Detection of Relic Gravitational Waves and Rotation of the Universe via 1-microarcsecond Triangulation of the Sky

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Short gravitational waves

- Orbiting binary stars, supernova explosions, coalescence of binary neutron stars and encounters of stars in dense clusters generate tensor metric perturbations (gravitational waves) propagating away from the source
- They result in radial and transverse deflection of light rays from background sources
- GRT predicts negligibly small astrometric effects from predictable sources of GW in the Galaxy
- Future facilities LISA and BBO hold best prospects for detection of short GW
Relic GW

- Models of early Universe predict long-wavelength gravitational radiation background, e.g. inflation or anisotropic phases
- Different modes of polarization and power spectrum can be present today, with energy density up to $\Omega_{GW} h^2 \approx 10^{-9}$, none detected yet
- A plane monochromatic, linear-polarized GW propagating along the axis of a cylinder of test particles changes its shape, and bends light rays from distant sources in the transverse directions

\[ g = h \cos \omega t (xx - yy) \]
Proper motions induced by long waves

- Distant sources (quasars) in the transverse directions to the wave vector are displaced from their “true” positions
- Instantaneous angular displacement is not observable but it changes periodically with time as the wave propagates which can be measured as “proper motion”

\[
\tilde{\mu} = \frac{1}{2} \sigma h \sin \omega \tau \sin \theta (\cos 2\phi - \bar{m} \sin 2\phi)
\]
Vector spherical harmonic signatures of GW

- Because of the quadrupole nature of GW, \( \sim 80\% \) of power spectrum is carried by 2\(^{\text{nd}}\) order vector harmonics of the proper motion field.

\[
\vec{\mu} = \sum_{m=-1}^{1} E_1^m + \sum_{m=-1}^{1} \vec{T}_1^m + \sum_{m=-2}^{2} E_2^m + \sum_{m=-2}^{2} \vec{T}_2^m + \ldots
\]

- secular aberration
- residual rotation
- gravitational waves

Astrophysics 2020: Large space missions beyond the next decade
Triangulation of sky

- The ancient technique of angular triangulation can be brought to $\sim 1$ μas by modern interferometry
- 6 equidistant quasars make the simplest triangulation network
- $\sim 300$ quasars are needed to realize the broadband capabilities and reach sensitivities $\sim h_{GW} = 5 \cdot 10^{-13}$ at $\nu \leq 10^{-8}$ Hz
- Detection of GW from anisotropic phases in early Universe is probable in coherent spectral lines
Tentative design

- Two Michelson interferometers with articulating siderostats and mutually orthogonal baseline vectors, plus two guide interferometers to monitor attitude changes by locking on guide stars, tied into a rigid external metrology system
- Technology proven at JPL at ~100 pm for 1 hr, needed ~20 pm
GW energy density limits and sensitivity

- Planned missions LISA and BBO operate at high frequency modes that reentered the horizon well before the matter-radiation equality and before the Big Bang nucleosynthesis \((\log \nu \approx -11 \text{ Hz}, T \approx 1 \text{ Mev})\)
- A Space Triangulation mission (GIST) will probe the epoch of nucleosynthesis in both monochromatic and broad-band regimes

![Graph showing GW energy density limits and sensitivity with BB nucleosynthesis highlighted.](image-url)
Rotation of universe

- Global rotation (and rotational perturbations, curls) are plausible in many cosmological models, with interesting consequences
- Estimated present-day rotation range $10^{-13}$ rad/yr (very slow) to $10^{-10}$ rad/yr (very fast)
- GIST capability is in the middle of the range $\sim 5 \cdot 10^{-13}$ rad/yr, but…
- a local gyroscope frame is needed
- Rotation of Earth around the Sun and rotation of the Sun around the Galactic barycenter are natural Machian frames, but…
- remains to be seen if the first-order magnetic harmonic can be tied to a local gyroscope in a self-consistent way
Other astrophysical capabilities

- Detection of habitable rocky planets around M dwarfs and white dwarfs
- Weak microlensing jitter from free-floating planetoids and comets in open clusters
- Dark matter potential profile of the Galactic halo
- Masses of black holes in stellar binaries
- …