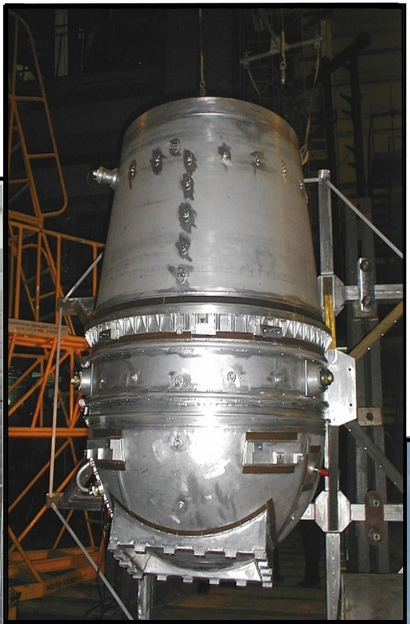
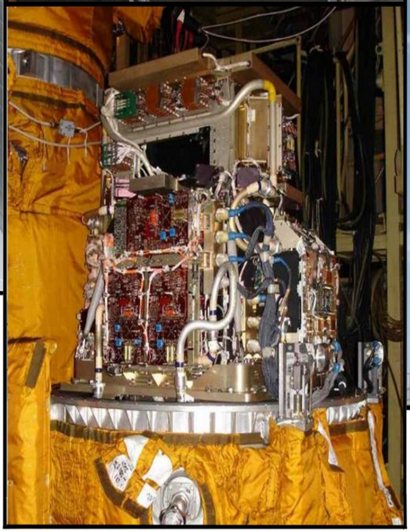
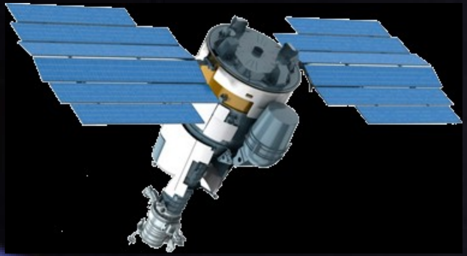
PAMELA experiment: cosmic rays deep inside the heliosphere

Riccardo Munini, INFN Trieste
On behalf of the PAMELA collaboration

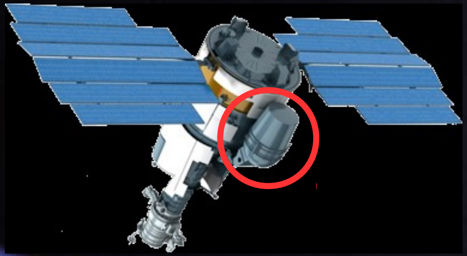
14th International Workshop Dark Side Of the Universe
27 June 2018 – Annecy, France


Launch: 15 June 2006 – Stopped in January 2016



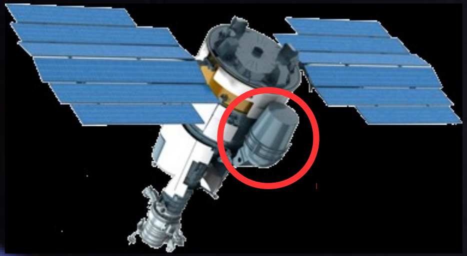
Launch: 15 June 2006 – Stopped in January 2016

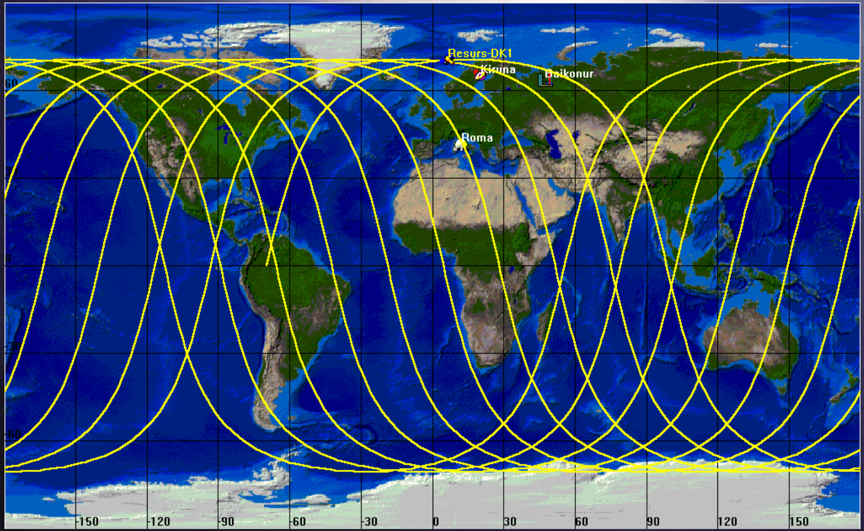


Resurs DK1 satellite

- High quality image;

Launch: 15 June 2006 – Stopped in January 2016

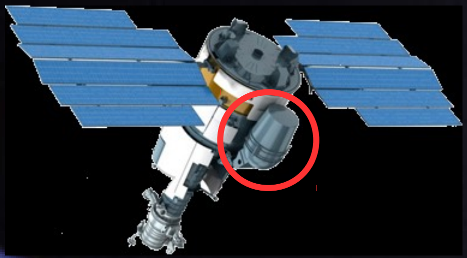


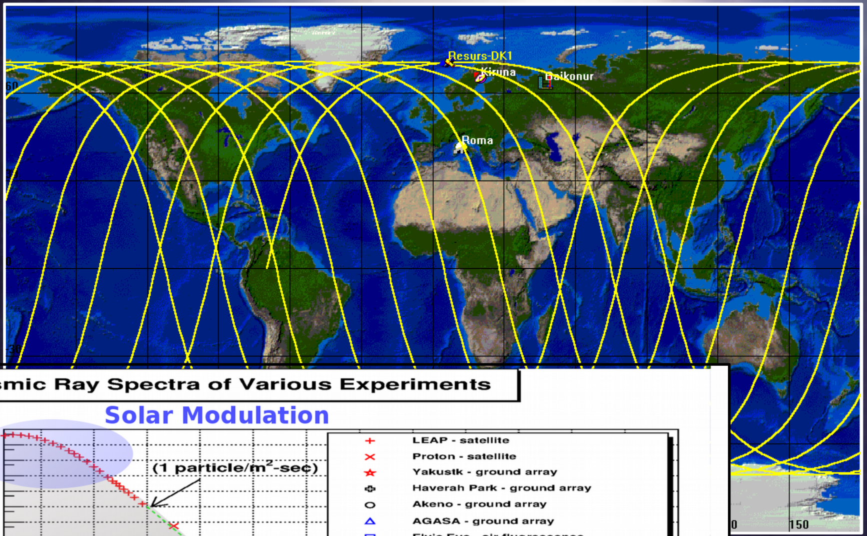


Resurs DK1 satellite

- High quality image;
- Quasi-polar elliptical orbit 70 degree inclination 350/610 km.

Launch: 15 June 2006 – Stopped in January 2016

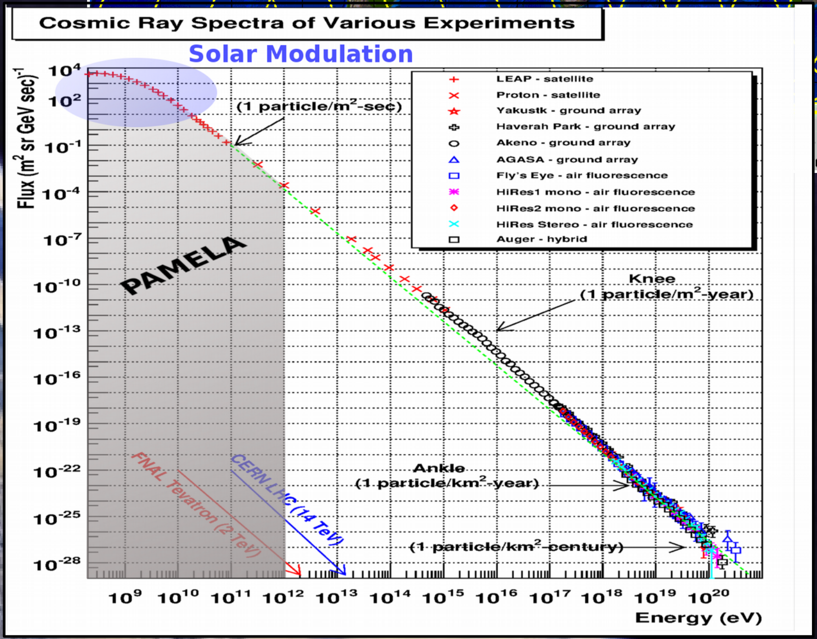




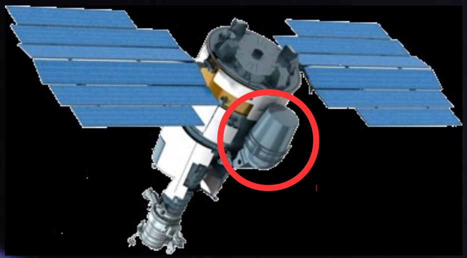
Resurs DK1 satellite

- High quality image;
- Quasi-polar elliptical orbit 70 degree inclination 350/610 km.

Multi-purpose cosmic ray experiment:



Launch: 15 June 2006 – Stopped in January 2016

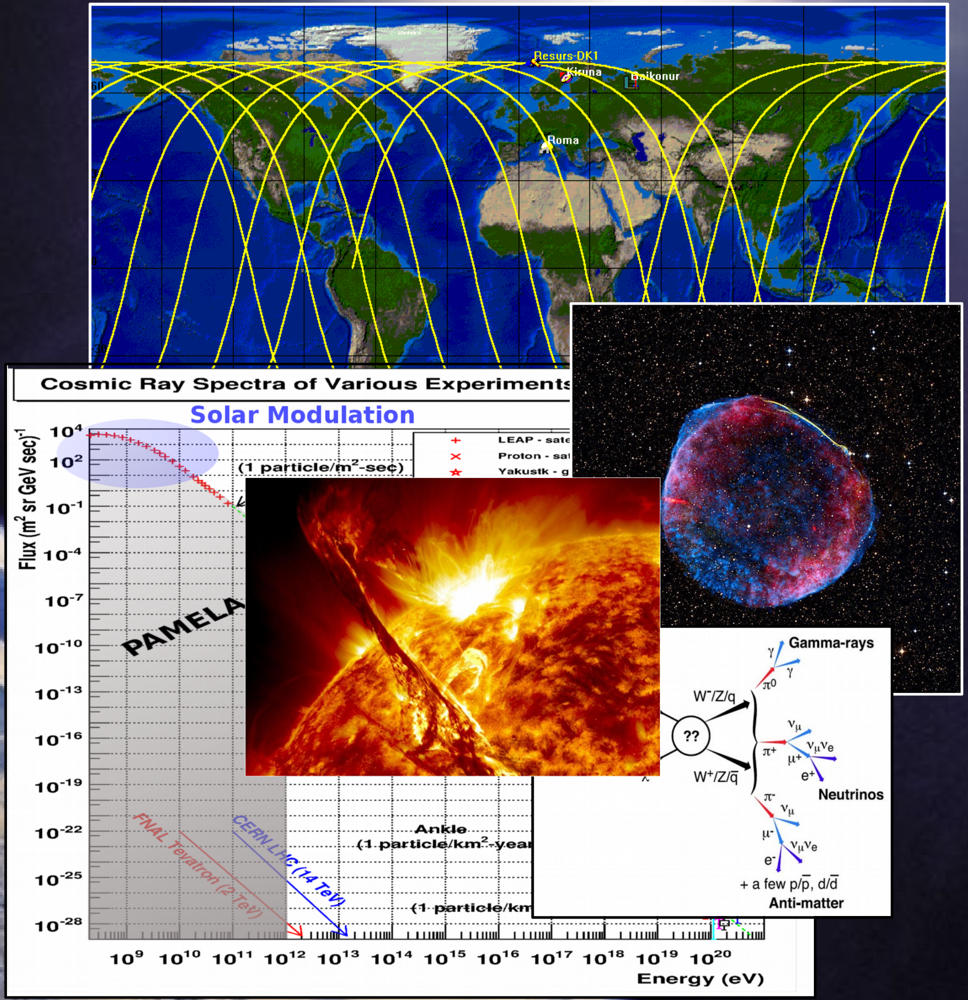


Resurs DK1 satellite

- High quality image;
- Quasi-polar elliptical orbit 70 degree inclination 350/610 km.

Multi-purpose cosmic ray experiment:

- Origin, propagation, composition;
- Antimatter component;
- Indirect dark matter detection;
- Solar physics and solar modulation.

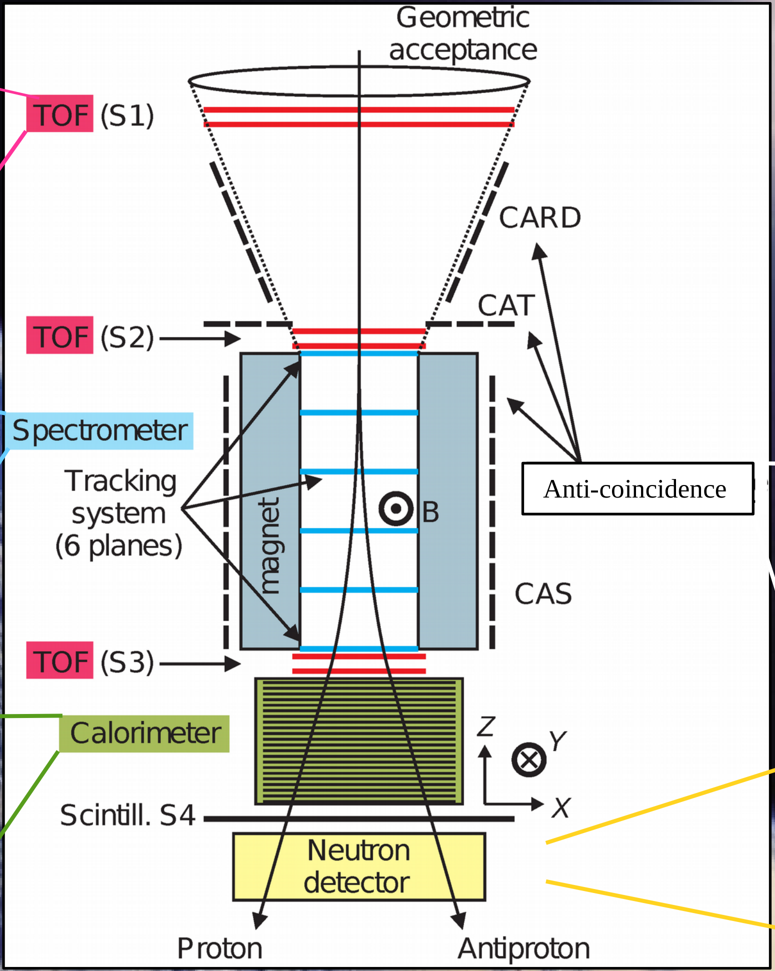


The PAMELA instrument

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.

