Local Structure from Surface Brightness Fluctuations with WFC3/IR & ACS

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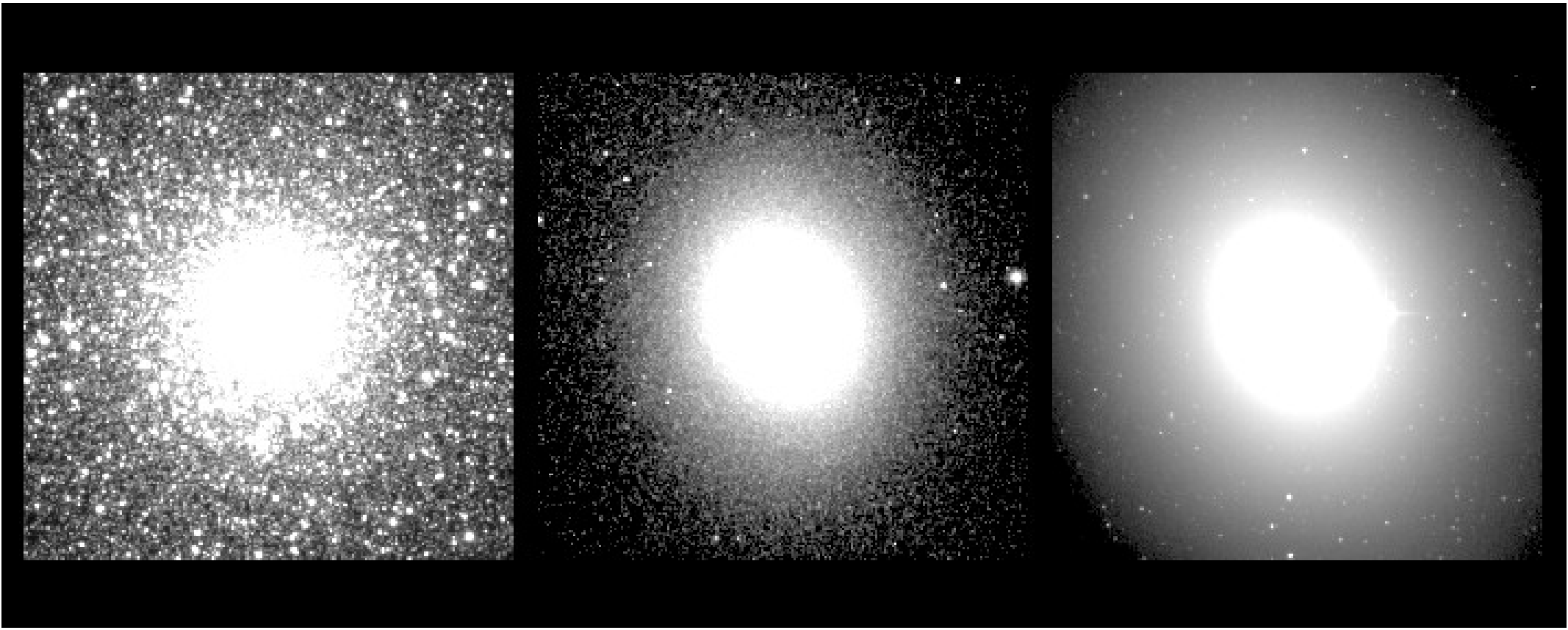
SBF: Galaxy surface brightness is independent of distance, but the variance (measured in Fourier space) goes as d^{-2}



globular star cluster
$N \sim 10^6$ stars
$d \sim 10$ kpc

M32 (Andromeda)
$N \sim 10^9$ stars
$d \sim 770$ kpc

M49 (Virgo)
$N \sim 10^{12}$ stars
$d \sim 16$ Mpc

SBF in the 90's:
Ground-based *I*-band survey of ~300 galaxies.

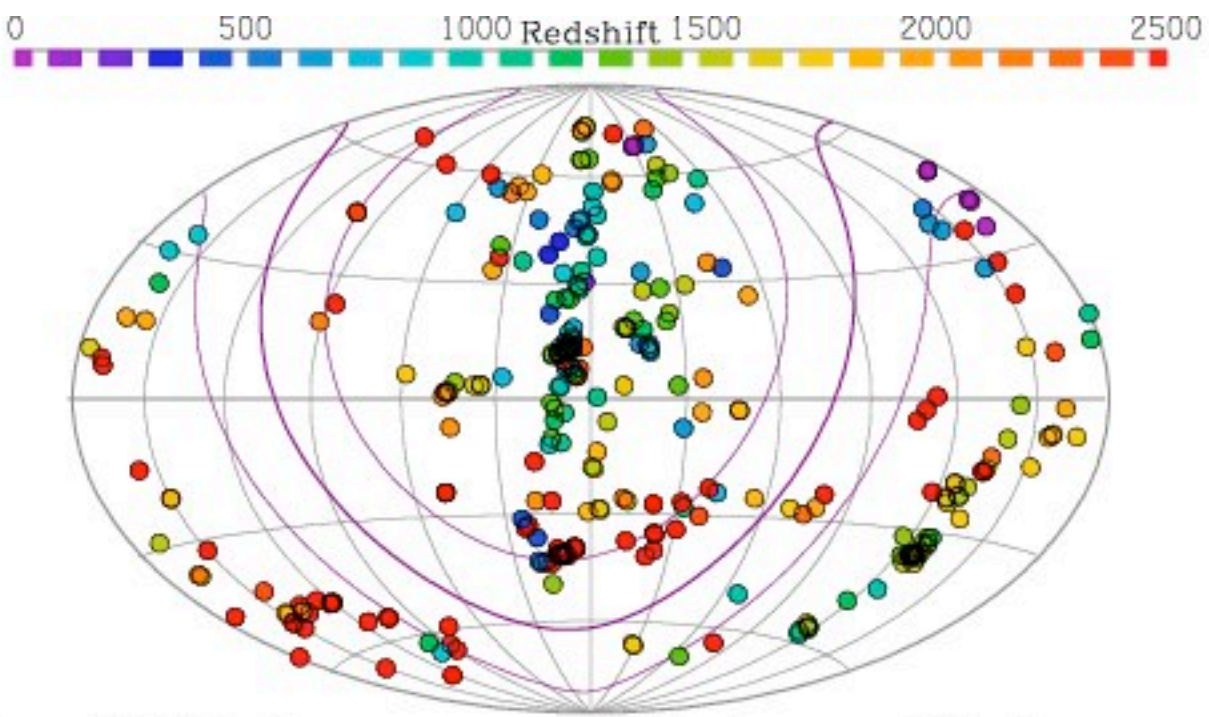
SBF distances used to constrain peculiar velocities, Virgo infall,

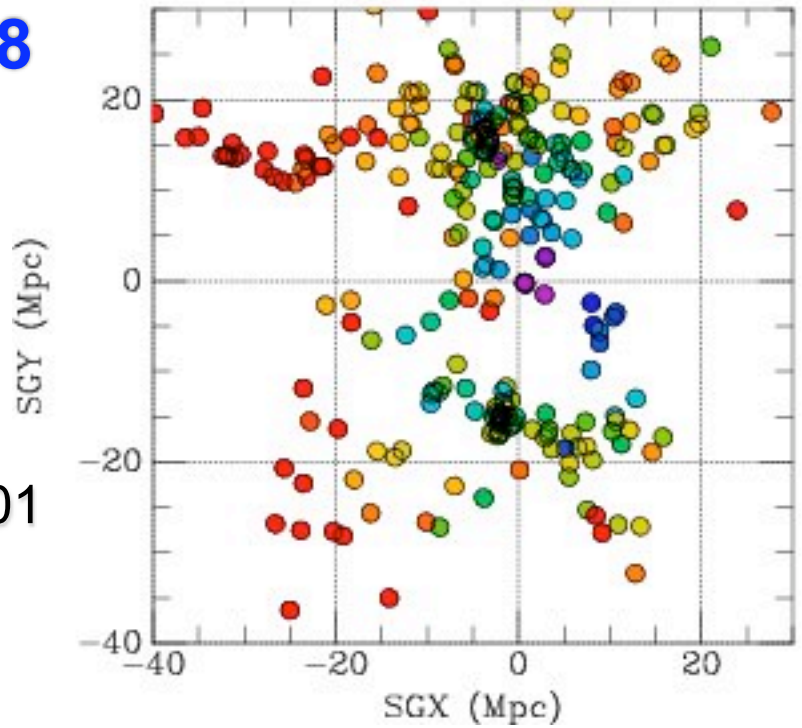
H_0 = **74 km/s/Mpc**

$\beta_I = \Omega^{0.6}/b$ = **.44 ± .08**

$\Omega \approx$ **0.25**

Tonry et al. 1997, 2000, 2001
Blakeslee et al. 1999, 2002

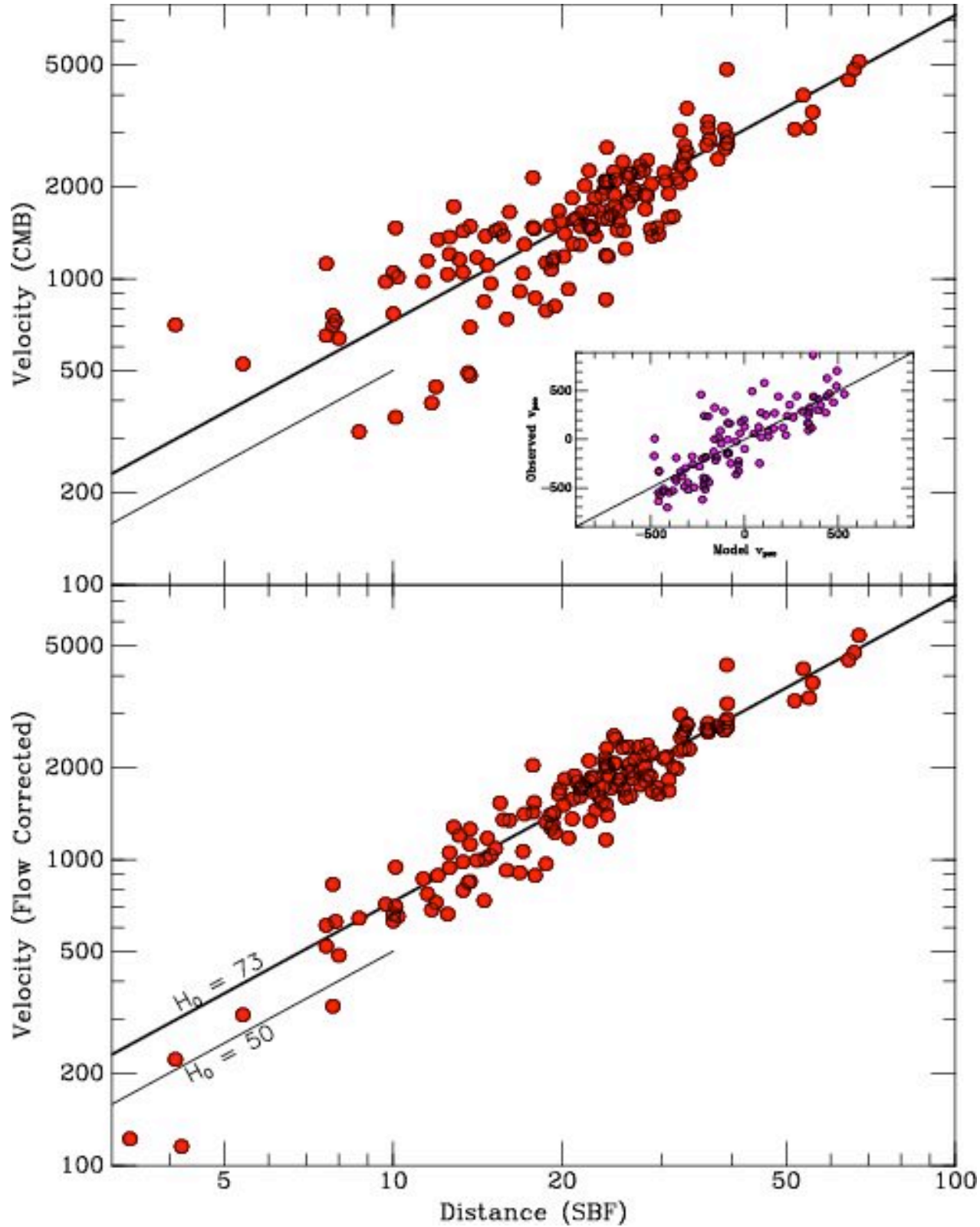




Data from:
MDM, CTIO,
KPNO, LCO, CFHT

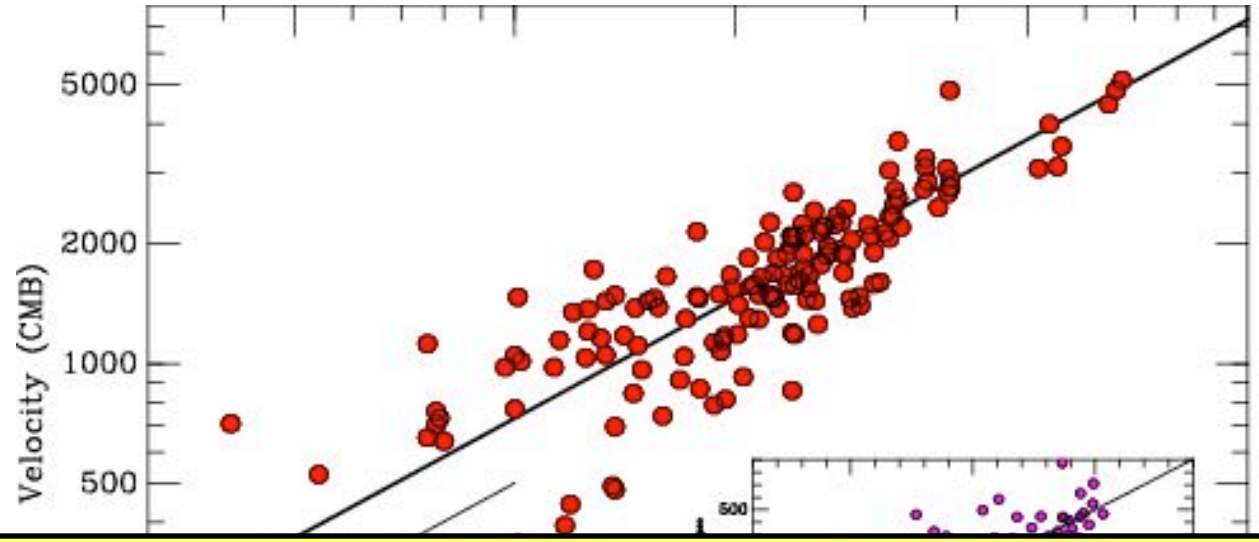
Hubble diagram: raw velocity versus distance

Hubble diagram with velocities corrected by SBF flow model.



