Preparing for Milky Way and Local Volume Science with LSST

Knut Olsen (NOAO)

Background

LSST Design Reference Mission

In 2004, the LSST Design Reference Mission (Strauss et al.) identified “the structure of our Milky Way” as one of the pillars of the LSST science case. It asked:

- What is the structure and accretion history of the Milky Way?
- What are the fundamental properties of all stars within 200 pc of the Sun?

Background

LSST Science Book 2.0

Background

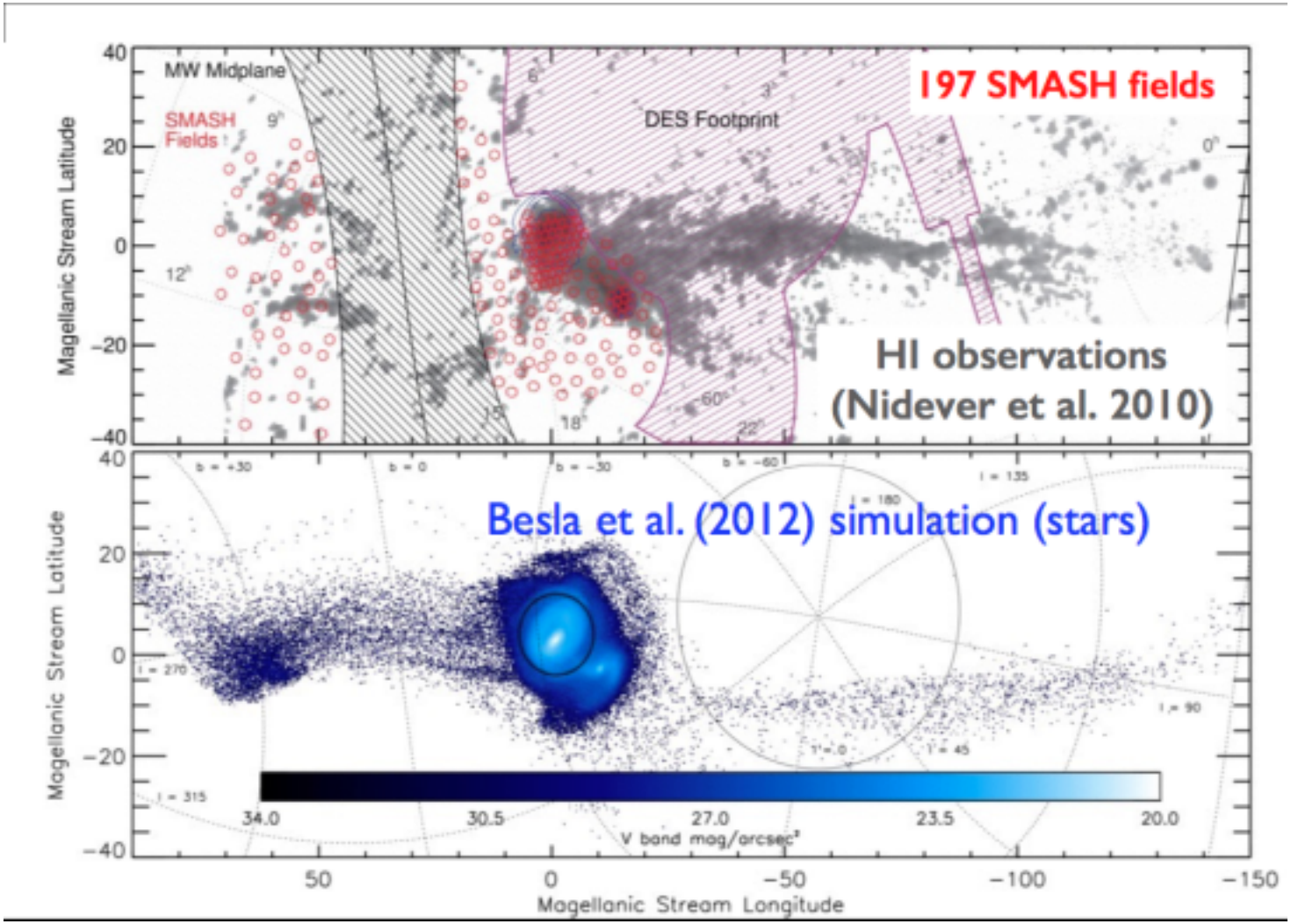
Stars, Milky Way, and Local Volume Collaboration

- milkyway.science.lsst.org
- Co-chairs John Gizis, Nitya Kallivayalil, and John Bochanski

Working Groups & Leads

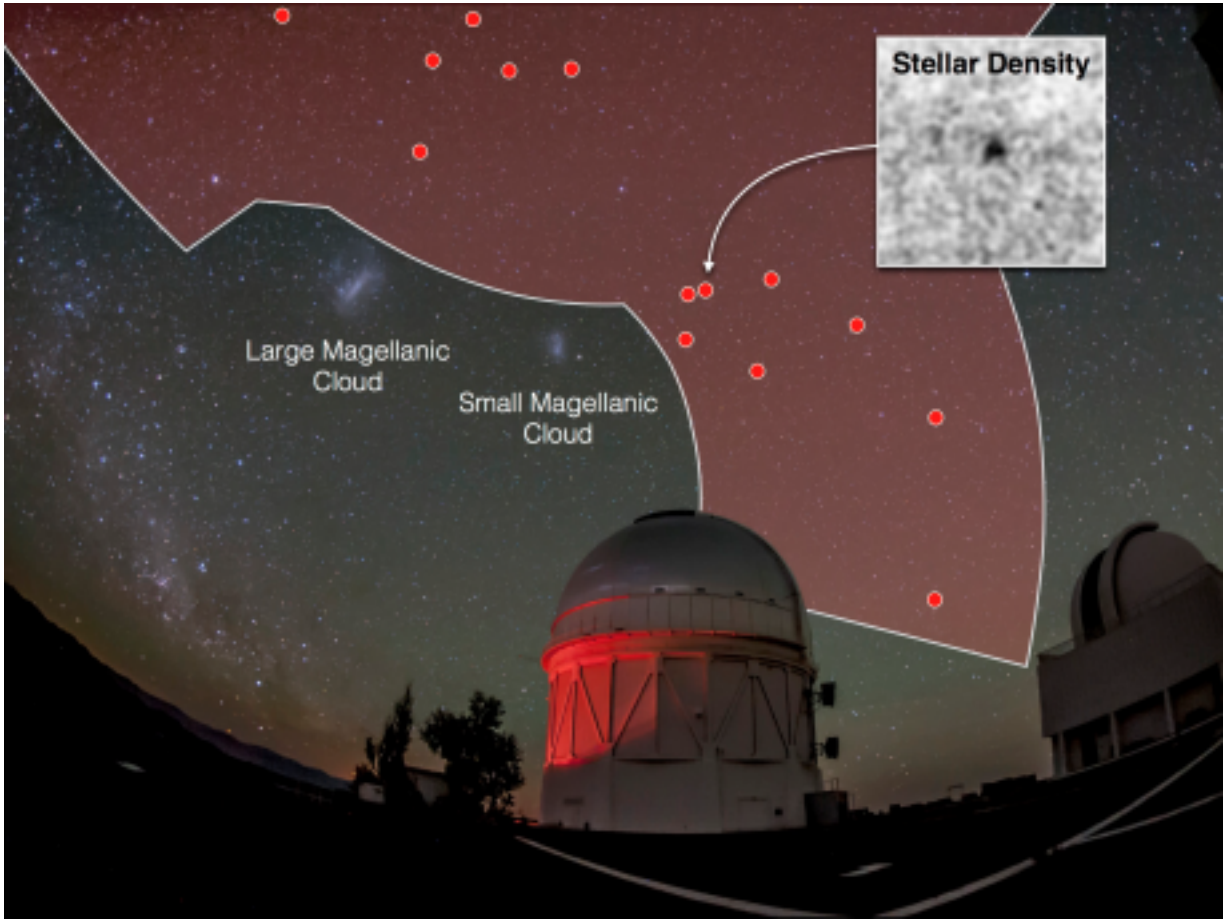
1. Variable Stars: David Ciardi, lsst-milkyway-var@lsstcorp.org
2. Star Clusters: Kevin Covey & Jay Strader, lsst-milkyway-sc@lsstcorp.org
3. Magellanic Clouds: Knut Olsen, lsst-milkyway-mc@lsstcorp.org
4. Near Field Cosmology: Marla Geha & Carl Grillmair, lsst-milkyway-nfc@lsstcorp.org
5. The Galactic Bulge: Will Clarkson & Victor Debattista, lsst-milkyway-bulge@lsstcorp.org
6. The Solar Neighborhood: Adam Burgasser & Todd Henry, lsst-milkyway-low@lsstcorp.org
7. Galactic Structure and ISM: Peregrine McGehee, lsst-milkyway-struct@lsstcorp.org

Why the Magellanic Clouds?



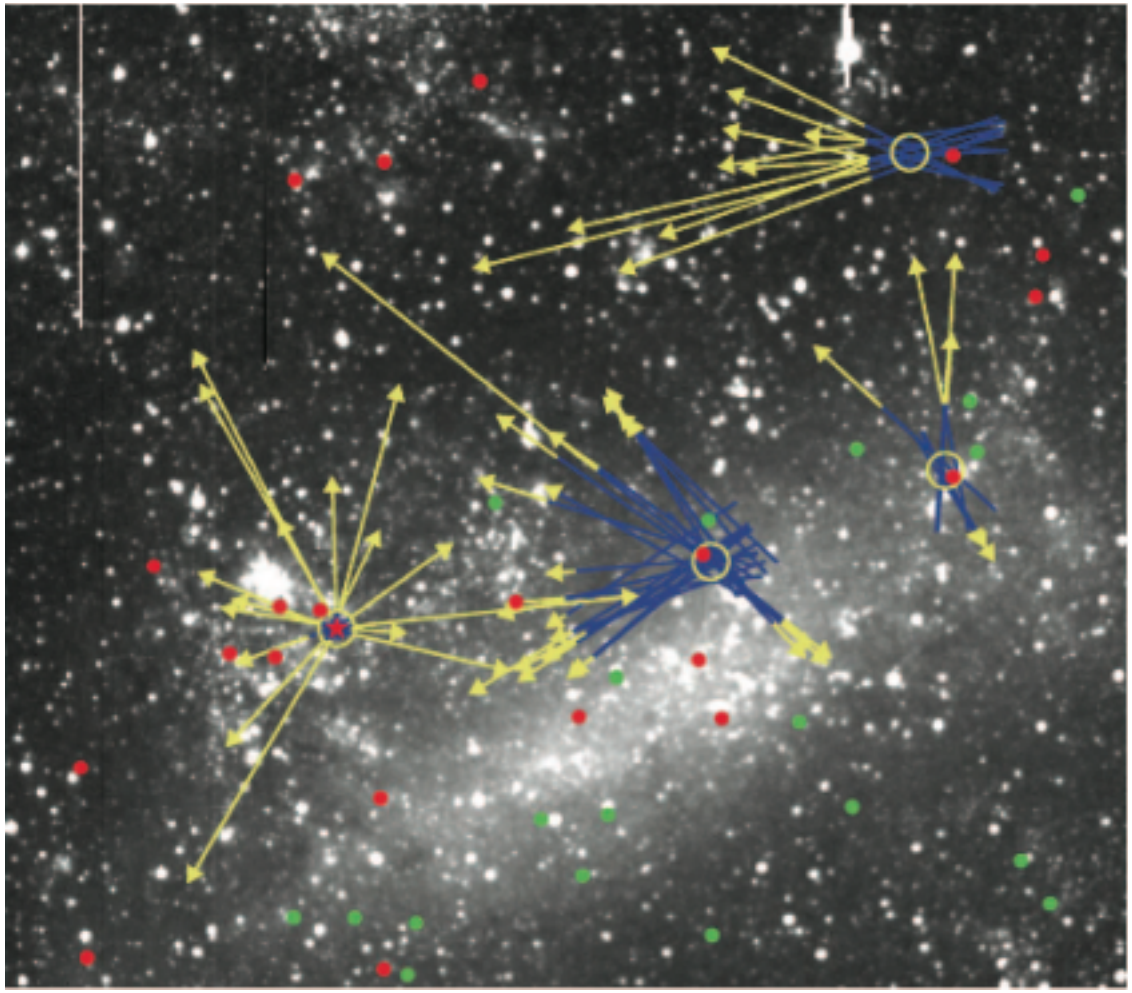
Nidever et al. (2017)

Why the Magellanic Clouds? cont.



