Simulations for spectroscopy of resolved stellar populations with the E-ELT

Giuseppina Battaglia
ESO

Thanks to:
Markus Kissler-Patig
Eline Tolstoy
Joe Liske

"UK E-ELT Science Workshop II", Cambridge, 17 Sep 2009

Motivation

- Low mass stars can have lifetimes comparable to the age of the Universe -> record of changing galaxy properties back to the oldest times
- By deriving ages, chemistry and kinematics of LARGE samples of individual stars we can gain insights on how galaxy properties were built up in time

Ideally one would like these observations for a representative sample of galaxies types and environments

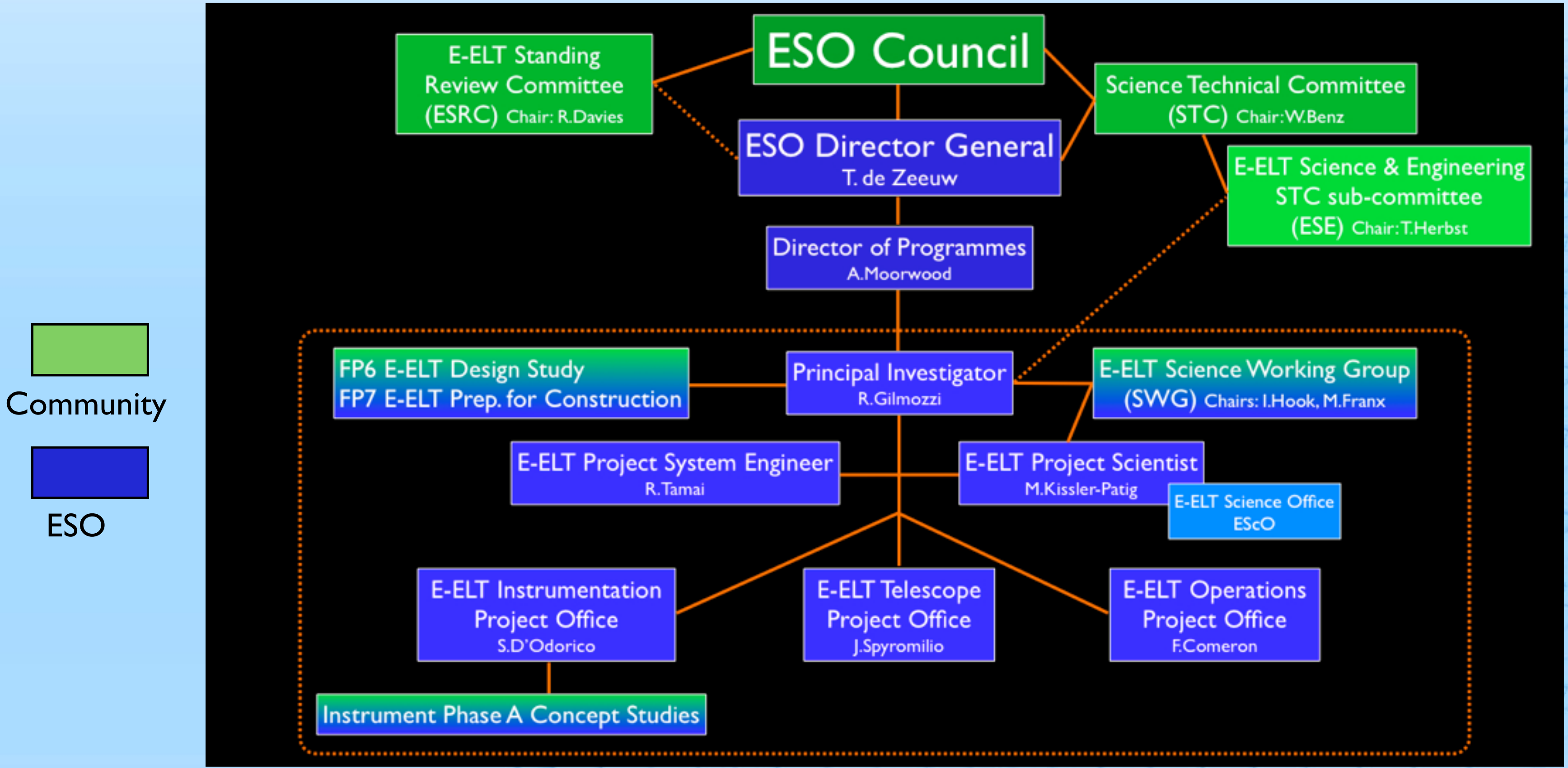
Many things already learned from current studies of resolved stellar population studies in the Local Group (see other talks…)

But there is still a lot to do…

- Better characterization of the properties of sparse systems (e.g. ultra-faint dwarfs) -> need to observe fainter stars
- Elemental abundances of individual stars in the outskirts of the Milky Way halo
- ……..
- Large spectroscopic surveys at the outskirts of the Local Group
- But also, important to explore a variety of galaxy types and in different environments => outside the Local Group

Project Organisation

- Project led by ESO on behalf on its 14 member states
- Strong involvement of member state industries and scientific communities



