3D Shape, Dynamical State, and Mergers of Nearby Clusters - Virgo and Fornax

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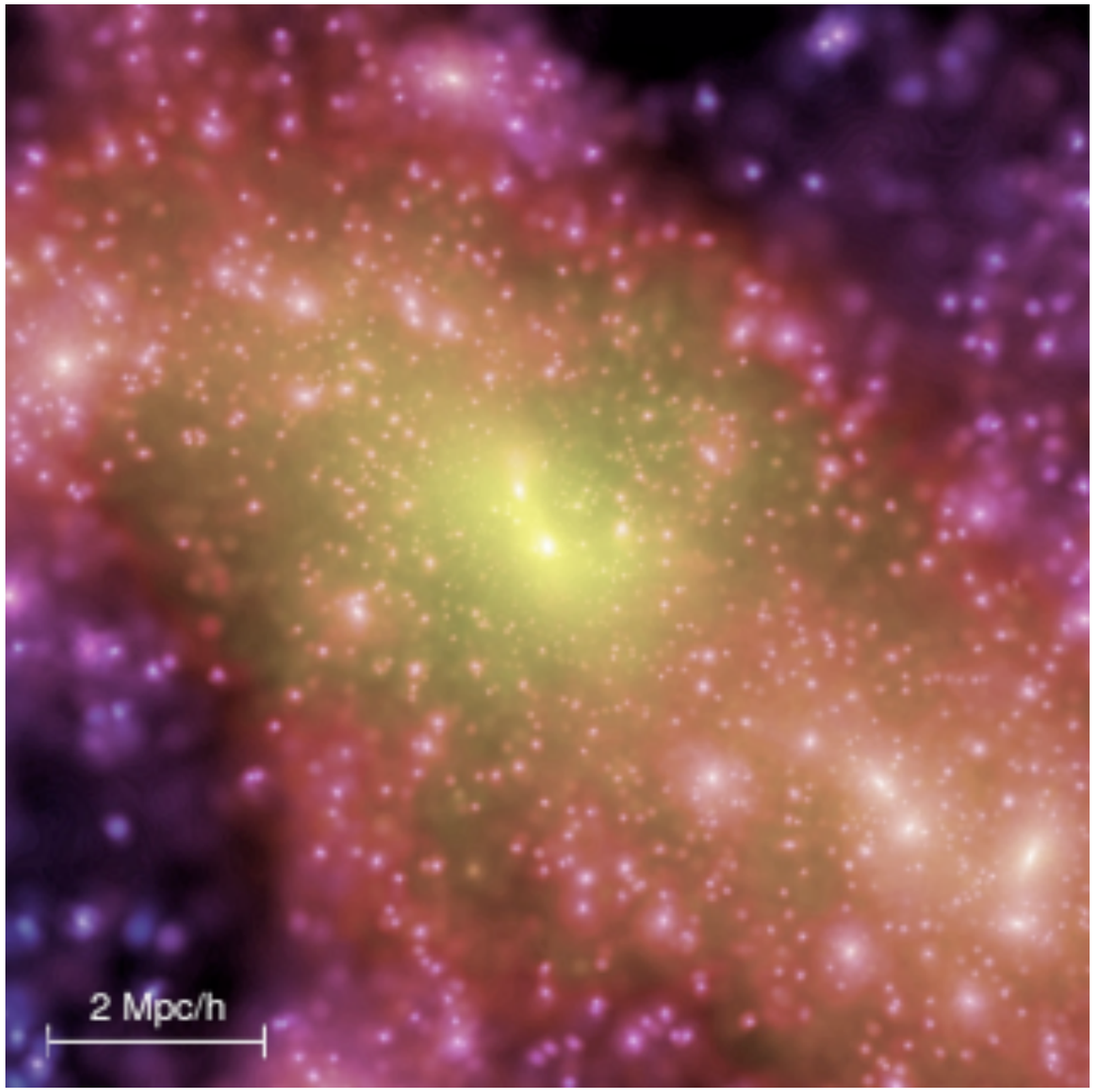
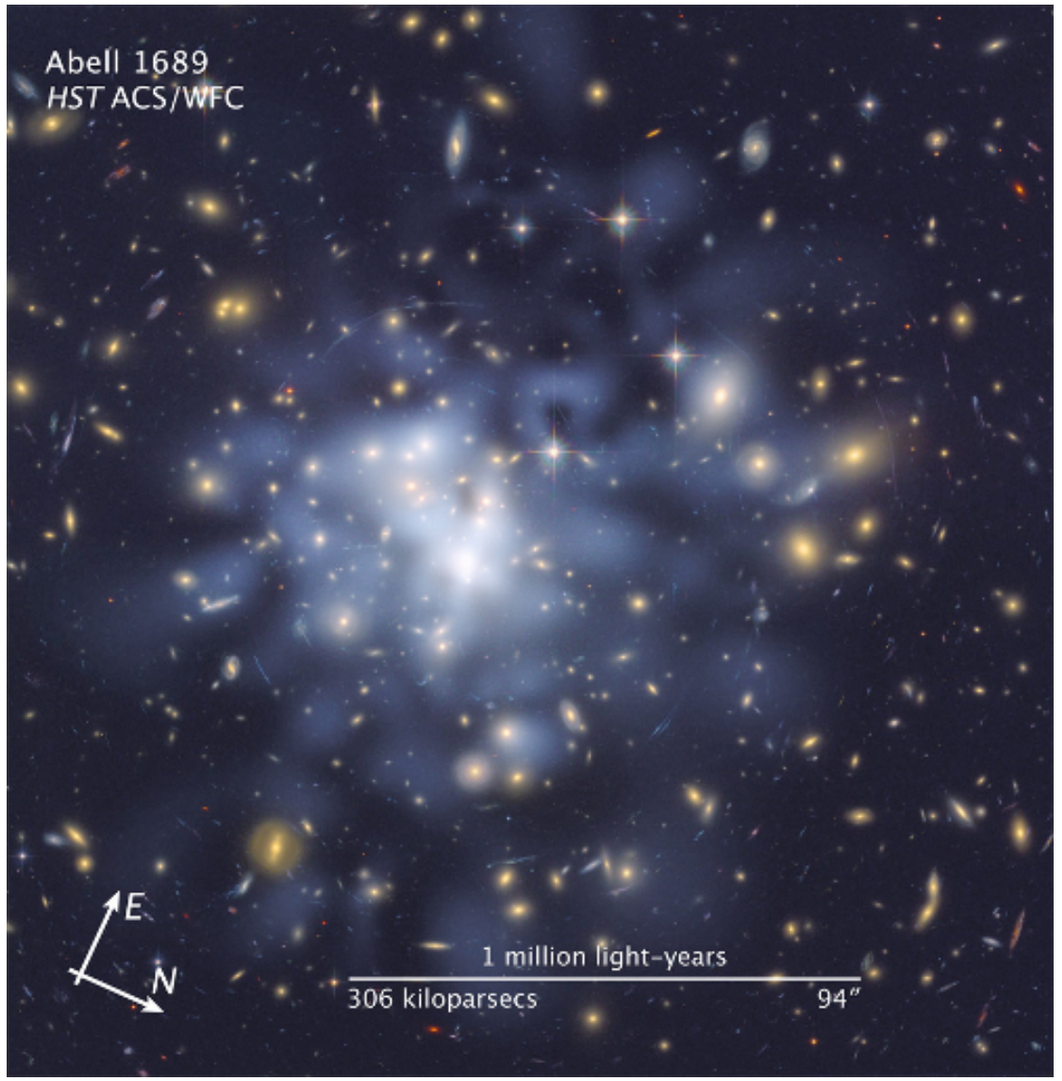
ACS Virgo and Fornax cluster survey teams
Blakeslee, Coté, Ferrarese, Jordán, Peng, Tonry, West

Fornax, Virgo, Coma et al. ESO Garching, 27 June - 1 July 2011

Substructure in Galaxy Clusters



Millennium simulations - Springel et al. (2005)



Coe et al. 2010

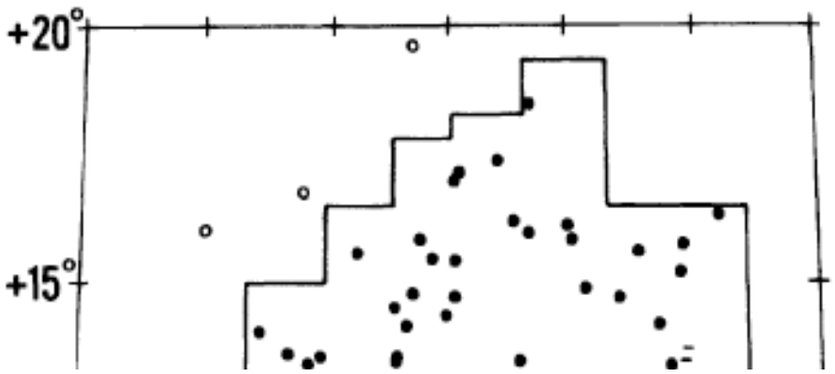
Resolve the substructures and their dynamics

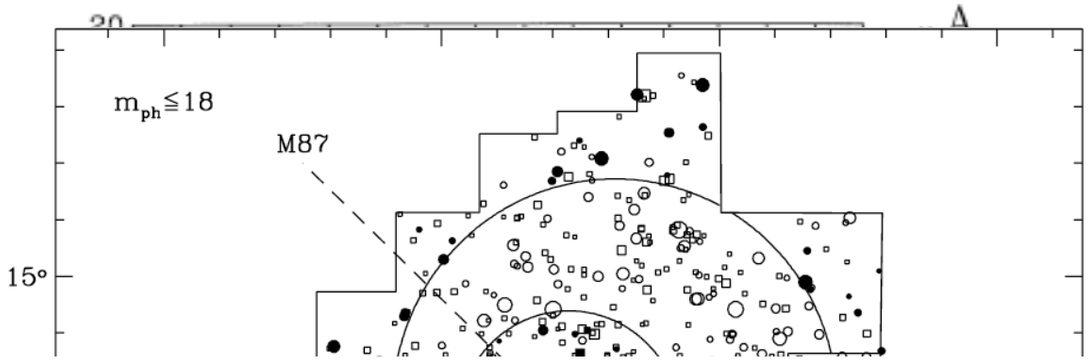
3D-To resolve the line of sight implies an uncertainty on distance measurements ≲ 1 Mpc

- Uncertainty in single galaxy distance modulus of ≲ 0.15 mag at the Virgo cluster distance, ≲0.10 mag at the Fornax distance, ≲ 0.02 mag at the Coma distance

- We can attain such precision in the Virgo and Fornax cluster : results on the 3D structure using HST/ACS Surface Brightness Fluctuation (SBF) distance measurements

