Stars are direct tracers of the early universe

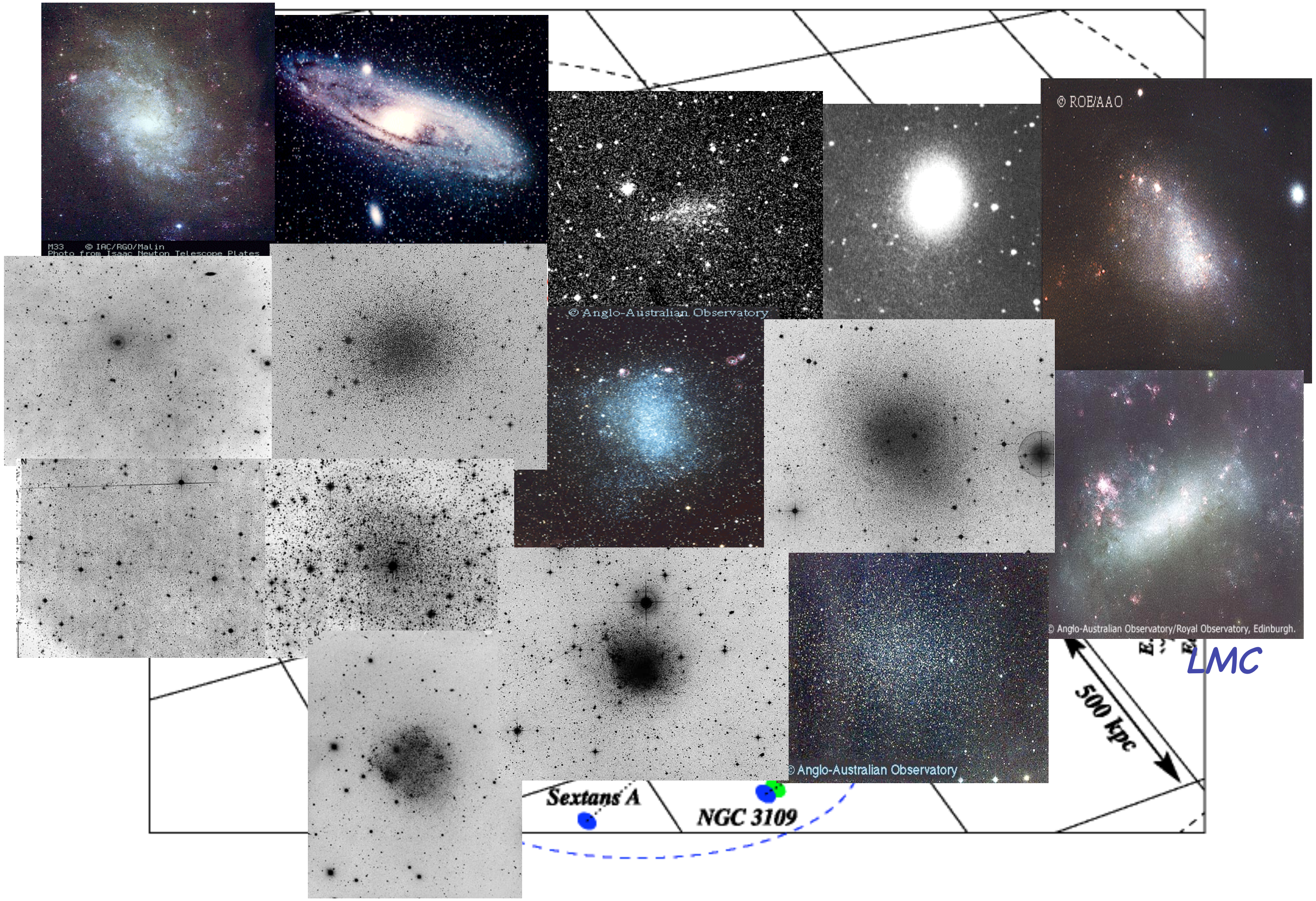
Stars, retain a sample of the interstellar medium out of which they were formed. Since there are stars who live (or will live) longer than the universe this is a very handy tracer of conditions under which stars formed from the earliest times to the present.

Star formation should also indicate the major episodes in the galaxy building process: from the formation to major mergers.

Resolving Stars beyond the Local Group

The Local Group consists of 2-3 spiral galaxies (MW, M31, M33) and a very large number of dwarf galaxies with a range of properties. To sample a larger range of galaxy type and environment we have to go some distance beyond the Local Group. Preferably to Virgo, where there is a large range of giant galaxy types and especially Elliptical galaxies.

