Is There a Core/Cusp Problem?

Matthew Walker – Carnegie Mellon University

Potsdam Dwarfs

27 August 2014

THE KINEMATIC STATUS AND MASS CONTENT OF THE SCULPTOR DWARF SPHEROIDAL GALAXY[1]

G. BATTAGLIA,[2,3] A. HELMI,[3] E. TOLSTOY,[3] M. IRWIN,[4] V. HILL,[5] AND P. JABLONKA[6]

Dark Matter Cores and Cusps: The Case of Multiple Stellar Populations in Dwarf Spheroidals

N. C. Amorisco[1⋆] and N. W. Evans[1]
[1] *Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK*

A METHOD FOR MEASURING (SLOPES OF) THE MASS PROFILES OF DWARF SPHEROIDAL GALAXIES

MATTHEW G. WALKER[1,2,3] & JORGE PEÑARRUBIA[2]
Draft version September 8, 2011

THE DARK MATTER DENSITY PROFILE OF THE FORNAX DWARF

JOHN R. JARDEL AND KARL GEBHARDT
Department of Astronomy, University of Texas at Austin, 1 University Station C1400, Austin, TX 78712, USA;
jardel@astro.as.utexas.edu, gebhardt@astro.as.utexas.edu
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A VIRIAL CORE IN THE SCULPTOR DWARF SPHEROIDAL GALAXY

A. AGNELLO AND N. W. EVANS
Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
Draft version December 20, 2013

The core size of the Fornax dwarf Spheroidal

N. C. Amorisco[1⋆], A. Agnello[1] and N. W. Evans[1]
[1] *Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK*

Dynamical models for the Sculptor dwarf spheroidal in a ΛCDM universe

Louis E. Strigari[1], Carlos S. Frenk[2] and Simon D. M. White[3]

Kinematics of Milky Way Satellites in a Lambda Cold Dark Matter Universe

Louis E. Strigari[1], Carlos S. Frenk[2] and Simon D. M. White[3]

MEASURING DARK MATTER PROFILES NON-PARAMETRICALLY IN DWARF SPHEROIDALS: AN APPLICATION TO DRACO

JOHN R. JARDEL[1], KARL GEBHARDT[1], MAXIMILIAN FABRICIUS[2], NIV DRORY[3], AND MICHAEL J. WILLIAMS[2]
ACCEPTED TO ApJ: *11 November 2012*

VARIATIONS IN A UNIVERSAL DARK MATTER PROFILE FOR DWARF SPHEROIDALS

JOHN R. JARDEL AND KARL GEBHARDT
Department of Astronomy, University of Texas at Austin, 1 University Station C1400, Austin, TX 78712;
jardel@astro.as.utexas.edu
ACCEPTED TO APJL: *16 August 2013*

On the dark natter profile in Sculptor: breaking the β degeneracy with Virial shape parameters

Thomas Richardson[⋆1], Malcolm Fairbairn[†1]
[1] *Physics, Kings College London, Strand, London WC2R 2LS, UK*

Orbit-based dynamical models of the Sculptor dSph galaxy

Maarten A. Breddels[1⋆], A. Helmi[1], R.C.E. van den Bosch[2], G. van de Ven[2], and G. Battaglia[3]
[1] *Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9700 AV Groningen, the Netherlands*
[2] *Max Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany*
[3] *European Organisation for Astronomical Research in the Southern Hemisphere, K. Schwarzschild-Str. 2, 85748 Garching bei Mnchen, Germany*

Cores in Classical Dwarf Spheroidal Galaxies? A Dispersion-Kurtosis Jeans Analysis Without Restricted Anisotropy

Thomas Richardson[⋆1], Malcolm Fairbairn[†1]
[1] *Physics, Kings College London, Strand, London WC2R 2LS, UK*

A UNIVERSAL MASS PROFILE FOR DWARF SPHEROIDAL GALAXIES?*

MATTHEW G. WALKER[1], MARIO MATEO[2], EDWARD W. OLSZEWSKI[3], JORGE PEÑARRUBIA[1], N. WYN EVANS[1], AND GERARD GILMORE[1]

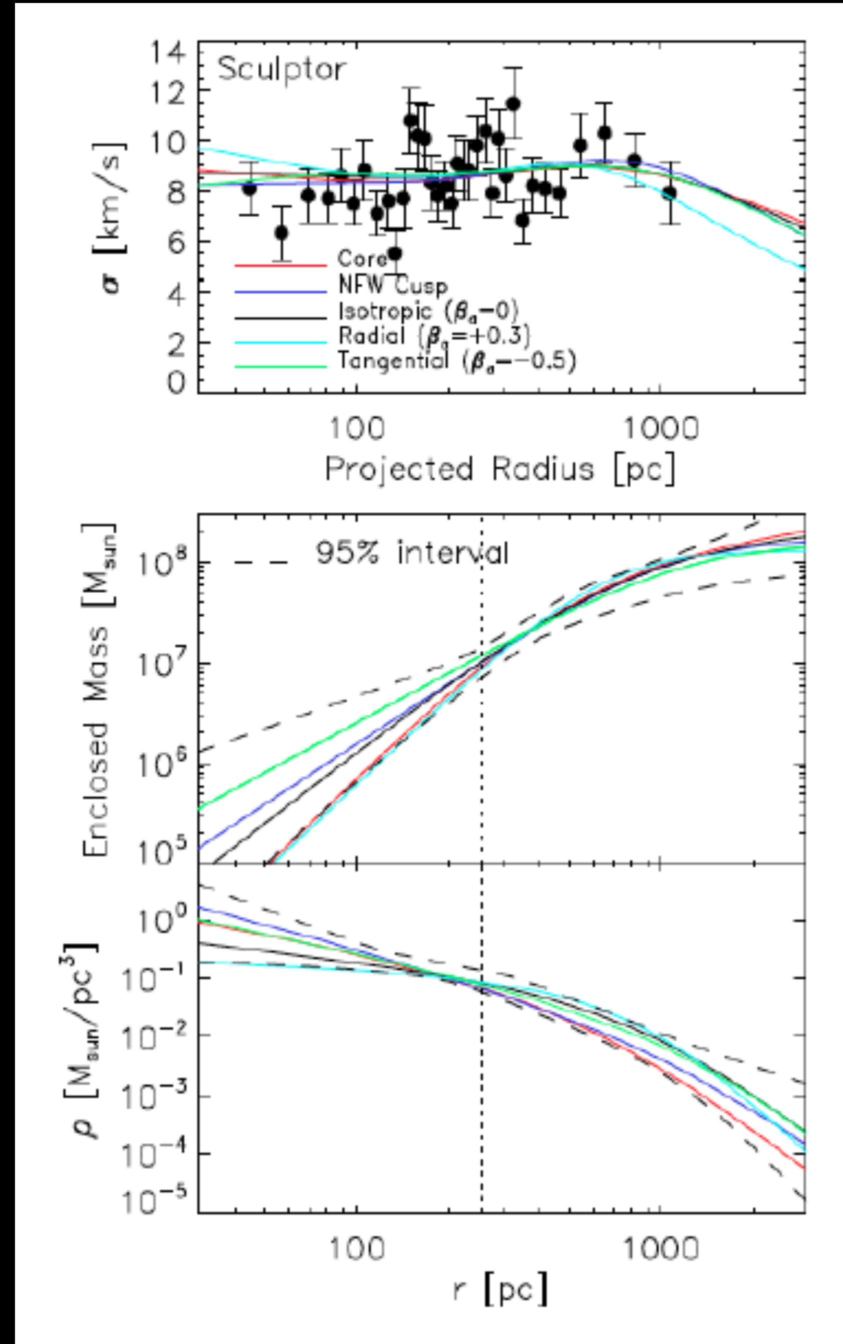
COMPLEXITY ON DWARF GALAXIES SCALE: A BIMODAL DISTRIBUTION FUNCTION IN SCULPTOR

MAARTEN A. BREDDELS AND AMINA HELMI
Kapteyn Astronomical Institute, University of Groningen and
P.O. Box 800, 9700 AV Groningen, The Netherlands
Draft version April 25, 2014

$$\sigma_p^2(R) = \frac{2}{I(R)} \int_R^\infty \left(1 - \beta \frac{R^2}{r^2}\right) \frac{\nu(r)\bar{v_r^2} r}{\sqrt{r^2 - R^2}} dr$$

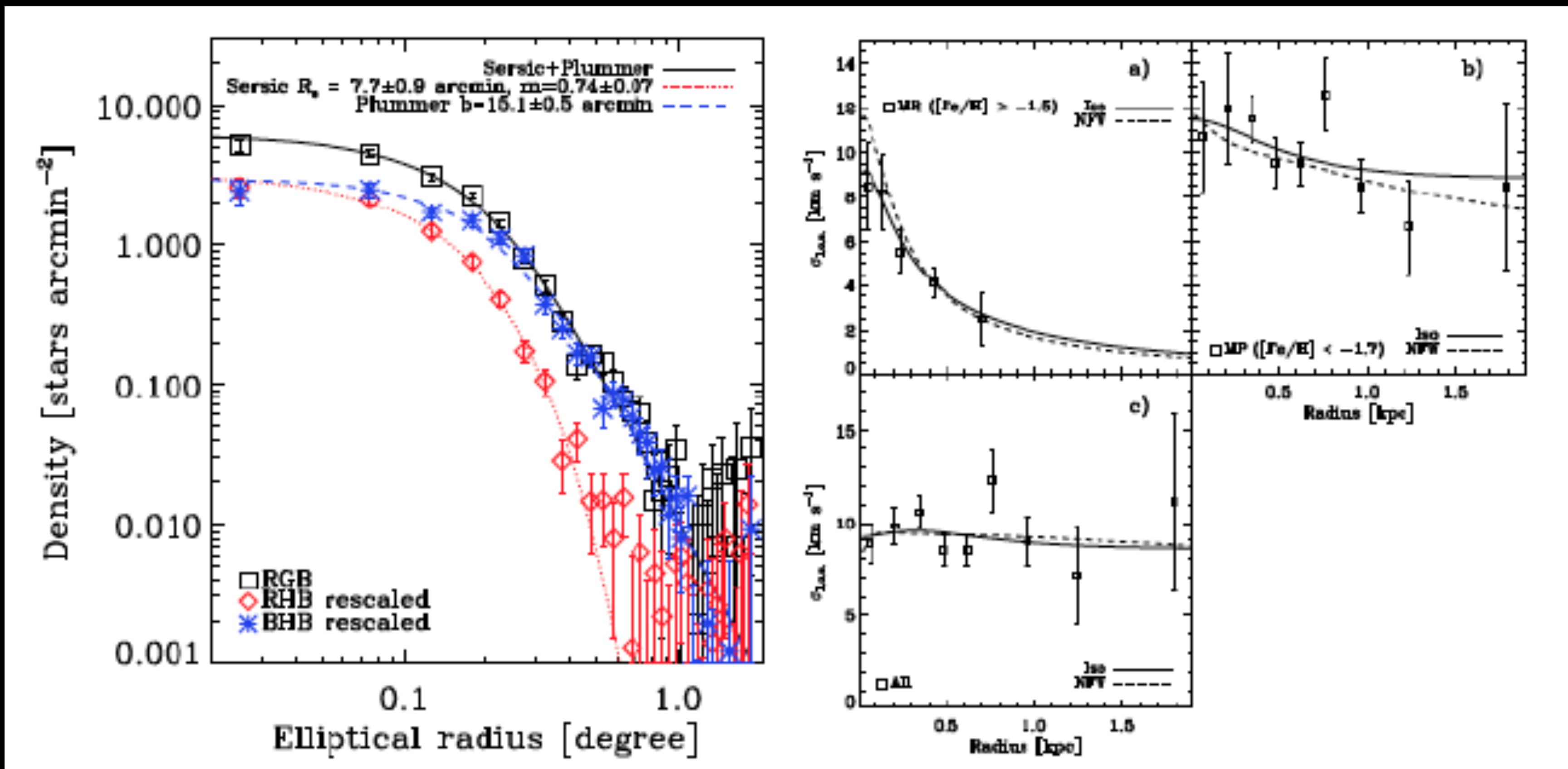
observed

not observed



THE KINEMATIC STATUS AND MASS CONTENT OF THE SCULPTOR DWARF SPHEROIDAL GALAXY[1]

