Forbush decrease model for expanding CMEs (ForbMod)

Mateja Dumbović

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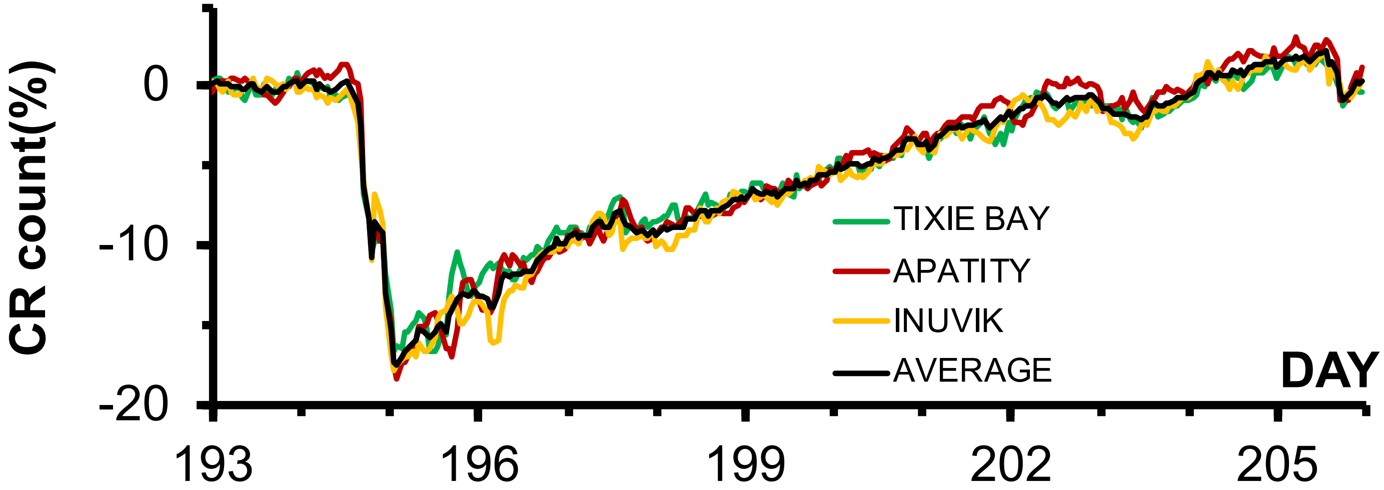
What are Forbush decreases?



Dumbovic PhD thesis,2015

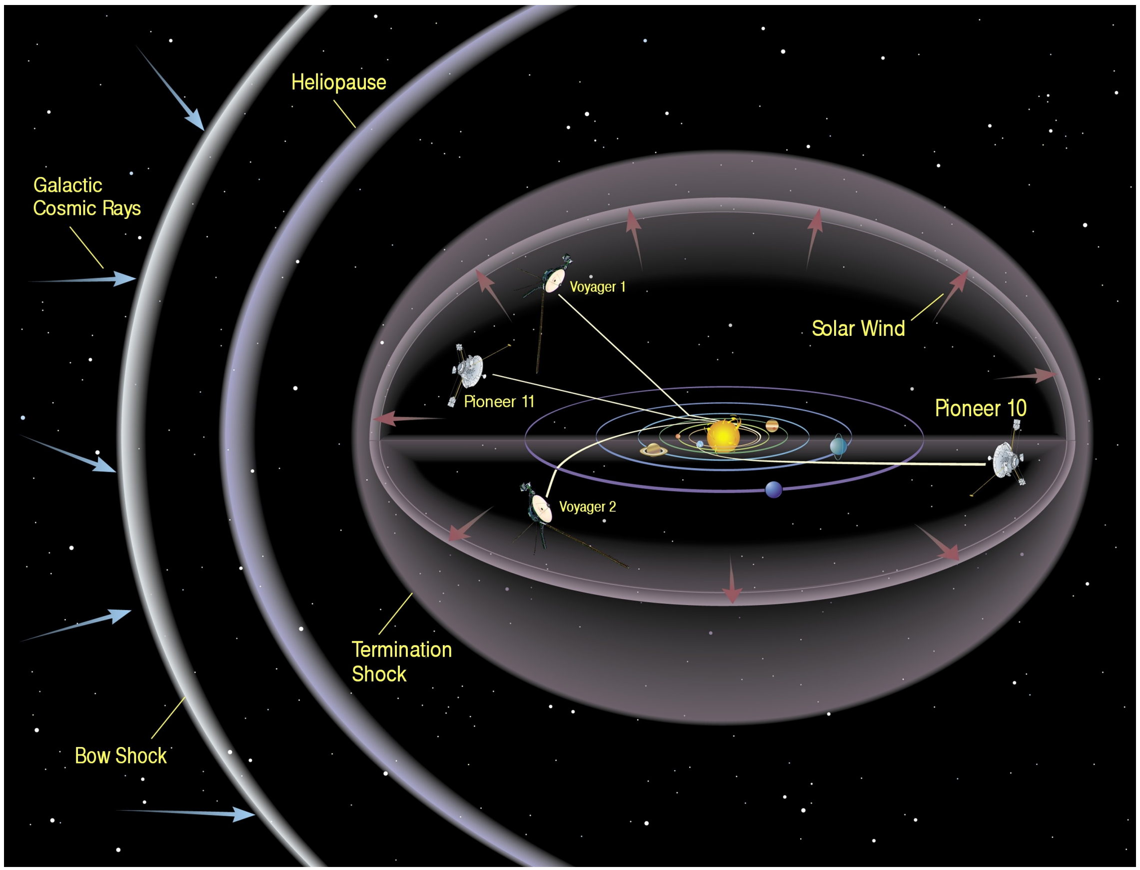
First observed by Forbush, 1937 and Hess & Demmelmair, 1937

Short term decreases in galactic cosmic ray count
Typical duration several days

Typical amplitudes several %

(depends on the detector)

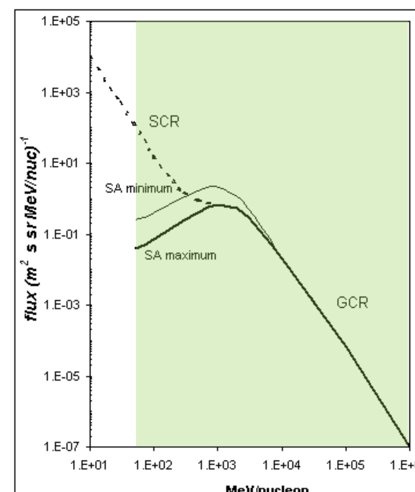
Cosmic rays in Heliosphere – in general



www.nasa.gov

THREE COMPONENTS:

1) Galactic cosmic rays



Mursula & Usoskin lectures, 2003, Uni. Oulu

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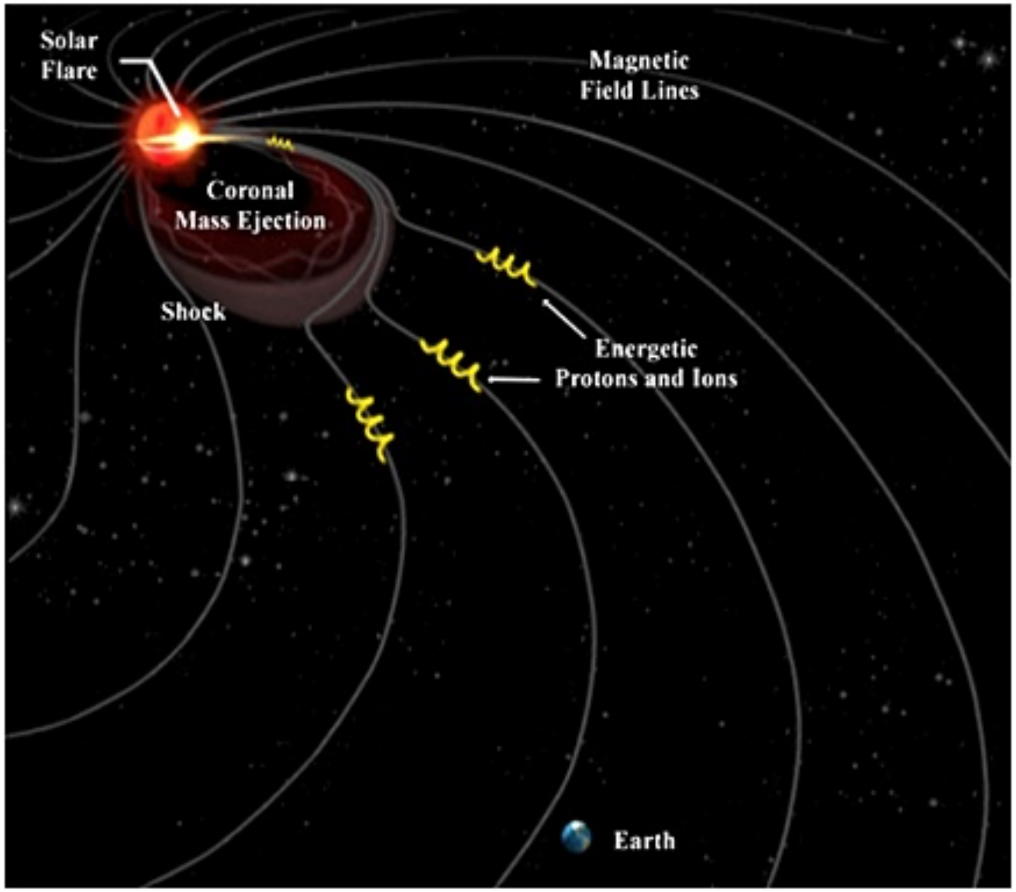
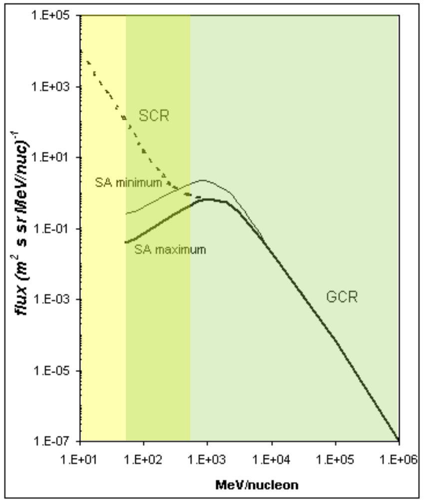


www.spaceweather.uma.es

THREE COMPONENTS:

1) Galactic cosmic rays

2) Solar cosmic rays (solar energetic particles, SEPs)



