National Observatory of Athens (NOA)

INSTITUTE OF ASTRONOMY AND ASTROPHYSICS
NATIONAL OBSERVATORY OF ATHENS

Space Weather Research at IAA/NOA: Solar Energetic Particle Investigations

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10th Hellenic Astronomical Conference

Ioannina
07.09.2011

SEPServer: Data Services and Analysis Tools for SEP Events and Related EM Emissions

SEVENTH FRAMEWORK PROGRAMME

✓The project is funded through the 7th Framework Programme of the EU (Contract No 262773) and coordinated by the University of Helsinki.

✓It will combine data and knowledge from **11 European partners** and several collaborating parties from Europe and US.

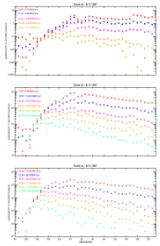
SEPServer

WP1

leader **UH**

Management

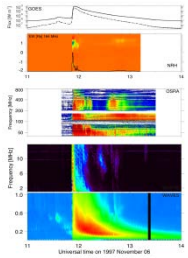
WP2



leader **CAU**

SEP Observations

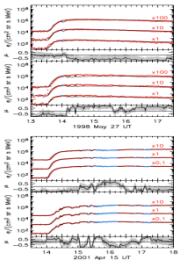
WP3



leader **CNRS**

EM Observations

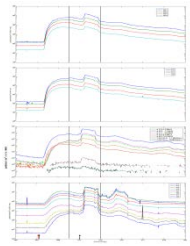
WP4



leader **UB**

Simulations / inversion methods

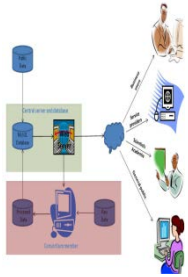
WP5



leader **NOA**

Scientific data analysis

WP6



leader **DHC**

Server development

WP7

leader **UH**

Dissemination of results and external coordination

✓The SEPServer project will **produce a new tool**, which greatly facilitates the investigation of solar energetic particles (SEPs) and their origin. This will be **an Internet server** providing:

- **high-quality SEP data**
- **related electromagnetic (EM) observations and state-of-the-art analysis methods**
- **a comprehensive catalogue of the observed SEP events**

will **provide educational** and **outreach material** on solar eruptions and space environment on its website.

Facts & Figures:

✓The project started in **December 2010** and will last **36 months**. The most significant milestones are planned as follows:

- **The prototype server populated with the first data sets will be running in October 2011**
- **The 1st catalogue of SEP events will be published on the project website in January 2012**
- **The server will be released in September 2013.**

✓The consortium will also **analyse the data** using the ***data-driven methods*** and ***numerical-simulation based inversion methods*** to be developed during the project.

✓A **scientific Workshop**, open to the community, **on SEP event analysis** will be organised in Paris in spring 2013

✓In addition the consortium will provide **educationa**l and **outreach material** on solar eruptions and space environment on its website

Datasets:

✓SEPServer will provide **public access** to a number of **SEP datasets** that **have been previously either unavailable or available only through the PI team**. SEP experiments to be included in the database come from a number of European and American missions:

- **SOHO: COSTEP, ERNE (electrons 44 keV – 9 MeV, ions 1 – 100 MeV/n)**
- **ACE: SIS, EPAM (electrons 40 – 310 keV, ions 0.05 – 100 MeV/n)**
- **Wind: 3DP (electrons 30 – 500 keV, protons 0.07 – 7 MeV)**
- **STEREO: SEPT and LET (electrons 30 – 400 keV, ions 0.07 – 30 MeV/n)**
- **Helios: E6 (electrons 0.3 – 2 MeV, ions 2 – 50 MeV/n)**
- **Ulysses: COSPIN/KET and LET, HI-SCALE (electrons 30 keV – GeV, ions 50 keV – 2 GeV/n)**

SEPServer will **also provide streamlined access to the data from ground-based Neutron monitors**.

✓In addition to energetic particle data, SEPServer will provide access to a comprehensive set of electromagnetic emissions related to the SEP events. These include:

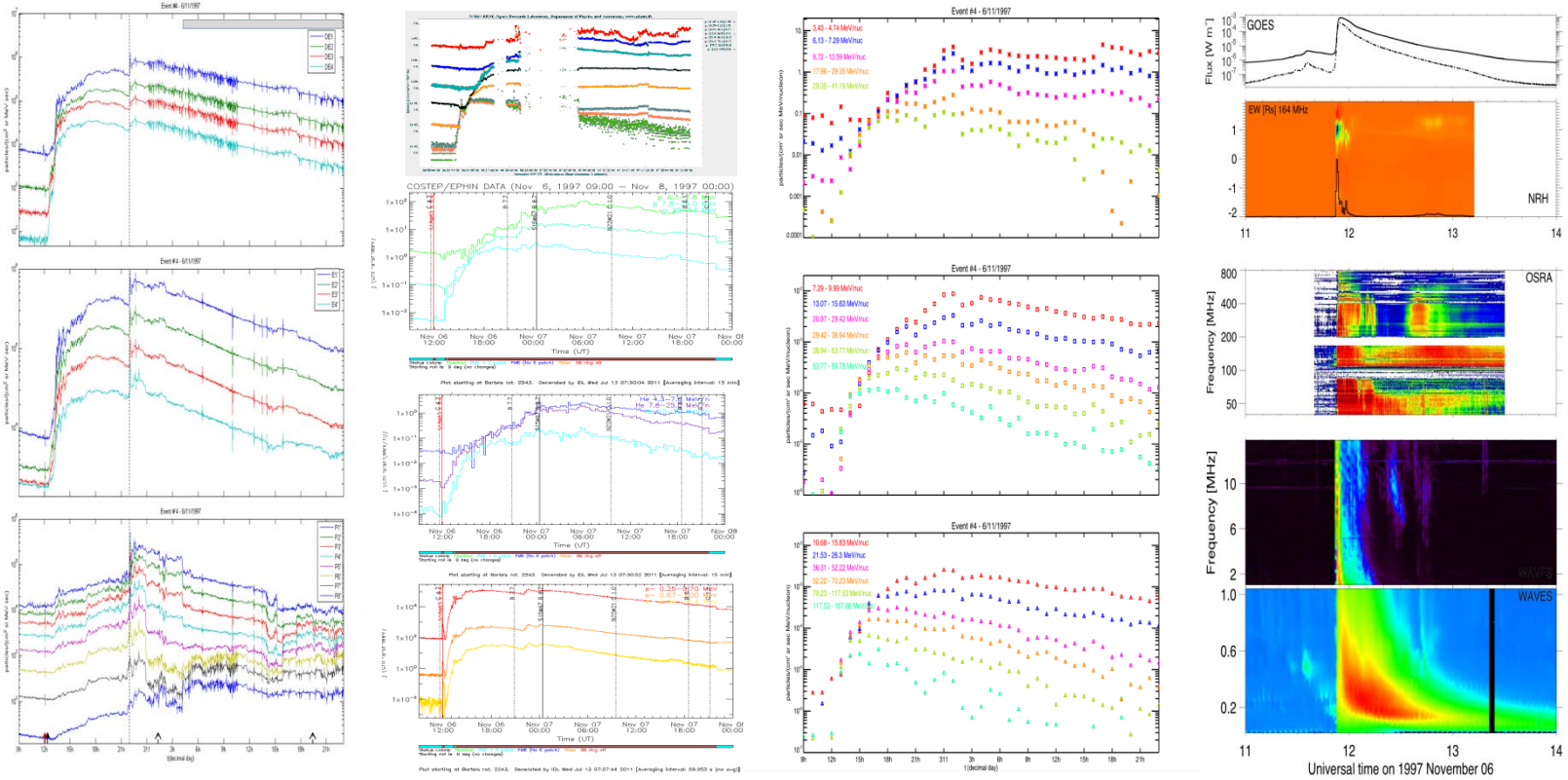
- **Spectrographic radio observations from AIP/Tremsdorf, ARTEMIS, Nancay Decameter Array and Wind/WAVES.**
- **Radio imaging observations from Nancay Radioheliograph**
- **Microwave observations from the University of Bern**
- **X-ray and gamma-ray observations from INTEGRAL, RHESSI, GRANAT/Phebus, Compton/BATSE**

All datasets will be accompanied with reports on the assessment of their quality

Scientific results I – Comparisons 1 AU:

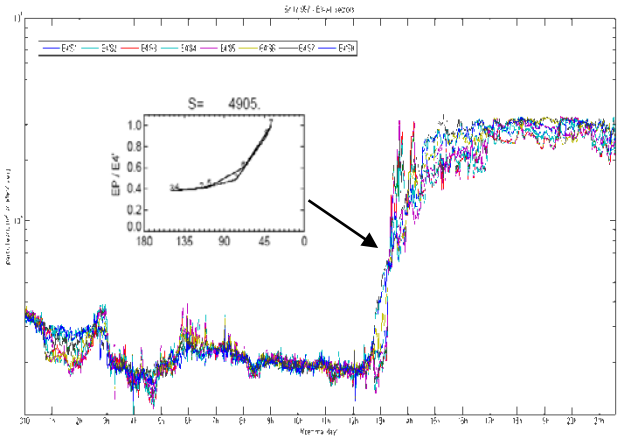
Case Study:
The SEP event of 6.11.1997

Particle Observations + **EM Observations**



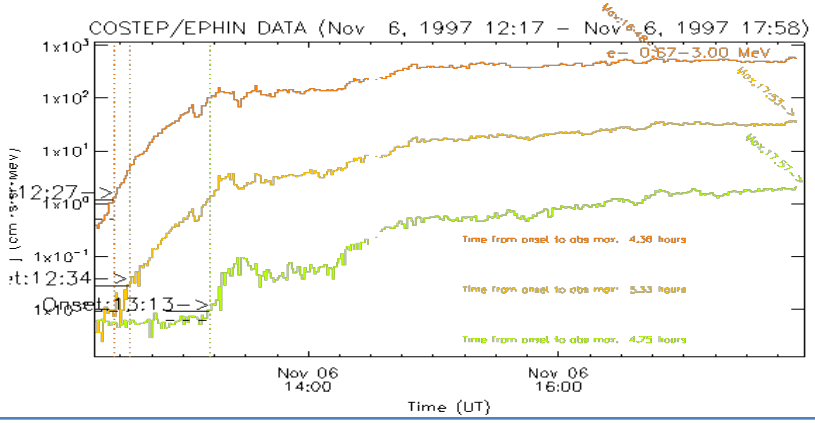
Scientific results I – Analysis 1 AU:

Pitch-Angle Distributions (PADs)



✓PADs calculated for all E's channels of ACE/EPAM. A beam-like structure was revealed and sector 7 of E'4 was directed along the magnetic field

Onset determination



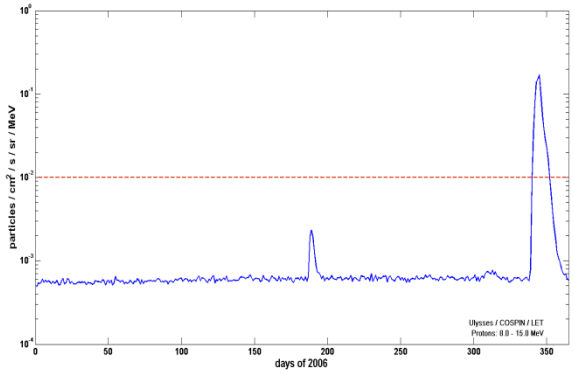
Instrument	Channel	Onset time	Sector
ACE/EPAM	E'4 (0.175-0.312 MeV)	12:36	7
Instrument	**Channel**	**Onset time**	
SOHO/EPHIN	Electrons (0.7-10 MeV)	12:27	
Instrument	**Channel**	**Onset time**	
SOHO/EPHIN	Protons (25-53 MeV)	13:13	
Instrument	**Channel**	**Onset time**	
SOHO/ERNE	Protons (54.8-80.3 MeV)	12:37	

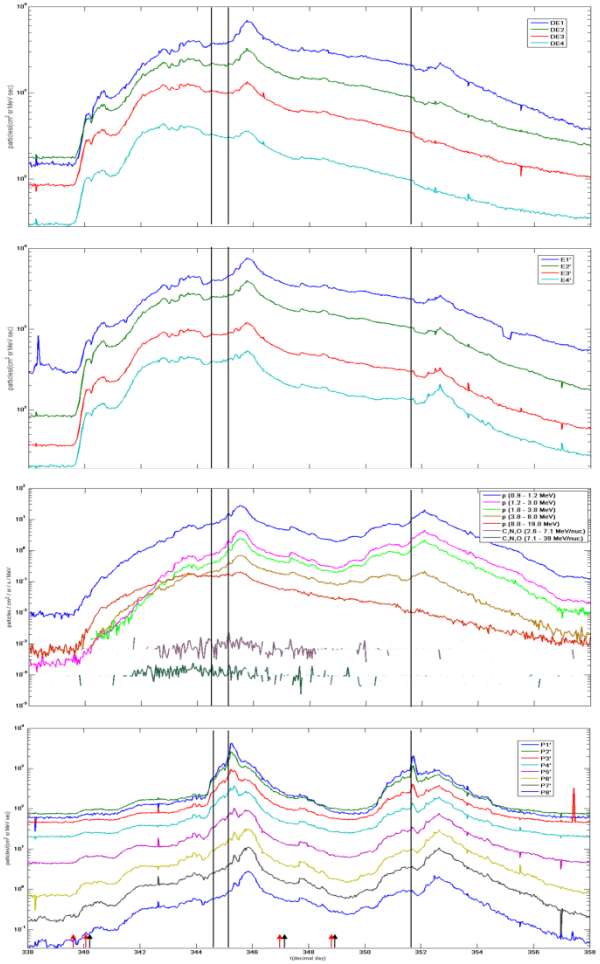
Scientific results II – Comparisons >1 AU:

December 05, 2006 SEP – Ulysses Observations

✓A novel **Ulysses SEP event list** of solar cycle 23 including data driven analysis of the events is currently in progress.

