muse

multi unit spectroscopic explorer

Resolving stellar populations with MUSE

- Sebastian Kamann for the MUSE Team
- with contributions from
  T.-O. Husser, M. M. Roth, P. Weilbacher, R. Bacon

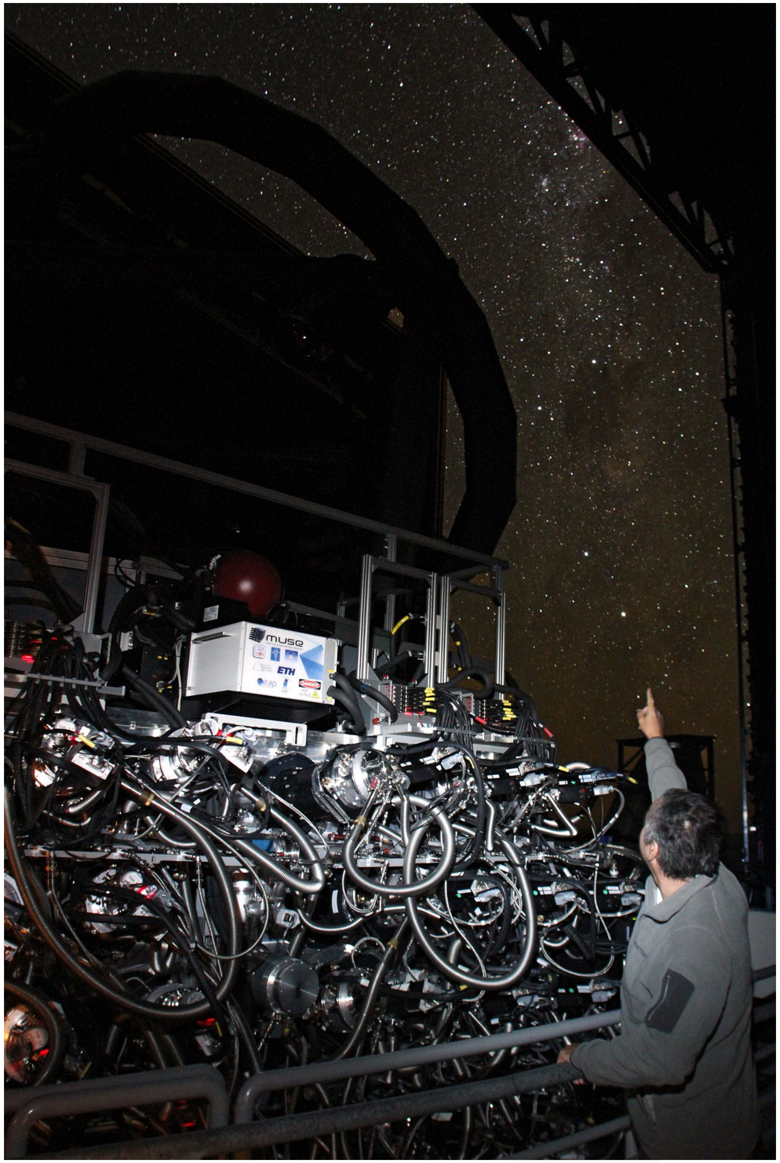
INSTITUT FÜR ASTROPHYSIK GÖTTINGEN

MUSE in a nutshell

- panoramic IFS
- combination of 24 IFUs
- 1'x1' FoV with 0.2” sampling
- λ ~ 4800Å – 9300Å
- R ~ 1770 – 3590

- very stable
- high throughput
- excellent optical quality

- “point and shoot”



“High-redshift machine”

- designed for 3D spectroscopy with unprecedented depth

Crowded stellar fields

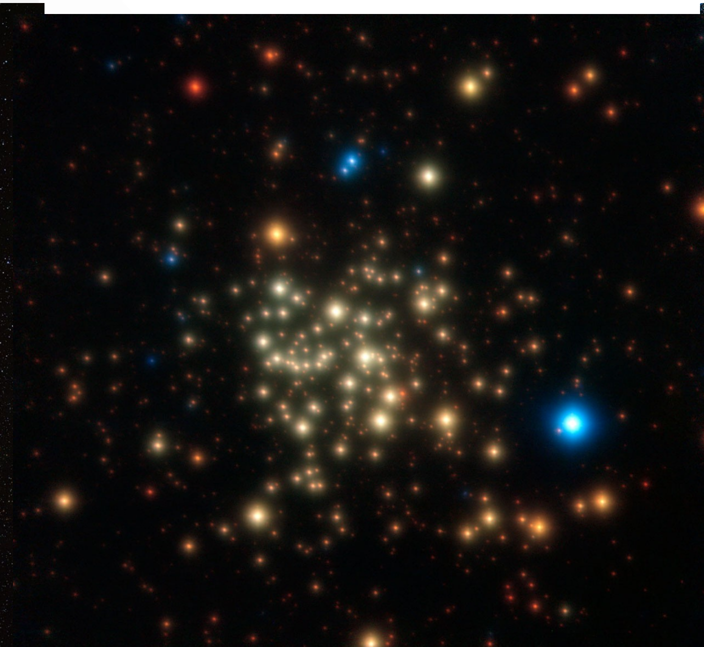
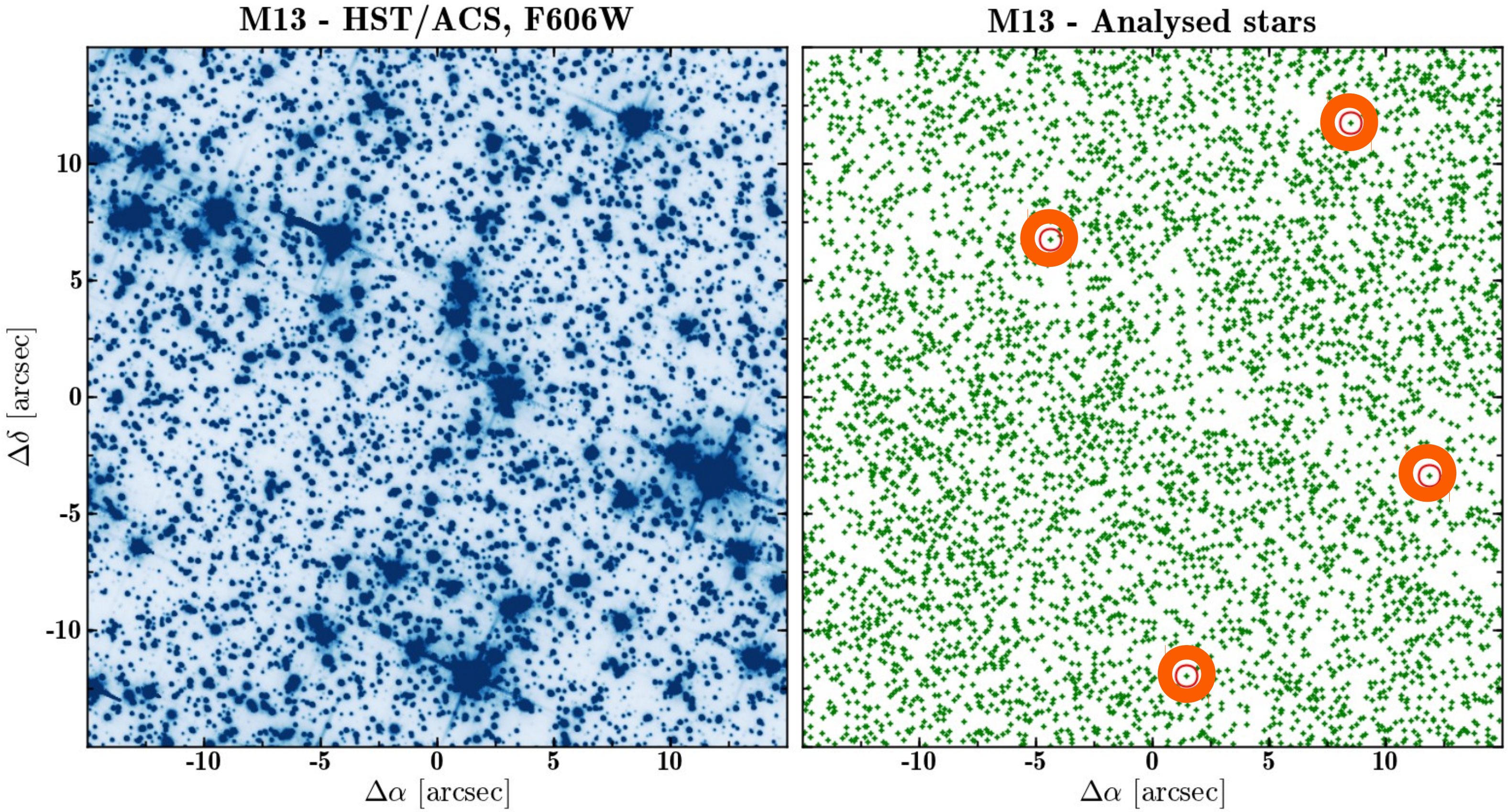


Image credit:
ESO

Problem: crowded field spectroscopy

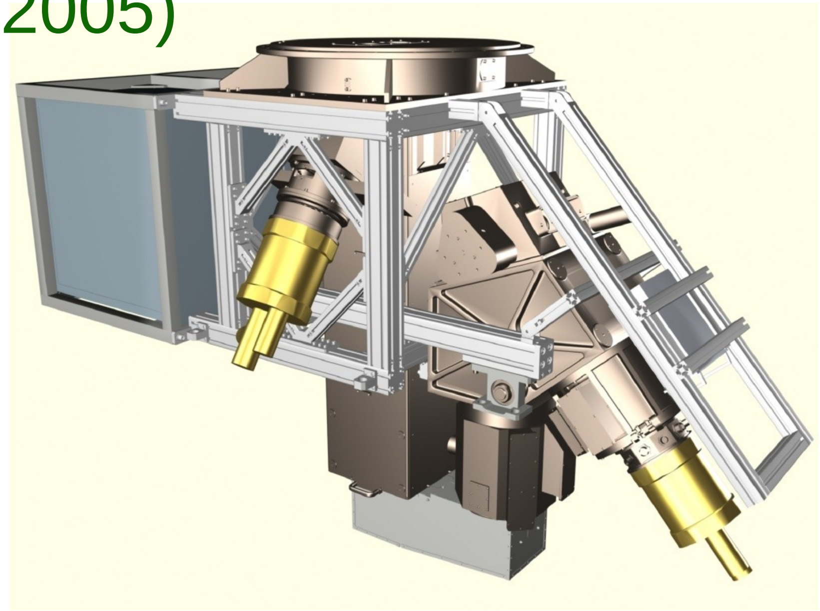
- traditional spectroscopy fails in crowded fields → few spectra
- Photometric vs. spectroscopic samples in the centre of M13:

