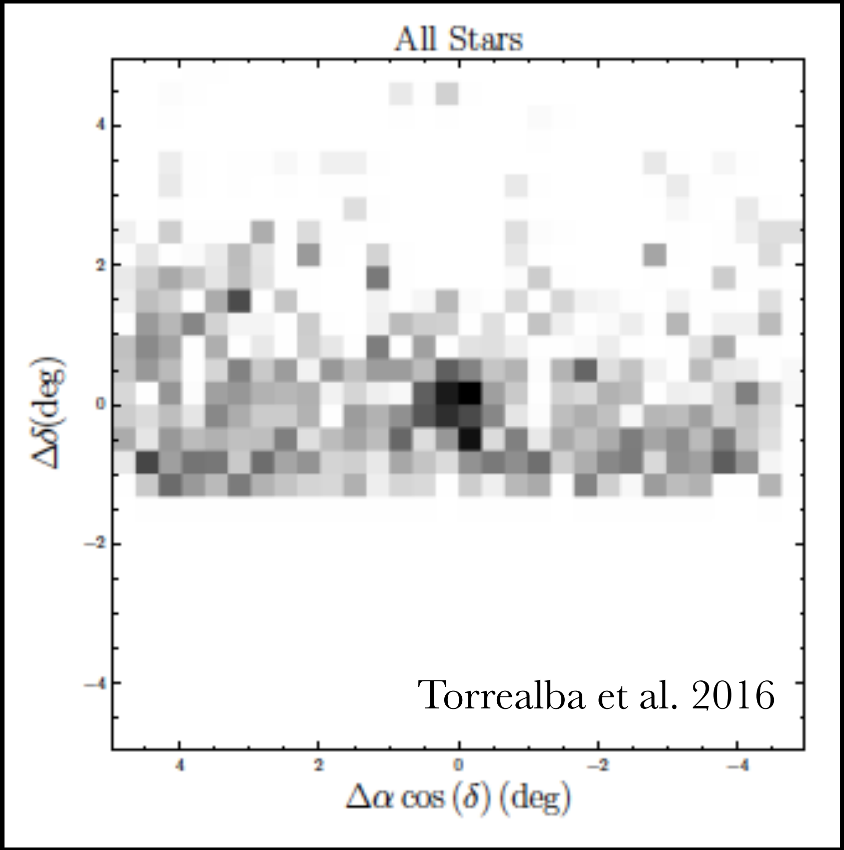
Dark Matter at Low Acceleration



Matthew G. Walker
Carnegie Mellon University

Cleveland
7 June 2017

ONE LAW TO RULE THEM ALL: THE RADIAL ACCELERATION RELATION OF GALAXIES

Federico Lelli[1,2,⋆], Stacy S. McGaugh[1], James M. Schombert[3], and Marcel S. Pawlowski[1,4,†]

[1]Department of Astronomy, Case Western Reserve University, Cleveland, OH 44106, USA

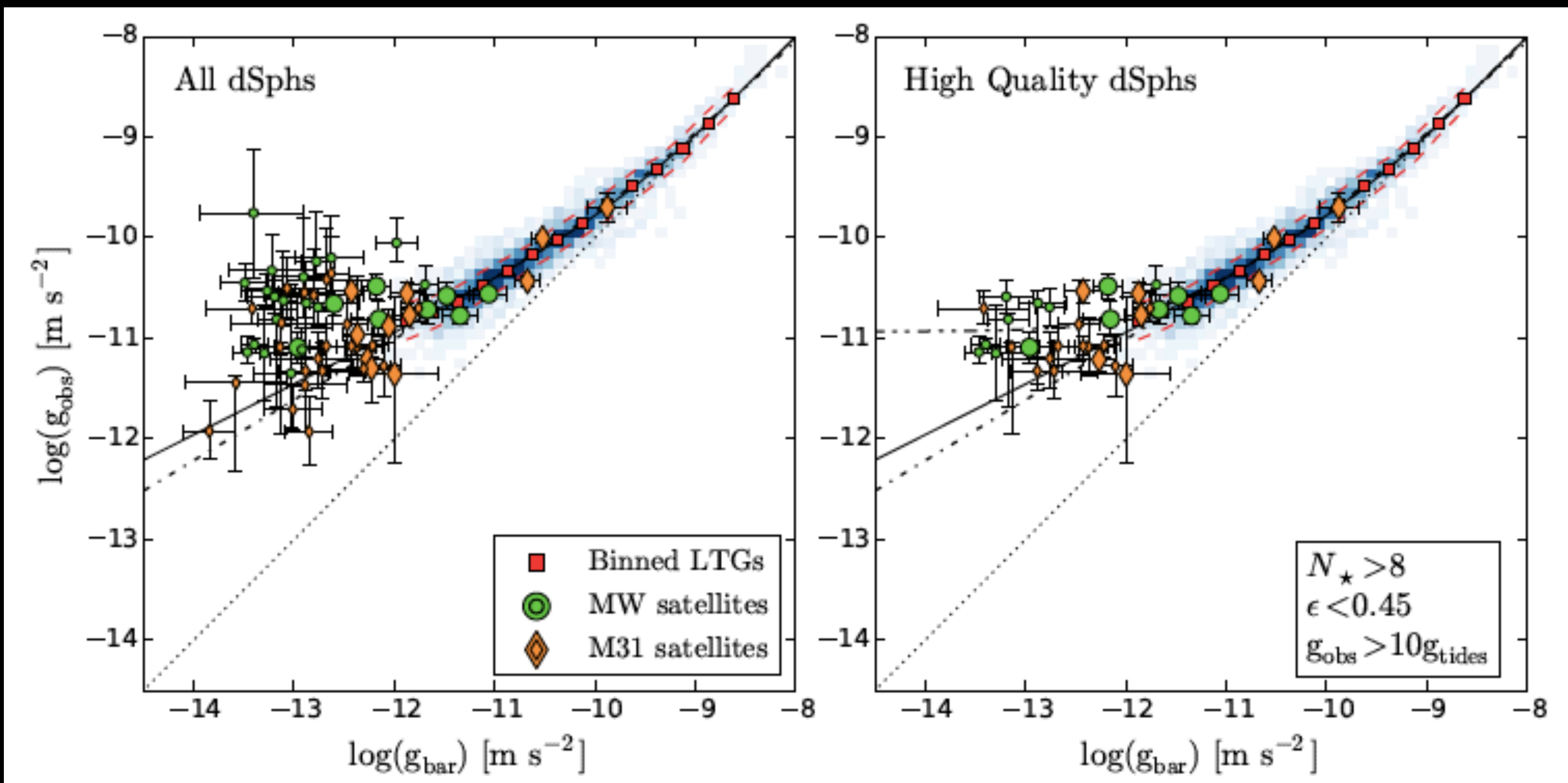
[2]European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748, Garching, Germany

[3]Department of Physics, University of Oregon, Eugene, OR 97403, USA

[4]Department of Physics and Astronomy, University of California, Irvine, CA 92697,

arXiv:1610.08981v2

Draft version January 25, 2017

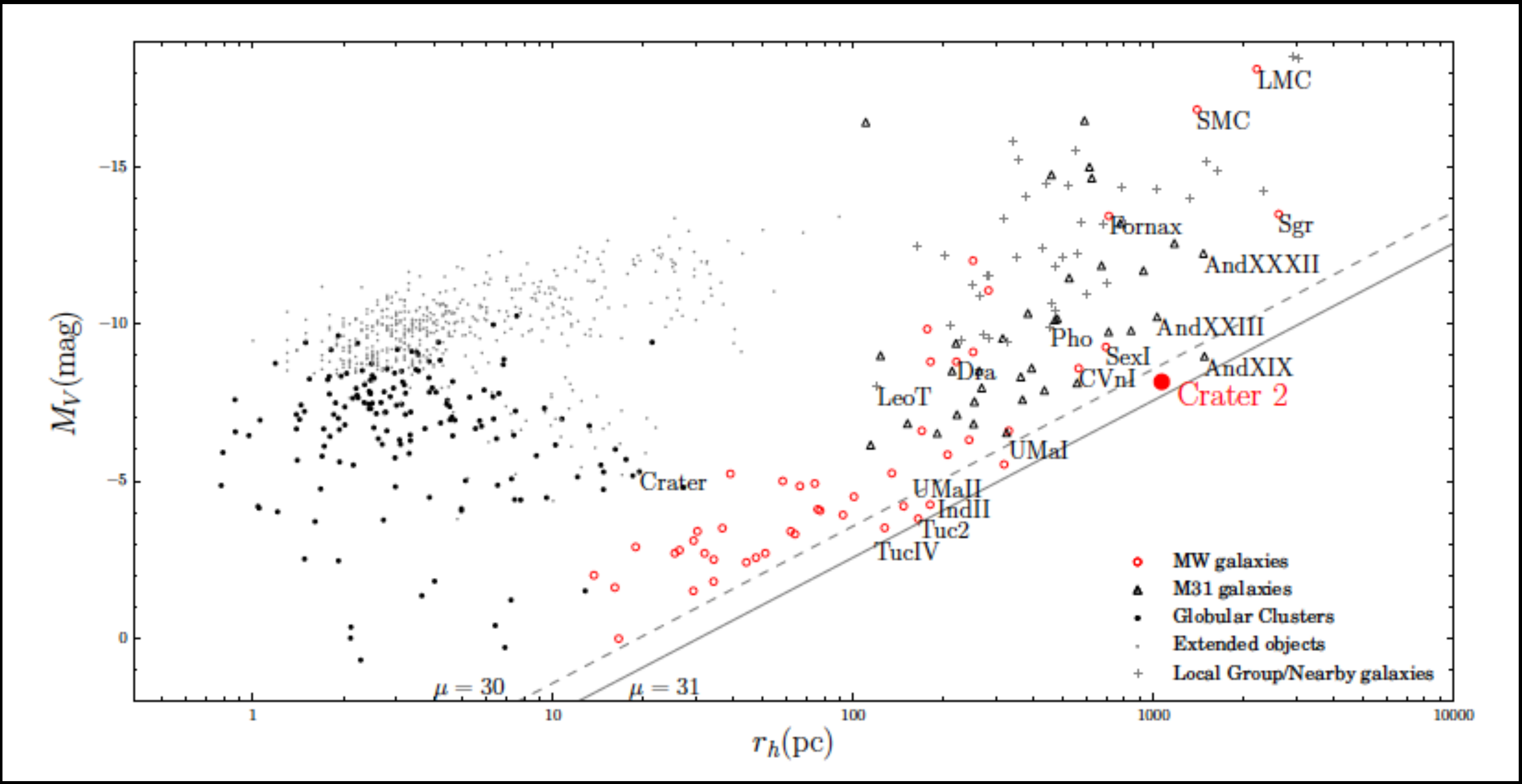


Mon. Not. R. Astron. Soc. **000**, 1–10 (2015) Printed 2 August 2016 (MN LATEX style file v2.2)

The feeble giant. Discovery of a large and diffuse Milky Way dwarf galaxy in the constellation of Crater⋆

