



DRM simulations for  
intermediate resolution spectroscopy  
of resolved stellar populations  
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Thanks to:

Markus Kissler-Patig

Eline Tolstoy

Joe Liske

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

## 1. Photometry ->

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

## 2. Intermediate resolution spectroscopy ->

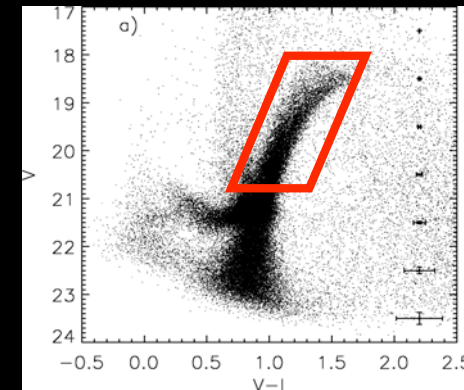
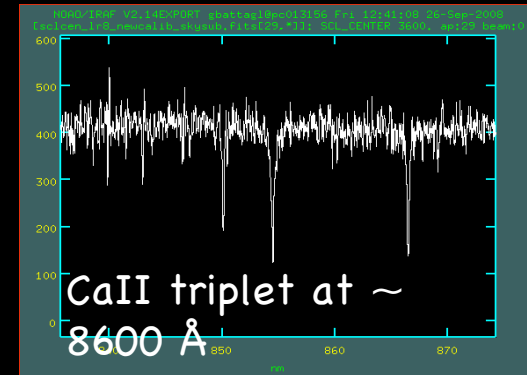
Goal: large scale metallicity and kinematic properties of galaxies out to the Virgo cluster (G.Battaglia)

## 3. High resolution spectroscopy ->

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

# Generalities

- **AIM:** collect about 1000 [Fe/H] and l.o.s. vel of individual stars in galaxies out to the Virgo cluster, possibly over a large portion of the galaxy
- 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 =  $10'' \times 10''$
  - Spatial pixel (spaxel) size =  $50 \text{ mas} \times 50 \text{ mas}$



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 :

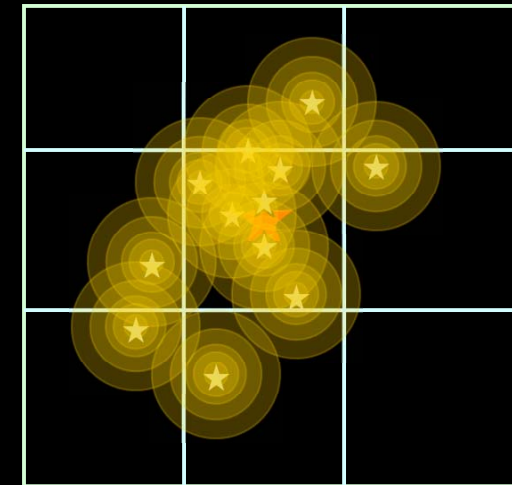
20.6

23.9

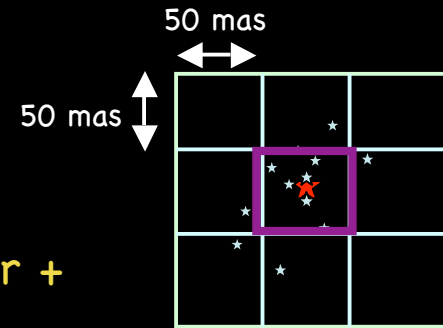
27.2

- 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 J. Liske & E.Tolstoy (need to fix the stellar population, surface brightness, distance modulus and internal kinematics)
  - 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  $(V_{\text{los\_simulated}} - V_{\text{los\_input}})$   
and  $(\Sigma W_{\text{simulated}} - \Sigma W_{\text{input}})$  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  $\Sigma W$  if they agree with the input values within
  - 0.7 Å -> 0.3 dex (  $\Delta[\text{Fe}/\text{H}] = 0.44 \times \Delta\Sigma W$  )
  - 20 km/s (large galaxies); 5 km/s (dwarf galaxies)(this is similar to accuracies of current studies)
- **EXPOSURE TIME (on source):** < 100 h on source to observe 1000 individual RGB stars per galaxy

