Distances and stellar population properties in galaxies from

Surface Brightness Fluctuations (SBF) analysis

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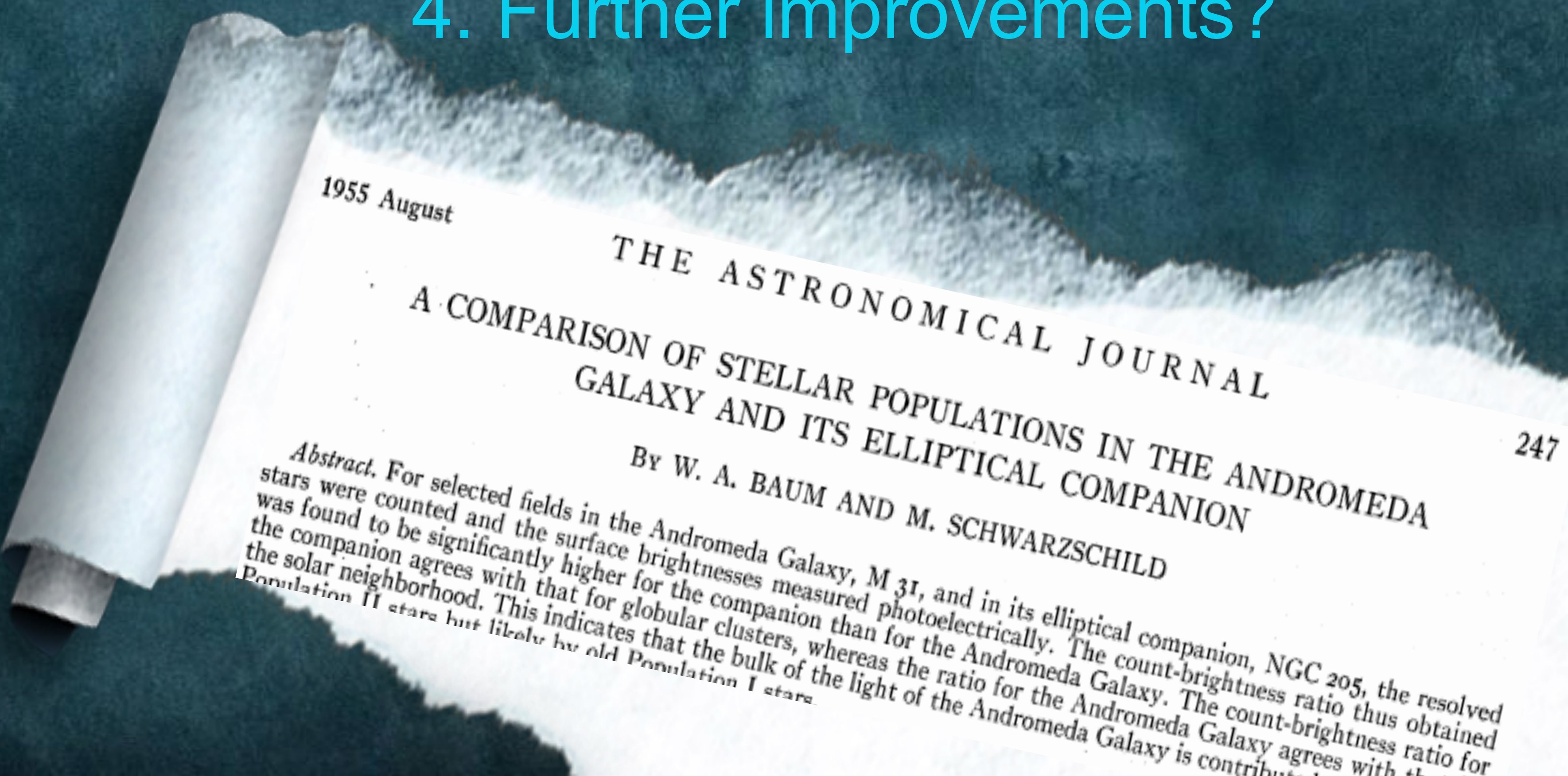
NATIONAL INSTITUTE FOR ASTROPHYSICS

Overview

1. What "SBF" is?
2. Why is it worth working on that?
3. Why LSST is important?
4. Further improvements?



1955 August

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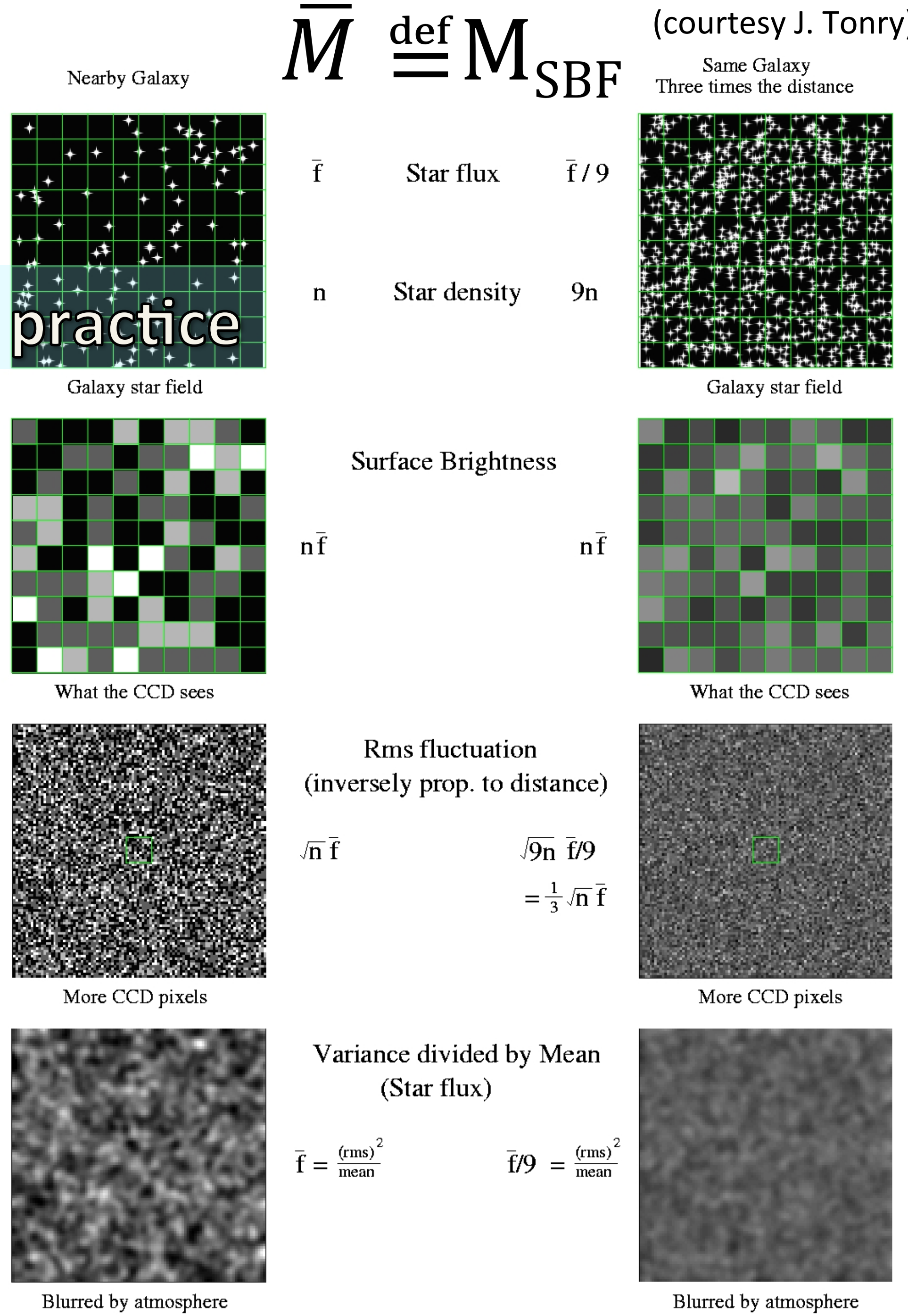
A COMPARISON OF STELLAR POPULATIONS IN THE ANDROMEDA GALAXY AND ITS ELLIPTICAL COMPANION

By W. A. BAUM AND M. SCHWARZSCHILD

Abstract. For selected fields in the Andromeda Galaxy, M 31, and in its elliptical companion, NGC 205, the resolved stars were counted and the surface brightnesses measured photoelectrically. The count-brightness ratio thus obtained was found to be significantly higher for the companion than for the Andromeda Galaxy. The count-brightness ratio for the companion agrees with that for globular clusters, whereas the ratio for the Andromeda Galaxy agrees with [illegible] the solar neighborhood. This indicates that the bulk of the light of the Andromeda Galaxy is [illegible] Population II stars but likely by old Population I stars

1.1 SBF what?

… in practice



1.2 SBF How-to...

$$[n, f] \Rightarrow f_{SBF} \equiv \sum_i n_i f_i^2 / \sum_i n_i f_i$$

SBF Measurement

(Tonry & Schneider, 1988; Tonry et al., 1990)

1. Model the galaxy
2. Original minus Model
3. Mask all internal (GCs, dust) and external sources of non-stellar fluctuations.
4. Estimate the amplitude of the fluctuation in the Fourier domain
5. Subtract to the total fluctuation flux the contribution from un-excised sources

- ✓ Measure m_{SBF}
- ✓ Calibrate M_{SBF}
- ✓ $m-M=m_{SBF}-M_{SBF}$

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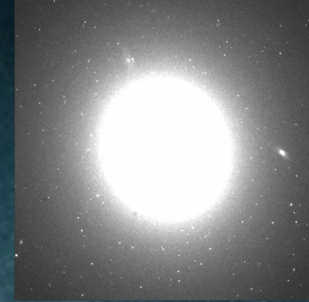

