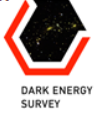
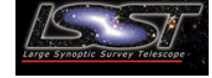




Texas A&M University Department of Physics and Astronomy is an institutional member of:



Collaborator: **Jennifer Marshall**, Kathryn Johnston, Allyson Sheffield, Steve Majewski, Keith Bechtol, Alex Drlica-Wagner, Eduardo Balbinot, Basilio Santiago, Brian Yanny, and MANY in DES Milky Way group

Exploring Milky Way Halo Substructures from Large-Area Sky Surveys

Ting Li

Department of Physics and Astronomy
Texas A&M University

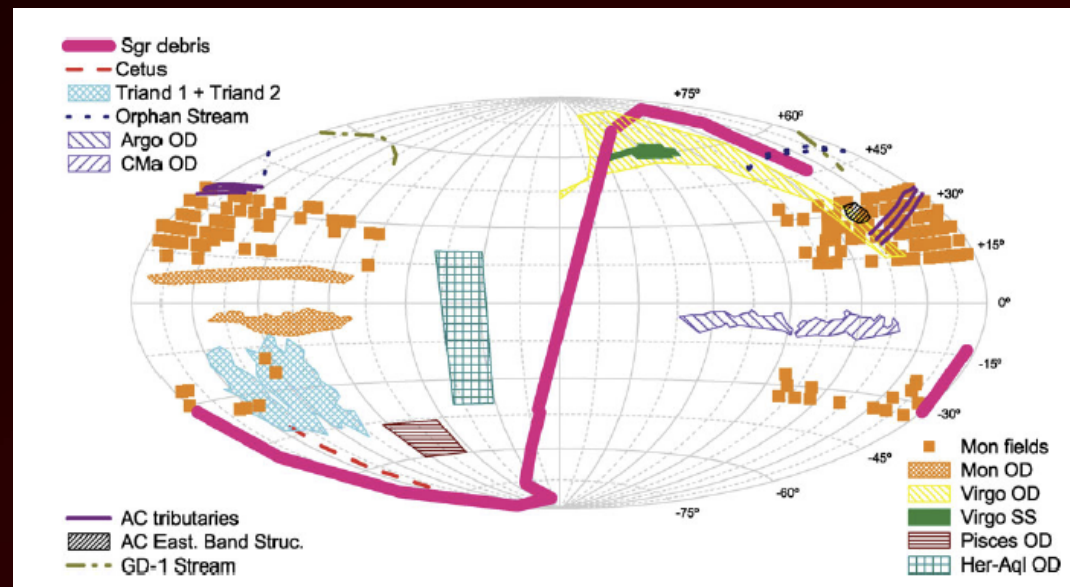
DECam Community Science Workshop

March 12, 2015

Halo Substructure

- Large-area sky surveys: SDSS, 2MASS....

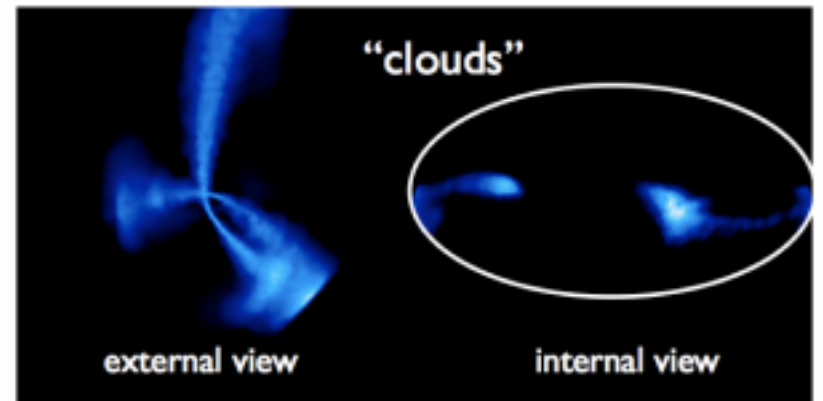
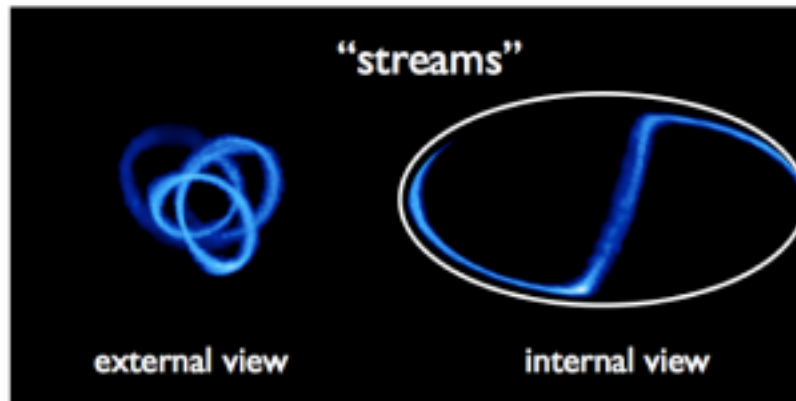
Rocha-Pinto 2010



