Resolved Stellar Populations with Visible Adaptive Optics on the VLT

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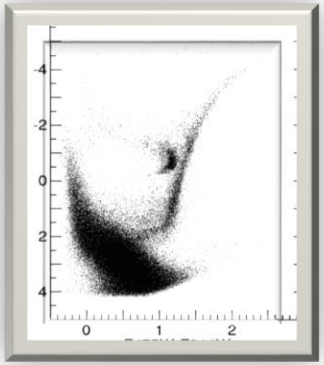
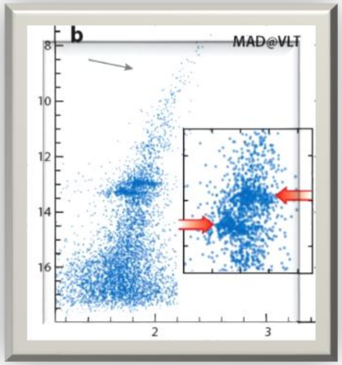
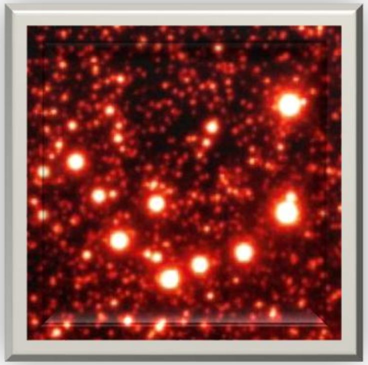
- HST legacy – Star formation histories of dwarf galaxies
- Anticipating the E-ELT
- Visible adaptive optics on the VLT







Spatially Resolved Stellar Populations in Nearby Galaxies

Science Goal is galaxy evolution: to understand *why*, *when*, & *where* stars formed in galaxies

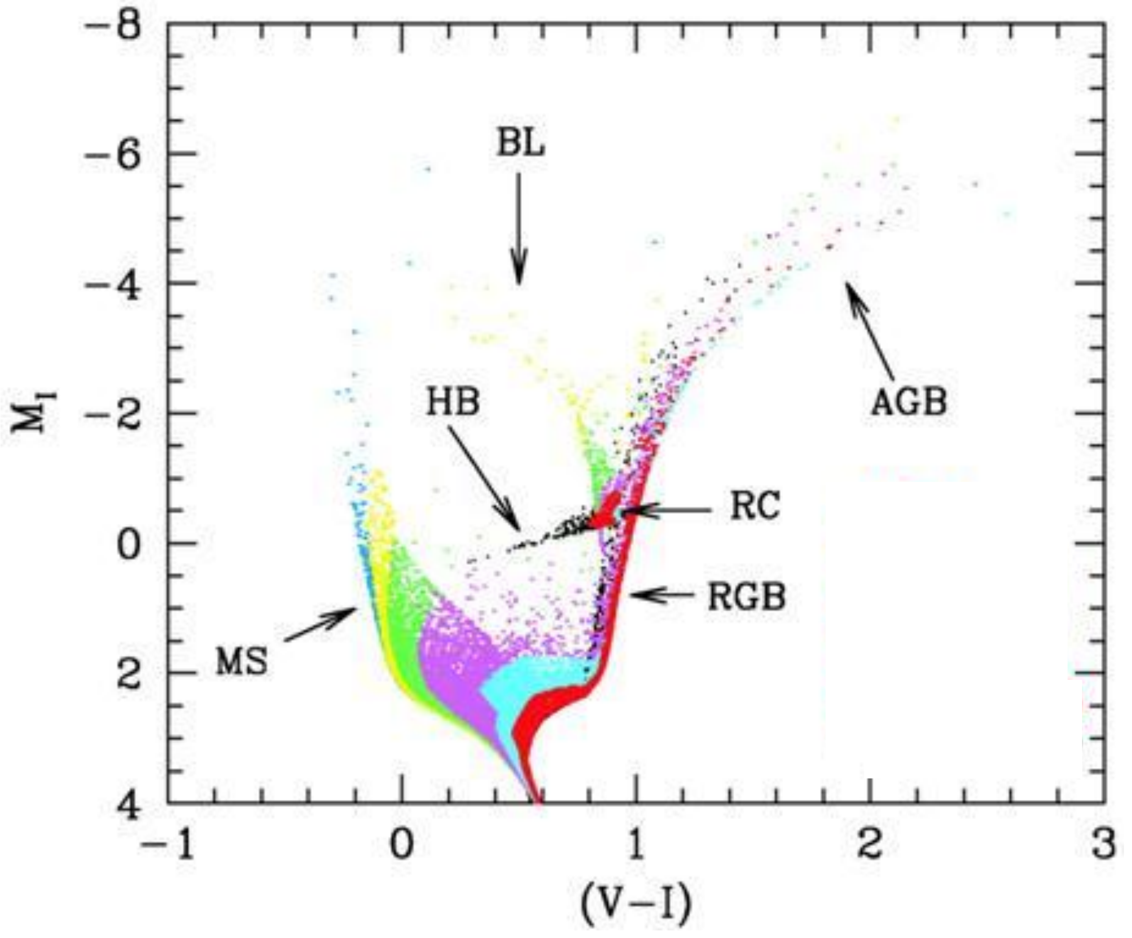
- Observe galaxies at different epochs & track evolution of the samples
- Infer the past star formation history from relic populations in local galaxies

- HST has been very successful: optical colours, wide field, stable PSF
- It has a reasonable chance of continuing to at least 2020

- In sparse fields, the limit is *sensitivity*
- In crowded fields, the limit is *resolution*
- *Key goal for ELTs* is to reach Virgo cluster – large sample of 'normal' ellipticals

Star Formation History from Colour Magnitude Diagrams

Illustrating features in a CMD:
Constant star formation over 13 Gyr, with increasing metallicity

