The spatial distribution and number of Milky Way dwarf galaxies

Beth Willman (Haverford College)

Potsdam AIP Thinkshop August 2014

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Jonathan Hargis (Haverford College), Willman & Peter
ApJL submitted

Too many, too few or just right? The predicted number and distribution of Milky Way dwarf galaxies.

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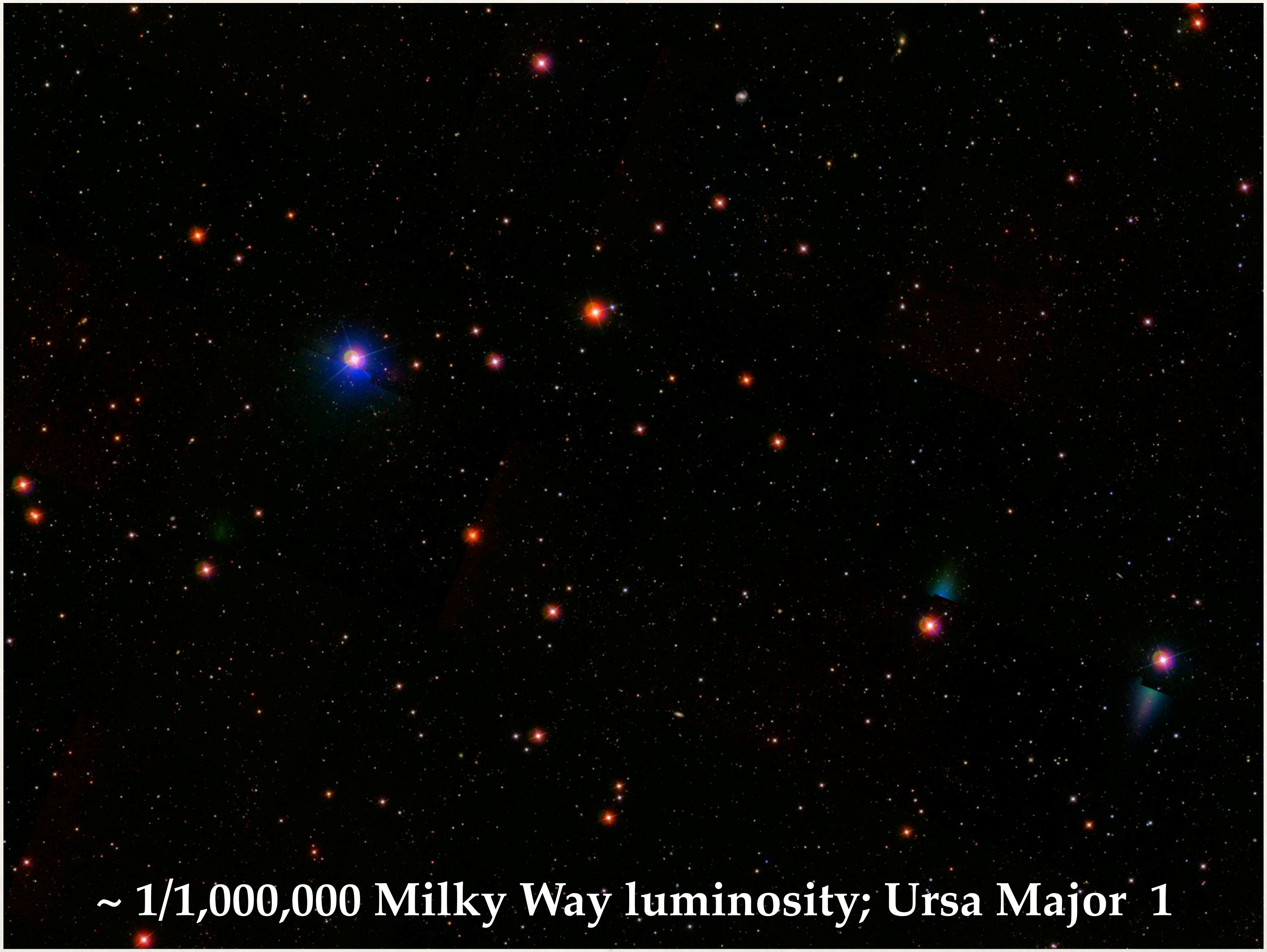
Milky Way dwarfs are discovered as overdensities of resolved stars in ground-based survey data

~ 1/15,000 Milky Way luminosity;   Leo II

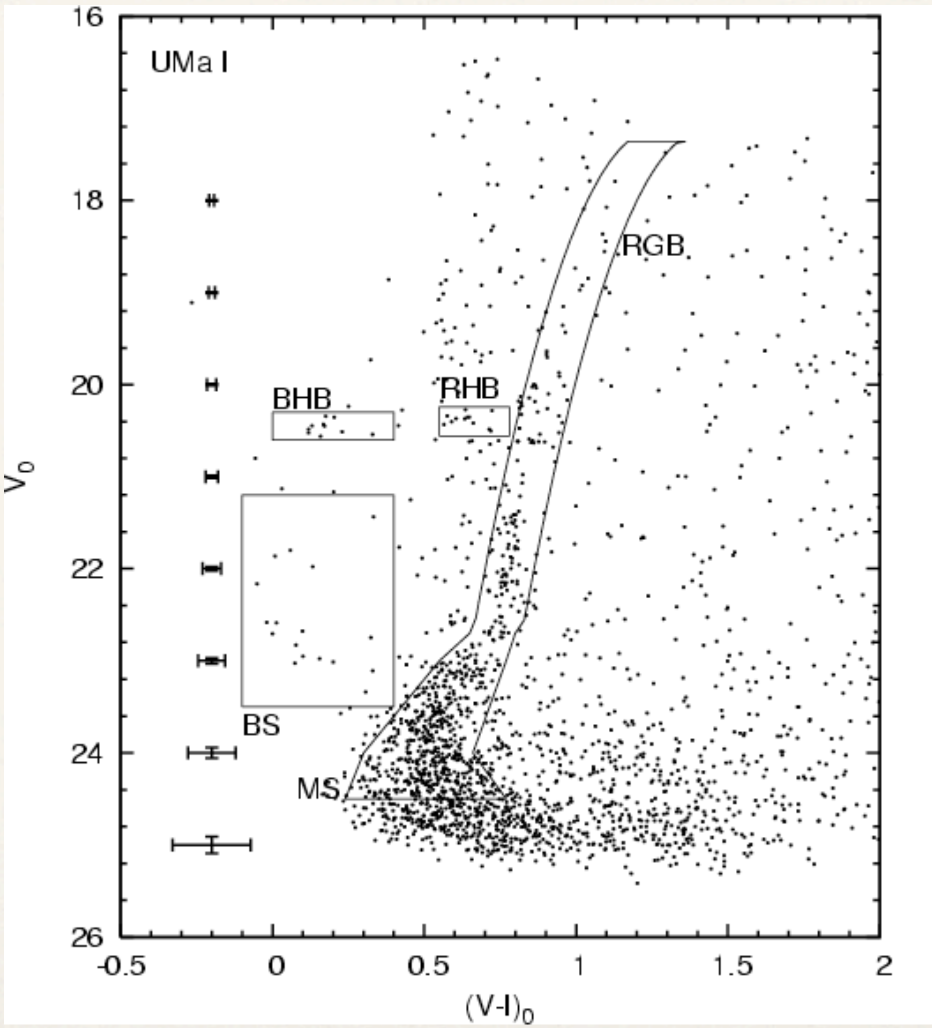
Milky Way dwarfs are discovered as overdensities of resolved stars in ground-based survey data

~ 1/40,000 Milky Way luminosity;   Draco

Milky Way dwarfs are discovered as overdensities of resolved stars in ground-based survey data

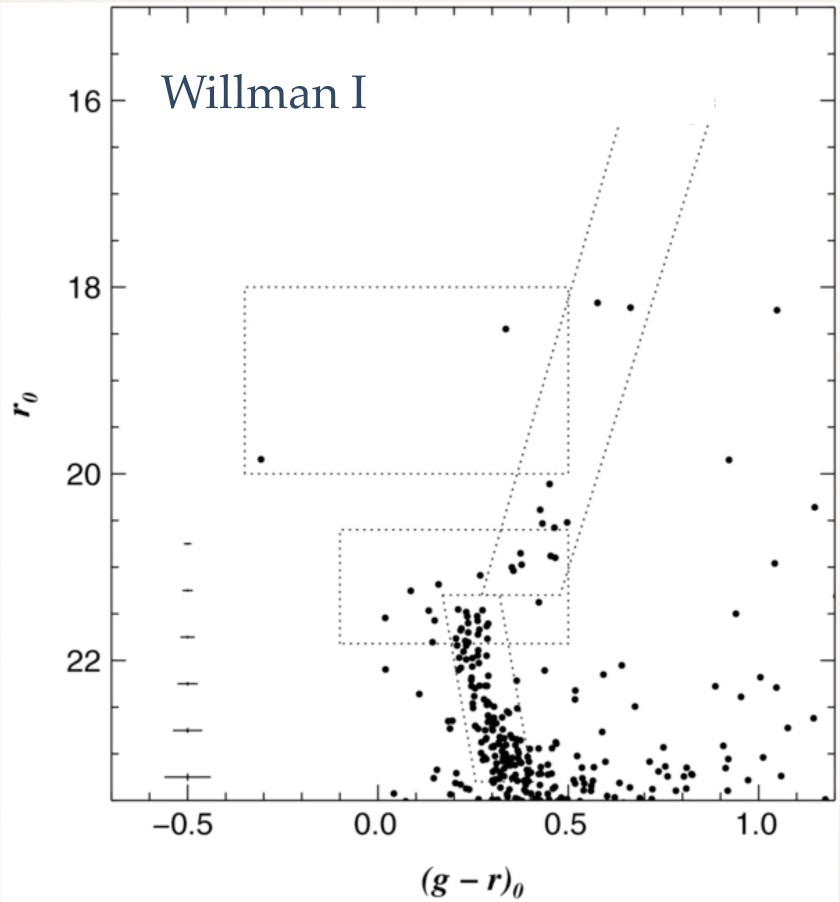


Milky Way dwarfs are discovered as overdensities of resolved stars in ground-based survey data

