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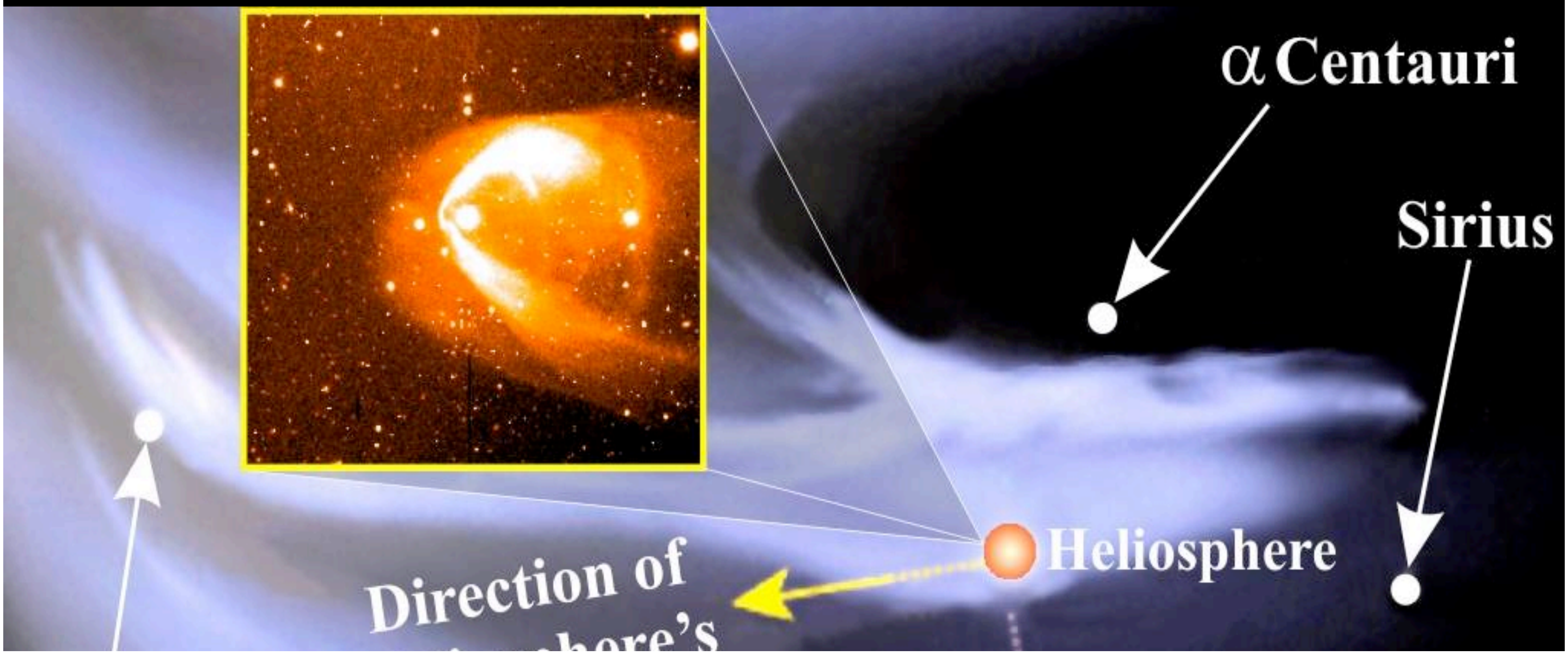
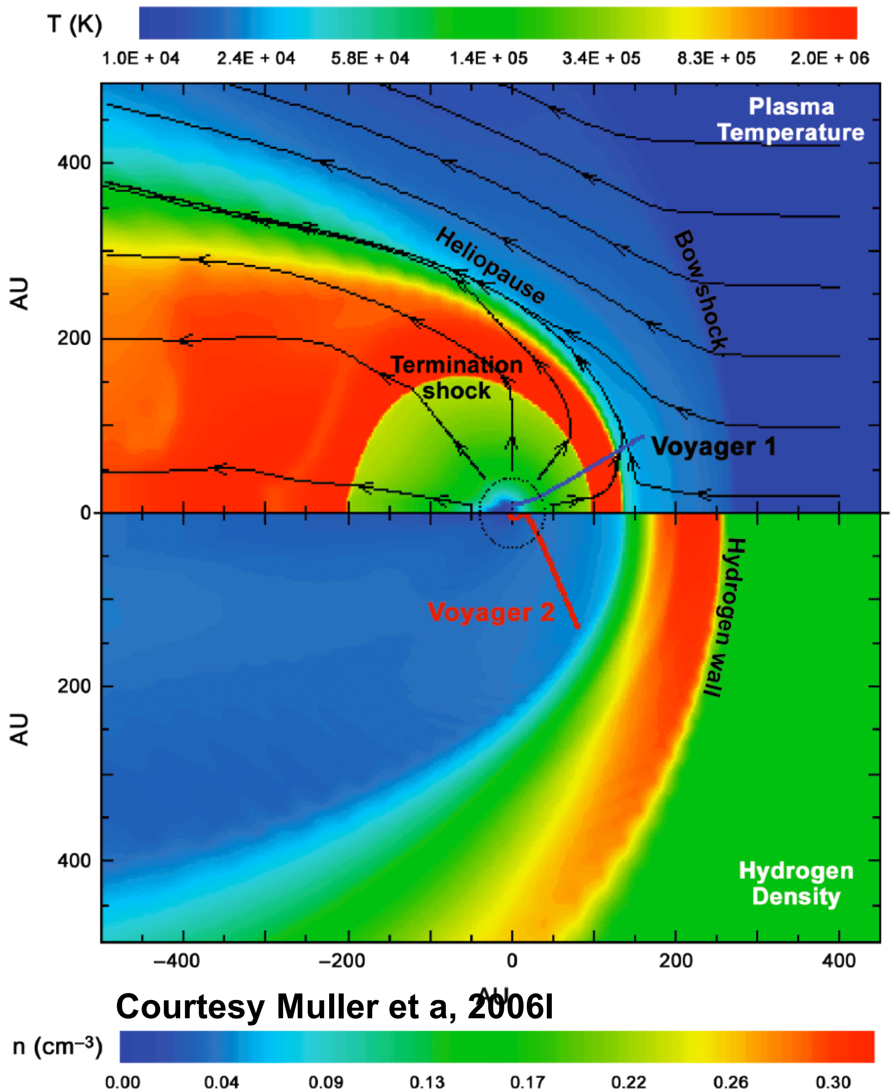
The Interstellar Interaction Observed

N. A. Schwadron on behalf of the IBEX Team



Interstellar Interaction Components

- Outflowing solar wind contributes vast majority of Ram Pressure
  - Time-dependence through Merged Interactior Regions and Solar Cycle and **longer term variations**
  - Heliospheric Magnetic Field (Heliospheric Falts?)
- The Local Interstellar Cloud
  - Inflowing neutral atoms give rise to a hydroge wall
  - Pickup Ions Carried Out By the Solar Wind (leading to ACRs)
  - Interstellar Magnetic Field
- Energetic Particles
  - Galactic Cosmic Rays
  - Anomalous Cosmic Rays
  - Suprathermal Tails
- Dust, Grains
  - From interstellar medium
  - Kuiper Belt grains
  - Outer Source for Pickup Ions (heavy composition)



Courtesy Muller et a, 2006l

Where is the Nose?

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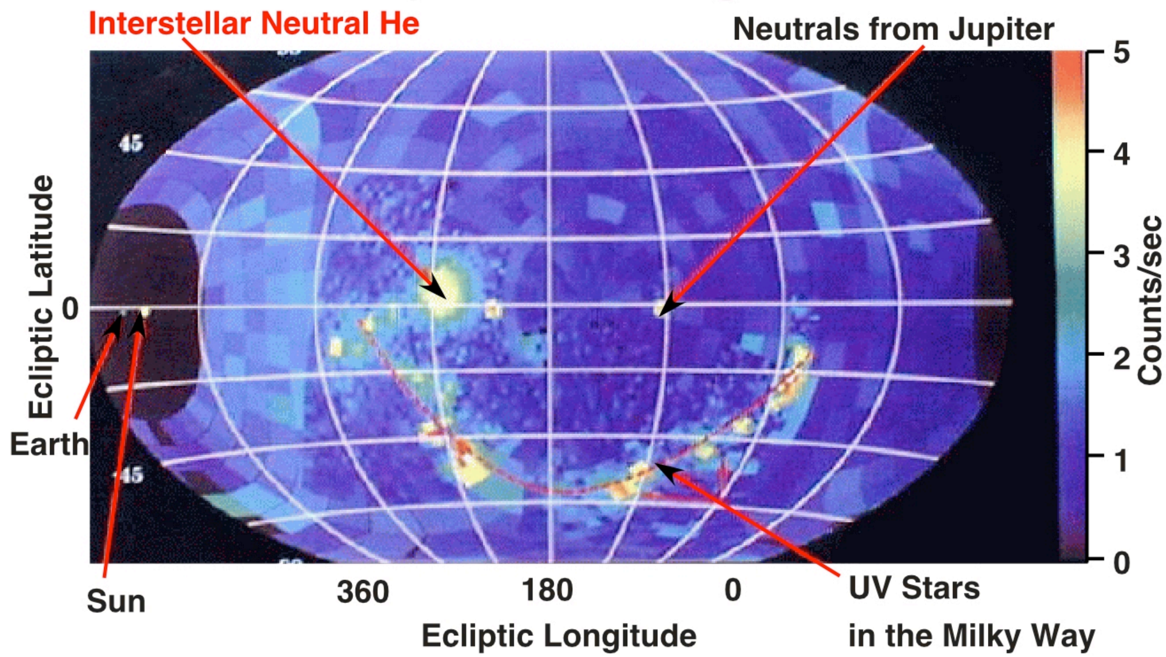
- Predominantly a mix of H, He, O (neutral and singly ionized particles, GCRs and dust
- High FIP neutrals penetrate deeply into the heliosphere (observed as neutrals and Pickup ions)
- Gravitational focusing (radiation press. Negligible)
- He neutral atoms measureed directly (Ulysses) and from Pickup Ions provide our best mesaurement of interstellar flow direction (*Witte et al., 1992, 2004; Moebius 2004, Gloeckler et al, 1996*)
  - Velocity = 26.3 ±0.4 km/s
  - T = 6300 ± 340 K
  - Ec. Long.(J2000) = 75.4°
  - Ec. Lat. = 5.1° ±0.2°
  - n = 0.015 ±0.002

Ulysses GAS Image



Evidence of N/S Asymmetry from H

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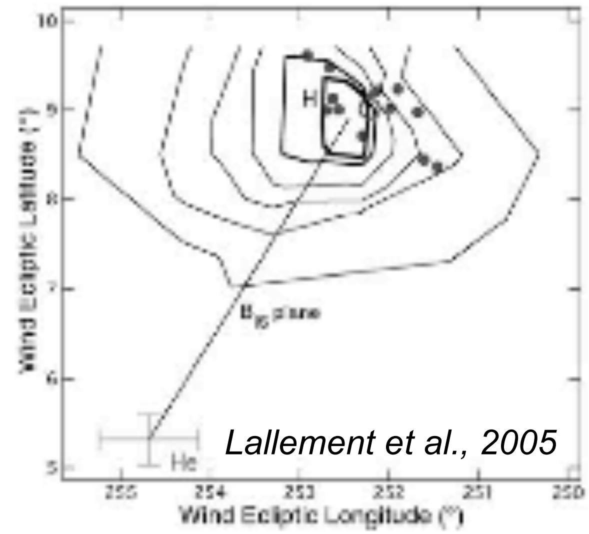
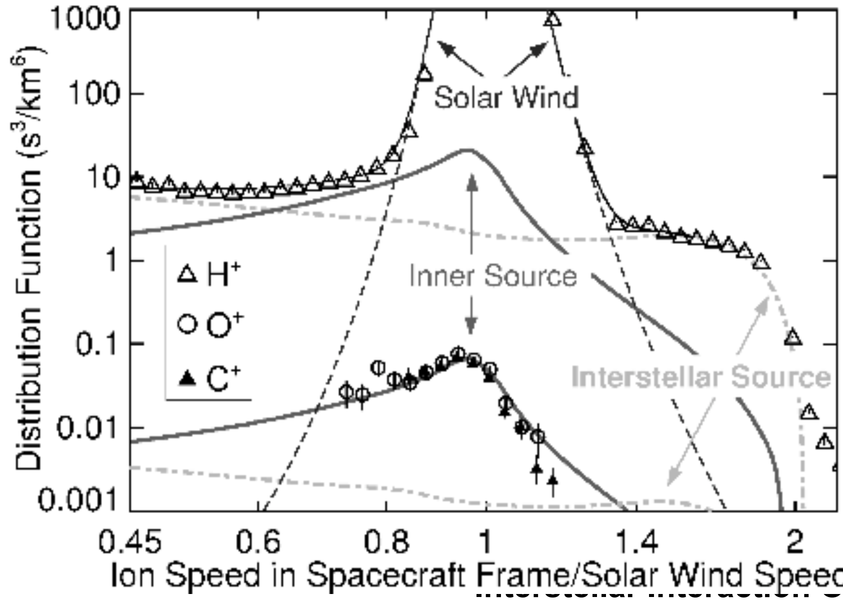
- Interstellar H observed
  - Ly-α
  - Pickup ions
  - Inferences from Mass Loading
- H experiences significant interaction (charge-exchange) in the heliosheath
  - inflow speed ~20 km/s, 6 km/s less than He, and higher 1600 K temp (*Lallement et al., 1993*)
  - SOHO/SWAN indicates flow deflection by ~4° *(Lallement et al., 2005)*
  - Filtration in the heliosheath lowers the density relative to the interstellar medium
    - LISM H - N_{int}~0.2±0.03 cm^{-3}
    - Filtered H - N_{filt}~0.1 cm^{-3}

Latitude



Longitude



Asymmetry due to the Interstellar Magnetic Field(?)

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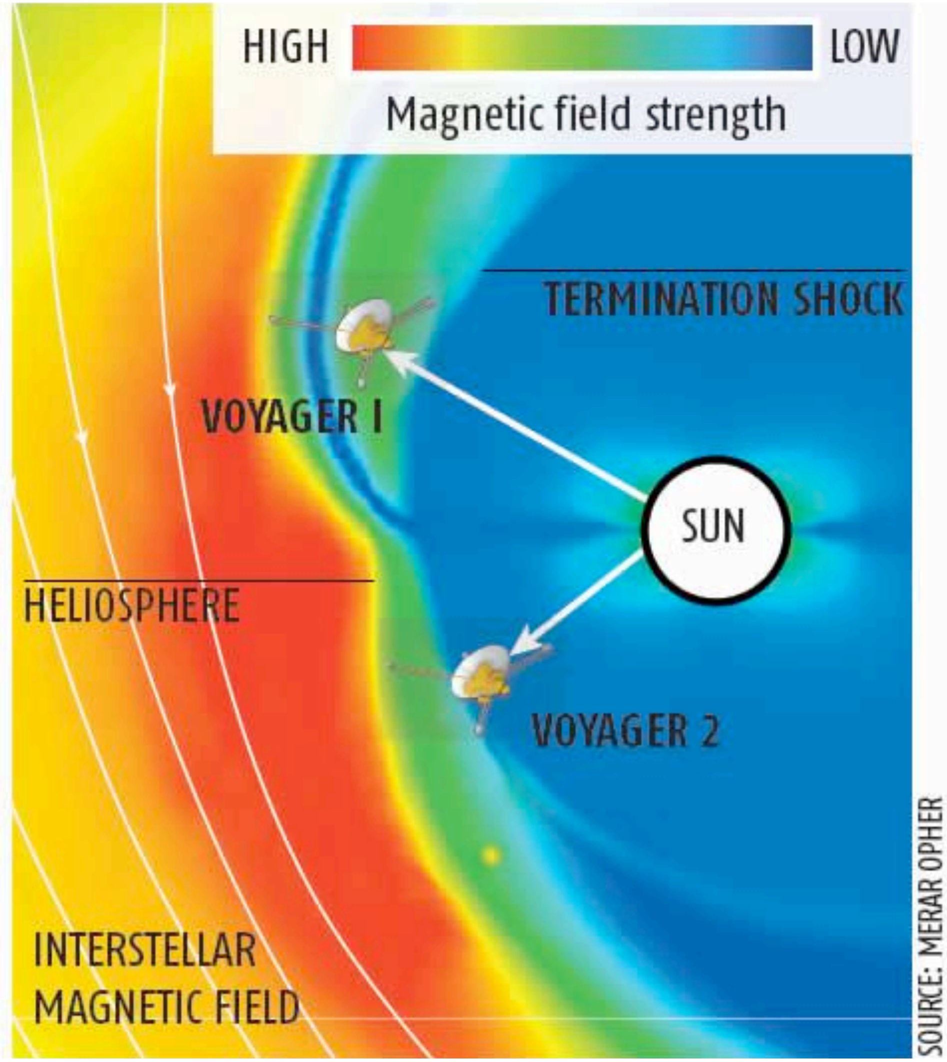
- Field strength thought to be ~1 μG; upper limit 2-4 μG
- Deflection of H observed by SOH/SWAN suggests effect of asymmetric interstellar magnetic