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NGC1399 WFC3/IR

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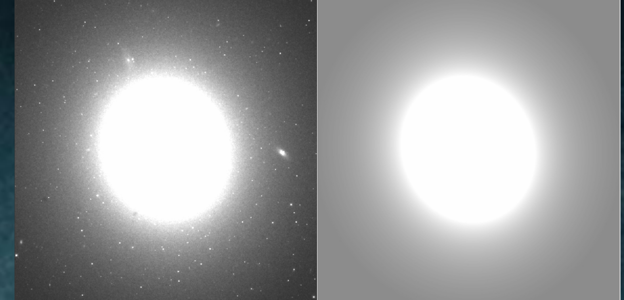

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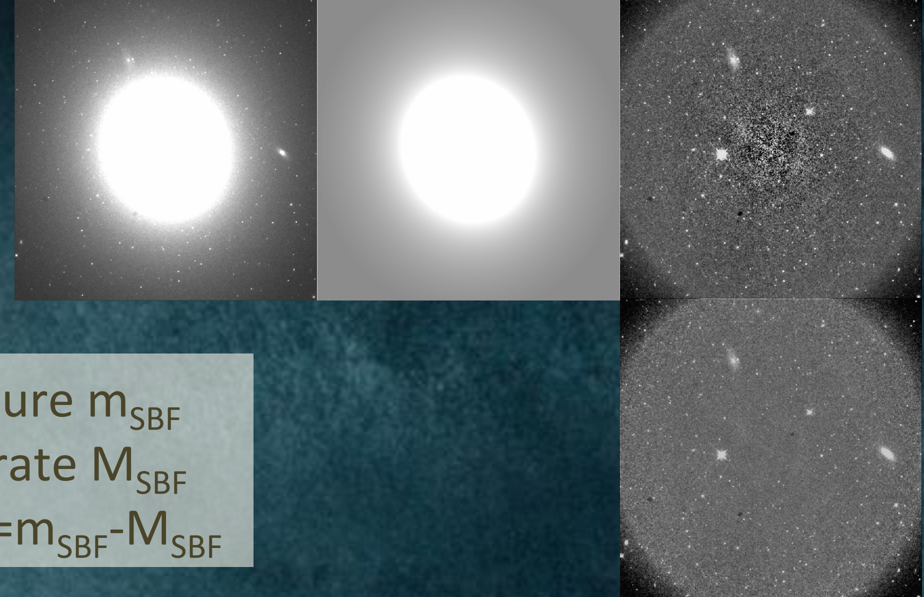

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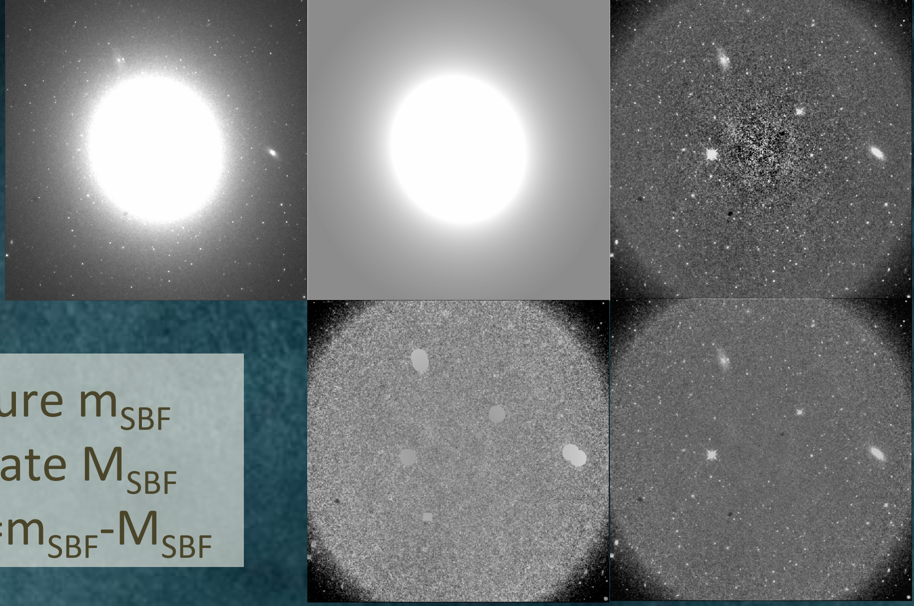

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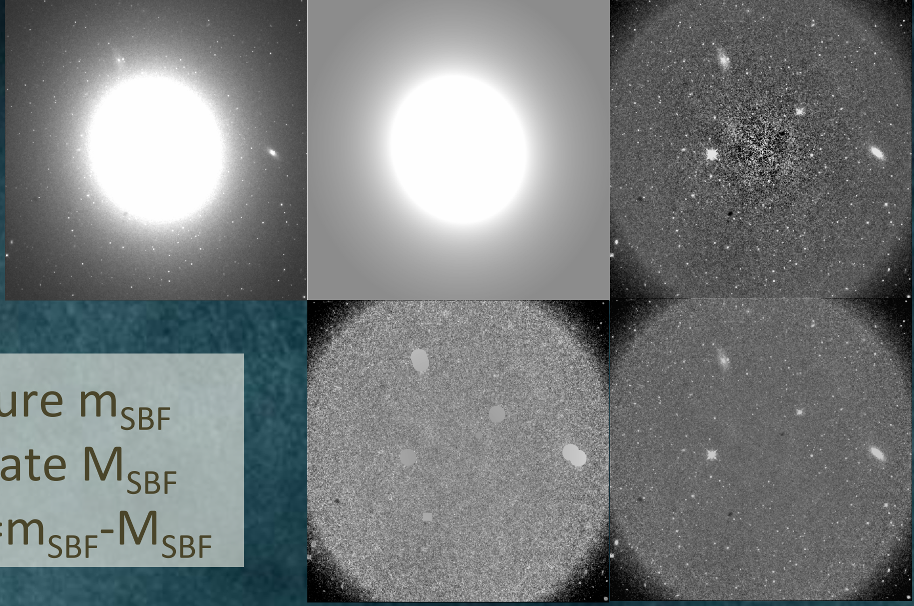

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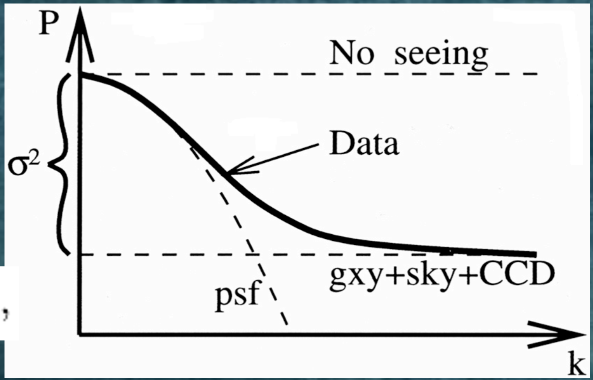

$$P(k) = P_0 E(k) + P_1,$$

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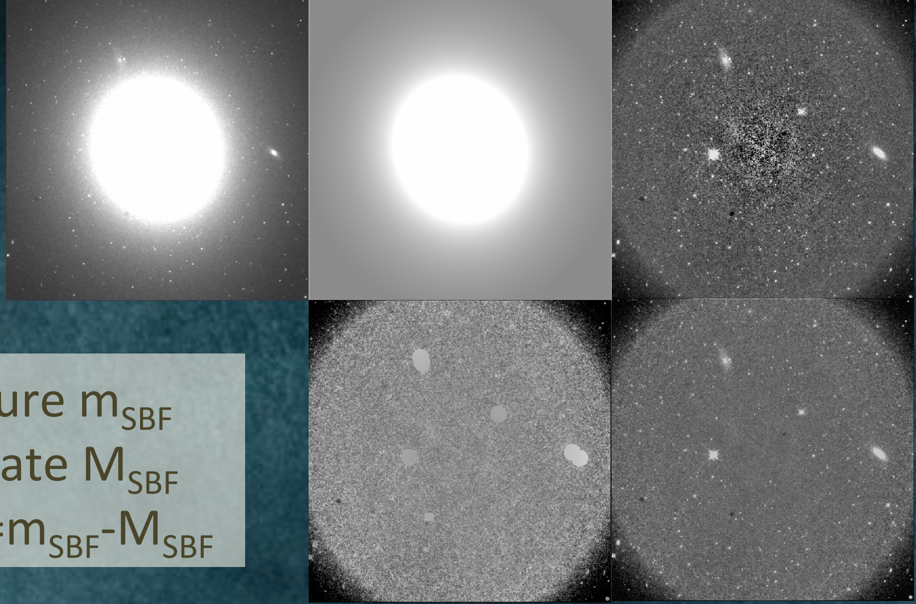
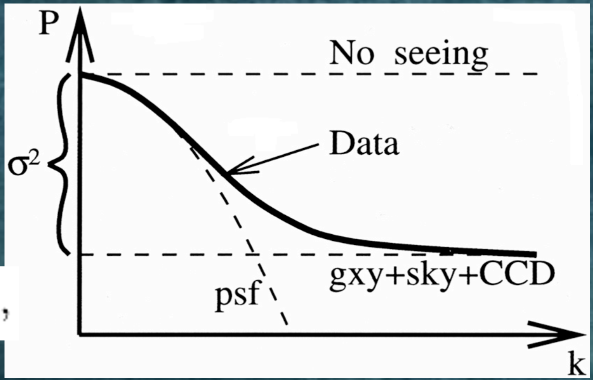