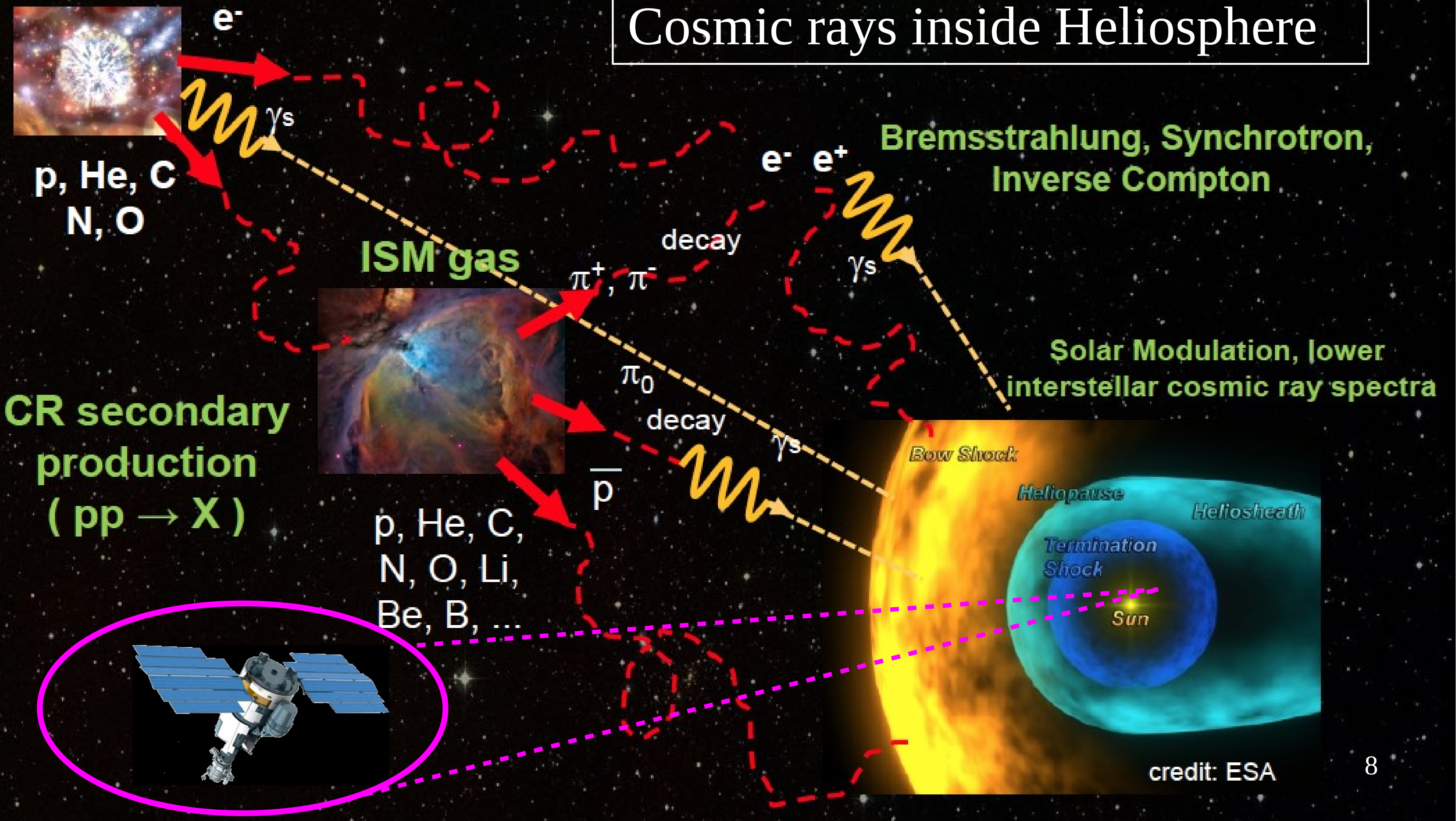


GF: 21.5 cm2 sr
Mass: 470 kg
Size: 130x70x70 cm
Power budget: 360 W

(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



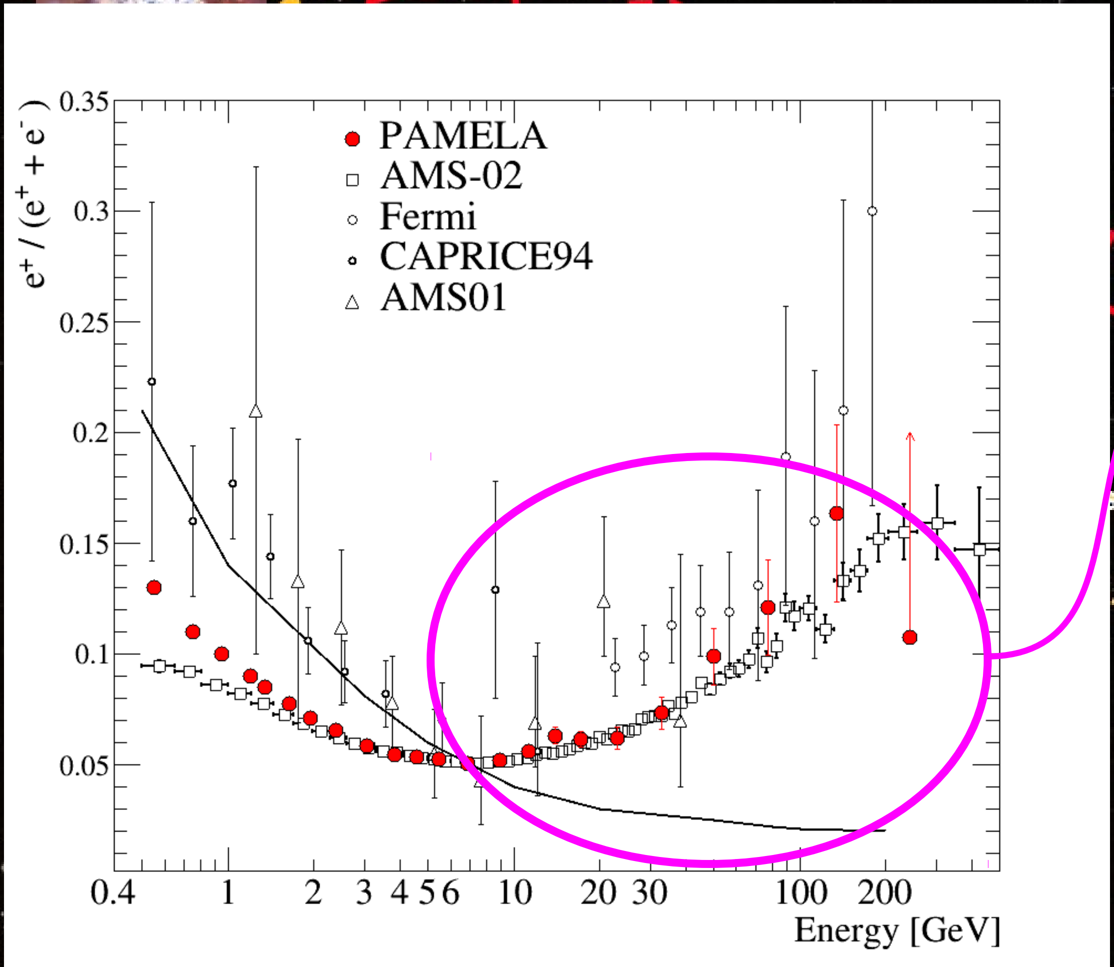
Positron fraction high energy excess

e-

Bremsstrahlung, Synchrotron,
Inverse Compton

e+

γs

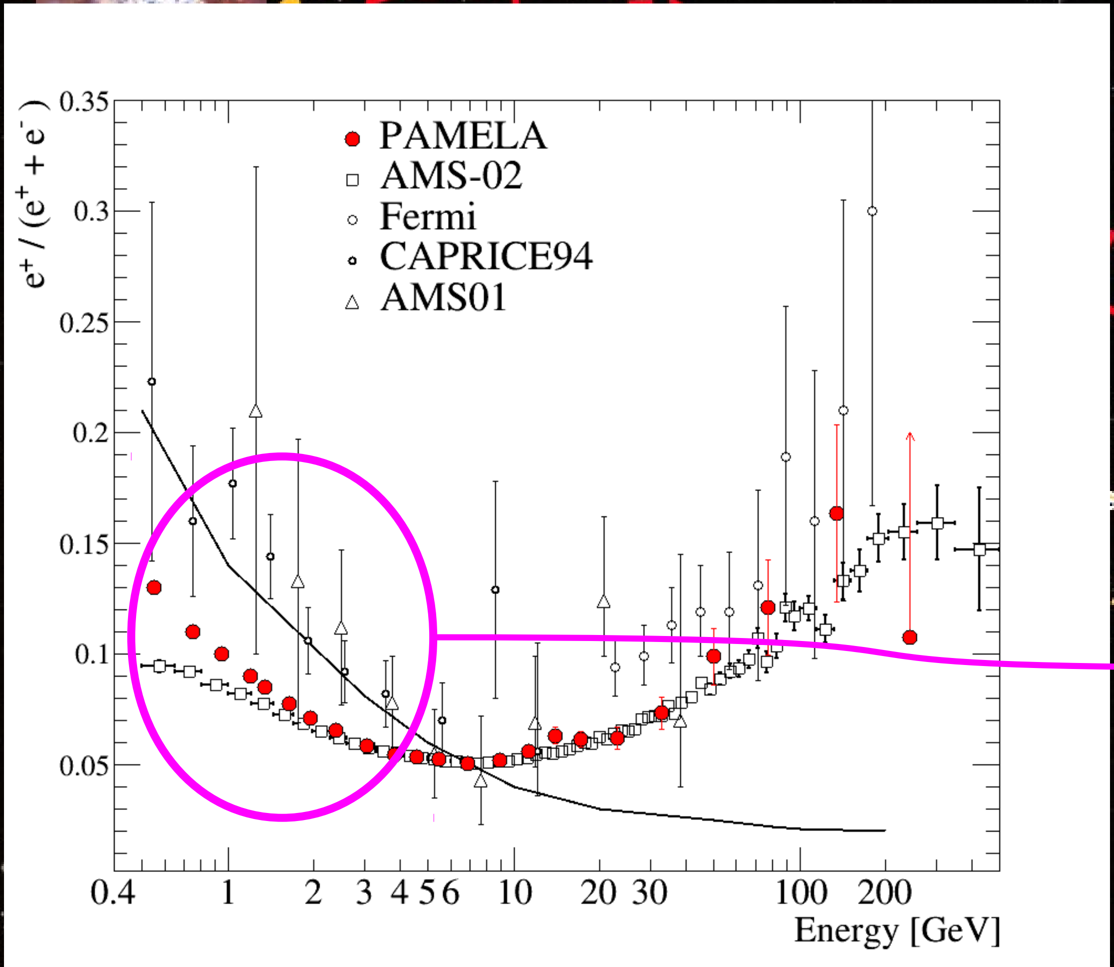


High energy: first evidence of positron excess above 10 GeV with respect to pure secondary production;

Adriani, O., et al., Nature 458 (2009) 607

Positron fraction and solar modulation

e⁻



Adriani, O., et al., Nature 458 (2009) 607

e⁺

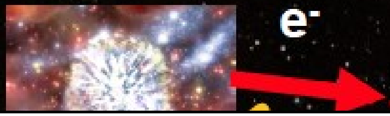
Bremsstrahlung, Synchrotron, Inverse Compton

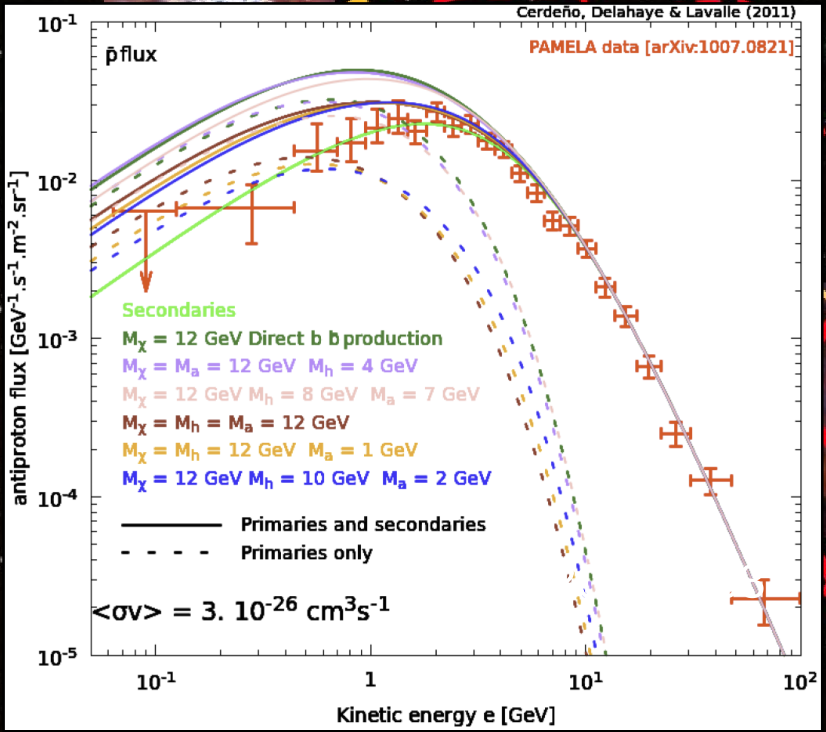
γs

High energy: first evidence of positron excess above 10 GeV with respect to pure secondary production;

Low energy: time dependence introduce by the solar modulation!

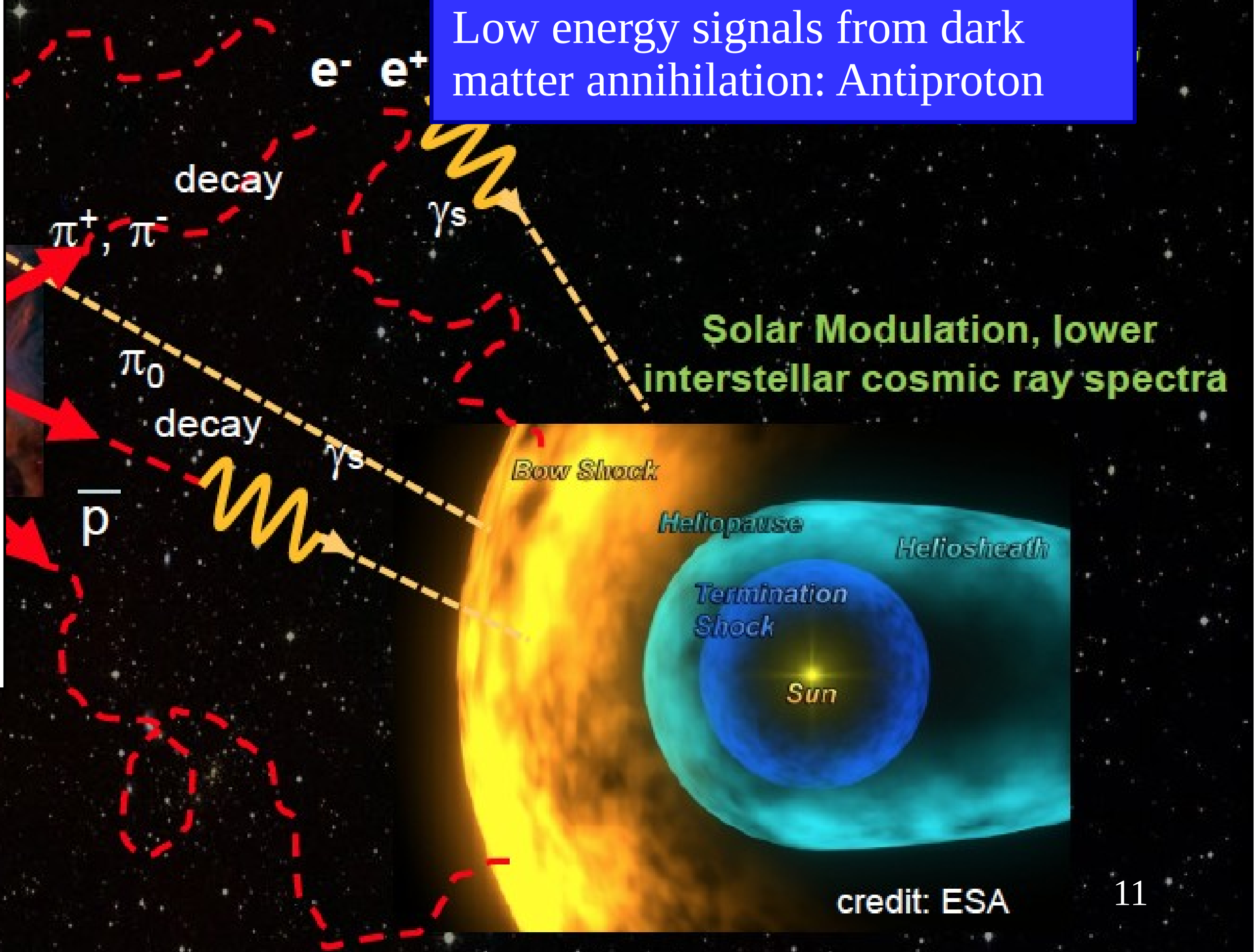
Propagation in the Heliosphere and dark matter



