The substellar mass function in the central region of the open cluster Praesepe from deep LBT observations^{*}

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Received 16 August 2010 / Accepted 2 May 2011

ABSTRACT

Context. Studies of the mass function (MF) of open clusters of different ages allow us to probe the efficiency with which brown dwarfs evaporate from clusters to populate the field. Surveys of older clusters (age ≥ 100 Myr) are not affected so severely by several problems encountered in young clusters, such as intra-cluster extinction and large uncertainties in brown dwarf models.

Aims. We present the results of a deep photometric survey to study the MF of the central region of the old open cluster Praesepe (age 590^{+150}_{-120} Myr, distance $190^{+6.0}_{-5.8}$ pc), down to the substellar regime.

Methods. We performed an optical (*r*iz and *Y*-band) photometric survey of Praesepe using the Large Binocular Telescope Camera covering an area of 0.59 deg^2 in the cluster centre from $i \sim 19.0$ mag ($\sim 100 M_{\text{Jup}}$) down to a 5σ detection limit at $i \sim 25.6$ mag ($\sim 40 M_{\text{Jup}}$). The survey is approximately 95% complete at $i = 23.8$ mag and $z = 22.0$ mag ($\sim 55 M_{\text{Jup}}$).

Results. We identify 59 cluster member candidates, of which 37 are substellar, by comparing with the predictions of a dusty atmosphere model. The MF of those candidates rises from the substellar boundary until $\sim 67 M_{\text{Jup}}$ and then declines. This is quite different from the form inferred for other open clusters older than 50 Myr, but seems to be similar to those found in very young open clusters, the MFs of which peak at $\sim 10 M_{\text{Jup}}$. Either Praesepe really does have a different MF from other clusters or they had similar initial MFs but a different dynamical evolution. Since most of the candidates are faint, we lack astrometric or spectroscopic follow-ups to test their memberships. However, the contaminations by field dwarfs, galaxies, or giants are found to have little effect on the shape of MF and therefore the MF of “real” cluster members should have similar characteristics.

Key words. brown dwarfs – stars: low-mass – stars: luminosity function, mass function – open clusters and associations: individual: Praesepe

1. Introduction

The mass functions (MFs) of stellar and substellar populations have been determined from optical and near-infrared surveys for several open clusters at different ages, such as the Orion Nebula Cluster, σ Orionis, ρ Ophiuchi, Taurus, IC 348, IC 2391, M 35, the Pleiades, and the Hyades. These MFs show clear heterogeneity (see Fig. 10), which may be partially caused by cluster evolution.

Studies of relatively old open clusters (age > 100 Myr) are important for two particular reasons: first, they allow us to study the intrinsic evolution of basic properties of brown dwarfs (BDs), e.g., luminosity and effective temperature, and to compare the evolution with structural and atmospheric models; second, we may investigate how the BD and low-mass star populations as a whole evolve, e.g., the efficiency with which BDs and low-mass stars evaporate from clusters. These investigations have been carried out for the Hyades (Bouvier et al. 2008 and references therein) and for Praesepe (Boudreault et al. 2010 and references therein).

The Praesepe open cluster has been surveyed extensively in the past (cf. Table 1), but only a few surveys have reached masses below the substellar limit (and then only just). Several BD candidates were detected in those surveys, some of which will be re-examined in the present work. The substellar MF of Praesepe remains uncertain.

Boudreault et al. (2010) observed a significant difference between the MFs of Praesepe and Hyades. While they found that the Hyades MF has a maximum at $\sim 0.6 M_{\odot}$ (Bouvier et al. 2008), the MF of Praesepe continues to rise from $0.8 M_{\odot}$ down to $0.1 M_{\odot}$. This is surprising, as both clusters share similar physical properties (ages, mass, metallicity, and tidal radii). Disagreement between the Praesepe and Hyades MFs could arise from variations in the clusters’ initial MFs, or from differences in their dynamical evolution (Bastian et al. 2010). Although different binary fractions could cause the observed (system) MFs to differ, there is no clear evidence of any variations in the binary fractions from measurements published in the literature (Boudreault et al. 2010).

In this paper, we present a survey of the very low-mass star and substellar populations of Praesepe using the blue and red Large Binocular Cameras, extending down to hitherto

^{*} Tables 2 and 3 are available in electronic form at <http://www.aanda.org>

Table 1. Summary of previous photometric surveys in the Praesepe around the hydrogen-burning limit.

Authors	Telescope/instrument	Area (deg ²)	BD candidates	Completeness limits (mag)
Hambly et al. (1995)	COSMOS/POS & UKSTU	19	0	$R_F \sim 20, I_N \sim 19$
Pinfield et al. (1997)	INT/WFC	1.0	$\sim 10^a$	$R = 21.5, I = 20.0, Z = 21.5$
Magazzù et al. (1998)	INT/WFC	0.22	1	$R = 22.2, I = 21.2$
Chappelle et al. (2005)	INT/WFC	2.6	4	$I_c = 21., Z = 20.5$
González-García et al. (2006)	3.5 m CAHA / LAICA & 5 m Hale / LFI	0.33	1	$i' = 23.8, z' = 23.3$
Boudreault et al. (2010)	3.5 m CAHA / $\Omega 2k$ & 2.2 m La Silla/WFI	3.1	6	$I_c = 23.2, J = 19.9, K_s = 18.6$
This work ^b	LBT/LBC	0.59	37	$r = 24.1, i = 25.6, z = 24.7, Y = 20.3$

Notes. The completeness limits correspond to a 10σ detection, while those of the present work and Boudreault et al. (2010) correspond to 5σ detections. ^(a) From Fig. 3 in Pinfield et al. (1997), about 10 of their 26 Praesepe member candidates have masses below $72 M_{Jup}$. ^(b) Our work was complemented by the the JK_s 3.5 m CAHA/ $\Omega 2k$ data from Boudreault et al. (2010).

unexplored mass regimes ($\sim 40 M_{Jup}$). The main aims of our study are to search for new BDs and determine the MF of the Praesepe for a large coverage of the substellar regime.

The candidate selection procedure, and mass and temperature determination methods employed in this study are similar to those adopted in Boudreault et al. (2010). However, we probe a lower mass regime and use an evolutionary model based on a dusty atmosphere instead of a combination of dust-free and dusty models.