Voyager 1 Unveils the Heliosheath

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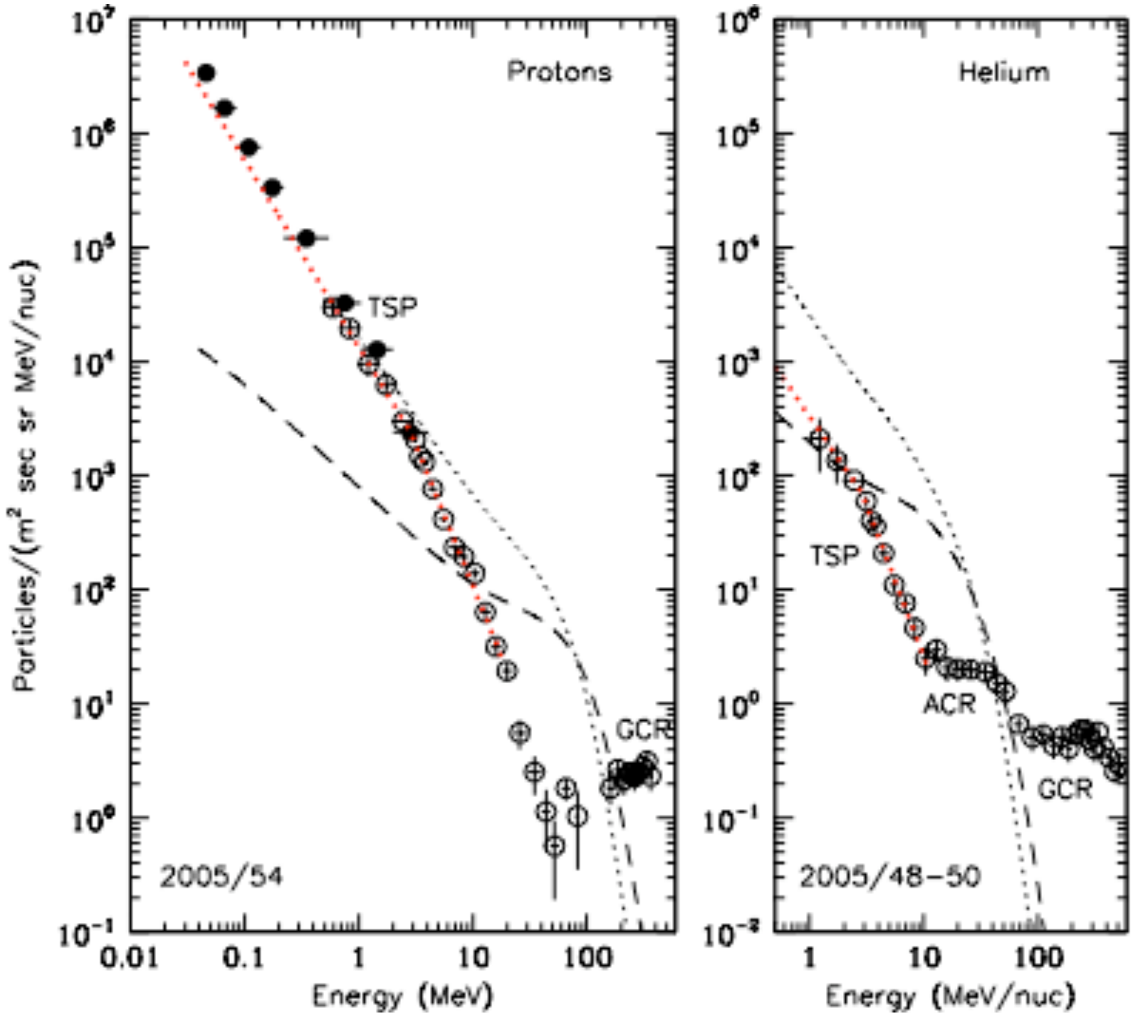
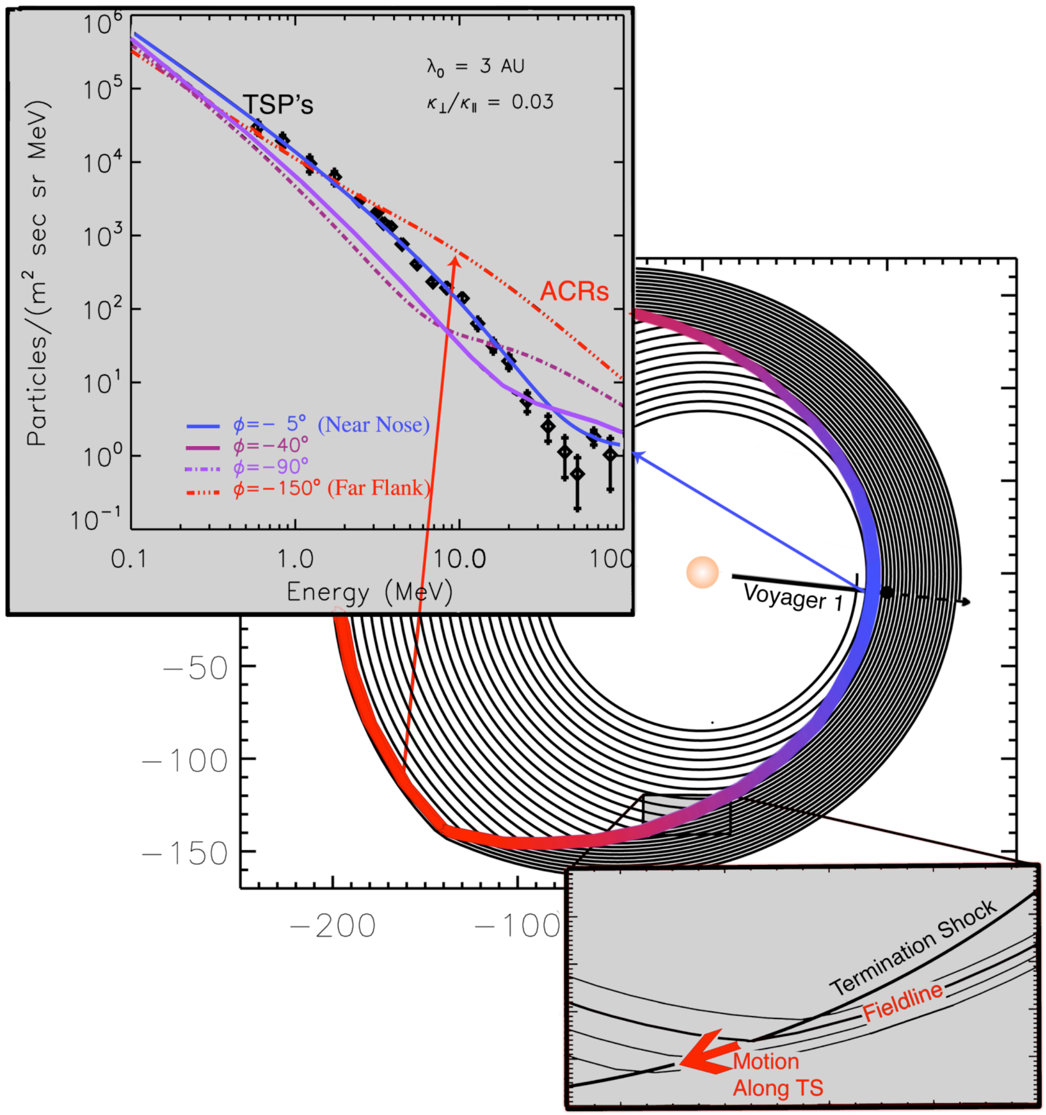
- The Source of Anomalous Cosmic Rays Missing from near the nose of the termination shock



Effects of a Blunt Termination Shock

- Acceleration of ACRs requires ~ 1 year (Mewaldt et al., 1996)
- This timescale is similar to that of the motions of field lines from the nose back to the flanks and tail of the termination shock
- But recent simulations (e.g., Pogorelov et al., 2006,8) show a more symmetric TS due to neutral interactions



V2 crosses the TS In Aug. 2007 at 84 AU

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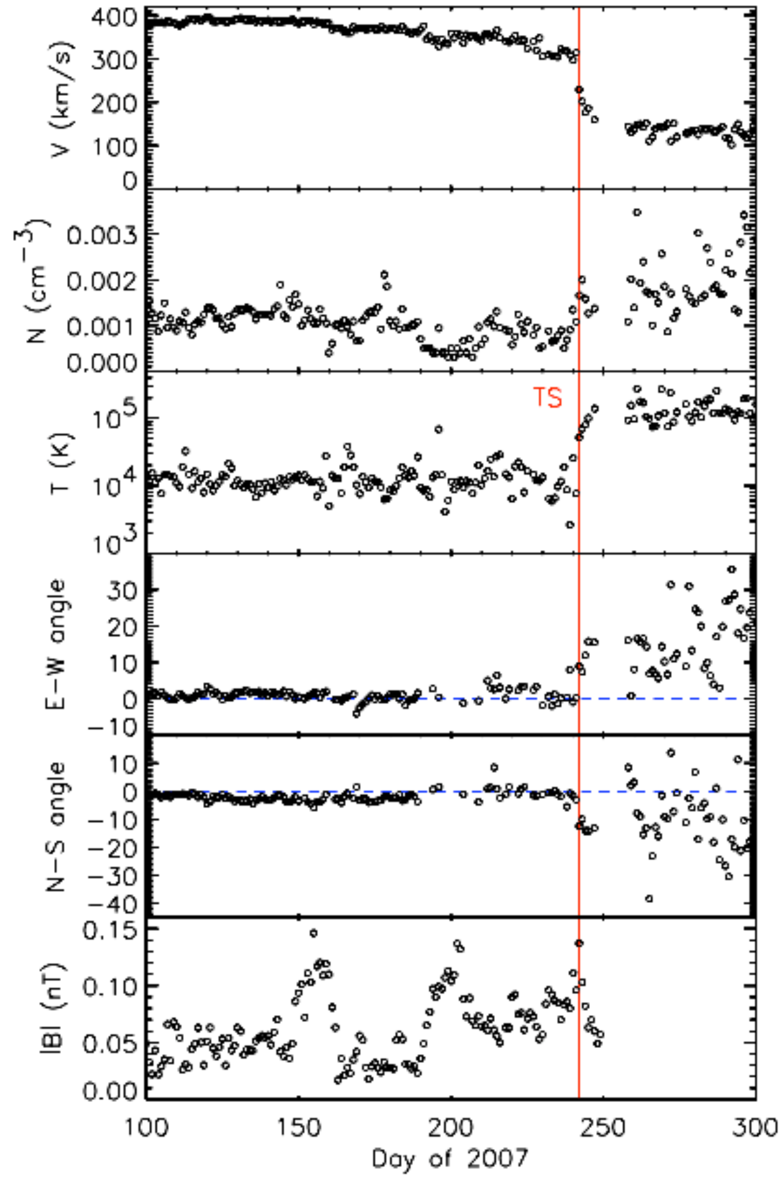
- Speed decrease starts 82 days, 0.7 AU before TS (but TS is likely moving outward).
- Crossing clear in plasma data
- Flow deflected as expected
- Crossing was at 84 AU, *10 AU closer than at V1*



Pickup Ions Carry Substantial Energy

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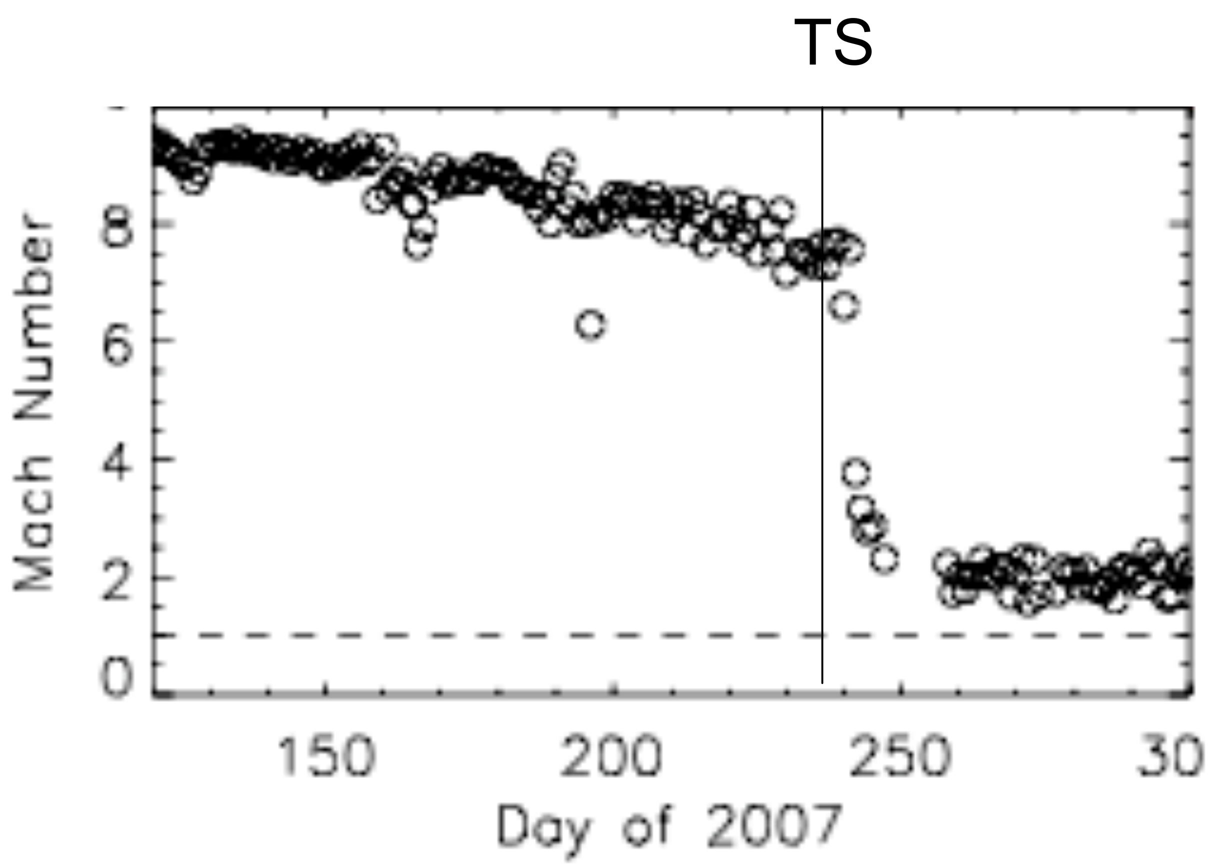
- Purpose of shock is to make flow subsonic
- BUT, flow remains supersonic wrt thermal plasma in heliosheath.
- Energy must reside in pickup ions. Pickup ion energy must be 6-10 keV



Decreasing Solar Wind Ram Pressure

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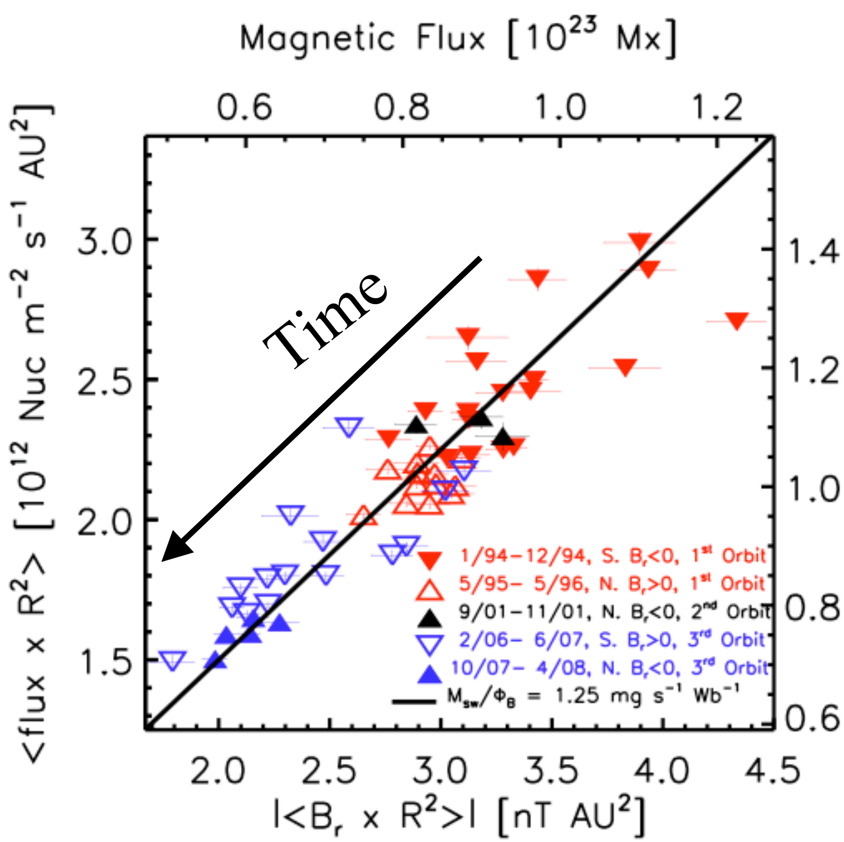
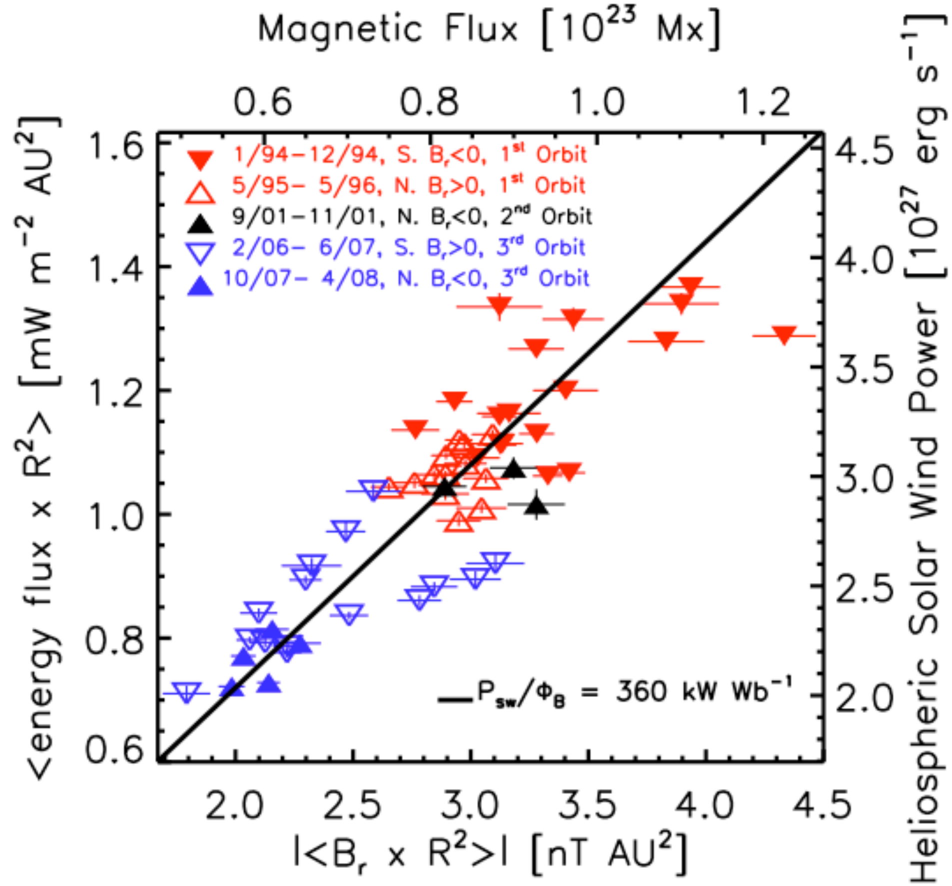
- Solar wind Ram Pressure decreasing with time
- At least part of the reason for the differences in TS location observed by V1/V2
- Solar wind Ram Pressure, Energy, Density Correlated with Magnetic Flux (Schwadron and McComas, 2003, 2006, 2008)





