Possible manifestations of compact stable dark matter objects in the solar system

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Plan:

1. **Introduction for Dark Matter (DM) problems**
2. **Particle, Gravity, and Dark Matter (DM) Lagrangians**
3. **DM particles, composite DM states, and Primordial Black Holes –-> DM Planets (DMP)**
4. **Solar system as a detector of DMP within the post Newtonian (pN) dynamics**
5. **DM planet in the solar system: Dynamical friction, DMP capture, and possible trajectories of DMP**
6. **Possible indications of DMP by means of**

   · triggering the 11-year solar cycle,

   · specific lensing of star light, or

   · knocking-out main-belt asteroids (285075 on September 6, 2011 with total mass ~3% of the Moon)

7. **Conclusion**

1. Dark Matter (DM) is still one of the biggest mysteries of the Universe

The DM candidates can be single particles, composite states, Primordial Black Holes (PBH), …

Data Gravity =>	**Newton Potential**	**General Relativity**	**ΛCDM**	**Conformal Gravity***
For large r =>	$-\frac{1}{r}$	$-\frac{1}{r}+O(v^2)$	$-\frac{1}{r}+O(v^2)+\frac{1}{2}\Lambda\, r$	$\frac{2\beta}{r}+\alpha+\gamma\, r-\kappa\, r^2$
Mercury Perihelium Precession	**Needs DM**	**Not need DM**	**Not need DM**	**Not need DM**
Galaxy Rotation Curvies	**Needs DM**	**Needs DM**	**Needs DM**	**Not need DM**
1. CMB – Cosmic Microwave Background. 2. Luminosity Distance (D_L) vs red shift ($z \lesssim 1$). 3. Large scale galaxy clusters including BAO - Baryon Acoustic Oscill.	**-**	**Needs DM and DE**	$\Omega_M \approx 0.05$ $\Omega_{DM} \approx 0.26$ $\Omega_{DE} \approx 0.69$	**Not need DM or DE**
Periodic activity of stars, and, in particular, the 11-year solar cycle	**Can be explaned by DM planet crossing the surface of the star**	**Can be explaned by DM planet crossing the surface of the star**	**Can be explaned by DM planet crossing the surface of the star**	**Can be explaned by DM planet crossing the surface of the star**

* M. Yasira, X.Tiechenga, F. Mushtaqa, K. Bambab, Testing new massive conformal gravity with the light deflection by black hole, NPB 993 (2023) 116257

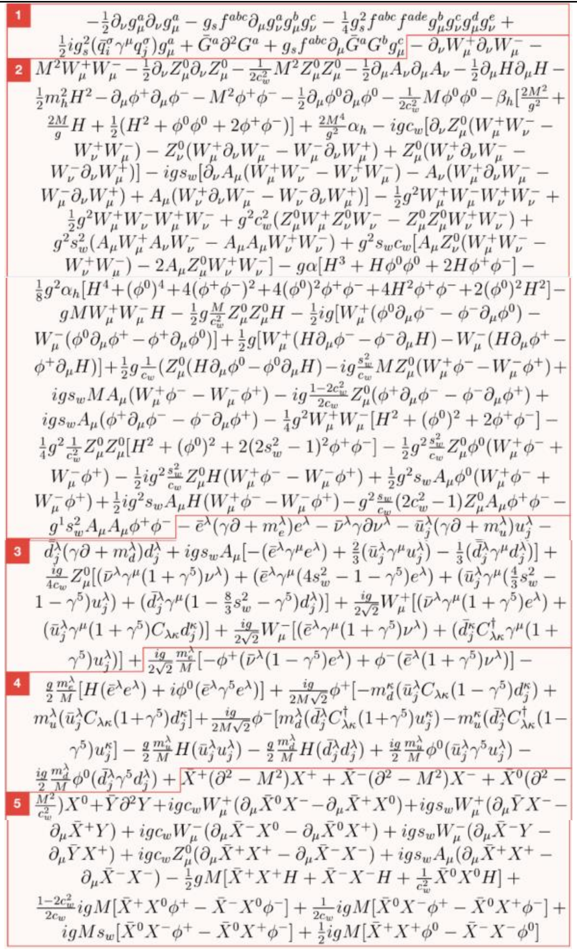
Thus, until there is no final theory of Gravity there is no clear indication for Dark Energy (DE), Dark Matter (DM) dominance as well as for the DE, DM absence.

