The Calar Alto Legacy Integral Field spectroscopy Area (CALIFA) survey

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CALIFA collaboration

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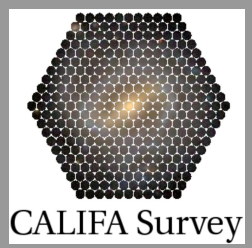
[2]Instituto de Astrophysica de Andalucia (IAA)

2011 April 18



Leibniz Institute for Astrophysics Potsdam

Outline

The idea of CALIFA

Legacy Survey of a large and representative sample of galaxies in the local Universe using **optical integral field spectroscopy**

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- 250 dark nights in 3 years at Calar Alto Observatory (Spain)
  - $\sim$2.5 Million Euros in telescope time
  - Competitive review process

The idea of CALIFA

Legacy Survey of a large and representative sample of galaxies in the local Universe using **optical integral field spectroscopy**

- 250 dark nights in 3 years at Calar Alto Observatory (Spain)
  - ~2.5 Million Euros in telescope time
  - Competitive review process
- Collaboration of 82 members in 13 countries
  - PI: S. F. Sánchez (IAA)
  - PS: J. Walcher (AIP)
  - Board (Chair: R. Kennicutt → P. Vilchez)
  - Mostly young researchers (~35 years)
- Project started on July 1st 2010

The PMAS integral field spectrograph

Potsdam Multi Aperture Spectrophotometer (PMAS)

- 3.5m telescope (Cassegrain focus)
- Optimized for 350nm-900nm
- High throughput $\leq 30\%$
- Exchangeable and rotatable grisms
- **2 integral field units (IFUs):**
  Lens Array
  16×16 lenslets ($0.5''$ sampling)
  Pmas fiber PAcK (PPAK)
  coarse fiber bundle
  $\sim 1'$ Field of View (FoV)
  $\Rightarrow$ Among the largest IFU FoV's

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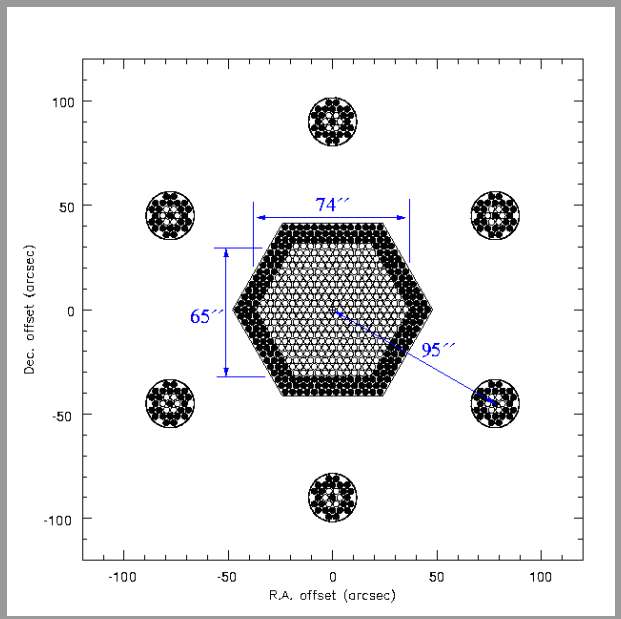
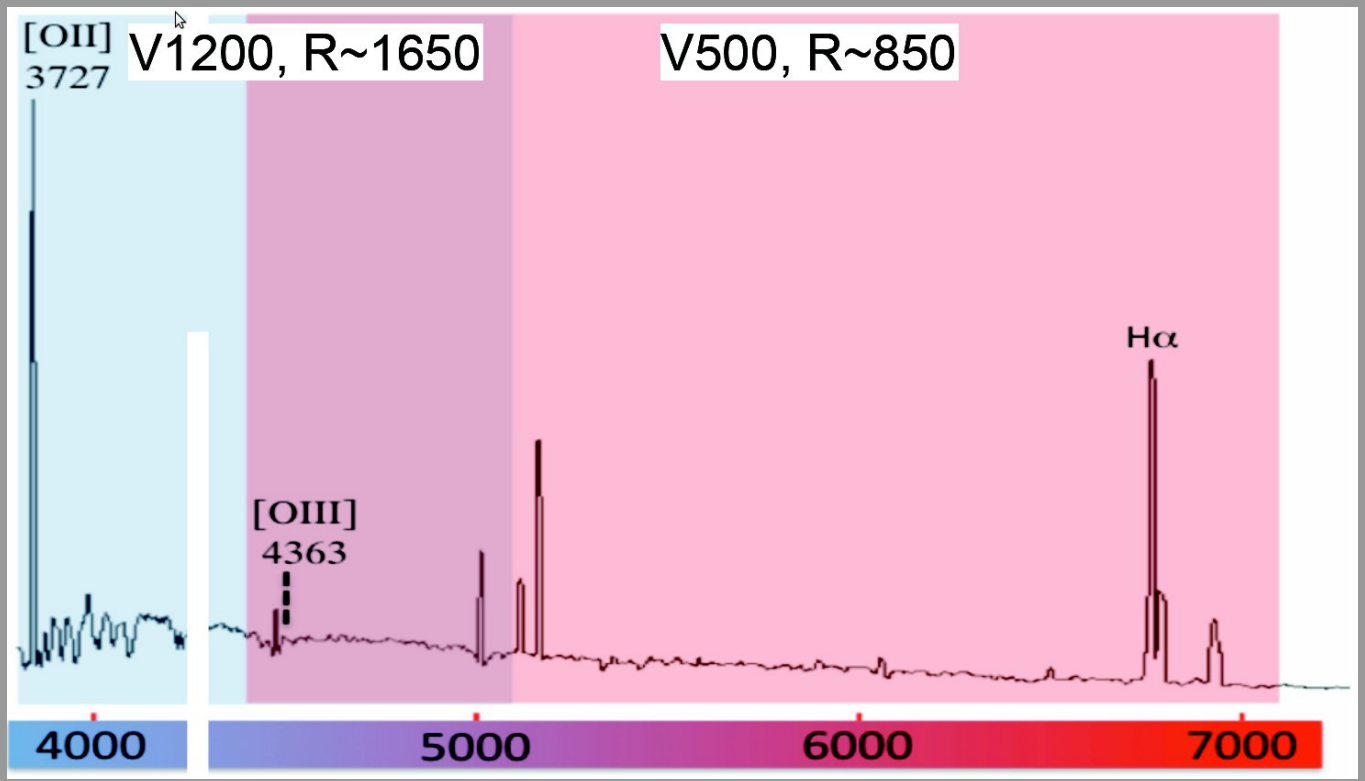
PPAK fiber bundle IFU



- 331 science fibers
- 36 dedicated sky fibers
- $2.7''$ diameter fibers
- 2/3 filling factor

Wavelength coverage for CALIFA

Two setups are used to cover the entire optical wavelength range:



higher resolution ⇒ Galaxy kinematics from Ca H+K region
lower resolution ⇒ Stellar population and ionised gas

The CALIFA galaxy sample

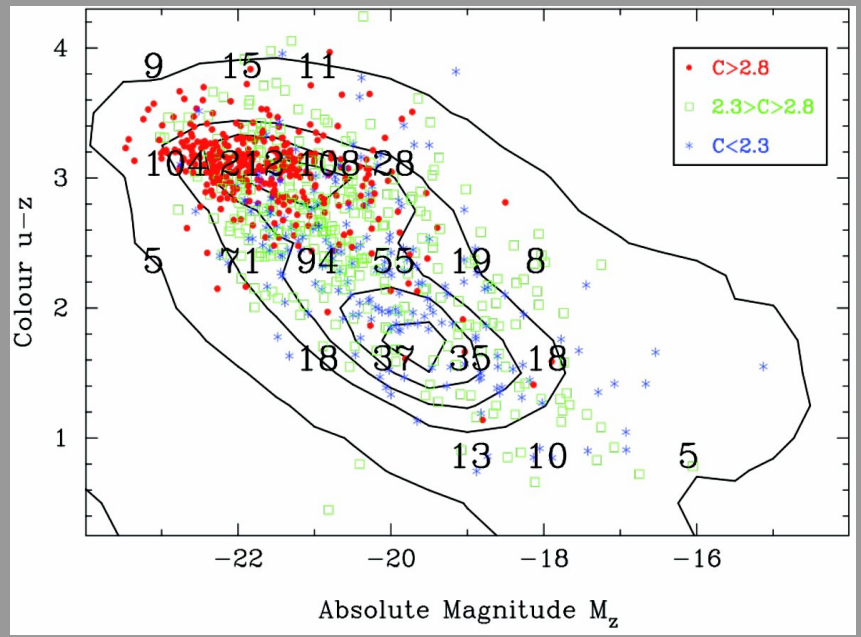
Mother sample is drawn from SDSS:

1. Diameter cuts: $45'' < D_{25} < 80''$
   $\Rightarrow$ effective usage of FoV
2. Redshift cuts: $0.003 < z < 0.03$
   $\Rightarrow$ excludes dwarf galaxies

987 galaxies within SDSS match these basic criterions

CALIFA will observe 600 galaxies!

Color-Magnitude space



Sanchez et al. 2012, A&A, 538, A8

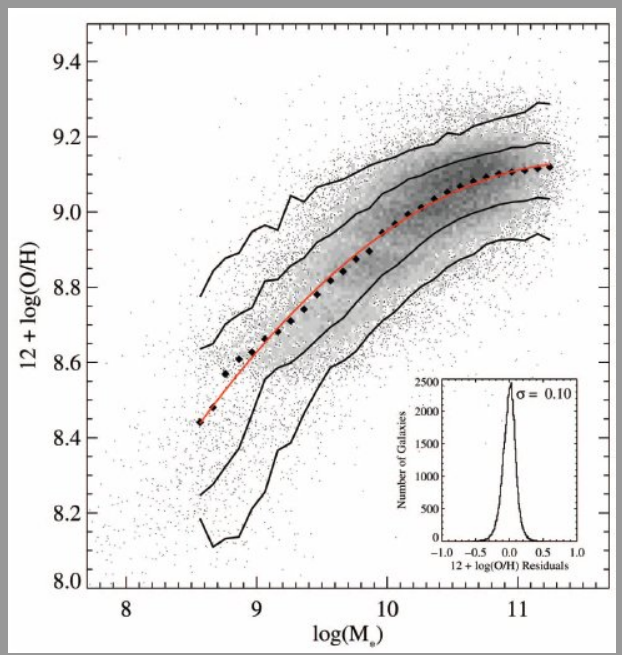
Science drivers for CALIFA

- What is the origin of the observed galaxy diversity?
- What drives the bimodality in the galaxy population?
- How galaxies evolve with time? (secular vs. interactions)
- Nearby galaxies: “fossil records“ of the formation and evolution of galaxies
- Relations between galaxy morphology, stellar population, kinematics and the ionised gas
- What does AGN do to their host galaxies and vice versa?
- Of course, many more interesting stuff ...

Precedent spectroscopic surveys

Sloan Digital Sky Survey

- Single fibre spectra (3″)
- 1 Million galaxy spectra
- Median redshift at $z \sim 0.1$



Tremonti et al. 2004

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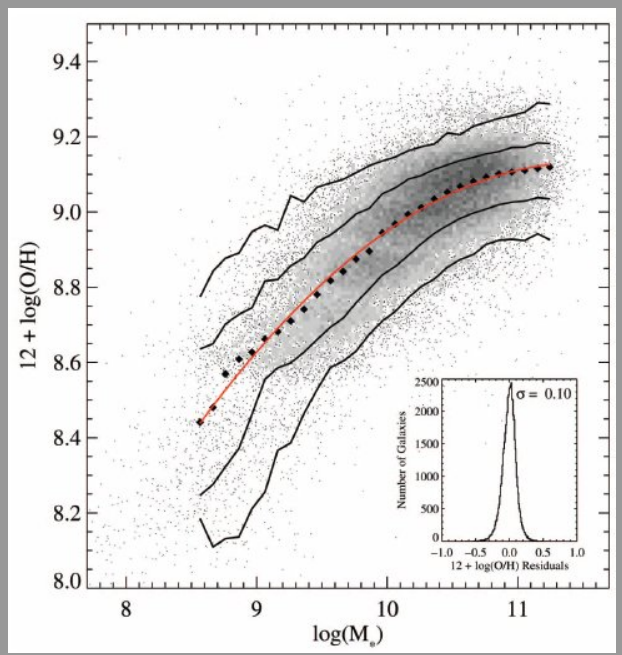
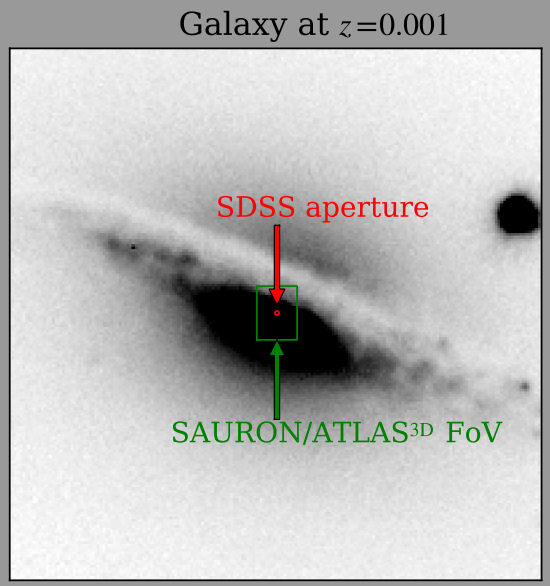


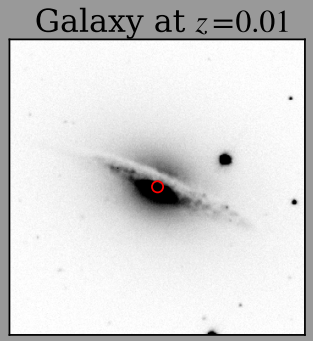
Tremonti et al. 2004

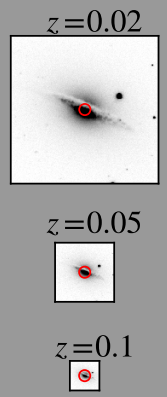
Previous IFS surveys

- SAURON/ATLAS3D
  - 72/~200 E-type galaxies
  - at $z < 0.01$ with limited FoV and spectral range
- PINGS
  - 12 L-type galaxies
  - at $z \sim 0.001$ but full galaxy covered (Mosaicking)
- DiskMass
  - 30 face-on spirals
  - kinematic weighting