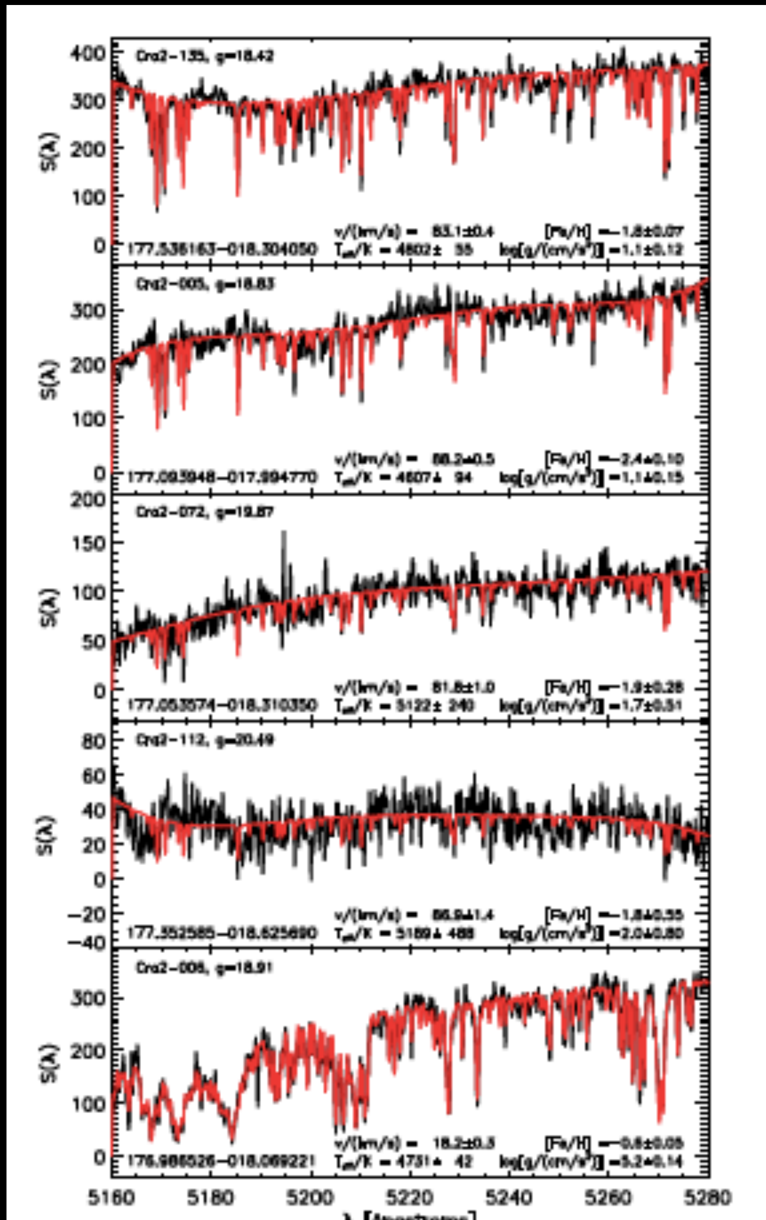
G. Torrealba[1], S.E. Koposov[1], V. Belokurov[1] & M. Irwin[1]
[1] *Institute of Astronomy, Madingley Rd, Cambridge, CB3 0HA*

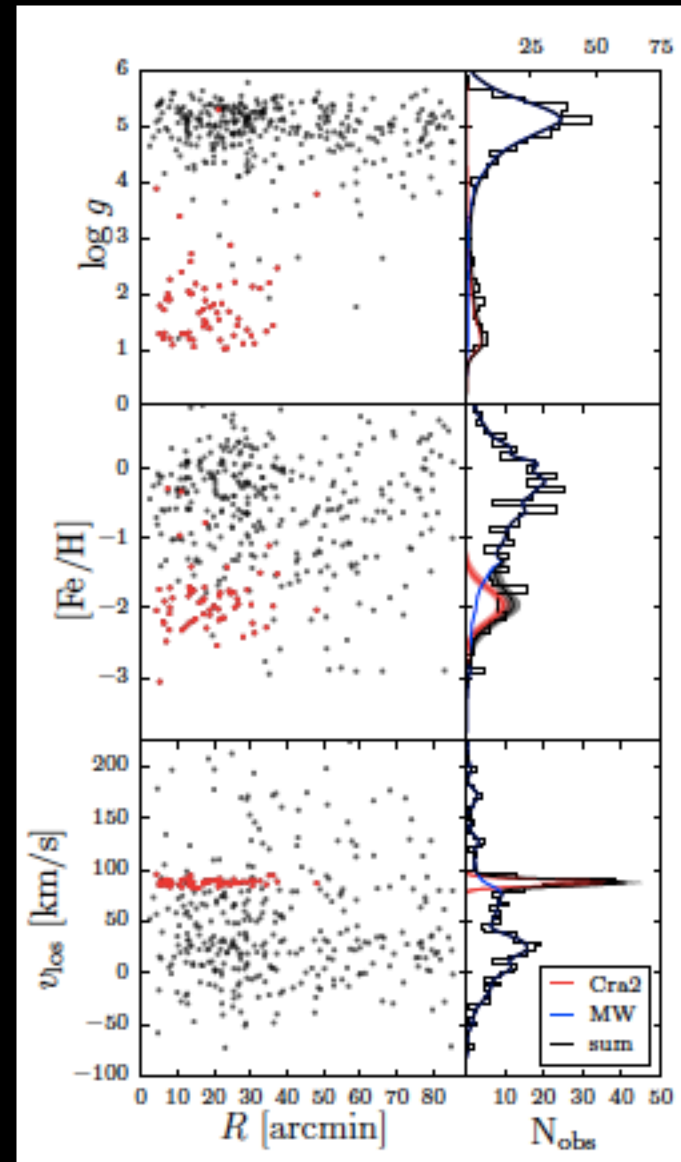
arXiv:1601.07178v4

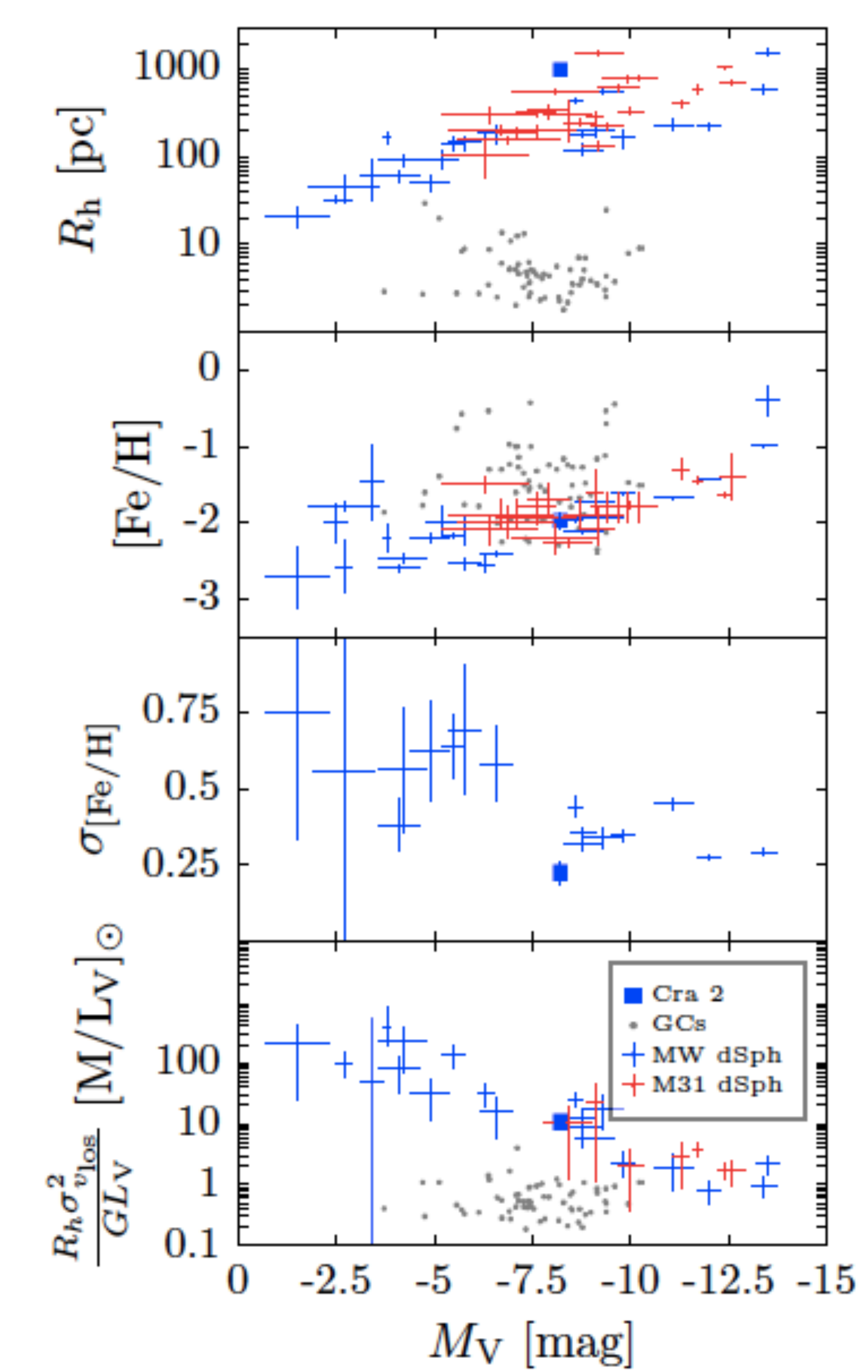


CRATER 2: AN EXTREMELY COLD DARK MATTER HALO*

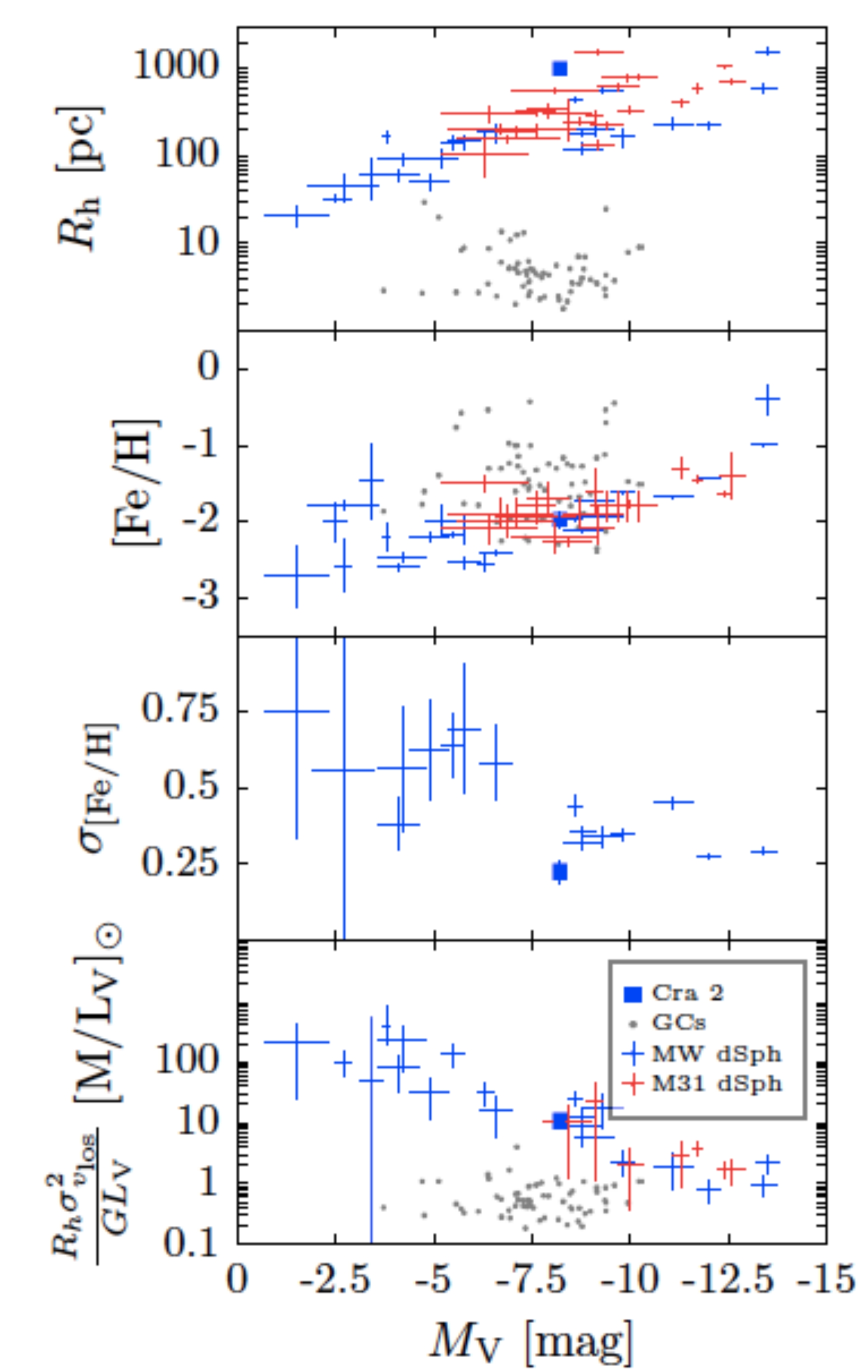
Nelson Caldwell[1], Matthew G. Walker[2], Mario Mateo[3], Edward W. Olszewski[4], Sergey Koposov[5], Vasily Belokurov[5], Gabriel Torrealba[5], Alex Geringer-Sameth[2] and Christian I. Johnson[1]



