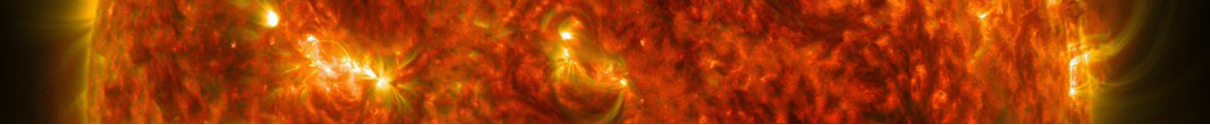


Recent observations and modelling of low-energy cosmic rays near Earth

Du Toit Strauss[1] (dutoit.strauss@nwu.ac.za), and many others . . .

[1]Center for Space Research, North-West University, South Africa

ECRS 2022; July 2022

Introduction

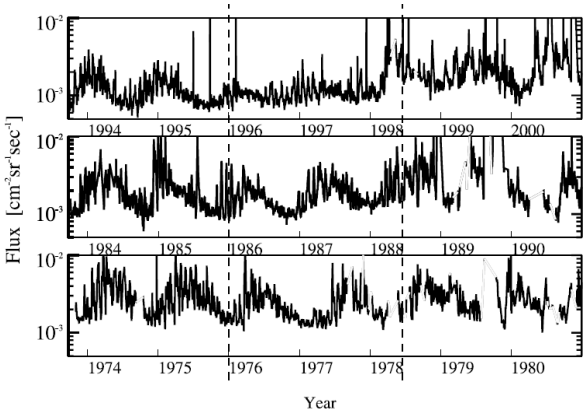
Traditionally cosmic rays are classified into four species:

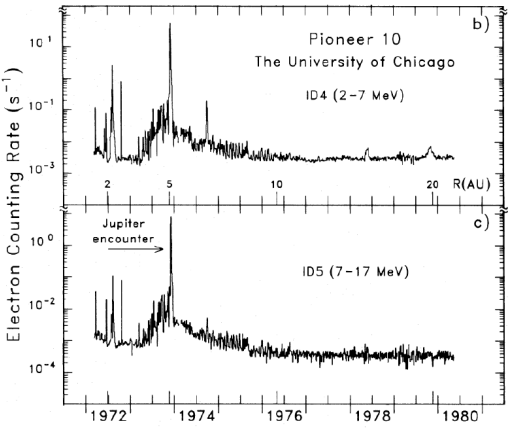
- Galactic cosmic rays
- Solar energetic particles
- Jovian electrons
- Anomalous cosmic rays

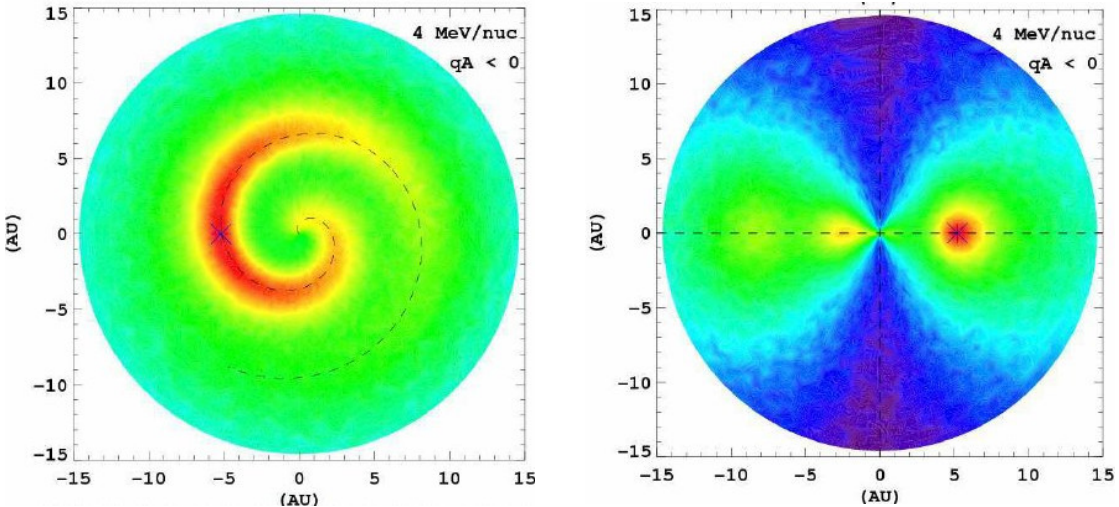
Traditionally cosmic rays are classified into four species:

- Galactic cosmic rays: See talks by Rankin & Tomassetti
- Solar energetic particles: See talks by Mishev, Waterfall, & Wimmer-Schweingruber
- Jovian electrons – discussed in this presentation
- Anomalous cosmic rays – discussed in this presentation

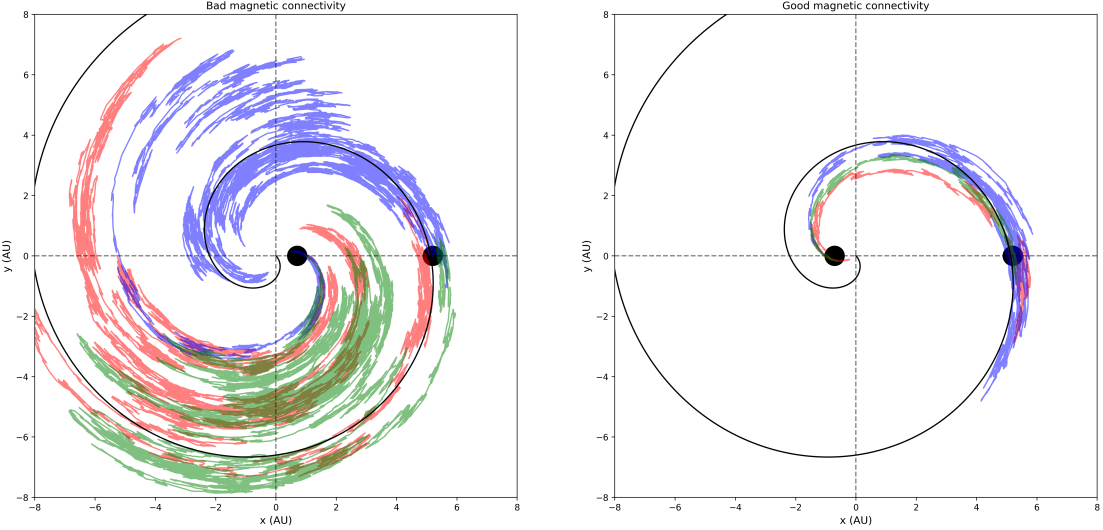
Jovian electrons


Flux [cm^{-2}sr^{-1}sec^{-1}]
10^{-2}
10^{-3}
1994
1995
1996
1997
1998
1999
2000
1984
1985
1986
1987
1988
1989
1990
1974
1975
1976
1977
1978
1979
1980
Year

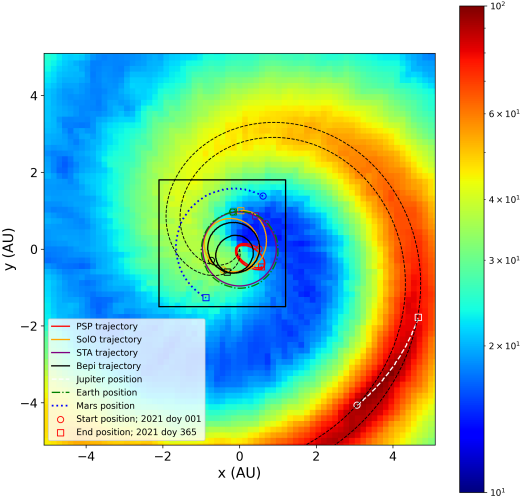

Pioneer 10
The University of Chicago
b)
ID4 (2-7 MeV)
2
5
10
20
R(AU)
c)
Jupiter
encounter
ID5 (7-17 MeV)
Electron Counting Rate (s^{-1})
10^{1}
10^{-1}
10^{-3}
10^{0}
10^{-2}
10^{-4}
1972
1974
1976
1978
1980

