Robo-AO:

The first autonomous laser guide star adaptive optics system for 1 to 3 meter telescopes

Reed L. Riddle
for the Robo-AO Team

Telescopes from Afar
March 1, 2011

The Robo-AO Team

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The Robo-AO Team

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Science Team

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Shriharsh Tendulkar	Marten van Kerkwijk

Technical Team

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Original CAMERA concept and testbed team

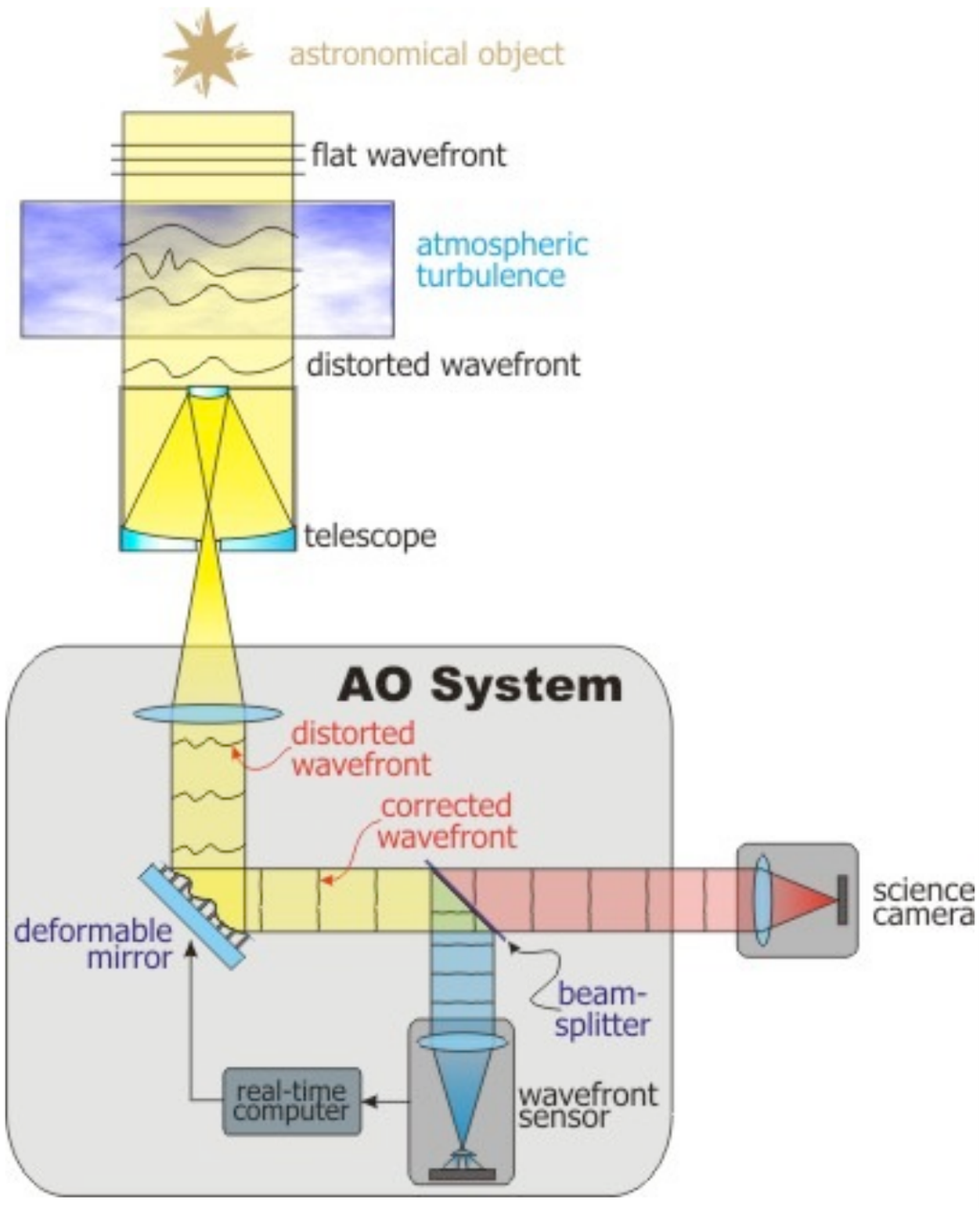
Matthew Britton	Nicholas Law
Viswa Velur	Dan Beeler (Pomona ’09
Lothar Ratschbacher (Vienna)	

What is Adaptive Optics?

- Remove atmosphere effects
  - "remove the twinkle of stars"

- Key components
  - Rapid readout sensor
  - Wavefront corrector
  - Fast computer(s)

- Comparison object
  - Natural Guide Star (NGS)
  - Laser Guide Star (LGS)
    - ✳ Requires tip tilt correction



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)

Robo-AO Performance

- Diffraction-limited resolution
  - ~0.1-0.15” in the visible
  - ~0.2-0.25” in the near-infrared
  - All targets brighter than m_V=17
  - 30% sky coverage at diffraction-limited resolution
- General imaging
  - Visible and infrared
- Observe lots of targets
  - Overhead ~70 seconds or less per target
  - 2 mins integration time => ~150 targets per night
- 4200 targets in 4 weeks
  - Actually possible with time available on a 2m-class telescope!