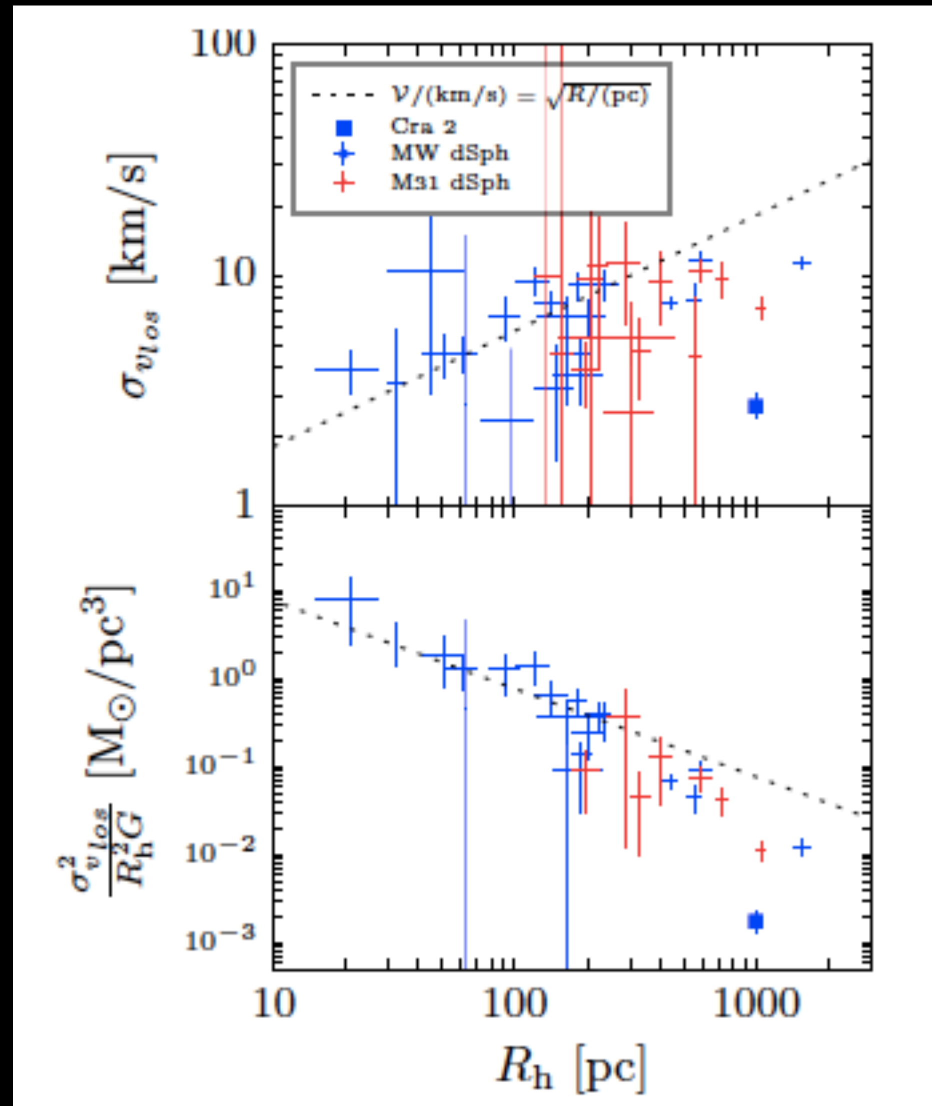




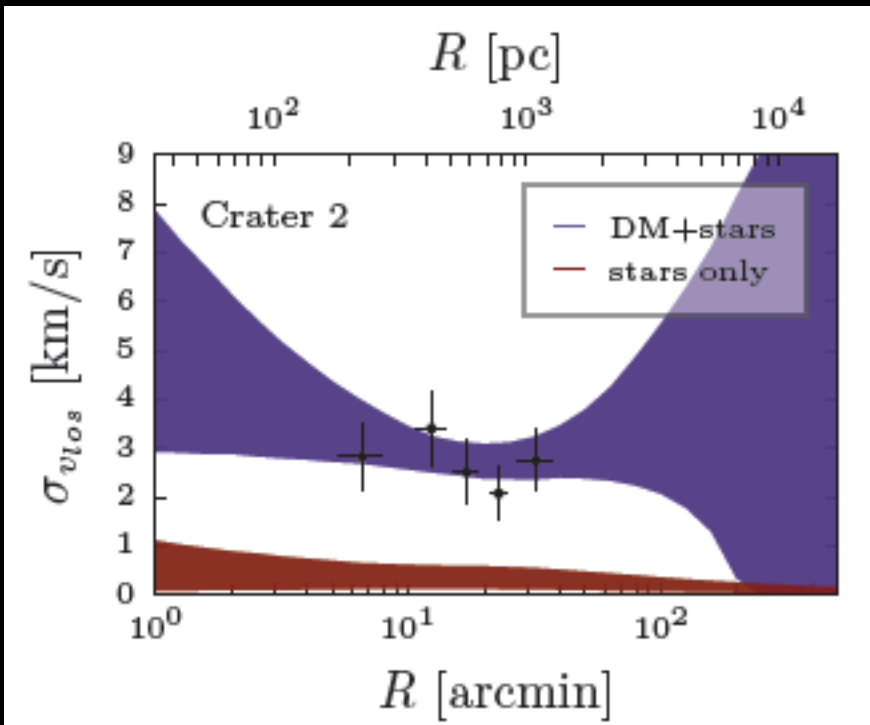
Caldwell et al. arXiv:1612.06398

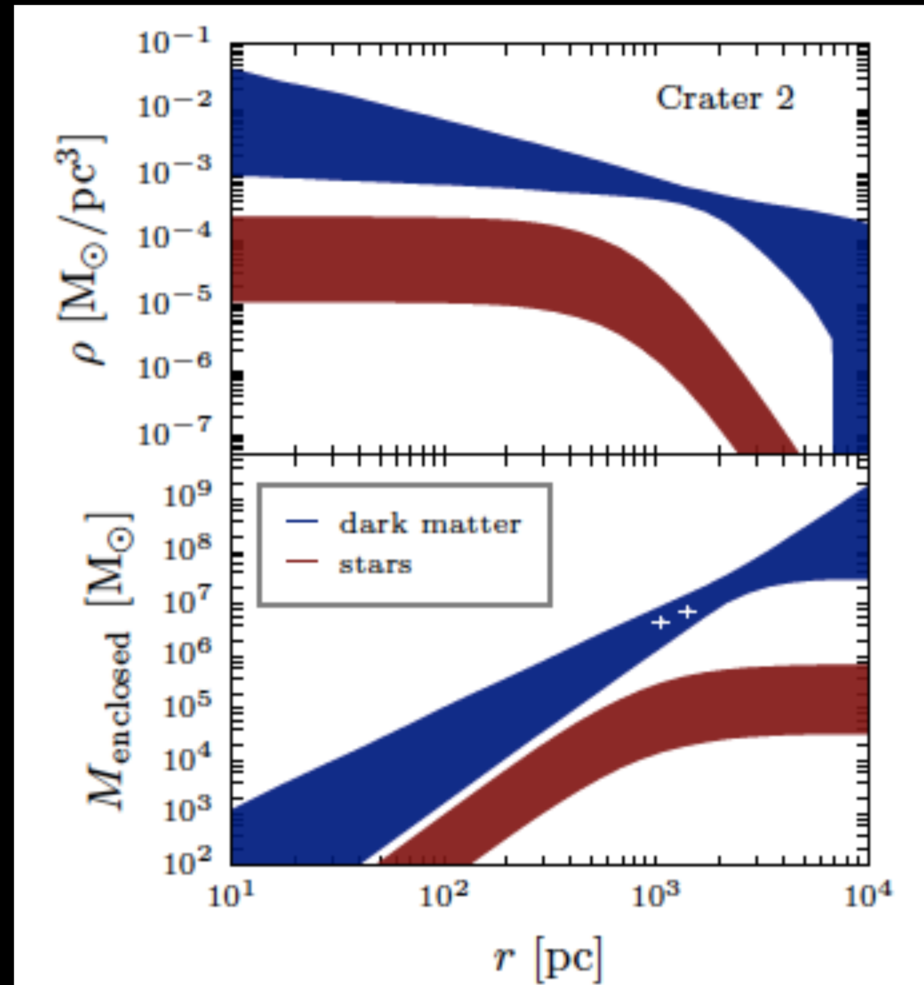


Caldwell et al. arXiv:1612.06398



Caldwell et al. arXiv:1612.06398

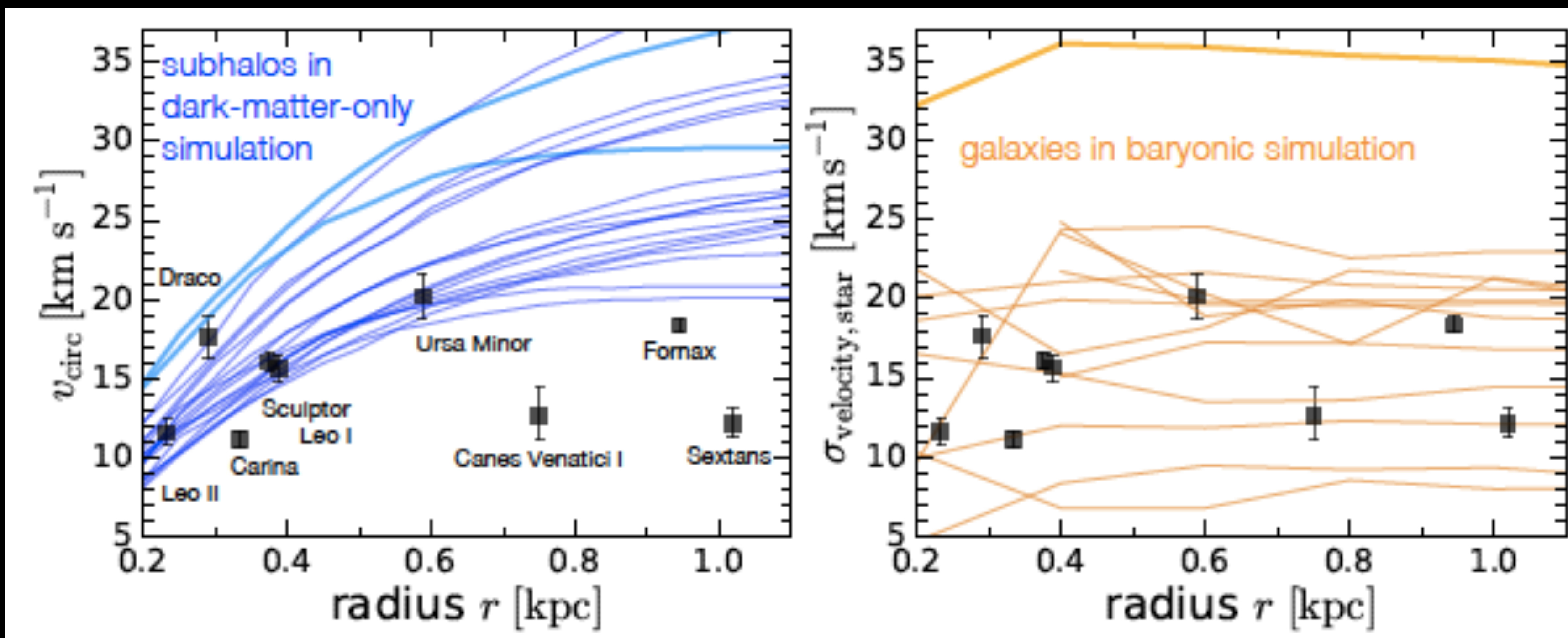




RECONCILING DWARF GALAXIES WITH ΛCDM COSMOLOGY:
SIMULATING A REALISTIC POPULATION OF SATELLITES AROUND A MILKY WAY-MASS GALAXY

ANDREW R. WETZEL[1,2,3,8,9], PHILIP F. HOPKINS[1], JI-HOON KIM[1,4,10], CLAUDE-ANDRÉ FAUCHER-GIGUÈRE[5], DUŠAN KEREŠ[6], AND ELIOT QUATAERT[7]

Draft version August 9, 2016



MOND PREDICTION FOR THE VELOCITY DISPERSION OF THE 'FEEBLE GIANT' CRATER II

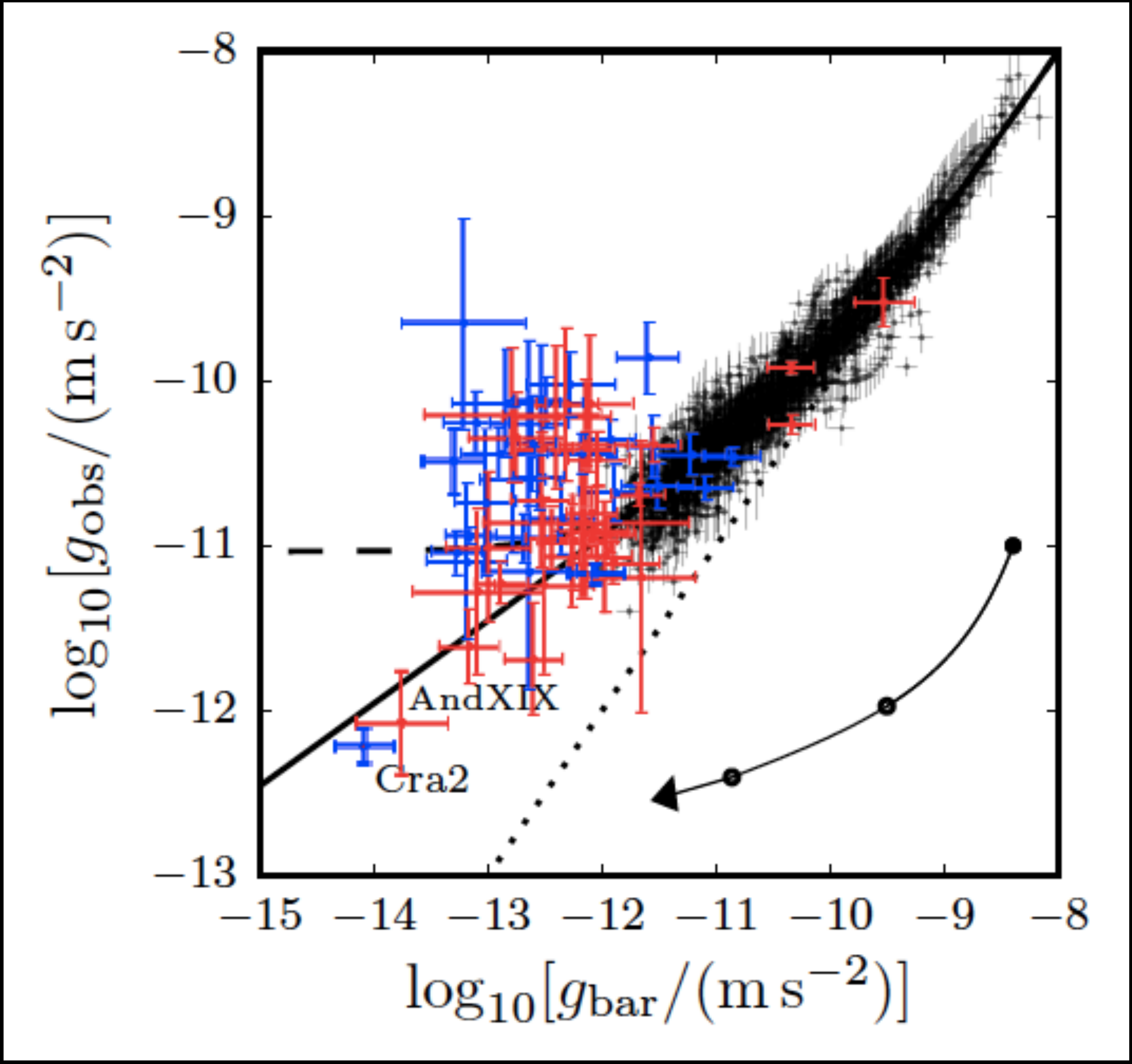
Stacy S. McGaugh[1]

[1]Department of Astronomy, Case Western Reserve University, Cleveland, OH 44106

