Radial and Latitudinal Gradients of Anomalous Cosmic Ray Oxygen in the Inner Heliosphere

A. C. Cummings (1), C. Tranquille (2), R. Marsden (2),
R. A. Mewaldt (1), and E. C. Stone (1)
(1) *Caltech*
(2) *ESTEC*

STEREO SWG#20

Meridith, NH

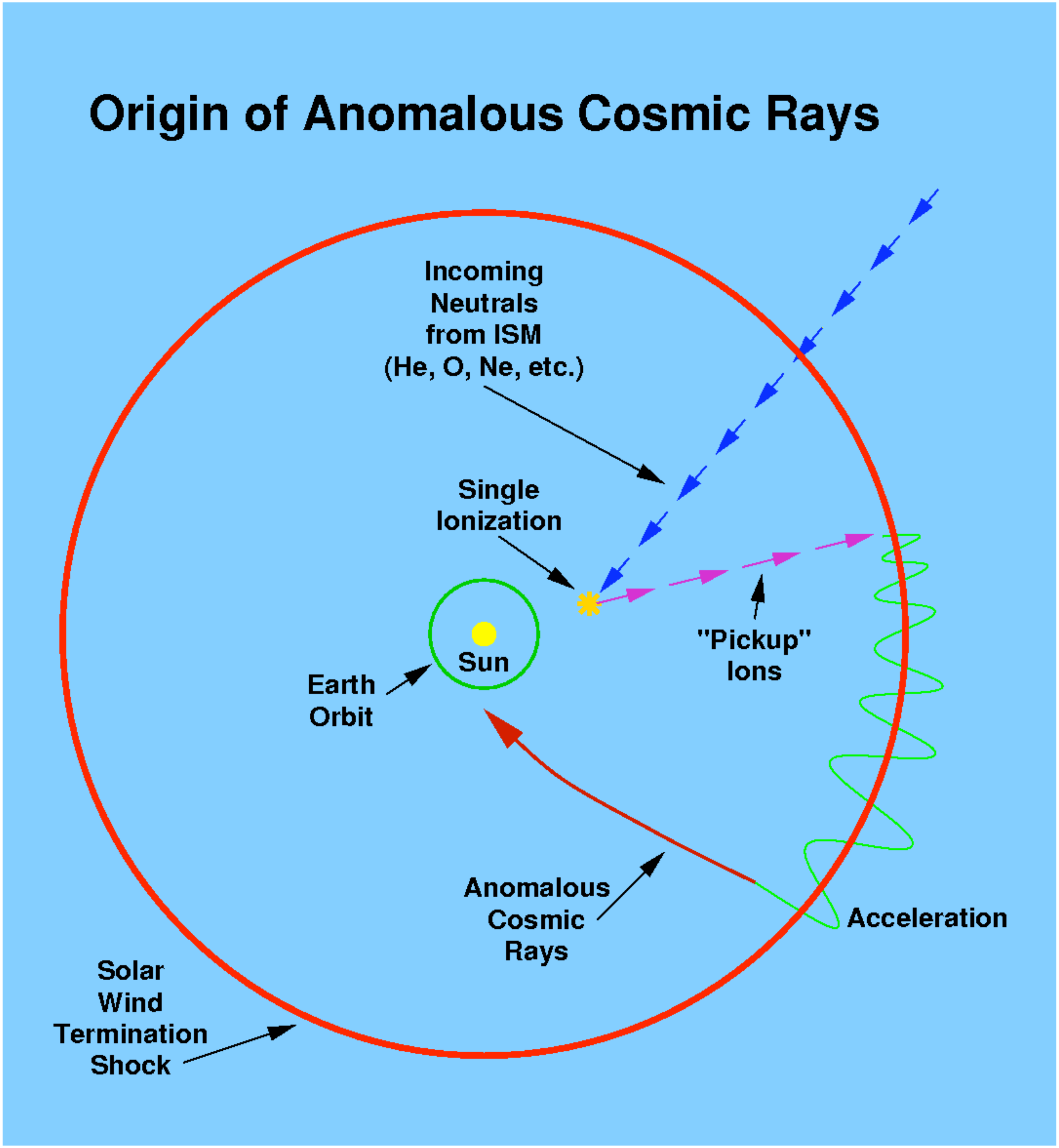
28 October 2009

GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L18103,
doi:10.1029/2009GL039851, 2009

