(Some humble suggestions for)

The Old Stellar Population Studies with Subaru

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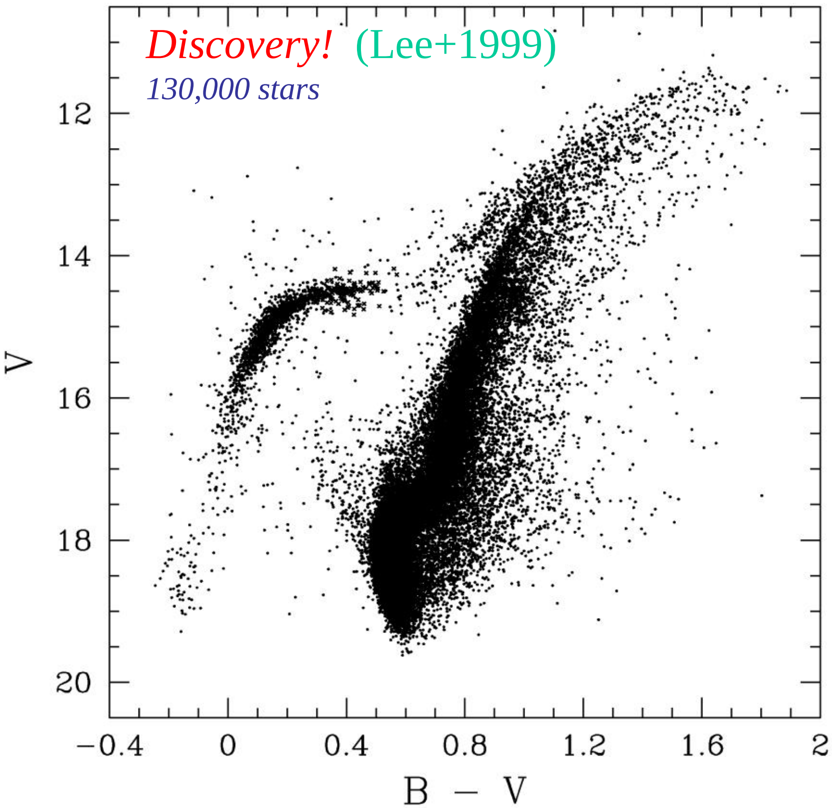
1. Globular cluster – Dwarf galaxy Connection

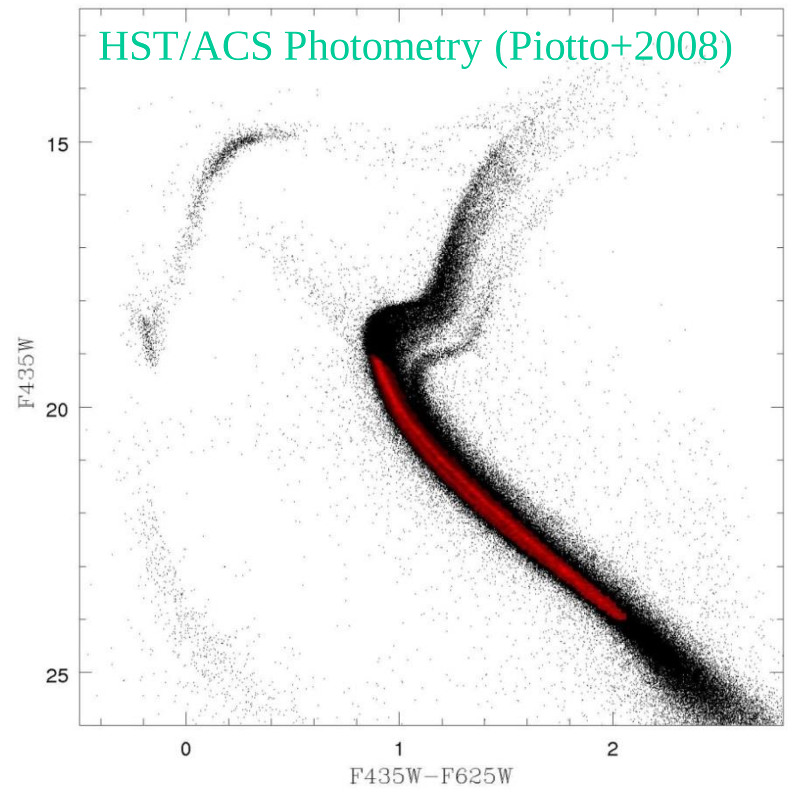
(Some) Globular clusters show multiple RGBs (SNe enrichment!)

→ Originated from dwarf galaxies?

→ Ca narrow-band photometry of dwarf galaxies with Subaru can provide a direct empirical connection, if any, with these GCs!

Discovery of Multiple & Discrete RGBs in ω Cen





"This was the first time that multiple populations were found in a GC."

Not just a spread , but discrete RGBs with different iron abundances

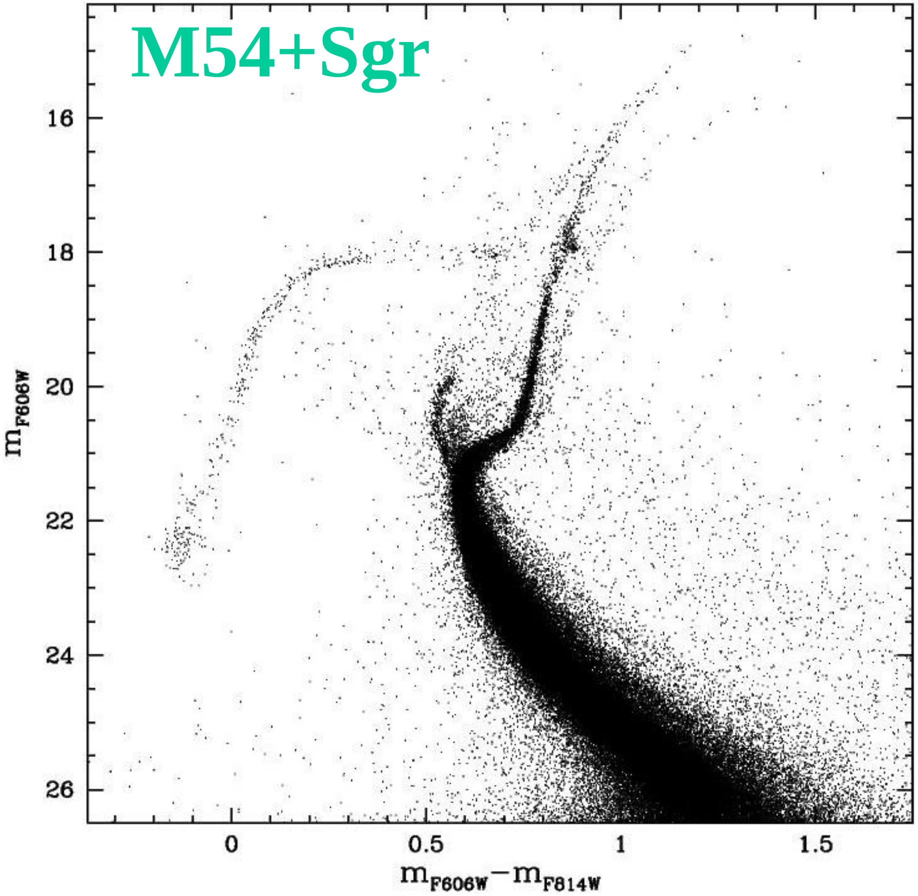
→ Formation of 2nd generation stars from the ejecta of the 1st

→ The system was massive enough to retain SNe ejecta

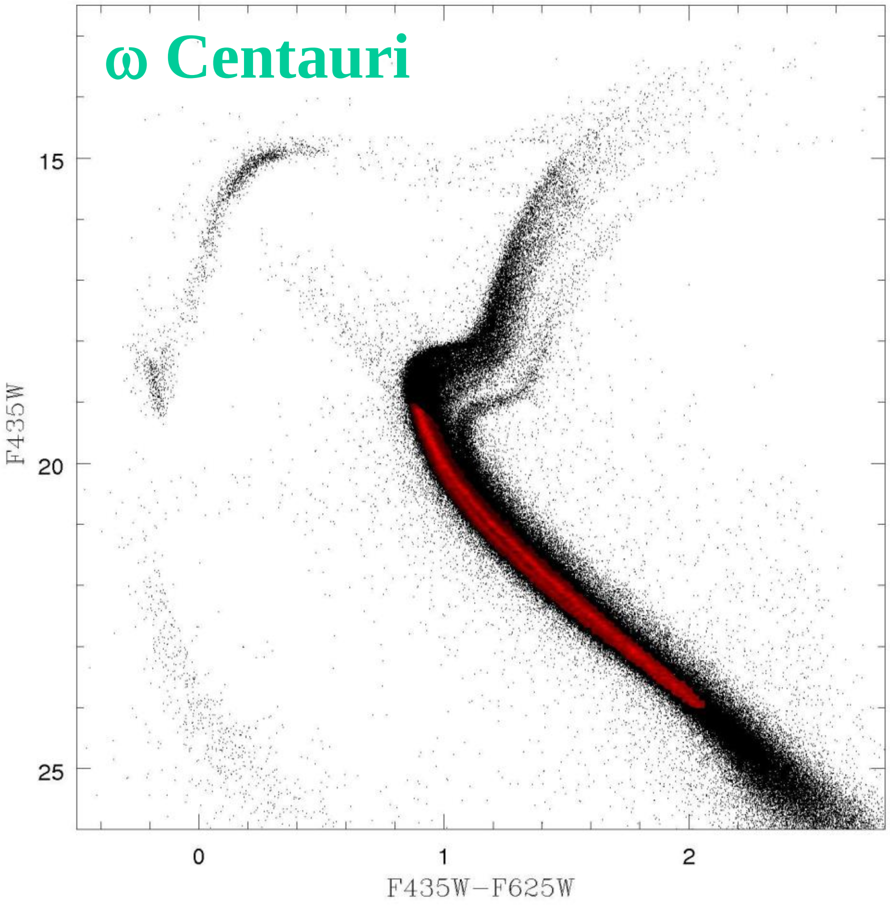
→ Remaining core of a disrupted dwarf galaxy!

