

Data Release 2 of S-PLUS

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Data Release 2 of S-PLUS: accurate template-fitting based photometry covering ~1000 square degrees in 12 optical filters

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ABSTRACT

The Southern Photometric Local Universe Survey (S-PLUS) is an ongoing survey of ~9300 deg² in the southern sky in a 12-band photometric system. This paper presents the second data release (DR2) of S-PLUS, covering 950 deg² in 12 optical filters covering an area of 950 deg². The data has been fully calibrated using a new photometric calibration pipeline, allowing for the first time the generation of wide-field multi-filter surveys. This technique consists of a χ^2 minimization of the photometric residuals against a set of already calibrated data from other surveys, eliminating the need for standard stars. We compare the template-predicted and S-PLUS instrumental magnitudes. We show that these ZPs can be further refined by fitting the template-predicted magnitudes. We constrain the models by adding the narrow-band information from the DR2 filters, which are ≤ 10 mags for filters J0410, J0430, g, J0515, r, J0660, and ≤ 25 mags for filters u and J0395. We describe the complete data flow of the DR2, from the raw data to the final catalogues and present a brief characterisation of the data. We show that, for a magnitude threshold of 3, the photometric depths of the DR2 range from 19.9 mag to 21.3 mag (measured in FWHM apertures), depending on the filter. The S-PLUS DR2 can be accessed from the website: <https://splus.cloud>.

Key words: surveys – techniques: photometric – catalogues – astronomical data bases: miscellaneous – stars: general – galaxies: general

1 INTRODUCTION

Wide-field photometric surveys are essential for research in astronomy, especially because of the large volume of data they are able to provide in a reasonable amount of time and with more extensive sky coverage compared to spectroscopic surveys. Surveys such as the Sloan Digital Sky Survey (SDSS, York et al. 2000), 2MASS (Skrutskie et al. 2006), ATLAS (Shanks et al. 2015), and PanSTARRS (Chambers et al. 2016), in mention a few, have contributed to the development of countless areas in astronomy: from the study of asteroids to the large scale structure of the Universe.

Following the success of these past surveys, several ongoing and planned projects are being executed to complement and supplement

the available data in terms of increasing i) the sky-coverage: mainly by including the southern hemisphere (e.g. DES, Abbott et al. 2018; SkyMapper Wolf et al. 2018); ii) the photometric-depth: reaching fainter magnitudes (e.g. LSST, Ivezić et al. 2019); or iii) the wavelength range and resolution: extending or increasing the number of pass-bands in previous filter systems and even replacing broadband with narrow-band filters to widen the spectral feature sensitivity (e.g. the Pristine Survey, Starkenburg et al. 2017).

Regarding the topic of expanding the wavelength resolution, three surveys clearly stand out: the Javalambre Physics of the Accelerating Universe Astrophysical Survey (JPAS, Benítez et al. 2014) and mini-PAS, Bonoli et al. 2020), the Javalambre Photometric Local Universe Survey (J-PLUS, Cenarro et al. 2019) and the Southern Photometric Local Universe Survey (S-PLUS, Mendes de Oliveira et al. 2019). Of these, J-PAS is the most ambitious and plans to cover an area

submitted to MNRAS

S-PLUS/DR2 Second Data Release



www.splus.iag.usp.br

DR2 Details

<https://arxiv.org/abs/2104.00020>

Unique Detections*

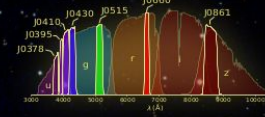
*with S/N > 3

~21 million

filter system 12-bands

flux corrected circular aperture for point sources (PStotal)

Adaptive elliptical apertures for extended sources (auto, petro)



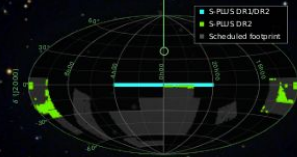
telescope T80-South 86 cm



5 years of observations (2016 - 2020)

514 2-deg² tiles

DR2 Footprint 950.5 deg²



Value Added Catalogs

- star/galaxy/quasar classification
- masks around bright stars
- photometric redshifts
- permanent object IDs

Data Access

<https://splus.cloud>

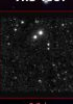
Catalog Tools

```
SELECT
  objid, RA/d, DEC
FROM
  detection_image AS di
WHERE
  di.RA < 2
  AND di.OBJID > 0
```