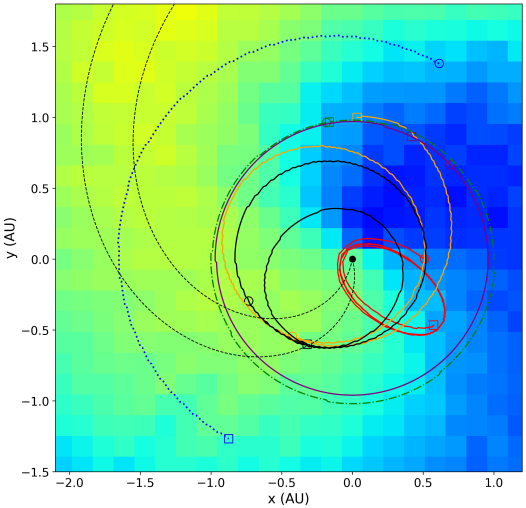


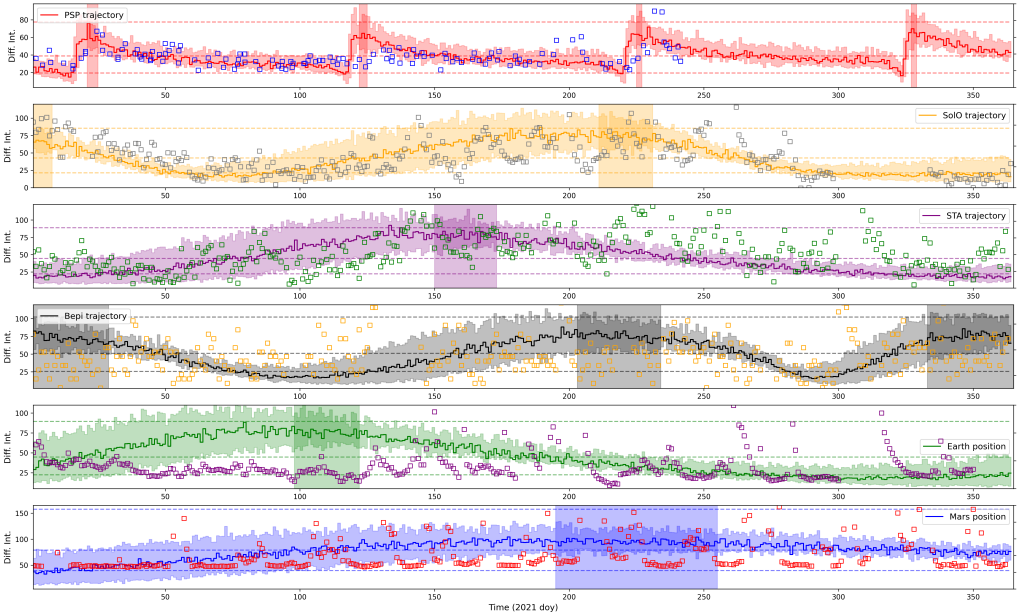
From Strauss et al. (2011)



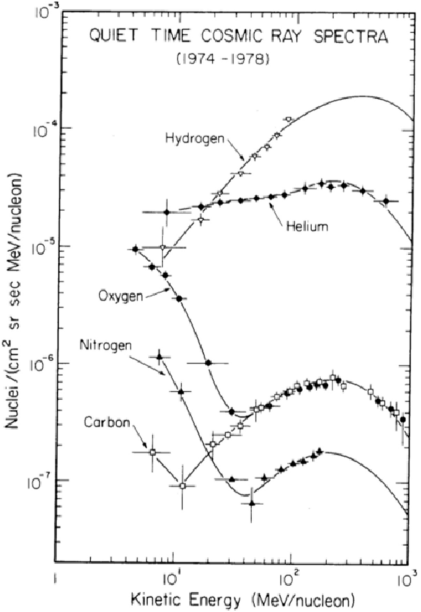
Adapted from Strauss et al. (2011)