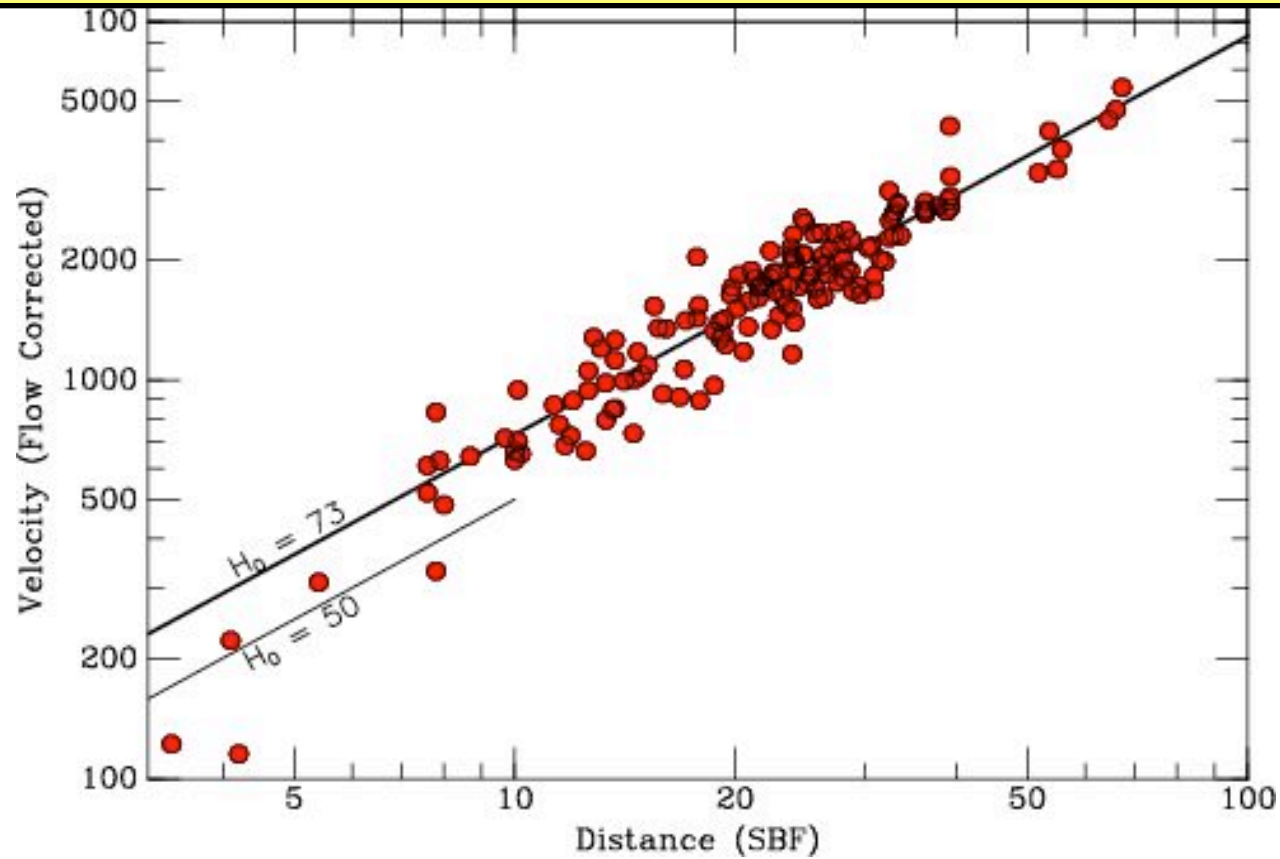
Tonry, Blakeslee, Ajhar & Dressler 2000

Hubble diagram:
raw velocity
versus distance



Virgo infall, but distance resolution insufficient for probing the true internal structure of Virgo.

Hubble diagram
with velocities
corrected by SBF
flow model.



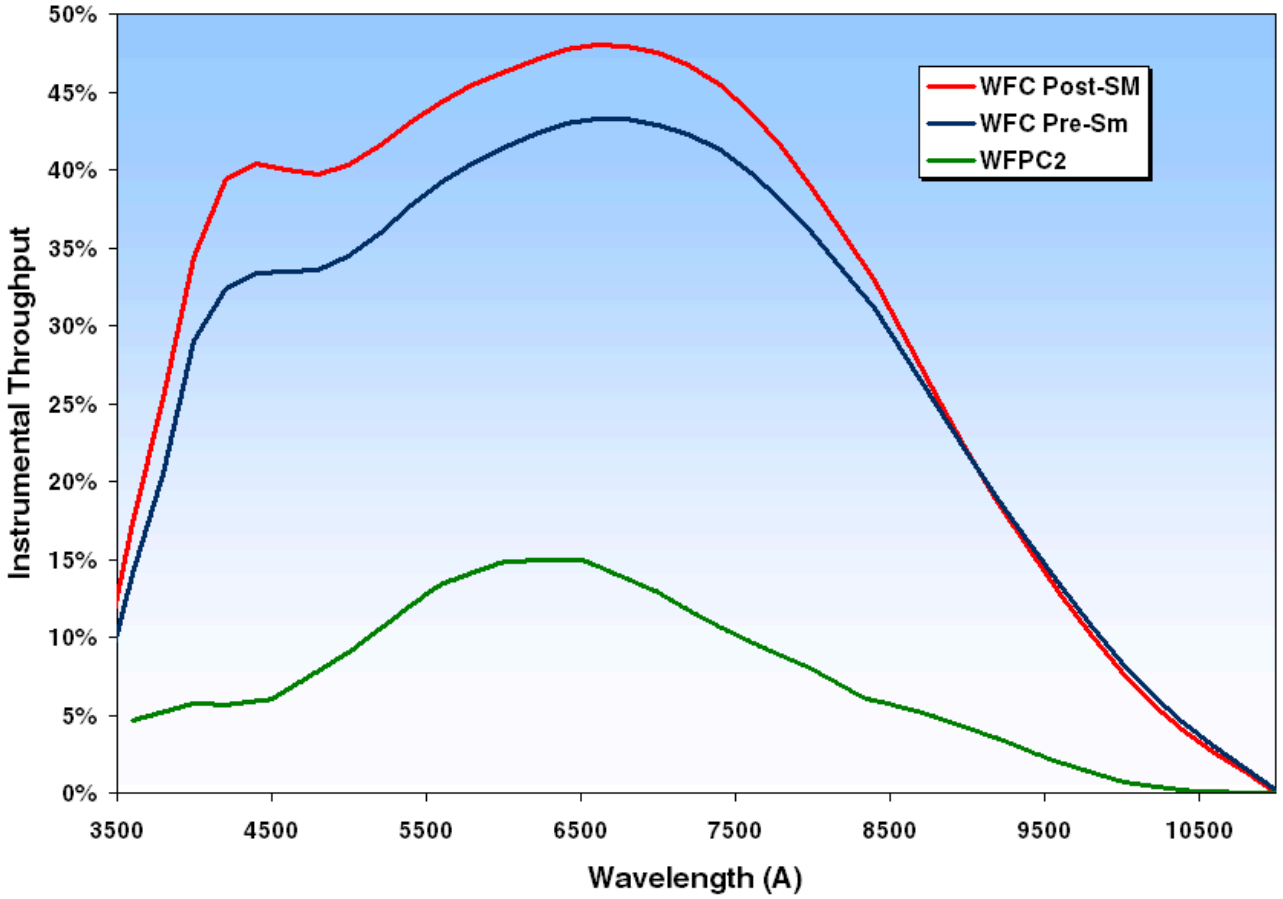
Tonry, Blakeslee, Ajhar
& Dressler 2000

Modern-Era HST SBF Programs

- [x] 9401 - ACS Virgo Cluster Survey (P. Cote)
- [x] 10217 - ACS Fornax Cluster Survey (A. Jordan)
- [x] 10911 - Calibration of ACS/F814w SBF (JPB)
- [ ] 10429 - Shapley Infall from ACS/F814w SBF (JPB)
- [ ] 11711 - SBF Distance to Coma, ACS+WFC3 (JPB)
- [ ] 11712 - SBF Calibration for WFC3/IR (JPB)

Modern-Era HST SBF Programs

- [x] 9
- [x] 10
- [x] 10
- [ ] 10
- [ ] 11
- [ ] 11712 - SBF Calibration for WFC3/IR (JPB)



PB)

(JPB)

Other HST SBF Studies

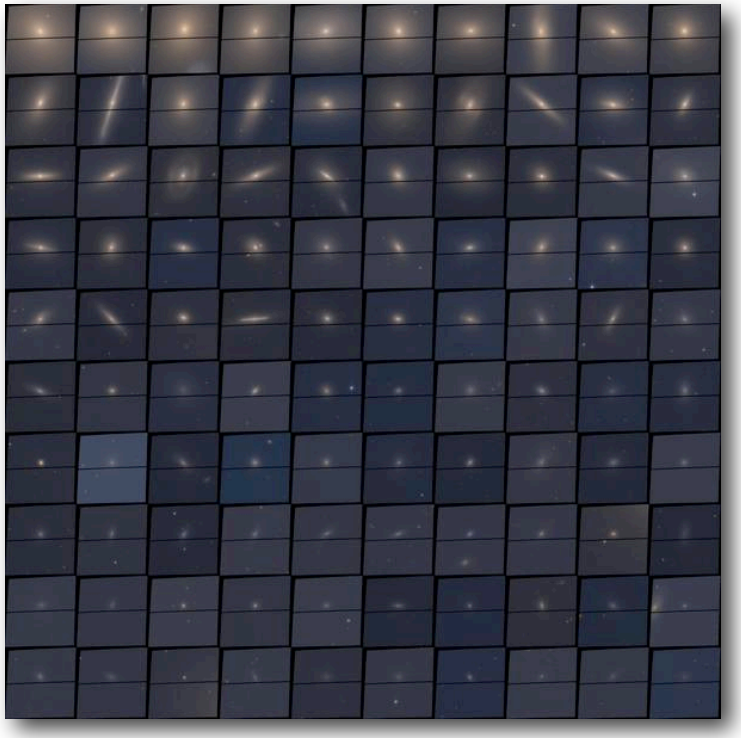
- Work on stellar population gradients in galaxies from multi-band measurements of *radial SBF gradients* (Cantiello et al 2005, 2007a,b)

- Far-field measurement of H_0 out to 100 Mpc, calibrated via stellar pop modeling, *independent of the Cepheid distance scale* (Biscardi et al. 2008)

- New SBF models for WFC3 from UV through IR, with measurements for ωCen (Hyejeon Cho's poster, *this conference*).

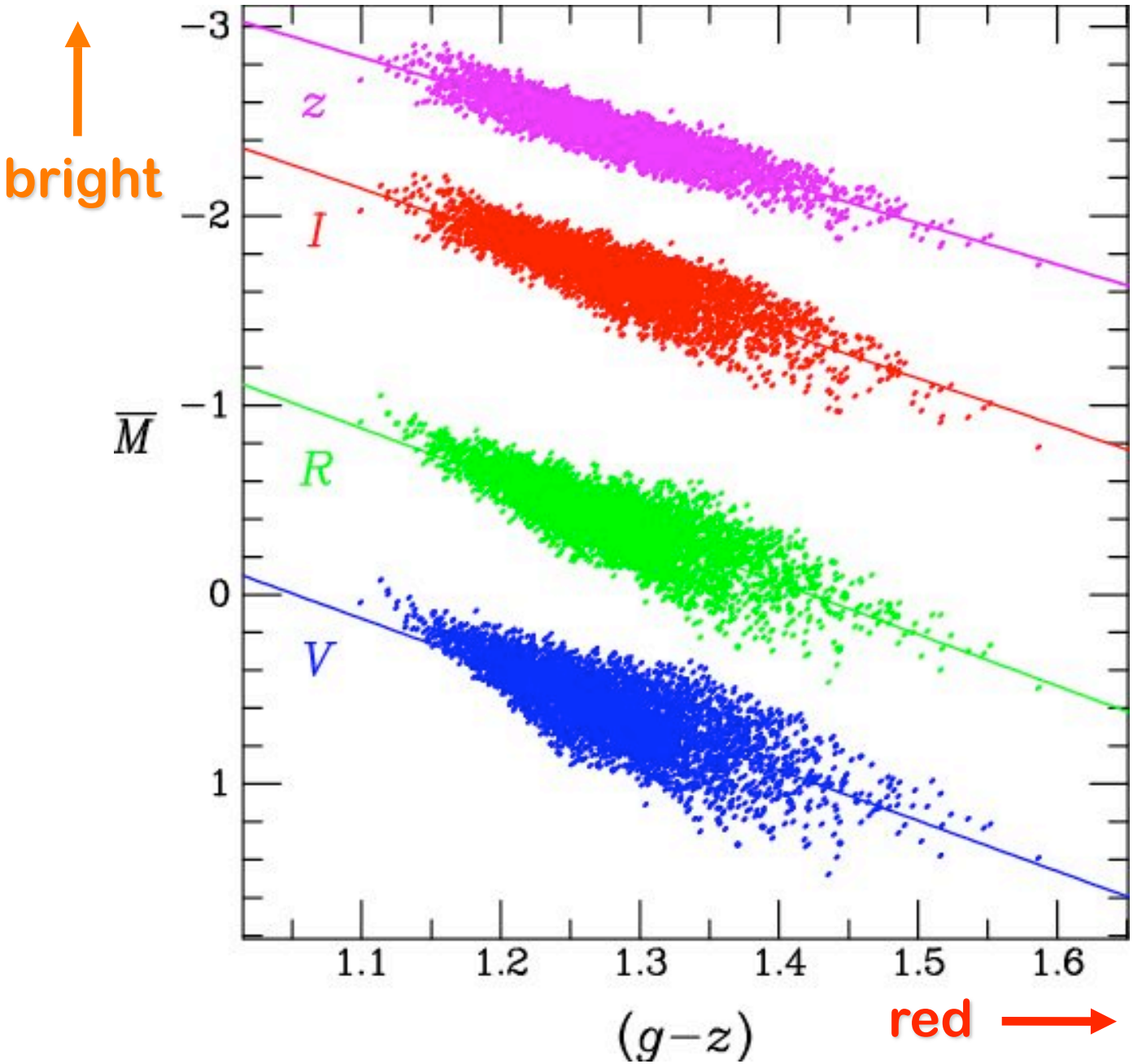
On to the New Era . . .

ACS Virgo + Fornax Surveys



- Imaging surveys of 100 [+43] early-type galaxies in the Virgo [+Fornax] clusters with ***g*+*z*** bandpasses of the *Advanced Camera for Surveys* (ACS) on HST
- **ACSVCS** (Cycle 11) and **ACSFCS** (Cycle 13)
- Scientific Objectives Include:
  - Properties of **globular clusters** (GCs) in early-type galaxies: half-light radii (Jordán et al. 2005), colors (Peng et al. 2006), masses (Jordán et al. 2006; 2007), LMXB connection (Jordán et al. 2004, Sivakoff et al. 2006), CMDs (Mieske et al. 2006), frequencies and formation efficiencies (Peng et al. 2007)
  - **Central structure** of early-type galaxies and their **nuclei** and **black holes** [Ferrarese et al. 2006ab; Côté et al. 2006, 2007]
  - Calibration of the **S**urface **B**rightness **F**luctuations method in ACS ***z***-band, map the **3-D galaxy distribution** in Virgo; exploration of effects from stellar population variation; precise relative Virgo/Fornax distance [Mei, Blakeslee, Tonry, et al. 2005ab, 2007; Blakeslee et al 2009]

SBF "fluctuation magnitude" versus (g-z) color: elliptical galaxy stellar population VRIz predictions



z-band SBF bright; ~ 0.06 mag scatter.

