Yale Observing Proposal *Standard proposal* **Semester:** *2018B*
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Tidal Tails around Distant Globular Clusters

PI: Pieter van Dokkum **Status:** P **Affil.:** Yale University
Astronomy, P.O. Box 208101, New Haven, CT 06520-8101 U.S.A.
Email: pieter.vandokkum@yale.edu Phone: ________________ FAX: 203-432-5048

CoI: Tim Miller **Status:** G **Affil.:** Yale University
CoI: Sarah Millholland **Status:** G **Affil.:** Yale University
CoI: Lily Zhap **Status:** G **Affil.:** Yale University

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:
Better characterization of the tidal tails associated with globular clusters can reveal how galaxies evolve and interact. The discovery of tidal features around Palomar 14, a globular cluster at a distance of 70 kpc, suggests that tidal shocks may not be the only mechanism responsible for the formation of tidal tails. More instances of tidal features at large distances are required to understand the alternative dynamical processes. Here, we propose using the Dragonfly Telephoto Array to establish a novel, more efficient method for discovering tidal tails using integrated starlight as opposed to the current, time-intensive method of counting stars. Observations of Palomar 14, with a known tidal tail, will establish the efficacy of such a method. This will establish a survey-friendly method for discovering tidal tails, grow the sample size of known tidal features at large distances, and move towards a better understanding of tidal tail formation around globular clusters.

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

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

Background: Tidal tails are ubiquitous around local globular clusters. It is thought that these tails are caused by tidal shocks that arise as globular clusters travel through the galactic disk (Leon et al. 2000). The impulse provided by the disk potential imparts kinetic energy to the stars. This causes some stars to exceed the escape velocity, becoming unbound. Generally speaking, tidal tails are currently identified through observing an overdensity of stars at large radii. Photometric data is needed to identify member stars, calculate the radial density profile and compare to expectations. Although proven successful, this method suffers from the effects of interlopers and the need for ever deeper photometry to observe GC's far from the galactic disk.

The Curious Case of Palomar 14: Palomar 14 is a globular cluster at a distance of 70 kpc. As displayed in Figure 1, Sollima et al. (2011) recently discovered a tidal tail associated with this globular cluster. This is curious as Palomar 14 is in an environment with only weak tidal forces, contradicting the understanding that tidal tails are caused by tidal shocks. The tidal tail of Palomar 14 must have followed a different evolutionary scenario, the details of which remain unclear.

Such tidal features are difficult to find and characterize. The current method for identifying tidal tails requires long exposure times to resolve and count red-giant branch stars within the tails. Main-sequence stars, being less luminous, are even more challenging to find. Due to these difficulties, Palomar 14 remains a unique, and ill-understood case, preventing any concrete understanding of if and how GCs in the halo came to posses tidal features.

This Proposal: We propose to address these issues by searching for tidal tails in the halo via integrated light from unresolved main-sequence stars using the Dragonfly Telephoto Array, which is optimized for this type of low surface-brightness detection. Instead of counting stars, a faint "blob" of emission will be observed. If this "blob" extends to large radii and shows asymmetry, this will be taken as evidence for a tidal tail surrounding the globular cluster.

We propose to observe the globular cluster Palomar 14, which is known to posses a tidal feature. Observations of the integrated light will be compared to pre-existing discovery data, providing a benchmark for this proposed method. Proof of the efficacy of integrated starlight for identifying tidal tails will greatly increase the efficiency of globular cluster surveys in search for tidal features. This will grow the sample size of know tidal tails and pave the way towards a better understanding of inter-galactic tidal dynamics and galactic evolution.

References

Leon, S., Meylan, G., & Combes, F. 2000, A& A, 359, 907

Sollima, A., Martínez-Delgado, D., Valls-Gabaud, D., & Peñarrubia, J. 2011, ApJ, 726, 47

