Putting the Robo in Robo-AO

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for the Robo-AO Team

Workshop on Astronomy with Adaptive Optics
on Moderate Sized Telescopes
IUCAA, Pune, India
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The Robo-AO Team

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The Inter-University Centre for Astronomy and Astrophysics, Pune, India

The Robo-AO Team

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Robo-AO Vision

- Design and deploy an AO system for 1-3 m telescopes
  - Laser Guide Star
  - Robotic
- Do high throughput science
  - Lots of small telescope time available
  - Unique science capability
- Make it affordable
- Put copies on 1-3 m telescopes around the world
  - Pomona College
  - IUCAA
  - Other discussions ongoing...

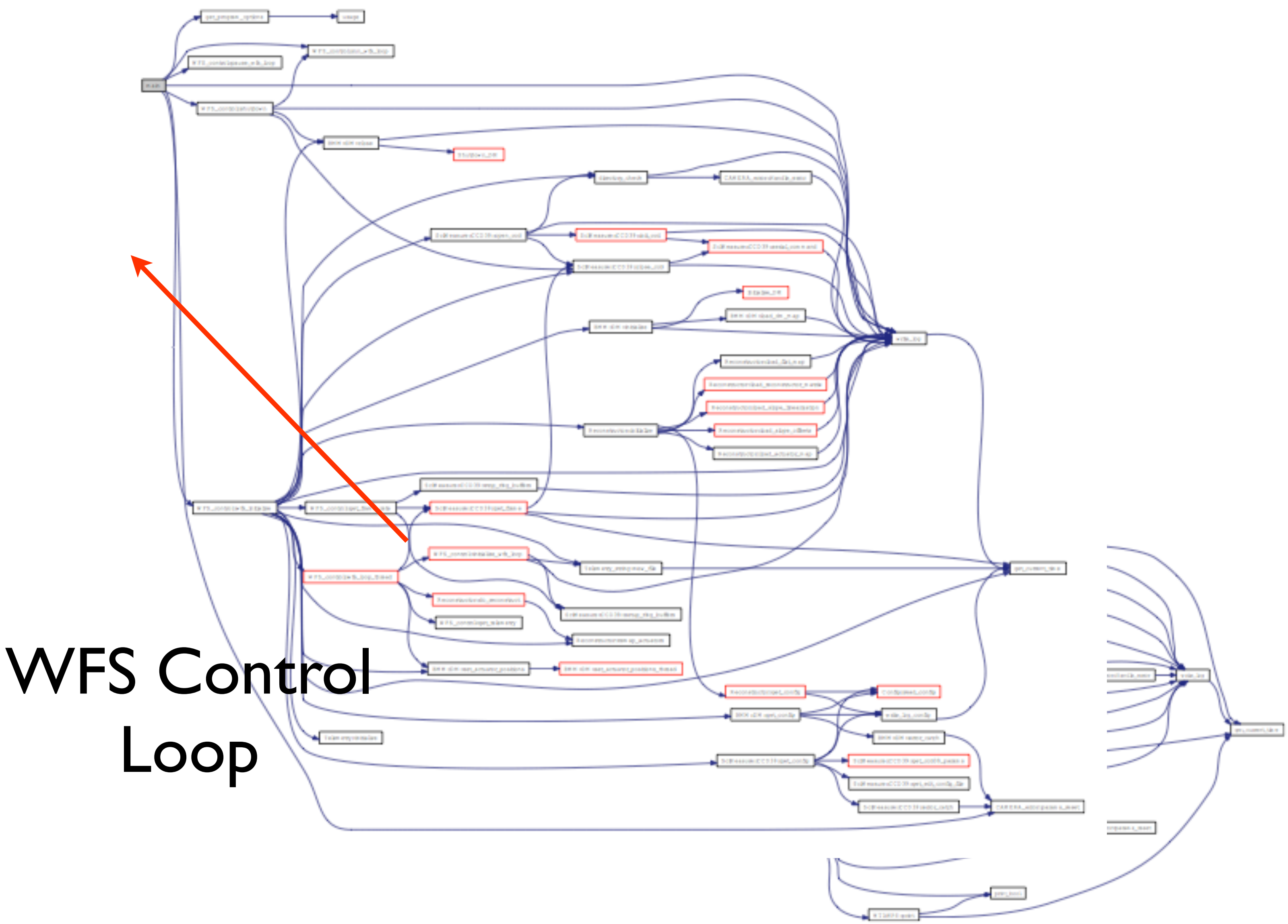
Robotic Adaptive Optics

- First system to operate LGS autonomously
  - Completely independent operations
  - Challenging, increases complexity
- Intelligence is hard to program
  - Error control and exception handling
  - Ability to adjust to changing conditions
- Safety
  - Safety system for all equipment
  - Fail safe operation of all subsystems
  - Aircraft safety no issue
  - Laser safety a priority
    - Laser must always beam properly (US STRATCOM)