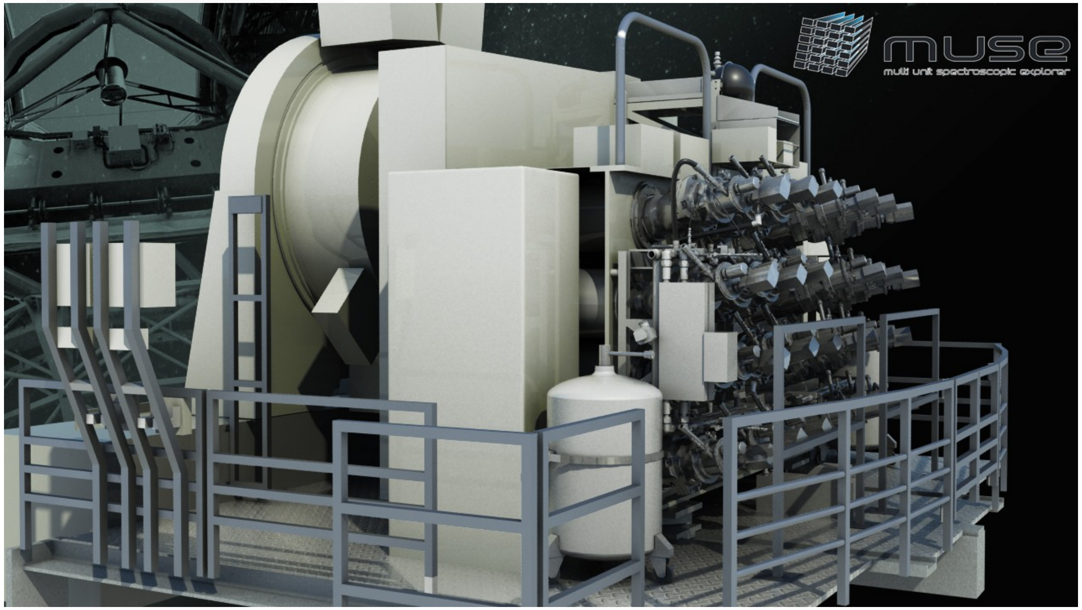


- **Solution:** IFS & PSF-fitting techniques

Why does MUSE make a difference?

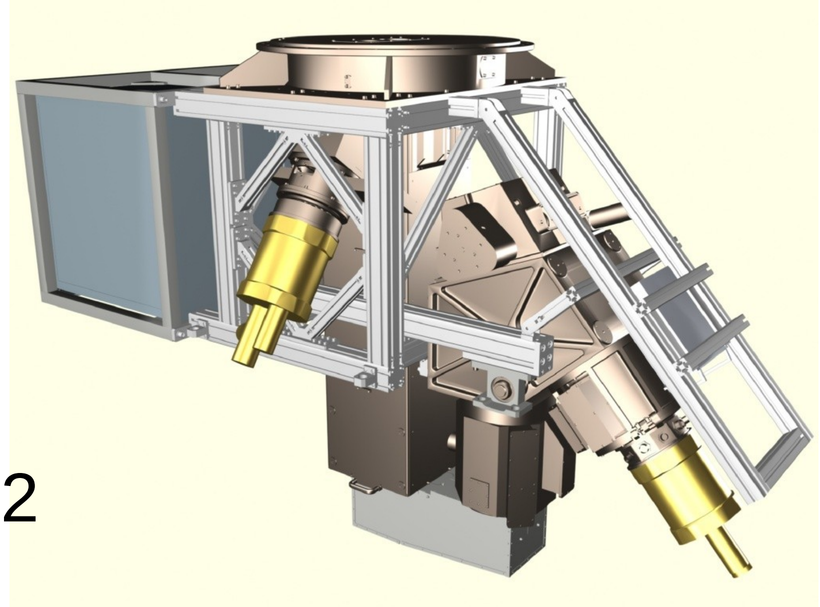
- Comparison to PMAS (Roth et al. 2005)



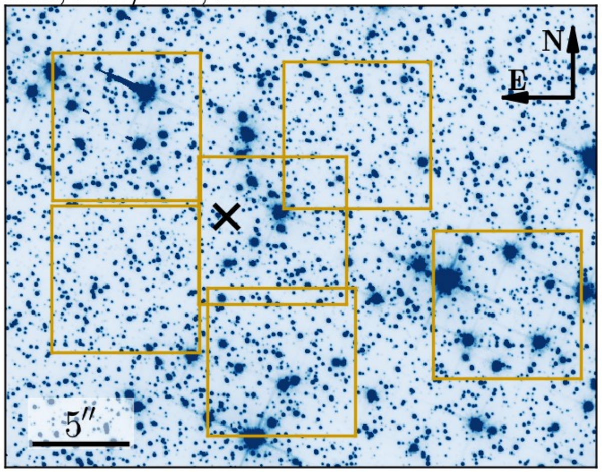


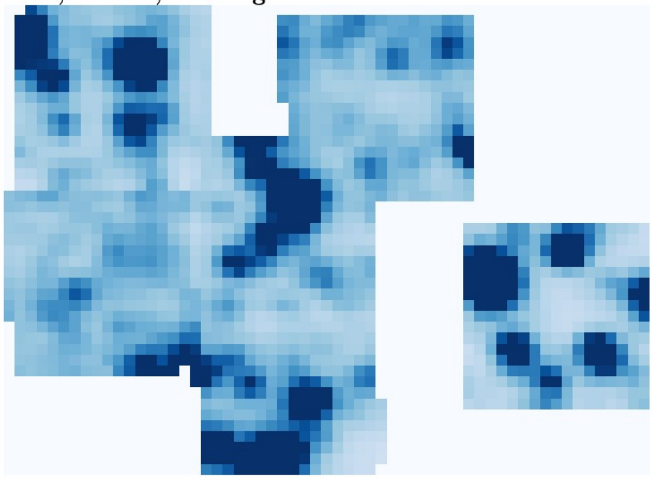
PMAS observations of globular clusters

- PMAS (Roth et al. 2005):
  - Calar Alto 3.5m telescope
  - 16x16 spaxel
  - R~7000 at Ca_{II} triplet



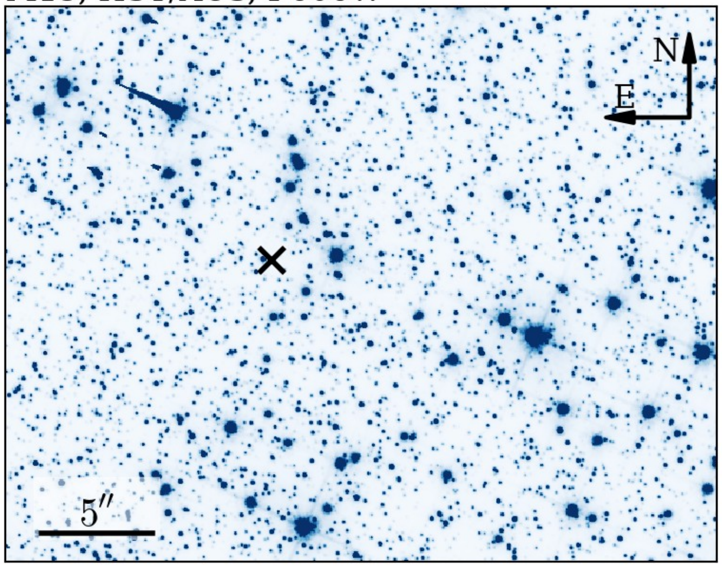
- Observations of M3, M13, and M92
- e.g. dataset for M13:





The method (Kamann et al. 2013)

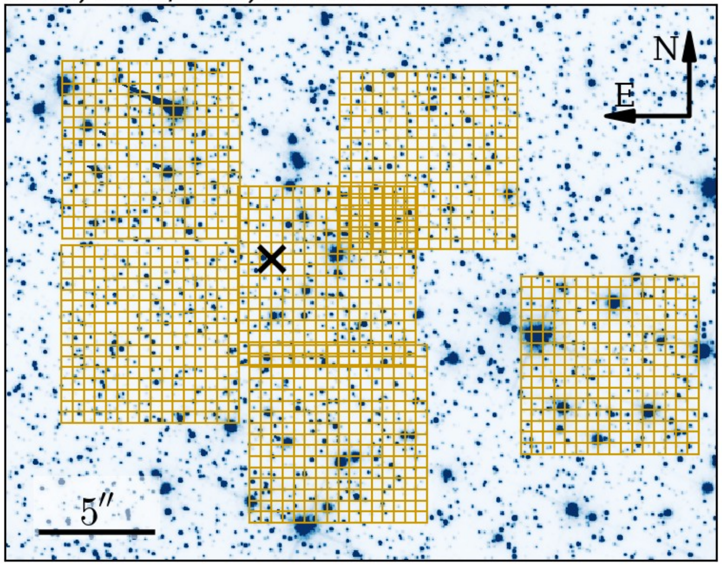
- start from astrometry



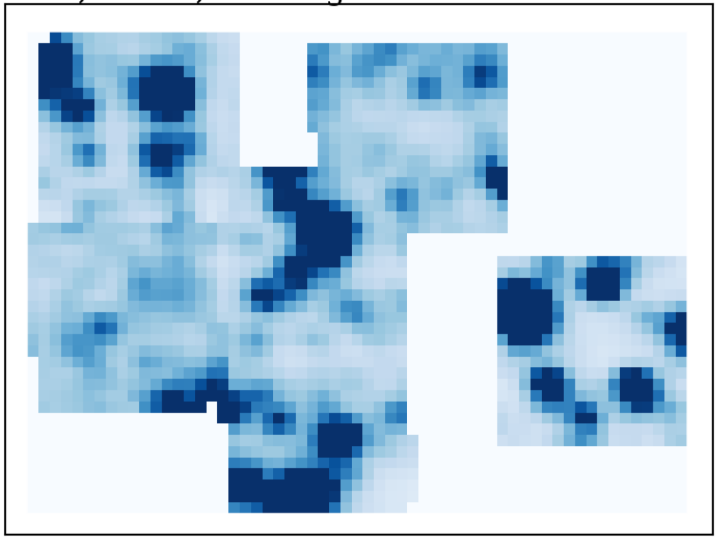
The method (Kamann et al. 2013)