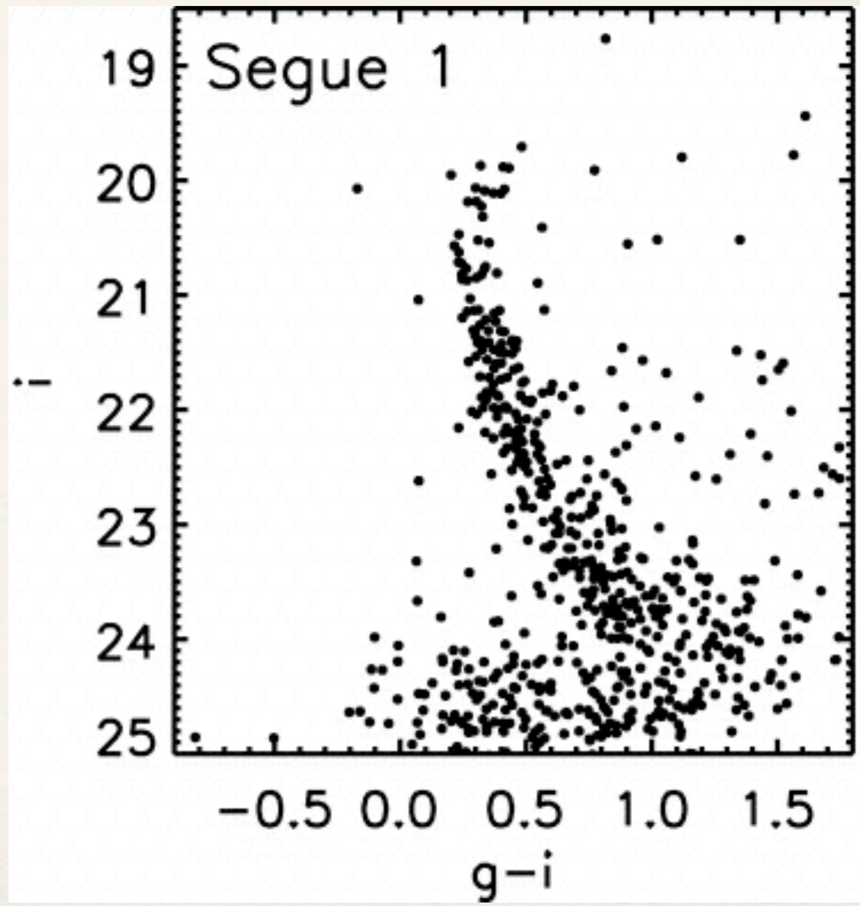


Okamoto et al 2008

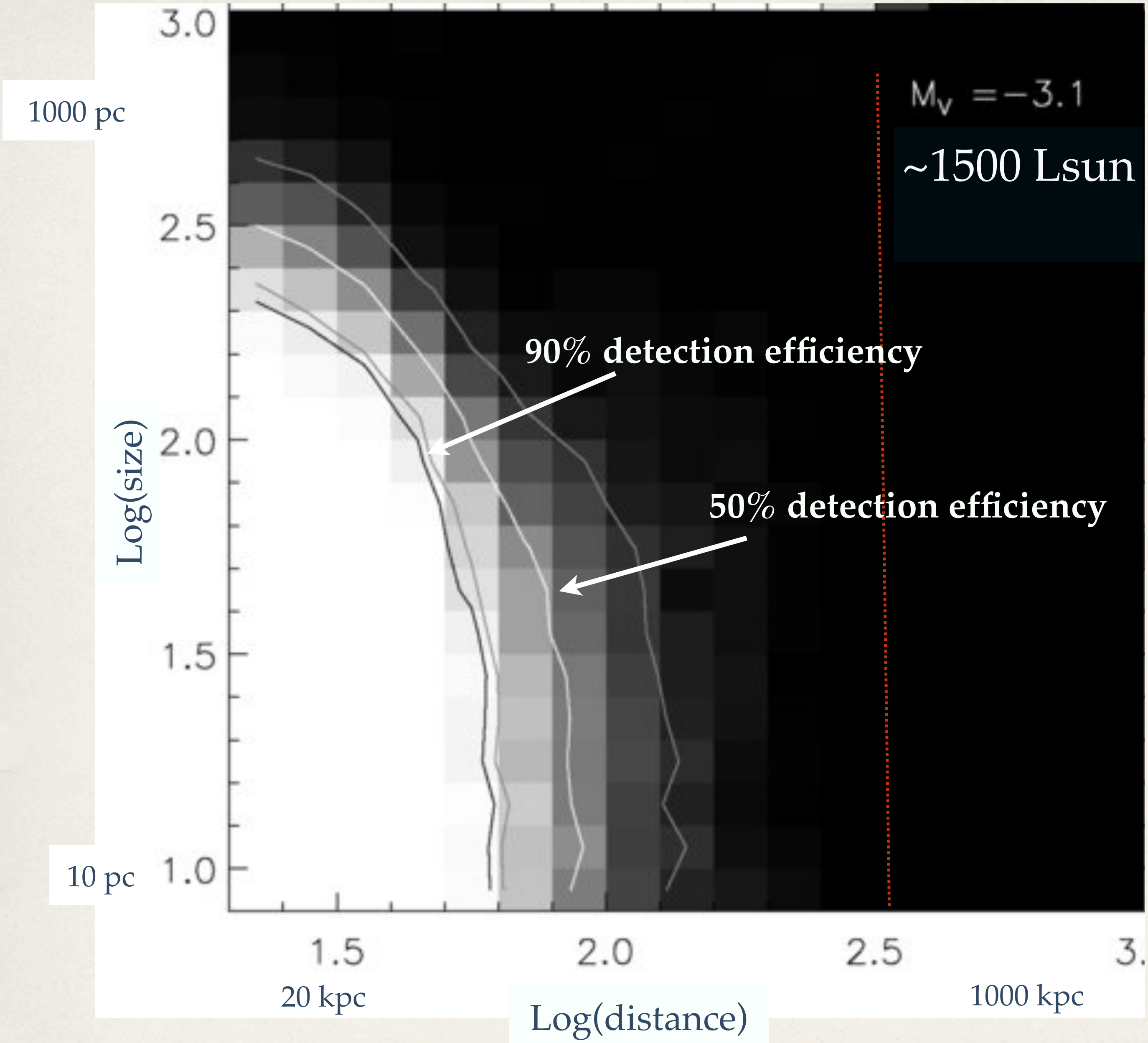
Main sequence turnoff stars must be resolved to discover (~ 500 L_{Sun}) galaxies



Willman et al 2011



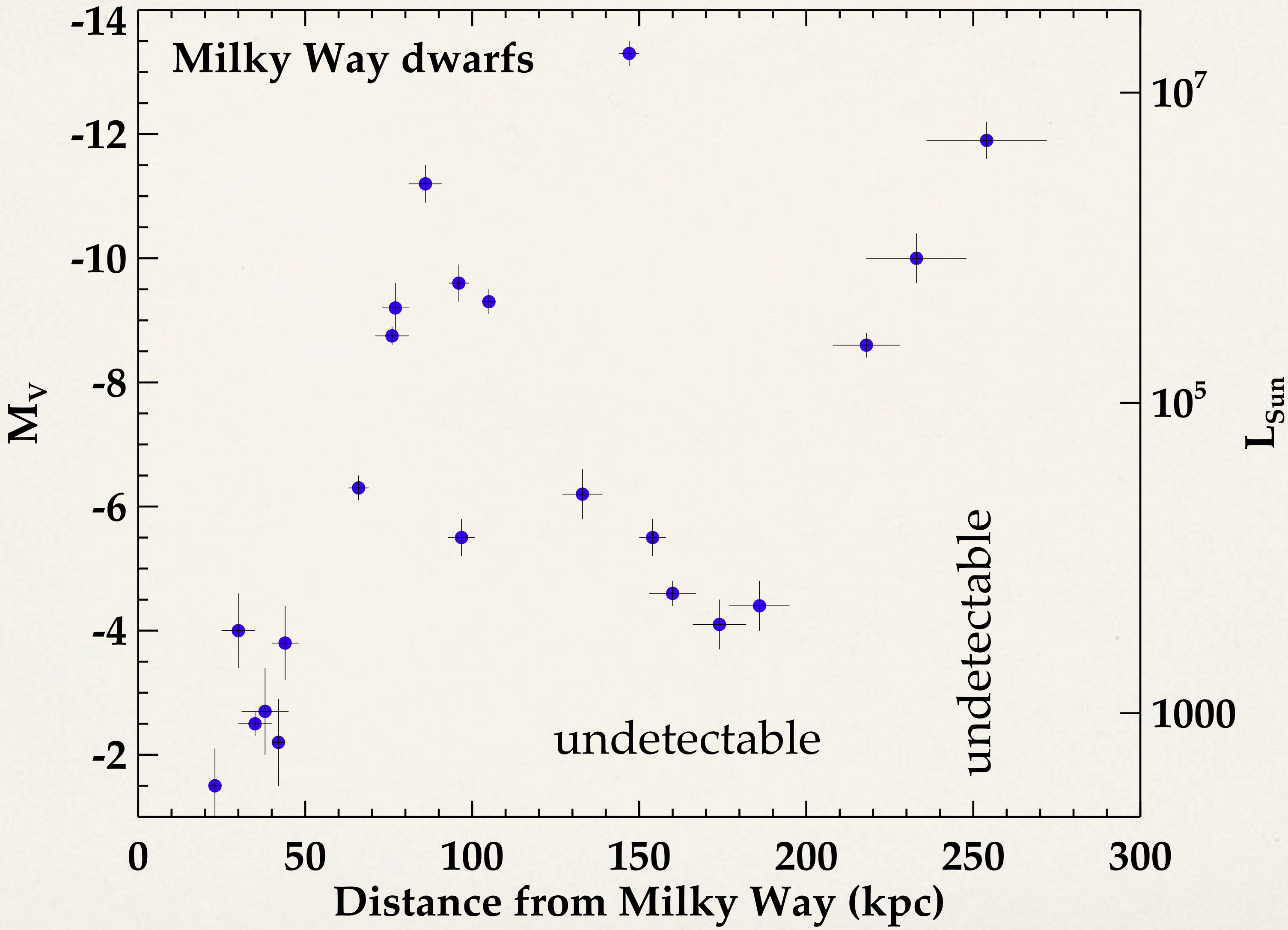
Belokurov et al 2007



Detectability of galaxies is a function of (distance, luminosity, and size)

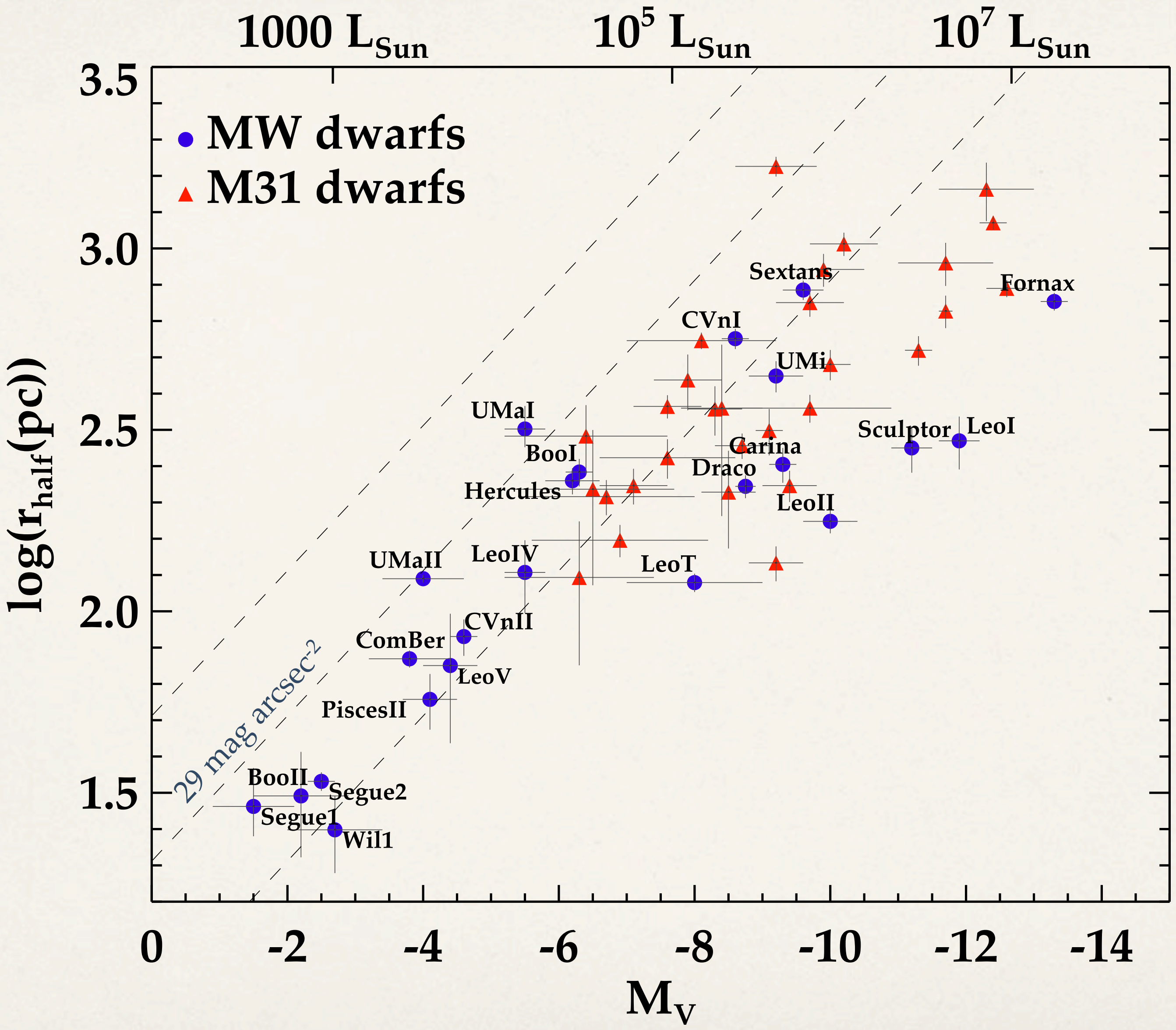
Figure from Walsh, Willman & Jerjen 2009