✓The **anticipated solar release time and the corresponding solar source** of each SEP event of the Ulysses event list will also be included.





Instrument	Channel	Onset time (UT)	Maximum time (UT)	Peak intensity (p/cm²/sr/s/MeV)
Ulysses/HI-SCALE (1-min averages)	**E'4 (0.178-0.290 MeV)**	**19:15 (DOY:339)**	**17:23 (DOY:345)**	**6.37 10^{2}**
Ulysses/COSPIN/LET (10-min averages)	**P5 (8.0-19.0 MeV)**	**23:40 (DOY:339)**	**15:30 (DOY:345)**	**2.01 10^{-1}**

more details at the poster P.9.8: A. Papaioannou et al.

COMESEP

COMESEP: Coronal Mass Ejections and Solar Energetic Particles: Forecasting the Space Weather Impact

SEVENTH FRAMEWORK PROGRAMME

✓The project is funded through the 7th Framework Programme of the EU (Contract No 263252) and coordinated by the BIRA.

✓It will combine data and knowledge from **7 European partners** and several collaborating parties from Europe and US.

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UNI GRAZ

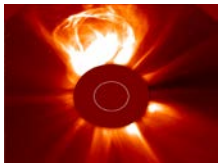
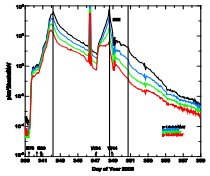
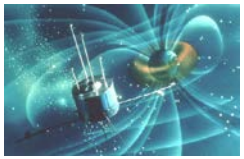
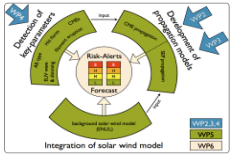
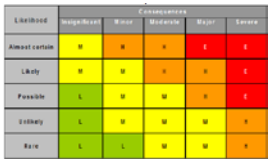
HO

DTU

uclan
University of Central Lancashire

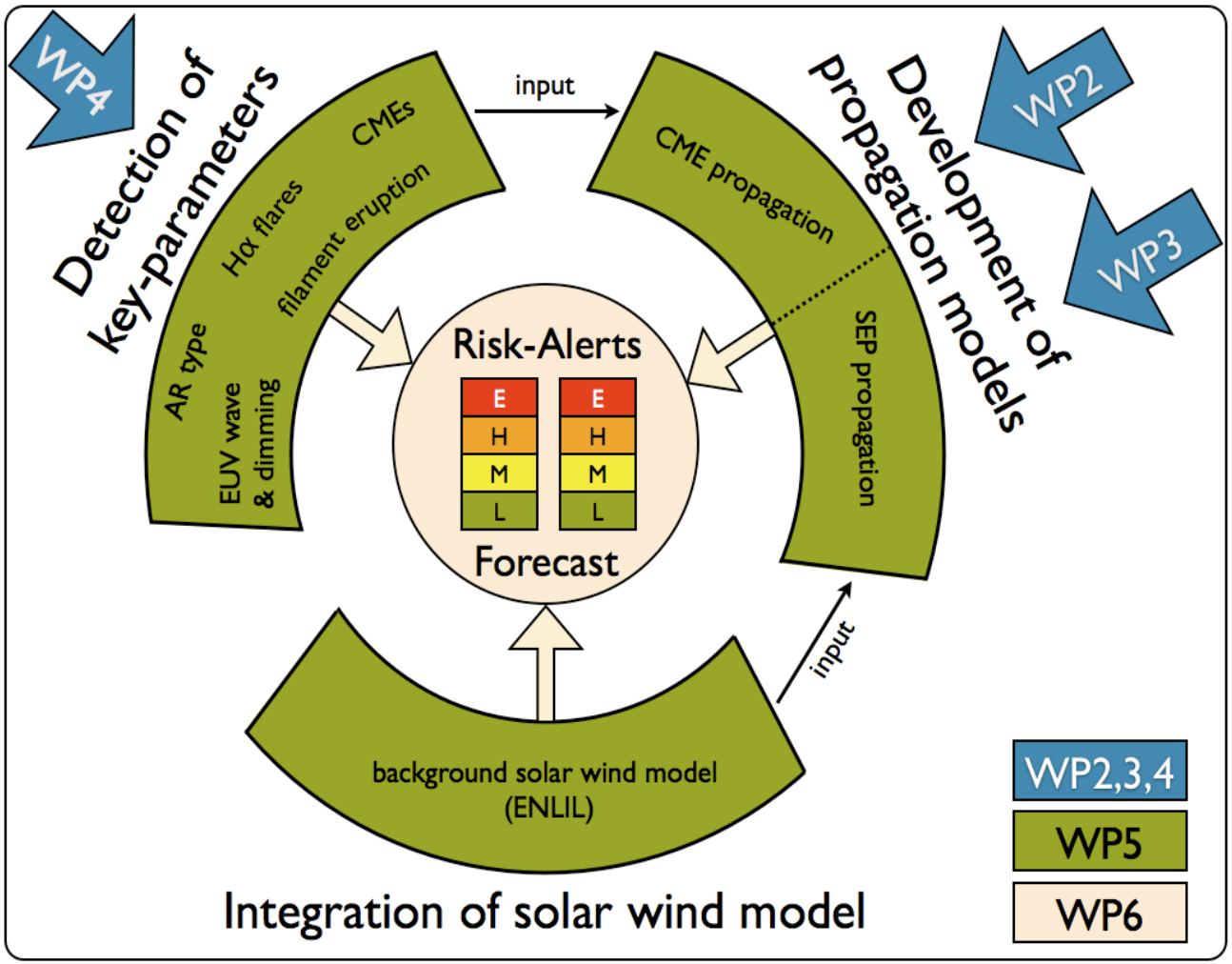
COMESEP

BASIC SCIENCE | MODELING | ALERT

WP1	WP2	WP3	WP4	WP5	WP6
					
leader **BIRA**	leader **HVAR**	leader **NOA**	leader **DTU**	leader **UCLan**	leader **ROB**
MANAGEMENT	CORONAL MASS EJECTIONS	SOLAR ENERGETIC PARTICLES	SPACE WEATHER IMPACT	DEVELOPMENT OF FORECASTING METHODS	SPACE WEATHER ALERT SYSTEM

- ✓ COMESEP Project will develop a **European space weather alert system**. This will include:
  - o **Combination of basic research on space weather events**
  - o **Optimization of the forecasting methods**
  - o **Linked Alert with real-time automated CME detection**
- ✓ Resulting into **an automated "start-to-end-service" system**.

COMESEP


WP4
Detection of key-parameters
CMEs
Hα flares
filament eruption
AR type
EUV wave & dimming
input
CME propagation
SEP propagation
Development of propagation models
WP2
WP3
Risk-Alerts
E
H
M
L
E
H
M
L
Forecast
input
background solar wind model (ENLIL)
Integration of solar wind model
WP2,3,4
WP5
WP6

COMESEP Facts & Figures:

✓The project started in **February 2011** and will last **36 months**. The most significant milestones are planned as follows:

- **ICME and SEP forecasting tools will be implemented by August 2013**
- **Alert systems producing near real-time forecasts will be running in January 2014**
- **COMESEP will be released in January 2014**

✓The consortium will use the scientific results obtained in the project for the **optimization of the detection and forecasting methods for SEPs and ICMEs**.

✓In addition the consortium will provide **SEP radiation storm** and **magnetic storm alerts** to the European space weather community.

COMESEP Services:

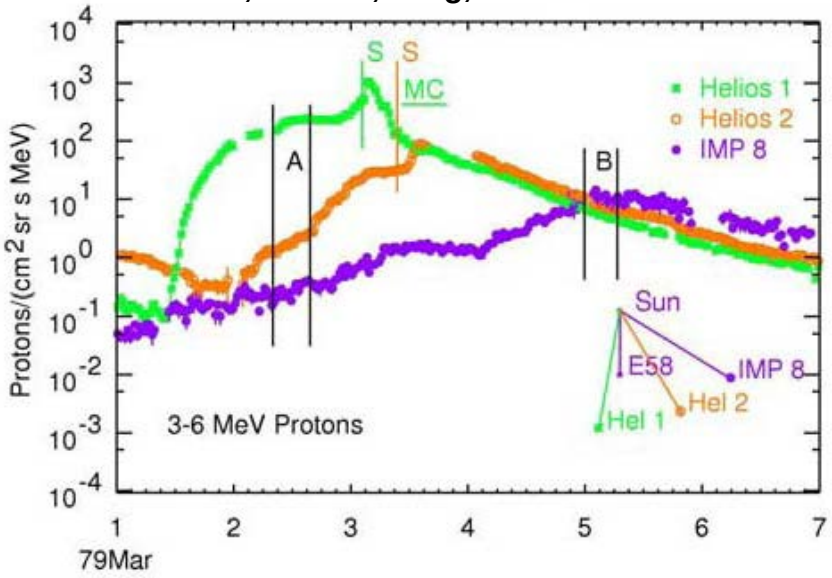
✓**Geomagnetic** and **SEP radiation storm** forecasts based on the automated detection of solar activity and modeling of the evolution of the ICME and energetic particles.

✓Illustration of the **Geomagnetic** and **SEP radiation** storm alerts based on the COMESEP definition of risk

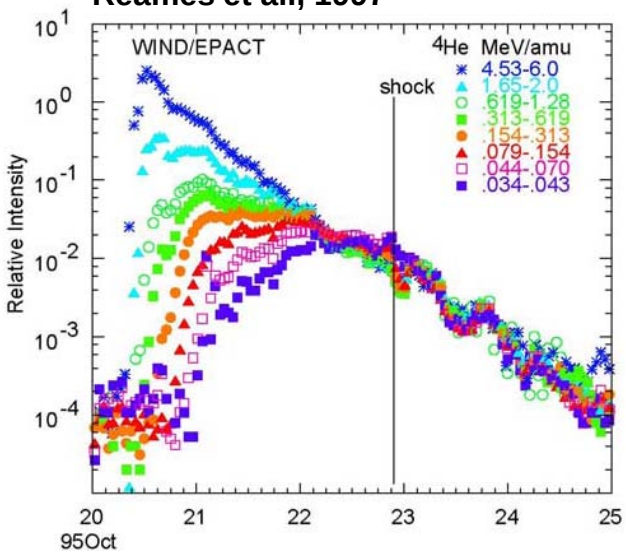
Likelihood	Consequences				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Elemental Composition in "Reservoir" / "Invariant Spectrum" Regions

