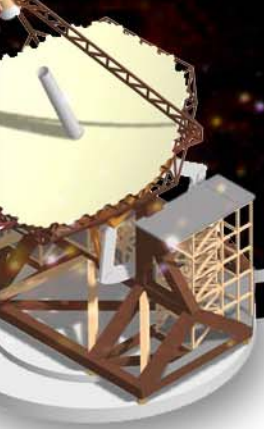

AURA NEW INITIATIVES OFFICE

Modern Control for the Secondary Mirror of a Giant Segmented Mirror Telescope

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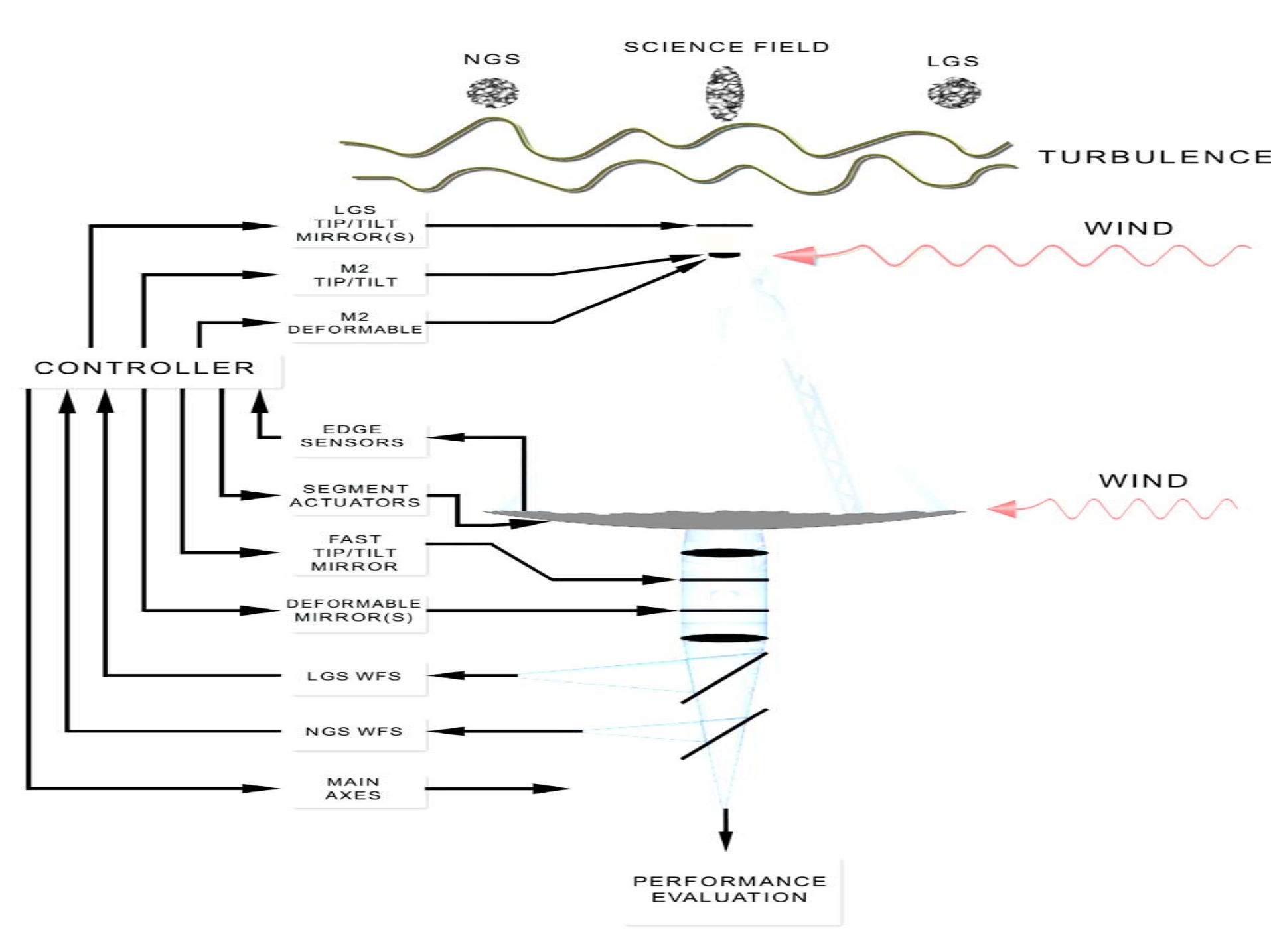
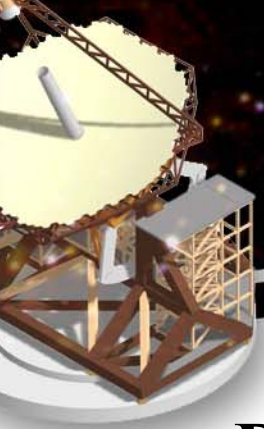
AURA New Initiatives Office

Overview

- GSMT Control Philosophy
- Modern Control Methods
- Secondary Mirror Control Design
- Closed Loop Analysis
- Conclusions