Milky Way Halo is complicated!

Morphology of Tidal Debris

- Stellar Debris Streams: mildly eccentric orbit
- Stellar Debris Clouds: highly eccentric orbit



Johnston et al. 2008

Need more data to support the theory!

- Most substructures were found through visual inspection
- EnLink (Sharma & Johnston 2009)
 - density-based group finder
 - objective analysis
 - irregular structures
 - good for large data set
- applied on a catalog of M-giants from 2MASS

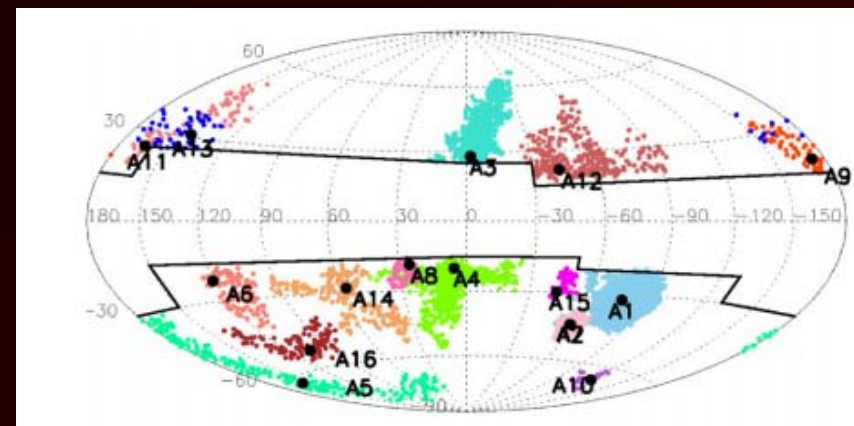
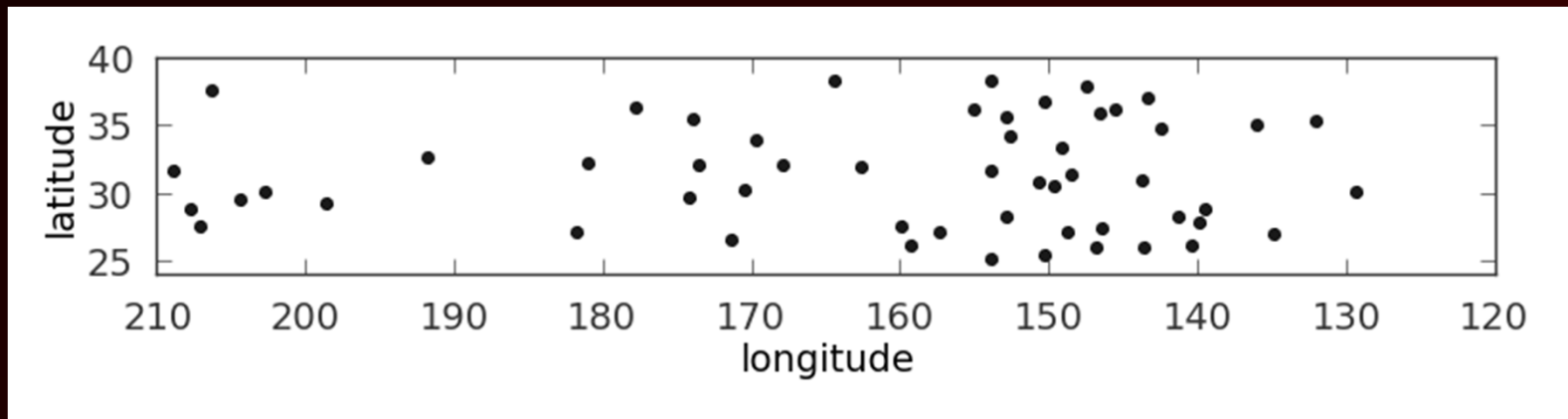