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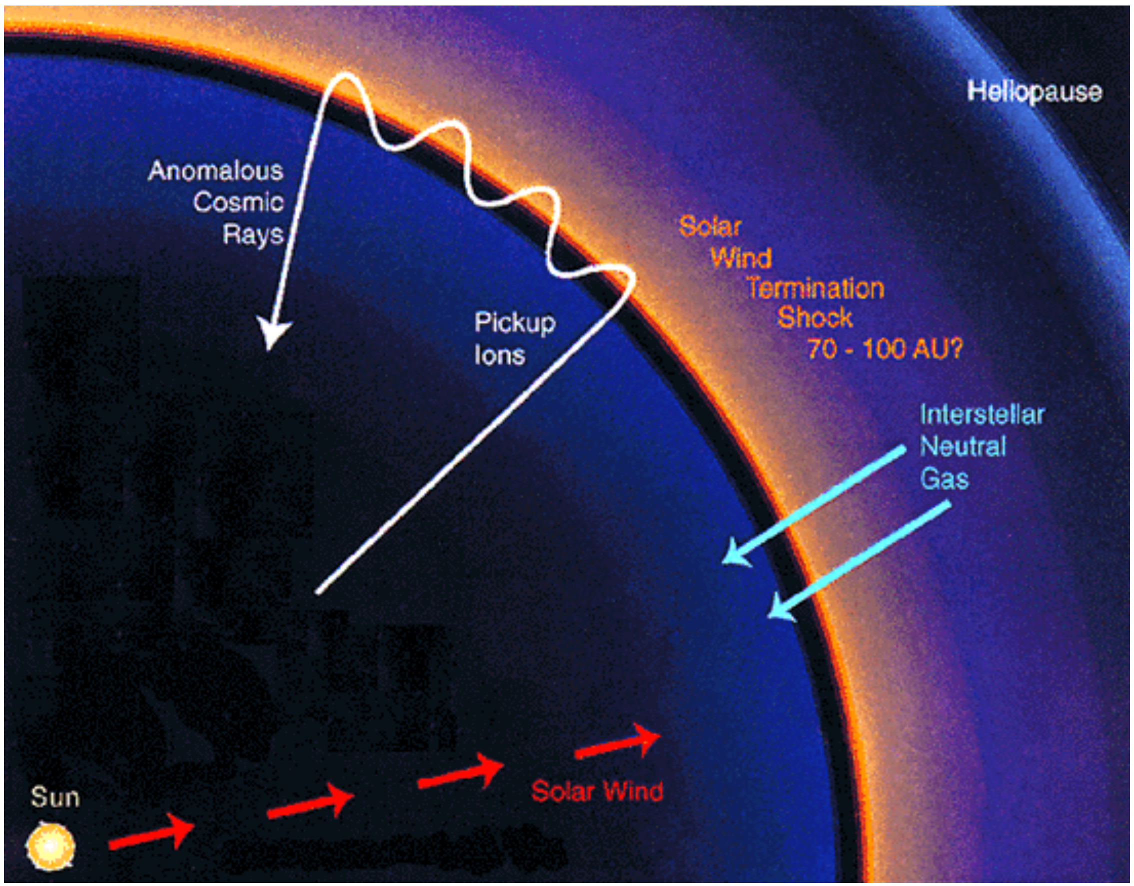
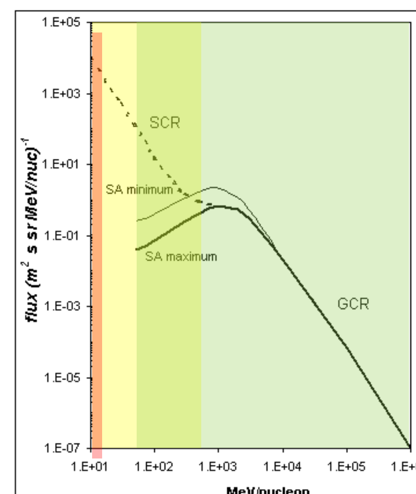


www.nasa.gov

THREE COMPONENTS:

1) Galactic cosmic rays
2) Solar cosmic rays (solar energetic particles, SEPs)
3) Anomalous cosmic rays



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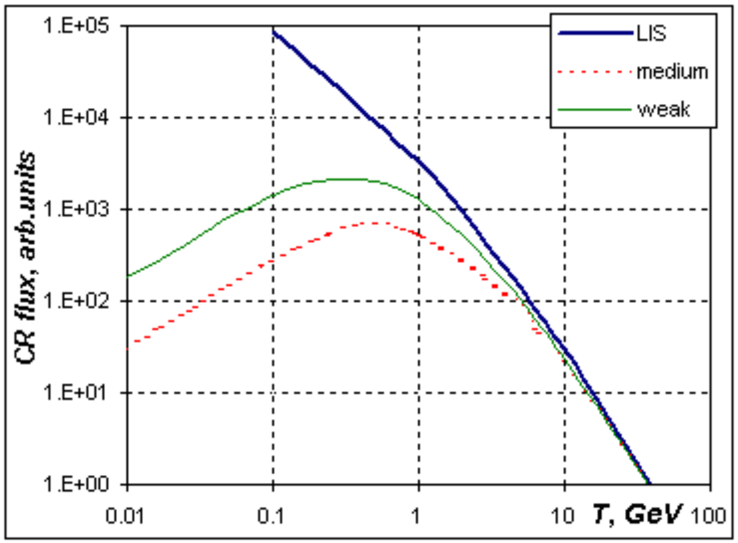
Modulation of Galactic Cosmic Rays (GCRs) in Heliosphere



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GCRs delayed or even prevented from reaching Earth

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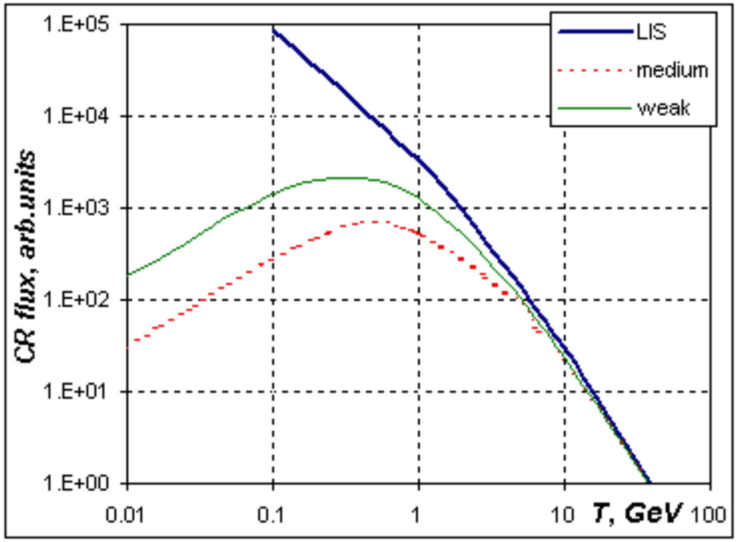

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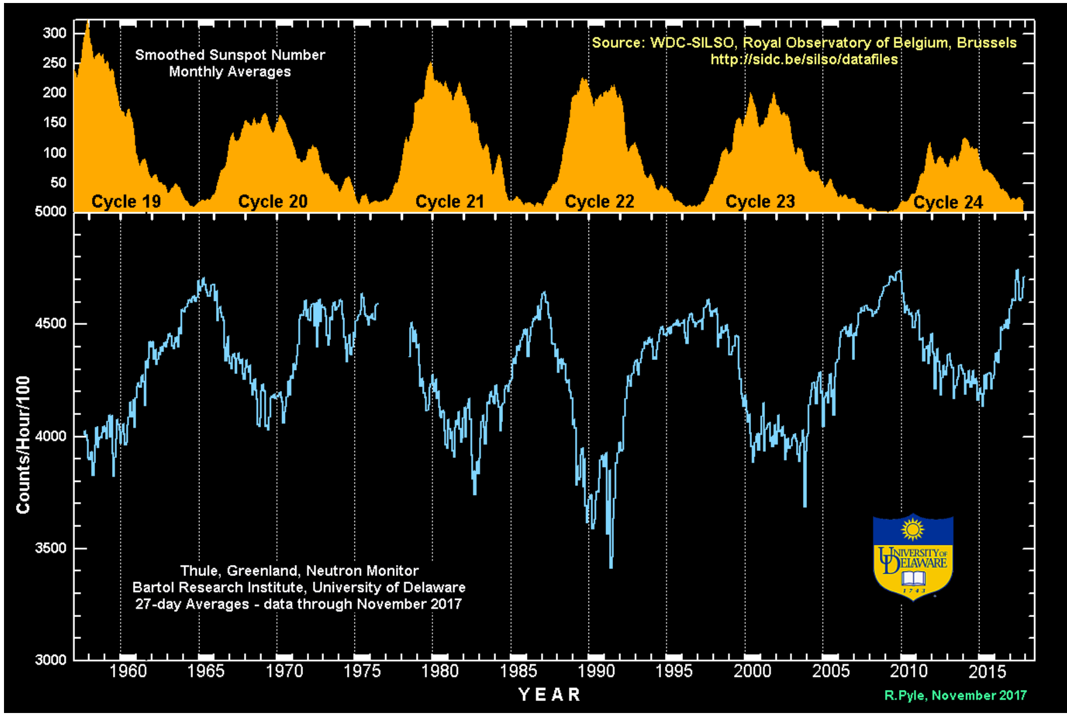

GCR flux anticorrelated with solar activity

www.neutron.bartol.udel.edu

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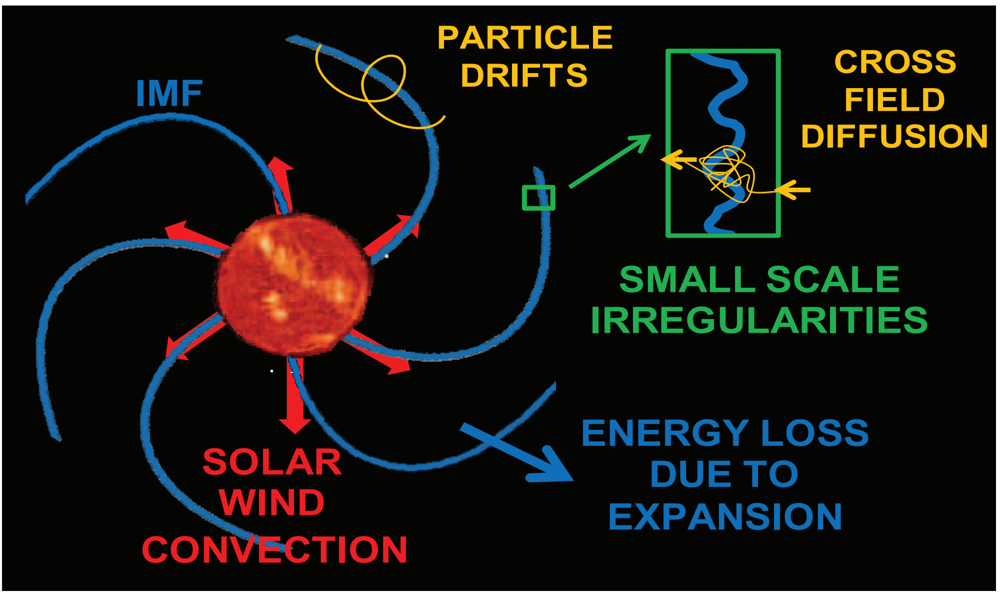


Dumbovic PhD thesis,2015

PARTICLE TRANSPORT EQUATION

Parker, 1965

$$\underbrace{\frac{\partial f}{\partial t}}_{\mathrm{a}} = -(\underbrace{\mathbf{V}}_{\mathrm{b}} + \underbrace{\langle \mathbf{v}_d \rangle}_{c}) \cdot \nabla f + \underbrace{\nabla \cdot (\mathbf{K}_s \cdot \nabla f)}_{d} + \underbrace{\frac{1}{3} (\nabla \cdot \mathbf{V}) \frac{\partial f}{\partial \ln P}}_{e},$$

a: GCR phase-space distribution function F(P,t,r)