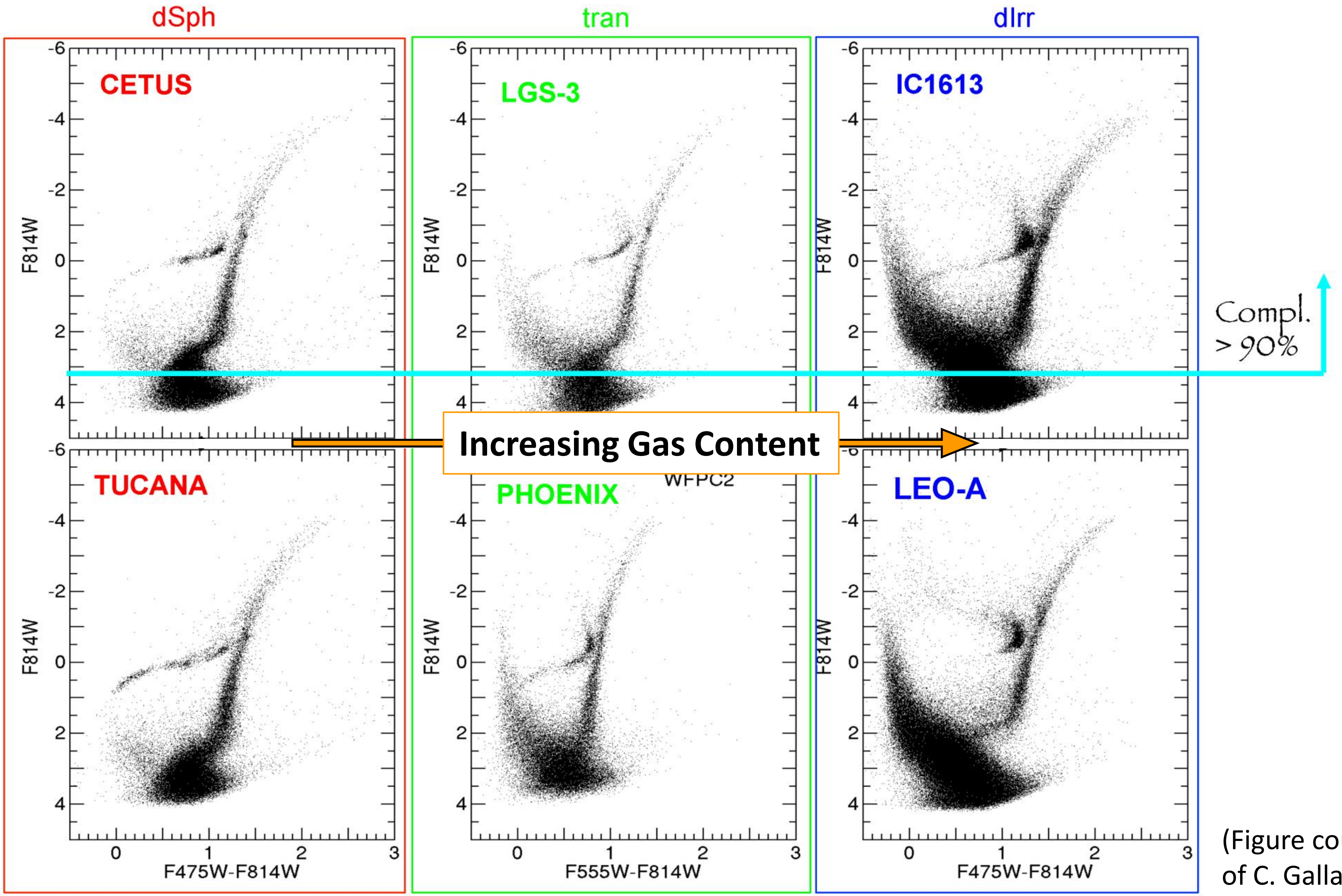


- ■ < 0.1 Gyr
- ■ 0.1 – 0.4 Gyr
- ■ 0.4 – 1.0 Gyr
- ■ 1.0 – 3.0 Gyr
- ■ 3.0 – 6 Gyr
- ■ 6 – 10 Gyr
- ■ 10 – 13 Gyr

Aparicio & Gallart (2004)

“Local Cosmology from Isolated Dwarfs” project

Top Quality HST CMDs from the LCID team (Gallart & others)



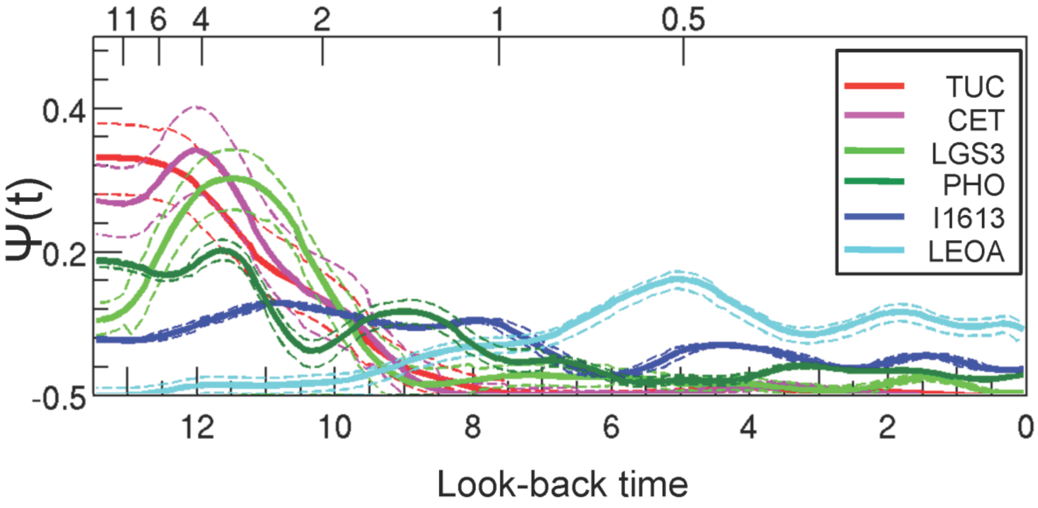
Increasing Gas Content

Compl.
> 90%

(Figure courtesy
of C. Gallart)