Cutout



Tile Tool



Colored Images



splusdata

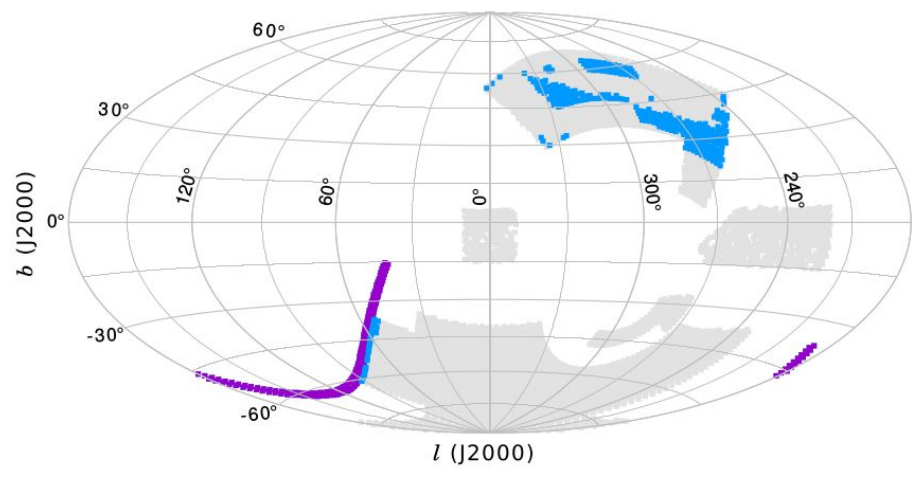
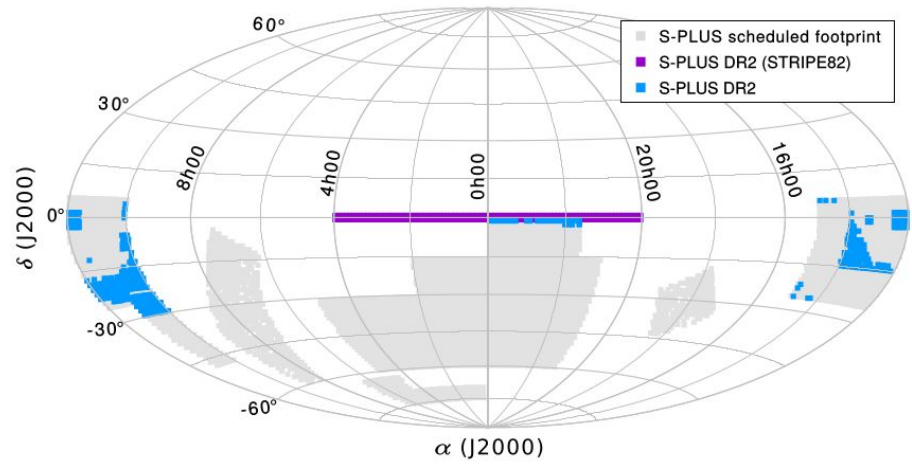
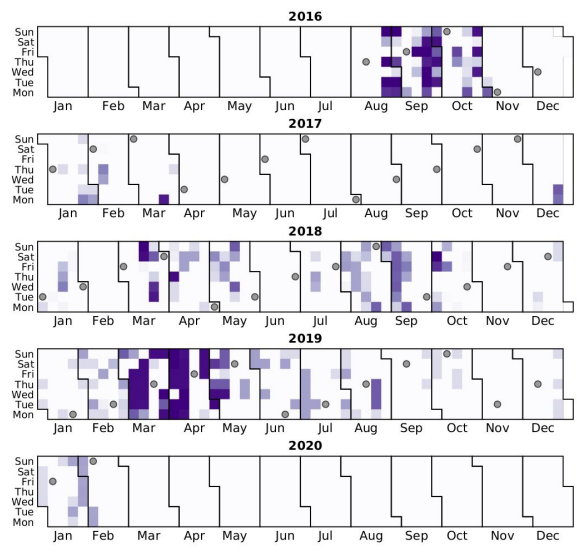


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 bright star's masks: Maria Luisa Buzzo <luisa.buzzo@gmail.com>
 photo-zs: Erik V. R. de Lima <erik.vira@iag.usp.br>

- 514 S-PLUS fields
- 950.5 sq degrees
- Observations between 2016 and 2020



Identification and Position			
Field	Name of the S-PLUS field of the observation		
ID	Observation ID in DR2		
RA	Right Ascension (J2000)	[deg]	
DEC	Declination (J2000)	[deg]	
X	CCD X-axis position (reduced image)	[pixel]	
Y	CCD Y-axis position (reduced image)	[pixel]	