2. Lagrangian density of the Standard Model, Gravity, and Dark Matter (DM)

Field theory in 4-dimentional curved spacetime with the interval $ds^2 = g_{\mu\nu}dx^\mu dx^\nu$

Standard Model Lagrangian (T.D. Gutierrez):
http://nuclear.ucdavis.edu/~tgutierr/files/stmL1.html

Based on the existing data



1

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc}f^{ade}g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar{q}^\sigma_i\gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2G^a + g_s f^{abc}\partial_\mu\bar{G}^a G^b g^c_\mu$$

2

$$-\partial_\nu W^+_\mu\partial_\nu W^-_\mu - M^2W^+_\mu W^-_\mu - \frac12\partial_\nu Z^0_\mu\partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2Z^0_\mu Z^0_\mu - \frac12\partial_\mu A_\nu\partial_\mu A_\nu - \frac12\partial_\mu H\partial_\mu H - \frac12 m_h^2H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \frac12\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac12(H^2+\phi^0\phi^0+2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu\partial_\nu W^-_\mu - W^-_\mu\partial_\nu W^+_\mu) + A_\mu(W^+_\nu\partial_\nu W^-_\mu - W^-_\nu\partial_\nu W^+_\mu)] - \frac12 g^2W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac12 g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2s_wc_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \frac18 g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] - gMW^+_\mu W^-_\mu H - \frac12 g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac12 ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac12 g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \frac12 g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_wMA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac14 g^2W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \frac14 g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2-1)^2\phi^+\phi^-] - \frac12 g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac12 ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac12 g^2s_wA_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac12 ig^2s_wA_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2-1)Z^0_\mu A_\mu\phi^+\phi^- - g^1s_w^2A_\mu A_\mu\phi^+\phi^-$$

3

$$-\bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar\nu^\lambda\gamma\partial\nu^\lambda - \bar u^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \bar d^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_wA_\mu[-(\bar e^\lambda\gamma^\mu e^\lambda) + \frac23(\bar u^\lambda_j\gamma^\mu u^\lambda_j) - \frac13(\bar d^\lambda_j\gamma^\mu d^\lambda_j)] + \frac{ig}{4c_w}Z^0_\mu[(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar e^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar u^\lambda_j\gamma^\mu(\frac43 s_w^2 - 1 - \gamma^5)u^\lambda_j) + (\bar d^\lambda_j\gamma^\mu(1 - \frac83 s_w^2 - \gamma^5)d^\lambda_j)] + \frac{ig}{2\sqrt2}W^+_\mu[(\bar\nu^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar u^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)] + \frac{ig}{2\sqrt2}W^-_\mu[(\bar e^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar d^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)] +$$

4

$$\frac{ig}{2\sqrt2}\frac{m_e^\lambda}{M}[-\phi^+(\bar\nu^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar e^\lambda(1+\gamma^5)\nu^\lambda)] - \frac g2\frac{m_e^\lambda}{M}[H(\bar e^\lambda e^\lambda) + i\phi^0(\bar e^\lambda\gamma^5e^\lambda)] + \frac{ig}{2M\sqrt2}\phi^+[-m_d^\kappa(\bar u^\lambda_jC_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar u^\lambda_jC_{\lambda\kappa}(1+\gamma^5)d^\kappa_j] + \frac{ig}{2M\sqrt2}\phi^-[m_d^\lambda(\bar d^\lambda_jC^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar d^\lambda_jC^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j] - \frac g2\frac{m_u^\lambda}{M}H(\bar u^\lambda_ju^\lambda_j) - \frac g2\frac{m_d^\lambda}{M}H(\bar d^\lambda_jd^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar u^\lambda_j\gamma^5u^\lambda_j) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar d^\lambda_j\gamma^5d^\lambda_j) +$$