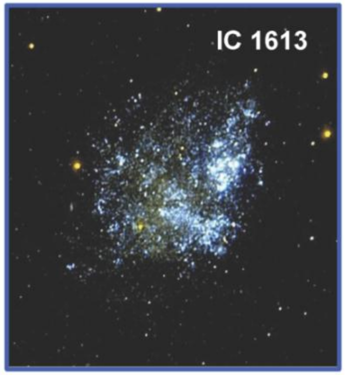
Differing Star Formation Histories of Dwarf Galaxies

Gallart+



(Figures courtesy of C. Gallart)

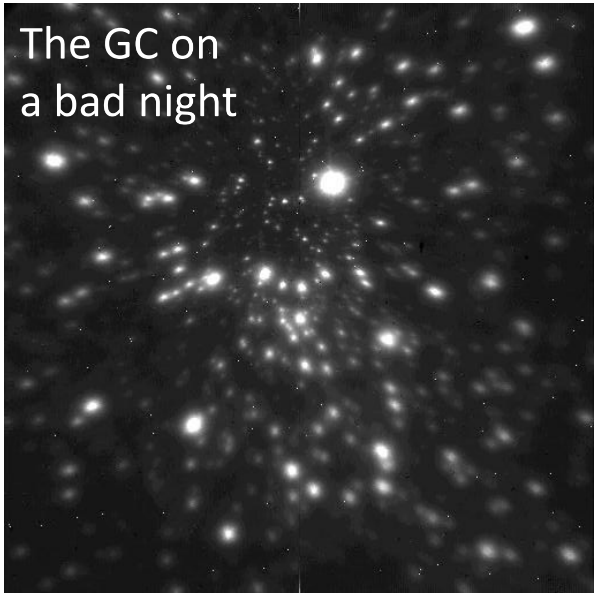
- Cetus & Tucana: no gas, very low surface brightness
- Both formed >90% of stars >10 Gyr ago
- No stars younger than ~8 Gyr



- IC1613 & LeoA contain gas & HII regions
- Both formed >60% of stars <9 Gyr ago, including last 1 Gyr

- ➢ star formation & stellar feedback
- ➢ impact of reionisation: does it halt star formation?
- ➢ cosmic web stripping (see also Benitez-Llambay+)

AO Requirements (1)



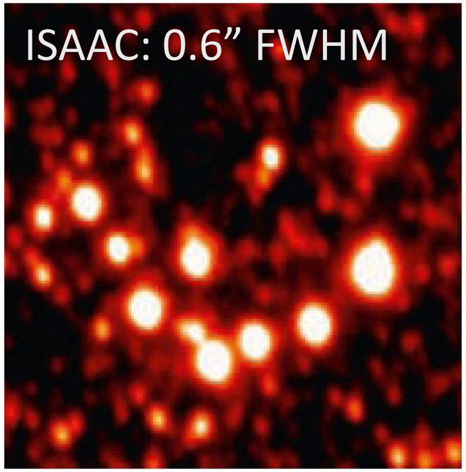
The need for a **uniform PSF over a finite field** drives one towards

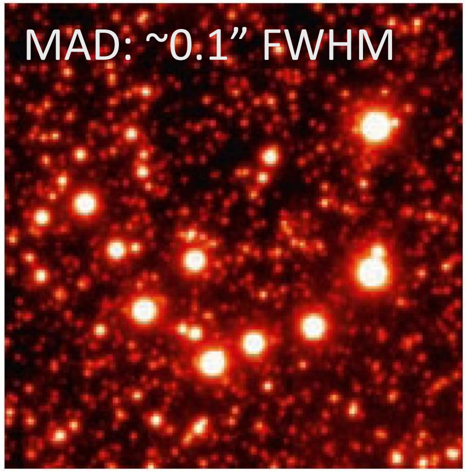
GLAO: wide field of 4 arcmin or more, enhanced resolution (2-3x better than seeing)

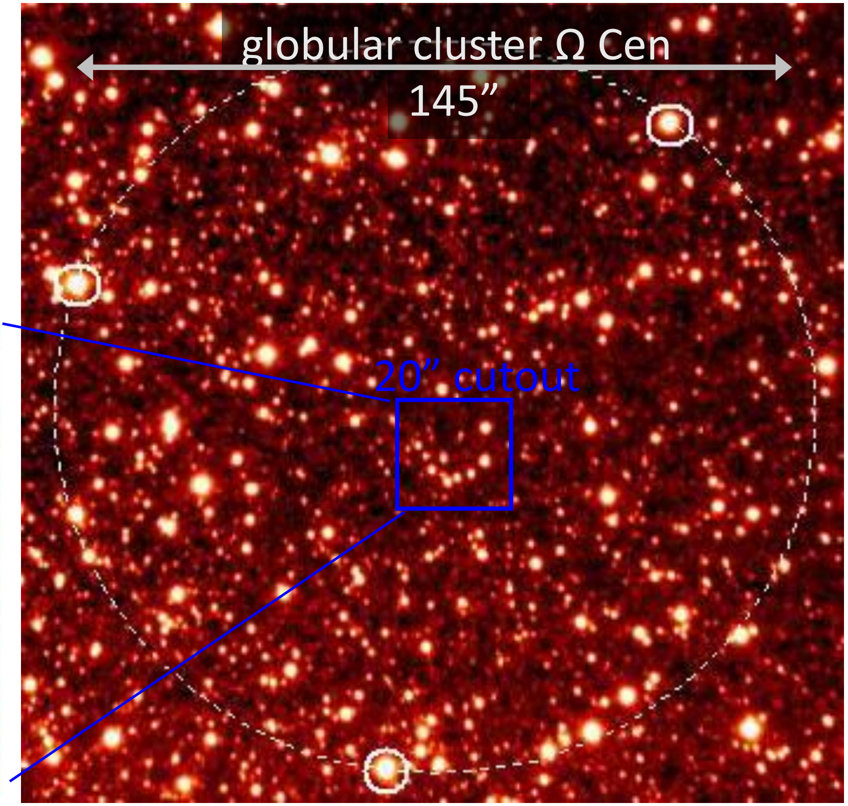
and, in crowded regions

MCAO: diffraction limited but moderate field of 1-2 arcmin (limited by number of DMs)

