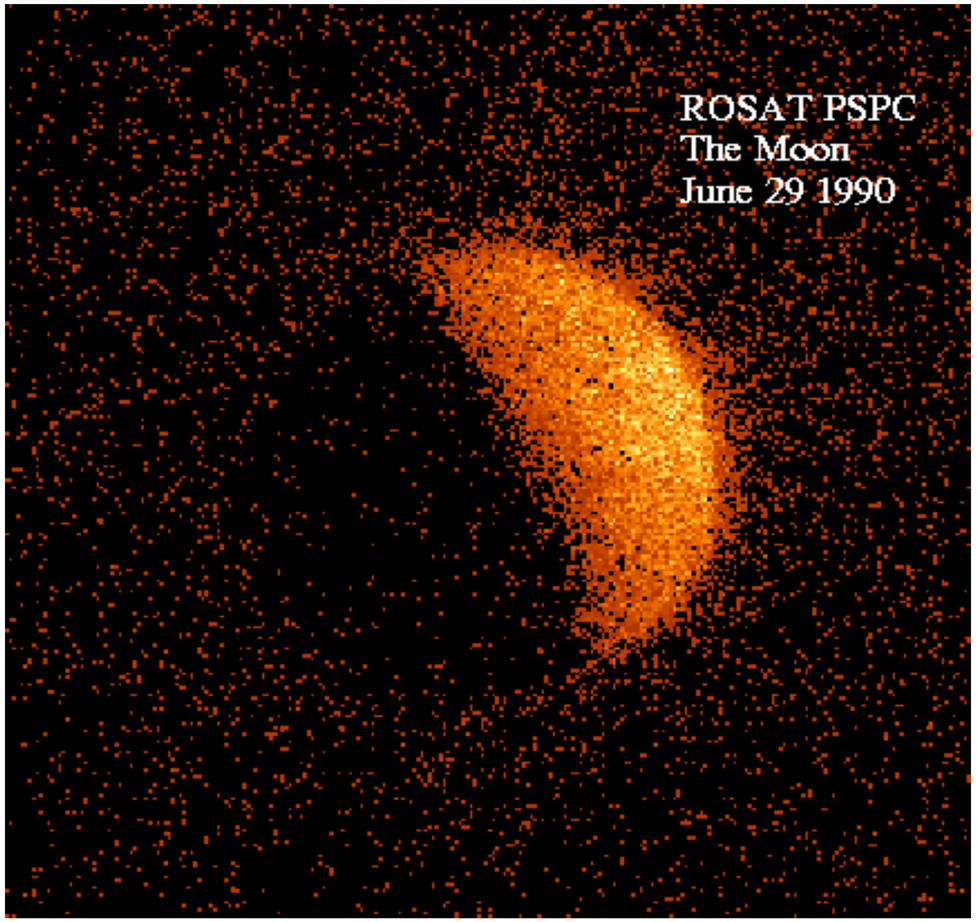
Summary

Some history, neglected topics, & questions

History

The unexpected detection of bright X-ray emission from comets, which could be explained only with charge-exchange



History

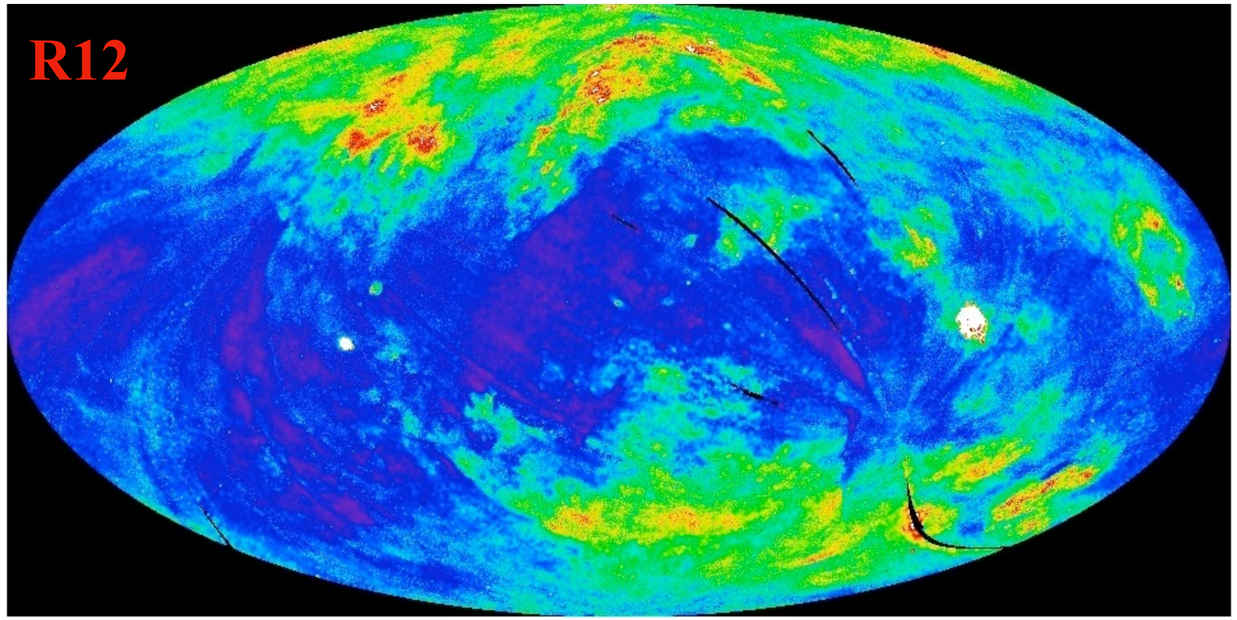
First seen by ROSAT in the All Sky-Survey, though it was not recognized.

The Long-Term Enhancements (LTEs) in the X-ray background with time-scales of hours to days.

Since each point viewed multiple times over successive orbits, the LTEs could be “measured” by a constrained minimization routine.

