Dark Matter Bodies In The Solar Structure

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1. **Data - solar surface oscillations observed at the frequencies**

$\nu_{CrAO} = 104.1891\ \mu Hz$ (160 minutes) $\nu_{SoHO} = 220.7\ \mu Hz$ (75 minutes)

$V_{CrAO} = 0.25 \pm 0.03$ m/s $V_{SoHO} = 0.0045 \pm 0.0015$ m/s

CrAO (Crimean Astrophysical Observatory), SoHO (Solar Helioseismic Observatory)

2. **Astroseismology and resonant excitations of Surface Rayleigh Waves by two Dark Matter Bodies (DMB) with masses** $M_{CrAO} \approx 1.2\ 10^{-7}\ M_{\Theta}$ ($\approx 0.73\ M_{♀}$), $M_{SoHO} \approx 3.7\ 10^{-9}\ M_{\Theta}$ ($\approx 0.02\ M_{♀}$) **and radii of matter distributions**

$R_{CrAO} \approx 20 - 200$ km, $R_{SoHO} \approx 60 - 400$ km **orbiting near the solar surface at radii**

$R_{OrbCrAO} = 1.54\ R_{\Theta}$, $R_{OrbSoHO} = 0.94\ R_{\Theta}$.

3. **These DMB radiate Gravitational Waves (GW) with amplitudes of metric tensor oscillations large enough to detect**

$h_{CrAO} \sim 9.5\ 10^{-20}$, $h_{SoHO} \sim 1.2\ 10^{-21}$ **near the Earth (near-zone) at frequencies** ν_{CrAO}, ν_{SoHO} **and could be detected by**

eLISA (European Laser Interferometer Space Antenna) or by

DULKYN-3 (Scientific Centre for Gravitational-wave Research "Dulkyn") at observation time much longer than

8 days **at** *νCrAO* , *5 - 10 years* **at** *νSoHO* , *9 years* **for** *PSR J0737-3039* ($h_{PSR\ J0737-3039} \sim 2\ 10^{-22}$).

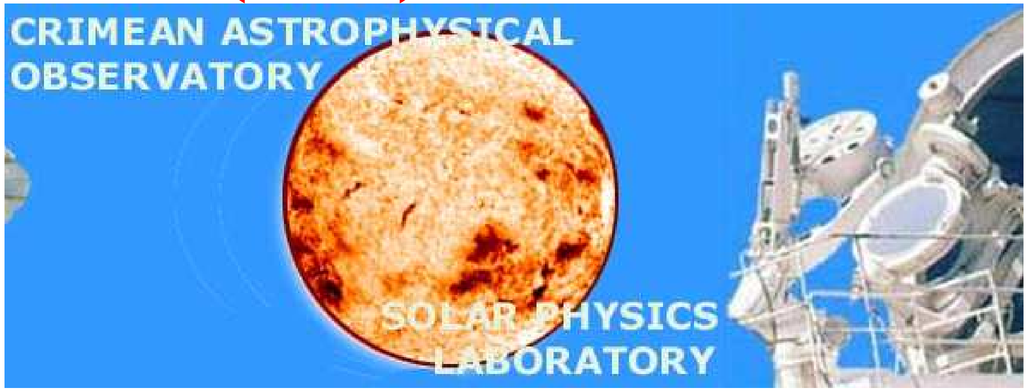
4. **Suggested experiment – a possible solution of two fundamental physical problems simultaneously –**

the direct detection of GW, and the direct detection of DMB in the Sun.

The first theoretical estimations – "Excitation of the solar oscillations by objects consisting of y-matter" by S. I. Blinnikov, M. Yu. Khlopov in Solar Physics 82(1983)383

Current Detectors:

CrAO (1974)