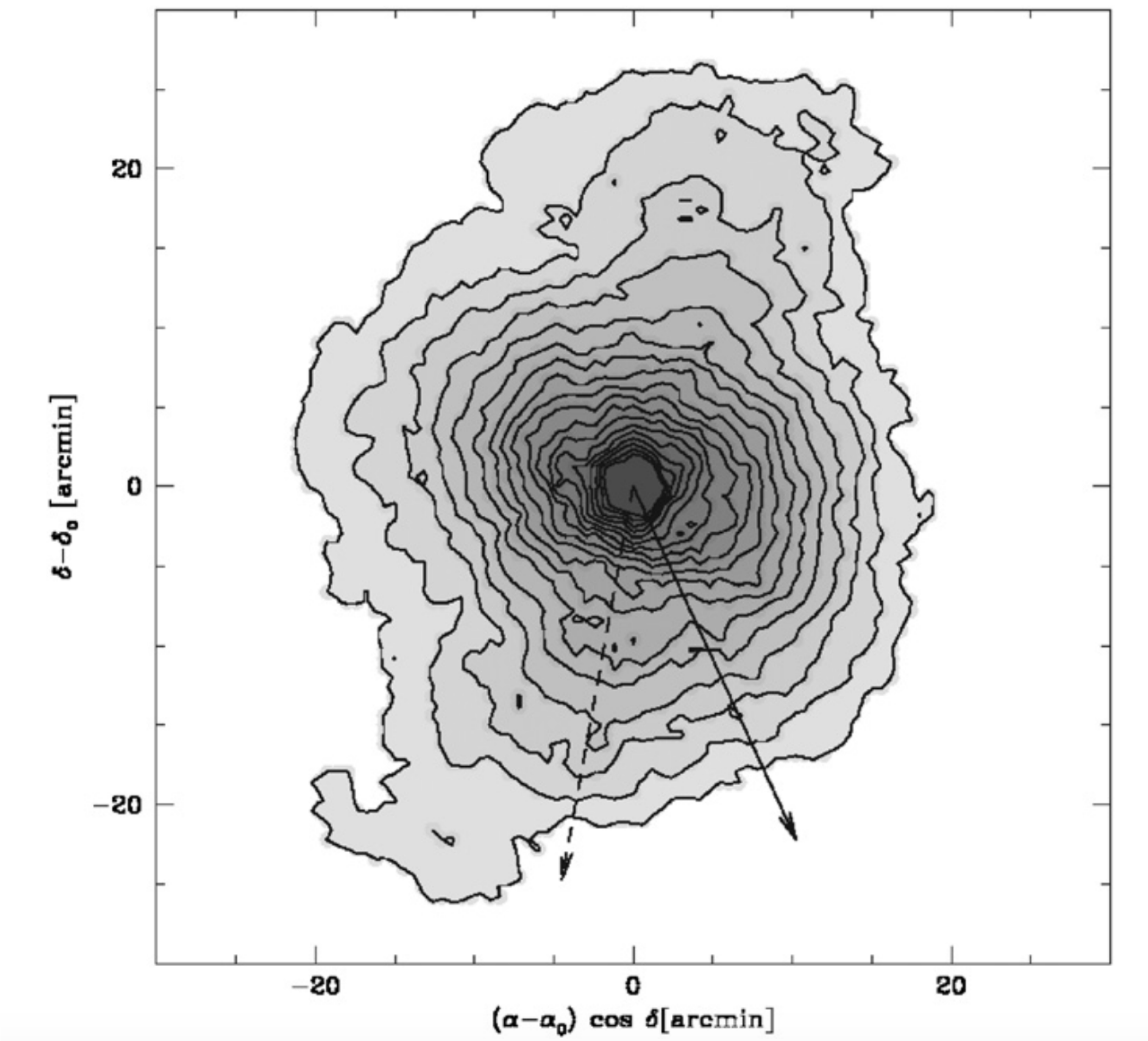

Figure 1: Surface density measurements of the globular cluster, Palomar 14, reproduced from Figure 4 of Sollima et al. (2011). Contours begin at 3σ and increase by 1σ. A tidal feature is seen extending from SW-NE for approximately one degree.

Impact to Yale Astronomy *Describe how this program fits into the Yale astronomy program. Will the data analysis and resulting papers be based at Yale? If the project is led by a faculty member, does the project involve students? What is the role of the PI viz-a-viz other non-Yale co-Is. Are the resources in place to analyze the data and come to a timely publication? (limit text to one page)*

This work, in many ways, is wholly inspired by the work of Yale Astronomy. It was written because of an assignment by a Yale professor and is being completed by Yale graduate students for a class based at Yale. It will allow several Yale graduate students–Tim Miller, Sarah Millholland, and Lily Zhao–to pass their required Yale Observation class and not fail out of Yale graduate school, ruining their Yale-based hopes and dreams. The end goal of these graduate students at Yale is to receive their PhD in astronomy from Yale. The analysis will be led by a combination of very willing graduate and undergraduate students, again at Yale. This analysis is sure to be timely; there are only a four weeks left in the semester.

Previous Use of Yale Facilities and Publications *Please list previous use of Yale observing facilities and any publications resulting from these data in the past 3 years. If this is a long term project, please state this here and describe the overall strategy of the project.*

Observing Run Details for Run :

Technical Description *Describe the observations to be made during the requested observing run. Justify the specific telescopes, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section.* **For Keck proposals only:** *Please include below whether your proposal can be implemented on a different instrument and describe what the resulting impact to your program. This information will not be used unless a program will not otherwise be awarded time on the primary instrument requested.*

What do we expect to see?
As reported in Sollima et al. (2011), the tidal tail of Palomar 14 is observed with a stellar density of ~ 0.5 stars arcmin^{-2}. However, as noted before, this includes only stars down the the main sequence (MS) turn-off due to the photometric limitations of their survey. It is likely that there are a factor of $\gtrsim 10$ times more MS stars that were not observed. This factor could be even larger then expected due to mass segregation in the outskirts of evolved GCs. **Based on these assumptions, we estimate the surface brightness of these tails to be ~ 29 mag arcsec^{-2}.**

Proposal Details:
In this proposal, we ask for 2 hr of integration time. Using the HSC ETC (https://hscq.naoj.hawaii.edu/cgi-bin/HSC_ETC/hsc_etc.cgi) and rescaling appropriately for the Dragonfly Telephoto Array, we calculate that we will reach a surface brightness of 29 mag arcsec^{-2} in both the g and r bands at a SNR of ~ 5 per pixel and ~ 4 per pixel respectively. This calculation assumes spatially binning the data by 8 pix by 8 pix leading to a spatial resolution of $\sim 20''$. Tidal tails around the GC are observed to extend $> 10'$ (Figure 1). This is therefore a reasonable sacrifice of spatial resolution for sensitivity. During the data analysis process, we have the option to more coarsely bin the data to search for even fainter emission at ~ 30 mag arcsec^{-2} on larger scales.

R.A. range of principal targets (hours): One target: $16^{\mathrm{h}}11^{\mathrm{m}}$

Dec. range of principal targets (degrees): One target: $+14^{\circ}$

Instrument Configuration

Filters:
Grating/grism:
Order: 1
Cross disperser:

Slit:
Multislit:
λ_{start}:
λ_{end}:

Fiber cable:
Corrector:
Collimator:
Atmos. disp. corr.: