Software and Controllers (and other stuff)

Everything You Always Wanted to Know About IT @ OAR , but you had had the good taste not to ask

Vincenzo Testa

INAF-OAR

Foreword and Caveat

- This is an incomplete and focused overview of the OAR activities/expertise in computer science.
- "Big Science" paradigm is entering only recently in the minds of astrophysicists
- Quite large activity at OAR in software for dedicated subjects , we are not computer scientists (professional programmers) but…
- …diffuse expertise on: languages (Fortran, C, C++, Java, Python, PHP, …), pipelines (scripting), databases and archives (relational and not), theoretical modeling computing issues
- Starting interest and expertise on: parallelization, GPU programming, large software projects handling
- Contact people indicated in blue

Overview

Macroarea / Realm	STARS AND STELLAR SYSTEMS	GALAXIES AND COSMOLOGY	SUN AND SOLAR SYSTEM	HIGH ENERGY ASTROPHYS.	TECHNOLOGY
Theory					
Observation					
Technology					

Software for Theory I – Stellar Structure Models

- Long term tradition at OAR
- Strong links with INAF-IAPS and Universities
- Strong link with other INAF institutes outside Rome (e.g. Teramo)
- At the moment:
  - FRANEC (Yields from nucleosynthesis – M. Limongi)
  - ATON (Stellar Structure – P. Ventura)

ATON

a code for stellar evolution

Allows the description of the evolution of stars of any mass from the early pre Main-Sequence phase to the white dwarf cooling ($M < 8M_{Sun}$) or the to central carbon exhaustion (massive stars, $M > 8M_{Sun}$)

Given a chemical composition, ATON solves the 4 differential equations describing the stellar equilibrium to find the internal stratification of pressure, temperature, radius and luminosity as a function of mass, the independent variable.

Boundary conditions

- Zero radius and flux in the center
- Pthotospheric boundary conditions found via grey or non grey atmospheric treatment

The system of differential equations is solved via the Henvey relaxation method: convergency is typically reached within 4-6 iterations

ATON

a code for stellar evolution

After convergency is reached the time step is applied, with the nuclear reactions going on. First order differential equations in time solved via a semi-implicit scheme to determine the change in the chemical composition

Nuclear network made up of 30 elements (Hydrogen, Helium + all the most important CNO isotopes) and 64 nuclear reactions (the most relevant p-captures and α-captures)

ATON properties:

* Gravitational settling
* Grey & non-grey atmospheric treatment
* Diffusive mixing coupled to nuclear burning
* Rotation (structural effects + internal angular momentum redistribution)
* Dust formation in the wind

Software for Theory II – Population Synthesis and Galaxy Formation

- GAMETE (R. Schneider)
- SPOT (E. Brocato)
- Semi-analytical models of galaxy formation (N. Menci)
- General characteristic: almost all of them are not-distributed, used for science production within the research group, sort of "industrial secret". Products are distributed and published.
- Main developing language: FORTRAN (all the flavours)

SPoT - Stellar POpulations Tool

Enzo Brocato, Gabriella Raimondo, Michele Cantiello, Roberta Carini

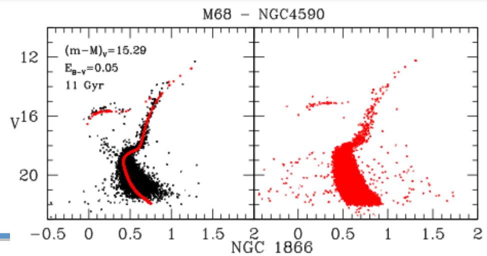
The SPoT code is devoted to compute Stellar Population Synthesis models to reproduce:

- ✧ Synthetic Color-Magnitude Diagram of globular clusters;
- ✧ Integrated Color Indices and their 1-sigma statistical uncertainties of extragalactic Star Clusters and Elliptical galaxies;
- ✧ Surface Brightness Fluctuations (SBF) amplitudes of stellar systems.
- ✧ Spectral energy distribution of Star Clusters and Elliptical galaxies;

Code features :

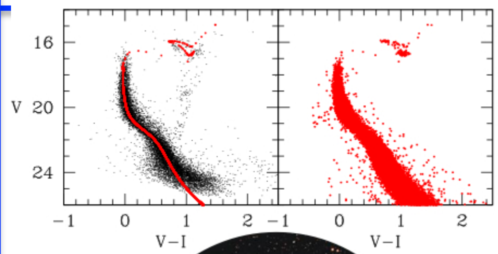
- ➢ Fortran 90 code developed in INAF by authors
- ➢ Monte Carlo simulations
- ➢ Simulated stars: 10^2 - 10^7 => stellar clusters
  10^8 - 10^{12} => galaxies
- ➢ Age range of the simulated stellar populations:
  few Myrs => 15 Gyrs
- ➢ Abundances of chemical elements:
  from < 1/100 Sun to 2 times solar abundances
- ➢ Stellar evolution models: ATON (OARoma) and BASTI (OATeramo)
- ➢ Initial Mass Functions: Scalo, Kroupa, Salpeter etc
- ➢ Stellar mass range : 0.4 Mo => 120 Mo

Contact (OAR): enzo.brocato@oa-roma.inaf.it

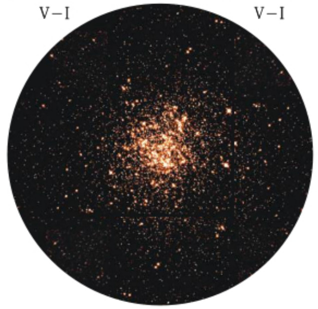


Color-Magnitude Diagram
Old globular cluster
T ~ 11 Gyr

• Data
• Simulation

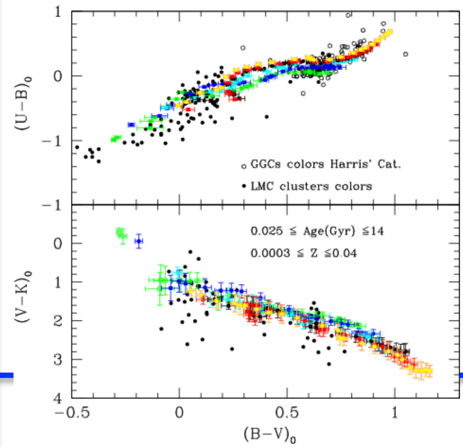


Color-Magnitude Diagram
Young cluster
T ~ 100 Myr



NGC 1866
a young star cluster of the Large Magellanic Clouds

Integrated Colors & Magnitudes



Simulation of Integrated colors of different age and abundances compared to data Of Galactic and extragalactic stellar clusters

Software for Data Analysis and Interpretation I - Overview

- Three main software categories:
  - Core functions / core programs
  - Pipelines and process control
  - Data Interpretation
- Core functions: ROMAFOT, CONVPHOT, GAIA, EUCLID, CTA, HE-Space Missions (AGILE, FERMI, …), SuperResolution
- Pipelines: LBC Image reduction, EUCLID, preprocess, AQuA, XRONOS, LBTI, HE-Space Missions
- Interpretation (bridge to theory): Genetic algorithms, ZPHOT, Pop. Synthesis, Transients Search

Software for Data Analysis II
Some Examples

- ROMAFOT (I. Ferraro, G. Iannicola)
- PreProcess (A. Di Paola)
- LBC Pipeline (D. Paris, S. Gallozzi)
- GAIA (M. Castellani, L. Pulone)
- CTA/ASTRI (S. Lombardi, D. Bastieri [PD])
- EUCLID (A. Grazian, A.Bonchi)
- Space Missions (with ASI-ASDC): SWIFT, NuSTAR, AGILE, … (M.Perri, L.A.Antonelli)

ROMAFOT
(Stellar Photometry Package)

- Developed in the early '80s after advent of PDP 11 , written in FORTRAN
- Reconstruction of PSF profiles of stars and 2-D fit of group of objects, based on Levenberg-Marqwardt method
- Recently improved to deal with AO imaging with variable PSF

Classic symmetric PSF Moffat formula

PSF=f(H,x0,y0,σ,β,x,y)

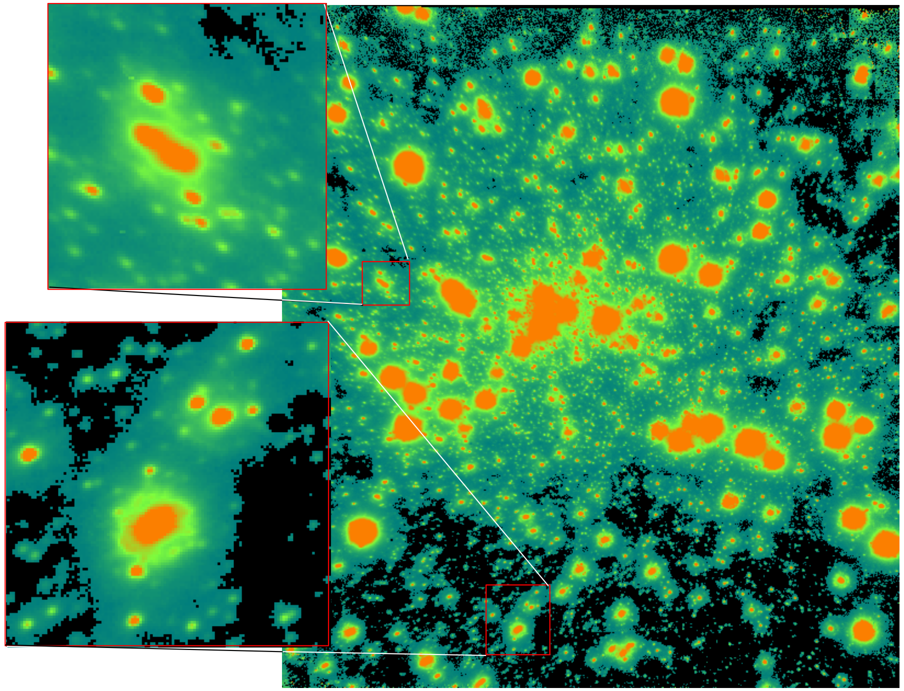
$$h*\left(1+\frac{((x-x0)^2+(y-y0)^2)}{\sigma^2}\right)^{(-\beta)}$$

New asimmetric PSF formula

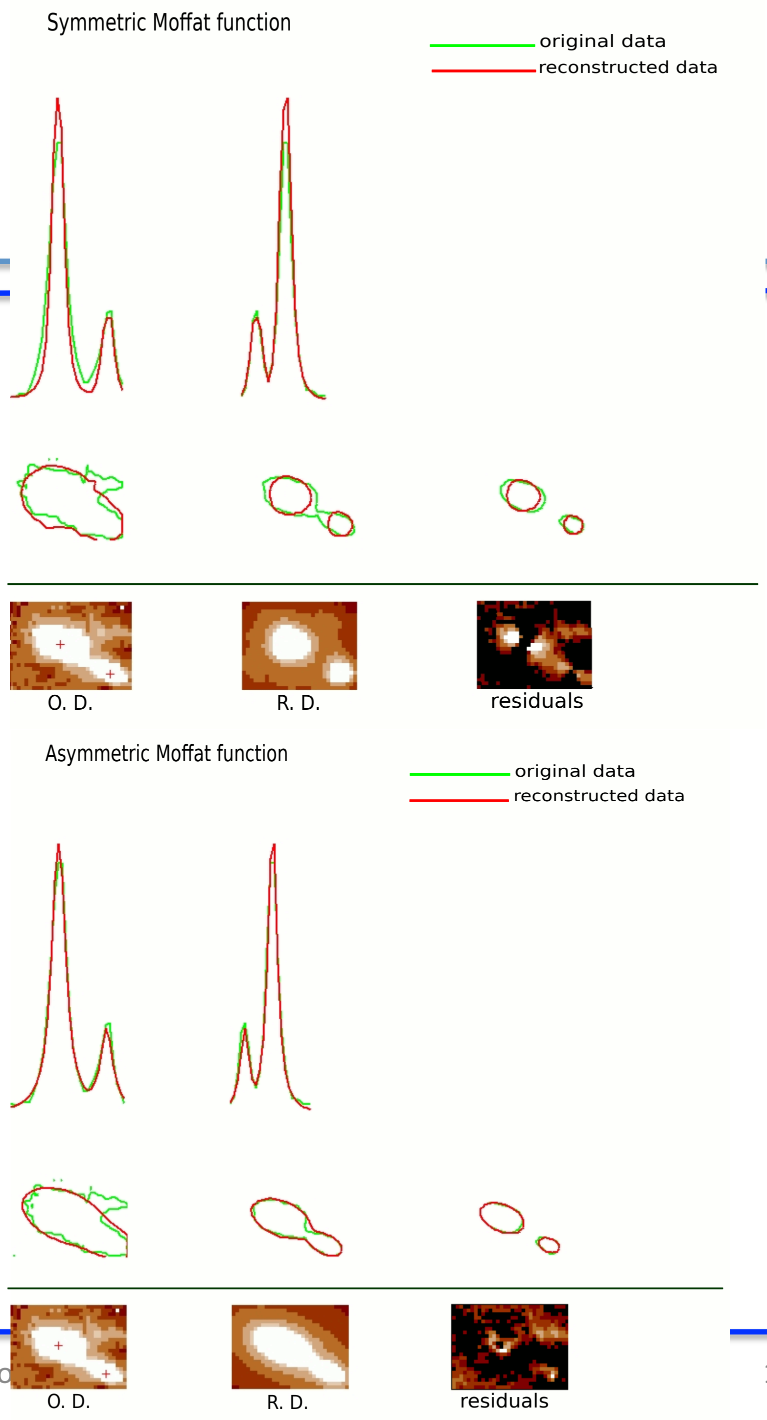
PSF=f(H,x0,y0,a,b,θ,c,β,x,y)

$$h*\left(1+\frac{((x-x0)\cos(\theta)+(y-y0)\sin(\theta))^2}{a^2}+\frac{((y-y0)\cos(\theta)+(x-x0)\sin(\theta))^2\cdot(c*((x-x0)\cos(\theta)+(y-y0)*\sin(\theta)))^2}{b^2}\right)^{(-\beta)}$$

