Data Mining & Exploration Program
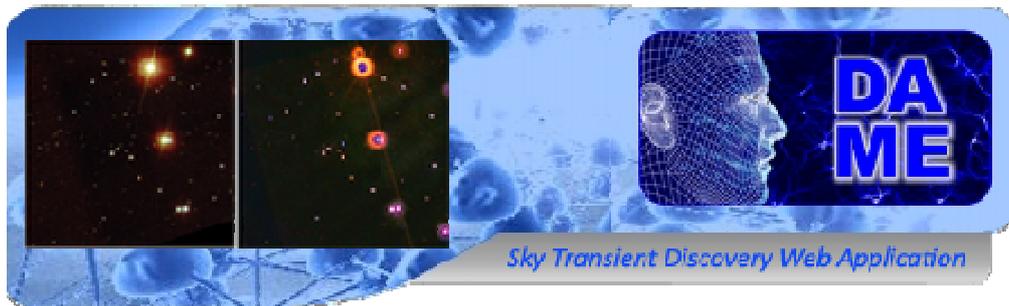
STraDiWA Project
Sky Transient Discovery Web Application

SOFTWARE Documentation
DAME-DOC-NA-0003

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Revision Matrix

Issue	Author	Date	Section/Paragraph Affected	Reason/Initiation/ Documents/Remarks
1.0	M. Brescia	24/01/2011	All	First draft release

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Tab. 1 – Reference & Applicable Documents

A & A	Meaning
AGN	Active Galactic Nuclei
AAVSO	American Association of Variable Star Observers
DAME	Data Mining & Exploration
DBMS	Database Management System
DM	Data Mining
DMM	Data Mining Model
FOV	Field Of View
GA	Genetic Algorithms
GE	Gated Experts
GRID	Global Resource Information Database
GUI	Graphical User Interface
IG	Interest Group
IVOA	International Virtual Observatory Alliance
KBO	Kuiper Belt Object
KDD	Knowledge Discovery in Databases
LSST	Large Synoptic Survey Telescope
MDS	Massive Data Sets
MLP	Multi Layer Perceptron
NN	Neural Network
PPS	Probabilistic Principal Surfaces
QNA	Quasi Newton Algorithm
SN	SuperNova
SOM	Self Organizing Maps
SPE	Specifications
SVM	Support Vector Machine
TBC	To Be Completed
TBI	To Be Investigated
UCD	Unified Content Descriptors
VO	Virtual Observatory
XML	eXtensible Markup Language

Tab. 2 – Abbreviations and acronyms

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1 Introduction

Scope of the following document is to introduce the project called STraDiWA (Sky Transient Discovery Web Application), as part of the DAME Program. This project consists of a scientific workflow to implement a set of tools for the real time detection and classification of photometric transients in multiband, multi-epoch surveys. Classification (in terms of probability density function) needs to be performed in real time in order to trigger possible follow-ups.

This project has been firstly proposed in [1] and technically detailed in [15].

Basic requirements are:

- ✓ Interface with VO is needed to provide multi-wavelength constraints to be fed as input to the classifiers (as additional constraints);
- ✓ A powerful distributed computing environment (CLOUD/GRID-SCOPE) needed to perform intensive simulation, image segmentation and detection experiments;
- ✓ DAMEWARE (Web Application REsource) infrastructure needed for classifiers (models based on machine learning paradigm) as well as to expose the simulation package to the wide community (this also imposes the largest possible flexibility and generality of the GUI).

Summary of working steps:

- ➢ Check for existing stuff;
- ➢ Define set of rules for most significant variable object models;
- ➢ Search for algorithms able to work on transients;
- ➢ Define a strategy to evaluate their performances in a realistic framework (i.e. simulations);
- ➢ Implement within DAME the simulation package;
- ➢ Evaluate and test classification algorithms on simulated data;
- ➢ Implement selected algorithms on real pipeline;

This project is directly connected with the KDD-IG[1], the Interest Group for data mining established within the IVOA Consortium.

We plan to implement most of the variable object models and to design and implement specific classifiers.

However, the participation is intended to be enlarged to externals collaborators, to improve science expertise and background on variable object modeling and to gain the possibility to test the workflow on real new generation survey pipelines or large programs, such as EUCLID.

More aspects of the project can also be found at: http://dame.dsf.unina.it/dame_td.html

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[1] http://www.ivoa.net/cgi-bin/twiki/bin/view/IVOA/IvoaKDD is the official wiki site of the Interest Group

2 Strategy

We plan to implement a simulated realistic workflow to be used for studying the optimal classifier (Fig. 1).

The evaluation of classifiers requires benchmarks, hence reference templates. At the moment, these templates are not available. The usage of existing data (cf. PQ survey, etc.) does not solve all problems due to: high threshold for detection (which rules out many variable objects), incomplete classification of most variable objects.

In our opinion, the best way to obtain these templates is to provide a realistic sky simulation framework.

These realistic simulations should take into account as many as possible relevant factors (except the random presence of artifacts which, however, could be inserted at a later stage). In particular:

- Instrumental realistic setup (telescope scale and mounting, S/N ratio, band, instrument features, optical design and optimization, residual aberrations, wavefront sensing, site environment and seeing parameters, etc…);
- Survey strategy (how many bands, how deep). A good guide on what are the relevant parameters could be derived from [9];
- Sampling mode (even, uneven, realistic, i.e. taken from existing surveys) and rate (how frequently is the same region of the sky observed in each band);
- Realistic distribution of pre-modeled variable objects (from the list of objects defined in the following);

By having this simulation framework available, a set of synthetic multi-band and multi-epoch sky images can be obtained.

It needs to be stressed however that simulation is just one module into the workflow. And therefore the strategy which is described in the following can be easily tuned to match the requirements of any other simulation pipeline (such as for instance, the simulation pipelines foreseen for both image and spectra in the Euclid mission).
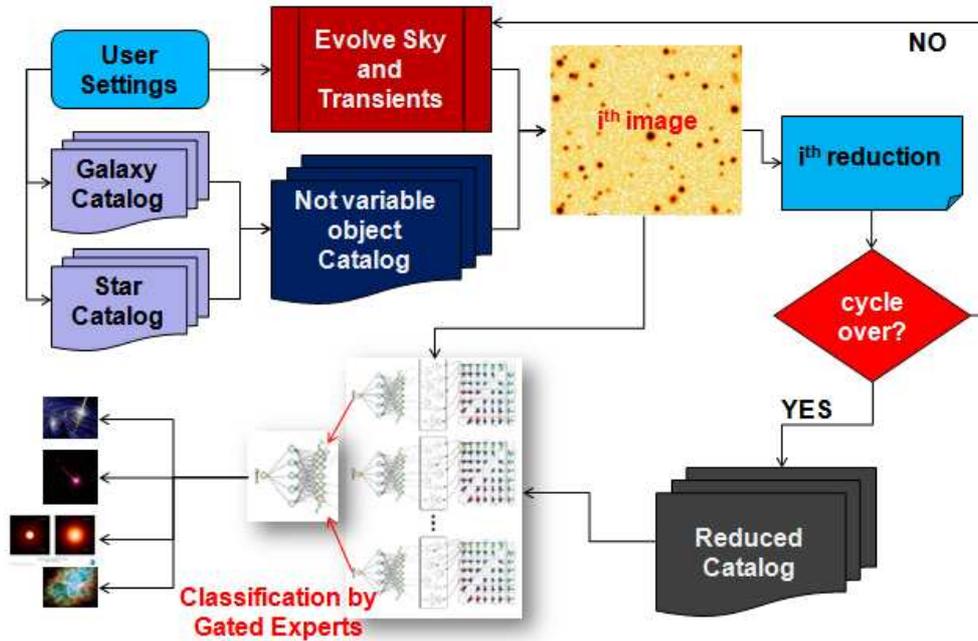
Fig. 1 – flow-chart of the proposed workflow

The second step of the workflow should hence be based on the analysis and implementation of data mining algorithms, deployed on the DAME Cloud/GRID platforms already available, that could perform detection and classification of such variable objects on the simulated images.

The final step should foresee the test of the best DM algorithms on real cases, i.e. next generation telescope and focal plane instrument survey pipelines, in order to evaluate the selected DM models in a realistic and operational environment.

3 The Simulation Framework

The LSST, [8], Image Simulation Group has implemented a simulation pipeline which, however, while being useful to test detection algorithms, is completely useless for testing classification algorithms. Transients are generated randomly with no physical reality attached to them.

Details can be found in [8]. Their flow-chart (Fig. 2) , however, is useful to better understand how to implement the simulation.
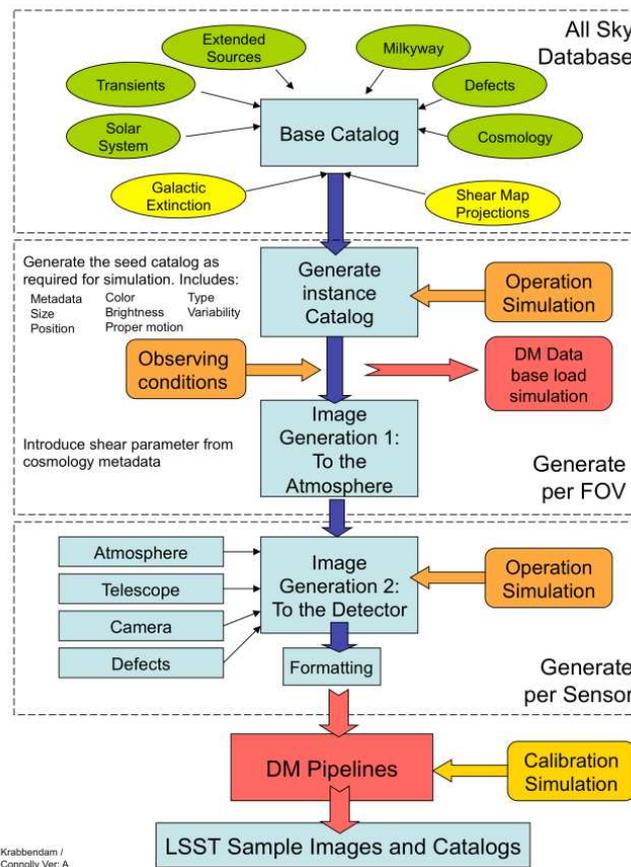
Fig. 2 – The LSST Simulation workflow

The core aspects of the simulation we propose are based on two software packages, publicly available at the site http://www.astromatic.net/software, mainly related to:

- Simulation of galaxies: Stuff, [10]. This package can also simulate stars but it does it in a rather naïve way. It is necessary to investigate whether the underlying assumptions are not too crude;
- Simulation of galactic foreground stars (based on Bahcall and Soneira model) to be added in Stuff .
- With reference to LSST simulation it is evident that for our purposes, the simulation of solar system objects (i.e. asteroids and KBO) is useless as well as the implementation of a shear map;

- Simulation of observing site conditions, telescope, optics, etc: SkyMaker [11]. This software package appears to be very flexible and can be used with further improvements mainly referred to telescope/instrument optical and site environment parameters.