Morphology			
ISOarea	Number of pixels exceeding 1.1 sigma threshold		
MU_MAX	Peak surface brightness above background	[mag/arcsec ²]	
A	Isophotal image major axis	[pixel]	
B	Isophotal image minor axis	[pixel]	
THETA	Isophotal image position angle	[deg]	
ELONGATION	A/B		
ELLIPTICITY	1 - B/A		
FLUX_RADIUS	Radius containing (0.2,0.5,0.7,0.9) fraction of the light	[pixel]	
KRON_RADIUS	Kron apertures in units of A or B		
FWHM	FWHM assuming a Gaussian core	[pixel]	
FWHM_n	Normalized FWHM		
FWHM_{filter}	FWHM at each filter	[pixel]	

Flags and classification Columns	
calibration_flag	Indication of the reference catalogue for calibration
PhotoFlag_{filter}	SExtractor 'FLAGS'
PhotoFlagDet	SExtractor 'FLAGS' in the Detection image
CLASS_STAR_{filter}	Star classification
CLASS_STAR	Star classification in the Detection image

Photometry Columns	
{filter}_{aperture}	AB magnitude
e_{filter}_{aperture}	Magnitude error
s2n_{filter}_{aperture}	Source's S/N
nDet_{aperture}	Number of detections
s2n_Det_{aperture}	Source's S/N in the detection image

+ Value Added Catalogs:

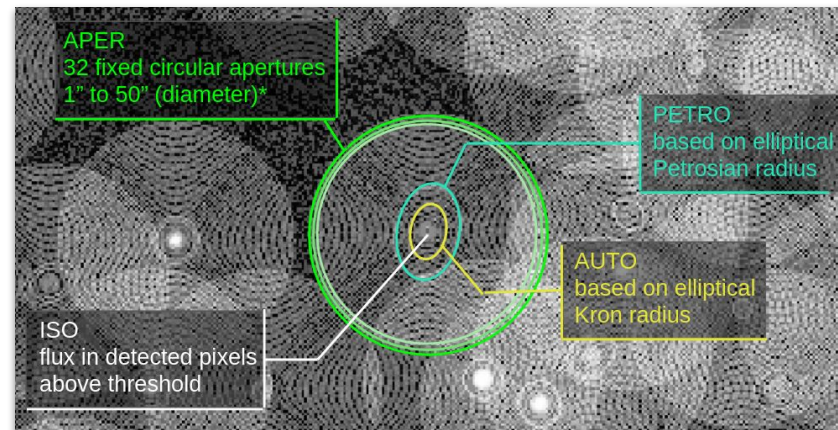
- Star/galaxy/quasar classification
- photometric redshifts
- masks around bright stars
- permanent S-PLUS ID

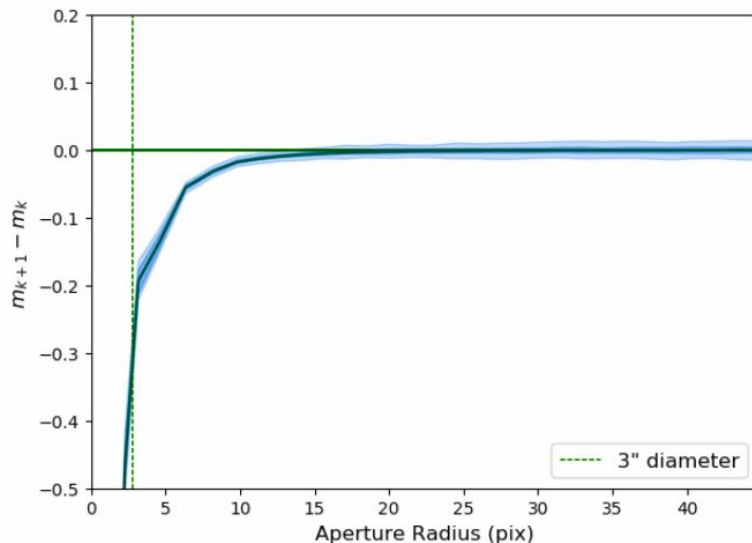
Identification and Position			
Field	Name of the S-PLUS field of the observation		
ID	Observation ID in DR2		
RA	Right Ascension (J2000)	[deg]	
DEC	Declination (J2000)	[deg]	
X	CCD X-axis position (reduced image)	[pixel]	
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Morphology			
ISOarea	Number of pixels exceeding 1.1 sigma threshold		
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ELONGATION	A/B		
ELLIPTICITY	1 - B/A		
FLUX_RADIUS	Radius containing fraction of the light (0.2,0.5,0.7,0.9)	[pixel]	
KRON_RADIUS	Kron apertures in units of A or B		
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{filter}_{aperture}	AB magnitude
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s2n_{filter}_{aperture}	Source's S/N
nDet_{aperture}	Number of detections
s2n_Det_{aperture}	Source's S/N in the detection image