Bechtol et al. (2015); Koposov et al. (2015)

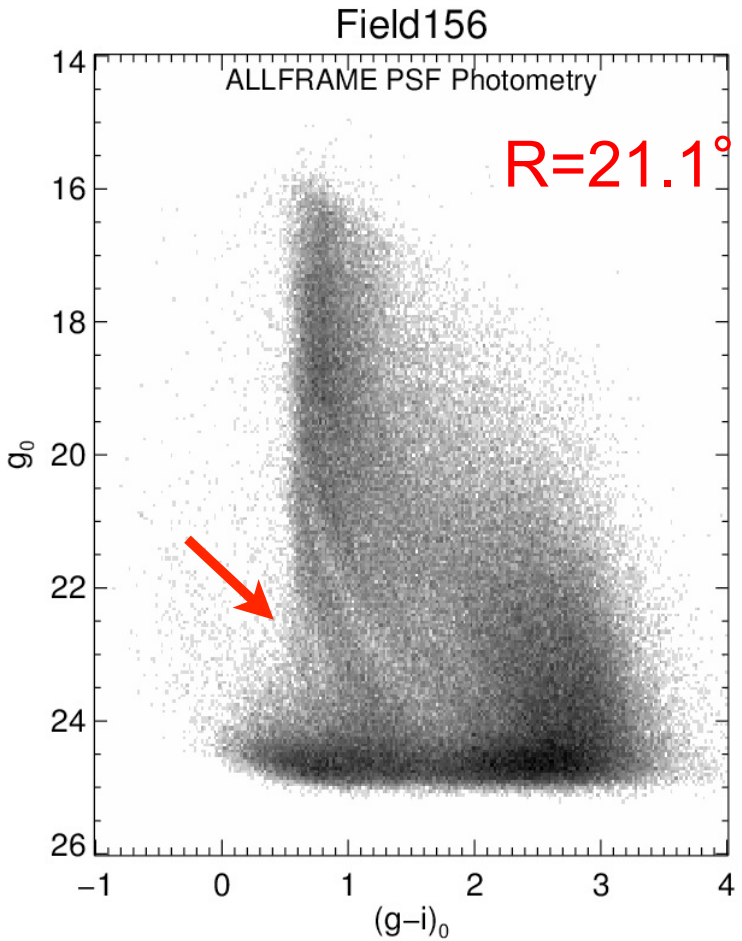
Why the Magellanic Clouds? cont.



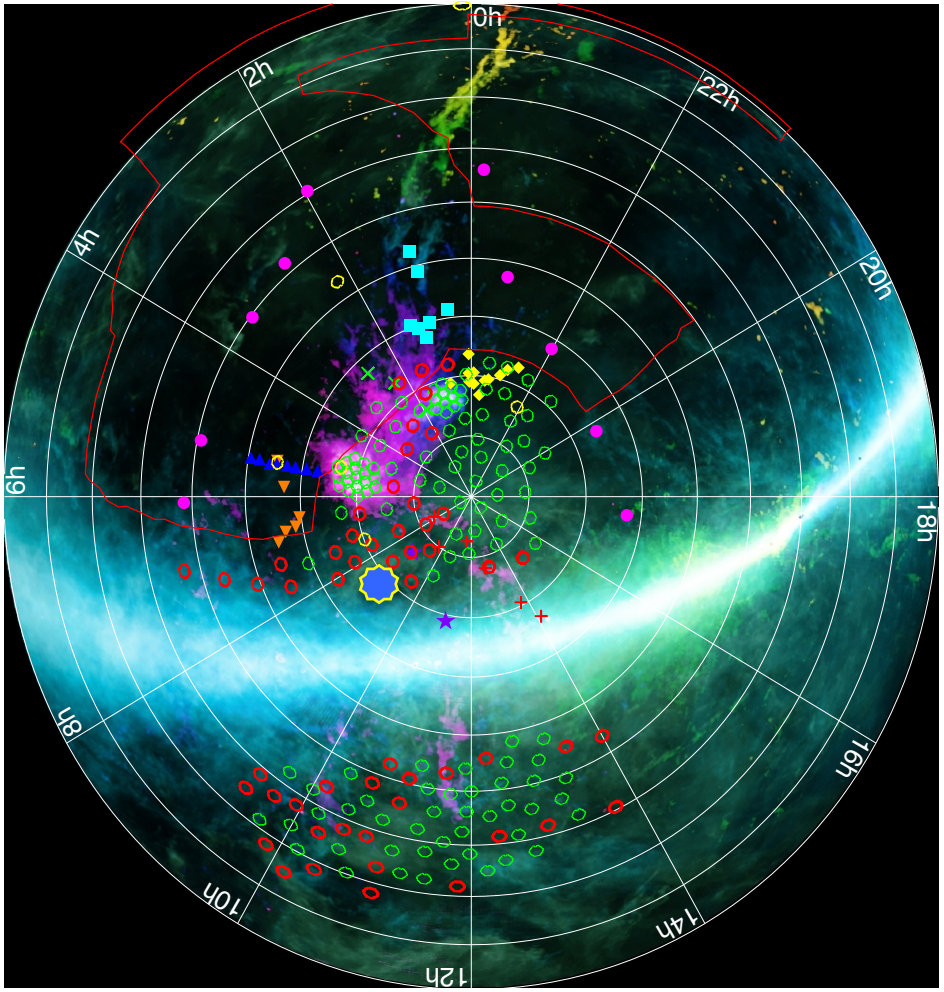
Rest et al. (2005)

How is LSST good for Milky Way science?

It goes deep



Nidever et al. (2017)



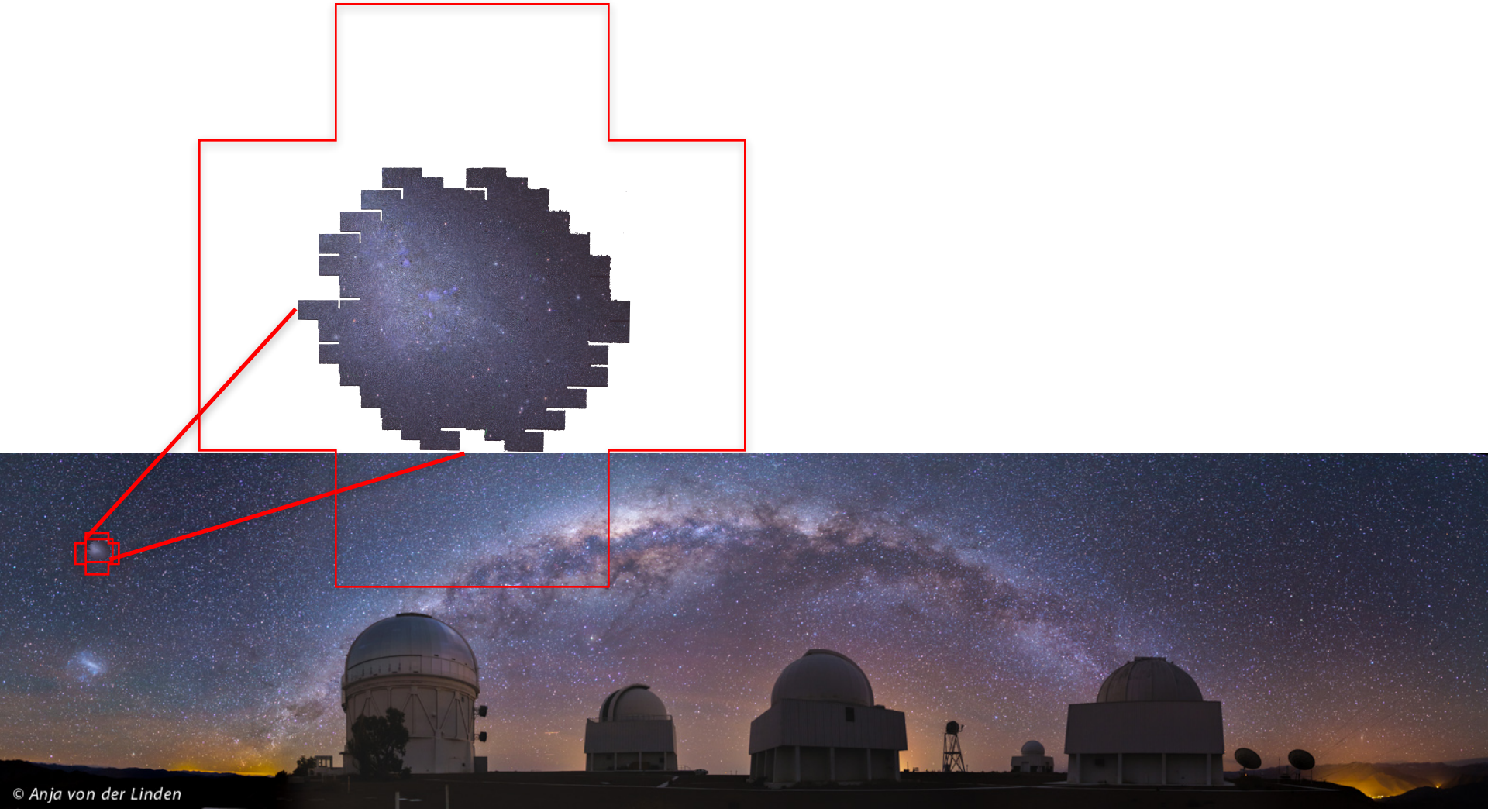
McClure-Griffiths et al.

How is LSST good for Milky Way science?

It's wide

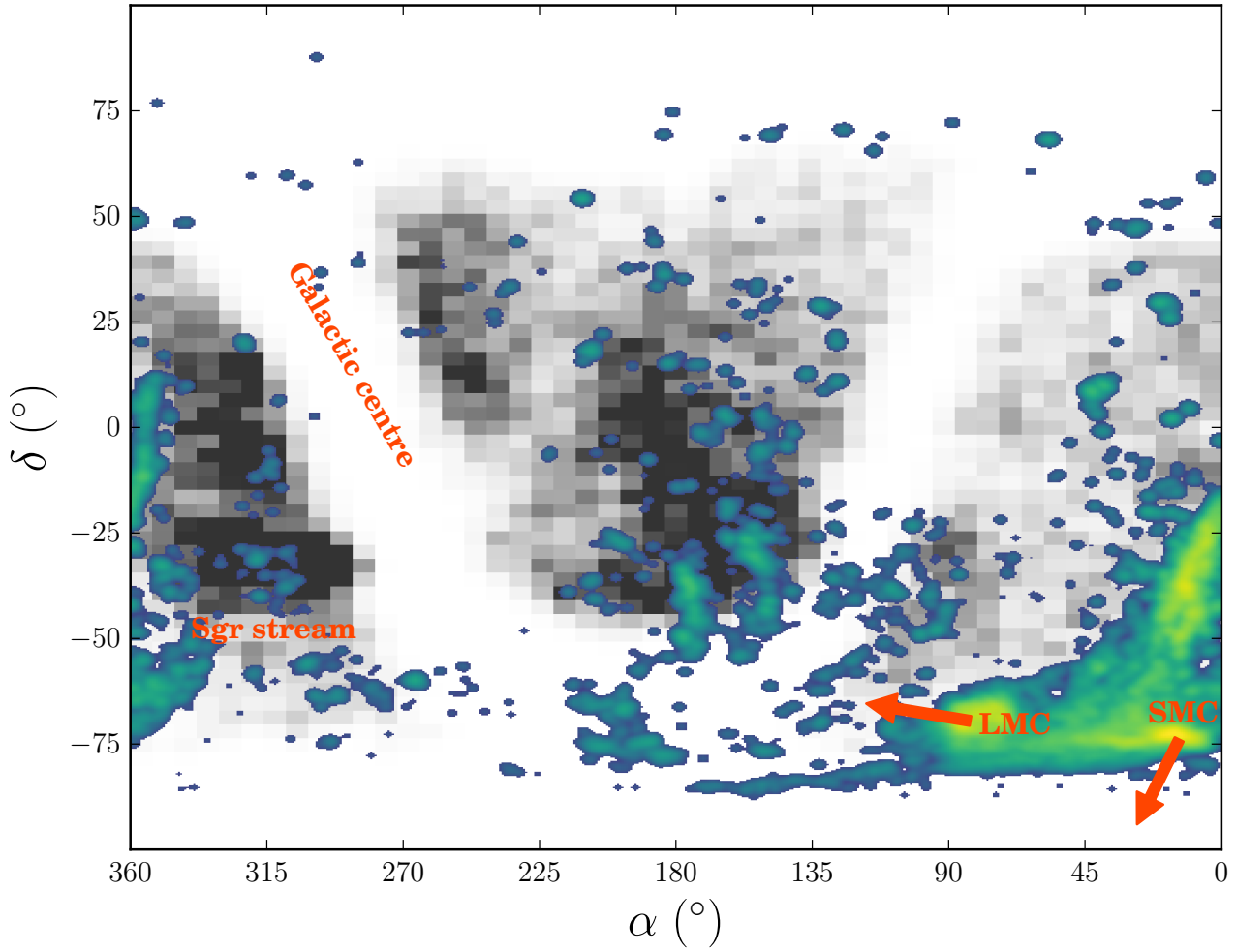
How is LSST good for Milky Way science?