ABSTRACT

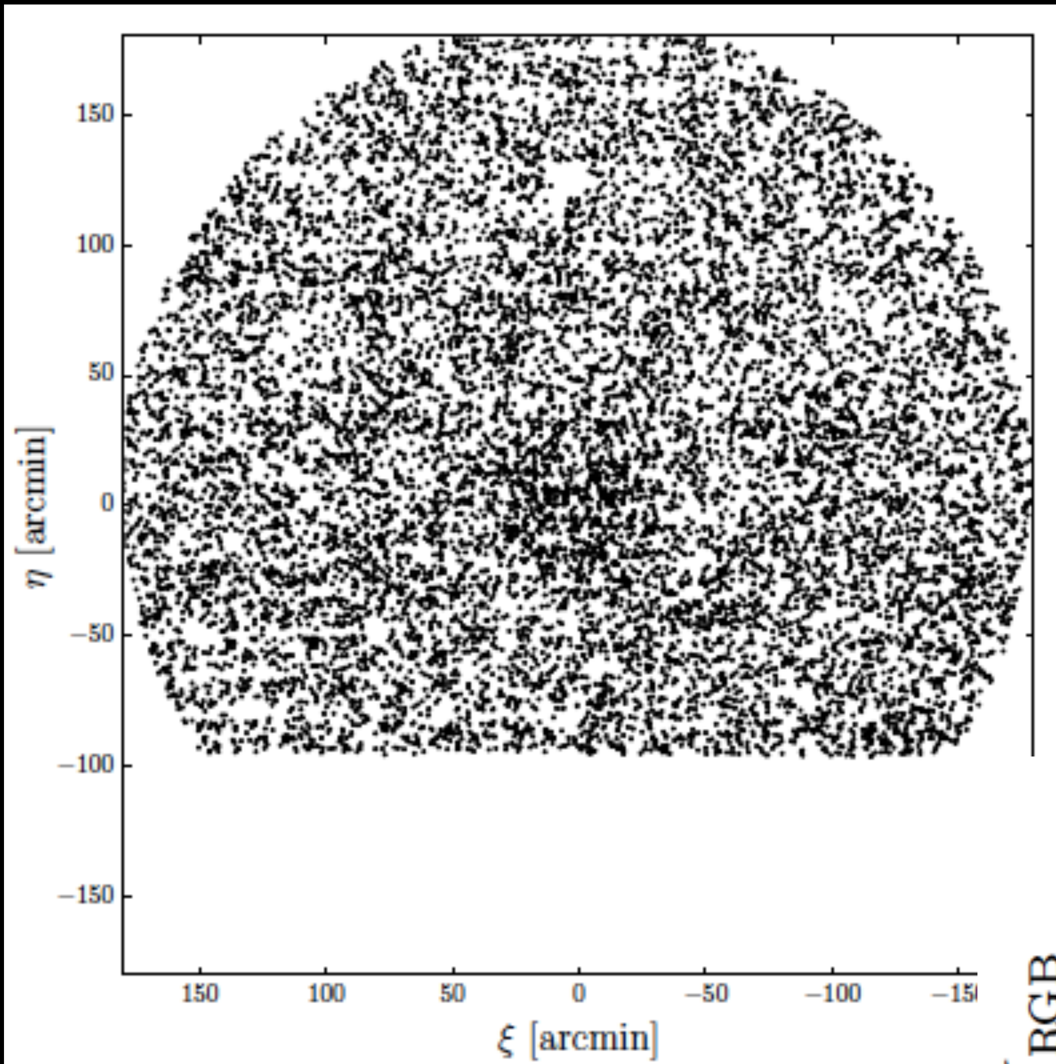
Crater II is an unusual object among the dwarf satellite galaxies of the Local Group in that it has a very large size for its small luminosity. This provides a strong test of MOND, as Crater II should be in the deep MOND regime ($g_{in} \approx 34\ \mathrm{km^2\,s^{-2}\,kpc^{-1}} \ll a_0 = 3700\ \mathrm{km^2\,s^{-2}\,kpc^{-1}}$). Despite its great distance (≈ 120 kpc) from the Milky Way, the external field of the host ($g_{ex} \approx 282\ \mathrm{km^2\,s^{-2}\,kpc^{-1}}$) comfortably exceeds the internal field. Consequently, Crater II should be subject to the external field effect, a feature unique to MOND. This leads to the prediction of a very low velocity dispersion: $\sigma_{efe} = 2.1^{+0.9}_{-0.6}\ \mathrm{km\,s^{-1}}$.

