# Search for Ultra-faint Satellite Galaxies in the Milky Way Halo

filtering techniques and first results

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SkyMapper Workshop
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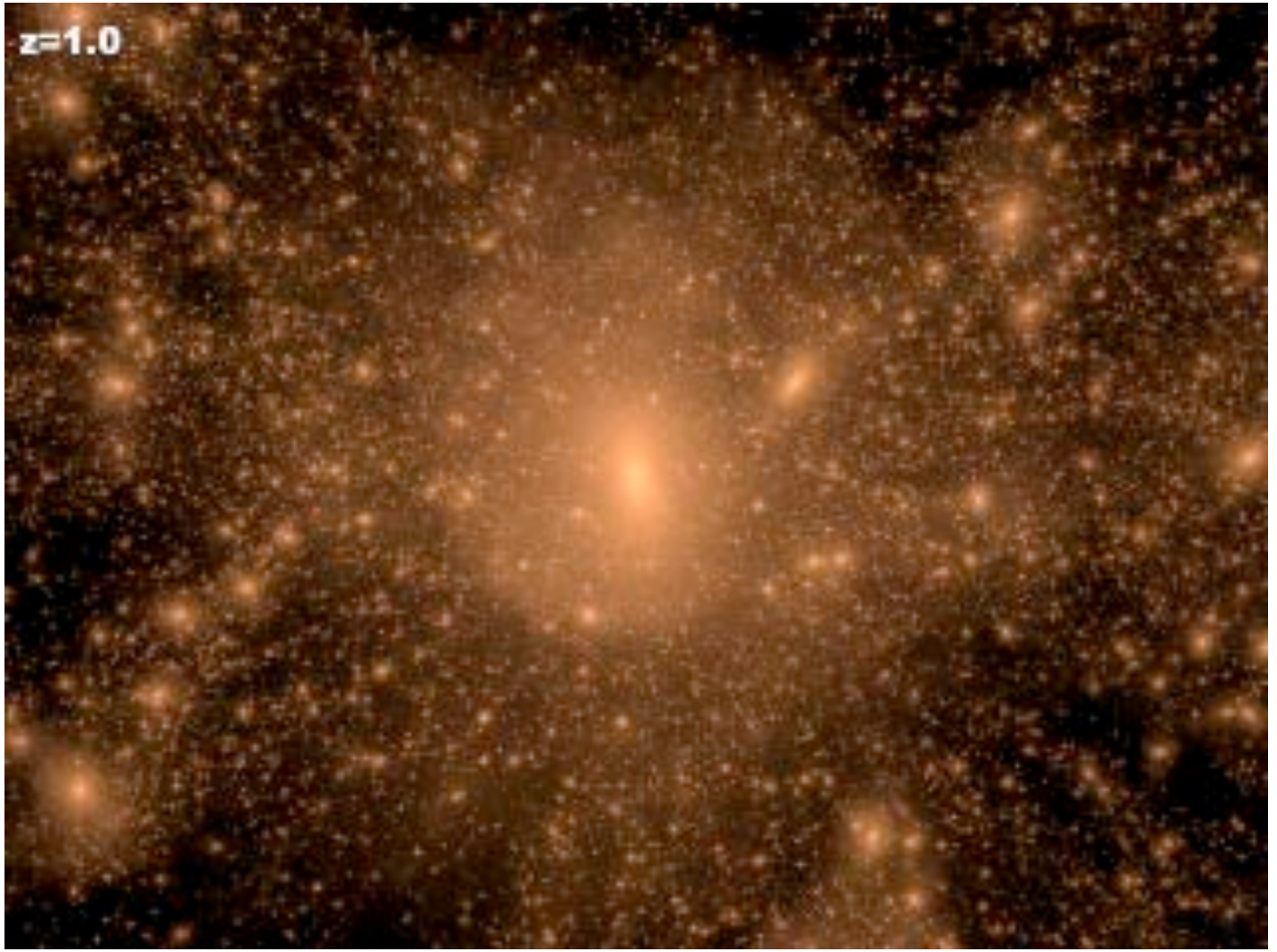
# Cold Dark Matter Simulations of the Milky Way
## (Millennium II or Aquarius project)