Two local building blocks:

CMDs show Extended HB (EHB) & Multiple RGBs

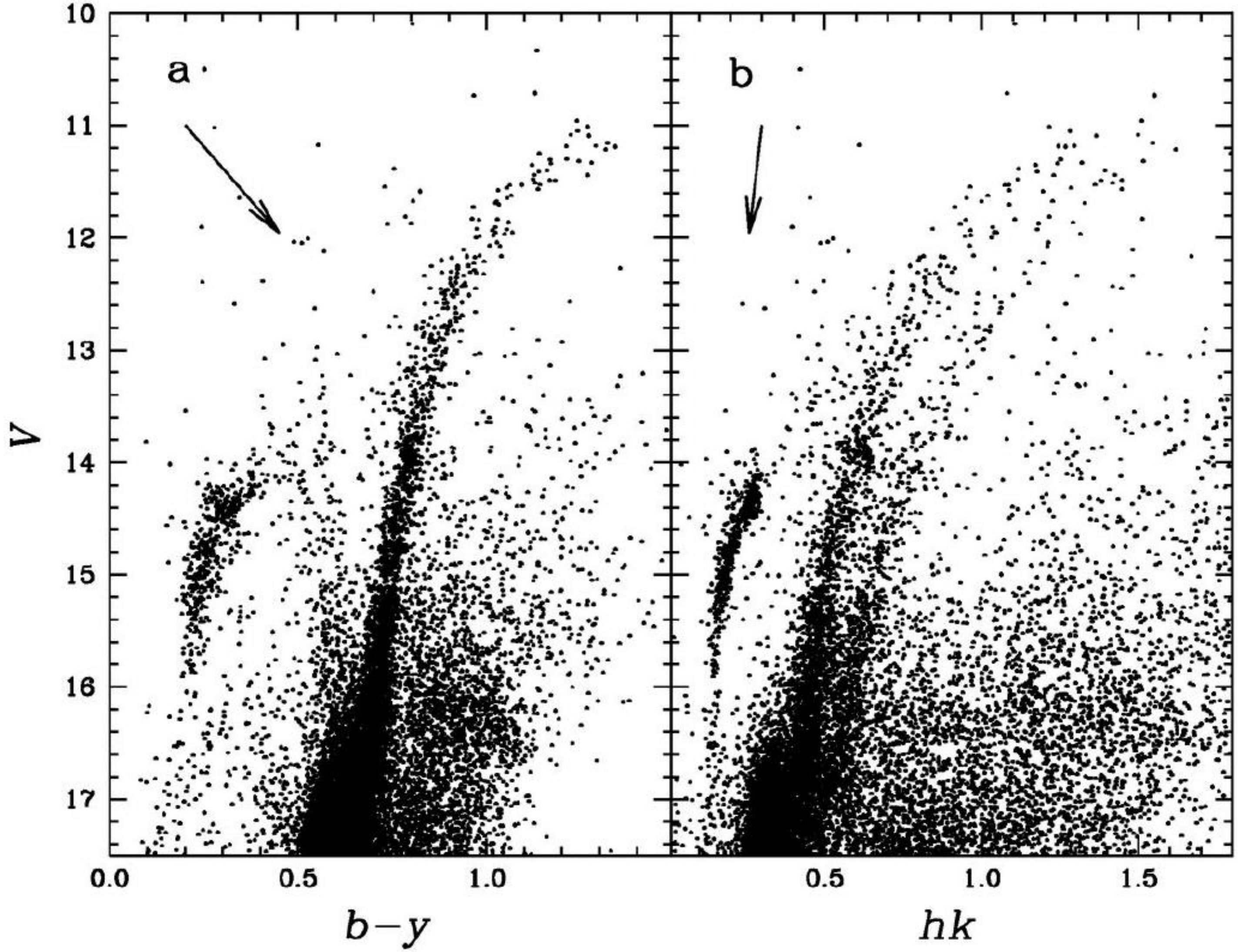


HST/ACS CMDs from Piotto+2008



Discovery of RGB split in M22

Narrow-band *Ca* photometry (J.-W. Lee, Y.-W. Lee+09)



Ca-by photometry

CTIO 1m

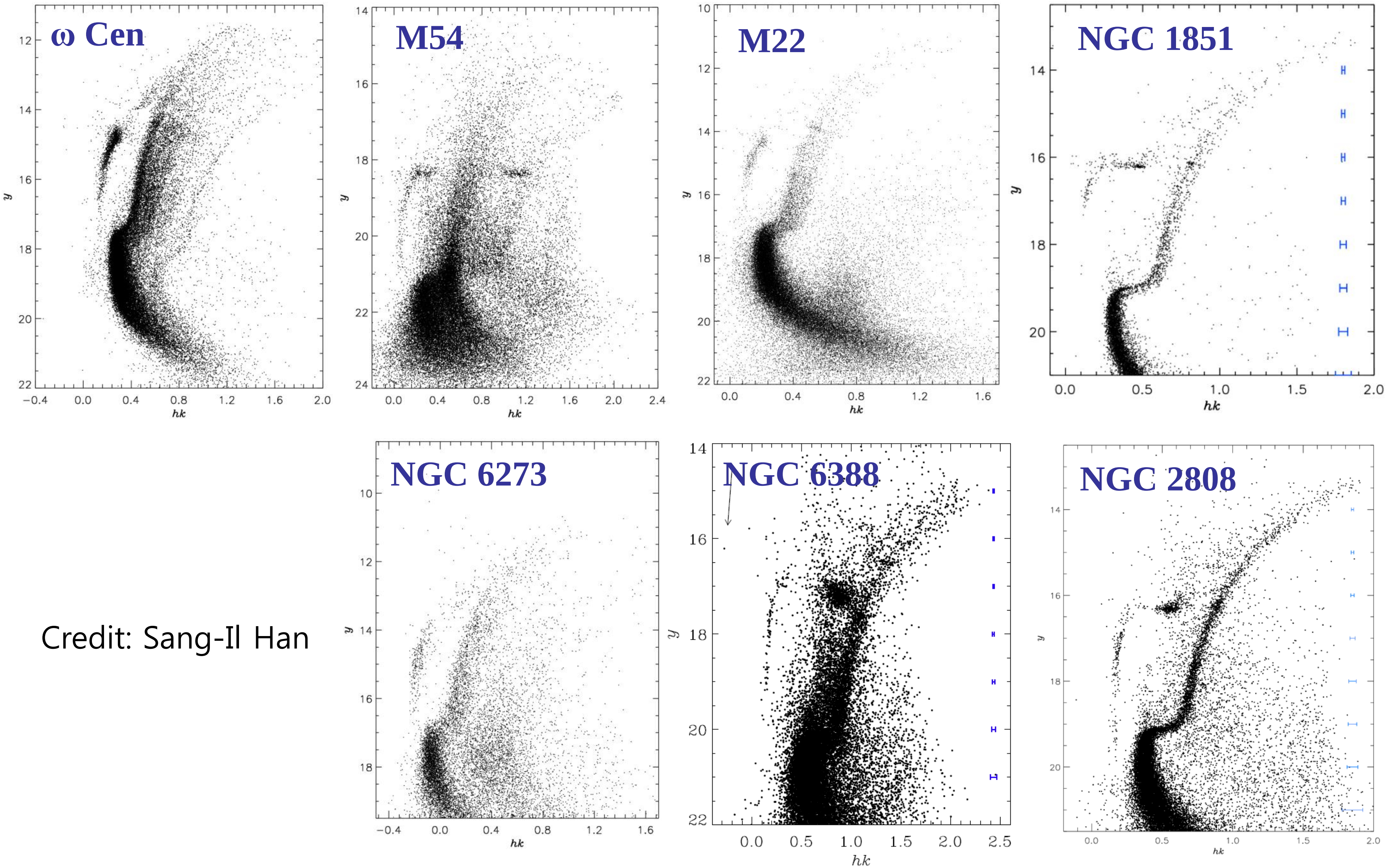
Narrow-band *Ca* & Stromgren *b*, *y* filters

hk = (Ca-b) – (b-y)

"*a measure of Ca abundance*"

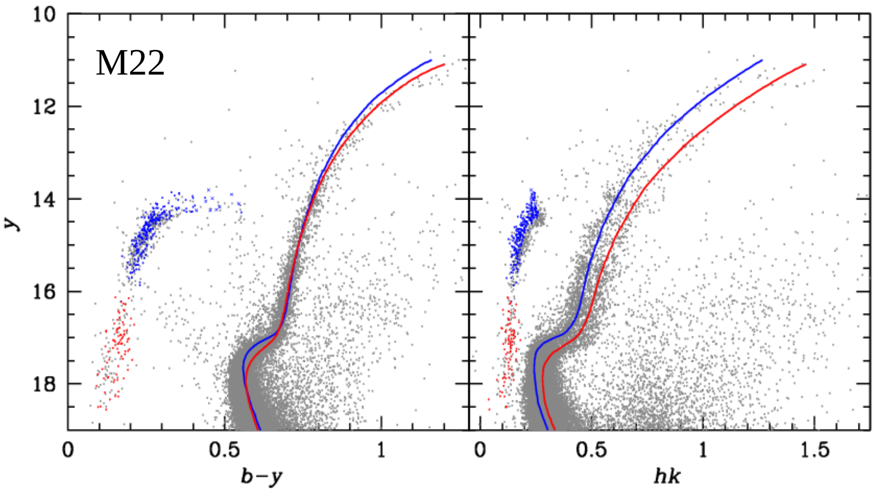
(Anthony-Twarog+91)

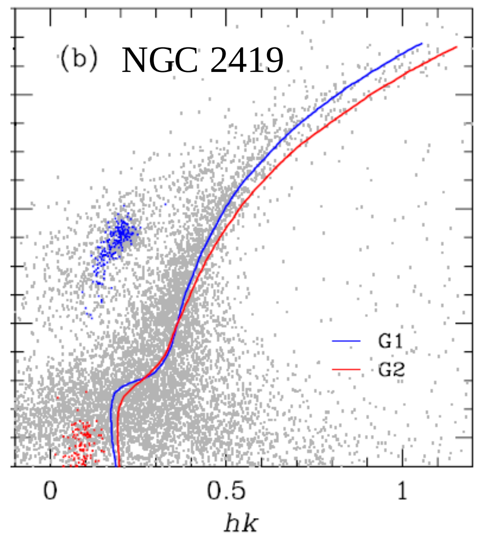
New *Ca-by* photometry: LCO 2.5m + New Ca filter

