COSMIC PARALLAX
A NEW TOOL IN OBSERVATIONAL COSMOLOGY

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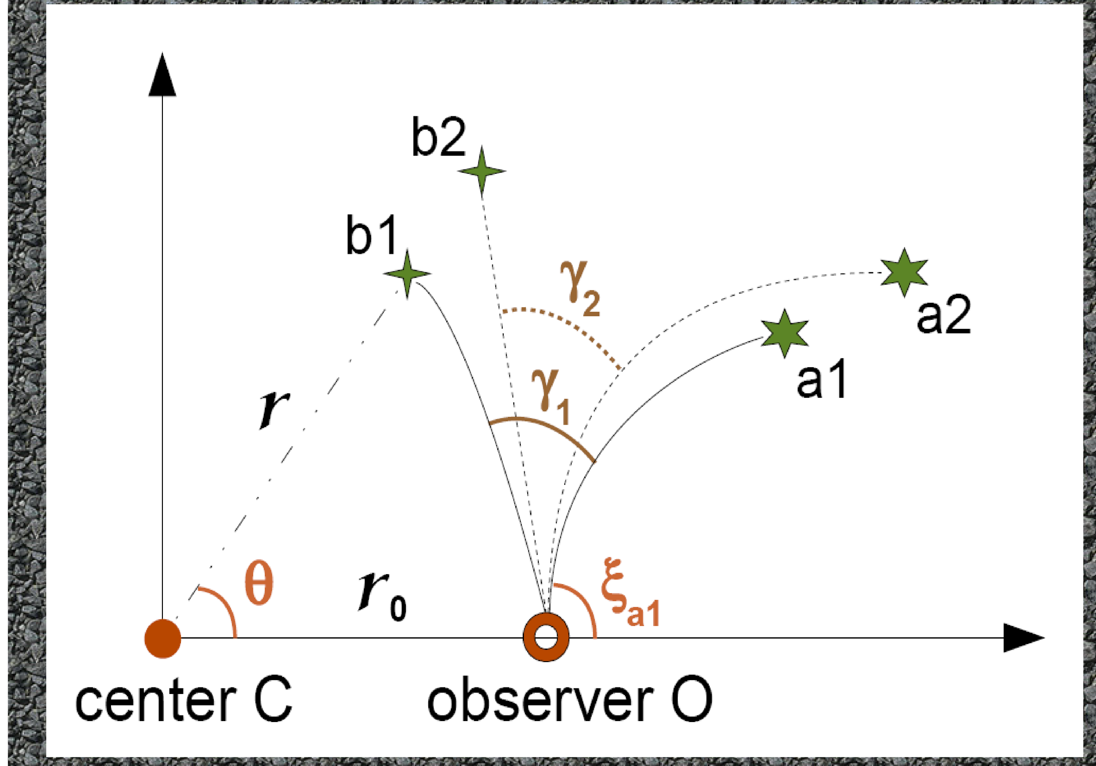
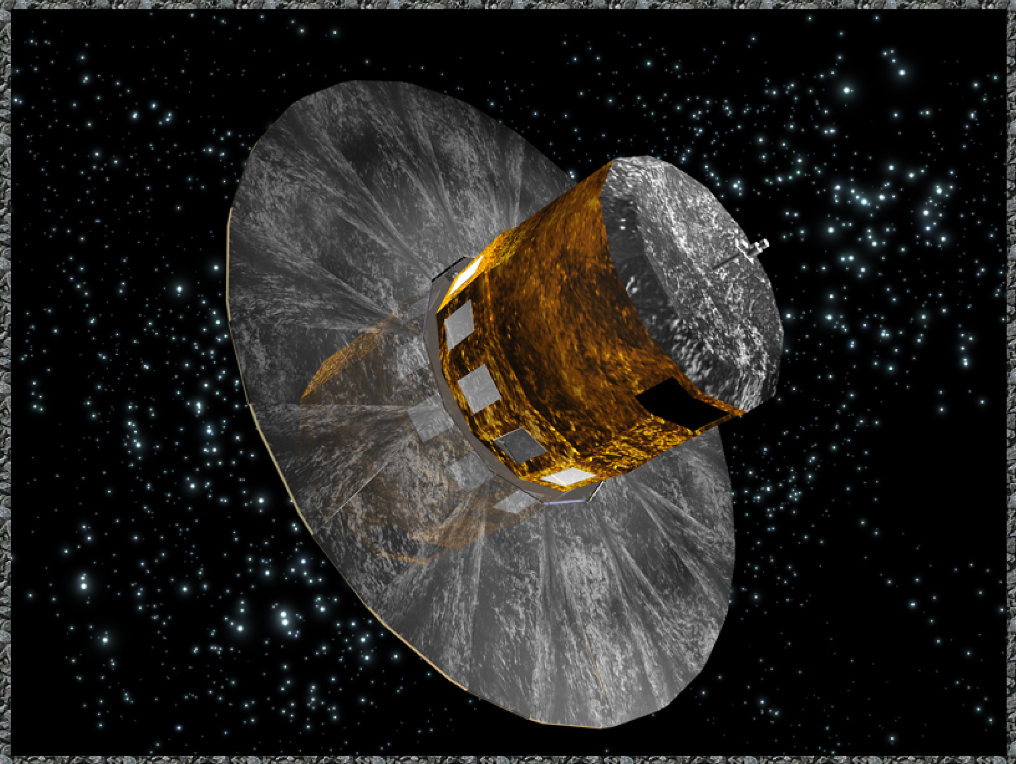