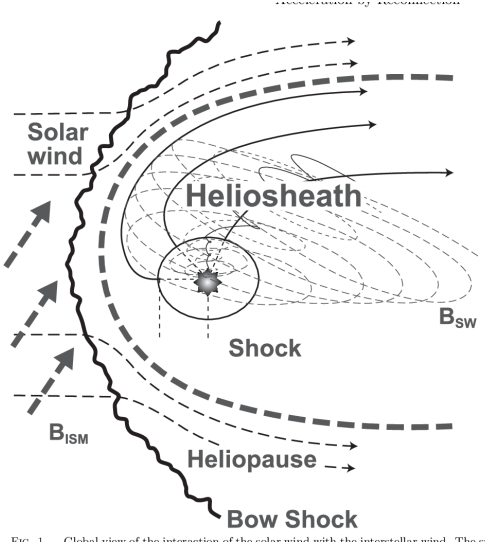

PSP trajectory
SolO trajectory
STA trajectory
Bepi trajectory
Jupiter position
Earth position
Mars position
Start position; 2021 doy 001
End position; 2021 doy 365
x (AU)
y (AU)
10^2
6×10^1
4×10^1
3×10^1
2×10^1
10^1

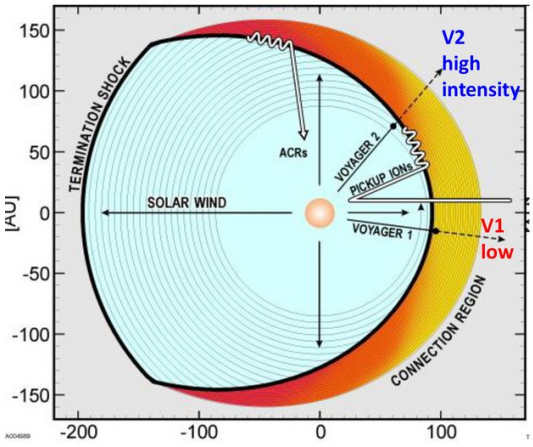

x (AU)
y (AU)

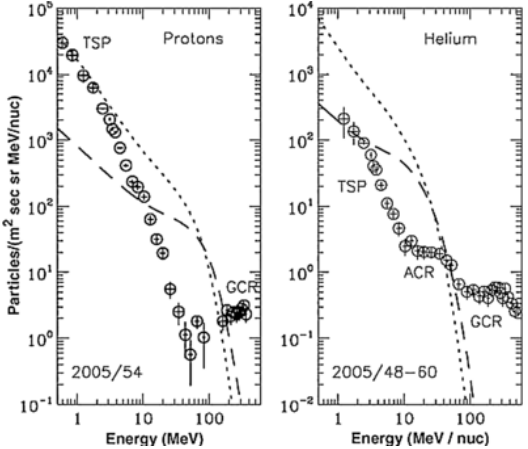

PSP trajectory
Diff. Int.
PSP/HET
SolO trajectory
SolO/HET
STA trajectory
STA/HET
Bepi trajectory
Bepi/BERM
Earth position
SOHO/EPHIN
Mars position
MAVEN/SEP1
Time (2021 doy)

