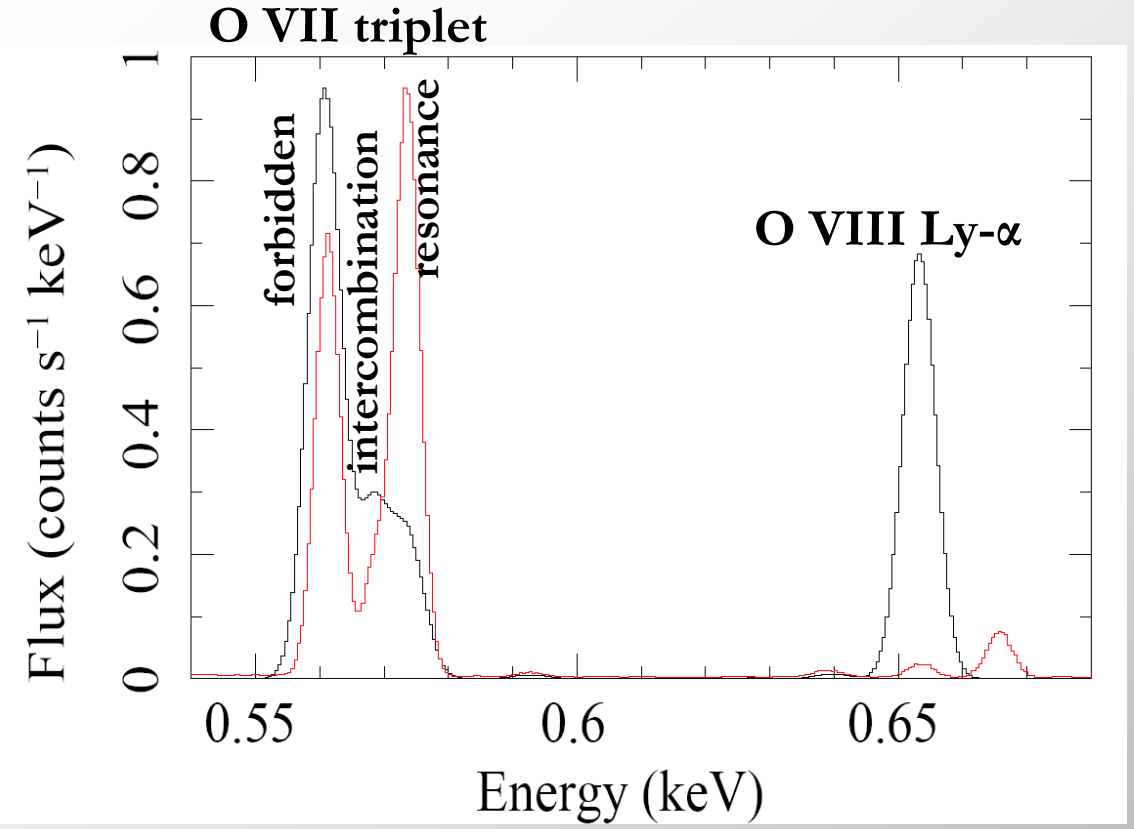




~General neutral distributions corresponding to the cycle period

~Simplified ±1 day real-time average O fluxes around each observation dates

CX spectral diagnostics



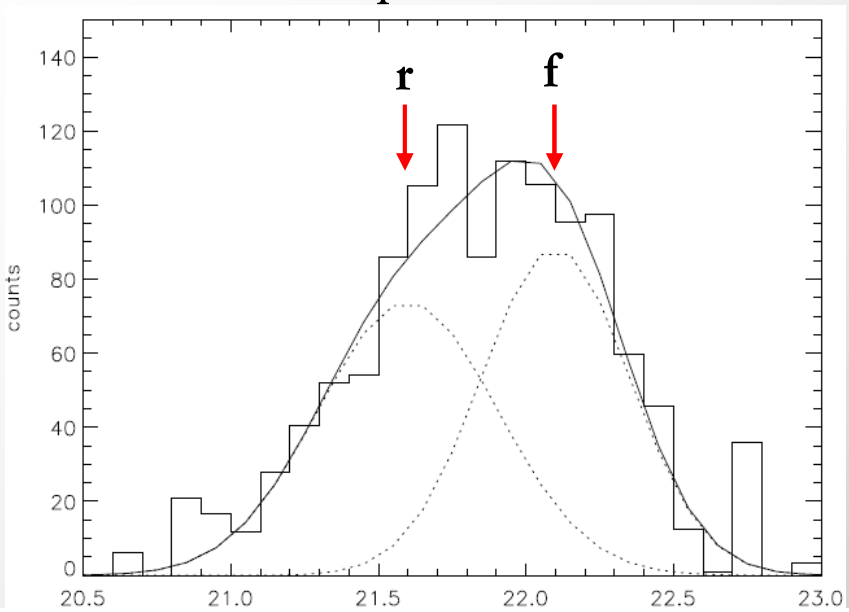
Thermal & CX models through a calorimeter (e.g. Astro-H), adapted from Snowden SSRV, 2009