Observational bias against low L, large d



MW dwarf galaxy discovery papers: Willman et al 05a,b; Zucker et al 06a,b; Belokurov et al 06,07,08,09,10; Walsh, Jerjen & Willman 07, Irwin et al 07; Detection limits: Walsh, Willman & Jerjen 2009, Koposov et al 2008

Observational bias against low surface brightness



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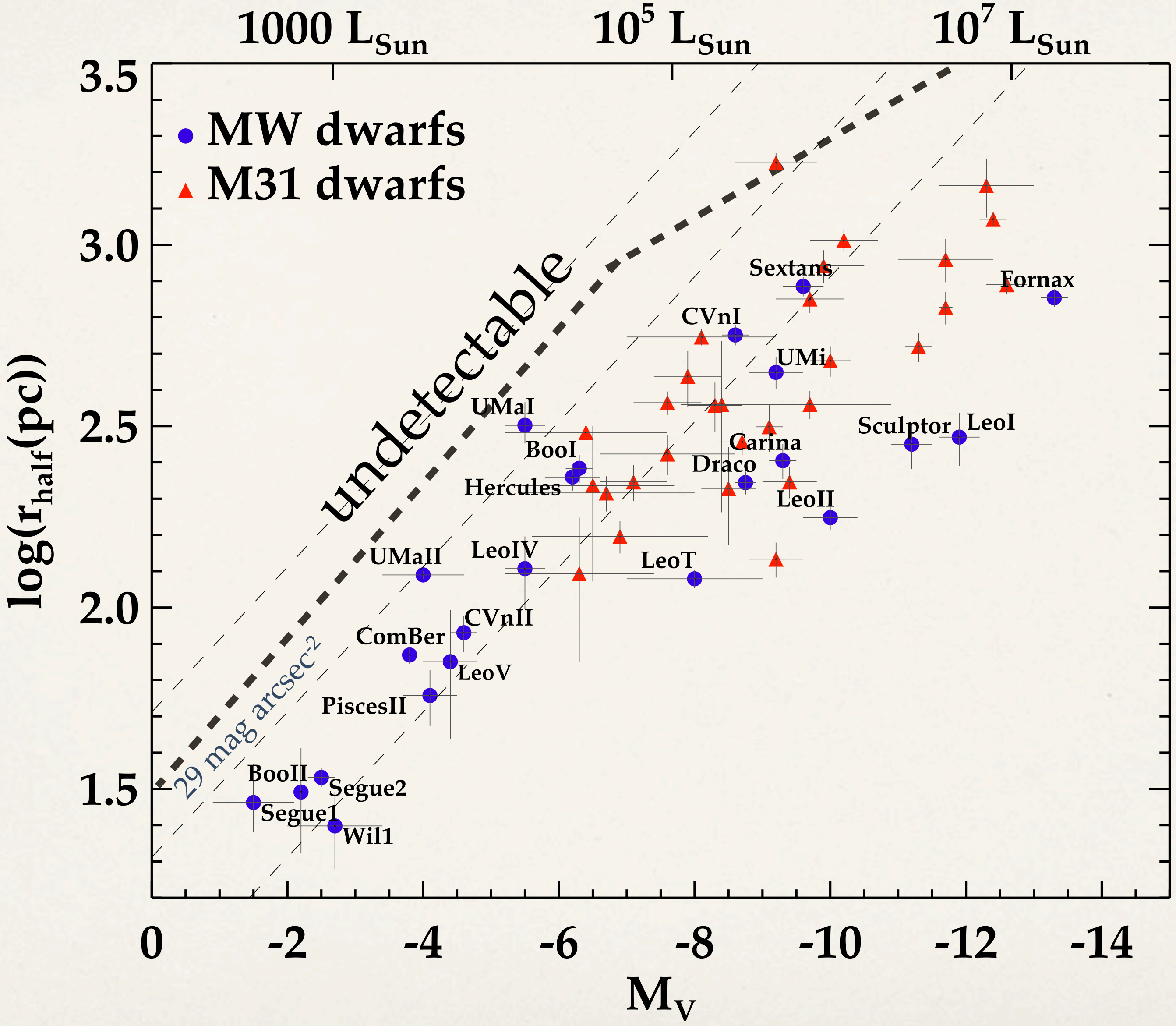
Observational bias against low surface brightness



The detectability line is approximate

MW dwarf galaxy discovery papers: Willman et al 05a,b; Zucker et al 06a,b; Belokurov et al 06,07,08,09,10; Walsh, Jerjen & Willman 07, Irwin et al 07; Detection limits: Walsh, Willman & Jerjen 2009, Koposov et al 2008