The E-ELT Science office at ESO

M.Kissler-Patig, J.Liske, A.Böhnert, A.Calamida, S.Gładysz, G.James, M.Kazmierczak, M.Lyubenova, D.Villegas, A.Küpcü Yoldas, G.Battaglia, L.Christensen, B.Venemans (former members: M.Puech, S.Toft)

And the Design Reference Mission

Simulate data for a set of selected observing proposals => (i) assess the extent to which the E-ELT addresses key scientific questions and (ii) to assist in critical trade-off decisions

Several prominent science cases chosen by the Science Working Group to be simulated by the DRM. "Demo cases" are:

- From giant to terrestrial exoplanets: detection, characterization and evolution
- Imaging and spectroscopy of resolved stellar populations in galaxies
- The physics of high redshift galaxies

Science case: Imaging and spectroscopy of resolved stellar populations in galaxies

1. Photometry (PI: E.Tolstoy) ->

   Goal: accurate Colour-Magnitude diagrams down to below the horizontal branch at the distance of Virgo (J.Liske)

2. Intermediate resolution spectroscopy (PI: E.Tolstoy) ->

   Goal: large number of line-of-sight velocities and [Fe/H] measurements out to the Virgo cluster (G.Battaglia)

3. High resolution spectroscopy (PI: V.Hill) ->

   Goal: accurate elemental abundances in the outer Milky Way halo and its satellites (G.James)

The simulations

Generalities

- AIM: collect about 1000 [Fe/H] and l.o.s. vel of individual stars in galaxies out to the Virgo cluster

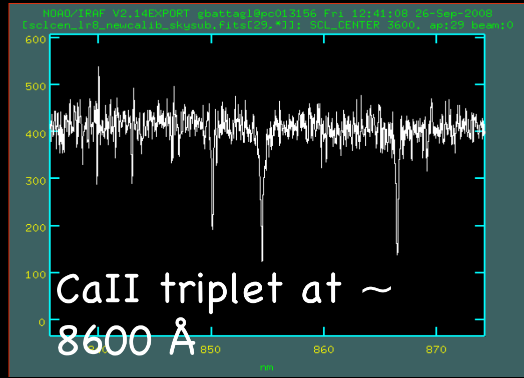
- NIR CaII triplet region (empirical relation exists between EW of CaT lines and [Fe/H]; well tested method; currently used in studies of Local Group dwarf galaxies, M31, RAVE, GAIA in the future…)

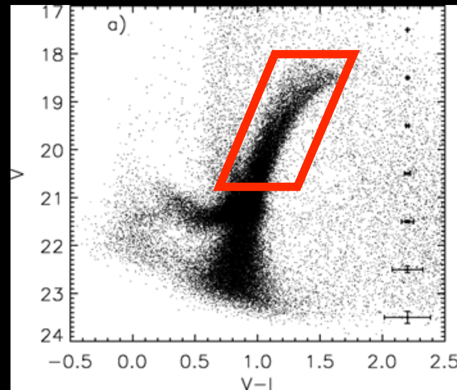
- Red Giant Branch stars as targets:

  -> bright in the NIR & cover wide age range (> 1 Gyr old)

- R = 6000

- Instrument characteristics:
  - Integral Field Unit (mono or multi)
  - Field-of-view = 10" x 10"
  - Spatial pixel (spaxel) size = 50 mas x 50 mas





ESO/WFI CMD of the Fornax dSph (Battaglia et al. 2006)

Main points to address:

- Distance range:

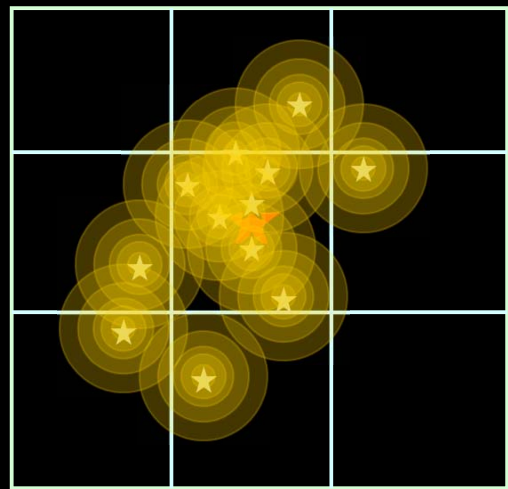
~1 Mpc (LG: NGC205) | 4 Mpc (CenA) | 17 Mpc (Virgo: M87)

Tip of the RGB in I-mag at about :

20.6 | 23.9 | 27.2

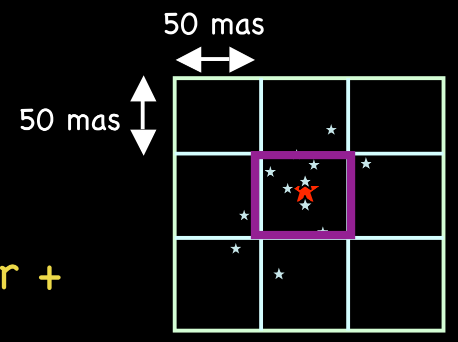
- Crowding: effect of stellar background in the spaxel on the properties of target RGB star

- PSF effects (with the best AO option in I-band 94% of the light is lost from the spaxel)



-> can we recover the CaT [Fe/H] and line-of-sight velocity of the target star?