Software Design and Documentation

- Linux environment (Fedora 13) on single computer
  - Developed in C++
    - Multi-threading
    - Extensive exception handing
    - 65,000+ lines of documented code (so far...)
  - Scripting in Bash
- Modular software design
  - Adding other hardware should be “easy”
  - Telescope interface
- Web display of operations, no proper GUI
- Not using real-time Linux
- Full documentation of code with Doxygen

WFS Test Program

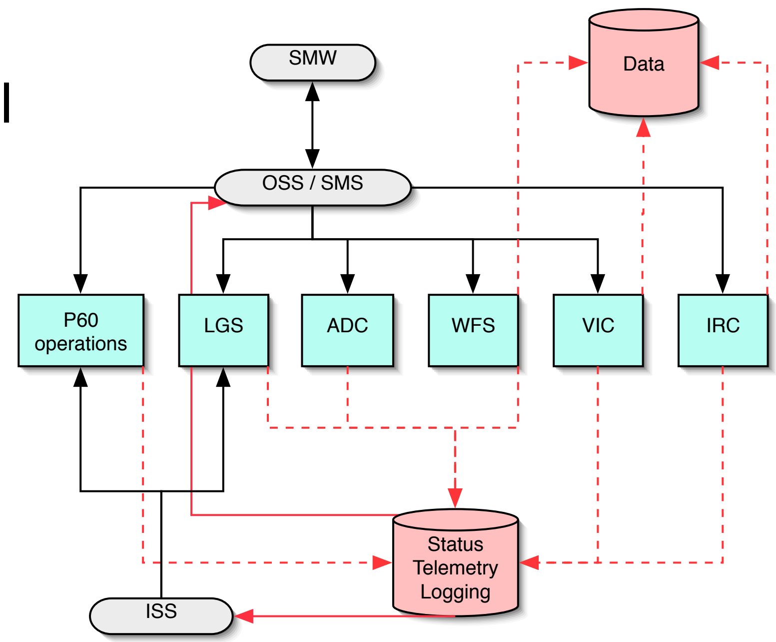


The Robo-AO System

- Several hardware subsystems
  - Each requires interface, control software
- Wave Front Sensor (WFS)
  - CCD, Deformable mirror, Tip/tilt mirror
- Laser Guide Star (LGS)
  - Laser, Chiller, Shutter, Beam steering mirror
- Atmospheric Dispersion Corrector (ADC)
- Visible Instrument camera (VIC)
- IR instrument camera (IRC)
- Palomar 60” (P60) operations