Keywords: dark matter — galaxies: dwarf — galaxies: kinematics and dynamics



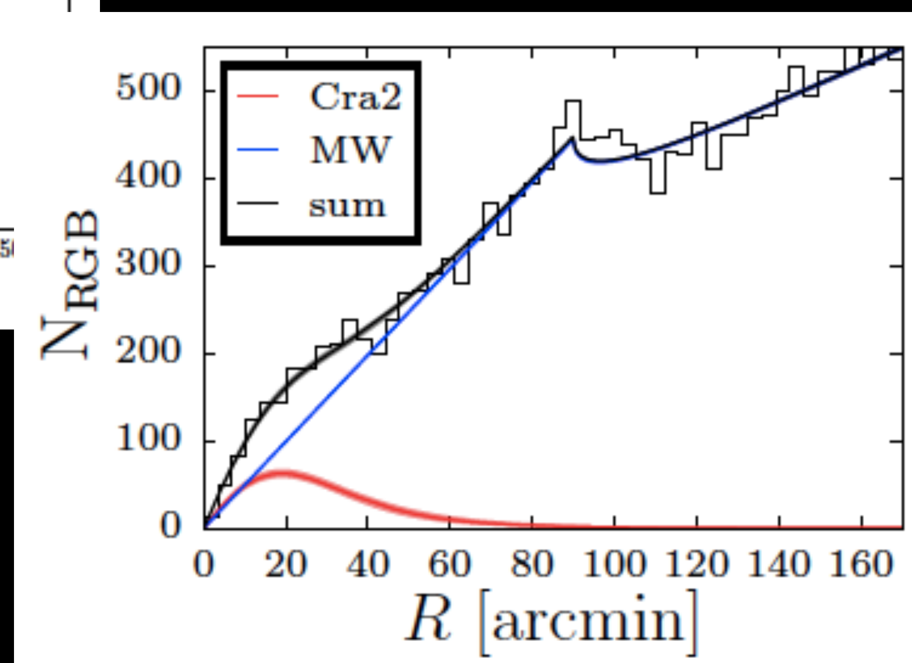
−8
−9
−10
−11
−12
−13
$\log_{10}[g_{\rm obs}/(\rm m\,s^{-2})]$
AndXIX
Cra2
−15
−14
−13
−12
−11
−10
−9
−8
$\log_{10}[g_{\rm bar}/(\rm m\,s^{-2})]$

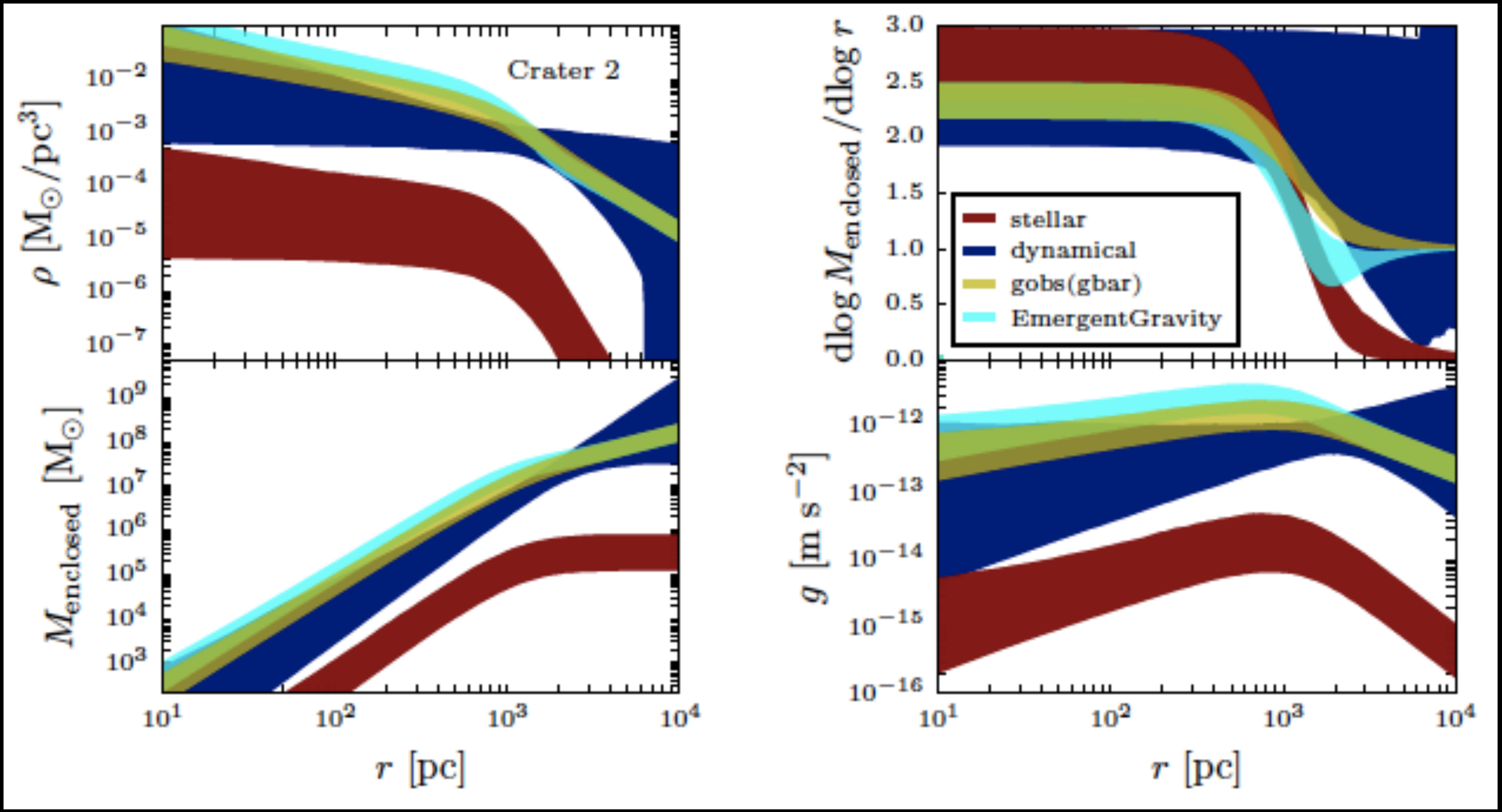
MGW et al.



$$g_{\rm obs} = \frac{g_{\rm bar}}{1 - \exp[-\sqrt{g_{\rm bar}/g_\dagger}]}$$

$$g_{\rm obs,EG} = g_{\rm bar} + \sqrt{\frac{g_\dagger}{r^2}\frac{\rm d}{{\rm d}r}(r^3 g_{\rm bar})}$$

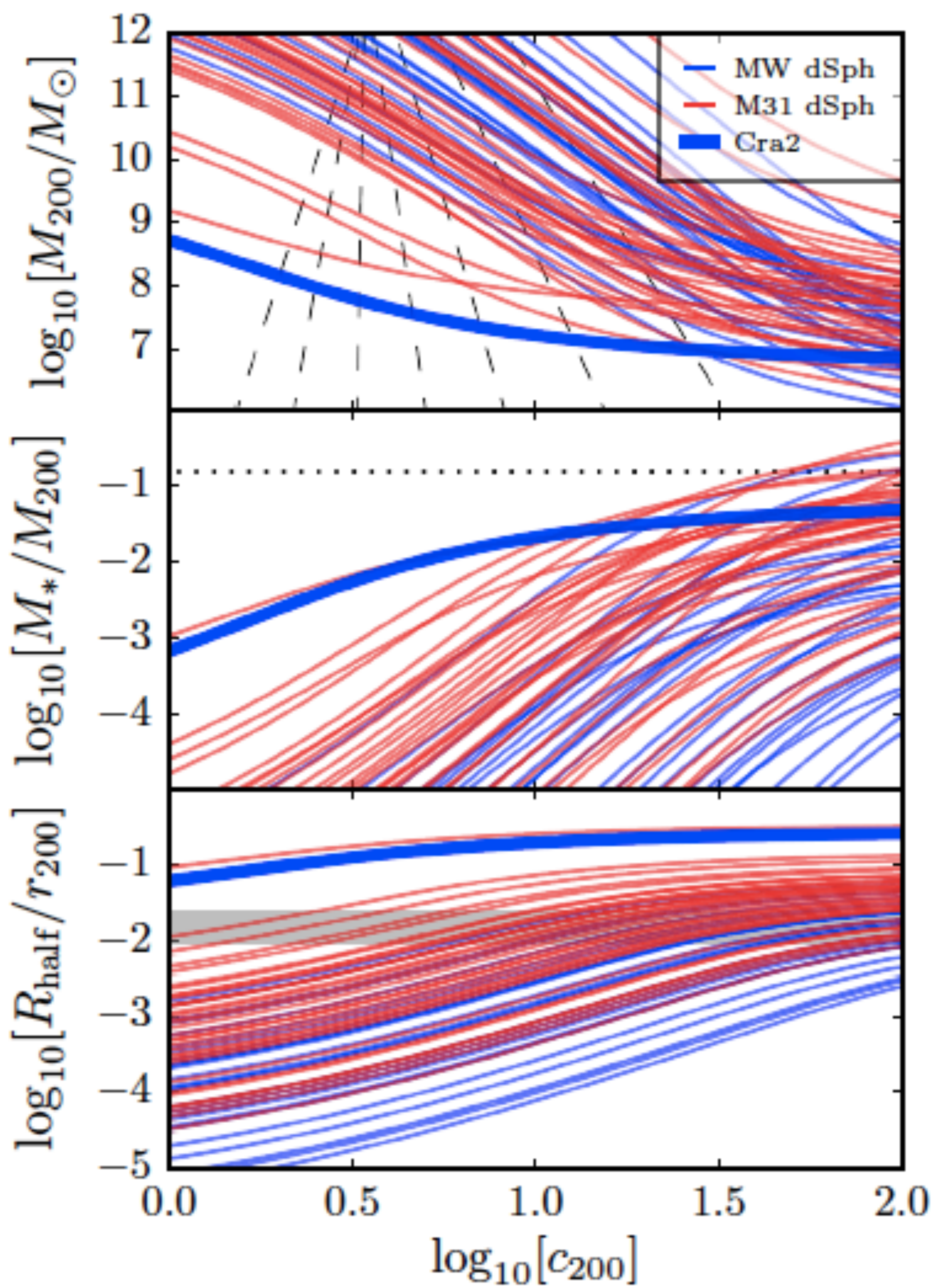




$$g_{obs} = \frac{g_{bar}}{1 - \exp[-\sqrt{g_{bar}/g_\dagger}]}$$

$$g_{obs,EG} = g_{bar} + \sqrt{\frac{g_\dagger}{r^2}\frac{d}{dr}(r^3 g_{bar})}$$

MGW et al.