NGC1399 WFC3/IR

$$\bar{m}_X = -2.5 \log (P_0 \quad) + m^{X,}_{zer}$$



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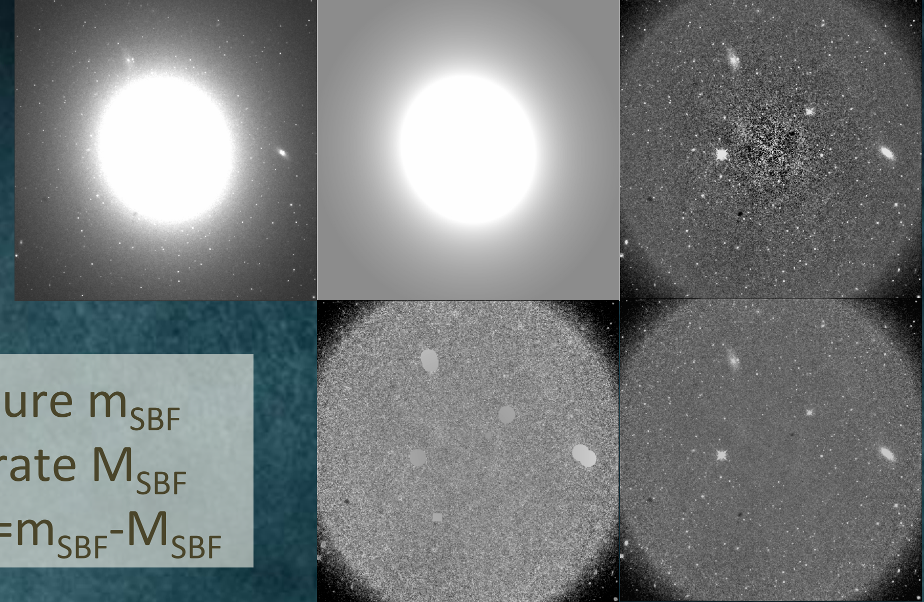
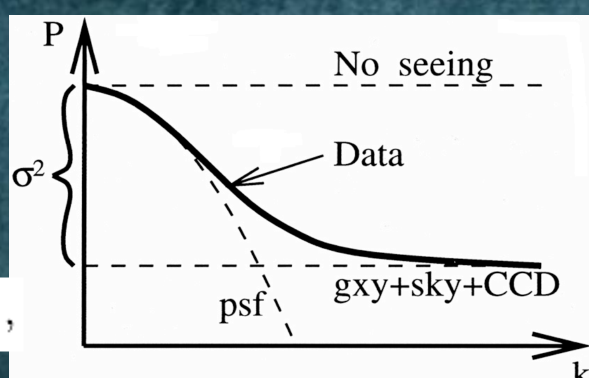


NGC1399 WFC3/IR

$$\bar{m}_X = -2.5 \log (P_0 - P_r) + m^{X,}_{zero}$$



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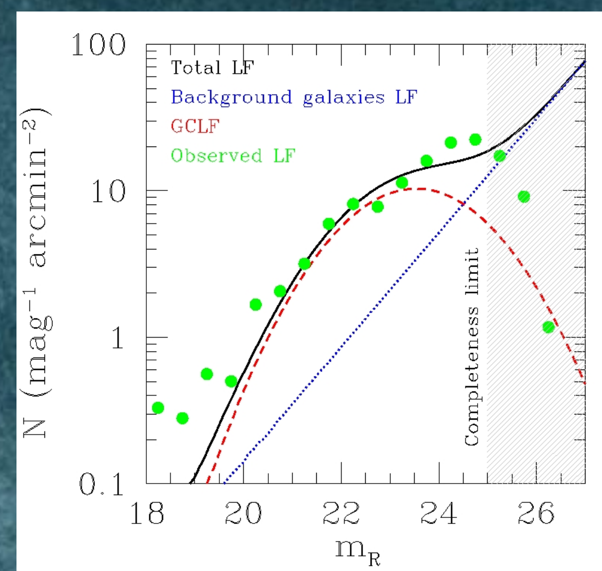


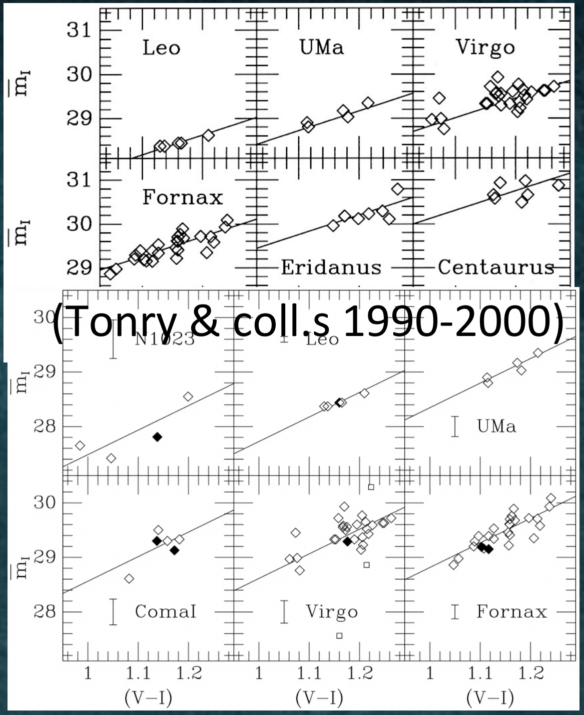
1.3 Empirical Calibrations

$$[n, f] \Rightarrow f_{SBF} \equiv \sum_i n_i f_i^2 / \sum_i n_i f_i$$

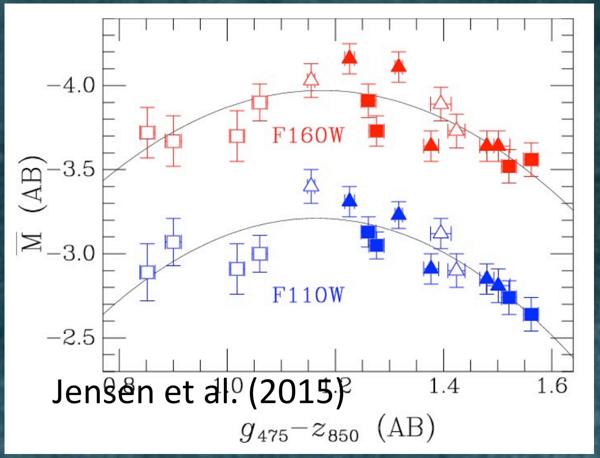
M_{SBF} ~ mean luminosity of RGB stars

First I-band Calibration:
M_{SBF}=-1.74(±0.16)+4.5(±0.25)[(V-I) -1.15]

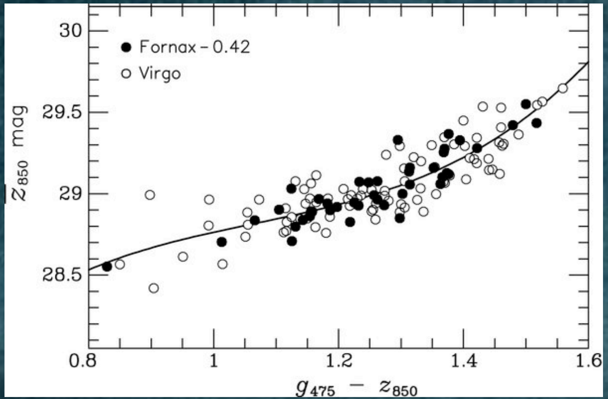
1. Measure m_{SBF}
2. **Calibrate M_{SBF}**
3. $m\text{-}M = m_{SBF} - M_{SBF}$



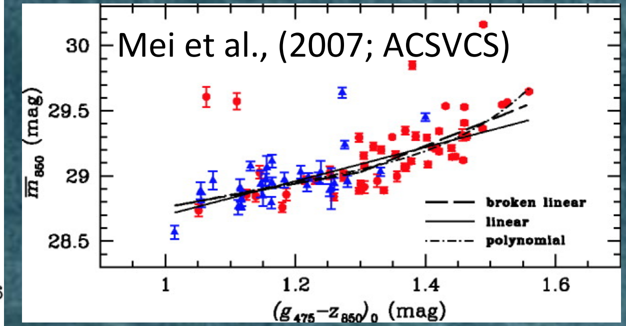
(Tonry & coll.s 1990-2000)



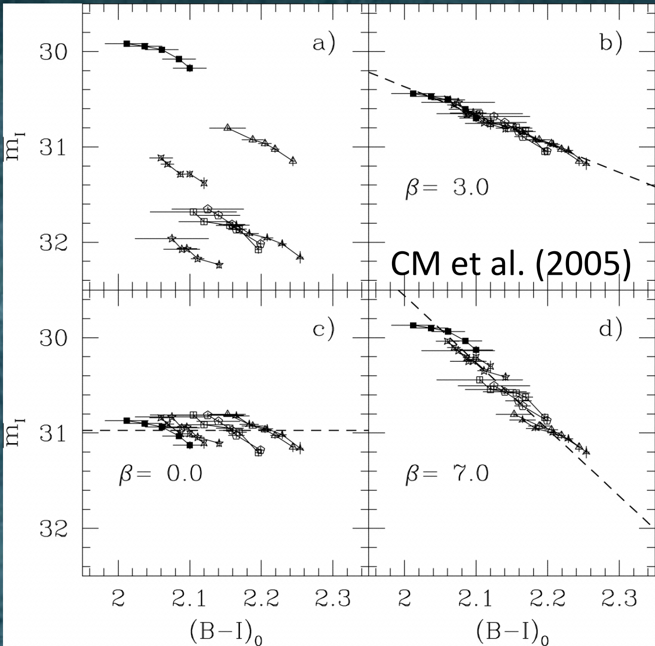
Jensen et al. (2015)



Blakeslee et al., (2009; ACSVCS & ACSFCS)



Mei et al., (2007; ACSVCS)



CM et al. (2005)

1.4 Theoretical Calibrations

1. Measure m_{SBF}
2. **Calibrate M_{SBF}**
3. $m\text{-}M = m_{SBF} - M_{SBF}$

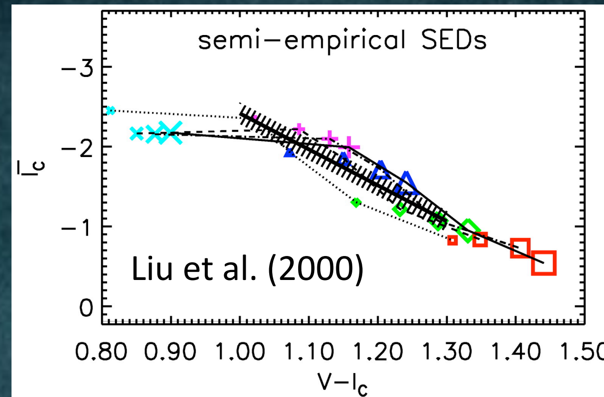
First attempts in the '90s (Tonry et al.,1990; Buzzoni, 1993; Worthey, 1994)