Reames, Barbier, & Ng, 1996



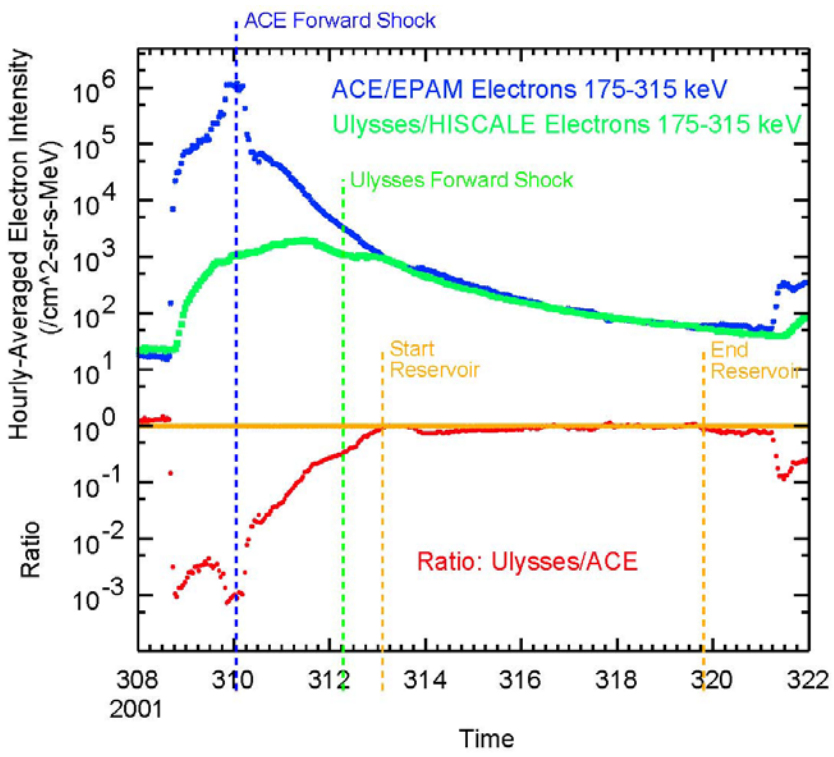
Reames et al., 1997



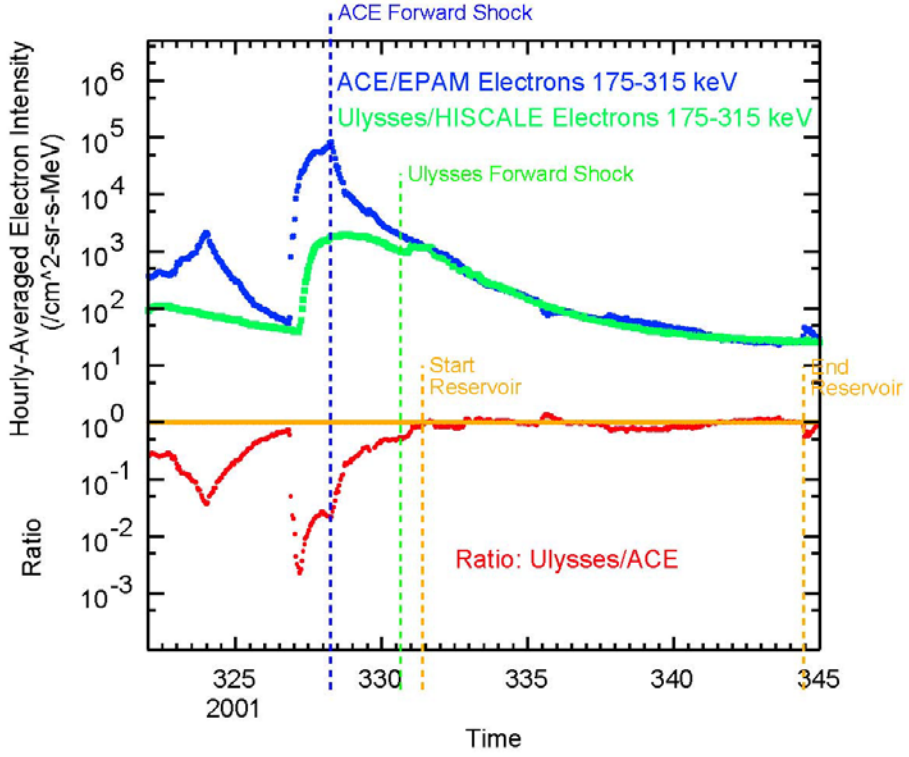
McKibben 1972, Roelof 1991, 1992,
Reames et al. 1996, 1997,
Maclennan et al. 2003,
McKibben et al. 2003, Lario et al. 2010

In this study, we use ACE and Ulysses electron data to identify reservoir periods. We take the first detailed examination of elemental spectra and composition in reservoirs.

Electron Time-Intensity Profiles & Ulysses/ACE Ratios



Reservoir Period #1:
2001 313/0200 – 319/1859
(160 hours)

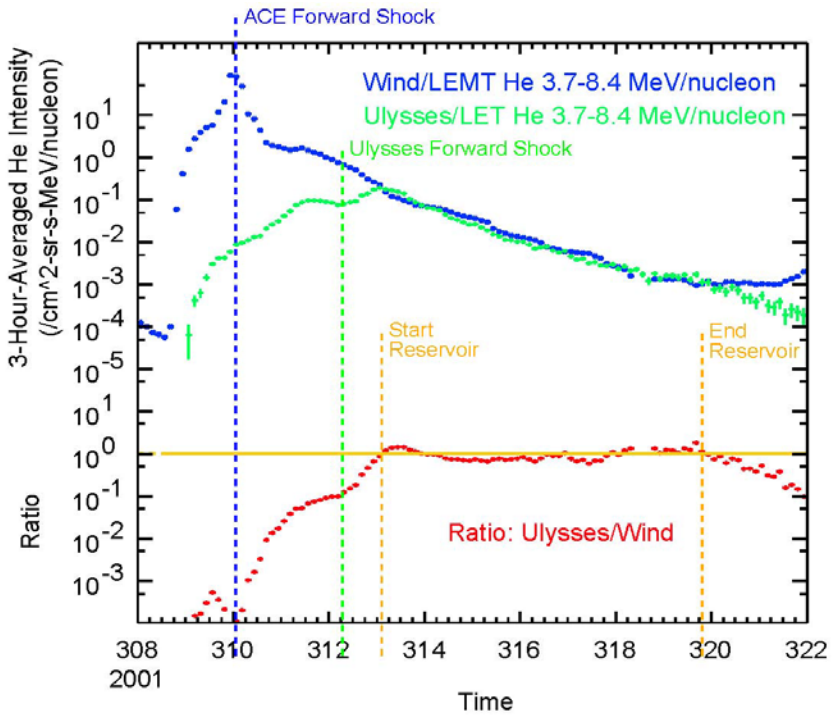


Reservoir Period #2:
2001 331/0900 – 344/0959
(313 hours)

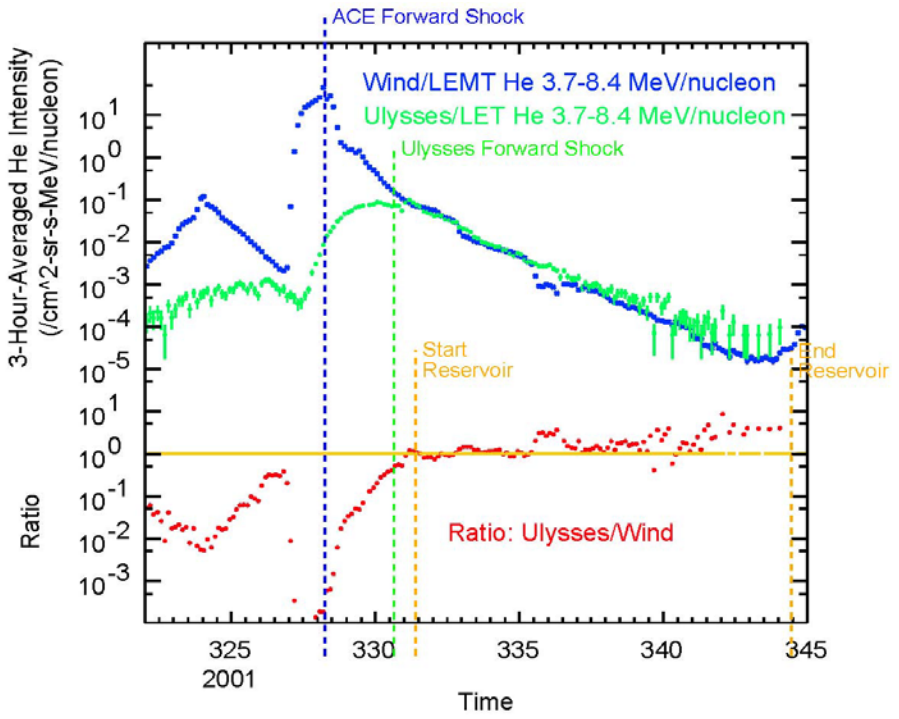
In both cases, at the time of the shock's arrival at Ulysses, we see an inflection point in the electron timeline, so that the intensity at Ulysses starts to increase so as to match the intensity at L1. Reservoir period begins (defined as HISCALE/EPAM ratio exceeding 90%) 24-36 hours later.

He Time-Intensity Profiles (3-hour averages)

Wind /LEMT measures He in 8 bins covering 1.65 - 9.64 MeV/nuc
Ulysses/LET measures He in 4 bins, including 3.70 - 8.40 MeV/nuc
Correct Wind data to this same energy bin and compare:



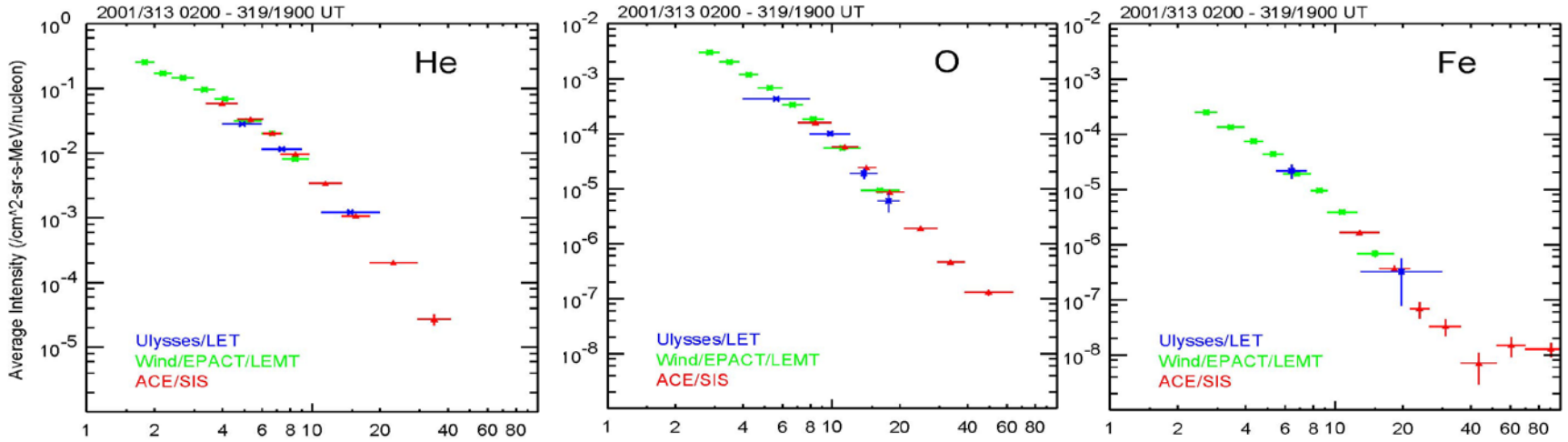
Reservoir Period #1:
2001 313/0200 – 319/1859
(160 hours)



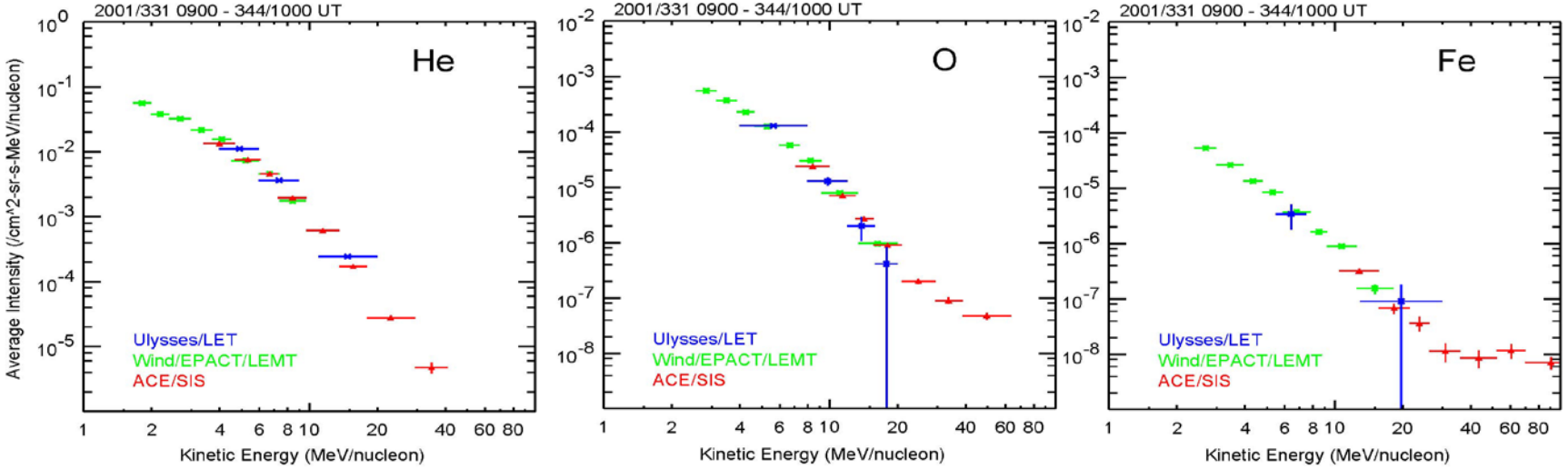
Reservoir Period #2:
2001 331/0900 – 344/0959
(313 hours)