How Big a Change in Ram Pressure between V1/V2 Crossings

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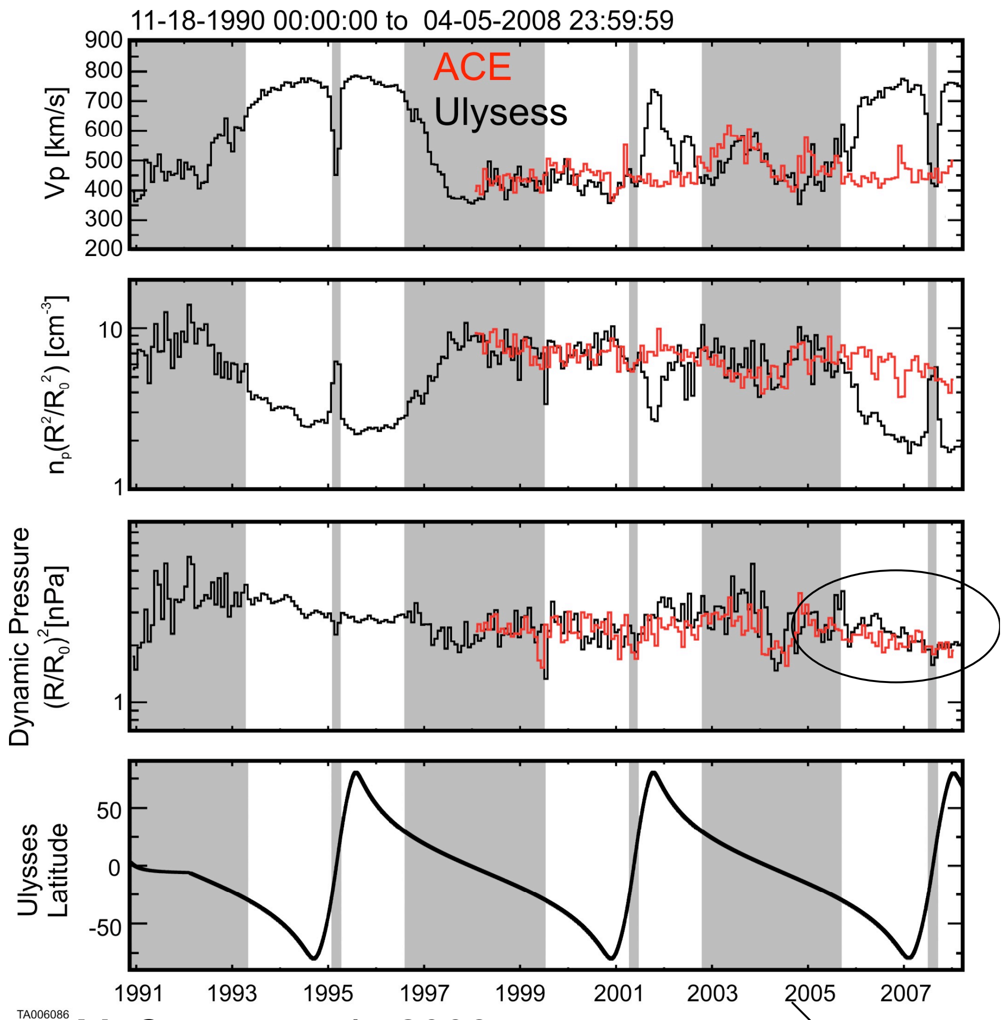
- V1 Crosses Dec, 2004 at 94
- V2 Crosses Aug, 2007 at 84 AU
- Dynamic Pressure Changes in Fast Wind ~30%
- Dynamic Pressure Changes in Slow Wind much smaller



McComas et al., 2008

Note ~1 year lag

N/S Asymmetry Reflected by V1-V2 Differences

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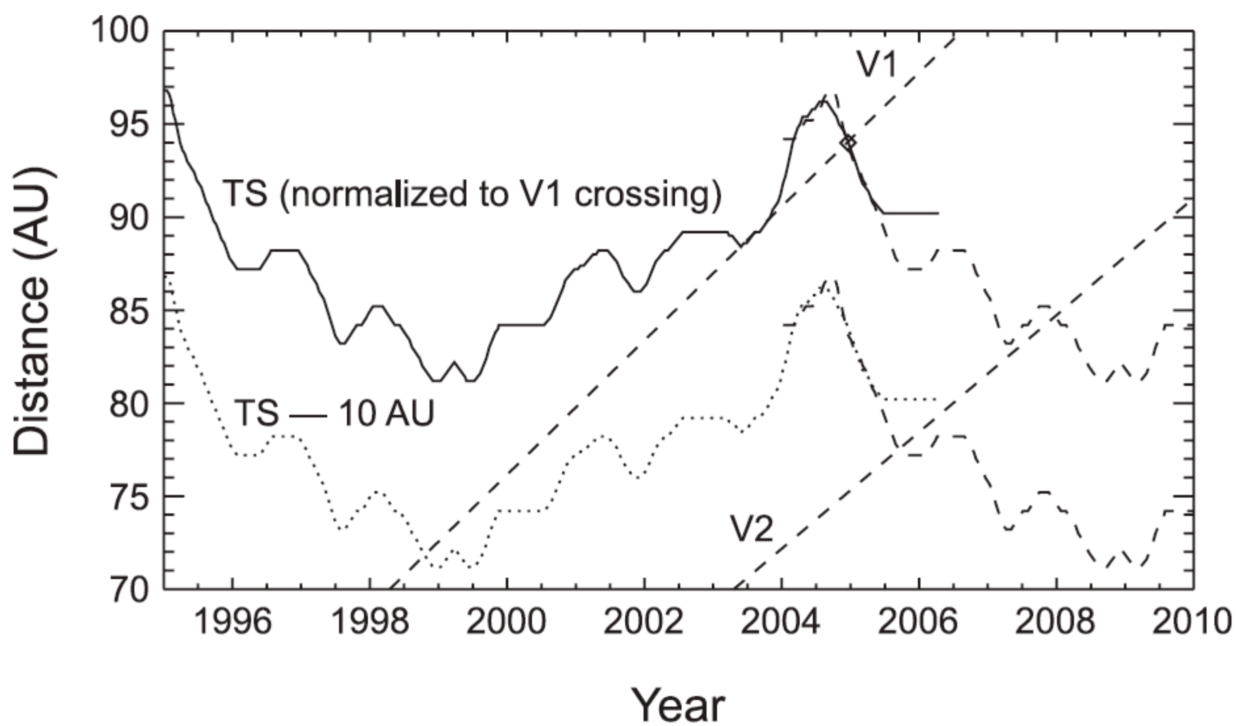
- Models of TS (e.g., Pogorelov et al, 2006, Opher et al., 2006, 2007) generally show V2 closer than V1 by ~ 10 AU at a given time
- The distance observed by V1-V2 difference reflects, in part, a real N/S asymmetry



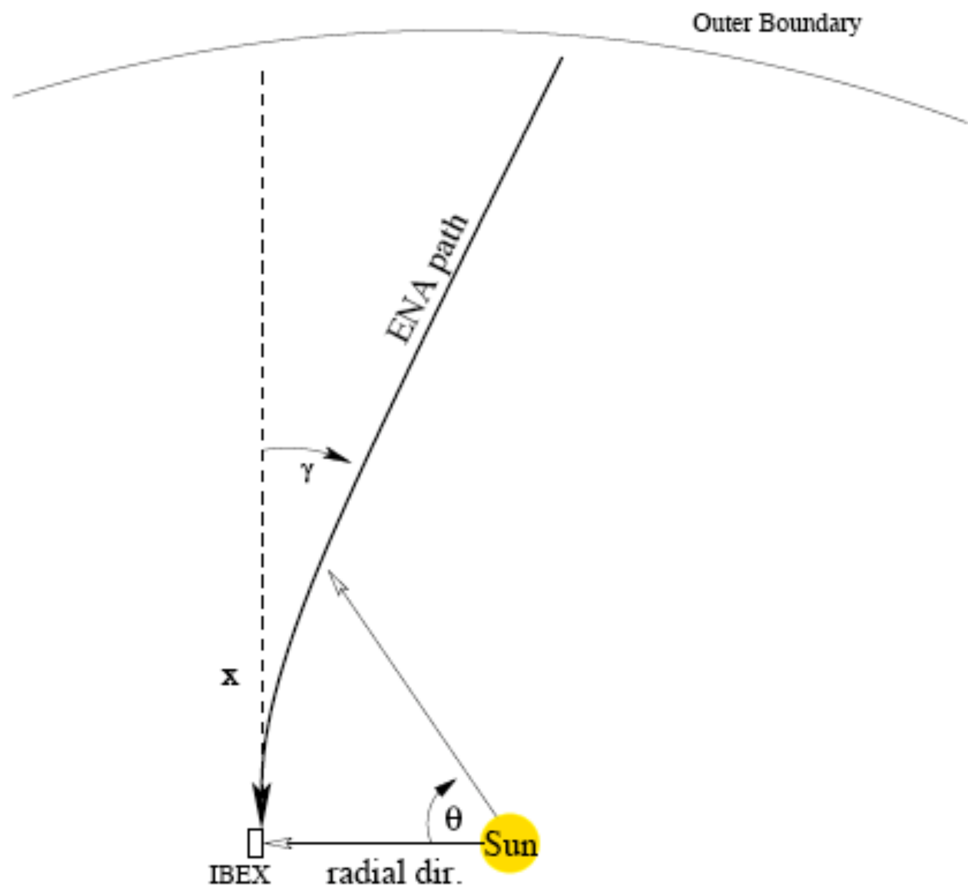
Richardson et al., 2006

Summary of Observational Evidence

- Where’s the nose?
  - He neutral observations (Ulysses) give us our main sense of direction
- Nose/Tail Asymmetry
  - Predicted from Models
  - Possible Evidence for Blunt Termination Shock from Absence of ACRs near Nose
  - Overall bluntness debated -- new models including neutral interactions show more spherical shock
- North/South Asymmetry
  - Ly-α observations suggest N/S asymmetry, possibly due to asymmetry in interstellar B
  - V1-V2 difference in TS location also suggests this asymmetry
  - Heliosheatht thicker in the North
- Voyager 2 seems to show dominance of the pickup ion energy
  - More consistent with the Gruntman et al (2001) weak shock limit

Forward Modeling

- Acounts for:
  - Loss by ionization
  - Deflection by rad pressure
  - Energy change through heliospheric transmission
  - Sensor response functions
    - Geometric Factors
    - Angular Response
    - Energy Response



Global Forward Mapping

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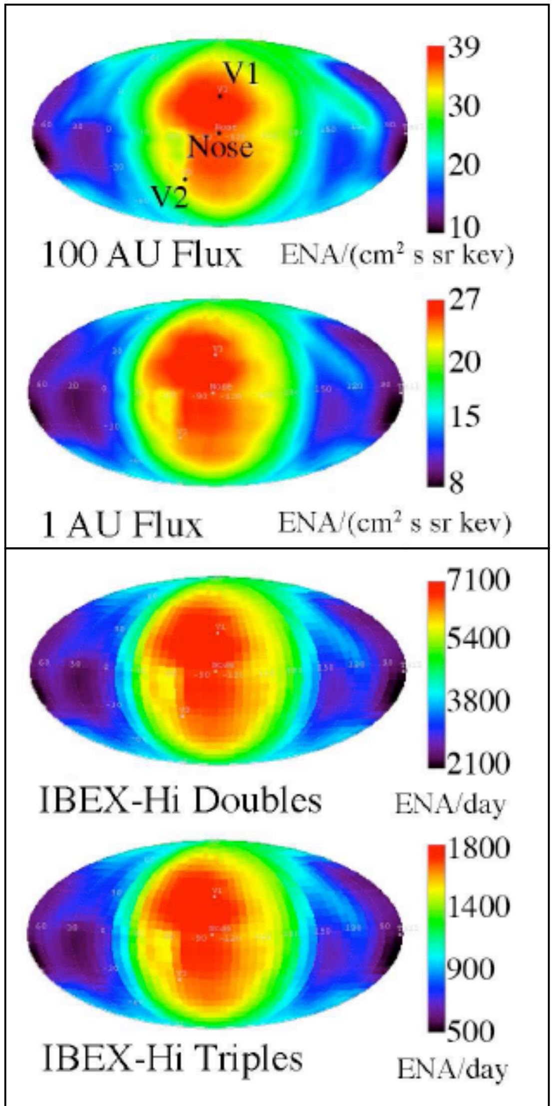
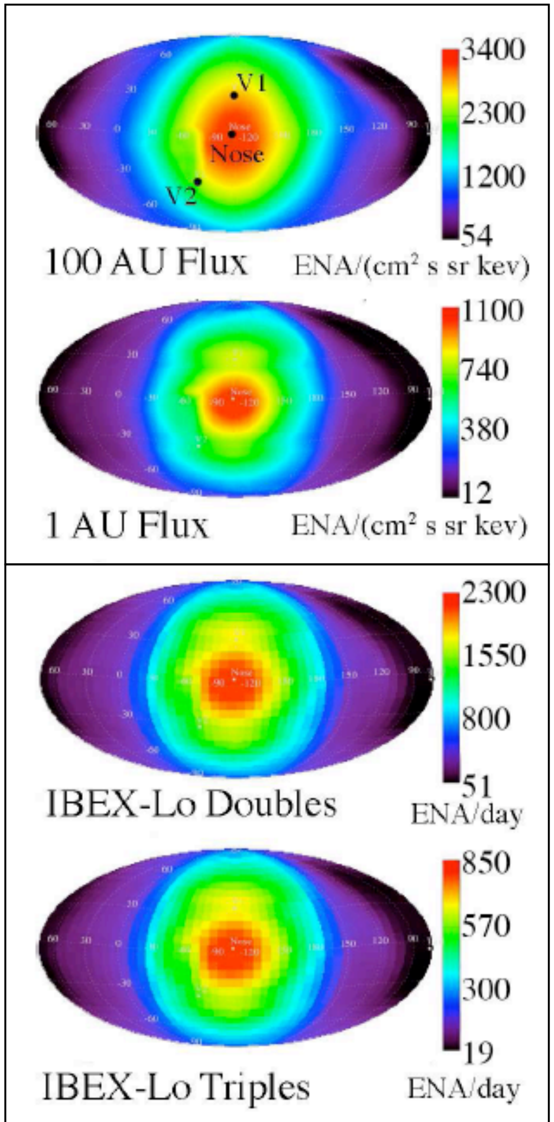
- Above 0.1 keV, the global symmetries of the heliosphere are preserved in ENA maps
- Reduction in magnitude due to ENA ionization-loss



(a) IBEX-Hi, ESA Step 4 (1.5 keV)



(b) IBEX-Lo, ESA Step 4 (100 eV)