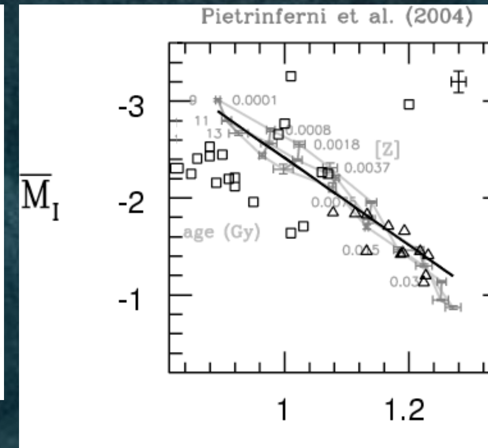
- Typical approach: SBF from isochrones
- SPoT group approach:

SBF from numerical synthesis of stellar populations: Stellar evolution theory + Statistical fluctuations (Brocato et al., 2000; CM et al., 2003; Raimondo et al., 2005)

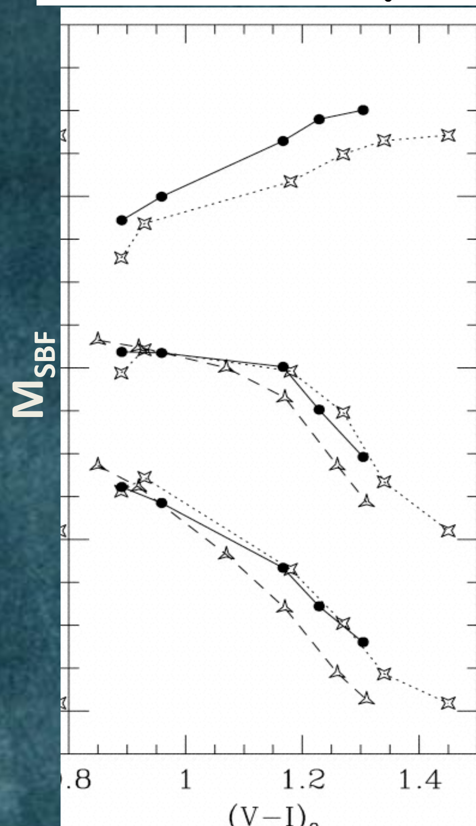
✓ Pros: All passbands you want in a single shot

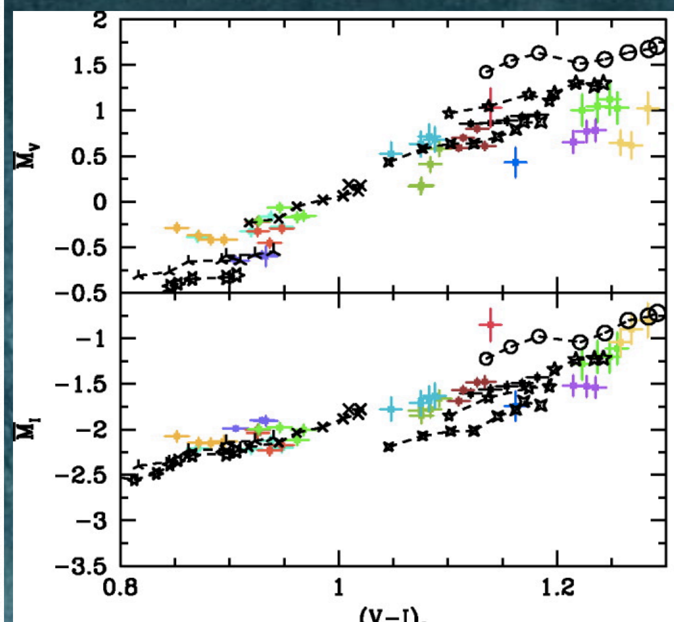
✓ Cons (naïve): Model dependent





Marin-Franch & Aparicio (2006)





Raimondo et al. (2005) CM et al. (2007)

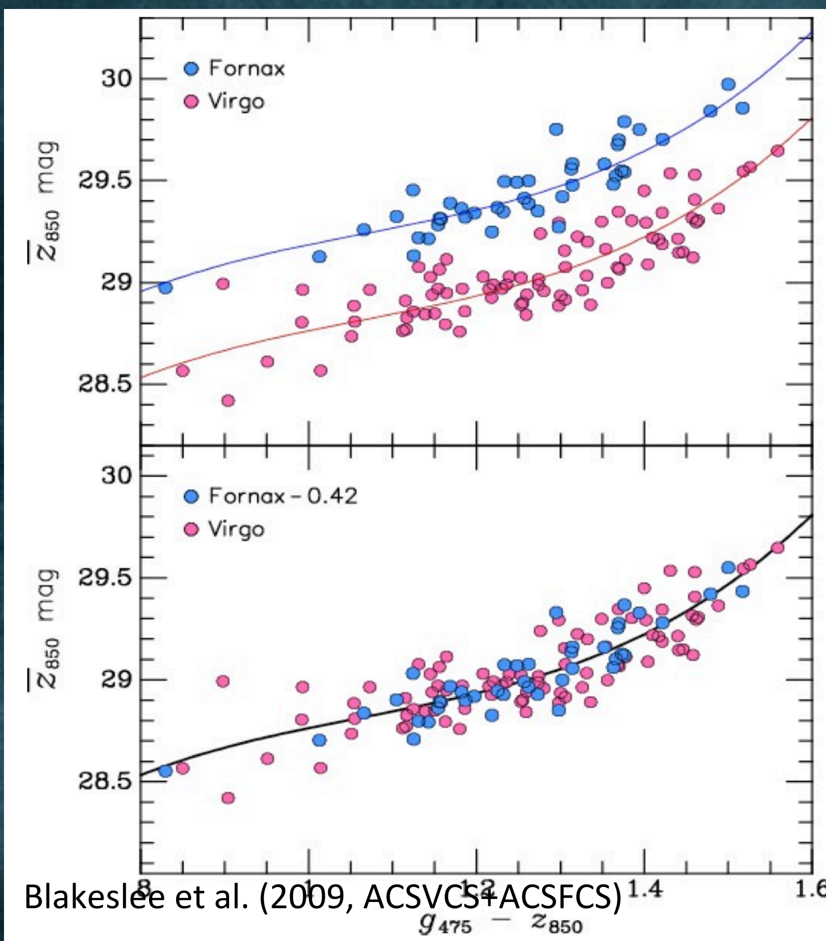
2. Why?
A (short) collection of Results

- Distances (from ~1 to 200 Mpc)!
- SBF & Stellar populations
- SBF & H_0
- SBF & velocity field (Virgo, G.A., "Laniakea")

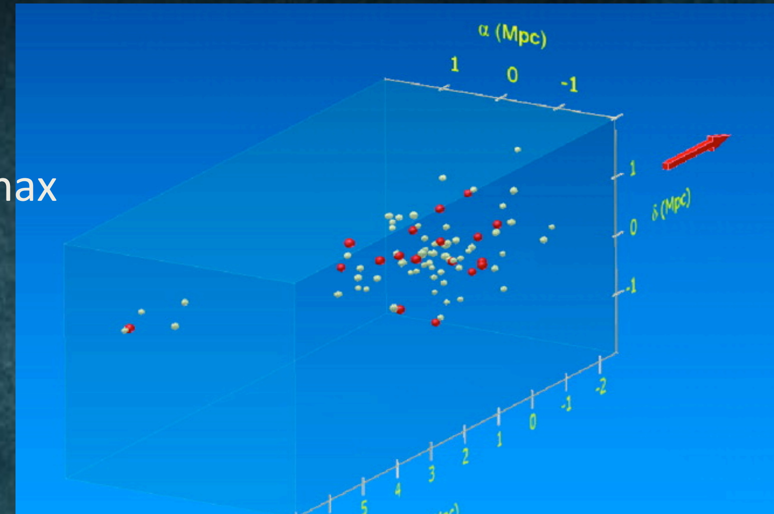
2.1 Distances

- Very accurate relative distance between Virgo & Fornax
- 3D Structure of Virgo
- SBF distances for BH studies
- … and a lot more

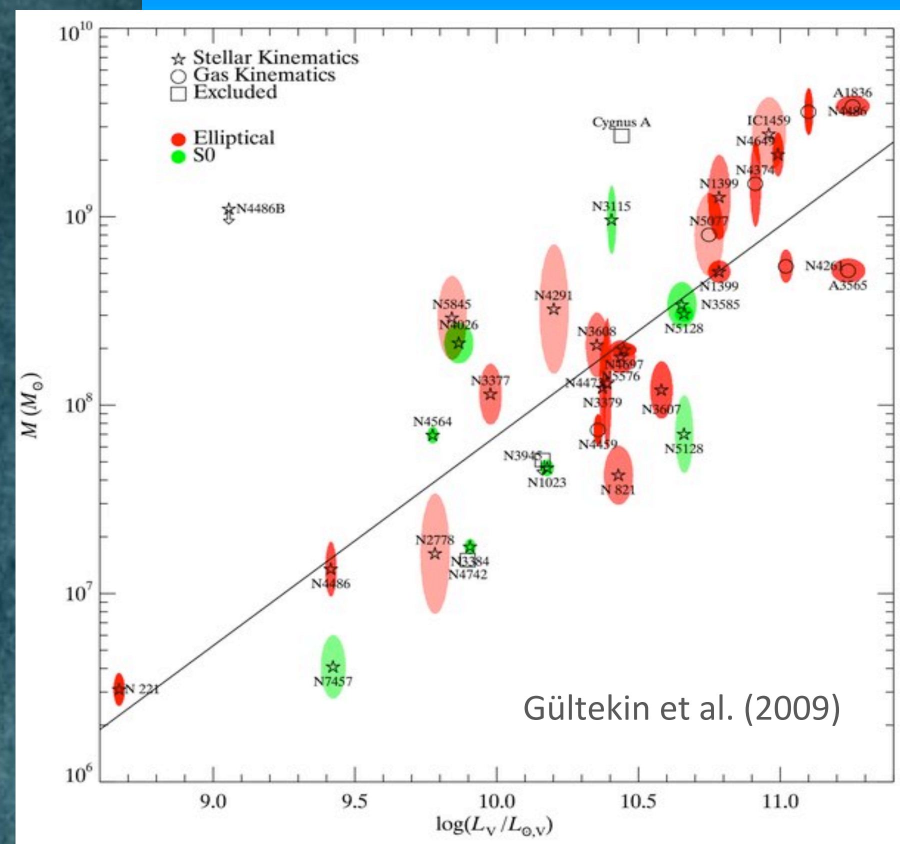
Fornax 21% ±1% more distant than Virgo



Blakeslee et al. (2009, ACSVCS+ACSFCS)