Comparison of Elemental Spectra at Ulysses and at L1 During Reservoir Periods

Reservoir Period #1

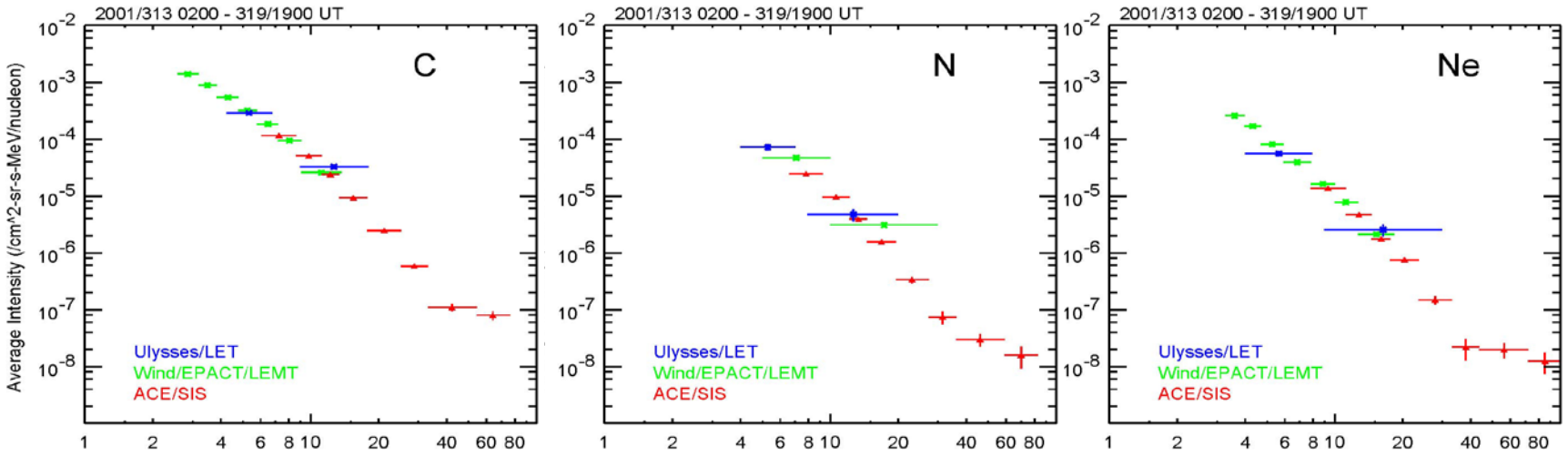


Reservoir Period #2

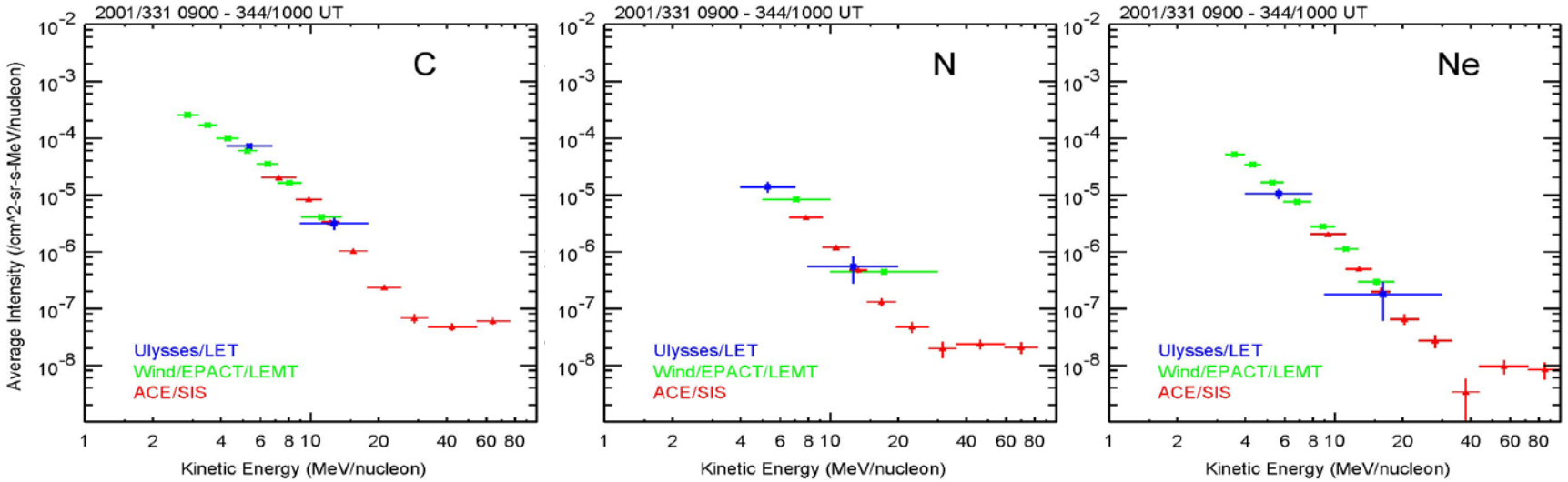


Comparison of Elemental Spectra at Ulysses and at L1 During Reservoir Periods *(cntd.)*

Reservoir Period #1



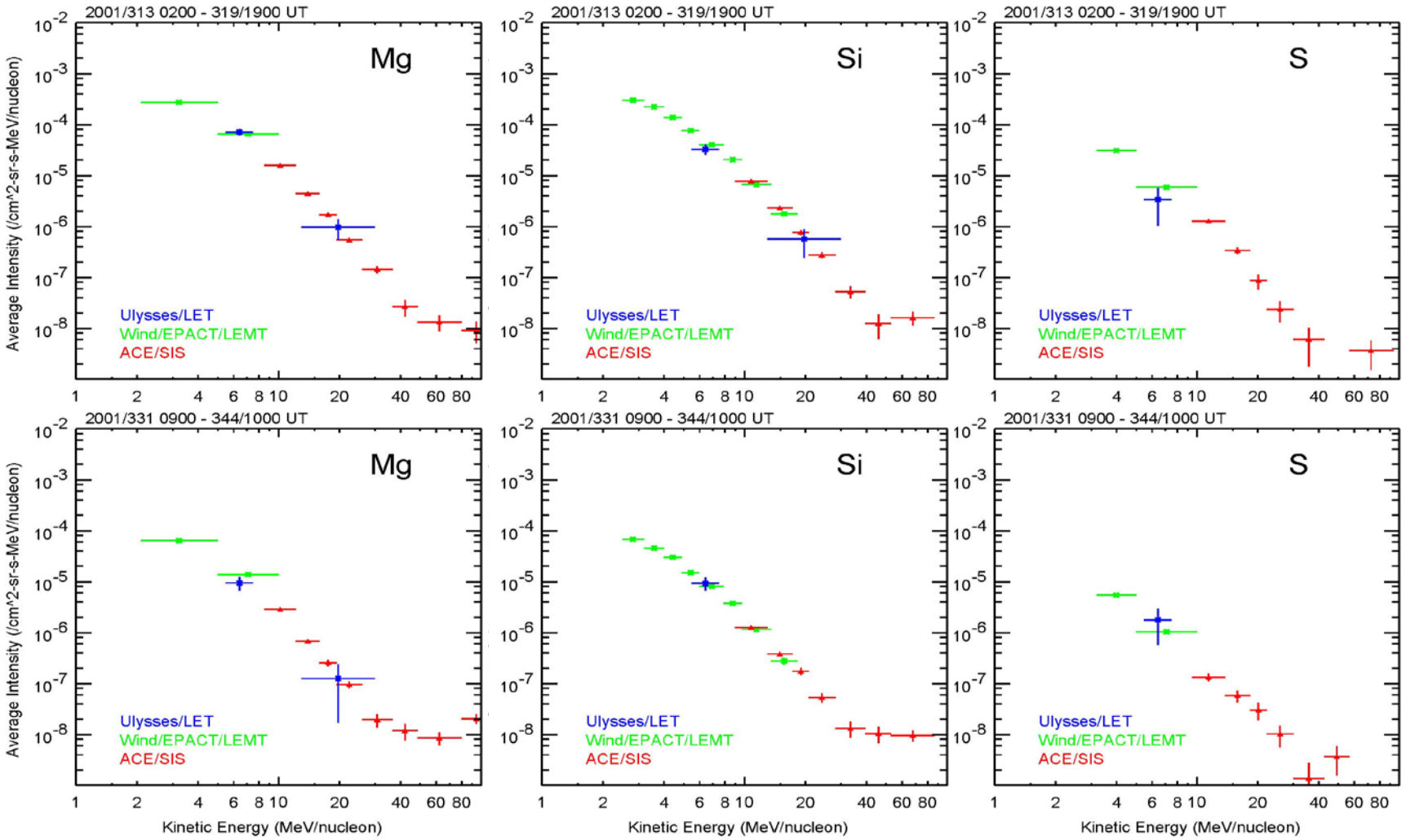
Reservoir Period #2



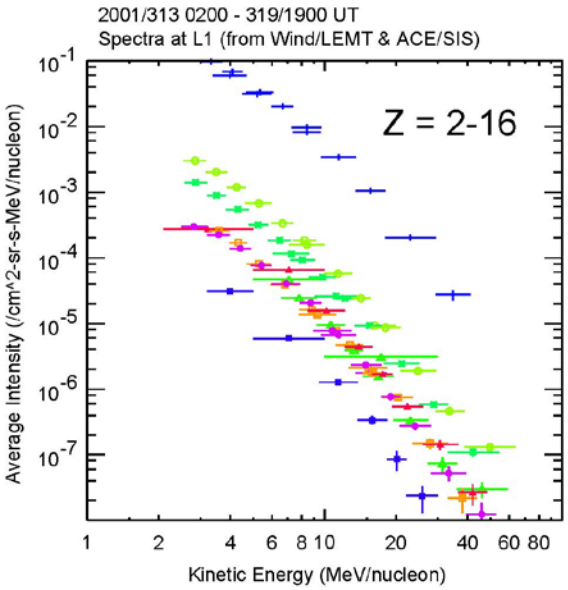
Comparison of Elemental Spectra at Ulysses and at L1 During Reservoir Periods *(cntd.)*