Detectability can also be a function of location in the sky

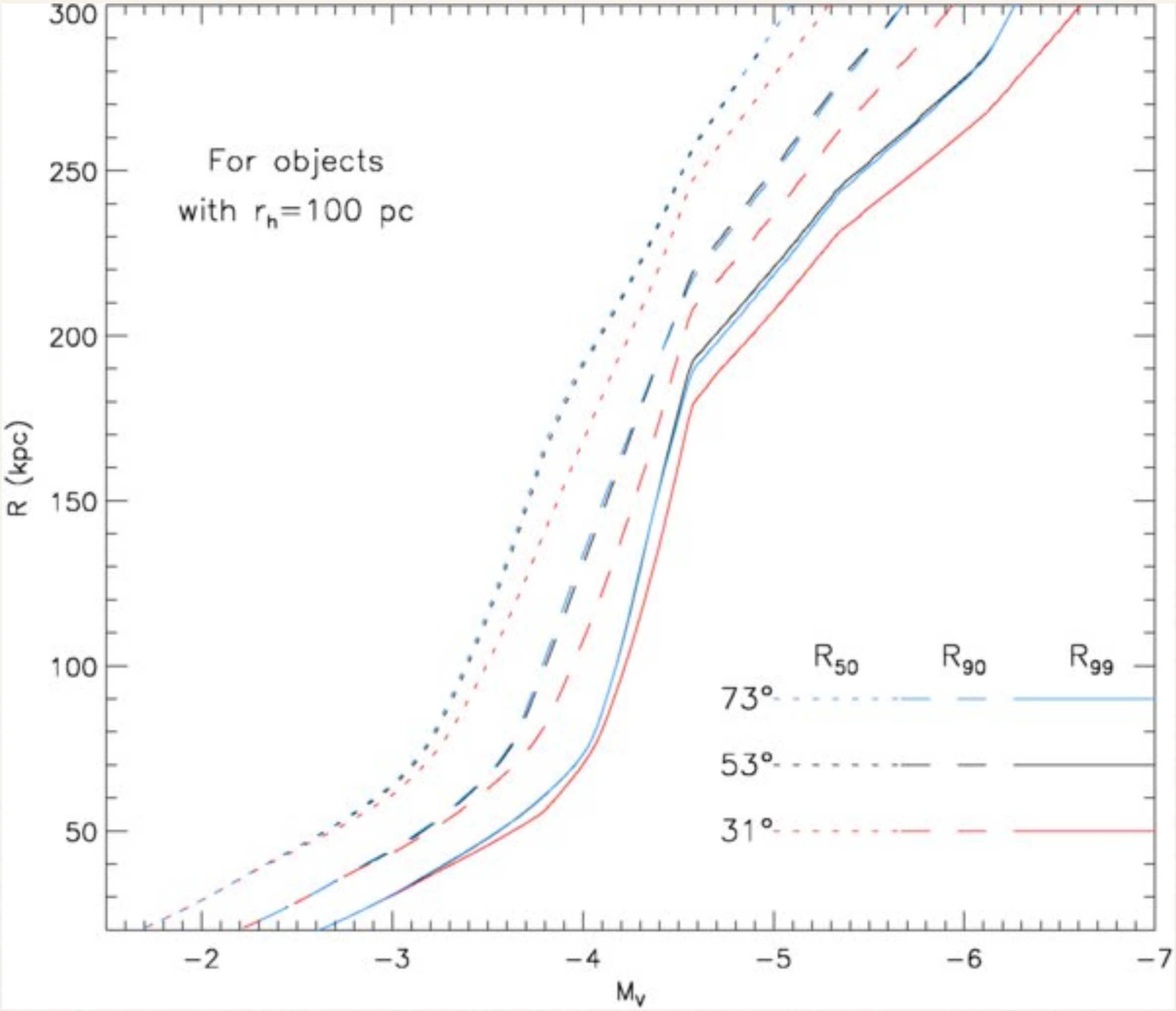


Figure from Walsh, Willman & Jerjen 2009

Detectability quickly decreases at low Galactic latitude

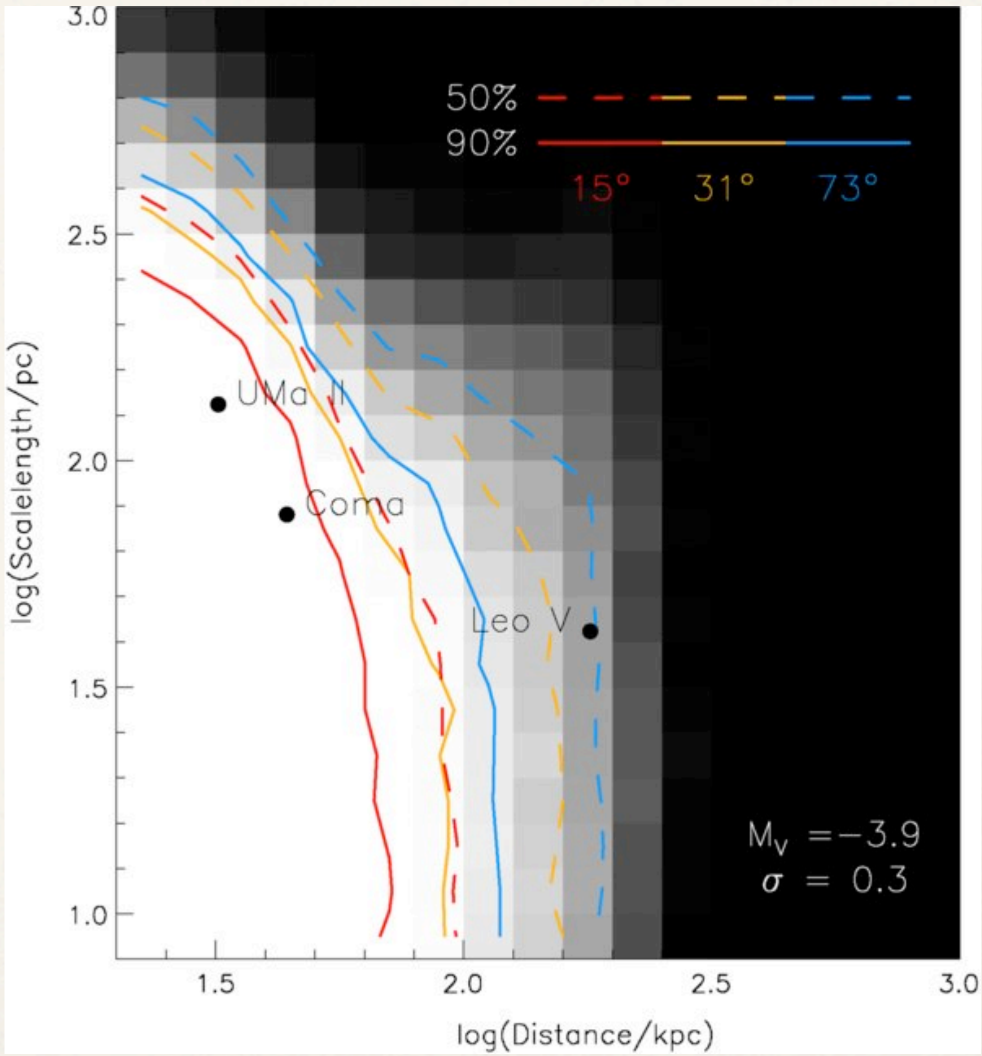
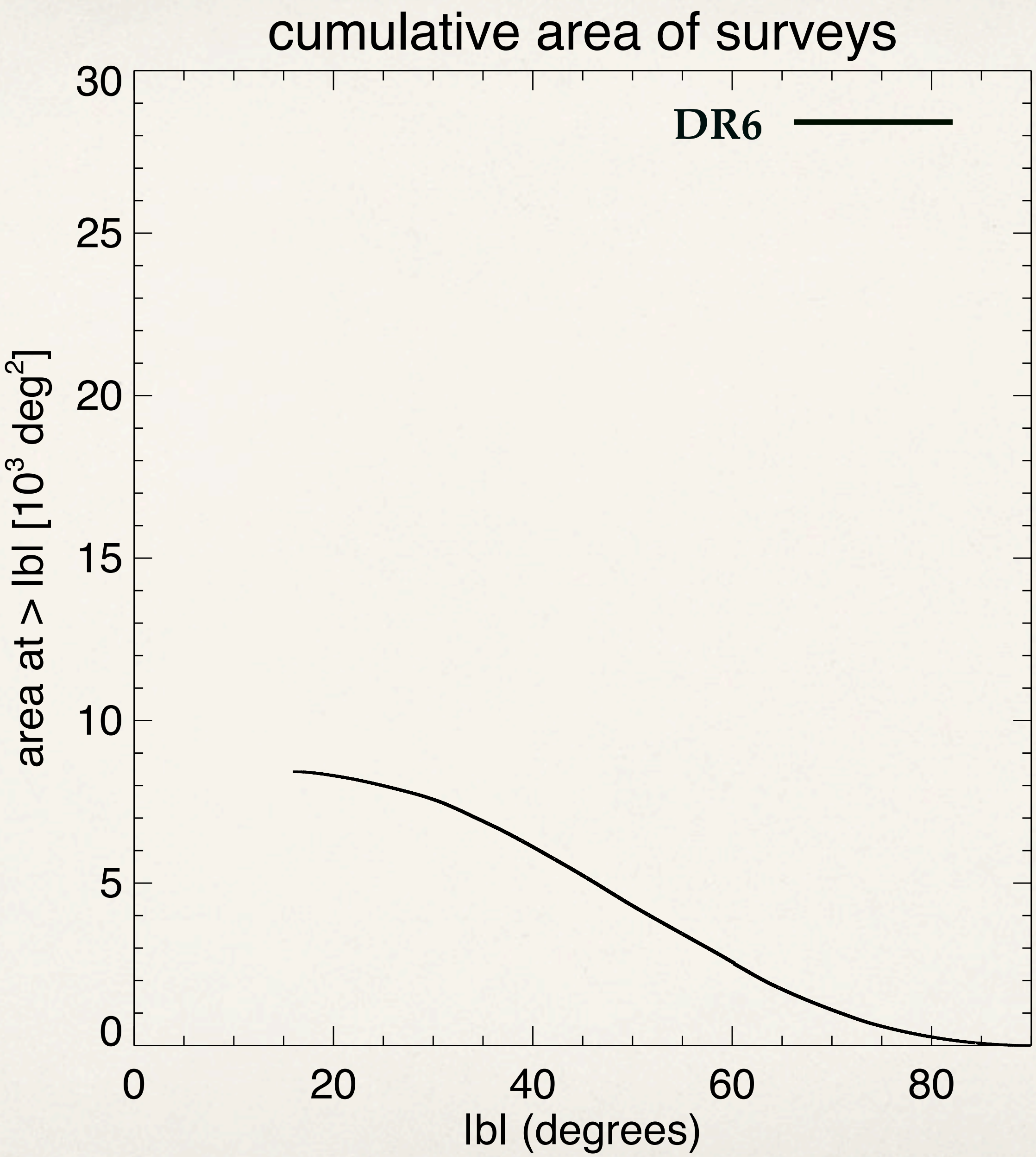
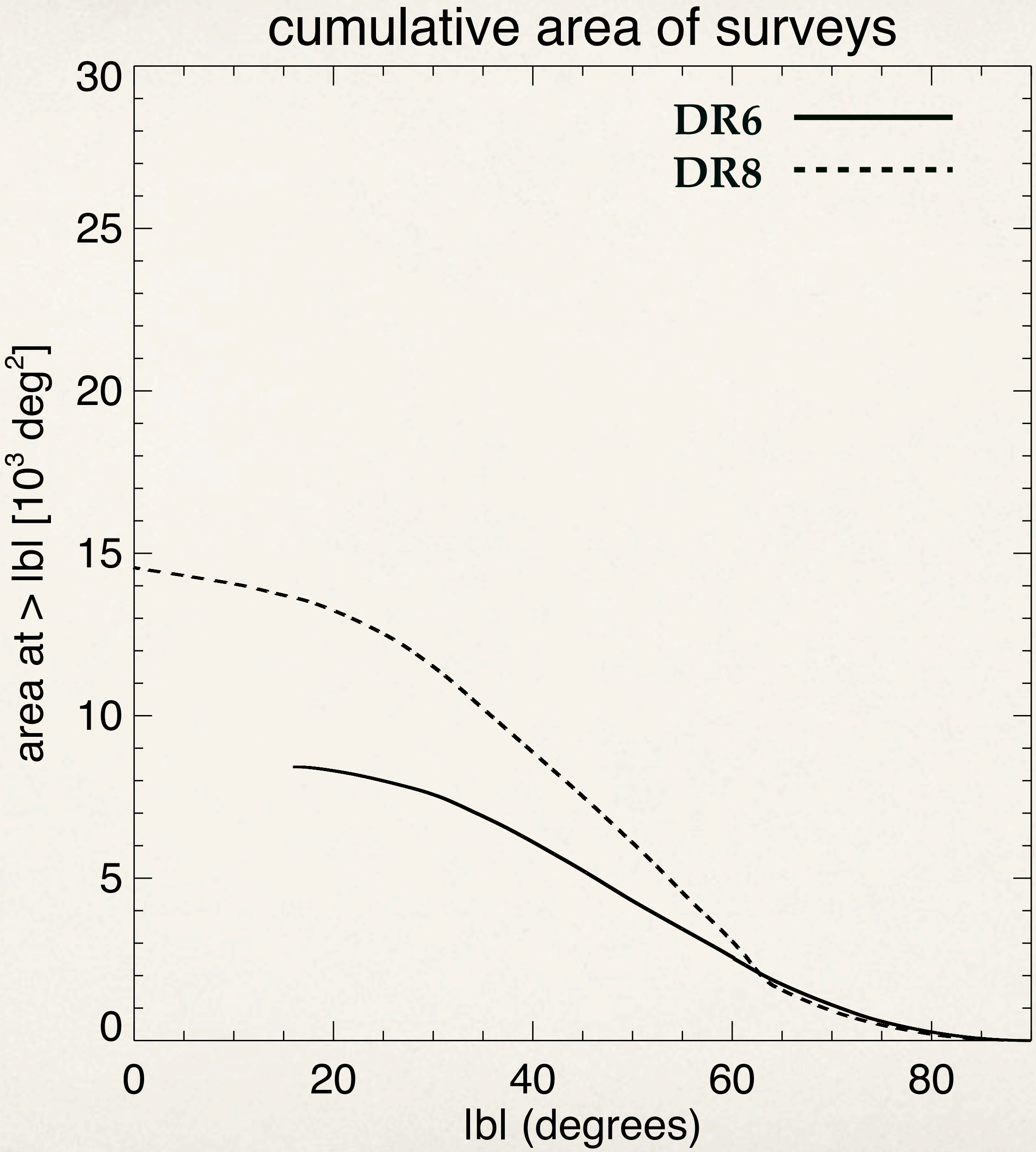


Figure from Walsh, Willman & Jerjen 2009



(DR6 shows Legacy only, missing 600 deg^2 at |b| > 25)