Taken all the above into account, it is realistic to assume that a prototype WEB based simulation pipeline and GUI can be implemented in few months. Hereinafter we shall call "instance" a simulated sky patch and "frames" the individual epochs of each instance.

In order to provide simulation of transients (see specific section for details), the idea is to use the instance[2] catalogue as "starting point" and then to perturb it with variable objects, obtained by taking into account the rules established in their modeling phase, and to produces the frames accordingly to the survey specification.

A possible structure of the Simulation could be:

1. define survey parameters;
2. produce catalogue of stars;
3. add galaxies and select a fraction of them as AGN;
4. randomly select among centroids those which shall become variable stars and attribute them variable properties using the simulation environment and variable stars rules defined as below;
5. place SN near galaxies and change their brightness accordingly specific rules (to be investigated);
6. change brightness of AGN (to be investigated);
7. Produce simulated frames for each instance;
8. Pipe the simulated images through NEXT-II[3] or other pipelines, and extract variable objects;

In order to be realistic, a large number of instances is needed. Therefore interface to the Cloud/GRID through the DAME distributed computing infrastructure is required.

As mentioned before, there is available a software package for simulations of sky patches and instrumentation FOV response.
We started to analyze in details the packages Stuff and SkyMaker. In both cases, their internal mechanism is quiet simple. They require to configure specific setup files, in order to specify the correct sky, instrument and observation site features for the current simulation.
In particular, in Stuff, after adding star objects, the main specification to simulate a variable object is to introduce a realistic (i.e. obtained through the set of rules discussed below) change in magnitude.
Hence, one of the main tasks of the variable object modeling is to identify a pseudo-analytical function (i.e. a look-up table) of the variation of magnitude with time, for each kind of objects: by giving as input a magnitude, a phase and a time, the pseudo-analytical function should return the changed magnitude (the beginning of the phenomena could be randomly generated). It can be also taken into account an overlap effect, induced by Stuff that works on centroids, together with transient effects on bulge and disk axes.
We verified also that it is possible to generate extended objects with SkyMaker.
By analyzing several releases of Stuff and SkyMaker, slight variations are present, that , however, do not seem to affect our final result. A special effort should be spent on the right integration of optical aberrations into the original software, depending on the specific telescope and instrument modeled in the simulation.

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[2] Multiple instances of each sky patch are needed to evaluate statistics

[3] NEXT-II is an image segmentation program developed by DAME team, currently under testing (http://dame.dsf.unina.it/next.html).

4 The variable objects

4.1 Rules for variable object modeling

An important aspect of the project is to identify relevant group of objects and derive rules for their definition. Starting point for stars: the VO ontology, [7]. Objects must be translated where possible in sets of analytic rules.

Example: RR-Lyrae Cepheid variables:

- Periodic;

- Amplitude of variation (as a function of band);

- If present: delay in epoch of maximum among different bands;

- Typical shape of the light curve (from parameterization of template light curves or from models);

- Multi-wavelength characterization: e.g. X ray or radio loud, etc.;

- Number density as a function of magnitude and galactic latitude (where available, in tabular forms, otherwise from models).

Periodic objects present no problems. Just work required to define set of rules. Some problems arise in order to derive rules from ontologies:

1. How to integrate in realistic way a-periodic transients (among which AGN, etc.). How to quantify their temporal behaviors;

2. Sporadic events like SN;

3. Completeness of simulations requires rules to be defined at various wavelengths;

Fig. 3 – Ontology Tree for stellar objects [7]

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4.2 Preliminary summary of Stellar Object

What follows is a preliminary summary of variable stellar objects for which it is intended to derive rules and is therefore just an outline of the types of objects to be considered. It is therefore, incomplete, naïve and might contain errors.

It needs to be stressed that, for the purposes of the present work, once classes have been defined by sets of rules, they can be agglomerated into the same simulation module.

Rules will include also parameters needed to establish the number of objects to be included in the simulation.

Eclipsing Binaries:

- **W Ursae Majoris**: close binaries, whose surfaces are in contact with one another. They are termed contact binaries because the two stars touch and they essentially share material in their outer layers. Through the neck between the two stars mass and heat is transferred between th e components. The latter one equalizes the temperatures of the two stars.

- **Algol**: class of eclipsing binary stars. When the cooler component passes in front of the hotter one, part of the latter's light is blocked, and the total brightness of the binary, as viewed from Earth, temporarily decreases. This is the primary minimum of the binary. Total brightness may also decrease, but less, when the hotter component passes in front of the cooler one; this is the secondary minimum.

- **Beta Lyrae**: class of close binary stars. Their total brightness is variable because the two component stars orbit each other, and in this orbit one component periodically passes in front of the other one, thereby blocking its light. The two component stars of Beta Lyrae systems are quite heavy (several solar masses each) and extended (giants or supergiants). They are so close, that their shapes are heavily distorted by mutual gravitation forces: the stars have ellipsoidal shapes, and there are extensive mass flows from one component to the other.

Symbiotic Star: is a variable binary star system in which one star has expanded its outer envelope and is shedding mass quickly, and another hot star (often a white dwarf) is ionizing the gas .

Spectroscopic Binary: the binary consists of a pair of stars where the spectral lines in the light emitted from each star shifts first toward the blue, then toward the red, as each moves first toward us, and then away from us, during its motion about their common center of mass, with the period of their common orbit.

X-ray Binary: when a binary system contains a compact object such as a white dwarf, neutron star or black hole, gas from the other, donor, star can accrete onto the compact object. This releases gravitational potential energy, causing the gas to become hotter and emit radiation. X-ray binaries are further subdivided in two subclasses. Note that the classification by mass (high, intermediate, low) refers to the optically visible donor. Low mass X-ray Binaries are semidetached binaries in which gas from a late-type donor star overflows the Roche lobe and falls towards the neutron star or black hole. High mass X-ray Binaries: contain a young, early type, high-mass donor star which transfers mass by its stellar wind.

Irregular Variable Star: These are usually red supergiants with little or no periodicity. They are often poorly studied semi-regular variables that, upon closer scrutiny, should be reclassified.

Eruptive variable Stars: stars who exhibit sudden changes in brightness, in the form of outbursts, flares, or

fades. The variations are caused by activity in the star's chromosphere or corona, and may be accompanied by mass loss through the ejection of shells or as an enhanced stellar wind.

Cataclysmic Variables: stars that undergo a cataclysmic change in their properties.

- **Nova**: star that brightens suddenly several hundred- to a million-fold, remains bright for a few days to several months and then returns to its former, low luminosity. Novae are classified according to the light curve development speed, thus in **NA**, fast novae, with a rapid brightness increase, followed by a brightness decline of 3 magnitudes — to circa 1/16 brightness — within 100 days, **NB**, slow novae, with a 3 magnitudes decline in 150 days or more , **NC**, very slow novae, staying at maximum light for a decade or more, fading very slowly and **NR**, recurrent novae, novae with more than one known explosion in historical times.

- **AM Herculis**: type of cataclysmic variable binary star system with a very strong magnetic field. Polars derive their name from the linearly and circularly polarized light that they produce.

- **DQ Herculis** (**Intermediate Polar**): type of cataclysmic variable binary star system. The name "intermediate polar" is derived from the strength of the white dwarf's magnetic field, which is between that of non-magnetic cataclysmic variable systems and strongly-magnetic systems.

- **Nova-like variables (NL)**: these systems have spectra that indicate that they are possibly novae that are either in a pre-or post-outburst stage. The period between outbursts is too long to have been seen by modern observations.

- **Dwarf Novae (DN)**: double stars involving a white dwarf star in which matter transfer between the component gives rise to regular outbursts. There are three types of dwarf nova: U Geminorum stars, which have outbursts lasting roughly 5-20 days followed by quiet periods of typically a few hundred days (during an outburst they brighten typically by 2 - 6 magnitudes), Z Camelopardalis stars, in which occasional plateau of brightness called *standstills* are seen, part way between maximum and minimum brightness, SU Ursae Majoris stars, which undergo both frequent small outbursts, and rarer but larger *superoutbursts*. These binary systems usually have orbital periods of under 2.5 hours.

- **RS Canum Venaticorum**: close binary systems with a longer period chromospheric activity, including flares, that typically last 1-4 years. This activity cycle is comparable to the solar cycle of the Sun. The prototype of this class is also an eclipsing binary.

Orion Variable: variable star which exhibit irregular and eruptive variations in its luminosity and is typically associated with diffuse nebulae. It is thought that these are young stars which will later become regular, non-variable stars on the zero-age main sequence. Brightness fluctuations can be as much as several magnitudes. Subtypes of Orion variable star are: **T Tauri** and **FU Orionis**. Variability of T Tauri stars is due to spots on the stellar surface and gas-dust clumps, orbiting in the circumstellar disks. FU Orionis variables are of spectral type A through G and are possibly an evolutionary phase in the life of *T Tauri* stars.

R Coronae Borealis (RCB): eruptive variable star that varies in luminosity in two modes, one low amplitude pulsation (a few tenths of a magnitude), and one irregular unpredictably sudden fading by 1 to 9 magnitudes. R Coronae Borealis variables are supergiant stars in the spectral classes F and G.

Rapid Irregular Variables: have no apparent connection with diffuse nebulae and showing light changes of about 0.5 - 1.0 mag within several hours or days.

