Star Formation Histories of Dwarf Satellite Galaxies: MODELS and OBSERVATIONS

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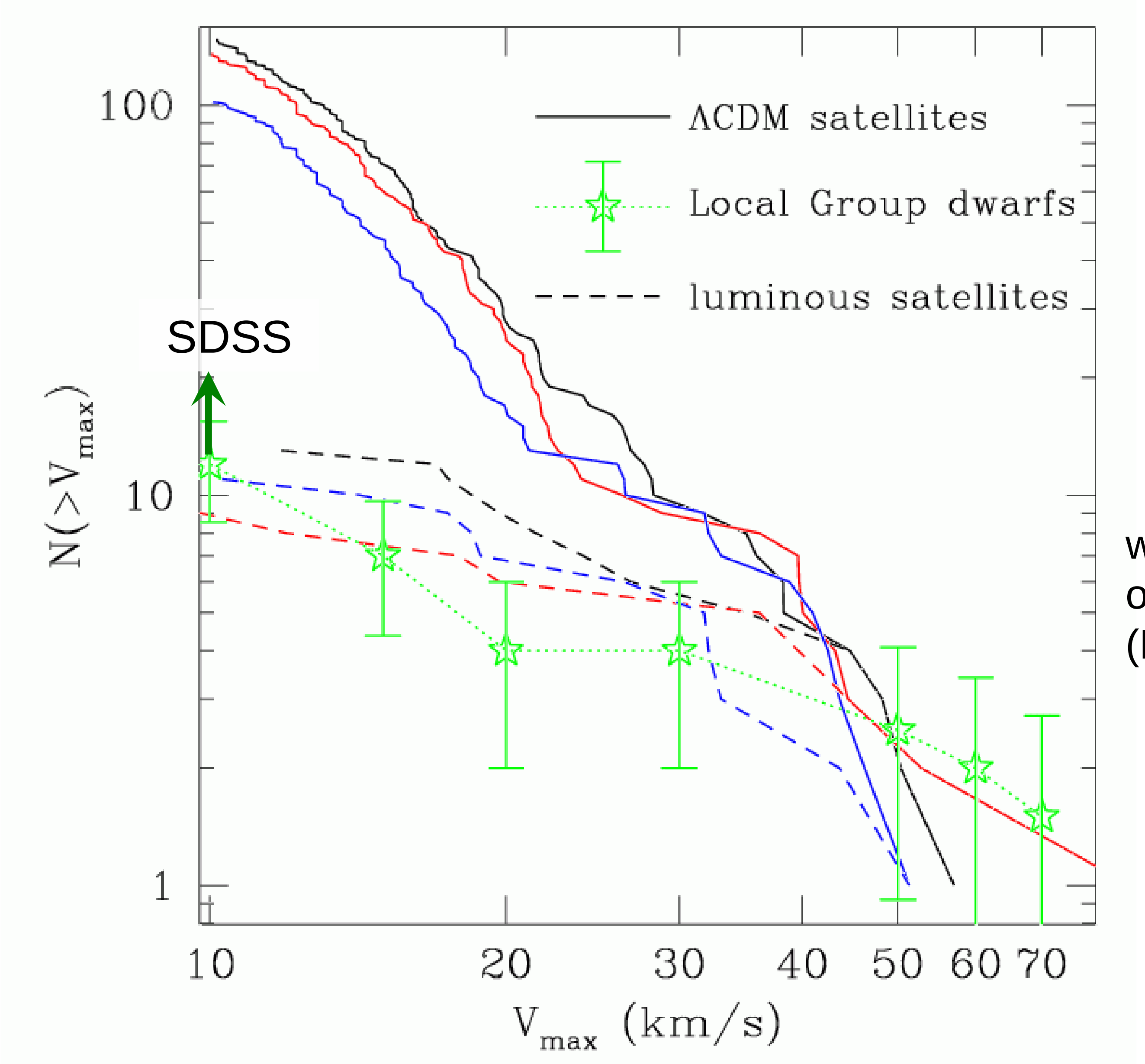
The Missing Satellites Problem in the Local Group: too many halos

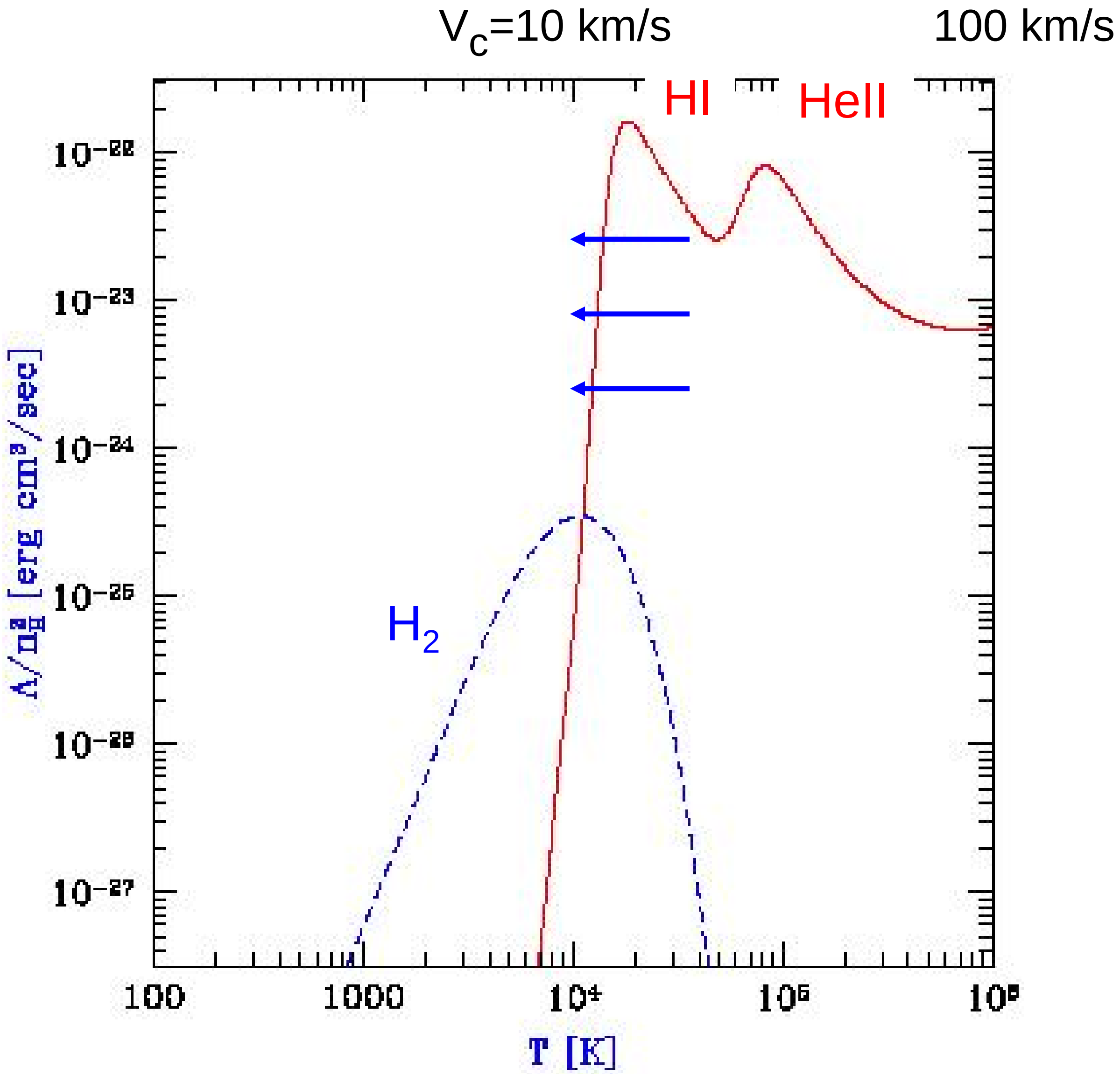


within 200 h^{-1} kpc
of each host halo
(MW and M31)

Kravtsov, OG, Klypin (2004)

Primordial gas can cool in all halos where T > 10^4 K

V_c=10 km/s 100 km/s

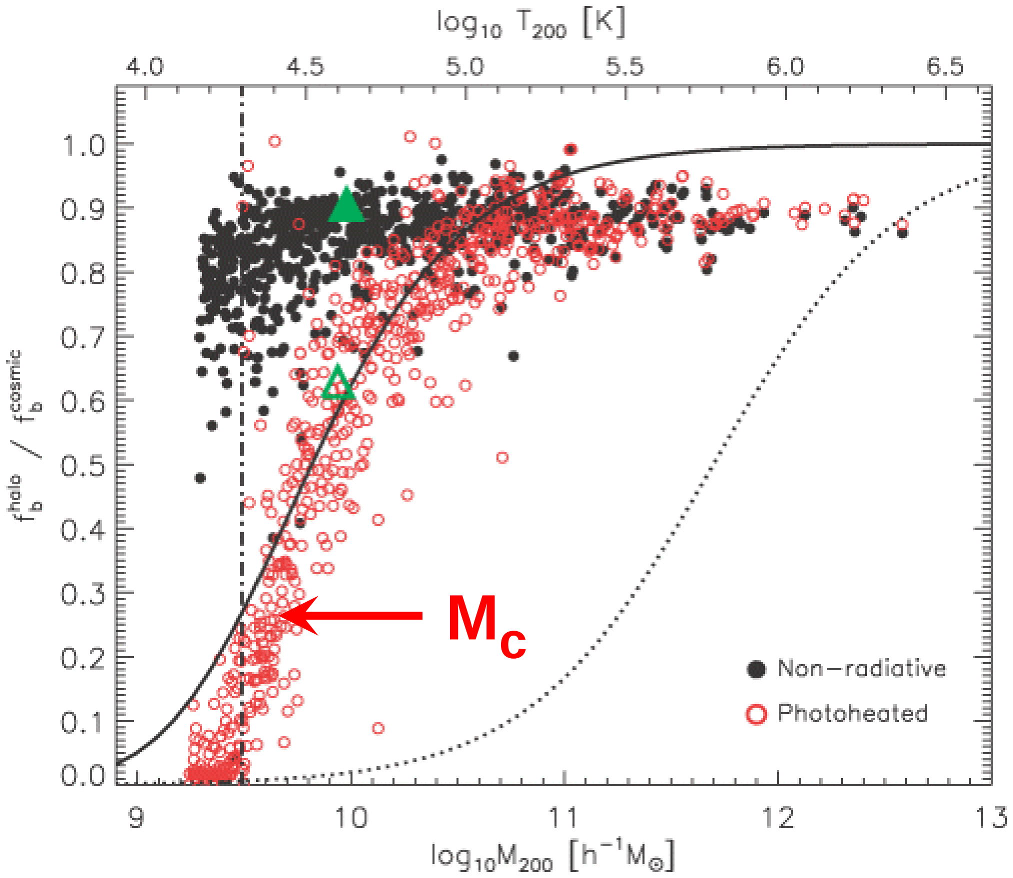


(figure from Barkana & Loeb 2001)