Science Programs

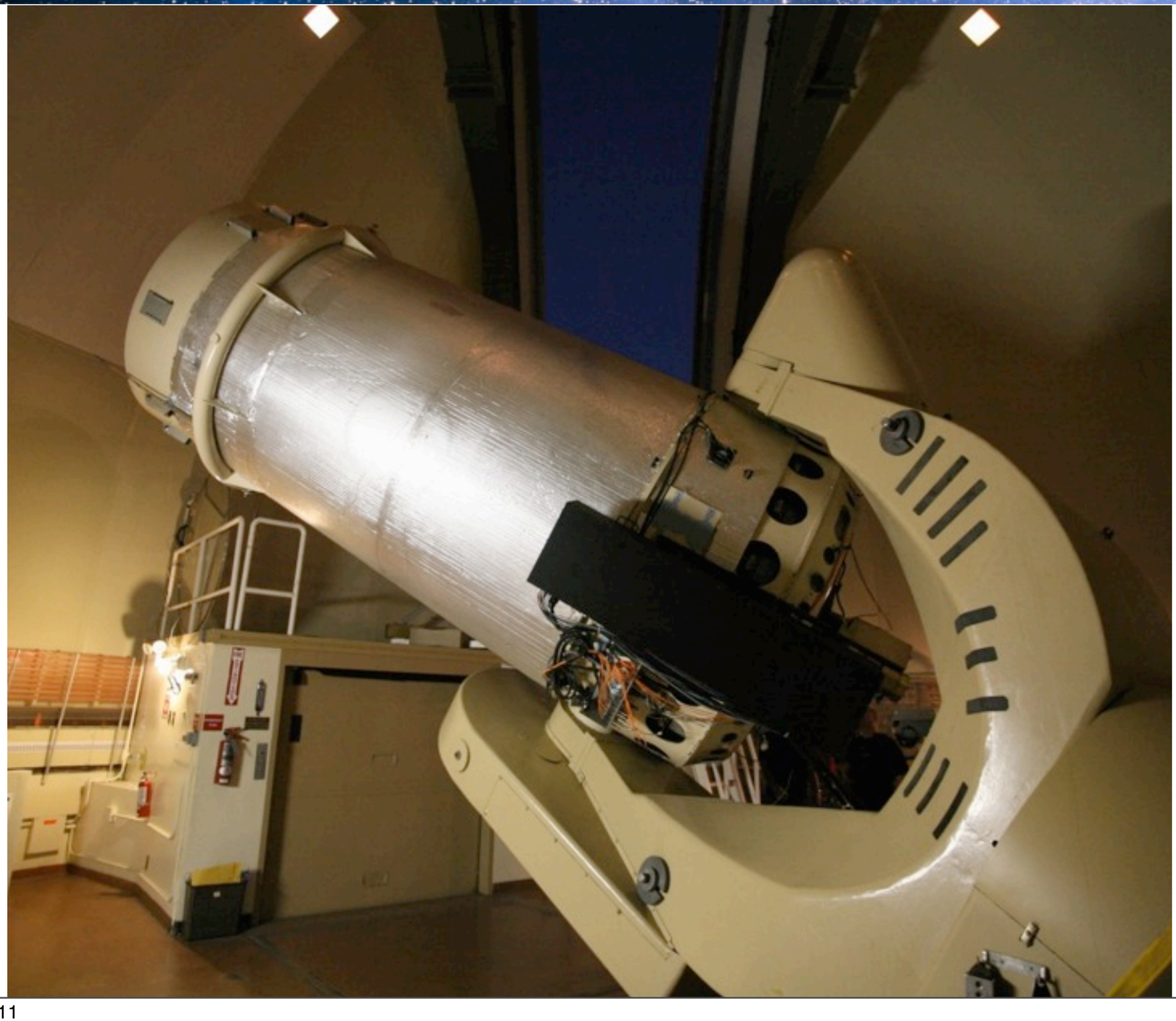
- High efficiency
- Large surveys
- Continual availability
- Visible-light & high speed imaging

- Sample scientific programs
  - Binary system studies (M and brown dwarfs)
  - Lensed quasars
  - High contrast AO (HR 8799)
  - Palomar Transit Factory, LSST follow up
  - And more.....

The Robo-AO System

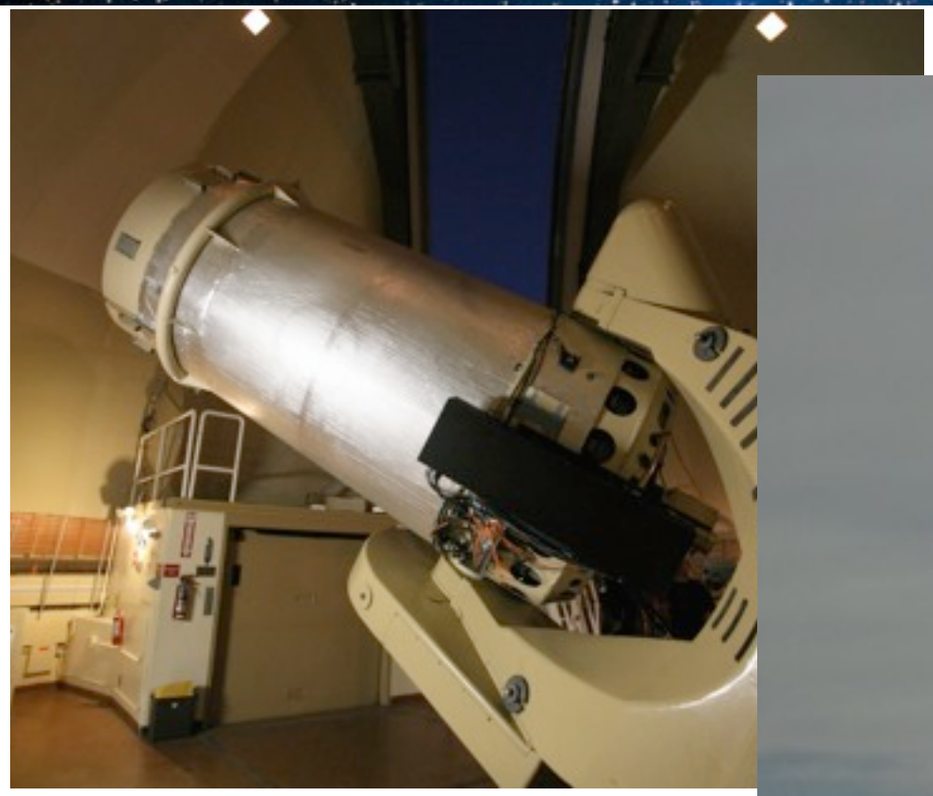
- Several hardware subsystems
  - Each requires interface, control software
- Wave Front Sensor (WFS)
  - CCD, Deformable mirror, Tip/tilt mirror
- Laser Guide Star (LGS)
  - Laser, Chiller, Shutter, Beam steering mirror
- Range Gate System (RGS)
- Atmospheric Dispersion Corrector (ADC)
- Visible Instrument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

