SEPARATING INTRINSIC AND MICROLENSING VARIABILITY USING PARALLAX MEASUREMENTS

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1. Introduction

In gravitational lens systems with 3 or more resolved images of a quasar, the intrinsic variability may be unambiguously separated from the microlensing variability through parallax measurements from 3 observers when there is no relative motion of the lens masses (Refsdal 1993). In systems with fewer than 3 resolved images, however, this separation is not straightforward. For the purpose of illustration, I make the following simplifications for the one-dimensional case: The observations consist of well-sampled time series of the observed flux $F_{\mathbf{A}}(t_i)$ and $F_{\mathbf{B}}(t_i)$ at two points in the observer plane. The separation vector of the two points is parallel to the direction of the transverse motion of the source-lens-observer system, and the distance $D_{\mathbf{AB}}$ between the observers is known. Furthermore, the distance $D_{\mathbf{AB}}$ is small compared to the typical length scale of fluctuations in the magnification $\mu(x)$.

It is possible to calculate the ratio of the instantaneous magnification at the two observers as a function of time, defined by

$$r(t_i) = F_{\mathbf{B}}(t_i)/F_{\mathbf{A}}(t_i) \tag{1}$$

where $F_{\mathbf{A}}(t_i)$ and $F_{\mathbf{B}}(t_i)$ are the observed fluxes at observer **A** and **B** respectively. I am assuming that observer **B** is the leading one.

With these assumptions, the magnification history $\mu_{\mathbf{A}}(t_i)$ for observer **A**, can be reconstructed (apart from boundary conditions) through the formula

$$\mu_{\mathbf{A}}(t_i) = \mu_{\mathbf{A}}(t_i - \Delta t) r(t_i - \Delta t) \quad \text{with} \quad \Delta t = \frac{D_{\mathbf{AB}}}{v_\perp} \tag{2}$$

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where $v_\perp$ is the unknown velocity perpendicular to the line of sight.

Given a velocity $v_\perp$, the microlensing magnification history $\mu_{\mathbf{A}}$ is uniquely determined, and thereby also the intrinsic flux, given by

$$F_{\mathbf{IA}}(t_i) = F_{\mathbf{A}}(t_i)/\mu_{\mathbf{A}}(t_i) \tag{3}$$

The velocity is chosen by minimizing some measure of the variability (e.g., χ^2) of $F_{\mathbf{IA}}$, given by $\chi^2 = \sum_{i=1}^{N}(F_{\mathbf{IA}}(t_i) - \langle F_{\mathbf{IA}}\rangle)^2$

2. Preliminary results

In order to test the method, dummy data for the intrinsic flux $F_{\mathbf{I}}(t_i)$ and the magnification $\mu(x_i) = \mu(v_\perp t_i)$ were made by simply filtering white noise, $N(t)$, with gaussian low-pass filters with characteristic scales $\tau_{\mathbf{I}}$ and τ_μ, and then exponentiating, e.g.:

$$\begin{aligned} F_{\mathbf{I}}(t) &= \exp(A_{\mathbf{I}}\Phi[N(t);\tau_{\mathbf{I}}]) \\ \mu(t) &= \exp(A_\mu\Phi[N(t);\tau_\mu]) \end{aligned} \tag{4}$$

where $\Phi[\ldots;\tau]$ denotes gaussian filtering with time scale τ, and then renormalization to make the variance equal to one. $A_{\mathbf{I}}$ and A_μ are the amplitudes of the intrinsic and microlensing variabilities, respectively. For simplicity, but without loss of generality, the units were chosen so that the "true" source-lens-observer transverse velocity $v_\perp$ and the characteristic scale of the magnification fluctuations $\tau_{\mathbf{I}}$ were equal to 1. The observations were simulated according to

$$\begin{aligned} F_{\mathbf{A}}(t_i) &= F_{\mathbf{I}}(t_i)\,\mu(v_\perp t_i) \\ F_{\mathbf{B}}(t_i) &= F_{\mathbf{I}}(t_i)\,\mu\left(v_\perp t_i + \frac{D_{\mathbf{AB}}}{v_\perp}\right) \end{aligned} \tag{5}$$

The flux ratio $r(t_i)$, the magnification history $\mu_{\mathbf{A}}(t_i)$ and the intrinsic flux $F_{\mathbf{IA}}(t_i)$ were calculated for a range of values for $v_\perp$. For a wide range of parameters, the χ^2 function is fairly well-behaved, with a quadratic minimum, although the minimum may be somewhat displaced compared to the true value of $v_\perp$. The most difficult cases seem to be those where $\tau_{\mathbf{I}} \approx \tau_\mu$ and $A_{\mathbf{I}} \gtrsim A_\mu$.

It is unclear how useful this method is for the two-dimensional case with two observers. This will be the subject of further study. The extension of the method to 3 observers in two dimensions is fairly straightforward. In cases where relative motion of the lensing point masses are important, only a partial separation will be possible.

References

Refsdal, S. 1993, in *Gravitational Lenses in the Universe*, eds. Surdej et al., Université de Liège, Belgium