Aperture Corrected magnitudes for Point Sources (PStotal)

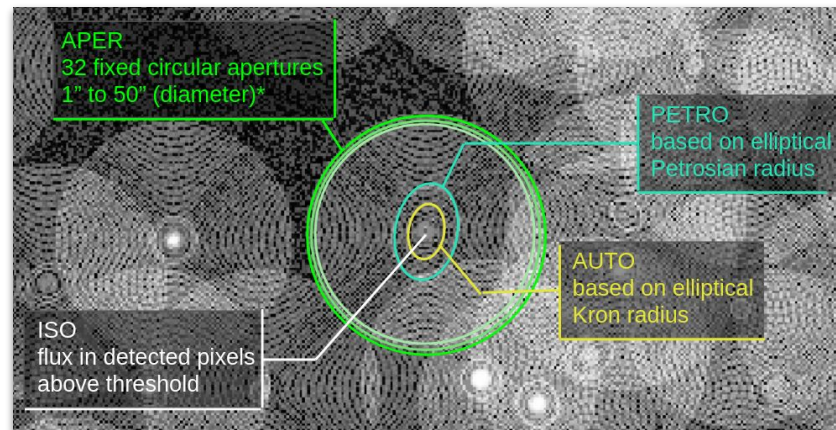
$$\{\text{filter}\}_{\text{PSTOTAL}} = \{\text{filter}\}_{\text{APER}_3} + \text{AC}_{\{\text{filter}\}}$$

Flags and classification Columns

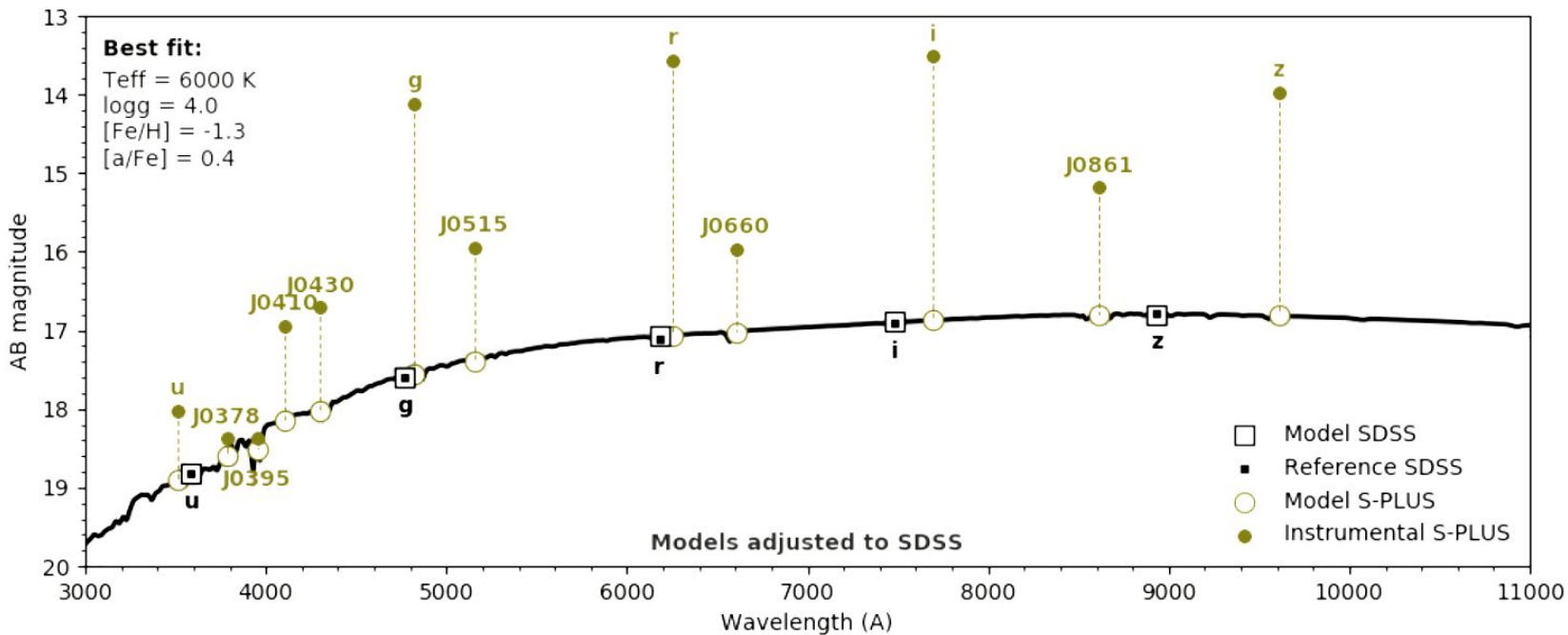
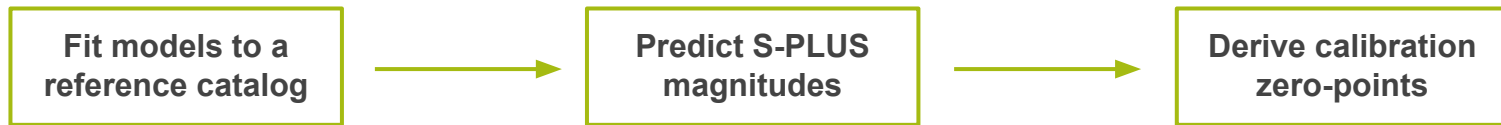
calibration_flag	Indication of the reference catalogue for calibration
PhotoFlag_{filter}	SExtractor 'FLAGS' in the Detection image
PhotoFlagDet	SExtractor 'FLAGS' in the Detection image
CLASS_STAR_{filter}	Star classification in the Detection image
CLASS_STAR	Star classification in the Detection image