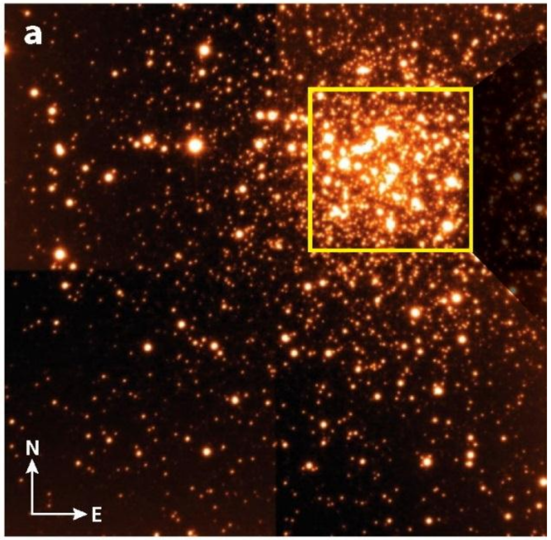
Marchetti+ 07



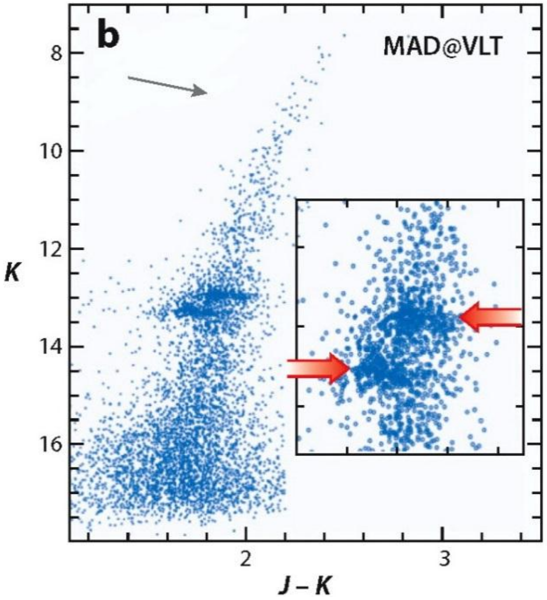


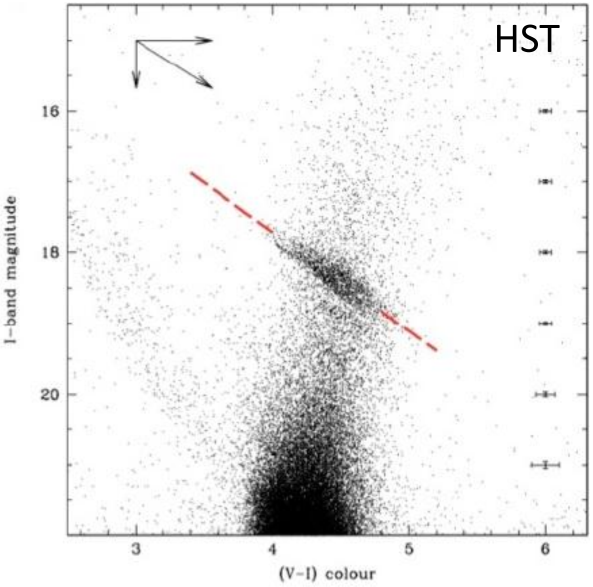


Terzan 5 Cluster



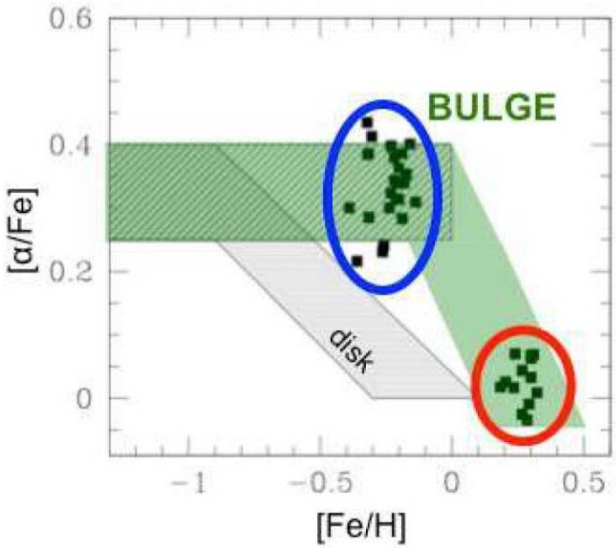
MAD





Ferraro+ 09

- 10^6 M_{sun}, thought to be a globular cluster
- 2 horizontal branch clumps:
- Brighter one is redder, more compact, [Fe/H]=0.3, 6 Gyr
- Fainter clump has [Fe/H]=-0.2, 12Gyr
- Remnant of dwarf galaxy as it merged with the bulge?



Origlia+11

- Differing α-element abundances, matching bulge stars
- Two short SF episodes
- Formed at same time as bulge, but survived intact?

What will the E-ELT be able to detect?

