

# Mapping the Milky Way and Beyond

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College of the Canyons, Santa Clarita, CA USA



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# About your speaker

Dr. Peregrine McGehee is with the Earth and Space Sciences Department at College of Canyons in Santa Clarita, California.

His doctorate is from New Mexico State University (2005), following a multi-decade career in observatory and and accelerator control systems engineering.



# Introduction: Science Themes

The Legacy Survey of Space and Time [LSST] is an ambitious program undertaken at the Vera C. Rubin Observatory, which is presently under construction on the summit of Cerro Pachon in Chile.

Within the LSST there are four main science themes:

- Understanding Dark Matter and Dark Energy
- Hazardous Asteroids and the Remote Solar System
- The Transient Optical Sky
- **The Formation and Structure of the Milky Way**

# Introduction: Stars, Milky Way, and Local Volume

The LSST Stars, Milky Way, and Local Volume [SMWLV] science collaboration is focused on the fourth theme concerning the past and present state of the Milky Way Galaxy and its neighbors.

During this webinar we will explore the diverse working groups within SWMLV including their science goals and relationships across the broader community.

# Part I: Introduction to the Vera Rubin Observatory and the Science Collaborations

# About the Vera Rubin Observatory

The 8.4-meter Simonyi Survey Telescope uses a special three-mirror design, which creates an exceptionally wide field of view, and has the ability to survey the entire sky in only three nights.

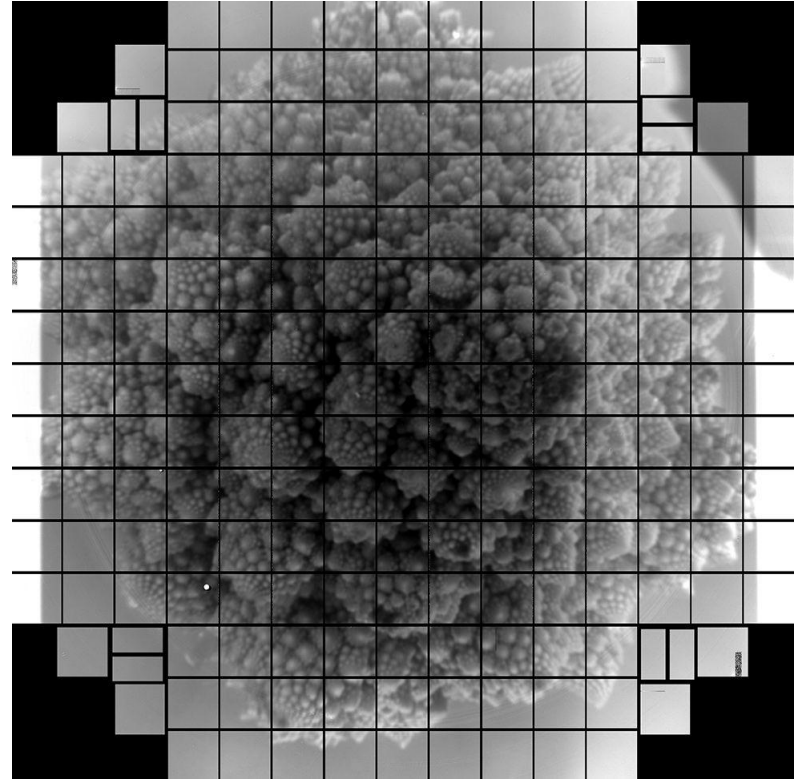
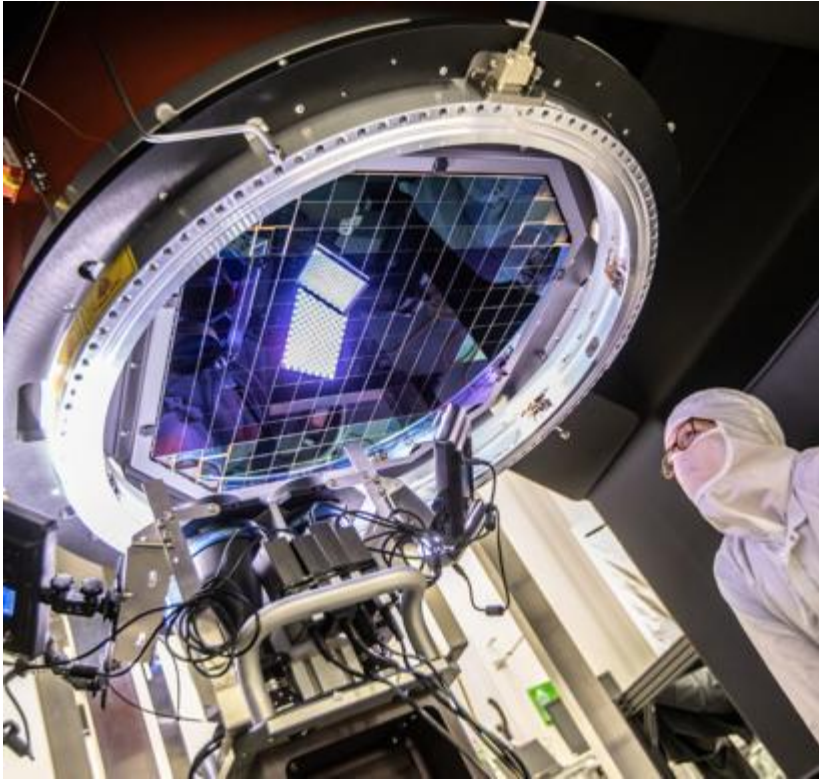
The Rubin Observatory Summit Facility is located on the Cerro Pachón ridge in north-central Chile.

The observatory site is inland and approximately 60 m (100 km) by road from the support town of La Serena, where the Rubin Observatory Base Facility is located.