Advantages over precedent spectroscopic surveys







- SDSS spectroscopy may cover the centre or the whole galaxy
  ⇒ Likely introducing aperture biasses for most studies
- SAURON/ATLAS3D covers only the central area ($\leq 1 R_{\rm eff}$)
  Very narrow wavelength range limit optical diagnostics

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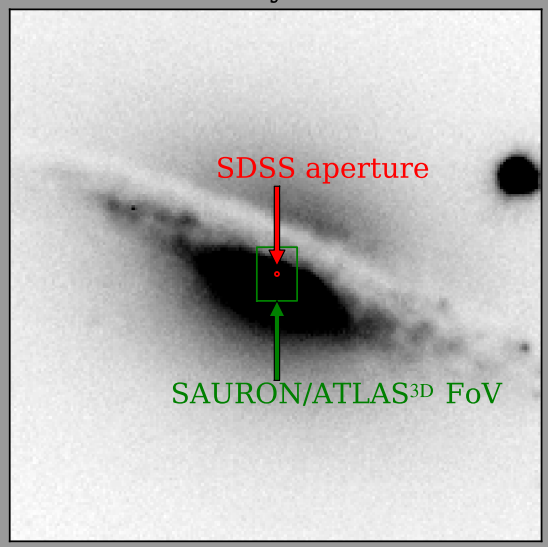

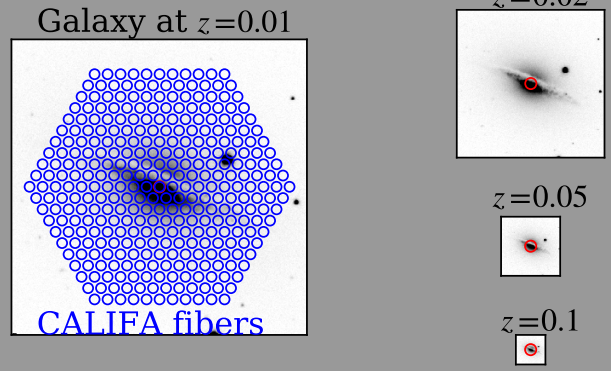

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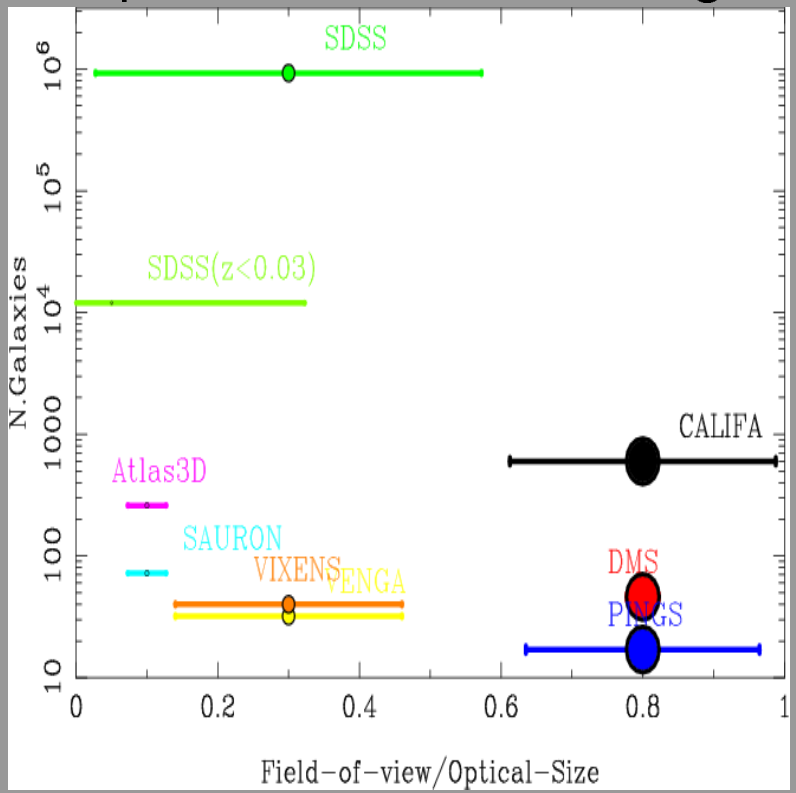
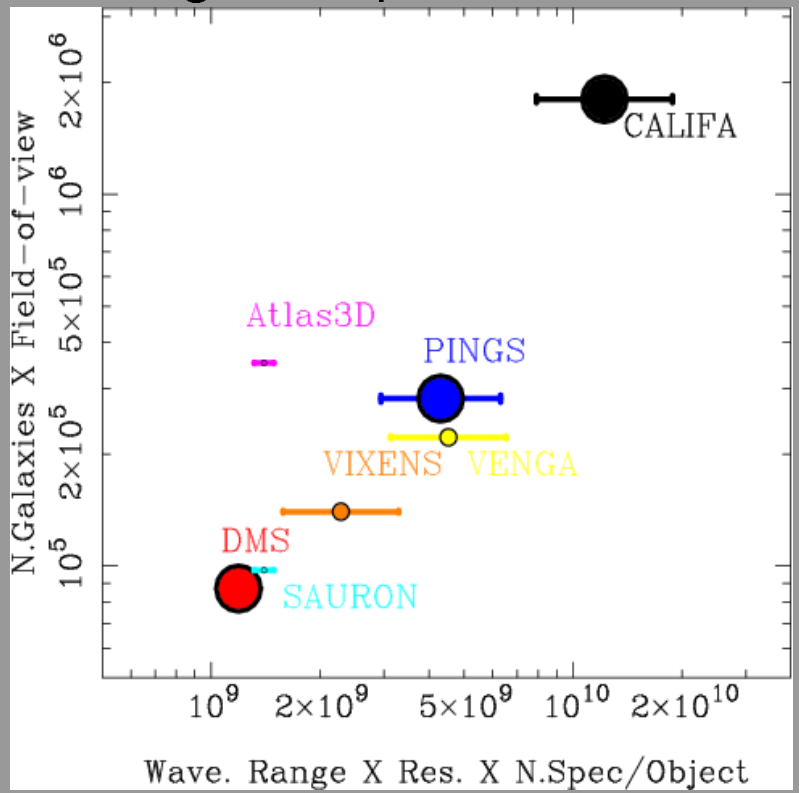
CALIFA covers an entire galaxies in a certain redshift range!

Comparison of spectroscopic survey efficiencies

Sample size vs. FoV coverage



Coverage vs. spectral content



- CALIFA will contain more galaxies than any IFU survey before
- CALIFA will collect ~1 Million spectra (similar to SDSS)

Uniqueness of CALIFA

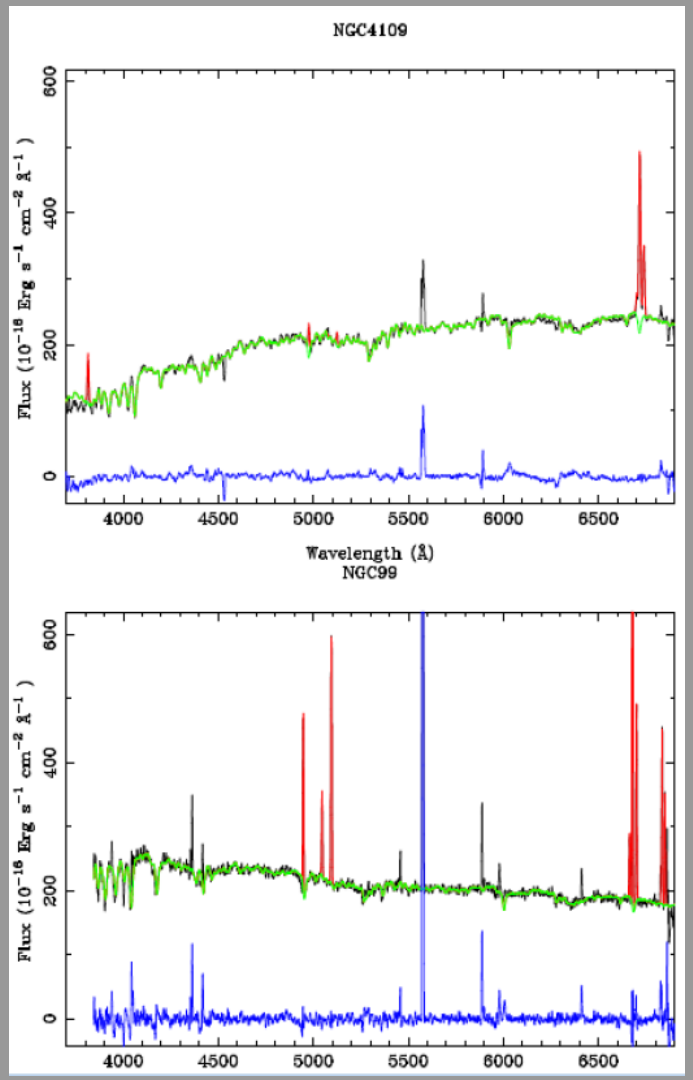
- **Large wavelength coverage**
  - Full optical emission-line diagnostic
  - Extended view on stellar populations
  - Suited to study galaxy kinematics
- **Spatial coverage and sampling**
  - Full optical size of galaxy covered
  - $\sim 1\,\mathrm{kpc}$ projected spatial resolution
- **Large homogeneous sample:**
  - Statistics, classification, rare objects
  - Comparison studies of different types
- **Legacy survey!**

Challenges for CALIFA

- Amount of spectra is equivalent to SDSS
- New techniques to display and analyse 3D data required
- High degree of automatization for data reduction and analysis
- PMAS was not build for surveys, e. g. unstable due to flexures
  ⇒ Appropriate scheme for homogeneous survey calibration
- And many more....

What calibrations are required for CALIFA science?

1. Wavelength calibration
   - stellar population modelling
   - kinematic maps of galaxies
2. Relative spectrophotometry
   - stellar population modelling
   - emission-line ratio (ISM physics)
   - dust extinction (continuum or emission lines)
3. Absolute spectrophotometry
   - absolute star formation rates
   - stellar masses
4. Astrometry
   - relate spectra to a position on the sky (galaxy part)
   - matching ancillary photometry to CALIFA spectra



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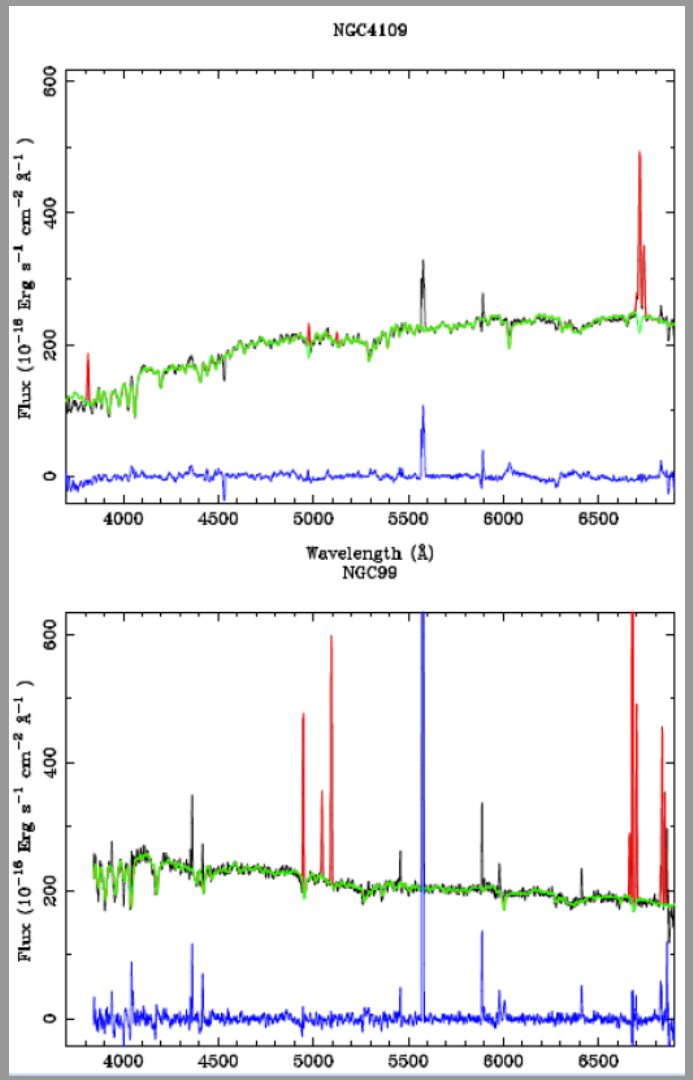

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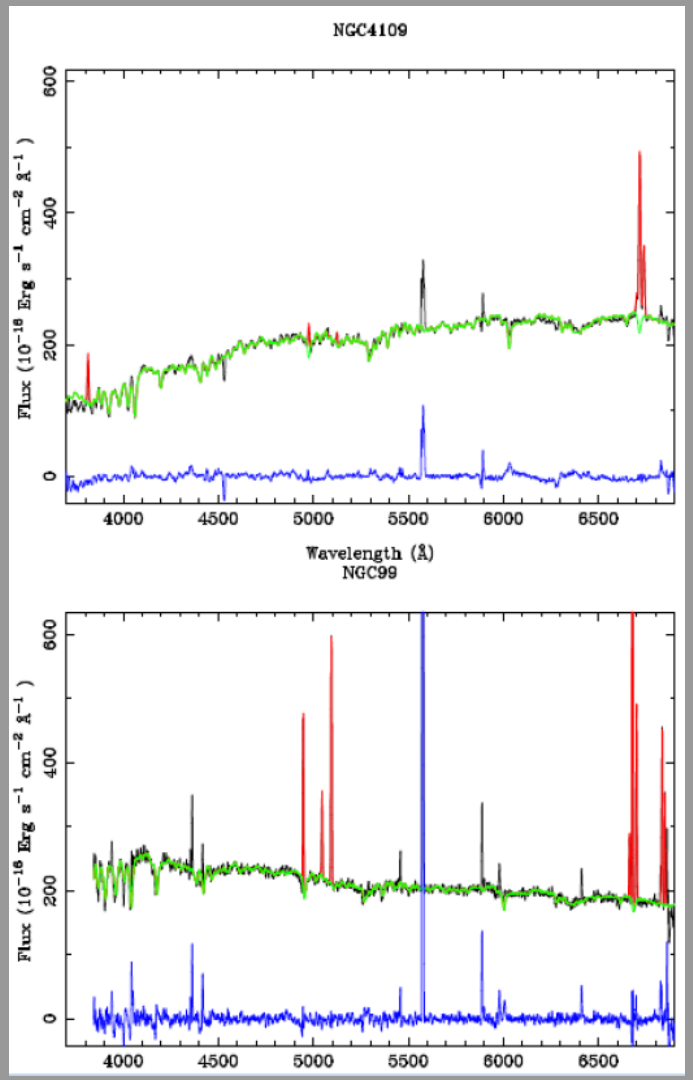