Methodology



1. Create the integrated spectrum (due to target RGB star + stellar background) in a spaxel of 50mas x 50 mas

   a) decide characteristics of the target RGB star (magn, color, [Fe/H], [alpha/Fe], velocity)

   b) create the stellar background using a code developed by Joe Liske & E.Tolstoy (need to fix the stellar population, surface brightness and distance modulus)

   c) associate to each star the appropriate spectrum (from Munari et al. 2005 synthetic spectra library at R=20000)

   d) sum up the spectra and include technical effects

2. Derive line-of-sight velocity and CaT [Fe/H] from the integrated spectrum

3. Compare to the input line-of-sight velocity and CaT [Fe/H] for the target star

4. Repeat 300 times to account for varying background and noise

We study the distribution of (V_los_simulated - V_los_input) and (ΣW_simulated - ΣW_input) where $\Sigma W = EW_2 + EW_3$

-> the systematics are quantified by the mean of the distributions

-> the errors are quantified by the scatter of the distributions

Figures of merit (accuracies)

We consider that the simulations produce accurate enough velocities and ΣW if they agree with the input values within

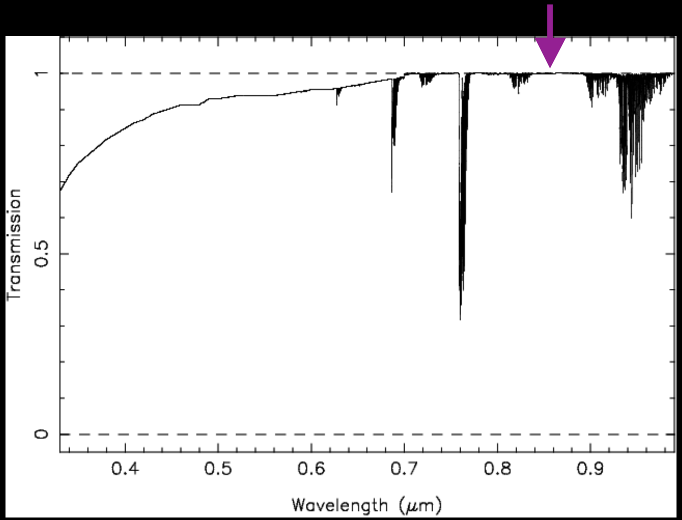
- 0.7 Å -> 0.3 dex ($\Delta[Fe/H] = 0.44 \times \Delta\Sigma W$)
- 20 km/s (large galaxies); 5 km/s (dwarf galaxies)

(this is similar to accuracies of current studies)

Explored parameter space

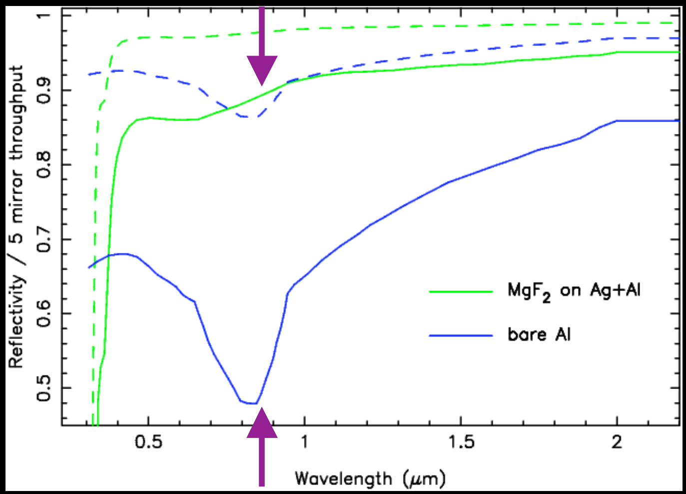
SCIENTIFIC PARAMETERS

- Objects: NGC205 (dwarf), CenA and M87 (large ellipticals)
- Distances: 800kpc, 4 Mpc, 17 Mpc
- Different projected radii
- Stellar population: old (constant SFH between 12-14 Gyr); MR: [Fe/H]=-1.0 & MP: [Fe/H]=-1.8



TECHNICAL PARAMETERS

- PSF: LTAO in I band (to minimize the loss of flux from the spaxel)
- AIRMASS = 1.0 & SEEING = 0.8″
- INSTRUMENT EFFICIENCY: 0.28
- Exposure time (20min to 50h)
- Site (Paranal-like; High&Dry)
- Mirror coating (bare Al; Ag/Al)