Radial and latitudinal gradients of anomalous cosmic ray oxygen in the inner heliosphere

A. C. Cummings, C. Tranquille, R. G. Marsden, R. A. Mewaldt, and E. C. Stone

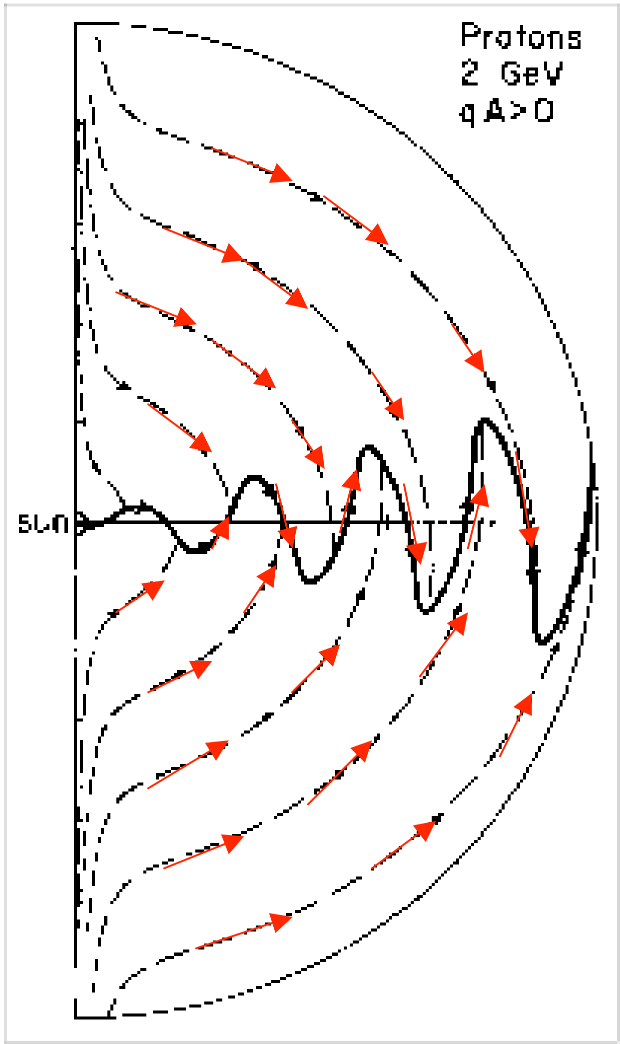
Received 8 July 2009; revised 11 August 2009; accepted 18 August 2009; published 19 September 2009.



This has been the paradigm since ~1974 up until Voyager 1 crossed the termination shock.

Some of this is probably still relevant.