Blakeslee, Vazdekis, & Ajhar 2001 composite models.

Other SBF models:

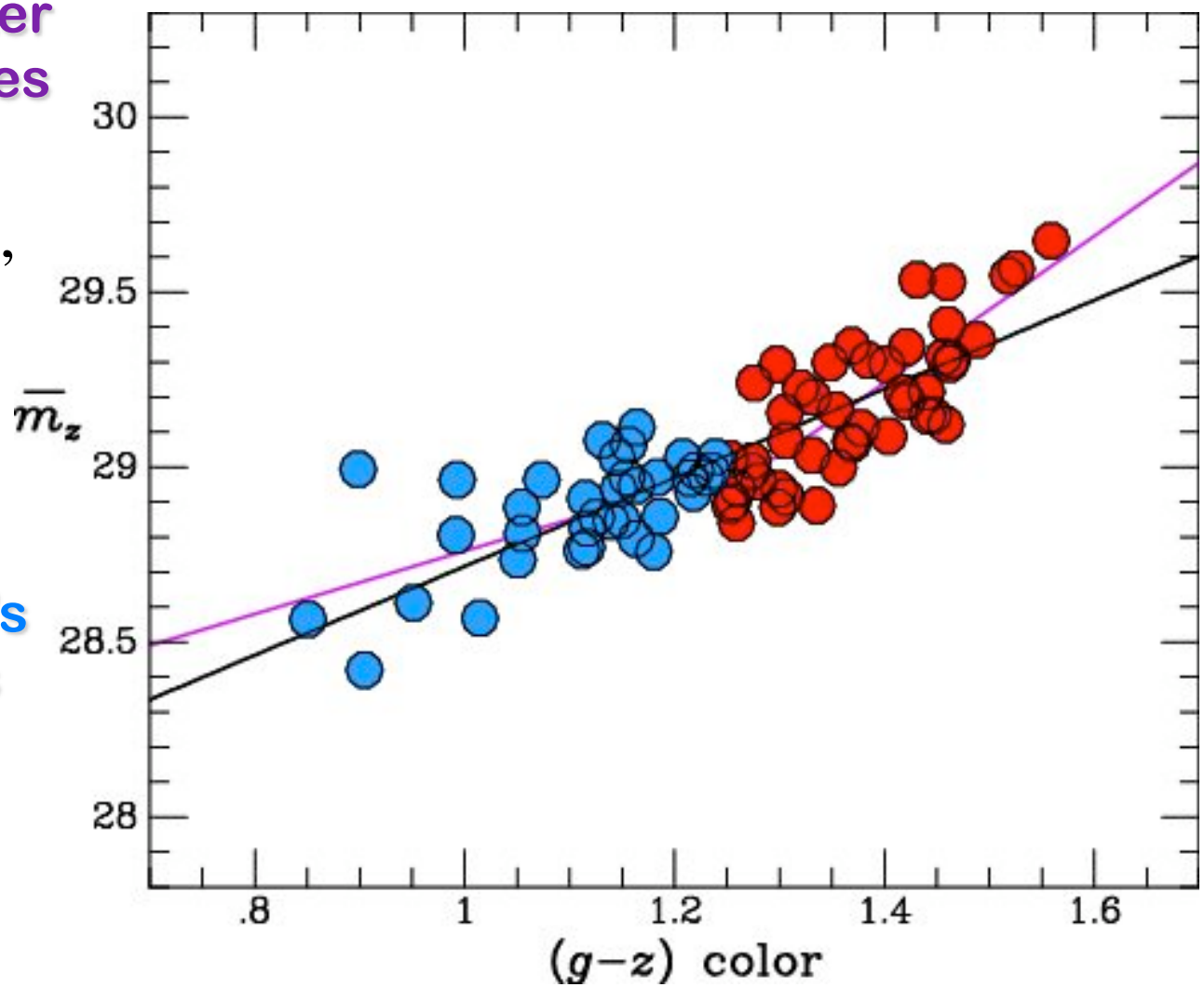
Worthey 1993
Liu et al. 2000
Cantiello et al. 2003
Raimondo et al. 2005
Marin-Franch & Apparicio 2006
Lee et al. 2008

Mei et al. 2005 z-band empirical calibration

z-band SBF magnitude versus (g-z) color: The Empirical Distance Calibration

85 Virgo Cluster Survey Galaxies

σ ~ 0.12 mag, including depth + obs effects



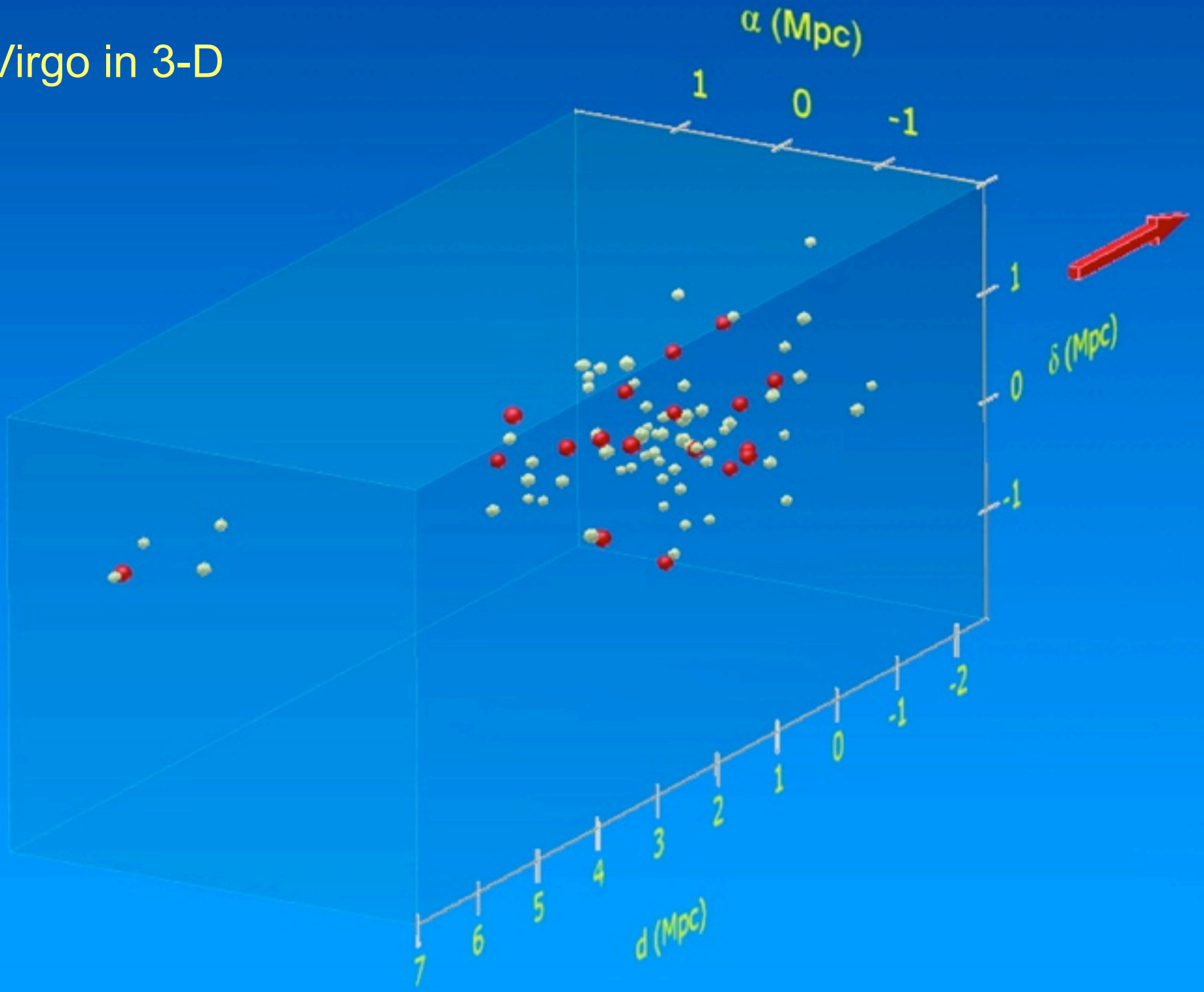
giant E's and S0's

dwarf E's and S0's

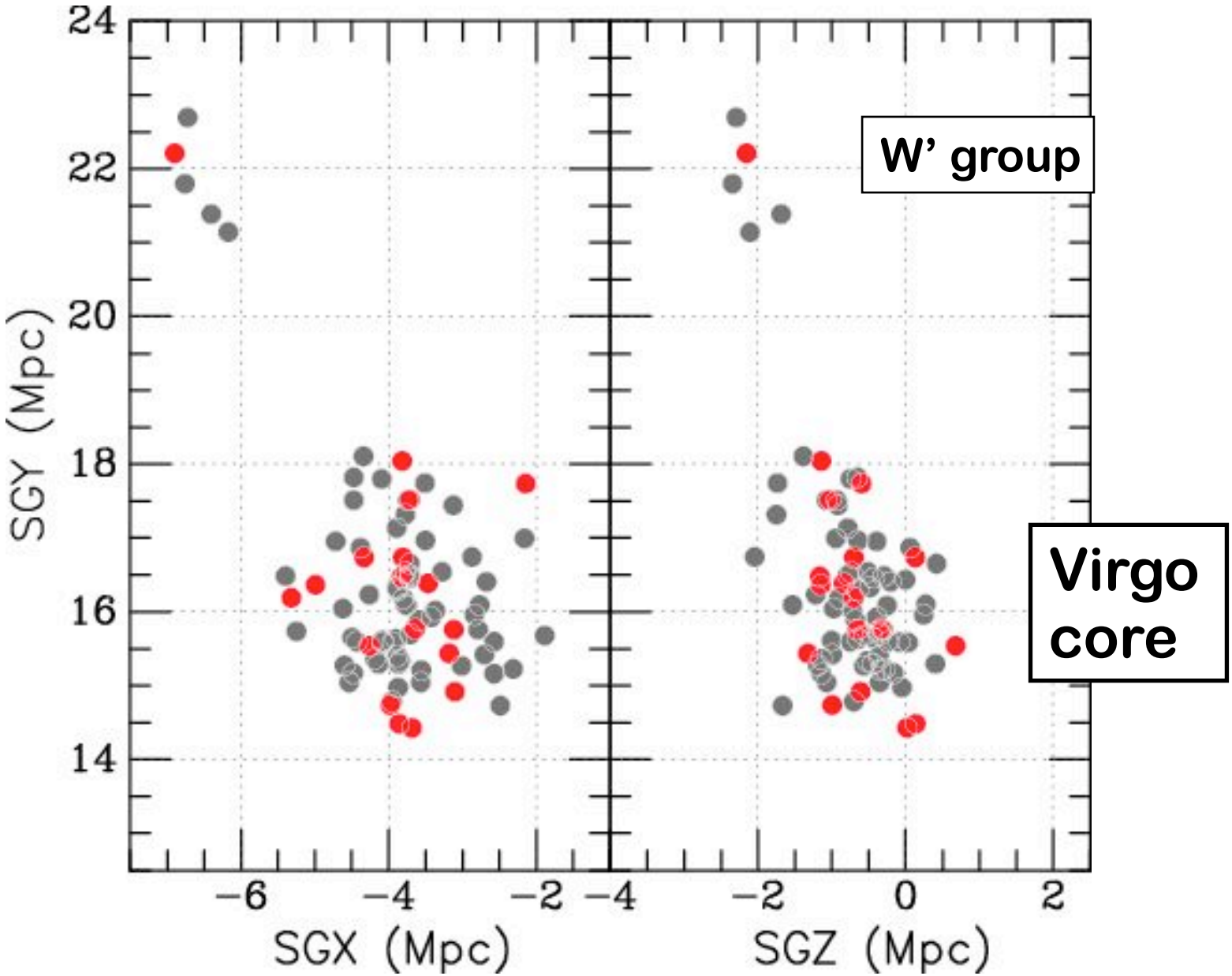
(Omitting background W' galaxies)

Mei, Blakeslee & ACS Virgo Team 2005, ApJ.