Table 2
Summary of Groups Found in the 2MASS M-giant Sample

Name	Description	l	b	N_{stars}	Sig S	ρ_{peak} (kpc)	Distance ^a
A1	LMC	282.865	-32.231	49234	52.9	2.7×10^4	60.1 ± 30
A2	SMC	301.823	-43.925	4001	33.4	3.0×10^4	64.0 ± 32
A3	Sag leading arm, north	358.130	27.985	3245	27.5	6.5×10^1	63.1 ± 32
A4	Sag core	5.51100	-20.053	1460	24.4	1.8×10^3	37.2 ± 19
A5	Sag trailing arm, south	157.190	-62.682	226	4.82	1.0×10^1	37.2 ± 19
A6	Andromeda	120.819	-22.212	117	4.49	6.5	122.0 ± 61^b
A7	Group in SMC	302.436	-43.837	83	5.13	1.7×10^4	48.6 ± 24
A8	NGC 6822	25.393	-18.378	78	4.74	1.5×10^1	92.6 ± 46
A9	Sag trailing arm, south	187.953	19.882	64	4.54	2.9	96.6 ± 48
A10	Fornax dwarf Sph	238.091	-65.798	39	7.58	7.3	121.3 ± 60
A11	Near mask	164.086	24.992	79	5.18	3.4	88.2 ± 44
A12	Probably Monoceros Ring	317.865	21.908	307	5.40	7.5	21.8 ± 11
A13	Near mask	143.738	30.936	54	3.93	2.1	22.6 ± 11
A14	Has protrusions to high b	56.9910	-27.865	203	5.23	8.9	97.7 ± 48
A15	Near a strong extinction region	316.906	-29.868	76	4.99	2.7×10^1	98.6 ± 49
A16	In Pisces constellation	104.793	-52.535	126	6.25	9.9	102.9 ± 51

Sample – A₁₃

- 54 stars (M giants)
- Ks: 10-11 mag (V~14-15 mag)
- J-Ks: 0.97 – 1.11
- Distance 22.6 ± 11 kpc (based on $[\text{Fe}/\text{H}] \sim -1$)

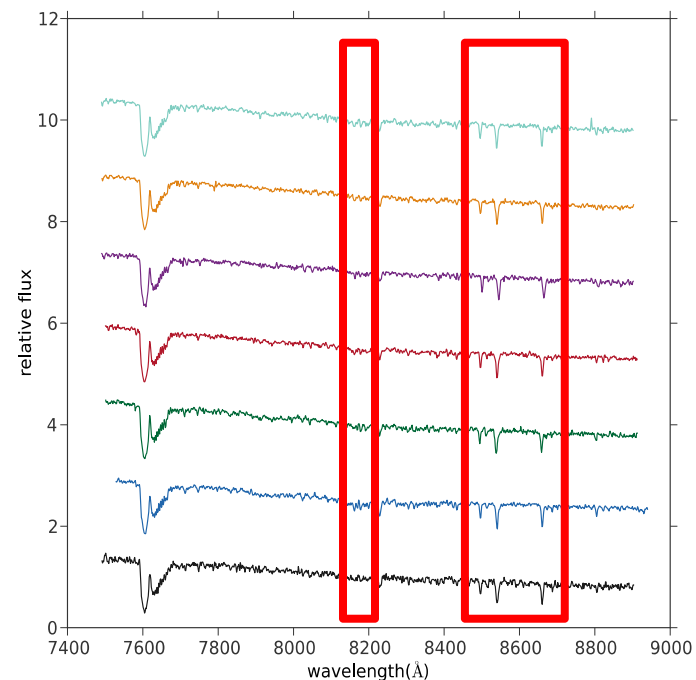


Observations

- Obtained spectra for all 54 stars
- 7500-8900 Å
- $R \sim 2,000$
- Na I doublet 8183Å, 8195Å -- dwarf/giant
- Ca II triplet -- [Fe/H]
- RV precision ~ 5 -10 km/s