It's wide



How is LSST good for Milky Way science?

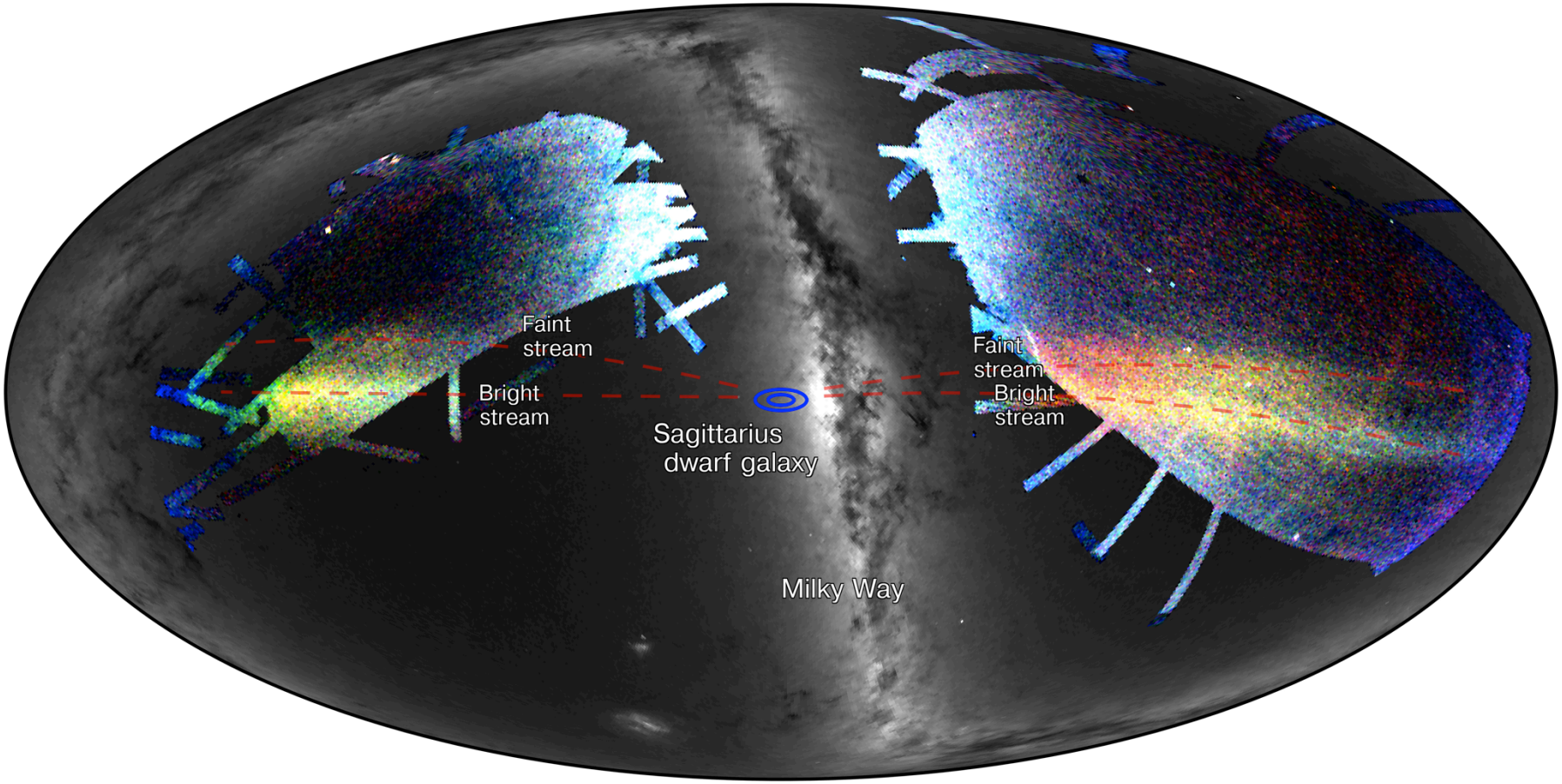
It will detect variables



Boubert et al. (2017)

How is LSST good for Milky Way science?

Wide, Fast, Deep



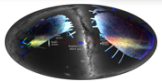
Koposov et al.

How is LSST good for Milky Way science?

Wide, Fast, Deep

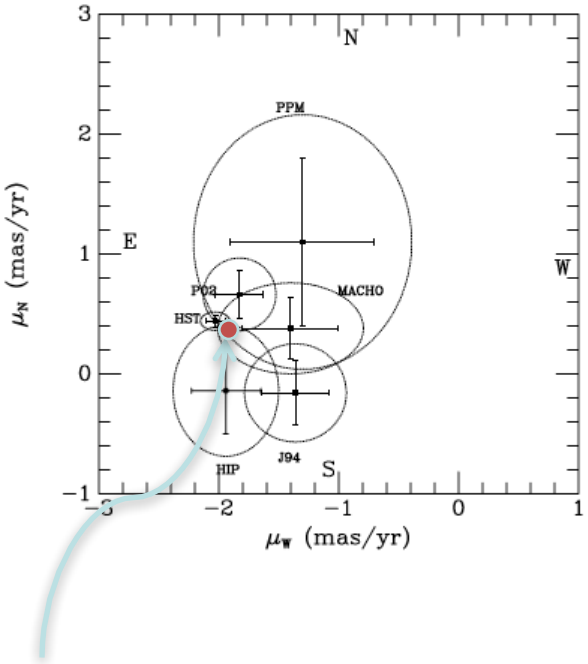
MSTO to ~200 kpc

RR Lyrae to 400 kpc

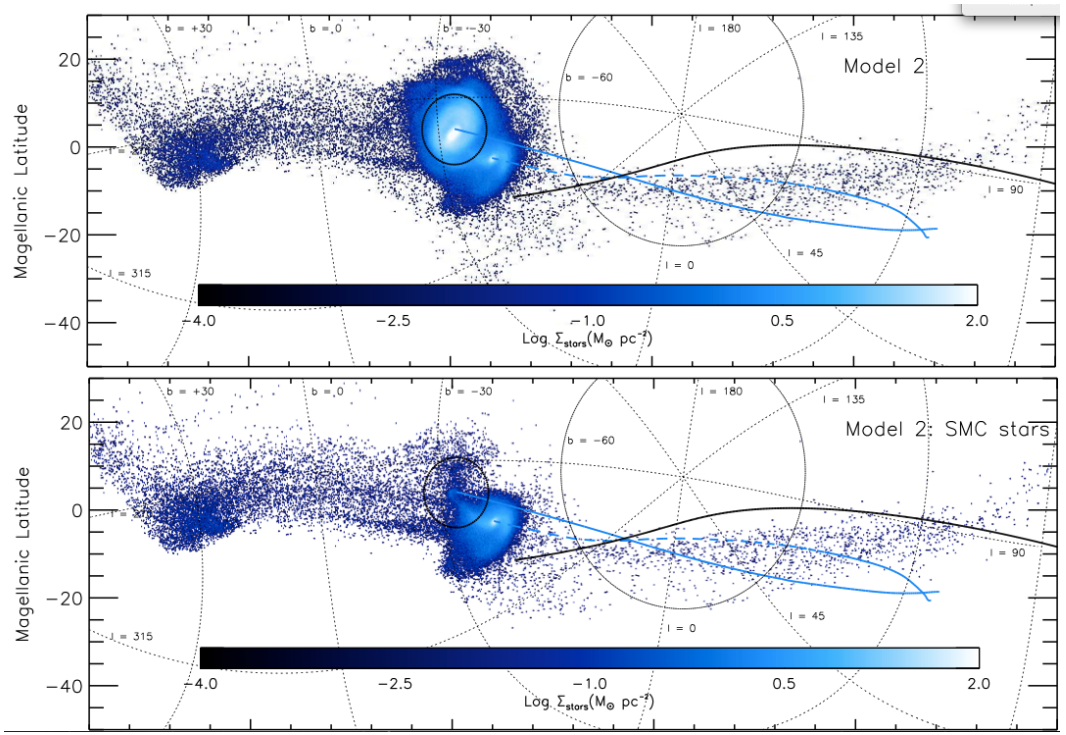


How is LSST good for Milky Way science?

It will measure proper motions



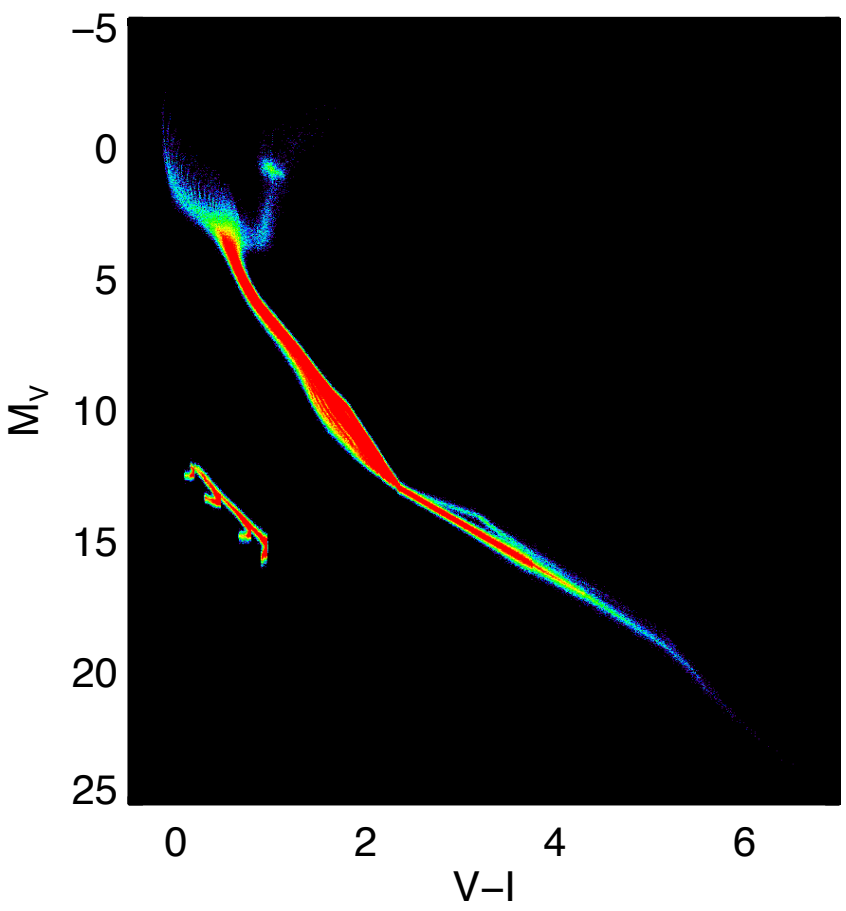
Kallivayalil et al. (2013)

