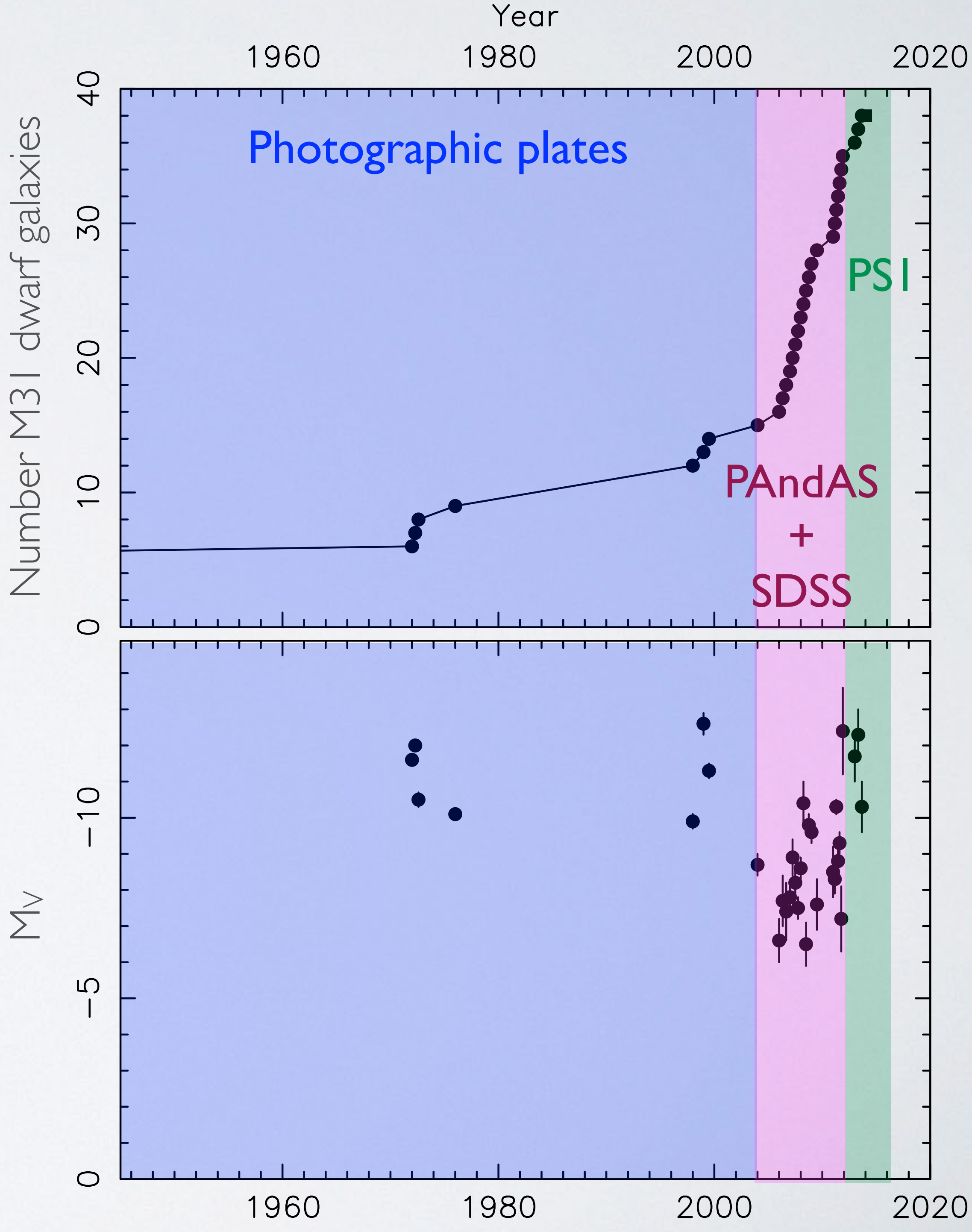
The PAndAS and PS1 views of the M31 satellite system

Observatoire astronomique de Strasbourg



Nicolas Martin

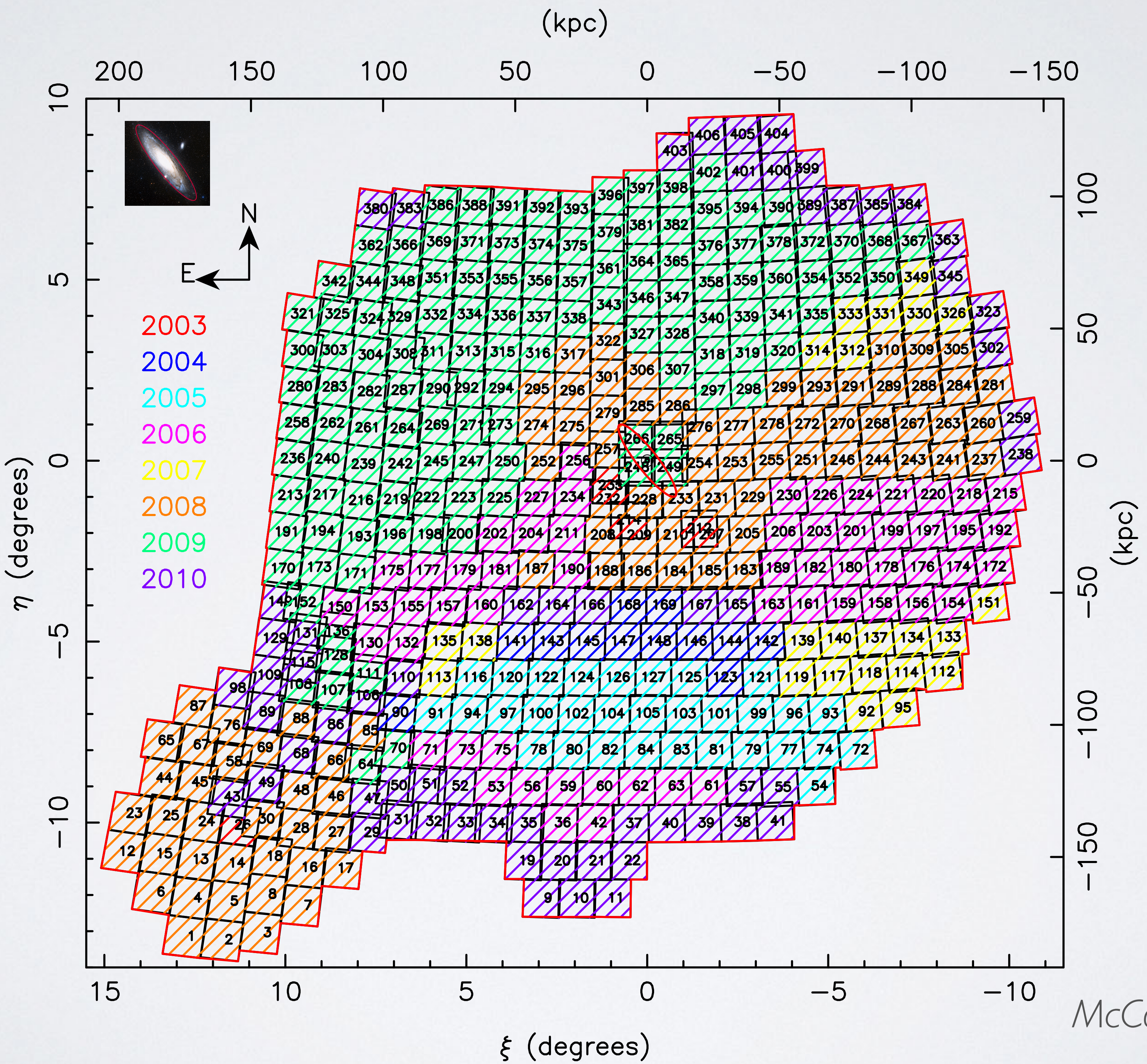
(Strasbourg Observatory & MPIA, Heidelberg)

and the PAndAS &
Local Group Pan-STARRS1 teams

@nfmartin1980

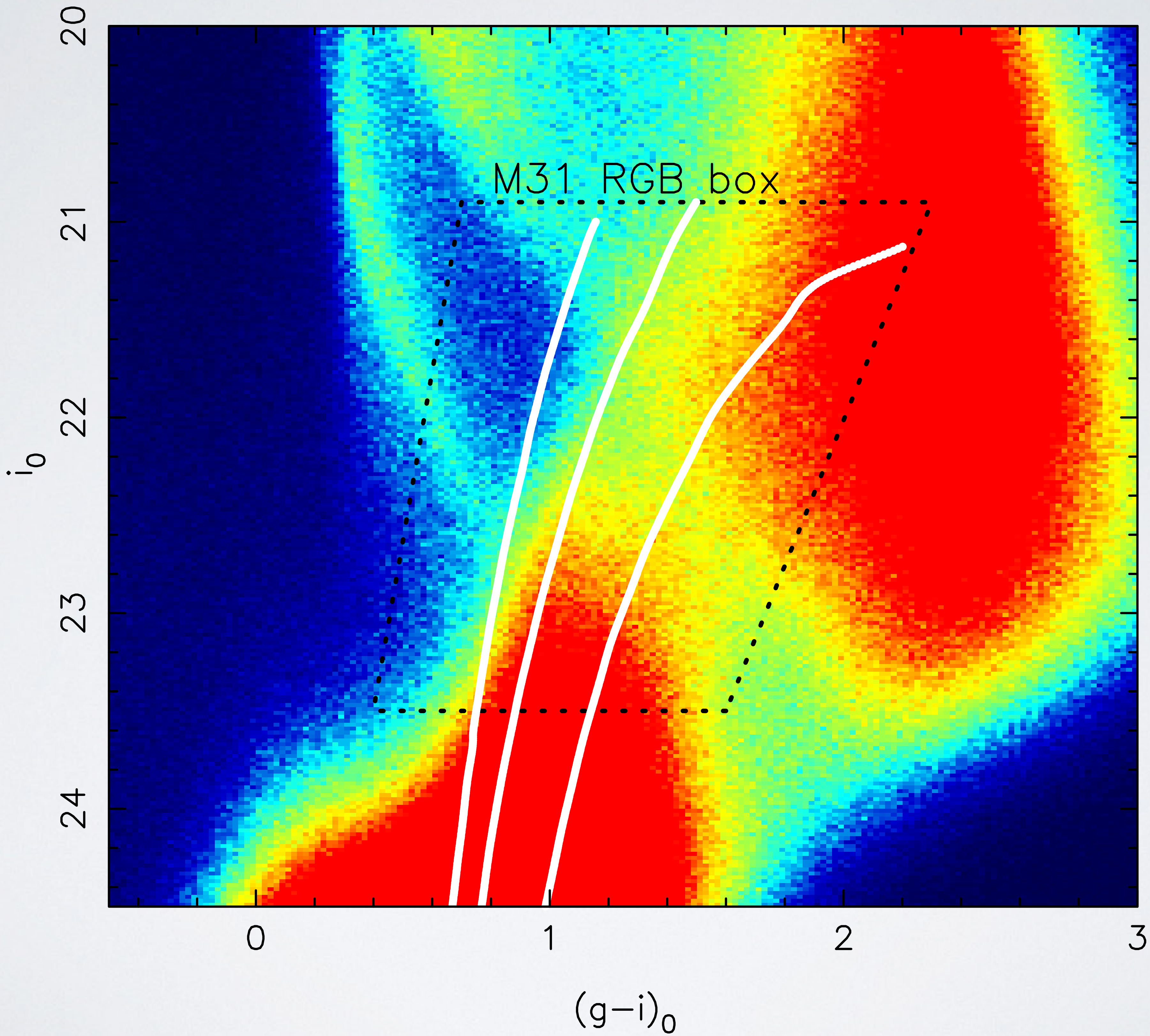
PAndAS

The Pan-Andromeda Archaeological Survey (2008–2011)



McConnachie et al. (2009)
Ibata et al. (2014)