Rotationally Variables: stars with sizable sunspots may show significant variations in brightness as they

rotate, and brighter areas of the surface are brought into view. Bright spots also occur at the magnetic poles of magnetic stars. Stars with ellipsoidal shapes may also show changes in brightness as they present varying areas of their surfaces to the observer.

- **Ellipsoidal Variables**: very close binaries, the components of which are non-spherical due to their mutual gravitation. As the stars rotate the area of their surface presented towards the observer changes and this in turn affects their brightness as seen from Earth.

- **Pulsars**: highly magnetized, rotating neutron stars that emit a beam of electromagnetic radiation. The observed periods of their pulses range from 1.4 milliseconds to 8.5 seconds. Three distinct classes of pulsars are currently known according to the source of the power of the electromagnetic radiation: *Rotation-powered pulsars*, where the loss of rotational energy of the star provides the power, *Accretion-powered pulsars* (accounting for most but not all X-ray pulsars), where the gravitational potential energy of accreted matter is the power source, *Magnetars*, where the decay of an extremely strong magnetic field provides the electromagnetic power.

- **Alpha-2 Canum Venaticorum**: these stars are chemically peculiar main sequence stars of spectral class B8p to A7p. They have strong magnetic fields and strong silicon, strontium, or chromium spectral lines. Their brightness typically varies by 0.01 to 0.1 magnitudes over the course of 0.5 to 160 days.

- **BY Draconis**: main sequence variable stars of late spectral types, usually K or M. They exhibit variations in their luminosity due to rotation of the star coupled with star spots, and other chromospheres activity. Resultant brightness fluctuations are generally less that 0.5 magnitudes on timescales equivalent to the star's rotational period, typically from a fraction of a day to several months.

Pulsating Variable Stars. Pulsating variable stars are intrinsic variables as their variation in brightness is due to a physical change within the star. In the case of pulsating variables this is due to the periodic expansion and contraction of the surface layers of the stars. The different types of pulsating variable are distinguished by their periods of pulsation and the shapes of their light curves.

- **Cepheids**: Typical classical Cepheids pulsate with periods of a few days to months, and their radii change by several million kilometers (30%) in the process. They are large, luminous stars, of spectral class F6 – K2, they are 5–20 times as massive as the Sun and up to 30000 times more luminous.

- **Delta Scuti**: variable star which exhibits variations in its luminosity due to both radial and non-radial pulsations of the star's surface. Typical brightness fluctuations are from 0.003 to 0.9 magnitudes in V over a period of a few hours, although the amplitude and period of the fluctuations can vary greatly. The stars are usually A0 to F5 type giant or main sequence stars.

- **RR Lyrae**: periodic variable stars, commonly found in globular clusters, and often used as standard candles to measure galactic distances. RR Lyrae are pulsating horizontal branch stars of spectral class A (and rarely F), with a mass of around half the Sun's. RR Lyrae are old, relatively low mass, metal-poor Population II stars. Their period is shorter, typically less than one day, sometimes ranging down to seven hours.

- **RV Tauri**: supergiant variable stars. They exhibit changes in luminosity which are tied to radial pulsations of their surfaces. Their changes in brightness are also correlated with changes in their spectral type. While at their brightest, the stars have spectral types F or G, at their dimmest, their

spectral types change to K or M. The formal period of brightness fluctuations is typically around 30 to 150 days, and exhibits alternating primary and secondary minima, which can change relative to each other. Difference between maximum and minimum brightness can be as much as four magnitudes.

- **Pulsating White Dwarf**: white dwarf star whose luminosity varies due to non-radial gravity wave pulsations within itself. These variables all exhibit small (1%–30%) variations in light output, arising from a superposition of vibration modes with periods of hundreds to thousands of seconds.

- **W Virginis**: are a subclass Cepheid variables in Population II which exhibit pulsation periods between 10–20 days and are of spectral class F6 – K2.

- **Long Period Variables**: type of variable star in which variations in brightness occur over long timescales of months or years. Long period variables are giant stars and brighter, from spectral class F and rewards, but most are red giants and AGB giants, meaning spectral class M, S or C. The following well defined variable star classes use to be counted into the LPV category:

- **Mira Ceti**: a class of pulsating variable stars characterized by very red colors, pulsation periods longer than 100 days, and light amplitudes greater than one magnitude. They are red giant stars in the very late stages of stellar evolution that will expel their outer envelopes as planetary nebulae and become white dwarfs within a few million years.

- **Semi-irregular variable stars**: giants or supergiants of intermediate and late spectral type showing considerable periodicity in their light changes, accompanied or sometimes interrupted by various irregularities. Periods lie in the range from 20 to more than 2000 days, while the shapes of the light curves may be rather different and variable with each cycle. The amplitudes may be from several hundredths to several magnitudes (usually 1-2 magnitudes in the V filter).

- **Slow Irregular Variables** (ascribed the GCVS types L, L and LC): variable stars that exhibit no or very poorly defined periodicity in their slowly changing light emissions. Most of them are late spectral types K and M, S stars or carbon stars. The LBs are generally giants, while the LCs are supergiants exhibiting a light variation interval of about 1 magnitude.

4.3 Supernovae

Supernovae are extremely luminous and cause a burst of radiation that often briefly outshines an entire galaxy, before fading from view over several weeks or months. Categories of supernovae are traditionally defined by the spectrum that reveals the composition of the ejected matter. Complementary information is obtained from the light curve, the pattern of rapid brightening and slower dimming followed by each event. From the studies of supernovae in other galaxies, astronomers have identified two basic types called Type I and Type II.

- Type Ia: appear in all kinds of galaxies—elliptical, spiral, and irregular. Type Ia tend to avoid the arms of spiral galaxies. Type Ia show characteristic elements in the spectrum, with elements such as magnesium, silicon, sulfur, and calcium near maximum light and iron later on. The light curve for Type Ia supernovae is also characteristic. There is an initial rise to a peak that takes about two weeks and then a long slower period of gradual decay over timescales of months that is very similar for all these events.

- Type Ib and Type Ic: are associated with massive stars. Type Ib show evidence for helium in the spectrum near maximum light. Type Ic show little or no such evidence for helium. On the other hand, both Type Ib and Ic show evidence for oxygen, magnesium and calcium at later times. Type Ib and Ic show little or no evidence for a strong line of silicon, a major characteristic of the spectra of Type Ia.

- Type II: occur occasionally in Irregular galaxies, but mostly in spiral galaxies and then within the confines of the spiral arms. There exist several categories of Type II supernovae , which are categorized based on the resulting light curve following the explosion. **Type II-L** supernovae show a steady (Linear) decline of the light curve following the explosion, whereas **Type II-P** display a period of slower decline (a *P*lateau) in their light curve followed by a normal decay.

4.4 Compound Object

Active Galactic Nuclei (AGN): compact regions at the centre of some galaxy which have a much higher than normal luminosity over some or all of the electromagnetic spectrum (in the radio, infrared, optical, ultra-violet, X-ray and/or gamma ray wavebands). Many AGNs vary in brightness by substantial amounts over timescales as short as years, months, days, or even hours. It is convenient to divide AGN into two classes, conventionally called radio-quiet and radio-loud. For a given IR through soft x-ray luminosity, the radio-loud AGNs are 2–3 orders of magnitude more luminous in the radio than the radio-quiet objects.

- **Radio-Quiet AGN**:

• Low-ionization nuclear emission-line regions (LINERs). These systems show only weak nuclear emission-line regions, and no other signatures of AGN emission. They constitute the lowest-luminosity class of radio-quiet AGN.
• Seyfert galaxies. . They show optical nuclear continuum emission, narrow and (sometimes) broad emission lines, (sometimes) strong nuclear X-ray emission and sometimes a weak small-scale radio jet. Originally they were divided into two types known as Seyfert 1 and 2: Seyfert 1s show strong broad emission lines while Seyfert 2s do not, and Seyfert 1s are more likely to show strong low-energy X-ray emission.

- Radio-quiet quasars/QSOs. Quasars has optical luminosities that is greater than that of their host galaxy. They always show strong optical continuum emission, X-ray continuum emission, and broad and narrow optical emission lines.

- **Radio-Loud AGN**:

- Radio-loud quasars. They show strong optical continuum emission, broad and narrow emission lines, and strong X-ray emission, together with nuclear and often extended radio emission.

- Blazars (BL Lac objects and OVV quasars). These classes are distinguished by rapidly variable, polarized optical, radio and X-ray emission. BL Lac objects show no optical emission lines, broad or narrow. OVV quasars behave more like standard radio-loud quasars with the addition of a rapidly variable component.

- Radio galaxies. These objects show nuclear and extended radio emission. They can broadly be divided into low-excitation and high-excitation classes. Low-excitation objects show no strong narrow or broad emission lines. By contrast, high-excitation objects (narrow-line radio galaxies) have emission-line spectra similar to those of Seyfert 2s.

5 Current status of the pipeline

At the present stage of the project we designed and developed a pipeline that allows the user to simulate images, as more realistic as possible, containing variable objects, then extracted catalogues by using S-Extractor. This well known software is also used in order to verify and validate the goodness of the simulated images, before to explore their segmentation and the detection of various objects.

So far, our simulation pipeline consists of the following steps:

1. Merge common parameters spread in Stuff, SkyMaker and S-Extractor configuration files, and collect them in a new single setup file (e.g., stradiwa.config);

2. create a first catalog of galaxies with Stuff;

3. add a star catalog, produced by simple star field generator coming from SkyMaker;

4. add variable objects (modeled offline) in number and type defined by the setup file;

5. evaluate temporal evolution of the magnitude for the transients, defined by appropriate rules;

6. produce simulated images through SkyMaker (with parameters defined by STraDiWA and SkyMaker setup files);

7. extract catalogues with S-Extractor .

An example of STraDiWA setup file is in Appendix I.
In the current version of the simulation the user has the opportunity to set the parameters related to the modeling of the extragalactic objects (cosmological parameters, luminosity function coefficients) in Stuff, all the information related to the simulated instrument and the observing conditions in SkyMaker, the behavior of those parameters that evolve over time and number and type of the transients to be included in STraDiWA setup file.
Until now the variable objects available for the simulation are Irregular Variable Objects (randomly assigned) and Classical Cepheids.
The rule used to find temporal evolution of Random Object is very simple: magnitudes at each time are randomly generated in the range defined by magnitude limits. This obviously can be performed in each band.
For classical Cepheids modeling, the rules used are slightly more complicated.

