TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA
Dipartimento di Fisica

Agenzia Spaziale Italiana

GSI

UNIVERSITÀ
DI PAVIA

HSERLAB
Human Space Exploration Radiation LAB

EAST-WEST ANISOTROPY OF GCR MEASURED INSIDE COLUMBUS BY LIDAL DETECTOR

Di Fino L, Baiocco G, Boretti V, Lunati L, Mentana A, Monnati F, Nigro G, Salina G & Narici L



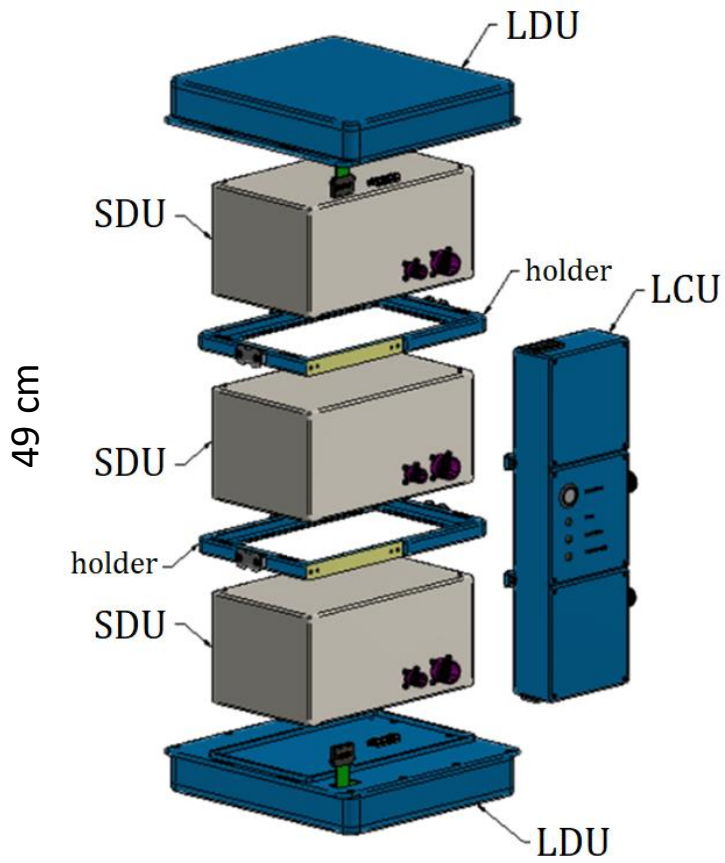
WRMISS 2026 Prague - Czech Republic

Contents

- The descending and ascending orbits and the ToF sign
- Measurement of the GCR asymmetry
- Modeling the GCR asymmetry with Störmer + DLR model
- A backtracing model to take account of the Earth
- Approximations to be improved

LIDAL

FoV 9° - 20°



GF: 15.32 $cm^2\ sr$ (bi-directional)

18 Si planes: [0.038 x (2 x 8) x 8] cm^3

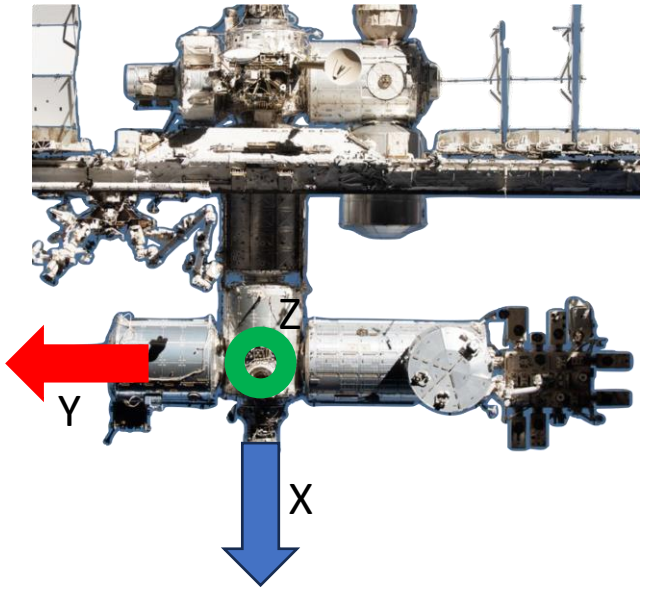
2 Scint. planes.: [0.4 x (8 x 2) x 8] cm^3

The unique **ToF** feature of LIDAL and its **narrow FoV**

allow for

the measurement of the GCR E-W asymmetry

Coordinates et al.

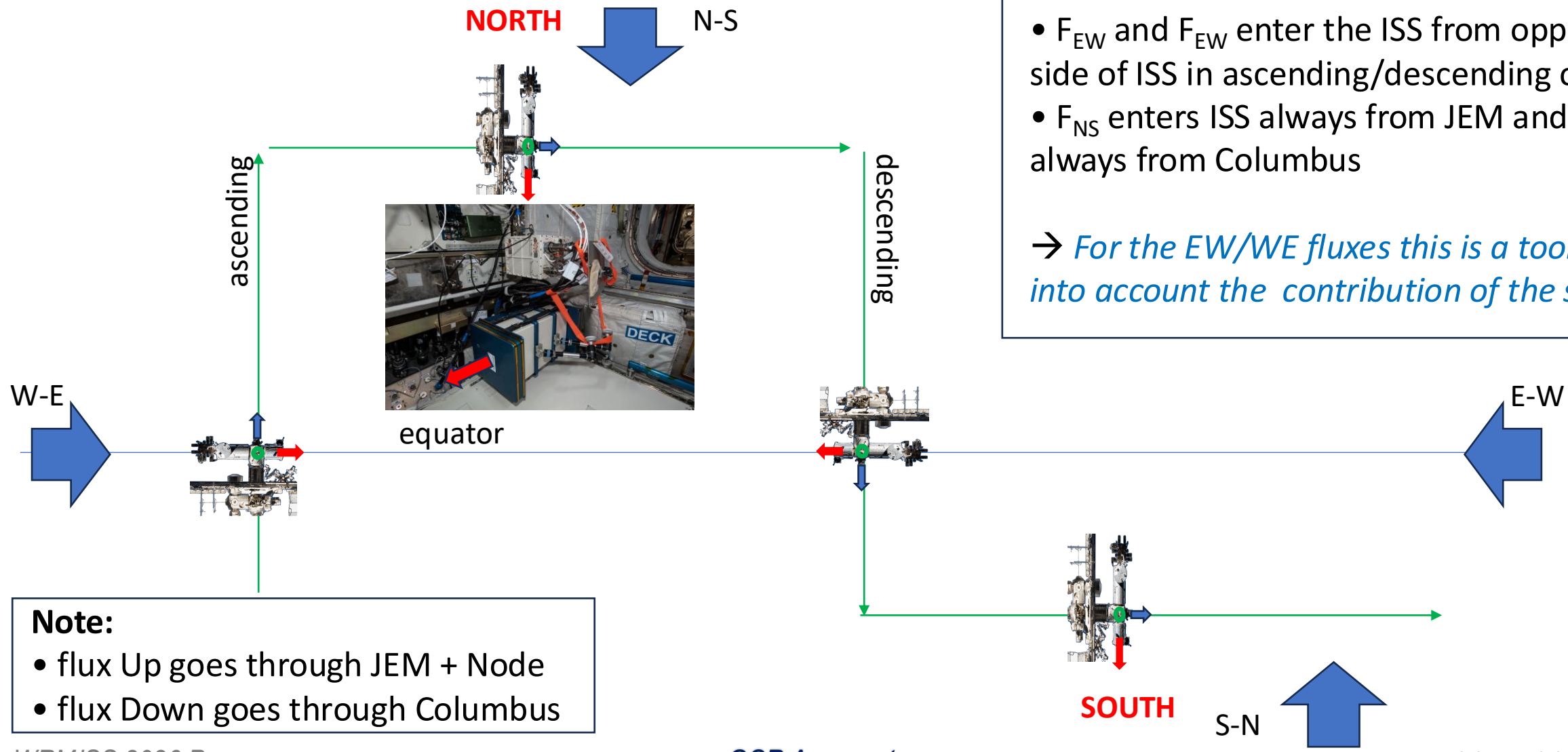


- ISS-referred coordinates **X Y Z** (**Z** is entering the plot)
- When LIDAL is in that direction **usually** 'UP' is parallel with the axis, 'DOWN' is antiparallel
- **Usually** the vector velocity **v** is parallel with **X**