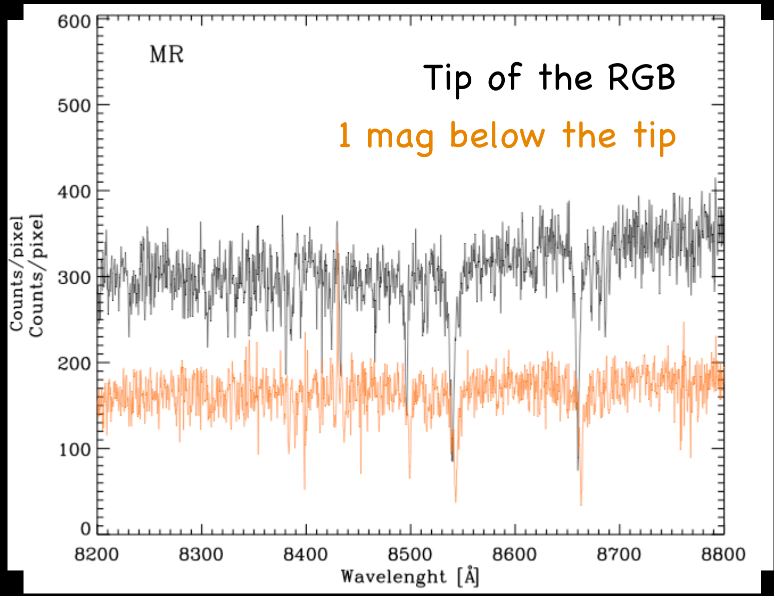


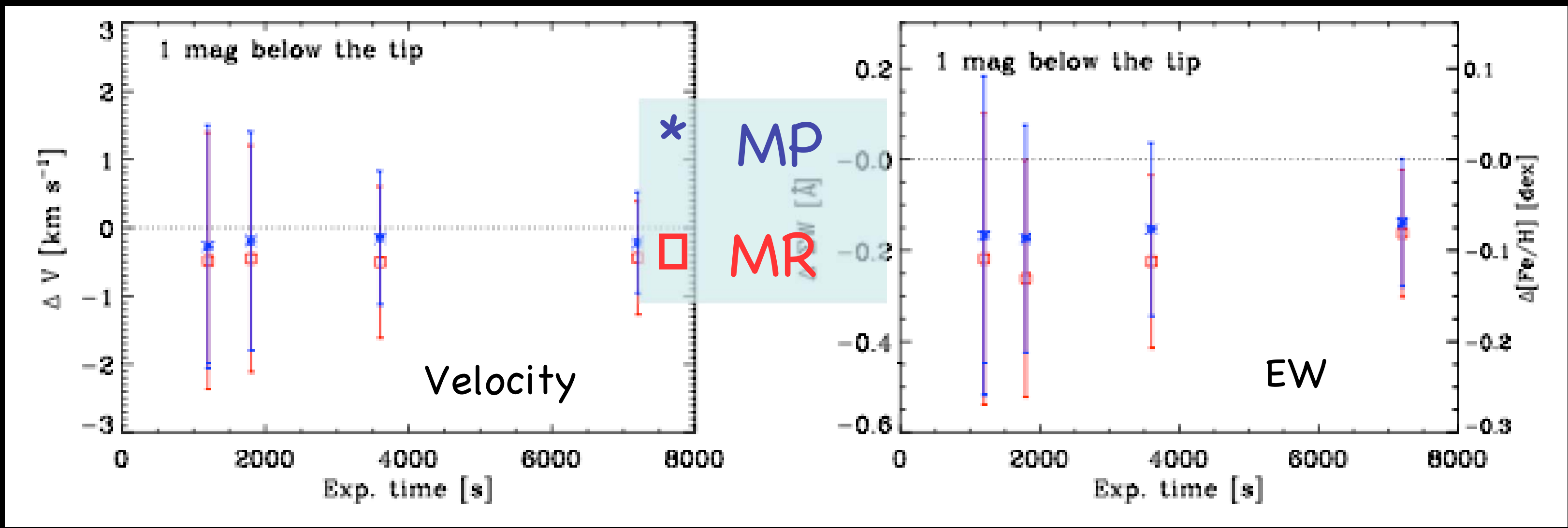
Results

Results for NGC205 (dwarf galaxy in the Local Group)

- Down to 1 mag below the tip (I ~ 21.4)
- Exp. times: 20m, 30m, 1h, 2h
- Stars resolved with a 50 mas spaxel at every radius
- 20min, Paranal-like site, bare Al coating

- 20m exposure time x pointing => ± 2 km/s (required accuracy : ± 5 km/s) ± 0.2 dex (required accuracy : ± 0.3 dex)





Approximate observing time to collect samples of 1000 targets

With a single IFU with 10”x10” field-of-view (spaxel size= 50mas)

NGC205 (10” = 40pc):

Down to 1 mag below the tip, with 20m exp. time per pointing

=> 45 pointings (within 2Re), I.e. 16h exposure time on source (good!)