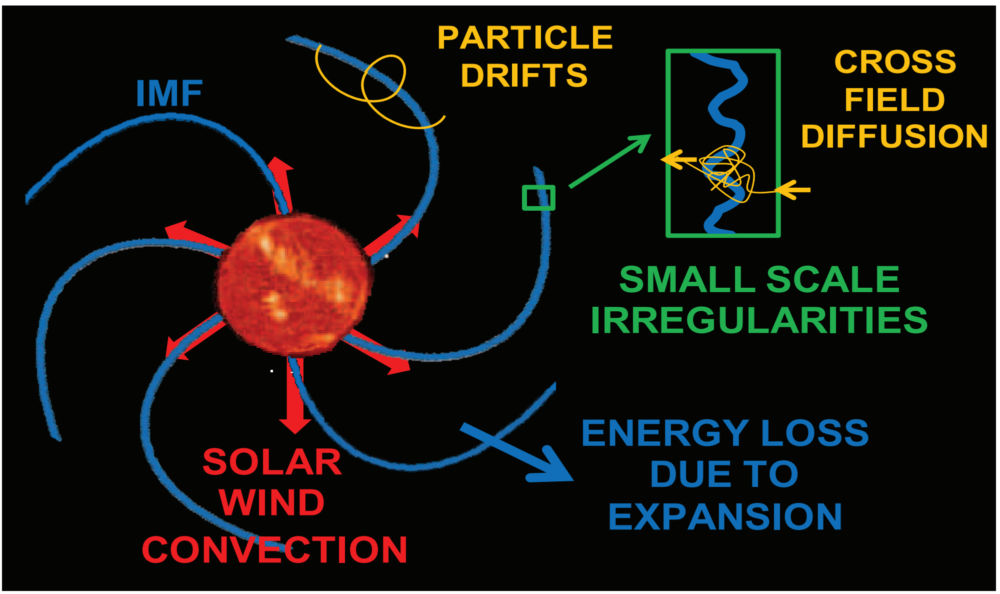
b: convection

c: drifts

d: diffusion

e: Adiabatic cooling

Modulation of Galactic Cosmic Rays (GCRs) in Heliosphere



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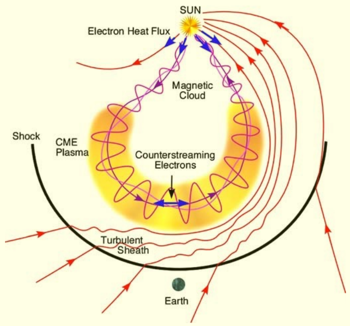
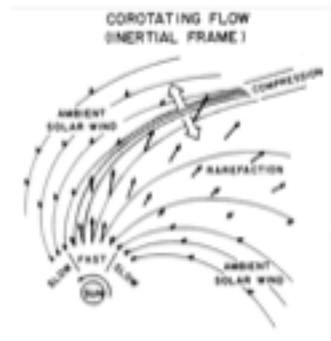
What are Forbush decreases?

What causes Forbush decreases?

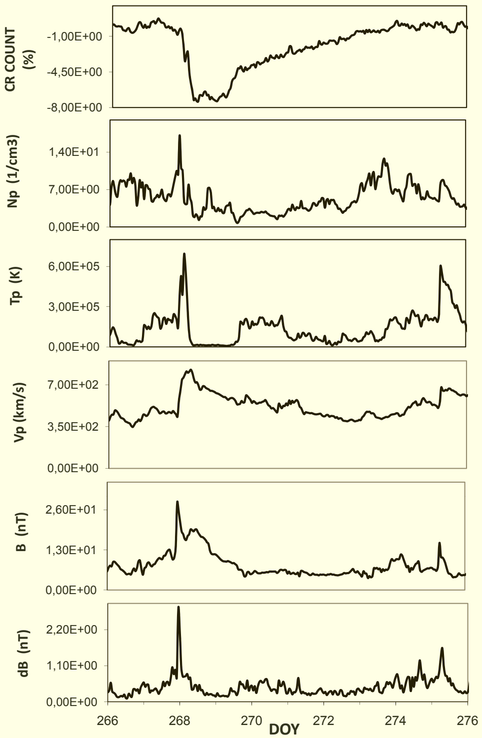


Zurbuchen&Richardson,2006

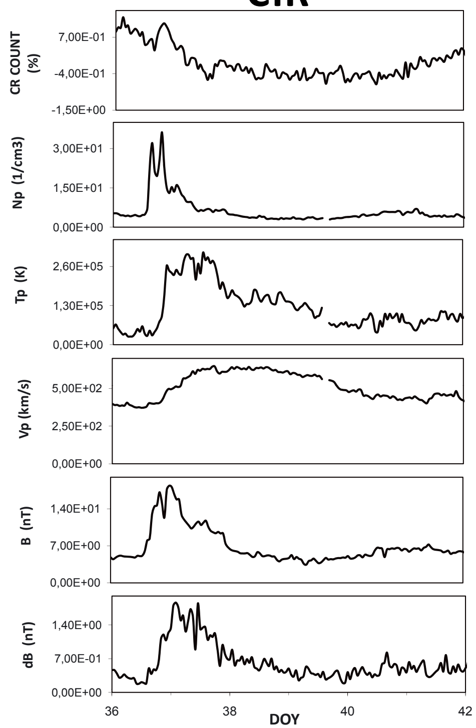


Gosling&Pizzo,1999

ICME



CIR



Dumbovic+,2012

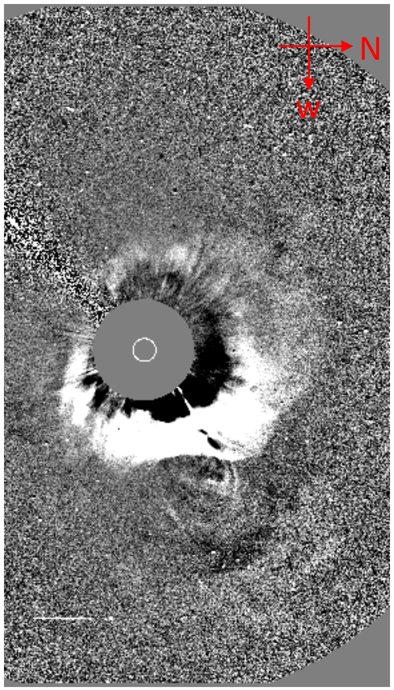
Various shapes and sizes

↑

Various interplanetary transients

Forbush decreases caused by Interplanetary Coronal Mass Ejections (ICMEs)

REMOTE OBSERVATION

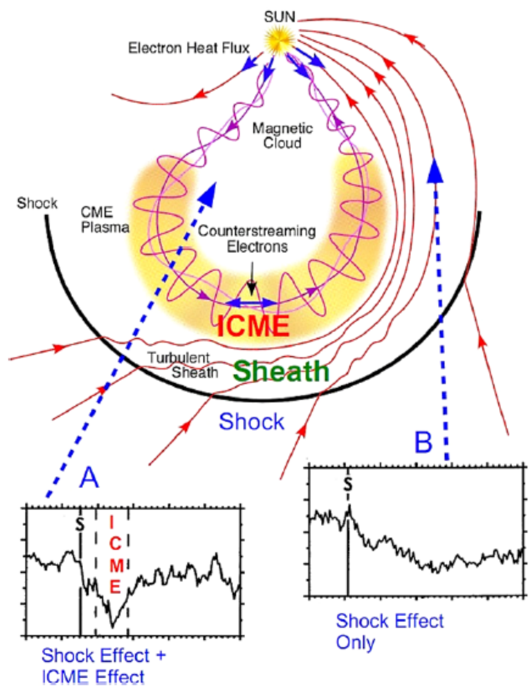


CME in SOHO/LASCO C3

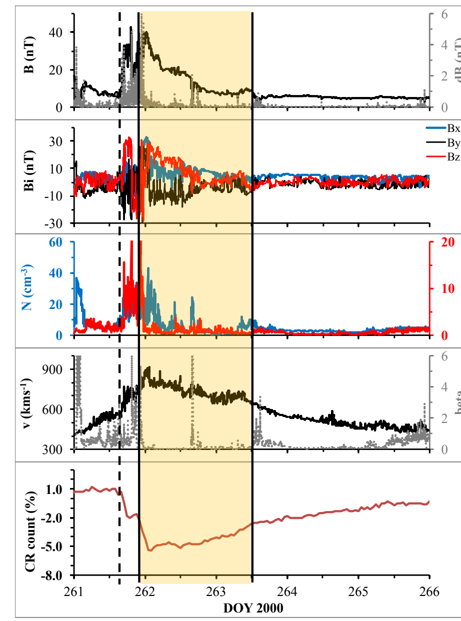
2000 September 16 06:18 UT
First C2 detection at 05:18

VISUALISATION

Adapted from Richardson & Cane, 2011, SolPhys



IN SITU MEASUREMENTS



ICME detected in situ by Wind

2000 September 17
Shock arrival at 17:00

+

2step Forbush decrease detected by NMs at Earth

adapted from Dumbovic+, 2011, A&A

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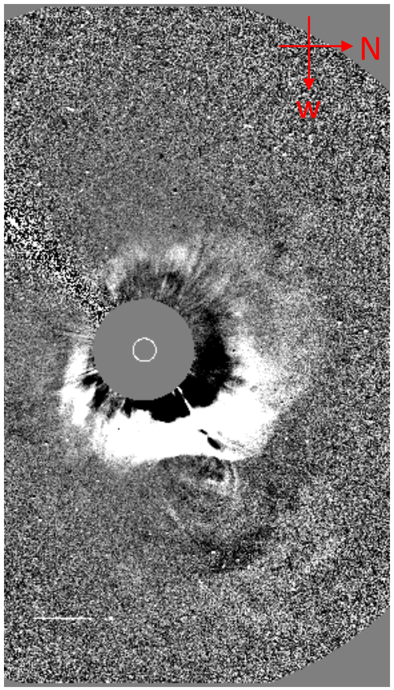

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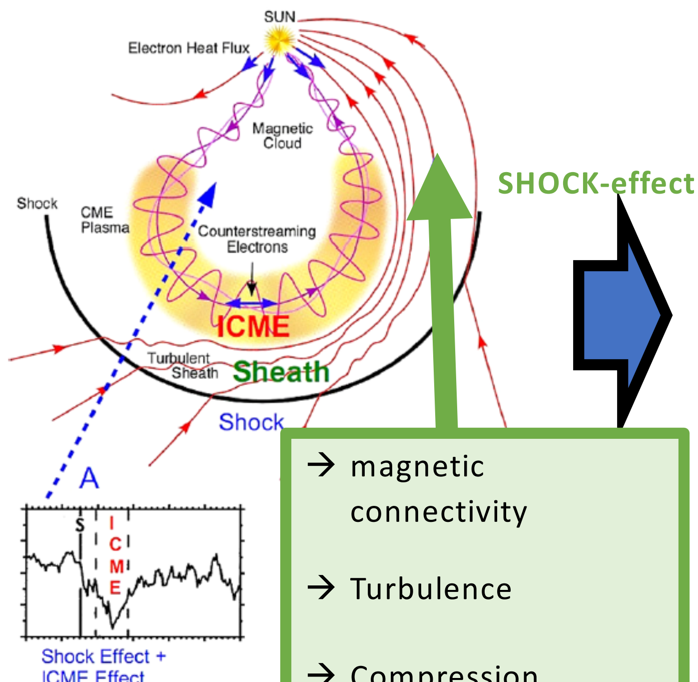

- → magnetic connectivity
- → Turbulence
- → Compression
- → Prolonged effect

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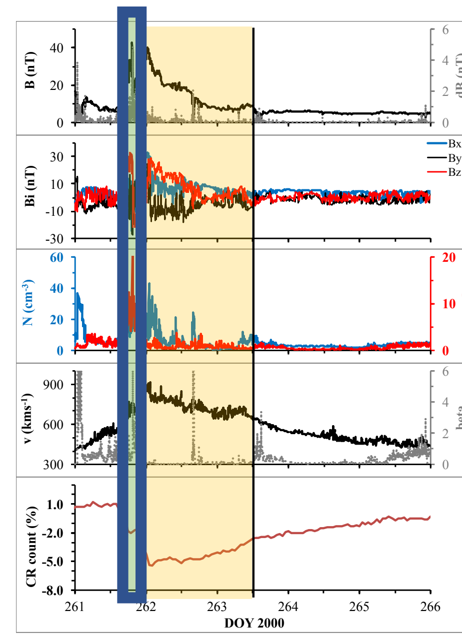

