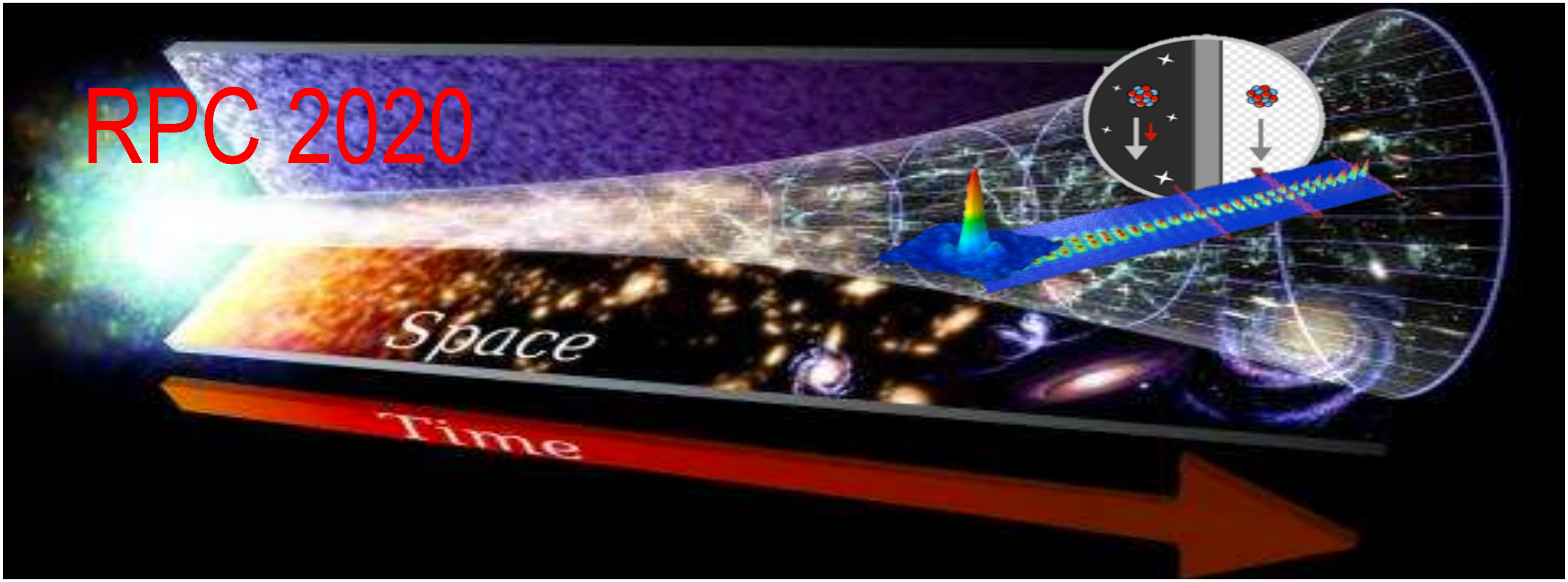


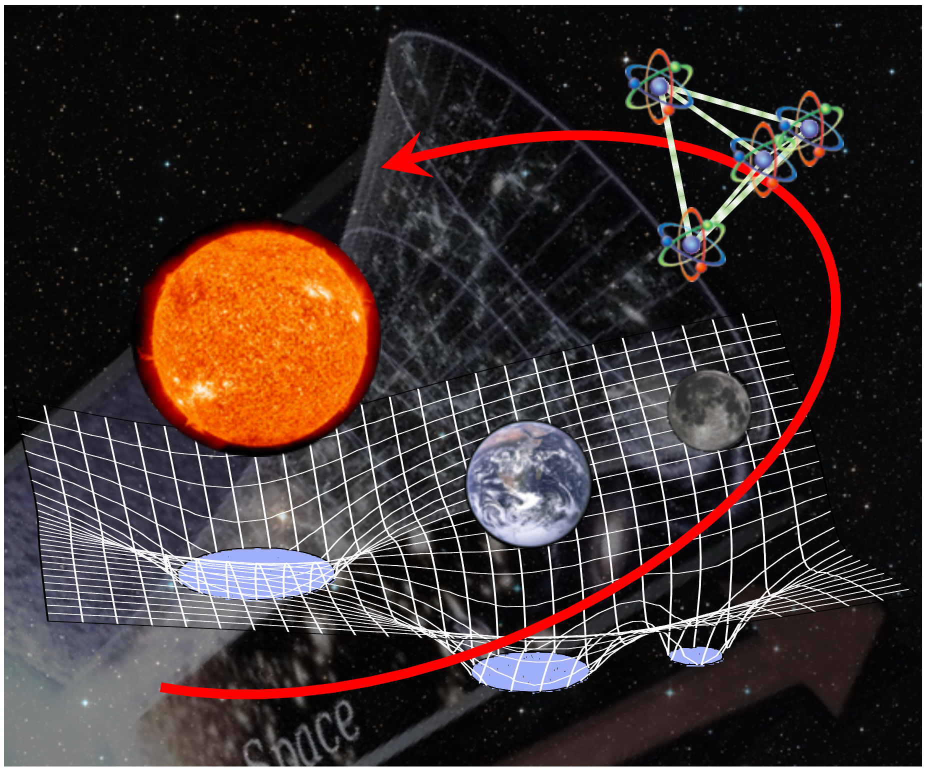
Virtual Research Presentation Conference