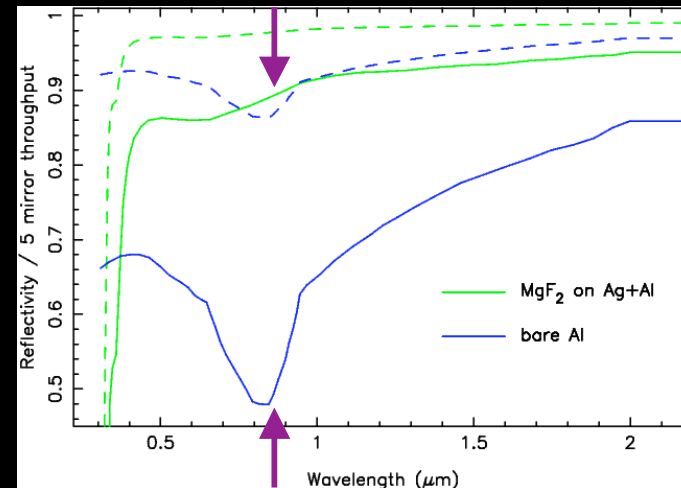
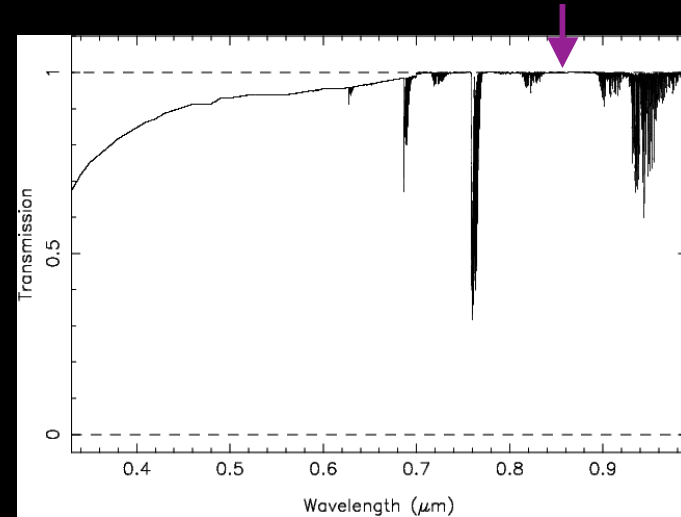
# Explored parameter space

## SCIENTIFIC PARAMETERS

- Objects: NGC205 (dwarf elliptical → dispersion = 35 km/s), CenA and M87 (large ellipticals → dispersion = 100 km/s)
- 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)

