This slide intentionally contains no significant content

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- Finally, I want to apologize to Rogelio Caballero-Lopez.

Summarizing ~1/3 of SH: Aspécts of Galactic and Anomalous Cosmic Rays

A. C. Cummings, *Caltéch*

30th Intérnational Cosmic Ray Conférécé

Mérida, México

11 July 2007

The Task at Hand: Summarize the Following

- **SH 3: Galactic cosmic rays in the heliosphere (75)**
  - SH.3.1 Acceleration and modulation models (19)
  - SH.3.2 Long-term variations (11 year and longer cycles) (30)
  - SH.3.3 Gradients (2)
  - SH.3.4 Anisotropies (19)
  - SH.3.5 Spectra, composition, and charge-state (5)
- **SH 4: Anomalous component in the heliosphere (4)**
  - SH.4.1 Theory and models, origin and acceleration (2)
  - SH.4.2 Gradients and time variations (1)
  - SH.4.3 Spectra, composition, and charge-state (1)
- **SH 5: Cosmic rays at the termination shock and in the heliosheath (12)**
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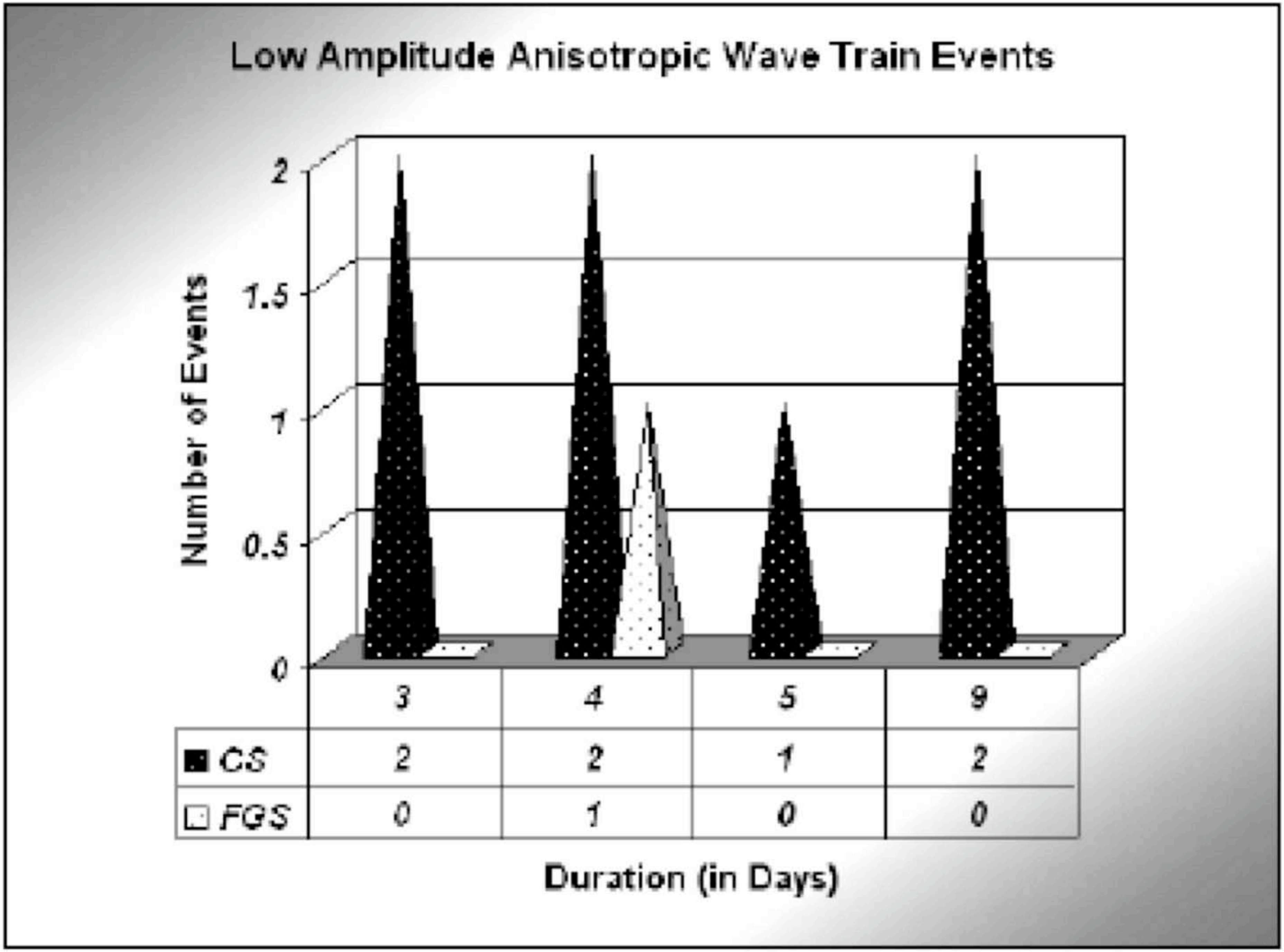
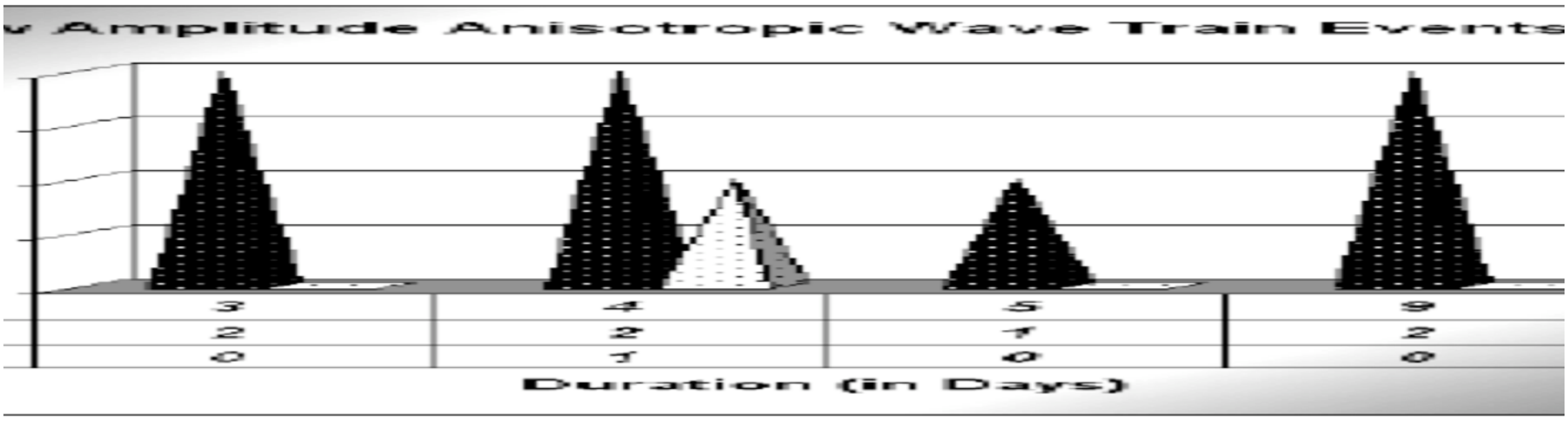
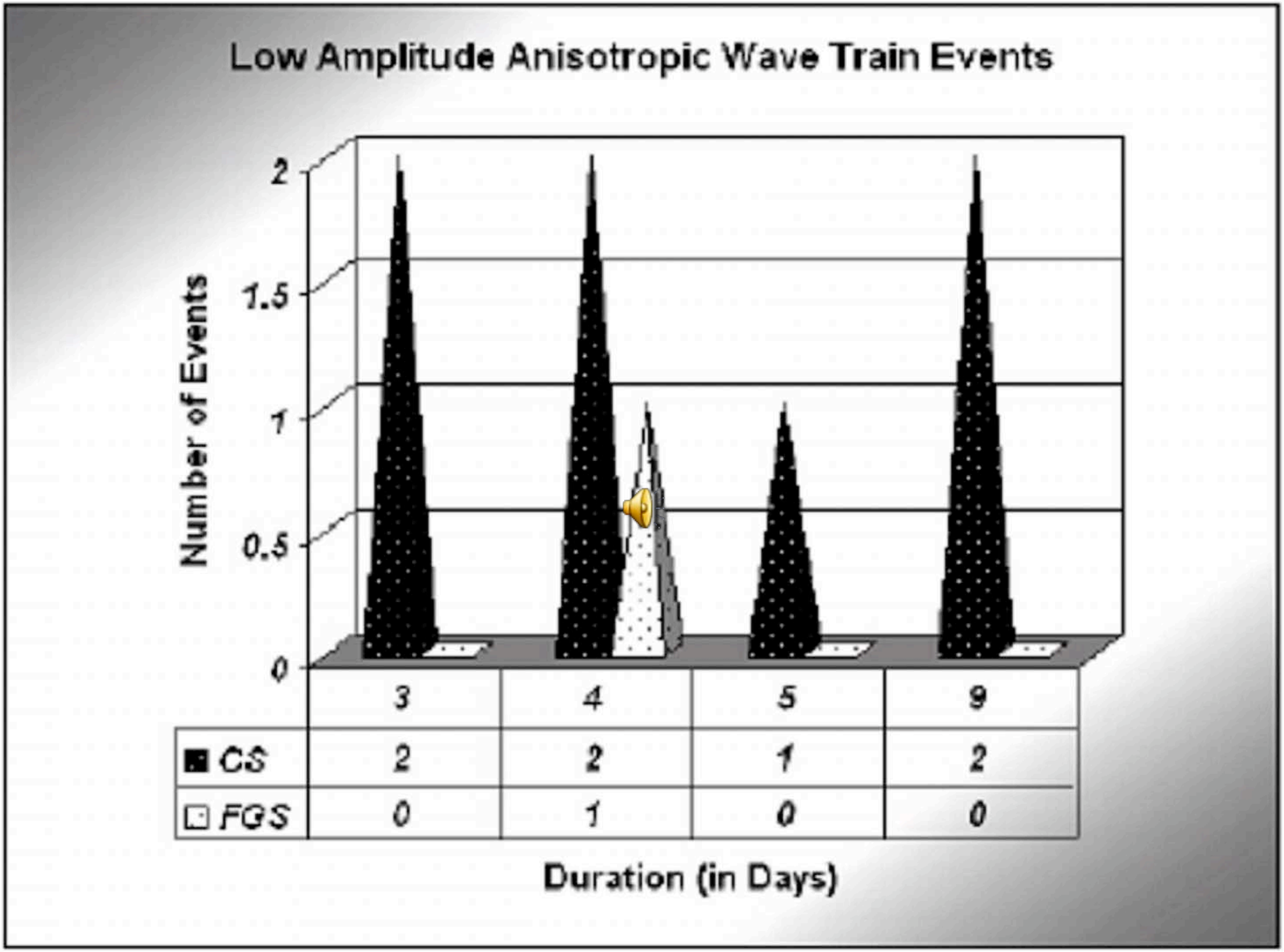
37 title changes since abstract submitted!

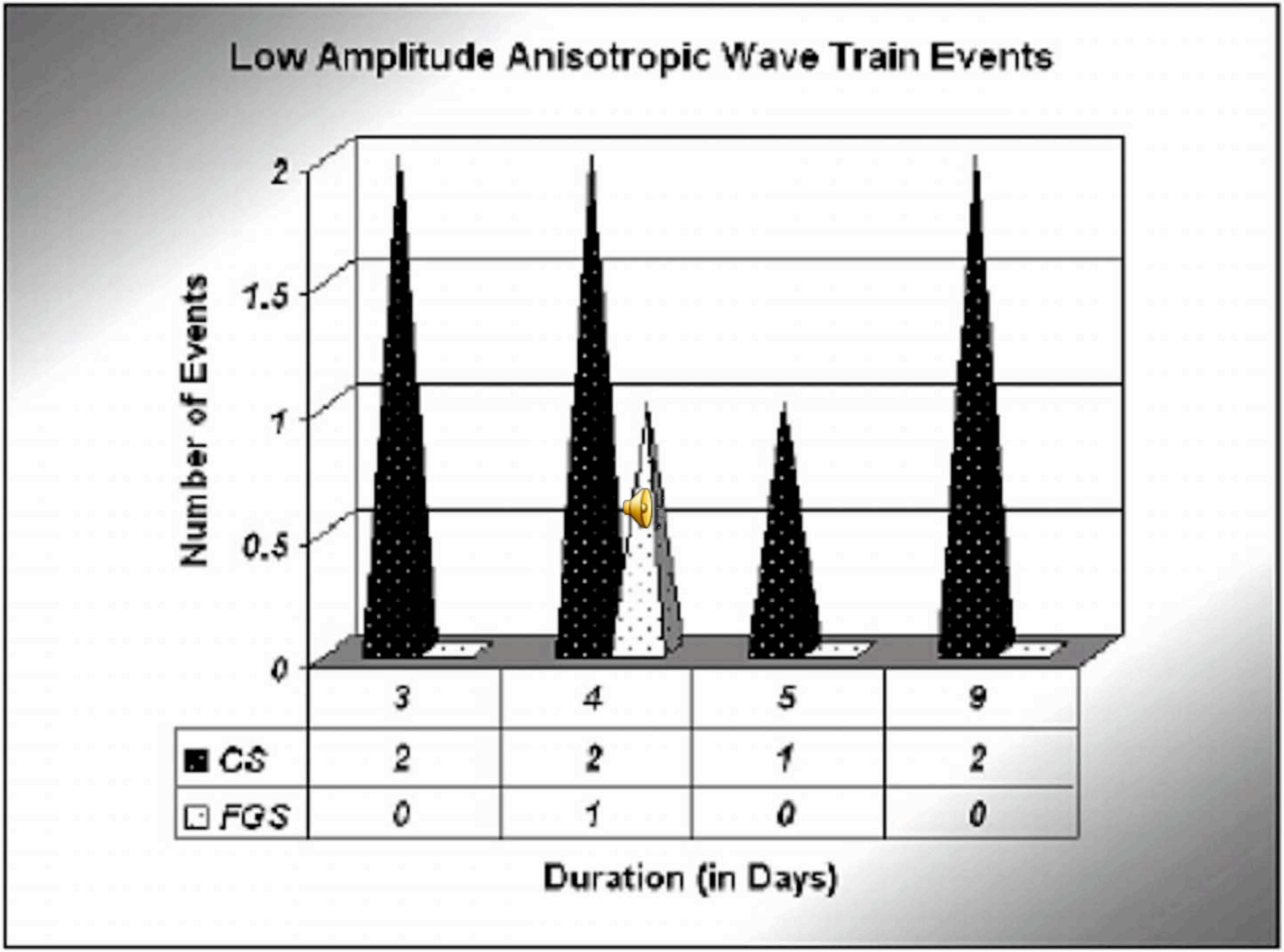


Mishra et al., icrc0039



Mishra et al., icrc0039, squashed


Low Amplitude Anisotropic Wave Train Events
Number of Events
2
1.5
1
0.5
0
3
4
5
9
CS
2
2
1
2
FGS
0
1
0
0
Duration (in Days)



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In Conclusion

Phrases I Didn’t Expect to See in a Title

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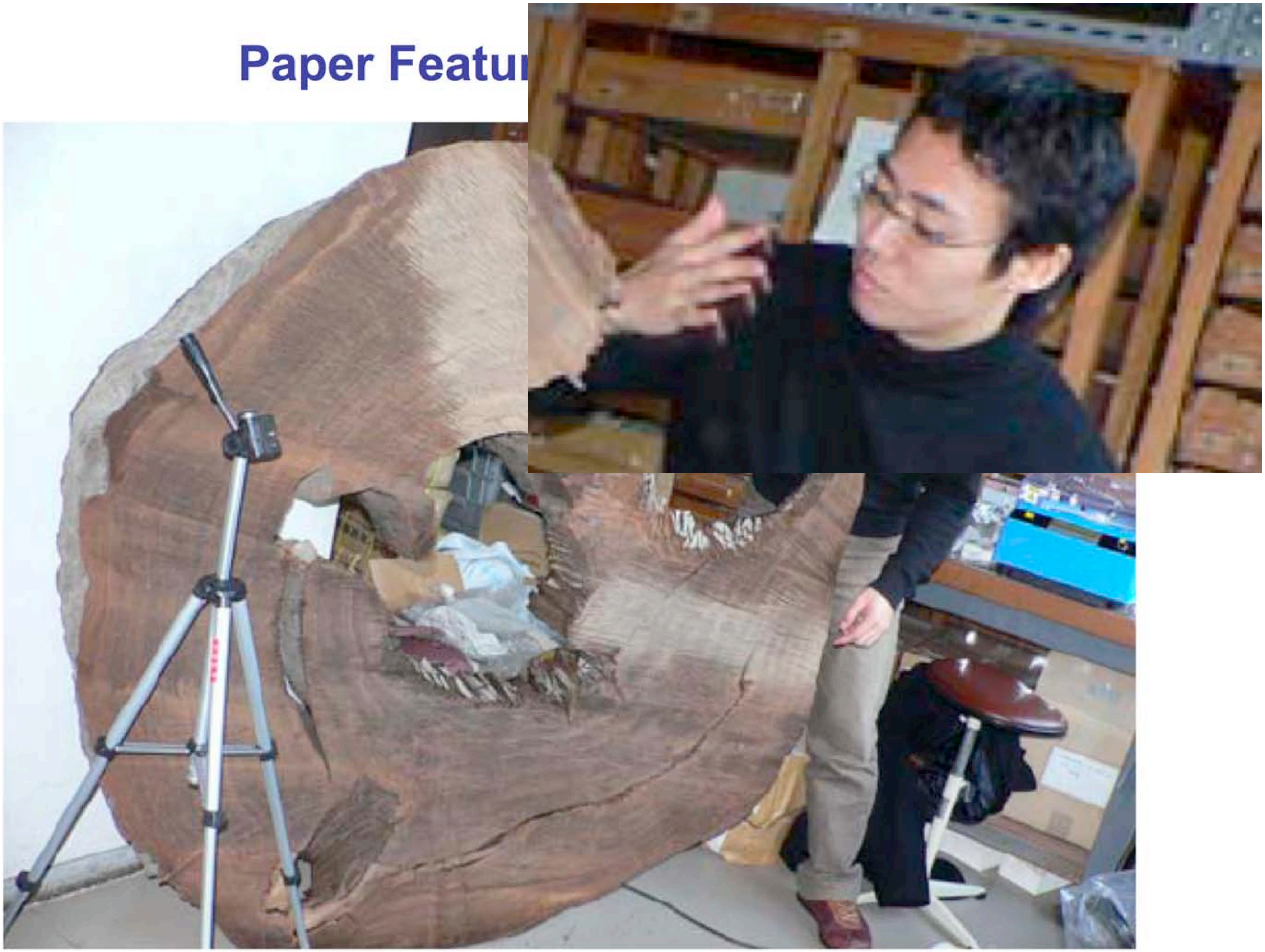
Paper Featuring a Photo of a Human Being

Nagaya et al., icrc0919

Paper Featu



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Paper Featu

What is wrong with this man's fingernails?

Nagaya et al., icrc0919

Another Paper Featuring a Photo of a Human Being

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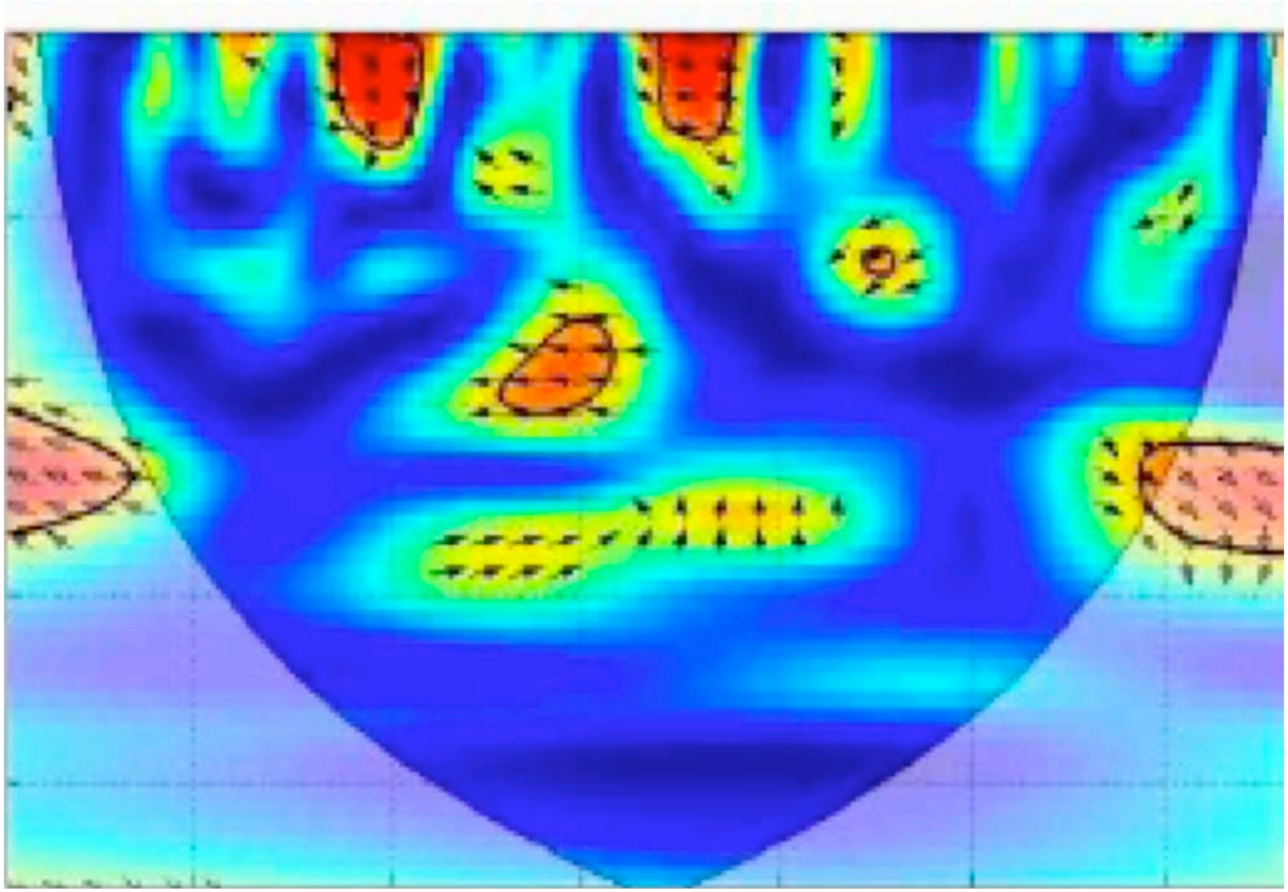

Osorio et al., icrc0740

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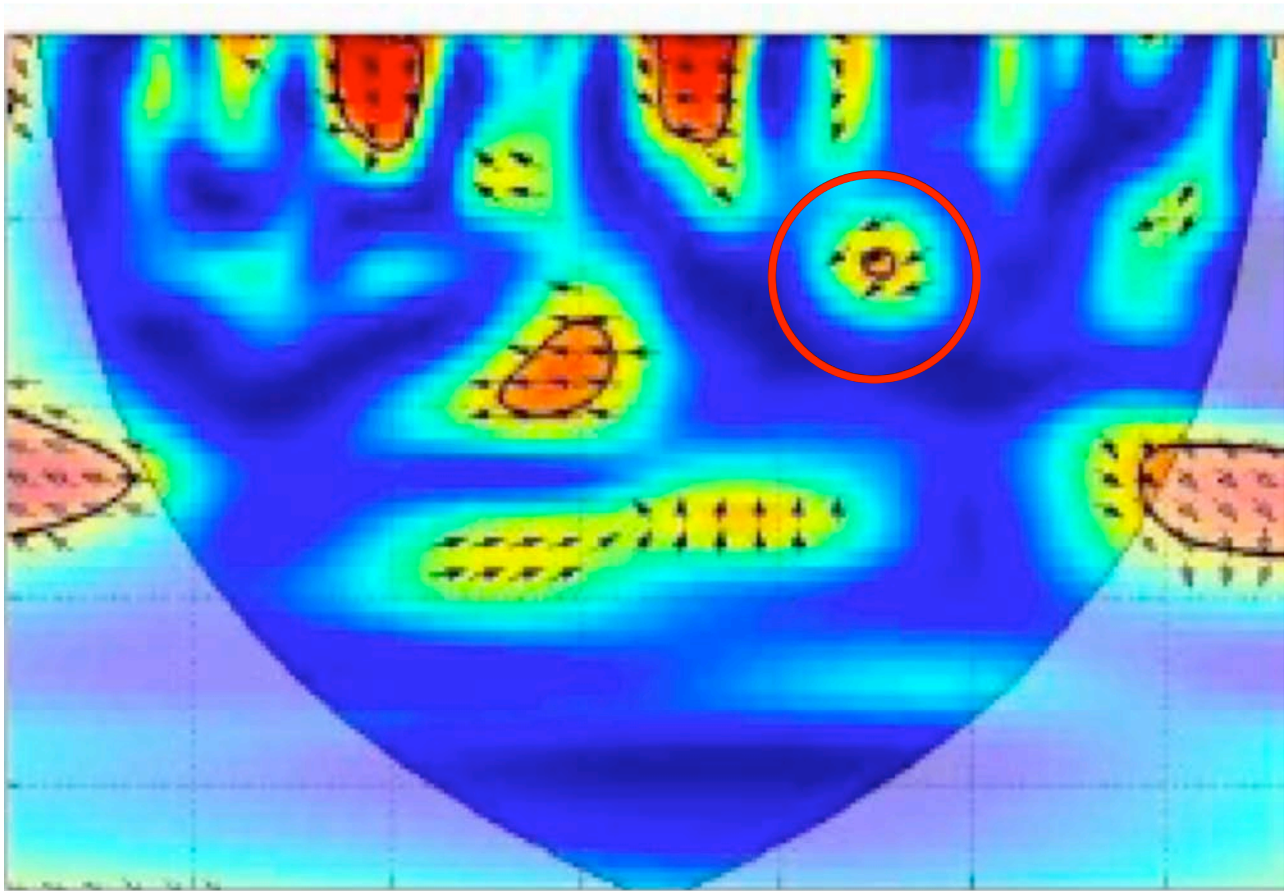


Osorio et al., icrc0740

Modified Parker Transport Equation

(Jokipii, 2006 & Ferreira et al., icrc0287)

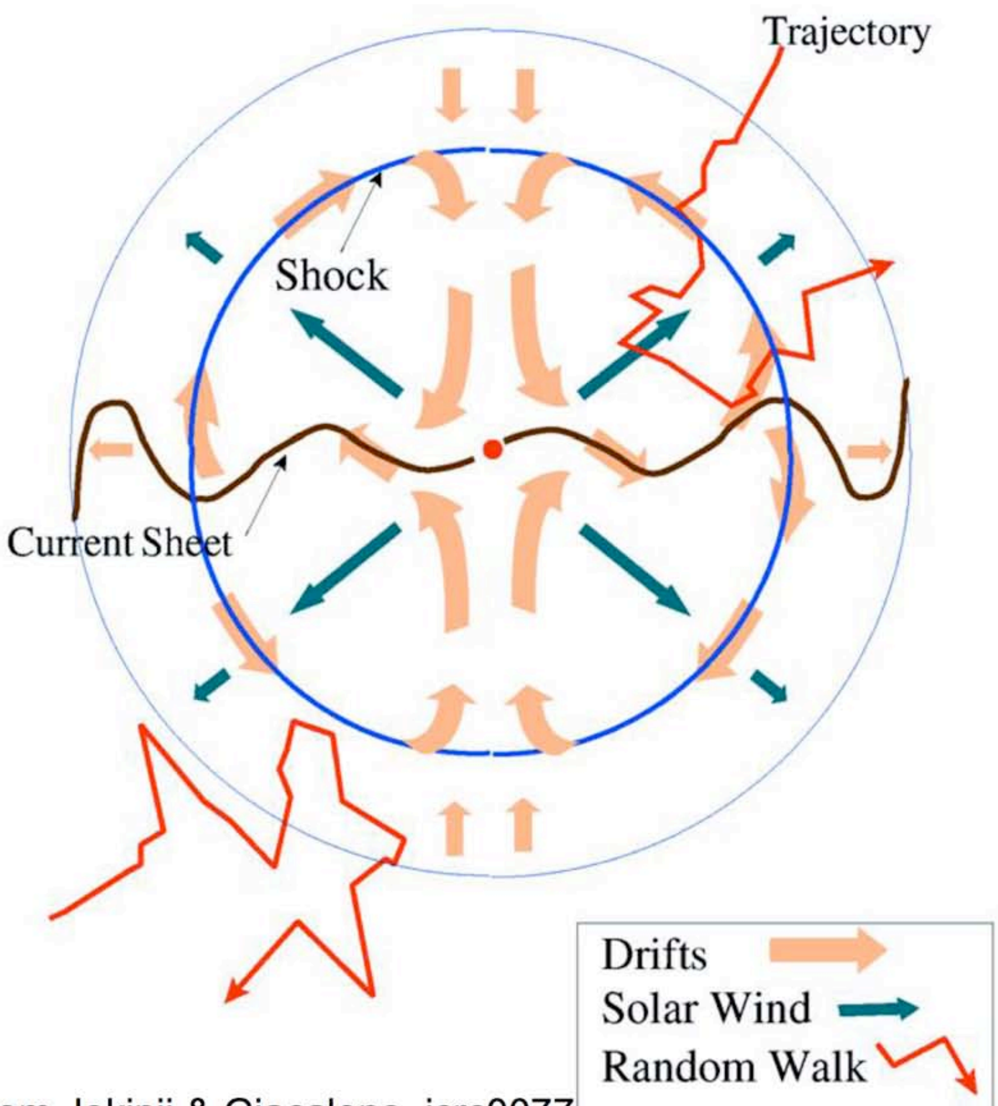
The Parker transport equation [6], for the quasi-isotropic distribution function $f(x_i, p, t)$ of cosmic rays of momentum p at position x_i and time t may be written:

$$\begin{aligned}
\frac{\partial f}{\partial t} &= \frac{\partial}{\partial x_i}\left[\kappa_{ij}\frac{\partial f}{\partial x_j}\right] && (diffusion) \\
&- U_i \frac{\partial f}{\partial x_i} && (convection) \\
&- V_{di}\frac{\partial f}{\partial x_i} && (guiding-center\ drift) \qquad (1) \\
&+ \frac{1}{3}\frac{\partial U_i}{\partial x_i}\left[\frac{\partial f}{\partial \ell np}\right] && (energy\ change) \\
&+ Q(x_i, t, p) && (source)
\end{aligned}$$

