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Voyage 2050 white paper: The local dark sector

Joel Bergé

Voyage 2050 white paper

The local dark sector

Probing gravitation's low-acceleration frontier and dark matter in the Solar System neighborhood

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Gravitation's potential—curvature plane

The Astrophysical Journal, 802:63 (19pp), 2015 March 20 Baker, Psaltis, & Skordis

magnitude of the Newtonian gravitational potential,

$$\epsilon \equiv \frac{GM}{rc^2}.$$

We will measure the approximate magnitude of the Riemann curvature tensor through the Kretschmann scalar $(R^{\alpha\beta\gamma\delta}R_{\alpha\beta\gamma\delta})^{1/2}$. The Kretschmann scalar for the Schwarzschild metric is

$$\xi = \left(R^{\alpha\beta\gamma\delta}R_{\alpha\beta\gamma\delta}\right)^{1/2} = \sqrt{48}\,\frac{GM}{r^3c^2}. \qquad (2)$$

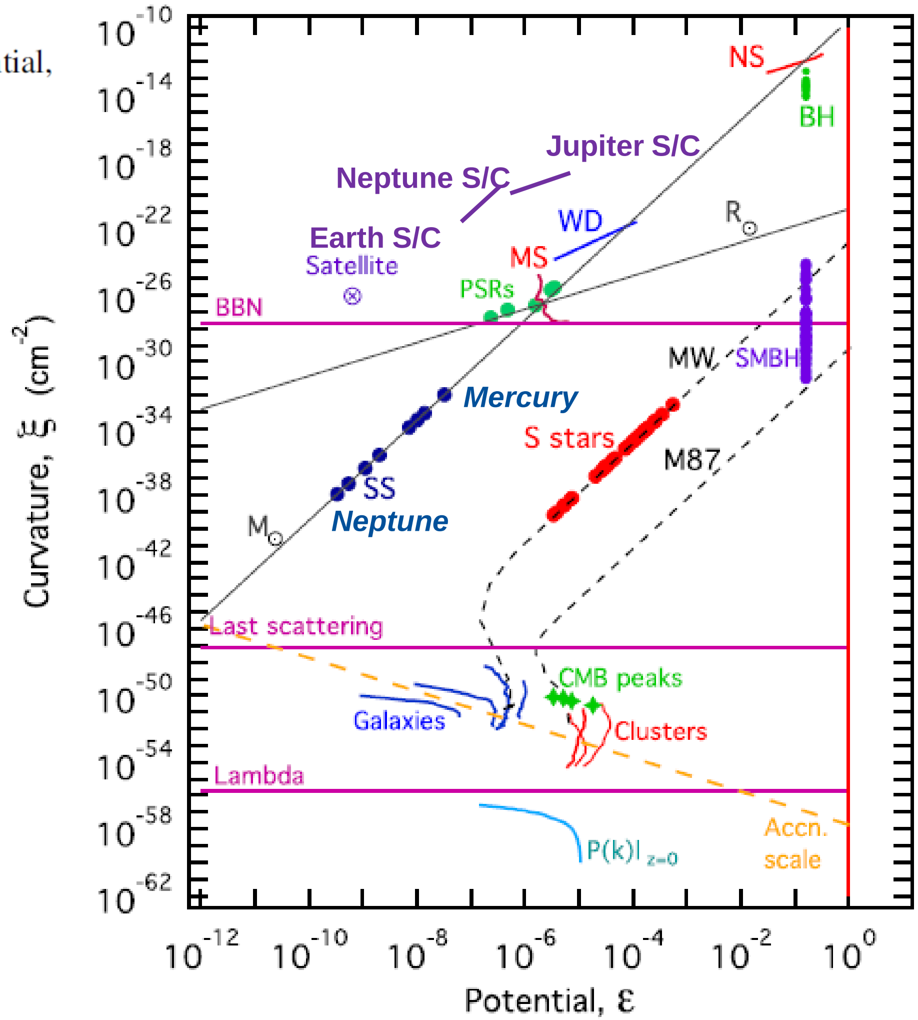

Figure 1. A parameter space for gravitational fields, showing the regimes probed by a wide range of astrophysical and cosmological systems. The axes variables are explained in Section 2 and individual curves are detailed in Section 3. Some of the label abbreviations are: SS—planets of the Solar System, MS—Main Sequence stars, WD—white dwarfs, PSRs—binary pulsars, NS—individual neutron stars, BH—stellar mass black holes, MW—the Milky Way, SMBH—supermassive black holes, BBN—Big Bang Nucleosynthesis.

