“Point of Interest” Variables Alert

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Rubin Observatory Project & Community Workshop 2020

Variable Objects

RR Lyrae, Cepheids:

- easy to detect: variable with specific light-curve profile
- distance measurement (period-luminosity relationship)

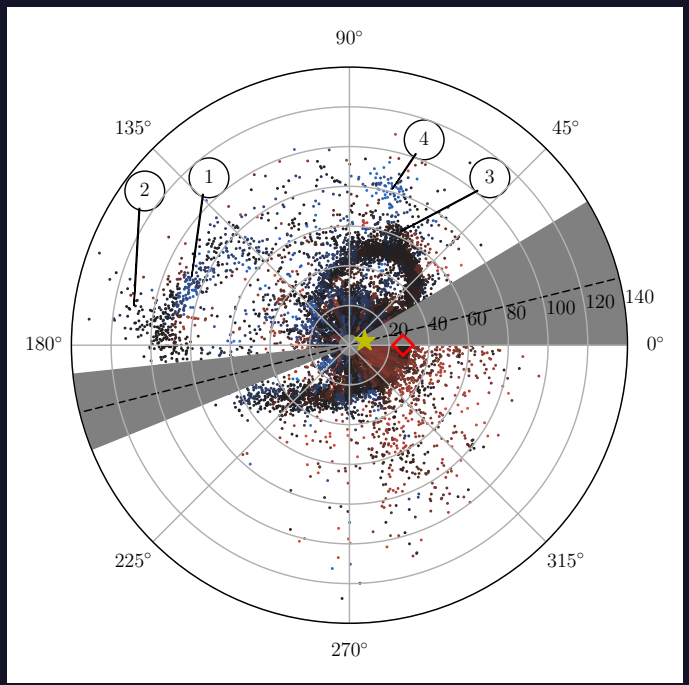
$\Rightarrow$ detection of structure such as tidal streams, dwarf galaxies

$\Rightarrow$ answering questions regarding the formation history of our Milky Way

Points of Interest

many "points" or regions of interest known:

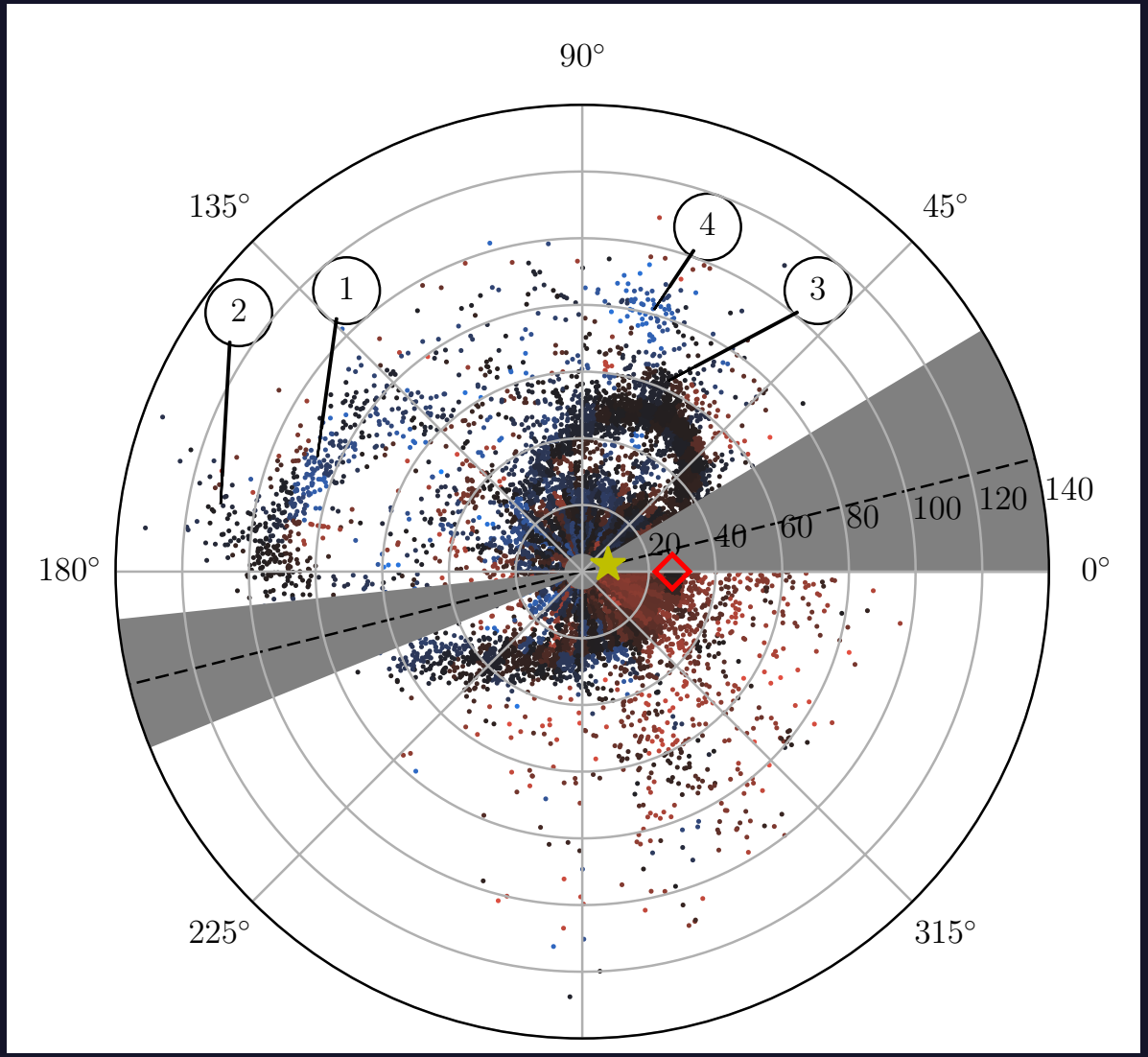
- dwarf galaxies
- globular clusters
- tidal streams & substructure within



$\Rightarrow$ can be traced by periodic variable stars

Points of Interest

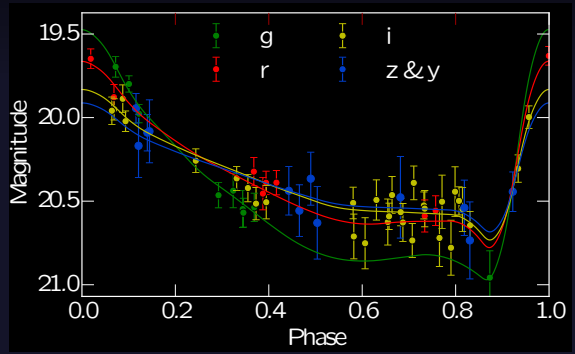
Sagittarius stream with "features":



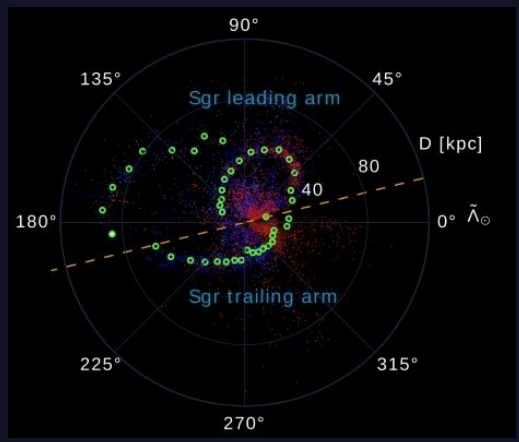
Points of Interest

example:

PS1 3π RRab stars identified by their specific light curve shape (and period/phase)