2. Observations and analysis

2.1. Observations

The observations presented in this paper were carried out with the Large Binocular Telescope (LBT) located on Mount Graham, Arizona (Hill et al. 2006), using the Large Binocular Cameras (LBCs, see Speziali et al. 2008). The LBCs are two wide-field, high-throughput imaging cameras, namely Blue (LBCB) and Red (LBCR), located at the prime focus stations of the LBT. Each LBC has a wide field of view ($23' \times 23'$), with four CCD detectors of 2048×4608 pixels each, providing images with a sampling of $0.23''/\text{pixel}$.

The optical design and detectors of the two cameras are optimized for different wavelength ranges: one for ultraviolet-blue wavelengths (320–500 nm, including the Bessel U , B , V and Sloan g and r bands), and one for the red-infrared bands (500–1000 nm, including the Sloan i , z and Fan Y bands). In the full binocular configuration, both cameras are available simultaneously, and both point in the same direction of the sky, thus doubling the net efficiency of the LBT.

To accomplish the entire survey of the inner region of Praesepe, we carried out three observing runs, in March 2008, December 2008, and February 2009. Table 2 summarizes the observations and Fig. 1 shows the areas surveyed. The total area covered is 0.59 deg^2 , about 1 percent of the cluster region. The transmission curves of the filters used in this survey is presented in Fig. 2, along with a synthetic spectrum of a brown dwarf with $T_{\text{eff}} = 2300 \text{ K}$, $\log g = 4.5$ [CGS], and solar metallicity (NextGen model).

2.2. Reduction and astrometry

The standard data reduction steps for the LBT data were performed using the IDL astronomy package and IRAF. The bias subtraction was executed on a nightly basis and for each CCD chip. To correct for pixel-to-pixel variations and global illumination, master flat frames were created for the nights using twilight

Fig. 1. Spatial distribution of the LBT pointings. **Fig. 2.** Transmission curves of the filters used in our survey compared to a synthetic spectrum of a brown dwarf with $T_{\text{eff}} = 2300 \text{ K}$, $\log g = 4.5$, and solar metallicity (NextGen model). The transmission curves include the quantum efficiency of the detectors.

exposures. For nights when no appropriate sky flat exposures were available, we used a master sky flat in the adjacent night. The individual images of a given field were registered and median combined, resulting in a combined science frame for each CCD, field and filter. To detect faint sources, we subtracted the strong background introduced by very bright stars¹. We then used the IRAF task *daofind* to detect sources in the “clean” frames. The sources were extracted from the original science frames and instrumental magnitudes calculated using both aperture and point-spread function photometry with the IRAF tasks *phot* and *allstar* respectively.

At this stage, weak fringes were still visible for several *Y*-band images. The method described by Bailer-Jones & Mundt (2001) for removing fringes does not apply well in the present case, since the images are seriously affected by bright stars and no clean fringe images could be created. However, as the *Y*-band images are ~ 1.5 dex shallower than expected, we decided not to use them in this study (although we still quote some statistics of the photometry below).

An astrometric solution was achieved using the Sloan Digital Sky Survey (SDSS York et al. 2000) catalogue as a reference. The root mean square (rms) accuracy of our astrometric solution is 0.10–0.15 arcsec. As with other reduction procedures, astrometry was also performed separately for each CCD, to ensure that the solutions were as robust as possible.

2.3. Photometric calibration

To correct for Earth atmospheric absorption of the photometry, we calibrated the inferred data using the *r*, *i*, and *z* band values of Sloan Digital Sky Survey (SDSS) objects that were observed in the science fields. Zero point offsets were determined from the difference between the SDSS magnitudes and our instrumental magnitudes. Since these were obtained with objects in the same field of view for each science frame, we did not perform a colour or airmass correction when reducing our *riz* photometry. The error introduced by this approximation is less than 0.05 mag.

To calibrate our *Y* band photometry, we used our LBT *i* and *z* photometry and the *Y* band photometry from the United Kingdom Infrared Telescope Infrared Deep Sky Survey (UKIDSS, Lawrence et al. 2007). We found that the differences between *Y* band LBT magnitudes and *Y* band UKIDSS magnitudes have a linear dependence on the *i* – *z* colours, which can be described by the equation

$$Y_{\text{UKIDSS}} - Y_{\text{LBT,raw}} = a_0 + a_1 \times (i - z), \quad (1)$$

On the basis of about 800 common objects between UKIDSS and our measurements, the $a_{0,1}$ coefficients were determined and the instrumental *Y* magnitudes were then transferred into the UKIDSS *Y* photometry system. For the same reasons as for our *riz* data, we did not (need to) perform a colour or airmass correction for our *Y*-band photometry.

The 5σ detection limits of our survey are ~ 25.6 mag and 24.7 mag for the *i* and *z* bands, respectively. However, we do not expect all targets brighter than these limits to be able to be detected. We estimate the survey completeness by comparing the number of objects detected to the number predicted assuming a uniform three-dimensional spatial distribution of stars. As shown in Fig. 3, the number of detected sources in each band deviates from a log-normal relationship at bright and faint limits. From this, we estimate the completeness to our 5σ detection

limit as 67.0% at $i = 25.6$ and 70.3% at $z = 24.7$ respectively, which corresponds to $\sim 40 M_{\text{Jup}}$ assuming a dusty atmosphere. A similar estimation yields a completeness of 82.0% at $r = 24.1$ mag and 82.6% at $Y = 20.3$ mag, respectively. Our survey is approximately 95% complete at $i = 23.8$ mag and $z = 22.0$ mag.

The relatively low completeness of our survey is possibly caused by the saturation of bright stars. For stars lying near to saturated stars, the photometric uncertainties are relatively large. A significant fraction of detected stars is then excluded because of their large photometric errors, which lowers the completeness. The total area seriously affected by bright stars in *i* band is 3–6 percent.

2.4. Candidate selection procedure

The candidate selection introduced by Boudreault et al. (2010) was adopted in the present work. Candidates were first selected based on the colour-magnitude diagram (CMD) using *iz* bands from our LBC observations². A second selection was performed using a colour-colour diagram. While our *rY* bands observations are not deep enough for our present investigations, data from the near-IR photometric survey by Boudreault et al. (2010) – which fully covers our survey area, with a 5σ detection limit at $\sim 55 M_{\text{Jup}}$ in *J* and *K_s* bands – was used instead for the second selection. In the third and final selection, we used the known distance to Praesepe to reject objects based on the discrepancy between their observed magnitude in *J* and the magnitude predicted from the isochrones and our estimation of T_{eff} . To be considered as a cluster member, an object had to satisfy all three of these criteria.