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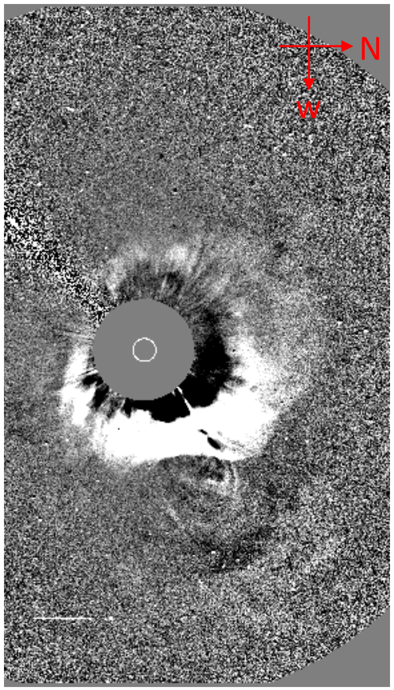

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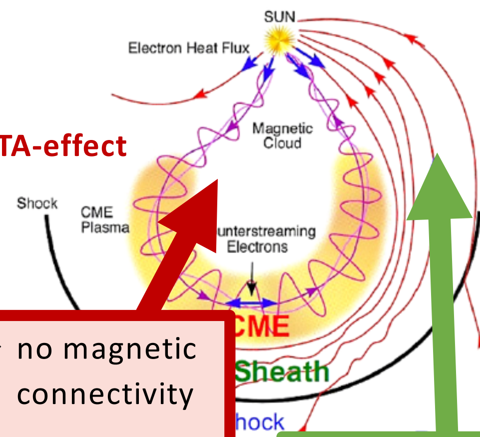


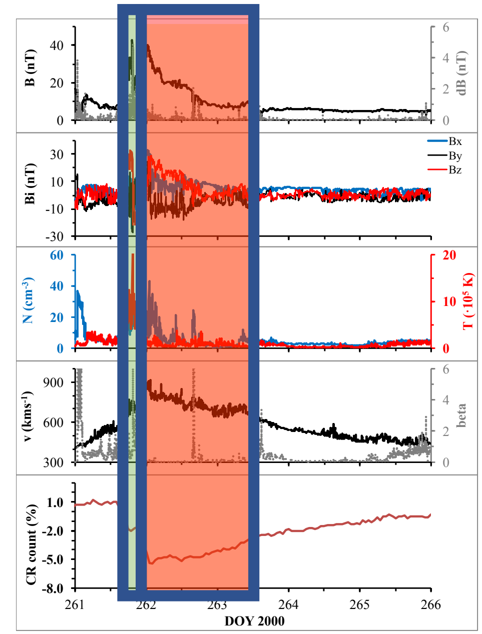
EJECTA-effect

- → no magnetic connectivity
- → Smooth & strong field
- → Timespan limited to ICME

SHOCK-effect

- → magnetic connectivity
- → Turbulence
- → Compression
- → Prolonged effect

IN SITU MEASUREMENTS



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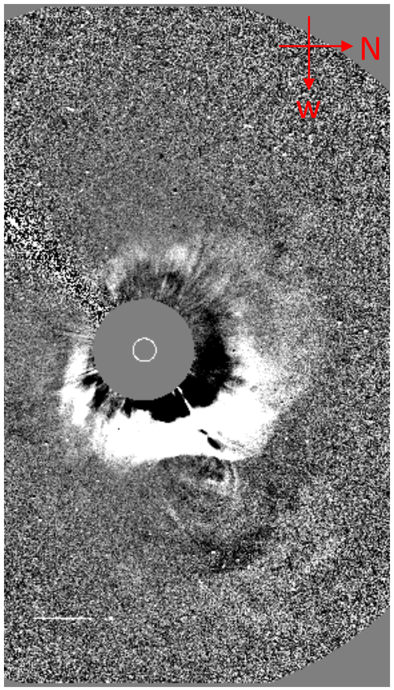

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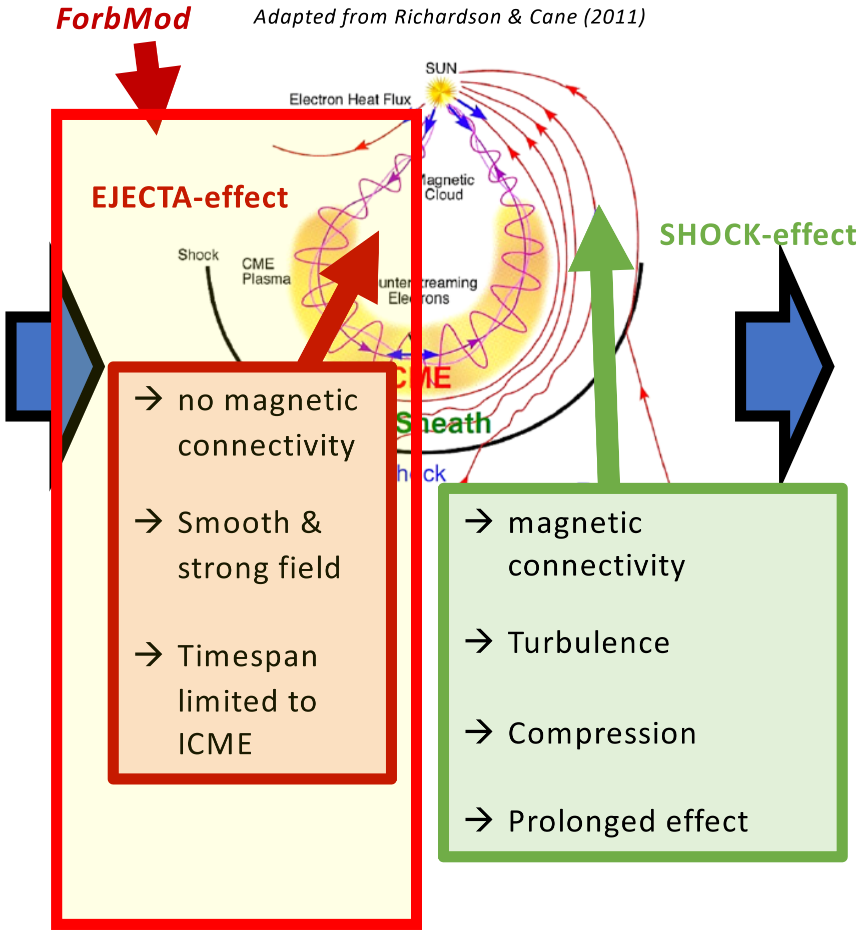

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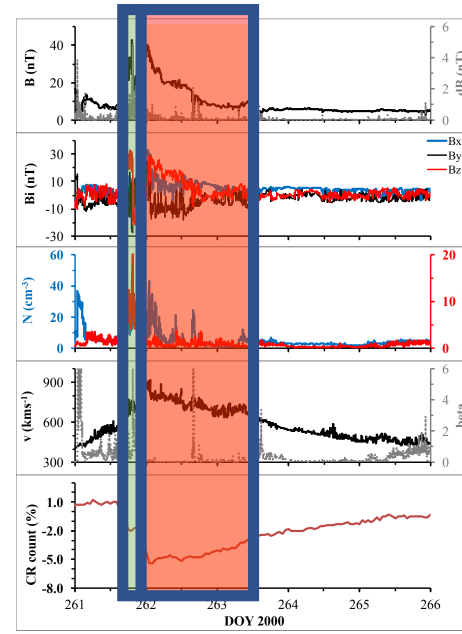

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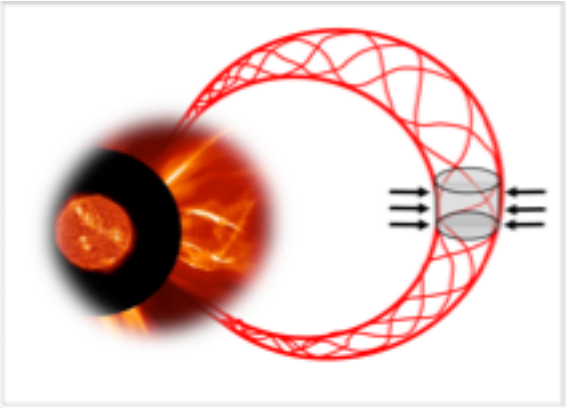

- a closed magnetic structure
- Initially empty of GCR
- Locally of cylindrical form
- Moves with constant velocity

First proposed by Morrison, 1956, PhysRev

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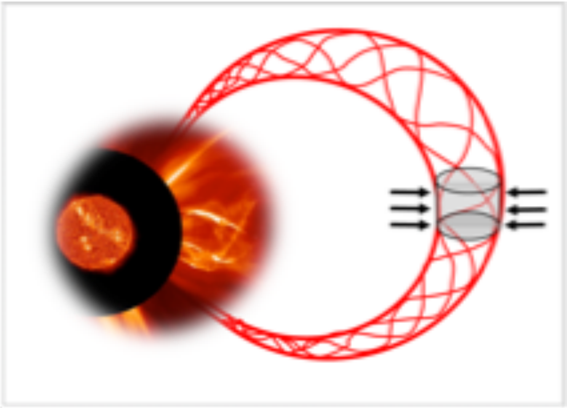

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- particles enter by perpendicular diffusion and slowly fill the structure

Similar to e.g. Cane+, 1995, ICRCproc; Quenby+, 2008, JGR

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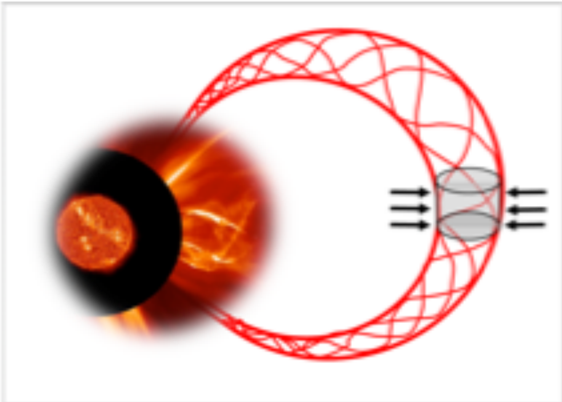

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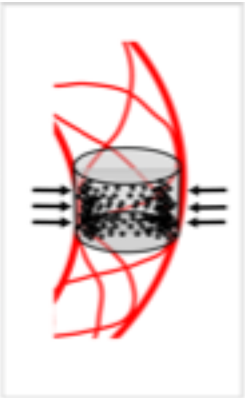

- expands self-similarly

Similar to e.g. Munakata+, 2006, AdvGeophys; Arunbabu+, 2013, A&A

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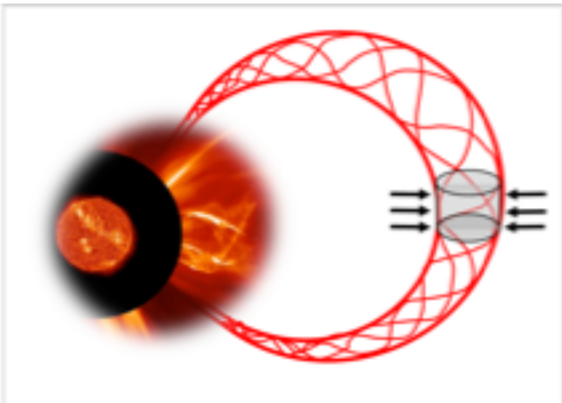

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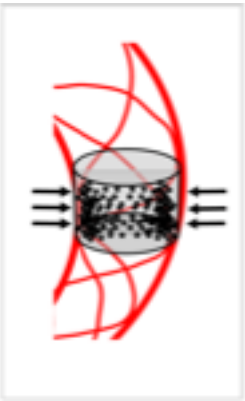

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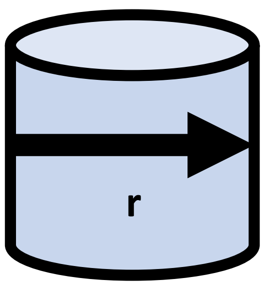
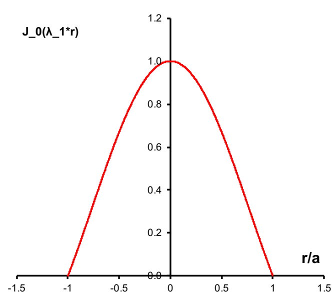
SPACE PART