Drift Patterns for qA>0

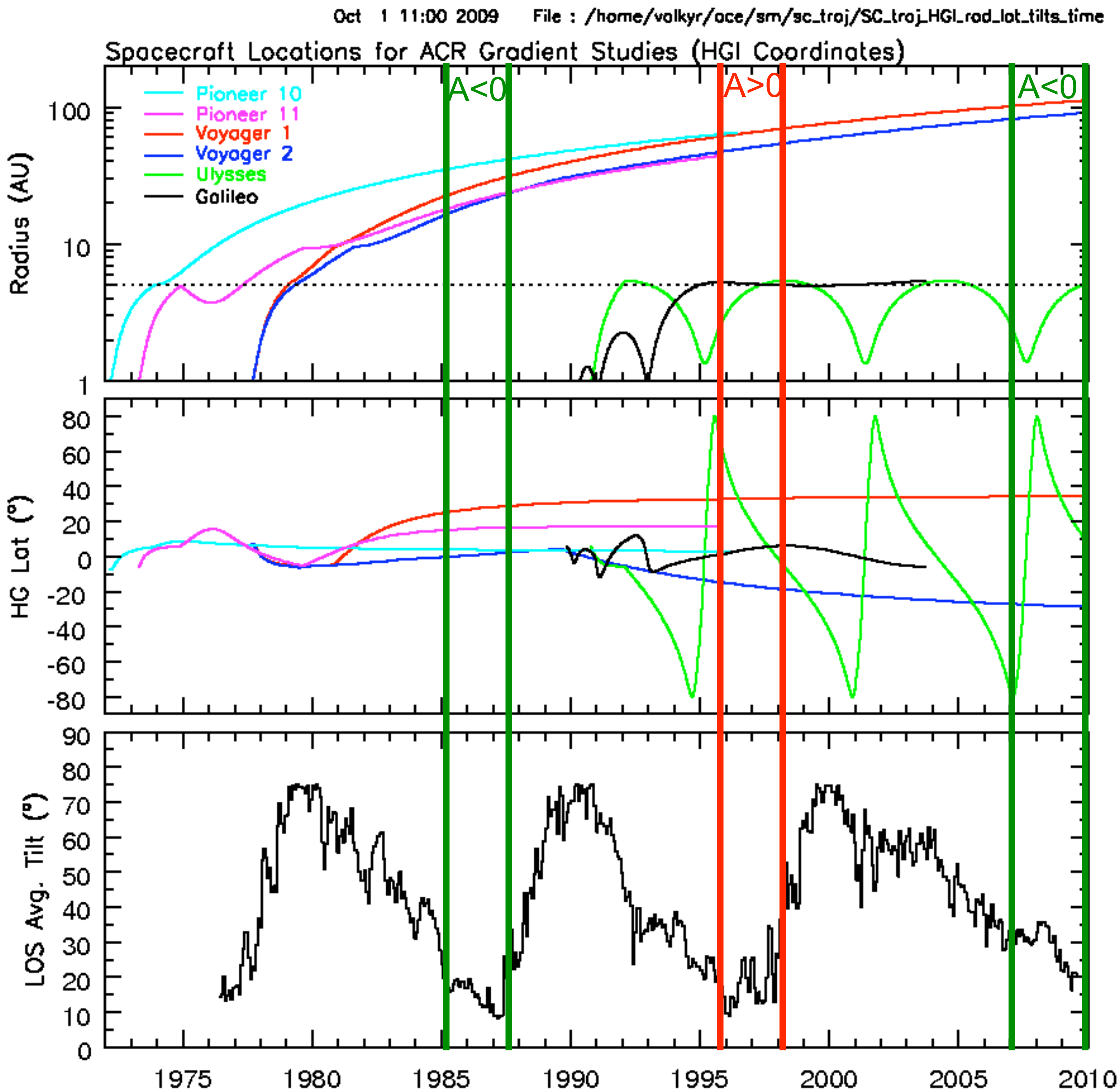


Drifts carry positive particles from high latitudes to low latitudes during A>0 portion of solar cycle. Expect positive latitudinal gradient in A>0.

Arrows reversed in A<0. Expect negative latitudinal gradient in A<0, which is the current situation. Expect HCS to be a conduit for particles to the inner heliosphere via rapid drift along the HCS

Expect radial gradient to depend on tilt angle during current A<0 period. Not so sensitive during A>0.