We use the evolutionary tracks of Chabrier et al. (2000) and the atmosphere models from Allard et al. (2001) – assuming a dusty atmosphere (the AMES-Dusty model) – to compute an isochrone for Praesepe using an age of 590^{+150}_{-120} Myr (Fossati et al. 2008), a distance of $190^{+6.0}_{-5.8}$ pc (van Leeuwen 2009), and a solar metallicity ($[\text{Fe}/\text{H}] = 0.038 \pm 0.039$, Friel & Boesgaard 1992). We neglect the reddening ($E(B - V) = 0.027 \pm 0.004$ mag, Taylor 2006). The transmission curves we used for the filters for these calculations are plotted in Fig. 2. The effective temperature varies from 500 K to 3900 K in steps of 100 K, while the gravity ranges from 4.0 dex to 6.0 dex in steps of 0.5 dex.

2.4.1. Colour-magnitude diagram

Candidates were first selected from our CMD by keeping all objects that are no more than 0.28 mag redder or bluer than the isochrones in all CMDs. This number accommodates errors in the magnitudes and uncertainties in the model isochrones. We also include the errors from the age estimate and distance to Praesepe. We additionally include objects brighter than the isochrones by 0.753 mag in order to include unresolved binaries. In Fig. 4, we show the CMD where candidates were selected based on their values of *z* versus *i*–*z*.

From a total of 44 209 objects above the 5σ detection limit in *i* and *z* filters and below our saturation limit, 709 objects are retained as candidate cluster members (98.4% are rejected). Of these, 160 were detected in the NIR observations of Boudreault et al. (2010). These objects are used in the selection process described below.

¹ The area fraction affected by bright stars is less than 3% for most of CCD images, and is about 6% in the worst case.

² Our *rY* bands observations do not reach a similar stellar mass, hence are not used here.

Fig. 3. Estimation of the completeness limit for our survey using the iz bands. The solid lines are the best linear fits before the turn offs. The vertical dashed lines are the 5σ detection limit and the vertical dotted lines are the saturation magnitudes.

2.4.2. Colour-colour diagram

From this step, The candidate selection is based on both the optical iz data and the NIR JK_s data. A candidate must be detected in every band.

The second stage of the candidate selection involves retaining only those objects that lie within 0.28 mag of the isochrone in the colour-colour diagram. This value accommodates the photometric errors, uncertainties in the model isochrones, and the uncertainty in the age estimation of Praesepe. The colour-colour diagram with the selection limits is shown in Fig. 5, where we also plot the theoretical colours of red giants (using the atmosphere models of Hauschildt et al. 1999b) and the theoretical colours of six galaxies with redshifts from 0 to 2 (Meisenheimer et al., in prep.). Neither the red giants nor the galaxies are expected to be a significant source of contamination; most of the low redshift galaxies that were not automatically discarded during PSF photometry with full-width-half-maxima ($FWHMs$) broader than the average stellar $FWHM$ by $\sim 30\%$, were rejected by means of the visual inspection of individual cluster member candidates after selection procedures. Of the 160 objects selected in the first step, 88 are kept here.

2.4.3. Observed magnitude vs. predicted magnitude

As indicated in Sect. 3.2, our determinations of T_{eff} and mass are based on the spectral energy distribution of each object, so are independent of the assumed distance. The membership status of an object can therefore be assessed by comparing its observed magnitude in a band with its magnitude predicted from its T_{eff} and Praesepe's isochrone (which assumes a distance). The predicted magnitude of a background contaminant would be lower (brighter) than its observed magnitude and higher (fainter) for a foreground contaminant. To avoid removing unresolved binaries that are real members of the cluster, we keep all objects with a computed magnitude of up to 0.753 mag brighter than the observed magnitude. We also take into account photometric errors and uncertainties in the age and distance of Praesepe. This selection procedure is illustrated in Fig. 6.

Of the 88 objects selected through CMDs and colour-colour diagrams in the first two steps, 74 are retained here. After this step, we perform a direct visual inspection of the images to reject resolved galaxies and spurious detections. This inspection removes 15 objects from the photometric selection, of which seven are possibly galaxies and eight are false detections.

The remaining objects constitute our final cluster member candidates, shown as large dots in Fig. 7. Those selected using

Fig. 4. CMD with i and z bands used in the first selection procedure. As solid lines we show the isochrone computed from an evolutionary model with a dusty atmosphere (AMES-Dusty). The numbers indicate the masses (in M_{Jup}) on the model sequence for various z magnitudes. The dashed lines delimit our selection band.

Fig. 5. Colour-colour diagram used in the second selection step. The solid line is the isochrone computed from an evolutionary model with a dusty atmosphere (the AMES-Dusty model; the masses in $M_{\odot}$ for each $z - K_s$ colour are shifted for clarity). The dashed lines show our selection area. We also show the theoretical colours of six galaxies as thin lines and the theoretical colours of red giants as thick lines. The six galaxies are two starbursts, one Sab, one Sbc, and two ellipticals of 5.5 and 15 Gyr, with redshifts from $z = 0$ to $z = 2$ in steps of 0.25 (evolution not considered). We assume that all red giants have a mass of $5 M_{\odot}$, $0.5 < \log g < 2.5$ and $2000 \text{ K} < T_{\text{eff}} < 6000 \text{ K}$.

only the iz photometry amount to 709, and are presented in Fig. 7 as small dots. We note that employing NIR JK_s data helps us to remove a significant fraction of contaminations. At each mass bin, we calculate the number of stars removed as a result of including JK_s data in the selection, and use this to estimate the

Fig. 6. Difference between the observed J magnitude and the model J magnitude computed from the derived mass and T_{eff} , as a function of T_{eff} . The vertical line marks the location of L0 dwarfs. The dotted line (at -0.753 mag) represents the offset due to the possible presence of unresolved binaries, the dashed-dotted lines represent the error in the magnitude determination, and the long-dashed lines represent the uncertainties in the age and distance of Praesepe. The horizontal solid line just traces zero.

Fig. 7. Same as Fig. 4, but with large dots standing for the 59 final candidates, and small dots for the 709 candidates that pass the first selection procedures.

number of stars in the final mass bin where JK_s data are unavailable.