Steve Snowden did a pretty good job, what remains are

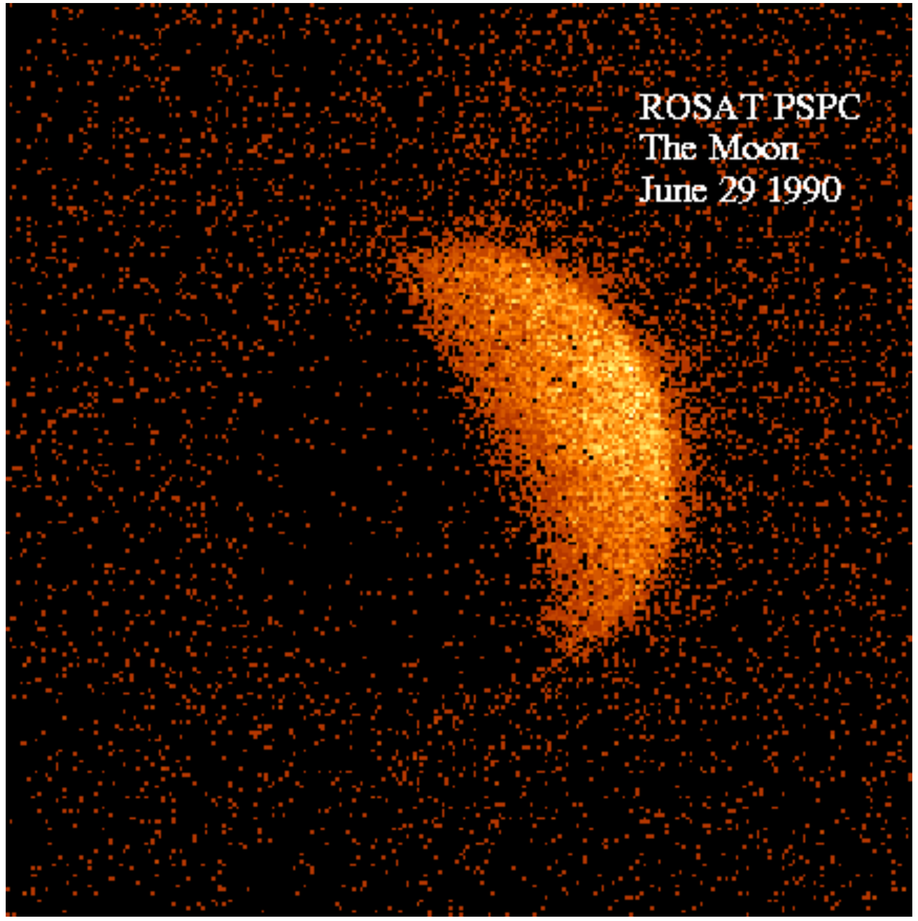
- Faint residuals of the LTEs
- Non-time-variable component of the SWCX



History

LTEs removed without actually knowing what they were, but…

Observation of the dark side of the moon had same rate as the contemporary LTE rate → the emission is cis-lunar



History

- Local Bubble and Beyond (1998, Garching, ROSAT/MPE)
  Correlation between ROSAT Long Term Enhancements and solar wind (Freyberg)
  Discussion of comet results
  Don Cox suggested that the entire heliosphere is glowing in the soft X-ray.
  Barry Welsh suggested that the Local Hot Bubble did not exist

- Local Bubble and Beyond (2008, Philadelphia, GSFC)
  Does the Local Bubble actually exist, or is the emission all due to charge exchange?
  Answer: tentatively yes.

- Charge Exchange X-rays in Current and Future Astrophysics (2015, Cambridge, SAO)
  “Down and Dirty” discussion of the nitty-gritty of the atomic data!

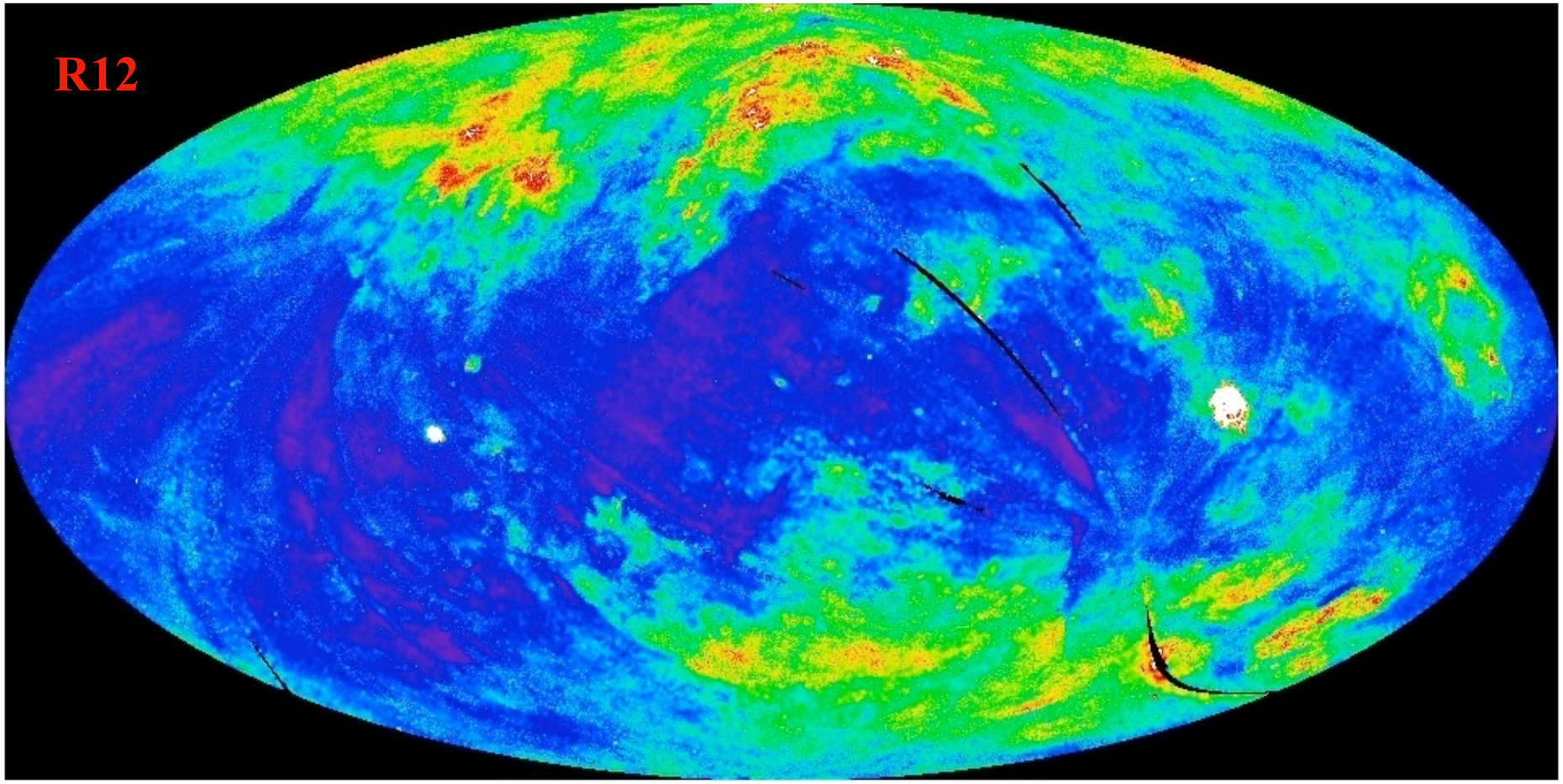
- Charge Exchange Universe (2024, Volos!)

History

The dark parts of the ¼ keV sky are still X-ray bright.

This emission is easily absorbed by very small columns of neutral H → local emission.

Is that emission due to the local Galaxy or is it heliospheric CX?