The PAndAS CMD



The PAndAS (MW) Field of Streams

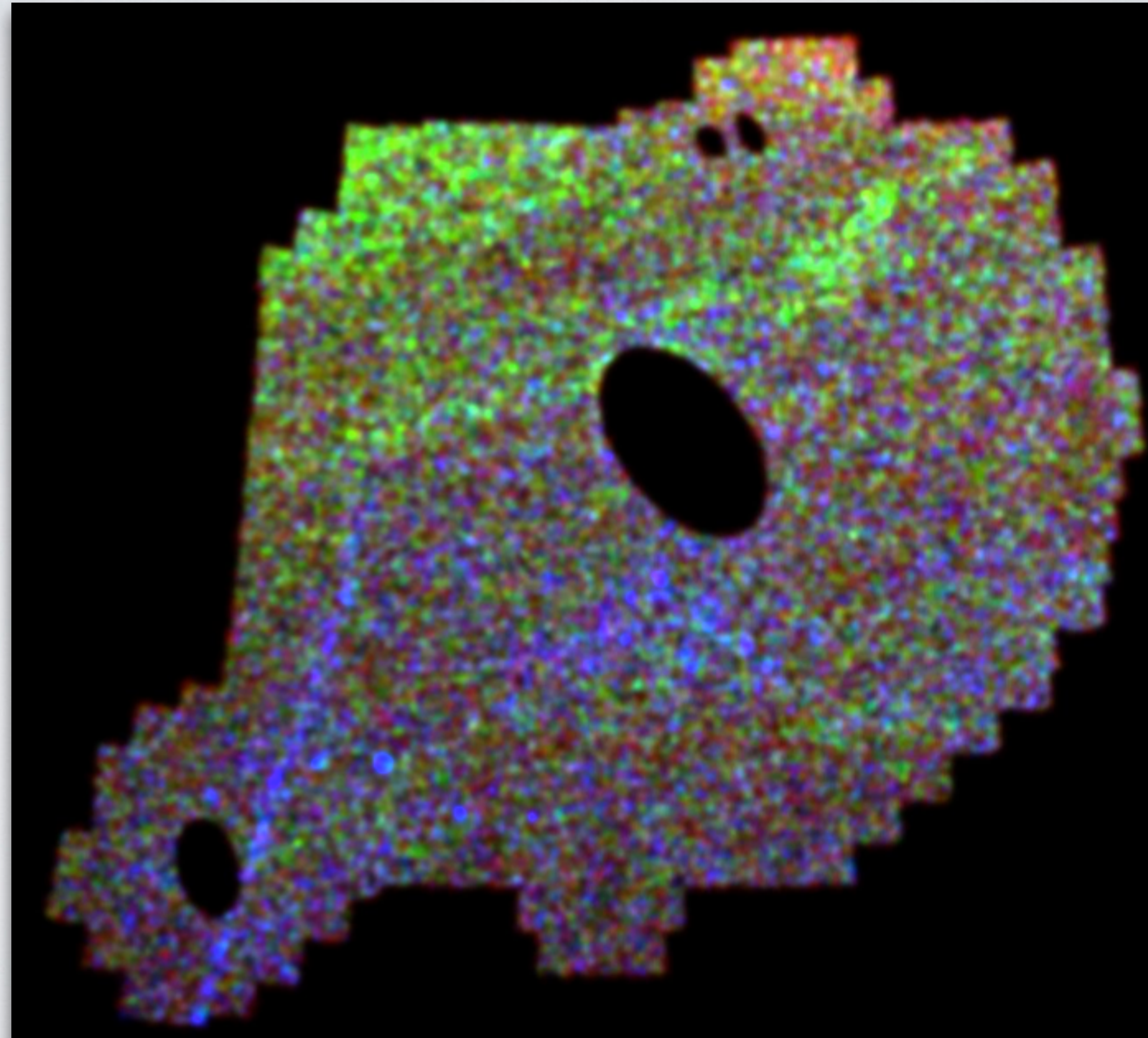
Martin et al. (2014a)