Photometry Columns

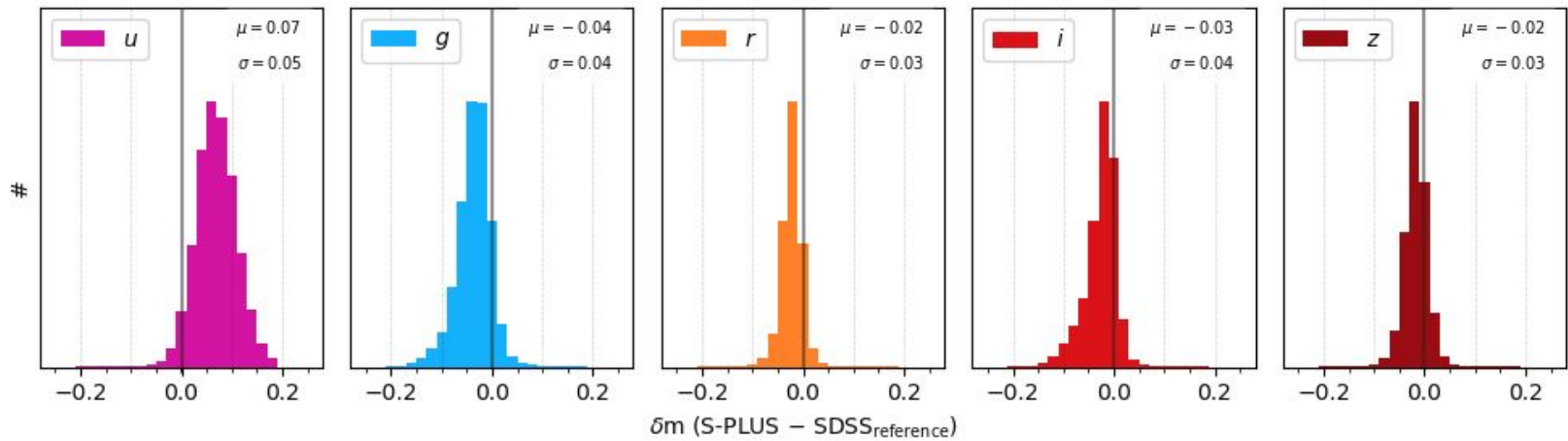
{filter}_{aperture}	AB magnitude
e_{filter}_{aperture}	Magnitude error
s2n_{filter}_{aperture}	Source's S/N
nDet_{aperture}	Number of detections
s2n_Det_{aperture}	Source's S/N in the detection image