M15 J band

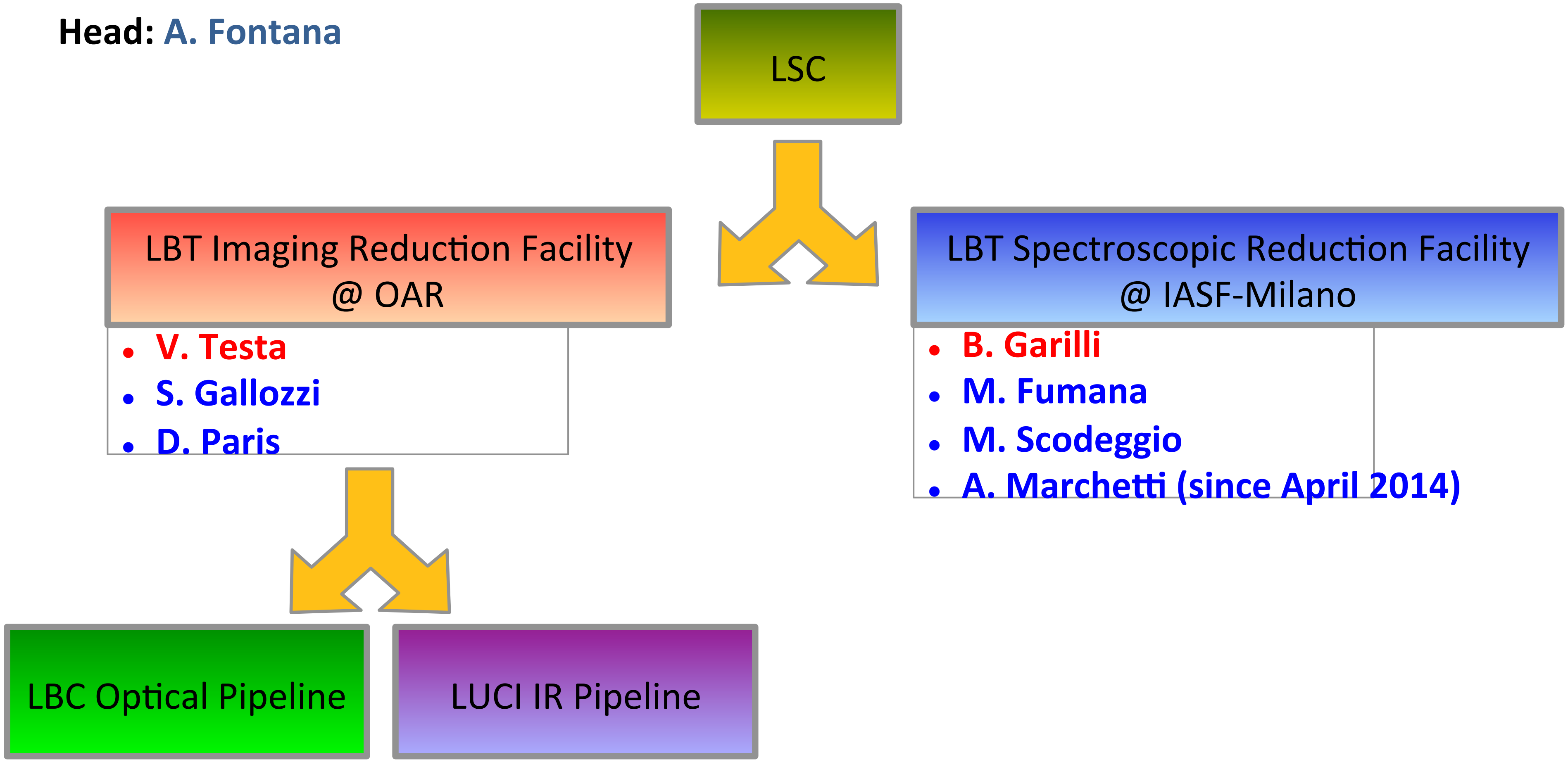


PISCES - LBT camera



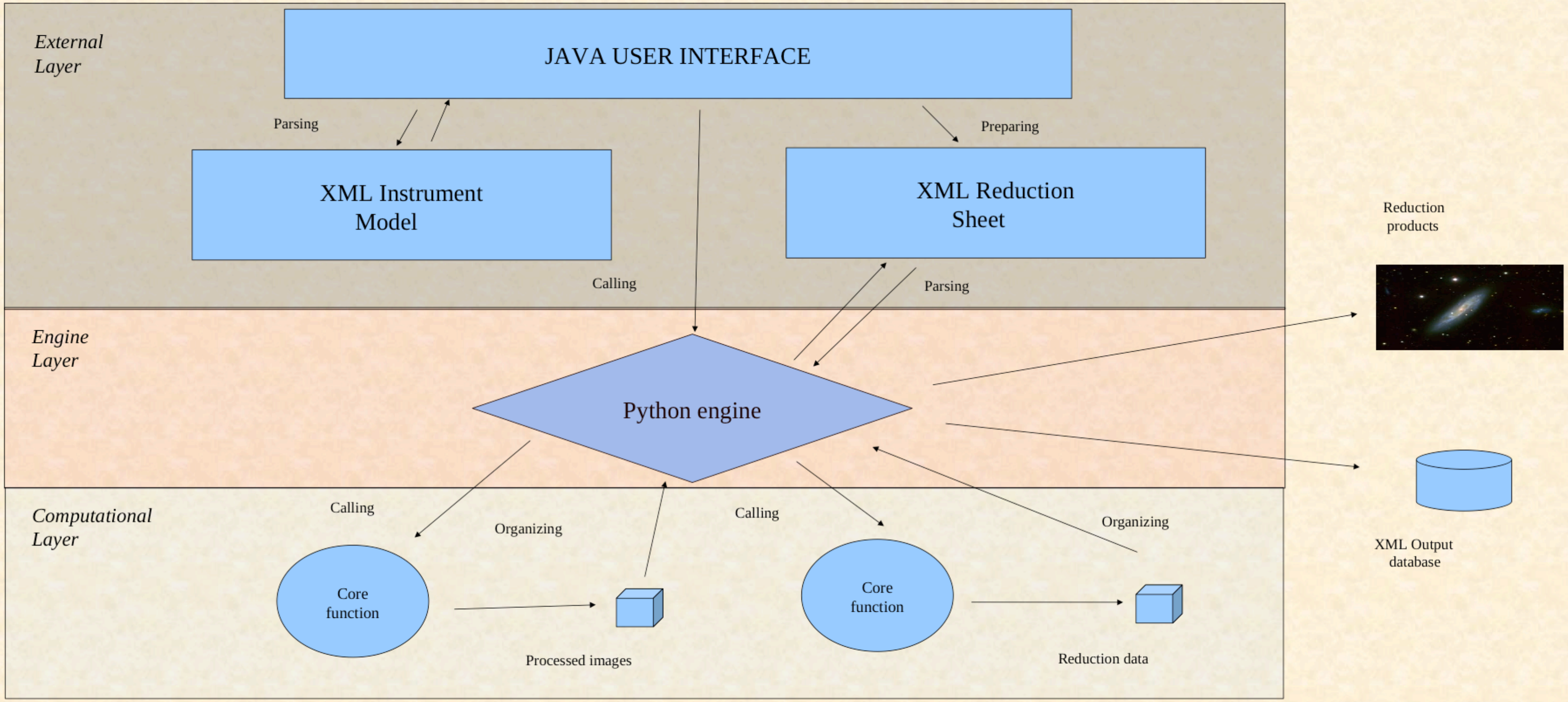
LBT Italian Coordination Facility
SERVICE DATA REDUCTION

Head: **A. Fontana**



Pipeline architecture

S. Gallozzi, D. Paris



Scheme of three-layer Pipeline architecture

IMAGING PIPELINE PERFORMANCE

- **<u>Input 5 Uspec RAW lbcb images,</u>**
- make masterflat ~565 sec / make masterbias ~120 sec
- crosstalk correction + standard prereduction ~75 sec
- trails mask ~460 sec
- area correction ~50 sec
- object masking ~115 sec
- build and apply superflat ~475sec
- sky evaluation and subtraction ~ 405 sec
- chip equalization ~70 sec
- cosmic rays mask ~1465 sec
- background subtraction (sextractor ~135 sec / constant ~70 sec)
- photometry correction ~15 sec
- chip extraction ~20 sec
- astrometry minimization ~110 sec
- resampling & coadd ~155 sec
- Build r.m.s./weight and exposure maps ~1010 sec

IMAGING PIPELINE PERFORMANCE

- total elapsed time ~ 4500 sec ~1.26 hours
- input files size:
- ~400MB (LBC RAW science frames) + ~600MB (MASTER CALIBS)
- output files size:
- ~1.2GB final (+ ~42GB intermediate files to be removed)
- GNU-parallel "embarassing parallelization" – serial parallelization, factor ~8 gain

Scientific Software for the ASTRI Project

Contacts: S. Lombardi, F. Lucarelli (INAF-OAR @ ASI-ASDC),
D. Bastieri (Univ. PD & INFN)

- ASTRI is the Flagship Project of INAF devoted to the development of Cherenkov small-size dual-mirror telescopes in the CTA framework

- ASTRI consists of two sub-projects:
  - Prototype Schwarz-Couder **SST-2M** and **SiPM camera** to be installed from fall 2014 at Serra La Nave (INAF Observatory, Mt. Etna – Catania)
  - Mini-array of ~5 SST-2M installed at CTA south site

ASTRI Collaboration

Principal Investigator G. Pareschi

Co-PIs O. Catalano & S.Vercellone
Program Manager M. Fiorini
System Engineer L. Stringhetti
INAF/CTA Responsible P. Caraveo

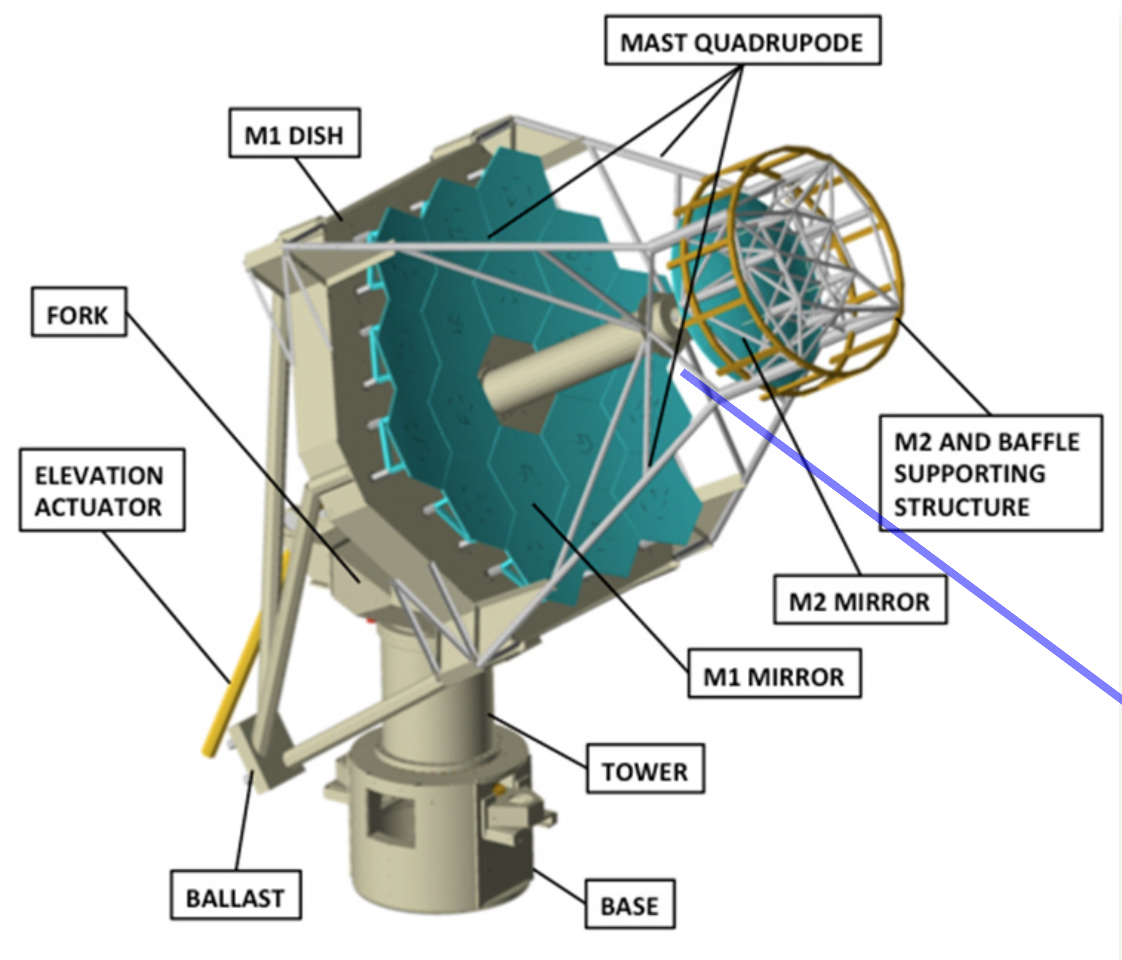
INAF Institutions

IASF Milano
IASF Bologna
IASF Palermo
INAF HQ Roma
OA Brera
OA Torino
OA Padova
OA Bologna
OA Arcetri
OA Roma / ASDC
OA Capodimonte
OA Catania