Figure 1: Overview, notation and conventions. Note that for clarity purposes we assumed here that the points C; O; a1; b1 all lie on the same plane. By symmetry, points a2; b2 remain on this plane as well. Comoving coordinates r and r0 correspond to physical coordinates X and X0.

Future satellite missions such as GAIA will achieve astrometry measurements with an accuracy of about 10 µas (microarcseconds) for bright sources; other satellite proposals aim at 1 µas. We show in this paper that such refined measurements allow us to detect large-scale deviations from isotropy through real-time observations of changes in the angular separation between sources at cosmic distances. We also show that this cosmic parallax effect is a powerful consistency test of Friedmann-Robertson-Walker metric and may set very strong constraints on alternative anisotropic models like Lemaître-Tolman-Bondi cosmologies with off-center observers.

We will refer to (t, r, θ, ϕ) as the comoving coordinates with origin on the center of a spherically symmetric model (see Figure 1). Peculiar velocities apart, the symmetry of such a model forces objects to expand radially outwards, keeping r, θ and ϕ constant.

In a FRW metric, $\Delta\gamma \equiv \gamma_2 - \gamma_1 = 0$ (see Figure 1). In any anisotropic metric, however, $\Delta\gamma \neq 0$, and we have **cosmic parallax**. In such cases, FRW-like estimates can give a reasonable prediction of the magnitude of this effect.



Artist conception of the ESA **GAIA** mission satellite. Expected launch date: Dec 2011. GAIA expects to perform astrometric measurements of some **500,000** distant quasars.

FRW-Like estimates for pair of sources at (i) the same redshift and (ii) same position in the sky.

$$X \equiv a(r,\, t_0)\, r \qquad s \equiv X_0/X$$

$$\Delta\gamma_\theta = 2\, s \cos\theta (H_0 - H_r)\Delta\theta\Delta t$$

$$\Delta\gamma_z = s\sin\theta\left[\frac{dH_r}{dX}\frac{1}{H(r,z)} + \frac{H_0 - H_r}{X H(r,z)}\right]\Delta z\Delta t$$

Peculiar velocity noise is **not** overwhelming.

$$\Delta\gamma_{\rm pec} = \left(\frac{v_{\rm pec}}{1000\,\frac{\rm km}{\rm s}}\right)\left(\frac{D_A}{1\,{\rm Gpc}}\right)^{-1}\left(\frac{\Delta t}{10\,{\rm years}}\right)10^{-11}\,{\rm rad}$$

The general LTB metric

$$ds^2 = -dt^2 + \frac{[R'(t,r)]^2}{1+\beta(r)}dr^2 + R^2(t,r)d\Omega^2$$

LTB metric for a matter dominated universe

$$R = (\cosh\eta - 1)\frac{\alpha}{2\beta} + R_{\rm lss}\left[\cosh\eta + \sqrt{\frac{\alpha+\beta R_{\rm lss}}{\beta R_{\rm lss}}}\sinh\eta\right]$$

$$\sqrt{\beta}t = (\sinh\eta - \eta)\,\frac{\alpha}{2\beta} + R_{\rm lss}\left[\sinh\eta + \sqrt{\frac{\alpha+\beta R_{\rm lss}}{\beta R_{\rm lss}}}(\cosh\eta - 1)\right]$$

The Alnes et al. [1] class of LTB models. We considered 2 such models, basically differing by the value of Δr.