Gravitation's low acceleration regime

THE ASTROPHYSICAL JOURNAL, 802:63 (19pp), 2015 March 20 BAKER, PSALTIS, & SKORDIS

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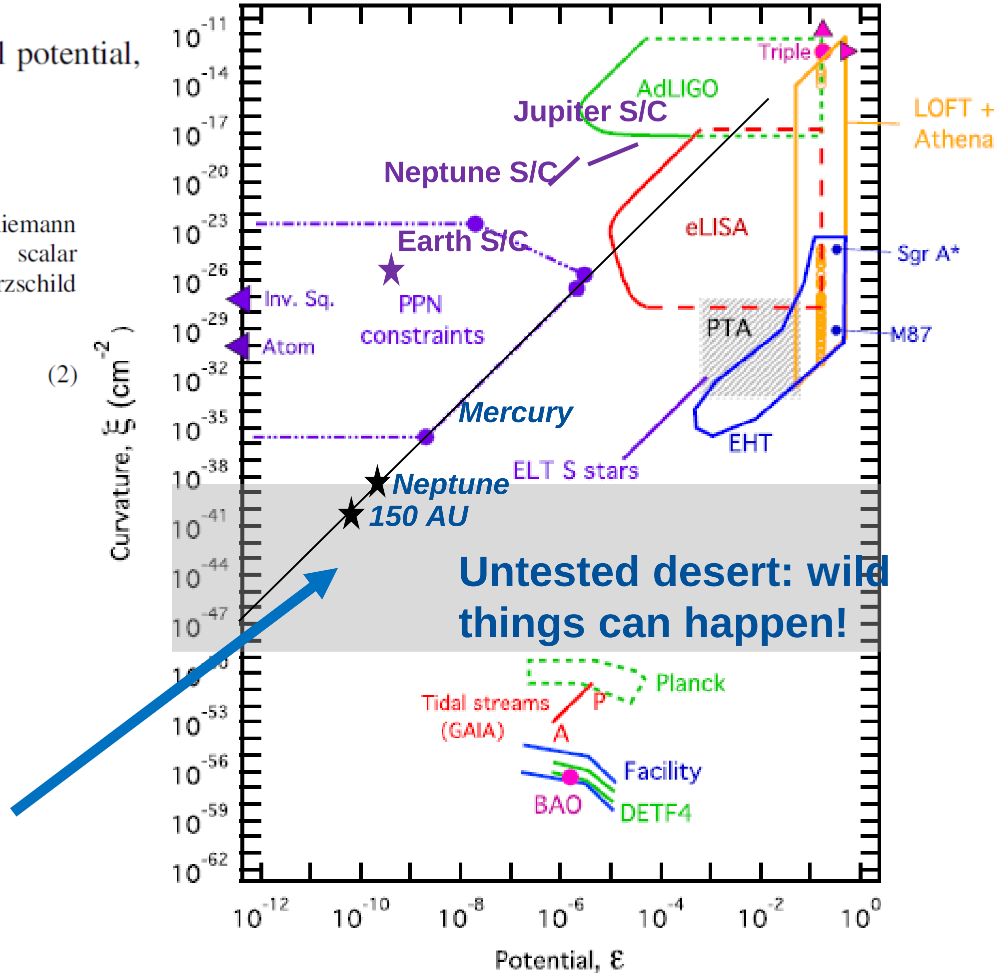

Transition from GR to beyond-Einstein?

Figure 2. The experimental version of the gravitational parameter space (axes the same as in Figure 1). Curves are described in detail in the text (Section 4). Some of the abbreviations in the figure are: PPN—Parameterized Post-Newtonian region, Inv. Sq.—laboratory tests of the $1/r^2$ behavior of the gravitational force law, Atom—atom interferometry experiments to probe screening mechanisms, EHT—the Event Horizon Telescope, ELT—the Extremely Large Telescope, DETF4—a hypothetical "stage 4" experiment according to the classification scheme of the Dark Energy Task Force (Albrecht et al. 2006), Facility—a futuristic large radio telescope such as the Square Kilometre Array.

Dark matter direct searches

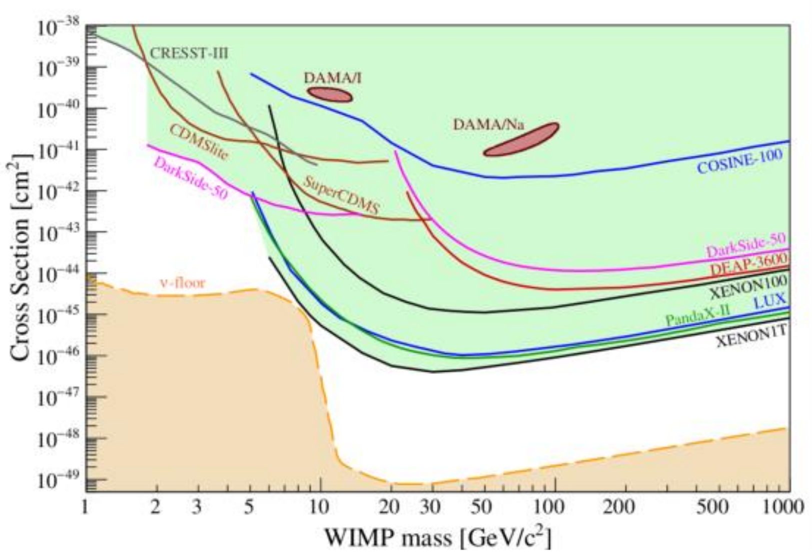

Figure 3: Current limits on spin-independent WIMP-nucleon scattering experiments (Abdelhameed et al. 2019; Agnese et al. 2016; Agnes et al. 2018; Agnese et al. 2018; Bernabei et al. 2018; Adhikari et al. 2018; Ajaj et al. 2019; Aprile et al. 2016; Akerib et al. 2017; Cui et al. 2017; Aprile et al. 2016, 2018). The orange shaded region represents the neutrino floor from the irreducible background from coherent neutrino-nucleus scattering. Figure from Schumann (2019).