By integrating on more than 1 spaxel:

-exposure time could be lowered

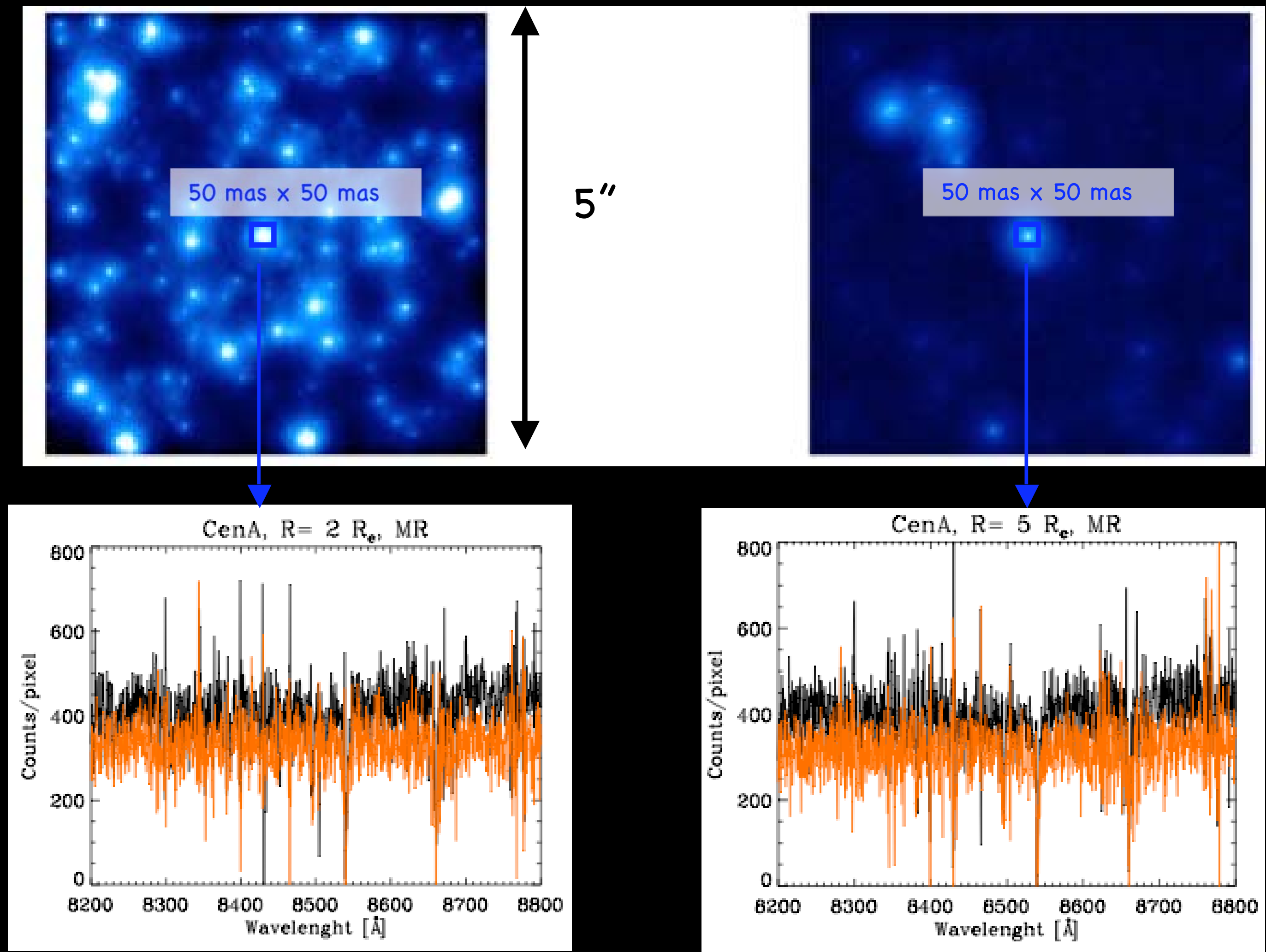
- or fainter magnitudes could be reached

Centaurus A: example of spectra

- Targets: MR and MP RGB down to 0.5 mag below tip (I= 24.4)
- R/Re = 1, 2, 3.5, 5 -> R ~ 6, 12, 22, 31 kpc
- Exp. time: 1h, 2h, 5h