Mei et al. (2007)



Gültekin et al. (2009)

2.2 SBF colours: lifting the t/Z degeneracy

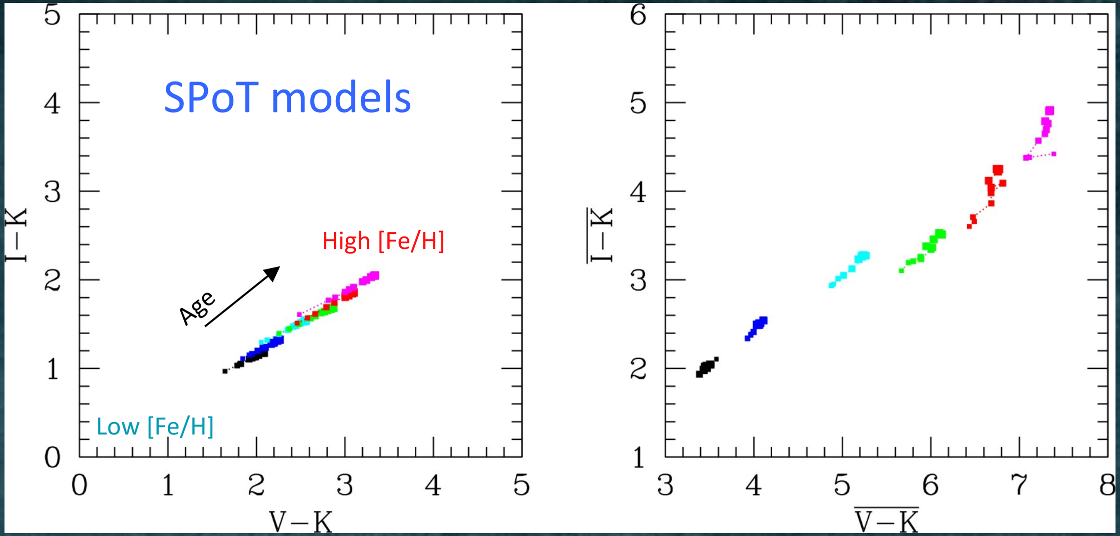
- SBF magnitudes ➔ properties of bright stars in a population
- Classical colors and magnitudes ➔ most populated phase (H-burning MS stars)

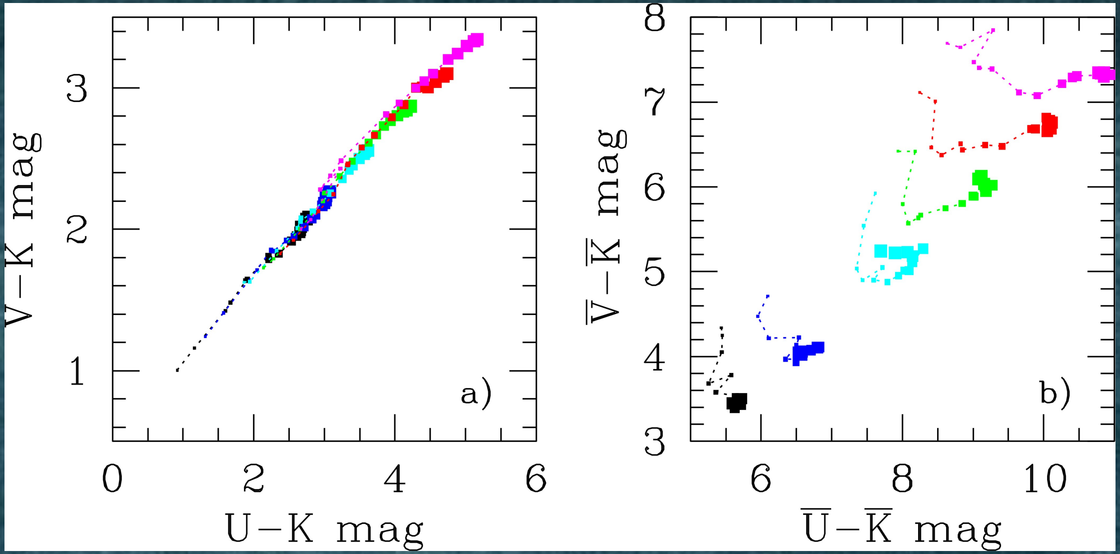
M_{SBF} approximately the mean luminosity of the brightest stars in a system:

➔Optical to near-IR: RGBs and AGBs

➔B (and U?): HB stars play a key role!

Only a few applications: Jensen et al. (2001); Blakeslee et al., (2001); CM et al. (2003)





Need more *wide wavelength coverage (LSST)*

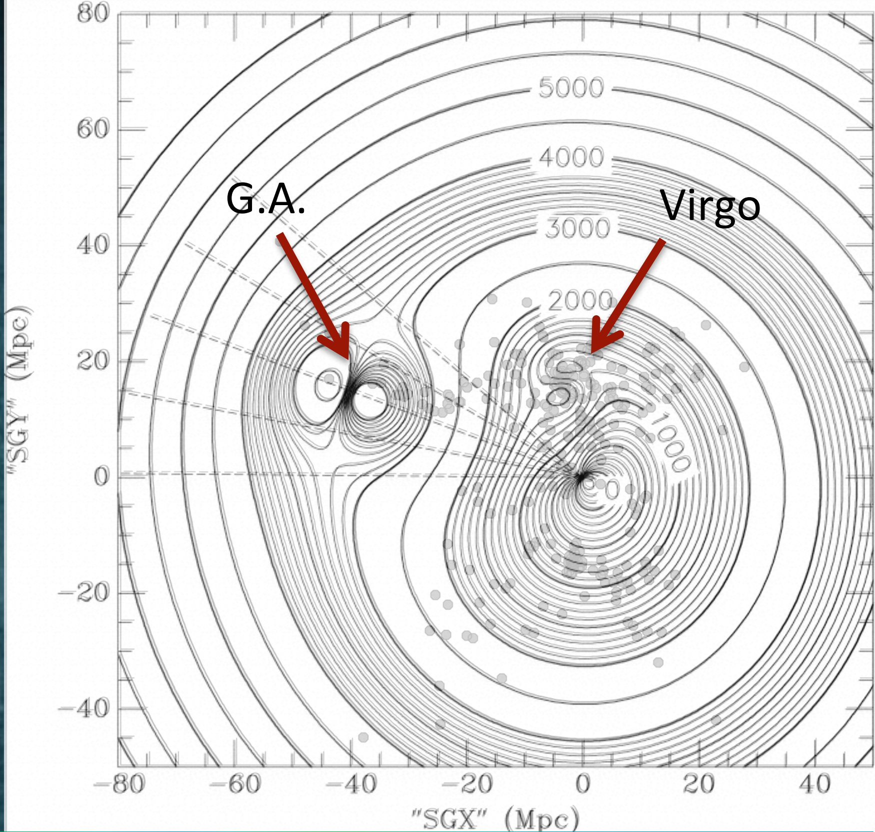
2.3 When SBF met H_0

Author	H_0 (km s^{-1} Mpc^{-1})	ΔH_0 Statistical	ΔH_0 Systematic	Notes
Tonry et al. (2000)	77	±4	±7	SBF survey, smooth cosmic flows. Cepheids ZP
Jensen et al. (2001)	76	±1.3	±6	Near-IR NICMOS/HST data. Cepheids ZP
Blakeslee et al. (2002)	73	±4	±11	SBF Survey + FP + IRAS Vel. Field model
Biscardi I. et al., (2008)	76	±6	±5	ACS optical Model calibration
Mould & Sakai (2009)	68	±6	±4	TRGB calibration

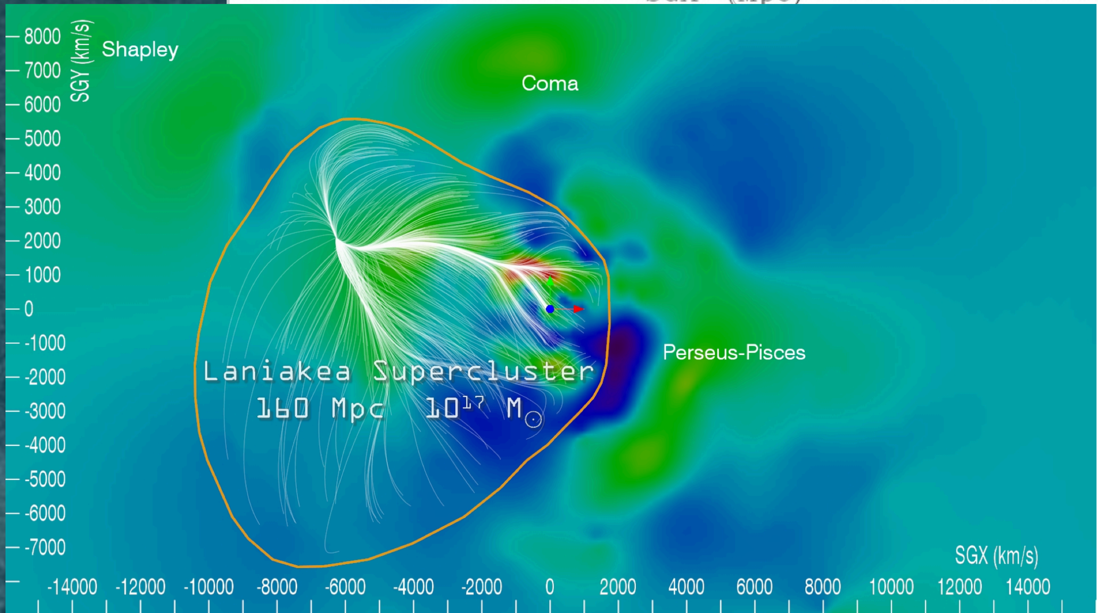
2.4 Cosmic Flows

(lead by B. Tully)

1. ~0.5% uncertainty on H_0 from deviations from a smooth Hubble flow due to large scale gravitational perturbations (peculiar velocities). An Accurate H_0 needs accurate corrections to these deviations.
2. The LG is moving at 630 km/s toward a well known direction (Fixen et al., 1996). Mapping accurate peculiar velocities & distances translates into a map of the distribution of matter.