Schmidt et al. (2010) and West et al. (2011) investigated the colors of L and M dwarfs, respectively, for every spectral types using the SDSS and Two Micron All Sky Survey (2MASS) catalogues. The observed colour ranges are consistent with our computed colour ranges for M and early L dwarfs. However, the observed $i - J$ color range for individual L dwarfs as shown in Fig. 2 in Schmidt et al. (2010) is 3.5–6.0 mag, broader and slightly redder than our model ranges (the dashed lines in our Fig. 5). We note that the Hammer spectral-typing procedure employed by

Schmidt et al. (2010), was developed by Covey et al. (2007), who sought to optimize only for K and M dwarfs. For L dwarfs, the uncertainties should be ~ 2 subclasses or larger. In addition, the Hammer is designed for solar-metallicity dwarfs, while Praesepe has a metallicity of 0.27 ± 0.10 dex (Pace et al. 2008), hence will be prone to significant, systematic errors (Covey et al. 2007). We therefore keep the use of our model colours alone for candidate selection for a homogeneous study. We found that if we use the observed color range from Schmidt et al. (2010) instead, the observed rise in the mass function around $60 M_{\text{Jup}}$ (cf. Sect. 4) remains – our main conclusion remains unchanged.

3. Results

3.1. Selected photometric candidates

We find that 59 photometric candidates survive the selection procedures (based on isochrones assuming dusty atmospheres), a density of about 100 objects per square degree. Details of all photometric candidates are listed in Table 3. The identification number (ID) of a candidate is defined according to the field in which it was found and a sequential number for that field. The last column, J_{model} , is the predicted J magnitude based on photometric determination of T_{eff} and mass.

Our survey concentrates on the substellar regime. Saturation occurs at ~ 18 mag in z band, corresponding to $\sim 100 M_{\text{Jup}}$. Therefore, most of the low mass candidates discovered in previous surveys (e.g. Pinfield et al. 1997; Hambly et al. 1995) are saturated in our LBT images. Only a few faint brown dwarfs classified by Pinfield et al. (1997), González-García et al. (2006), and Boudreault et al. (2010) are rediscovered in the current survey (cf. Table 4). These objects are M 5–9 dwarfs, according to the photometric relations given by West et al. (2008).

Some of our targets were previously identified as cluster members but rejected by our selection procedures or visual inspection. For example, eleven of the 150 Boudreault et al. (2010) candidates are detected in our LBT survey (the rest are mostly saturated). However, nine of them are rejected in this work (cf. Table 5). Among them, seven are rejected on the basis of the z vs. $i-z$ CMD selection, because they are bluer than the isochrone area. Another one is obviously not a point-like source in the LBT image, and another is rejected because its observed J magnitude is inconsistent with its model-predicted magnitude. The remaining two targets are confirmed to be cluster dwarf stars. As our current work employed more photometric bands than Boudreault et al. (2010), it is unsurprising that our selection is more conservative.

Most of our candidates are in the substellar regime, and other than the five targets listed in Table 4, no other accurate photometric observations are available from past epochs. This precludes using proper motions as a means of cluster membership assessment at this time.

3.2. Photometrically-derived masses and effective temperatures

From the evolutionary tracks and atmosphere models described previously, we obtained the magnitudes m_A from the average flux of a star in a specific band A using the equation

$$m_A = -2.5 \log f_A + c_A, \quad (2)$$

where m_A is the magnitude observed in a given passband, f_A the flux received on Earth in this passband, and c_A is a constant that remains to be determined. The flux f_A was obtained

Table 4. Previously discovered low-mass Praesepe candidates found in our survey.

ID	RA(J2000) (^h ^m ^s)	Dec(J2000) ([°] ['] ^{''})	Alternative name	Ref. ^a
A16	8:41:24.916	19:57:26.19	NGC2632 PHJ20	(1)
A17	8:41:26.483	19:51:59.73	J084126.5+195200	(2)
C12	8:39:47.778	19:28:03.10	Praesepe017	(3)
			NGC2632 PHJ11	(1)
D12	8:40:53.559	19:41:00.05	Praesepe001	(3)
D08	8:40:39.292	19:28:39.49	J084039.3+192840	(2)

References. (1) Pinfield et al. (1997); (2) González-García et al. 2006; (3) Boudreault et al. (2010).

using the total transmission function of the passband for a given filter, convolved with the quantum efficiency of the CCDs (we assumed that the telescope and instrumental throughput is flat over each passband). To transform our optical i and z band magnitudes from the models to the Johnson photometric system, we assumed all magnitudes m_A to be equal to 0.03 when f_A is the average Vega flux received on Earth. The constant c_A for each passband is then determined using the Vega flux from Colina et al. (1992). The fitted values for these constants are $i = -22.180$ and $z = -22.706$ mag. The values computed by Boudreault et al. (2010) for J and K_s were -23.687 and -25.908 mag, respectively.

The masses and effective temperatures were estimated in the way described by Boudreault & Bailer-Jones (2009)³. For the faintest objects where only i and z are available, the colour $i-z$ is used to compute masses and T_{eff} . There are different sources of errors for the estimation of the mass and T_{eff} , including the photon noise, the photometric calibration, the least squares fitting (imperfect model), and the uncertainties in the age of and distance to Praesepe. The latter two are the most significant errors and give the uncertainties of $0.008 M_{\odot}$ and 263 K for a $0.05 M_{\odot}$ substellar object ($T_{\text{eff}} = 1690$ K), $0.010 M_{\odot}$ and 260 K for a $0.06 M_{\odot}$ substellar object ($T_{\text{eff}} = 1990$ K), and $0.008 M_{\odot}$ and 201 K for a $0.072 M_{\odot}$ object at the hydrogen burning limit ($T_{\text{eff}} = 2293$ K).

3.3. Contamination by non-members

As mentioned above, the three main sources of contamination are background red giants, unresolved galaxies, and Galactic M and L dwarfs. Red giants contaminate the high mass end of this study, as seen in the $i-J$ vs. $z-K_s$ diagram, hence can be ignored. Although some types of galaxies have similar colours to Praesepe cluster members more massive than $60 M_{\text{Jup}}$, these low-redshift galaxies are in general extended sources and therefore easily rejected by our visual inspection. Among the 74 candidates that passed our selection procedures, we identify four as galaxies on the basis of their LBT images. Other possible sources are field L dwarfs and high redshift quasars (for instance at redshift $z \sim 6$; Caballero et al. 2008). However, because these quasars have spectral energy distributions similar to mid-T dwarfs, whereas our faintest candidates have colours of early L dwarfs, and given that they are rare (0.25 quasars at

³ We first normalized the energy distribution of each object to the energy distribution of the model using the J filter. The energy distribution was then fitted via a least squares fit of the model magnitudes to the measured ones.

Table 5. The 9 Praesepe cluster candidates identified by Boudreault et al. (2010) that were rejected in this work by colour or brightness.

