NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: March 26, 2008 **Category:** Stellar Remnants

Measuring the Surface Inhomogeneity of Calciuim on G 29-38

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:

In the last three years a handful of white dwarfs (WDs) with circumstellar debris disks have been discovered. The debris disks are either left over from the late stages of stellar evolution or are the result of tidally disrupted asteroids or comets, and are thus signposts of planetary systems. At present, we do not understand the accretion process, even at the basic level of whether magnetic fields channel the accreting material onto the star or the physical thickness of the disk.

The pulsating WD G29-38 is the prototype debris disk WD; it is the brightest such WD known and it has the most pronounced IR excess. We plan to take advantage of the pulsations of G29-38 to measure the surface inhomogeneity of calcium. Due to the short timescale of gravitational settling as compared to horizonatal mixing, we expect a larger abundance of calcium at the latitude of accretion from the debris disk. This will be the first test of chemical inhomogeneity in a WD due to non-spherical accretion and it will constrain the geometry and size of the inner debris disk.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	GEM-NQ	GMOSN	2	bright	Sep - Sep	Sep - Oct
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to four lines).*

G29-38 is known to show different pulsation periods each observing run, so it is best if the photometry closely aligns with the spectroscopy. To get the most out of the photometric observations, with the fewest number of telescopes, we must choose nights where G29-38 is up for the entire night. Therefore we restrict the Gemini Observations to fall between September 1 and October 10.

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

Twenty years ago the white dwarf (WD) G29-38 was discovered by Zuckerman & Becklin (1987) to have a pronounced IR excesses, which we now know (Reach et al. 2005, and references therein) to be caused by silicate dust in a debris disk. These objects are not rare – seven other dusty debris disk WDs are known (Becklin et al. 2005; Kilic et al. 2005, 2006; Kilic & Redfield 2007; von Hippel et al. 2007; Jura et al. 2007). Presently, observations outpace theory, yet it appears WD debris disks are caused by the tidal disruption of comets or asteroids that stray too close to the WD (Debes & Sigurdsson 2002; Jura 2003; von Hippel et al. 2007; Zuckerman et al. 2007).

WDs with $T_{\rm eff} \lesssim 25000$ K have an amazing property that intimately connects current accretion to their photospheres. The gravitational settling time for heavy elements in their high gravity atmospheres is weeks to years (e.g., Dupuis et al. 1992; Koester & Wilken 2006). For G29-38, the timescale for 1/e depletion of Ca is just 7 days (from the tables of Koester & Wilken).

Given that G29-38 is actively accreting metals, it is natural to assume that the distribution of metals on its surface is nonuniform, since accretion usually occurs from a disk onto a star's equator or onto a star's pole, as in magnetic accretion. Other than gravitational settling, the only other process affecting the metal distribution is horizontal mixing due to convective turbulent fluid motions. G29-38 has a surface convection zone, and the competition between horizontal mixing and gravitational settling should determine the metal distribution (see Fig. 1).

Besides having a debris disk and atmospheric metals, G29-38 is a pulsating star (Kleinmanet al. 1998) with luminosity variations of order 30%. These luminosity variations are caused by temperature changes on the observed face of the star, which also affect the strengths of its metal lines. We have recently developed a technique which uses the varying strength of the Ca line on G29-38 to constrain the distribution of metals across the stellar surface. This allows us to determine whether the metals have a higher abundance at either the equator or the pole, or whether they are distributed uniformly across G29-38's surface. This, in turn, will determine whether the metals are being accreted onto the star's equator or pole.

Our technique rests on the fact that WD pulsations are nonradial so that induced temperature changes are *not* uniform across the stellar surface. Since the equivalent width (EW) of a line is a function of the local temperature, a pulsation mode produces a change in the observed EW as well as in the observed total flux of the star. The diagnostic we have developed is $R \equiv A_{\rm EW}/A_F$, where $A_{\rm EW}$ is the amplitude of the fractional EW variation (δEW/EW) and A_F is the amplitude of the fractional flux variation ($\delta F/F$). While these values depend strongly on whether the metals have a polar or equatorial distribution (Fig. 2), they also depend to a lesser extent on the inclination angle $\theta_{\rm i}$, which is the angle between the pulsation axis of the star and our line of sight.