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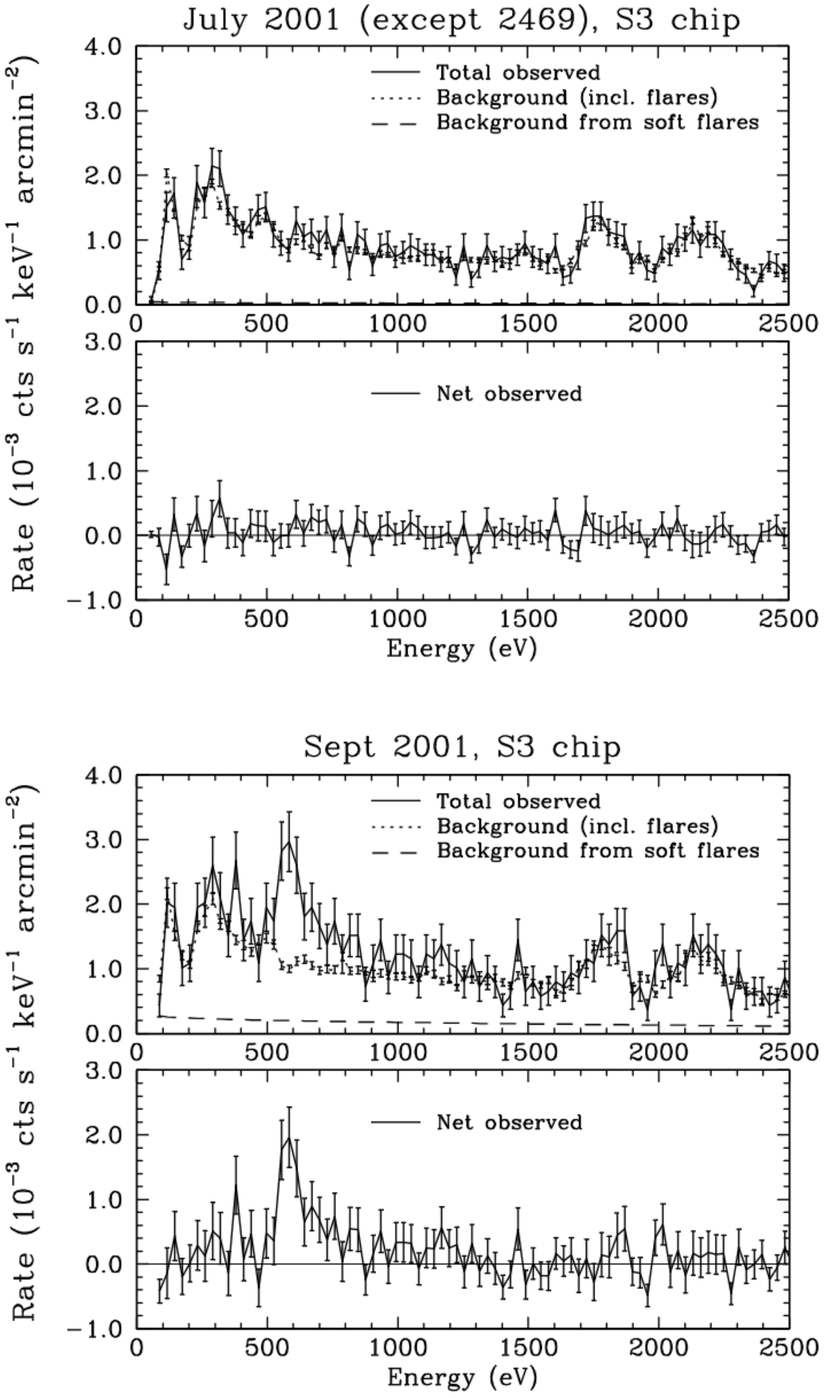
History

- X-rays from the dark side of the moon:
  - Time variable with O VII!



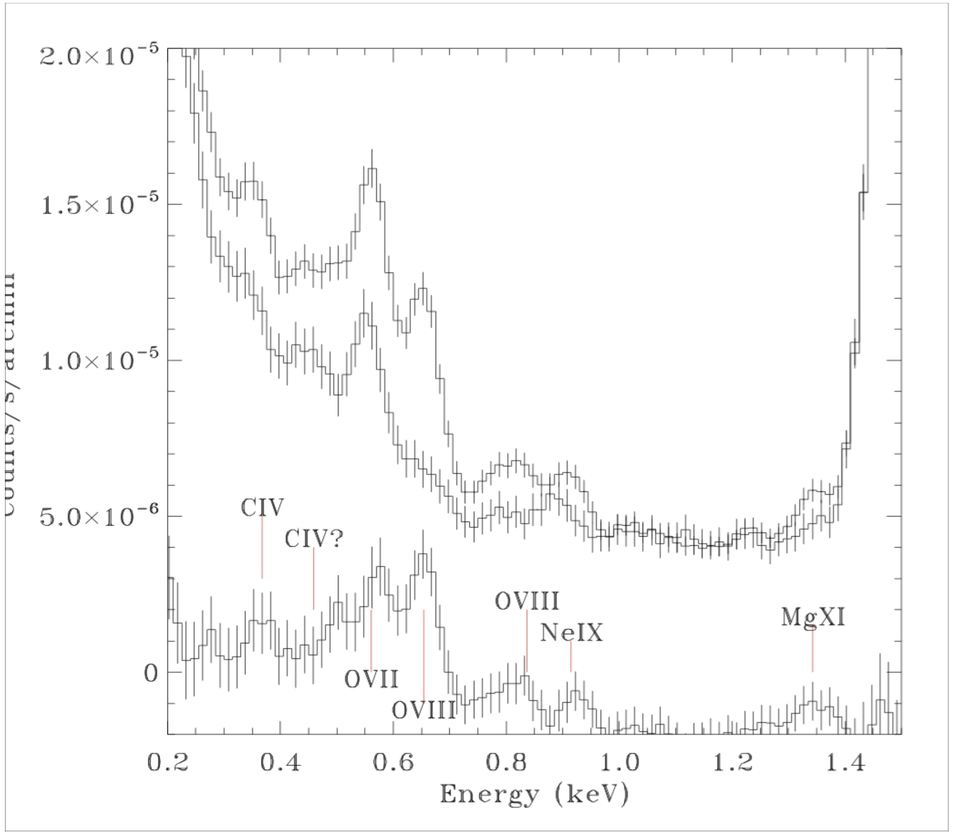
Wargelin et al 2004

Observational Verification

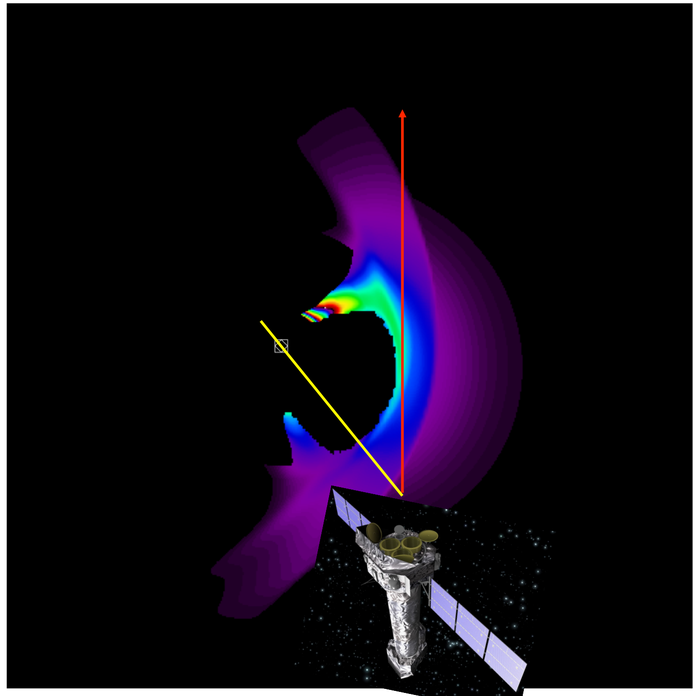
Magnetospheric Emission:

Detection in XMM observations of HDF-N

- comparing different observations of same field
- line of sight near the sub-solar point of magnetosheath



Snowden, Collier, Kuntz (2004)



xz cut of emissivity

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This Meeting

Tools for Understanding Charge eXchange

Using Charge eXchange as a Tool

Tools for Understanding CX: Atomic Data

• Calculation of σ

Significant progress over past years! Need theory to span parameter space not coverable by experiment.

