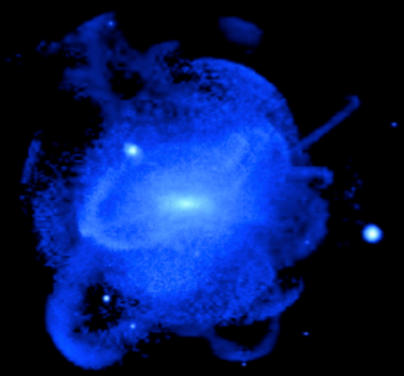

Galactic Archeology: Searching for Tidal Debris Streams with WFIRST

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Why are Stellar Debris Streams Interesting?

- Tidal streams closely follow the progenitor's orbit.
  - $\Delta E/E < 1\%$ for globular clusters, $< 5\%$ for dwarf galaxies
  - debris streams therefore give us the shape of the progenitor's orbit.
  - As fossil remnants, debris streams can be used to reconstruct the formation process of galaxies.
- In our own Galaxy, stars in debris streams can be used to accurately measure the exchange of potential and kinetic energy along an orbit.
  - Debris streams therefore provide the most sensitive available probes of the Galactic potential field.
  - Debris streams sample the Galactic halo potential over a range of otherwise inaccessible radii and quadrants
- The morphologies of debris streams tell us about their orbital histories
  - Heating and scattering by dark matter subhaloes
  - Orbital precession in non-spherical potentials
  - Dynamical friction
- Tidal streams may help us to understand gravity at very low accelerations.

Photometric Detection of Halo Streams

- Due to their proximity, MW halo streams are too extended and tenuous to be detected in integrated light.
  – surface densities of streams detected to date are of order 10-100 stars per square degree to g ~ 22.
- Instead we use color-selected star counts, where signal-to-noise ratio goes roughly as $N_{stream}/\sqrt{N_{foreground}}$. This requires that we:
  -- select on a particular stellar population
  – push as far down the stellar luminosity function as possible
  – keep the photometric errors small, the color selection envelope narrow, and foreground contamination as low as possible
- Advantage is that, once detected, we can measure positions and velocities for stream stars ***much*** more accurately than for any other galaxy.

