The APEX Control System*
Past, Present & Future

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* APECS

Dirk Muders, MPIfR, March 10, 2006

APECS' Roots in ALMA

- Early (1999/2000) contact to ALMA software development groups since APEX will be a copy of an ALMA prototype antenna
- Worked in SSR & HLA groups
- Later followed Test Interferometer Control Software (TICS) developments
- Evaluated ALMA-TI FITS raw data format for use at APEX
- Now still working for ALMA (DC, Heuristics)

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Lessons learned from ALMA Work

- *Interfaces must be stable early on*
- *Object-oriented software analysis & design*
- *Unified Modeling Language (UML)* (A standardized way of translating requirements into a class and object structure)
- *Distributed computing using a middleware like CORBA* (Common Object Request Broker Architecture)

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Don't panic ! I'm just an object.

Name: FLASH810

Properties: Frequency, Sideband

Methods: On, Tune, Off

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Inherited ALMA Software

- APECS re-uses a large portion of the original ALMA Test Facility (ATF) software
- Advantages:
  - Common hardware & interfaces
  - Real-time software already developed
  - Big development team (->2003: 15, 2003->: 50)
  - Potential upgrades (and support) in the future
- Disadvantages:
  - APEX is an early adopter. Steep learning curve.
  - Initial releases are typically unstable

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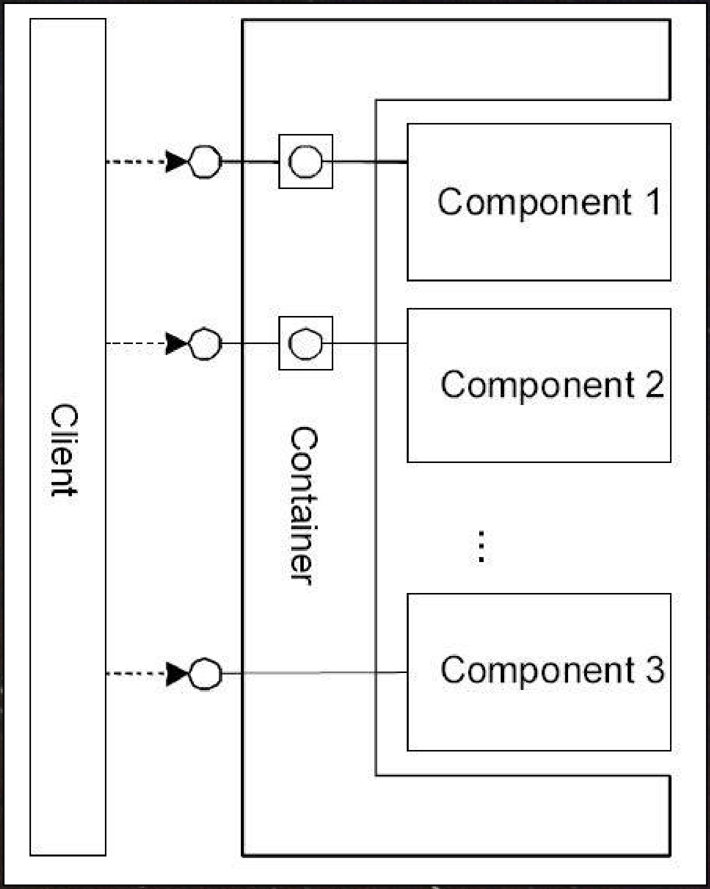
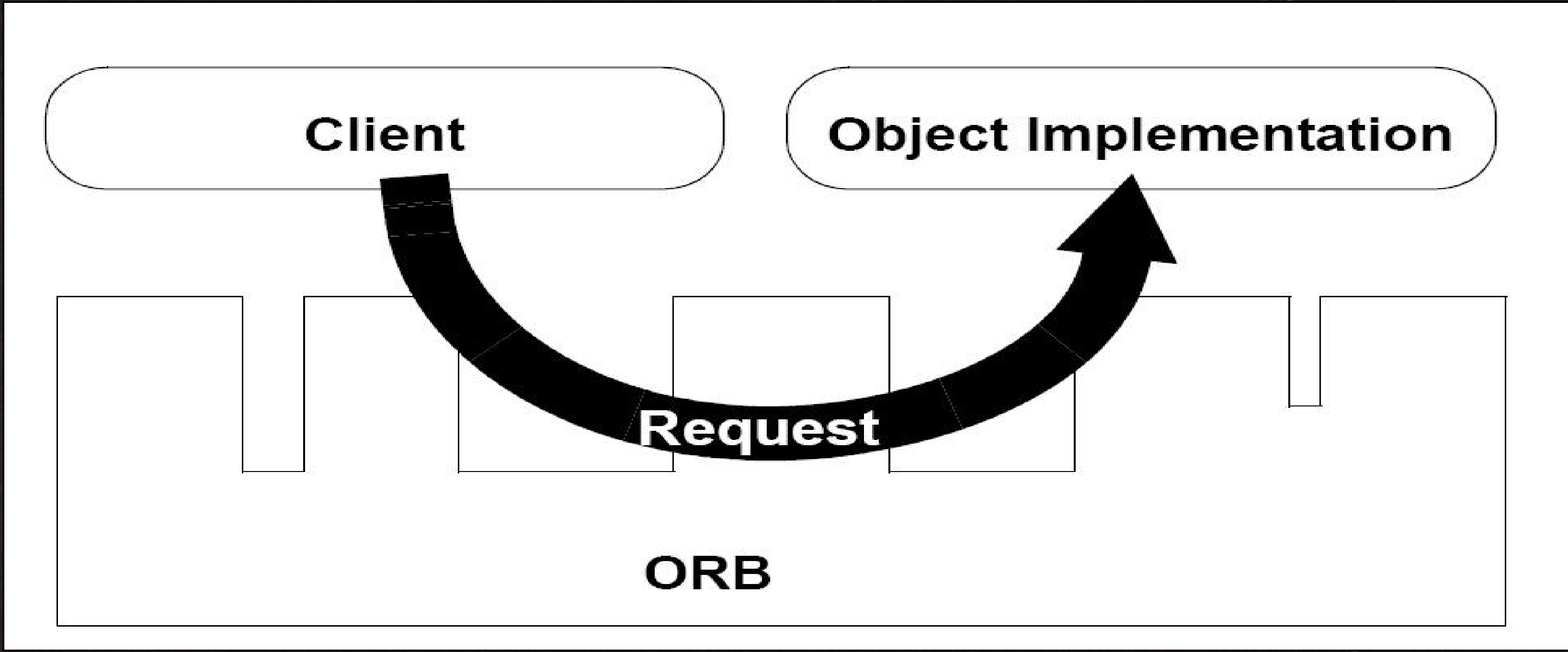
ALMA Common Software