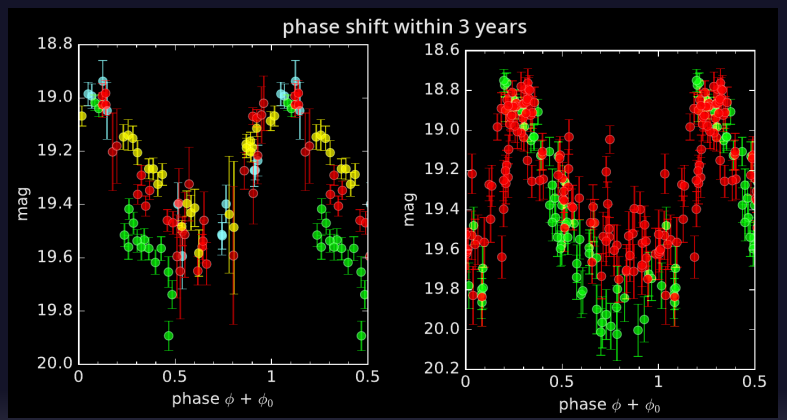


$\Rightarrow$ using RRab stars as tracers for $\sim$360 view on Sgr stream



$\Rightarrow$ spectroscopy to detect comoving structure

$\Rightarrow$ we need updated lightcurves as RRab stars can undergo a period/phase shift



Scientific goals of the proposed broker system

Our proposed alert broker should **enable users to get updates on variable star observations within such interesting regions**.

predefined
known stellar streams, dwarf galaxies and globular clusters

user-created

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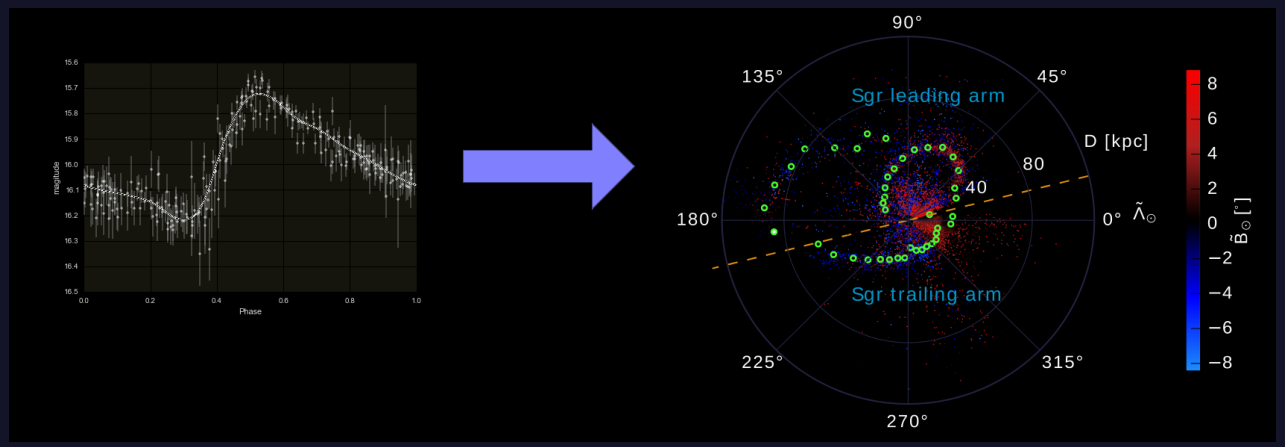

large and deep sets of such variable stars
⇒ understanding the nature of the stellar halo of our Milky Way
⇒ constraining its history