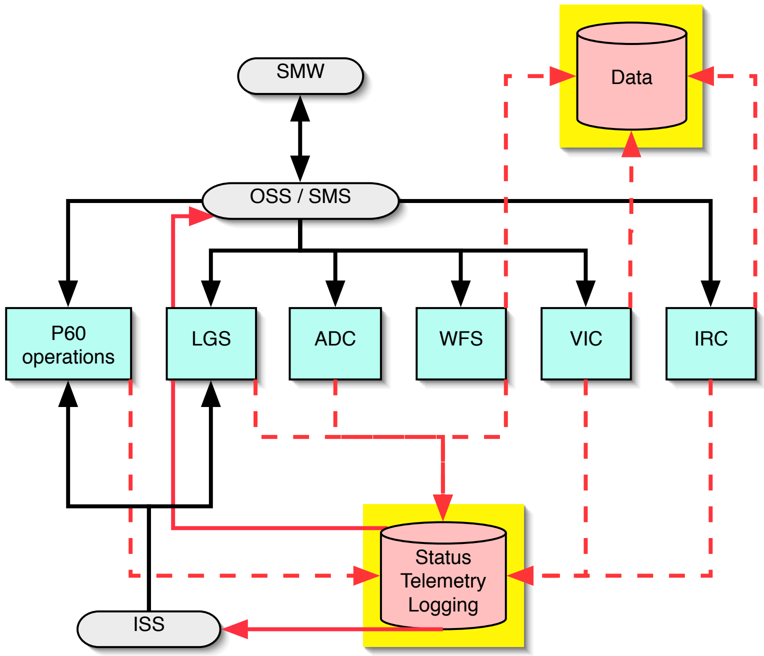
Robotic Software Architecture

- Fully robotic control system
  - Each requires interface and control software
  - Subsystems as daemons
- Supervisor controls scheduling, operations, oversight
- Watchdog processes
- Robotic system operates all of the subsystems as one instrument



Robo-AO Utilities Library

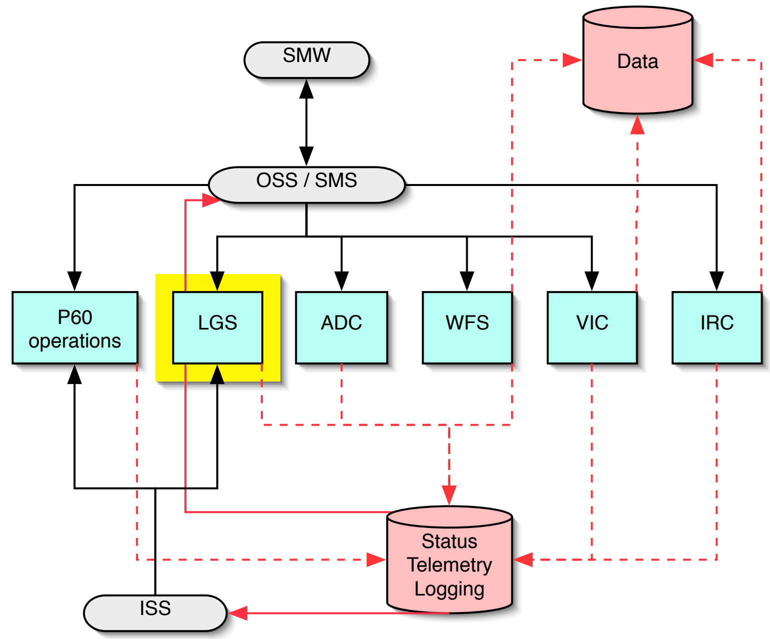
- Threaded message logging
- Threaded FITS handling system
- Threaded asynchronous TCP/IP communications layer
- Threaded high speed telemetry
- Serial port communications
- Network Power Switch control
- File operations
- Astronomy and time functions



- Various other common operations

Laser Guide Star

- JDSU UV laser
  - Serial interface
  - Chiller system
- Cleared for use with aircraft



- Control software
  - System monitoring
  - Error control
  - Command operations
- “Complete” and in production form
  - Most mature software

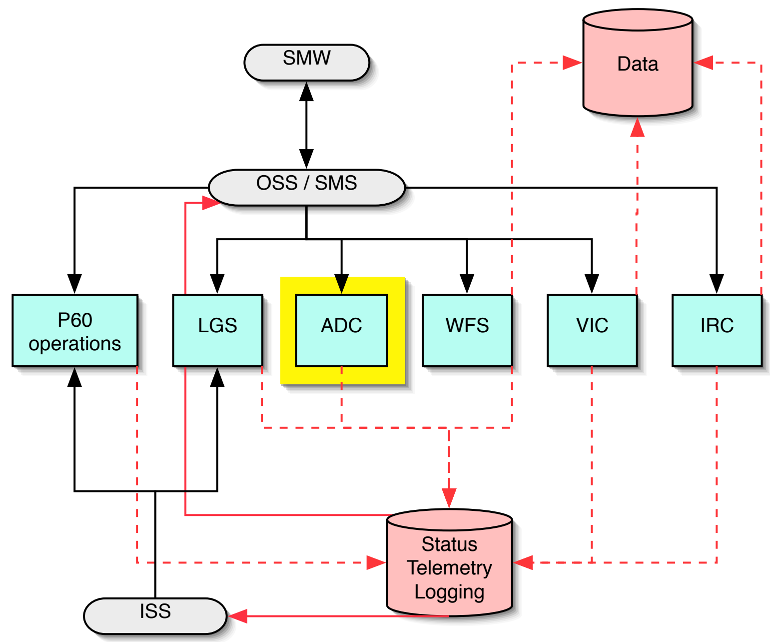
LGS and US STRATCOM

- US STRATCOM requires all US lasers to register for satellite safety
  - Send targets 3-4 days in advance
  - Receive "open window" times
- LGS monitoring software
  - Open windows
  - Telescope position
  - File updates