DM local density

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = N_N \frac{\rho_0}{m_w} \int_{v_{\min}}^{v_{\max}} \mathrm{d}\mathbf{v}\, f(\mathbf{v}) v \frac{\mathrm{d}\sigma}{\mathrm{d}E_R}$$

Need to know local DM density to infer constraints on DM particles' characteristics

Numerical simulation may not be precise enough => direct measurement

A mission out of the Solar System

- Go to 150 AU (low acceleration regime)
  - Current propulsion techniques: 25+ years
  - Breakthrough Starshot's laser propulsion: 2-3 years
- Clock (PHARAO)
  - Direct measure of gravitational potential
  - Sensitive to DM clumps
- On-board accelerometer + S/C tracking (ONERA's)
  - Precise knowledge of non-gravitational accelerations
  - Precise measure of S/C trajectory / comparison with GR expectation
  - Sensitive to DM distribution
  - Mature technology: CHAMP, GRACE, GOCE, MICROSCOPE
  - Possibility to have a cold atom accelerometer

ONERA's GAP: MicroSTAR + bias rejection system

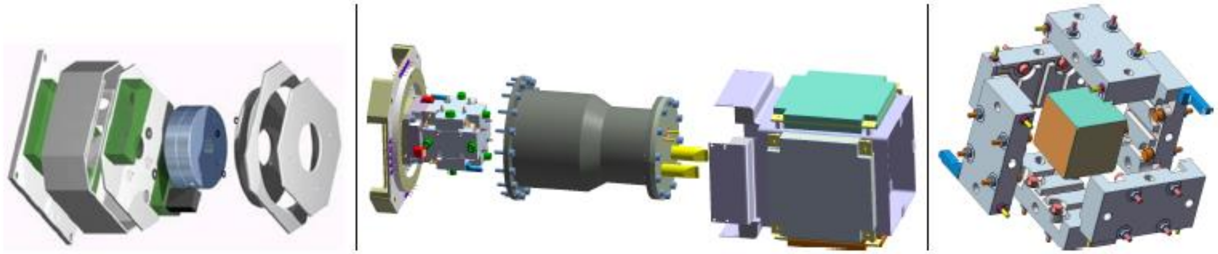

Figure 5: GAP DC accelerometer. *Left*: Bias Rejection System. *Center*: Exploded view of MicroSTAR accelerometer. *Right*: Exploded view of MicroSTAR's test mass in its cage.

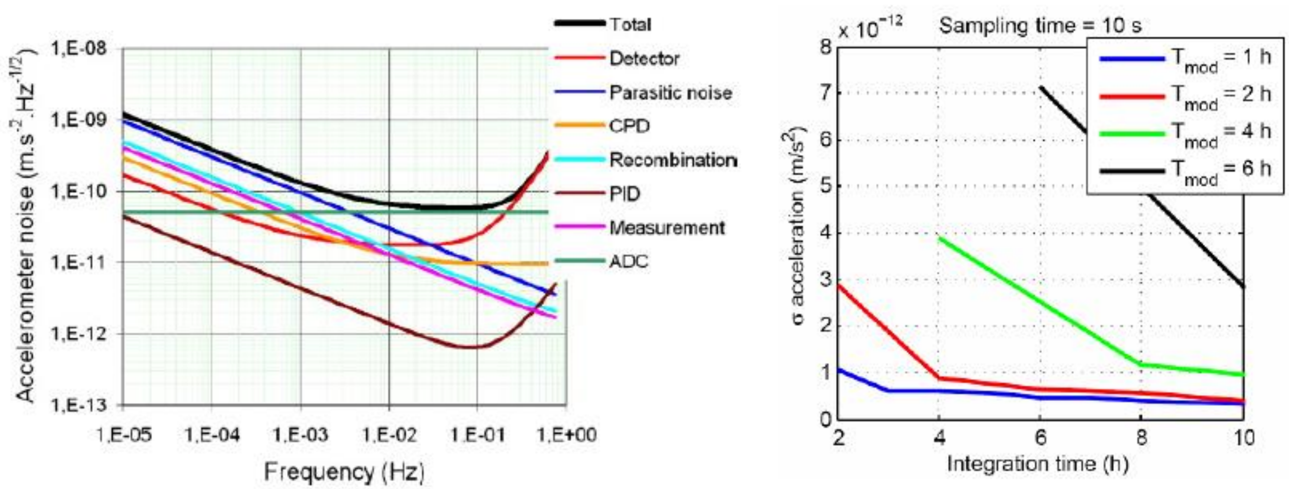

Figure 6: Current GAP performance. *Left*: MicroSTAR's noise. *Right*: Bias rejection system's resolution.