Energy Spectra in Strong and Weak limits

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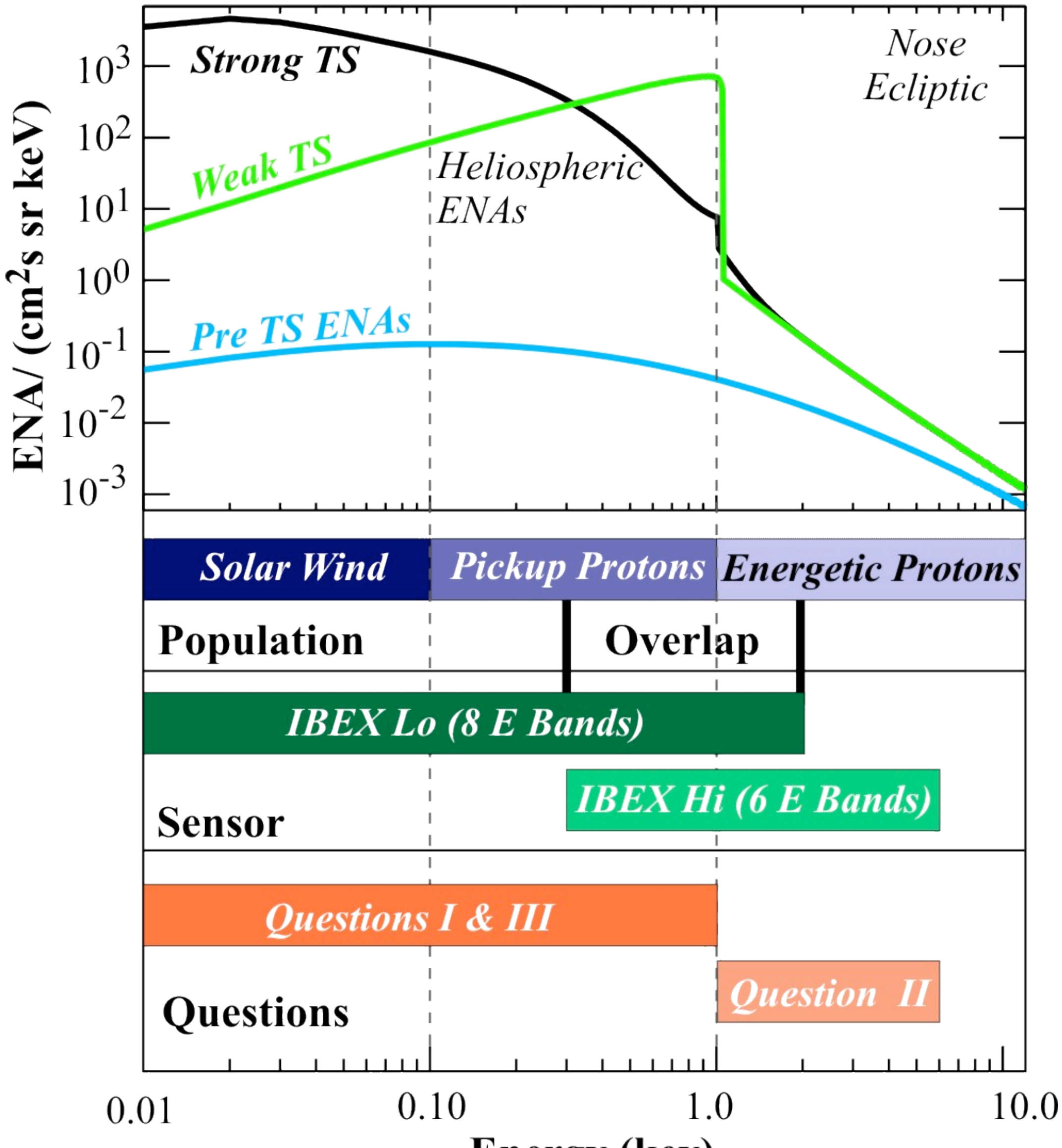

- ENA energy spectra provide direct measures of ions beyond TS:
  - Solar wind
  - Pickup Protons
  - Energetic protons
- Spectra as a function of direction show 3D configuration of the shock and energy partition of the ions at the shock
- Spectra also provide information about how EP pressure modifies the TS and what types of injection processes may be at work there

Predicted ENA distributions near HSp nose for strong (black) and weak (green) TS [Gruntman et al., 2001]. ENAs >1 keV are accelerated inner heliosheath protons based on projecting observed distributions beyond TS.

Energy Distribution Mapping

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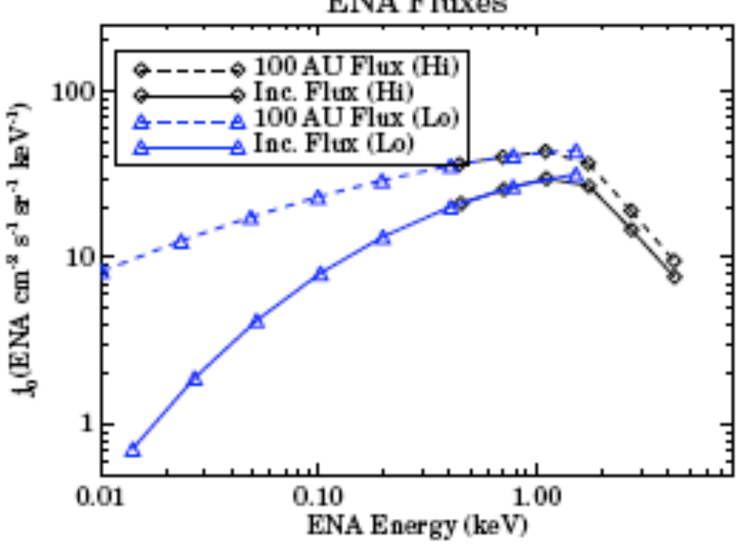
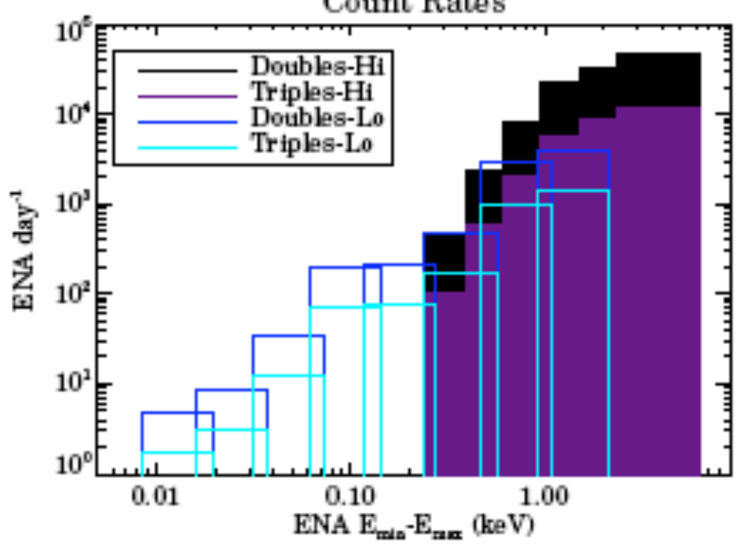
- Energy dependent ..
  - ENA ionization loss
  - ENA deflection
  - These effects are all stronger at low energies



(a) ENA fluxes at 100 and 1 AU



(b) Resulting ENA Count Rates

More dramatic Effects at Low Energies

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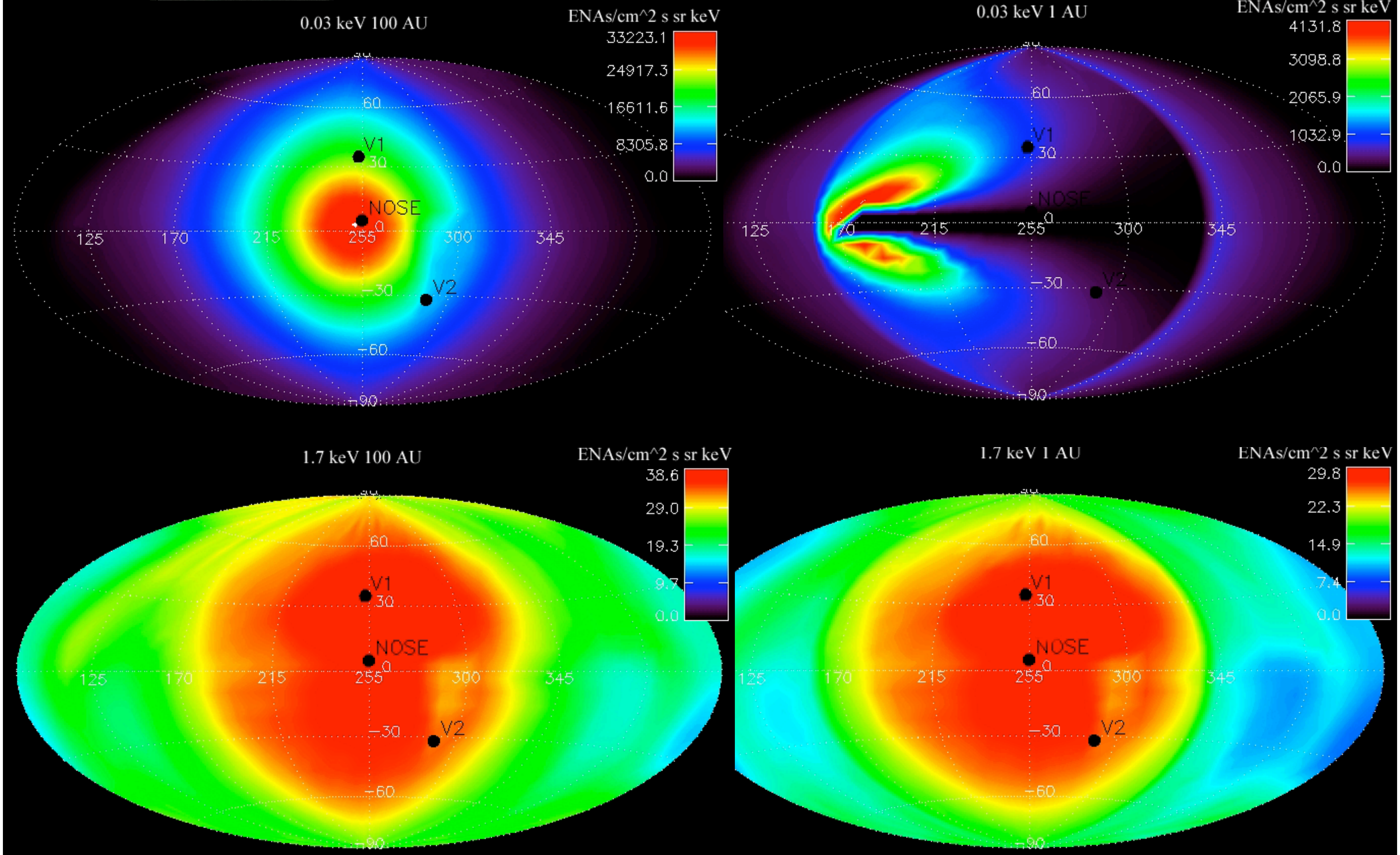
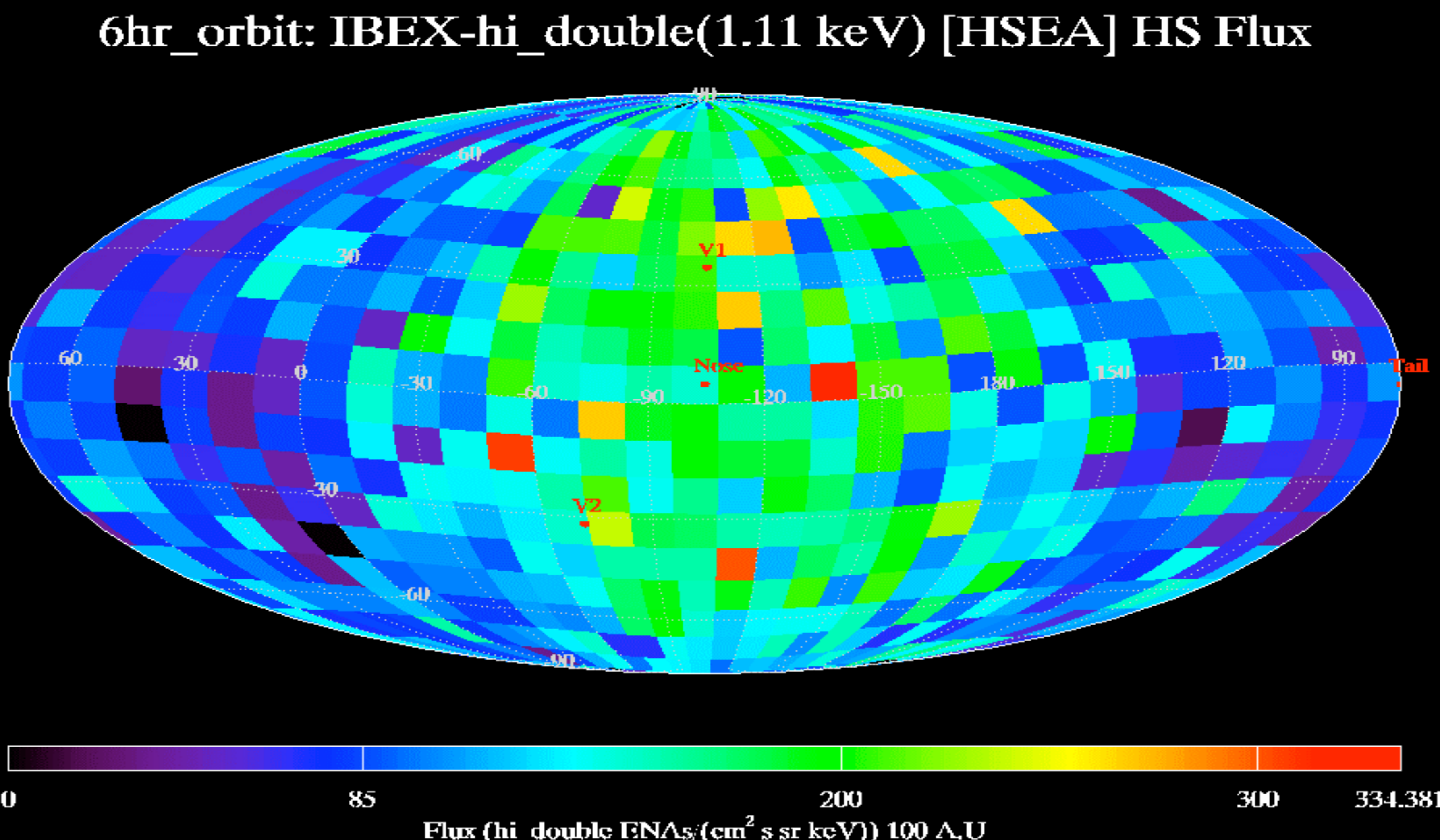