Note: UP and DOWN are the signs of the ToF measured by LIDAL

The effect of the ascending-descending orbits

Temporary approximation: polar orbit



Note:
- F_{EW} and F_{EW} enter the ISS from opposite side of ISS in ascending/descending orbits.
- F_{NS} enters ISS always from JEM and F_{SN} always from Columbus

→ *For the EW/WE fluxes this is a tool to take into account the contribution of the shielding*

Note:
- flux Up goes through JEM + Node
- flux Down goes through Columbus

Consider the shielding

Very crude approximations: 1) shielding as a multiplicative factor (s_{JEM}, s_{COL}); 2) etc.

Asymmetry as a flux ratio

$$\alpha = \frac{F_{EW}}{F_{WE}}$$

Consider LIDAL in direction Y

$$\alpha = \frac{f_{Ud}}{f_{Ua}} = \frac{f_{Da}}{f_{Dd}}$$

$$\frac{s_{JEM}}{s_{COL}} = \frac{f_{Ud}}{f_{Da}} = \frac{f_{Ua}}{f_{Dd}}$$

$f_{Ua} = F_{WE}\, s_{JEM}$
$f_{Ud} = F_{EW}\, s_{JEM} = F_{WE}\, s_{JEM}\, \alpha$
$f_{Da} = F_{EW}\, s_{COL} = F_{WE}\, s_{COL}\, \alpha$
$f_{Dd} = F_{WE}\, s_{COL}$

$f_{Ua} = F_{WE}\, s_{JEM}$
$f_{Ud} = F_{WE}\, \alpha\, s_{JEM}$
$f_{Da} = F_{WE}\, \alpha\, s_{COL}$
$f_{Dd} = F_{WE}\, s_{COL}$

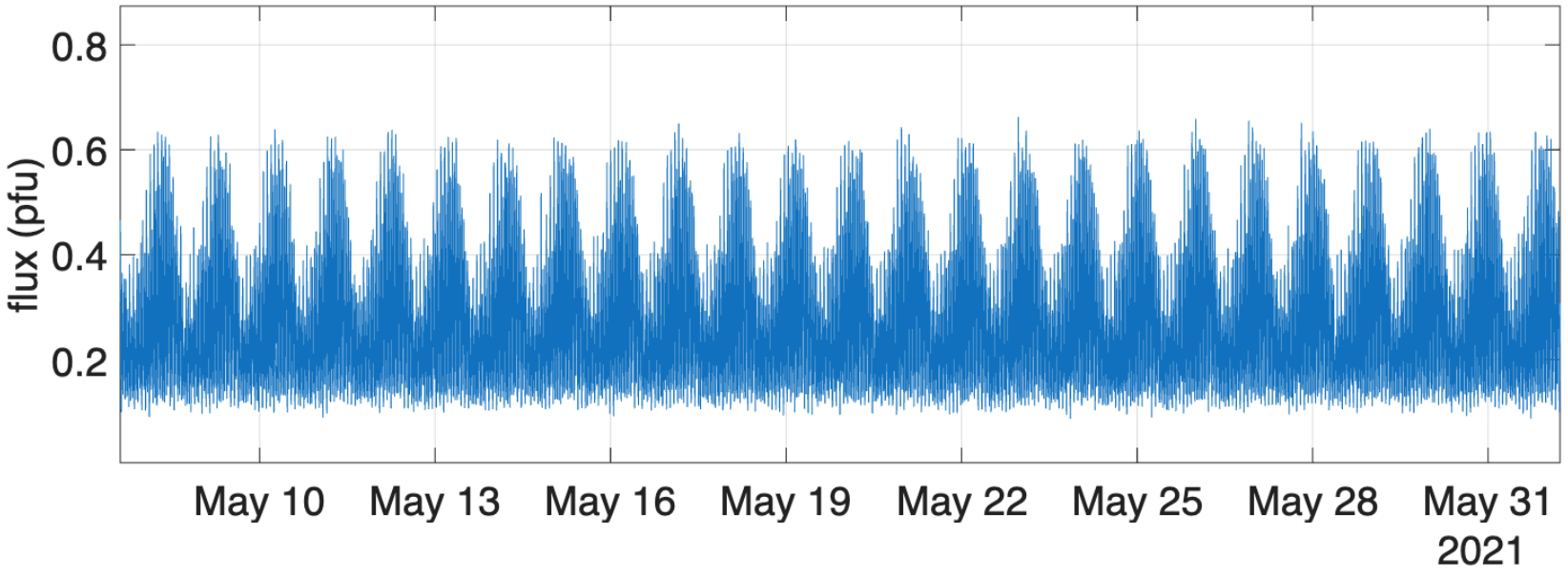
Legend:

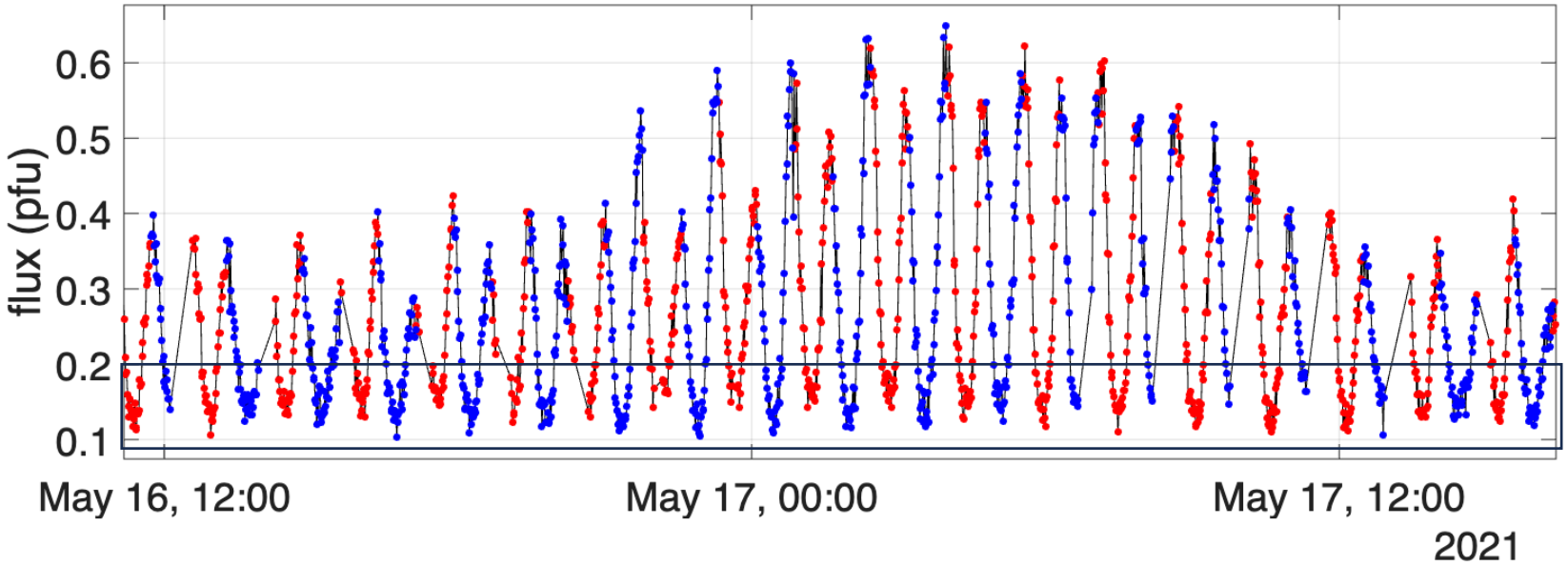
f = measured flux	U = up, parallel to Y axis
F = flux outside ISS	D = down, antiparallel to Y axis
	d = descending orbit
	a = ascending orbit