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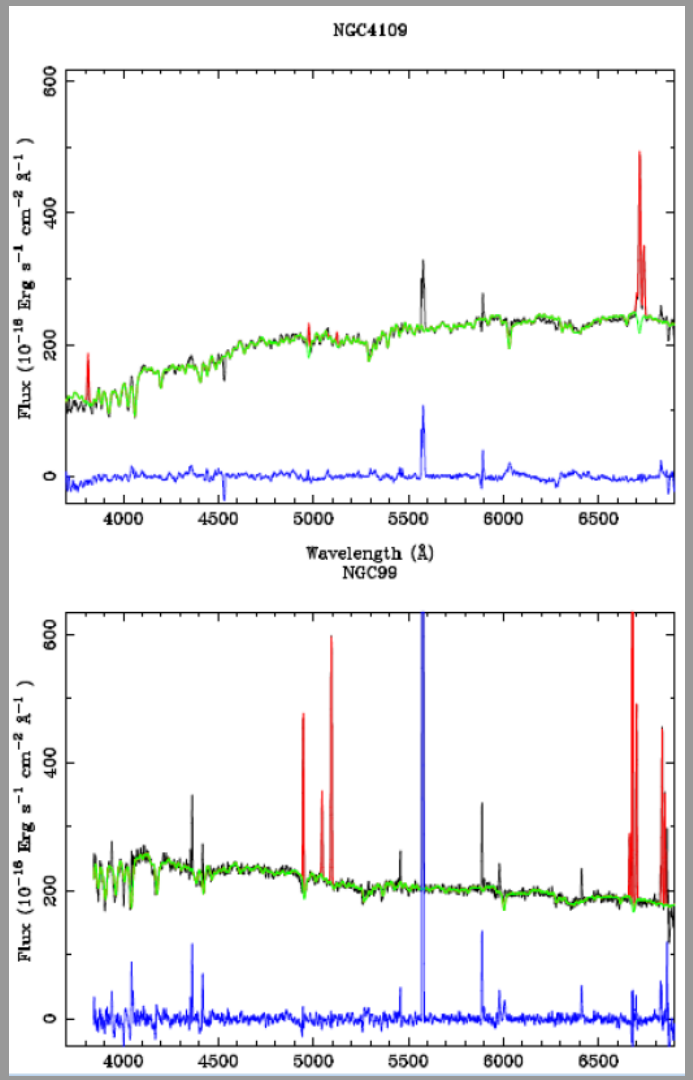
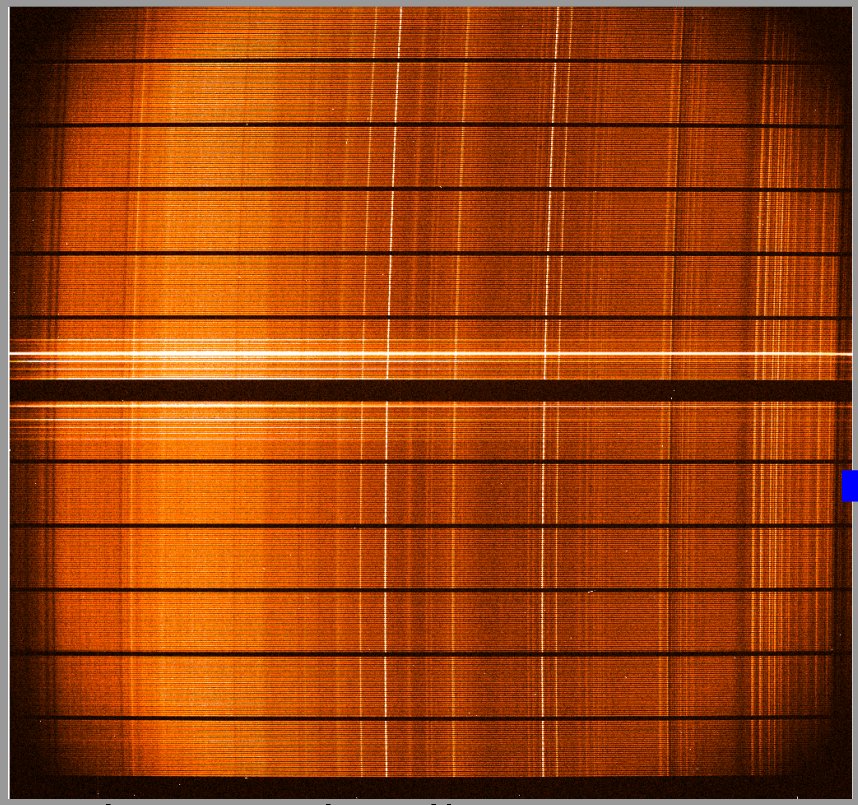


IFU data reduction is still quite an ART!



Things to handle:

Cosmic rays→extraction→flexures→flat-fielding→vignetting→ sky subtraction→ wavelength and flux calibration→etc...

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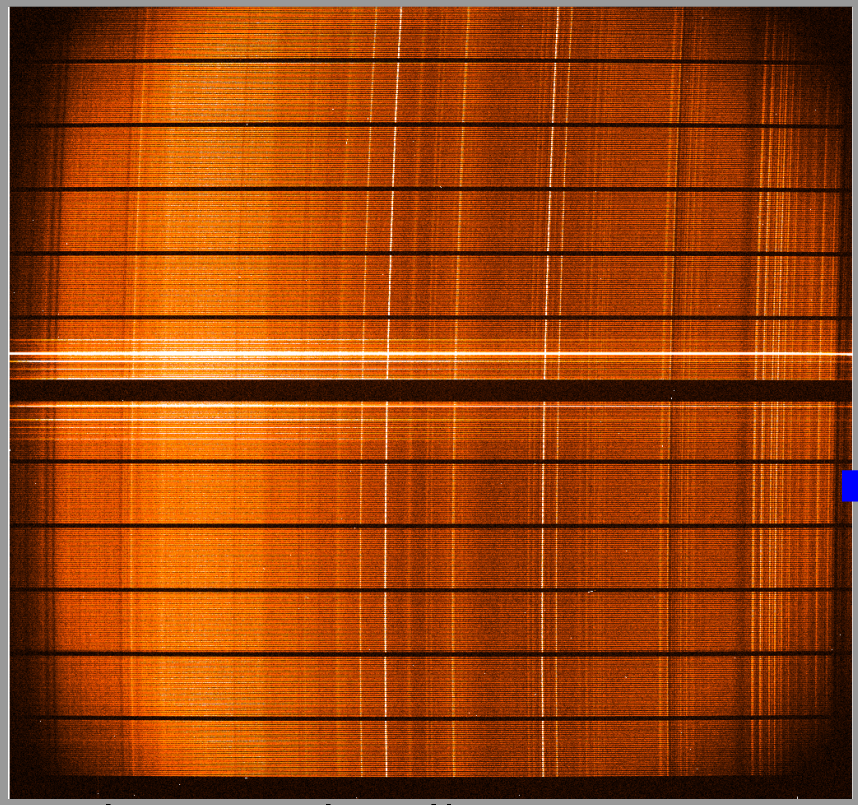

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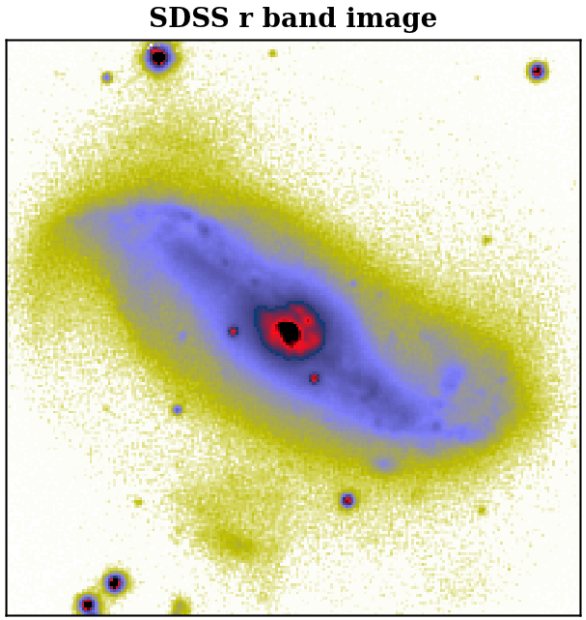
Will not bother you with a IFU data reduction lesson...

Dither pattern and image reconstruction



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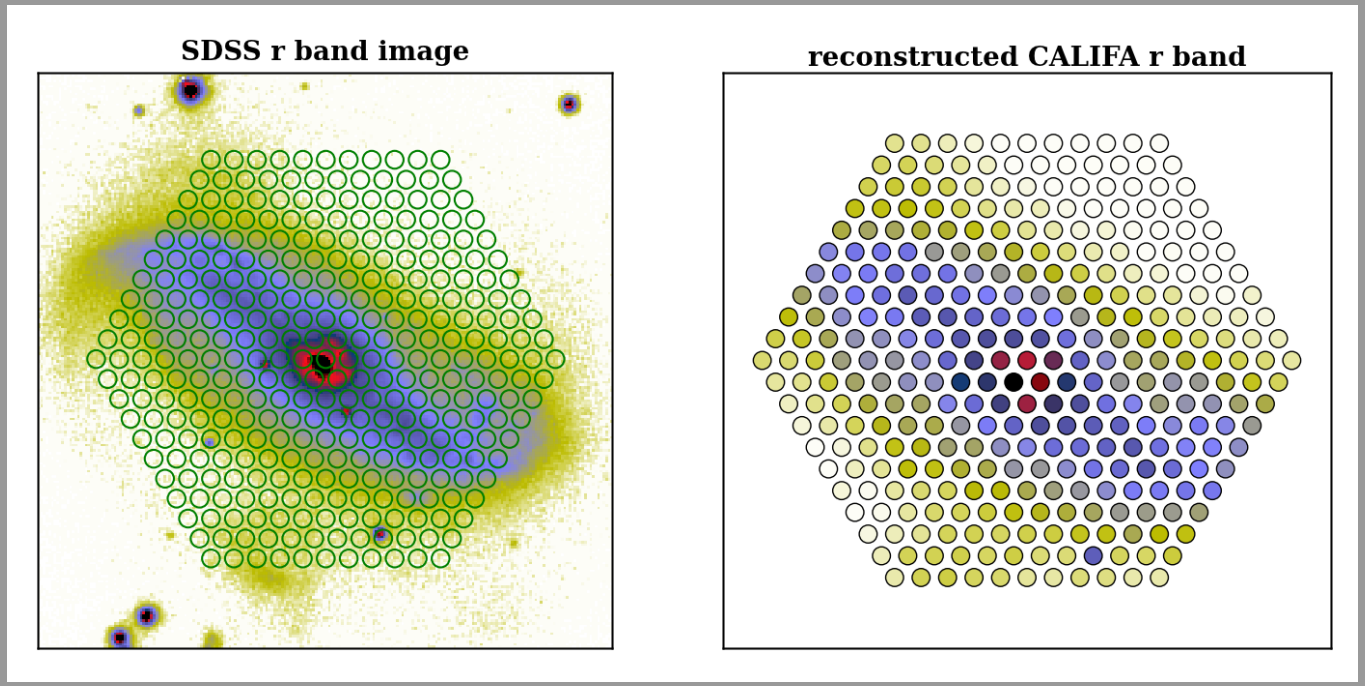

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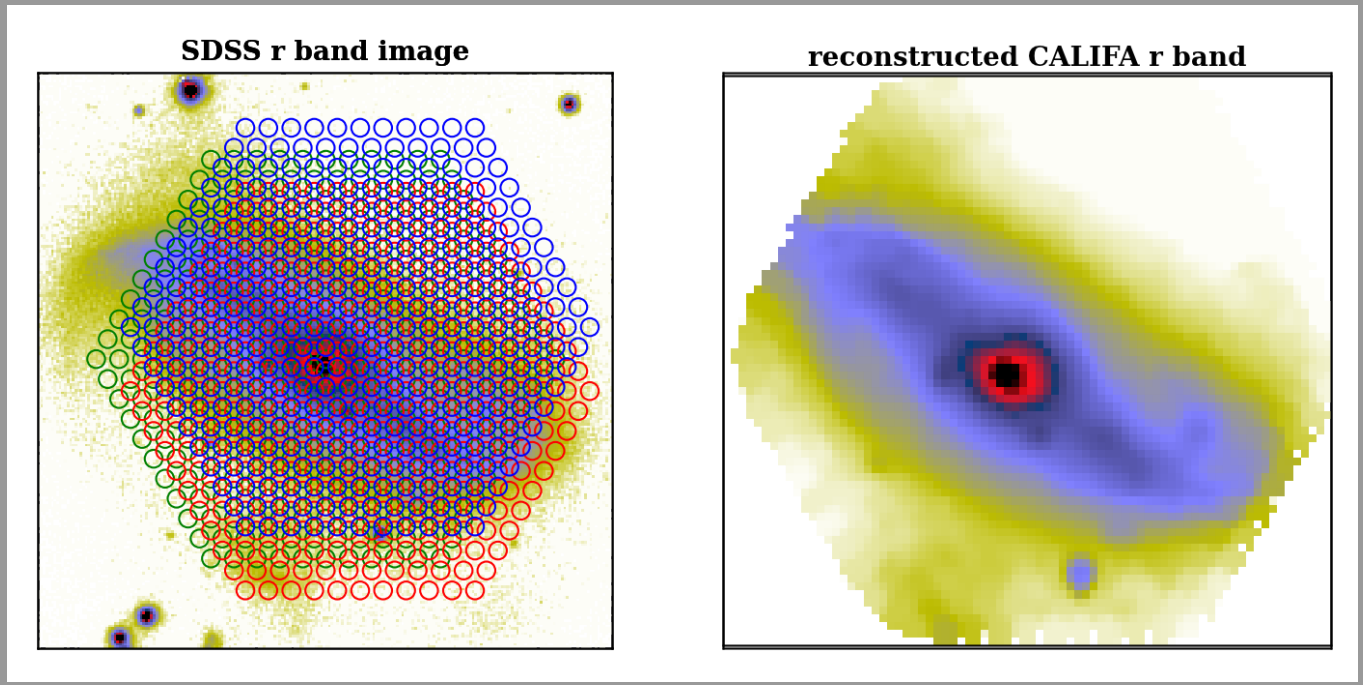