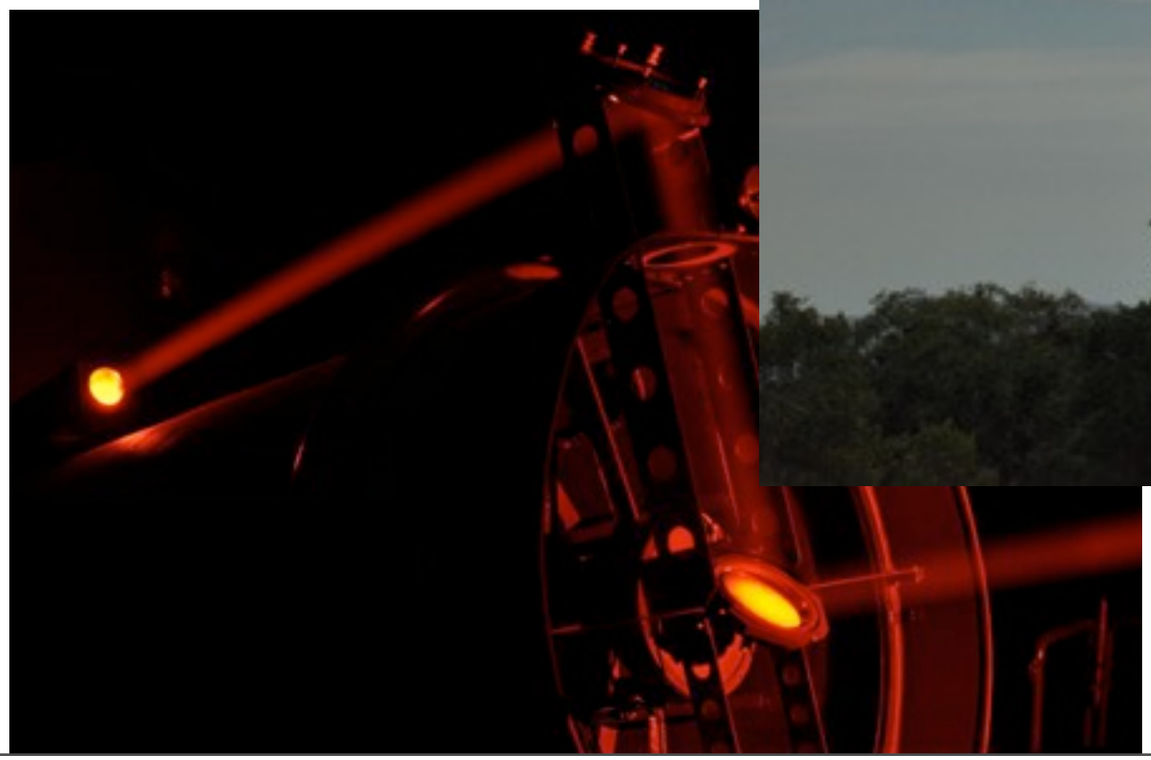
UV LGS at the P60



UV LGS at the P60

UV LGS at the P60





Robotic Adaptive Optics