- ACS (v1.1 & v2.0.1) provides:
  - CORBA
  - Distributed Objects (Container / Component model) to abstract hardware
  - Configuration database
  - Property value monitoring
  - Multi-language environment (C++, Python, Java)



CORBA

- CORBA facilitates the communication among pieces of software in distributed, heterogeneous, multilanguage environments



Test Interferometer Control Software

- TICS (v0.2, v0.5 & April 2004) provides:
  - Real-time software (VxWorks)
  - CAN (Controller Area Network) CORBA objects and bus interface to VERTEX ACU/PTC
  - Astronomical coordinate handling (descriptive RA/Dec and horizontal)
  - Basic patterns (linear, arc, curve strokes includ-ing On-The-Fly mode)
  - Monitoring database
  - Optical pointing

APECS Developments

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- ACS & TICS provide the basic infrastructure but a full telescope control system requires:
  - Hardware interfaces (“IDL”, “SCPI”)
  - Raw data format (“MBFITS”)
  - High-level observer interface (“apecs CLI”)
  - Observation coordination (“Observing Engine”)
  - Raw data writing (“FitsWriter”)
  - Online calibration pipeline (“Calibrator”)
  - Automatic observation logging (“Observation Logger”)
  - Monitoring tools (“Monitoring Engine”)

Hardware Interfaces

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- For each device one needs a CORBA Interface Definition Language (IDL) file
- CORBA C++ code is complicated. Instead embedded APEX systems use a simple ASCII protocol based on SCPI* commands sent via UDP sockets
- SCPI commands are derived from naming hierarchy and method and property names
- C++ code is auto-generated from IDLs

*Standard Commands for Programmable Instrumentation

SCPI Syntax Example

Component sends the device:

```
[APEX:]<device name>:<property name>?
```

The device replies:

```
[APEX:]<device name>:<property name> <value> \
       <ISO 8601 time stamp>
```

Example:

```
APEX:HET460:LO2:MULTI1:backShort2?
```

```
APEX:HET460:LO2:MULTI1:backShort2 2.341 \
     2003-11-05T10:19:38.310+00.00
```


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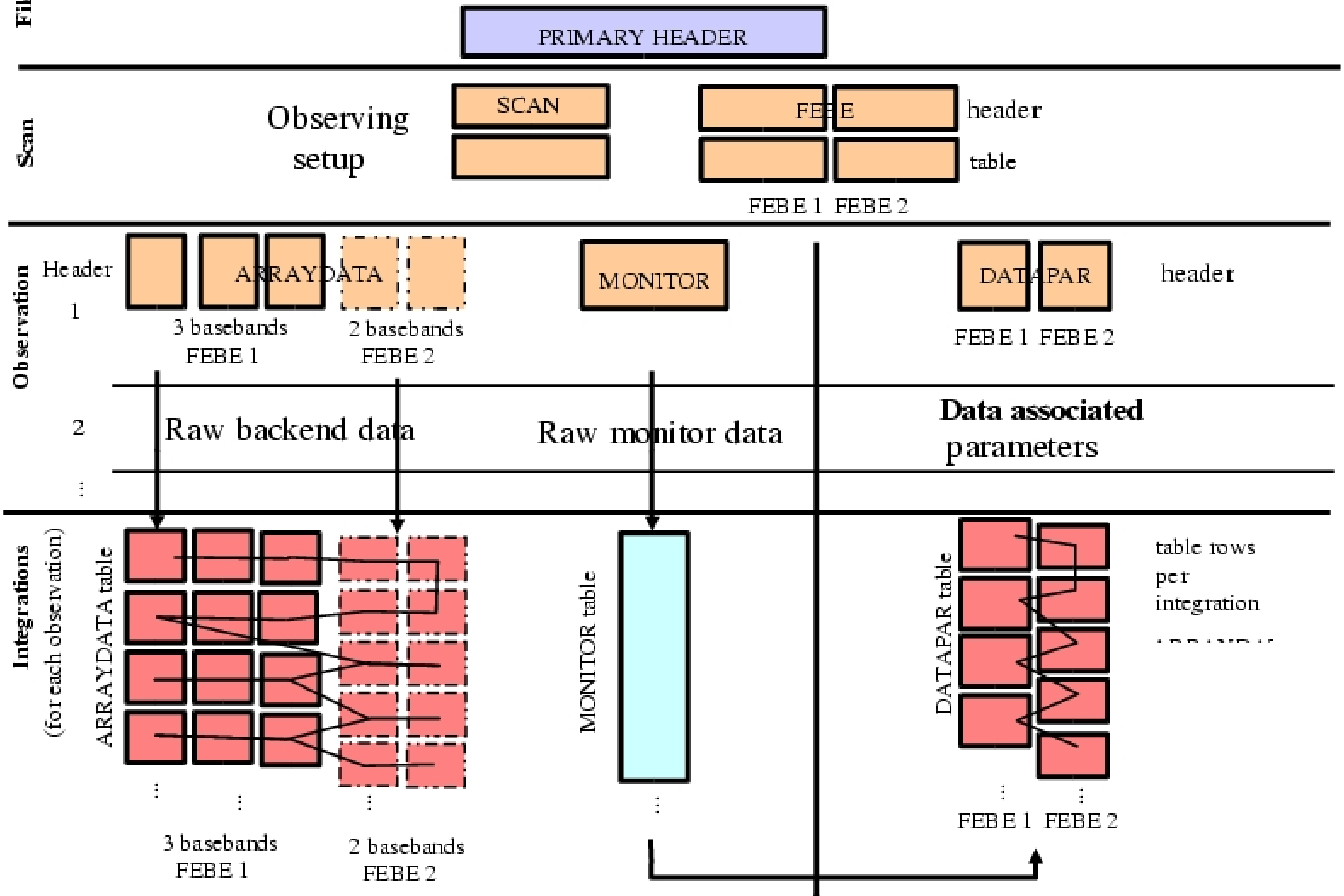
Generic Instrument Interfaces