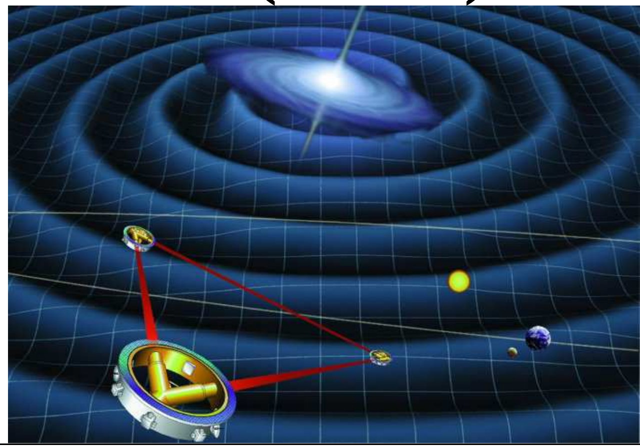


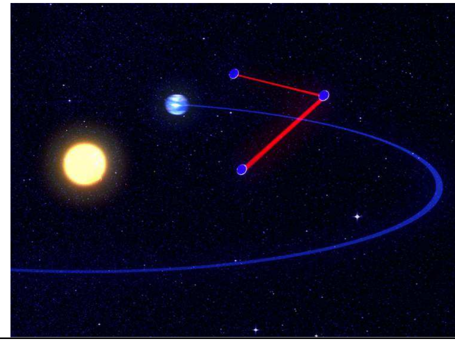
SoHO (1996)

Future Detectors:

DULKYN-3 (2015?) ~ 1 m

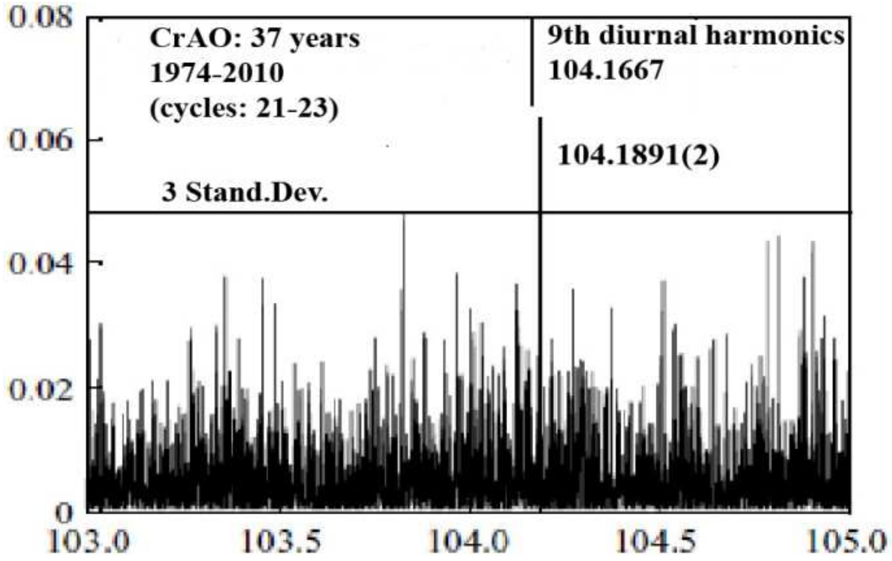
eLISA (2016?) ~ 1000000 km





Solar oscillation data

<u>CrAO</u> (Crimean Astrophysical Observatory)

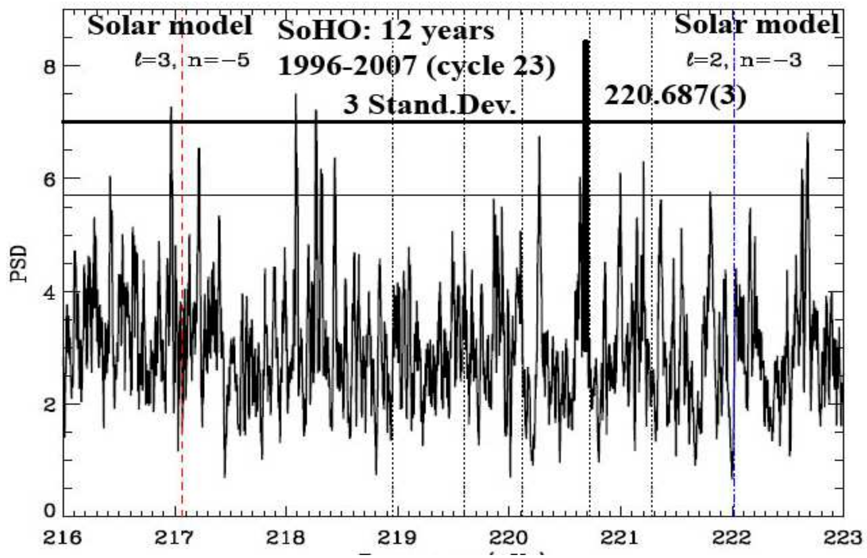


ν, μHz

Power of the Fourier spectrum density extracted from differential (center - limb) <u>velocity spectrum</u> of solar surface oscillations (CrAO data) in 1974–2010 (21, 22, 23 solar cycles).