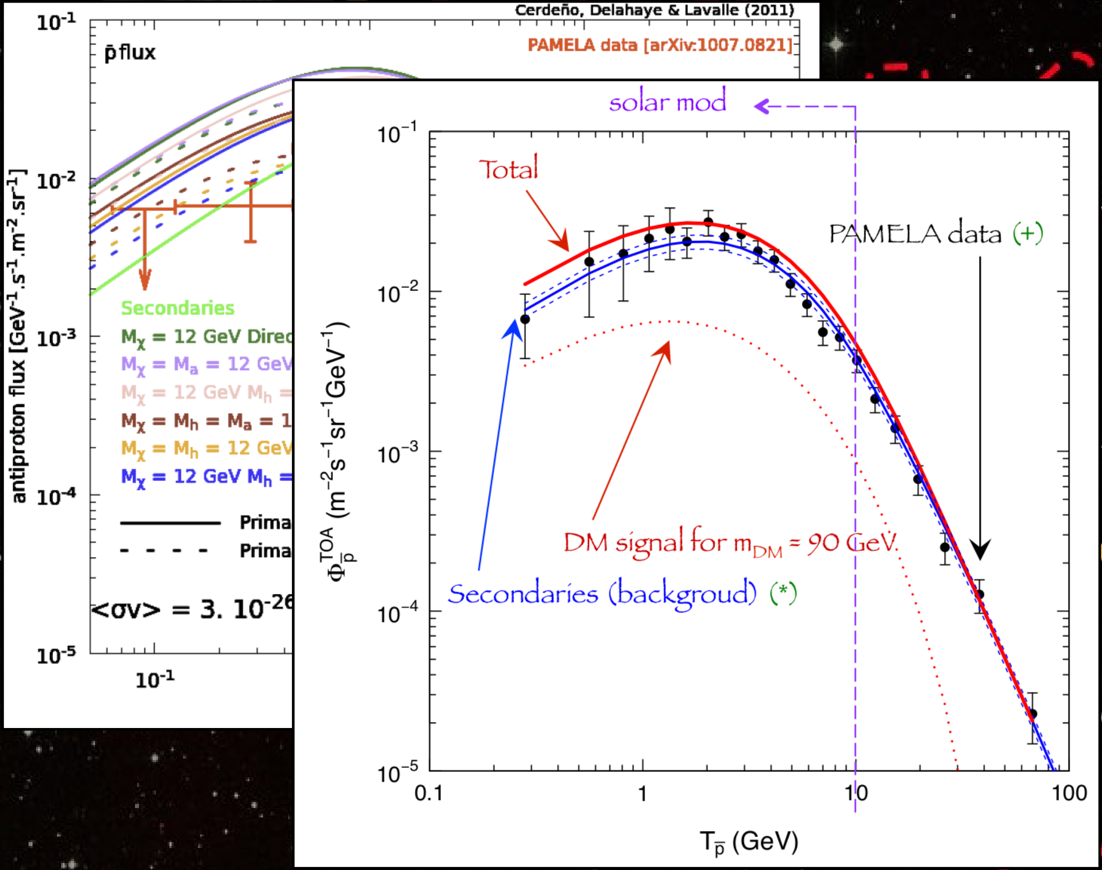


D. G. Cerdeno, T. Delahaye, J. Lavalle, Nucl. Phys. B

Low energy signals from dark matter annihilation: Antiproton



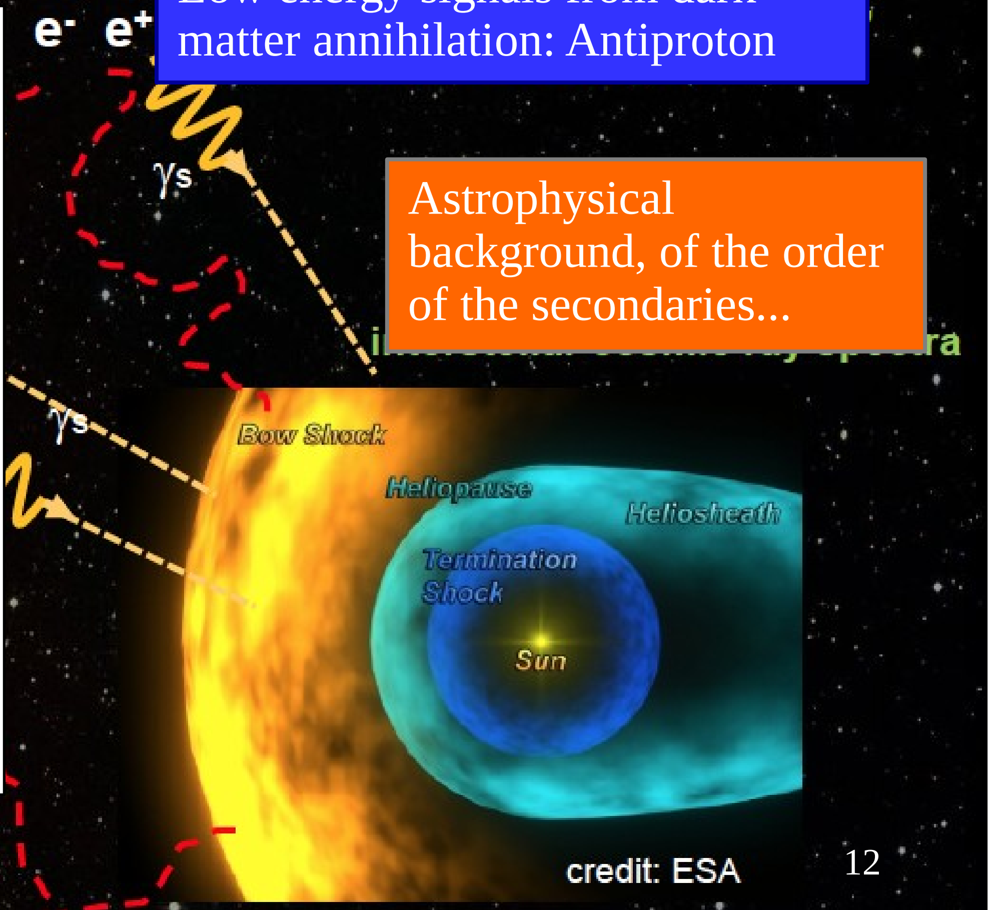
Propagation in the Heliosphere and dark matter



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

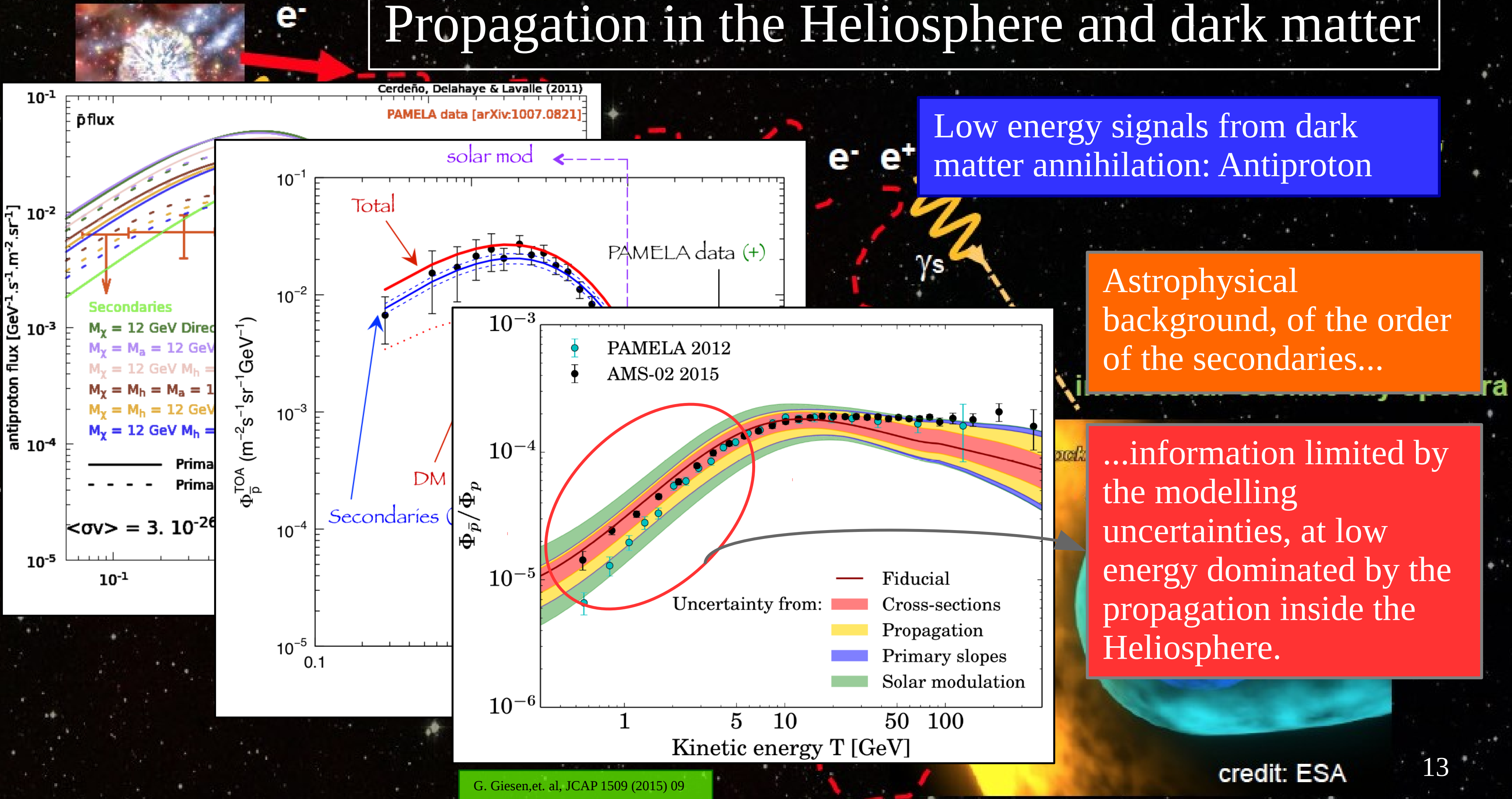
Low energy signals from dark matter annihilation: Antiproton

Astrophysical background, of the order of the secondaries...



Propagation in the Heliosphere and dark matter

Low energy signals from dark matter annihilation: Antiproton



Astrophysical background, of the order of the secondaries...

...information limited by the modelling uncertainties, at low energy dominated by the propagation inside the Heliosphere.

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

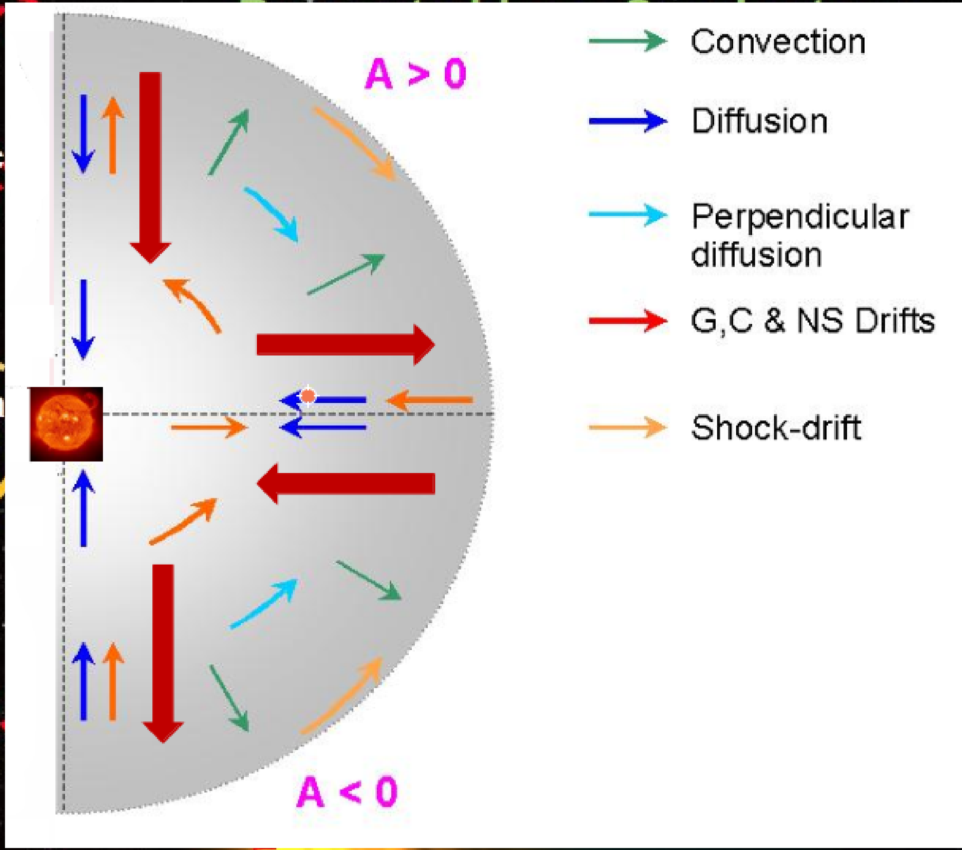
Cosmic rays propagation inside Heliosphere

