Study galactic cosmic ray modulation with AMS-02 observation

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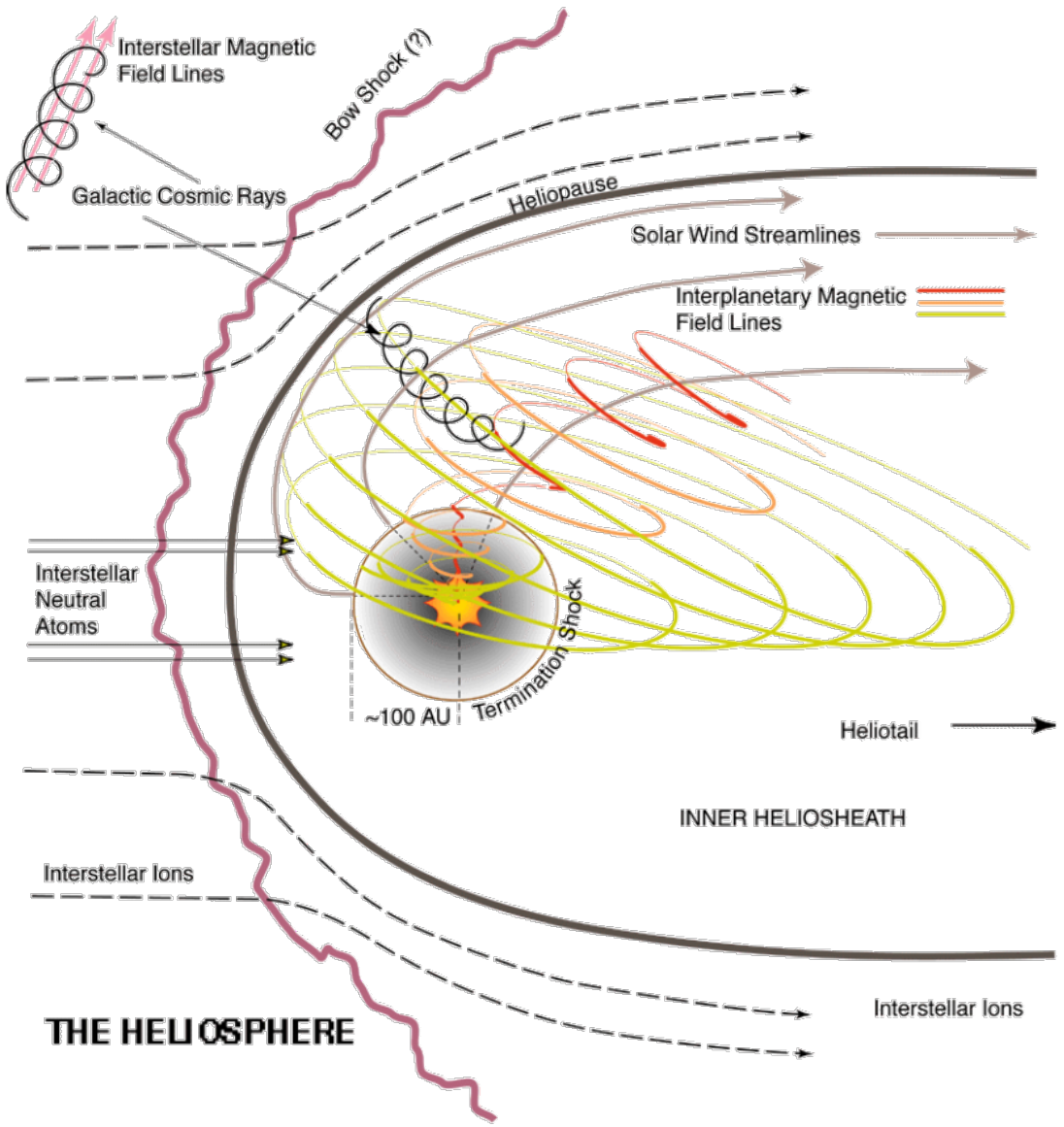
Origin and transport



- Originated outside the solar system
- Accelerated by energetic processes in the interstellar medium
- Isotropic outside the heliopause
- Modulated by solar wind and heliospheric magnetic field:
  - Convection
  - Drift
  - Diffusion
  - Adiabatic energy loss

