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

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CALIFA collaboration

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Outline

1. Survey Introduction
2. Astrometric and Spectrophotometric calibration
3. First results and data release
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)
  - ~2.5 Million Euros in telescope time
  - Competitive review process
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  - ~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 ≤ 30%
- Exchangeable and rotatable grisms
- **2 integral field units (IFUs):**
  - **Lens Array**
    - $16 \times 16$ lenslets (0.5″ sampling)
  - **Pmas fiber PAcK (PPAK)**
    - coarse fiber bundle
    - ~ 1′ Field of View (FoV)

⇒ 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!

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
Precedent spectroscopic surveys

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**Previous IFS surveys**
- **SAURON/ATLAS3D**
  - 72/$\sim$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

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Tremonti et al. 2004
Advantages over precedent spectroscopic surveys

- SDSS spectroscopy may cover the centre or the whole galaxy ⇒ Likely introducing aperture biases for most studies
- SAURON/ATLAS3D covers only the central area ($\leq 1R_{\text{eff}}$) Very narrow wavelength range limit optical diagnostics
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CALIFA covers an entire galaxies in a certain redshift range!
Comparison of spectroscopic survey efficiencies

- 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
  - $\sim 1$ 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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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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Will not bother you with a IFU data reduction lesson...
Dither pattern and image reconstruction

SDSS r band image

An individual PP AK pointing has a low weighting 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.
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Possible solution: Registering to SDSS images

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

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Remaining problems:
1. No simultaneous standard star observations
2. Standard star observations prone to aperture losses

⇒ photometric re-calibration!

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
Photometric scale factor strongly variable within ±20% ⇒ expected! A MEAN instrumental sensitivity curve was used.
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- Individual nights have a dispersion of only ±5% in the mean
- Time evolution modulated by the primary mirror reflectivity
Survey Introduction

Astrometric and Spectrophotometric calibration

First results and data release

Time evolution of internal photometry and colors

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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
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- 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
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⇒ 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

Emision-line maps (NGC 5966)  Emision-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?

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

⇒ Likely detection of a Galactic outflow
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!