“Oscillations of the Sun: Results of observations in 1974–2007” by V. A. Kotov, V. I. Haneychuk, Bulletin of Crimean Astrophysical Observatory, 104 (2008) 45; “Pulsations of the Sun and a Beat Period of 399 Days” by V. A. Kotov, V. I. Khaneichuk, Bulletin of the Crimean Astrophysical Observatory 107 (2011) 67

SoHO (Solar Helioseismic Observatory)



ν, μHz

Power of the Fourier spectrum density extracted from <u>intensity spectrum</u> of solar surface oscillations (VIRGO/SPM at SoHO - blue channel data) in 1996-2007 (23 solar cycle). The vertical dashed lines at ≈ *217* and *222 μHz* are the expected theoretical frequencies for the g-modes *(ℓ,n) = (2,-5)* and *(3,-2)* from the Saclay seismic model.

“Update on g-mode research” by R.A. Garcia, A. Jimenez, S. Mathur, J. Ballot, A. Eff-Darwich, S.J. Jimenez-Reyes, P.L. Palle, J. Provost, S. Turck-Chieze. Astron. Nachr. AN 999(2006)88; arXiv:0802.4296 [astro-ph]

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Equations of Astroseismology with tidal excitation by DMB +

Surface Boundary Conditions: Lagrange variations δp'(R) = 0, δ(δp'(R)) = 0 => Resonances like Surface Rayleigh Waves.

G-mode Resonances? - Do not appear at the star surface. **For DMB orbit** $\mathbf{R}_{orb}(t) = \left\{R_{orb}(t), \frac{\pi}{2}, \Phi(t)\right\}$,

$$U(r,t) = -\frac{G\, m_{DMB}}{|\mathbf{r} - \mathbf{R}_{orb}(t)|} = \frac{G\, m_{DMB}}{r_>} \sum_{l,lz} W_{l,lz} \left(\frac{r_<}{r_>}\right)^l e^{-i\, lz\, \Phi(t)} Y_l^{lz}(\theta,\varphi)$$

$$W_{l,lz} = Re\left((-1)^{\frac{l+lz}{2}}\right) \frac{\left[\frac{4\pi}{2l+1}(l+lz)!\,(l-lz)!\right]^{1/2}}{\left[2^l \left(\frac{l+lz}{2}\right)!\left(\frac{l-lz}{2}\right)!\right]}, \qquad W_{2,2} = \sqrt{\frac{3\pi}{10}}, \qquad W_{6,\{2,4,6\}} = \left\{\sqrt{\frac{105\pi}{3328}}, -\sqrt{\frac{126\pi}{3328}}, \sqrt{\frac{231\pi}{3328}}\right\}$$

$$\boldsymbol{\xi}(r,t) = \sqrt{4\pi} \sum\nolimits_{n,l,lz} C_{n,l,lz} \left\{\xi_r(r) Y_l^{lz}(\theta,\varphi), \frac{1}{\sqrt{l(l+1)}} \xi_h(r) \frac{d}{dr} Y_l^{lz}(\theta,\varphi), \frac{1}{\sqrt{l(l+1)}\sin\theta} \xi_h(r) \frac{d}{d\varphi} Y_l^{lz}(\theta,\varphi)\right\} e^{-i\omega_{n,l,lz} t},$$

$$\xi_r(R) = -\frac{1}{\omega_{Dyn}{}^2} \frac{\frac{1}{R} U_{l,lz}(R) + \frac{1}{l(l+1)} \frac{\omega^2}{\omega_{Dyn}{}^2} U'_{l,lz}(R)}{1 - \frac{4}{(l+1)(l+2)} \frac{\omega^2}{\omega_{Dyn}{}^2}\left(1 + \frac{1}{4}\frac{\omega^2}{\omega_{Dyn}{}^2} - \frac{\pi\, G\, \rho(R)}{\omega_{Dyn}{}^2} + \frac{1}{l+2} \frac{\pi\, G\, R\, \rho'(R)}{\omega_{Dyn}{}^2}\right)},$$