# Observatory construction is well underway!



# The camera at the heart of the observatory (3.2 Gigapixels)





# Rubin LSST Science Collaborations

SC Coordinator: Federica Bianco [fbianco@udel.edu](mailto:fbianco@udel.edu)

## Who are we?

- NSF-DOE Rubin funding extends to construction of Rubin and operation of the LSST
- 8 self-managed self-governed science teams are preparing to do science with LSST data

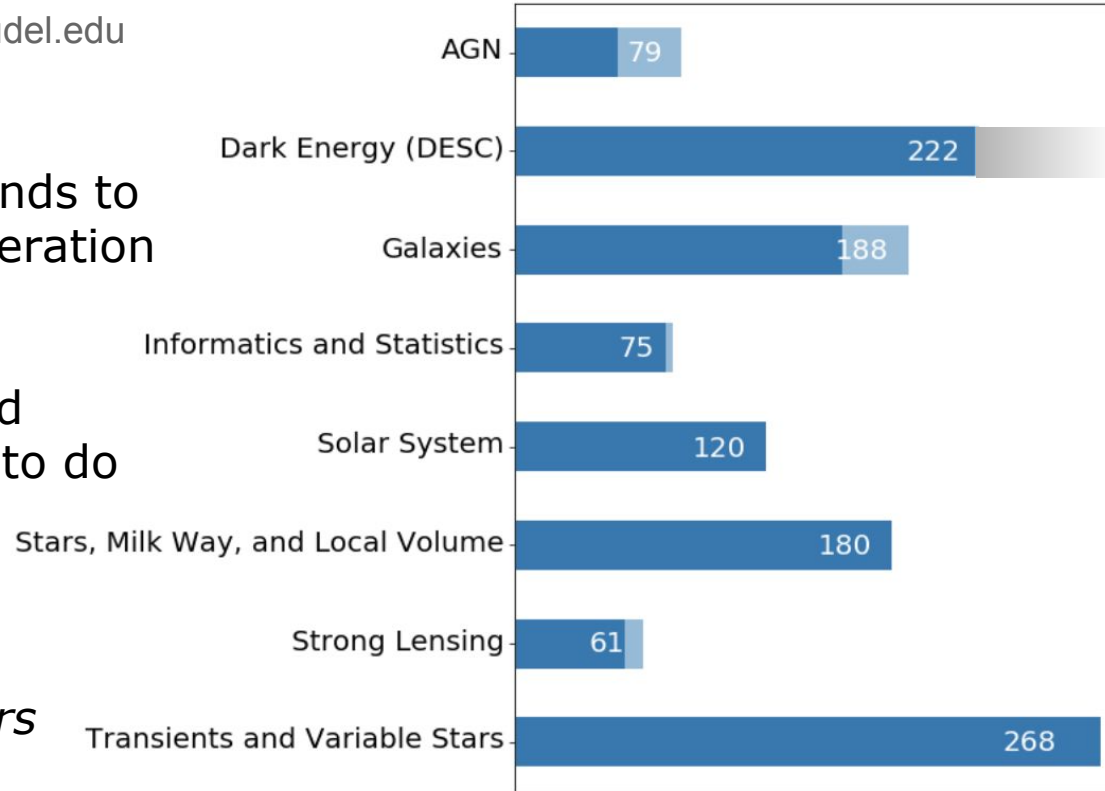


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*1500+ members,  
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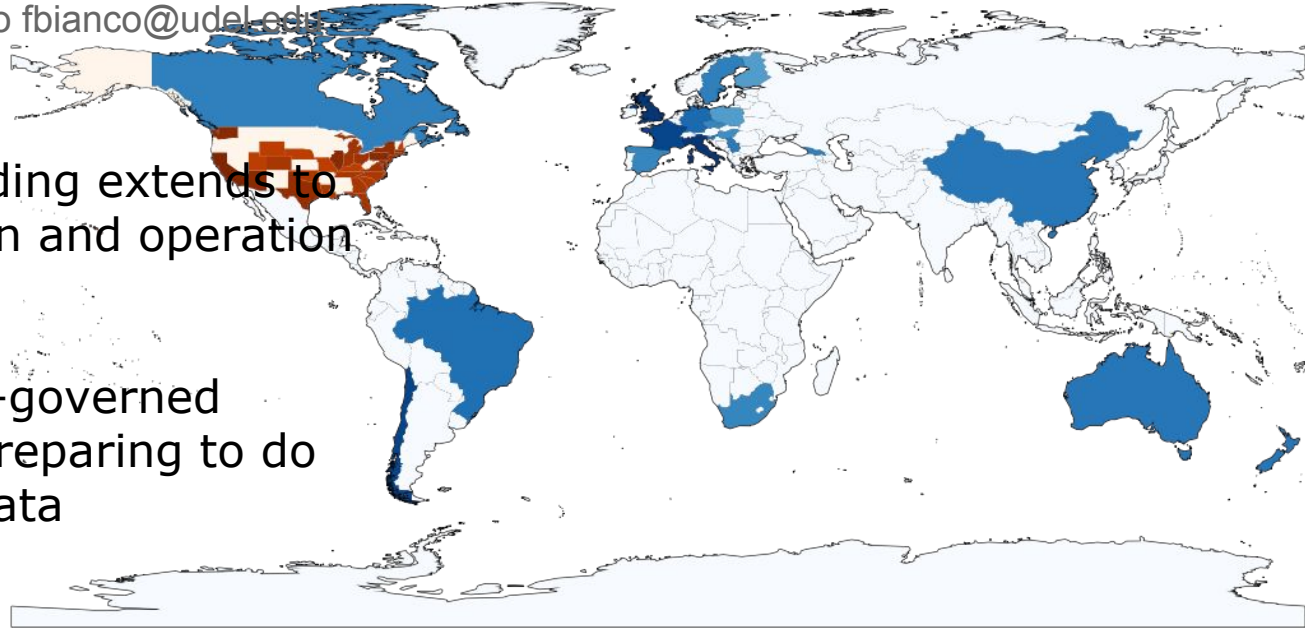
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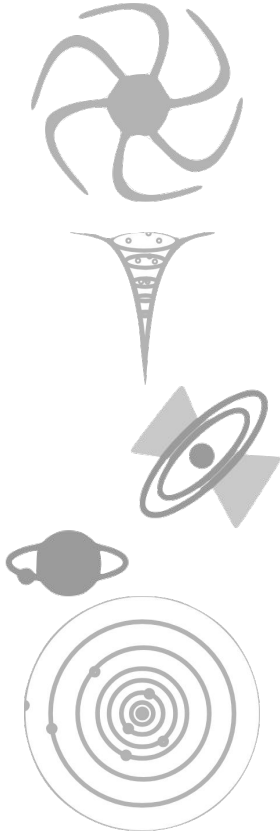
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*1500+ members,  
physicists, astronomers,  
data scientists, software engineers*