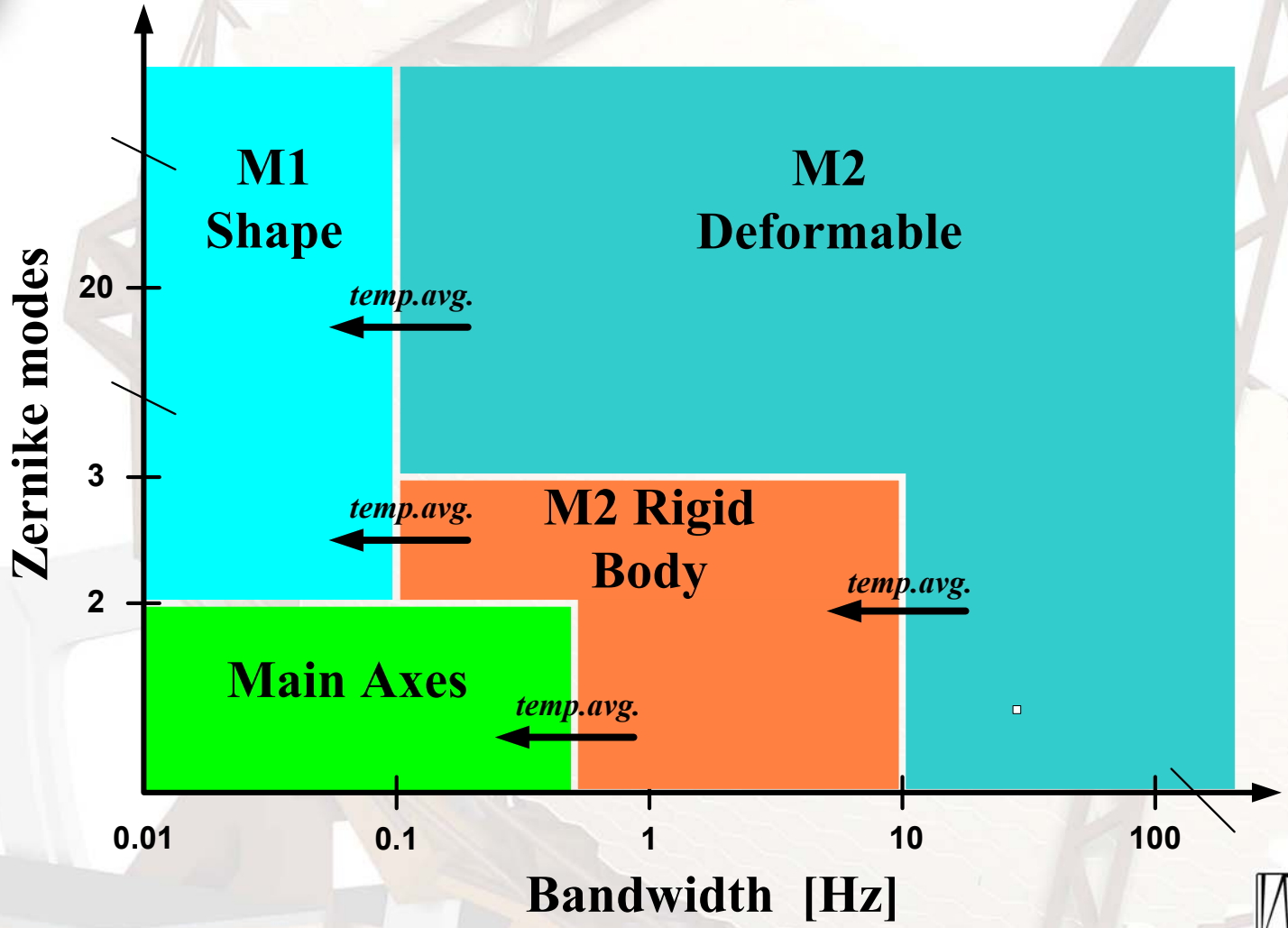

NGS
SCIENCE FIELD
LGS
TURBULENCE
LGS TIP/TILT MIRROR(S)
M2 TIP/TILT
M2 DEFORMABLE
WIND
CONTROLLER
EDGE SENSORS
SEGMENT ACTUATORS
WIND
FAST TIP/TILT MIRROR
DEFORMABLE MIRROR(S)
LGS WFS
NGS WFS
MAIN AXES
PERFORMANCE EVALUATION



Control Philosophy

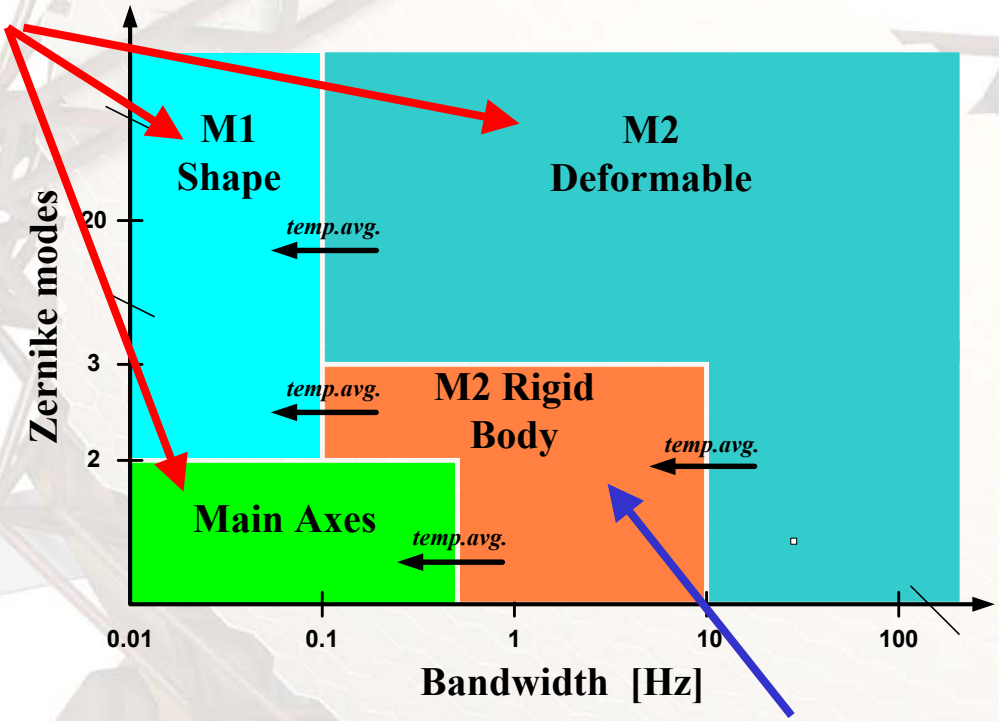
- **Decentralized Global Control:**
  - **Forced decoupling of subsystems**
  - **Simplifies design and implementation**
  - **Allows sophisticated control methods where warranted**
- **Control Architecture:**
  - **Separated in spatial frequency by different sensor/actuator groups**
  - **Separated in temporal frequency by decoupling control loops from structural dynamics except for one**