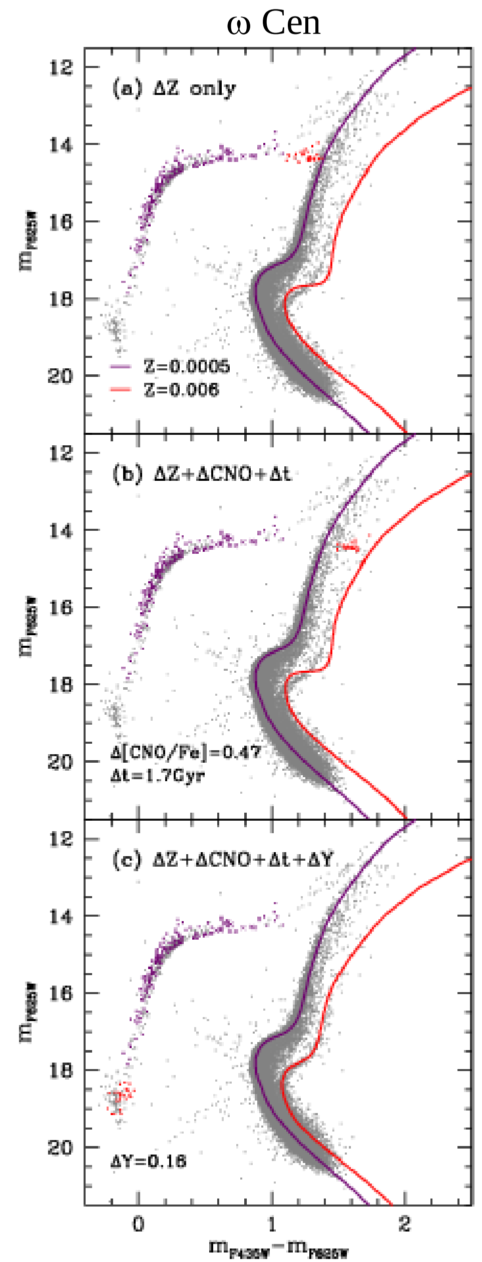


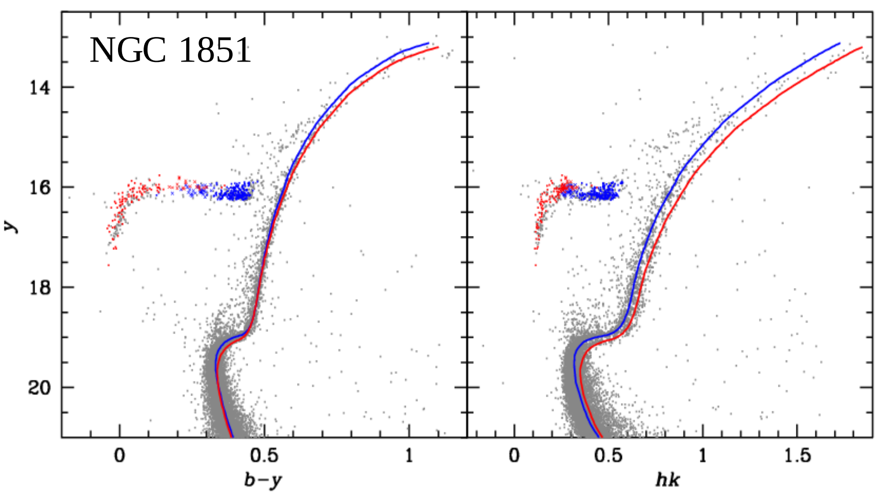
Credit: Sang-Il Han

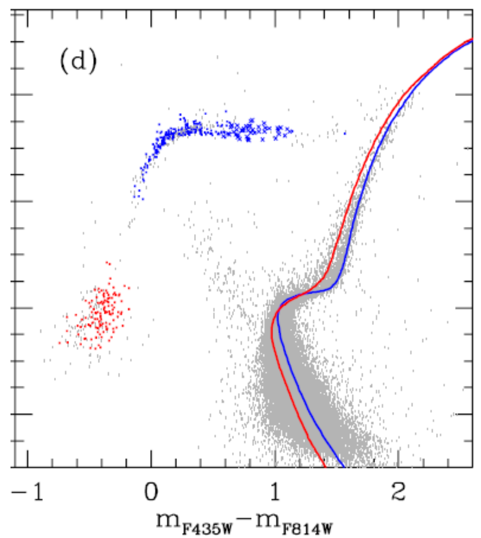
Population Models







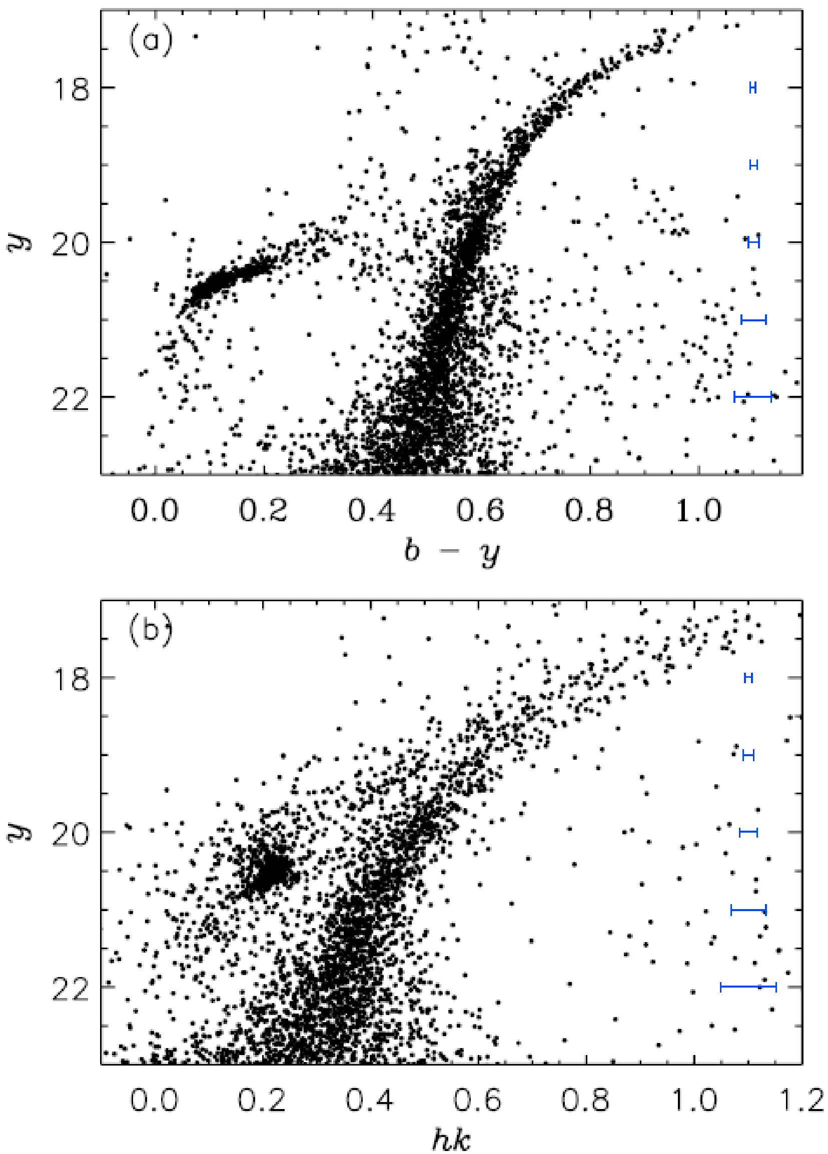




Metal-rich subpopulation is slightly younger (Δt = 0.3 – 2 Gyr) and helium rich (ΔY = 0.06 – 0.18) compared to metal-poor subpopulation (Joo & Lee 2013; Lee et al. 2013)

Subaru Observation for NGC 2419 (Lee, Han, Arimoto+2013)

Astrophysical Journal Letters, 778:L13 (5pp), 2013 November 20



08-Dec-2012
Subaru/Supreme-Cam (seeing ~1.2")

Subaru calcium photometry (in April) for the Local Group dwarf galaxies would help to establish an empirical connection with these GCs!

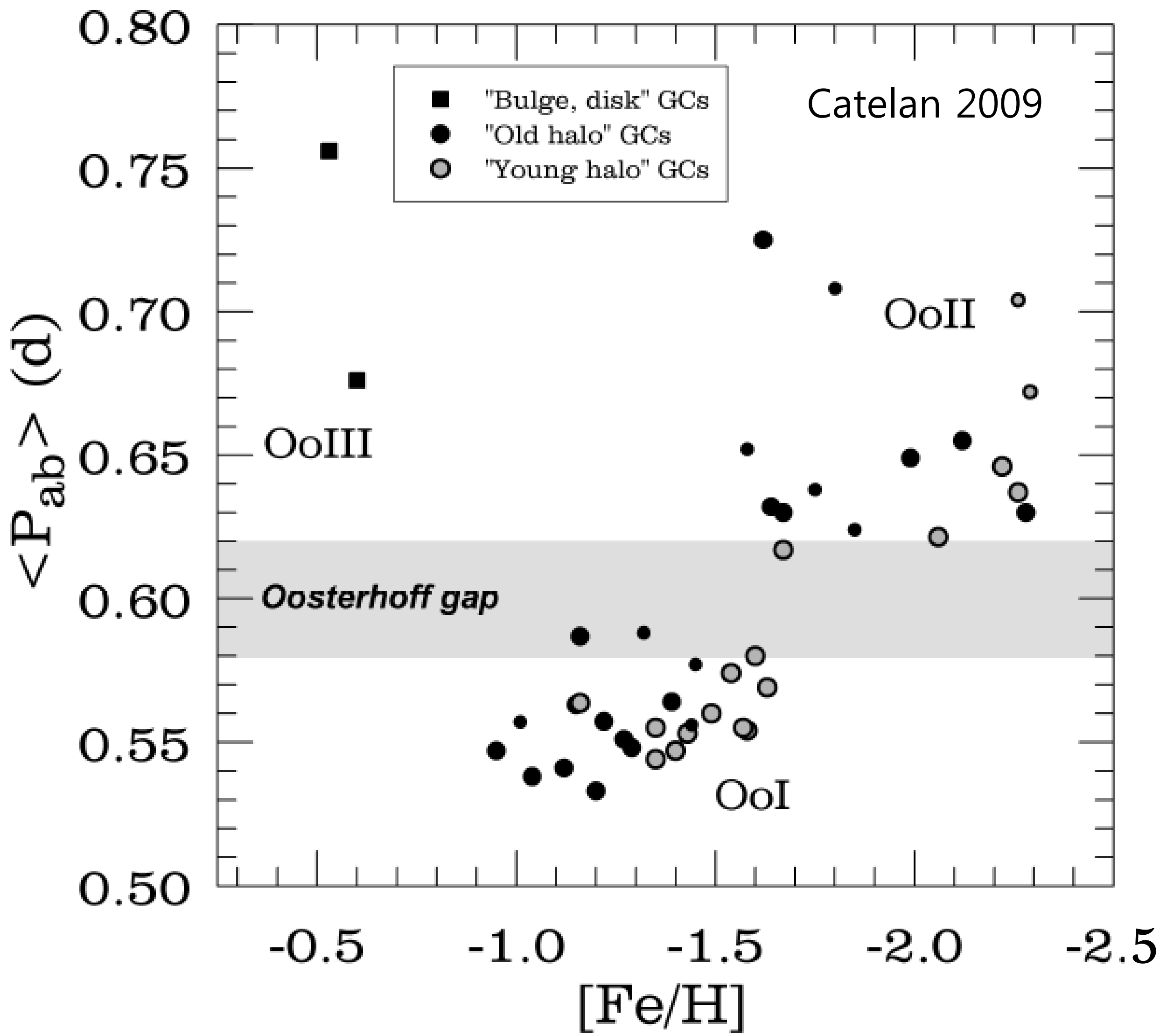
2. Multiple Populations in Globular Clusters & the Origin of the Oosterhoff (1939) Period Groups

One of the long-standing problems in modern astronomy!
(cf. Sandage 1981, Lee, Demarque, & Zinn 1990)

→ "Population shift" within the instability strip!

