Decaying Dark Matter in the light of the proposed e-Astrogam for different Axino-Gravitino scenarios

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Abstract

Axino and gravitino particles are among the most promising candidates from supersymmetry (SUSY) to solve the dark matter identity problem. Both of them can easily evade the stringent direct detection limits and provoke fundamental changes in the cosmology of the Universe. Whether either, axino or gravitino, is the lightest supersymmetric particle (LSP) and the other is the next-to-LSP (NLSP) an exciting interplay arise. Moreover, distinct cosmological scenarios befall depending on the era in which the NLSP decays to the LSP in a so-called decaying dark matter model (DDM). If the decay takes place between recombination and present era, stringent constraints exist, and studies claim that DDM models can relax some cosmological tensions. Furthermore, the breaking of R-parity in SUSY models implies that the gravitino and the axino, can decay to a neutrino and a photon, giving a potentially detectable signal. In this work, we carry out a complete analysis of the parameter space for SUSY models considering constraints from cosmological observations, γ-ray experiments, and neutrino physics. In particular, we pay careful attention to the μνSSM, which solves the μ problem of SUSY frameworks and reproduces neutrino data, only using couplings with right-handed neutrinos ν's. Finally, we show that the gravitino or the axino can produce a γ-ray signal detectable by the proposed e-Astrogam mission, and in a particular parameter region, a double 'smoking gun' could be present simultaneously from both candidates.

Decaying Dark Matter Scenario

NLSP → LSP + axion

gravitino NLSP → axino LSP + axion: $\Gamma(\psi_\mu \to \tilde{a} + a) = \dfrac{m_{3/2}^3}{192\pi M_P^2}(1-r_{\tilde{a}})^2(1-r_{\tilde{a}}^2)^3$

axino NLSP → gravitino LSP + axion: $\Gamma(\tilde{a} \to \psi_\mu + a) = \dfrac{m_{\tilde{a}}^5}{96\pi m_{3/2}^2 M_P^2}(1-r_{\tilde{a}}^{-1})^2(1-r_{\tilde{a}}^{-2})^3$

gravitino thermal relic density: $\Omega_{3/2}h^2 \simeq 0.02\left(\dfrac{T_R}{10^5\ \text{GeV}}\right)\left(\dfrac{1\ \text{GeV}}{m_{3/2}}\right)\left(\dfrac{M_3(T_R)}{3\ \text{TeV}}\right)^2\left(\dfrac{\gamma/(T_R^6/M_P^2)}{0.4}\right)$

axino thermal relic density: $\Omega_{\tilde{a}}h^2 \simeq 0.30 * g_3(T_R)^4\left(\dfrac{F(g_3(T_R))}{23}\right)\left(\dfrac{m_{\tilde{a}}}{1\ \text{GeV}}\right)\left(\dfrac{T_R}{10^4\ \text{GeV}}\right)\left(\dfrac{10^{12}\ \text{GeV}}{f_a}\right)^2$

- In a multicomponent scenario, the dark matter relic density come from thermal and from non-thermal production (NLSP decay) → $\Omega_{LSP}h^2 = \Omega_{LSP}^{TP}h^2 + \Omega_{LSP}^{NTP}h^2 = \Omega_{LSP}^{TP}h^2 + \dfrac{m_{LSP}}{m_{NSLP}}\Omega_{NLSP}h^2$

