Photometric calibration of imaging datasets

OU-MER overview

OU–MER (A. Fontana)
SDC-ITA (M. Frailis)

Alexandre Boucaud (IAS, Orsay)

Overview

1. Introduction to MER
2. Multi-wavelength photometry
3. Photometric validation tests
4. Open issues/questions

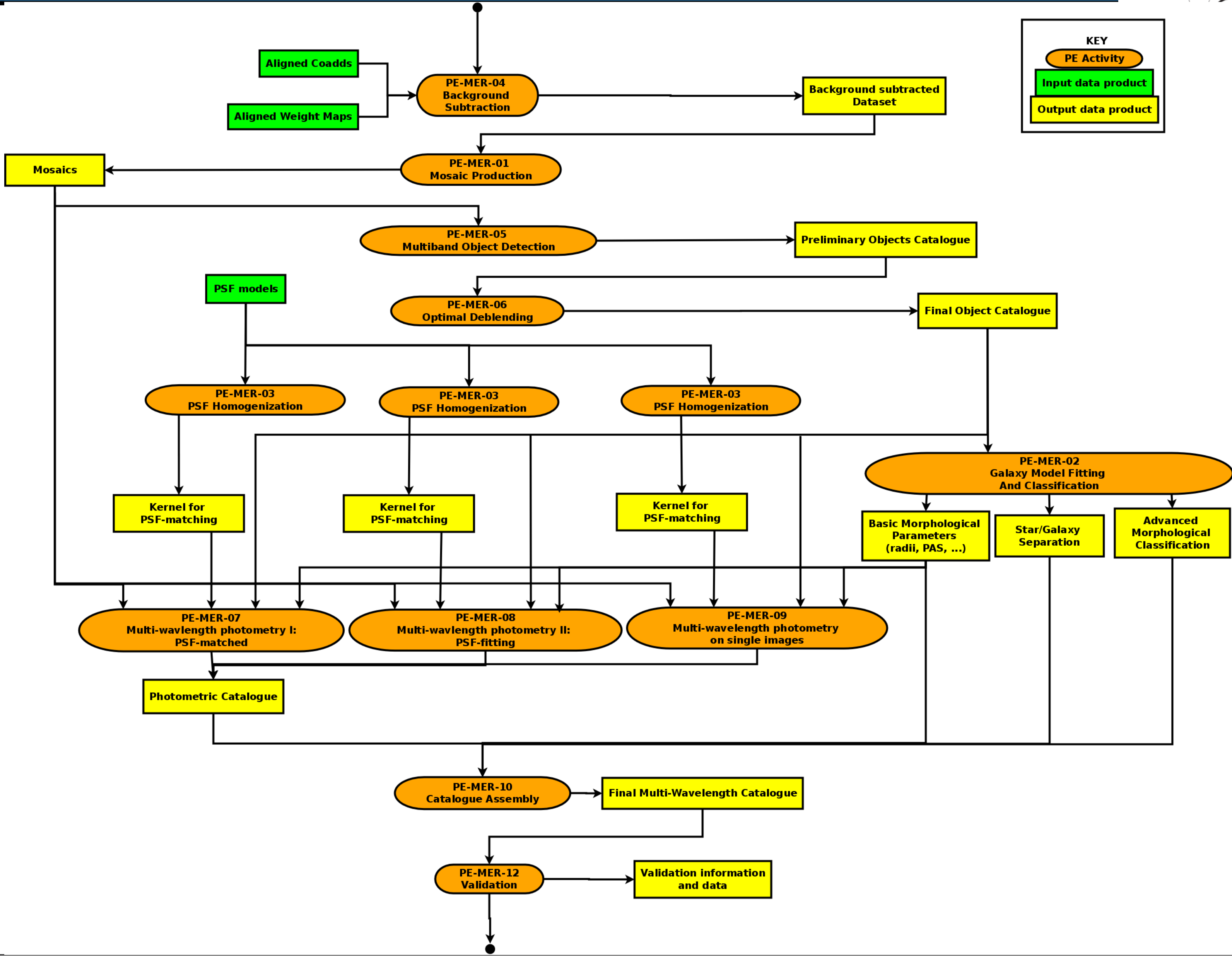
MER rationale

- Goal: compute the multi-wavelength catalogue, combining VIS & NIR Euclid images and external images delivered by EXT.
- Main steps:
  - mosaic production
  - background subtraction
  - multi-band detection
  - deblending
  - PSF matching kernel production
  - multi-wavelength photometry
  - morphological measurements
- Outputs: object catalogue with full multi-wavelength photometry and galaxy properties.

WP and Processing Elements

Processing Element	WP	WP Manager	Institution
All	4-3-06-1100 OU-MER Management	A.Fontana	INAF-OAR (Italy)
All	4-3-06-1200 OU-MER Processing function specification	S. Pilo	INAF-OAR (Italy)
PE-MER-01	4-3-06-2100 Mosaic production	H. Israel	LMU (Germany)
PE-MER-02	4-3-06-2200 Galaxy model fitting and classification	H. Dole	IAS (France)
PE-MER-03	4-3-06-2300 PSF Homogenization	A. Boucaud	IAS (France)
PE-MER-04	4-3-06-2400Background subtraction	T. Vassallo	LMU (Germany)
PE-MER-05	4-3-06-3100 Multiband object detection	M.Kuemmel	LMU (Germany)
	4-3-06-3200 Optimal deblending	M. Castellano	INAF-OAR (Italy)
PE-MER-06	4-3-06-4100 Multi-wavelength photometry I: PSF-matched	E. Merlin	INAF-OAR (Italy)
PE-MER-07	4-3-06-4200 Multi-wavelength photometry II: PSF-fitting	E. Merlin	INAF-OAR (Italy)
PE-MER-08	4-3-06-4300Multi-wavelength photometry on single images	M. Kuemmel	LMU (Germany)
None	4-3-06-5100 Simulations based on high resolution real images	S. Pilo	INAF-OAR (Italy)
None	4-3-06-5200 Simulations based on mock catalogues	A. Boucaud	IAS (France)
	4-3-06-5300 Catalogues	S. Pilo	INAF-OAR (Italy)
All	4-3-06-6100 Pipeline design and development	D. Paris	INAF-OAR (Italy)
All	4-3-06-7100 Processing Function Validation	M.Kuemmel	LMU (Germany)

MER PF Workflow



MER Challenges

- Size of the survey (~1.6×10^9 objects)
- High resolution (0.1″) and dynamical range (20 magnitudes)
- Multi-wavelength coverage
- Inhomogeneous data quality
- Tight requirements on accuracy and characterisation

MER PF timeline

Next OU-MER milestone:

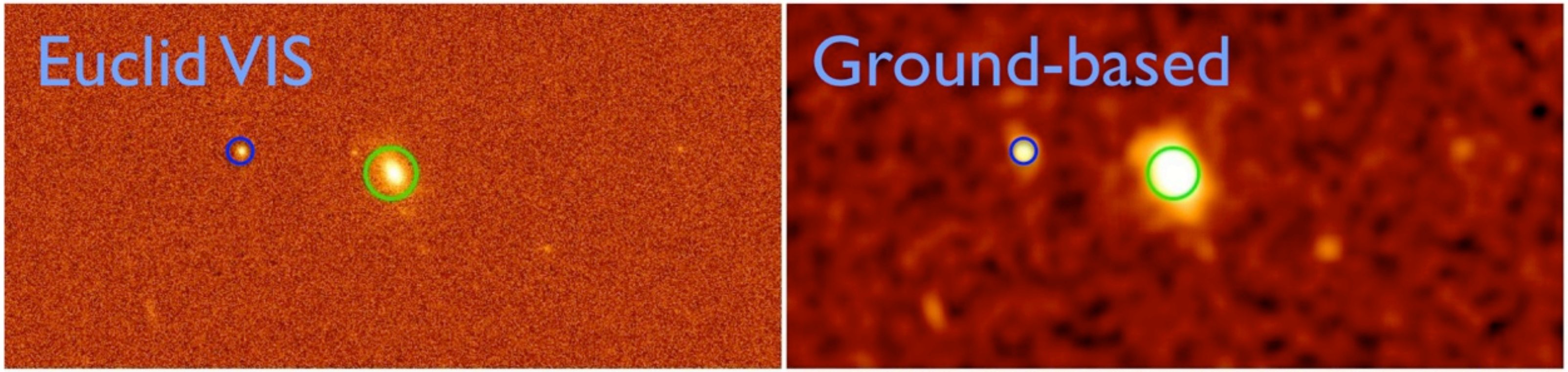
Scientific Challenge #3 & IV&V Test #3
(VIS/NIR/EXT/MER/SIM)

- Start in october 2016 – end in april 2017
- Objectives: Production of a merged catalogue of sources (each source has a single ID).
- Astrometric/photometric quality of this merged catalogue shall be challenged according to MER scientific requirements

Processing Element	IKP#1	SC#3	SC#4,5,6	SC#7
PE-MER-01				
VIS common Grid		X		
VIS/NISP/EXT common grid				X
Noise correlation minimization			X	
VIS/NISP/EXT astrometric consistency check				X
PE-MER-02				
Basic star/galaxy separation		X		
Advanced star/galaxy separation				X
PE-MER-03				
"Worst" reference PSF	X			
Optimal reference PSF				X
PE-MER-04				
Legacy background subtraction		X		
Advanced background subtraction				X
PE-MER-05				
Single-band object detection	X			
VIS+NIR mosaic combination			X	
Multi-band object detection			X	
Variable stars flagging				X
Basic source deblending		X		
Advanced source deblending			X	
PE-MER-06				
First photometry proto	X			
Final photometry strategy				X
PE-MER-07				
Mission catalogue essential parameters	X			
Additional Object parameters				X
PE-MER-08				