→ Subaru high-resolution spectroscopy of RR Lyrae and HB stars in GCs (M15 & M3) can test this new model!

Oosterhoff Period Groups among GCs



M15 (Oo II)

Buonanno+1985

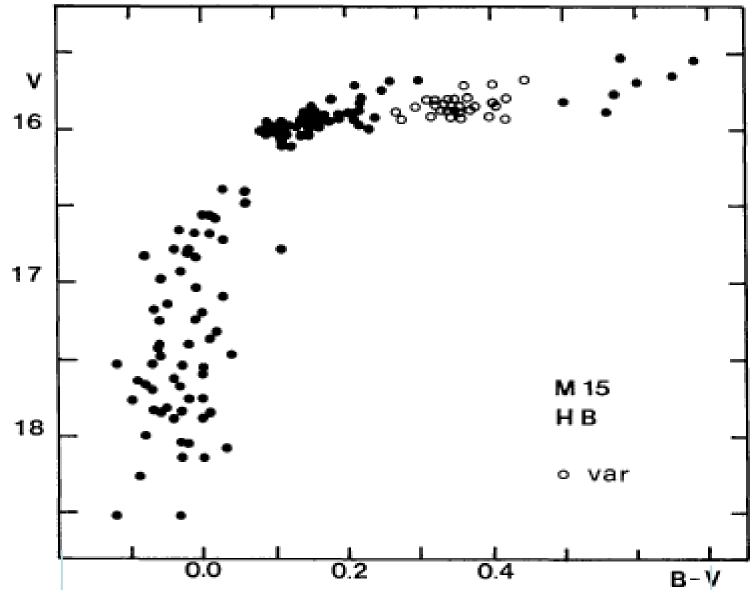


Fig. 9. Color-magnitude diagram of all HB stars in M 15 within the annulus defined by 1.′9 < *r* < 5.′0 using data from Paper III for non-variable stars and from Paper VII for RR Lyraes

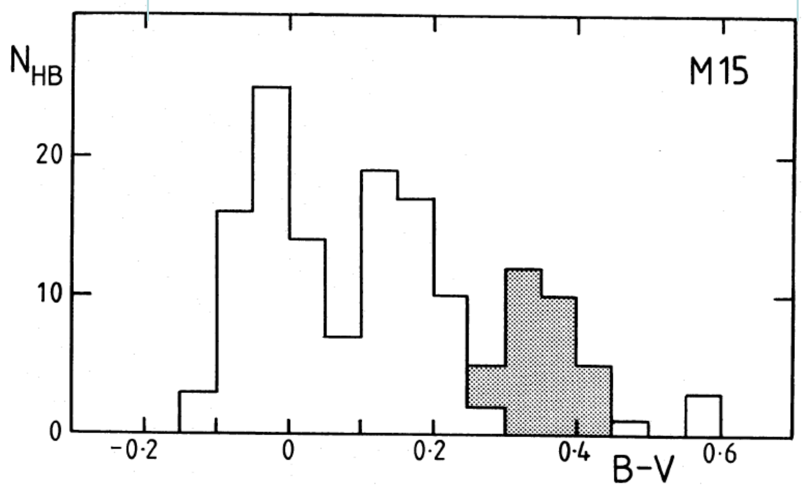
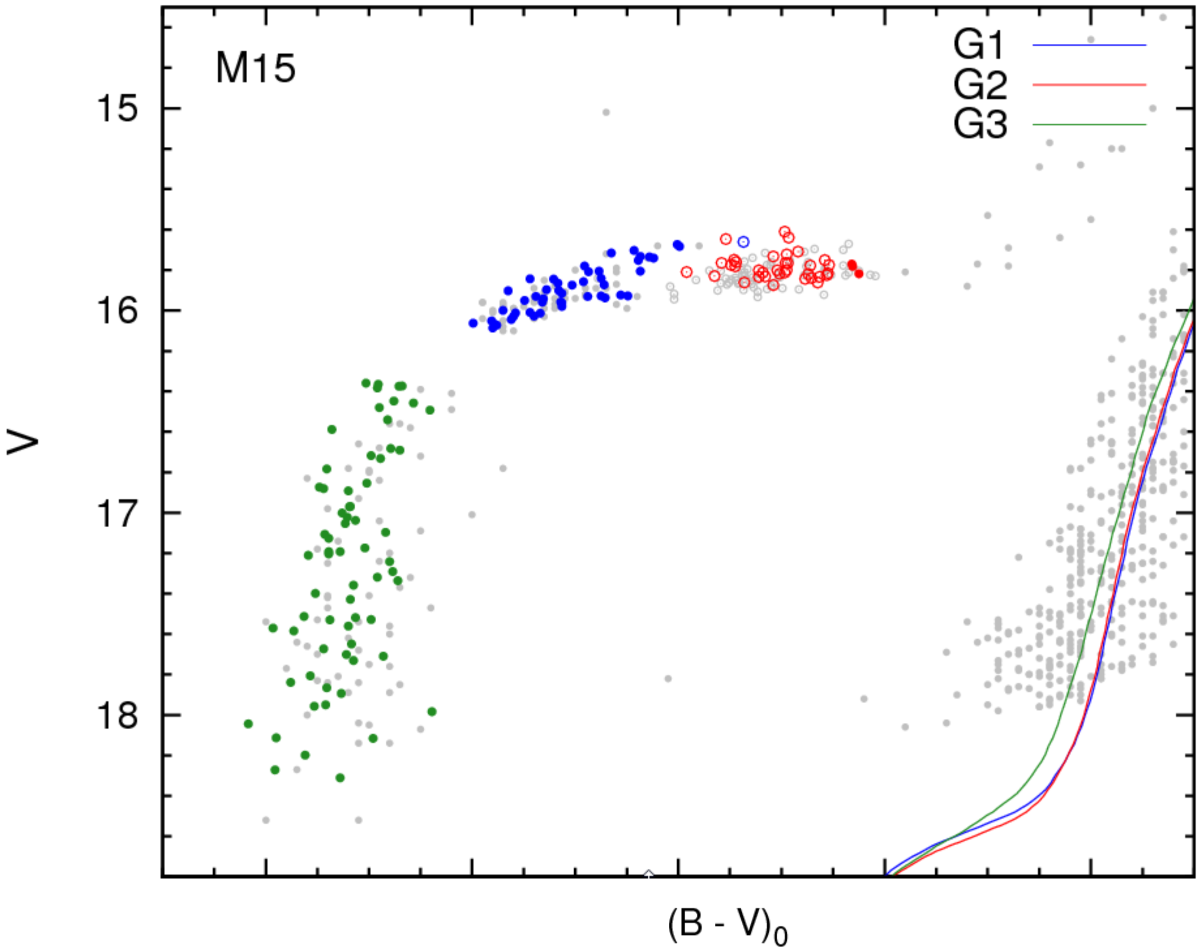


Figure 15. Histogram of the distribution with colour over the whole HB, using data for non-variables from Buonanno *et al.* and the present RR Lyrae photometry, both from the region (1.9 < *r* < 5.0 arcmin) (see Fig. 22). The RR Lyraes are represented by the shaded area. Note the distinctly non-uniform distribution along the HB.



Credit: Sohee Jang

Table 1. Parameters from our best-fit simulation of M15.

Population	[Fe/H][a]	$\Delta Z_{\rm CNO}$	Y	Age (Gyr)	Mass Loss[b] ($M_\odot$)	$\langle M_{\rm HB}\rangle$[c] ($M_\odot$)	Fraction	$\Delta\log P'$[d]	$\Delta\langle P_{\rm ab}\rangle$ (day)
G1	-2.2	0	0.230	12.5	0.140	0.686	0.36	-	-
G2	-2.2	0.00026	0.245 ± 0.01	11.4 ± 0.2	0.142	0.684	0.22	0.040	0.087
G3	-2.2	0	0.327 ± 0.01	11.3 ± 0.2	0.129	0.589	0.42	-	-

Assigning G1, G2, & G3 on the HB of M15

G1: Blue HB ([Fe/H] = -2.2, t = 12.5 Gyr, eta = 0.42)

G2: RR Lyraes (Helium and CNO enhanced, ~ 1 Gyr Younger)