Reservoir Period #1

Reservoir Period #2

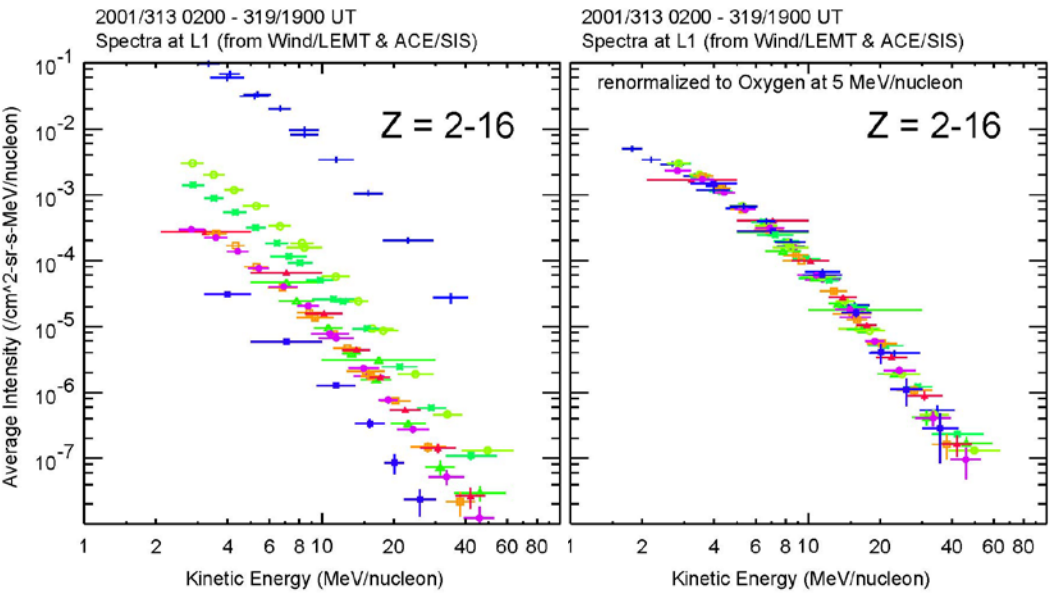


Spectral Comparisons: A Closer Look at Reservoir Period # 1



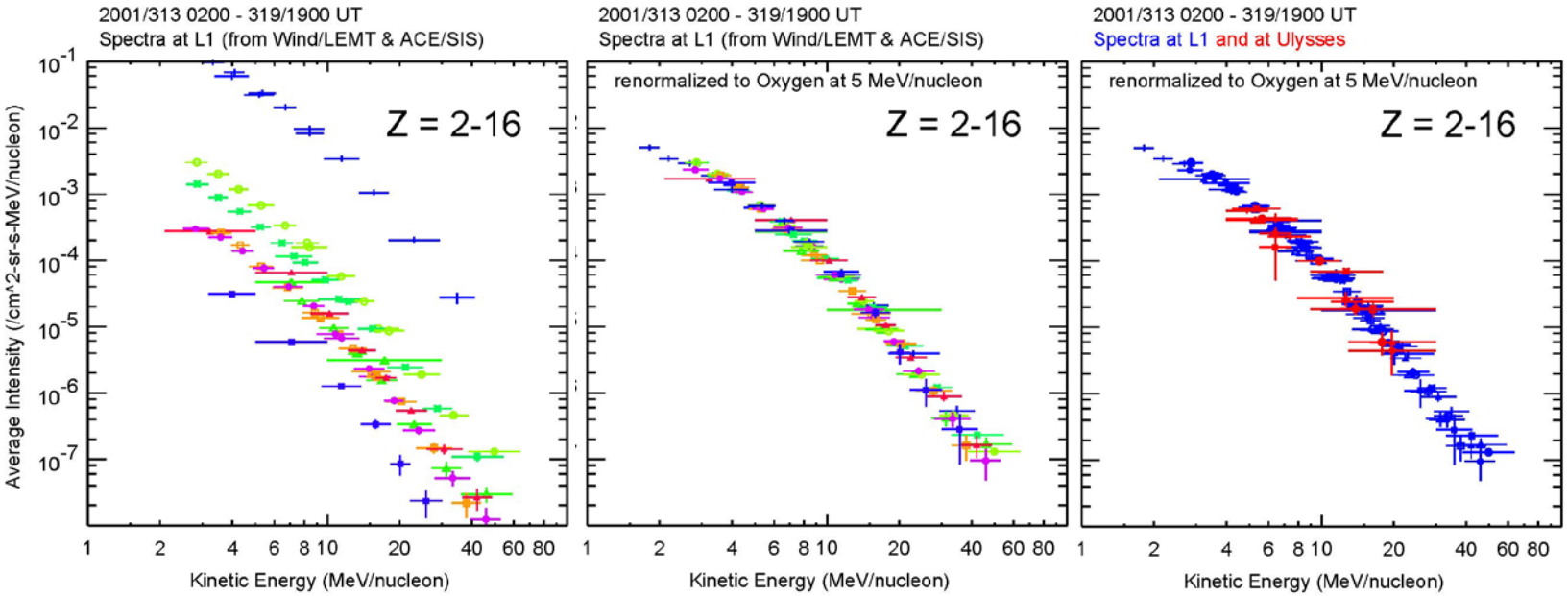
Spectra for elements He-S, all of which have M/Q ~2.

Spectral Comparisons: A Closer Look at Reservoir Period # 1



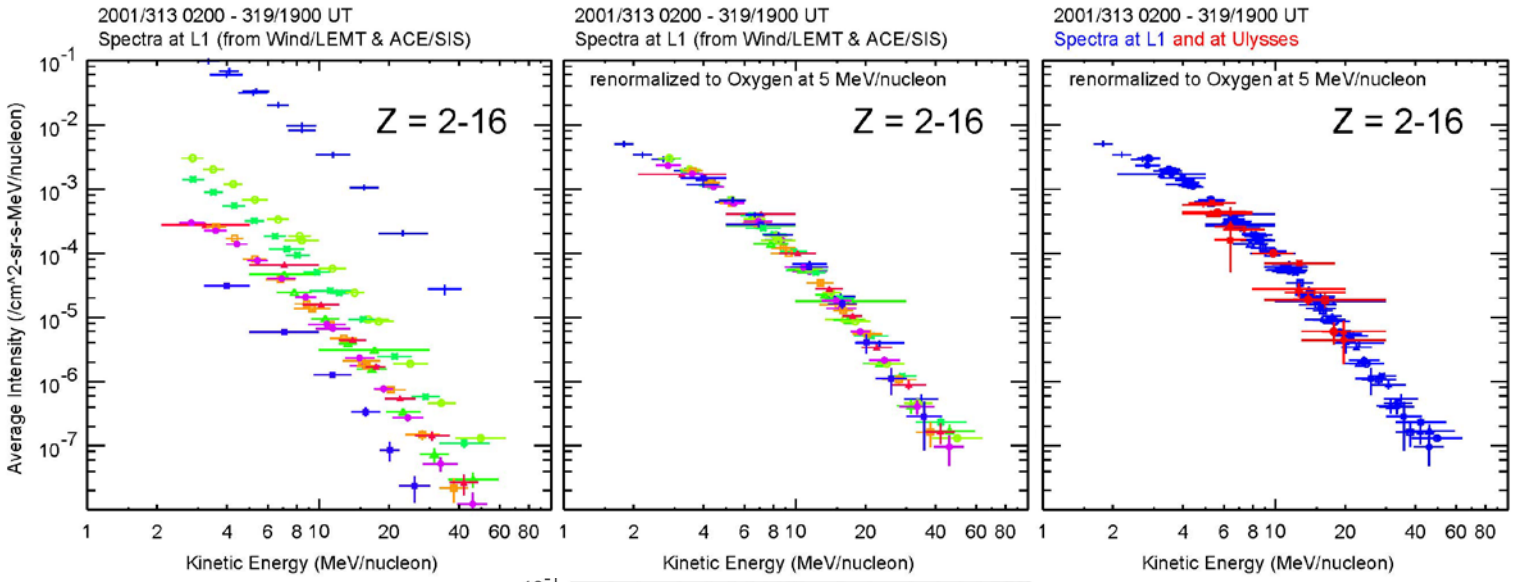
Renormalize each elemental spectrum to the value of oxygen at 5 MeV/nuc.

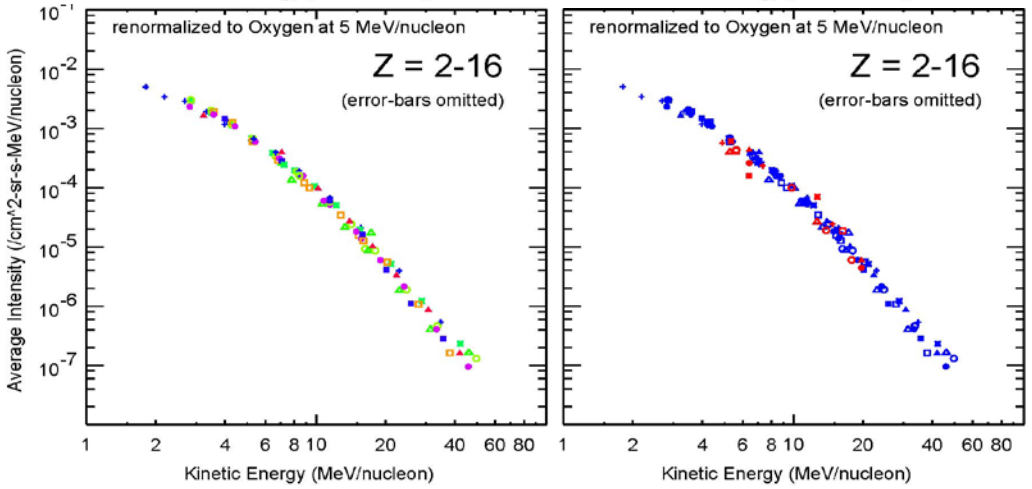
Spectral Comparisons: A Closer Look at Reservoir Period # 1



Now add Ulysses datapoints, using the same element-by-element renormalization factors determined at L1.

Spectral Comparisons: A Closer Look at Reservoir Period # 1

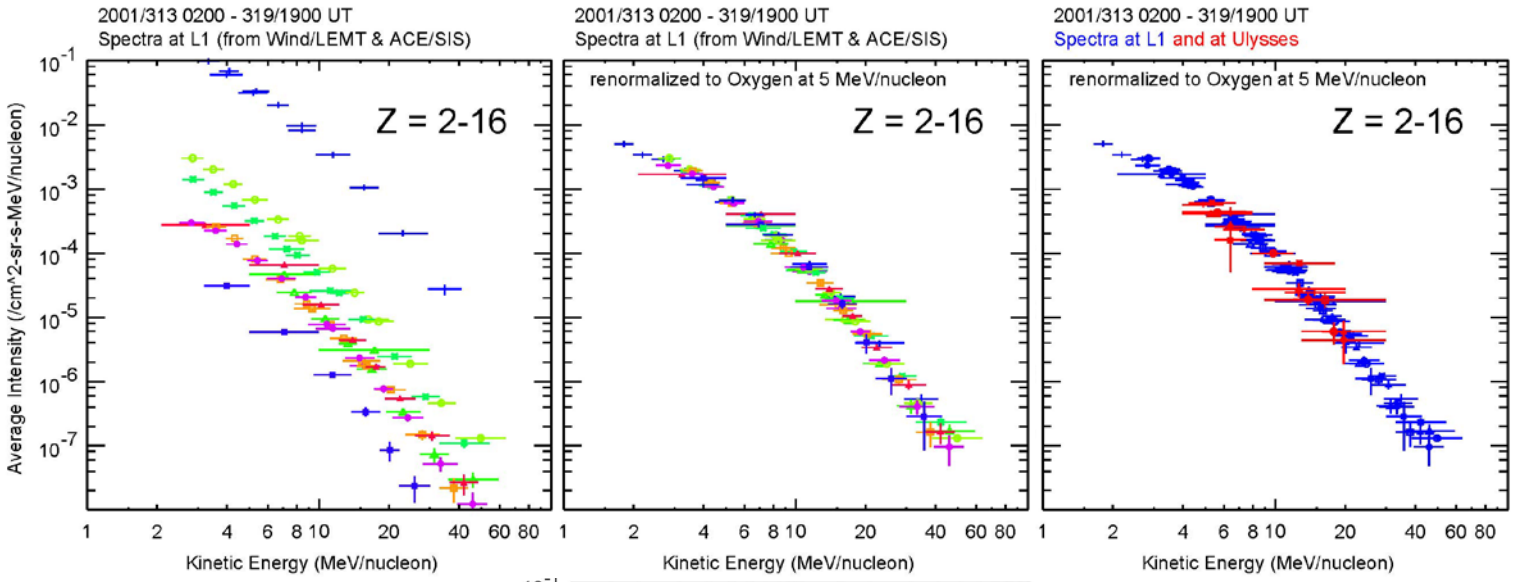




Omit error bars for clarity.

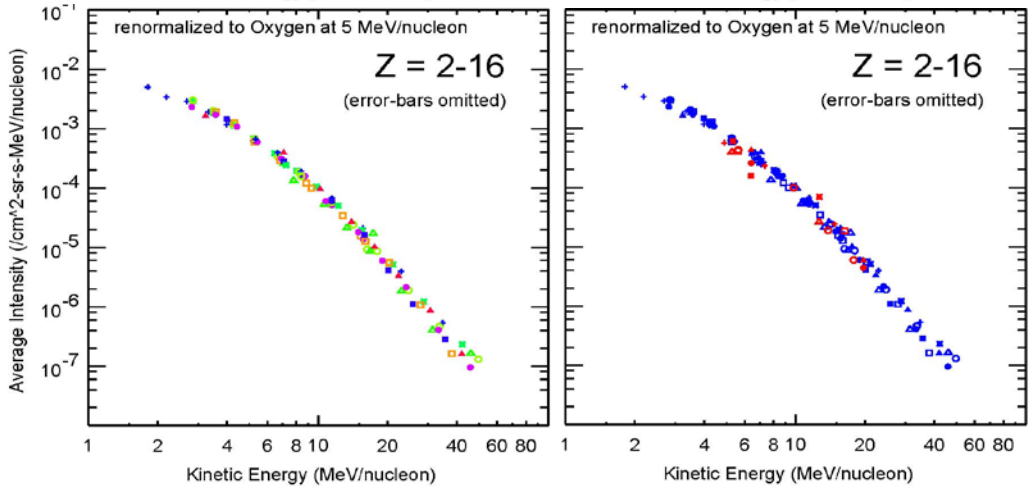
Datapoints are very tightly clustered.