IBEX-Hi at 1.11 keV



Summary

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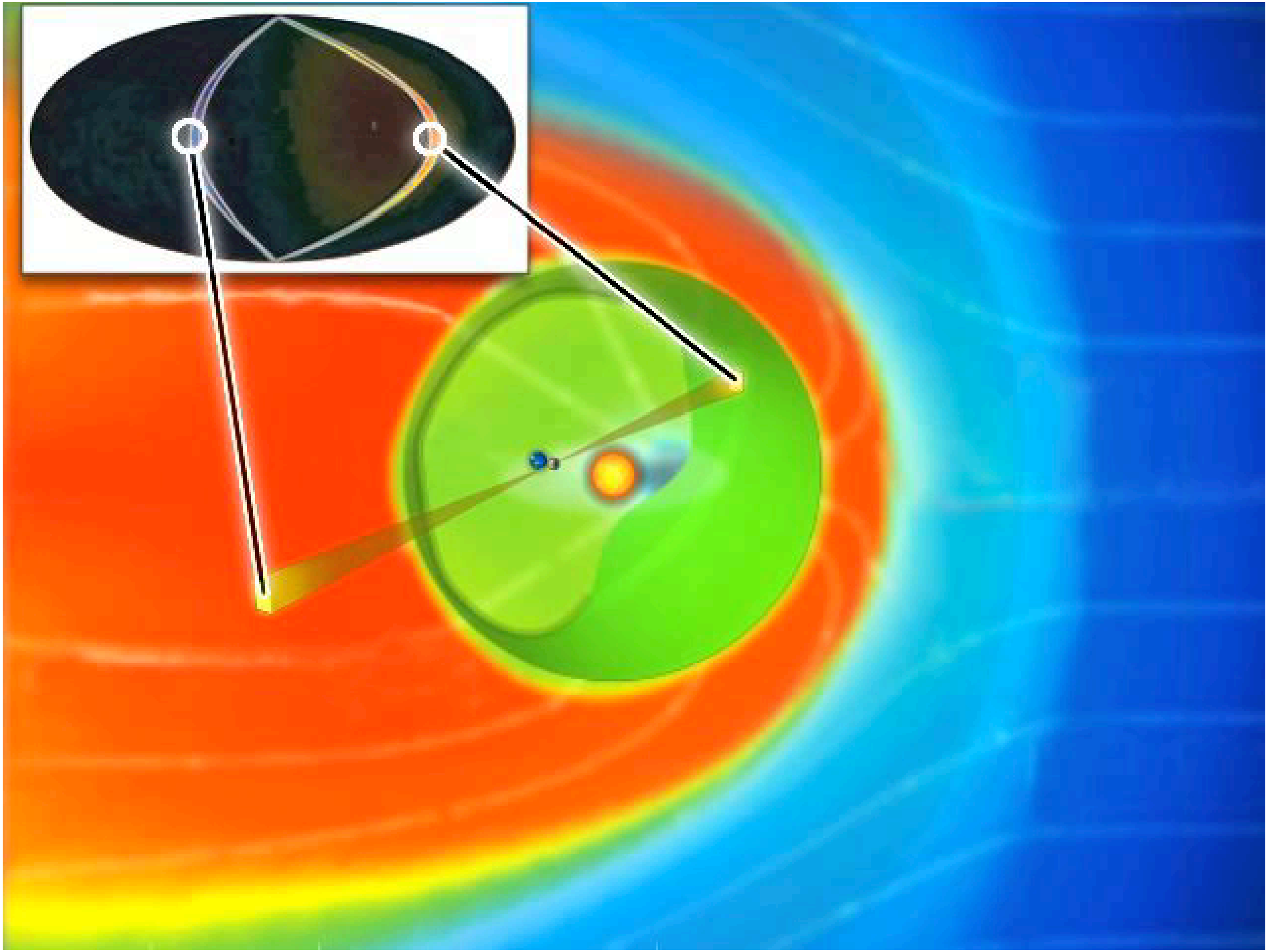
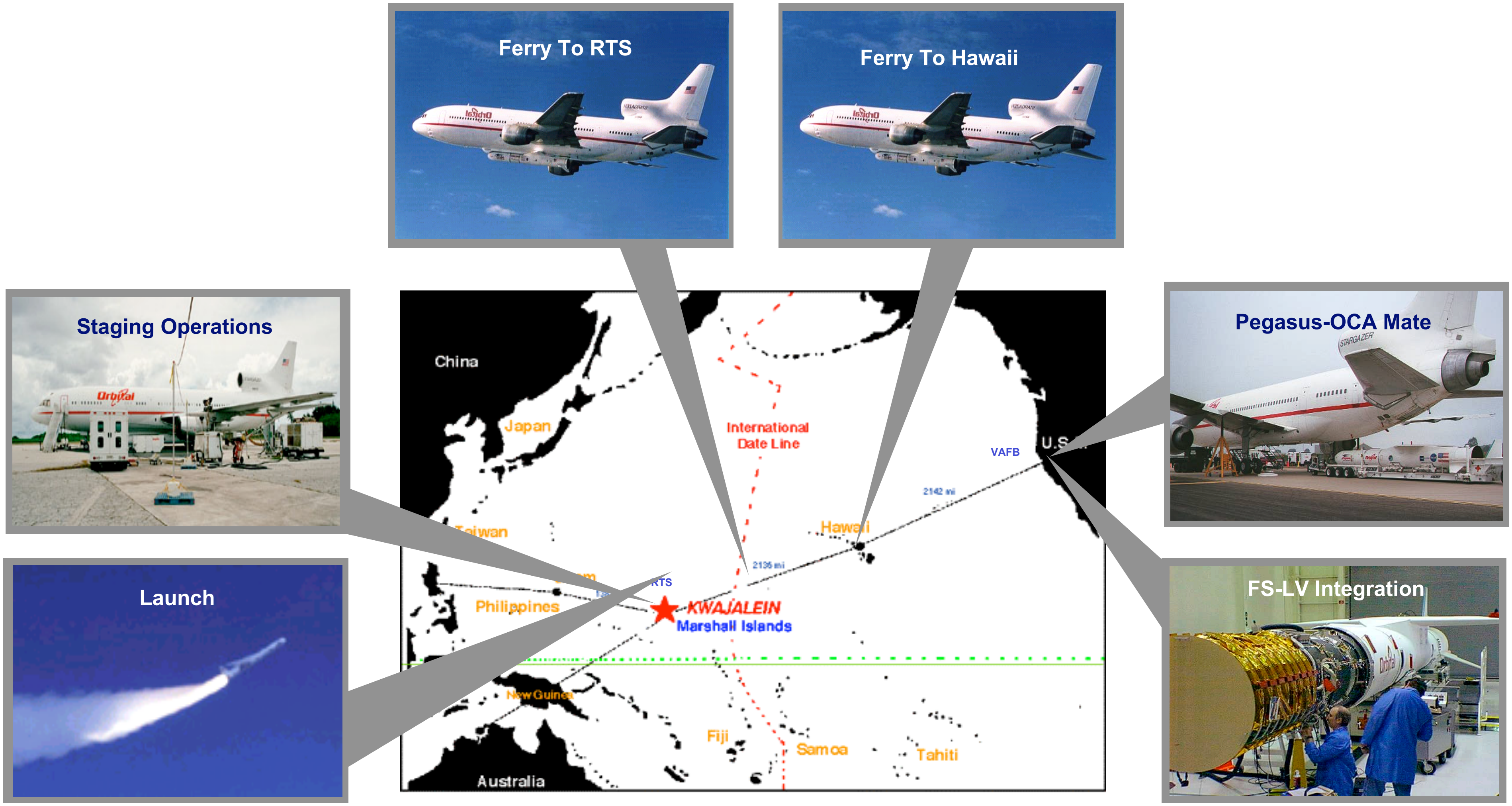
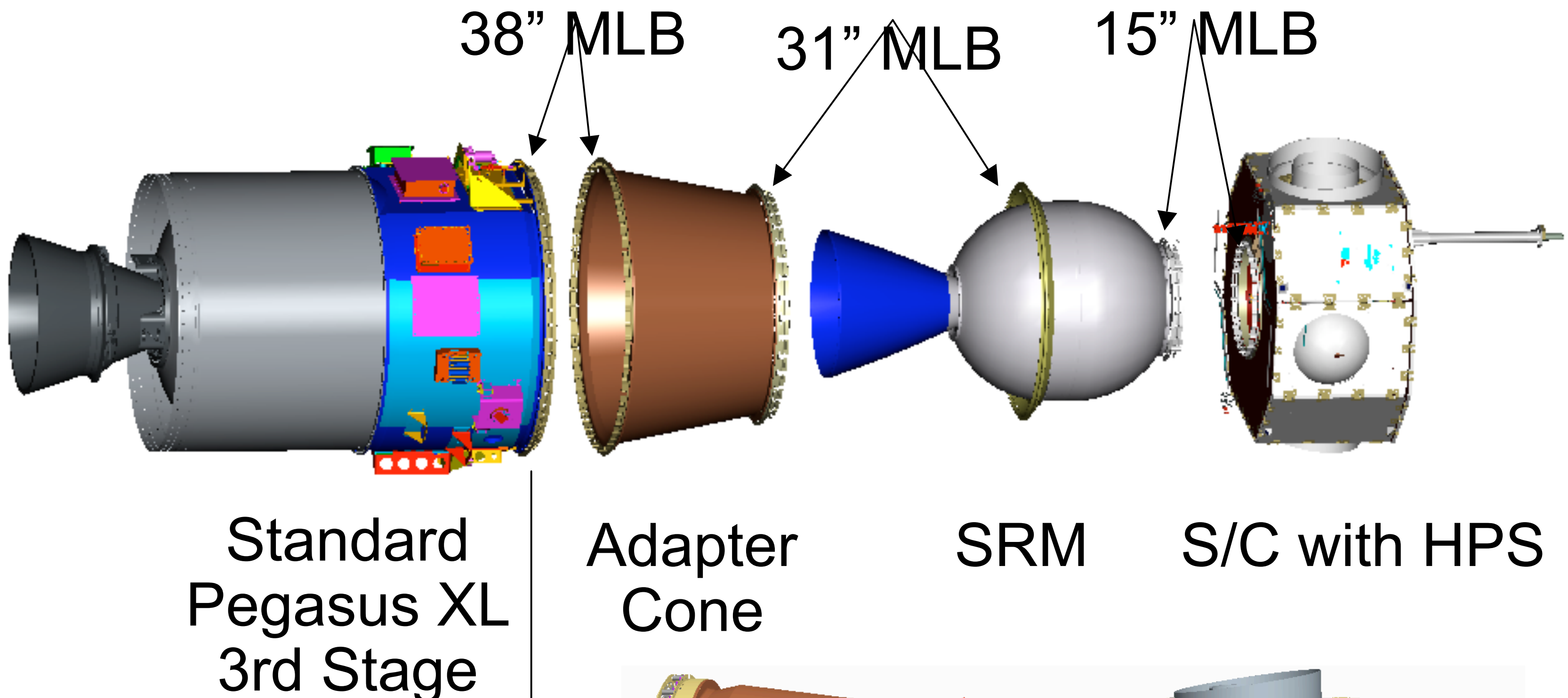
- We are about to discover a new global view of the heliosphere from ENAs!
- We expect to see asymmetries
  - Nose/Tail asymmetry (which one should be brighter, we don't yet know)
  - North/South asymmetry (perhaps). Brighter emissions from the North?
- The energy distribution
  - Voyager 2 results suggest prominence of pickup ions
  - Will we see a knee in the pickup ions
  - Relative contribution of kappa function & pickup-like distribution?
- Model interface at the IBEX Science Operations Center
  - A first version up and running
    - Forward modeling interfaces to models (to be expanded as much as possible/desired)
    - Reverse modeling account for heliospheric transmission effects