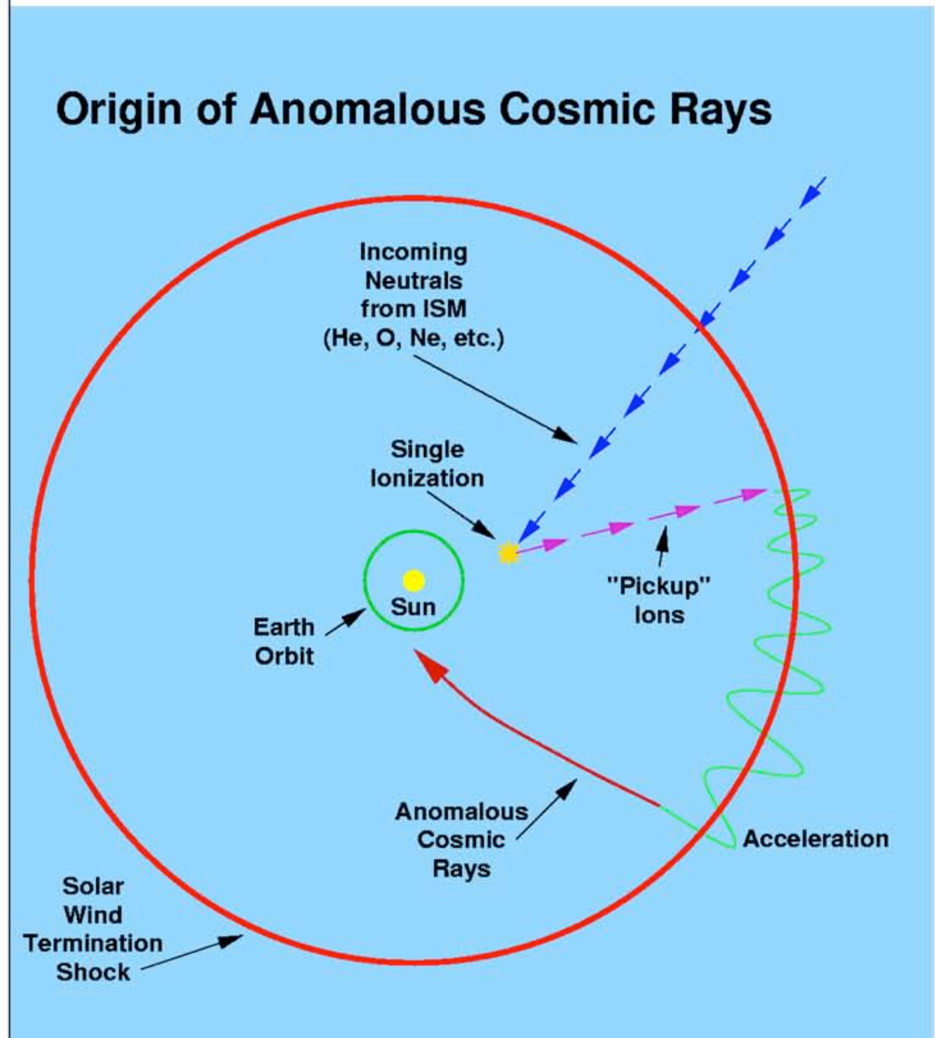
The guiding-center drift velocity is given in terms of the local magnetic field $\mathbf{B}$ and the particle charge q by $\mathbf{V}_d = (pcw/3q)\ \nabla \times (\mathbf{B}\ /B^2)$.

$$+\frac{1}{P^2}\frac{\partial}{\partial P}(P^2 D \frac{\partial f}{\partial P}) \qquad \textit{(stochastic acceleration)}$$

Galactic Cosmic Rays



from Jokipii & Giacalone, icrc0077



New Categories

Diff_coeff (11)

Mod_model (11)

Mod_model_emp (4)

Near_TS (11)

New_capability (9)

Not_SH (5)

Oddlot (5)

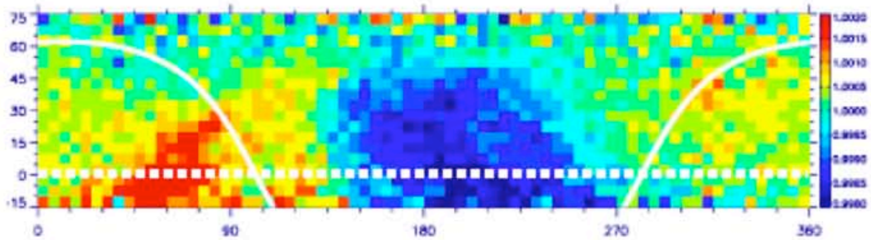
Period_long (16)

Period_short (13)

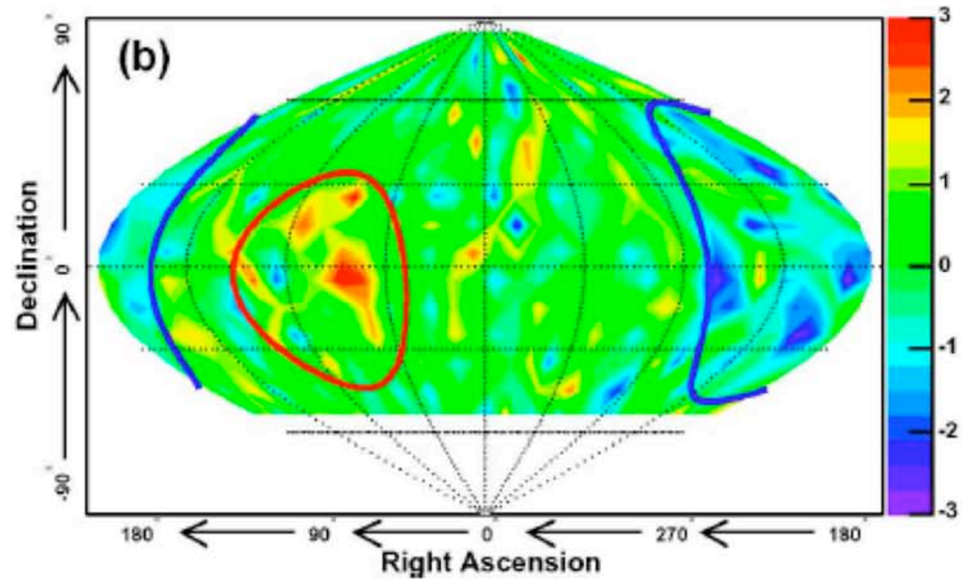
Rad_grad (6)

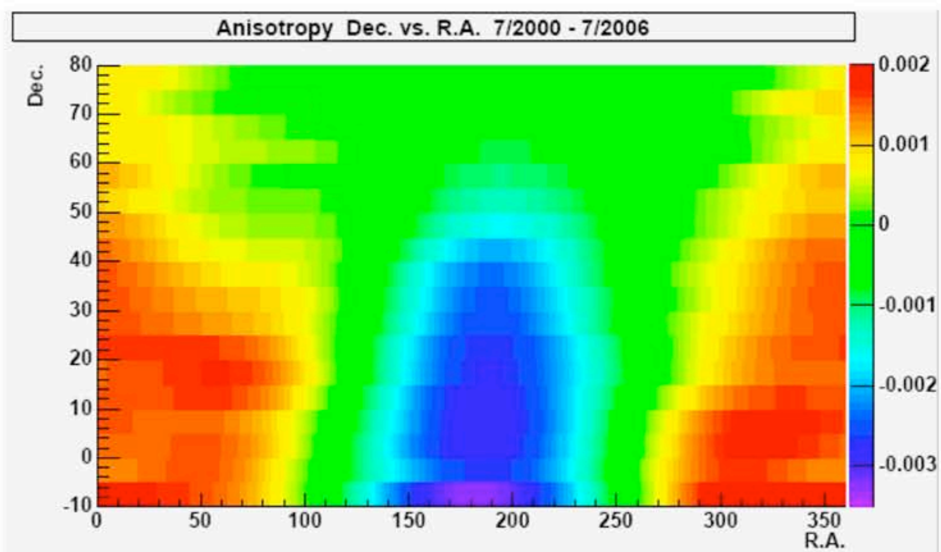
- **Four groups report observations from air shower and underground muon detectors of a sidereal anisotropy in the multi-TeV range.**
- **Observations are in general agreement but interpretation by one group is at odds with others.**

Tibet AS array, ~5 TeV (Amenomori et al., icrc0256)



Super-Kamiokande detector, ~10 TeV (Oyama et al., icrc0394)

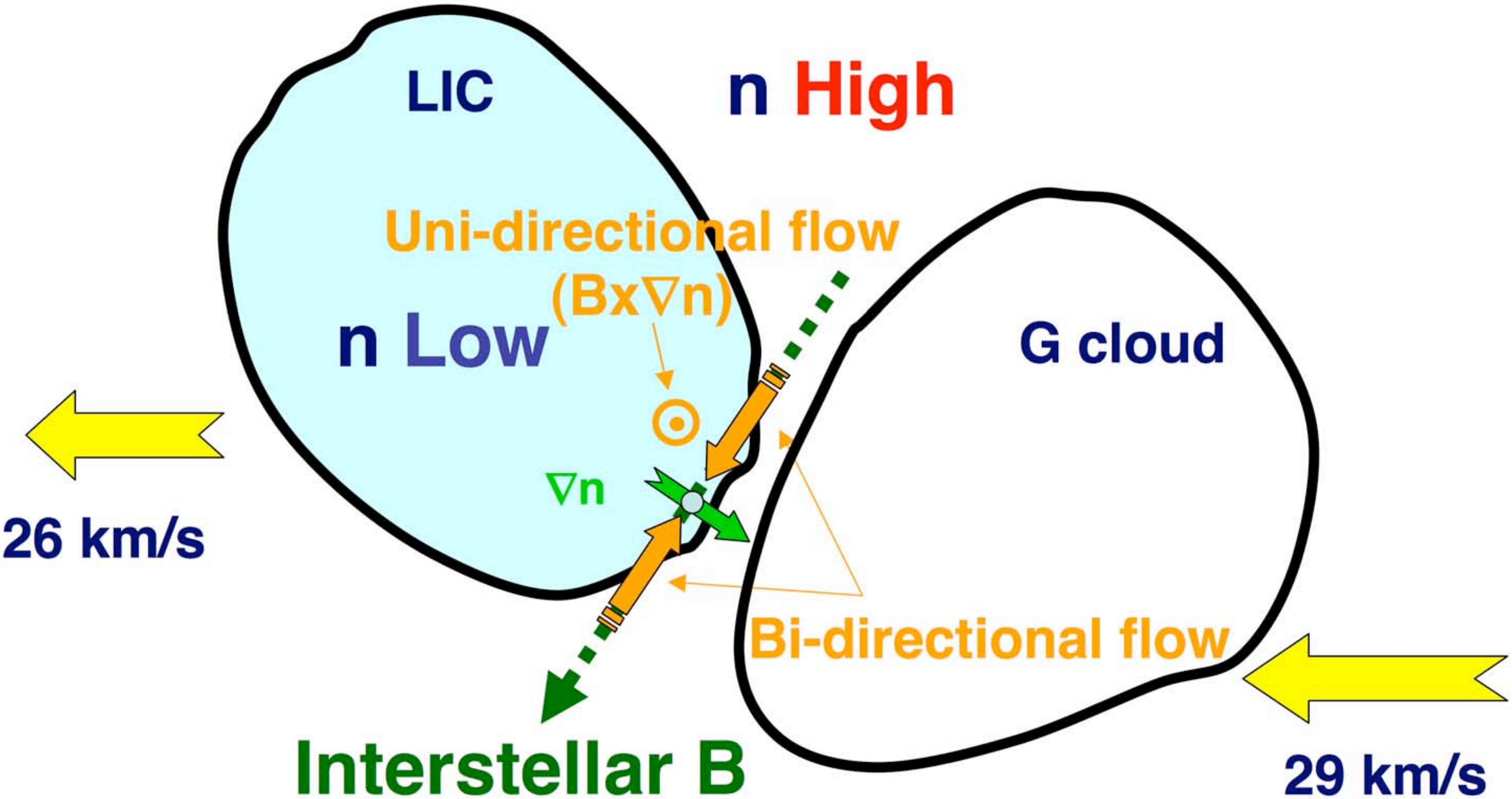




Milagro observatory, ~3 TeV (Kolterman et al., icrc0722)

LIMC (Local Interstellar Magnetic Cloud) model

If cosmic ray density (n) is lower inside LIC than outside….



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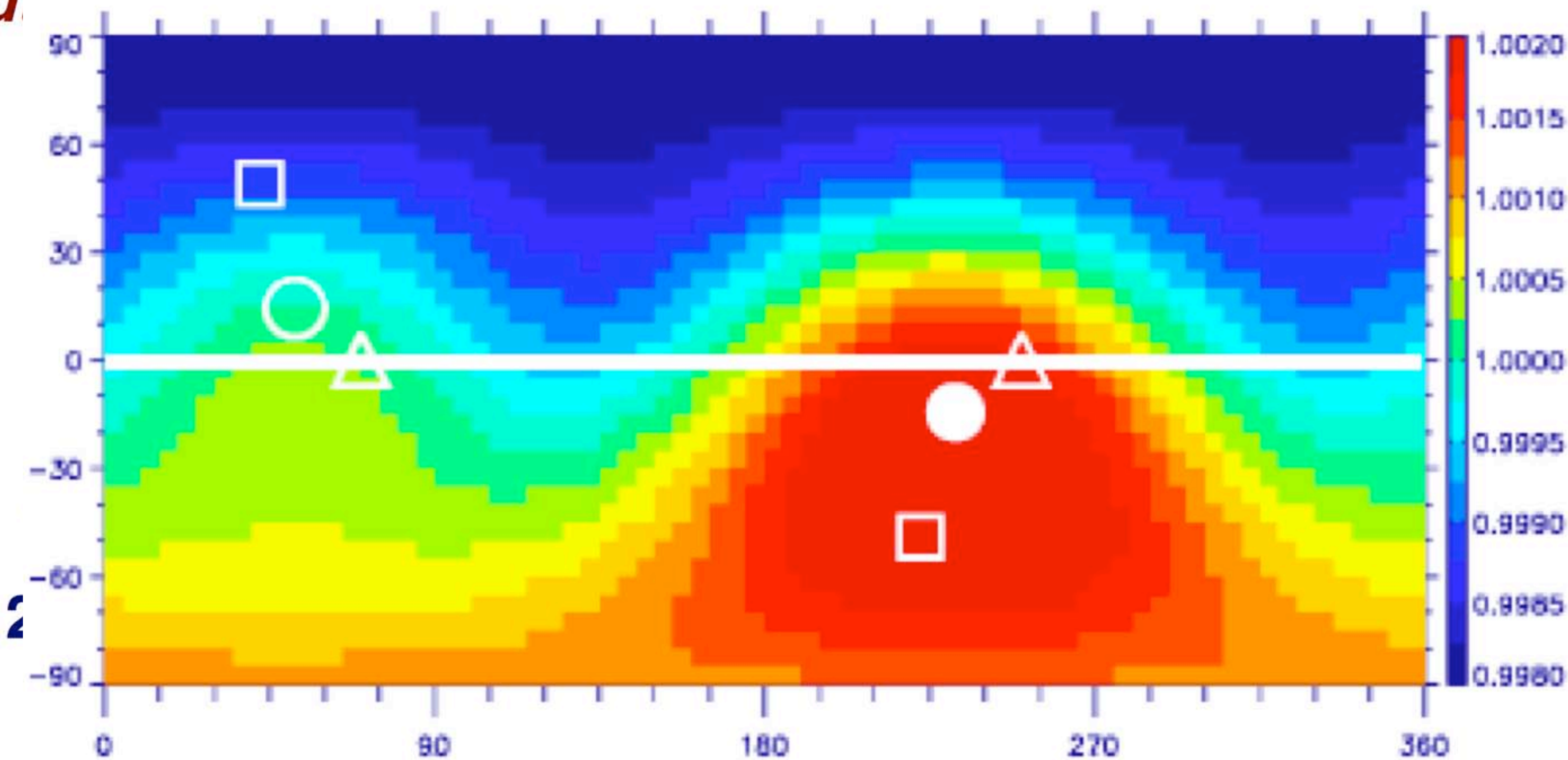
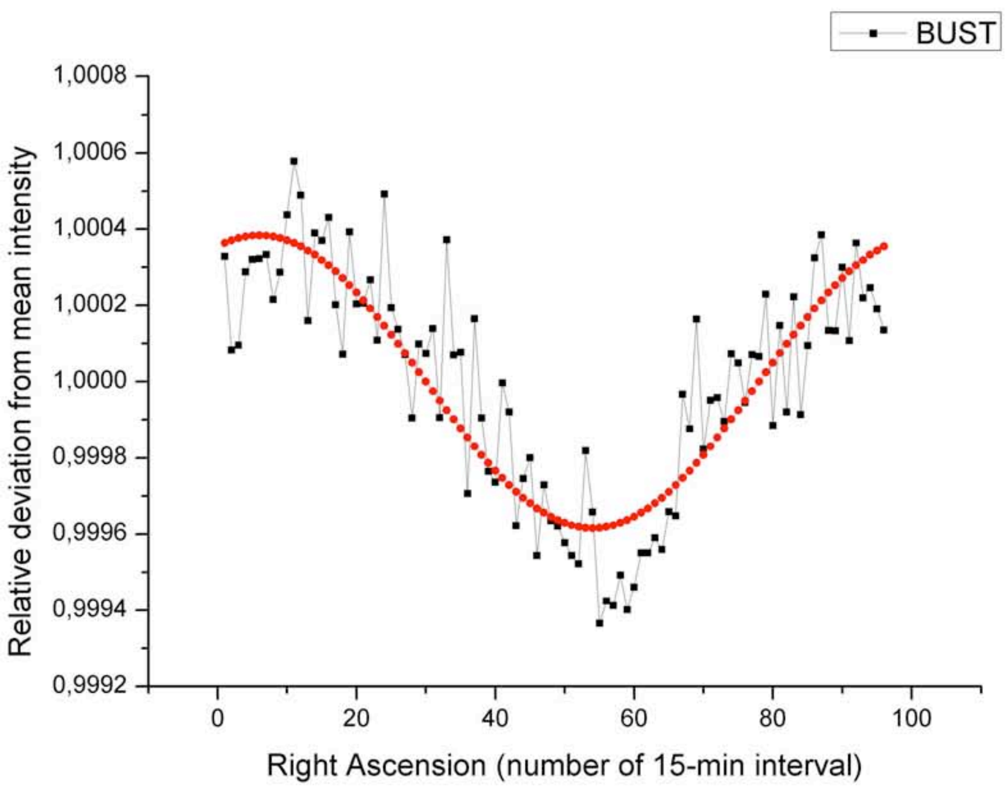


Interstellar B

29 km/s

Amenomori et al., icrc0256

- Lidvansky et al. (icrc0492) dispute this interpretation and say that the declination and amplitude of the source cannot be determined even from 2D observations, if the average intensity in each narrow declination belt is normalized to unity (as Super-K and Tibet do). They say one needs two identical telescopes with different declinations to get at the true anisotropy direction. They do such an analysis using the Baksan array and find preliminary
- $\alpha_0 = (1.5 \pm 0.5)$ h RA and $\delta_0 = (62 \pm 5)°$, which means that the anisotropy vector lies in the galactic plane: $l \cong (120\text{-}130)°$, $b \cong 0°$. They also find no deviations from simple dipole anisotropy (see below).



BUST underground array, ~2.5 TeV
(Lidvansky et al., icrc0492)

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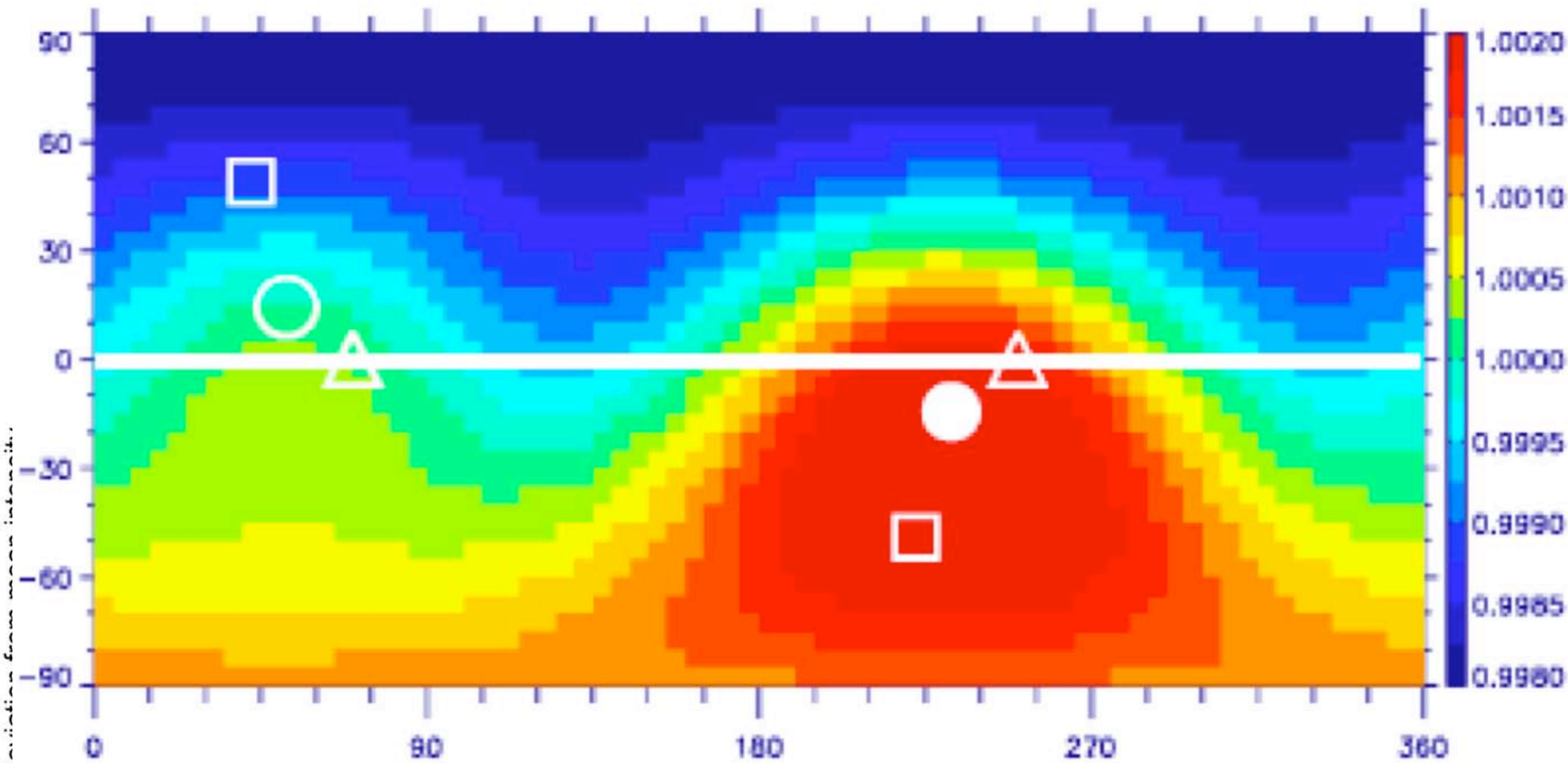

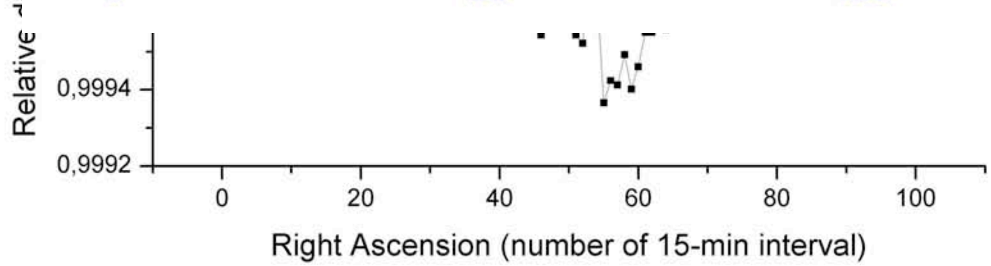

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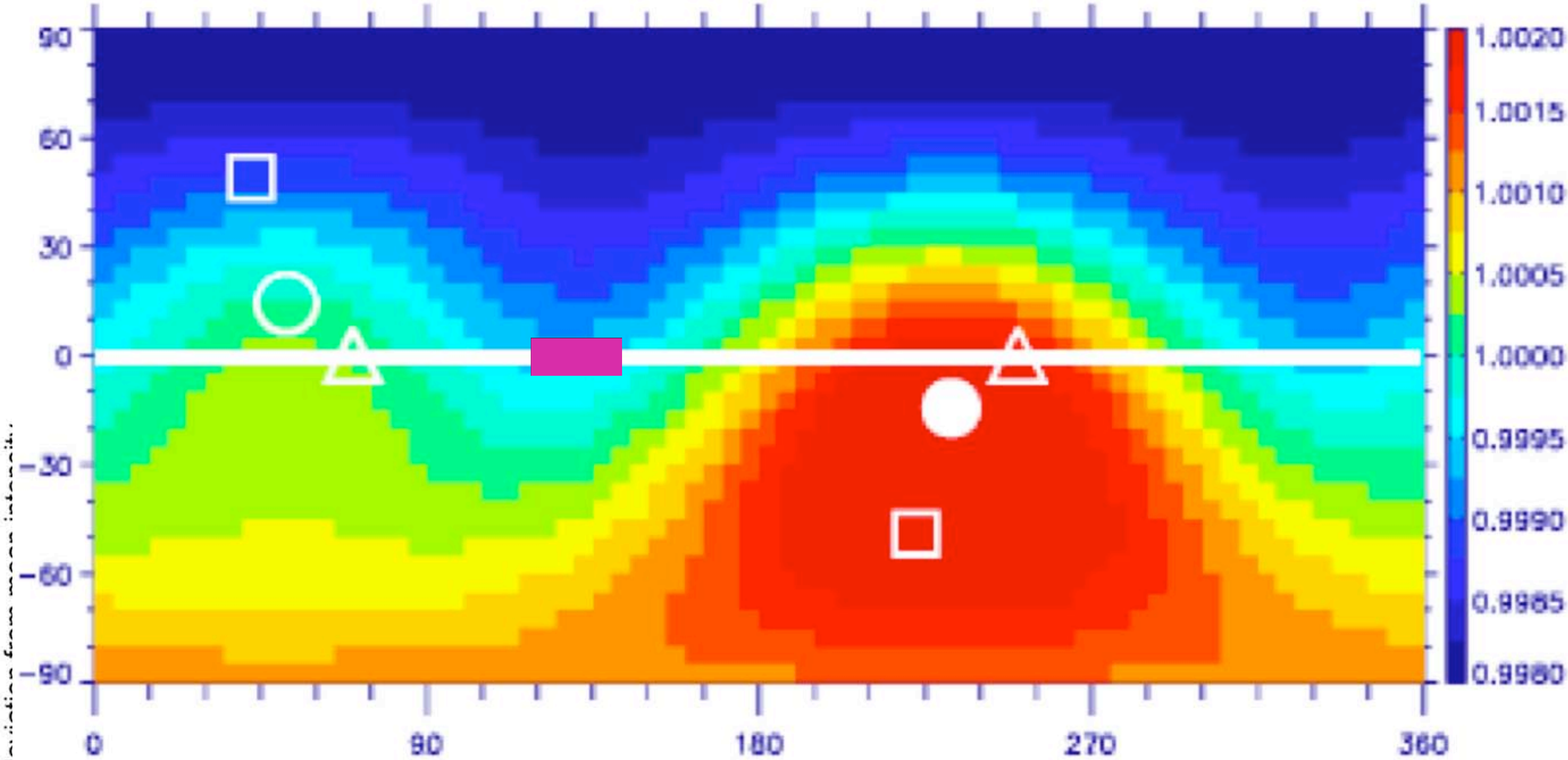