5.1 Rules for Classical Cepheids modeling

In our work we referred to the classification of Cepheids provided by AAVSO (American Association of Variable Star Observers) .

The AAVSO identifies three types of Cepheids:

DCEP (Classical Cepheid)

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Period Range: 1-135 d.
$A_V = 0.1 – 2$ mag.

CEP(B) (Beat Cepheids)

Cepheids displaying the presence of two or more simultaneously operating pulsation modes (usually the fundamental tone with the period P0 and the first overtone P1).

Period Range: 2 – 7 d.
P1/P0 ~ 0.71 .

DCEPS (S Cepheids)

These star have almost symmetrical light curves. They are probably first-overtone pulsators and/or are in the first transition across the instability strip after leaving the main sequence.

Period Range: 3 - 10 d.
$A_V < 0.5$ mag.
$A_b < 0.7$ mag.

Currently we focused on Classical Cepheids because there obey the well-known Period-Luminosity relation. This relationship is linear in *logP* and has been calibrated in several bands. We used the results from Sandage & Tammann 2004 in B, V, and I bands.

We give now a brief summary of what are the steps of the simulation of a Classical Cepheid:

- the Period can be assigned by the User or extract randomly within the AAVSO values;

- use P-L relation in order to find mean absolute magnitude;

- the Phase can be assigned by the User or extract randomly;

- the Amplitude can be assigned by the User or extracted randomly within the AAVSO values;

- it is possible to assume a sinusoidal law and evaluate the temporal evolution of the absolute magnitudes;

- The apparent magnitude of each star can be estimated by using the values of absorption coefficients given by Tammann and extracted randomly the color excess.

For a Classical Cepheid the parameters that must be set in the STraDiWA configuration file then: P, A, φ . As an initial example we produced a simulation of 3 Classical Cepheids and 2 Irregular Variable, using VST (VLT Survey Telescope) parameters. The simulation is related to three consecutive observing days, with an uniform sampling mode and in the B, V, and I bands.

A movie of the simulation, in RGB colors, is available at http://dame.dsf.unina.it/dame_td.html#se

An example of an image, extracted from the movie at t=0 in each band, can be found in Appendix II.

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5.2 Catalog Extraction

In order to verify the consistence of the imposed parameters (also taking into account the forthcoming test with several classifiers), we submitted the reduced images to S-Extractor, by opportunely tuning its parameters.

We performed several tests (in Johnson B, V and I bands) in which we have:

- changed one parameter at time;

- changed the FILTER or THRESHOLD parameters in S-Extractor configuration file, or the MAG_ZEROPOINT or AUREOLE RADIUS parameters in SkyMaker configuration file;

- replicated the tests by changing values of seeing, respectively 0.7 and 1.07;

- performed the tests with objects simulated in the range [18, 26] mag and extracted in [18, 24] mag, binning them in intervals of 1 mag.

We simulated an image with exposure time of 1500 s, so that the MAG ZEROPOINT in S-Extractor is the MAG ZEROPOINT in ADU per sec (set in SkyMaker) minus $-2.5\log_{10}(GAIN) + 2.5\log_{10}(T\exp)$ plus $log_{10}(\text{t}_{\_exp} * \text{GAIN})$, where GAIN is expressed in [e⁻/ADU] and Texp is in [sec].

The most significant tests are those with FILTER parameter set to **gauss_5.0_9x9.conv** with seeing 1.07 and **gauss_4.0_7x7.conv** with seeing 0.7 (see tab.4 in Appendix III for references).

The detection rates performed by S-Extractor show that for Stellar Objects, with a seeing of 1.07, we can't go deeper of 23 mag, while with a lower seeing of 0.7 the results are quite acceptable up to 24 mag.
We report the S-extractor detection rates related to this test. In Appendix II and III you can find some results of performed tests.

We want to point out that the parameter THRESHOLD set to 0.8 is chosen in order to avoid spurious objects (the simulation environment is done for not crowded universe).
The results obtained by S-Extractor are a well suited starting point to estimate what threshold we can use in the evaluation and tuning of the classifiers.

We also provided a plot with the difference between the magnitudes in input and output *versus* the input magnitude (as in Fig. 4)
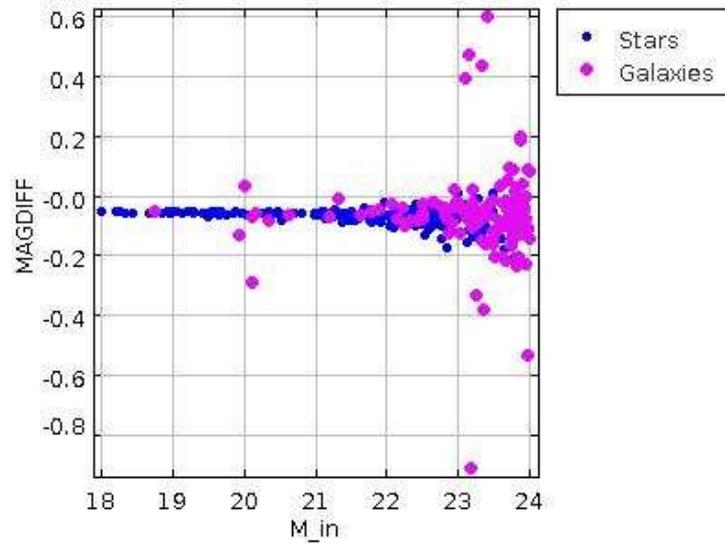
Fig. 4 – input/output magnitudes versus input magnitude

(The bright galaxies that deviate from the value of 0.05 mag are, in a case almost on the edge of the image, in the others overlap another fainter object)

S-Extractor was our preliminary choice. We intend to investigate more crowded fields in which to evaluate results by using other more specific reduction software packages (such as DAOPHOT).

Examples of simulated images and of checked images produced by S-Extractor can be found in Appendix II.

6 Algorithms for variable object identification

This is the section related with the DM methods and algorithms to be explored in order to perform the required detection and classification of variable objects. We are currently at the very beginning of this phase. It requires a preliminary review of all existing algorithms which could be relevant to the classification in real time of transients. For instance we intend to explore detection models based on the machine learning paradigm, such as:

- Bayesian Networks;

- Wavelets and segmentation methods;

- Supervised classifiers trained on simulations;

- Unsupervised clustering models;

- Multi-model gated experts;

The application of such methods could also arise from the analysis of algorithms and applications already available in the DAME framework. At the moment, these are listed in the following table.

MODEL	CATEGORY	FUNCTIONALITY
MLP with Back Propagation	Supervised	Classification, Regression
MLP with Genetic Algorithm	Supervised	Classification, Regression
MLP with Quasi-Newton	Supervised	Classification, Regression
Support Vector Machine (SVM)	Supervised	Classification, Regression
Multilayer Clustering (Self Organizing Maps - SOM)	Unsupervised	Clustering
NEXT-II	hybrid	Image segmentation and clustering
Principal Probabilistic Surfaces (PPS)	Unsupervised	Dimensional reduction, pre-clustering

Tab. 3 – data mining models currently available in DAME

Further methods, after the decision to be employed in this project, will be implemented in the forthcoming releases of DAME applications and services.

Various indicators for variable objects (uniformity index, etc…) need also to be explored.

Details of above methods can be found on DAME official website: http://dame.dsf.unina.it/

7 Appendix I – Samples of setup files

In the following, a sample of our custom setup files is reported. As underlined in the previous sections, one of the project tasks is the integration of such setup files, together with the corresponding updating of the source code which are needed to implement such improvements.

Main output values coming from Stuff sky simulation framework (verbosely described in [15]) are:

- Label 100 → star object; 200 → galaxy object;
- pixel position in simulated image;
- apparent magnitude;
- bulge-to-total ratio;
- bulge effective radius;
- bulge apparent aspect ratio;
- bulge position angle (degrees, CCW with respect to horizontal axis);
- disk scale length (in arcsec);
- disk axis ratio and position angle (degrees, CCW with respect to horizontal axis);
- galaxy redshift.

In the following, two samples of customized and Sex-Extractor setup files are reported.

7.1 STraDiWA setup file

The setup file reported below is referred to the simulation of Cepheids as described in the document.

```
#STraDiWA v1.0
1# Default configuration file Version 1.0

#------------------------------Setup Files---------------------------------
SETUP_FILES ./default.stuff,./defaultVST.sky,./default.sex
      #name and path of configuration files of  Stuff, SkyMaker and S-Extractor

#------------------------------Stuff Parameters----------------------------
STUFF_CATALOG_NAME B.list,V.list,I.list      # different for each band
PASSBAND_OBS sandage/B,sandage/V,johnson/I    # Observed passband(s) in Stuff
(sandage, johnson etc are the folders contains filters)

#--------------------Common parameters to Stuff and SkyMaker---------------
IMAGE_SIZE 1024                          # Width,[height] of the output frame
MAG_LIMITS 18,26.0                       # allowed range of apparent magnitudes

#---------------Common parameters to Stuff,SkyMaker and Sextractor----------
GAIN 0.53                                # detector gain in e-/ADU
PIXEL_SIZE 0.213                         # size of pixel in arcsec

#-------------Common parameters to SkyMaker and Sextractor ----------------
SATUR_LEVEL 65535                        # saturation level (ADU)
```

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```
#--------------------------------SkyMaker Parameters-------------------------
EXPOSURE_TIME 1500.0                      #(s)
BACK_MAG 22.81,21.81,19.78               # background surface brightness
(mag/arcsec2), one for each band to take in to account

