Observing Time Request
MDM Observatory

Date: May 4, 2013	*Proposal number:*

TITLE: Probing the Milky Way's Dark Matter Halo with RR Lyraes in Tidal Debris: the Triangulum-Andromeda Stellar Feature

PI: Adrian Price-Whelan adrn@astro.columbia.edu Y

CoI: Allyson Sheffield asheffield@astro.columbia.edu Y

CoI: Kathryn Johnston kvj@astro.columbia.edu N

CoI: Branimir Sesar bsesar@astro.caltech.edu N

Abstract of Scientific Justification: This proposal requests time to obtain radial velocity measurements for a sample of RR Lyrae in the Triangulum-Andromeda stellar cloud – one of several amorphous stellar structures discovered recently in the Galactic halo. Models suggest that, like the more well-known stellar streams, these clouds could result from the disruption of satellites during the hierarchical formation of our Galaxy. Thus, this debris is equally suited for probing the shape, orientation, and radial profile of dark matter in the Galactic halo. At the distance of TriAnd ($\sim$ 25 kpc), we will soon have accurate proper motions from GAIA. Combined with accurate distances using the mid-IR period-luminosity relation for RR Lyrae, we only need radial velocity measurements to obtain full 6-D phase-space information for this sample of stars. We will then use this 6D information to model the orbit of the progenitor and subsequently infer new constraints on the mass, axis ratios, and orientation of the Milky Way's dark matter halo.

- *Is this proposal part of a PhD thesis?* N
- *Requesting long-term status? If 'Y', please give # of semesters and nights on the next line.* ____

Summary of observing runs requested for this project

Run	Telescope	Instrument, detectors, grisms, gratings, filters, camera optics, etc.
1	2.4-m	ModSpec, Wilbur, 600 l mm^{-1} blazed at 5000 Å
2		
3		

Run	No. nights	Moon age (d)	Optimal dates	Acceptable dates
1	5	grey	Oct 4 - Oct 8	Oct 1 - Oct 20
2				
3				

- *List dates you cannot use for non-astronomical reasons on the next line.*

Scientific Justification *Try to include overall significance to astronomy.*

Galaxies, by mass, are mostly composed of *Dark Matter*. Simulations of structure and galaxy formation – both with and without baryons – lead us to believe that such *halos* of dark matter have universal density profiles (Navarro, Frenk, & White 1997) and are triaxial in shape (Jing & Suto 2002). Including baryons in such simulations tends to soften the triaxiality and alters the radial density profile. Thus, precise measurements of the shape, orientation, and radial profile of dark matter halos provides information about both dark matter physics and the baryonic processes that helped shape them. Tidal streams from infalling satellite galaxies have been used to constrain properties of the Milky Way's halo (e.g., Law & Majewski 2010); typically found outwards of 20 kpc, the orbits of associated stars are still largely under the influence of the dark matter and thus serve as potentiometers (e.g., Johnston et al. 1999). Using an updated method that utilizes full phase-space (6D) kinematic information for a small sample (∼100s) of stars stripped from a known progenitor (Law & Majewski 2010; Price-Whelan et al. 2013, in prep), it is possible to accurately constrain the axis ratios, total mass, and orientation of the Milky Way's dark matter halo. This method relies on a technique for deriving distances to individual RR Lyrae stars with 2% accuracy (Madore & Freedman 2012), along with anticipated GAIA proper motion errors of $\sim 10 - 20$ μas/yr for such stars at ∼ 20-30 kpc. This leaves one remaining velocity component – the radial velocity.

Figure 1 shows an application of this method to simulated observations of star particles from the Law & Majewski (2010) N-body simulation of the Sagittarius stream. By bootstrap resampling the observed particles, we can empirically estimate the errors on the derived halo parameters. The points in the figure show inferred parameters for 100 bootstrap resamples of the observed particles and the vertical/horizontal lines show the parameters used in the simulation. Though morphologically disparate, Sagittarius and TriAnd are both coherent debris structures formed from disrupted, infalling satellites; thus, this method is applicable to TriAnd.

We plan to observe a sample of RR Lyrae stars selected to be likely members of the TriAnd structure using a catalogs of RRab stars from the Palomar Transient Factory (Law et al. 2009).