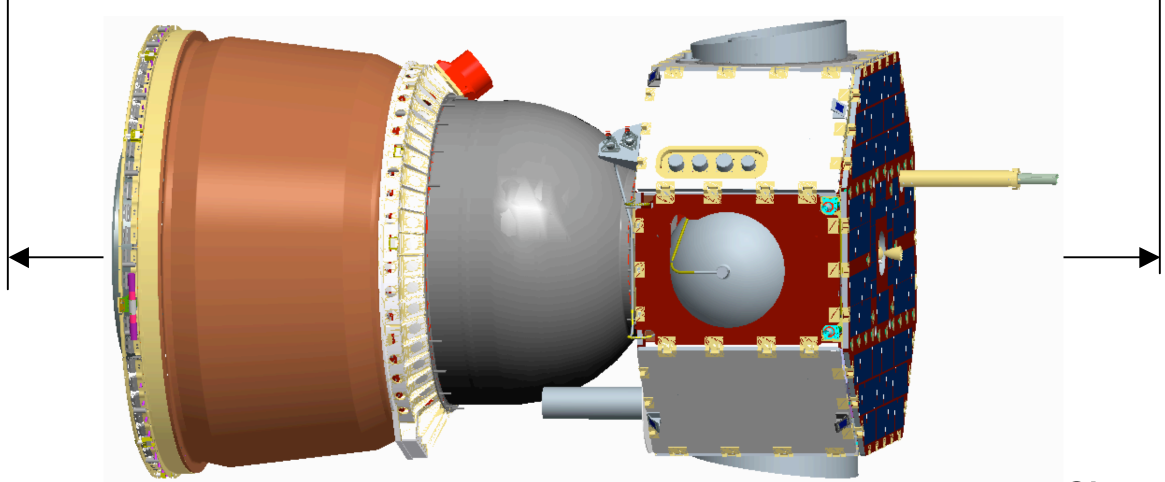


NASA-Supplied Pegasus Launch Vehicle



IBEX Flight System



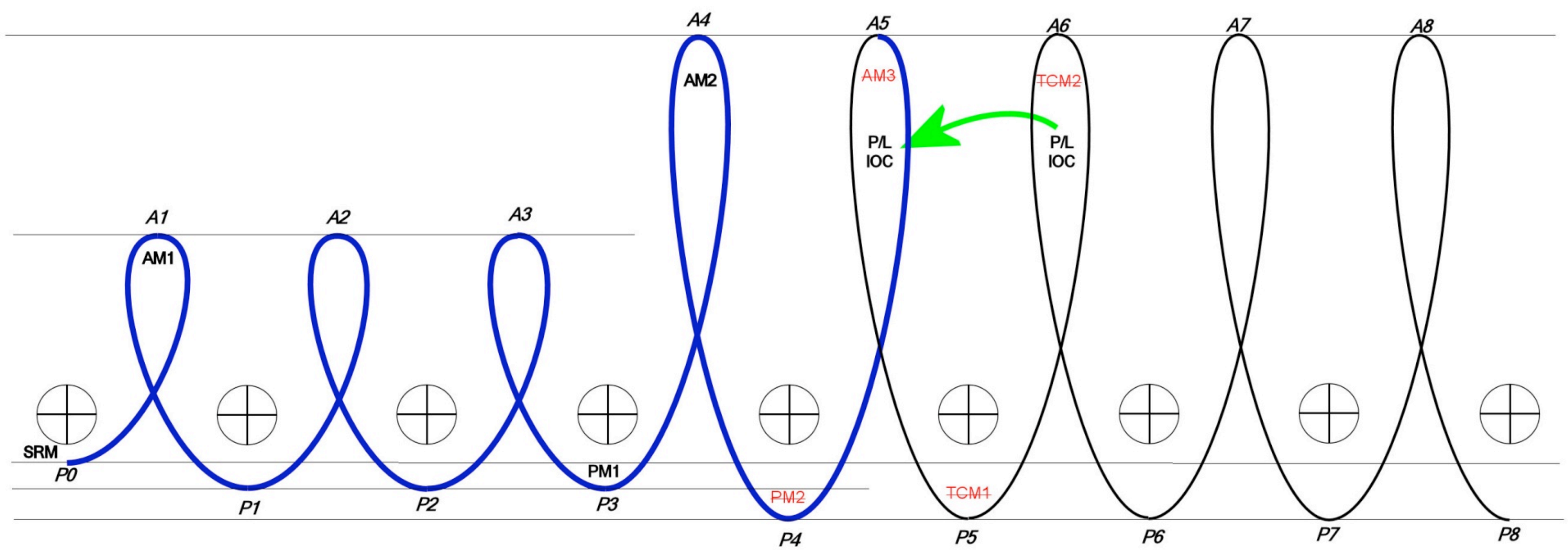


MLB = Motorized LightBand separation system

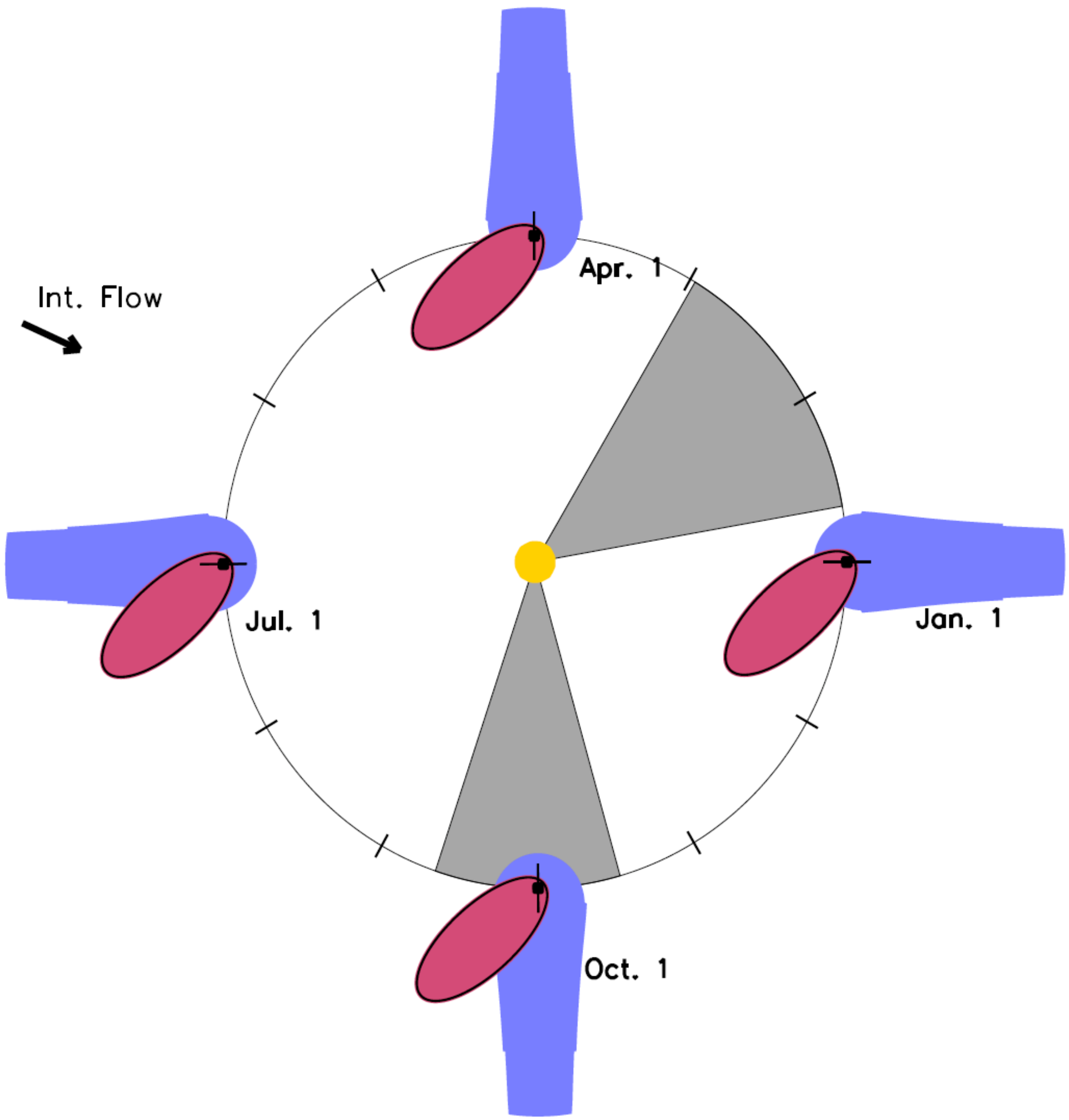
Interstellar Boundary Explorer
IBEX

Orbit Raising

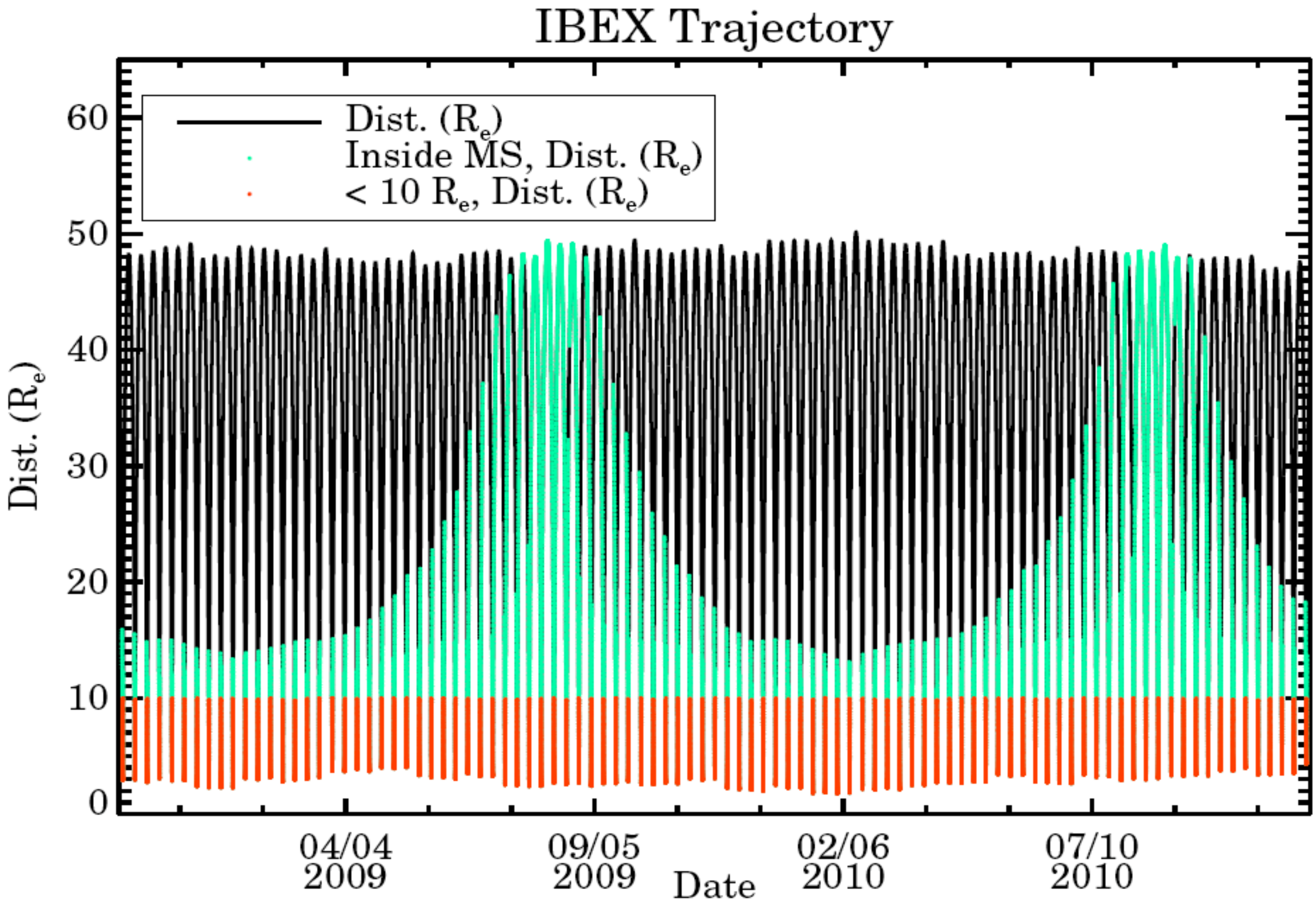
- Used extra propulsion to significantly raise apogee
- Able to waive off PM2 and AM3 and AM5 because orbit met requirements
- Orbit raising completed 12 November 2008



Final Orbit Orientation



Two Year Nominal Mission



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Apogee/Perigee over Two Years

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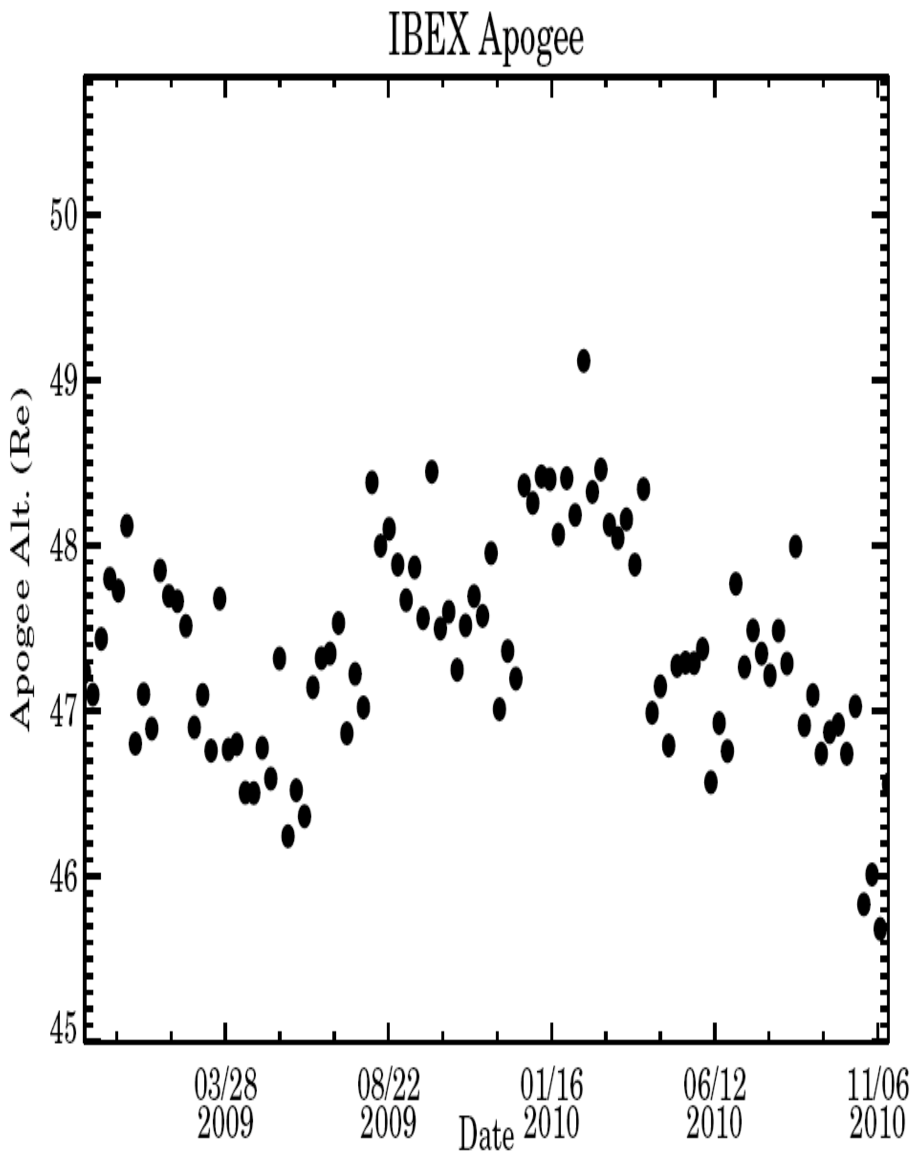

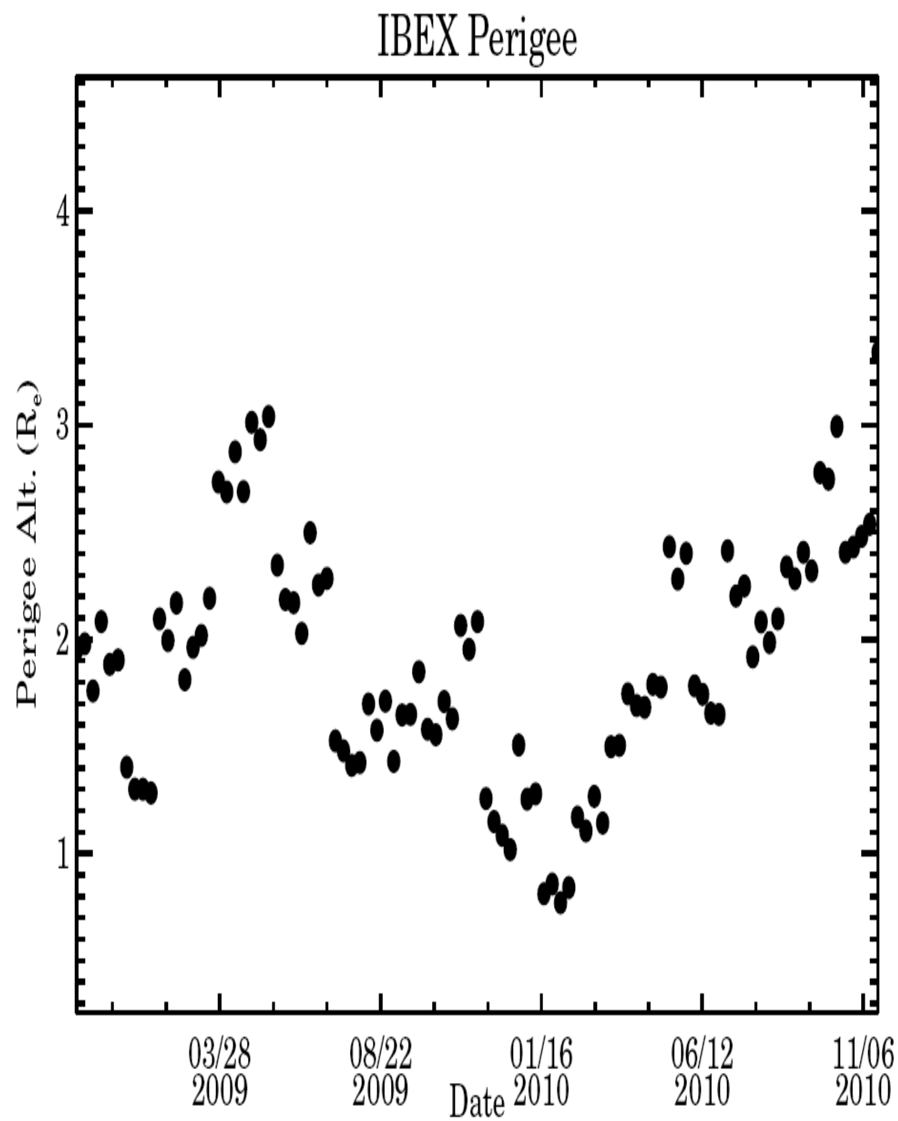

Orbit Moves over Lat and Long

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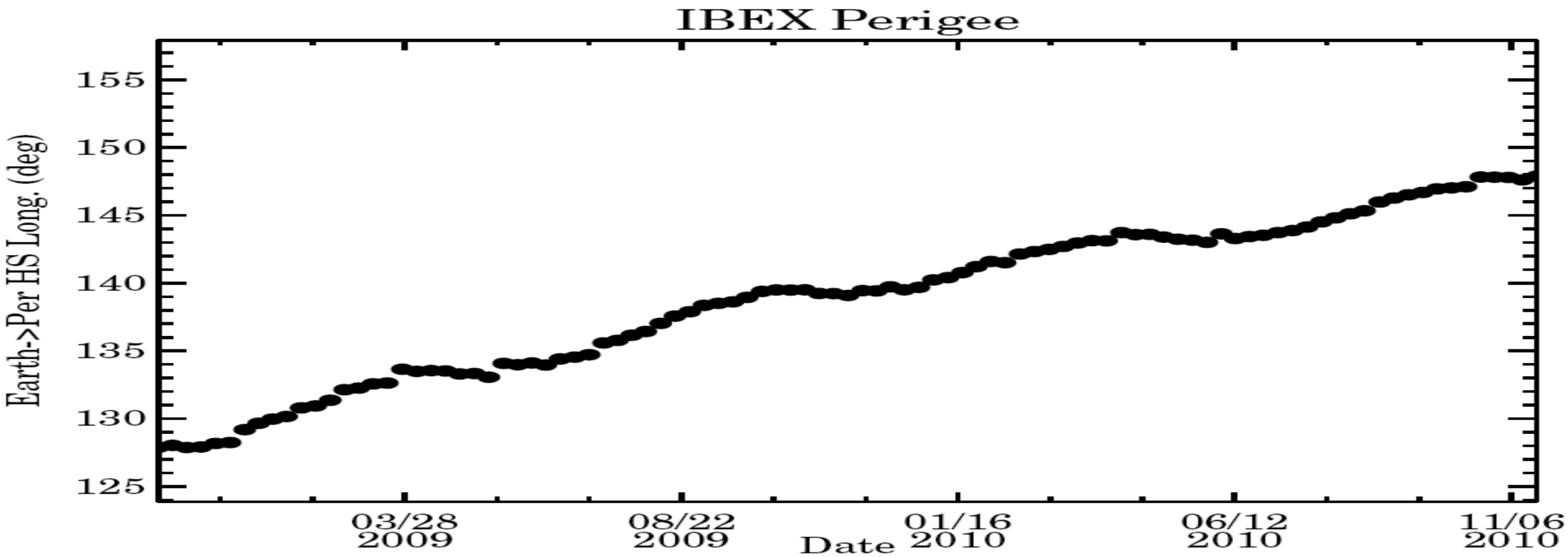