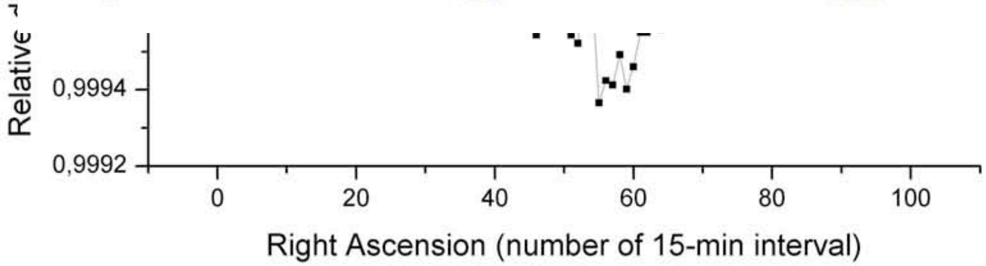

BUST underground array, ~2.5 TeV
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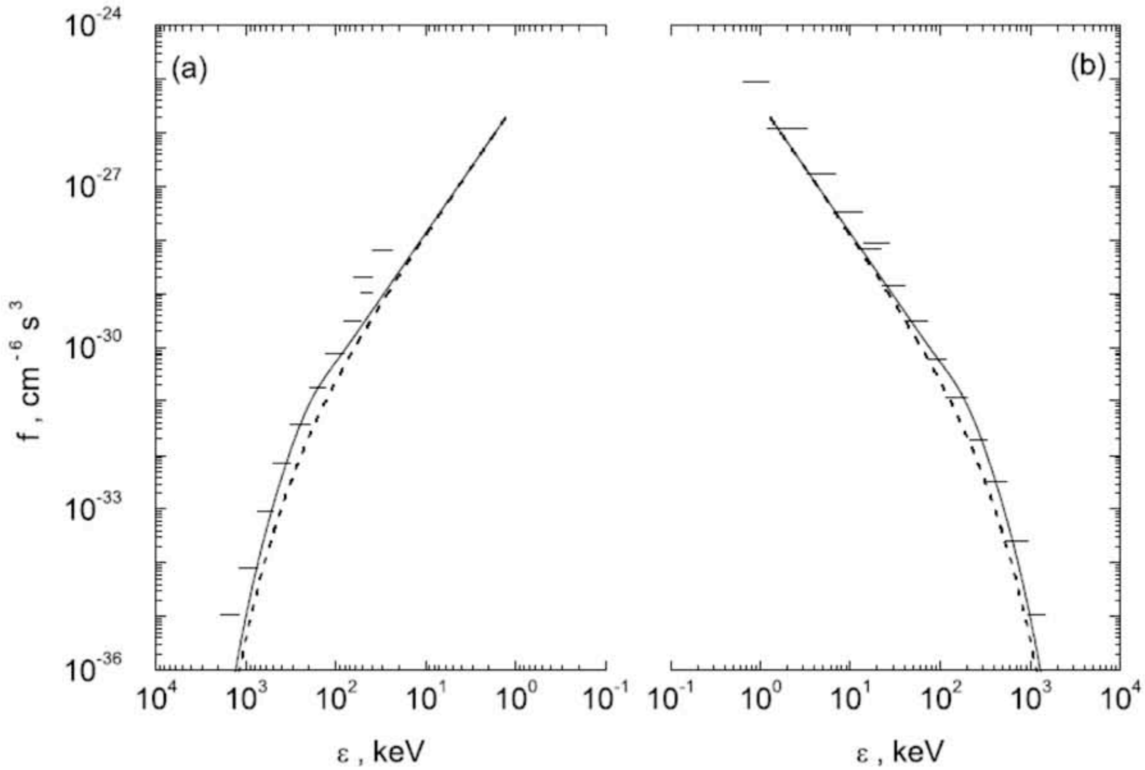
New_capability

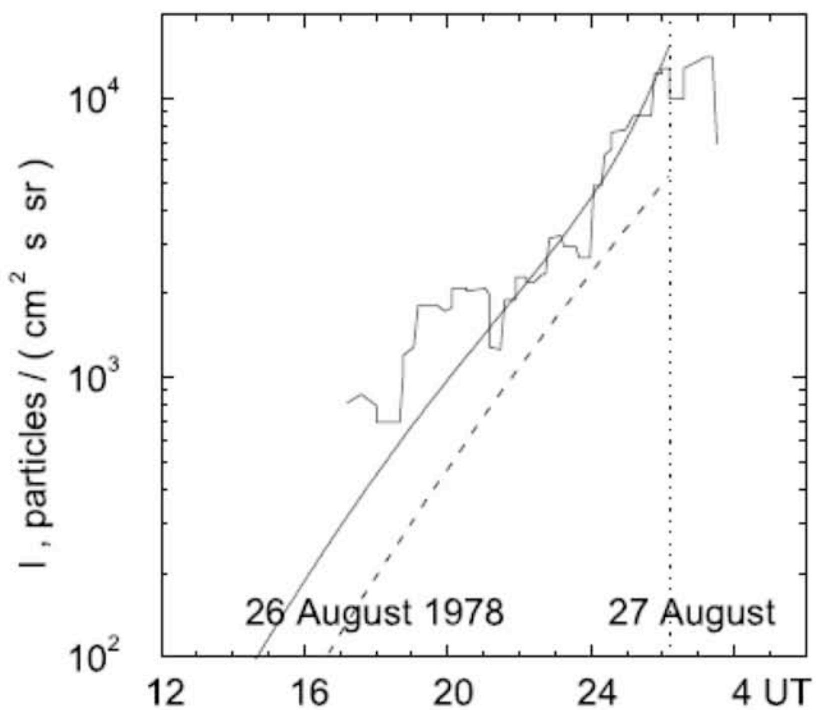
- **New instruments**
  - **IBEX-Lo (Moebius et al., icrc0768)**
    - **To fly on IBEX, launch June 2008**
    - **Measure energetic neutrals from charge-exchange of hot ions in heliosheath with interstellar neutrals.**
    - **New triple coincidence TOF system will improve performance over previous instruments.**
  - **PAMELA (Casolino et al., icrc0501) , launched 15 June 2006**
    - **Can measure p+, p-, e+, e-, n and more to higher energies than previous S/C.**
    - **Analyzing data from Dec 2006 flares.**
  - **CALET (Komori et al., icrc0769)**
    - **Proposed cosmic ray electron (1-100 GeV) and γ-ray instrument for ISS/JEM.**
    - **Big geometry factor. At highest altitude of ISS orbit, 10 min of 1-5 GeV e gives 2% statistics.**
  - **GOSAT (Sasaki et al., icrc0793), launch in mid 2008 (Green House Gas Obs Satellite)**
    - **Comprehensive set of low-energy particle detectors in sun-synchronous sub-recurrent orbit with altitude 666 km and inclination of 98 deg.**
- **New capability of existing instruments**
  - **ACE/CRIS/SOFT (de Nolfo et al., icrc0663)**
    - **New He efficiencies will lead to new studies**
  - **ARGO-YBJ (Cappa et al., icrc0857)**
    - **Air shower array at 4300m altitude in Tibet and in scaler mode can get down to a few GeV to study signals of solar and celestial origin.**
    - **Now analyzing data from Dec 2006 flares.**

New_capability (continued)

- **New capability of existing instruments (continued)**
  - Regular Balloon Monitoring (RBM) of cosmic rays in Russia (Krainev et al., icrc0132)
    - More than 1500 flights since July 1957.
    - Propose to upgrade instrumentation to add pulse-height waveforms to data collected.
- **New data bases**
  - Virtual Cosmic Ray Observatory (VICRO) (Cooper et al., icrc0377)
    - Will contain data from heliospheric network of S/C + neutron monitors and balloon experiment data, as well as ancillary data.
  - Interactive DataBase of Cosmic Ray Anisotropy (Asipenka et al., icrc1006)
    - Online now
    - Contains 10 GV amplitude, spectral characteristic, and anisotropy components from GSM (60 neutron monitors) from 1957 forward.
    - http://cr20.izmiran.rssi.ru/AnisotropyCR/Index.php

- **Ion acceleration and Alfvén wave excitation at interplanetary shocks (Berezhko and Taneev, icrc0116)**





Uses self-consistent theory of ion diffusive shock acceleration and the associated generation of Alfvén waves to fit observations of traveling interplanetary shock of 26-27 August 1978 by ISEE 3.

On left is calculated spectrum toward and away from Sun together with observations and on right is intensity vs time for protons with 91-237 keV.

Oddlot

- **Group reporting measurements to characterize radiation environment on ISS and to study effectiveness of shielding materials (Casolino et al., icrc0506)**
- **Group reporting radiation belt measurement from TSUBASA satellite (Hareyama et al., icrc0811)**
- **Group reporting vertical muon flux at 5.3 GV cutoff at ground level and 12 m rock depth (25 m water equiv) for 2002-2006 (Dragic et al., icrc0957).**
- **Jupiter electrons influence interplanetary magnetic field and hence neutron monitor rates (Timofeev et al, icrc0216).**

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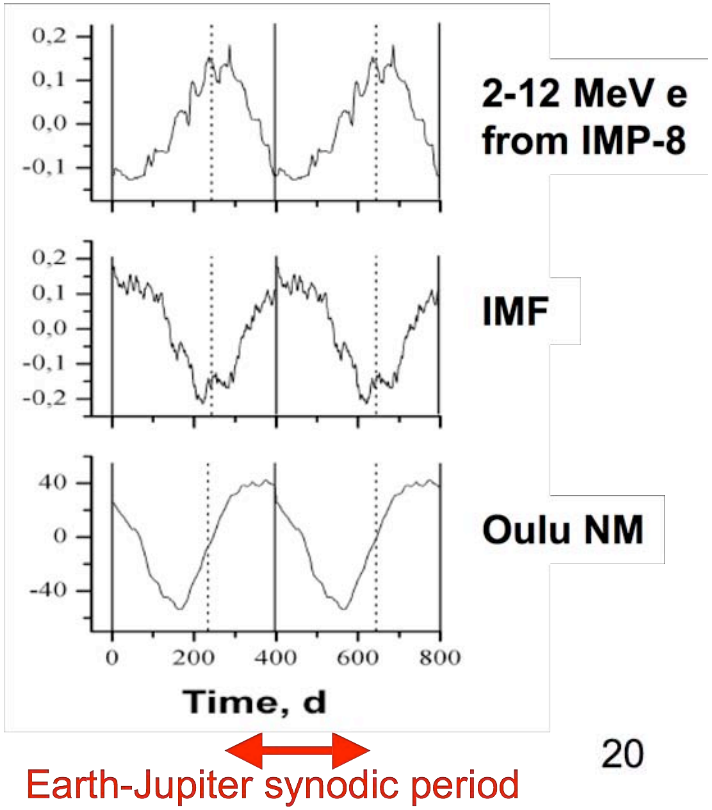
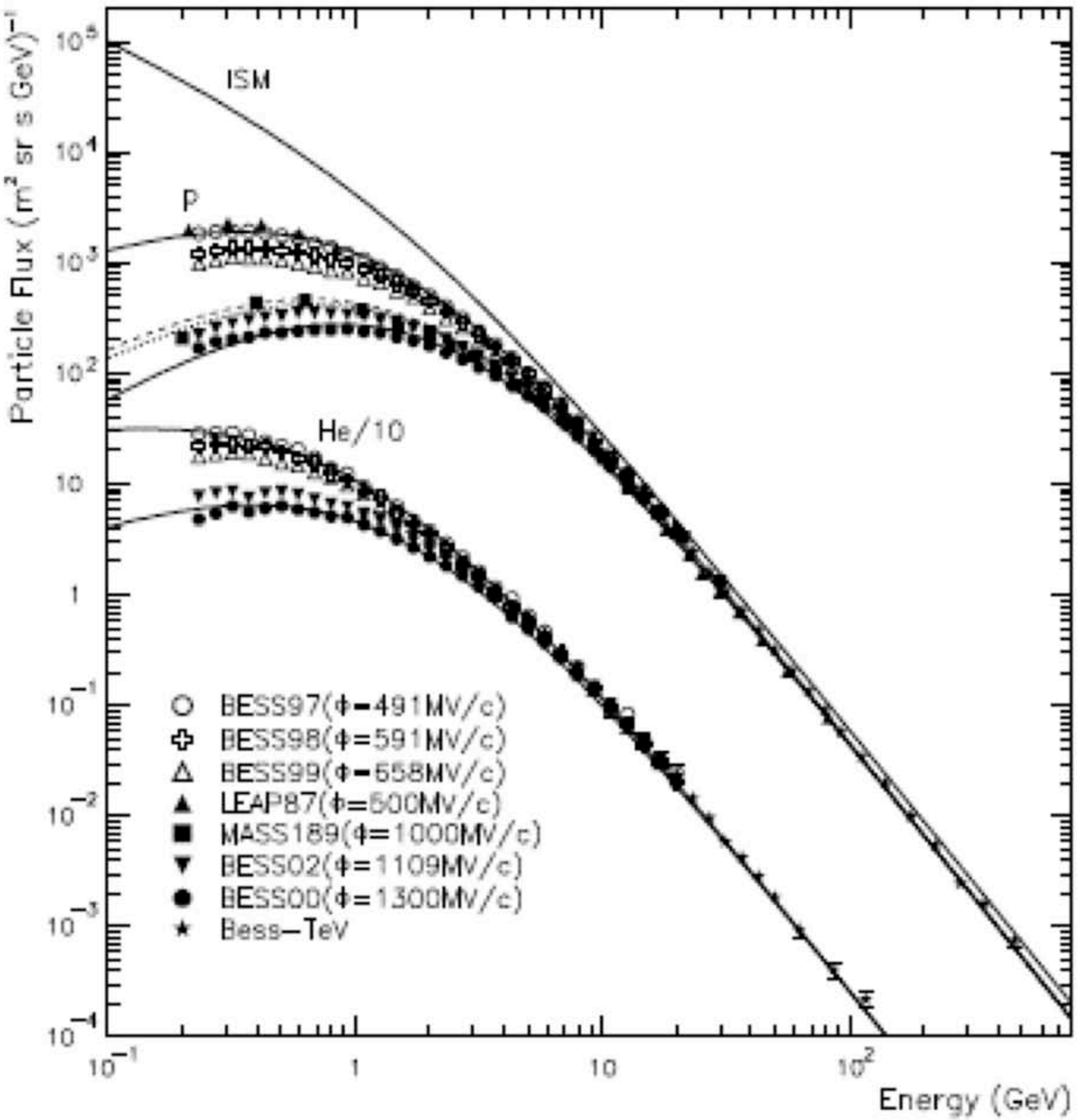
Superposed epoch analysis



- **Parameterization of GCR and ACR H and He spectra at 1 AU:**



Developed as a predictive tool for what LISA will see.

Grimani et al., icrc0326

Mod_model_emp (continued)

- **Belov et al. (icrc0225) establish a new flare index to improve their semi-empirical model of intensity of 10 GV cosmic rays vs time near Earth. Based on class of flare and longitudinal location relative to Earth's.**

$$Fx = \left[1 + \alpha \ln\left(\frac{I_x}{I_c}\right)\right] \exp\left(-\left(\frac{\varphi - \varphi_0}{\sigma_\varphi}\right)^2\right)$$

- **Okhlopkov & Stozhkov (icrc0317) parameterize the RBM cosmic ray intensity variations from 1957 to present using indices based on a variety of solar activity parameters that vary every 10 years.**

Mod_model

- **New wrinkles:**
  - **Allow particles to escape heliosphere and come back in (Bobik et al., icrc0083).**

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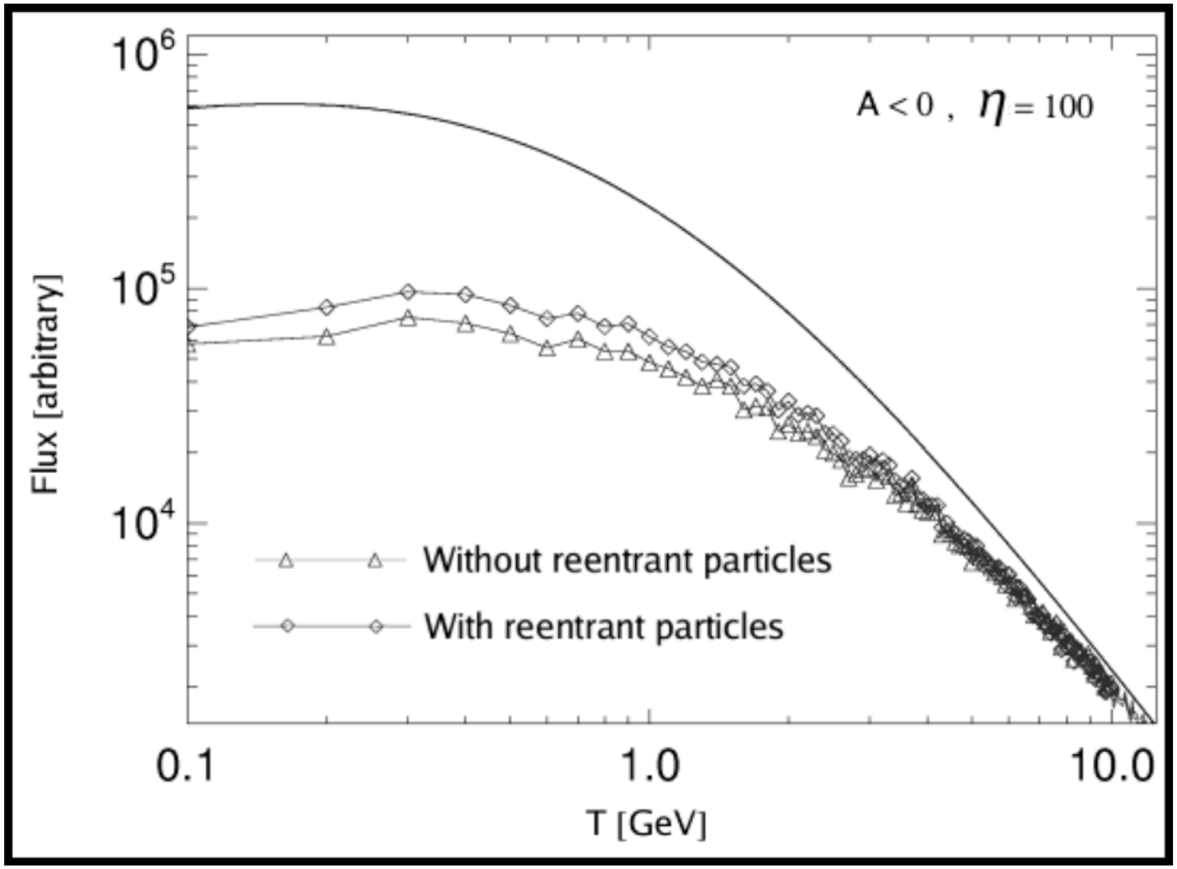

Mod_model

- **New wrinkles:**
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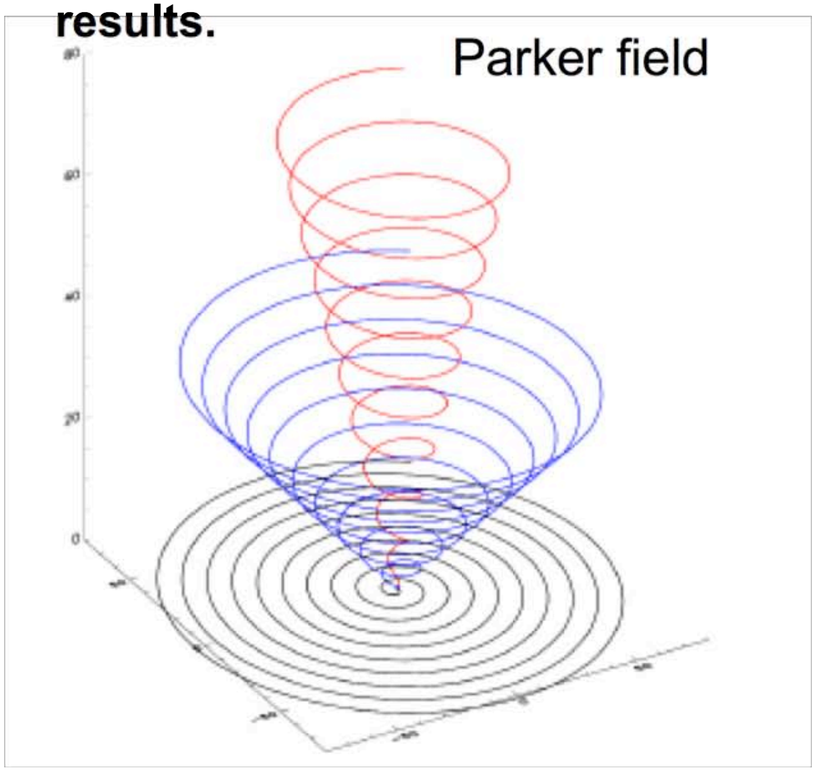
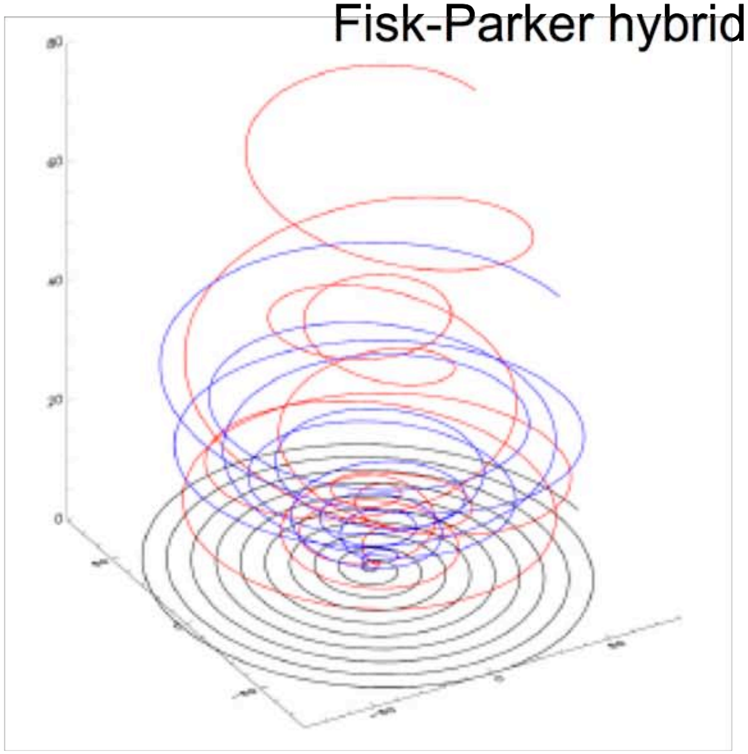
  - **Incorporate Fisk-type magnetic field or Fisk-Parker hybrid field into models (Miyake et al., icrc0807, Hitge & Burger, icrc0808). Both incorporate latitude dependent SW speed in 3D model for 1st time. Latter find latitude dependence of SW speed is not very important and that global modulation results are similar to those using pure-Parker field, in contrast to earlier 2D results.**

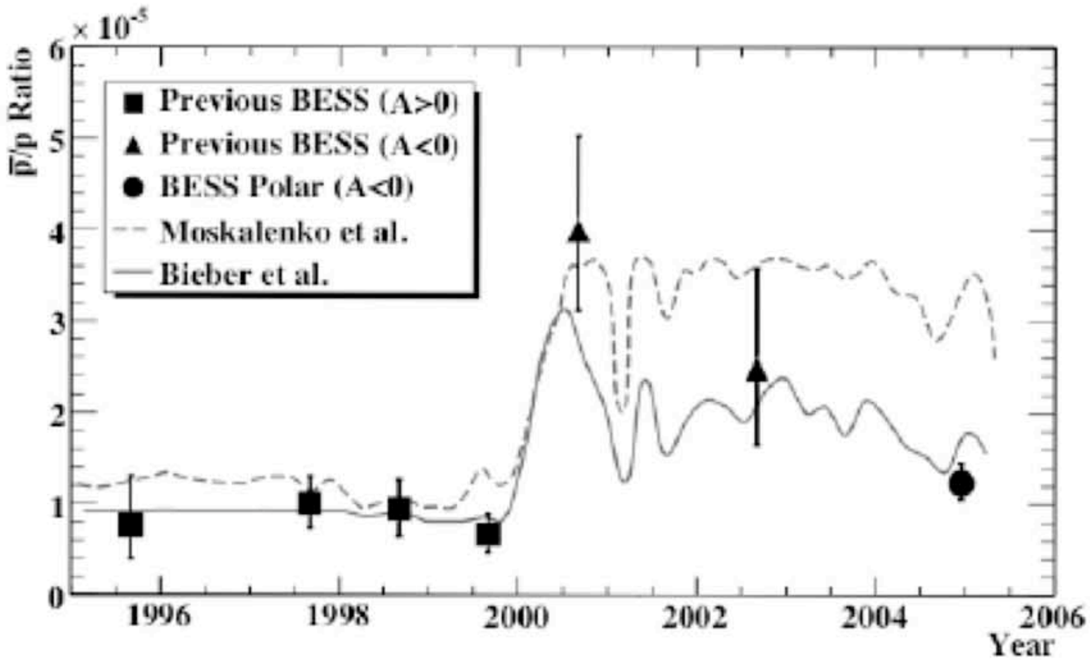


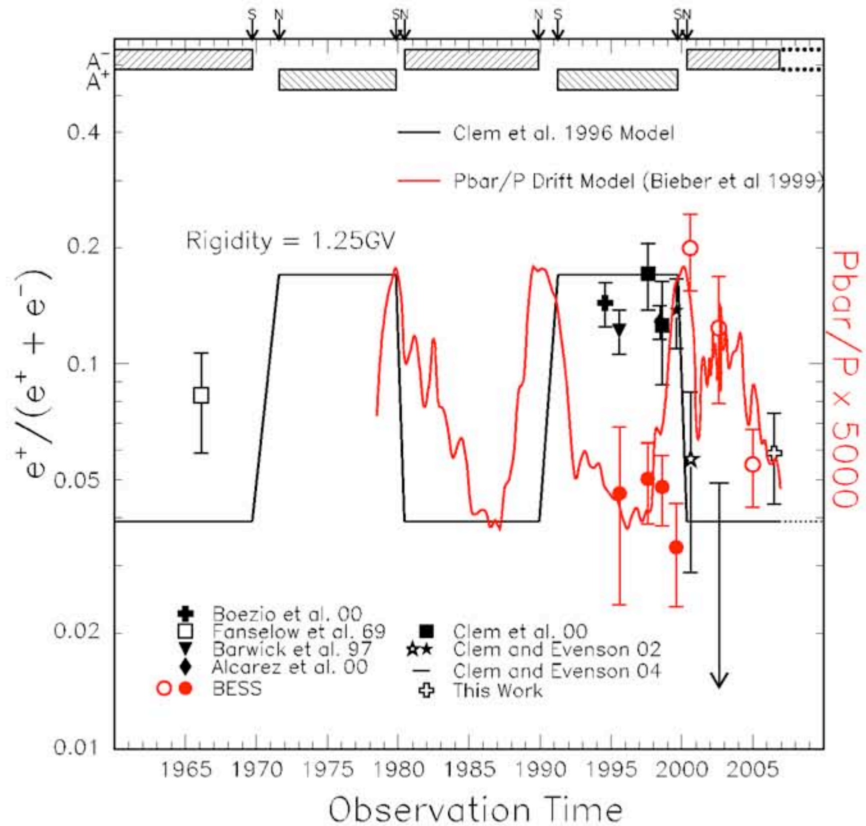


Figures from Sternal et al., icrc0885

Mod_model (continued)

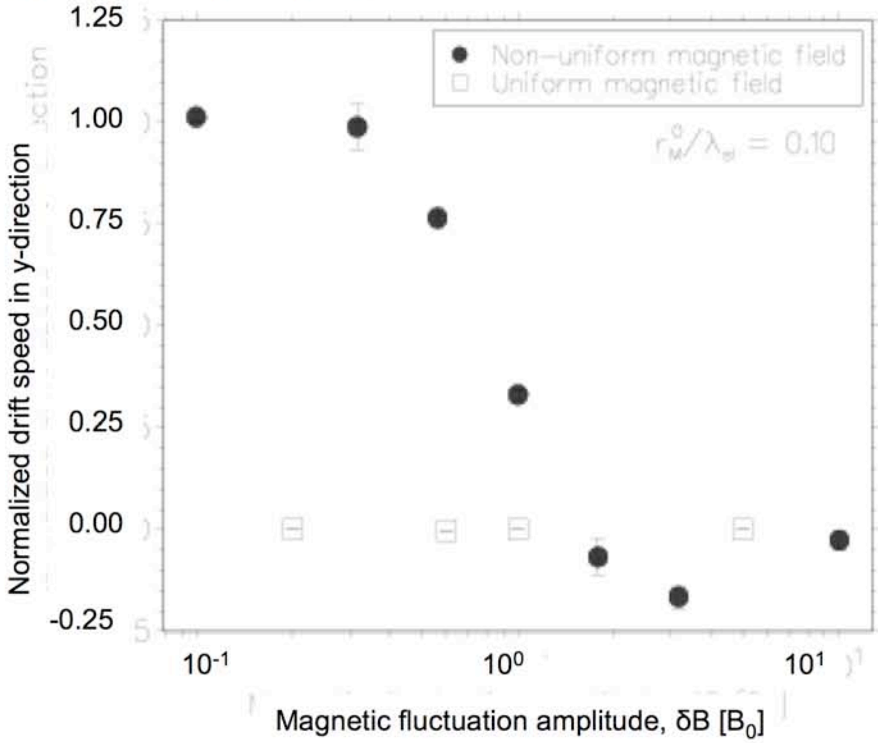
- **Charge-sign effects (drifts):**
  - New positron fraction observations from June 2006 balloon flight (Clem & Evenson, icrc0242) and new pbar/p measurements from 2004 BESS flight (Mitchell et al., icrc1149).