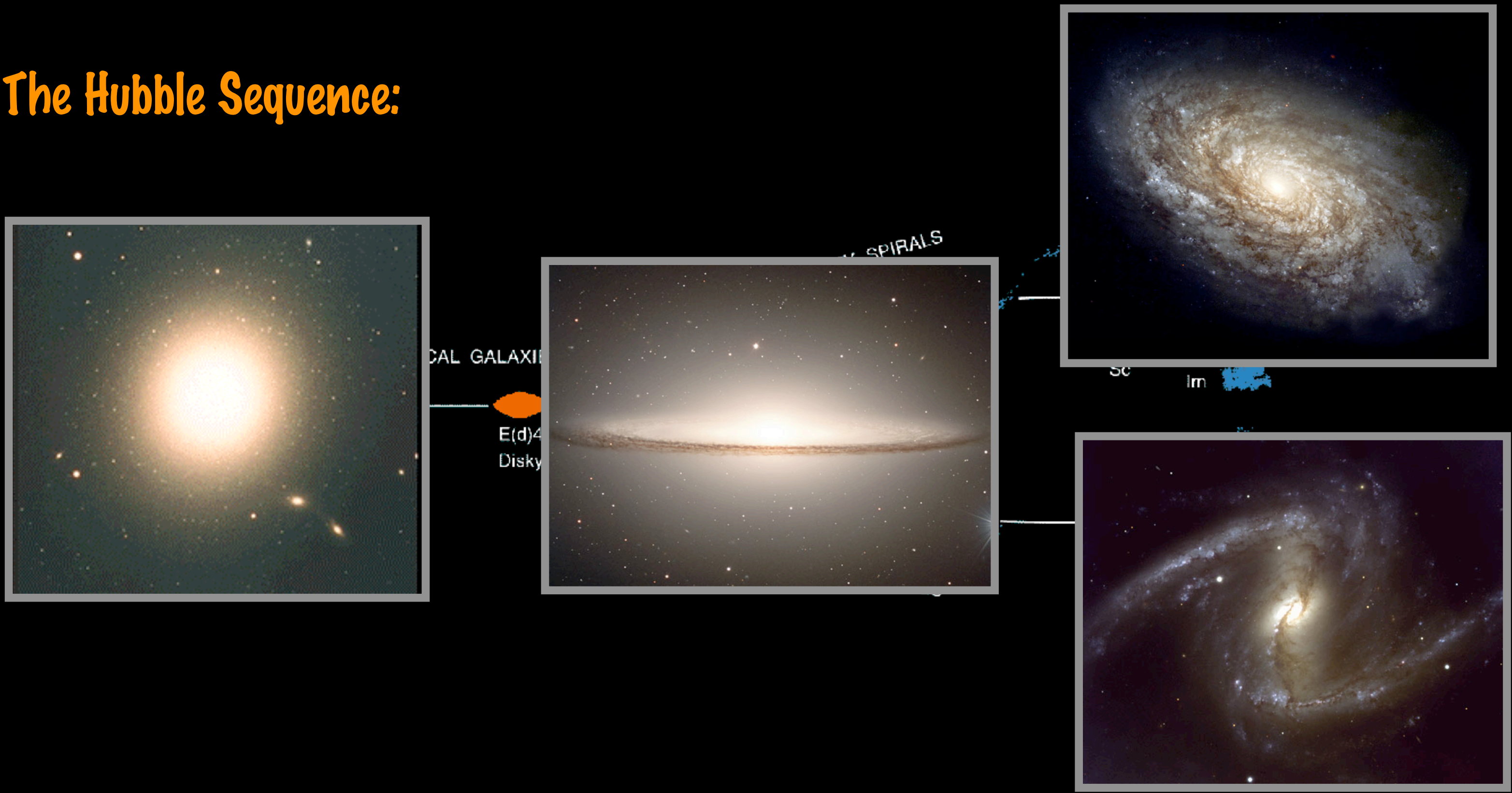
The Local Group



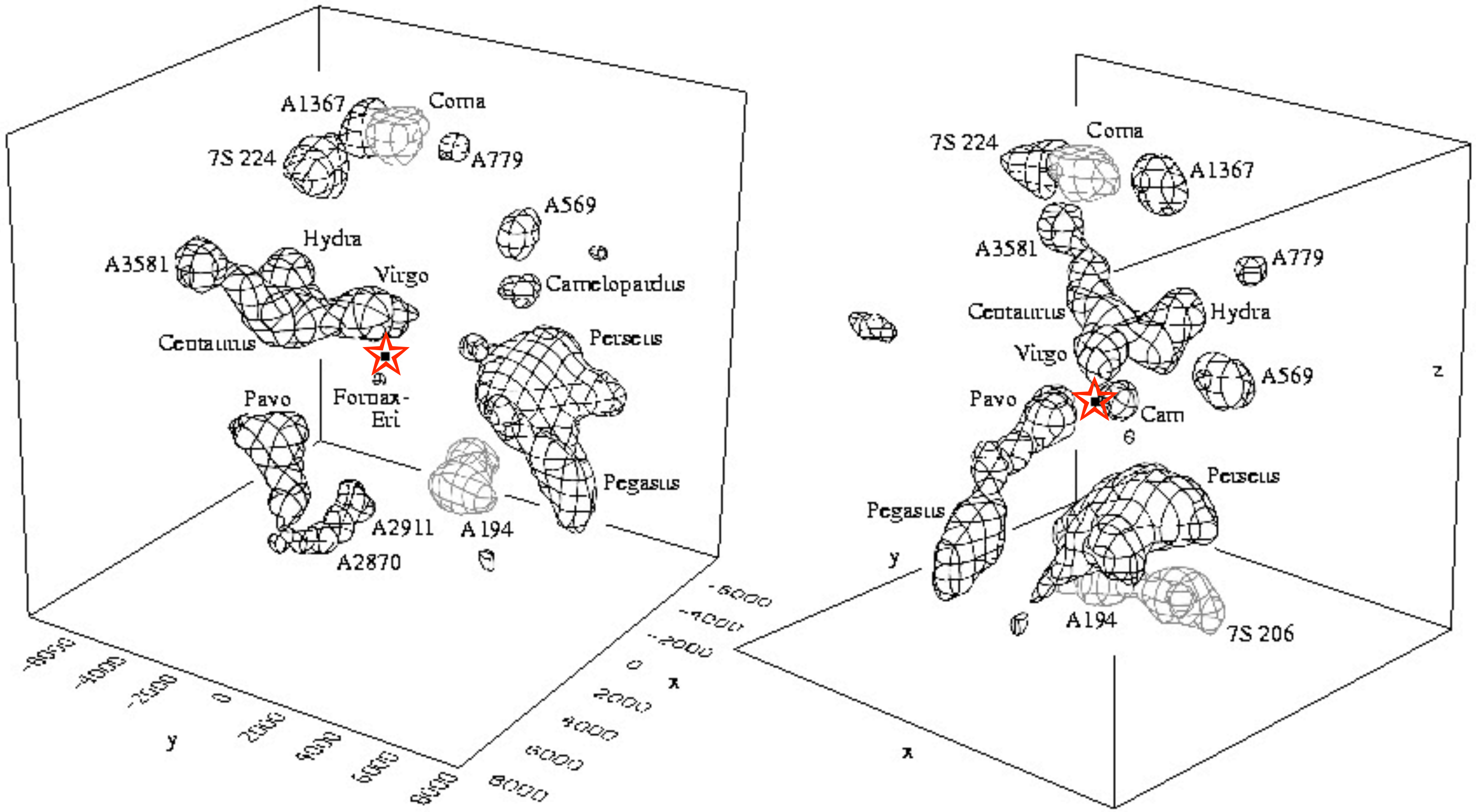
Galaxy Evolution

To understand the formation of the various types of galaxies have to investigate the properties of their stellar components.

The Hubble Sequence:

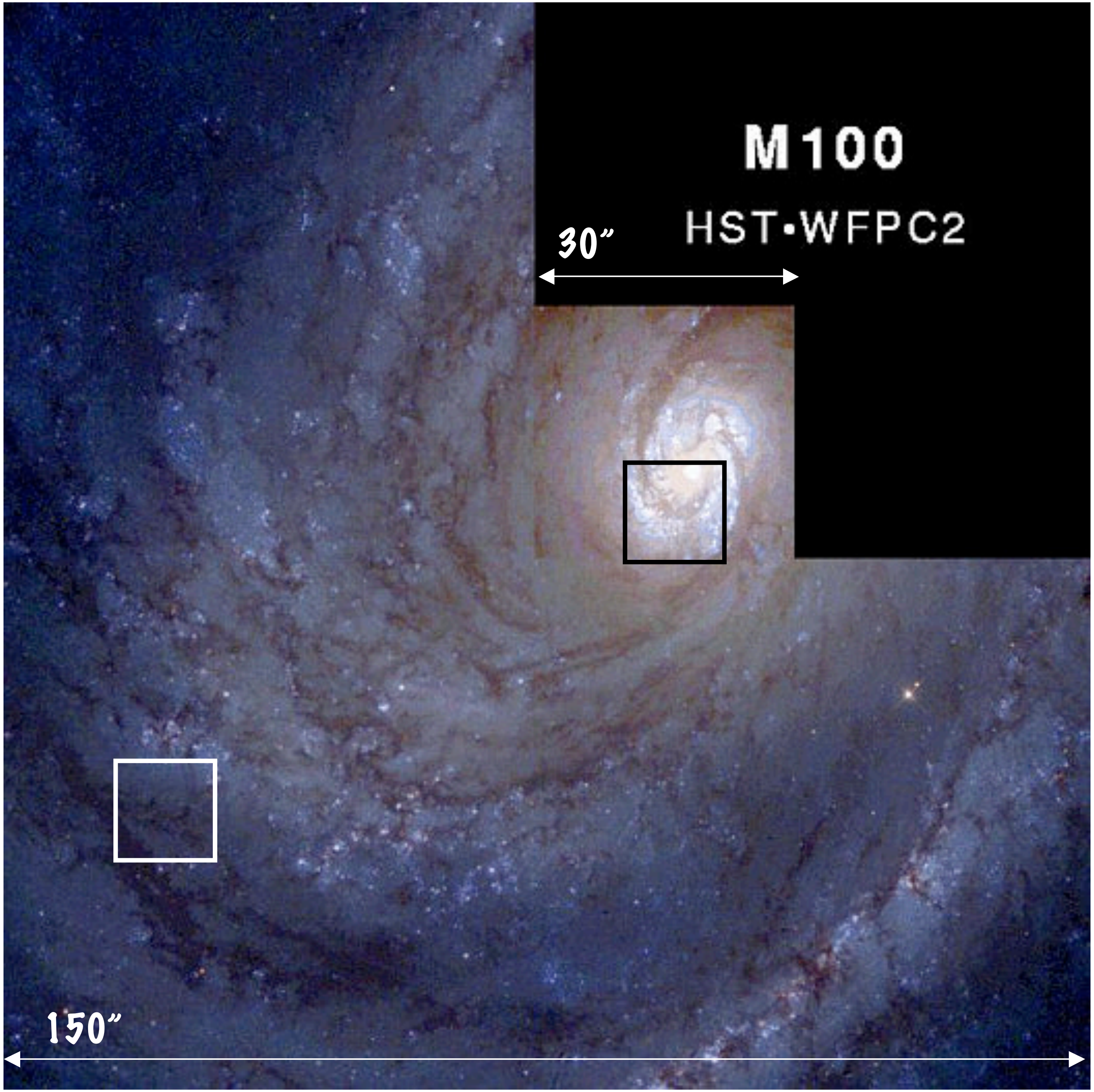


Local Universe

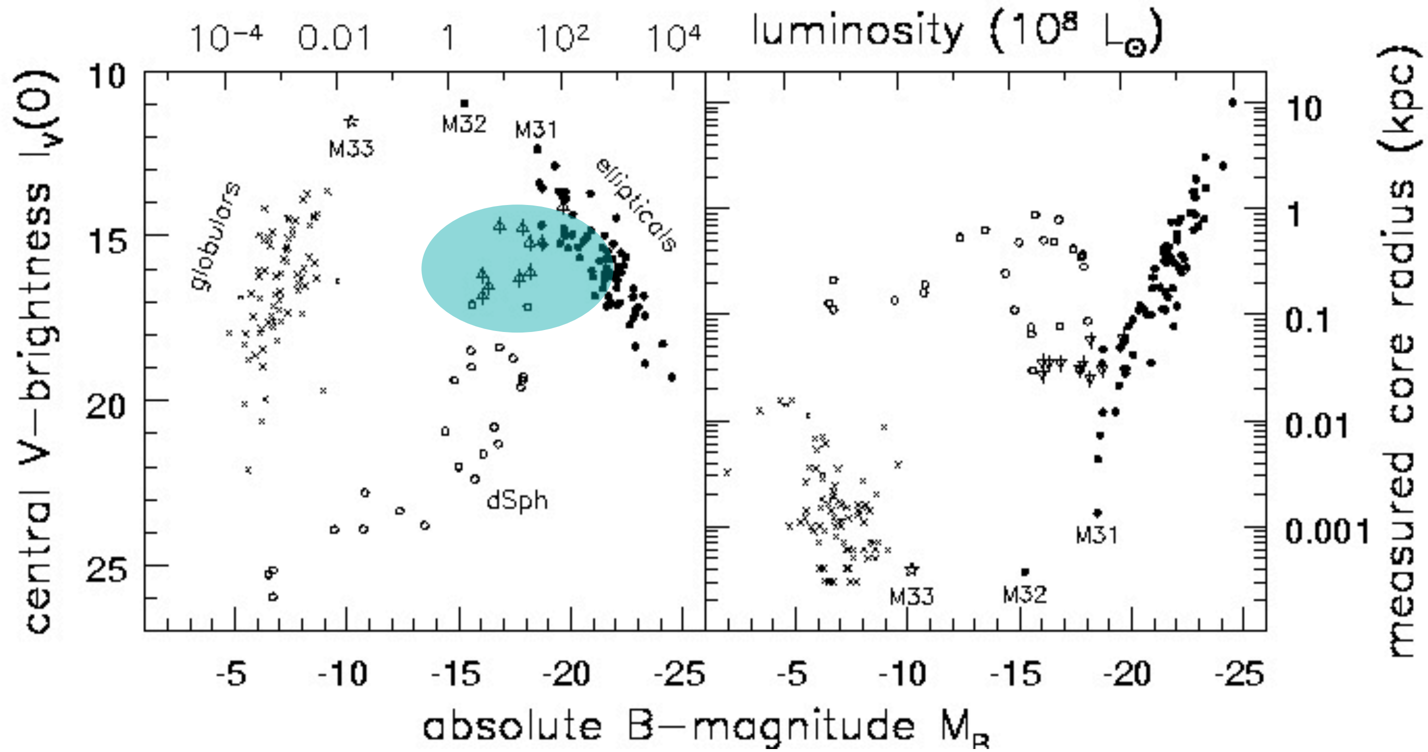


Hudson 1993 via Sparke & Gallagher

Virgo Spiral



Global Properties



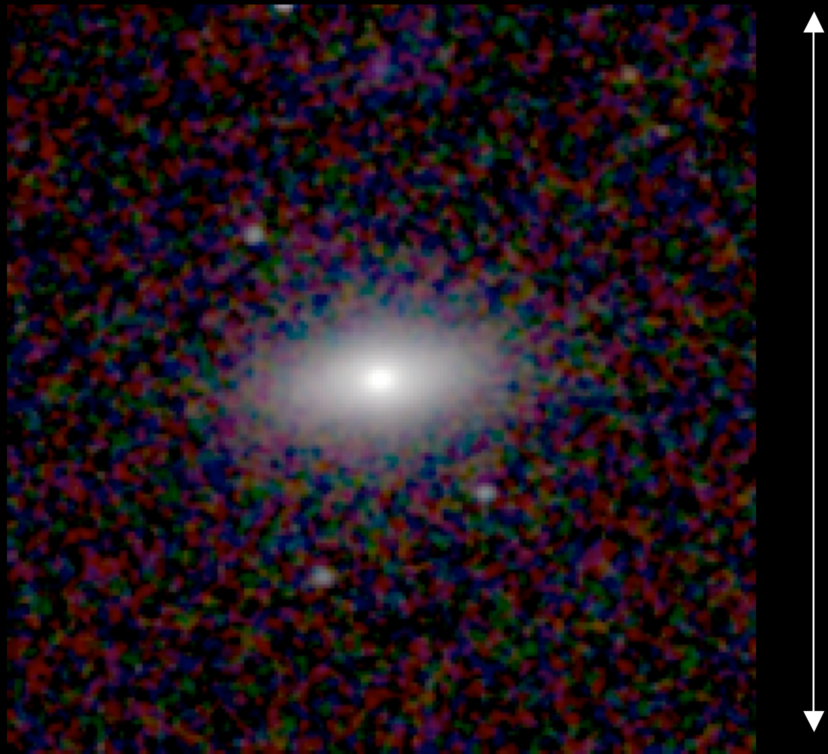
Kormendy via Sparke & Gallagher

M59

5′

I_0 =15.8 mag arcsec^2
R_e = 39″

NGC4660