- High n transitions
- Triplets (e.g. O VII): G=(f+i)/r
  - Thermal: G < 1
  - CX (depending on the neutral target): G > 2.2
- RGS resolution for point sources
- No instrument available for diffuse sources

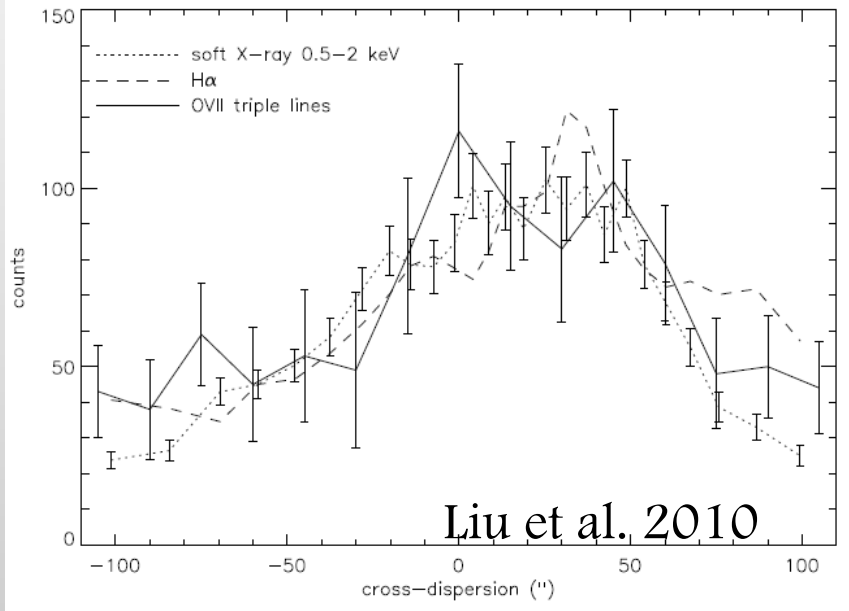
CX plasma diagnostics:
-Neutral/Ion Densities, composition
-Velocimetry (e.g. remote SW diagnostics from comet observations)
-Need for good spectral resolution (calorimeters)

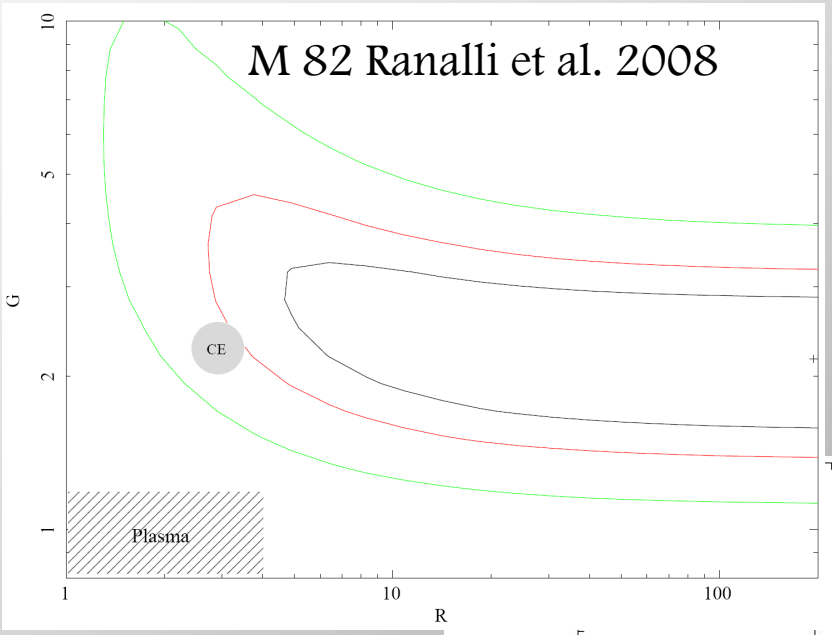
Possible CX examples beyond the solar system

