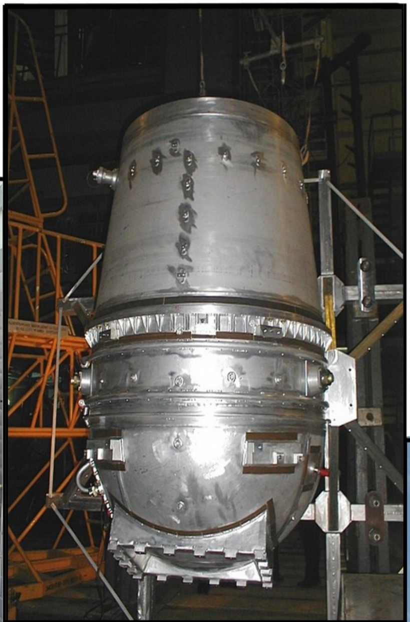
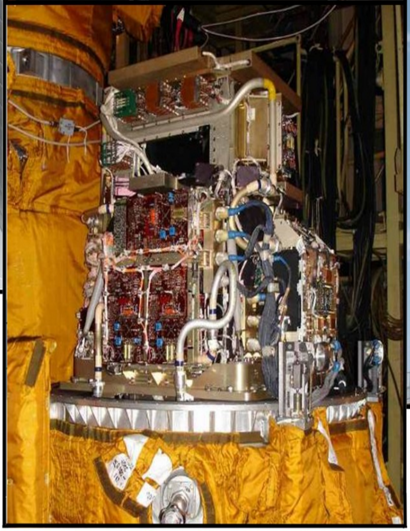


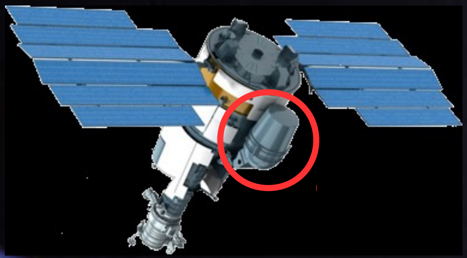


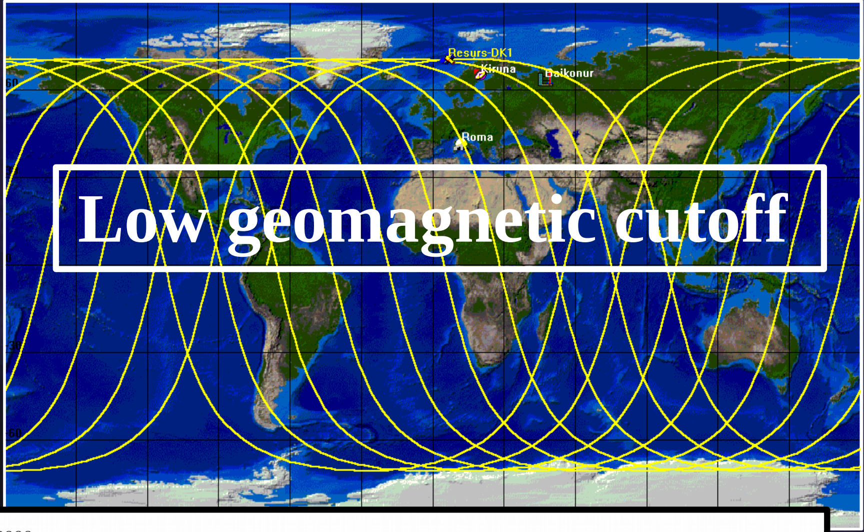
Solar modulation of cosmic rays with the PAMELA experiment: an important study for indirect dark matter detection

Riccardo Munini, INFN Trieste

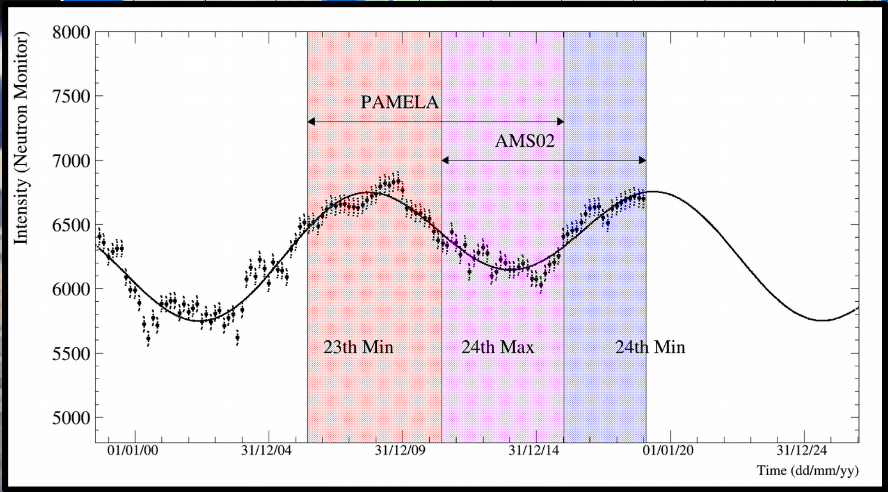
2nd AntiD workshop
27 March 2019 – UCLA, Los Angeles

Launch: 15 June 2006 – Stopped in January 2016





Quasi-polar elliptical orbit 70 degree inclination 350/610 km.
Allows to measure low energy particles (70 MeV electrons)



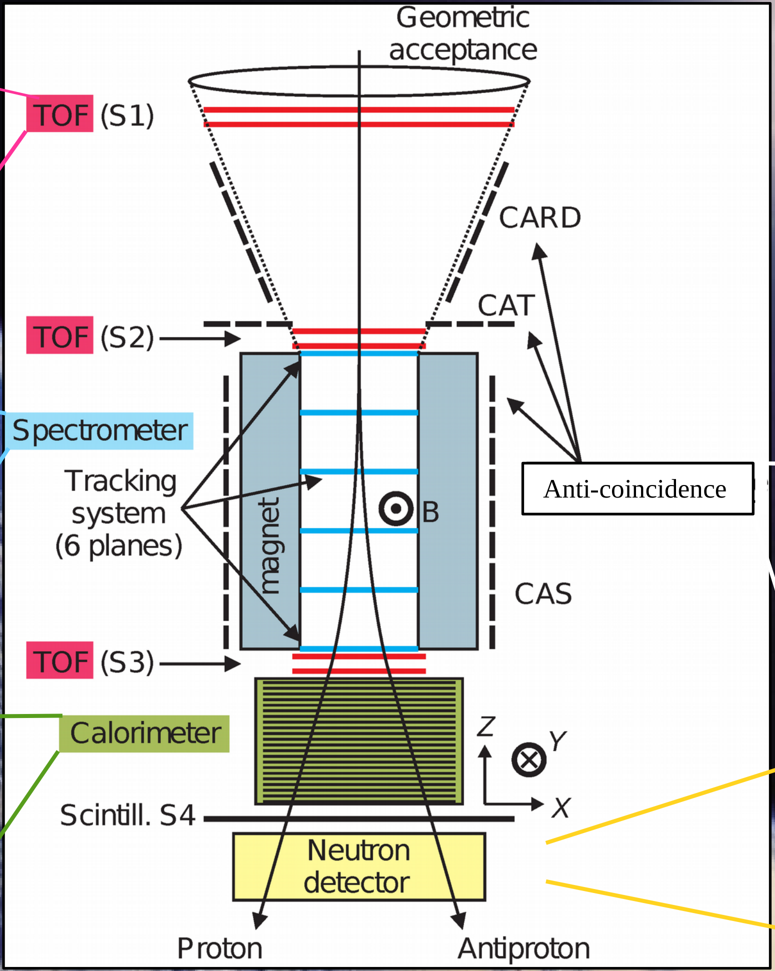
Long flight duration: 10 years of data
Allows to test model over different period of solar activity

The PAMELA instrument

24 bars of plastic scintillator disposed on six plane, S11, S12, S21, S22, S31, S32: velocity, absolute charge Z<8.

Six plane of double side microstrip silicon detector inside a magnetic cavity: rigidity, absolute charge Z<6, charge sign.

44 planes of Si detector interleaved with 22 tungsten planes, 16.3 radiation length: hadron lepton separation.

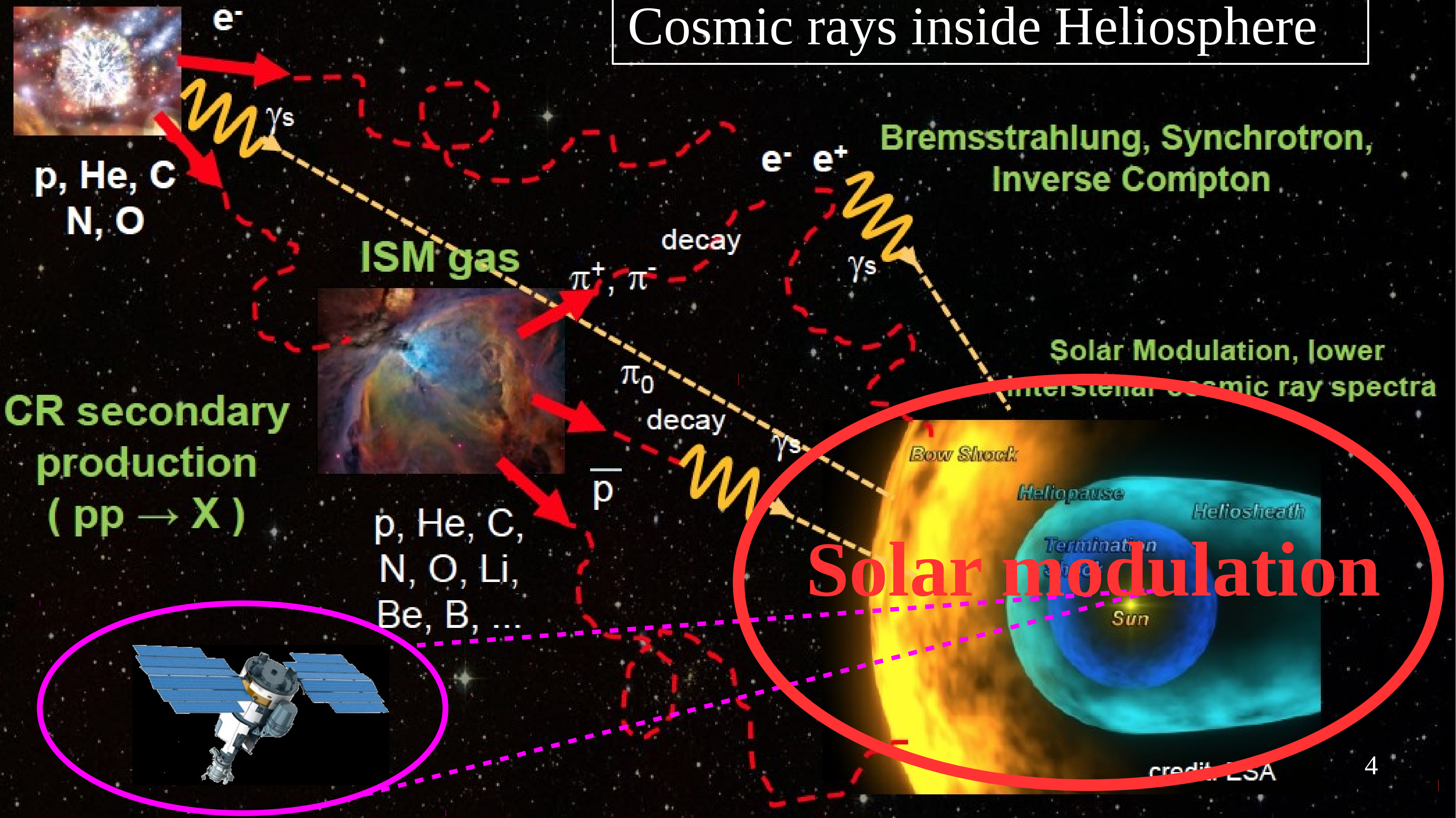


GF: 21.5 cm2 sr
Mass: 470 kg
Size: 130x70x70 cm
Power budget: 360 W

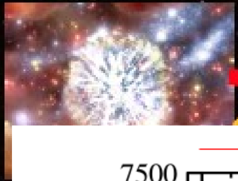
(CAS, CARD e CAT) nine plane of plastic scintillator around the apparatus: reject false trigger or multi-particle events.

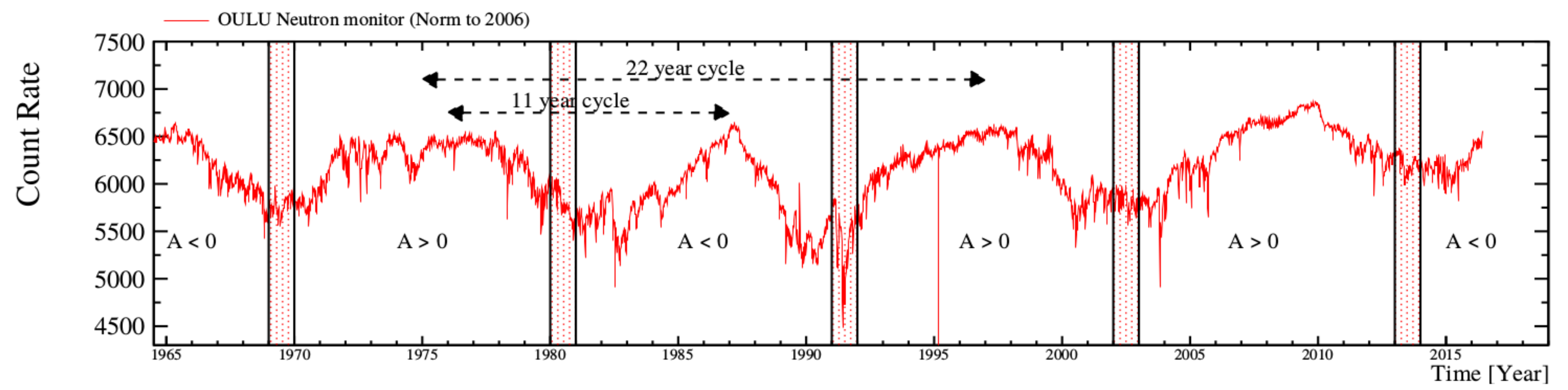
36 proportional counter filled with 3He: improve hadron rejection.

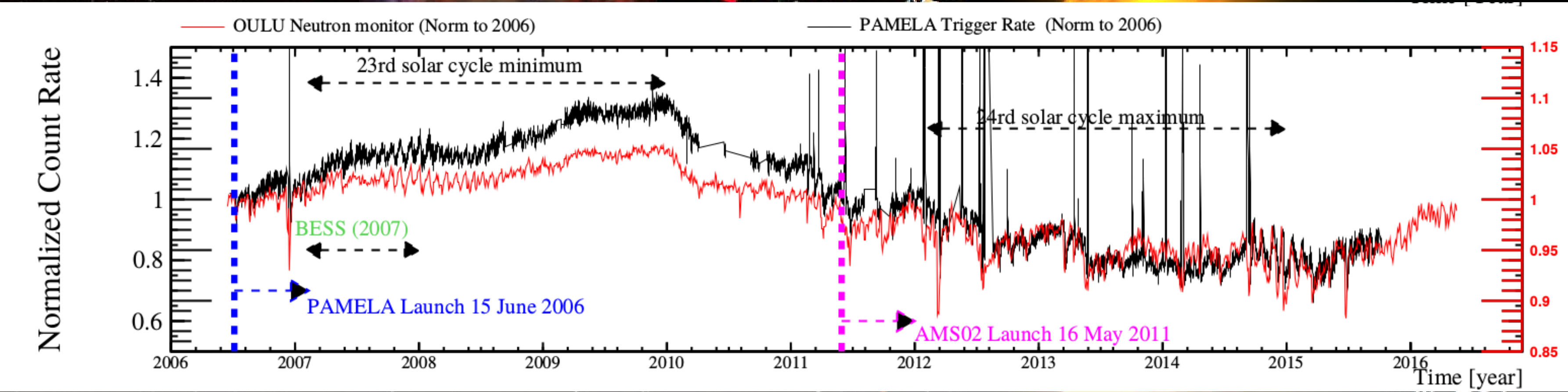
Cosmic rays inside Heliosphere



Propagation in the Heliosphere







credit: ESA

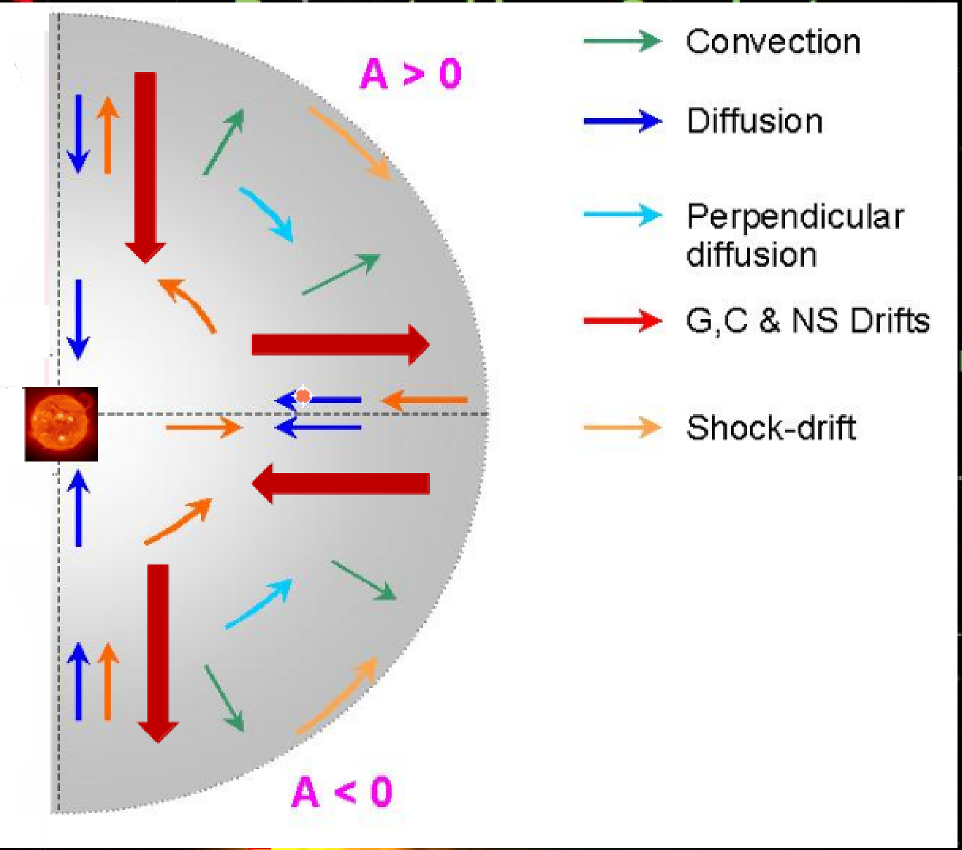
Cosmic inside Heliosphere: a full 3D numerical model