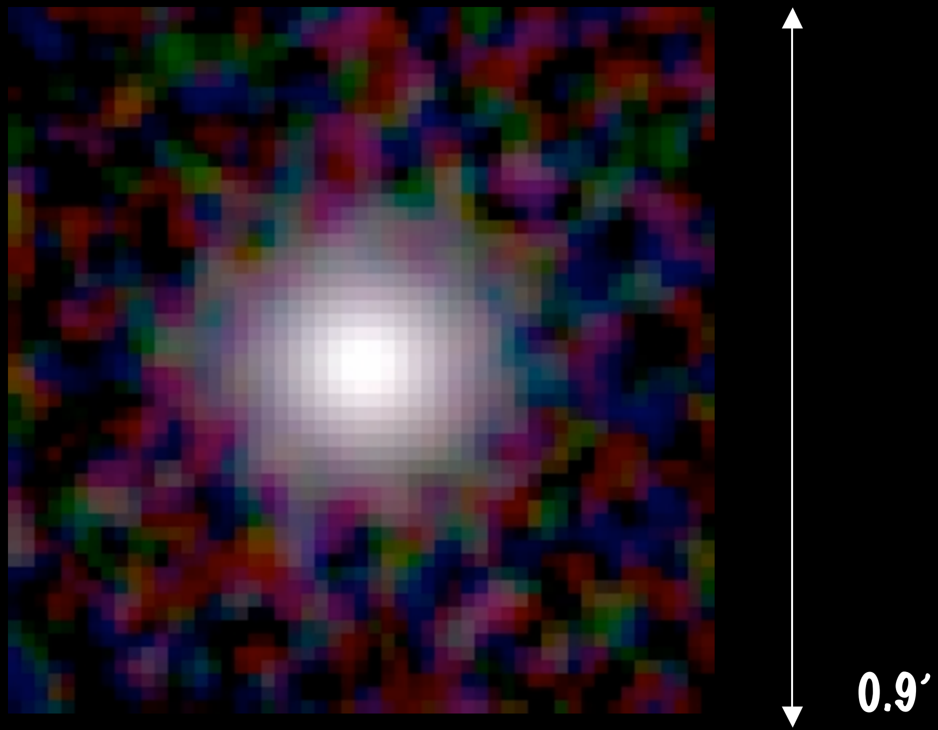


3.3′

I_0 =16.03 mag arcsec^2

R_e = 14″

NGC4486B



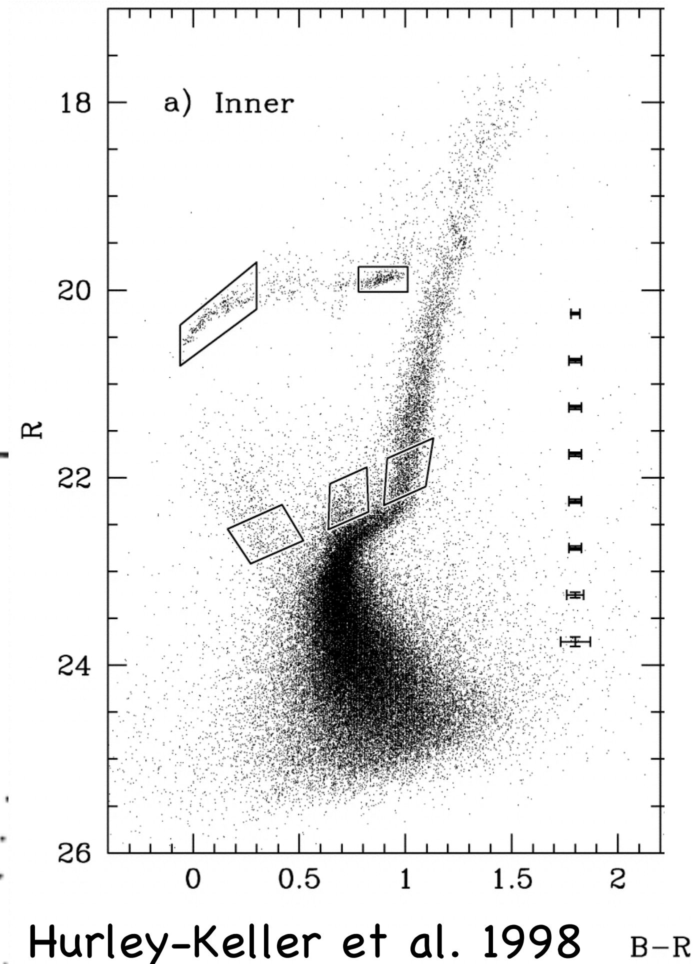
I_0 =14.26 mag arcsec^2
R_e = 3″

How to study resolved stars?

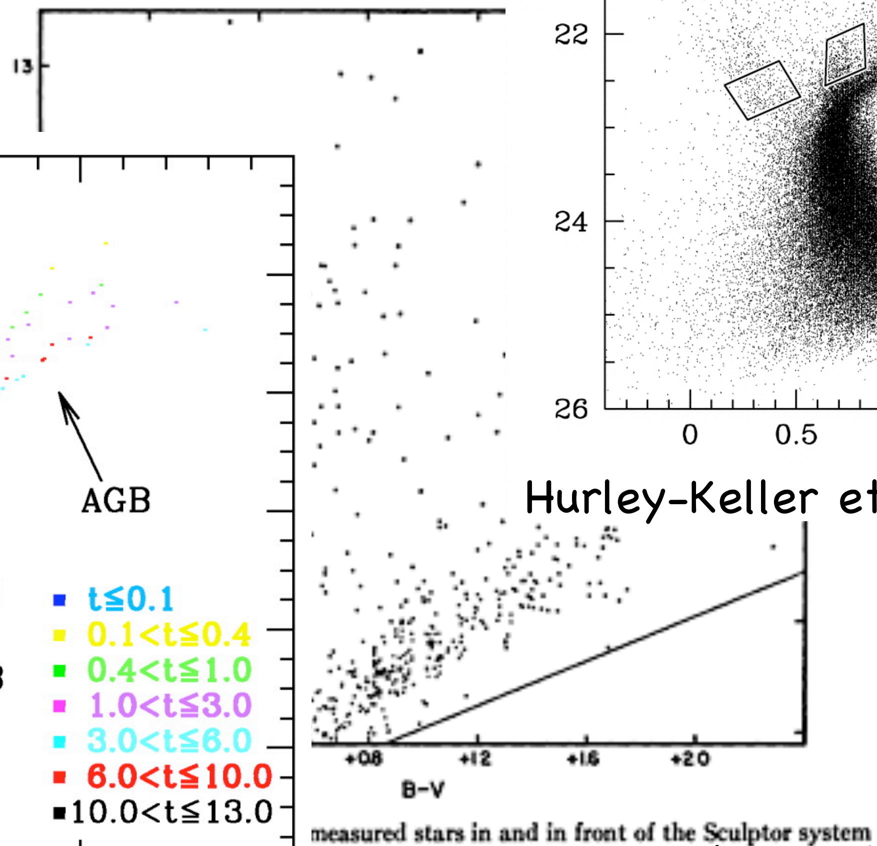
- **Colour-Magnitude Diagrams (photometry)**
- **Metalliciities (spectroscopy)**

History (CMDs)