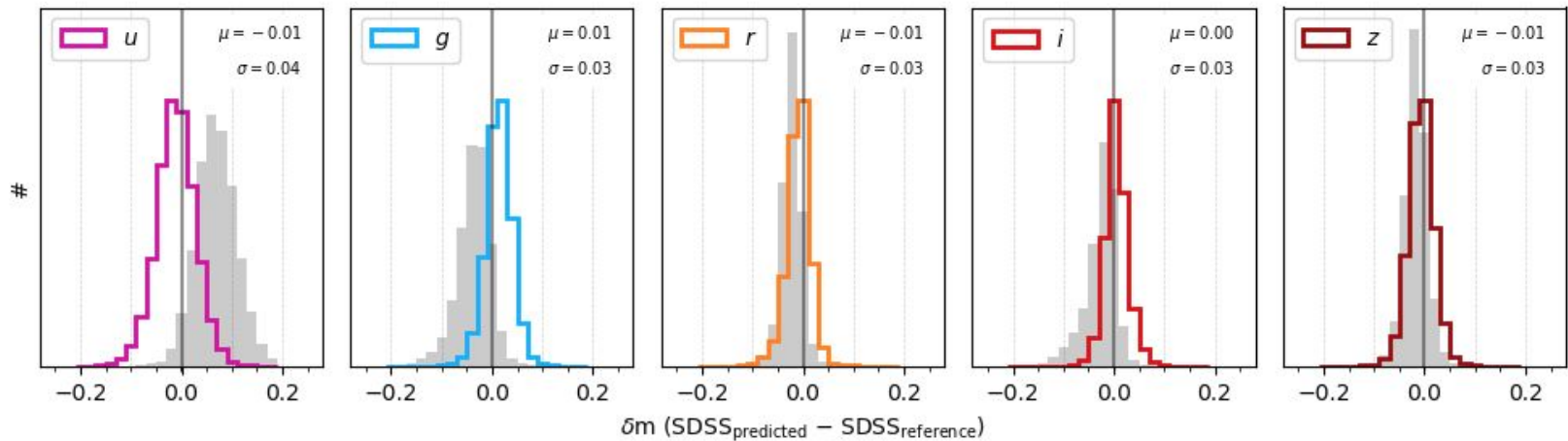
Calibration approach:



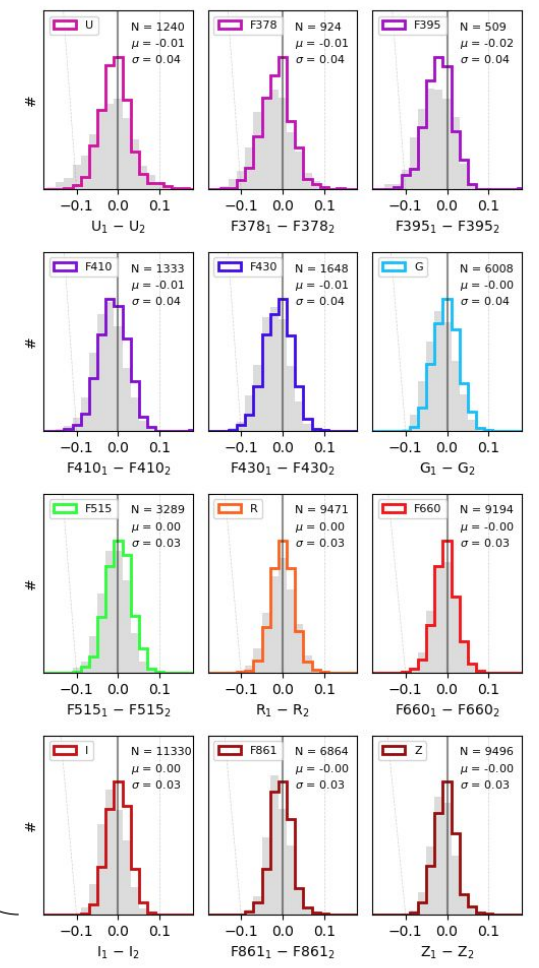
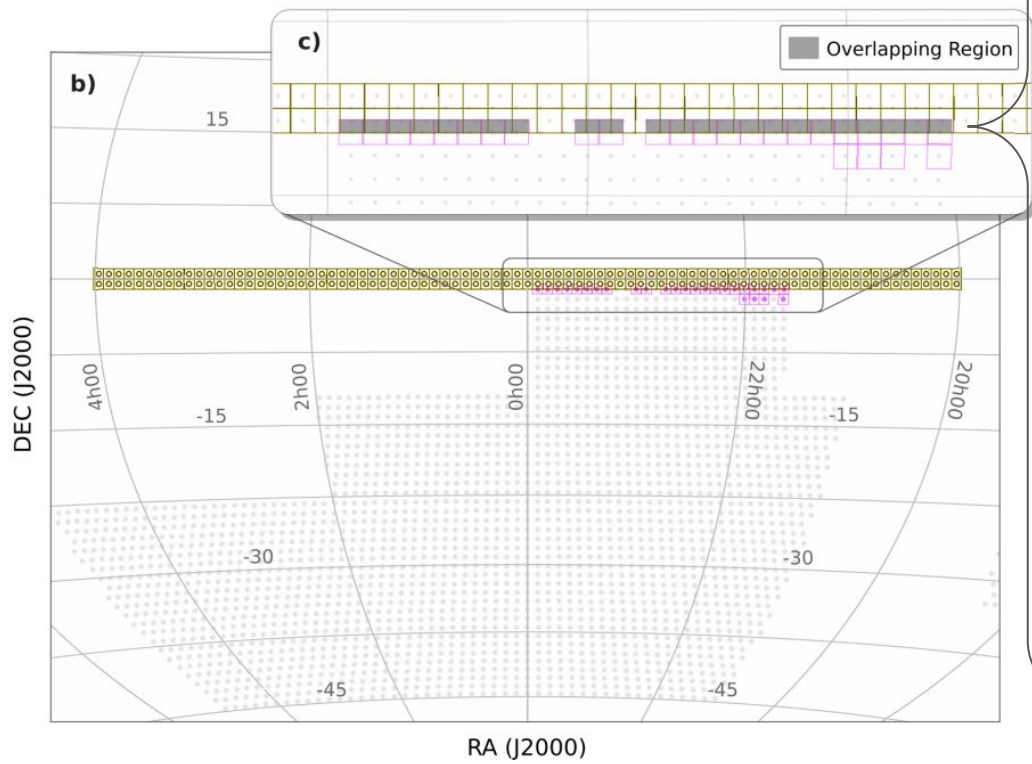
Direct comparison to SDSS