University Partners

Univ. of Padova
Univ.. of Perugia

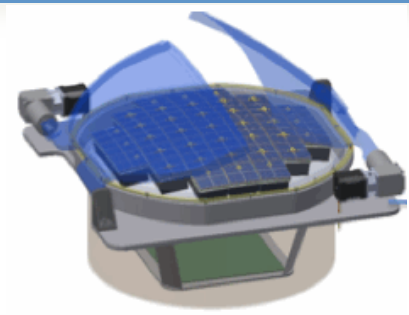
ASTRI-SST-2M main features



ASTRI SST-2M concept:

Dual mirror (Schwarschild-Couder)
- Primary Mirror: 4.3m⦸
- Secondary Mirror: 1.8m⦸
- Large FoV (9.6°)

SiPM camera
- light (~50 kg)
- compact (~50x50x50 cm^3)
- 2000 pixel



ASTRI SiPM CAMERA

ASTRI Scientific Software Specifications

ASTRI Scientific Software for Data Reduction and Analysis shall:

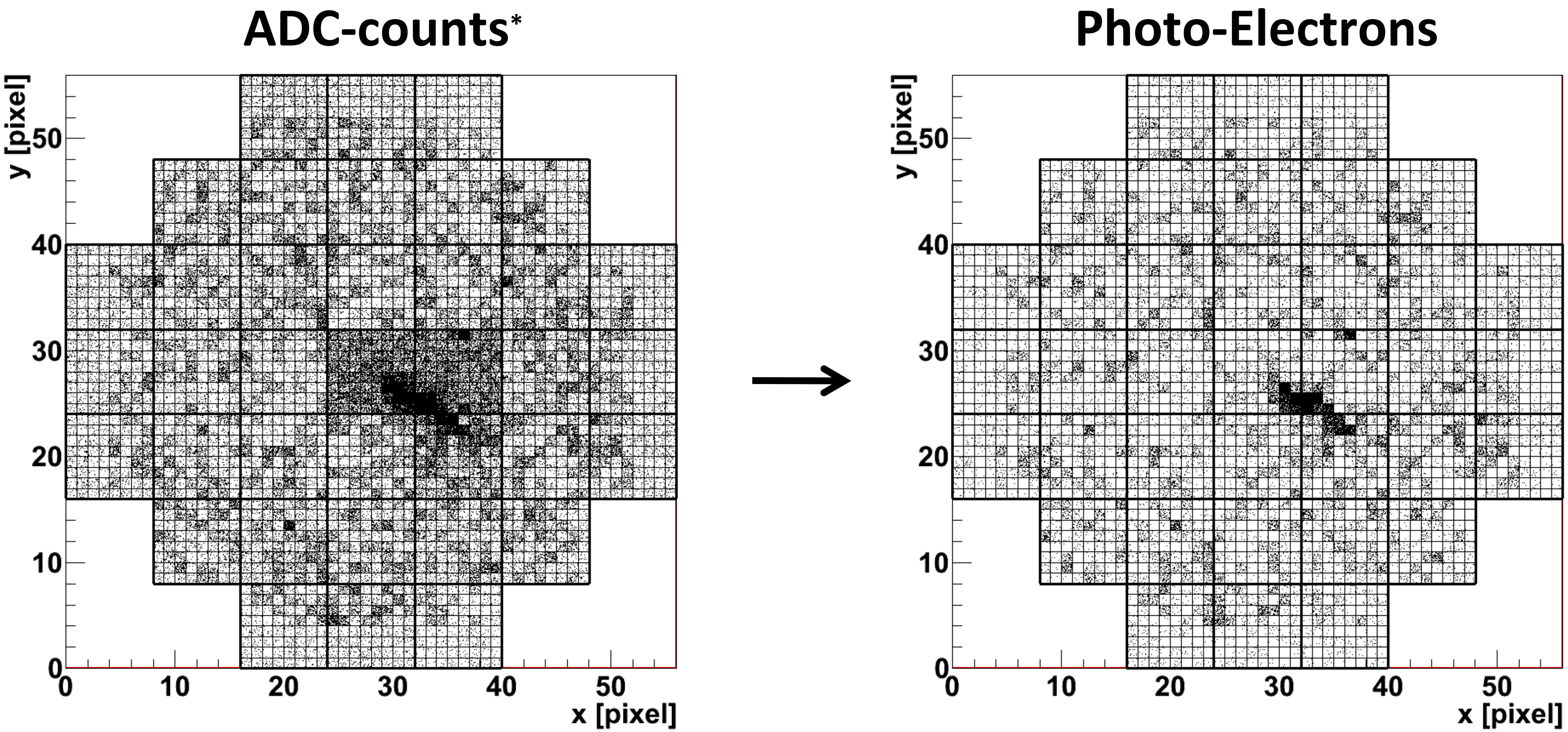
- Manage FITS data (L0-FITS formats for EVT0/CAL0/TECH0 defined) adopting CFITSIO libraries
- Be written in C(++) (Unix environment) / CUDA (for GPU coding*)
- Be developed in independent software modules linked by efficient pipelines written in Python:
  - ✓ "***ASTRICALEXT/ASTRICAL***" (*SiPM*-camera CALIBRATION, **DL0 → DL1**)
  - ✓ "***ASTRICLEAN/ASTRIPAR***" (IMAGE CLEAN. and PAR., **DL1 → DL1b**)
  - ✓ "***ASTRIMER***" (MERGING MULTI-TELESCOPE-INFO, **DL1b → DL2**)
  - ✓ "***ASTRIREC***" (EVENT RECONSTRUCTION, **DL2 → DL3**)
  - ✓ "***ASTRISCI***" (SCIENCE TOOLS, possibly linked to CTOOLS, **DL3 → DL4**)

* The C version of the code will be ported in CUDA to perform parallel computing using both CPUs and GPUs

ASTRI Scientific Software Framework

- ***Standard C(++)*** (Unix environment) / ***CUDA*** (for GPU coding)
- Compiled with ***gcc***
- ***CFITSIO*** libraries
- ***Python*** wrappers for pipelines
- Documentation: ***DOXYGEN***
- Versioning: ***SVN/GIT***
- Code-Quality: ***SONAR***
- Deployment: ***SCONS***
- Maintaining: ***JENKINS***

ASTRI Scientific Software: CALIBRATION MODULE



* Int. charge, HG/LG, all pixels: ~10kB per event

ASTRI Scientific Software: next step...