$$\alpha(r) = \left(H_0^{\rm out}\right)^2 r^3\left[1 - \frac{\Delta\alpha}{2}\left(1 - \tanh\frac{r - r_{\rm vo}}{2\Delta r}\right)\right]$$

$$\beta(r) = \left(H_0^{\rm out}\right)^2 r^2\,\frac{\Delta\alpha}{2}\left(1 - \tanh\frac{r - r_{\rm vo}}{2\Delta r}\right)$$

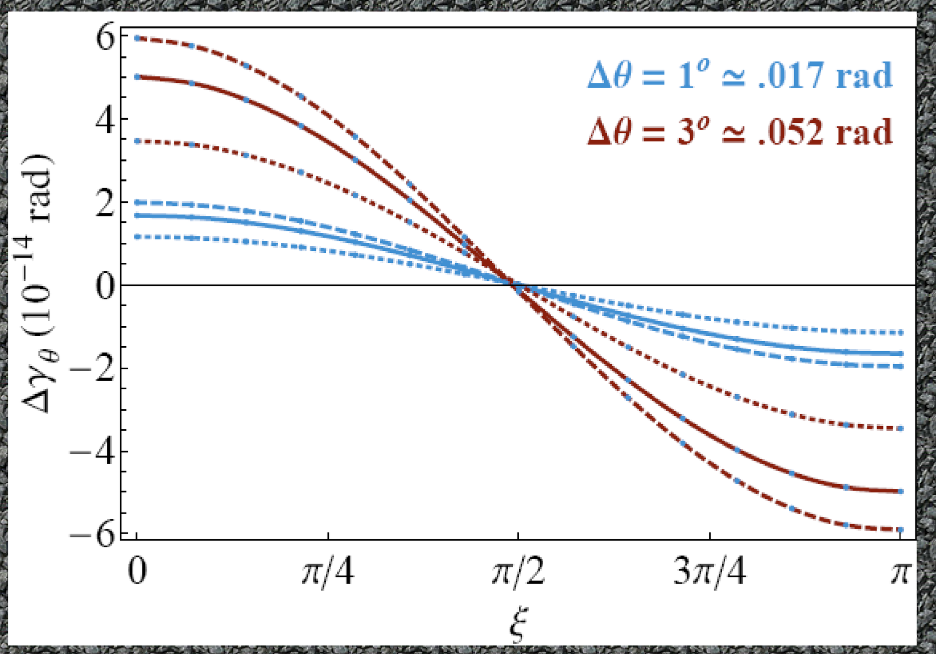


Figure 2: Δγ for three sources at the same shell, at z = 3, for both models I (full lines) and II (dashed), and the FRW-like estimate (dotted). The dark, red lines correspond to a separation Δθ of 3°, while the light, blue lines represent a separation of 1°. As expected, Δγ is linear in Δθ.

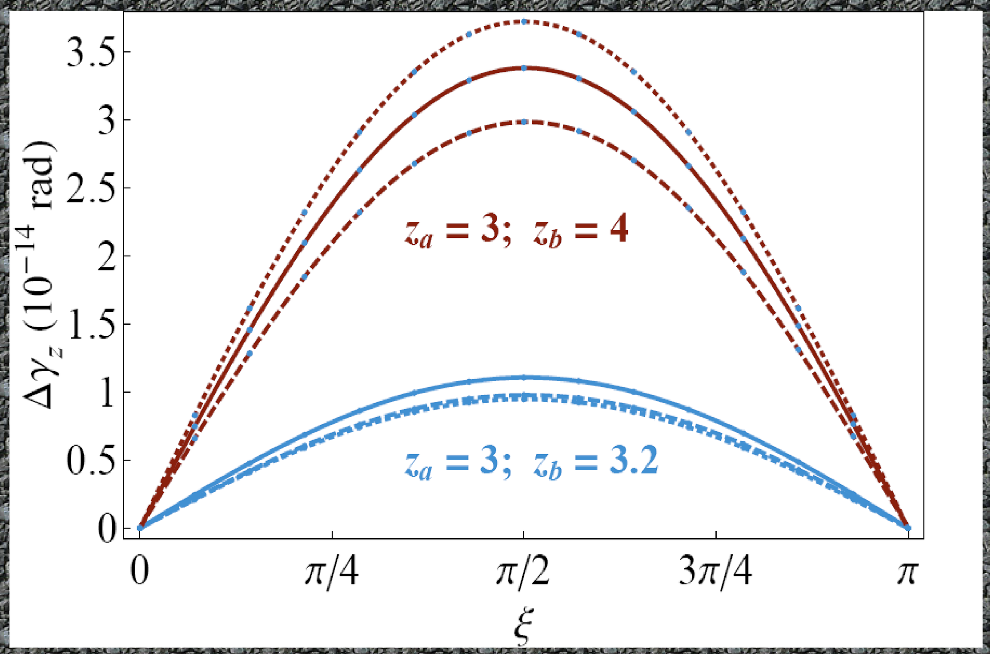


Figure 3: Same as Figure 2 but for Δθ = 0 and redshift pairs {3, 3.2} (lighter, blue lines) and {3, 4} (darker, red lines).