Spectral Comparisons: A Closer Look at Reservoir Period # 1



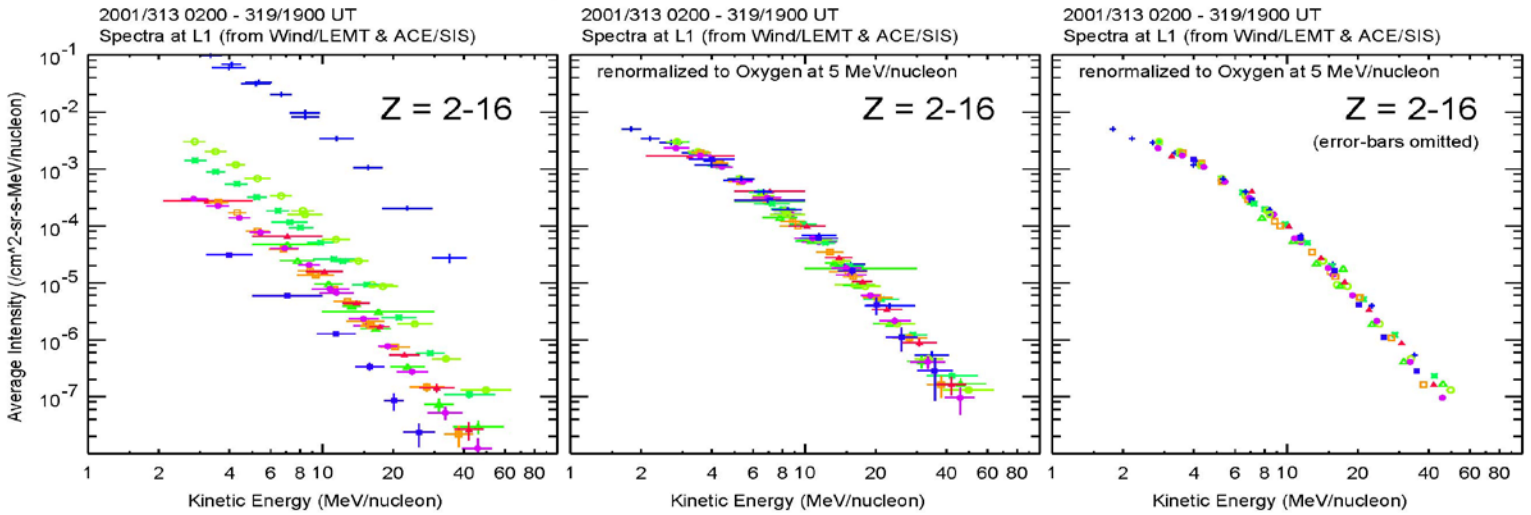
Within the reservoir, all species with M/Q ~2 have the same spectral form at ~2-40 MeV/nuc.

The spectral form is the same at L1 and at Ulysses.

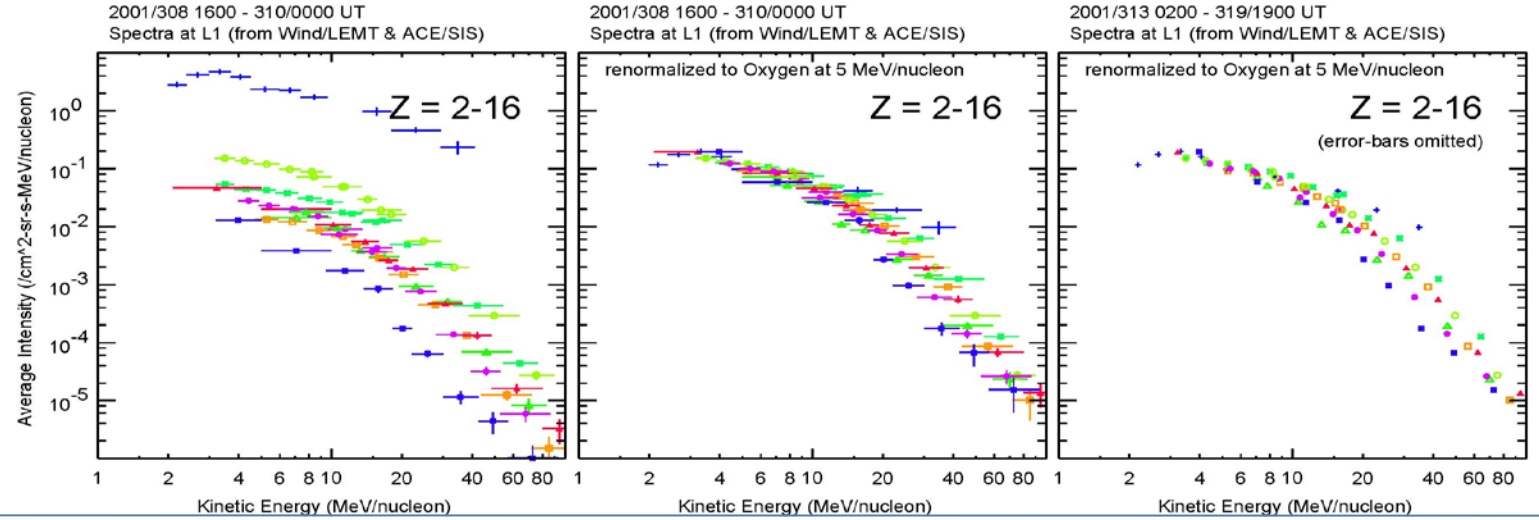


Spectral Comparisons: Reservoir vs. Pre-Reservoir

Reservoir



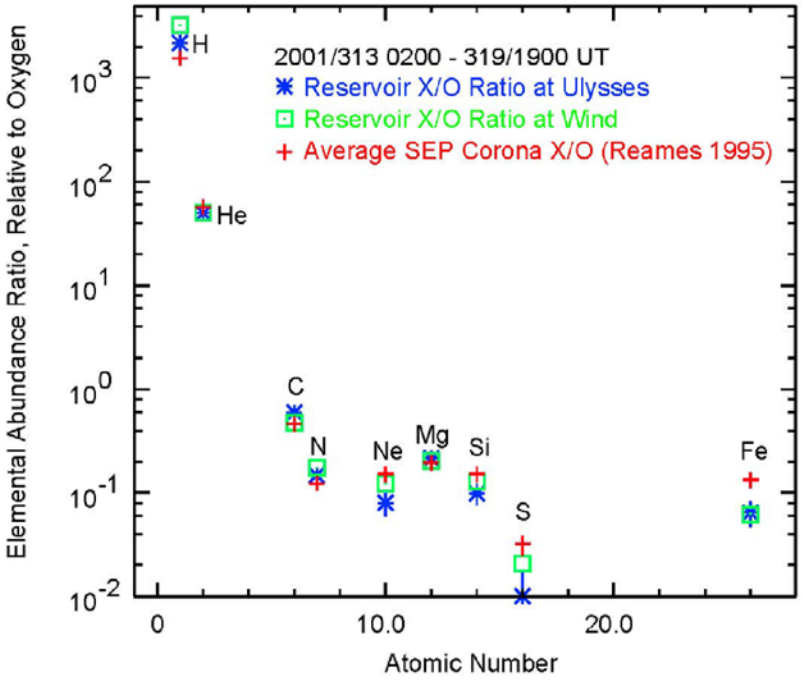
Pre-Reservoir (first 32 hrs)



Elemental Composition in the Reservoir

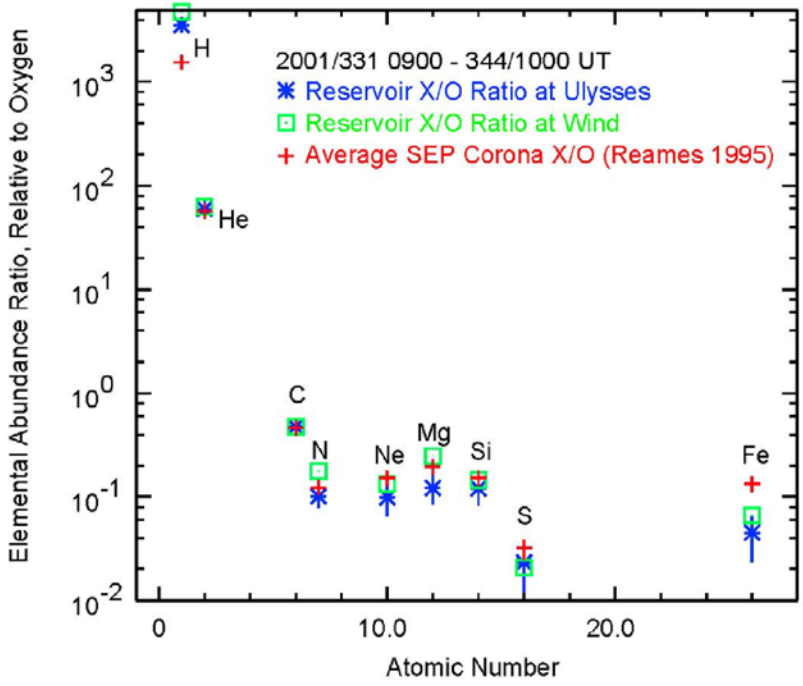
Reservoir-integrated fluences at ~5 MeV/nucleon, normalized to Oxygen, plotted vs. Atomic Number. Reames (1995) average SEP coronal values shown for comparison

Reservoir Period #1



Energy Ranges: H at 4.0-6.0 MeV; He,C,N at 4.25-6.75 MeV/n; Ne,Mg,Si,S,Fe at 5.50-7.50 MeV/n
Reames Energy Ranges: H/He at 1.0-4.0 MeV/n; Others at 5-12 MeV/n.

Reservoir Period #2



Energy Ranges: H at 4.0-6.0 MeV; He,C,N at 4.25-6.75 MeV/n; Ne,Mg,Si,S,Fe at 5.50-7.50 MeV/n.
Reames Energy Ranges: H/He at 1.0-4.0 MeV/n; Others at 5-12 MeV/n.

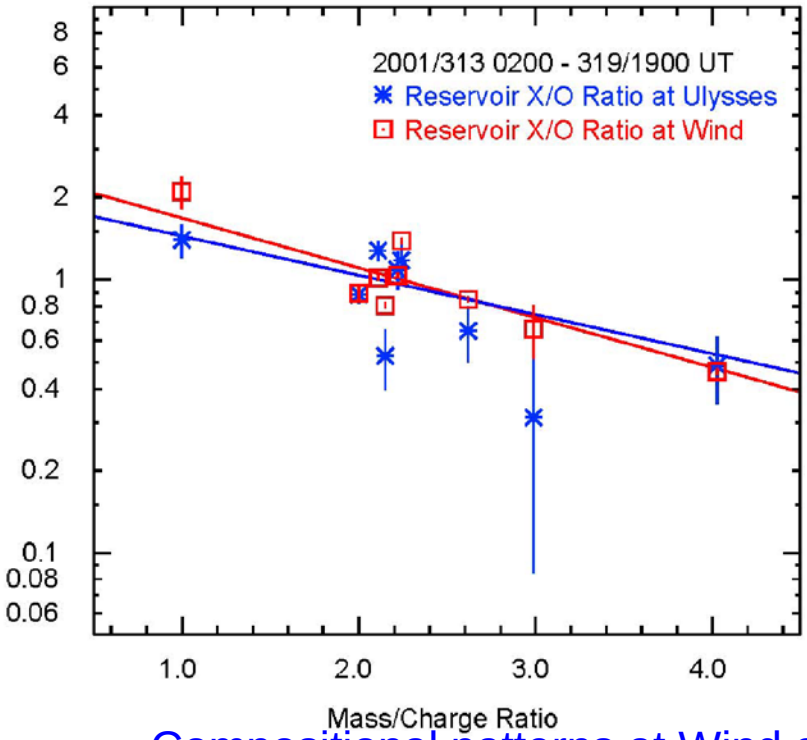
In both cases, reservoir X/O values at Ulysses and L1 agree to within uncertainties. Some systematic differences with Reames (1995) are apparent

Elemental Composition in the Reservoir: A Closer Look

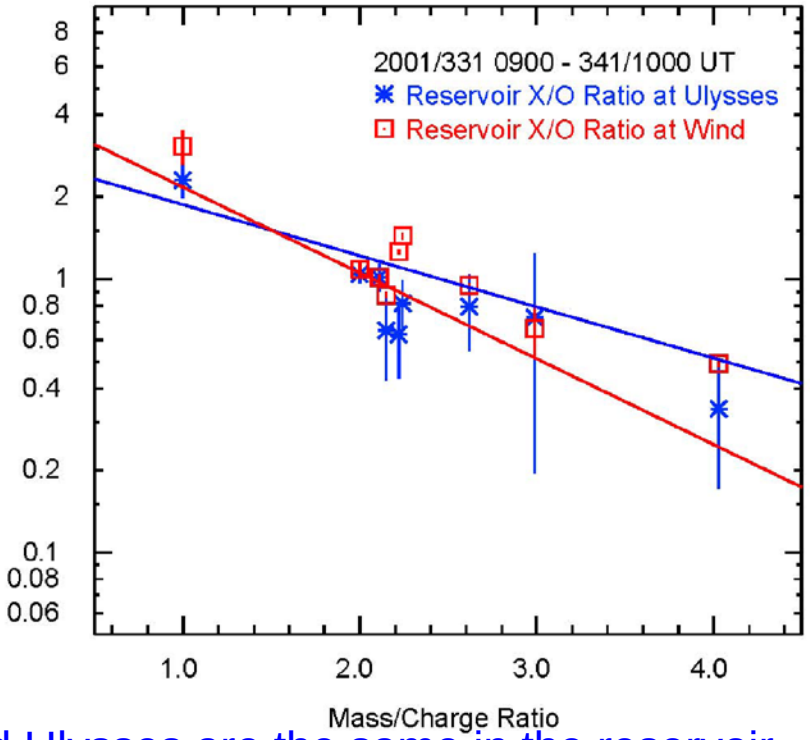
Normalize reservoir-X/O values to Reames (1995) SEP corona mean values.

