Abstract: We derive the metallicity distribution for the globular cluster ω Centauri, and combine this with both a new determination of its orbit as well as its other unique properties to argue that ω Cen may be the remains of a formerly larger dwarf galaxy that has undergone substantial tidal stripping.

1 Introduction

We focus on two aspects of ω Cen that are rather uncharacteristic of globular clusters: its metallicity distribution and its orbit. Of course, ω Cen has other properties, such as mass and shape, that lend support to the idea that it is a “transitional” object with properties between those of dwarf galaxies and globular clusters. A dependence of kinematics on metallicity (Norris et al. 1997, “NFMS”) and an apparent dependence of spatial distribution on metallicity within the cluster (Jurcsik 1998), bring even more complexity to the question of ω Cen’s origin.

Given the spread in our metallicity distribution function (MDF), as derived from Washington + DDO photometry, as well as the orbital parameters of ω Cen and the other unusual aspects named above, we propose that this object is the remains (nucleus) of a once larger satellite dwarf galaxy that has been substantially reduced by tidal stripping.

2 Photometric Catalogue

Our color magnitude diagram (CMD; Fig. 1), containing over 130,000 stars, was constructed from CCD images taken on UT March 15-17, 1997 with the Swope 1-m at Las Campanas Observatory through the Washington $M$ and $T_2$ filters and covering ~ 1 deg$^2$ around ω Cen. We also have images in the gravity-sensitive, intermediate-band DDO51 filter, which allows us to discriminate foreground field dwarfs from giants (Majewski et al. 1999, “MOKP”). We proceed by limiting our analysis to all stars with magnitude errors < 0.05 mag. Next, by using the $(M - DDO51)_o$ color, which is sensitive to the Mg features around 5150Å, we weed out dwarfs from giants (MOKP; Fig. 2); this exercise is particularly helpful for finding stray, metal-rich ω Cen giants among Galactic foreground stars, and allows us to explore the cluster to low densities without fear of Galactic dwarf contamination.

Metallicities are obtained from the secondary dependence of the DDO51 filter on metallicity, and
the metallicity scale is obtained (Fig. 2; see MOKP) by adjusting the Pal toglo& Bell (1994) synthetic photometry to stars observed spectroscopically by Sun tzeff & Kraft (1996, “SK”).

The “raw” MDF is shown in Fig. 3 (dashed + solid lines). As a check on the possibility of field giant contamination in our sample, we obtained radial velocities from Du Pont 2.5-m spectra for all of the giant stars with $1.35 < (M − T_2)_o < 1.40$. The velocities of this sample show a rather sharp division in that all but one of 31 giant stars with photometric $[\text{Fe/H}] > −1.19$ are not members of ω Cen (and the one member in this interval has a photometric $[\text{Fe/H}] = −1.14$), while all 32 giants with lower photometric $[\text{Fe/H}]$ are ω Cen members. Presumably the non-member giants are from the field disk population. We have applied this near-step-function membership probability distribution to correct the MDF, as shown in Fig. 3 (solid lines). Our technique becomes insensitive outside of $−2.23 < [\text{Fe/H}] < −0.47$, and we show outliers at the edge of our MDF.

3 Discussion

We discuss several particularly germane features of ω Cen:

**MASS and SHAPE** The large mass ($M \sim 7 \times 10^6 M_\odot$, the most massive Galactic globular) and flatness ($\epsilon = 0.121$, Geyer et al. 1983, compared with a median of 0.006 and mode of 0.03 for a sample of 100 globulars, White & Shawl 1987) are the most obvious characteristics that distinguish ω Cen from other globulars in the Milky Way. That the major axis of ω Cen is almost perpendicular to the orbit derived by Dinescu et al. (1999) is not a problem for our hypothesis that ω Cen may be in the process of tidal disruption since the observed flattening is due to rotation and probably primordial (Merritt et al. 1997). Low latitude, differential reddening problems over the scale of several tidal radii ($r_t \sim 45^\prime$) will make a search for the likely more extended ω Cen tidal features difficult (see Meylan discussion of his work with Leon and Combes in these proceedings).

**ABUNDANCE** The chemical composition of ω Cen has long been recognized as atypical for globulars. A number of papers have analyzed the MDF, and agree that it is at least very wide, with a tail towards high $[\text{Fe/H}]$ (Norris at al. 1996, SK). Our results affirm the significant spread, with a well populated MDF at all $[\text{Fe/H}]$ where our technique is sensitive, but with few stars having $[\text{Fe/H}] \geq −1.2$. The spread points to a complex formation process, and one that may have left a curiously inhomogeneous spatial and kinematical distribution of stars with different $[\text{Fe/H}]$ (Jurcsik 1998, NFMS).