Below ∼ 30 GV heliosphere strongly affects CRs at Earth

$$\underbrace{\frac{\partial f}{\partial t}}_{a} = -\underbrace{\mathbf{V}\cdot\nabla f}_{b} + \underbrace{\nabla\cdot(\mathbf{K_s}\cdot\nabla f)}_{c} - \underbrace{\langle \mathbf{v_D}\rangle\cdot\nabla f}_{d} + \underbrace{\frac{1}{3}(\nabla\cdot\mathbf{V})\frac{\partial f}{\partial \ln p}}_{e} + \underbrace{Q(\mathbf{x},p,t)}_{f}$$

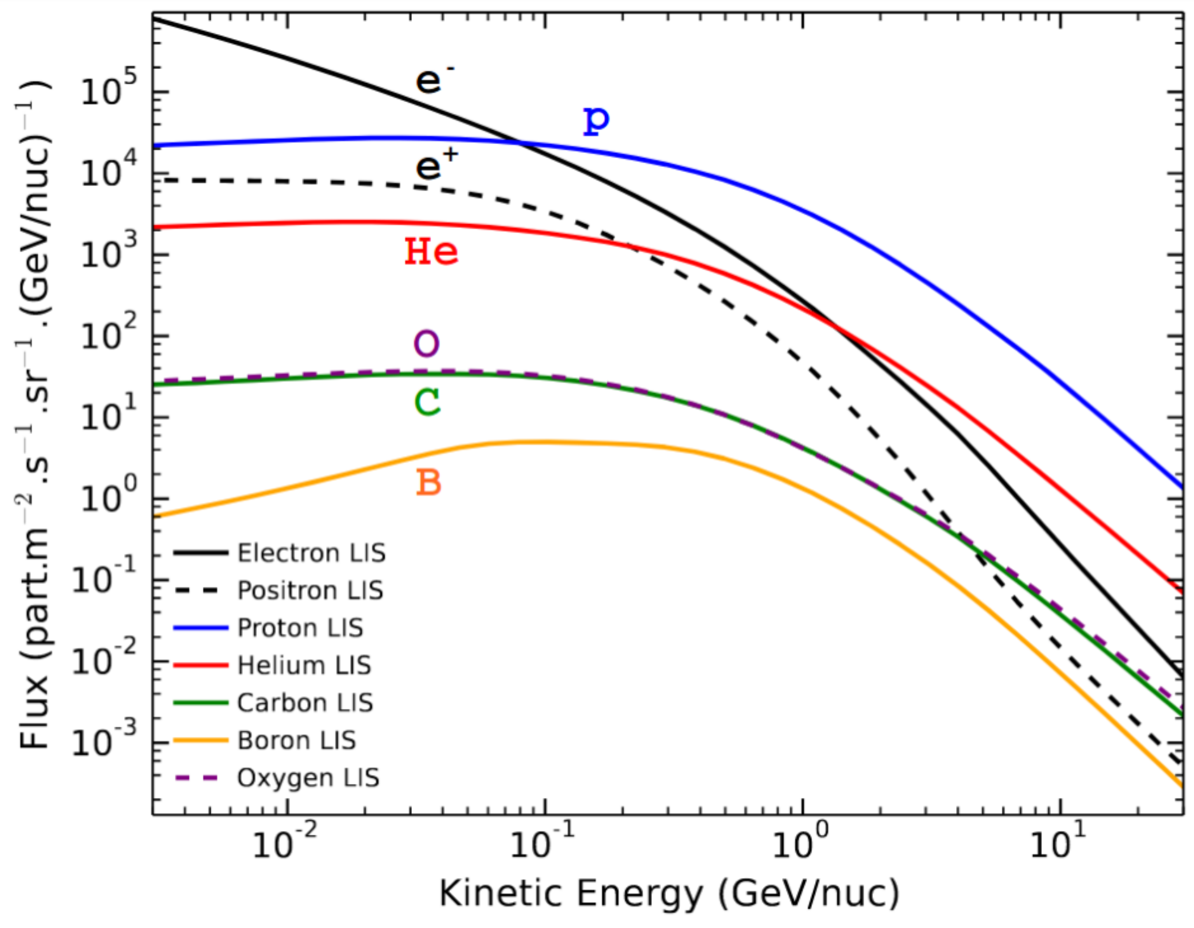
(a) $f(\mathbf{x},p,t)$, omnidirectional function distribution of CRs; **(b)** convection with solar wind **V**; **(c)** diffusion by magnetic field irregularities; **(d)** drift, curvature and gradient in magnetic field; **(e)** adiabatic energy losses; **(f)** local sources (Jovian electrons);

Heliosphere: ideal environment to test the theory for propagation of charged particles under conditions which well approximate cosmic condition.



credit: ESA

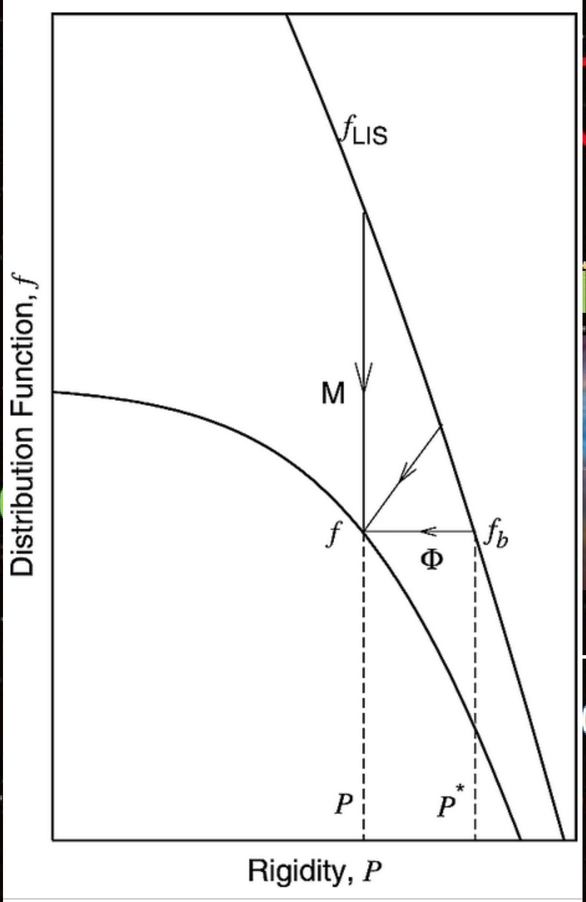
Cosmic inside Heliosphere: a full 3D numerical model



- LIS (Local Interstellar Spectrum): cosmic ray intensity outside the heliospheric boundary
- Based on propagation model (GALPROP) and Voyager data
- Parameter set to reproduce low energy Voyager data and high energy PAMELA and AMS02 data (proton, electron, boron/carbon ratio)

credit: ESA

Force field vs 3D numerical model

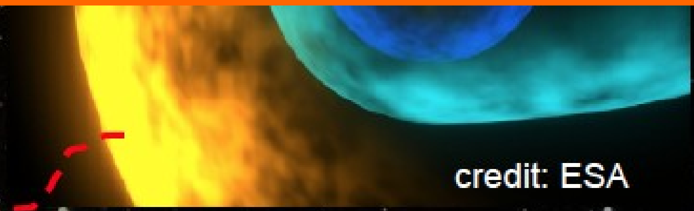


Force field:

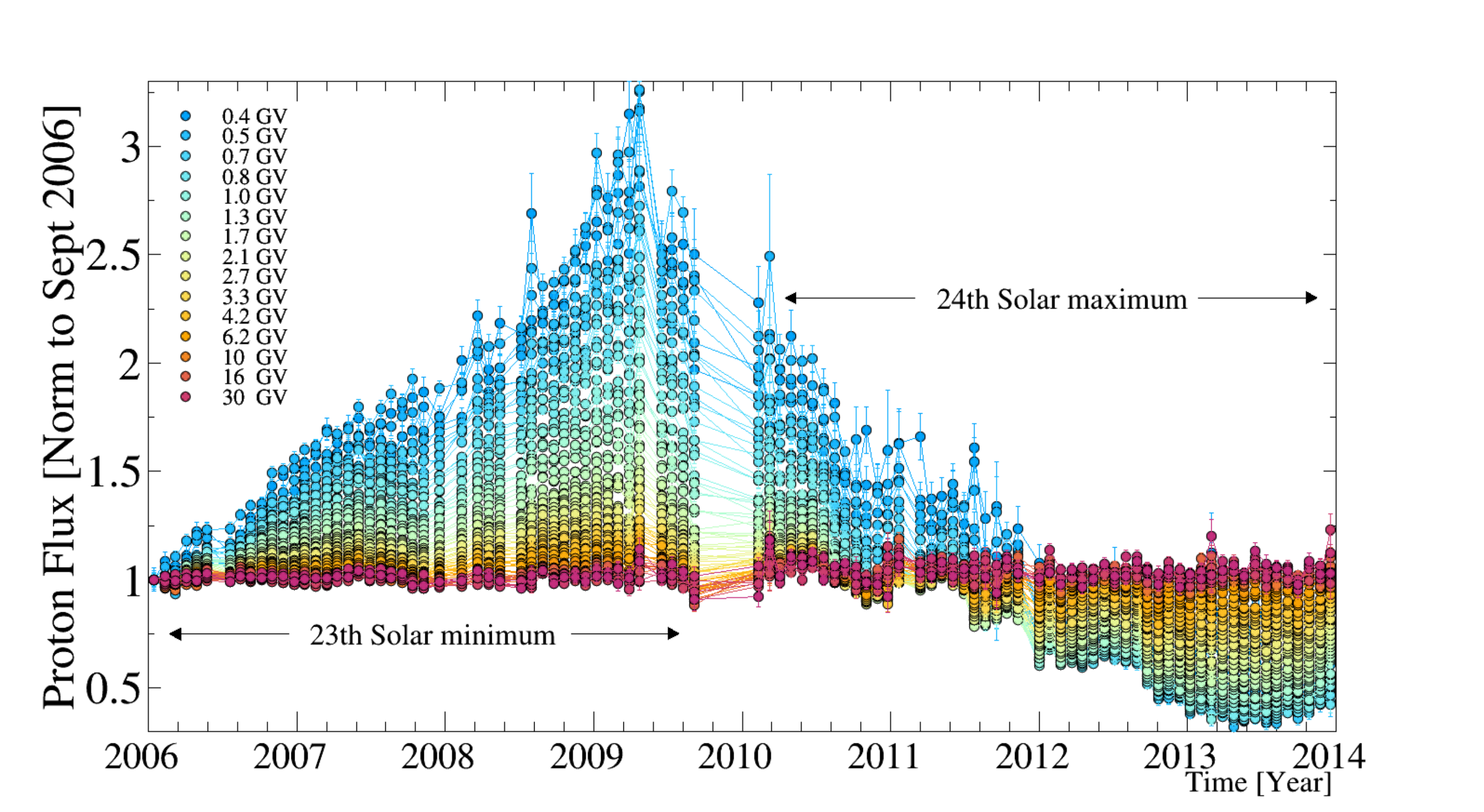
- No physical meaning in there;
- Works only at 1 AU;
- Works only for protons;
- No charge sign dependence;

Numerical model:

- All the propagation mechanisms;
- Works at every heliosphere location;
- Works for all the particles;
- Charge sign dependence;



Propagation in the Heliosphere: protons over a solar cycle



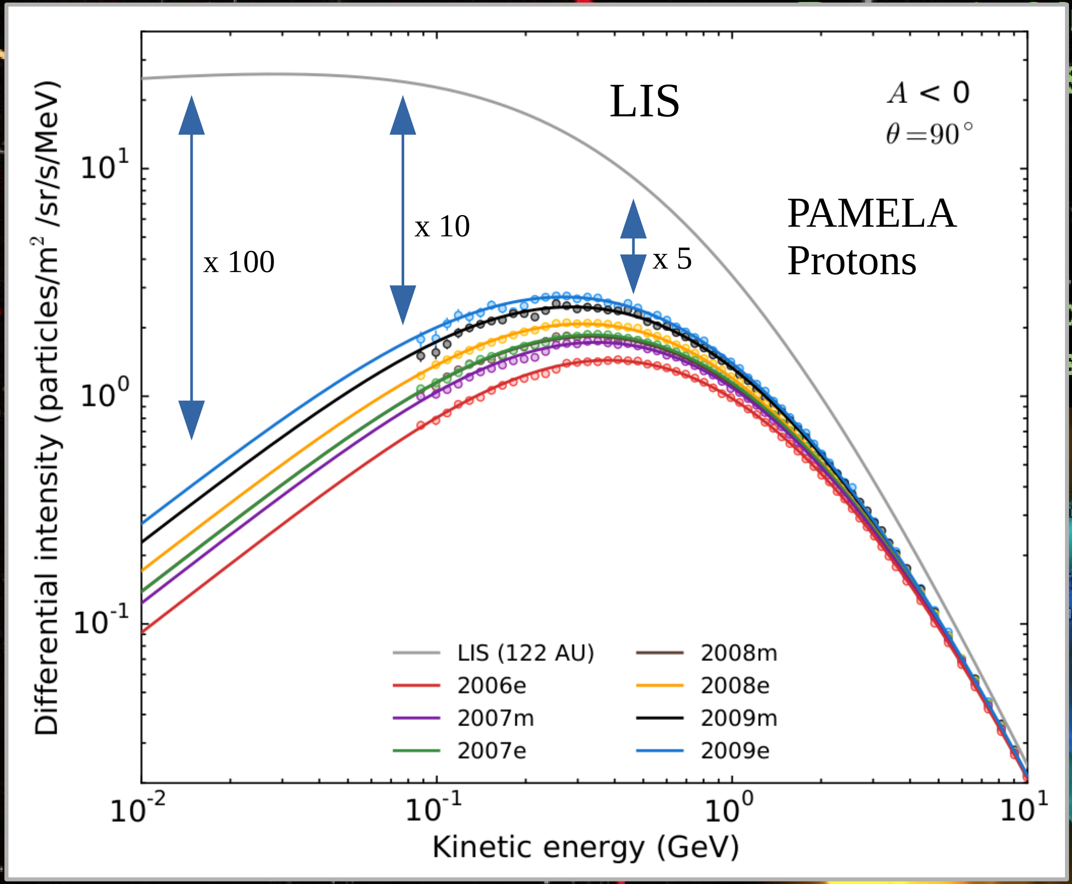
Adriani, O. et al. 2017, NUOVO CIMENTO, 40, 473

credit: ESA

Protons modulation modeling

ung, Synchrotron,
se Compton

CR secondary production
(pp → X)