Known Halo Streams

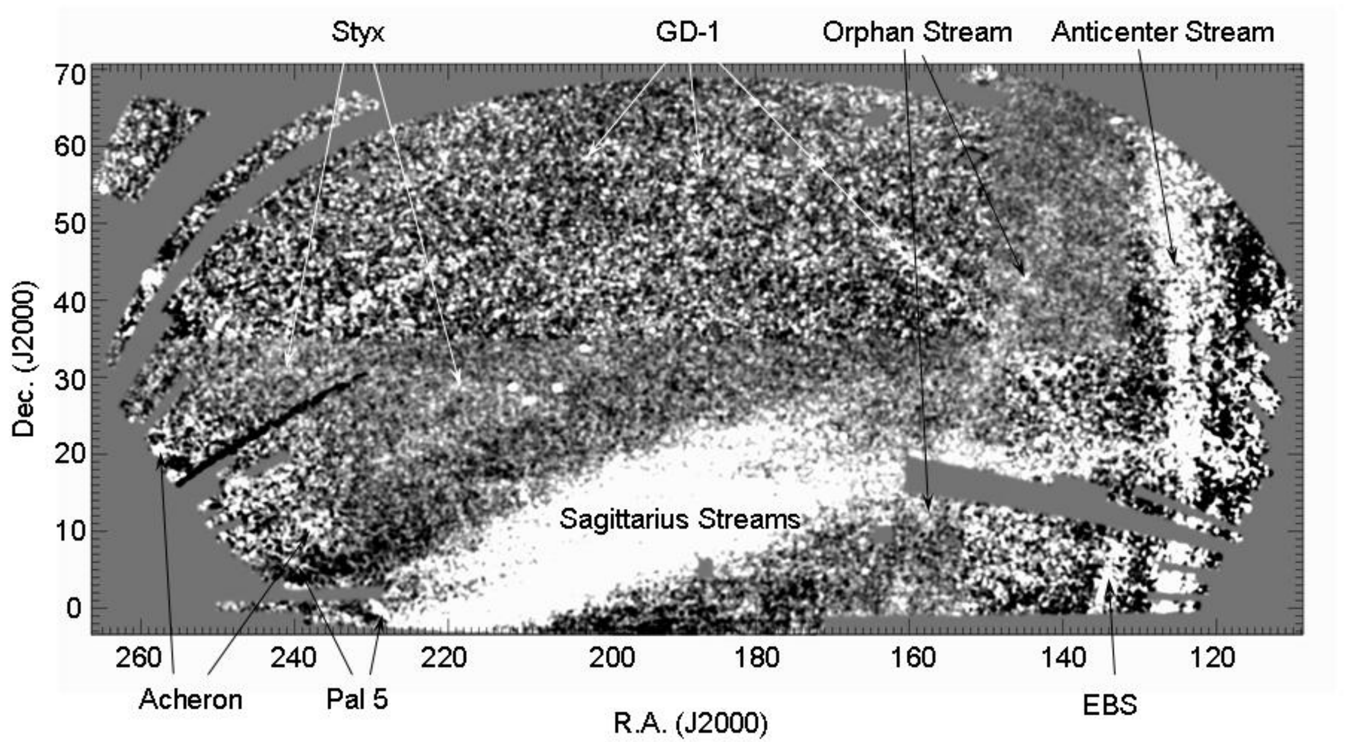
Table 1 Known Distant Galactic Streams

Designation	Progenitor	Selected References
Sagittarius	Sagittarius Dwarf Galaxy	Ibata et al. 1994, Mateo et al. 1996, Alard 1996, Toten & Irwin, 1998, Ibata et al. 2001, Martinez-Delgado et al. 2004, Majewski et al. 2004, Vivas et al. 2005, Belokurov et al. 2006b, Fellhauer et al. 2006, Bellazzini et al. 2006, Chou, M-Y et al. 2007, Law et al. 2009
Virgo Stellar Stream	NGC 2419?	Vivas et al. 2001, Duffau et al, 2006, Newberg et al. 2007
Palomar 5	Palomar 5	Odenkirchen et al. 2001, 2003, 2009, Rockosi et al. 2002, Grillmair & Dionatos 2006b
Monoceros Ring	Unknown (dwarf galaxy?)	Newberg et al. 2002, Yanny et al. 2003, Ibata et al. 2003, Rocha-Pinto et al. 2003, Penarrubia et al. 2005
NGC 5466	NGC 5466	Belokurov et al. 2006a, Grillmair & Johnson 2006, Fellhauer 2007
Orphan Stream	Unknown (dwarf galaxy?)	Grillmair 2006a, Belokurov 2007 Fellhauer et al. 2007, Sales et al. 2008, Newberg et al. 2010
GD-1	Unknown (globular cluster?)	Grillmair & Dionatos 2006b, Willet et al. 2009, Koposov, Rix, & Hogg 2009
AntiCenter Stream	Unknown (dwarf galaxy?)	Grillmair 2006b, Grillmair, Carlin, & Majewski 2008
EBS	Unknown (dwarf galaxy?)	Grillmair 2006, Grillmair, Carlin, & Majewski 2008
Acheron	Unknown (globular cluster?)	Grillmair 2009
Cocytos	Unknown (globular cluster?)	Grillmair 2009
Lethe	Unknown (globular cluster?)	Grillmair 2009
Styx	Bootes III dwarf?	Grillmair 2009
Cetus Polar Stream	NGC 5824?	Newberg, Yanny, & Willett 2009

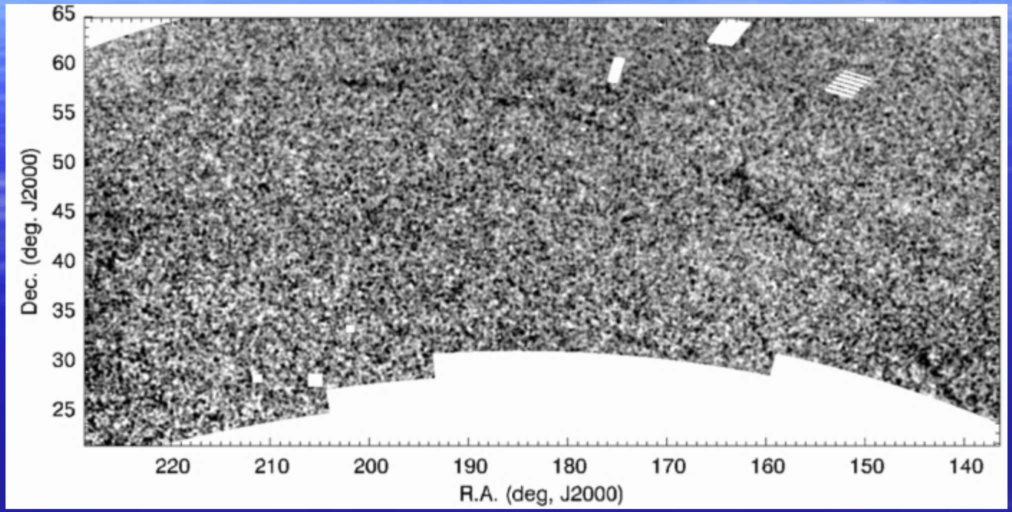
Grillmair 2010

“Oh! what a tangled web we weave…”

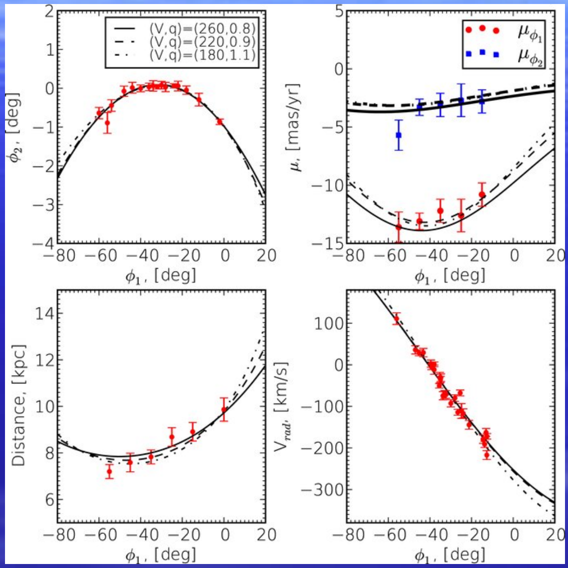
(apol. to Sir Walter Scott)



GD-1 and the Mass of the Galaxy

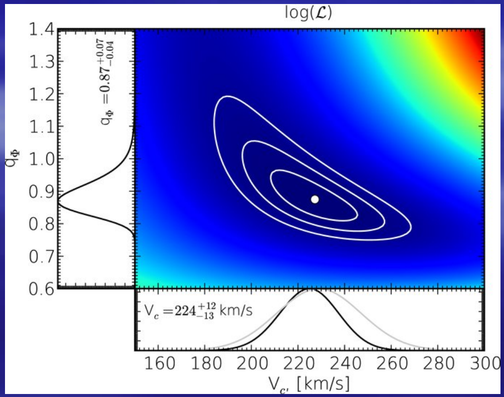


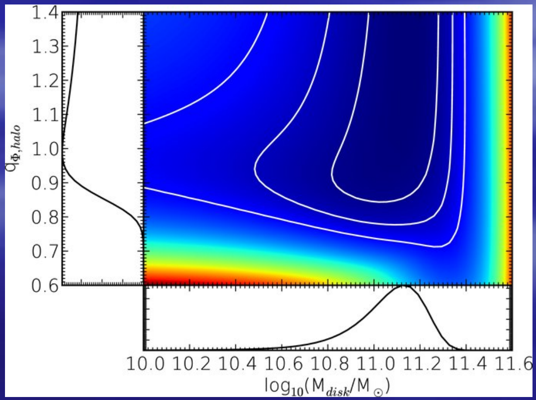
Grillmair & Dionatos 2006



Koposov, Rix, & Hogg (2009)