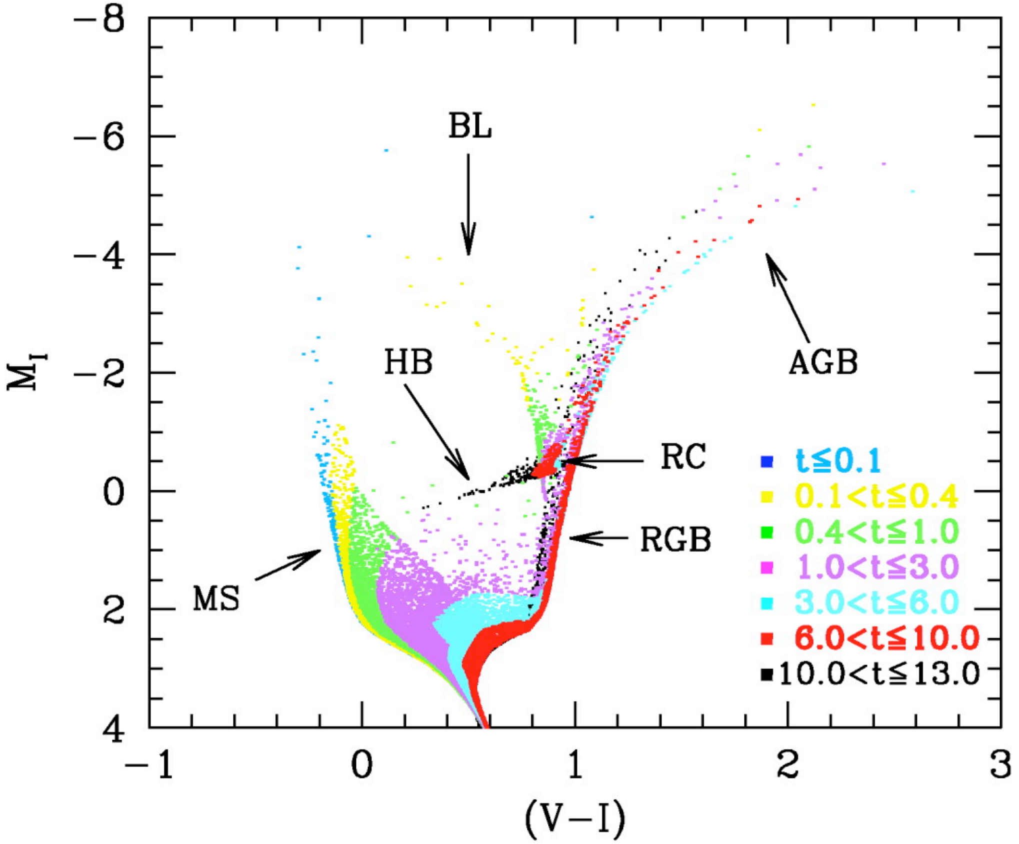
First CMDs with photographic plates, wide field but not very sensitive - pioneering work!
e.g. Sculptor dSph