Below ∼ 30 GV heliosphere strongly affects CRs at Earth

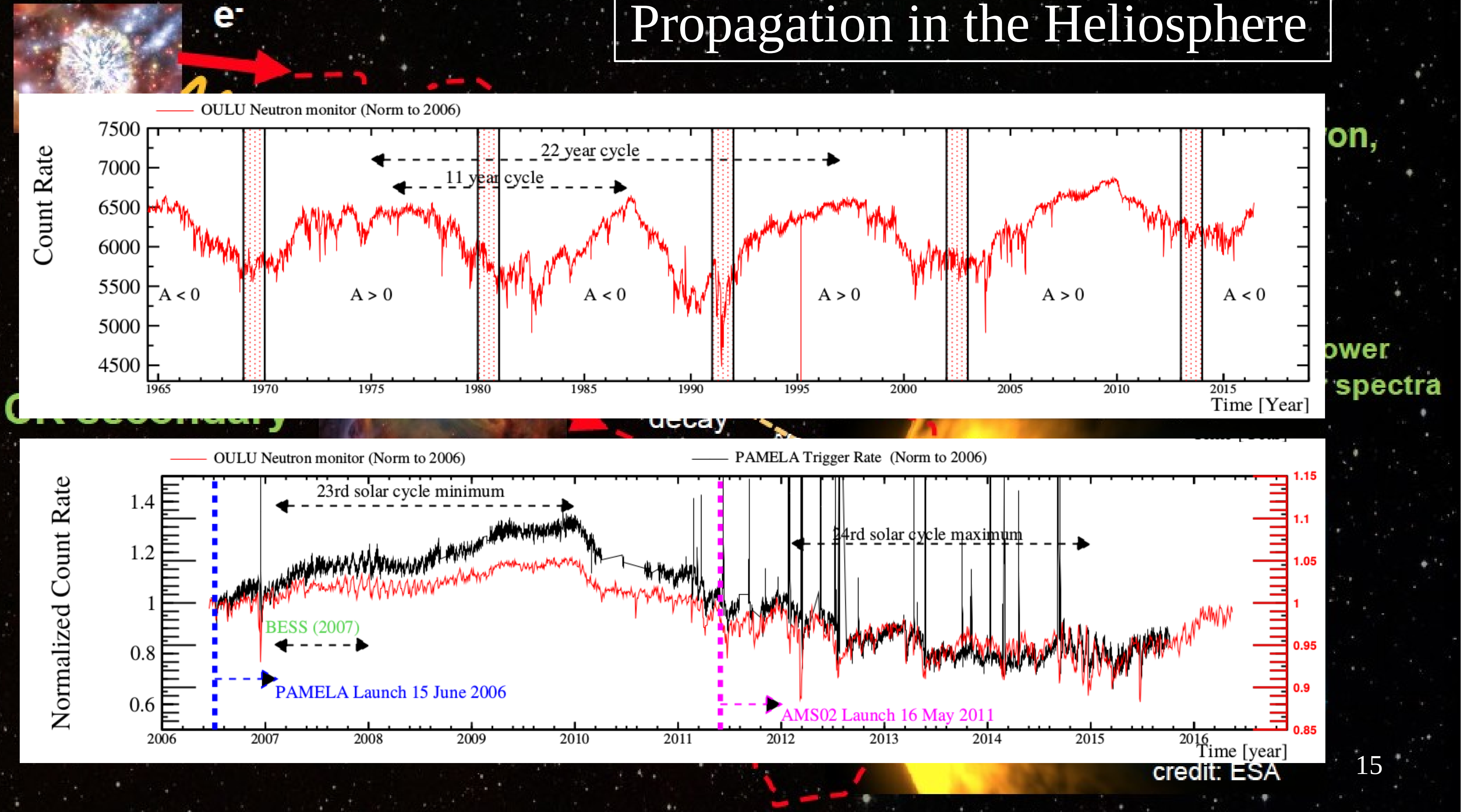
$$\underbrace{\frac{\partial f}{\partial t}}_{a} = -\underbrace{\mathbf{V}\cdot\nabla f}_{b} + \underbrace{\nabla\cdot(\mathbf{K_s}\cdot\nabla f)}_{c} - \underbrace{\langle \mathbf{v_D}\rangle\cdot\nabla f}_{d} + \underbrace{\frac{1}{3}(\nabla\cdot\mathbf{V})\frac{\partial f}{\partial \ln p}}_{e} + \underbrace{Q(\mathbf{x},p,t)}_{f}$$

(a) $f(\mathbf{x}, p, t)$, omnidirectional function distribution of CRs; **(b)** convection with solar wind $\mathbf{V}$; **(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.



Propagation in the Heliosphere



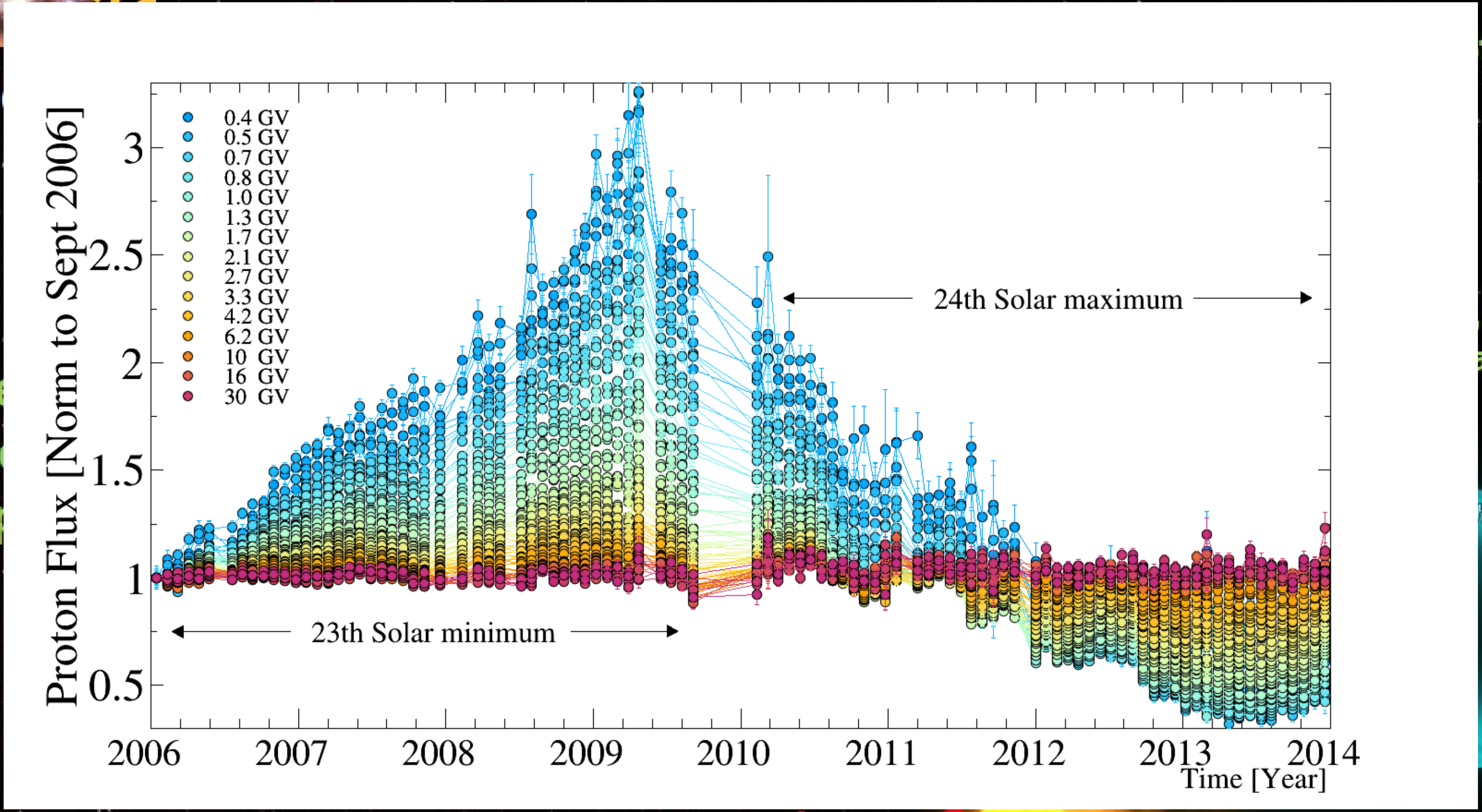
Propagation in the Heliosphere: protons over a solar cycle

p, H
N,

tron,

CR se
proc
(pp

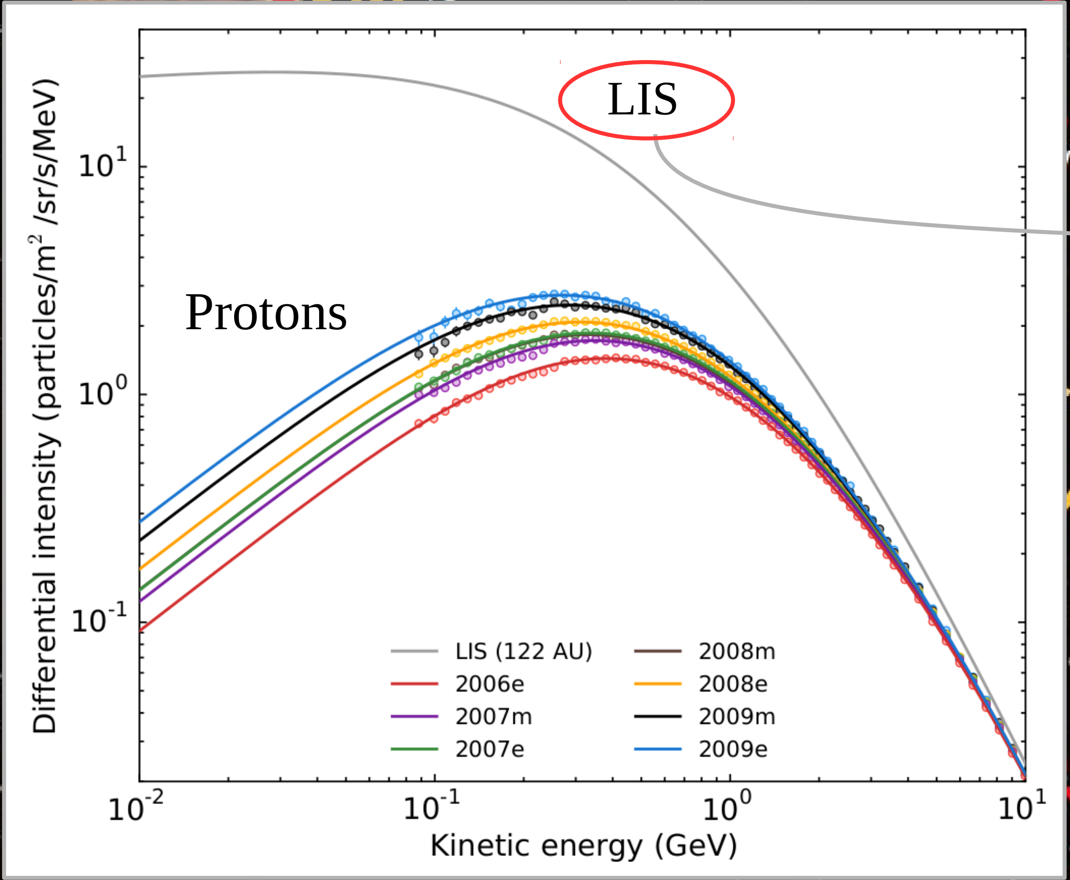
lower
ay spectra

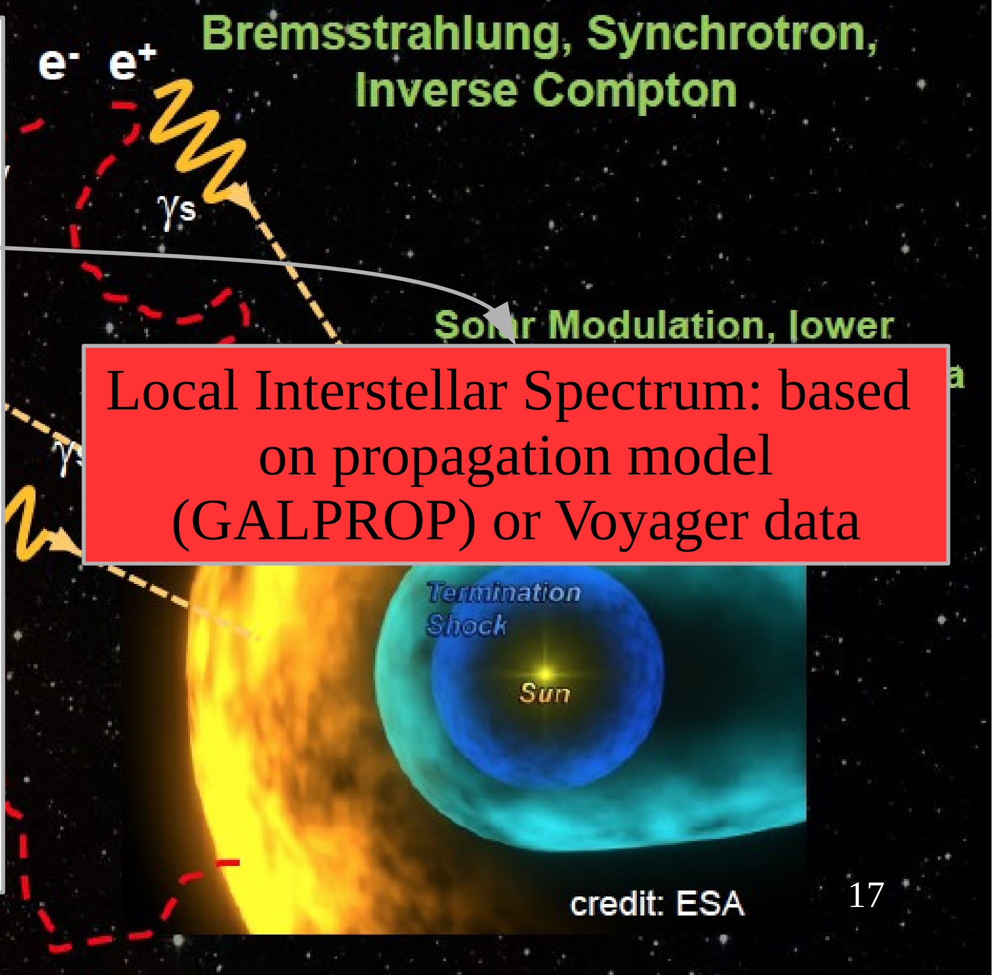


Adriani, O. et al. 2017, NUOVO CIMENTO, 40, 473

credit: ESA

Propagation in the Heliosphere

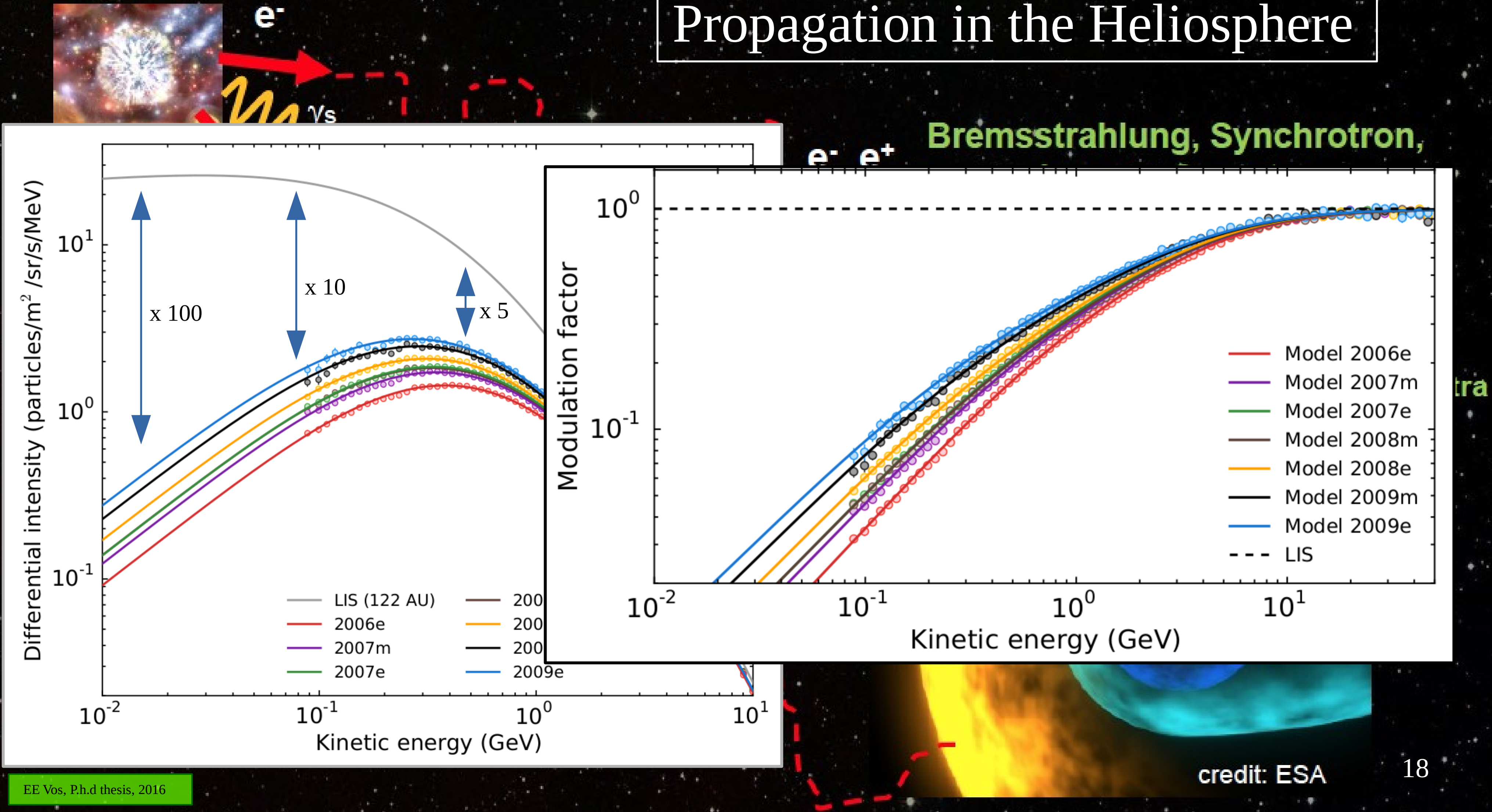




Local Interstellar Spectrum: based on propagation model (GALPROP) or Voyager data