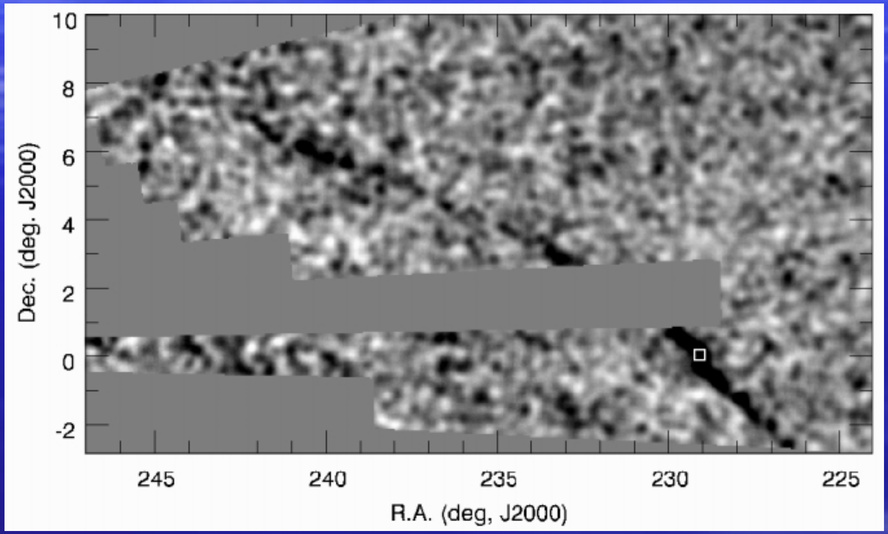
Full 6-d phase space analysis of GD-1 has yielded the tightest constraint yet on V_c (224 +/- 13 km/s) and the mass of the Galaxy.



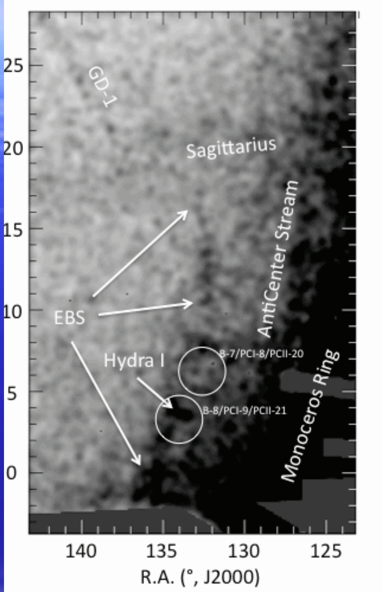


Halo Lumpiness

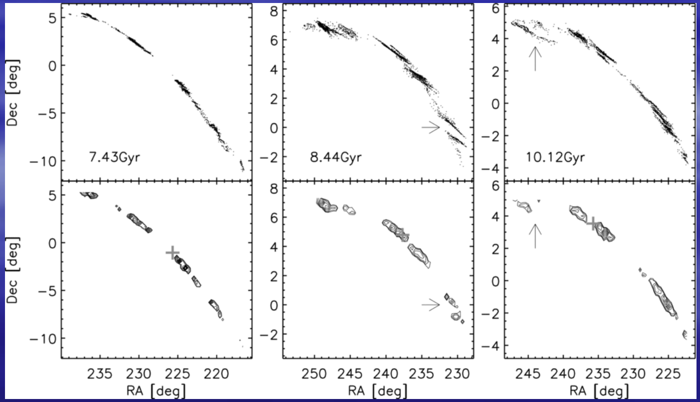
Pal 5 – evidence of dark matter subhalos?