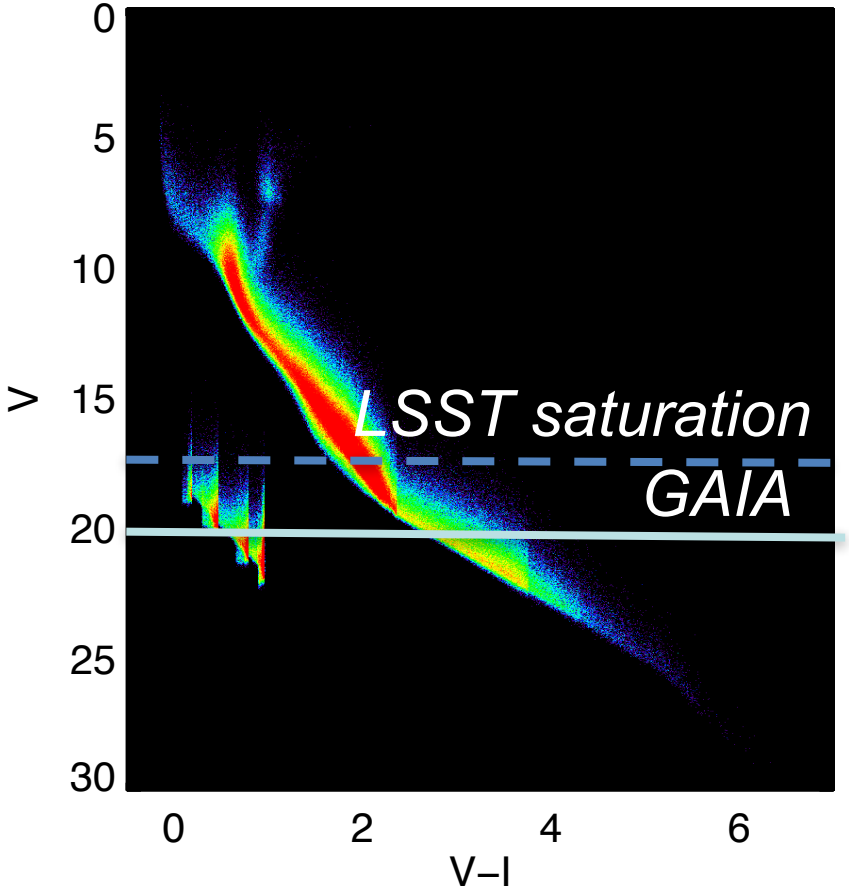


Besla et al. (2013)

How is LSST good for Milky Way science?

