Multi-Conjugate Adaptive Optics Simulation Tools

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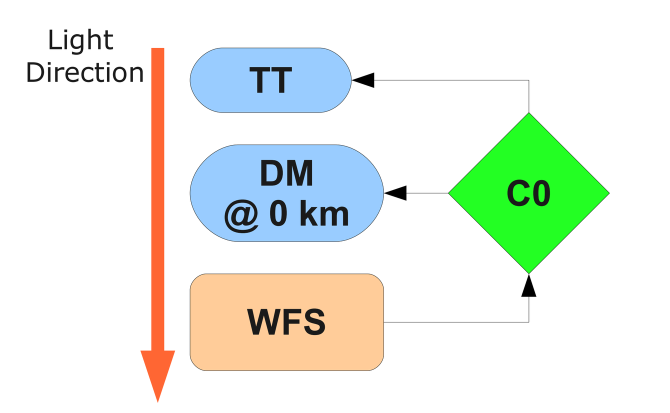
Abstract: The next generation of large aperture solar telescopes will require high-order Adaptive Optics (AO) systems and Multi-Conjugate Adaptive Optics (MCAO) systems to produce high resolution observations. Computer simulations of these systems together with tests on current solar telescopes are necessary to evaluate their expected performance. Simulation tools also assist in the design process of these systems and allow the study and fine tuning of different reconstruction algorithms.
We present a modular AO/MCAO simulation tool for solar physics applications written in IDL. The code is capable of simulating any particular system configuration, with as many wavefront sensors, deformable mirrors and turbulent layers as necessary. The code allows the individual system components to be connected together as a single system or split as different independent subsystems.

System:

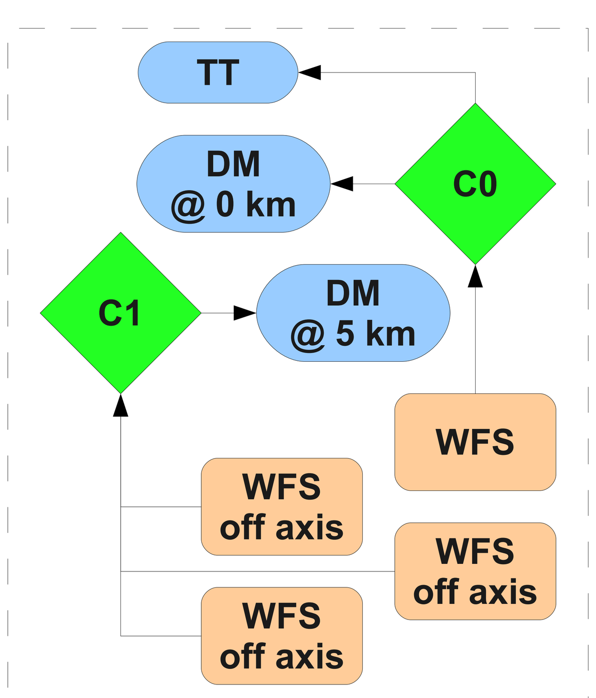
The system is defined by adding elements in the order they are found by the incoming light. There are 3 kinds of elements: tip-tilt mirrors (TT), deformable mirrors (DM) and wavefront sensors (WFS).

Define single-conjugated AO

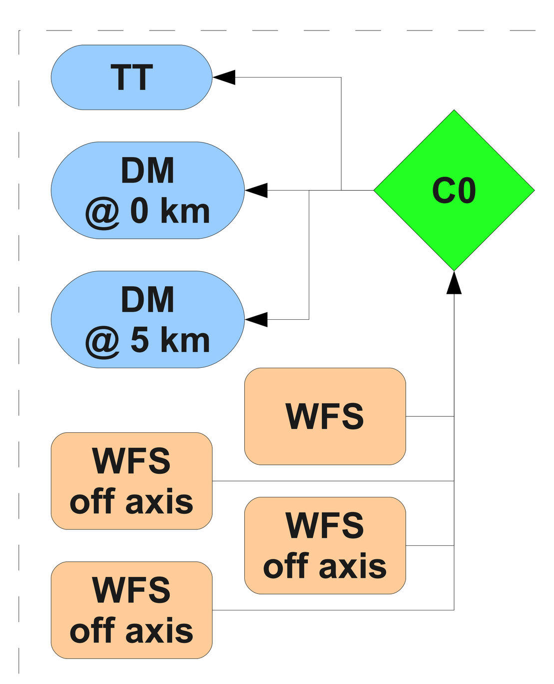
- Add TT conjugated to telescope pupil Connect to controller C0.
- Add DM conjugated to telescope pupil Connect to controller C0.
- Add Shack-Hartmann WFS. Connect to controller C0.