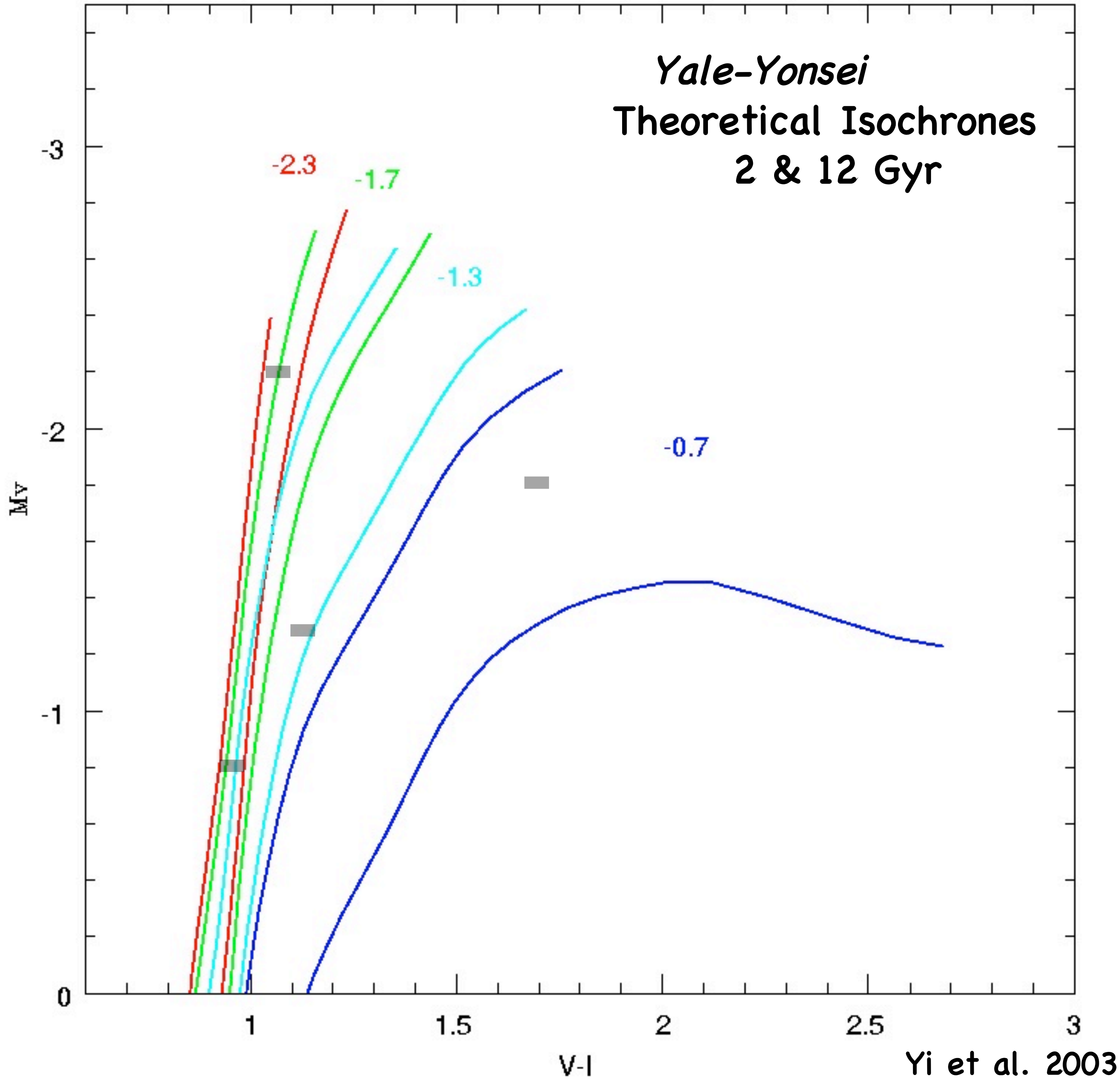


Hurley-Keller et al. 1998



Hodge 1965



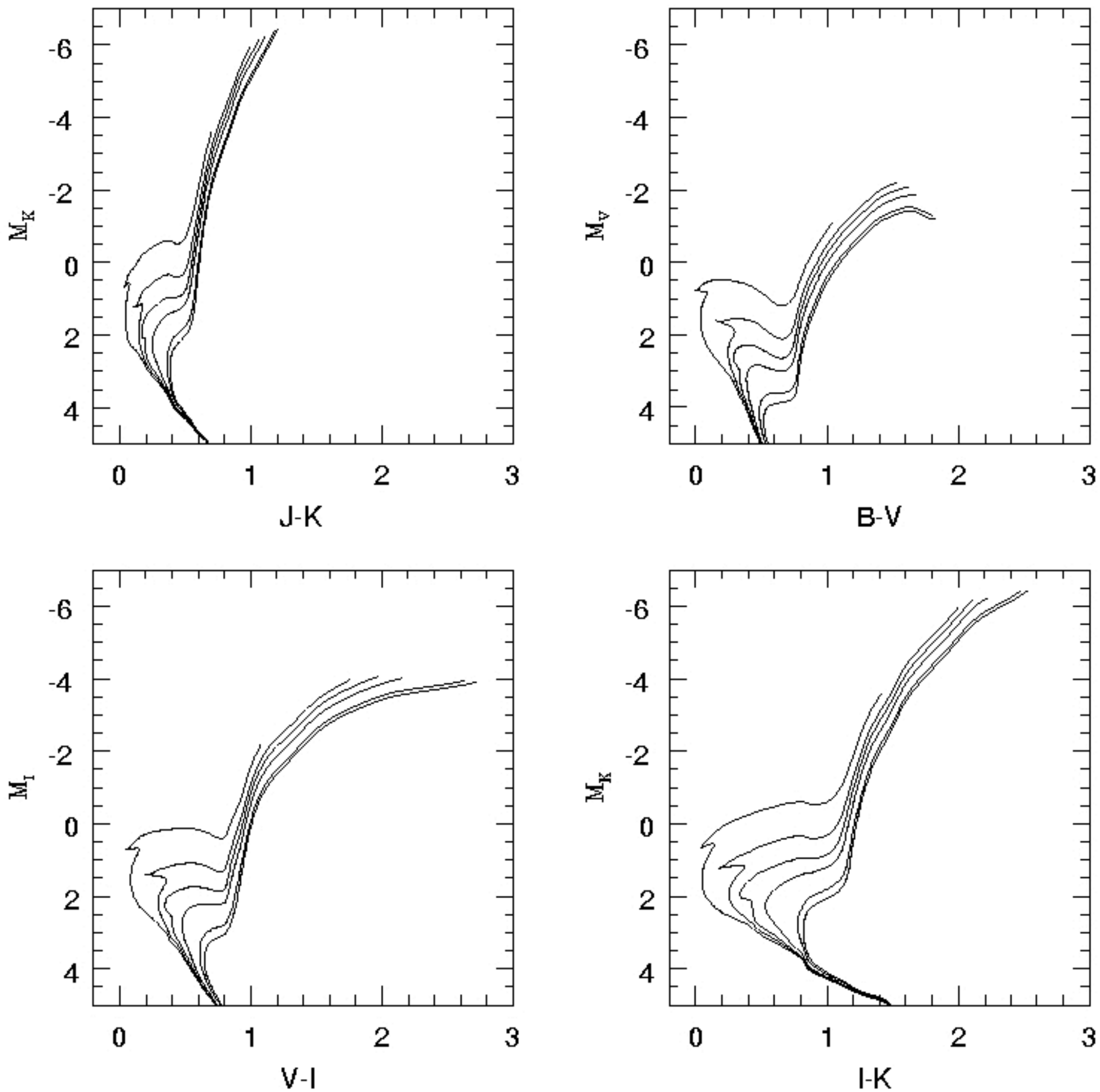

Yale-Yonsei
Theoretical Isochrones
2 & 12 Gyr
-2.3
-1.7
-1.3
-0.7
-3
-2
-1
0
Mv
1
1.5
2
2.5
3
V-I
Yi et al. 2003

Virgo m-M= 31.   (17Mpc)

NGC3379 m-M= 30.   (10Mpc)

M81/Scl m-M= 27.7 (3.5Mpc)

M31   m-M= 25.   (1Mpc)



[Fe/H] = -0.7; 1,2,3,5,10,13 Gyr

Yi et al. (2003, ApJS, 144, 259),

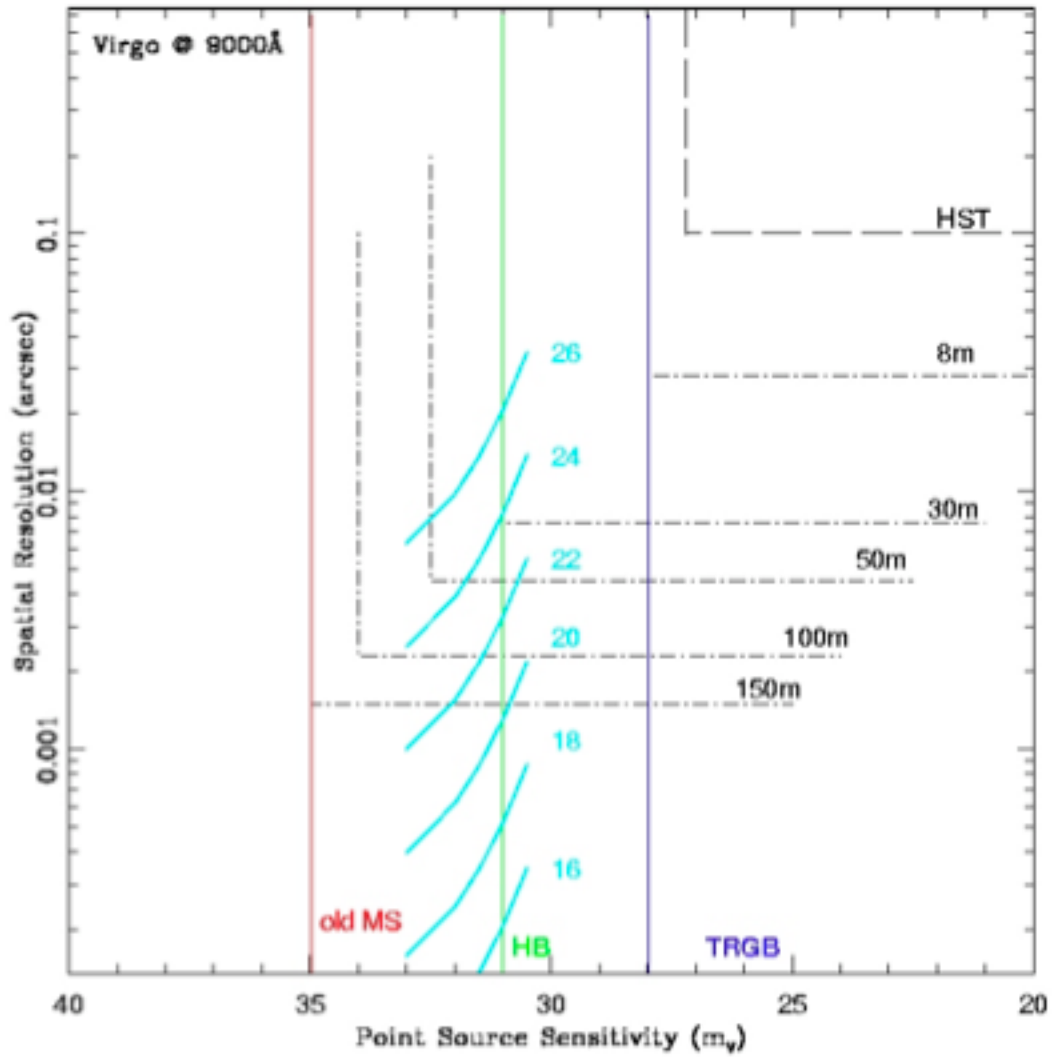

Virgo @ 9000Å
HST
8m
30m
50m
100m
150m
26
24
22
20
18
16
old MS
HB
TRGB
0.1
0.01
0.001
Spatial Resolution (arcsec)
40
35
30
25
20
Point Source Sensitivity (m_v)

Table 1. Potential targets for an ELT

Object	$(m-M)_0$	θ(1 pc)	Ra(J2000)	Dec
LMC	18.5	4”	05 23	–69 45
M31	24.3	0.3”	00 43	+41 16
Sculptor Group	26.5	0.1”	00 23	–38 00
M81/82	27.8	0.06”	09 55	+69 40
Cen A	28.5	0.04”	13 25	–43 00
Leo Group	30.0	0.02”	10 48	12 35
Virgo Cluster	31.2	12 mas	12 26	+12 43
Fornax cluster	32.0	11 mas	03 37	-35 37
50Mpc	33.5	4 mas	…	…
Arp220	34.5	2 mas	15 34	+23 30
Perseus Cluster	34.5	2 mas	03 18	+41 31
Stephan’s Quintet	35.0	2 mas	22 36	+33 57
Coma Cluster	35.0	2 mas	13 00	+28 00
Redshift z~0.1	38.5	0.5mas		…
Redshift z~0.3	41	0.2mas		…