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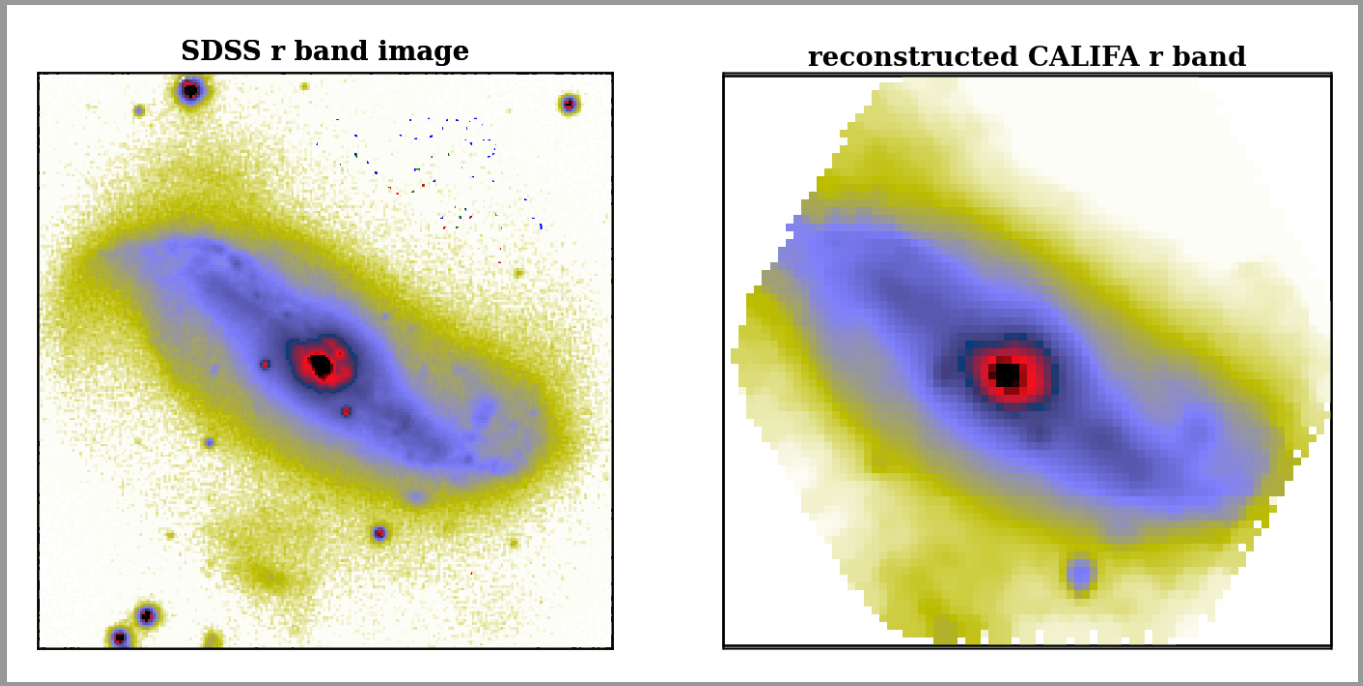
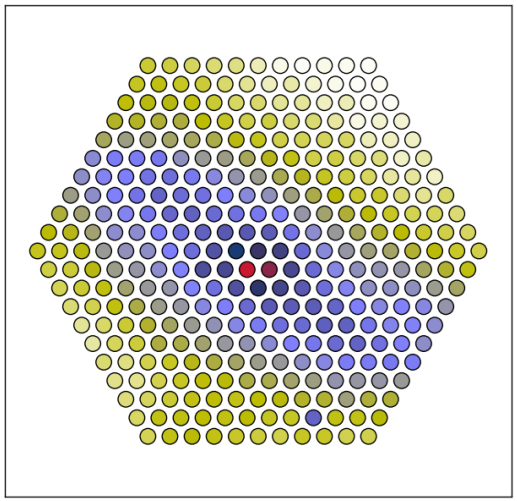
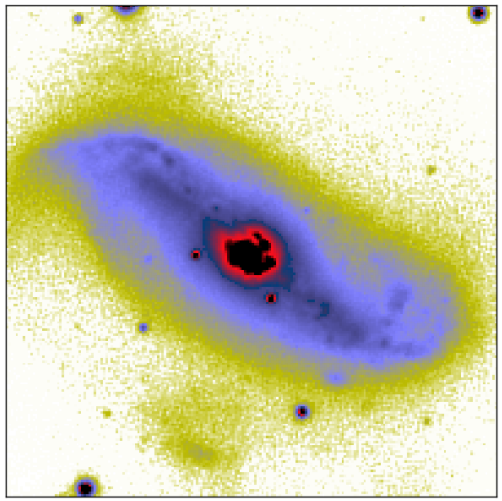


- An individual PPAK pointing has a low filling factor
- 3 dither pointings allow image reconstruction (1″)
  ⇒ Relies on accurately known dither offsets
- Intrinsic spatial information still undersampled
  ⇒ Low precision for standard astrometry, i.e. galaxy centre

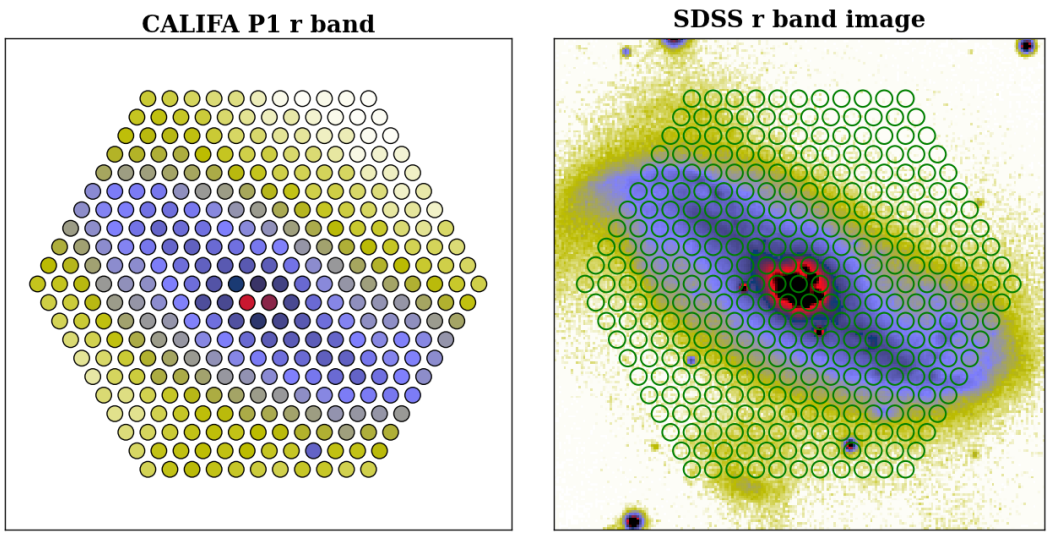
Possible solution: Registering to SDSS images





How to properly register the CALIFA data to SDSS images?

Possible solution: Registering to SDSS images



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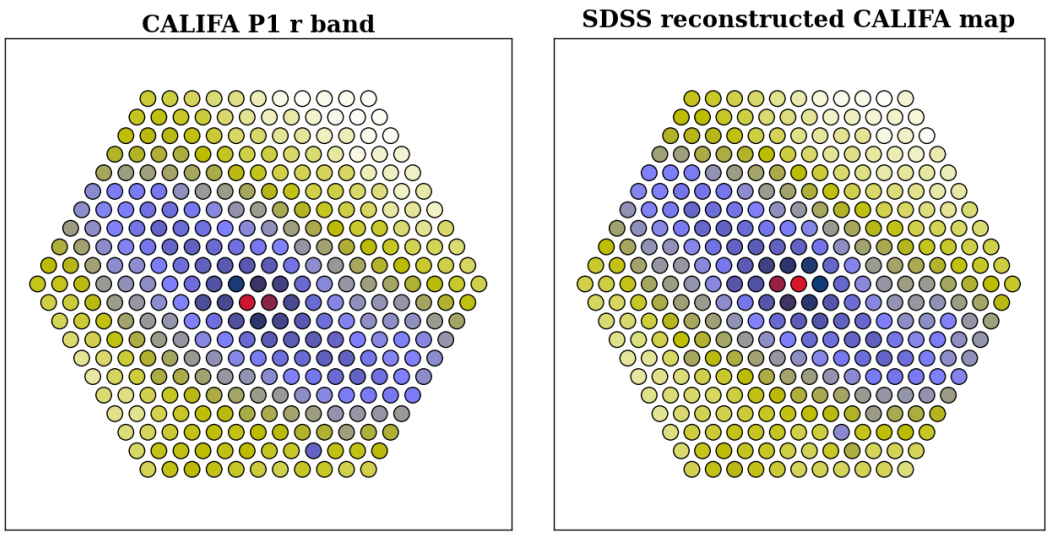
1. Overlay the fiber pattern

Possible solution: Registering to SDSS images



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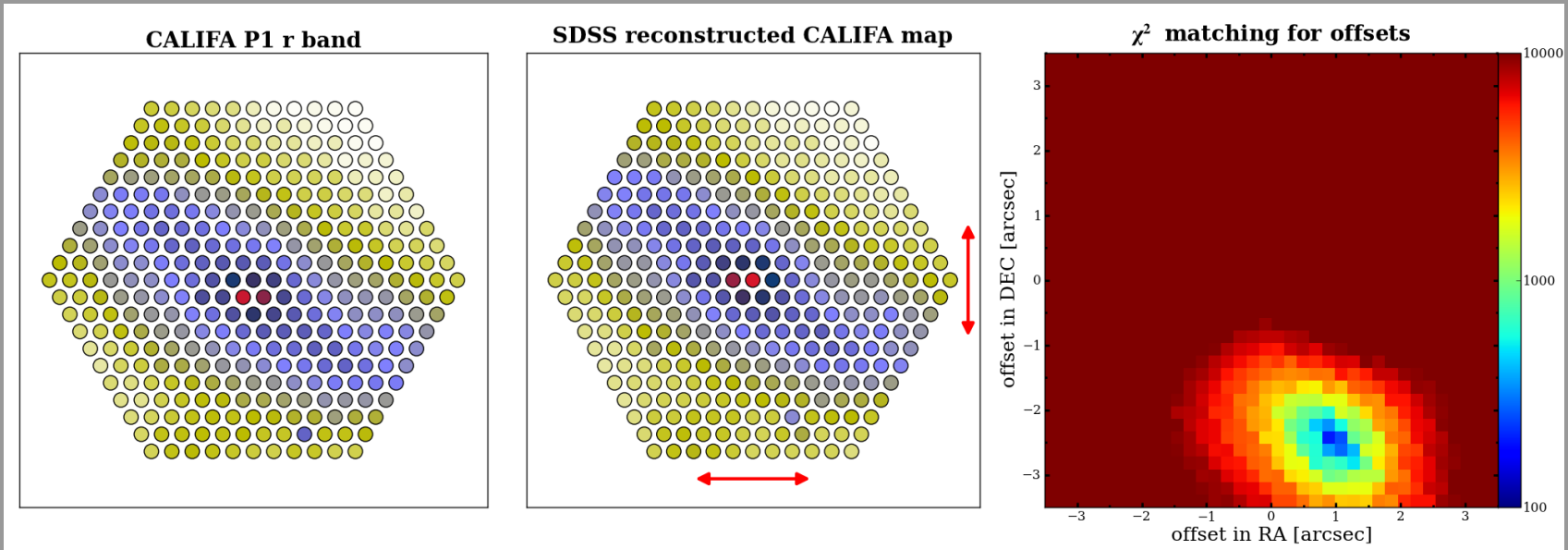

How to properly register the CALIFA data to SDSS images?