Conclude that pbar/p drift effects are consistent with Bieber et al. model but apparently not Moskalenko et al.; e+/e- drift effects ~consistent with Clem et al. model.

- **Drift suppression:**
  - **Minnie et al. (icrc0360) and Usoskin et al. (icrc1310) consider effects of turbulence and tilt angle of HCS on drifts, respectively.**



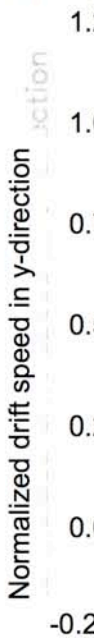
Minnie et al. find that increasing magnetic turbulence in a non-uniform field reduces drift speed. Results may lead to revision of modulation models in the way drift effects are suppressed.

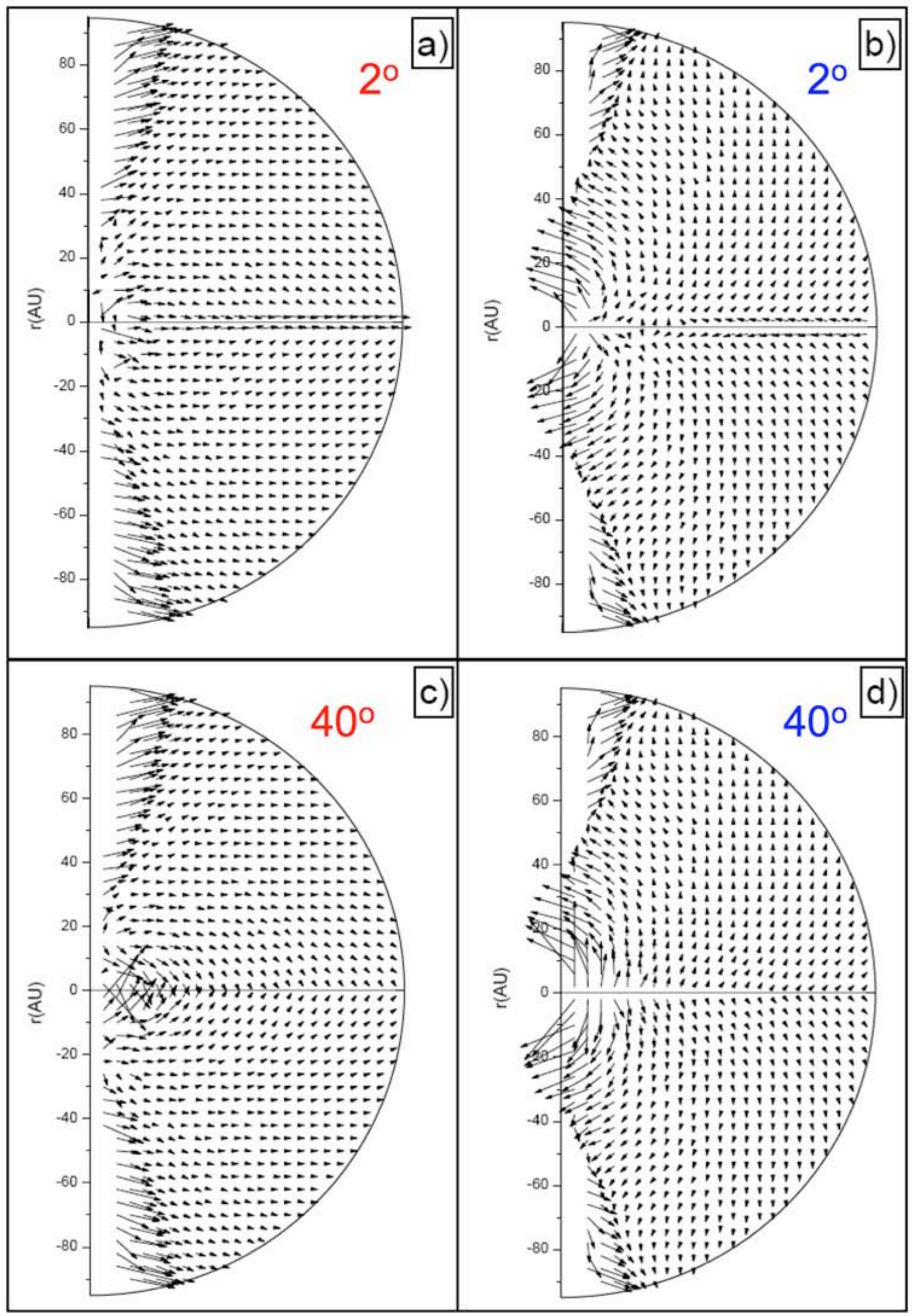
Mod_model (continued)

qA>0

qA<0

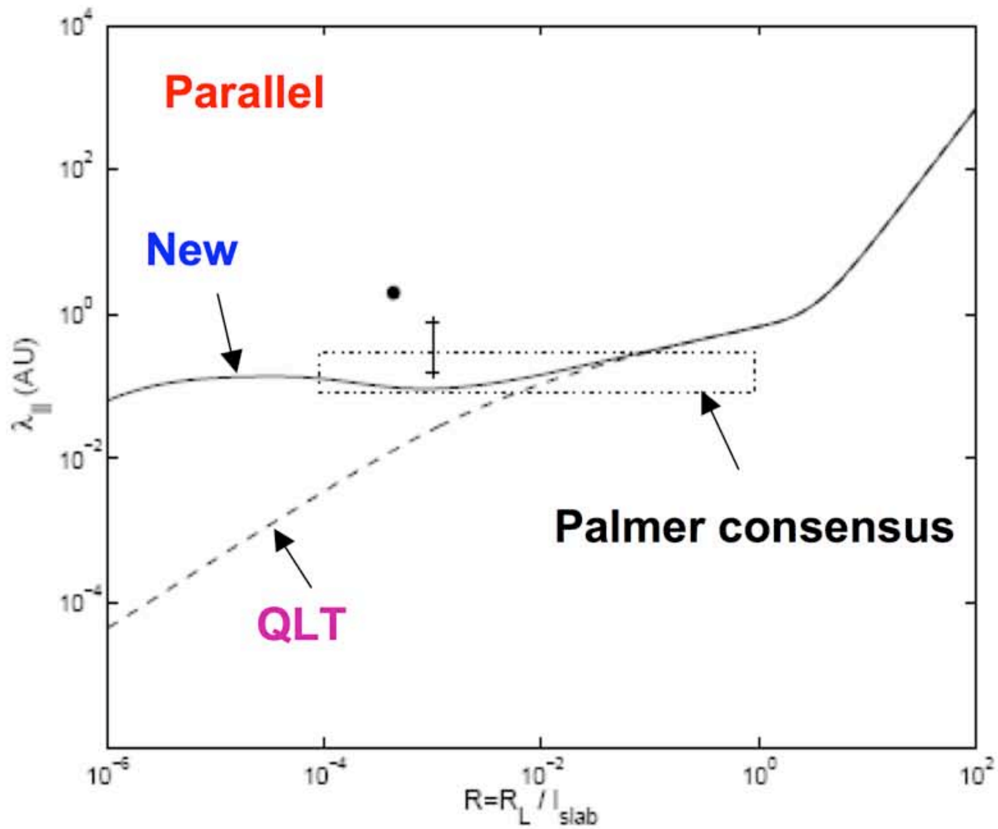
- **Drift suppre**
  - **Minnie et consider on drifts,**

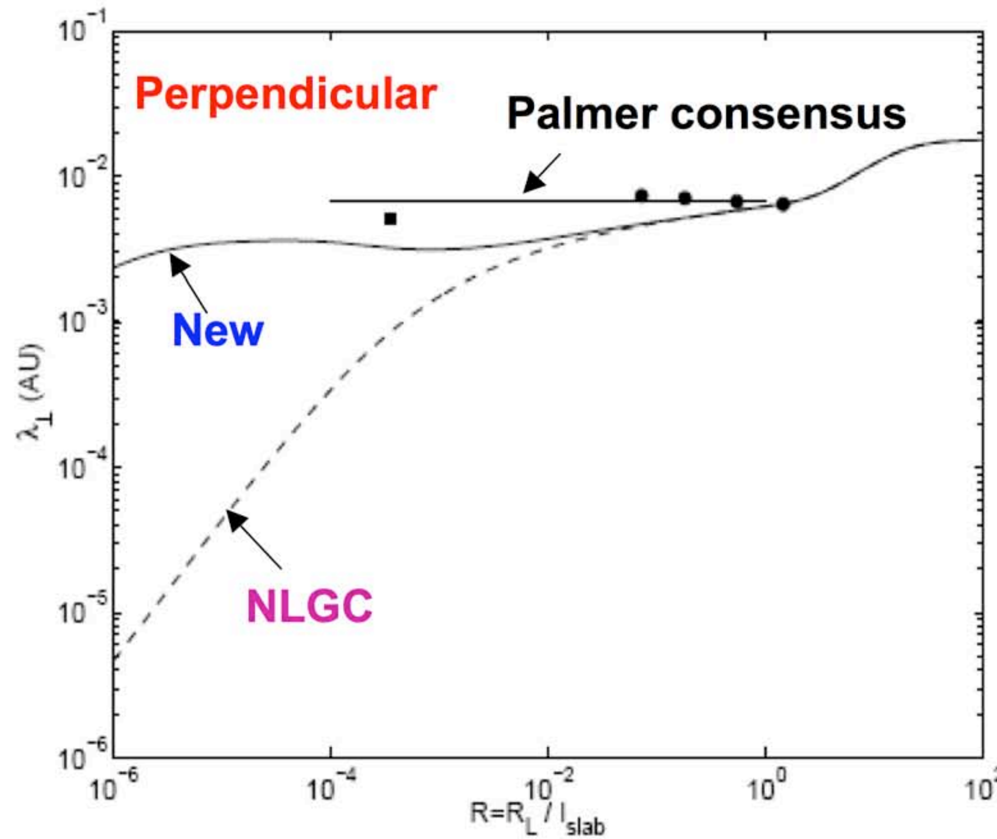




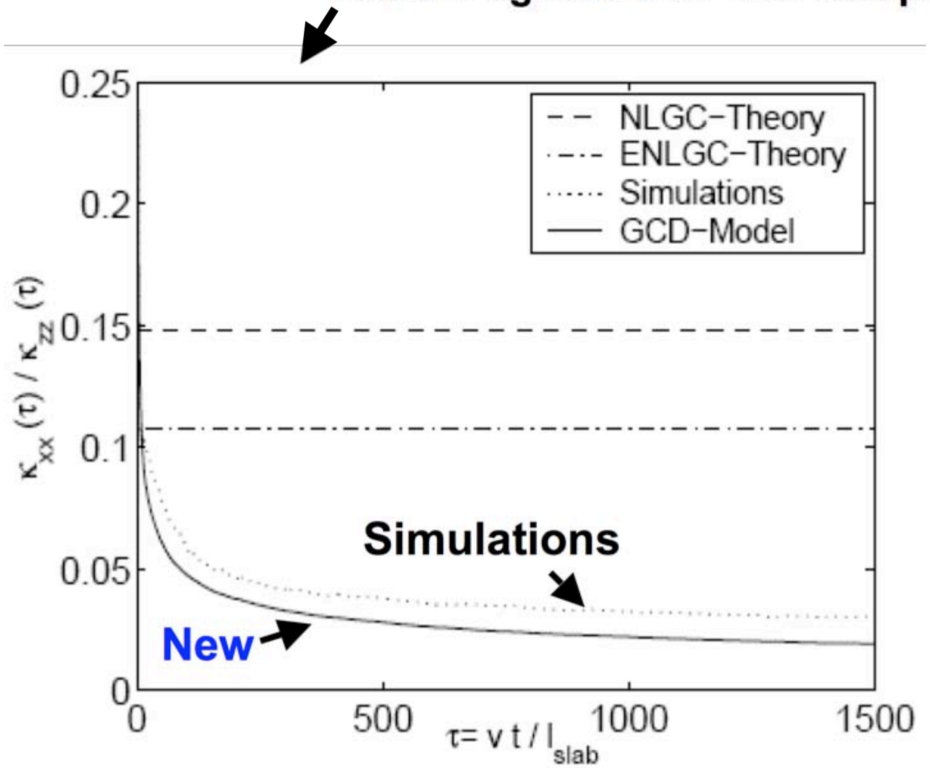
Note that at HCS tilt of 40° the rapid drift along HCS is washed out and large-scale curvature and gradient drifts dominate. (Usoskin et al., icrc1310)

- **New developments:**
  - **New NADT turbulence model in combination with QLT for parallel diffusion and NLGC for perpendicular diffusion can reproduce the Palmer consensus (Shalchi et al., icrc0047). Uses composite geometry and wavespectrum used by Bieber et al. 1994 but assumes different forms of slab and 2D correlation functions.**





- **New developments:**
  - **New theoretical treatment of perpendicular transport (Shalchi & Kourakis, icrc0045) – Generalized Compound Diffusion (GCD) model.**
    - **Improved formulation of field line random walk.**
    - **Results agree better with test particle simulations than earlier theories.**



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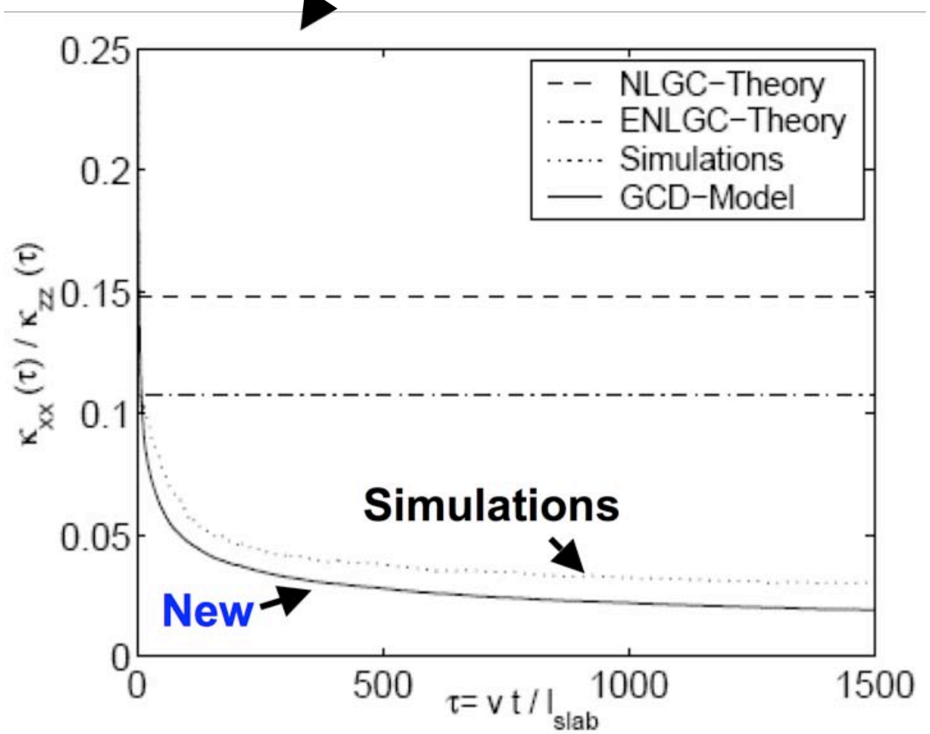
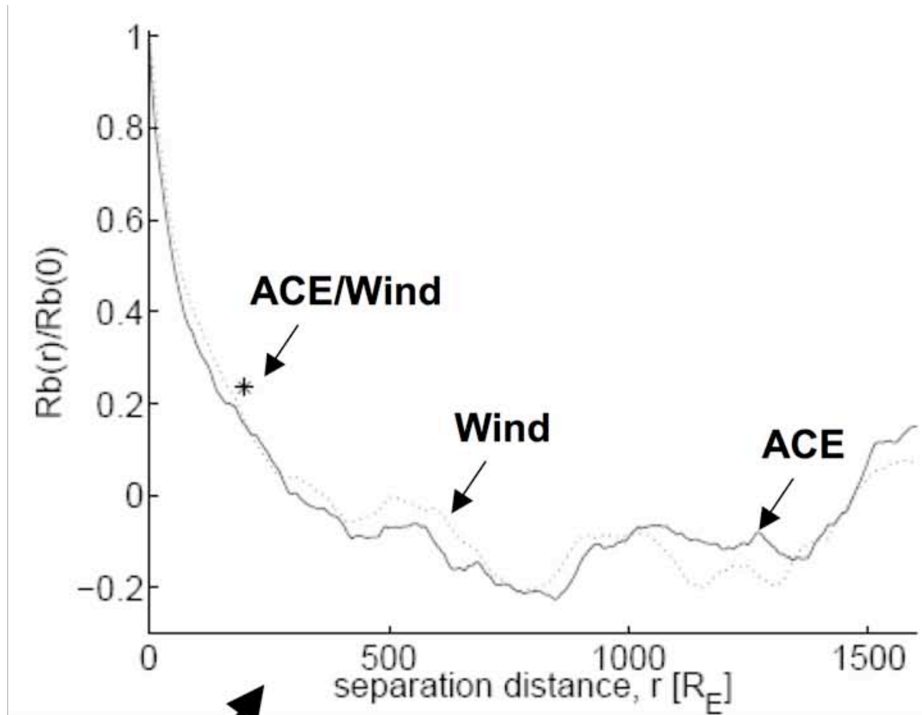
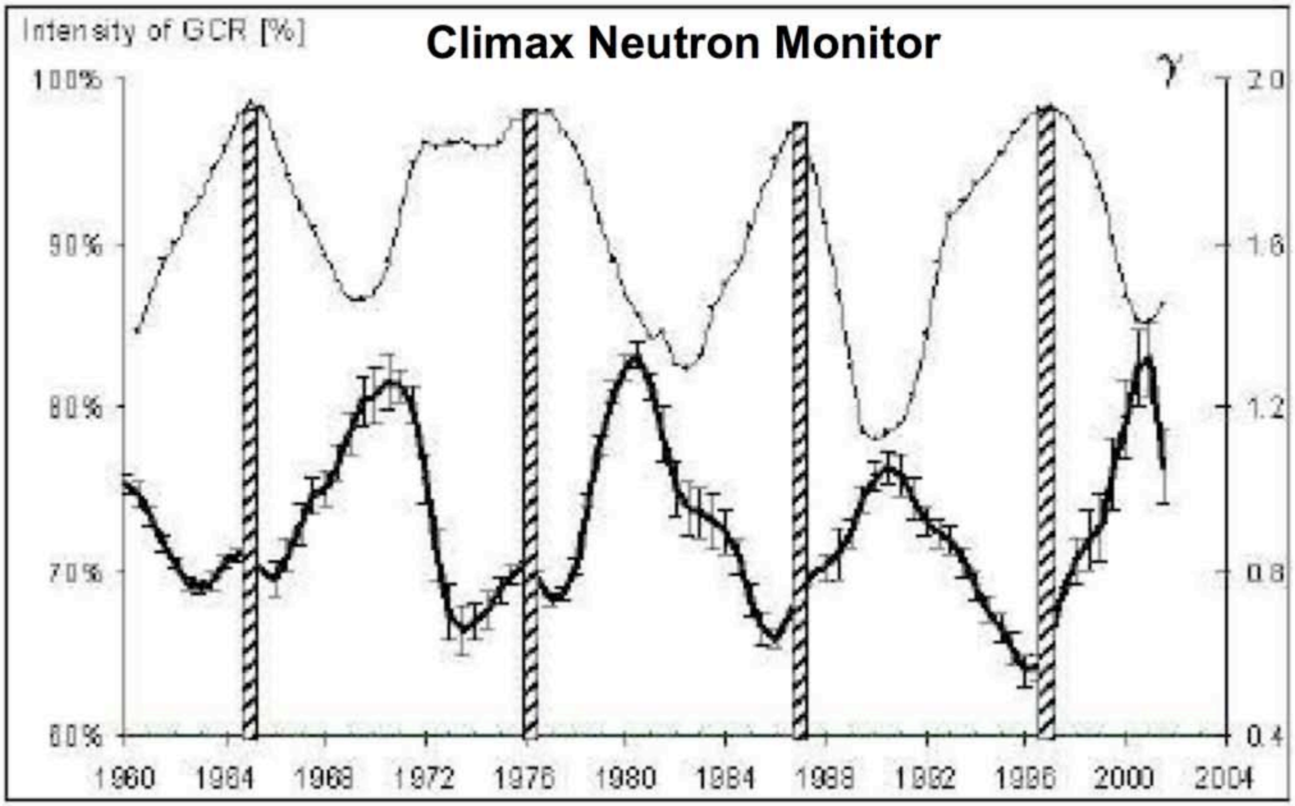




  - **New comparison between magnetic field correlations done on a single spacecraft at two different times (SSC) with correlations from two spacecraft at a single time (TSC) (Dasso et al., icrc0937).**
    - **Used ACE and Wind data**
    - **Will be useful for investigating slab vs 2D turbulence**

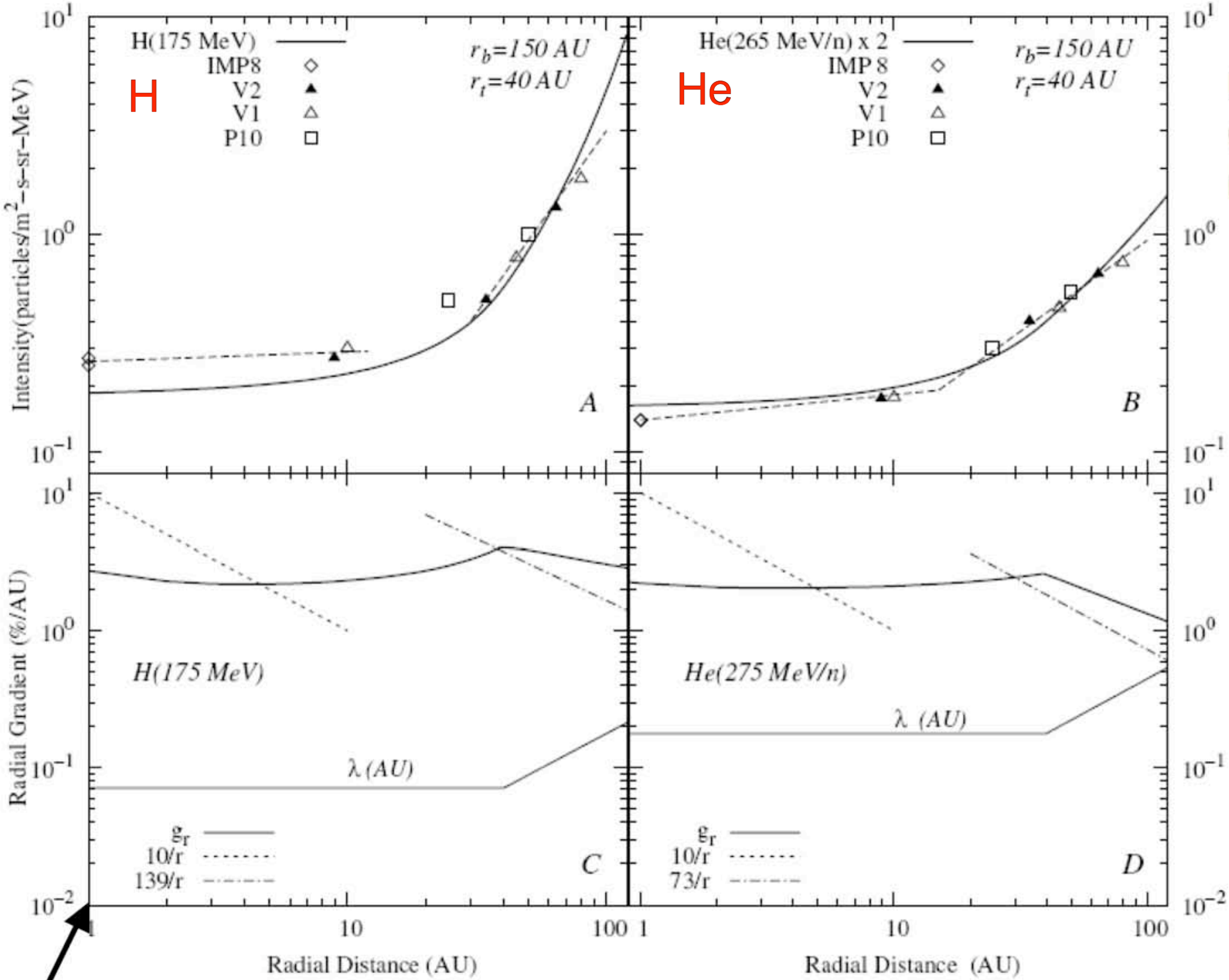
- **New developments (continued):**
  - **Alania et al. (icrc0724) find power-law index of rigidity dependence of neutron monitor intensity variations allows one to determine the magnetic turbulence power spectrum index in the 10^{-6} – 10^{-5} Hz frequency range.**



Alania et al., icrc0724

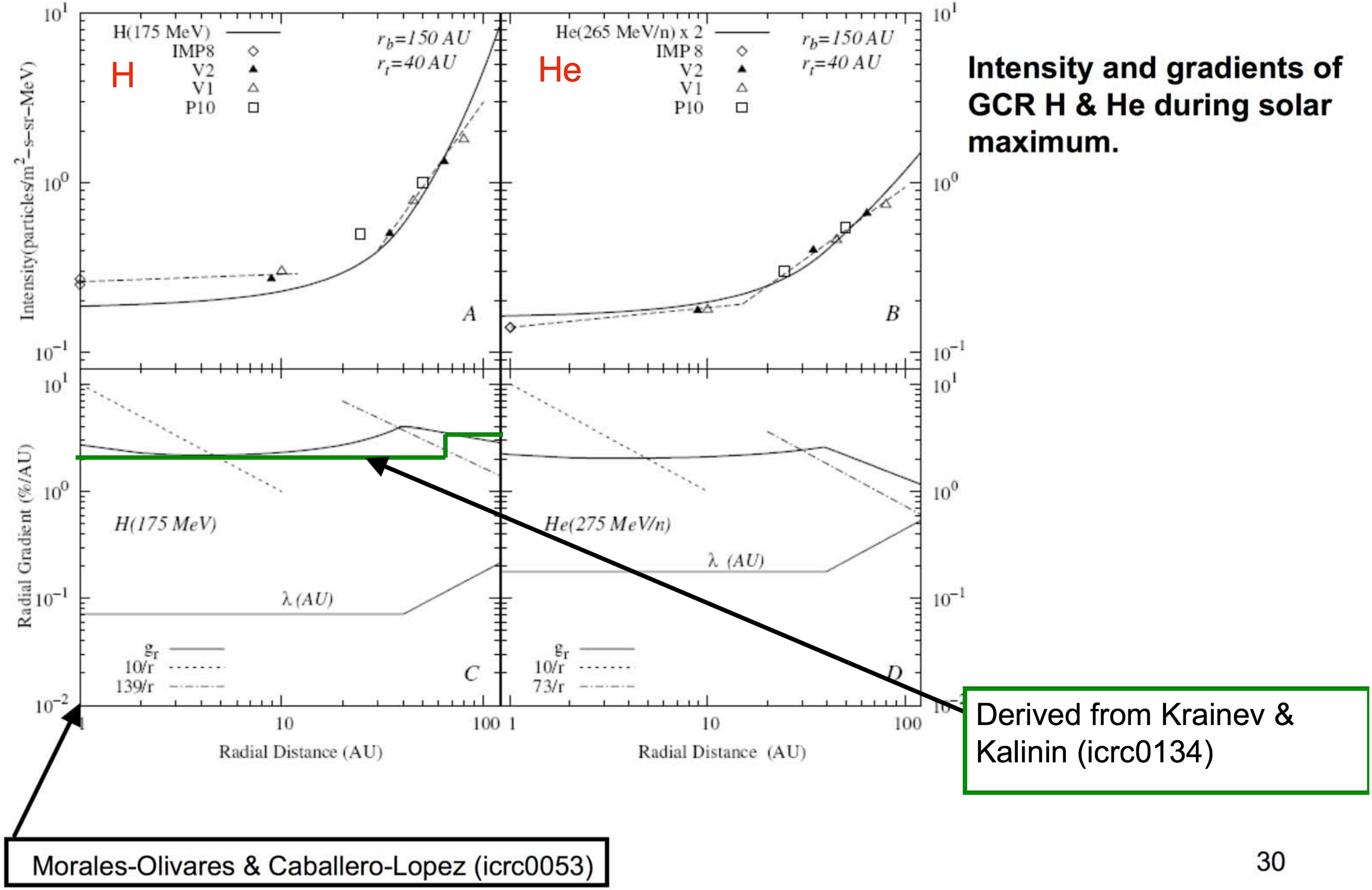
Find that 75-80% of amplitudes of 11-year GCR intensity variation is caused by IMF turbulence variations.