#--------------------------------Variable Objects----------------------------
TRANSIENT 1,20.3,2.5,RANDOM,RANDOM        # OBJECT TYPE, INITIAL MAGNITUDE,
PERIOD (days), AMPLITUDE( mag), PHASE(rad) (to have random values, RANDOM)
TRANSIENT 1,21.3,1.2,1.8,2Pi              # OBJECT TYPE, INITIAL MAGNITUDE,
PERIOD (days), AMPLITUDE( mag), PHASE(rad) (to have random values, RANDOM)
TRANSIENT 1,19.5,3.0,0.7,RANDOM           # OBJECT TYPE, INITIAL MAGNITUDE,
PERIOD (days), AMPLITUDE( mag), PHASE(rad) (to have random values, RANDOM)
TRANSIENT 0, RANDOM,RANDOM,RANDOM,RANDOM  # OBJECT TYPE, INITIAL MAGNITUDE,
PERIOD (days), AMPLITUDE( mag), PHASE(rad) (to have random values, RANDOM)
TRANSIENT 0, RANDOM,RANDOM,RANDOM,RANDOM  # OBJECT TYPE, INITIAL MAGNITUDE,
PERIOD (days), AMPLITUDE( mag), PHASE(rad) (to have random values, RANDOM)
SAMPLING B,3,2,9
#SAMPLING        # First character identifies the selected behavior between:
                 #A) time series (in hours) from t = 0, eg:
                     A,0,111,3143,32432,5454,454
                 #B) fixed sampling with number of days , time(hours), and
                     length of night (hours), es: B,50,4,9
                 #note that param time(hours) has to be consistent to
                     exposure_time;
SEEING_FWHM B,0.6,1.1
#SEEING_FWHM     #  First character identifies the selected behavior between:
                 #A) series of specific values, eg:
                     A,123,234,5543,543543643,232432
                 #B) random value between min and max, for each image: B,min,max
                     (min+ RAND(0,1)*max-min
INSTR_ZEROPOINT A,26          # instrumental magnitude zero-point
#Variable Objects available in the current version of STraDiWA
#0) RANDOM,                   for each band
#1) Classical Cepheid,        available band  B,V,I
```

7.2 S-Extractor setup file

The following setup file is referred to the test Nr. 1, reported in this document.

```
#----------------------------- Catalog ----------------------------------
CATALOG_TYPE     ASCII_HEAD    # NONE,ASCII,ASCII_HEAD, ASCII_SKYCAT,
                               # ASCII_VOTABLE, FITS_1.0 or FITS_LDAC
PARAMETERS_NAME  default.param # name of the file containing catalog contents

#----------------------------- Extraction -------------------------------
DETECT_TYPE     CCD            # CCD (linear) or PHOTO (with gamma correction)
DETECT_MINAREA  5              # minimum number of pixels above threshold
DETECT_THRESH   0.8            # <sigmas> or <threshold>,<ZP> in mag.arcsec-2
ANALYSIS_THRESH 0.8            # <sigmas> or <threshold>,<ZP> in mag.arcsec-2
FILTER          Y              # apply filter for detection (Y or N)?
FILTER_NAME     gauss_5.0_9x9.conv  # name of the file containing the filter
DEBLEND_NTHRESH 64             # Number of deblending sub-thresholds
DEBLEND_MINCONT 0.001          # Minimum contrast parameter for deblending
```

```
CLEAN              Y              # Clean spurious detections? (Y or N)?
CLEAN_PARAM        1.0            # Cleaning efficiency
MASK_TYPE          CORRECT        # type of detection MASKing: can be one of
                                  # NONE, BLANK or CORRECT


#----------------------------- Photometry -----------------------------------
PHOT_APERTURES     5              # MAG_APER aperture diameter(s) in pixels
PHOT_AUTOPARAMS    2.5, 3.5       # MAG_AUTO parameters: <Kron_fact>,<min_radius>
PHOT_PETROPARAMS   2.0, 3.5       # MAG_PETRO params: <Petrosian_fact>,<min_radius>
SATUR_KEY          SATURATE       # keyword for saturation level (in ADUs)
MAG_GAMMA          4.0            # gamma of emulsion (for photographic scans)
GAIN_KEY           GAIN           # keyword for detector gain in e-/ADU


#---------------------- Star/Galaxy Separation ------------------------------
STARNNW_NAME       default.nnw    # Neural-Network_Weight table filename


#----------------------------- Background -----------------------------------
BACK_SIZE          64             # Background mesh: <size> or <width>,<height>
BACK_FILTERSIZE    3              # Background filter: <size> or <width>,<height>
BACKPHOTO_TYPE     GLOBAL         # can be GLOBAL or LOCAL


#----------------------------- Check Image ----------------------------------
CHECKIMAGE_TYPE    APERTURES      # can be NONE, BACKGROUND, BACKGROUND_RMS,
                                  # MINIBACKGROUND, MINIBACK_RMS, -BACKGROUND,
                                  # FILTERED, OBJECTS, -OBJECTS, SEGMENTATION,
                                  # or APERTURES


#-------------------- Memory (change with caution!) -------------------------
MEMORY_OBJSTACK    3000           # number of objects in stack
MEMORY_PIXSTACK    300000         # number of pixels in stack
MEMORY_BUFSIZE     1024           # number of lines in buffer
#-------------------- Image -------------------------------------------------