- start from astrometry
- make observations

M13, HST/ACS, F606W



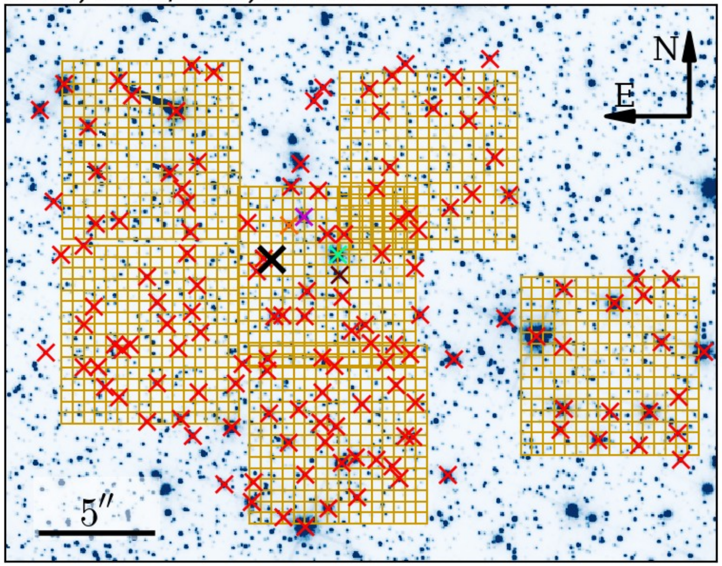
M13, PMAS, whitelight



The method (Kamann et al. 2013)

- start from astrometry
- make observations
- identify sources

M13, HST/ACS, F606W



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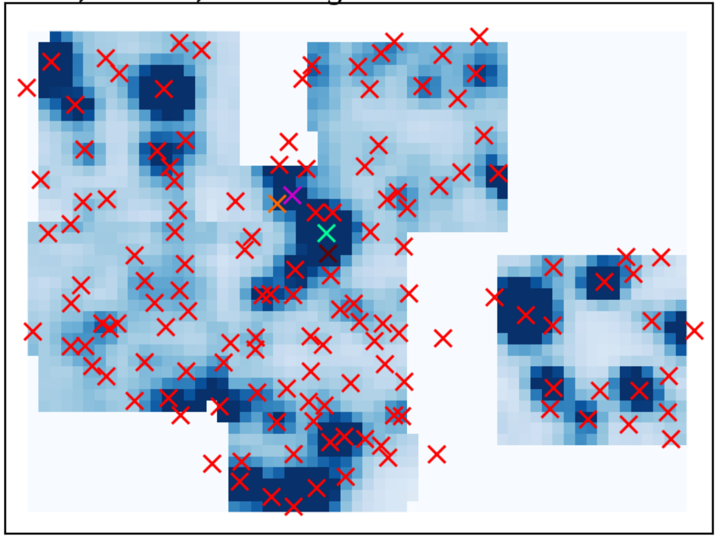
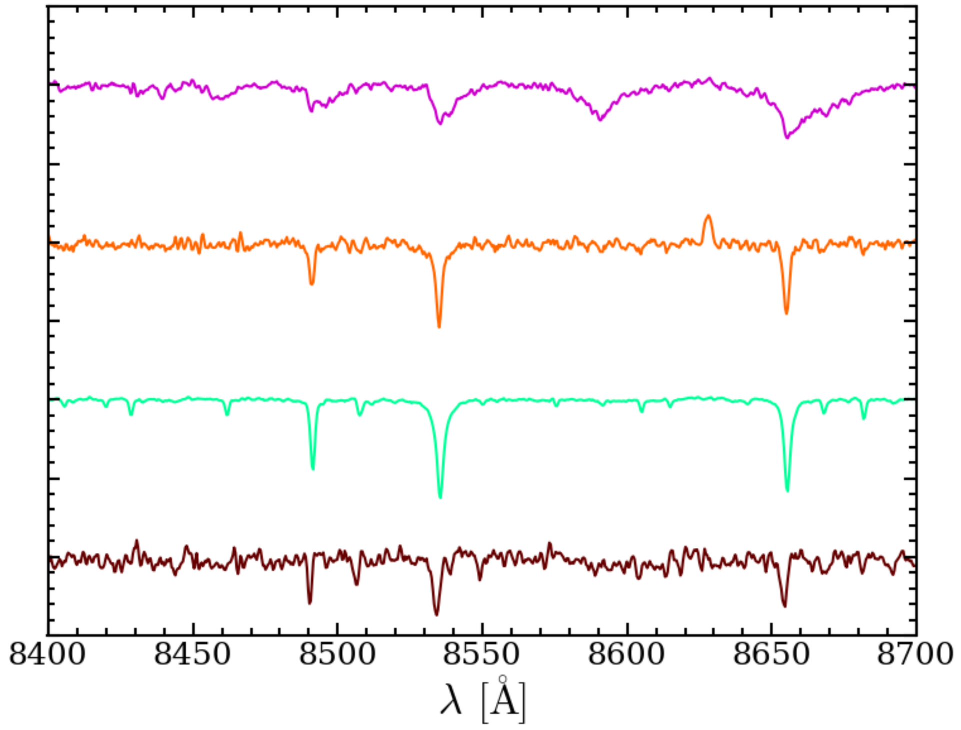
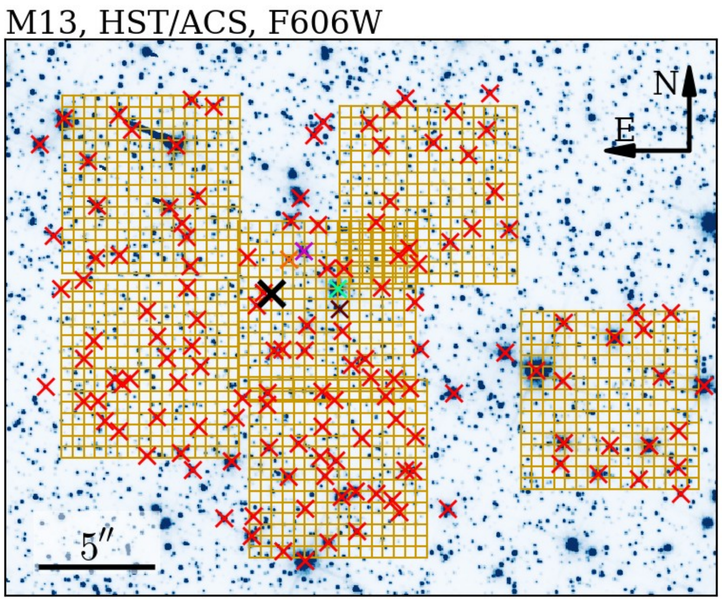
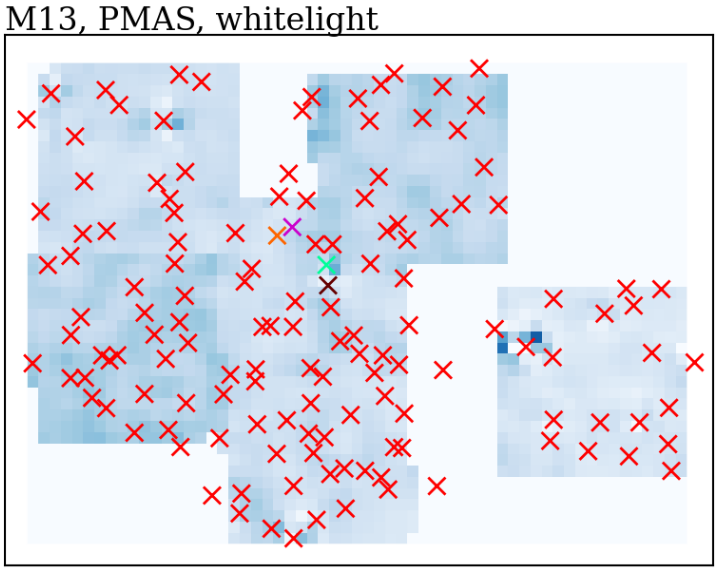


The method (Kamann et al. 2013)

- start from astrometry
- make observations
- identify sources
- deblend all simultaneously







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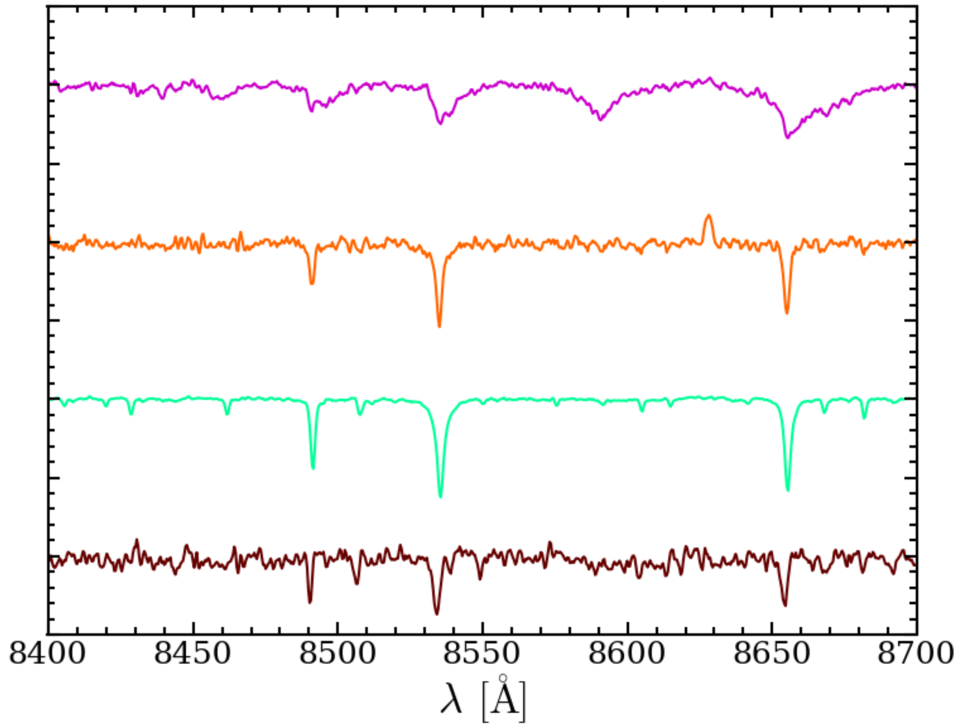
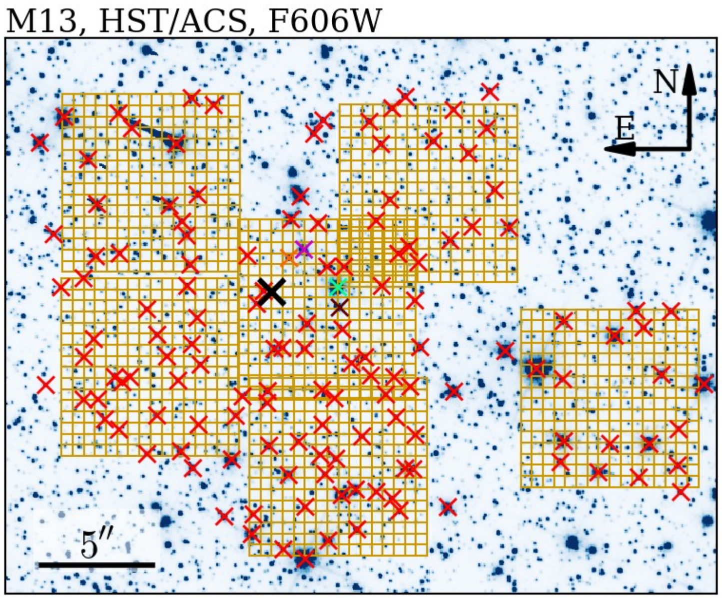
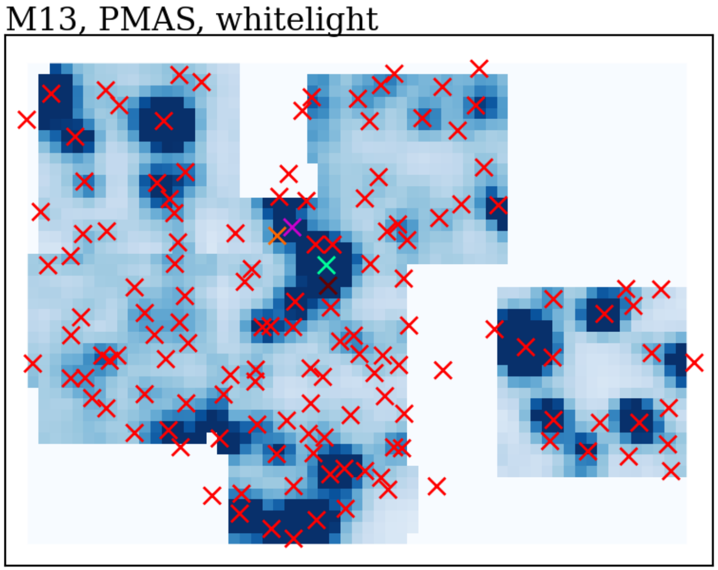