ID	RA(J2000)	Dec(J2000)	i (mag)	z (mag)	I_c (mag)	J (mag)	K_s (mag)	M ($M_\odot$)	T_{eff} (K)	J_{model} (mag)
005	8:41:08.50	+19:54:02.0	20.19	18.70	19.02	16.58	15.39	0.088	2636	17.06
007	8:39:39.56	+19:47:54.3	18.93	17.80	17.95	16.10	15.07	0.104	2860	16.58
009	8:39:55.84	+19:53:14.3	18.05	17.78	20.29	17.50	16.54	0.081	2520	17.32
018	8:39:42.79	+19:35:48.2	—	—	18.27	16.20	15.21	0.097	2782	16.78
022	8:41:04.20	+19:31:27.8	20.12	19.15	18.89	16.67	15.75	0.092	2702	16.97
901	8:39:59.45	+19:43:37.4	18.05	18.30	19.09	17.16	16.41	0.084	2574	17.20
902	8:39:23.72	+19:52:01.8	20.41	19.46	20.15	17.77	16.88	0.073	2348	17.72
903	8:40:00.20	+19:30:27.0	19.59	19.01	19.74	17.50	16.62	0.076	2409	17.57
914	8:38:52.02	+19:35:05.3	19.48	18.69	19.12	17.25	16.35	0.085	2591	17.16

Notes. The IDs in the first column are taken from Boudreault et al. (2010). The fourth object is not a point-like source in the LBT image, thus no optical photometry measurement is available.

Table 6. Number density of the cluster member candidates.

$\log M$ (M_{Jup})	T_{eff} (K)	J_{model} (mag)	$N(\text{cand.})$ (deg $^{-2}$)	$N(\text{cont.})$ (deg $^{-2}$)	Fraction
1.625	1412	23.29	13	195	1500%
1.675	1692	20.28	27	41	150%
1.725	1839	19.27	18	3.3	15%
1.775	1981	18.87	33	4.8	13%
1.825	2244	18.01	38	2.3	5.7%
1.875	2361	17.71	17	3.2	16%
1.925	2479	17.43	8.4	1.7	17%
1.975	2668	17.01	8.4	1.6	16%

$5.5 < z < 6.5$ in a 0.59 deg^2 survey, Stern et al. 2007), the MF should not be affected by quasar contamination.

The contamination by field dwarfs is not negligible. Caballero et al. (2008) identified possible field dwarf contaminants covering spectral types from M3 to T8 from the literature and presented the spatial density in the solar neighbourhood in their Table 3. From this, the spatial density of field dwarfs in the vicinity of Praesepe can be easily inferred, given the Galactic latitude of Praesepe of $b = +32.5 \text{ deg}$ and its distance of 190 pc, assuming an exponential decrease for stellar density perpendicular to the Galactic disk with a scale height of 500 pc. The absolute J band magnitude range constrained by our selection procedures is $\sim \pm 2 \text{ mag}$, as shown in Fig. 6, corresponding to a certain distance interval and a survey “volume”, which is defined by the product of survey area and depth. We calculated the number of contaminants by multiplying the survey volume by spatial density at each mass bin. The result is shown in Table 6. The first column gives the central value of $\log M$ in each interval, while the second and third columns present the corresponding T_{eff} and J_{model} values at that mass. The fourth column is the number density of cluster member candidates (also show in Fig. 8 as filled triangles) after applying all corrections (except for in the lowest two bins, where contaminations are too high to be corrected). The final two columns give the number density of field dwarf contaminants and corresponding fraction. We found that the field dwarf contaminants do not affect the MF shape. The contamination is significant for $J_{\text{model}} \gtrsim 20 \text{ mag}$. At this magnitude, the Boudreault et al. (2010) J band has a completeness of 88%. Therefore, below this magnitude, the mass functions we derived are probably upper limits.

We conclude that the various contaminants are either negligible, or do not affect the MF shape in the range that we can investigate quantitatively, i.e., from about 53 to $94 M_{\text{Jup}}$.

4. Mass function of very low mass and substellar population of Praesepe

The mass function, $\xi(\log_{10} M)$, we present here is the total number of objects per square degree in each logarithmic mass interval $\log_{10} M$ to $\log_{10} M + 0.1$. Since we do not make any corrections for binaries, we compute here a *system* MF.

As our candidates have been selected only from their photometric properties, cluster membership confirmation via spectroscopy is desirable. However, these observations will not be feasible in the near future because of the faintness of our candidates. The following discussion is therefore based on the assumption that the MF of candidates is similar to that of “real” cluster members. The assumption is possibly valid because our derived MF is consistent with that given by Boudreault et al. (2010) in the common mass bin, and the contamination by field dwarfs, giants, and galaxies should not affect the shape of the MF significantly.

To account for the survey detection efficiency, we use a simple simulation. For example, to calculate the detection efficiency of candidate A01 in i band, we select a bright but unsaturated star in the i band CCD image in which A01 resides, scale it down to the magnitude of A01 (i.e., $i = 20.29$), and randomly cast this “fake” star in the CCD image 100 times. We then search and re-measure the “fake” star with our procedures. The detection efficiency is the fraction of “fake” stars that have been re-discovered. We run this test for each filter (i, z, J, K_s) and multiply the detection efficiencies together (as we need a detection in every filter) to evaluate the overall detection efficiency for each candidate. This detection efficiency (or recovery rate) is about 90% for the brightest candidates and drops very quickly to 10% for the faintest candidates.

We mentioned in Sect. 2 that our optical photometry reaches lower masses than the NIR photometry that we used. To compute the MF of Praesepe to the lowest mass bin reached without optical data, we first computed a MF⁴ using only the optical iz photometry. This “MF” is presented in Fig. 8 as filled dots. We computed a second MF from the list of candidates that pass the three selection criteria and are also detected in the survey of Boudreault et al. (2010) in the NIR J and K_s bands (presented on Fig. 8 as filled triangles). For each mass bin, we computed the number of objects removed as a result of adding the J and K_s filters to our selection process and mass determination procedure (plotted as a function of mass in Fig. 8, top panel). We fitted a linear function to estimate the number of objects that

⁴ Note that this is an inaccurate “MF”, because of serious contaminations.