Grillmair & Dionatos 2006



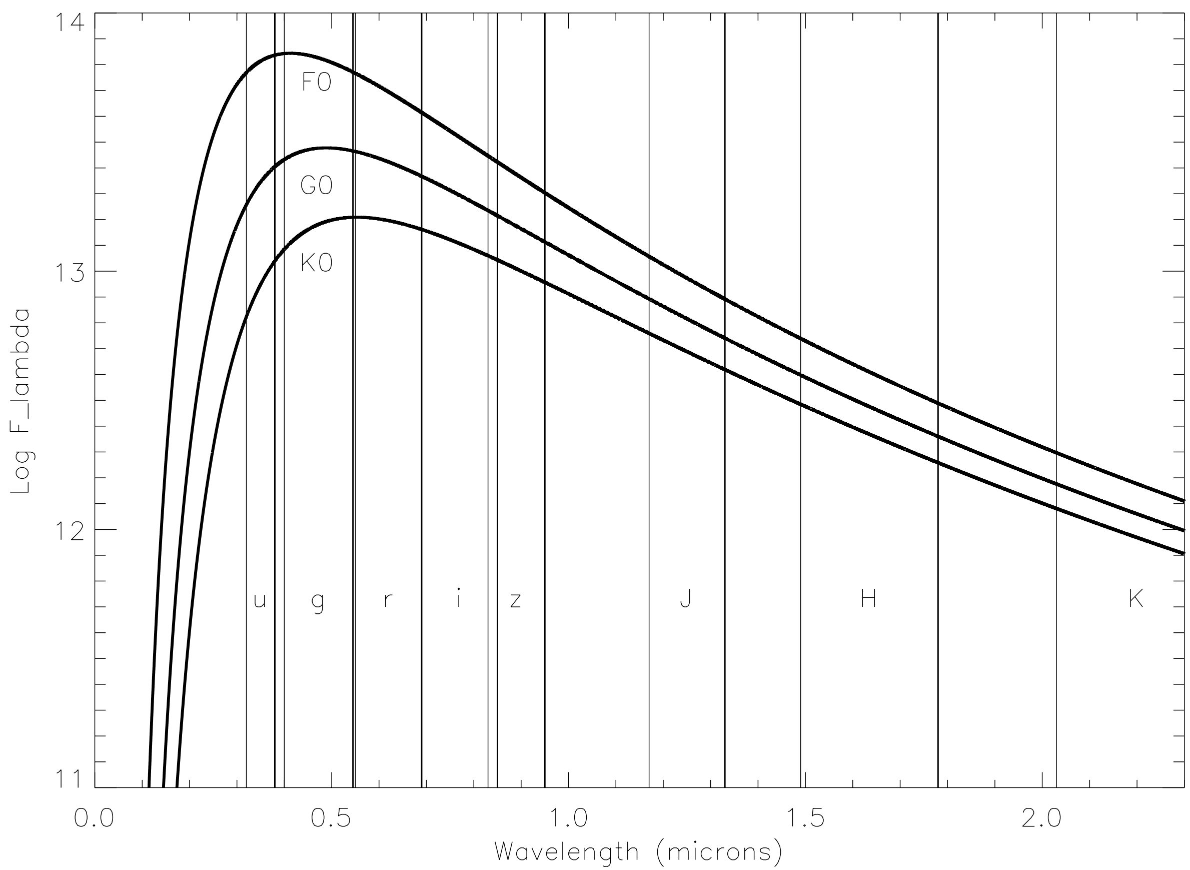
Grillmair 2011



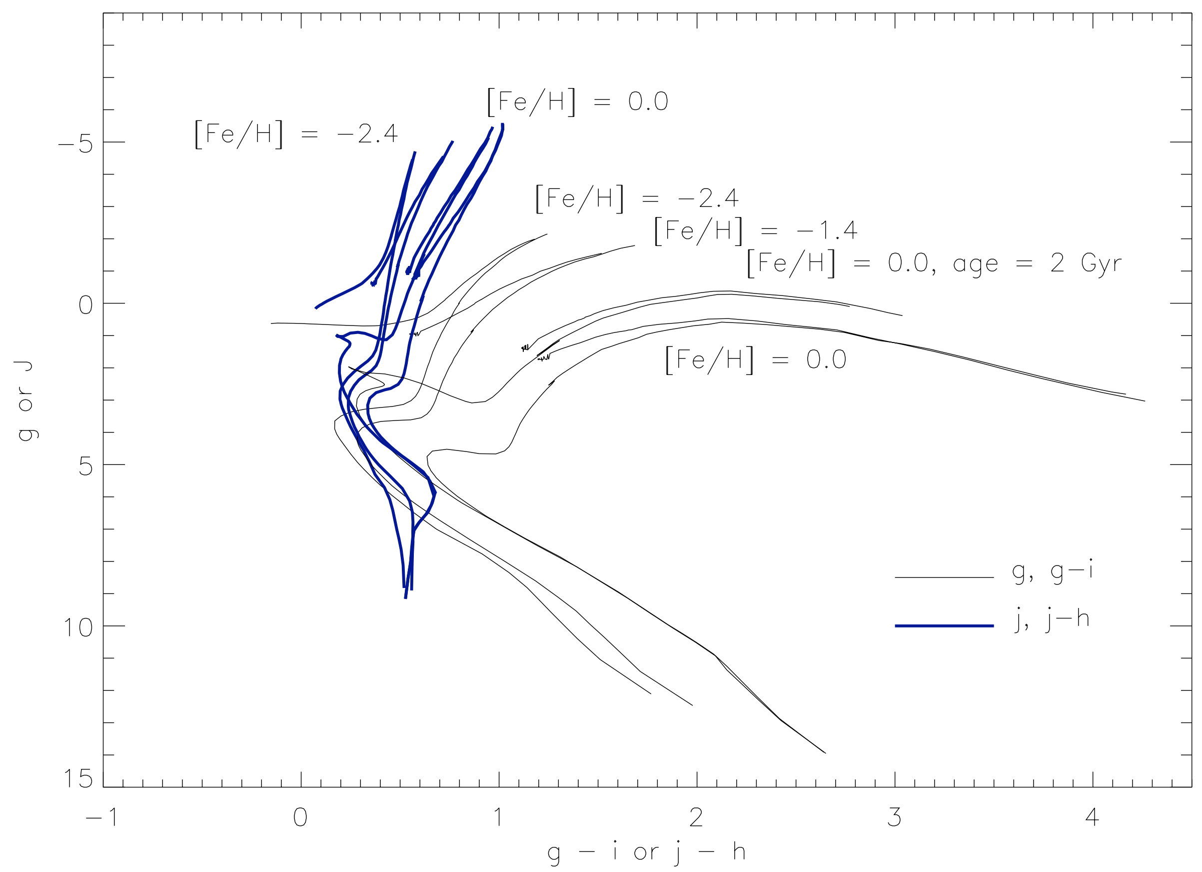
Yoon, Johnston, & Hogg 2011

Stream morphologies may favor many hundreds of ~10^7 $M_\odot$ subhalos.

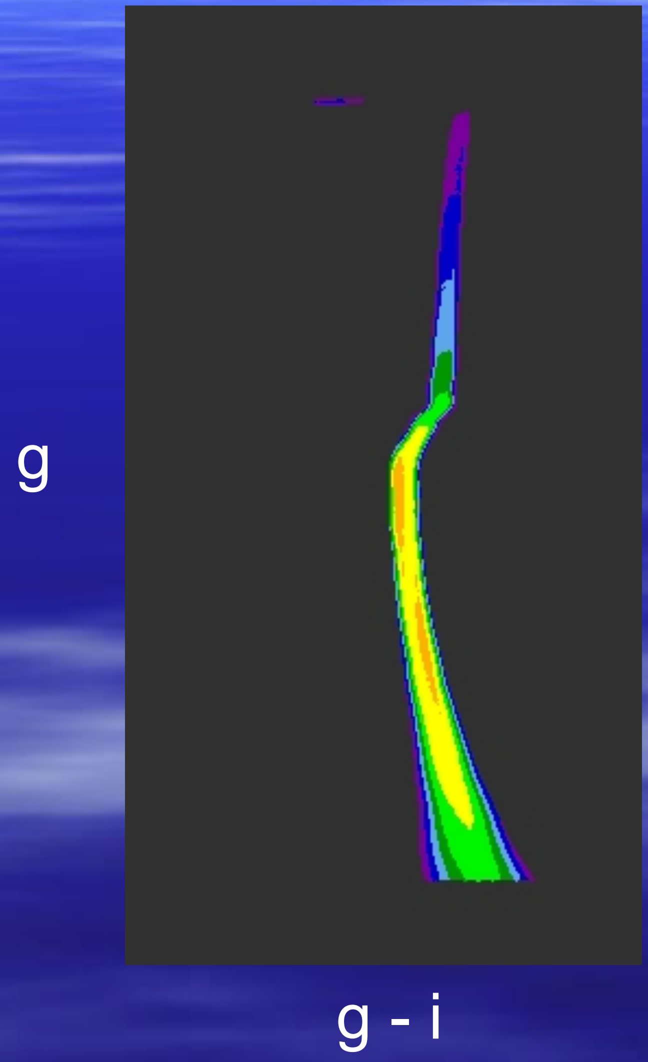
Streams with WFIRST?