***D**Sun*

~11 kpc

~17 kpc

~27 kpc



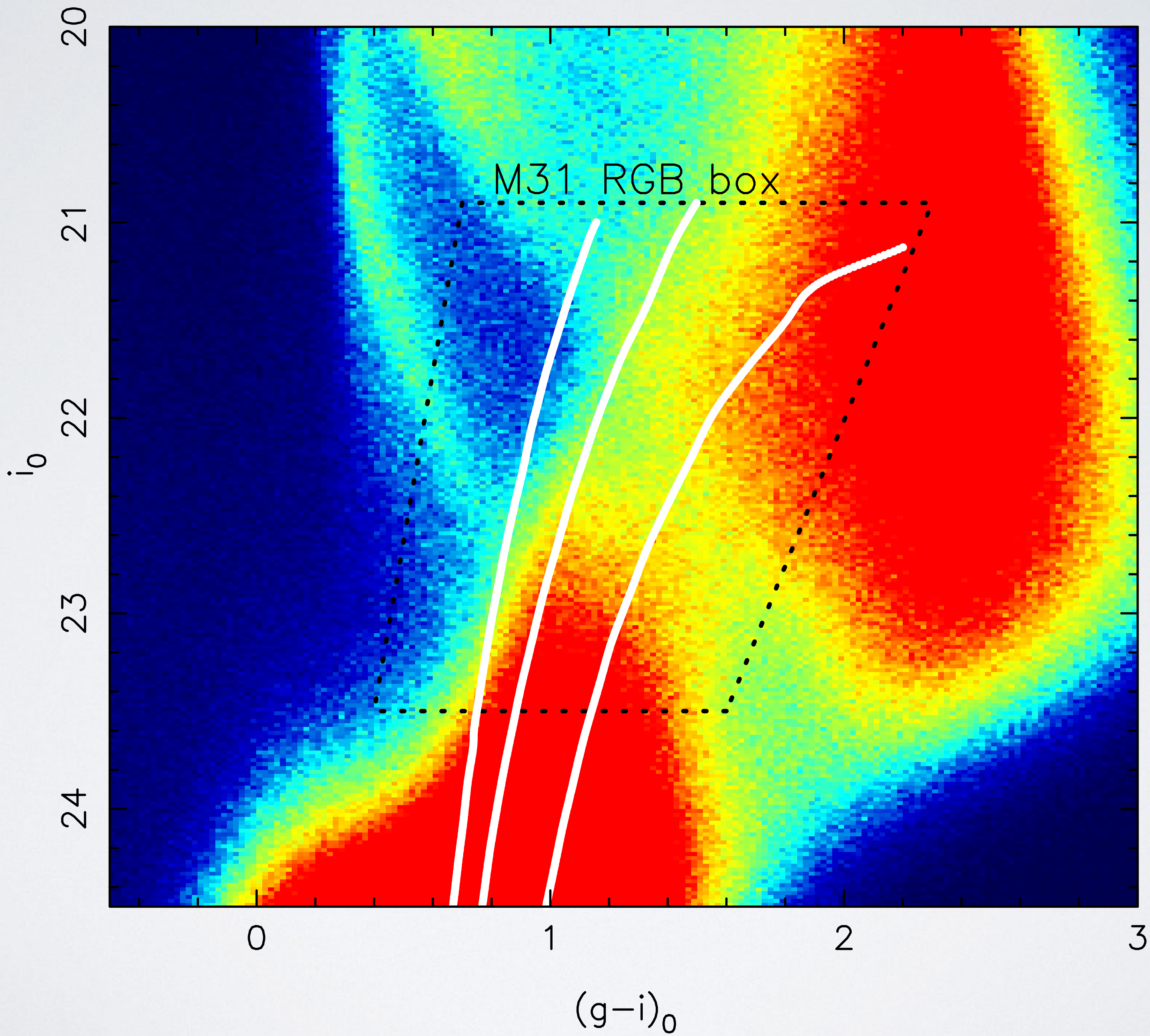
***D**GC*

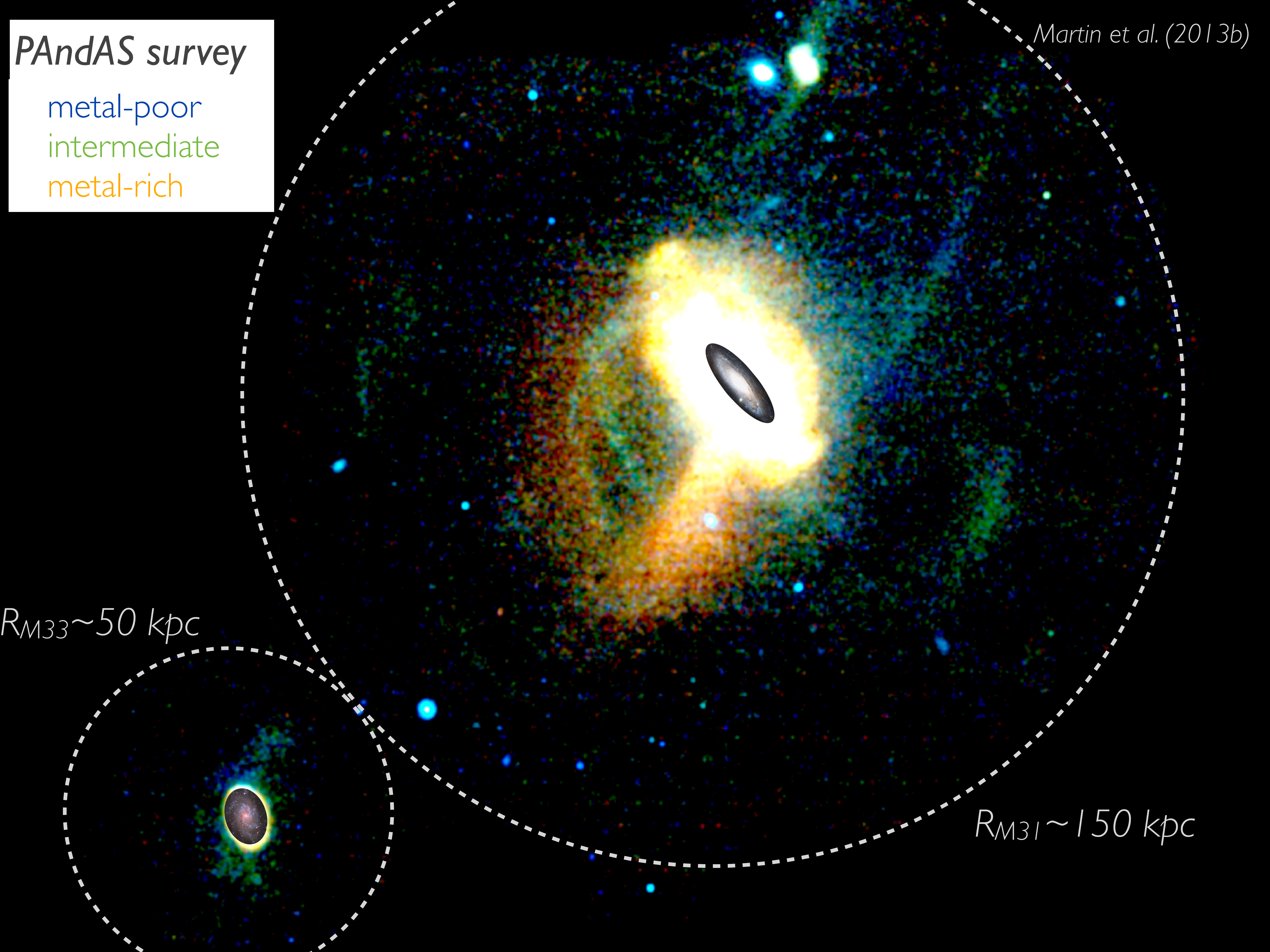
~17 kpc

~22 kpc

~32 kpc

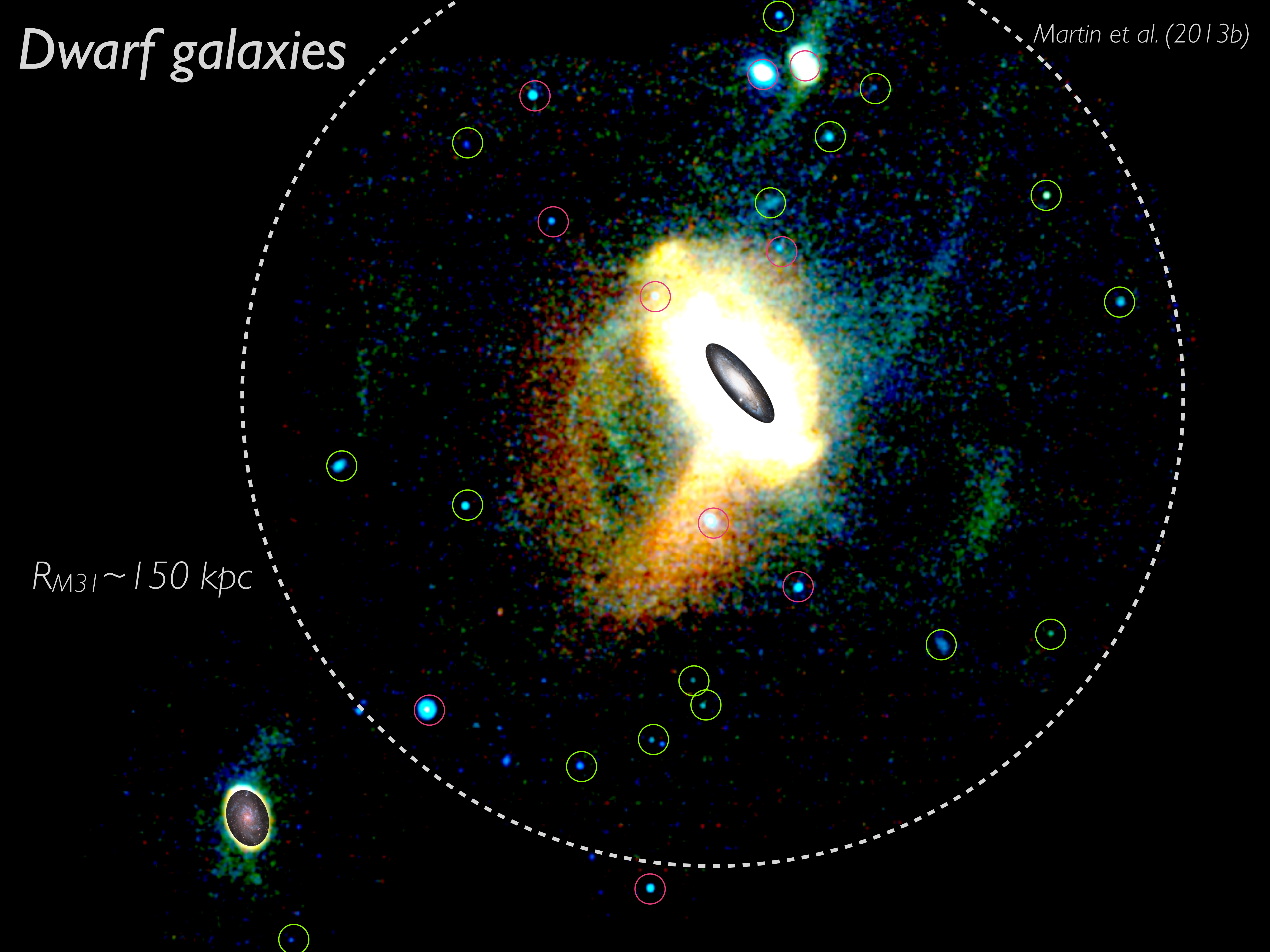
The PAndAS CMD





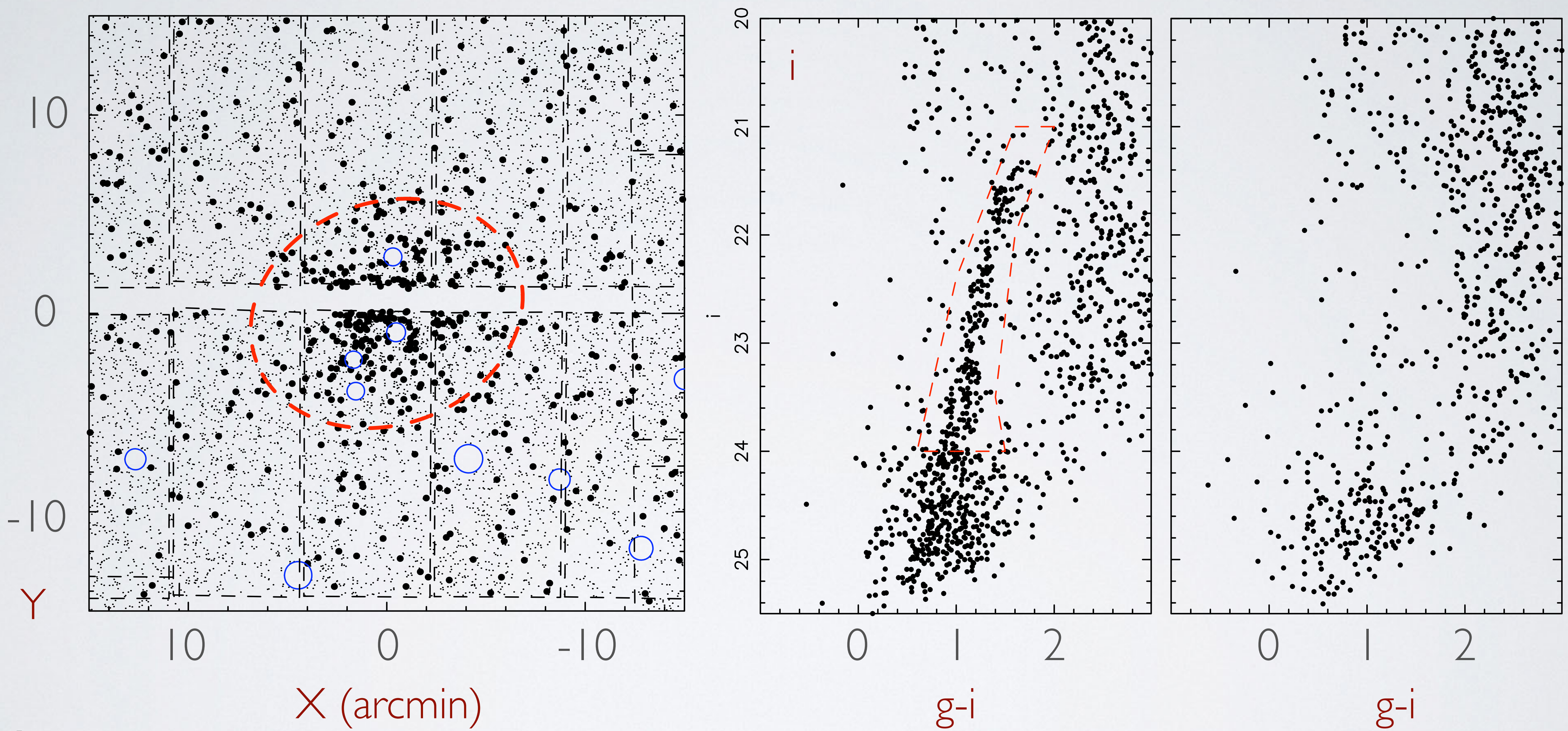
PAndAS survey
metal-poor
intermediate
metal-rich
Martin et al. (2013b)
R_{M33}~50 kpc
R_{M31}~150 kpc

Dwarf galaxies



Two examples in PAndAS

Martin et al. (2009)



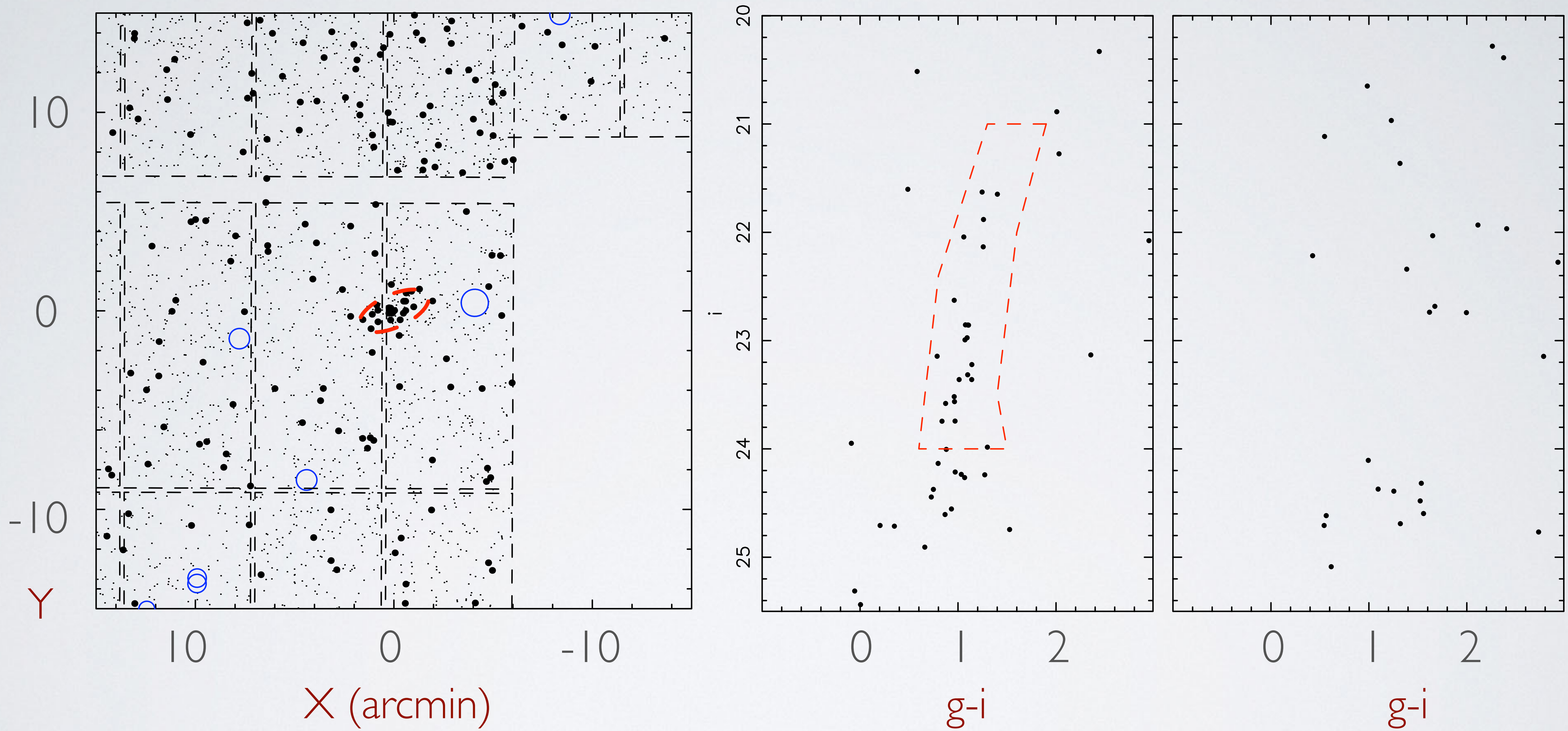
And XXI

$M_V = -9.9 \pm 0.6$

$r_h = 990 \pm 160$ pc

Two examples in PAndAS

Martin et al. (2009)



And XXII

$M_V = -6.5 \pm 0.8$

$r_h = 230 \pm 80$ pc

Automating the dwarf galaxies search

Martin et al. (2013b)

- Automated search:
  - $M_V > -6.5$ candidate dwarf galaxies
  - completeness function as f(X,Y,r_h,[Fe/H],m-M,…)
  - → *to "observe" simulations*

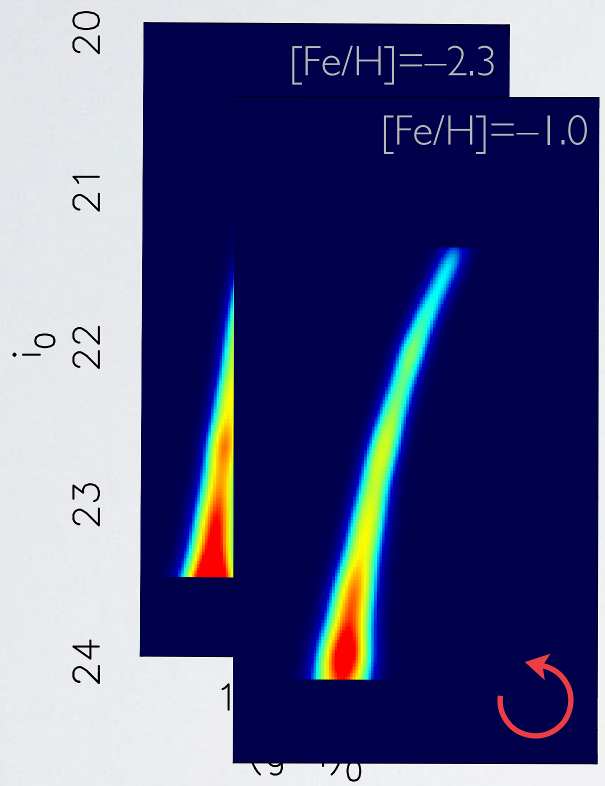
- Full statistical analysis of ***spatial + CMD information***
  - Accounting for varying ***MW*** foreground contamination, very structured ***M31*** "contamination"