Frequency separation of subsystems



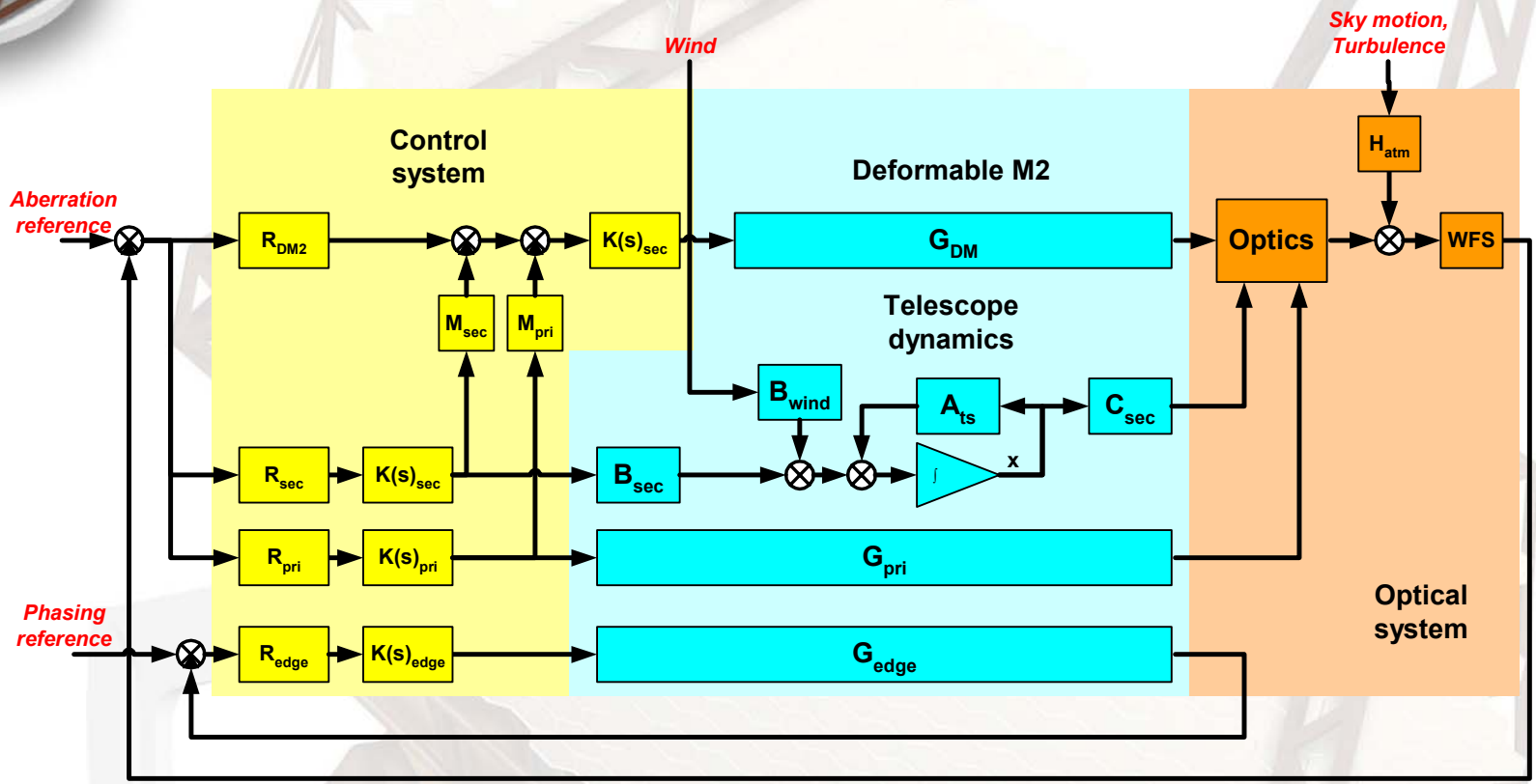
Frequency separation of subsystems

Kinematic

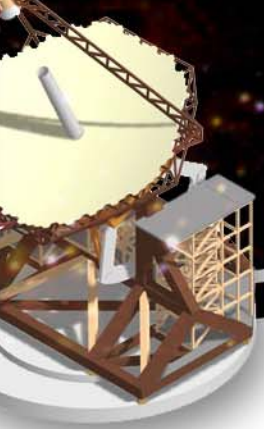


Dynamic

Control configuration



Objective: demonstrate feasibility of overall control architecture by addressing the M2 dynamic control design



Control Methods

- **Classical Control:**
  - **Single Input/Single Output**
  - **Well developed / mature theory**
  - **Does not address multivariable coupling**
- **Modern Control:**
  - **Multivariable, linear, coupled dynamic systems**
  - **Distinct set of analysis and design tools**
  - **Well suited for flexible structures and uncertain dynamic systems**

Evolution of Telescope Control

Telescope systems < 5 m are essentially rigid

⇒ Simple control methods

(*not simple implementation!*)

Evolution of Telescope Control

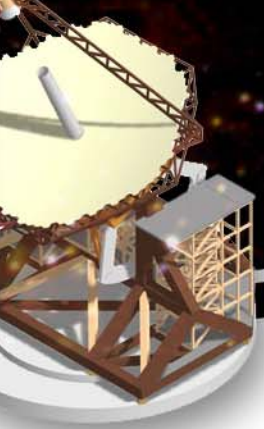
Telescopes in 5 – 10 m class require controlled optics:

- **Low frequency M1 figure maintenance for deformations**
- **High frequency AO for atmospheric effects**

hoto Courtesy of Gemini Observatory

Very little interaction between telescope structural dynamics and control systems

Giant Telescope Control



- **Giant telescopes require more advanced control technology**
  - **Multivariable coupling between sensor-actuator pairs**
  - **Complex and uncertain structural dynamics**
  - **Greater potential for wind disturbances**
  - **Control / structure interaction**

Giant Telescope CSI

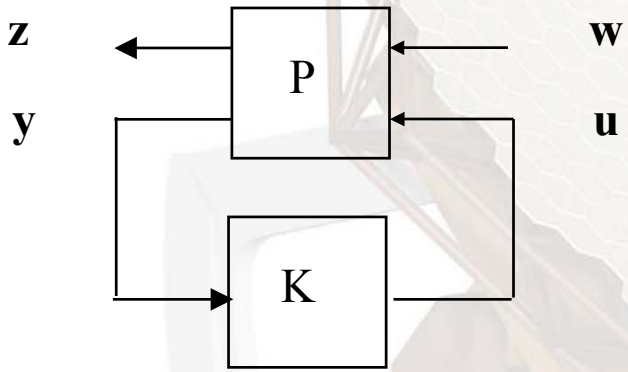
Lightly damped, clustered low frequency structural modes