*Represented in 5 continents,  
Over 20 countries!*





**Studying the structure of the Milky Way via resolved stellar populations with 17B stars**

**Revealing the nature of dark energy and dark matter**

**Exploring the transient and variable universe**

**Producing an unprecedentedly complete inventory of the Solar System, from Near Earth Asteroids to Outer Solar System Objects**

# Part II: Introduction to the Stars, Milky Way, and Local Volume Science Collaboration



# Stars, Milky Way, and Local Volume Science

The study of the structure and evolution of the Milky Way requires observations across the entire Galactic sky, including into the crowded fields found in the Disk, the Bulge, and the Magellanic Clouds.

While SMWLV science cases are known for a focus static and deep co-added images, there are many explorations that make use of time domain imaging.

In the following we list some of the science that has been proposed - there are doubtless many more that can make use of the unique data produced by Legacy Survey of Space and Time.

# SMWLV Broad-scale Science Drivers

*Shed light upon the assembly history and structure of the Milky Way and the Local Volume*

*Understand the fundamental properties of stars within several hundred parsecs of the Sun*

# Example Science Cases - Time Domain Photometry

- Detailed studies of variable star populations
  - 2% or better accurate multicolor light curves will be available for a sample of at least 50 million variable stars
  - Enabling studies of cataclysmic variables, eclipsing binary systems, and rare types of variables
- Measurements of physical properties of stars using large samples of eclipsing binary stars



# Example Science Cases - Time Domain Astrometry

- Discovery of rare and faint high proper motion objects:
  - Probing the faint end of the stellar mass function
  - Searching for free-floating planet candidates
- Direct measurement of the faint end of the stellar luminosity function using trigonometric parallaxes
  - A complete census of the solar neighborhood to a distance of 100 pc based on trigonometric parallax measurements for objects as faint as  $M_r = 17$
  -

# Example Science Cases - Static [Coadds]

- Conduct the faintest ever search for galaxy satellites and intergalactic stars over much of the Local Group
- Separation of halo M sub-dwarfs from disk M dwarfs, using the  $z - y$  color which is sensitive to their rich molecular band structure
- Studies of white dwarfs using samples of several million objects, including the determination of the halo white dwarf luminosity function
- High-resolution three-dimensional studies of interstellar dust using 5-color SEDs of main sequence stars

# And more...

- Conduct high-resolution studies of the distribution of stars in the outer halo. For example, the chemistry and proper motion of a sample of about 200 million F/G main-sequence stars will be detected out to a distance of 100 kpc.
- Create deep and highly accurate color-magnitude diagrams for over half of the known globular clusters, including tangential velocities from proper motion measurements.
- Map the chemical composition, motions and spatial profile of the Sagittarius Dwarf tidal stream.
- Map the Milky Way's halo and the Local Group out to 400,000 parsecs, using RR Lyrae stars as cosmic yardsticks.

# Structure and Leadership

The SMWLV science collaboration presently has a single-tiered structure of 180 members.

The three co-chairs, who nominally serve for 3 year terms, are:

- Will Clarkson (Univ Michigan - Dearborn, [wiclarks@umich.edu](mailto:wiclarks@umich.edu))
- John Gizis (Univ Delaware, [gizis@udel.edu](mailto:gizis@udel.edu))
- Peregrine McGehee (College of the Canyons, [peregrine.mcgehee@gmail.com](mailto:peregrine.mcgehee@gmail.com))

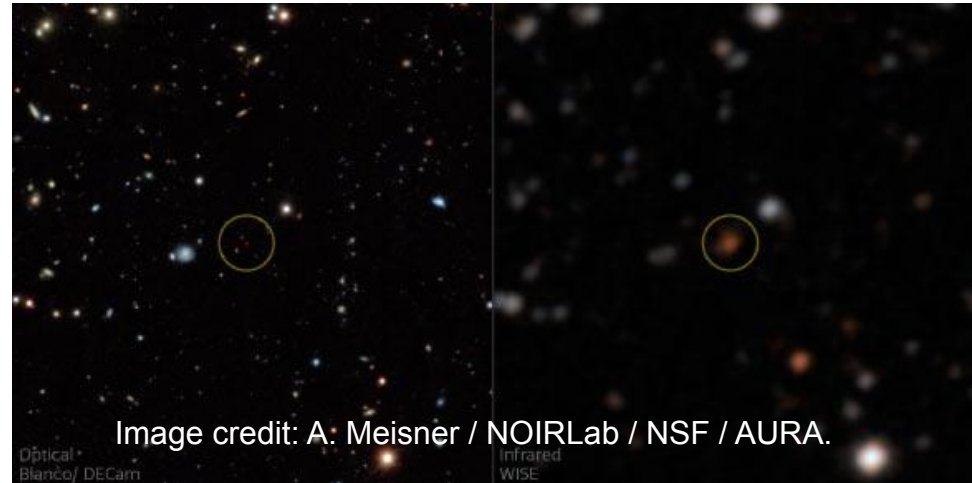
SMWLV is organized into seven science working groups:

- The Solar Neighborhood, Star Clusters, Variable Stars, Galactic Bulge, Galactic Structure and ISM, Magellanic Clouds, Near Field Cosmology

# The Solar Neighborhood

Chairs: Ben Buringham (Hertfordshire),  
Sebastian Lepine (CHARA)

Status: Active



# Star Clusters

Chairs: TBD

Status: Reforming.