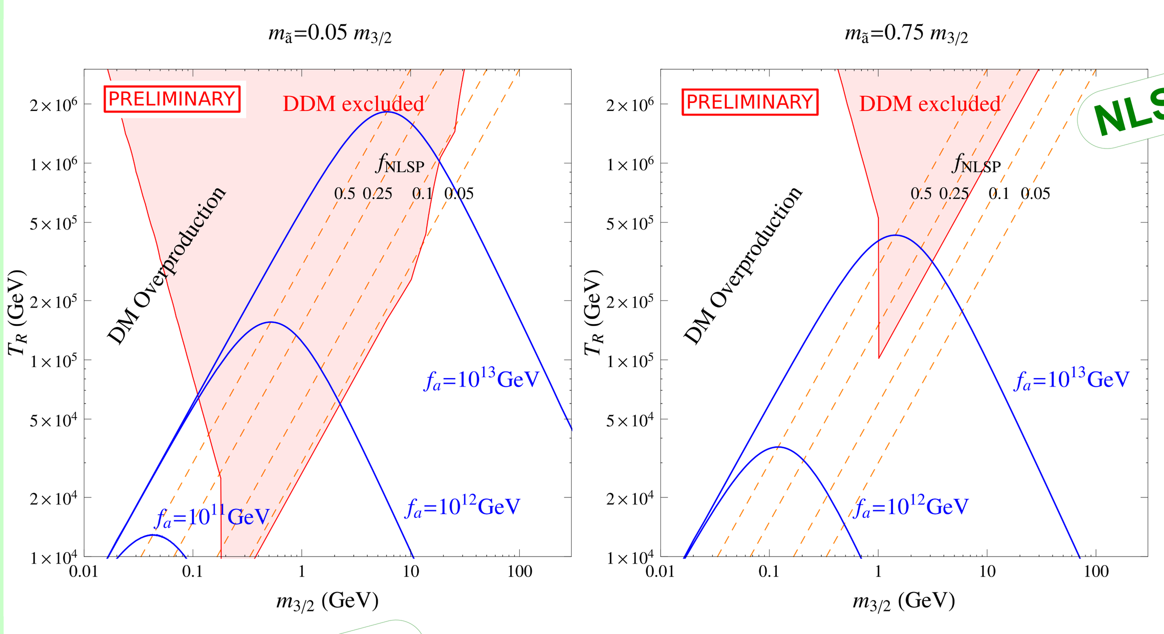
DM decaying to photon-neutrino

- In R-parity breaking models, axino and gravitino can decay to photon-neutrino → γ-ray signal is a sharp line with an energy half its mass → can be detected by γ-ray satellite experiments, such as Fermi-LAT or e-ASTROGAM.

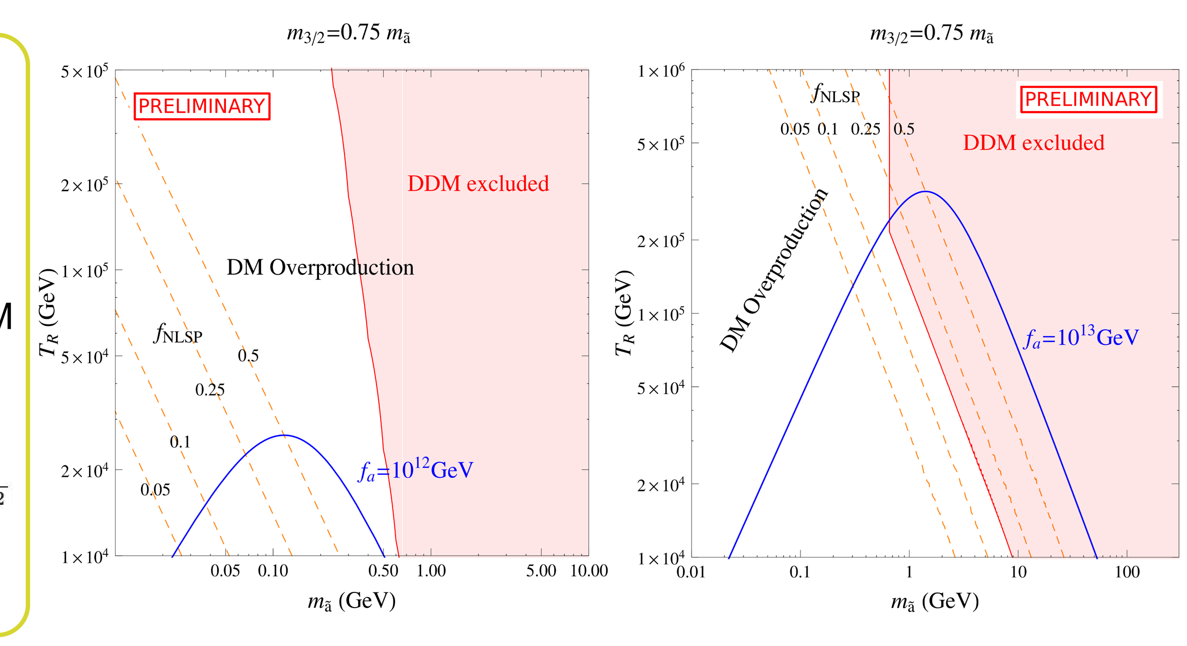
gravitino → photon + neutrino: $\Gamma(\Psi_{3/2} \to \sum_i \gamma\nu_i) \simeq \dfrac{m_{3/2}^3}{64\pi M_P^2}|U_{\tilde{\gamma}\nu}|^2$