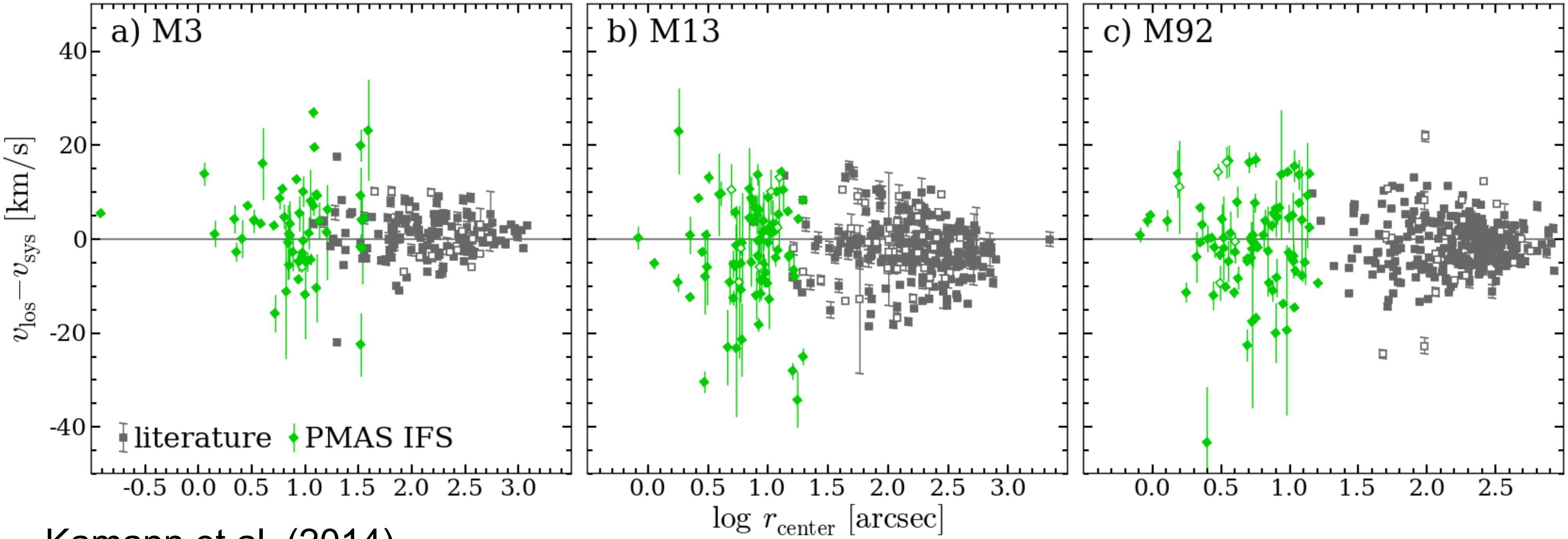
Some details...

- many advantages compared to simpler approaches:
  - automatic sky subtraction
  - automatic subtraction of stellar background
  - wavelength dependencies (PSF, DAR) correctly handled
  - S/N optimization

- PampelMuse
  - Potsdam Advanced Multi-PSF Extraction Algorithm for MUSE
  - computationally very efficient
  - extensively tested using simulated and real data
    - PMAS, ARGUS, KMOS, MUSE
  - plan to publish it

Radial velocities

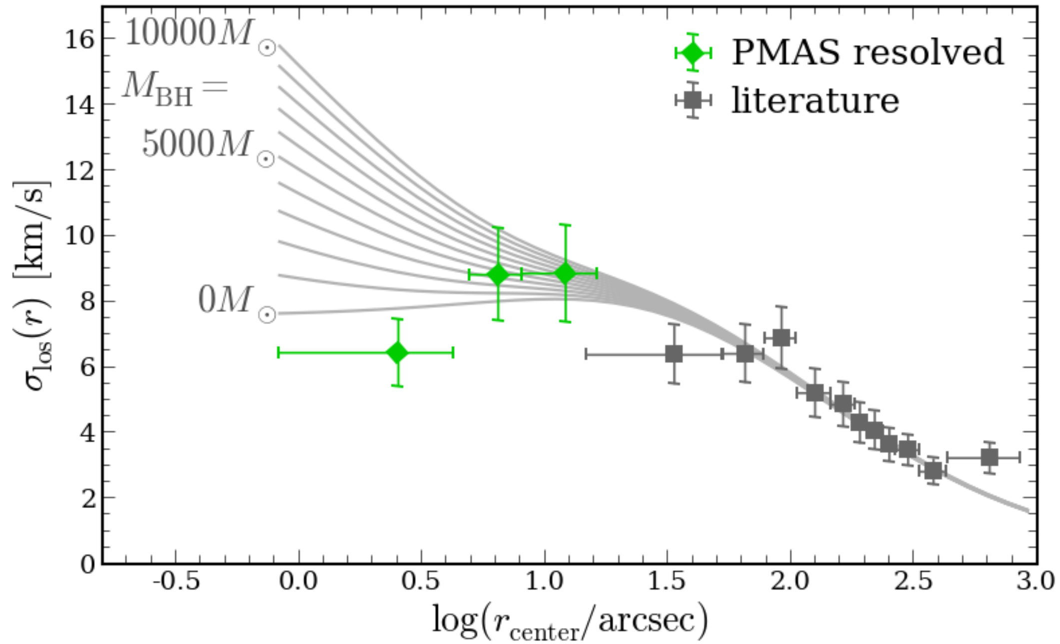
- measured for ~80 stars per cluster
- complementary to existing data
- different S/N ratios → uncertainties ≤10km/s



Kamann et al. (2014)

Constraints on black hole masses

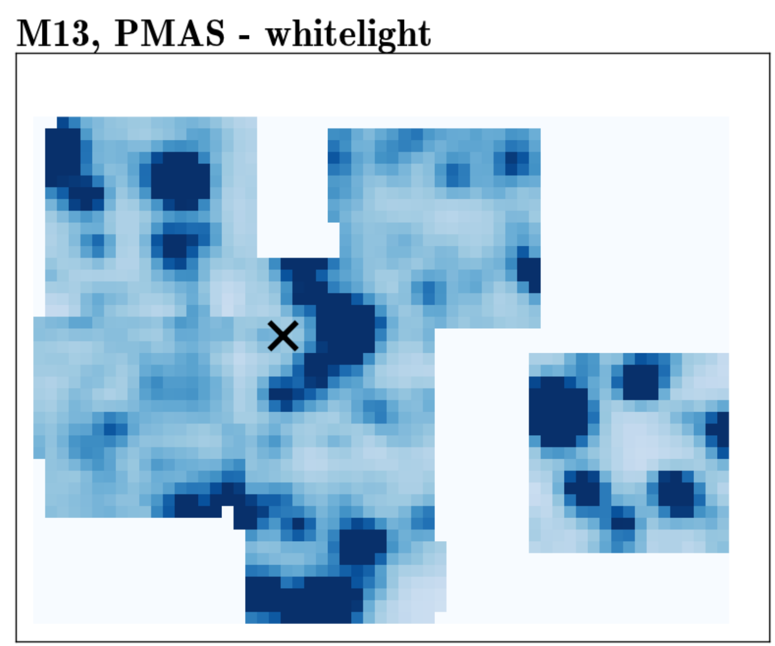
- Measured velocity dispersions compared to models with different black hole masses:
  - **for M92: M_{BH} < 980 M_{sun}**
  - less stringent constraints (~8000 M_{sun}) for M3 & M13



- Comparison with other studies:
  - M92 limit among most stringent obtained so far
  - despite 3.5m telescope, no AO, mediocre seeing
  - shows huge potential of approach

Why MUSE makes a difference

- >2 nights of PMAS:



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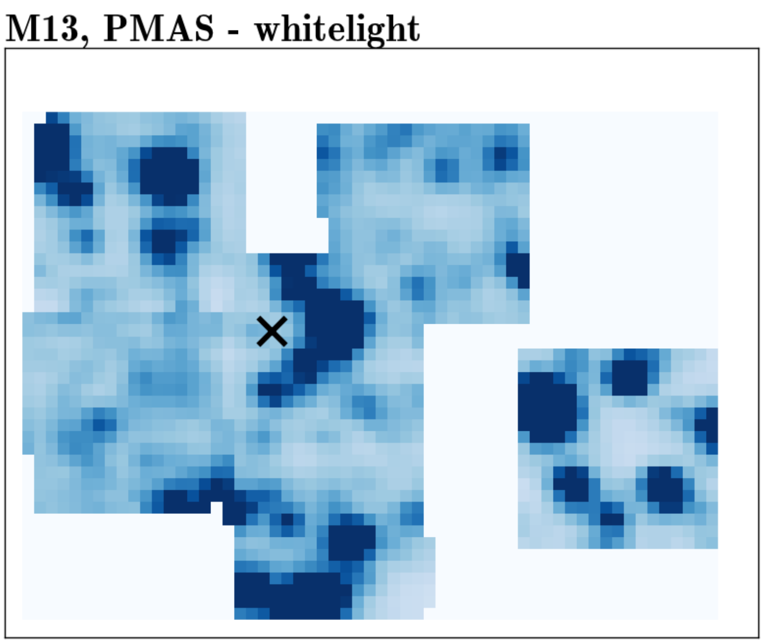
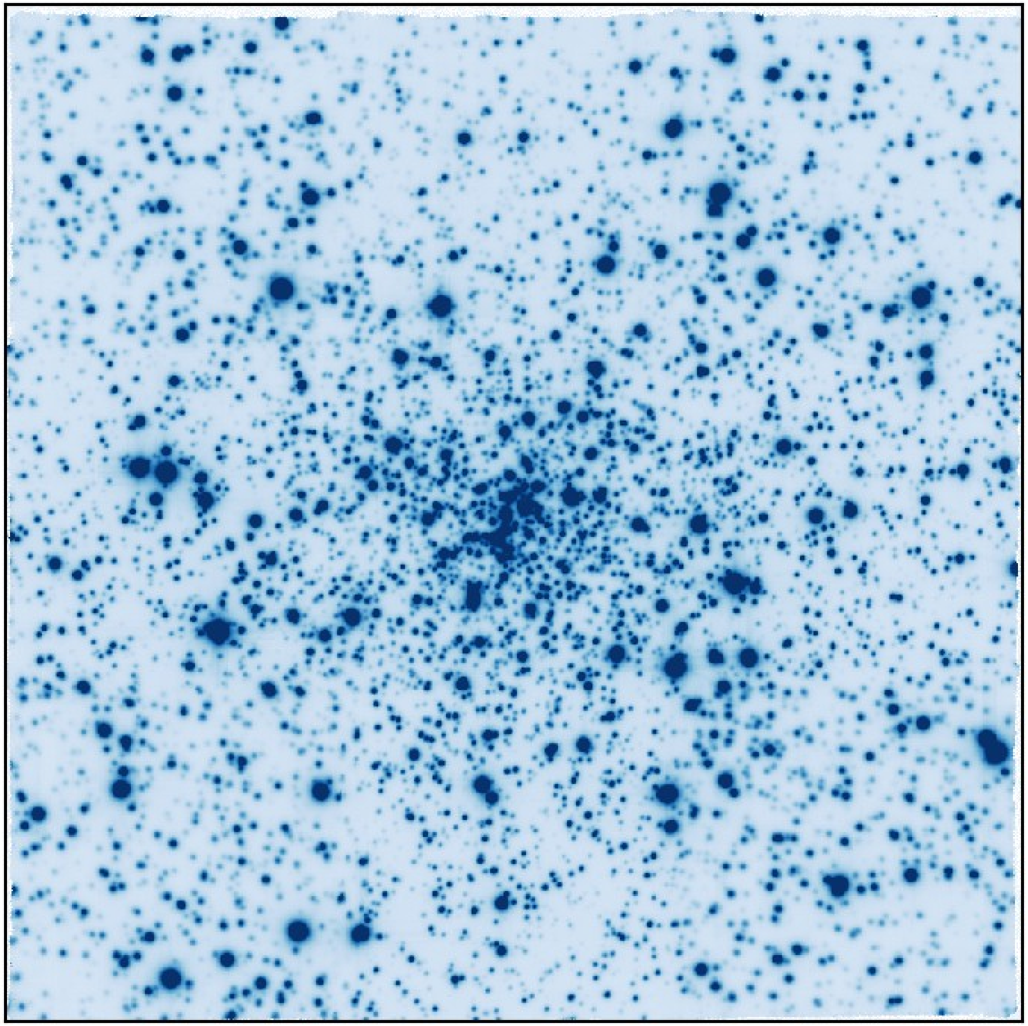


- <2 hours of MUSE:



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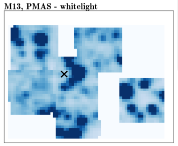

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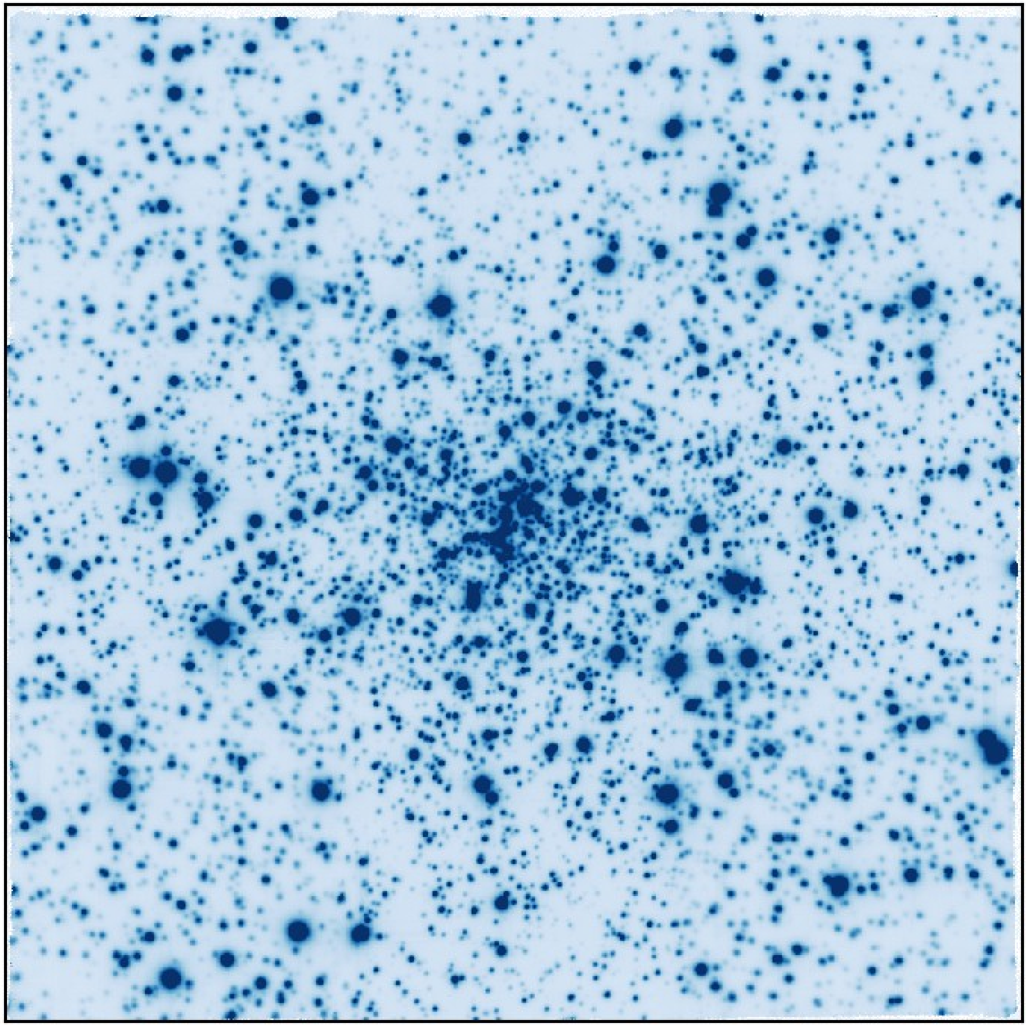
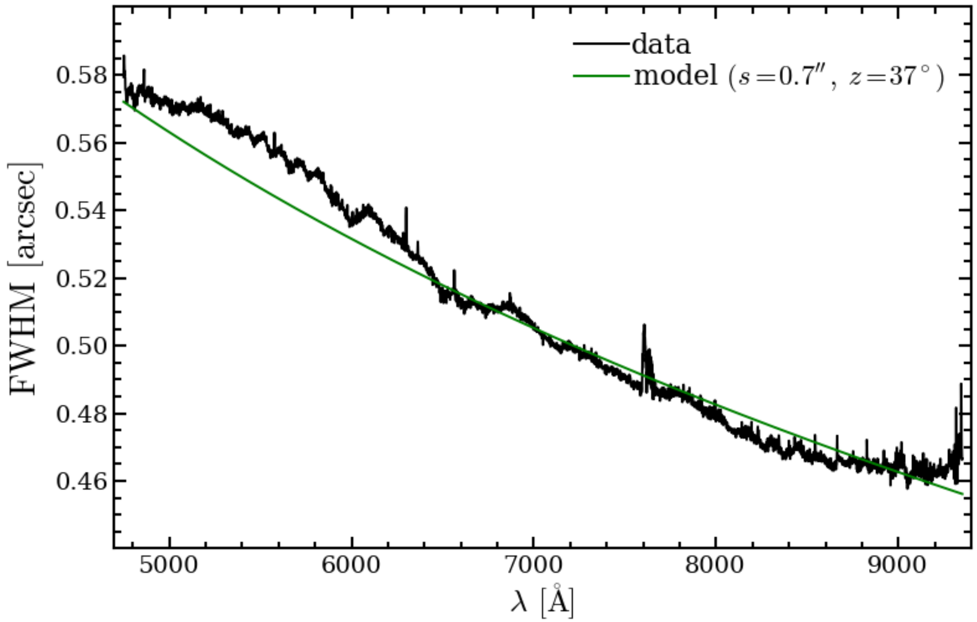
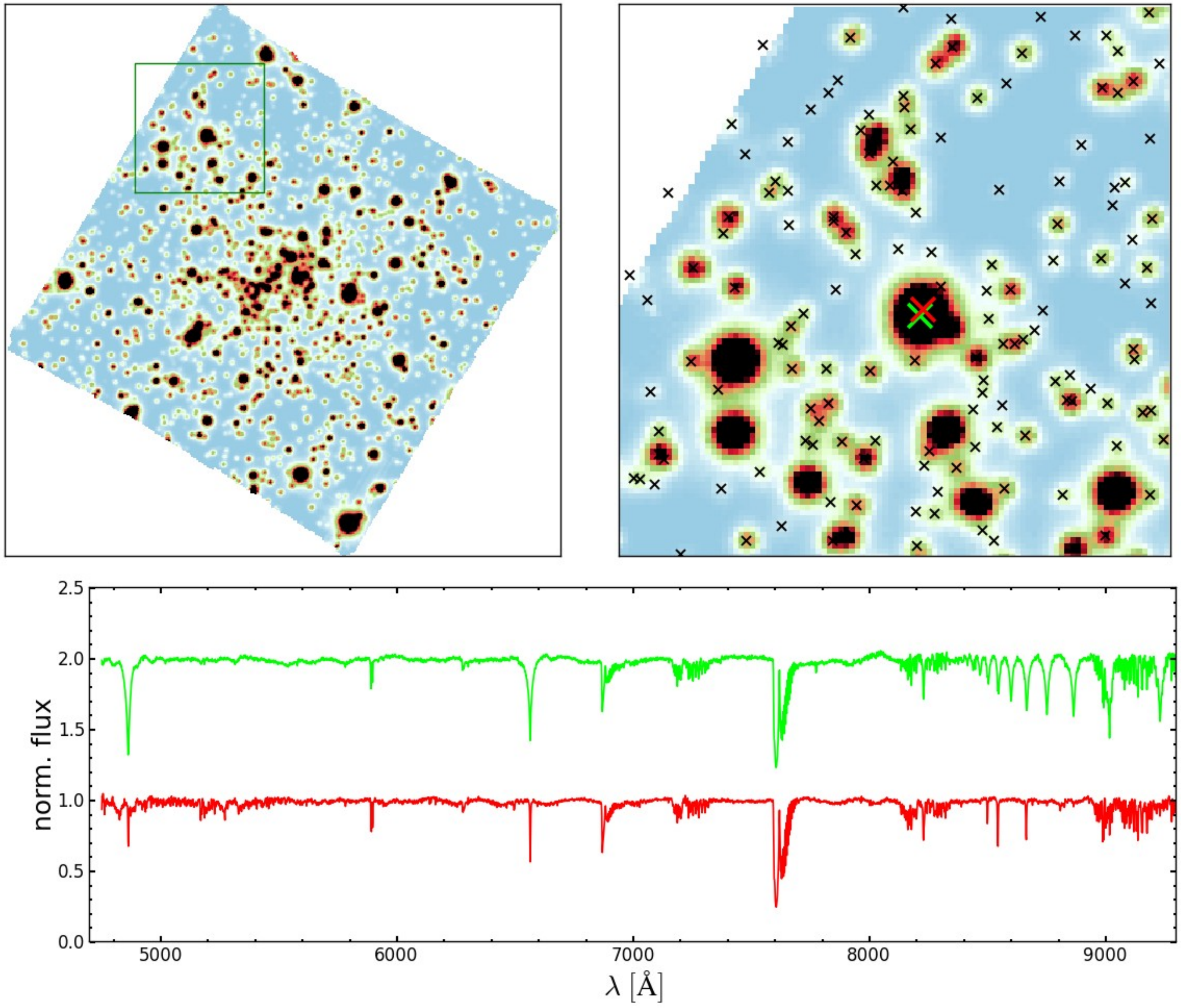