Comparison after converting to SDSS filter system



Internal comparison of overlapping fields

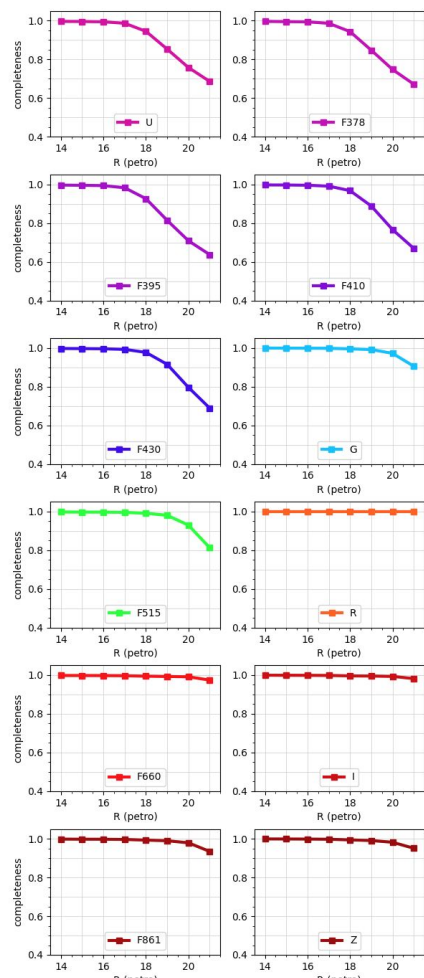
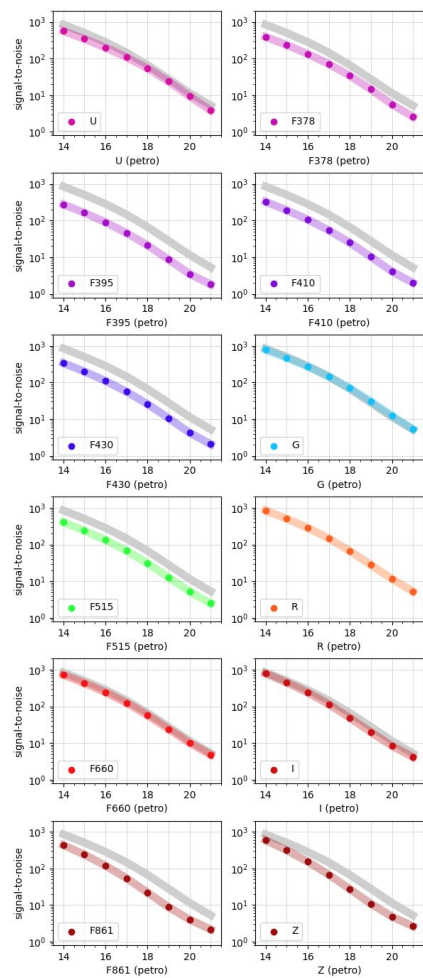
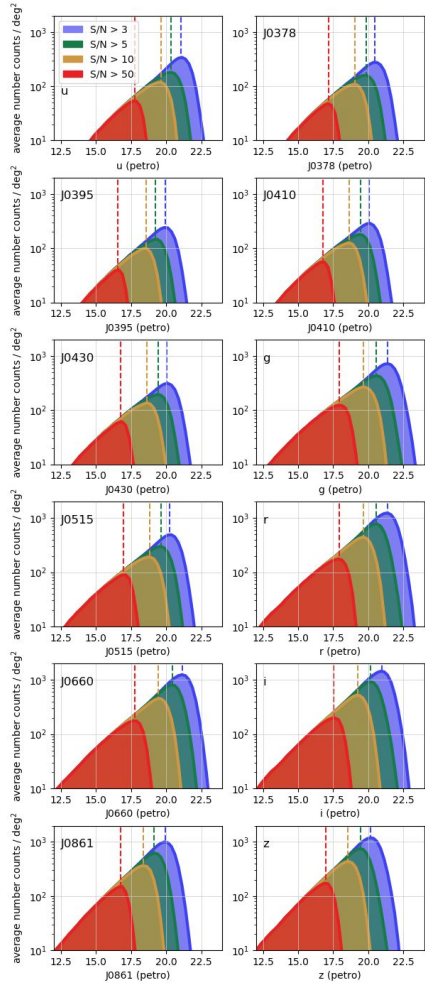


