Preliminary Orbit and Masses of the Nearby Binary L Dwarf GJ 1001BC

David A. Golimowski (Johns Hopkins University), Dante Minniti (Pontificia Universidad Católica de Chile), Todd J. Henry (Georgia State University), Holland C. Ford (Johns Hopkins University)

Abstract

We present preliminary results of a continuing VLT program to map the orbit of the nearby binary L4.5 dwarf GJ 1001BC. Since discovering its duplicity in 2003 using *HST's* NICMOS and ACS, we have obtained high-resolution images of GJ 1001BC at 3 epochs between Oct 2004 and Nov 2005 using NAOS/CONICA at VLT-UT4. Our *HST* and VLT images cover ~75% of GJ 1001BC's four year orbit. A least-squares fit of a Keplerian orbit yields a total mass of 0.100 ± 0.026 M_{sun} for a recent distance measurement of 13.01 ± 0.67 pc to the M dwarf GJ 1001A. Assuming a 3:2 mass ratio for the nearly equal-luminosity L dwarfs, we estimate masses of 0.060 ± 0.016 M_{sun} and 0.040 ± 0.010 M_{sun} for GJ 1001B and C, respectively. If these values are sustained by our continuing orbit and parallax measurements, then GJ 1001C will be the least massive L dwarf for which a dynamical mass has been measured.

1. Motivation

❖ About 550 L and T dwarfs are now known. Over 200 of these are unambiguous brown dwarfs.

❖ Brown dwarfs cool with age, so their masses cannot be inferred from their luminosities at a single epoch.

❖ Only by mapping the orbits of binary brown dwarfs can their masses be derived and evolutionary models tested.

❖ Deriving the stellar IMF depends on accurate empirical determination of the dwarf mass-luminosity relation (MLR). For M, L, and T dwarfs, the MLR is sensitive to metallicity and dependent on age.

❖ The faint end of the MLR has only recently been mapped (Henry et al. 1999; Delfosse et al. 2000). Programs that track the orbits of close binary stars are filling in this end of the MLR, but they are mostly insensitive to brown dwarfs.

❖ Recent dynamical-mass measurements of 3 likely binary brown dwarfs, GJ 569BC (M8.5+M9; Zapatero Osorio et al. 2004), 2MASS J0746+2000 (L0.5+L1.5; Bouy et al. 2004), and 2MASS J0535-0546 (M6.5+M6.5; Stassun et al. 2006), provide the first empirical data for the substellar MLR.