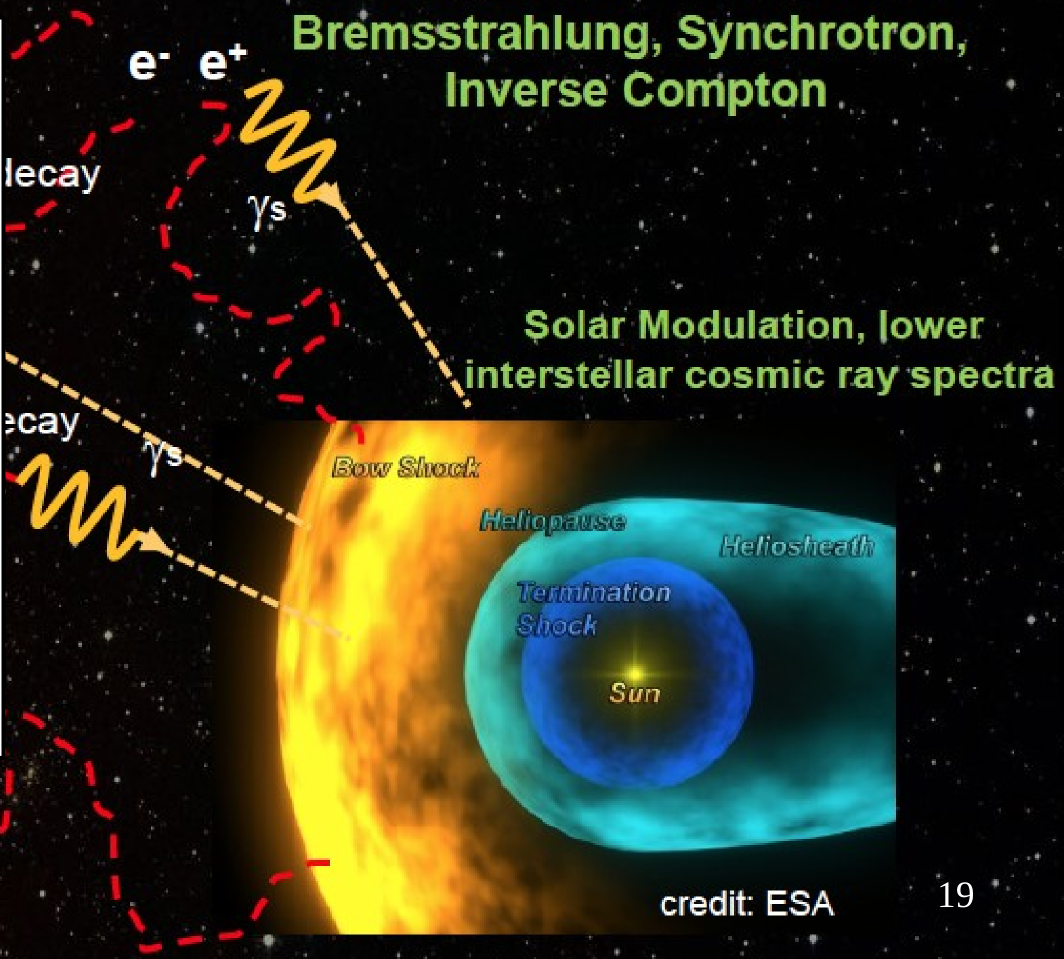
EE Vos, P.h.d thesis, 2016

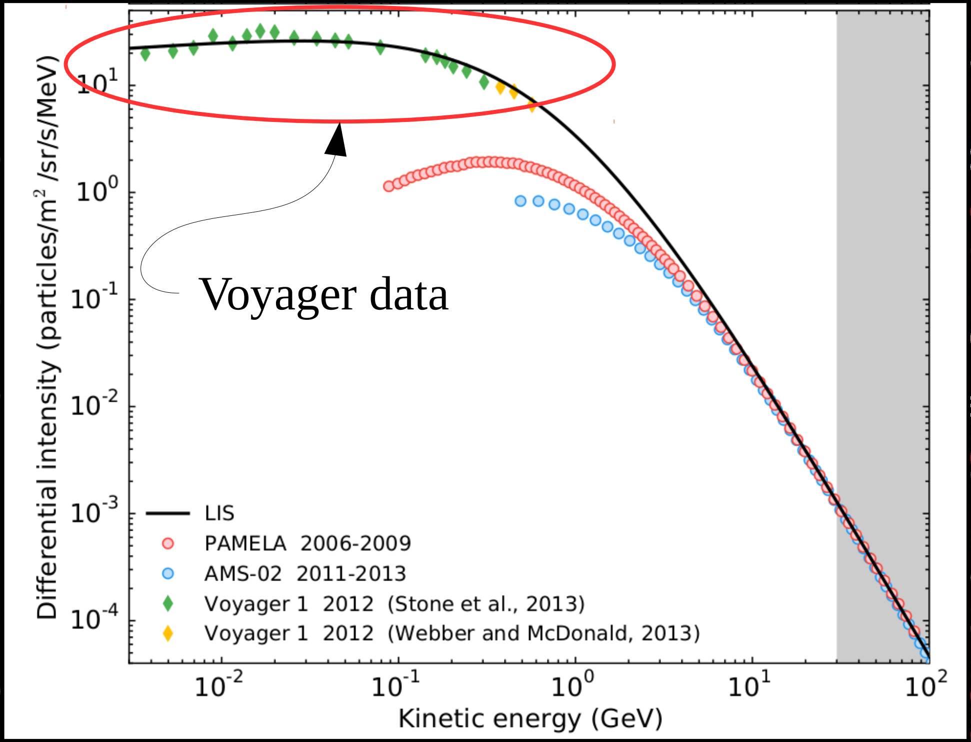
Propagation in the Heliosphere



EE Vos, P.h.d thesis, 2016

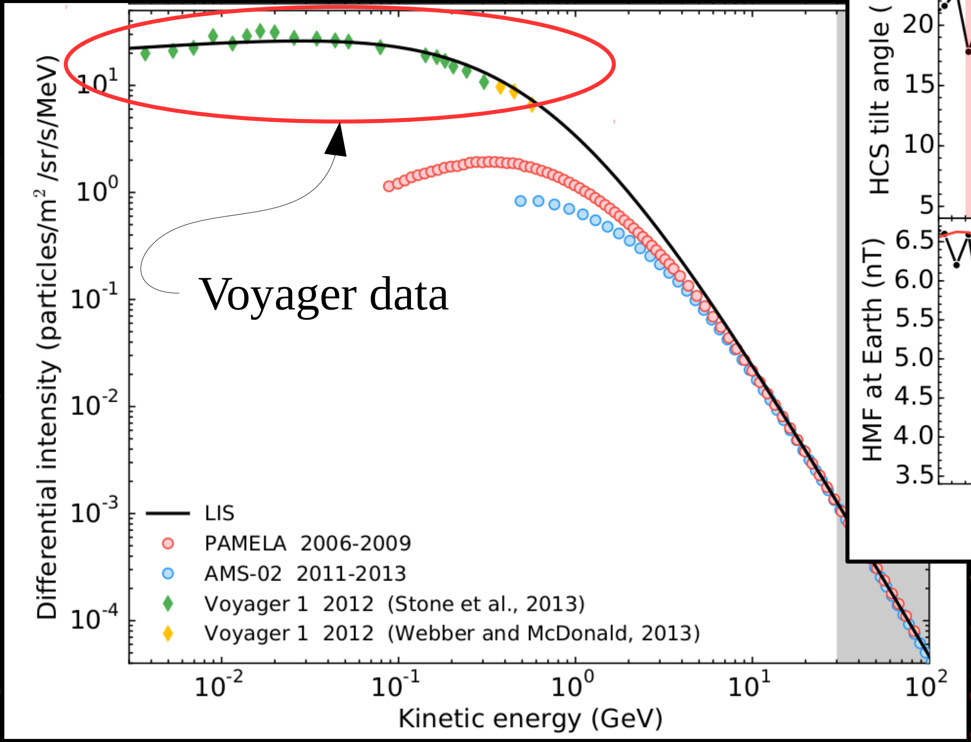
Propagation in the Heliosphere: Modeling