Used data

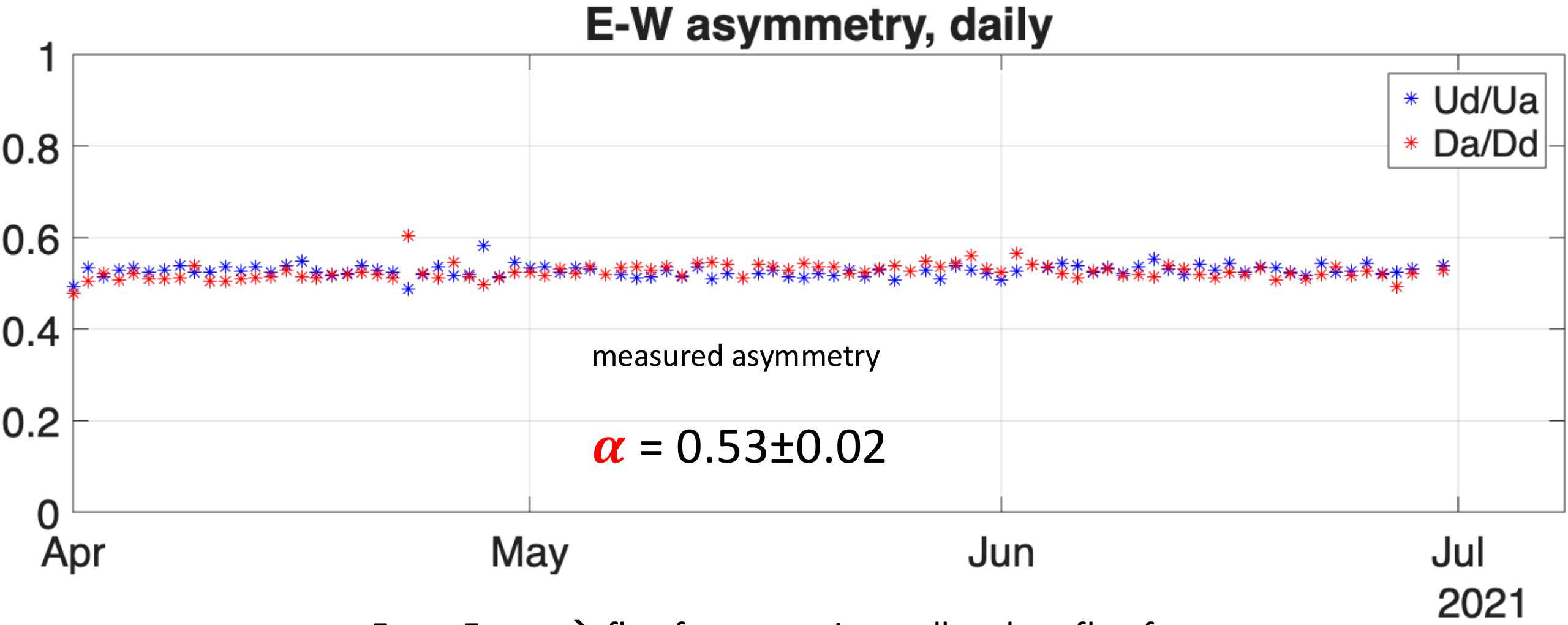
Type:	Flux, 1 min LIDAL data
Period	from April 1st to June 30th 2021 (Y direction, quite period)
Cuts	0 < Lat < 16°, 3°
Integration	1 day