Fig. 8. Lower panel. Mass function based on **a)** the LBT *i* and *z* photometry (filled dots) after detection efficiency corrections, and **b)** the LBT photometry plus the *J* and *K_s* photometry from Boudreault et al. (2010) (dotted open triangles: the original MF; filled triangles: the MF after detection efficiency corrections and removing contaminants). The selection and mass calibration are based on dusty atmospheres. Error bars are Poissonian arising from the number of objects in each bin, except for the lowest-mass bin, for which the error bar is from the linear fit in the top panel. The vertical thin dotted lines are the mass limits at which detector saturation occurs in the *i* and *z*-bands. The vertical thin long dashed line is the mass at the 5σ detection limit of our optical LBT data while the thick short dashed line is the mass at the 5σ detection limit of the NIR data of Boudreault et al. (2010). Top panel. Difference of the log of the number of objects (in each mass bin) between the MF computed using the optical *iz* data and the MF computed using both *iz* and NIR *JK_s* data from Boudreault et al. (2010). The dotted line is a linear fit.

would be removed if we had additional *J* and *K_s* photometry to 40–45 M_{Jup} , which is our lowest mass data point in Fig. 8. However, as shown in Table 6, the contamination in the two lowest mass bins is so overwhelming that the MFs in these two bins can only be regarded as upper limits and are no longer discussed in the paper.

Our derived MF (presented in Figs. 8–10) shows a rise from 105 M_{Jup} to 67 M_{Jup} and then a turn-over at $\sim 67 M_{\text{J}}$. This turn-over occurs well above the 5σ of either *iz* bands or *JK_s* bands (e.g. at $\sim 67 M_{\text{Jup}}$, $i \sim 22$) and we note that we have corrected the incompleteness of our survey and field dwarf contaminations. We therefore believe that this feature is genuine. This is the first time a clear rise in the substellar MF in an old open cluster has been observed.

The MF of Praesepe near the hydrogen-burning limit was previously obtained in several studies. However, only Boudreault et al. (2010) provide a common mass range for comparison, as shown in Fig. 9. In the first substellar mass bin ($\sim 80 M_{\text{Jup}}$) we see that, both surveys give consistent results within their error bars. However, for the second bin at $\sim 70 M_{\text{Jup}}$, our MF is much higher than that of Boudreault et al. (2010); the

Fig. 9. MF of Praesepe based on our survey LBT *iz* and $\Omega 2k$ *JK_s* photometry (triangles), compared with that from Boudreault et al. (2010) (open dots assuming a dusty atmosphere and filled dots assuming a dust-free atmosphere). Error bars are Poissonian arising from the finite number of objects observed in each bin, except for the last bin, for which the error bar is derived from the linear fit. The vertical thin dotted line is the mass limit above which detector saturation occurs in the *i* and *z*-bands. The vertical thin long-dashed line is the mass at the 5σ detection limit of our optical LBT data.

discrepancy is smaller when considering the MF from that work using the dusty atmosphere (open dots), which is still a reasonable model for such low mass stars ($\sim M9/L0$). This may indicate that some faint candidates are missing in the Boudreault et al. (2010) survey, as these authors did not make any corrections for the detection efficiencies.

We emphasize that our LBT survey covers the very central 0.59 deg^2 of Praesepe, while the $\Omega 2k$ survey by Boudreault et al. (2010) covers a much wider area ($\sim 3.1 \text{ deg}^2$). If no significant candidates are missing in the $\Omega 2k$ survey, this discrepancy may suggest that the very low mass cluster members are mostly concentrated in the cluster centre, in contrast to what is expected from a “dynamical evaporation” of brown dwarf in open clusters. The basic idea of dynamical evaporation is that lower mass stars in a cluster have higher speeds according to equipartition of energy, so are able to move higher in the gravitational potential well of the cluster. Hence the fraction of low mass stars should increase with increasing distance from the cluster centre. By comparing the Praesepe and Hyades MFs, Boudreault et al. (2010) concluded that Praesepe might have been less affected by dynamical evolution.

Owing to its large distance and old age, no other published MF determination of Praesepe has reached masses below $70 M_{\text{Jup}}$. We therefore compare our results with those from other clusters in Fig. 10. This includes IC 2391 from Boudreault & Bailer-Jones (2009), ONC from Hillenbrand & Carpenter (2000), σ Orionis from (Caballero et al. 2007; Bihain et al. 2009), and the Hyades from Bouvier et al. (2008). The MF of Praesepe is quite different from both IC 2391 (age of ~ 50 Myr) and the Hyades (~ 625 Myr). Either the “dynamical evaporation” does not have (or has not yet had) the same effect on these three clusters, or they had different initial mass functions.

Fig. 10. Mass functions of various open clusters. *From top to bottom:* ρ Oph (~ 1 Myr, Marsh et al. 2010); S 106 (~ 1 Myr, Oasa et al. 2006, their Fig. 10, middle panel for example); Trapezium (~ 0.8 Myr, Muench et al. 2002); IC2391 (~ 50 Myr, Boudreault & Bailer-Jones 2009); ONC (~ 5 Myr, Hillenbrand & Carpenter 2000); σ Ori (~ 3 Myr, Bihain et al. 2009); Hyades (~ 625 Myr, Bouvier et al. 2008); Praesepe (~ 590 Myr, Boudreault et al. 2010 and from this work). We also show the lognormal fit to the Galactic field star MF from Chabrier (2003) as a dashed line. All the other MFs are normalized to this at the substellar limit ($\sim 72 M_{\text{Jup}}$).

Another possibility is that Praesepe has a different binary fraction. Employing different cluster member selection criteria may also account for the observed MF discrepancies among clusters. Further studies are necessary to clarify these points.

The continuing rise of the MF into the substellar regime that we observe has also been observed in young clusters (as shown in Fig. 10), especially in σ Orionis (Bihain et al. 2009), Trapezium (turn-over at $\sim 10\text{--}20 M_{\text{Jup}}$, Muench et al. 2002), ρ Oph (MF rising to $\sim 10 M_{\text{Jup}}$, Marsh et al. 2010), and in the very low luminosity young cluster in S 106, where the MF increases or at least remains flat down to $\sim 10 M_{\text{Jup}}$ (Oasa et al. 2006). If we assumed a universal IMF, then it seems that the substellar MF of Praesepe has not evolved significantly since the cluster formed.

5. Conclusions

We have carried out the deepest survey to date of the old open cluster Praesepe, covering the central 0.59 deg^2 in the $rizY$ bands. The survey probed a mass range from ~ 100 to $40 M_{\text{Jup}}$ at 5σ detection limit, with which we have derived the very low mass and substellar mass function of this cluster.

We compared our optical iz -bands data, combined with the $\Omega 2k$ NIR (J and K_s) band observations from Boudreault et al. (2010), with theoretical loci of cluster members based on a dusty atmosphere (the AMES-Dusty model), to select cluster member candidates. Our final sample comprises 59 photometric candidates. We estimate that the contamination by field dwarfs is about 15%, and that this does not affect the shape of MF. The contamination by galaxies and red giants is believed to be negligible. About two thirds of our cluster members have theoretical masses below the hydrogen-burning limit at $0.072 M_{\odot}$, and are therefore brown dwarf candidates. We emphasize that to claim cluster memberships for the candidates, follow-up astrometric or spectroscopic observations are required. However, given that the candidates are generally faint and these observations are very time-consuming, none of them has yet been confirmed in this way. The discussion in this contribution therefore refers to the mass function of photometric cluster member *candidates*.