1. Overlay the fiber pattern
2. Re-construct flux from SDSS images
3. Offset fiber pattern and compute $\chi^2 = \sum_{i,j} \frac{(f_{ij}^{\mathrm{CALIFA}} - f_{ij}^{\mathrm{SDSS}})^2}{\sigma_{ij}^{\mathrm{CALIFA}\,2} + \sigma_{ij}^{\mathrm{SDSS}\,2}}$

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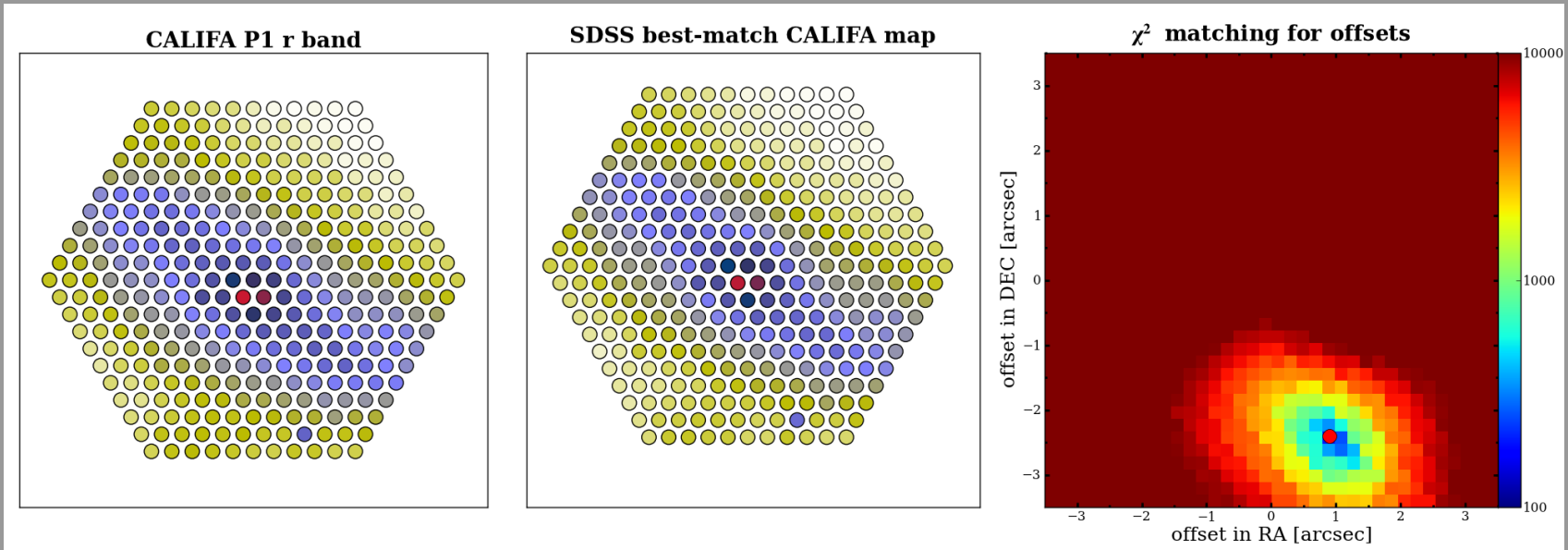

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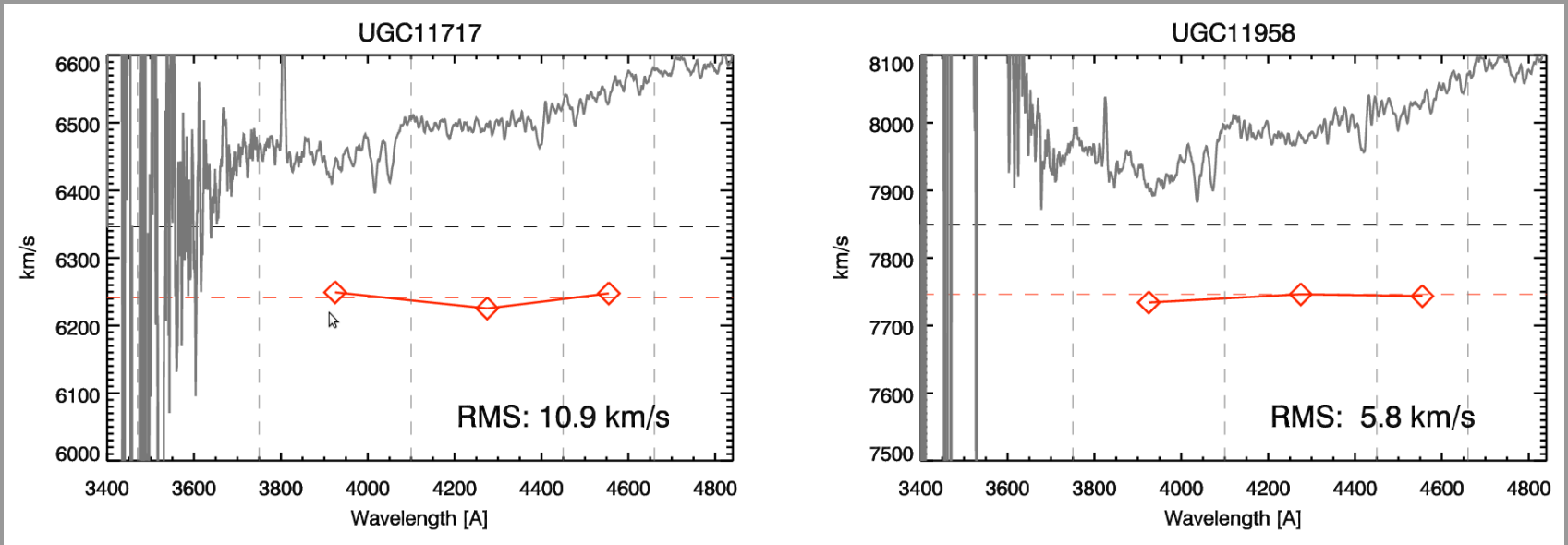
4. Position can be estimated with sub-arcsec precision

Wavelength calibration

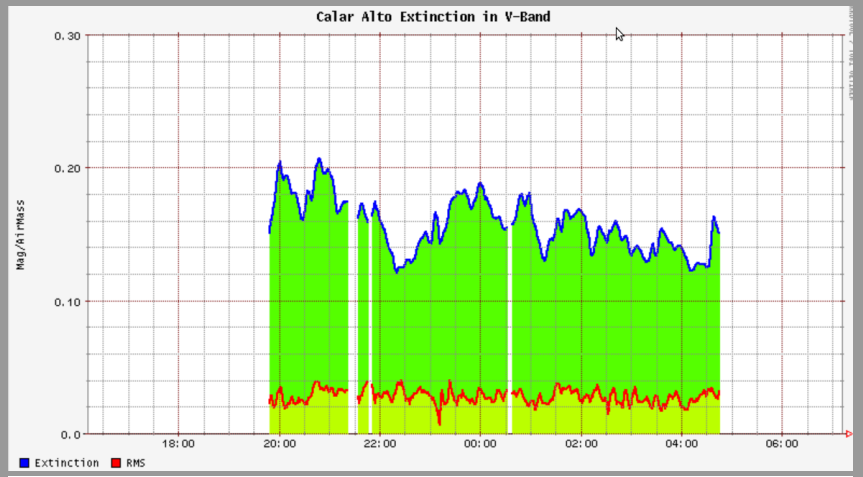
- Pretty standard using arc lamp frames obtained per objects
- Instrument flexures have to be corrected though

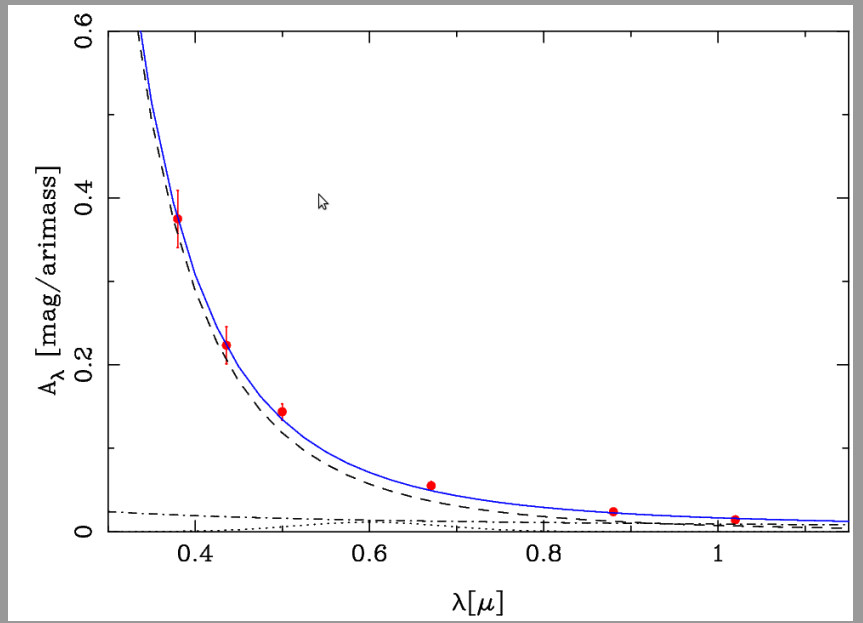


⇒ Checks on the data show an rms of 5-10 km/s as expected (V1200)

Spectrophotometric calibration scheme

- Spectrophotometric stars observed each night
- Atm. Extinction monitored at observatory (CAVEX)
- Mean extinction curve at Calar Alto is known





Sánchez et al. 2007, PASP, 119, 1186

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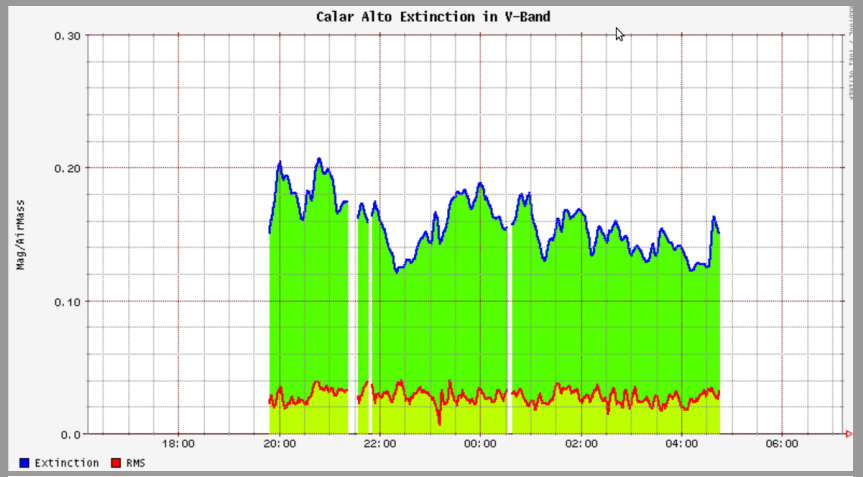
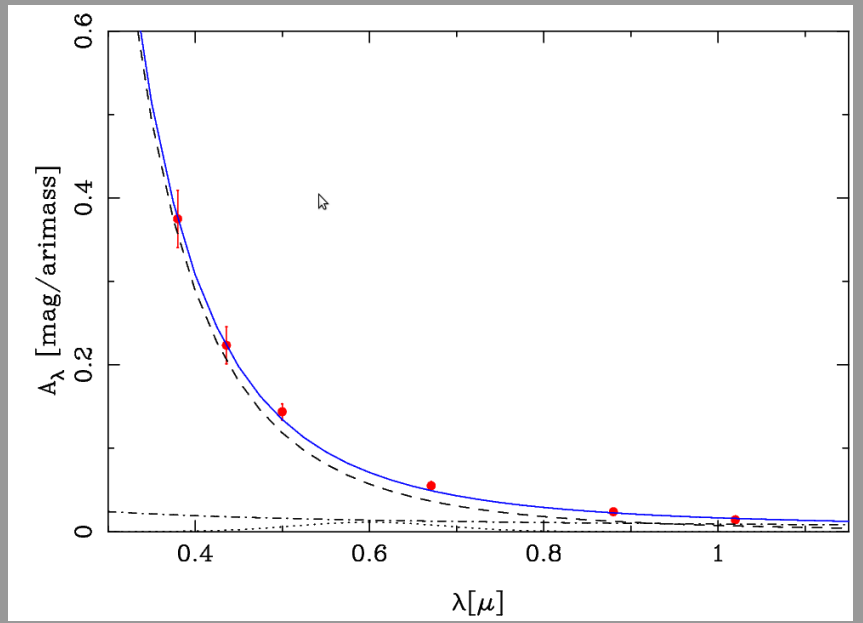
Remaining problems:

1. No simultanoues standard star observations
2. standard star observations prone to aperture losses

⇒ photometric re-calibration!



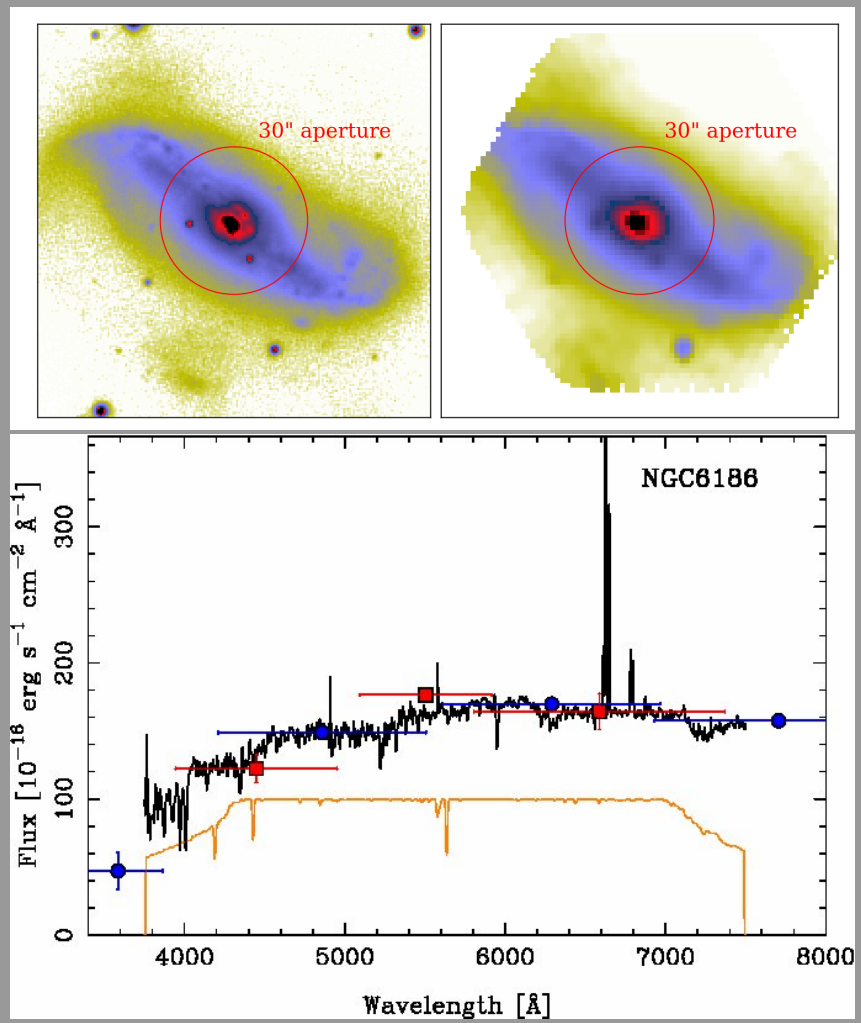


Sánchez et al. 2007, PASP, 119, 1186

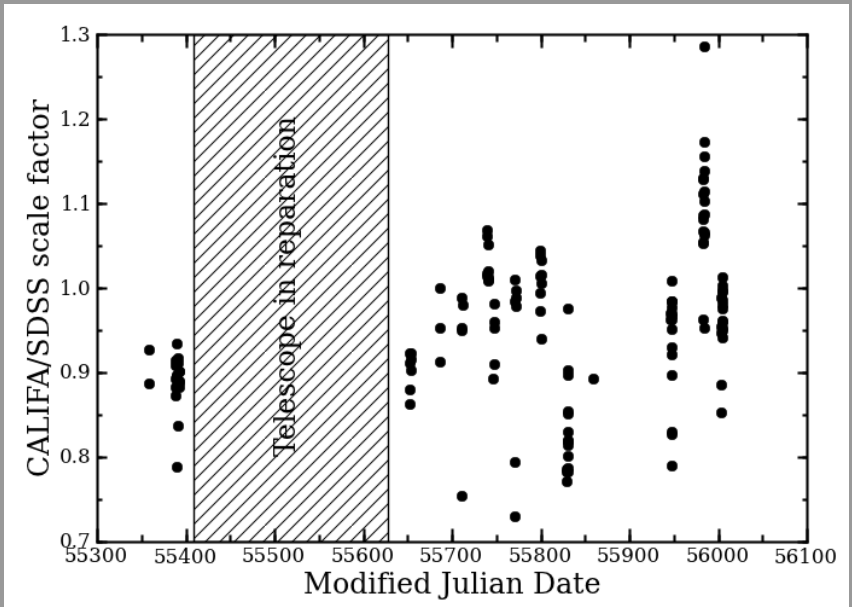
Anchor the absolute photometry to SDSS

1. Extract 30″ aperture photometry in u, g, r, i from SDSS images
2. Synthesize g and r photometry from the corresponding CALIFA spectra