But very little benchmarking so far.

• Laboratory Measurement of σ

L-shell!!!!!!

Simple lab set-ups produce results that are hard to compare to calculations, and good comparisons require difficult lab set-ups.

Remarkable progress has been made…and there are so many groups now…but it seems so slow.

In part because we often don't see the immediate resulting papers AND we generally have to wait for the results to show up in KRONOS…where we don't notice how much additional data has been added.

Is there a current review-type paper?

• Missions (Observation/Measurements of σ)

The era of high resolution spectroscopy of CX is (nearly?) upon us.

LEM *could* allow benchmarking using the object that we really want to study.

Tools for Understanding CX: Spectral Packages

ACX2 vs SPEX

Headline Saturday Night Fight!

But it would be nice if we had
a good understanding of
the differences in the results
of these two packages.

Using CX as a Tool

Anywhere "hot" gas and cold gas meet…

Using CX as a Tool

For a man with a hammer, the whole world's a nail…

We need to be careful, for example, an over-ionized plasma has the same triplet ratios as charge exchange. We can tell the difference *IF* we can see the higher-n transitions, but this may be difficult with complex spectra.

Charge eXchange as a tool

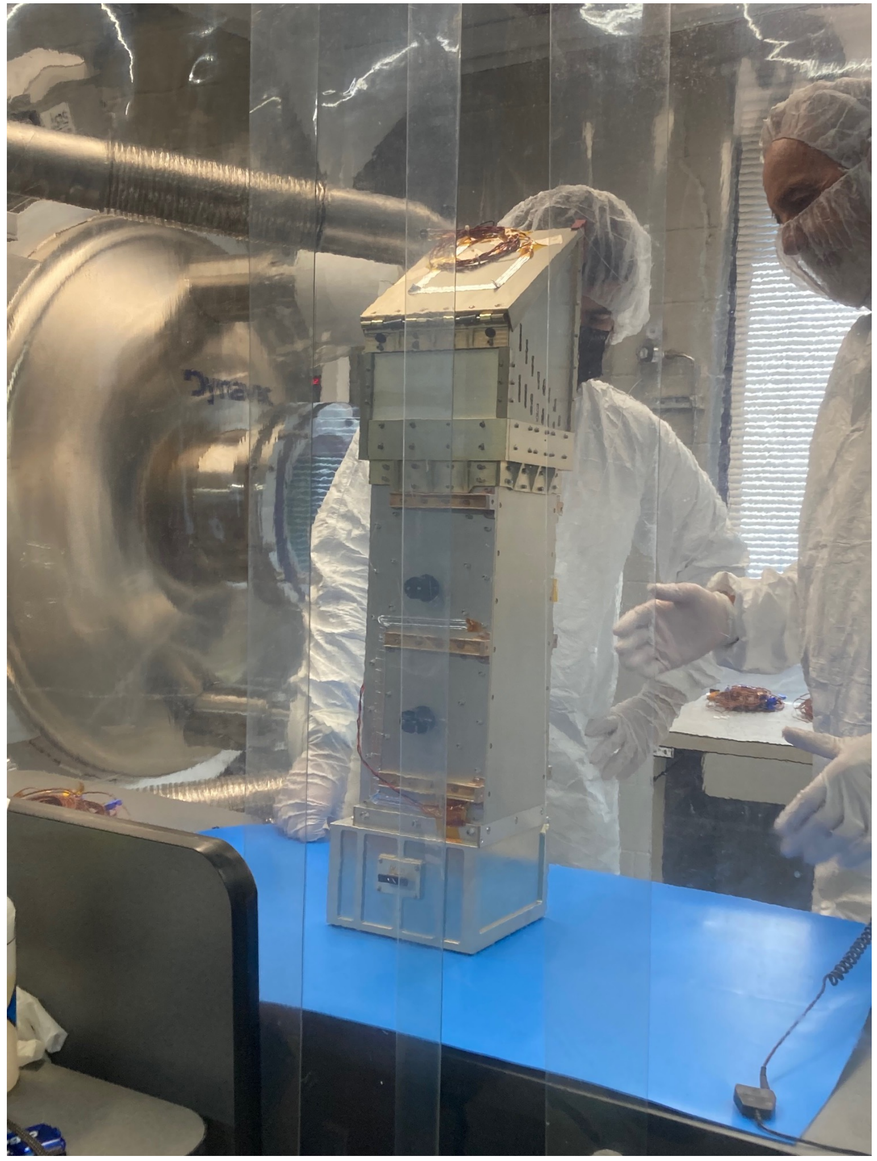
- Astrophysics Calibration - removing foregrounds
  If we want to diagnose faint emission from diffuse plasmas (LHB, Galactic Halo) we need to remove contribution from SWCX that is in the same lines.
- Space Physics - allows us to trace magnetic fields
  May or may not not require spectral information to separate CX from reflected X.
- Planetary - can use different species to track different sources of the ions
  Allows diagnosis of acceleration mechanisms and locations
- Heliophysics - samples solar wind abundances at different places in heliosphere
- Astrophysics -
  - Clusters of galaxies
  - Star-burst galaxies vs. AGN
  - Star-formation regions
  - Supernovae
  - Novae
  - Stars, stellar binaries, XRBs
  - Local Hot Bubble (at the boundaries?)
  - Heliosphere and Astrospheres