Photo-Electrons

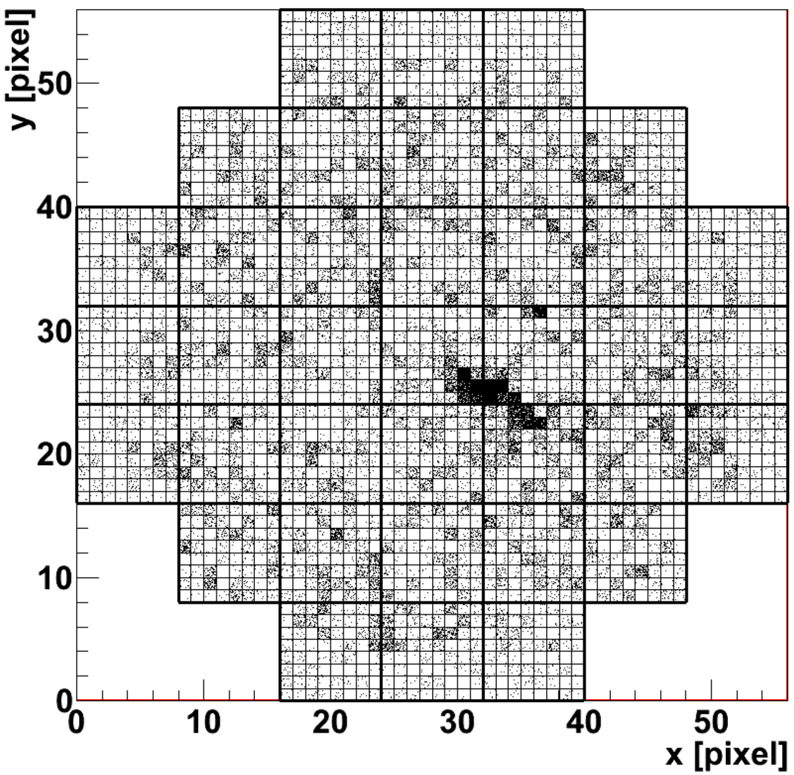


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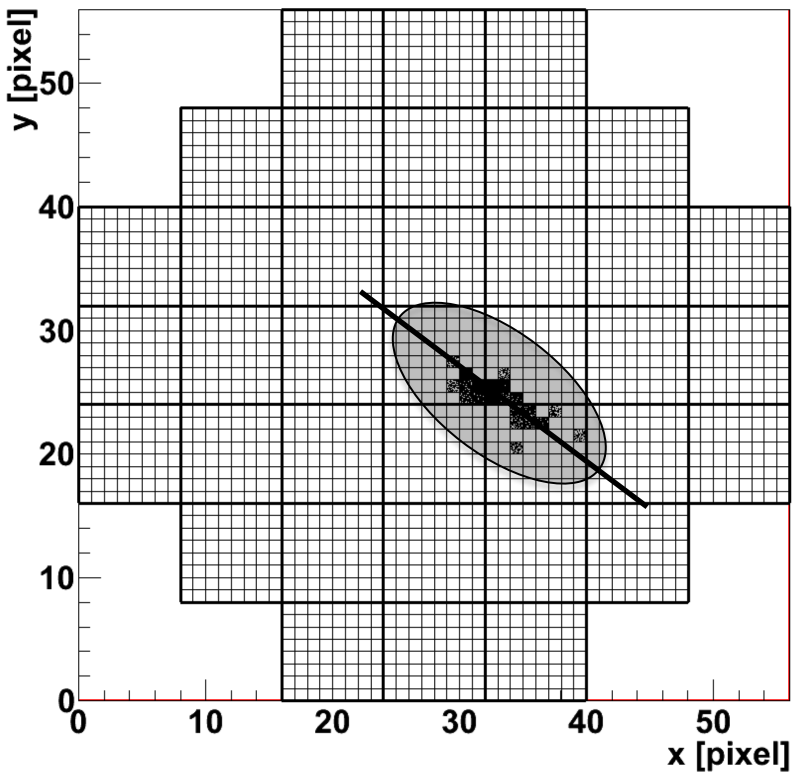
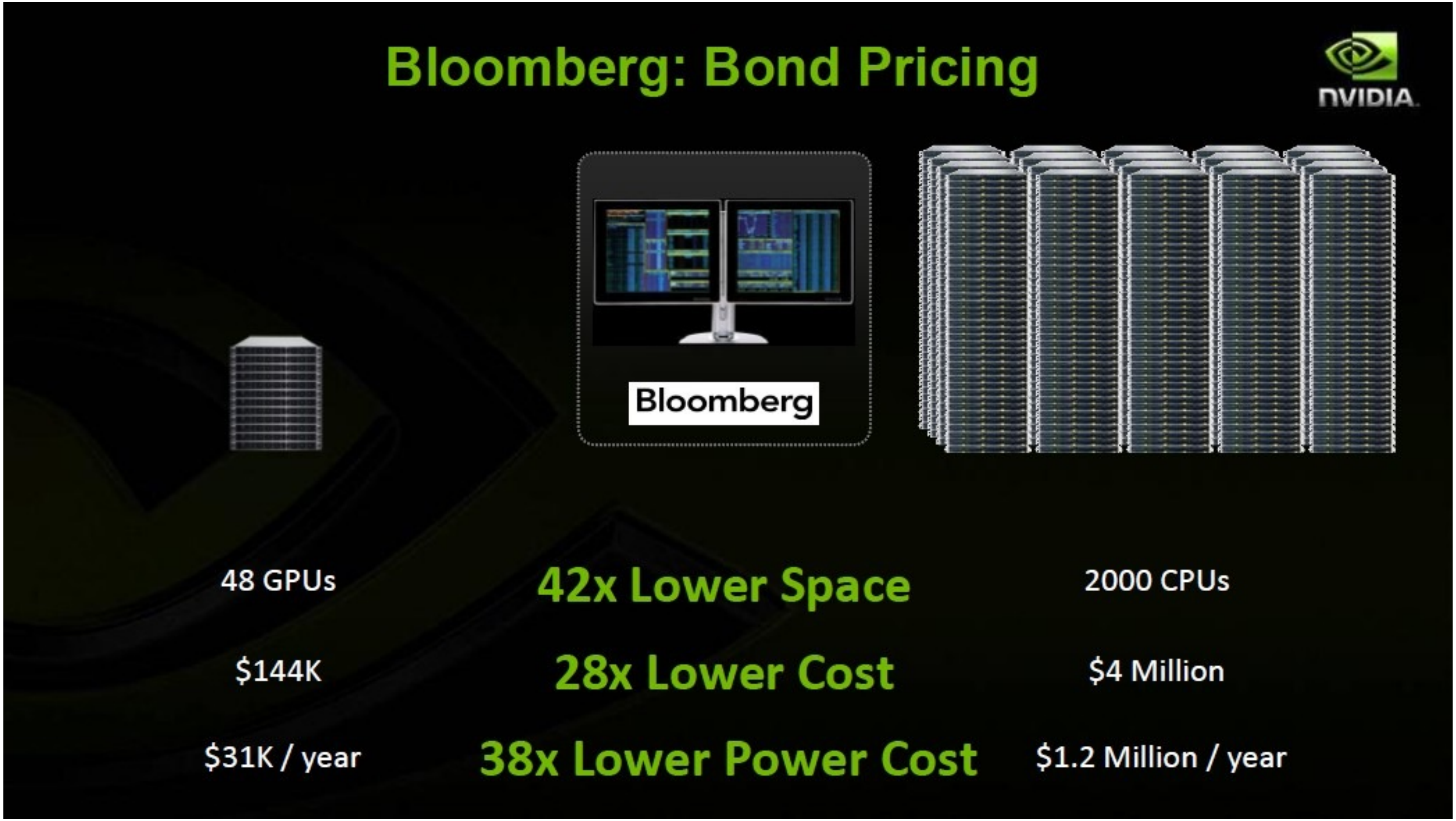
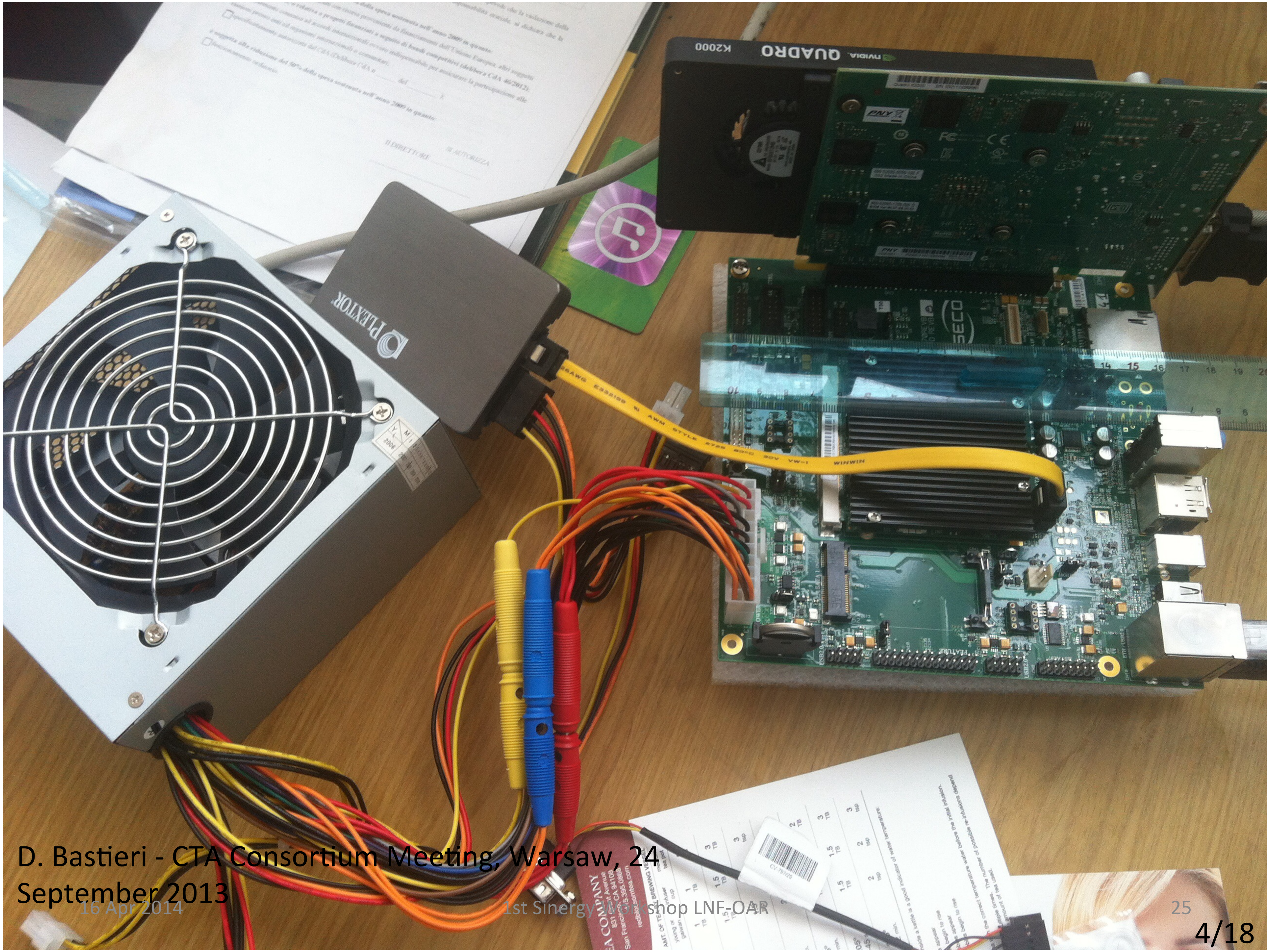
Image Parameters



Why GPUs ?



Bloomberg: Bond Pricing
NVIDIA
Bloomberg
48 GPUs
42x Lower Space
2000 CPUs
$144K
28x Lower Cost
$4 Million
$31K / year
38x Lower Power Cost
$1.2 Million / year



D. Bastieri - CTA Consortium Meeting, Warsaw, 24 September 2013

Data Crunching: recipe from OAR

1) Evaluate pedestal offsets from 2k random events
2) Real data input (2GB = 50 s on MAGIC II @200Hz)
3) Pedestal subtraction
4) signal integration via *sliding window* (short[] -> int)
5) ADC counts (int) -> (× calibration) -> phe (float)
6) phe sorting/clustering/cleaning
7) evaluation of first 10 momenta
8) data output

Courtesy D. Bastieri - CTA Consortium Meeting, Warsaw, 24 September 2013

L.A. Antonelli, S. Buson, D. Gasparrini, S. Lombardi, F. Lucarelli & G. Pivato

Input/Output

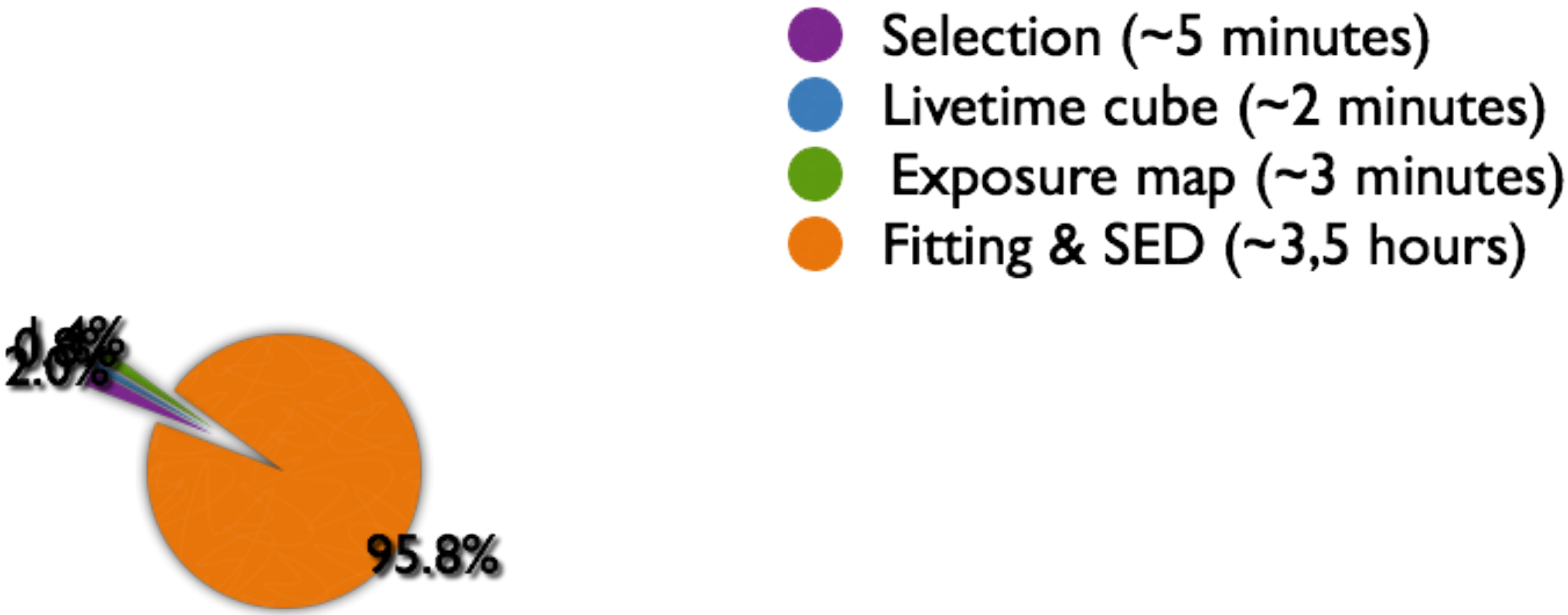
Data stored in a SSD, connected via SATA

Tests from July 9th to Sept. 10th ≈ 60 days

for a 2GB chunk	*Input*	*Output*	*Input &Output*
<time> in s	***15 s***	***15 s***	***35÷45 s***