EE Vos, P.h.d thesis, 2016

olar Modulation, lower
stellar cosmic ray spectra

credit: ESA

Protons modulation modeling

e⁻

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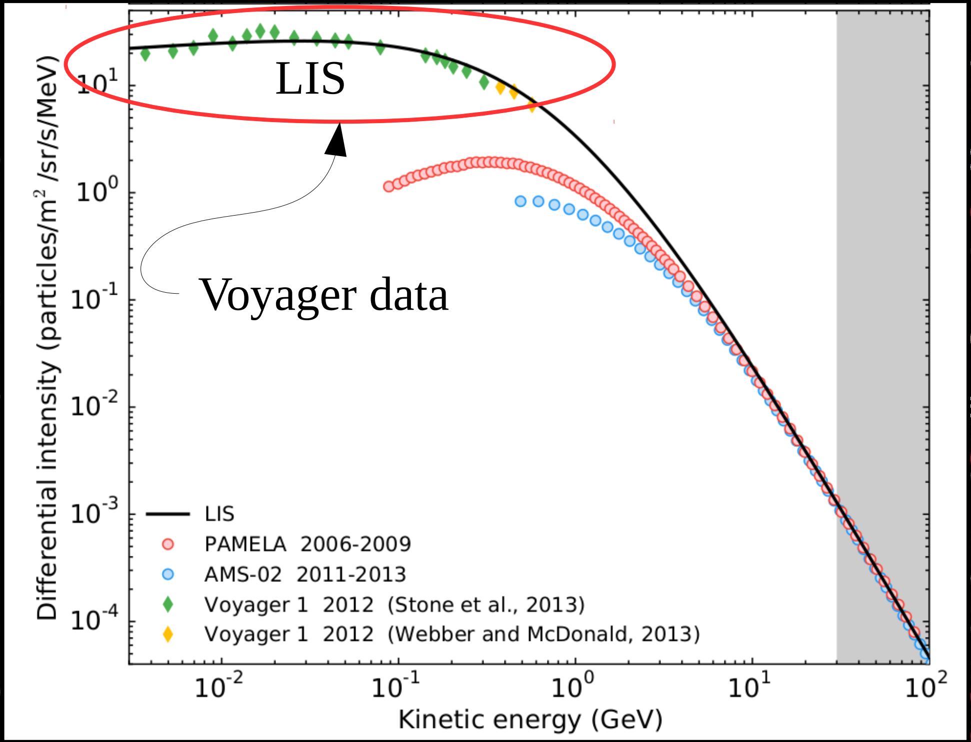


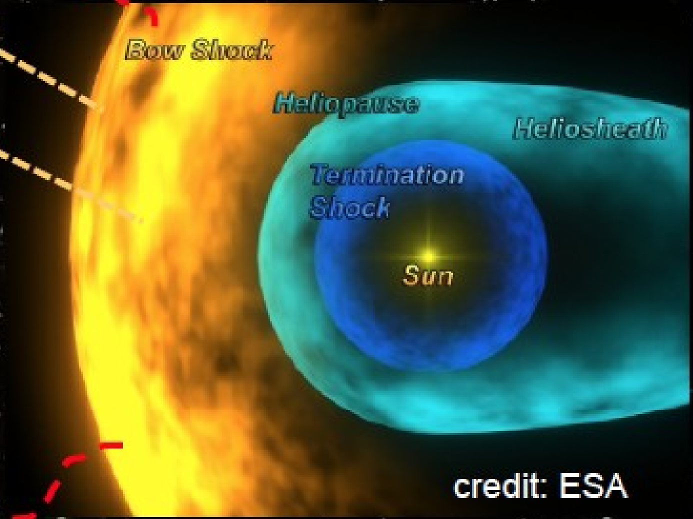
O. Adriani et al., ApJ 765 (2013) 91

e⁻ e⁺

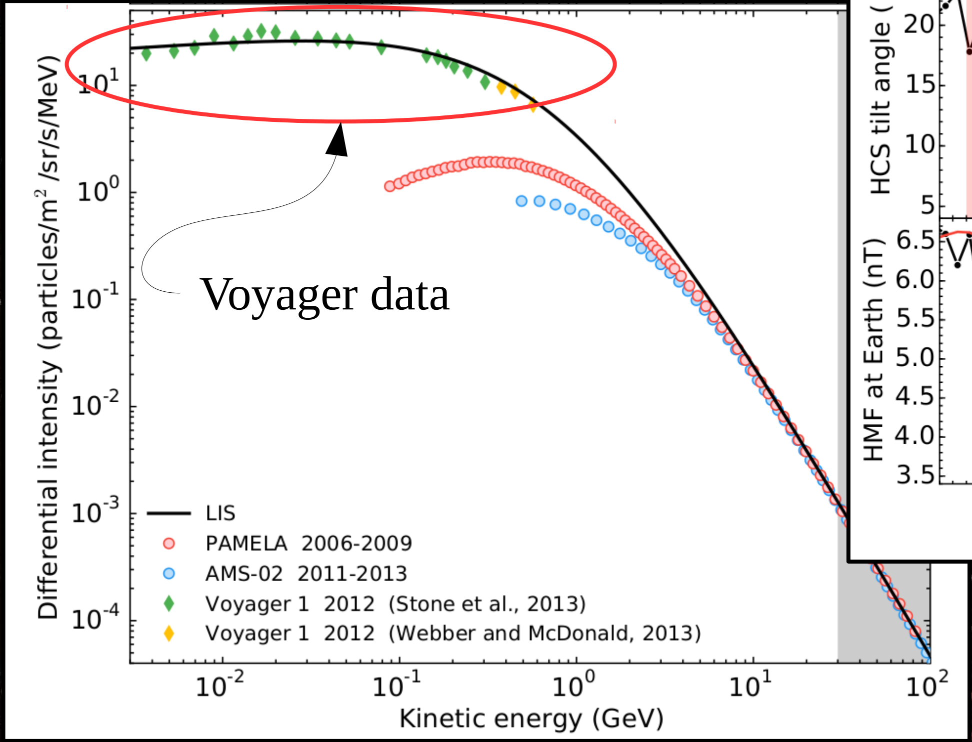
Bremsstrahlung, Synchrotron, Inverse Compton

γs

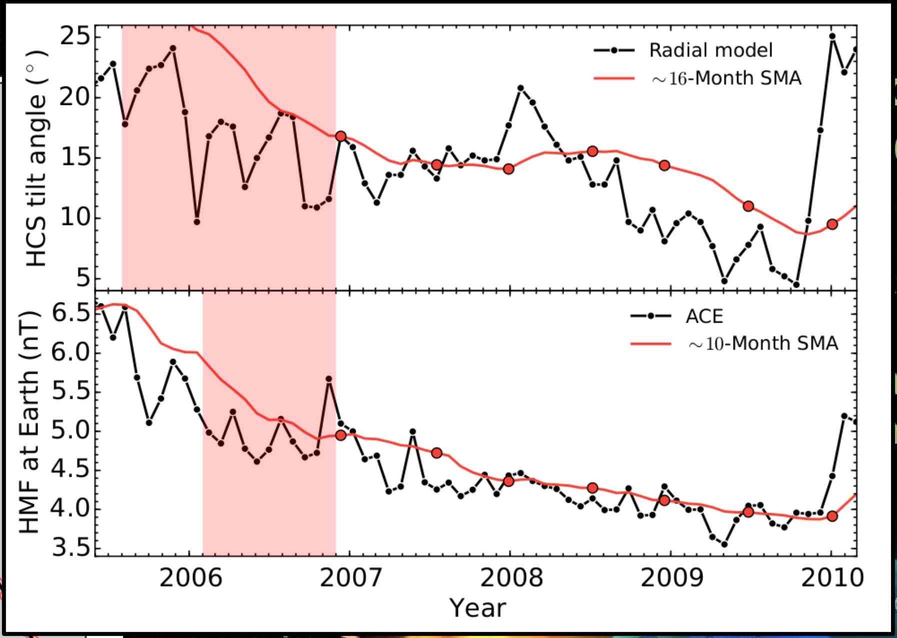
Solar Modulation, lower interstellar cosmic ray spectra