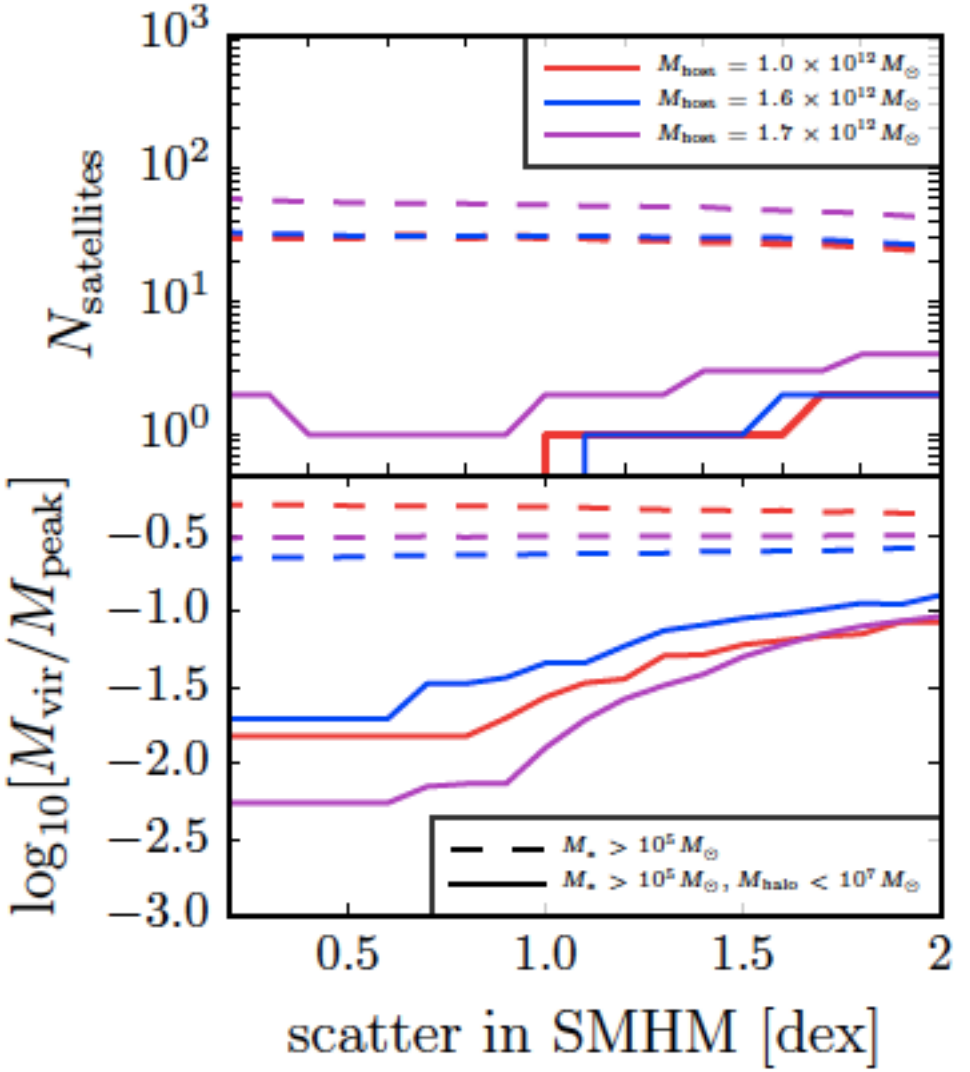


MW dSph
M31 dSph
Cra2
$\log_{10}[M_{200}/M_\odot]$
$\log_{10}[M_*/M_{200}]$
$\log_{10}[R_{\rm half}/r_{200}]$
$\log_{10}[c_{200}]$
12
11
10
9
8
7
−1
−2
−3
−4
−5
0.0
0.5
1.0
1.5
2.0

MGW et al.

Organized Chaos: Scatter in the relation between stellar mass and halo mass in small galaxies

Shea Garrison-Kimmel[1*], James S. Bullock[2], Michael Boylan-Kolchin[3], Emma Bardwell[4]
[1]TAPIR, California Institute of Technology, Pasadena, CA 91125, USA
[2]Center for Cosmology, Department of Physics and Astronomy, University of Ca
[3]Department of Astronomy, The University of Texas at Austin, 2515 Speedway,
[4]Case Western Reserve University, Cleveland, Ohio 44106, USA

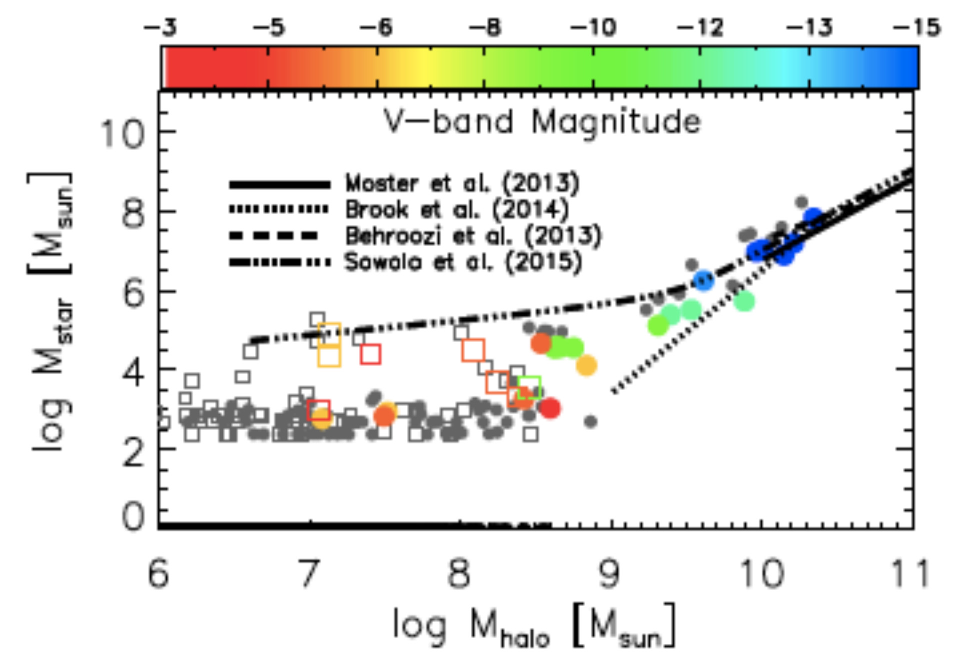


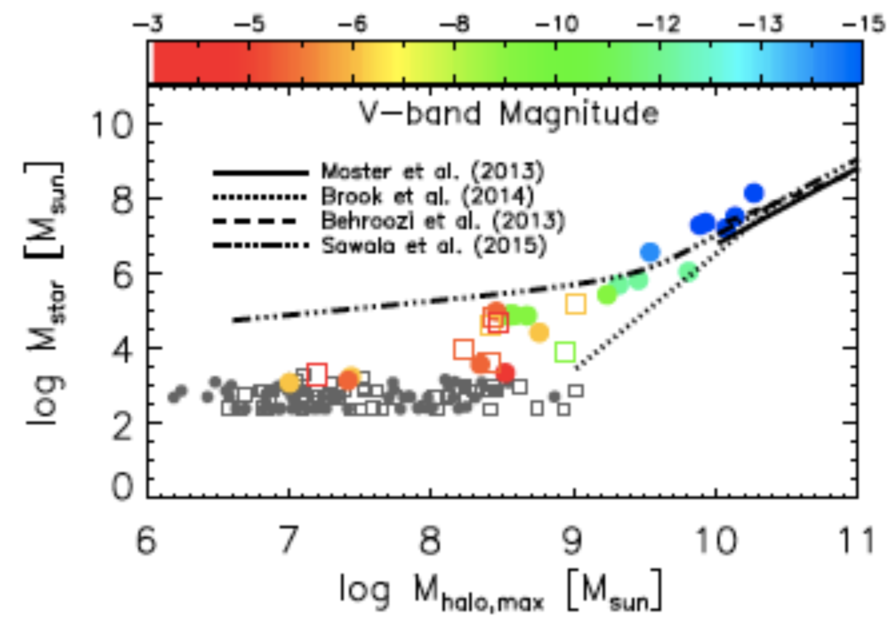
$$M_\star \propto M_{\rm halo}^{\alpha}$$

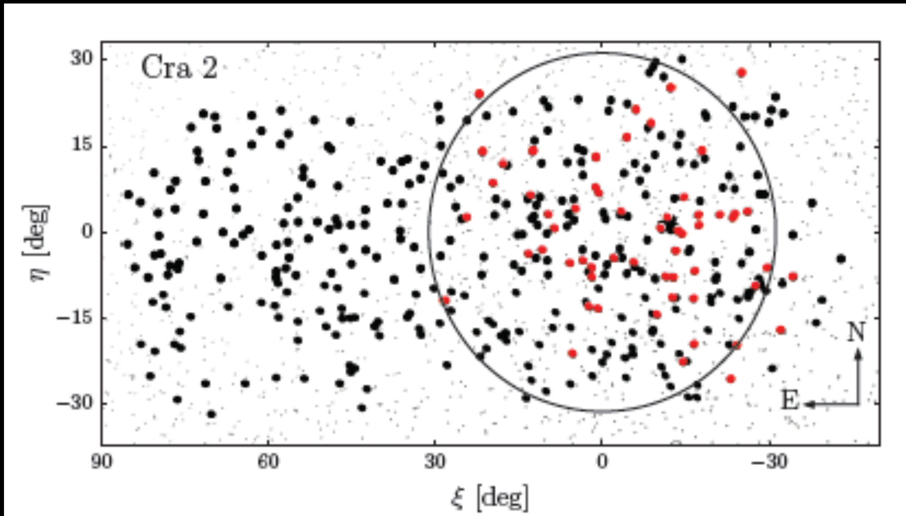
$$\alpha_{\rm sats} \cong 0.14\sigma^2 + 0.14\sigma + 1.79$$

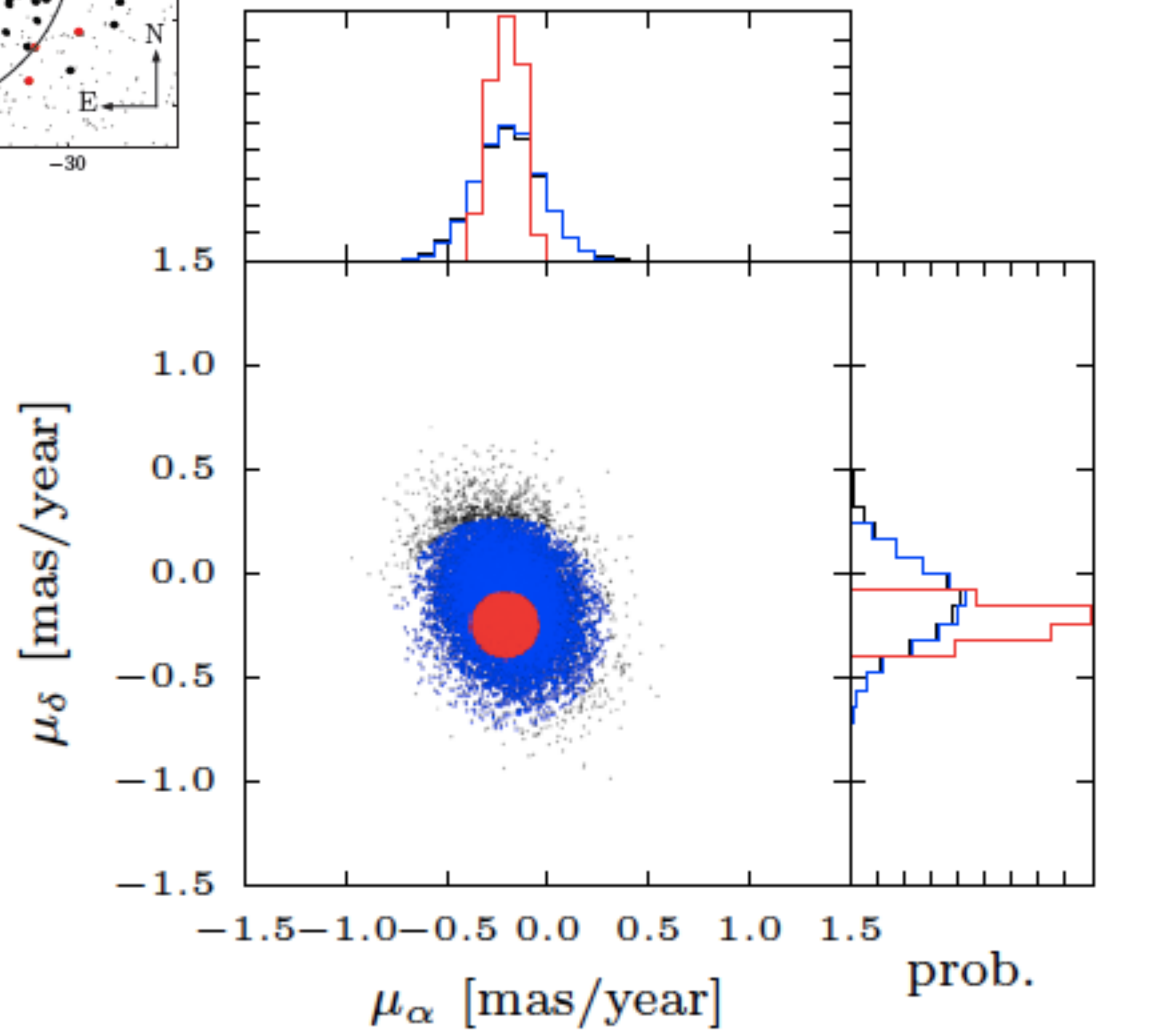
Going, going, gone dark: Quantifying the Scatter in the Faintest Dwarf Galaxies