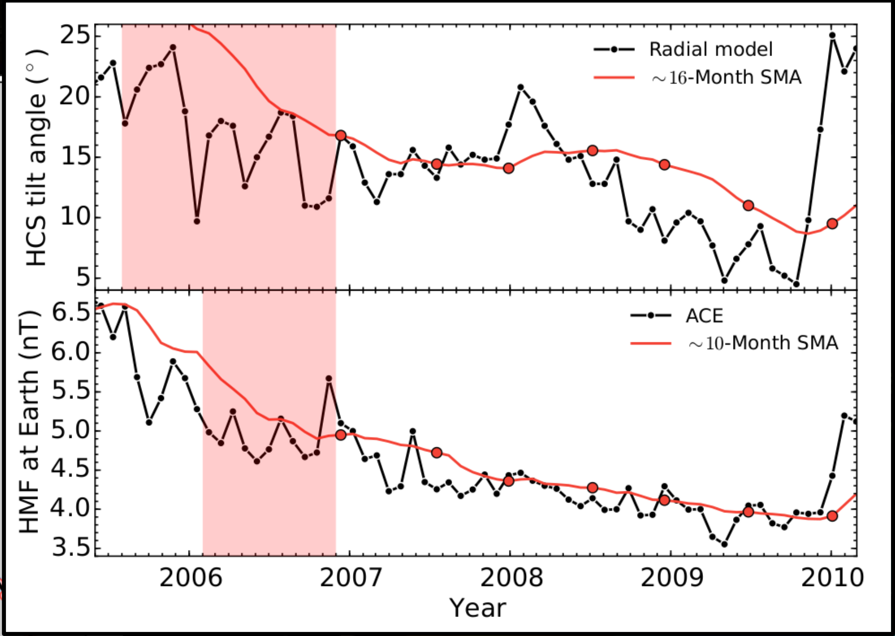


O. Adriani et al., ApJ 765 (2013) 91

Propagation in the Heliosphere: Modeling

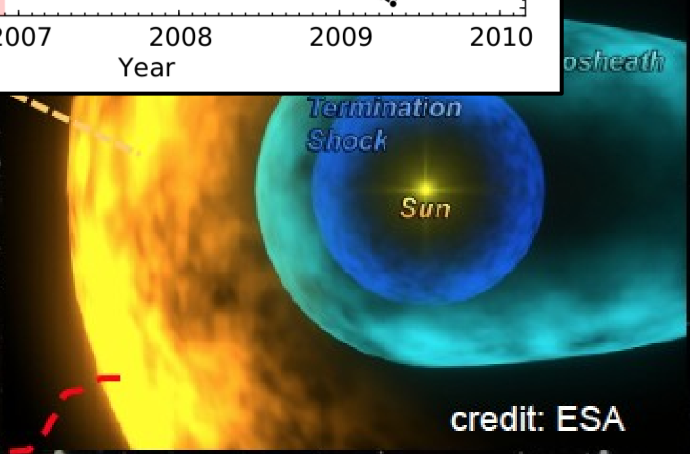


O. Adriani et al., ApJ 765 (2013) 91

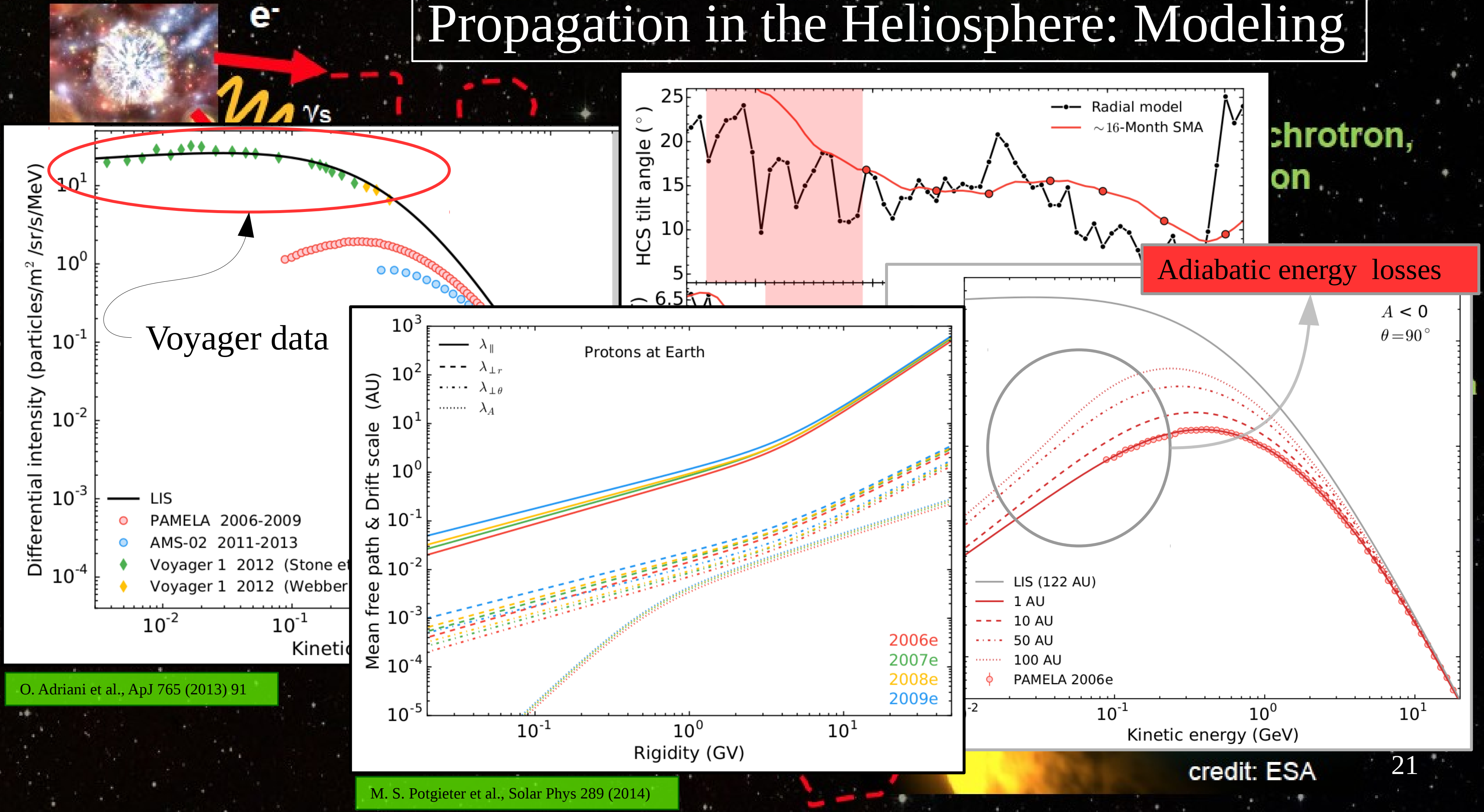


chrotron,
on

ition, lower
nic ray spectra



Propagation in the Heliosphere: Modeling

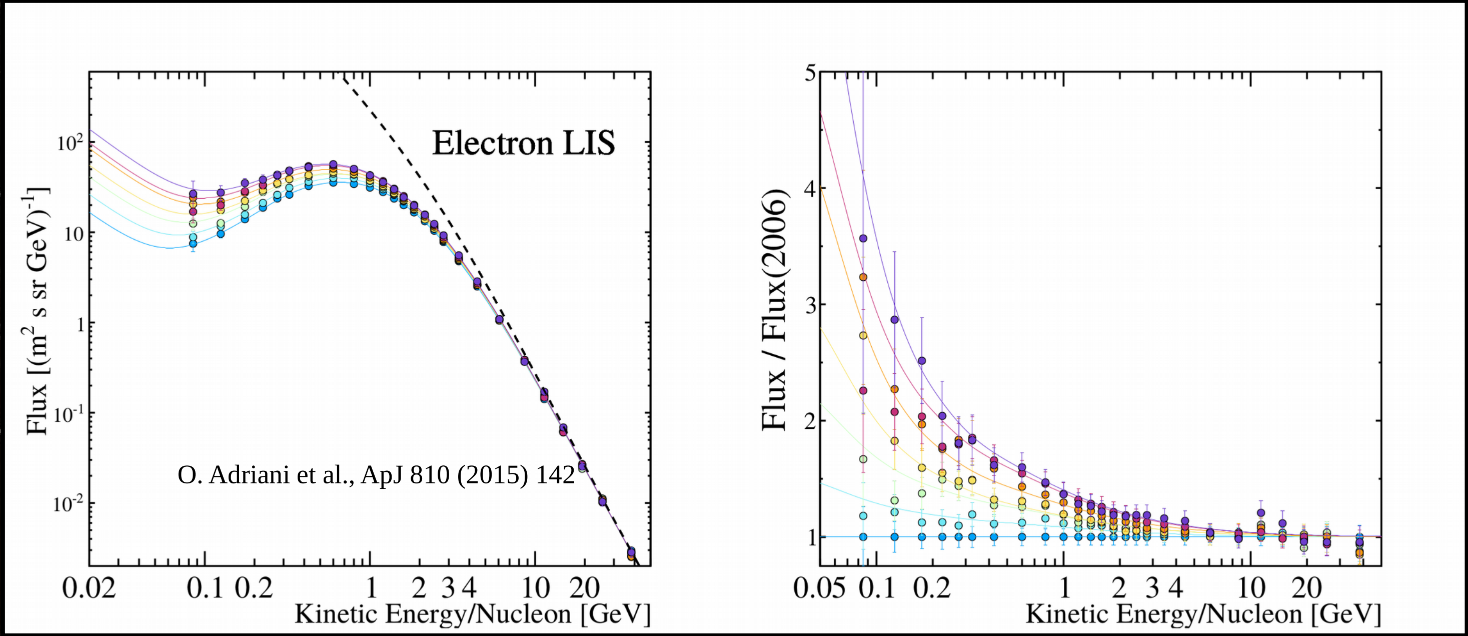


O. Adriani et al., ApJ 765 (2013) 91

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

e^-

Propagation in the Heliosphere: other elements

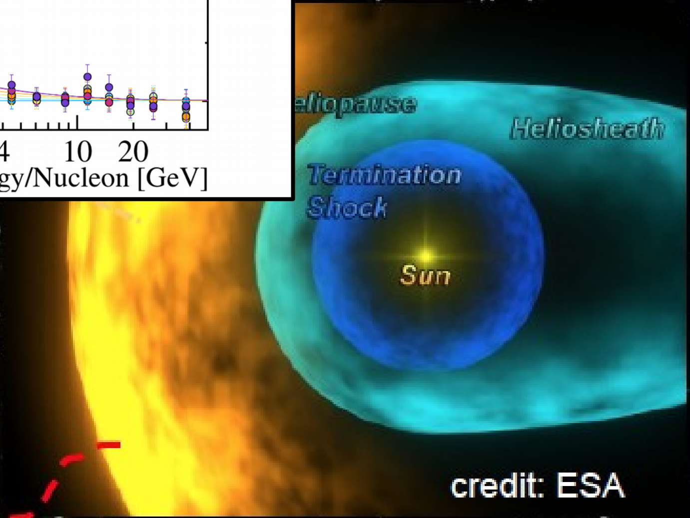


ahlung, Synchrotron,
verse Compton

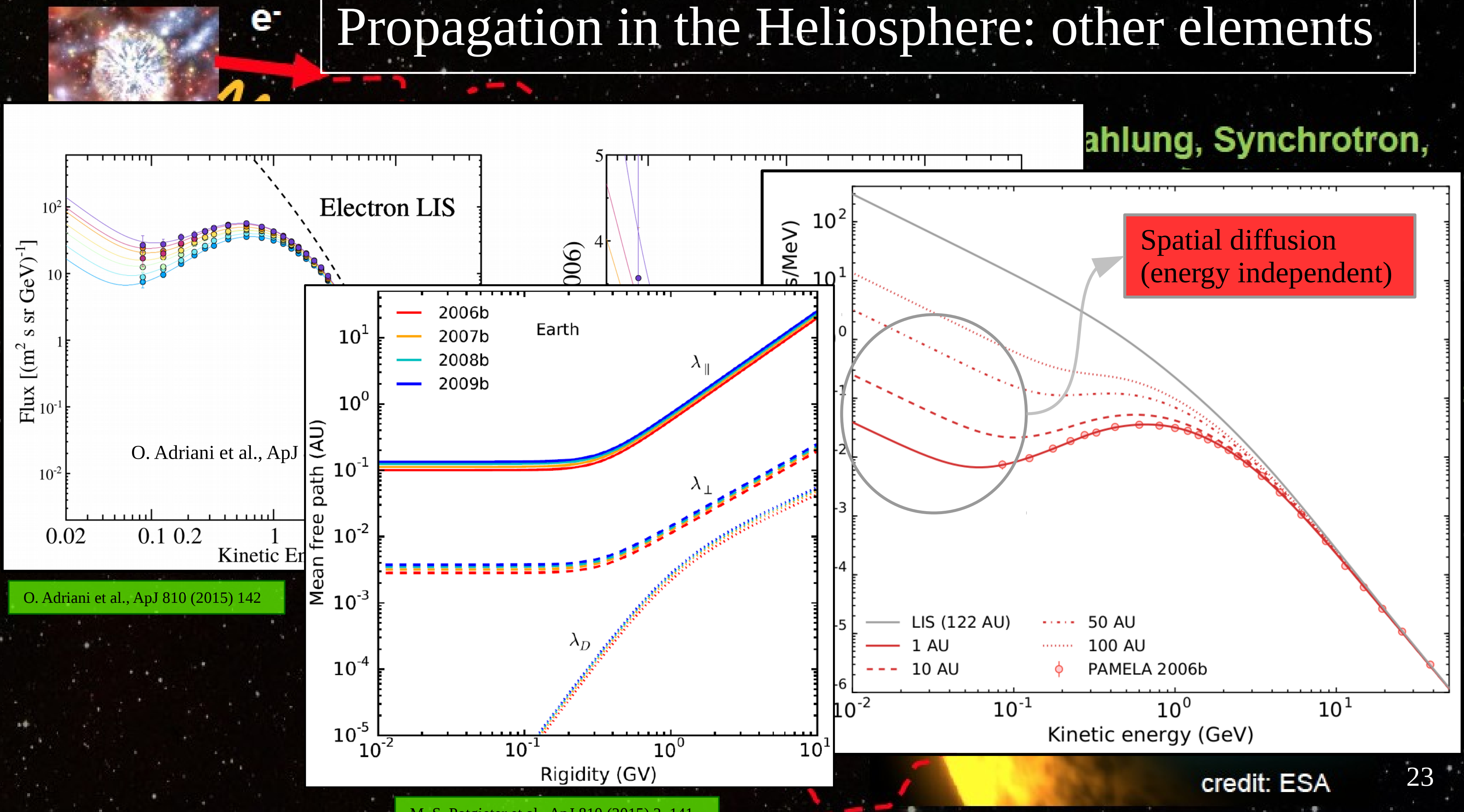
Solar Modulation, lower
terstellar cosmic ray spectra

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

N, O, Li,
Be, B, ...



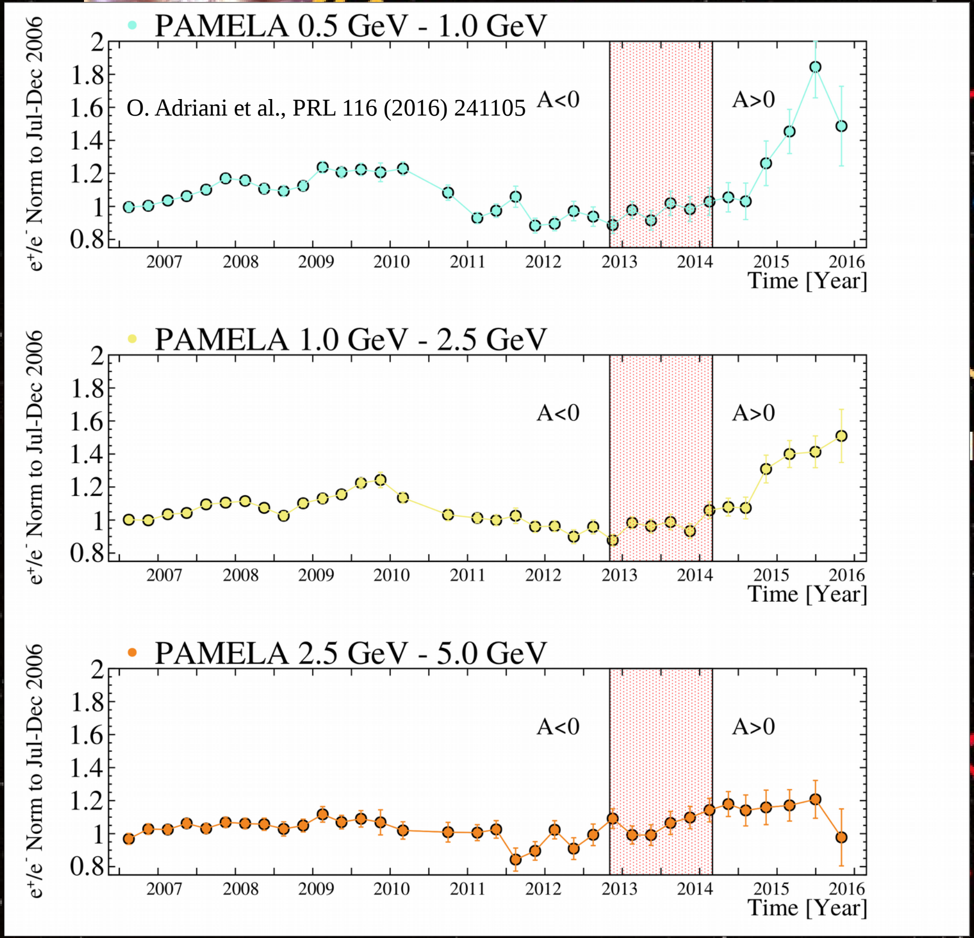
Propagation in the Heliosphere: other elements