Small halos accrete a smaller gas fraction

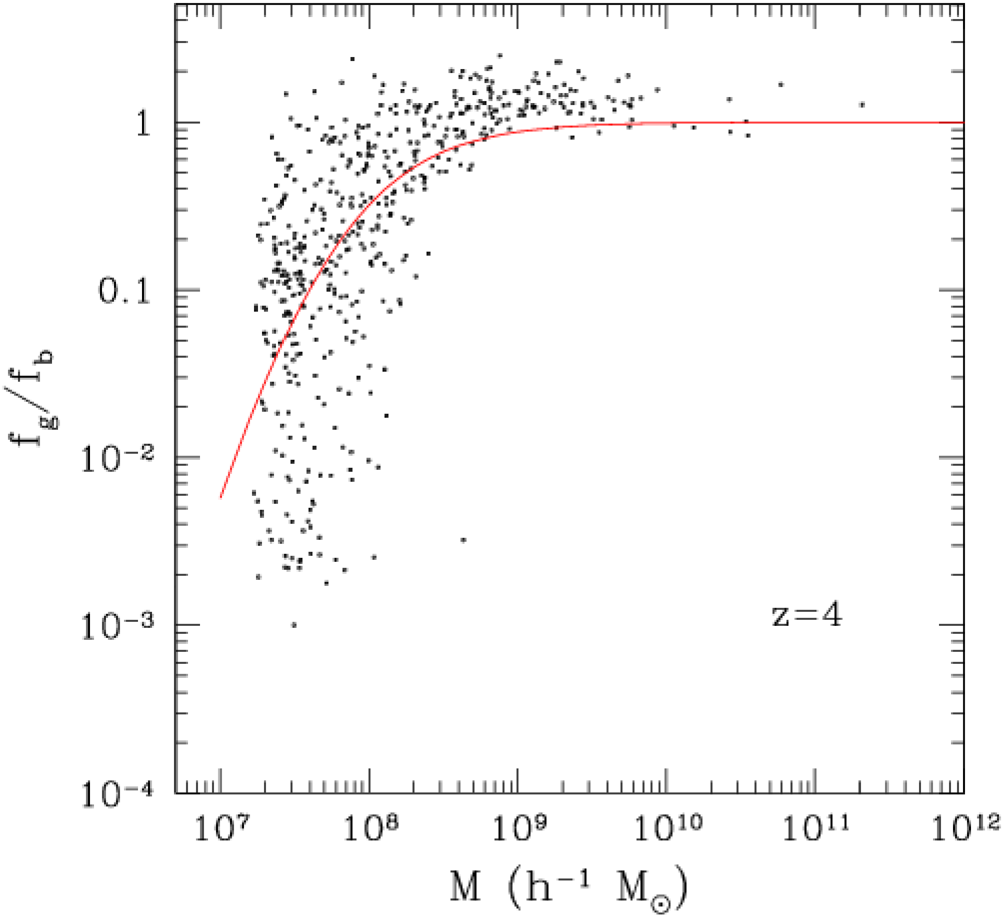
Often done using Nick Gnedin's (2000) filtering mass M_F at high *z*

Recent SPH simulations suggest the cutoff mass is ~5 times lower at *z*=0



Crain et al. (2007), also
Hoeft et al. (2006)

New ART simulations including Radiative Transfer



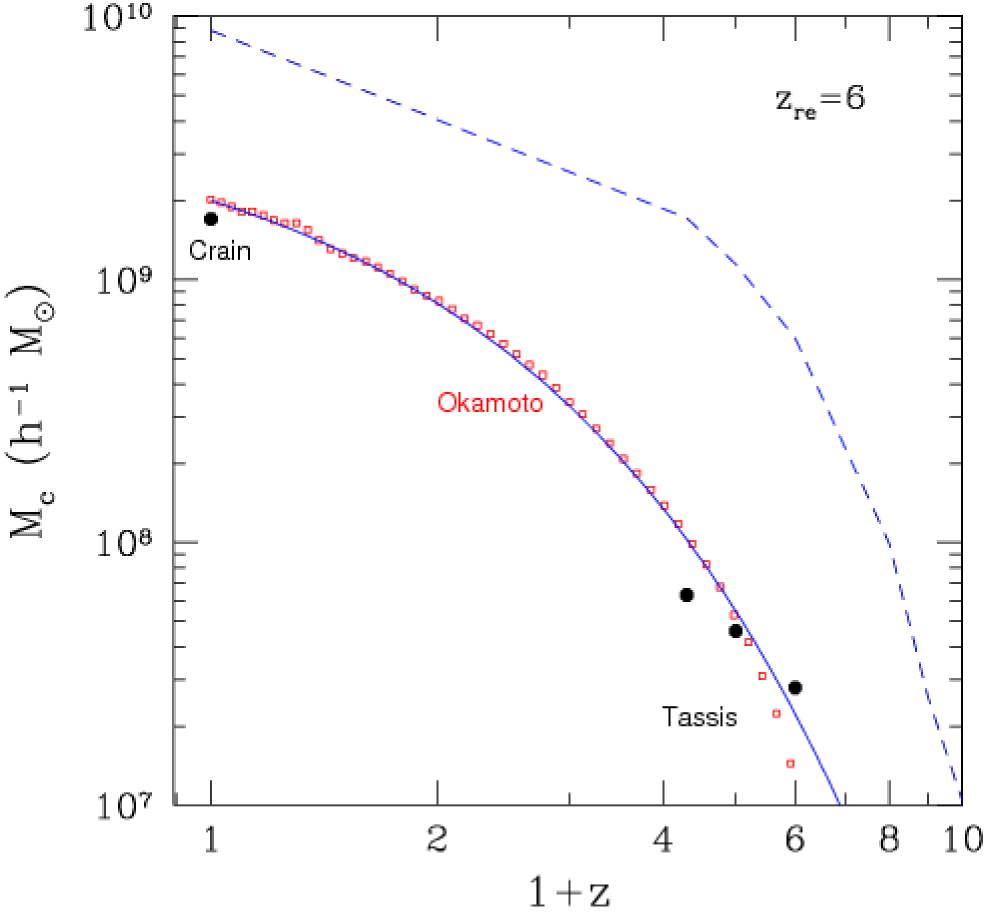
$$f_g/f_b = (1+M_c/M)^{-3}$$

$$M_c(z) < M_F(z)$$

Tassis et al. (2008)