- Lab & on sky tests successful
- Used as LGS safety system

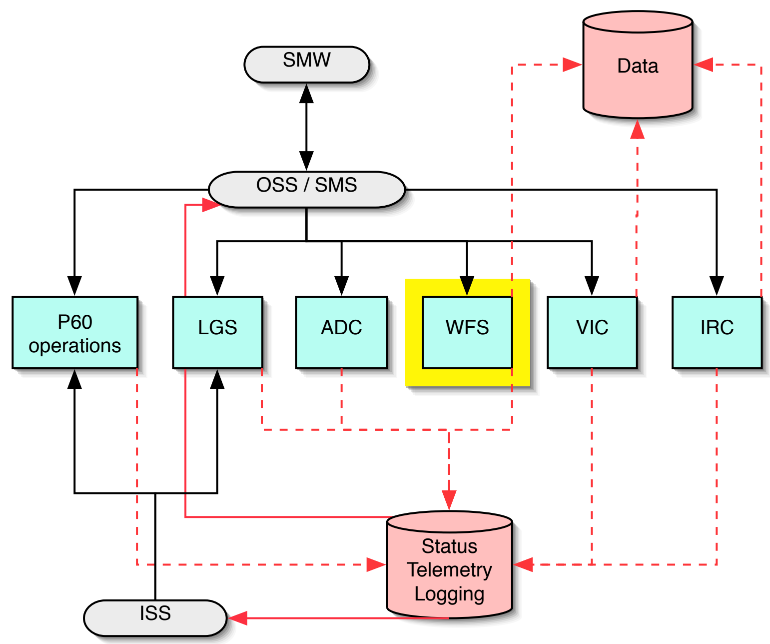
Atmospheric Dispersion Corrector

- Newport ESP300 controller
  - Serial interface
  - Two rotation stages
- Control software
  - System monitoring
  - Error control
  - Command operations
- Lab tests successful
- “Complete” and daemonized
  - Needs testing on sky



Wave Front Sensor

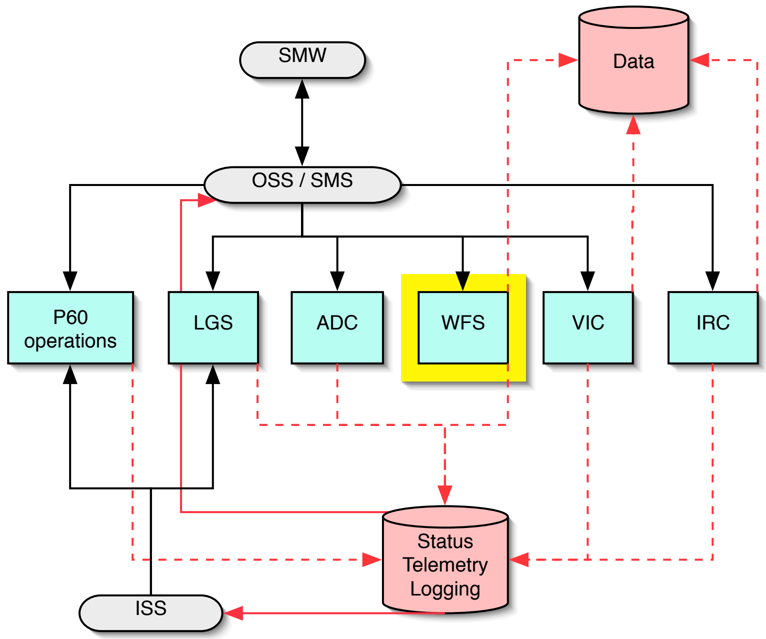
- SciMeasure CCD39
- BMC 140 actuator DM
  - IUCAA USB interface driver
- PI tip/tilt mirror controller
- Tip/tilt detector
  - Visible and IR channels