- **Other developments:**
  - **Strong anisotropies of Jovian electrons off equatorial plane can be used to study perpendicular diffusion (Nkosi et al., icrc0310).**
  - **Burger & Englebrecht (icrc0479) used Fisk-Parker hybrid field and 3 year old version of perpendicular mean free path to explain amplitude of recurrent 26-day variations being larger in A>0 cycles than A<0 for both low and high rigidities.**
  - **Sternal et al. (icrc0885) compare diffusion tensors in a Parker field vs a Fisk-Parker hybrid field.**
    - **Fisk-Parker hybrid field can at least partly explain enhanced latitudinal transport but it's not the only possible explanation.**



Intensity and gradients of GCR H & He during solar maximum.

Morales-Olivares & Caballero-Lopez (icrc0053)



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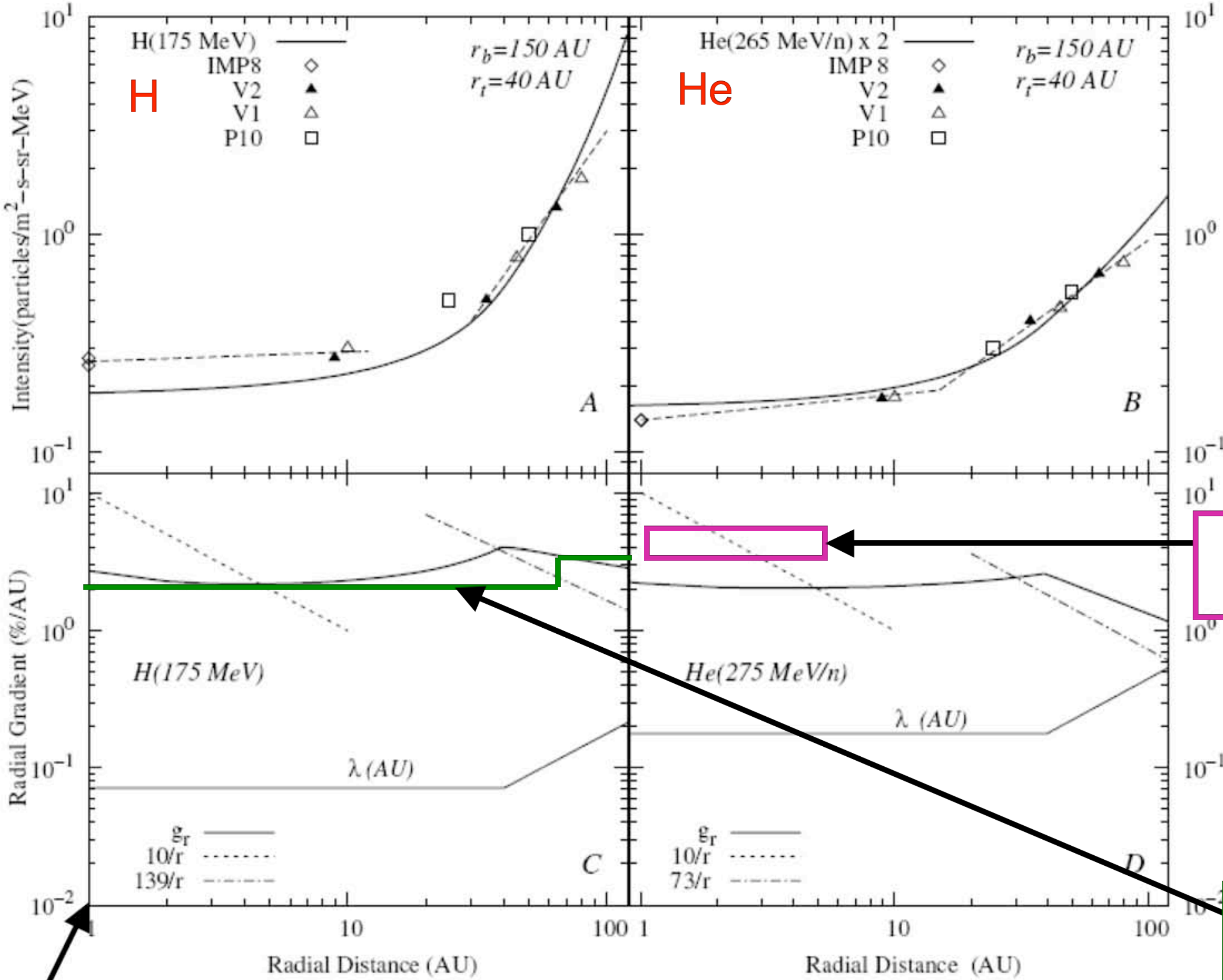


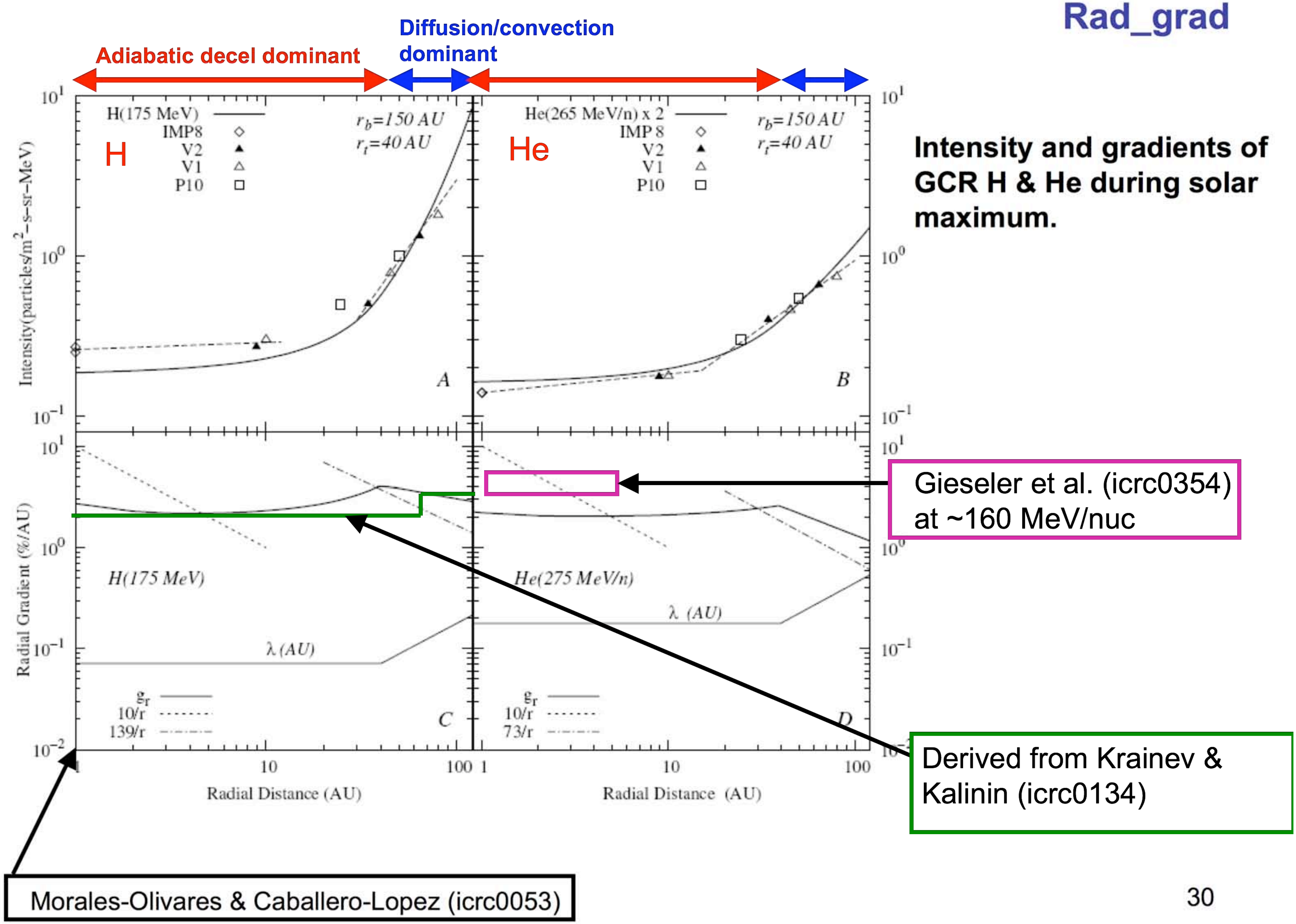
Gieseler et al. (icrc0354) at ~160 MeV/nuc

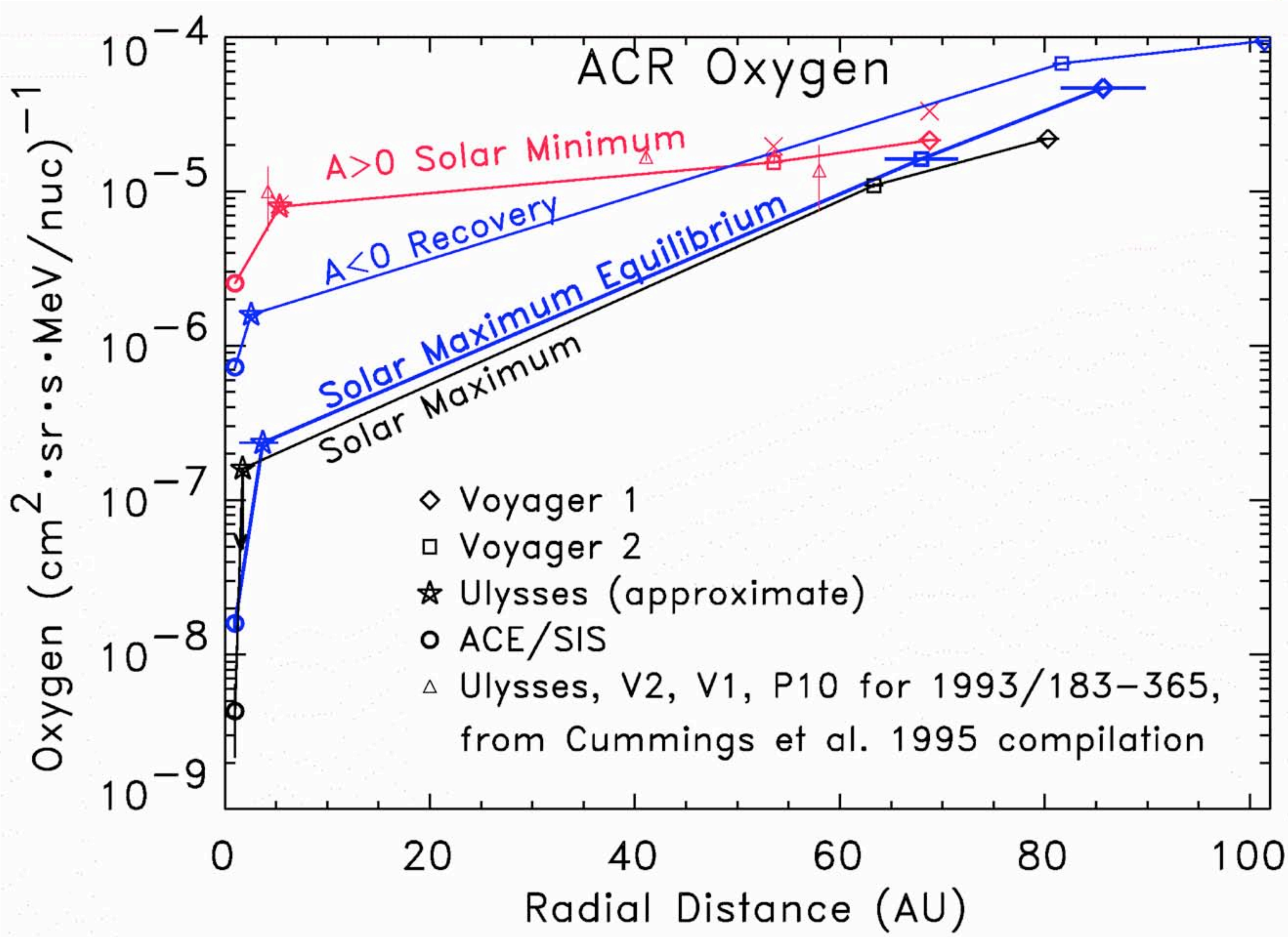
Derived from Krainev & Kalinin (icrc0134)

Morales-Olivares & Caballero-Lopez (icrc0053)

Rad_grad

Intensity and gradients of GCR H & He during solar maximum.





Leske et al., icrc0734

Only one gradient paper on anomalous cosmic rays.
Gradients sensitive to polarity of magnetic field and tilt of HCS due to drift effects.

Period_long

How old is Ken McCracken?

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"McCracken [8] has used the ^{10}Be data for the past 500 years to infer that the 11 year average strength…" (McCracken & Beer, icrc1248).

How old is Ken McCracken?

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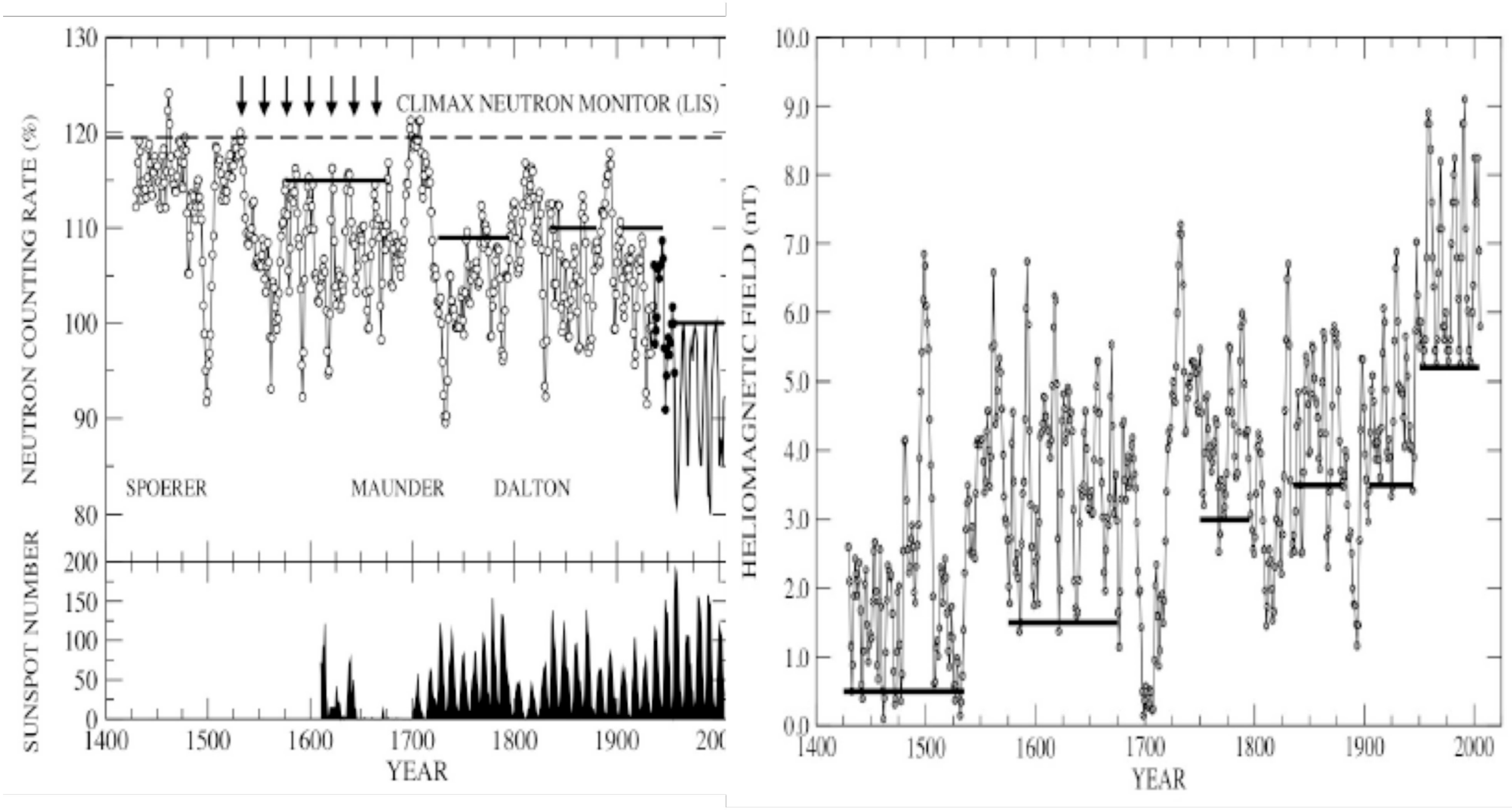
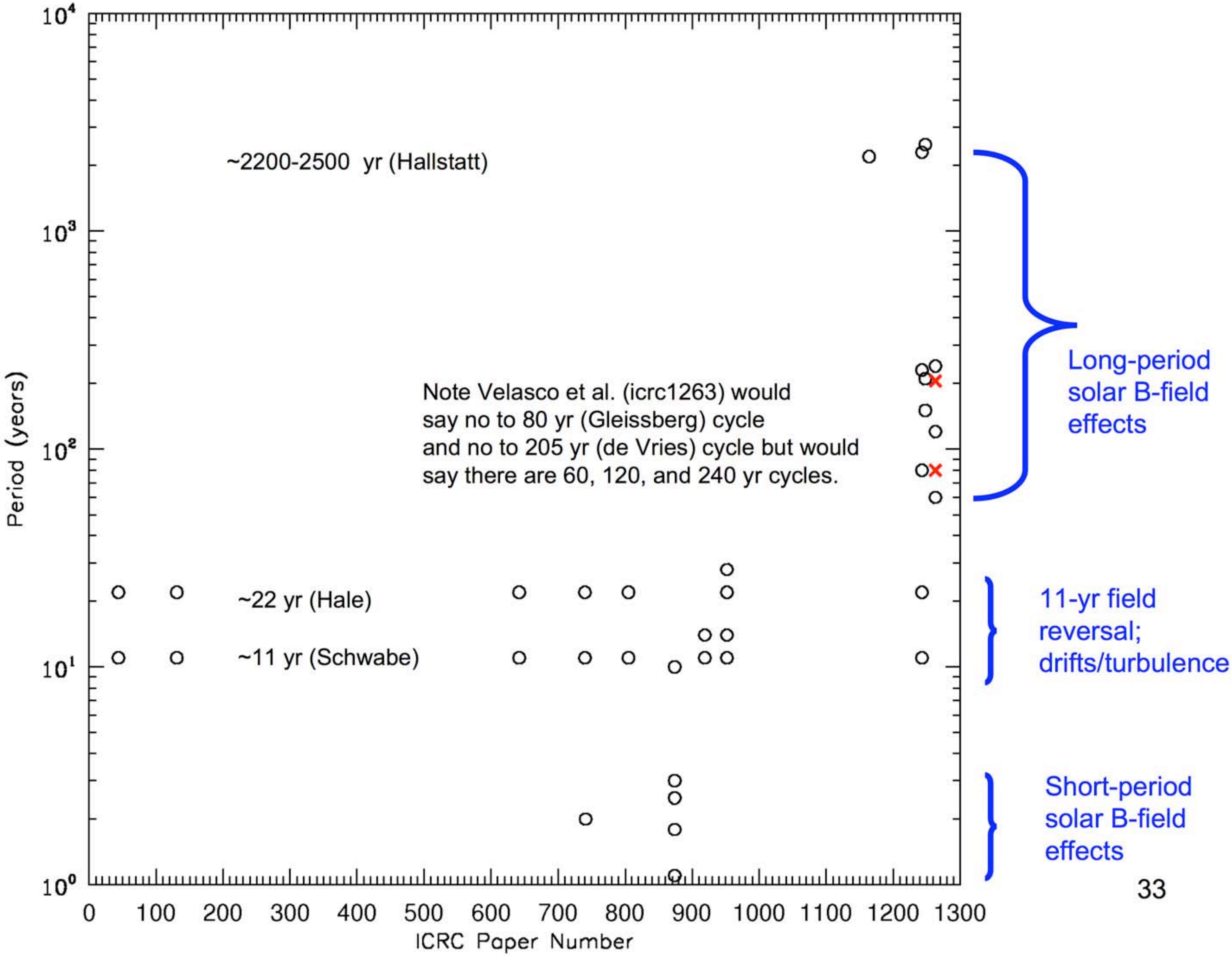
- **Galactic cosmic ray intensity at Earth varies on many time scales, from parts of a day to thousands of years.**



Estimated NM intensities and HMF strength over last 600 years. (McCracken, icrc1243)

Period_long (continued)

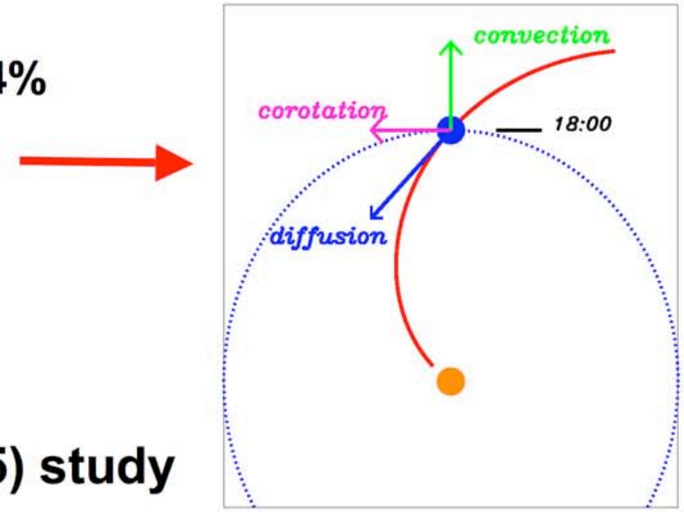


Period_long (continued)

- **Correlations and physical reasons:**
  - NM vs sunspots, IMF – diffusion/drifts
  - Methane sulphonic acid vs time -- Cosmic rays might influence climate but I didn't see a conclusion (Osorio et al., icrc0740)
  - Various indices vs time, 2 yr period – double solar dynamo (de Caso et al., icrc0741)
  - Neutron monitor vs time – short periods (2 – 3 years) related to oscillations of photospheric field modes of oscillation, e.g., in toroidal or poloidal components (Laurenza et al., icrc0874)
  - ^{14}C and ^{10}Be vs time – longer periods and trends related to B field on sun (McCracken, icrc1243 and McCracken and Beer, icrc1248)
  - Diurnal anisotropy phase has mainly a 22-yr periodicity at high latitude NMs and mainly 11-yr periodicity at low latitude NMs, likely due to drift effect being larger at low energy (Yi & Oh, icrc0805). Dorman (icrc1147) also finds drift effects on amplitude of variation larger at low energies.
  - Gnevyshev gap (period of low solar activity in middle of solar maximum) has been questioned but its existence is re-confirmed (Storini et al., icrc0998)

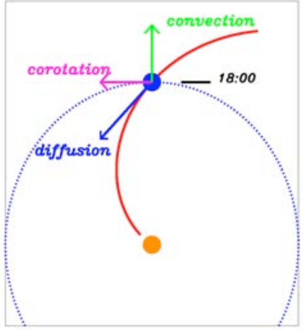
Period_short

- **GCR anisotropies at neutron monitor energies (multi-GeV):**
  - Solar diurnal (co-rotation of 400 km/s IP field -> 0.4% amplitude at 1800 hr)
  - Semi-diurnal
  - Tri-diurnal
  - Quart-diurnal
  - 27-day variations
- **Richharia and co-workers (icrc0094 and icrc0115) study tri-diurnal and quart-diurnal variations**
  - Obtain characteristics but no explanations offered
- **27-day variations**
  - Of anisotropy during solar minimum (Modzelewska & Alania, icrc0347)
    - Due to solar wind speed variations with heliolongitude
    - Amplitudes and phases more clearly established in A>0 rather than A<0
    - Amplitudes do not depend significantly on tilt angle of HCS

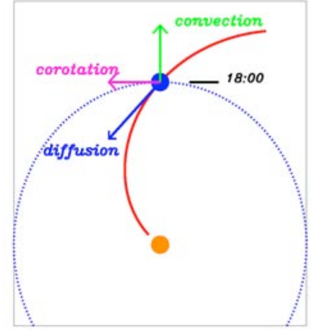


Period_short

- **GCR anisotropies at air shower energies (multi-TeV):**
  - **Solar diurnal (Compton-Getting effect of 30 km/s orbital motion of Earth -> 0.04% amplitude at 0600 hr)**
  - **Sidereal-diurnal**
  - **Sidereal semi-diurnal**



Period_short



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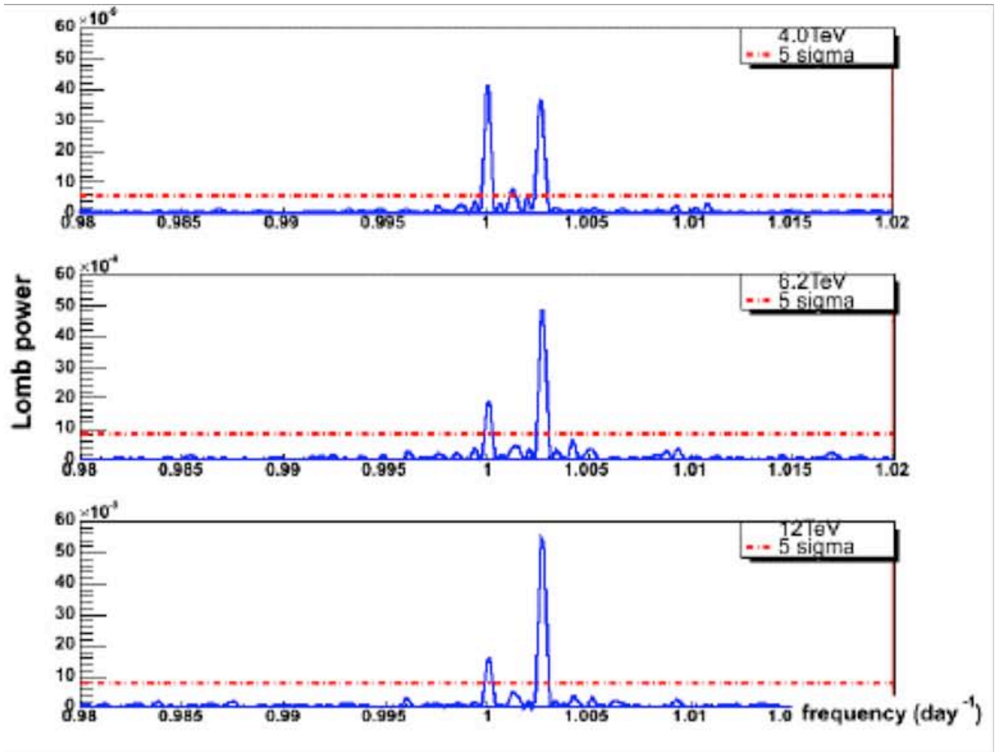

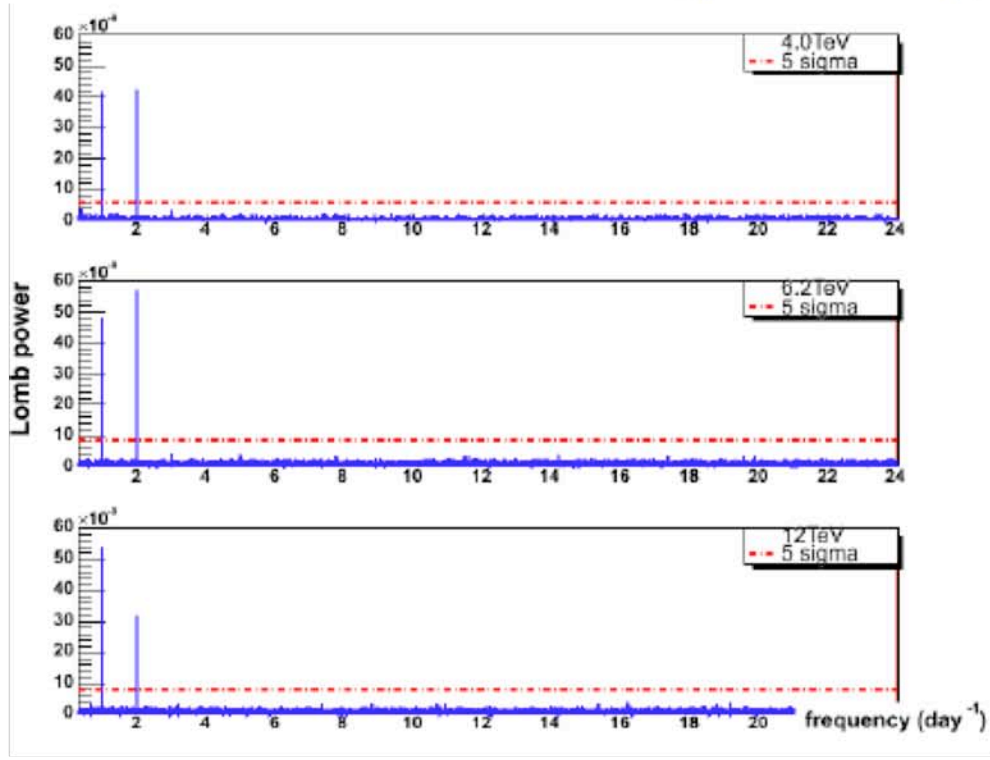

Li et al. (icrc0445) find these three and no other periodicities in 37 billion Tibet III air shower array events from Nov 1999 to Nov 2005 in energy range 4-12 TeV in periodicity range from 1 hour to 2 years. Solar diurnal amplitude is strongly energy dependent while sidereal is not.