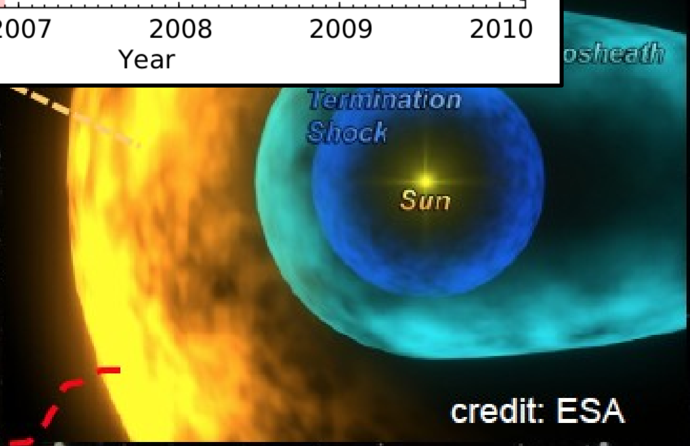


Protons modulation modeling

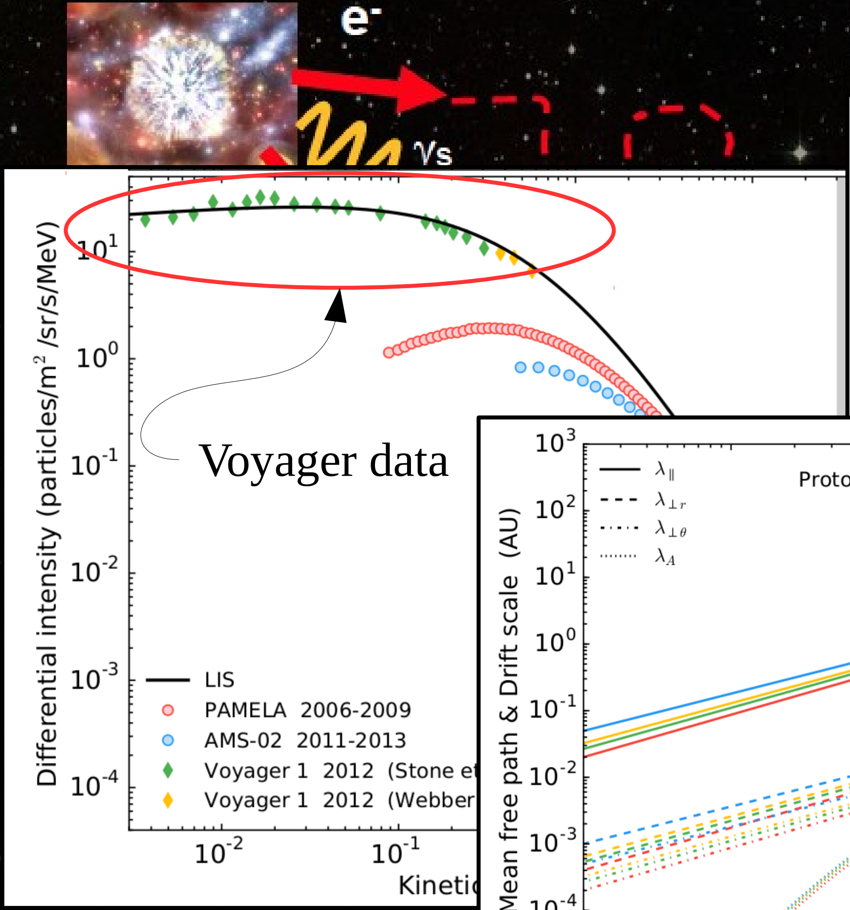


O. Adriani et al., ApJ 765 (2013) 91

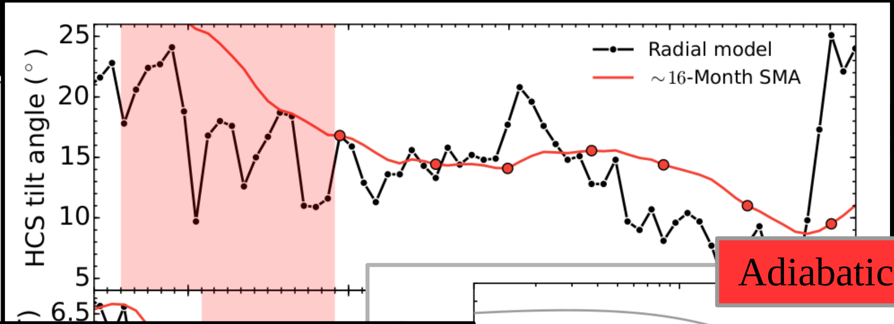


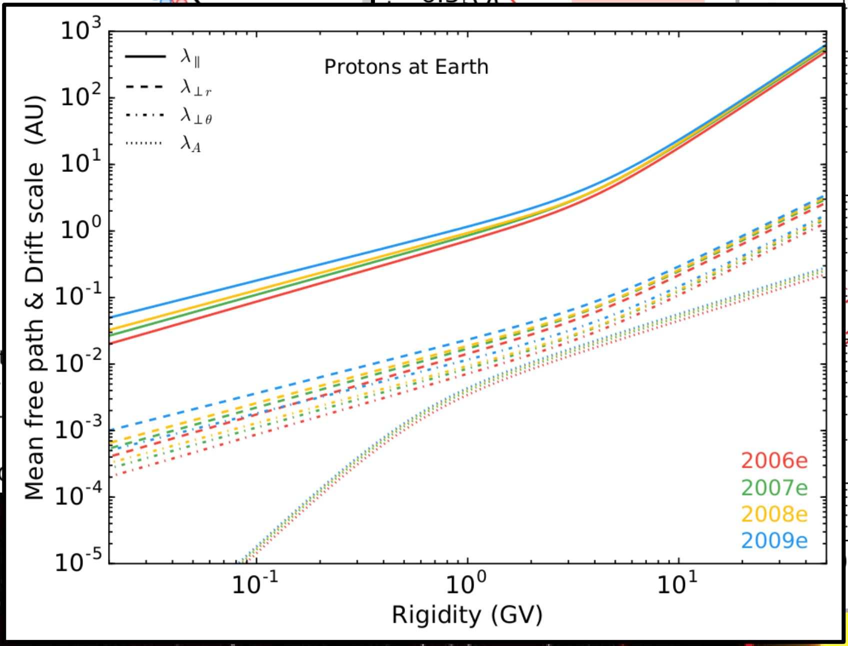


Protons modulation modeling

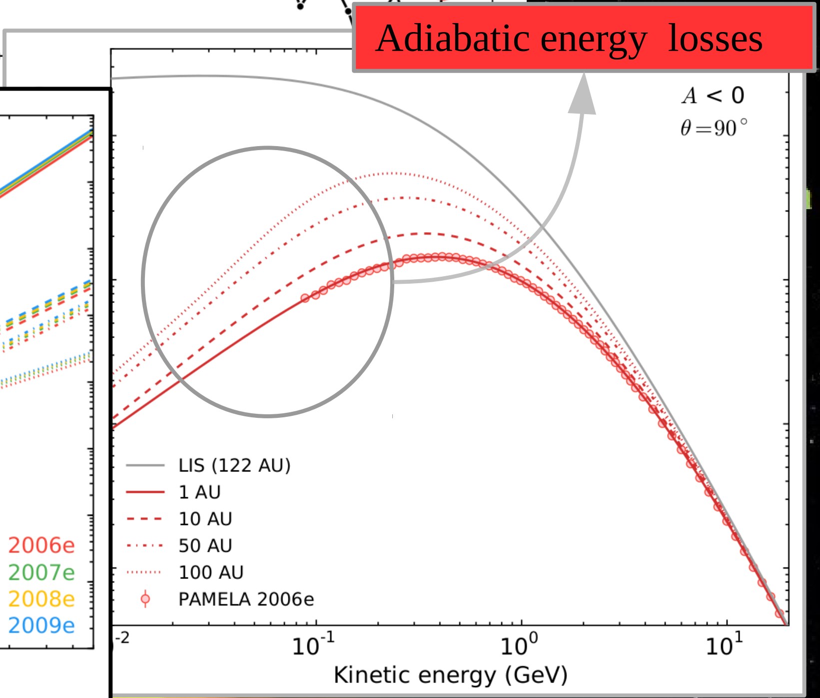


O. Adriani et al., ApJ 765 (2013) 91





M. S. Potgieter et al., Solar Phys 289 (2014)



credit: ESA

Electron modulation modeling

Synchrotron,
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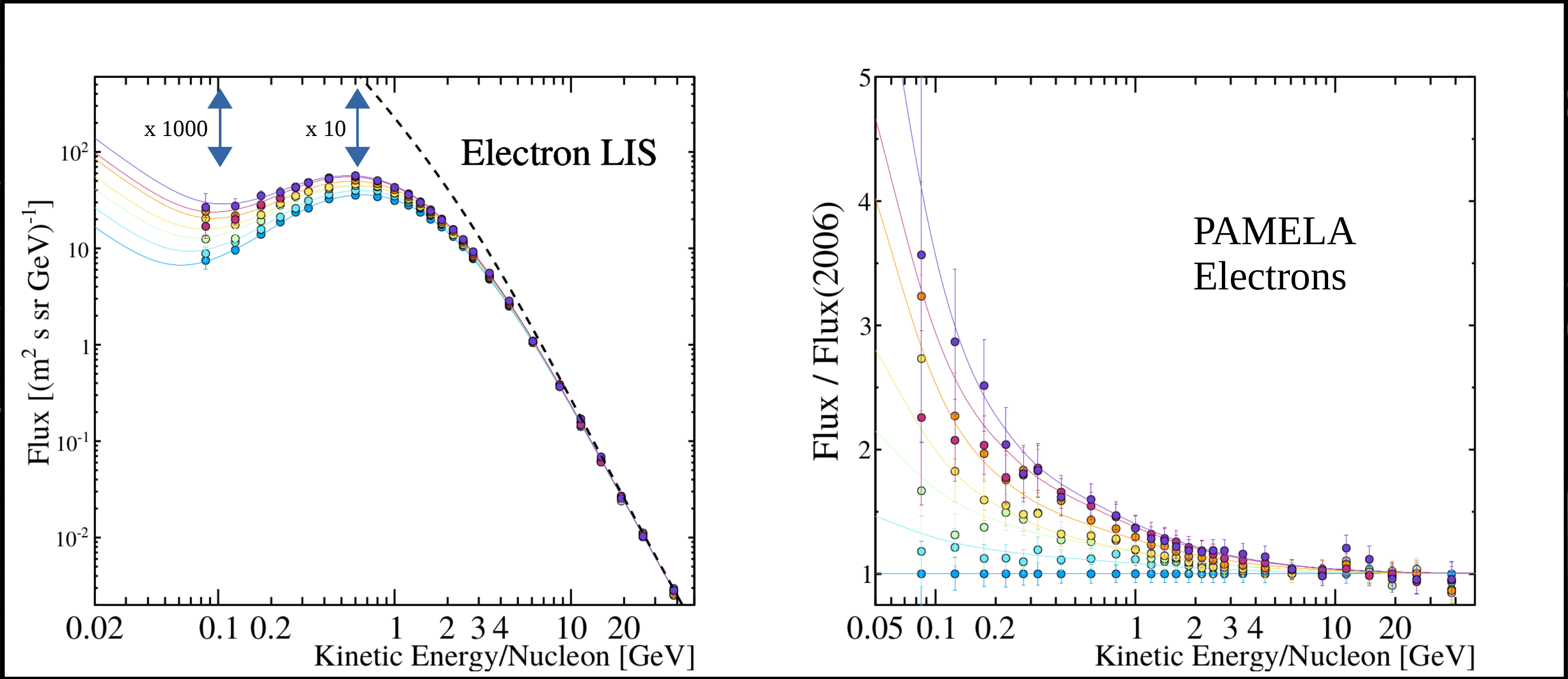
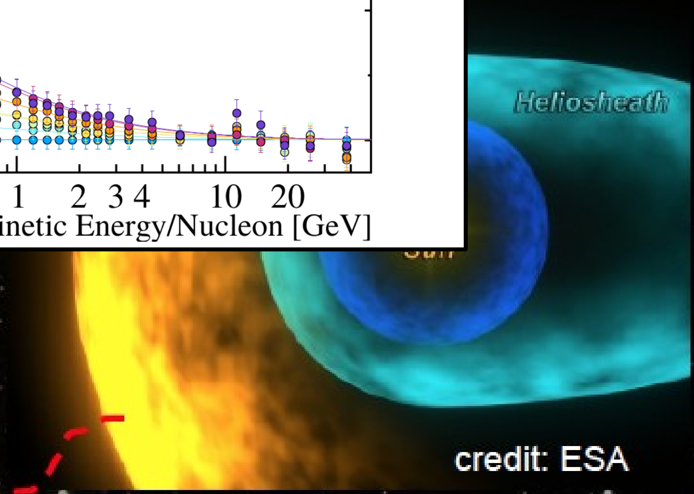
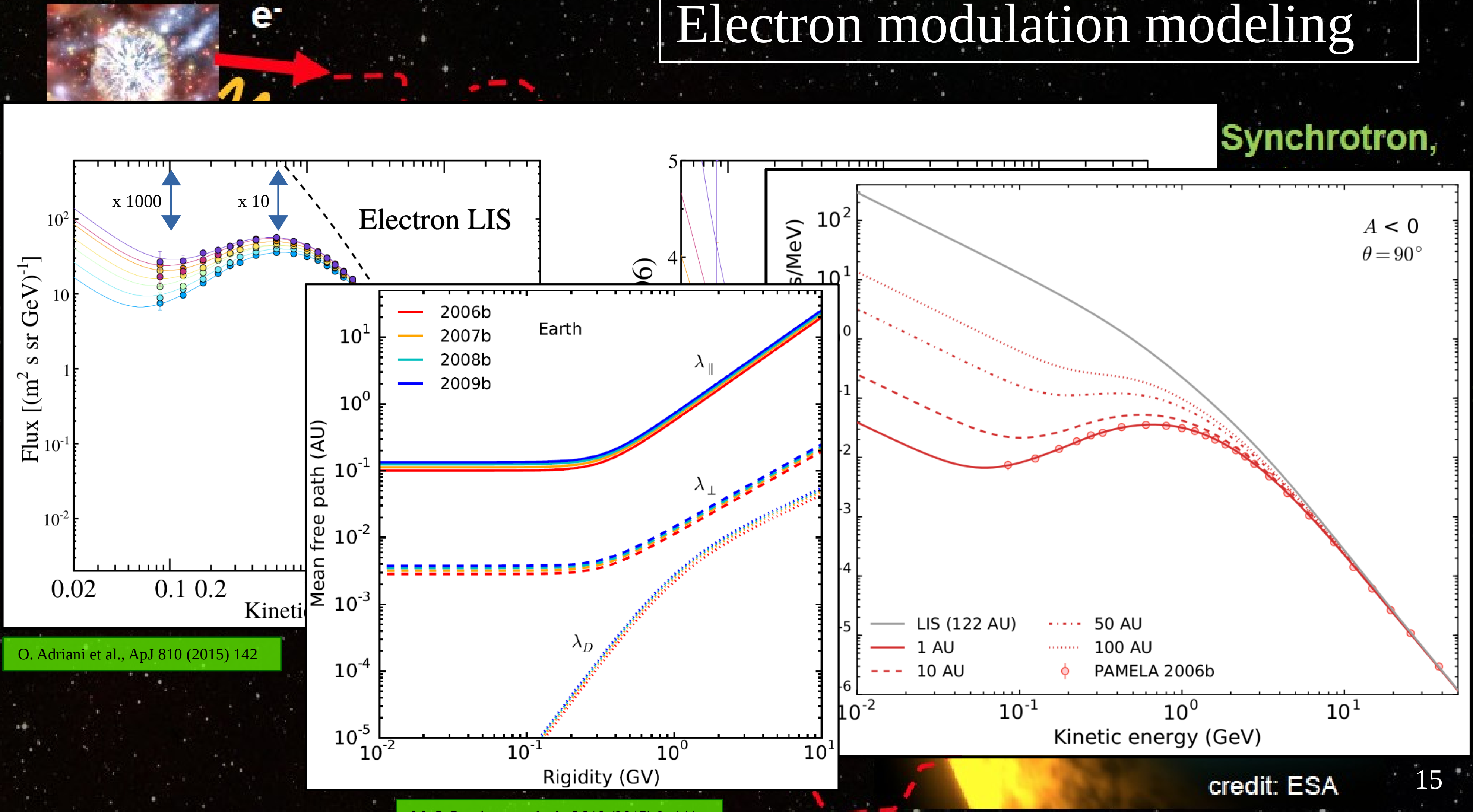
... cosmic ray spectra



O. Adriani et al., ApJ 810 (2015) 142



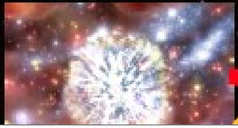
Electron modulation modeling

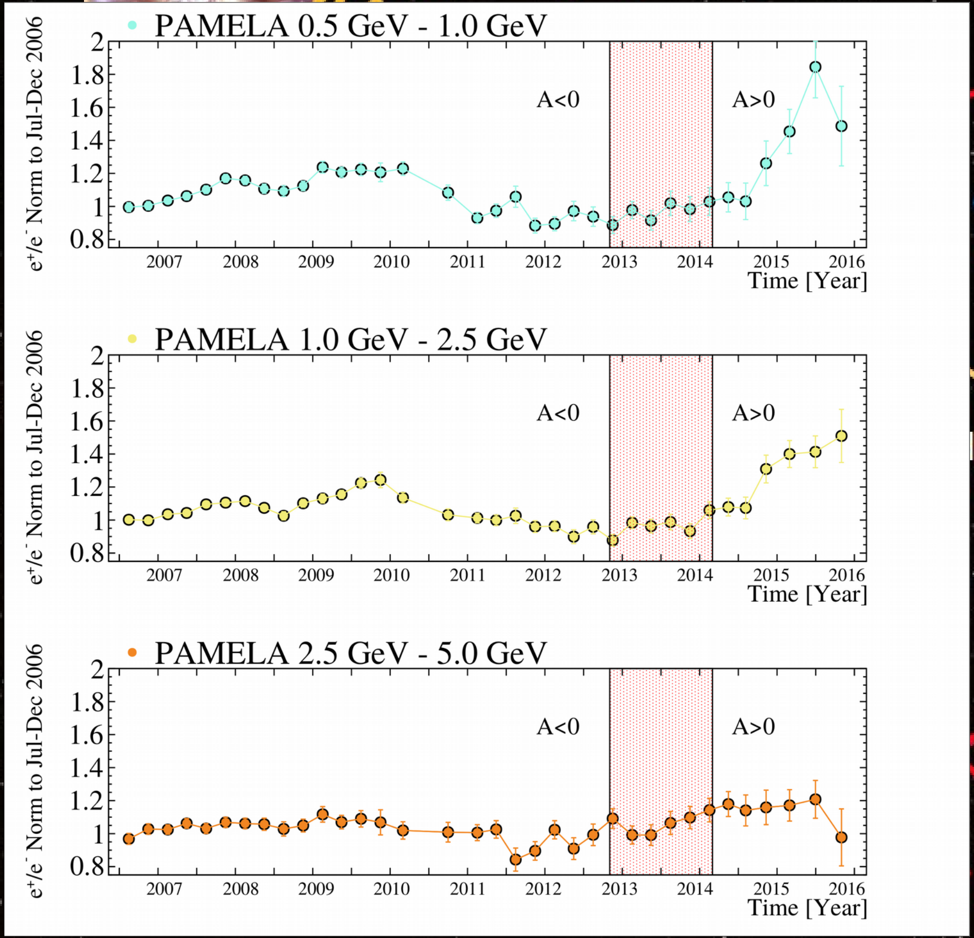


O. Adriani et al., ApJ 810 (2015) 142

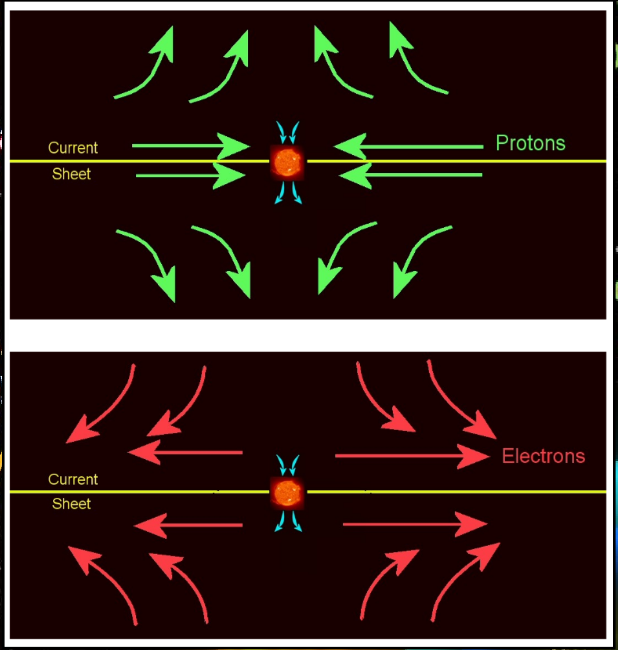
M. S. Potgieter et al., ApJ 810 (2015) 2, 141.

e+ Propagation through Heliosphere: charge sign dependence





O. Adriani et al., PRL 116 (2016) 241105



Bremsstrahlung, Synchrotron,
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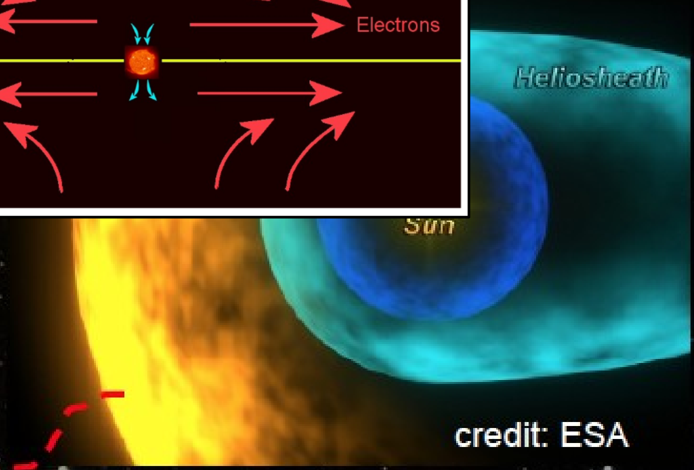
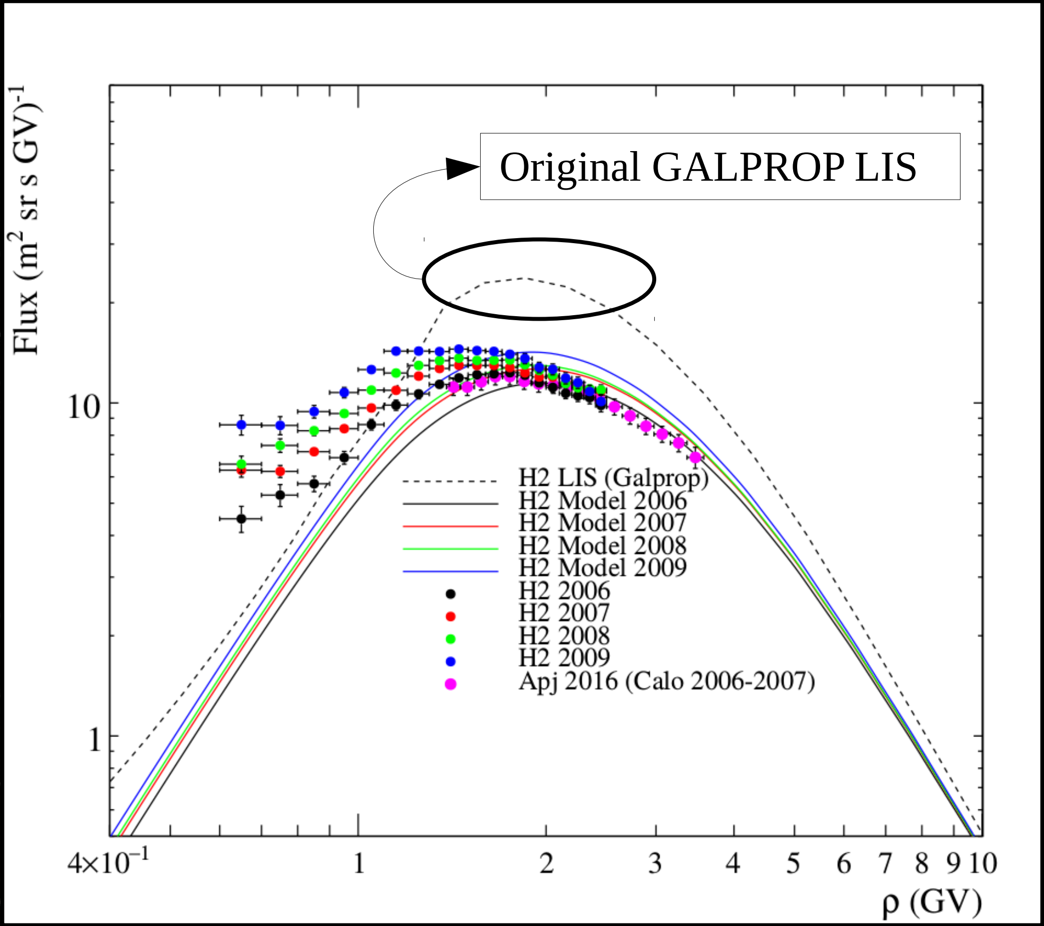
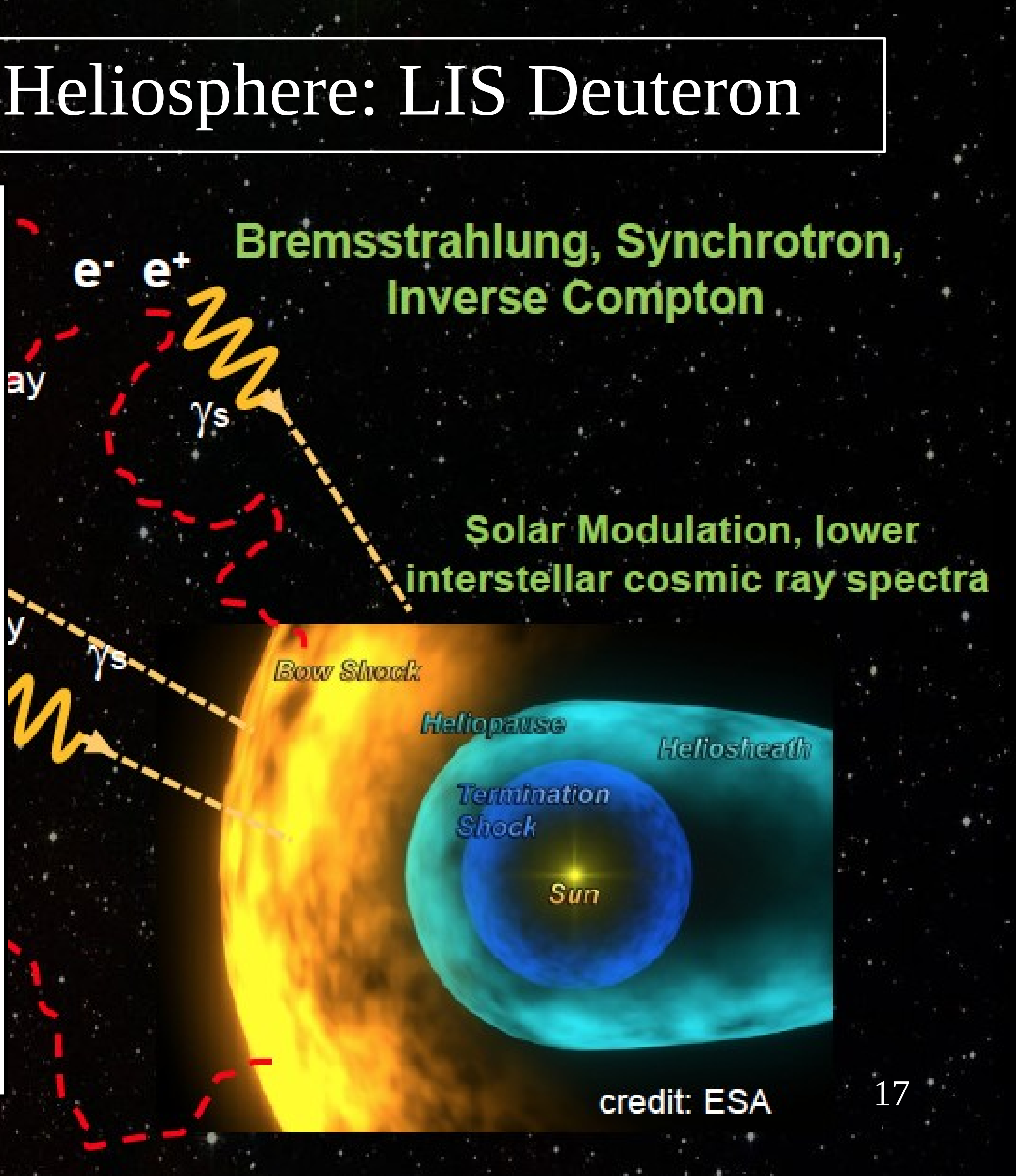
odulation, lower
cosmic ray spectra