Virgo in 3-D

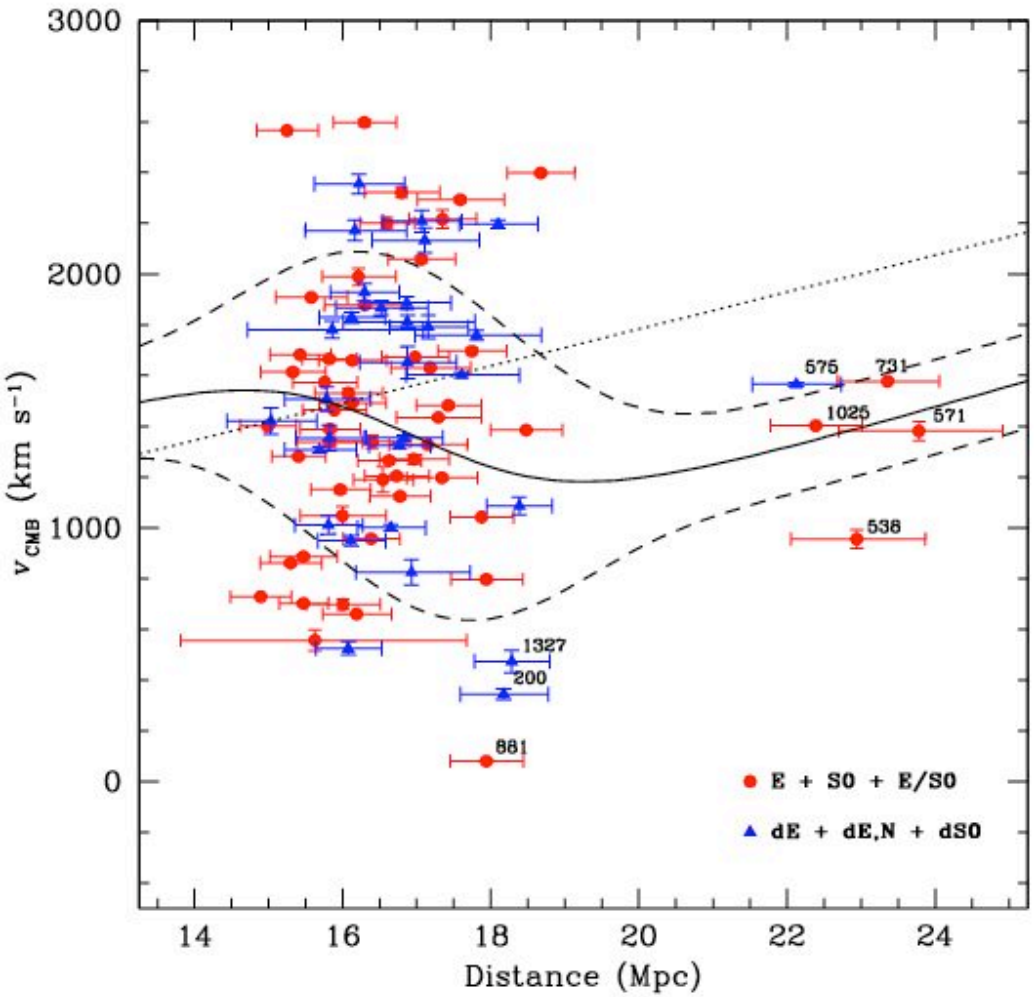


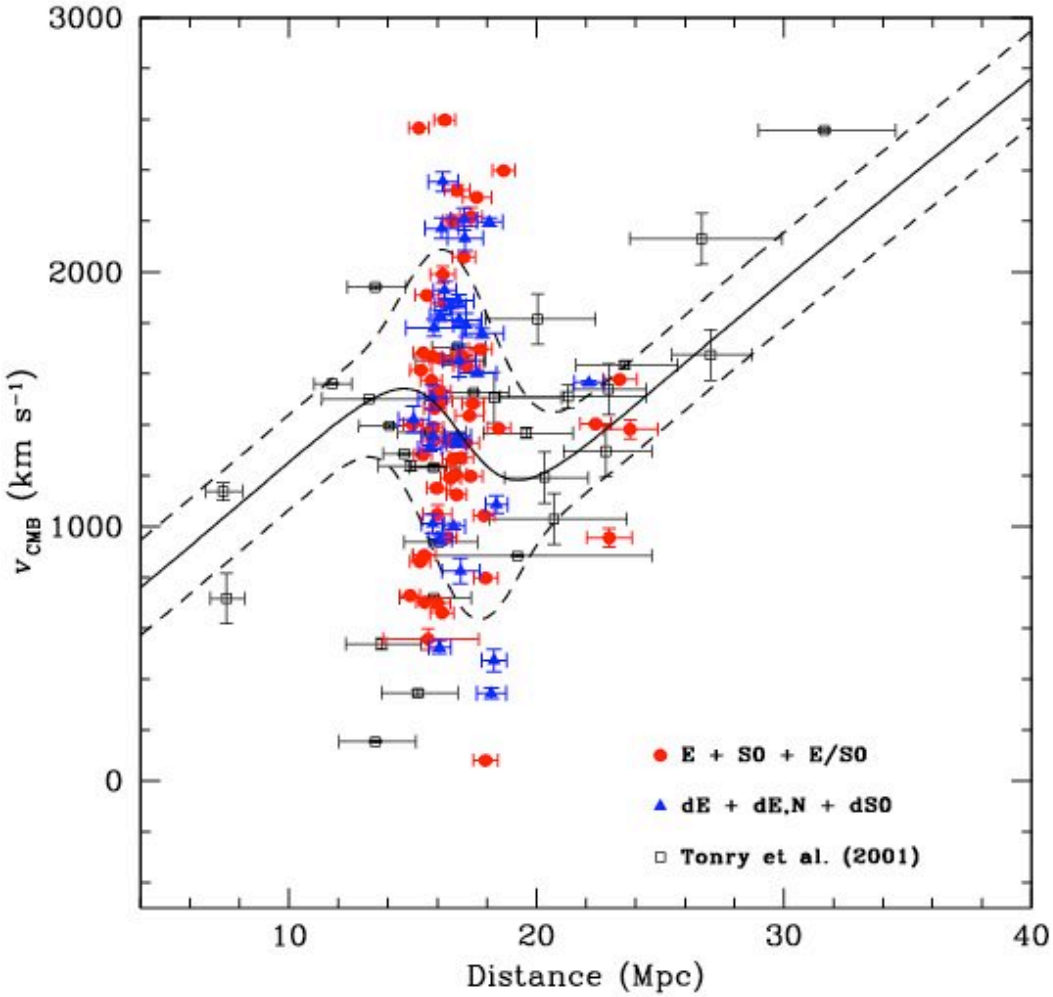
The 3-D Structure of Virgo: Projections in the Supergalactic Plane



Mei et al. 2007

The 3-D Structure of Virgo: Velocity-distance relation





Mei et al. 2007

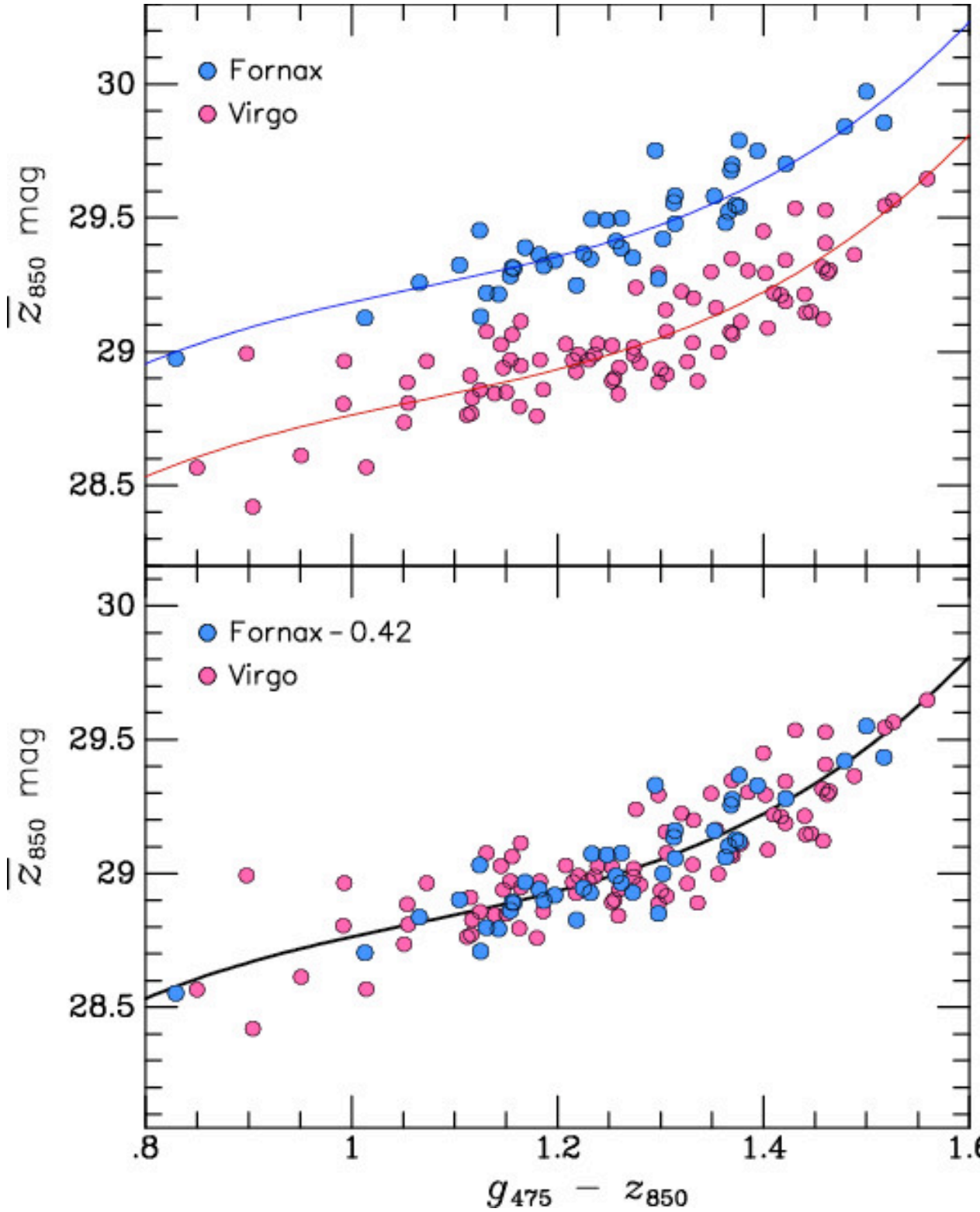
3-D Structure of Virgo

- Mean error per galaxy: σ (m-M) = 0.074 mag, or $\approx$ 0.5 Mpc.
- Triaxial structure, with axial ratios about **1 : 0.7 : 0.5**
- Line-of-sight depth of main cluster = 2.4$\pm$0.4 Mpc (i.e., $\pm$ 2σ intrinsic distribution).
- Spatial distribution of dwarfs follows that of giants.
- Group of galaxies associated with NGC 4365 (W' Cloud) about 6.5 Mpc behind main cluster and infalling at ~ 450 km/s.
- Other substructure evident, e.g., the high-velocity galaxy M86 (NGC4406) and companions are ~ 1.4 Mpc beyond the core.
- M87 and M49 subclusters at essentially identical D $\approx$ 16.5 Mpc.

What about Fornax?

The Fornax Cluster:

- more regular and dynamically evolved than Virgo
- core radius ≈ 40% that of Virgo
- central density (≈ 500 Mpc^{-3}) twice that of Virgo
- velocity dispersion (≈ 370 km s^{-1}) half that of Virgo
- order of magnitude higher collision rate
- compact structure ideal for distance calibration
  - *allows us to improve work on Virgo structure*



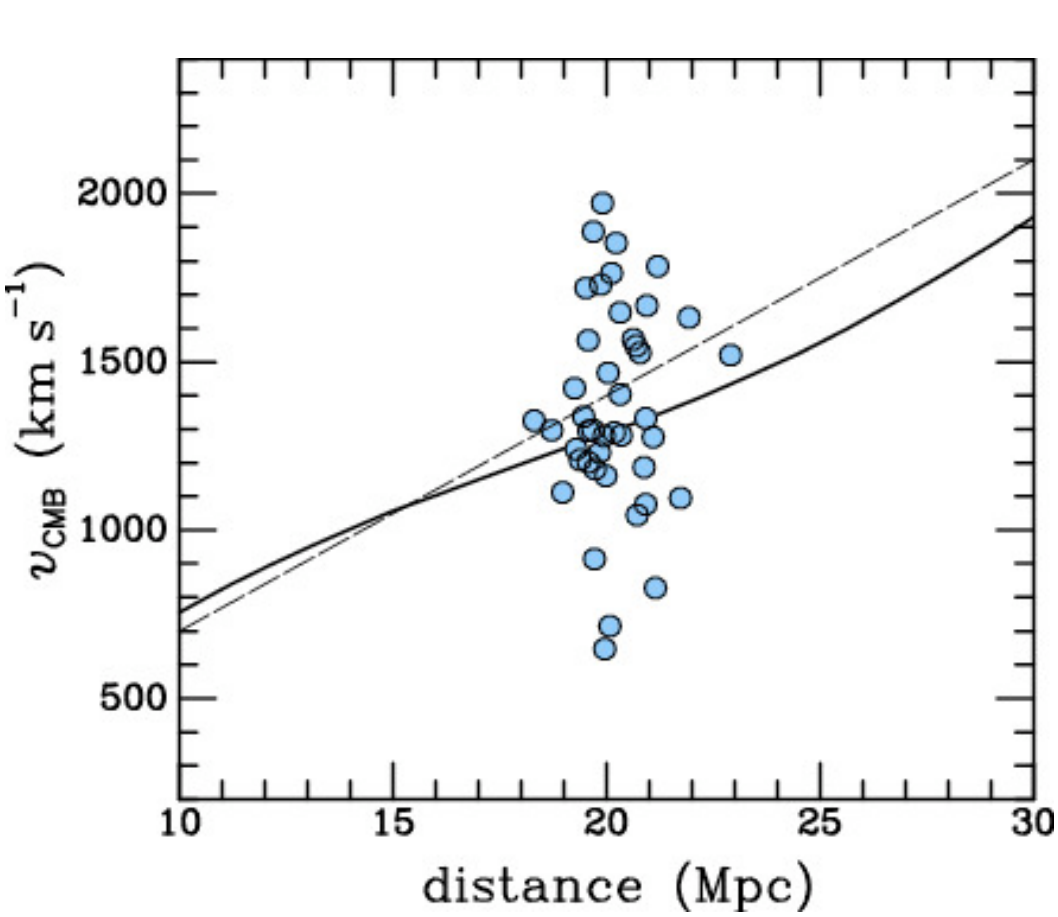
SBF Results from ACS Fornax + Virgo Surveys

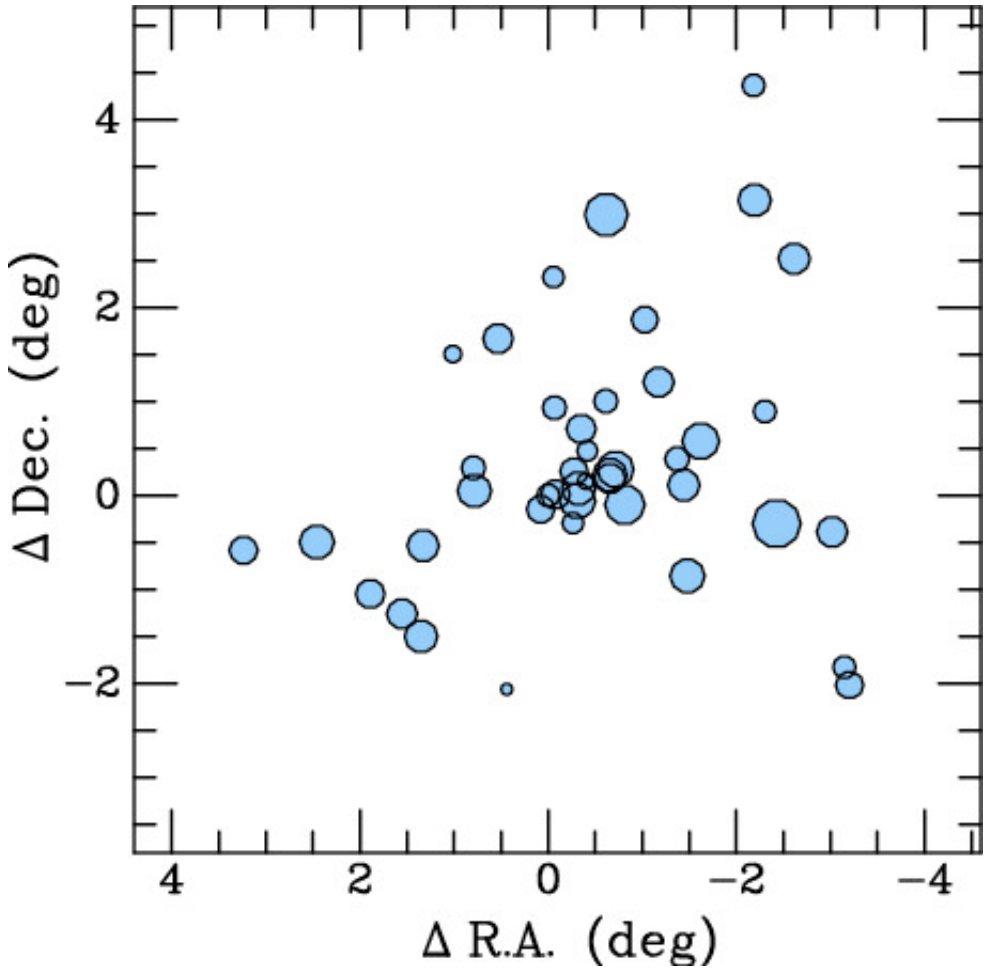
Fornax cluster 21±1% more distant than Virgo cluster.