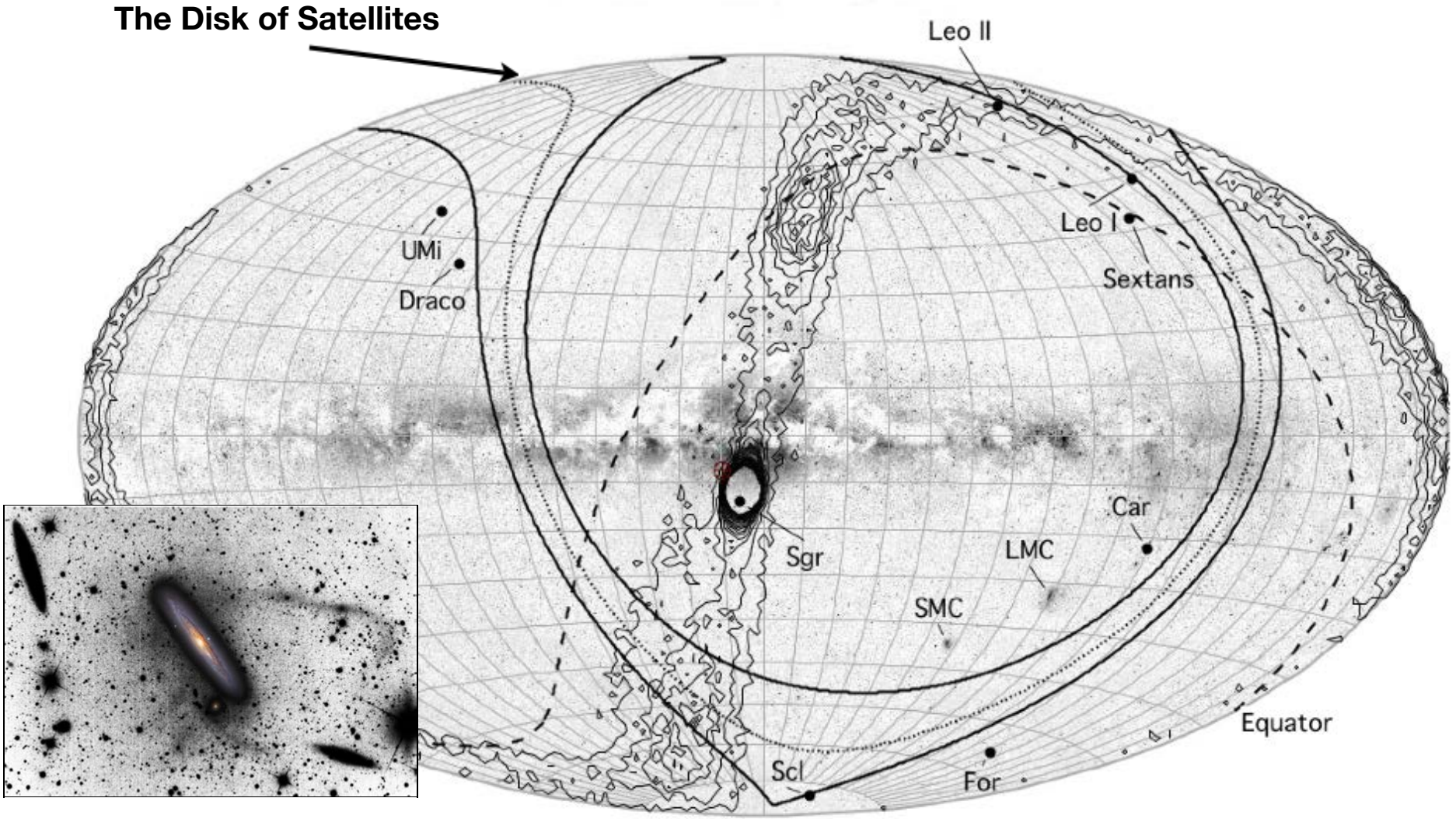



0.5 Mpc

# Cold Dark Matter Simulations of the Milky Way
## (Millennium II or Aquarius project)

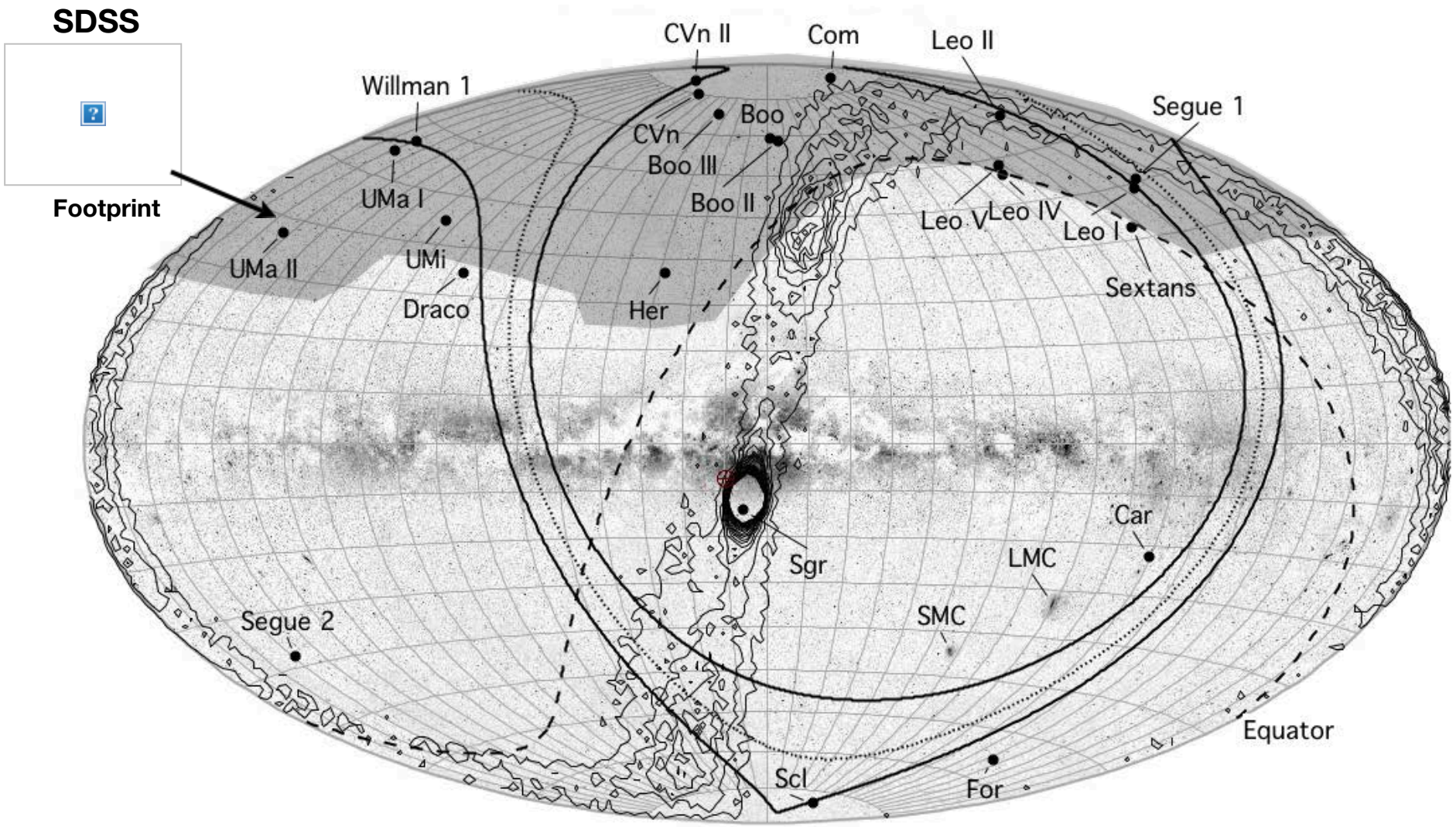
predict ~1000 dark matter subhalos in the MW potential (e.g. Diemand et al. 2006, 2008) distributed spherically symmetric
⇒optical manifestation: **satellite dwarf galaxies**