- ✓ Estimate distances, d
- ✓ Peculiar velocities: $V_{pec}=V_{obs}- H_0 d$
- ✓ 3D velocities + density field



2.5 Error budget…

- ~0.1 mag SBF zero point (from Cepheids, systematic)

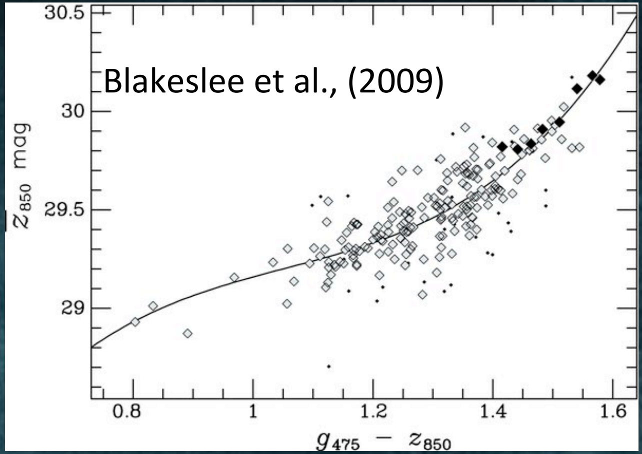
  <<0.05 mag after Gaia!!

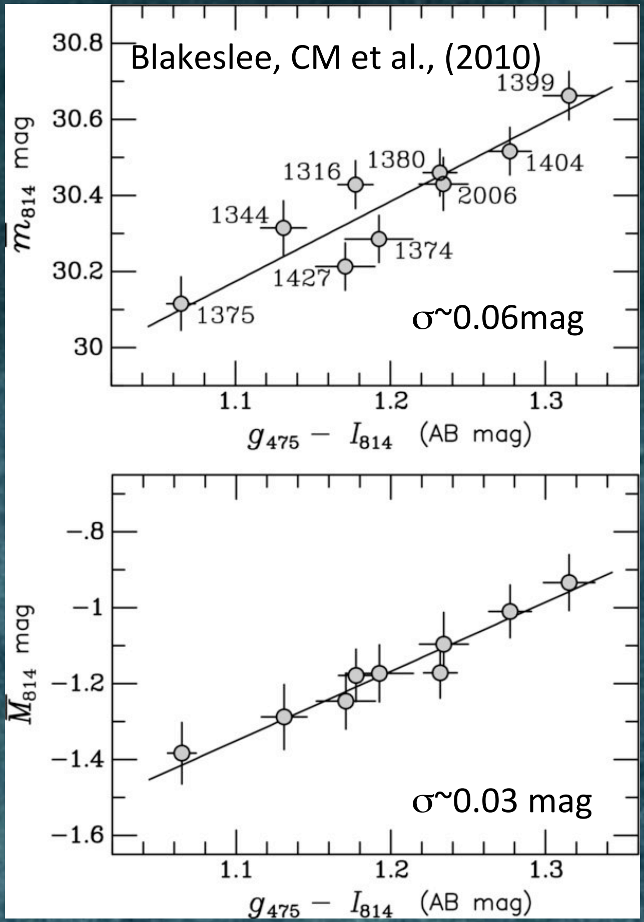
- ~0.1 mag SBF scatter, lowers to ~0.06 mag in *I* & *z* bands from space

  <<0.05 mag after LSST?

- Other minor sources of error:

Source	σ
PSF normalization	≤0.03 mag
Sky subtraction	negligible
LF fitting	<0.03 mag
Filter ZP	~0.01 mag
Flat Field	~0.01 mag





3.1 From *LSST Science Book*

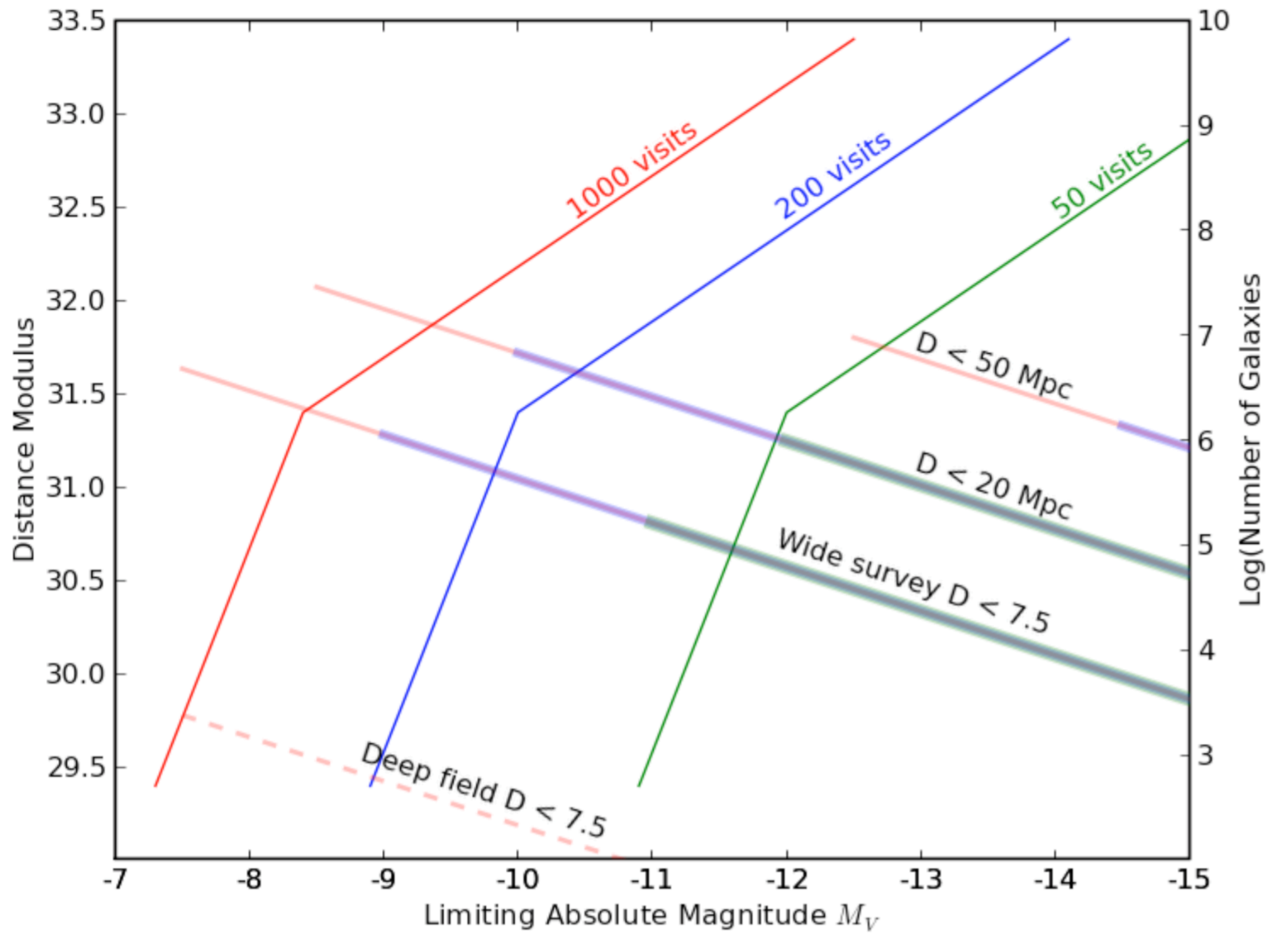
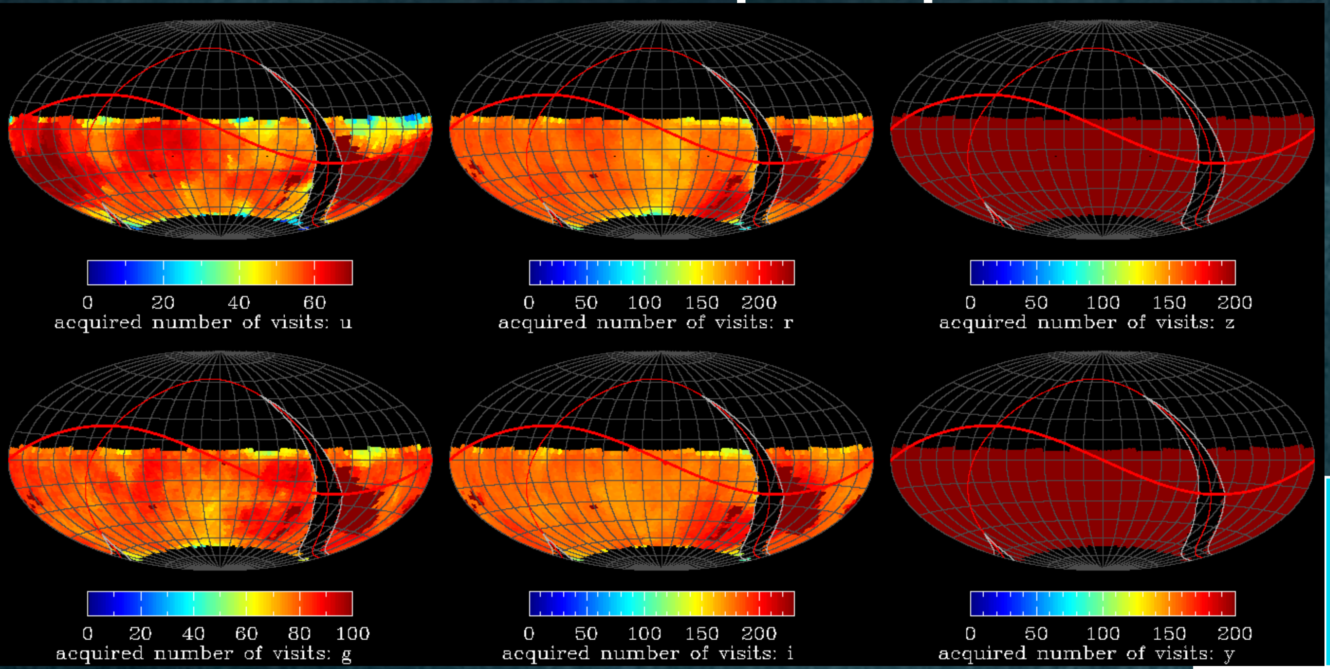


Figure 9.12: LSST surface brightness fluctuations, whereby mottling of the galaxy image due to the finite number of stars in each pixel is a measure of the distance to the galaxy. The curves moving upwards to the right show distance modulus vs. absolute magnitude for distance modulus determination to a precision of 0.5 mag for 50, 200, and 1,000 r-band visits (the latter appropriate to the deep drilling fields). This is derived by scaling from the realistic image simulations of Mieske et al. (2003), which include the effects of photon statistics, resolution, and image size. The curves moving upwards to the left show the expected number of galaxies in a 20,000 deg^2 survey (solid lines) or a 10 deg^2 deep-drilling field with 1,000 visits (dashed line near the bottom). Numbers are based on the luminosity function of Croton et al. (2005).