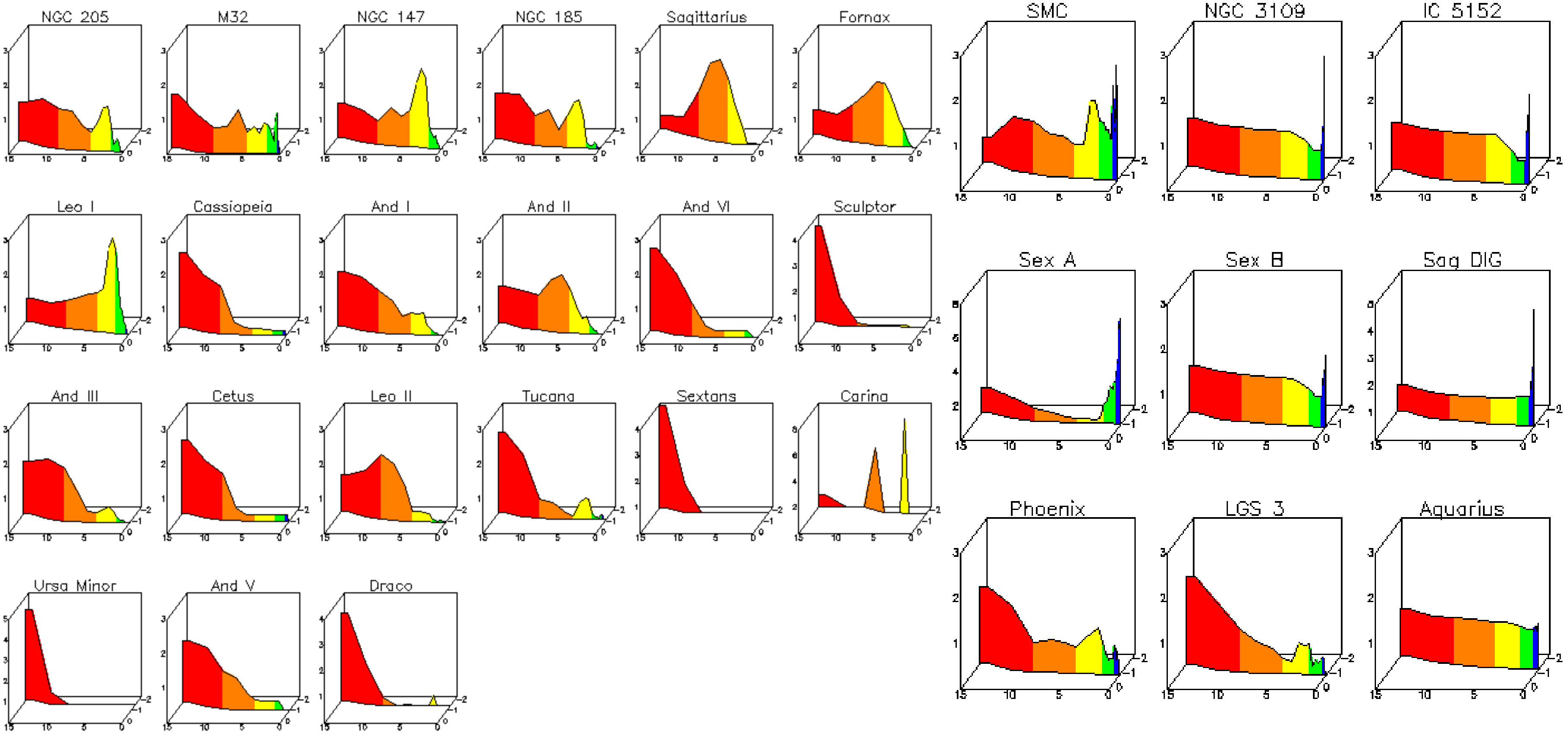
New fit for cutoff mass $M_c(z)$

$$M_c \approx 2\ 10^9\ e^{-5.4\ z/z_{re}}\ h^{-1}\ M_\odot$$

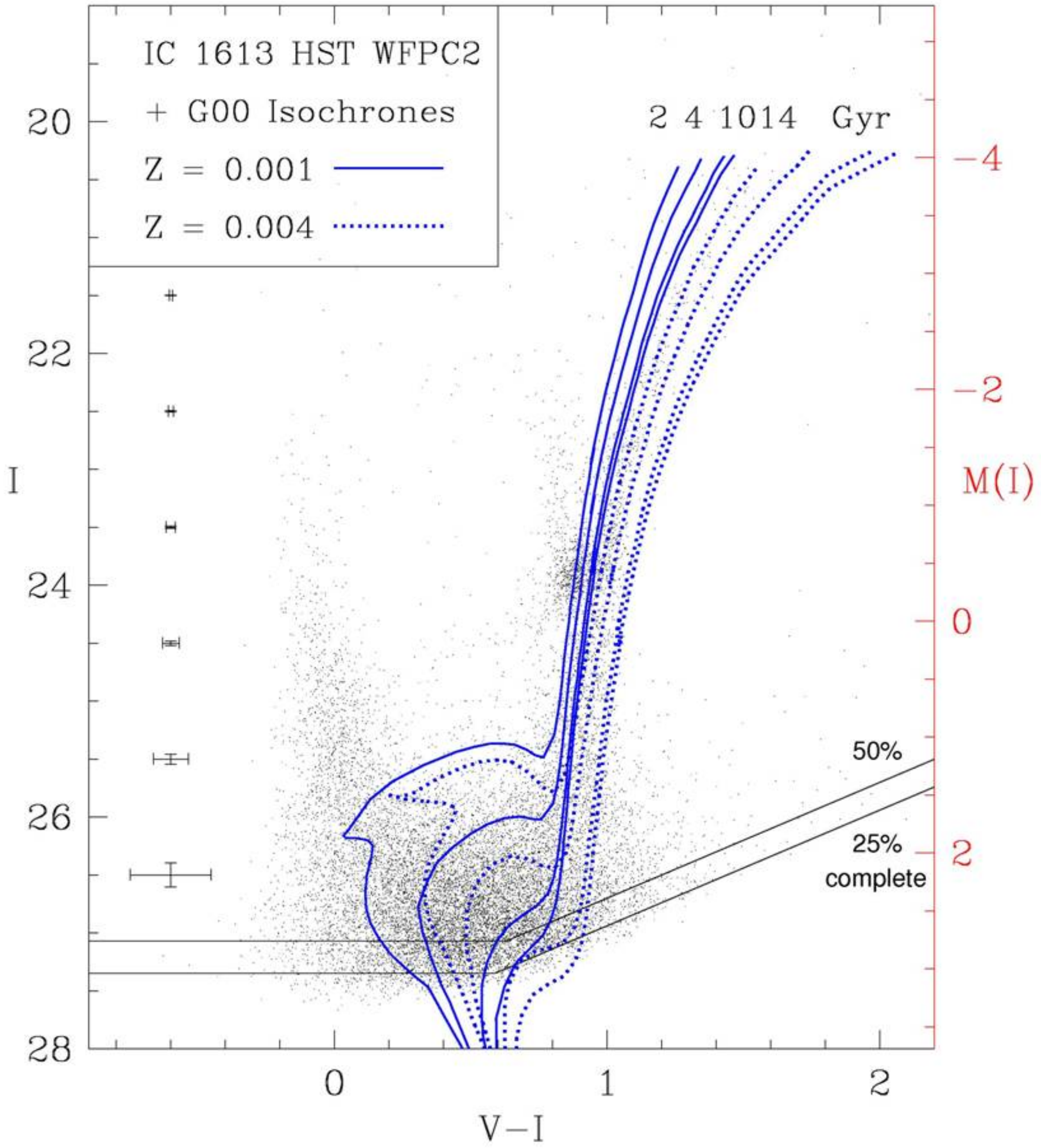


New detailed star formation histories of ALL classic Local Group dwarfs from archival HST CMDs:

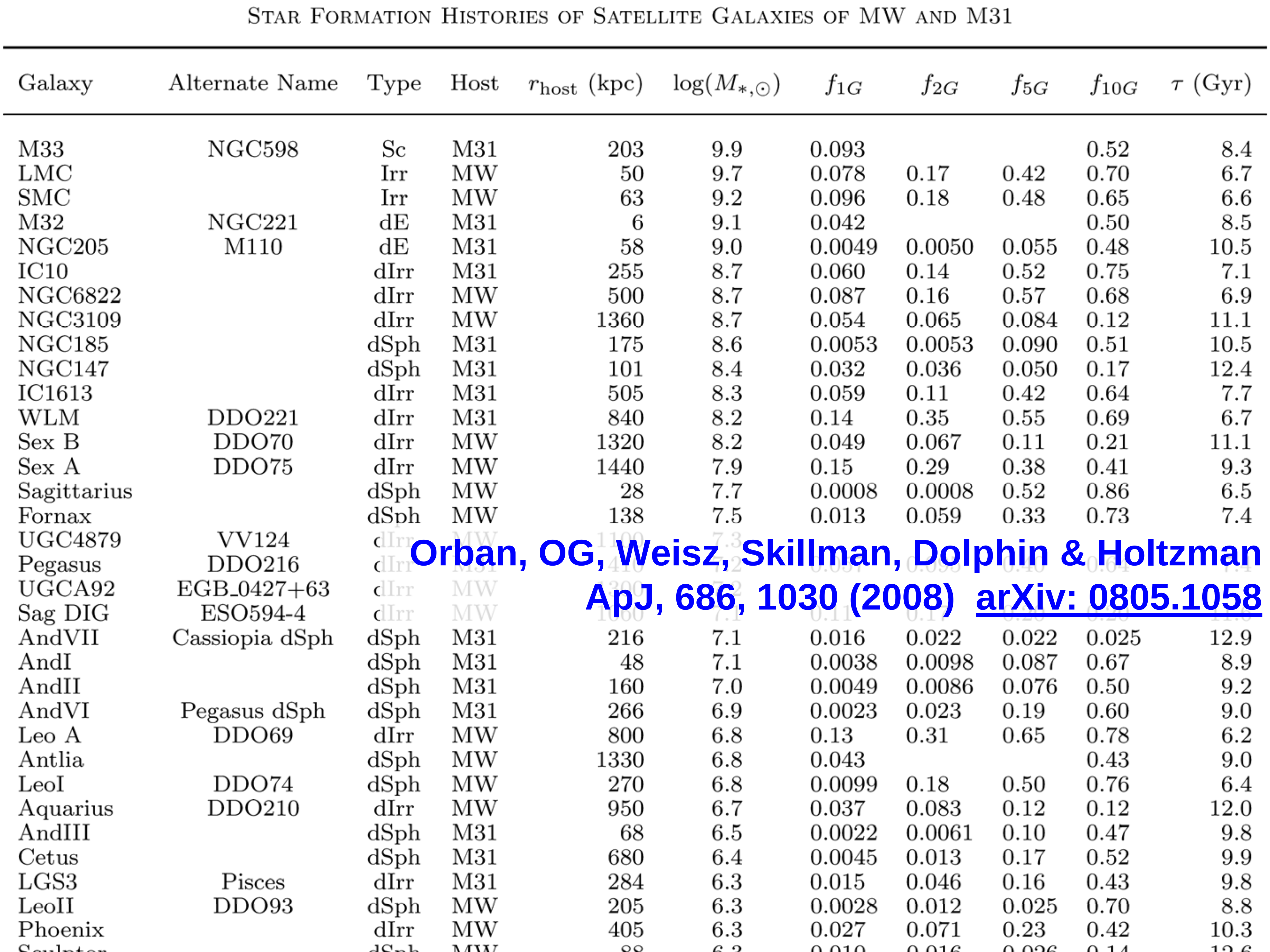
Dolphin et al. 2005 and Holtzman et al. 2006