# Milky Way Satellite Census (2004)



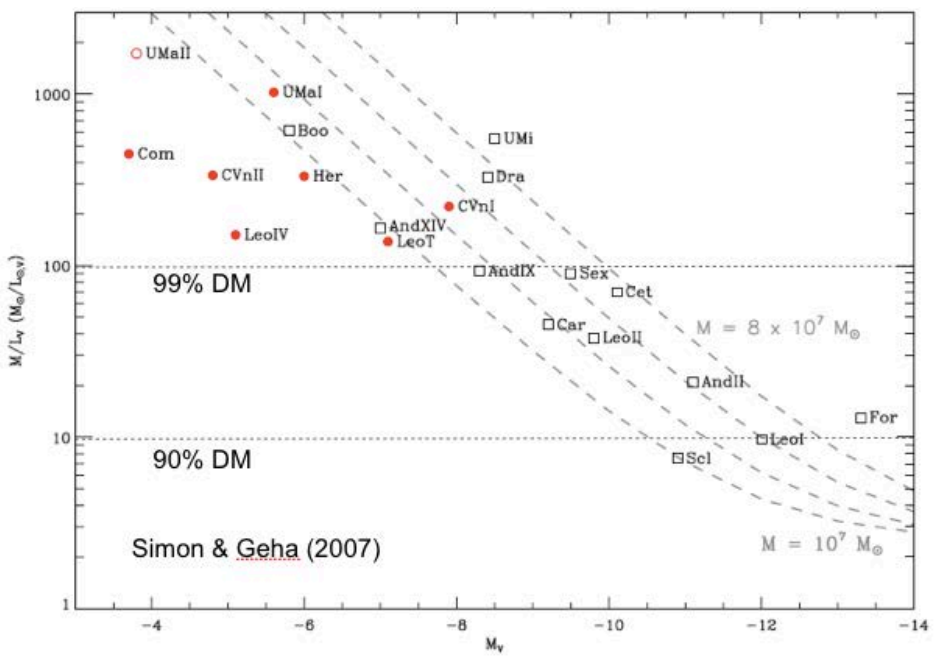

- Only 11 dwarf satellite galaxies known within the gravitational influence of the MW
- 10 satellites are distributed in a common plane (Lynden-Bell 1976; Kroupa et al. 2005; Metz, Kroupa & Jerjen 2007, 2009) -> result of a major merger?