Gemini			GSMT		
Mode #	Freq (Hz)	Damping (%)	Mode #	Freq (Hz)	Damping (%)
1	1.82	2.12	1	0.50	2
2	3.24	1.14	2	0.50	2
3	4.13	0.25	3	0.50	2
4	7.08	0.10	4	0.50	2
5	7.74	0.49	5	0.50	2
6	8.88	1.36	6	2.17	2
			7	2.49	2
			8	3.14	2
			9	4.00	2
			10	4.11	2
			11	4.26	2
			12	4.46	2
			13	5.05	2
			14	5.40	2
			15	6.66	2
			16	7.61	2
			17	8.09	2
			18	8.34	2
			19	8.81	2
			20	9.75	2

Giant telescope controllers must bridge the gap between M1 figure maintenance and high-frequency AO to compensate for telescope induced aberrations

H_2 Control Methods

- Good nominal performance
- Performance metric well suited for vibration control
- Potentially poor robustness
- High order controllers

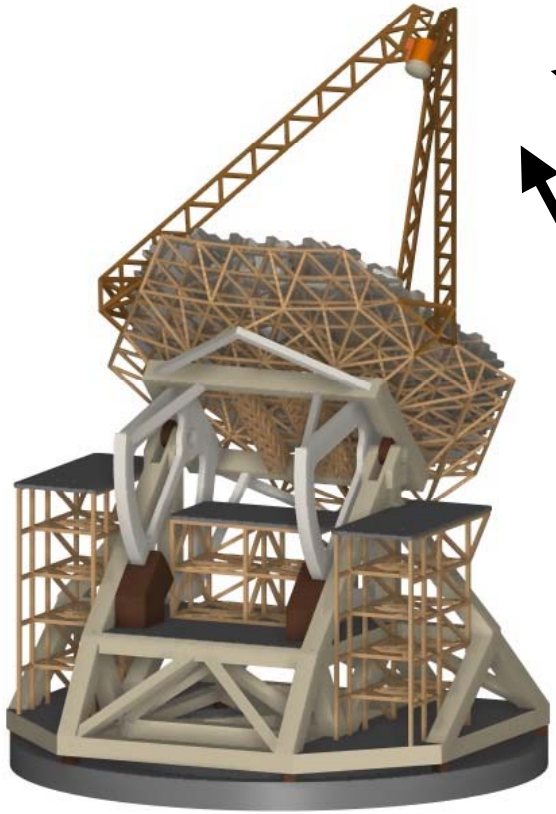


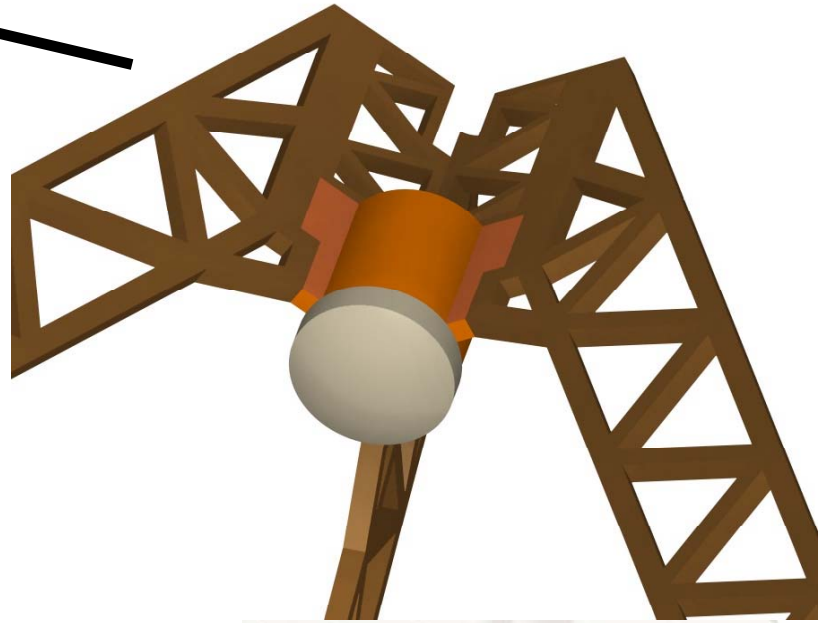
$$K_2 = \arg\left\{ \min_K \left\| T_{zw} \right\|_2 \right\}$$

where $$\left\| T_{zw} \right\|_2 = \lim_{t \to \infty} E\{z(t)^T z(t)\}\}$$

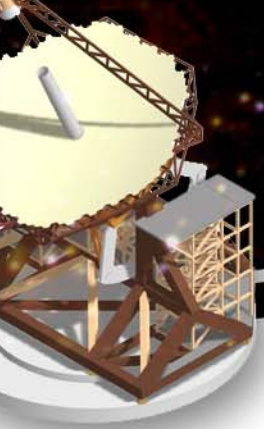
$$K_2 : \left\{ \begin{array}{c} \dot{x}_c = A_c x_c + B_c y \\ u = C_c x_c \end{array} \right\} \qquad x_c \in \Re^{nc}$$