Best constraints on SFH are from main sequence turnoff



Skillman et al. 2003



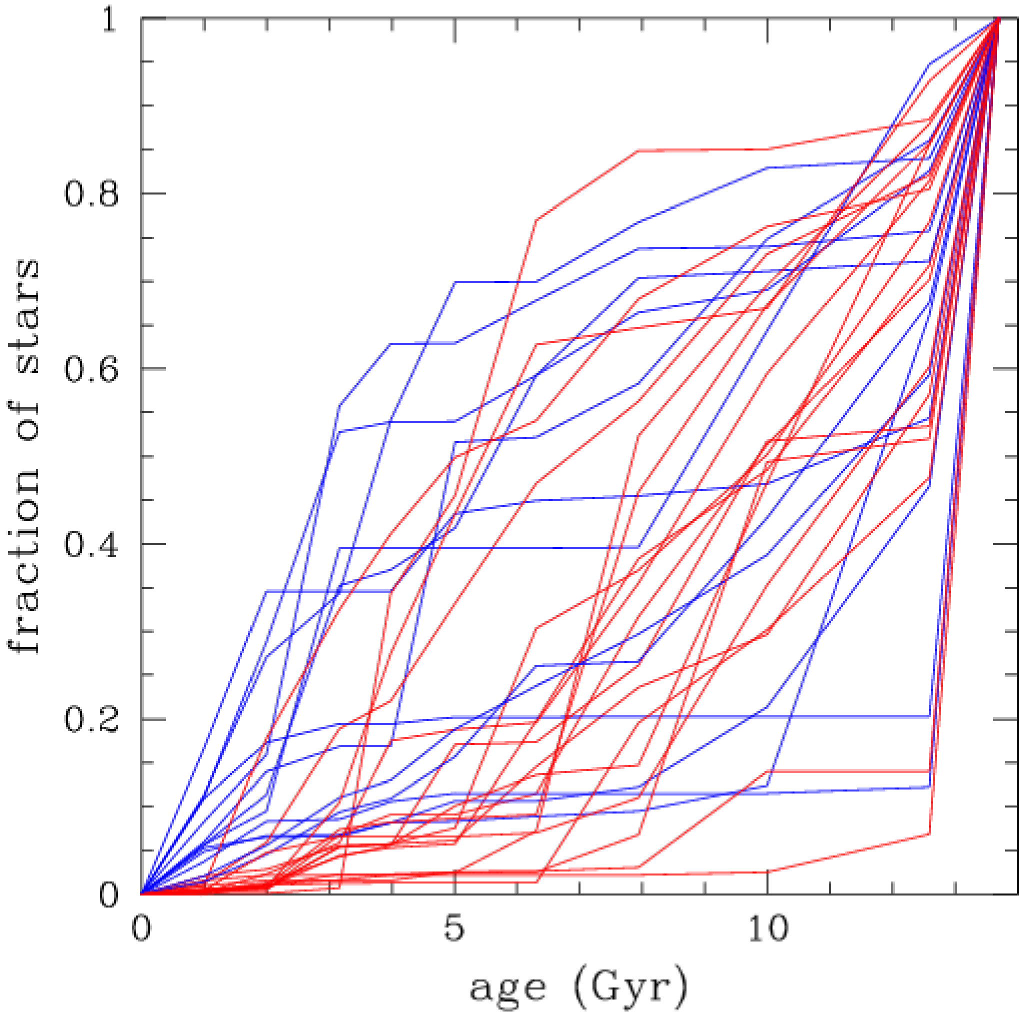
STAR FORMATION HISTORIES OF SATELLITE GALAXIES OF MW AND M31

Galaxy	Alternate Name	Type	Host	r_{host} (kpc)	$\log(M_{*,\odot})$	f_{1G}	f_{2G}	f_{5G}	f_{10G}	τ (Gyr)
M33	NGC598	Sc	M31	203	9.9	0.093			0.52	8.4
LMC		Irr	MW	50	9.7	0.078	0.17	0.42	0.70	6.7
SMC		Irr	MW	63	9.2	0.096	0.18	0.48	0.65	6.6
M32	NGC221	dE	M31	6	9.1	0.042			0.50	8.5
NGC205	M110	dE	M31	58	9.0	0.0049	0.0050	0.055	0.48	10.5
IC10		dIrr	M31	255	8.7	0.060	0.14	0.52	0.75	7.1
NGC6822		dIrr	MW	500	8.7	0.087	0.16	0.57	0.68	6.9
NGC3109		dIrr	MW	1360	8.7	0.054	0.065	0.084	0.12	11.1
NGC185		dSph	M31	175	8.6	0.0053	0.0053	0.090	0.51	10.5
NGC147		dSph	M31	101	8.4	0.032	0.036	0.050	0.17	12.4
IC1613		dIrr	M31	505	8.3	0.059	0.11	0.42	0.64	7.7
WLM	DDO221	dIrr	M31	840	8.2	0.14	0.35	0.55	0.69	6.7
Sex B	DDO70	dIrr	MW	1320	8.2	0.049	0.067	0.11	0.21	11.1
Sex A	DDO75	dIrr	MW	1440	7.9	0.15	0.29	0.38	0.41	9.3
Sagittarius		dSph	MW	28	7.7	0.0008	0.0008	0.52	0.86	6.5
Fornax		dSph	MW	138	7.5	0.013	0.059	0.33	0.73	7.4
UGC4879	VV124	dIrr	MW	1100	7.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Pegasus	DDO216	dIrr	M31	410	7.2	[illegible]	[illegible]	0.40	0.64	7.4
UGCA92	EGB_0427+63	dIrr	MW	1300	7.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Sag DIG	ESO594-4	dIrr	MW	1060	7.1	0.11	0.17	[illegible]	[illegible]	[illegible]
AndVII	Cassiopia dSph	dSph	M31	216	7.1	0.016	0.022	0.022	0.025	12.9
AndI		dSph	M31	48	7.1	0.0038	0.0098	0.087	0.67	8.9
AndII		dSph	M31	160	7.0	0.0049	0.0086	0.076	0.50	9.2
AndVI	Pegasus dSph	dSph	M31	266	6.9	0.0023	0.023	0.19	0.60	9.0
Leo A	DDO69	dIrr	MW	800	6.8	0.13	0.31	0.65	0.78	6.2
Antlia		dSph	MW	1330	6.8	0.043			0.43	9.0
LeoI	DDO74	dSph	MW	270	6.8	0.0099	0.18	0.50	0.76	6.4
Aquarius	DDO210	dIrr	MW	950	6.7	0.037	0.083	0.12	0.12	12.0
AndIII		dSph	M31	68	6.5	0.0022	0.0061	0.10	0.47	9.8
Cetus		dSph	M31	680	6.4	0.0045	0.013	0.17	0.52	9.9
LGS3	Pisces	dIrr	M31	284	6.3	0.015	0.046	0.16	0.43	9.8
LeoII	DDO93	dSph	MW	205	6.3	0.0028	0.012	0.025	0.70	8.8
Phoenix		dIrr	MW	405	6.3	0.027	0.071	0.23	0.42	10.3
Sculptor		dSph	MW	88	6.3	0.010	0.016	0.026	0.14	12.6

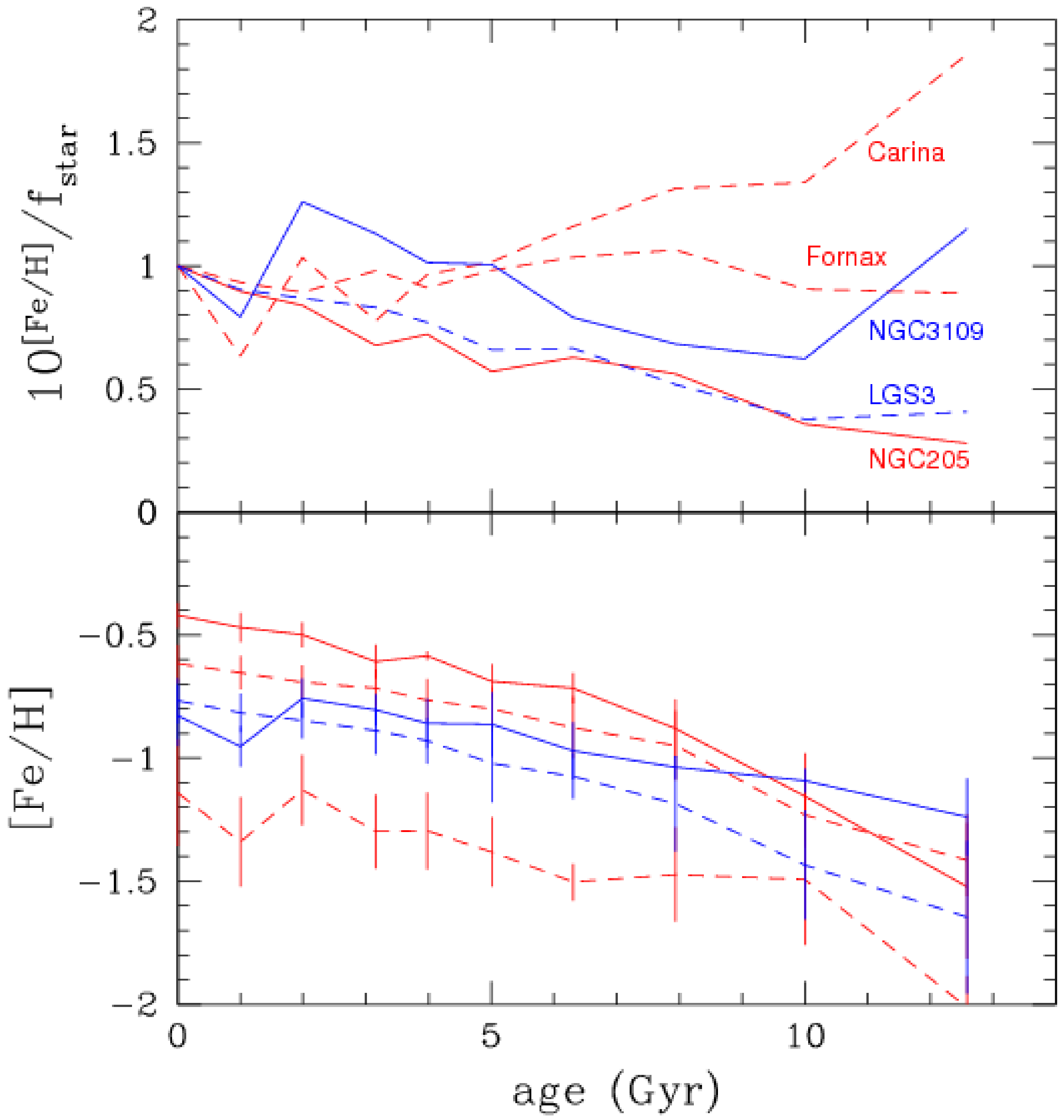
Orban, OG, Weisz, Skillman, Dolphin & Holtzman