Ferah Munshi[1,2], Alyson M. Brooks[1], Elaad Applebaum[1], Daniel R. Weisz[3], Fabio Governato[4], Thomas R. Quinn[4]

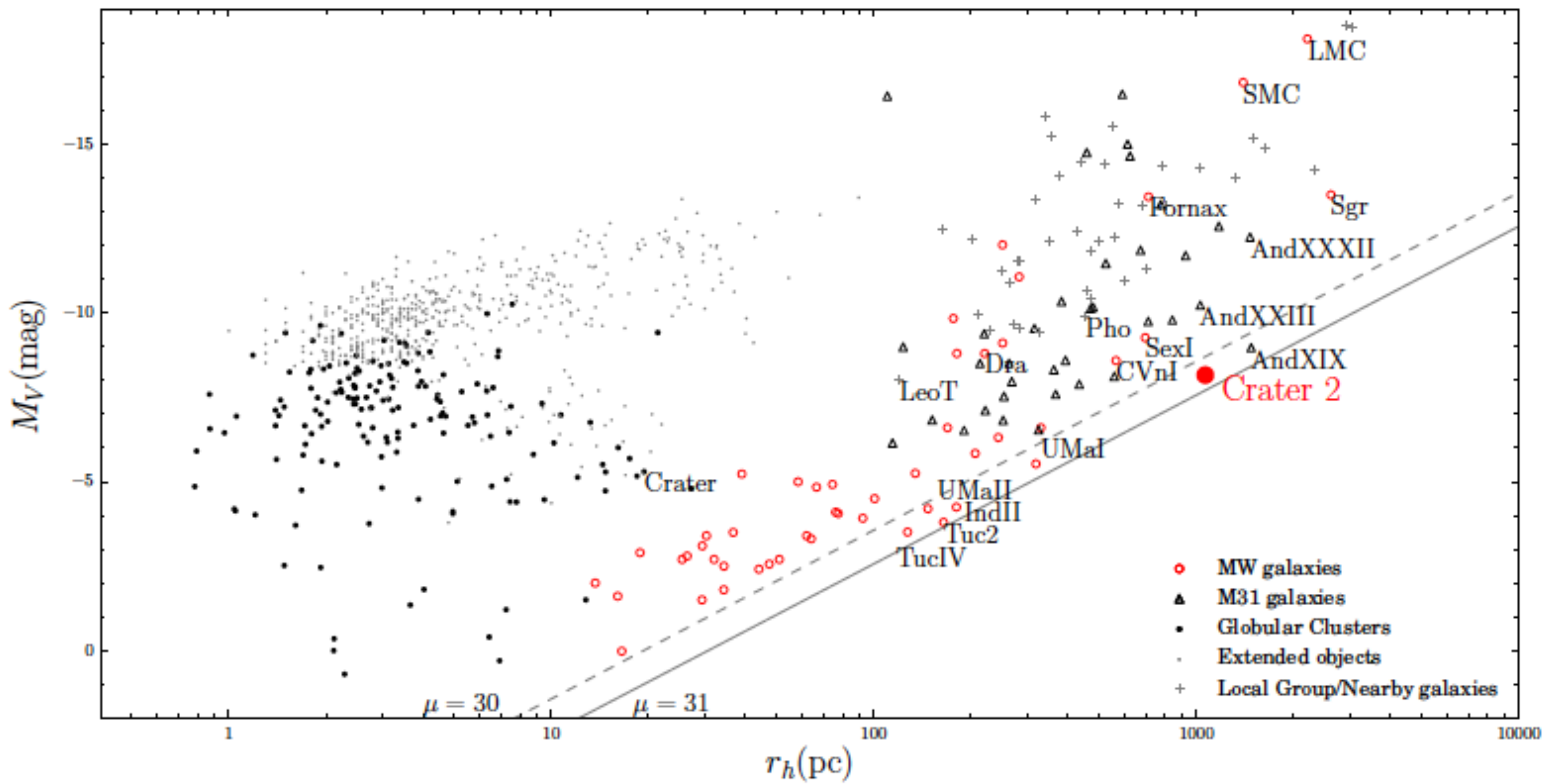








MGW et al.



LMC
SMC
Fornax
Sgr
AndXXXII
AndXXIII
Pho
SexI
AndXIX
CVnI
Crater 2
Dra
LeoT
UMaI
Crater
UMaII
IndII
Tuc2
TucIV
MW galaxies
M31 galaxies
Globular Clusters
Extended objects
Local Group/Nearby galaxies
$\mu = 30$
$\mu = 31$
M_V(mag)
r_h(pc)

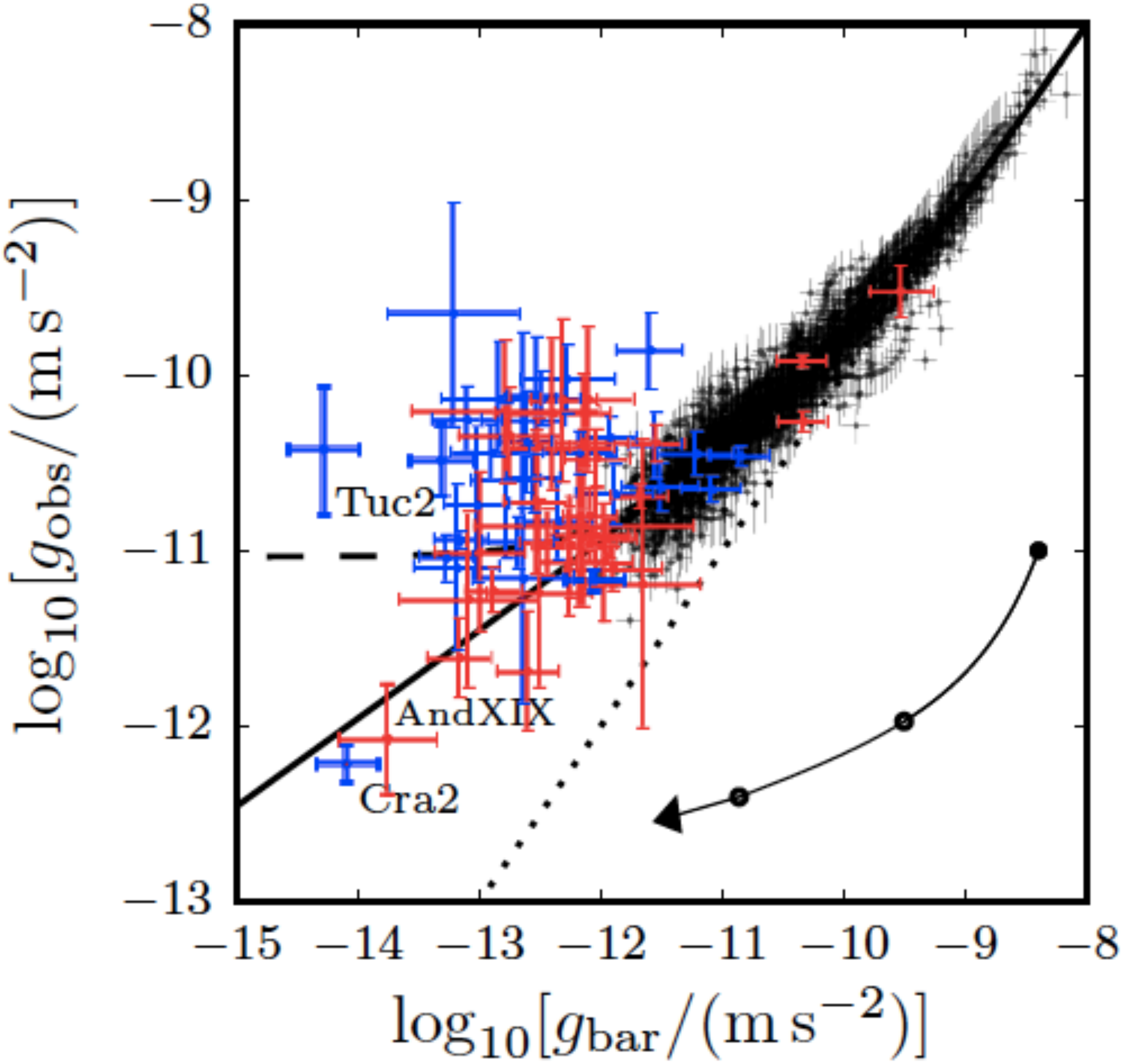
MAGELLAN/M2FS SPECTROSCOPY OF TUCANA 2 AND GRUS 1*

MATTHEW G. WALKER[1], MARIO MATEO[2], EDWARD W. OLSZEWSKI[3], SERGEY KOPOSOV[4], VASILY BELOKUROV[4], PRASHIN JETHWA[4], DAVID L. NIDEVER[2,5], VINCENT BONNIVARD[6], JOHN I. BAILEY III[2], ERIC F. BELL[2], SARAH R. LOEBMAN[2]