intrinsic scatter
σ = 0.06 mag

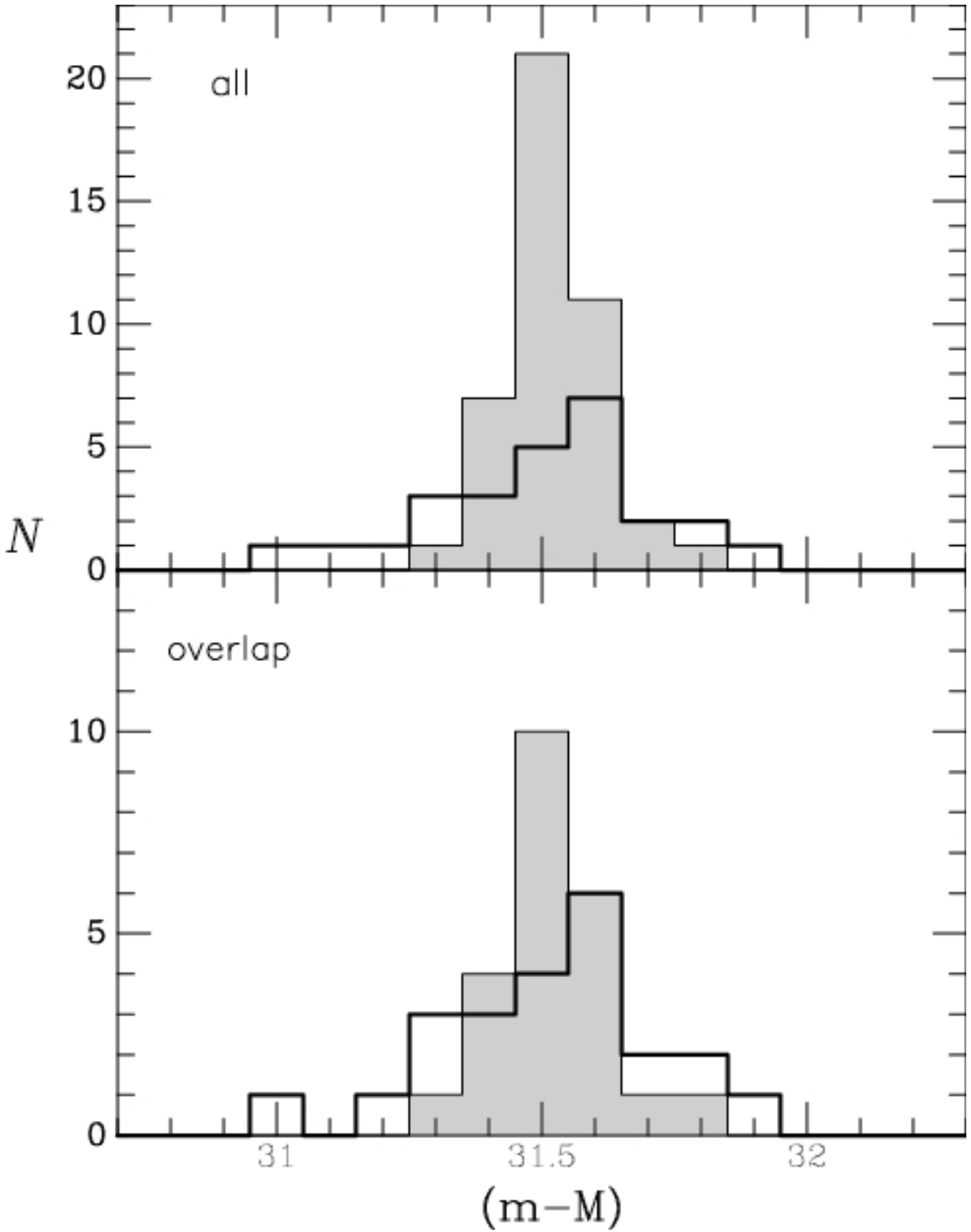
Blakeslee et al. 2009

Fornax Hubble Diagram & Structure





No sign of velocity-distance relation, unlike Virgo.



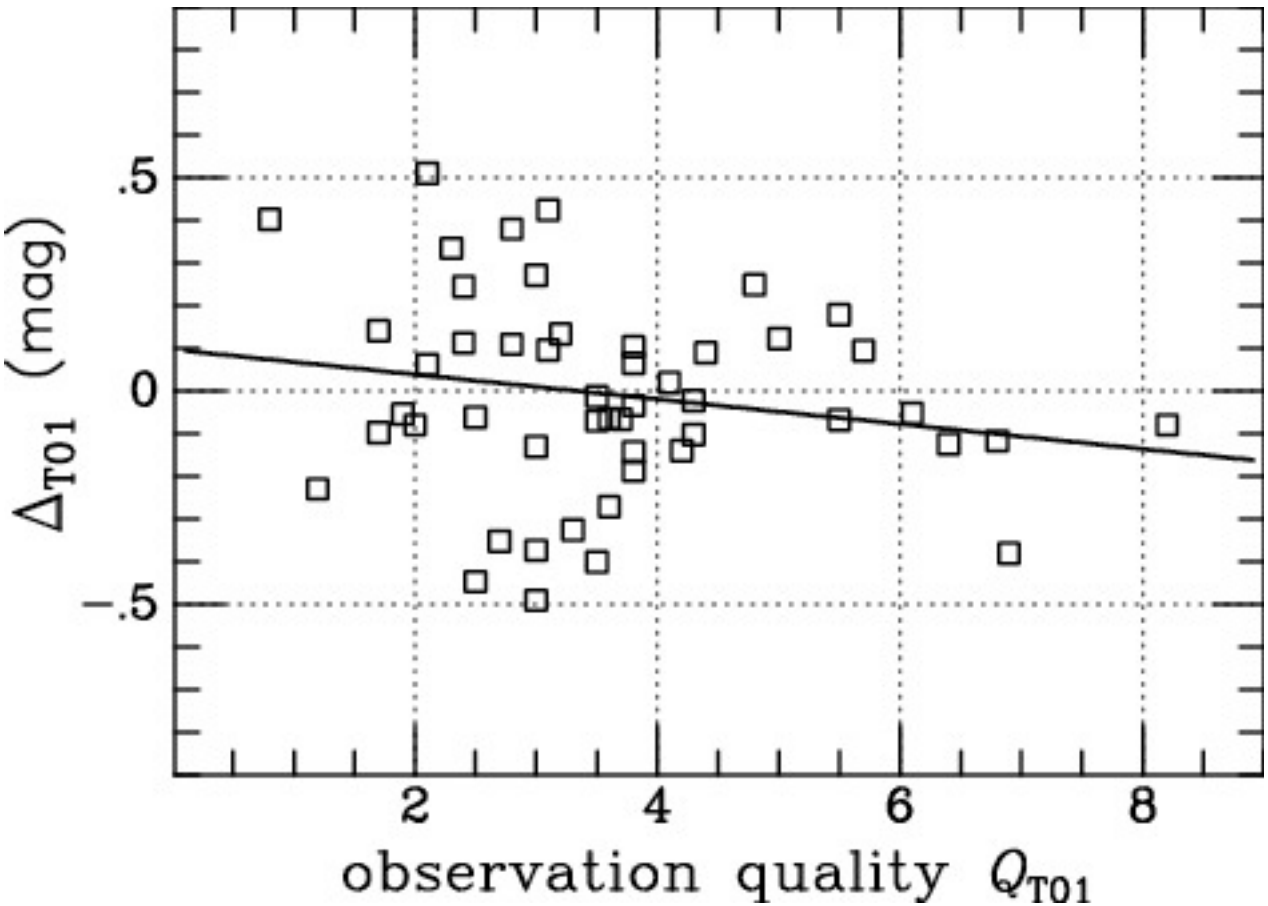
ACS Fornax Survey compared to Tonry et al. 2001 distances

4x improvement in measurement error;

>2x improvement in distance uncertainty.

Corrections to Tonry et al. 2001?

Δ(m-M) of Ton01 w/respect to ACS SBF result



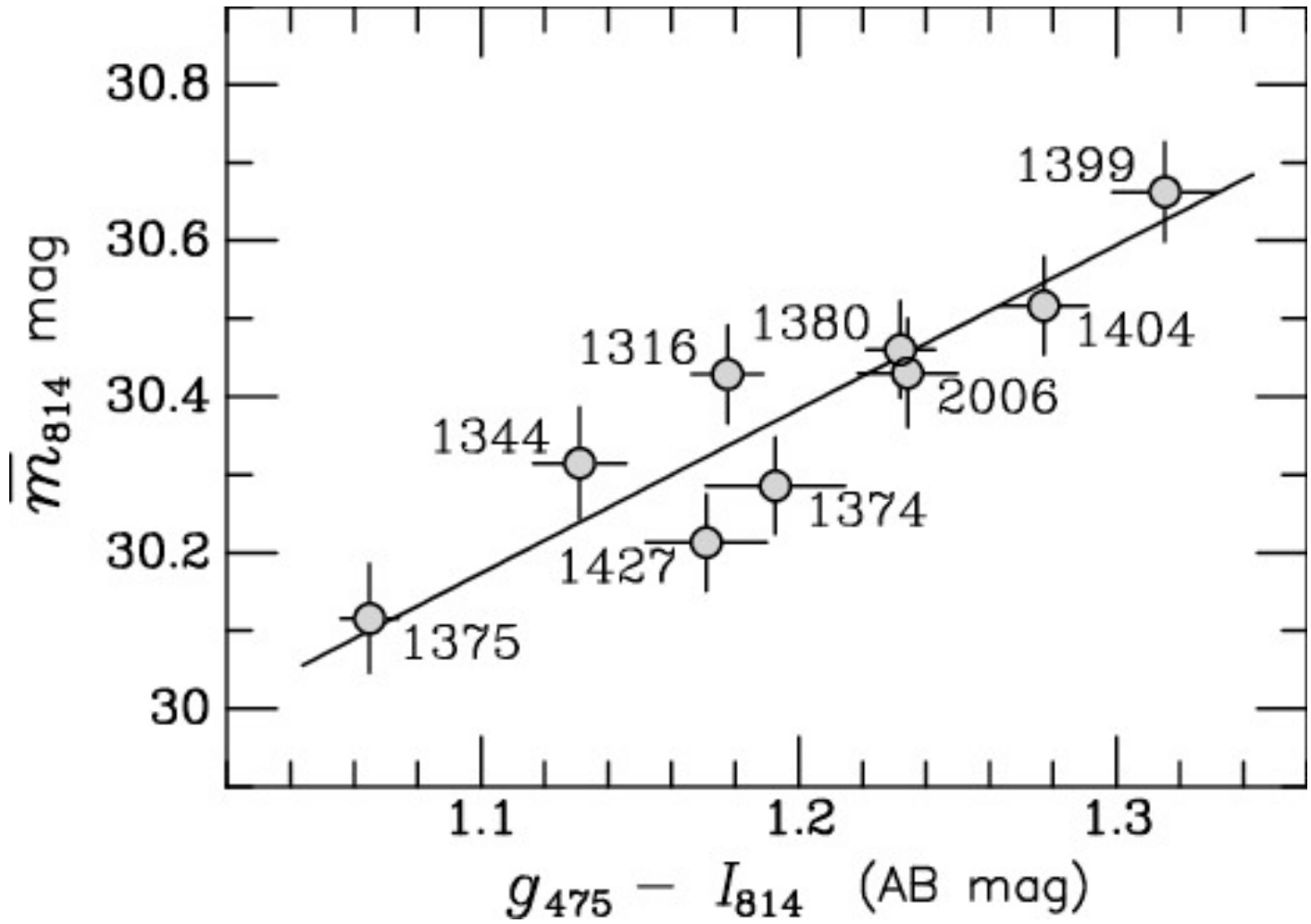
Based on 50 of the 300 ground-based SBF Survey galaxies

Blakeslee et al. 2010 (arXiv:1009.3270)

SBF Calibration for ACS/F814W

- ACS Virgo and Fornax surveys used ACS F850LP (*z*-band) bandpass for SBF, and calibrated it based on *g*-*z* color
- works really well, but F850LP is not a very efficient bandpass
- F814W (~Cousins I) has similar properties but lets through ~2.5x as much light, making it more useful for distant SBF work
- A new ACS/F814 SBF calibration was needed; so we called on Fornax once again...

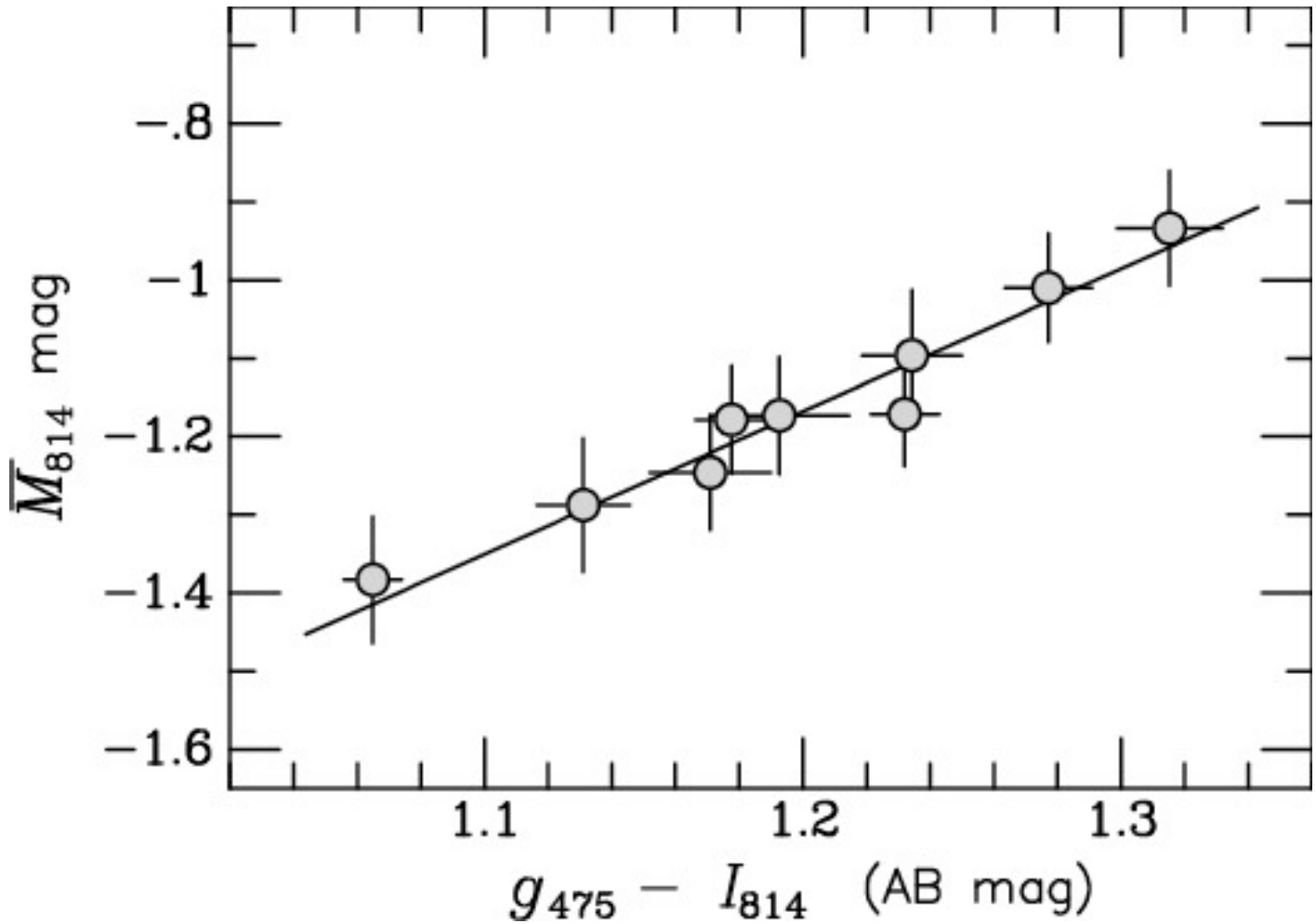
ACS/F814W SBF-color relation in Fornax



σ = 0.064 mag

Blakeslee et al. 2010 (arXiv:1009.3270)