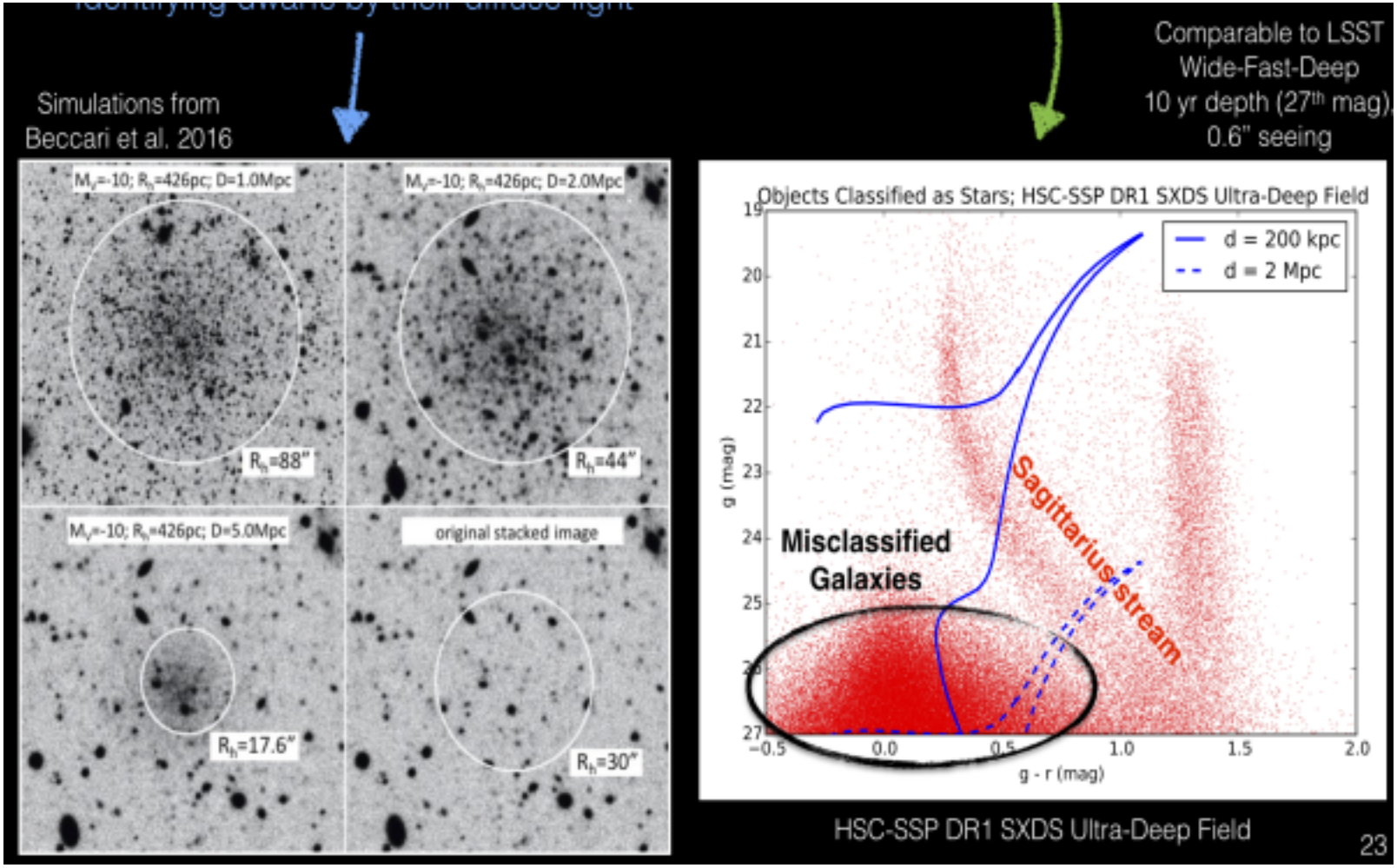
It will measure parallax



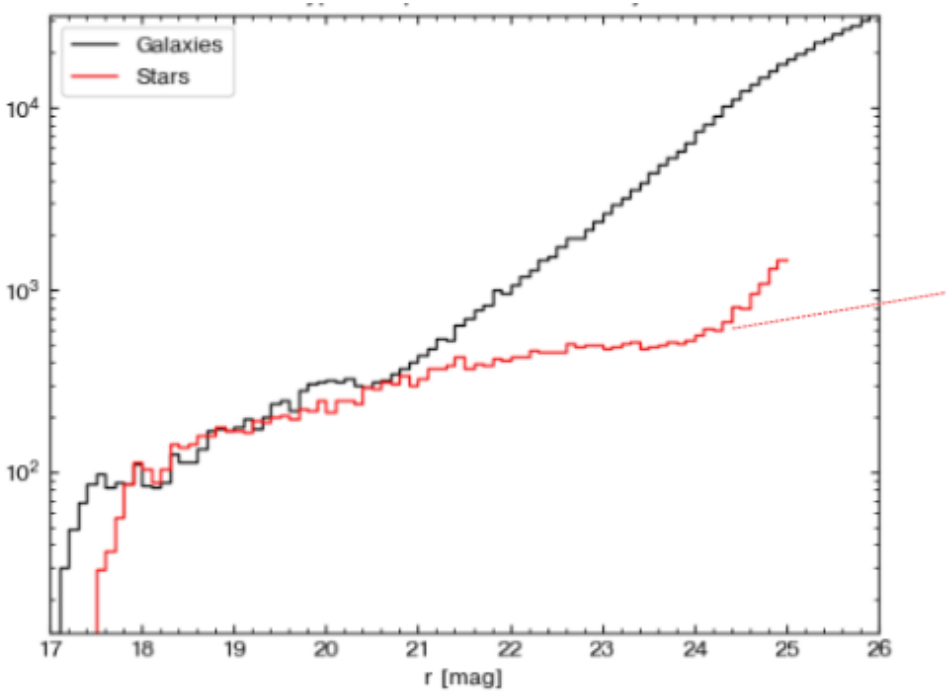


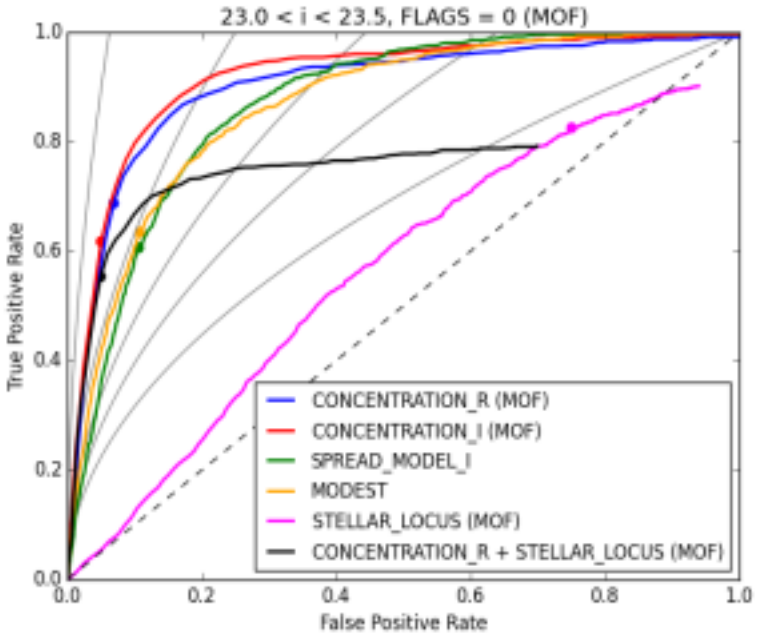
LSST: ~200 pc volume, 10% parallaxes

Challenges
Star/galaxy separation



Challenges
Star/galaxy separation

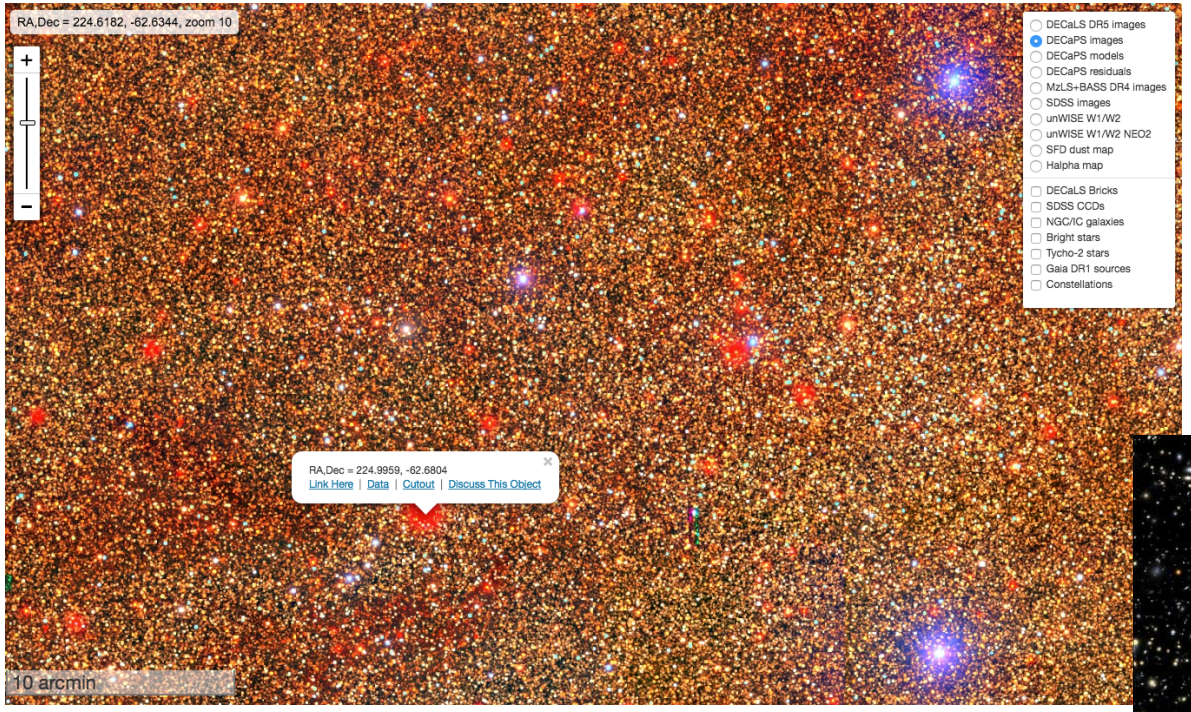




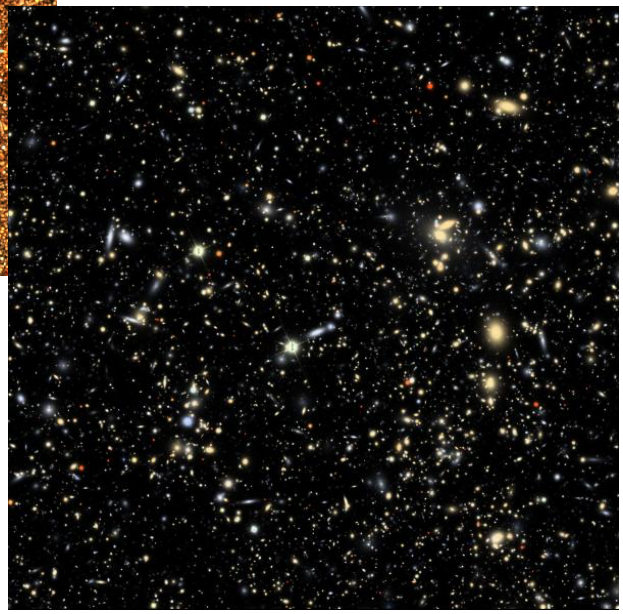
Presented by Sergey Koposov at Dwarf Companions workshop

Challenges

Crowded field photometry and astrometry



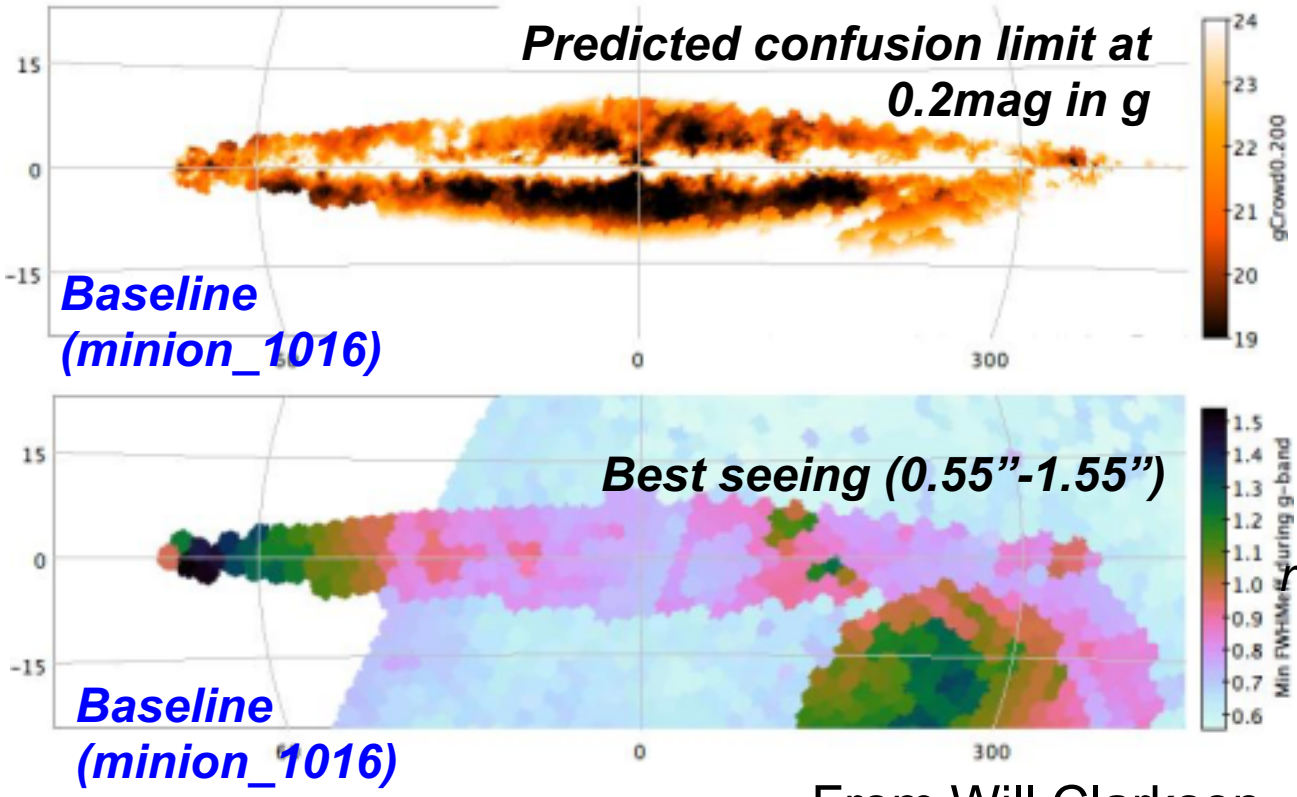
DECaPS (Schlafly et al.)

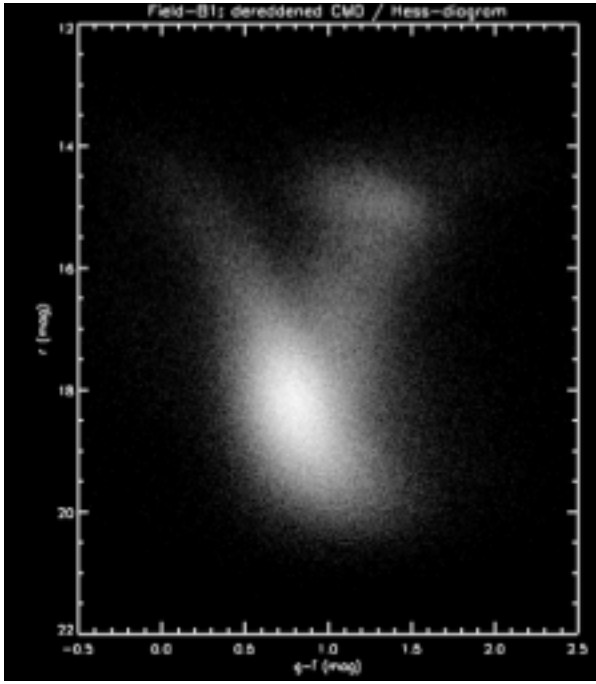


LSST ImSim section

Challenges

Crowded field photometry and astrometry





Above: (r, g-r) color magnitude diagram (de-reddened) towards Baade’s Window using DECam (Saha et al. 2017 in prep)

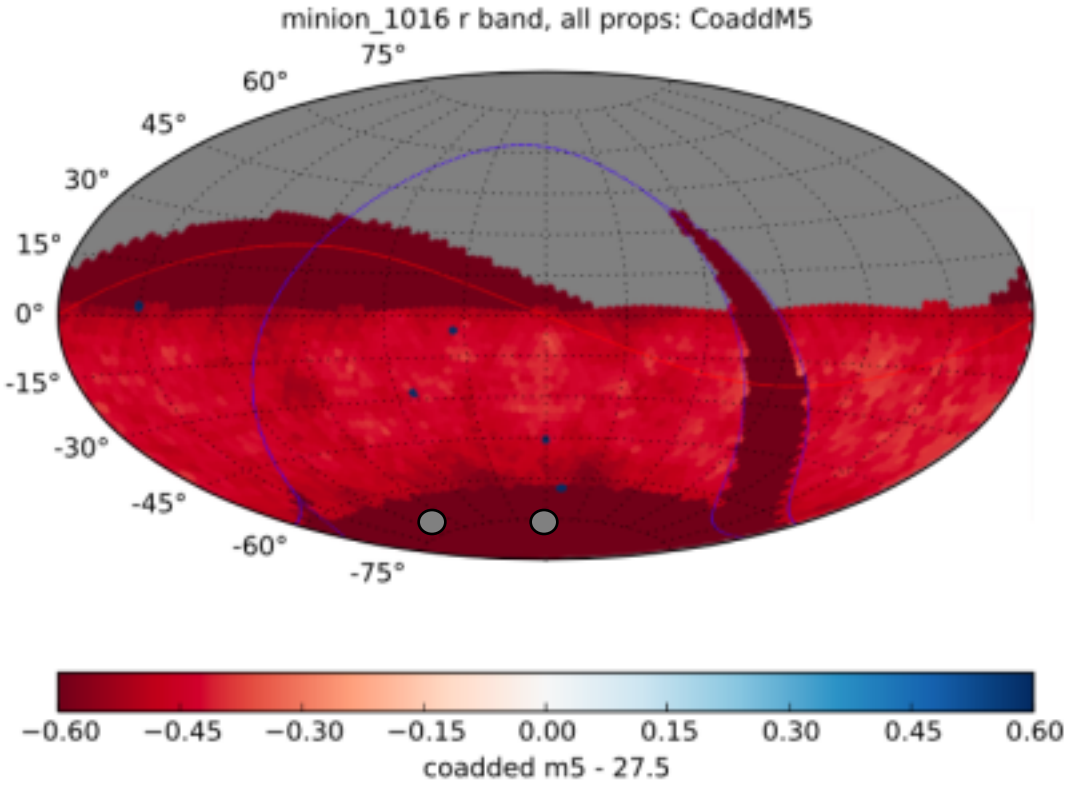
From Will Clarkson

Challenges
Observing cadence

- Observing strategy white paper (Marshall et al. 2017)
  - https://github.com/LSSTScienceCollaborations/ObservingStrategy
- Example metrics for MW science:
  - Co-added depth
  - Number of visits
  - Spacing of visits
  - Confusion depth
- Example Figures of merit:
  - Surface brightness limit for structure
  - Number of detected objects (dwarfs, variables, transients)
  - Proper motion accuracy