Plots for an off-center distance of 15 Mpc

The cosmic parallax effect can be combined with measurements of the time-drift of the redshift of the sources [3], to fully reconstruct the 3D cosmic flow of distant sources [4].

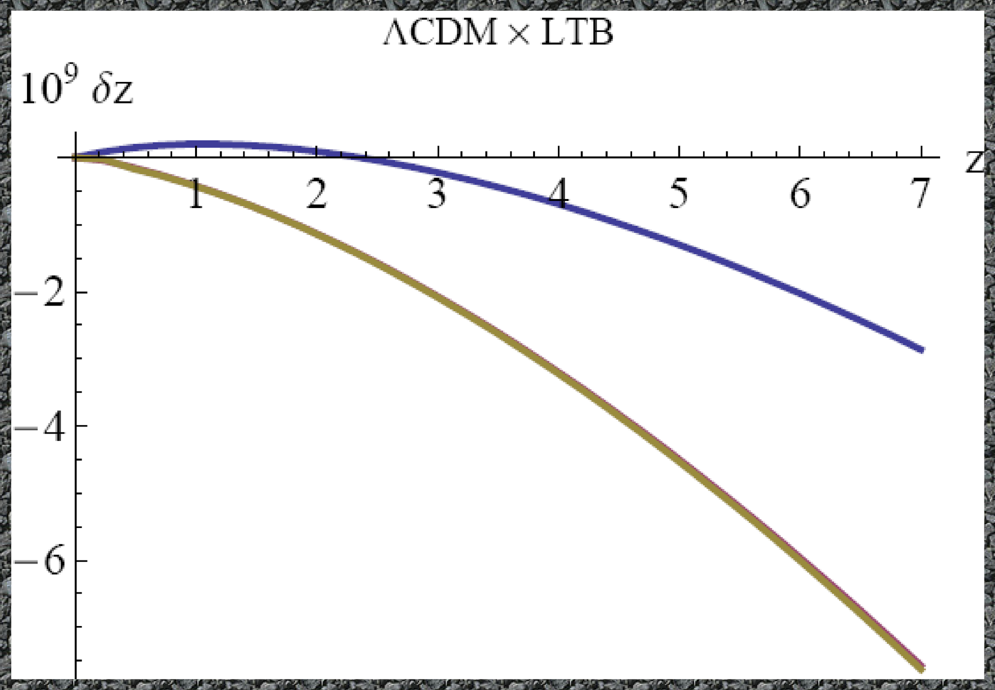


Figure 4: Time-drift of redshift in ΛCDM (upper, blue curve) and in both LTB models (lower, superimposed curves), for a time interval of 10 years. The drift is **much more proeminent in an LTB model** [4]. The angle dependence of δz in ξ is only marginal, so the effect is almost isotropical. Note the **insensitivity to the specifics of the LTB model**.

Conclusions:

* Parallax effects, i.e. the apparent change in position of an object relative to the observer, are among the simplest and historically more important method to measure astronomical distances;
* The cosmic parallax of quasars and other distance sources in a LTB model **is withing observable reach** of some planned near-future mission such as GAIA;
* Cosmic parallax is a tool to measure cosmic anisotropy, and as such can distinguish FRW from other metrics as well, such as some Bianchi ones.
* In an off-center LTB model, cosmic parallax can be an **1+ order of magnitude better probe** of off-center distance than the current best: the CMB dipole [1];
* Cosmic parallax **avoids 2 intrinsic limitations** of the CMB dipole effect:
  1. It cannot be completely countered by the observer's own peculiar velocity;
  2. Limitation by cosmic variance.
* Combined with a measurement of the time-drift of redshift [3], cosmic parallax can in principle fully reconstruct the 3D cosmic flow of distant sources.

References:

[1] Havard Alnes & Morad Amarzguioui, Phys. Rev. D74 (2006) 103520.
[2] Claudia Quercellini, Miguel Quartin & Luca Amendola, arXiv: 0809.3675v1
[3] Jean-Philippe Uzan, Chris Clarkson & George F.R. Ellis, Phys. Rev. Lett. **100** 191303 (2008).
[4] Miguel Quartin and Luca Amendola, in preparation.

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