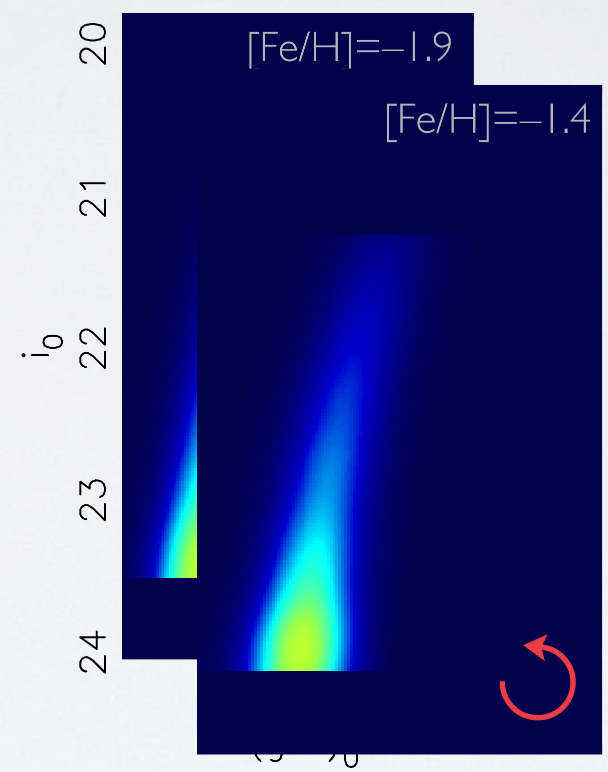
Automating the dwarf galaxies search

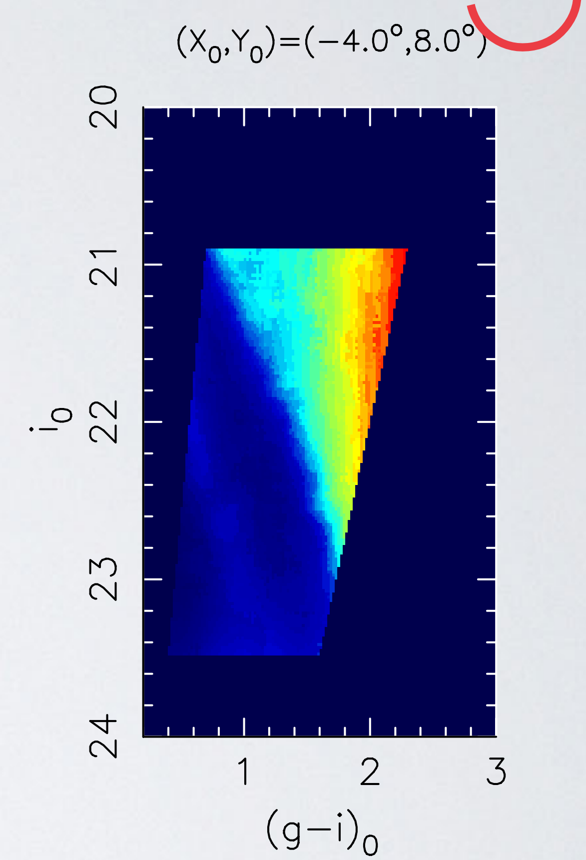
For every location in PAndAS

Martin et al. (2013b)

N_{dwarf} + N_{M31} + N_{cont}



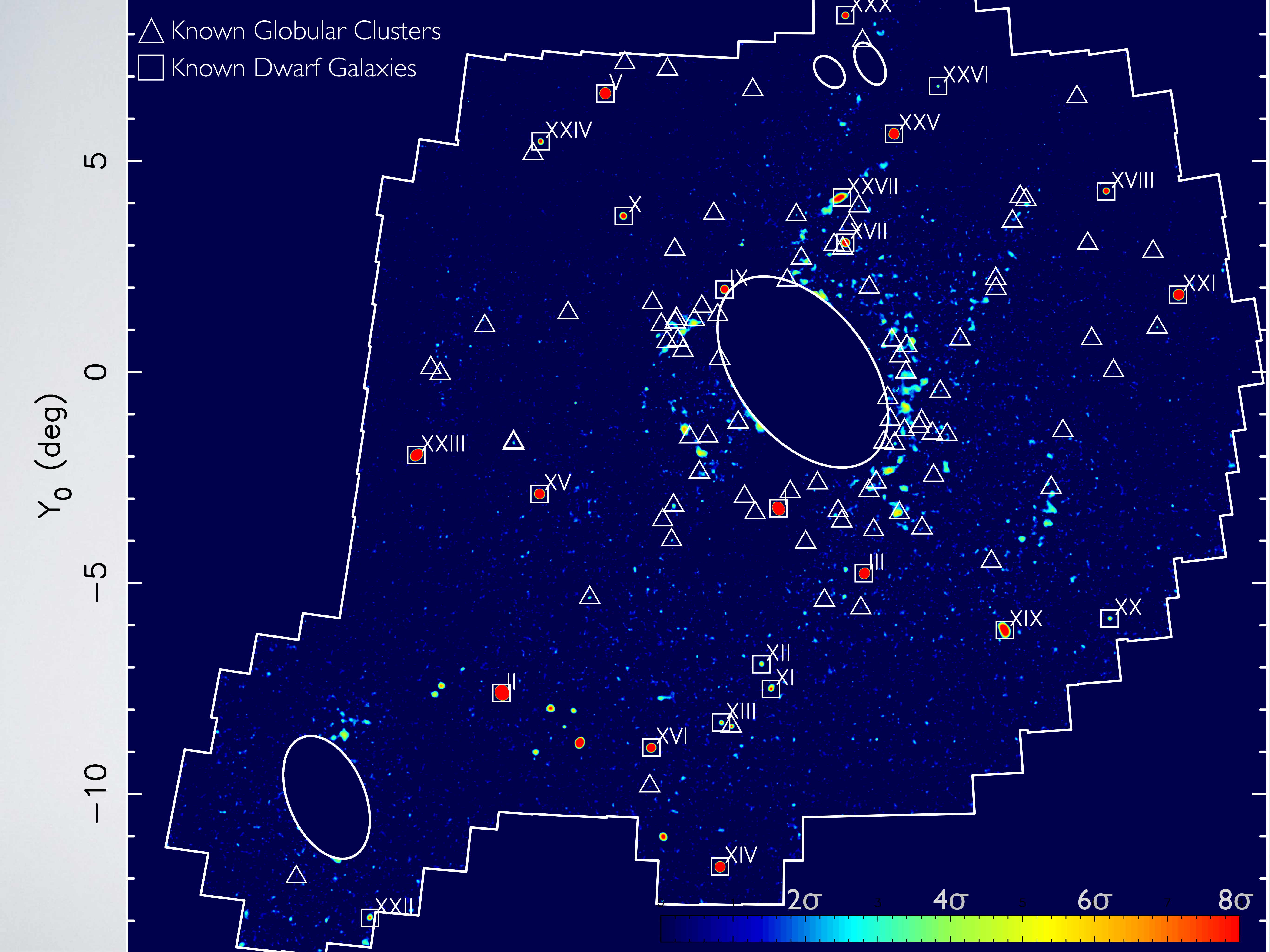




× Exponential profile (r_h)

× Spatially flat

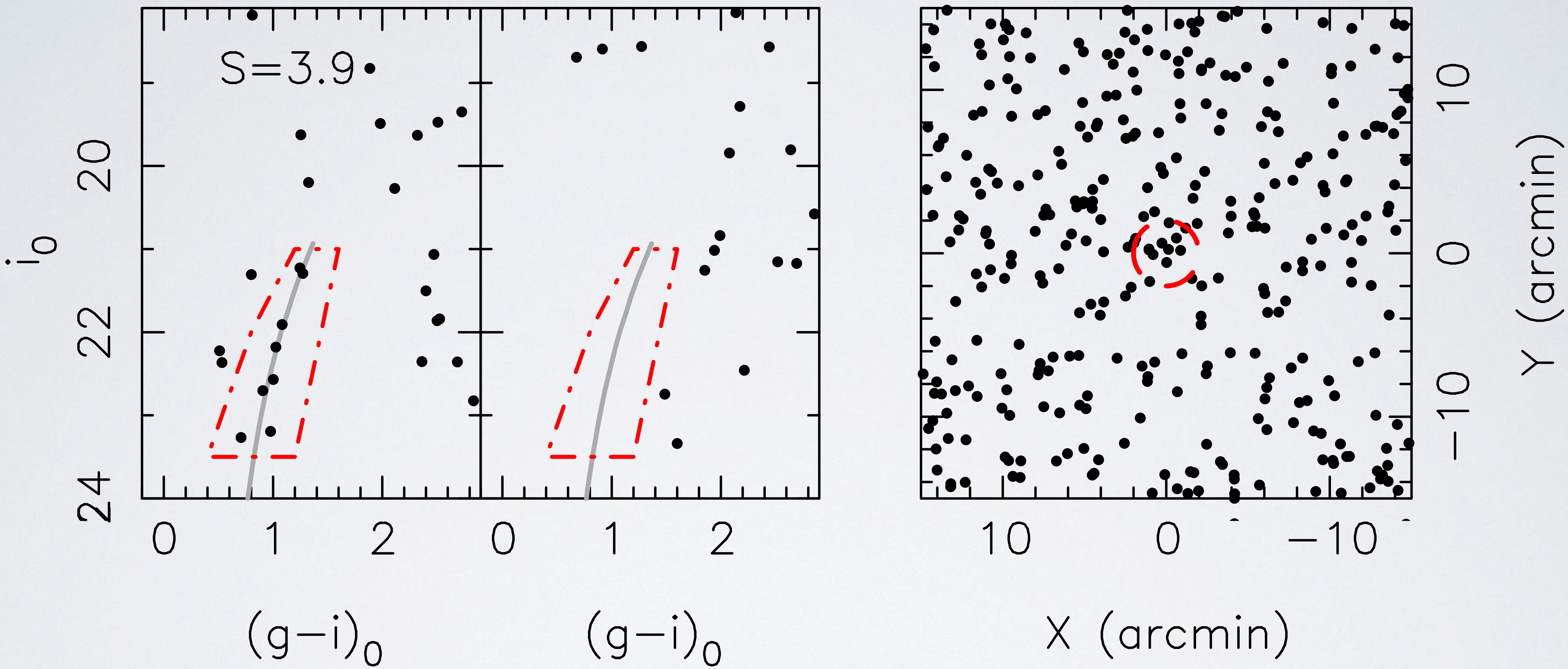
× Spatially flat



Known Globular Clusters
Known Dwarf Galaxies
Y0 (deg)
5
0
−5
−10
XXX
XXVI
V
XXV
XXIV
XXVII
XVIII
X
XVII
IX
XXI
XXIII
XV
III
XX
XIX
XII
XI
II
XIII
XVI
XIV
XXII
2σ
4σ
6σ
8σ

Invisible PAndAS dwarf galaxies?