Challenges
Observing cadence

- Responding to call for mini-surveys: Magellanic Clouds



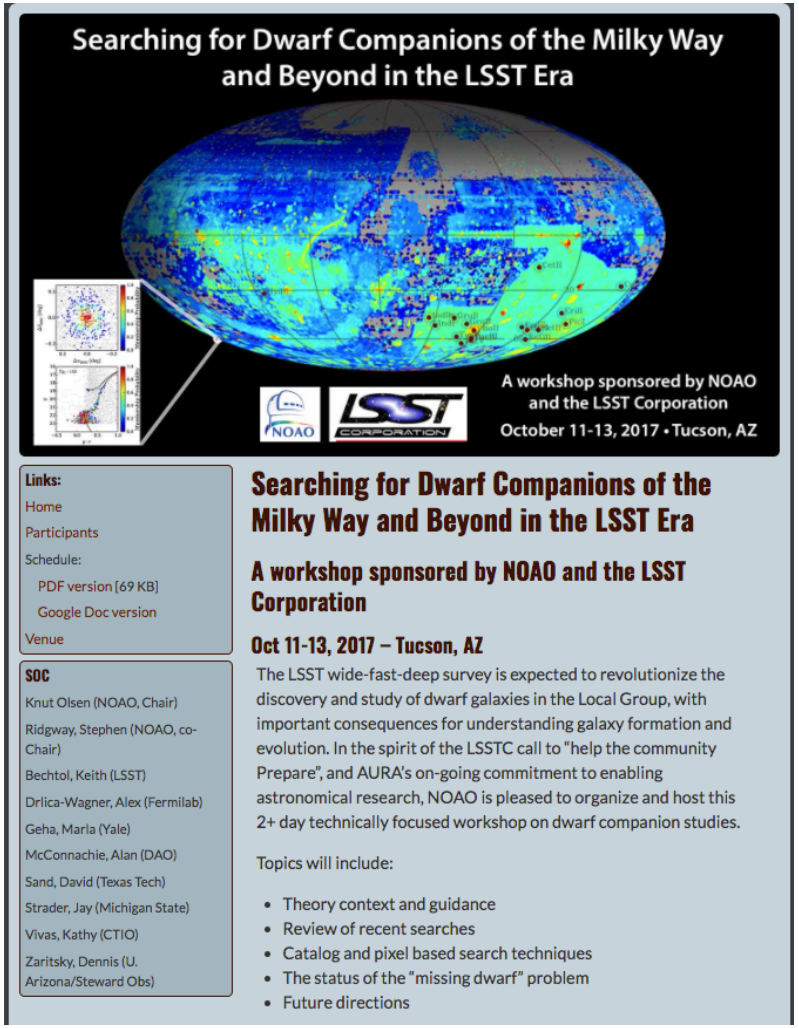
- A Wide-Fast-Deep-like survey around the South Celestial Pole
- A Deep Drilling survey covering the main bodies of the Magellanic Clouds, up to 250 deg^2

Magellanic Clouds mini-survey Proposal

	Coadds	Single epochs
Select field(s)	Legacy survey of the Magellanic Clouds	Variable star populations (Szkody) Microlensing (Dawson) Transiting extragalactic planets (Lund) New short-timescale transients Interstellar scintillation (Moniez) Light echoes
Many-fields	Structure and tidal debris Dwarf satellites	Proper motions RR Lyrae as tracers of 3D structure

Preparing for LSST
Getting organized

- Meetings like LSST Chile are a good start
- Small topical meetings can take planning further
- LSSTC and NOAO sponsored meeting on dwarf galaxies in LSST era an example



Preparing for LSST

Getting organized

Some keys:

- Focus on organized discussion
- Many topics to discuss: theory, observation, relevant questions for LSST, LSST data products, challenges, observing cadence, follow-up and synergy with other facilities, needed resources, next steps
- Invite a diverse group and give them all work to do
- Take notes and write a report

Preparing for LSST
Dwarf galaxies

LSST gives:

Depth
- Detection of dwarfs about the MW, Local Volume & out to 100 Mpc

Variable Stars
- Distances through RRLyr

Proper Motions
- Internal motion and orbits around the MW

Wide field
- Volumes probed, field vs. groups/clusters

Theoretical interests:

Number and distribution of dwarfs about MW/MW analogues within 100 Mpc

Tidal effects
- Streams, morphological evolution

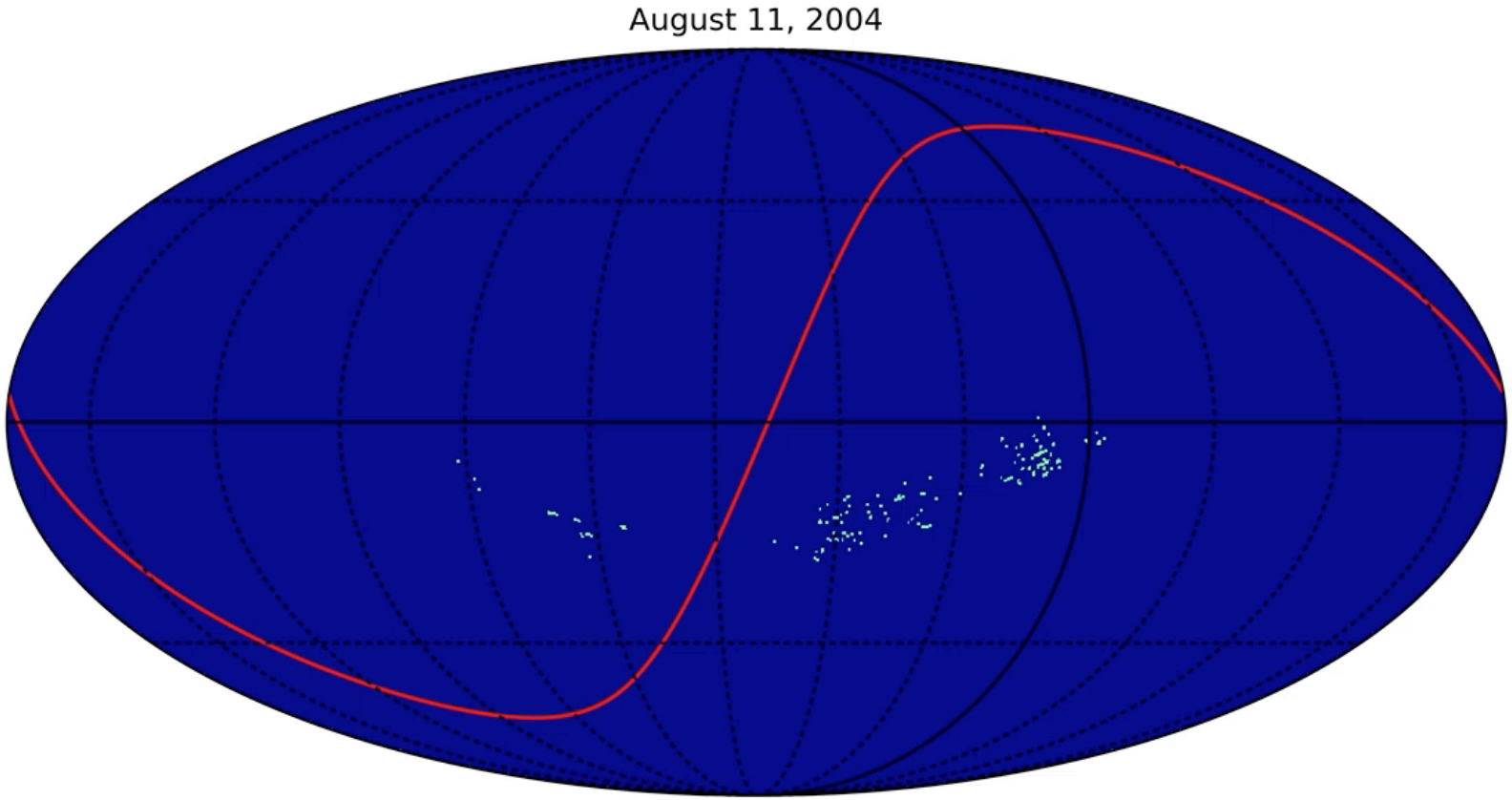
Quenching of low-mass galaxies
- Role of environment

Dark Matter Halos
- Mass/structure/kinematics

Hierarchical Evolution
- Dwarf groups in the field & infall on massive hosts

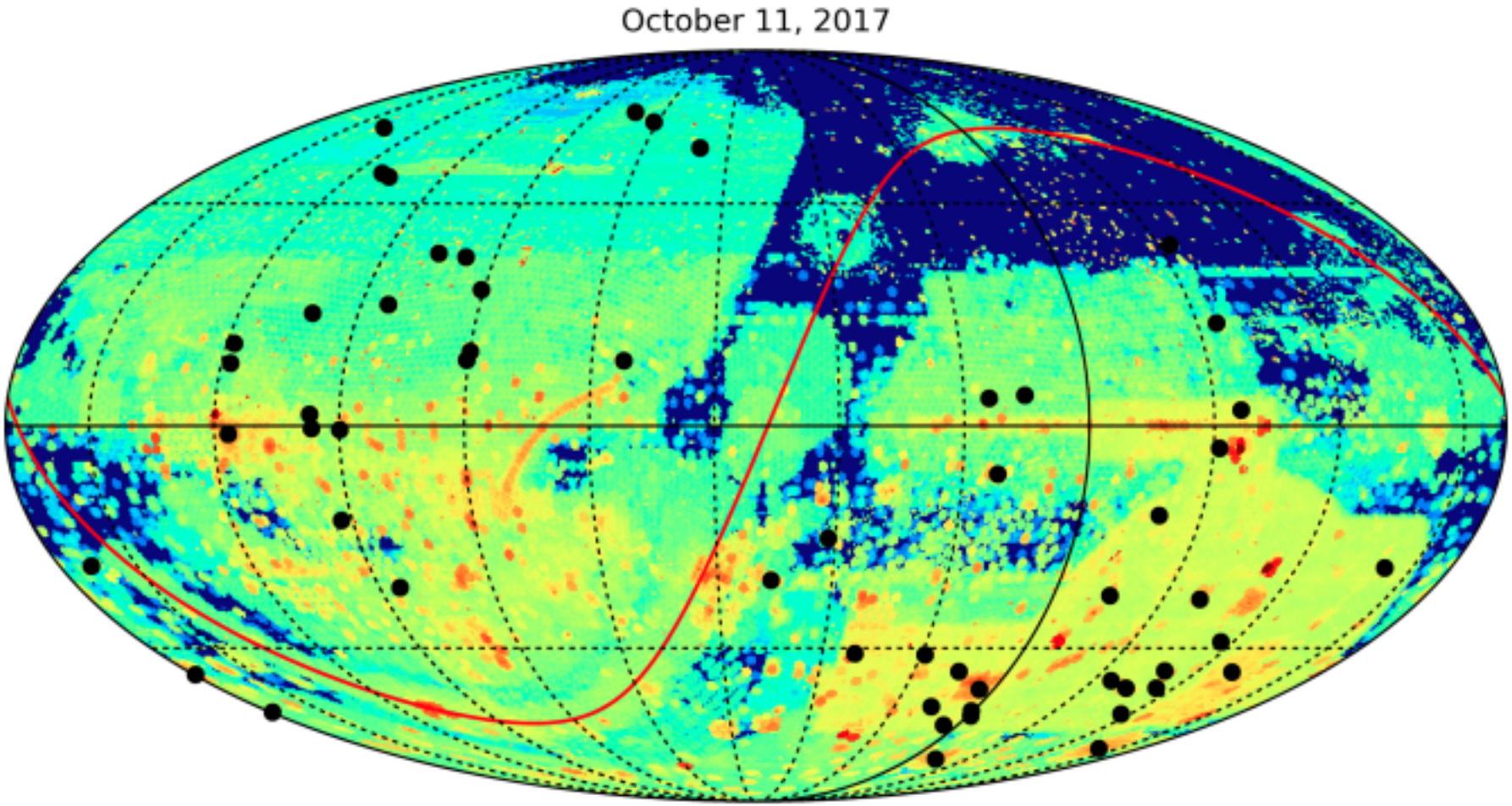
Preparing for LSST

Using existing data



Preparing for LSST

Using existing data



Preparing for LSST
NOAO Data Lab

Goal:

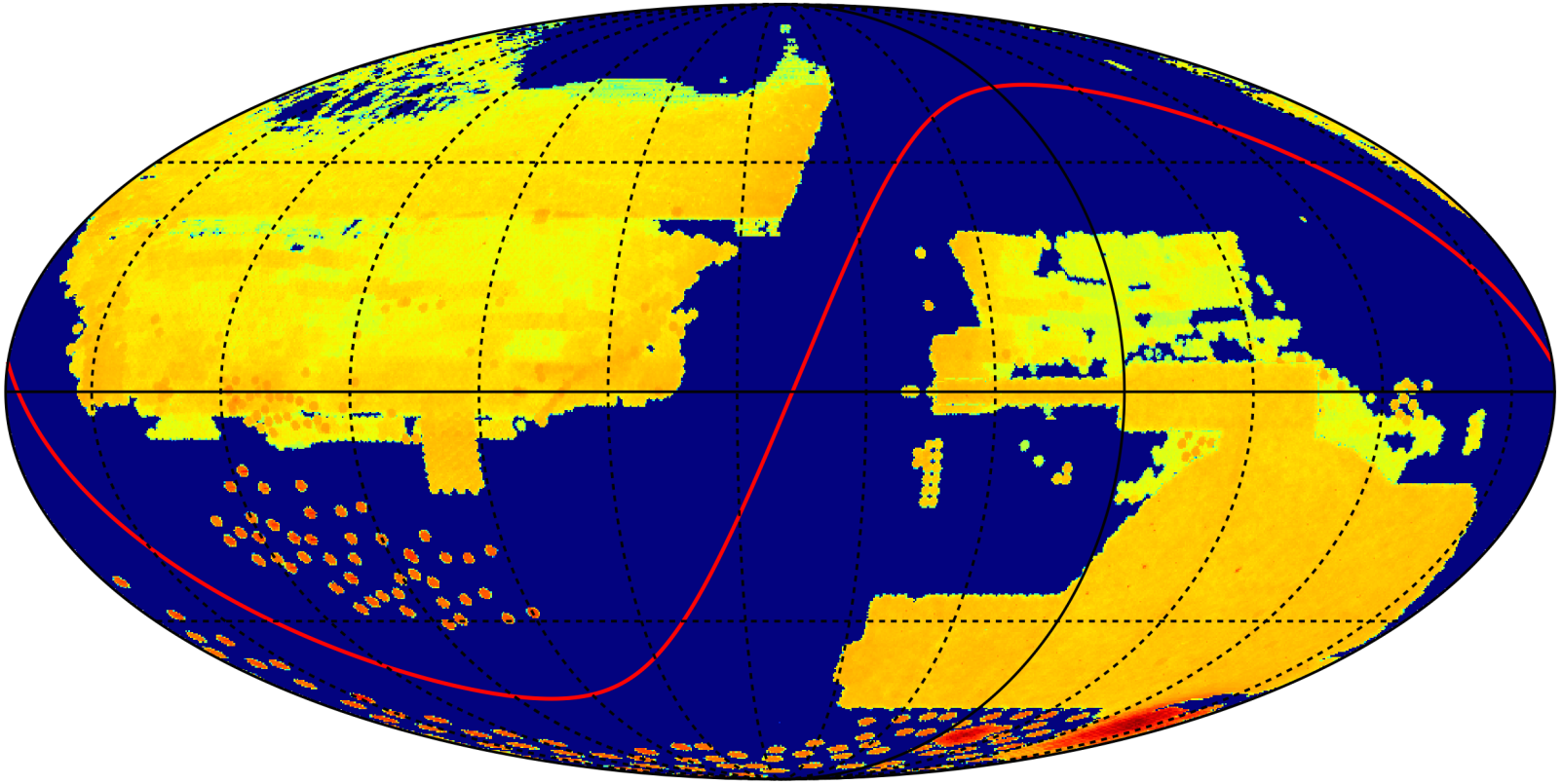
- Efficient exploration and analysis of large datasets with an emphasis on NOAO wide-field 4-m telescopes

Approach:

- High-value catalogs from NOAO and external sources (e.g. SDSS, GAIA) and NOAO-based images linked to catalog objects
- Data discovery
- Developing intuition through interaction with selected catalog and image set of known objects
- Automation of analysis to aid discovery of unknown objects

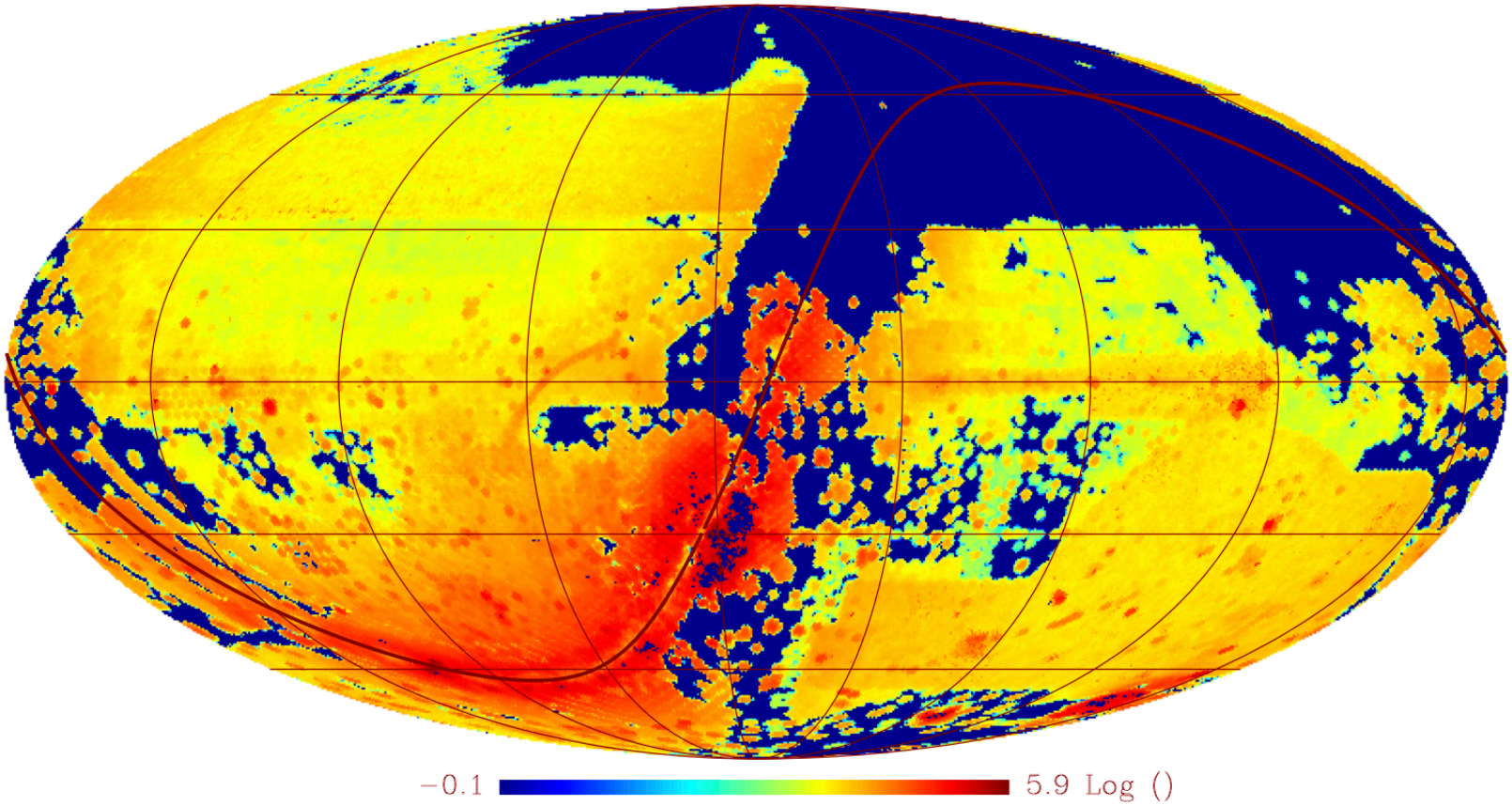
Catalogs available through Data Lab

Legacy Survey DR3/4/5, SMASH, DES DR1, DECaPS



- ~1+ billion objects available now/soon through Data Lab database from these catalogs
- Also available: DES SVA1, GAIA DR1, select tables from SDSS DR13, the Allen NEO catalog, and USNO-A2/B

An NOAO All Sky Catalog



- ~3 billion objects, 30 billion measurements; basic aperture photometry
- Released January 2018

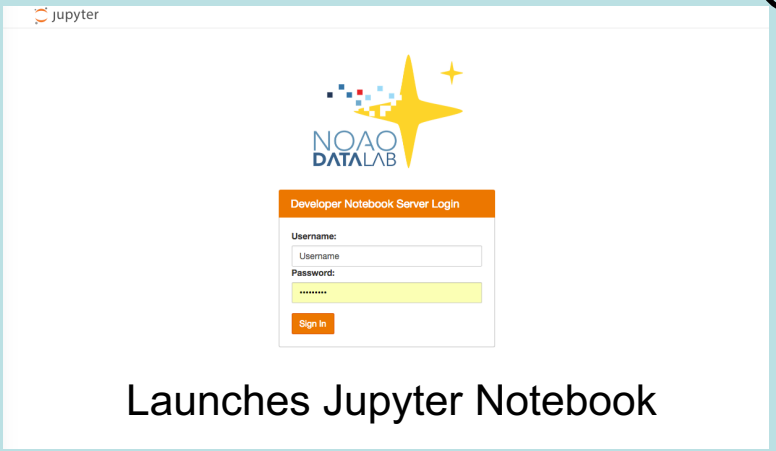
Summary of Current Functions

Function	Method
Sky exploration	Image discovery tool Catalog overlay tool
Authentication	Web interface datalab command Python authClient, DL interface
Catalog query	Web interface datalab command line (CLI) Python queryClient, DL interface TOPCAT
Image query	Simple Image Access (SIA) service
Query result storage	myDB Virtual storage space
File transfer	datalab command and Virtual storage space
Analysis	Jupyter notebook server

Example Notebook
Star/galaxy/QSO separation

User logs in to Data Lab

1



Launches Jupyter Notebook

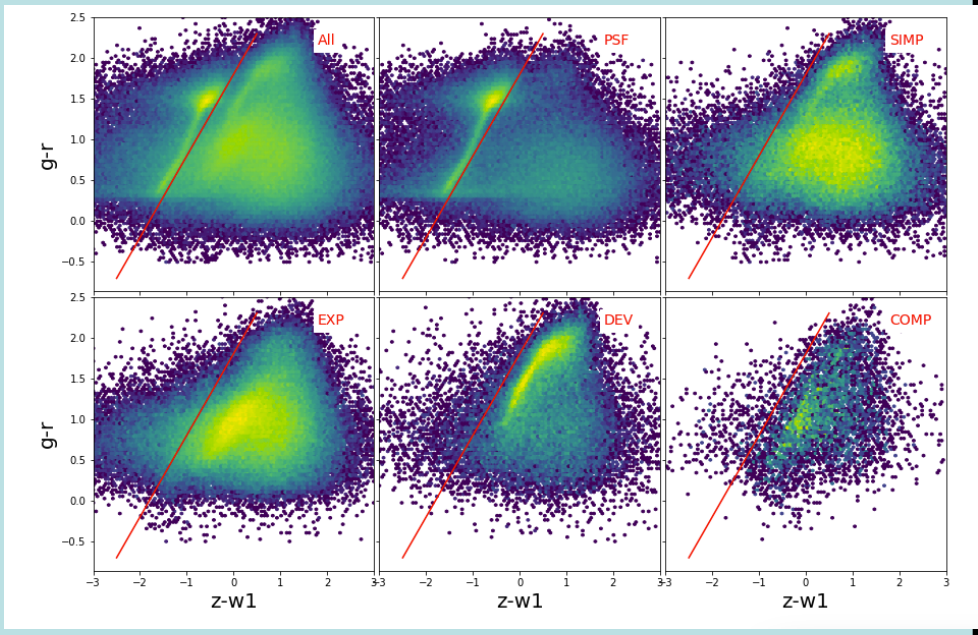
Queries database for DECaLS Tractor and AllWISE photometry