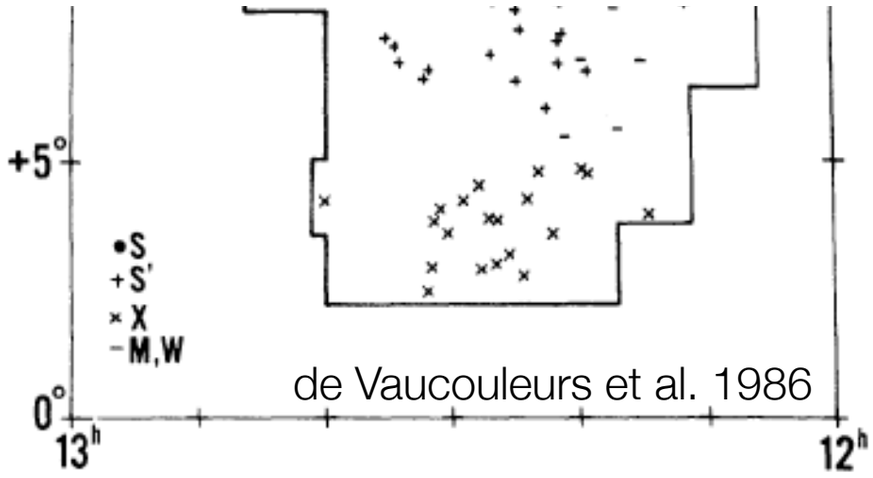
Structures in Virgo

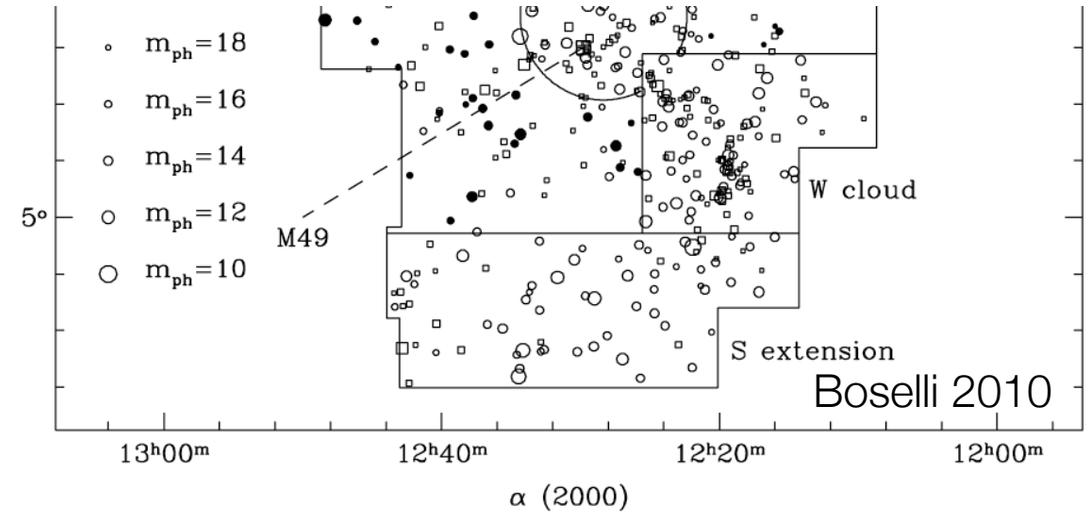




Typical statistical uncertainties in single galaxy distance:

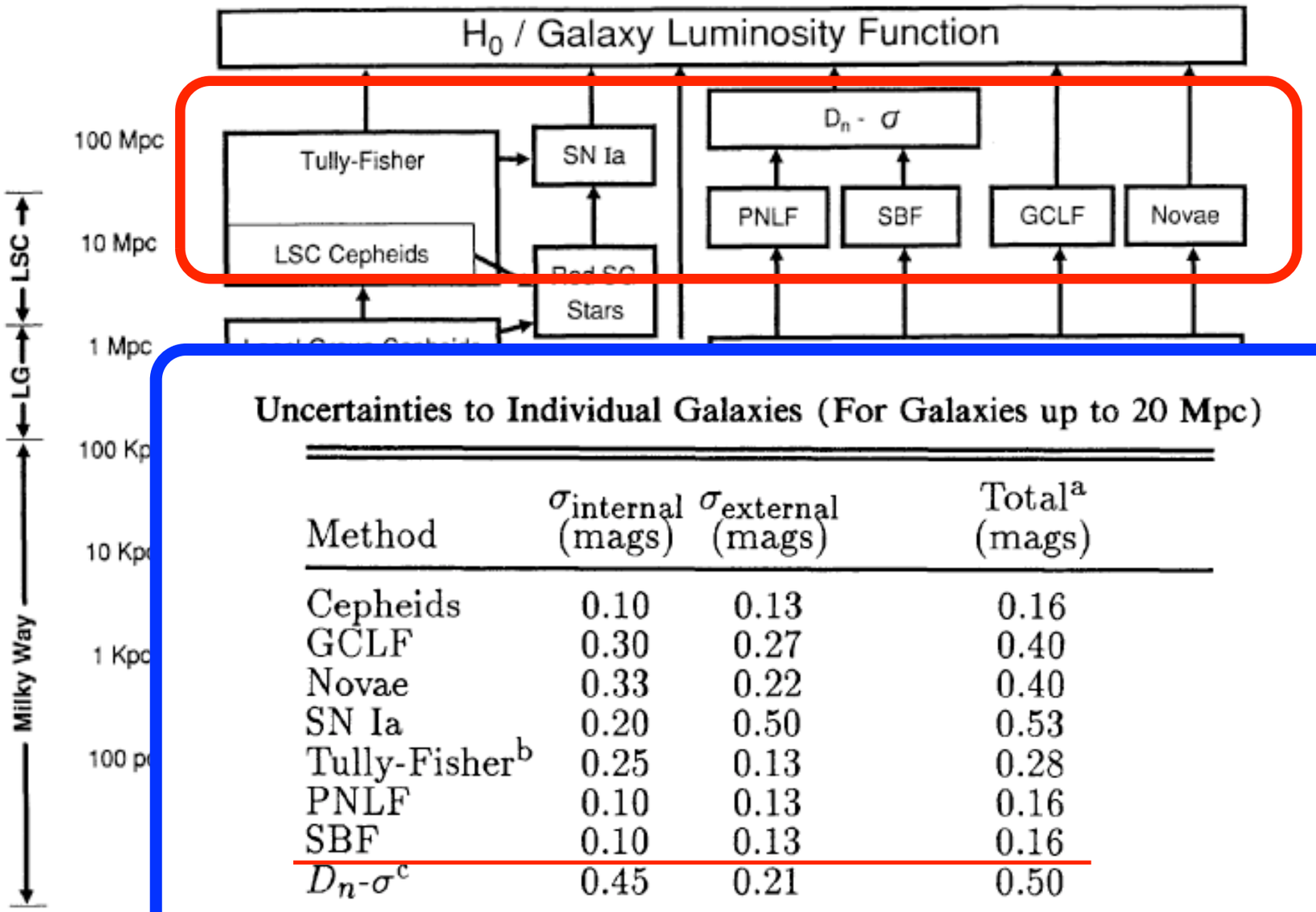
TF ~0.3 mag/2 Mpc; FP ~0.4-0.5 mag/3Mpc





de Vaucouleur 1961, 1986, Helou et al. 1979; Tully&Shaya 1984; Huchra 1985; Tanaka 1985, Binggeli et al. 1985, 1987,1993, Pierce & Tully 1988, Boehringer et al. 1994, Schindler et al. 1999, Fukugita et al. 1993, Yasuda et al.1997, Federspiel et al. 1998, Gavazzi et al. 1999, Fouque et al. 2001 and Solanes et al. 2002, ...

Distance scale and uncertainties

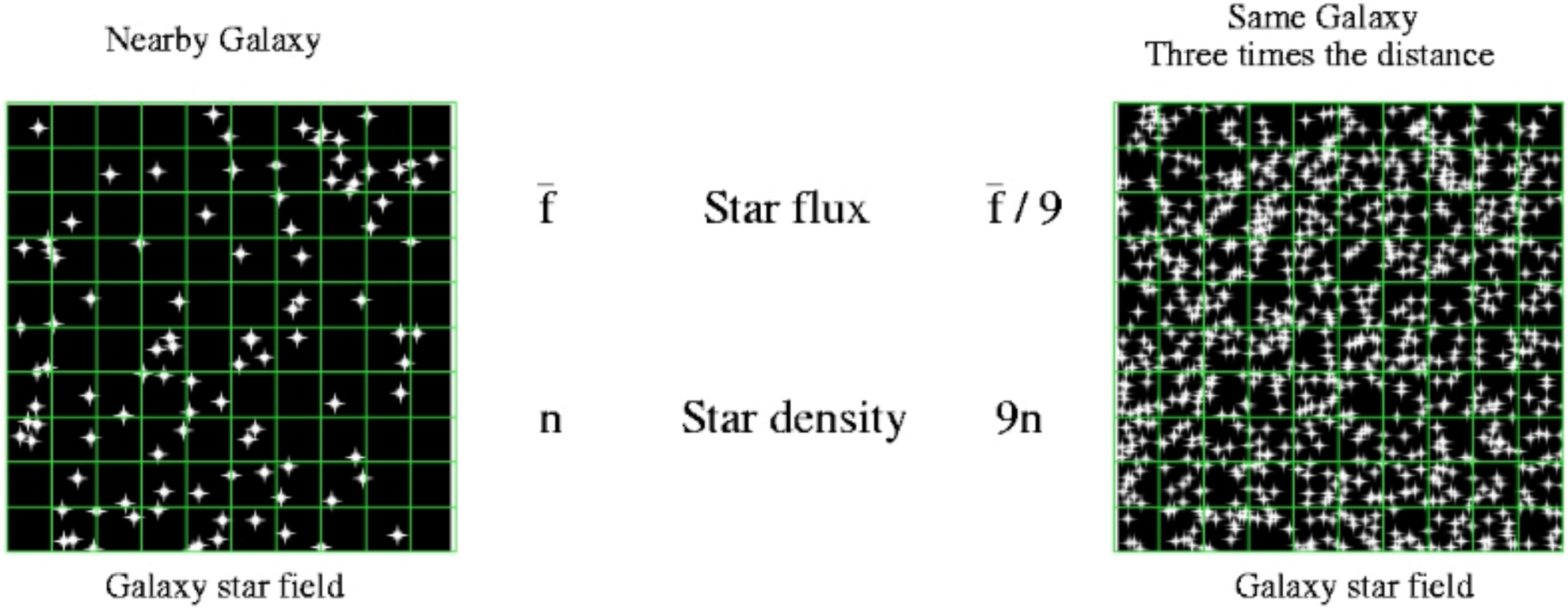


Uncertainties to Individual Galaxies (For Galaxies up to 20 Mpc)

Method	$\sigma_{internal}$ (mags)	$\sigma_{external}$ (mags)	Total[a] (mags)
Cepheids	0.10	0.13	0.16
GCLF	0.30	0.27	0.40
Novae	0.33	0.22	0.40
SN Ia	0.20	0.50	0.53
Tully-Fisher[b]	0.25	0.13	0.28
PNLF	0.10	0.13	0.16
SBF	0.10	0.13	0.16
D_n-σ[c]	0.45	0.21	0.50

Jacoby 1992

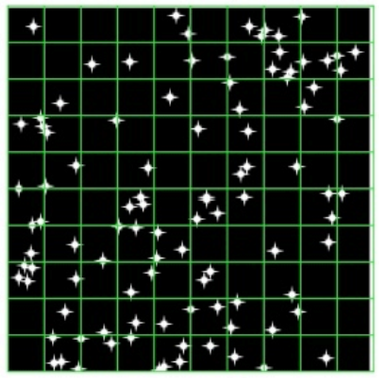
Surface Brightness Fluctuations



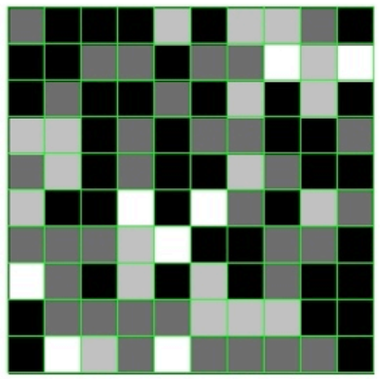
Tonry & Schneider 1988

J. Tonry's web page

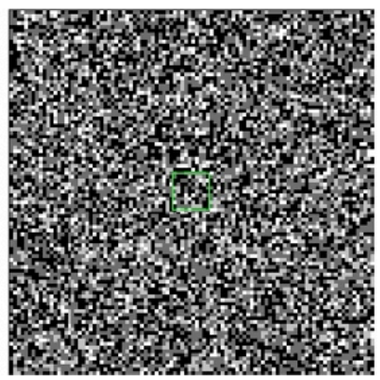
Nearby Galaxy



Galaxy star field



What the CCD sees

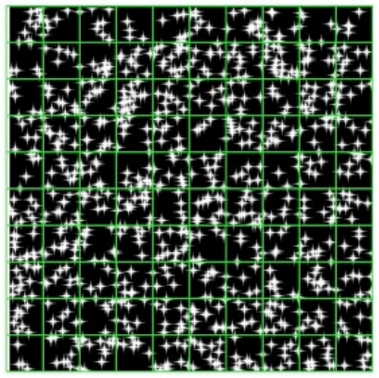


More CCD pixels

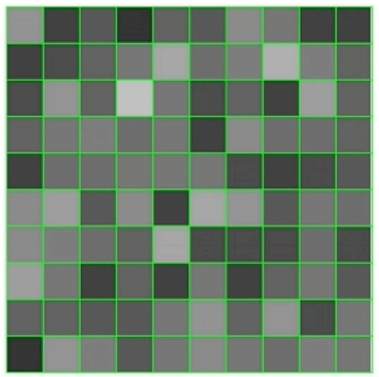
Blurred by atmosphere

$\bar{f}$	Star flux	$\bar{f}/9$
n	Star density	$9n$
$n\bar{f}$	Surface Brightness	$n\bar{f}$
$\sqrt{n}\,\bar{f}$	Rms fluctuation (inversely prop. to distance)	$\sqrt{9n}\,\bar{f}/9 = \frac{1}{3}\sqrt{n}\,\bar{f}$
	Variance divided by Mean (Star flux)	