With several hrs integration, it can reach H_{AB} ~ 31mag for isolated sources.

from Deep+ 11 & Greggio+ 12:

old Main Sequence Turnoffs out to ~2 Mpc

Local Group	several large spirals
Sculptor & M81 groups	

Horizontal Branch out to ~10 Mpc

Cen A	closest elliptical, but peculiar
Leo Group	closest normal elliptical (NGC3379)

Red Giant Branch

Virgo Cluster	many large galaxies including ellipticals

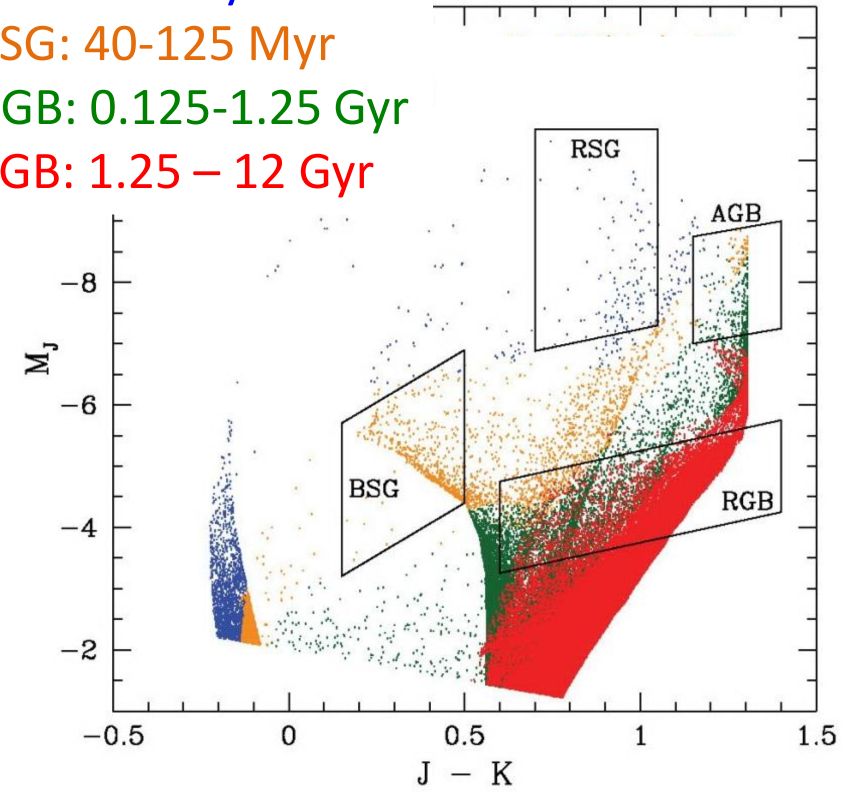
tip of Red Giant Branch out to >100Mpc

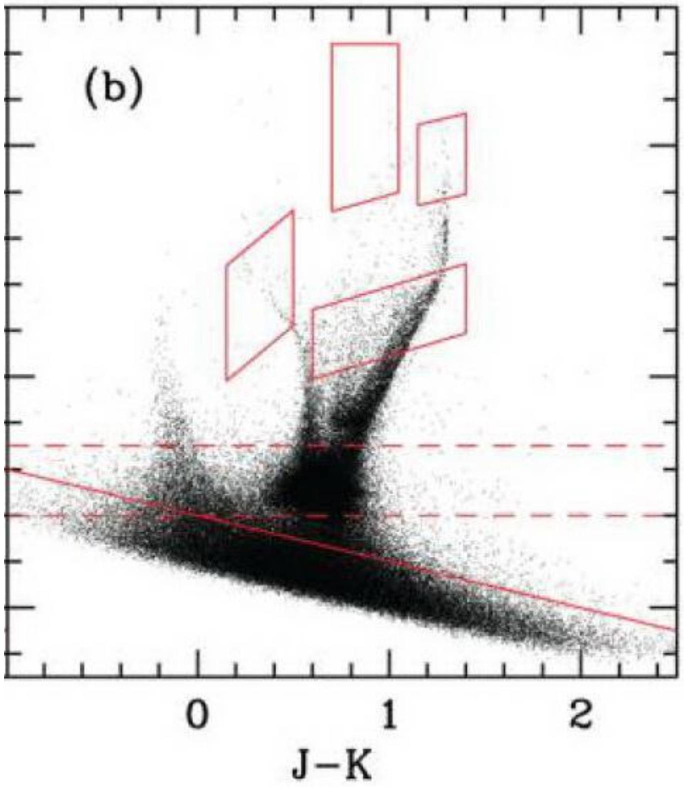
E-ELT simulations

Greggio+ 12

Spiral disk in Centaurus Group (4.6 Mpc):
model has constant SFR over 12 Gyr with increasing Z

RSG: <40 Myr
BSG: 40-125 Myr
AGB: 0.125-1.25 Gyr
RGB: 1.25 – 12 Gyr



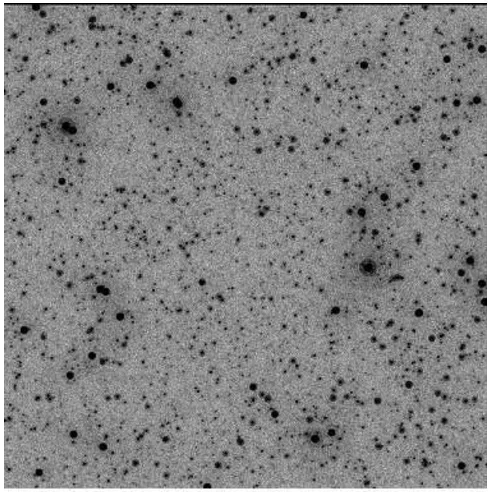


Anticipating the ELTs

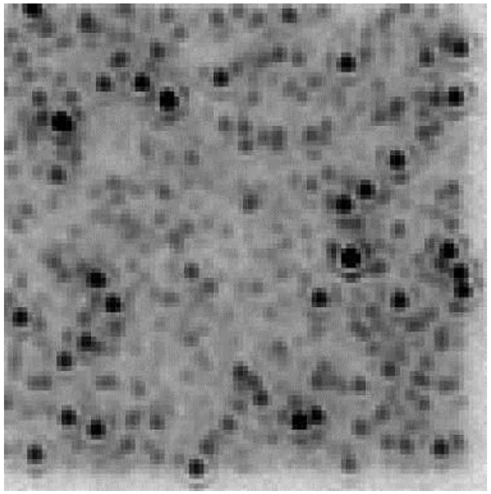
Resolution gives an effective sensitivity gain wrt JWST – cf. 3mag for MAD vs ISAAC.