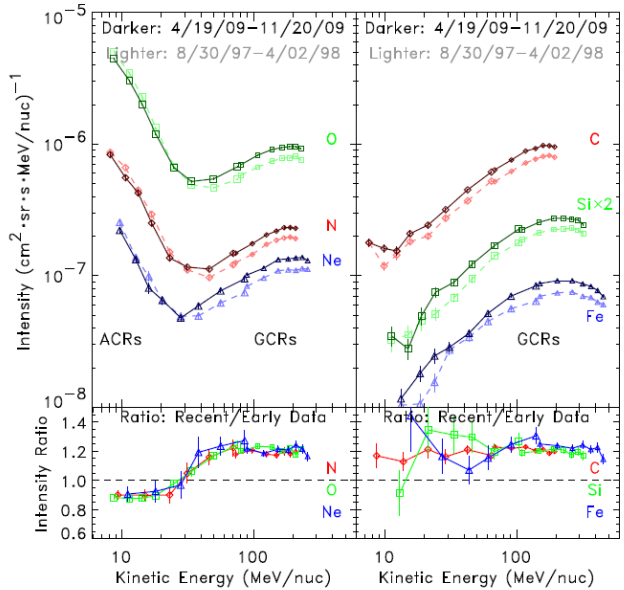
Anomalous cosmic rays


QUIET TIME COSMIC RAY SPECTRA
(1974 - 1978)
Hydrogen
Helium
Oxygen
Nitrogen
Carbon
Nuclei/(cm² sr sec MeV/nucleon)
Kinetic Energy (MeV/nucleon)

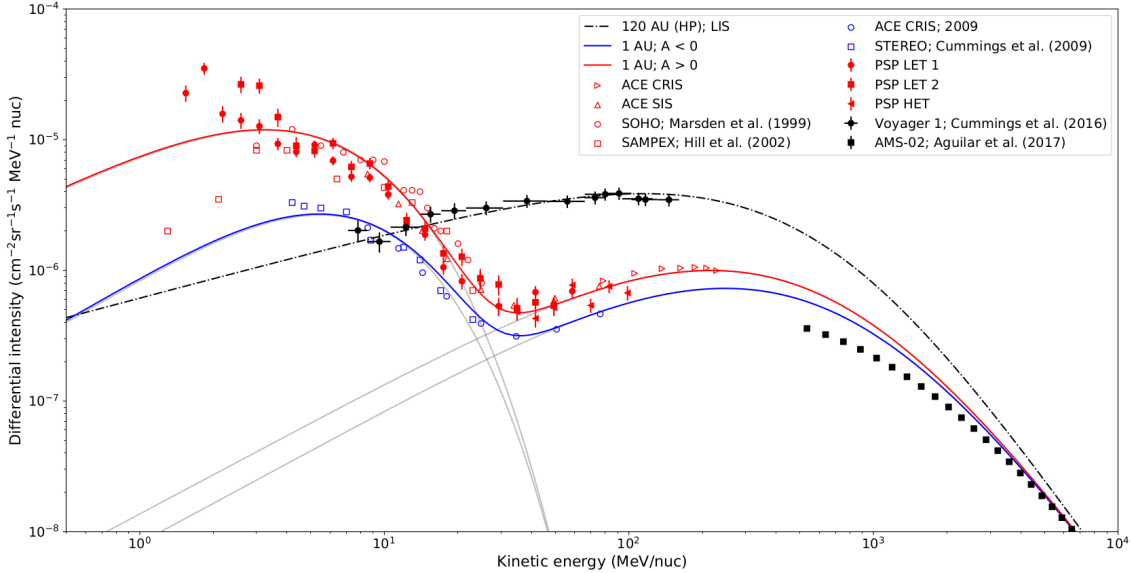

Solar wind
Heliosheath
B_SW
Shock
B_ISM
Heliopause
Bow Shock

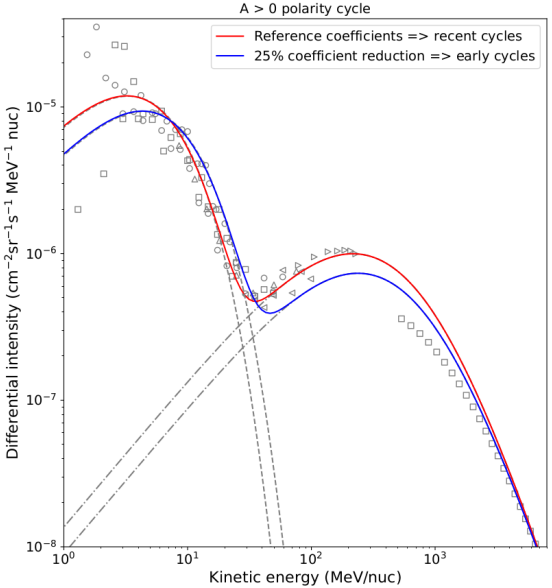

TERMINATION SHOCK
ACRs
VOYAGER 2
PICKUP IONs
SOLAR WIND
VOYAGER 1
CONNECTION REGION
V2
high
intensity
V1
low
[AU]
150
100
50
0
-50
-100
-150
-200
-100
0
100