The mass function we have inferred for the central 0.59 deg^2 of Praesepe is consistent with that inferred for a wider area by Boudreault et al. (2010) at a mass just below the substellar boundary, but deviates by ~ 0.6 dex in the next lowest mass bin, which may indicate that there is either a significant number of objects missing in the Boudreault et al. (2010) survey, or a higher concentration of substellar objects in the centre of Praesepe (as the Boudreault et al. survey is at a larger cluster radius). The latter possibility suggests that the dynamical evolution of very low mass stars is inefficient in this cluster, as proposed by Boudreault et al. (2010) for explaining the discrepancy between the Praesepe MF and Hyades MF.

The steady rise in the Praesepe MF down to $\sim 70 M_{\text{Jup}}$ and a turn-over there were unexpected for this old cluster. Such a significant peak has never been observed in any other cluster older than 50 Myr, but has been observed in several very young open clusters such as σ Orionis or clusters in star-forming regions (e.g., Trapezium). This suggests that the dynamical interactions in Praesepe have very little effect on MFs, if we assume there is a universal initial MF.

Acknowledgements. This project was supported by DFG-Sonderforschungsbereich 881 “The Milky Way System”. Some of the observations on which this work is based were obtained during LBT programme “LBT-F08-02”. The LBT is an international collaboration among institutions in Germany, Italy and the United States. LBT Corporation partners are: LBT Beteiligungsgesellschaft, Germany, representing the Max-Planck Society, the Astrophysical Institute Potsdam, and Heidelberg University; Istituto Nazionale di Astrofisica, Italy; The University of Arizona on behalf of the Arizona university system; The Ohio State University, and The Research Corporation, on behalf of The University of Notre Dame, University of Minnesota and

University of Virginia. Some data analysis in this article has made use of the freely available R statistical package, <http://www.r-project.org>. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. This publication makes use of data products from the Two Micron All Sky Survey, Sloan Digital Sky Survey, and United Kingdom Infrared Telescope Infrared Deep Sky Survey.

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Table 2. Journal of the LBT/LBC observations.

Field	RA	Dec	Date	Filter	t_{exp} (min)	Seeing (arcsec)	$m_{5\sigma}$ (mag)
PraeA	08:40:53.76	+19:52:41.9	2009-02-28	<i>r</i>	114	1.0	25.8
			2009-02-28	<i>i</i>	42	1.0	25.8
			2009-02-28	<i>z</i>	54	1.0	24.8
			2009-02-28	<i>Y</i>	18	1.0	21.3
PraeB	08:39:14.23	+19:52:41.9	2009-02-28	<i>r</i> ^a	54	1.0	25.1
			2008-03-06	<i>i</i>	42	2.2	25.7
			2009-02-28	<i>z</i>	54	1.0	25.2
			2008-03-04	<i>Y</i>	48	1.4	22.2
PraeC	08:39:14.36	+19:27:18.0	2008-03-07	<i>r</i>	90	1.9	25.6
			2008-03-07	<i>i</i>	30	2.0	25.8
			2008-03-07	<i>z</i>	30	1.0	25.1
			2009-02-28	<i>Y</i>	18	1.0	21.2
PraeD	08:40:53.63	+19:27:18.0	2008-12-29	<i>r</i>	99	1.0	25.8
			2008-12-29	<i>i</i>	42	1.0	25.8
			2008-12-29	<i>z</i>	39	1.0	24.8
			2008-12-29	<i>Y</i>	18	1.0	21.9

Notes. ^(a) We also performed a shallower, 84-min pointing in *r* on 2008-12-30.

Table 3. The 22 low mass and 37 brown dwarf candidates in Praesepe.