Martin et al. (2013b)

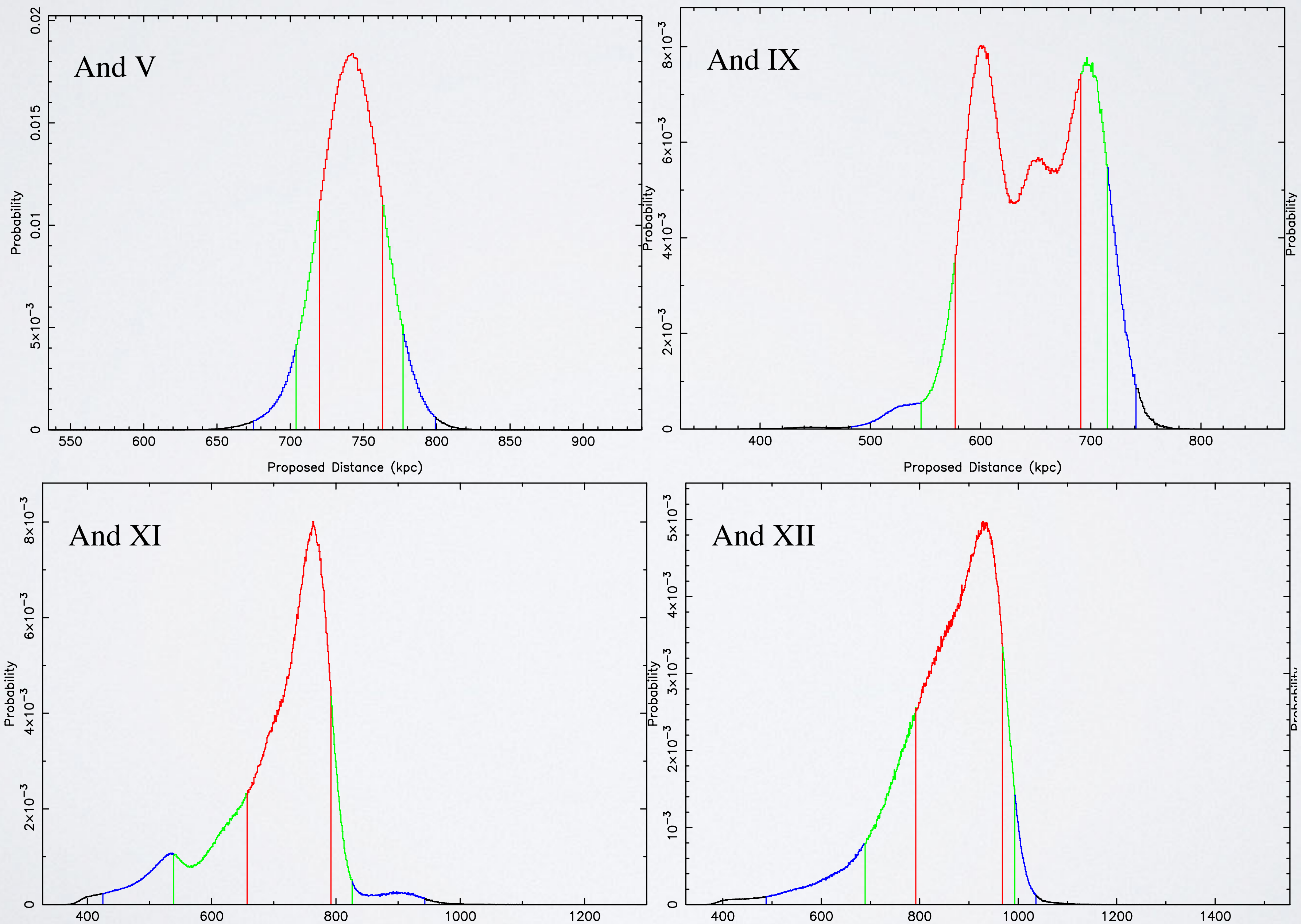


A handful followed up to push the M31 dwarf galaxy luminosity function

The satellite system of M31

A homogeneous analysis of all PAndAS dwarf galaxies

- TRGB distances *(Conn et al. 2011, 2012, 2013)*



The satellite system of M31

A homogeneous analysis of all PAndAS dwarf galaxies

- TRGB distances *(Conn et al. 2011, 2012, 2013)*
- Structural parameters and luminosities *(Martin et al., in prep, 2014?)*

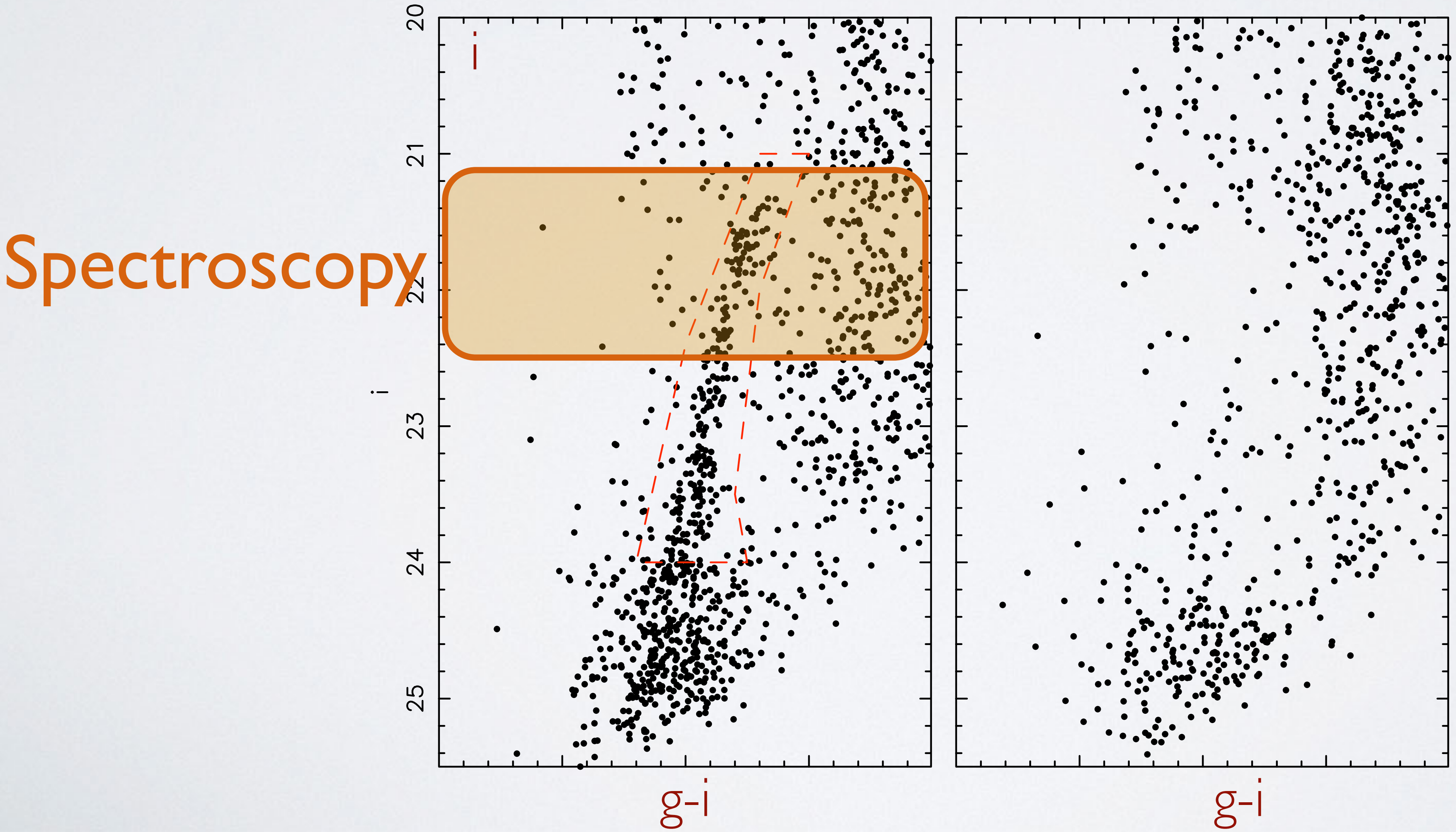
TABLE 1
DERIVED PROPERTIES OF THE SATELLITES

Name	α (J2000)	δ (J2000)	ϵ	θ (deg)	r_h (arcmin)	r_h (pc)[a]
And I	$0^h45^m39.8^s \pm 0.4^s$	$+38°02'14'' \pm 6''$	0.29 ± 0.03	31 ± 4	$3.98^{+0.15}_{-0.15}$	837^{+35}_{-42}
And II	$1^h16^m27.0^s \pm 0.4^s$	$+33°26'06'' \pm 5''$	0.14 ± 0.02	30 ± 5	5.13 ± 0.10	938^{+38}_{-44}
And III	$0^h35^m30.9^s \pm 0.5^s$	$+36°29'54'' \pm 8''$	0.59 ± 0.04	139 ± 3	1.88 ± 0.16	389 ± 37
And V	$1^h10^m17.3^s \pm 0.3^s$	$+47°37'45'' \pm 5''$	$0.29^{+0.08}_{-0.07}$	52^{+9}_{-7}	$1.64^{+0.17}_{-0.11}$	360 ± 34
And IX	$0^h52^m52.8^s \pm 0.7^s$	$+43°11'59'' \pm 8''$	$0.02^{+0.13}_{-0.02}$	107^{+90}_{-90}	$1.78^{+0.26}_{-0.22}$	327 ± 53
And X	$1^h06^m35.1^s \pm 0.6^s$	$+44°48'31'' \pm 9''$	$0.29^{+0.22}_{-0.29}$	30^{+16}_{-12}	$1.00^{+0.32}_{-0.18}$	192^{+54}_{-39}
And XI	$0^h46^m19.6^s \pm 0.6^s$	$+33°48'07'' \pm 8''$	$0.05^{+0.35}_{-0.05}$	42 ± 36	$0.64^{+0.23}_{-0.15}$	121^{+46}_{-37}
And XII	$0^h47^m28.0^{s}{}^{+1.4s}_{-0.9}$	$+34°22'45'' \pm 37''$	$0.49^{+0.26}_{-0.49}$	-4^{+28}_{-16}	$1.95^{+1.25}_{-0.75}$	499^{+280}_{-240}
And XIII	$0^h51^m51.0^s \pm 0.7^s$	$+33°00'16'' \pm 14''$	$0.61^{+0.15}_{-0.19}$	-23^{+12}_{-9}	$0.85^{+0.36}_{-0.30}$	133^{+93}_{-47}
And XIV	$0^h51^m35.0^s \pm 0.5^s$	$+29°41'17'' \pm 8''$	$0.21^{+0.11}_{-0.14}$	-7 ± 13	1.52 ± 0.16	255[b]
And XV	$1^h14^m18.7^s \pm 0.4^s$	$+38°07'18'' \pm 7''$	$0.26^{+0.09}_{-0.11}$	33 ± 13	$1.35^{+0.16}_{-0.12}$	238^{+37}_{-27}
And XVI	$0^h59^m30.3^s \pm 0.4^s$	$+32°22'34'' \pm 4''$	$0.30^{+0.08}_{-0.09}$	93 ± 9	$0.98^{+0.09}_{-0.07}$	131^{+25}_{-19}
And XVII	$0^h37^m06.2^s \pm 0.5^s$	$+44°19'22'' \pm 6''$	$0.47^{+0.06}_{-0.14}$	112 ± 11	$1.33^{+0.25}_{-0.21}$	276^{+57}_{-36}
And XVIII	$0^h02^m16.1^s \pm 0.4^s$	$+45°05'32'' \pm 8''$	$0.02^{+0.32}_{-0.02}$	90^{+24}_{-20}	$0.76^{+0.10}_{-0.12}$	267 ± 40
And XIX	$0^h19^m36.9^{s}{}^{+2.0s}_{-3.3}$	$+35°03'28'' \pm 47''$	$0.46^{+0.08}_{-0.09}$	40^{+6}_{-7}	$11.82^{+1.78}_{-1.49}$	2072^{+1098}_{-422}
And XX	$0^h07^m30.7^s \pm 0.5^s$	$+35°07'40'' \pm 9''$	$0.10^{+0.37}_{-0.10}$	54^{+52}_{-32}	$0.50^{+0.24}_{-0.14}$	102^{+53}_{-27}
And XXI	$23^h54^m48.7^s \pm 1.6^s$	$+42°28'03'' \pm 22''$	$0.35^{+0.11}_{-0.14}$	147^{+10}_{-14}	$4.04^{+0.65}_{-54}$	989 ± 156
And XXII/Tri I	$1^h27^m40.5^s \pm 0.8^s$	$+28°05'22'' \pm 10''$	$0.64^{+0.11}_{-0.15}$	123 ± 9	$0.90^{+0.35}_{-0.18}$	230^{+72}_{-87}
And XXIII	$1^h29^m20.9^s \pm 0.8^s$	$+38°43'28'' \pm 13''$	$0.39^{+0.05}_{-0.06}$	139 ± 5	$5.38^{+0.44}_{-0.37}$	1170^{+120}_{-100}
And XXIV	$1^h18^m31.6^s \pm 1.7^s$	$+46°22'16'' \pm 17''$	$0.11^{+0.20}_{-0.11}$	90^{+23}_{-20}	$2.41^{+0.71}_{-0.47}$	610^{+213}_{-107}
And XXV	$0^h30^m10.8^s \pm 1.0^s$	$+46°51'41'' \pm 18''$	$0.22^{+0.12}_{-0.18}$	$8^{\pm}16$	3.14 ± 0.37	634 ± 93
And XXVI	$0^h23^m45.8^s \pm 0.9^s$	$+47°54'46'' \pm 17''$	$0.15^{+0.39}_{-0.15}$	146^{+28}_{-52}	$1.14^{+0.62}_{-0.28}$	188^{+138}_{-79}
And XXVII	$0^h37^m52.0^s \pm 11^s$	$+45°20'02''{}^{+96''}_{-80}$	$0.76^{+0.06}_{-0.04}$	124 ± 4	$19.74^{+3.37}_{-2.89}$	7212[c]
And XXX/Cas II	$0^h36^m34.6^s \pm 0.5^s$	$+49°38'47'' \pm 5''$	$0.40^{+0.06}_{-0.07}$	-65 ± 7	$1.44^{+0.17}_{-0.13}$	260 ± 43
NGC 147	$0^h33^m12.6^s \pm 0.6^s$	$+48°30'31'' \pm 10''$	0.31 ± 0.02	29 ± 3	$8.4^{+0.28}_{-0.23}$	1945^{+65}_{-76}
NGC 185	$0^h38^m58.1^s \pm 0.2^s$	$+48°20'15'' \pm 4''$	0.22 ± 0.02	43 ± 2	$5.03^{+0.12}_{-0.07}$	925^{+37}_{-43}