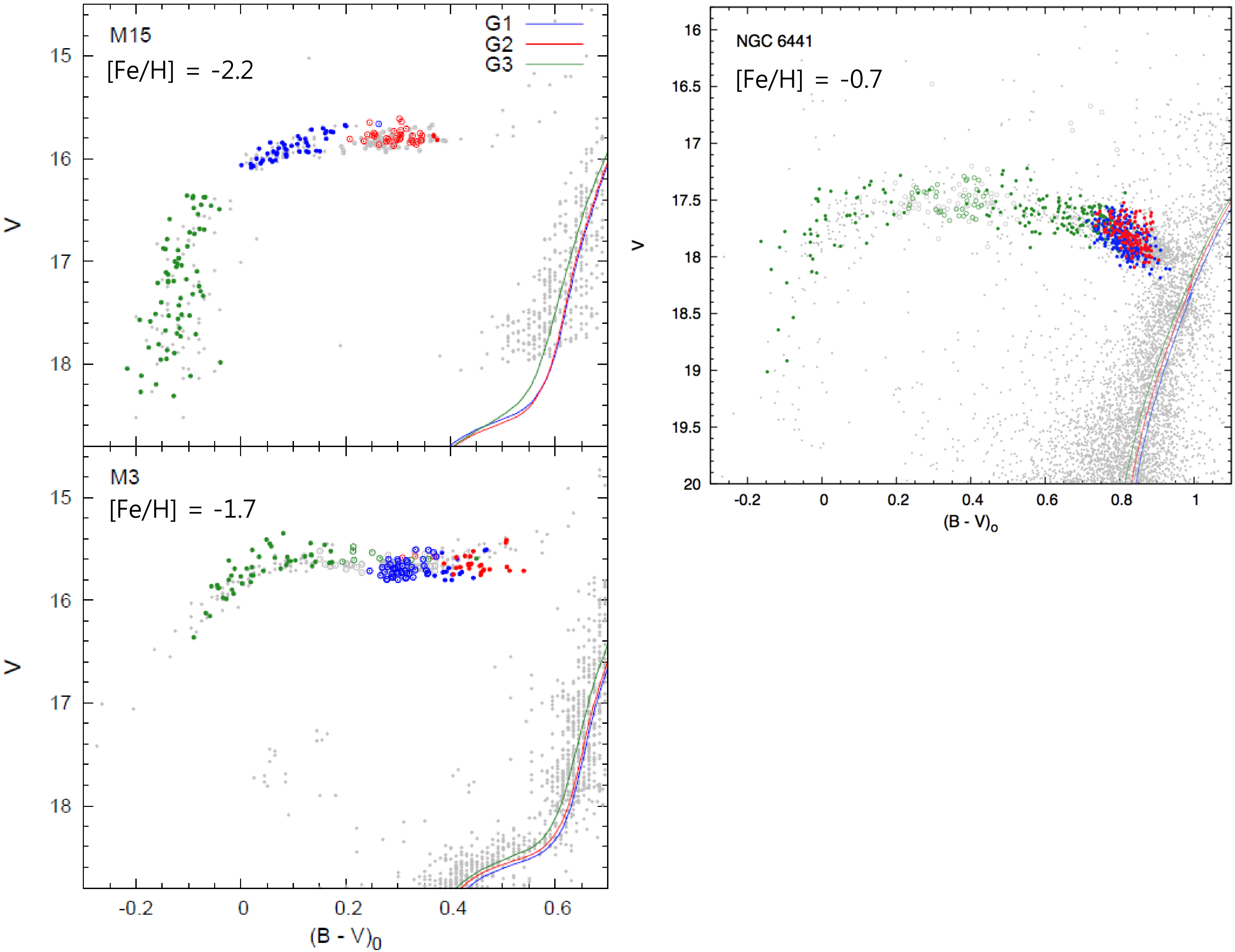
G3: "Blue tail" or Extreme Blue HB (Super-He-rich)

G2 is enhanced in He and CNO?

Theory (AGB): Fenner+2004; Ventura & D'Antona 2009; Karakas 2010; Decressin+2009

Observations: Sneden+1997 (CNO); Cohen et al. 2005 (Δ[N/Fe] ~ 1.6 dex); Alves-Brito+2012 (M22); Marino+2012 (ω Cen)

Both helium and CNO abundances play a role in increasing the period of RR Lyrae variables!


M15
[Fe/H] = -2.2
G1
G2
G3
M3
[Fe/H] = -1.7
NGC 6441
[Fe/H] = -0.7
V
(B - V)0
(B - V)o
15
16
17
18
16
16.5
17
17.5
18
18.5
19
19.5
20
-0.2
0
0.2
0.4
0.6
0.8
1

"Population shift"

within the instability strip

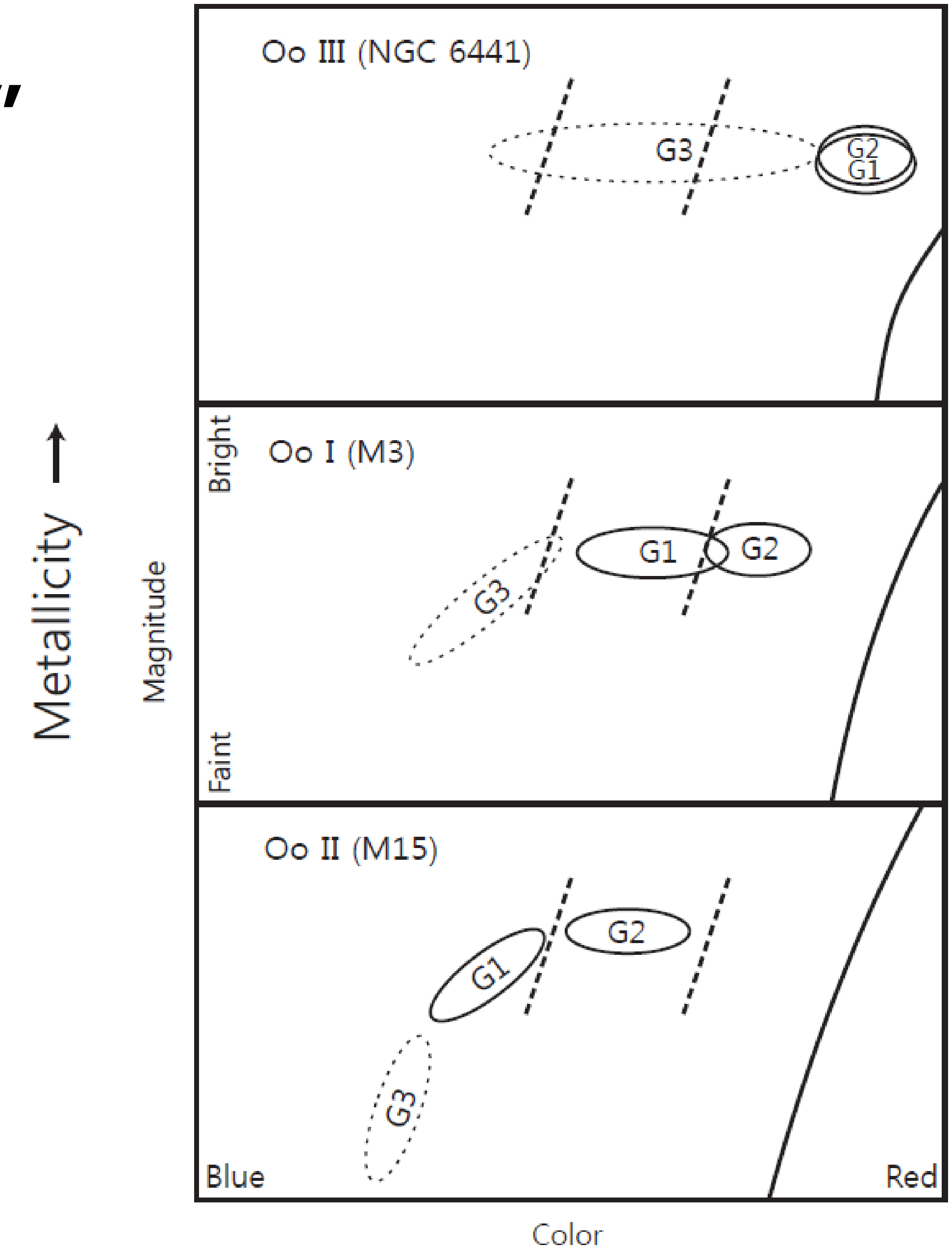
→ P-shift

(For the most general cases,)

RR Lyraes are produced by

G1, G2, & G3, respectively,

for the Oo I, II, & III !



Na – O anti-correlation in "Normal" GCs

G1: Na-poor, O-rich, He-normal
G2: Na-intermediate, O-rich, He-rich
G3: Na-rich, O-poor, Super-He-rich

Subaru high-resolution spectroscopy of RR Lyrae and HB stars in northern GCs (e.g., M15 & M3) can test this new model!

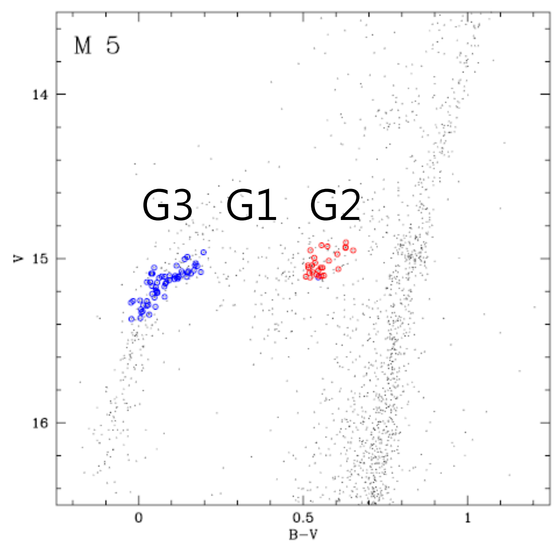


Fig. 3. Colour–magnitude diagram of M 5. Red circles are RHB stars, blue circles are BHB stars. Dots are stars not observed in this paper.