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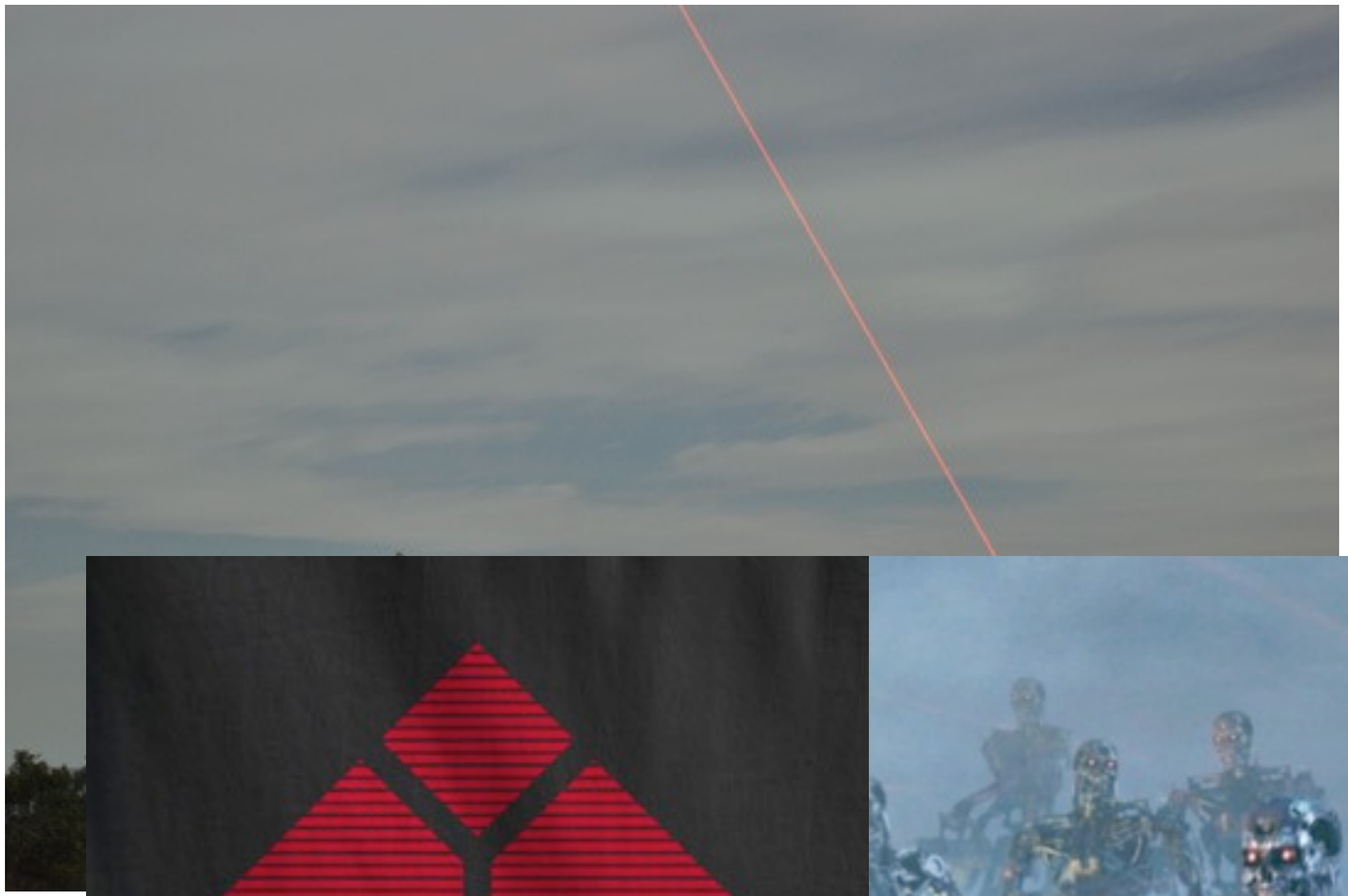
