A complete sample of gravitationally lensed quasars to be detected with GAIA

presentation given by J. Surdej[*], J.-F. Claeskens[*] and A. Smette[*]
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Abstract: Assuming that onboard data analysis or selected data transmission to the ground will enable to identify quasars showing a complex structure within a field of 3", GAIA observations will lead to the detection of a complete sample of more than 3,500 (resp. 2,000) gravitational lenses among optical quasars down to the limiting magnitude V = 21 (resp. V = 20). These brightest multiply imaged quasars distributed all over the sky will offer unique tools for decisive astrophysical and cosmological applications, including reliable and independent constraints on the cosmological parameters Ω_0 and λ_0.

Given the angular resolution and dynamical range of GAIA in its direct imagery mode, we may wonder how many gravitational lenses could be discovered among quasars down to a limiting magnitude V = 20 - 21 over the whole sky (41253 square degrees)?

To answer this question and for sake of simplicity, we model the foreground galaxies as Singular Isothermal Sphere (SIS) lenses, and assume a population of galaxies made of 30% of E/S0 (σ^* = 225 km/sec, corresponding to a value of the efficiency parameter for macro-lensing F = 0.025) and of 70% of spiral (σ^* = 144 km/sec, F = 0.007; cf. Fukugita and Turner 1991).

Given a galaxy with luminosity L, corresponding to a value σ for its velocity dispersion (Tully-Fischer or Faber-Jackson), located at a redshift z_l, and under the conditions of a perfect alignment, a background quasar will be imaged as an Einstein ring having an angular diameter $2\theta_E = 8 \pi D_{ds} \sigma^2 / D_{os} c^2$. If the alignment is not perfect, the ring will break in two lensed images having an angular separation also equal to $2\theta_E$, whose magnitude difference Δm increases as the alignment between the observer, the lens and the source gets worse (but $\theta_S < \theta_E$).

Adopting a uniform cosmological distribution of lenses, the expected angular image separations for a quasar at redshift $z_q = 2$ take the shapes illustrated below (Figure 1).

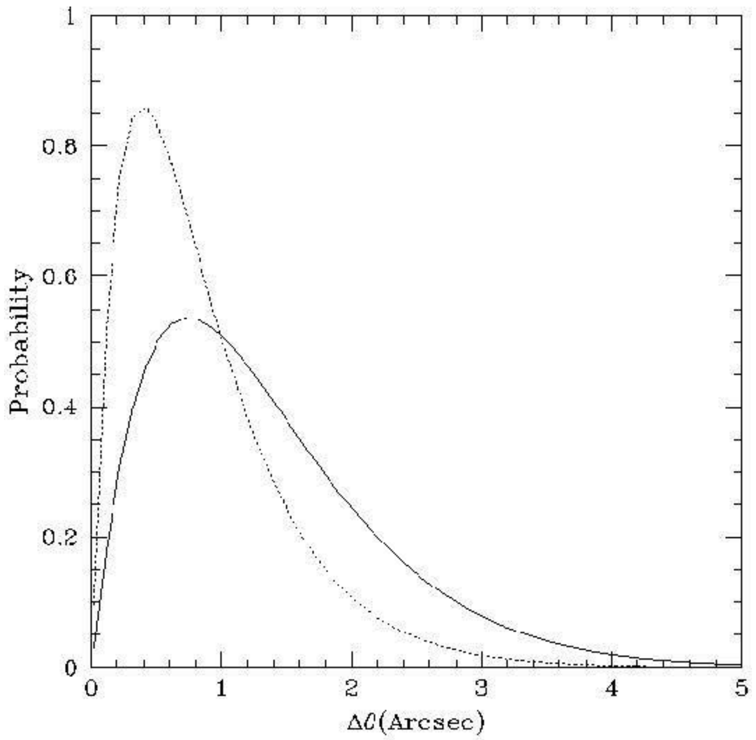

Figure 1: Probability distributions P(Δθ) for the angular separations Δθ expected between the multiple images of a quasar at $z_q = 2$, lensed by a cosmological population of SIS galaxies (dots = spiral ones, continuous line = elliptical ones)

Of course, GAIA is characterized by a limited angular resolution and dynamical range and will not be capable of resolving all double QSO images. Its angular selection function ASF is shown in figure 2 for different QSO V apparent magnitudes.