2

```
In [58]: # Write query statement (adql)
         query = """
                 SELECT g as gmag, r as rmag, z as zmag, w1 as w1mag, w2 as w2mag, type,
                        decam_flux_2*sqrt(decam_flux_ivar_2) as snr_g,
                        decam_flux_3*sqrt(decam_flux_ivar_3) as snr_r,
                        decam_flux_5*sqrt(decam_flux_ivar_5) as snr_z
                 FROM ls_dr3.tractor_primary
                 WHERE (decam_flux_2*sqrt(decam_flux_ivar_2)>3 and
                        decam_flux_3*sqrt(decam_flux_ivar_3)>3 and
                        decam_flux_5*sqrt(decam_flux_ivar_5)>3)
                 LIMIT 800000"""

         #         WHERE (decam_nobs_2>1 and decam_nobs_3>1 and decam_nobs_5>1)

         # type          = object type (PSF, SIMP, EXP, DEV, COMP)
         # g,r,z         = AB magnitudes in DECam g,r,z bands
         # w1,w2         = AB magnitudes in WISE bands W1 & W2
         # decam_nobs_X = number of observations in bands g (2), r (3) & z (5)
         #
         # WHERE: requirement that there are more than 1 (i.e., at least 2) observation in each DECaLS band

         print query

                 SELECT g as gmag, r as rmag, z as zmag, w1 as w1mag, w2 as w2mag, type,
                        decam_flux_2*sqrt(decam_flux_ivar_2) as snr_g,
                        decam_flux_3*sqrt(decam_flux_ivar_3) as snr_r,
                        decam_flux_5*sqrt(decam_flux_ivar_5) as snr_z
                 FROM ls_dr3.tractor_primary
                 WHERE (decam_flux_2*sqrt(decam_flux_ivar_2)>3 and
                        decam_flux_3*sqrt(decam_flux_ivar_3)>3 and
                        decam_flux_5*sqrt(decam_flux_ivar_5)>3)
                 LIMIT 800000
```

3

Visualizes color-color diagrams by morphology type

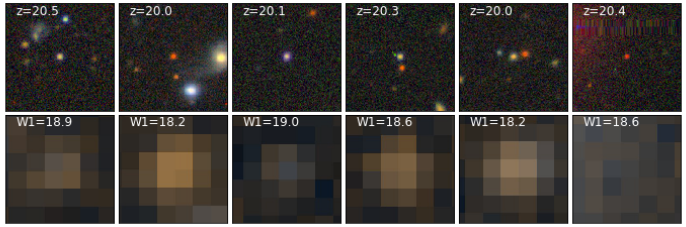


Stéphanie Juneau

...

4

Checks image cutouts of selected objects



Joins objects to SDSS DR13 spectroscopic catalog

5

Below is the result of a hack by Bela Abolfathi (UCI) put together during the LSSTC Data Science Fellowship program (April 2017).

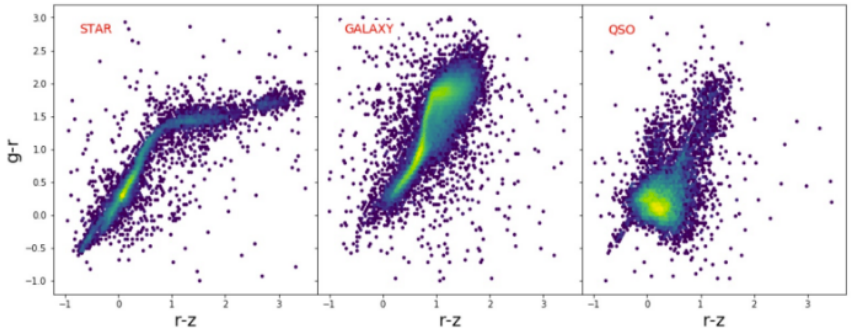


Figure: Joint query with SDSS SpecObj table and split by CLASS (Star, Galaxy, QSO).

Uses as training set for machine learning classification

Below is the result of a hack by Jan-Torge Schindler (UofA) put together during the NOAO Data Lab Tutorial (May 2017).

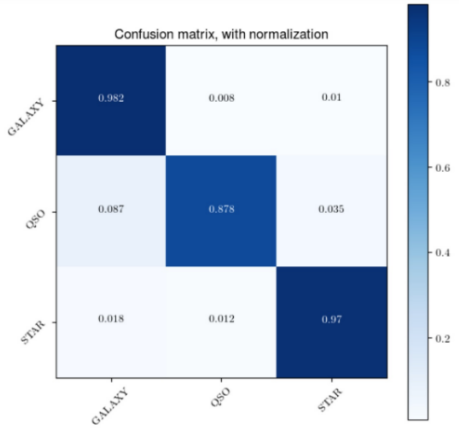


Figure: Confusion matrix, normalized by number in each category. Done from joint query with SDSS SpecObj to build training classify validation set with Machine Learning (Random Forest).

6

Applies classification techniques to find new objects of interest!

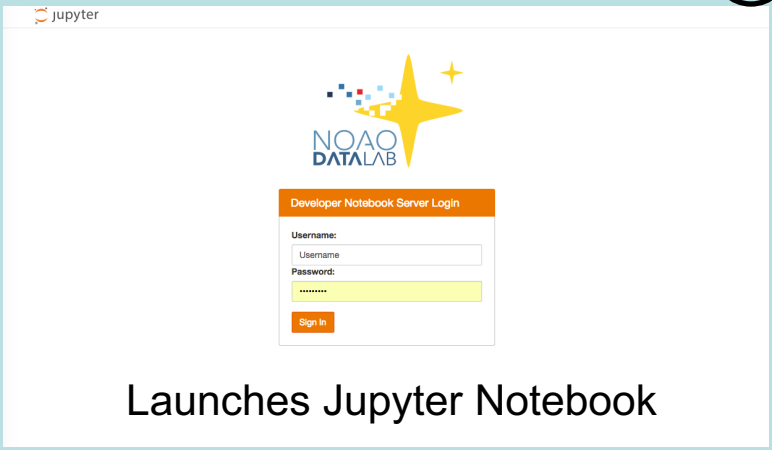
7

Example Notebook

Detecting a faint dwarf galaxy

User logs in to Data Lab

1



Launches Jupyter Notebook

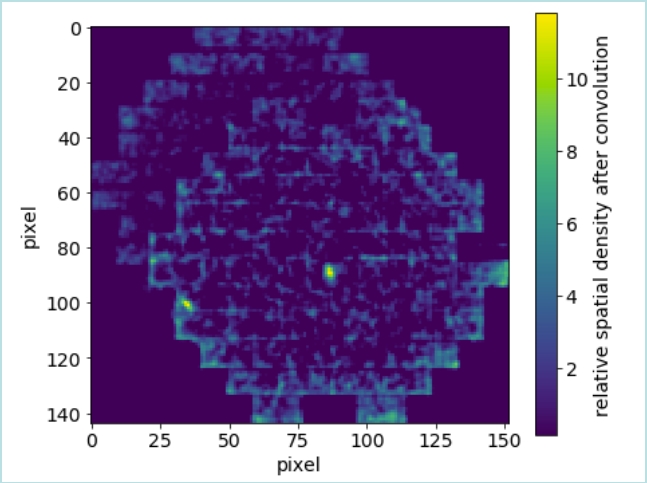
Queries database for blue stellar objects in SMASH DR1 Field

2

```
field = 169 # SMASH field number to query
depth = 1   # depth (=no short exposures please)

# Create the query string; SQL keyword capitalized for clarity
query_template =\
"""SELECT ra,dec,gmag,rmag,imag FROM smash_dr1.object
   WHERE fieldid = '%d' AND
         depthflag > %d AND
         abs(sharp) < 0.5 AND
         gmag BETWEEN 9 AND 25 AND
         (gmag-rmag) BETWEEN -0.4 AND 0.4"""

query = query_template % (field, depth)
```

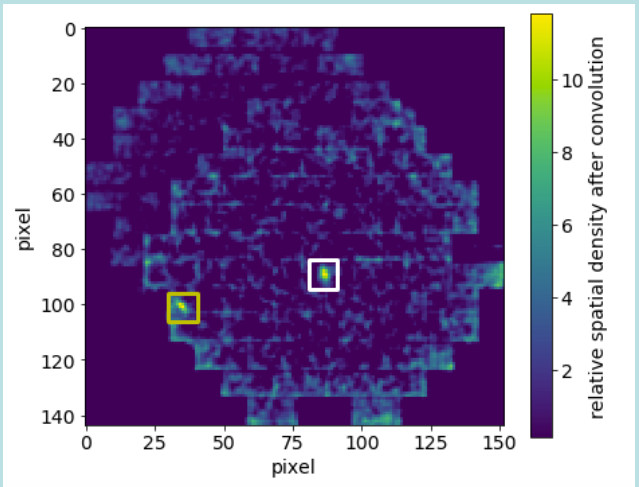
Applies filter to spatial distribution

3



Runs automatic peak detection

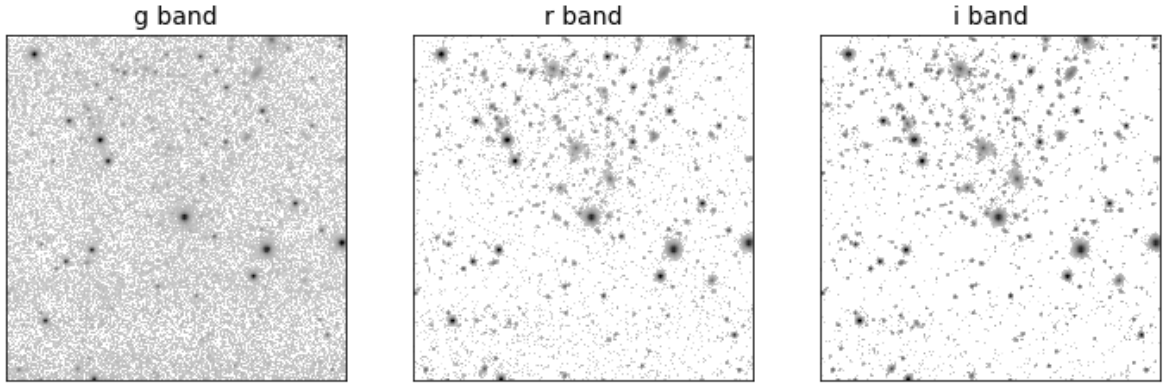
4



...

Queries peak locations for image cutouts

5



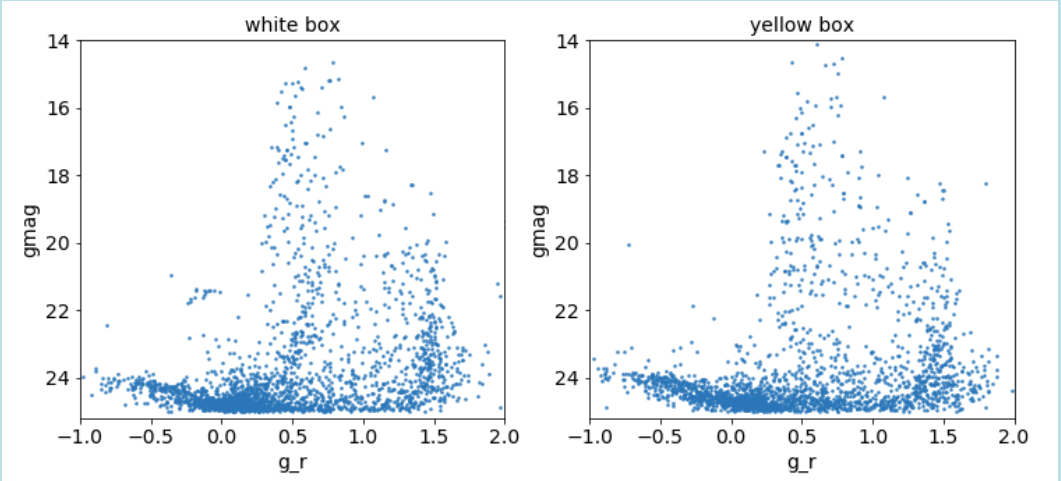
Stores all results in virtual storage…

…and repeat!

7

Queries peak locations for full photometry

6



Robert Nikutta

Contacting Data Lab

- Web: datalab.noao.edu
- Helpdesk: datalab.noao.edu/help
- Email: datalab@noao.edu
- GitHub: https://github.com/noao-datalab
- Twitter: @NOAODataLab

Conclusions

- LSST will have a profound effect on Milky Way science
- Stars, Milky Way, and Local Volume Collaboration is organizing to work on it – *lots* of room for growth!
- Organize small topical meetings to speed preparation
- Work with existing survey data
- Try out the NOAO Data Lab and other science platforms