**ABSTRACT**

We present observations of the Main-Belt Comet P/2008 R1 (Garradd) allowing the study of the object’s phase function. Main-Belt Comets are characterized as having orbits indistinguishable from main-belt asteroids and exhibiting cometary activity. While inactive, images of Garradd were taken by the Gemini North telescope atop Mauna Kea allowing us to measure the absolute magnitude $H_p = 20.3 \pm 0.1$ mag and slope parameter $G_p = 0.08 \pm 0.05$ used in the IAU phase function. Assuming an R-band albedo of $p_R = 0.05$ we determine an effective radius of $r_e \approx 0.22$ km. Knowledge of the phase function and radius allows us to look at 2008 observations of Garradd when it was active and quantify dust mass loss.

**INTRODUCTION**

First identified in 2006 [1], main-belt comets (MBCs) have orbits completely confined to the main asteroid belt yet exhibit cometary activity indicative of the sublimation of volatile ice. By providing evidence that ice exists in the present-day asteroid belt, they present an invaluable opportunity to evaluate the plausibility of hypotheses that icy main-belt objects may have played a significant role in the primordial delivery of terrestrial water [2].

MBC P/2008 R1 (Garradd) (semimajor axis, $a = 2.726$ AU; eccentricity, $e = 0.342$; inclination, $i = 15.90^\circ$) was the fourth MBC to be discovered and was thoroughly studied by [3] while it was active. [3] estimated a dust production rate of 1.5 kg s$^{-1}$ during its 2008 activity and determined that it was dynamically unstable on timescales of ~ 20 - 30 Myr. This dynamical result indicates that P/Garradd is unlikely to be native to its current location, and is thought to originate elsewhere in the asteroid belt, perhaps in the outer belt where other MBCs are found [3]. An origin elsewhere in the outer solar system, however, cannot be ruled out. Photometry by [3] indicated that the nucleus had an effective radius no larger than $r_e < 0.7$ km, but since the object remained active throughout their observational campaign, they were unable to ascertain the true nucleus size.

**OBSERVATIONS**

Images were taken using the 8 m Gemini North telescope located at Mauna Kea Observatory in Hawaii. The imaging mode of the Gemini Multi-Object Spectrograph (GMOS), which uses the Sloan Digital Sky Survey g′r′i′z′ filters, was used along with non-sidereal tracking along the motion of Garradd in all observations. In this study of Garradd observations were taken when the object has just passed aphelion where it is not suspected to harbor visible dust production. A plot of the locations of Garradd in its orbit when it was observed to be active in 2008 and observations for this study in 2011 are included in Figure 1. Data was collected on six nights between UT 2011 February 5 and April 1 (Figure 2).

Standard image calibration (bias subtraction and flat-field reduction) was performed for all images. Flat fields were constructed from dispersed images of the twilight sky. Absolute calibration of object magnitude was done using a selection of 3 - 8 field stars from the SDSS catalog [4] and a circular aperture around the object ranging from 0.5' to 0.7', depending on the seeing conditions during each night. We transform our measurements to the BVRI system assuming solar colors, to allow our phase function to be computed in the R-band.

**DUST ACTIVITY**

Using the parameters obtained from the phase function of Garradd we can estimate the amount of dust that was present in the 2008 observations. The calculated reduced R-band magnitudes are used with the predicted reduced magnitudes to determine the ratio of scattering surfaces of dust, $A_d$, to that of the nucleus, $A_N$, using

$$ A_d = \frac{A_N - 10^{A_N (2.5 \log (1+p_R + A_N))}}{10^{A_N (2.5 \log (1+p_R + A_N))}} $$

where $m_{dust}$ is the calculated reduced magnitude from [3] when the total flux of Garradd was measured, including dust surrounding the coma, and $m_{N}$ is the expected reduced magnitude according to the IAU phase function with our newly measured parameters. Using the estimated radius for Garradd in Section 2, a total dust mass can be calculated if we assume $a = 10 \mu$m radius grain size with bulk density $\rho = 1300$ kg m$^{-3}$ [5] by the following:

$$ M_d = \frac{4}{3} \pi a^3 \rho \left( \frac{2}{3} \right) $$

Dust to nucleus scattering surface ratios and dust mass values derived from the 2008 observations of Garradd are included in Table 1, along with the predicted magnitudes presented in [3].

**DISCUSSION**

Based on the magnitude measurements of Garradd on the nights of March 31, 2011 and April 1, 2011 the photometric range for the object is > 0.8 mag. This value, along with a rotation period, can be constrained by further, more comprehensive observations of Garradd while it remains inactive. Currently, most MBCs consistently show activity only near perihelion [9], thus it is important to monitor Garradd during its next perihelion passage in January 2013. Observations of further dust loss will confirm that Garradd’s activity is cometary and driven by the sublimation of water ice at or beneath the surface. The range of activity over next perihelion can be measured, and compared to other MBCs to investigate the driving mechanism behind cometary activity.

**CITATIONS**