Sustained data transfer rate: 1 Gb/s

Computational Cost



from 3 days to **4 hours** per source for ~5 years worth of data

New Pipeline · NVIDIA S2050 · 3 GB RAM

Software for GAIA Mission

ESA only mission

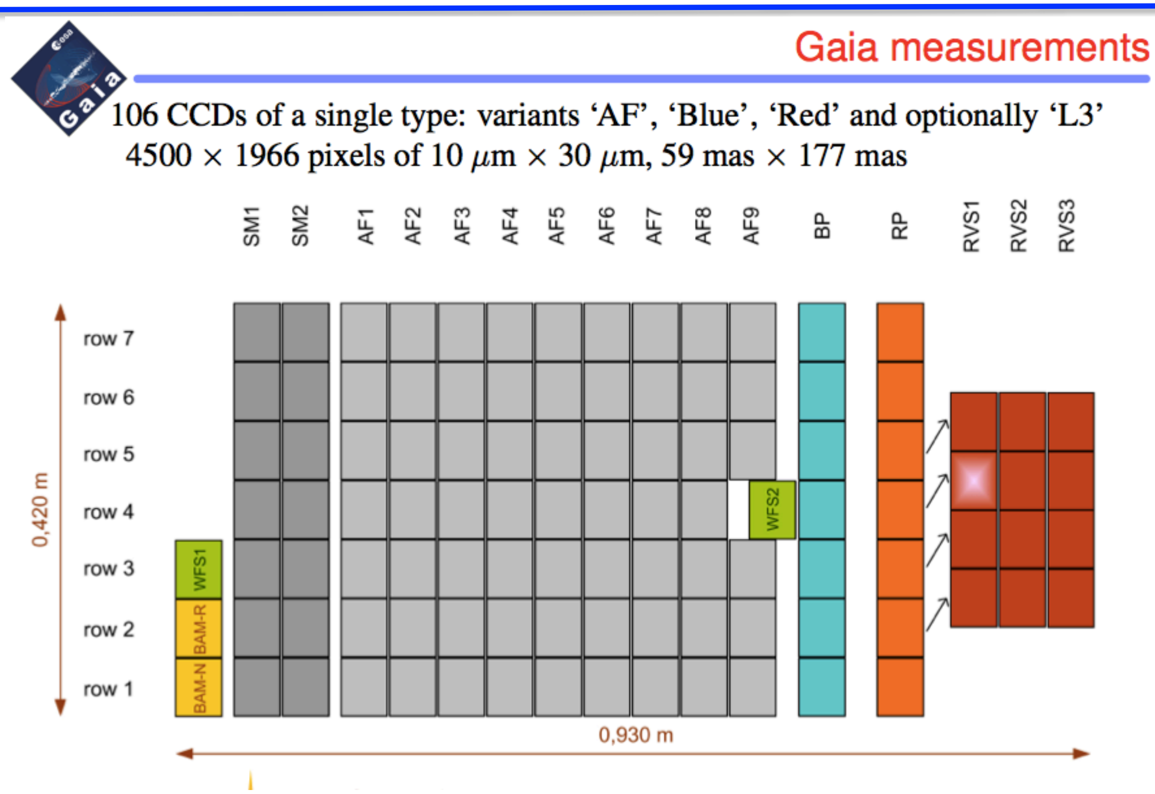
Launch date: February 2014

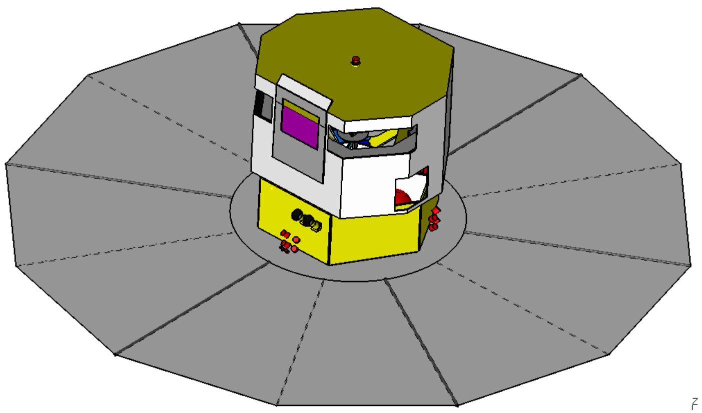
Lifetime: 5 years

Launcher: FREGAT

Orbit: L2

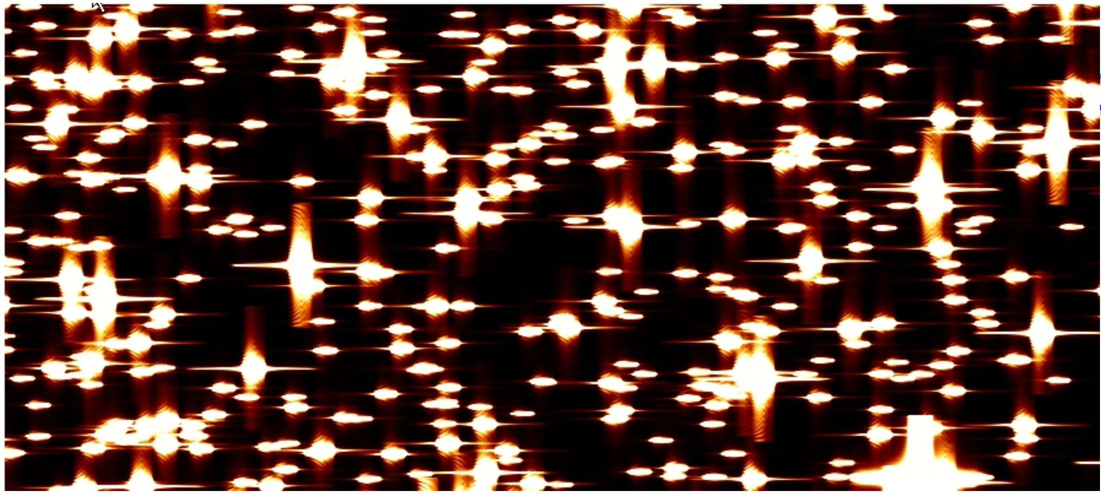
Data rate: 1 Mbps



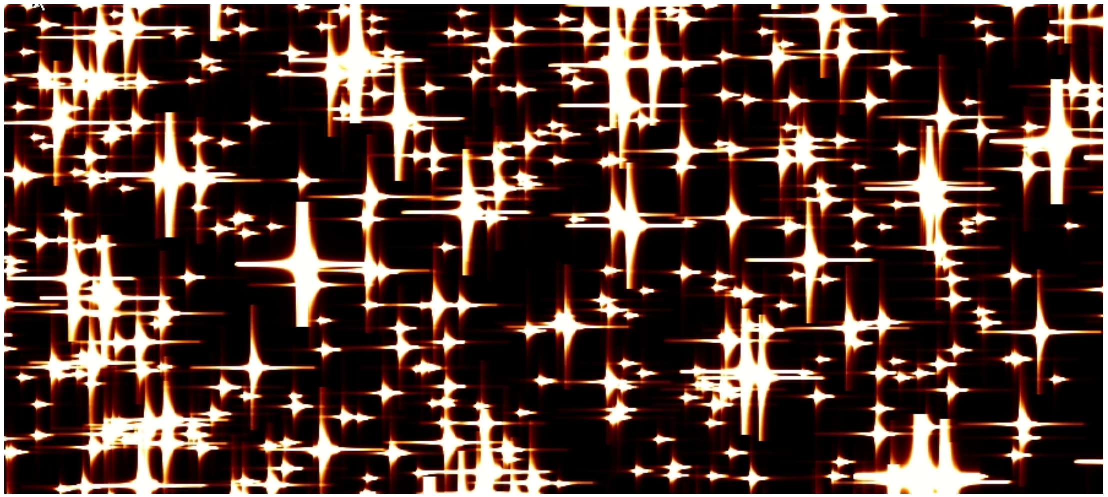


Contact: L. Pulone

GAIA – Simulations of crowded field as observed by GAIA spectrophotometers



Red channel



Blue channel

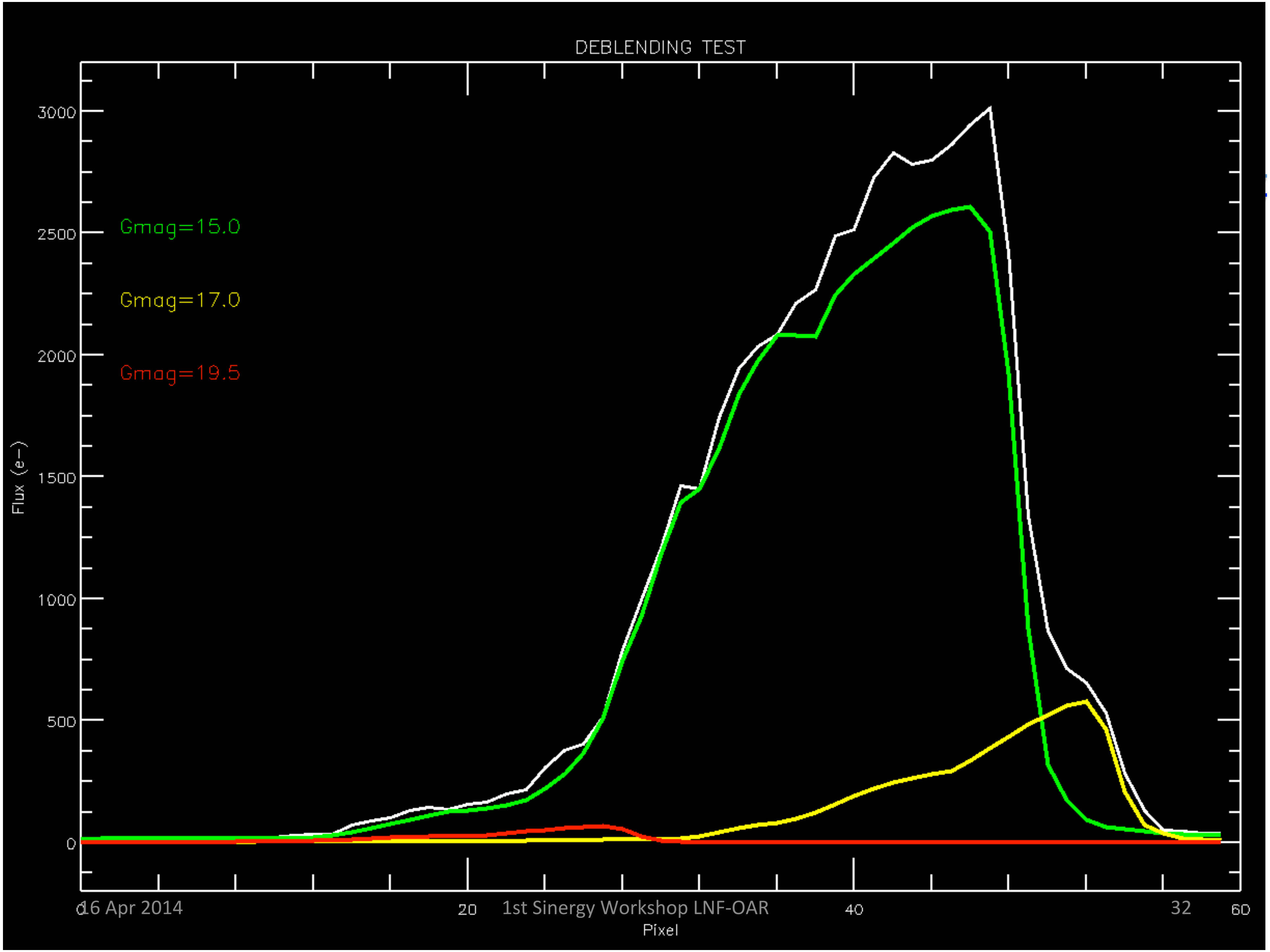
Rome group

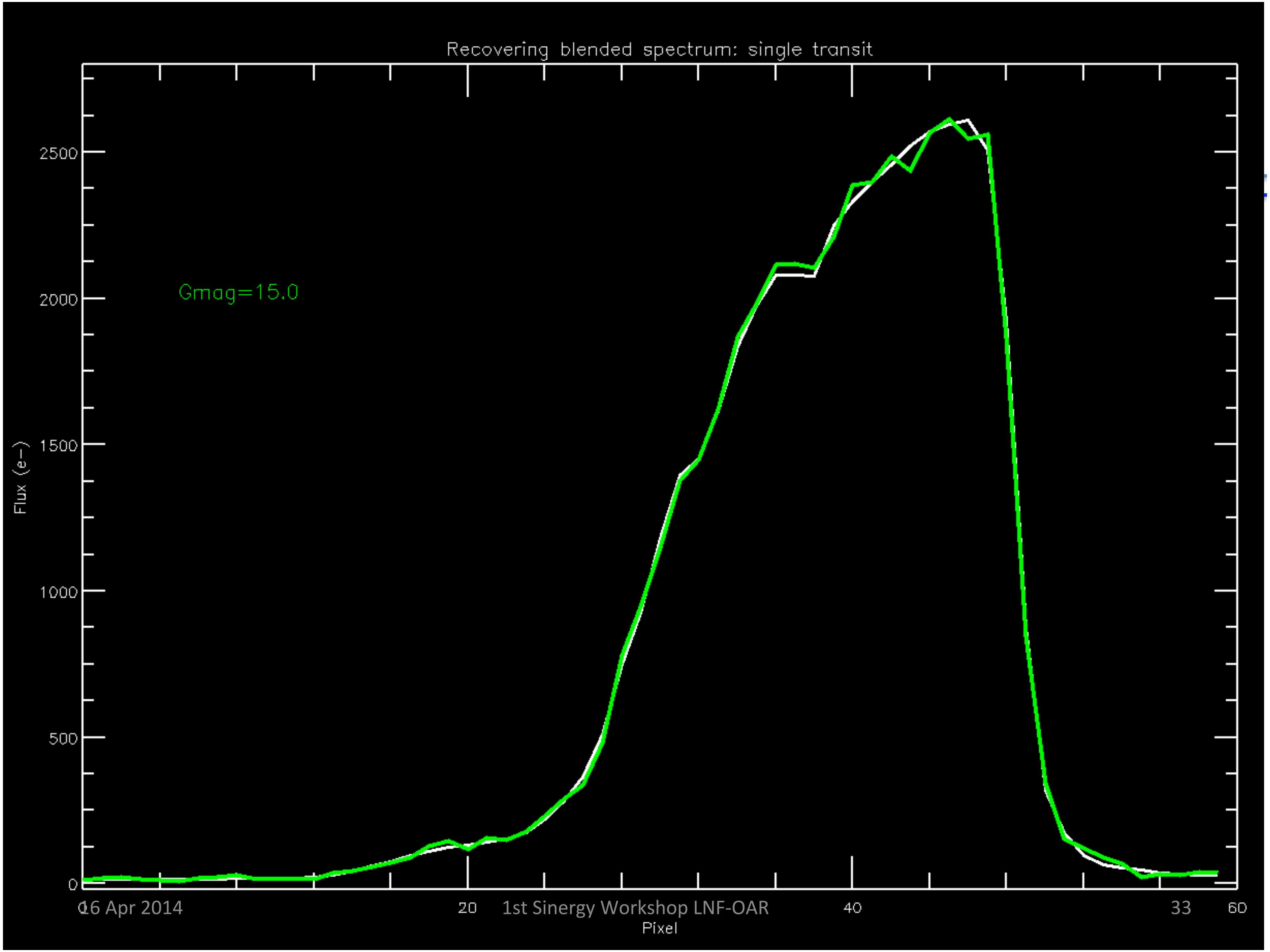
Deblending of connected groups due to:

- Overlapping of spectra of different sources in connected windows
- Objects in nearby windows whose spectra extend into the program window
- Objects for which the on-board detection software has not assigned a window
- Barely detectable sources beyond the survey magnitude limit (20 < G < 22).