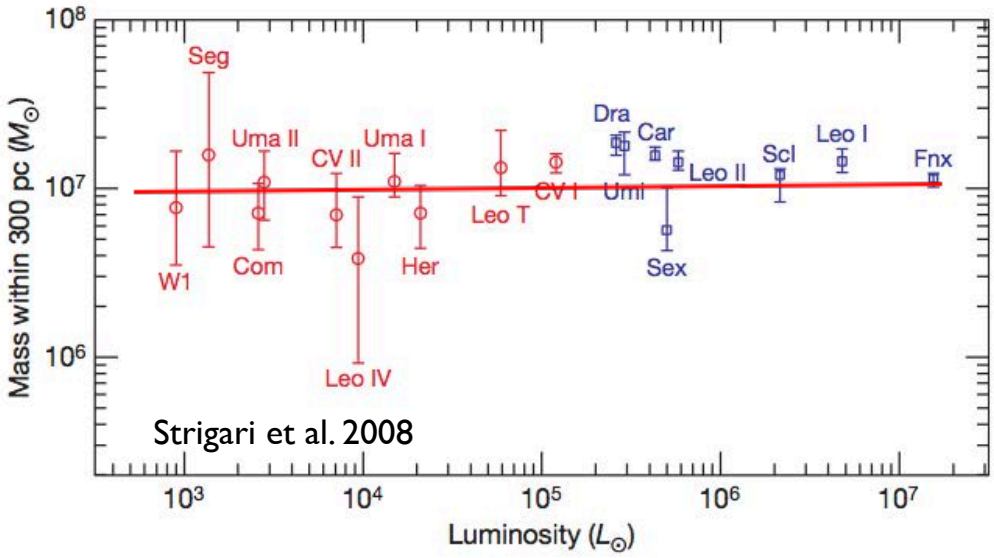
# Known Satellite Galaxies in Milky Way Halo (2014)




2004-10: 14 new Milky Way Satellites discovered out to 250 kpc (-7.9<Mv<-2.7), many consistent with DoS and 9 out the 11 brightest share the same dynamical orbital properties (Metz et al. 2008; Palowski & Kroupa 2013).

# More Results and Open Questions

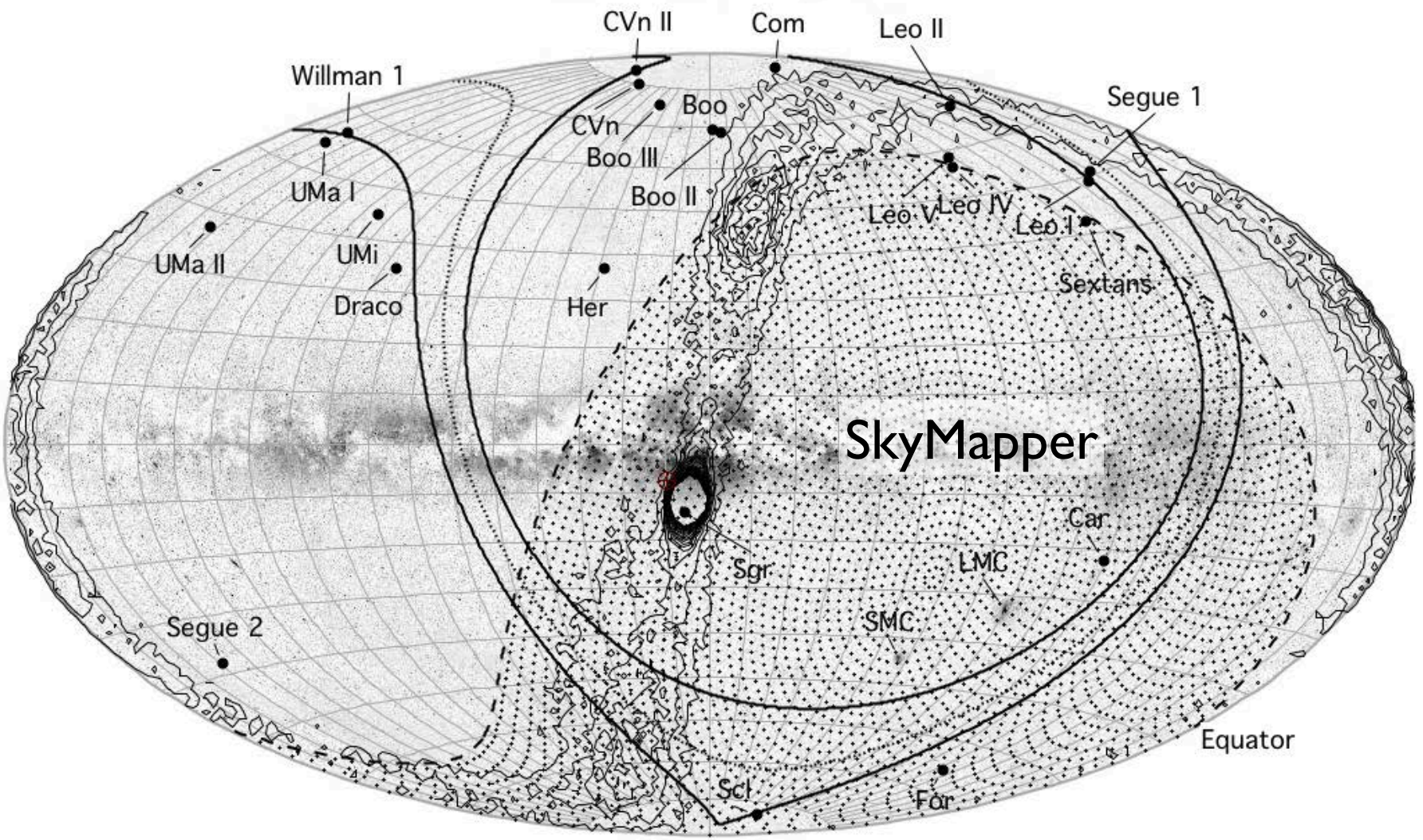



- How many MW satellites are in the southern hemisphere?
- What is their distribution and are there satellite galaxies that do not follow the DoS?
- How much dark matter is in these MW satellite galaxies? (some may not be virialised)
- Are there possibly two different types of satellites (tidal and cosmological origin)?
- Do all MW satellites have the same total mass?
- What is the evolutionary link between satellites and MW?