Transport equation

$$j(r,E,t) = p^2 f(r,p,t)$$

$$\frac{\partial f}{\partial t} = -(V_{sw} + \langle V_d \rangle)\cdot\nabla f + \nabla\cdot(K\cdot\nabla f) + \frac{1}{3}(\nabla\cdot V_{sw})\frac{\partial f}{\partial \ln p}$$

$$V_d = \nabla\times\left(K_A \frac{qP\beta}{3B}\frac{(P/P_0)^2}{1+(P/P_0)^2}\frac{\vec{B}}{B}\right)$$

$$K_{\parallel} = K_0\left(\frac{B_{eq}}{B}\right)\left(\frac{P}{P_0}\right)^b\left(\frac{\left(\frac{P}{P_0}\right)^d + \left(\frac{P_k}{P_0}\right)^d}{1+\left(\frac{P_k}{P_0}\right)^d}\right)^{\frac{c-b}{d}}$$

$$K_{\perp,r} = 0.02K_{\parallel}$$

$$K_{\perp,\theta} = f(\theta)K_{\perp,r}$$

- Input parameters:
  - Solar wind speed
  - Heliospheric magnetic field
  - Current sheet tilt angle
  - Solar polarity

  Obtained by observation at Earth

- Time-varying coefficients:
  - Ka
  - K0
  - b
  - c
  - Pk

  Obtained by MCMC method

Markov Chain Monte Carlo

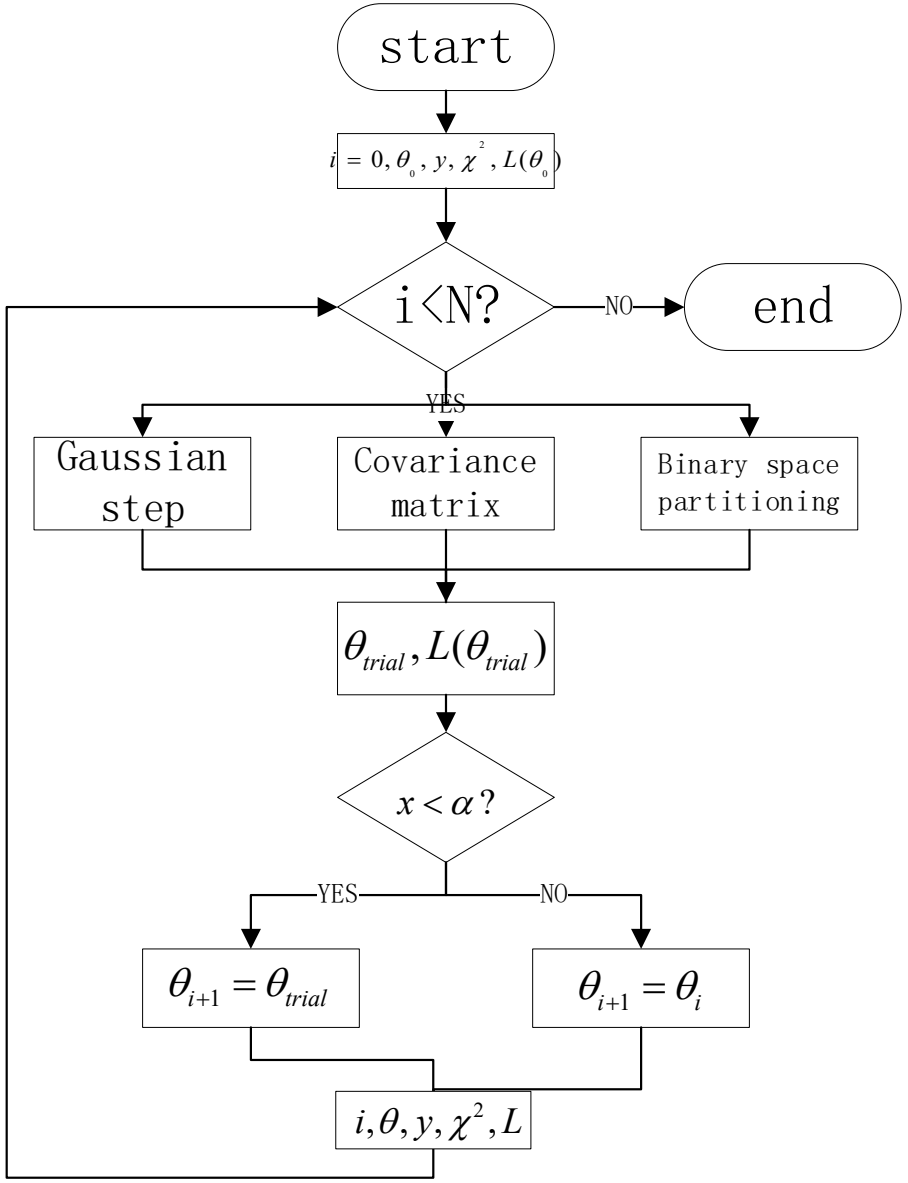
$$P(\theta|data) = \frac{P(data|\theta)P(\theta)}{P(data)} \equiv \frac{L(\theta)P(\theta)}{P(data)}$$