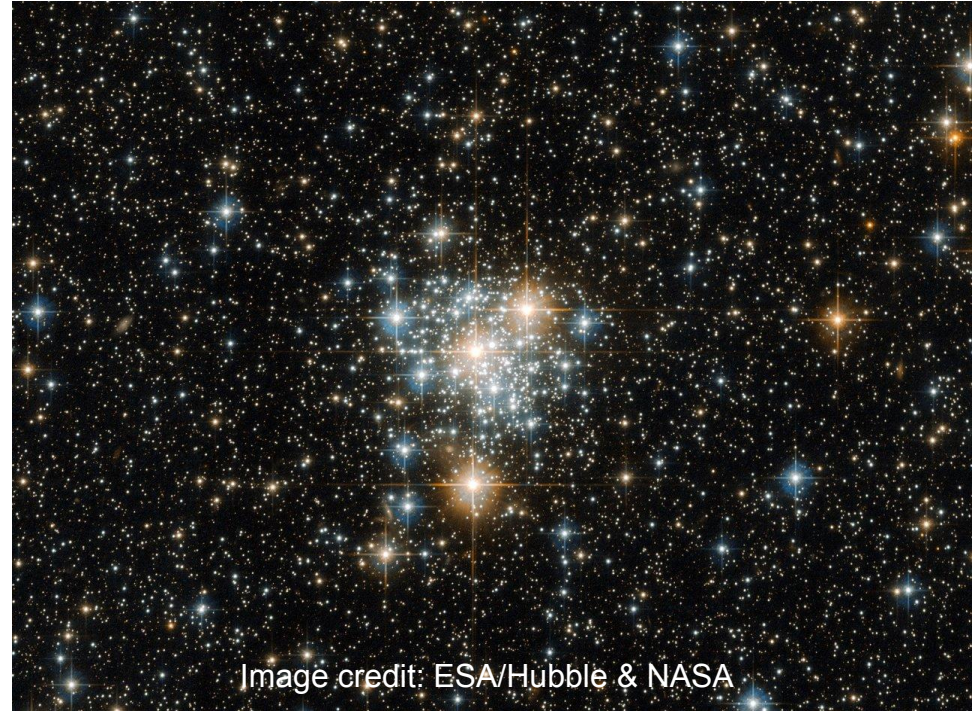


Image credit: ESA/Hubble & NASA

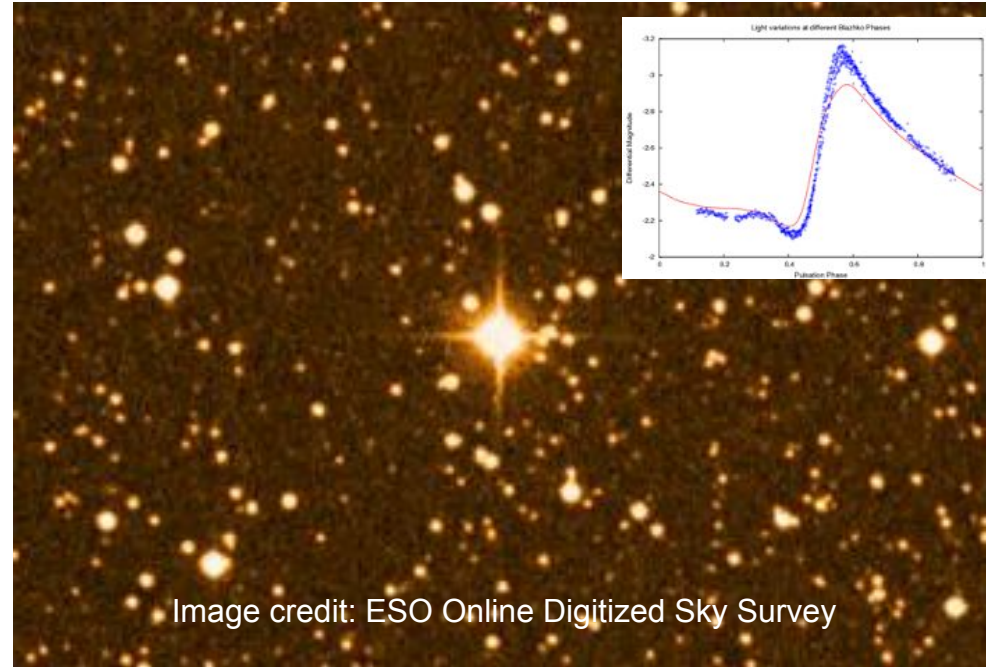
# Variable Stars

Chairs: TBD

Status: Reforming

Synergy: TVS science collaboration.