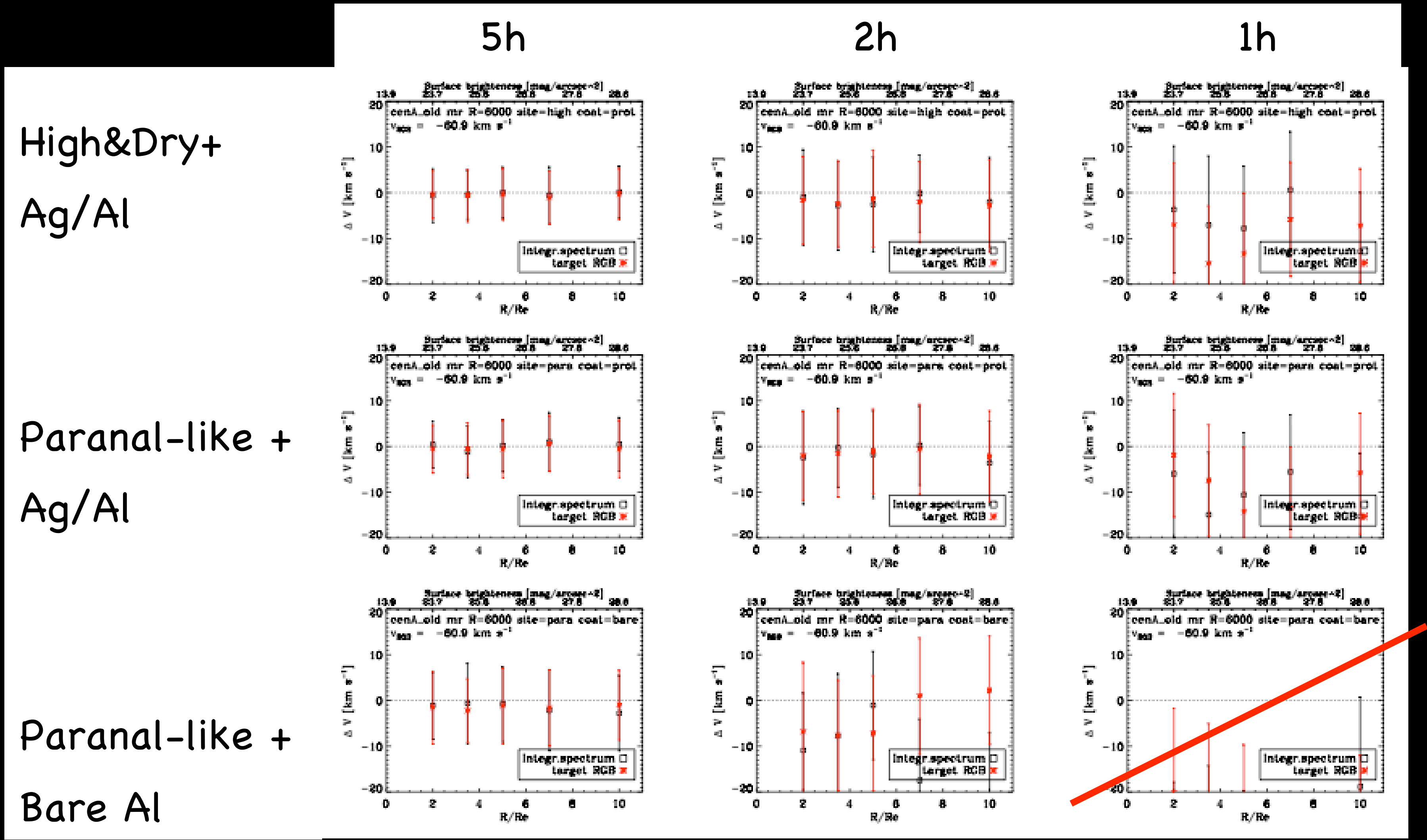
2 Re ~ 12 kpc

5 Re ~ 30 kpc



5h exposure time, Paranal-like, Ag/Al

Centaurus A: distribution of velocity differences (target = 0.5 mag below the RGB tip)