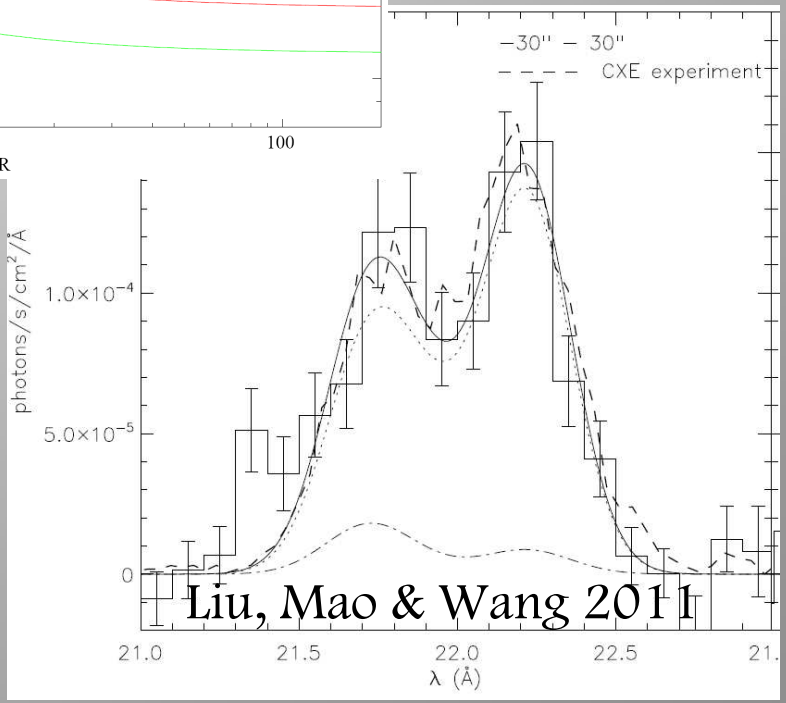
M 31: triplet OVII → CX



Corelation with cold gas Hα emission







Also:

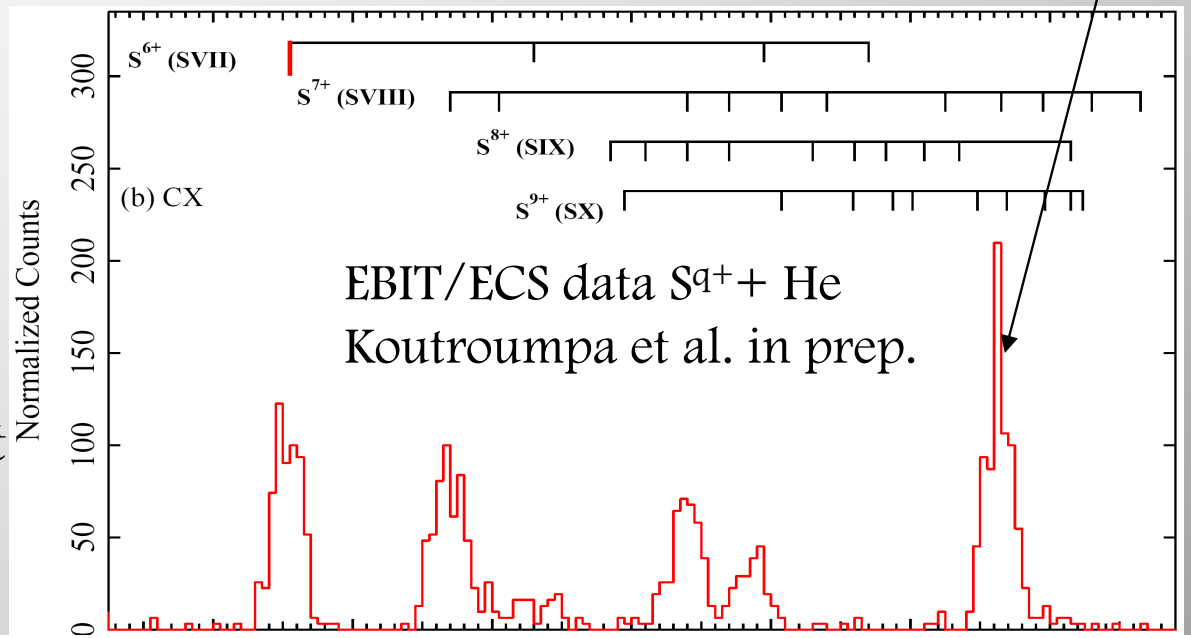
~Cygnus Loop: Enhanced He-like O K($\gamma + \delta + \varepsilon$)