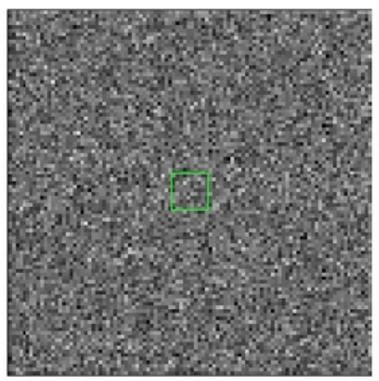
Same Galaxy
Three times the distance



Galaxy star field



What the CCD sees



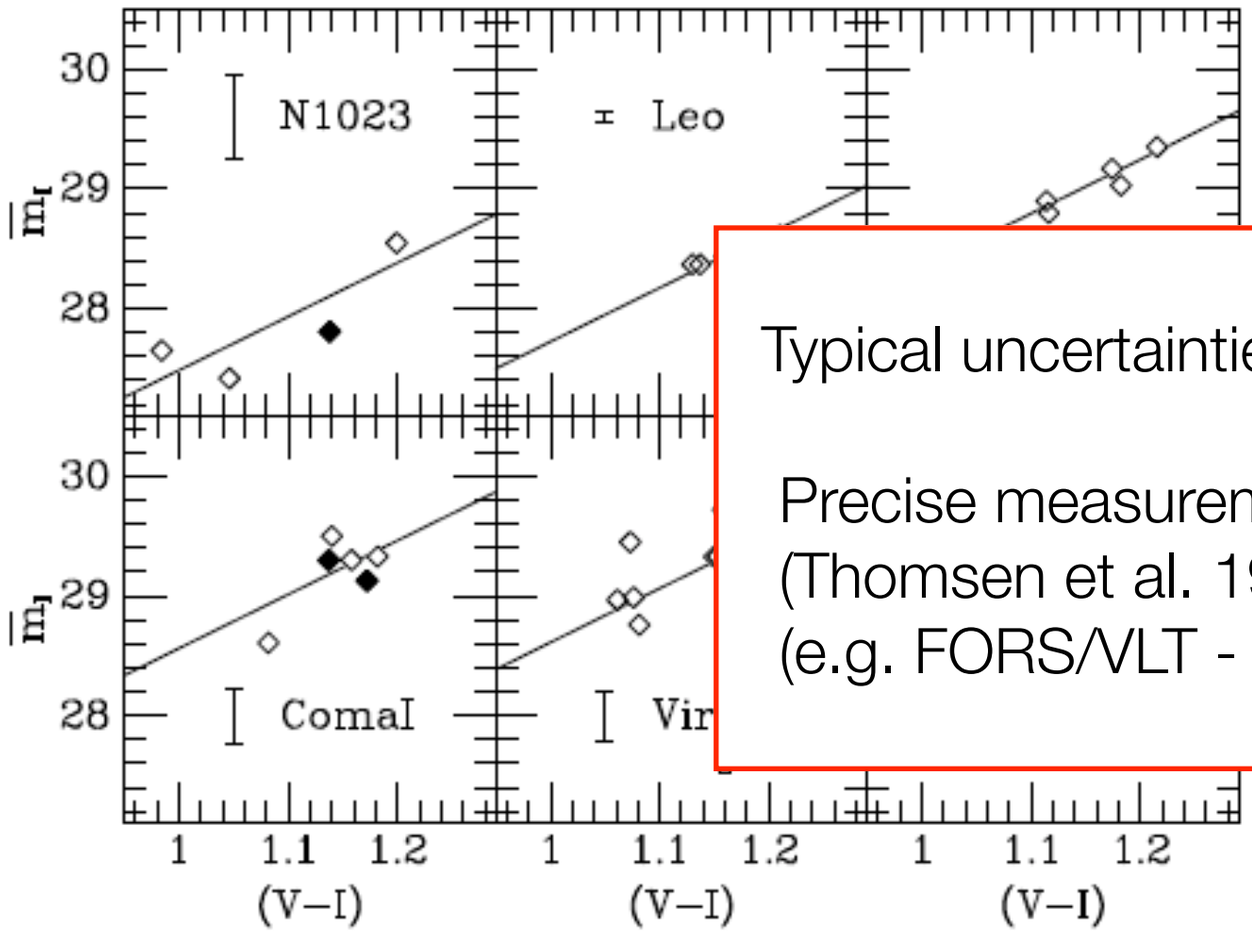
More CCD pixels

Blurred by atmosphere

+ Stellar Population Calibration

J. Tonry's webpage

SBF measurements



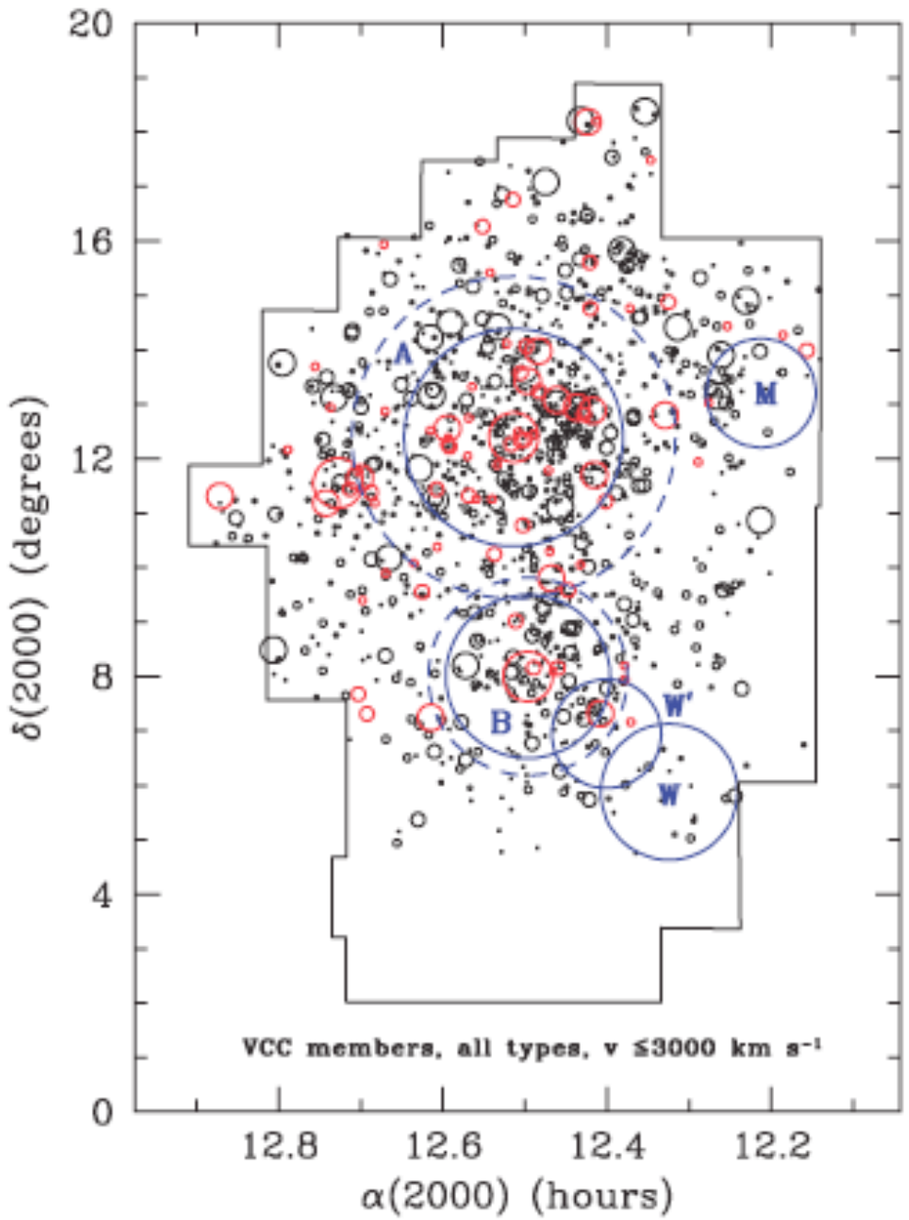
SBF Distance Survey Tonry et al. 1997, 2000, 2001