- Configuration files for parameters
- Modal reconstructor, Zernike N=12
- DM commands threaded

Wave Front Sensor

- First closed loop Dec. 2009
  - 1.2kHz with telemetry
  - Drop no frames, handful with telemetry
- On sky operation in August 2011
  - Tip/tilt control from visible camera
- Daemonized
- Still work to do



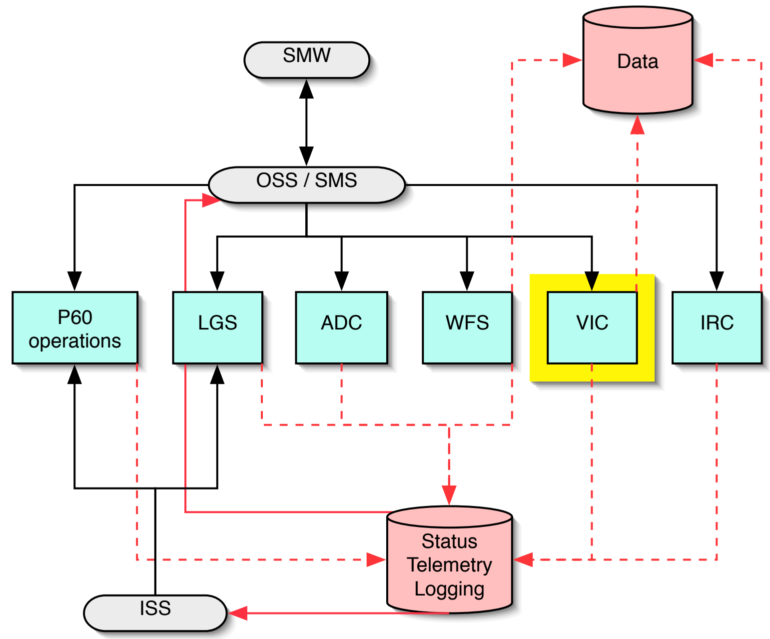
SciMeasure rate: 1.965 kHz
No telemetry

CCD readout	382.46	0.0000254
Reconstructor	111.14	0.0736
DM	13.37	0.136
Total	506.96	0.0155

Dropped frames: 0

Visible Instrument Camera

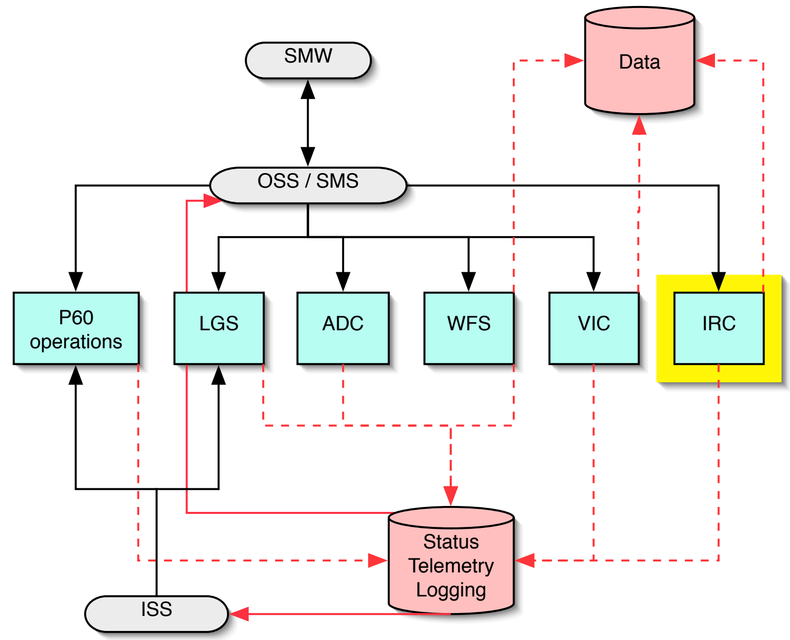
- Andor iXon 888 EMCCD
  - Both science and tip/tilt operations
- Control software
  - Same architecture as LGS, ADC
  - Command layer to SDK
  - High speed and science modes
  - IUCAA filter wheel software



- Basic operational software
- Integrated into WFS as tip-tilt CCD
- Need to finalize science ops software