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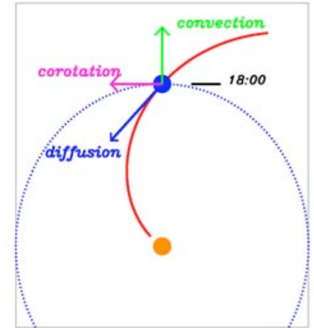

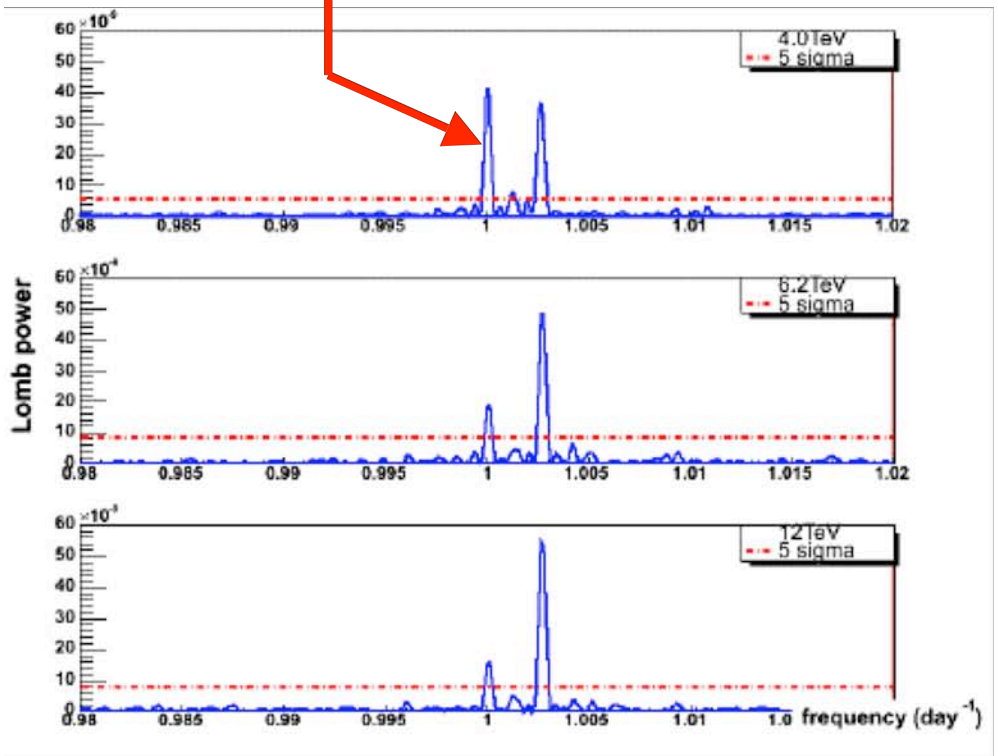

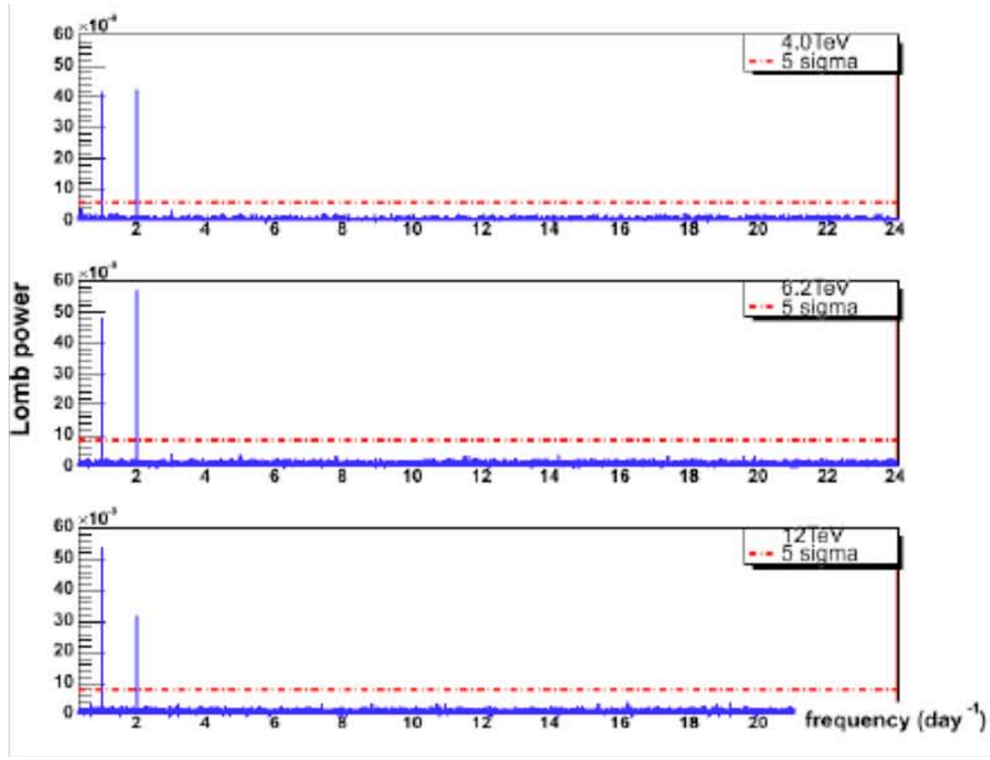

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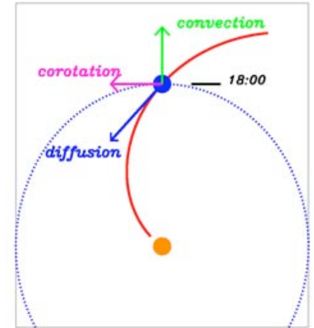

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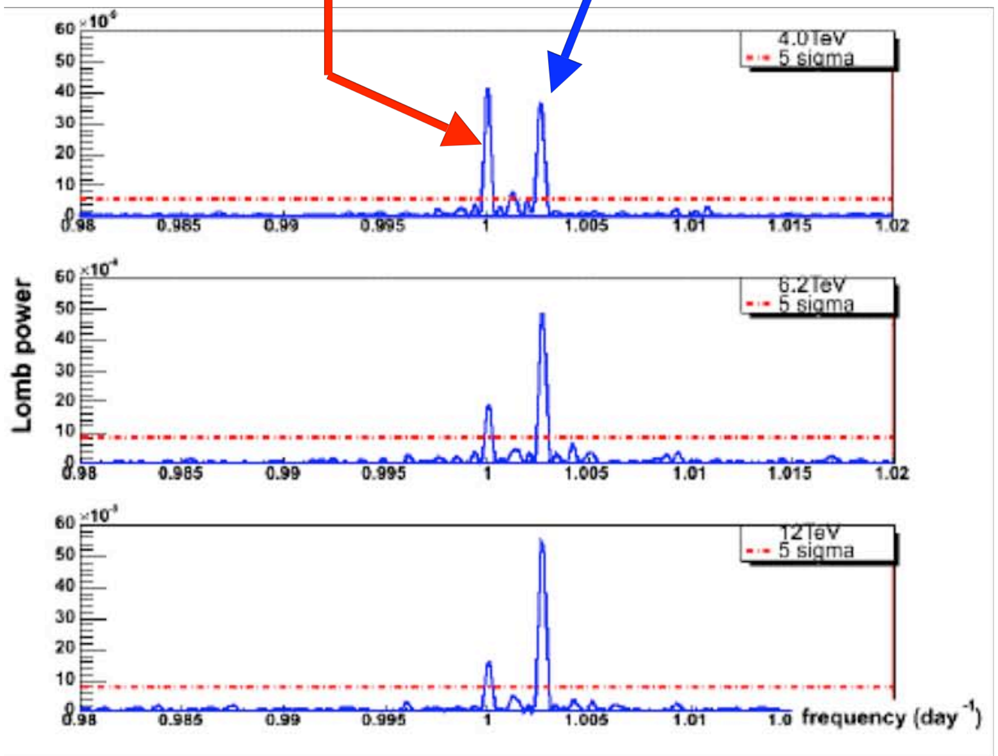

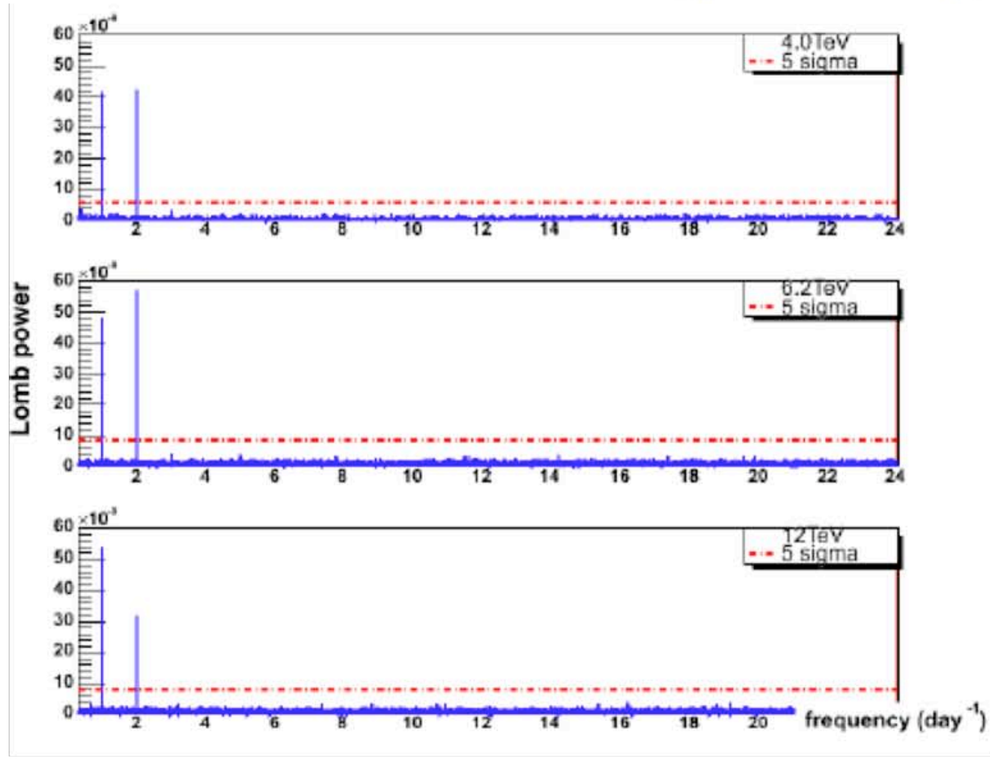

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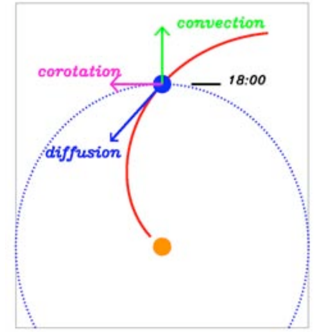

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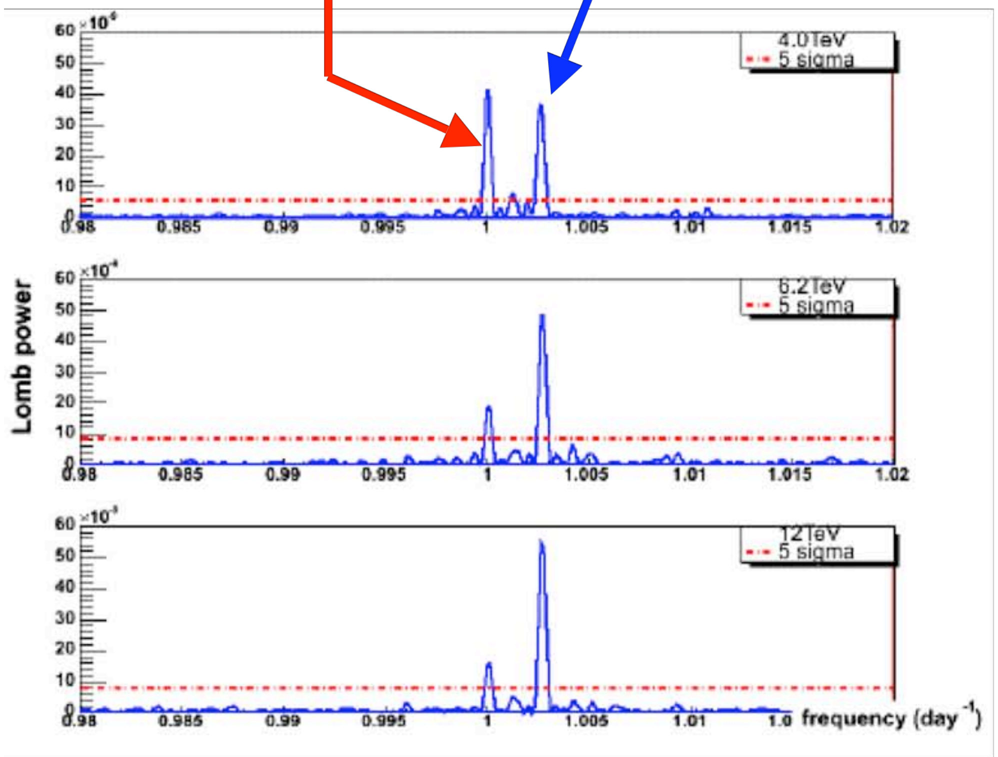

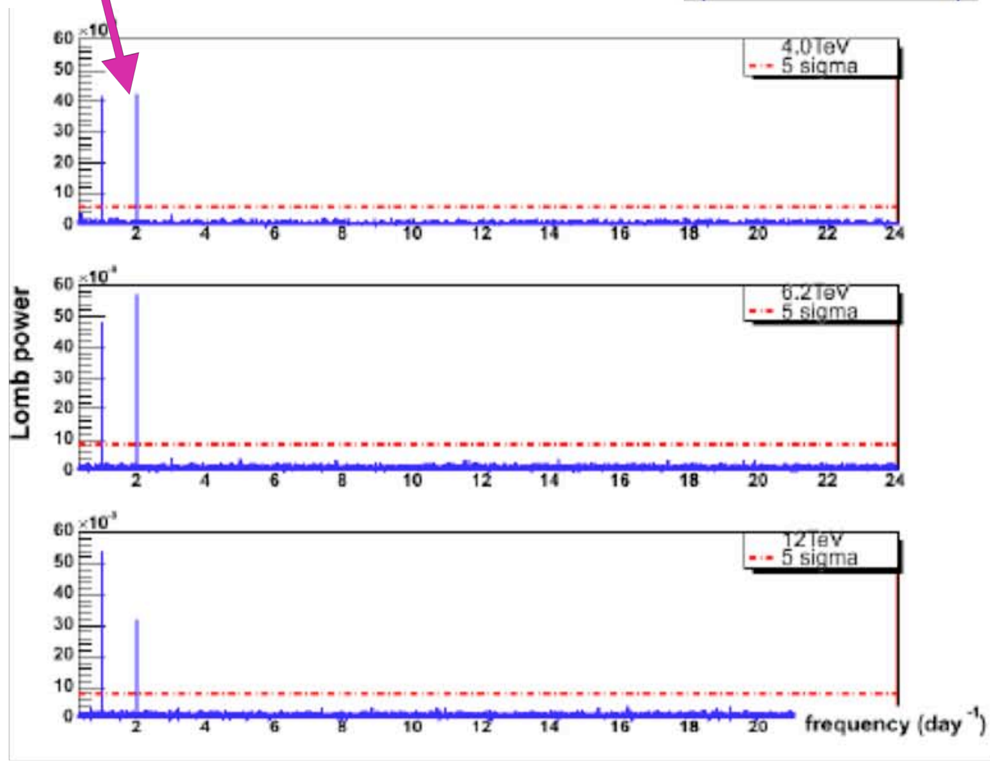

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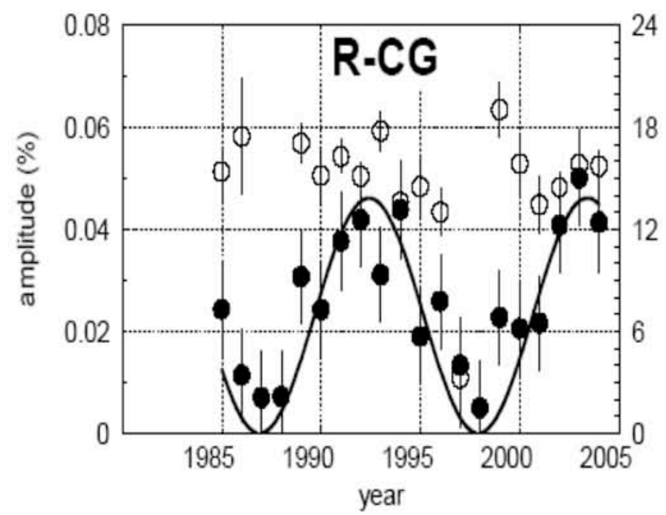
- **One wrinkle in GCR anisotropies at high energies:**
  - **Tibet AS array group (Amenomori et al., icrc0101) finds that at 4 TeV there is a residual anisotropy after correcting for the Compton-Getting anisotropy**
  - **Kota et al. (icrc0229) report similar finding from Matsushiro underground muon telescope at ~600 GV during periods of solar maximum**
    - **Amplitude of residual modulation is almost as big as GC anisotropy (~0.04%)**
    - **Simulation study indicates it can be explained with model including highly tilted and warped current sheet**

Solar min max min max

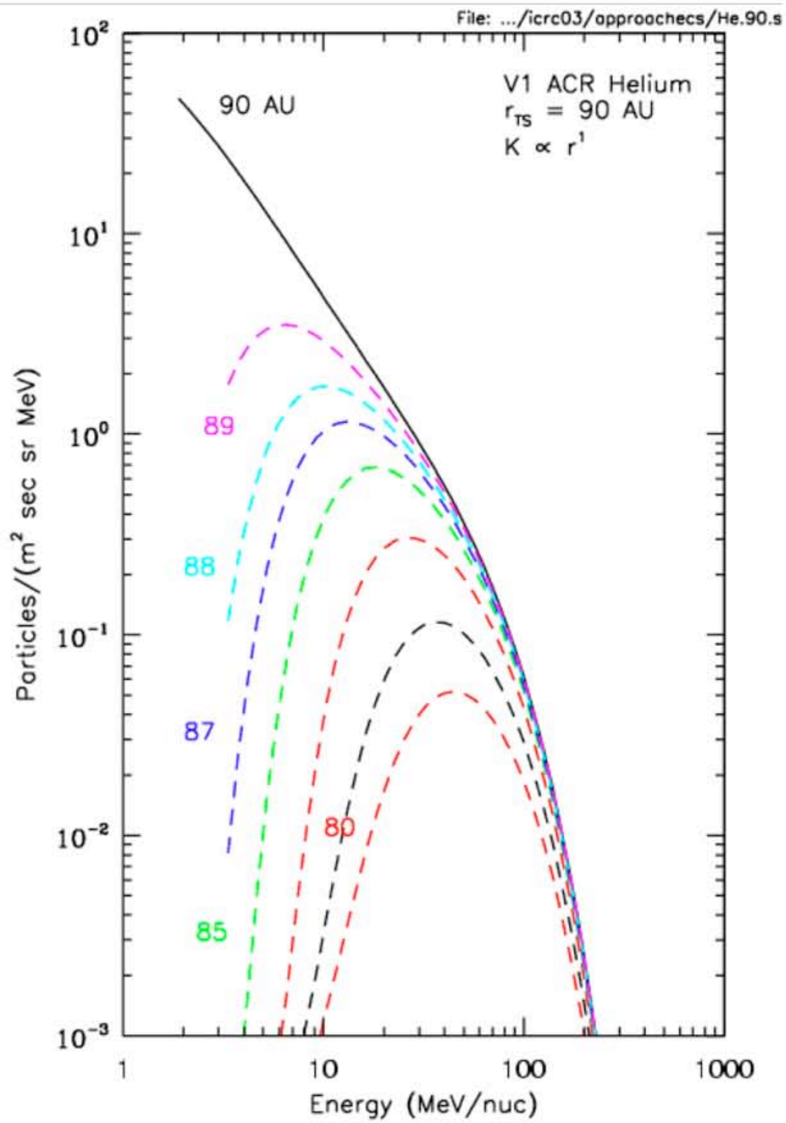


Amplitude (●) & Phase (o) in 1984-2004

SDV present during Sol.Max

Expected evolution of ACR He spectrum as V1 approached termination shock.

Not observed.



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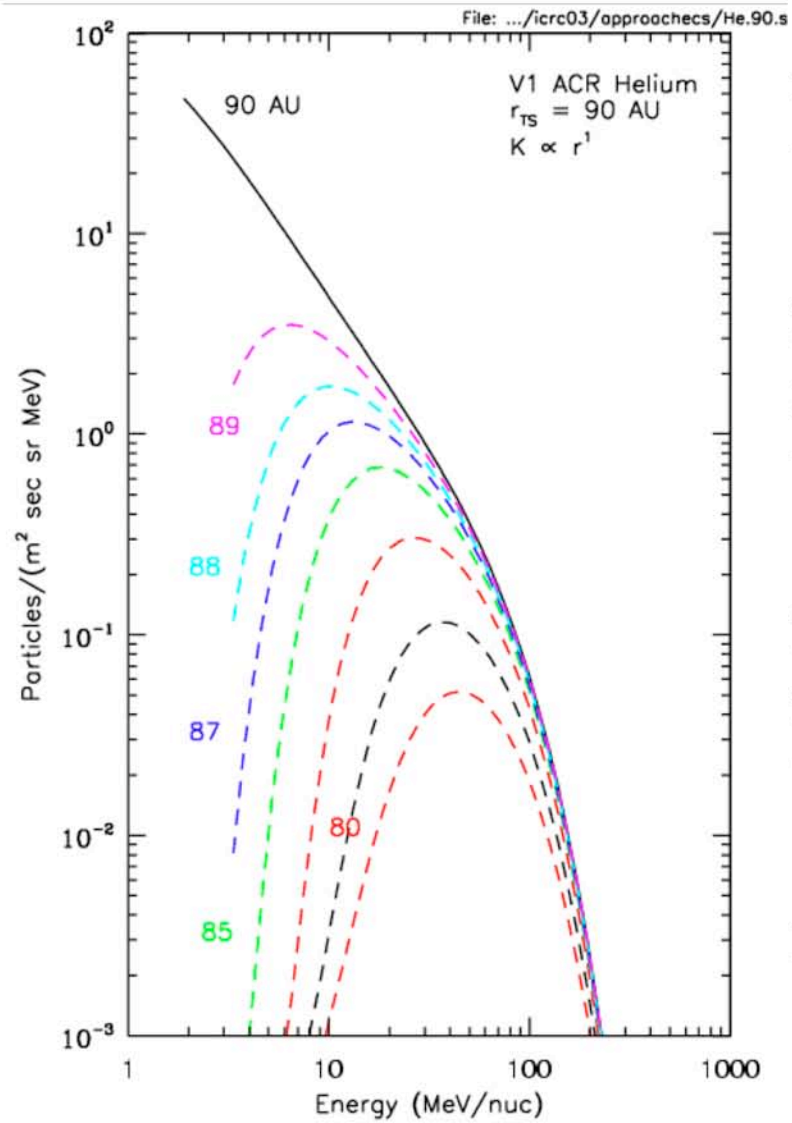
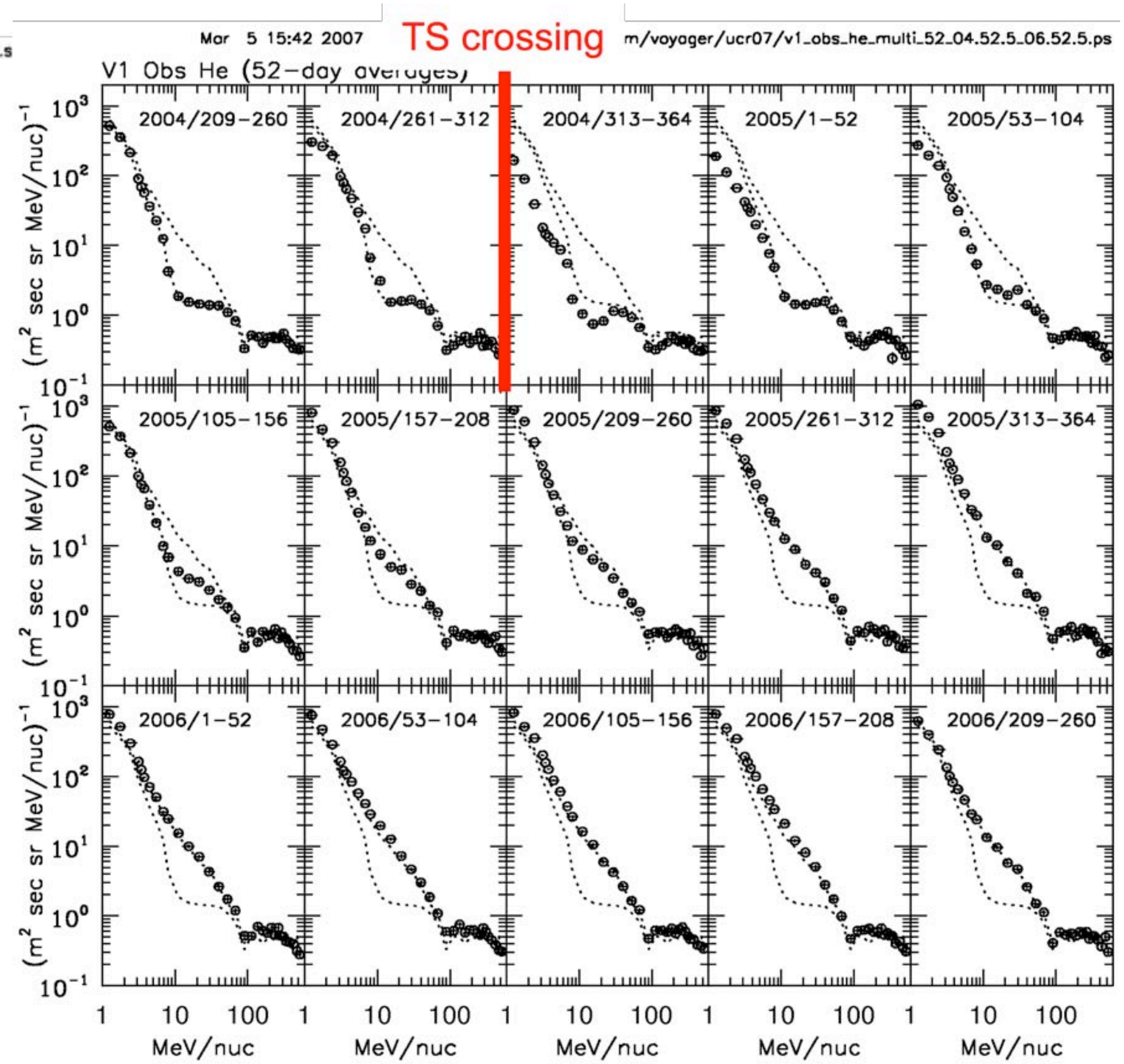
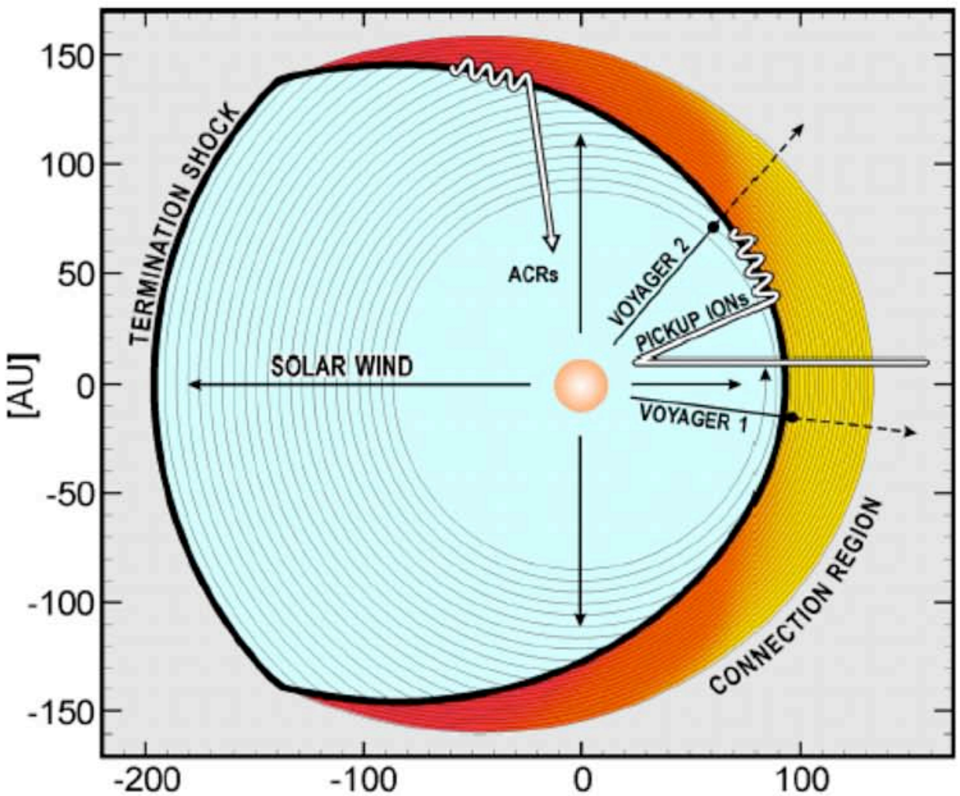
Near_TS