ApJ, 686, 1030 (2008) arXiv: 0805.1058

Star formation histories of dSph and dIrr galaxies are similar

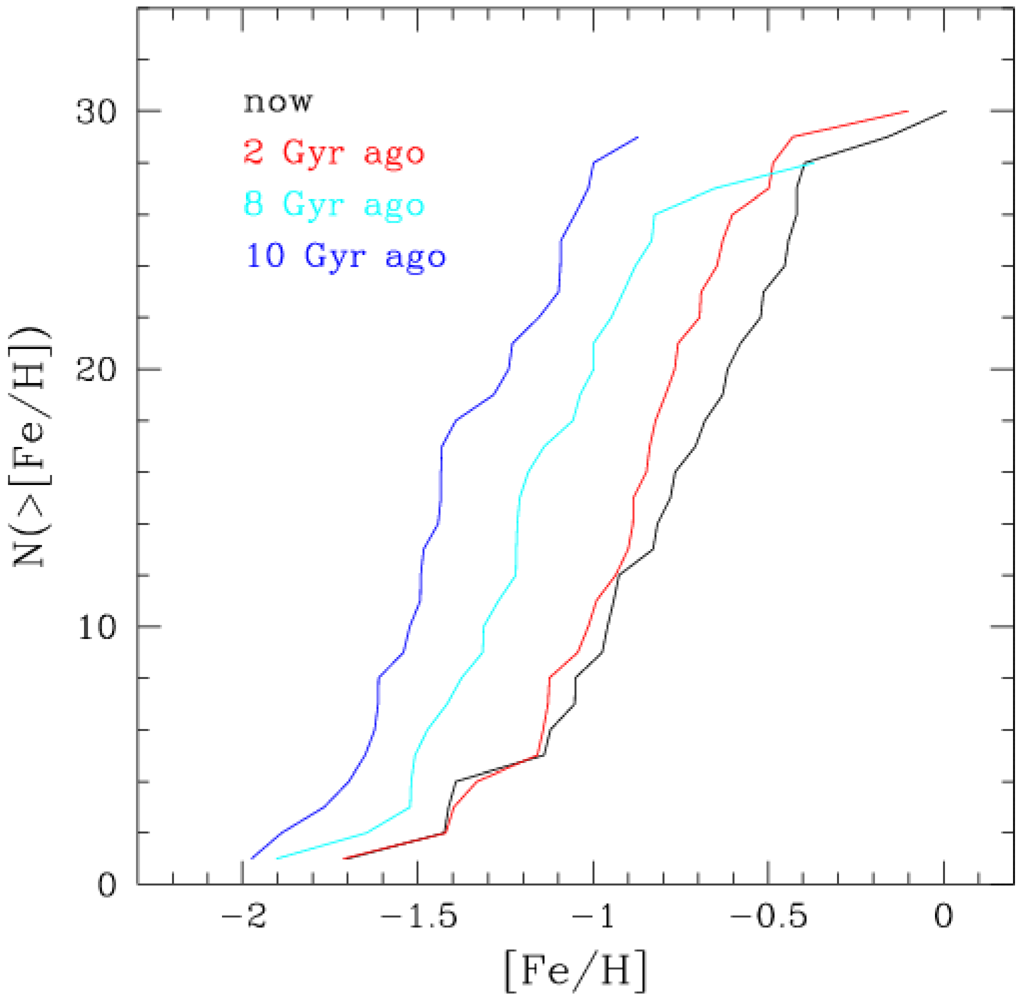


Metallicities are tightly linked to stellar mass

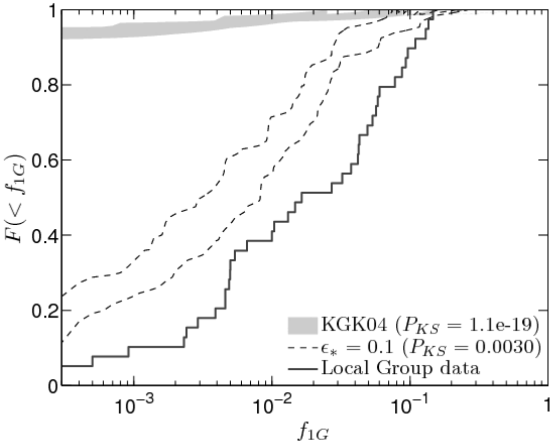


Evolution of the metallicity function

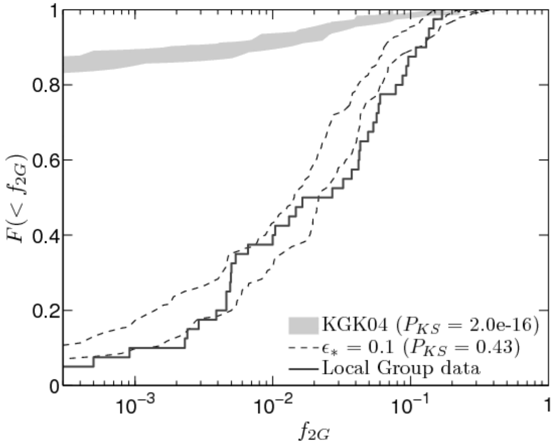
(only classic dwarfs, no ultrafaints)