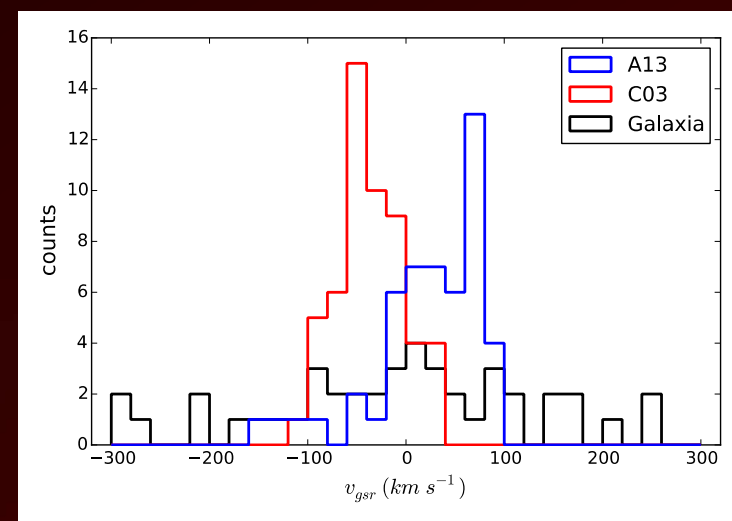
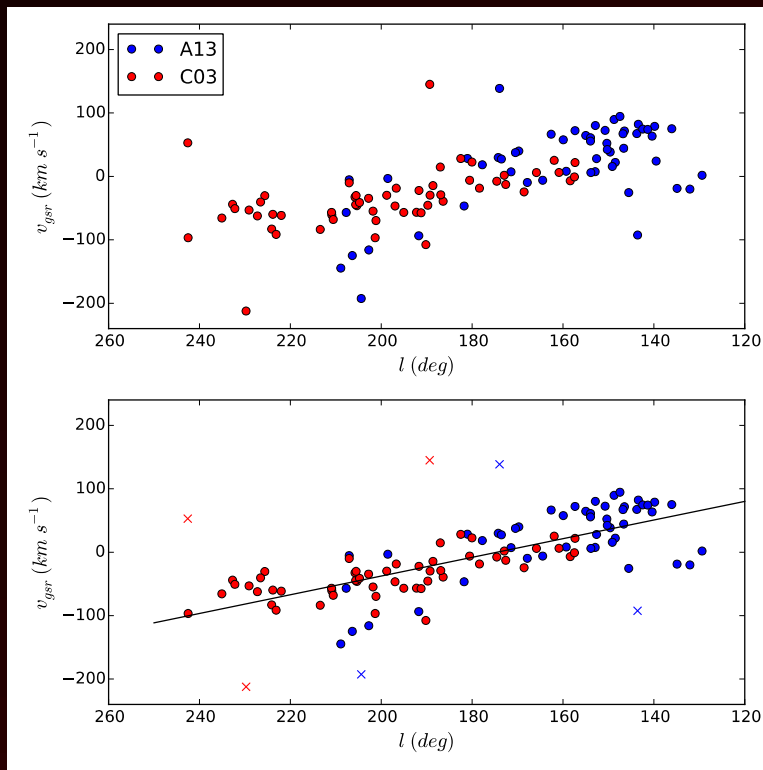
Table 1. Summary of Observing Runs

UT	Telescope	Spectrograph
2011 Nov 10	Hiltner 2.4 m	Modspec
2011 Nov 15-20	KPNO 2.1 m	Goldcam
2012 Nov 28-30	McDonald 2.1 m	ES2
2012 Oct 27-29	Hiltner 2.4 m	Modspec
2014 Jan 09-12	McDonald 2.1 m	ES2



