Astrometry with LSST: Objectives and Challenges

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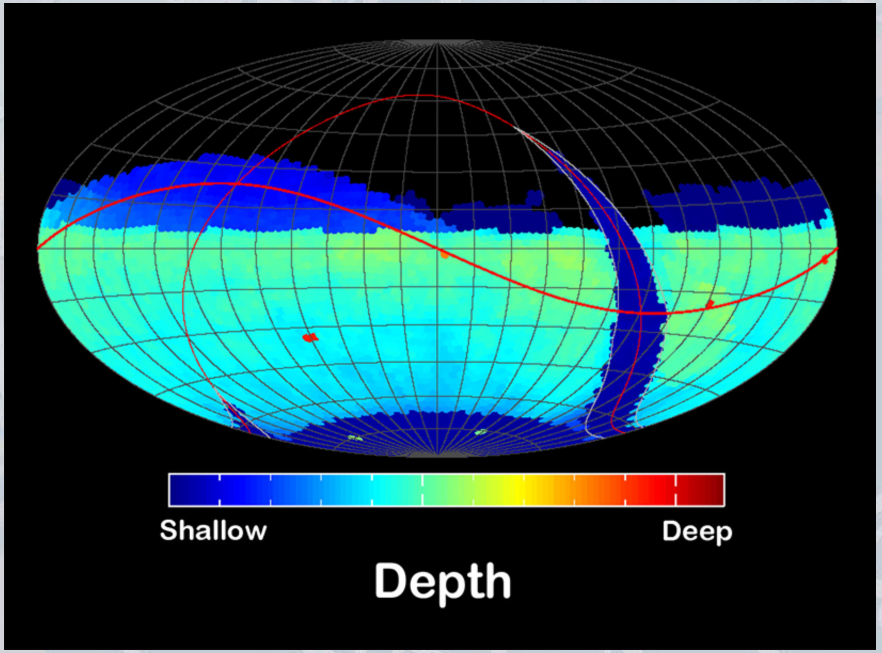
OUTLINE

- Introduction / Objectives
- Projected Astrometric Precision / Kinematical Studies
- Challenges: Observing Strategy
- Challenges: Lessons from Existing Imagers

LSST: *What it is in Brief*

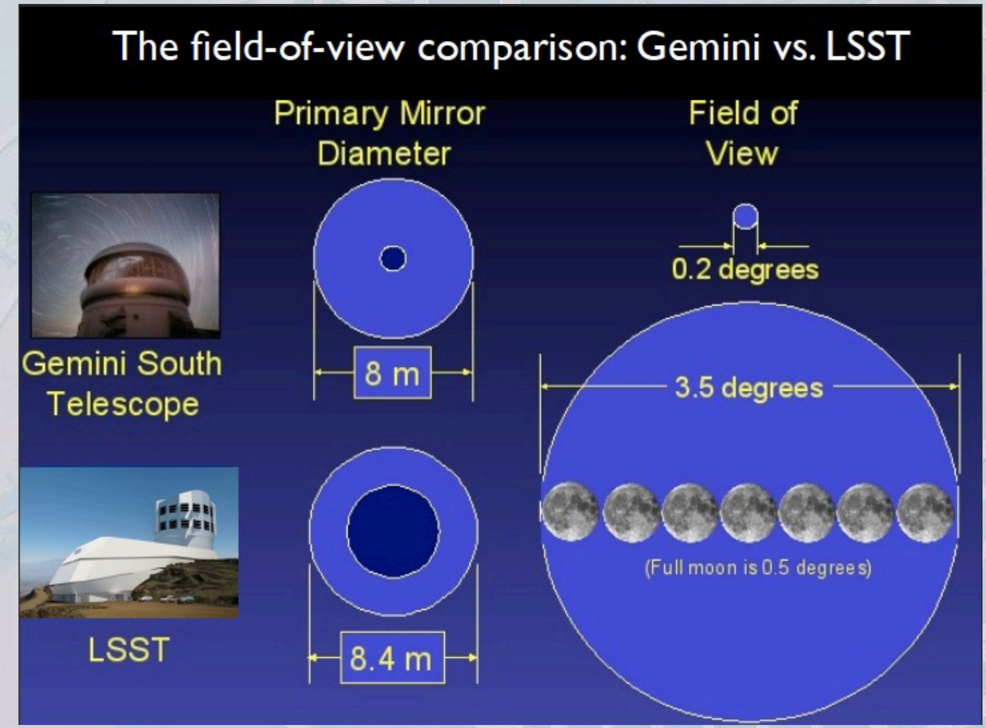
1) An optical/near IR survey that will cover half of the sky in 6 filters (ugrizy) to r~27.5 (co-add), with ~ 1000 visits in 10 years.



www.lsst.org

LSST: *What it is in Brief*

2) A novel concept: wide-fast-deep - a telescope with an enormous étendue of ~320 m^2deg^2 to address a wide range of science topics.



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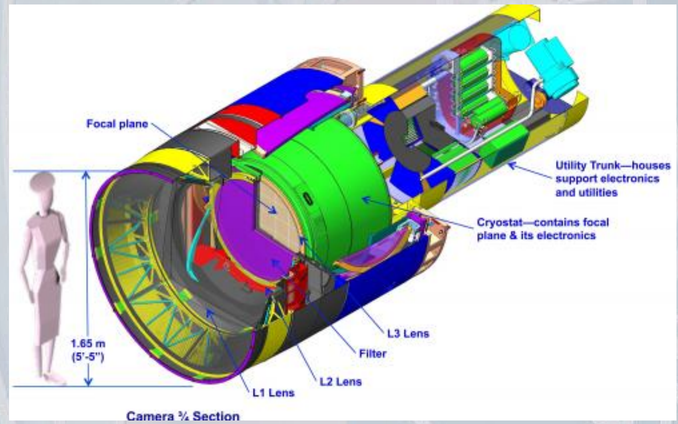
LSST: *What it is in Brief*

3) A catalog of 20 billion stars and 20 billion galaxies with exquisite photometry and astrometry; largest camera ever constructed: 3.2Gpix; ~30 Tb/night.



www.lsst.org

LSST: *Science Themes*

- Dark energy and dark matter (measurements of weak and strong lensing, large-scale structure, clusters of galaxies, supernovae).
- Exploring the transient and variable universe.
- Study of the Milky Way and neighbors via resolved stellar populations.
- An inventory of the Solar System.

https://github.com/LSSTScienceCollaborations/ObservingStrategy

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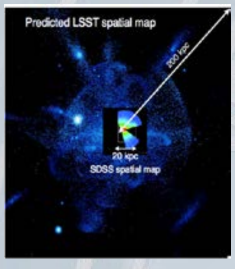
Science Theme: *Milky Way and Neighbors*



What is the accretion history of the MW?

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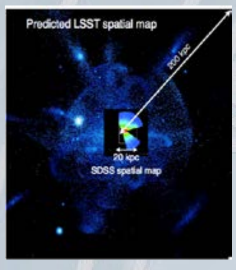
Science Theme: *Milky Way and Neighbors*



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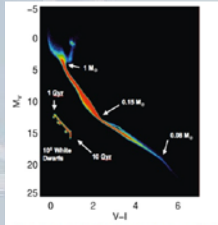


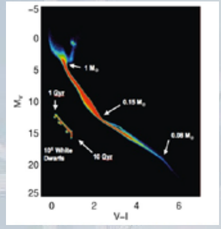
What are the fundamental properties of **all** stars within 300 pc of the Sun?

https://github.com/LSSTScienceCollaborations/ObservingStrategy

Science Theme: *Milky Way and Neighbors*

What is the accretion history of the MW?

Astrometry: proper motions



What are the fundamental properties of **all** stars within 300 pc of the Sun?

Astrometry: parallaxes

https://github.com/LSSTScienceCollaborations/ObservingStrategy

LSST: *Astrometry – The Good News!*

There is a working group dedicated to astrometry! Differential Astrometry Working Group – DAWG lead by Dave Monet (USNO).

LSST-DAWG -- AdHoc Differential Astrometry Working Group

About LSST-DAWG	English (USA)

Differential Astrometry Working Group

There are three ways membership of a list is handled: Project Controlled, Auto-enrollment, Ad Hoc.

- Project Controlled Lists maintain membership via the Contacts Database: Go Here to Make Changes.
- Auto-enrollement Lists maintain membership via the Contacts Database: By definition it is automatic.
- Ad Hoc Lists maintain membership via the usual Mailman Subscription process: Choose a list.

To see the collection of prior postings to the list, visit the LSST-DAWG Archives. (*The current archive is only available to the list members*.)

You may also now Search the Archives.

Using LSST-DAWG

To post a message to all the list members, send email to lsst-dawg@listserv.lsstcorp.org.

You can subscribe to the list, or change your existing subscription, in the sections below.

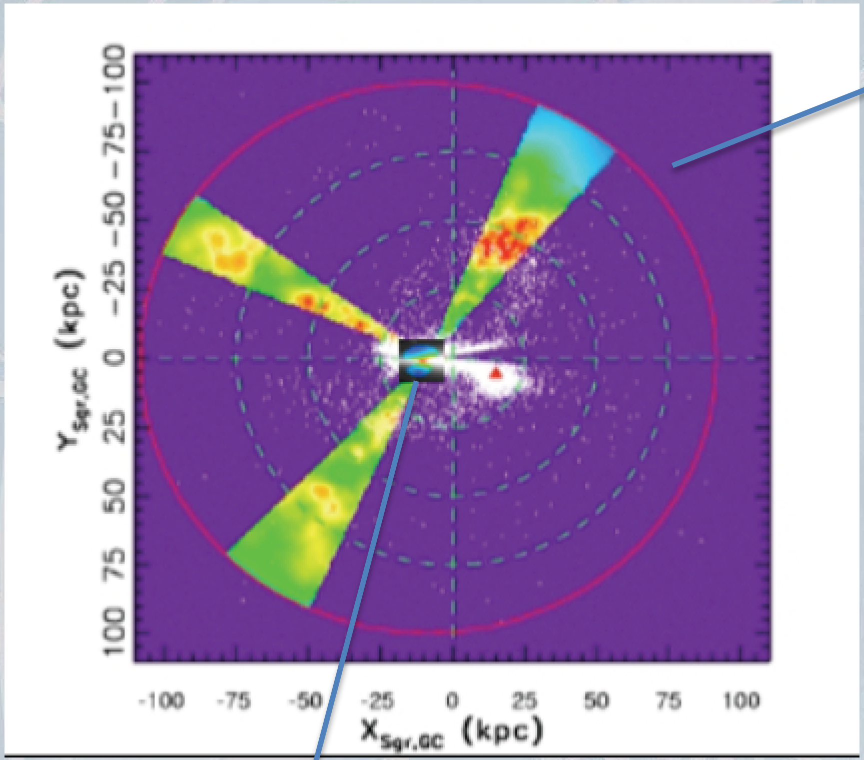
Subscribing to LSST-DAWG

Subscribe to LSST-DAWG by filling out the following form. You will be sent email requesting confirmation, to prevent others from gratuitously subscribing you. Once confirmation is received, your request will be held for approval by the list moderator. You will be notified of the moderator's decision by email. This is also a private list, which means that the list of members is not available to non-members.

Your email address:	
Your name (optional):	

https://listserv.lsstcorp.org/mailman/listinfo/lsst-dawg

LSST MW & Neighbors: *Objectives*



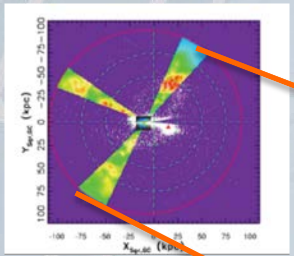
100 kpc – LSST studies of main sequence stars; current limit for RR Lyrae studies (SDSS stipe 82)

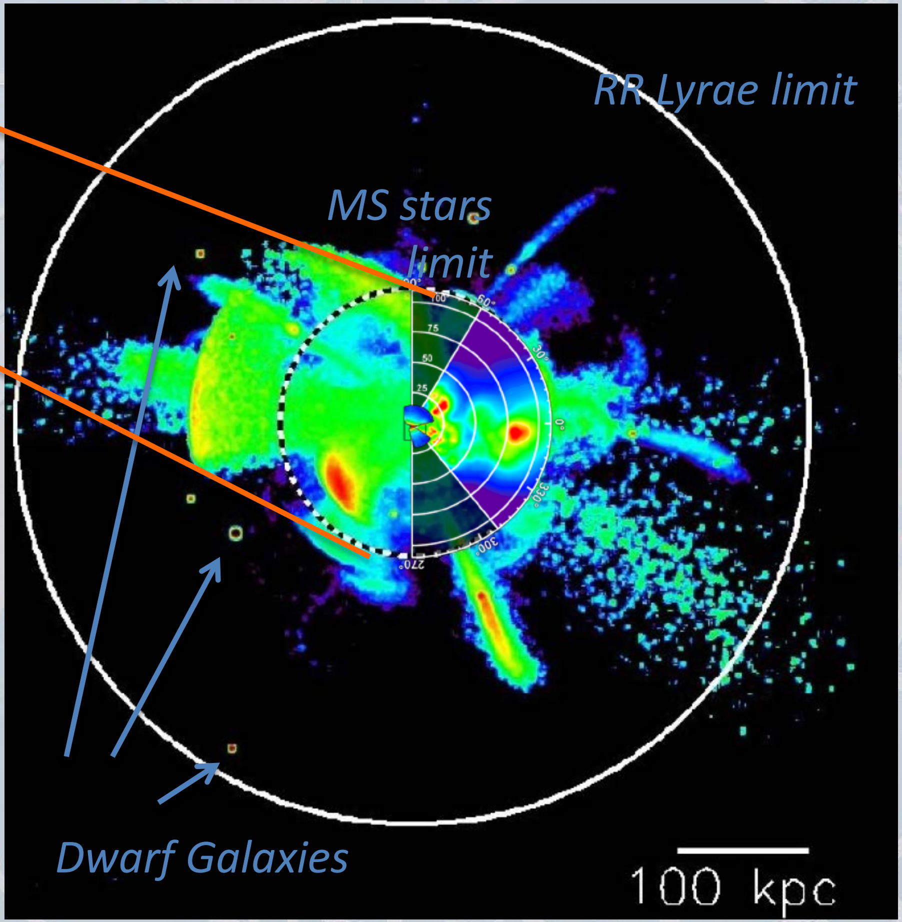
400 kpc – LSST RR Lyrae studies

10 kpc – SDSS and Gaia studies of main sequence stars

Ivezic 2014 – Barcelona

LSST MW & Neighbors: *Objectives*





Ivezic 2014, Juric 2015, Bullock & Johnson 2005

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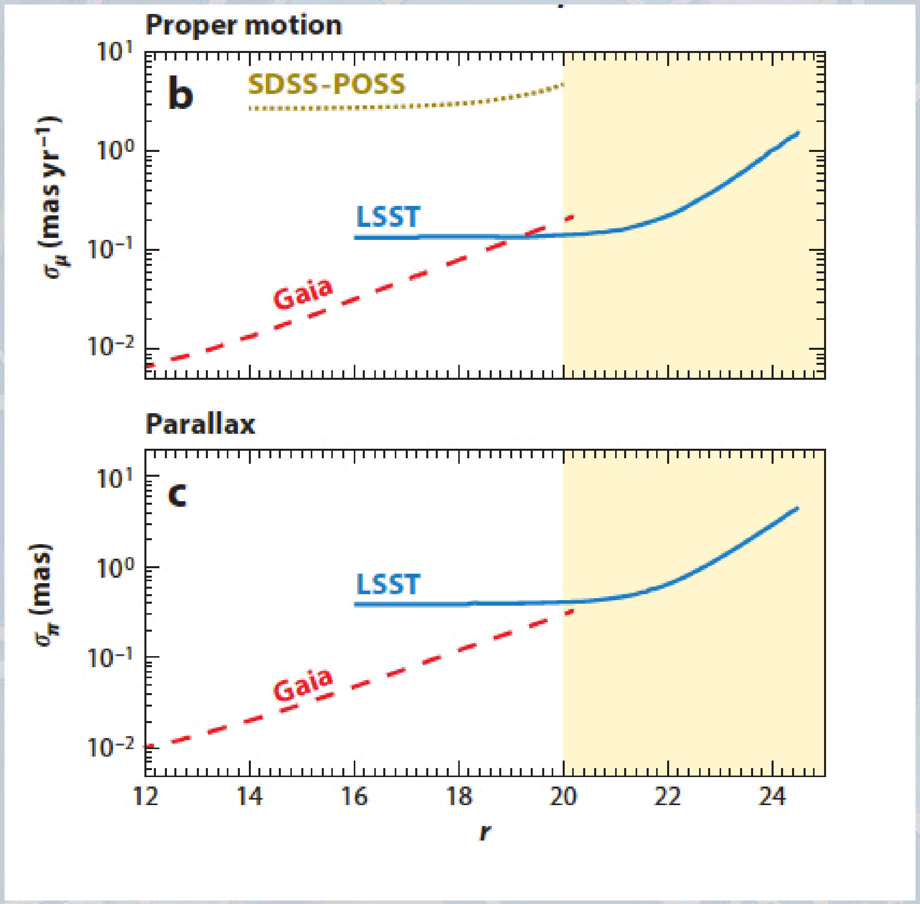
LSST Astrometry: *Projected Errors*



- a G2V star
- @ end of surveys

- LSST: using a nominal relative astrometric precision of **10 mas** for
  - a well-measured star r~20.5
  - single measurement
  - over 20 arcmin

Ivezic, Beers, Juric 2012- ARAA 50, 251

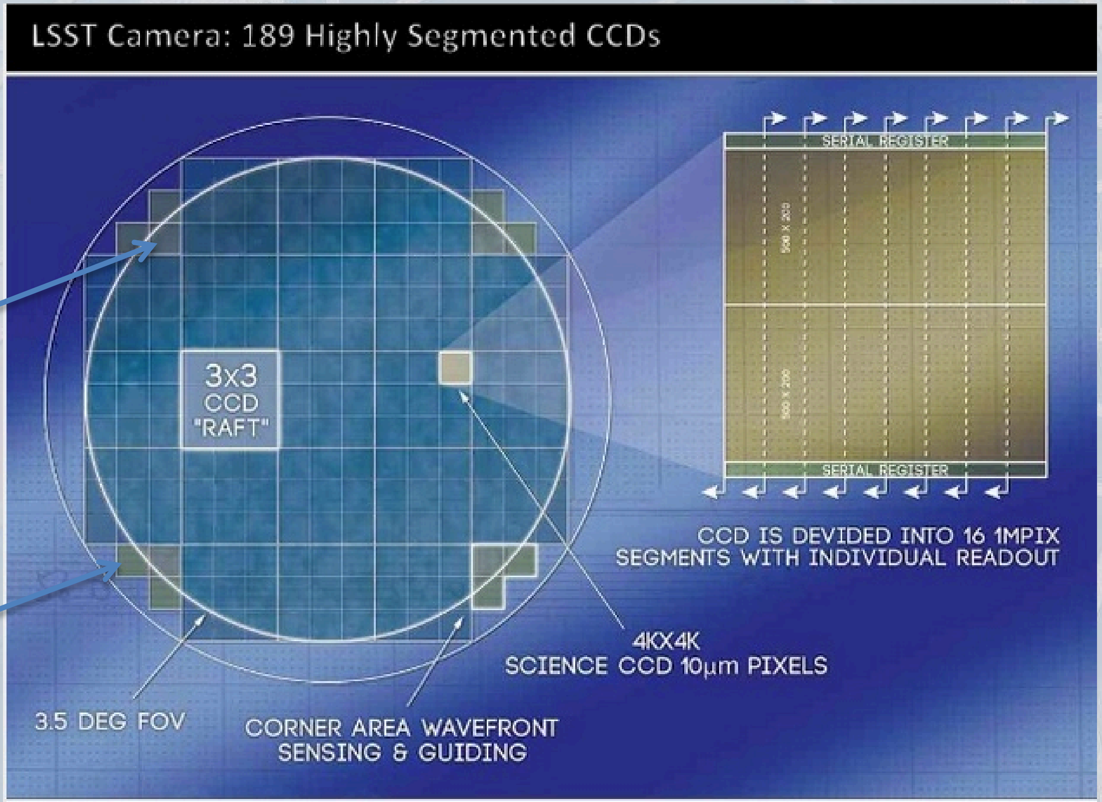
https://docushare.lsstcorp.org/docushare/dsweb/Get/LPM-17

LSST Astrometry: *Projected Errors*

- 189 science CCDs:
  3x3 CCDs = raft

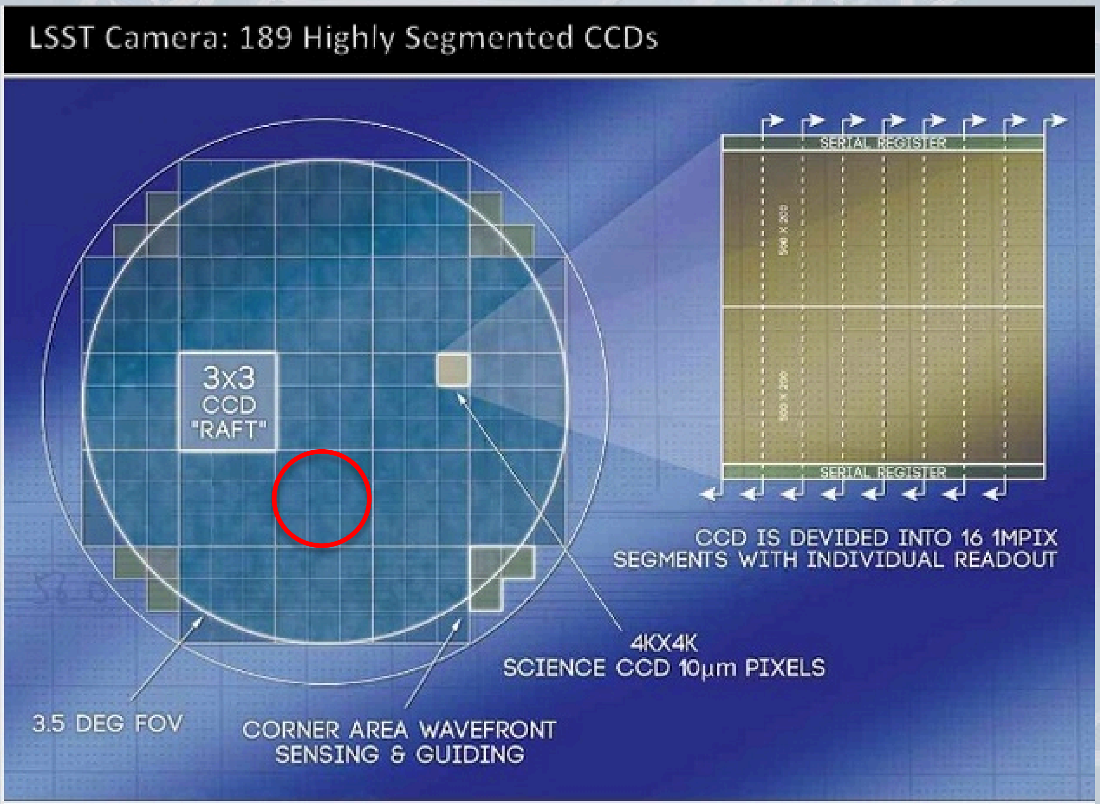
- 4 wavefront sensors

- 8 guide sensors



www.lsst.org

LSST Astrometry: *Projected Errors*

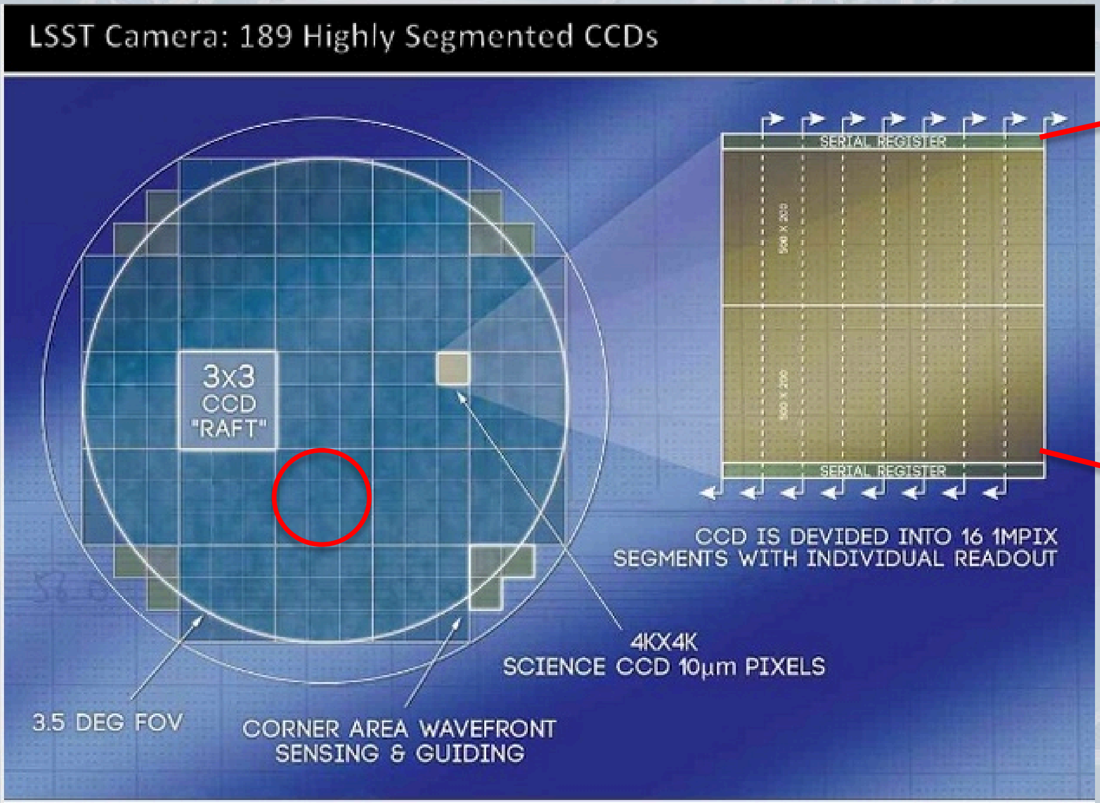


- 189 science CCDs
- pixel: 10μm; 0.2”/pix.
- segment: 500x200 pix~1.7’
- CCD: 16 segments ~13.6’
- raft: 3x3 CCDs ~ 41’

- Projected positional precision of 10 mas is over ~20’ (radius of a raft).

www.lsst.org

LSST Astrometry: *Projected Errors*



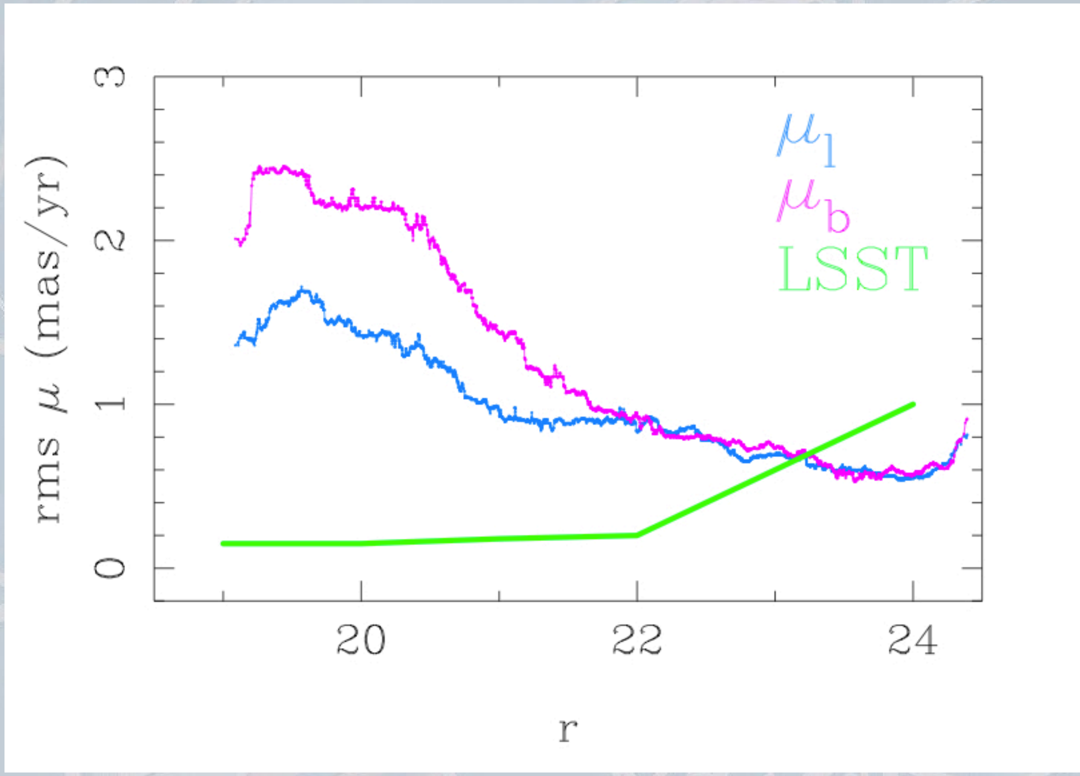
For r < 21

- 80 stars at SGP (minimum)
- 130 galaxies

Divide by 16, per segment (readout)

www.lsst.org

LSST Astrometry: *Proper-Motion Error*



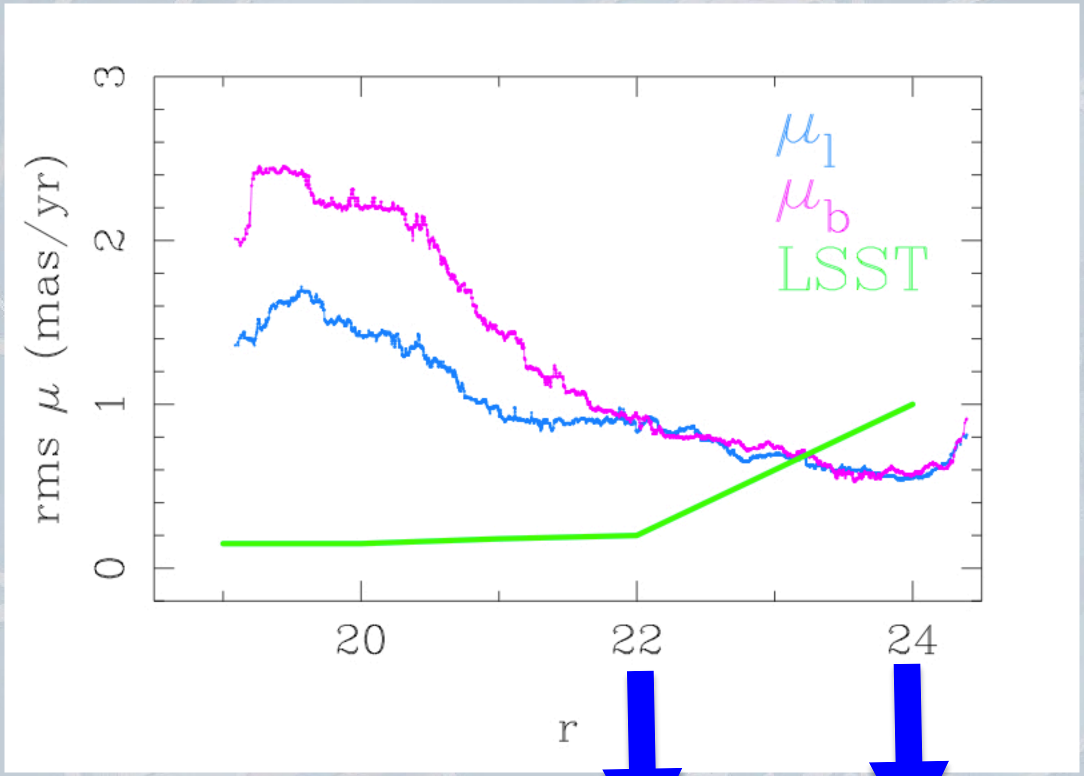
Tidal streams

Besançon model: rms proper motion for blue objects (r-i) < 0.4 (l=86, b=35 – Draco dwarf-galaxy field):

- down to r ~ 22.5 tidal streams can be identified via proper-motions only;

(caveat ~ 40' raft size!)

LSST Astrometry: *Proper-Motion Error*



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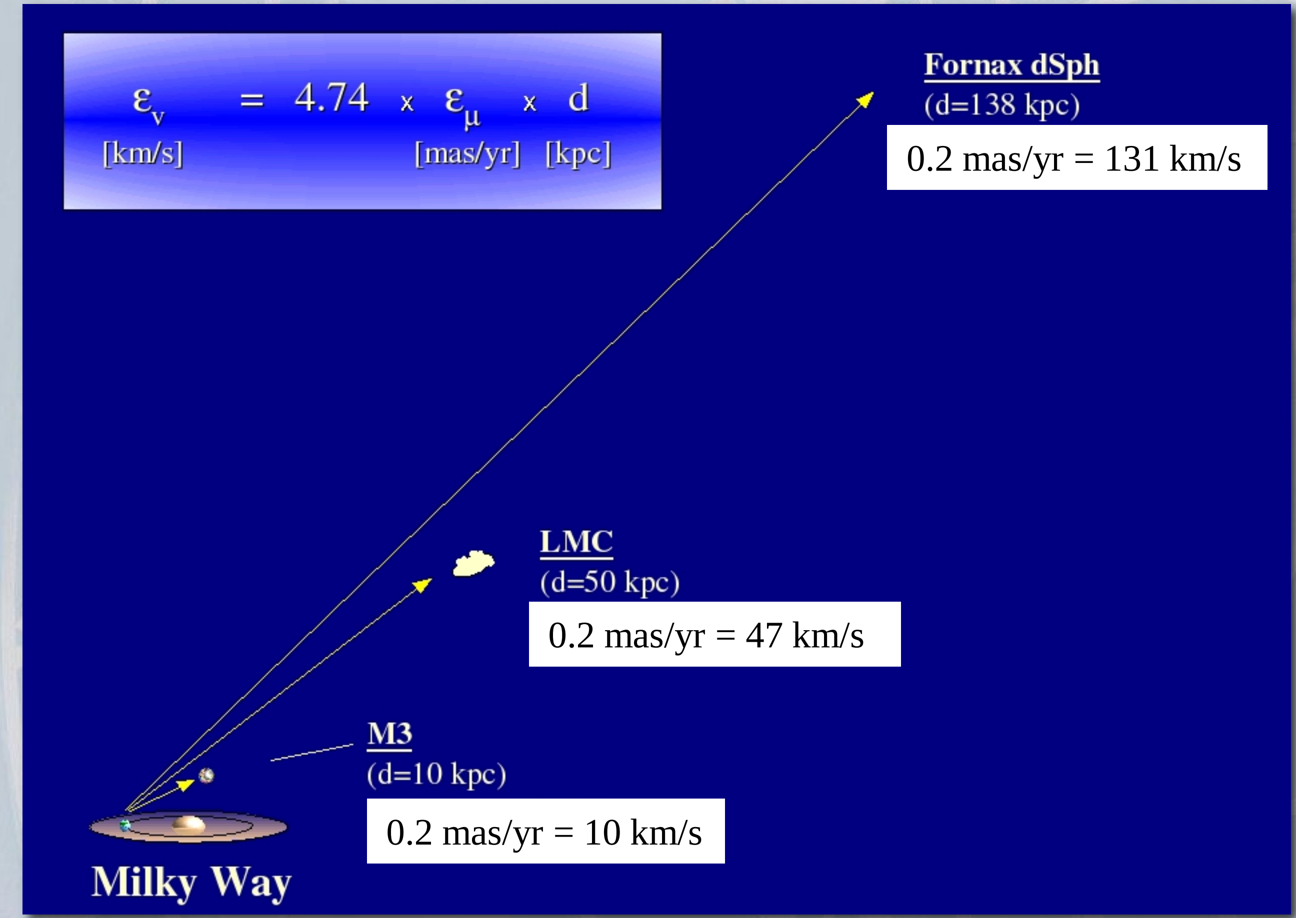
(caveat ~ 20' raft size!)

40 kpc - old main seq. turnoff

100 kpc - old main seq. turnoff

LSST Astrometry: *Proper-Motion Error*



MW satellite orbits

0.2 mas/yr insufficient; **need ~4-10x better**

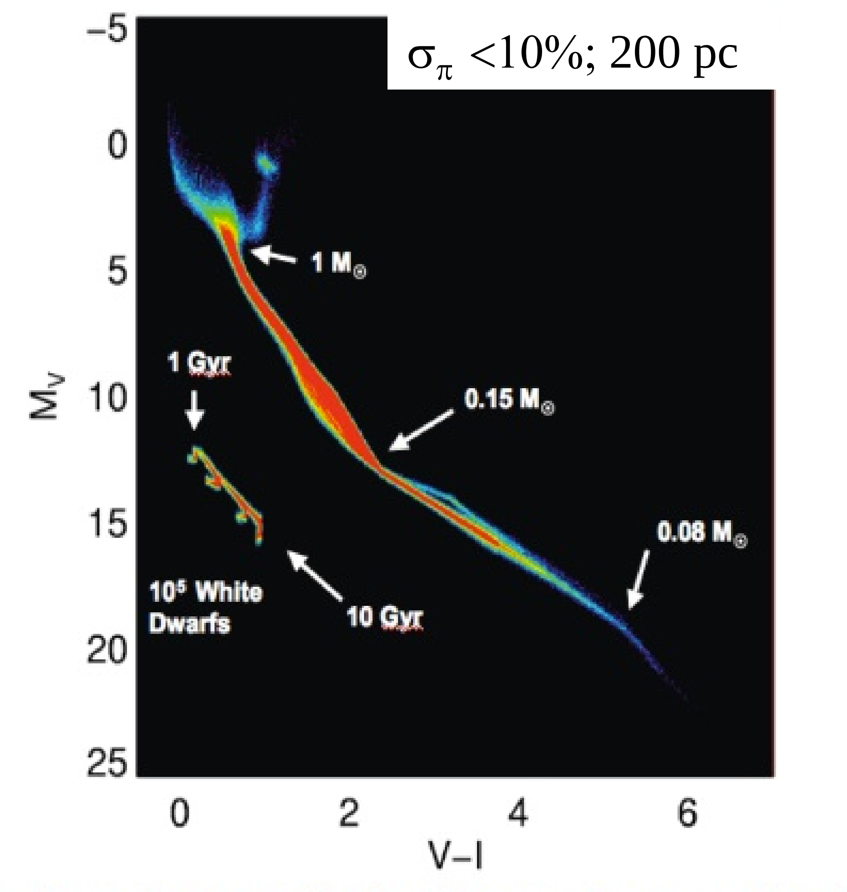
- need many stars averaged over the area of the satellite.
- calibration to absolute: tie to extragalactic and/or Gaia.

LSST Astrometry: *Parallax Error*

Complete stellar census – S.N. to 300 pc; other intrinsically faint objects:

- ~10^5 M dwarfs; hydrogen-burning limit stars to 300 pc (3σ geometric distances; M_r ~15)
-thousands of L/T brown dwarfs; to tens of pc.
-white dwarfs: LF of the thin disk, thick disk and halo.

r mag	σ_π (mas)
21	0.6
22	0.8
23	1.3
24	2.9



www.lsst.org; Saha et al.

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LSST: *Observing Strategy*

1) "Universal Cadence" - Deep-Wide-Fast - ~18,000deg^2, 85% of observing time.

2) Specialized Surveys – 15% of the observing time.

1) + 2) = "Baseline Cadence"

https://github.com/LSSTScienceCollaborations/ObservingStrategy

LSST: *Observing Strategy*

1) "Universal Cadence" - Deep-Wide-Fast - ~18,000deg^2, 85% of observing time.

- Gives uniform coverage at any given time; entire visible sky at any time of the year can be covered in three nights.
- Designed to reach survey goals for stellar parallax and proper motions over 10 years.
- Airmass <1.4; $-75^o < dec < +15^o$.
- 1 visit=15sec x 2 ; r ~ 24.5 for single visit.
- ~825 visits (summing over 6 filters) per point in the sky.

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LSST: *Observing Strategy*

1) Specialized Surveys: 15% of the observing time

- (GP) Observations at low Galactic latitude: a wedge which is broader closer to Galactic Center; number of repeated observations is reduced.

- (SCP) South Celestial Cap: observations at dec < -75^o (i.e. airmass>1.4) to cover the Magellanic Clouds; shallower depth.

- (DD) Deep Drilling Fields (4?) – 5x more exposures in all filters; ~one mag fainter than limit from survey stack.

- (NES) Northern Ecliptic Spur: northern portions of the ecliptic plane (dec > $+15^o$) . Again, reduced cadence.

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Observing Strategy: *Baseline Cadence*

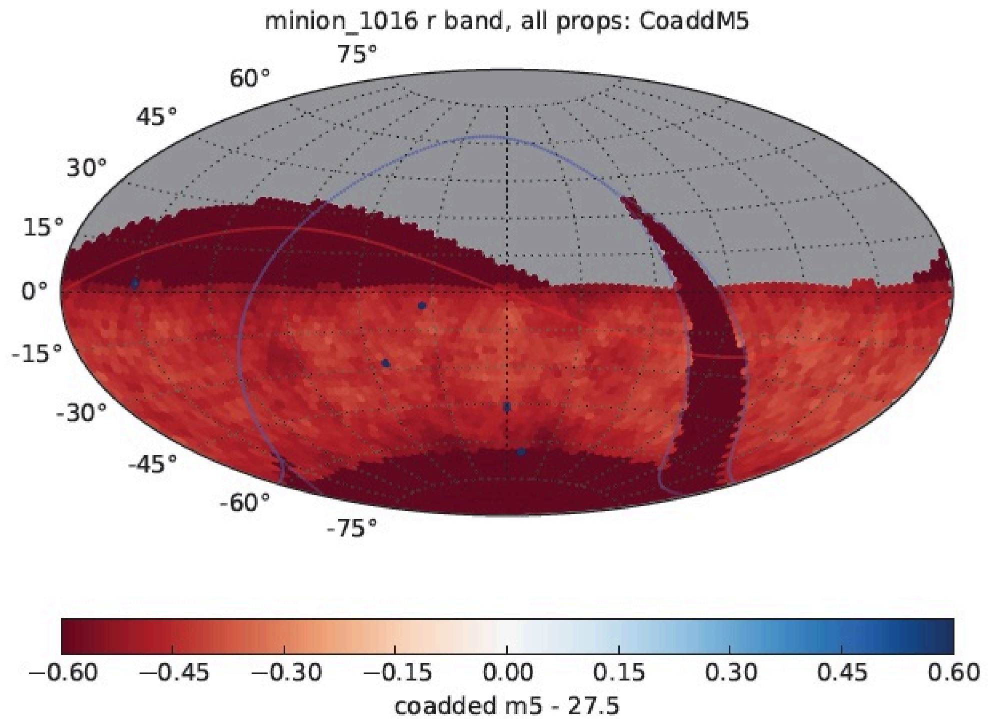

Figure 2.2: The coadded 5σ depth for point sources in the r band across the sky for simulated cadence minion_1016 is shown in Aitoff projection of equatorial coordinates. The red line shows the Ecliptic and the blue line shows the Galactic equator (it bifurcates around the so-called "Galactic confusion zone"). The median value across the Universal Cadence area is 27.1, with RMS scatter of only 0.04 mag. The small dark dots are deep drilling fields, with a median 5σ depth of 28.6.

https://github.com/LSSTScienceCollaborations/ObservingStrategy

Observing Strategy: *Proper Motions*

Proper motions – reasonable epoch coverage during the survey

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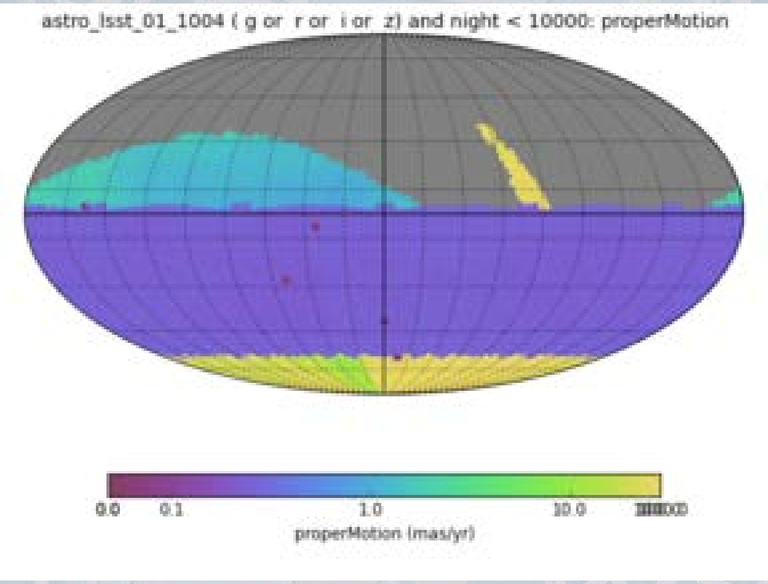

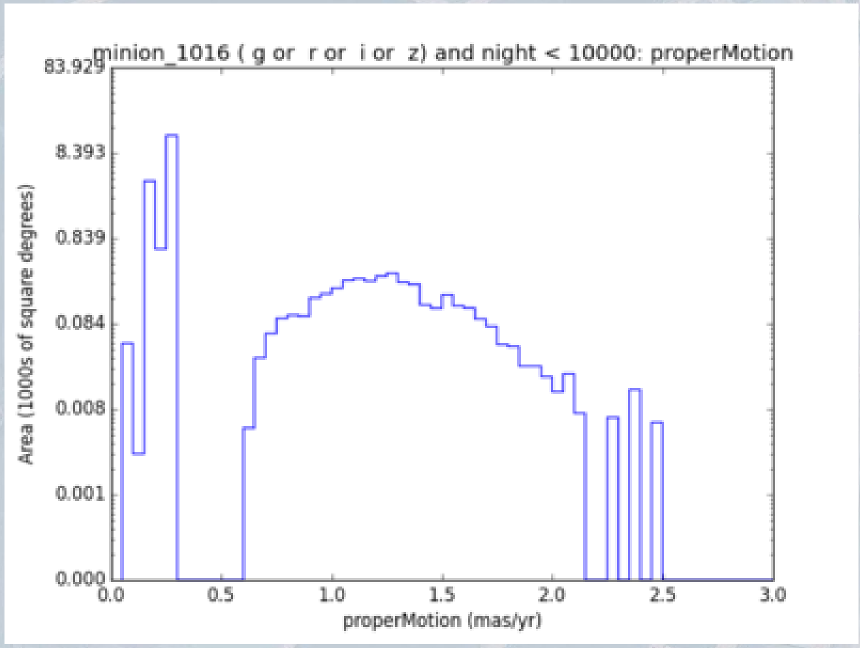

- At end of 10-year survey; r = 21.0; uncrowded regions; (histogram does not include all range of values in the map).

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Observing Strategy: *Parallaxes*

- Parallax factor – widest possible range.
- $0 \leq r \leq 1$;
- r=1.0 uniform coverage on ecliptic pole; r=0.5 uniform coverage on ecliptic, r=0.0 all obs. at identical parallax factor.

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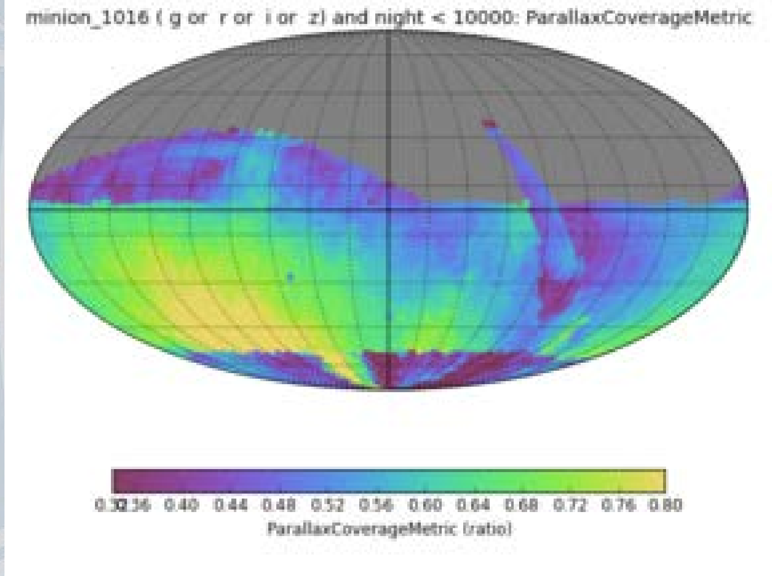

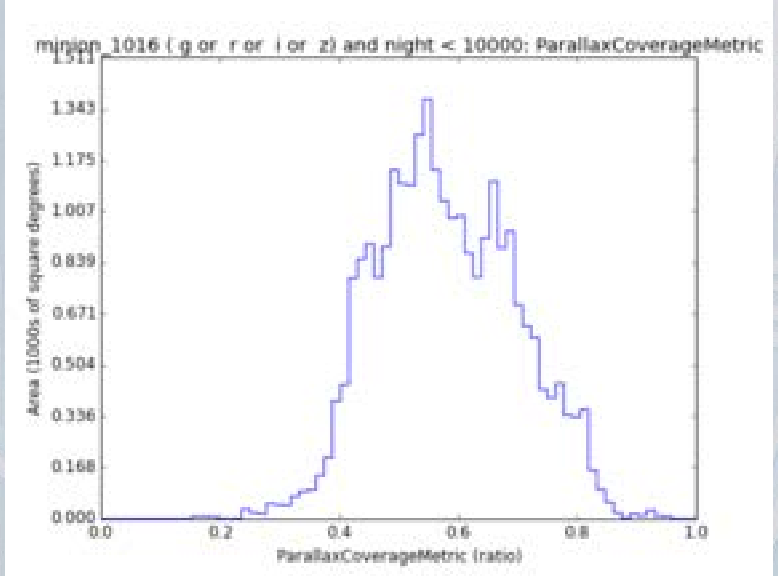

https://github.com/LSSTScienceCollaborations/ObservingStrategy

Observing Strategy: *Parallaxes*

- Minimize correlation between hour angle (differential color refraction – DCR) and parallax factor.
- ρ – Pearson correl. coeff bet. parallax amplitude and DCR amplitude; $-1.0 \leq \rho \leq 1.0$; acceptable $|\rho| < 0.7$ (?).

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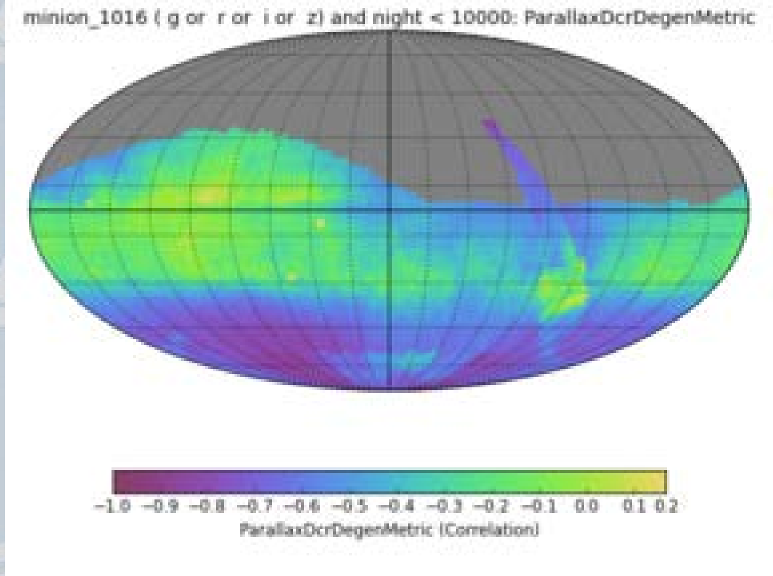

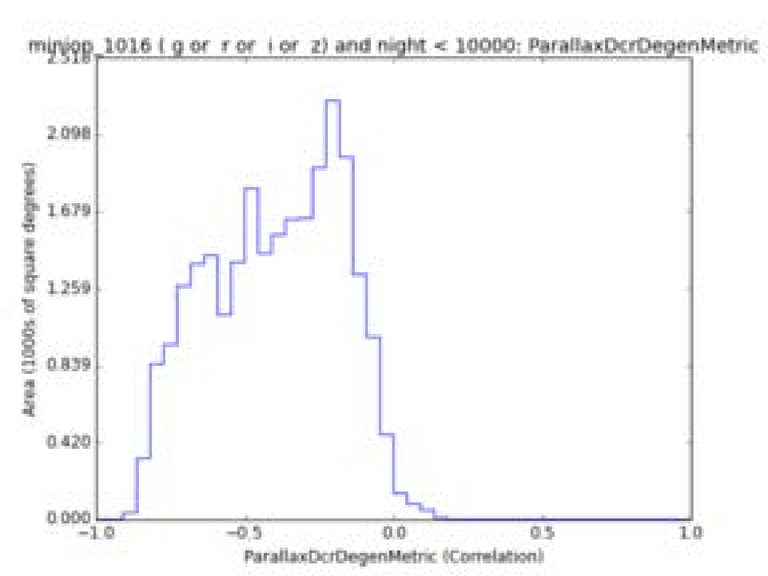

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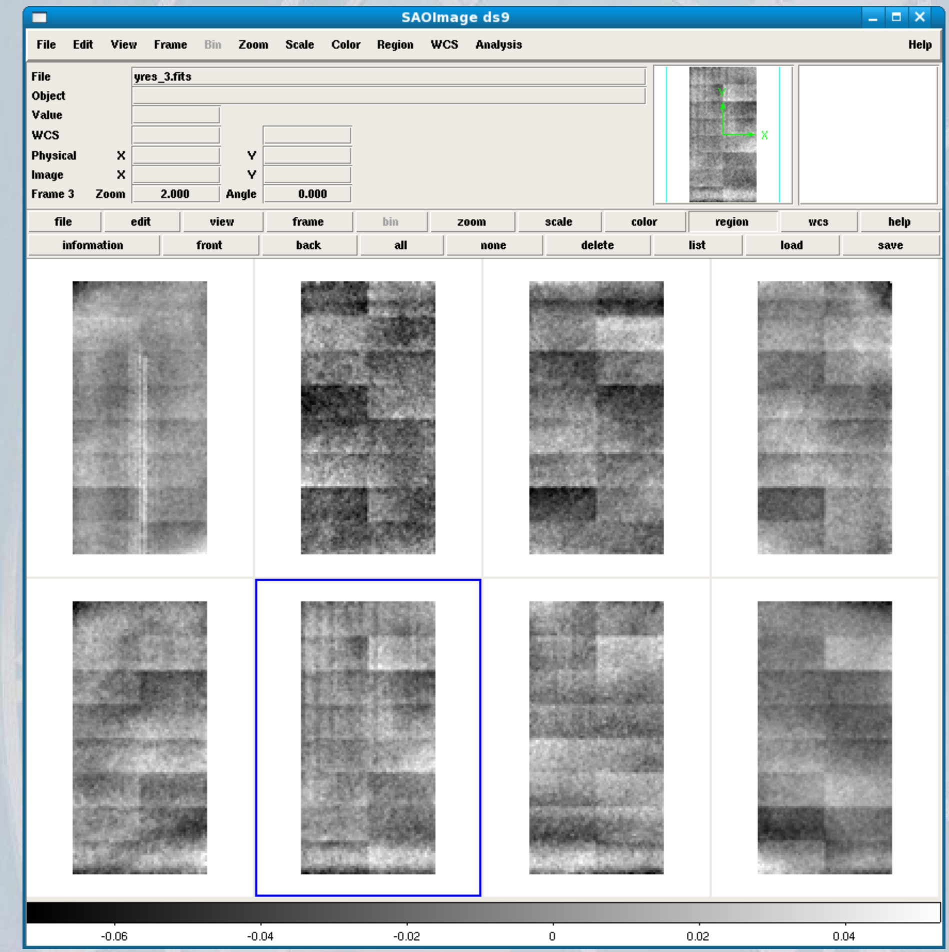
LSST: *Lessons from Existing Imagers*

- Lithographic and/or other causes of patterns in CCDs: two examples
- Galaxies-versus-stars astrometry: a Subaru-data case study
- Gaia as an absolute proper-motion reference

LSST: *Lessons from Existing Imagers*

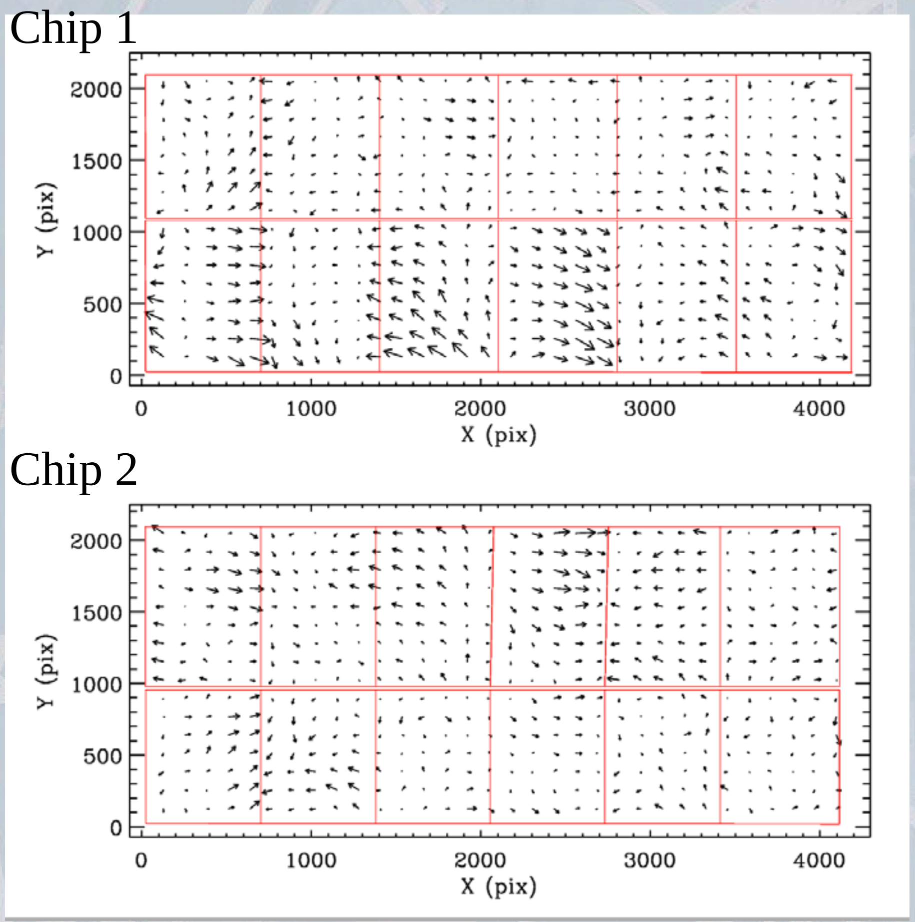


Map of Y (Dec.) residuals for each WFI chip (8'x16'). Notice the box pattern in all of the chips. Amplitude of residuals is ~ 0.02 pix, which corresponds to 5 mas. The WFI pixel scale is 0.238 arcsec/pix. Sown, average residuals in one cell (32 WFI chip pixels, ~ 50 resid per cell).

WFI on ESO 2.2m

- Team: *D. Casetti, T. Girard, R. Mendez, R. Petronchack*
- Instrument: 2Kx4K, 8-chip mosaic
- Observations: 56 offset/dithered V images in Plaut window
- Findings: each chip has a 16-box pattern in position residuals, with amplitude 0.02 pix~5 mas.

LSST: *Lessons from Existing Imagers*

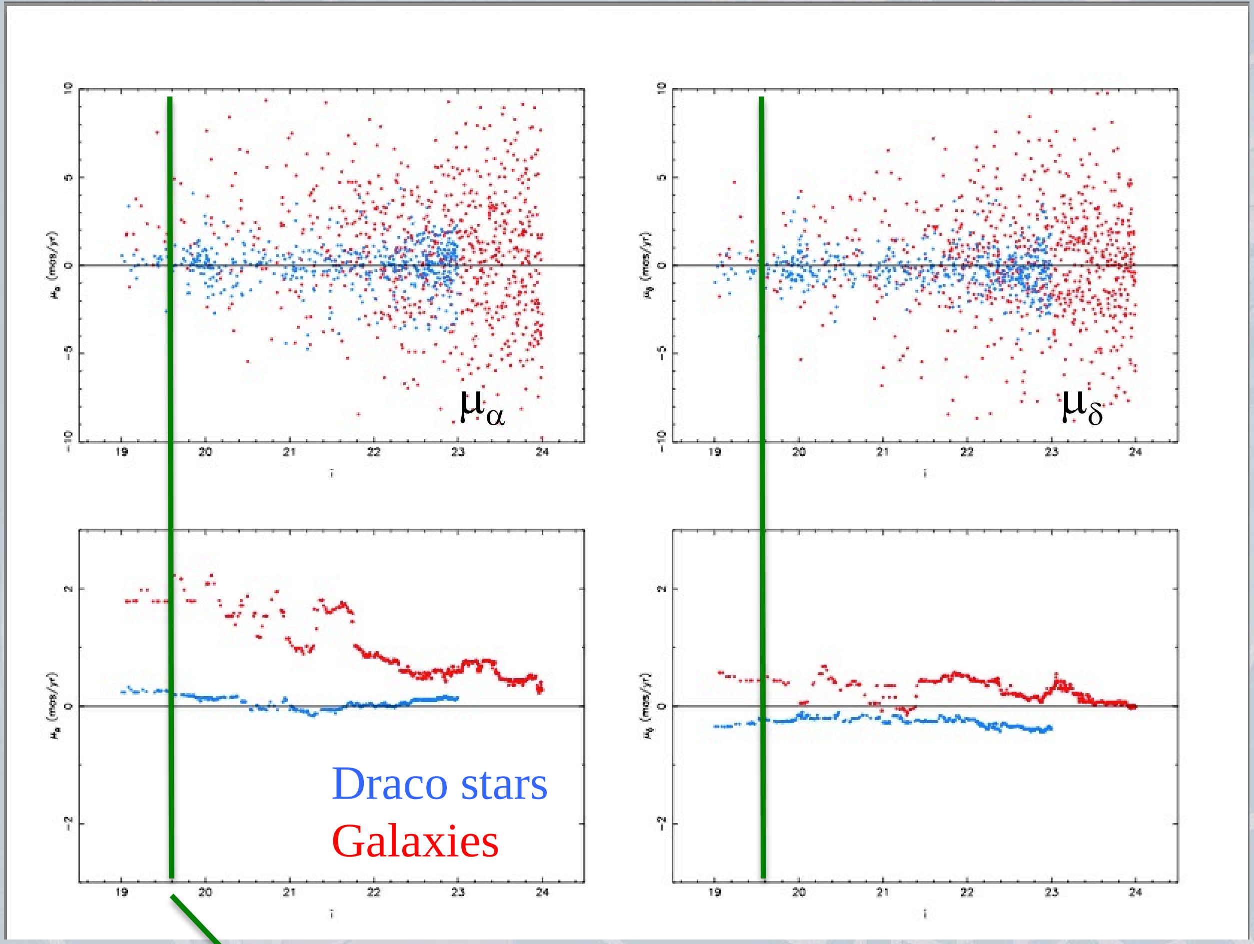


2–D XY residual map between the UVIS positions after the geometric distortion is removed and the standard astrometric catalog.
The top panel shows the XY residuals for the WFC3/UVIS1 CCD chip and the bottom panel – XY residuals for WFC3/UVIS2 CCDchip. The largest vector is ~0.15 pixels, magnified by 2500. The unis are WFC3/UVIS pixels.

WFC3/UVIS – HST

- Team: *V. Kozhurina-Platais, et al. (Instrument science report WFC3 2014-12)*
- Instrument: 2Kx4K, 2-chip camera
- Observations: 13 dithered images in F606, (ω Cen field, used as an astrometric catalog from ACS data)
- Findings: each chip has a 12-box pattern in position residuals, with amplitude 0.15 pix~6 mas.

LSST: *Lessons from Existing Imagers*



Gaia faint limit for (r-i) = 0.4

Galaxies vs stars

Proper motions in the field of Draco dwarf galaxy, from Suprimecam on 8m Subaru; ($\Delta t \sim 4$ years, one chip-pair solution). CTE different for galaxies vs stars…

Note: readout along Dec.

LSST: *Lessons from Existing Imagers*

Gaia as a calibrating tool

Number of stars/galaxies within an individual LSST CCD sensor (13.4’x13.4’), with r < 21 (projections from Table 3.4 – Science Book V2.0)

Galactic center	1340
Anticenter	1330
South Galactic Pole	80
Galaxies	130

- LSST saturation: r = 16; bright end r ~ 20 (CTE effects may be strong)
- Gaia faint end r ~ 20-21
- Gaia also measures galaxies! How well?

Astrometry with LSST: *Summary*

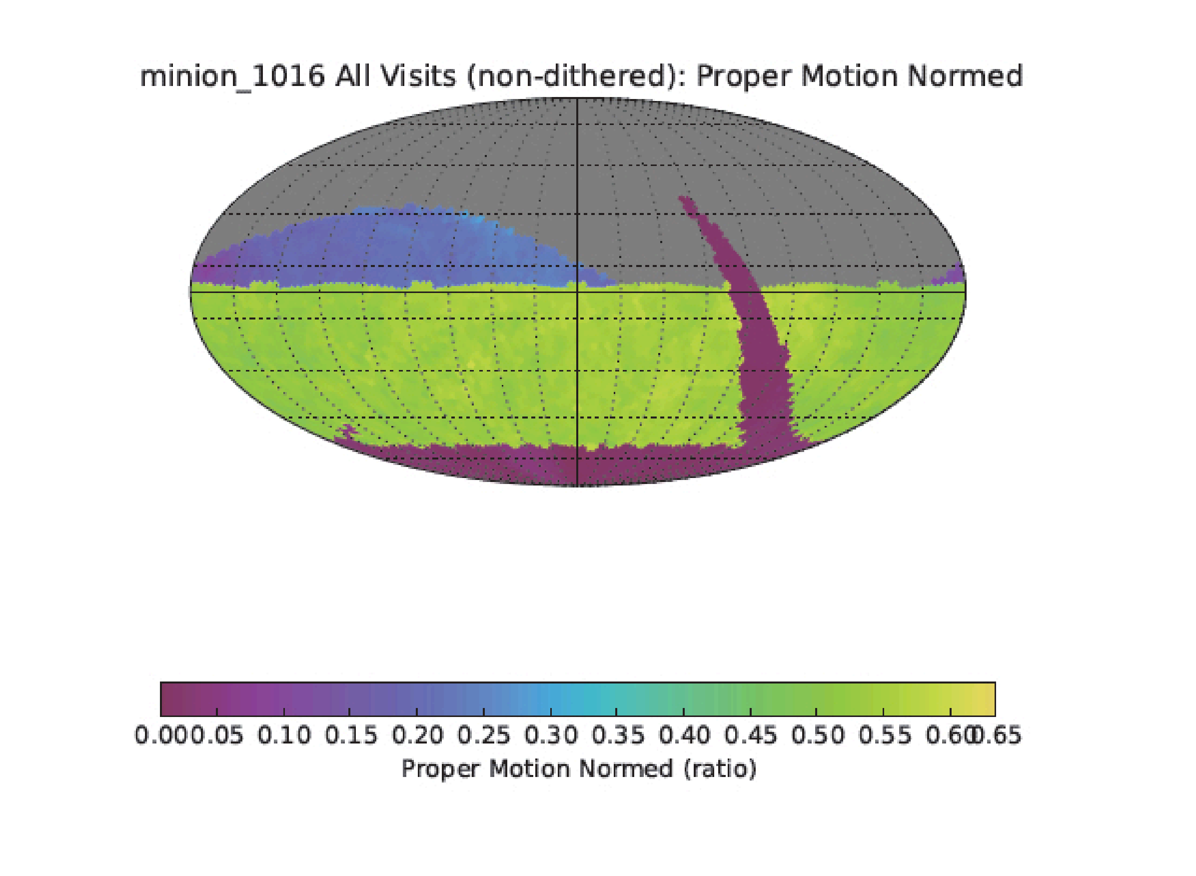
- Unprecedented tool – area + depth + monitoring

- Astrometrically – great potential in detecting and characterizing tidal streams and intrinsically faint objects in the solar neighborhood.

- With careful planning and testing, can be the next generation astrometric tool, in a post-Gaia era.

Observing Strategy: *Proper Motions*

Proper motions – reasonable epoch coverage during the survey



Ideal (1.0): Half visits on first day of survey, the rest on the last day of survey.

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