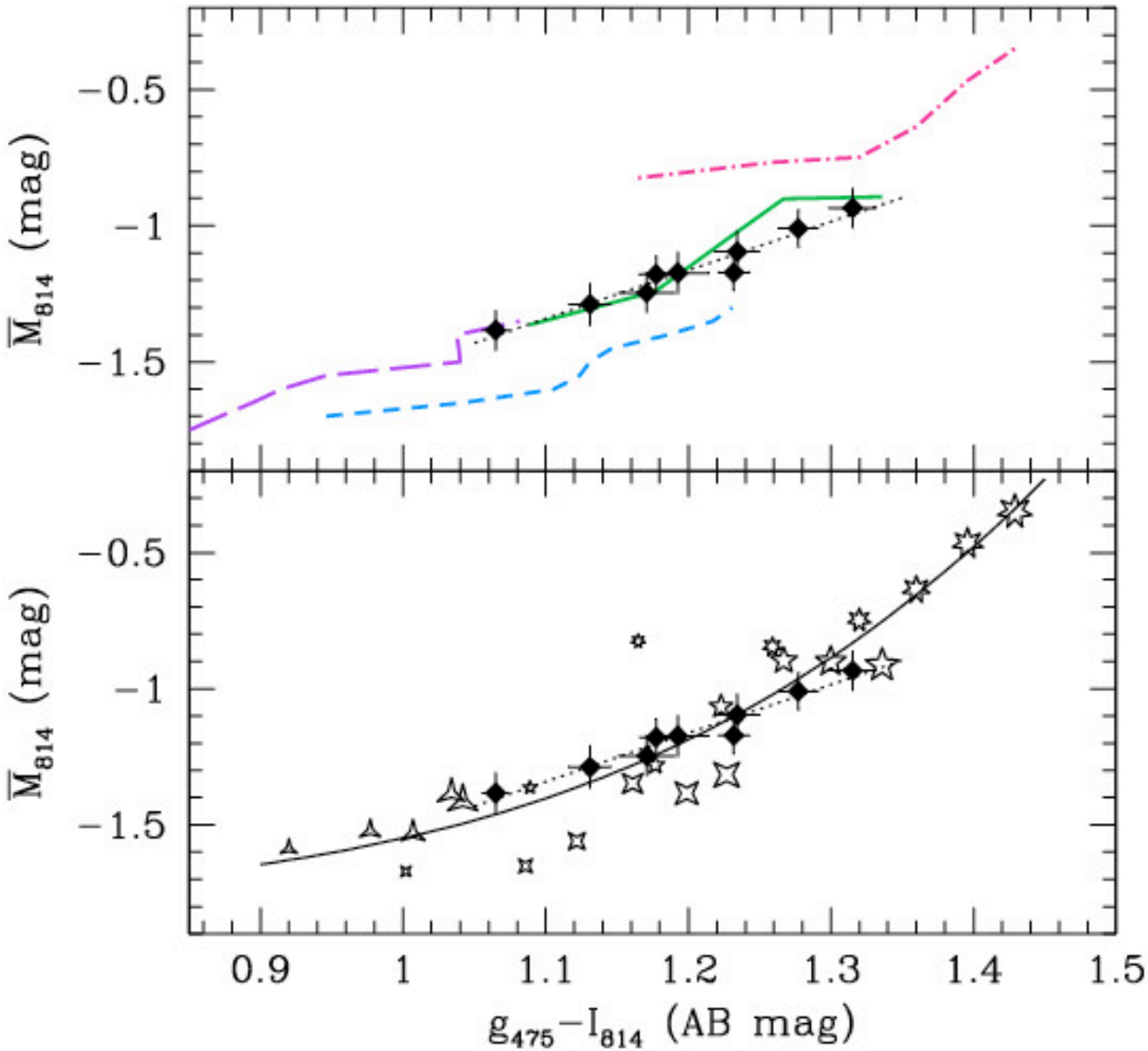
ACS/F814W SBF converted to absolute



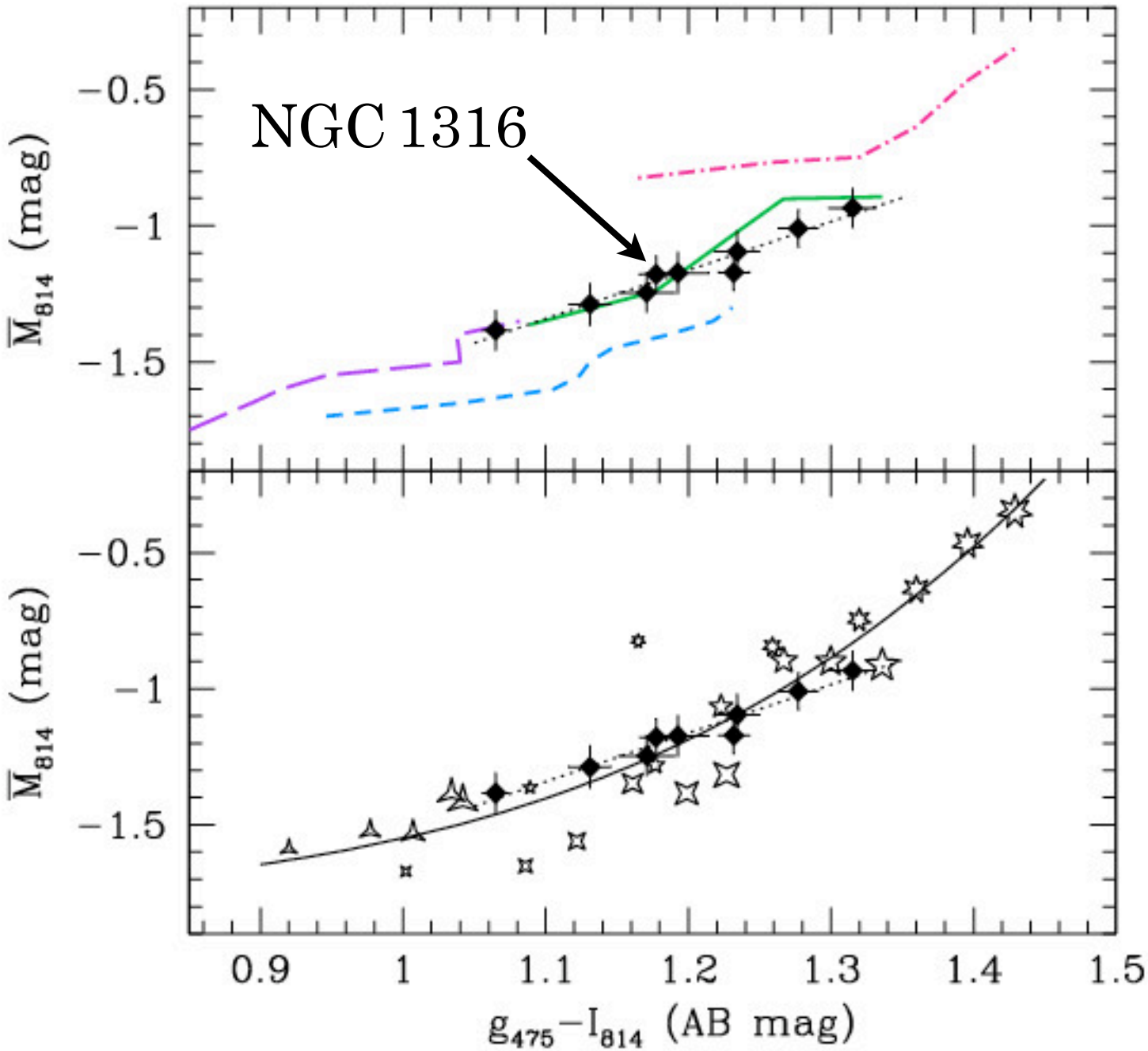
σ = 0.029 mag

Blakeslee et al. 2010 (arXiv:1009.3270)