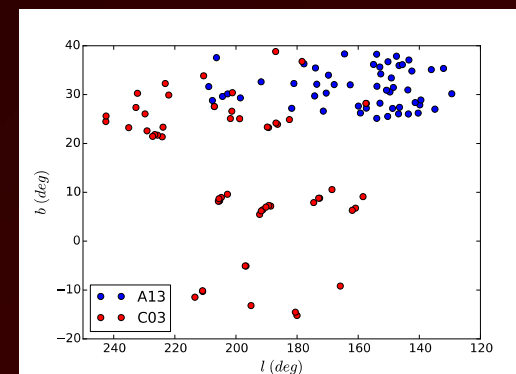
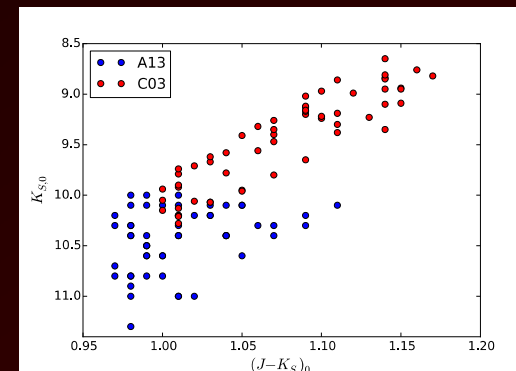
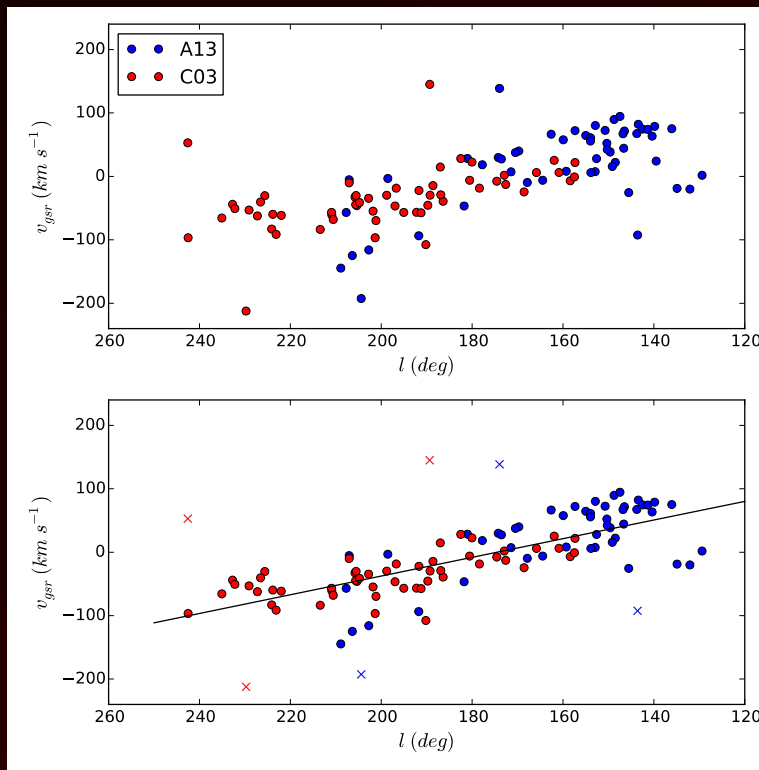
Results

- V_{gsr} very close to what Crane et al. 2003 (C03) found at the Galactic anticenter,
- Velocity dispersion $\sim 33 \text{ km/s}$, much smaller compared to dispersion in a mock galaxy (Galaxia; Sharma et al. 2011)
- $[\text{Fe}/\text{H}] \sim -0.4$ (quite enriched population), distance $\sim 10 \text{ kpc}$ from the Sun
- Velocity dispersion also very close to TriAnd (Sheffield et al. 2014)