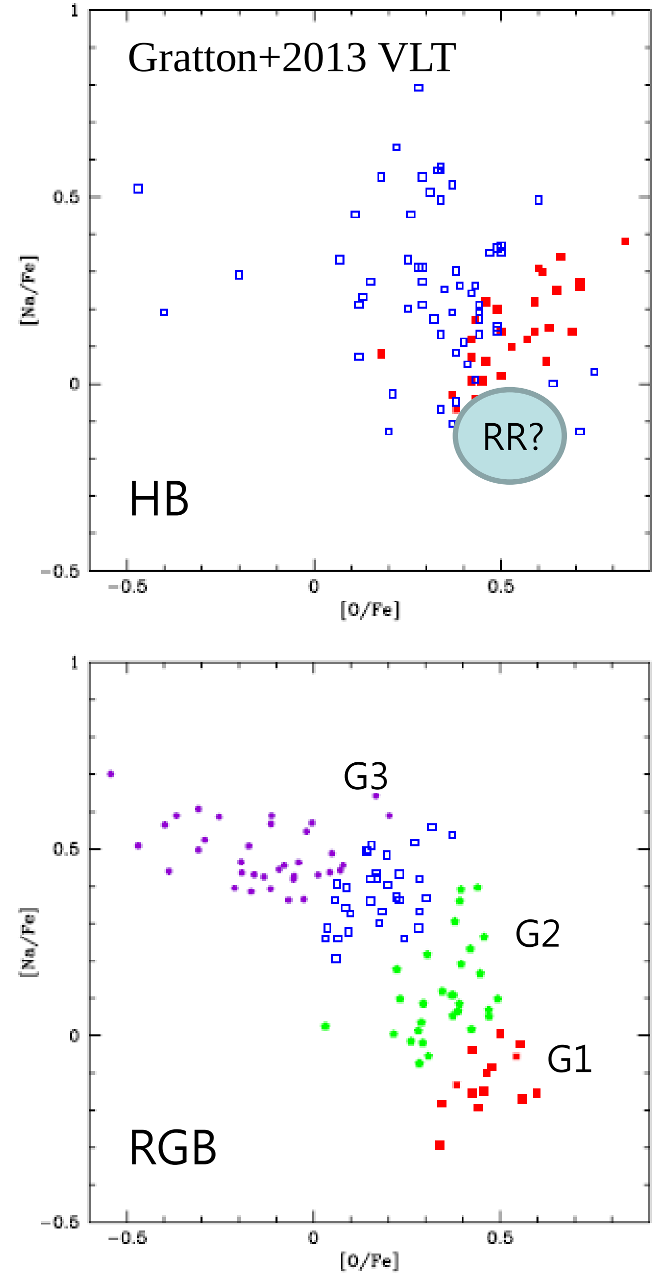


Fig. 9. *Upper panel*: Na-O anticorrelation for HB stars in M 5; filled red squares are RHB stars, blue open squares are BHB stars. *Lower panel*: the same for RGB stars (from Carretta et al. 2009a). In this panel, we plotted with different symbols stars that might be expected to have

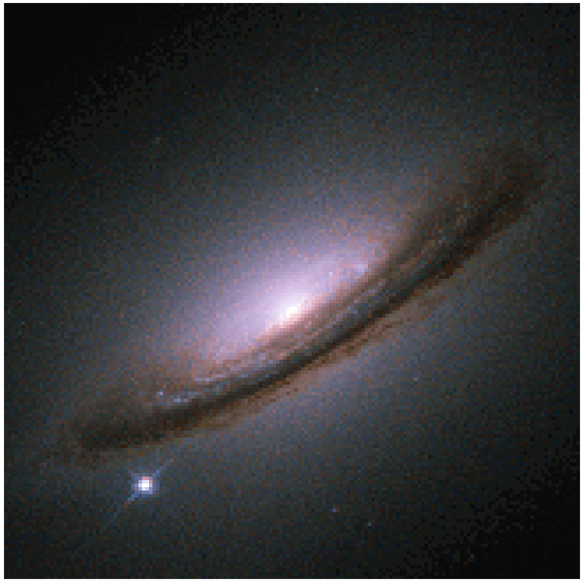
3. Luminosity Evolution of Type Ia SNe ?

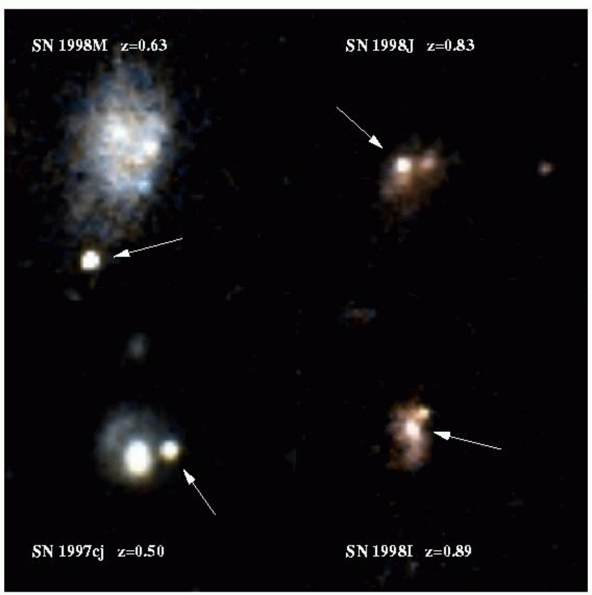
The major systematic uncertainty in “Supernova Cosmology”

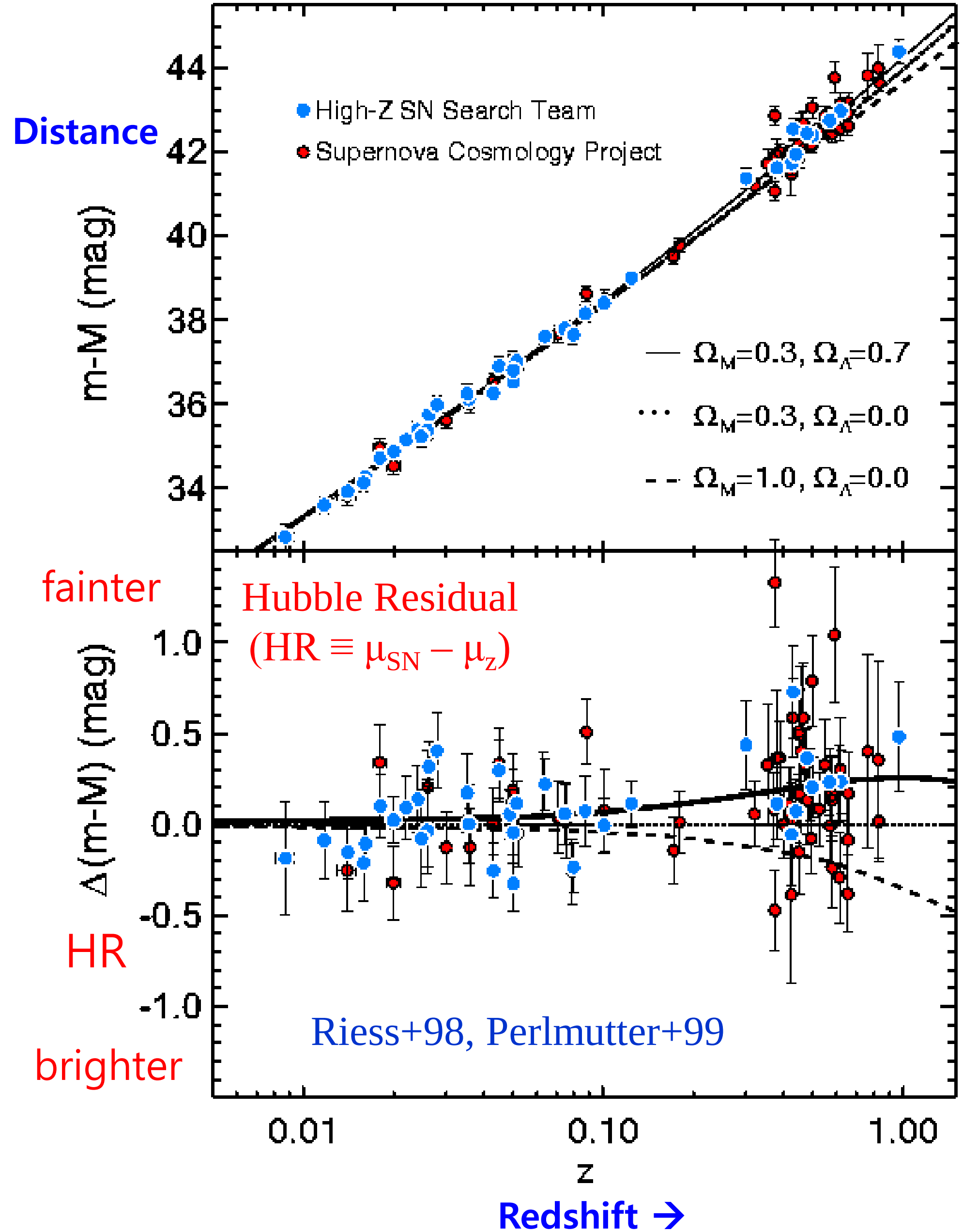
→ SNe in host galaxies at high redshift (younger population age) might be fainter (after LC correction)?!

→ Subaru low-resolution spectroscopy of early-type host galaxies can provide a critical test!

The Discovery of the Dark Energy from Type Ia SNe Distances







What is the evidence that there is no evolution in SNe Ia luminosity?

→ No correlation between SNe luminosity (after LC correction) and host galaxy properties (age related) at local universe (Riess+98; Schmidt+98; Perlmutter+99)

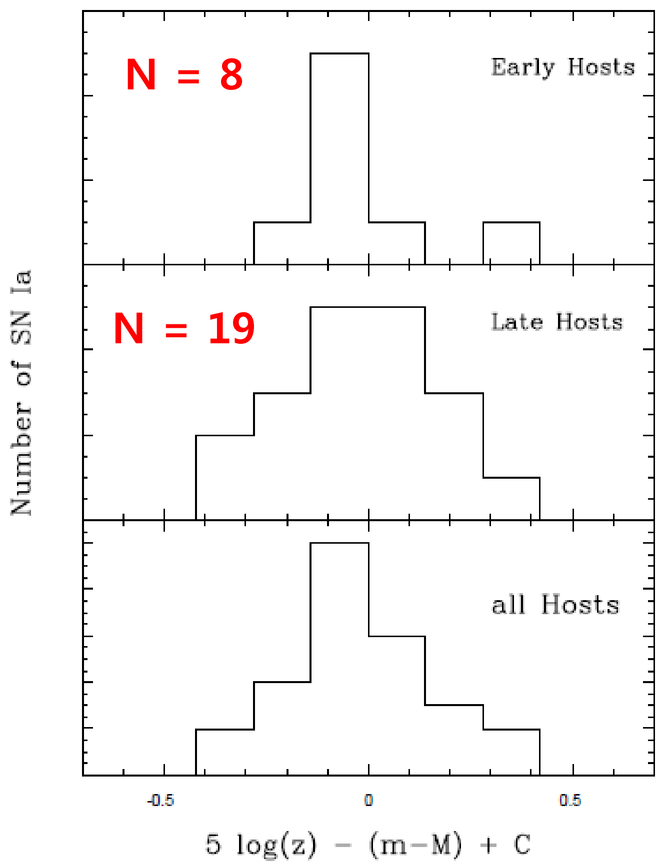


FIG. 3.—Residual of SN Ia distances from RPK96 plotted as a function of galaxy type. The offset between the early-type and late-type galaxies is 0.006 ± 0.07 mag.