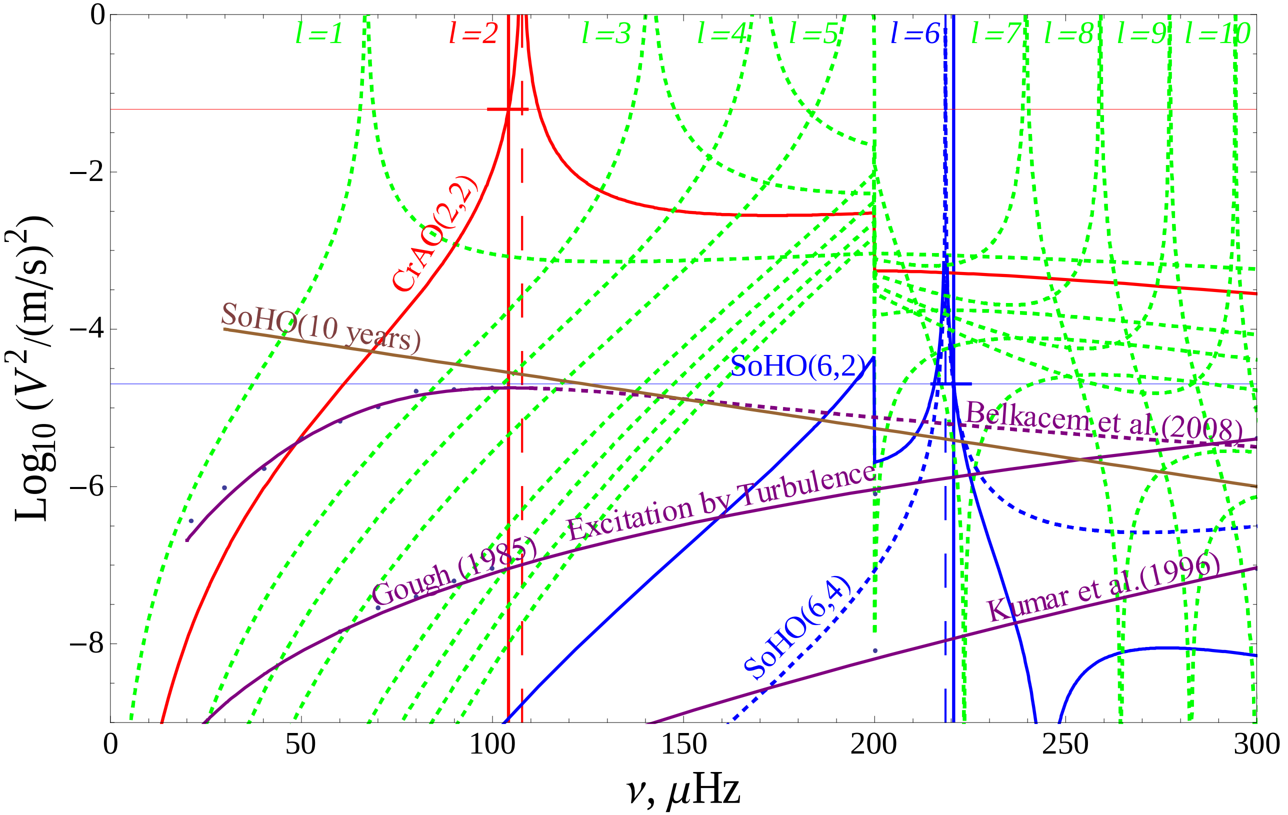
$$\xi_h(R) =$$

$$-\frac{4}{l(l+1)} \frac{1}{\omega_{Dyn}{}^2} \frac{\frac{1}{R}\left(1 + \frac{1}{4}\frac{\omega^2}{\omega_{Dyn}{}^2} - \frac{\pi\, G\, \rho(R)}{\omega_{Dyn}{}^2} + \frac{1}{l+2}\frac{\pi\, G\, R\, \rho'(R)}{\omega_{Dyn}{}^2}\right) U_{l,lz}(R) + \frac{1}{4}\left(1 + \frac{4}{(l+1)(l+2)} \frac{\pi\, G\, R\, \rho'(R)}{\omega_{Dyn}{}^2}\right) U'(R)}{1 - \frac{4}{(l+1)(l+2)}\frac{\omega^2}{\omega_{Dyn}{}^2}\left(1 + \frac{1}{4}\frac{\omega^2}{\omega_{Dyn}{}^2} - \frac{\pi\, G\, \rho(R)}{\omega_{Dyn}{}^2} + \frac{1}{l+2}\frac{\pi\, G\, R\, \rho'(R)}{\omega_{Dyn}{}^2}\right)},$$