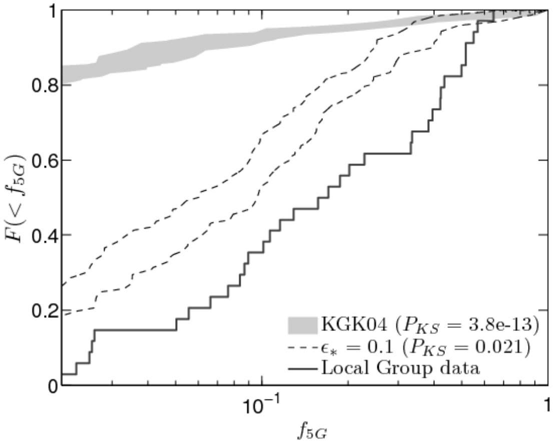
1 Gyr



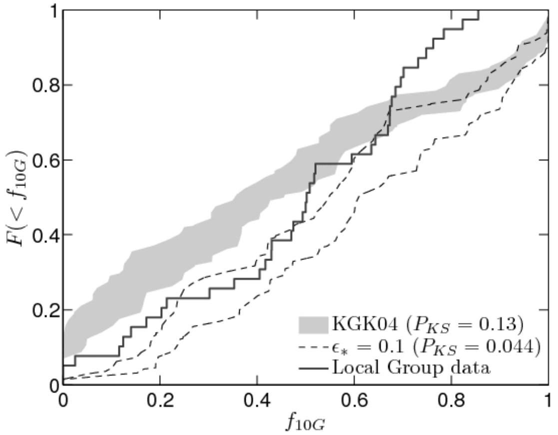
2 Gyr



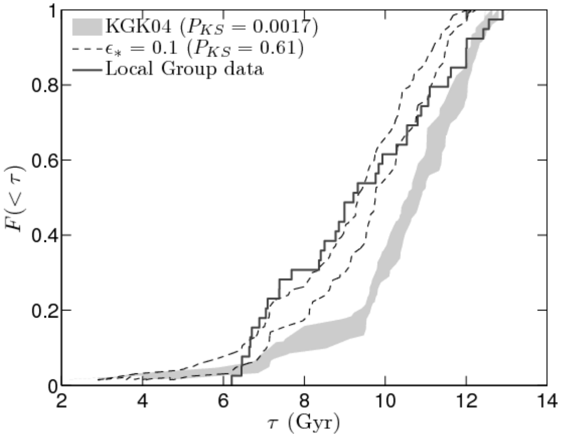
5 Gyr



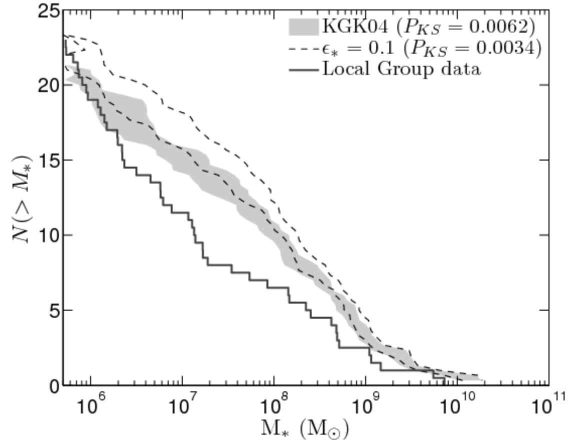
10 Gyr

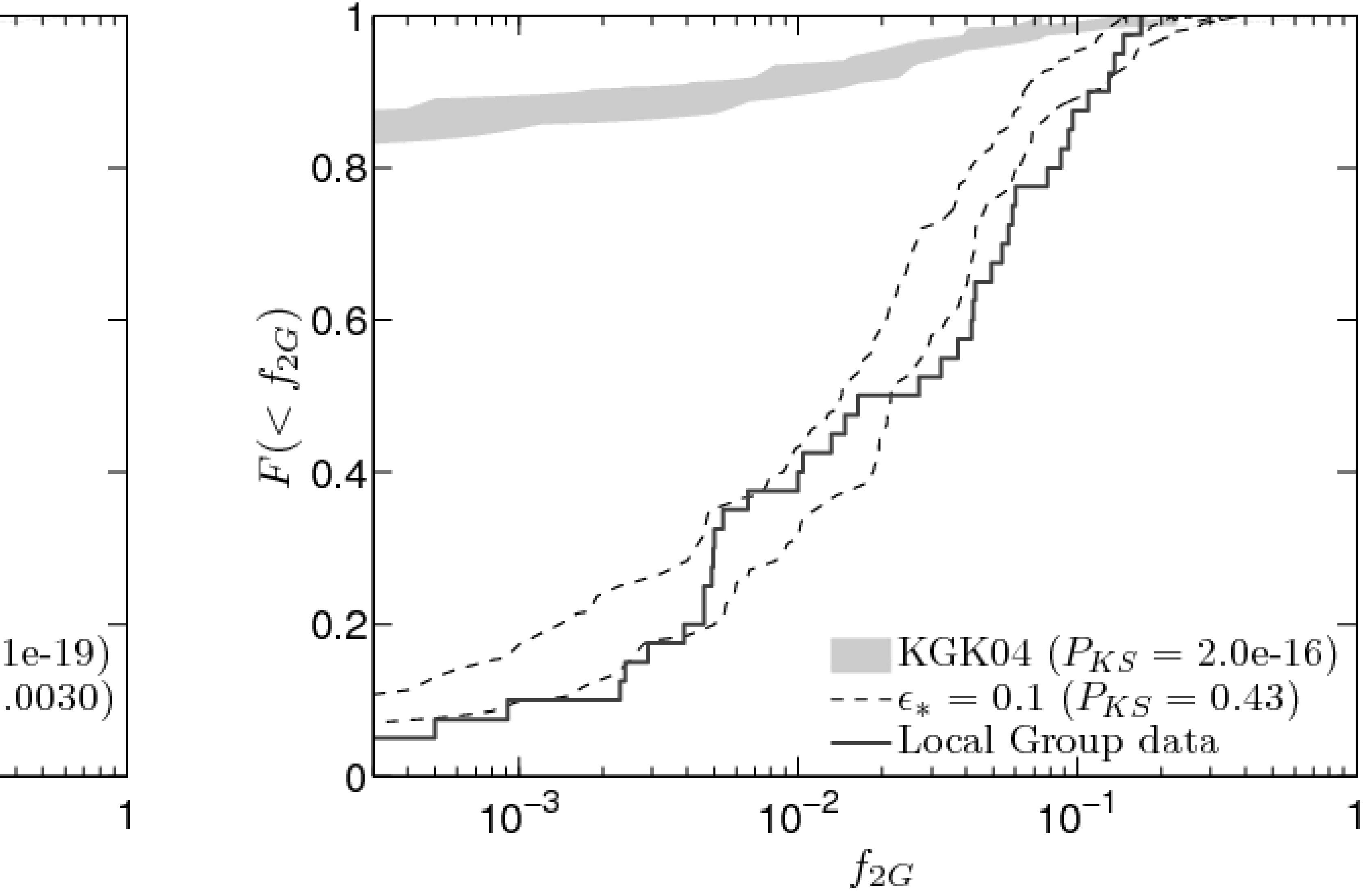


mean age

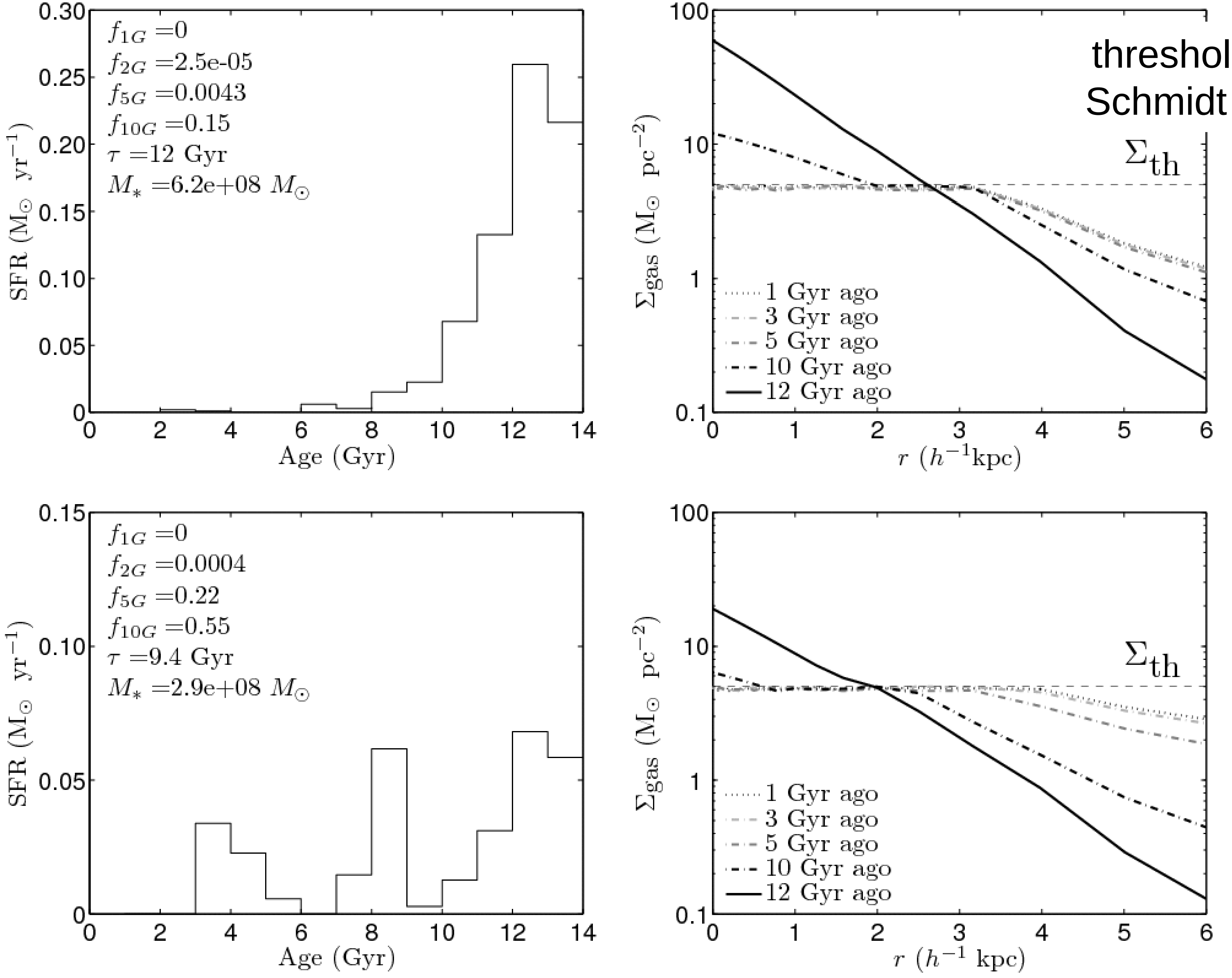


stellar
mass
function



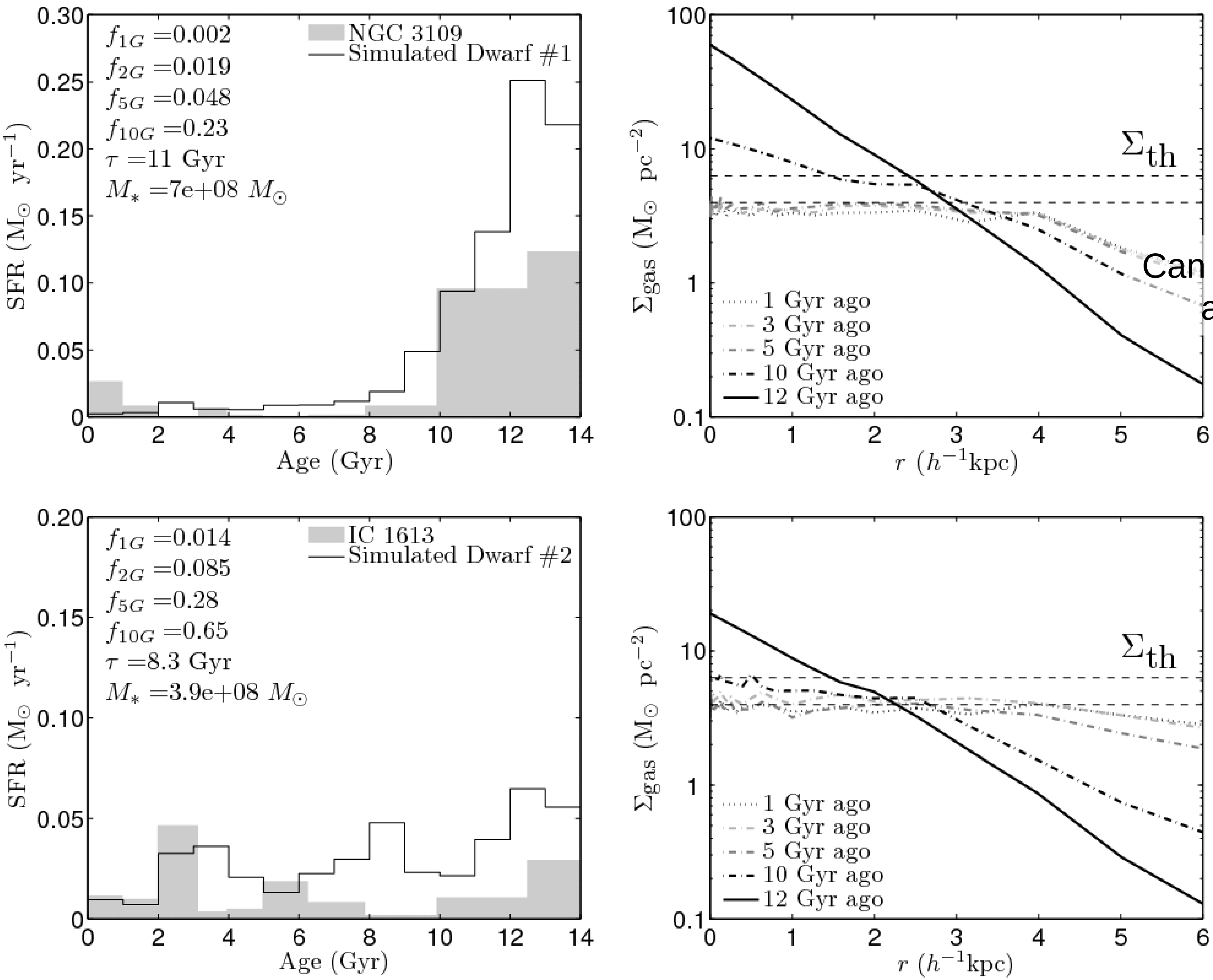

1e-19)
.0030)
1
1
0.8
0.6
0.4
0.2
0
$F(< f_{2G})$
10^{-3}
10^{-2}
10^{-1}
1
f_{2G}
KGK04 (P_{KS} = 2.0e-16)
$\epsilon_* = 0.1$ ($P_{KS} = 0.43$)
Local Group data