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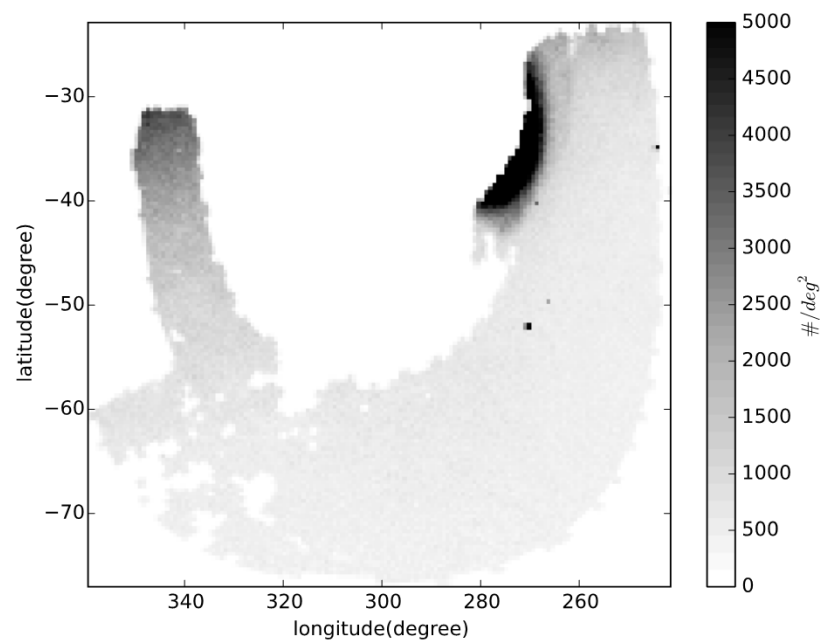
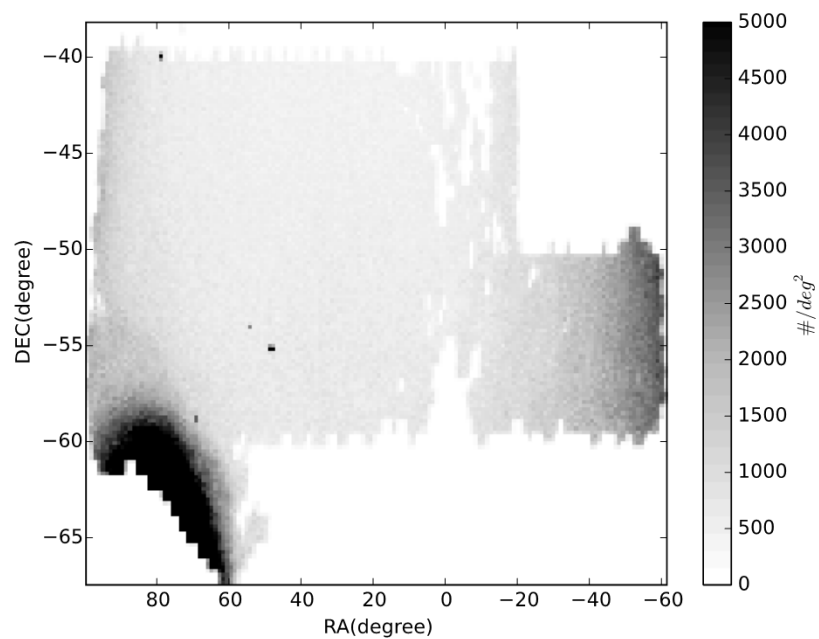
a cut of
 $K_S > 10$
 $b > 25$
in
Sharma
et al. 2010