$\omega_{Dyn}{}^2 = \frac{G\,M}{R^3}$, $U_{l,lz}(r) = \frac{G\, m_{DMB}}{r_>} \sum_{l,lz} W_{l,lz} \left(\frac{r_<}{r_>}\right)^l$ **– for a circular orbit. For solar like stars:** $\frac{G\,\rho(R)}{\omega_{Dyn}{}^2} \ll 1$, $\frac{G\,R\,\rho'(R)}{\omega_{Dyn}{}^2} \ll 1$,

$$\omega^2 \rightarrow \omega_{l,l_z}(\omega_{l,l_z} - l_z\Omega_{star}) \Rightarrow \omega_{l,l_z} = \omega_{Dyn}\sqrt{\sqrt{l(l+1)+4} - 2 + \frac{l_z^2}{4}\frac{\Omega_{star}^2}{\omega_{Dyn}^2}} + \frac{1}{2}l_z\,\Omega_{star} \Rightarrow \omega_l = \omega_{Dyn}\sqrt{\sqrt{l(l+1)+4} - 2}$$

Amplitudes of solar surface oscillations



For the Sun:

$$\frac{\Omega_{Sun}^2}{\omega_{Dyn}^2} \ll 1 \quad \Rightarrow$$

$$\omega_{l,l_z} = \omega_{Dyn}\sqrt{\sqrt{l(l+1)+4} - 2} + \frac{1}{2}l_z\,\Omega_{Sun}\,,$$

$$\nu_{Dyn} = \frac{\omega_{Dyn}}{2\pi} = 99.9178\ \mu\text{Hz} \quad (166.804')$$

$M_{CrAO} \approx 1.2\ 10^{-7}\ M_\Theta$ (≈0.73 M♀), l = 2, l_z = 2

$M_{SoHO} \approx 3.7\ 10^{-9}\ M_\Theta$ (≈0.02 M♀), l = 6, l_z=2,4,6.