axino → photon + neutrino: $\Gamma(\tilde{a} \to \sum_i \gamma\nu_i) \simeq \dfrac{m_{\tilde{a}}^3}{128\pi^3 f_a^2}\alpha_{em}^2 C_{a\gamma\gamma}^2|U_{\tilde{\gamma}\nu}|^2$

Axino LSP plus Gravitino NLSP dark matter



Gravitino LSP plus Axino NLSP dark matter



Parameter space

NLSP → LSP + axion

- The blue curves are in agreement with Planck DM relic density measurements:

$$\Omega_{3/2}h^2 + \Omega_{\tilde{a}}h^2 \simeq 0.12$$

the regions below are allowed if considering a third DM contribution (e.g. axions).

- The red region is excluded by cosmological observations for Decaying DM models (excess of relativistic species).
- The orange dashed curves correspond to different values of NLSP fraction:

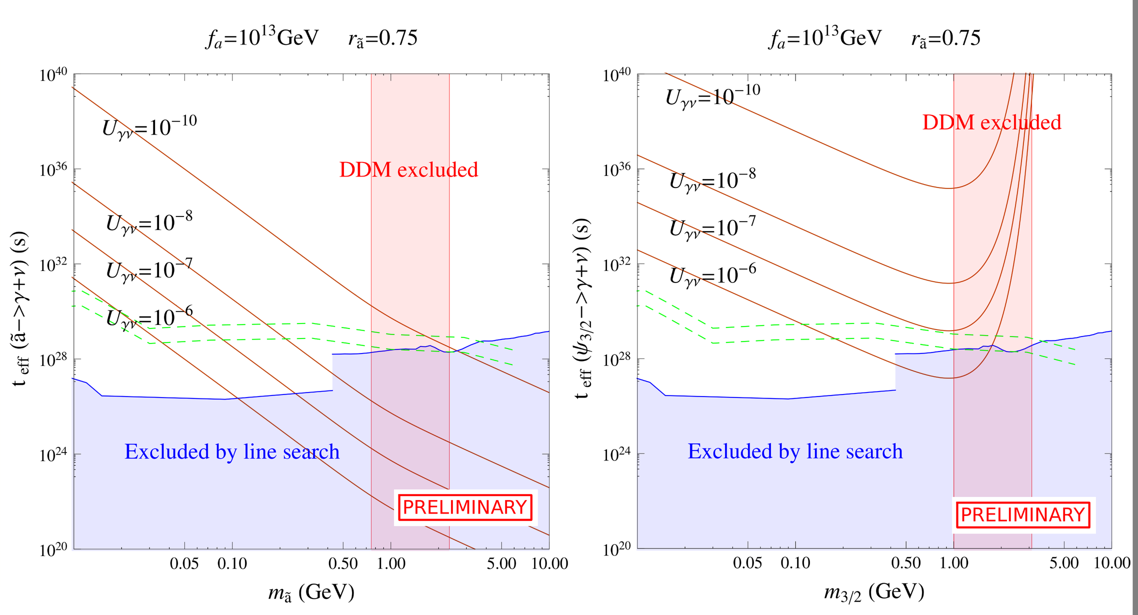
Axino LSP → $f_{NLSP} = \dfrac{\Omega_{3/2}h^2}{\Omega_{cdm}^{Planck}h^2}$ Gravitino LSP → $f_{NLSP} = \dfrac{\Omega_{\tilde{a}}h^2}{\Omega_{cdm}^{Planck}h^2}$