2- Multi-λ photometry

MER Multi-λ photometry

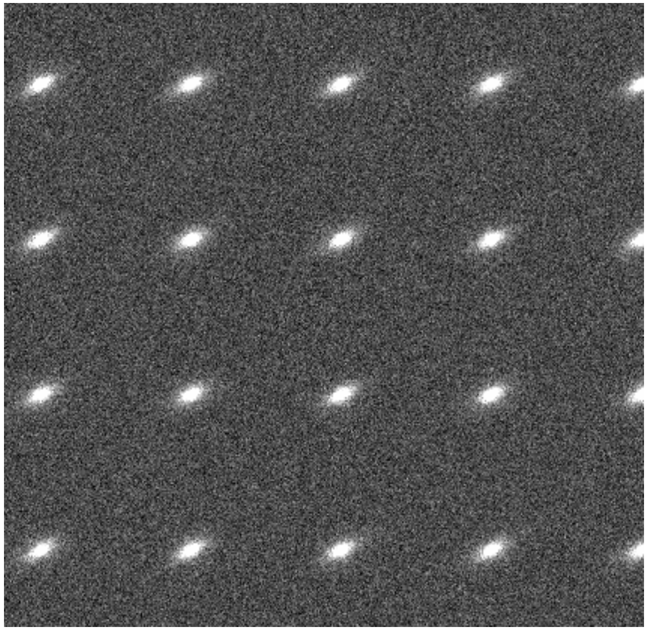


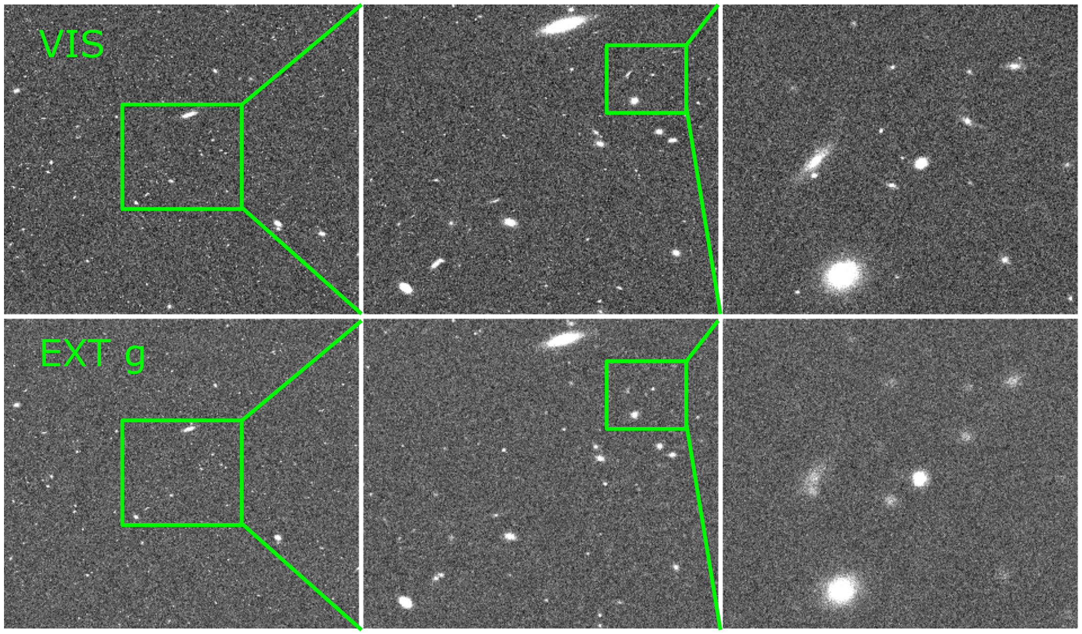
- Goal: consistently derive photometry in all EXT / VIS / NIR images
- Requirement: obtain **optimal** photometry **for PHZ**
  - maximise S/N
  - obtain unbiased colors
  - avoid systematics owing to different PSFs
- Two main approaches:
  - aperture photometry
  - template fitting photometry

MER internal simulations

Dataset

- Simulated VIS & EXT-g images (TBD on NIR), with Euclid expected depth &FWHM
    - 0.05 sq. deg. field from realistic EGG catalog (used to test colors)
    - grids with 100 replicas of a template object (used to test total magnitude)
- Images are generated using SkyMaker:
- Noise is Poisson + Gauss. (R.O.N.) and is uncorrelated
- PSFs internally generated by EGG (from now on VIS simulated PSF will be used)
- RMS is constant, obtained from noise map

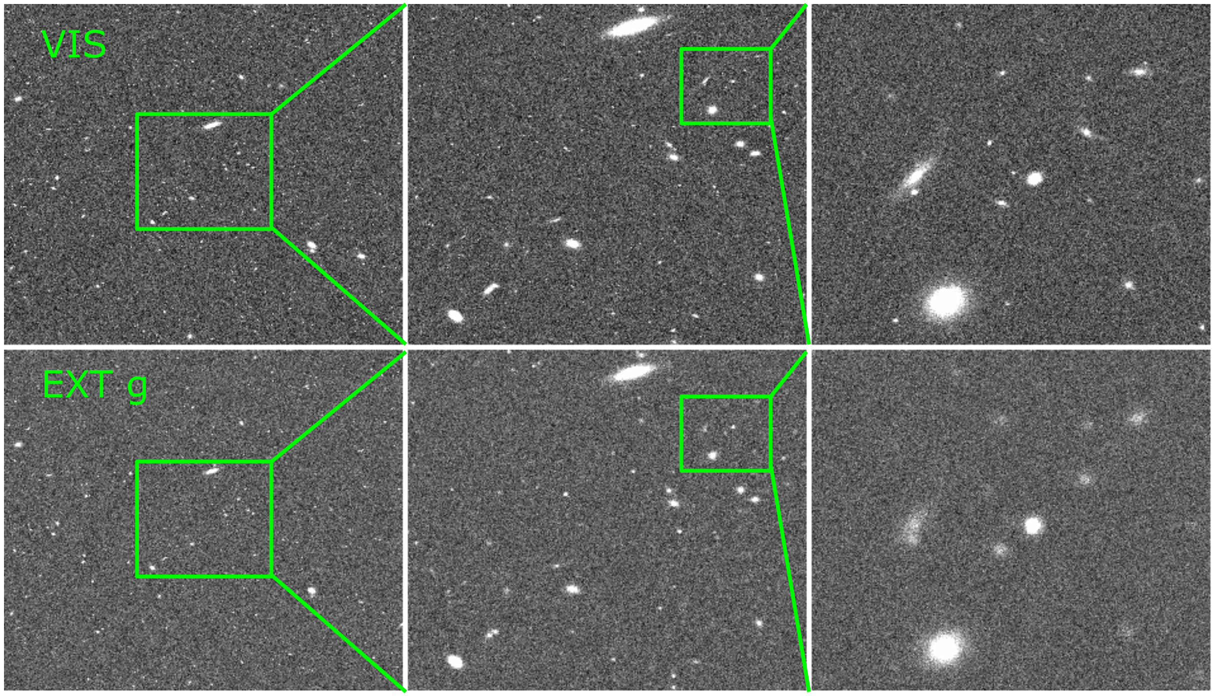




MER internal simulations

Caveats

- Morphology: no irregulars, just bulge+disc with fixed Sersic index 4,1; no spiral arms
- Background is just a constant added to the whole image; no local variations
- PSFs are gaussian (using VIS PSFs from now on)
- No transients / imperfections / depth differences
- No photon noise included in RMS maps so far



Multi-λ photometry option #1

Multi-wavelength photometry I: PSF-matched

- Measure fluxes within circular/elliptical apertures on all the bands **after PSF matching** (convolution step);
- Advantages:
  - solid and well tested approach;
  - computationally fast;
- Disadvantages:
  - not using the full resolution of VIS;
- Current implementation: A-PHOT (E. Merlin)
  - stand-alone code in C
  - improved numerical accuracy w.r.t. Sextractor
  - optimal apertures (S/N)

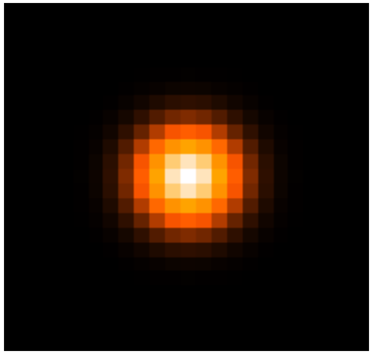
PSF-matched photometry

A-PHOT

- computes fluxes within any arbitrary chosen set of **circular and elliptical apertures** centered on each detected source. Pixels overlapping with the apertures limit are divided into sub-pixels and the consistent fraction of their ADUs is included in the summation.
- can automatically compute the **best S/N elliptical aperture** and the flux within it; local background subtraction is in progress.
- **needs** input **morphological parameters** that will be computed in advance during the detection/deblending stages. At present, SExtractor estimations are used.