G. Battaglia,[2,3] A. Helmi,[3] E. Tolstoy,[3] M. Irwin,[4] V. Hill,[5] and P. Jablonka[6]

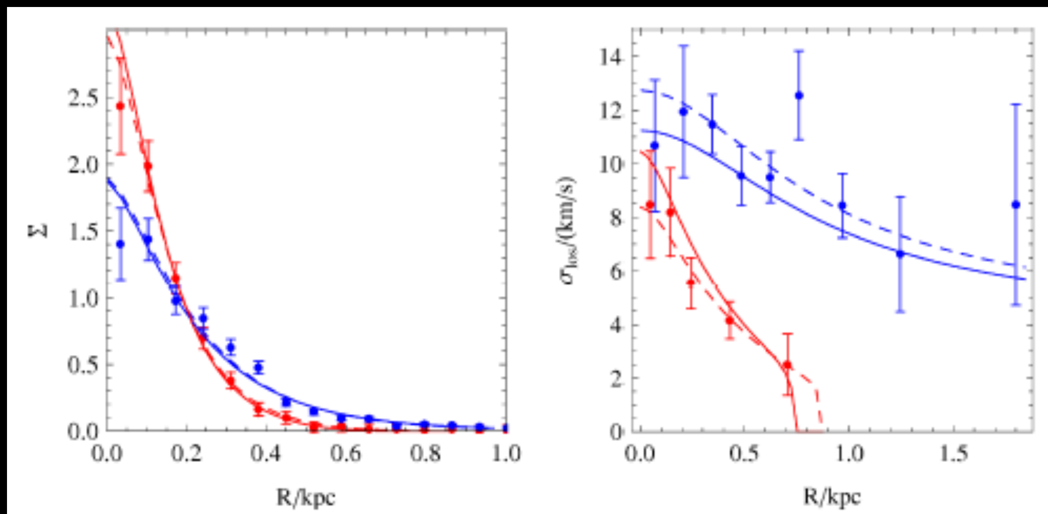


Battaglia etal (2008)

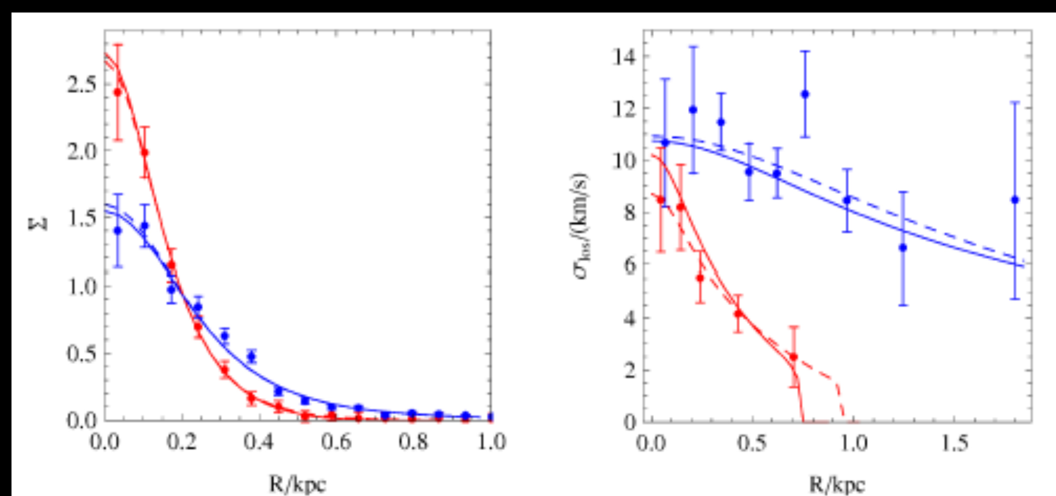
Dark Matter Cores and Cusps: The Case of Multiple Stellar Populations in Dwarf Spheroidals

N. C. Amorisco[1]* and N. W. Evans[1]

[1] *Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK*



Amorisco & Evans (2012)



Dynamical models for the Sculptor dwarf spheroidal in a ΛCDM universe

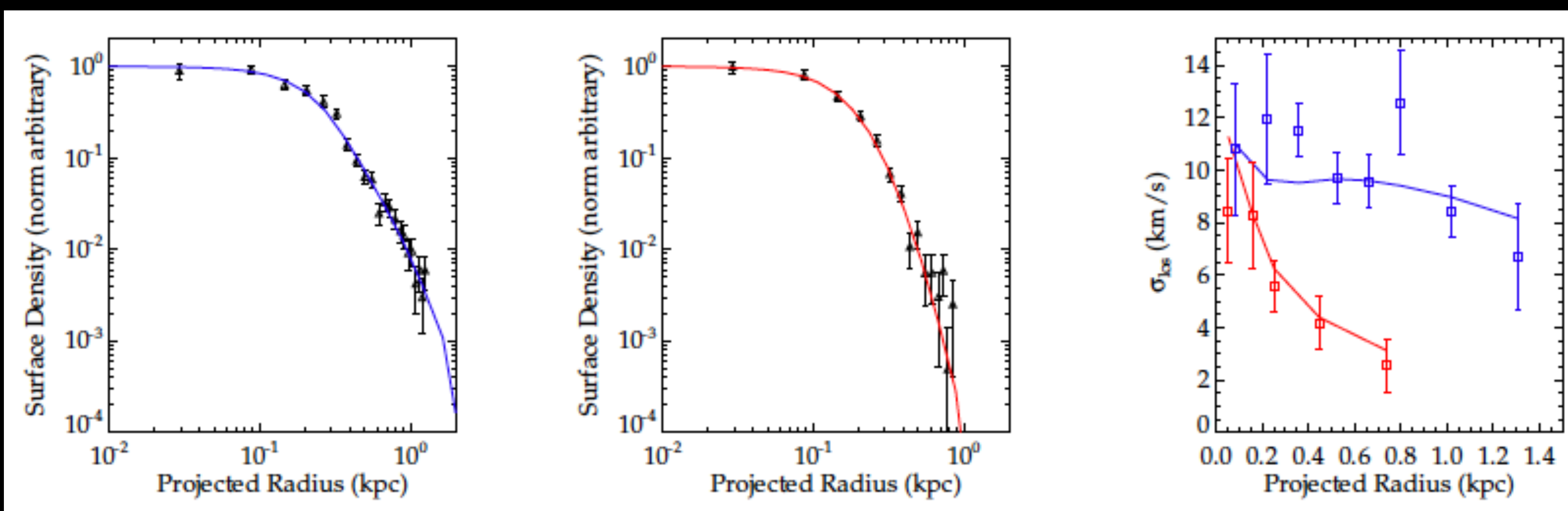
Louis E. Strigari[1], Carlos S. Frenk[2] and Simon D. M. White[3]

$$f(E,J) = g(J)h(E),$$

$$g(J) = \begin{cases} \left[1+(J/J_\beta)^{-b}\right]^{-1}, & \text{for } b \leq 0 \\ 1+(J/J_\beta)^{b}, & \text{for } b > 0. \end{cases}$$

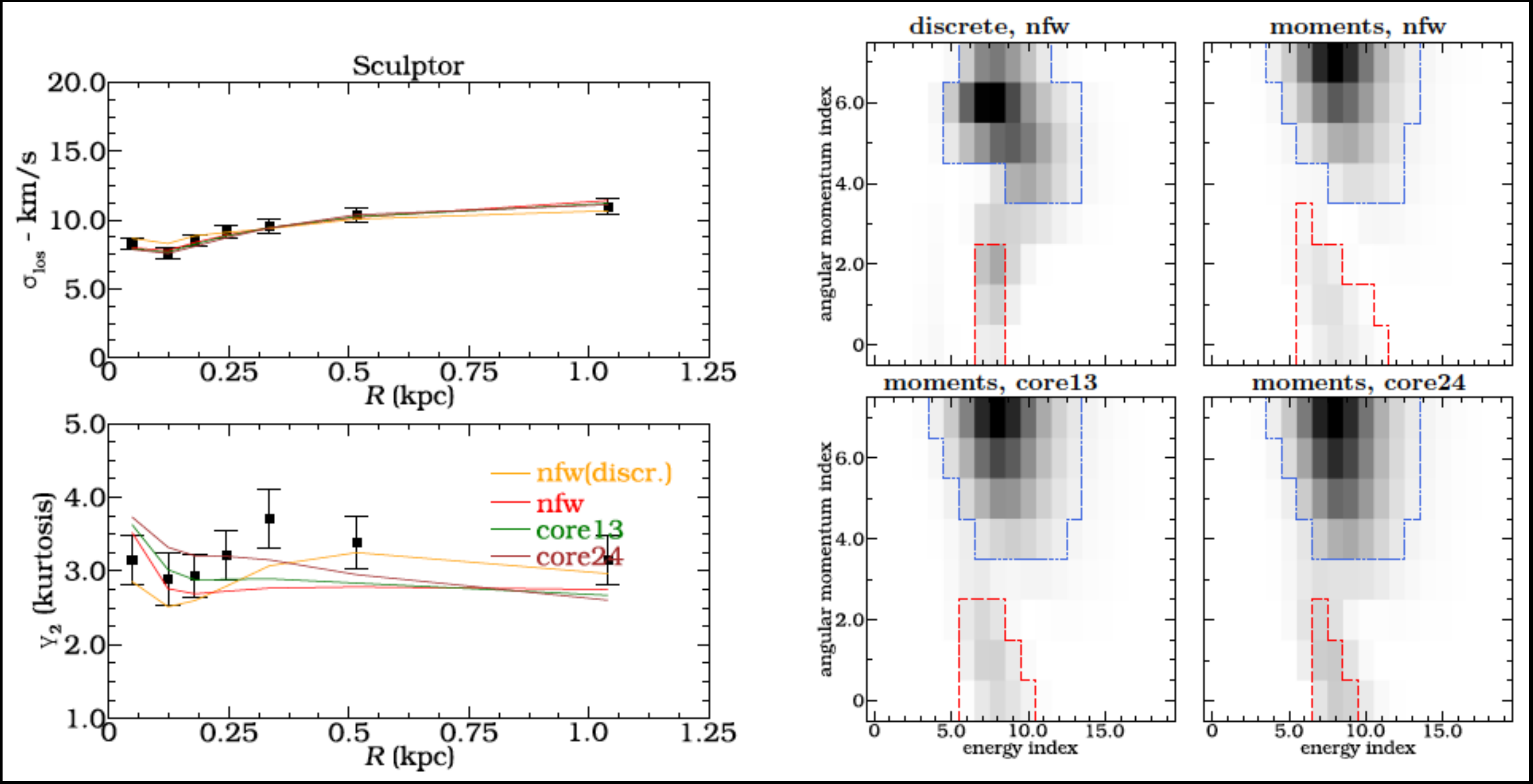
$$h(E) = \begin{cases} NE^a(E^q+E_c^q)^{d/q}(\Phi_{lim}-E)^e & \text{for } E < \Phi_{lim} \\ 0 & \text{for} E \geq \Phi_{lim}, \end{cases}$$

Population	a	d	e	E_c	Φ_{lim}	r_{lim}	b	q	J_β	V_{max}	r_{max}
MR	2.0	-5.3	2.5	0.16	0.45	1.5	-9.0	6.9	8.6×10^{-2}	21	1.5
MP	2.4	-7.9	1.1	0.17	0.60	3.0	0	8.2	–		



COMPLEXITY ON DWARF GALAXIES SCALE: A BIMODAL DISTRIBUTION FUNCTION IN SCULPTOR

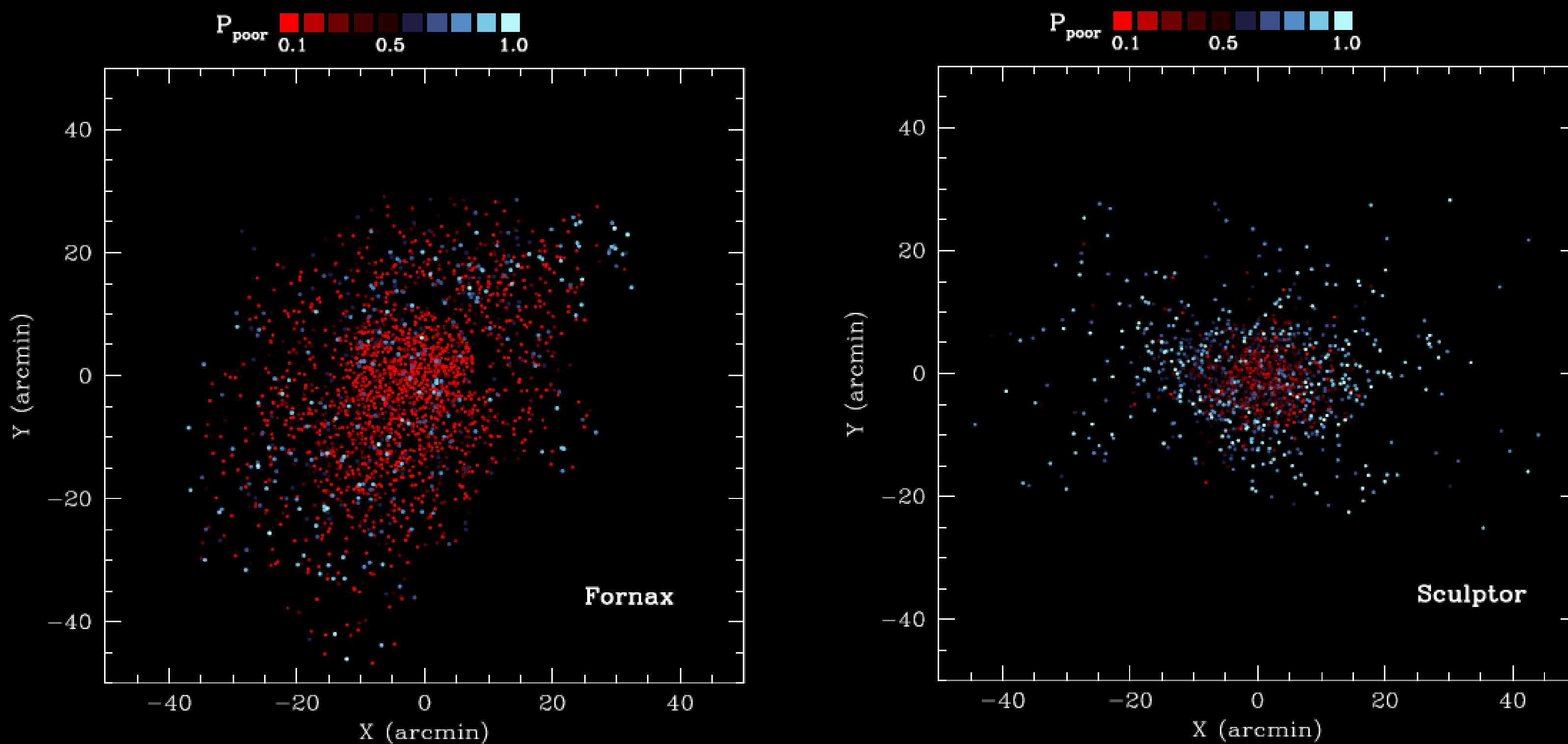
Maarten A. Breddels and Amina Helmi



Breddels & Helmi (2014)