Direct Detection of Dark Energy Through Precision Local Measurements in Space

Principal Investigator: Nan Yu (332J)
Co-Is: Jason Rhodes (3200), Olivier Doré (3268), Jeffrey Jewell (398L), Eric Huff (3268), Curt Cutler (3268), Sheng-wey Chiow (332J), Kristofer Pardo (3268)
Program: Strategic Initiative
Assigned Presentation #RPC-013

Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction



- Dark energy constitutes 70% of our Universe, but *little is known about the nature of it*.
- Complimentary to the current cosmological observations, we propose direct detection of possible new dark energy scalar fields and help answer what dark energy is.
- The approach is to take advantage of the advent of new weak force measurement capabilities by the atomic quantum sensors.
- The measurement strategy is to suppress the dominating gravity forces in the solar system by measuring small deviation from Newtonian inverse square law (ISL) with the gradient tensor trace.
- This RTD effort focuses on building up the science measurement justification by simulating dark energy field distributions and signal strengths as well as identifying and addressing key technology challenges.

Problem Description

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

Equation of motion of the cubic galileon scalar field

a) **Why this problem and why now** Current dark energy missions will be soon to obtain all there is to know about the observable effects of dark energy but still far from understanding its nature. At the same time, invention of atomic test mass quantum sensors in the form of atom-wave interferometers provide new capabilities not possible before. The new technology makes it possible now for a direct detection of dark energy, differentiating various dark energy models, that will lead to the new understand of dark energy and discover new physics.

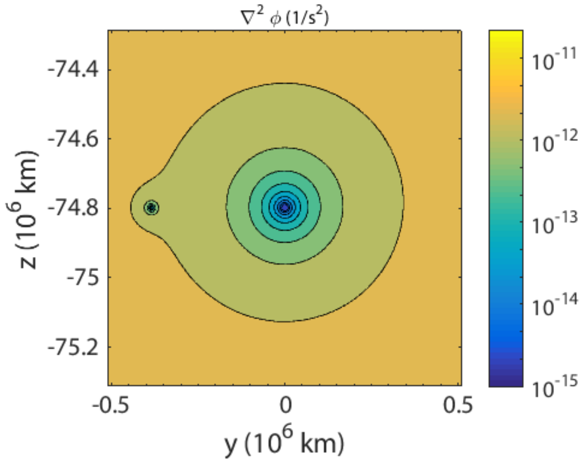
b) **Comparison or advancement over current state-of-the-art** Among promising dark energy models, we focus on the cubic galileon scalar field. The field is governed by a highly nonlinear equation of motion, and the solution of a many body system (such as in the solar system) is very challenging and has not been done before. Thus, the feasibility of detecting cubic galileon in the solar system had not been strongly established.

c) **Relevance to NASA and JPL** The study of the physical nature of dark energy is one of the most important science problems in the new century, and therefore a high priority area in the NASA science strategic goals. JPL has been a center of excellence for space dark energy studies, and it is of strategic importance of leading new ways and new approaches to continue the quest for understanding of dark energy and our universe at JPL.