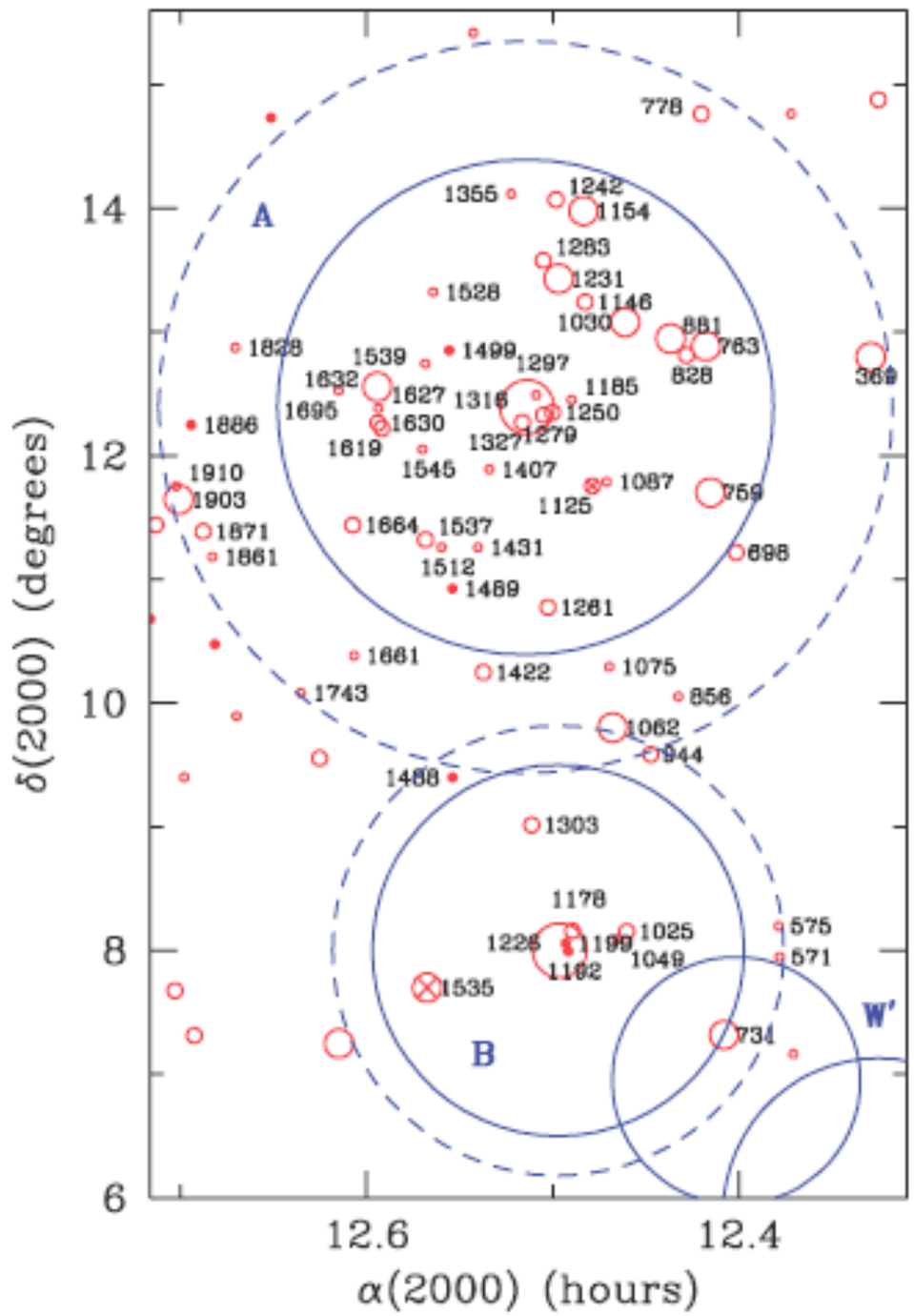
Typical uncertainties ~10% distance

Precise measurements up to ~100 Mpc with HST (Thomsen et al. 1997) and 8m telescopes (e.g. FORS/VLT - Mei et al. 2003)

Ajhar et al. 1997, 2001; Thomsen et al. 1997; Mei et al. 2000, 2001abc, 2003; Ferrarese et al. 2000ab; Neilsen & Tsvetanov 2000; Blakeslee et al. 2001, 2002; Liu & Graham 2001; Liu et al. 2002; Jensen et al. 2003; Mieske et al. 2003; Jerjen et al. 2004

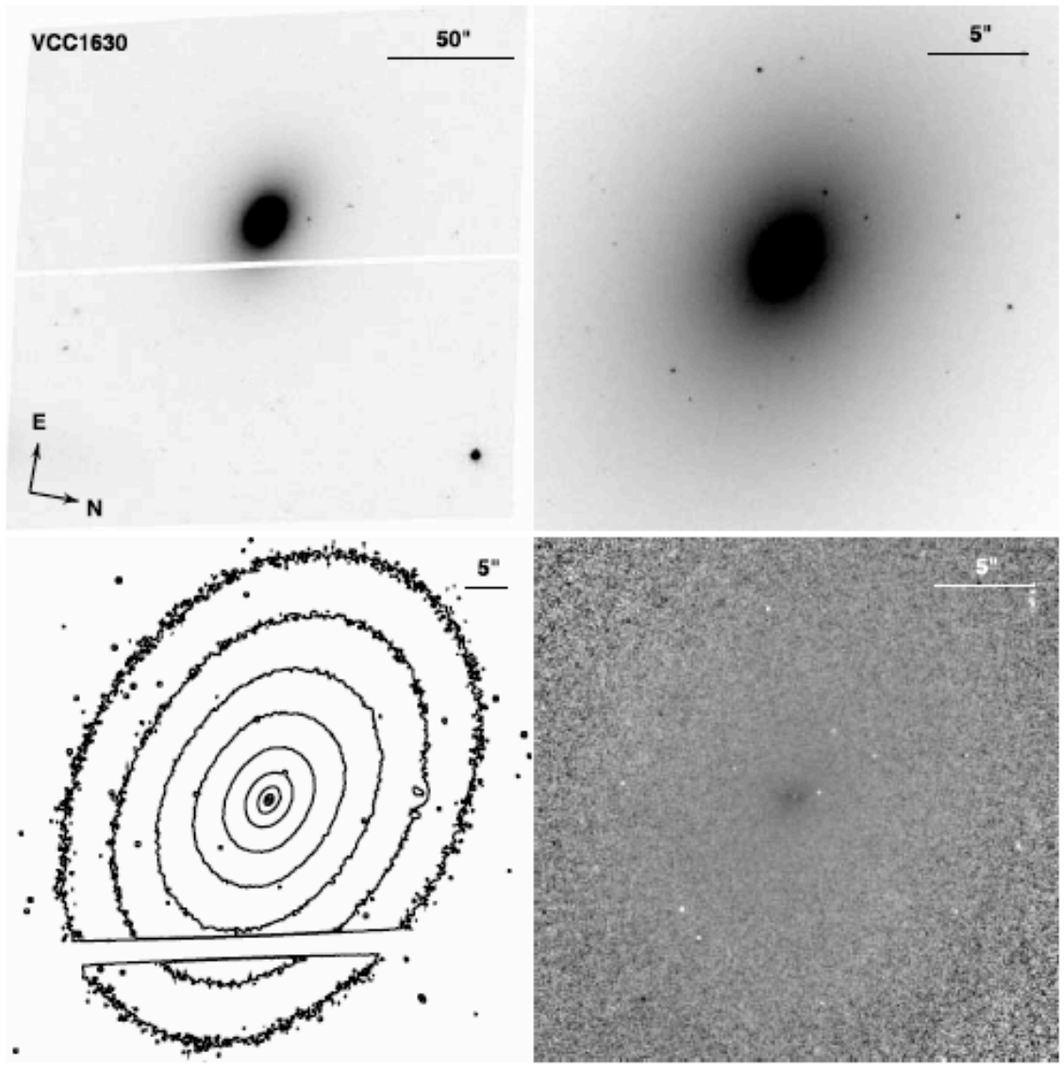
The ACS Virgo Cluster Survey (PI: Pat Coté)