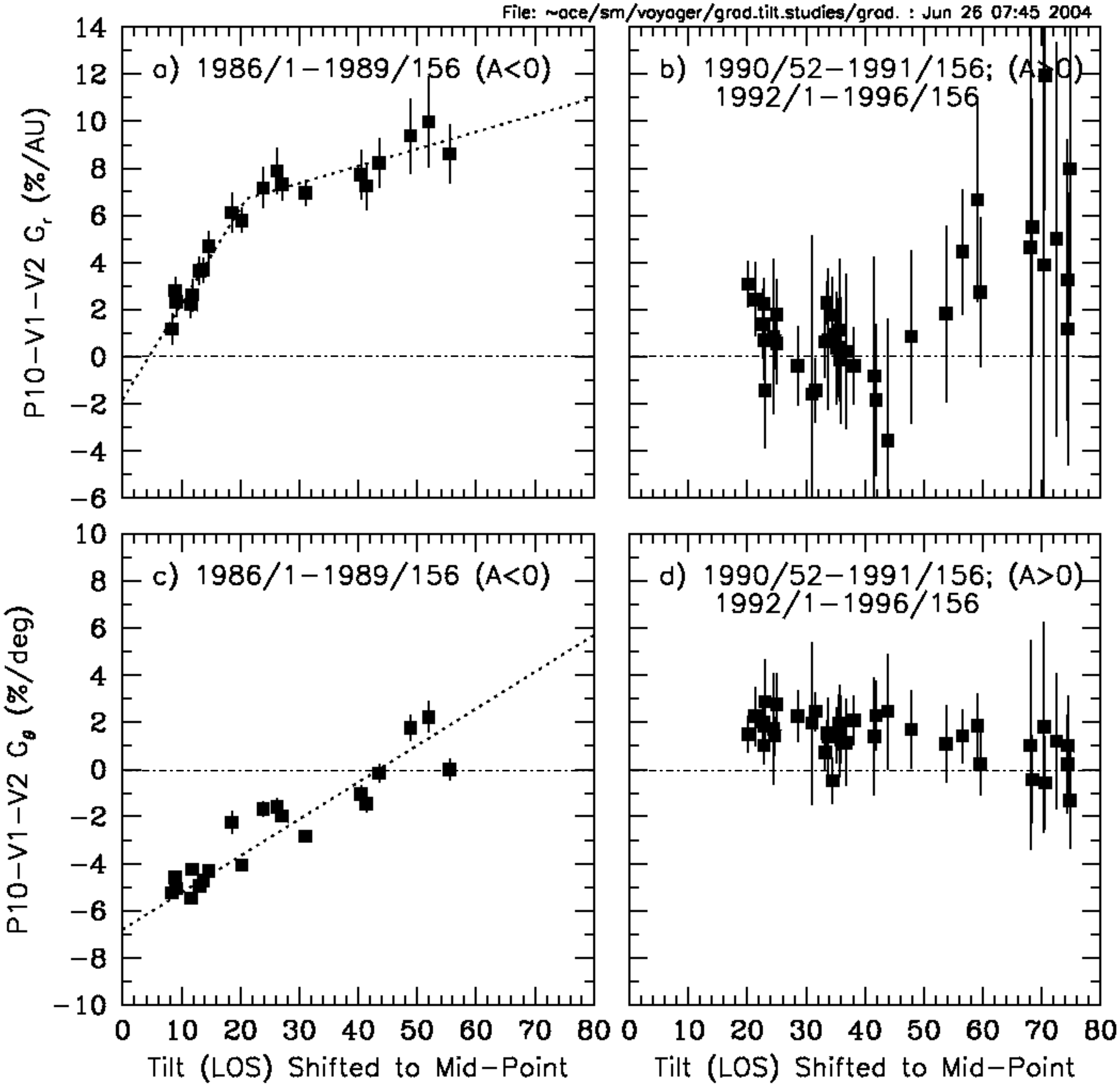
Adapted from Jokipii & Thomas, 1981



Spacecraft Locations for ACR Gradient Studies

Now is first time S/C have been positioned to measure ACR gradients in inner heliosphere during an A<0 solar minimum period. We will use Ulysses, ACE, and STEREO data to explore gradients inside 5 AU.