References

Jing, Y. P., & Suto, Y. 2002, ApJ, 574, 538

Johnston, K. V., Zhao, H., Spergel, D. N., & Hernquist, L. 1999, ApJL, 512, L109

Law, D. R., & Majewski, S. R. 2010, ApJ, 714, 229

Law, N. M., Kulkarni, S. R., Dekany, R. G., et al. 2009, PASP, 121, 1395

Madore, B. F., & Freedman, W. L. 2012, ApJ, 744, 132

Navarro, J. F., Frenk, C. S., & White, S. D. M. 1997, ApJ, 490, 493

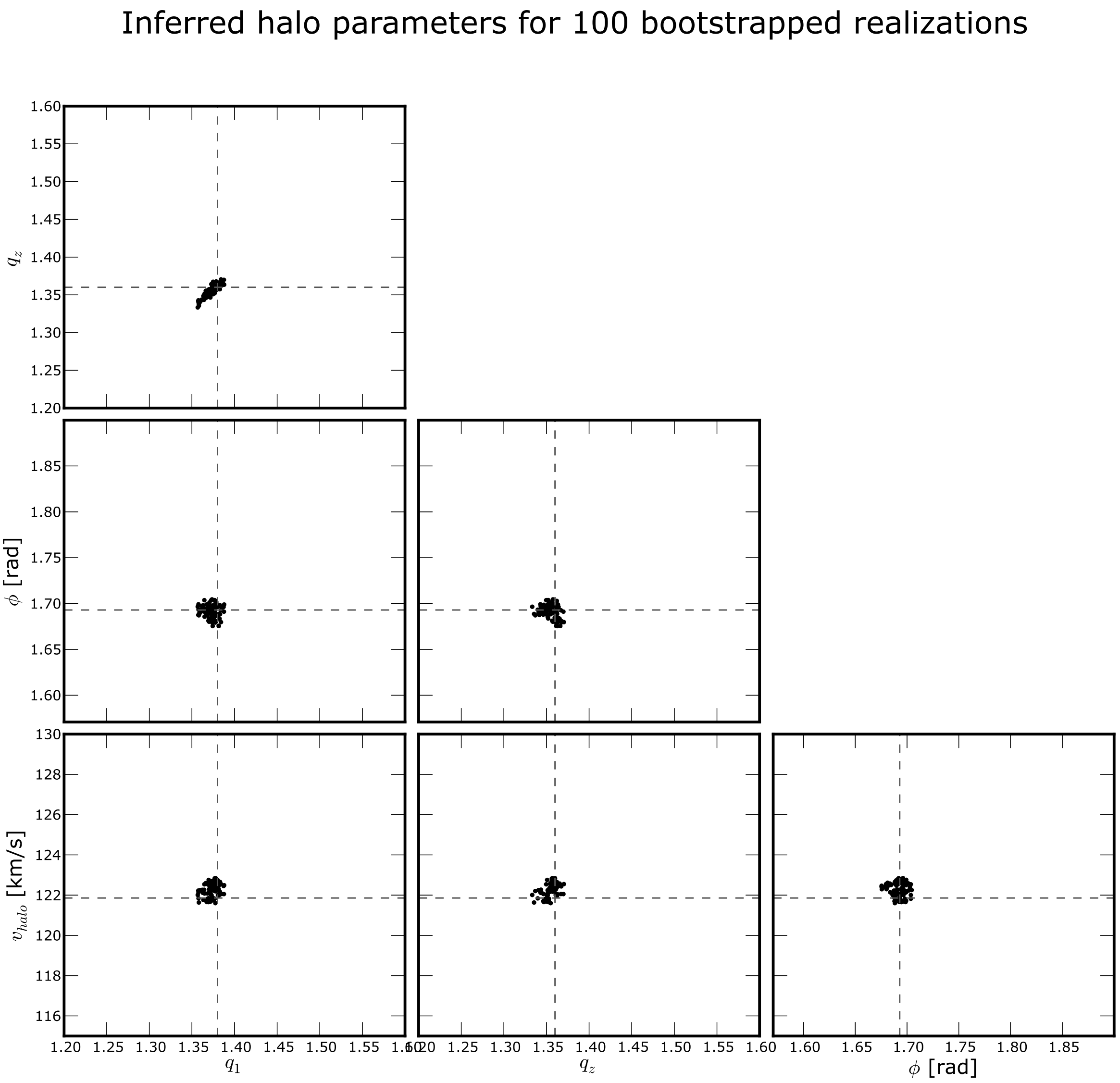

Figure 1: The results of bootstrap resampling of particles from the Law & Majewski (2010) simulations of the Sagittarius tidal stream. The panels show several different halo parameters.