Split AO + MCAO



Global MCAO



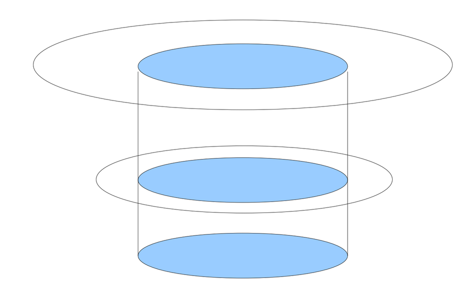
System Loop:

The reconstruction at each iteration uses the WFS measurements taken in the previous iteration. This simulates the loop delay that occurs in real systems.
At each iteration the following steps are taken:

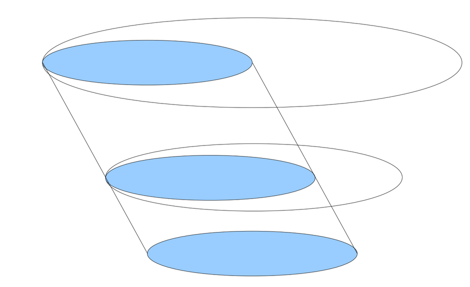
- Atmospheric layers are shifted according to their wind speed
- Project atmospheric phase along the direction of each WFS
  - Store phase "seen" by each WFS in **WFS_PHASE**
- Visit system components in order:
  - If tip-tilt mirror (TT):
    - Project mirror shape along direction of each WFS
    - For each WFS substract from **WFS_PHASE**
  - If deformable mirror (DM):
    - Project mirror shape along direction of each WFS
    - For each WFS substract from **WFS_PHASE**
  - If wavefront sensor (WFS):
    - Measure residual phase stored in **WFS_PHASE**
    - Store WFS measurements in **SHIFTS**
- For each subsystem:
  - Gather all **SHIFTS** from all WFS in subsystem and store for next iteration
  - Retrieve subsystem **SHIFTS** from previous iteration
  - Reconstruct with control matrix:
    COMMANDS = **CMAT** x **SHIFTS**
  - Apply gain and add to current mirror commands
  - Calculate mirror shape from commands
- Repeat loop

Atmosphere:

Phase screens can be added at different altitudes to represent an atmosphere formed by discrete turbulent layers. The effect of wind is emulated by shifting the phase screens.
Each phase screen is computed from the Kolmogorov power spectrum by Fourier inversion.

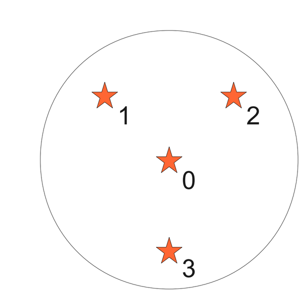


Projection of pupil on three turbulent layers along two field directions:
- on-axis (left)
- off-axis (right).



Simulation Results:

Snapshot of the system state while running a simulation of a global MCAO system.



WFS Configuration
Of-axis stars at 15"

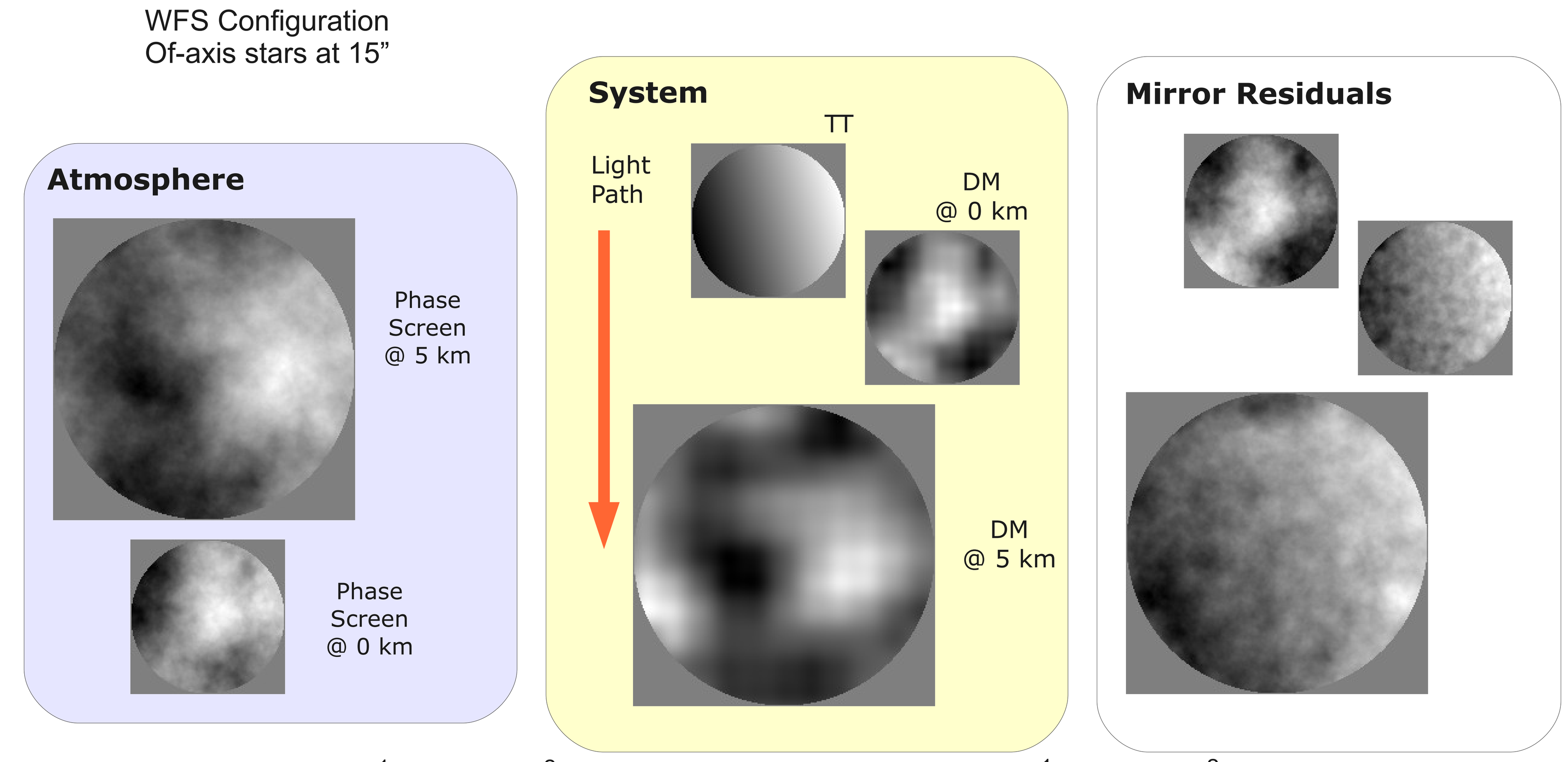
Simulation Setup:

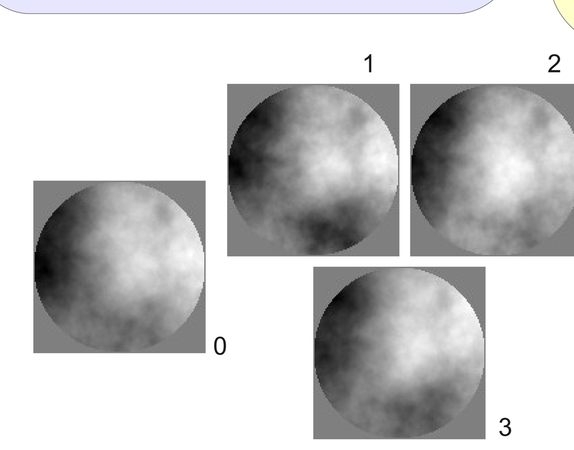
Telescope Aperture: 76 cm

Two atmospheric layers:
- at 0 km (r0=10 cm)
- at 5 km (r0=50 cm)

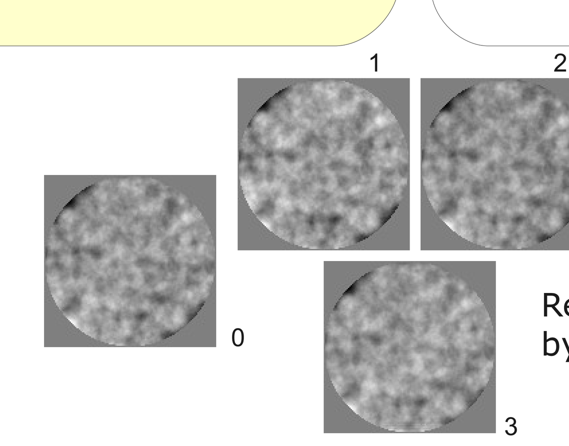
Mirrors:
- Tip-tilt mirror
- 97 actuator DM conj. at pupil
- 97 actuator DM conj. at 5 km

Wavefront sensors;
Shack-Hartmann 76 subapertures:
- 1 on-axis (10" FOV)
- 3 off-axis @ 15" (5" FOV)

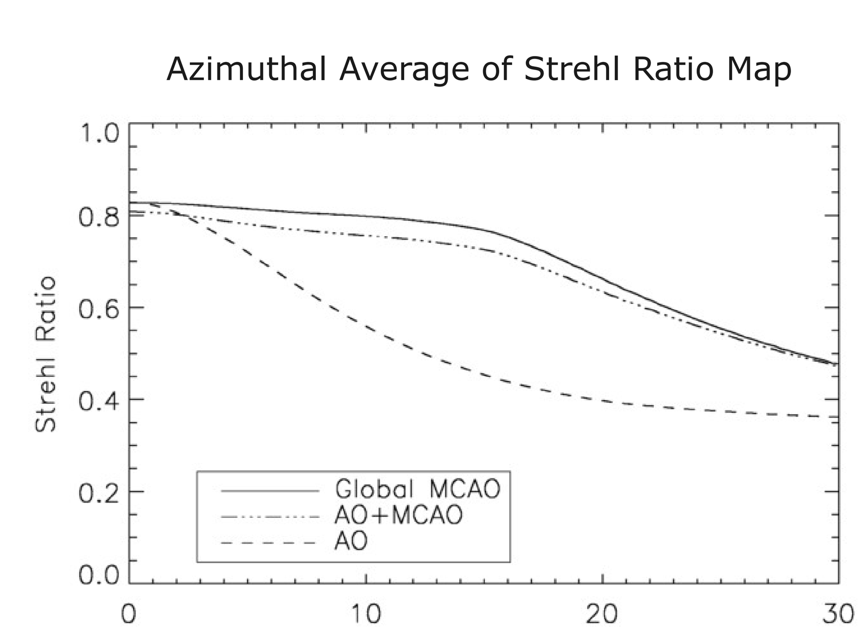


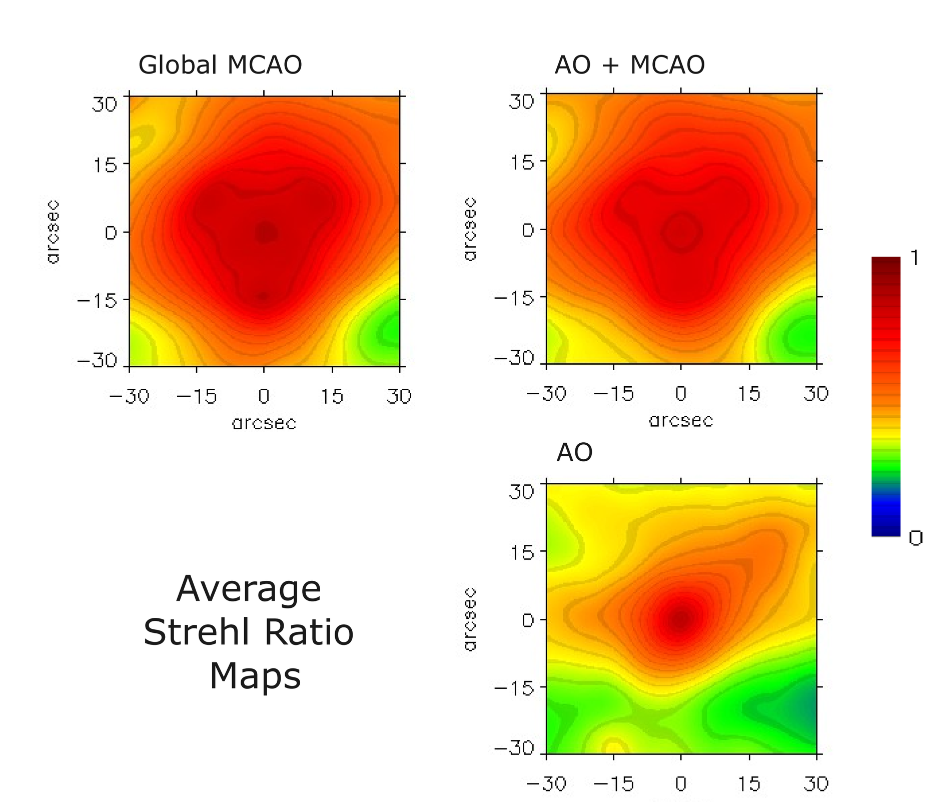


Phase sensed by WFS with no correction.



Residual phase sensed by WFS after correction.





Average Strehl Ratio Maps