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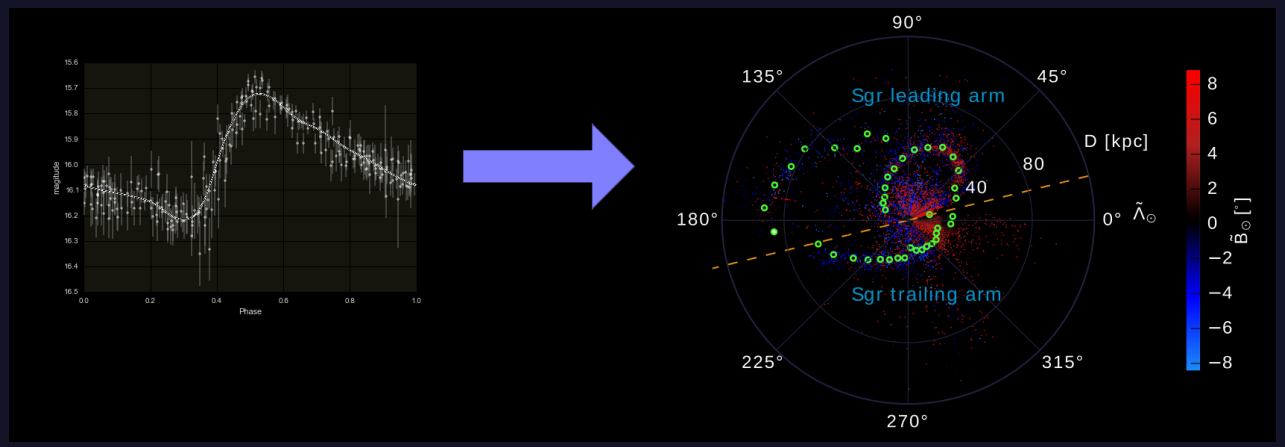

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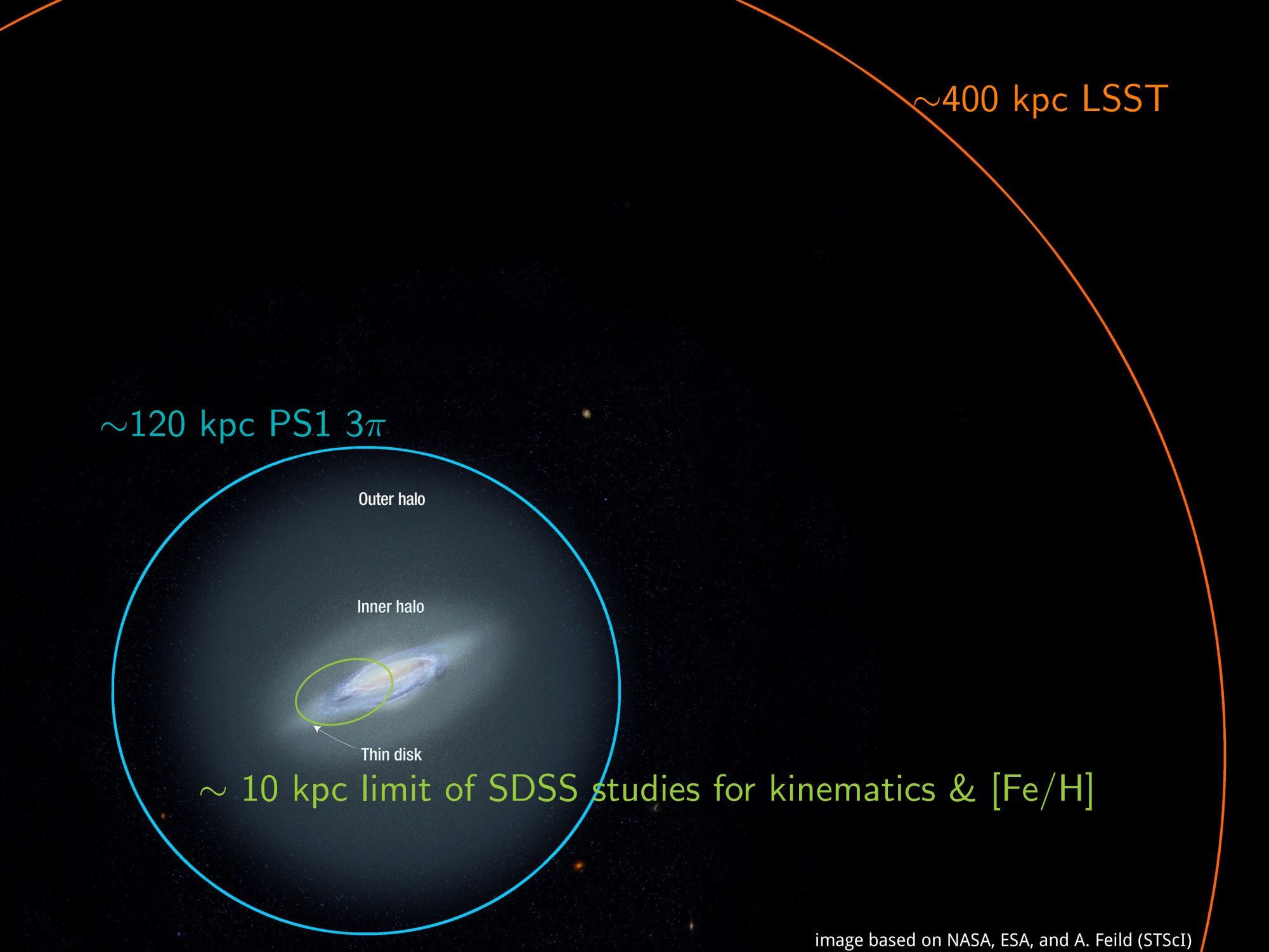
PS1 3π is pushed to its limits - LSST will be at least 2 mag deeper