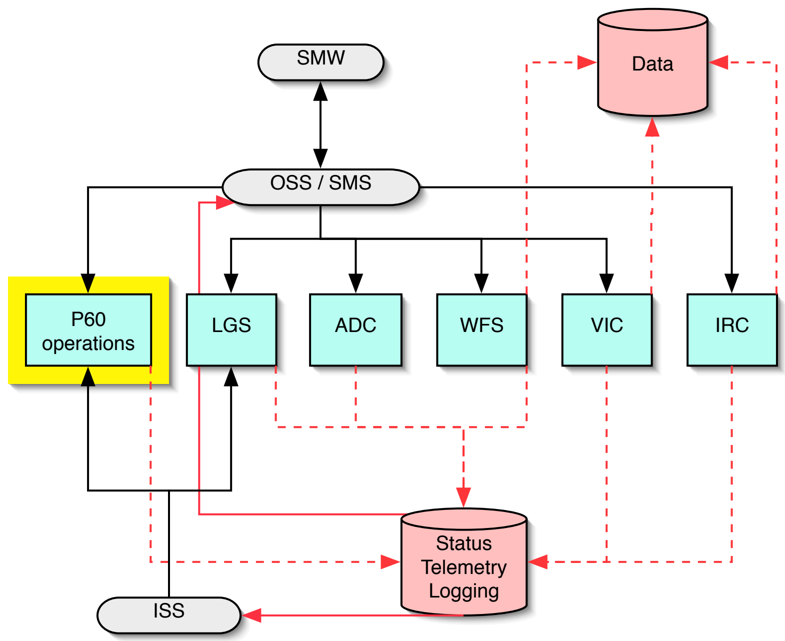
IR Camera

- Using Xenics InGaAs camera for engineering tests
- Developing H2RG based science camera
- Software under development
  - Based on Andor system
  - IUCAA filter wheel software
  - Will do tip-tilt and science observations



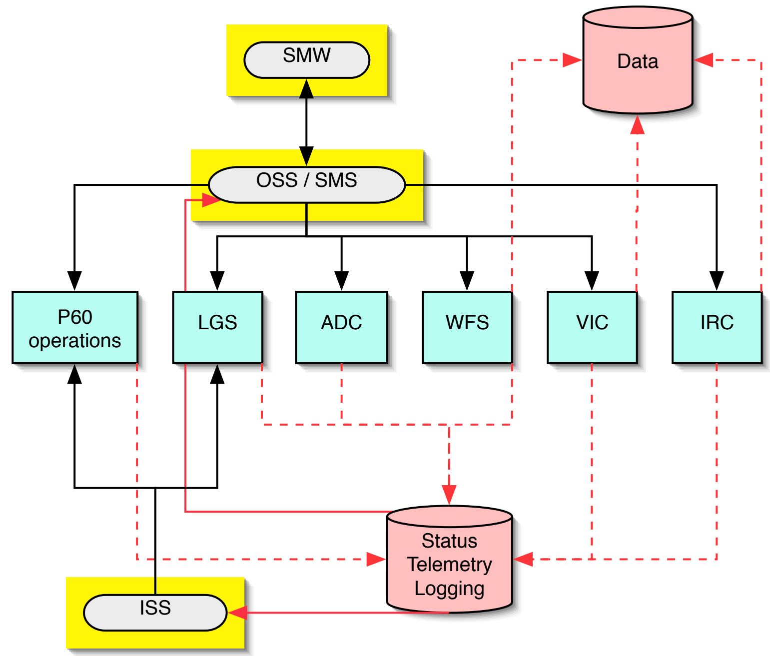
P60 Operations

- Telescope is automated, interface straightforward
- Three parts to interface:
  - Telescope position (~10 Hz)
  - TCS status (1 Hz)
  - Environment (1 Hz)
    - ✳ Weather station
    - ✳ Internal sensors (IUCAA)
- Functional, needs work
  - Multi-channel communications