Secondary Mirror Detail



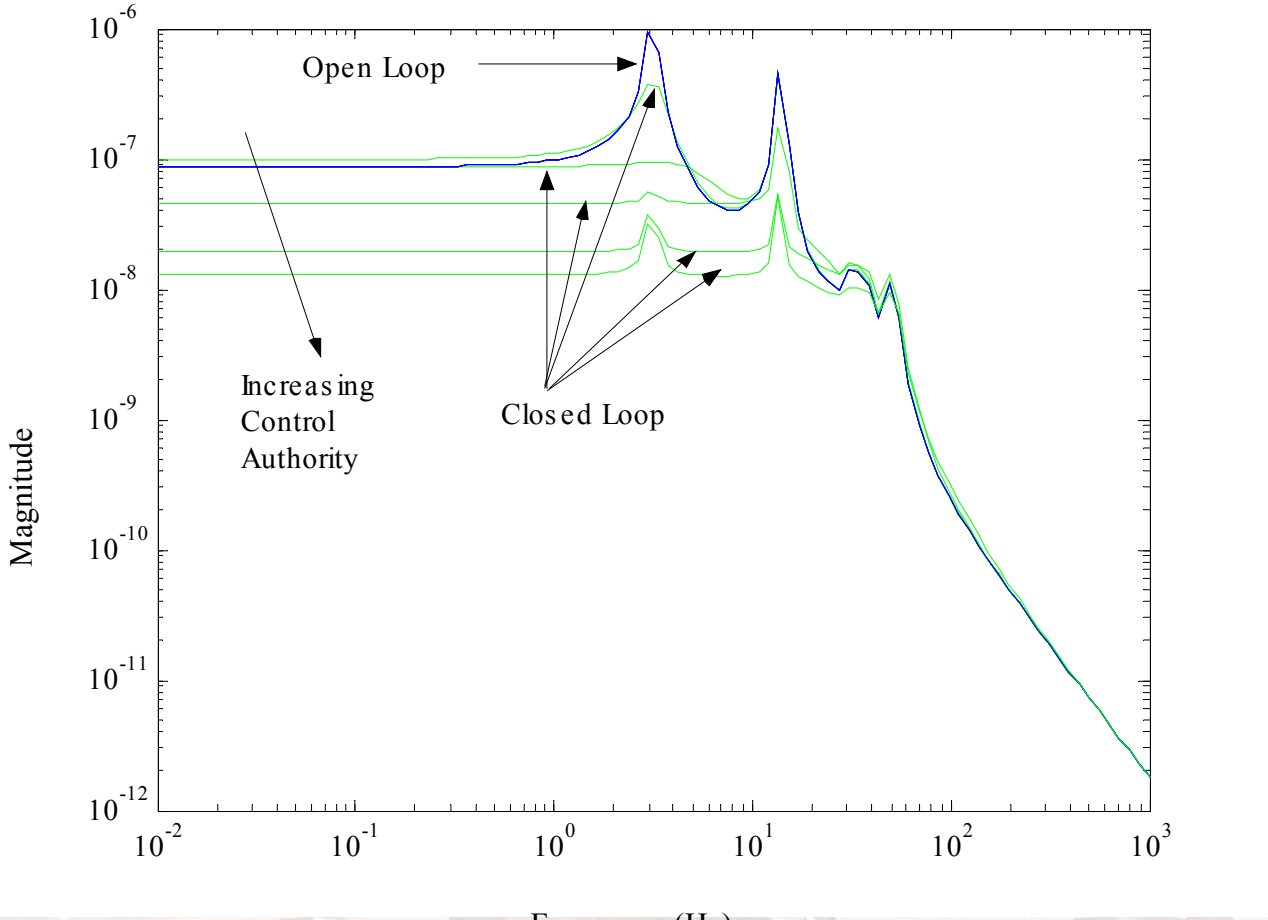


Secondary Mirror Control



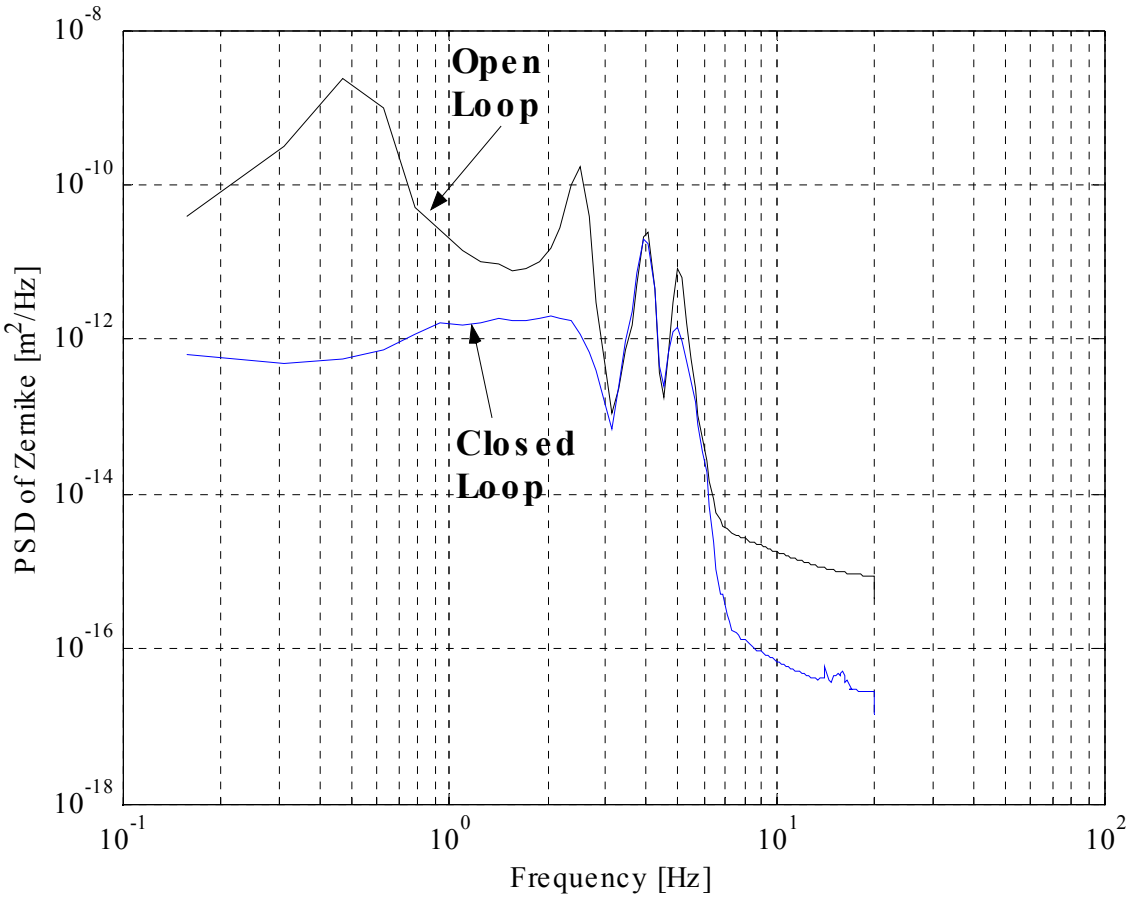
Control Design Results