Circular apertures: ideal test (without noise) on an low-sampled gaussian (compared to SExtractor and to analytical estimate)

Aperture	Analytical	SExtractor	A-PHOT
4.2466	0.39347	0.38108	0.39098
8.4930	0.86466	0.86017	0.86301
12.7398	0.98889	0.98758	0.98872
16.9846	0.99966	0.99963	0.99966
21.2330	0.99999	0.99999	0.99999

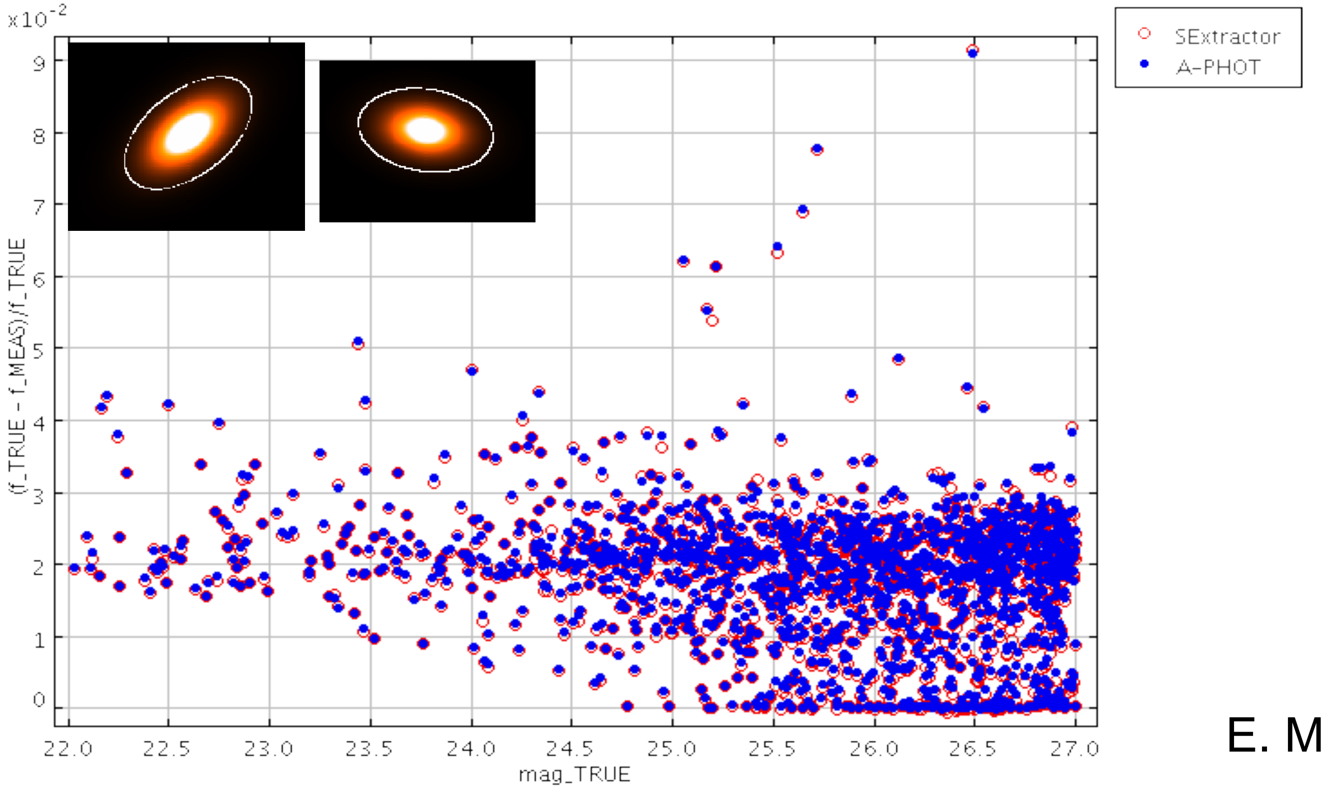


E. Merlin

PSF-matched photometry

A-PHOT elliptical aperture validation tests

- ideal test (without noise) on a **grid** of 1600 simulated galaxies (EGG + SkyMaker) to compare with SExtractor Kron apertures.
- relative error in measured flux w.r.t. true input flux
- A-PHOT and SExtractor yield **almost identical results** (differences of the order of 10^{-4} df/f)

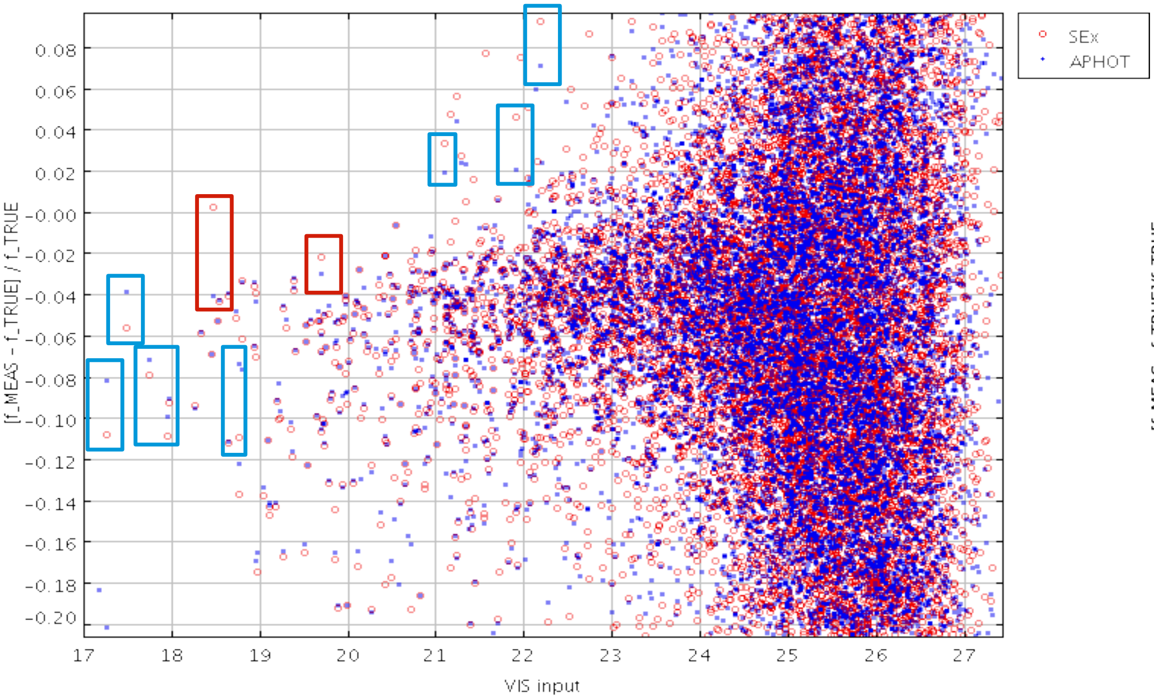


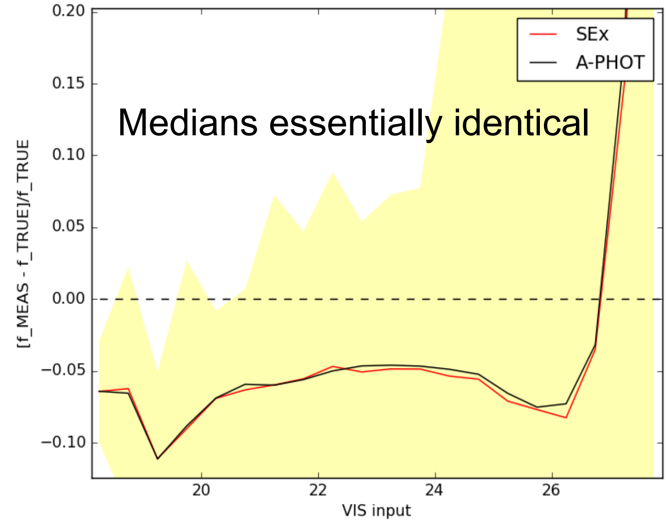
E. Merlin

PSF-matched photometry

A-PHOT elliptical aperture validation tests

- test on **VIS simulated image** (with noise and blended sources)
- comparison with SExtractor Kron apertures of the relative error in measured flux w.r.t. input true flux
- results are not identical but difficult to understand why and which code does generally better