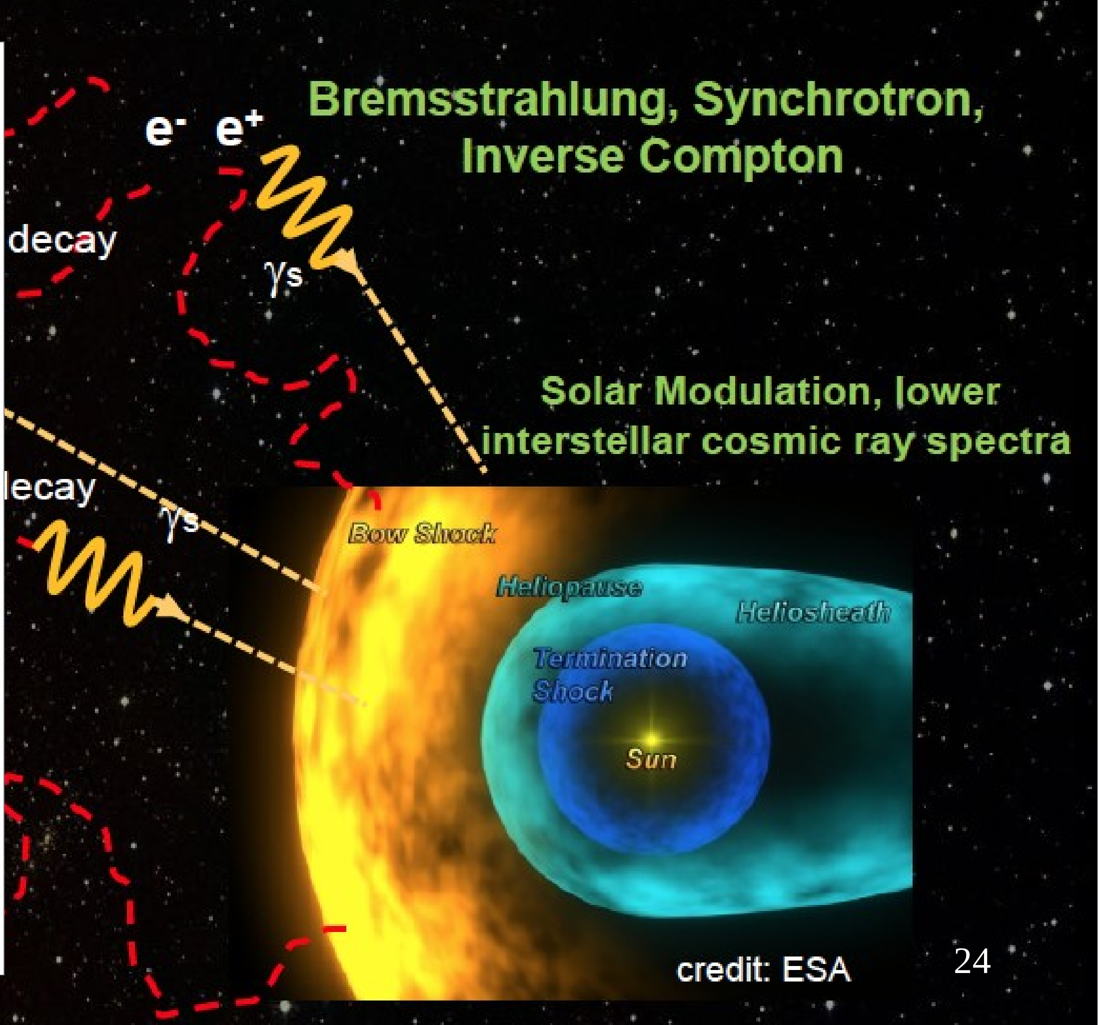


O. Adriani et al., ApJ 810 (2015) 142

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

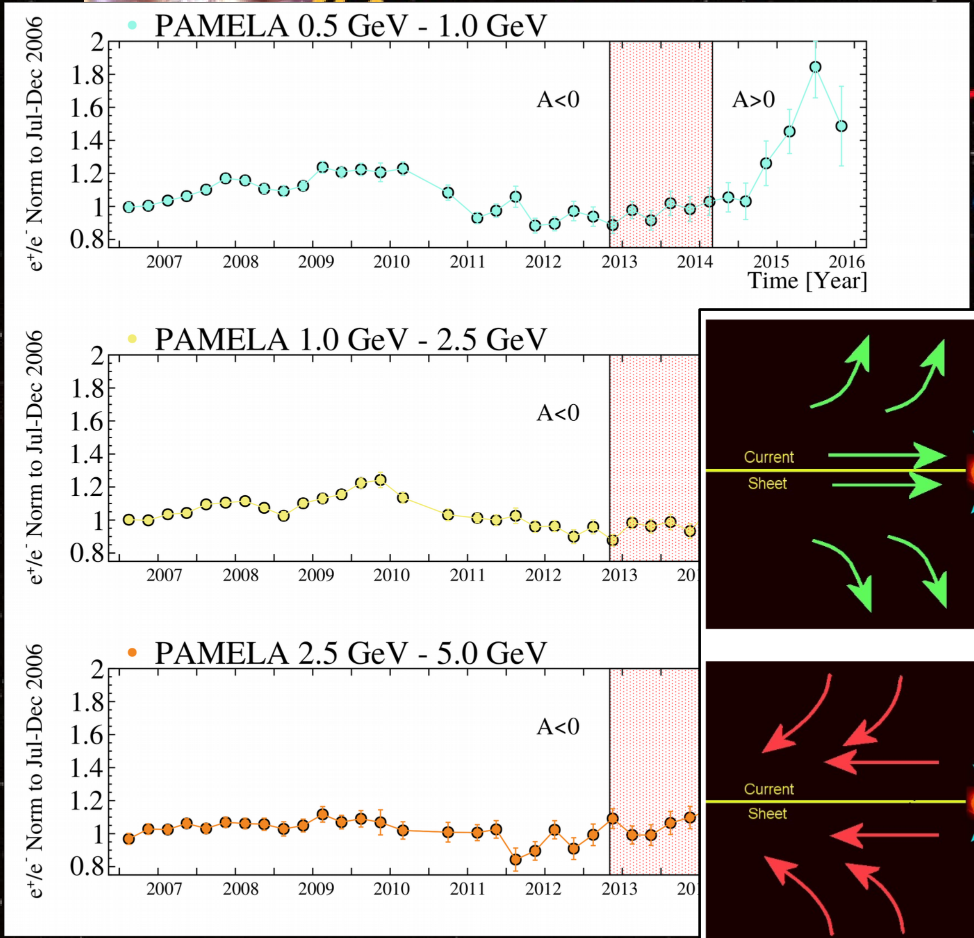
Propagation in the Heliosphere: charged sign dependence

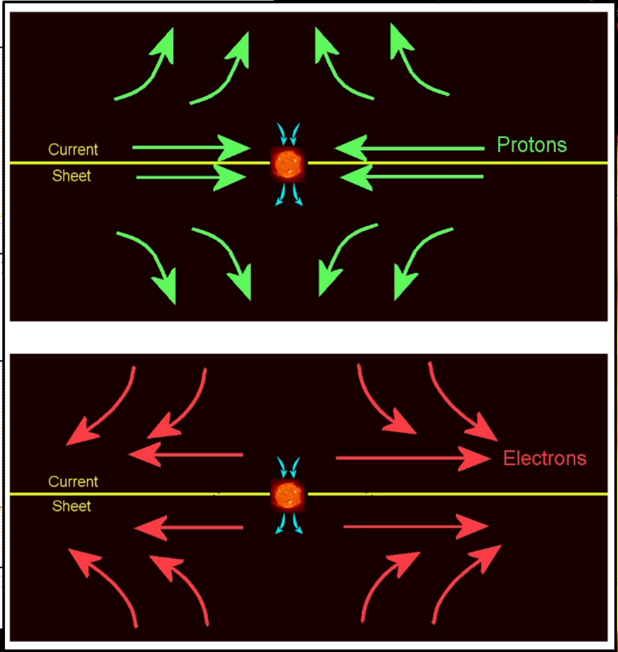


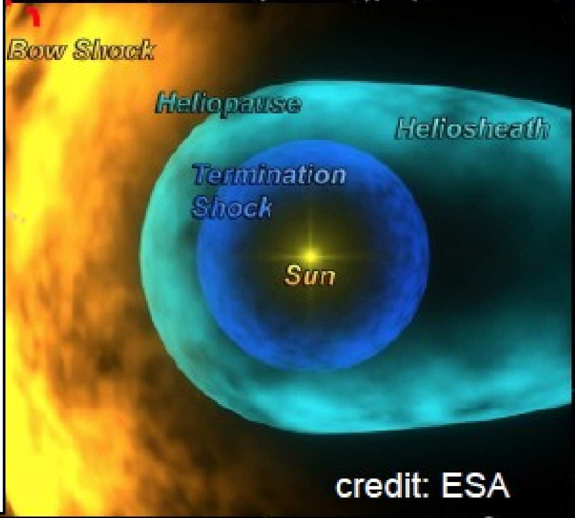


O. Adriani et al., PRL 116 (2016) 241105

Propagation in the Heliosphere: charged sign dependence

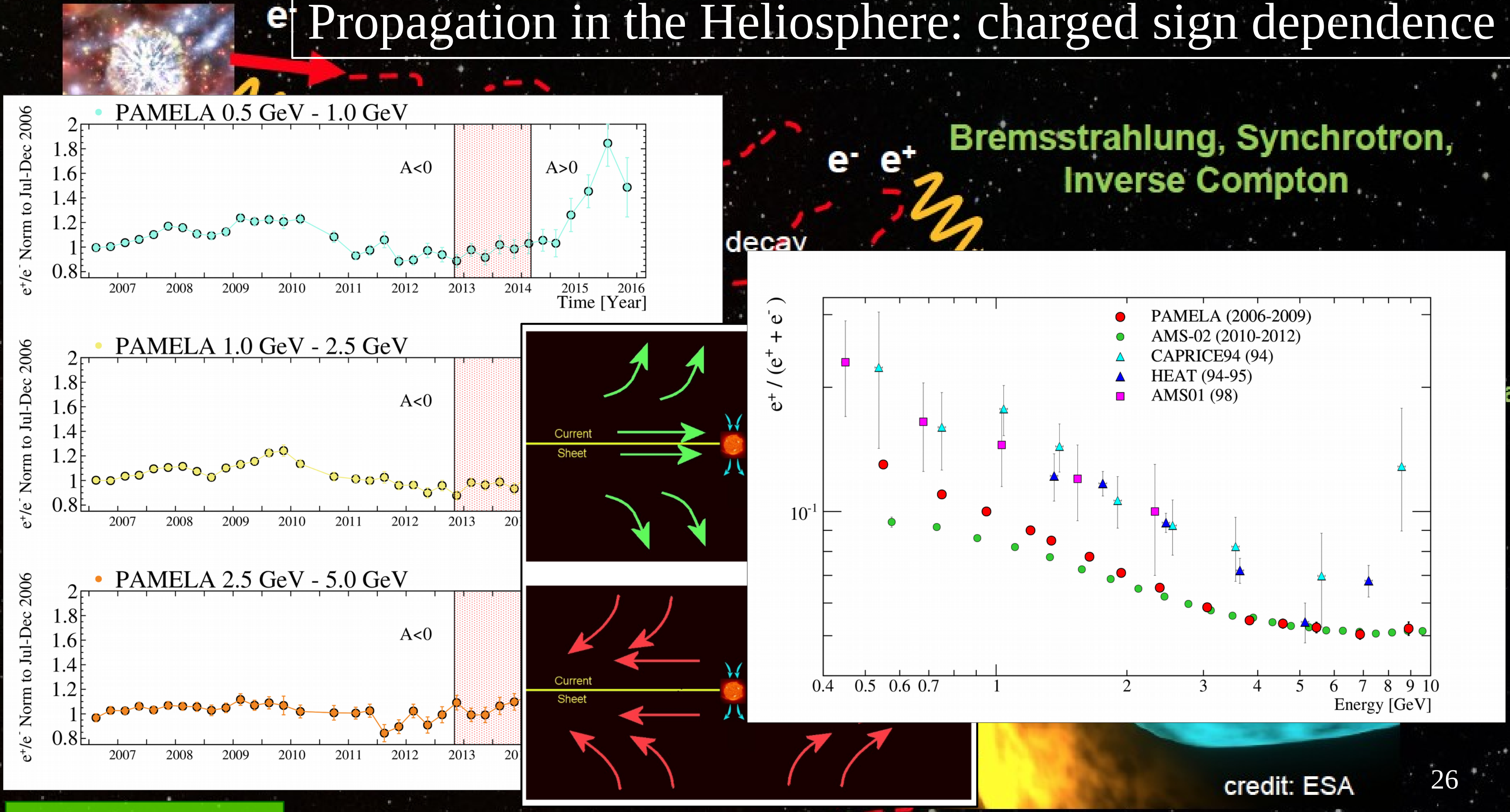






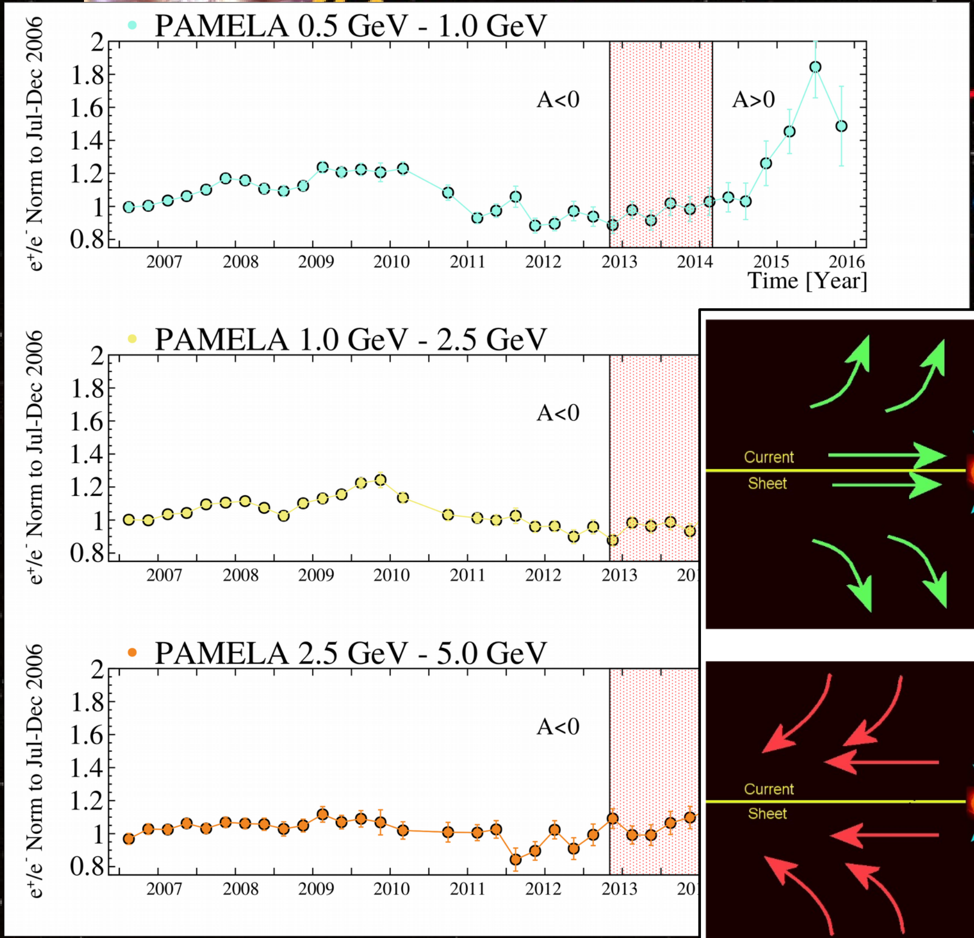
O. Adriani et al., PRL 116 (2016) 241105

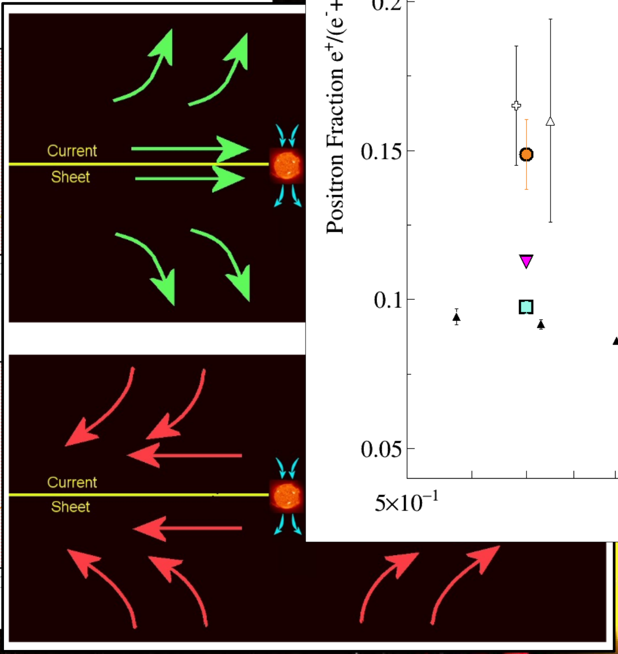
Propagation in the Heliosphere: charged sign dependence