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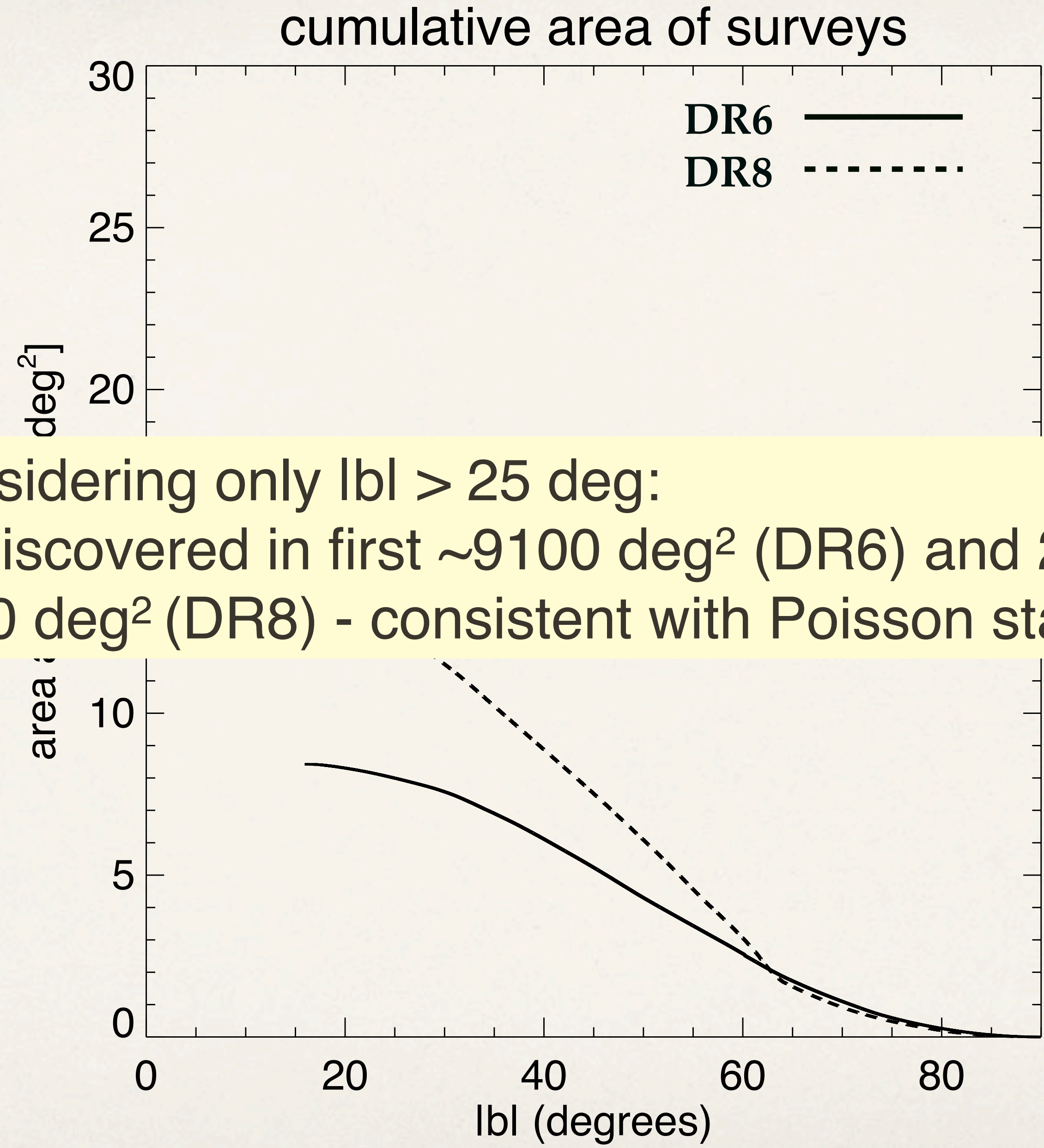
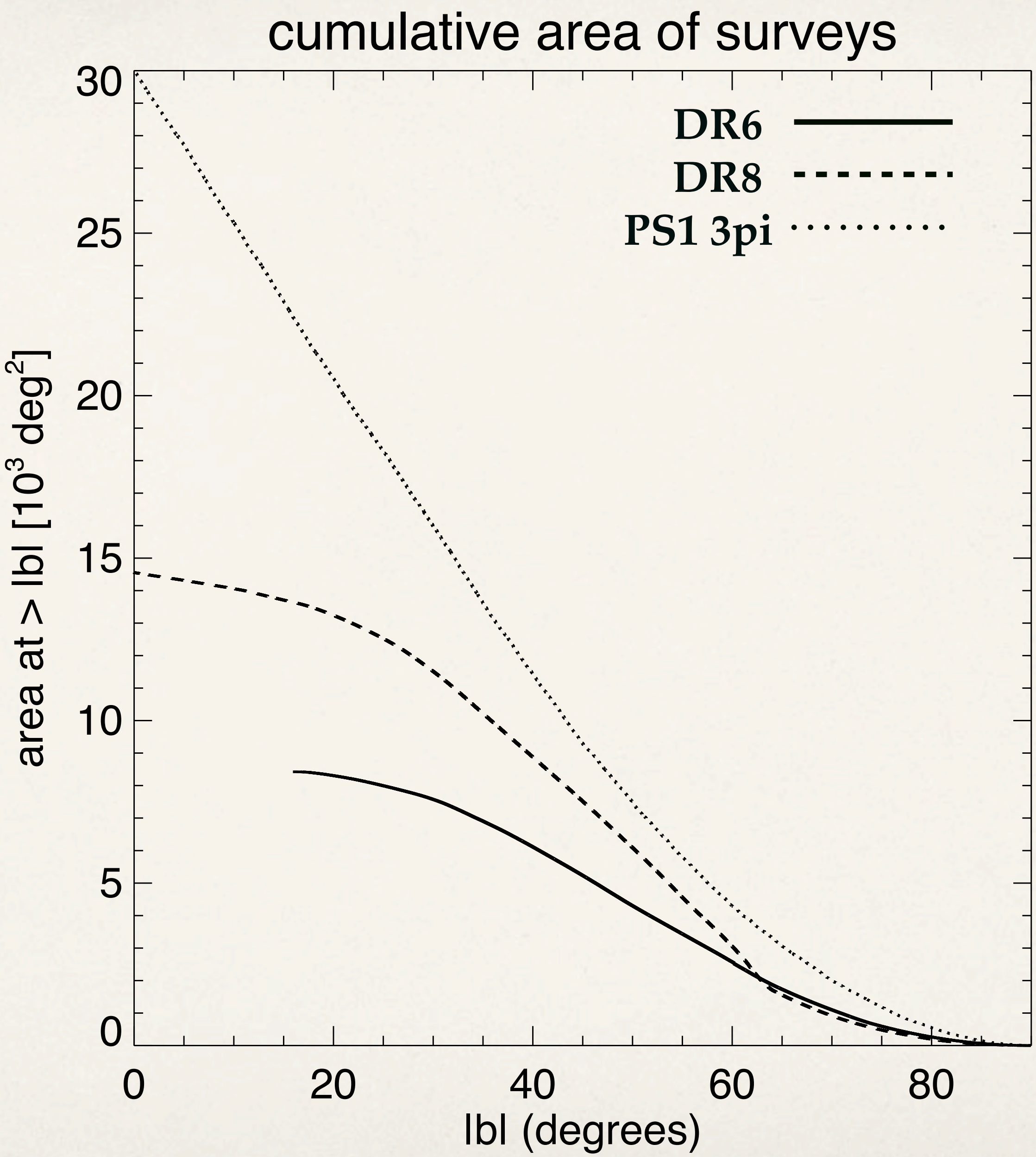
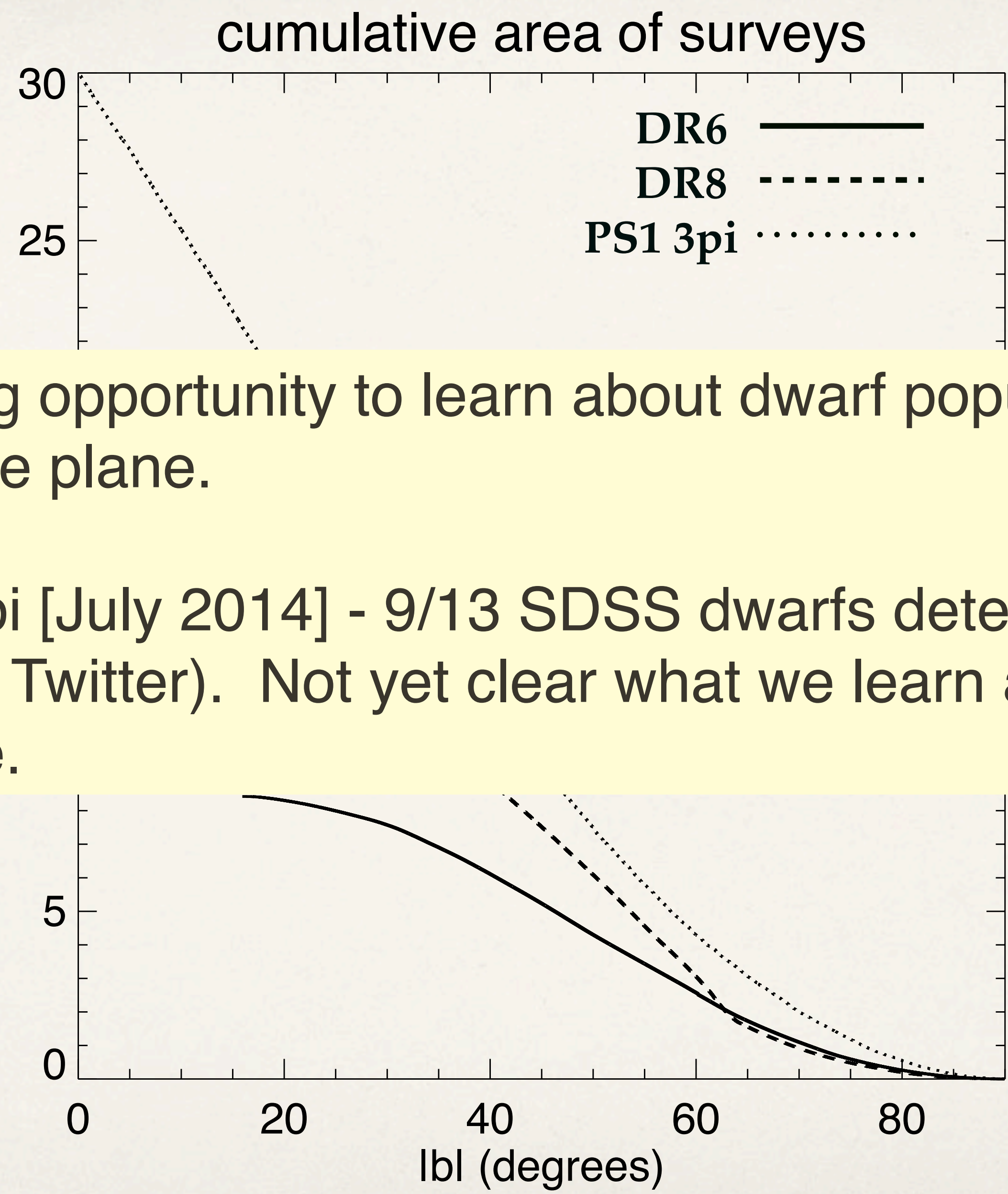


(DR6 shows Legacy only, missing 600 deg² at |b| > 25)

Considering only |b| > 25 deg:
12 discovered in first ~9100 deg² (DR6) and 2 in next 2900 deg² (DR8) - consistent with Poisson statistics



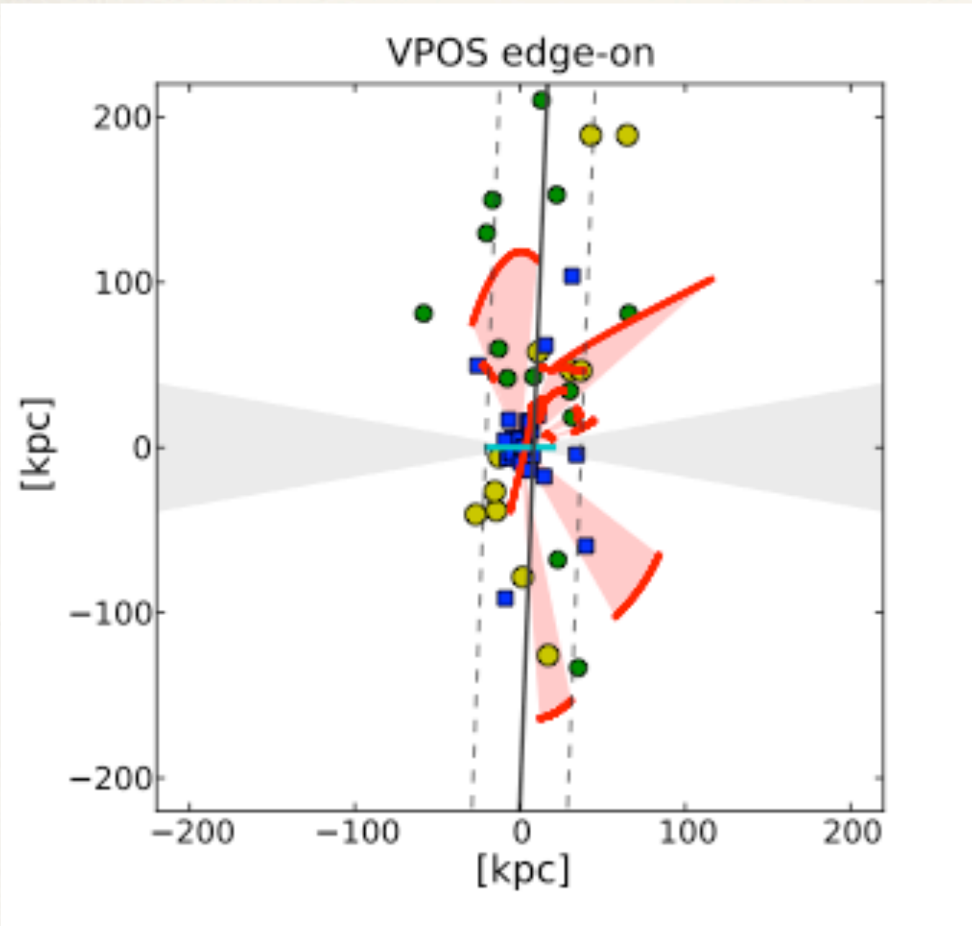
cumulative area of surveys
DR6
DR8
PS1 3pi
area at > |b| [10^3 deg^2]
|b| (degrees)
0
5
10
15
20
25
30
0
20
40
60
80



Exciting opportunity to learn about dwarf population near the plane.