3.2 The LSST perspective



Number of Visits for the Deep & Wide survey

Number of targets reached? $>>10^6$

	N. of visits (15s)	Max Distance modulus	Max D (Mpc)
u	70	28-30?	4-10?
g	100	>32	>25
r	230	~35	~100
$r_{D.D.}$	1000	~36.5	~200
i	230	~36	~150
z	200	>36	>150
y_2	200	~35	~100
y_4	200	>36	>150

$T_{exp} \sim 5 \times 10^{0.4(DM - M_{sbf} - ZP_{mag})}$

(Blakeslee et al.,1999)

- ✓ $M_{sbf} \sim 5/2.2/0.6/-0.5/-1.8/-2.4$ $u/g/r/i/z/y_N$ *(Teramo SPoT models, G. Raimondo & E. Brocato)*
- ✓ ZP_{mag} LSST web-pages *(~Ivezich et al. 2010)*

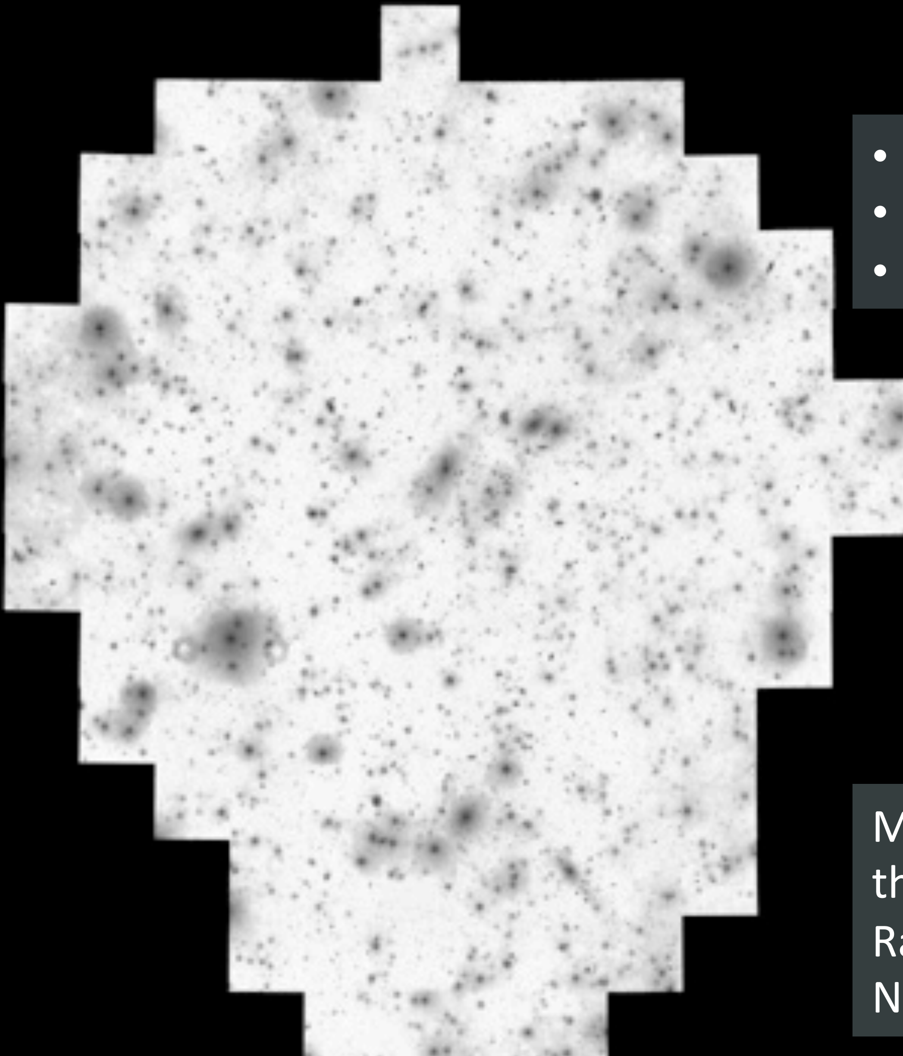
3.3 NGVS

The Next Generation Virgo Cluster Survey

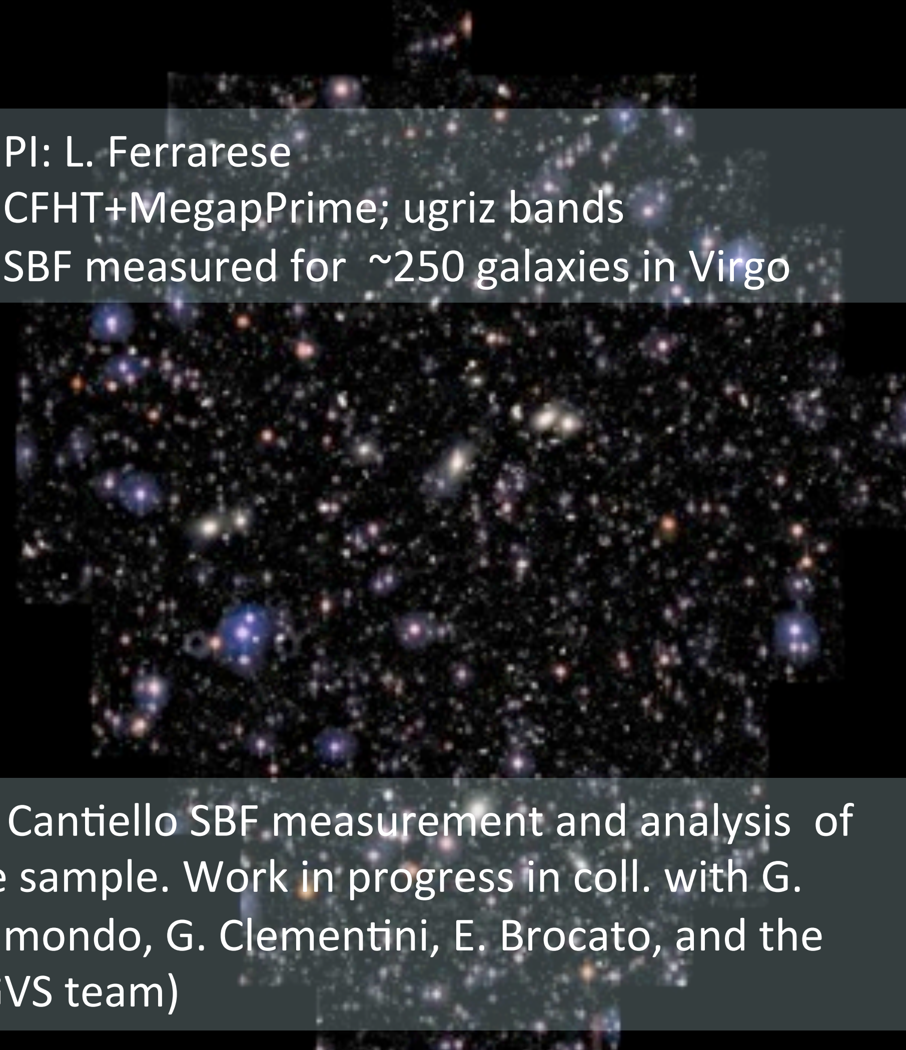
The NGVS is five–year large program with MegaCam on CFHT (2009/2013)

- PI: L. Ferrarese
- CFHT+MegapPrime; ugriz bands
- SBF measured for ~250 galaxies in Virgo

M. Cantiello SBF measurement and analysis of the sample. Work in progress in coll. with G. Raimondo, G. Clementini, E. Brocato, and the NGVS team)



Completed 104 sq. deg. mosaic in MegaCam g'–band
Image quality: 0.8", 53 mn integration per 0.187" pixel
Point source detection at SNR=5: g'=26.2

