The "Core" of the Quasar 3C 454.3 as the Extragalactic Reference for the Proper Motion of the Gravity Probe B Guide Star

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Abstract

We used very-long-baseline interferometry (VLBI) radio observations at 8.4~GHz between 1997 and 2005 to determine the coordinates of the ``core'' of the quasar, 3C 454.3, relative to the extragalactic sources, B2250+194, and for the last half of the time also to another extragalactic source, B2252+172, both nearby on the sky. The core of 3C 454.3 is stationary relative to these two sources, with the 1σ upper limit on its proper motion being 15 μas yr^{-1} in right ascension and 25 μas yr^{-1} in declination. The corresponding upper limit on the proper motion of this core with respect to the quasi-inertial reference frame determined from separate VLBI observations of many extragalactic radio sources, including B2250+194, is 30 μas yr^{-1} in each of the coordinates. The core of 3C 454.3 provides a sufficiently stable reference with which to measure the proper motion of the Gravity Probe B guide star, IM Pegasi, relative to the distant universe.

Introduction

Gravity Probe B (GP-B) is the spaceborne relativity experiment developed by NASA and Stanford University to test two predictions of general relativity (GR) with gyroscopes in low-earth orbit. GP-B measured the predicted precession of the gyroscopes relative to distant inertial space, represented by an extragalactic reference frame. Because of technical restrictions, the spacecraft could not measure the precession directly relative to that frame but only to an optically bright star, the guide star chosen to be IM Pegasi (HR 8703, HD 216489). IM Pegasi's proper motion (see talk by I. Shapiro et al.) is independently determined relative to the extragalactic reference frame. In particular, the proper motion is determined relative to the "core" of the quasar 3C 454.3 which we tied to two other extragalactic sources and the International Celestial Reference Frame (ICRF).

Observations

Between 1997 and 2005, we carried out 35 sessions of VLBI observations at 8.4 GHz of IM Pegasi and two extragalactic sources, 3C 454.3 and B2250+194, supplemented by another extragalactic source, B2252+172 during the last third of the observations. We used a worldwide network of radio telescopes including the 10 dishes of the Very Long Baseline Array (VLBA) and the Very Large Array of the National Radio Astronomy Observatory, the Effelsberg telescope of the Max-Planck-Institut für Radiostronomie in Germany, and the 70-m dishes of the NASA Deep Space Network in the USA, Spain and Australia. Each session used typically 15 telescopes and was of about 15 hours in length. The data were correlated using the VLBA processor in Socorro, New Mexico.

Results

In Figure 1 we show the sky chart of the relative positions of our three extragalactic reference sources, 3C 454.3, B2250+194, and B2252+172, and the guide star IM Pegasi (HR 8703). The source 3C 454.3 is our primary reference source. Its brightness distribution is shown in Figure 2. We indicate three major components, located by fitting Gaussians to the brightness distributions. Component C1 has always been suspected to be most closely identified with the "core" and the gravitational center of the quasar. We select three epochs to show that the components are slightly moving relative to each other. In Figure 3 we show the brightness distributions of the other two reference sources (see poster by M. Bietenholz et al. for images of IM Pegasi).

In Figure 4 we show the coordinates of B2250+194 and B2252+172 relative to those of C1 in 3C 454.3 as a function of time. C1 is stationary relative to these two reference sources within a 1σ upper bound on the proper motion of 15 μas yr^{-1} in RA and 25 μas yr^{-1} in decl., equivalent to subluminal velocity limits of 0.4 and 0.8 c for a flat universe with H_0 = 70 km s^{-1} Mpc^{-1}, Ω_M=0.3, and Ω_Λ=0.7.

In Figure 5 we show the coordinates of B2250 +194 as determined from routine geodetic VLBI observations of many extragalactic sources, most of them ICRF sources. Combined with these data, the 1σ upper bound on the proper motion of C1 in the ICRF is 30 μas yr^{-1} in each of the coordinates.