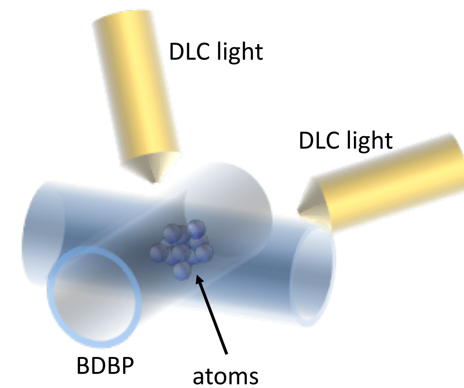
Methodology

a) From the start, we explored different approaches to tackle the convergence challenges of the nonlinear differential equation. In collaboration with Caltech, we eventually developed a finite difference method to allow exploring the real solar system problem, both in 2-body and 3-body scenarios, and investigating the impact of a third body to the dark energy screening effect. The results provide a detailed map of the dark energy signals in the solar system. This led us to rethink of the architecture of the mission concept developed in the NIAC Phase I.

b) In addition, we took on one of the most critical technology gaps in realizing the direct detection of dark energy using atom-wave interferometers, a high flux ultra-cold atom source. Specifically, the number of ultracold atoms needed to support desired sensitivity is 1000x more than current state of the art. We studied use of a box made of light sheets (Blue-Detuned Box Potential, BDBP) to trap a large volume of thermal atoms, and then to use lasers to cool them down (direct laser cooling, DLC). This is different from conventional atom cooling, where atoms are trapped at light focus and cooled evaporatively which limits the number of atoms achievable.



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



New atom source scheme under development

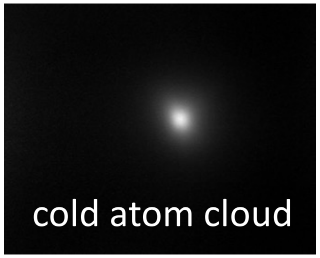
Results

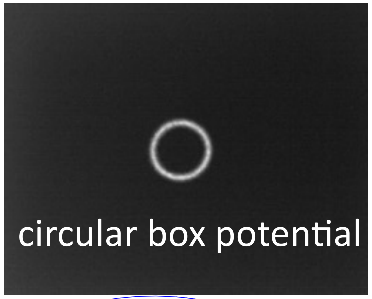
a) Accomplishments versus goals

- ● Secondary science targets identification and preliminary requirements
- ● Construction of the source experiment setup
- ○ Experimental work was not completed due to Covid19 lockdown, but instead, we looked into more analysis of the atom source scheme and measurement schemes.

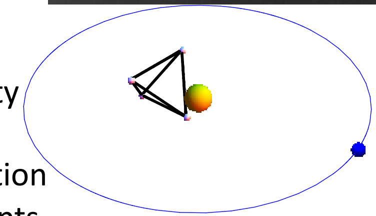
b) Significance. In the first-year effort, we explored different approaches to tackle the PDE convergence challenges in the presence of nonlinear terms and its sensitivity to boundary conditions. In the second year, we established a finite difference method that allows exploring the real solar system problem, both in 2- and 3-body scenarios, and investigate the impact of a third body to the dark energy screening effect. In the third year, we progressed on tackling major technical challenges that were identified in the earlier years, and investigated feasible secondary science objectives. Both developments enhanced the measurement validation and feasibility of the dark energy mission.

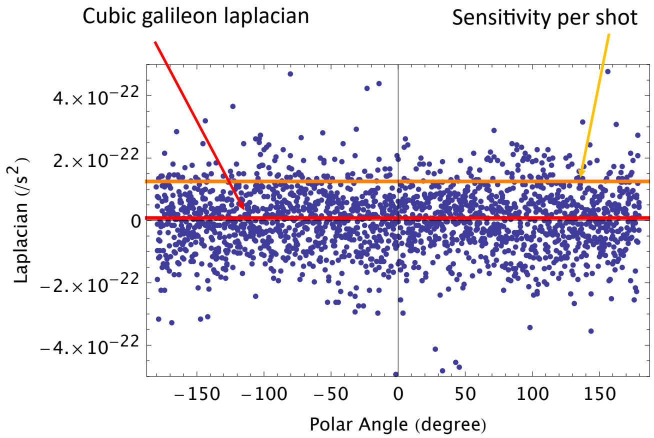
c) Next step. Continue maturation of the mission concept in the upcoming NIAC Phase II study





Suppression of gravity signals with the tetrahedral constellation for trace measurements.





Publications and References

PUBLICATION

N. White, S. Troian, J. Jewell, C. Cutler, S.-w. Chiow, and N. Yu, "Robust numerical computation of the 3D scalar potential field of the cubic Galileon gravity model at solar system scales," *Physical Review D* **102**, 024033 (2020).

REFERENCES

[1] Jeremy Sakstein. “Tests of gravity with future space-based experiments.” *Physical Review D* **97**, 064028 (2018).

[2] E. V. Pitjeva. “Determination of the Value of the Heliocentric Gravitational Constant (GM#) from Modern Observations of Planets and Spacecraft.” *Journal of Physical and Chemical Reference Data* **44**, 031210 (2015).