TIME PART

Axial symmetry



Bessel function 0th order



Symmetric + normalized

Dumbovic+,2018,ApJ(submitted)

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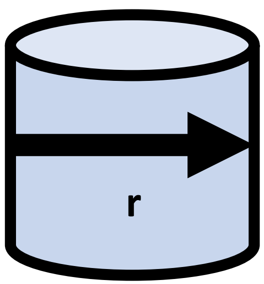

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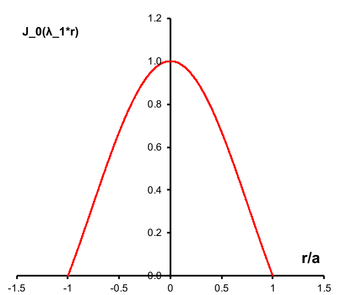

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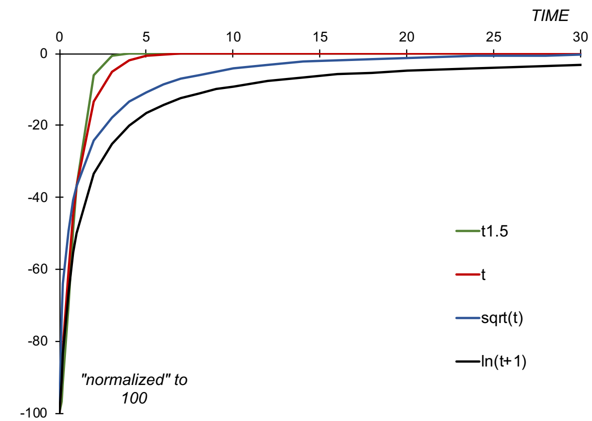

Exponential function of time

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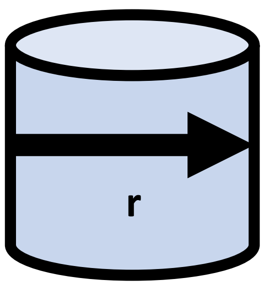

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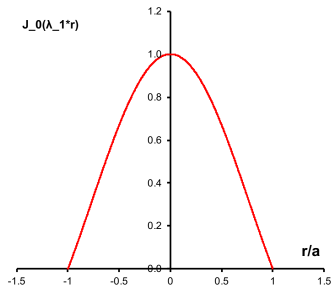

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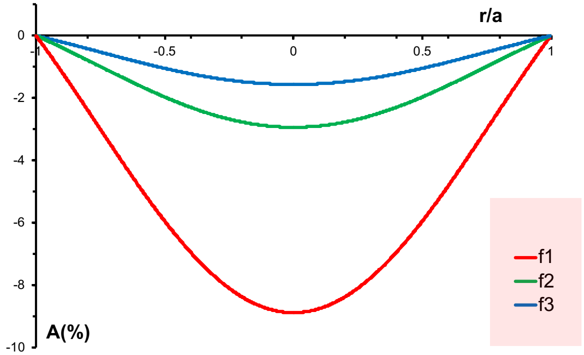

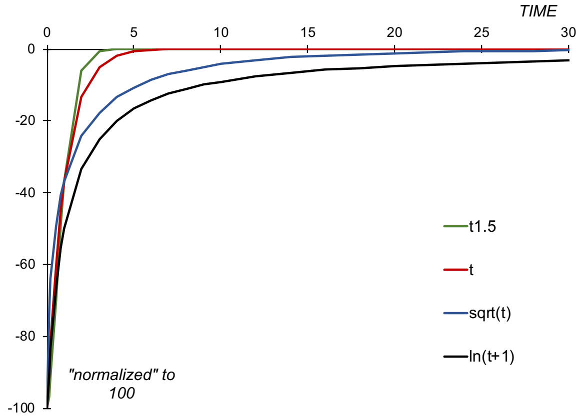

Exponential function of time

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$$f(t) = \int D(t)/a(t)^2 \mathrm{d}t$$

Dumbovic+,2018,ApJ(submitted)

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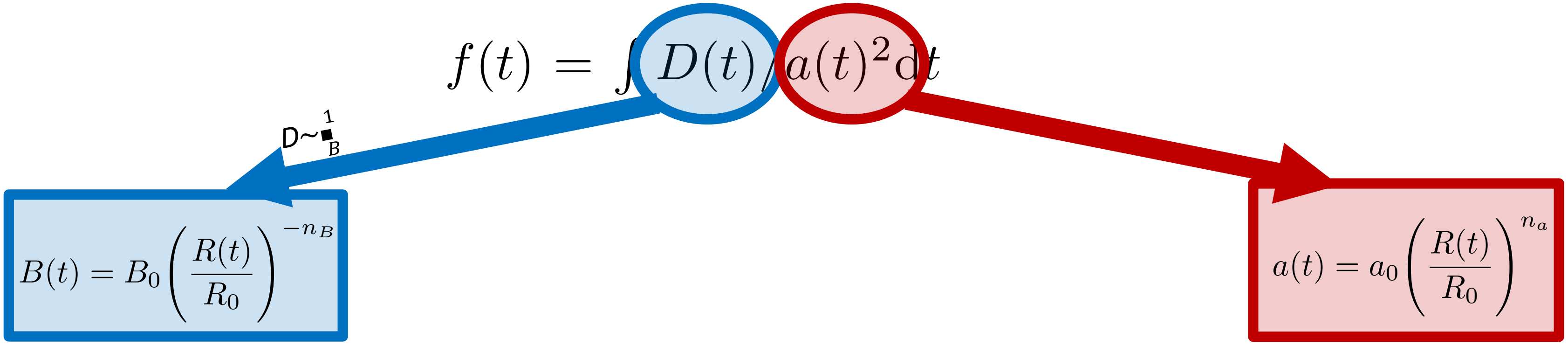
$$f(t) = \int D(t)/a(t)^2 \mathrm{d}t$$

$D \sim \frac{1}{B}$

$$B(t) = B_0 \left(\frac{R(t)}{R_0} \right)^{-n_B}$$

e.g. Demoulin, 2008, SolPhys

ForbMod = analytical diffusion-expansion model for Forbush decreases caused by flux ropes



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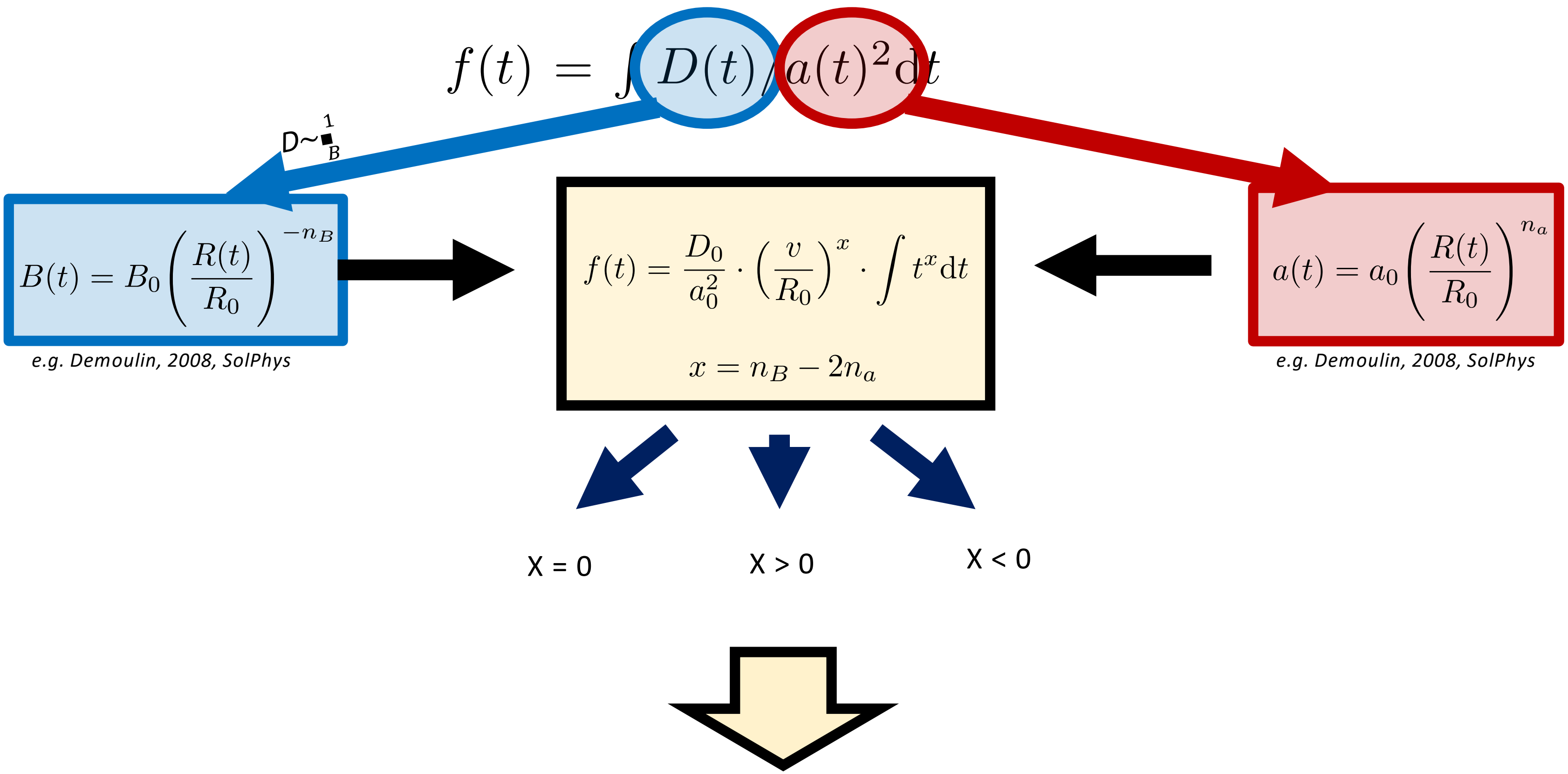

COMPETITION

BETWEEN CHANGE IN THE MAGNETIC FIELD

AND THE CHANGE IN THE SIZE

Dumbovic+,2018,ApJ(submitted)