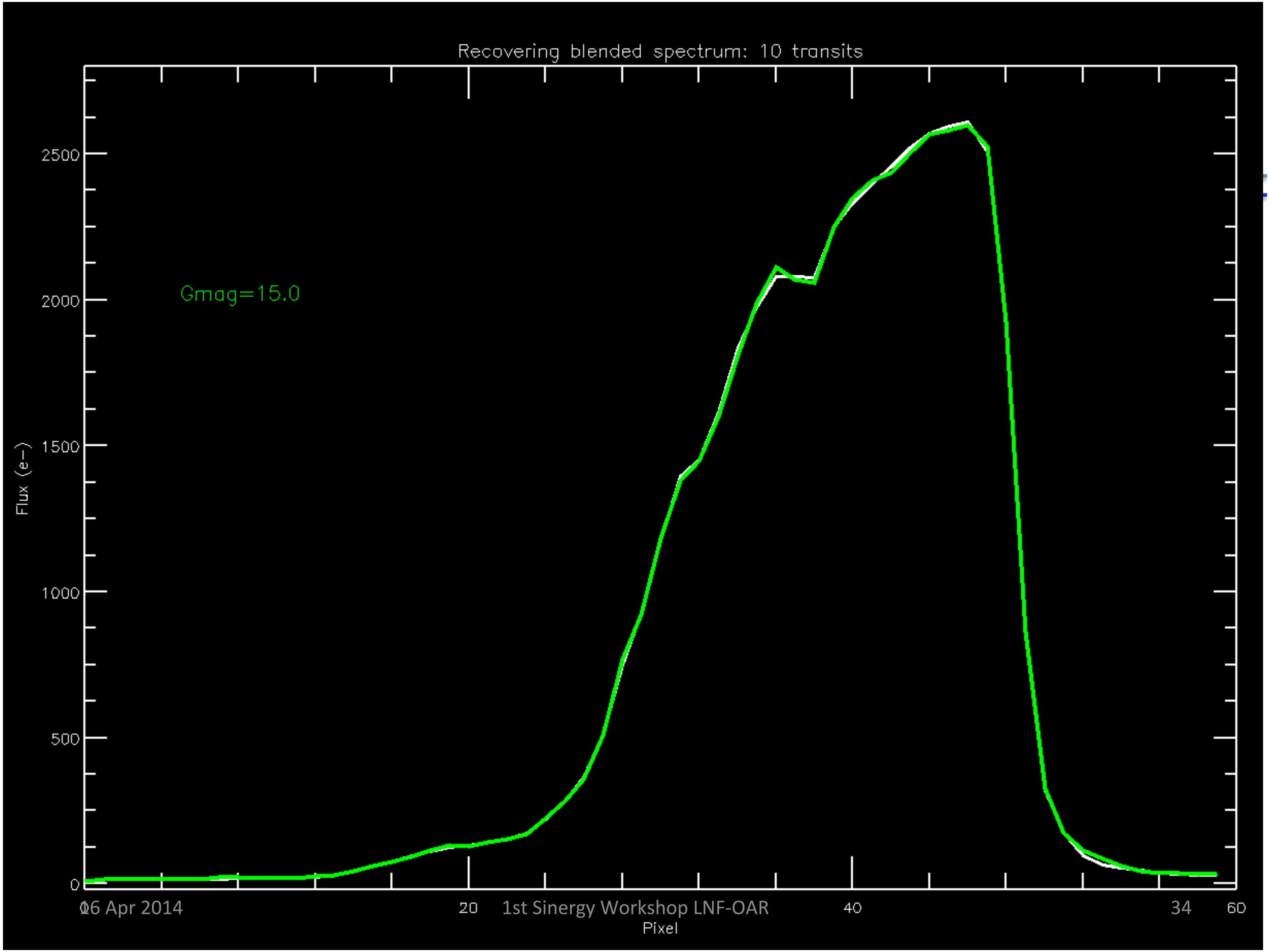
- Data analysis completely performed on-board
- Language: Java

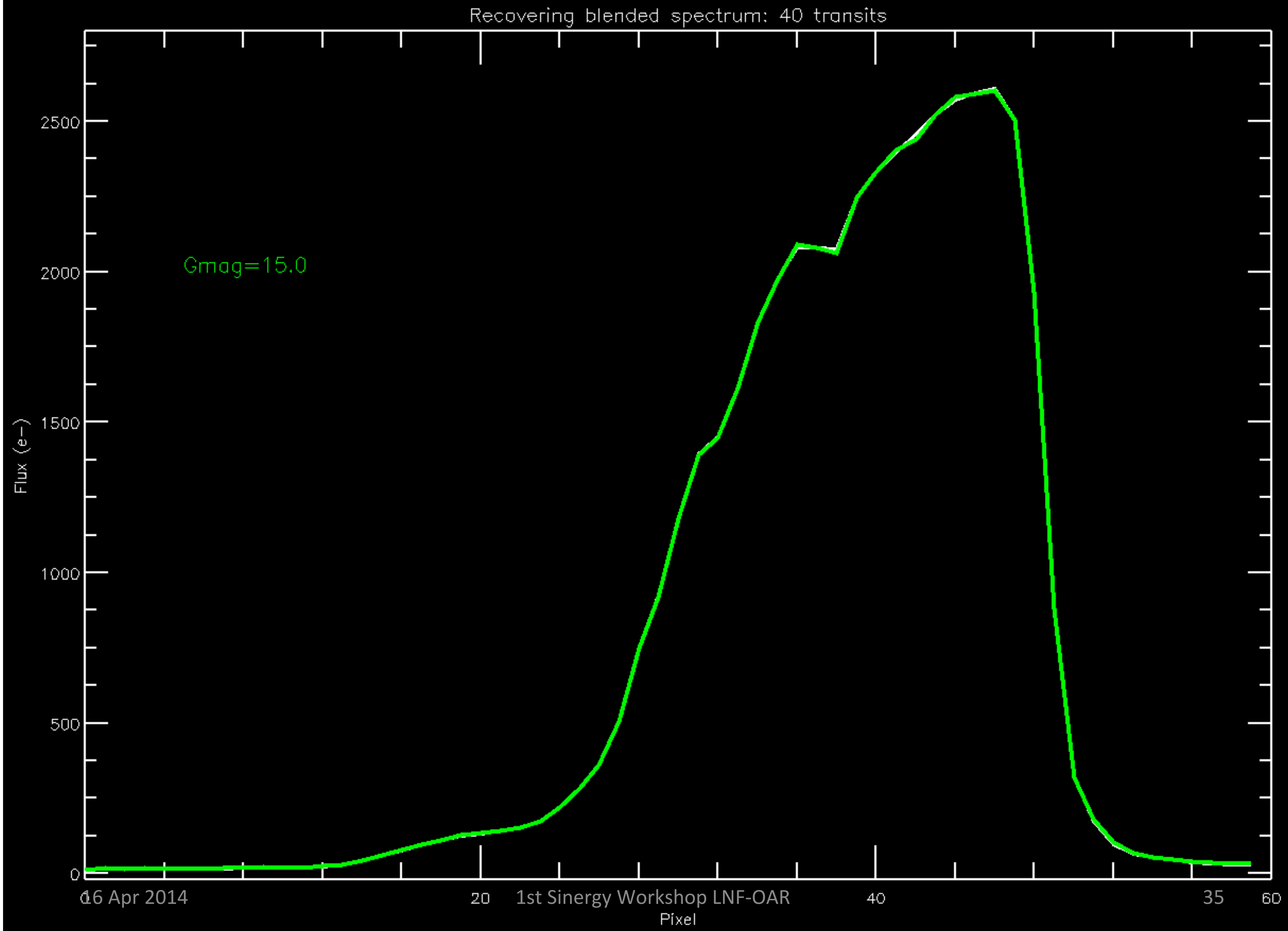
ASI-ASDC: Paola Marrese, Giuliano Giuffrida, Silvia Marinoni
INAF-OAR: Marco Castellani, Giacinto Iannicola, Luigi Pulone
Univ. Roma2: Roberto Buonanno, Giuseppe Bono


DEBLENDING TEST
Gmag=15.0
Gmag=17.0
Gmag=19.5
Flux (e−)
3000
2500
2000
1500
1000
500
0
0
20
40
60
Pixel



Recovering blended spectrum: single transit
Gmag=15.0
Flux (e−)
0
500
1000
1500
2000
2500
0
20
40
60
Pixel


Recovering blended spectrum: 10 transits
Gmag=15.0
Flux (e−)
0
500
1000
1500
2000
2500
0
20
40
60
Pixel

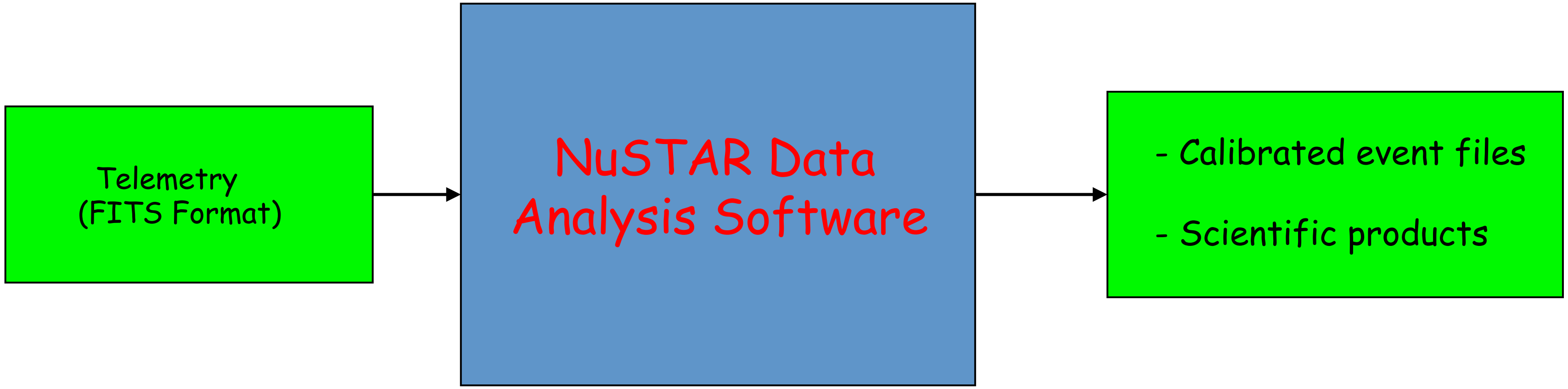

Recovering blended spectrum: 40 transits
Gmag=15.0
Flux (e−)
0
500
1000
1500
2000
2500
0
20
40
60
Pixel

Software for HE space based mission: NuStar

Contact: M. Perri (INAF-OAR @ ASI-ASDC)

NuSTAR Data Analysis Software (NuSTARDAS):

- software package for the generation of cleaned and calibrated event list files and of standard high-level scientific products from FITS formatted telemetry data