A METHOD FOR MEASURING (SLOPES OF) THE MASS PROFILES OF DWARF SPHEROIDAL GALAXIES

MATTHEW G. WALKER[1,2,3] & JORGE PEÑARRUBIA[2]



$$L(\{R_i,V_i,W_i'\}_{i=1}^{N_{\rm sample}}|\vec{S}) = \prod_{i=1}^{N_{\rm sample}} \left[f_1 \frac{w(R_i)p_1(R_i,V_i,W_i')}{\int\int\int w(R)p_1(R,V,W')dRdVdW'} + f_2 \frac{w(R_i)p_2(R_i,V_i,W_i')}{\int\int\int w(R)p_2(R,V,W')dRdVdW'} + (1-f_1-f_2)\frac{w(R_i)p_{\rm MW}(R_i,V_i,W_i')}{\int\int\int w(R)p_{\rm MW}(R,V,W')dRdVdW'} \right]$$

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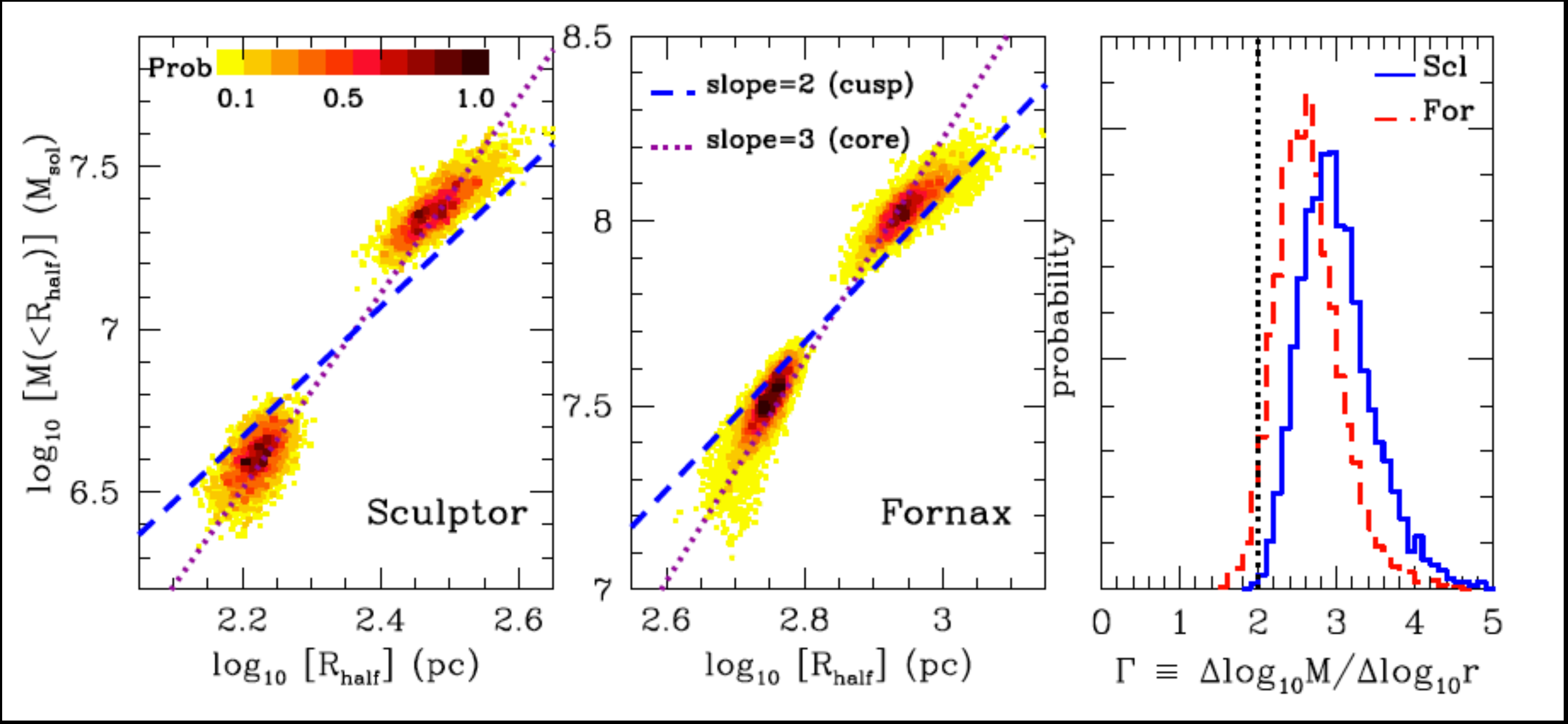
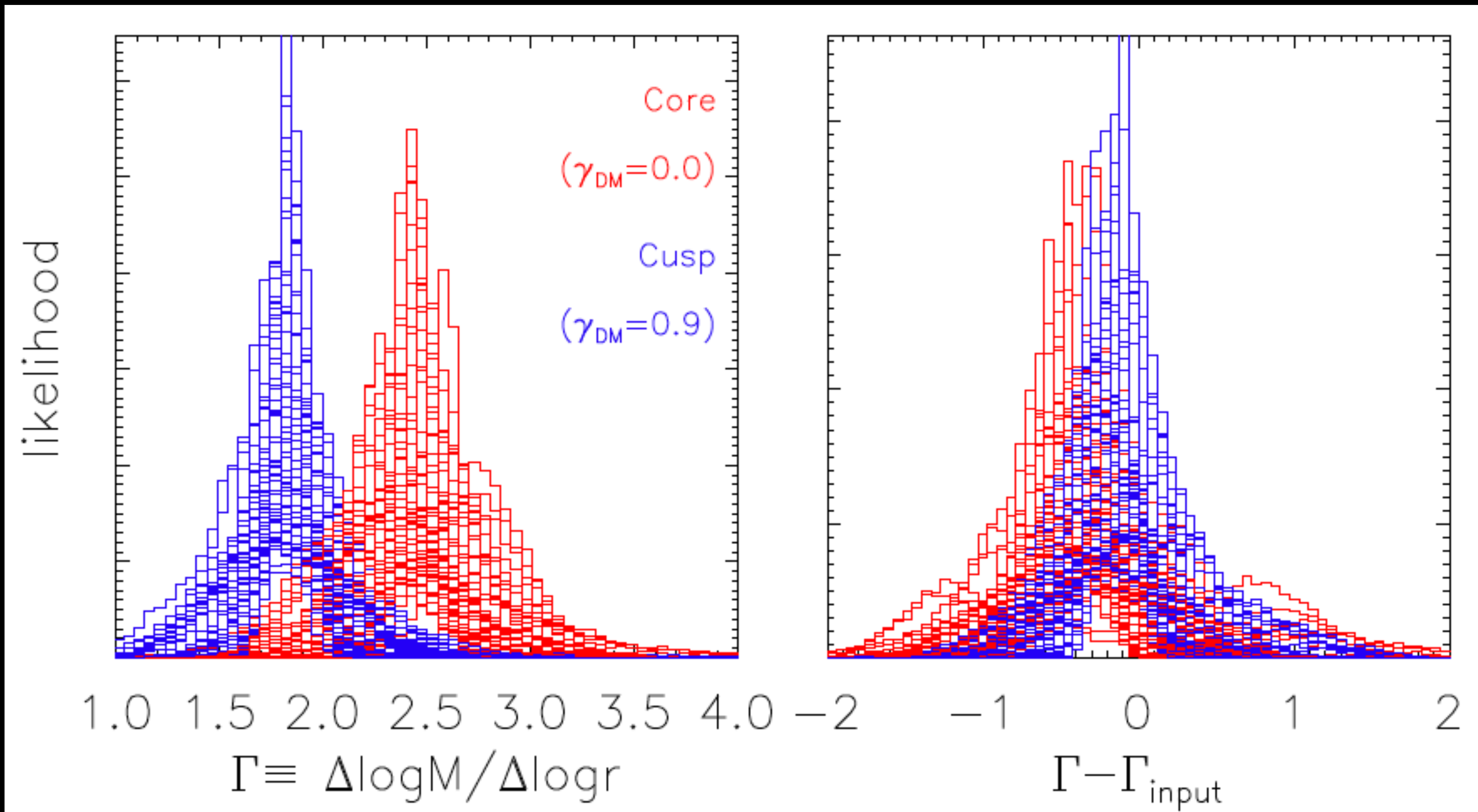
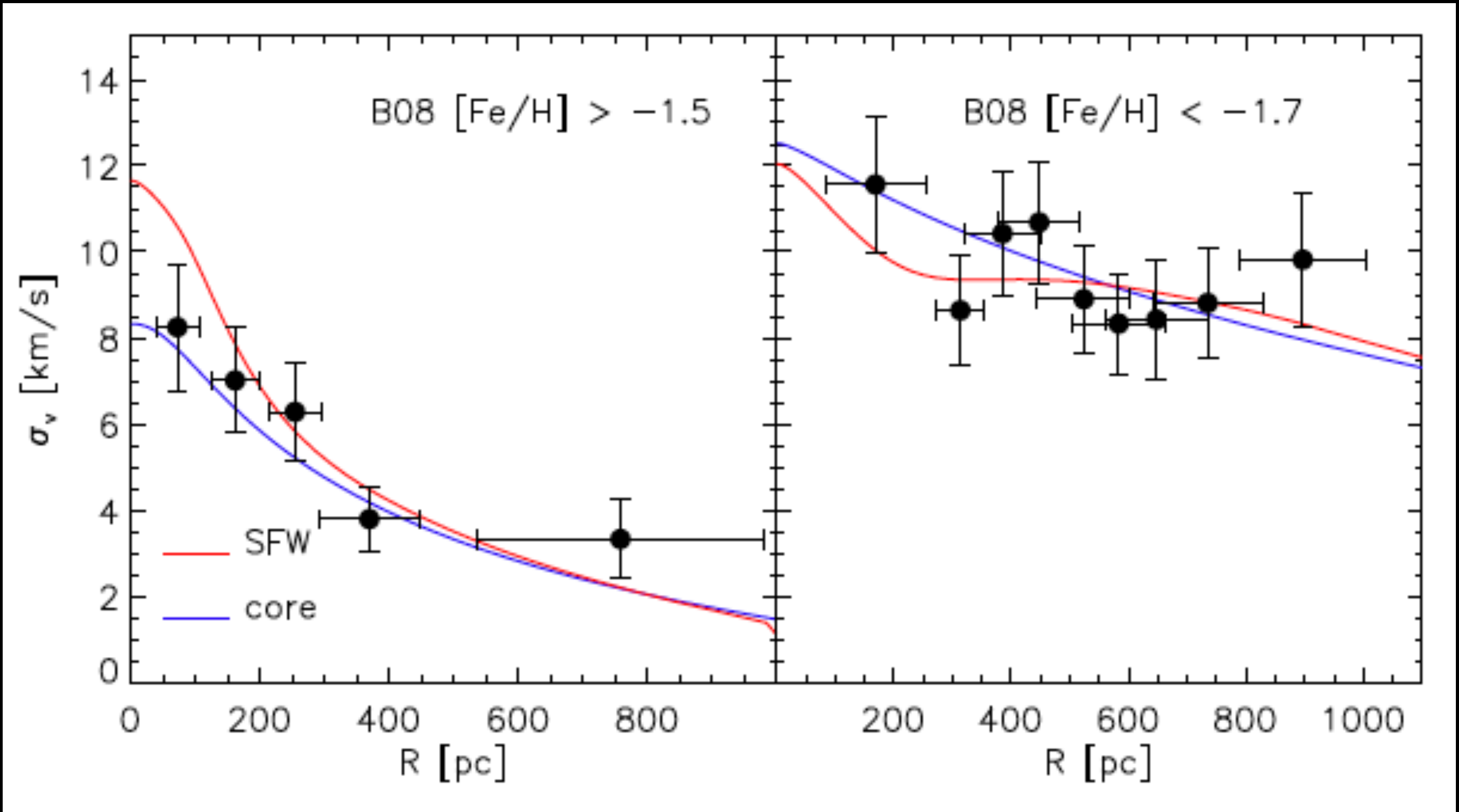
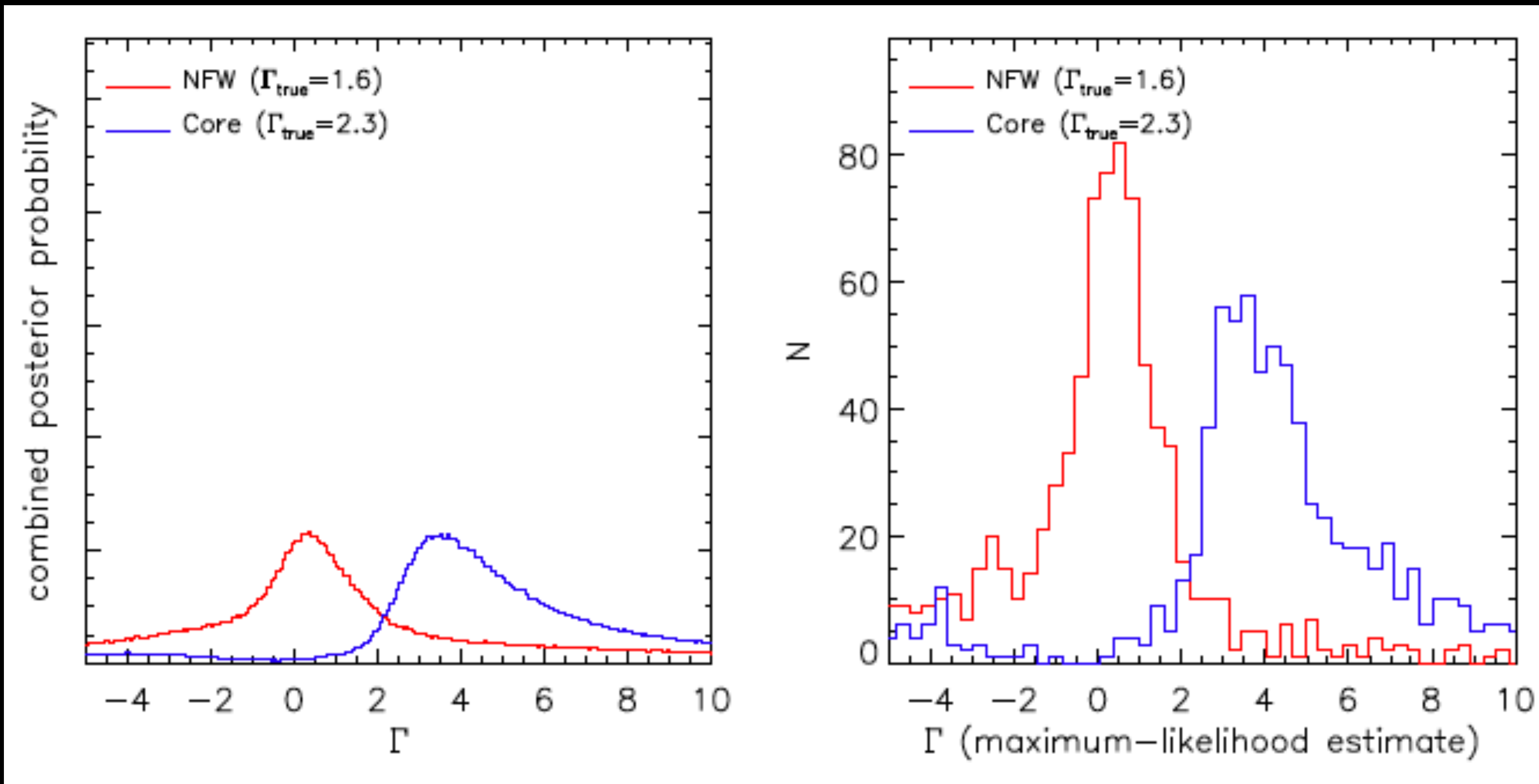