# The Stromlo Milky Way Satellite Survey

## SkyMapper key project




Search for satellite galaxies to similar depth as SDSS over 20,000 sqr degrees.

# The Stromlo Milky Way Satellite Survey

WEBSITE:
http://msowww.anu.edu.au/~jerjen/SMS_Survey.html

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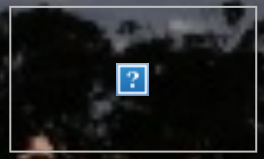

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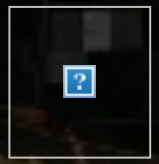

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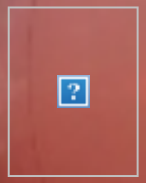

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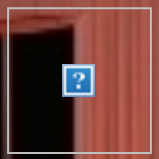
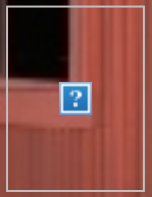


Pavel Kroupa



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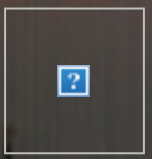
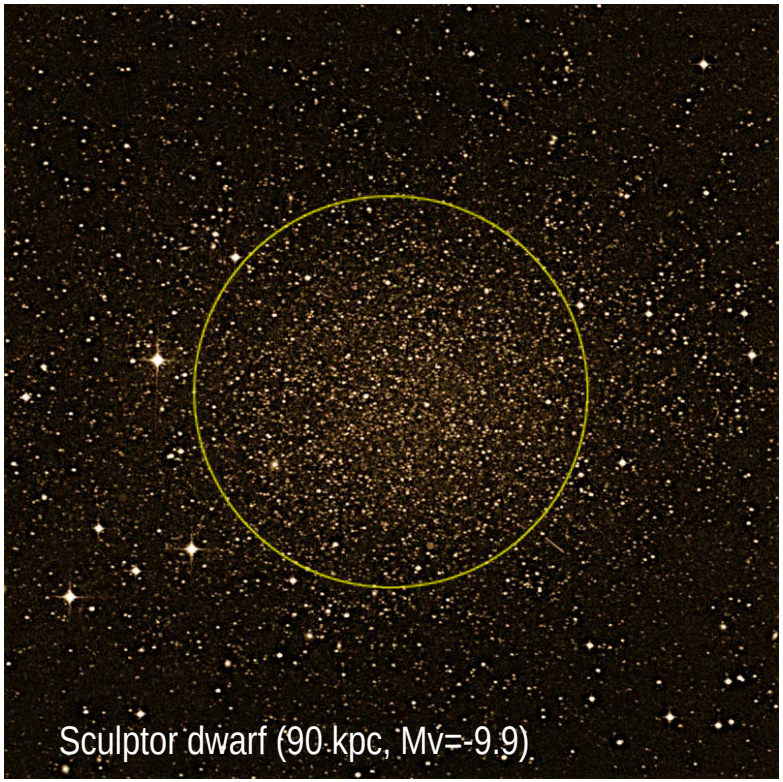
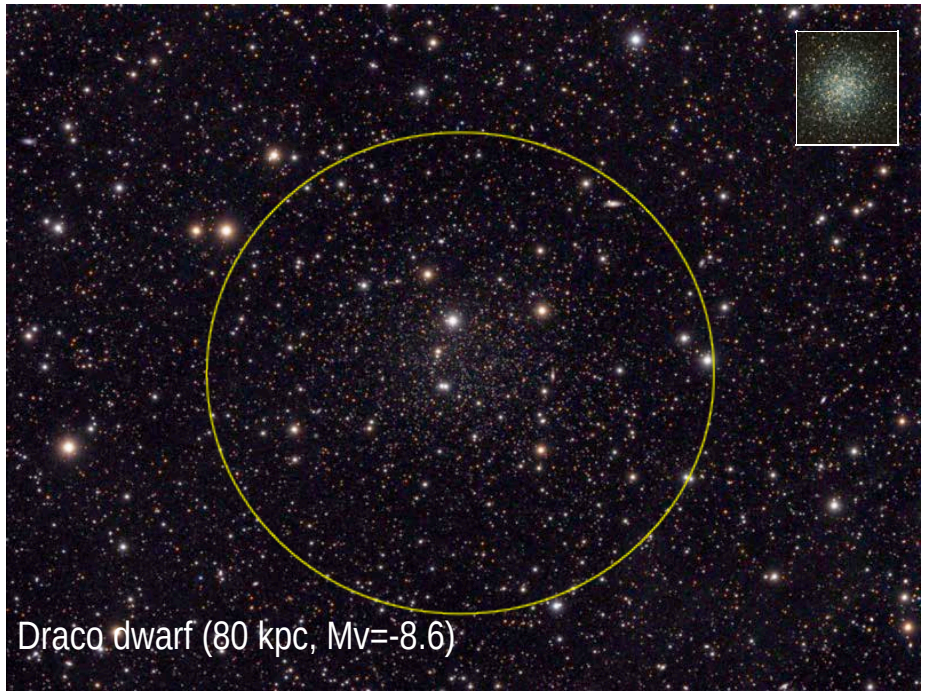