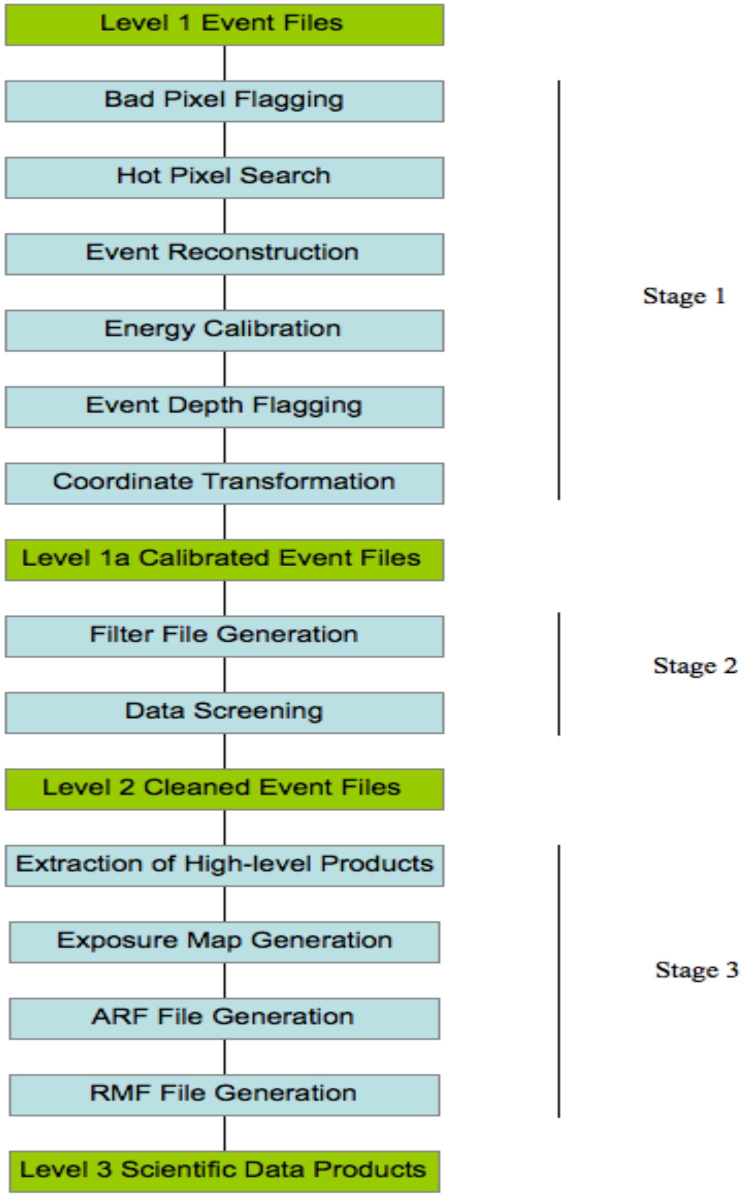
- composed by a set set of software modules, each dedicated to a specific task, + main script, the NuSTAR pipeline which runs in sequence all the tasks.
- developed at the ASI Science Data Center (ASDC, Italy)

NuSTARDAS software characteristics

- Developed under HEASoft package environment
  - sharing main libraries, makefiles + use of existing multi-mission tools
- Use FITS data formats as input and output (following the NASA-OGIP standards) and of standard Parameters Interface Library (PIL) and FITSIO library (FTOOLS like)
- Exclusive use of open source software (e.g. C and Perl) + designed to run on most UNIX platforms (Linux, Mac OS X)
- Calibration files retrieval via HEASARC's calibration database (CALDB) system
- Level 2 and Level 3 data files compatible with popular high-energy astronomy data analysis packages (e.g. XSELECT for data products extraction; XIMAGE, XSPEC, XRONOS for data analysis)
- Designed to allow users to re-process Level 1/Level 2 data (e.g. changes in the calibration files and/or in the software, use of non-standard data screening)

- The NuSTAR software is built reusing/adapting existing software as much as practicable
- Code adaptation improves reliability and significantly cuts development costs and risks
- Code adaption mostly from the Swift X-Ray Telescope (XRT) Data Analysis Sofware (XRTDAS), a software package for the Swift-XRT scientific data reduction designed and developed under the responsibility of the ASI Science Data Center
- Multi-mission software (e.g. FTOOLS) were used without modifications

NuSTARDAS data flow



1. Data Calibration

2. Data Screening

3. Products extraction

EUCLID OU-NIR SOFTWARE

- GOAL: Image Analysis from RAW level to STACKING level
- Pipeline development with a Python/C++ scheme used in other big projects (HST, Planck, see also LBC Pipeline)
- GUIs in python
- At the moment OAR aims at building the prototype to be engineered somewhere else (ASDC?)
- Contact people: A. Grazian, A. Bonchi

Databases and Archives

- Actual DBs/Archives:
  - Solar Archive (I. Ermolli, F. Giorgi)
  - LBT Science Archive (S. Gallozzi)
  - Campo Imperatore (A3 archive system – A. Di Paola)
  - other smaller ones, often for restricted use
- Multimission archive @ASI-ASDC strong link with ASI, Univ. ToV, IAPS (M. Perri, L.A. Antonelli)
- Projects for large archives: CTA, EUCLID, EST
- New infrastructure and paradigm (i.e.: non-relational DBMS)

Technology oriented software: Simulators and Controllers

- Hardware controllers: LBC Controller , Universal CANBus (F. Pedichini), IR camera controller (F. D'Alessio)
- Process controllers: AQuA (V. Testa), LBC Control Software, ASTRI/CTA DHS (A. Di Paola)
- Simulators for new instrumentation: MOONS (fiber spectrograph, G. Li Causi), SHARK (adaptive optics camera and coronograph, E. Giallongo), Optical Interferometry (LINC-NIRVANA, S. Antoniucci)

VIRTUAL MOONS

the MOONS focal plane simulator

Contact: G. Li Causi

ZEMAX → ***PSF***

Zemax Drawing → **VIRTUAL MOONS** ← ***PSF***

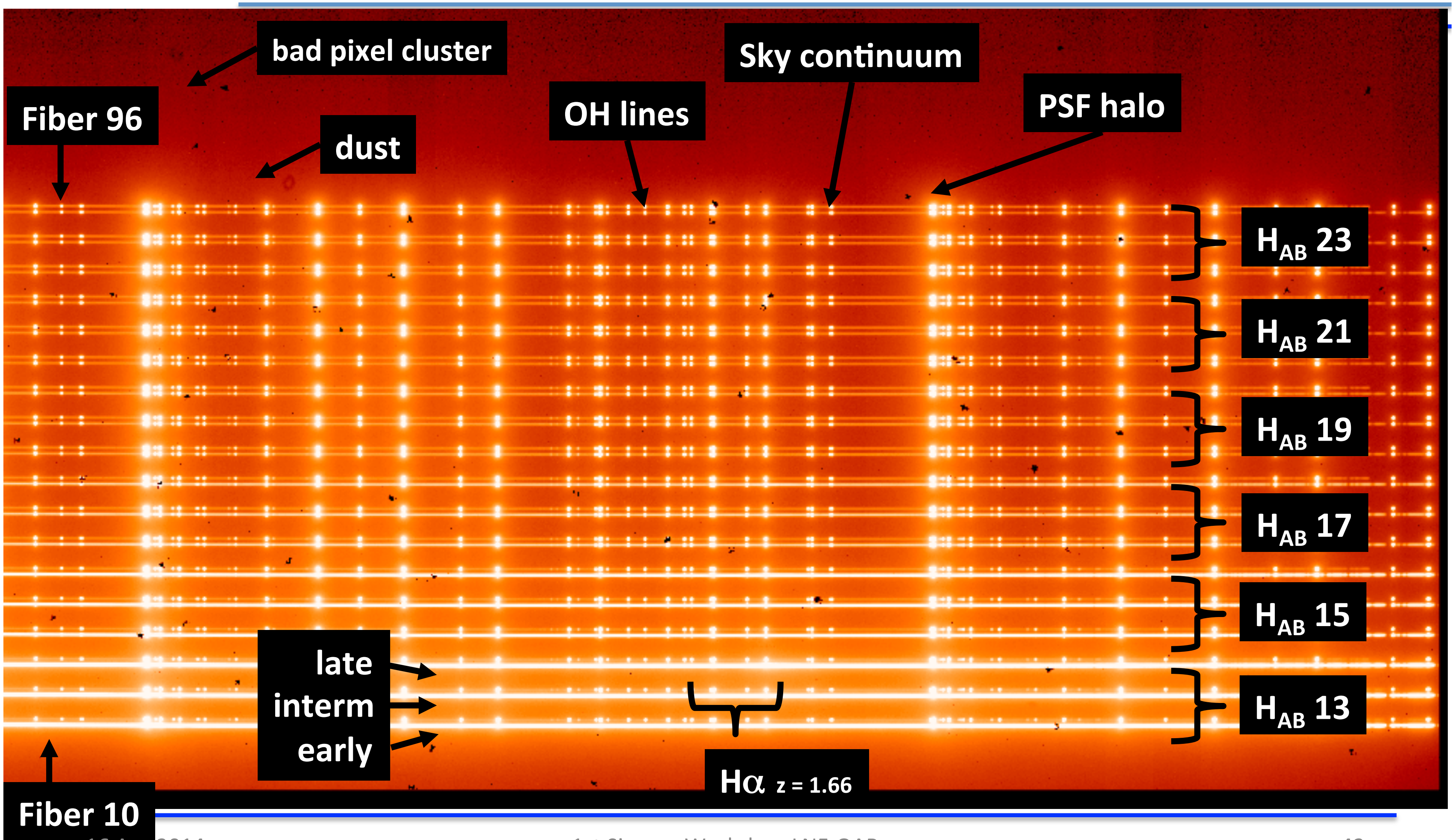
VIRTUAL MOONS → **ZEMAX**

VIRTUAL MOONS → ***Simulated Image***

To do:

- extend to all spectrograph modes
- simulation of cosmic rays
- simulation of OH subtraction

- direct communication IDL – ZEMAX:


bad pixel cluster
Fiber 96
dust
OH lines
Sky continuum
PSF halo
H_{AB} 23
H_{AB} 21
H_{AB} 19
H_{AB} 17
H_{AB} 15
H_{AB} 13
late
interm
early
Hα z = 1.66
Fiber 10

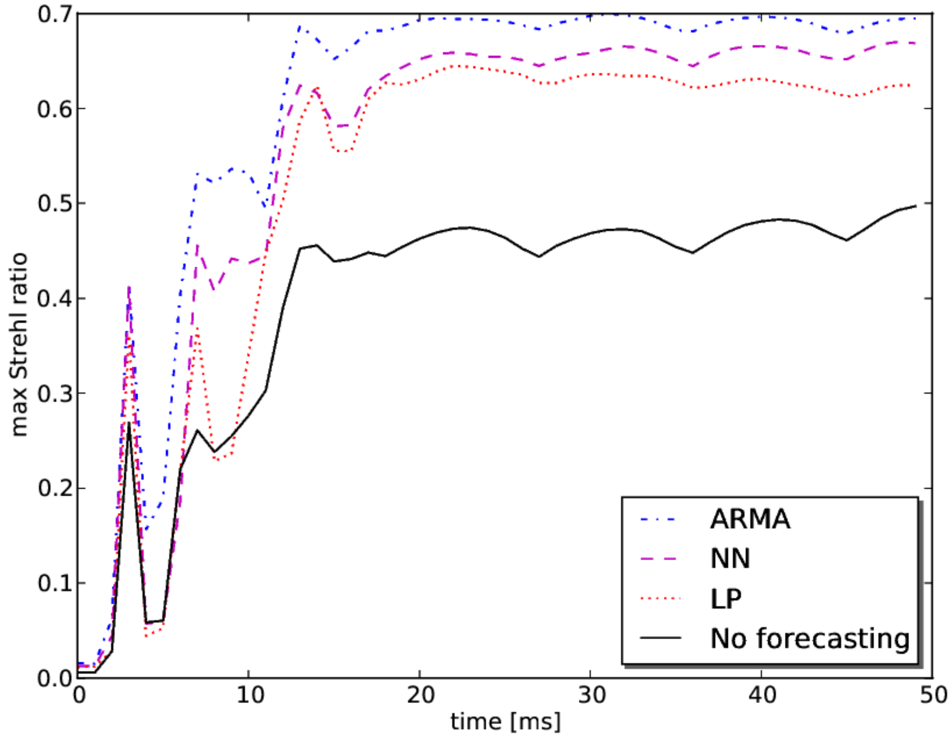
Prediction-based AO control

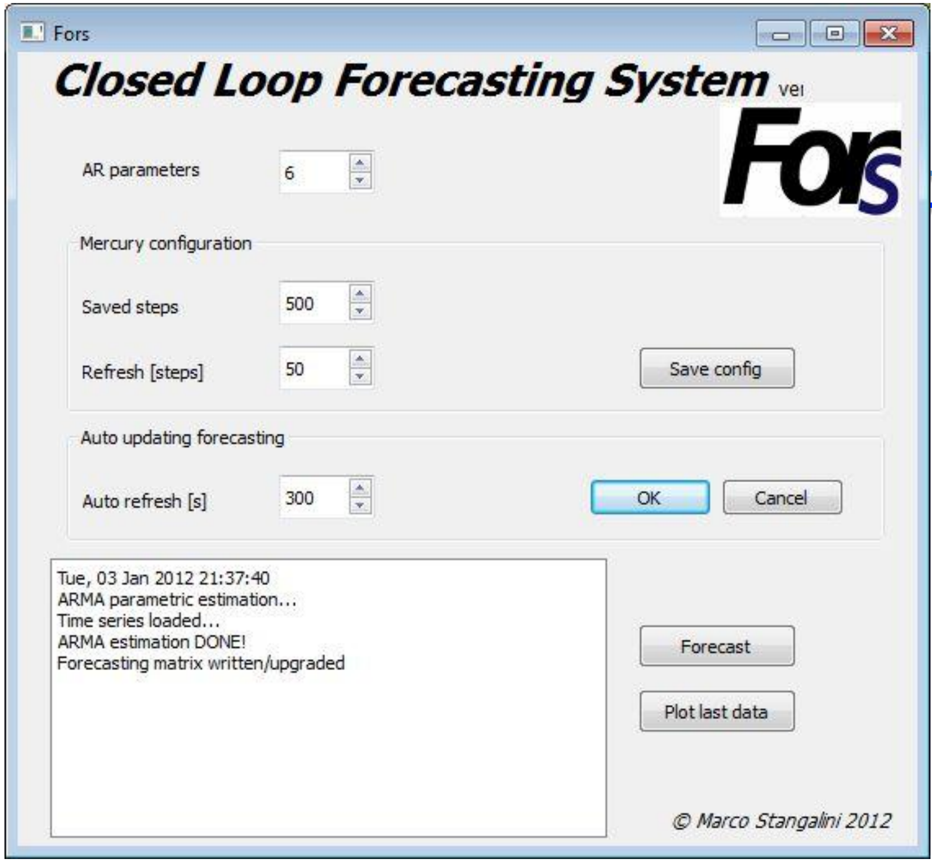
Contact: M. Stangalini, I. Ermolli, F. Pedichini