NGC 6397 – observed in Comm2B

- central pointing:
  - 60s of exposure time
  - seeing ~0.6 arcsec
- measured FWHM:

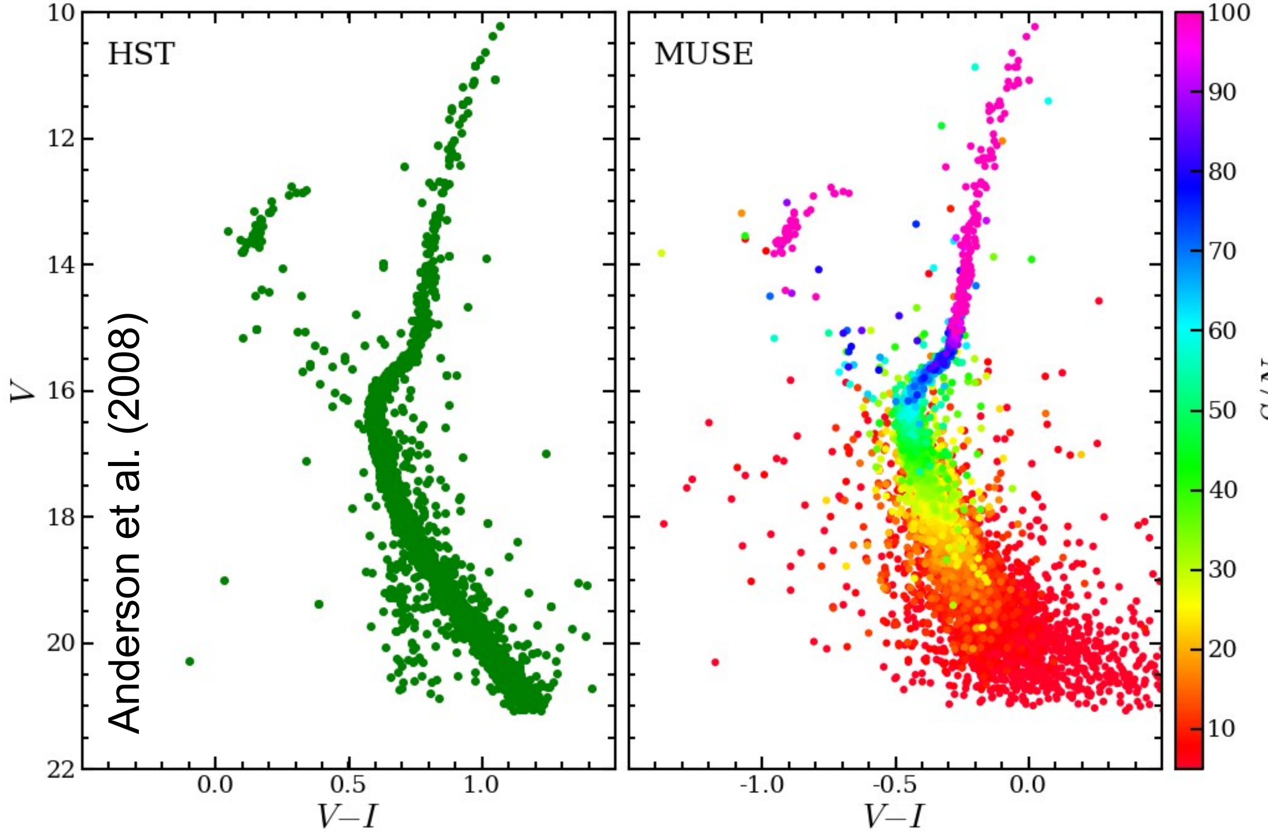


Source extraction on MUSE data



Extracted sources

- 4600 sources with S/N>10 in 3x3 mosaic
  - not limited by crowding
- spectra across the complete CMD



