UNIVERSITY OF HAWAII • INSTITUTE FOR ASTRONOMY
RESEARCH PROPOSAL – OBSERVING TIME REQUEST

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Program Title

A. Measuring the structure of the Milky Way spiral arms and testing a new method of distance measurement using ISM

B.

C.

Abstract: Using various data reduction techniques, we will measure the structure and age of the Milky Way galaxy's spiral arms and test a new method of distance measurement using ISM. We request 90 hours using Pathfinder to obtain g, r, and i imaging for variable stars in the galactic plane. From the spatial distribution of variable stars, we will determine the structure and age of spiral arms. From estimating amount of ISM near variable stars, we will test a distance measurement method to stars near variable stars.

TELESCOPE TIME REQUESTED

Run	Program	Telescope	Instrument	Nights (n) or hours (h)	Observers' initials
1	A	Pathfinder		15 n	DH & CM

COLLABORATORS

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1 SCIENTIFIC JUSTIFICATION

1.1 Immediate Objective

To determine the size and shape of particular spiral arms, variable star distributions must be spatially mapped. In observed regions, the density of variable stars will give insight into the age (*and star formation epoch?*) of our galaxy. The distance to each star will be calculated using the distance modulus,

$$d = 10^{(m-M+5)/5},$$

where d is the distance in $parsecs$, m is the apparent magnitude, and M is the absolute magnitude.

Catalogs such as the Sloan Digital Sky Survey (SDSS) Abazajian et al. (2009), will act as sources of data. Using the search capabilities of VizieR Ochsenbein et al. (2000), variable star locations and magnitudes are easily accessible. From available catalogs, variable star locations within our galaxy will be mapped. Existing catalogs only allow for the distribution of known variable stars to be determined.

Data collected by the gri project will be used to identify new variable stars. Analyzing the gri data, in its entirety, is a cumbersome task. Subtraction of data collected by the gri project will cause transient objects to emerge. Light curves will be used in identification and categorization of desired variable stars. Variable stars comprising less than 1% of all observable stars Allen et al. (2016), significantly reduces the amount of data to analyze. Required computing time also decreases substantially.

1.2 Scientific Rationale

Of the different types of variable stars, we will focus on RR Lyrae, Type 1 Cepheid, and Type 2 Cepheid. These pulsating variables have well established absolute magnitudes B. et al. (2012). From this the luminosity is known, permitting the distance to each star to be calculated using Period-Luminosity (PL) relationship.

1.2.1 RR Lyrae

RR Lyrae have short periods, $1.5 - 24$ hours, and are generally classified as stars with spectral type A or F. On average, absolute magnitudes of RR Lyrae stars fall between 0.6-0.7 Tsujimoto et al. (1998). Using the distance modulus assuming no ISM extinction yields the upper limit on RR Lyrae distance measurements of 12.6 kpc with $m = 16$ (photometric accuracy of 10%). Figure 1 shows the PL relationship for variable stars classified as RR Lyrae Ngeow et al. (1998) (*how do we calibrate different band passes?*). Since the typical age of RR Lyrae is 10 Gyr, it can be used as the lower limit of the age of spiral arms.

1.2.2 Cepheid

Other variable stars that will be identified are Cepheid Type 1 and Cepheid Type 2. A typical pulsation period of Cepheid star is $1 - 50$ days Ryden et al. (2010). These sugergiants span the F, G, and K spectral classes, with average absolute magnitudes between $M = -0.5$ and $M = -6$ Ryden et al. (2010). The PL relation of Cepheid Type 1 and Cepheid Type 2 is shown in Figure 2a. From the PL relation we can extract distances Ngeow et al. (2013). Using $m = 16$, 20 s exposures will allow for photometric accuracy of 10%. A Hertzsprung-Russell diagram of pulsating variable stars is shown by Figure 2b Turner et al. (2012). (*Relatively young, star formation epoch?*). Cepheid variables are relatively young, a few million years, which indicates star formation regions.

1.2.3 Spatial Distribution of Variable Stars

Since Cepheid variables are young, it stays near star formation regions, while RR Lyrae stars are old and may move away from star formation regions. The spatial deviations of RR Lyrae stars from star formation regions indicate the structure history and dynamics of spiral arms.

