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WP-AION-PHYSICS

WP-AION-Physics

Three focus areas:

+ First physics exploitation with AION-10 & AI Networking

+ Phenomenology of strontium Atom Interferometry

+ Theory/Phenomenology of AION Physics Case

AION-10 Physics Exploitation & AI Networking

High Level Task List:

- Physics exploitation of AION-10 and physics link with WP-AION-100 and WP-MAGIS
  - What physics can we do with AION-10
  - What are the requirements for AION-100
  - What are physics lings with MAGIS-100
- Physics of the AI Networks
  - Links with network implementation in WP-AION-100
  - Links with network options with MAGIS-10/100
- Preparation of Physics Case for future funding application – AION-100.lonk
  - Link with other tasks in the WP and beyond

Phenomenology of Strontium AI

High kevel Tasks List

- Solve Schrodinger equation for external and internal dynamics of atoms propagating through fields of AI and interacting with laser pulses
- Investigate effects of imperfect detuning & intensity, timing jitter, pointing jitter, wavefront distortion, phase noise, magnetic noise, gravity noise, vibrations, rotations, temperature fluctuations, velocity & spatial distribution, collisional shifts…
- Design matter wave lenses and investigate sensitivity to imperfections
- Determine best parameters for launching into interferometer with minimal heating
- Determine effectiveness of methods for high-fidelity momentum transfer between atoms and light. Implement a quantum optimization algorithm and use it to find the most effective pulse-sequence for practical constraints.
- Find parameters that optimize AI sensitivity, subject to realistic constraints, and specify the key design requirements of a long-baseline AI.
- Understand constraints on phase-space density achievable by laser cooling, including effects of photon re-scattering, interatomic collisions etc. Design apparatus to deliver highest flux of quantum degenerate Sr atoms.
- Determine effectiveness of spin squeezing methods, including cavity and Rydberg methods. Model spin squeezing, optimize squeezing protocol. Evaluate compatibility with transport, launch, and delta-kick lensing methods.

AION Physics Case

Dark Matter

- Ultra-light bosons with masses in the range 10^-22 to 1 eV are motivated in many extensions of the Standard Model, e.g., axion-like particles, ultra-light scalar fields such as moduli, dilatons or radions and ultra-light hidden vector bosons. In the context of dark matter.

- Could have correct dark matter and are consistent with theory of structure formation, which demands that dark matter should be 'cold'.

- AION will be sensitive to the frequency band between 10 and 0.01 Hz, i.e., bosons in the range 10^-16 to10^-13 eV, complemeningt torsion-balance, atomic co-magnetometer and atomic spectroscopy experiments.

Theoretical tasks related to light dark matter include:

- Understanding the synergies between dark matter searches in this mass range and other astrophysical and cosmological observations.
- Exploring the synergies between AION and other laboratory probes of ultra-light bosonic dark matter.
- Showing how to identify unambiguously dark matter as the origin of a signal in AION, rather than a signal from, e.g., time-varying physical parameters or GWs, and extract the dark matter properties from the signal.

AION Physics Case

Gravitational waves

- Near term: LIGO, Virgo and KAGRA @ frequencies ~ 10 Hz to KHz range.
- Longer term: LISA @ frequencies below ~ 0.01 Hz, 3ird-generation ground instruments such as Einstein Telescope @ ~ 1Hz to few kHz, on a similar timeline.
- The mid-frequency band between 10 and 0.01 Hz interesting: GWs from phase transitions in early universe; track astrophysical sources evolving from LISA range towards LIGO/Virgo/KAGRA range; new intermediate-mass BH sources.
- AION would complement MAGIS, just as Virgo complements LIGO.

Theoretical tasks related to mid-frequency GWs include:

- Calculating mid-frequency GW signatures of cosmological phase transitions, e.g., at the electroweak scale, and relating them to collider signatures of possible extensions of the Standard Model.
- Understanding synergies of multiband GW astronomy combining GW searches in this frequency range with LISA, LIGO/Virgo/KAGRA & other astrophysical observations, e.g., for predicting timing, directions & distances of future merger events.
- Novel tests of the strong-gravity regime via, e.g., accurate timing of the GW phase evolution, that are not accessible with ground-based interferometers and LISA alone.
- Modelling astrophysical sources whose GWs peak in mid-frequency range, e.g., intermediate-mass BHs (seeds for supermassive BHs observed today), providing insight into their evolution and their host galaxies.

AION Physics Case

Beyond dark matter and gravitational waves

Ultra precision interferometry may also be sensitive to other phenomena beyond dark matter and GWs, and we also propose exploratory studies of such possibilities, including:

Exploratory theoretical tasks

- The possibility of detecting the astrophysical neutrinos that traverse the Earth with high flux though very small cross-section and tiny momentum;
- Precise interferometry may also be relevant for understanding long-range fifth forces, and it remains to be clarified whether AION (or a similar set-up) may play a role in constraining these scenarios.

Crude Budget Estimate

- Each high-level task in this WP with have one FTE over 3 years assigned.
- Therefore, assuming 100K/year for an RA the total budget of this WP would be:

FTE:
3 RA x 3 years x £100K = £900K
Travel
3 x 15K/year = £45K

Total £945K