Can probe tip of RGB out to Virgo ($\delta_{\mathrm{Virgo}} = +12.5^{\circ}$, zd at transit is 37° -> seeing ~0.1” worse)

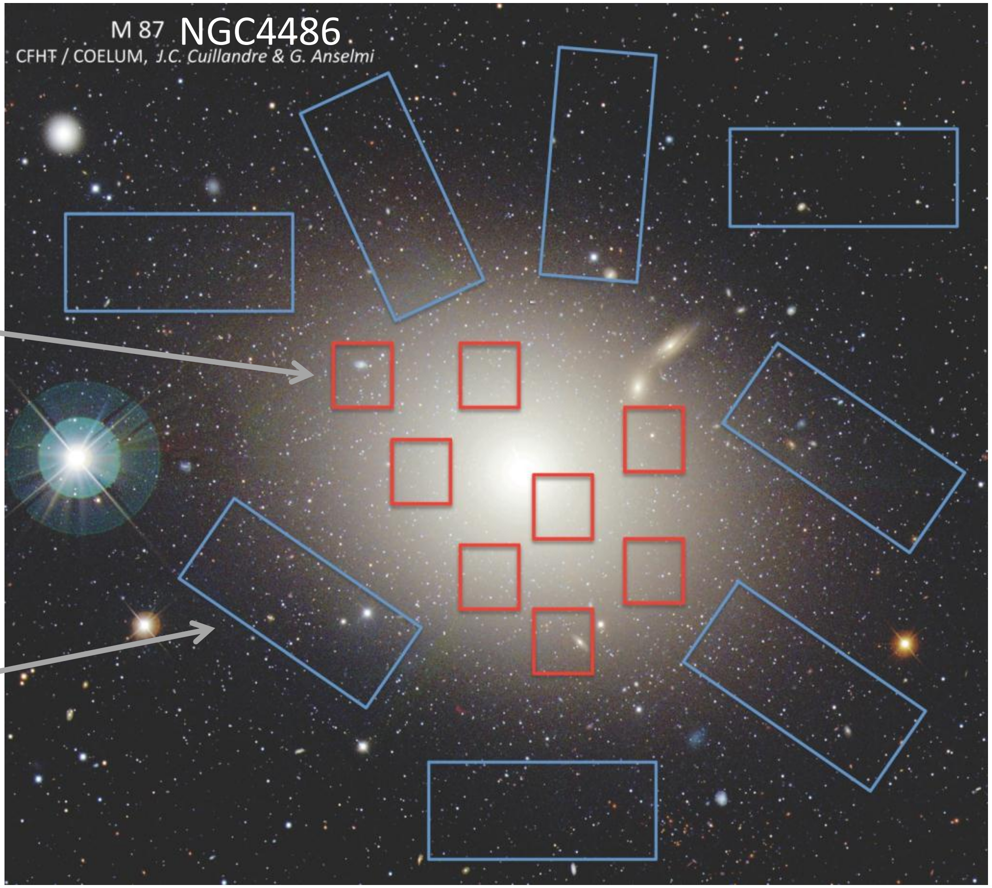
5-hr K-band simulated exposures



MICADO
@ E-ELT



NIRCAM
@ JWST



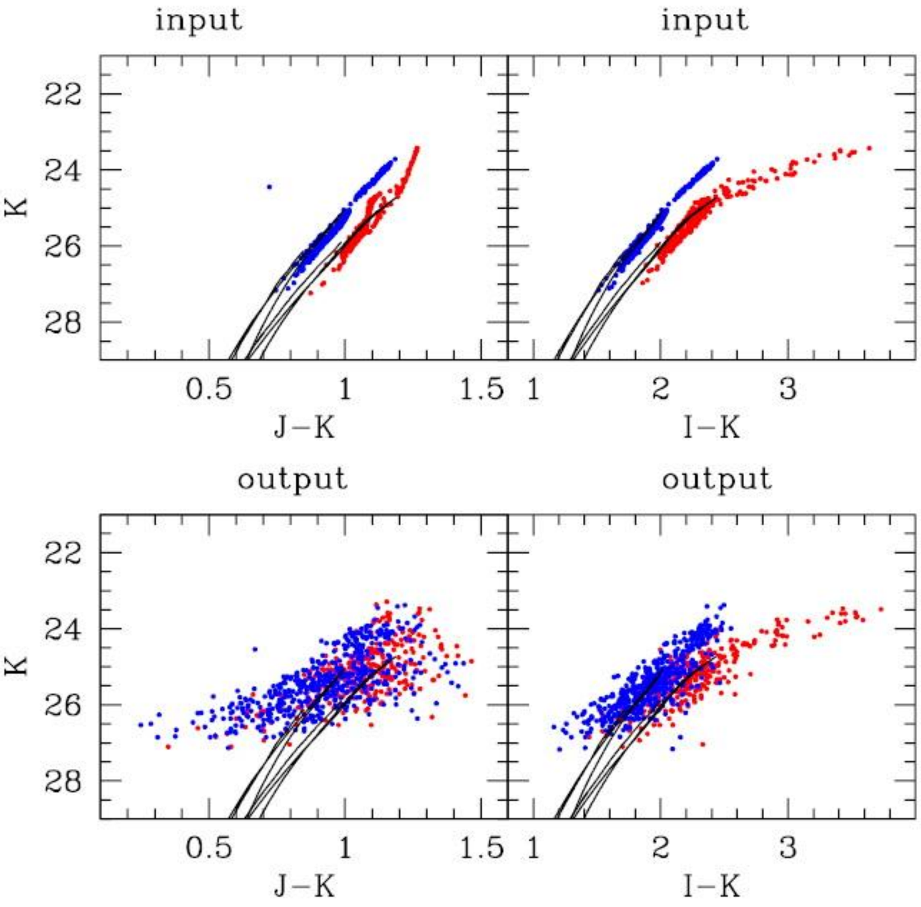
CFHT / COELUM, J.C. Cuillandre & G. Anselmi