5

$$\bar X^+(\partial^2 - M^2)X^+ + \bar X^-(\partial^2-M^2)X^- + \bar X^0(\partial^2 - \frac{M^2}{c_w^2})X^0 + \bar Y\partial^2Y + igc_wW^+_\mu(\partial_\mu\bar X^0X^- - \partial_\mu\bar X^+X^0) + igs_wW^+_\mu(\partial_\mu\bar YX^- - \partial_\mu\bar X^+Y) + igc_wW^-_\mu(\partial_\mu\bar X^-X^0 - \partial_\mu\bar X^0X^+) + igs_wW^-_\mu(\partial_\mu\bar X^-Y - \partial_\mu\bar YX^+) + igc_wZ^0_\mu(\partial_\mu\bar X^+X^+ - \partial_\mu\bar X^-X^-) + igs_wA_\mu(\partial_\mu\bar X^+X^+ - \partial_\mu\bar X^-X^-) - \frac12 gM[\bar X^+X^+H + \bar X^-X^-H + \frac{1}{c_w^2}\bar X^0X^0H] + \frac{1-2c_w^2}{2c_w}igM[\bar X^+X^0\phi^+ - \bar X^-X^0\phi^-] + \frac{1}{2c_w}igM[\bar X^0X^-\phi^+ - \bar X^0X^+\phi^-] + igMs_w[\bar X^0X^-\phi^+ - \bar X^0X^+\phi^-] + \frac12 igM[\bar X^+X^+\phi^0 - \bar X^-X^-\phi^0]$$

Axions (strong CP problem in QCD)

Gravity: $f(R, R_{\mu\nu}R^{\mu\nu}, R^{\alpha\beta}_{\mu\nu}R^{\mu\nu}_{\alpha\beta}, G, \dots)$

$R(g_{\mu\nu})$ – **Ricci curvature scalar,**

$R_{\mu\nu}(g_{\mu\nu})$ – **Ricci curvature tensor,**

$R_{\mu\nu\alpha\beta}(g_{\mu\nu})$ - **Riemann curvature tensor**

$G(g_{\mu\nu}) = R^2 - 4R_{\mu\nu}R^{\mu\nu} + C^{\alpha\beta}_{\mu\nu}C^{\mu\nu}_{\alpha\beta}$ – **Gauss-Bonnet topological invariant**

1. These three lines in the Standard Model are specific to the gluon, the boson that carries the strong force. Gluons come in eight types, interact among themselves and have what's called a color charge.

2. Almost half of this equation is dedicated to explaining interactions between bosons, particularly W and Z bosons.

Bosons are force-carrying particles, and there are four species of bosons that interact with other particles using three fundamental forces. Photons carry electromagnetism, gluons carry the strong force and W and Z bosons carry the weak force. The most recently discovered boson, the Higgs boson, is a bit different; its interactions appear in the next part of the equation.

3. This part of the equation describes how elementary matter particles interact with the weak force. According to this formulation, matter particles come in three generations, each with different masses. The weak force helps massive matter particles decay into less massive matter particles.

This section also includes basic interactions with the Higgs field, from which some elementary particles receive their mass.

Intriguingly, this part of the equation makes an assumption that contradicts discoveries made by physicists in recent years. It incorrectly assumes that particles called neutrinos have no mass.

4. In quantum mechanics, there is no single path or trajectory a particle can take, which means that sometimes redundancies appear in this type of mathematical formulation. To clean up these redundancies, theorists use virtual particles they call ghosts.