Summary for Spectroscopic follow-up

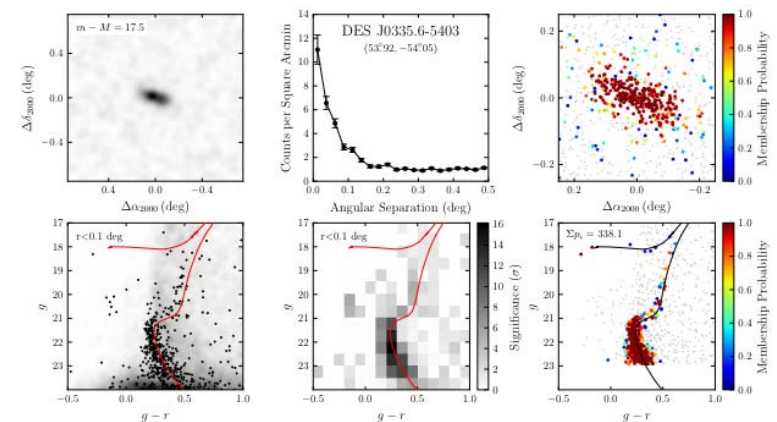
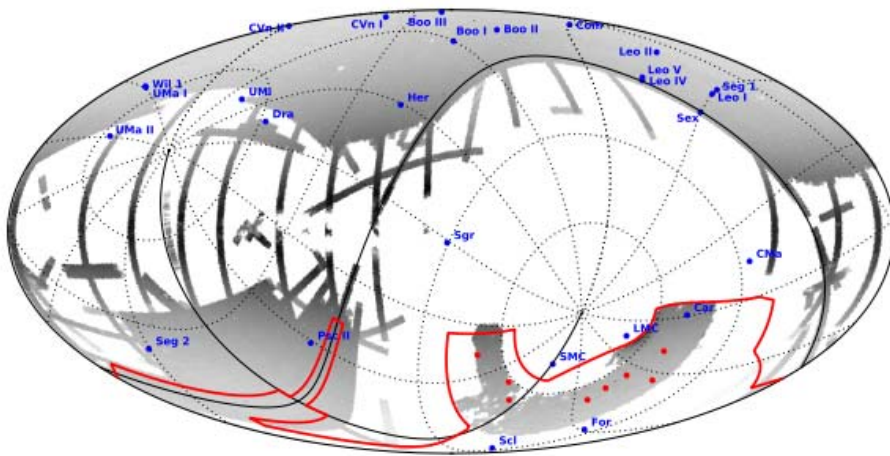
- A overdensity structure found by an objective group finding algorithm
- Confirmed additional members in stellar structure found by Crane et al. 2003 at the Galactic anticenter , over 100 stars in total.
- Velocity dispersion $\sim 33\text{km/s}$. (24km/s with 2.5 sigma clipping)
- $[\text{Fe}/\text{H}] \sim -0.4$ (quite enriched population), distance ~ 10 kpc from the Sun
- Part of the Monoceros Ring/Galactic Anticenter Stellar Stream
 - accreting dwarf galaxy
 - Galactic warp, disk oscillation Xu et al. 2015
- Group finder found more members that missed by visual inspection

Dark Energy Survey!

- Year 1 data release (Y1A1 catalog)



8 new satellite candidate from Y1A1!