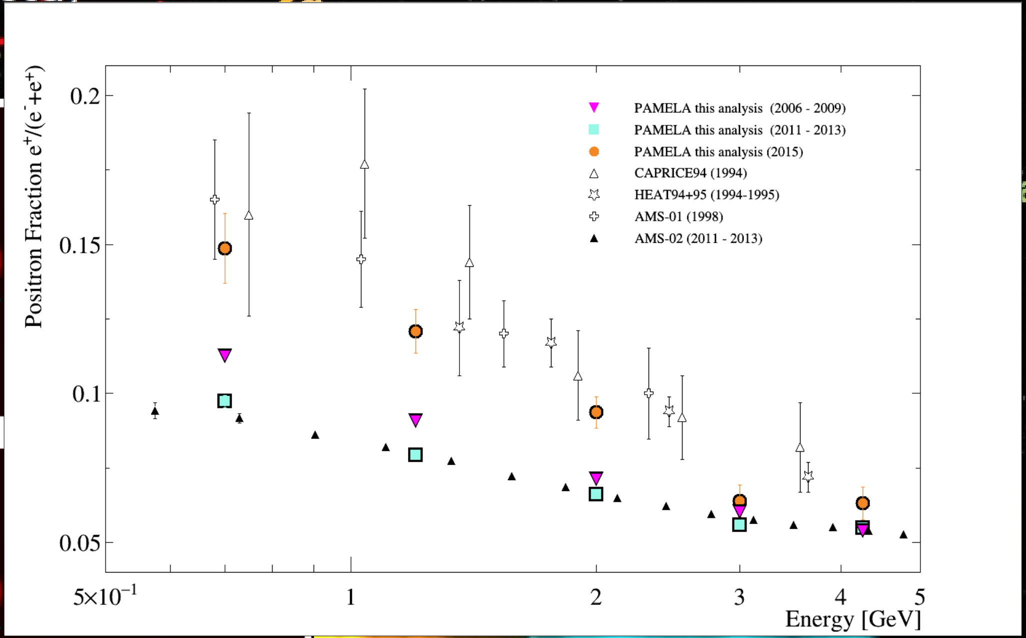


O. Adriani et al., PRL 116 (2016) 241105

Propagation in the Heliosphere: charged sign dependence

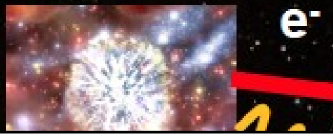


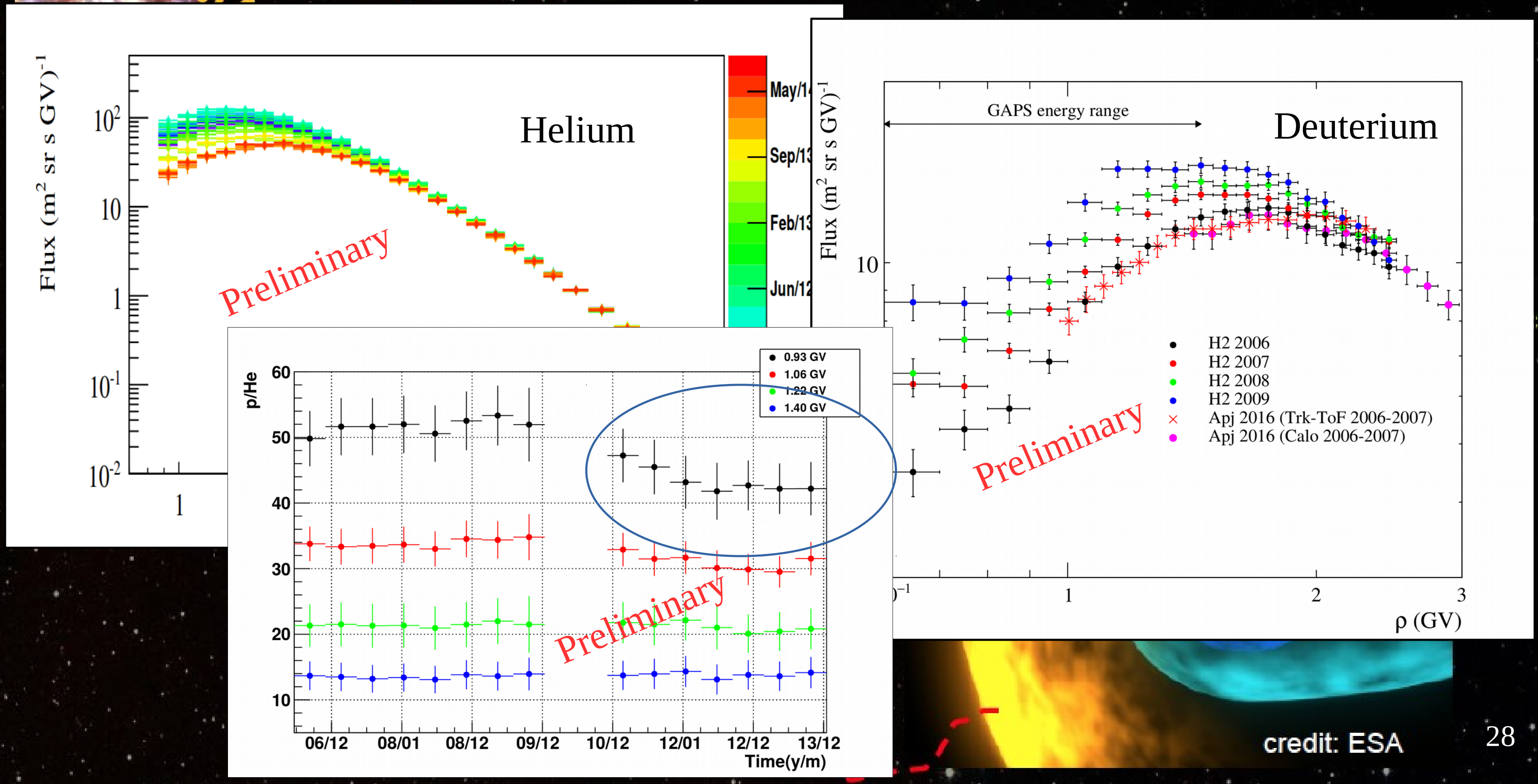




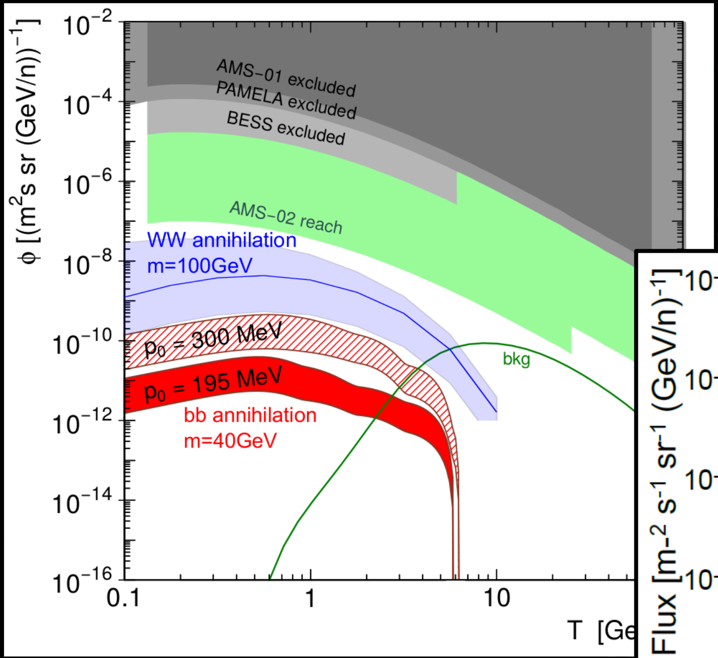
O. Adriani et al., PRL 116 (2016) 241105

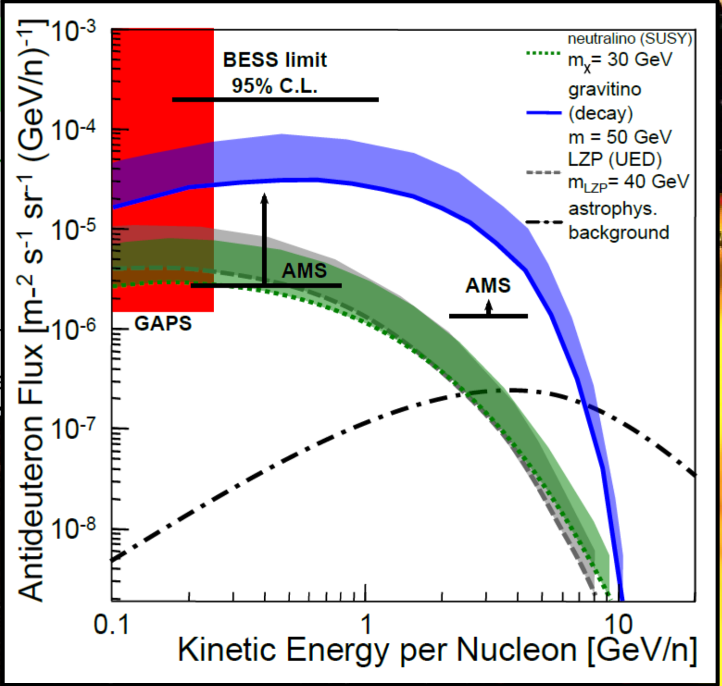
Propagation in the Heliosphere: other elements





Propagation in the Heliosphere and dark matter





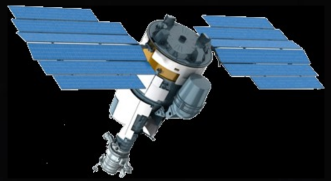
Low energy signals from dark matter annihilation: AntiDeuteron, antiHe

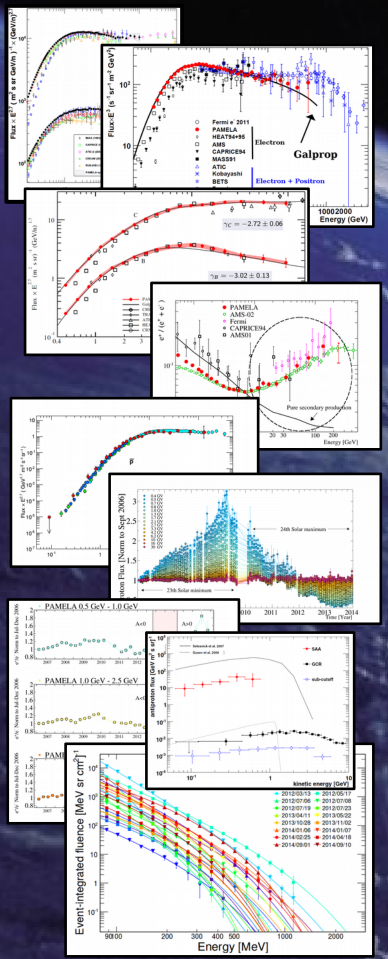
Very low astrophysical background, 2 orders of magnitude lower...

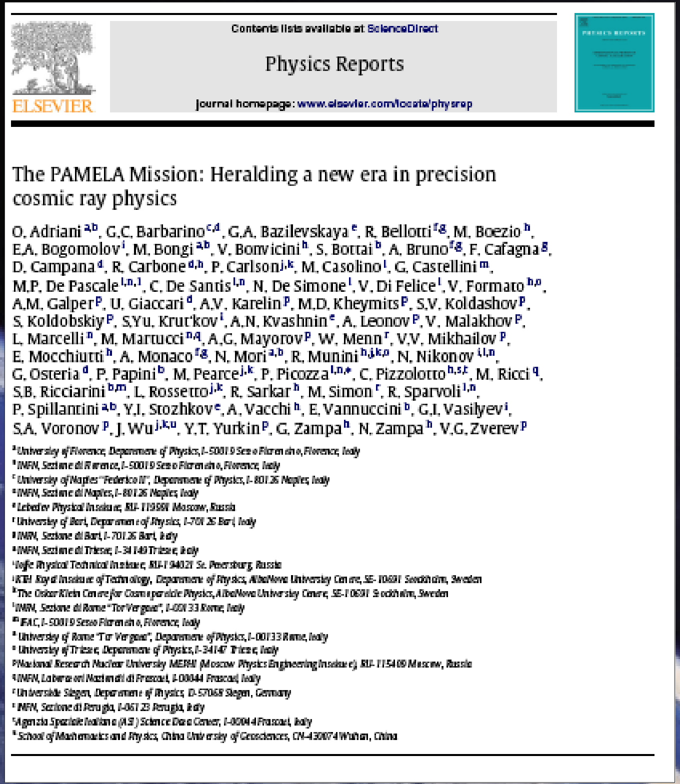
..in a region strongly affected by solar modulation, needs to improve the modelling in order to reduce the associated uncertainties.

credit: ESA

Ten years of PAMELA data






Contents lists available at ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

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]

[a] University of Florence, Department of Physics, I-50019 Sesto Fiorentino, Florence, Italy
[b] INFN, Sezione di Florence, I-50019 Sesto Fiorentino, Florence, Italy
[c] University of Naples "Federico II", Department of Physics, I-80126 Naples, Italy
[d] INFN, Sezione di Naples, I-80126 Naples, Italy
[e] Lebedev Physical Institute, RU-119991 Moscow, Russia
[f] University of Bari, Department of Physics, I-70126 Bari, Italy
[g] INFN, Sezione di Bari, I-70126 Bari, Italy
[h] INFN, Sezione di Trieste, I-34149 Trieste, Italy
[i] Ioffe Physical Technical Institute, RU-194021 St. Petersburg, Russia
[j] KTH, Royal Institute of Technology, Department of Physics, AlbaNova University Centre, SE-10691 Stockholm, Sweden
[k] The Oskar Klein Centre for Cosmoparticle Physics, AlbaNova University Centre, SE-10691 Stockholm, Sweden
[l] INFN, Sezione di Rome "Tor Vergata", I-00133 Rome, Italy
[m] IFAC, I-50019 Sesto Fiorentino, Florence, Italy
[n] University of Rome "Tor Vergata", Department of Physics, I-00133 Rome, Italy
[o] University of Trieste, Department of Physics, I-34147 Trieste, Italy
[p] National Research Nuclear University MEPhI (Moscow Physics Engineering Institute), RU-115409 Moscow, Russia
[q] INFN, Laboratori Nazionali di Frascati, I-00044 Frascati, Italy
[r] Universität Siegen, Department of Physics, D-57068 Siegen, Germany
[s] INFN, Sezione di Perugia, I-06123 Perugia, Italy
[t] Agenzia Spaziale Italiana (ASI) Science Data Center, I-00044 Frascati, Italy
[u] School of Mathematics and Physics, China University of Geosciences, CN-430074 Wuhan, China


LA RIVISTA DEL NUOVO CIMENTO

YEAR 2017 - ISSUE 10 - OCTOBER

Ten years of PAMELA in space

Authors: *PAMELA Collaboration - O. Adriani, G. C. Barbarino, G. A. Bazilevskaya, R. Bellotti, M. Boezio, E. A. Bogomolov, M. Bongi, V. Bonvicini, S. Bottai, A. Bruno, F. Cafagna, D. Campana, P. Carlson, M. Casolino, G. Castellini, C. De Santis, V. Di Felice, A. M. Galper, A. V. Karelin, S. V. Koldashov, S. Koldobskiy, S. Y. Krutkov, A. N. Kvashnin, A. Leonov, V. Malakhov, L. Marcelli, M. Martucci, A. G. Mayorov, W. Menn, M. Mergè, V. V. Mikhailov, E. Mocchiutti, A. Monaco, R. Munini, N. Mori, G. Osteria, B. Panico, P. Papini, M. Pearce, P. Picozza, M. Ricci, S. B. Ricciarini, M. Simon, R. Sparvoli, P. Spillantini, Y. I. Stozhkov, A. Vacchi, E. Vannuccini, G. Vasilyev, S. A. Voronov, Y. T. Yurkin, G. Zampa, N. Zampa*

DOI: 10.1393/ncr/i2017-10140-x
pp. 473-522
Published online 27 September 2017
Download fulltext