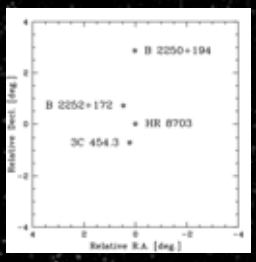
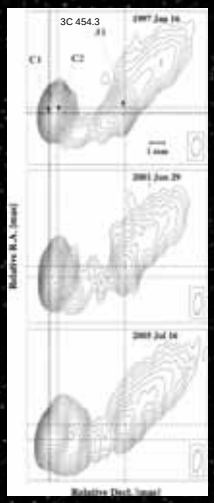
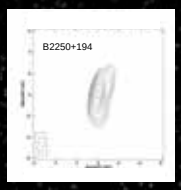


Fig. 1: A sky chart with relative coordinates of the three extragalactic reference sources and the guide star IM Pegasi (HR 8703).





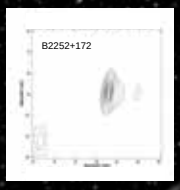
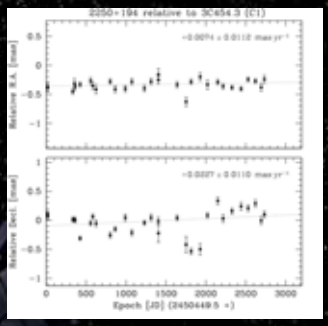
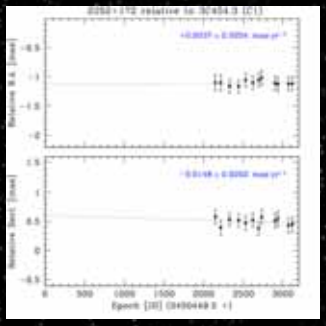


Fig. 3: Images of B2250+194 and B2252+172 at 8.4 GHz. The contour levels for B2250+194 are 0.3, 0.5, 1, 2, 5, 10, 20, 40, and 80% of the peak brightness of 431 mJy/bm. The contour levels for B2252+172 are 3, 5, 10, 20, 30, …, 80, and 90% of the peak brightness of 11.6 mJy/bm. The convolving beam is given at the lower left for each panel.

Fig. 2: Images of 3C 454.3 at 8.4 GHz at three epochs, with the core component, C1, and two other components, C2 and J1, indicated for the first of the epochs at the crossing points of horizontal and vertical lines. The contour levels start at 10 mJy/bm and increase by factors of 1.41. The peak brightnesses for the images from top to bottom are 4.78, 4.23, and 2.34 mJy/bm. The convolving beam is given at the lower right of each panel.





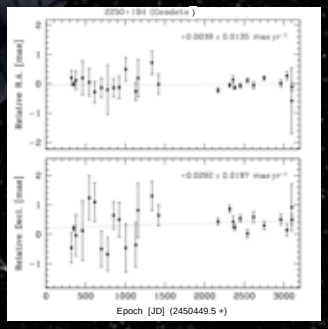


Fig. 4 (upper two panels): The coordinates of the brightness peaks of B2250+194 and B2252+172 relative to the coordinates of C1 in 3C 454.3. Error bars indicate preliminary estimates of standard errors. The straight lines are the weighted least-squares fits to the data points. The solutions of the fits are printed in the panels.

Fig. 5 (left panel): The coordinates of B2250+194 as determined from routine geodetic VLBI observations. The uncertainties are statistical standard errors. The straight lines are the weighted least-squares fits to the data points. The solutions of the fits are printed in the panels.

Conclusion

The core of 3C 454.3 provides a sufficiently stable reference with which to measure the proper motion of the Gravity Probe B guide star, IM Pegasi, relative to the distant universe.

The poster background is an image of the Gravity Probe B satellite in orbit, with several VLBA radio dishes, rendered by A. Jeziak.