AO Requirements (2)

Improved correction at shorter wavelengths

- Optical colours:
  - better discrimination of stellar populations because peak of SED is typically 300-700nm
  - better sensitivity than near-IR due to lower background
- Combining optical & near-IR colours can break age-metallicity degeneracy

Deep+ 11,
Virgo elliptical on E-ELT,
populations of 6 & 10 Gyr



Visible AO on the VLT

- Diffraction limited resolution of 8-m at 450nm matches that of E-ELT at 2.2µm
- one can get optical and near-infrared images at similar resolution

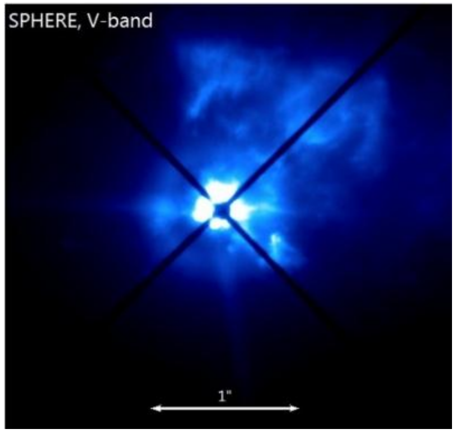
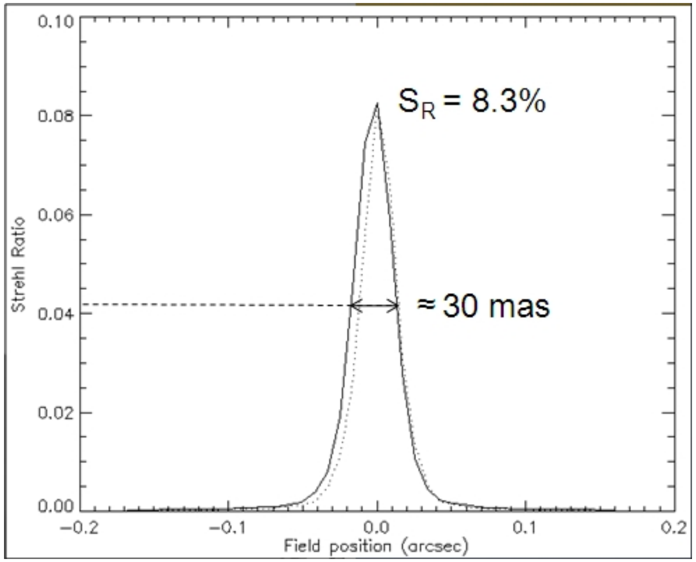


Image from **SPHERE** ZIMPOL, at 15mas resolution in V-band, of the red hypergiant star VY CMa. [Credit: R. Siebenmorgen / ESO]

Visible AO is planned for **MUSE+GALACSI**:
- FoV 7.4”×7.4”
- predicted performance: 5-10% Strehl at 650nm
- TT star (=science target): within FoV, to J=15mag



Realizing a visible AO system

Can one adapt an MCAO system like GeMS (Neichel+ 14) to visible wavelengths?

Basic limitation of visible AO on an 8-m is the FoV (Rigaut+ 00, Davies & Kasper 12):

FoV (arcsec) ~ 10 **d** (cm) x **N_{DM}** / **H** (km)

d is matched to r_0 which is related to

- seeing: $r_0 \sim \lambda/\mathrm{FWHM}$
- wavelength: $r_0 \sim \lambda^{6/5}$

GeMS: FoV=60, H=12km, N_{DM}=3,

FoV at optical wavelengths is limited to 10-15arcsec

Realizing a visible AO system

Split the challenge into 2 parts

Hard part

High order correction:
- Puts flux into the core of the PSF
- Provides the contrast

Difficulty goes as $\tau_0.r_0^2 \sim 1/\lambda^{3.6}$
e.g. Need 100x more photons than near-IR AO

Adopt a ‘brute force’ approach: better technology for lasers, WFS, DMs, computing power

Other hard part

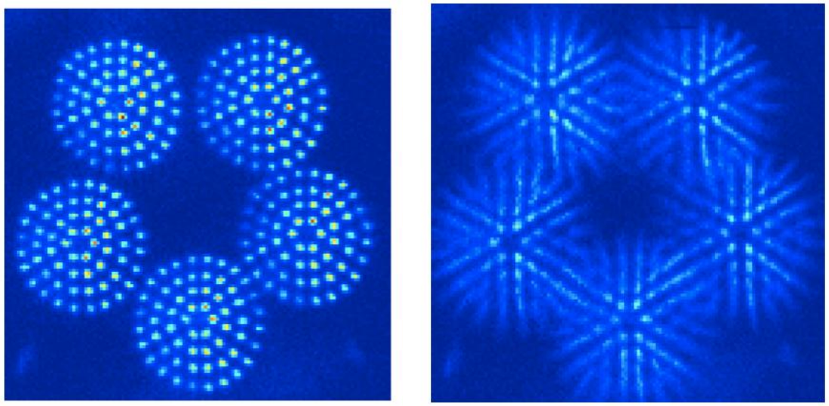
Tip-tilt correction:
- Makes the PSF core narrower
- Provides the resolution