Requirements	imaging	spectroscopy
Field of view	stars at 3Mpc: 10' stars at 10Mpc: 3'-10' stars at 18Mpc: 10"-1'	10"-5'
-diameter of 50% enclosed energy circle -strehl ratio (or "diff. lim." for diffraction limited)	diffraction limited	diffraction limited
photometric uniformity in field and/or time	field: 0.02 mag time: repeatability important	
photometric accuracy	0.05 mag (goal: 0.02)	
spectral resolution		5000-40000
wavelength (μm)	0.6-3μm	0.4-1.5μm
multiplex	N/A	100+ @LR (~5000) 50+ @ IR (~20 000) 5+ @ HR (~40 000)
typical magnitude	see table below	see table below
object size	1" - 5" (10"-5')	
typical exposure time	8-10 hours	8-10 hours
target density	stars at 3Mpc: 10^3 stars/arcsec^2 stars at 10Mpc: >10^3 stars/arcsec^2 stars at 18Mpc: >10^3 stars/arcsec^2	
dynamic range	maximum ~10^4	
background/emissivity	as dark and stable as possible	as dark and stable as possible
astrometric/plate scale stability	critical for spectroscopic targets	critical
polarisation	no importance	no importance
sky coverage		north and south ok
Date/Time constraint	no importance	no importance
can be done with 30m can be done with 42m can be done with 60m	For both imaging and spectroscopy the larger the aperture the more can be done at greater distances	
can be done with JWST		
obs type	imaging	mulit-object or single-object spectroscopy
comments - add additional requirements	Preferred ELT aperture: 50m (or more) pixel scale: 1-5mas Adaptive Optics: LTAO S/N central pixel: >10 Virgo Cluster of galaxies preferably less than 30° from Zenith in the meridian	Preferred ELT aperture: 50m (or more) pixel scale: 1-5mas Adaptive Optics: LTAO S/N central pixel: >10@LR --->>40@IR and HR Virgo Cluster of galaxies preferably less than 30° from Zenith in the meridian

The Proposal

EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
Europäische Organisation für astronomische Forschung in der südlichen Hemisphäre

VISITING ASTRONOMERS SECTION • Karl-Schwarzschild-Straße 2 • D-85748 Garching bei München • e-mail: visas@eso.org • Tel.: +49-89-32 00 64 73

APPLICATION FOR OBSERVING TIME PERIOD: **78A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of COIs and the agreement to act according to the ESO policy and regulations, should observing time be granted

1. Title Category: **B–2**

The Resolved Stellar Populations of Elliptical Galaxies

2. Abstract

Elliptical galaxies represent the majority of luminous mass in the Universe and all the indirect observational indications, from the discovery of Elliptical galaxies in high red-shift surveys, to studies of integrated stellar populations, suggest that they are predominantly very old systems. However, the main theory of galaxy formation predicts that they assembled their mass relatively recently, and should therefore be dynamically young. It is important to accurately quantify this apparent contradiction. The only way to uniquely resolve this issue is to make CMDs of the resolved stellar populations in a sample of Elliptical galaxies, using the techniques developed for studies of Local Group galaxies. This means we need to reach the Virgo cluster, 17Mpc away. The detailed properties of Ellipticals will also be compared to the properties of a range of other large galaxies in the Local Group, and at distances out to and beyond Virgo to understand the effect of environment.

To make significant progress we need to study large numbers of resolved stars in a range of galaxy types and this requires us to look beyond the halo of the Milky Way.

NGC4660

A Virgo Elliptical - the most challenging case. $(m - M)_0 \sim 31.2$.

This means that the tip of the RGB is at I~27.2, K~25.; the HB at I~31.8, K~31.7; the oldest MSTO at I~35.7, K~35. The central surface brightness of this galaxy is given as $I(0)= \mu_0 = 16$ mag/arcsec^2 (in B), with a half-light radius $r_e = 8.6$arcsec and $I(R_e) =$ 14.7 mag/arcsec^2 in H [H-K = 0.25mag, typically]; $r_e = 15.3$arcsec and $I(R_e) = 19.6$ mag/arcsec^2 in B.

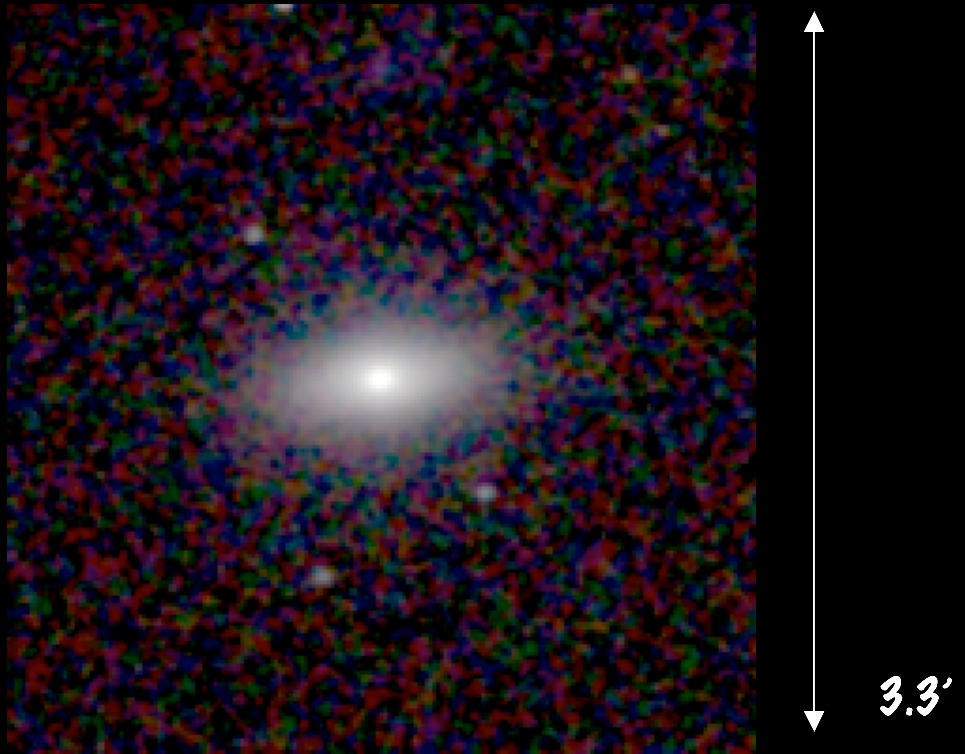
The major axis of this galaxy is 1.9 arcmin; minor axis 1.24 arcmin. The total extent (~4 disk scale lengths, 25mag/arcsec^2) is 140 arcsec ($2 \times r_{ext}$).

I estimate, at r_e we will have more than 5000 stars per arcsec^2 at the Horizontal branch magnitude (average star to star separation of 15mas), and in the centre, r_0, around 1 million stars per arcsec^2 (average star to star separation of 1mas), also at the Horizontal Branch.

This means that the positioning of the image field depends strongly upon the achievable resolution, and the depth of the photometry.

There are 2MASS images (in J,H,K), these can be obtained from web (via NED). There are HST images (ACS), from Andres Jordan (g, z sloan filters).

NGC4660



I_0 =16.03 mag arcsec^2
R_e = 14″

NGC3379

A slightly closer Giant Elliptical Galaxy, in Leo Group.
At a distance modulus $(m-M)_0 \sim 30.3$.
This means that the tip of the RGB is at I~26.3, K~24.1; the HB at I~30.9, K~30.8; the oldest MSTO at I~34.8, K~34.1. The surface brightness at the half-light radius r_e = 28.5arcsec is $I(R_e)$ = 15.5 mag/arcsec^2 in K (16.5 in J).
The major axis of this galaxy is 4.5 arcmin; minor axis 4.5arcmin (in R).
There are 2MASS images (in J,H,K), you can also find them via NED.
There are HST images (ACS + NICMOS, apparently quite deep).