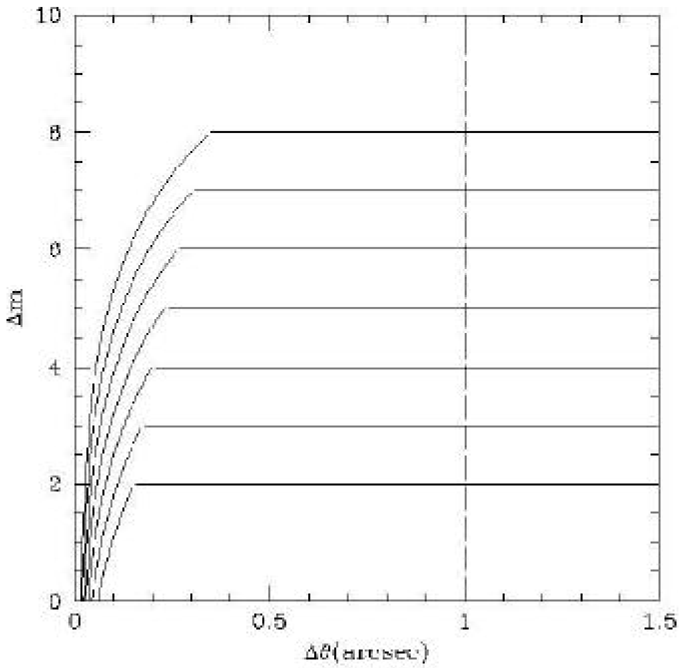

Figure 2: Angular Selection Function (ASF) of GAIA for different QSO V apparent magnitudes (from V=15 at the top down to V= 21). We have $\Delta m = \Delta m(\Delta\theta, V)$.

The lensing optical depth $\tau(\Delta m=\infty, \Delta\theta, b_q)$, or probability for a quasar to be imaged by a galaxy in two lensed images with an angular separation $\Delta\theta + d\Delta\theta$ is given by the expected number of such galaxies that are sufficiently well aligned between the source and the observer (taking into account all relative distances and luminosities L). This corresponds to the fractional number of galaxies expected in an effective volume between the observer and the source.

Given the ASF of GAIA, the real optical depth should be corrected as follows:

$$\tau(\Delta m(\Delta\theta),b_q) = \tau(\Delta m=\infty,\Delta\theta,b_q)\ \mathrm{Bias}(\Delta m(\Delta\theta),b_q),$$

where Bias represents the well known magnification bias.

Finally, integrating over all image separations $\Delta\theta_i$, we obtain:

$$\tau_{tot}(b_q) = \sum P(\Delta\theta_i)\ \tau(\Delta m(\Delta\theta_i),b_q)\ \Delta\theta_i,$$

and the total number of expected multiply imaged quasars is then found to be

$$N_L = \sum \tau_{tot}(b_{qj})\, N_q(b_{qj})\, 41253$$

where (Boyle et al. 1988)

$$N_q(b_q) = 10\ 10^{0.86}(b_q\text{-}19.15) \quad \text{if } b_q < 19{,}15, \text{ and}$$
$$N_q(b_q) = 10\ 10^{0.28}(b_q\text{-}19.15) \quad \text{if } b_q > 19{,}15.$$

In our calculations, we have considered the case of a quasar with $z_q = 2$ and B-V = 0.3.

As illustrated in Figure 3, the total optical depth τ decreases with larger V mag. of quasars because the magnification bias decreases and that the dynamical range of GAIA also becomes less favourable (equal to zero above V = 23).