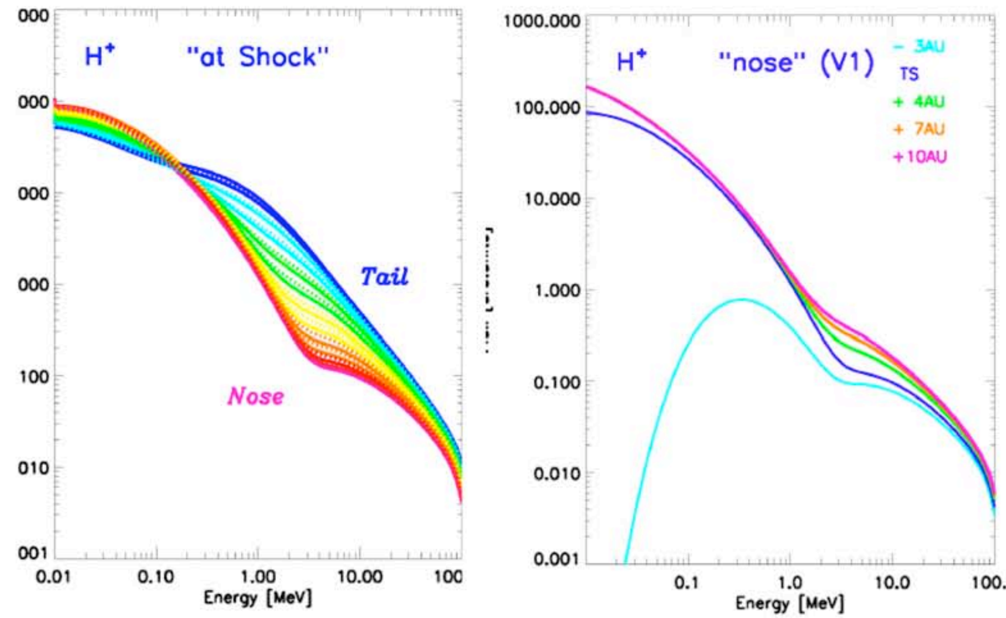


Three main theories, all addressed at this ICRC

1. **ACRs are preferentially accelerated along flanks or tail region of the blunt termination shock.**



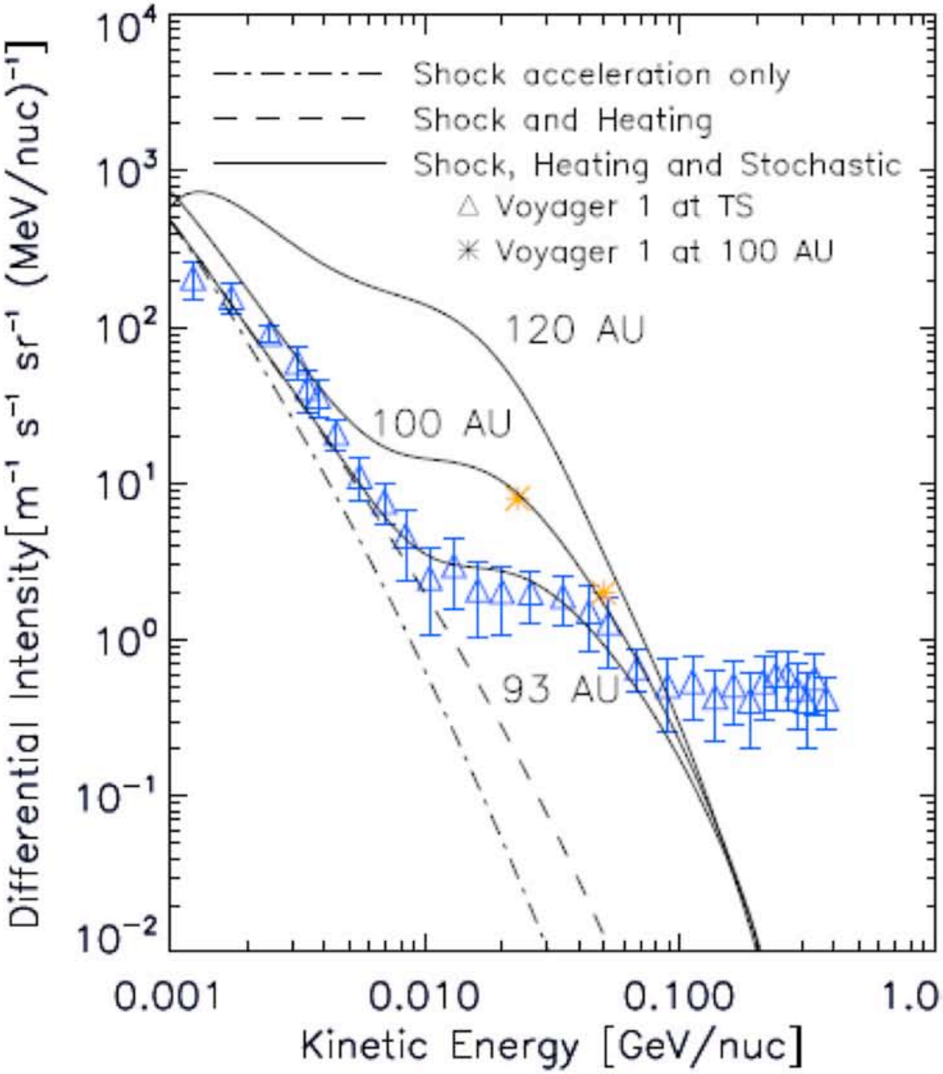
McComas and Schwadron, 2006



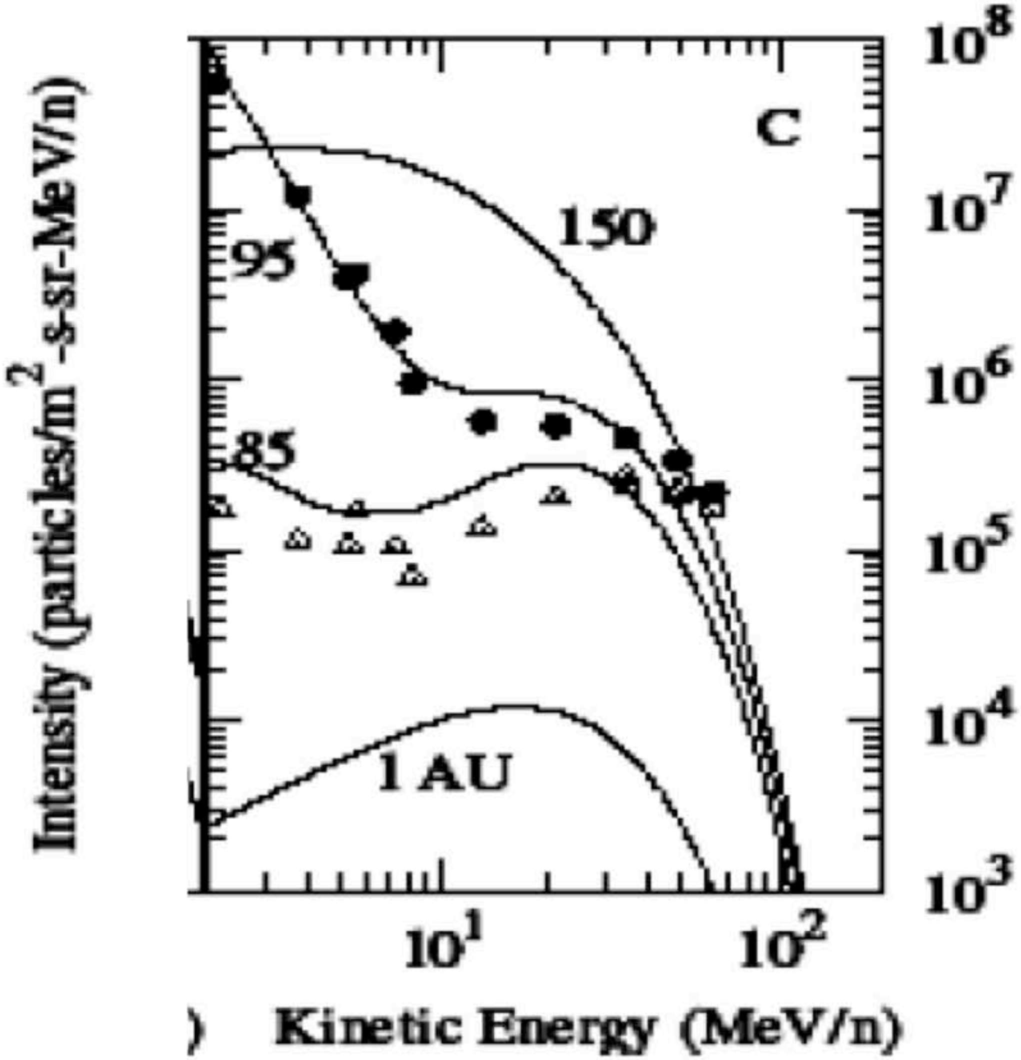
Kota, icrc0231

Three main theories, all addressed at this ICRC (continued)

2. **ACRs continue to get accelerated by stochastic acceleration in the heliosheath.**

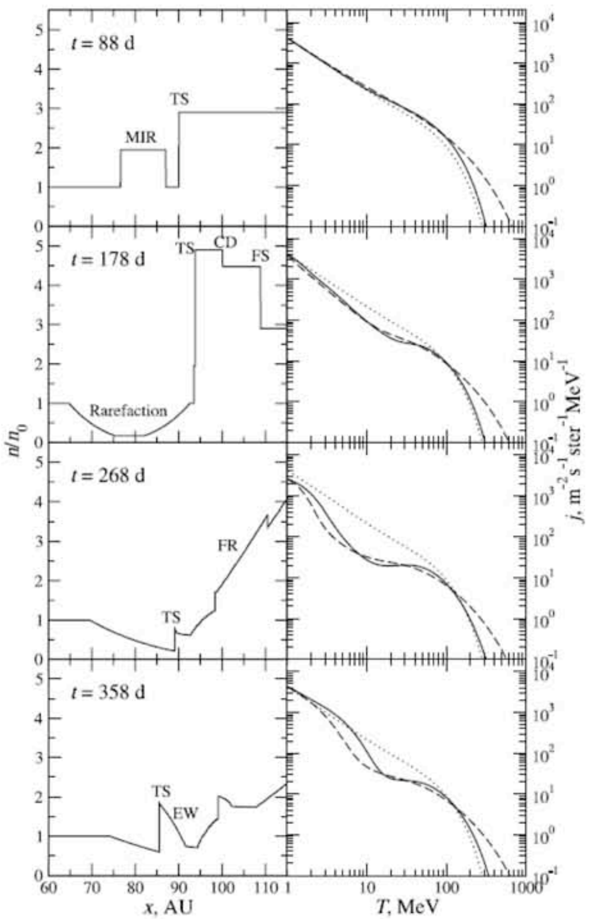


Ferreira et al., icrc0287



Moraal et al., icrc1157

3. **ACR spectrum was disturbed by MIRs interacting with shock.**



Florinski & Zank, 2006

Effect of one MIR on shock. Jokipii found similar effect with shock motion only.

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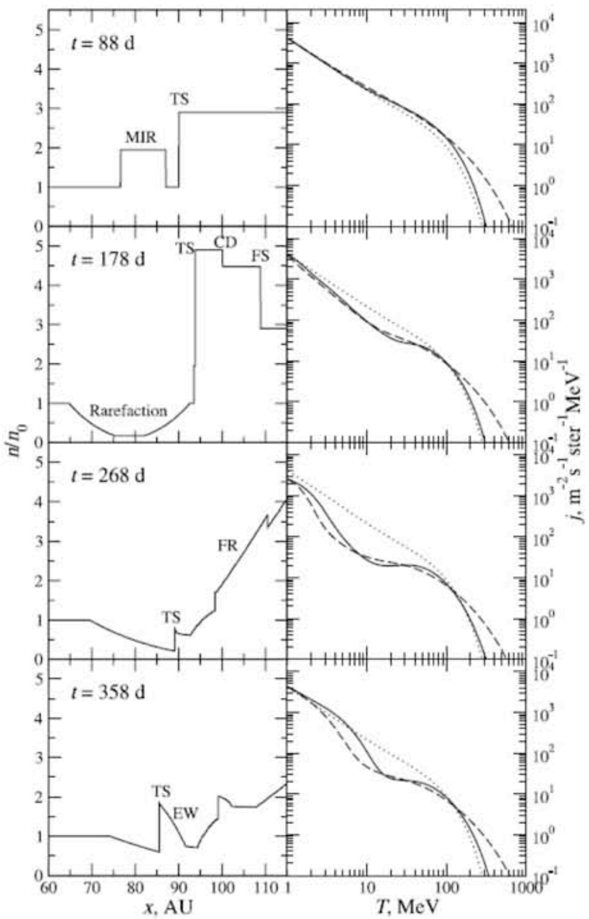

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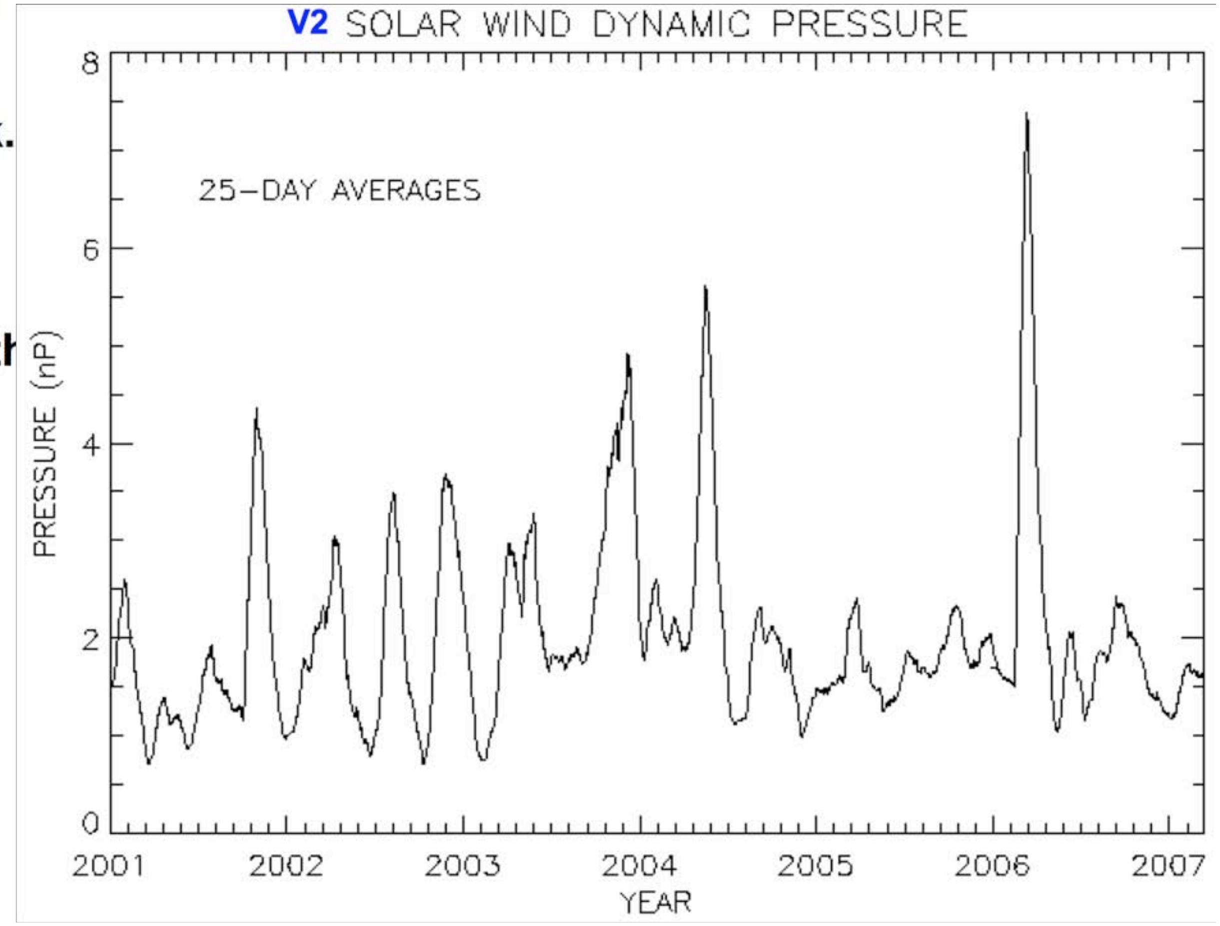
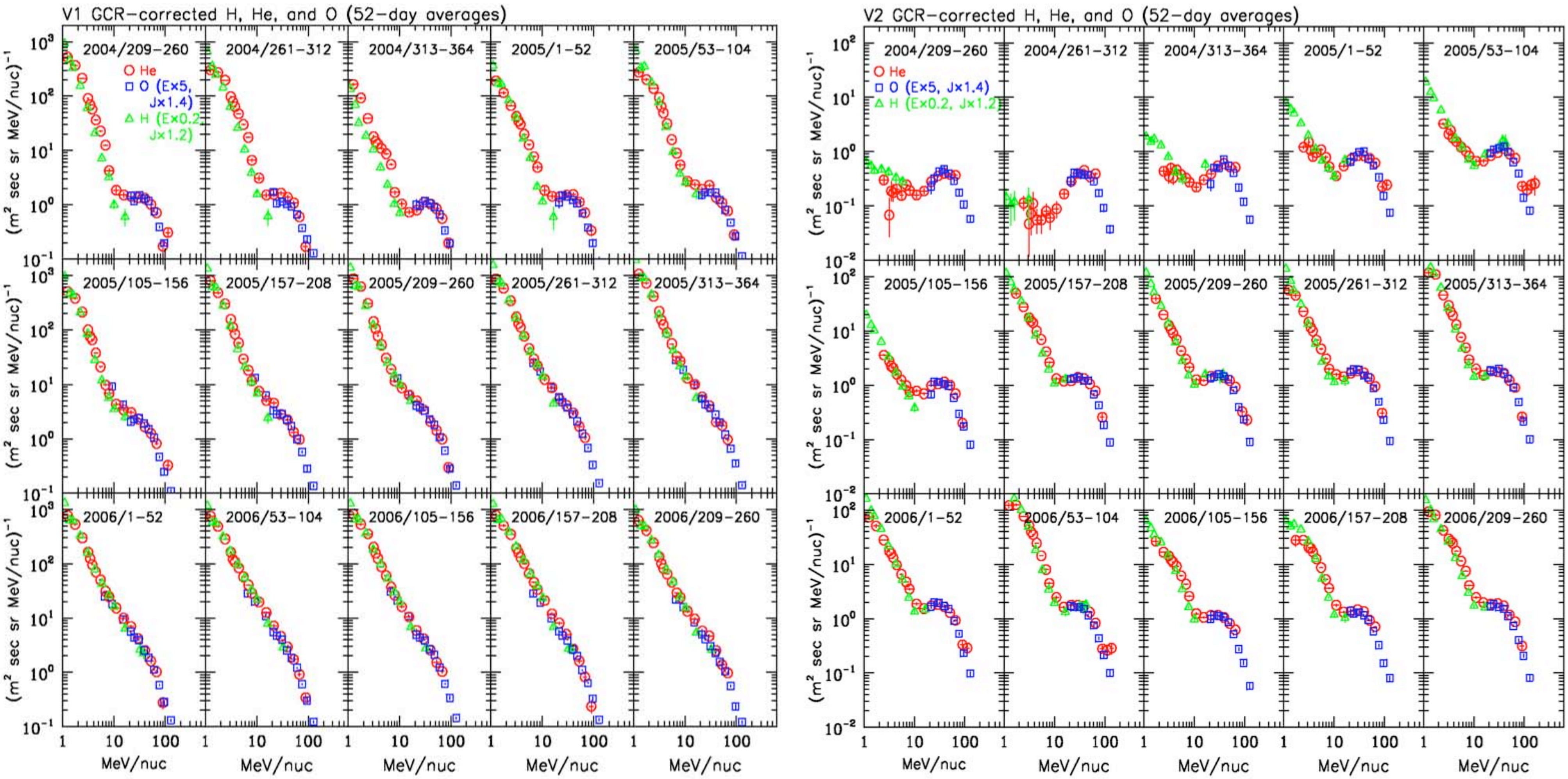


And there were a whole series of MIRs, until recently

http://web.mit.edu/afs/athena/org/s/space/www/voyager/voyager_data/pressure_25day.gif

3. **ACR spectrum was disturbed by MIRs interacting with shock (continued).**

Both V1 and V2 spectra have unrolled since V1 crossed TS -> likely temporal, not spatial effect



Cummings & Stone, icrc1118 **Scaled H and O spectra to He imply Q = +1 and** $\kappa \propto \beta R^{1.4}$

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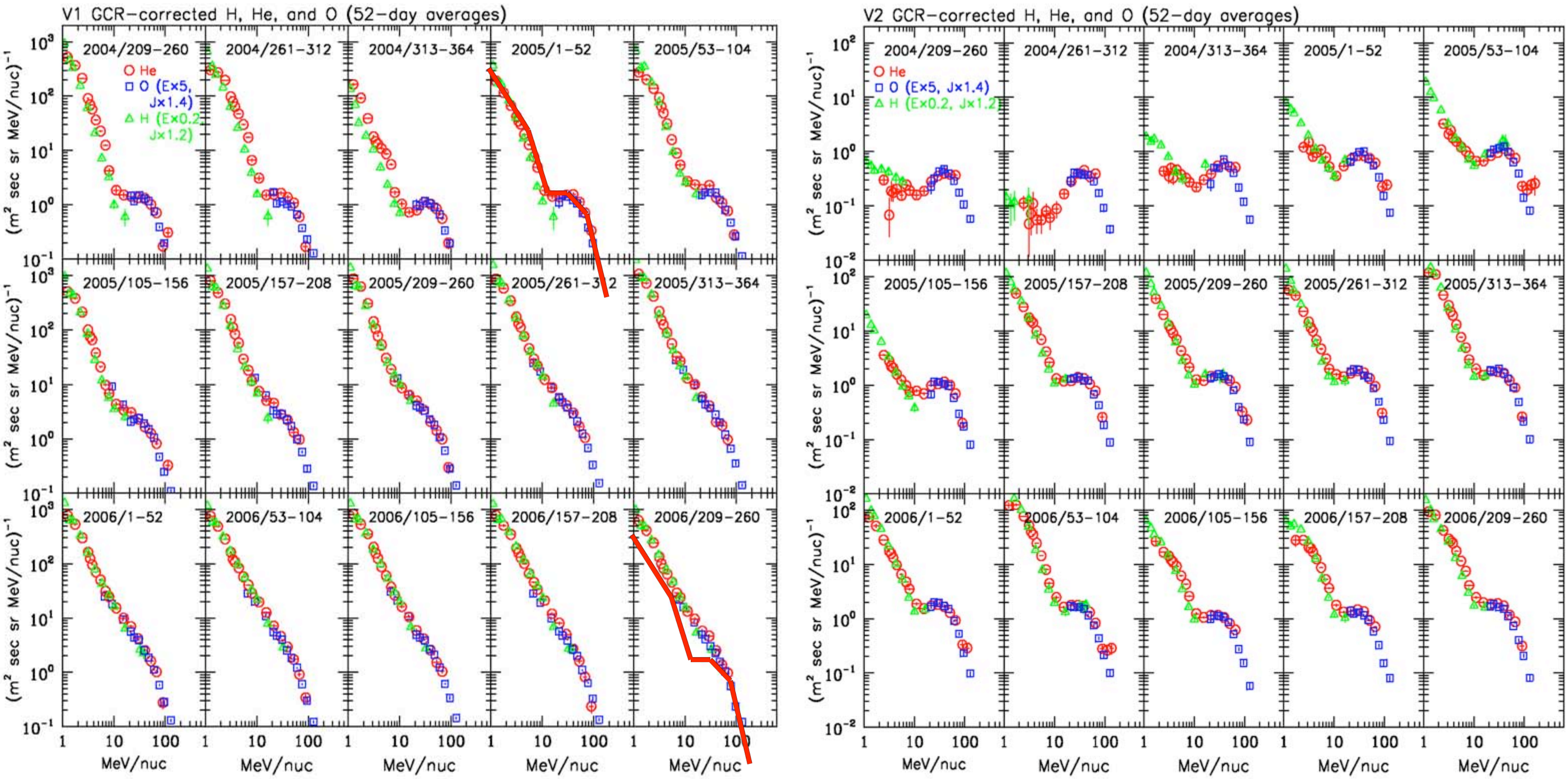