Ed Olszewski

# The Needles in the Haystack
# Ultra-faint MW satellite galaxies



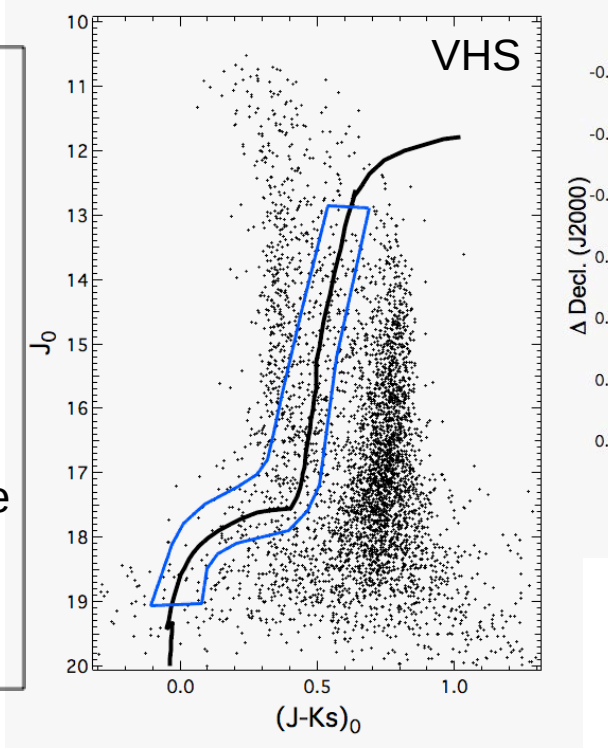



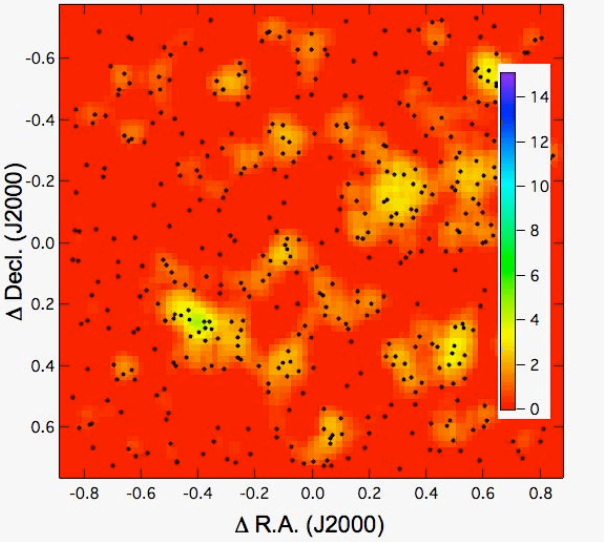

- extreme low star density (resolved into stars)
- no HI gas detected (Grcevich & Putman 2009)
- old (8-10 Gyr), metal-poor (-2.5<[Fe/H]<-1.5) stellar population
- large angular size ($R_h$~10-20')

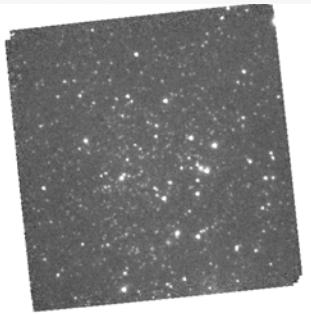
# SMS Survey - Pre-SkyMapper activities

## Development of fast Detection Algorithm

(1) Select a 1 sqr deg field
(2) Generate CMD
(3) Choose model isochrone (e.g. age=10Gyr, [Fe/H]=-2.0, [α,Fe]=0.0)
(4) Select distance
(5) Generate a probability mask (photometric error, age/[Fe/H] variation)
(6) Select stars in mask
(7) Run clustering algorithm to determine S/N of overdensity
(8) Catalog significant overdensities (area and peak S/N)