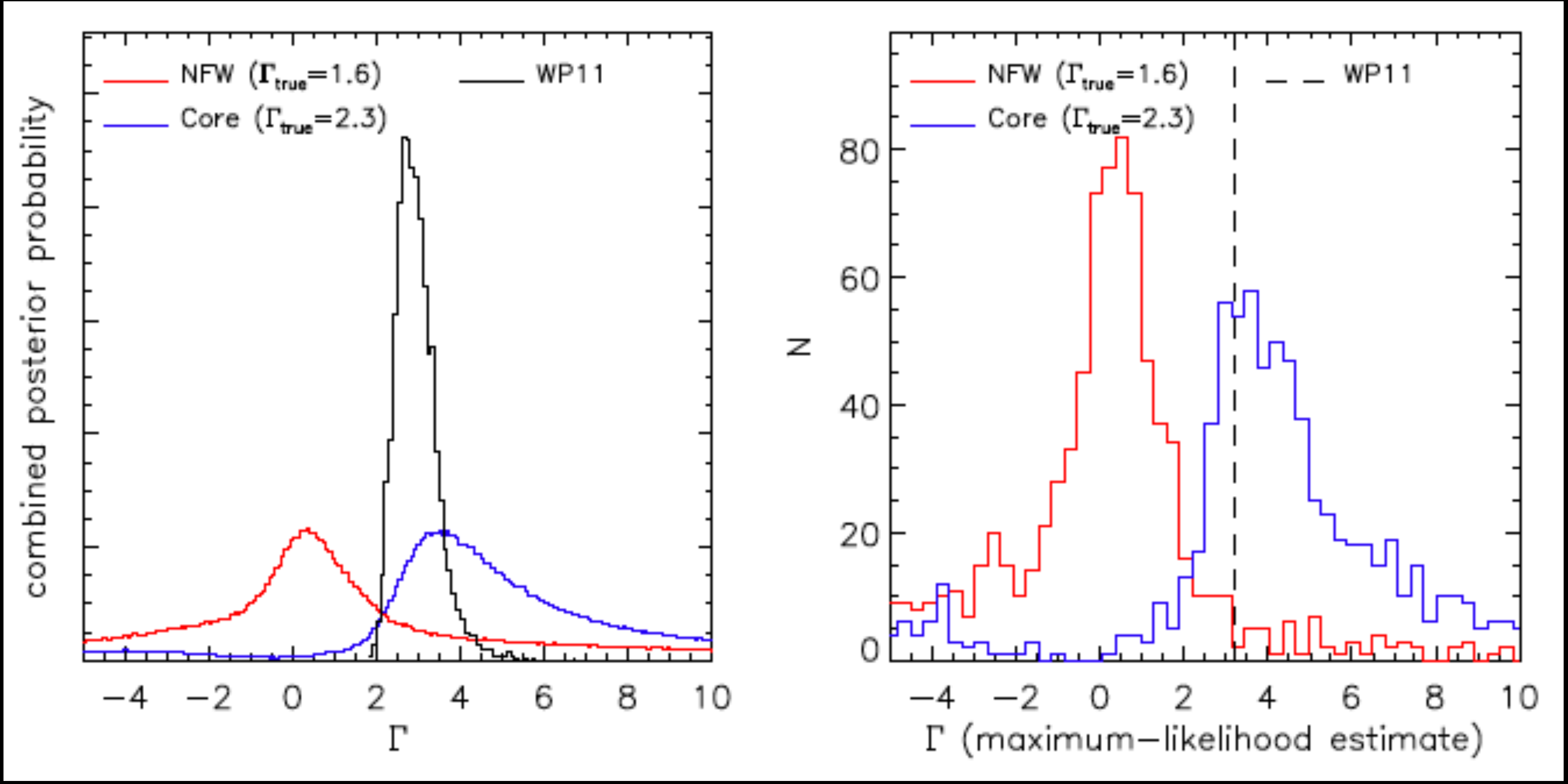


Core
(γ_{DM}=0.0)
Cusp
(γ_{DM}=0.9)
likelihood
1.0 1.5 2.0 2.5 3.0 3.5 4.0
$\Gamma \equiv \Delta \log M / \Delta \log r$
−2 −1 0 1 2
$\Gamma - \Gamma_{input}$


B08 [Fe/H] > −1.5
B08 [Fe/H] < −1.7
SFW
core
σ_v [km/s]
R [pc]
R [pc]
0
2
4
6
8
10
12
14
0
200
400
600
800
200
400
600
800
1000



NFW (Γtrue=1.6)
Core (Γtrue=2.3)
combined posterior probability
−4
−2
0
2
4
6
8
10
Γ
NFW (Γtrue=1.6)
Core (Γtrue=2.3)
N
0
20
40
60
80
−4
−2
0
2
4
6
8
10
Γ (maximum−likelihood estimate)



NFW (Γ_{true}=1.6)
Core (Γ_{true}=2.3)
WP11
combined posterior probability
−4 −2 0 2 4 6 8 10
Γ
NFW (Γ_{true}=1.6)
Core (Γ_{true}=2.3)
WP11
N
0 20 40 60 80
−4 −2 0 2 4 6 8 10
Γ (maximum−likelihood estimate)

Bayesian analysis of resolved stellar spectra: application to MMT/Hectochelle Observations of the Draco dwarf spheroidal

Matthew G. Walker[1,2]⋆, Edward W. Olszewski[3] and Mario Mateo[4]†

[1]*McWilliams Center for Cosmology, Carnegie Mellon University, 5000 Forbes Ave., Pittsburgh, PA 15213, United States*

[2]*Harvard-Smithsonian Center for Astrophysics, 60 Garden St., Cambridge, MA 02138, United States*

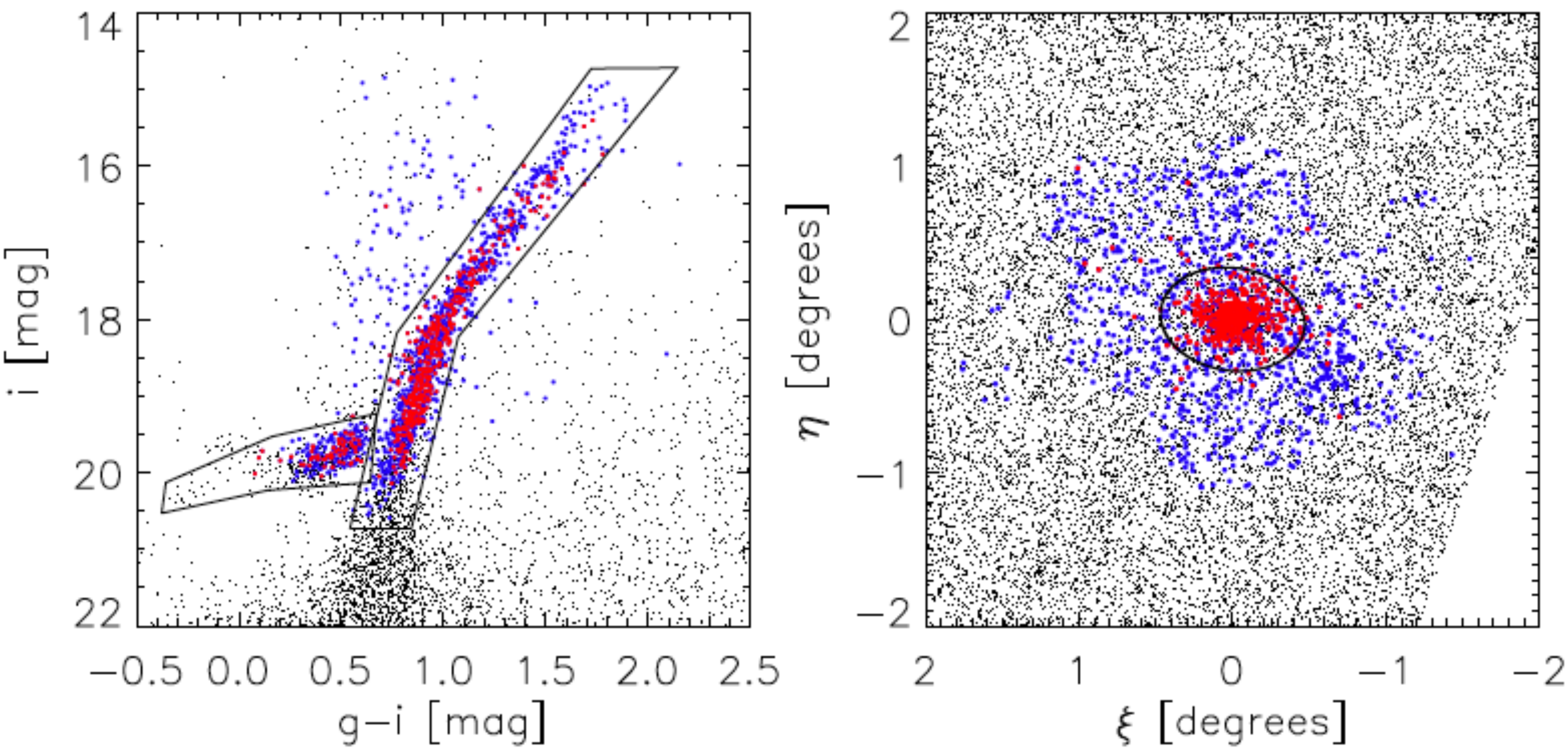
[3]*Steward Observatory, The University of Arizona, 933 N. Cherry Ave., Tucson, AZ 85721, United States*