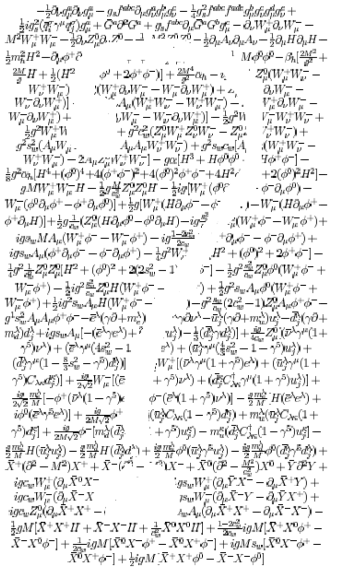
This part of the equation describes how matter particles interact with Higgs ghosts, virtual artifacts from the Higgs field.

5. This last part of the equation includes more ghosts. These ones are called Faddeev-Popov ghosts, and they cancel out redundancies that occur in interactions through the weak force.

Primordial Black Holes with $M_{BH} > 5 \cdot 10^{-20} M_{Sun}$

Dark Matter Lagrangian

No direct data yet



Arbitrary particles are possible without electromagnetic interaction with Standard Model particles

3. DM particles, composite DM states, and Primordial Black Holes –-> DM Planets (DMP)

There are a lot of papers concerned with the Dark Matter (DM) problems:

·Dark sector models that could form macroscopic states include fermion solitons fermi-balls,

T. D. Lee and Y. Pang, Fermion Soliton Stars and Black Holes, Phys. Rev. D 35 (1987) 3678.
A. L. Macpherson and B. A. Campbell, Biased discrete symmetry breaking and Fermi balls, Phys. Lett. B 347 (1995) 205-210
J.-P. Hong, S. Jung, and K.-P. Xie, Fermi-ball dark matter from a first-order phase transition, Phys. Rev. D 102 (2020), no. 7 075028

·Scalar nontopological solitons/Q-balls,

R. Friedberg, T. D. Lee, and A. Sirlin, A Class of Scalar-Field Soliton Solutions in Three Space Dimensions, Phys. Rev. D 13 (1976) 2739-2761.
S. R. Coleman, Q-balls, Nucl. Phys. B 262 (1985), no. 2 263. [Addendum: Nucl.Phys.B 269, 744 (1986)].
T. D. Lee and Y. Pang, Nontopological solitons, Phys. Rept. 221 (1992) 251-350.
E. Pont_on, Y. Bai, and B. Jain, Electroweak Symmetric Dark Matter Balls, JHEP 09 (2019) 011,
E. Y. Nugaev and A. V. Shkerin, Review of Nontopological Solitons in Theories with U(1)-Symmetry, J. Exp. Theor. Phys. 130 (2020), no. 2 301-320,
J. Heeck, A. Rajaraman, R. Riley, and C. B. Verhaaren, Understanding Q-Balls Beyond the Thin-Wall Limit, Phys. Rev. D 103 (2021), no. 4 045008,
Y. Bai, S. Lu, and N. Orlofsky, Q-monopole-ball: a topological and nontopological soliton, JHEP 01 (2022) 109,
Y. Bai, S. Lu, and N. Orlofsky, Origin of nontopological soliton dark matter: solitosynthesis or phase transition, JHEP 10 (2022) 181
A. Ansari, L. Singh Bhandari, and A. M. Thalapillil, Q-balls in the sky

·Dark quark nuggets,

G. Krnjaic and K. Sigurdson, Big Bang Darkleosynthesis, Phys. Lett. B 751 (2015) 464-468,
Y. Bai and A. J. Long, Six Flavor Quark Matter, JHEP 06 (2018) 072,
Y. Bai, A. J. Long, and S. Lu, Dark Quark Nuggets, Phys. Rev. D 99 (2019), no. 5 055047,
X. Liang and A. Zhitnitsky, Axion field and the quark nugget's formation at the QCD phase transition, Phys. Rev. D 94 (2016), no. 8 083502,