Distribution of gas in satellites determines their star formation history



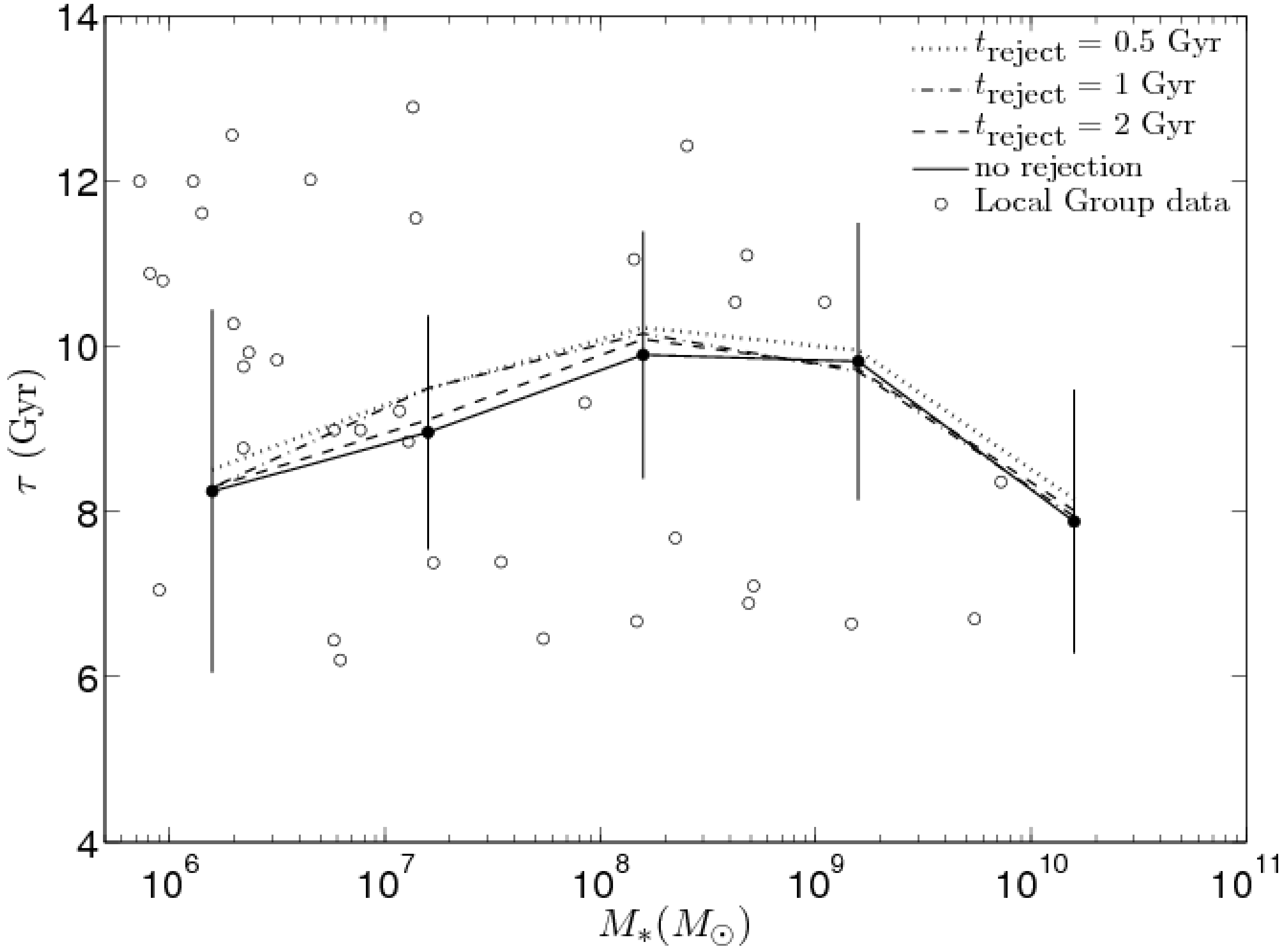
threshold of
Schmidt law

Stochastic star formation threshold allows recent SF



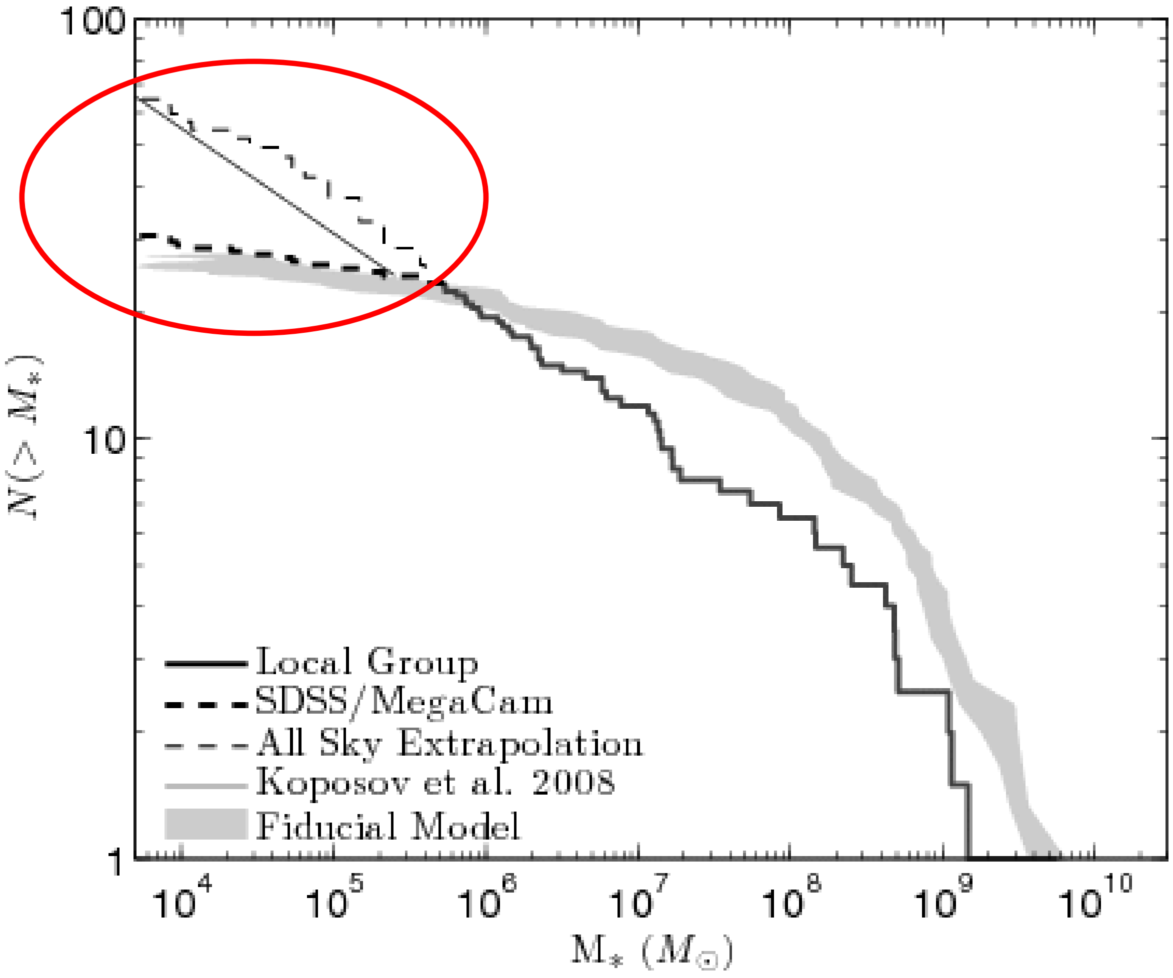
↕ Can determine amount

Mean age of stellar population vs. stellar mass

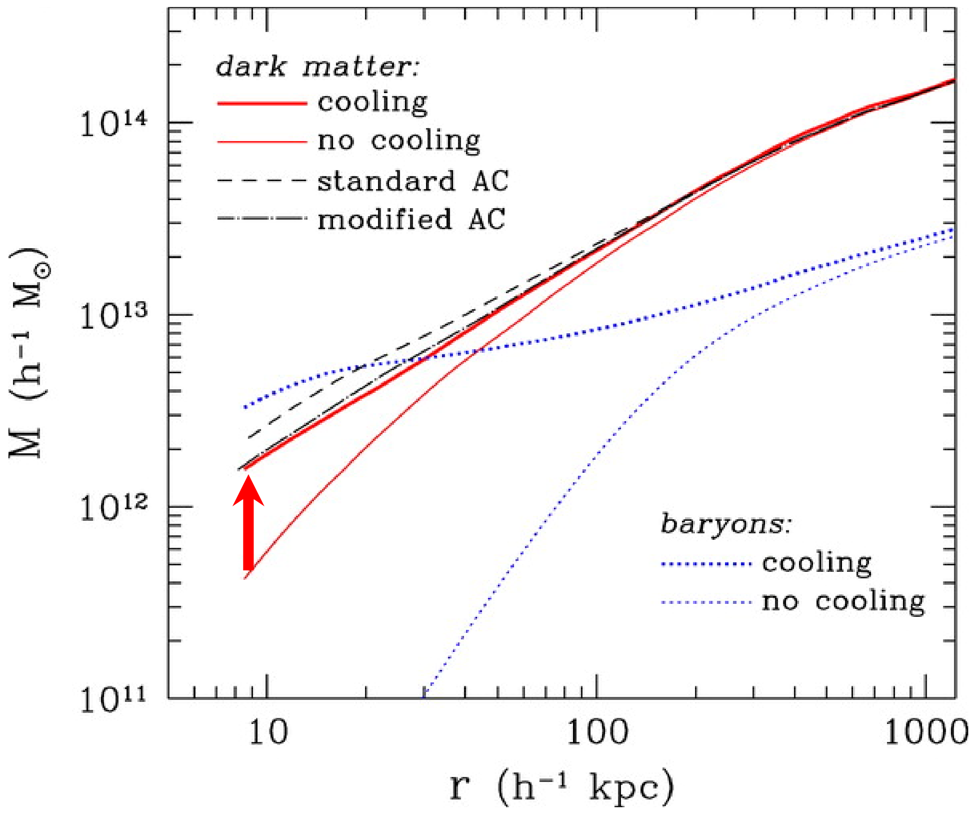


Schmidt law does not work for ultrafaint dwarfs

+ our description of cold gas distribution is simplified



Update on (Adiabatic) Halo Contraction



Cosmological simulations of 8 galaxy clusters at z=0 and one galaxy at z=4: compare runs *with* and *without* gas cooling, for the same initial conditions (OG, Kravtsov, Klypin & Nagai 2004)

Modified model of halo contraction

Standard model is based on conservation of angular momentum for circular orbits *or* radial action for purely radial orbits.

Orbits in real halos have a wide distribution of eccentricities.