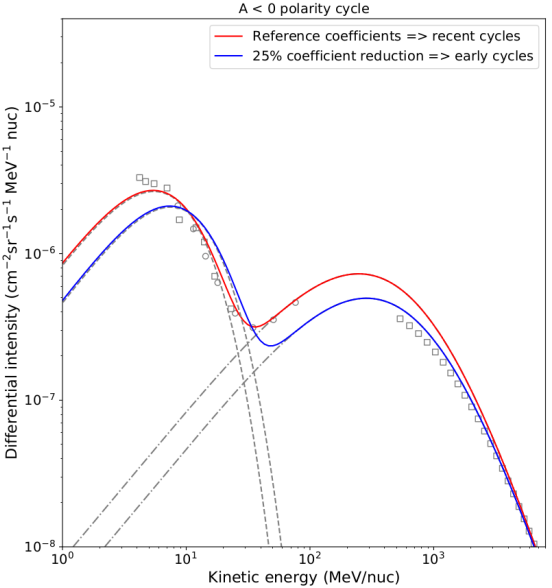

TSP
Protons
GCR
2005/54
Particles/(m² sec sr MeV/nuc)
Energy (MeV)
Helium
TSP
ACR
GCR
2005/48–60
Energy (MeV / nuc)

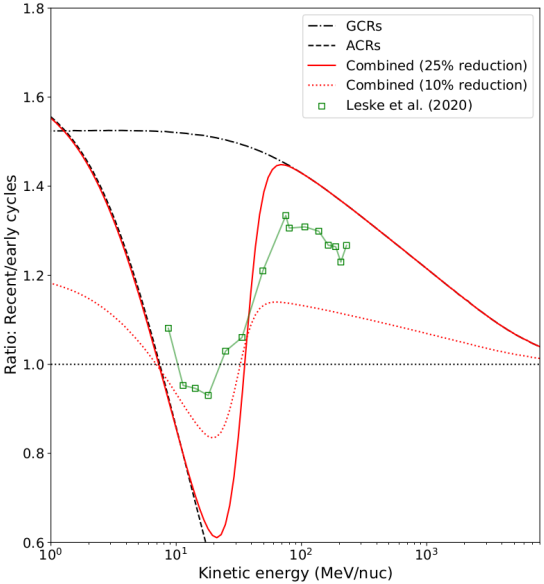


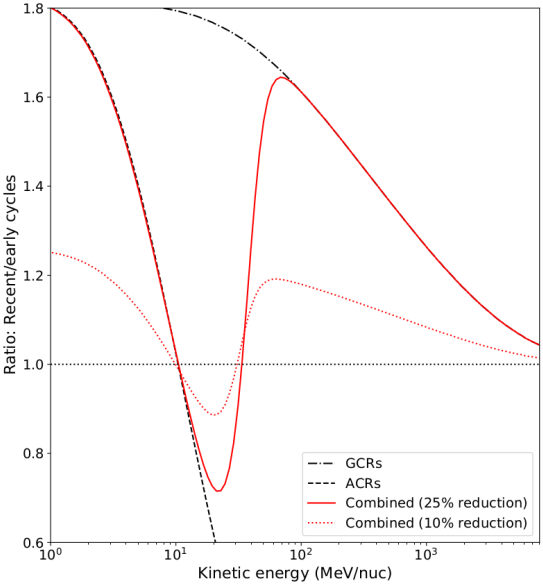
- We had record-setting GCR intensies in 2009 and again in the 2020 solar minimum.
- The heliosphere seems to be dominated in recent solar cycles by very quiet conditions.
- While GCR intensities increased, ACR intensities decreased. Why is this?