Used data: example



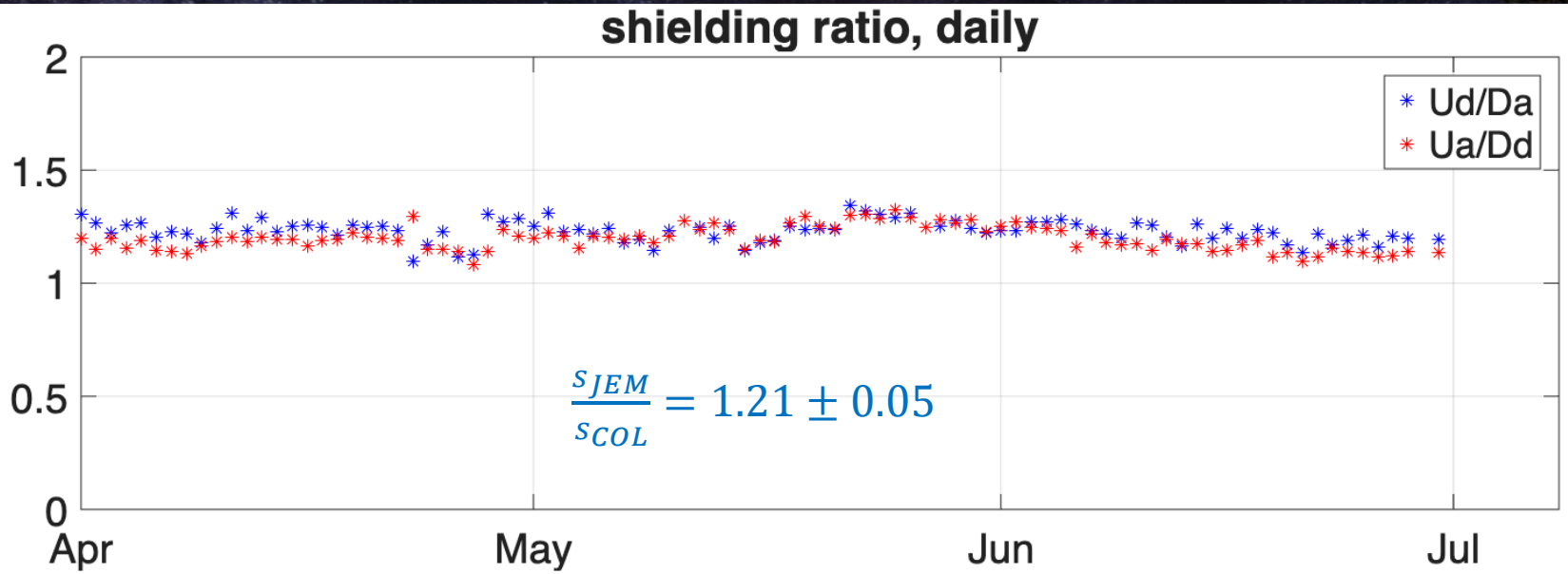


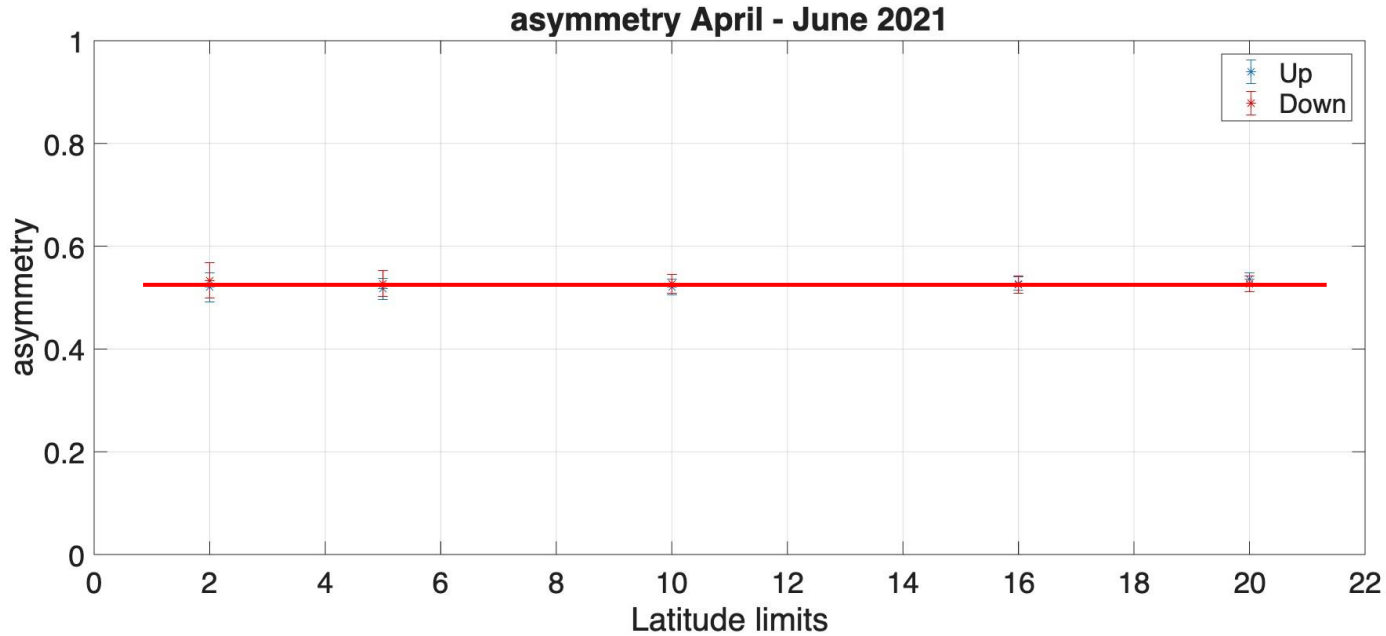
Results



$F_{EW} = F_{WE}\ \alpha$ → flux from east is smaller than flux from west

Results 2

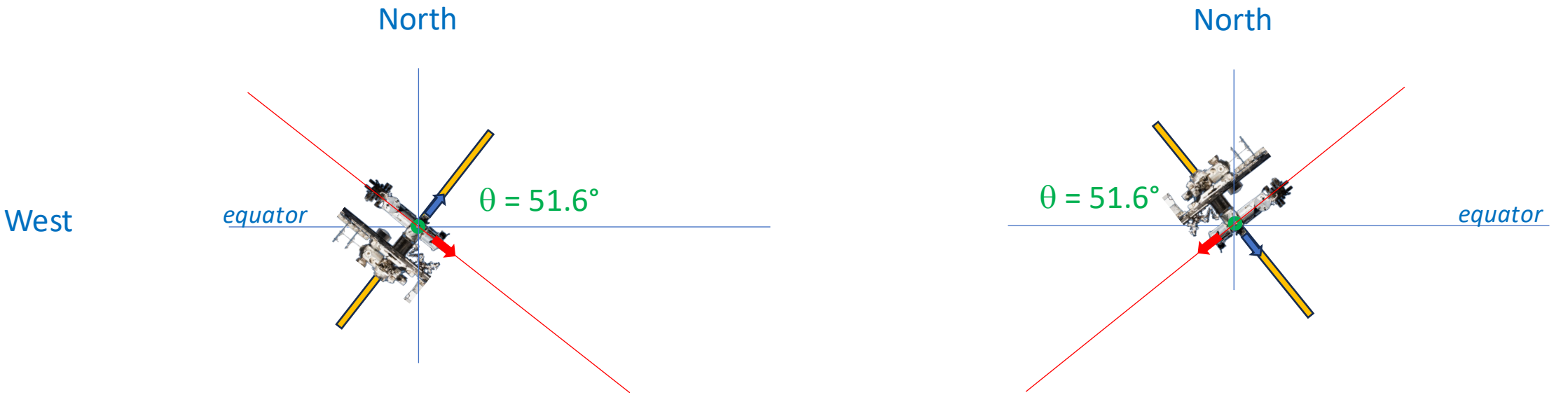




GCR Asymmetry

Introduce real orbital inclination

θ = orbital inclination = 51.6°

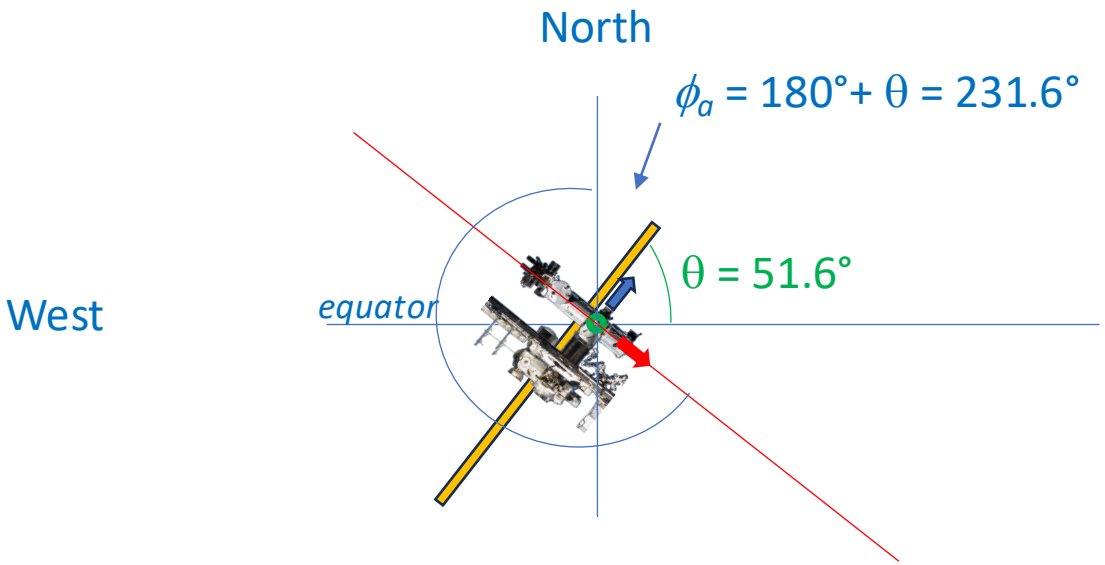


Note: We are on the plane orthogonal to equatorial plane, tangential to the orbit crossing the equator.