Supervisor Processes

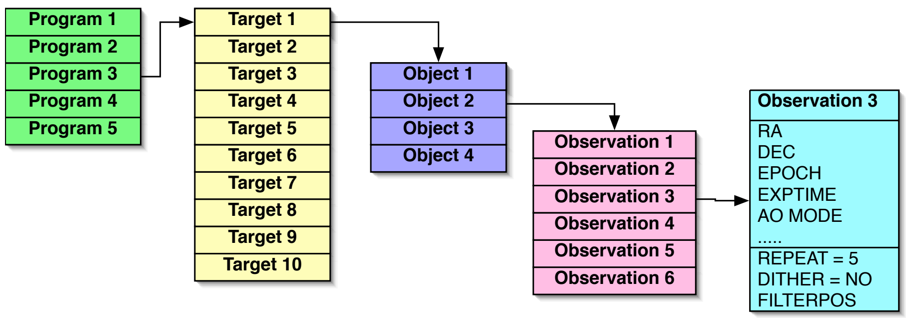
- Four parts
  - Status Monitoring System (SMS)
  - Observation Sequencing System (OSS)
  - Instrument Safety System (ISS)
  - System Monitor Watchdog (SMW)
- Data management
- Comprehensive telemetry and logging



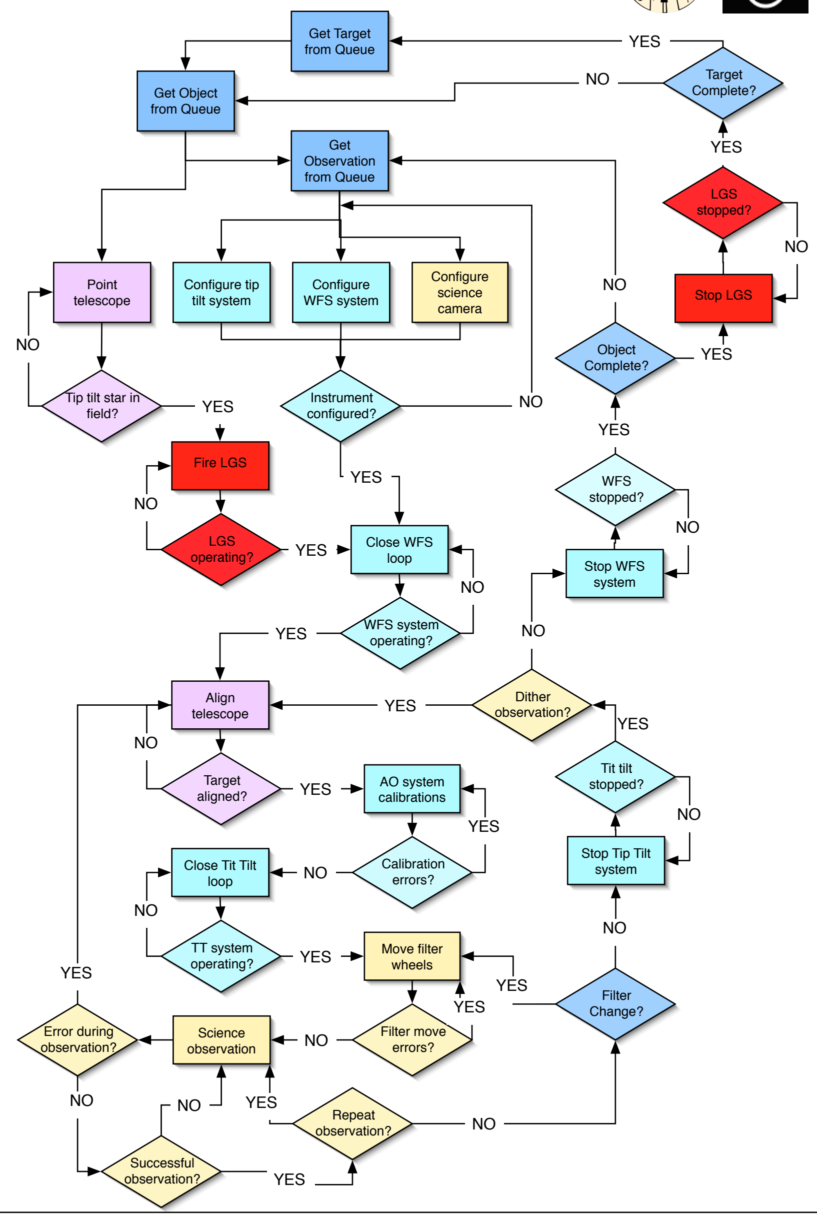
- Under development

Observing Sequencing System

- Target based queue system



- Queue output sent to OSS
  - Instrument configuration
  - Telescope alignment
  - AO system operations
  - Science!