G29-38 simultaneously drives several pulsation modes sampling a range of different ℓ and m values (see Clemens 2000 and Kleinman 1998). If G29-38 has a nonuniform surface distribution of metals, then the zeroth order indication of this will be different R values for modes with different ℓ and m values and a clustering of R values for modes with the same ℓ and m values; this will be straightforward to measure. In addition, the ℓ and m values for many of the larger modes can be obtained from how the Balmer lines change due to the pulsations (Clemens et al. 2000) and from light curve fits to simultaneous photometry, the latter will also give the inclination angle $\theta_{\rm i}$ (Montgomery 2005). These techniques, should provide ℓ and m values for many modes, which can then be used to place constraints on the distribution of metals on G29-38's surface. This will be the first direct test of chemical inhomogeneity due to non-spherical accretion, and it should constrain the geometry and size of the inner edge of the debris disk.

References

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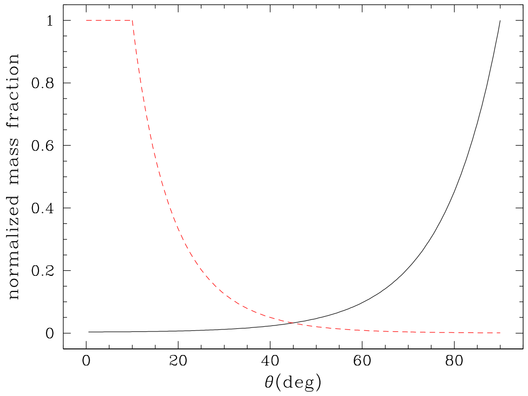

Figure 1: Two possible metal distributions, using the settling timescales of Koester & Wilken and estimates from our models for the horizontal mixing rate. The expected Ca abundance profiles are given as a function of polar angle, θ, the distance from the star's pulsation axis. The solid curve is for accretion onto the equator and the dashed curve is for accretion onto a polar cap having $\theta \leq 10°$.