ID	RA(J2000)	Dec(J2000)	i (mag)	Err	z (mag)	Err	J (mag)	Err	K_s (mag)	Err	T_{eff} (K)	M (M_{Jup})	J_{model} (mag)
A01	8:40:12.599	19:56:50.33	20.29	0.03	19.01	0.06	18.14	0.05	17.01	0.05	3023	109	16.39
A02	8:40:18.893	19:57:07.40	20.17	0.02	18.74	0.06	17.75	0.03	16.77	0.04	2729	93	16.90
A03	8:40:20.624	19:43:40.72	23.42	0.06	21.75	0.10	19.55	0.11	17.88	0.10	1921	58	19.04
A04	8:40:24.901	19:57:15.52	22.93	0.05	21.19	0.03	19.25	0.18	17.53	0.08	1940	59	18.99
A05	8:40:25.044	19:41:44.56	19.23	0.02	18.40	0.02	17.37	0.02	16.47	0.03	3093	113	16.27
A06	8:40:25.773	19:57:08.28	19.84	0.03	18.79	0.04	17.63	0.04	16.72	0.04	2821	98	16.74
A07	8:40:25.981	19:57:07.02	19.72	0.03	18.69	0.04	17.55	0.04	16.63	0.04	2900	102	16.61
A08	8:40:27.459	19:43:19.69	22.06	0.08	20.66	0.08	18.60	0.04	16.96	0.04	1997	61	18.82
A09	8:40:32.282	19:43:53.72	25.33	0.15	23.23	0.07	20.28	0.20	18.84	0.24	1855	56	19.22
A10	8:40:33.639	19:53:08.76	23.94	0.03	22.41	0.02	19.77	0.06	18.37	0.08	1902	57	19.09
A11	8:40:35.313	19:44:54.81	19.72	0.01	18.80	0.02	16.66	0.01	15.83	0.02	2351	75	17.73
A12	8:40:44.975	20:00:24.80	23.43	0.02	21.83	0.02	19.09	0.02	17.56	0.04	1842	55	19.26
A13	8:40:49.194	19:59:12.88	23.19	0.02	21.59	0.03	19.31	0.04	18.41	0.08	2040	62	18.68
A14	8:41:08.239	19:47:08.93	23.13	0.09	21.55	0.04	19.05	0.02	17.69	0.03	1905	57	19.08
A15	8:41:15.526	19:44:11.43	20.49	0.02	19.20	0.01	17.00	0.07	16.13	0.03	2169	67	18.25
A16	8:41:24.916	19:57:26.19	19.11	0.01	18.12	0.06	16.13	0.01	15.25	0.01	2356	75	17.72
A17	8:41:26.483	19:51:59.73	21.38	0.01	20.13	0.02	18.24	0.02	17.34	0.02	2294	72	17.86
B01	8:38:39.176	19:42:54.85	20.21	0.01	18.99	0.01	17.30	0.03	16.26	0.02	2373	76	17.68
B02	8:38:59.208	20:02:32.63	22.99	0.03	21.31	0.01	19.29	0.12	17.95	0.10	2050	63	18.65
B03	8:39:06.931	19:51:00.19	19.28	0.01	18.26	0.09	16.98	0.01	16.13	0.02	2712	92	16.93
B04	8:39:28.285	19:44:01.63	19.62	0.01	18.69	0.09	17.64	0.04	16.66	0.03	3093	113	16.27
B05	8:39:34.775	19:43:06.65	22.61	0.05	21.28	0.03	19.11	0.07	17.77	0.09	2060	63	18.61
B06	8:39:37.010	19:52:30.06	22.20	0.02	20.72	0.03	18.32	0.05	16.68	0.03	1892	57	19.12
B07	8:39:38.172	20:01:17.52	19.32	0.01	18.49	0.01	17.04	0.02	16.06	0.02	2674	90	17.00
B08	8:39:51.841	19:50:42.94	22.63	0.02	20.90	0.03	18.31	0.05	16.84	0.03	1867	56	19.19
B09	8:39:56.429	19:47:31.41	22.96	0.03	21.17	0.04	19.36	0.09	17.95	0.11	2112	65	18.44
C01	8:38:34.501	19:31:08.83	19.27	0.01	18.44	0.01	16.81	0.09	16.13	0.02	2590	86	17.18
C02	8:38:48.106	19:31:43.17	23.21	0.06	21.28	0.02	19.73	0.10	18.14	0.12	2181	68	18.21
C03	8:38:49.426	19:16:43.34	23.50	0.03	21.74	0.02	18.98	0.06	17.34	0.05	1808	54	19.49
C04	8:38:59.835	19:31:52.00	21.71	0.01	20.37	0.01	18.62	0.04	17.59	0.07	2310	73	17.83
C05	8:39:00.756	19:37:38.70	19.08	0.01	18.21	0.01	16.70	0.01	15.77	0.01	2626	88	17.10
C06	8:39:02.279	19:37:38.47	22.32	0.01	20.85	0.01	18.72	0.07	17.88	0.08	2159	67	18.29
C07	8:39:11.773	19:36:35.63	21.53	0.01	20.27	0.01	18.61	0.10	17.44	0.06	2381	76	17.66
C08	8:39:22.309	19:38:37.41	22.06	0.01	20.35	0.01	18.42	0.10	16.96	0.04	2062	63	18.61
C09	8:39:35.180	19:34:13.22	19.97	0.01	18.94	0.01	16.50	0.10	16.41	0.03	2160	67	18.28
C10	8:39:35.196	19:33:50.49	20.21	0.01	19.16	0.01	17.51	0.01	16.47	0.02	2462	79	17.47
C11	8:39:36.737	19:34:55.25	24.59	0.12	22.83	0.03	20.16	0.18	18.43	0.13	1786	53	19.64
C12	8:39:47.778	19:28:03.10	20.15	0.01	18.80	0.01	16.90	0.01	15.82	0.01	2217	69	18.09
C13	8:39:54.504	19:20:09.00	23.06	0.03	21.55	0.01	19.16	0.07	18.16	0.11	2007	61	18.79
D01	8:40:10.438	19:24:07.42	19.39	0.01	18.49	0.02	17.08	0.01	16.25	0.02	2683	91	16.98
D02	8:40:13.215	19:27:00.51	24.64	0.07	22.92	0.04	20.14	0.19	18.06	0.11	1703	50	20.21
D03	8:40:13.829	19:26:55.82	24.33	0.05	22.58	0.05	20.35	0.24	18.65	0.20	1896	57	19.11
D04	8:40:20.994	19:38:46.21	24.11	0.14	22.15	0.07	19.72	0.17	18.10	0.12	1848	55	19.24
D05	8:40:21.561	19:38:51.23	23.88	0.15	21.81	0.06	19.31	0.12	17.40	0.06	1760	52	19.81
D06	8:40:25.698	19:36:25.68	19.52	0.01	18.56	0.04	16.89	0.01	16.10	0.02	2504	81	17.37
D07	8:40:26.220	19:37:54.58	23.70	0.08	22.28	0.05	19.71	0.13	18.44	0.16	1947	59	18.97
D08	8:40:39.292	19:28:39.49	22.04	0.02	20.44	0.01	18.07	0.02	16.76	0.02	1962	59	18.93
D09	8:40:43.705	19:29:52.89	25.40	0.17	23.39	0.10	21.10	0.38	18.66	0.14	1705	50	20.19
D10	8:40:50.371	19:29:46.29	22.55	0.05	21.22	0.04	18.88	0.05	17.20	0.04	1898	57	19.11
D11	8:40:53.452	19:19:13.98	23.02	0.03	21.33	0.03	18.82	0.04	17.10	0.03	1847	55	19.25
D12	8:40:53.559	19:41:00.05	19.85	0.02	18.60	0.03	16.82	0.05	15.61	0.02	2320	73	17.81
D13	8:40:56.008	19:25:31.85	24.62	0.10	22.55	0.06	20.01	0.12	17.67	0.06	1682	50	20.39
D14	8:41:00.974	19:32:00.88	23.01	0.08	21.23	0.06	19.08	0.06	17.81	0.07	2015	61	18.76
D15	8:41:02.632	19:22:13.66	23.66	0.04	22.09	0.04	20.22	0.16	19.35	0.25	2216	69	18.10
D16	8:41:06.062	19:27:47.71	24.41	0.08	22.88	0.06	20.26	0.17	19.41	0.30	1903	57	19.09
D18	8:41:15.768	19:28:15.81	19.79	0.01	18.83	0.02	17.35	0.01	16.49	0.02	2588	86	17.19
D19	8:41:17.045	19:28:13.46	22.84	0.02	21.41	0.02	19.44	0.08	18.38	0.12	2184	68	18.20
D20	8:41:32.924	19:32:13.40	24.01	0.03	22.40	0.04	19.52	0.09	17.86	0.07	1807	54	19.49
D21	8:41:36.404	19:25:06.45	20.71	0.01	19.60	0.01	18.01	0.03	17.24	0.05	2513	82	17.35