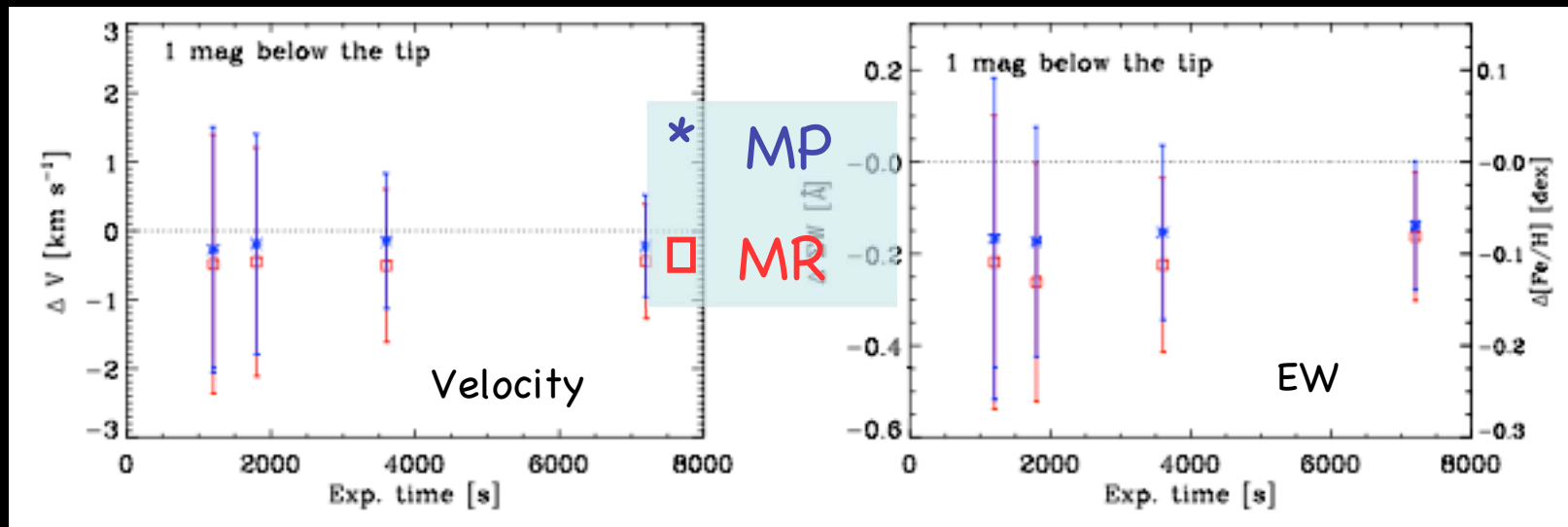
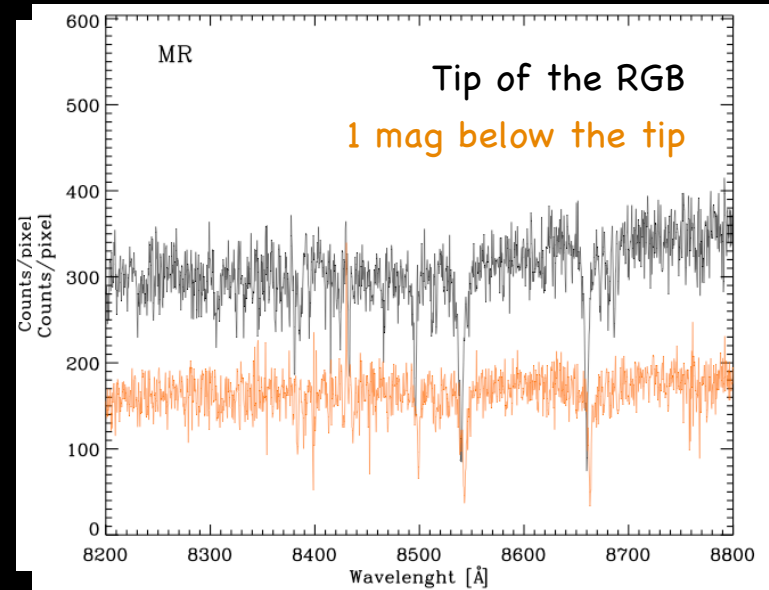


# Results



# Results for NGC205 (dwarf galaxy in the Local Group)

- Down to 1 mag below the tip  
( $I \sim 21.4$ )
- 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  $\Rightarrow$   
 $\pm 2$  km/s (required accuracy :  $\pm 5$  km/s)  
 $\pm 0.2$  dex (required accuracy :  $\pm 0.3$  dex)



## Approximate observing time to collect samples of 1000 targets

With a single IFU with 10" x 10" 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  $2R_e$ ), I.e. 16h exposure time on source (good!)

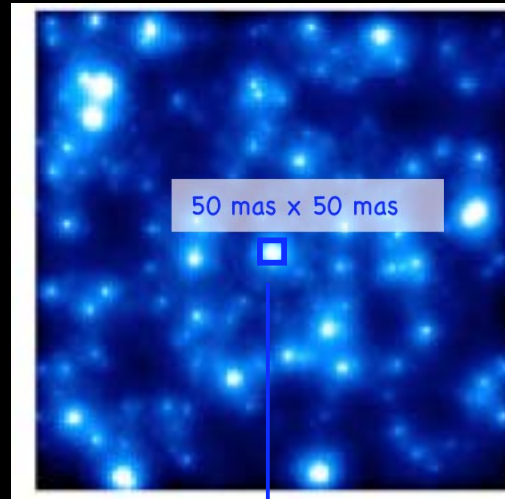
By integrating on more than 1 spaxel:

- exposure time could be lowered
- or fainter magnitudes could be reached

# Centaurus A: example of spectra

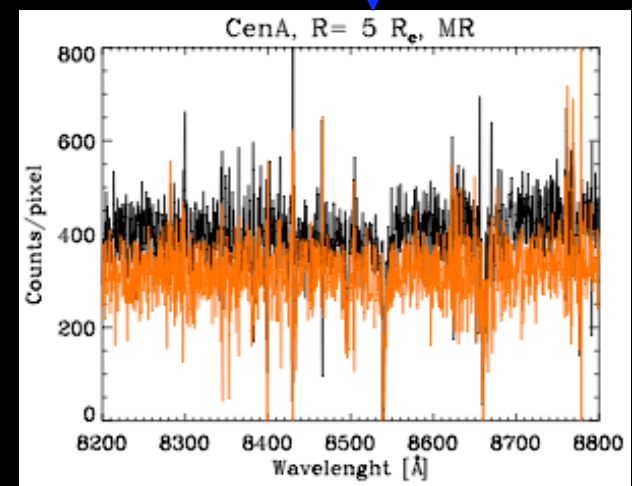
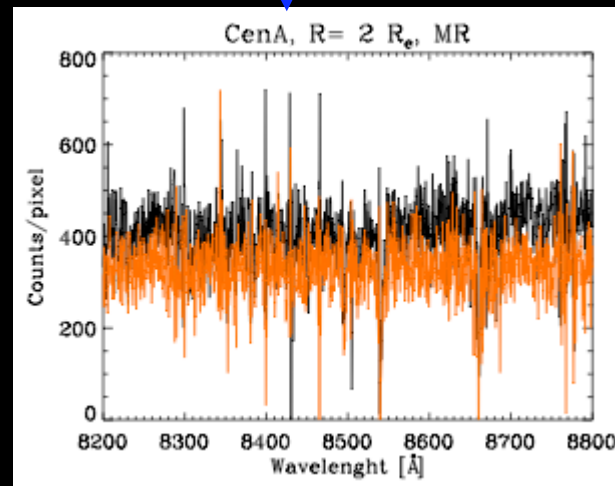
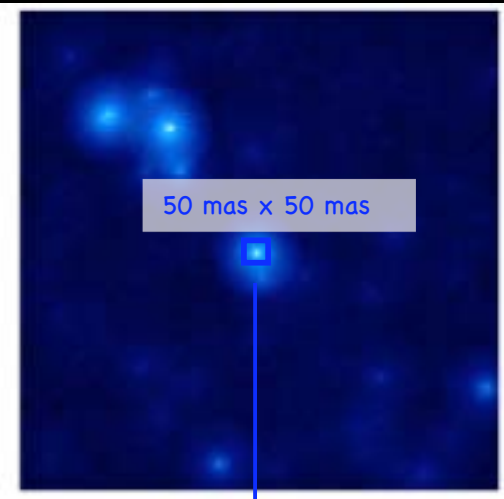
- Targets: MR and MP  
RGB down to 0.5 mag  
below tip  
( $I = 24.4$ )
- $R/R_e = 1, 2, 3.5, 5..$  -  
>  $R \sim 6, 12, 22, 31..$   
kpc
- Exp. time: 1h, 2h, 5h