Isolating Stellar Populations



Optimal Matched Filtering



- majority of power comes from main sequence turn-off and below.

Isolating Stellar Populations

SDSS

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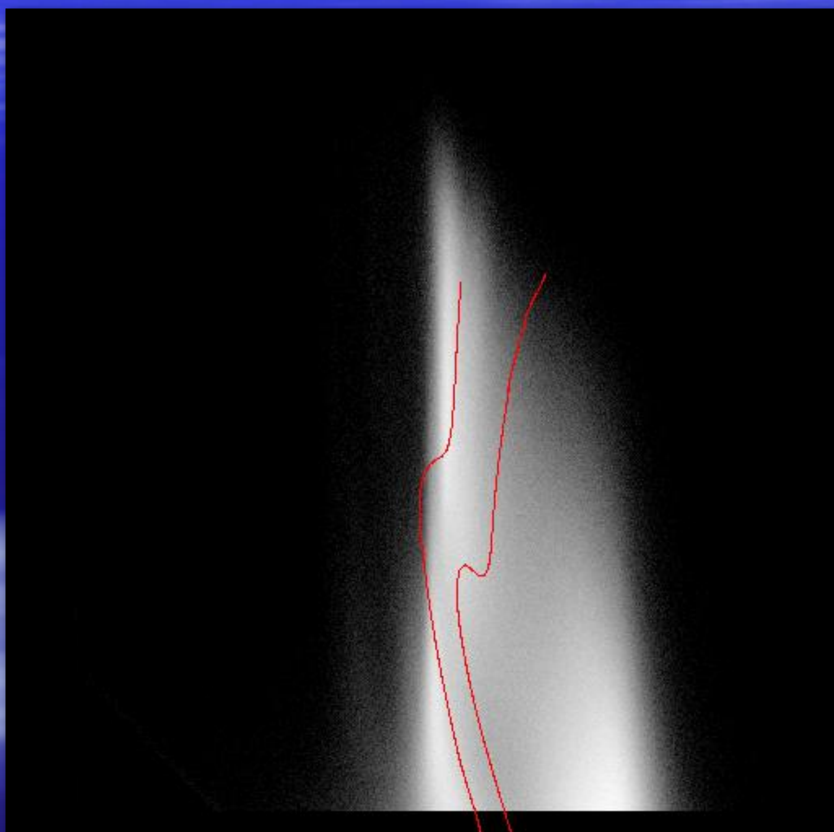