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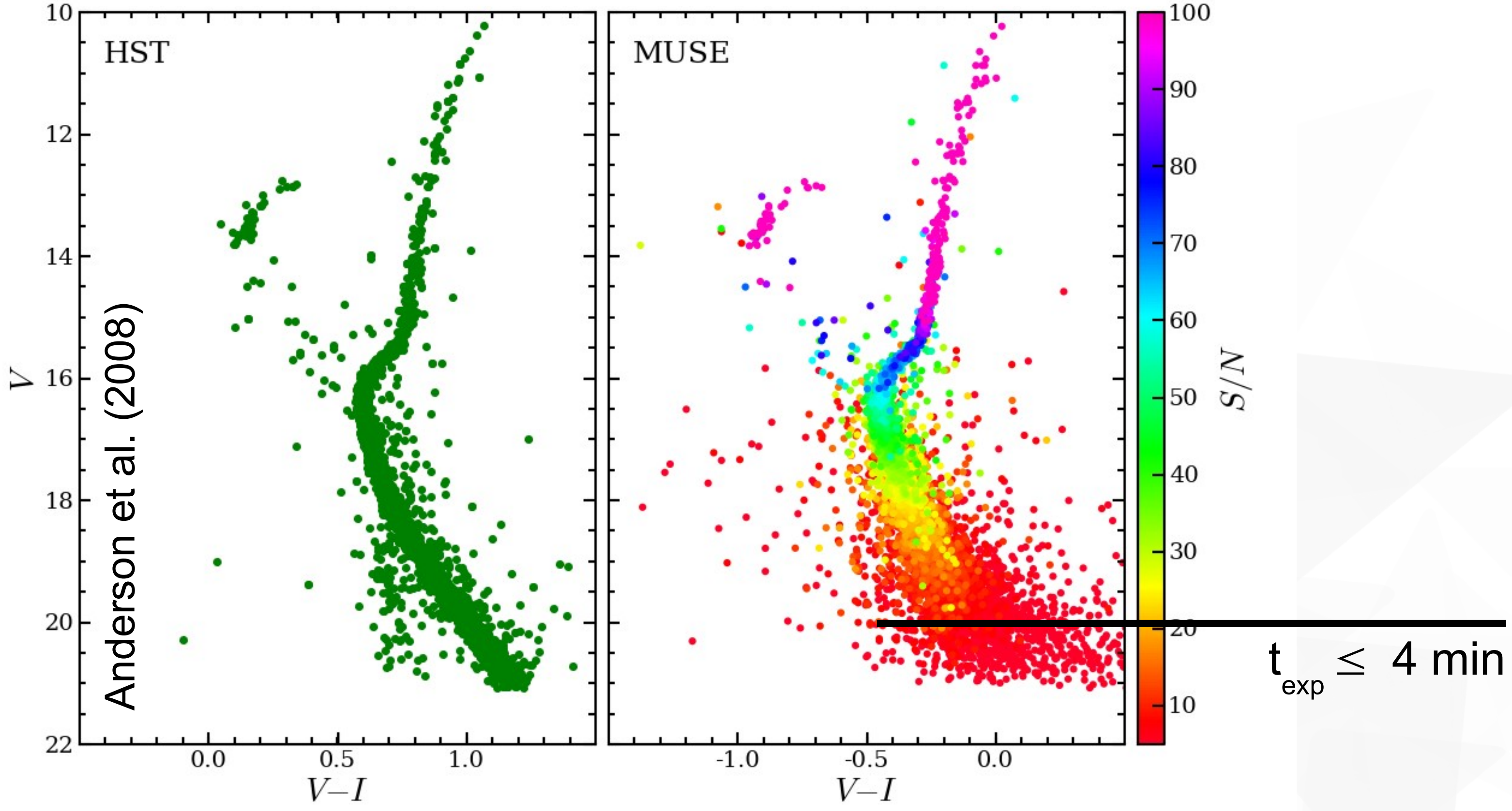
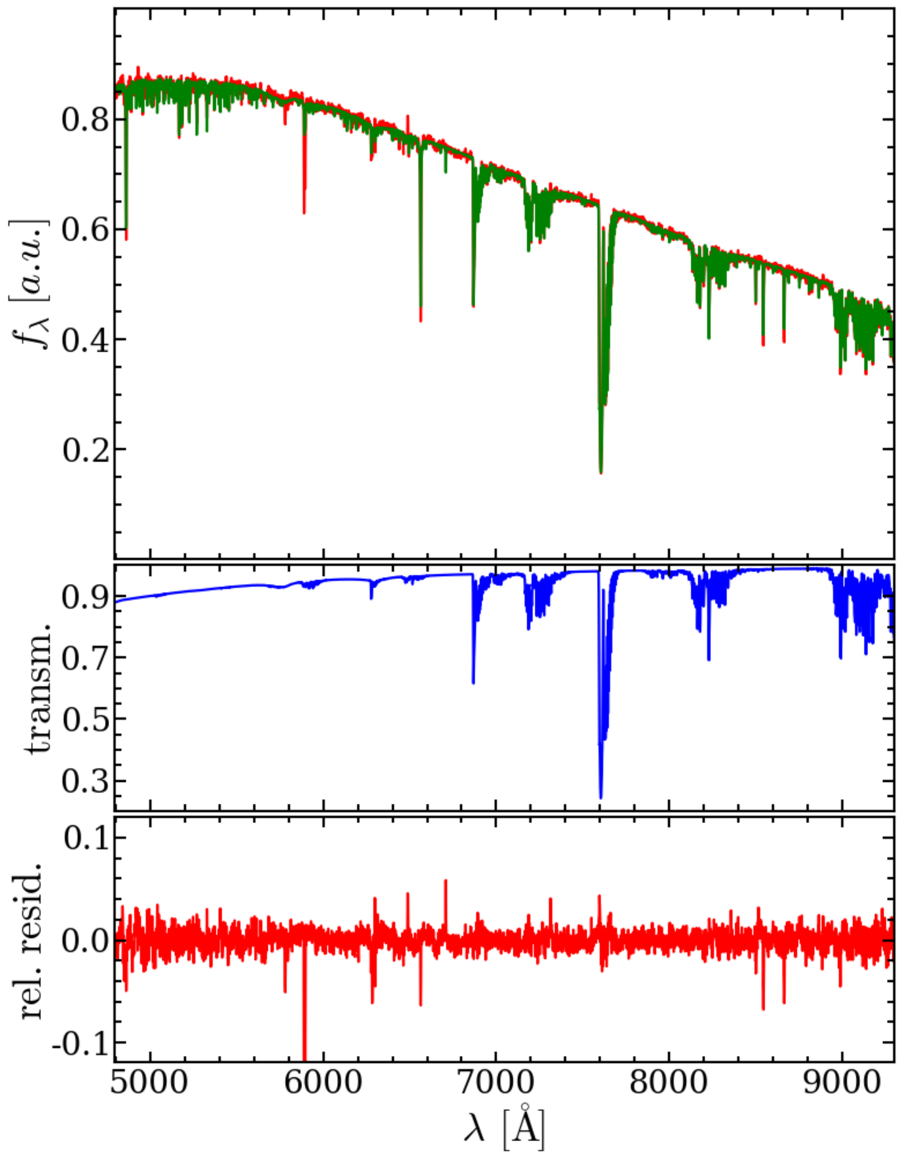
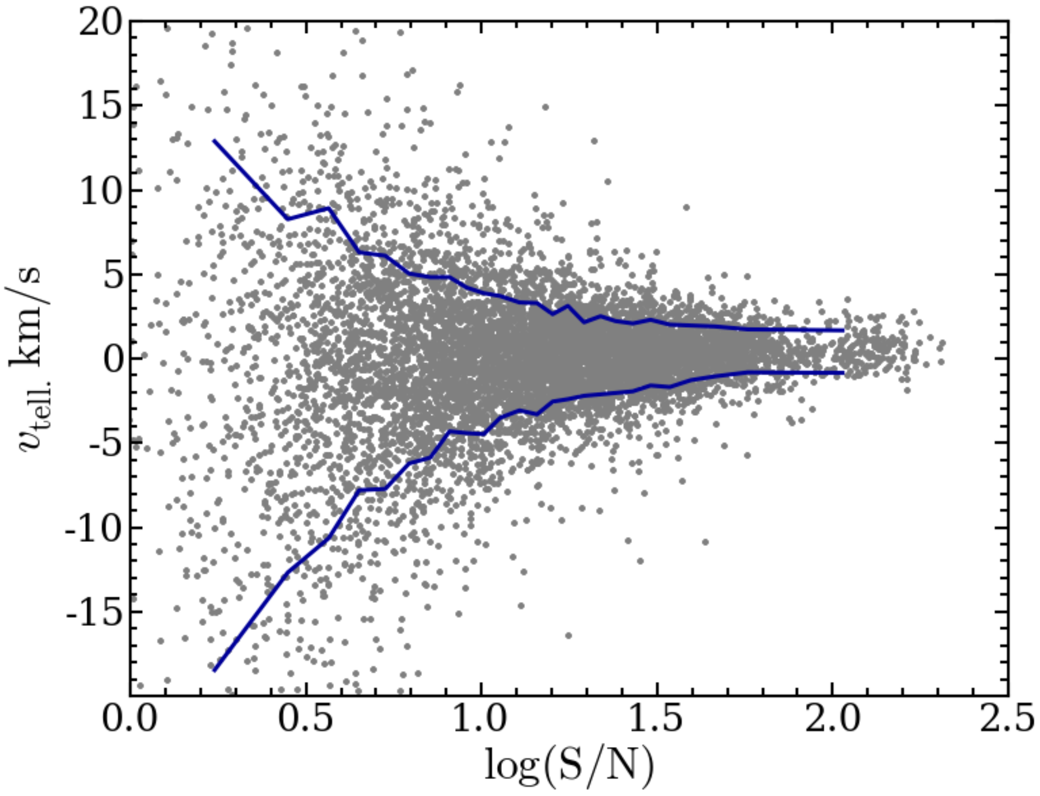


Spectral analysis



- full spectral fitting using grid of synthetic PHOENIX spectra (Husser et al. 2013)
- fitting corrects for telluric absorption
- Grid complete in
  - log g
  - T_{eff}
  - Fe/H
  - alpha (in progress)

Radial velocity accuracy

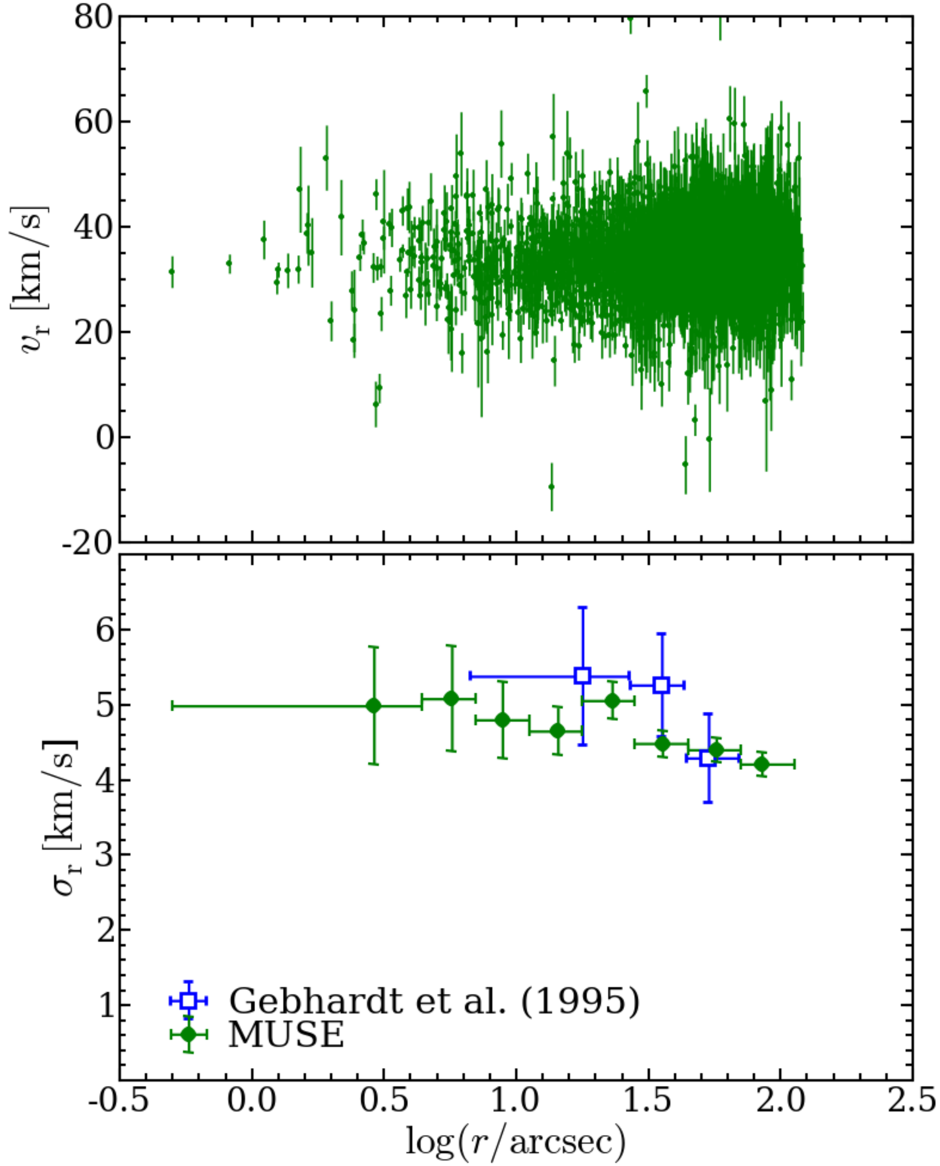


- Possible drawbacks
  - rather low resolution
  - MUSE combines 24 IFUs
  - LSF critically sampled
- Analysis of telluric absorption
  - no systematic errors across FoV
  - achievable accuracy ~1km/s