⇒ Photometry matching leads to a re-scaling factor



Time evolution of internal photometry and colors



- Photometric scale factor strongly variable within ±20%
  ⇒ expected! A MEAN instrumental sensitivity curve was used

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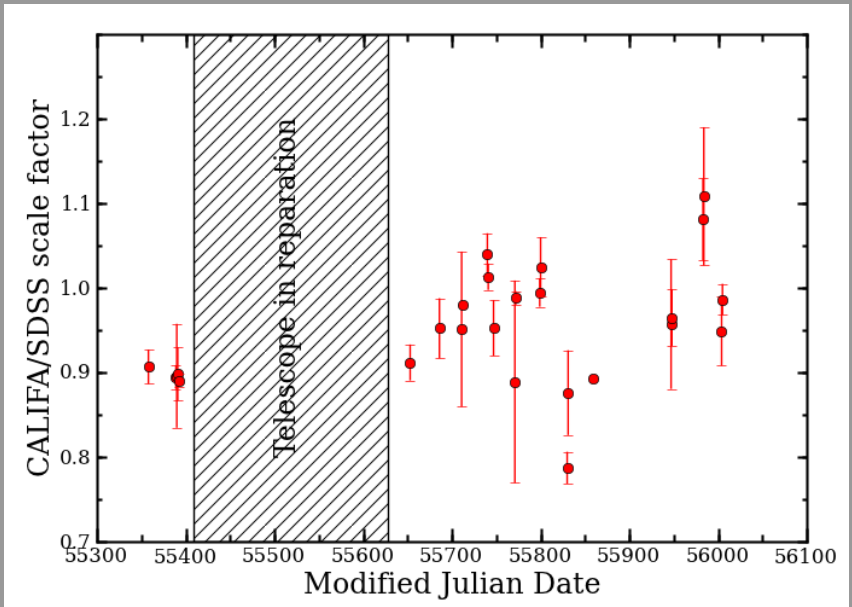

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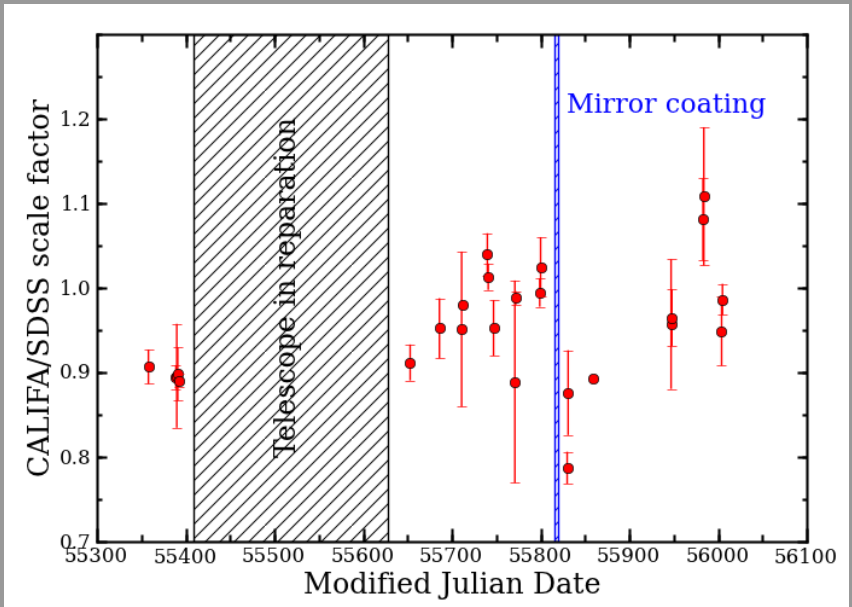

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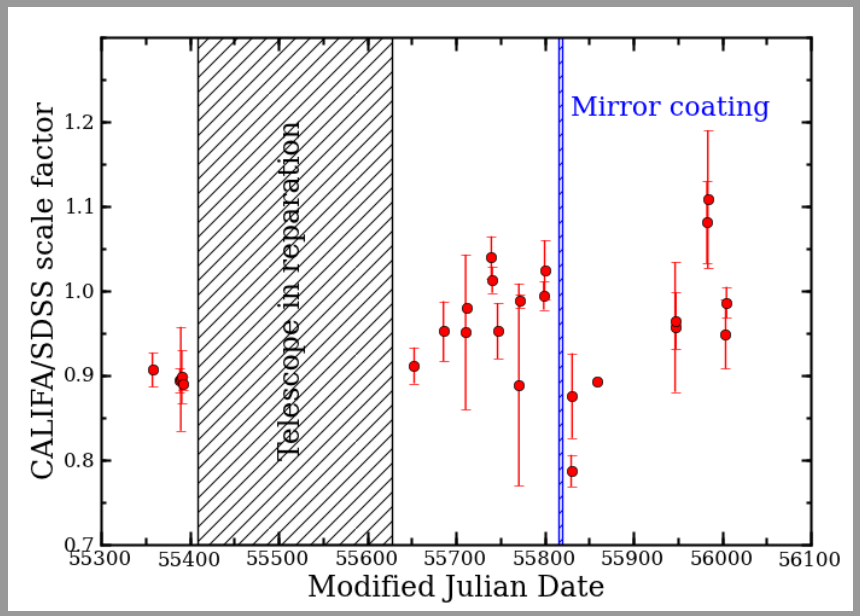
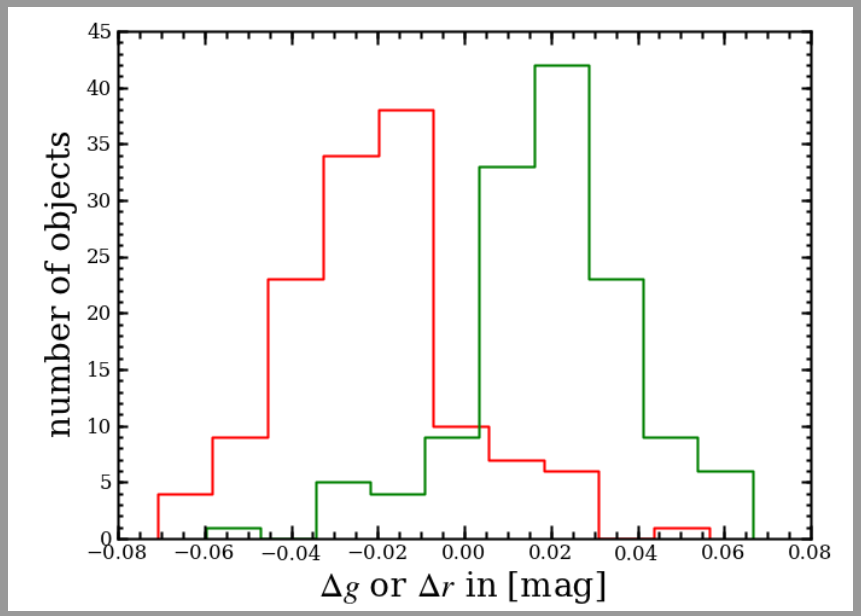
- Time evolution modulated by the primary mirror reflectivity

Time evolution of internal photometry and colors





- Photometric scale factor strongly variable within ±20%
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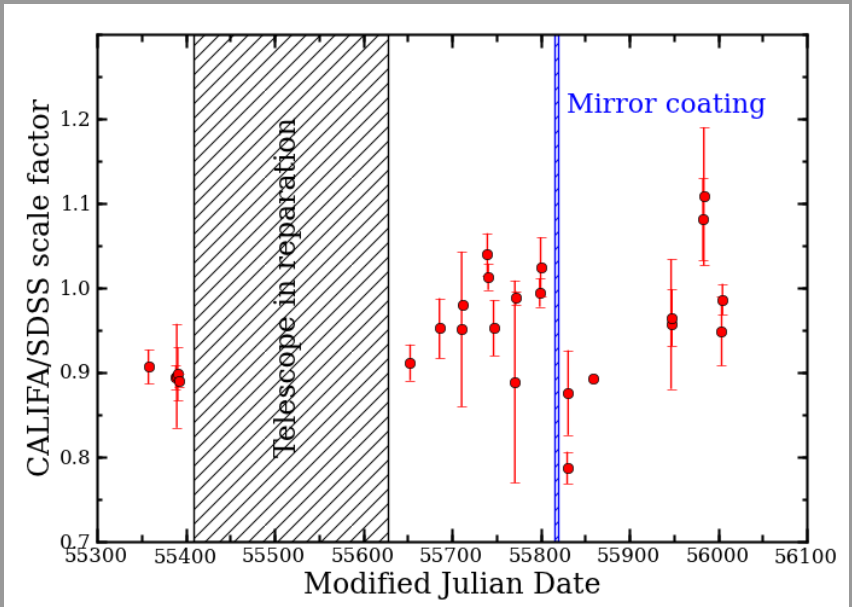
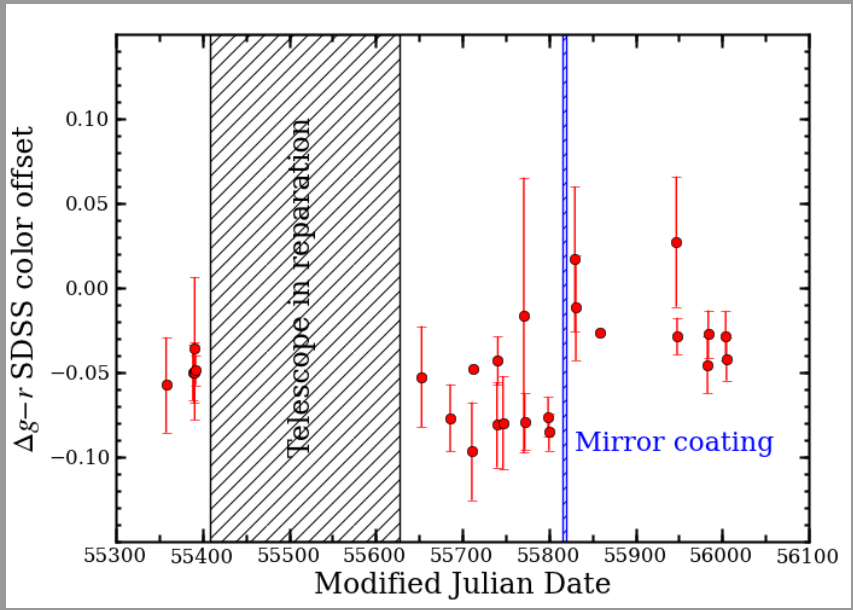
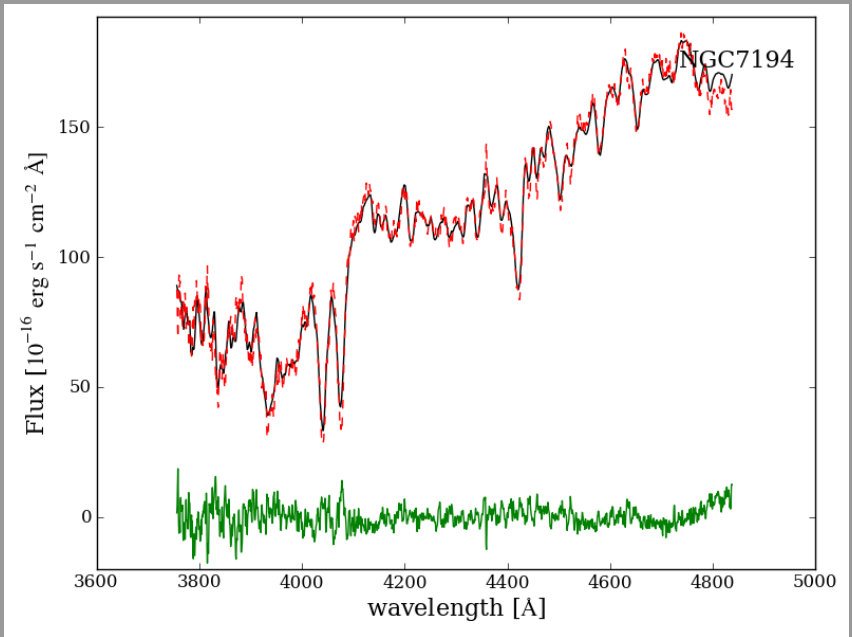
Time evolution of internal photometry and colors