$2 R_e \sim 12$  kpc



$5''$

$5 R_e \sim 30$  kpc



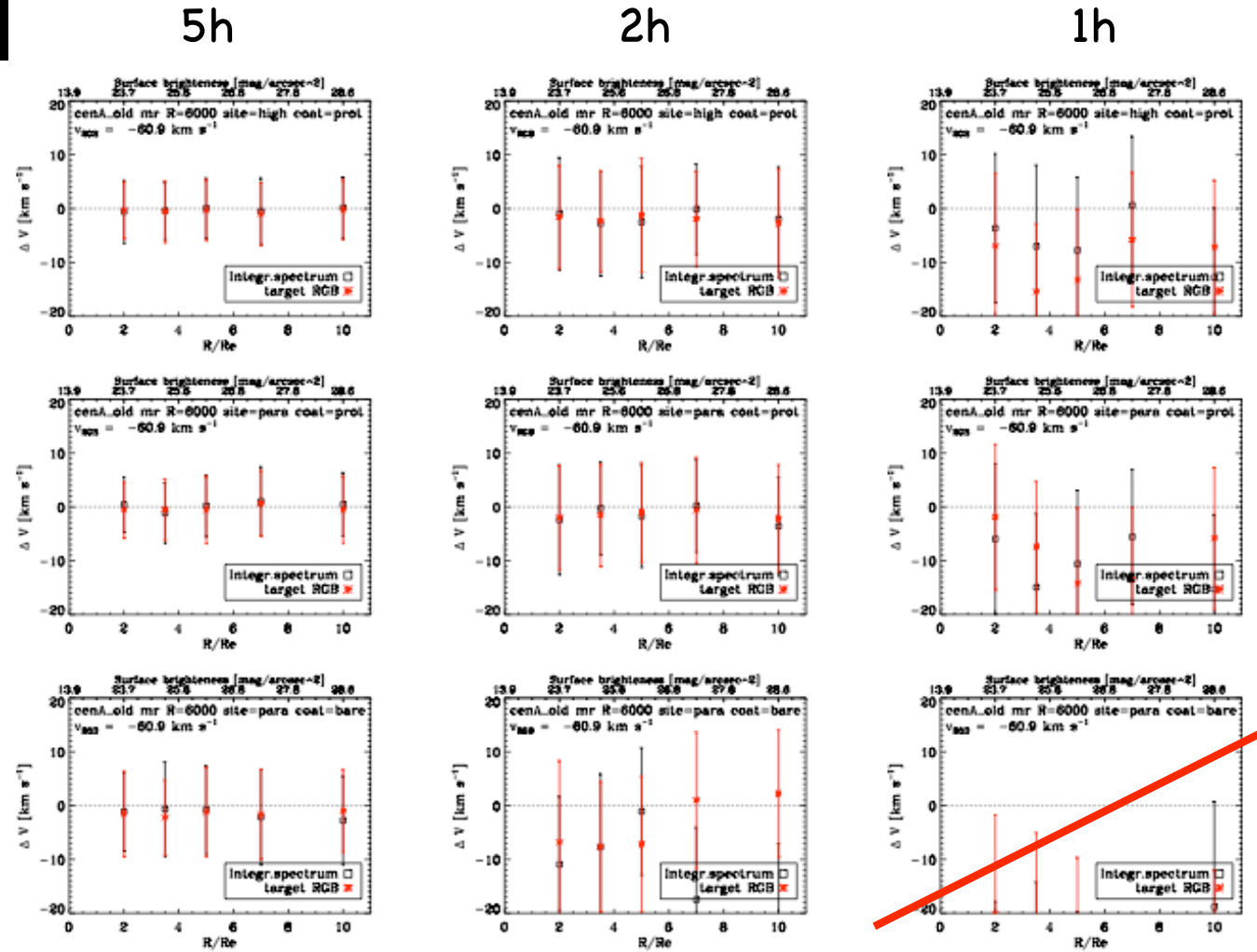
5h exposure time, Paranal-like, Ag/Al

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

High&Dry+  
Ag/Al

Paranal-like +  
Ag/Al

Paranal-like +  
Bare Al



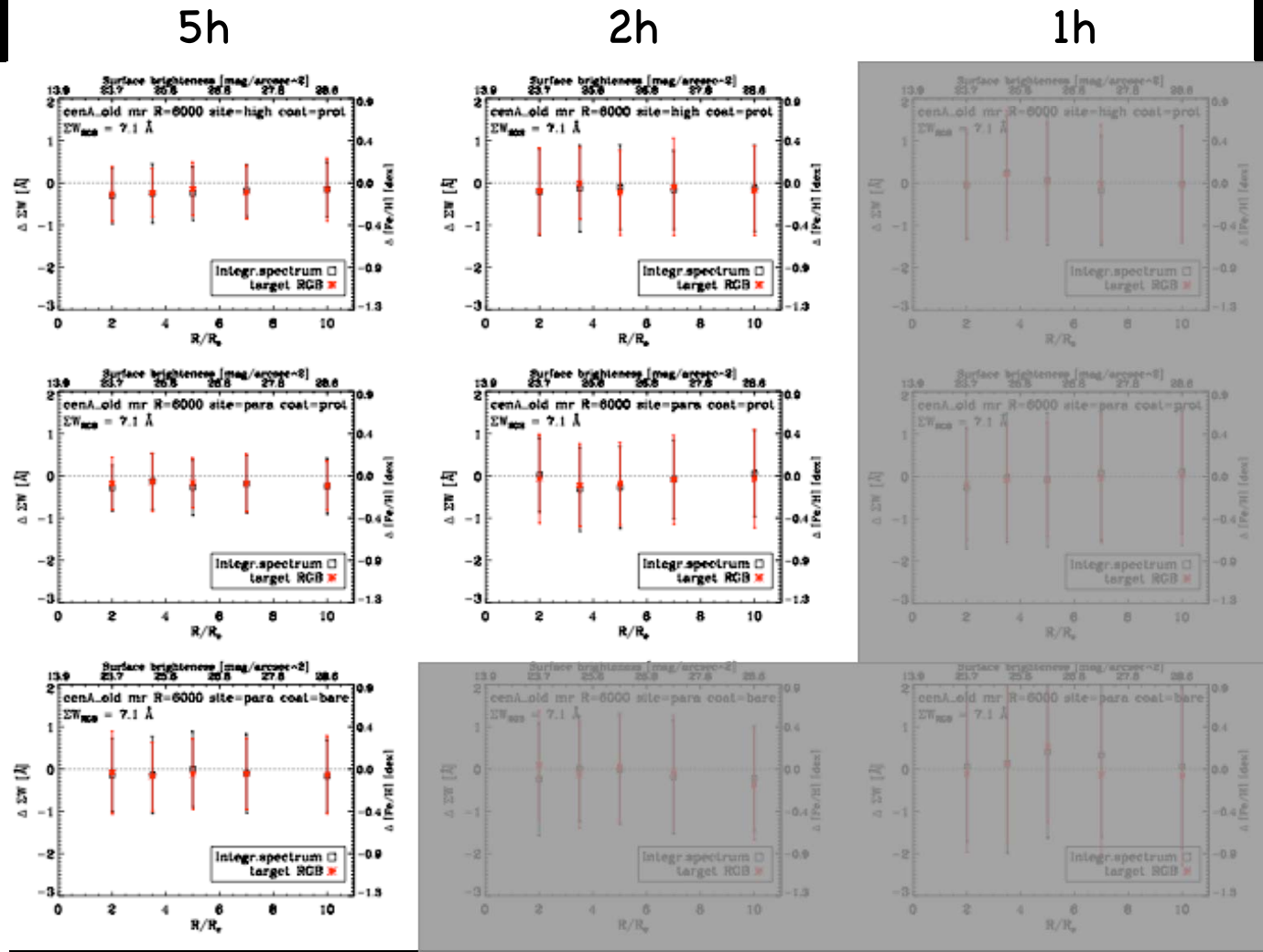
Crowding is not a problem; site not important, coating yes

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

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" x 10" 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 A1), 50 pointings within 5Re  
=> 230h on source

-2h exp. time per pointing (Paranal-like, Ag/A1), 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 ( $R \geq 2 R_e$ ) -> need to explore innermost radii

