THE TYCHO DATABASE
AS A CONTROL MICROLENSING EXPERIMENT

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Abstract

The amount of dark matter in the solar neighbourhood is a poorly constrained quantity which is nevertheless used to normalise the properties of the dark halo. While the current surveys towards the LMC, SMC and the Galactic bulge probe the dark matter content at large distances from the Sun, the HIPPARCOS satellite provides a unique way to constrain the dark matter within about 1 kpc. The TYCHO program observed about a million stars in two passbands down to a magnitude of about 12, all over the sky. The large number of observations taken during the 3 year mission make such a catalogue a useful probe to validate the microlensing technique to detect baryonic compact objects, since the results can be compared to the local dynamical constraints. We predict here that about 0.1 events could be present in the TYCHO database, but after extensive Monte Carlo simulations that take into account both temporal sampling and photometric errors, we find that the efficiency is only 9\% for typical events of 15 days, reducing the expected number of events to 0.01.

1 Dark matter in the solar neighbourhood

The detection, by means of the gravitational amplification of light, of invisible objects has ceased to be a dream\textsuperscript{3} to become a reality thanks to the efforts of a number of teams (see\textsuperscript{11} for a review). This technique may shed new light on the nature of dark matter, and is totally independent of more or less direct methods of detection. Hence it seems important to “calibrate” it by performing “control” experiments in volumes where the dynamical amount of dark matter is thought to be reasonably well constrained by a variety of methods, between about 46 to 90 $M_\odot$ pc$^{-2}$ (to be compared to the observed density in gas and stars which amounts to about 40 $M_\odot$ pc$^{-2}$). This is also important because so far the experiments towards both the LMC and the Galactic bulge have given surprising results. Here we suggest using the TYCHO database to test for the presence of microlensing events in the solar neighbourhood. This is the best control experiment to calibrate not only the other experiments, but also the theoretical predictions which use, as a normalisation, this local amount of dark matter\textsuperscript{3}. 
Table 1. Basic 3-component model for the solar neighbourhood

| Component | \( \rho_o \) | H | h | U | V | W | \( V_{\text{rot}} \) | a |
|-----------|----------------|---|---|---|---|---|----------------|---|
| Thin disc | 0.05 \( \text{M}_\odot \text{ pc}^{-3} \) | 300 | 3.0 | 35 | 25 | 25 | 220 | – |
| Thick disc | 0.002 \( \text{M}_\odot \text{ pc}^{-3} \) | 800 | 3.0 | 67 | 51 | 40 | 167 | – |
| Halo | 0.01 – – | – | – | 156 | 156 | 156 | 0 | 5.0 |

2 Predicting microlensing events in the TYCHO database

The TYCHO experiment has used the star mapper of the HIPPARCOS satellite to produce a photometric and astrometric catalogue over the full sky of about a million stars down to a magnitude of about 12 \([5]\). This is the first catalogue to contain measures of both northern and southern stars with the same instrument and a well defined colour system (quasi \(B\) and \(V\)), with over a hundred measures per star spanning the 36 months of data acquisition by HIPPARCOS \([5]\) \([14]\) \([4]\). The TYCHO experiment is thus an ideal database to look for possible microlensing signatures of lenses within the solar neighbourhood.

We have used an improved Monte Carlo code \([7]\) to estimate the microlensing properties of the solar neighbourhood. The thick and thin discs were modelled as double exponential discs, with properties as given in Table 1, derived from recent surveys \([10]\) \([13]\). The lenses are randomly distributed following the 3 components given in Table 1, while the sources are assumed to be essentially in the thin disc. Given the shallow depth of TYCHO, there was no need to include the bulge and spheroid components.

There are two main sources of uncertainty in the present analysis, in addition to the uncertainties in the dynamical properties of the sources.

- First, the actual optical depth depends on the luminosity function of the sources. The preliminary HR Diagram from HIPPARCOS \([12]\) markedly shows a maximum at about +4, along with a densely populated giant branch and clump at about +1. Given that the HIPPARCOS data are not yet available, we used the INCA catalogue \([2]\) restricting the analysis to the 1612 stars whose parallaxes are quoted with less than 20% error. The depth is comprised between 0.4 and 1 kpc with this approximate luminosity function at a limiting magnitude of 12.