- APECS uses high-level interfaces that are designed to be generic, i.e. applicable to any instrument of a given class (e.g. heterodyne receivers or continuum backends)
- The instrument setup thus needs to be implemented only once
- Adding new instruments to the system is reduced to simply adding names

Multi-Beam FITS (MBFITS)

- ALMA-TI FITS turned out to be unsuitable for the multi-beam single-dish data expected for APEX
- Began extending ALMA-TI FITS together with IRAM 30m and Effelsberg with the goal to share (mainly calibration) software
- Many detailed iteration cycles led to the MBFITS format which is now well iterated, stable and has been in use for 2 years

MBFITS block diagram v.1.2



"apecs" Command Line Interface

- IPython based CLI with extensible scripting language including user macros
- High-level commands to set up:
  - Catalogs (source, line)
  - Targets (coordinates, velocity)
  - Instruments (frontends, backends)
  - Calibrations (sky-hot-cold, skydip, point, focus)
  - Switch modes (total power, wobbling, freq. sw.)
  - Patterns (single, raster, OTF, (spiral))

dmuders@apecs:~

```
                 <heterodyne frontend name>.derotate, <frontend name>.backends,
                 <continuum / spectral backend name>,
                 <spectral backend name>_group
    Target:      source
    Calibration: calibrate, skydip, point, pcorr, pcorr_reset, focus, fcorr,
                 fcorr_reset
    Pattern:     offset, reference, use_ref, on, raster, otf, spiral, repeat
    Switch mode: tp, wob, fsw
    Antenna:     tolerance, park, stow, unstow


APECS> frontends 'flash810'
-----> frontends('flash810')
Modifying original frontend delta pointing model by (0.0", 0.0")
to recenter to feed number 1.

APECS> flash810.backends 'ffts'
-----> flash810.backends('ffts')
Setting dump time of 1.000000 seconds for backend FFTS.
Connecting section group 1 of backend FFTS to frontend FLASH810.
Configuring section group 1 of backend FFTS.
Resetting number of repeats to 1.

APECS> source 'jupiter'
-----> source('jupiter')
Setting up solar system body Jupiter.
Currently at Az=73.0° / El=70.6°. Distance to the Sun: 118.7°.
Resetting source offsets to (0.0, 0.0, system='EQ').
Resetting number of repeats to 1.

APECS>
```

Observing Engine

- Central coordinating process that sets up all devices according to the “Scan Objects” sent via the “apecs” CLI
- Pattern loop to set up receivers, IF, back-ends, antenna motion and start / stop FitsWriter and backends
- Background threads to update weather and IERS parameters needed for coordinate and refraction calculations

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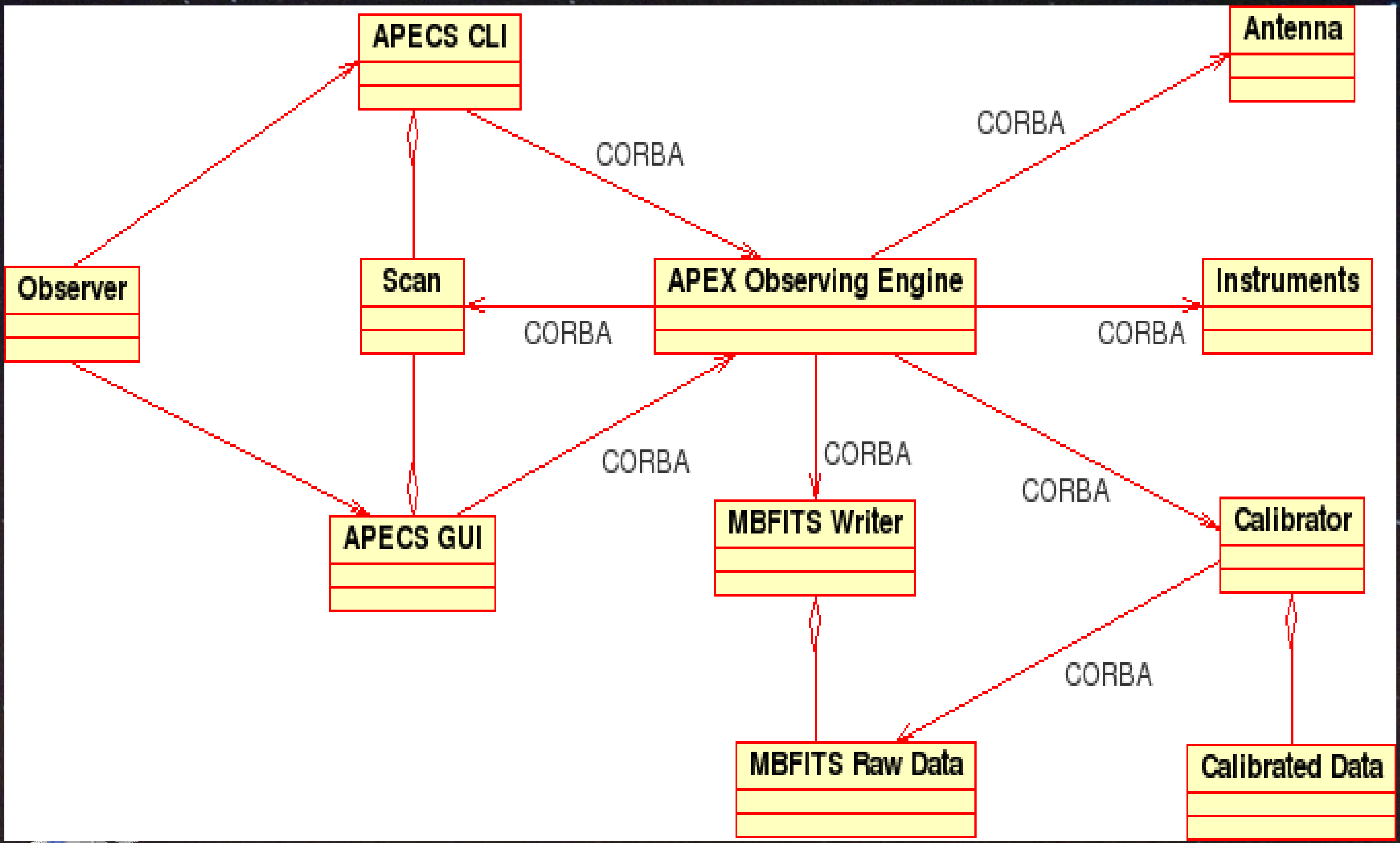
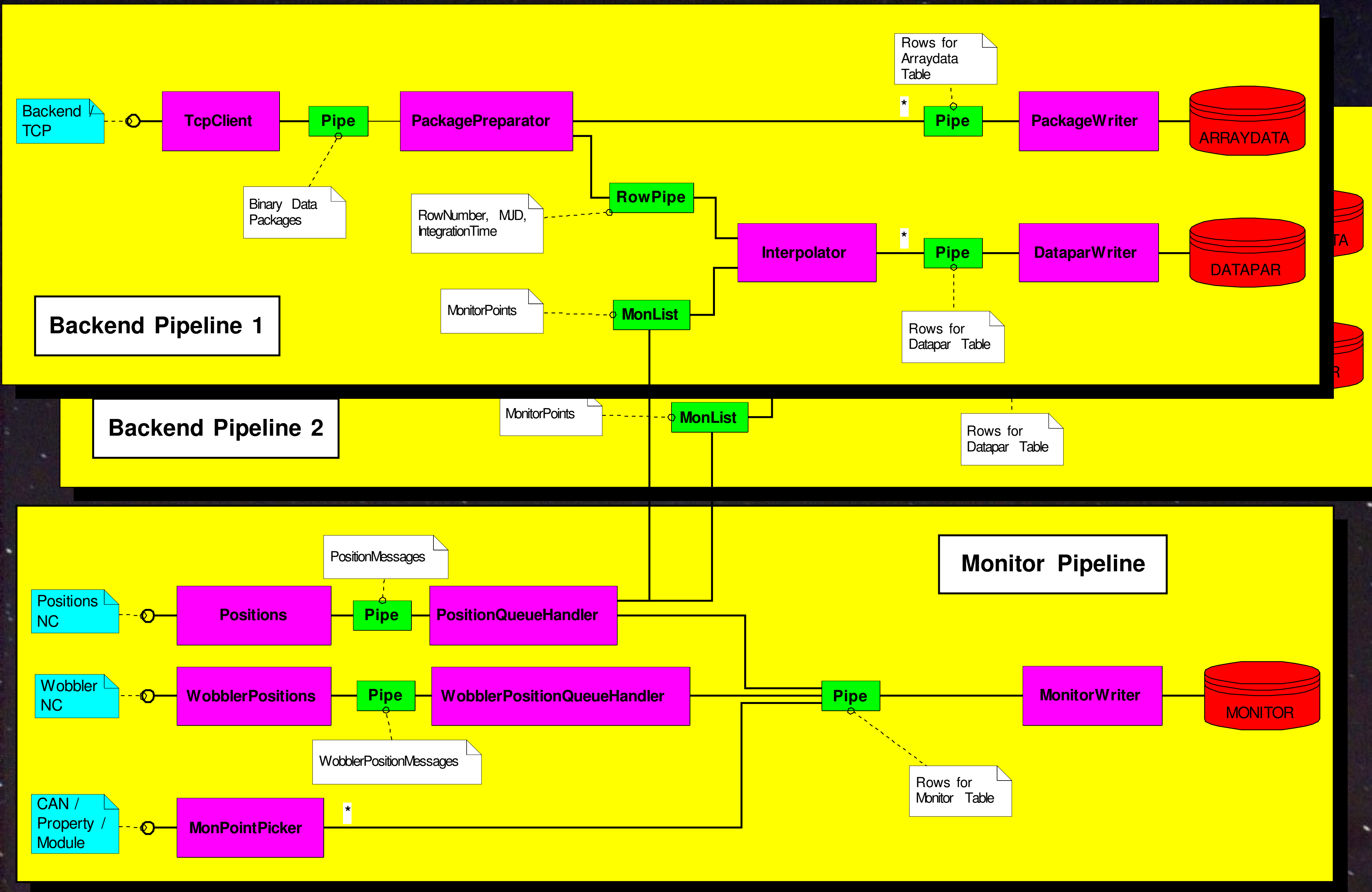
Observing Engine Interactions



FitsWriter

- The FitsWriter creates MBFITS files by collecting telescope, backend and monitoring data via a set of pipelines
- Each pipeline consists of pipes and filters and feeds a particular type of MBFITS binary table
- A flexible mechanism allows to store any CORBA property at any given rate in the MONITOR table


Backend TCP
TcpClient
Pipe
PackagePreparator
Rows for Arraydata Table
*
Pipe
PackageWriter
ARRAYDATA
Binary Data Packages
RowNumber, MJD, IntegrationTime
RowPipe
Interpolator
*
Pipe
DataparWriter
DATAPAR
Backend Pipeline 1
MonitorPoints
MonList
Rows for Datapar Table
Backend Pipeline 2
MonitorPoints
MonList
Rows for Datapar Table
PositionMessages
Monitor Pipeline
Positions NC
Positions
Pipe
PositionQueueHandler
Wobbler NC
WobblerPositions
Pipe
WobblerPositionQueueHandler
Pipe
MonitorWriter
MONITOR
WobblerPositionMessages
Rows for Monitor Table
CAN / Property / Module
MonPointPicker
*

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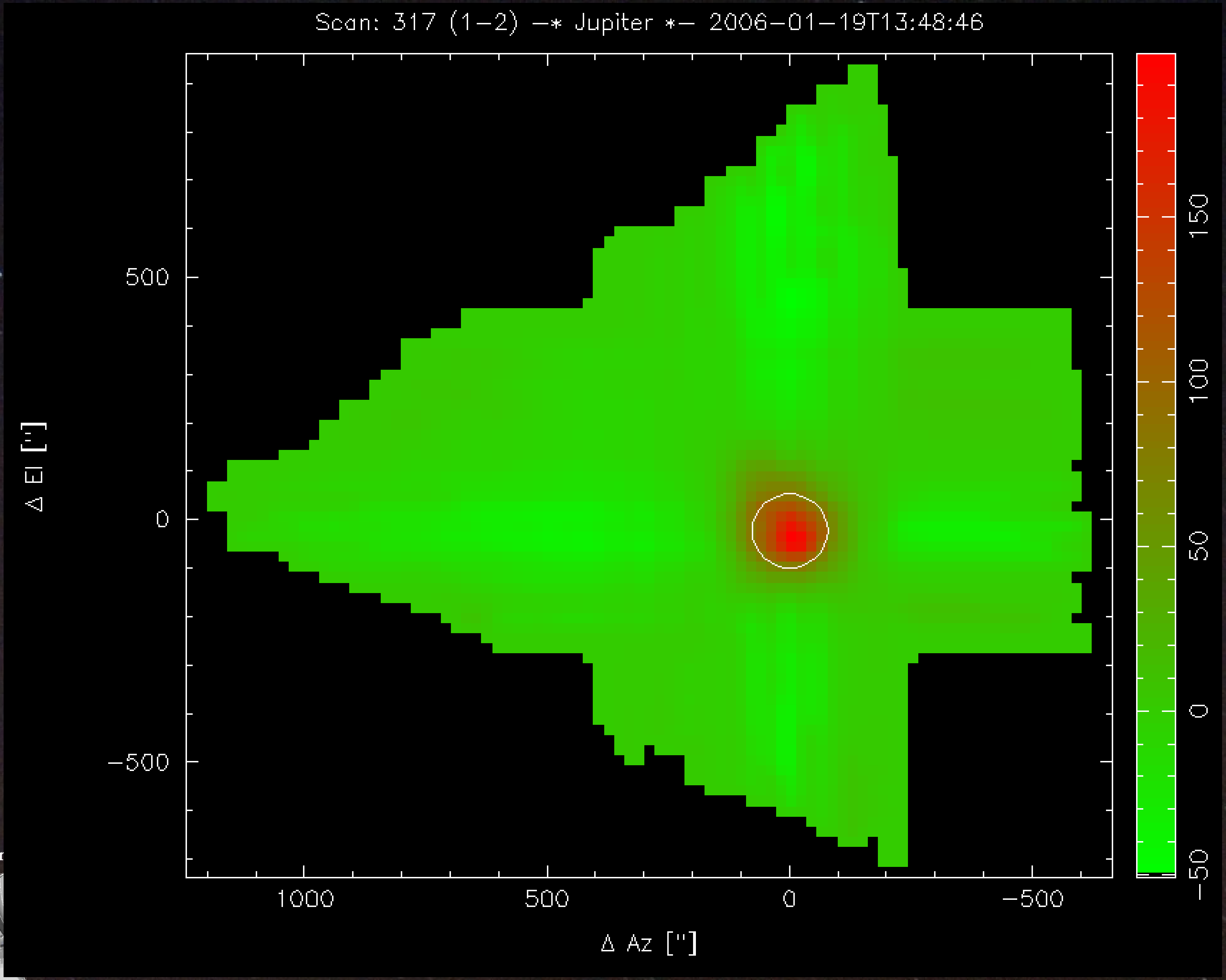
Calibrator

- The calibrator provides the online pipeline to process the MBFITS files after each sub-scan
- Spectral line data is calibrated to T_A^* scale using ATM and written to CLASS format
- Bolometer data is processed using the BoA modules
- Pointing & focus results are made available to the “apecs” CLI for corrections



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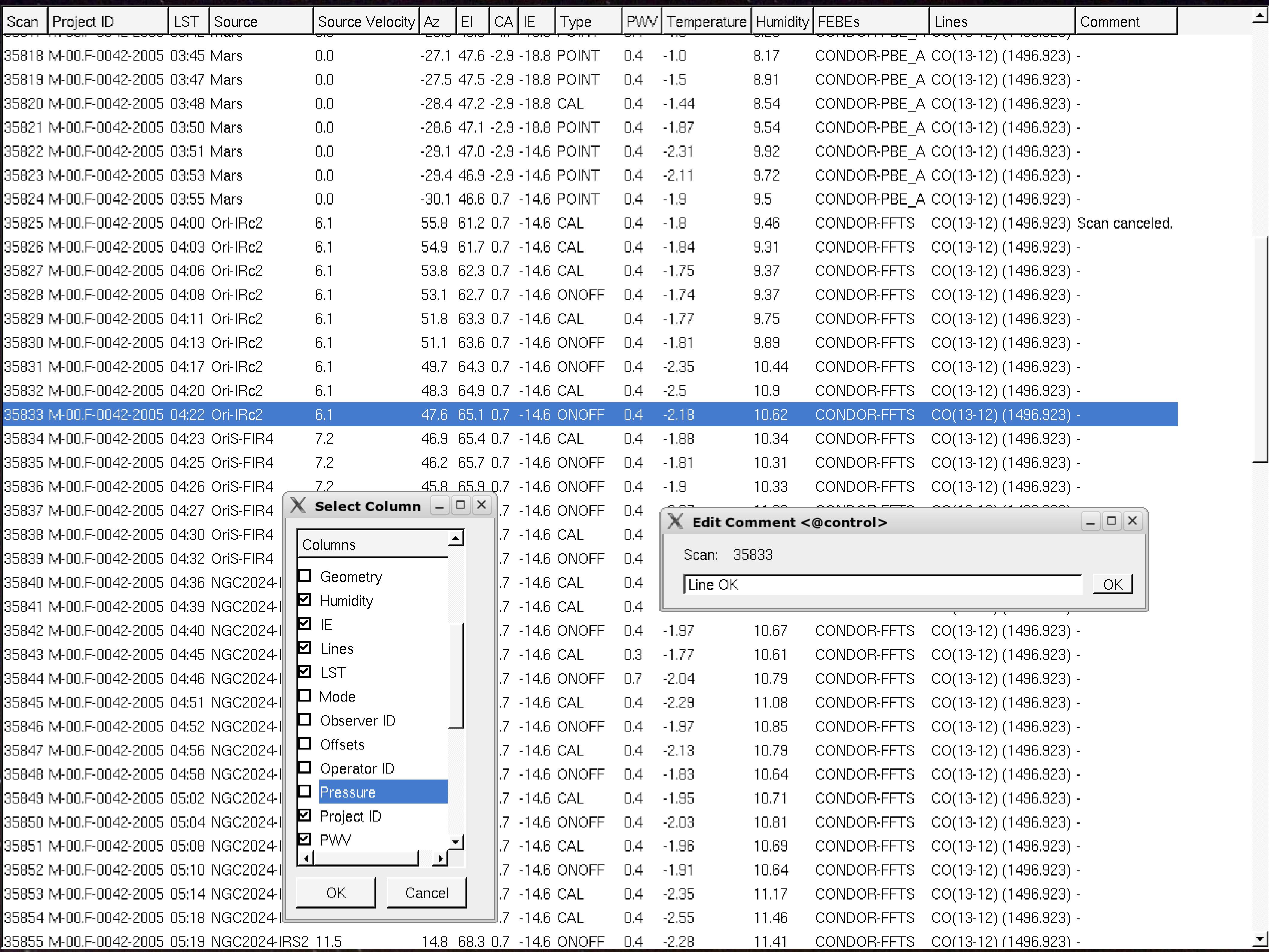
Observation Logger

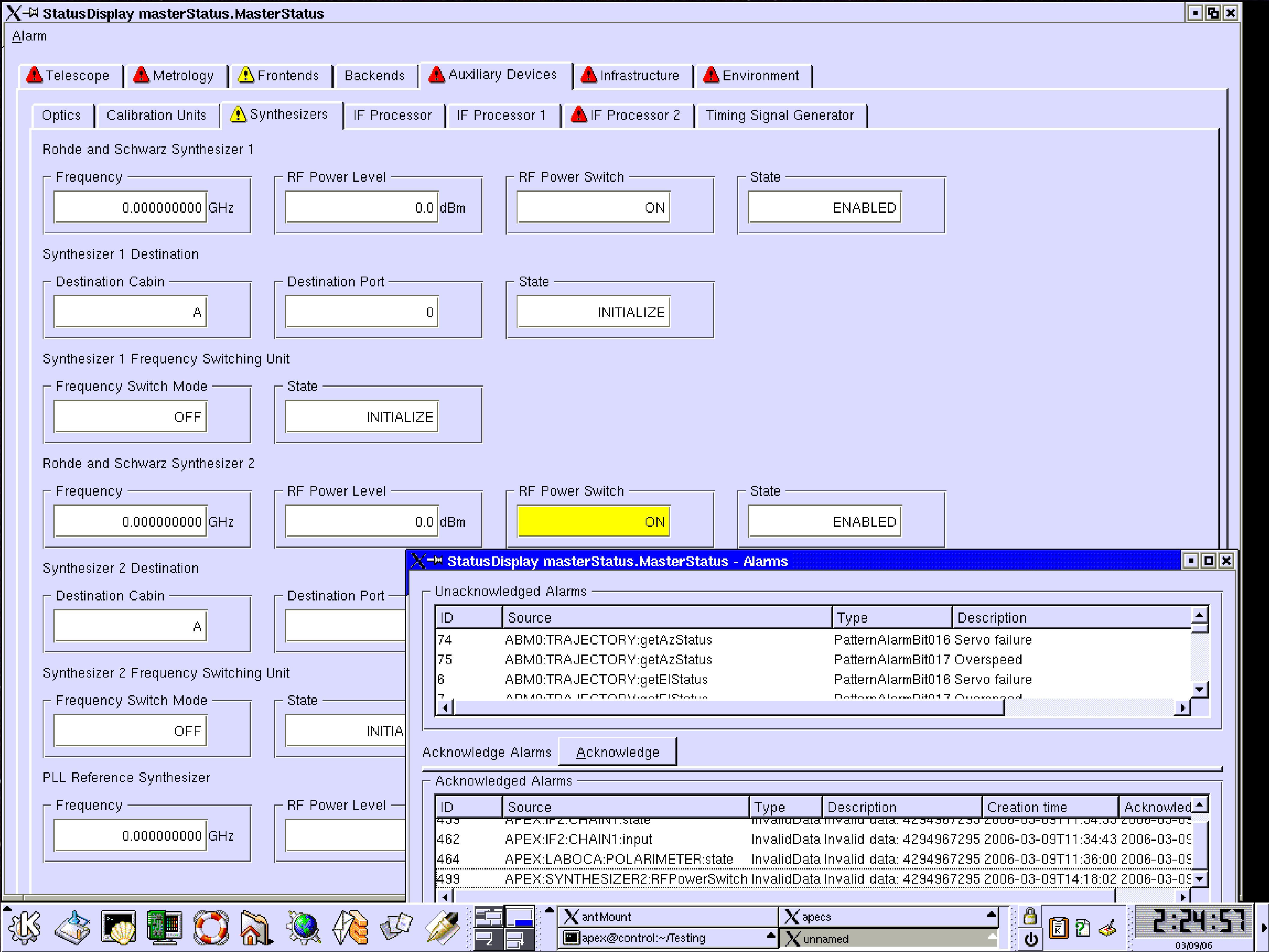
- Automatic creation of the observer's log (XML & HTML) using the online information
- Allows editing a comment field for each scan
- Visible columns can be selected individually