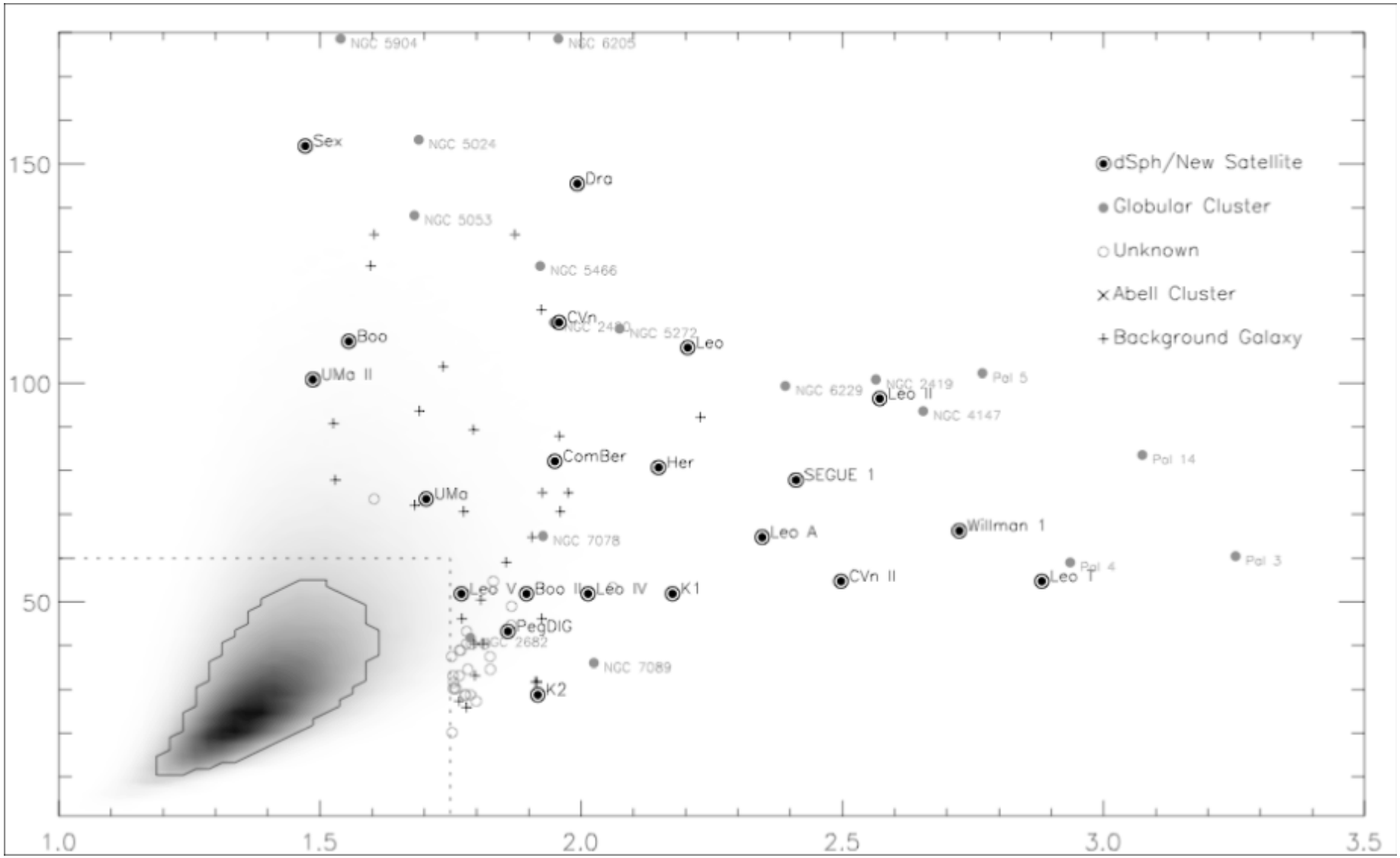



Phoenix dwarf at 440kpc

Conservative estimate: **~20-30 new MW satellites** in Southern hemisphere:
~1 per 700 sqr deg
~1 per 1200 sqr deg within 100kpc
Processing time for SDSS-DR7 on a 12 core machine is a few days.

# All stellar overdensities in SDSS

Walsh, Willman & HJ (2009)