Schmidt et al. 1998

ΔHR = 0.006 +/- 0.07 mag. Between Early (old) & Late (young) Hosts

→ No Evolution

But, this was based on small sample!

Recent data from CfA show different result (Hicken+09)

Table 9
Standard Deviation and Weighted Means of Hubble Residuals by Host-Galaxy Morphology

Fitter	Morph	N	StdDev	WMEAN	RelativeWM	σ_{WM}
SALT	E-S0	21	0.170	−0.0641	−0.0712	0.0366
	S0a-Sc	63	0.173	0.0071	0.0	0.0224
	Scd/Sd/Irr	9	0.064	0.0506	0.0435	0.0602
SALT2	E-S0	26	0.208	−0.0686	−0.0490	0.0411
	S0a-Sc	72	0.163	−0.0196	0.0	0.0242
	Scd/Sd/Irr	14	0.108	0.0717	0.0913	0.0560
MLCS31	E-S0	19	0.166	−0.0187	−0.0405	0.0432
	S0a-Sc	59	0.172	0.0218	0.0	0.0234
	Scd/Sd/Irr	9	0.118	0.1367	0.1149	0.0583
MLCS17	E-S0	21	0.186	−0.0521	−0.0537	0.0416
	S0a-Sc	64	0.155	0.0016	0.0	0.0221
	Scd/Sd/Irr	10	0.109	0.1138	0.1122	0.0538
Average	E-S0		0.182		−0.0536	0.0406
	S0a-Sc		0.166		0.0	0.0230
	Scd/Sd/Irr		0.100		0.0905	0.0571
Diff.	Scd-Irr−E-S0				0.1441	0.0701

Notes. For these results, SN Ia with $0.7 < \Delta < 1.2$ and $A_V > 0.5$ have been excluded from MLCS31 and MLCS17. SN Ia

ΔHR = 0.144 +/- 0.07 mag between E/SO & Scd/Sd/Irr !

This is after LC & extinction corrections

Project YONSEI:

Yonsei Nearby Supernovae Evolution Investigation

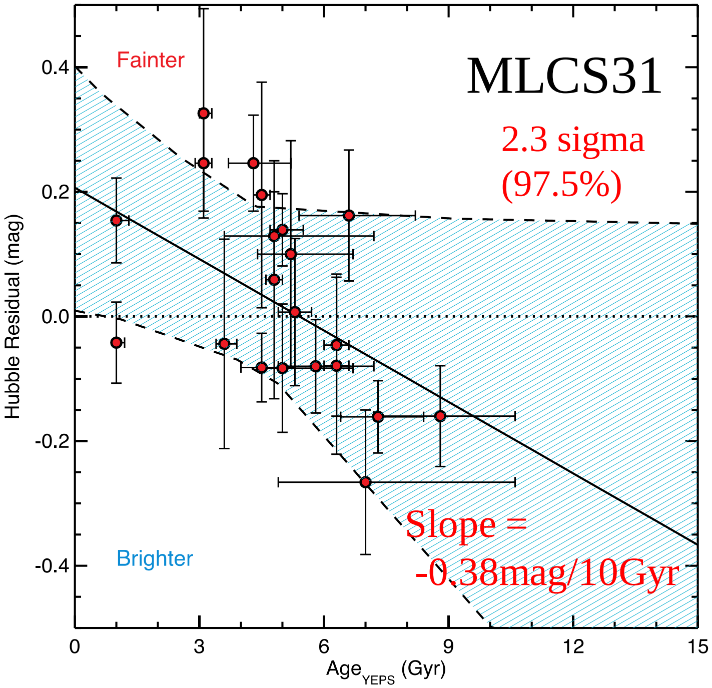
Low-resolution spectroscopy of ~ 60 nearby early-type host galaxies

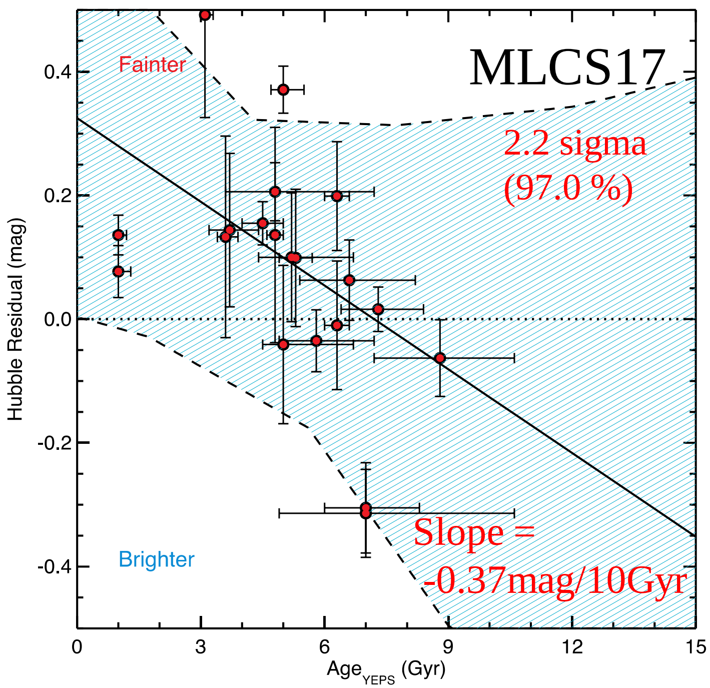
→ du Pont 2.5m, McDonald 2.7m

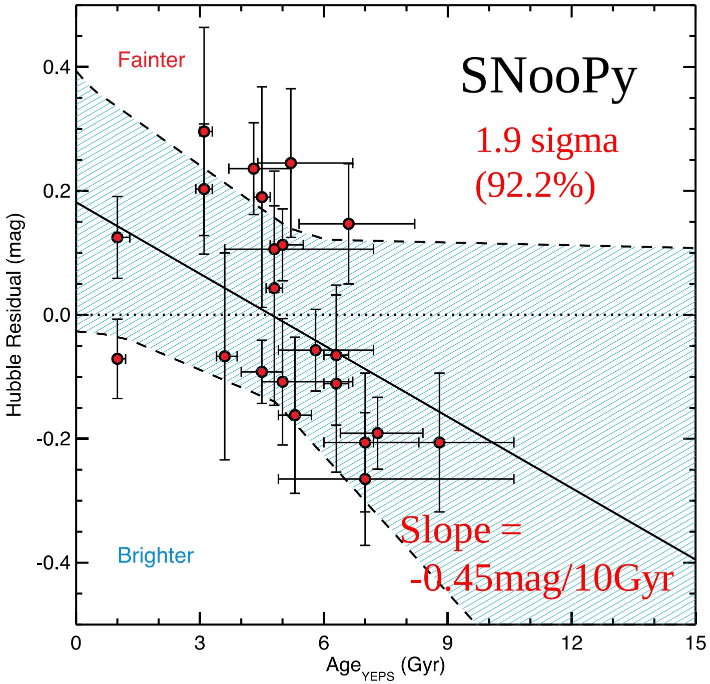
→ Direct age dating and metallicity measurement using Lick indices (e.g., H_β) & population synthesis models

→ ETGs preferred because of age dating & dust extinction

→ SNANA (Kessler+09) is used for the SNe LC analysis





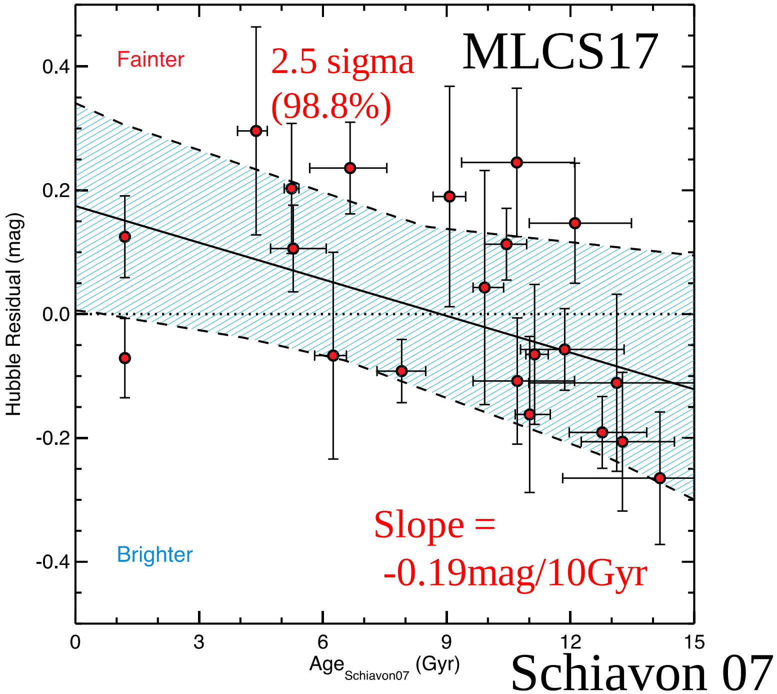


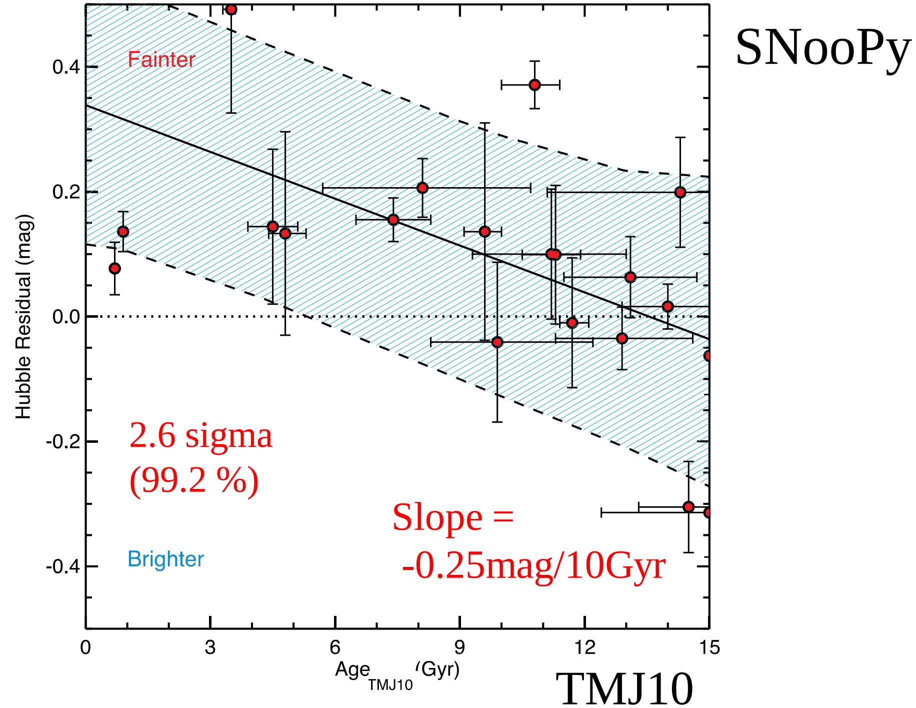
Age vs. Hubble Residual (HR)