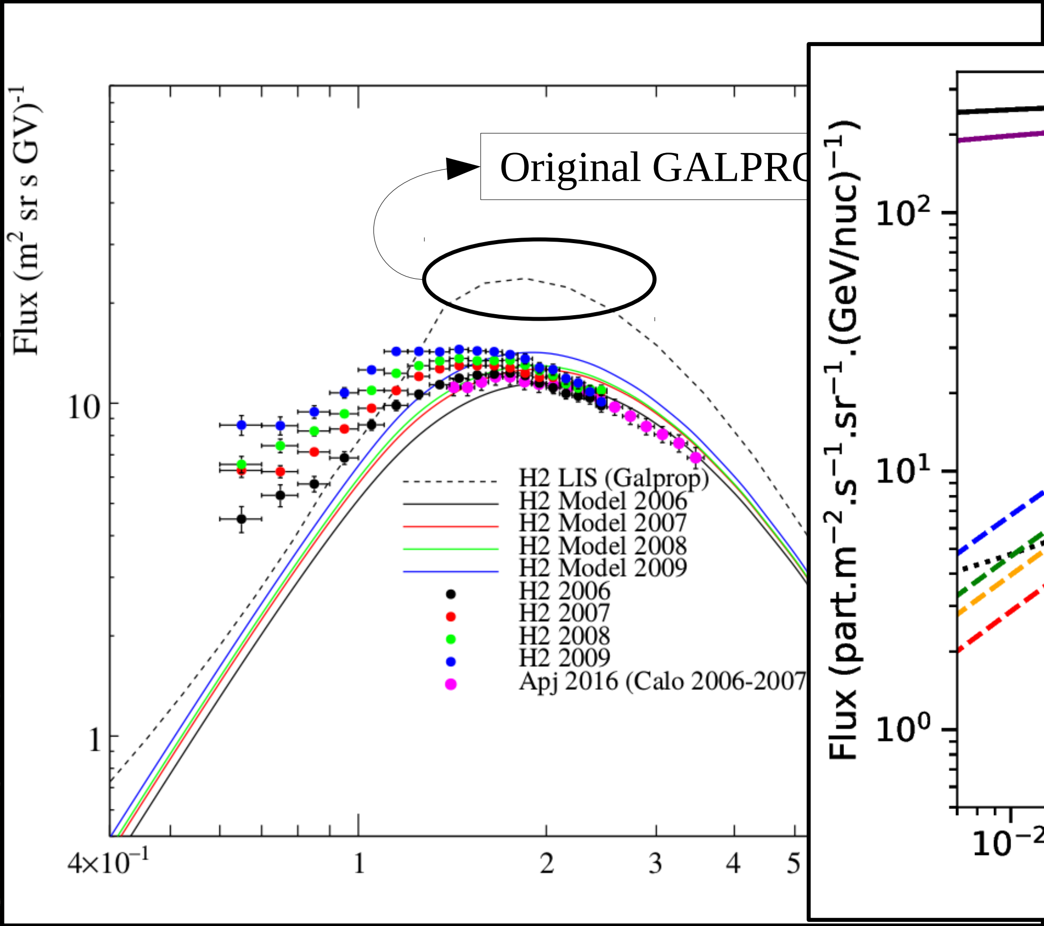


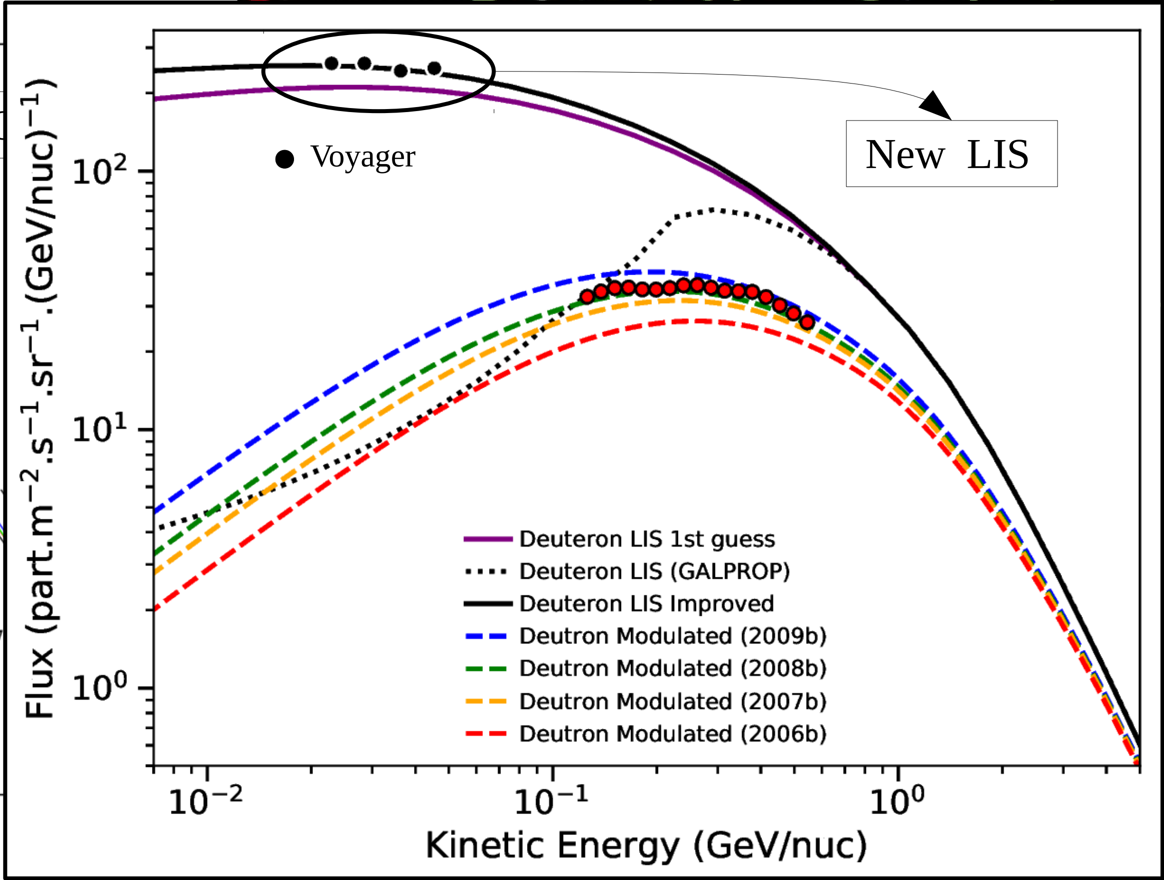
Propagation in the Heliosphere: LIS Deuteron





Propagation in the Heliosphere: LIS Deuteron

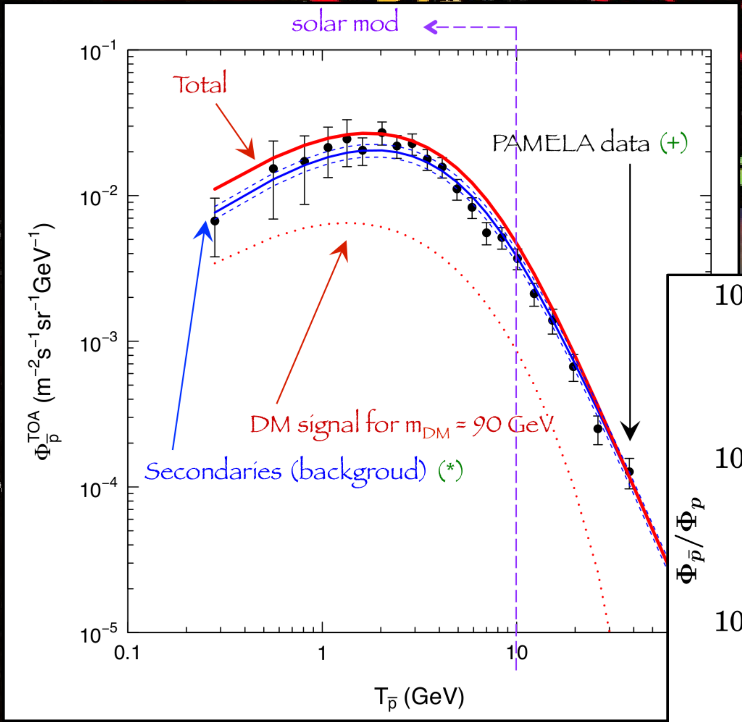




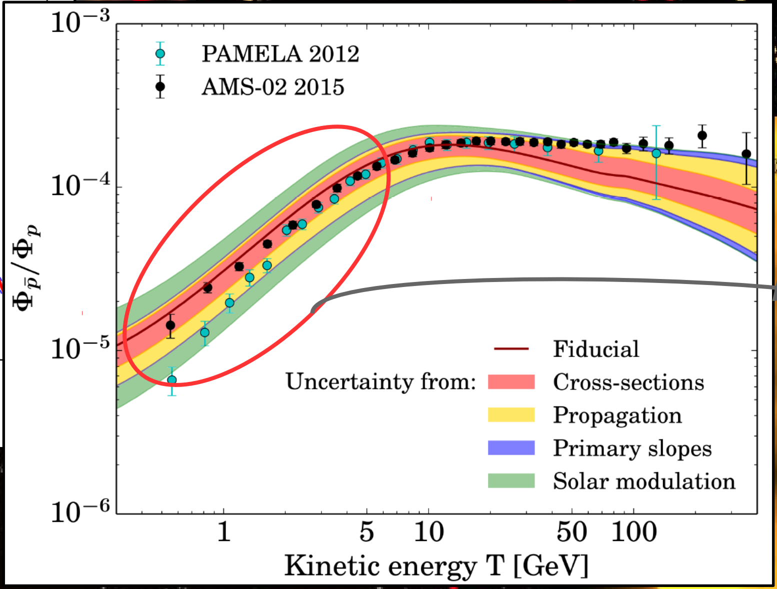
credit: ESA

Propagation in the Heliosphere and dark matter

Low energy CR from dark matter annihilation: Antiproton



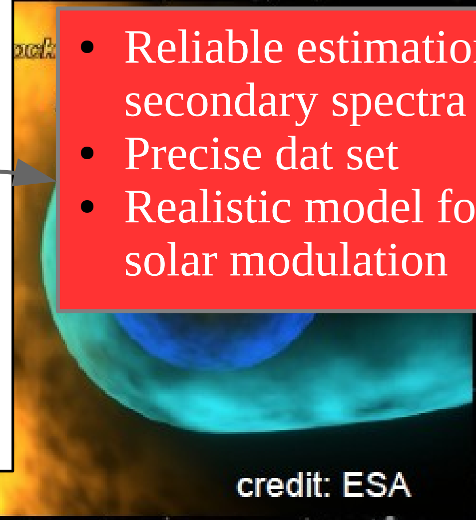
Donato, Maurin, Brun, Delahaye, Salati, PRL 102 (2009) 07130



G. Giesen,et. al, JCAP 1509 (2015) 09

Astrophysical background, of the order of the secondaries…

- Reliable estimation of secondary spectra
- Precise dat set
- Realistic model for solar modulation