PS1 3pi [July 2014] - 9/13 SDSS dwarfs detectable (N. Martin, Twitter). Not yet clear what we learn at low latitude.

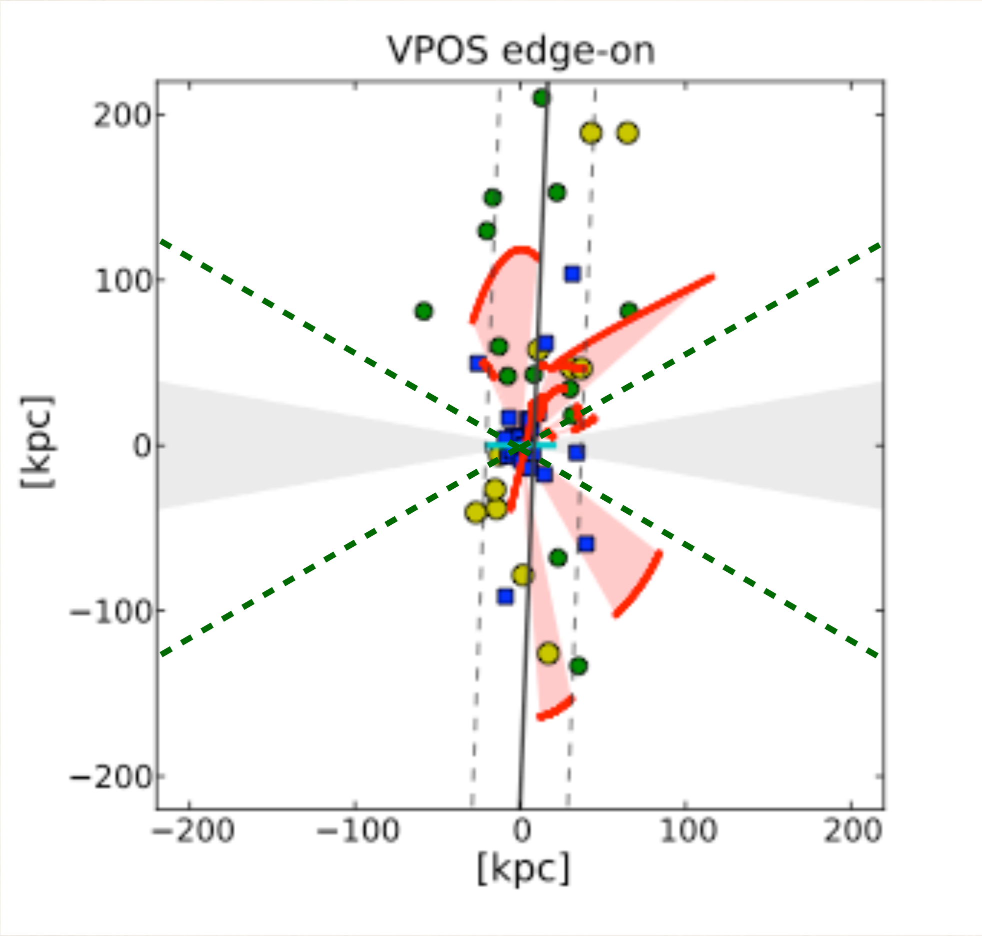
Spatial distribution of MW dwarfs: an important constraint on formation models



yellow circles = classical MW dwarfs
green circles = post-SDSS dwarfs
grey = |b| < 10°

Pawlowski et al 2013

Spatial distribution of MW dwarfs: limited survey footprint + Galaxy limits our view



yellow circles = classical MW dwarfs
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grey = |b| < 10°

Little has been known within 20° of the disk (Irwin 1994, Kleyna et al 1997)

What can PanSTARRs teach us?

Pawlowski et al 2013

We don’t yet know the number or luminosity function of Milky Way satellites fainter than $M_V \sim -9$ (even away from the plane).

We don’t yet know the spatial distribution of Milky Way satellites fainter than $M_V \sim -9$ (even away from the plane).

We have a quite incomplete picture of the MW dwarf population within ~30 degrees of the plane.

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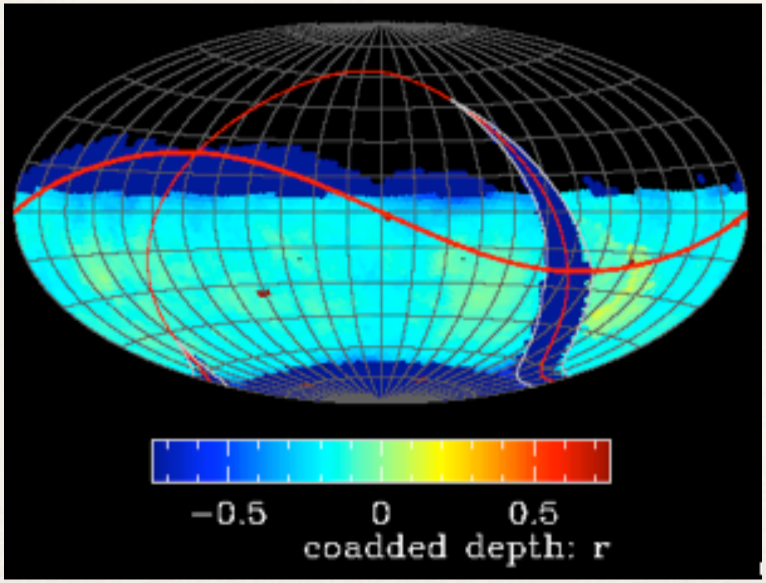
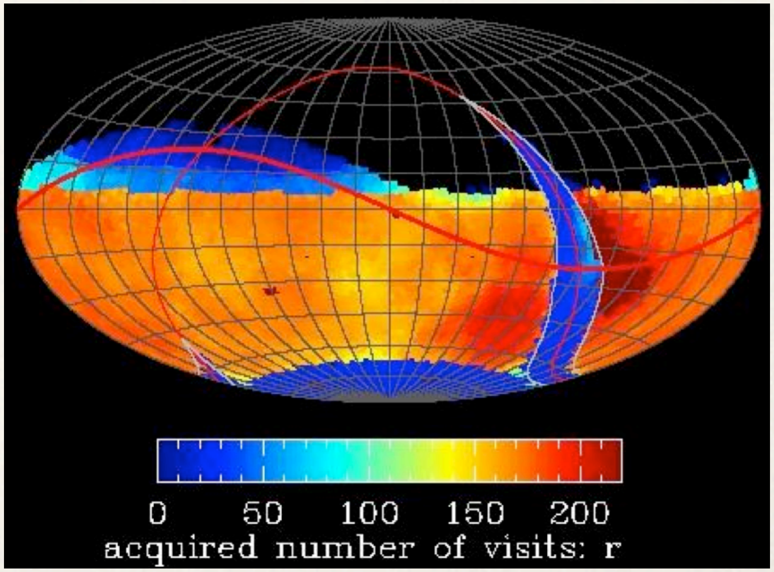
How can current observational biases be overcome?

LSST

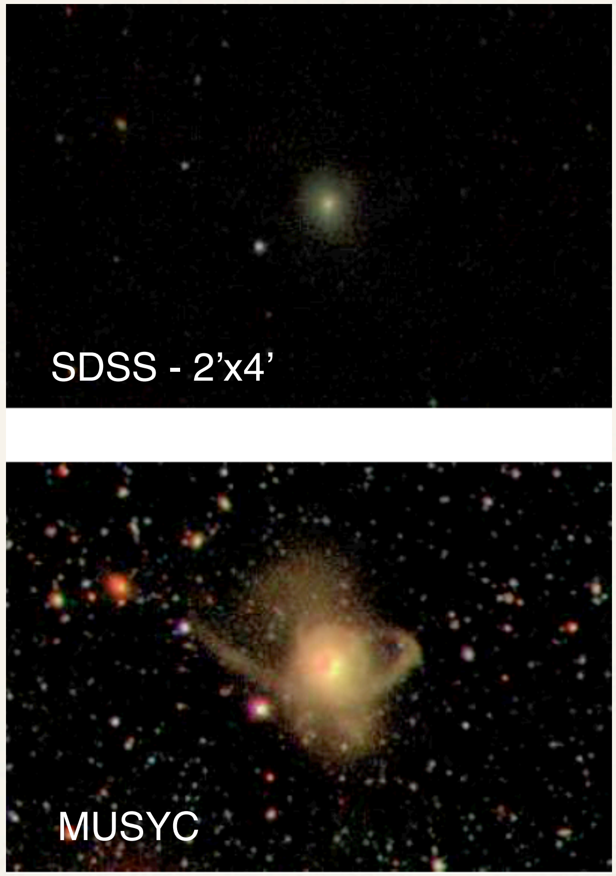
- ~1/2 the sky - ~18,000 deg^2 in fiducial survey, ~25,000 deg^2 total
- 90% of time on a universal survey; Other 10%: deep drilling fields and mini-surveys
- ~900 visits per location over a 10 year period; $r_{limit,single}$ ~ 24.5 mag, $r_{limit,stack}$ ~ 27.5 mag
- Science verification - 7 years away





Figures from www.lsst.org and Ivezic et al. arXiv:0806.2366

LSST-like Images

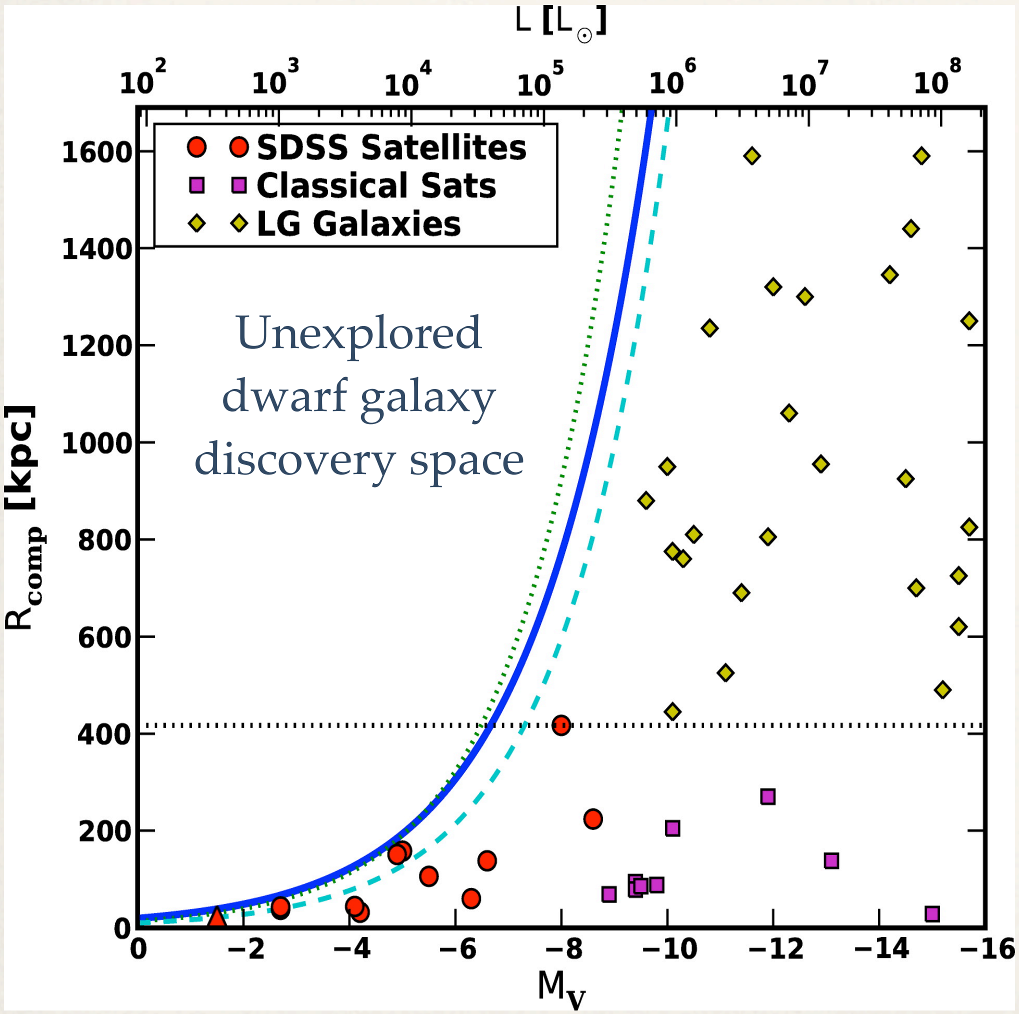


The Deep Lens Survey image is an analog in depth and image quality to a single LSST epoch