[4]*University of Michigan, 311 West Hall, 1085 S. University Ave., Ann Arbor, MI 48109, United States*

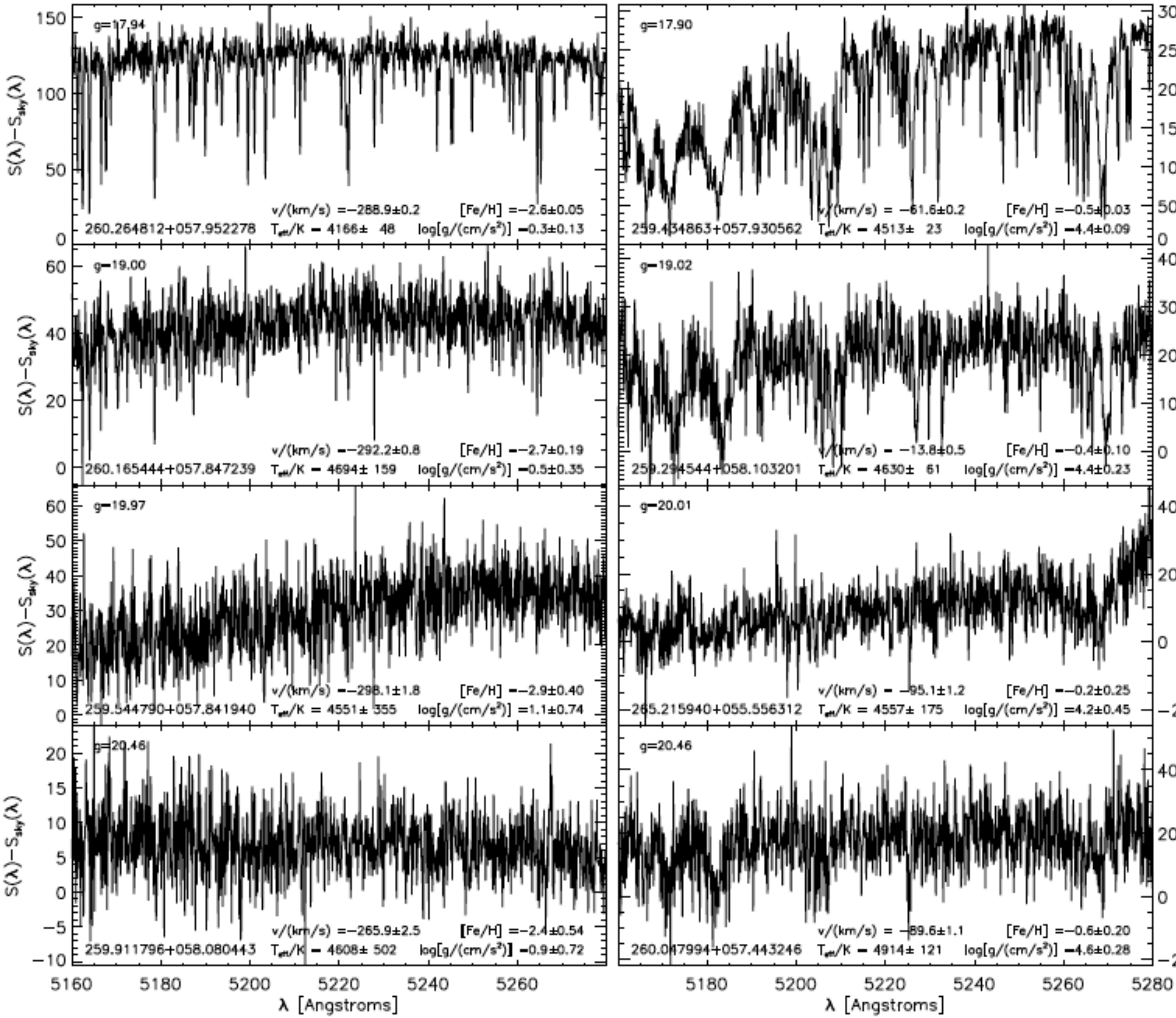
22 August 2014

ABSTRACT

We introduce a Bayesian method for fitting resolved stellar spectra in order to obtain simultaneous estimates of redshift and stellar-atmospheric parameters. We apply the method to thousands of spectra—covering $5160-5280$ Å at $\mathcal{R}\sim 20,000$—that we have acquired with the MMT/Hectochelle fiber spectrograph for red-giant and horizontal branch candidates along the line of sight to the Milky Way's dwarf spheroidal satellite in Draco. The observed stars subtend an area of ~ 4 deg^2, extending ~ 3 times beyond Draco's nominal 'tidal' radius. After rejecting low-quality measurements, we retain a new sample consisting of 2705 independent observations of 1478 unique stars, including 1847 independent observations for 620 unique stars with (as many as 13) repeat observations. For each observation we tabulate the first four moments—central value, variance, skewness and kurtosis—of posterior probability distribution functions representing the following physical parameters: line-of-sight velocity ($v_{\rm los}$), effective temperature ($T_{\rm eff}$), surface gravity ($\log g$) and metallicity ([Fe/H]). These estimates have median (minimum, maximum) errors of 0.87 (0.43, 4.59) km s^{-1}, 152 (44, 1069) K, 0.36 (0.08, 1.53) dex and 0.20 (0.05, 0.98) dex, respectively. Relations among these physical parameters distinguish ~ 450 likely Draco members from interlopers in the Galactic foreground.



14
16
18
20
22
i [mag]
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
g−i [mag]
2
1
0
−1
−2
η [degrees]
ξ [degrees]



g=17.94
v/(km/s) =−288.9±0.2 [Fe/H] =−2.6±0.05
260.264812+057.952278 T_eff/K = 4166± 48 log[g/(cm/s²)] =0.3±0.13
g=17.90
v/(km/s) = −61.6±0.2 [Fe/H] =−0.5±0.03
259.434863+057.930562 T_eff/K = 4513± 23 log[g/(cm/s²)] =4.4±0.09
g=19.00
v/(km/s) =−292.2±0.8 [Fe/H] =−2.7±0.19
260.165444+057.847239 T_eff/K = 4694± 159 log[g/(cm/s²)] =0.5±0.35
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v/(km/s) = −13.8±0.5 [Fe/H] =−0.4±0.10
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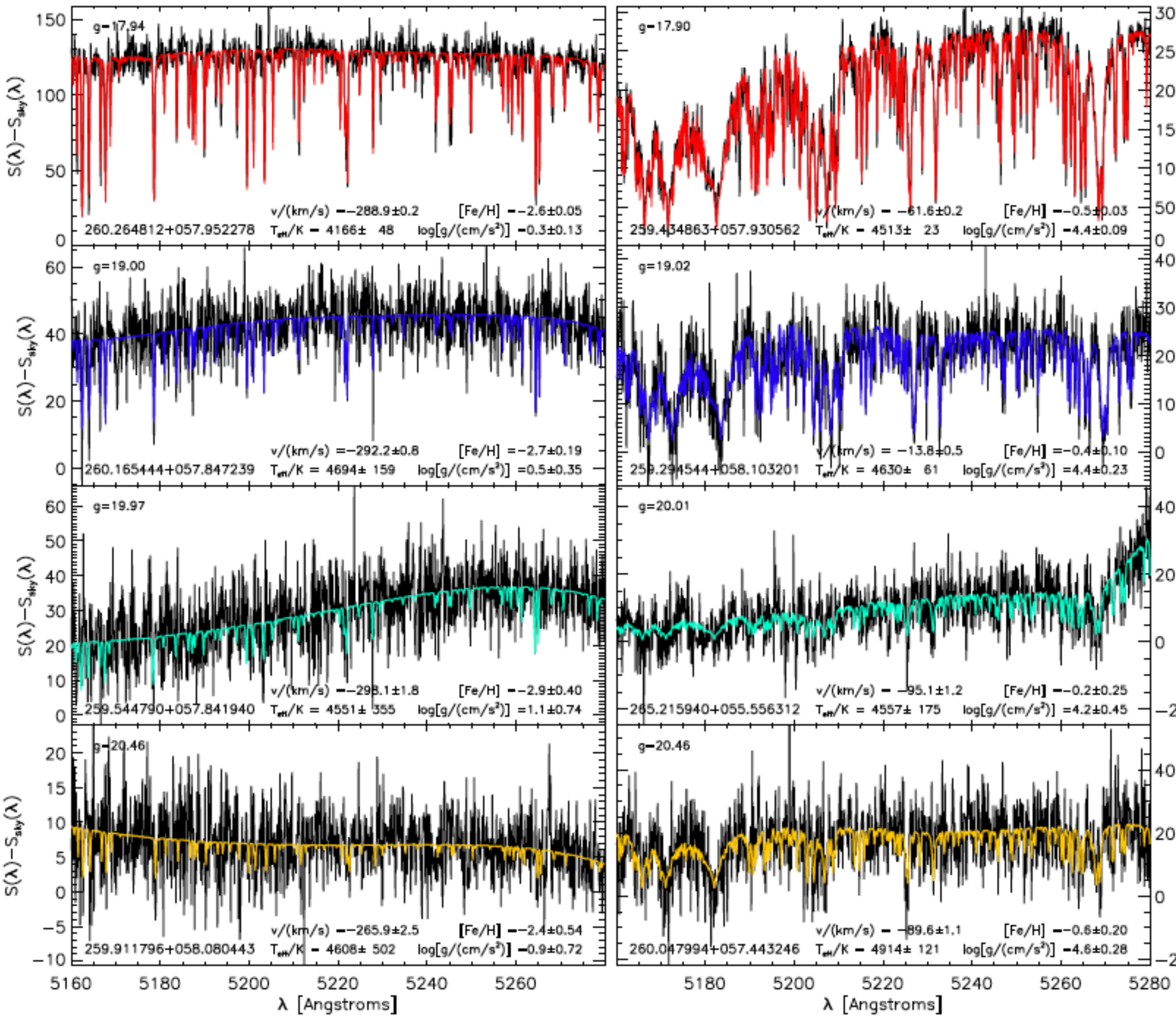
g=19.97
v/(km/s) =−298.1±1.8 [Fe/H] =−2.9±0.40
259.544790+057.841940 T_eff/K = 4551± 355 log[g/(cm/s²)] =1.1±0.74
g=20.01
v/(km/s) = −95.1±1.2 [Fe/H] =−0.2±0.25
265.215940+055.556312 T_eff/K = 4557± 175 log[g/(cm/s²)] =4.2±0.45
g=20.46
v/(km/s) =−265.9±2.5 [Fe/H] =−2.4±0.54
259.911796+058.080443 T_eff/K = 4608± 502 log[g/(cm/s²)] =0.9±0.72
g=20.46
v/(km/s) = −89.6±1.1 [Fe/H] =−0.6±0.20
260.047994+057.443246 T_eff/K = 4914± 121 log[g/(cm/s²)] =4.6±0.28
S(λ)−S_sky(λ)
λ [Angstroms]