Impacts sky coverage:
e.g. SPHERE corrects on bright stars
e.g. MUSE+GALACSI requires tip-tilt star inside FoV so that it can be sharpened by high-order correction

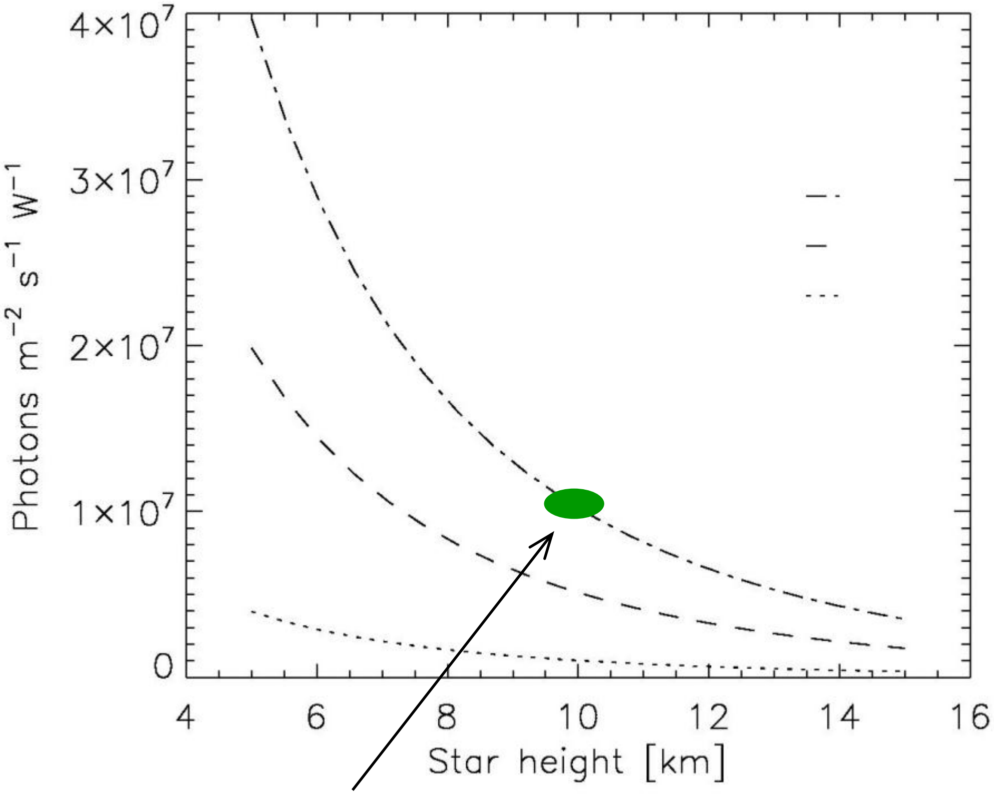
There are ways to get around this limitation…

Visible AO: high order correction

- Sodium lasers not practical: would need >100W
- Green or UV Rayleigh lasers are a possible alternative
- Dynamical refocus can increase return flux by factor 10, so reduces power requirements, e.g. as demonstrated at MMT



Courtesy of M. Hart



10W, 532nm

10km height

1km range gate

->10^8 Photons return

Dynamic refocus required

Visible AO: tip-tilt correction

- Diffraction limit is 15mas.

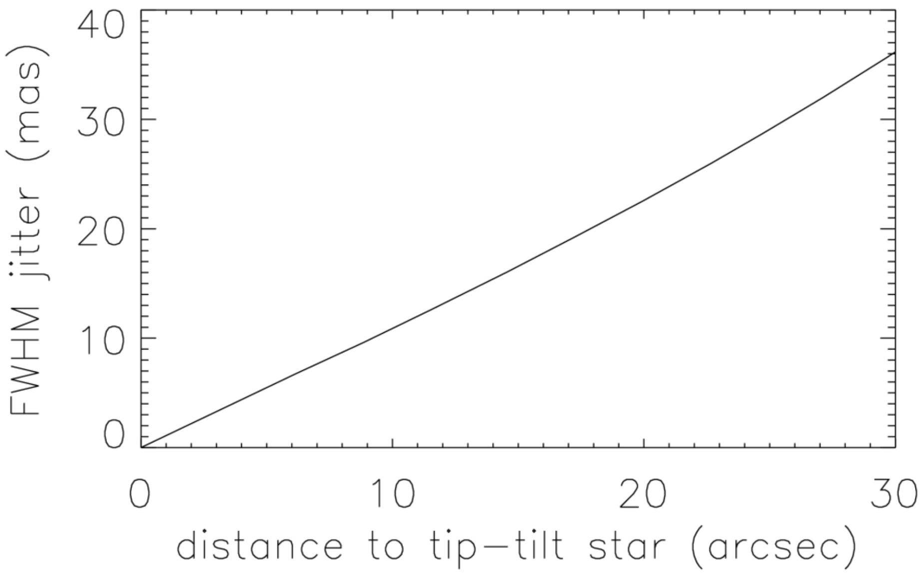
  How small should residual tip-tilt be? *This drives the AO complexity & sky coverage*

- Good sky coverage -> faint stars -> image sharpening (e.g. MUSE+GALACSI)

- Even so, suitable stars within ~5” are rare -> need to use off-axis tip-tilt star.

- Image sharpening then requires a separate AO system: “dual AO” (Rigaut & Gendron 92)

- Other options are also available, e.g. ‘Propagation delay’ (Ragazzoni+ 96)



(adapted from van Dam+ 06)

Summary

- Probing galaxy formation & evolution by reconstructing star formation histories of nearby galaxies from their spatially resolved stellar populations is a key science case.
- HST has done great work with local dwarfs.
- JWST & E-ELT will extend this to Virgo Cluster galaxies.
- A visible AO system on the VLT is highly complementary & really enhances the scientific return.
- Building such a system would be hard, but certainly feasible.
- There are many other science cases for vis-AO