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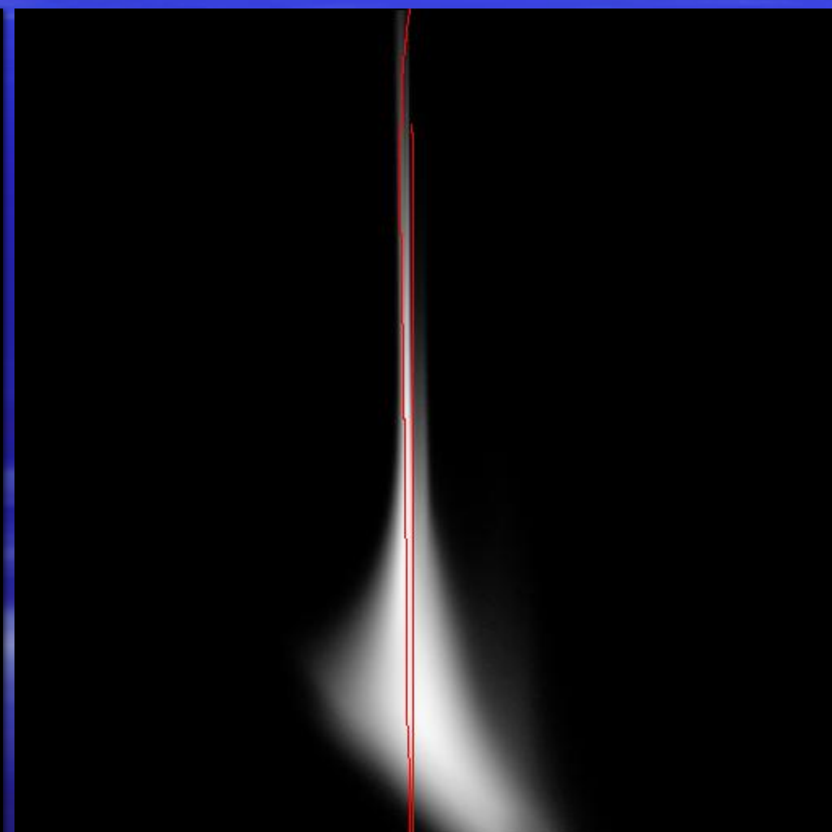
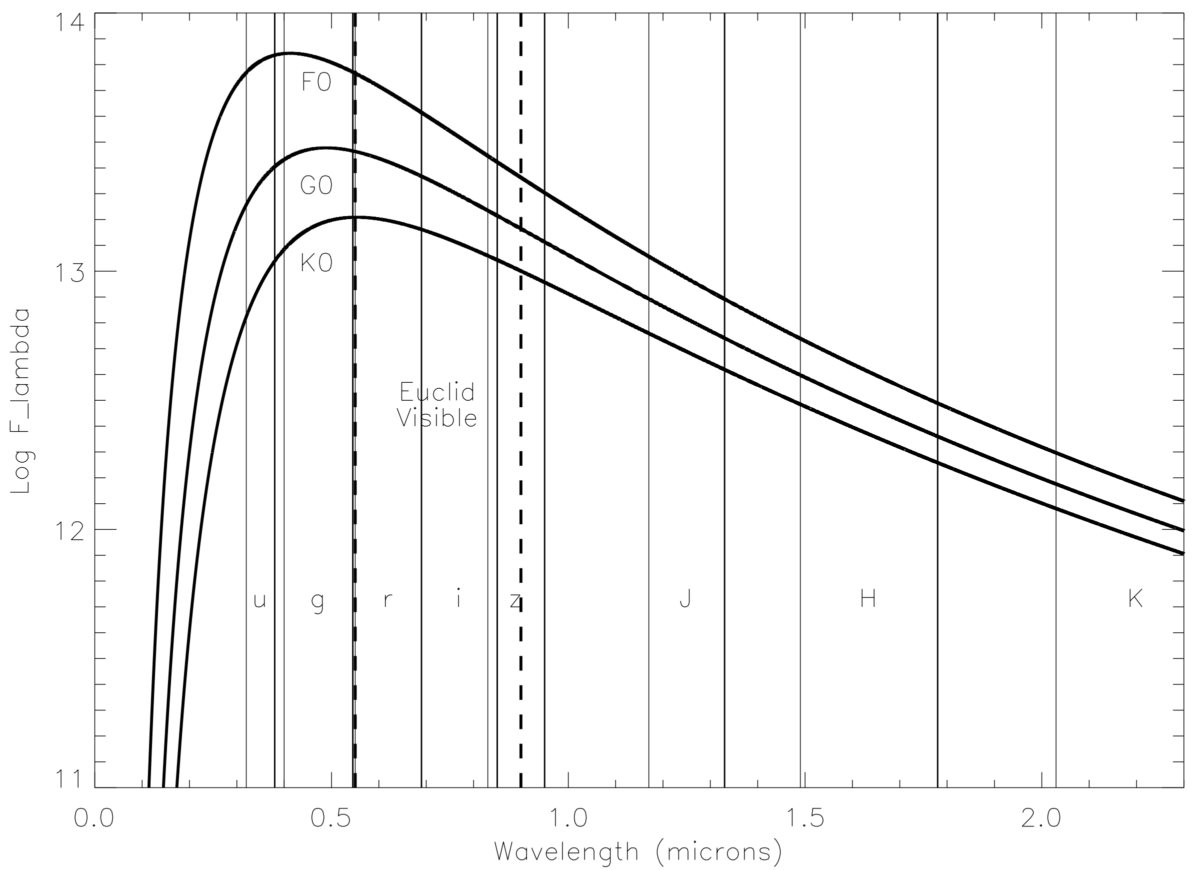
WISE