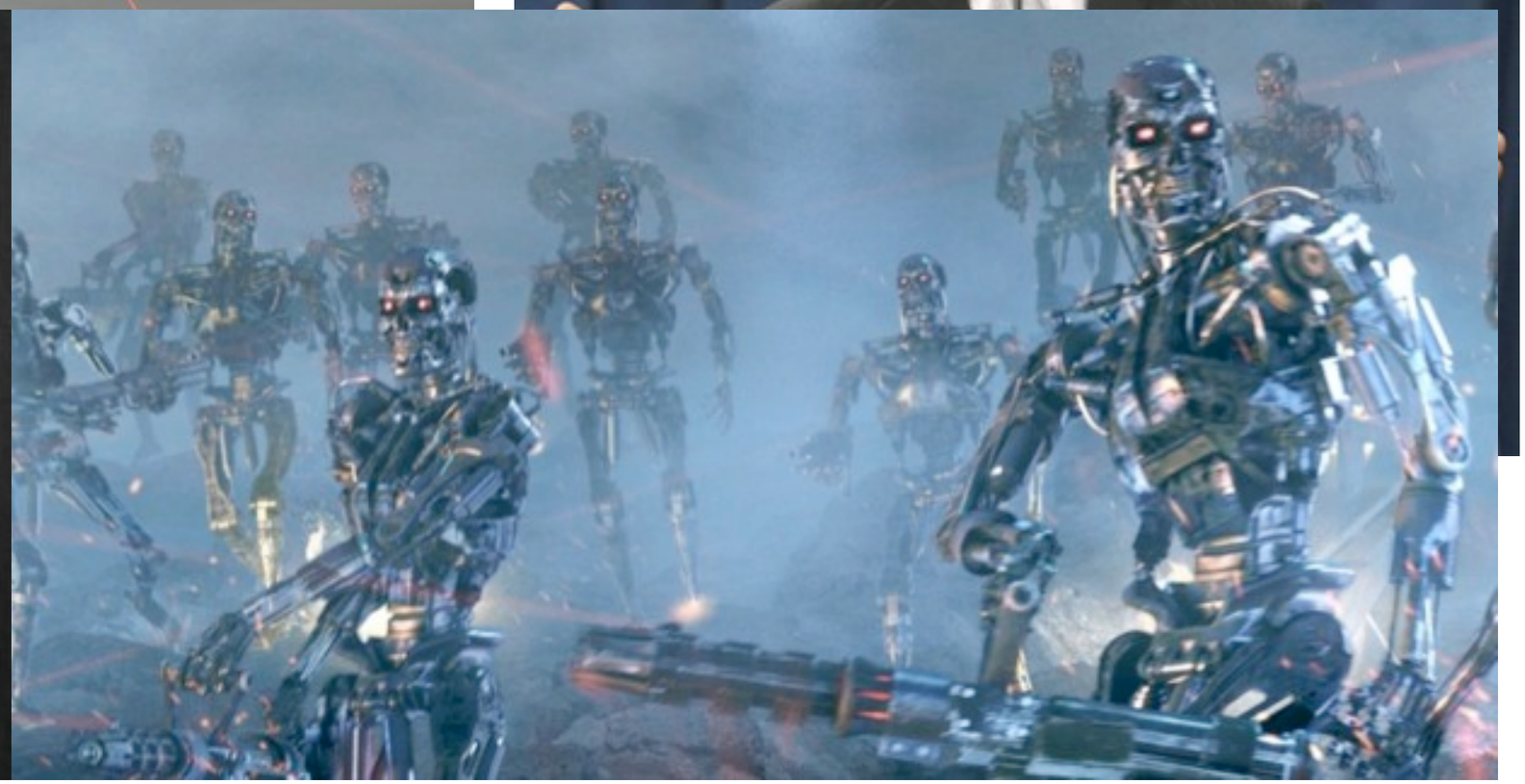
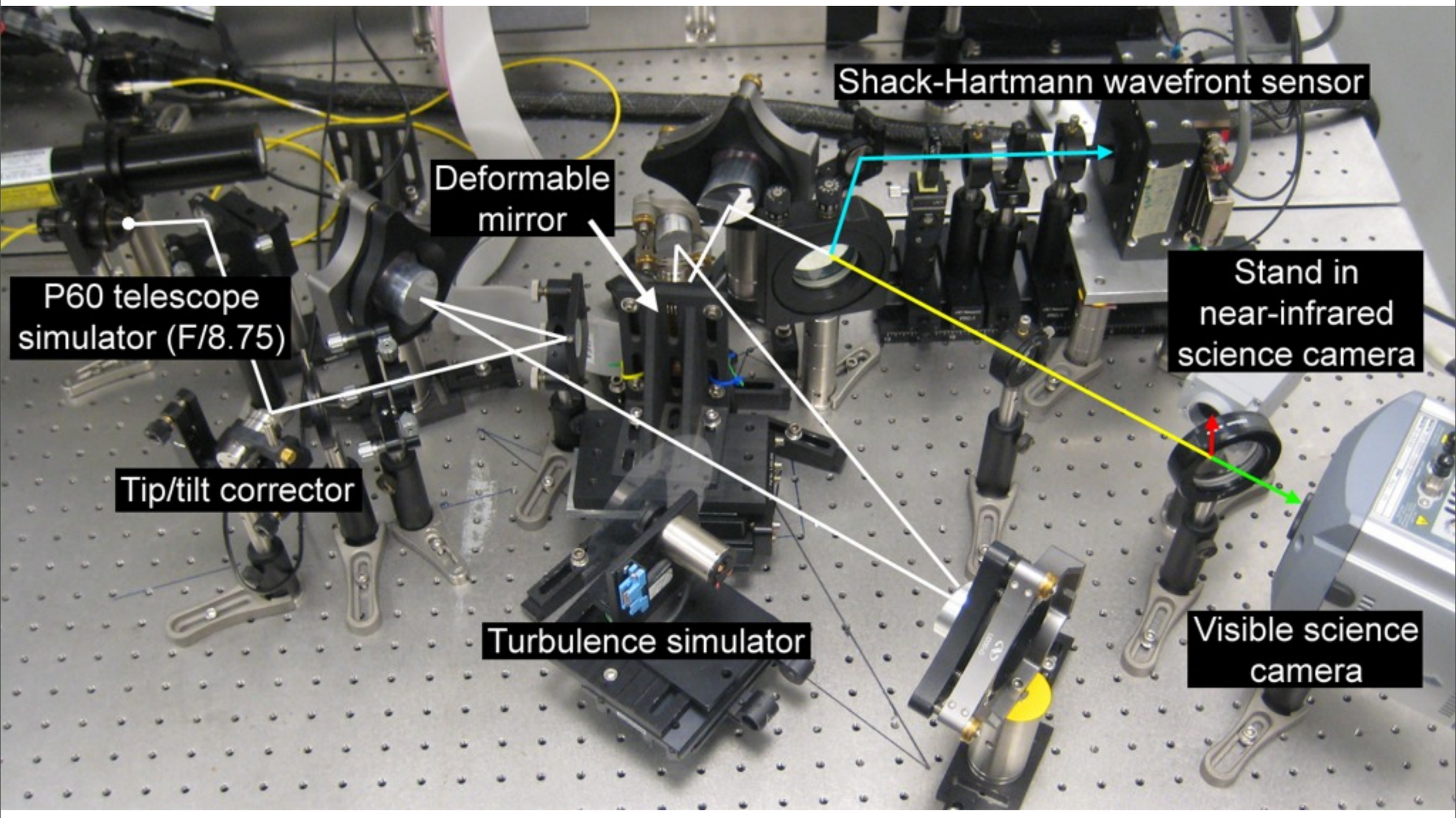
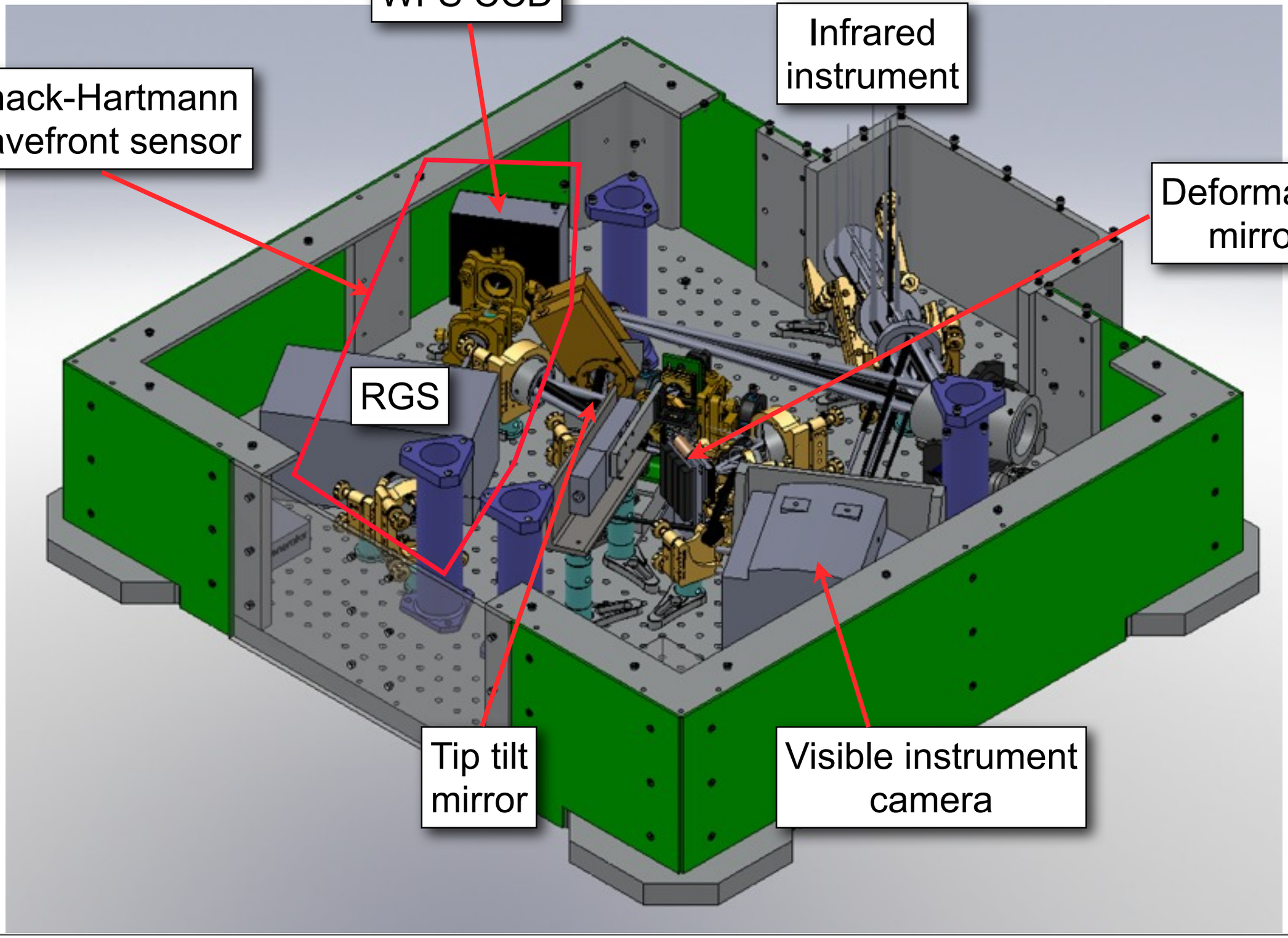