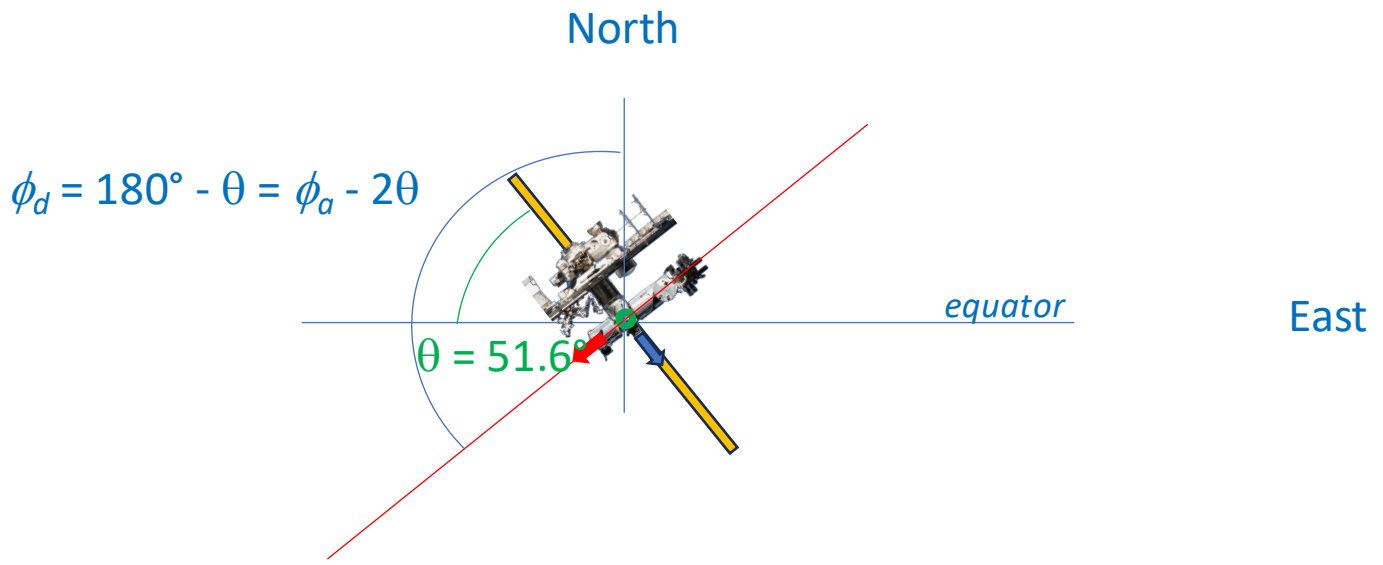
Introducing Störmer angles

ϕ *is* analog to ζ used by Störmer to describe the rigidity due to the Earth magnetic dipole <u>but relative to the geographical axes:</u>

it is the azimuthal angle measured clockwise from the LIDAL direction (red line) to the north geographical pole



Ascending orbit



Descending orbit

Note: We are on the plane orthogonal to equatorial plane, tangential to the orbit crossing the equator. θ is the orbit inclination.

Introducing the angle between geo and mag axes

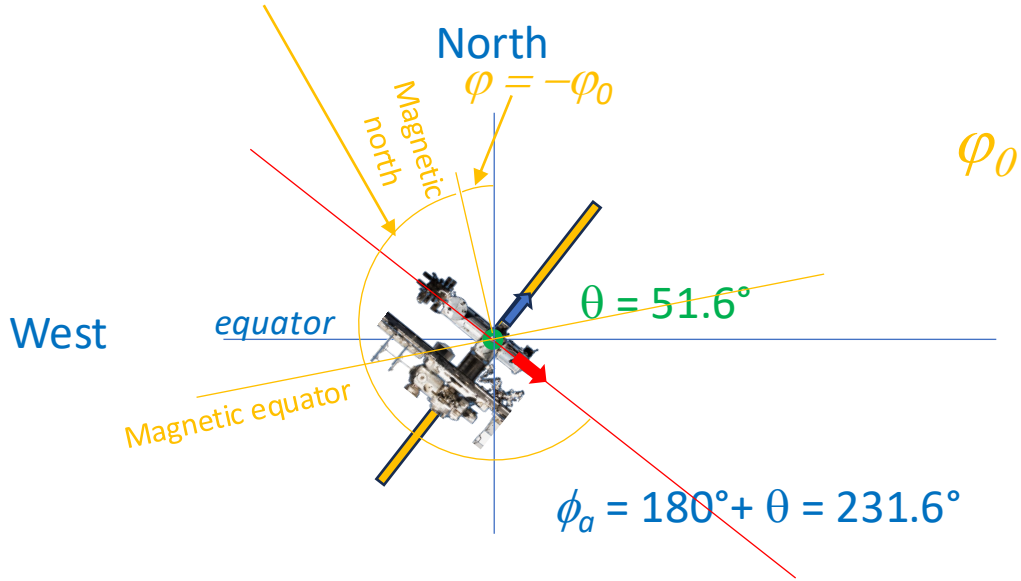
As we are going to use the Störmer equation to calculate the rigidity values we start using all the Störmer angles (coordinates)

ζ *is the azimuthal angle measured clockwise from the LIDAL direction (red line) to the north dipole axis*
λ *is the latitude from the magnetic equator*
ε *is the angle from the zenith direction (where the zenith direction is a radial from dipole center)*

} Störmer coordinates

ϕ *is the azimuthal angle measured clockwise from the LIDAL direction (red line) to the north geographical pole axis*

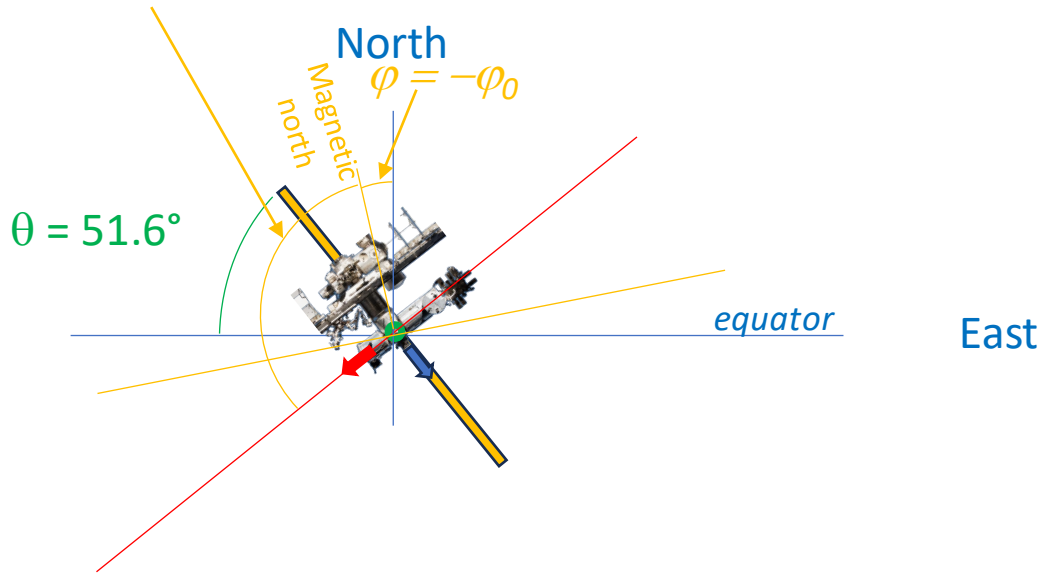
$\zeta_a = \phi_a - \varphi_0 = 180 + \theta - \varphi_0 = 221.6°$