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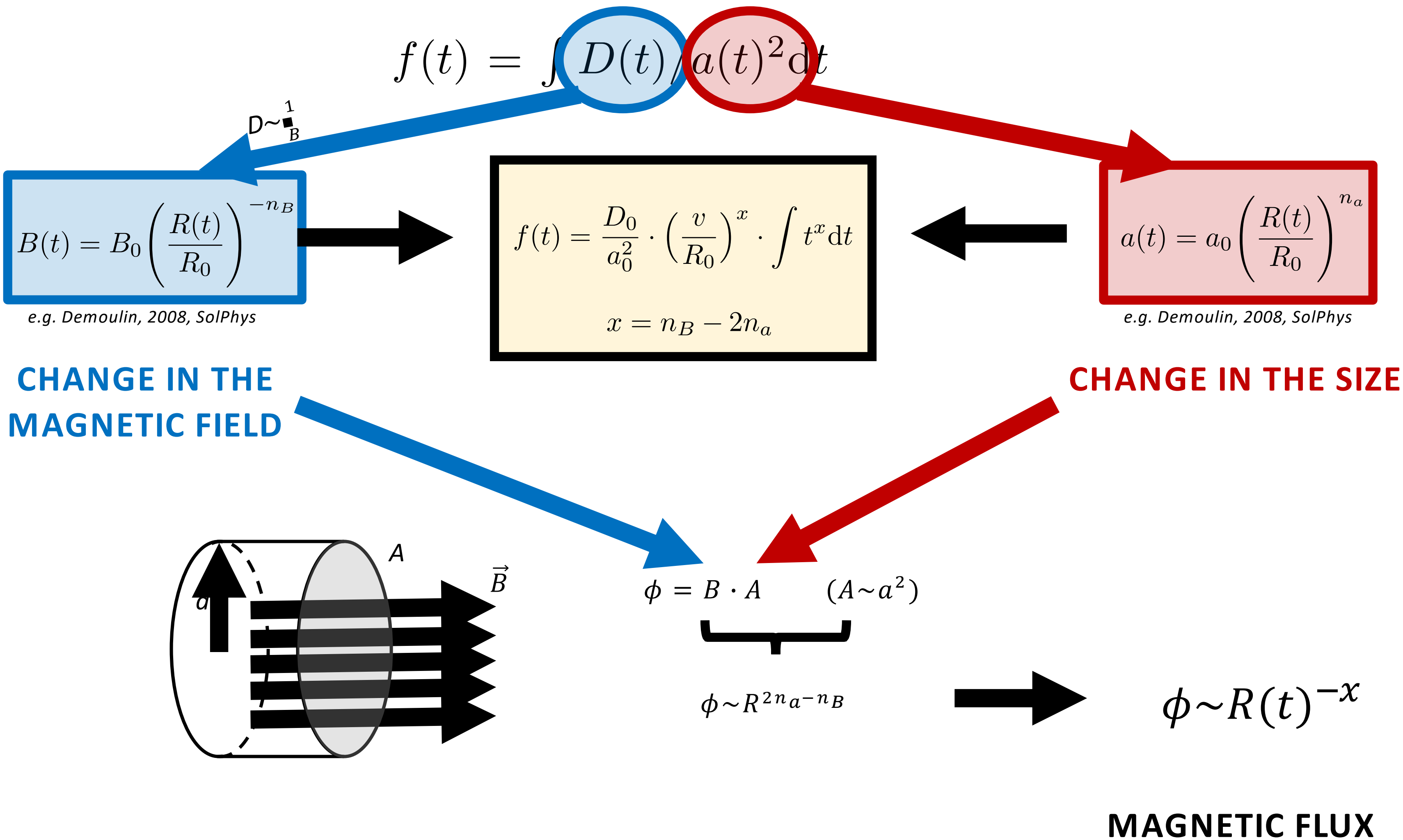

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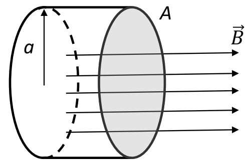


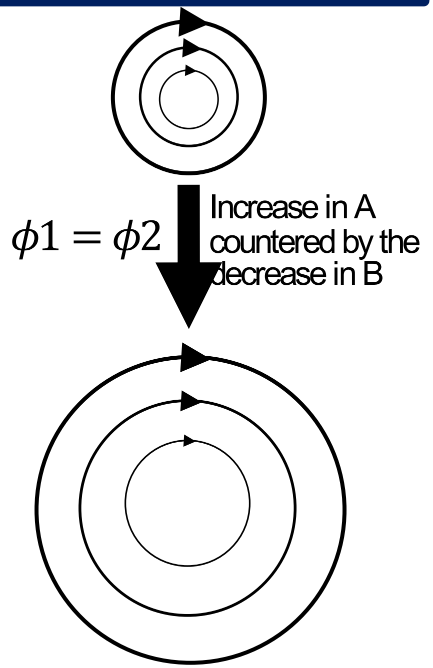
$$\phi \sim R(t)^{-x}$$

$$x = n_B - 2n_a$$

MAGNETIC FLUX

X = 0

(magnetic flux conserved)



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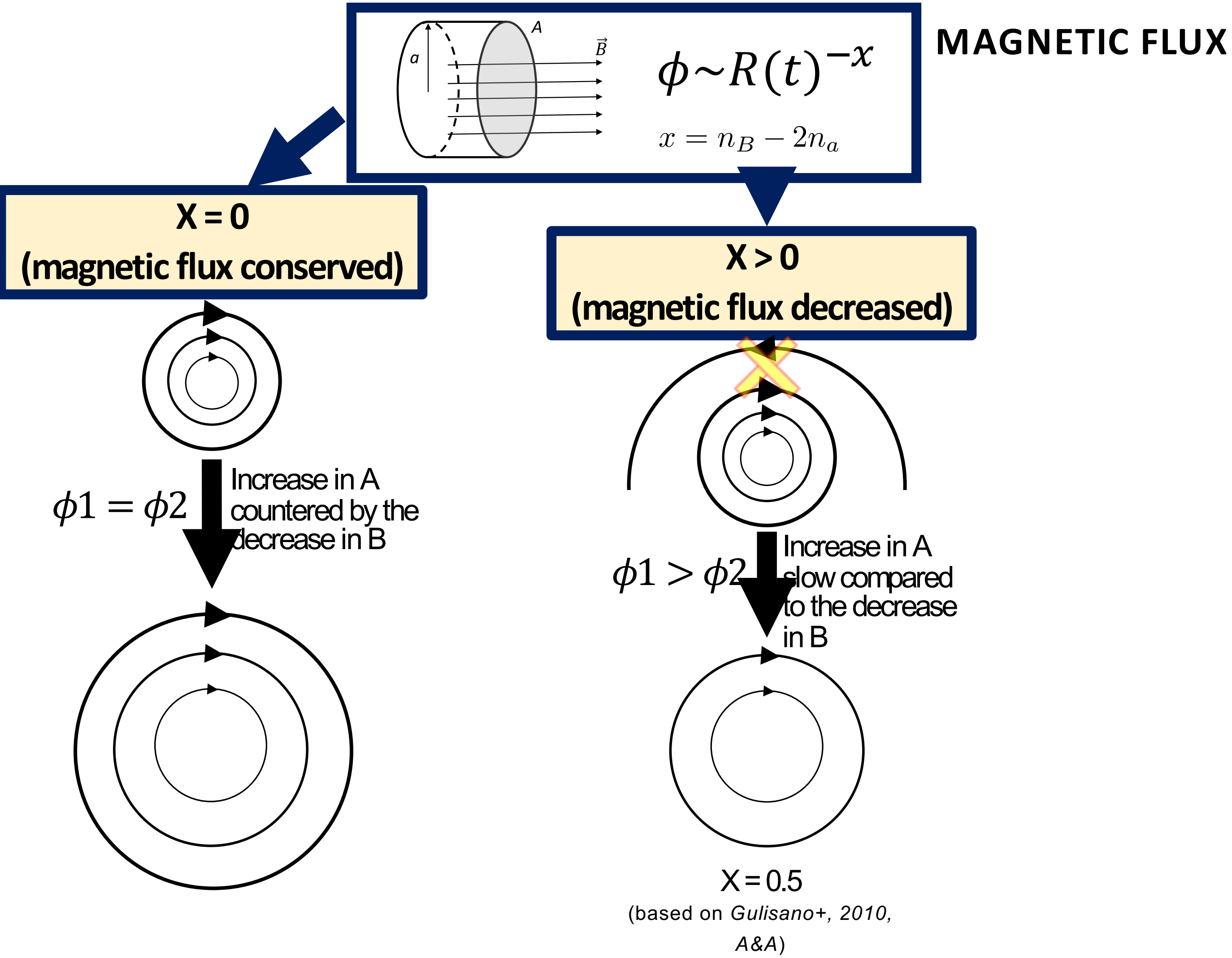

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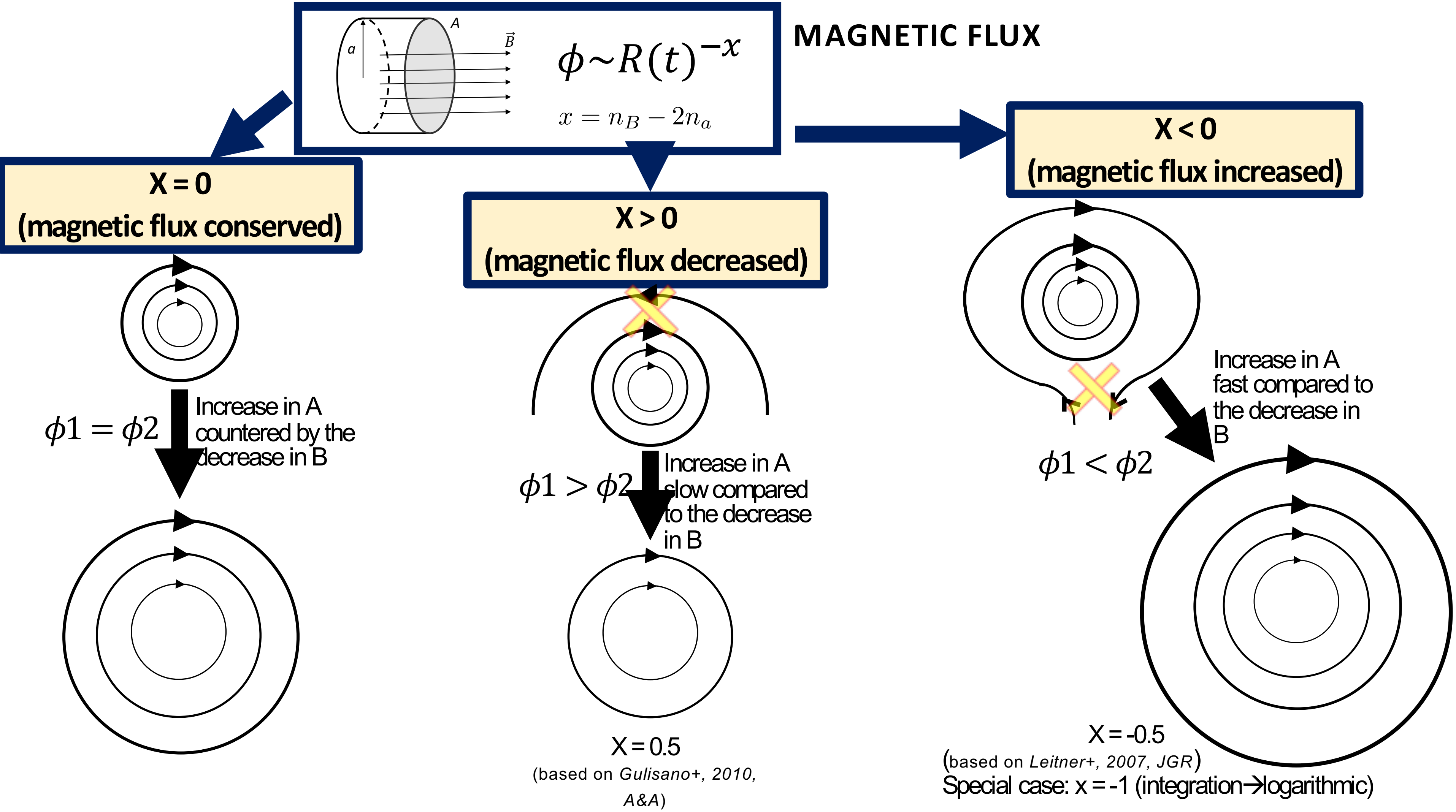