120 AU (HP); LIS
1 AU; A < 0
1 AU; A > 0
ACE CRIS
ACE SIS
SOHO; Marsden et al. (1999)
SAMPEX; Hill et al. (2002)
ACE CRIS; 2009
STEREO; Cummings et al. (2009)
PSP LET 1
PSP LET 2
PSP HET
Voyager 1; Cummings et al. (2016)
AMS-02; Aguilar et al. (2017)
Differential intensity (cm^{-2}sr^{-1}s^{-1} MeV^{-1} nuc)
Kinetic energy (MeV/nuc)


A > 0 polarity cycle
Reference coefficients => recent cycles
25% coefficient reduction => early cycles
Differential intensity (cm^{-2}sr^{-1}s^{-1} MeV^{-1} nuc)
Kinetic energy (MeV/nuc)


A < 0 polarity cycle
Reference coefficients => recent cycles
25% coefficient reduction => early cycles
Differential intensity (cm^{-2}sr^{-1}s^{-1} MeV^{-1} nuc)
Kinetic energy (MeV/nuc)

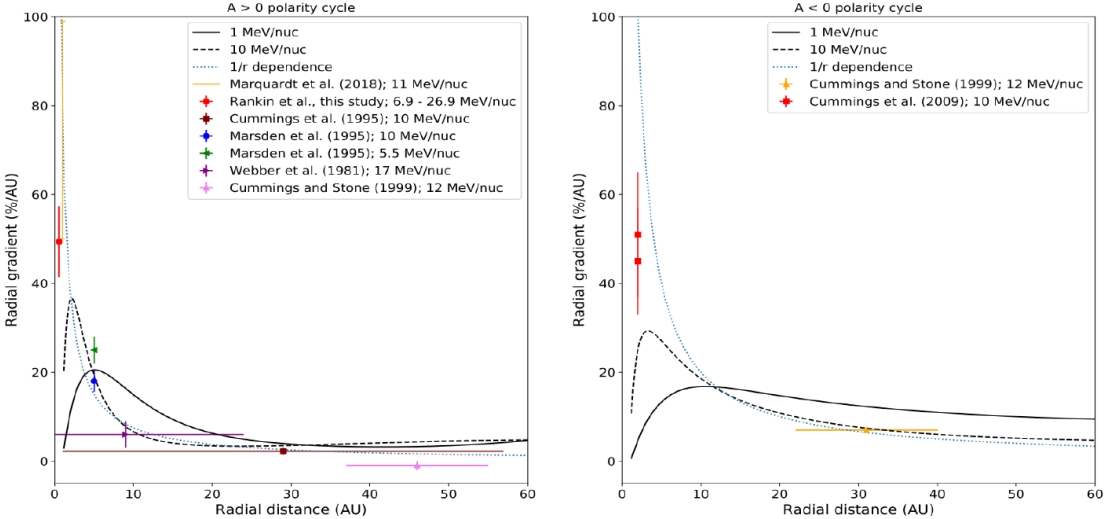

GCRs
ACRs
Combined (25% reduction)
Combined (10% reduction)
Leske et al. (2020)
Ratio: Recent/early cycles
Kinetic energy (MeV/nuc)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
10^0
10^1
10^2
10^3


GCRs
ACRs
Combined (25% reduction)
Combined (10% reduction)
Ratio: Recent/early cycles
Kinetic energy (MeV/nuc)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
10^0
10^1
10^2
10^3

Why does this happen:

- GCRs experience less modulation (scattering) during the recent quiet solar minimum conditions with less turbulent solar conditions. Their intensity at Earth increases.
- ACRs are accelerated at the TS by DSA. Less turbulence mean less scattering and this leads to less efficient DSA. This is especially noticeable at the highest ACR energies.
- For these particles there is an interplay between less efficient acceleration, but more efficient transport,

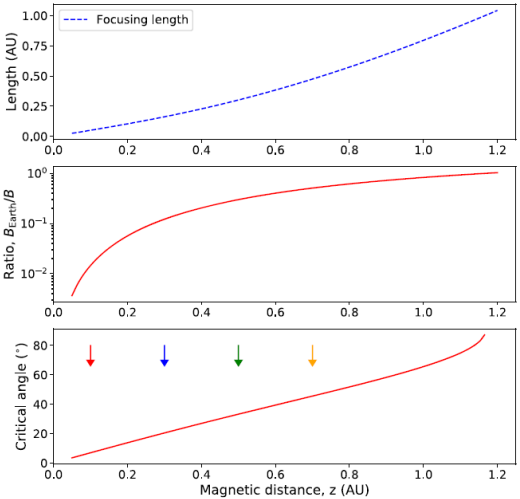
But all it not well.... some details are still missing...