The satellite system of M31

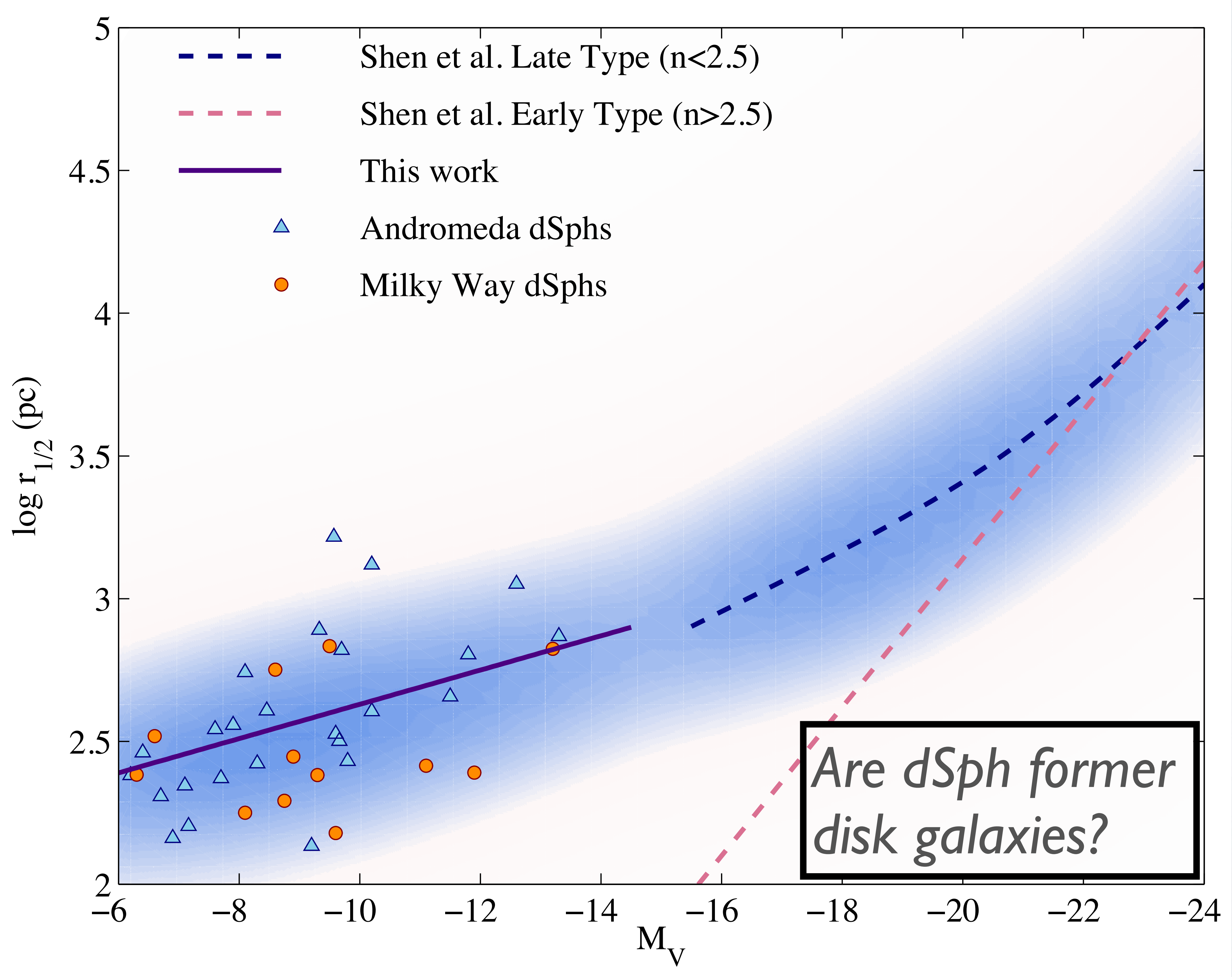
A homogeneous analysis of all PAndAS dwarf galaxies

- TRGB distances *(Conn et al. 2011, 2012, 2013)*
- Structural parameters and luminosities *(Martin et al., in prep, 2014?)*
- Radial velocities *(Collins et al. 2013a,b + Tollerud et al. 2013)*



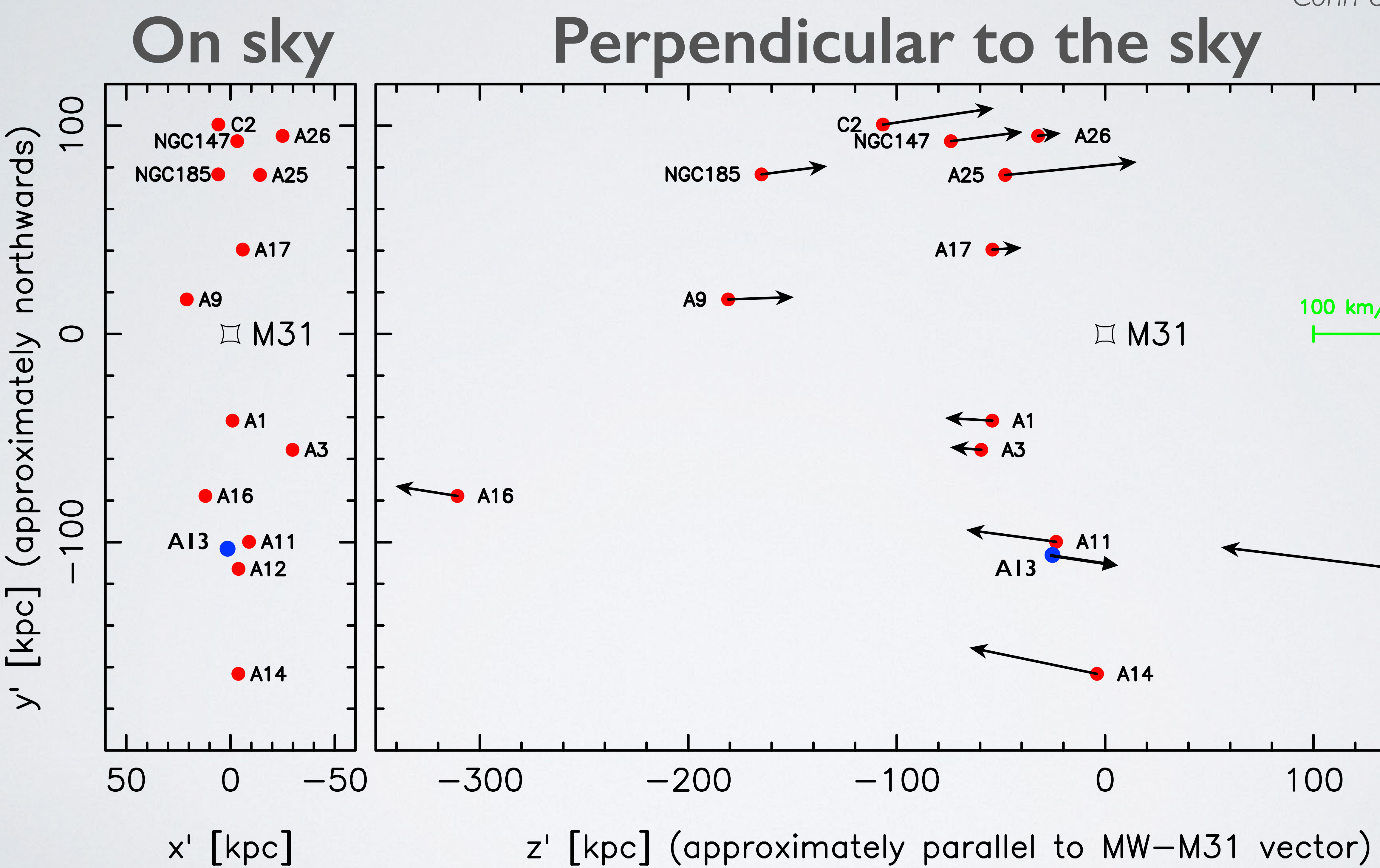
The Local Group dSph size-luminosity relation

Brasseur, Martin et al. (2011)



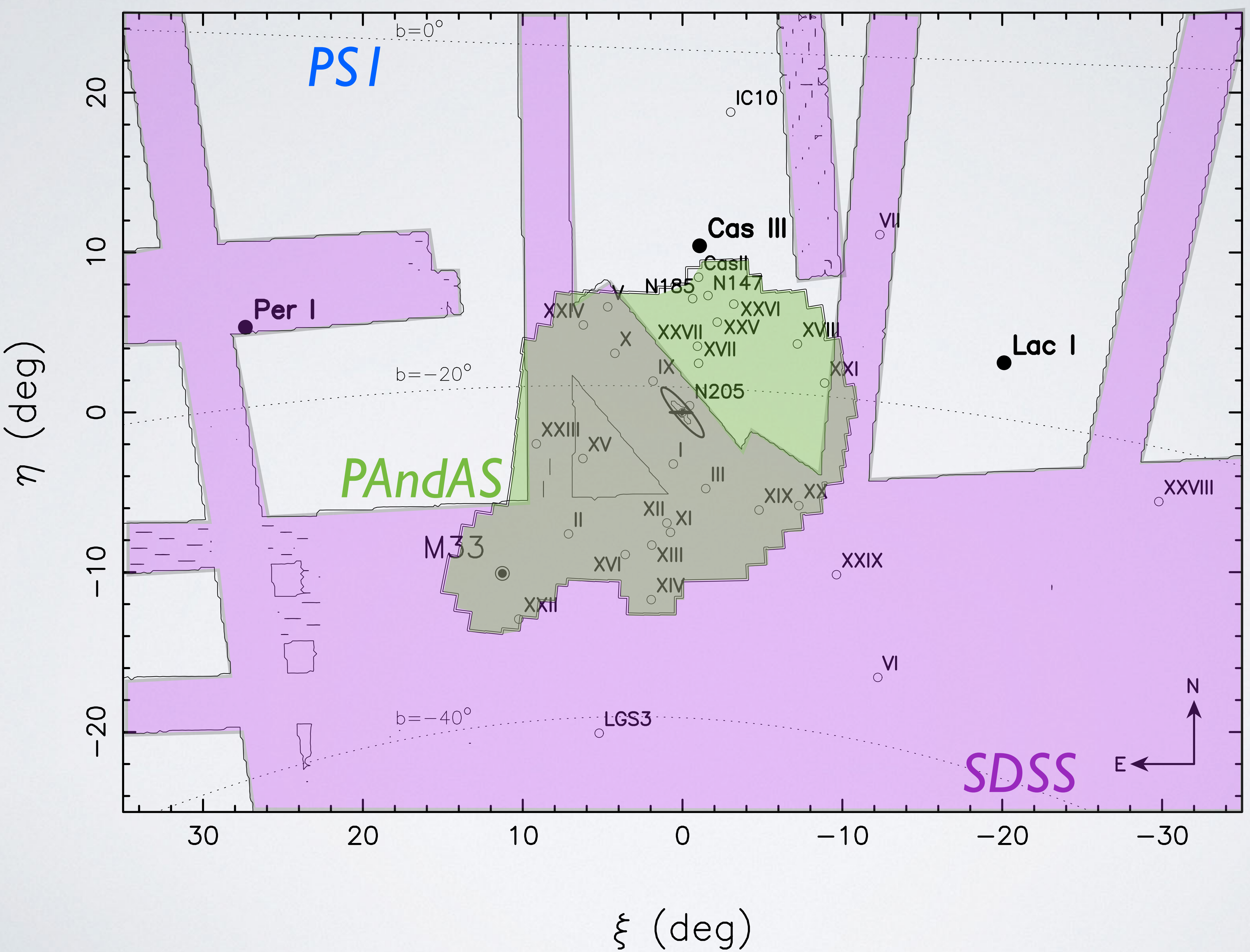
A rotating disk of satellites

Ibata et al. (2013)
Conn et al. (2013)