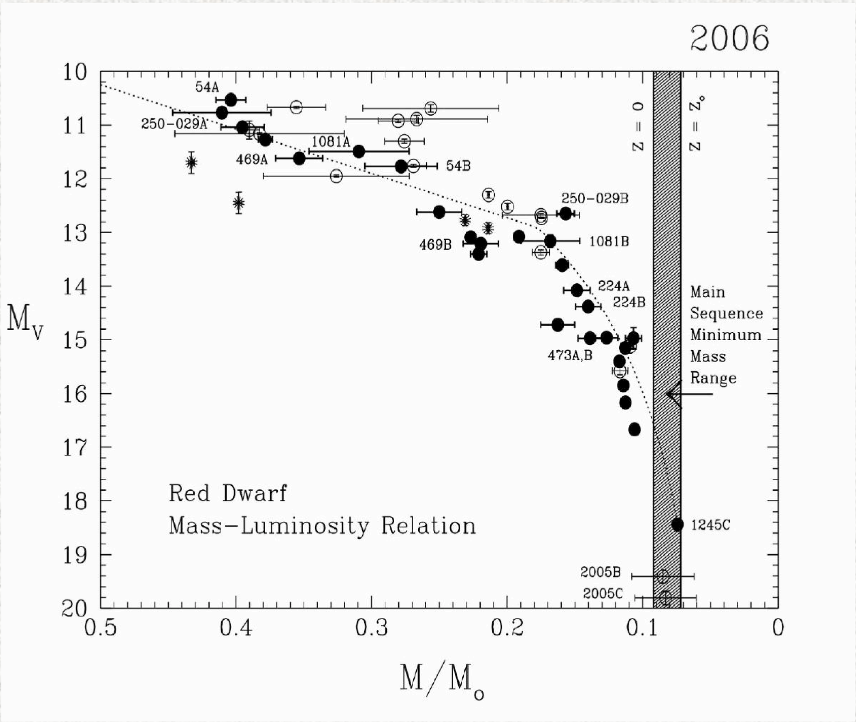

Figure 1. *M_V versus mass for faint nearby stars. The dotted curve represents the combined MLRs of Henry et al. (1993) and Henry et al. (1999) for data known at those times.*

2. Facts about the GJ 1001 (LHS 102) system

❖ Triple system of M3.5 dwarf and binary L4.5 dwarf separated by 18″.2.

❖ GJ 1001B discovered in proper motion survey by Goldman et al. (1999).

❖ Published parallax of GJ 1001A indicates distance of 9.55 ± 1.05 pc (van Altena et al. 1995). New parallax from CTIOPI puts system at 13.01 ± 0.67 pc (Henry et al. 2006).

❖ Duplicity of GJ 1001B discovered from *HST* NICMOS survey of stars within 10 pc and confirmed with *HST* ACS (Golimowski et al. 2004a).

❖ GJ 1001B and C are separated by 0″.087 (~ 1.2 AU) and have a differential brightness of Δmag ≈ 0.1-0.2.

❖ ***GJ 1001BC's estimated period of ~4-5 years allows quick determination of the orbit and masses of this pair of unambiguous brown dwarfs.***

3. Tracking the orbit of GJ 1001BC at VLT

❖ We have begun a multiyear imaging program at VLT to track the orbit and compute the dynamical masses of GJ 1001BC.

❖ With spectral types of L4.5 (1750 ≤ T_{eff} ≤ 1975 K; Golimowski et al. 2004b), GJ 1001B and C are the coolest brown dwarfs ever to be studied in this manner.

❖ Close separation requires superb resolution afforded by VLT-UT4's adaptive optics system and near-infrared imager, NAOS-CONICA (NACO).

❖ *J*, *H*, and *Ks* exposures totaling 1 hour recorded at intervals of at least 2-3 months.

❖ S27 (0″.027 pix^{-1}) and S13 (0″.013 pix^{-1}) imaging modes are used to obtain highest-resolution images of A+BC and B+C components, respectively.

❖ 4 epochs executed (Oct 2004, Jan & Nov 2005, Jun 2006); 2 epochs scheduling (Sep & Dec 2006); 4 more epochs proposed.