Propagation in the Heliosphere: Antiproton LIS

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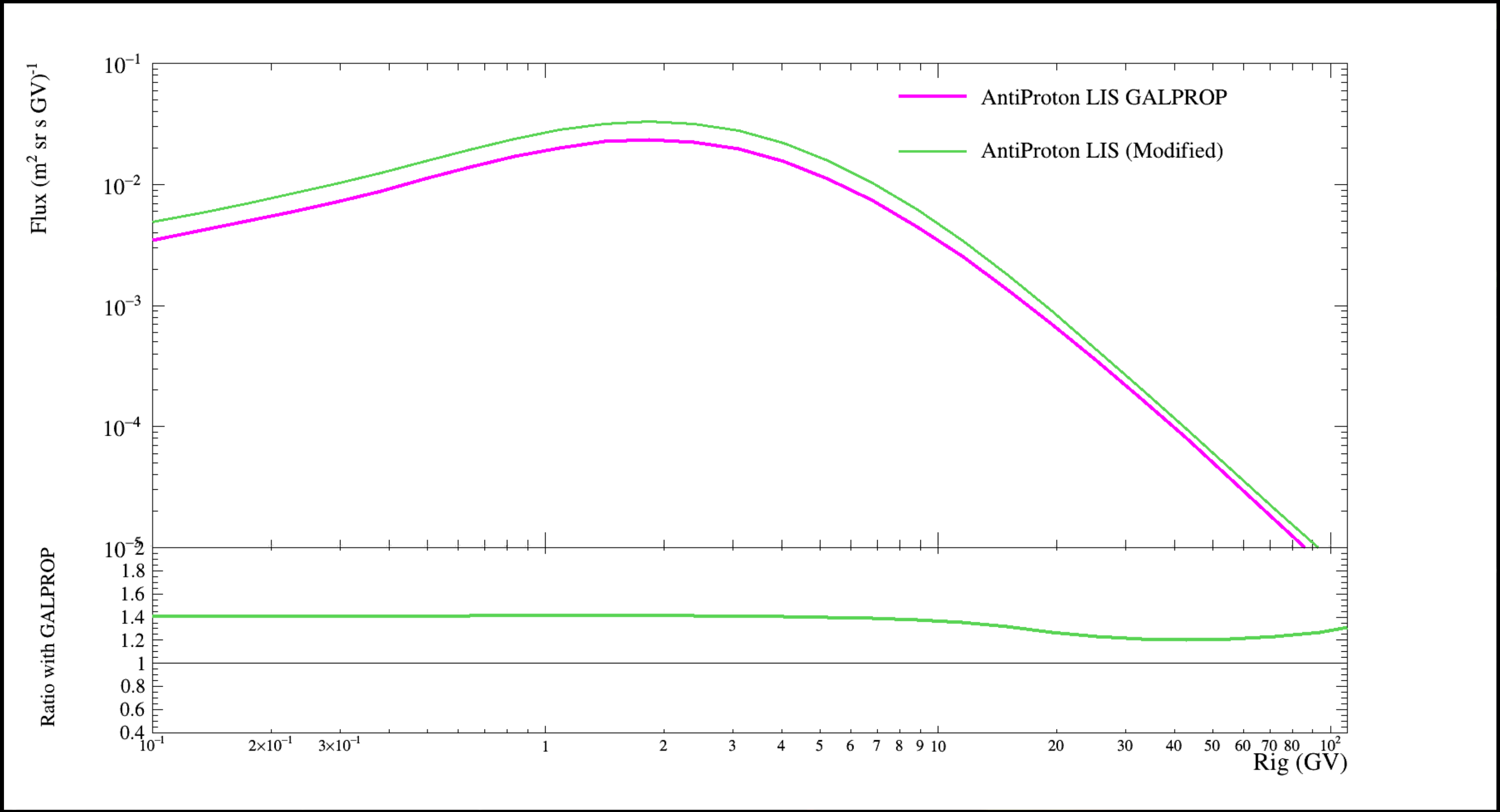
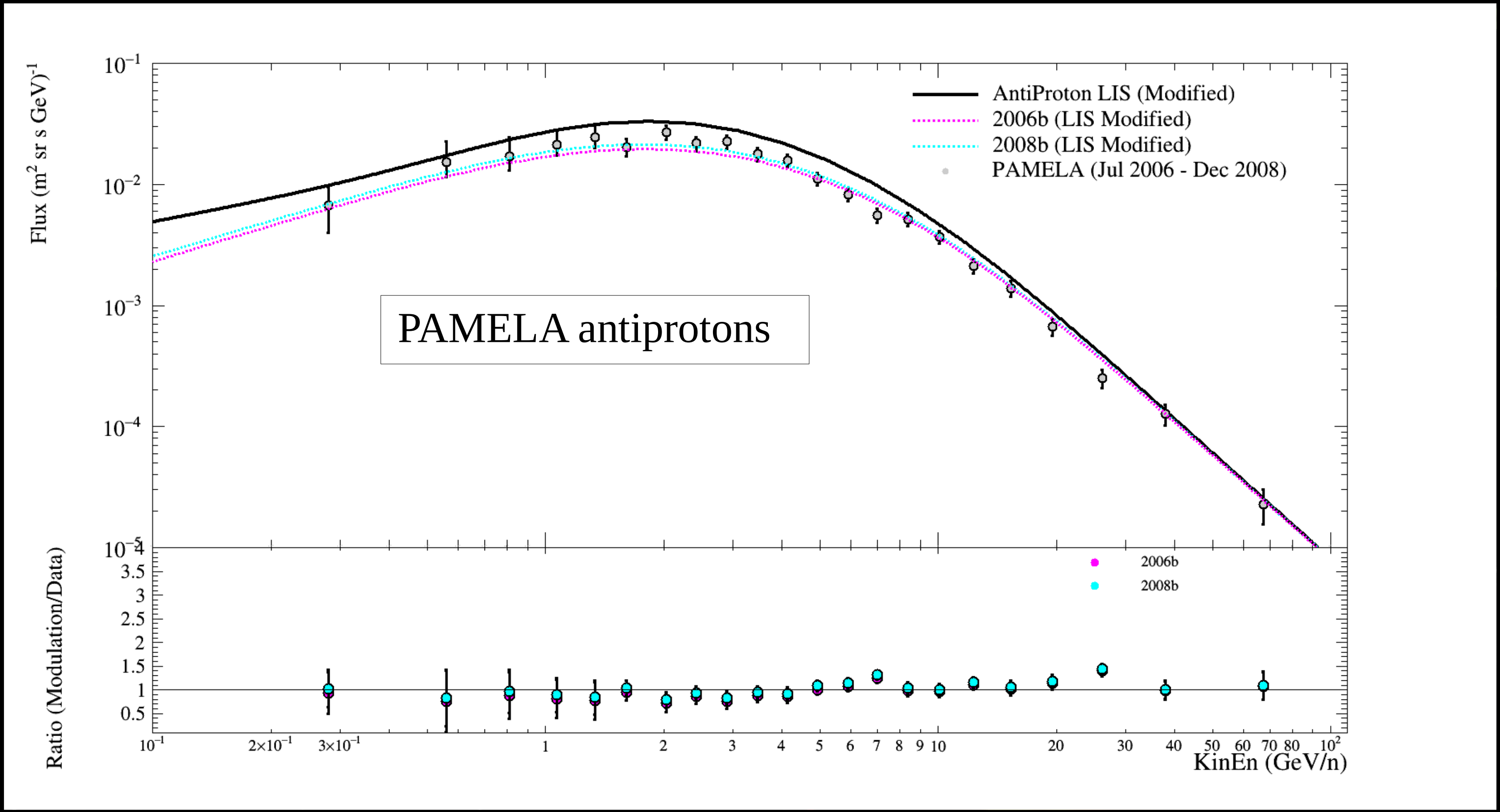
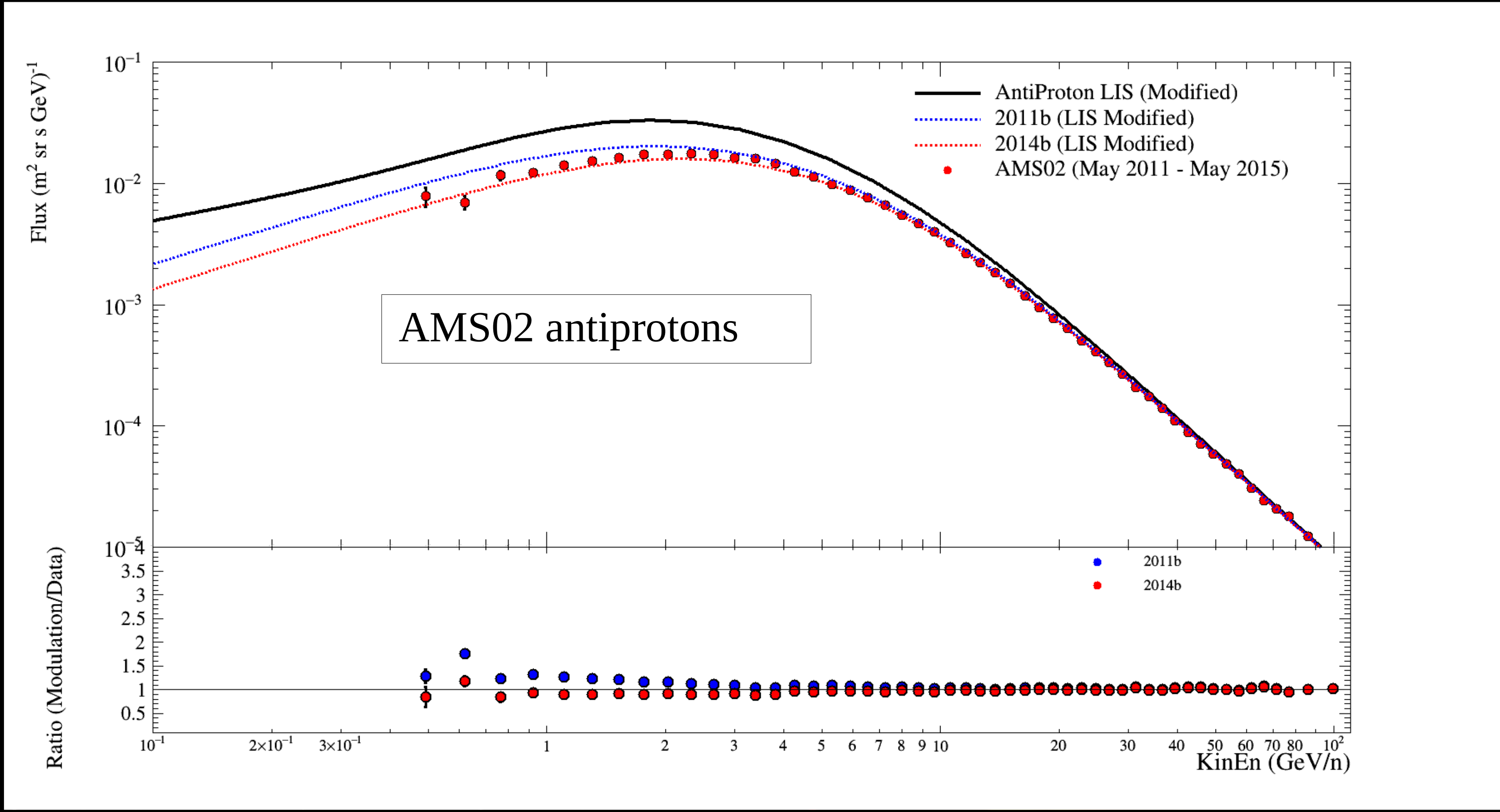


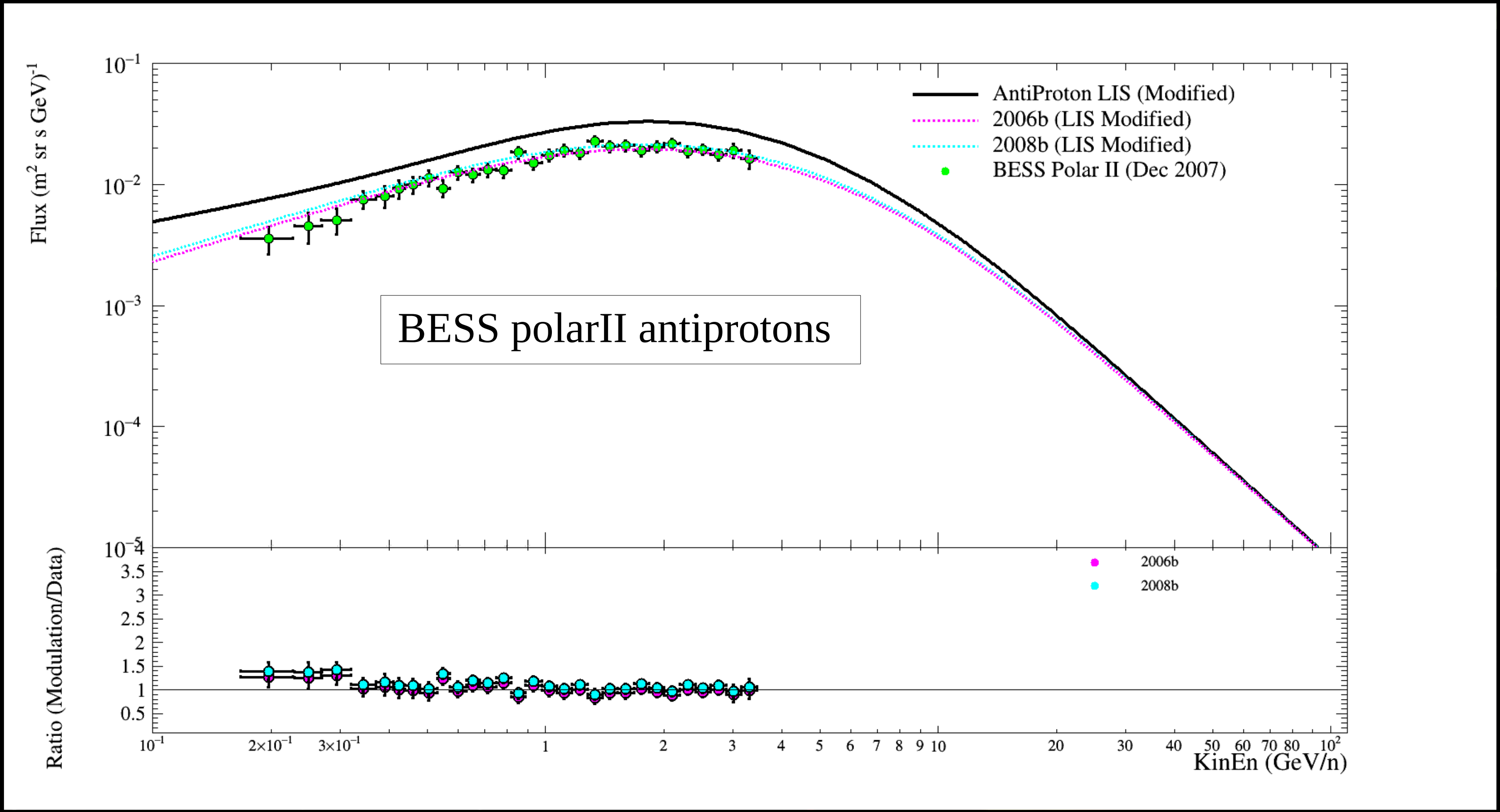
Propagation in the Heliosphere: Antiproton LIS



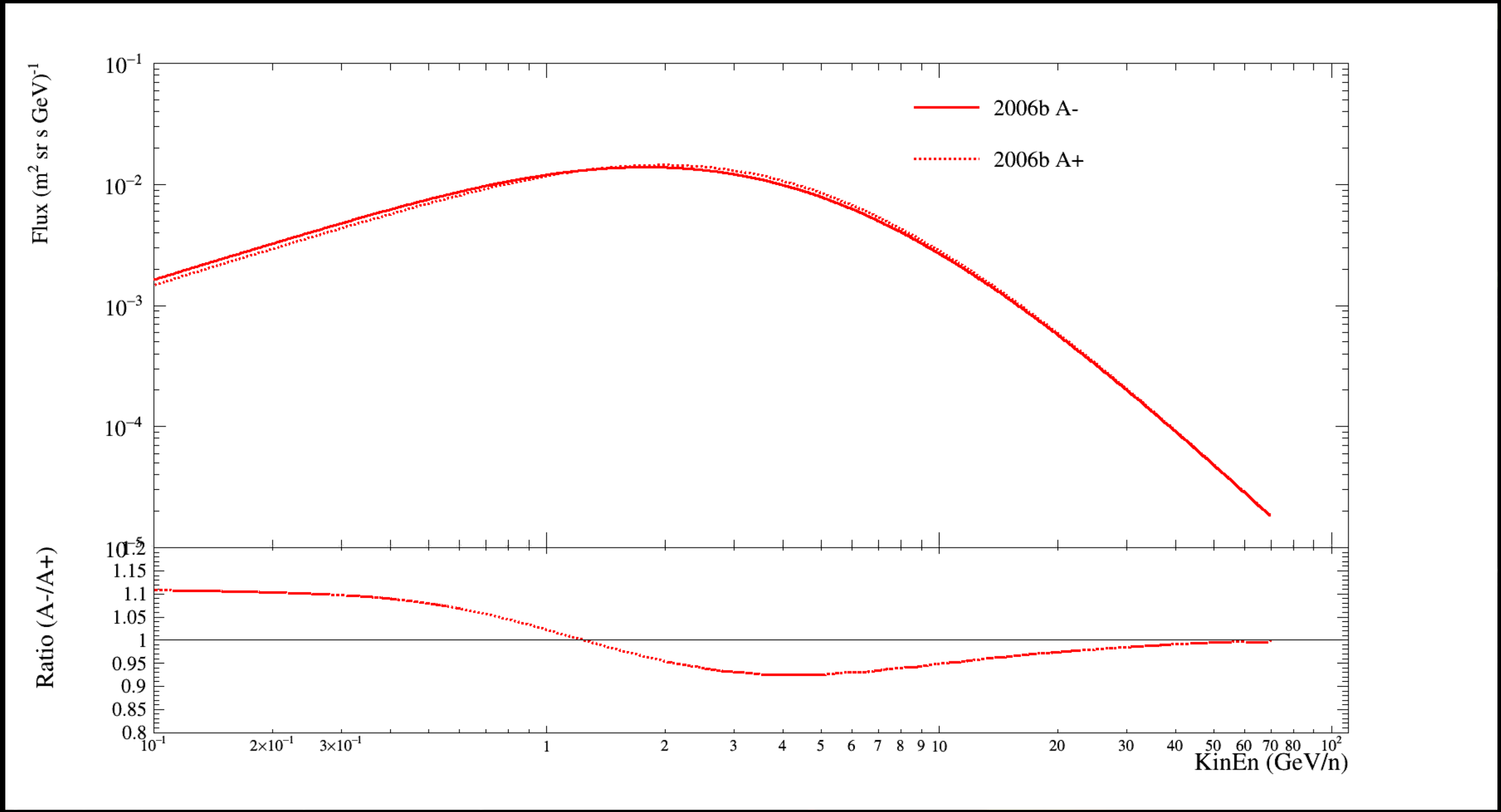
Propagation in the Heliosphere: Antiproton LIS



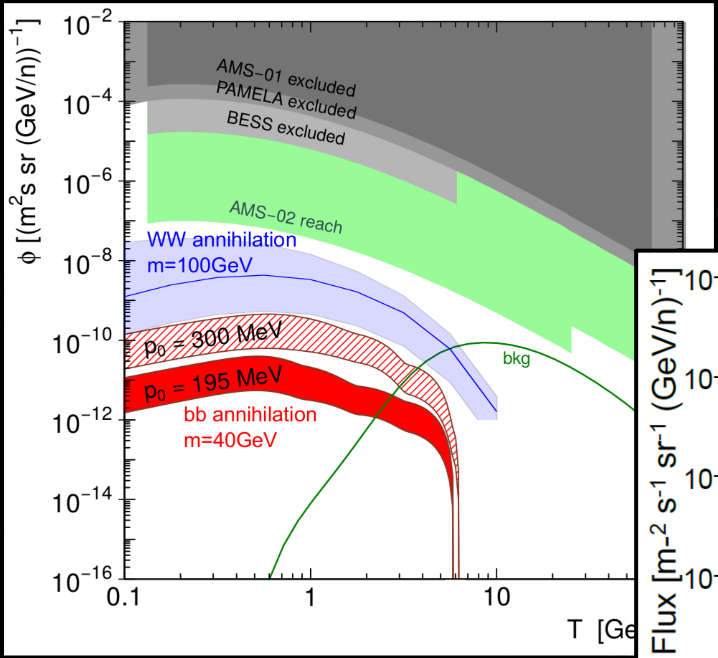
Propagation in the Heliosphere: Antiproton LIS

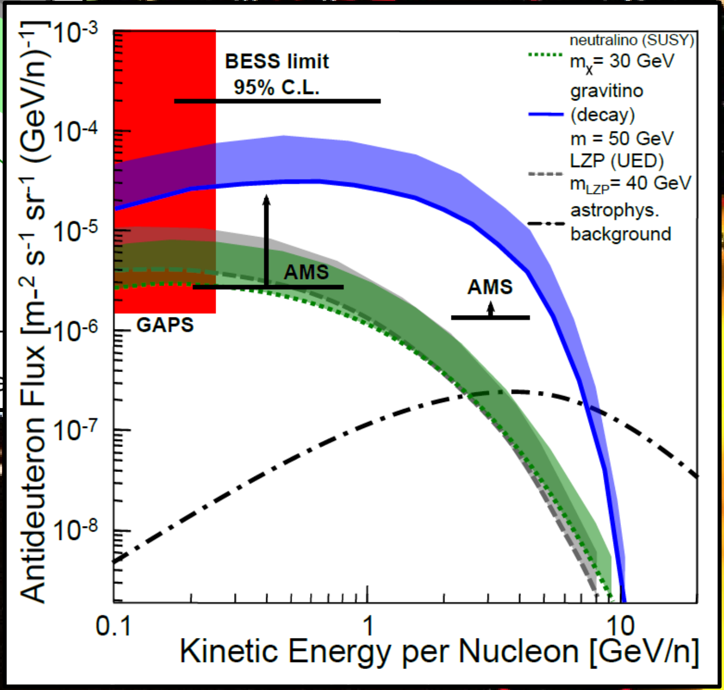


Propagation in the Heliosphere: charge sign effect



Propagation in the Heliosphere and dark matter





Low energy signals from dark matter annihilation: AntiDeuteron, antiHe

Very low astrophysical background, 2 orders of magnitude lower...