CATALOG_NAME       sky_newimage.cat
GAIN               1.0
SATUR_LEVEL        65535
MAG_ZEROPOINT      33.9402
PIXEL_SCALE        0.213
SEEING_FWHM        1.07
CHECKIMAGE_NAME    check_newimage.fits
```

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8 Appendix II – Simulation of Variable Objects

Images containing variable objects defined in the STraDiWA setup file in B, V and I bands at t = 0.
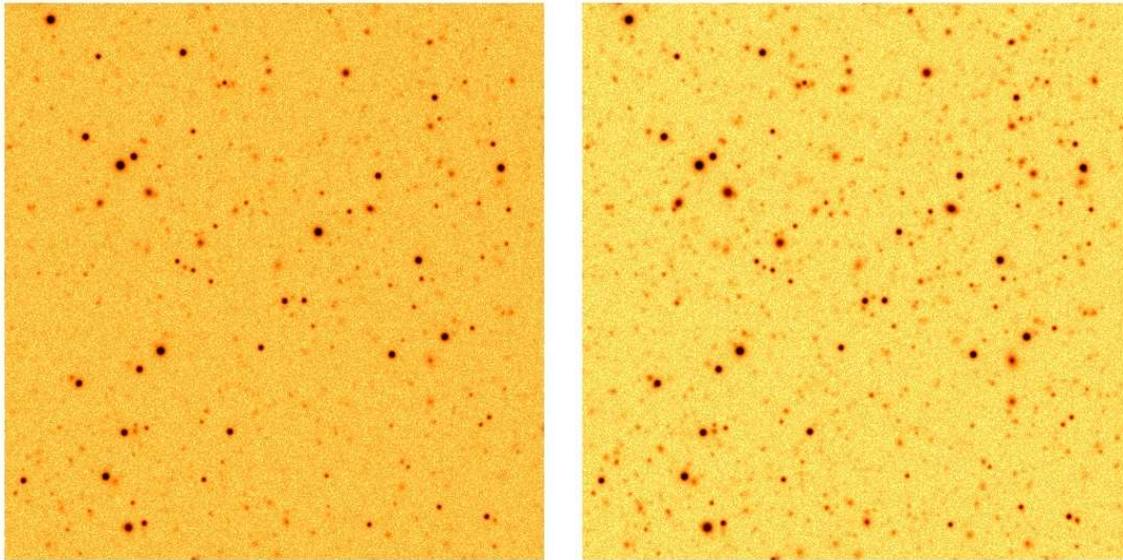
Fig. 5 – simulated image in the B band (left) and V band (right)
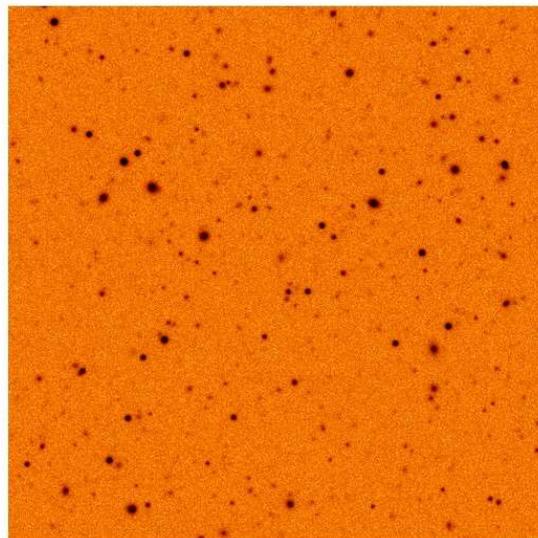
Fig. 6 – simulated image in the I band

The images reported above are some frames taken from the movie (http://dame.dsf.unina.it/dame_td.html#se) for Cepheids/Irregular variable objects simulation (parameters are reported in the Appendix I).

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9 Appendix III – S-Extractor detection rate tests

Remind that the detection rates are divided by bins of magnitude, however the images reported below are referred to objects always extracted in the limits [18 – 24] mag. The difference between following tests is in terms of change of some parameters (see tables below the images for details), mainly seeing, filter, threshold and aureole radius of PSF.

In the tables reported for the tests, S_{out} and G_{out} are the objects well classified by S-Extractor, that is with Stellarity index $SI >= 0.98$ for the stars and $SI < 0.98$ for the galaxies. Obviously the quantities S_{in} and G_{in} are known.

A summary of reported tests, in terms of main parameters, is shown in Tab.4.

TEST ID	MAG ZEROPOINT [ADU per sec]	AUREOLE RADIUS [pixel]	GAIN [e-/ADU]	SEEING [arcsec]	THRESHOLD	FILTER
1	26.0	188	1.0	1.07	0.8	gauss_5.0_9x9.conv
2	26.0	188	1.0	1.07	0.5	gauss_5.0_9x9.conv
3	28.0	188	1.0	1.07	0.8	gauss_5.0_9x9.conv
4	26.0	0	1.0	1.07	0.8	gauss_5.0_9x9.conv
5	26.0	188	1.0	1.07	0.8	default.conv
6	26.0	188	1.0	1.07	0.8	gauss_4.0_7x7.conv
7	26.0	188	1.0	1.07	0.8	gauss_3.0_7x7.conv
8	26.0	188	1.0	1.07	0.8	gauss_3.0_5x5.conv
9	26.0	188	1.0	0.7	0.8	default.conv
10	26.0	188	1.0	0.7	0.8	gauss_4.0_7x7.conv
11	26.0	188	1.0	0.7	0.8	gauss_3.0_7x7.conv
12	26.0	188	1.0	0.7	0.8	gauss_3.0_5x5.conv
13	26.0	188	1.0	0.7	0.8	gauss_5.0_9x9.conv

Tab. 4 – Summary of test parameters

Test 1
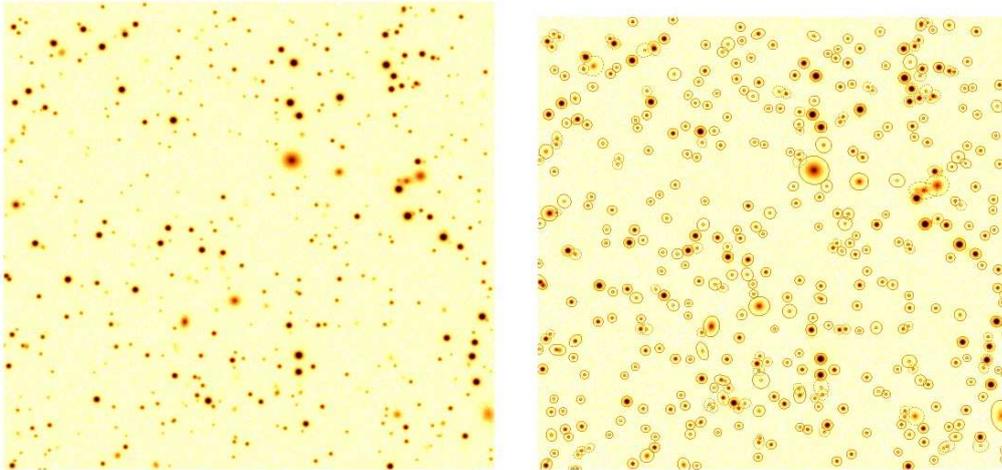
Fig. 7 – Test 1, Simulated image produced (left); image verified by S-extractor (right)

Test 1					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	1.07
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	gauss_5.0_9x9.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	94.7	100%	4.25%	0%		
23 – 24 mag	32.1%	96.3%	64.1%	0%		

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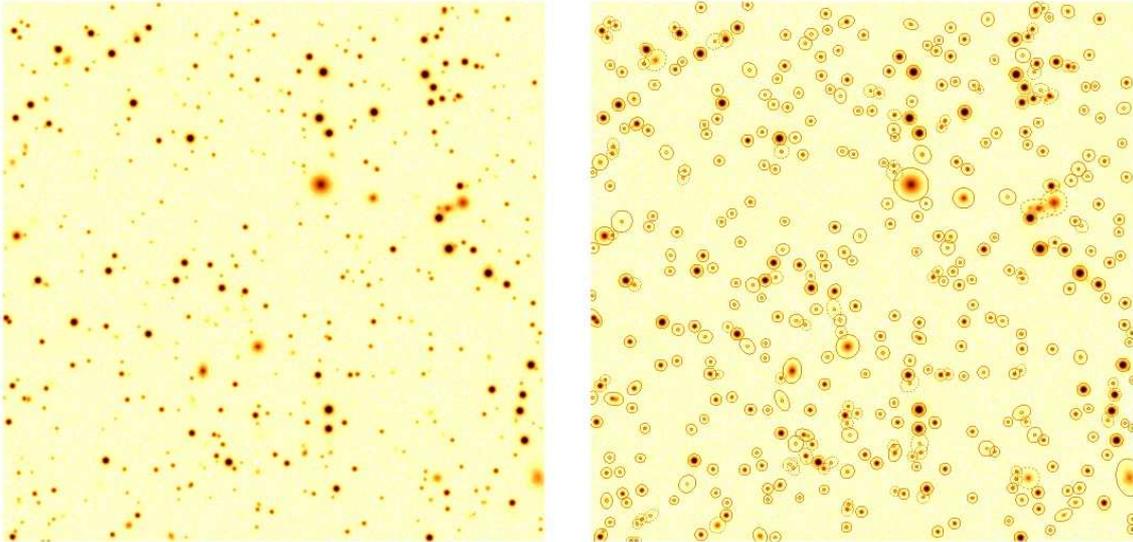
Test 2

Fig. 8 – Test 2, Simulated image produced (left); image verified by S-extractor (right)

Test 2					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	1.07