Characterization of DR2 data

- Photometric depths

filter	S/N > 50	S/N > 10	S/N > 5	S/N > 3
<i>u</i>	17.7	19.6	20.3	21.0
J0378	17.1	19.0	19.8	20.4
J0395	16.5	18.5	19.2	19.9
J0410	16.7	18.6	19.4	20.0
J0430	16.7	18.6	19.4	20.0
<i>g</i>	17.9	19.6	20.5	21.3
J0515	16.9	18.8	19.6	20.2
<i>r</i>	17.9	19.6	20.5	21.3
J0660	17.7	19.4	20.4	21.1
<i>i</i>	17.5	19.2	20.1	20.9
J0861	16.7	18.3	19.1	19.9
<i>z</i>	16.9	18.5	19.4	20.1

- Average s/n per magnitude bin
- Completeness in relation to the r-band



Overview

Footprint

Contents

Calibration

DR2 data

Next steps

S-PLUS is suitable for many different sciences



It is very challenging to provide quality data for so many different applications

will remain the highest resolution large photometric survey in this area in the near future.

The extended resolution of these surveys, covering key spectral features, enables their application in many different fields. In particular, S-PLUS data has been used to study clusters of galaxies, considering accurate photometric redshifts in Stripe-82 using template fitting (Molino et al. 2020) and machine learning (Vinicius-Lima et al., submitted), ultra-diffuse galaxies (Barbosa et al. 2020), lenticular galaxies (Cortesi et al. 2021), the Hydra cluster galaxies (Lima-Dias et al. 2021), conduct searches for quasars (Nakazono et al. submitted), determine galaxy morphology (Bom et al. submitted), perform star/galaxy separation (Costa-Duarte et al. 2019), analyse stellar populations in and around the Milky Way, including stellar groups in the CMa OB1 association (Santos-Silva et al. submitted), determine and study the photometric metallicity and carbon distributions of stars in the Milky Way's Halo (Whitten et al. accepted), find and characterize compact planetary nebulae (Gutiérrez-Soto et al. 2020) and ultra metal-poor stars (Placco et al., in prep) and study active low-mass stars in CMa R1 star-forming region (Gregorio-Hetem et al. 2021), as well as several ongoing projects. Given this wide range of applications, it is of utmost importance to provide precise and accurate photometry that is reliable for both point and extended sources.

The photometric calibration is the process of translating photon counts measured at the detector into physical fluxes at the top of the

Recent improvements

Detection

- New detection images generated by SWARP
- Support to weight images

Photometry

- Inclusion of single mode photometry
- Inclusion of psf photometry (DOPHOT)

Aperture Correction

- Refined parameters for moderately crowded fields

Calibration (work in progress)

- Improvements in the model fitting process
- Extinction correction for MC and low galactic latitudes

Data Access

- new database: splus.cloud
- new python package: [splusdata](https://pypi.org/project/splusdata/)
- support to Topcat TAP service

Recent improvements

Detection

- New detection images generated by SWARP
- Support to weight images

Photometry

- Inclusion of single mode photometry
- **Inclusion of psf photometry (DOPHOT)**

Aperture Correction

- Refined parameters for moderately crowded fields



join us in the afternoon session if you want to know more about this.