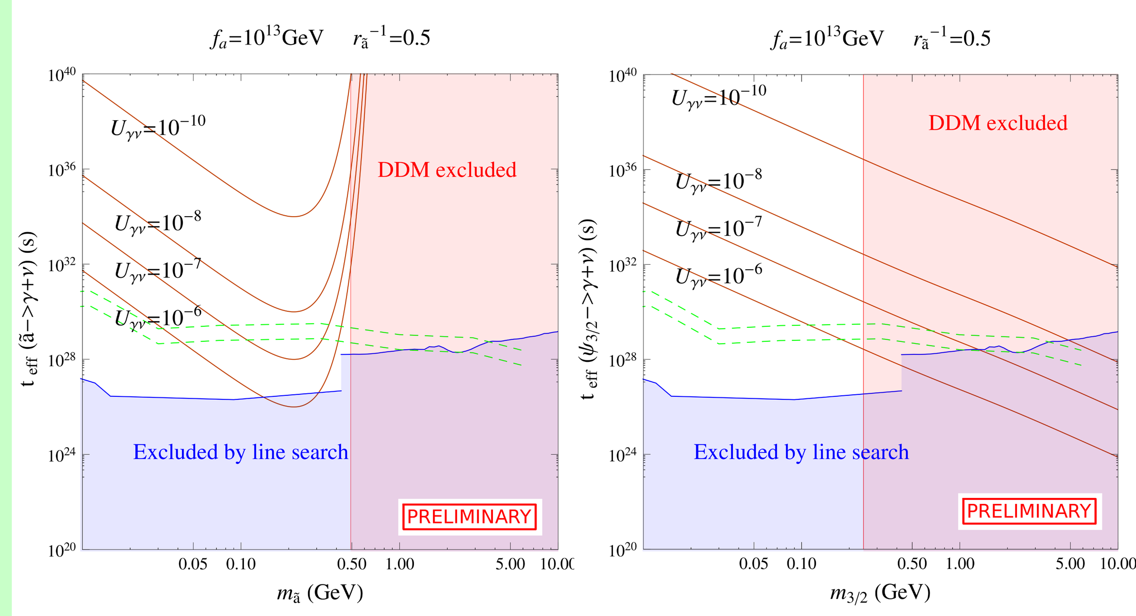
We will focus on the allowed parameter space shown in the blue curve: multicomponent and decaying DM scenario!

Lifetime vs DM mass

DM → photon + neutrino

- Region between orange curves reproduces neutrino data for different values of |Uγν| (photino-neutrino mixing).
- Red region excluded by cosmological observations for DDM models.
- Blue regions are excluded by γ-ray line searches (Fermi-LAT).
- Green dashed curves: e-ASTROGAM max sensibility (DM profile dependent).





- NLSP effective lifetime depicts the depletion behavior:

$$f_{\rm NLSP}(t) = f_{\rm NLSP}(t=t_0)e^{-t/\tau_{NLSP}}$$

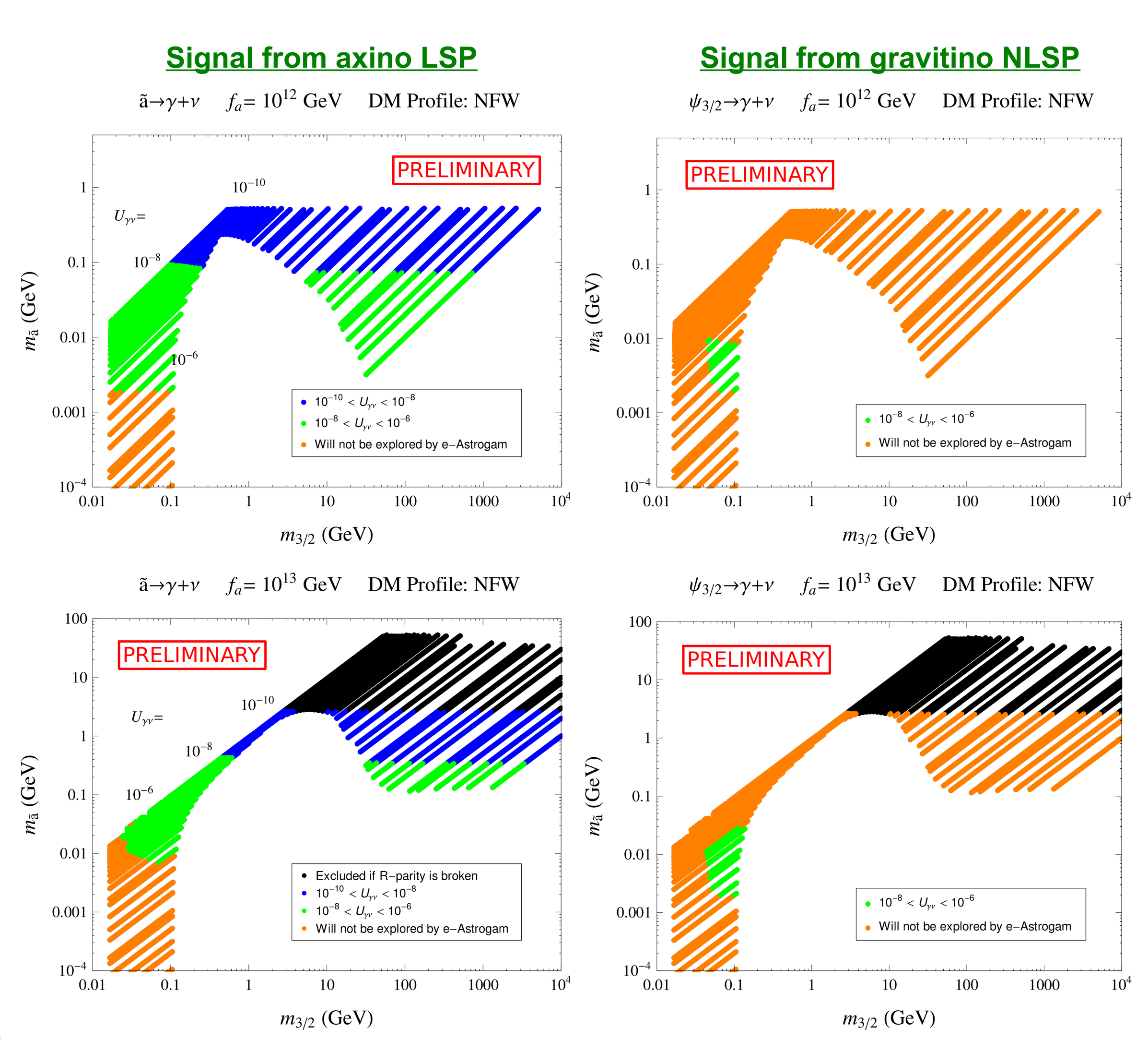
- LSP effective lifetime involves:

$$f_{\rm LSP}(t) = f_{\rm LSP}(t=t_0) + r_{\tilde{a}}\left[f_{\rm NLSP}(t=t_0)(1-e^{-t/\tau_{NLSP}})\right]$$

. no initial LSP fraction equal to 1, as usually assumed.

. late time production from:

NLSP → LSP + axion



Prospects for detection

- Scan:

Axino LSP → $0.0001 \le \dfrac{m_{\tilde{a}}}{m_{3/2}} \le 0.95$ Gravitino LSP → $0.0001 \le \dfrac{m_{3/2}}{m_{\tilde{a}}} \le 0.95$