E. Merlin

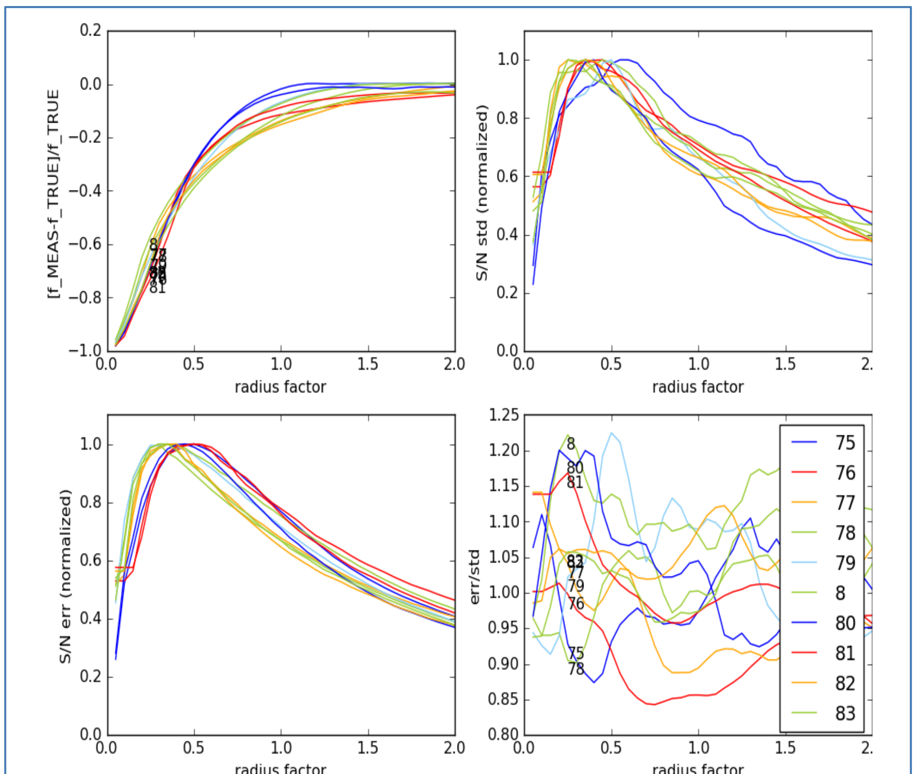
PSF-matched photometry

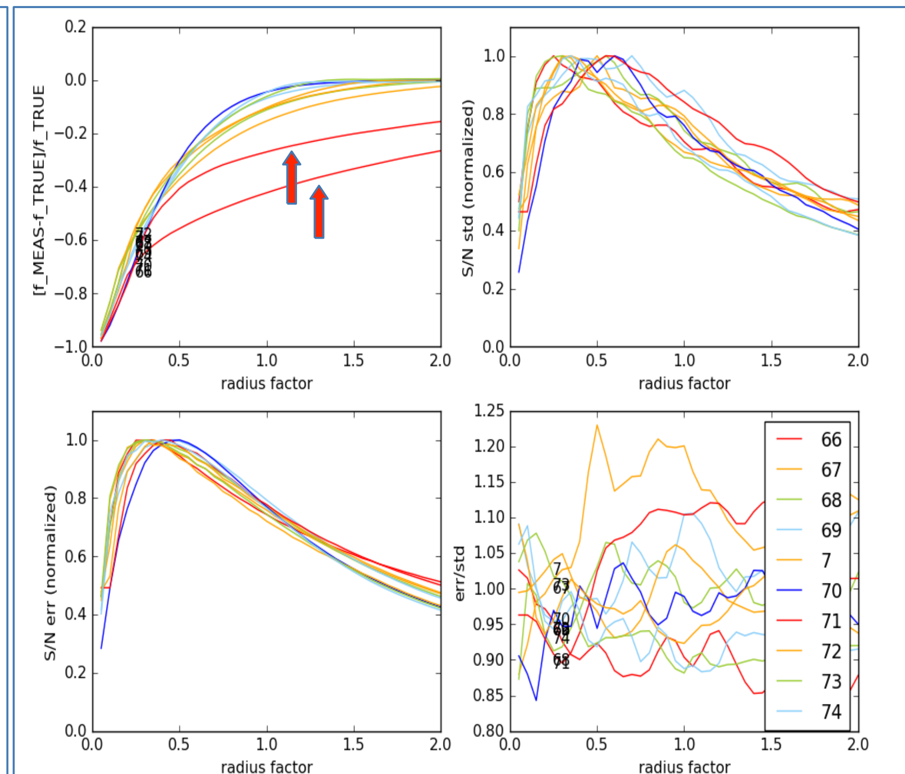
Detection tests:

- **is Kron magnitude a good estimate of the total magnitude?**
- **is the nominal error a good estimate of the real uncertainty?**

Dataset: images with 100 replicas of an object from the 201 selected templates

Method: the flux within an elliptical aperture with radius *k*R_Kron* is computed, using A-PHOT, for the 100 replicas, and the average is computed. This is repeated for 21 values of *k* from 0.05 to 2.0





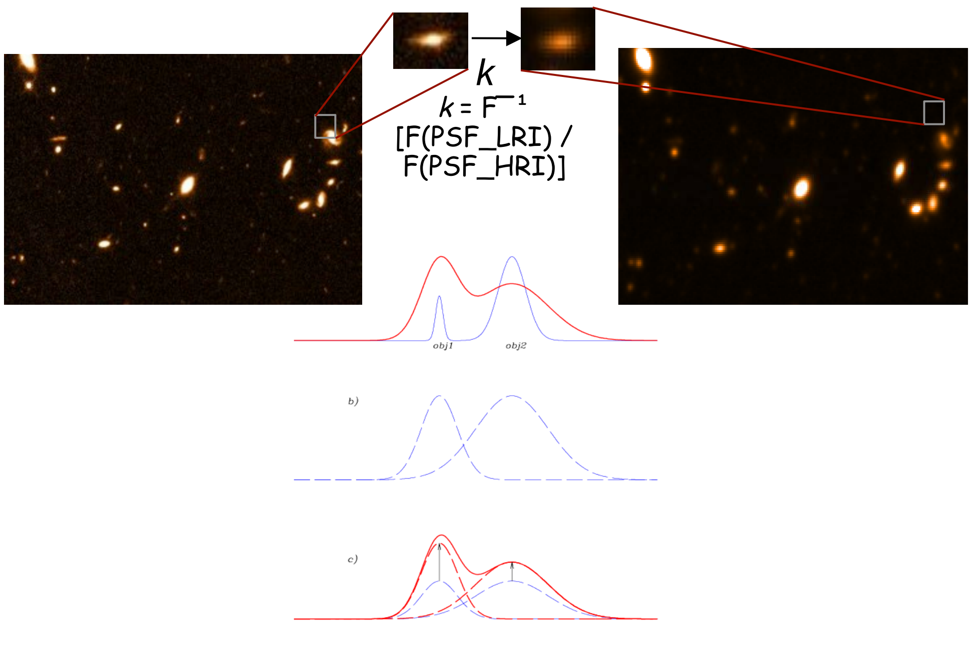
Multi-wavelength photometry II: PSF-fitting

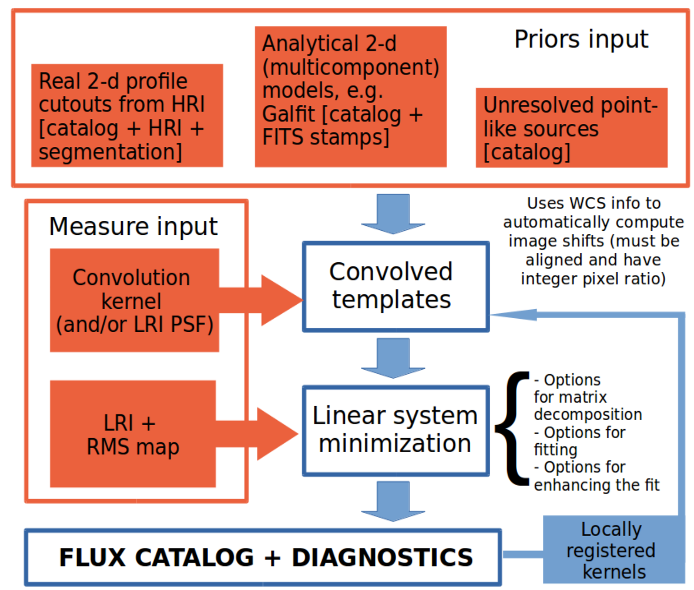
- Measure fluxes on all the bands **via PSF fitting**, minimizing resolution and blending issues;
- A prior for each object is matched to the resolution of each band using PSF-matching kernels.
- Advantages:
  - uses the best resolution of each image;
  - works on blended objects;
- Disadvantages:
  - computationally expensive;
- Current implementation: TPHOT (E. Merlin)

PSF-fitting photometry

T-PHOT

- template fitting code released within the *ASTRODEEP* project
- written in C and C++, with CFITSIO and FFTW3 library dependences, within a Python architecture
- downloaded by ~100 users and currently used by several research groups worldwide (see e.g. Merlin+2016a, on Frontier Fields photometry; Bourne +2016, Kuang+2016 etc.)





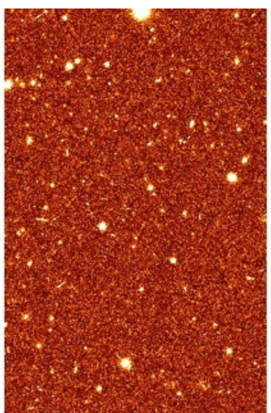
Merlin+15, Merlin+16 arXiv:1609.00146

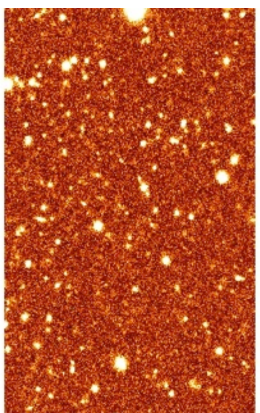
PSF-fitting photometry

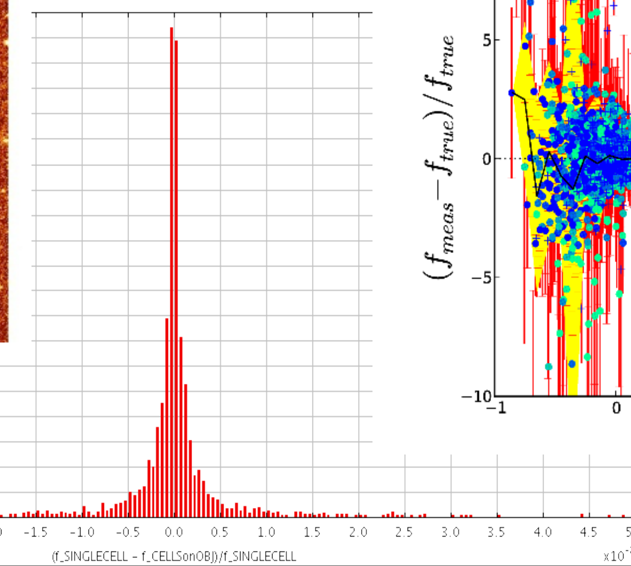
T-PHOT validation tests (general)

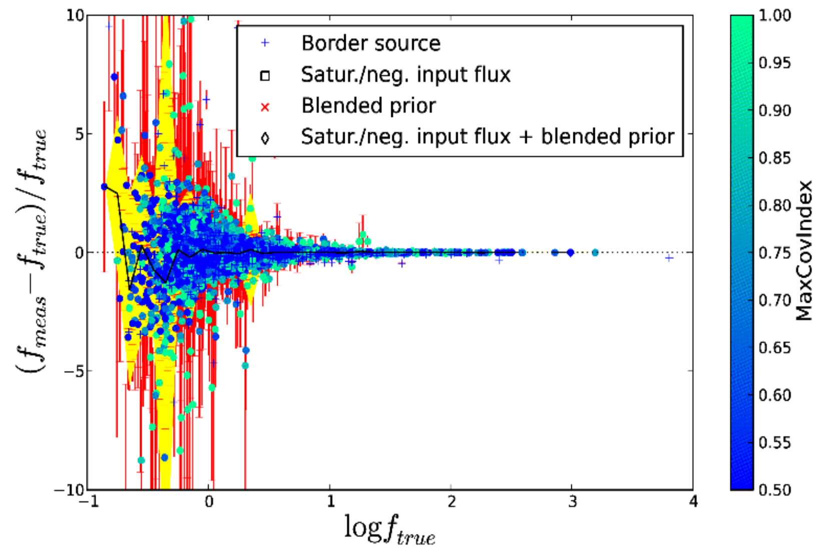
- T-PHOT computes the flux of all the objects in a field, using high-resolution priors degraded to low resolution to simultaneously fit blended sources, solving a X^2 minimization problem
- To deal with large images like Euclid FoVs, a "*cells-on-objects*" fitting technique can be used, ensuring computational time and RAM savings.