Missions

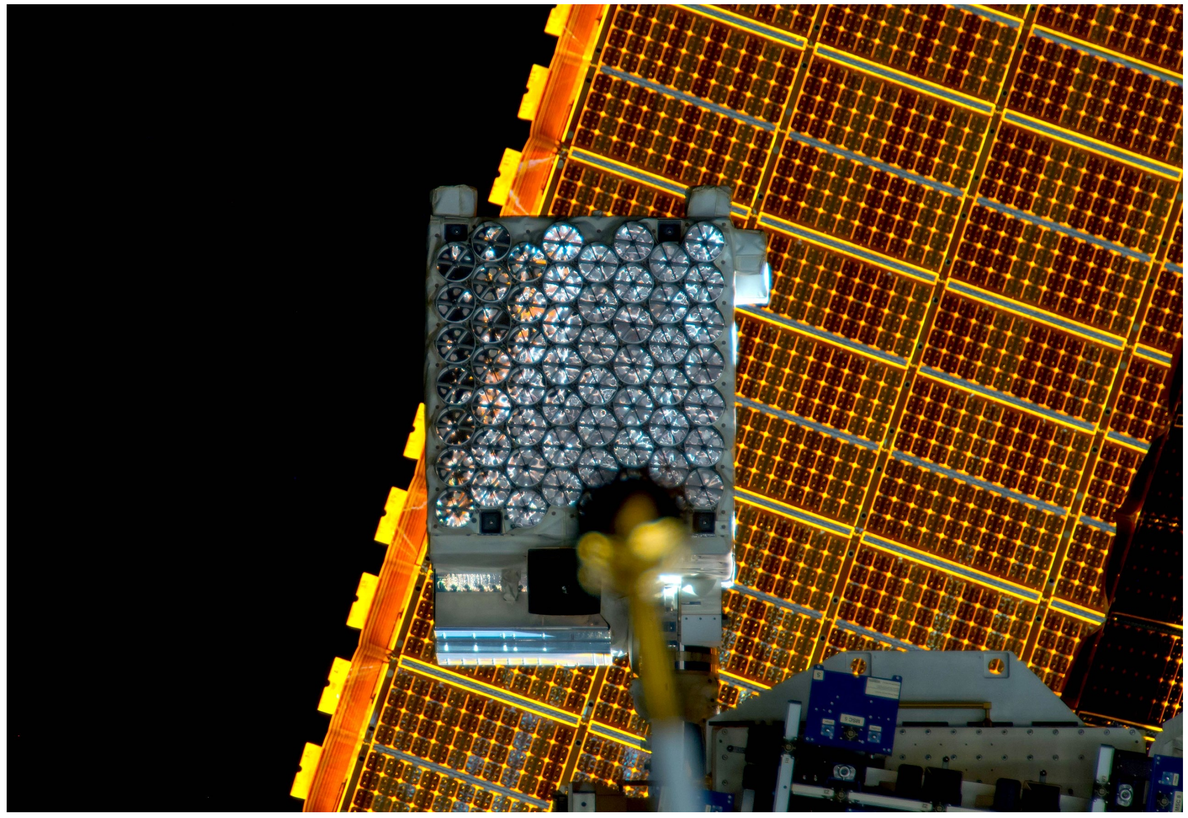
	Laboratory Astrophysics	Magnetosphere	Heliosphere	Astrophysical Objects
No Energy Resolution		LEXI STORM OWLEYE		
Minimal Resolution	ROSAT DXL	ROSAT DXL	ROSAT DXL	
Silicon/CCD Resolution		Chandra XMM Suzaku XTEND HaloSat NICER SMILE Geo-X	XMM HaloSat eROSITA (HSWCX)	Chandra (RGS) XMM Integral!
Maximally Resolved	RESOLVE? LEM	RESOLVE LEM	LEM-ASS	DXS XQC Gratings RESOLVE LEM

Some Missions Not Mentioned

LEXI ready for the Moon



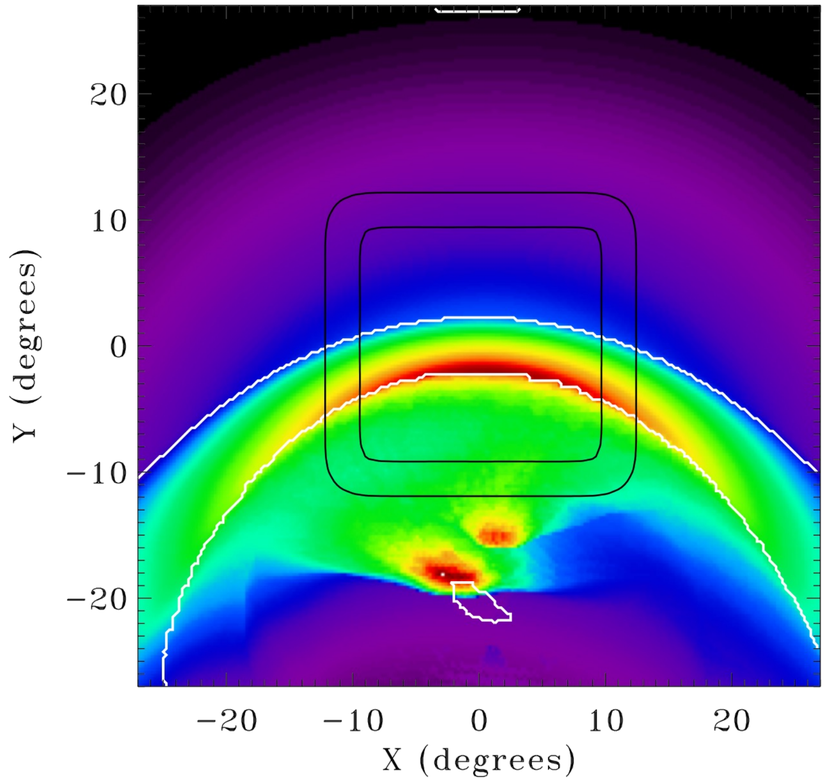
NICER on the ISS



No Energy Resolution

- No energy resolution required if you are just trying to figure out where the emission is:
  - LEXI (MCP), STORM (MCP planned) looking for magnetospheric from outside
  - OWLEYE (MCP) looking for cusp emission from sounding rocket

- OF COURSE energy resolution is useful, to remove backgrounds if nothing else
  - SMILE (CCD) most observations will sum over substantial fraction of bandpass

