National Aeronautics and Space Administration

Direct Detection Of Dark Energy Through Precision Local Measurements In Space

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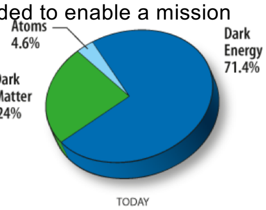
Program: Strategic Initiative

Project Objectives:

- Validate specific dark energy detection measurement concepts;
- Develop key technologies needed to enable a mission design and development.



Motivation:

- Dark energy could be a form of new **scalar fields**.
- The scalar fields lead to a "**fifth force**" when interacting with matter, and are "screened" to be consistent with precision tests to date.
- Cubic galileon is one of the scalar field models, whose screening effect (the **Vainshtein model**) is manifested through nonlinearity in the kinetic term of the Lagrangian.
- We conduct on numerical simulation of cubic galileon for multiple source bodies, to valid the science measurement concept and to enable detailed mission design.
- A measurement scheme in the solar system (Figure 1) forms the basis of the measurement, and risks in the required technologies are being addressed.

Challenge: Solving highly nonlinear Vainshtein equation for galileon field ϕ:

$$\nabla^2\phi + \frac{r_c^2}{3}\left[(\nabla^2\phi)^2 - \left(\nabla_{ij}\phi\right)^2\right] = 8\pi G\rho$$

$r_c \sim 6.5\times10^{41}\ GeV^{-1}$, $8\pi G \simeq 1.69\times10^{-37}\ GeV^{-2}$, $\rho \sim 2\times10^{-17}\ GeV^4$ *for Earth*

5^{th} force due to dark energy field: $-\nabla\phi$, direct detection of dark energy

Suppress gravity contribution by measuring $\nabla^2\phi$

FY19 Results:

3D Numerical Solutions –

- Implemented a finite difference approach for the numerical solution of the Vainshtein model and tested it by comparison with the analytic single-body solution. (Figure 2)
- Identified trajectory where DE signal is modulated by 10x. (Figure 3)
- Mapped out dark energy field in the Sun-Earth-Moon system. (Figures 3,4)
- Verified that Vainshtein dark energy is indeed detectable within the solar system.

Cold Atom Sources –

- Cold atoms will serve as the inertial reference for constraining 5^{th} force due to dark energy, and be the primary limit on the measurement sensitivity.
- Identified bottleneck and mitigations on cold atom flux: loading efficiency into trap, and cooling efficiency.

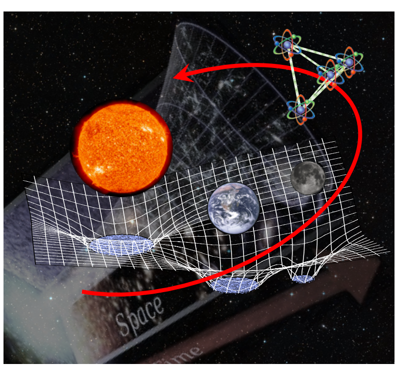


Figure 1: Conceptual scheme for direct detection of galileon in the solar system.

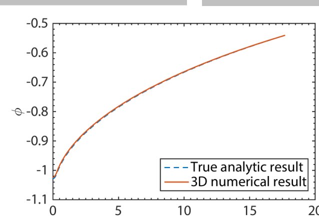


Figure 2: Comparison of numerical and analytic solutions for a single spherical source body.

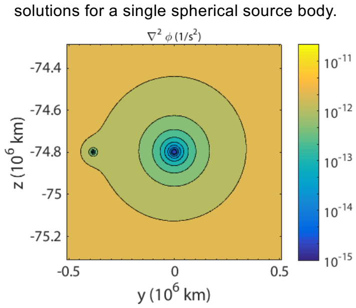


Figure 4: Relative strength of 5th force to gravity in Earth-Moon system.

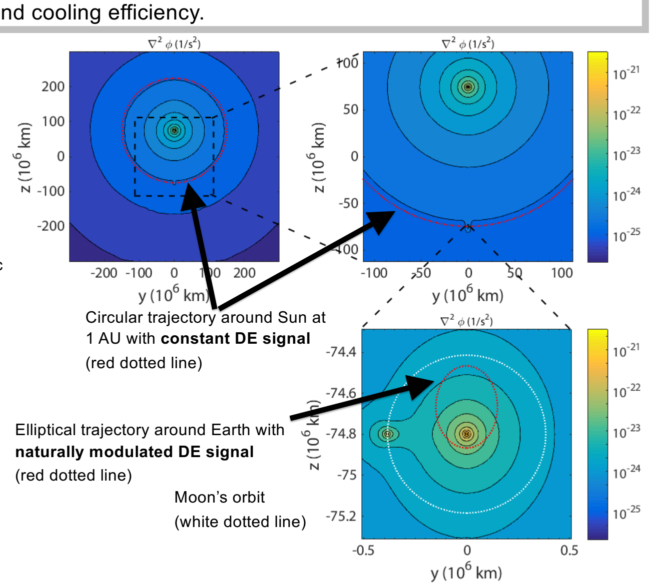


Figure 3: Anticipated DE signal in the Sun-Earth-Moon system

Benefits to NASA and JPL:

- The scientific community and NASA have strong interest and effort in studying dark energy; JPL has emerged as a world leader in dark energy cosmology mission development and in the exploitation of current surveys aimed at elucidating the nature of dark energy.
- The detailed and rigorous simulations of novel theories of dark energy scalar fields will position JPL in a unique position for future mission design for direct detection of dark energy.
- The establishment of the development roadmap for mitigating major technical risk, the flux of cold atom, will not only increase the TRL of the concept of direct detection of dark energy in the solar system, but also advance atomic sensor technology for space applications.

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Publications:

N. White, J. Jewell, C. Cutler, S. Troian, S.-w. Chiow, and N. Yu, "Accurate numerical simulation of the Vainshtein mechanism at Solar System scales," In preparation.

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