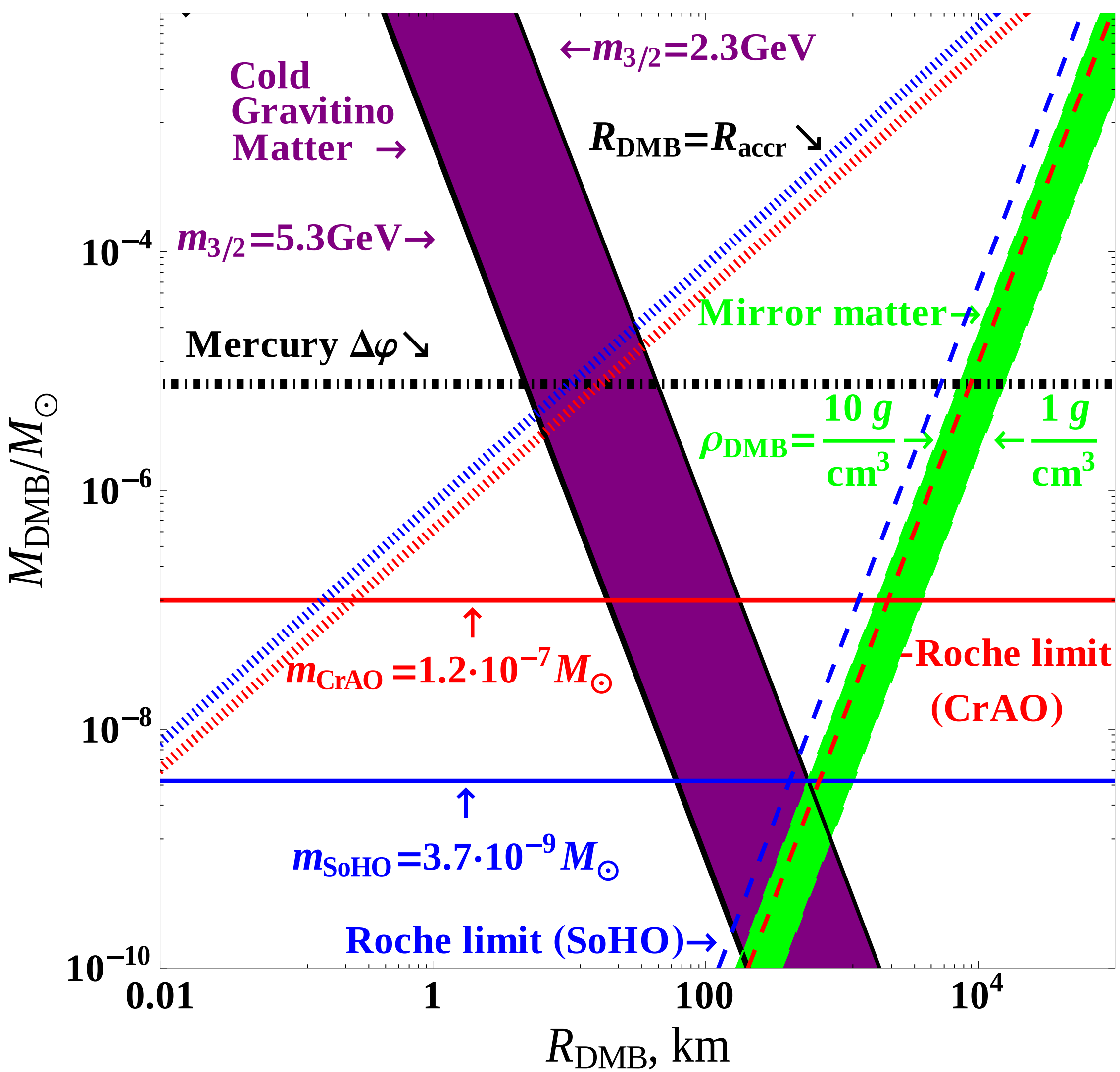
More accurate solar surface experiments or Gravitational Wave experiments are needed

D. O. Gough in E. Rolfe, B.Battrick (eds.), Future Missions in Solar, Heliospheric and Space Plasma Physics, ESA SP-235, ESA Publications Division, Noordwijk, The Netherlands, (1985) 183

P. Kumar, E. J. Quataert, J. N. Bahcall, "Observational searches for solar g modes: Some theoretical considerations", ApJ Letters 458 (1996) L83

K. Belkacem, R. Samadi, M. J. Goupil, M. A. Dupret, A. S. Brun, and F. Baudin, "Stochastic excitation of nonradial modes II. Are solar asymptotic gravity modes detectable?", Astronomy & Astrophysics manuscript no. 0827 c ESO 2008