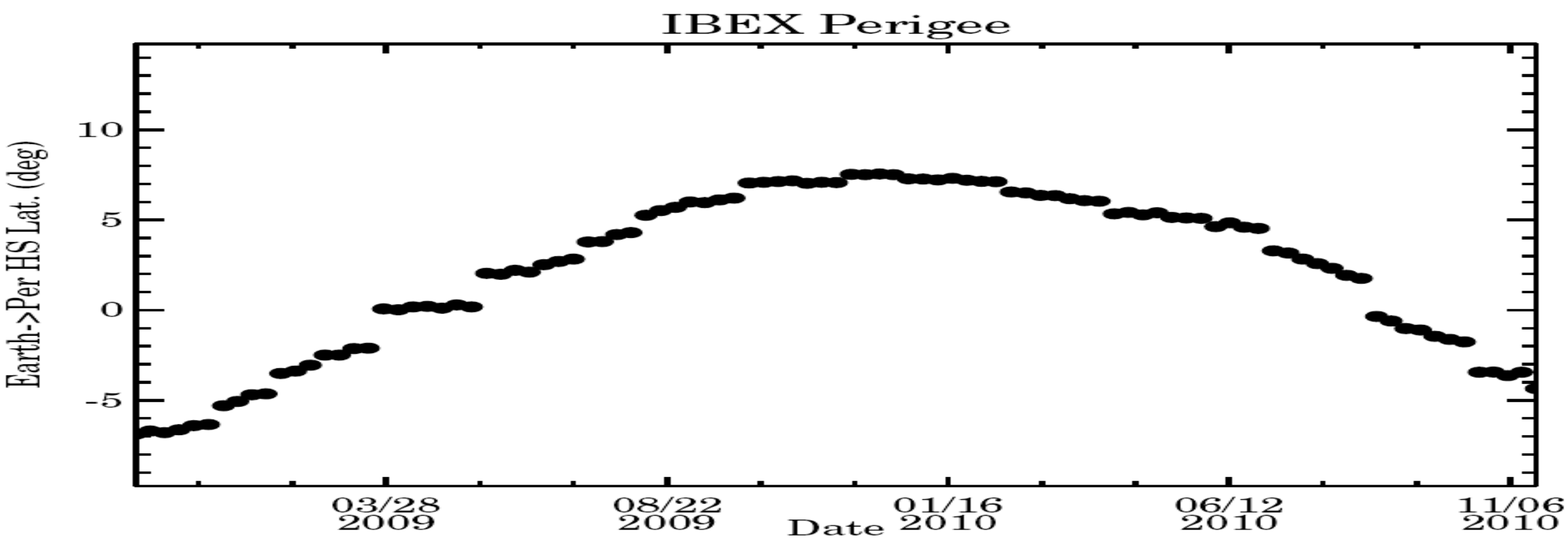

Exposure/Pixel over Two Year Mission

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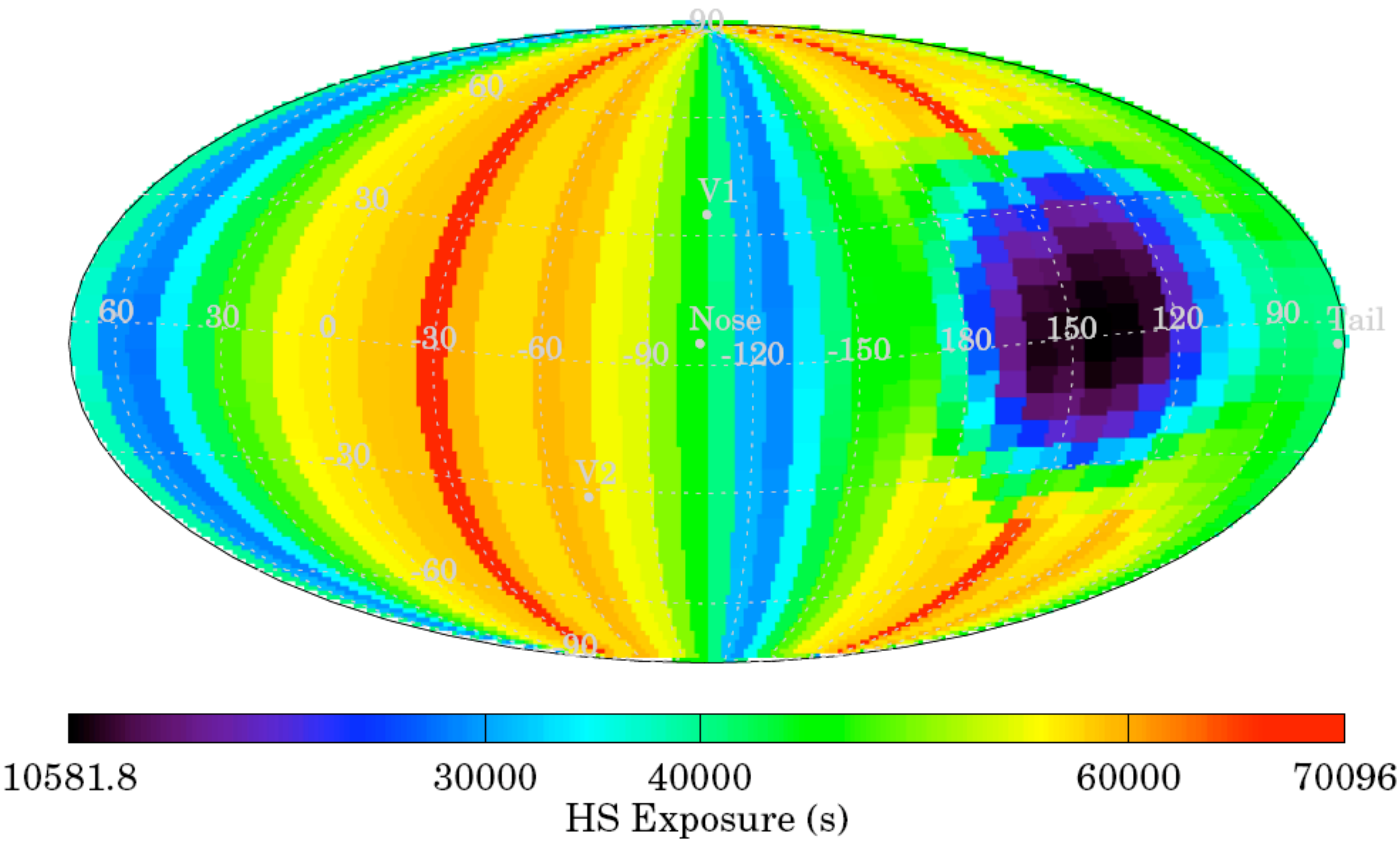
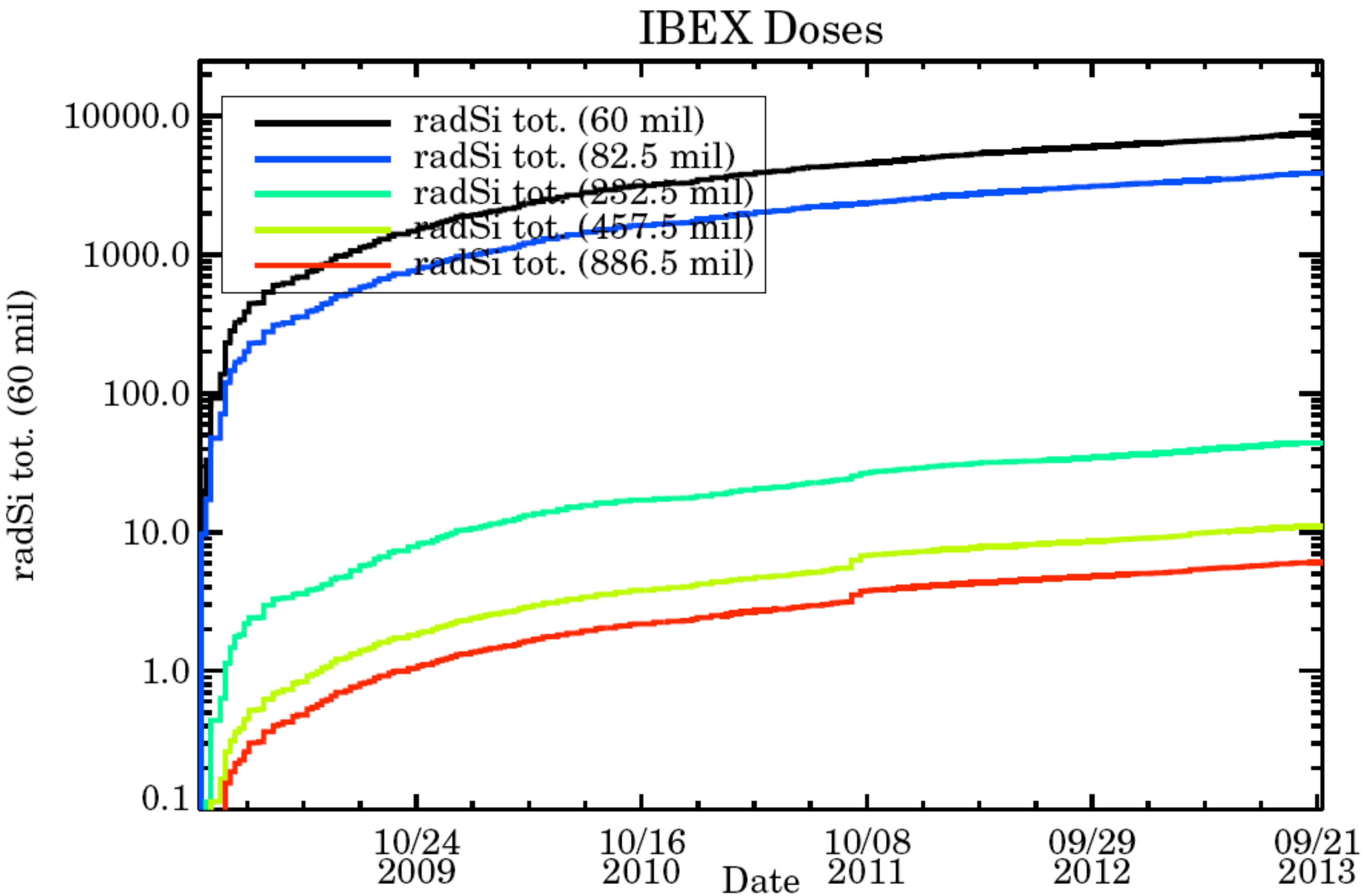
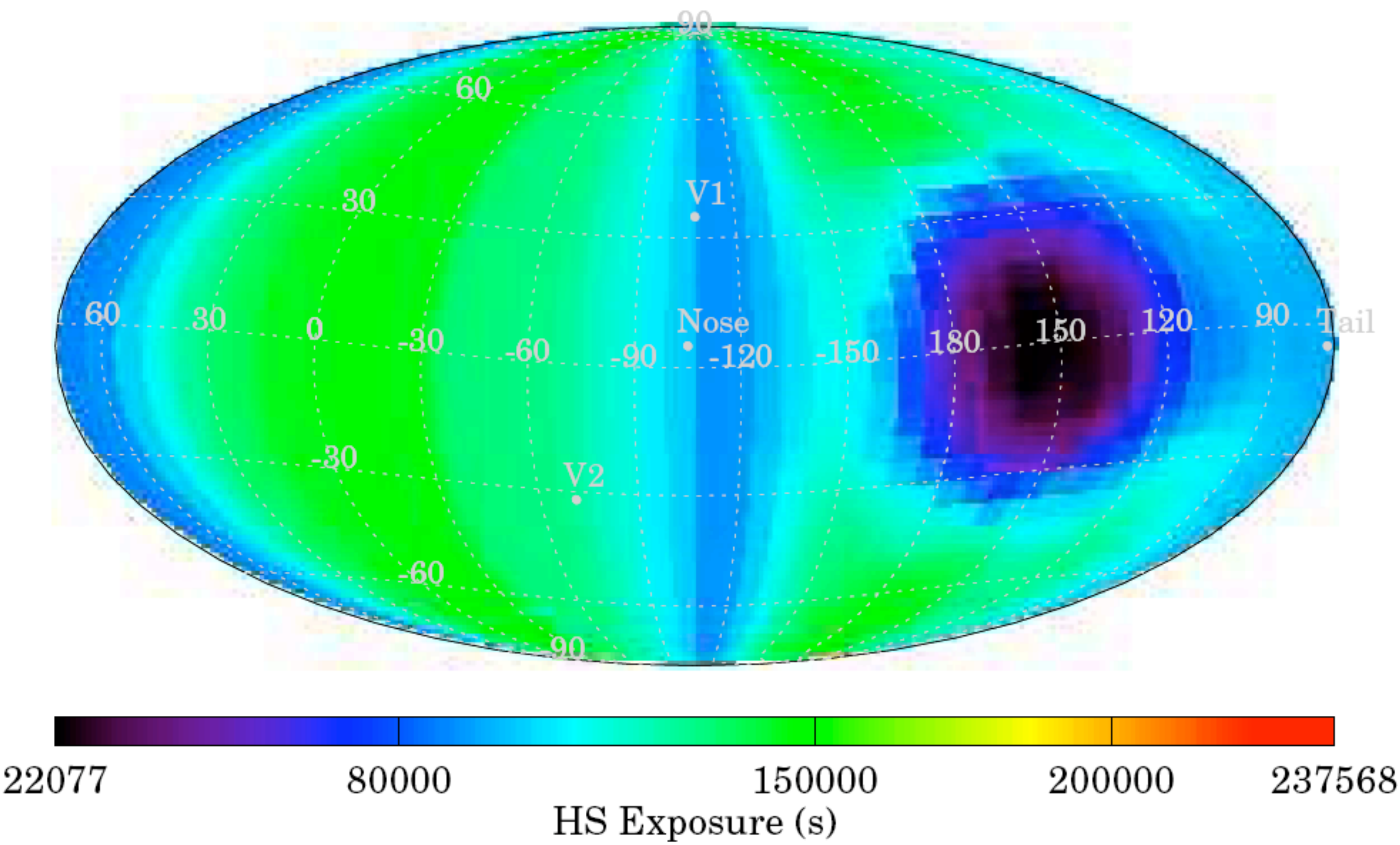


~1800 7 deg pixels in the sky

Fluence over 5 Years



Exposure/Pixel over Five Years



Potential Noise and Background Sources

- Noise: the result of particles that generate uncorrelated (non-coincident) counts in the sensor detectors
  - UV
  - X-rays
  - Photo and secondary electrons
  - Penetrating radiation
- Background: the result of an ion or atom that masquerades as a signal ENA in the IBEX sensors
  - ENAs
  - Ions

Noise Source	Background Source
Diffuse UV, UV from stars	ENAs from planetary magnetospheres
X-rays from photoelectron acceleration toward, and impact with, biased collimator grids	Ions from magnetosheath and foreshock
Photoelectrons and secondary electrons generated at conversion surface	Charge exchange of plasma ions with outgassing spacecraft species
Penetrating radiation: radionuclide decay in detectors	Secondary ions generated in entrance subsystem
Penetrating radiation: cosmic rays	ENAs from CMEs, CIRs, and pickup ion charge exchange in the heliosphere
Penetrating radiation: Solar Energetic Particle events	
Penetrating radiation: Magnetospheric energetic particles	

Solar Wind Background in IBEX-Hi

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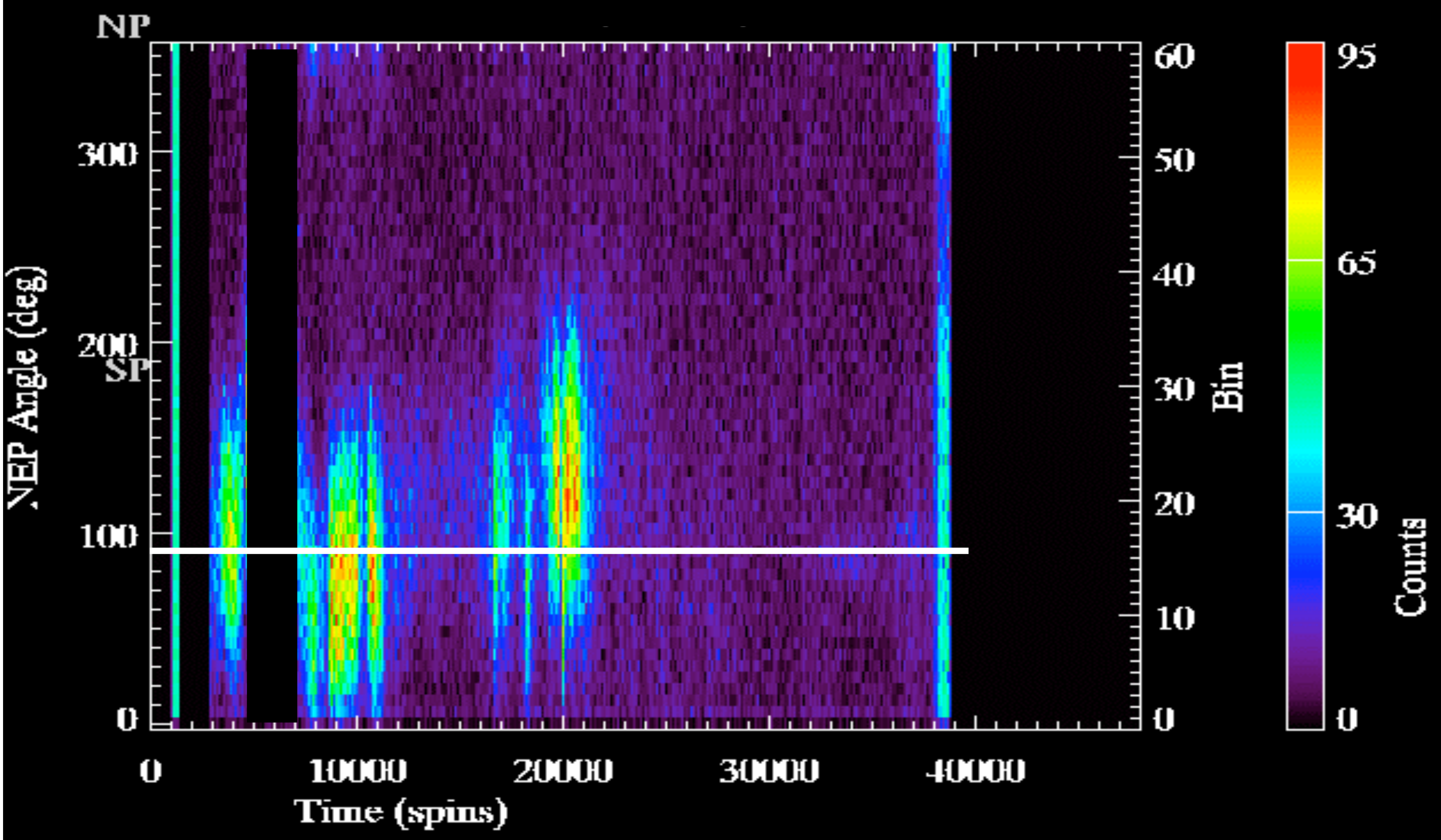