SBF and new stellar pop models



SBF and new stellar pop models



Elliptical Galaxy NGC 1316

Hubble Heritage

NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope ACS • STScI-PRC05-11

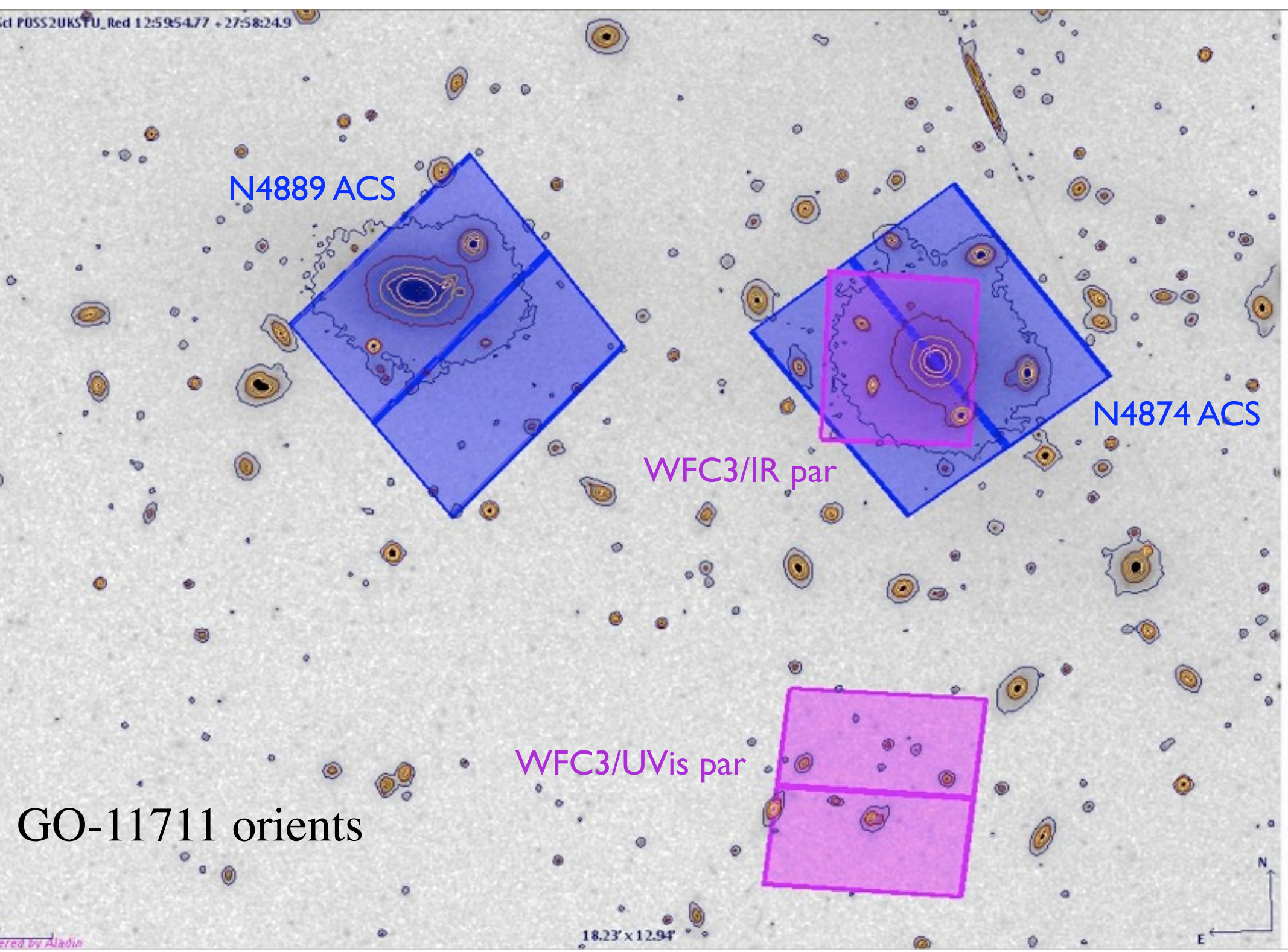
SBF Distances to NGC 1316

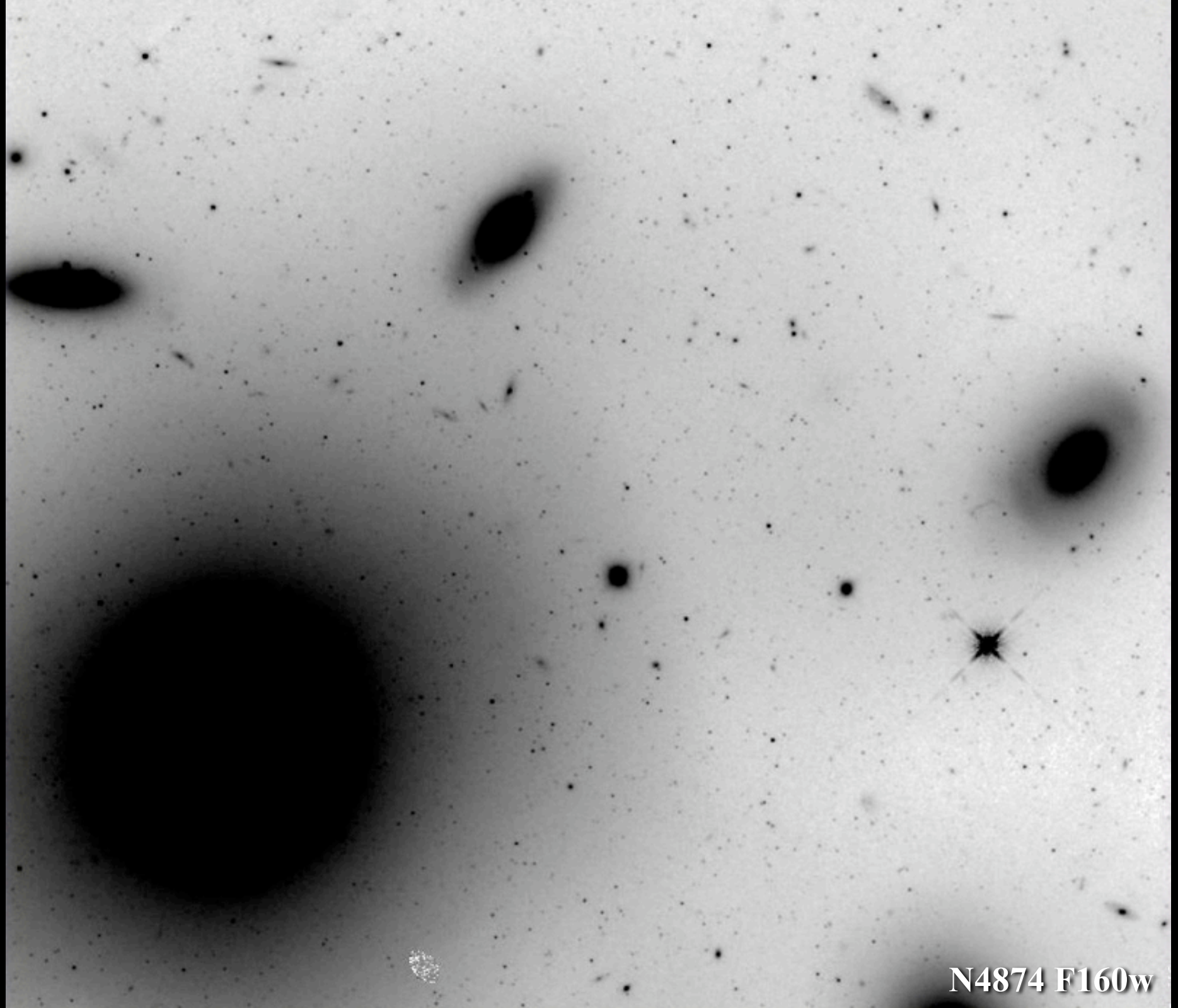
Tonry et al. 2001	ground I-band, V-I calib	31.66 ± 0.17
Cantiello et al. 2007	ACS I_{814}, V_{555}-I_{814} calib	31.59 ± 0.08
JPB et al. 2009	ACS z_{850}, g_{475}-z_{850} calib	31.61 ± 0.07
JPB et al. 2010	ACS I_{814}, g_{475}-I_{814} calib	31.64 ± 0.07

SNe in NGC 1316

And then there was Coma...

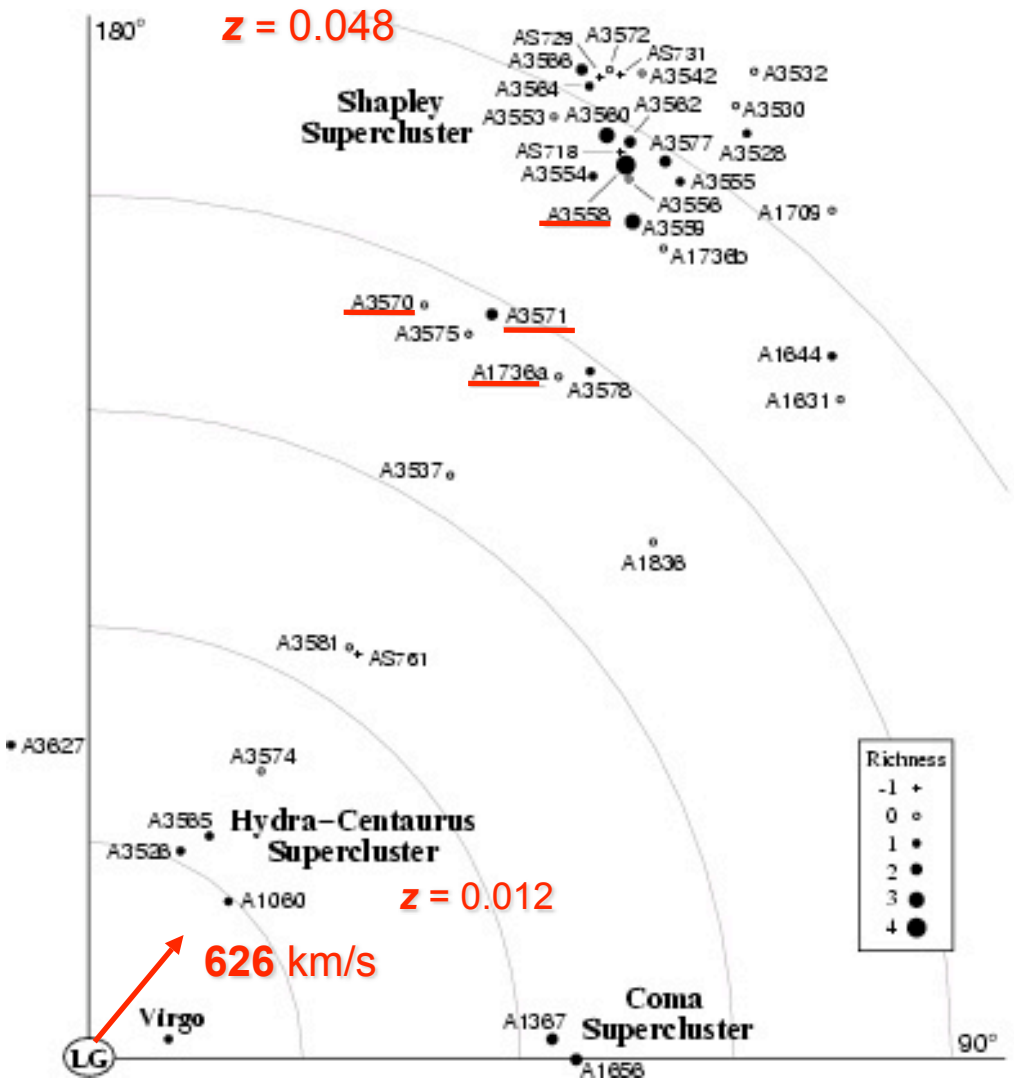
* Coma is ~6x the distance of Virgo, or ~5x Fornax.
* The richest cluster within ~100 Mpc; important to know relative distance for comparisons to Virgo, Fornax, etc.
* ACS Coma Treasury Survey and Cepheid distance programs never completed.
* "The Definitive Distance to the Coma Core Ellipticals" Cycle 17 HST/ACS program (PI: JPB), data acquired this spring, **both ACS/F814W & WFC3/IR**

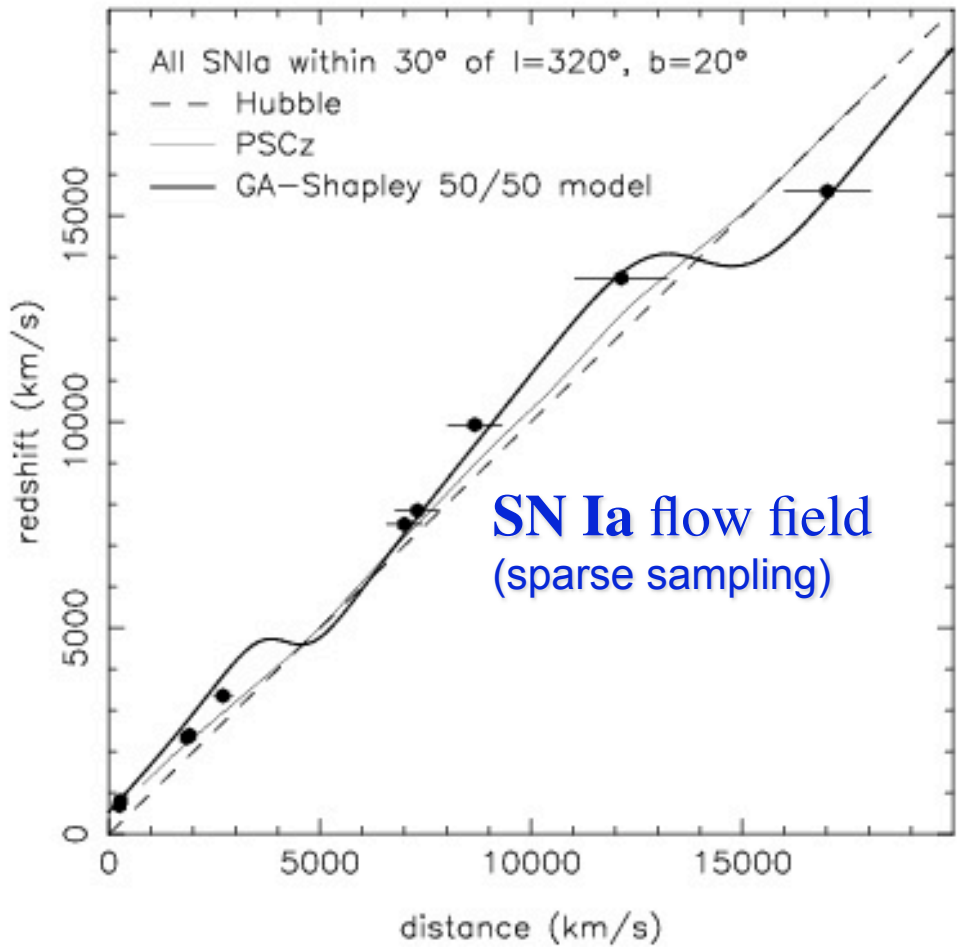

N4889 ACS
N4874 ACS
WFC3/IR par
WFC3/UVis par
GO-11711 orients
18.23' x 12.94'
N
E


N4874 F160w

"Streaming Towards Shapley"

114 orbits, analysis in progress





Determine mass of this extreme supercluster and its influence on Local motion by measuring infall of foreground clusters.


ESO325-004
in AS0740
Distance and peculiar motion analyses are ongoing...

Some thoughts and questions on *optical* SBF studies w/HST

- Efficient, wide-field, well-sampled optical detectors like ACS/WFC, and WFC3/UVis (a bit less sensitive), make SBF extremely powerful, with distance errors < 5% per galaxy;

- multi-cycle SNIa-type effort of hundreds of orbits could solve most remaining questions about large-scale peculiar motions and 3-d mass distribution...

- but may not be the most efficient approach. Try instead with WFC3/IR? or just wait for JWST?

Infrared SBF

- SBF is ~30× more luminous at *K* than at *I*
  - ✦ Dominated by luminous RGB stars
- Increased contrast with (less contamination from) globular clusters & background galaxies
- Seeing is better in the near-IR
- Extinction is much lower than in the optical
- Sensitive to young populations and AGB stars
- Age-metallicity degeneracy is broken