- **The main goals** of TPHOT are to:
  - measure best estimate of ***total flux* in detection band**
  - measure best estimate of ***colors* in other bands** and **apply color correction**







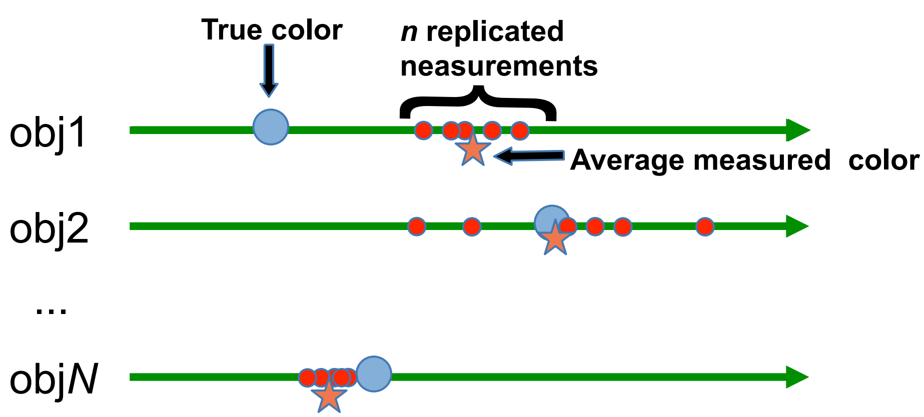


Multi-λ photometry – color tests

Colors: survey of methods

Dataset: 0.05 sq. deg. simulation, VIS and EXT g (g has ben replicated 10 times)
Methods:
- $VIS_{Kron} - g_{TPHOT}$ (no PSF matching)
- VIS – g in 2 FWHM circ. aperture
- VIS – g in 3 FWHM circ. aperture
- $VIS_{TPHOT} - g_{TPHOT}$
- VIS – g in 3FWHM circ. aperture + contaminants removal via TPHOT
- VIS – g in ellipt. aperture with a = 0.5 Kron (~best S/N)*
- VIS – g in ellipt. aperture with a = 1.0 Kron *

*($a_g = \mathrm{sqrt}(a_{VIS}^2+(FWHM_g/FWHM_{VIS})^2)$,
$b_g = \mathrm{sqrt}(b_{VIS}^2+(FWHM_g/FWHM_{VIS})^2)$)



3 different quantities computed to compare methods:

a. Average color offset of all sources in a given magnitude bin

b. Dispersion (STD) of color offset of all sources in a given magnitude bin

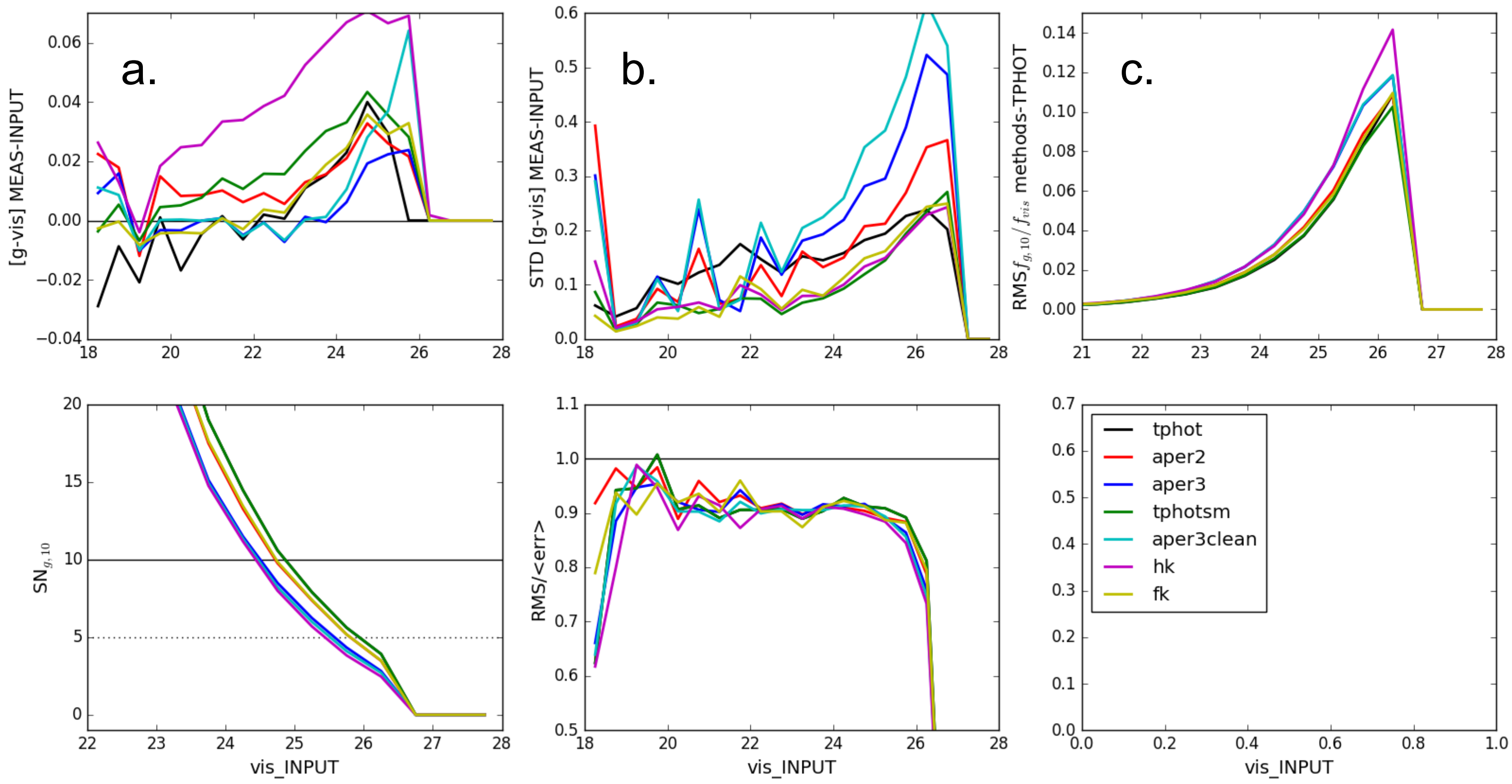
c. Average of dispersion (STD) of the 10 replicated measurement for each object in a magnitude bin

Multi-λ photometry – color tests

Comparison of the medians (measured vs. input)

- no method clearly stands out
- 3 FWHM aper. phot. and TPHOT currently favoured
- nominal error slightly overestimating uncertainties

PRELIMINARY RESULTS



Multi-λ photometry option #3

Multi-wavelength photometry III: single epoch images

- Similar to PSF-fitting;
- BUT: applied to single epoch images, NOT co-added mosaics;
- Advantages:
  - Better treatment of the (2D) variable PSF;
  - Better treatment of masked pixels;
- Disadvantages:
  - Higher computational load;
  - Higher data I/O
- Prototype available;
- Lower priority compared to photometry I and II

3- Photometric calibration tests

Photometric validation

- Input images (VIS-NIR-EXT) are calibrated
- MER must validate the photometry (calibration + photometric measurement)

  => **Stellar Locus**

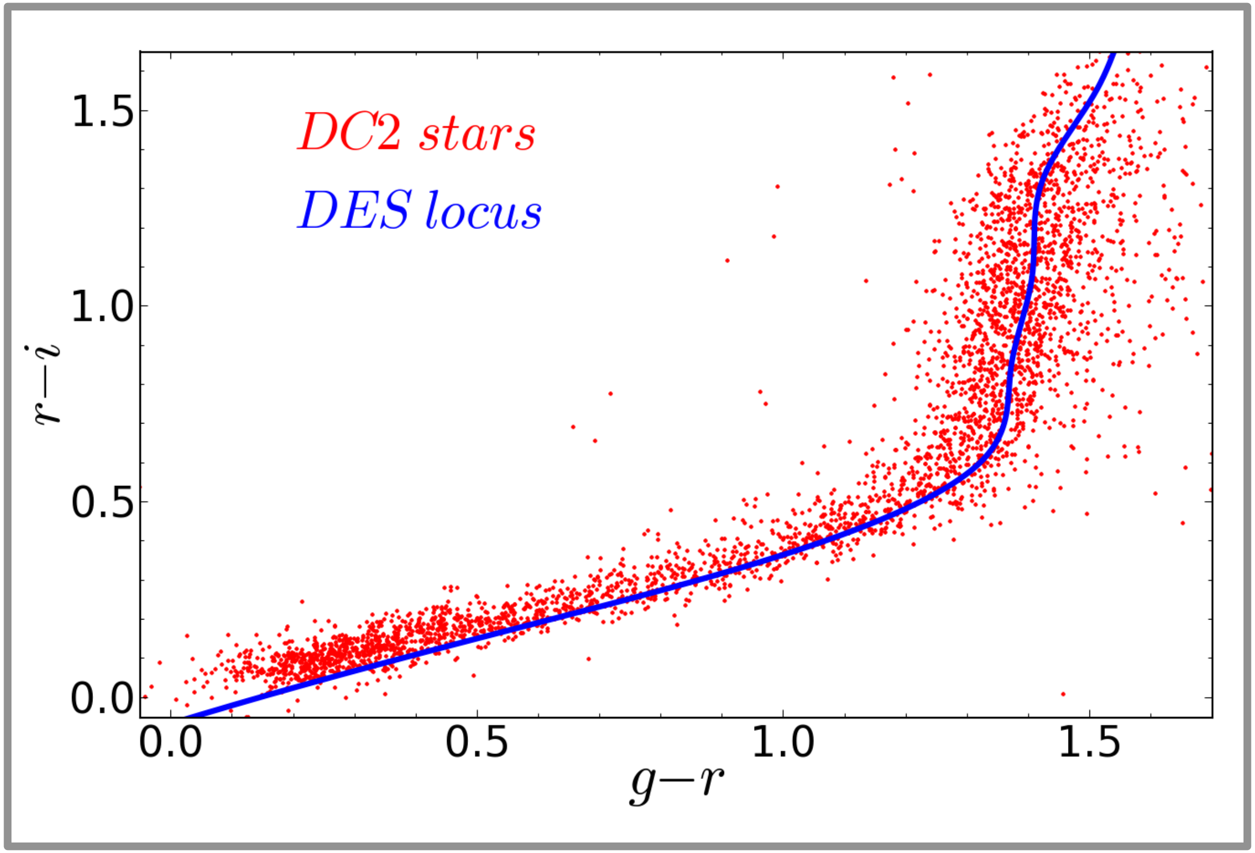
- Procedure:
  1. From object list select point-like objects
  2. Compare colours with reference value