~400 kpc LSST
~120 kpc PS1 3π
Outer halo
Inner halo
Thin disk
~ 10 kpc limit of SDSS studies for kinematics & [Fe/H]
image based on NASA, ESA, and A. Feild (STScI)

anticipated output

a) light curves of RR Lyrae, Cepheids and other variable stars (classification!) in specific regions of interest

Astronomers working with variable stars are usually interested in **precise light curve information** $\Rightarrow$ fit periods $\Rightarrow$ determine e.g.

- distances
- phases at given time stamps - crucial for spectroscopic follow-up studies as e.g. demonstrated currently by the *Caltech/Carnegie Survey of the Outer Halo of the Milky Way* (Hernitschek et al. 2020, in prep).

anticipated output

a) light curves of RR Lyrae, Cepheids and other variable stars (classification!) in specific regions of interest

b) value-added information: periods, phase offsets

c) specific value-added information: e.g. some RR Lyrae show a modulation of the pulsation phase or amplitude (Blazhko efect)

LSST's high cadence will provide better features:
$\Rightarrow$ amplitude, period, phase offset, possible modulations

cross-matches

To provide information on variable stars within defined regions, the alert broker should perform

a) cross-matching with variable catalogs such as the PS1 Sample RR Lyrae catalog (Sesar & Hernitschek 2017)
$\Rightarrow$ as early as LSST gets operational

b) classifying variable light curves
$\Rightarrow$ as soon as the light-curve quality is sufficient

also: re-classify stars previously found by e.g. PS1
$\Rightarrow$ **catalog-cleaning** due to LSST's higher cadence!

user access

data products should be easily accessible:

website showing individual information for each star within a region of interest

retrieving data: simple GUI & SQL-like data-query language for advanced tasks

table download

- light curves (filtered: number of epochs, specific coordinates...)
- overview tables: observed within a region
- light curve features