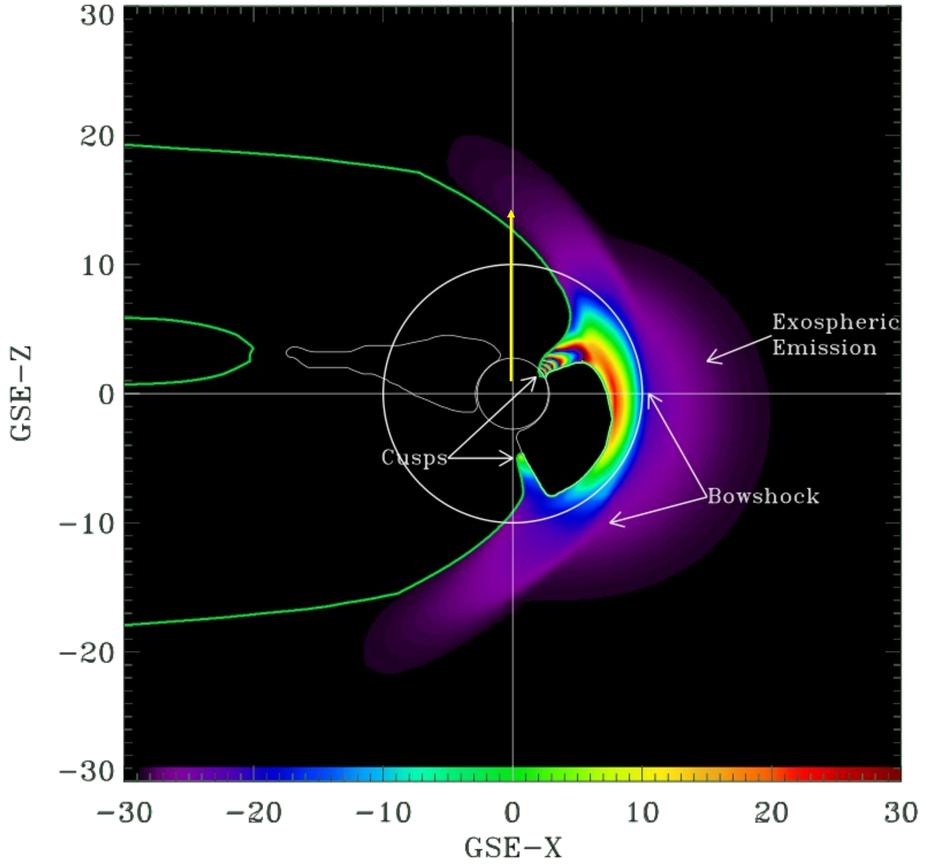


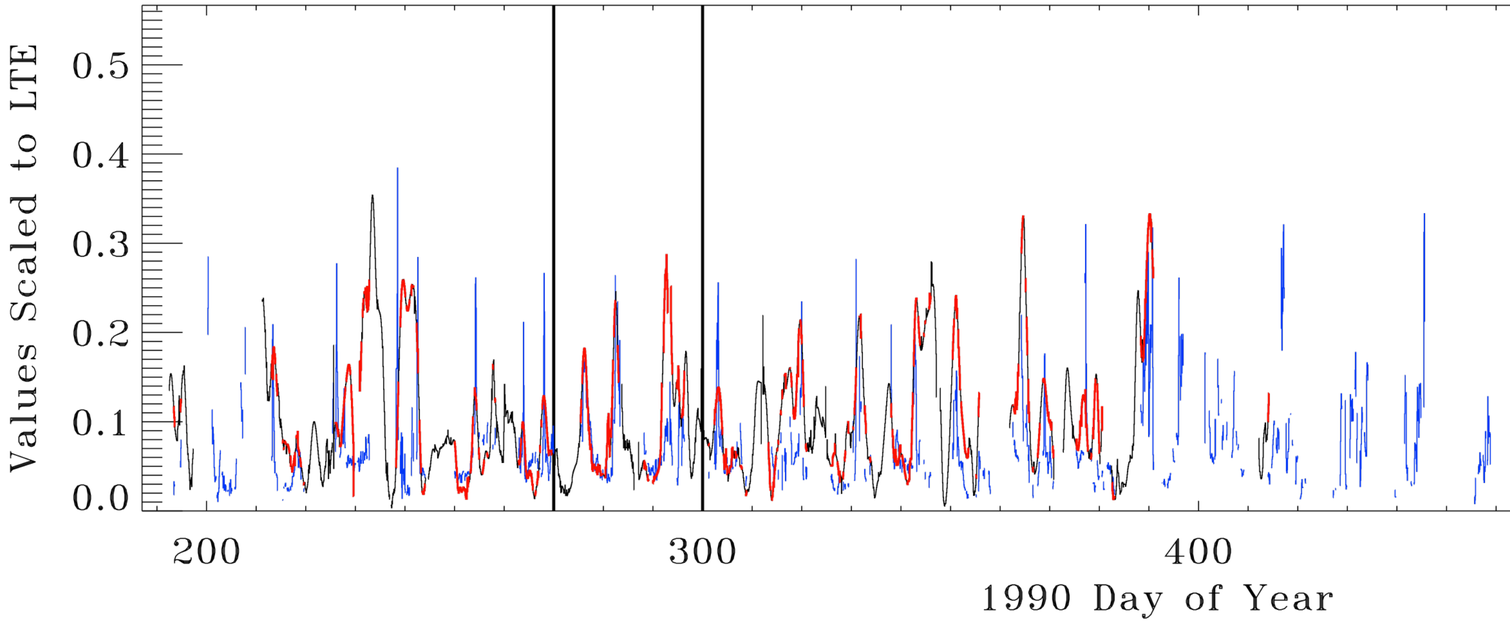
Minimal Energy Resolution

- Sounding rockets with proportional counters ($E/\Delta E \sim 1$) have large collecting areas

Silicon/CCD Resolution

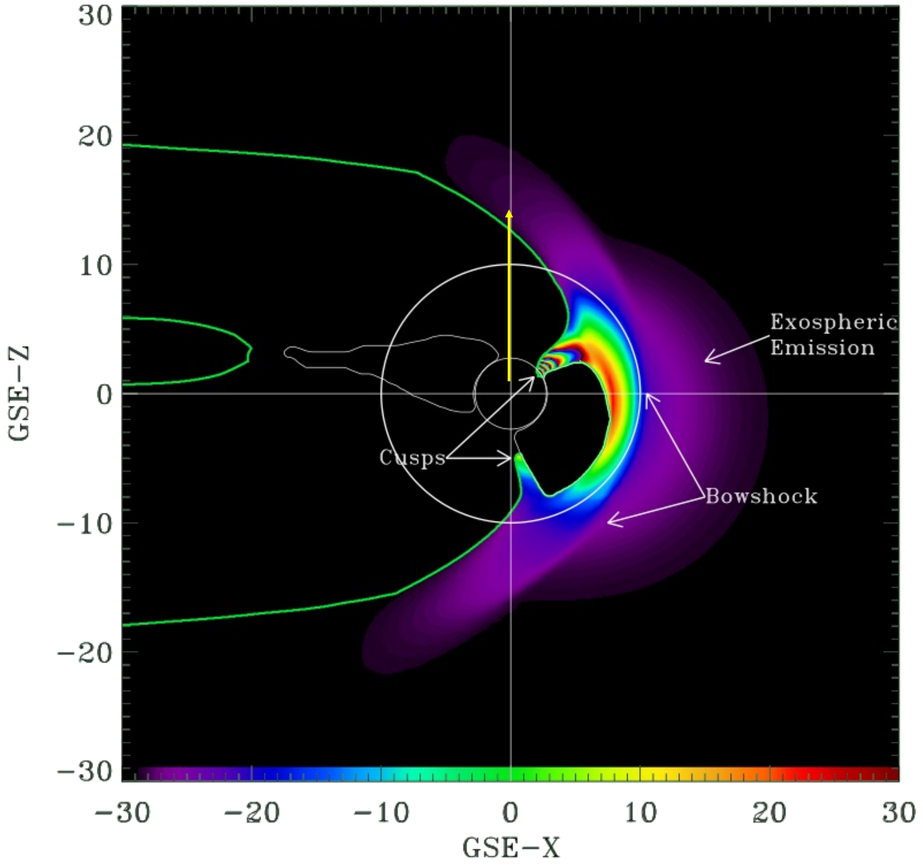
- LEO Missions provide a unique view of the magnetospheric emission
  - Short- and long-term correlations between SWCX and solar wind parameters





Silicon/CCD Resolution

- LEO Missions provide a unique view of the magnetospheric emission
  - Short- and long-term correlations between SWCX and solar wind parameters
  - The Suzaku archive is still producing interesting new results - mostly CME
    - e.g. the abundance evolution during the CME interaction
  - XRISM-XTEND will continue this work!



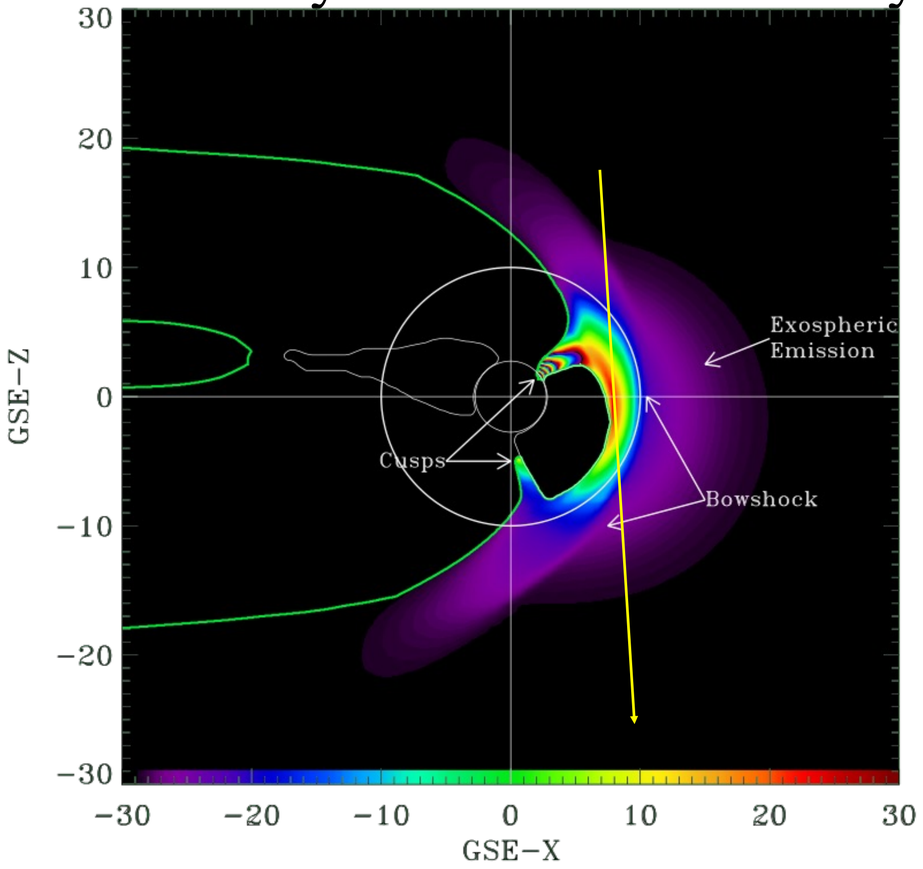
From Matteo Guianazzi's talk:

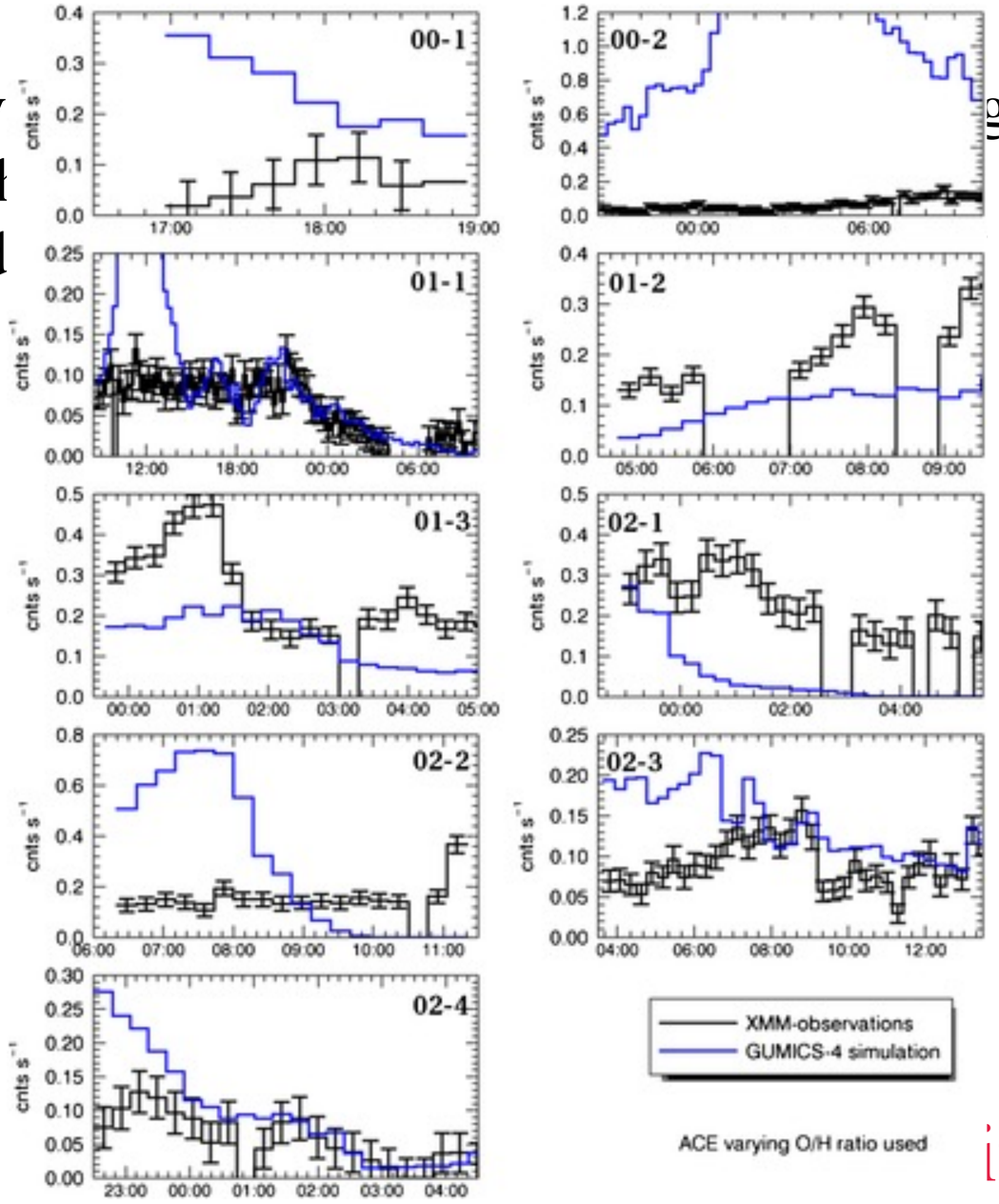
Fukushima et al. (soon)

Silicon/CCD Resolution

HEO missions

- Study of magnetospheric CX requires very
- Often FOV is very small, so easy to miss th
  - MHD models are notoriously bad at pred
  - Many correlations are really bad! (ACE)