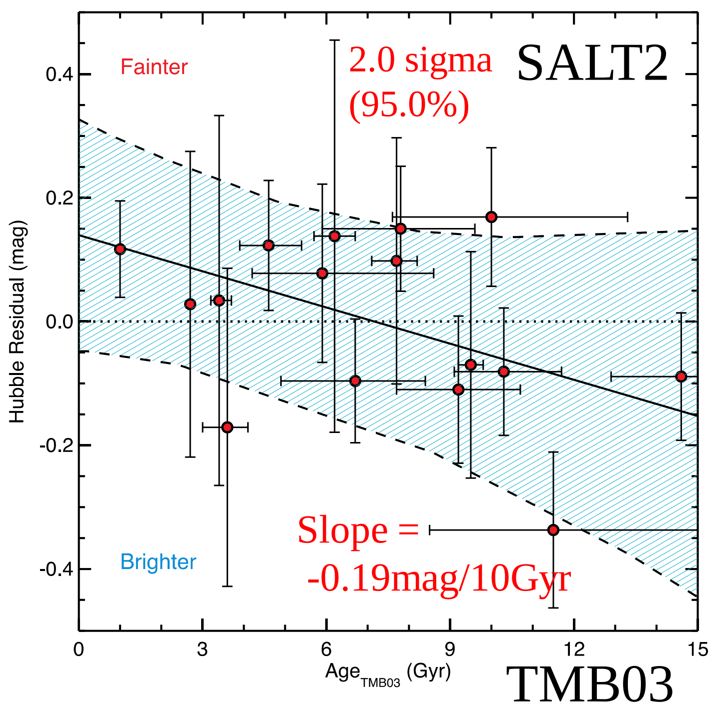
Yonsei Model

MCMC (Markov Chain Monte Carlo) analysis
→Correlations are significant at
1.9 – 2.3 sigma levels!

Credit: Yijung Kang







Age vs. Hubble Residual (HR)

Other models

→Correlations are significant at
2.0 – 2.6 sigma levels!

Our results are insensitive to the choices of pop model, light-curve fitter, & A/N used in the emission line correction!!

Evidence for the luminosity evolution appears to be significant at ~2 sigma level !

Taken at face value, this effect can mimic a large fraction of the Hubble Residual used in the discovery of the dark energy!

8m class observations are required to confirm this preliminary result…especially for northern targets!

(to increase sample size with high S/N, to include high z sample…)

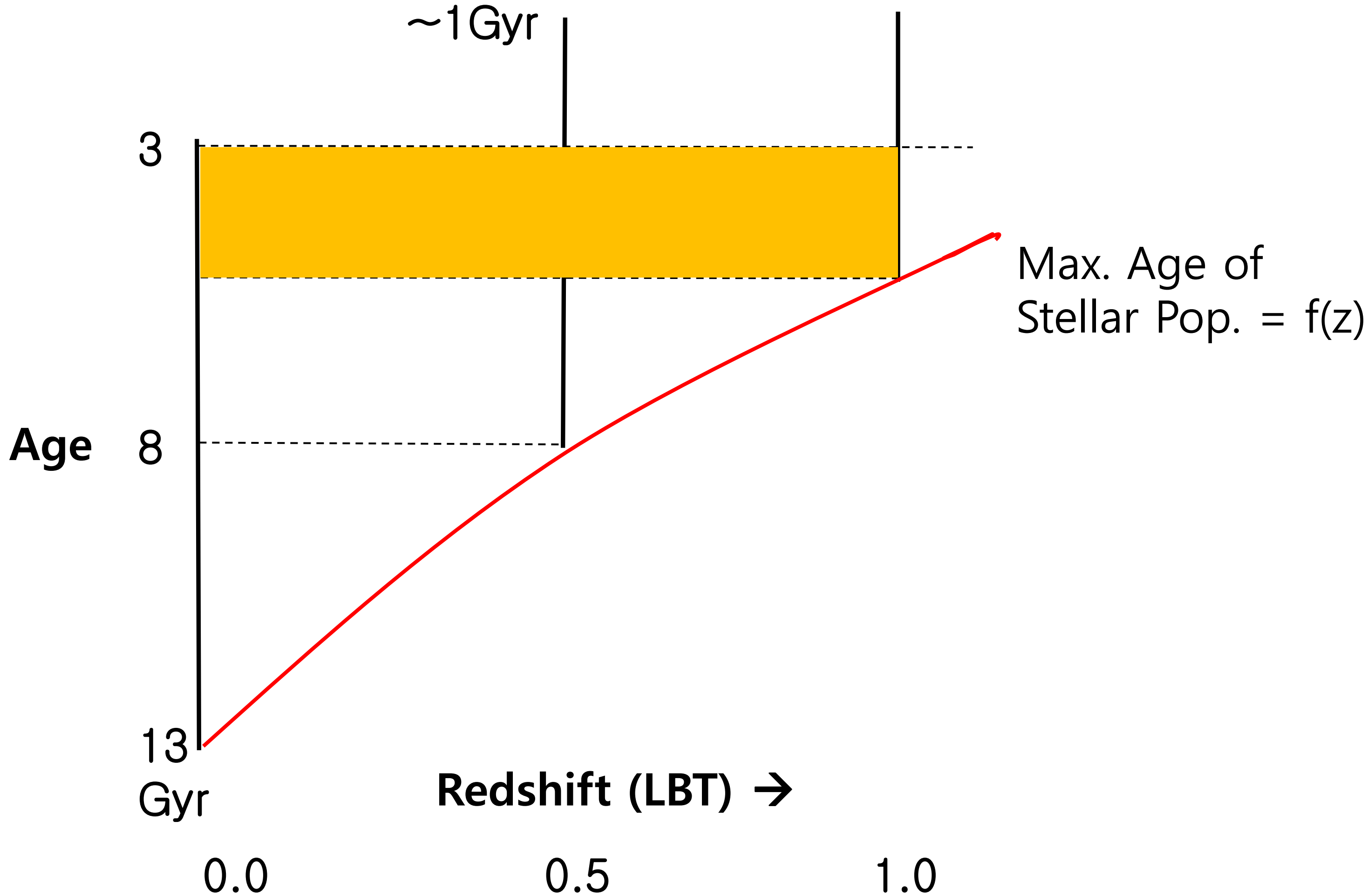
Evolution-Free & Dust-Free Dark Energy Test

Low resolution spectroscopy of early-type host galaxies at high redshift → Ages & Metallicities

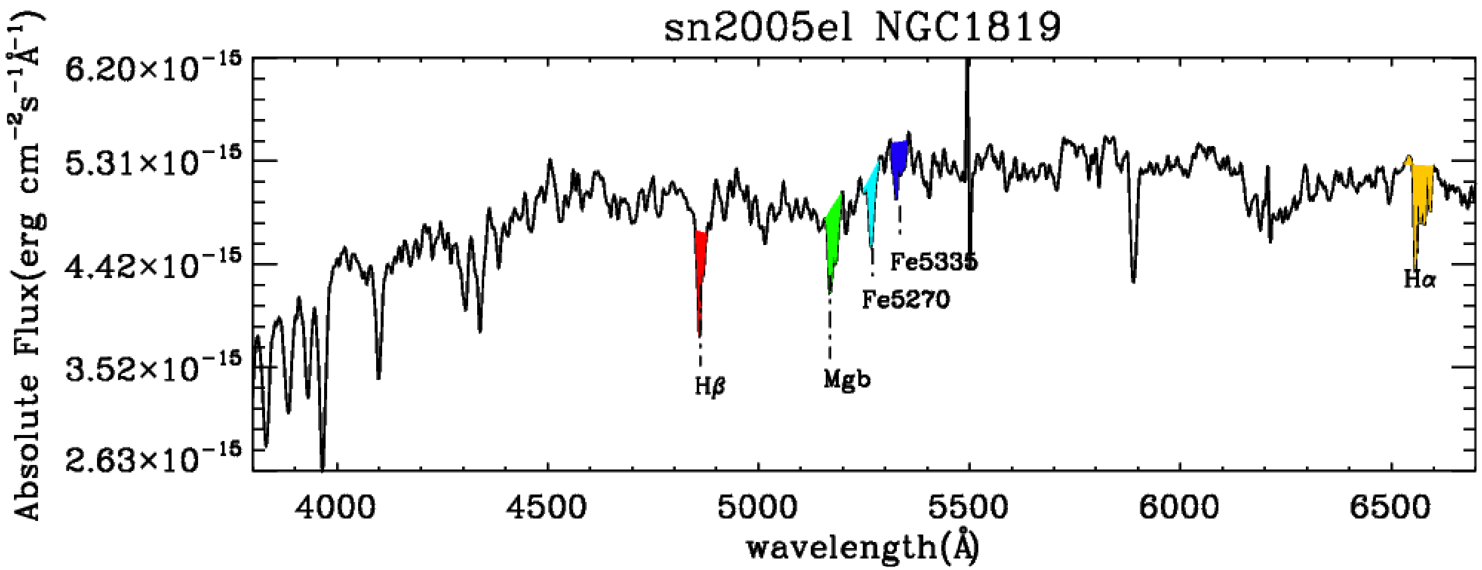
2m: nearby
8m: z ~ 0.2 – 0.4
25m: z ~ 0.4 – 1.0

Plot Hubble diagram with hosts having ~same age
→ No worries about evolution and dust (ETGs)!

To confirm that Dark Energy is not a Delusion!
To investigate the nature of the Dark Energy!



In order to compare at fixed population age, relatively younger hosts in local universe should be compared with relatively older hosts in high-z.



We need **4500 – 7000 Å** wavelength range **at rest-frame** to obtain Lick indices.

→ the wavelength range moves to **6300 – 9800 Å at z = 0.4**.