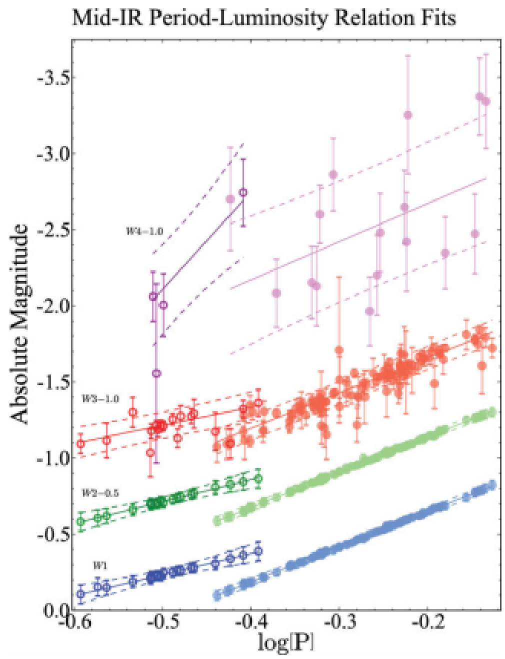
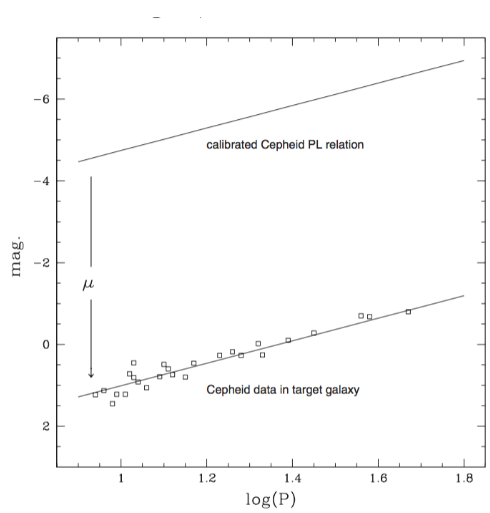
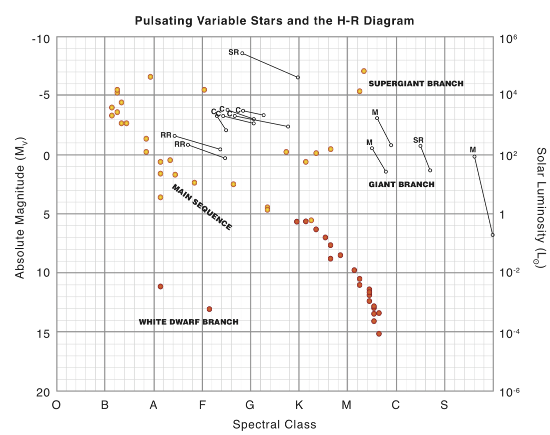


Figure 1: *Period-Luminosity relationship of RR Lyrae variable stars.*



(a) Period-Luminosity relationship.



(b) HR-Diagram of pulsating variable stars.

Figure 2: Cepheid Type 1 and Cepheid Type 2 stars.

1.2.4 ISM

Near the galactic center, ISM is dense, and the number density of stars is high, which makes optical investigations quite difficult. Figure 3 shows the distribution of gasses in the Milky Way (Nakanishi and Sofue 2015). In order to determine the spiral arm structure of the Milky Way galaxy, we will avoid the galactic center. To take into account for the ISM extinction, we will use the ratio of total to selective extinction $R = \frac{1}{(\tau_1/\tau_2)-1} = \frac{1}{(\lambda_{eff,2}/\lambda_{eff,1})-1}$ assuming the optical depth $\tau \propto \lambda^{-1}$ according to the Mie scattering for $\lambda < D$ where the D is the dimension of a dust grain (Ryden et al. 2010 & Carroll et al. 2007).