Scan	Project ID	LST	Source	Source Velocity	Az	El	CA	IE	Type	PWV	Temperature	Humidity	FEBEs	Lines	Comment
35818	M-00.F-0042-2005	03:45	Mars	0.0	-27.1	47.6	-2.9	-18.8	POINT	0.4	-1.0	8.17	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35819	M-00.F-0042-2005	03:47	Mars	0.0	-27.5	47.5	-2.9	-18.8	POINT	0.4	-1.5	8.91	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35820	M-00.F-0042-2005	03:48	Mars	0.0	-28.4	47.2	-2.9	-18.8	CAL	0.4	-1.44	8.54	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35821	M-00.F-0042-2005	03:50	Mars	0.0	-28.6	47.1	-2.9	-18.8	POINT	0.4	-1.87	9.54	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35822	M-00.F-0042-2005	03:51	Mars	0.0	-29.1	47.0	-2.9	-14.6	POINT	0.4	-2.31	9.92	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35823	M-00.F-0042-2005	03:53	Mars	0.0	-29.4	46.9	-2.9	-14.6	POINT	0.4	-2.11	9.72	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35824	M-00.F-0042-2005	03:55	Mars	0.0	-30.1	46.6	0.7	-14.6	POINT	0.4	-1.9	9.5	CONDOR-PBE_A	CO(13-12) (1496.923)	-
35825	M-00.F-0042-2005	04:00	Ori-IRc2	6.1	55.8	61.2	0.7	-14.6	CAL	0.4	-1.8	9.46	CONDOR-FFTS	CO(13-12) (1496.923)	Scan canceled.
35826	M-00.F-0042-2005	04:03	Ori-IRc2	6.1	54.9	61.7	0.7	-14.6	CAL	0.4	-1.84	9.31	CONDOR-FFTS	CO(13-12) (1496.923)	-
35827	M-00.F-0042-2005	04:06	Ori-IRc2	6.1	53.8	62.3	0.7	-14.6	CAL	0.4	-1.75	9.37	CONDOR-FFTS	CO(13-12) (1496.923)	-
35828	M-00.F-0042-2005	04:08	Ori-IRc2	6.1	53.1	62.7	0.7	-14.6	ONOFF	0.4	-1.74	9.37	CONDOR-FFTS	CO(13-12) (1496.923)	-
35829	M-00.F-0042-2005	04:11	Ori-IRc2	6.1	51.8	63.3	0.7	-14.6	CAL	0.4	-1.77	9.75	CONDOR-FFTS	CO(13-12) (1496.923)	-
35830	M-00.F-0042-2005	04:13	Ori-IRc2	6.1	51.1	63.6	0.7	-14.6	ONOFF	0.4	-1.81	9.89	CONDOR-FFTS	CO(13-12) (1496.923)	-
35831	M-00.F-0042-2005	04:17	Ori-IRc2	6.1	49.7	64.3	0.7	-14.6	ONOFF	0.4	-2.35	10.44	CONDOR-FFTS	CO(13-12) (1496.923)	-
35832	M-00.F-0042-2005	04:20	Ori-IRc2	6.1	48.3	64.9	0.7	-14.6	CAL	0.4	-2.5	10.9	CONDOR-FFTS	CO(13-12) (1496.923)	-
35833	M-00.F-0042-2005	04:22	Ori-IRc2	6.1	47.6	65.1	0.7	-14.6	ONOFF	0.4	-2.18	10.62	CONDOR-FFTS	CO(13-12) (1496.923)	-
35834	M-00.F-0042-2005	04:23	OriS-FIR4	7.2	46.9	65.4	0.7	-14.6	CAL	0.4	-1.88	10.34	CONDOR-FFTS	CO(13-12) (1496.923)	-
35835	M-00.F-0042-2005	04:25	OriS-FIR4	7.2	46.2	65.7	0.7	-14.6	ONOFF	0.4	-1.81	10.31	CONDOR-FFTS	CO(13-12) (1496.923)	-
35836	M-00.F-0042-2005	04:26	OriS-FIR4	7.2	45.8	65.9	0.7	-14.6	ONOFF	0.4	-1.9	10.33	CONDOR-FFTS	CO(13-12) (1496.923)	-
35837	M-00.F-0042-2005	04:27	OriS-FIR4				.7	-14.6	ONOFF	0.4					
35838	M-00.F-0042-2005	04:30	OriS-FIR4				.7	-14.6	CAL	0.4					
35839	M-00.F-0042-2005	04:32	OriS-FIR4				.7	-14.6	ONOFF	0.4					
35840	M-00.F-0042-2005	04:36	NGC2024-I				.7	-14.6	CAL	0.4					
35841	M-00.F-0042-2005	04:39	NGC2024-I				.7	-14.6	CAL	0.4					
35842	M-00.F-0042-2005	04:40	NGC2024-I				.7	-14.6	ONOFF	0.4	-1.97	10.67	CONDOR-FFTS	CO(13-12) (1496.923)	-
35843	M-00.F-0042-2005	04:45	NGC2024-I				.7	-14.6	CAL	0.3	-1.77	10.61	CONDOR-FFTS	CO(13-12) (1496.923)	-
35844	M-00.F-0042-2005	04:46	NGC2024-I				.7	-14.6	ONOFF	0.7	-2.04	10.79	CONDOR-FFTS	CO(13-12) (1496.923)	-
35845	M-00.F-0042-2005	04:51	NGC2024-I				.7	-14.6	CAL	0.4	-2.29	11.08	CONDOR-FFTS	CO(13-12) (1496.923)	-
35846	M-00.F-0042-2005	04:52	NGC2024-I				.7	-14.6	ONOFF	0.4	-1.97	10.85	CONDOR-FFTS	CO(13-12) (1496.923)	-
35847	M-00.F-0042-2005	04:56	NGC2024-I				.7	-14.6	CAL	0.4	-2.13	10.79	CONDOR-FFTS	CO(13-12) (1496.923)	-
35848	M-00.F-0042-2005	04:58	NGC2024-I				.7	-14.6	ONOFF	0.4	-1.83	10.64	CONDOR-FFTS	CO(13-12) (1496.923)	-
35849	M-00.F-0042-2005	05:02	NGC2024-I				.7	-14.6	CAL	0.4	-1.95	10.71	CONDOR-FFTS	CO(13-12) (1496.923)	-
35850	M-00.F-0042-2005	05:04	NGC2024-I				.7	-14.6	ONOFF	0.4	-2.03	10.81	CONDOR-FFTS	CO(13-12) (1496.923)	-
35851	M-00.F-0042-2005	05:08	NGC2024-I				.7	-14.6	CAL	0.4	-1.96	10.69	CONDOR-FFTS	CO(13-12) (1496.923)	-
35852	M-00.F-0042-2005	05:10	NGC2024-I				.7	-14.6	ONOFF	0.4	-1.91	10.64	CONDOR-FFTS	CO(13-12) (1496.923)	-
35853	M-00.F-0042-2005	05:14	NGC2024-I				.7	-14.6	CAL	0.4	-2.35	11.17	CONDOR-FFTS	CO(13-12) (1496.923)	-
35854	M-00.F-0042-2005	05:18	NGC2024-I				.7	-14.6	CAL	0.4	-2.55	11.46	CONDOR-FFTS	CO(13-12) (1496.923)	-
35855	M-00.F-0042-2005	05:19	NGC2024-IRS2	11.5	14.8	68.3	0.7	-14.6	ONOFF	0.4	-2.28	11.41	CONDOR-FFTS	CO(13-12) (1496.923)	-