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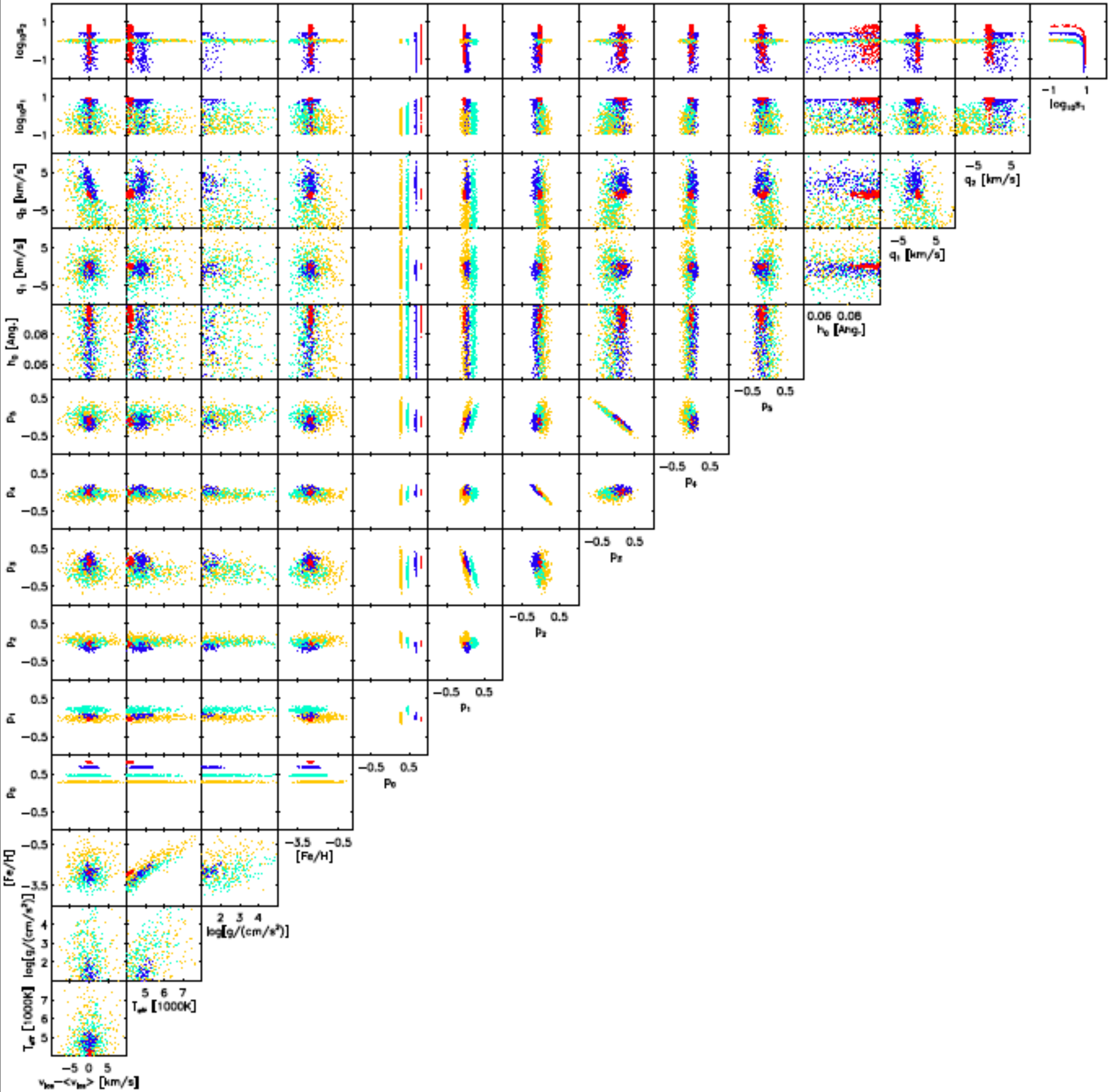
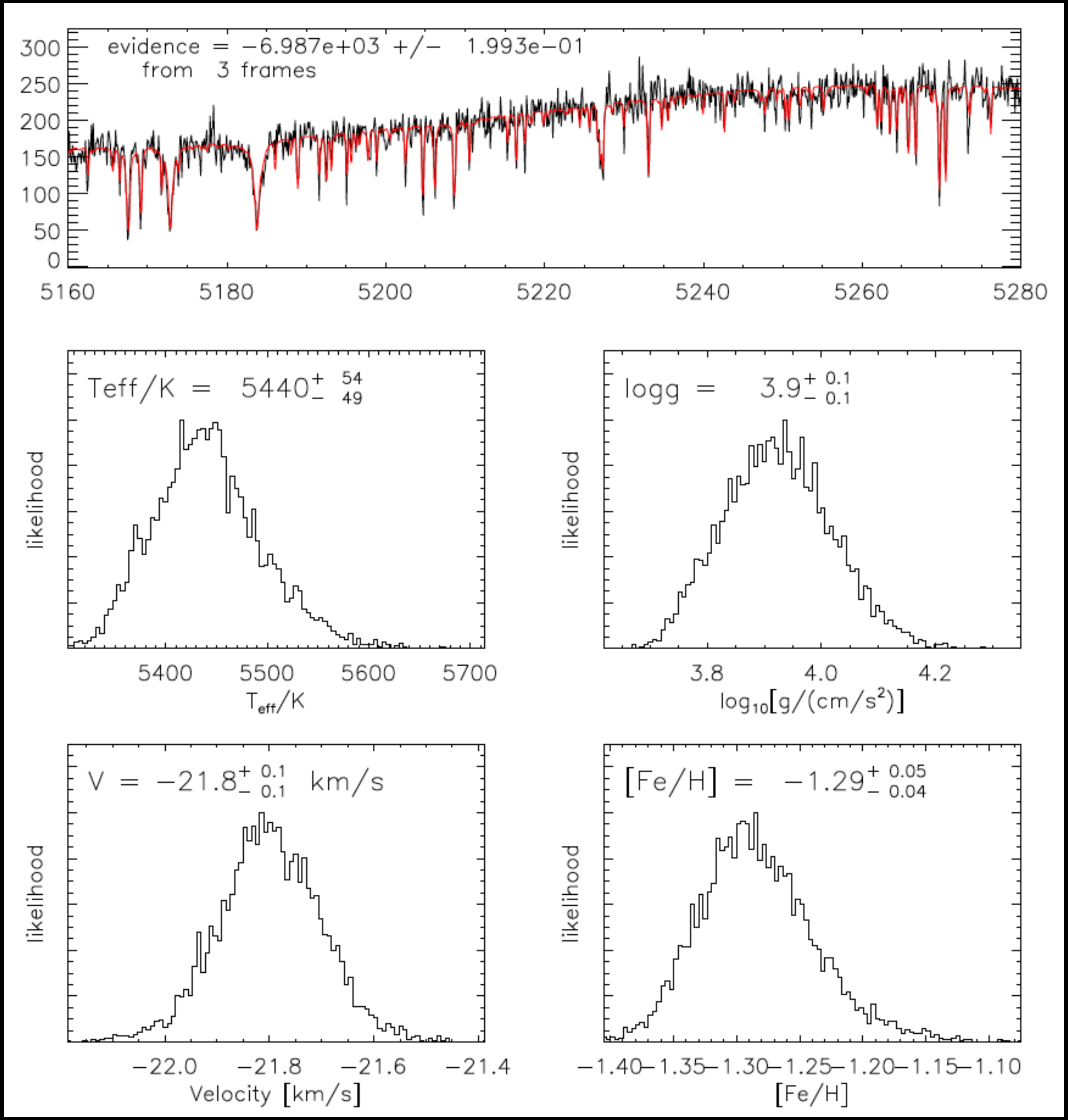
S(λ)−S_sky(λ)
λ [Angstroms]



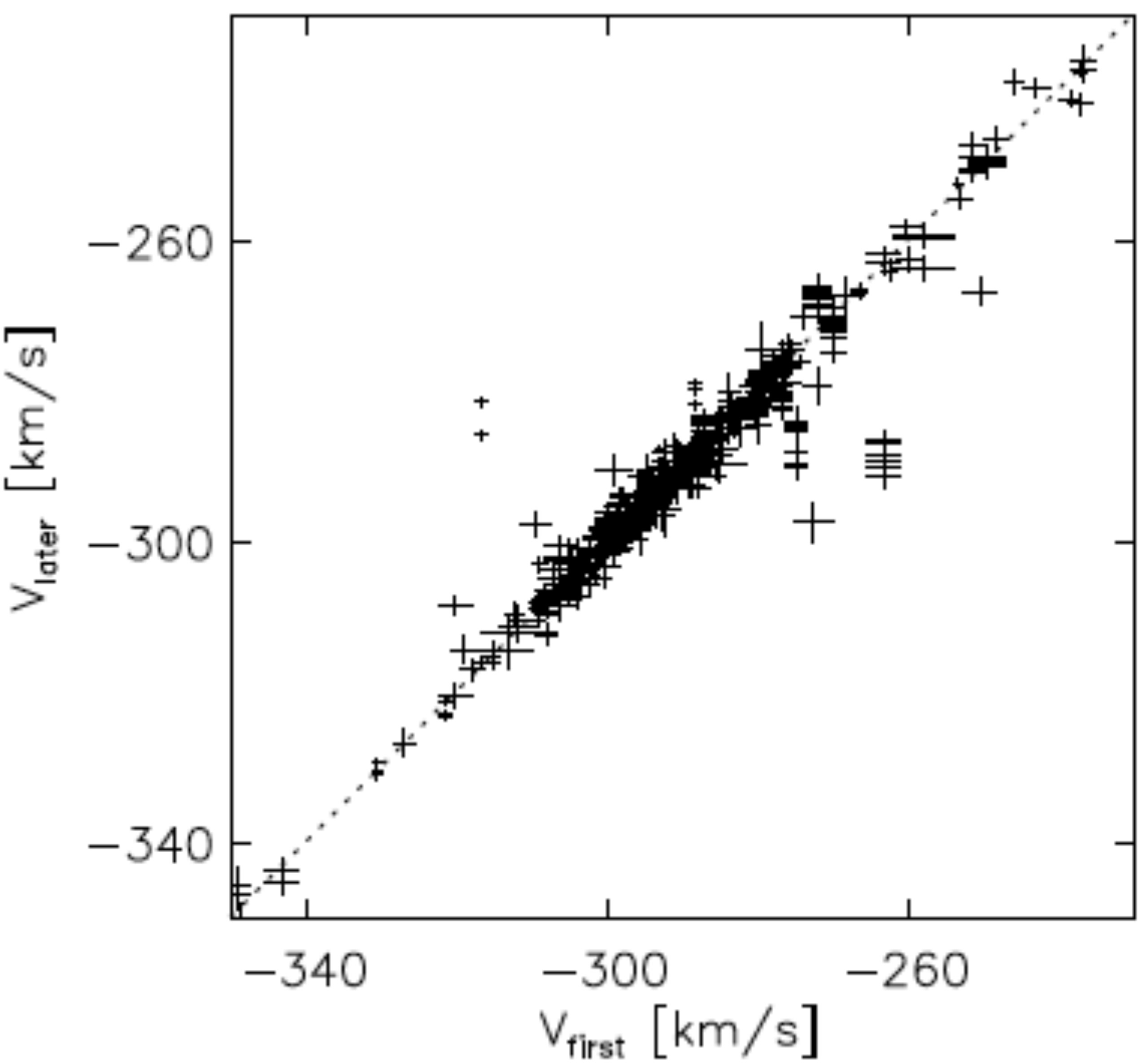
log10s2
log10s1
q2 [km/s]
q1 [km/s]
h0 [Ang.]
p5
p4
p3
p2
p1
p0
[Fe/H]
log[g/(cm/s²)]
Teff [1000K]
vlos−<vlos> [km/s]
Teff [1000K]
log[g/(cm/s²)]
[Fe/H]
p0
p1
p2
p3
p4
p5
h0 [Ang.]
q1 [km/s]
q2 [km/s]
log10s1



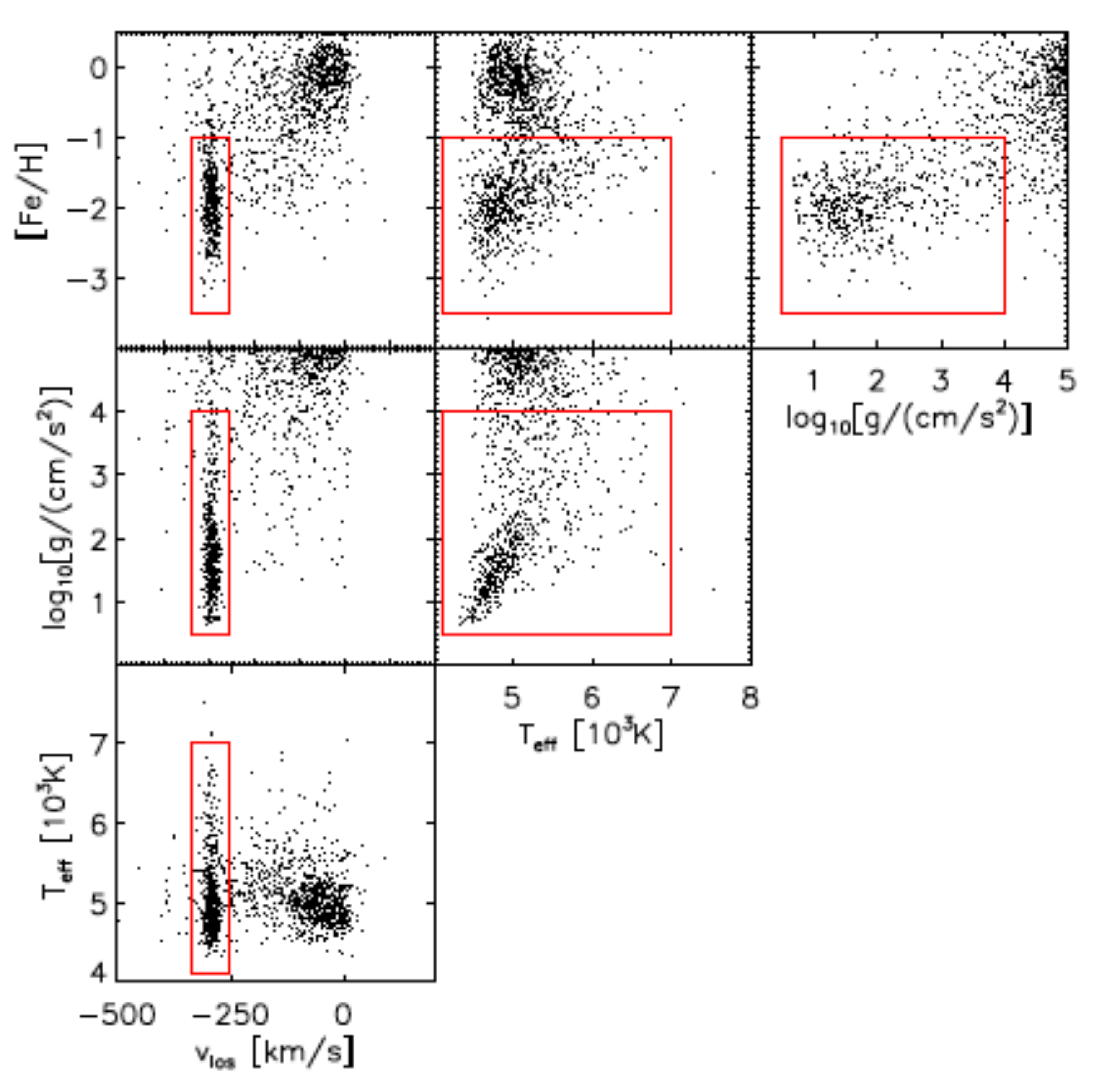
evidence = −6.987e+03 +/− 1.993e−01
from 3 frames
Teff/K = 5440+ 54 − 49
logg = 3.9+ 0.1 − 0.1
V = −21.8+ 0.1 − 0.1 km/s
[Fe/H] = −1.29+ 0.05 − 0.04
likelihood
T_eff/K
log10[g/(cm/s²)]
Velocity [km/s]
[Fe/H]