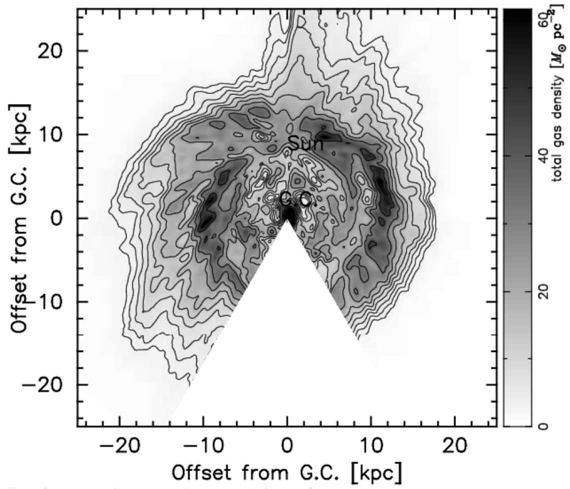


Figure 3: *Column density distribution of the sum of HI and H_2 gases.*

To test a distance measuring method using ISM, we will use observed raw data without using the ratio of total to selective extinction. From observed periods of variable stars, the absolute magnitudes can be calculated. From the calculated absolute magnitude and catalog distances, obtained by parallax, the absolute magnitudes at g,r, and i can be estimated. By comparing the estimated absolute magnitudes and calculated absolute magnitudes from the raw data, we can estimate the amount of ISM. Assuming the amount of ISM near the variable stars are similar, the distances to star near variable stars can be determined.

References

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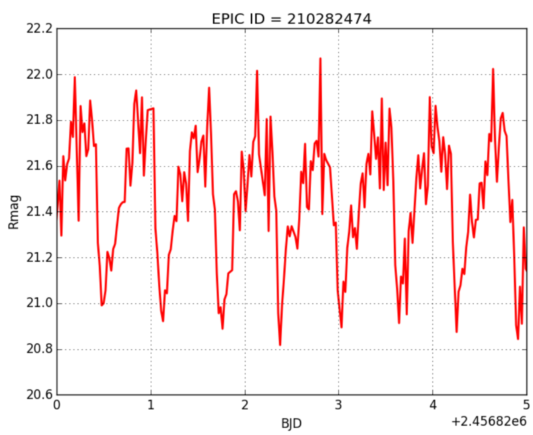
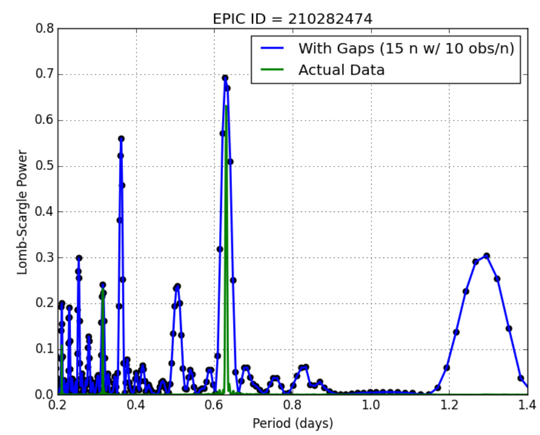
TECHNICAL JUSTIFICATION

We request 6 hours a night for 15 nights, using Pathfinder to obtain g, r, and i imaging for variable stars in the galactic plane.

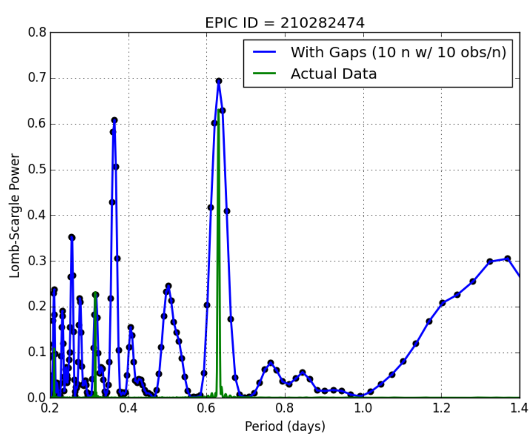
To calculate an appropriate sampling frequency, a typical RR Lyrae star, EPIC ID 210282474, was used (Molnr et al. 2015) with artificially introduced gaps following the Gaussian distribution. Since sampling in astronomy is always uneven, we used the Lomb-Scargle analysis (Lomb 1976 & Scargle 1982). The light curve of 210282474 is shown in Figure 4a, and Lomb-Scargle power plots with various sampling conditions are shown in Figures 4b, 4c, and 4d. We want a distinguishable and narrow peak in power plots. To determine distances from the PL relations with $\simeq 5\%$ accuracy, we need peaks with FWHM $\simeq 0.02$ days. From this condition, it looks like 15 nights with 10 observations/night is the lower limit sampling rate. The uncertainty in magnitude was taken to be 10%, and the changes, $1\% - 10\%$, in the uncertainty did not affect the period determinations significantly; we only need 10% photometry.