W1

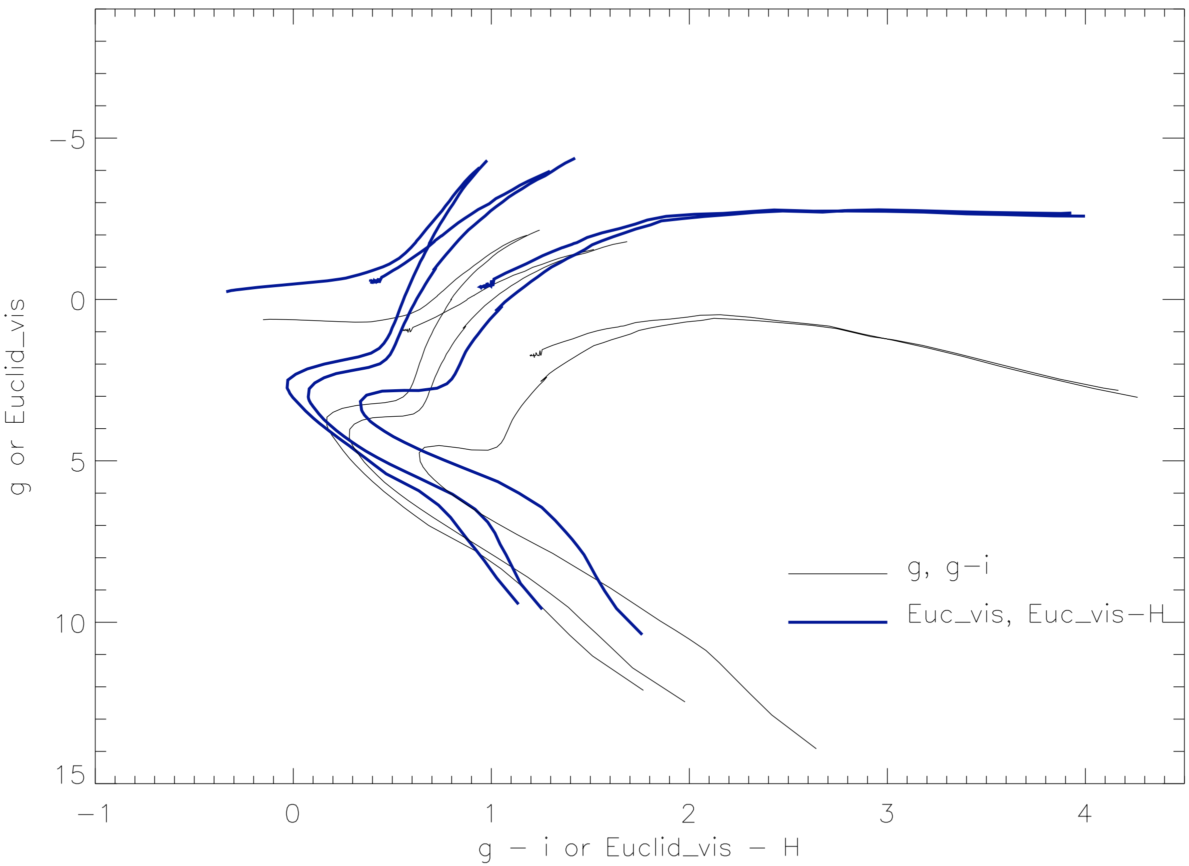


W1 – W2

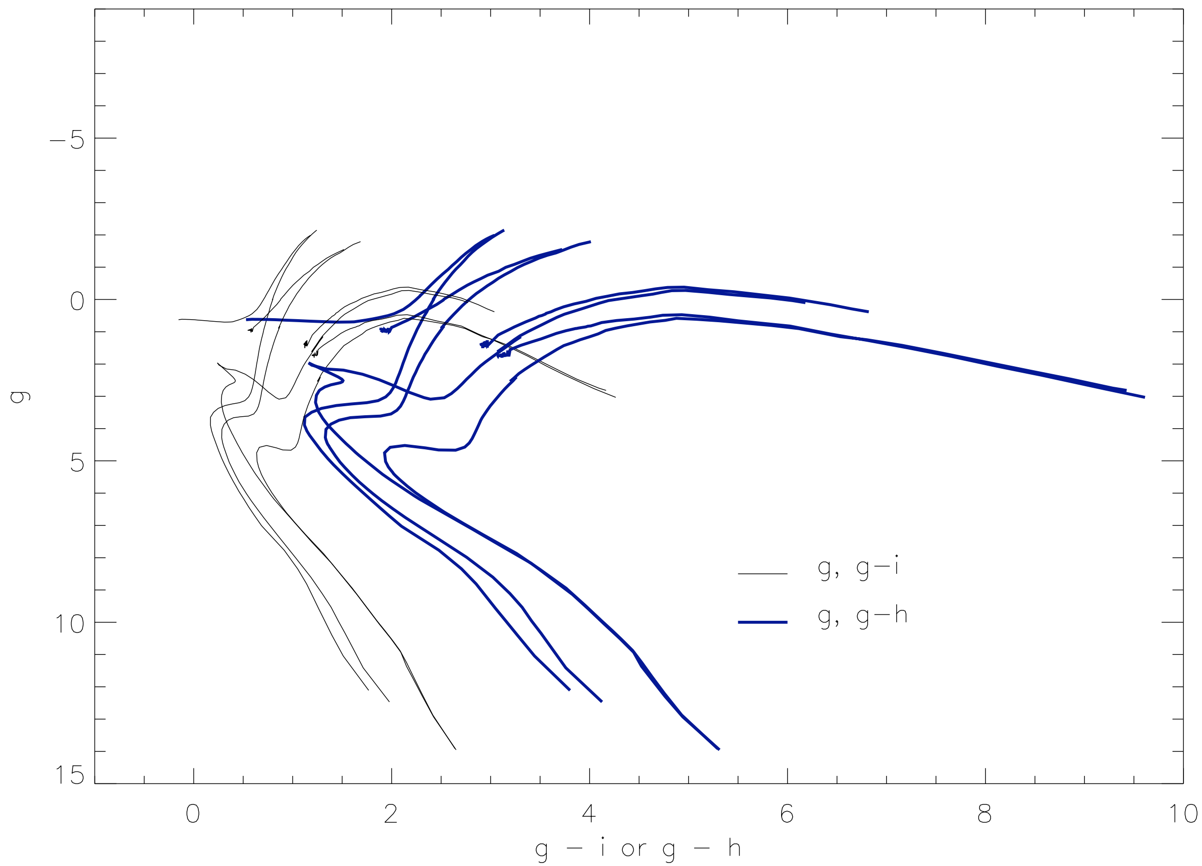
Euclid Photometry



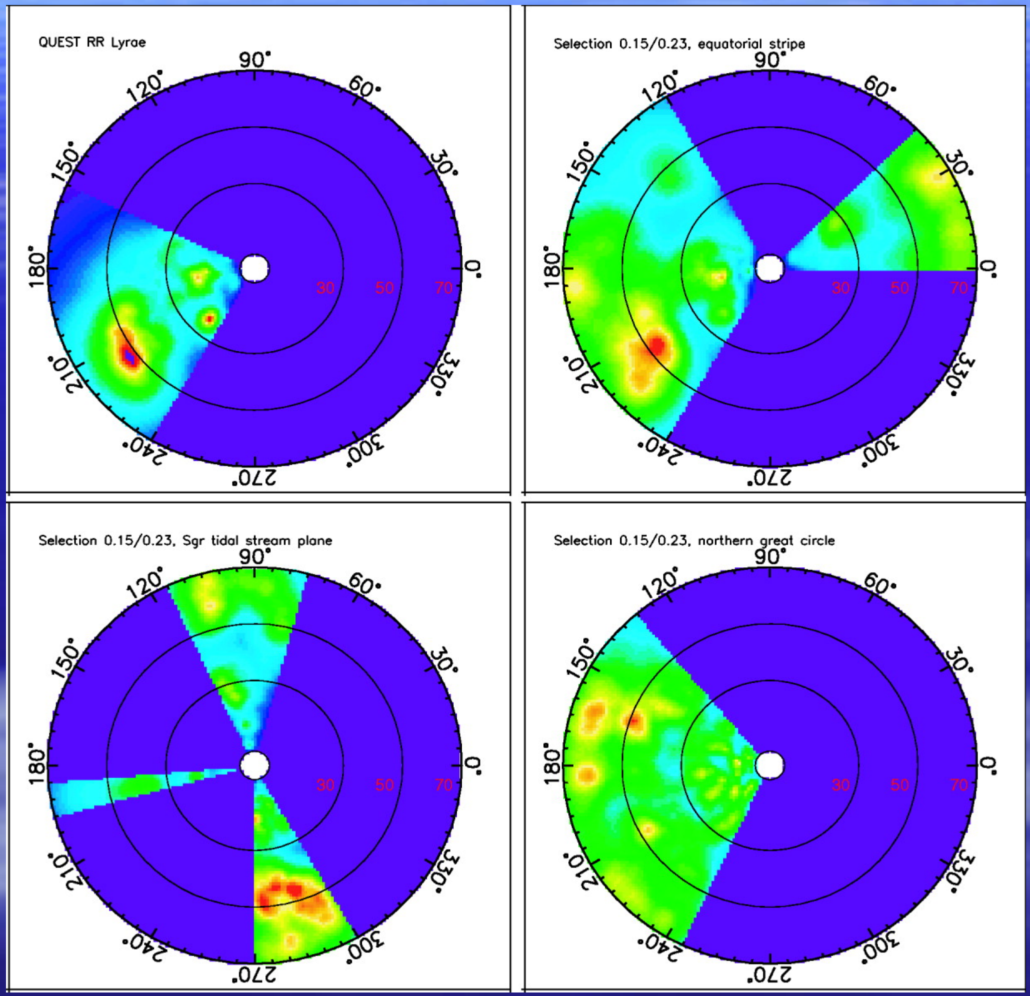
Euclid Photometry



LSST Photometry



RR Lyrae



Ivezic et al. 2005

3643 RR Lyrae from single epoch SDSS colors.

With an appropriate observing cadence, WFIRST could detect RR Lyrae out to 2 Mpc using variability signatures.

S/N per stream would necessarily be low, but corresponding distance estimates will be crucial.

Conclusions

-WFIRST will go extremely deep, sampling nearly all stars within 25 kpc, turn-off stars out to 300 kpc, and giant stars throughout the Local Group.