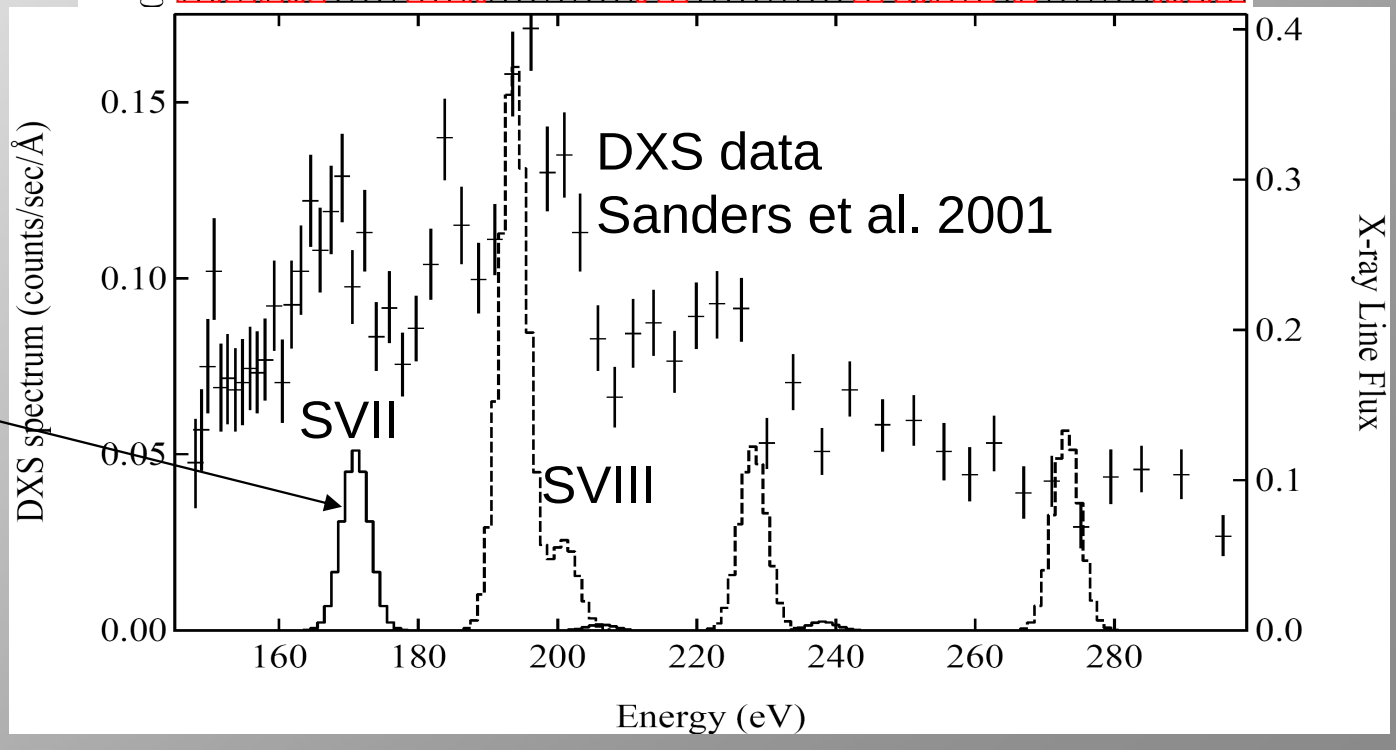
(Katsuda et al. 2011)

~Carina Nebula (Townsley et al. 2011a, b)

Need for detailed spectral models

- Atomic data:
  - Theoretical calculations
  - Laboratory data
- Models of hot/cold interfaces (see poster #22 Lallement et al.)





EBIT normalized data corrected for the ECS filter transmission & scaled to the respective S^{8+}, S^{7+} SW abundances

Conclusions - Perspectives

- SWCX → trace the short or long-term SW variations (comb. of geocoronal & heliospheric)
- You SHOULD care, because it's there even when it's NOT varying!
- SWCX (100AU) emission ≈ LB (100pc) emission → proves the efficiency of CX mechanism
- Multiple observations towards the same fields are the key to improve statistics, sample different solar activity periods
- DXL rocket mission to measure the SWCX variations through the He cone (2012)
  - Proportional counters with high effective area & large FOV (5 – 8 min data)

- CX important in other astrophysical objects (interfaces of cold/hot gas) + connexion to IS neutral gas distribution
  - Need to develop detailed spectral models
  - Atomic data (cross-sections, emission probabilities) imperative
- Future instruments (calorimeters) imperative for spectral diagnostics!