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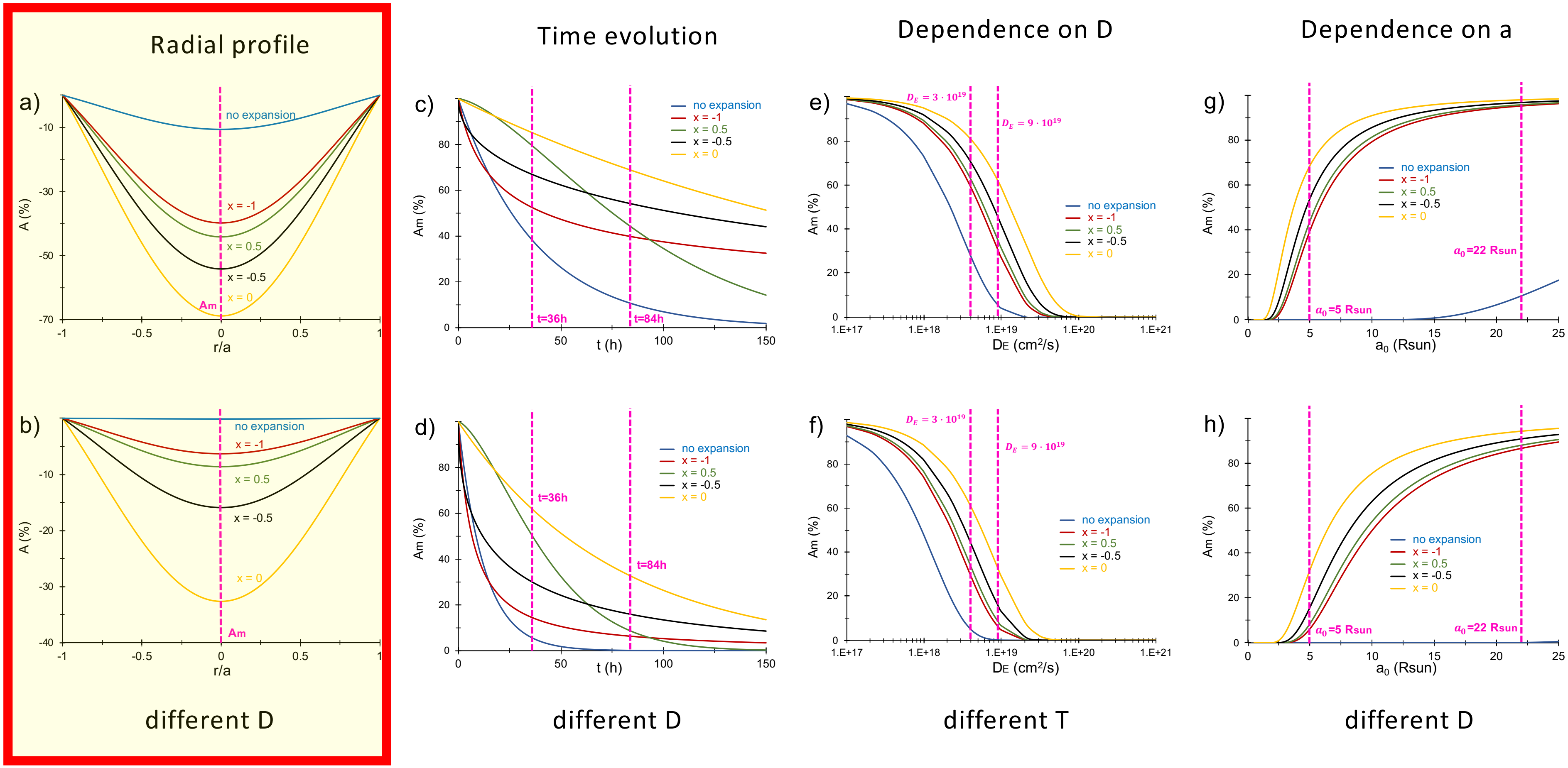
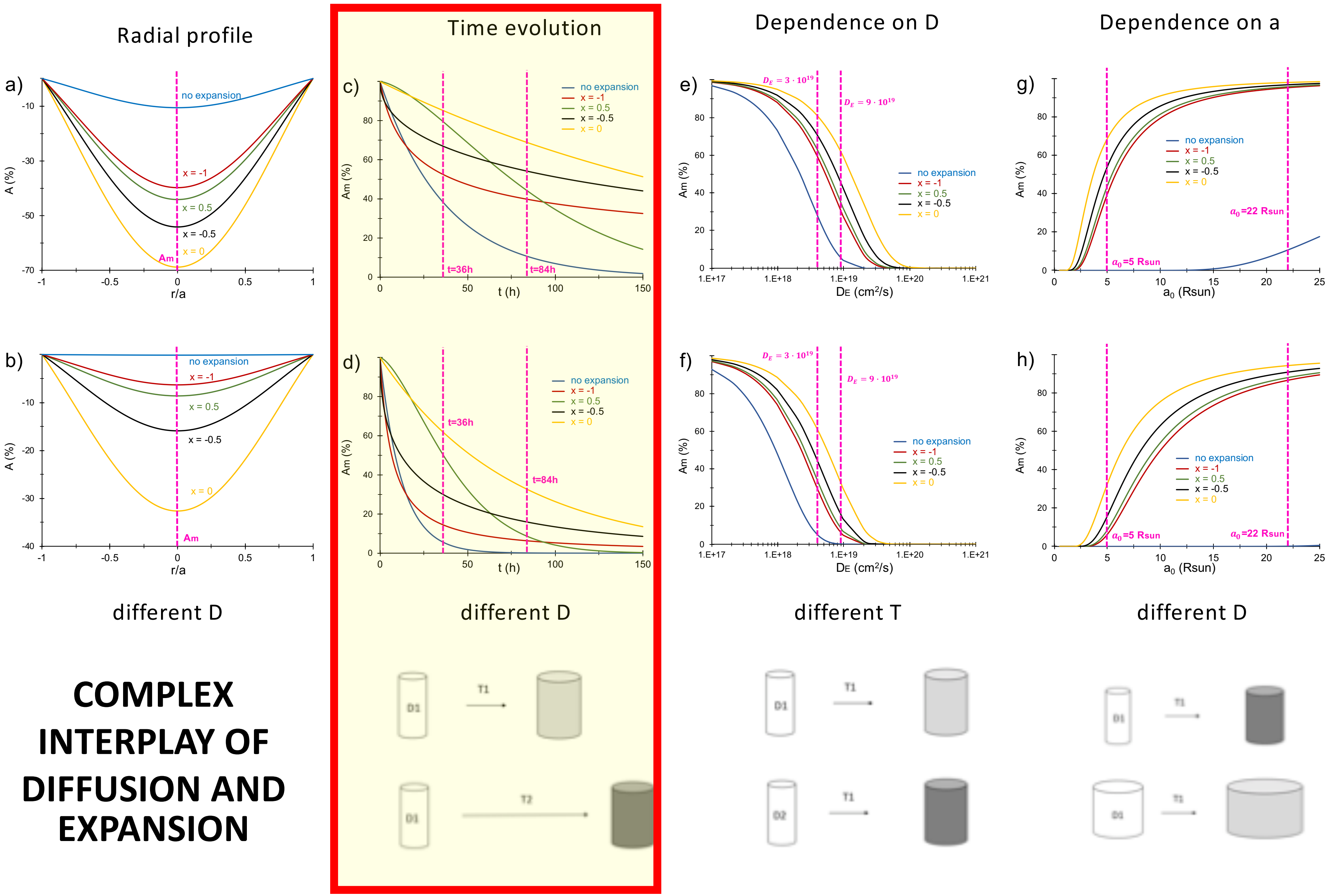


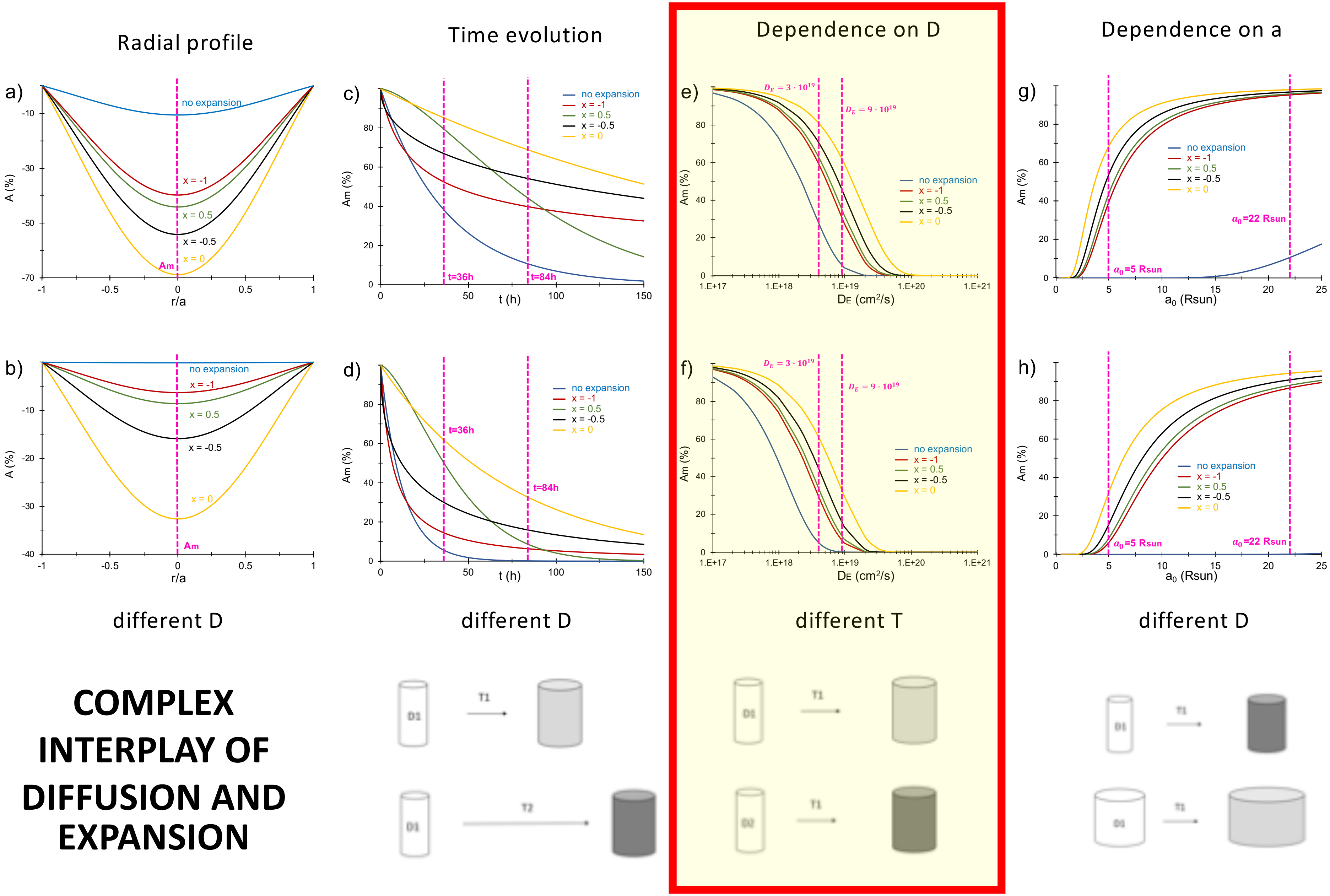
Dumbovic+,2018,ApJ(submitted)

***ForbMod** = analytical diffusion-expansion model for Forbush decreases caused by flux ropes*



Dumbovic+,2018,ApJ(submitted)