Observing Specifications

Time Justification: (including seeing overhead) Using the ELT- Experimental ETC (Version 2.4WG) assuming that Laser tomography Adaptive Optics is available, 5mas pixels for an average star (e.g., A0) we can obtain images with point sources down to a magnitude of V=28, I=31 and K=28 in approximately one hour of integration per filter. This means that in I, K filters we can detect the oldest MSTOS in a CMD for galaxies closer than (m-M)<25.; the Horizontal Branch for galaxies (m-M)< 27.5 - 30.5 (depending upon the HB properties); the tip of the RGB for galaxies closer than (m-M)<35.

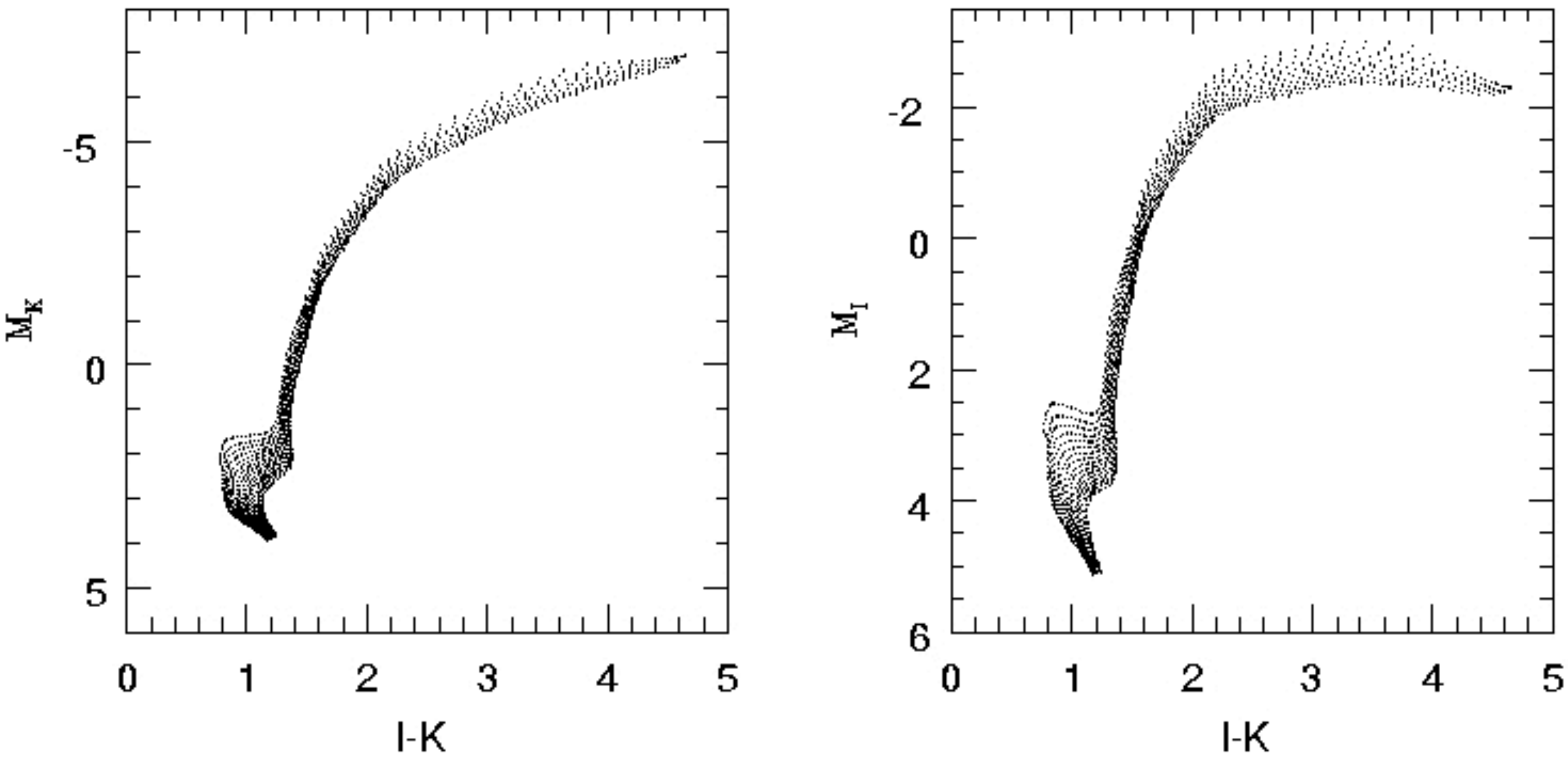
In the case of the two galaxies in observing run A - we would like to detect the Horizontal Branch - which means V, I and K∼ 31. I have not used the ETC to determine accurate exposures times instead I await the results of more detailed determinations of feasibility- and for each galaxy I list (run A and B) the required depth for detecting the TRGB (basic requirement); HB (intermediate requirement); Main Sequence Turnoffs (dream requirement).

Targets

12. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	name	RA	DEC	time(hrs)	mag	DM	ang diam(')	note
A	NGC3379 (M105)	10 47 50	+12 34 54	5 fields	30.9, 30.8	30.3	5	second closest giant early type galaxy
A	NGC4660	12 44 32	+11 11 26	5 fields	31.8, 31.7	31.2	2	Virgo Elliptical
B	M87 (NGC4486)	12 30 49	+12 23 28	10x2hrs	31.8, 31.7	31.2	11	central elliptical in Virgo
B	M59 (NGC4621)	12 42 02	+11 38 49	5x2hrs	31.8, 31.7	31.2	8	Typical Virgo Giant Elliptical
B	M 32 (NGC221)	00 42 42	+40 51 55	5 fields	29, 28.3	24.5	9	Local Group dwarf elliptical
B	CenA (NGC5128)	13 25 28	-43 01 08.8	10x2hrs	30.5, 29.8	26	30	Closest giant early type galaxy
B	NGC4486B	12 30 32	+12 29 26	2hrs	31.8, 31.7	31.2	0.5	Virgo compact dwarf elliptical
B	Sombrero (M104)	12 39 59	-11 37 23	5x2hrs	30.3, 30.2	29.7	9	Nearest Sa galaxy
B	M83	13 37 00	-29 51 57	10x2hrs	28.9, 28.8	28.3	12	Nearest face on MW-type spiral
B	NGC300	00 54 54	-37 41 04	10x2hrs	30.3, 30.1	26.3	22	Sculptor Spiral galaxy
B	M100 (NGC4321)	12 22 55	+15 49 21	5x2hrs	31.6, 31.5	31	8	Virgo Spiral Galaxy
B	NGC 891	02 22 33	+42 20 57	5x2hrs	30.6, 30.5	30	15	Edge-on Milky Way twin
B	IC5052	20 52 01	-69 11 36	3x2hrs	29.4, 29.3	28.8	6	Edge-on galaxy
B	M 31	00 42 44	+41 16 09	20x2hrs	28.9, 28.2	24.4	200	Local Group Spiral Galaxy
B	M 33	01 33 51	+30 39 36	10x2hrs	29.1, 28.4	24.6	70	Local Group small spiral galaxy
B	NGC 55	00 14 54	-39 11 48	10x2hrs	30.2, 29.5	25.8	32	Nearby Edge-on irregular/spiral galaxy

Target Notes: The targets in run A and the main ones for this exercise; the targets in run B give a more general impression of the types of (large) galaxy we might like to observe with an ELT with the same requirements as run A.
Number of points per field listed with time, I, K mags listed. Angular diameter is the total size of the entire galaxy not always necessary to observe the entire galaxy.



a “typical” elliptical galaxy, which stopped forming stars 5Gyr ago.

Thus a representative stellar population to begin the modelling. It is just a list of stars with no fancy assumptions - no incompleteness - no noise etc. this should ideally come from the conversion into an image. It is assuming a V band surface brightness= 24 mag/arcsec^2