..in a region strongly affected by solar modulation, needs to improve the modelling in order to reduce the associated uncertainties.

credit: ESA

Propagation in the Heliosphere and dark matter

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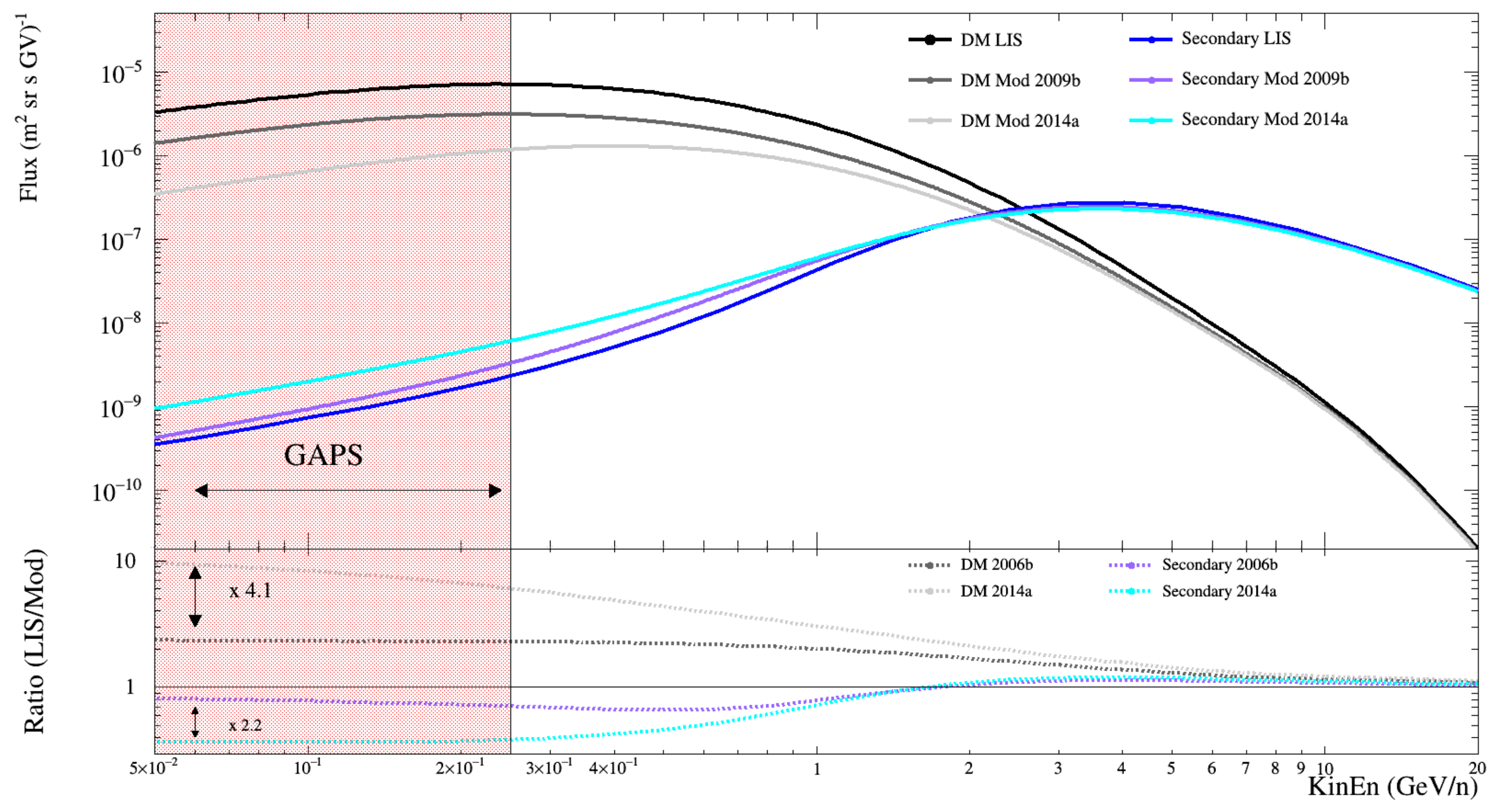
DM spectra provided by Michael Korsmeier, Phys. Rev. D 97, 103011 (2018)



Propagation in the Heliosphere and dark matter

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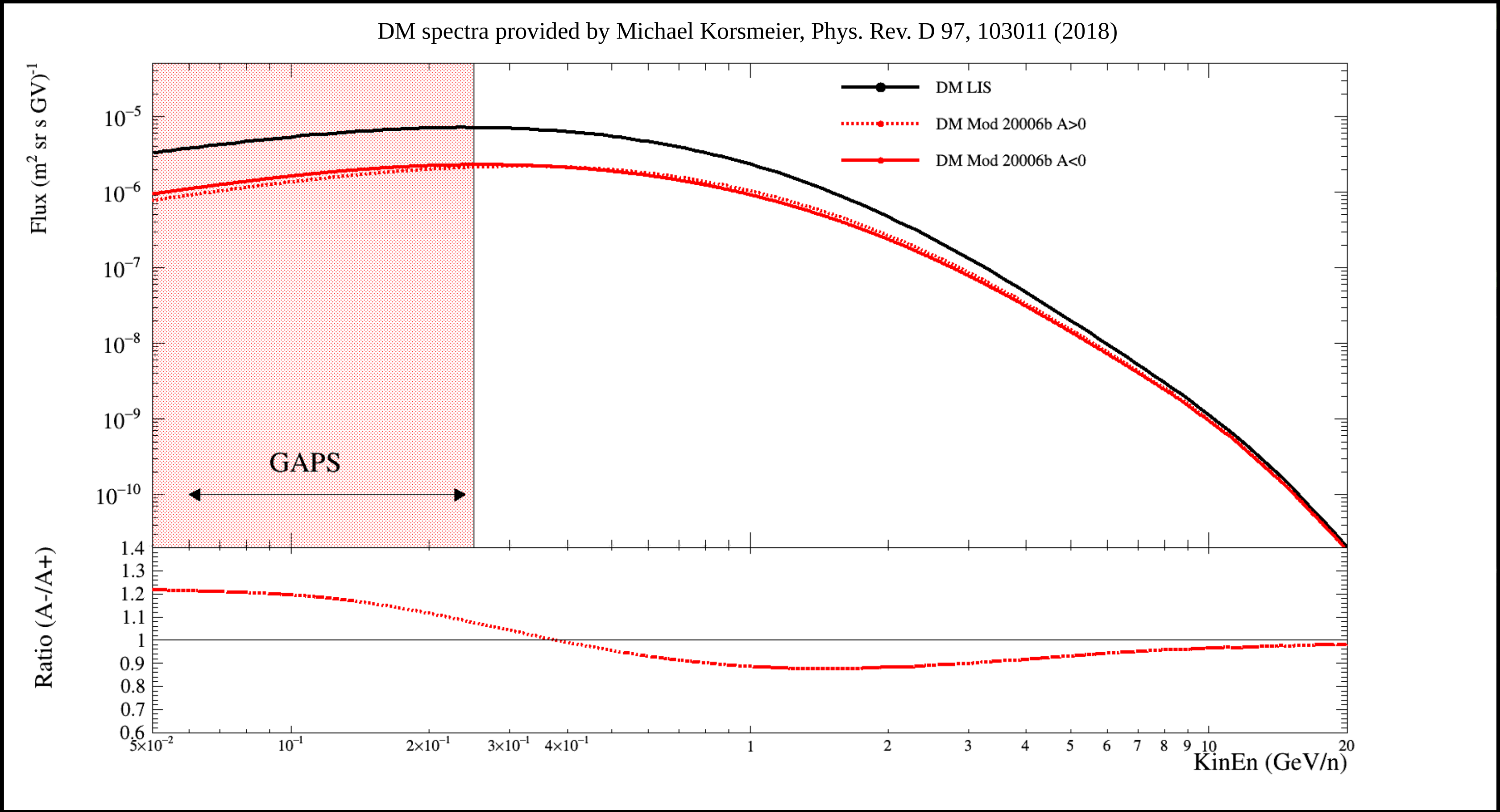
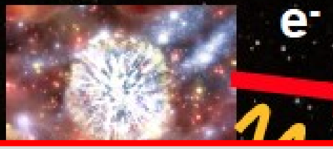
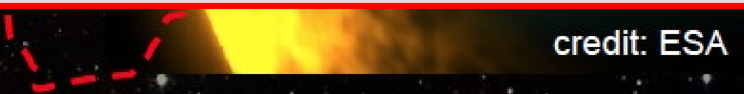


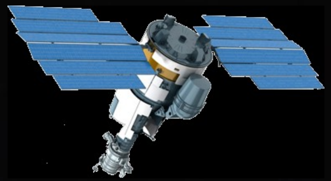


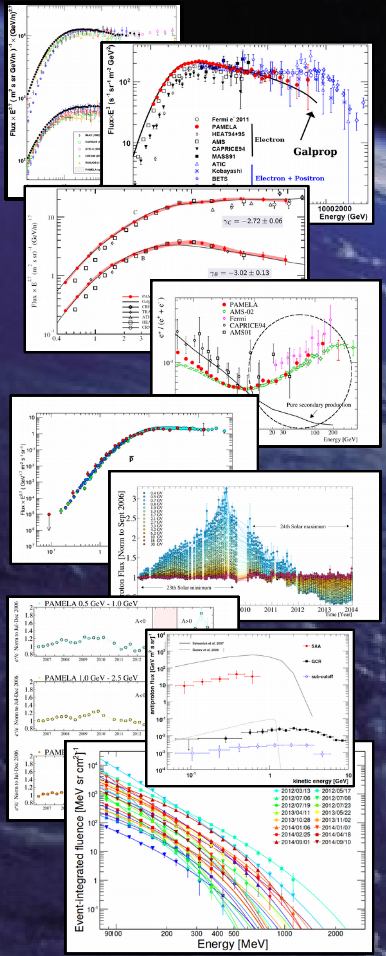
Conclusions

- PAMELA measured temporal variation on several particles species over a whole solar cycle
- This data are very important to test and calibrate propagation model of cosmic rays inside heliosphere
- Simple model like force field cannot be used in order to make precise and reliable studies of cosmic rays at the lowest energy
- Especially for antiparticle cosmic rays the charge sign dependence has to correctly take into account
- In this context indirect search of dark matter with low energy cosmic rays needs sophisticated model for solar modulation
- More study in order to give reliable uncertainties related to solar modulation which could depend from the different epochs of solar activity.



Ten years of PAMELA data





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The PAMELA Mission: Heralding a new era in precision cosmic ray physics

O. Adriani[a,b], G.C. Barbarino[c,d], G.A. Bazilevskaya[e], R. Bellotti[f,g], M. Boezio[h], E.A. Bogomolov[i], M. Bongi[a,b], V. Bonvicini[h], S. Bottai[b], A. Bruno[f,g], F. Cafagna[g], D. Campana[d], R. Carbone[d,h], P. Carlson[j,k], M. Casolino[l], G. Castellini[m], M.P. De Pascale[l,n,1], C. De Santis[l,n], N. De Simone[l], V. Di Felice[l], V. Formato[h,o], A.M. Galper[p], U. Giaccari[d], A.V. Karelin[p], M.D. Kheymits[p], S.V. Koldashov[p], S. Koldobskiy[p], S.Yu. Krut'kov[i], A.N. Kvashnin[e], A. Leonov[p], V. Malakhov[p], L. Marcelli[n], M. Martucci[n,q], A.G. Mayorov[p], W. Menn[r], V.V. Mikhailov[p], E. Mocchiutti[h], A. Monaco[f,g], N. Mori[a,b], R. Munini[h,j,k,o], N. Nikonov[i,l,n], G. Osteria[d], P. Papini[b], M. Pearce[j,k], P. Picozza[l,n,*], C. Pizzolotto[h,s,t], M. Ricci[q], S.B. Ricciarini[b,m], L. Rossetto[j,k], R. Sarkar[h], M. Simon[r], R. Sparvoli[l,n], P. Spillantini[a,b], Y.I. Stozhkov[e], A. Vacchi[h], E. Vannuccini[b], G.I. Vasilyev[i], S.A. Voronov[p], J. Wu[j,k,u], Y.T. Yurkin[p], G. Zampa[h], N. Zampa[h], V.G. Zverev[p]

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Ten years of PAMELA in space

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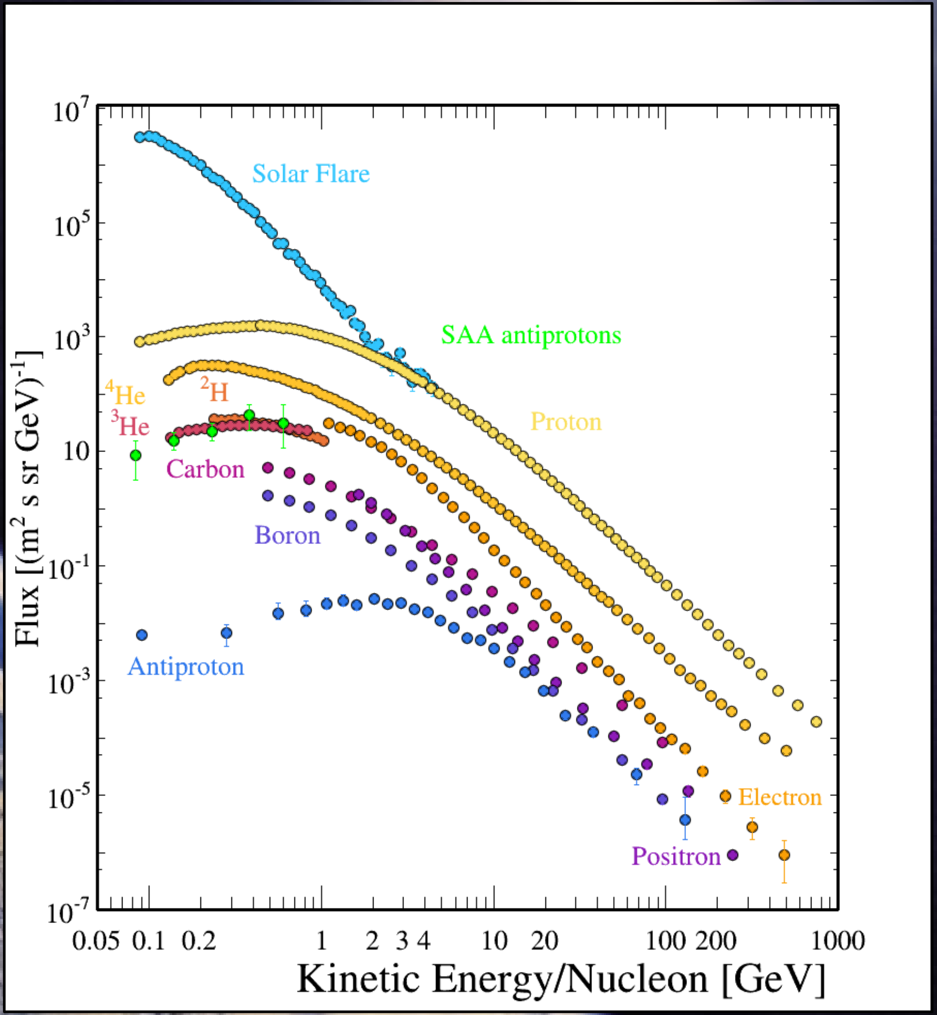