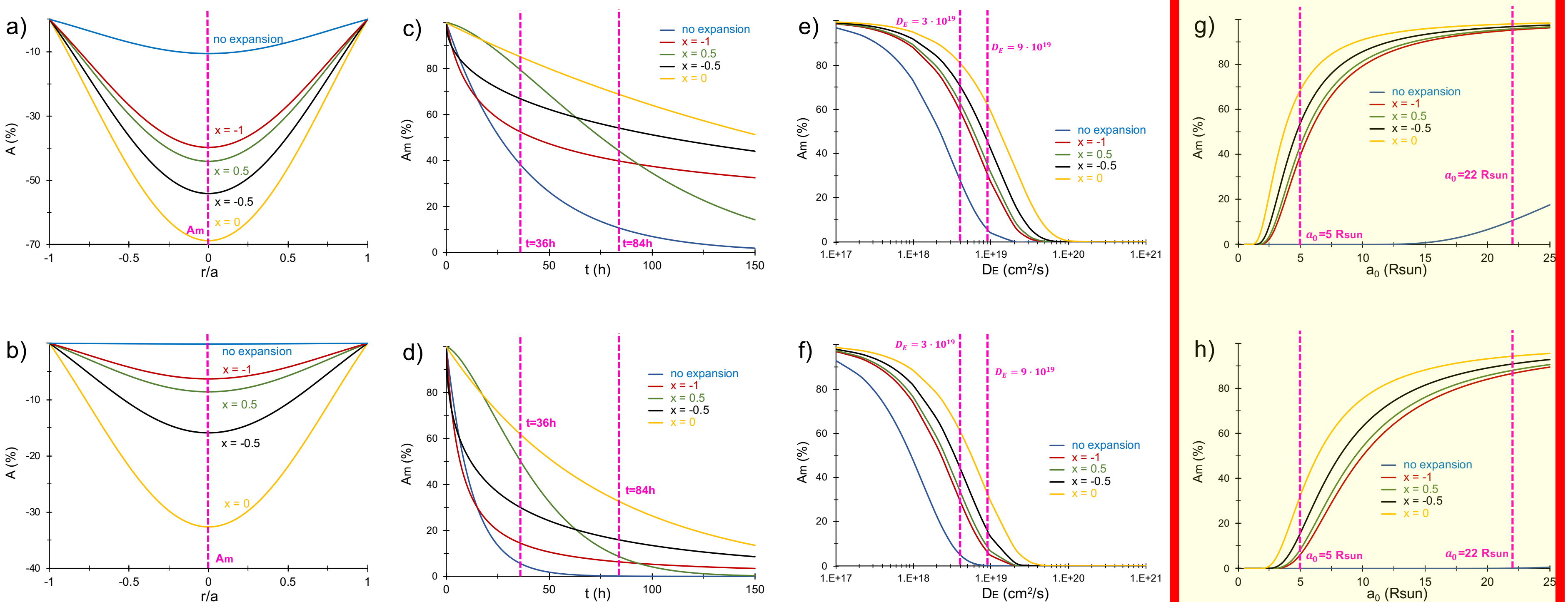
***ForbMod** = analytical diffusion-expansion model for Forbush decreases caused by flux ropes*



COMPLEX INTERPLAY OF DIFFUSION AND EXPANSION

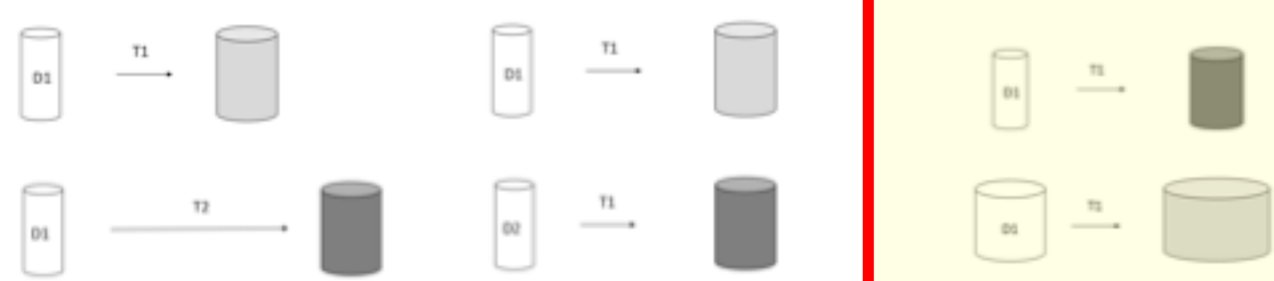
***ForbMod** = analytical diffusion-expansion model for Forbush decreases caused by flux ropes*

Radial profile | Time evolution | Dependence on D | Dependence on a

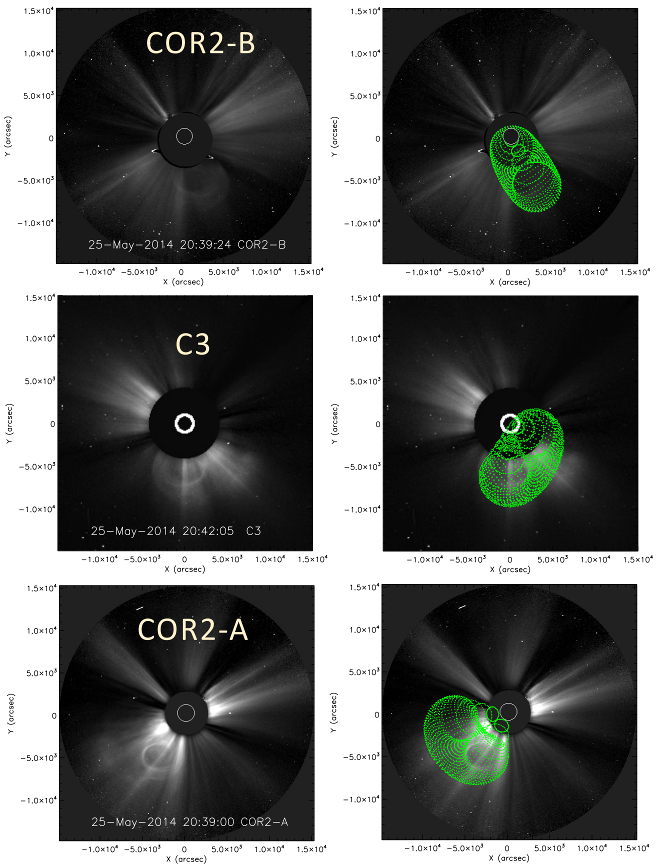


different D | different D | different T | different D

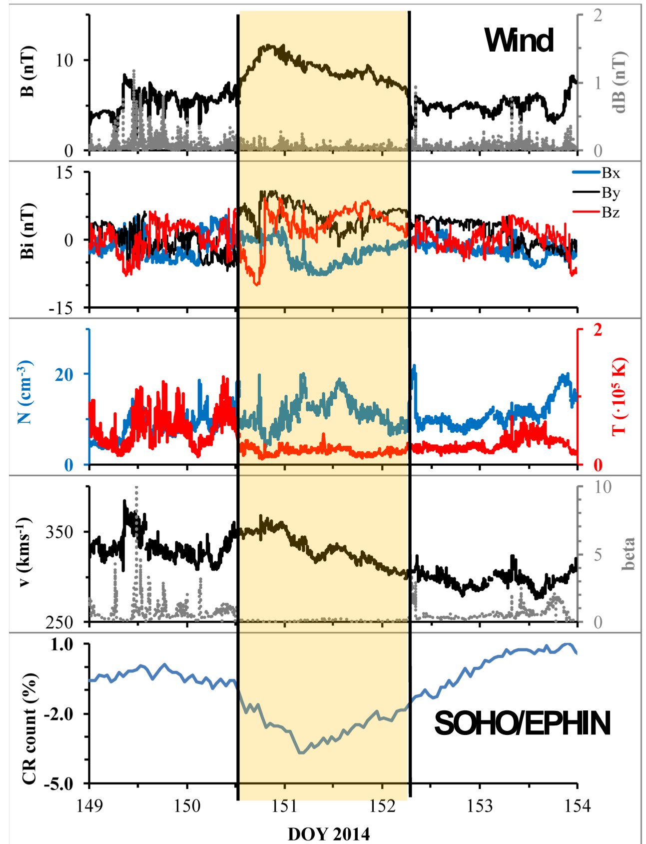
COMPLEX INTERPLAY OF DIFFUSION AND EXPANSION



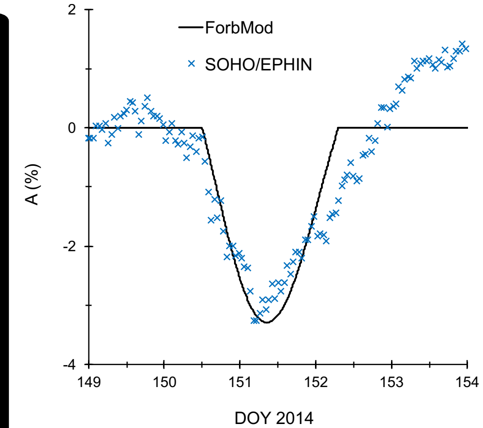
THE CASE STUDY – TEST EVENT



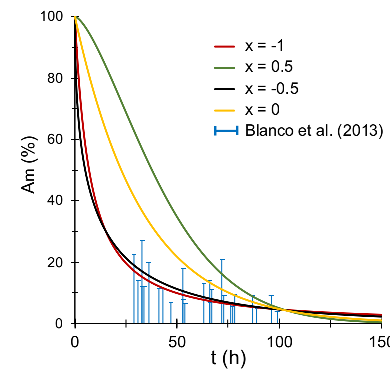
CME: 2014 May 25



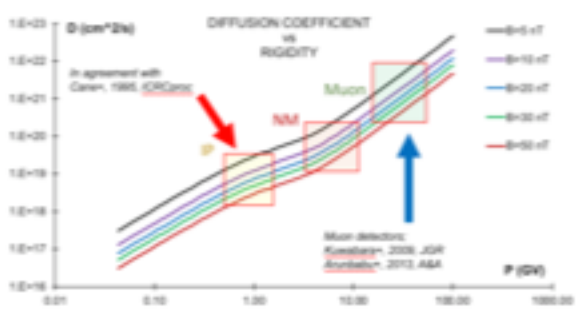
ICME & FD: 2014 May 30



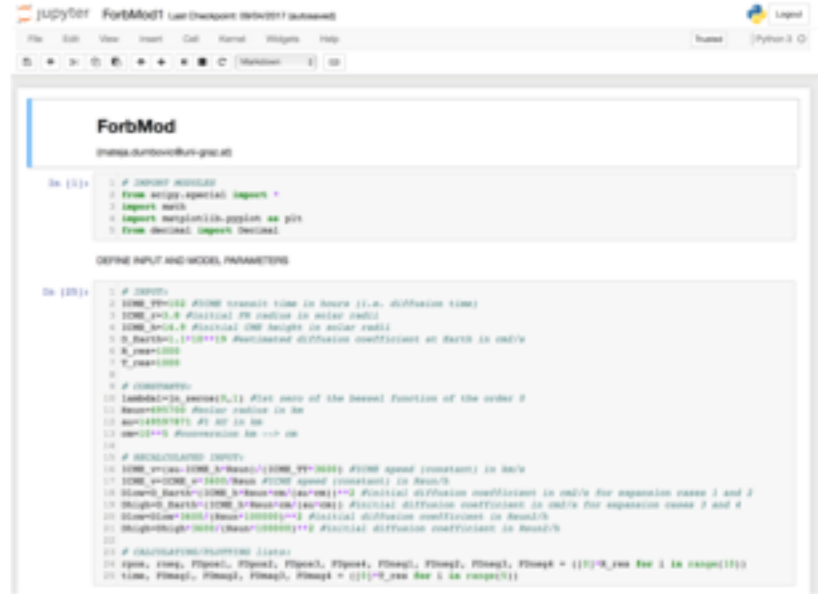
BEST FIT
(diffusion coefficient free parameter)



TIME EVOLUTION
model compared to observations from a statistical study by Blanco+, 2013
(error bars = possible ejecta only FD range)



Dumbovic+,2018,ApJ(submitted)



CONCLUSIONS & FUTURE WORK

- *ForbMod* is analytical diffusion-expansion model for ejecta-only FDs
- FD amplitude depends on the interplay of diffusion and expansion
- Qualitatively agrees with observation
- Case study indicates quantitative agreement
- **NEXT STEPS: testing and constraints using statistics, FR forward modeling and multispacecraft measurements**

Thank you for your attention!

Acknowledgements:

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