Evidences for the presence of an intermediate mass black hole in Omega Centauri

Eva Noyola¹, Karl Gebhardt², Marcel Bergmann³

1) Max Planck Institute for Extragalactic Physics, 2) University of Texas at Austin, 3) GEMINI observatory

Abstract

The globular cluster Omega Centauri is one of the largest and most massive members of the galactic system. However, its classification as a globular cluster has been challenged by the severity of its central black hole. We measure the surface brightness profile from integrated light on an HST/ACS image of the center, and find a central power-law cusp of logarithmic slope -0.08. We analyze Gemini GMOS-IFU kinematic data for a 5" x 5" field centered on the nucleus of the cluster, as well as for a field 14" away. We detect a clear rise in the velocity dispersion from 18.6 km/s at 14" to 23 km/s in the center. Given the very large nearly flat core in Omega Centauri (2.55"), an increase in the dispersion in the central 10" is difficult to attribute to stellar remnants. An isotropic, spherical dynamical model requires a highly concentrated configuration of dark remnants assuming a constant M/L of 2.7 for the visible stars within the core. We create a series of orbit-based models in order to explore possible anisotropies that would produce the observed velocity dispersion rise. The best-fitting model rules out such anisotropies and implies a black hole mass of 4.0 ± 0.04 × 10⁶ M☉ and excludes the no black hole case at a great significance.

Photometry

We measure integrated light from an ACS F813W image applying the technique in Noyola & Gebhardt (2006), which uses a robust statistical estimator, the bi-weight, to calculate number of counts per pixel on a given annulus around the center of the cluster. As a test, we also measure the profile from a narrow band H-alpha image with lower spatial resolution. Since both images have a limited radial extent, we need to complete the SB profile to cover the entire cluster: for this we use the Chebyshev fit of Trager et al. (1995). This profile also provides the means to normalize our photometry, so in effect, we are updating the profile for the inner 40". The measured central photometric points from the two images are consistent as can be seen on Figure 2. The solid line is a fit to the combination of the photometric points from ACS inside 40" and Trager's Chebyshev fit outside 40". For comparison, we include Trager et al photometric points in the plot. The surface brightness profile shows a consistent rise toward the center with a logarithmic slope of -0.08, which is in contrast to the common notion that ΩCen has a flat core. Baumgardt et al. (2005) performed N-body models of star clusters containing a central black hole. They predict the formation of a shallow cusp of -0.25 logartihmic slope.

Models

In order to explore the effect of a central black hole inside ΩCen, we create a set of isotropic models using the non-parametric method described in Gebhardt et al. (1996). We deproject the surface brightness profile to obtain a luminosity density profile. Assuming a constant mass luminosity ratio of 2.7, we obtain a velocity dispersion profile. We then add a central black hole mass of various masses ranging from 5×10⁶ M☉ to 7.5×10⁹ M☉. Figure 4 shows the comparison of the different models and the measured dispersion profile. As it can be seen, an isotropic model with no black hole present predicts a small decline in velocity dispersion, but we instead observe a clear rise toward the center. Thus Cen has a close to flat central density profile, this implies that the potential is very shallow and therefore mass segregation cannot be an important effect. If we assume the velocity rise due to an extended dark component, the density profile for such component is required to be very cusp configuration that makes it practically decoupled from the luminous component (Fig. 5). Such a concentrated component is not expected to be stable over the age of the cluster, so it is unlikely to be the explanation for the rise. Lastly, we also create orbit-based models (Gebhardt et al., 2003) to explore the effects of anisotropy. We find that anisotropy cannot account for the observed velocity dispersion rise above.

References


Kineamtics

We obtain nod-and-shuffle observations using the GEMINI-GMOS integral field unit (IFU) with a 5" x 5" field of view. Two fields are observed, one around the cluster center and one more centered 14" away from it. We obtain a spectra for every fiber on each field and analyze the Ca triplet region (450 to 8700 Å). Figure 3 shows the reconstructed image from the IFU fibers for the central frame and the acquisition image as well as the same region on the ACS image. We also show a convolved image of the ACS frame. The same match is performed for the field 14" away. Both ACS fields contain ~110 resolved stars. We measure the velocity dispersion from the integrated spectra of the ~40 brightest stars. We use an archival UVES spectrum as a template to measure velocity dispersion of the combined spectra. We combine individual spectra using a bi-weight estimator for each frame. Since we do not want to be dominated by the brightest stars, a cut in brightness is chosen in order to exclude the fibers for which the contribution of a single bright star is large. Once the bright fibers have been excluded, we combine the spectra of all remaining fibers into one and we use it to measure line of sight velocity dispersion (LOSVD). Our analysis technique uses a maximum-likelihood likelihood estimate to obtain a nonparametric line of sight velocity distribution, it is described in detail in Gebhardt (2000). We measure a 23 km/sec dispersion for the central field and 18.6 km/sec for the field 14" away. The latter value coincides with the central velocity dispersion value measured for ΩCen by various authors. The two measurements provide us with the two intermediate points of a velocity dispersion profile completed with radial velocity measurements of individual stars (Fig. 4).

M-(σ o), relation

Figure 6 shows the M-(σ o) relation established for early galaxies and bulges (Tremaine et al., 2002). For comparison, we plot intermediate mass black holes measured in low luminosity AGNs and those measured for a few globular clusters (M15, ΩCen and 47 Tuc). It can be seen that the few globular clusters lie on the low-mass extrapolation of the relation within the scatter. It is worth nothing that both ΩCen and 47 Tuc are suspect nuclei of accreted dwarf galaxies, which might explain the fact that they follow this correlation.

Figures 1-6: Photometry, Kinematics, Models, M-(σ o) relation, etc.

Fig 1: Two images of Omega Centauri. Left: A wide field image which was the "astronomy picture of the day", by Steve Crouch. Right: WFCPC Hubble Heritage image of the central region.

Fig 2: Surface brightness profiles for ΩCen. The circles show our measured photometric points from the ACS (full) and Hα images. The triangles show photometric points from ground based images by Trager et al. The dotted line is Trager's Chebyshev fit. The solid line is our smooth fit to the combination of the ACS points inside 40" and Trager's.

Fig 3: The central field observed with the IFU. a) ACS image of the observed region. The red circle marks the center of the cluster. b) Convolved ACS image. c) GMOS acquisition image. d) Reconstructed GMOS-IFU image.

Fig 4: Our measured velocity dispersion profile over a series of isotropic spherical models containing varying BH masses. The filled squares indicate the measurements from the two GMOS points, while the open circles are measured from individual radial velocities.

Fig 5: Deprojected density profile for the luminous component (solid line) assuming a constant M/L ratio. The dashed line represents the density of the extended dark component needed to reproduce the observed kinematics.

Fig 6:M-(σ o) relation for elliptical galaxies and bulges (filled points). Filled triangles are low luminosity AGNs. Filled pentagons are globular clusters.