·Dark nuclei,

M. B. Wise and Y. Zhang, Stable Bound States of Asymmetric Dark Matter, Phys. Rev. D 90 (2014), no. 5 055030, Erratum: PRD 91, 039907 (2015).
M. B. Wise and Y. Zhang, Yukawa Bound States of a Large Number of Fermions, JHEP 02 (2015) 023, Erratum: JHEP 10, 165 (2015).
E. Hardy, R. Lasenby, J. March-Russell, and S. M. West, Big Bang Synthesis of Nuclear Dark Matter, JHEP 06 (2015) 011,
M. I. Gresham, H. K. Lou, and K. M. Zurek, Nuclear Structure of Bound States of Asymmetric Dark Matter, Phys. Rev. D 96 (2017), no. 9 096012,
M. I. Gresham, H. K. Lou, and K. M. Zurek, Early Universe synthesis of asymmetric dark matter nuggets, Phys. Rev. D 97 (2018), no. 3 036003,

·Mirror sectors or any dark sector with an analog of chemistry or nuclear physics,

D. Curtin and J. Setford, How To Discover Mirror Stars, Phys. Lett. B 804 (2020) 135391,
D. Curtin and J. Setford, Signatures of Mirror Stars, JHEP 03 (2020) 041,

·Degeneracy pressure,

A. Maselli, P. Pnigouras, N. G. Nielsen, C. Kouvaris, and K. D. Kokkotas, Dark stars: gravitational and electromagnetic observables, PRD 96(2017)2,
M. Hippert, J. Setford, H. Tan, D. Curtin, J. Noronha-Hostler, and N. Yunes, Mirror neutron stars, Phys.Rev.D 106 (2022), no.3 035025,
C. Gross, G. Landini, A. Strumia, and D. Teresi, Dark Matter as dark dwarfs and other macroscopic objects: multiverse relics?, JHEP 09 (2021) 033,
M. Ryan and D. Radice, Exotic compact objects: The dark white dwarf, Phys. Rev. D 105 (2022), no. 11 115034,

·These composite states may contain macroscopic dark matter with mass reaching the planet mass scale (DMP) or even higher, and some of them may be compact enough to be stable under tidal forces:

D. M. Jacobs, G. D. Starkman, and B. W. Lynn, Macro Dark Matter, Mon. Not. Roy. Astron. Soc. 450 (2015), no. 4 3418-3430,
C. Kouvaris and N. G. Nielsen, Asymmetric Dark Matter Stars, Phys. Rev. D 92 (2015), no. 6 063526,
G. F. Giudice, M. McCullough, and A. Urbano, Hunting for Dark Particles with Gravitational Waves, JCAP 10 (2016) 001,
J. A. Dror, H. Ramani, T. Trickle, and K. M. Zurek, Pulsar Timing Probes of Primordial Black Holes and Subhalos, Phys.Rev.D 100 (2019), 2
D. Croon, D. McKeen, and N. Raj, Gravitational microlensing by dark matter in extended structures, Phys. Rev. D 101 (2020), no. 8 083013,
Y. Bai, A. J. Long, and S. Lu, Tests of Dark MACHOs: Lensing, Accretion, and Glow, JCAP 09 (2020) 044,
Y. E. Pokrovsky, Stable Compact Dark Matter Objects in Planetary Systems, Journal of Physics: Conference Series 1557 (2020) 012033.
A.Bhoonah, J.Bramante, S.Schon, and N.Song, Detecting composite dark matter with long-range and contact interactions in gas…, PRD 103 (2021) 12
P.Dhakal, S.Prohira, C.V.Cappiello, J.F.Beacom, S.Palo, and J.Marino, New constraints on macroscopic dark matter using radar meteor detectors, Phys. Rev. D 107 (2023), no. 4 043026,

And, as the most perspective, the Primordial Black Holes (PBH)