WFS and Instrument Package



WFS Mechanical Design

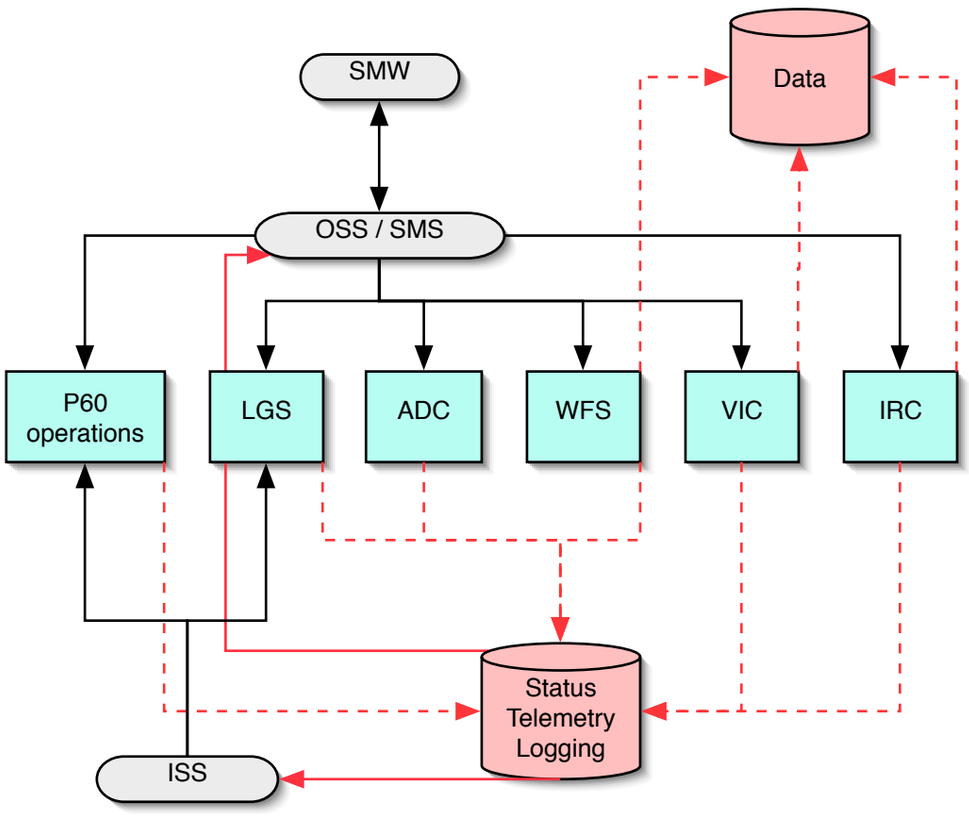


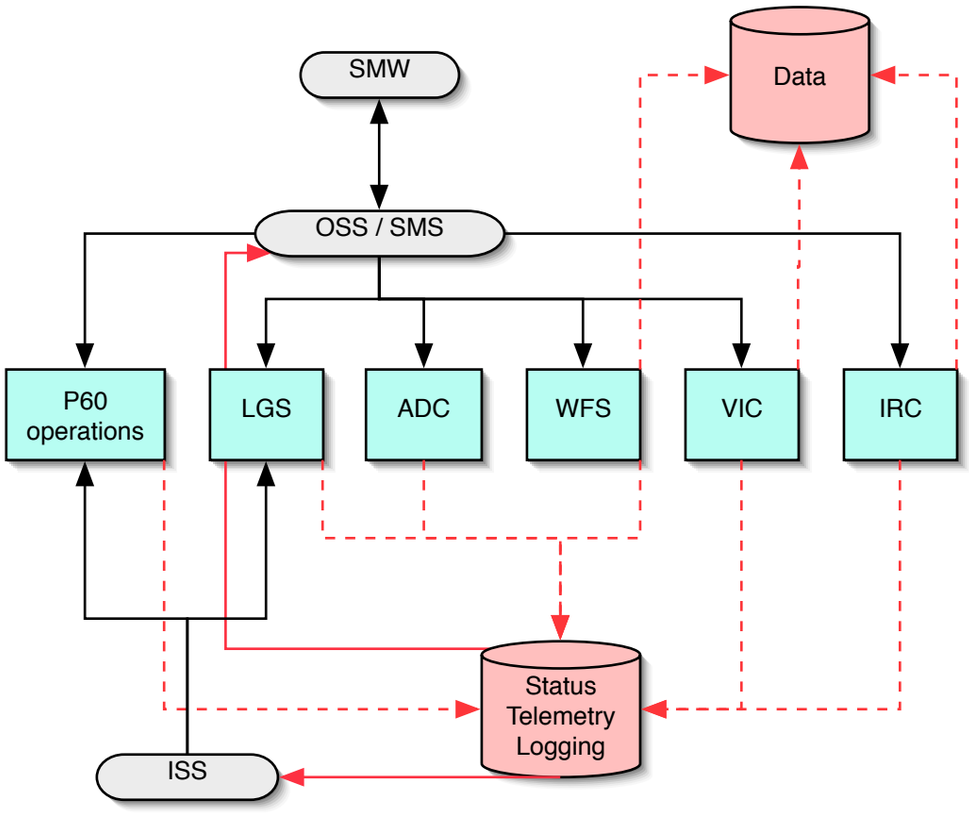
Software Design and Documentation

- Linux environment (Fedora 13) on a single computer
  - Developed in C++
    - Multi-threading
    - Extensive exception handing
  - Scripting in Bash
- Web display of operations, no proper GUI
- Not using real-time or 64 bit Linux
- Full documentation of code with Doxygen