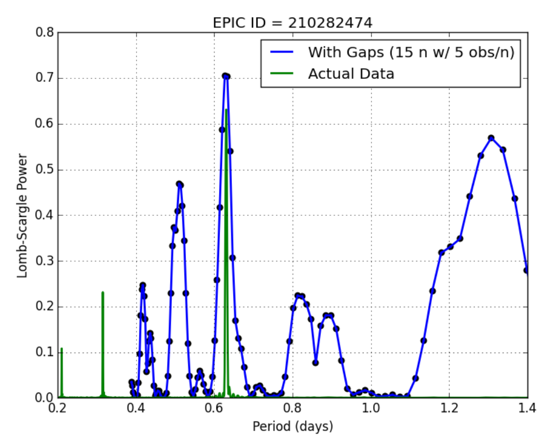
(a) Light curve of 210282474.



(b) Power plot with 15 nights with 10 observations/night.



(c) Power plot with 10 nights with 10 observations/night.



(d) Power plot with 15 nights with 5 observations/night.

Figure 4: EPIC ID 210282474.

For $m_g = m_r = 16$ and $m_i = 15.7$, an exposure time of 20 sec yields 10% photometry. We want to cover the galactic plane, $165° < l < 195°$ and $b = \pm 10°$ avoiding the galactic center and the sun. With the magnitudes, exposure time, and size of the field, we request 6 hr/night for 15 nights, resulting the total observational time of 90 hr.

Since typical pulsation periods of Cepheid variables are longer than that of RR Lyrae stars, we would be able to sample Cepheid light curves as well by using the sampling rate discussed above.

2 Observation Specifics

In order to achieve photometric accuracy of 10% and $SNR = 10$, seeing conditons must not exceed 1.5 $arcsec$ during the collection of each 20 s exposure. Pathfinder residing on Mauna Loa minimizes chances of poor seeing conditions. The sky transparency for each filter are $\mu_g^{sky} = 21.9$, $\mu_r^{sky} = 21.0$, $\mu_i^{sky} = 20.1$ Asteroid et al. (2010). Better observing conditions occur as light from the Moon is minimized, making nights containing the New Moon ideal. A New Moon will occur on March 9^{th} and April 7^{th}. Due to upcoming dedlines, it is requested that observations occur in the nights surrounding the March 9^{th} New Moon. The minimum requirement is to avoid a Full Moon, which will occur on March 23^{rd} or April 22^{nd}.

To properly measure the Milky Way only a portion of the galactic plane needs to be observed, bound by $165° < l < 195°$ at $b = \pm 5°$. Starting with $l = 165°$ centered at $b = 5°$, data will be gathered using g, then r, then i filters. Once data from each filter is recorded, the FOV will be shifted by 3 °. Observations in each of the three filters will be recorded, then the FOV shifted by another 3 °. Once $l = 195$ is reached, the FOV will move to center around $b = -5°$. Data collected by changing filters before moving the FOV will reduce potential aliasing. To collect the necessary data, we will need 6 hours a night for 15 nights. During each 6 hour time slot, 10 observations will be made. With the addition of overhead time, a total of 22 exposures will be recorded each night.

LIST OF PRINCIPAL OBJECTS *(to be studied in run justified above)*

Program	Object	RA (deg)	Dec (deg)	Mag (specify band)	Exposure Time (s)
A	Galactic Plane	81.60342023	44.25952438	$m_g = 16$	20
A	Galactic Plane	81.60342023	44.25952438	$m_r = 16$	20
A	Galactic Plane	81.60342023	44.25952438	$m_i = 15.7$	20
A	Galactic Plane	83.82934318	41.75280277	$m_g = 16$	20
A	Galactic Plane	83.82934318	41.75280277	$m_r = 16$	20
A	Galactic Plane	83.82934318	41.75280277	$m_g = 15.7$	20