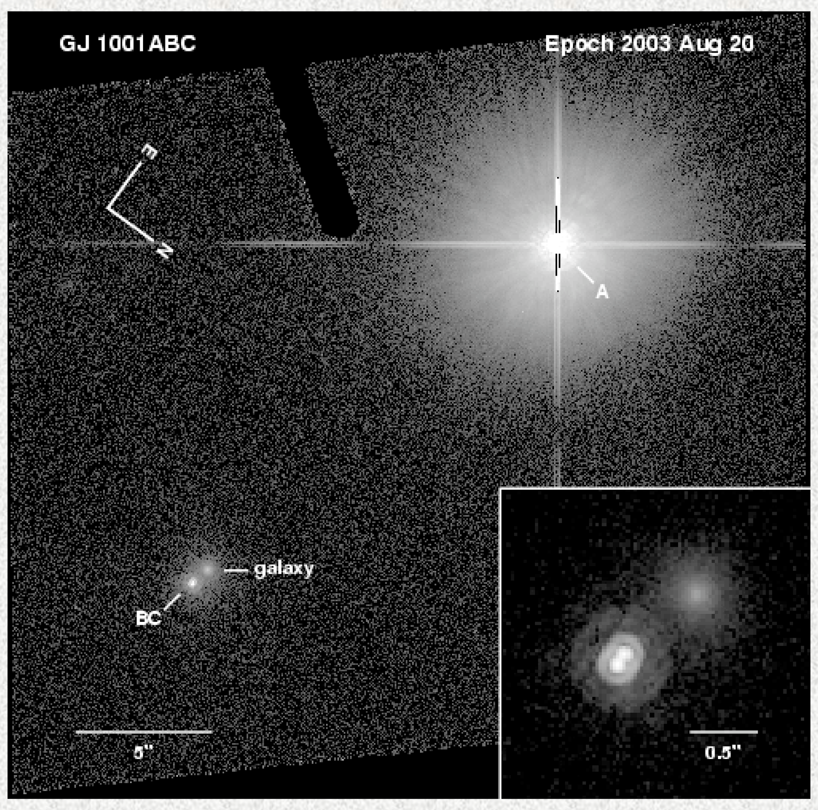

Figure 2: *i-band image of the GJ 1001 triple system obtained with the HST Advanced Camera for Surveys on 2003 August 20 (Golimowski et al. 2004a). The inset shows a magnified and rescaled region centered on the binary L dwarf. The fuzzy object about 0″.74 from GJ 1001BC is a background galaxy.*

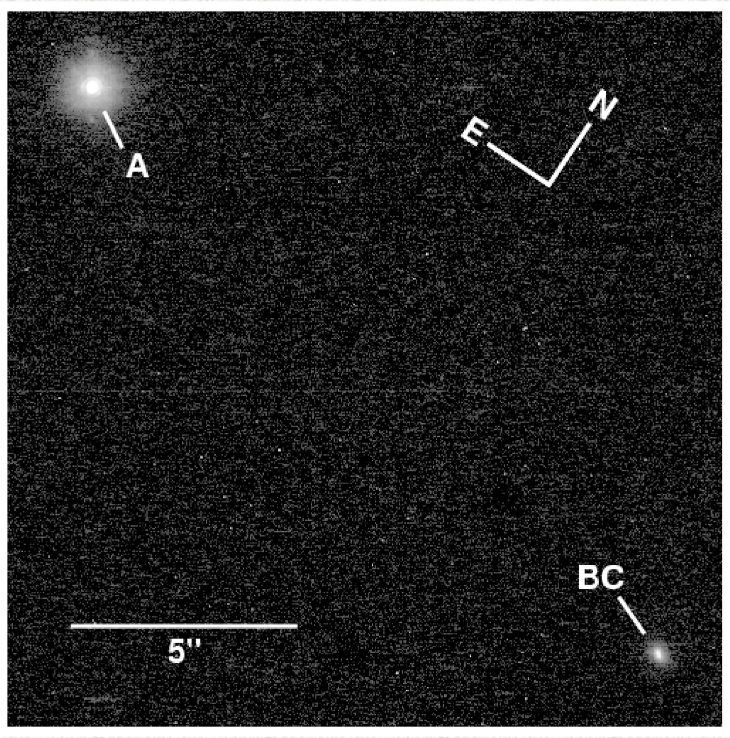

Figure 3. *Ks-band VLT/NACO image of GJ 1001ABC recorded in S27 mode with the camera rotated to allow simultaneous imaging of all three components. At a galactic latitude of -73°, GJ 1001A serves as the only astrometric reference for the barycentric motion of GJ 1001BC. The orbital motion of BC around A is a negligible 0°.005 yr^{-1}.*

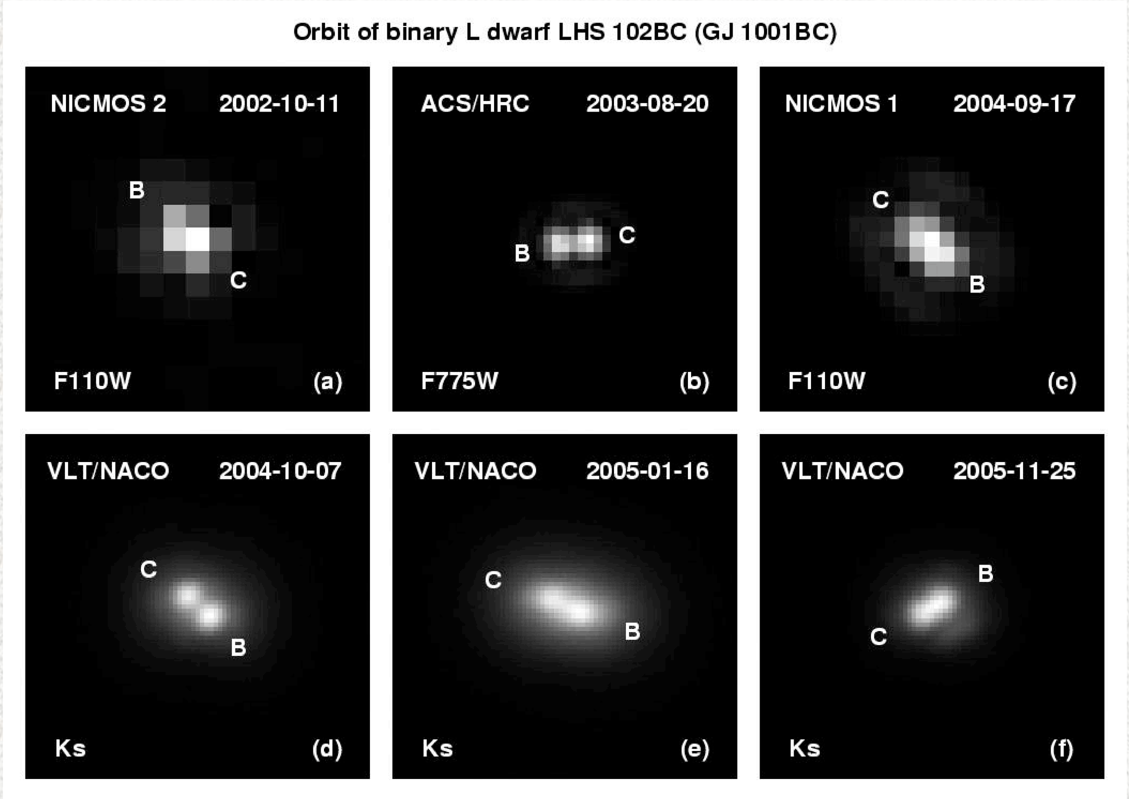

Figure 4. *HST and VLT images of GJ 1001BC recorded over 37 months from Oct 2002 to Nov 2005. Each panel has a field of view of 1″× 1″; north is up and east is left. (a) HST NICMOS Camera 2 (J band; 0″.076 pix^{-1}). (b) HST ACS/HRC (i band; 0″.025 pix^{-1}). (c) HST NICMOS Camera 1 (J band; 0″.043 pix^{-1}). (d)-(f) VLT/NACO (Ks band; 0″.013 pix^{-1}). About 75% of the 4 year orbit has been mapped (~25% with VLT/NACO). The identities of GJ 1001B and C in the HST images are inferred from their positions in the VLT/NACO images.*

4. Preliminary orbit and masses

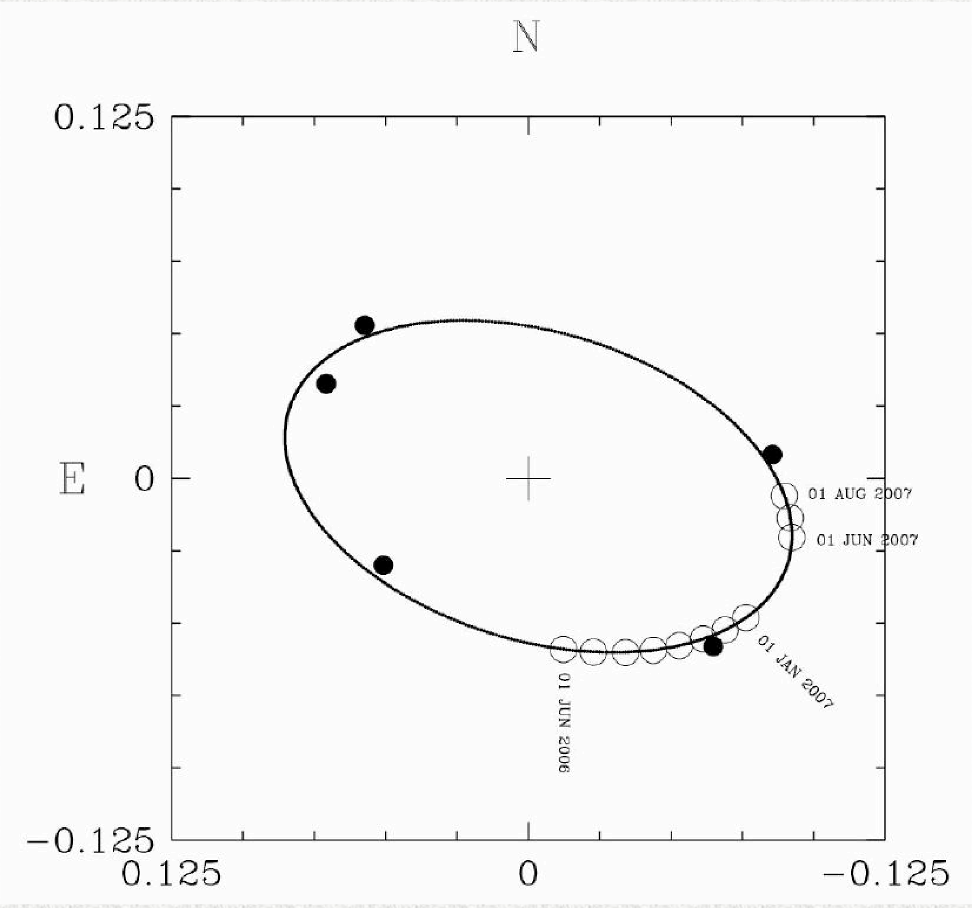

Figure 5. *Preliminary orbit of GJ 1001BC. Filled circles are measured positions of component C relative to B, obtained from the HST and VLT images shown in Figure 4. The ellipse is the Keplerian orbit that best fits the measurements. The open circles show the expected positions of GJ 1001C at 1-month intervals between the labeled dates. The orbit progresses counterclockwise.*

Preliminary Keplerian orbital elements

CTIOPI Parallax (Henry et al. 2006)	0″.07686 ± 0″.00397
Period (P)	4.0981 ± 0.3124 yr
Periastron passage (T)	2000.7400 ± 0.8786
Eccentricity (e)	0.0554 ± 0.0630
Semimajor axis (a)	0″.0914 ± 0″.0044
Inclination (i)	54°.27 ± 6°.73
Longitude of ascending node (Ω)	73°.50 ± 5°.52
Longitude of periastron (ω)	325°.20 ± 58°.53
Total system mass (M_B+ M_C)	0.100 ± 0.026 M_{sun}

❖ The barycentric orbit is needed to compute masses of B & C separately. *Obtaining this orbit is complicated by paucity of reference stars and nearly equal brightnesses of B & C.*

❖ Assuming (hypothetically) a 3:2 mass ratio, then:

$$M_B = 0.060 \pm 0.016\ M_{sun}$$

$$M_C = 0.040 \pm 0.010\ M_{sun}$$

If these values are sustained by our continuing orbit and parallax measurements, then GJ 1001C will be the least massive L dwarf for which a dynamical mass has been measured.

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