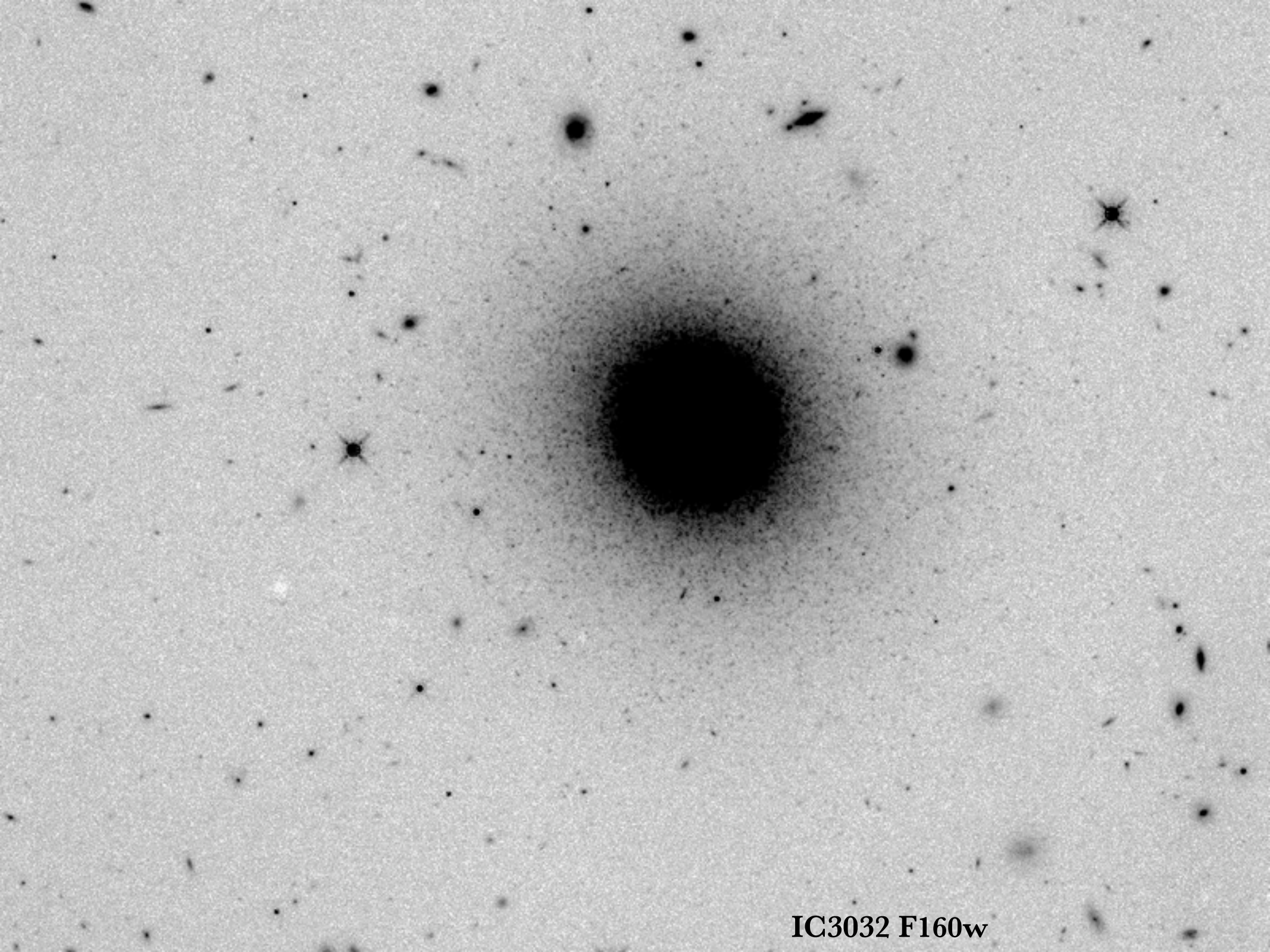
→ IR SBF can reach greater distances

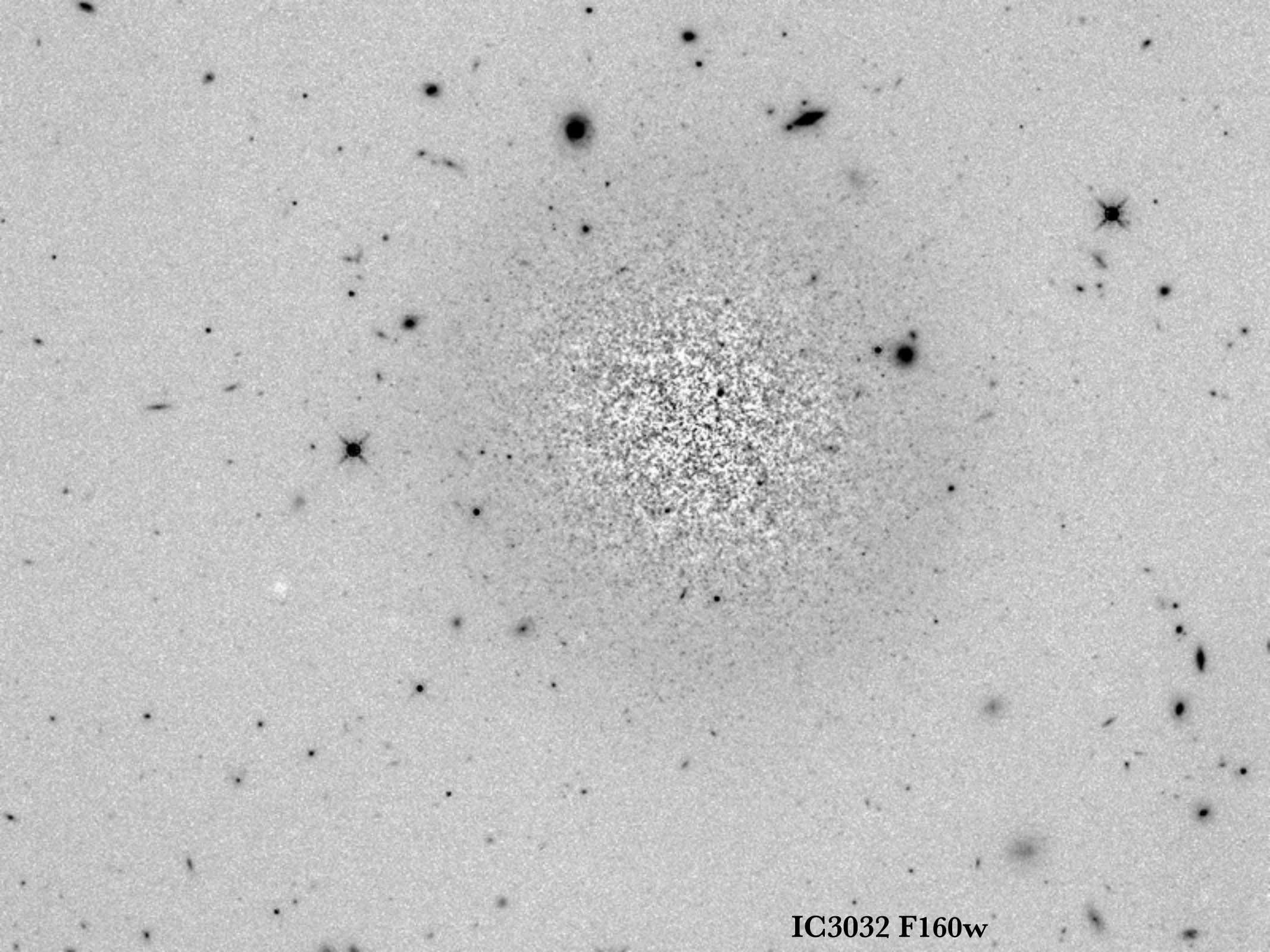
→ IR SBF can reveal young and intermediate components in unresolved stellar populations

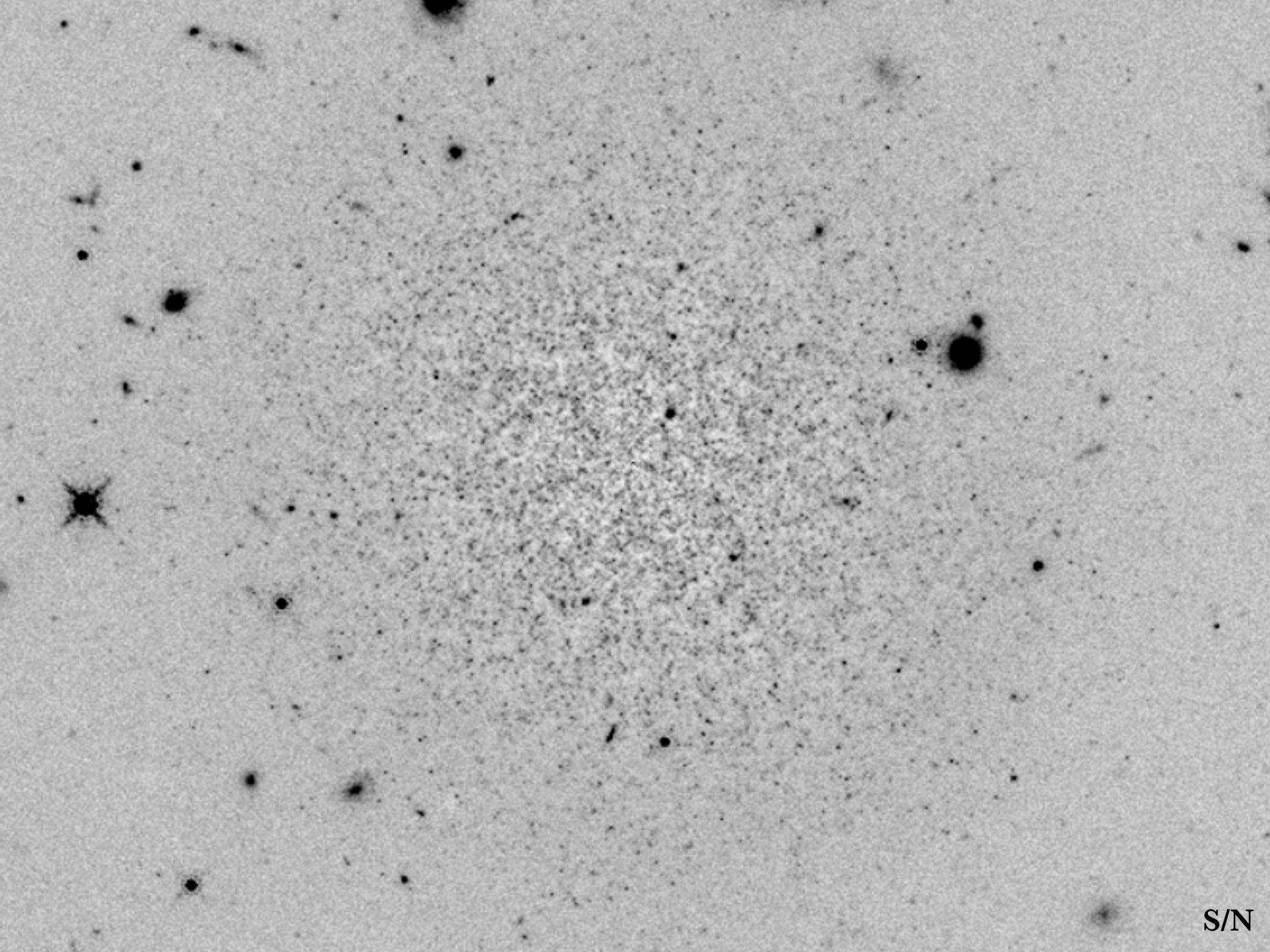
IR SBF with HST/WFC3

* Cycle 17 Hubble Space Telescope Program: "Calibration of Surface Brightness Fluctuations for WFC3/IR", PI: JPB.
  - target 16 galaxies in the Virgo and Fornax clusters with the F110W and F160W bandpasses of WFC3
  - all have measured optical SBF from ACS
  - IR SBF is bright, so exposures short; with calibration, will be easy to get distances from future WFC3/IR single-orbit observations (for black hole masses, etc)

* data collection completed last spring; **H. Cho** making progress on SBF & globular clusters


IC3032 F160w

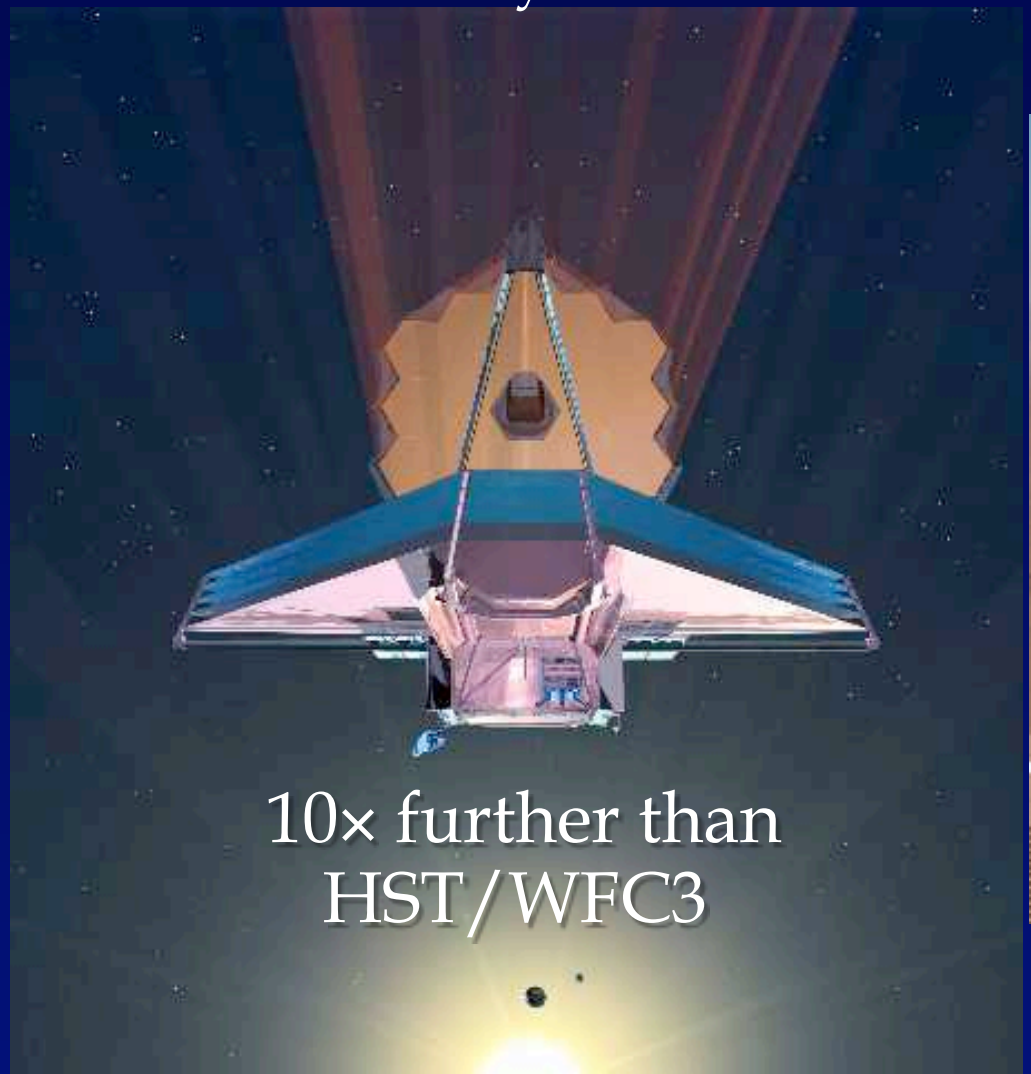

IC3032 F160w


S/N

IR SBF: looking ahead . . .

JWST NIRCam

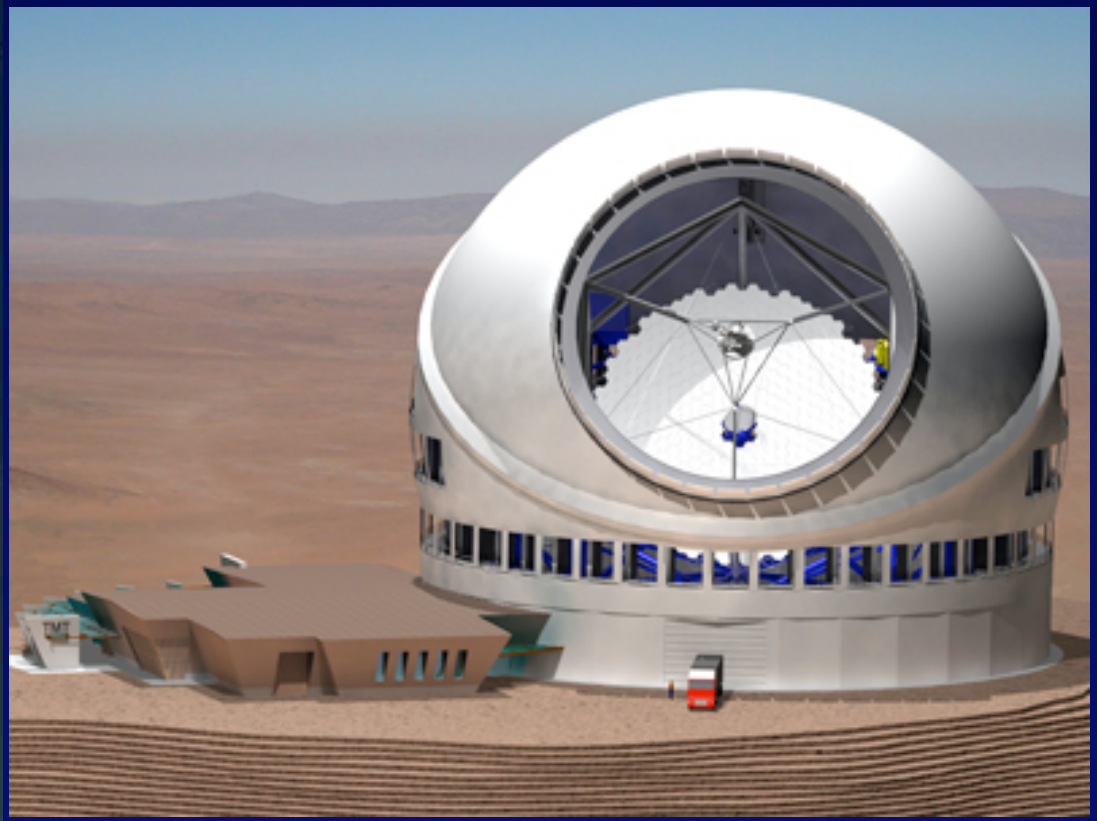
- Very low background
- Extremely stable PSF



10× further than HST/WFC3

TMT IRIS

- Enormous collecting area
- Very high spatial resolution diffraction-limited images



50× faster than HST/WFC3

Conclusion/Outlook

- We've enjoyed a renaissance in optical SBF studies, and now with WFC3/IR channel, may be beginning one for near-IR SBF, too.
- WFC3/IR SBF measurements could give distances to ~all E's/S0's/bulges in local volume, useful for absolute Mass, Luminosity, & size estimates.
- The future looks bright, especially for near-IR SBF studies with HST+WFC3/IR, MCAO systems, and the far horizon of JWST & TMT/EELT.
- Also many interesting applications of optical-IR SBF data sets for globular clusters, so stay tuned!