**AGE** Wallerstein (this conference) reports a 4 Gyr age spread in ω Cen. We cannot confirm this from our data: Although the MSTO region in the Hess diagram (Fig. 1) appears to be wider than one would expect solely from the metallicity spread observed in the giant branch (which should have a similar width for a given single age), we are reserved in our interpretation because of degenerate combinations of $[\text{Fe/H}]$ and age that can account for the MSTO spread.

**ORBIT** The orbit of ω Cen is also rather unusual in that it is relatively strongly retrograde, but of
a small size, and relatively confined to the Galactic plane. A comparison to other clusters is made in Fig. 4, which shows orbital inclination to the Galactic plane, $\Psi$, versus the normalized orbital angular momentum, $L_z/L_{z,\text{max}}$ (where $L_z$ is the actual angular momentum, and $L_{z,\text{max}}$ the orbital angular momentum of a circular orbit of the same total energy). The upper-left panel of Fig. 4 shows all clusters with orbital data (38 clusters), with $\omega$ Cen labeled. The other panels show different groups of clusters defined by their horizontal branch (HB) morphology and metallicity (Zinn 1996): BHB – blue HB clusters for their metallicity (typical first-parameter clusters), MP– metal poor clusters ([Fe/H] $\leq$−1.8), and RHB – red HB clusters for their metallicity (second-parameter clusters). Two metal-rich disk clusters are also labeled in the BHB sample.

From the standpoint of the orbital trends in Fig. 4 alone, $\omega$ Cen shows the worst fit with the very cluster group to which it normally would be assigned, i.e., the BHB group. A better orbital match is had with the RHB group, however, the size (and therefore total energy) of $\omega$ Cen’s orbit is much smaller than that of the RHB clusters (the smallest apocentric radius in the RHB group is $\sim$ 11 kpc, compared to 6.4 kpc for $\omega$ Cen, Dinescu et al. 1999), and, in any case, $\omega$ Cen has an unambiguous, very blue HB. The mean [Fe/H] of $\omega$ Cen is only slightly higher than the upper limit for the MP group, which also might be taken to show a better match to $\omega$ Cen’s orbital properties; however, the one cluster (NGC 6779) in the MP group with an orbit almost as extreme as $\omega$ Cen is actually about 0.3 dex more metal poor (at [Fe/H] = −1.94).

A possible scenario producing a strongly retrograde orbit with small apocentric radius and closely confined to the Galactic plane is that $\omega$ Cen originated in, or as, a massive satellite (that happened to have an originally retrograde orbit) that experienced significant dynamical friction from the dark halo, and subsequently also from the disk, before it underwent significant disruption. The present mass of $\omega$ Cen is unlikely to have generated strong enough dynamical friction to modify its orbit to its presently small apocentric radius. This proposed scenario resembles the N-body models of Walker et al. (1996, “WMH”), which show that inclined orbits of satellites first sink towards the Galactic plane before substantial radial decay of the orbit, and significant disruption, ensue. In their models, retrograde satellites face considerable shredding as they pass through the disk.

In light of the characteristics that make $\omega$ Cen unique among Galactic globular clusters, we suggest that $\omega$ Cen may be the surviving nucleus of a dwarf spheroidal that has been accreted by the Galaxy. The abundance, age and orbital parameters of $\omega$ Cen are consistent with such an origin, and a present-day counterpart of this process can be seen in the Sagittarius dSph system, for which the globular cluster M54, which has a mass similar to $\omega$ Cen, has been purported to be the nucleus (e.g., Bassino & Muzzio 1995). The idea that some globular clusters may be the remains of dwarf nucleated ellipticals
Figure 4: Orbital parameters for classes of globular clusters.

(Zinnecker et al. 1988, Freeman 1993) may find representatives in M54 and ω Cen. Moreover, the WMH models predict that the surviving remnants of merging satellites form compact, globular cluster-like bodies as they burrow through the disk. Under this scenario, the more diffuse outer envelope of proto-ω Cen would have been accreted by the Milky Way and contributed to the field halo and thick disk populations. In addition, a disintegrating proto-ω Cen plowing through the disk backwards may have contributed substantial disk heating, perhaps aiding thick disk formation (see WMH).

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