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Three main theories, all addressed at this ICRC (continued) Near_TS

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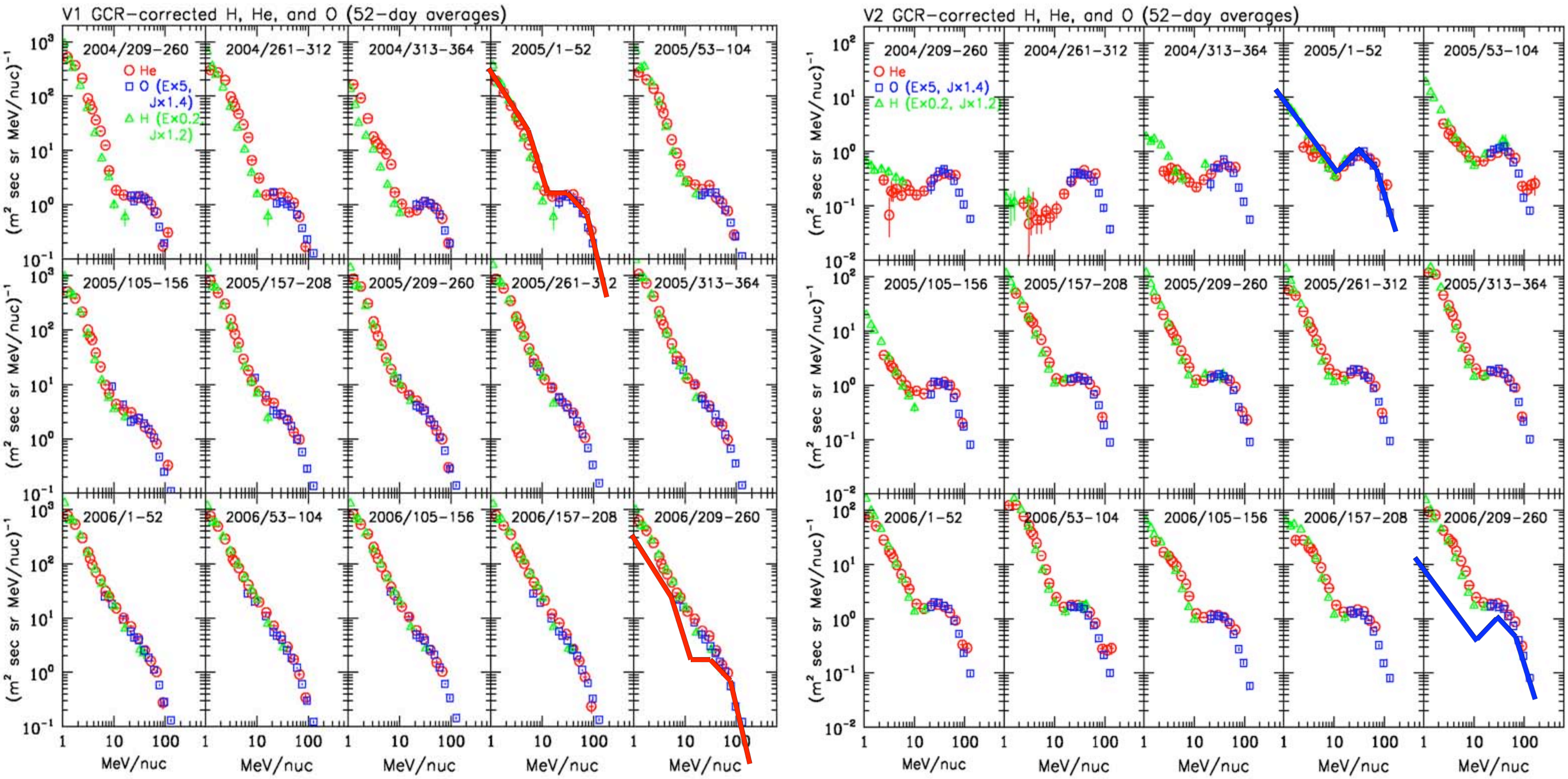
Both V1 and V2 spectra have unrolled since V1 crossed TS -> likely temporal, not spatial effect



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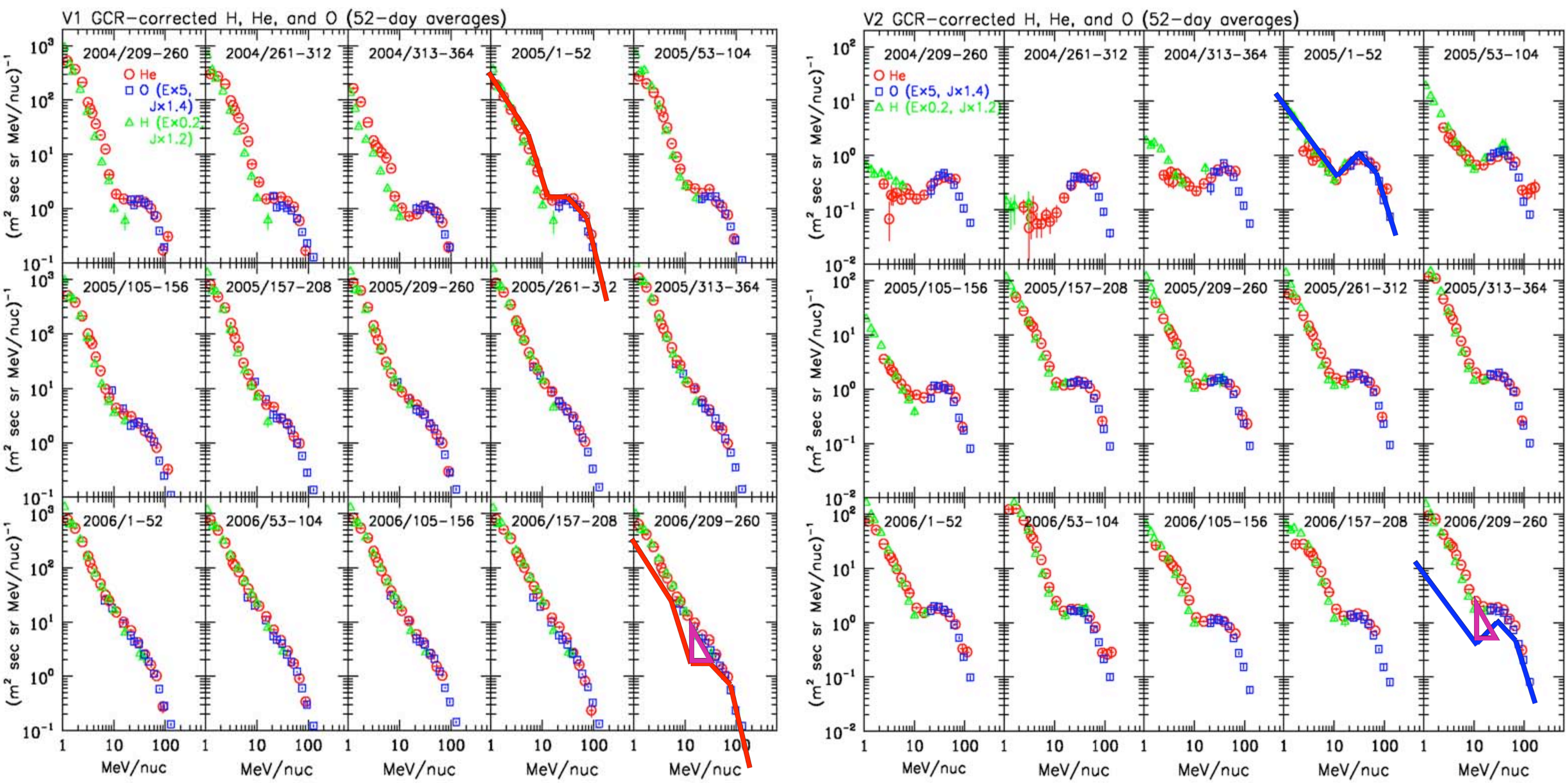

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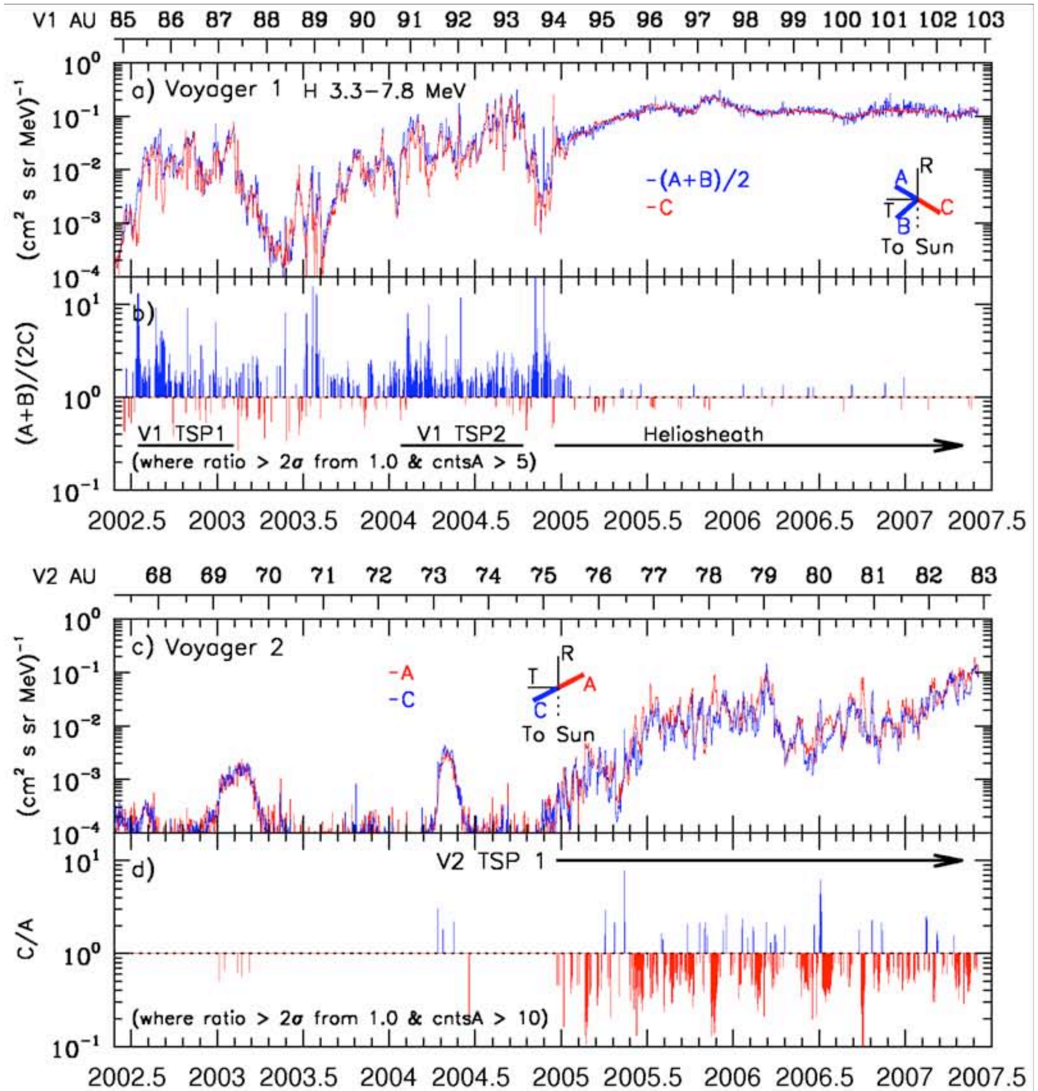

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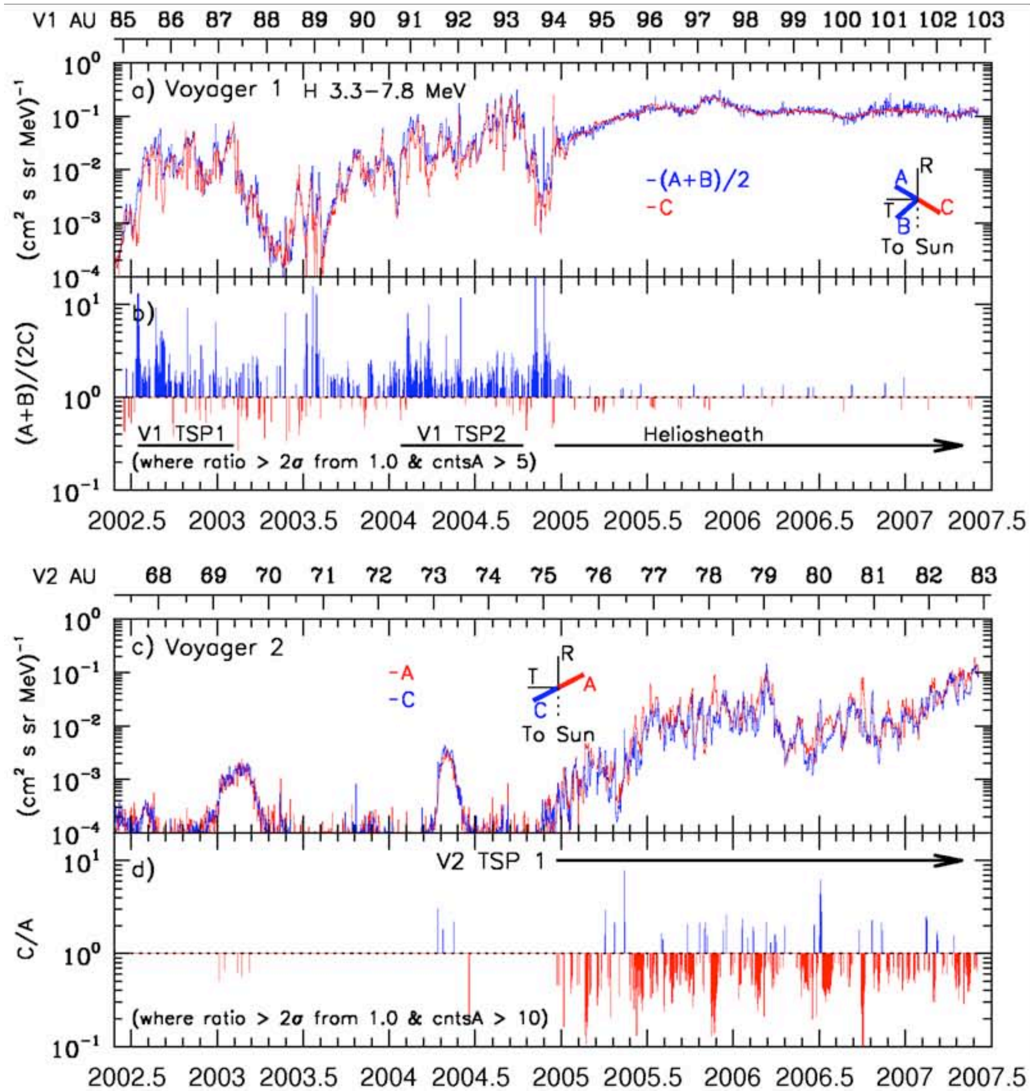

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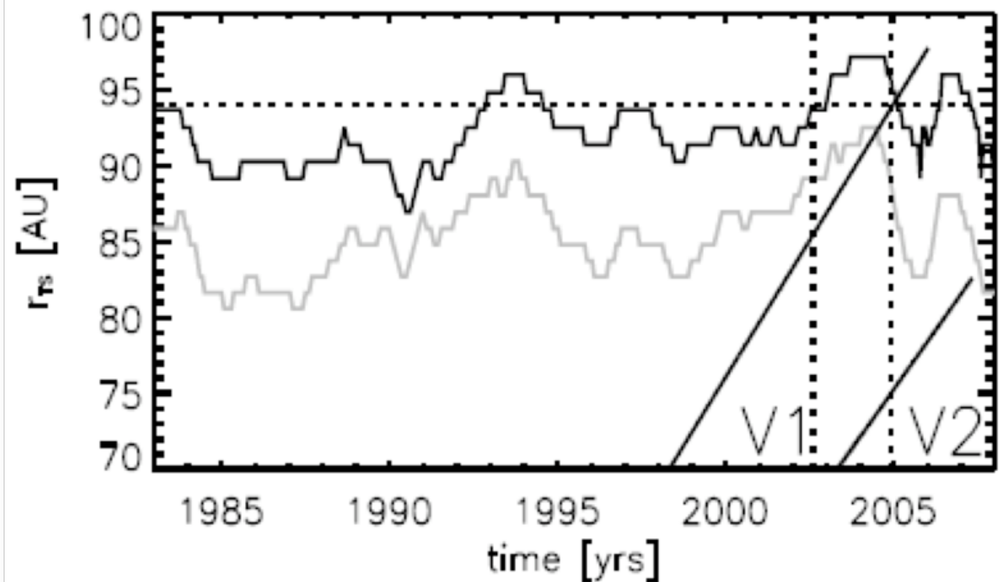

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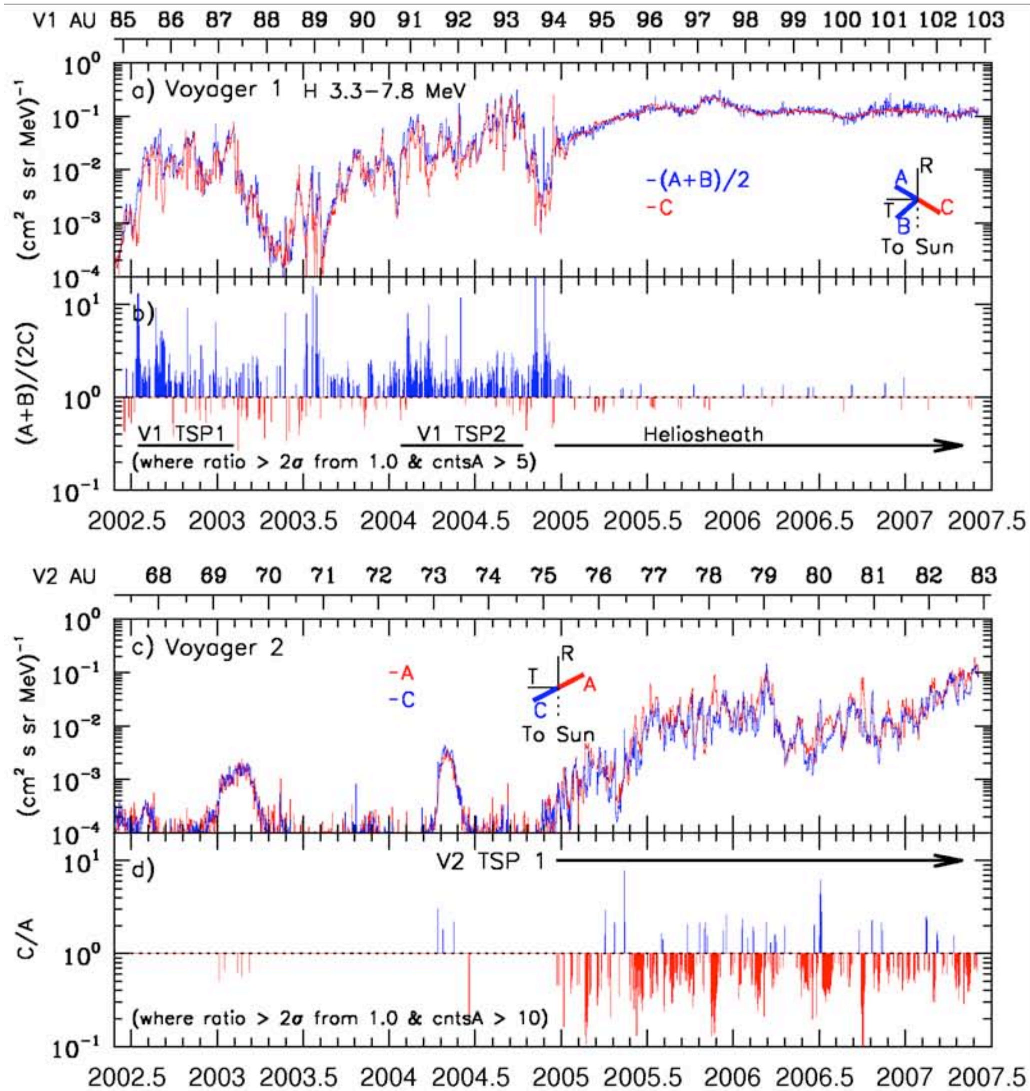

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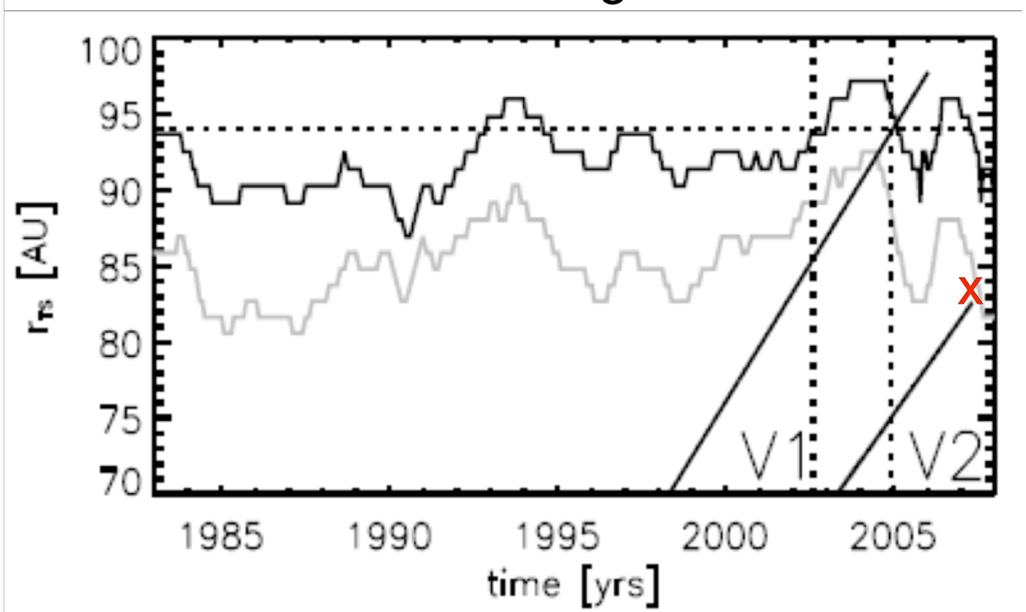

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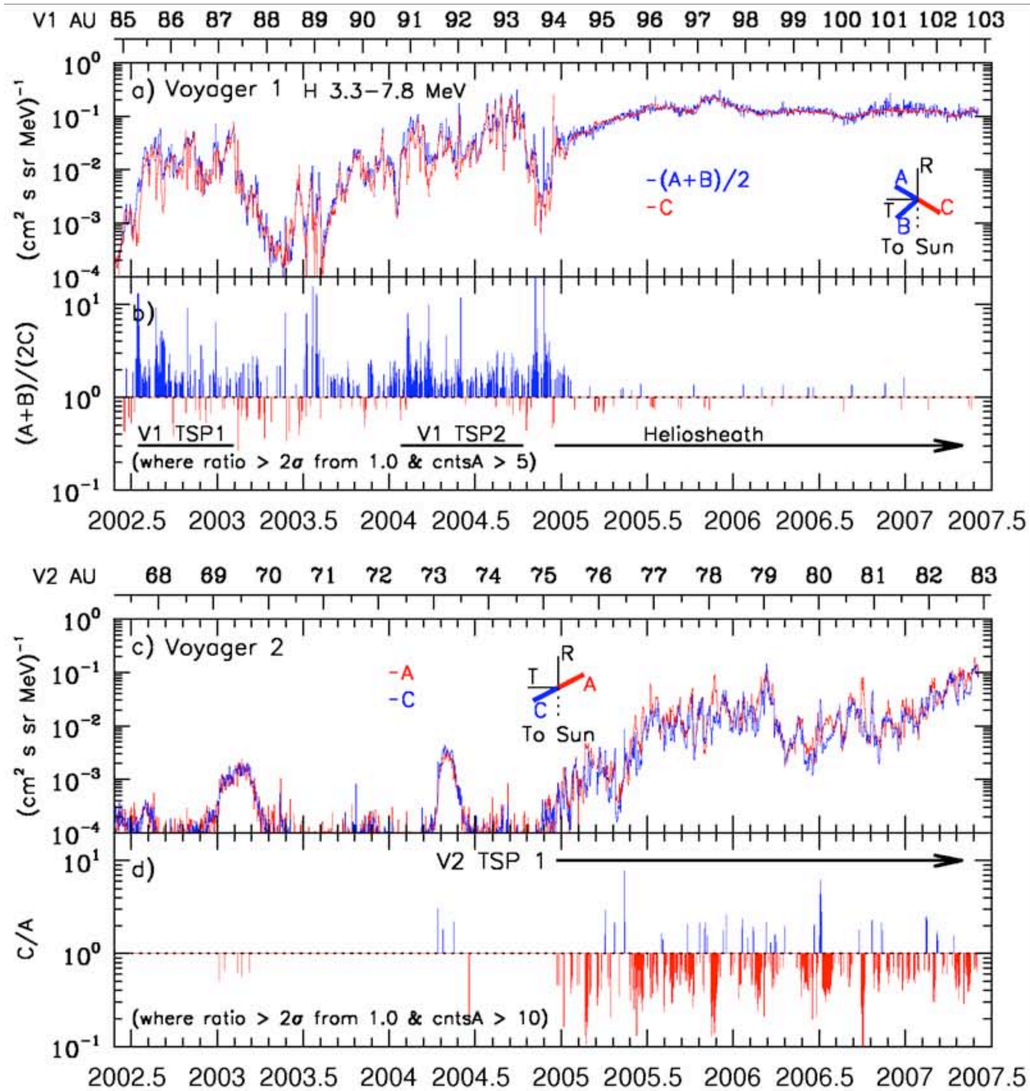

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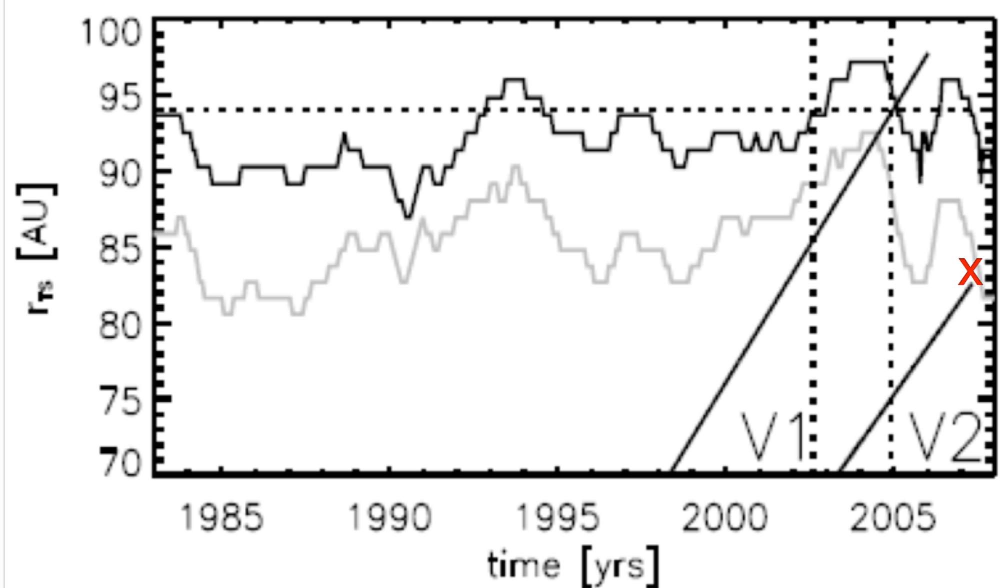

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V2 He spectrum when V2 crosses shock compared to V1 spectrum may discriminate between the 3 main theories.

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- Near_TS: Will Voyager 2 solve the mystery of the acceleration site of ACRs when it crosses the termination shock? And will it solve other puzzles as well?

Sobering Thought

- The Mayan calendar ends 21 December 2012 and the world is predicted come to an end.
- Hilchenbach et al. (icrc0090) and Czechowski et al. (icrc0092) think the heliosheath is about 31 AU thick in the apex direction based on SOHO energetic neutrals observations.
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- So, can you believe the bad luck? Voyager 1 gets within 2 AU of the heliopause and the world blows up!

The End