- Second, the patchiness of the extinction is a severe problem that limits the accuracy of the predictions. We assume a uniform extinction of \(A_V = 1\) mag kpc\(^{-1}\) within a disc of thickness \(H_z=100\) pc, which is a bit larger than the usual 0.8 mag kpc\(^{-1}\), but in better agreement with the extinction maps of the solar neighbourhood \([3]\). The effect of extinction can be noted on Figs. 1 and 2, where the maximum optical depth and rate are not on the plane, but slightly above and below. Note also that the strong dependence with longitude is due to the fact that the sources are in the thin disc, and so the density is smaller in the anticentre direction.

The microlensing rate, averaged over the sky, is \(3.6 \times 10^{-8}\) events/year for 0.5 \(\text{M}_\odot\) lenses. Since during the 3 years of observations an average of 100 observations were taken per star, for a target number of a million stars, a total of 0.11 events can be expected\([1]\). Microlensing time scales averaged over the Earth’s motion are given in Fig. 3, where both the Sun’s motion with respect to the LSR and the orbital motion of the Earth were taken into account. They span the range from 8 to 50 days for a 0.5 \(\text{M}_\odot\) lens.

Monte Carlo error estimates for the optical depth, rate and time scales are 3–4 %, 5–6% and 6–7% respectively, hence the difference between neighbouring contours should not be taken too literally. Also the small spikes that appear at high \(|b|\) are a signature of the Monte Carlo noise only.

\(^1\)This is in sharp contrast to a previous analysis \([8]\) which only considered lenses arising from the halo.
Figure 1: Predicted angular dependence of the microlensing optical depth for the TYCHO database.

Figure 2: Predicted TYCHO microlensing event rate across the sky. Note the effects of extinction across the galactic disc.
Figure 3: Predicted microlensing time scales for TYCHO, ranging from 8 days to about 40 days, for a 0.5 $M_\odot$ lens.

Figure 4: Simulated microlensing event with the TYCHO time sampling and photometric errors. The upper left panel shows the photometry vs. observation number; the upper right panel the $B$ light curve, the lower left panel the $B - V$ simulated colours, and the lower right panel gives the $V$ lightcurve. The dotted line indicates the $3\sigma$ level above the median magnitude in each passband.
However, one has to take into account the effects of sampling and the photometric errors. We used simple approximations based on the preliminary analysis of TYCHO data [14] [4] to make extensive Monte Carlo simulations to derive the efficiency of TYCHO as a microlensing experiment (see Fig. 4). This gave an efficiency of about 9% for events of 10 days, and up to 15% for durations of a couple of months. Hence the efficiency decreases the expected number of events down to about 0.01. Even though this is disappointing, we argue that the experiment should be carried out, given the unexpected results obtained by the current microlensing surveys of the LMC and Galactic bulge.

3 Conclusions

We have shown that the TYCHO database could be used as a control microlensing experiment to probe the local dark matter content in the solar neighbourhood. The same methodology as the current microlensing surveys can be used to set limits on the local dark matter probed by the microlensing experiments, which can then be compared to the limits obtained by dynamical methods. The low rate expected for the nearby stars probed by TYCHO is somehow compensated by the large number of stars in the survey, and by the large number of observations per star. The sampling efficiency is best suited to long events (months), although very short time scales (20 to 120 minutes) are also probed. Even though the predicted number of events detectable in the final database (when available in 1997) is very small, we argue that it is important to carry out this experiment to validate the basic microlensing methodology.

In the future, the full analysis of the entire TYCHO database and the astrometric satellite projects such as DIVA [1], or GAIA and ROEMER [6], monitoring some $10^8$ stars down to $V=16.5$ (and hence probing some 6 kpc), could be used to validate the microlensing technique to probe the dark matter content of the solar neighbourhood.

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