Example: Galactic-structural indicators (like RR Lyrae); accretion/outflow indicators (X-ray binaries and young stellar objects); microlensing (planetary, stellar, and compact objects)



# Galactic Bulge

Chairs: Will Clarkson (Michigan) &  
Victor Debattista (Central Lancashire)

Status: Active

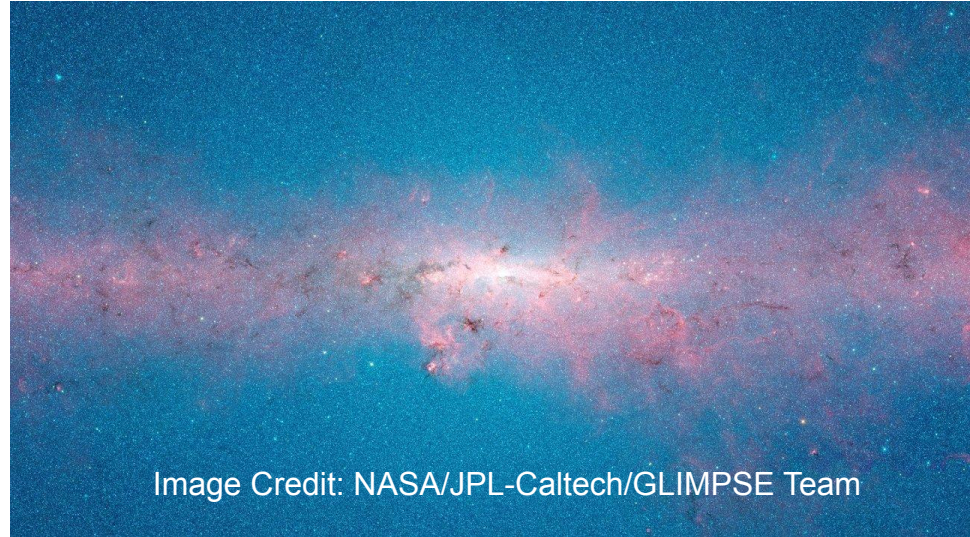




# Galactic Structure and the ISM

Chairs: Peregrine McGehee (College of the Canyons)

Status: Active



# Magellanic Clouds

Chairs: Knut Olsen (NOIRLab)

Status: Active



Image Credit: A. Fujii

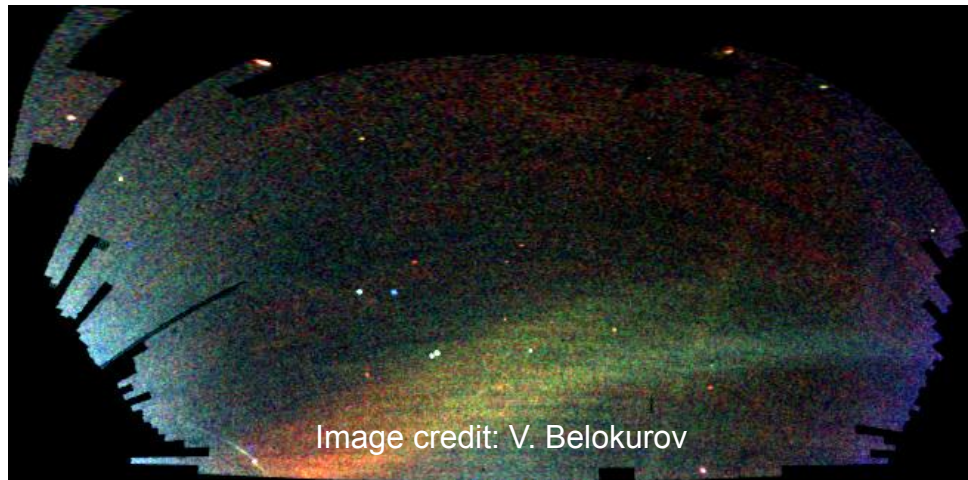
# Near Field Cosmology

Chairs: TBD

Status: Reforming

Synergy: The DESC-led Dark Matter program

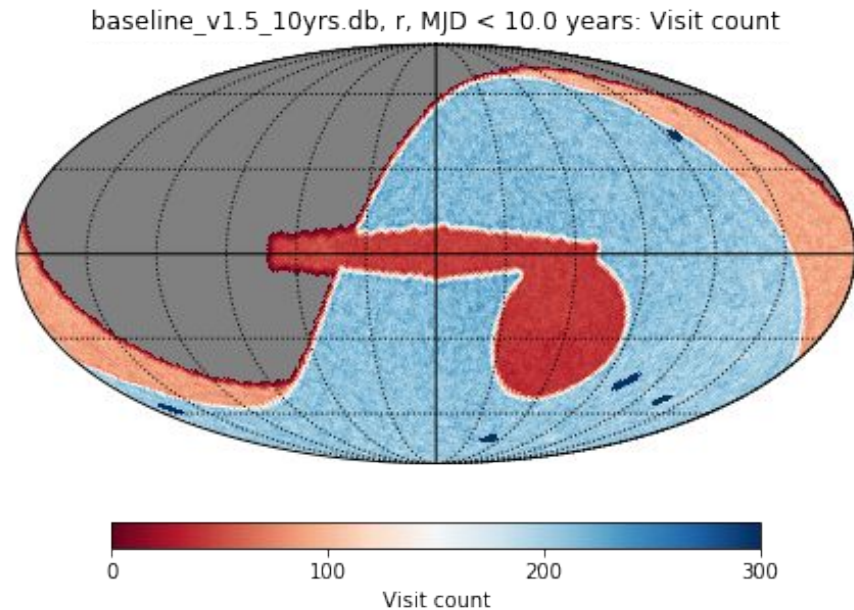
Example: Constraining black hole dark matter by hunting for slow microlensing towards the Bulge and Magellanic Clouds