-WFIRST can explore the more highly extincted regions near the Galactic plane, though constrained by limited WFIRST population discrimination and/or the reach of visible light photometry.

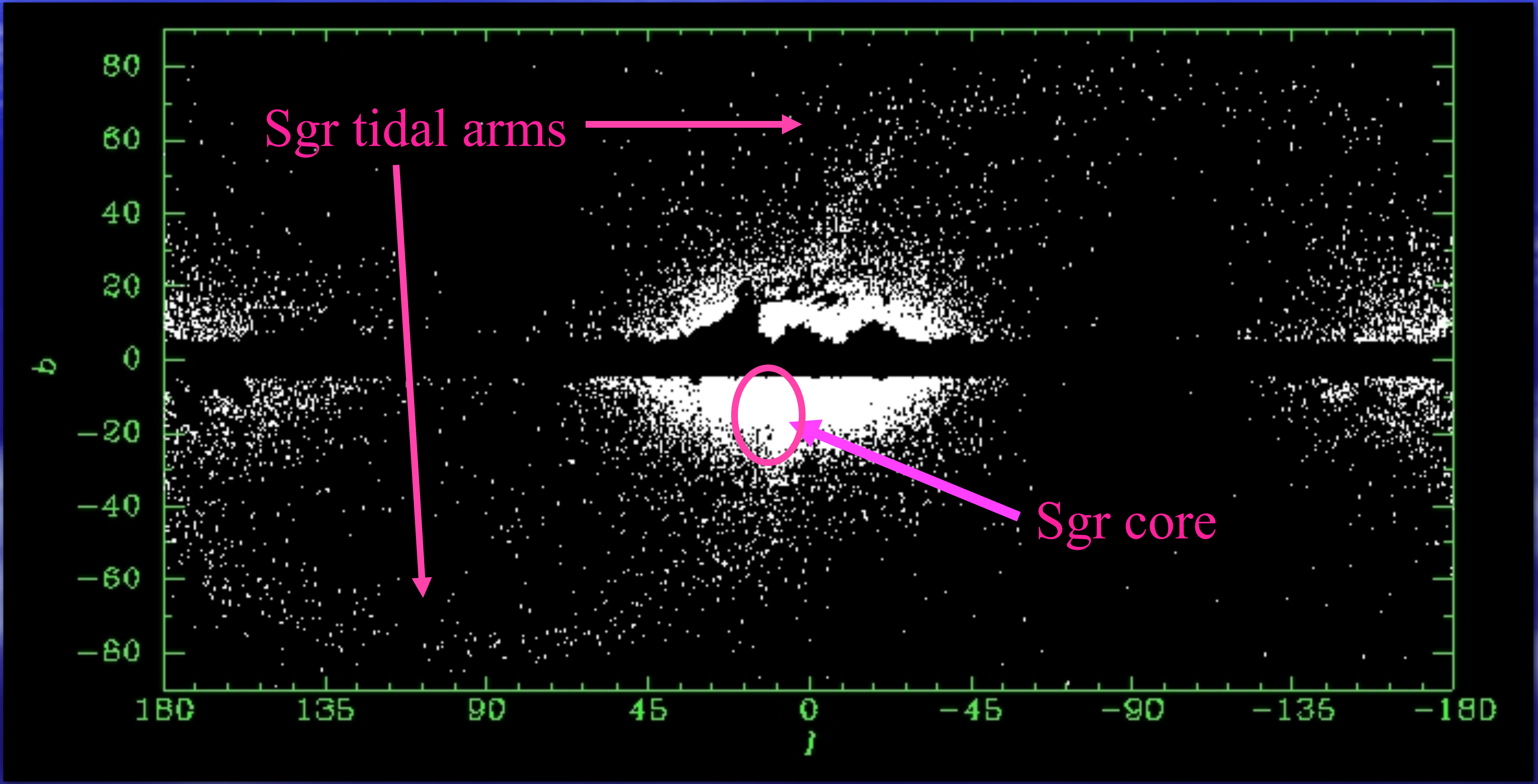
-Depending on observing cadence, WFIRST could detect many thousands of remote RR Lyrae.

-- combining WFIRST and LSST photometry would improve S/N of streams and substructures in the Galactic halo by a factor of ~2 compared with LSST alone.

Backup Slides

Sagittarius dSph cont' d

All-sky view of 2MASS M giant star distribution



Majewski et al. 2003