Robotic Operations and Observations

- Each evening, system starts autonomously
  - ~2 hr before sunset, LGS initialization
  - At sunset, start subsystem operations
    - Calibration data
    - TCS initialization

- Observation sequence
  - Check conditions
  - Select target, point to it
  - Configure WFS, LGS, ADC, data instrument
  - Start WFS system, calibrate
  - Complete observations

Robotic Operations and Observations

- Morning shutdown
  - Power down instruments safely, park and close telescope
  - Archive data, logs, telemetry
  - Send night report

- In parallel during operations:
  - Monitoring of instrument status
  - Monitoring of weather status
  - Monitoring of safety of systems

Error and Exception Handling

- Errors will happen!

- Daemon status thread identifies error
  - SMS/OSS monitors daemon operation
- Error handling thread tries to “fix” error
  - Fix depends on error (this is the intelligence part)
  - Have to identify errors to fix them
- If unsuccessful X times, system shuts down

- SMS/OSS attempts restart of system
- Finally, call for help!

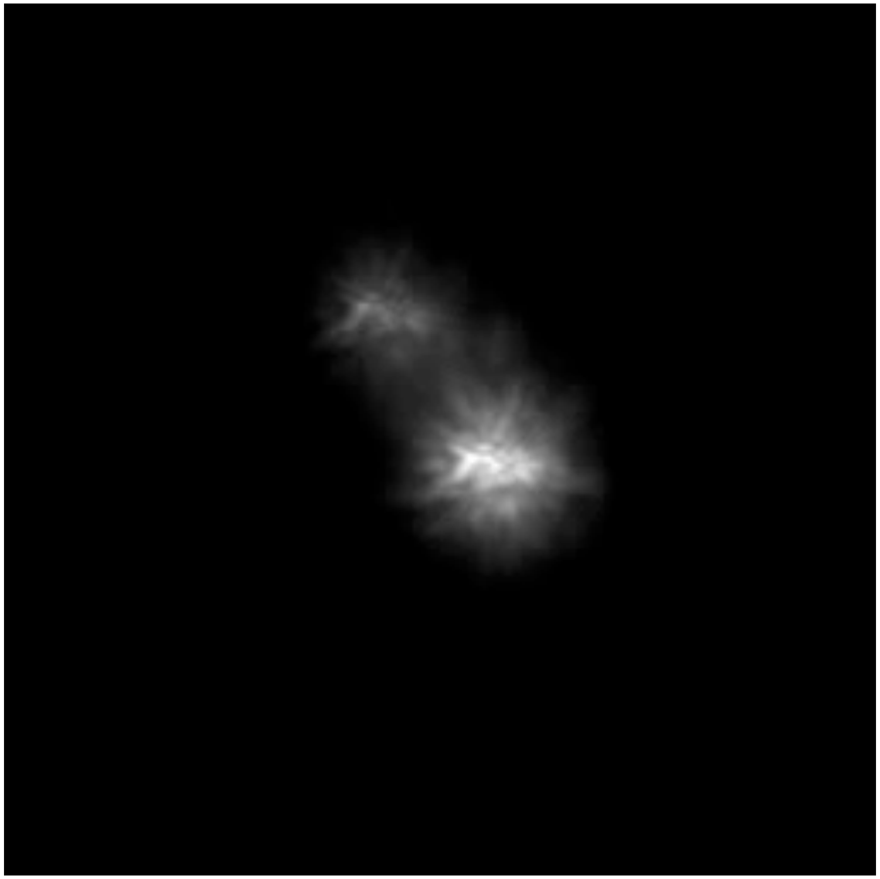
Next Steps for Robo-AO Software

- Continue development
  - Supervisor processes
  - Operational testing
  - Fix bugs
- On sky engineering testing through end of year
- Science demonstration period
- Future expansion to other telescopes
  - Software design already preparing for this

Conclusion

- First autonomous AO system with LGS
- Designed to operate in fail safe fashion
- Under development now
- August 2011: First light with entire instrument, successful operation of basic capabilities
- 2011 and 2012: Development, one month total of demonstration science observations

So, does it really work?



http://www.astro.caltech.edu/Robo-AO/