Ascending orbit

$\varphi_0 = 10°$

$\zeta_a = \phi_a - \varphi_0 = 180 - \theta - \varphi_0 = 118.4°$

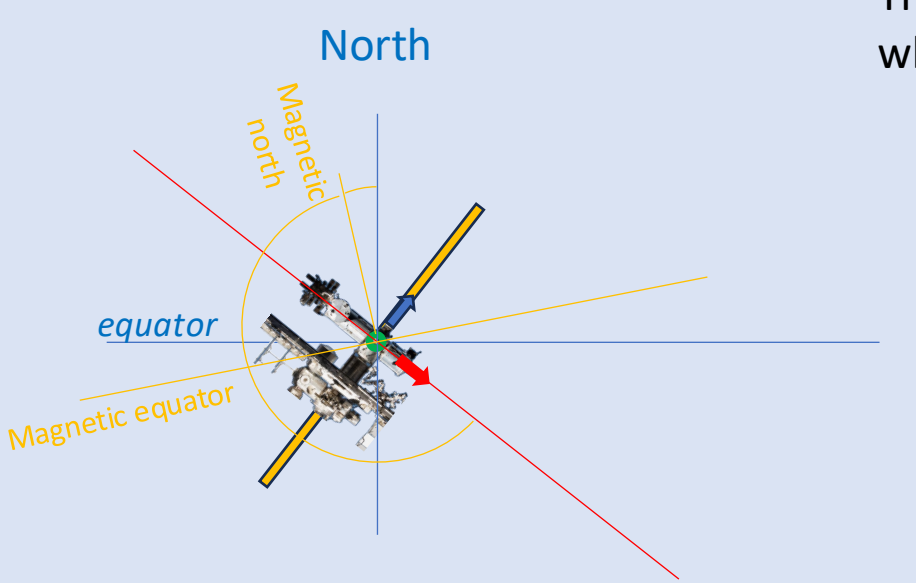


Descending orbit

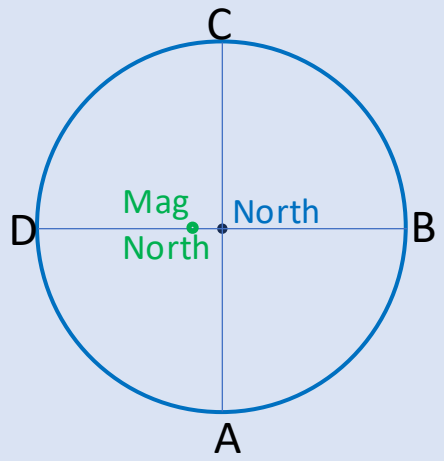
The dynamics around the orbit

In time, the passages of the ISS over the equator in the ascending orbit occurs over meridians separated by ≈ 23°. Going from pass to pass:

- The direction of north magnetic pole is oscillating from $-\varphi_0$ to φ_0 with respect to the geographical pole
- the latitude λ (with respect to the magnetic equator) is oscillating from $-\varphi_0$ to φ_0
- $\varepsilon = 90°$ always



There are 4 "extreme" cases where the orbit is passing:



ascending

Case	ζ_a	λ
A	*221.6*	0
B	231.6	*-10*
C	*241.6*	0
D	231.6	*+10*

descending

Case	ζ_d	λ
A	*118.4*	0
B	128.4	*-10*
C	*138.4*	0
D	128.4	*+10*

NOTE: What said is for LIDAL direction UP, for the DOWN direction ζ differs by 180°

Introducing Störmer equation

Smart & Shea 1994 for the Störmer equation

$$R_c = \frac{\frac{M\ cos^4\lambda}{r^2}}{\left[1+\sqrt{1-sin\varepsilon\ sin\zeta cos^3\lambda}\right]^2}$$

Legend

M : *magnitude of the dipole moment (GV)*
r : *distance from dipole centre in Earth radii*

λ : *latitude from the magnetic equator*
ε : *angle from the zenith direction (where the zenith direction is a radial from dipole center)*
ζ: *azimuthal angle measured clockwise from the direction to the north dipole axis*
R_c: *geomagnetic cutoff*

$\varepsilon = 90$ → $\boldsymbol{sin\varepsilon = 1}$ (LIDAL-Y axis is always normal to the zenith direction)

M = 56
r = 1 + 400/6371 = 1.063 → M/r^2 = 49.6

$$R_c = \frac{49.6\ cos^4\lambda}{\left[1+\sqrt{1-sin\zeta cos^3\lambda}\right]^2}$$

Calculating rigidities

Case	ζ_{Ua}	ζ_{Ud}	ζ_{Da}	ζ_{Dd}	λ
A	221.6°	118.4°	41.6°	298.4°	0°
B	231.6°	128.4°	51.6°	308.4°	-10°
C	241.6°	138.4°	61.6°	310.4°	0°
D	231.6°	128.4°	51.6°	308.4°	10°

$$R_c = \frac{49.6\ cos^4\lambda}{\left[1+\sqrt{1-sin\zeta cos^3\lambda}\right]^2}$$

Case	R_{Ua}	R_{Ud}	R_{Da}	R_{Dd}
A	9.46	23.81	19.88	8.40
B	9.09	20.69	23.11	8.65
C	8.82	18.11	27.34	8.71
D	9.09	20.69	23.11	8.65

Rigidity spectrum from Matthiä's model

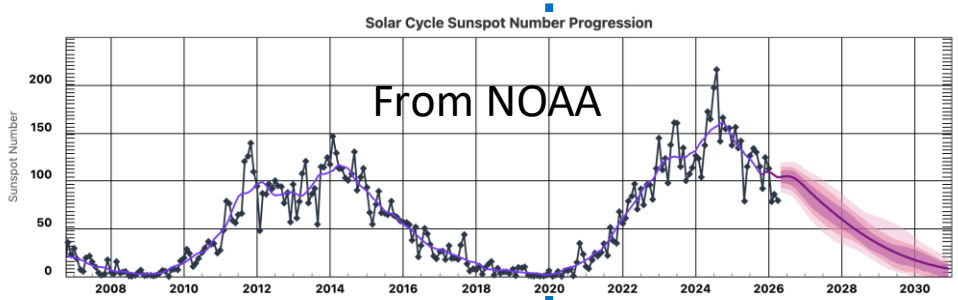
From Matthiä et al 2013

$$\Phi_i(R,t) \equiv \frac{dN}{dAdt'd\Omega dR}(R,t) = \frac{C_i\beta^{\alpha_i}}{R^{\gamma_i}}\left[\frac{R}{R+R_0(R,t)}\right]^{\Delta_i(R,t)}$$

$$\Phi_i(R,t) = \frac{C_i\beta^{\alpha_i}}{R^{\gamma_i}}\left[\frac{R}{R+(0.37+3\cdot10^{-4}\cdot W(t)^{1.45})}\right]^{b\cdot W(t)+c}$$