Radial velocity analysis

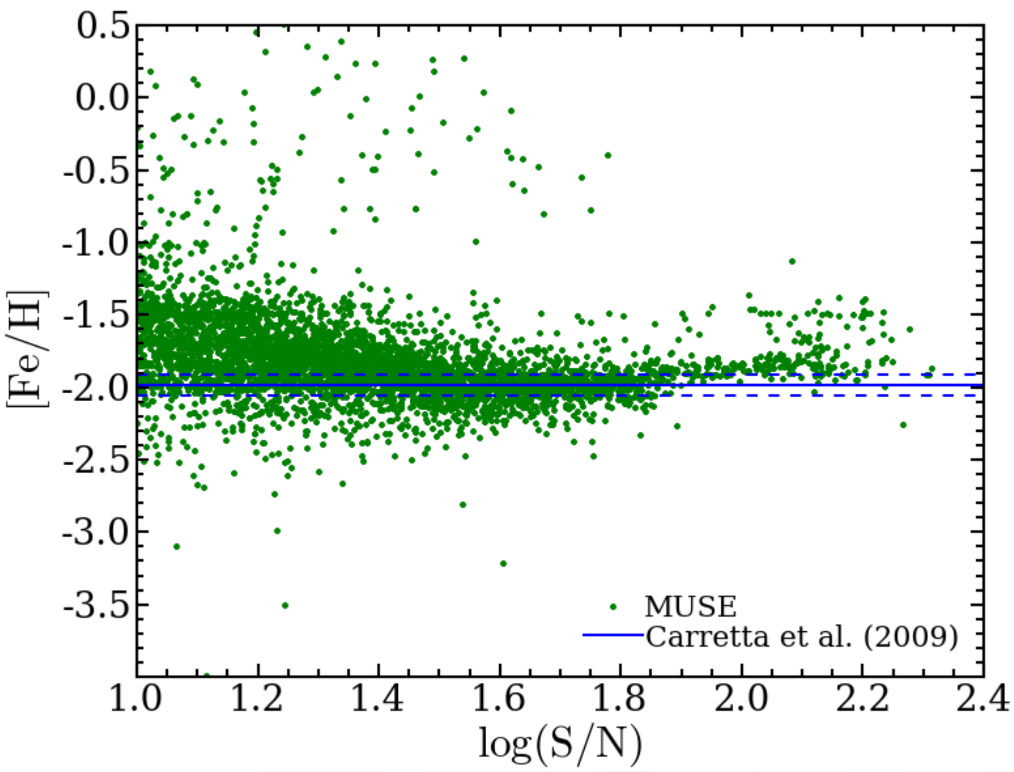
- Using measurements from 4600 stars with S/N>10
- correction for foreground stars
- central velocity dispersion to precision <1km/s

- potential for dynamical studies
  - binarity
  - mass-to-light ratios
  - internal rotations
  - peculiar (high-velocity) stars
  - intermediate-mass black holes (best with AO)



Metallicity measurements

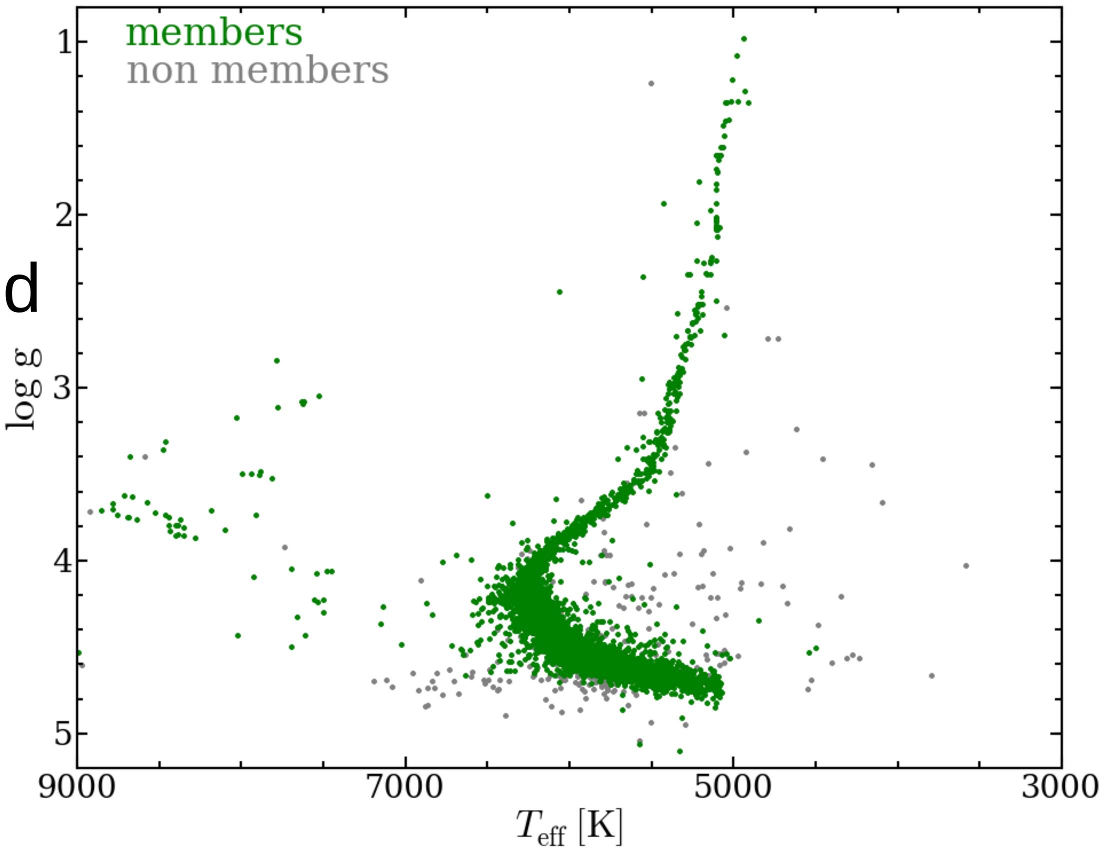
- preliminary!
- expect ~0.1dex precision for S/N>30
- unique calibration possibilities with large samples
- not only giants, but complete CMD
- serendipitous discoveries



- α-elements are being worked on

Effective temperatures

- created physical CMD
  - T_{eff} from spectral fit
  - log g from isochrone
- flagged non-members based on v_{rad} and [Fe/H]
- RBG, SGB remarkably narrow
  - high precision on T_{eff}



Resolved stellar populations in nearby galaxies

- major science driver for ELT
- can MUSE do some of the science already?

- pilot study on NGC300 (PI: Roth)
  - planetary nebulae
  - massive stars
  - HII regions
  - …

- huge legacy value

VRI composite, seeing ~0.6“

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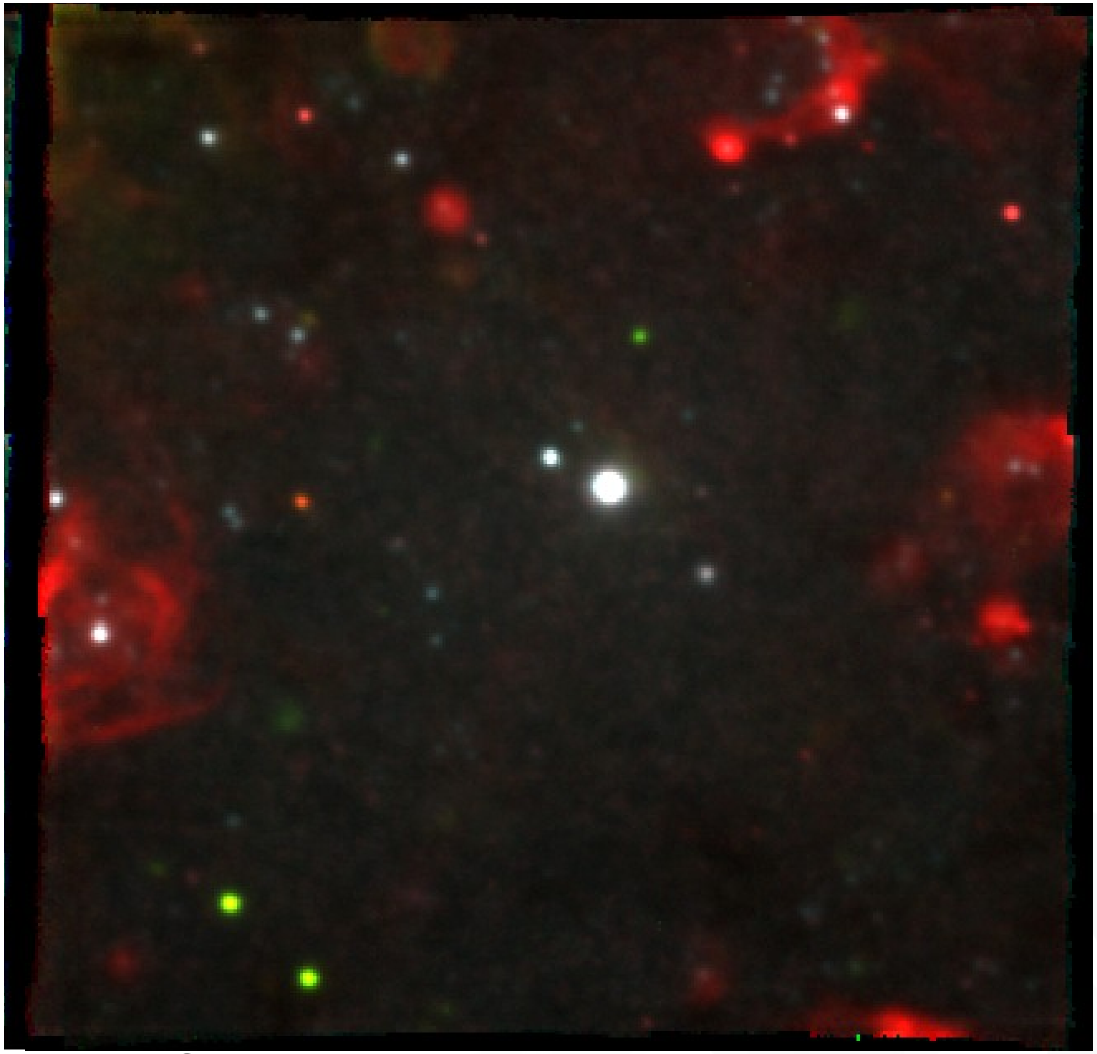

green: OIII 5007, red: H-alpha

Conclusions

- MUSE is available and working great.
- PSF-fitting techniques provide a powerful method to study resolved stellar populations.
- Combining MUSE & PSF-fitting techniques results in an unprecedented multiplex-factor.
- Despite the low spectral resolution, there is a lot to analyse (velocities, Fe/H, stellar parameters,...) and to discover.

Thank you!