$$L(\theta) = \exp(-\frac{\chi^2(\theta)}{2})$$

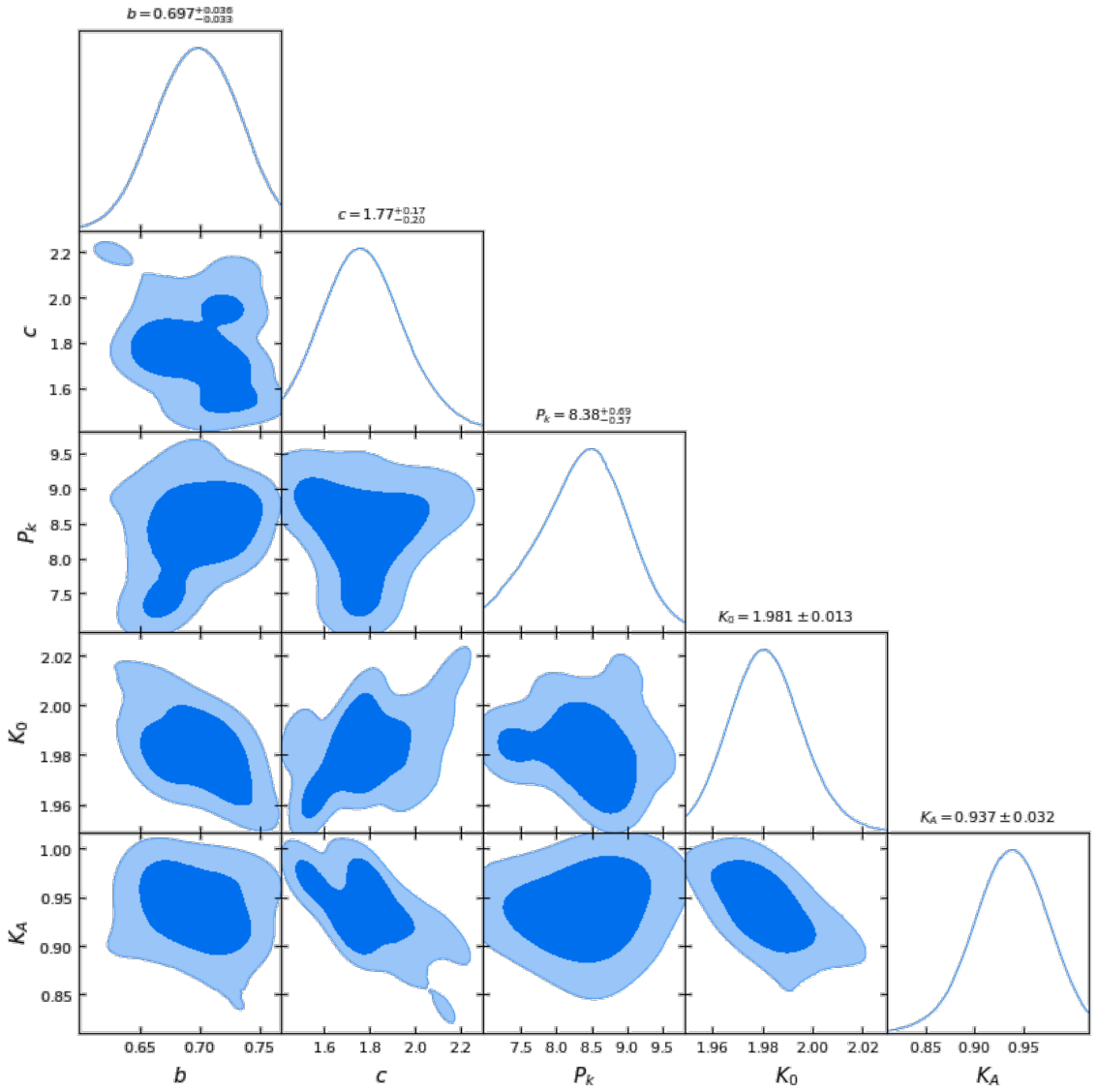
$$\chi^2(\theta) = \sum_{k=1}^{n_{data}} \frac{(y_k^{\exp} - y_k^{theo})^2}{\sigma_k^2}$$