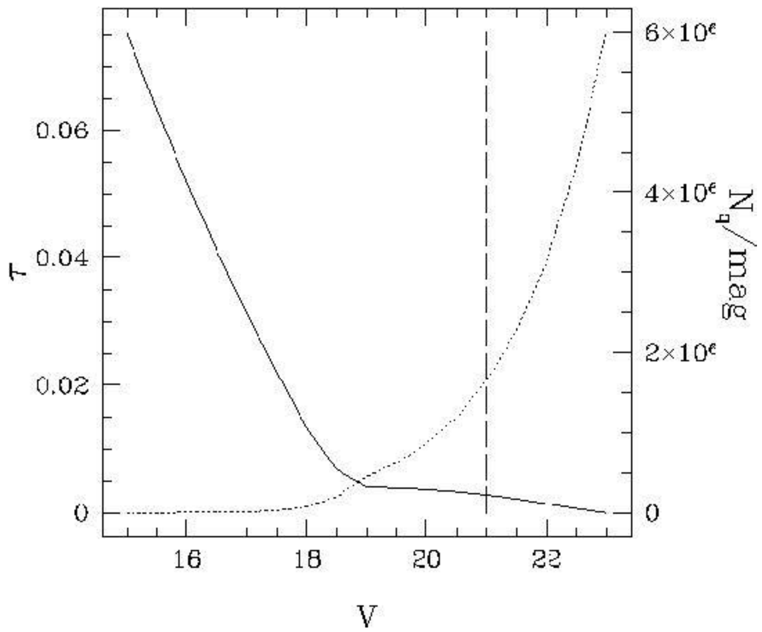

Figure 3: Optical depth τ for macro-lensing (left ordinates) and number of QSOs per mag. bin as a function of their V apparent magnitude (right ordinates).

CONCLUSIONS

As illustrated in Fig. 4, approximately 3,500 multiply imaged quasars ought to be detected with GAIA over the whole sky for V < 21, $\Delta\theta$ < 3" and the less favourable Universe with $\Omega_0 = 1$, $\lambda_0 = 0$. This represents 96% of the total number of expected lenses. If the field of view is further reduced to 2" or 1", only 83% or 46% of these will be detected, respectively. As expected, the contribution due to E/S0 galaxies remains the most important one.

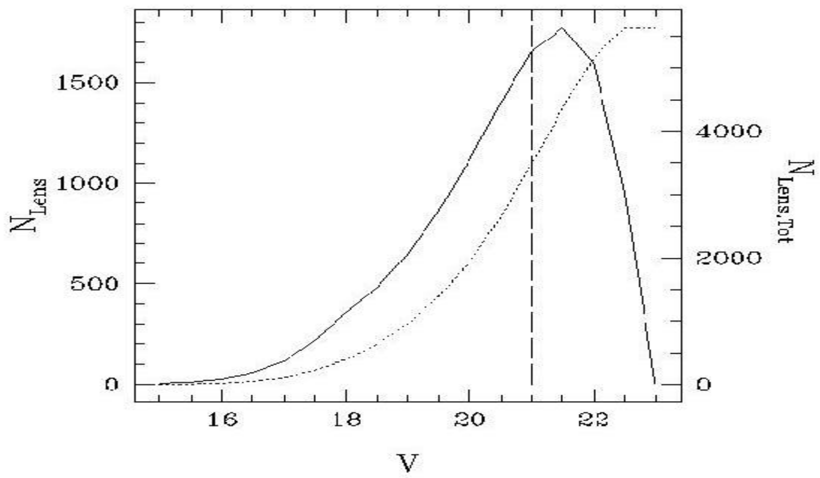

Figure 4: Number of lenses expected per magnitude bin (left ordinates) and integrated number of lenses (right ordinates) which ought to be detected with GAIA as a function of the V limiting magnitude in a Universe with $\Omega_0 = 1$, $\lambda_0 = 0$.

In a Universe with $\Omega_0 = 0$, $\lambda_0 = 1$, we find that the total number of multiply imaged quasars gets 13 times larger. All these results are of course independent on H_0.

Based upon the analysis of the image structure (multiple and variable point-like components) of the available sub-images transmitted by GAIA, it should be easy to identify most of multiply imaged quasars.

From the observed fraction of gravitational lenses identified among quasars as a function their V apparent magnitude, GAIA thus offers high prospects to very efficiently and independently constrain the values of cosmological parameters.