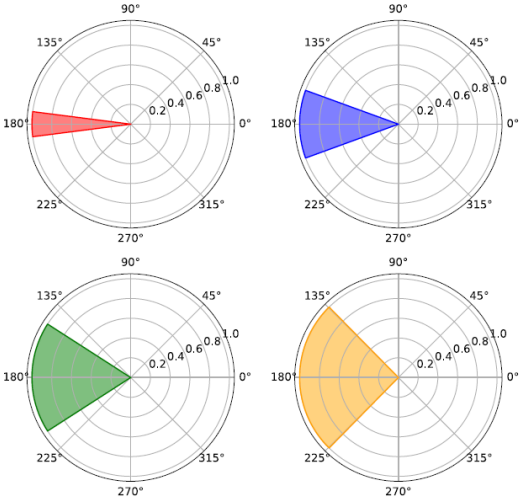


From Rankin et al. (2021)

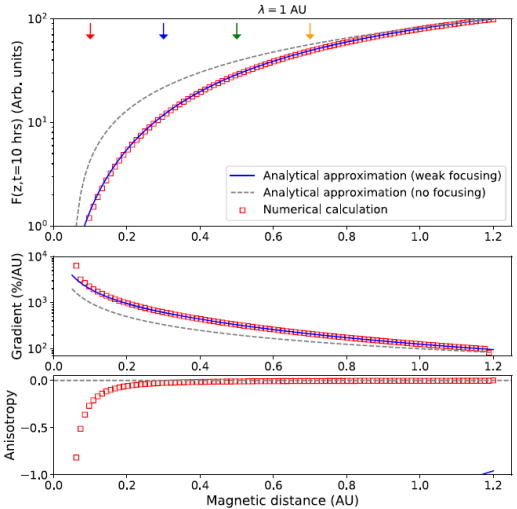
One possible reason might be the validity of the Parker TPE:

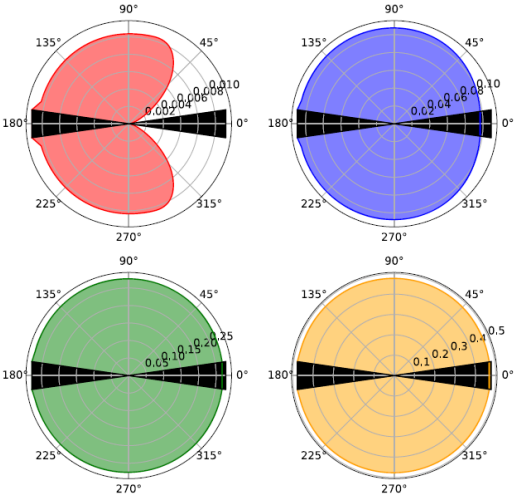
- The Parker TPE is only valid for nearly isotropic CR distributions.
- However, close to the Sun there is a strong magnetic gradient that can lead to magnetic mirroring and possibly anisotropic distributions.
- Magnetic focusing is characterized by a lengthscale $L = -d \ln B/dz$. If $L \ll \lambda_{||}$ we can expect anisotropies.
- For this case we need to move to a more fundamental transport description.





From Strauss et al. (2022)





From Strauss et al. (2022)

Summary and discussion

- We live in very exciting times for CR physics: The Voyager spacecraft are outside the heliosphere and PSP and SolO in the very inner heliosphere. Combined with AMS-02 and PAMELA give very exciting opportunites to constrain the remaining free transport parameters.
- The lesser CR species (ACRs and Jovian electrons) can give additional information of the acceleration and transport processes.
- The lessons learned in the heliosphere can be extrapolated to larger astrophysical systems.

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– fin –