Robotic Software Architecture

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

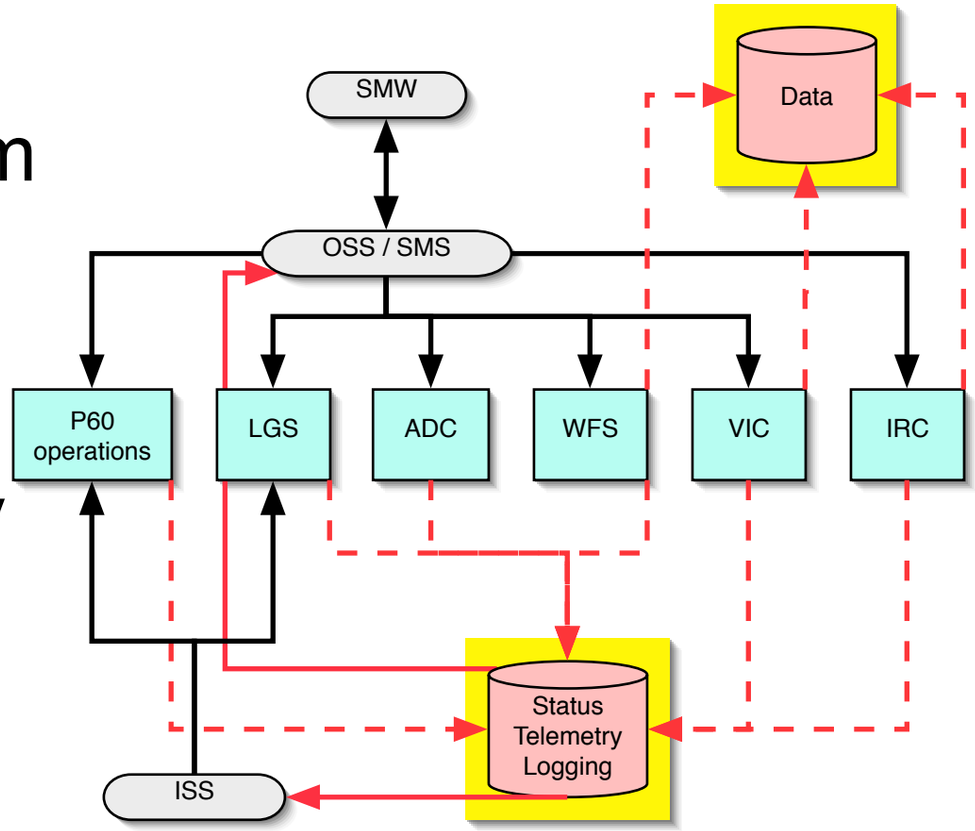


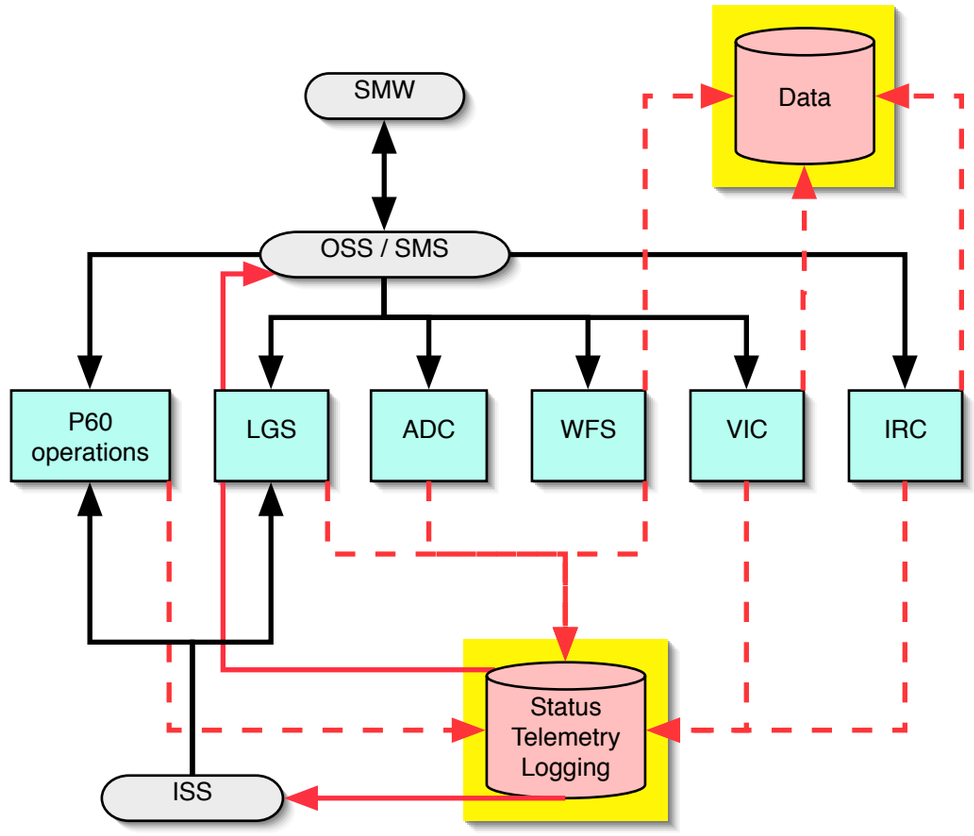

SMW
Data
OSS / SMS
P60
operations
LGS
ADC
WFS
VIC
IRC
Status
Telemetry
Logging
ISS

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

- Various other common operations

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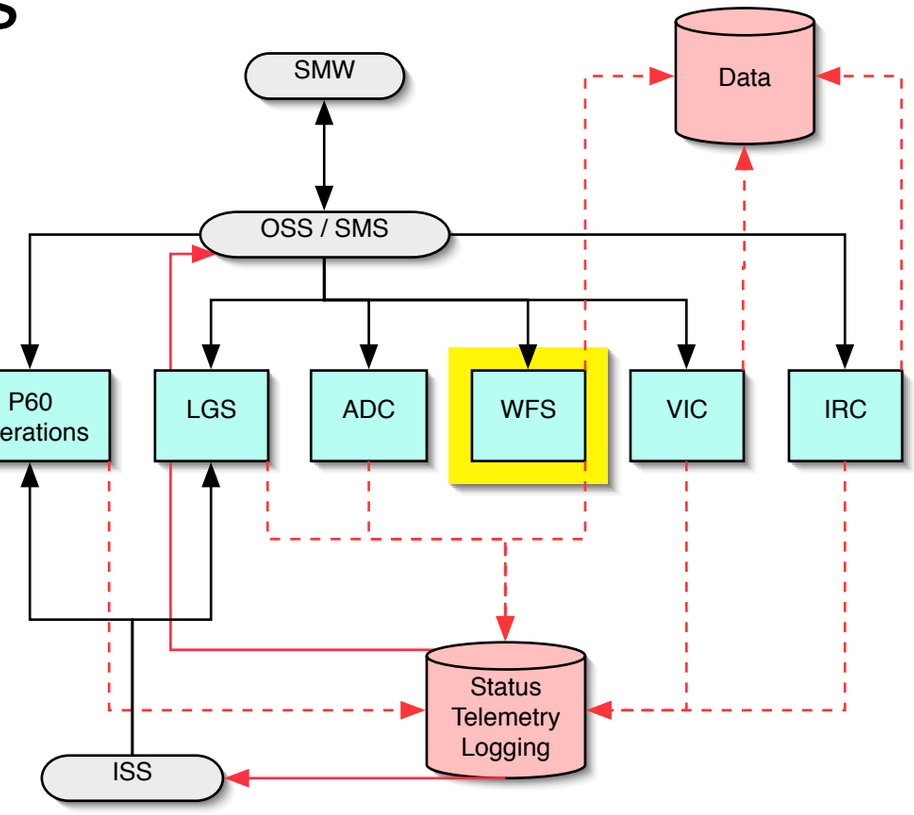
Wave Front Sensor

- Configuration files for parameters
- First closed loop Dec. 2009
  - 1.2kHz with telemetry, NGS mode
  - Drop almost no frames

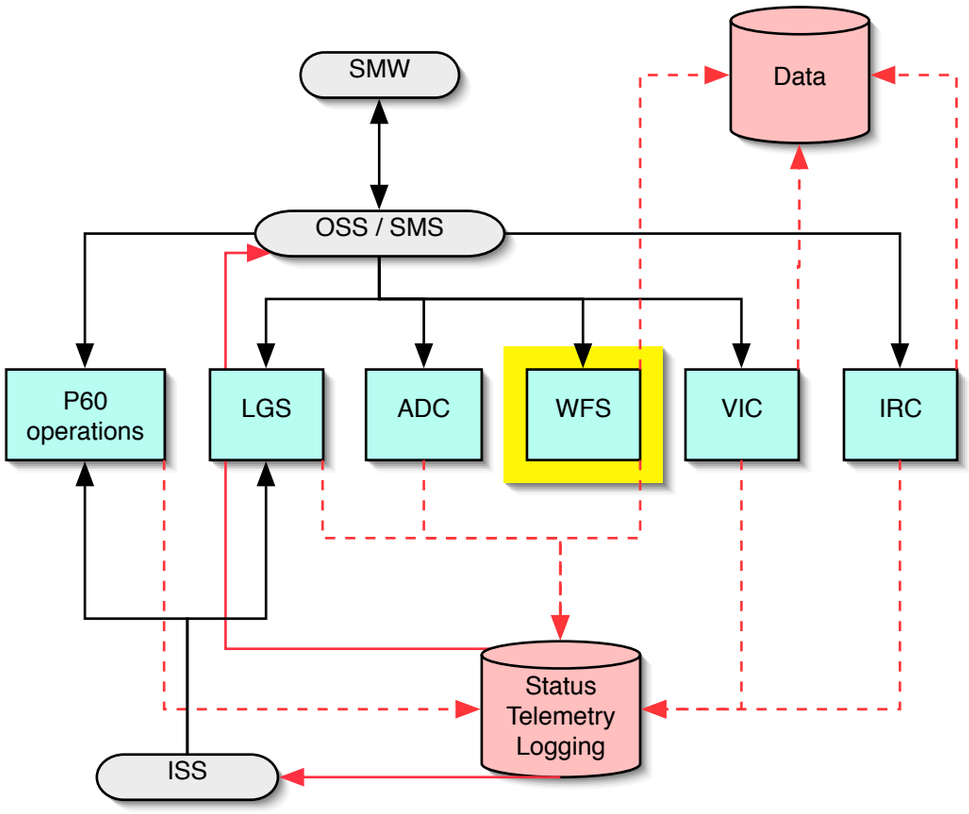


- Current operational system
  - 1.5kHz operation, LGS mode
  - Tip/tilt control from visible camera
  - Threaded FITS system
  - Currently daemonizing