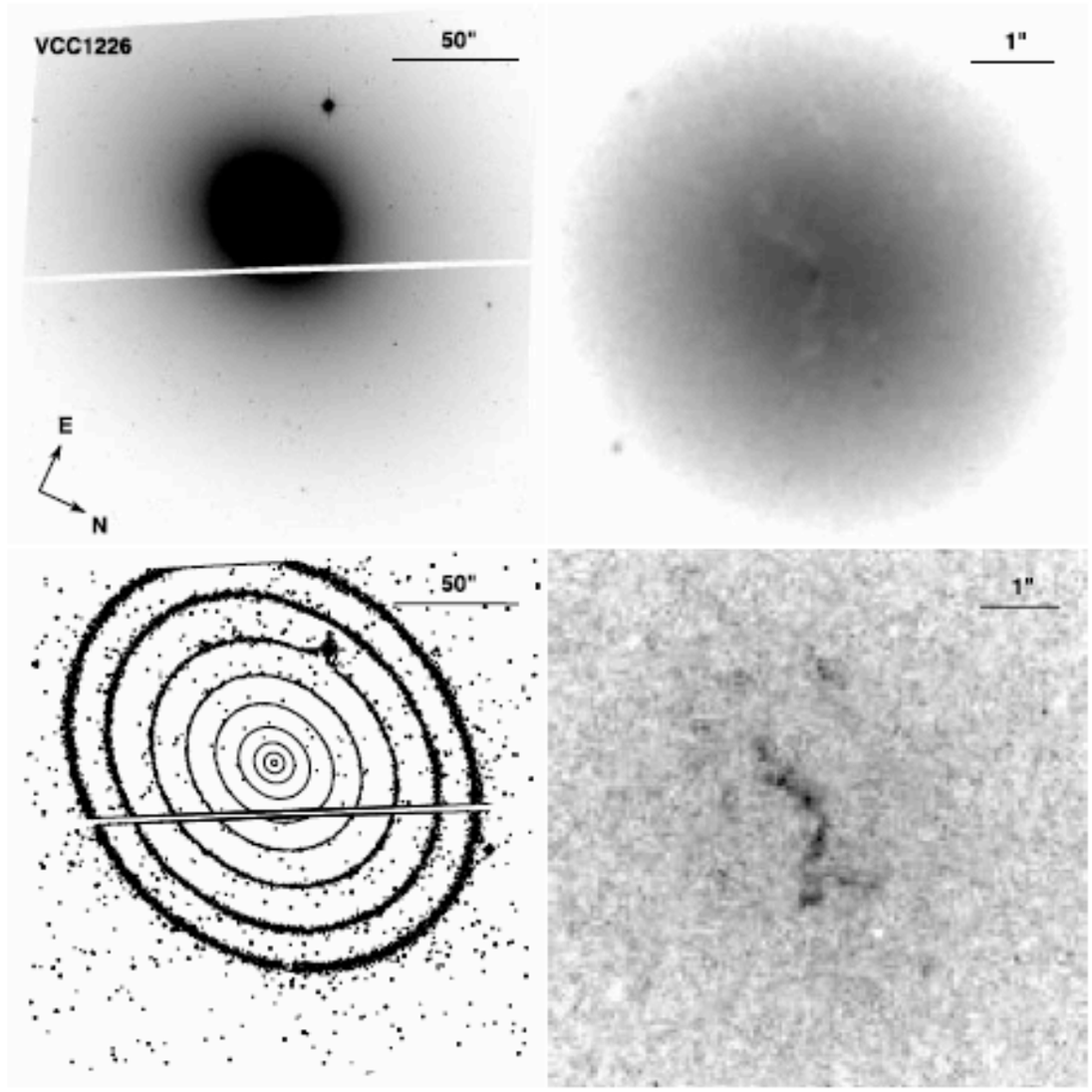




Coté et al. 2004

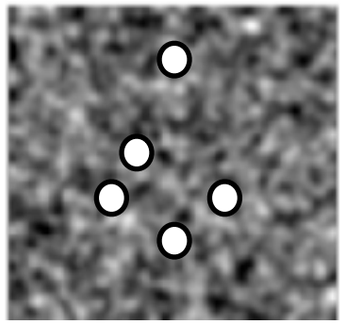
Surface Brightness Fluctuations

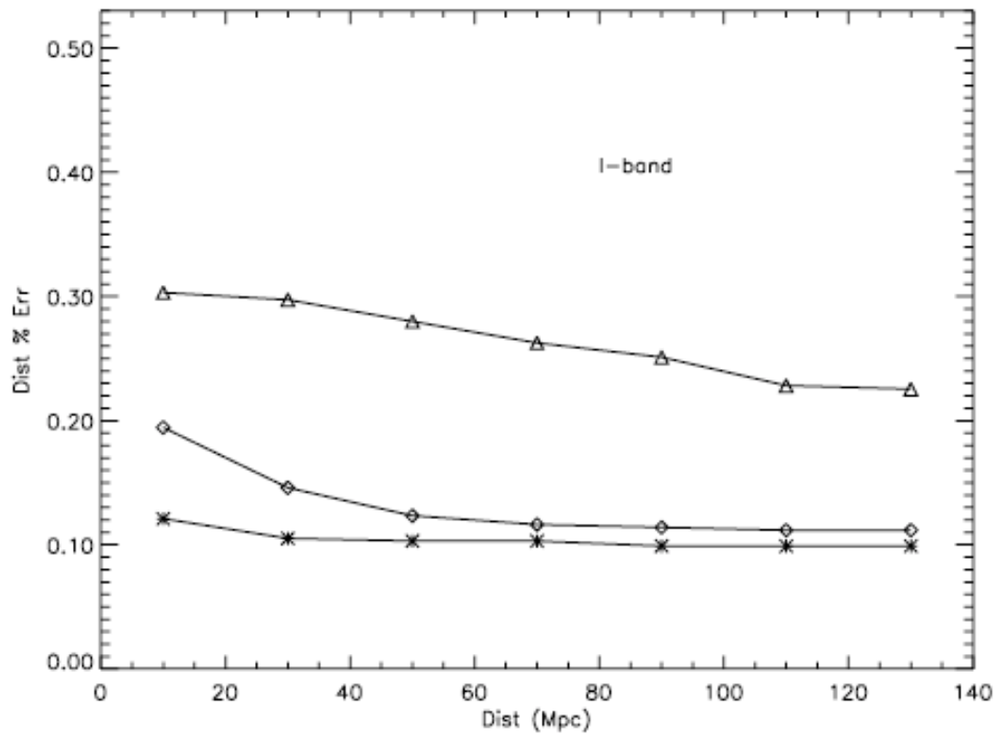


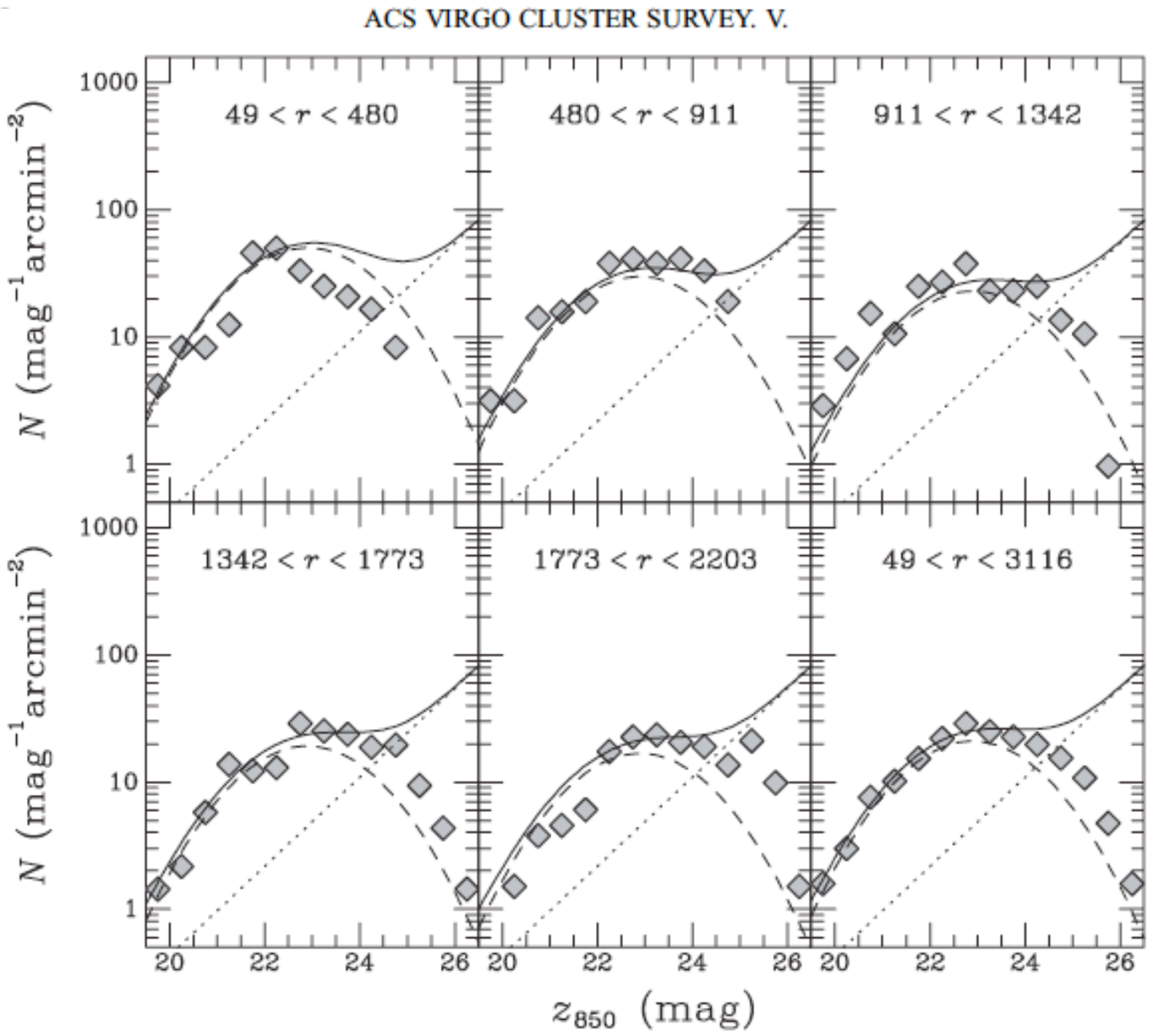


Galaxy profiles from Ferrarese et al. 2006, globular cluster and background galaxies from Jordán et al. 2007, Peng et al. 2008

External source contribution : GCs and background galaxies

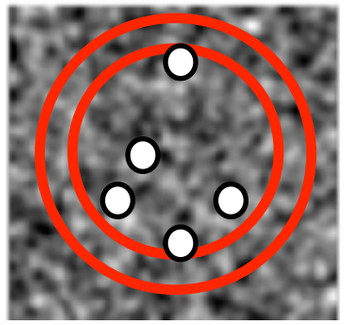


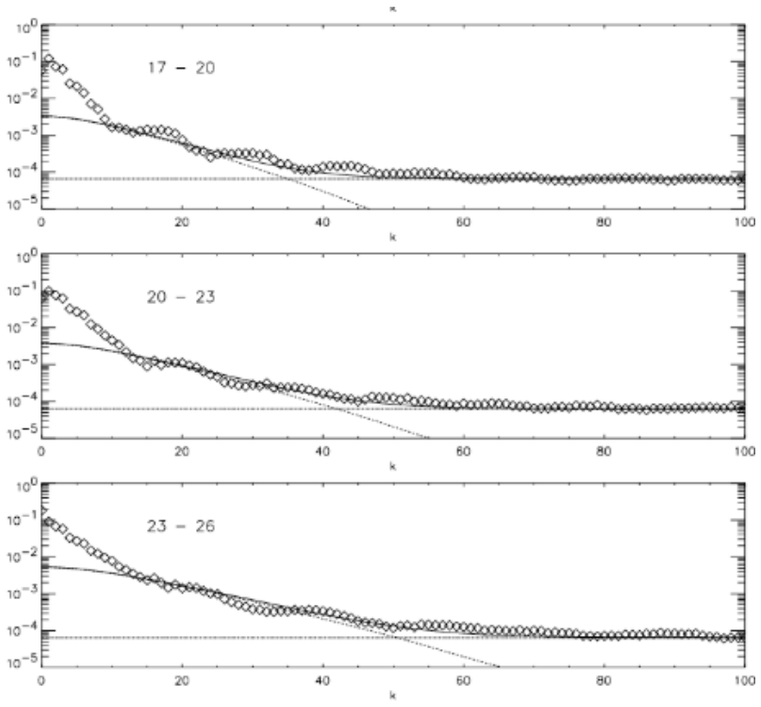




Mei et al. 2001, 2005a; globular cluster and background galaxies from Jordán et al. 2007, Peng et al. 2008