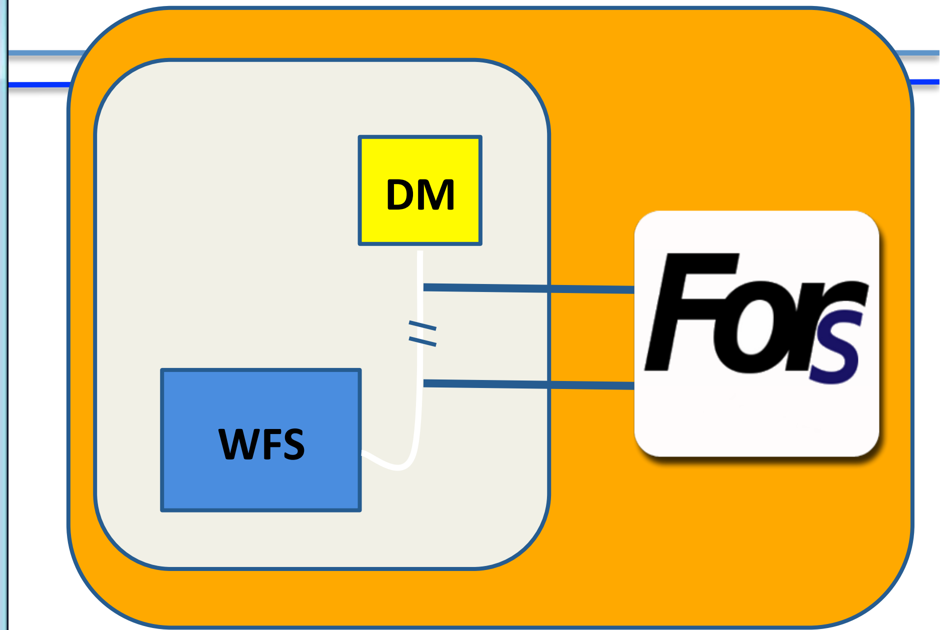
- Adaptive Optics systems are currently used in many solar and night-time telescopes to compensate for the effects of atmospheric turbulence
- One of the most important problems in solar adaptive optics systems is time lag between the wavefront sensing and the deformable mirror correction(comparable with the turbulence time scale: a few ms)
- This is a general problem of servo loop systems

- In order to reduce the effects of the time lag we use a short term forecasting system based upon the past measurements of the atmospheric induced aberrations
- This forecasting method is based on ARMA processes and is used to predict the future evolution (5-10 ms) of the turbulence induced aberrations in order to optimize the correction of the deformable mirror
- This approaches has been tested on simulations and real telescope data and its validity has been demonstrated

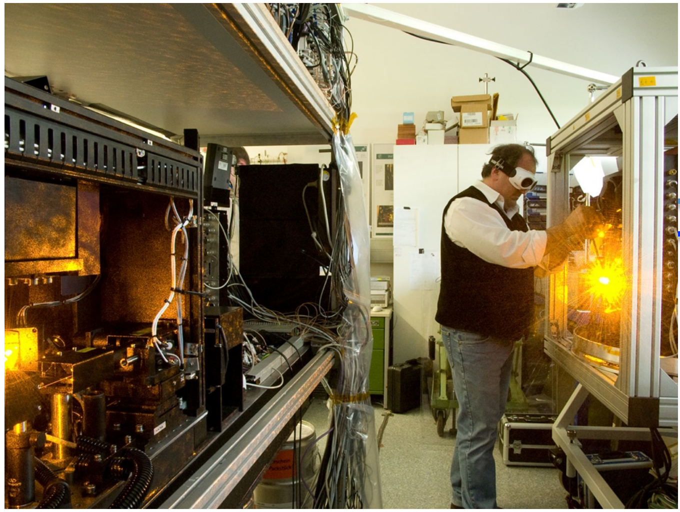
The strehl ratio achieved with the forecasting system is much better, meaning a higher image quality

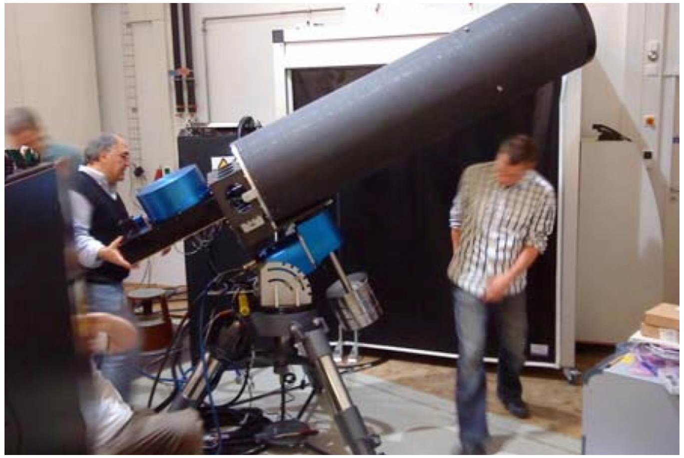


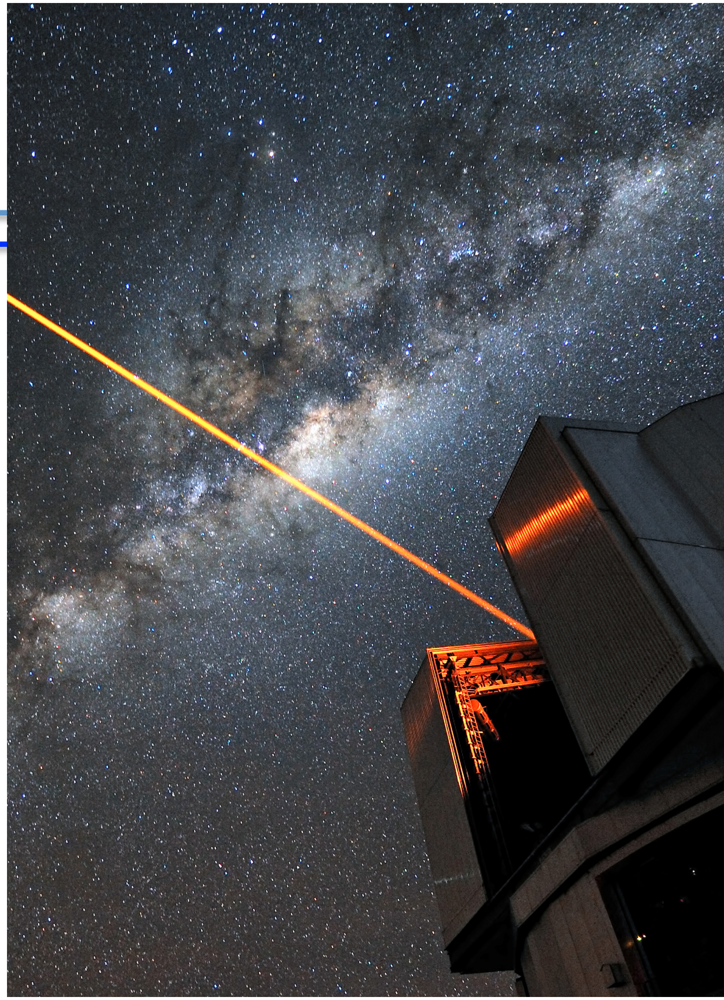




FORS is a forecasting-based AO loop control software which is designed to be easily integrated into existent servo loop systems.







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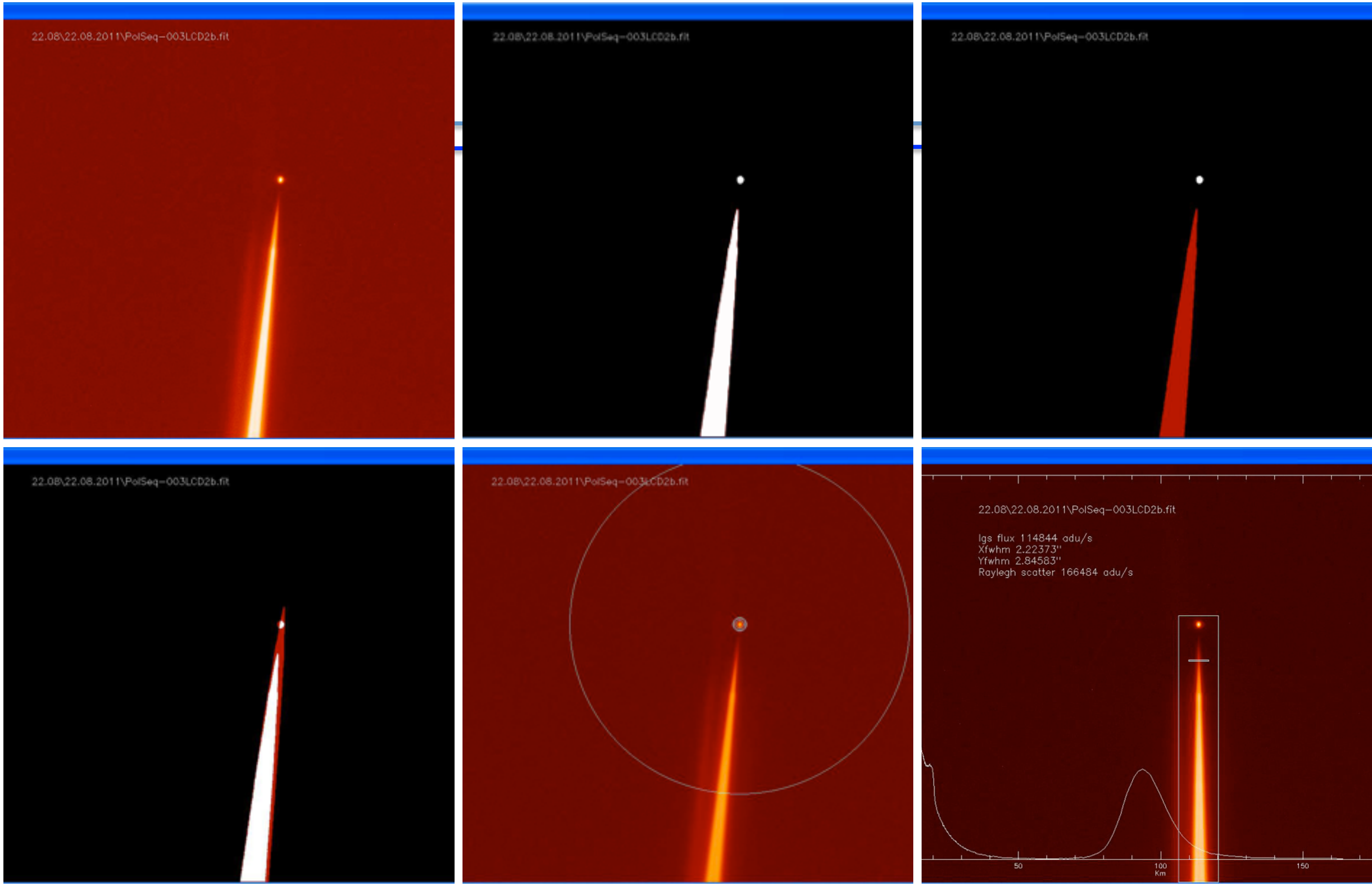
WENDELSTEIN LGS TRANSPORTABLE UNIT

Contact: M. Centrone

PI DOMENICO BONACCINI CALIA

IDL DATA REDUCTION SW



UPLINK\LGS RECOGNITION

PHOTOMETRIC FLUX OF THE UPLINK BEAM

LABVIEW CONTROLLING WLGSU OBSERVATION System SW

ESO - WLGSU

THE OB TAB MENU

WLGSU OBSERVATION SYSTEM LABVIEW SW

… and that's IT! (for the moment)

Thank you for your attention!

and don't shoot the pianist, please…