Technical and Scientific Feasibility *List objects, coordinates, and magnitudes (or surface brightness, if appropriate), desired S/N, wavelength coverage and resolution. Justify the number of nights requested as well as the specific telescope, instruments, and lunar phase. Indicate the optimal detector, as well as acceptable alternates. If you've requested long-term status, justify why this is necessary for successful completion of the science.*

Our program aims to observe a sample of 35 RR Lyrae stars selected to be likely members of the TriAnd stellar structure. The RR Lyraes that we will target span the sky in the region roughly $0^h < \alpha < 4^h$ and $30^\circ < \delta < 40^\circ$. This range of equatorial coordinates is best observed in October 2013.

All targets are selected as RR Lyraes and the range in magnitude is $16.2 \leq R \leq 18.2$, with the majority, 33, having $R < 17.5$.

Using the 600 groove mm^{-1} grating blazed at 5000 Å and a 2048x2048 detector with 15 micron pixels (Wilbur), we will have wavelength coverage of about 1300 Å including the Hβ line at 4861 Å and the [OI] sky line at 5577 Å (the latter to aid in the radial velocity determination by identifying any systematic offsets). We will collect bias and flat field (quartz lamp) frames at the beginning and end of the night, and ThAr arc lamp spectra for wavelength calibration will be taken throughout the night to account for telescope flexure. Radial velocity standards will be selected that are of a similar spectral type as the targets.

We expect to be able to get an RV precision of 15-20 km s^{-1}, which is sufficient for this work. Using the IRAF *sptime* task, we expect to be able to achieve S/N=20 per pixel in 750 sec for a $R = 16$ RR Lyrae, and in 2400 sec for one of the faintest targets at $R = 17.5$. An average exposure time is 1200 seconds. With 1-2 hours every night reserved for obtaining RV standards and calibration frames, we can expect to observe about 10 targets per night. We request 5 nights to obtain spectra of 35 RR Lyrae stars, with multiple observations at different points on the RR Lyrae light curves.

Tech Spec Summary:

Groove density: 600 lines mm^{-1}

Blaze λ=5000 Å

CCD="Wilbur": 15 μm pixels

Why MDM? *If other optical/IR facilities are being used for this project, explain the role that MDM observations will play.*

ModSpec on the 2.4-m Hiltner Telescope is a good choice for our TriAnd RR Lyrae radial velocity survey – the stars are too faint for the 1.3-m telescope but we will be able to observe our entire target list easily over a few nights with the 2.4-m. Our group has already identified members of the TriAnd stellar feature using ModSpec on the 2.4-m.

How is it Going? *List your allocations of telescope time at MDM during the past 3 years, together with the current status of the project (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. For ongoing projects, are they achieving their goals?*

Co-I Sheffield has used both the 1.3-m and 2.4-m telescopes at MDM:

- Mark III on the 1.3-m telescope in January, 2011. The run was very successful — spectra for close to 200 M giants, and the RVs are preliminarily at the 10-20 km s^{-1} precision level.
- ModSpec on the 2.4-m telescope in May, 2011. This was an excellent run. The SkyCalc application made the acquisition of guide stars a very simple task (more time was needed to do this on the January 1.3-m run).
- ModSpec on the 2.4-m telescope in November, 2011. TriAnd stellar cloud. A generally unsuccessful run, due to weather and instrument problems.
- ModSpec on the 2.4-m telescope in June, 2012. HerAql stellar cloud. Observations to compliment this work will be carried out by Sheffield at the SOAR 4-m from 16-18 July 2013.
- ModSpec on the 2.4-m telescope in October, 2012. Continuation of TriAnd November, 2011 work; publication expected summer, 2013.