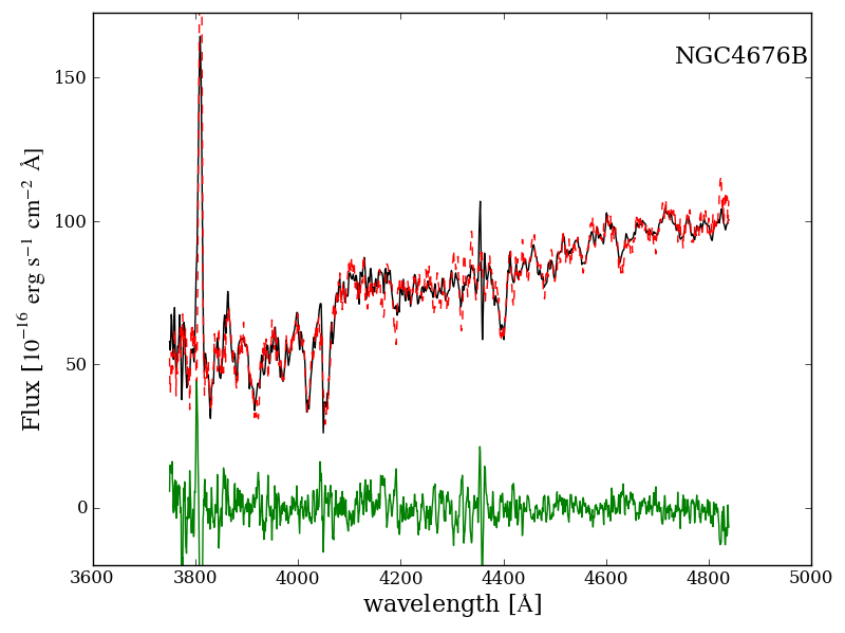




- Photometric scale factor strongly variable within ±20%
  ⇒ expected! A MEAN instrumental sensitivity curve was used
- Individual nights have a dispersion of only ±5% in the mean
- Time evolution modulated by the primary mirror reflectivity
- $g-r$ color is offset, stable before and after mirror coating within ±0.05 mag

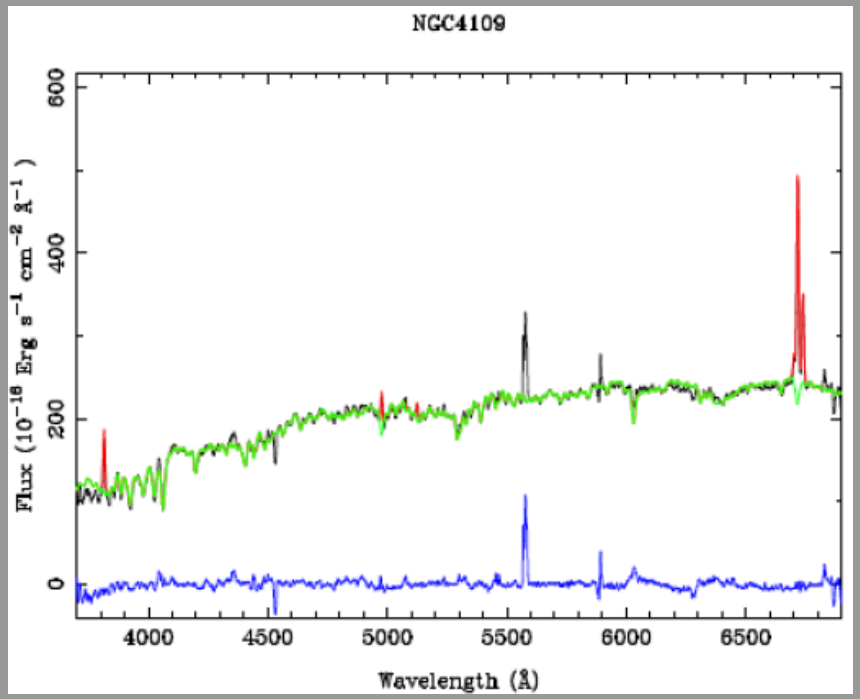
Cross-matching the V1200 to the V500 data





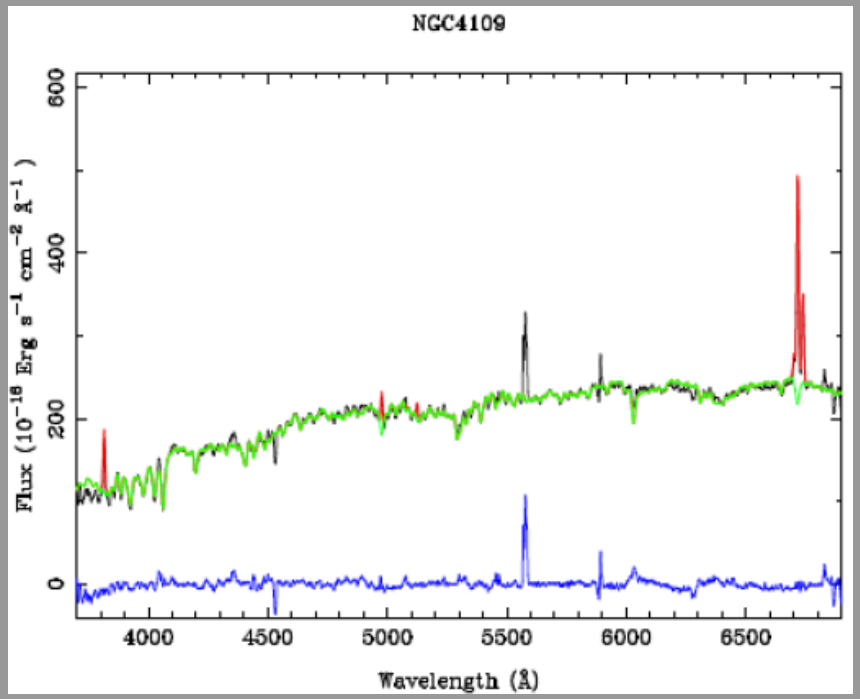
- 20″ spectra are extracted from the both calibrated cubes
- 4th-order polynomial is used to re-scale the V1200 spectrum
- Achieved a pretty good match dominated by noise only
- Highlights a matching wavelength calibration of both setups

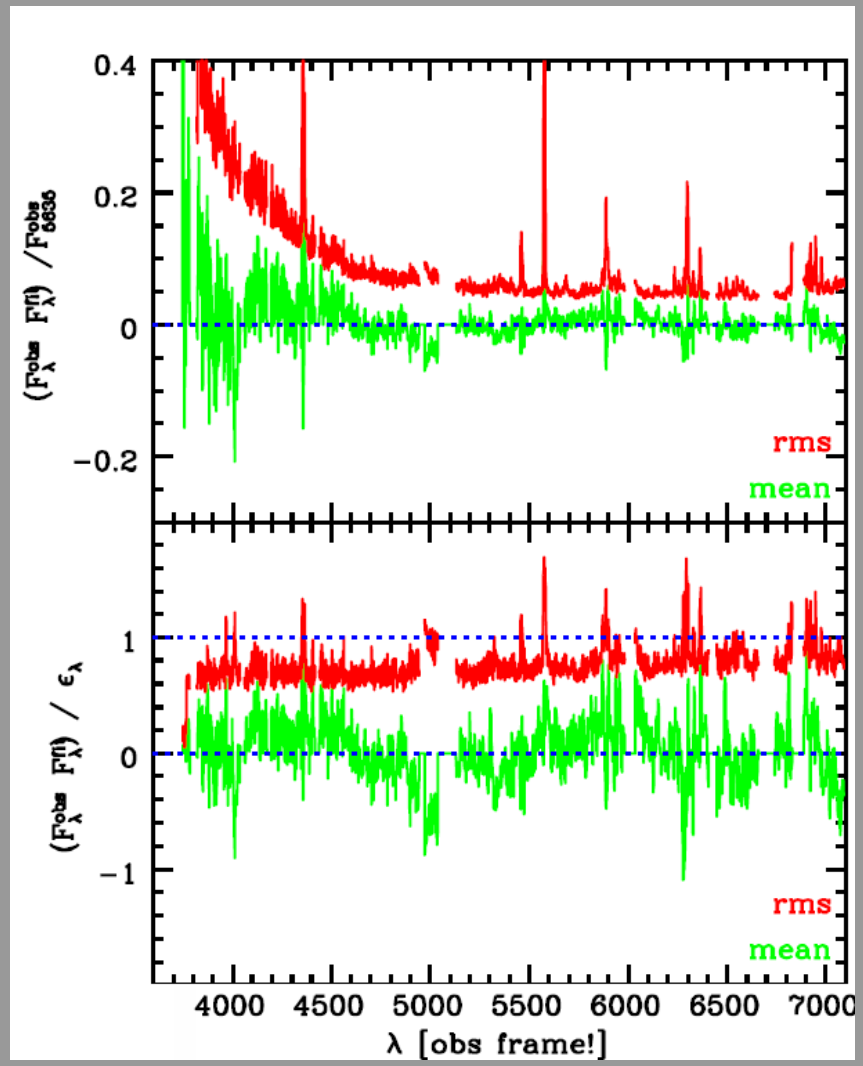
Testing the error propagation



- Error important for fitting
- Residuals as error estimator

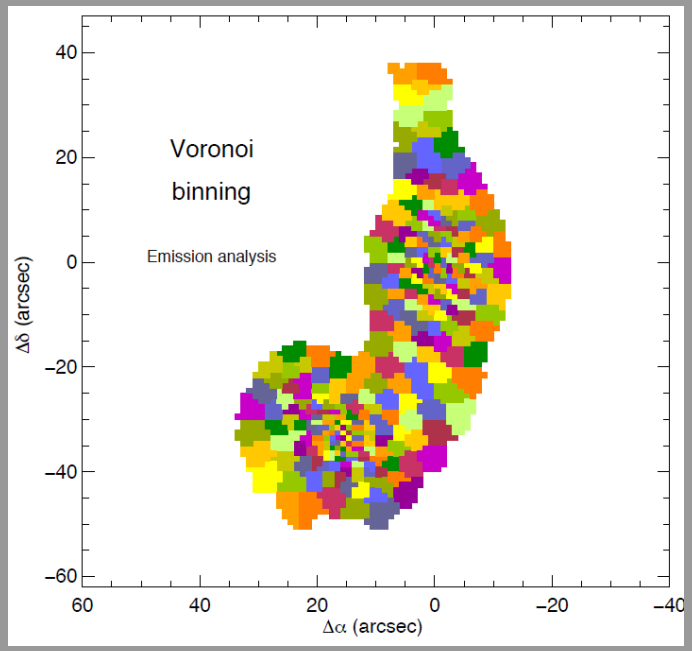
Testing the error propagation





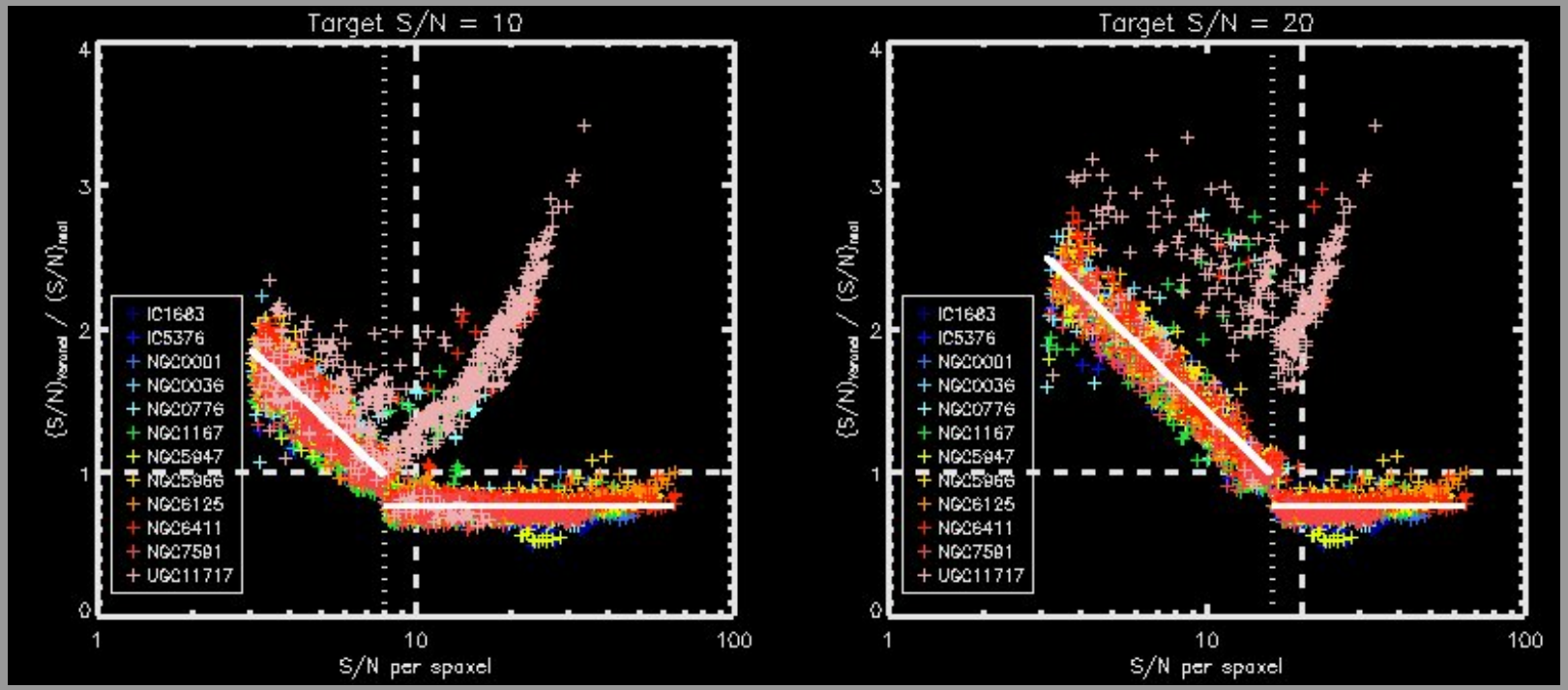
- Error important for fitting
- Residuals as error estimator
- Comparison with pipeline errors show:
  flat, but has a 20% offset