- **S.W. Hawking, Commun.Math. Phys. 43 (1975) 199 : Original article proposing existence of radiation**
- **D. Page, Phys. Rev. D13 (1976) 198 : First detailed studies of the evaporation mechanism**
- **B.J. Carr & S.W. Hawking, Mon. Not. Roy. Astron. Soc 168 (1974) 399 : Describes links between primordial black holes and the early universe**
- **A. Barrau et al., Astron. Astrophys. 388 (2002) 676, Astron. Astrophys. 398 (2003) 403, Astrophys. J. 630 (2005) 1015 : Experimental searches for primordial black holes due to the emitted antimatter**
- **A.Barrau, G.Boudoul, Review talk given at the International Conference on Theoretical Physics TH2002 : Cosmology with primordial black holes**
- **A. Barrau & J. Grain, Phys. Lett. B 584 (2004) 114 : Searches for new physics (quantum gravity) with primordial black holes**
- **P. Kanti, Int. J. Mod. Phys. A19 (2004) 4899: Evaporating black holes and extra-dimensions**
- **Bird, Simeon; Albert, Andrea; Dawson, Will; Ali-Haimoud, Ali-Haimoud, Yacine; Coogan, Adam; Drlica-Wagner, Alex; Feng, Qi; Inman, Derek; Inomata, Keisuke; Kovetz, Ely; Kusenko, Alexander; Lehmann, Benjamin V.; Muñoz, Julian B.; Singh, Rajeev; Takhistov, Volodymyr; Tsai, Yu-Dai. 2022. Snowmass2021 Cosmic Frontier White Paper: Primordial Black Hole Dark Matter**
- **Inman, Derek; Ali-Haïmoud, Yacine. 2019. Early structure formation in primordial black hole cosmologies.**
- **Lincoln, Don. 2022. Is dark matter real? Astronomy's multi-decade mystery**
- **Vaskonen, Ville; Veermäe, Hardi. 2021. Did NANOGrav See a Signal from Primordial Black Hole Formation?**
- **Caputo, Andrea. 2019. Radiative axion inflation.**
- **Allahverdi, Rouzbeh; Brandenberger, Robert; Cyr-Racine, Francis-Yan; Mazumdar, Anupam. 2010. Reheating in Inflationary Cosmology: Theory and Applications.**
- **Mazumdar, Anupam; White Graham. 2019. Review of cosmic phase transitions: their significance and experimental signatures.**

Inspite of the Hawking radiation, Primordial Black Holes (PBH) with $M_{PBH} > 5 \cdot 10^{-20} M_{Sun}$, are not evaporated up to date, and are the most perspective objects for triggering dynamo in the 11-year solar cycle.

This talk: The 11-year periodic activity of the Sun, as well as the specific gravitational lensing of star light, and the specific knowking out of asteroids from the main (Mars-Jupiter) asteroid belt can be used for the direct detection of PBH in the solar system.

4. Solar system as a detector of DMP within the post Newtonian (pN) dynamics

Possible gravitational influence of Dark Matter (DM) in the Solar system based on the EPM2011 planetary ephemerides using about 677 thousand positional observations of planets and spacecraft is searched for and estimated, in particular, by

N.P.Pitjev, E.V.Pitjeva, Constraints on Dark Matter in the Solar System, Astronomy Lett., 39, 3 (2013) p141:

The Dark Matter Planet mass in the sphere within Saturn's orbit $M_{DMP} < 1.7\ 10^{-10} M_{\odot}$.

Planetary ephemerides

R. S. Park , W. M. Folkner , J. G. Williams , and D. H. Boggs, The JPL Planetary and Lunar Ephemerides DE440 and DE441, Astronomical Journal, 161(2021)105;

E.V. Pitjeva, N.P. Pitjev, Development of planetary ephemerides epm and their applications, Celest. Mech. Dyn. Astron. 119,3 (2014) 237.

and $\vec{r}$, $\vec{v}$ for DMP were used as initial conditions numerical integration of solar system equations with DMP.