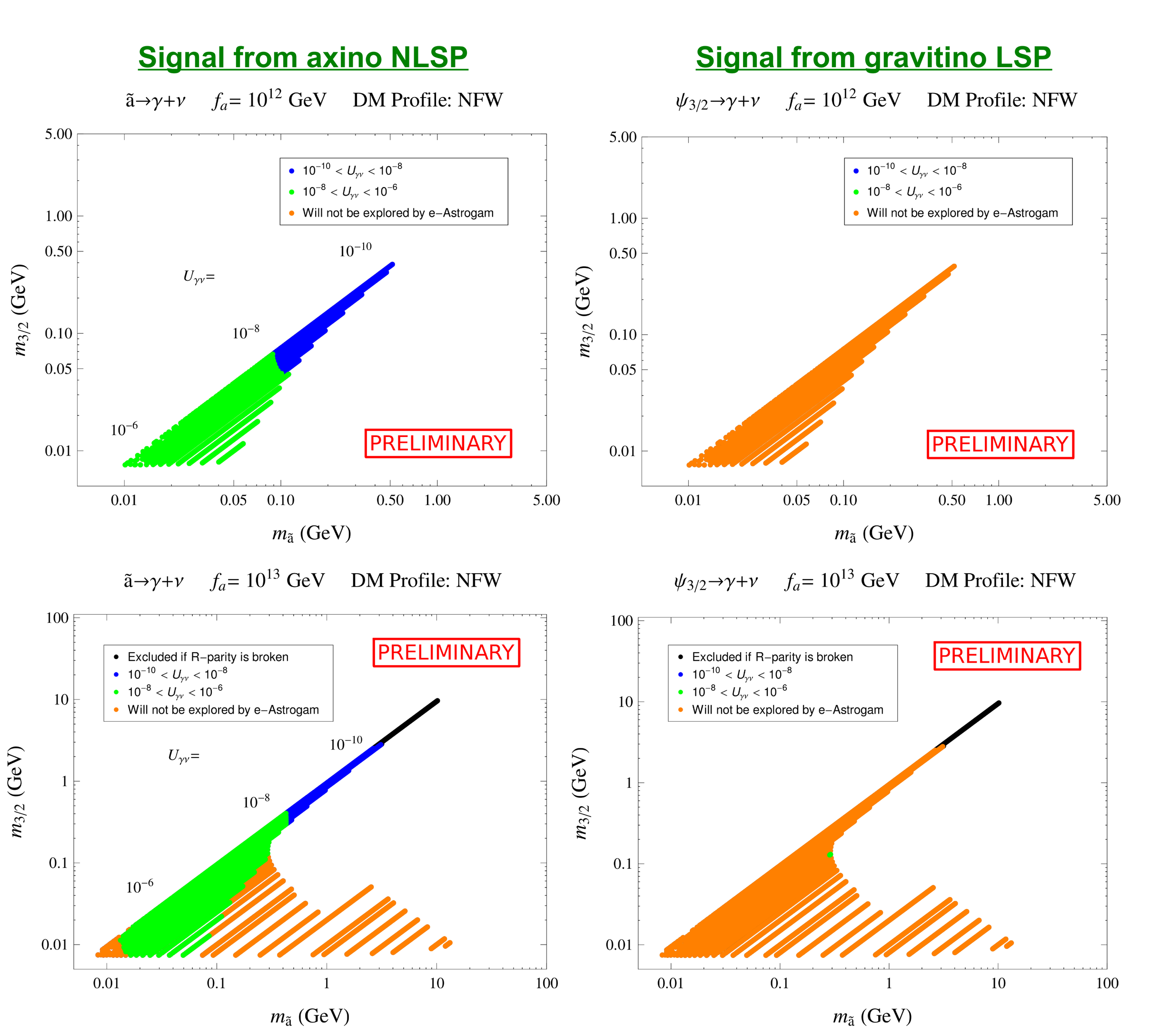
- Every point satisfy: Planck CDM relic density measurement and Decaying DM constraints.
- For **R-parity conserving models**, like the MSSM, every point shown is allowed.
- For **R-parity breaking models**:

. black points are excluded by γ-ray searches like Fermi-LAT, from either axinos or gravitinos,

. green and blue points correspond to the regions that could be explored by e-ASTROGAM for different values of photino-neutrino mixing parameter (reproduces neutrino data),

. orange points are not excluded by the current γ-ray constraints, but can not be explored by e-ASTROGAM.

If a signal coming from each DM candidate is detectable for the same parameter region: *a double γ-ray line would be possible to detect with e-ASTROGAM!*



Conclusions

- We explored the multicomponent dark matter scenario considering axino and gravitino as DM candidates in the context of Decaying DM models, taking into account constraints from cosmological observation, γ-ray experiments and neutrino physics.
- We showed the allowed mass range for R-parity conserving and breaking models. In the later case, both the gravitino and the axino can decay to a neutrino and a photon, giving a potentially detectable signal.
- We applied the current γ-ray limits and we showed the mass region where a γ-ray signal would be detectable by the proposed e-Astrogam mission.
- Finally we found that in a special parameter region a *double 'smoking gun'* could be present simultaneously from both candidates.