				S-Extractor parameters	THRESHOLD	0.5
					FILTER	gauss_5.0_9x9.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	93.6%	100%	5.32%	0%		
23 – 24 mag	47.3%	97.5%	48.1%	0%		

The meaning of the rates are the same for all the tests.

Test 3
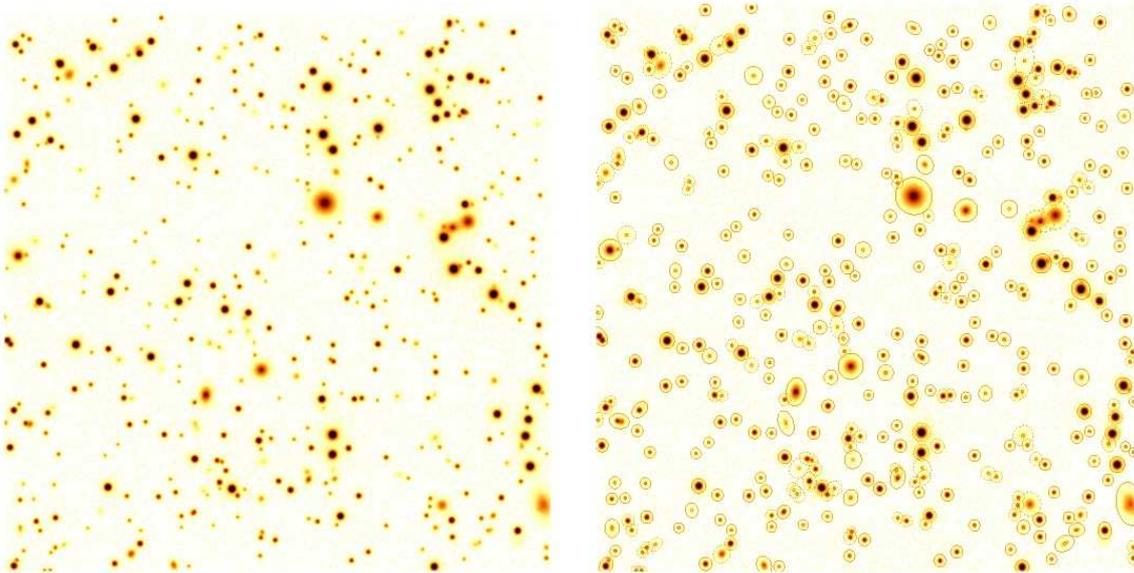
Fig. 9 – Test 3, Simulated image produced (left); image verified by S-extractor (right)

Test 3					*Image Parameters*	*Value*
					MAG ZEROPOINT	28.0 ADU per sec
				SkyMaker parameters	AUREOLE RADIUS	188
					GAIN	1.0 e-/ADU
				Common parameters	SEEING	1.07
					THRESHOLD	0.8
				S-Extractor parameters	FILTER	gauss_5.0_9x9.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	96.8%	100%	2.13%	0%		
23 – 24 mag	90.1%	97.5%	5.34%	0%		

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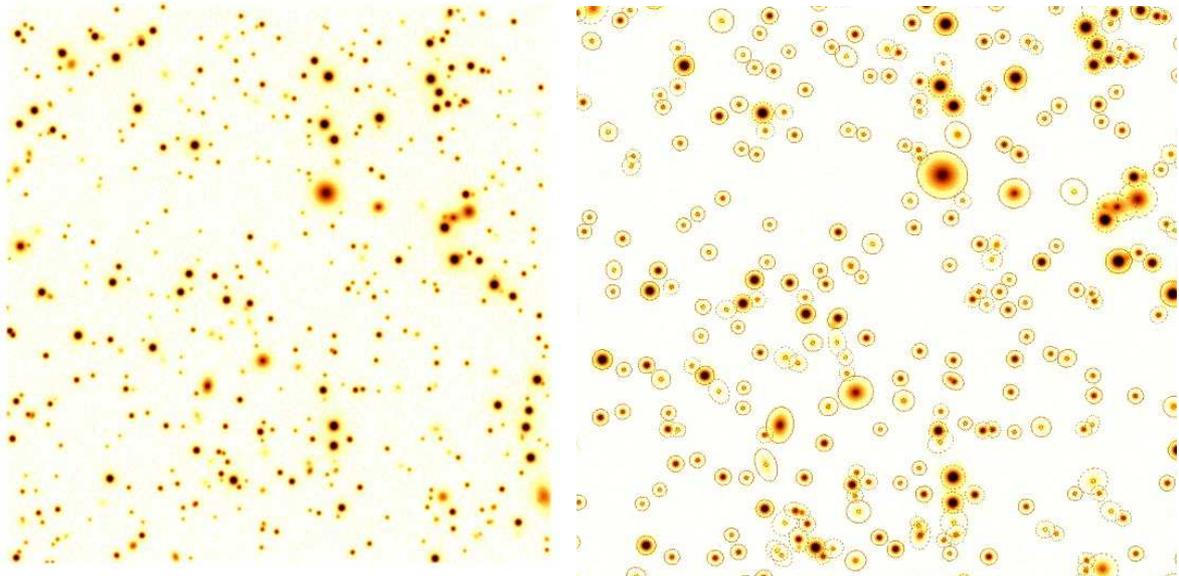
Test 4

Fig. 10 – Test 4, Simulated image produced (left); image verified by S-extractor (right)

Test 4					*Image Parameters*	*Value*
					MAG ZEROPOINT	26.0 ADU per sec
			SkyMaker parameters		AUREOLE RADIUS	0
					GAIN	1.0 e-/ADU
			Common parameters		SEEING	1.07
					THRESHOLD	0.8
			S-Extractor parameters		FILTER	gauss_5.0_9x9.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	95.7%	100%	3.19%	0%		
23 – 24 mag	32.1%	97.5%	64.1%	0%		

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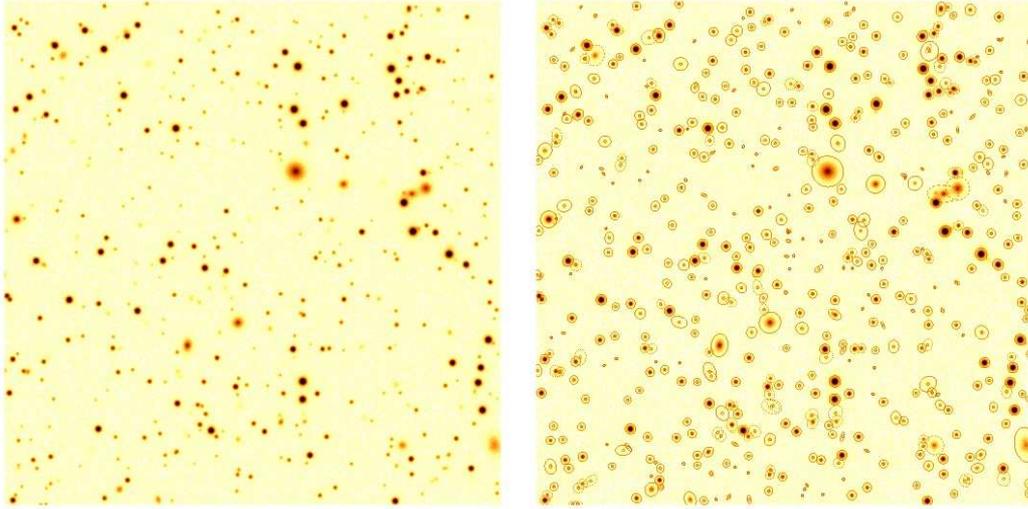
Test 5

Fig. 11 – Test 5, Simulated image produced (left); image verified by S-extractor (right)

Test 5					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	1.07
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	default.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	91.5%	100%	7.45%	0%		
23 – 24 mag	28.2%	97.5%	68.7%	0%		

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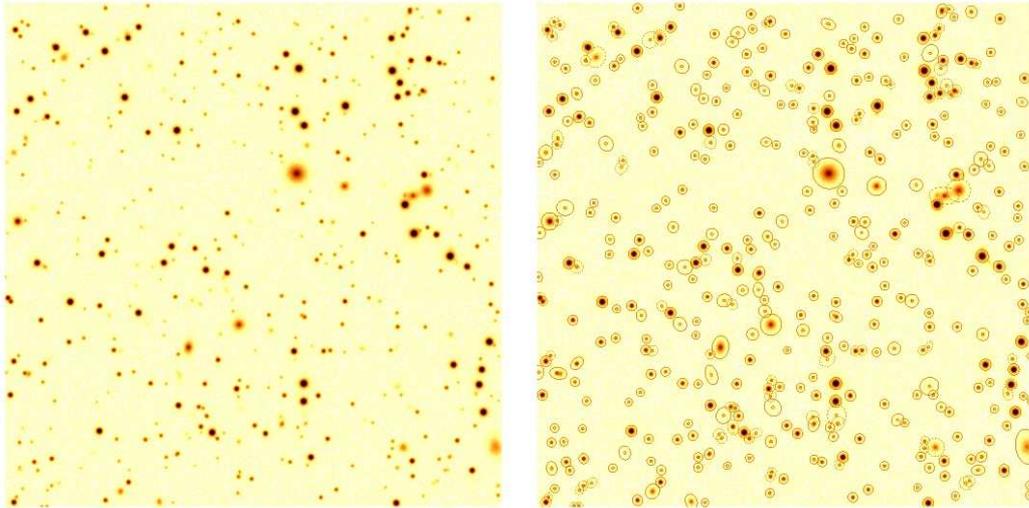
Test 6

Fig. 12 – Test 6, Simulated image produced (left); image verified by S-extractor (right)

Test 6					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	1.07
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	gauss_4.0_7x7.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	92.5%	100%	6.38%	0%		
23 – 24 mag	25.2%	98.8%	69.5%	0%		

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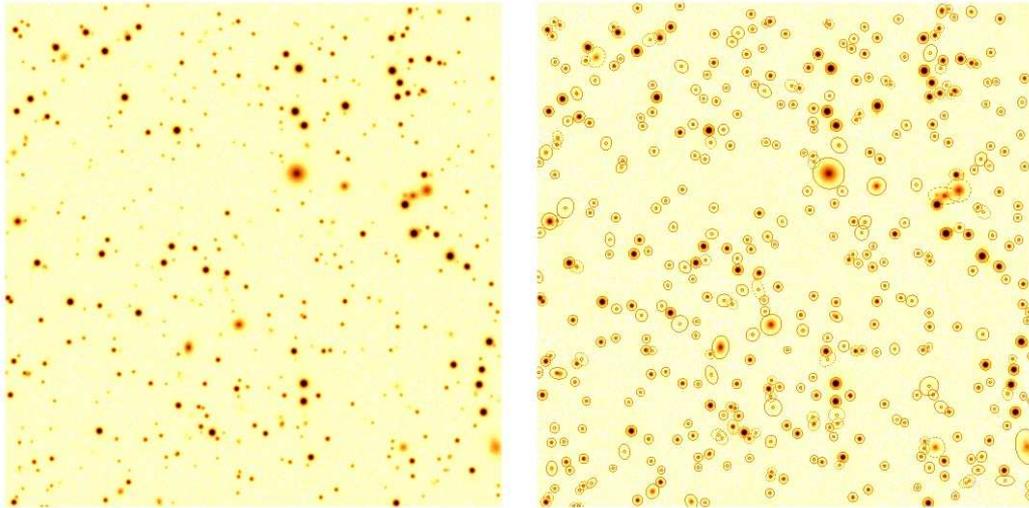
Test 7

Fig. 13 – Test 7, Simulated image produced (left); image verified by S-extractor (right)

Test 7					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	1.07
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	gauss_3.0_7x7.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	94.7%	100%	4.25%	0%		
23 – 24 mag	31.3%	95.1%	66.4%	1.23%		

STraDiWA project documentation
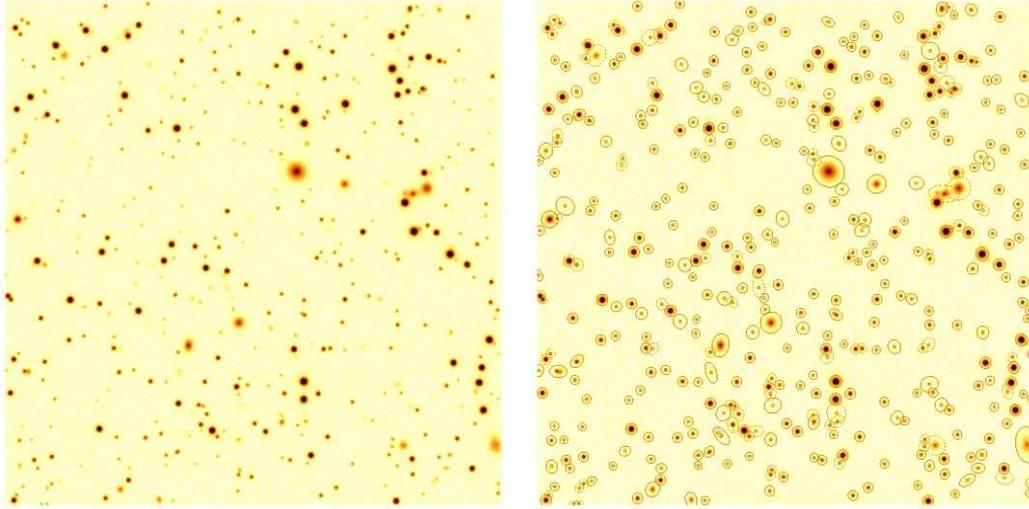
Test 8

Fig. 14 – Test 8, Simulated image produced (left); image verified by S-extractor (right)

Test 8					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	1.07