# Part III: Activities

# Work Underway (1)

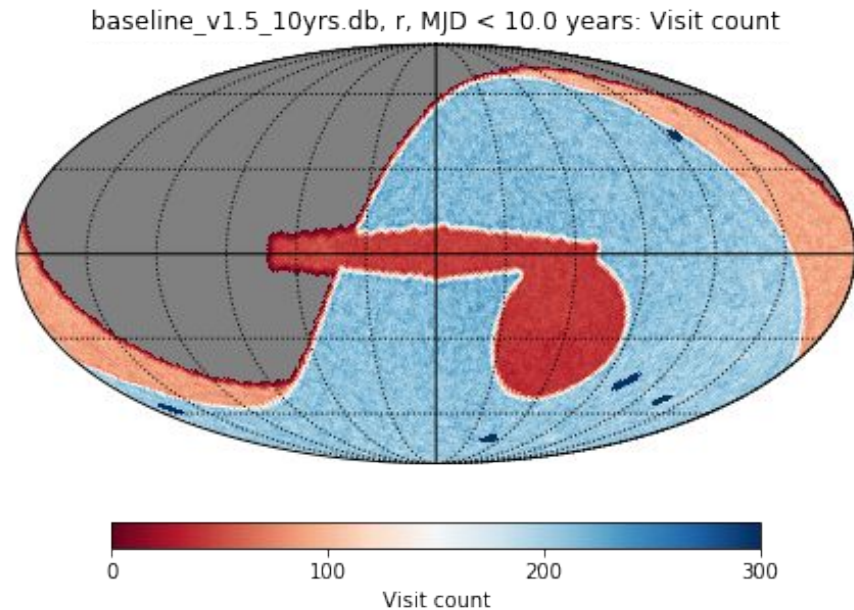
- **Helping the Project help SMWLV science:**
  - The LSST observing strategy: MAF [Metric Analysis Framework] applications and Figures of Merit
  - Commissioning needs (e.g. early astrometry validation)
  - Early-science (e.g. synergy with external datasets)



Survey footprint in Galactic coordinates

## Work Underway (2)

- **Improving responsiveness to the Community and Project**
  - Informal task forces (e.g. observing strategy; crowded field)
  - Liaisons with other SCs and with the project (e.g. Commissioning Liaison)
  - Reaching out to new potential members in the Community



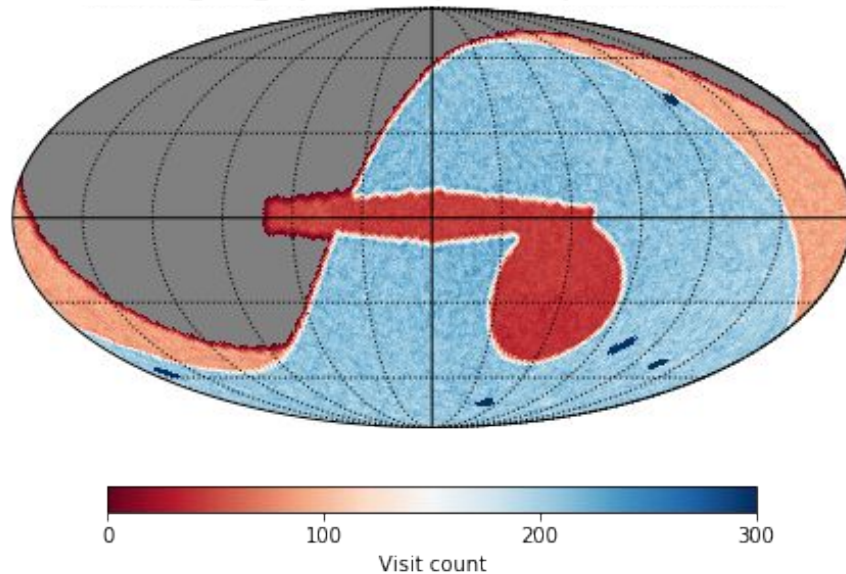
Survey footprint in Galactic coordinates

# Work Underway (3)

- **Preparing for LSST science**

- Updating the science roadmaps
- Helping WGs prepare for LSST science
- TVS/SMWLTV joint workshop (@ UDel 2019)

baseline\_v1.5\_10yrs.db, r, MJD < 10.0 years: Visit count



Survey footprint in Galactic coordinates

## Part IV: Into the Future (an example)



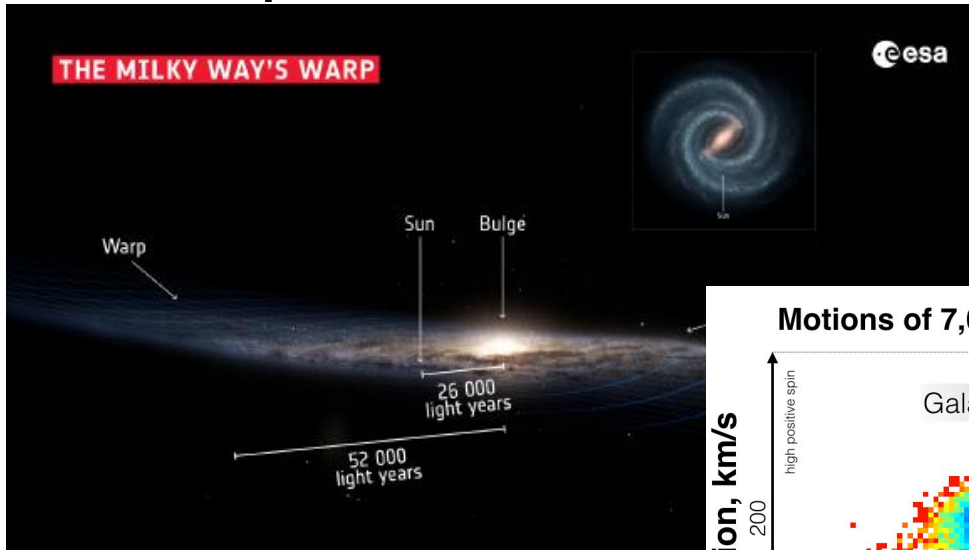
# Galactic Structure and the Interstellar Medium

What does this field look like when the Vera Rubin Observatory starts science operations?