Plot versus M/Q, using average gradual-event Q values (Luhn et al. 1984)

Reservoir Period #1



Reservoir Period #2

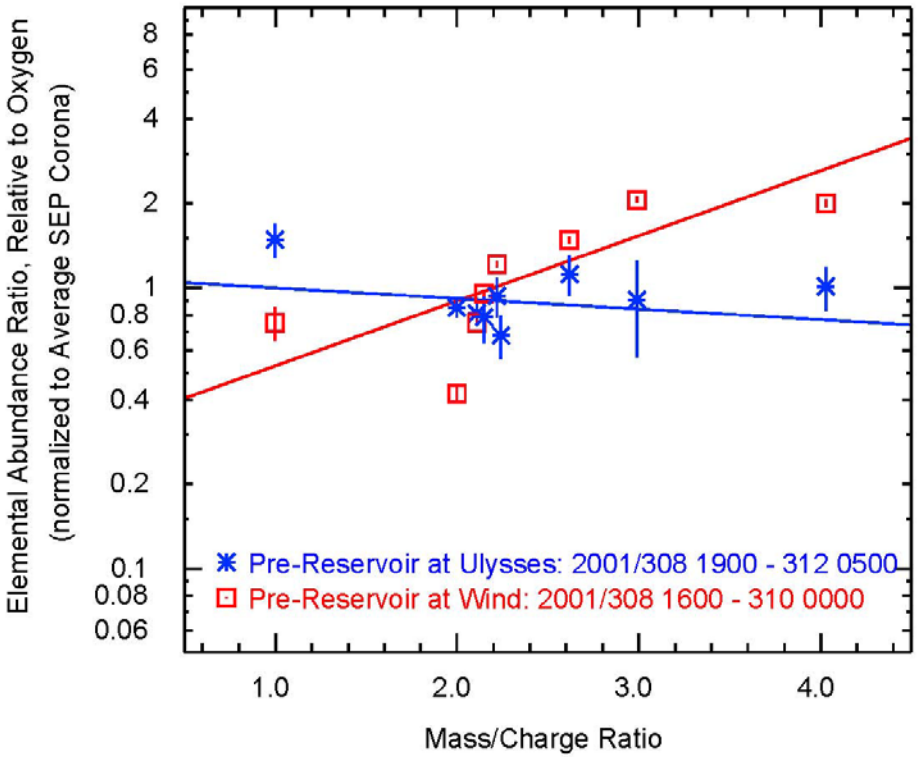


Compositional patterns at Wind and Ulysses are the same in the reservoir.

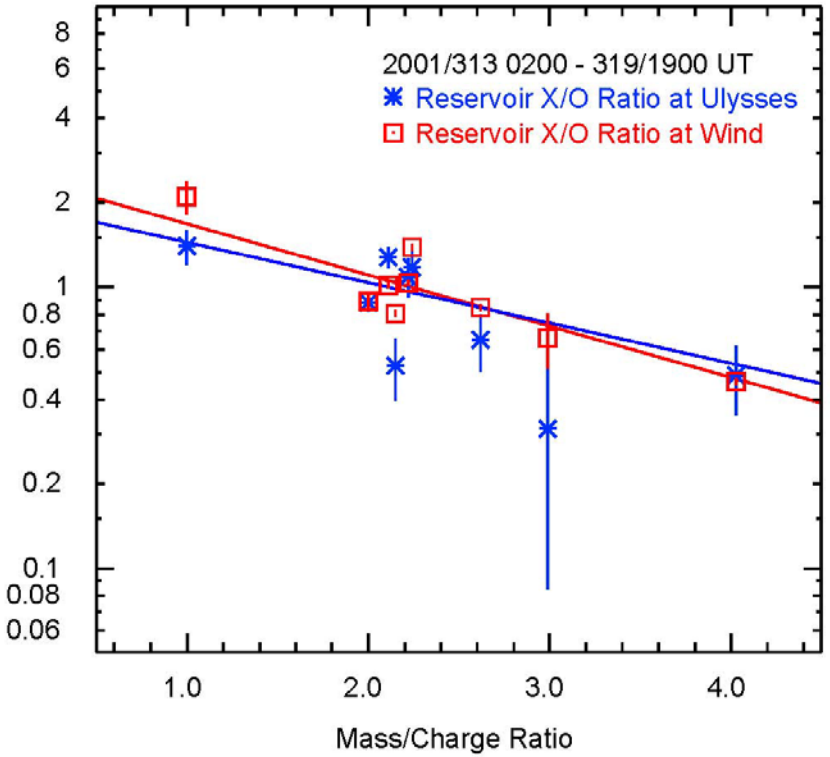
In both cases, X/O values are systematically depleted with increasing M/Q.

Elemental Composition in the Reservoir: A Closer Look

Before Reservoir #1



Reservoir Period #1



Different compositional patterns seen before the reservoir period, upstream of the shocks at Wind and at Ulysses.

Compositional patterns at Wind and Ulysses are the same in the reservoir.

H & He in the pre-reservoir period may be affected by backgrounds during high-rates.

Conclusions

- **The first detailed examination of elemental spectra and composition carried out within reservoirs**
- **Heavy ion spectra comparisons reveal that within the reservoirs, all species with M/Q ~2 have the same spectral form at ~2-40 MeV/nuc. The spectral form is the same at L1 and at Ulysses**
- **Ulysses/L1 comparisons suggest that these reservoir regions are "compositionally-invariant", with widely-separated spacecraft showing the same heavy-ion spectra and very similar (if not identical) systematic trends in the relative elemental composition**
- **The observations presented are a challenge and pose constraints to models of SEP propagation in the 3-D Heliosphere - important for Space Weather studies and SEP forecasting** (e.g. Zhang et al. 2009 invoke cross-field diffusion to reproduce observations for >10 MeV proton during reservoirs)

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Back up slides

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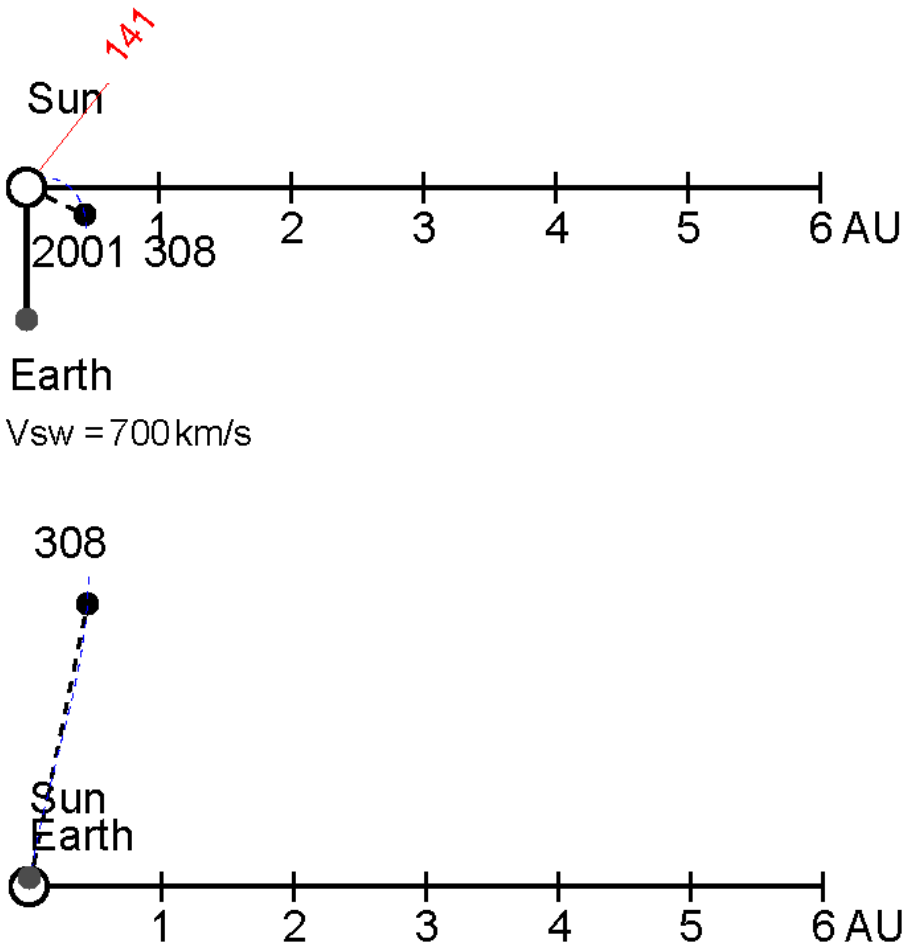
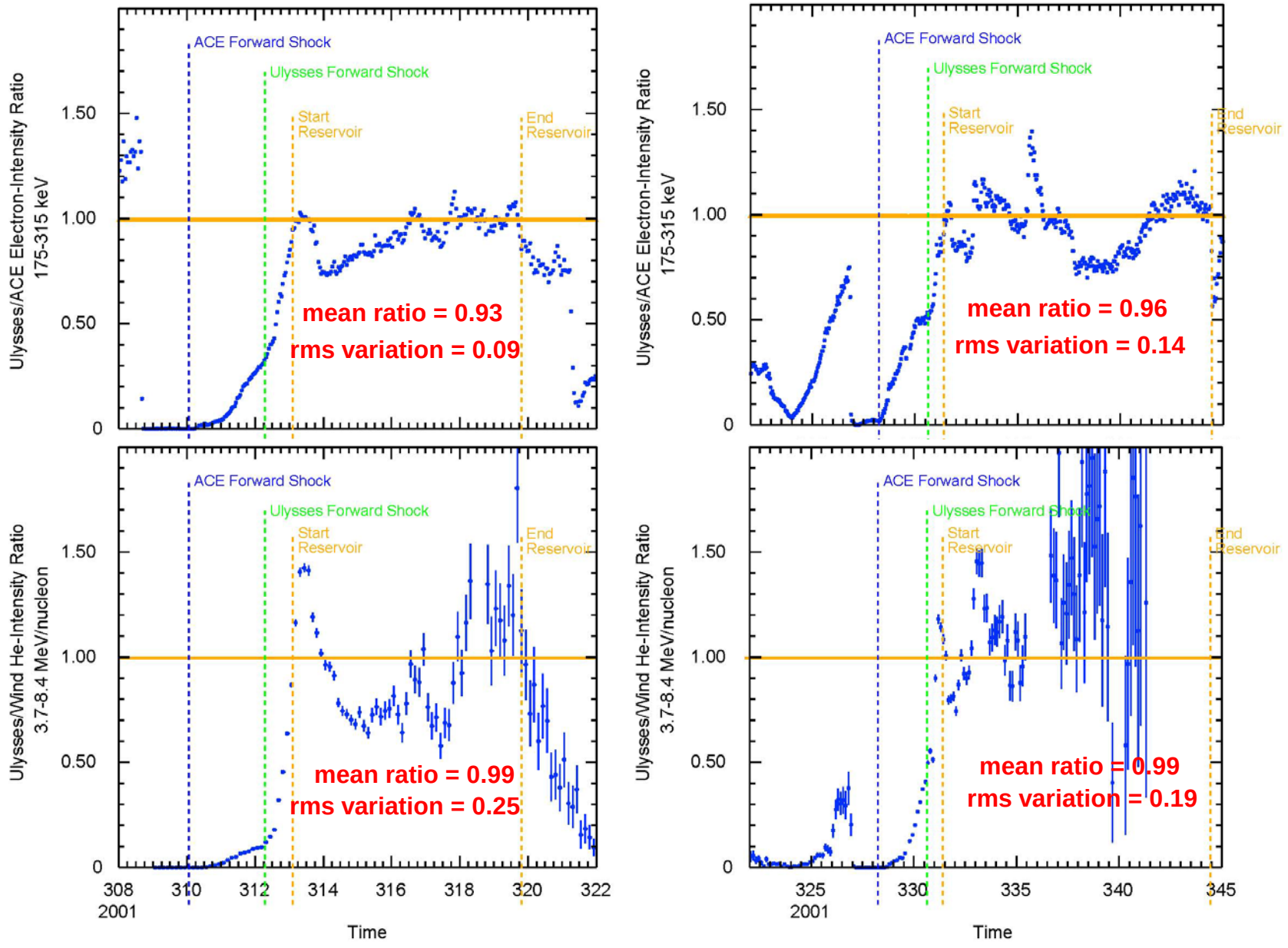
Ulysses HelioRadius: 2.19 AU
Heliolatitude: 77º N (North Pole)



Ulysses/L1 Intensity Ratios *Plotted on Linear Scales*

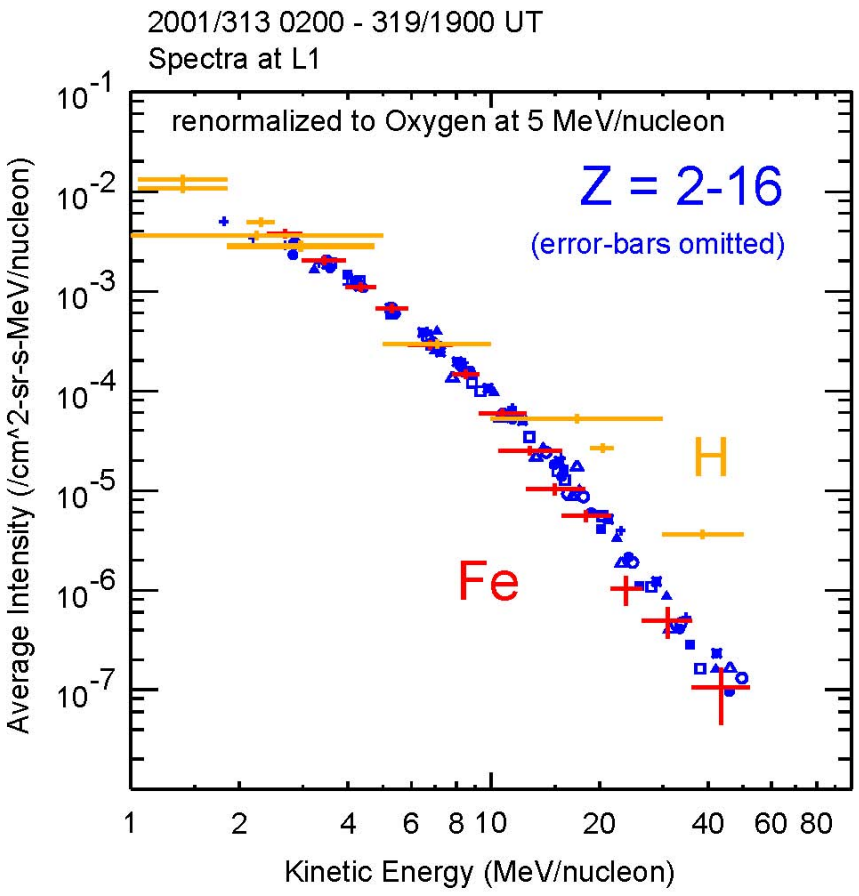
Electrons

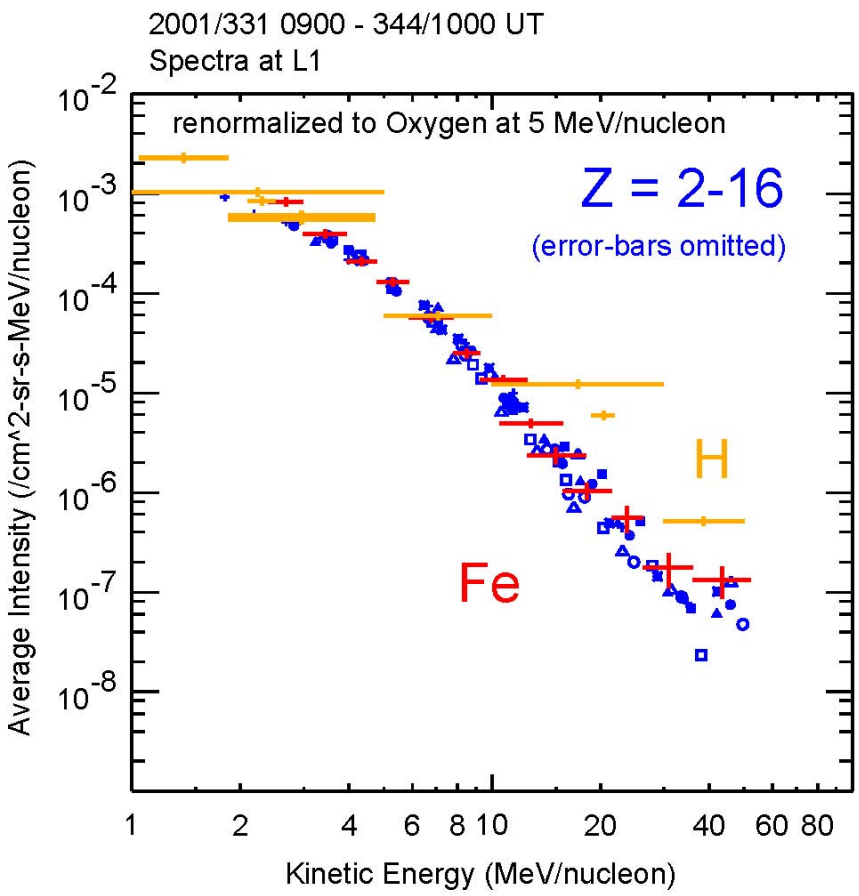
Helium



Reservoir Period #1 **Reservoir Period #2**

Other Spectral Comparisons

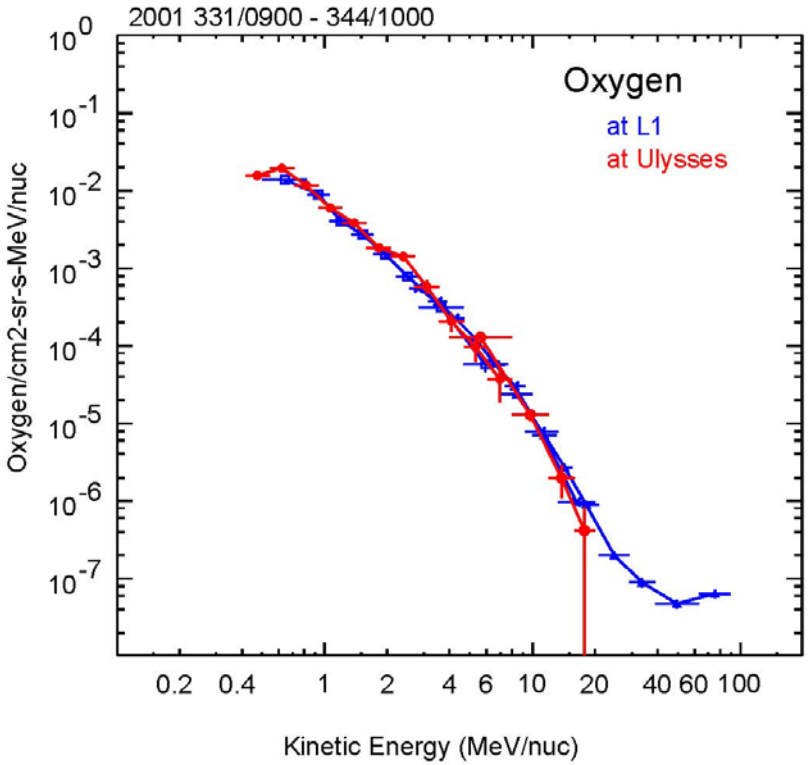


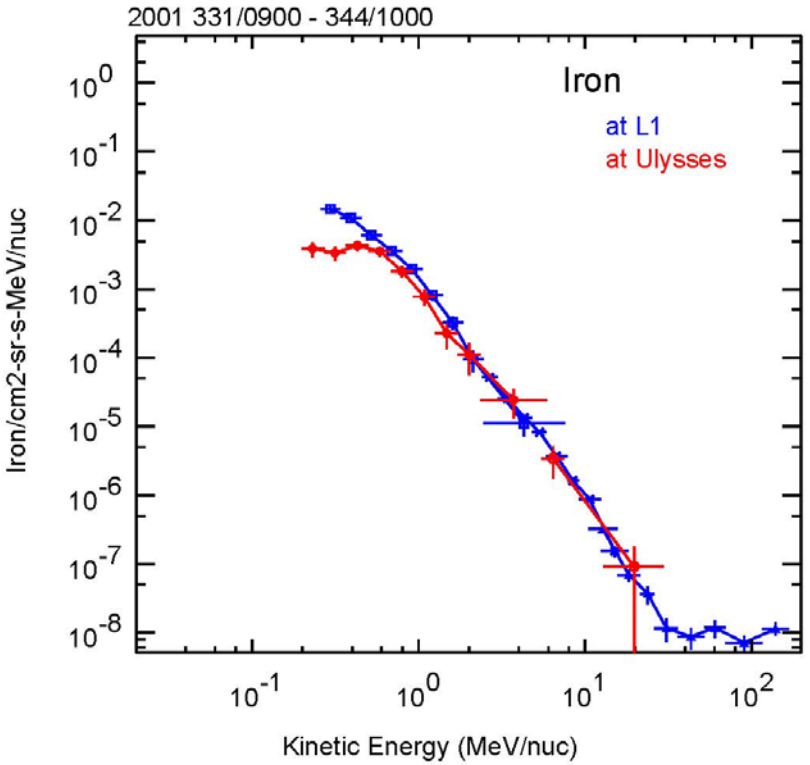


Compared to spectra for elements with Z=2-16 in the reservoir:

- Proton spectra in the reservoir are harder.
- Iron spectra in the reservoir *may be* slightly softer.

Reservoir Comparisons below ~2 MeV/nuc



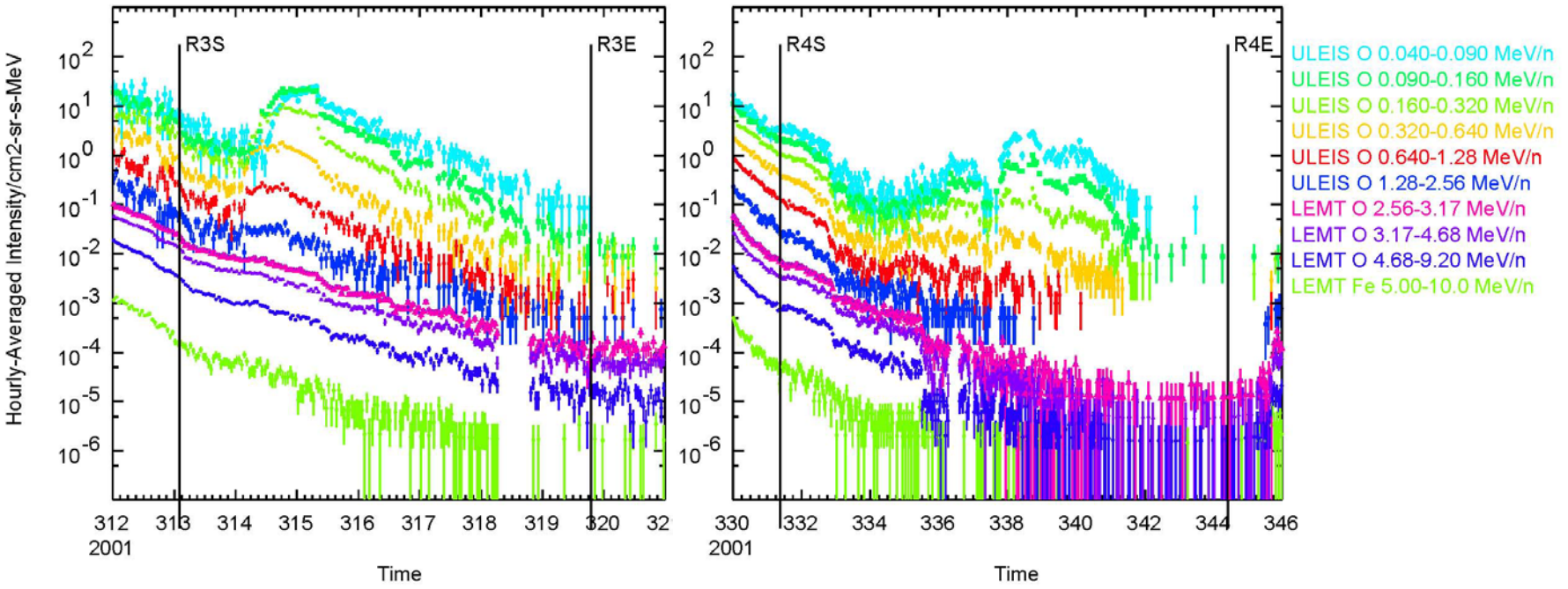


So far, our comparisons have focused on Wind/LEMT and Ulysses/LET, which measure above ~2 MeV/nuc. But the Ulysses/HISCALE and ACE/EPAM instruments are identical. They give us the opportunity to extend the spectral comparisons down to 0.4 MeV/nuc (0.2 MeV/nuc for Fe).

A Complication : Injection of New Events at L1.

Reservoir #1

Reservoir #2



These plots show time-lines from ULEIS and LEMT (at L1), for oxygen ions at various energies between 0.040 and ~10 MeV/nucleon.

In Reservoir #2, new injections are significant only at energies that are below the EPAM energy range.

In Reservoir #1, the new injection is larger. To extend the study to lower energies in this event, we can try to truncate the integration before the new event begins. But this cut loses ion statistics.