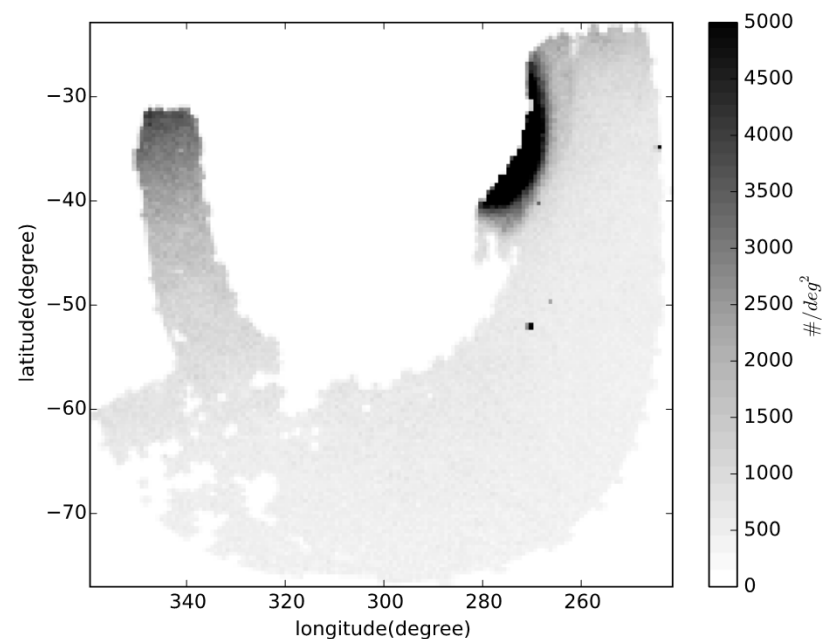
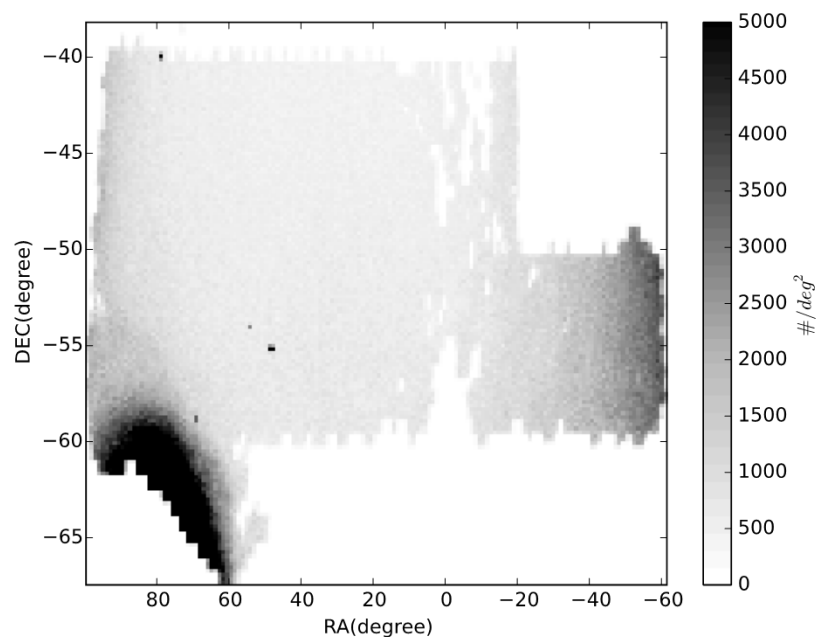
Available on arXiv this week!
Bechtol et al. 2015
arXiv: 1503.02584

Table 1. Detection of new satellite galaxy candidates in DES Y1A1

Name	α_{2000} (deg)	δ_{2000} (deg)	$m - M$	Map Sig (σ)	TS Scan	TS Fit	r_h (deg)	ϵ	ϕ (deg)	Σp_i
DES J0335.6-5403 (Ret II)	53.92	-54.05	17.5	24.6	1466	1713	$0.10^{+0.01}_{-0.01}$	$0.6^{+0.1}_{-0.2}$	72^{+7}_{-7}	338.1
DES J0344.3-4331 (Eri II)	56.09	-43.53	22.6	23.0	322	512	$0.03^{+0.01}_{-0.01}$	$0.19^{+0.16}_{-0.16}$	90^{+30}_{-30}	96.9
DES J2251.2-5836 (Tuc II)	343.06	-58.57	18.8	6.4	129	167	$0.12^{+0.03}_{-0.03}$	—	—	114.9
DES J0255.4-5406 (Hor I)	43.87	-54.11	19.7	8.2	55	81	$0.04^{+0.05}_{-0.05}$	—	—	30.6
DES J2108.8-5109 (Ind I)	317.20	-51.16	19.2	5.5	—	75	$0.010^{+0.002}_{-0.002}$	—	—	26.6
DES J0443.8-5017 (Pic I)	70.95	-50.28	20.5	7.1	—	63	$0.02^{+0.01}_{-0.01}$	—	—	19.1
DES J2339.9-5424 (Phe II)	354.99	-54.41	19.9	5.1	—	61	$0.02^{+0.01}_{-0.01}$	—	—	19.4
DES J0222.7-5217 (Eri III)	35.69	-52.28	19.9	5.4	—	57	$0.007^{+0.005}_{-0.003}$	—	—	8.9

Dark Energy Survey!

- Year 1 data release (Y1A1 catalog)
- Look for more stellar streams and stellar clouds!
- Visual inspection + group finding algorithm



Thanks for your attention
and
Questions?