Whittaker et al 2016

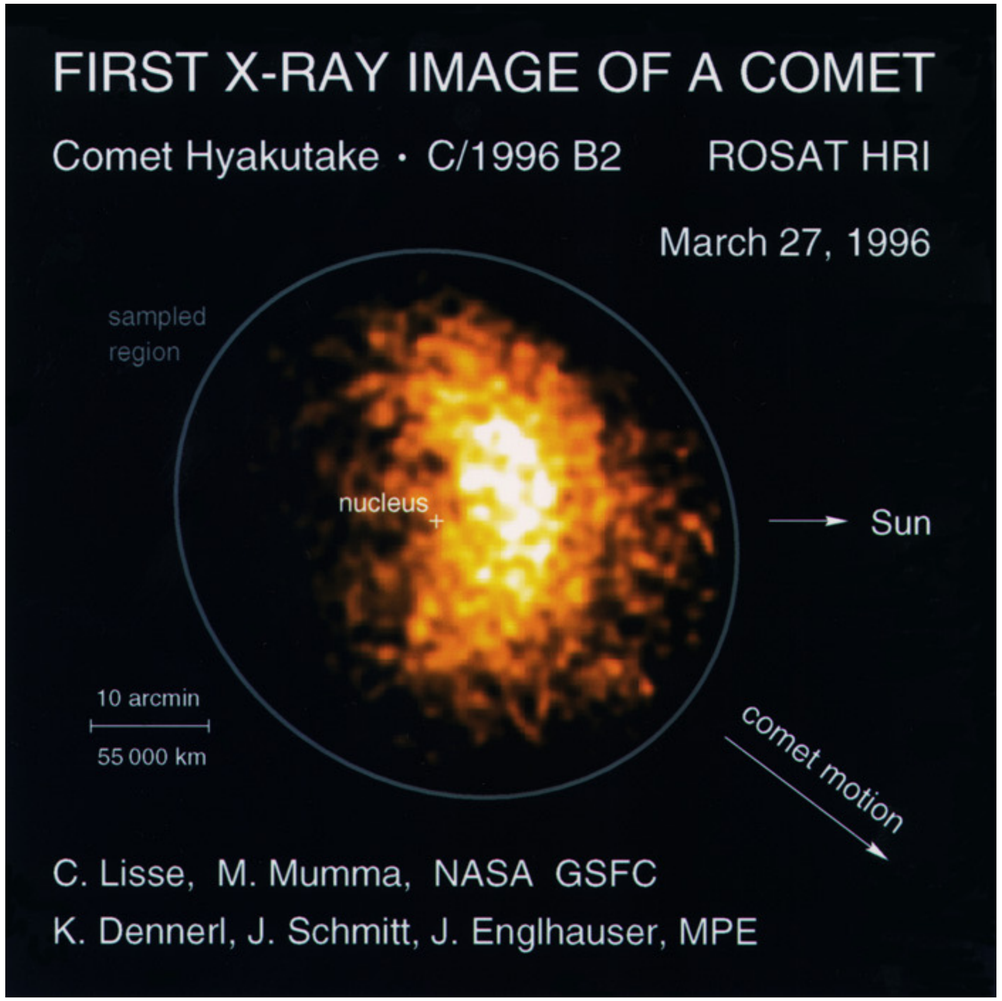
get

ifficult!

Silicon/CCD Resolution

Comets (LEO & HEO)

- Comet spectra reveal the abundances of the solar wind *at the location of the comet.*
- At CCD resolution the information is limited, but still of interest, esp. at high ecl. lat.
  - How much is enough at this energy resolution?



Maximal Resolution: XRISM-Resolve

- Small Astrophysical Objects - should be really good
  - Planets & comets? FOV may be problematic.

- SWCX observations of the magnetosheath or the heliosphere
  - Data restricted to corners as point source PSF files the bulk of the detector
  - After several years of building up the archive SWCX studies might be possible…

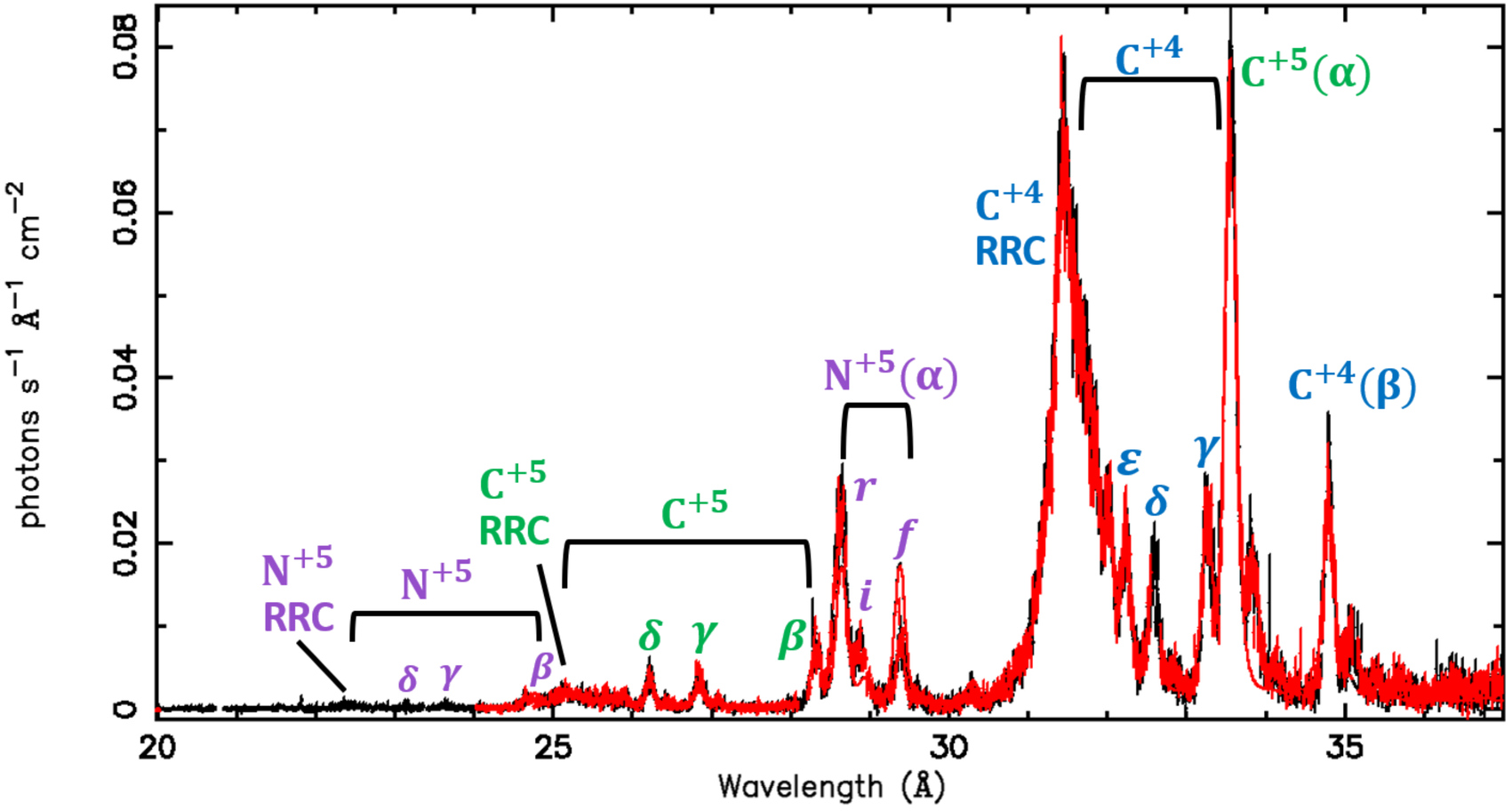
    …but would require a great deal of work!

Maximal Resolution

Complexity!

• Note how many talks about astrophysical objects spent more time talking about the system than talking about charge exchange; these systems are complex!

From Sharon Mitrani's talk an RGS spectrum:



Maximal Resolution

Complexity!

- Note how many talks about astrophysical objects spent more time talking about the system than talking about charge exchange; these systems are complex.
- At this resolution we do have to worry about the neutral donor!

  There are always going to be multiple species acting as donors in the ISM.

  To what extent may they average out?
- Multiple impact velocities along LOS?
- multi-e^- capture?
- dust/nano-particles?

Misc.

- Continued need for *in situ* measurements of the solar wind abundances
  - Vital for magnetospheric and heliospheric SWCX studies
  - Vital for removing SWCX from astrophysical observations
  - ACE (at L1) has always been a bit more restrictive than *Ulysses* (solar polar orbit)
    - Since 2011 has been very problematic to use
  - But significant issues with *in situ* measurements particularly at L1
  - *Elfen* is absolutely necessary at this point.

- UV!
  - Another important player in CX, but not well explored?

Thank You!