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	gauss_3.0_5x5.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	92.5%	100%	6.38%	0%		
23 – 24 mag	29.0%	98.8%	66.4%	0%		

Test 9
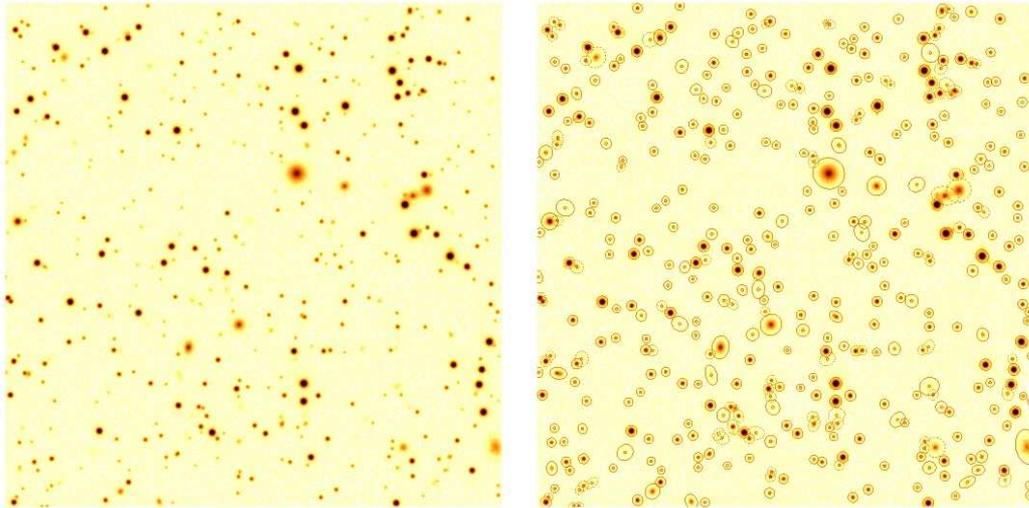
Fig. 15 – Test 9, Simulated image produced (left); image verified by S-extractor (right)

Test 9					Image Parameters	Value
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	0.7
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	default.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	Misclassified Stars	Misclassified Gal.		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	97.9%	100%	1.06%	0%		
23 – 24 mag	77.1%	97.5%	20.6%	0%		

Test 10
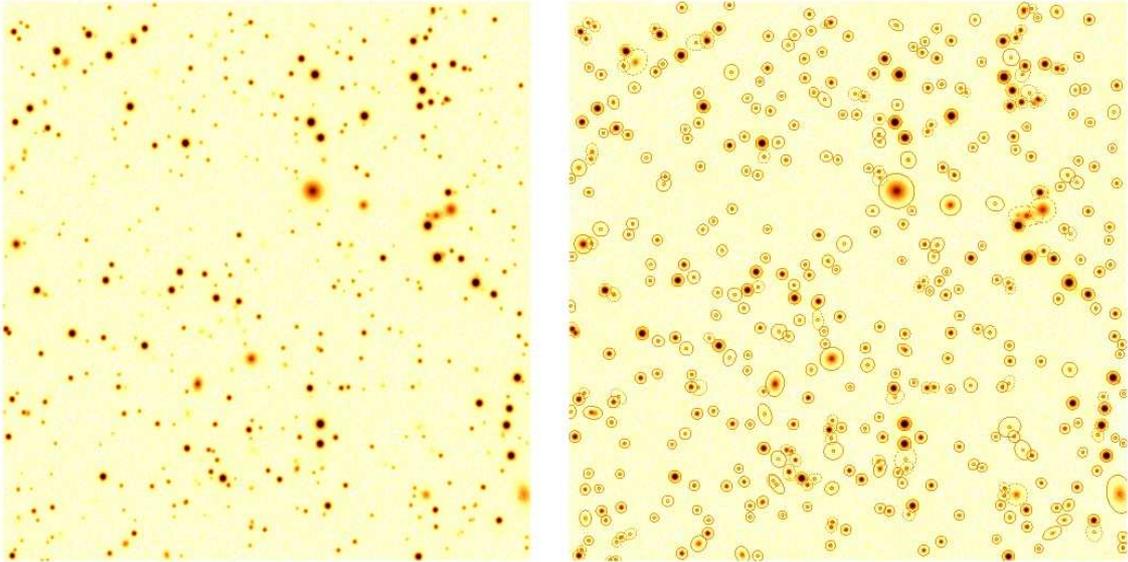
Fig. 16 – Test 10, Simulated image produced (left); image verified by S-extractor (right)

Test 10					*Image Parameters*	*Value*
SkyMaker parameters					MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
Common parameters					GAIN	1.0 e-/ADU
					SEEING	0.7
S-Extractor parameters					THRESHOLD	0.8
					FILTER	gauss_4.0_7x7.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	97.9%	100%	1.06%	0%		
23 – 24 mag	78.6%	97.5%	18.3%	0%		

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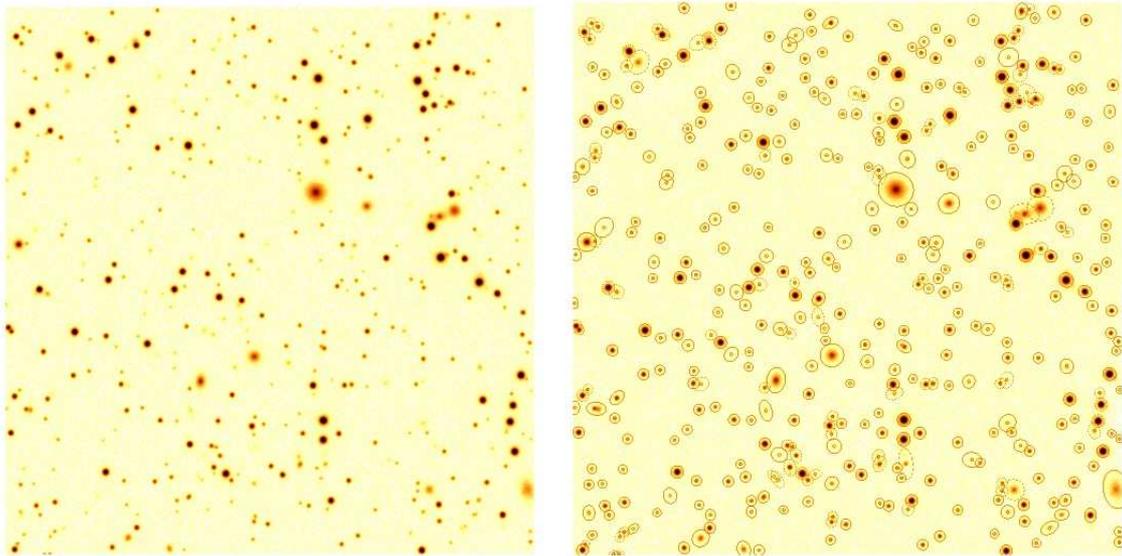
Test 11

Fig. 17 – Test 11, Simulated image produced (left); image verified by S-extractor (right)

Test 11					*Image Parameters*	*Value*
				SkyMaker parameters	MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
				Common parameters	GAIN	1.0 e-/ADU
					SEEING	0.7
				S-Extractor parameters	THRESHOLD	0.8
					FILTER	gauss_3.0_7x7.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	97.9%	100%	1.06%	0%		
23 – 24 mag	74.8%	97.5%	22.1%	0%		

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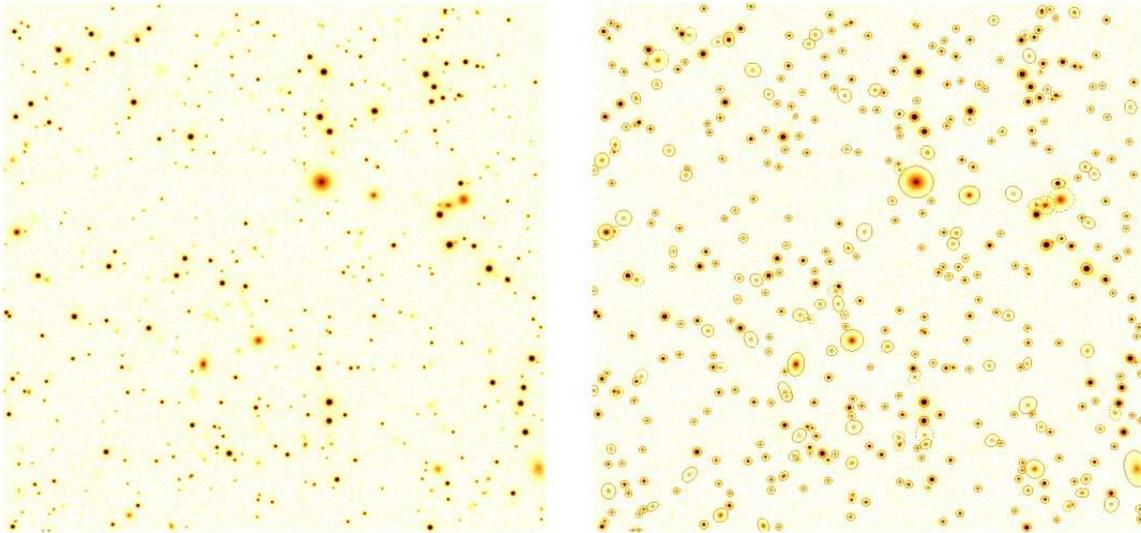
Test 12

Fig. 18 – Test 12, Simulated image produced (left); image verified by S-extractor (right)

Test 12					*Image Parameters*	*Value*
SkyMaker parameters					MAG ZEROPOINT	26.0 ADU per sec
					AUREOLE RADIUS	188
Common parameters					GAIN	1.0 e-/ADU
					SEEING	0.7
S-Extractor parameters					THRESHOLD	0.8
					FILTER	gauss_3.0_5x5.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	97.9%	100%	1.06%	0%		
23 – 24 mag	77.1%	97.5%	19.8%	0%		

Test 13
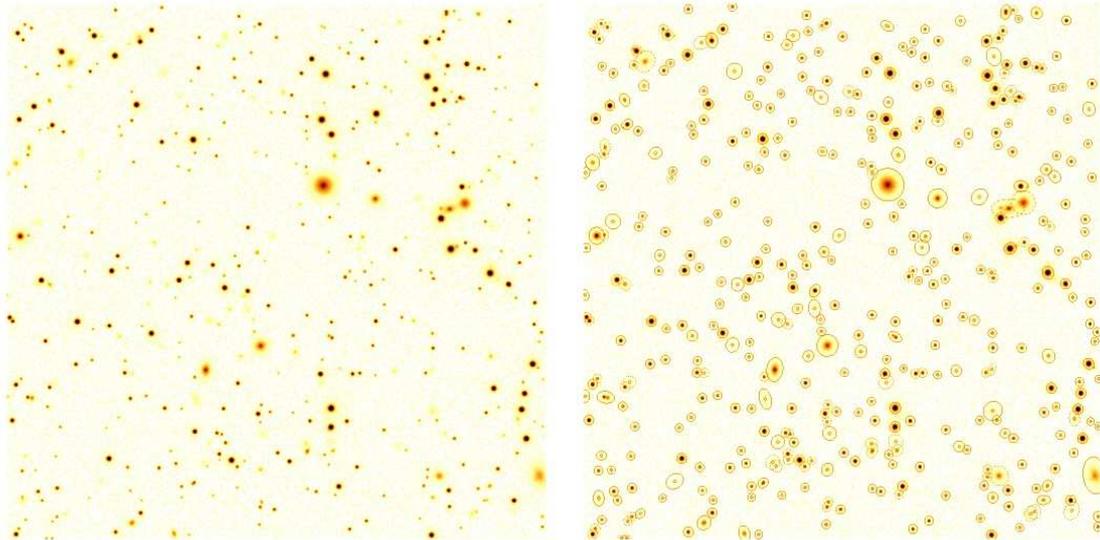
Fig. 19 – Test 13, Simulated image produced (left); image verified by S-extractor (right)

Test 13					*Image Parameters*	*Value*
					MAG ZEROPOINT	26.0 ADU per sec
			SkyMaker parameters		AUREOLE RADIUS	188
					GAIN	1.0 e-/ADU
			Common parameters		SEEING	0.7
					THRESHOLD	0.8
			S-Extractor parameters		FILTER	gauss_5.0_9x9.conv
Mag Bin	S_{out}/S_{in}	G_{out}/G_{in}	*Misclassified Stars*	*Misclassified Gal.*		
18 – 19 mag	100%	100%	0%	0%		
19 – 20 mag	100%	100%	0%	0%		
20 – 21 mag	100%	100%	0%	0%		
21 – 22 mag	100%	100%	0%	0%		
22 – 23 mag	96.8%	100%	2.13%	0%		
23 – 24 mag	75.6%	97.5%	20.6%	0%		

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