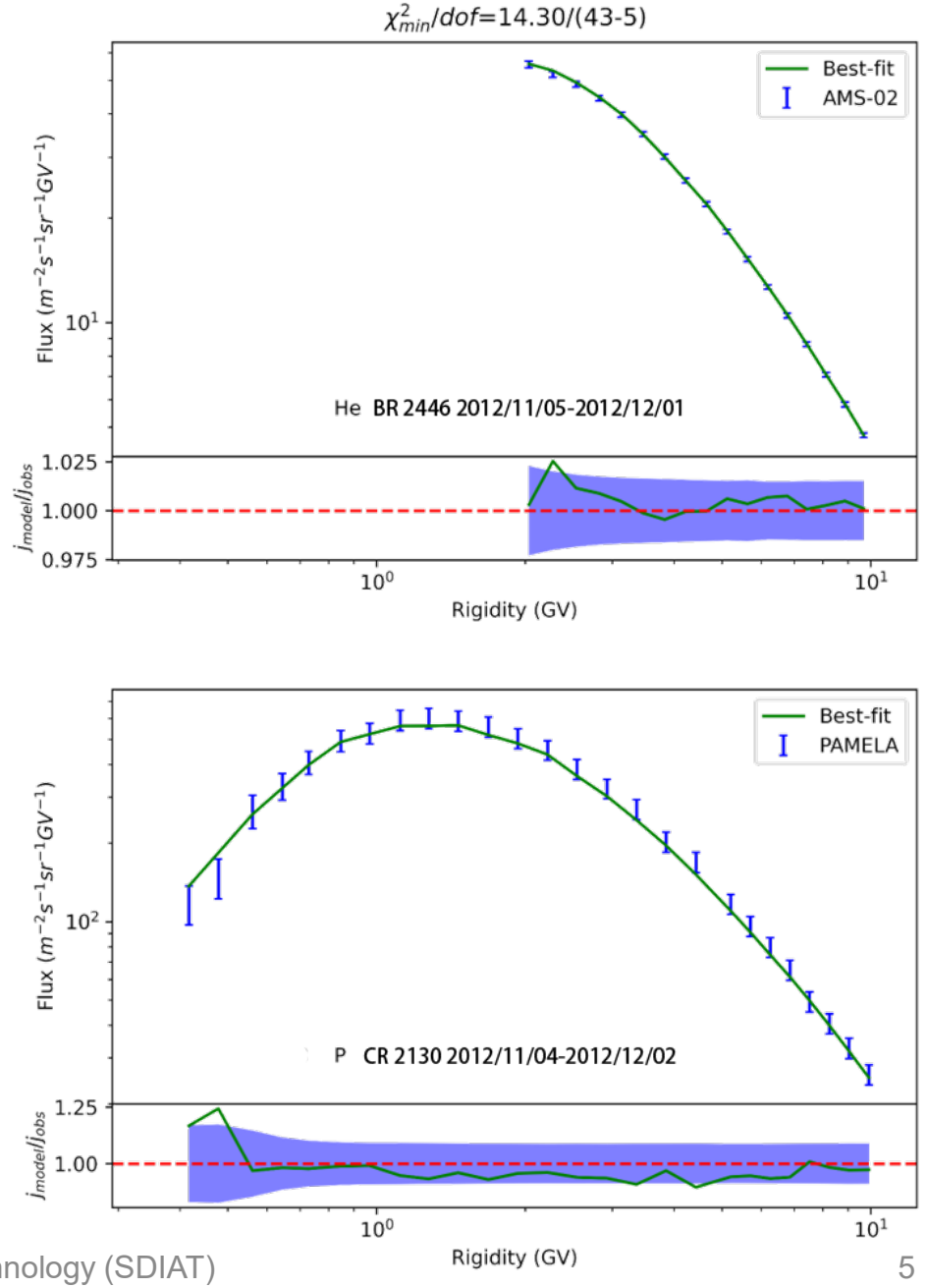
coefficients

Deviation between observation and simulation

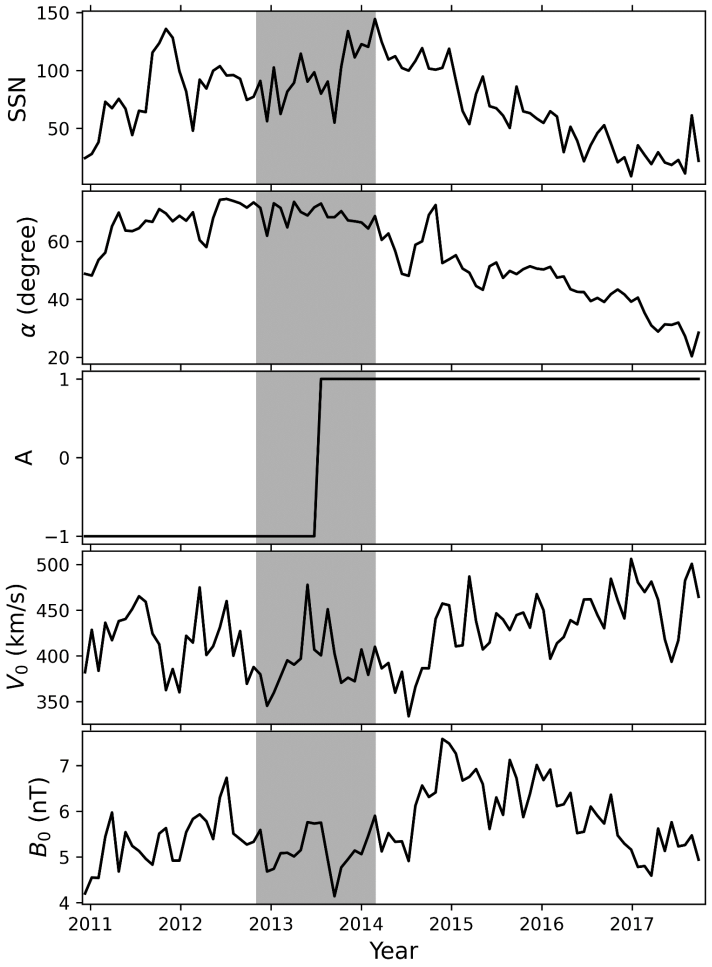


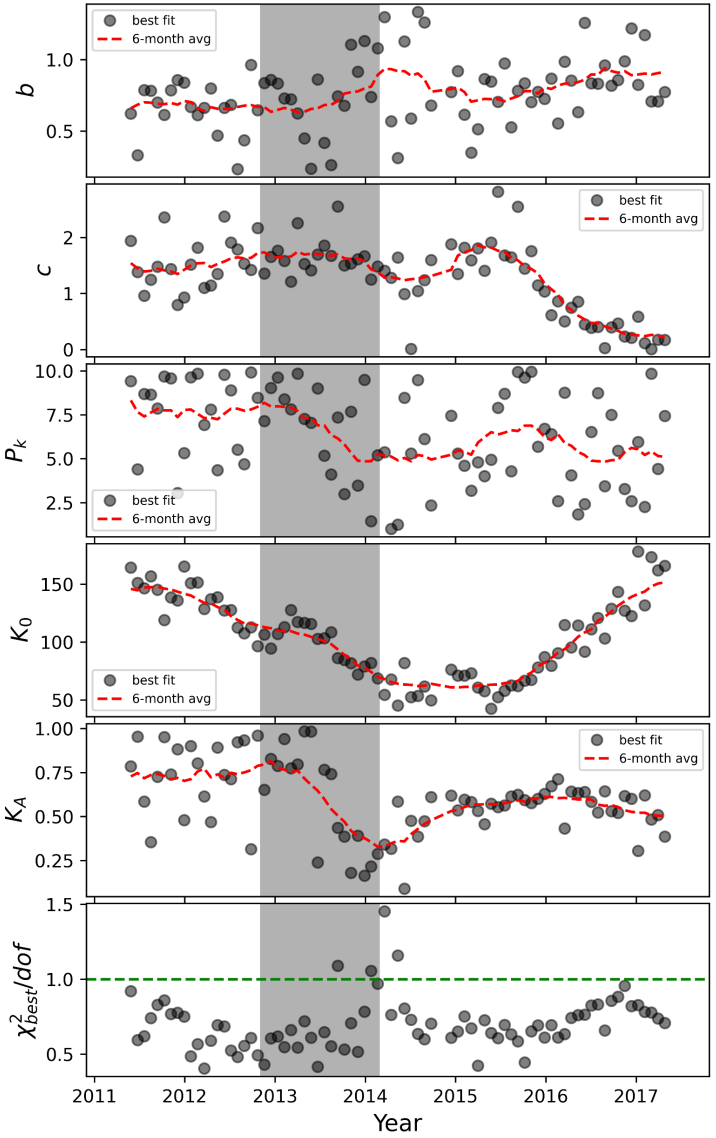
Simulation result





Coefficient over time



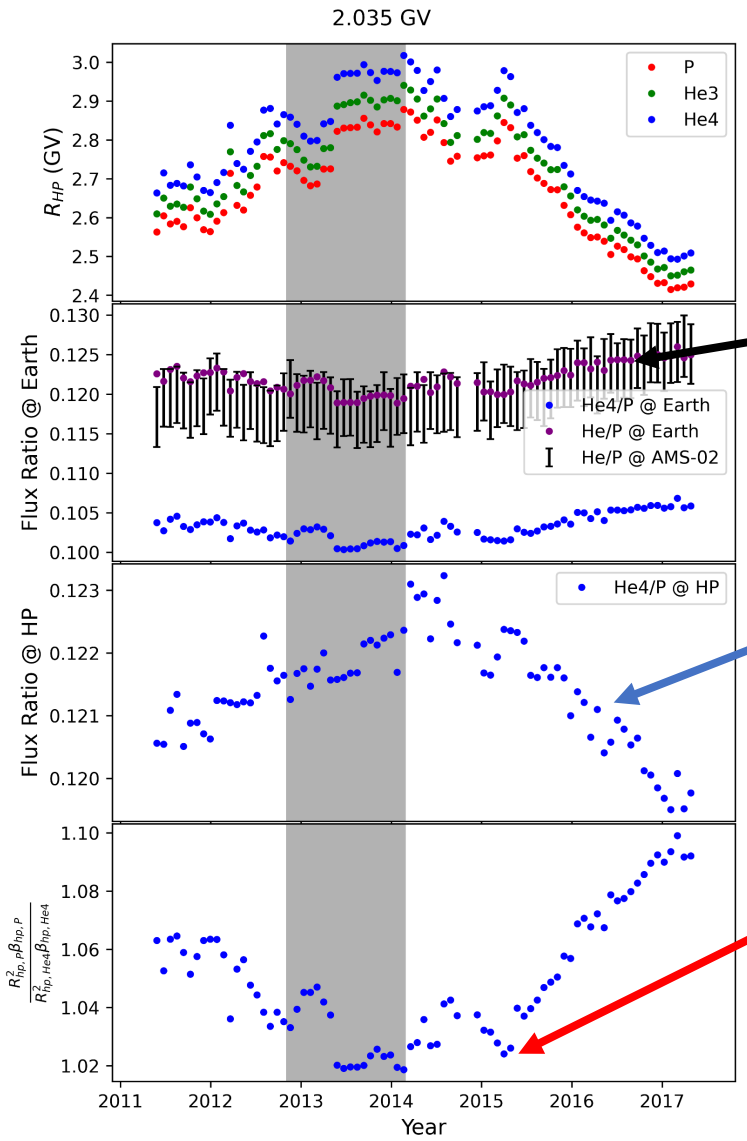


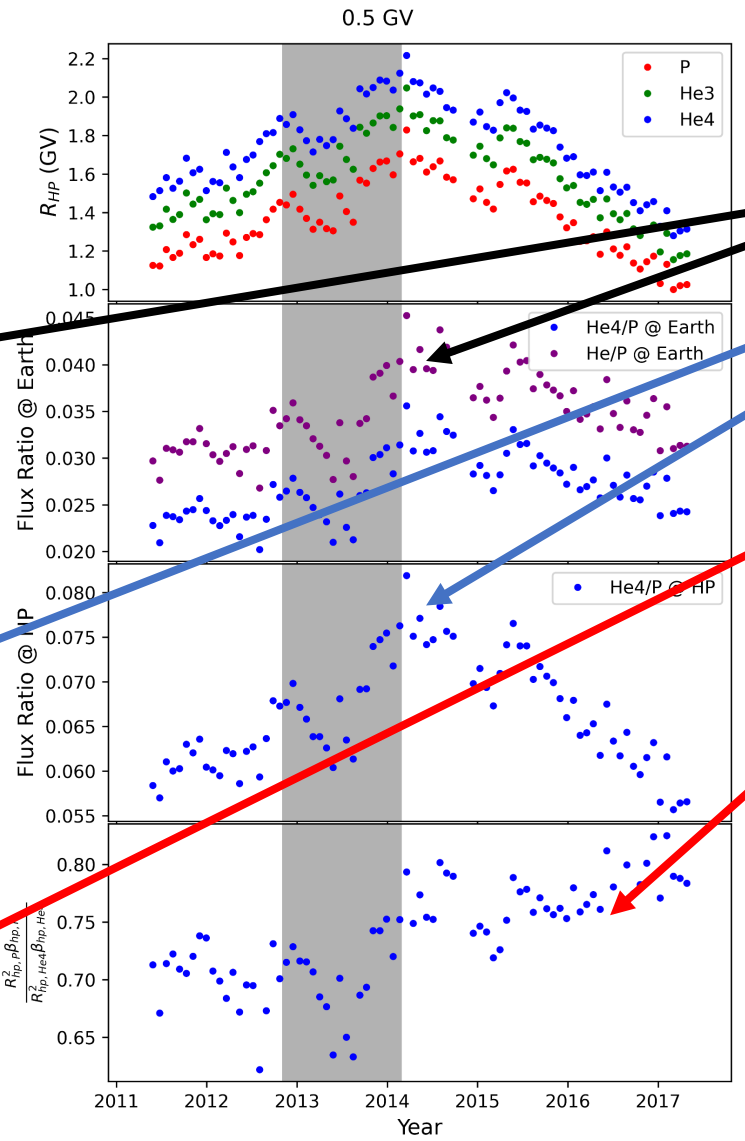
- c is larger than b before 2016, but smaller than b after 2016.