follow-up observations

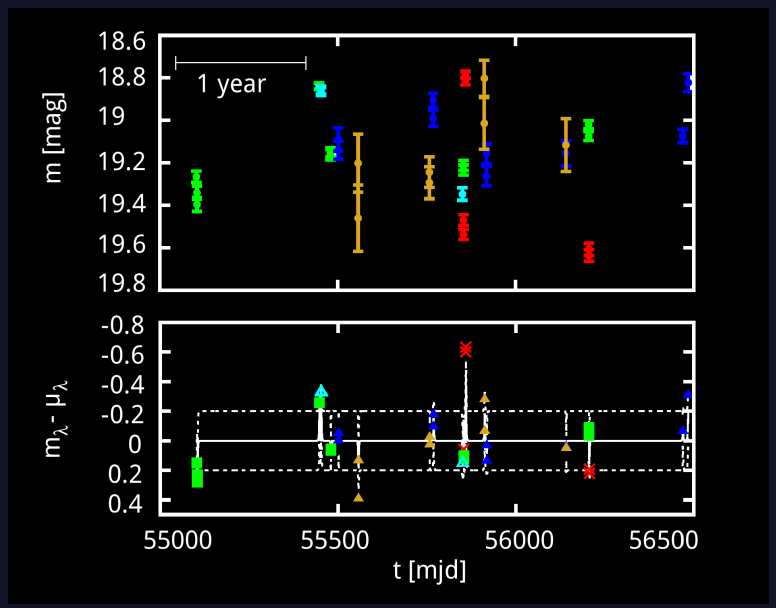
variable star spectroscopy: periods & phases from precise light curves are crucial

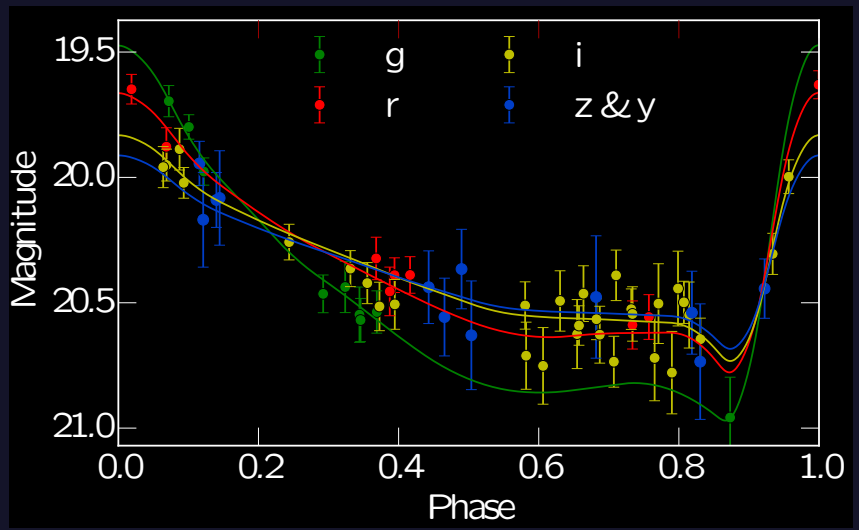
possible: follow-up in different wavebands (space & ground, including radio, X-ray...)

Prototyped Algorithms

general techniques for detection & classification of periodic variables are developed, tested and applied:

Hernitschek et al. 2016, Sesar & Hernitschek 2017 and following: describing and classifying variable sources from sparse PS1 3π light curves, precise distances, catalog of variable sources incl. $\sim$44,000 RR Lyrae stars with periods, phases and distances





Experience

Data Science Institute (@Vanderbilt University) enables and supports data-intensive research: dedicated computational resources, incl. disk storage, CPU & GPU nodes in Vanderbilt's Advanced Computing Center for Research and Education (ACCRE)

LSST broker team:
Nina Hernitschek (Vanderbilt University): software architecture, variable star classification, time-series, machine learning, follow-up surveys for all-sky surveys.

Andreas Berlind (Vanderbilt University, Co-Director DSI): statistical analysis of large surveys, especially spatial clustering.

Keivan Stassun (Vanderbilt University): variable star classification, time-series analysis, machine learning, data visualization (e.g. Filtergraph).

Summary & Discussion

What have you learned from experience with precursor surveys?

PS1 3π: working with a huge (10^9 sources) survey with sparse (70 observations over 5 years over 5 bands) light curves
Caltech/Carnegie Survey of the Outer Halo of the Milky Way: developing spectroscopic follow-up survey for PS1 3π RR Lyrae stars

Are there specific technical challenges you are looking for solutions to? Or solutions you've found that you'd like to make others aware of?

solutions: using

- feature extraction: multi-band structure functions for general description
- template fitting to calculate period & phase for sparse light curves
- classification (RFC)