Gradients of 7.1-17.1 MeV/nuc ACR O in Outer Heliosphere vs Tilt

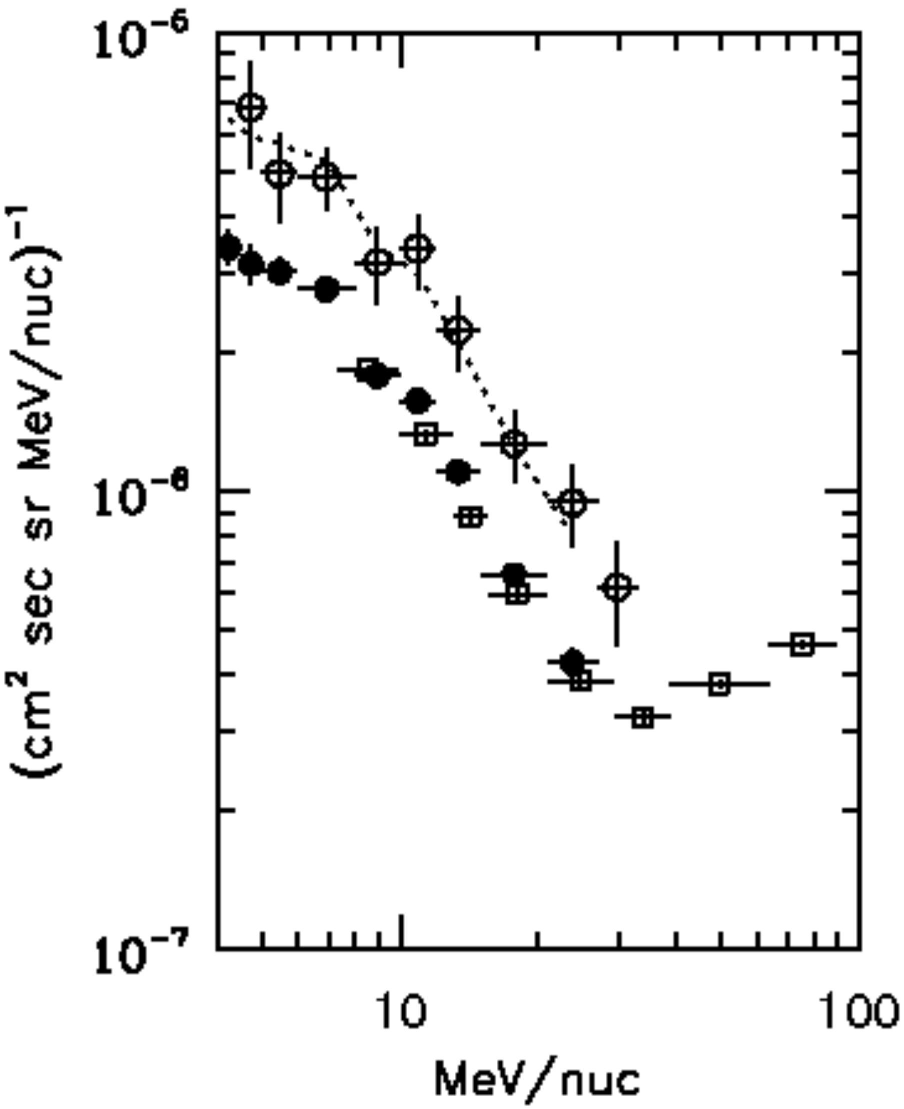


Current period of study is 2007-2008, A<0

Previous History in Inner Heliosphere

- **Pioneer 10 & 11 launched in early 70's during A>0 solar minimum**
  - **P10, P11, & IMP 1972-1978: 25±5%/AU for 1-5 AU (Webber et al. 1979) for ~9-24 MeV/nuc O**
  - **Could not infer latitudinal gradient**
- **Previous Ulysses studies (all during A>0)**
  - **Ulysses + SOHO/ERNE 1997 at 10 MeV/nuc: 18±2.4 %/AU and 0.6±0.1 %/deg**
  - **Other Ulysses studies found positive lat grads from ~1-5 %/deg., similar to what was found in outer heliosphere**
- **Gradient studies have never been done observationally for A<0 period inside 5 AU**
  - **Cummings et al. tilt models inferred ~30-50 %/AU radial gradients inside 5 AU**
  - **If latitudinal gradients are similar in inner and outer heliosphere in A<0, expect approx. -2%/deg for tilt of ~30 deg.**

O Energy Spectra at Ulysses, ACE, and STEREO for 2008/43-150



Open circle: Ulysses
Open square: ACE/SIS
Solid circle: STEREO A+B avg

Dotted line is STEREO x 1.9 and indicates the gradients are approximately independent of energy

Determining radial and latitudinal gradients from Ulysses and 1 AU Oxygen data

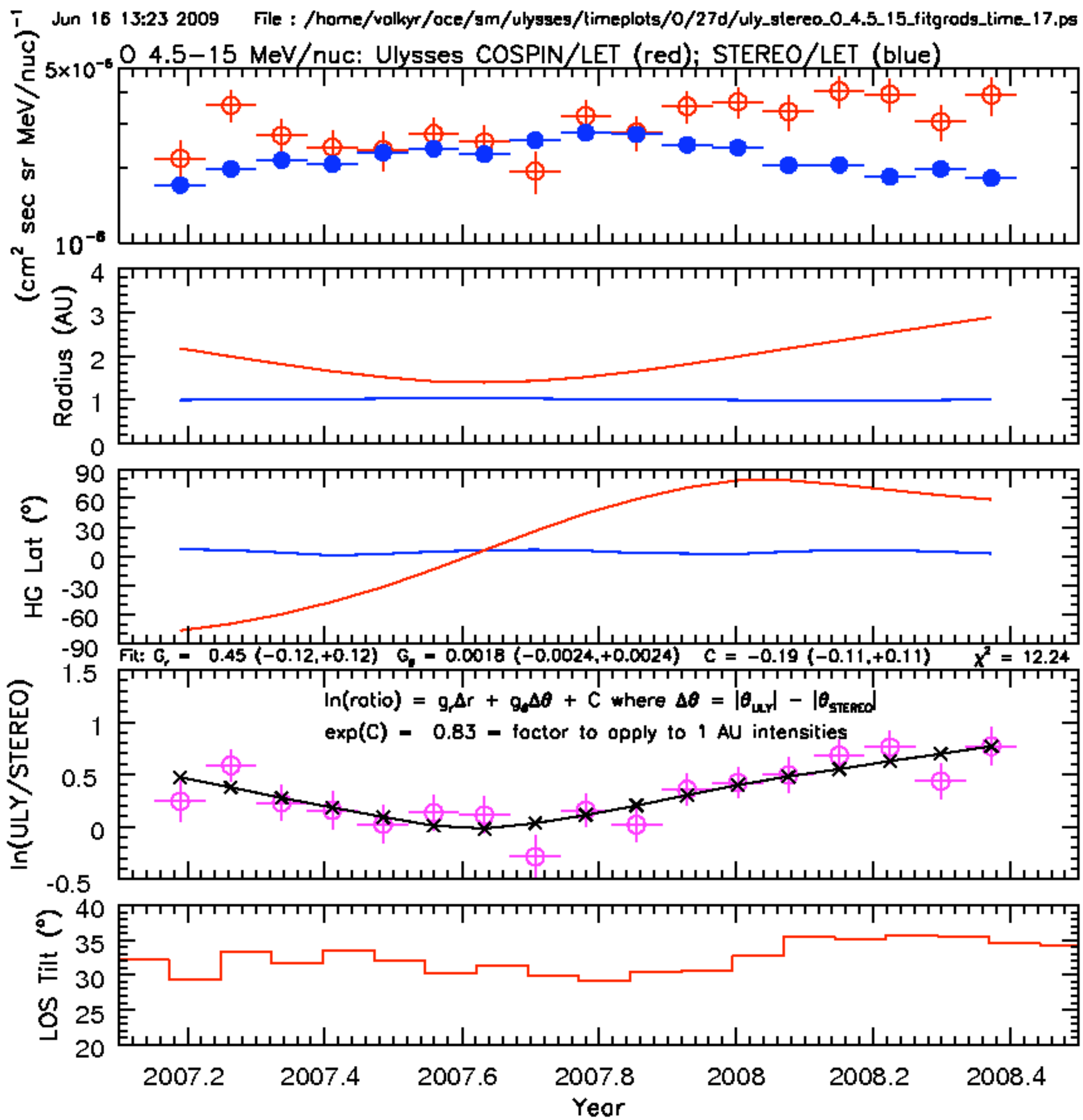
$$ln(f_U/f_S) = g_r\Delta r + g_\theta\Delta\theta + C$$

Where

$$\Delta\theta = |\theta_{Uly}| - |\theta_{1AU}|$$

- C accounts for possible normalization factor between spacecraft instruments
- Assume gradients constant