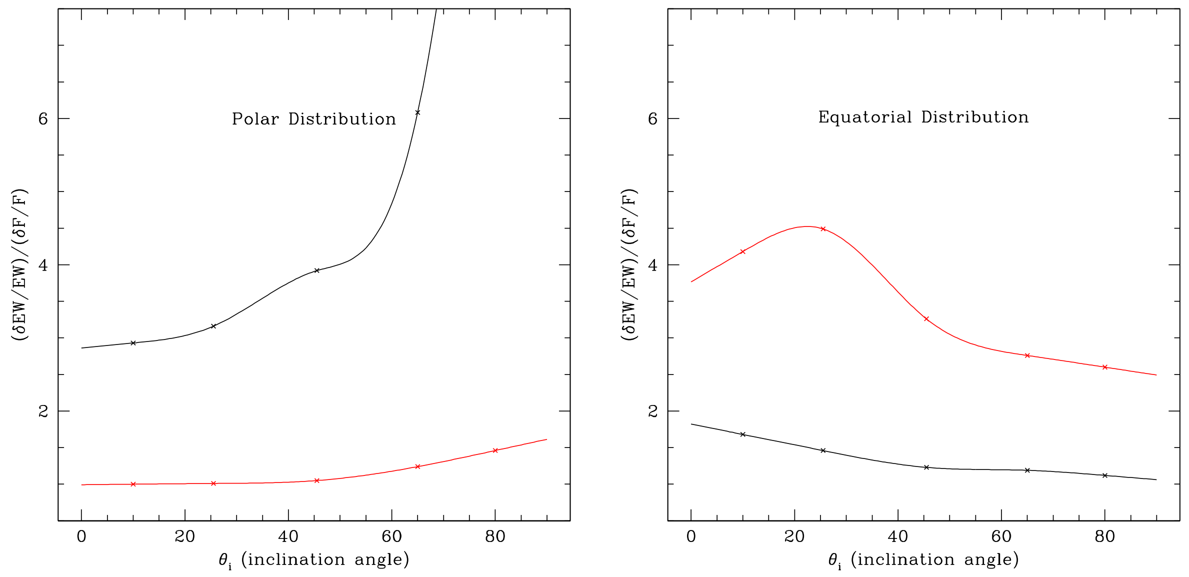

Figure 2: The ratio of the fractional equivalent width amplitude of the Ca line (due to a pulsation mode) to the fractional flux amplitude (of the same pulsation mode), as a function of the inclination angle $\theta_{\rm i}$. The black curves are for an $\ell = 1$, $m = 0$ mode, and the red curves are for an $\ell = 1$, $m = 1$ mode.

Experimental Design *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. (limit text to one page)*

To determine the calcium distribution on G29-38 we must accurately measure the pulsation periods (between 1000s and 200s), their fractional flux amplitudes (<4%), and calcium's fractional equivalent width (EW) amplitudes. We plan to take advantage of our deep involvement with the Whole Earth Telescope (WET) network to obtain photometric time series to accurately measure each pulsation's flux amplitude and periods. Gemini with GMOS-N will gather enough light in short enough exposures to measure the variations in Ca EW that occur with the pulsations. In 10 hours of data from Gemini we expect $<8\%$ error in the Ca EW amplitude. With both the photometric and spectroscopic observations we will distinguish between a polar and an equatorial Ca distribution.

Typically, half a dozen modes are strongly driven ($4\% > A_{\rm F} > 1\%$) at any one time on G29-38 (Kleinman et al. 1998). While only one pulsation mode is necessary to determine if the Ca distribution is uniform, polar, or equatorial, we are more likely to observe several modes, each giving us an independent measurement of the Ca distribution.

The amount of spectroscopic data we need depends on the expected amplitude of the Ca EW. These were measured by von Hippel & Thompson (2007) to be on the order of 10% for the larger flux amplitude modes ($A_{\rm F} = 2.5\%$). While the amplitudes are consistent with the theory presented by Koester & Kompa (2007), their Ca EW amplitudes are not precise enough to distinguish between different surface calcium distributions. The spectral signal-to-noise and resolution at the calcium line were not sufficient to obtain the necessary accuracy in the Ca EW. Additionally, the 4–6 hours of these spectroscopic series were not enough to resolve closely spaced modes. If one measures two modes as one, one would have inaccurately measured both the flux and the Ca EW amplitudes.

Our observing plan for G 29-38 will improve over these previous observations in three ways: 1) We will increase the spectral dispersion and resolution to properly sample the Ca line. 2) We will spread the spectroscopic observations over at least two nights to increase the frequency resolution of the pulsation modes, enabling us to distinguish closely spaced modes. 3) We will use concomitant photometry to accurately measure all the periods and flux amplitudes of the pulsation modes.

The first two improvements will be carried out by obtaining time series spectroscopy with Gemini-N and are explained in the GMOS description of this proposal. The third improvement comes from obtaining time series photometry at the same epoch as the Gemini observations. We plan to use our connections with the WET to acquire at least one week of photometry with 1-2 m class telescopes. We plan to use approximately 3 telescopes placed at different longitudes to gain nearly constant temporal coverage. This reduces alias peaks in the Fourier transform and will allow us to choose the correct pulsation periods. Overall, we expect to obtain a frequency resolution of $\leq 3\mu$Hz and $\leq 1\%$ error in the fractional flux amplitudes.

Since G 29-38 is a bright, northern target, the WET has a variety of telescopes that can donate several nights on short notice to coincide with the Gemini Observations. A similar event was carried out in November 2007 where we gathered 10 telescopes to observe a pulsating white dwarf star (m_v=15 mag) in less than one month to coincide with time we suddenly obtained at a 3.5 m telescope (see Thompson et al. 2008). We will have little trouble gaining similar extended photometry for G 29-38 within 3 weeks of the spectroscopy obtained by Gemini.

Proprietary Period: 18 months