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Control Software and Data Reduction

Michèle Peron

Software Development Division

Directorate of Engineering

… or why being a software engineer to serve astronomy is fascinating, challenging and rewarding …

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Talk Outline

- Introduction
- Long-Term Scheduling of Observations
- Control System
- Data Reduction of Astronomical Data
- Archiving of Astronomical Data, Data Mining, VO..
- Software Engineering
- Conclusions

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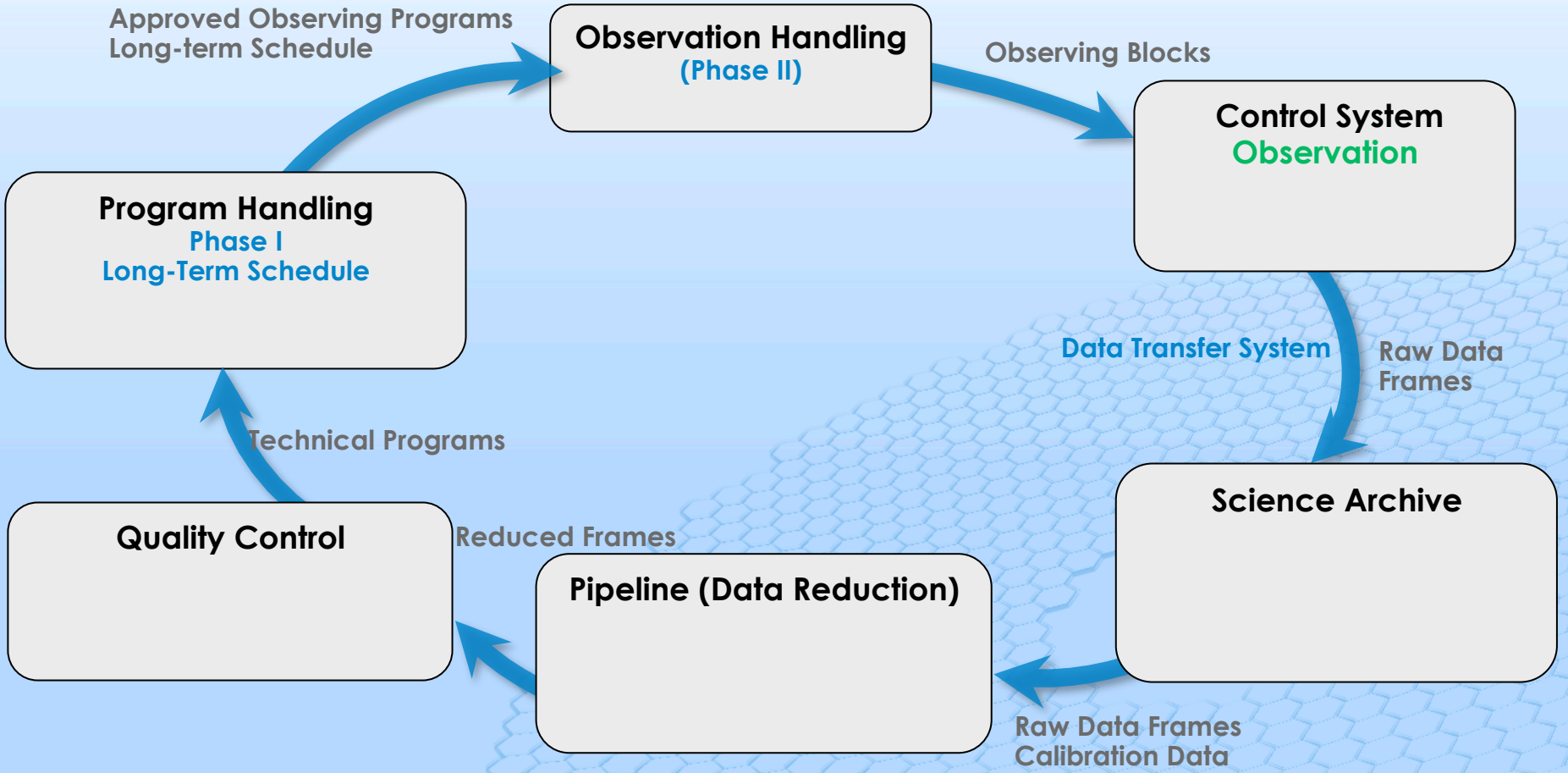
Software at the ESO Paranal/La Silla Observatory



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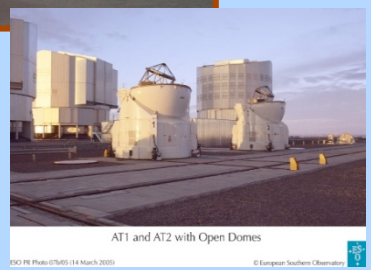
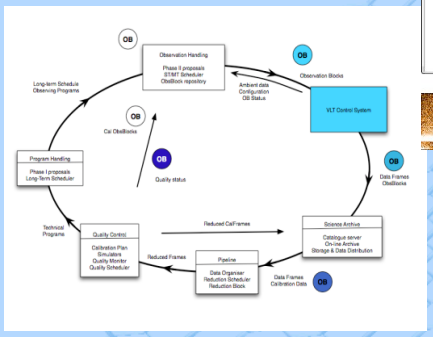
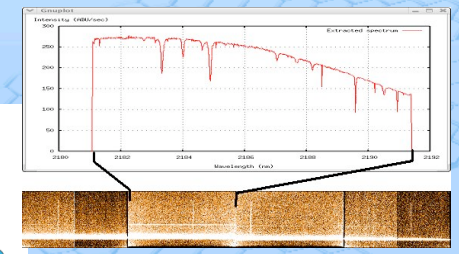






La Silla-Paranal Observatory

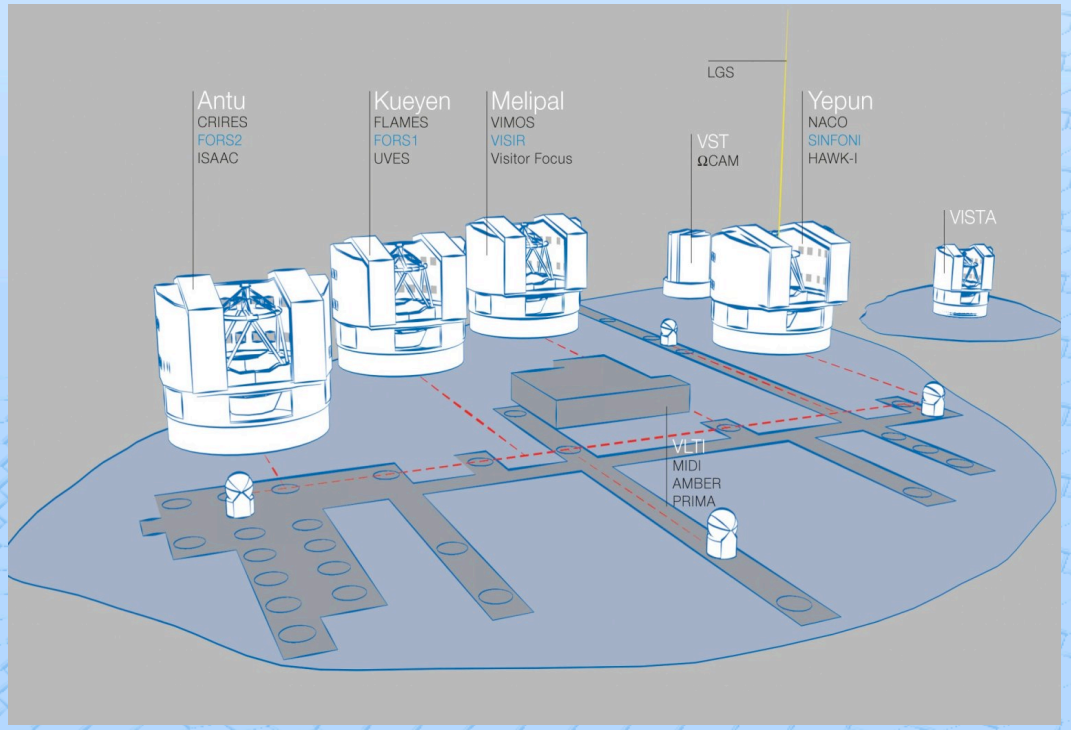
Paranal

La Silla

Where is the VLTSW used?

- All ESO optical telescopes and their instruments are based on the VLT Common Software and on the VLT Instrumentation Software

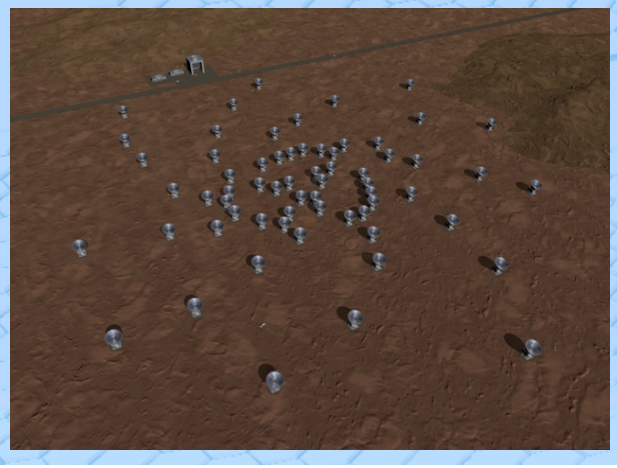
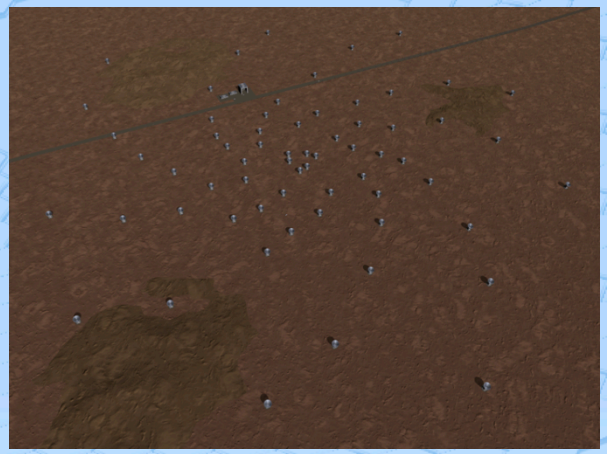
- VLT Unit Telescopes
- VLTI facilities
- VLT Auxiliary Telescopes
- VISTA
- VST
- 3.6
- NTT…….

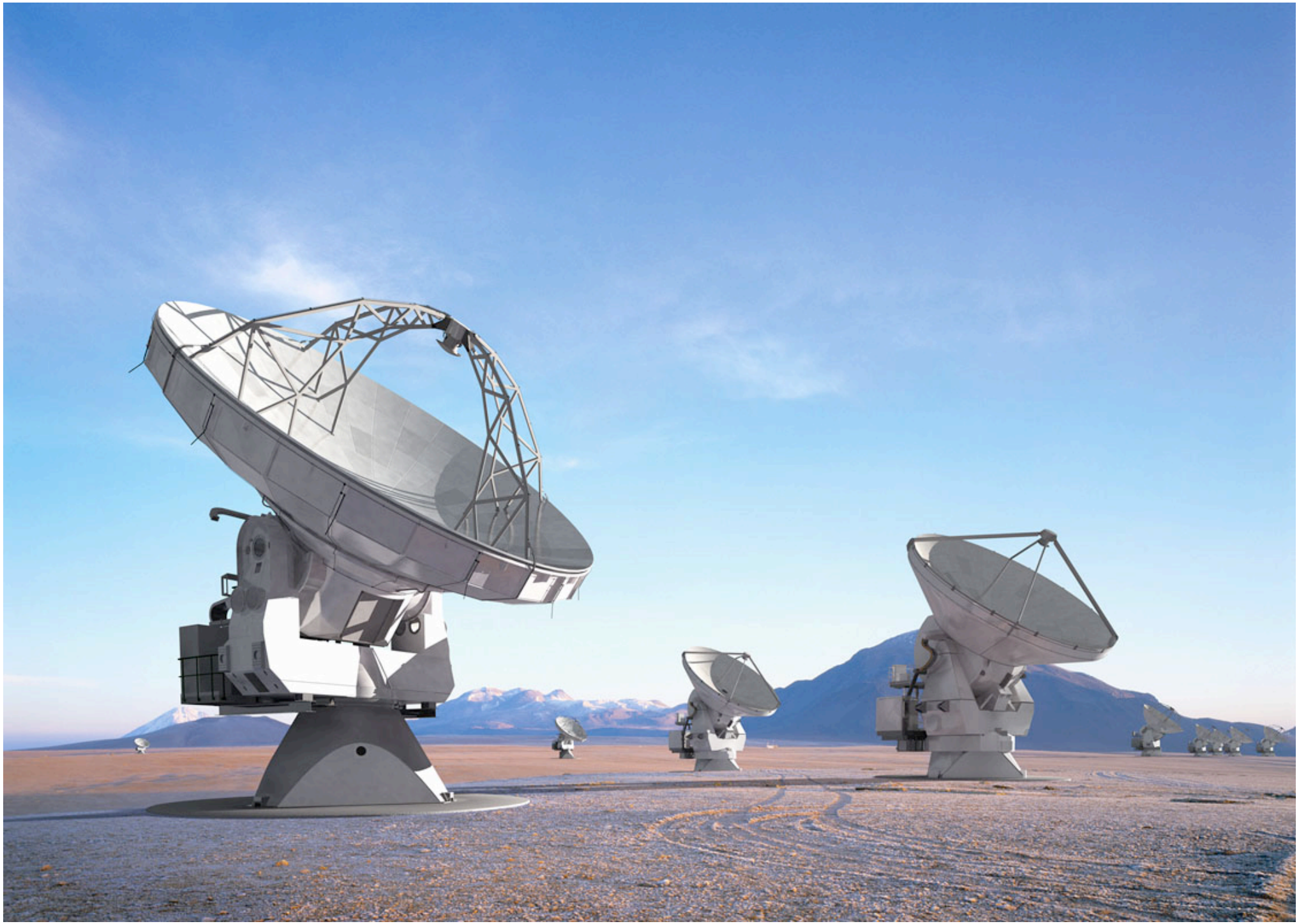



ALMA

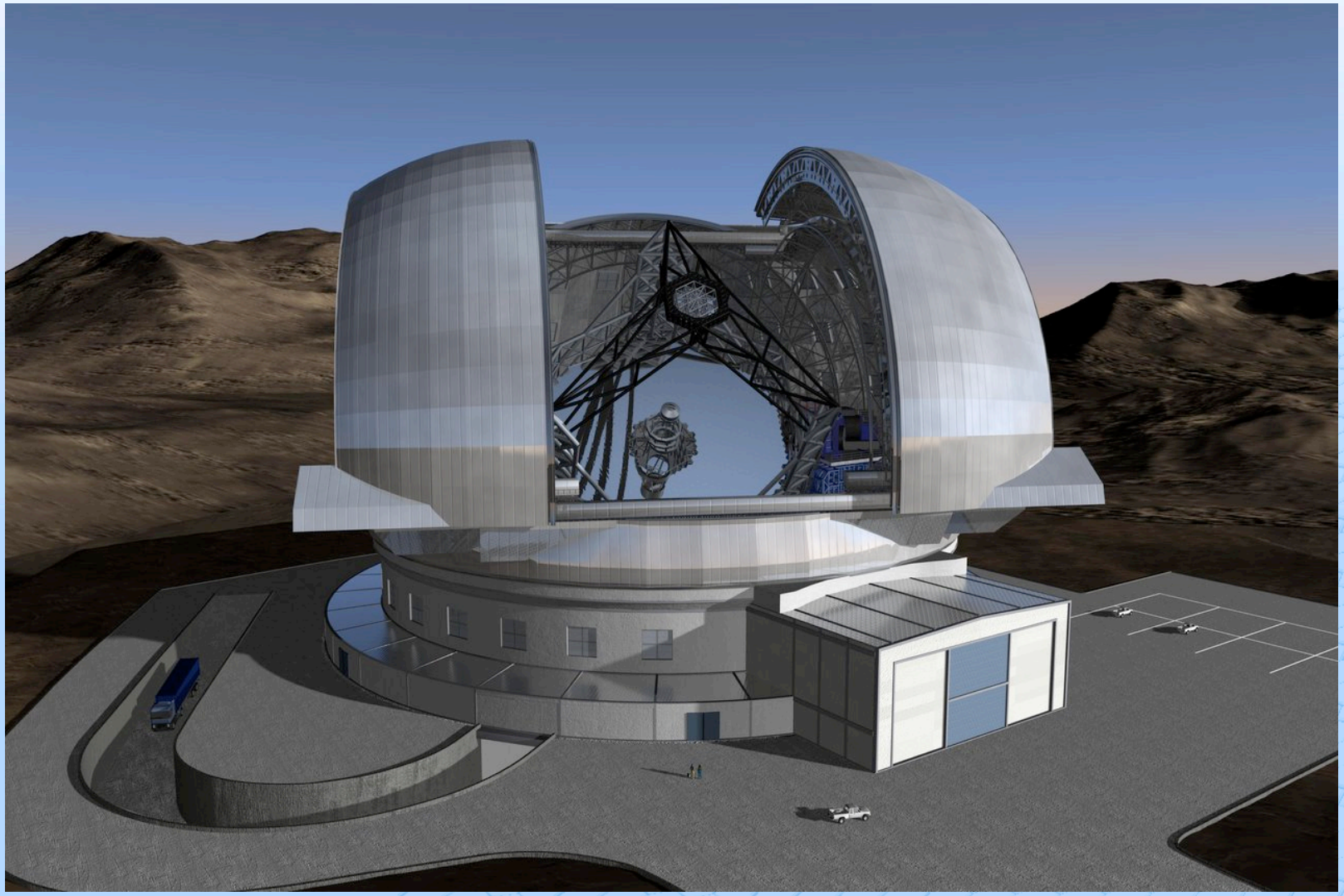
The ALMA project

- 50x12m antennas
- 4x12m antennas optimized for total-power (Japan)
- Compact array of 12x7m antennas for higher sensitivity to broad, low-surface brightness features (Japan)
- Antennas can be moved to ~185 different pads.
- Maximum baselines from 150m to 18km, resolutions from 1” to <0.01” at 850 μm, 10 times better than HST.
- The first antennas are already in Chile and “First fringes” have been observed at the high site in 2009
- Early science operations in 2011
- Full completion in 2013

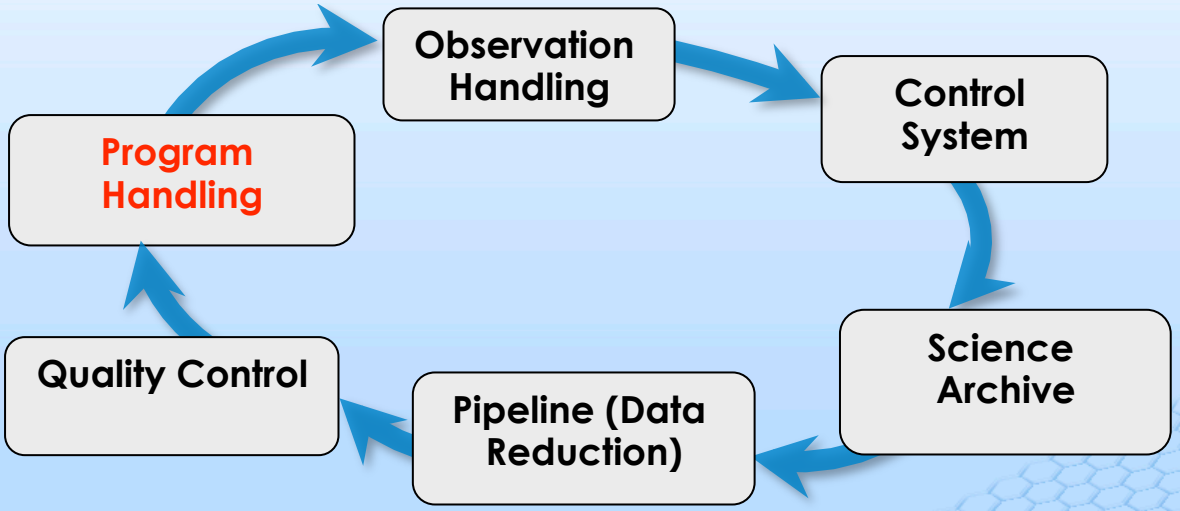






European Extremely Large Telescope



Talk Outline



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Observation Preparation – Example -

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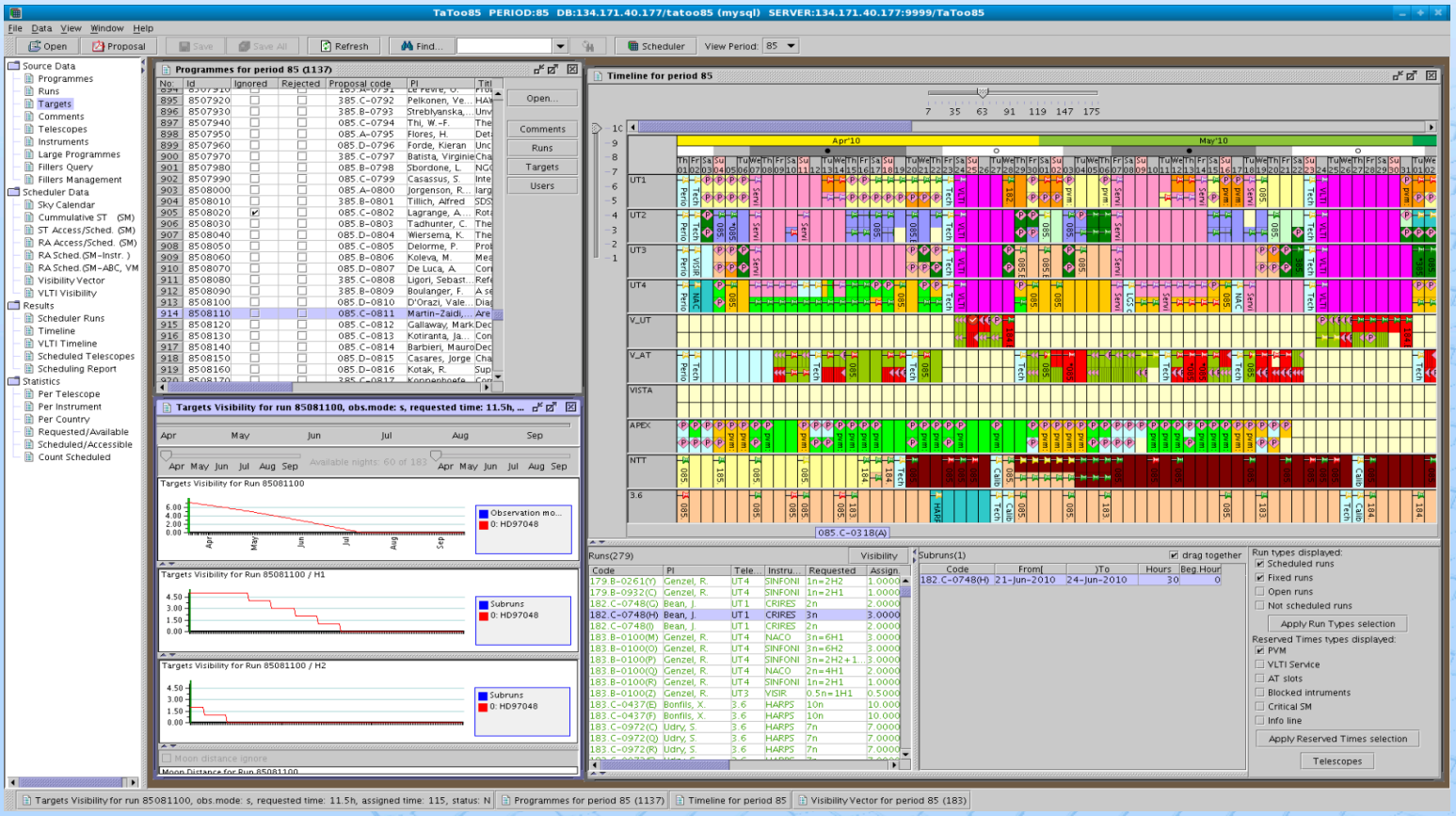
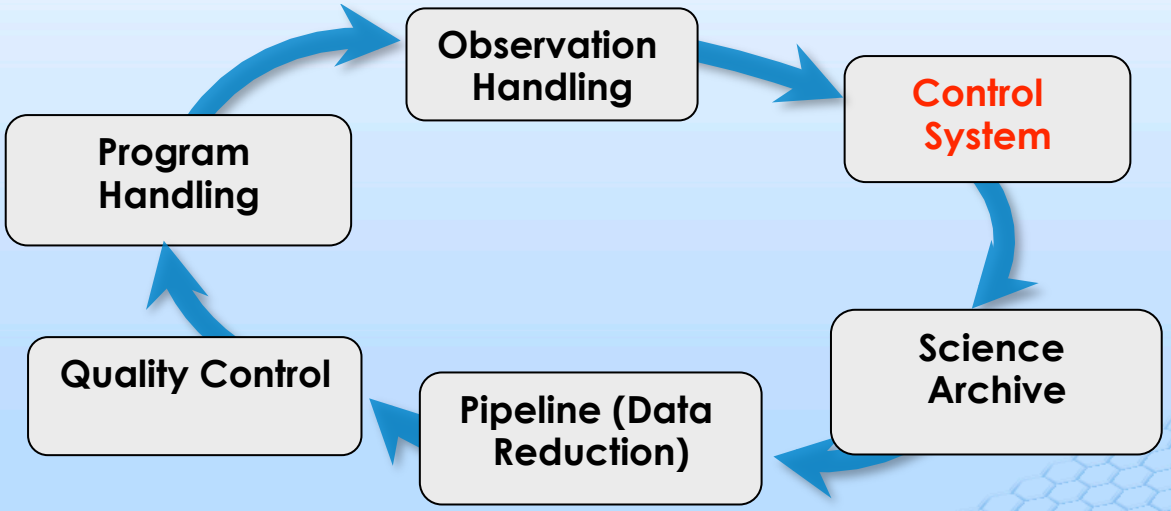
- Scheduling of Observations for an observation period of six months
- GUI and an constraint programming engine taking in account all constraints of the recommended programs
- Java & Databases, ILOG



Talk Outline



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Control System

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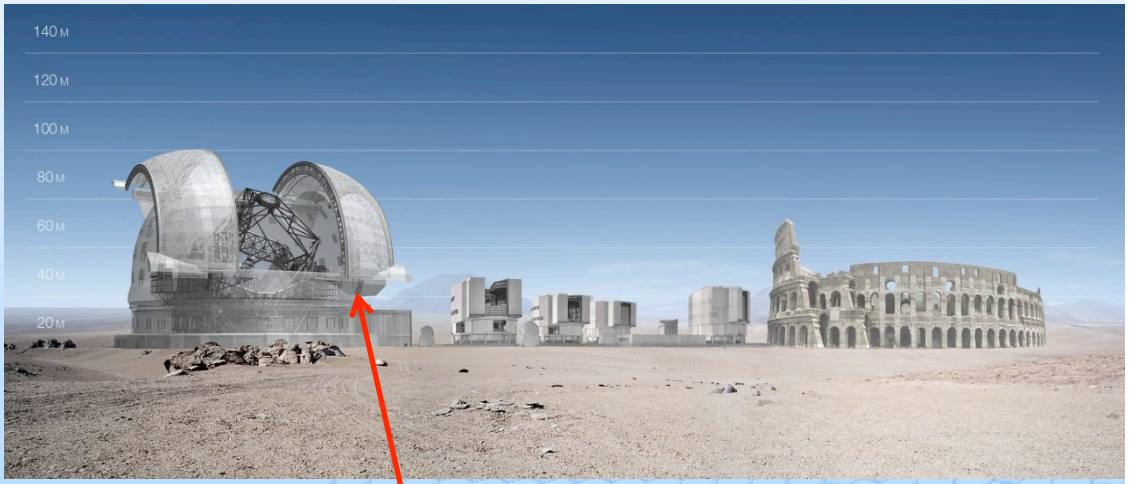
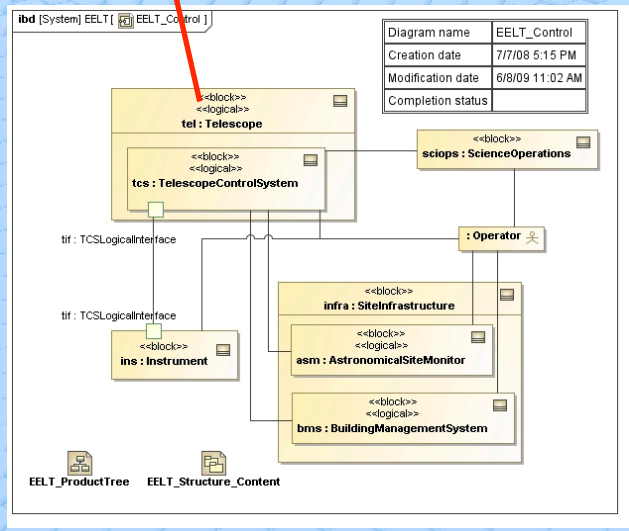
- The Control System includes all hardware, software and communication infrastructure required to control the System.
- Provides access to the opto-mechanical components.
- Manages and coordinates system resources (subsystems, sensors, actuators, etc…)
- Performs fault detection and recovery
- Based on Control Engineering, Software Engineering and Electrical Engineering





E-ELT Telescope Control System (cont)

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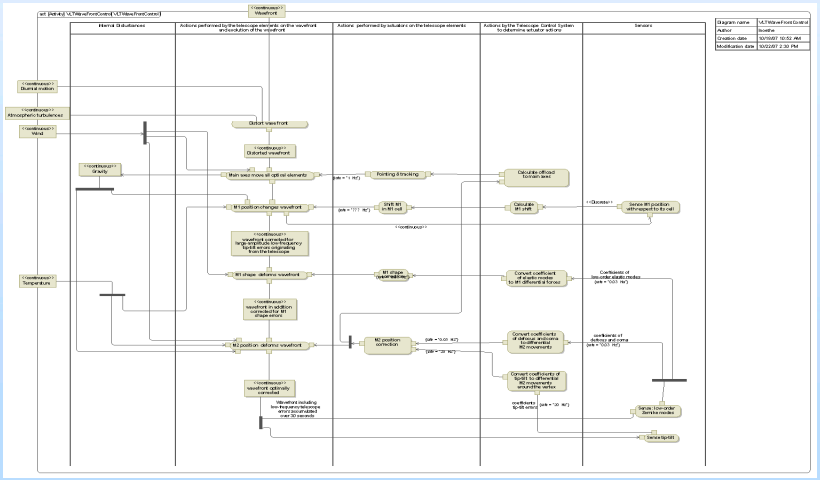
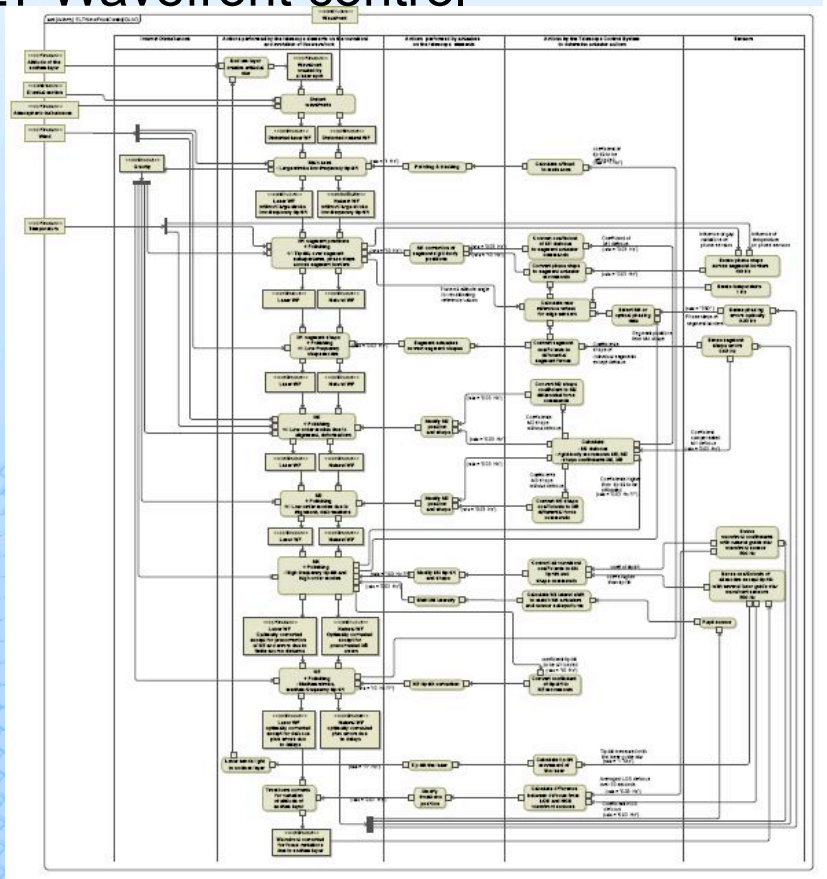
VLT Wavefront control



E-ELT Wavefront control



- 10000 tons of steel and glass
- 20000 actuators, 1000 mirrors
- 60000 I/O points, 700Gflops/s, 17Gbyte/s
- Many distributed control loops
- Use SysML to model the control system since 2008

E-ELT TCS (M1)

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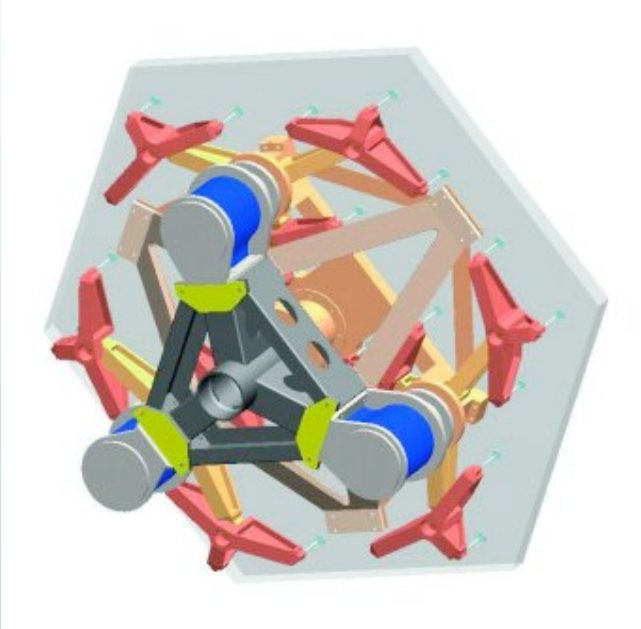

- The position of the 1000 mirrors must be coordinated to deliver a continuous surface with an error below 50nm across the 42m.
- 3000 actuators and 6000 sensors must work in a1Khz closed loop to meet this requirement.
- Moreover 12000 actuators (12 motors per segment, the warping harness) are responsible for deforming each individual segment in order to correct aberrations at a lower rate
- The control strategy must be flexible and adaptable to e.g. failure of sensors

E-ELT Control System Baseline Technologies

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TCS Application

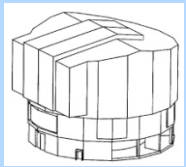
DDS

LCU (NI PXI/Windows)

OPC

PLC (Siemens S7-300)

Profinet



Sensors/Actuators

Integration & High-level applications

- Data oriented architecture (DDS)
- User Interface (LabVIEW)

Subsystem local control:

- PLCs
- OPC standard (open automation interface)
- Field buses (Profinet, Ethercat....)
- Safety functions

Multi-core for large MIMO control.

- LabVIEW graphical parallel computing

Dedicated time distribution system (µsec).

- Evaluation of IEEE1588-2008 standard protocol
- Sub-microsecond synchronization
- COTS network equipment (Cisco, NI-PXI, Ethernet)

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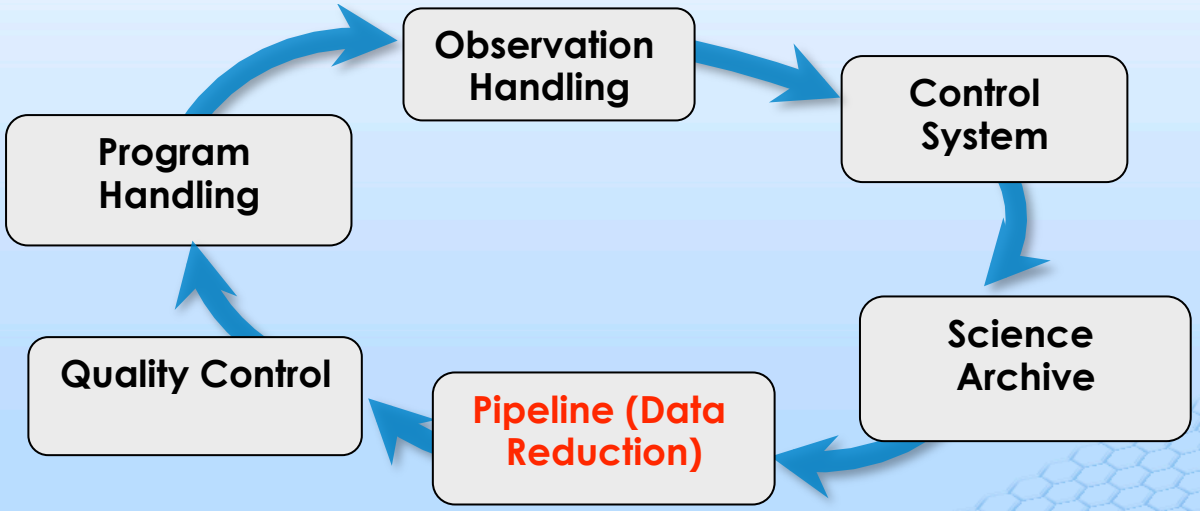
Talk Outline



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Which Data? Image and Spectrum

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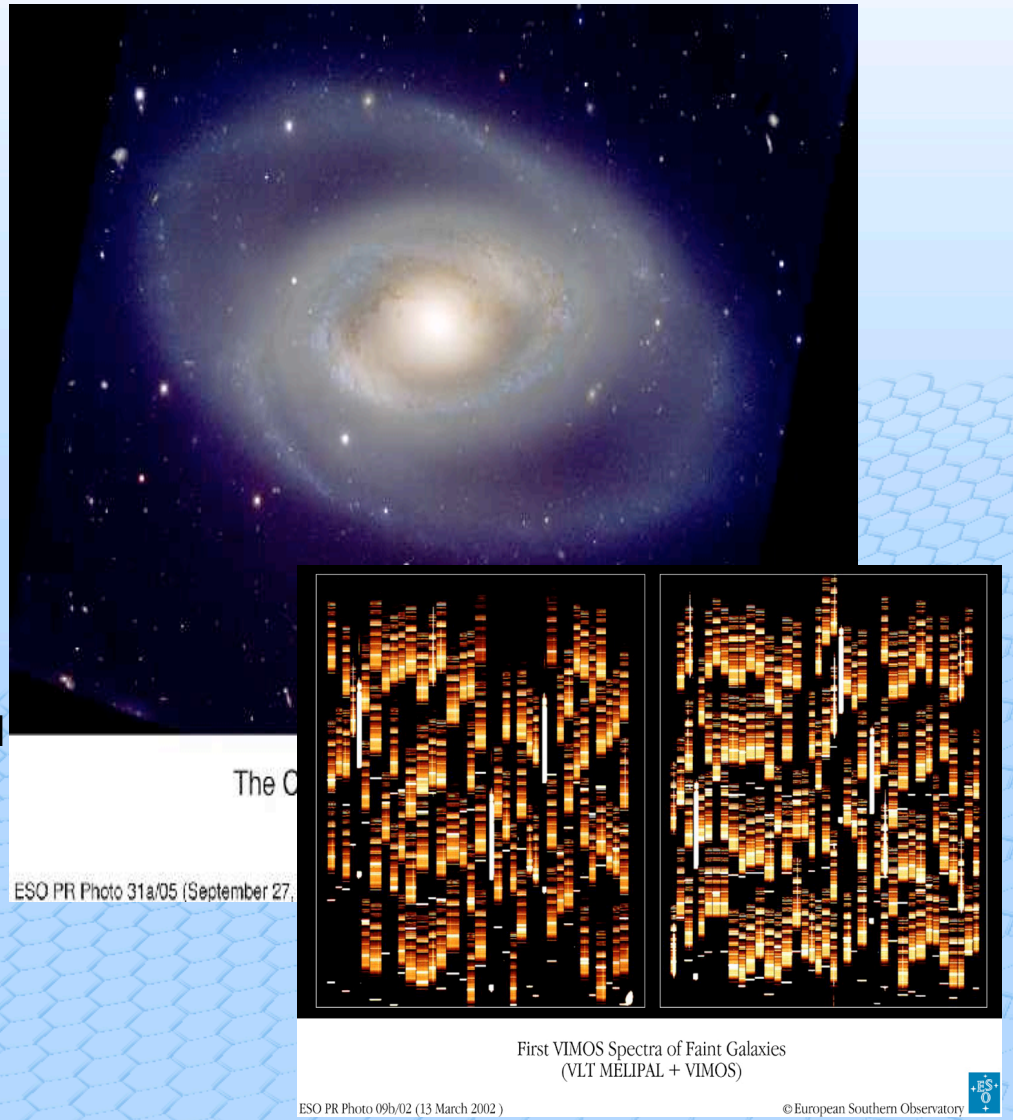
- Image
  - Intensity as a function of two directions I(α,δ)
  - Within a wavelength domain
    - Broad-band, narrow-band filters
  - Image size up to 67 Mpixel
- Spectrum
  - Intensity as a function of one direction and the wavelength I (λ, δ)
  - > 200 simultaneous spectra



MOS spectra

Calibration Process

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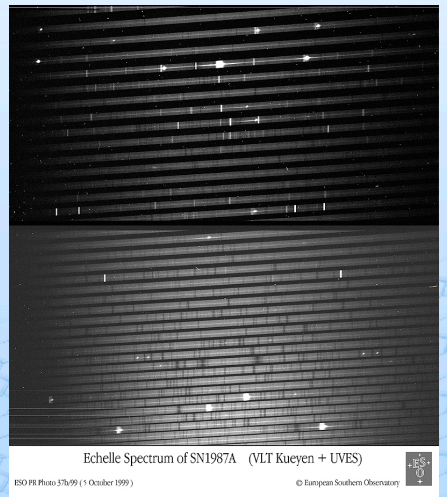
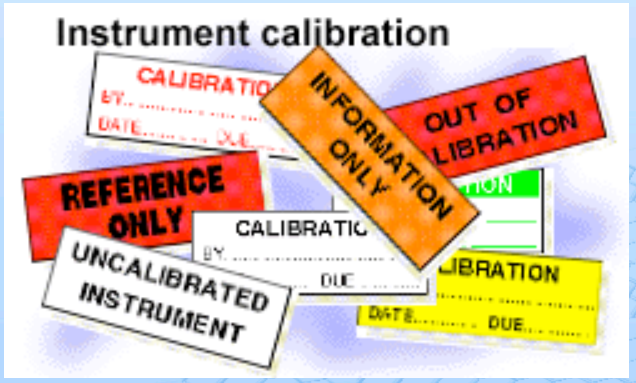
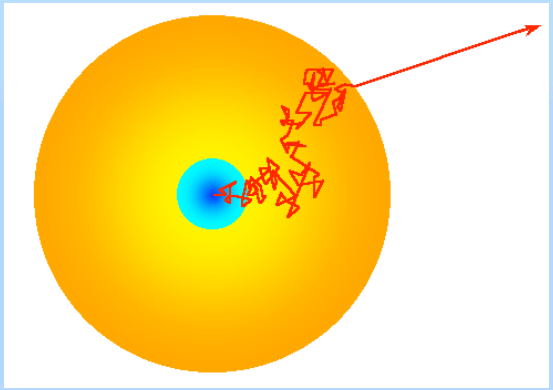
1. An optical instrument maps photons to a given detector location
2. On the detector only electrons are recorded
3. Unwanted sky, scattered light, noise are also present in the data
4. The calibration process recovers the physical quantities







Instrument Readouts
Pixel location (x,y)
Electron counts (ADU)

Calibration/Reduction
Known sources
Inverse solutions: $\lambda = f(x,y)$
Science reduction

Physical Quantities
(α, δ, λ, S, Δt)

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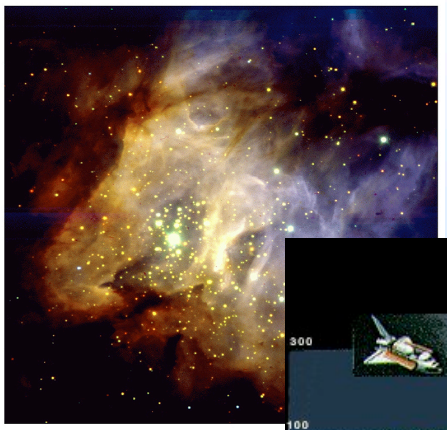
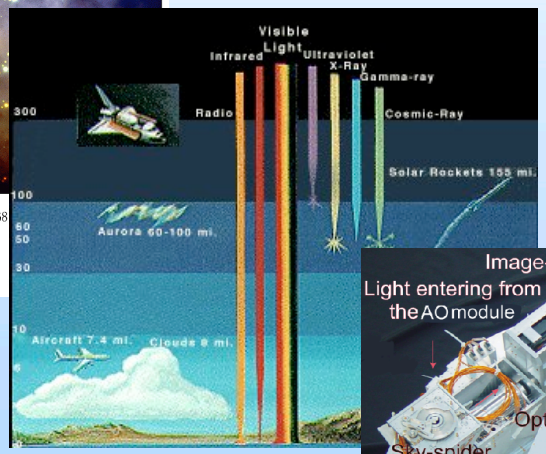


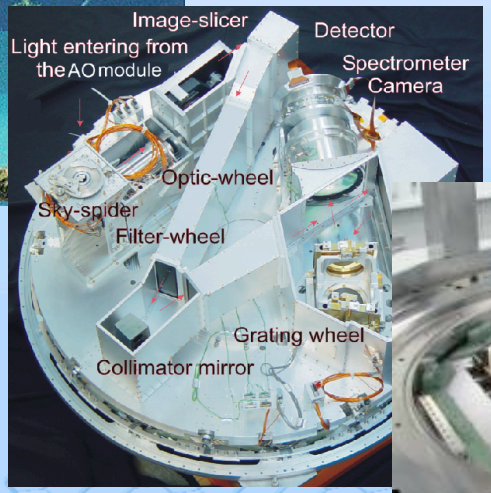
IR Colour Composite of RCW38
(VLT UT1 + ISAAC)

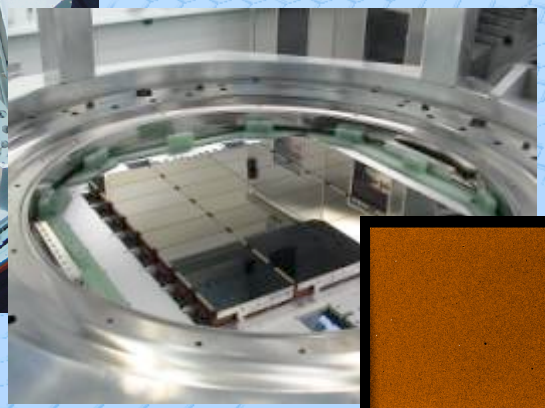
ESO PR Photo 46b/98 (26 November 1998)

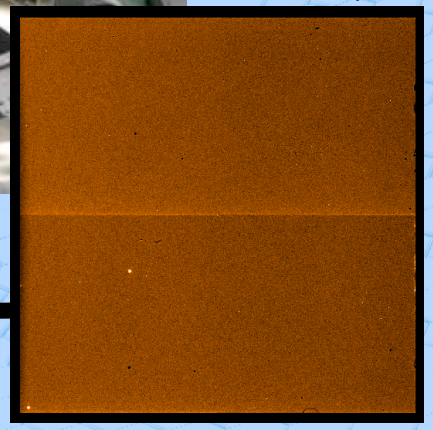
Astronomical Calibrators
(Position, Spectral flux, Diameter, etc..)



Instrumental Calibrators
(Internal sources)







Data Reduction

Correct for detector and instrument effects
Correct for atmospheric effects
Separate science data from noise and background

Data Reduction at the Telescope

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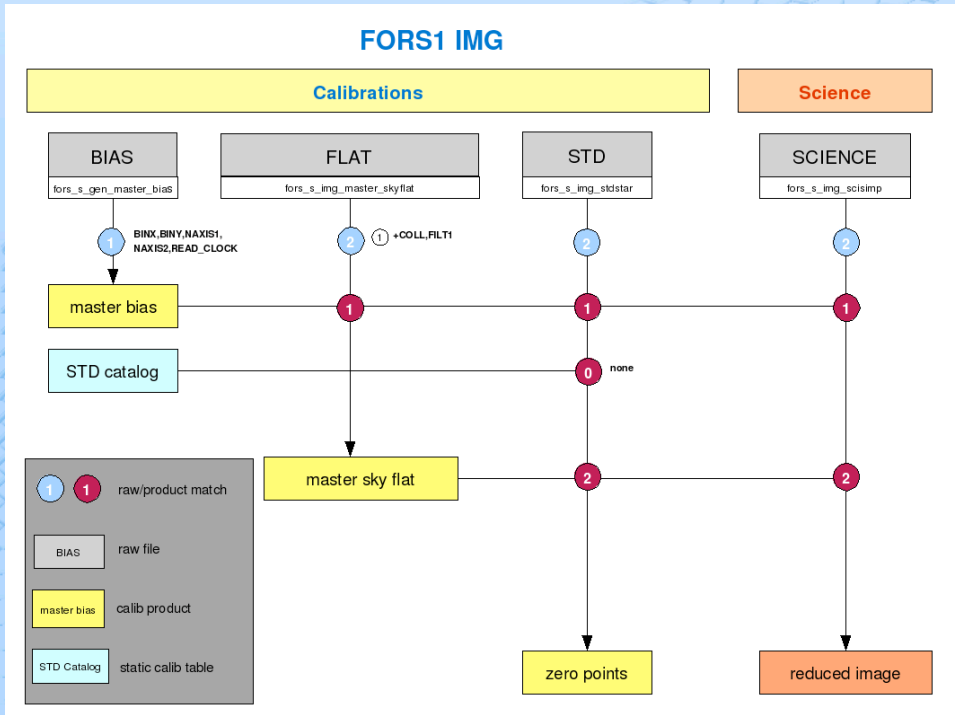
- Must be done automatically and in quasi real-time
  - Large amount of data (few hundreds of Gibabytes per night) require multi-core hardware and parallel processing
- Required to control the health of the instruments and check the quality of observation
  - Instruments complexity requires complex reduction algorithms
- Software technologies: C, C++, Condor, expert systems, open MP



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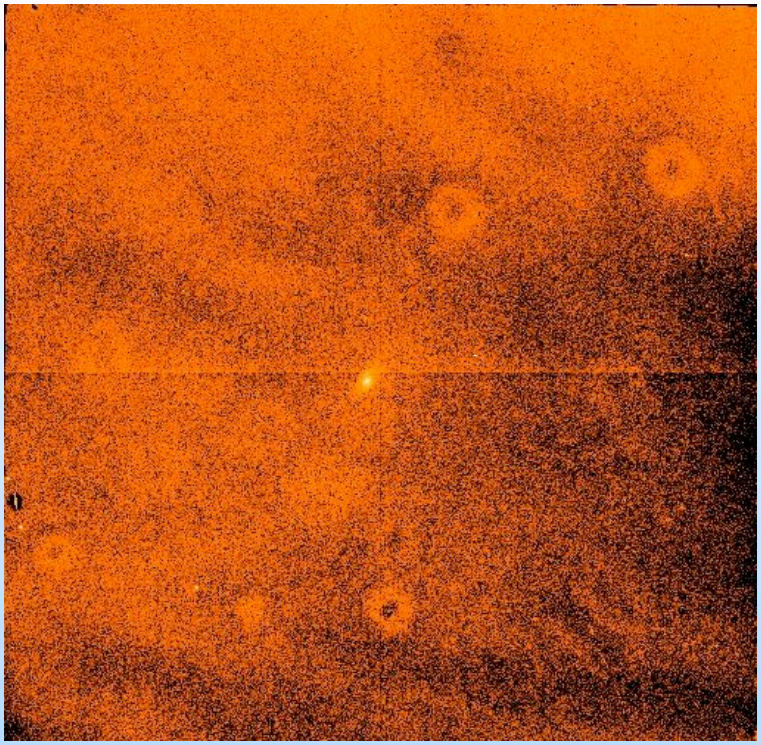
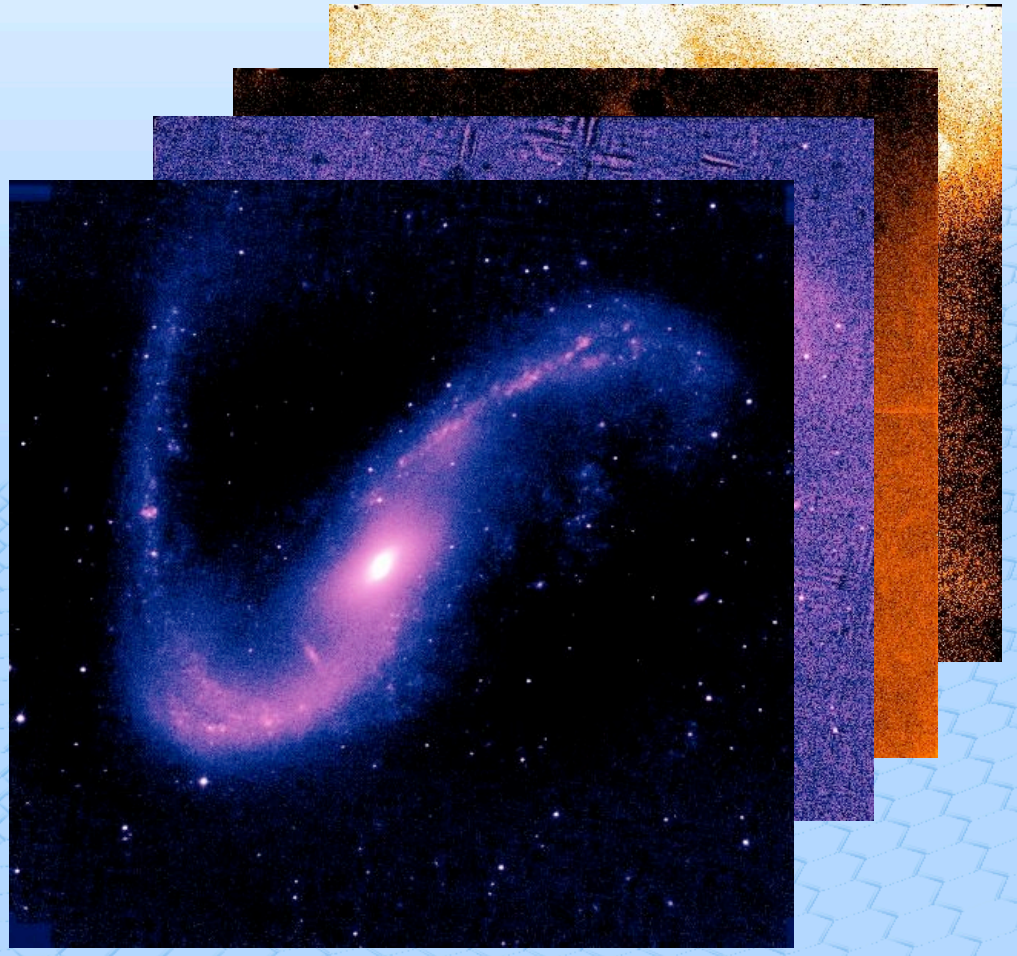
IR Background Subtraction (Shift-and-Add Method)





- Raw images (sky = 10,000 star = 1) and Dome Flat
- Estimating the sky from N jittered exposures
- Subtracting the sky and correcting for flat-field
- Co-adding the sky corrected images
- Photometry !! (not cosmetic)

Automated Wavelength Calibration

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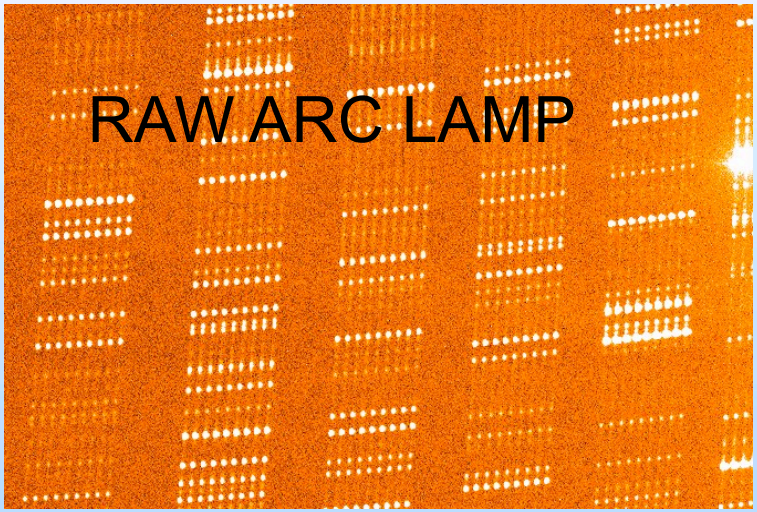
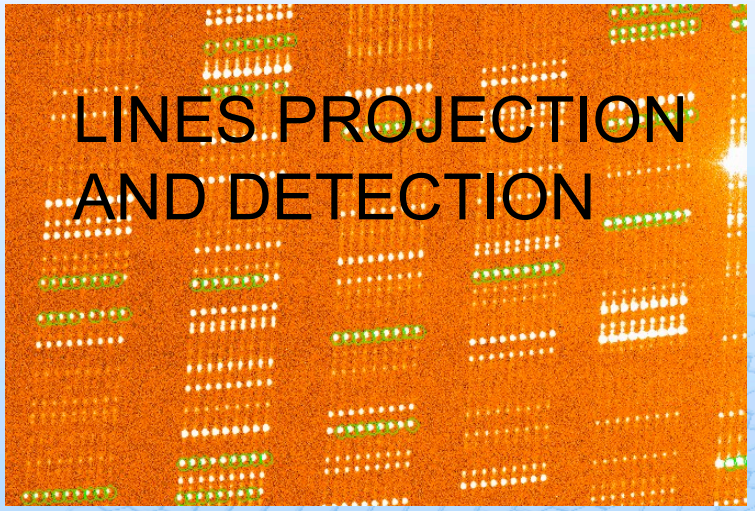
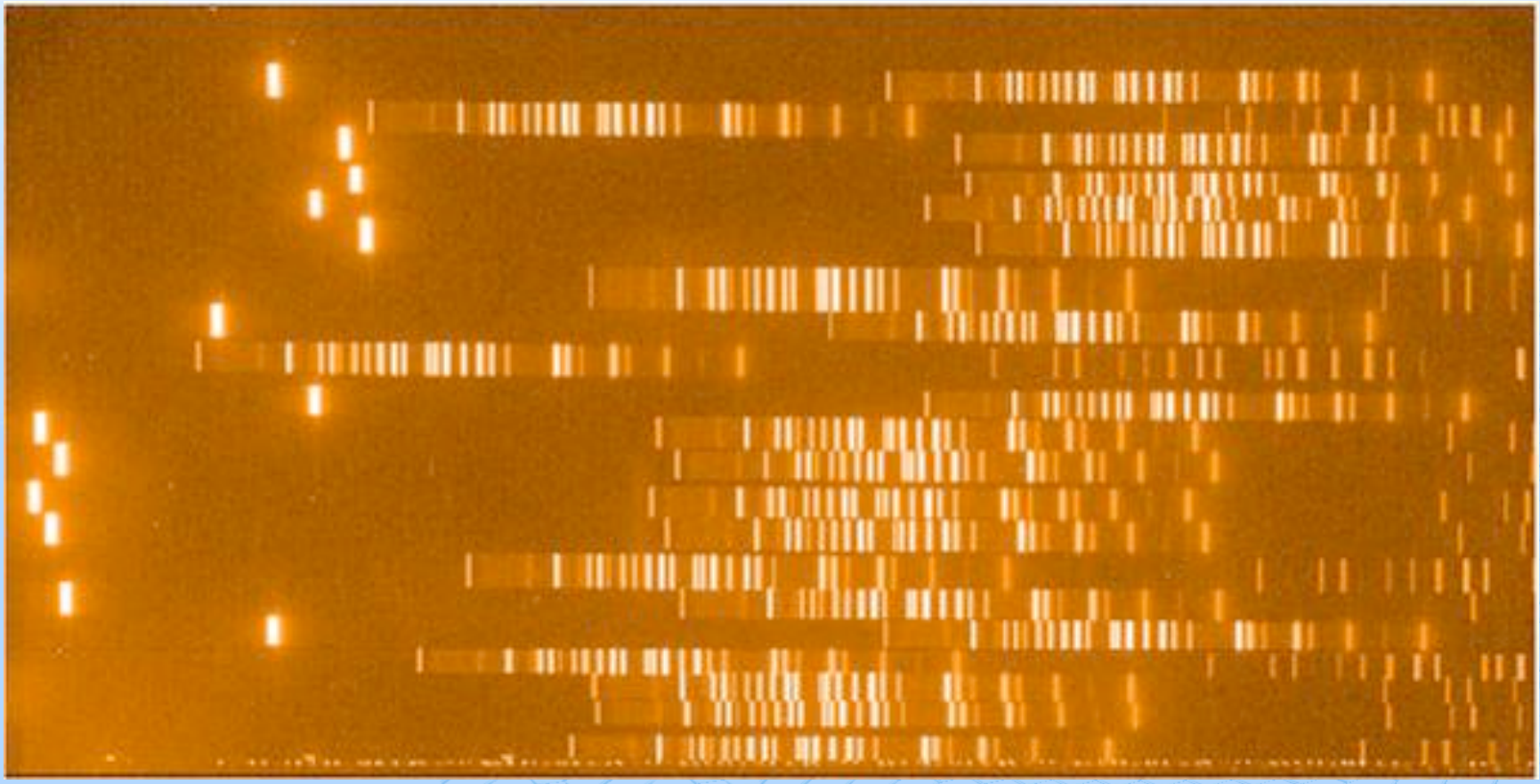


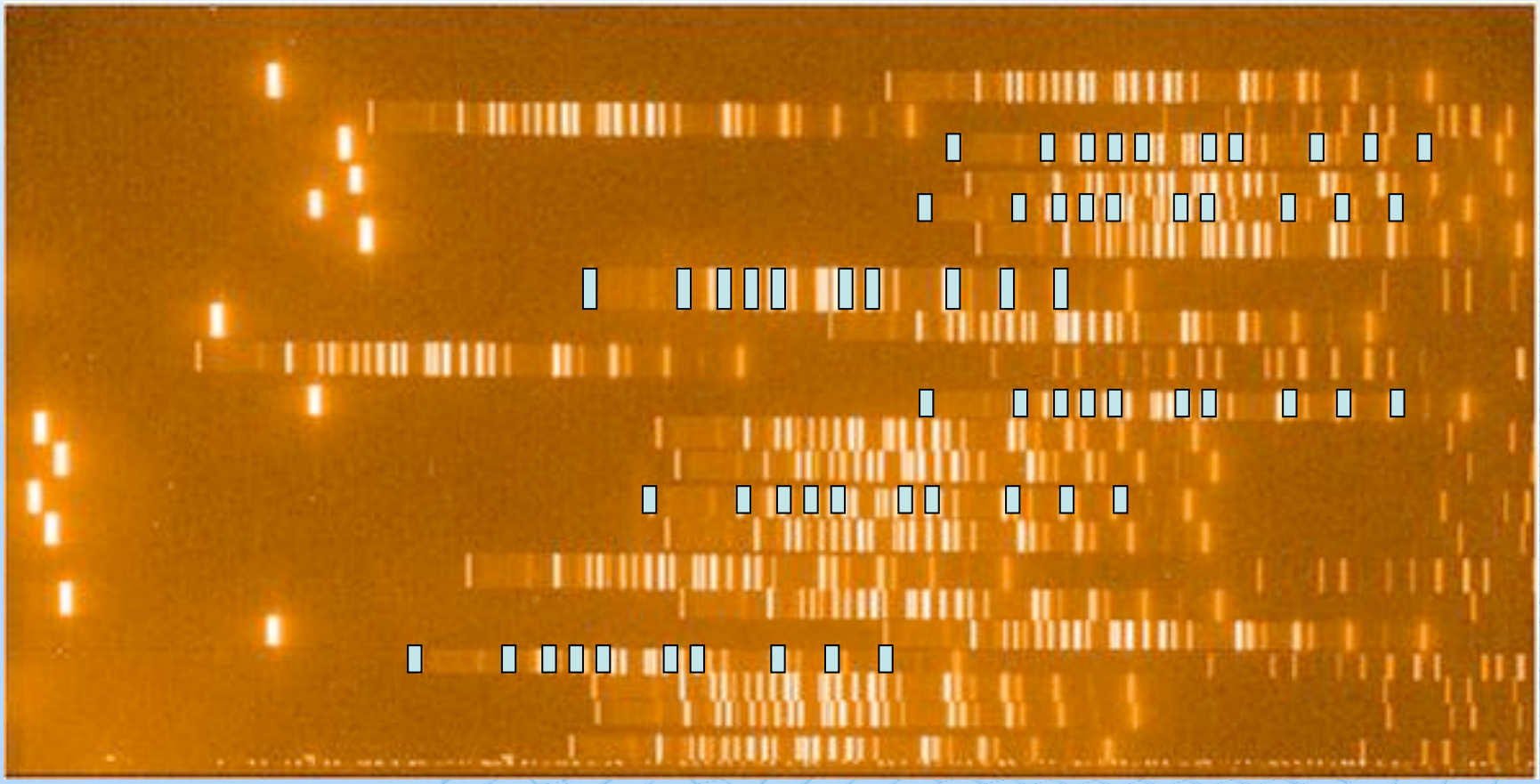


- Raw Science Image and Arc Lamp
- Identifying reference objects using instrument model or pattern matching algorithms
- Estimating dispersion relation
- Applying wavelength calibration

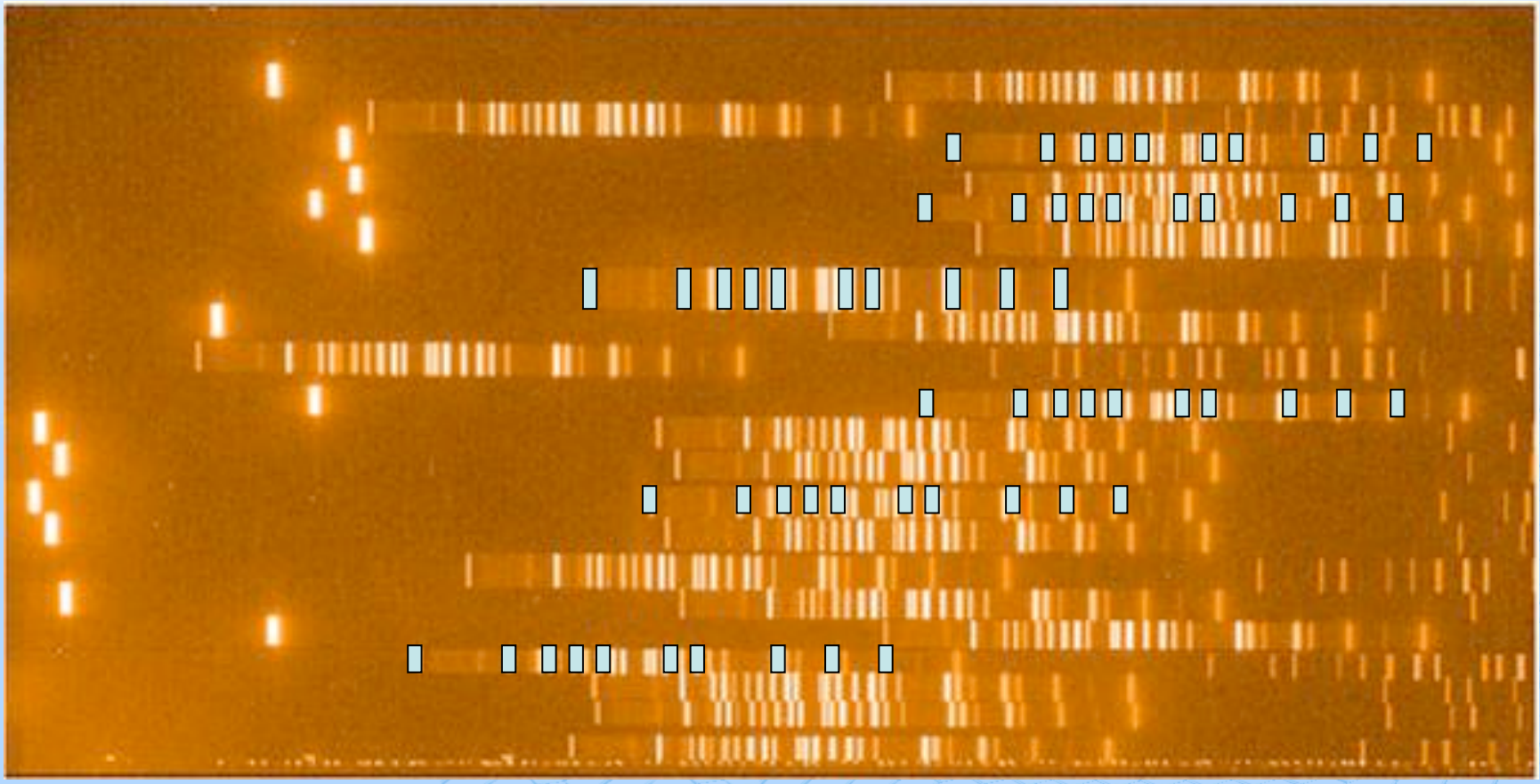
A typical MOS arc lamp exposure



Using first-guess model to find reference lines…



Earthquake!



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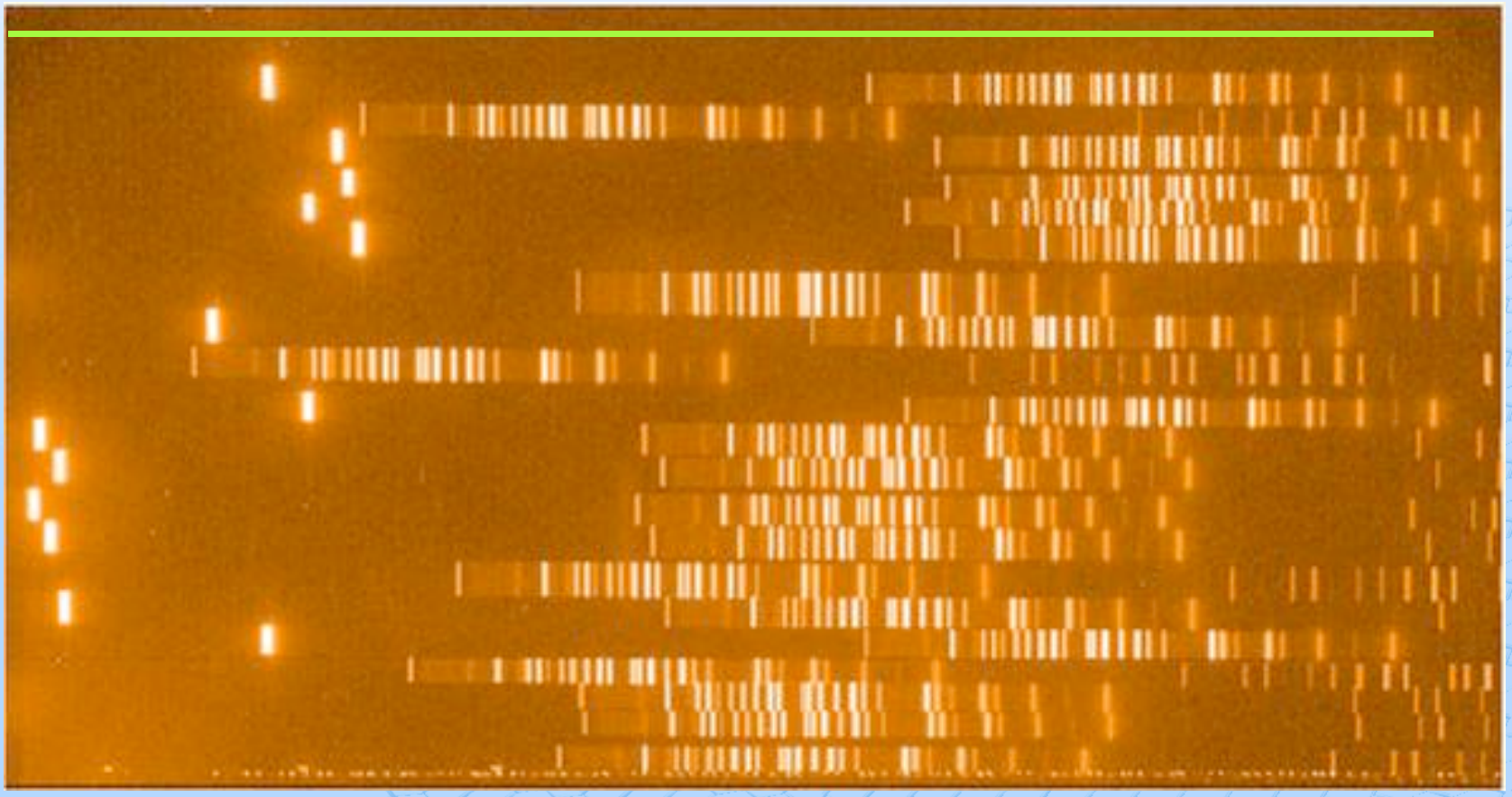
Looking for peaks



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Looking for patterns

The pattern: wavelengths

- ...
- 5400.562
- 5460.742
- 5764.419
- 5769.598
- 5790.656
- 5852.488
- 5875.620
- 5881.900
- ...

The data: pixel positions

- ...
- 1220.64
- 1253.23
- 1299.44
- 1304.07
- 1339.30
- 1400.33
- 1450.28
- 1457.32
- 1471.00
- 1496.21
- ...

Looking for patterns

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- 1450.28
- 1457.32
- 1471.00
- 1496.21
- …

Integral Field Unit Data Reduction

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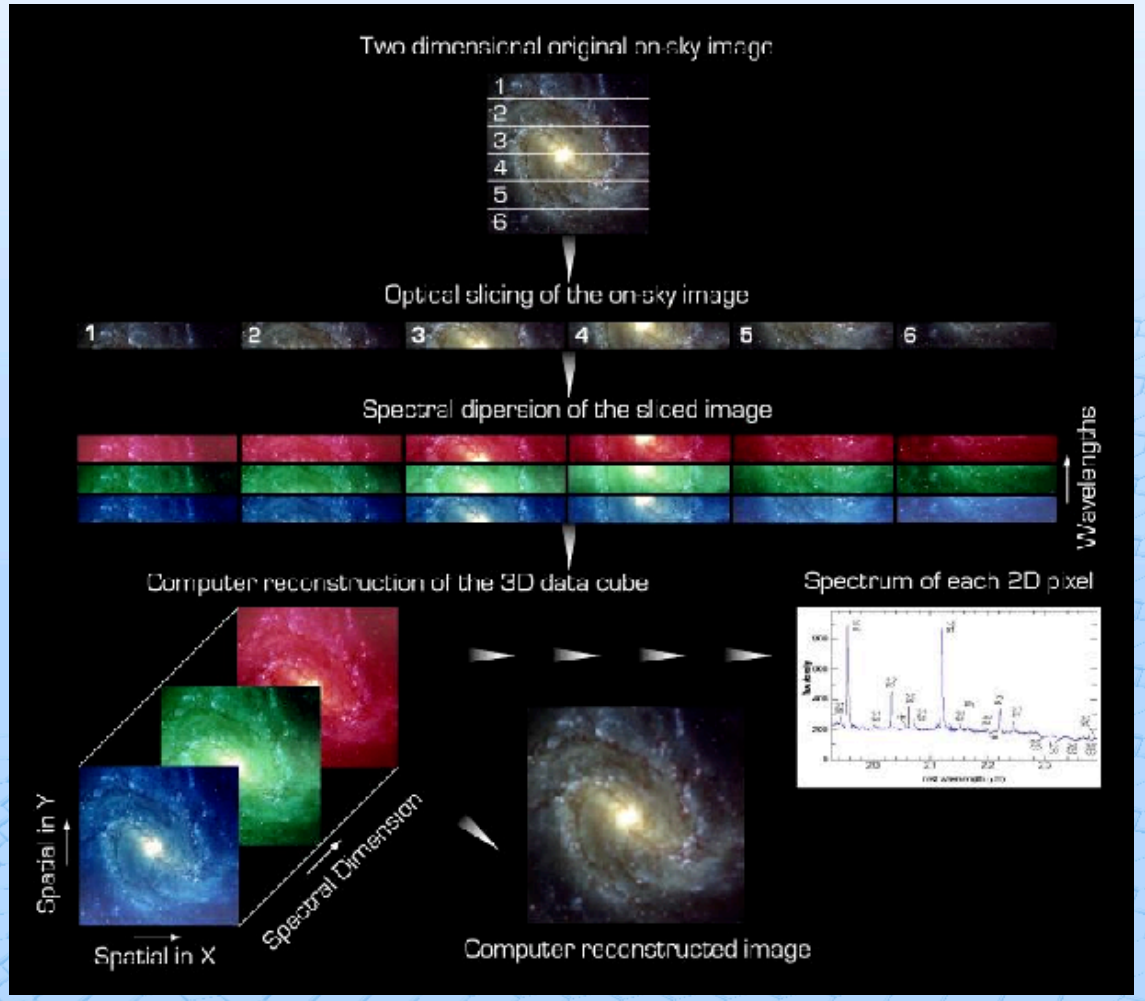
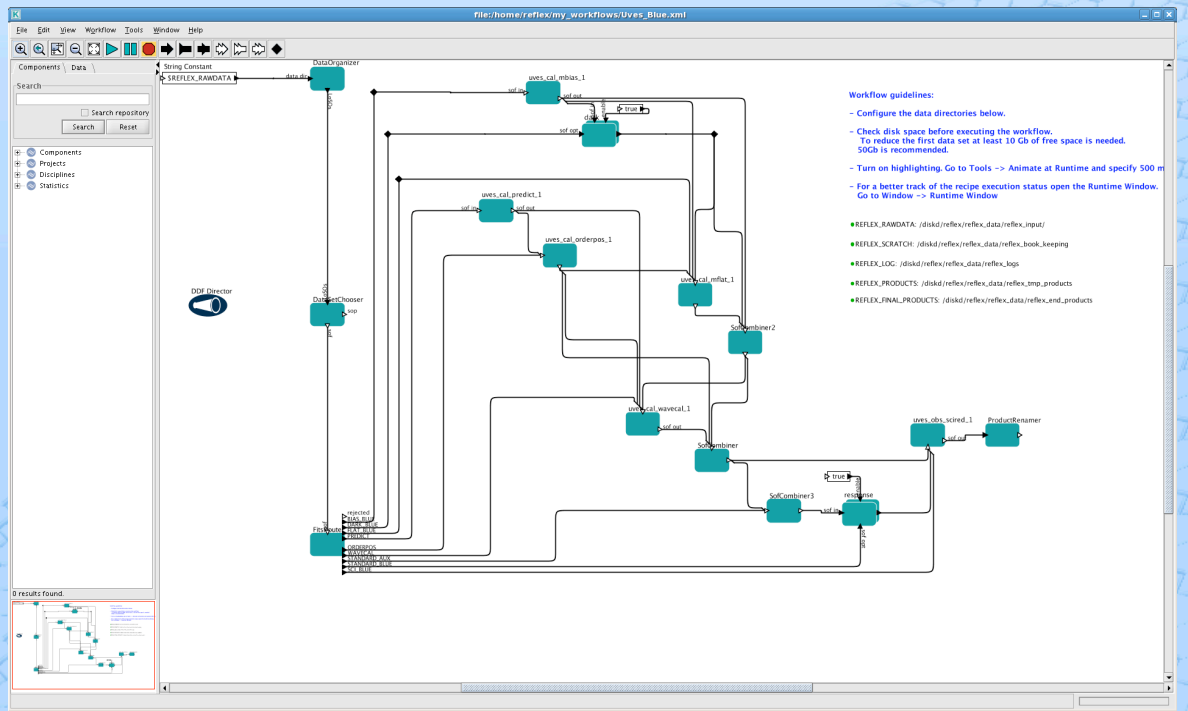
- Raw science image, BIAS, DARK, FF, Arc Lamp
- Correcting for the detector signature (bias, FF, geometric distortions)
- Performing wavelength calibration
- Reconstructing the image FOV
- Removing sky contribution



Data Reduction at home: Reflex

- Highly interactive
- Based on workflow technology (Kepler)
- Highly customisable
- Supports the concept of plugin



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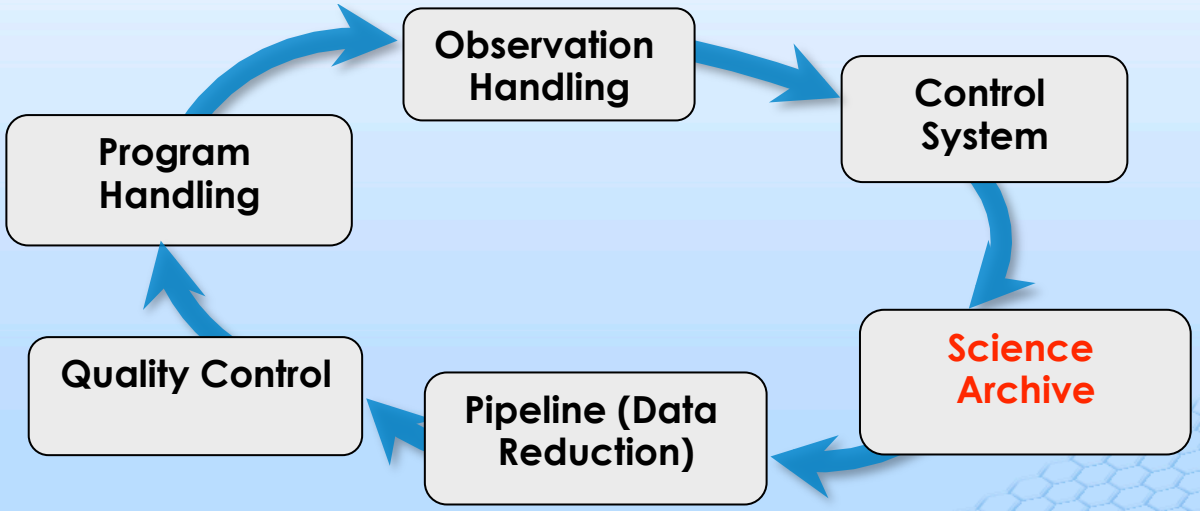

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Archiving of Astronomical Data, Data Mining, VO

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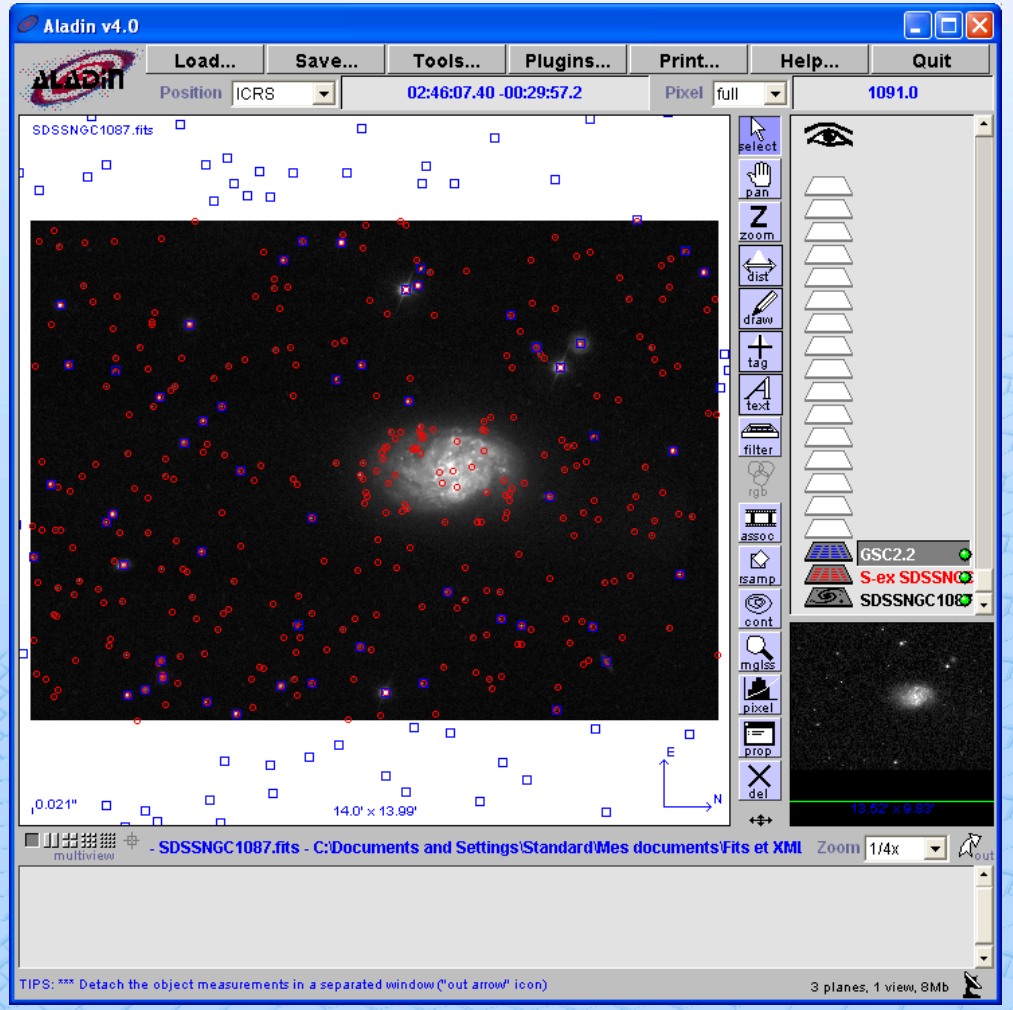
- Large amounts of data to store (ALMA will generate 6.4 Mbytes/s)
- Tools required to store, query, request data from the archive, visualize data, cross-correlate catalogs, etc…
- The Virtual Observatory provides access to archives of astronomical data across the whole range of wavelength
- Technologies: Java, databases, WEB and standalone applications



Aladin (CDS, Strasbourg)

Software Integration, Verification and Validation
Software Engineering

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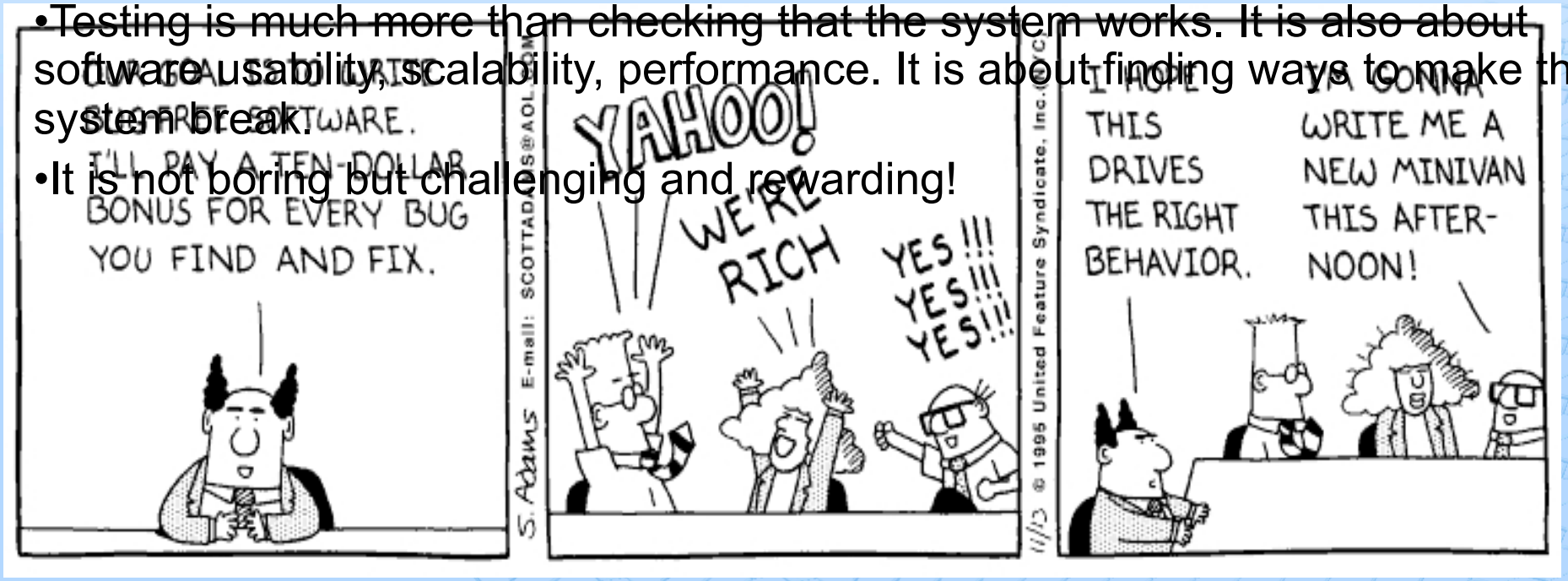
- Independent Software testing is essential to the success of a project.
- Testing is much more than checking that the system works. It is also about software usability, scalability, performance. It is about finding ways to make the system break.
- It is not boring but challenging and rewarding!



Conclusions

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