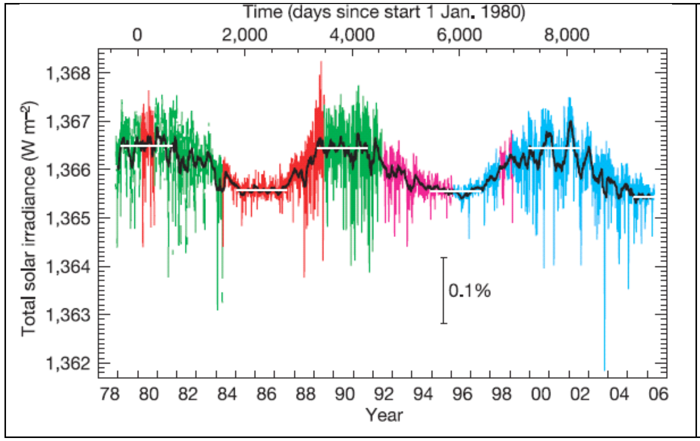
Standard solar model (BP2000) was used for mass density $\rho_{\odot}(r)$, and sound speed $C_{\odot}(r)$ to calculate the gravitational dynamics, and dynamical friction of the Dark Matter Planet in the Sun.

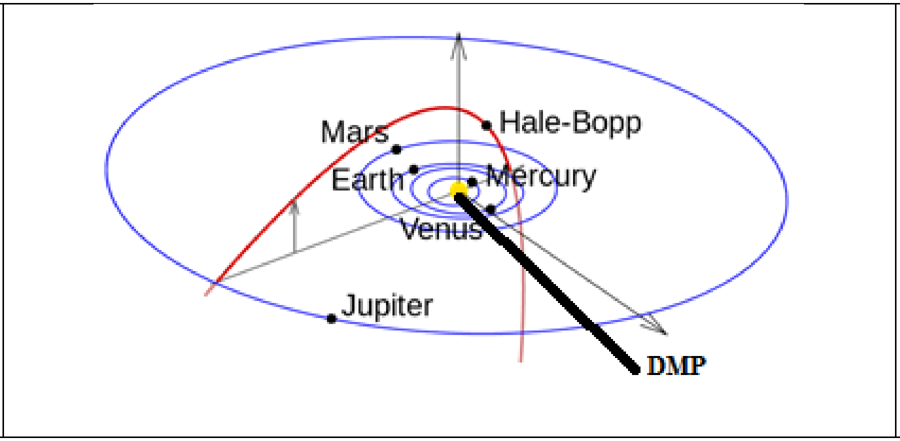
5. DM planet (DMP) in the solar system:

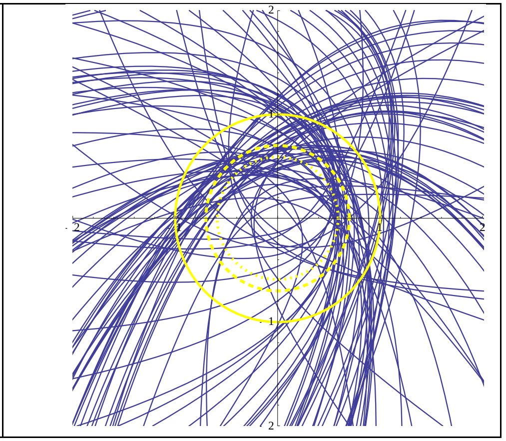
Dynamical friction in the Sun,
DMP capture, and
possible trajectories of DMP

Only PBH with $M_{BH} \approx 1.7\ 10^{-10} M_{\odot}$ can transfer <u>enough</u> energy to the Sun for $\Delta L_{\odot} \sim 0.001 L_{\odot}$ due to the Dynamical Friction (DF) of BH in the Sun for the Super Sound (SS) v_{BH}:

DF force: $$F_{SS} = \frac{4\pi (GM_{BH})^2 \rho_{\odot}(r)}{v_{BH}{}^2}\, ln\left[\frac{r_{max}}{r_{min}}\right] = \frac{4\pi (GM_{BH})^2 \rho_{\odot}(r)}{v_{BH}{}^2}\, ln\left[\frac{c^2}{2 v_{BH} c_S}\right].$$ **For the PBH** $ln\left[\frac{c^2}{2 v_{BH} c_S}\right] \sim 13$