# Results for M87 (Virgo): $R = 2R_e = 18$ kpc

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

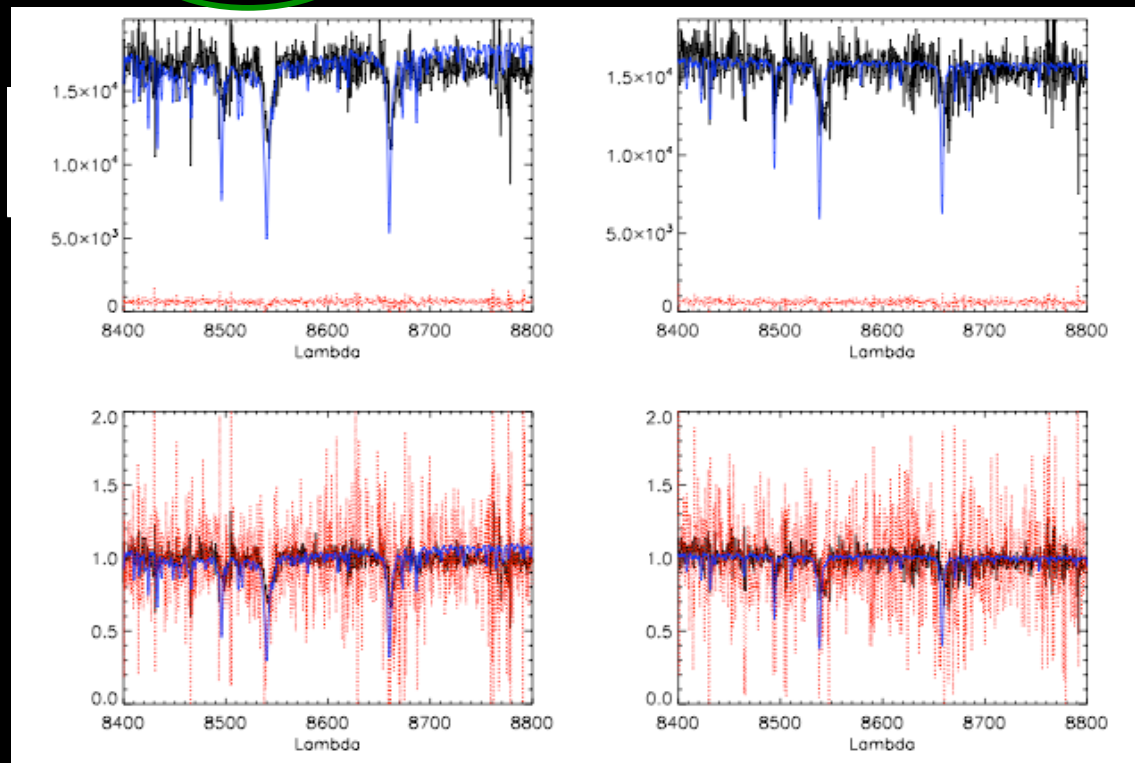
High&Dry, Ag/Al, 50h, tip of the RGB

-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): $R = 5R_e = 45$ kpc

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

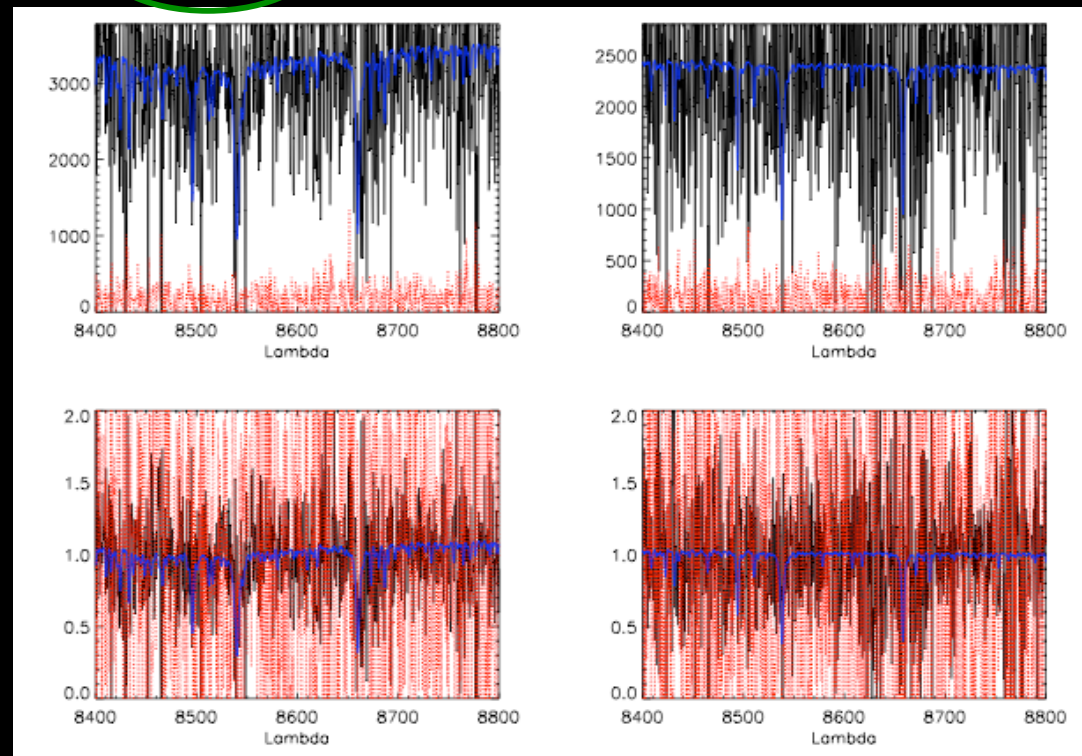
High&Dry, Ag/Al, 50h, tip of the RGB

-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

- **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)

## Some possible prospects/improvements

- 1) look for [Fe/H] indicator in IR in alternative to CaT?
- 2) AGB stars instead than RGB stars for intermediate stellar populations?
- 3) Better way to solve crowding issue?

# Sensitivity to input parameters

SITE: negligible influence

MIRRORS COATING:

Appears to be important for

-CenA => reduced exp. time per pointing (e.g. 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

# Resolved stellar populations: 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 -> out to the Virgo cluster