TABLE 1
HECTOCHELLE DATA FROM INDIVIDUAL OBSERVATIONS[a]

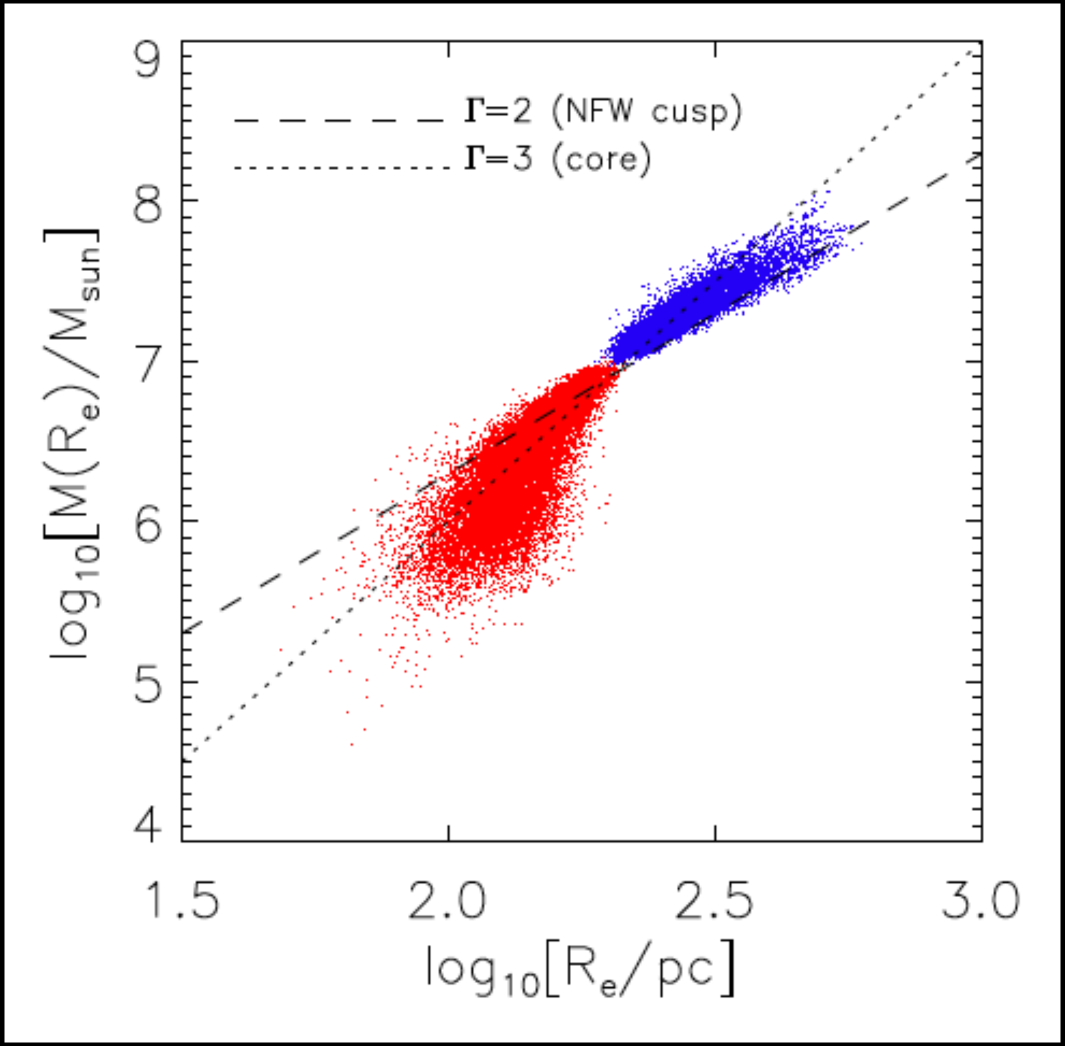
α_{2000} [hh:mm:ss]	δ_{2000} [dd:mm:ss]	g_{SDSS} [b] [mag]	i_{SDSS} [b] [mag]	HJD [days]	v_{los} [c] [km s^{-1}]	T_{eff} [K]	$\log_{10} g$ [d] [dex]	[Fe/H] [dex]
17:21:30.28	+57:50:16.3	17.963	16.642	2453850.781	$-299.6 \pm 0.9^{(-0.1,3.5)}$	$4980 \pm 245^{(0.4,3.5)}$	$2.1 \pm 0.4^{(-0.1,3.4)}$	$-2.71 \pm 0.27^{(-0.0,3.2)}$
				2455331.743	$-301.1 \pm 0.5^{(0.0,3.0)}$	$4402 \pm 109^{(-0.0,3.4)}$	$0.6 \pm 0.3^{(0.1,2.6)}$	$-2.62 \pm 0.14^{(0.2,3.2)}$
17:23:05.89	+57:43:53.1	19.210	18.471	2453850.781	$-277.8 \pm 1.2^{(0.2,3.2)}$	$5290 \pm 572^{(0.9,4.2)}$	$2.0 \pm 0.8^{(0.2,3.2)}$	$-2.04 \pm 0.54^{(0.3,3.3)}$
17:22:32.22	+58:17:46.9	18.767	17.706	2453850.781	$-278.9 \pm 1.3^{(-0.2,3.1)}$	$6066 \pm 813^{(0.3,2.6)}$	$2.9 \pm 0.8^{(-0.1,3.0)}$	$-1.84 \pm 0.64^{(-0.2,2.9)}$
				2454165.899	$-280.4 \pm 0.5^{(-0.0,3.1)}$	$4463 \pm 113^{(0.0,3.1)}$	$0.6 \pm 0.3^{(0.1,2.5)}$	$-2.70 \pm 0.15^{(0.1,2.9)}$
				2455331.842	$-280.8 \pm 0.6^{(-0.2,2.8)}$	$4480 \pm 102^{(0.1,3.3)}$	$0.3 \pm 0.3^{(0.6,2.9)}$	$-2.62 \pm 0.14^{(0.1,2.9)}$
				2455332.850	$-282.3 \pm 0.5^{(-0.0,3.2)}$	$4542 \pm 113^{(-0.1,3.2)}$	$0.2 \pm 0.2^{(1.0,3.9)}$	$-2.41 \pm 0.16^{(-0.2,2.9)}$
				2455590.988	$-280.7 \pm 1.2^{(0.1,2.9)}$	$4305 \pm 216^{(0.7,3.7)}$	$1.1 \pm 0.5^{(0.2,2.9)}$	$-2.71 \pm 0.28^{(0.7,3.6)}$
				2455706.844	$-281.5 \pm 0.5^{(0.0,2.8)}$	$4447 \pm 106^{(0.0,3.0)}$	$0.8 \pm 0.3^{(-0.1,2.8)}$	$-2.84 \pm 0.14^{(0.2,2.7)}$
				2455707.754	$-281.4 \pm 0.5^{(-0.1,2.9)}$	$4333 \pm 101^{(-0.1,3.3)}$	$0.5 \pm 0.3^{(0.4,2.7)}$	$-2.85 \pm 0.12^{(0.1,3.3)}$
				2455708.932	$-282.0 \pm 1.0^{(-0.1,3.0)}$	$4670 \pm 219^{(0.3,3.4)}$	$1.2 \pm 0.6^{(-0.0,2.5)}$	$-2.27 \pm 0.30^{(0.2,2.9)}$
				2455712.874	$-281.2 \pm 0.8^{(-0.0,2.9)}$	$4480 \pm 130^{(-0.1,3.3)}$	$0.5 \pm 0.3^{(0.5,2.9)}$	$-2.59 \pm 0.17^{(-0.0,3.0)}$
17:23:07.55	+57:34:27.1	18.480	17.742	2453850.781	$-68.4 \pm 0.8^{(-0.1,3.1)}$	$5058 \pm 177^{(0.5,3.3)}$	$3.4 \pm 0.4^{(0.3,3.2)}$	$-1.20 \pm 0.21^{(0.1,3.0)}$
				2454168.899	$-59.5 \pm 0.3^{(-0.1,3.0)}$	$4873 \pm 47^{(0.8,4.4)}$	$3.1 \pm 0.1^{(0.5,3.9)}$	$-0.58 \pm 0.06^{(0.3,3.3)}$
17:23:43.32	+58:14:55.8	17.655	17.180	2453850.781	$-65.7 \pm 0.6^{(0.0,3.1)}$	$5370 \pm 177^{(0.4,3.6)}$	$3.1 \pm 0.2^{(0.0,3.3)}$	$-1.56 \pm 0.19^{(0.2,3.4)}$
17:21:35.28	+57:35:24.5	17.399	16.599	2453850.781	$-115.5 \pm 0.4^{(-0.1,2.8)}$	$4914 \pm 114^{(0.2,3.3)}$	$2.0 \pm 0.2^{(-0.1,3.3)}$	$-2.28 \pm 0.14^{(-0.0,3.2)}$
				2454168.899	$-116.9 \pm 0.2^{(-0.2,3.1)}$	$4635 \pm 46^{(0.4,2.8)}$	$1.4 \pm 0.1^{(0.0,3.1)}$	$-2.04 \pm 0.06^{(0.5,3.5)}$
17:24:03.57	+58:00:45.3	17.335	16.272	2453850.781	$9.6 \pm 1.6^{(-0.0,3.1)}$	$5011 \pm 47^{(0.1,4.6)}$	$4.9 \pm 0.1^{(-1.2,4.3)}$	$-1.77 \pm 0.08^{(-0.1,4.0)}$
				2454213.832	$-2.3 \pm 1.9^{(0.5,3.3)}$	$4795 \pm 61^{(0.5,3.7)}$	$5.0 \pm 0.0^{(-1.3,4.9)}$	$-2.05 \pm 0.09^{(0.1,3.6)}$
17:23:29.63	+57:39:19.2	17.569	16.751	2453850.781	$-201.0 \pm 0.4^{(-0.0,3.0)}$	$4928 \pm 114^{(0.2,3.2)}$	$1.8 \pm 0.2^{(-0.1,3.1)}$	$-1.74 \pm 0.15^{(0.0,3.0)}$
				2454168.899	$-193.0 \pm 0.2^{(0.1,3.1)}$	$4707 \pm 43^{(-0.1,2.6)}$	$1.6 \pm 0.1^{(-0.1,2.9)}$	$-1.68 \pm 0.06^{(-0.1,2.5)}$
17:20:15.22	+58:00:35.0	19.105	18.074	2453850.781	$-289.4 \pm 2.3^{(0.0,2.9)}$	$5761 \pm 751^{(0.3,2.8)}$	$2.2 \pm 1.4^{(0.2,2.1)}$	$-2.74 \pm 0.60^{(-0.2,2.9)}$



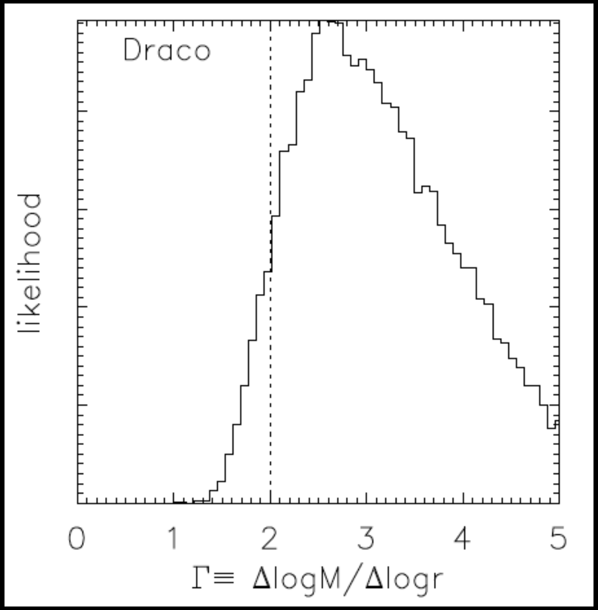
−260
−300
−340
−340
−300
−260
V_later [km/s]
V_first [km/s]