Monitoring Engine

- Generic graphical status display engine using the ACS archiving notification channel
- Displays can be created using the standard “Qt Designer” program obeying a given naming convention for values, descriptions and units


StatusDisplay masterStatus.MasterStatus
Alarm
Telescope
Metrology
Frontends
Backends
Auxiliary Devices
Infrastructure
Environment
Optics
Calibration Units
Synthesizers
IF Processor
IF Processor 1
IF Processor 2
Timing Signal Generator
Rohde and Schwarz Synthesizer 1
Frequency
0.000000000 GHz
RF Power Level
0.0 dBm
RF Power Switch
ON
State
ENABLED
Synthesizer 1 Destination
Destination Cabin
A
Destination Port
0
State
INITIALIZE
Synthesizer 1 Frequency Switching Unit
Frequency Switch Mode
OFF
State
INITIALIZE
Rohde and Schwarz Synthesizer 2
Frequency
0.000000000 GHz
RF Power Level
0.0 dBm
RF Power Switch
ON
State
ENABLED
Synthesizer 2 Destination
Destination Cabin
A
Destination Port
Synthesizer 2 Frequency Switching Unit
Frequency Switch Mode
OFF
State
INITIA
PLL Reference Synthesizer
Frequency
0.000000000 GHz
RF Power Level
StatusDisplay masterStatus.MasterStatus - Alarms
Unacknowledged Alarms
ID Source Type Description
74 ABM0:TRAJECTORY:getAzStatus PatternAlarmBit016 Servo failure
75 ABM0:TRAJECTORY:getAzStatus PatternAlarmBit017 Overspeed
6 ABM0:TRAJECTORY:getElStatus PatternAlarmBit016 Servo failure
Acknowledge Alarms
Acknowledge
Acknowledged Alarms
ID Source Type Description Creation time Acknowled
462 APEX:IF2:CHAIN1:input InvalidData Invalid data: 4294967295 2006-03-09T11:34:43 2006-03-09
464 APEX:LABOCA:POLARIMETER:state InvalidData Invalid data: 4294967295 2006-03-09T11:36:00 2006-03-09
499 APEX:SYNTHESIZER2:RFPowerSwitch InvalidData Invalid data: 4294967295 2006-03-09T14:18:02 2006-03-09
antMount
apecs
apex@control:~/Testing
unnamed
2:24:57
03/09/06

APECS Key Facts

- Modern object-oriented & distributed design
- Generic instrument interfaces facilitate adding new devices
- Automatic interface code generator
- Simple ASCII communication to embedded systems
- High-level scripting language
- Generic GUIs
- Monitoring database
- Simulation system for developments (demo)

Future APECS Developments I

- New observing patterns (spirals, circles, more complex lists of strokes)
- Array de-rotation
- Frequency switching mode
- Wobbler mode

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Future APECS Developments II

- MBFITS split into several files using FITS hierarchical groups
- Porting to ACS 5 under Scientific Linux 4.2
- New servers for Chajnantor
- “xapecs” GUI

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