Important Present Day Developments:

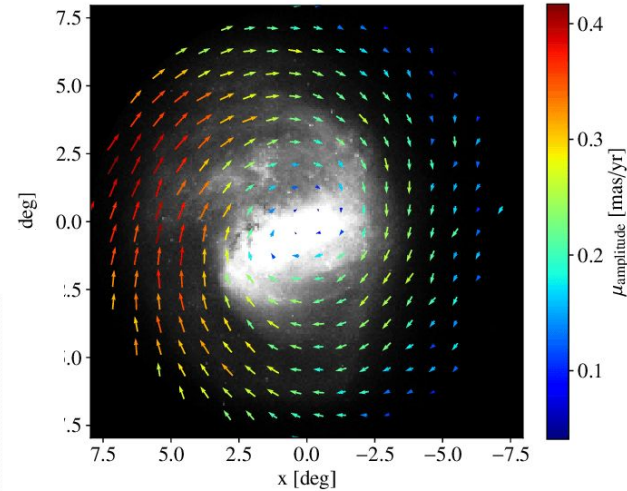
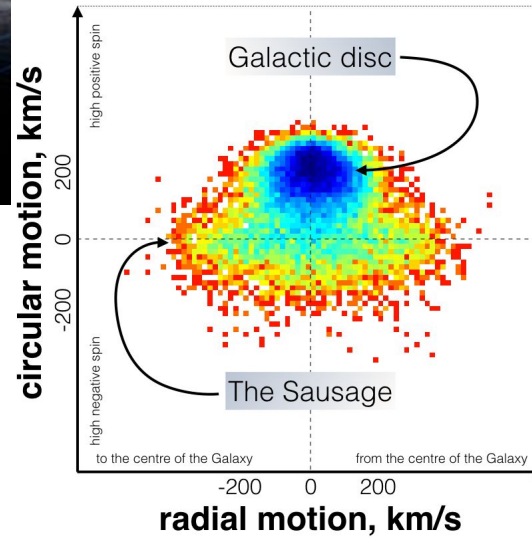
- Gaia - precision parallax and proper motion survey
- Dust mapping - The Pan-STARRS1 team, e.g. Green+2019 “A 3D Dust Map Based on Gaia, Pan-STARRS 1 and 2MASS”, has produced a detailed Bayesian analysis of the 3-D extinction.

# Example results from Gaia DR2



A precessing warp in the MWG disk; evidence of a recent merger; rotation of the LMC