R = rigidity

b = 0.02
c = 4.7



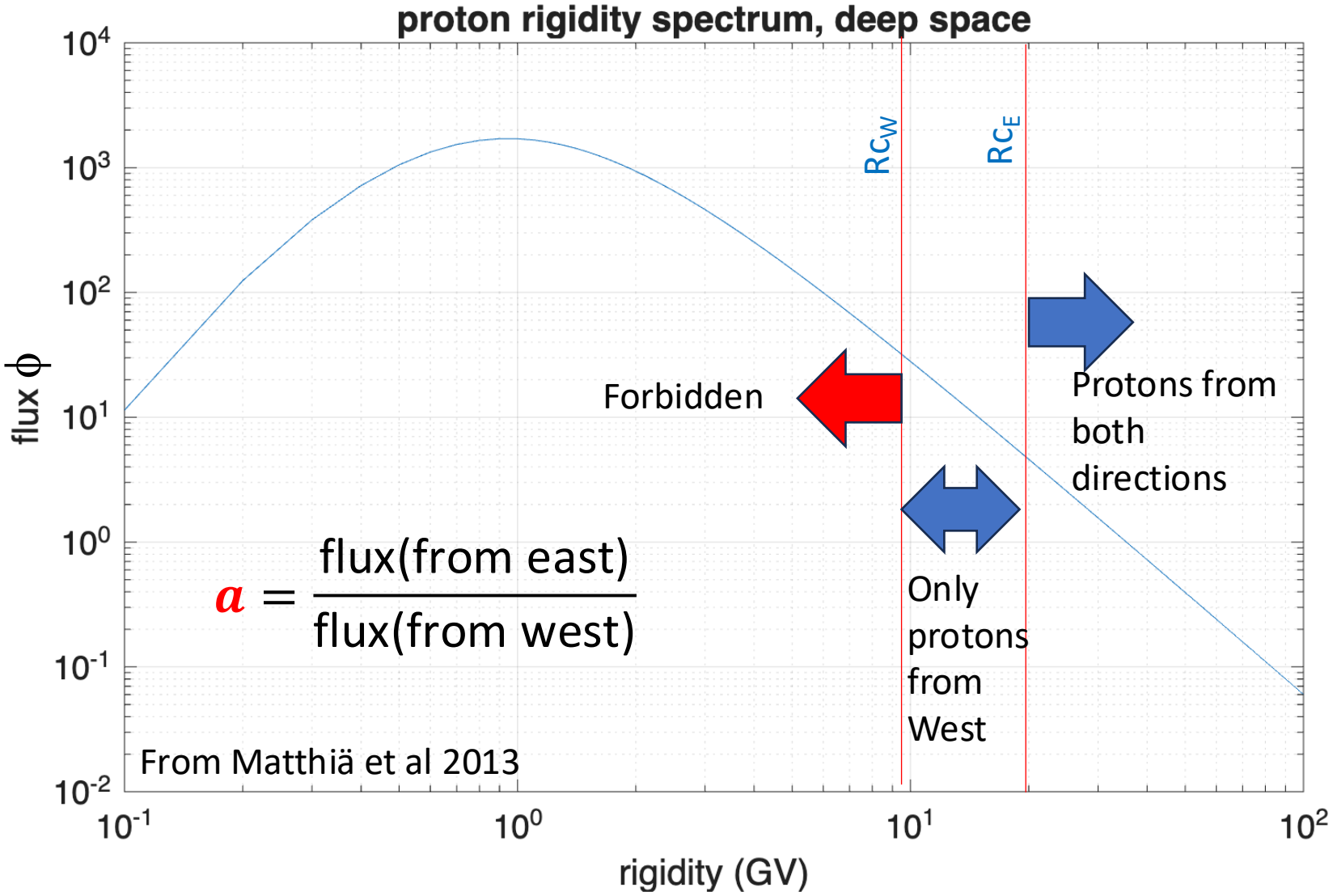
From NOAA

→ W ~ 0
for 2021

For protons:

α = 2.85
γ = 2.74
C = 1.85 x 10^4 (s sr m^2 GV)$^{-1}$

Model results



Case	R_{Ua}	R_{Ud}	R_{Da}	R_{Dd}
A	9.46	23.81	19.88	8.40
B	9.09	20.69	23.11	8.65
C	8.82	18.11	27.34	8.71
D	9.09	20.69	23.11	8.65

$$\alpha = \frac{f_{Ud}}{f_{Ua}} = \frac{f_{Da}}{f_{Dd}} = 0.2$$

Approximations … to be improved

→ • Cone of LIDAL acceptance {no appreciable changes from preliminary calculations}

• Width of the measured strip around the equator

• Only protons

• Atmosphere

→ • Earth **{important changes, but in the opposite direction}**

• Shielding as a multiplicative factor → secondaries (also from primaries from other directions)

Considering the Earth

- Störmer does not consider the Earth

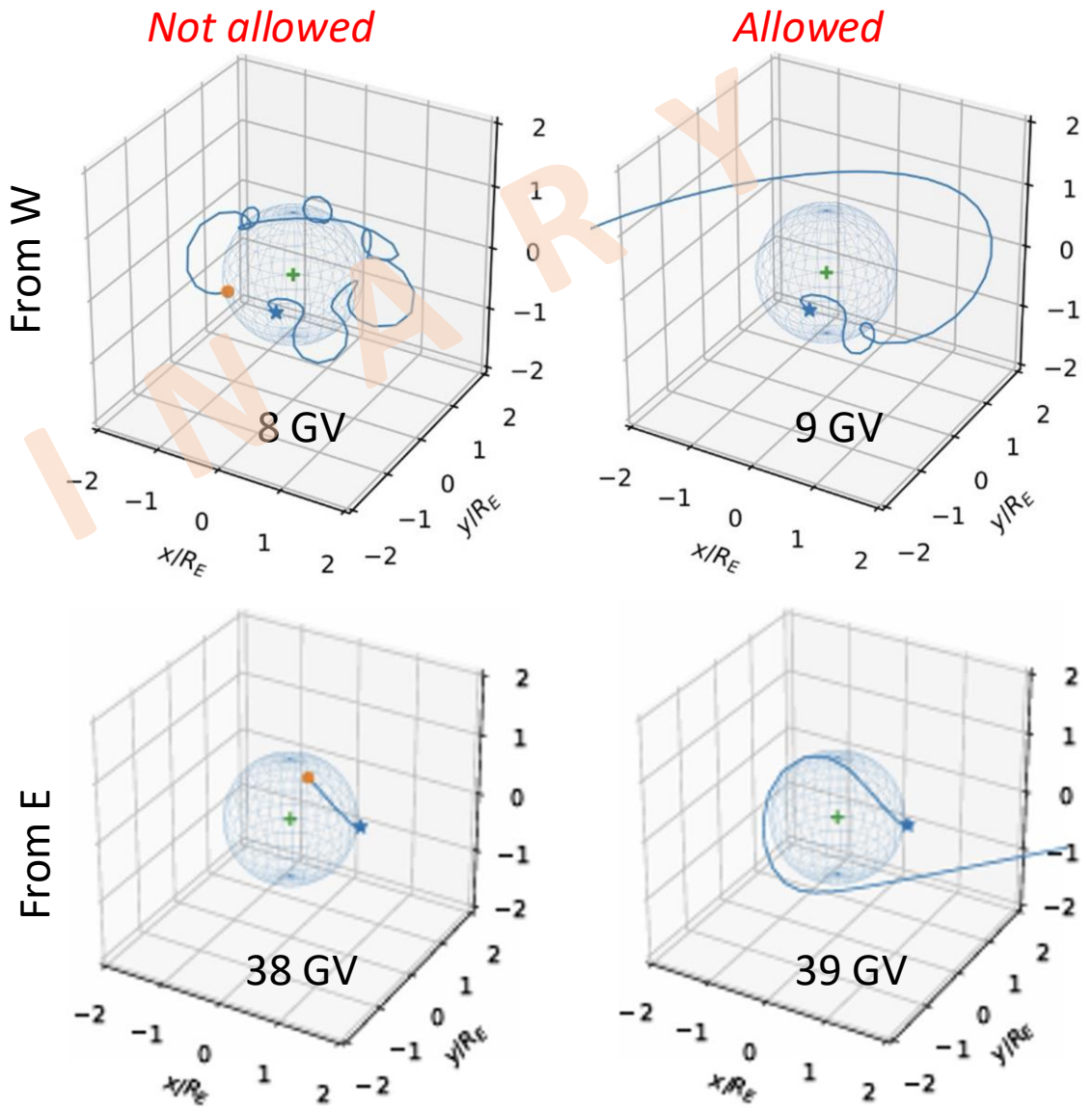
→ Backtracing model:

- the Earth does not appreciably affect Rc_W
- it makes a significant contribution for Rc_E,

(Rc limit up to ~ 40 GV from ~ 20 GV)

If we use 9 GV and 39 GV we would obtain:

$$\alpha = 0.07$$



PRELIMINARY

Final remarks

- Using the unique LIDAL features we have been able to measure, for the first time, the GCR E-W asymmetry (in an habitat).
- The shielding effect is (partially) taken into account considering ascending and descending orbits.
- We use the Störmer equation, to provide a simple model to show the same effect.
- The Earth contribution has been modeled with a backtracing approach.
- The shielding may still play a major role in the amount of the measured asymmetry, due to secondary production (playing with the ions energy may provide insights, very preliminary results are confirming this).
- Ray tracing, CAD based, calculations centered on the LIDAL detector would improve the agreement of the model to the measurements.

Thank you for your attention

Back up slides

Estimation of M for the Störmer equation

From Smart and Shea 1994

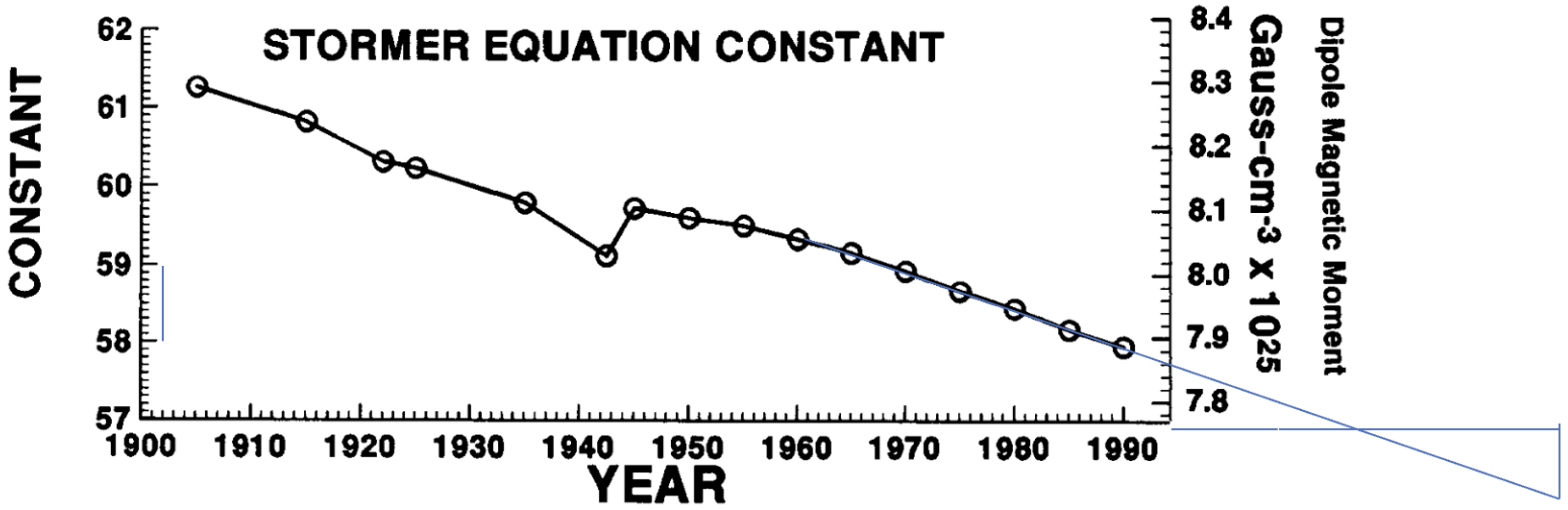
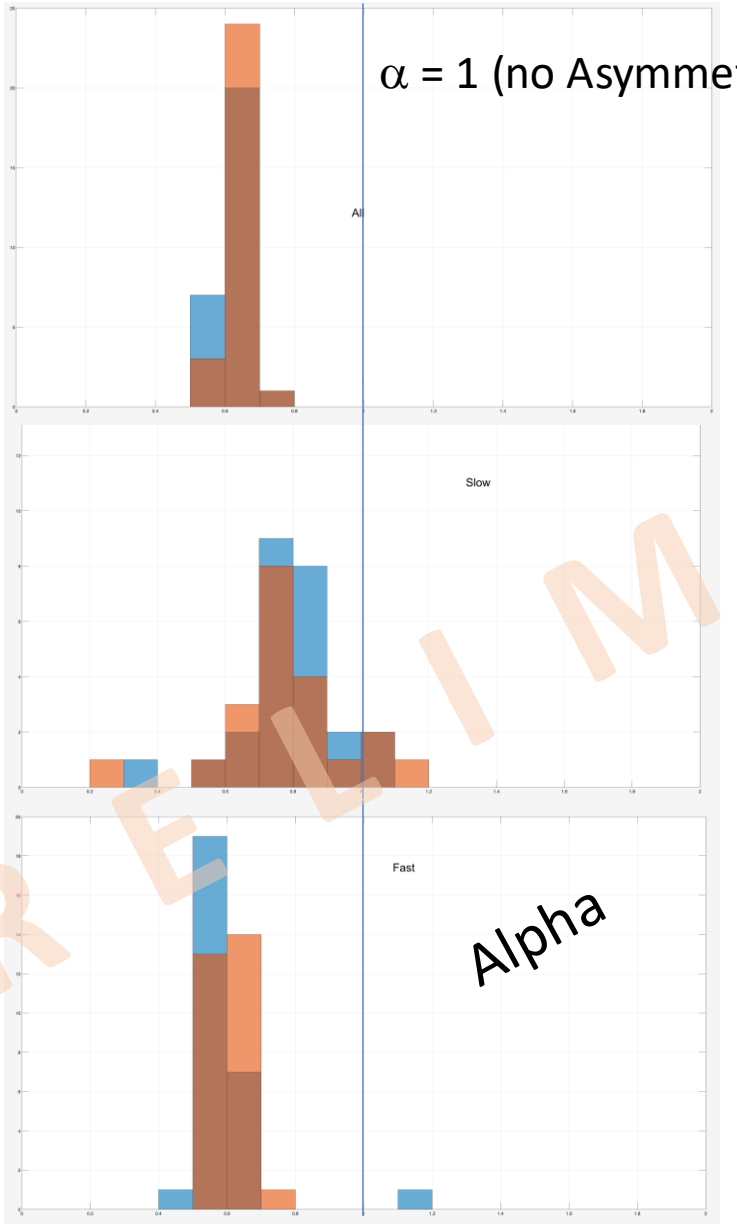


Figure 2. The magnitude of the constant appropriate for use in the Störmer equation as derived from various magnetic field models. The values prior to 1945 are from a compilation by Akasofu and Chapman /5/. The dipole moment values from 1945 to 1990 are derived from the International Geomagnetic Reference Fields models /4/.

M(2021) ≈ 56

Kinetic energy dependence of α

Using single particle LIDAL data (only 1-28 April 2021)



α = 1 (no Asymmetry)

All Tof

ToF > 2.2 ns (low kinetic energy)

Alpha

ToF <1.8 ns (high kinetic energy)

PRELIMINARY