- Pk vary considerably from case to case.
- K0 decreases to the minimum value after solar polarity reversal (SPR), and increases after it.
- Ka before SPR larger than that after SPR, decreases remarkably during SPR, and increases slightly after SPR.

He/P over time

$$\frac{j(R)}{R^2\beta} = \frac{1}{N}\sum_{i=1}^{N}\frac{j_{hp}(R_i)}{R_i^2\beta_i} = \frac{j_{hp}(R_{hp})}{R_{hp}^2\beta_{hp}}$$

$$\frac{j_{He^*}(R)}{j_P(R)} = \frac{j_{hp,He^*}(R_{hp,He^*})}{j_{hp,P}(R_{hp,P})}\frac{R_{hp,P}^2\beta_{hp,P}}{R_{hp,He^*}^2\beta_{hp,He^*}}\frac{\beta_{He^*}}{\beta_P}$$





- Simulation result fit well with observation from AMS-02
- The effective rigidity for He3 larger than that for proton and smaller than that for He4.
- At 2.035GV, main factor is modulation dependence on A/Z
- At 0.5GV, main factor is LIS's ratio
- The implicit dependence of LIS's ratio on A/Z can be ignored.

Summary

- Get the time variation of drift and diffusion coefficients from 2011 to 2017.
- Reproduce the proton and helium spectrum observed by AMS-02.
- Study the dominating factor of He/P variation over time at different rigidity.

THANKS