Open and Closed Loop Maximum Singular Values



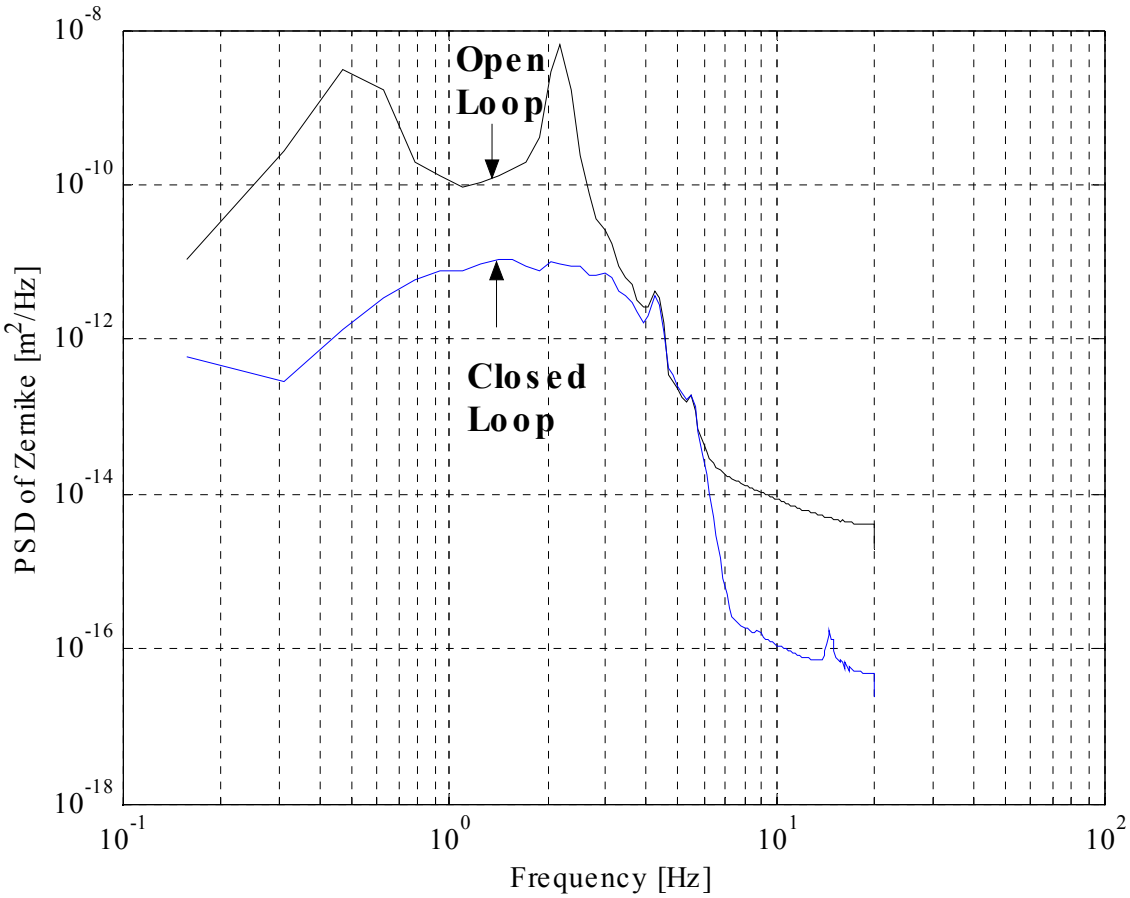
Control Design Results

Open and Closed Loop PSD of X-Tip (Total OPD)