Triple Coincidences

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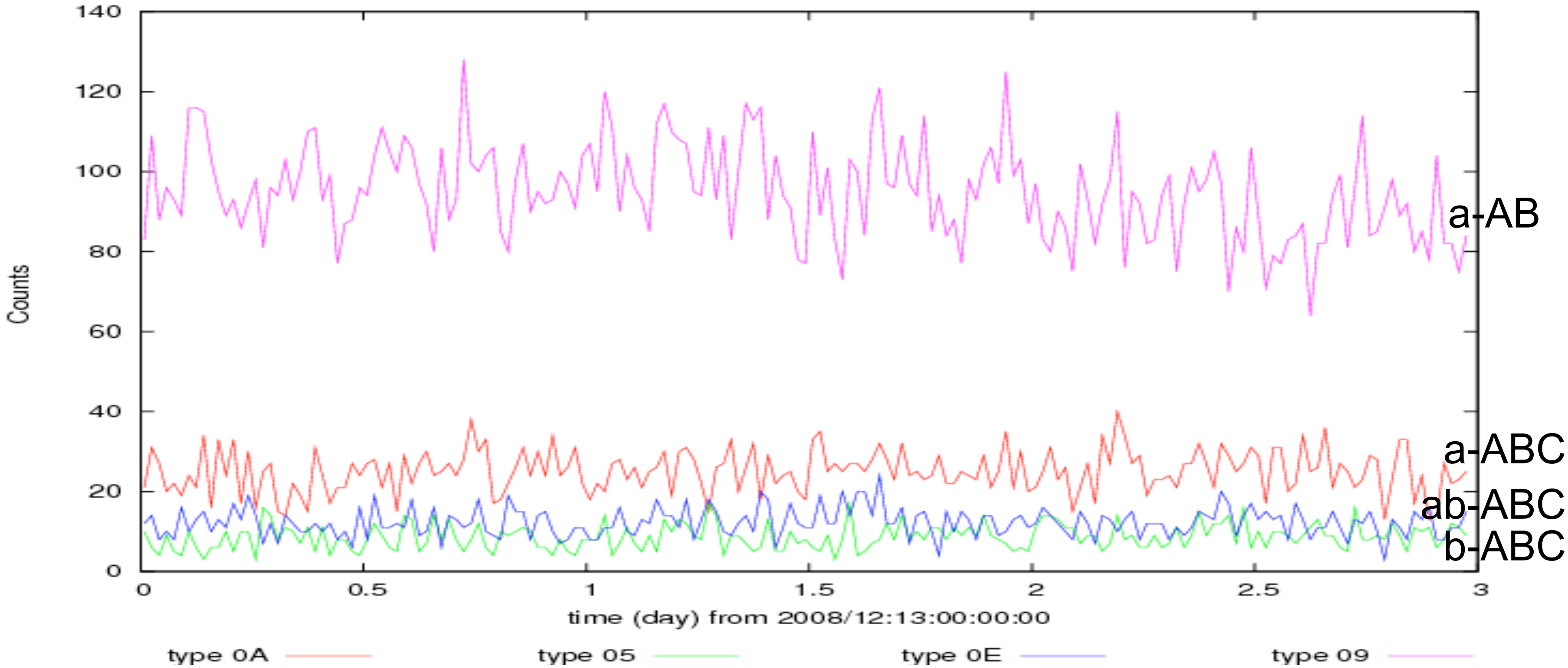

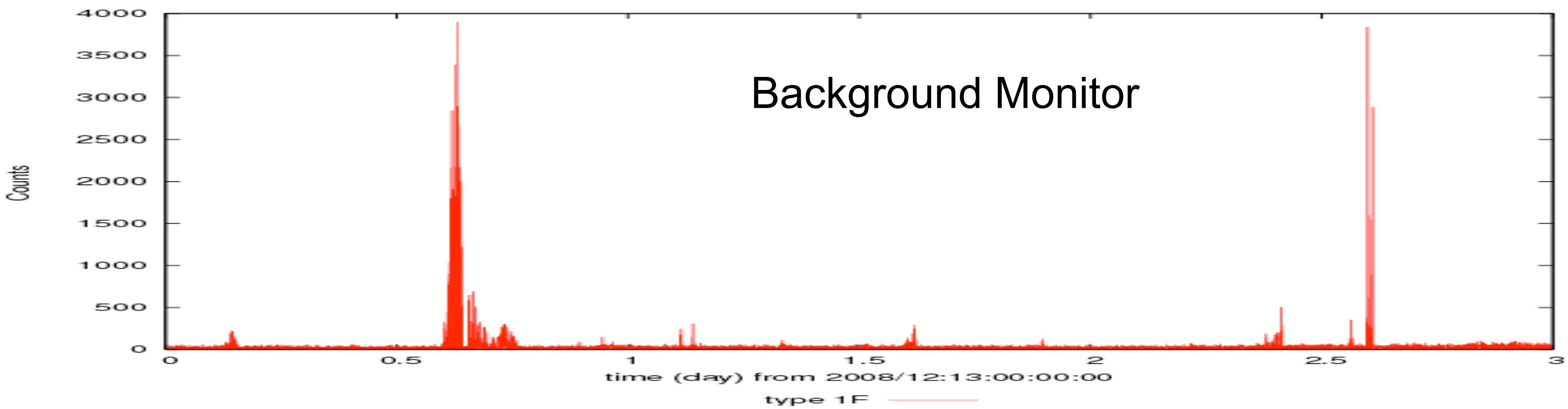

What Will the Sky Map Show ???

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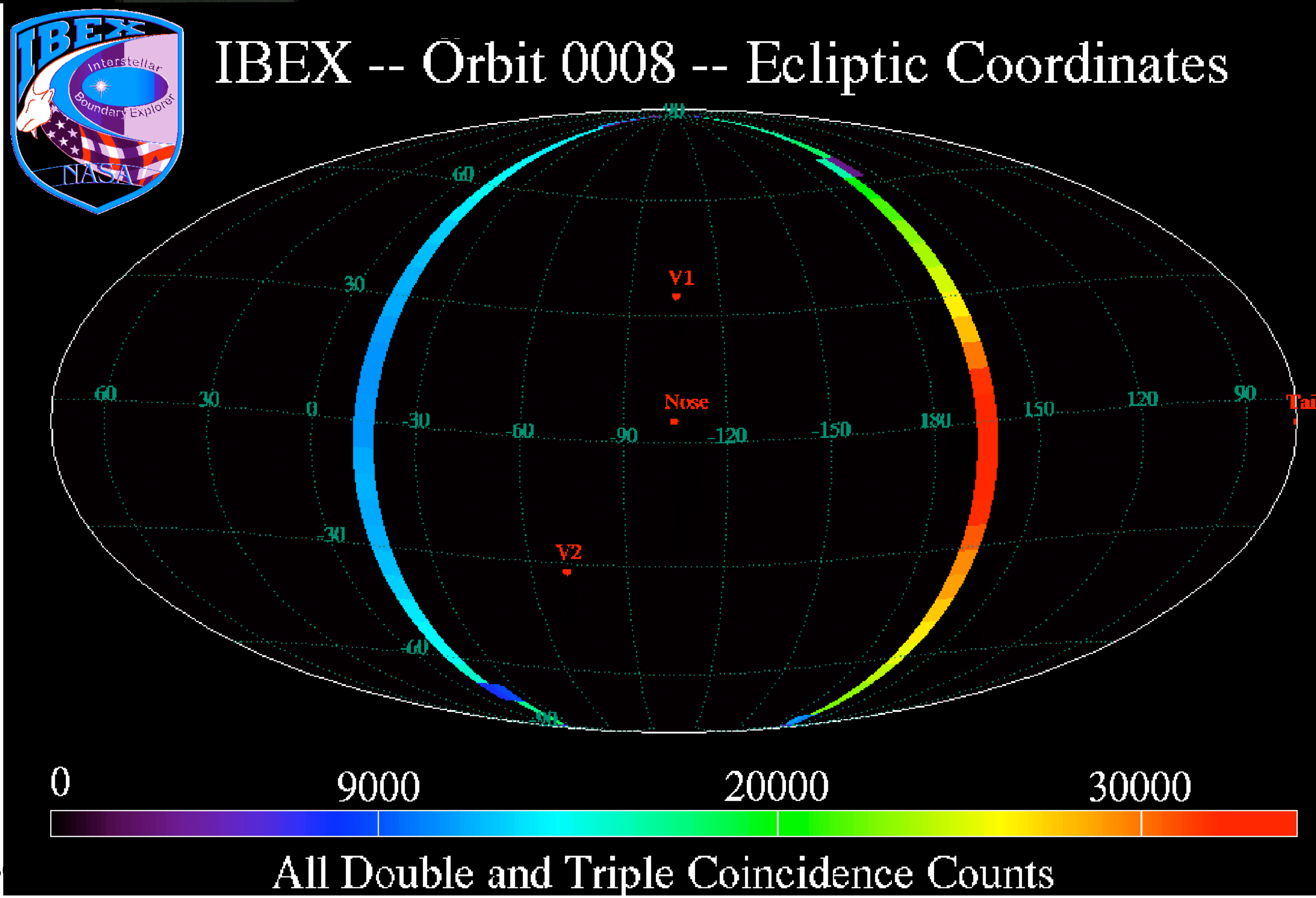

IBEX-Lo In-Flight Performance

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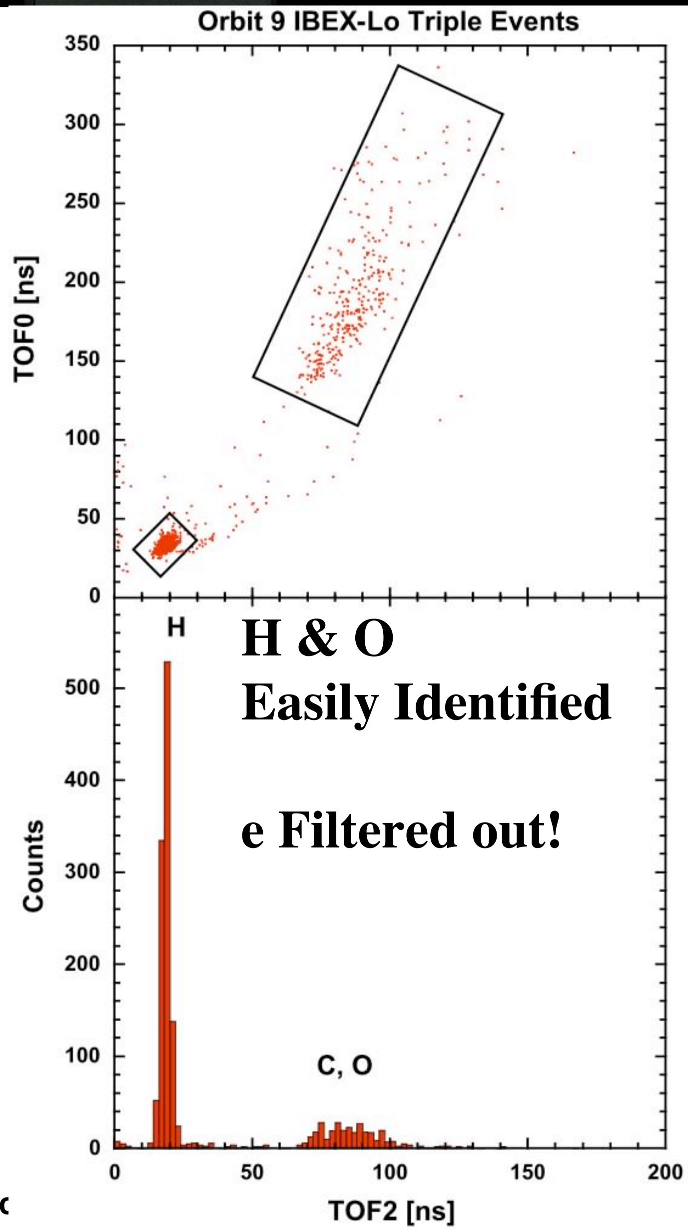
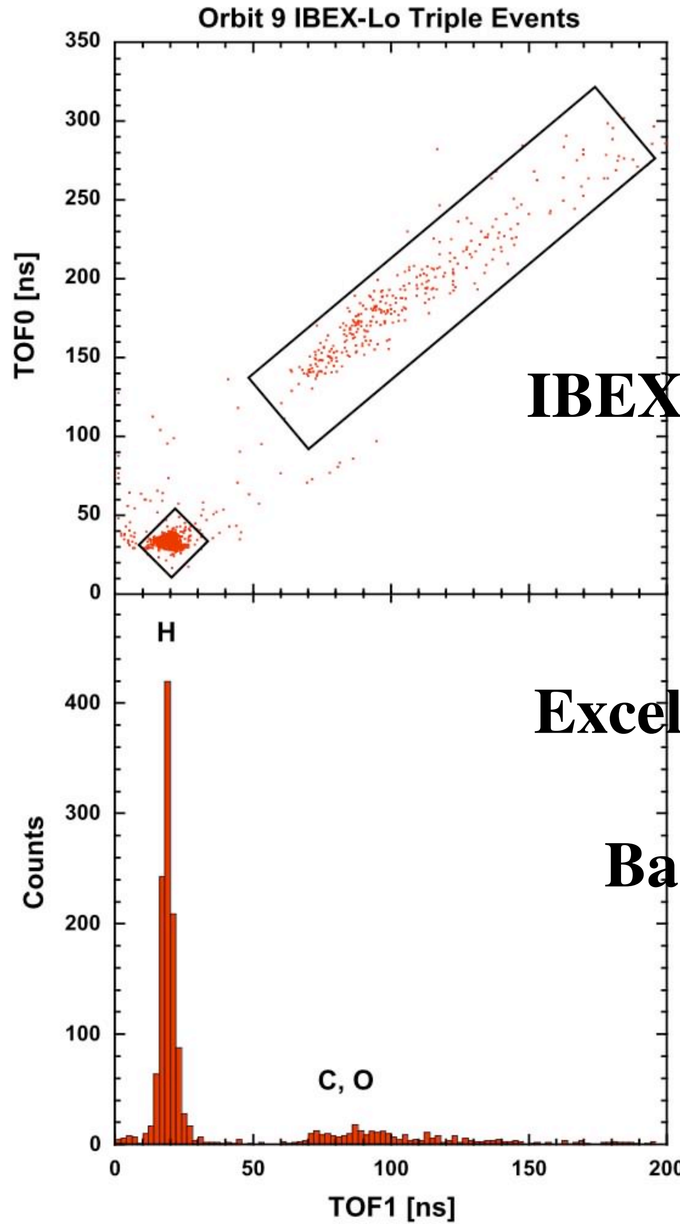


H & O
Easily Identified

e Filtered out!



IBEX-Lo TOF
Works
Great!

Excellent Tool
to Tackle
Background

IBEX-Lo Will See Interstellar Neutrals

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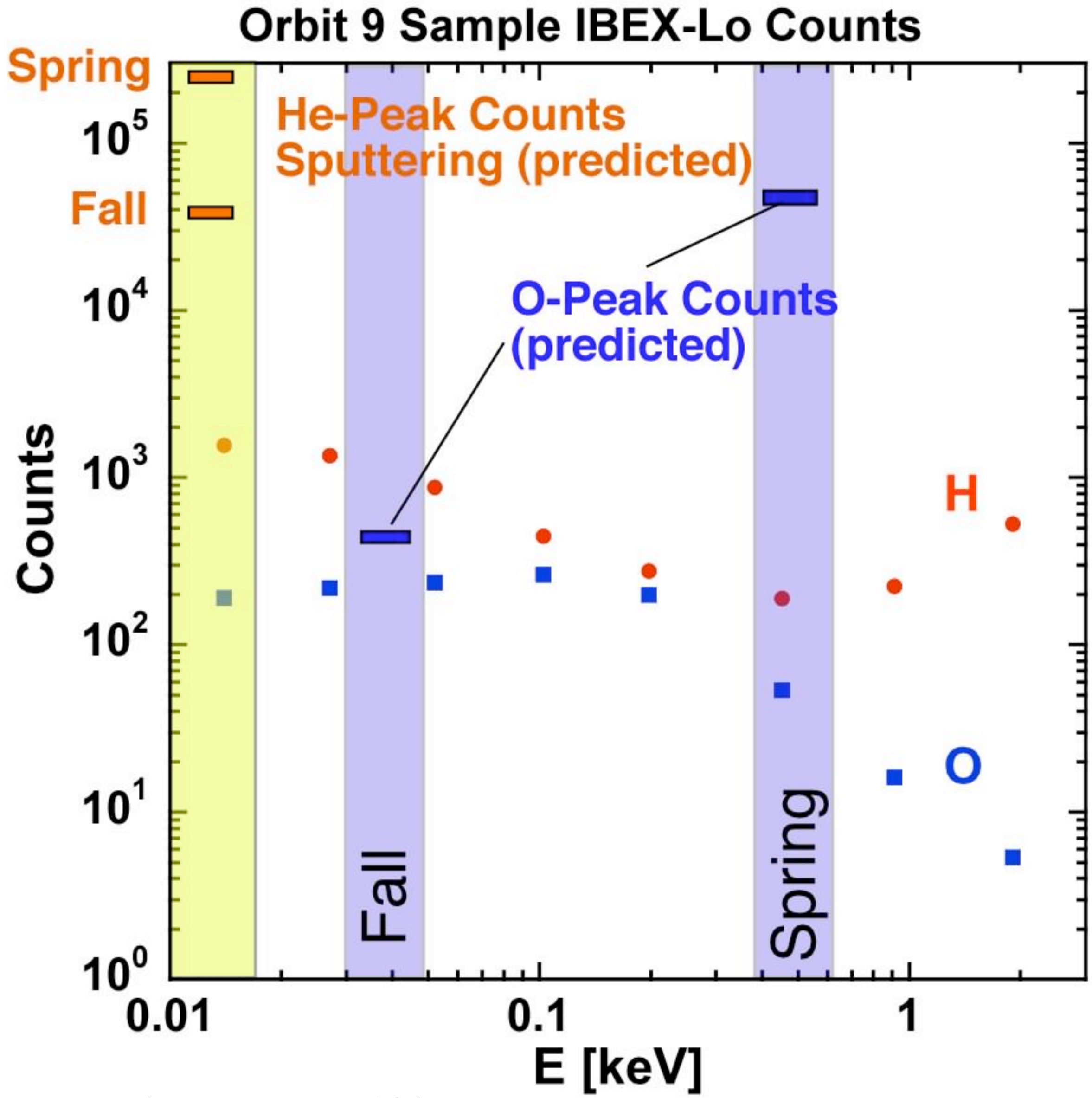

Arbitrary
Orbit 9 Sample
No Selection
or Background
Subtraction!
Normalized to
ISM Flow Viewing

Both ISM O & He
will be well Visible!

First Spring Period
Starts Now!