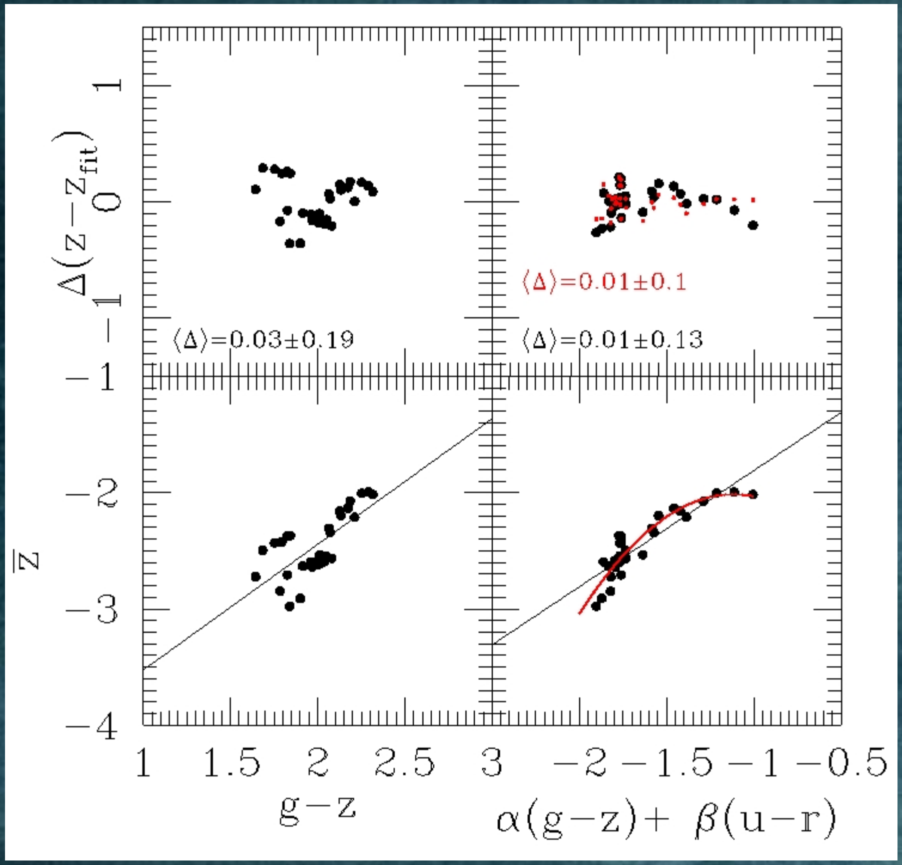


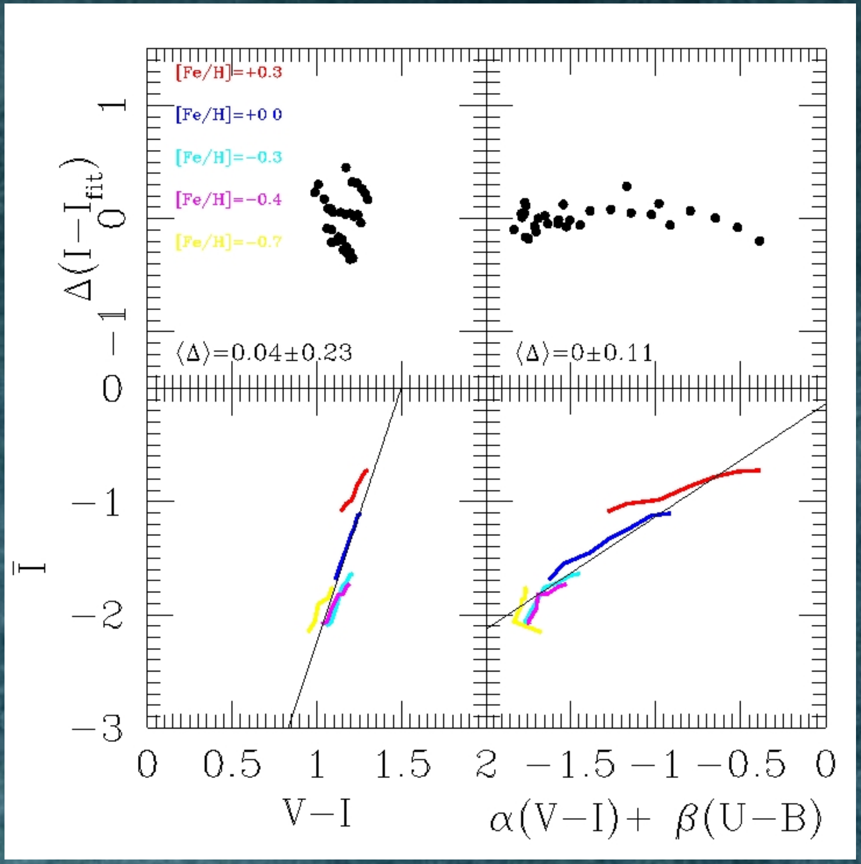
Completed 104 sq. deg. mosaic in MegaCam g'i'z' bands
Image quality: 0.8", 0.6", 0.7" (53/34/64 mn per pixel)
Point source detection at SNR=5: g'=26.2 i'=24.9 z'=24.2

4.1 Further improvements with LSST?

Pop II (and I) indicators take into account [Fe/H] through colour. What about age?

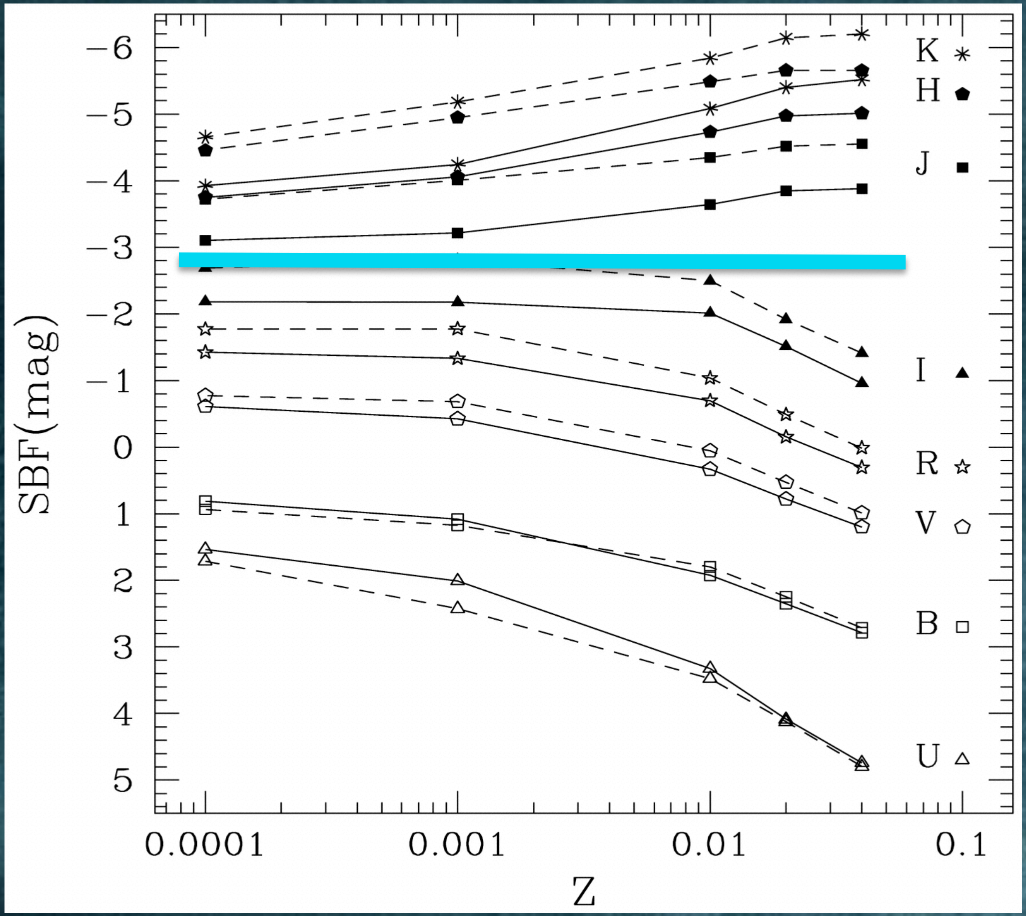
Two Colour calibrations: take into account metallicity and age effects on the stellar pops.
Preliminary simulations from SSP models~50% lower scatter.





4.2 Further improvements with LSST?

Y-band: metallicity free predicted from different SSP models



Y-band (~1μm)
~metallicity-free

(Worthey 1993; MC et al, 2003)

Conclusions (by Wendy Freedman)

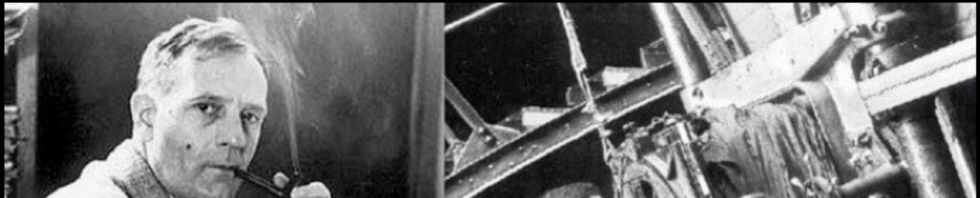
SBF:

- Scatter is 1.5%
- Need to overcome giggle factor (Jeremy excepted)
- Consensus: Promising, more people need to work on this

The Hubble Constant:
Current and Future Challenges

Kavli Institute for Particle Astrophysics and Cosmology
Stanford University

February 6-8, 2012



Chris Blake - Swinburne
Roger Blandford - KIPAC
Jim Braatz - NRAO
Frederic Courbin - EPFL
Joanna Dunkley - Oxford
Wendy Freedman - Carneg
Lincoln Greenhill - Harvard
Stefan Hilbert - KIPAC
Elizabeth Humphreys - ES(
Saurabh Jha - Rutgers
Robert Kirshner - Harvard
Fred Lo - NRAO
Lucas Macri - Texas A&M

Barry Madore - Carnegie
Phil Marshall - Oxford
Georges Meylan - EPFL
Jeremy Mould - Swinburne
Beth Reid - LBNL
Mark Reid - Harvard
Adam Riess - Johns Hopkins
David Schlegel - LBNL
Vicky Scowcroft - Carnegie
Sherry Suyu - UCSB/KIPAC
Tommaso Treu - UCSB
Licia Verde - Barcelona

Conclusions (by me) pros & cons

- ❑ LSST Deep & Wide Survey: (u)grizy$_N$ SBF for:
  - ✓ Distance estimates out to ~150 Mpc. Even deeper for the "drilled" fields
  - ✓ Stellar population characterization, via SBF colors & gradients
- ❑ A complete 3D-mapping of southern sky galaxies within ~150 Mpc with accuracy <<5%
  - ✓ Gaia+2-color calibration
- ❑ Possible interest of Canadians at Victoria
- ❑ Automatized procedure for measuring SBF to tens of thousands (or way more) galaxies;
- ❑ Data storage and access…
- ❑ FTE ??? (discuss the details here)