Calibrating the errors for correlated noise



- Data will be binned to increase the S/N
- Spectra are NOT independent due to image reconstruction
- Storing of covariance matrix for each spectrum is not practical

Calibrating the errors for correlated noise



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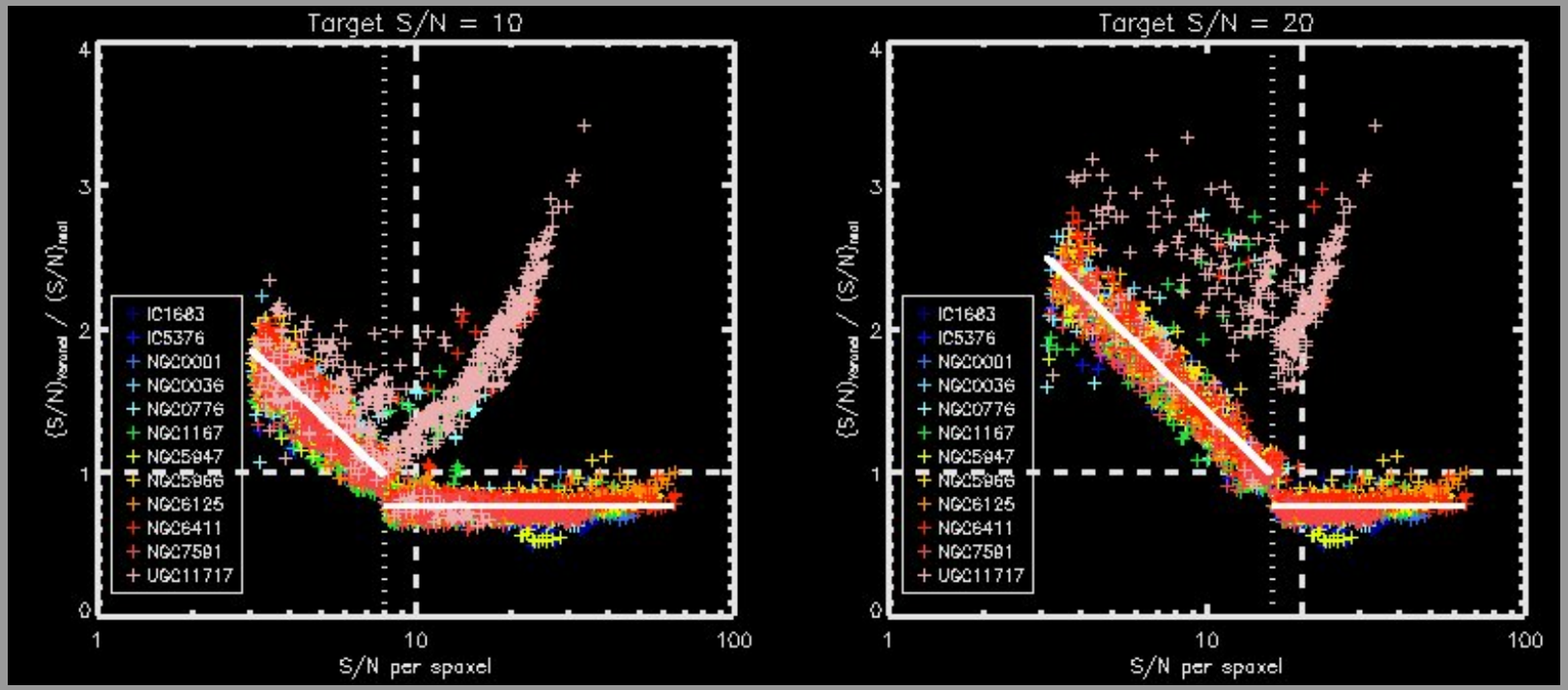
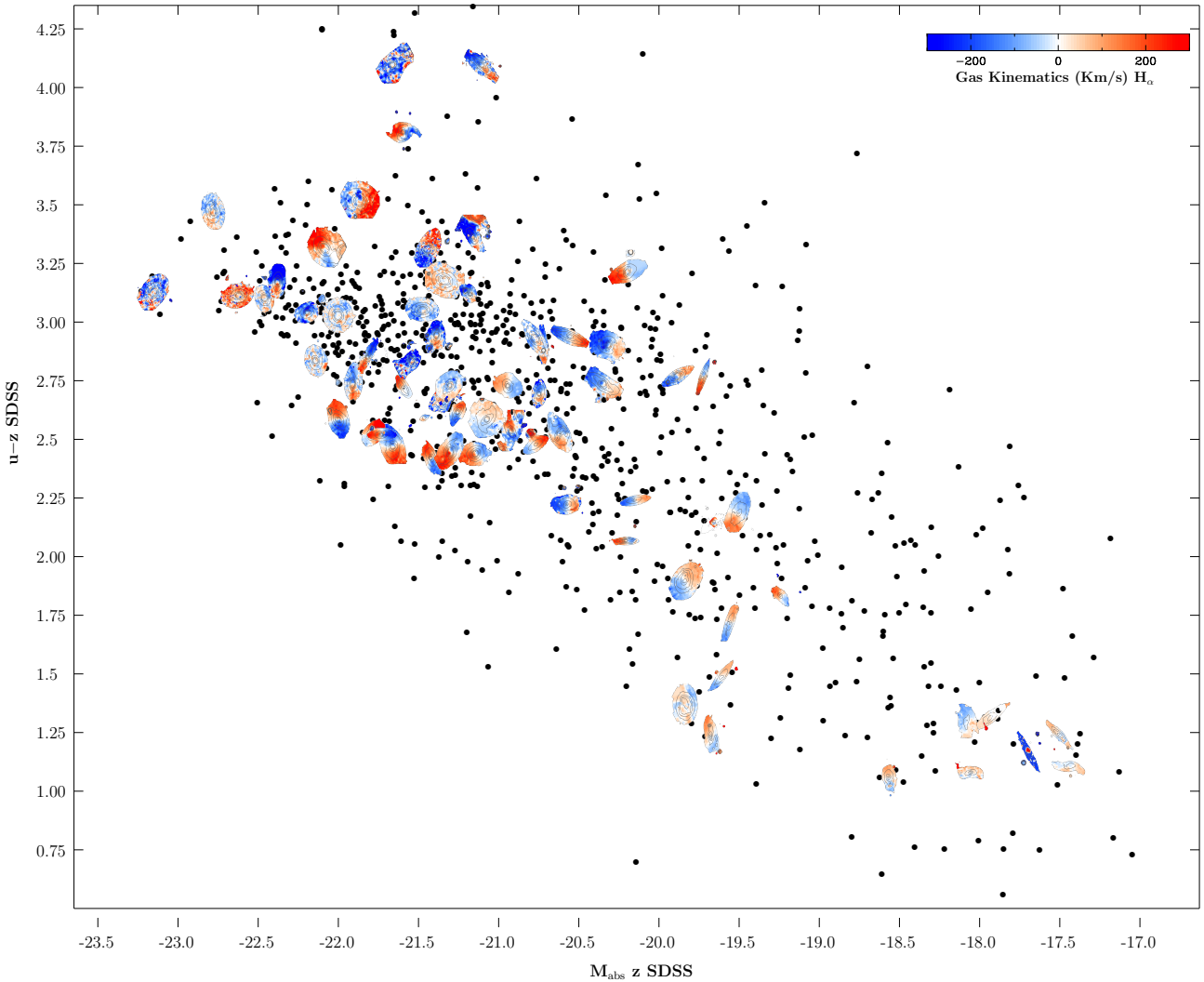


- Data will be binned to increase the S/N
- Spectra are NOT independent due to image reconstruction
- Storing of covariance matrix for each spectrum is not practical

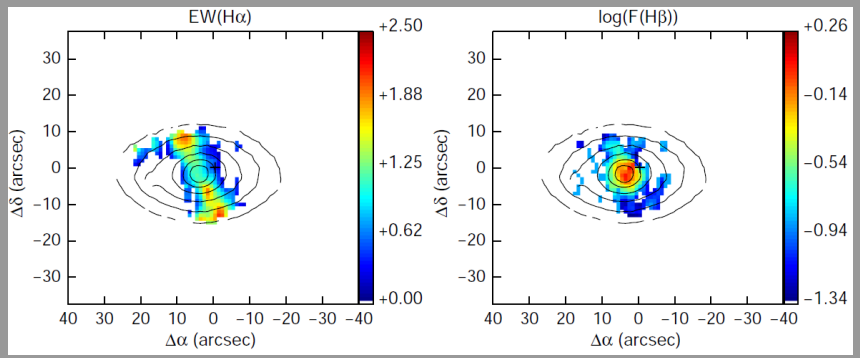
$\Rightarrow$ it seems that errors can be empirically corrected quite nicely!

Gas velocity maps across the color-magnitude space



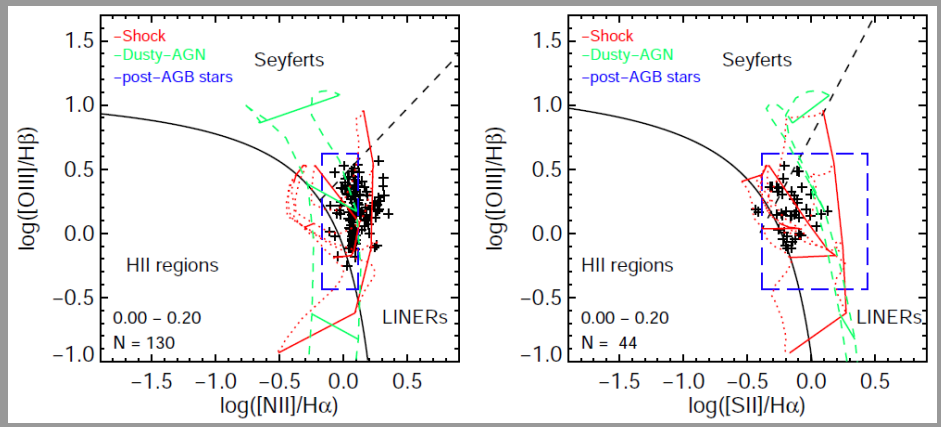
The ionised gas in CALIFA early-type galaxies

Emission-line maps (NGC 5966)



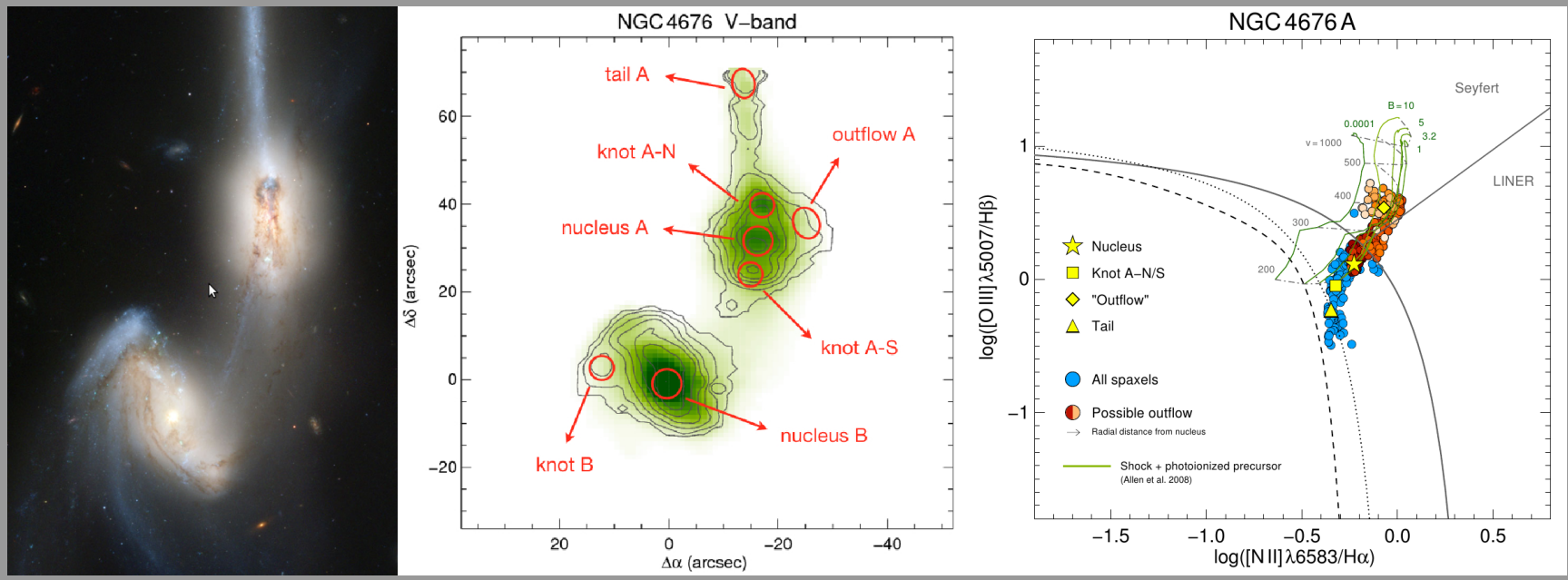
Kehrig et al. 2012, A&A, 540, A11

Emission-line diagnostic (NGC 5966)



- Emission-line maps reveal ionised gas on several kpc in some early-type galaxies
- Central source is classified as a LINER nucleus
- Cone-like shape points to an AGN origin for the ionisation
- Emission-line diagnostics still allow for hot stars as alternative

The Mice galaxy - Detection of a galactic outflow?



Wild et al. (in preparation)

- Extended ionised gas region detected West of nucleus A
- Emission-line ratios nicely follow shock+precursor models

⇒ Likely detection of a Galactic outflow

CALIFA Data Release 1

First public data release currently in preparation:

- 100 galaxies in both setups (V500 and V1200)
- Fully calibrated datacubes + errors will be distributed
- Extensive automatic and manual quality control checks
- Dedicated DR1 web service as well as VO access

⚠1st CALIFA data release scheduled for autumn this year⚠

The CALIFA team

Please have a look at our website:
www.caha.es/CALIFA

Thank you for your attention!