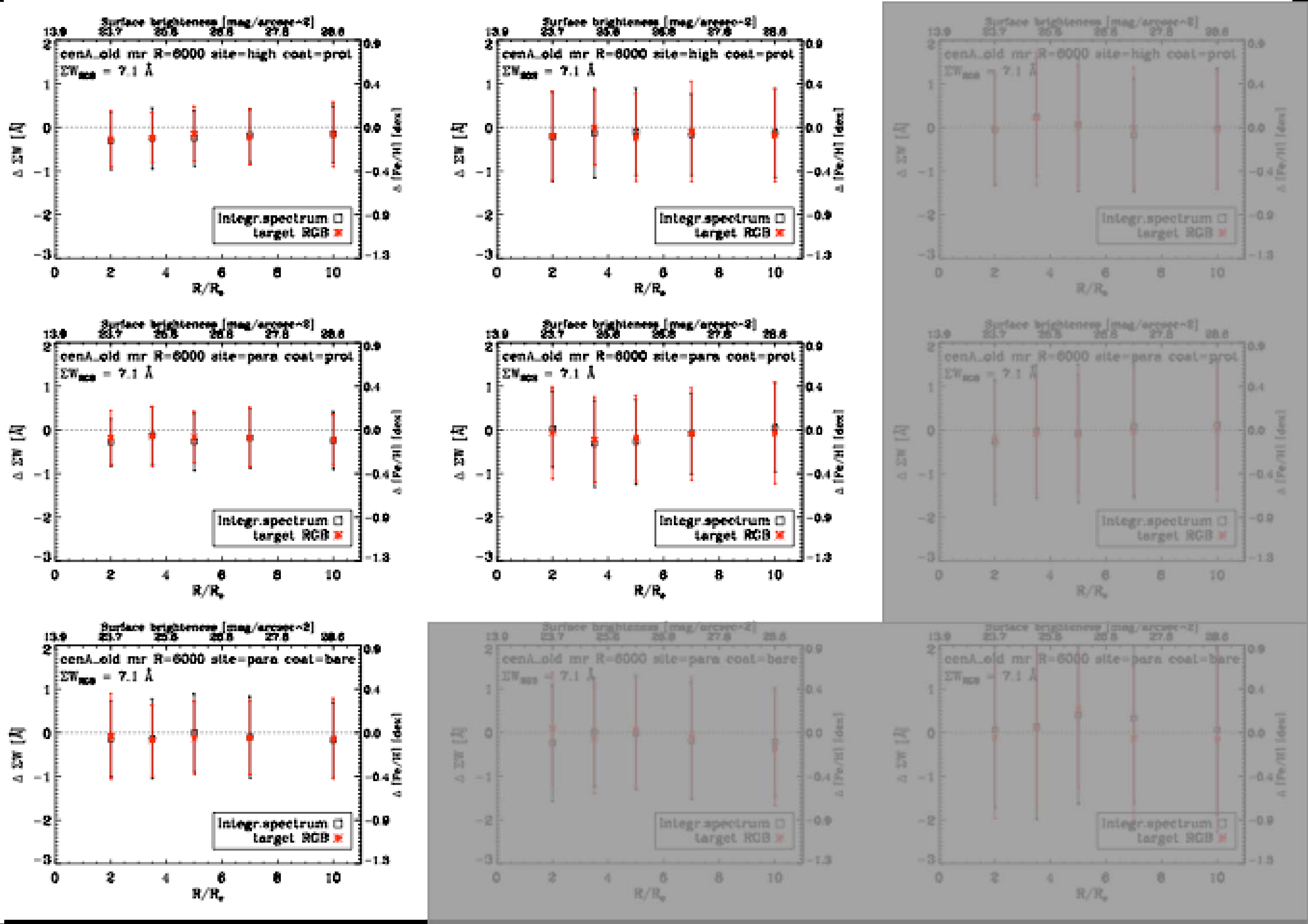


Crowding is not a problem; site not important, coating yes

Centaurus A: distribution of EW differences

(target = 0.5 mag below the RGB tip)

	5h	2h	1h
High&Dry+ Ag/Al			
Paranal-like + Ag/Al			
Paranal-like + Bare Al			



Crowding is not a problem; site not important, coating yes

Approximate observing time to collect samples of 1000 targets

With a single IFU with 10"x10" field-of-view (spaxel size= 50mas)

Centaurus A (10" = 180pc):

Down to 0.5 mag below the tip:

-5h exp. time per pointing (Paranal-like, bare Al), 50 pointings within 5Re
=> 230h on source

-2h exp. time per pointing (Paranal-like, Ag/Al), 50 pointings within 5Re
=> 90h on source (ok time for a normal program at ESO)

By integrating on more than 1 spaxel:

-exposure time could be lowered

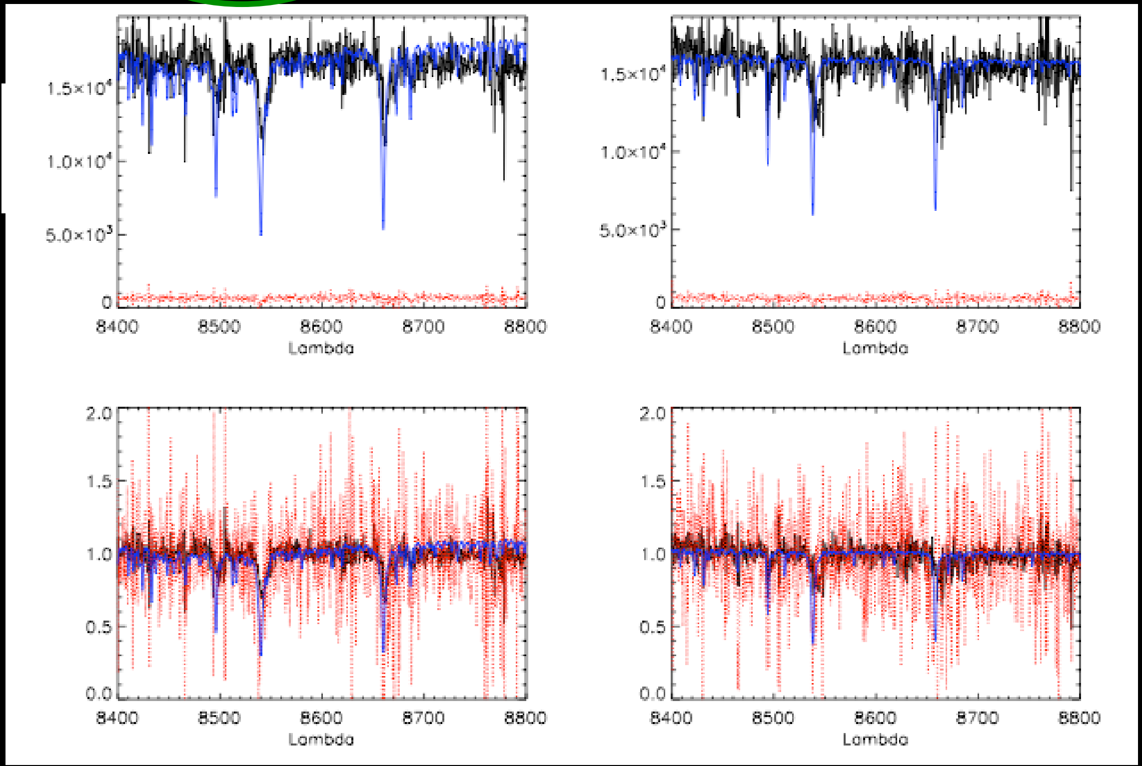
- or fainter magnitudes could be reached

Crowding is not a problem for the region explored (R>= 2 Re) -> need to explore innermost radi