Surface Brightness Fluctuations





$$P(k) = P_0 \times P_{PSF}(k) + P_1$$

From this we derive

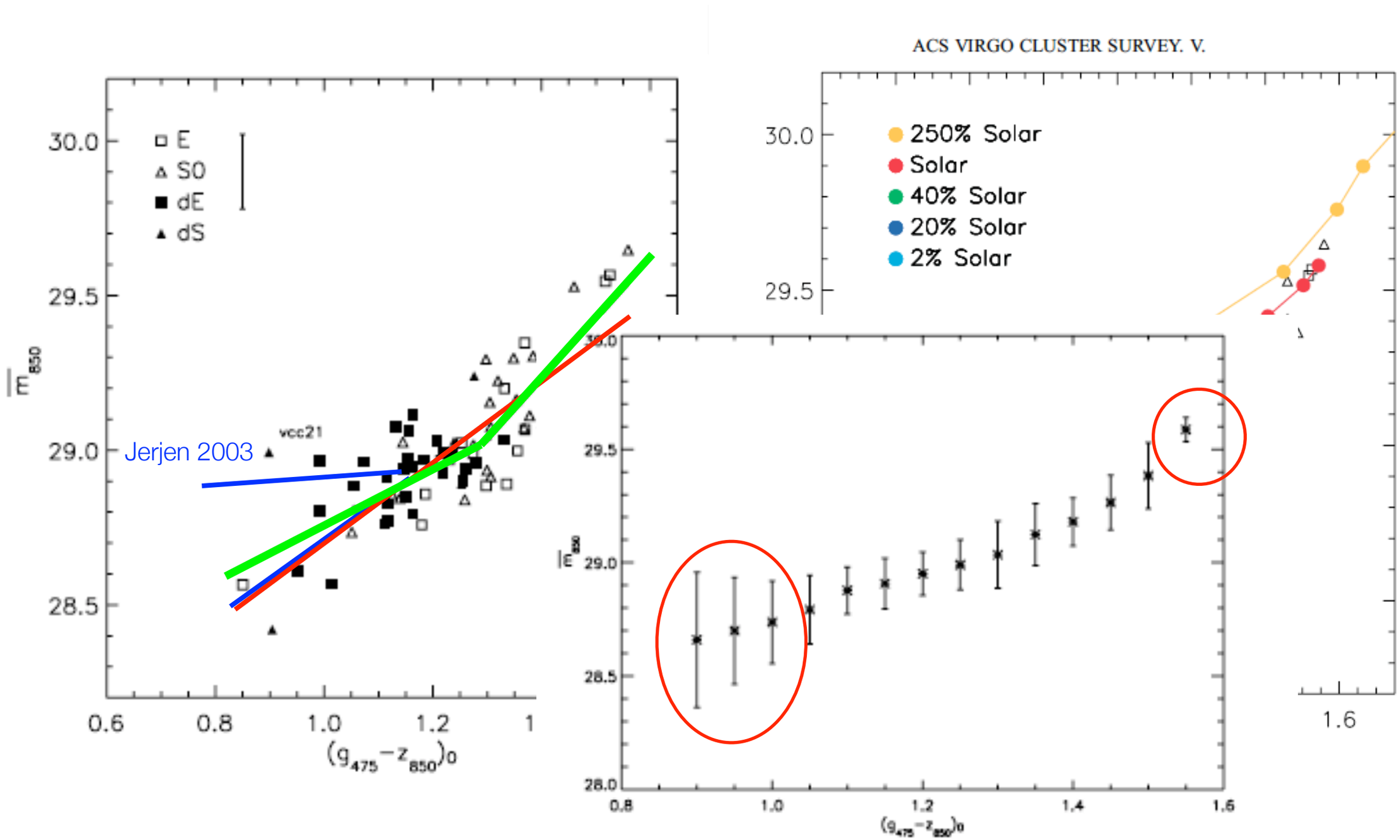
$$P_0 = \sum \sigma^2_{\rm SBF}$$

and

$$P_1 = \sum \sigma^2_{\rm ph} + \sum \sigma^2_{\rm RON},$$

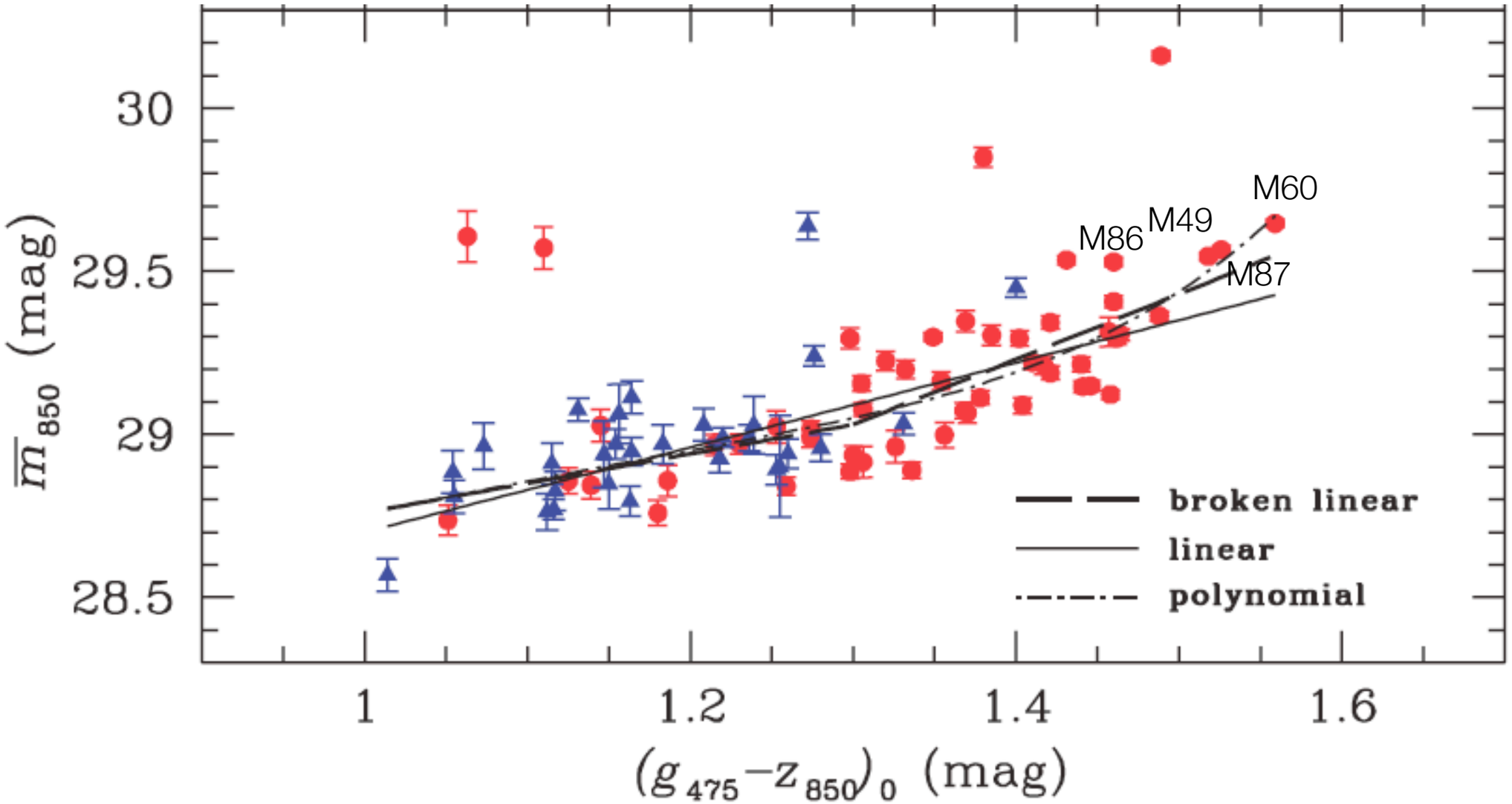
$$\overline{m} = -2.5\ log\left(\frac{P_0 - P_{ES}}{t_{exp}}\right) + m_0$$

Stellar population calibration



Mei et al. 2005b

Stellar population calibration



Mei et al. 2007

From SBF to distances

$$\overline{M}_{850} = \begin{cases} -2.06 \pm 0.04 + (0.9 \pm 0.2)[(g_{475} - z_{850})_0 - 1.3], \\ \quad \text{if } 1.0 \leq (g_{475} - z_{850})_0 \leq 1.3, \\ -2.06 \pm 0.04 + (2.0 \pm 0.2)[(g_{475} - z_{850})_0 - 1.3], \\ \quad \text{if } 1.3 < (g_{475} - z_{850})_0 \leq 1.6, \end{cases}$$

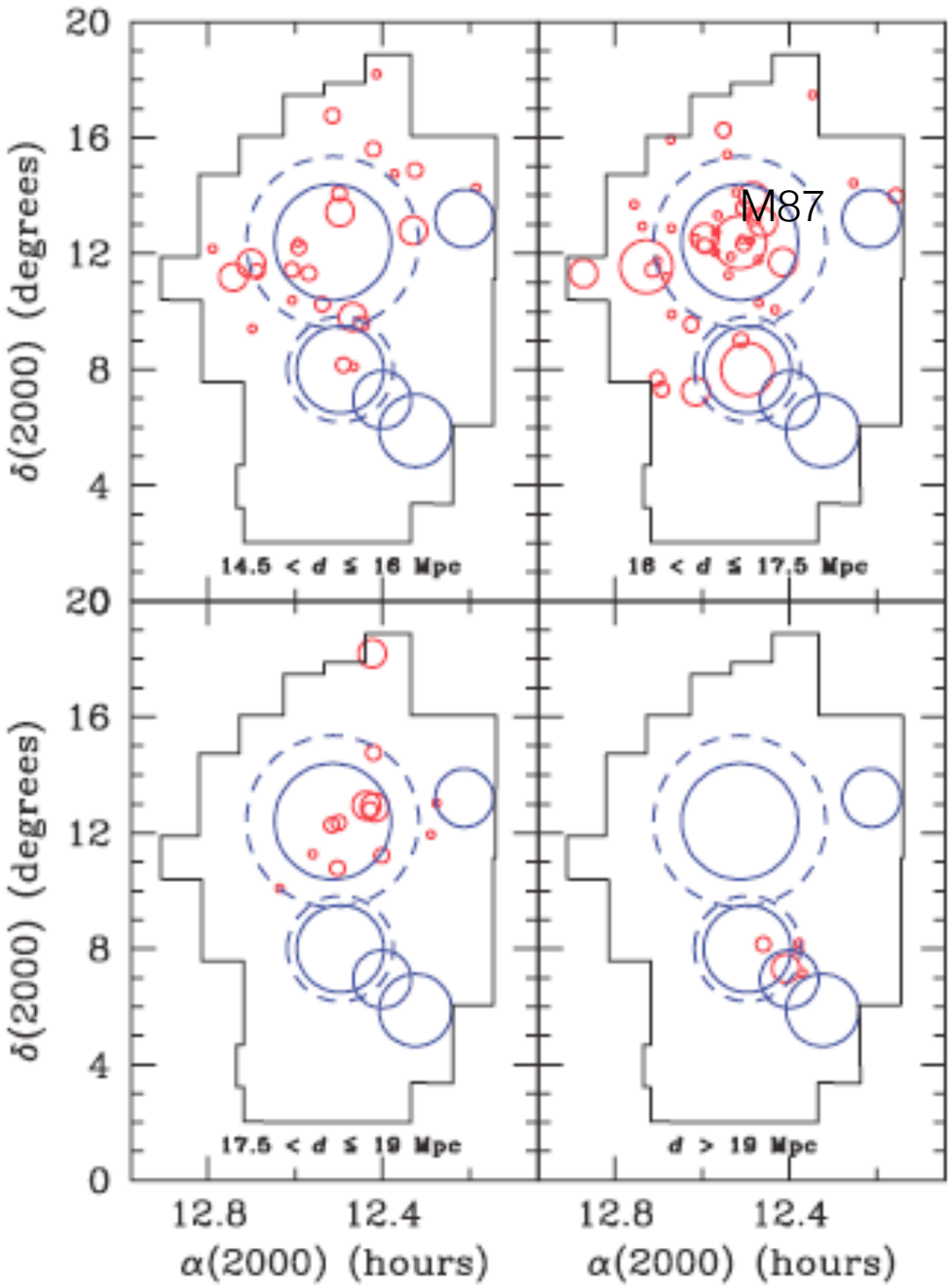
The absolute zero point was derived from the Tonry et al. (2001) Virgo distance modulus, corrected by the Udalski et al. (1999) Cepheid period-luminosity relation adopted for the H_0 Key Project distances (Freedman et al. 2001), DM = 31.09 ± 0.03 mag

$$(\overline{m} - \overline{M}) = log_{10}\left(\frac{Dist}{10pc}\right)$$

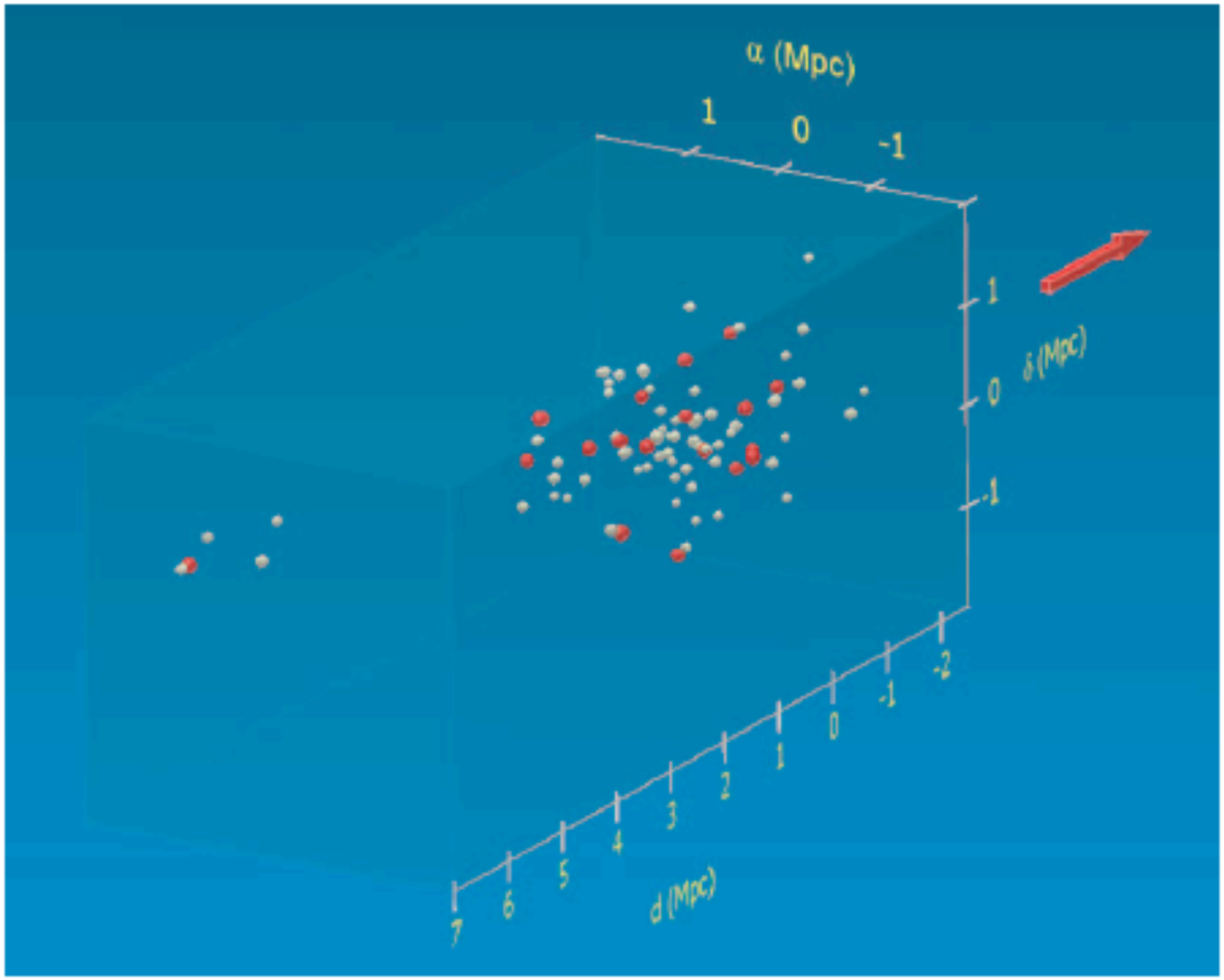
Mei et al. 2005b, 2007

SBF Distances

- Typical measurement statistical uncertainty of 0.07 mag/0.5 Mpc
- D = 16.5 ± 0.1 (stat.) ±1.1 (sys.) Mpc; σ_D = 0.6 ±0.1
- Depth of the cluster 2.4 ± 0.4 Mpc
- The M87 (cluster A) and M49 (cluster B) subclusters are found to lie at distances of 16.7 ± 0.2 and 16.4 ± 0.2 Mpc, respectively. There may be a third subcluster associated with M86.
- Five galaxies lie at a distance of 23 Mpc and are members of the W' cloud (even if they were selected in the B subcluster)