Ulysses/STEREO O gradients



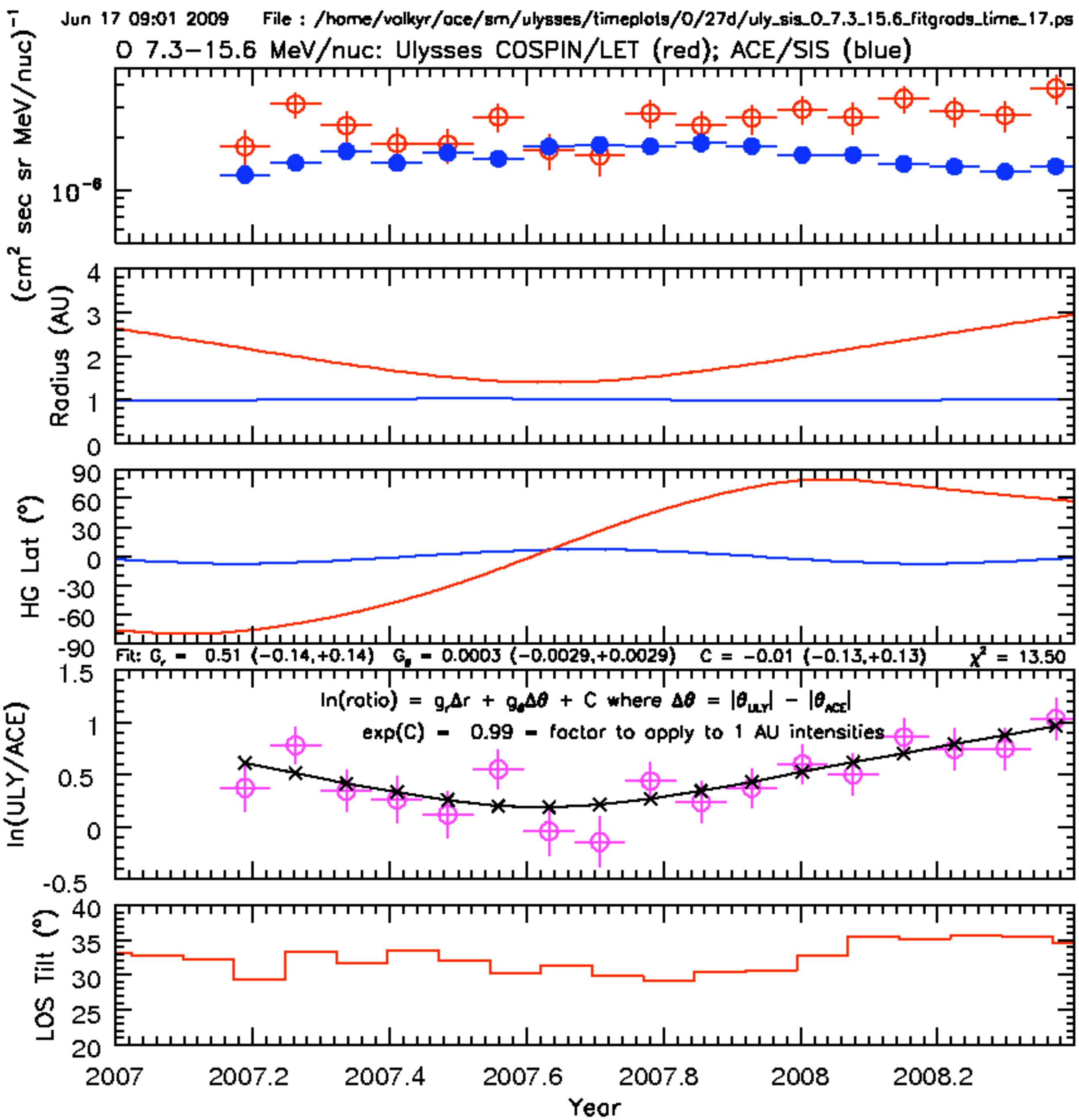
C = -0.19 -> norm factor = 0.83

Rad grad = 45 ± 12 %/AU

Lat grad = 0.18 ± 0.24 %/º

Chisq = 12.2 for 14 degrees of freedom

Ulysses/ACE O gradients



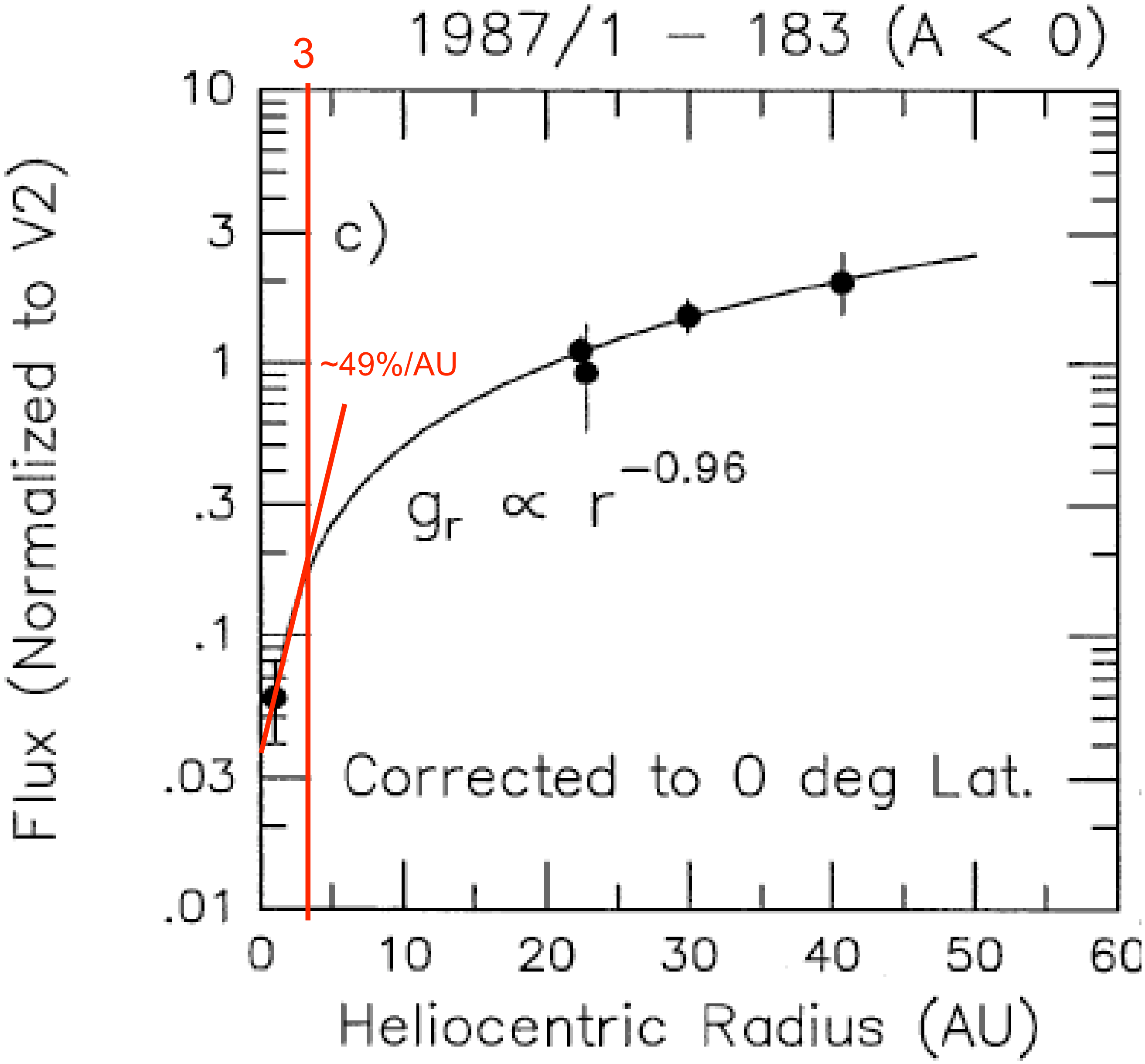
C = -0.01 -> norm factor = 0.99

Rad grad = 51 ± 14 %/AU

Lat grad = 0.03 ± 0.3 %/º

Chisq = 13.5 for 14 degrees of freedom

Radial Gradient of 7-25 MeV/nuc ACR O during A<0



Indirect inference from 5-S/C study suggests G_r~49%/AU from 1-3 AU, similar to this result.

From Cummings et al., 1995

Summary

- **ACR O (4.5-15.6 MeV/nuc) gradients in inner heliosphere for A<0:**
  - **Radial gradient from ~1-3 AU: 48 ± 13 %/AU**
    - **Consistent with inferences from multi-S/C studies**
  - **Latitudinal gradient: 0.03 ± 0.3 %/deg**
    - **Previous A>0 studies were in range 1-5%/deg, reasonably consistent with outer heliosphere studies**
    - **Previous A<0 result in outer heliosphere for 30 deg tilt was -2%/deg, inconsistent with new result for inner heliosphere**
- **HCS is not an effective conduit to the inner heliosphere during A<0 when tilts are as large as 30 deg**
  - **Pathlength along the HCS is too long -> diffusion dominates**
  - **Expected negative latitudinal gradients might show up if tilt continues to drop significantly below 30 deg**