Title = DBja48x
n_spatial_dimensions = 2
r_min = 00.0 min r
r_max = 20.00 max r
dr = 1.0 delta r
z_min = -4.0 min z
z_max = +4.0 max z
dz = 0.1 delta z
x_min = 0.0 min x
x_max = +15.0 max x
dx = 0.2 delta x
y_min = 0.0 min y
y_max = +15.0 max y
dy = 0.2 delta y
p_Ekin_grid = Ekin p||Ekin alignment
p_min = 1000 min momentum (MV)
p_max = 4000 max momentum (MV)
p_factor = 1.3 momentum factor
Ekin_min = 2.0e0 min kinetic energy per nucleon (MeV)
Ekin_max = 1.0e7 max kinetic energy per nucleon (MeV)
Ekin_factor = 1.3 kinetic energy per nucleon factor
gamma_rays = 0 1=compute gamma rays 2=compute HI, H2 skymaps separately.
pi0_decay = 1 1= old formalism 2=Blattnig et al. 3=Kamae et al.
IC_isotropic = 1 1=compute isotropic IC: 1=compute full; 2=store skymaps components
IC_anisotropic = 0 1=compute anisotropic IC
bremss = 1 1=compute bremsstrahlung
integration_mode = 0 integr.over part.spec.: =1-old E*logE; =0-PL analyt.
E_gamma_min = 1.0e1 min gamma-ray energy (MeV)
E_gamma_max = 1.0e6 max gamma-ray energy (MeV)
E_gamma_factor = 1.4 gamma-ray energy factor
ISRF_factors = 1.0,1.0,1.0 ISRF factors for IC calculation: optical, FIR, CMB
synchrotron = 0 1=compute synchrotron
nu_synch_min = 1.0e6 min synchrotron frequency (Hz)
nu_synch_max = 1.0e10 max synchrotron frequency (Hz)
nu_synch_factor = 2.0 synchrotron frequency factor
long_min = 0.50 gamma-ray intensity skymap longitude minimum (deg)
long_max = 359.50 gamma-ray intensity skymap longitude maximum (deg)
lat_min = -89.50 gamma-ray intensity skymap latitude minimum (deg)
lat_max = +89.50 gamma-ray intensity skymap latitude maximum (deg)
d_long = 1.0 gamma-ray intensity skymap longitude binsize (deg)
d_lat = 1.0 gamma-ray intensity skymap latitude binsize (deg)
healpix_order = 6 order for healpix skymaps. 6 gives ~1.0 degree resolution and it changes by an order of 2.
lat_substep_number = 1 latitude bin splitting (0,1=no split, 2=split in 2...)
LoS_step = 0.01 kpc, Line of Sight (LoS) integration step
LoS_substep_number = 1 number of substeps per LoS integration step (0,1=no substeps)
DM_positrons = 0 1=compute DM positrons
DM_electrons = 0 1=compute DM electrons
DM_antiprotons = 0 1=compute DM antiprotons
DM_gammas = 0 1=compute DM gammas
DM_double0 = 0 not used
DM_double1 = 0 not used
DM_double2 = 0 not used
DM_double3 = 0 not used
DM_double4 = 0 not used
DM_double5 = 0 not used
DM_double6 = 0 not used
DM_double7 = 0 not used
DM_double8 = 0 not used
DM_double9 = 0 not used
DM_int0 = 1 not used

DM_int1 = 1 not used
DM_int2 = 1 not used
DM_int3 = 1 not used
DM_int4 = 1 not used
DM_int5 = 1 not used
DM_int6 = 1 not used
DM_int7 = 1 not used
DM_int8 = 1 not used
DM_int9 = 1 not used
D0_xx = 5.1e28 diffusion coefficient at reference rigidity
D_rigid_br = 4.0e3 reference rigidity for diffusion coefficient, MV
D_g_1 = 0.3 diffusion coefficient index below reference rigidity
D_g_2 = 0.4 diffusion coefficient index above reference rigidity
diff_reacc = 1 1=include diffusive reacceleration
v_Alfven = 30. Alfven speed in km s^{-1}
damping_p0 = 1.e6 some rigidity, MV, (where CR density is low)
damping_const_G = 0.02 a const derived from fitting B/C
damping_max_path_L = 3.e21 Lmax~1 kpc, max free path
convection = 1 1=include convection
v0_conv = 0. V0 convection in km s^-1
dvdz_conv = 5.0 dV/dz=grad V in km s^-1 kpc^-1
nuc_rigid_br = 9.0e3 reference rigidity for primary nucleus injection index in MV
nuc_g_1 = 1.86 nucleus injection index below reference rigidity
nuc_g_2 = 2.36 nucleus injection index above reference rigidity
inj_spectrum_type = rigidity rigidity||beta_rig||Etot nucleon injection spectrum type
electron_g_0 = 1.90 electron injection index below electron_rigid_br0
electron_rigid_br0 = 4.0e3 reference rigidity0 for electron injection index in MV
electron_g_1 = 2.70 electron injection index between electron_rigid_br0 and electron_rigid_br
electron_rigid_br = 1.0e9 reference rigidity for electron injection index in MV
electron_g_2 = 5.0 electron injection index above reference rigidity
He_H_ratio = 0.11 He/H of ISM, by number
n_X_CO = 9 an option to select functional dependence of X_CO=X_CO(r)
n_X_CO_values = 0 only for n_X_CO=3, number of values in X_CO_values
X_CO_values = 0 only for n_X_CO=3
X_CO_radius = 0 only for n_X_CO=3
propagation_X_CO = 0 not used
X_CO = 1.9E20 CO to H2 conversion factors, used both in propagation and skymap genergation
X_CO_parameters_0 = 1.0E20 Parameter X0 for n_X_CO = 2
X_CO_parameters_1 = 1 Parameter A for n_X_CO = 2
X_CO_parameters_2 = 0 Parameter B for n_X_CO = 2
X_CO_parameters_3 = 0 Parameter C for n_X_CO = 2
nHI_model = 1 an option to select analytical HI model
nH2_model = 1 an option to select analytical CO model
nHII_model = 1 an option to select analytical HII model
COR_filename = rbands_co10mm_v2_2001_qdeg.fits
HIR_filename = rbands_hi12_v2_qdeg_zmax1_Ts125.fits H I maps
GCR_data_filename = GCR_data_1.dat
fragmentation = 1 1=include fragmentation
momentum_losses = 1 1=include momentum losses
radioactive_decay = 1 1=include radioactive decay
K_capture = 1 1=include K-capture
ionization_rate = 0 1=compute ionization rate
start_timestep = 1.0e9 (years)
end_timestep = 1.0e2 (years)
timestep_factor = 0.25
timestep_repeat = 20 number of repeats per timestep in timestep_mode=1
timestep_repeat2 = 0 number of repeats per timestep in timestep_mode=2
timestep_print = 10000 number of timesteps between printings
timestep_diagnostics = 10000 number of timesteps between diagnostics
control_diagnostics = 0 control details of diagnostics
network_iterations = 1 number of iterations of entire network

network_iter_compl = 2 number of iterations of entire network
network_iter_sec = 1 number of iterations for secondary particles with A<=1
prop_r = 1 1=propagate in r (2D)
prop_x = 1 1=propagate in x (3D)
prop_y = 1 1=propagate in y (3D)
prop_z = 1 1=propagate in z (2D, 3D)
prop_p = 1 1=propagate in p (2D, 3D)
use_symmetry = 0 0=no symmetry, 1=optimized symmetry, 2=xyz symmetry by copying (3D)
vectorized = 0 0=unvectorized code, 1=vectorized code
source_specification = 0 2D::1:r,z=0 2:z=0 3D::1:x,y,z=0 2:z=0 3:x=0 4:y=0
source_model = 1 0=zero 1=parameterized 2=case-B 3=pulsars 5=S-Mattox 6=S-Mattox with cutoff 7=Gaussian 8=Table 9=HI+H2 10=H2 11=HII
source_parameters_0 = 0 not used
source_parameters_1 = 0.5 model 1:alpha
source_parameters_2 = 1.0 model 1:beta
source_parameters_3 = 20.0 model 1:rmax
source_parameters_4 = 20.0 model 1:rmax
source_parameters_5 = 0.0 model 1:rmax
source_parameters_6 = 0 not used
source_parameters_7 = 0 not used
source_parameters_8 = 0 not used
source_parameters_9 = 0 not used
source_model_elec = 1 source model for electrons, definitions as for nuclei
source_pars_elec_0 = 0 not used
source_pars_elec_1 = 0.5 model 1:alpha
source_pars_elec_2 = 1.0 model 1:beta
source_pars_elec_3 = 20.0 model 1:rmax
source_pars_elec_4 = 20.0 model 1:rmax
source_pars_elec_5 = 0.0 model 1:rmax
source_pars_elec_6 = 0 not used
source_pars_elec_7 = 0 not used
source_pars_elec_8 = 0 not used
source_pars_elec_9 = 0 not used
n_source_values = 0 only used with source_model/source_model_elec=8
source_values = 0 list of source ring values for source_model=8
source_radius = 0 list of source ring values for source_model=8
n_cr_sources = 0 number of pointlike cosmic-ray sources 3D only!
cr_source_x_01 = 10.0 x position of cosmic-ray source 1 (kpc)
cr_source_y_01 = 10.0 y position of cosmic-ray source 1 (kpc)
cr_source_z_01 = 0.1 z position of cosmic-ray source 1 (kpc)
cr_source_w_01 = 0.1 sigma width of cosmic-ray source 1
cr_source_L_01 = 1.0 luminosity of cosmic-ray source 1
cr_source_x_02 = 3.0 x position of cosmic-ray source 2 (kpc)
cr_source_y_02 = 4.0 y position of cosmic-ray source 2 (kpc)
cr_source_z_02 = 0.2 z position of cosmic-ray source 2 (kpc)
cr_source_w_02 = 2.4 sigma width of cosmic-ray source 2
cr_source_L_02 = 2.0 luminosity of cosmic-ray source 2
cr_source_x_03 = 0.0 x position of cosmic-ray source 3 (kpc)
cr_source_y_03 = 0.0 y position of cosmic-ray source 3 (kpc)
cr_source_z_03 = 0.0 z position of cosmic-ray source 3 (kpc)
cr_source_w_03 = 0.0 sigma width of cosmic-ray source 3
cr_source_L_03 = 0.0 luminosity of cosmic-ray source 3
cr_source_x_04 = 0.0 x position of cosmic-ray source 4 (kpc)
cr_source_y_04 = 0.0 y position of cosmic-ray source 4 (kpc)
cr_source_z_04 = 0.0 z position of cosmic-ray source 4 (kpc)
cr_source_w_04 = 0.0 sigma width of cosmic-ray source 4
cr_source_L_04 = 0.0 luminosity of cosmic-ray source 4
cr_source_x_05 = 0.0 x position of cosmic-ray source 5 (kpc)
cr_source_y_05 = 0.0 y position of cosmic-ray source 5 (kpc)
cr_source_z_05 = 0.0 z position of cosmic-ray source 5 (kpc)
cr_source_w_05 = 0.0 sigma width of cosmic-ray source 5
cr_source_L_05 = 0.0 luminosity of cosmic-ray source 5

SNR_events = 0 handle stochastic SNR events
SNR_interval = 1.0e4 time interval in years between SNR in 1 kpc^-3 volume
SNR_livetime = 1.0e4 CR-producing live-time in years of an SNR
SNR_electron_sdg = 0.0 delta electron source index for Gaussian sigma
SNR_nuc_sdg = 0.0 delta nucleus source index for Gaussian sigma
SNR_electron_dgpivot = 5.0e3 delta electron source index pivot rigidity (MV)
SNR_nuc_dgpivot = 5.0e3 delta nuclei source index pivot rigidity (MV)
ISRF_file = ISRF/Standard/Standard.dat input ISRF file
ISRF_filetype = 3
ISRF_healpixOrder = 3
B_field_name = galprop_original the name of the B-field model
n_B_field_parameters = 10 number of B-field parameters
B_field_parameters = 0,0,0,0,0,0,0,0,0,0 parameters of the model specified by B_field_name
B_field_model = 050100020 bbrrrzzz bbb=10*B(0) rrr=10*rscale zzz=10*zscale
proton_norm_Ekin = 1.00e+5 proton kinetic energy for normalization
electron_norm_Ekin = 34.5e3 electron kinetic energy for normalization
proton_norm_flux = 4.90e-9 flux of protons at normalization energy (cm^-2 sr^-1 s^-1 MeV^-1)
electron_norm_flux = .40e-9 flux of electrons at normalization energy (cm^-2 sr^-1 s^-1 MeV^-1)
source_norm = 1.0 absolute normalization for proton CR source function (only if electron_norm_flux=proton_norm_flux=0)
electron_source_norm = 1.0 absolute normalization for electron CR source function (only if electron_norm_flux=proton_norm_flux=0)
rigid_min = 0.0 min rigidity for sources
rigid_max = 1.0E38 max rigidity for sources
max_Z = 28 the largest atomic number (Z) in the nuclear reaction network
iso_abundance_01_001 = 1.06e+06 H
iso_abundance_01_002 = 34.8 H
iso_abundance_02_003 = 9.033 He
iso_abundance_02_004 = 7.55895e+04 He
iso_abundance_03_006 = 0 Li
iso_abundance_03_007 = 0 Li
iso_abundance_04_007 = 0.0 Be
iso_abundance_04_009 = 0 Be
iso_abundance_04_010 = 0.0 Be
iso_abundance_05_010 = 0 B
iso_abundance_05_011 = 0 B
iso_abundance_06_012 = 2537.1 C
iso_abundance_06_013 = 5.268e-07 C
iso_abundance_07_014 = 182.8 N
iso_abundance_07_015 = 5.961e-05 N
iso_abundance_08_016 = 3822 O
iso_abundance_08_017 = 6.713e-07 O
iso_abundance_08_018 = 1.286 O
iso_abundance_09_019 = 2.664e-08 F
iso_abundance_10_020 = 312.5 Ne
iso_abundance_10_021 = 0.003556 Ne
iso_abundance_10_022 = 100.1 Ne
iso_abundance_11_023 = 22.84 Na
iso_abundance_12_024 = 658.1 Mg
iso_abundance_12_025 = 82.5 Mg
iso_abundance_12_026 = 104.7 Mg
iso_abundance_13_027 = 76.42 Al
iso_abundance_14_028 = 725.7 Si
iso_abundance_14_029 = 35.02 Si
iso_abundance_14_030 = 24.68 Si
iso_abundance_15_031 = 4.242 P
iso_abundance_16_032 = 89.12 S
iso_abundance_16_033 = 0.3056 S
iso_abundance_16_034 = 3.417 S
iso_abundance_16_036 = 0.0004281 S
iso_abundance_17_035 = 0.7044 Cl
iso_abundance_17_037 = 0.001167 Cl
iso_abundance_18_036 = 9.829 Ar
iso_abundance_18_038 = 0.6357 Ar
iso_abundance_18_040 = 0.001744 Ar
iso_abundance_19_039 = 1.389 K
iso_abundance_19_040 = 3.022 K
iso_abundance_19_041 = 0.0003339 K
iso_abundance_20_040 = 51.13 Ca
iso_abundance_20_041 = 1.974 Ca
iso_abundance_20_042 = 1.134e-06 Ca
iso_abundance_20_043 = 2.117e-06 Ca
iso_abundance_20_044 = 9.928e-05 Ca
iso_abundance_20_048 = 0.1099 Ca
iso_abundance_21_045 = 1.635 Sc
iso_abundance_22_046 = 5.558 Ti
iso_abundance_22_047 = 8.947e-06 Ti
iso_abundance_22_048 = 6.05e-07 Ti
iso_abundance_22_049 = 5.854e-09 Ti
iso_abundance_22_050 = 6.083e-07 Ti
iso_abundance_23_050 = 1.818e-05 V
iso_abundance_23_051 = 5.987e-09 V
iso_abundance_24_050 = 2.873 Cr
iso_abundance_24_051 = 0 Cr
iso_abundance_24_052 = 8.065 Cr
iso_abundance_24_053 = 0.003014 Cr
iso_abundance_24_054 = 0.4173 Cr
iso_abundance_25_053 = 6.499 Mn
iso_abundance_25_055 = 1.273 Mn
iso_abundance_26_054 = 49.08 Fe
iso_abundance_26_055 = 0 Fe
iso_abundance_26_056 = 697.7 Fe
iso_abundance_26_057 = 21.67 Fe
iso_abundance_26_058 = 3.335 Fe
iso_abundance_27_059 = 2.214 Co
iso_abundance_28_058 = 28.88 Ni
iso_abundance_28_059 = 0 Ni
iso_abundance_28_060 = 11.9 Ni
iso_abundance_28_061 = 0.5992 Ni
iso_abundance_28_062 = 1.426 Ni
iso_abundance_28_064 = 0.3039 Ni
use_Z_1 = 1
use_Z_2 = 1
use_Z_3 = 1
use_Z_4 = 1
use_Z_5 = 1
use_Z_6 = 1
use_Z_7 = 1
use_Z_8 = 1
use_Z_9 = 1
use_Z_10 = 1
use_Z_11 = 1
use_Z_12 = 1
use_Z_13 = 1
use_Z_14 = 1
use_Z_15 = 1
use_Z_16 = 1
use_Z_17 = 1
use_Z_18 = 1
use_Z_19 = 1
use_Z_20 = 1
use_Z_21 = 1

Bremsstrahlung, Synchrotron,

use_Z_22 = 1
use_Z_23 = 1
use_Z_24 = 1
use_Z_25 = 1
use_Z_26 = 1
use_Z_27 = 1
use_Z_28 = 1
use_Z_29 = 0
use_Z_30 = 0
total_cross_section = 2 =0 -Letaw83; =1 - WA96 Z.gt.5 and BP01 Z.lt.6; =2 -BP01 (2-best)
cross_section_option = 012 100*i+j i=1: use Heinbach-Simon C,O->B j=kopt j=11=Webber, 21=ST
t_half_limit = 1.0e4 year - lower limit on radioactive half-life for explicit inclusion
primary_electrons = 1
secondary_electrons = 1
knock_on_electrons = 0 1,2 1=compute knock-on electrons (p,He) 2= use factor 1.75 to scale pp,pHe
secondary_positrons = 1
secondary_protons = 1
secondary_antiproton = 2 1=uses nuclear scaling; 2=uses nuclear factors by Simon et al. (1998)
tertiary_antiproton = 1
skymap_format = 0 fitsfile format: 0=old format (the default), 1=mapcube for glast science tools, 2=both, 3=healpix
output_gcr_full = 0 output full galactic cosmic ray array
warm_start = 0 read in nucle file and continue run
verbose = 0 verbosity: -1=min,10=max
test_suite = 0 test suite instead of normal run