Mei et al. 2007

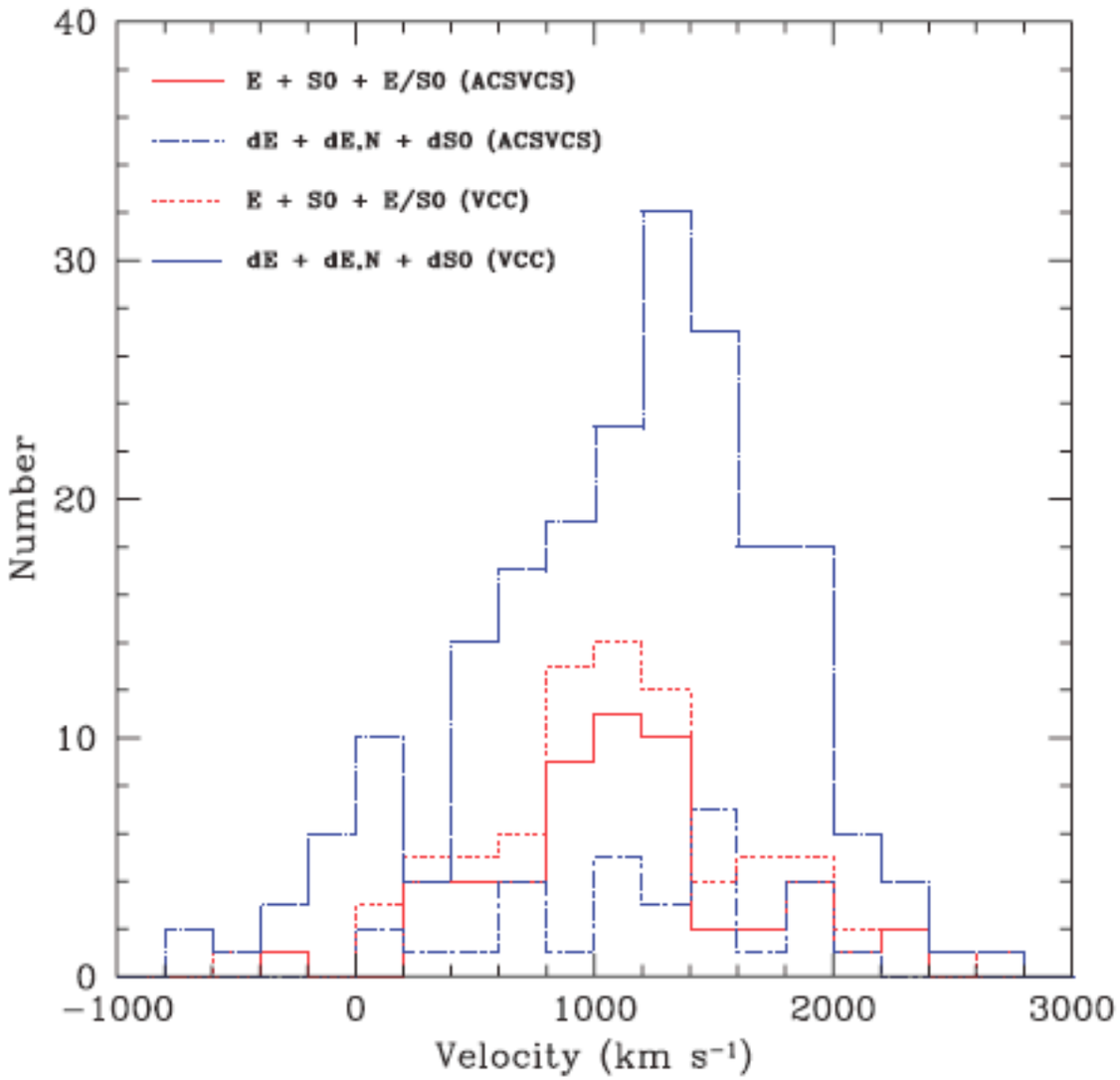


Slightly triaxial distribution, with axis ratios of (1:0.7:0.5)

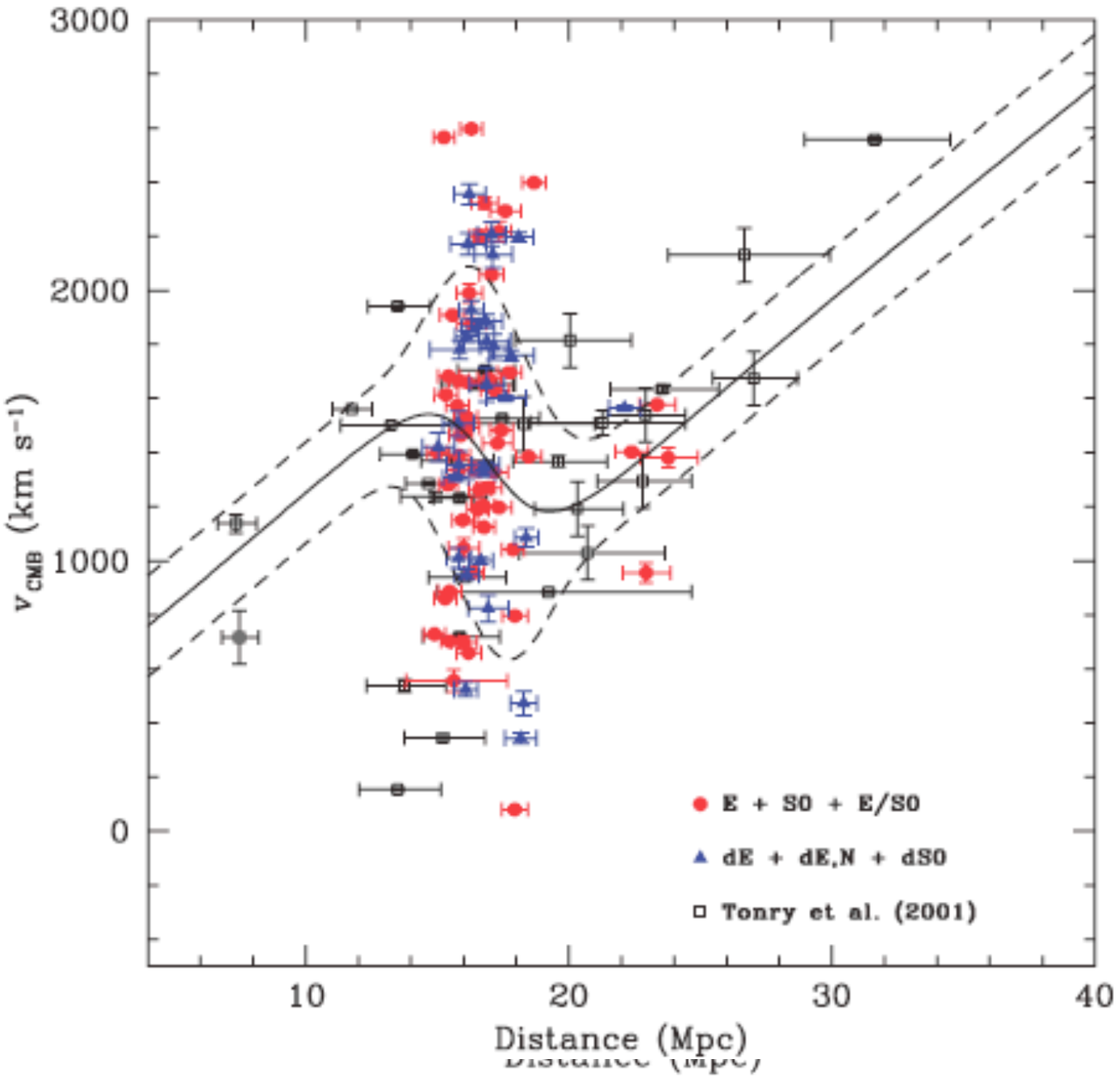
The principal axis of the best-fit ellipsoid is inclined ~20- 40^0 from the line of sight, while the galaxies belonging to the W' cloud lie on an axis inclined by 10-15^0

Mei et al. 2007

ACS VCS Sample



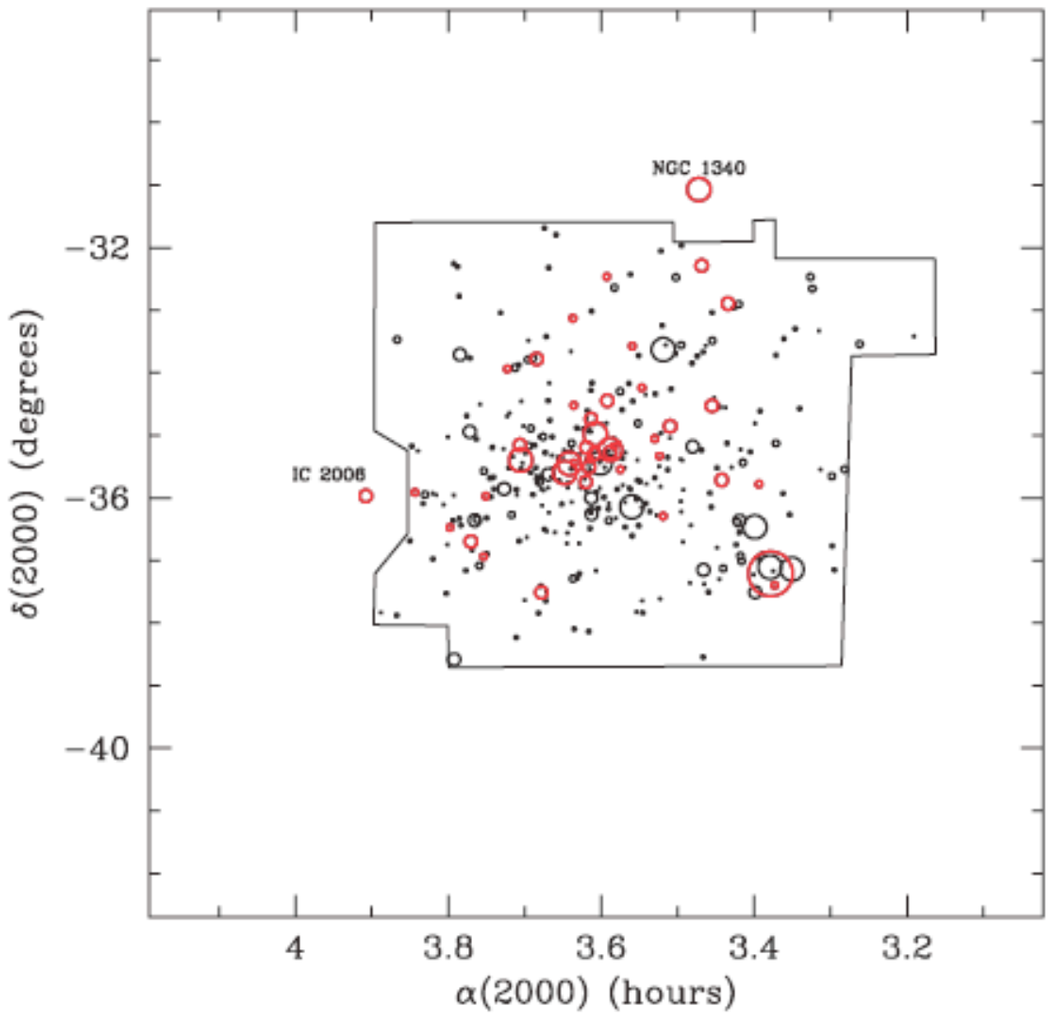
Dynamical status of the cluster



Mei et al. 2007

ACS Fornax Cluster Survey (PI: A. Jordán)