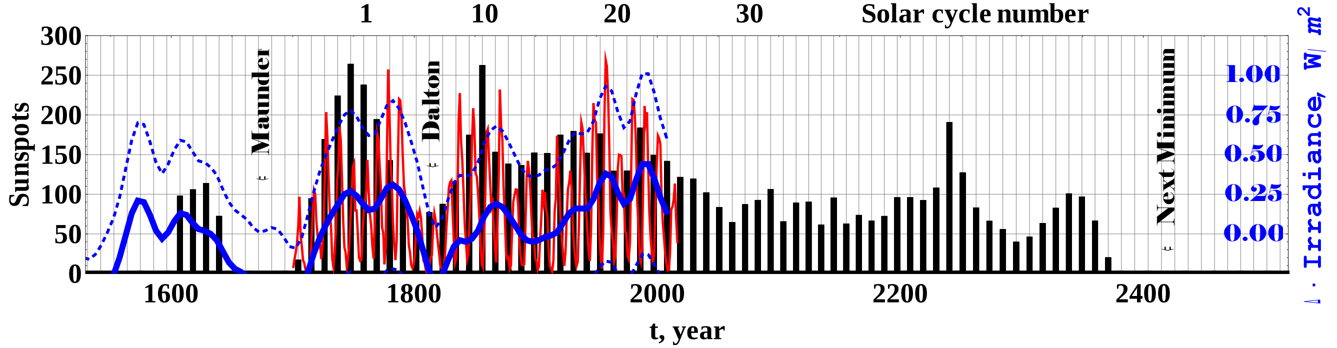


Every solar cycle amplitude depends on of the trajectory of DMP in the Sun (initial condition for DMP).

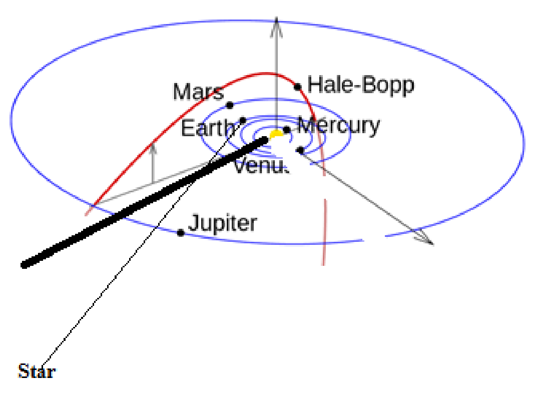
Gravitational interaction of this PBH with Mercury, Venus, Mars, Jupiter, and Saturn strongly change trajectory of this PBH in the Sun, change energy transfer, and change luminosity of the solar cycles.

This initial conditions can be chosen so that all calculated solar cycles are in agreement with the data.

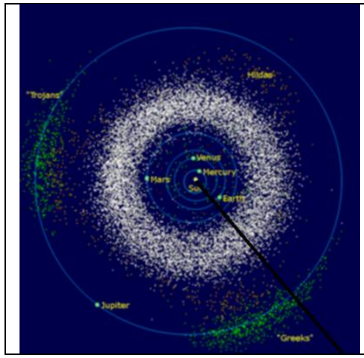
6. Possible indications of DMP by means of



- **triggering the solar dynamo in the 11-year solar cycle**



- **specific lensing of star light**



- **knocking-out main-belt asteroids (285075 asteroids on 6.09.2011 with total mass ~3% of the Moon mass)**

7. Conclusions

1. **Primordial Black Hole (PBH) with $M_{BH} \approx 2 \cdot 10^{-10} M_{\odot}$ on the very eccentric orbit, crossing the Sun surface with 11-year period, can trigger solar dynamo and determine amplitude of the solar cycle luminosity dependent on energy transferred to the Sun via the dynamical friction.**

2. **Gravitational interaction of this PBH with Mercury, Venus, Mars, Jupiter, and Saturn strongly change trajectory of this PBH in the Sun, change energy transfer, and change luminosity of the solar cycles.**

3. **This Primordial Black Hole in the solar system could be detected via specific lensing of star light.**

4. **This Primordial Black Hole in the solar system could be detected via knocking-out a main-belt asteroid.**

Thank you.