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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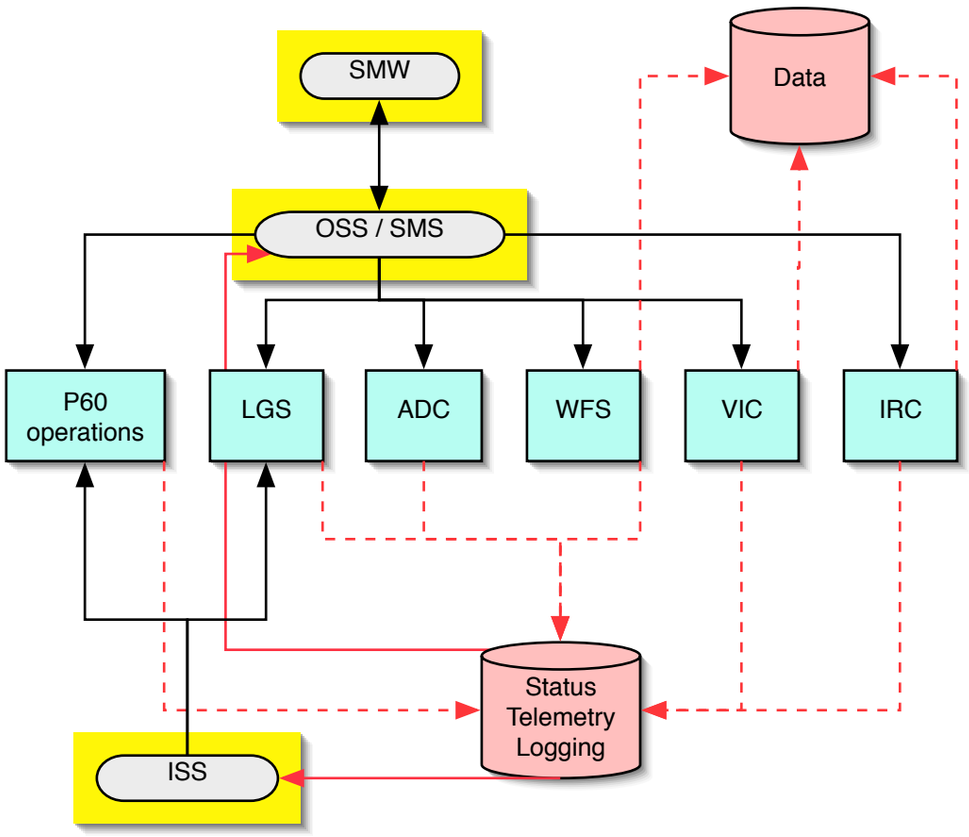
Supervisor Processes

- 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



Conclusion

- First autonomous AO system with LGS
- Under development now
- April 2011: First light with entire instrument
- August 2011: One month demonstration of robotic operations

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

Does it work?

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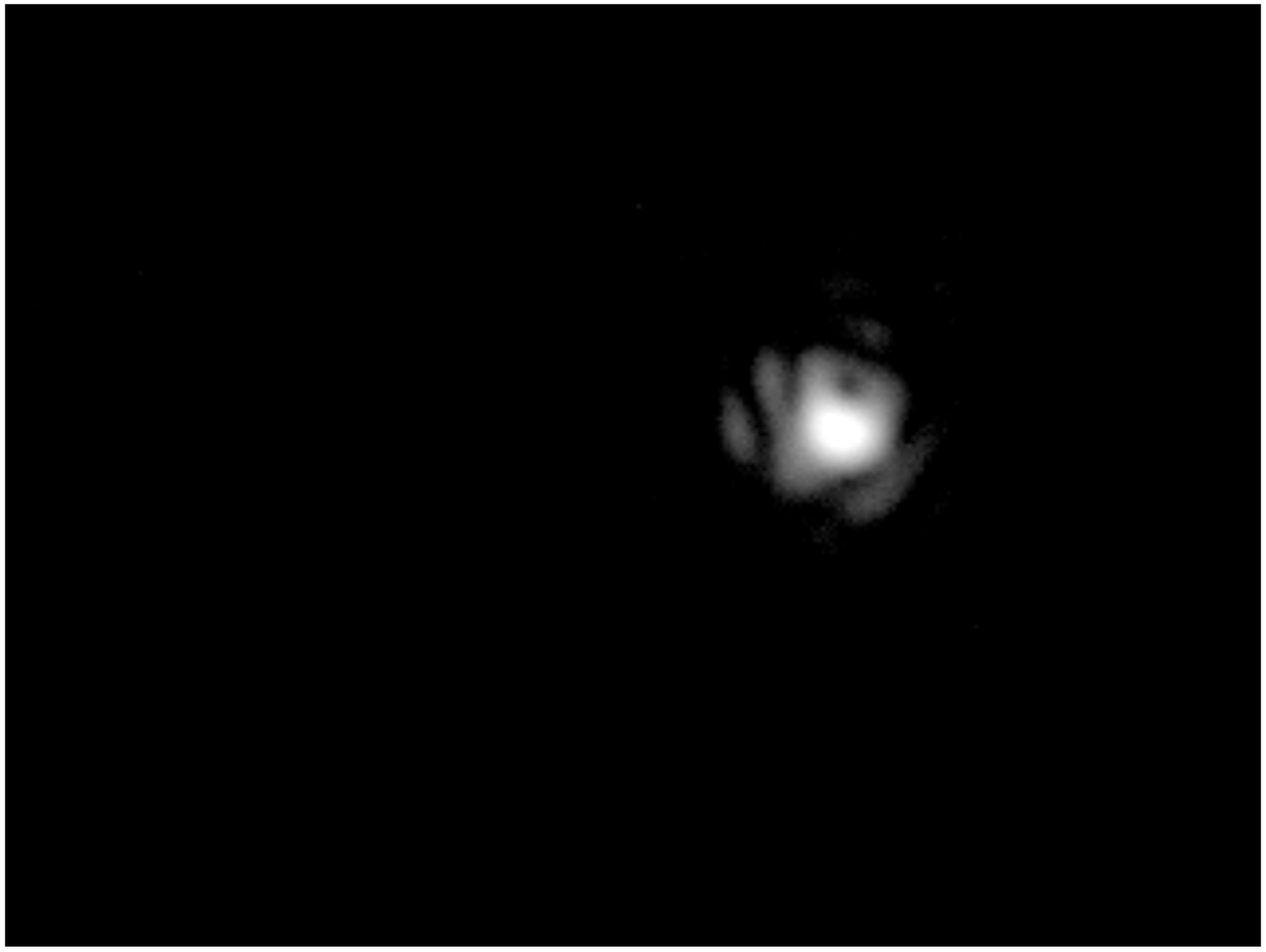

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