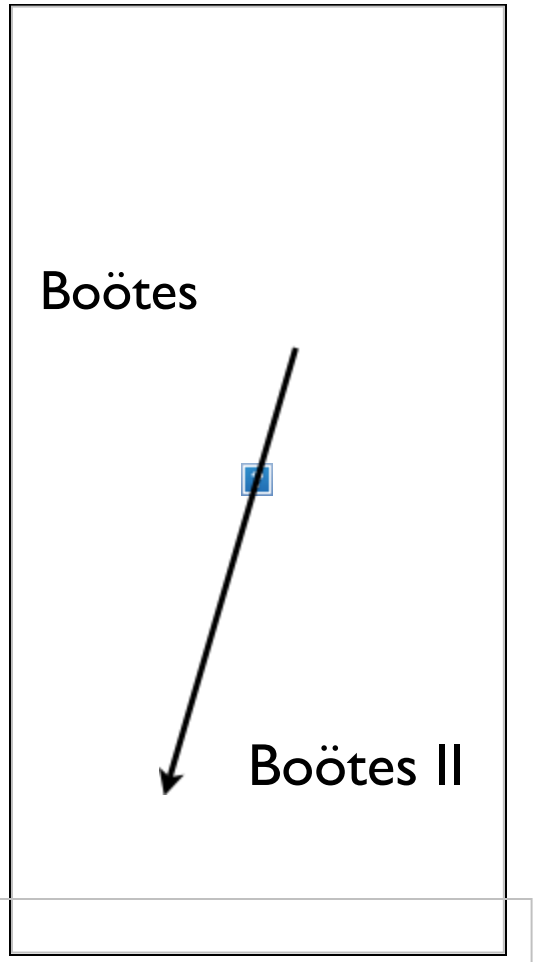


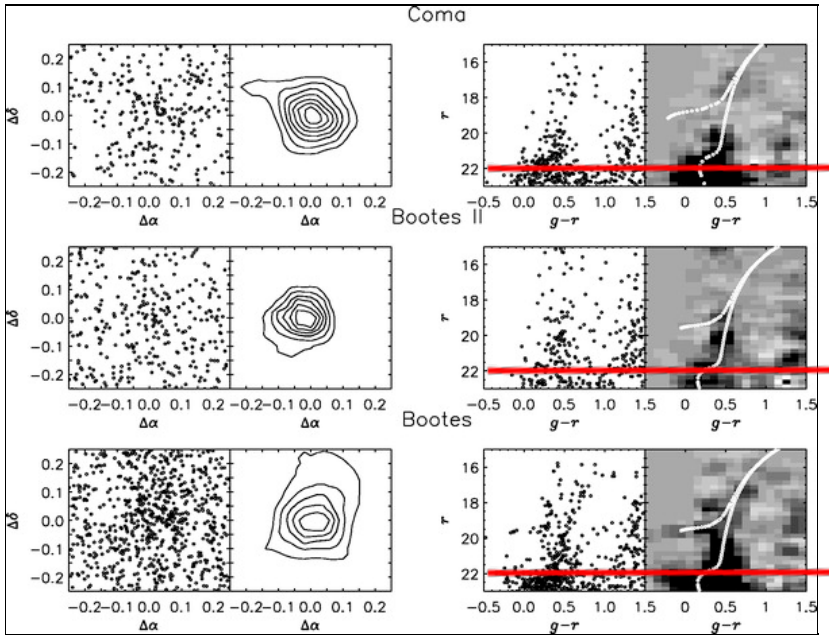

--- at least one false positive detection over DR6

$$max(\sigma)/\sigma_{th} \qquad \sigma_{th} = 1.7\sigma_{fg}$$

# A Pair of Boötes

Walsh et al. (2007, 2008)




Boötes II Properties

| Parameter | Measured | Uncertainty |
|---|---|---|
| R.A. | $13^h58^m05.1^s$ | ±7.2 s |
| Decl. | +12°51′31″ | ±23″ |
| $(l, b)$ | (353.75, 68.86) | ... |
| $(m - M)$ | 18.1 | ±0.06 |
| Distance | 42 kpc | ±1.6 kpc |
| $r_h$ (Plummer) | 2.8′ | ±0.7 |
| | 35 pc | ±9 |
| $r_h$ (exponential) | 2.5′ | ±0.8 |
| | 31 pc | ±10 |
| $M_V$ (Plummer) | −2.3 | ±0.7 |
| $M_V$ (exponential) | −2.2 | ±0.7 |
| $\mu_{0,V}$ (Plummer) | 27.76 mag arcsec$^{-2}$ | ±0.31 |
| $\mu_{0,V}$ (exponential) | 27.70 mag arcsec$^{-2}$ | ±0.33 |
| $r_c$ | 25 pc | ±9 |
| $r_t$ | 127 pc | ±35 |
| $\theta$ | −33° | ±57° |
| $\epsilon$ | 0.27 | ±0.15 |

# SMS collaboration - Pre-SkyMapper results

- Development of data mining algorithms to search for stellar overdensities in star catalogues (Walsh et al. 2009).
- Discovery of the satellite Bootes II (Mv=-2.25) (Walsh et al. 2007, 2008).
- No more satellites in the SDSS footprint detected (Jerjen et al. 2013; Laevens et al. 2013).
- Other less significant overdensities in SDSS are stellar hotspots in tidal streams.
- Virgo overdensity region is dominated by Sgr dwarf MS stars (Jerjen et al. 2013)
- Two satellite candidates in the VHS data (Honours thesis Dongwon Kim). Follow-up in progress.
- Comparative study of stellar populations in GCs and satellite galaxies (Milone et al. 2013a, b, c; 2014)

# Stromlo Milky Way Satellite Survey

http://msowww.anu.edu.au/~jerjen/SMS_Survey.html

(1) Search for new MW dwarf satellite candidates (stellar concentrations and tidally disrupted streams) with sophisticated data mining algorithms over the entire Southern hemisphere with SkyMapper. About 20 satellites predicted by SDSS stats. Can start as soon as data are available.

(2) Imaging follow-up program (HST, Magellan, Blanco), to confirm the nature of the dwarf candidates, measure accurate 3D distance, SFH, [Fe/H], age.

(3) IRS follow-up program (AAT, Magellan) to study the stellar kinematics, radial velocity profiles, infer the dark matter content of the systems, testing universal mass hypothesis.

(4) HRS (Keck, VLT, Magellan) to measure Fe and $\alpha$ elements (Mg, Ti, O, Si,..) to constrain the star formation efficiency, and compare them with the abundance pattern of the MW components to address the building block scenario.

(5) Testing LCDM cosmology predictions using the radial velocity profiles, observed spatial distribution and luminosity function of a highly complete sample of MW satellites down to $M_V \sim -5$ mag, including detection limits.