     → colour-colour plots
  3. Measure offsets in colour space

Stellar locus

Data Challenge 2 vs. DES

- EXT-colours *r-i* vs. *g-r*
- Locus data from DES
- Small offsets

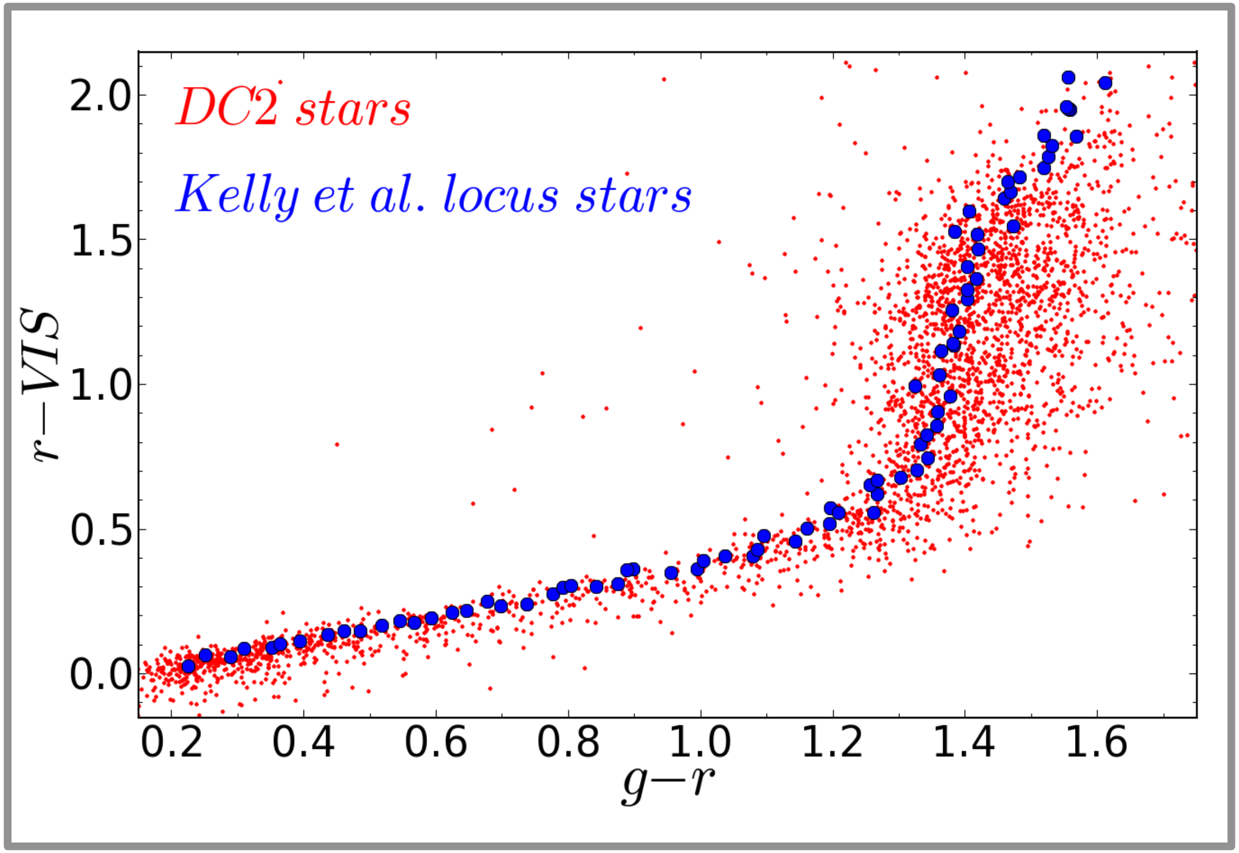


M. Kuemmel

Stellar locus

Data Challenge 2 vs. SDSS

- Colours *r-VIS* vs. *g-r*
- Locus data from SLOAN spectra (not contiguous)
- Small offsets



M. Kuemmel

Photometry validation - prospects

- Check stellar locus using the few thousands of stars in each frame
  - on various parts of each frame (**homogeneity**)
  - on overlapping frames (**consistency**)
- Cross-check with other surveys
  - band overlap with

    Gaia Red Photometer (640 – 1050 nm) => VIS

    2MASS J and H bands => NIR

  BUT
  - intercalibration issues
  - comparison difficult since Euclid will provide the best photometry

4- Open questions

Open issues

- Compliance of the MER PF to the **GDPRD** requirements
(see RID – Science 261)
- Currently **5 requirements** are **not applicable** to MER PF as they are expressed or phrased. 3 of them are relative to photometry
- MER needs **operational** requirements

Description	Parent Requirement ID
The source extraction data processin shall contribute less than 0.2% (TBC) to the VIS relative photometric error.	R-GDP-CAL-084
The background subtraction data processing shall contribute less than 0.3% (TBC) to the VIS relative photometric error.	R-GDP-CAL-085
The 'weak lensing weight'-weighted fraction of point sources in the catalog of galaxies used for weak lensing shall be known to better than 5×10^{-5} (TBC) for each tomographic bin (TBD) used in the weak lensing analysis.	R-GDP-DL2-060
The ground data processing shall provide estimates of the covariance of the pixel values at the locations of galaxies used in the weak lensing analysis with a relative precision of 3x10-3 (TBC) r.m.s. on the diagonal elements and TBD on the off-diagonal elements.	R-GDP-DL2-082
External Data shall be provided in order to limit bias in photometry for PSF modeling to less than 0.2% on scales used to model the PSF.	R-GDP-EXT-370

Open questions

In case calibration/validation tests on photometry do not pass:

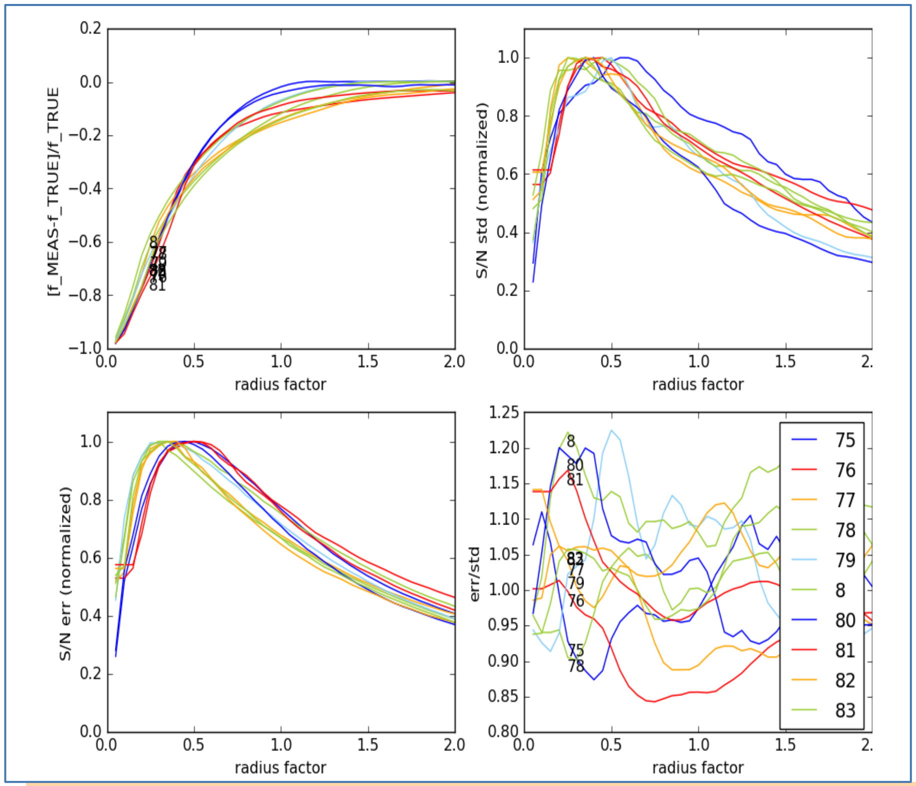
- What to do with the data ?
  - keep and flag
  - put aside
  - raise a warning
  - TBD
- How should the information circulate between OU's ?