Mass – Radius Limitations for DMB



$M_{DMB} << 8\ 10^{-6} M_\Theta$
Mercury Perihelion Prececcion

$R_{DMB} << R_{RocheLimit}$

$R_{DMB} >> R_{accr}$

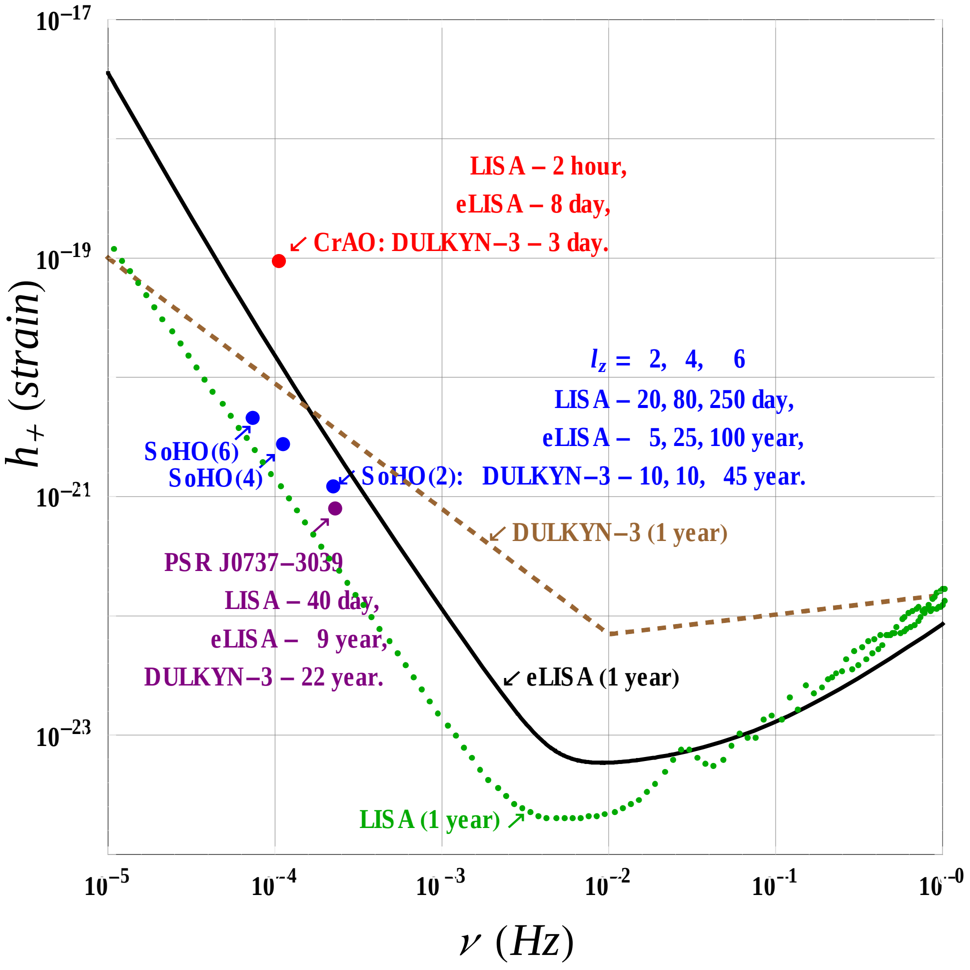
Cold GravitinoMatter?

Estimations for future GW experiments

$$h_+ = -\frac{1}{R}\frac{G^2}{c^4}\frac{2m_1m_2}{r}(1+\cos^2\theta)\cos\left[2\omega(t-R)\right],$$

$$h_\times = -\frac{1}{R}\frac{G^2}{c^4}\frac{4m_1m_2}{r}(\cos\theta)\sin\left[2\omega(t-R)\right].$$

+ near zone terms



Conclusions:

CrAO and SoHO data for oscillation of solar surface indicate two DMB in the solar structure at

Mass of DM particles << 30 GeV/c^2

$M_{CrAO} \approx 1.2\ 10^{-7} M_\Theta$ (≈0.73 M♀)	$M_{SoHO} \approx 3.7\ 10^{-9} M_\Theta$ (≈0.02 M♀)
$R_{CrAO} \approx 20 - 200$ km,	$R_{CSoHO} \approx 60 - 400$ km
$R_{OrbCrAO} = 1.54\ R_\Theta$,	$R_{OrbSoHO} = 0.94\ R_\Theta$.

At the Earth the Sun is the brightest source of GW at frequences

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$h_{CrAO} \sim 9.5\ 10^{-20}$	$h_{SoHO} \sim 1.2\ 10^{-21}$

$\nu_{PSR\ J0737\text{-}3039} = 231.5\ \mu Hz$

$h_{PSR\ J0737\text{-}3039} \sim 2\ 10^{-22}$

eLISA (2016?)	DULKYN-3 (2015?)
8 days at ν_{CrAO}	3 days at ν_{CrAO},
5, 25, 100 years at ν_{SoHO}	10, 10, 45 years at ν_{SoHO}
9 years at $\nu_{PSR\ J0737\text{-}3039}$	22 years at $\nu_{PSR\ J0737\text{-}3039}$

GW experiments to detect at least two DMB in the Sun, to fix the l_z = 2, 4, 6 uncertanty for SoHO oscillations, and to detect other possible DMB in the Sun which do not appear in surface oscillations because their frequencies are too far from the surface resonances and amplitudes are too small to detect.

Suggested experiment – a possible solution of two fundamental physical problems simultaneously –
the direct detection of GW, and
the direct detection of DMB in the Sun.

In the case of success, this experiment opens a new epoch in Astro, Particle and GW physics.