Property (1)		References (4)
Richness Class		1,2
B-M Type		1,2
Mass	$M_\odot$	3,4,5
Distance (Mpc)		6,7
$\langle v_r \rangle$ (km sec^{-1})		5,8
σ_v (km sec^{-1})		5,8
r_c (Mpc)		9
n_0 (gal Mpc^{-3})		9
N		9
$f_{\rm E+dE+S0+dS0}$		9
$\langle kT \rangle_X$ (keV)		10
$\langle {\rm Fe} \rangle_X$ (solar)		10

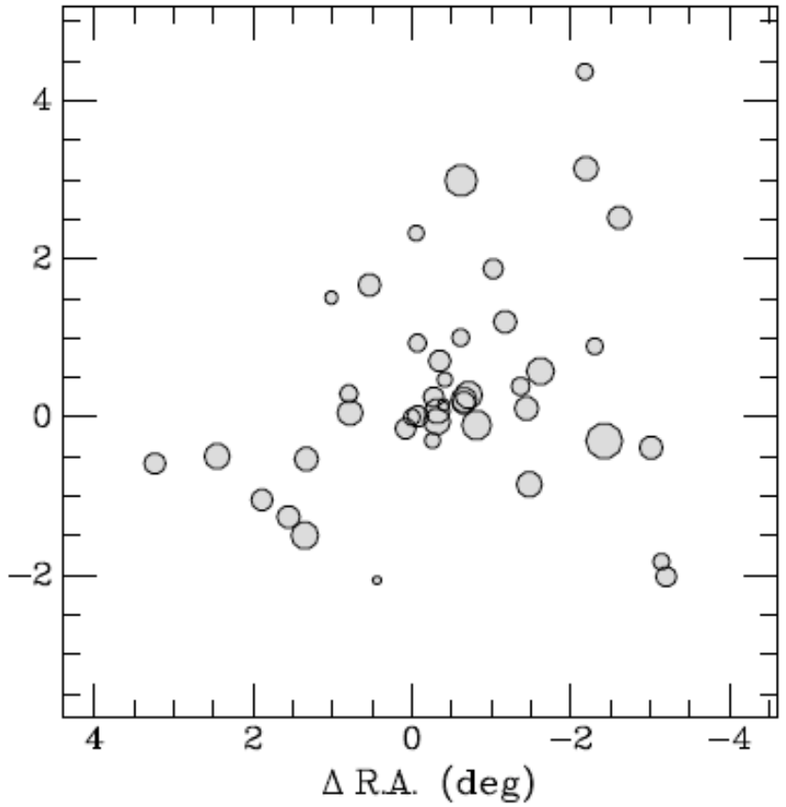


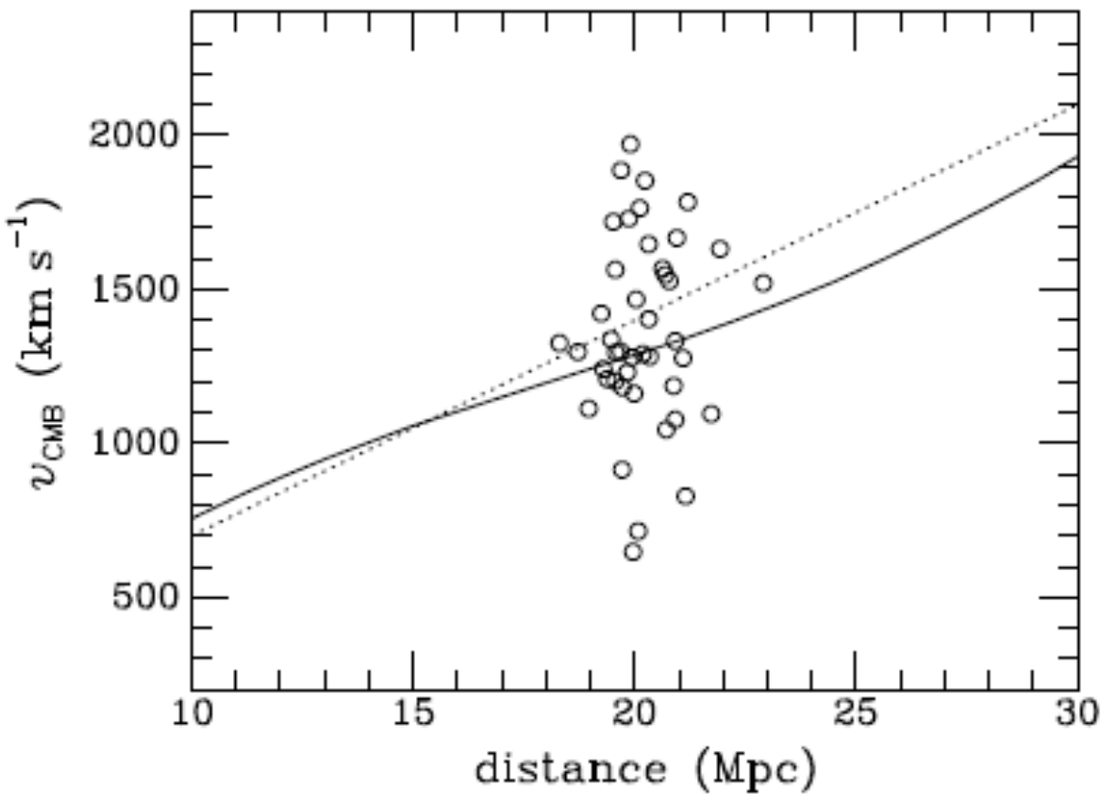
NOTE. — Key to colu
average heliocentric radi
N with $B \lesssim 18$ and wit
and Fe abundance, $\langle {\rm Fe} \rangle$
of given property for th
Girardi et al. 1995; 3.- M
Binggeli, Sandage & Tamman 1987; 9.- Ferguson 1989b; 10.- Fukazawa et al. 1997.

utz-Morgan (B-M) Type, mass, distance,
al galaxy density n_0, number of members
0), and the average temperature, $\langle kT \rangle_X$,
ing the inner cluster regions); (2-3) Value
e: 1.- Abell, Corwin & Olowin 1989; 2.-
Mei et al. 2007; 7.- Tonry et al. 2001; 8.-

Jordán et al. 2007

Fornax SBF Distances



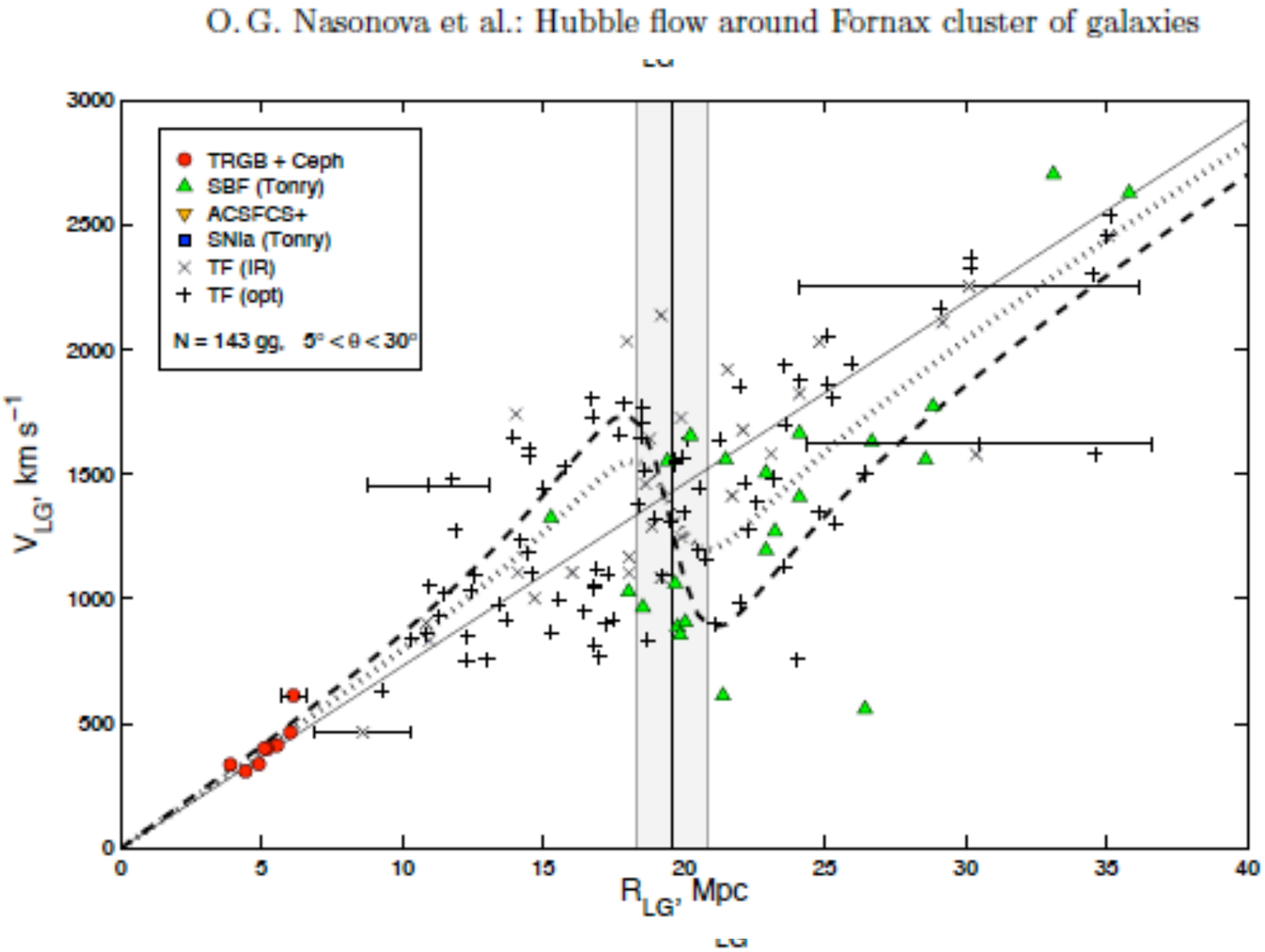


Fornax distance : D = 20 ± 0.3 ±1.4 Mpc; σ_D = 0.5 ±0.1
Depth of the cluster : 2.0 ± 0.4 Mpc

No evidence for systematic trends of the galaxy distances with position or velocity (e.g., no current infall); the Fornax cluster appears both compact and well virialized.

Blakeslee et al. 2010

The Hubble Flow around the Fornax Cluster



Nasonova et al. 2011; see also Drinkwater et al. 2001, Dunn & Jerjen 2006

Conclusions

- Surface Brightness Fluctuation measurements from HST/ACS permit us to measure early-type distances with a typical statistical uncertainty of ~0.5 Mpc at the Virgo distance

- Virgo distance : D = 16.5 ± 0.1 ±1.1 Mpc; σ_D = 0.6 ±0.1;
  Fornax distance : D = 20 ± 0.3 ±1.4 Mpc; σ_D = 0.5 ±0.1;

- Depth of the cluster Virgo: 2.4 ± 0.4 Mpc
  Fornax : 2.0 ± 0.4 Mpc

- The Virgo cluster appears not yet virialized. For the Fornax cluster we might need to extend SBF measurements to a larger sample