The MUSYC image is ~1 mag shallower than the co-added LSST; highlights possible LSB science

images from Ivezic et al. arXiv:0806.2366

Predicting the number and spatial distribution of Milky Way dwarfs with via Lactea

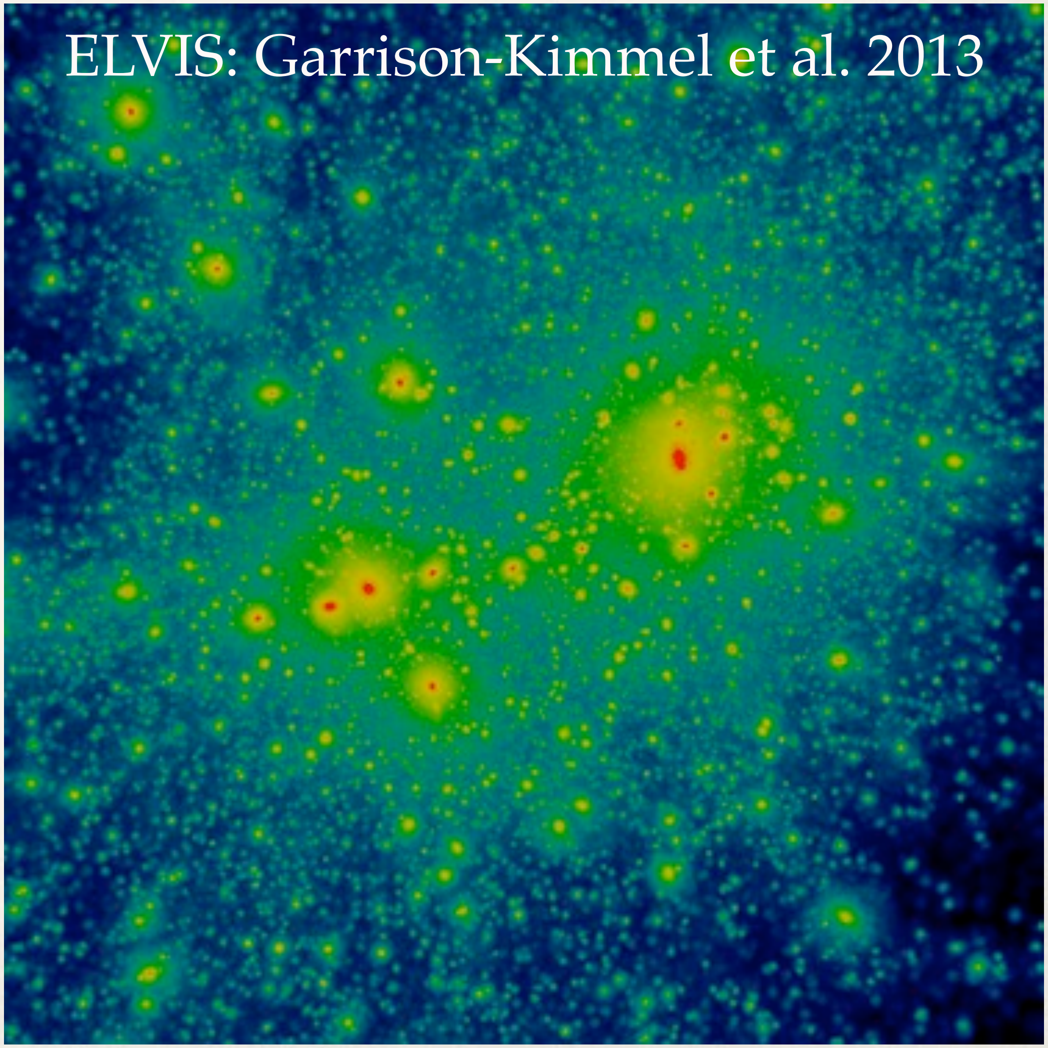


- Completeness correction of the observed MW dwarf population.

- Assuming demographics, spatial distribution, and correcting for SDSS DR5 footprint and luminosity bias suggested ~100-300 dwarfs. (Tollerud et al 2008, Koposov et al 2008).

Tollerud et al. 2008

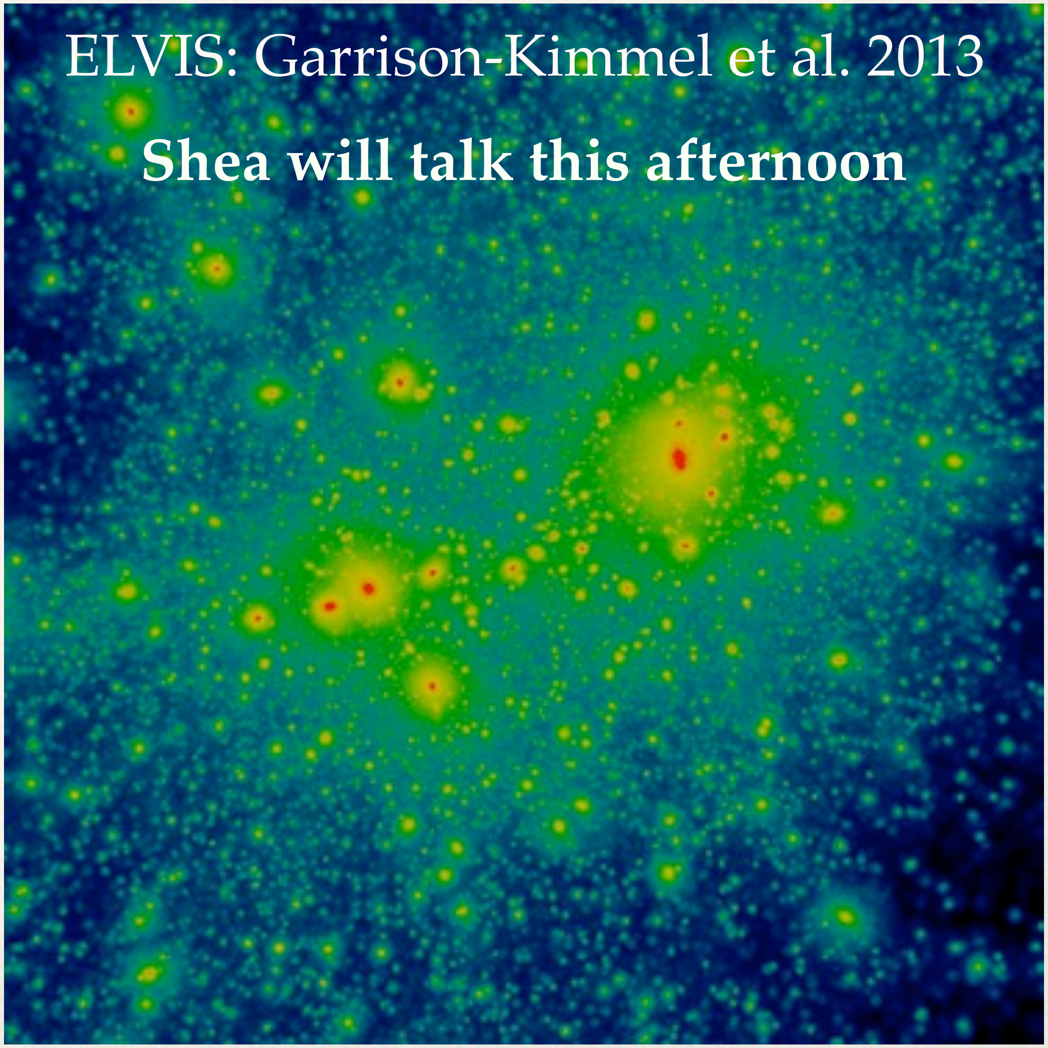
Predicting the number and spatial distribution of Milky Way dwarfs with ELVIS



Hargis et al. 2014

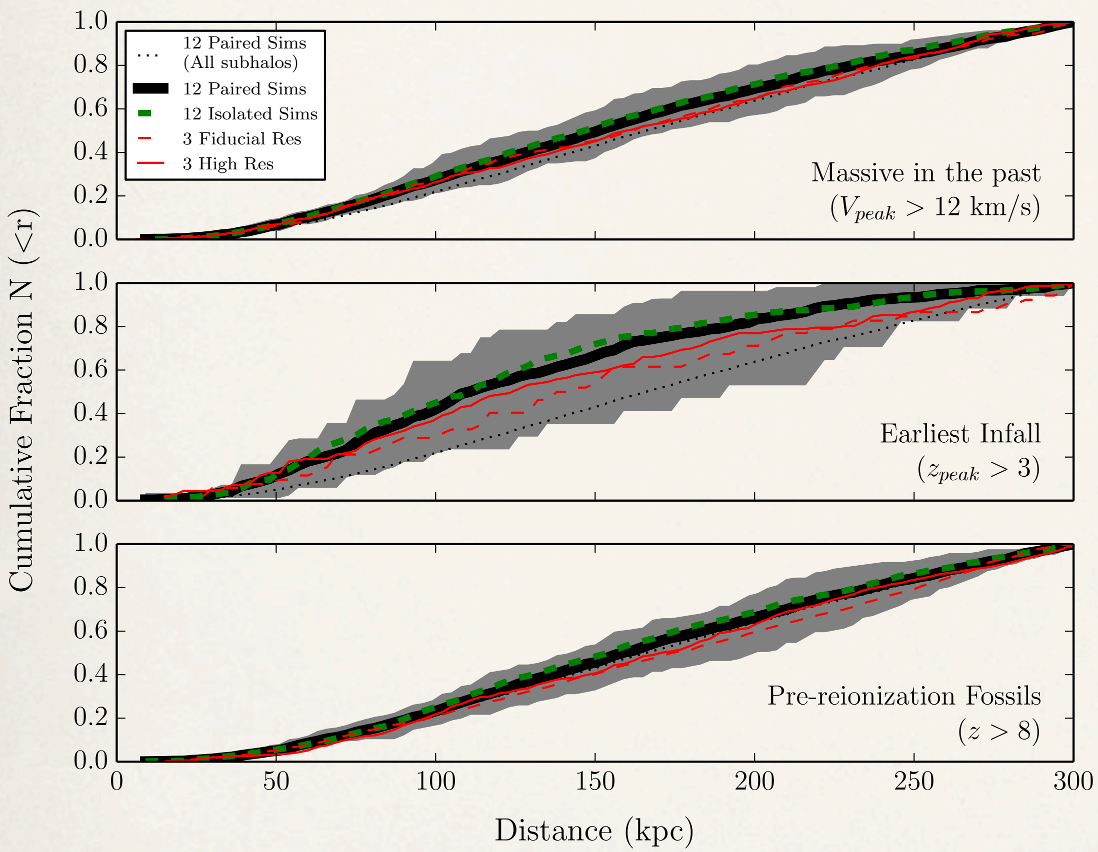
Predicting the number and spatial distribution of Milky Way dwarfs with ELVIS