[Fe/H]
log10[g/(cm/s2)]
Teff [10^3K]
vlos [km/s]
0
−1
−2
−3
4
3
2
1
7
6
5
4
−500
−250
0
5
6
7
8
1
2
3
4
5



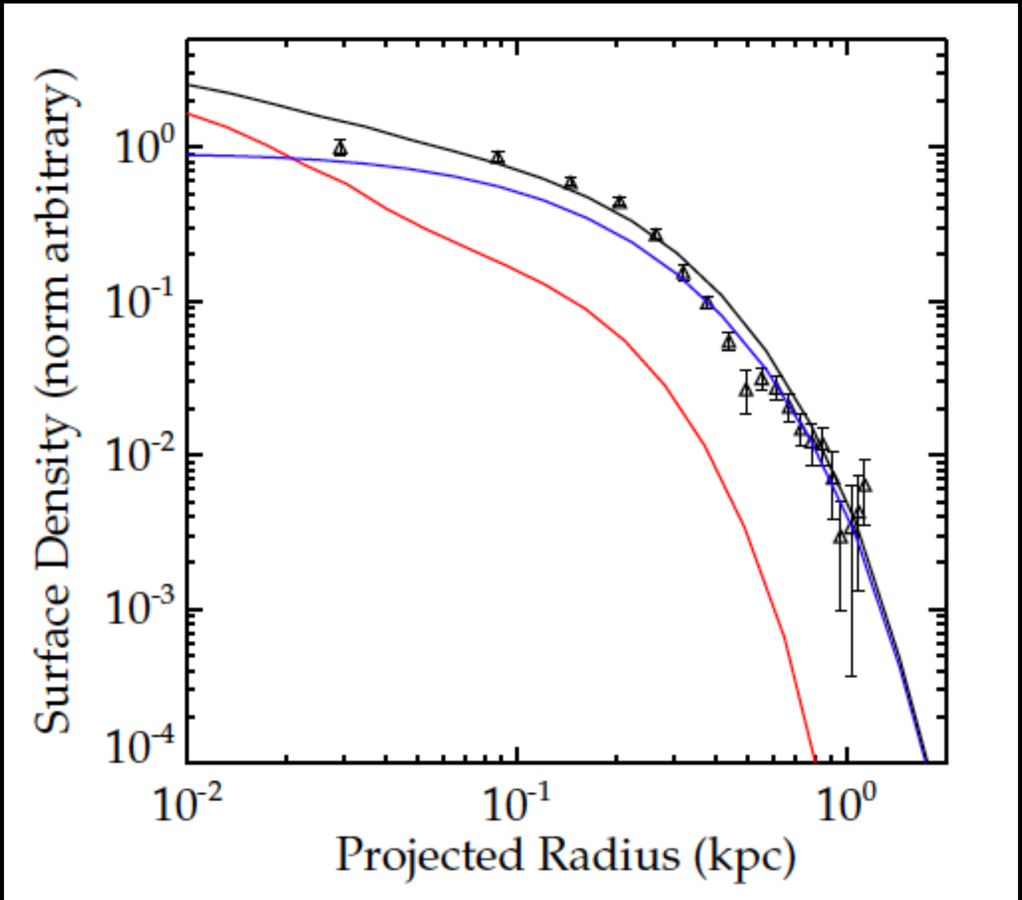
PRELIMINARY

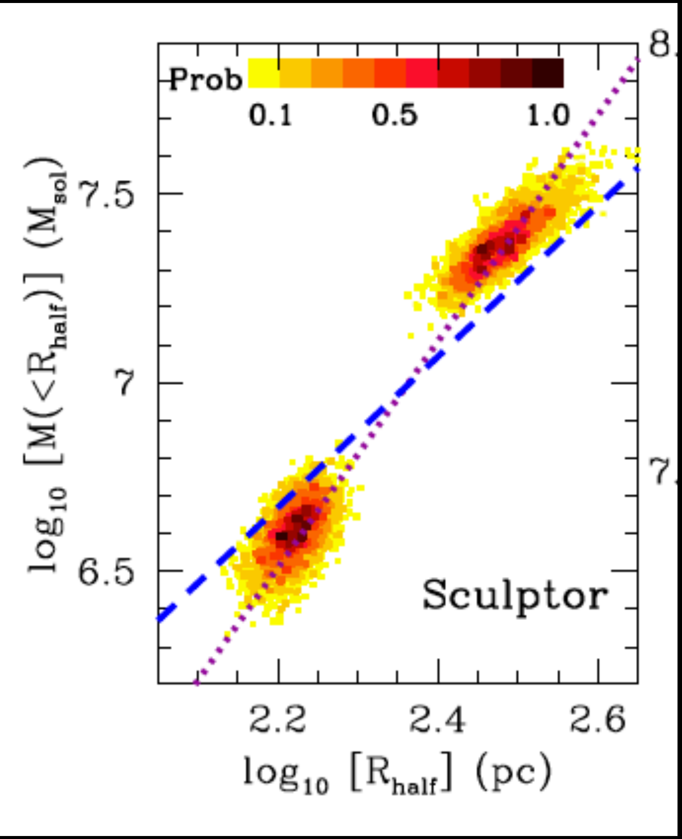


extra slides

Dynamical models for the Sculptor dwarf spheroidal in a ΛCDM universe

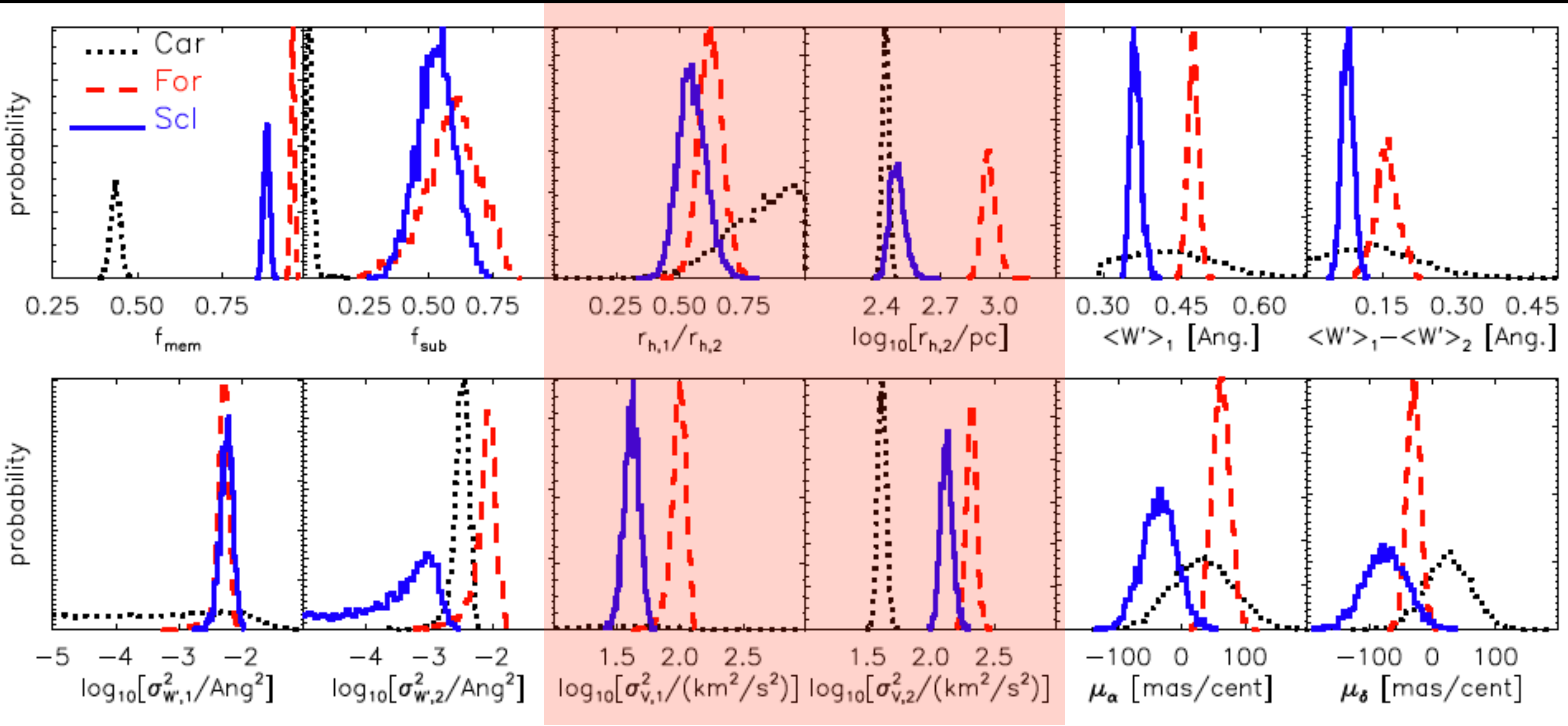
Louis E. Strigari[1], Carlos S. Frenk[2] and Simon D. M. White[3]



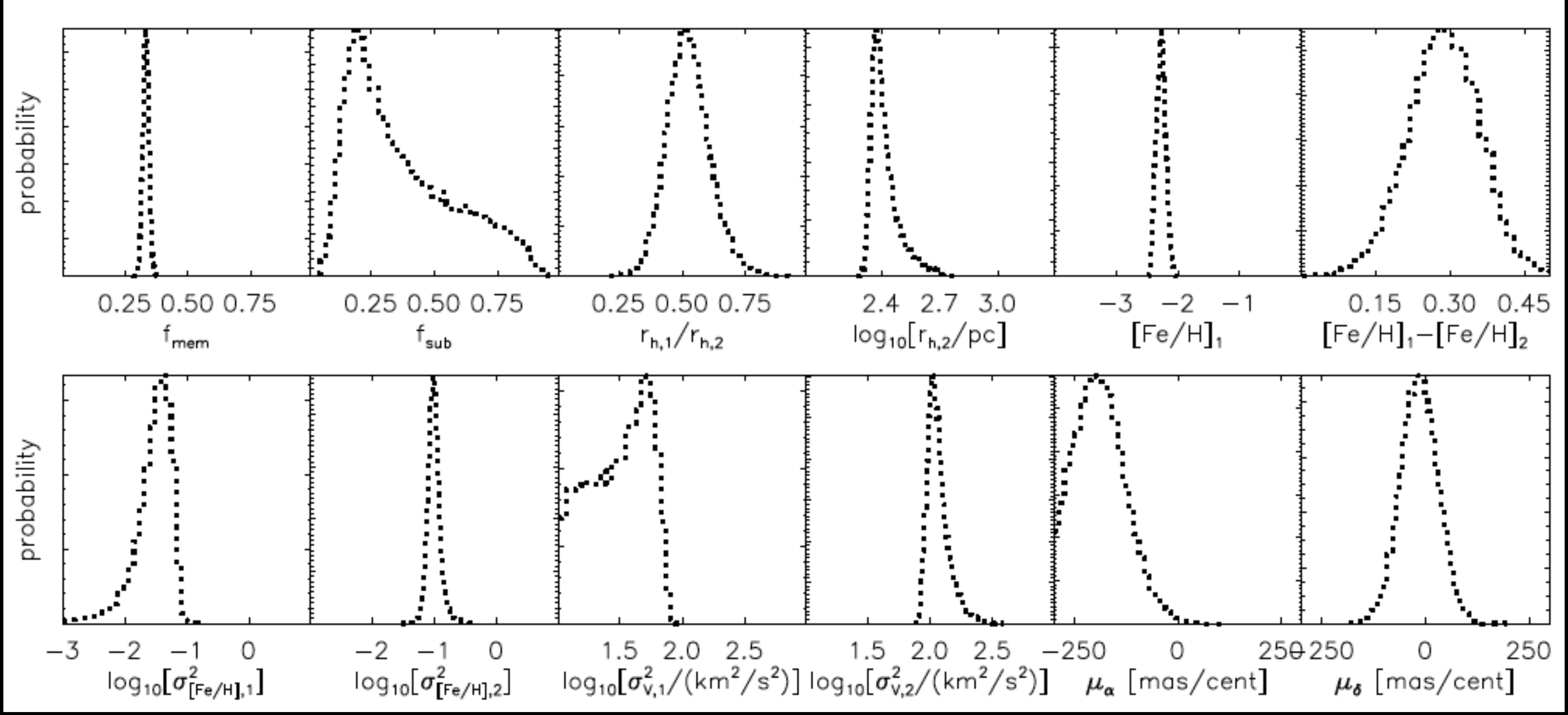


A METHOD FOR MEASURING (SLOPES OF) THE MASS PROFILES OF DWARF SPHEROIDAL GALAXIES

MATTHEW G. WALKER[1,2,3] & JORGE PEÑARRUBIA[2]



PRELIMINARY



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