Circular orbit: $J^2 \propto M(r)\, r$

Radial orbit, self-similar potential: $I_r^2 \propto M(r_a)\, r_a$

General case:

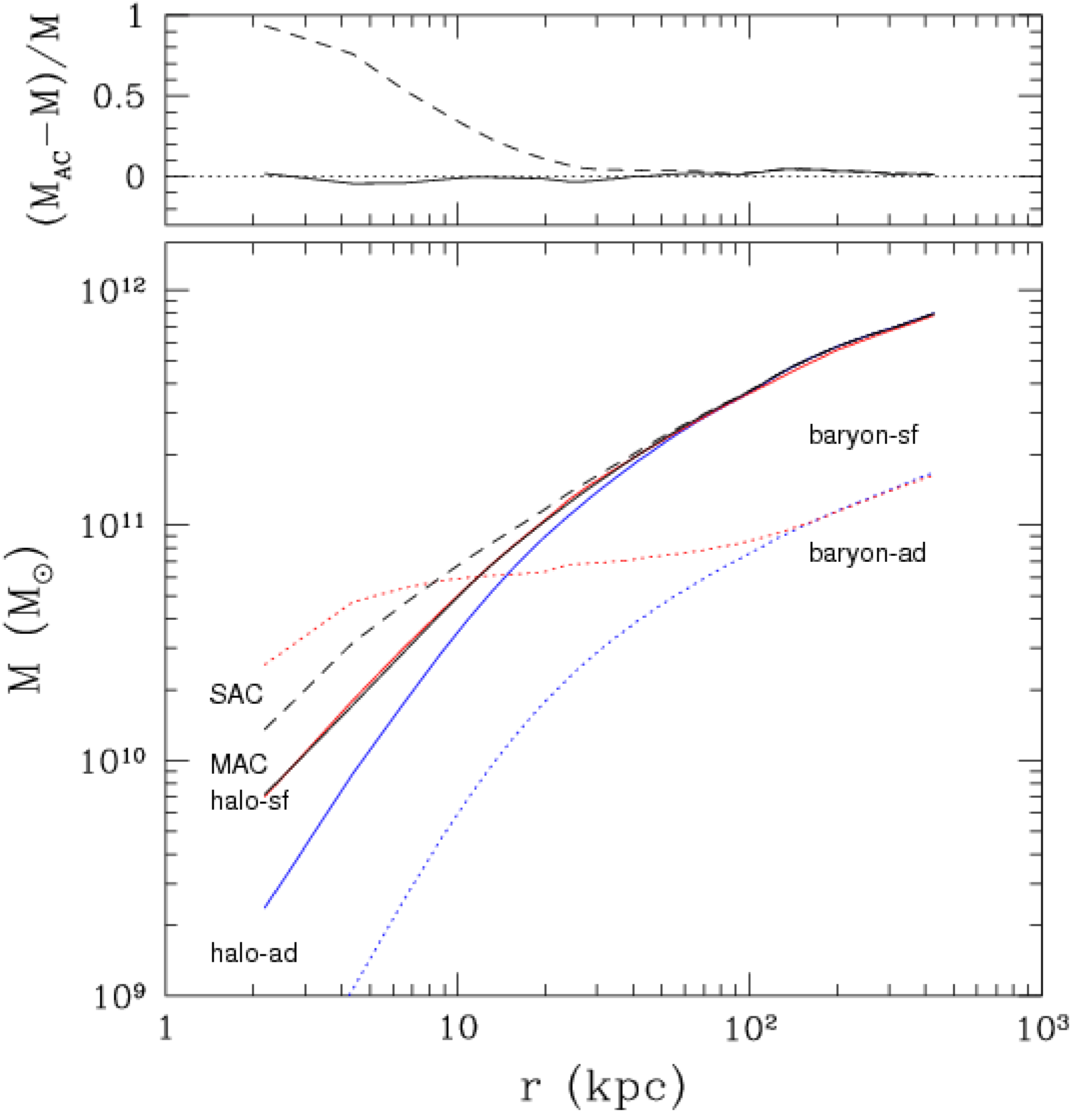
$$\text{modified invariant} = M(\langle r\rangle)\, r, \quad \langle r\rangle / r_{vir} = A\, (r/r_{vir})^w$$

(*approximately correct but maintains the simplicity)*

Contra : a code for halo contraction

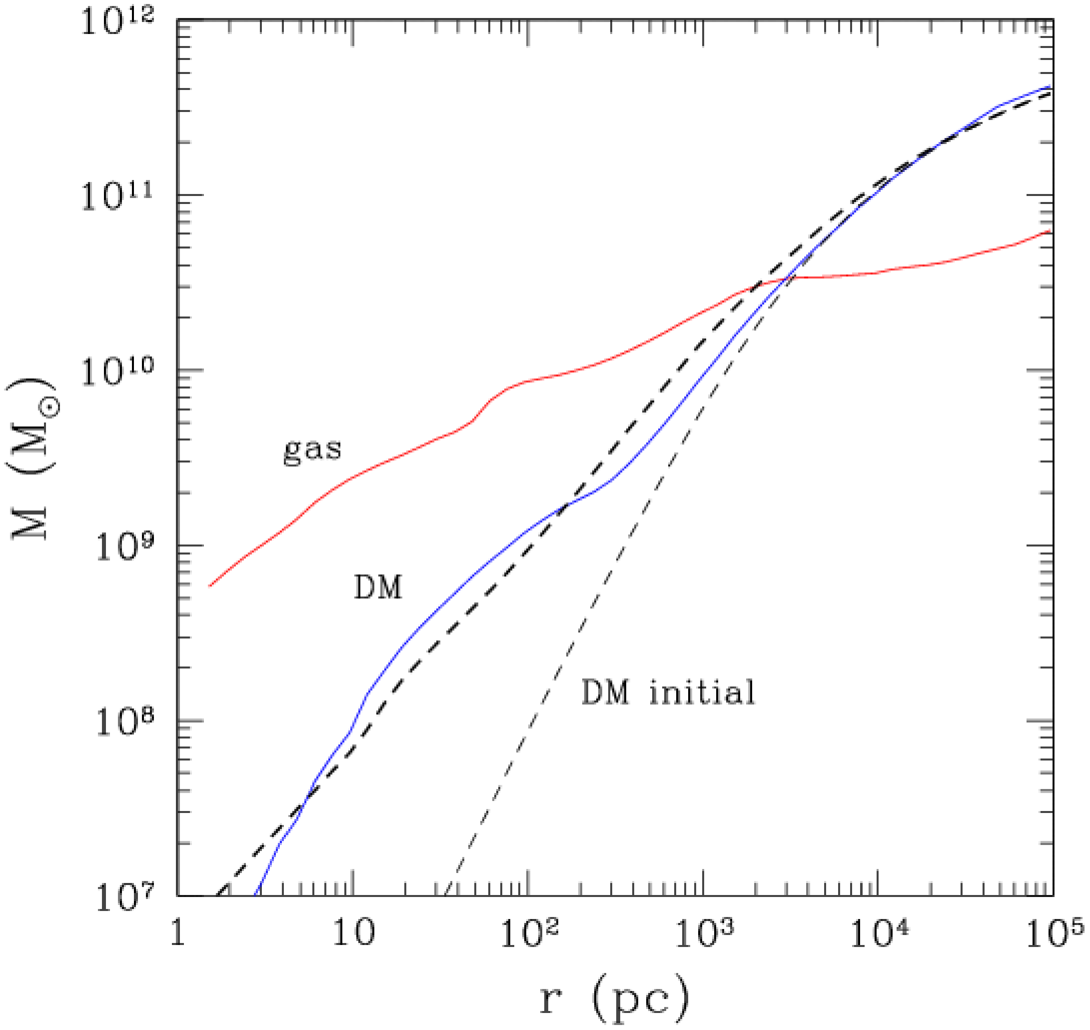
http://www.astro.lsa.umich.edu/~ognedin/contra/

New hydro simulation results:
Dark matter density is still increased by baryonic infall



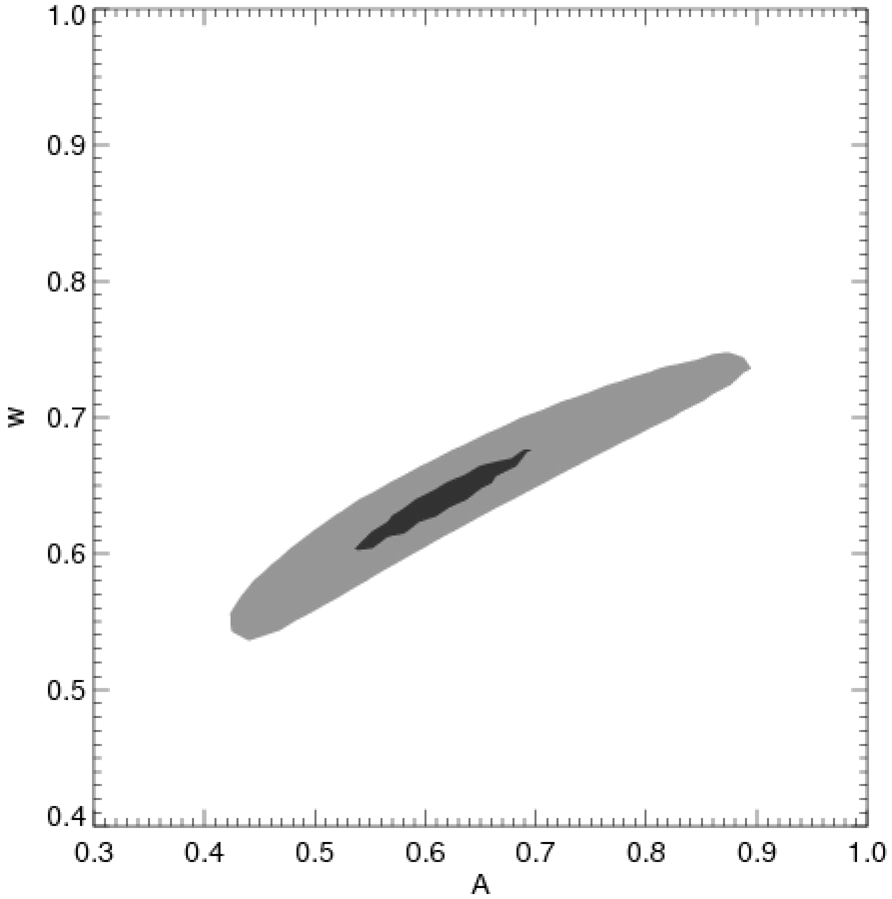
Milky Way-sized
galaxy at z=0
(F. Governato)

Extreme BH simulation: extending the dynamic range



Levine et al. (2008)

Calibrating the Modified Model



Summary

- New dataset of star formation histories of all massive Local Group dwarfs with time resolution < 1 Gyr
- Cutoff mass for accretion of gas is significantly revised
- Dwarf galaxies form stars continuously, as long as their gas density is high enough to form molecules clouds
- Stellar populations of ultrafaint dwarfs are still a mystery!
- The overall effect of gas dissipation, including *non-sphericity, non-adiabaticity, dynamical friction, galaxy mergers, etc.*, is halo contraction