- 12 MW / M31 analogs: halo-to-halo scatter, paired vs. isolated; azimuthal variation
- updated detection limits
- separate treatment of L < 10^3 L_{Sun} dwarfs
- consider a range of point source depths for DES and LSST



Hargis et al. 2014

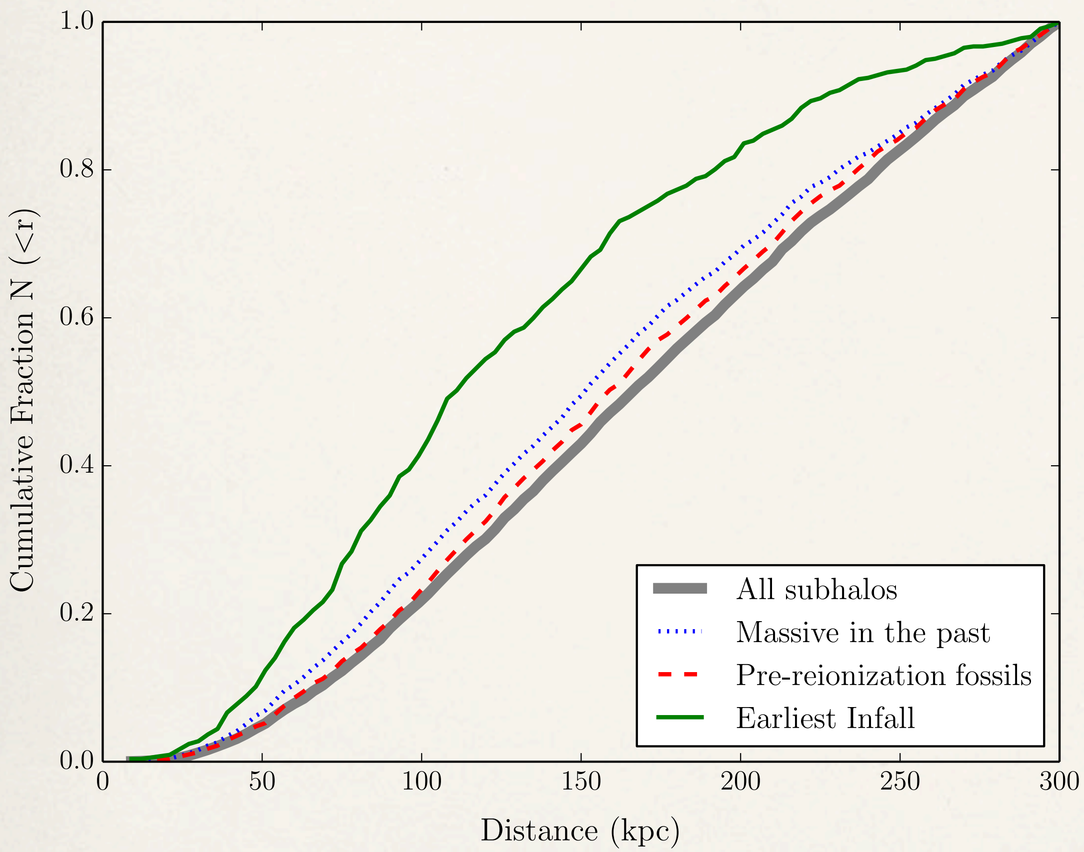
Toy model + subhalos = assumed spatial distribution



- paired and isolated simulations have the same radial distributions
- high-res and fiducial res sims are also the same
- large halo-to-halo variation in early infall model

Hargis et al. 2014

Toy model + subhalos = assumed spatial distribution



- early infall and reionization models may be distinguishable by radial distribution of dwarfs

- early infall models yield lower total numbers of dwarfs

Hargis et al. 2014

Predicted number of dwarfs at d < 300 kpc

TABLE 2
PREDICTED NUMBER OF DWARF GALAXIES WITHIN $d = 300$ KPC

	All Sky (± 10/90)
$L > 10^3 L_\odot$	
Massive in the past	69^{+19}_{-14}
Pre-reionization Fossils	78^{+36}_{-21}
Earliest Infall	53^{+30}_{-16}
$L < 10^3 L_\odot$	
Massive in the past	477^{+305}_{-185}
Pre-reionization Fossils	485^{+277}_{-246}
Earliest Infall	197^{+145}_{-66}

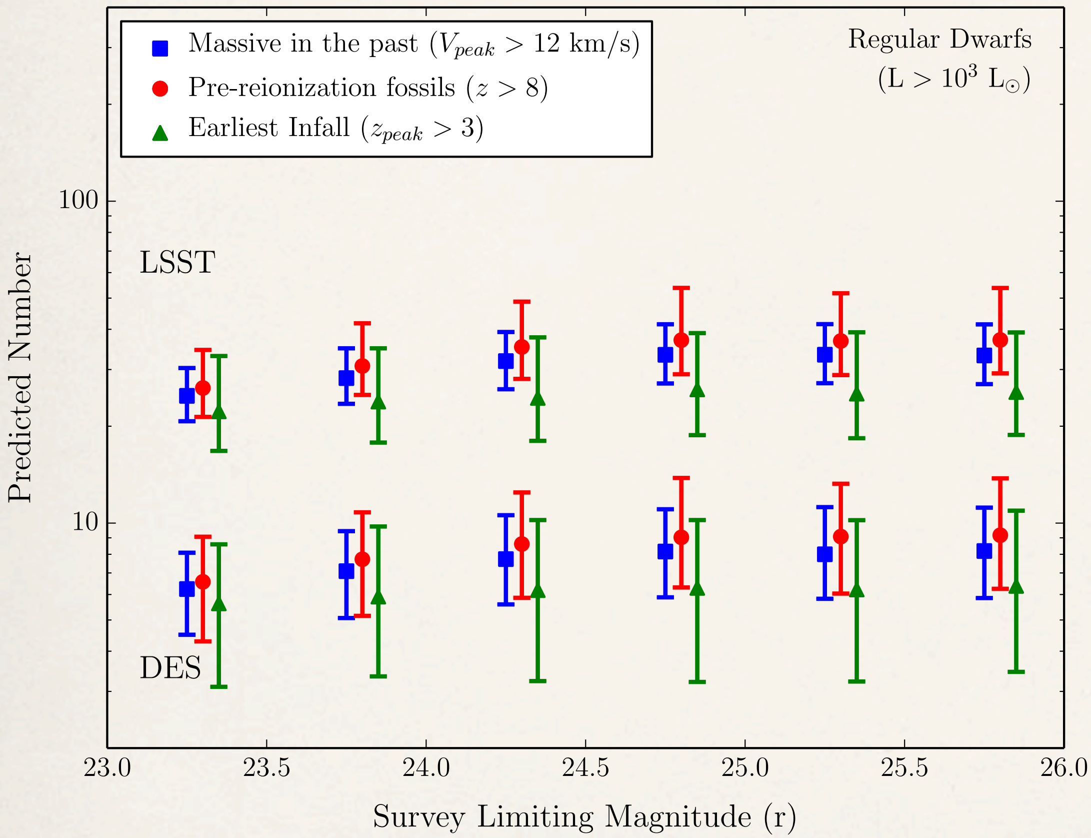
[a]These numbers do not include objects like the "classical" dwarf galaxies.

- 37 - 114 $L > 10^3 L_{Sun}$ dwarfs lower than previous expectations

- 131 - 782 $L < 10^3 L_{Sun}$ dwarfs

Hargis et al. 2014

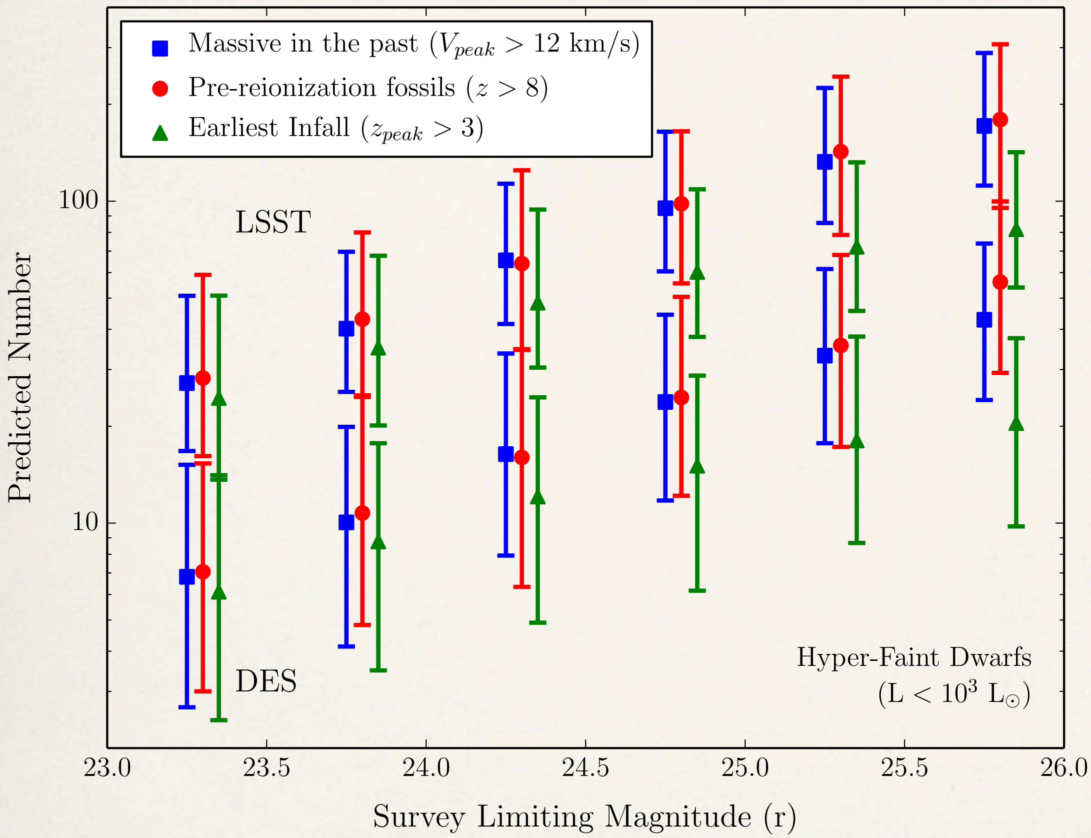
Predicted number of L > 10^3 L_{Sun} dwarfs



- 100 sets of mock surveys per MW analog
- predict for a range of depths - the challenges of star-galaxy separation
- 3-13 in DES, 18-53 in LSST (assuming no latitude bias)

Hargis et al. 2014

Predicted number of L < 10^3 L_{Sun} dwarfs



- averages calculated using azimuthally averaged distribution
- 9 - 99 in DES, 53 - 307 in LSST (assuming no latitude bias)

Hargis et al. 2014

- Revised detection limits and a slowed rate of dwarf detections yield smaller expected N_{dwarfs}
- An enormous range of N_{dwarfs} is consistent with expectations from toy galaxy formation + LCDM models.
- Radial distribution of dwarfs may discriminate between basic models (e.g. early infall v. reionization supression)
- DES and LSST should easily recover $L > 10^3\ L_{Sun}$ dwarfs within their footprints (many assumptions go into this statement)