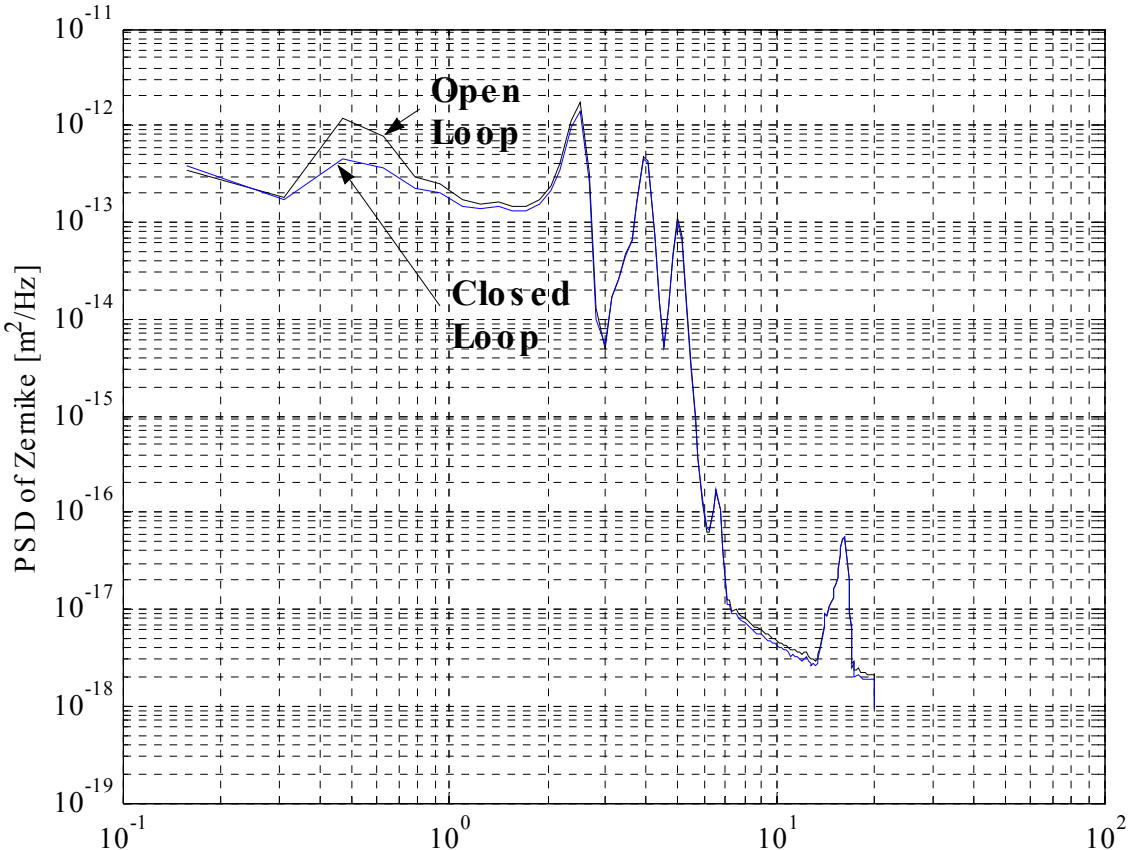
Control Design Results

Open and Closed Loop PSD of Y-Tip (Total OPD)



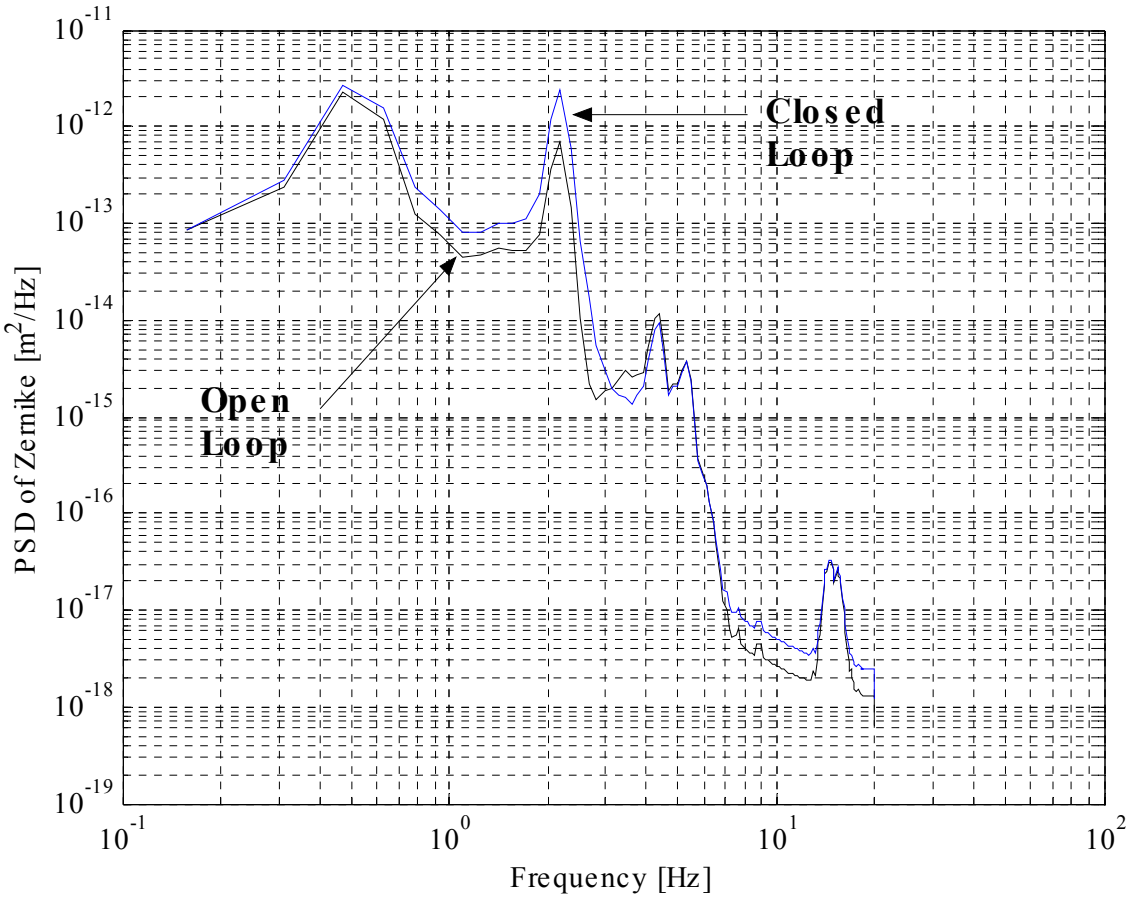
Control Design Results

Open and Closed Loop PSD of 0° Coma (Total OPD)