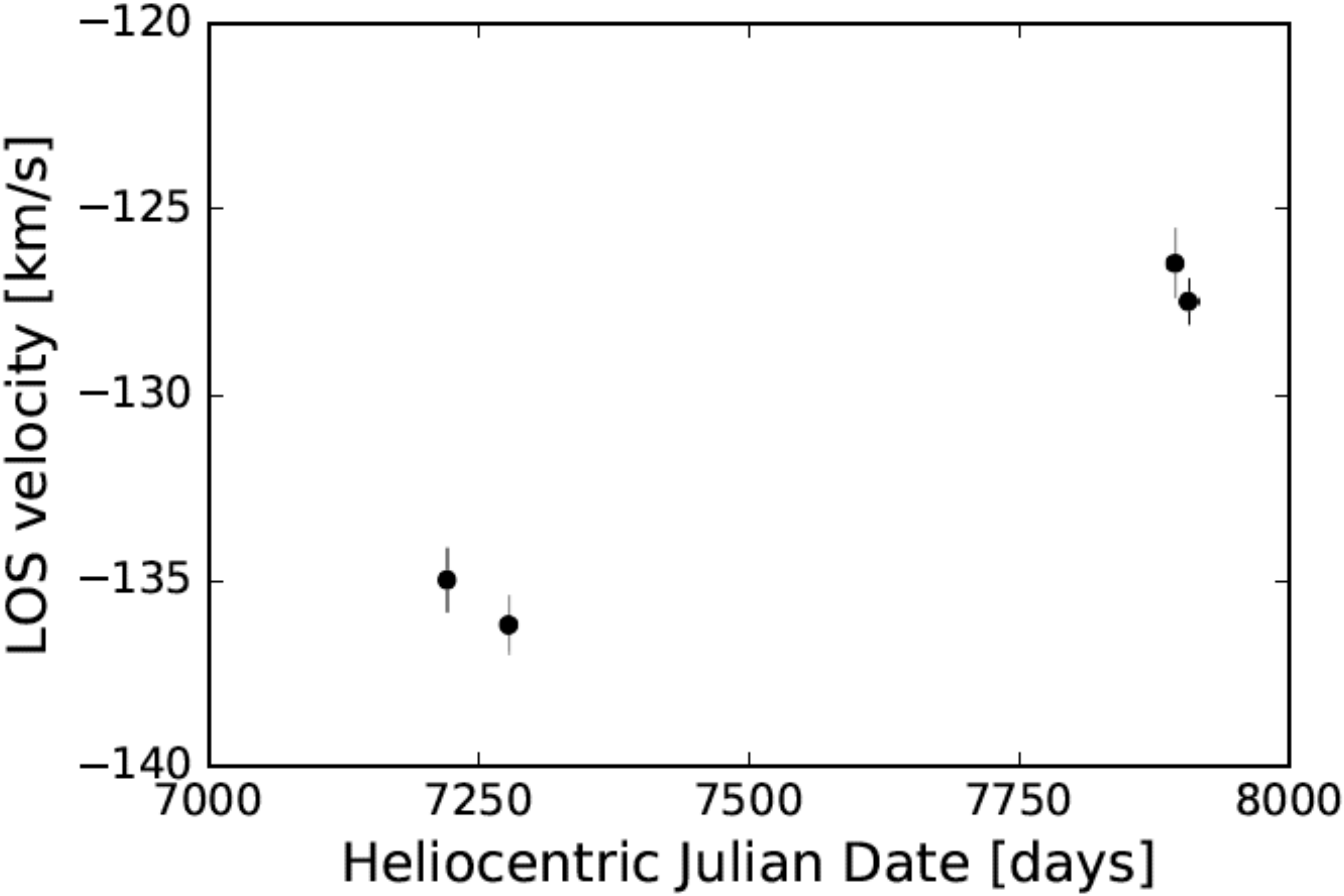
Draft version November 19, 2015

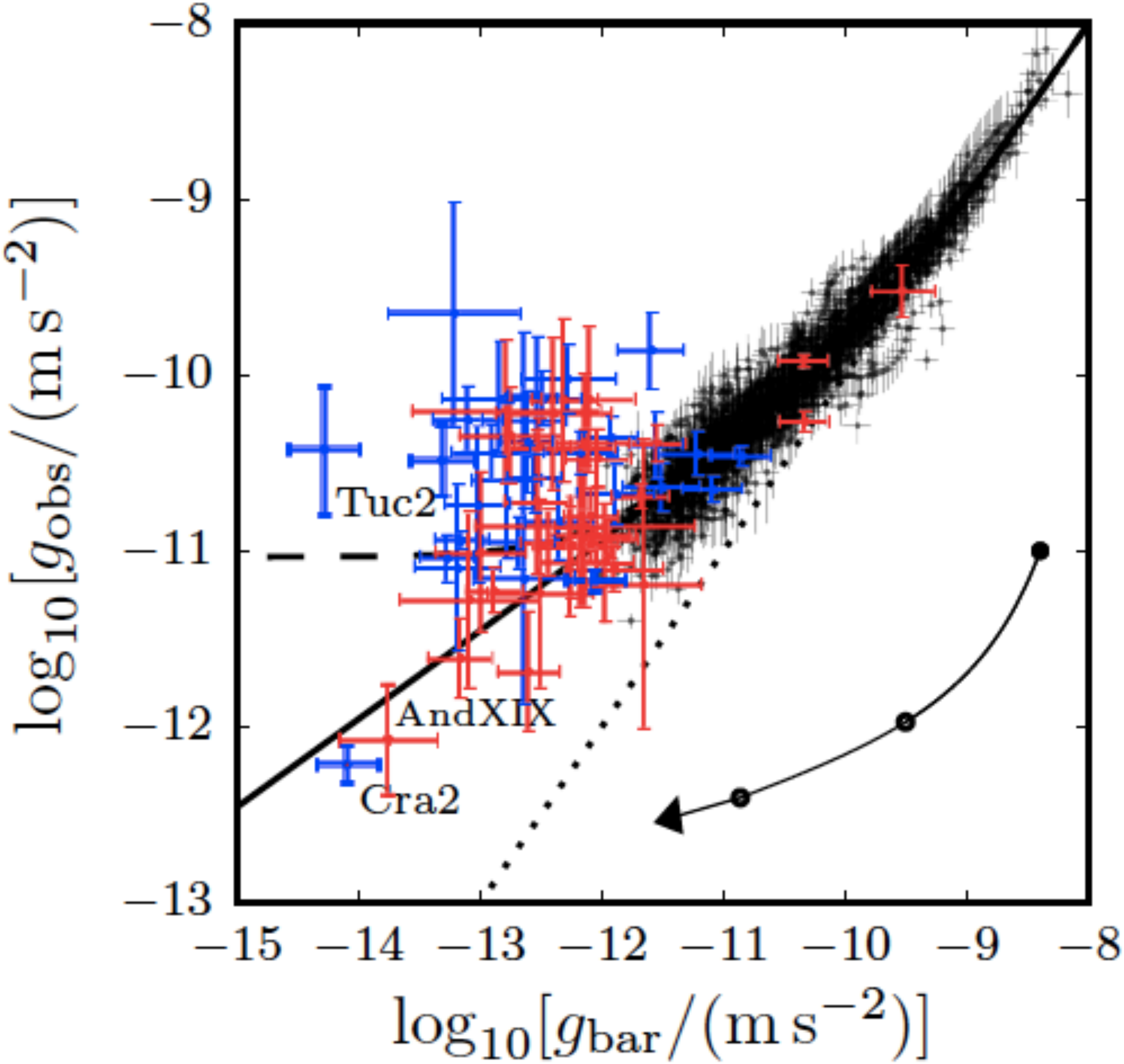
TABLE 1
M2FS STELLAR SPECTROSCOPY OF TUCANA 2 AND GRU 1[a]

ID	α_{2000} [hh:mm:ss]	δ_{2000} [°:′:″]	g [mag]	r [mag]	HJD[b] [days]	S/N[c]	$v_{\rm los}$ [km s^{-1}][d]	$T_{\rm eff}$ [K]	$\log_{10}[g/({\rm cm/s^2})]$ [dex][d]	[Fe/H] [dex]	$P_{\rm member}$
Tuc2-006	22:51:43.06	-58:32:33.7	18.78	18.12	7221.82	11.9[H]	$-128.5\pm0.7^{(0.0,3.3)}$	$5050\pm149^{(0.2,3.0)}$	$1.92\pm0.38^{(-0.2,3.1)}$	$-2.48\pm0.19^{(0.1,2.9)}$	1.00 ± 0.00
					7278.50	14.5[H]	$-127.9\pm0.8^{(0.6,4.4)}$	$4985\pm141^{(0.3,3.1)}$	$1.96\pm0.50^{(-0.1,2.6)}$	$-2.77\pm0.18^{(0.3,2.9)}$	
Tuc2-011	22:51:50.28	-58:37:40.2	18.27	17.57	7221.82	18.9[H]	$-127.6\pm0.5^{(0.1,2.9)}$	$4779\pm101^{(0.4,3.1)}$	$2.04\pm0.23^{(-0.1,3.2)}$	$-2.42\pm0.14^{(0.3,2.9)}$	1.00 ± 0.00
					7278.50	17.8[H]	$-127.0\pm0.5^{(-0.1,3.0)}$	$4728\pm93^{(0.4,3.2)}$	$1.30\pm0.28^{(-0.1,2.9)}$	$-2.35\pm0.12^{(0.3,3.1)}$	
Tuc2-022	22:52:21.38	-58:31:07.3	19.52	18.93	7221.82	6.4[H]	$-120.2\pm2.0^{(-0.2,2.8)}$	$5322\pm171^{(0.1,3.0)}$	$1.95\pm0.73^{(-0.0,2.5)}$	$-2.42\pm0.26^{(-0.1,2.9)}$	1.00 ± 0.00
Tuc2-033	22:51:08.32	-58:33:08.1	18.68	17.97	7221.82	11.6[H]	$-126.4\pm0.5^{(-0.3,3.1)}$	$4814\pm118^{(0.3,3.0)}$	$1.26\pm0.29^{(-0.3,3.1)}$	$-2.21\pm0.16^{(0.2,2.9)}$	1.00 ± 0.00
					7278.50	12.4[H]	$-128.5\pm0.5^{(-0.2,3.0)}$	$4538\pm109^{(0.2,3.0)}$	$1.28\pm0.29^{(-0.1,3.0)}$	$-2.56\pm0.15^{(0.3,3.0)}$	
Tuc2-047	22:52:22.99	-58:27:51.0	20.91	20.37	7221.82	6.8[M]	$-140.1\pm7.2^{(-0.5,4.5)}$	$5561\pm204^{(0.2,3.0)}$	$1.79\pm0.91^{(0.2,2.5)}$	$-1.60\pm0.32^{(-0.2,3.5)}$	0.88 ± 0.12
Tuc2-052	22:50:51.63	-58:34:32.5	18.83	18.17	7221.82	9.8[H]	$-122.8\pm0.7^{(-0.1,3.5)}$	$5206\pm166^{(0.1,3.0)}$	$1.95\pm0.50^{(-0.3,3.0)}$	$-2.61\pm0.21^{(0.0,2.8)}$	1.00 ± 0.00
					7278.50	11.6[H]	$-123.9\pm0.9^{(0.7,4.2)}$	$4966\pm149^{(0.3,3.1)}$	$1.86\pm0.47^{(-0.1,2.8)}$	$-2.71\pm0.19^{(0.2,3.0)}$	
Tuc2-074	22:53:06.67	-58:31:16.0	19.19	18.77	7221.82	9.4[H]	$-126.0\pm1.5^{(0.0,3.4)}$	$5877\pm210^{(0.1,2.9)}$	$2.23\pm0.68^{(-0.2,2.7)}$	$-1.87\pm0.25^{(-0.1,2.9)}$	0.95 ± 0.09
					7278.50	7.6[H]	$-130.3\pm1.8^{(-0.0,2.9)}$	$5887\pm211^{(0.2,3.0)}$	$2.00\pm0.79^{(0.1,2.4)}$	$-1.75\pm0.27^{(-0.1,2.9)}$	
Tuc2-078	22:50:41.07	-58:31:08.3	18.62	17.97	7221.82	8.9[H]	$-135.0\pm0.9^{(0.1,3.1)}$	$5090\pm149^{(0.3,3.0)}$	$2.11\pm0.41^{(-0.3,3.2)}$	$-2.14\pm0.19^{(0.1,2.9)}$	0.99 ± 0.04
					7278.50	11.3[H]	$-135.8\pm0.8^{(-0.2,3.4)}$	$4936\pm133^{(0.3,3.1)}$	$1.96\pm0.35^{(-0.2,3.1)}$	$-2.22\pm0.17^{(0.2,2.9)}$	



−8
−9
−10
−11
−12
−13
−15
−14
−13
−12
−11
−10
−9
−8
Tuc2
AndXIX
Cra2
$\log_{10}[g_{\rm obs}/(\rm m\,s^{-2})]$
$\log_{10}[g_{\rm bar}/(\rm m\,s^{-2})]$


−120
−125
−130
−135
−140
LOS velocity [km/s]
7000
7250
7500
7750
8000
Heliocentric Julian Date [days]



Tuc2
AndXIX
Cra2
−8
−9
−10
−11
−12
−13
−15
−14
−13
−12
−11
−10
−9
−8
$\log_{10}[g_{\rm obs}/(\rm m\,s^{-2})]$
$\log_{10}[g_{\rm bar}/(\rm m\,s^{-2})]$

Summary

- dSphs on gobs(gbar) are a mess.
  - mass loss, core formation, binary stars, external field, …
- At lowest observed accelerations, Cra2, (& AndXIX) agree with MOND
- CDM requires Cra2 to have lost significant halo mass. This is a testable prediction.
- other known low-acceleration targets: Indus 2, Tucana 2, Tucana 4