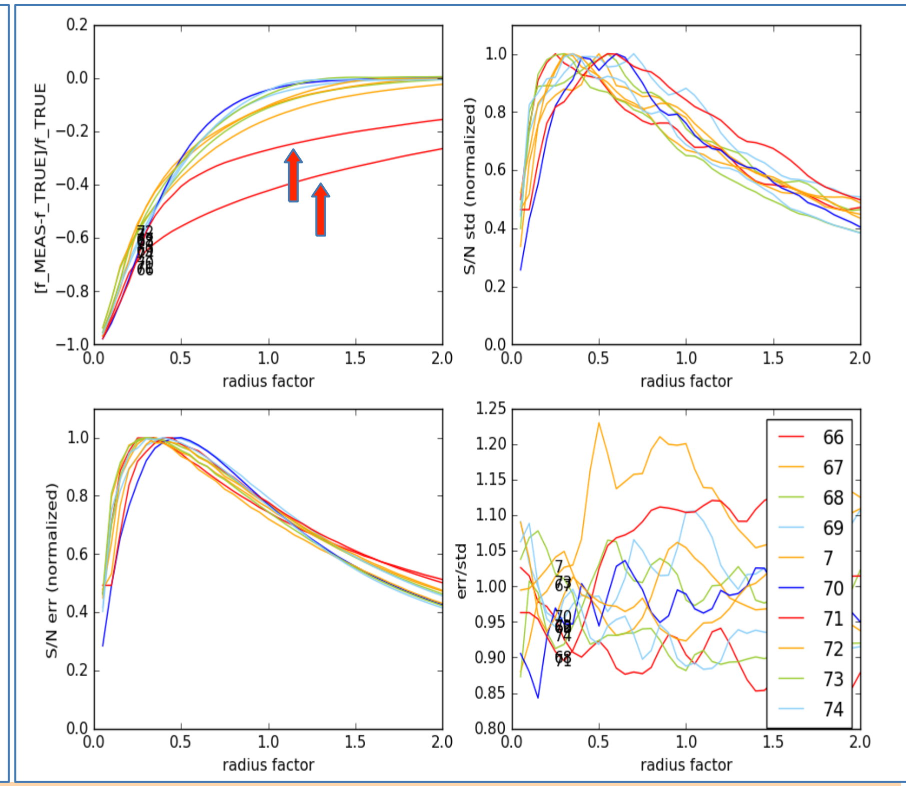
Thank you for your attention !

Additional Material

OU-MER – Photometry: survey and comparison of methods

- ***Detection: Is Kron magnitude a good estimate of the total magnitude?***
- ***Is the nominal error a good estimate of the real uncertainty?***
- Dataset: images with 100 replicas of an object from the 201 selected templates
- Method: the flux within an elliptical aperture with radius *k*R_Kron* is computed, using A-PHOT, for the 100 replicas, and the average is computed. This is repeated for 21 values of *k* from 0.05 to 2.0





TOP LEFT panels: [flux_meas − flux_true]/flux_true vs. *k* for subsamples of the template objects. In general the flux is well recovered as soon as *k* > 1 – 1.5 (however a few percent of flux is missed); further enlarging yields little change. For some objects, however, the flux is always largely underestimated (red arrows): they usually are sources which have underestimated Kron radius (not shown). Choosing e.g. *k*=2 should be ok (SExtractor uses *k* = 2.5?).

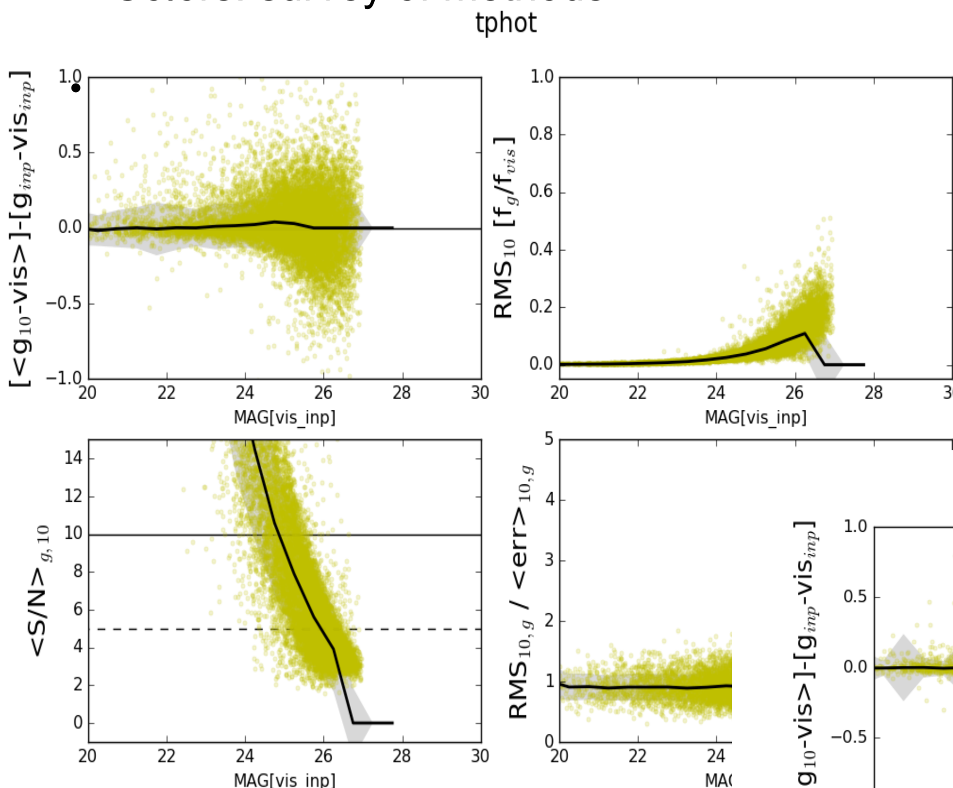
TOP RIGHT panels: S/N vs. *k* for subsamples of the template objects. Noise is the standard deviation of the 100 measurements. The highest S/N is reached between 0.25 and 0.5 Kron radii.

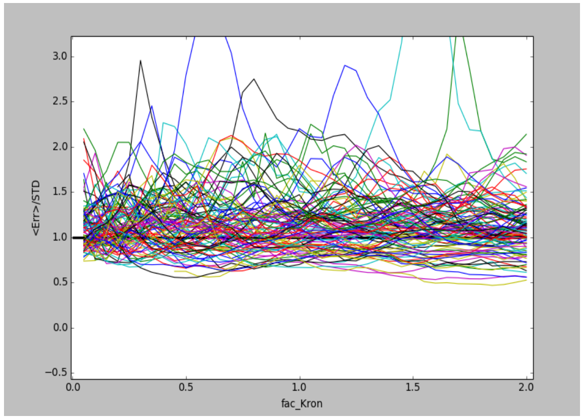
BOTTOM PANELS: S/N vs. *k* computed using nominal errors output by A-PHOT (LEFT) and ratio nominal error / standard deviation of the 100 measurements. Excluding pathological cases, the nominal error yields a reasonable estimate of the real uncertainty of the measurements, *provided photon noise is included*.

OU-MER – Photometry: survey and comparison of methods

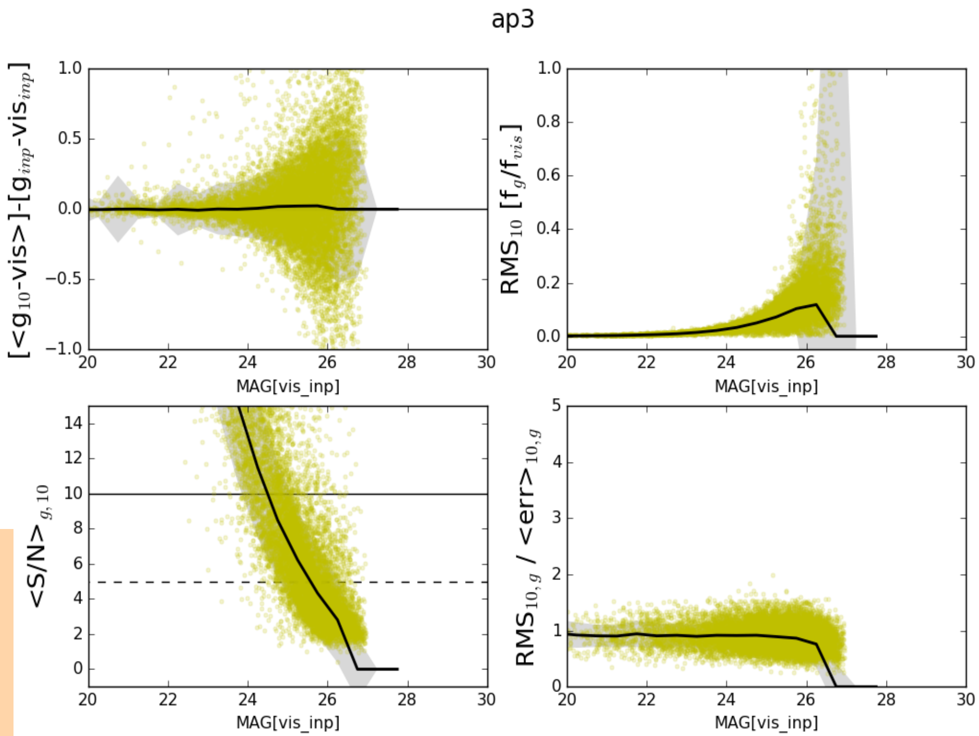
PRELIMINARY RESULTS

- Colors: survey of methods





Ratio of average nominal A-PHOT error and STD of measurements, over 10 replicas of DC1 g images, as a function of the elliptical aperture factor *k* (sample of 100 objects)



Examples of the resulting diagnostic plots: yellow dots are the median on the 10 replicas of the g image for each object in the simulation; the solid black line is the **median** of the distribution.