Beyond 150 kpc with PS1

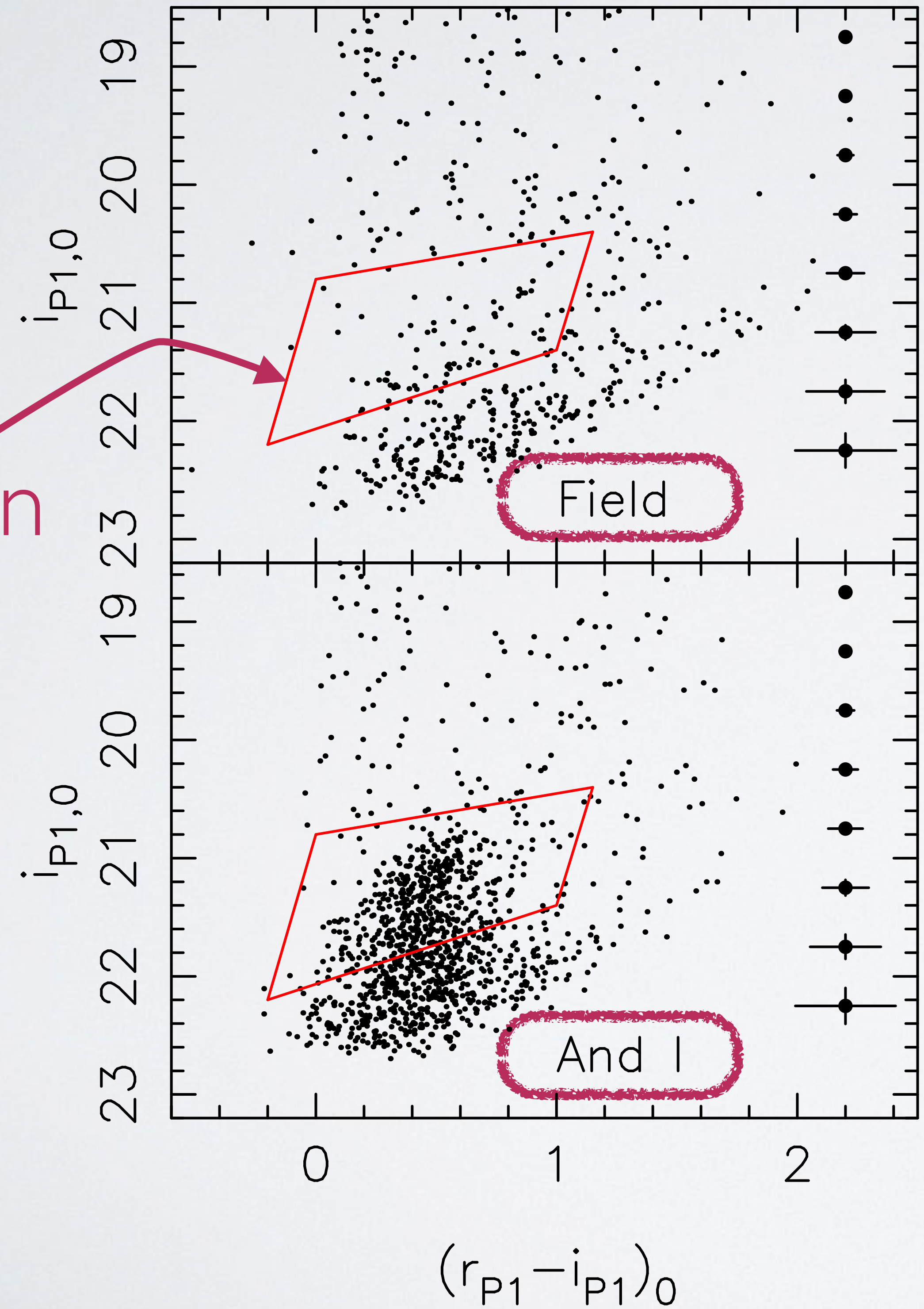
Martin et al. (2013ac)

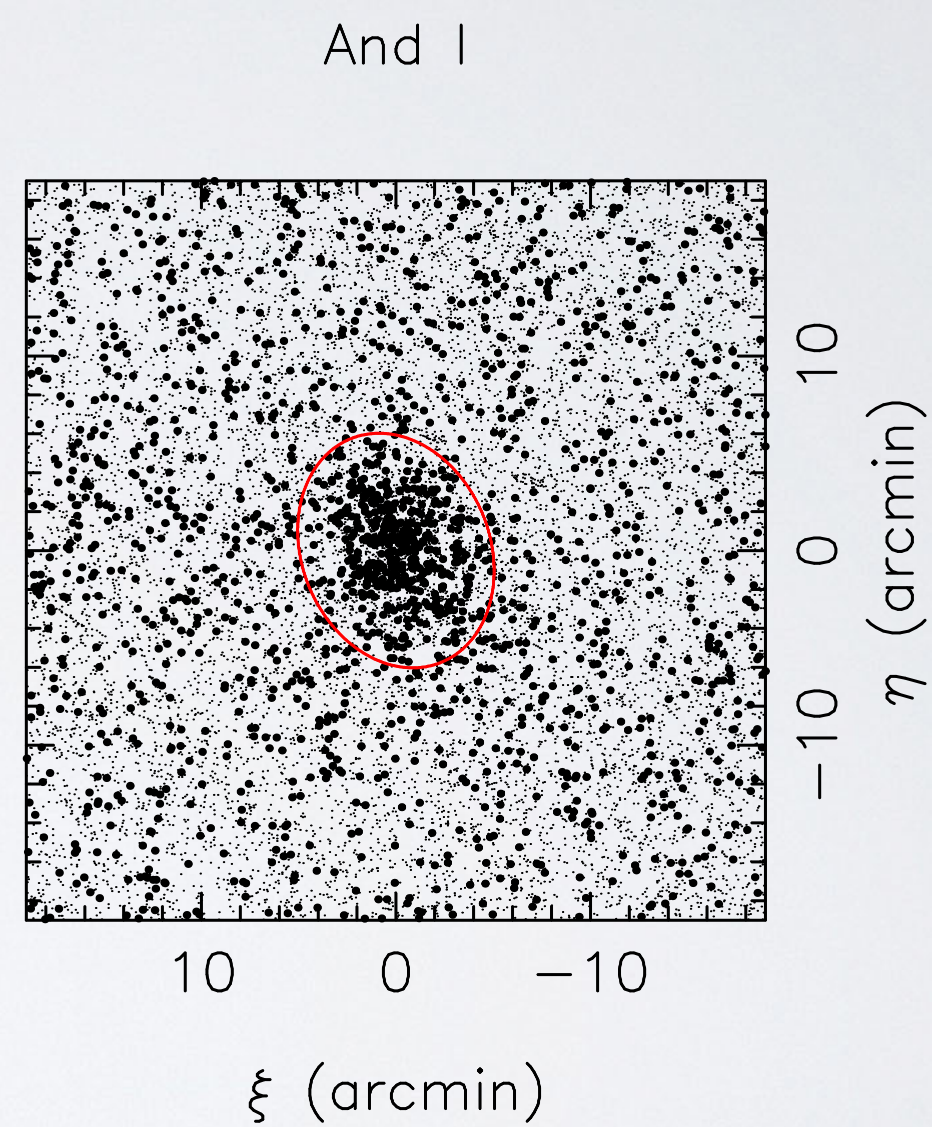


What do Andies look like in PS1?