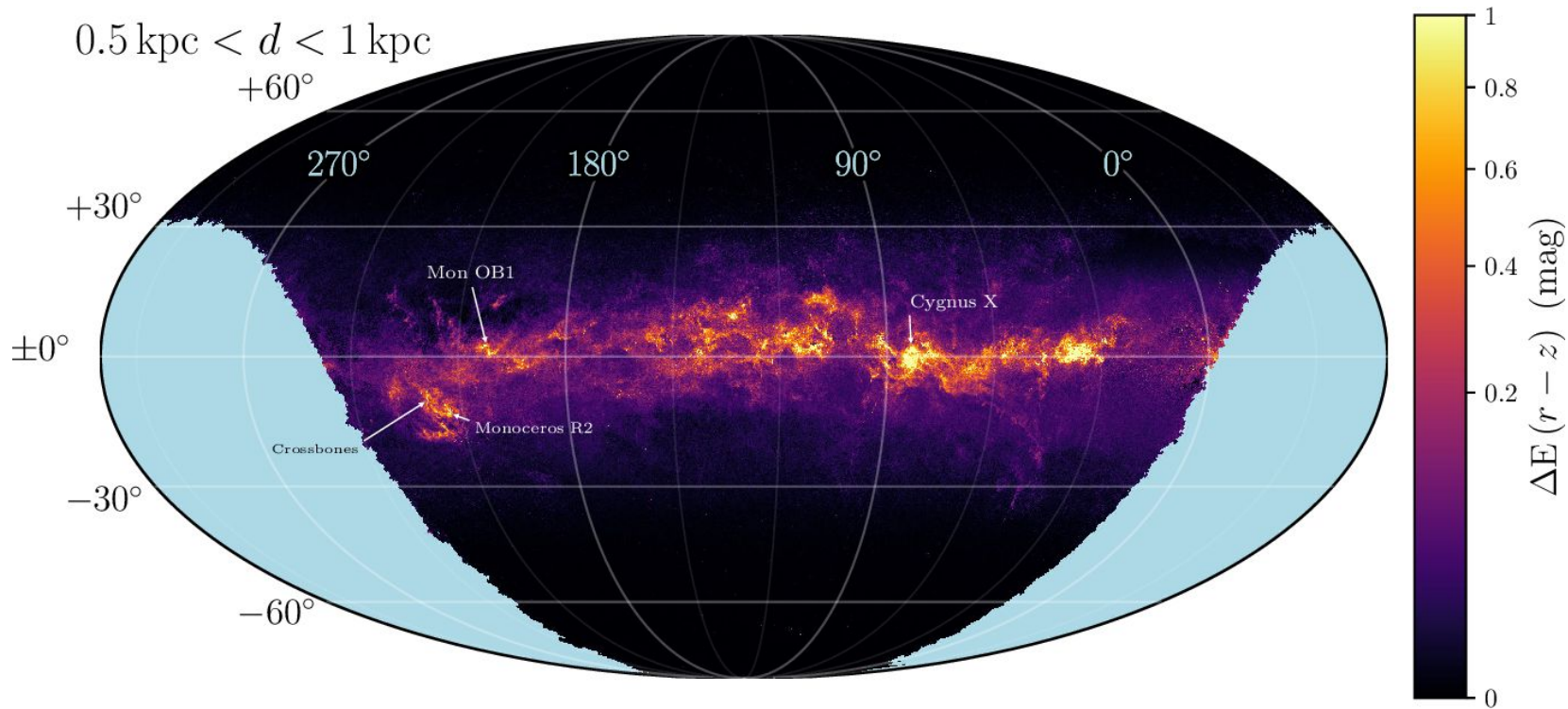
Motions of 7,000,000 Gaia stars



***Gaia DR3 is being released at the end of 2020... more to come.***

# State of the art (so far) in extinction mapping

*From Green+2019: Based on Gaia, Pan-STARRS 1, and 2MASS.*



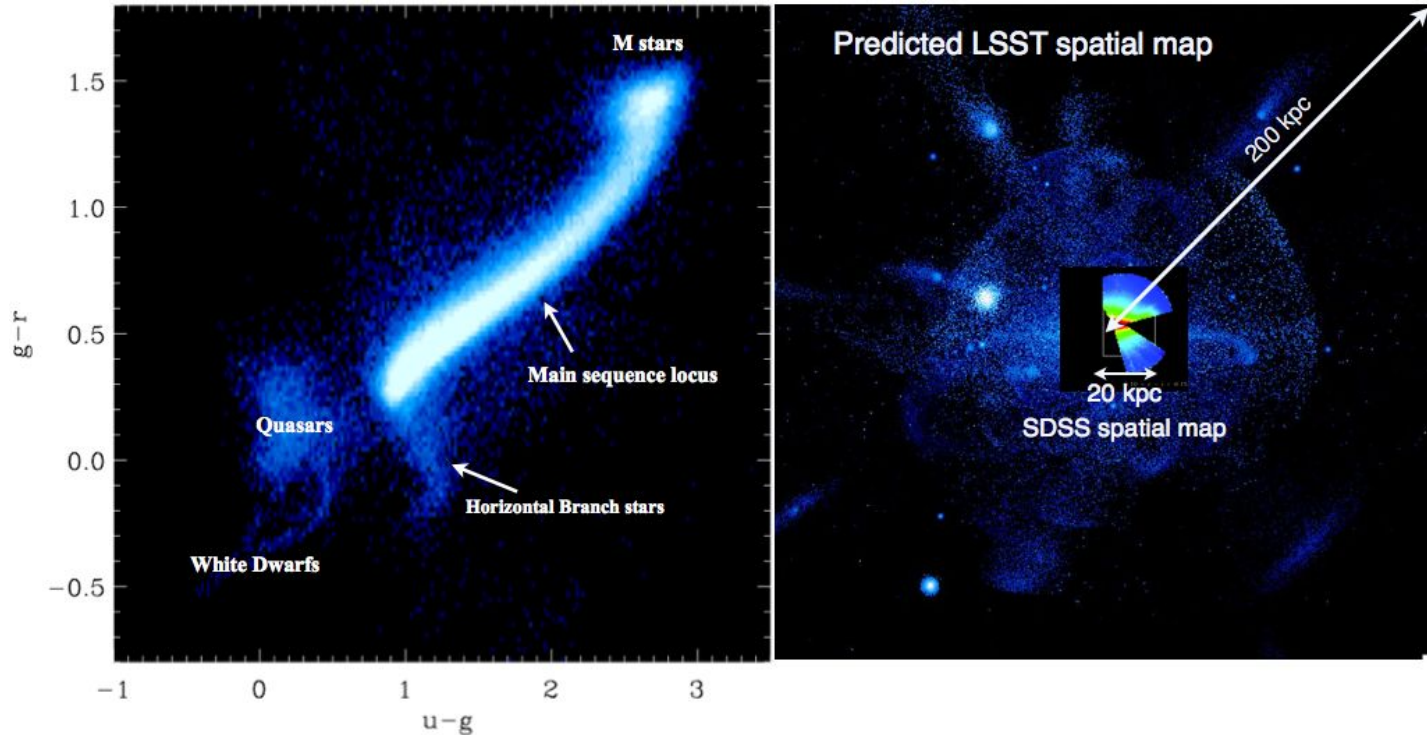
# Galactic Structure and the Interstellar Medium

Rubin Observatory strengths:

- Deeper and multi-band photometry for improved stellar luminosity priors
- For brighter sources will leverage off of Gaia astrometry and extend the temporal baseline
- Can probe deeper into regions of high extinction and at greater distances
- Well-calibrated extended source photometry would result in multi-band maps of extended ISM regions
- And more...

# Predicted LSST Spatial Map

Extremely precise photometric and astrometric data for 20 billion MW stars



# Part V: Participate!

# Resources

## Website:

- The SMWLV website is <http://milkyway.science.lsst.org>.

## Communication:

- E-mail: The main e-mail list for the SMWLV science collaboration is [lsst-milkyway-etc@lists.lsst.org](mailto:lsst-milkyway-etc@lists.lsst.org).
- Slack: The LSST science collaborations use the LSSTC slack workspace (<http://lsstc.slack.com>) The channel specific to SMWLV concerns is #milkyway.
- Discussion Forums: The LSST community discussion forums are hosted at <http://community.lsst.org>.
- SMWLV topics can be found at <https://community.lsst.org/c/sci/milkyway>.

# Summary

Our understanding of the evolution and structure of the Milky Way Galaxy - and our intergalactic neighborhood - will be revolutionized by the Legacy Survey of Space and Time conducted at the Vera Rubin Observatory.

Only a few of the possible science themes have been touched on here today.

**There are many more to explore!**





# And finally... a Construction Update

Limited construction activities resumed on Cerro Pachón on September 28th, coinciding with the easing of the quarantine restrictions for the La Serena area, and following a thorough review to ensure that summit work could resume safely.

Work will ramp up gradually over the next few months to ensure the team has time to re-adapt to working on the summit, and to adjust to the new COVID-19 protocols and procedures that are now in place.

# View of the Summit Today!

Cerro Pachón Summit



12:29 pm CLST

NOTE: Camera 2 is powered by a generator that is shut down at the end of the day.