Results for M87 (Virgo): R= 2Re= 18 kpc

- Targets: MR and MP RGB at the tip (down to I = 27.2)
- R/Re = 2 (a lot of crowding)
- Exp. time: 20h, 50h
- Integration on: 1 spaxel, 9 spaxels, 25 spaxels

High&Dry, Ag/Al, 50h, tip of the RGB



-integrated spectrum on 25 spaxels

- integrated spectrum on 1 spaxel

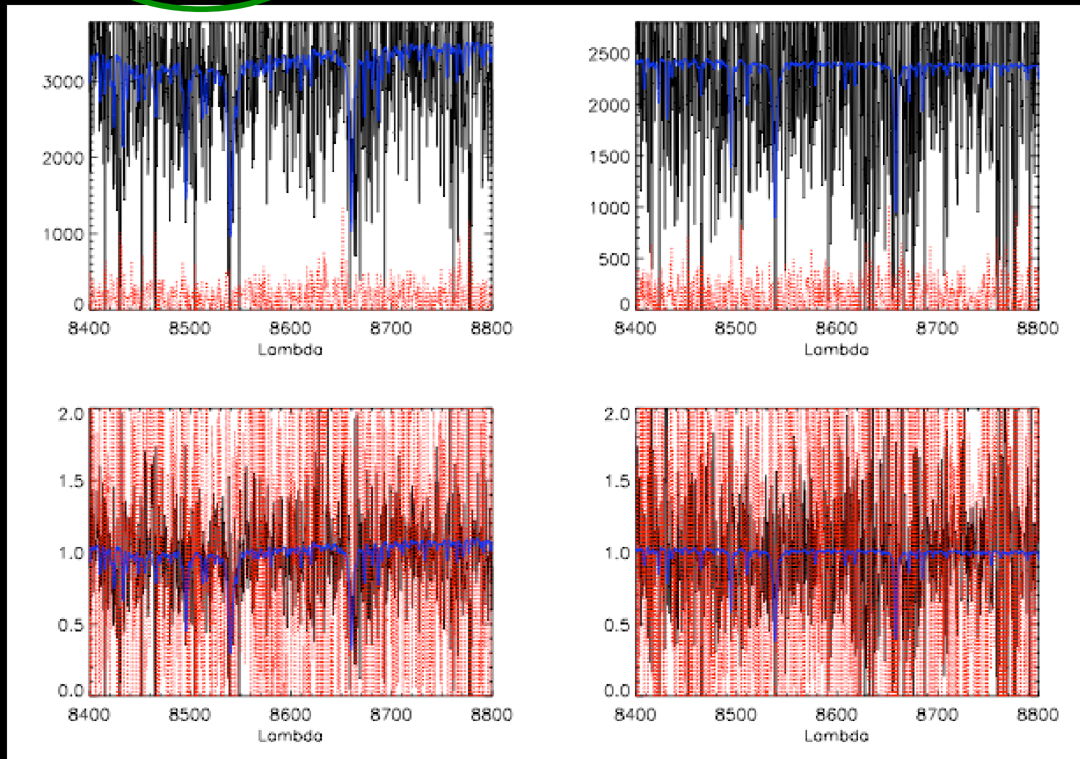
- rescaled spectrum of the target RGB star

Integrated spectrum on 25 spaxels dominated by stellar background

Results for M87 (Virgo): R= 5Re = 45 kpc

- Targets: MR and MP RGB at the tip (down to I = 27.2)
- R/Re = 5 (not so much crowding)
- Exp. time: 20h, 50h
- Integration on: 1 ~~spaxel~~, 9 spaxels, 25 spaxels

High&Dry, Ag/Al, 50h, tip of the RGB



-integrated spectrum on 25 spaxels

- integrated spectrum on 1 spaxel

- rescaled spectrum of the target RGB star

Integrated spectrum on 25 spaxels considerable improvement

Summary & prospects

- Local Group dwarf and CenA: CaT surveys of large numbers of individual stars are feasible (crowding is not a problem for the explored instrument configuration)

- M87: challenging (too much crowding in the inner regions, low s/n in the outer parts where crowding is not a problem)

1) look for [Fe/H] indicator in IR in alternative to CaT?
2) AGB stars instead than RGB stars for intermediate stellar populations?

Sensitivity to input parameters

SITE: negligible influence

MIRRORS COATING:

Appears to be important for

-CenA => reduced exp. time per pointing from 5h to 2h

FIELD-OF-VIEW:

A 10"x10" field-of-view is sufficient in most cases.

Given the goal of acquiring large number of targets over large areas,

a larger field-of-view (or multi-IFUs) would allow shorter exposure times

INSTRUMENT EFFICIENCY:

M87 case appears to be "border-line" -> important to have values as realistic as possible

Type of AO:

May have an important effect where crowding starts becoming an issue

ESO

European Organisation for Astronomical Research in the Southern Hemisphere

More information?

- The public web pages: http://www.eso.org/public/astronomy/projects/e-elt.html
- The science users web pages: http://www.eso.org/sci/facilities/eelt/
- Brochures, Posters, etc: http://www.eso.org/public/outreach/products/publ/brochures/index.html
- Gallery: http://www.eso.org/gallery/v/ESOPIA/EELT
- Watch out for science meetings every year