CAVEATS:
- excluding objects with g_TRUE>27
- how to deal with low S/N objects, having **some** of the 10 measured fluxes < 0 ? At present they are plotted as upper limits in the color offset panel (up left) and RMS panel (up right); S/N (bottom left) is the computed

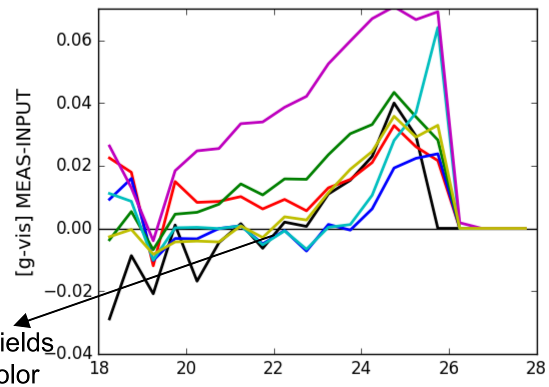
OU-MER – Photometry: survey and comparison of methods

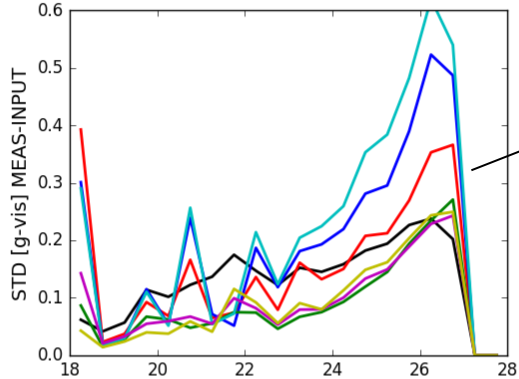
PRELIMINARY RESULTS

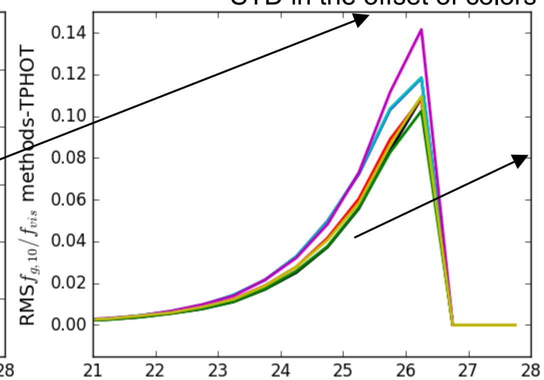
- Colors: survey of methods

Comparison of medians

TPHOT smoothed has lowest STD in the offset of colors

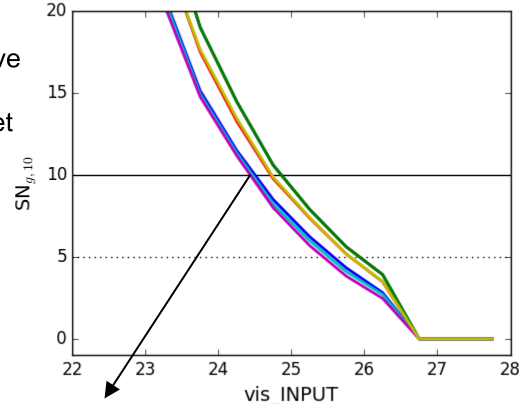


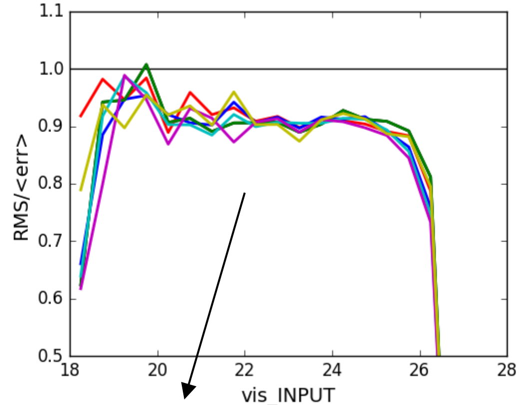


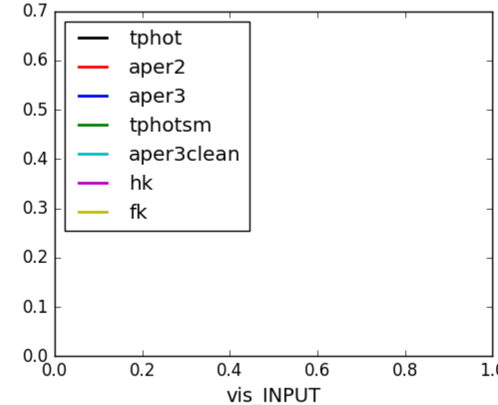


TPHOT has lowest RMS in the 10 measures of each object (uncertainty)

3 FWHM aperture yields the best color estimate; however all methods have <0.02 mag median offset (but see means...)





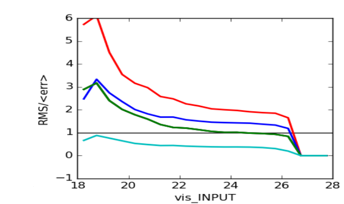


Small apertures (obviously) have better S/N; T-PHOT does best

… however the nominal error seems to slightly overestimate the true uncertainty (~10%)

TOP:
LEFT: medians in bins of magnitude of the offset between median measured colors (on the 10 replicas of each object) and true colors; **CENTER:** STD of the offset between median measured colors (on the 10 replicas) and true colors; **RIGHT:** STD of the measured g/vis flux ratio (on the 10 replicas)
BOTTOM:
LEFT: medians in bins of magnitude of the median measured S/N (on the 10 replicas); **CENTER:** medians of the ratio between the STD of the measured g flux and the nominal uncertainty output by each method (for each object).

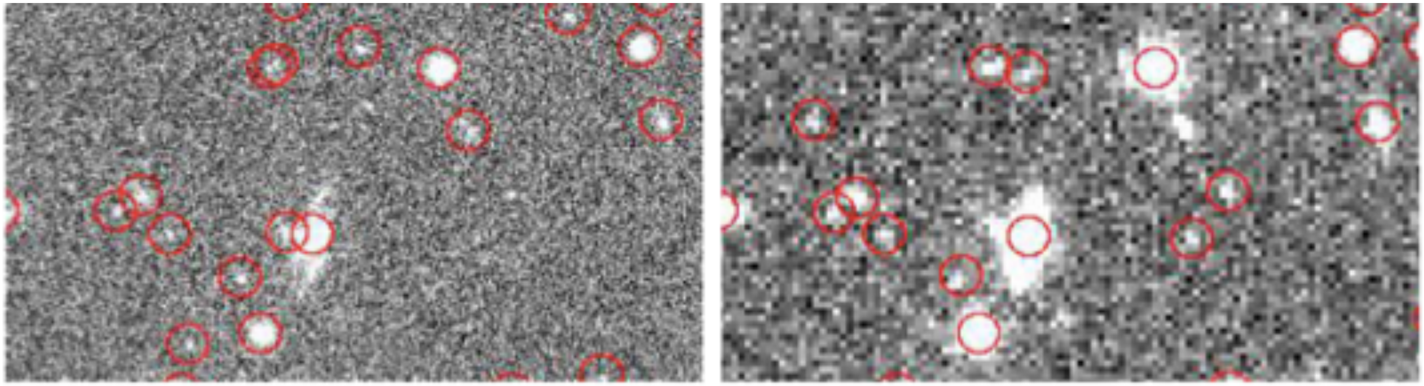
NB: Photon noise - modifying the simulated RMS map to include PhN reconciles the nominal error with the true RMS uncertainty



MER-4-3-06-3100 Multiband Detection :Rationale

- Input: VIS mosaic + Y/J/H mosaics
- Output: preliminary object list; here an object is a number of connected pixels above the background
- Fulfill core-science detection requirements from SHE+SIR
- Which objects need to be detected?
  - \- Weak lensing: VIS sources
  - \- Galaxy Clustering: NISP sources
  - \- Legacy science: all sources

⟹ Need to detect objects simultaneously in some coaddition of VIS+NIR

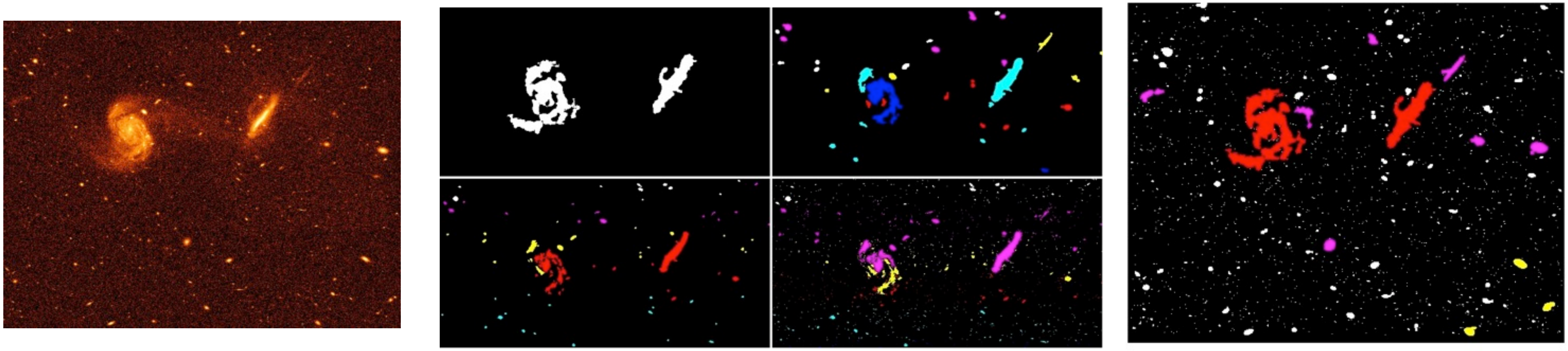


- scale 0.1"/pix, FWHM=0.2"
- scale 0.3"/pix, FWHM=0.3"

MER Multiband Detection : Multiscale Approach

This approach fails on large galaxies (problem for legacy):

Arp 87 (HST) “Euclid-like” detection "Large" detection



We are now testing multi-scale approaches to detect objects at all scales