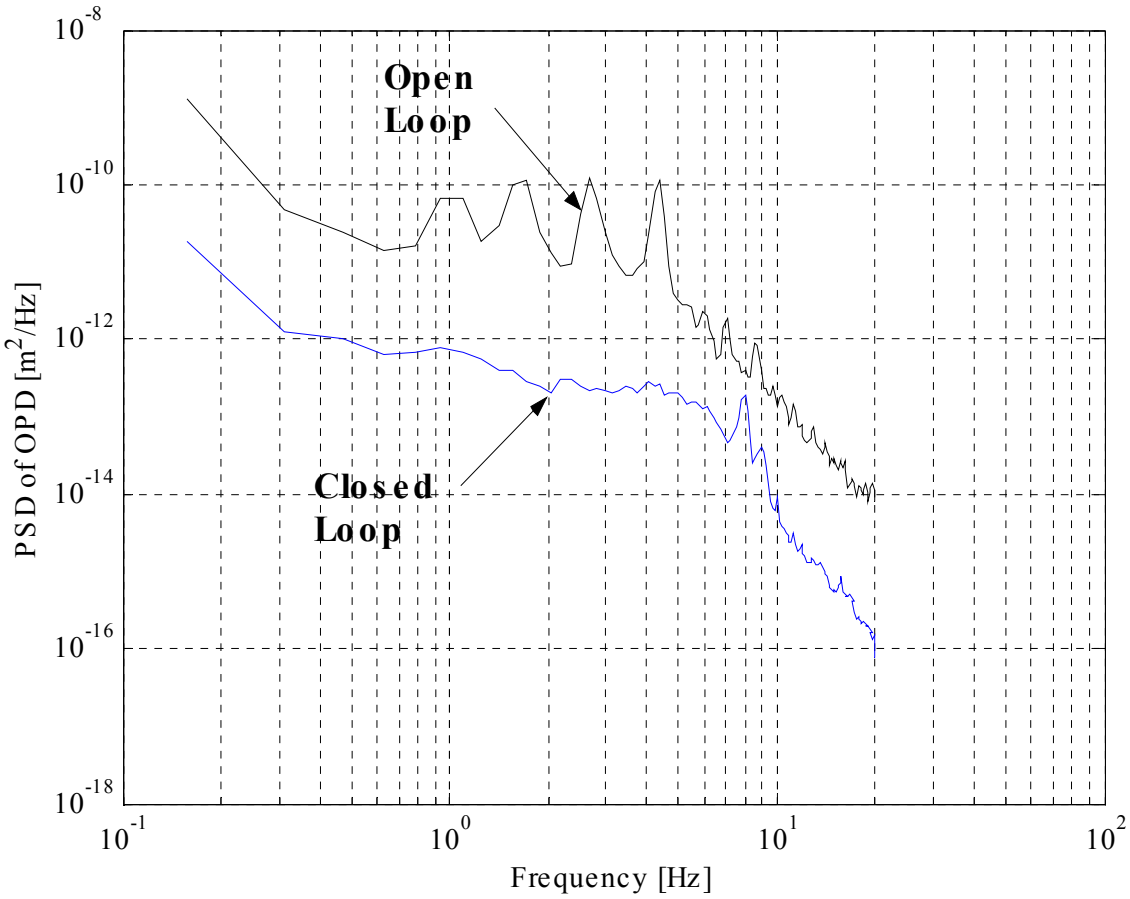
Control Design Results

Open and Closed Loop PSD of 90° Coma (Total OPD)



Control Design Results

Open and Closed Loop PSD of Spatial RMS of Total OPD

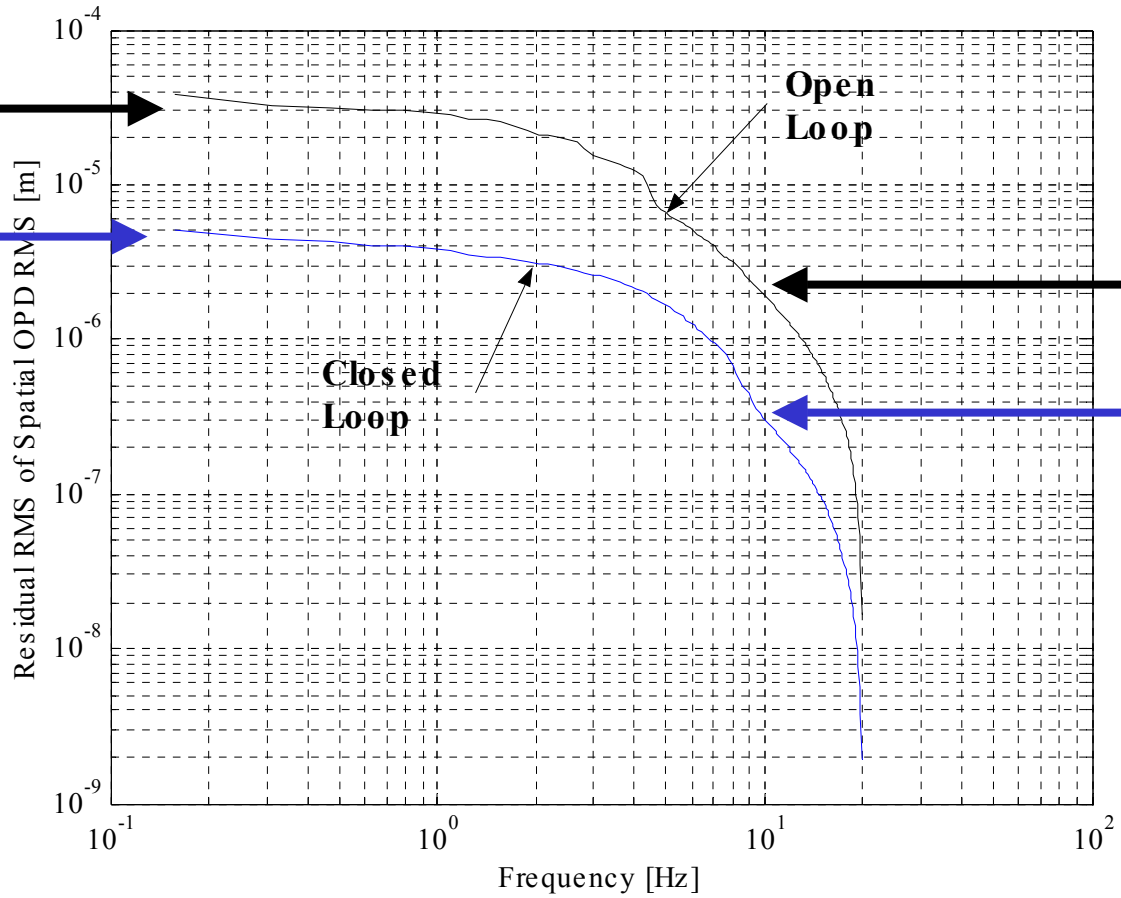


Control Design Results

Residual RMS of the Spatial RMS of Total OPD

~ 40 microns

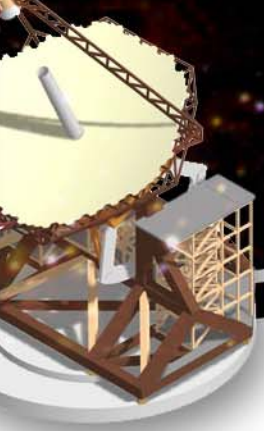
~ 5 microns



~ 2 microns

~ 0.3 microns

Conclusions



- **Identified evolution of control challenge to giant telescopes**
- **Investigated feasibility of control architecture applied to rigid secondary support**
- **Demonstrated reduction of image aberrations induced by telescope vibration**
- **Provided motivation and demonstration of utility of modern control method**