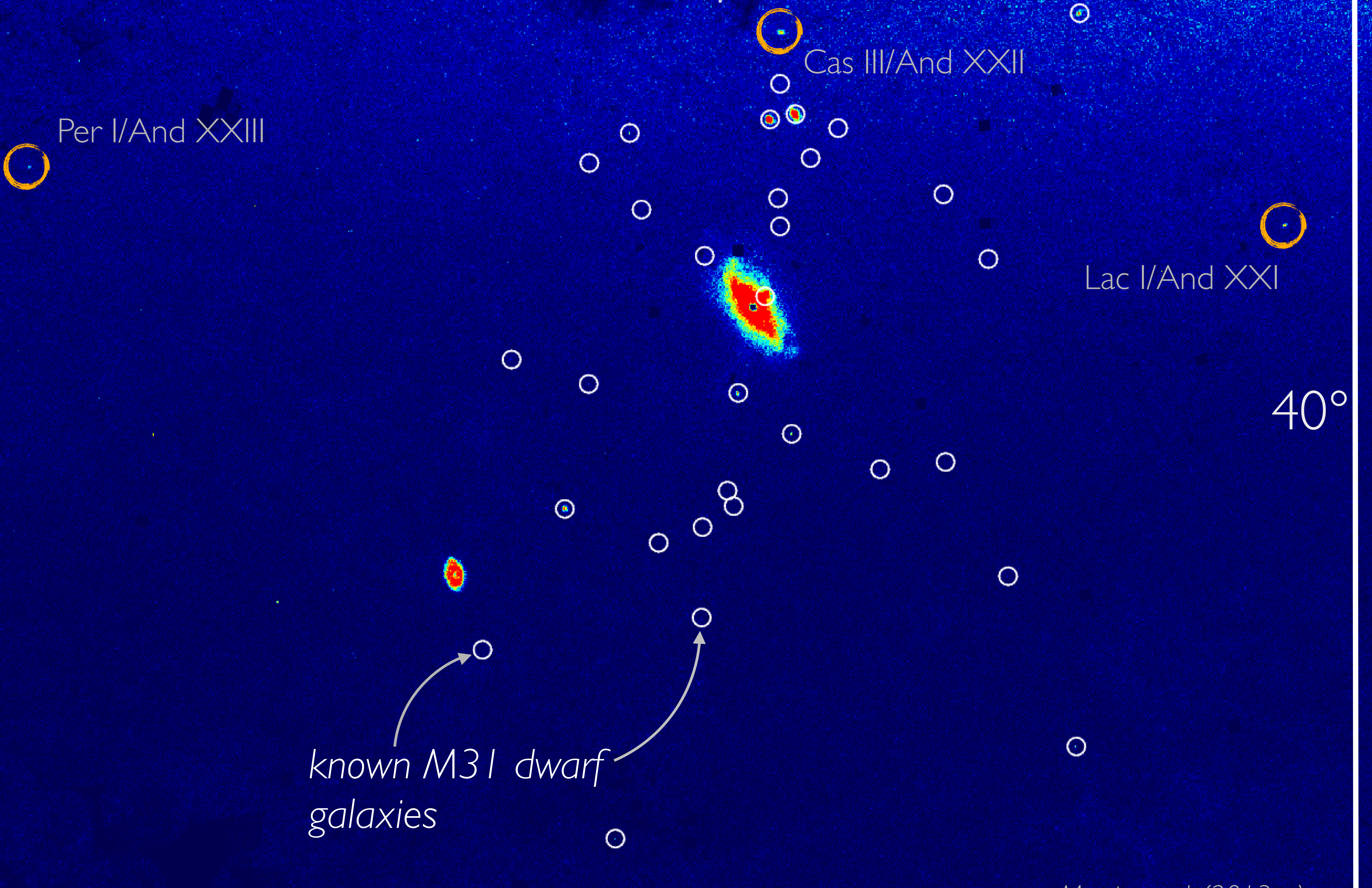
Andromeda I

RGB selection box





PS1 M31 candidate RGB map

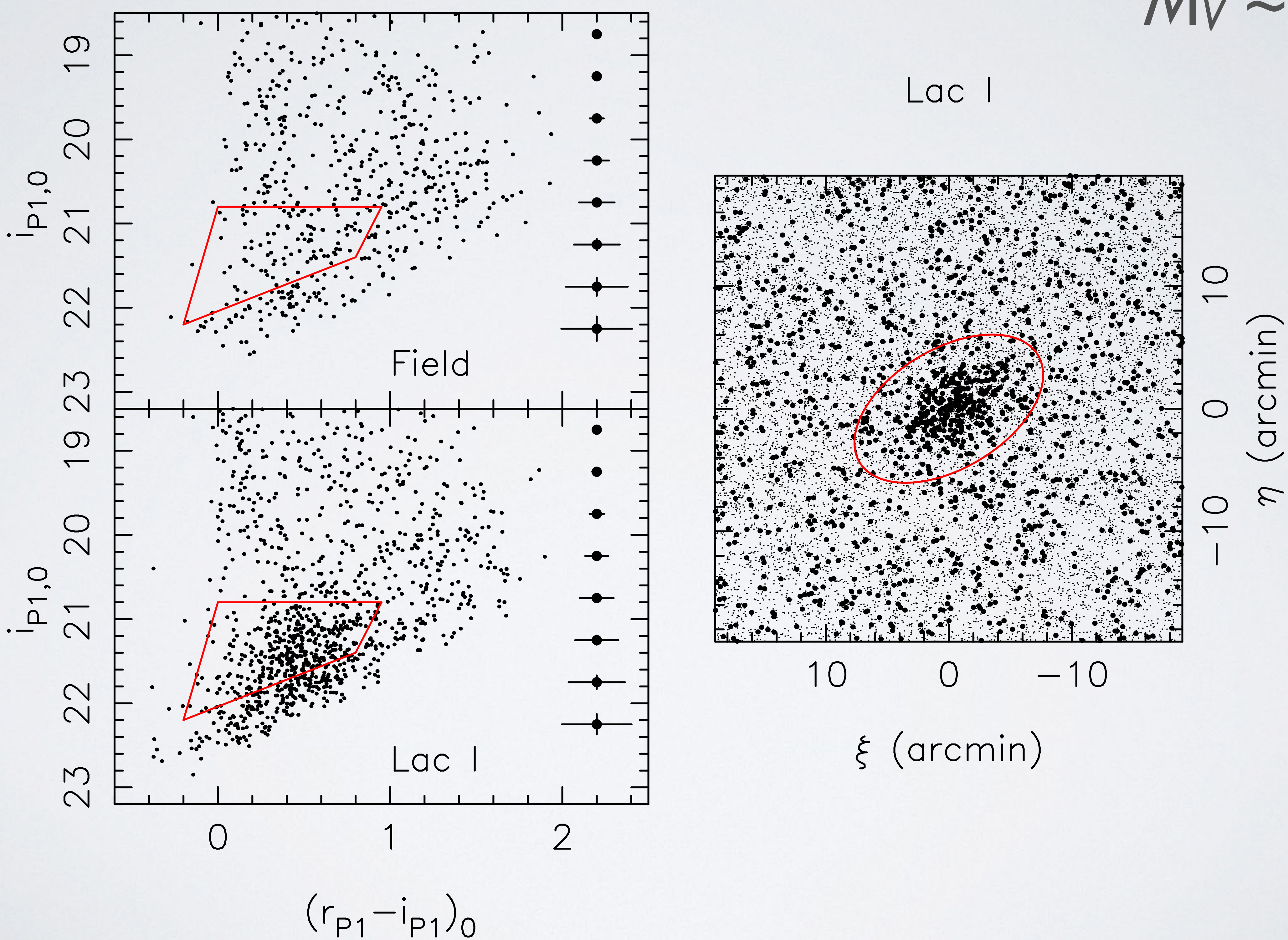


Martin et al. (2013ac)

Lacerta I

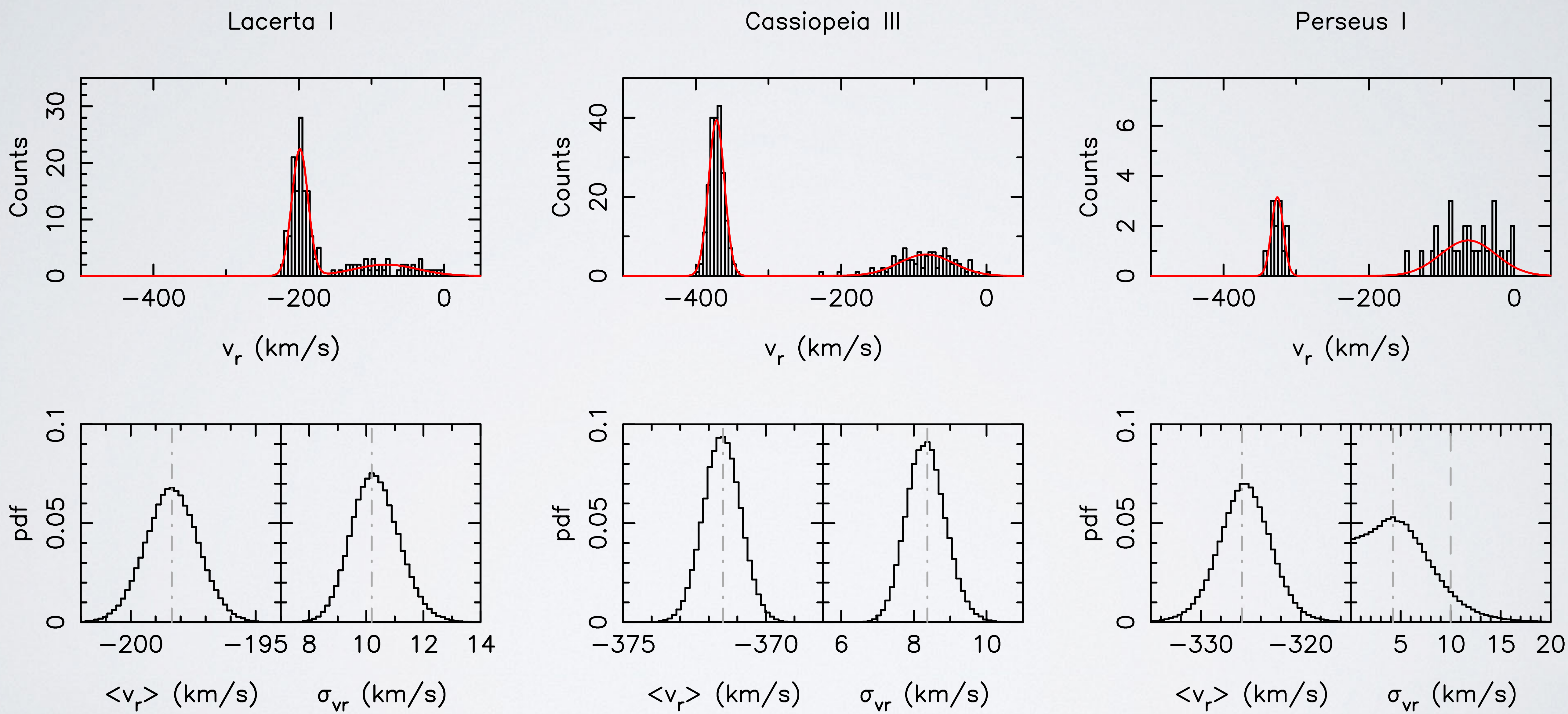
Andromeda XXXI

$M_V \sim -11.5$



Spectroscopic confirmation

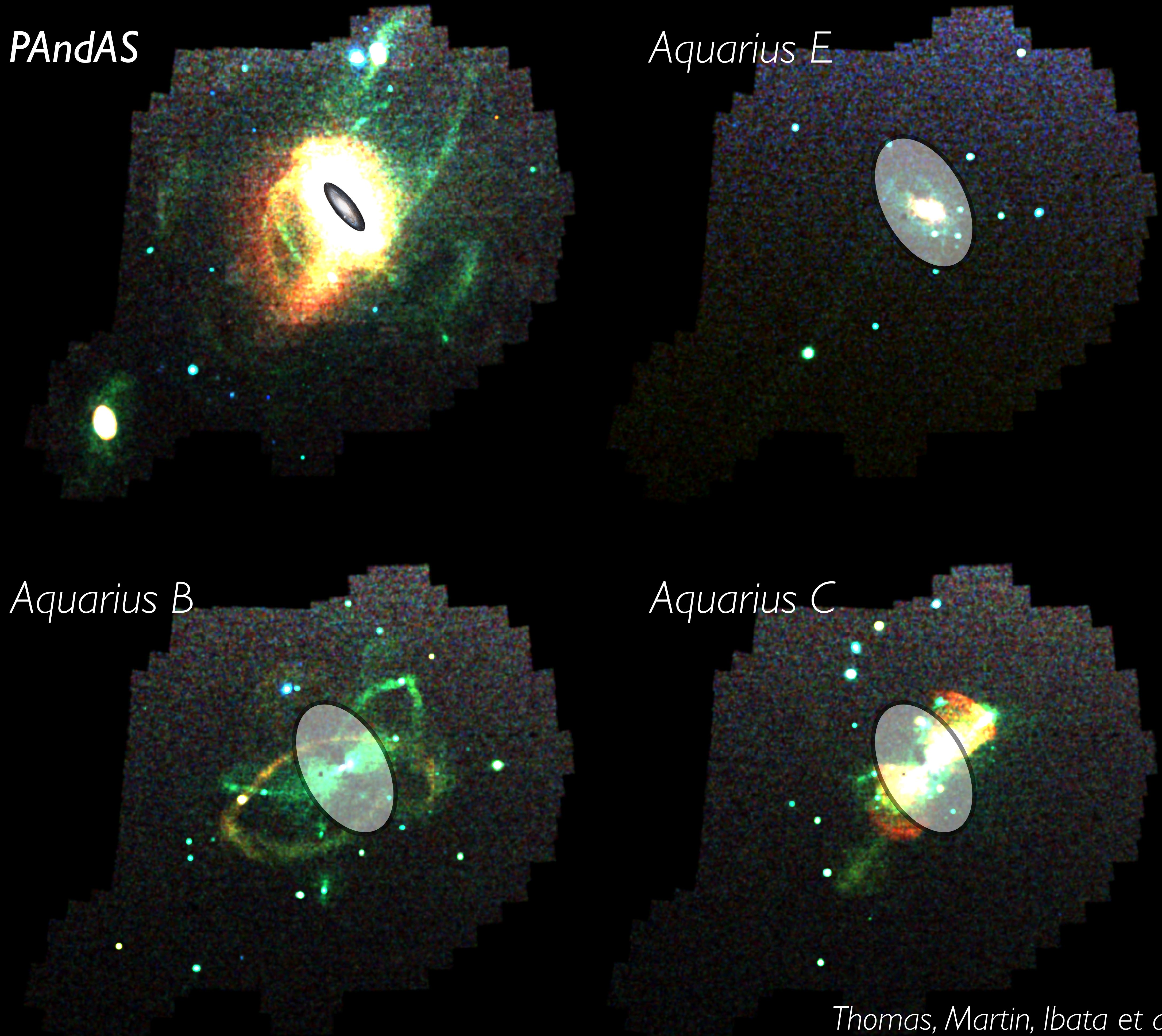
Martin et al. (2014b)



Summary

- **~40 dwarf galaxies around Andromeda**
  - 16+ from PAndAS, 3+ from PS1 (+ upcoming follow up)
  - Testing faint end of galaxy formation in a cosmological context:
    - ➔ The M31(/Local Group) dwarf galaxy (mass) profile (Collins et al. 2013, 2014)
    - ➔ The M31(/Local Group) size-luminosity relation
    - ➔ Anisotropic distribution of M31 dwarf galaxies

- *Upcoming HST observations for 17 M31 dwarf galaxies* *(accurate distances, SFH,…)*
- *Towards "observations" of simulations*



Thomas, Martin, Ibata et al. (in prep)
based on Lowing et al. (2014)