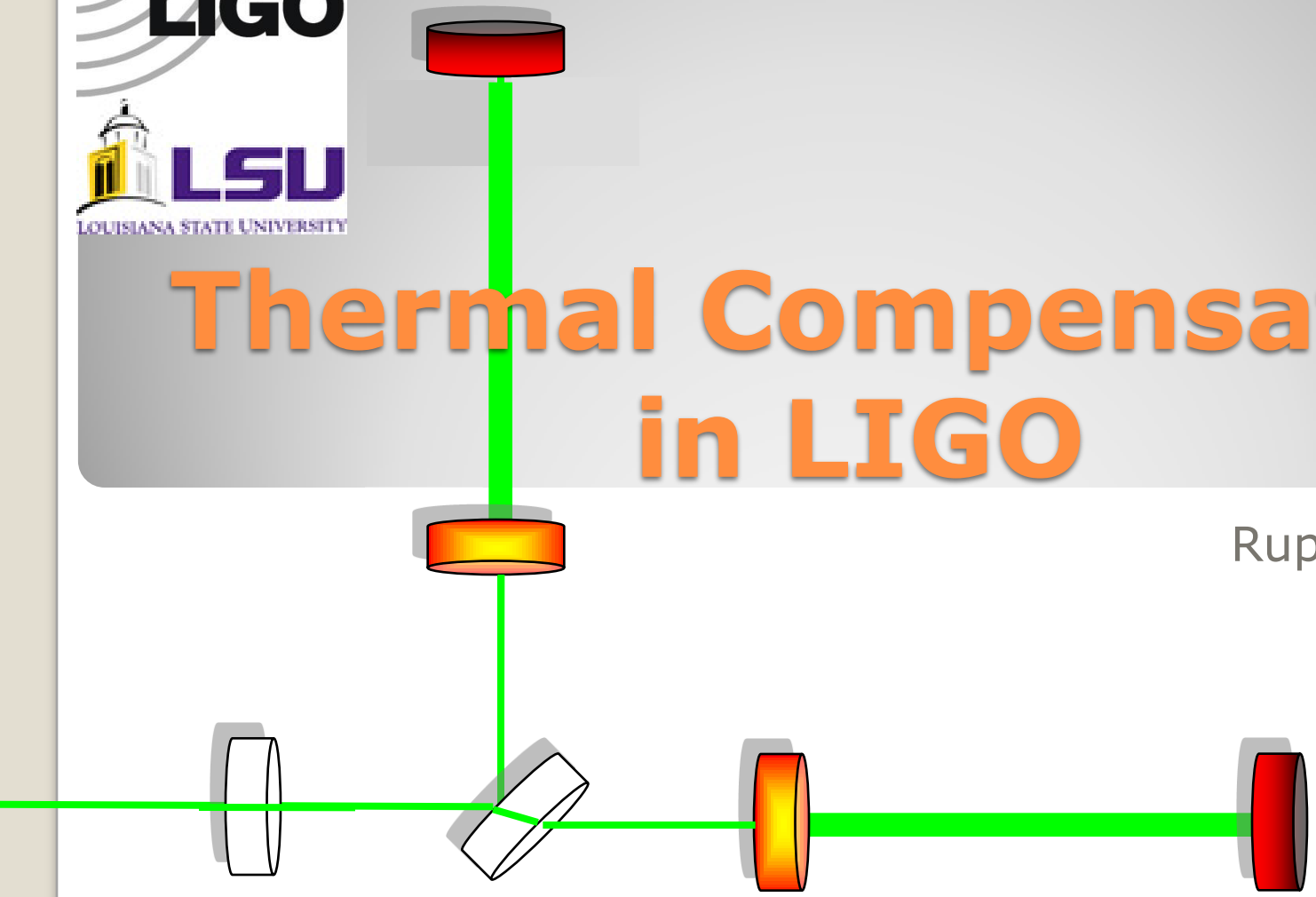
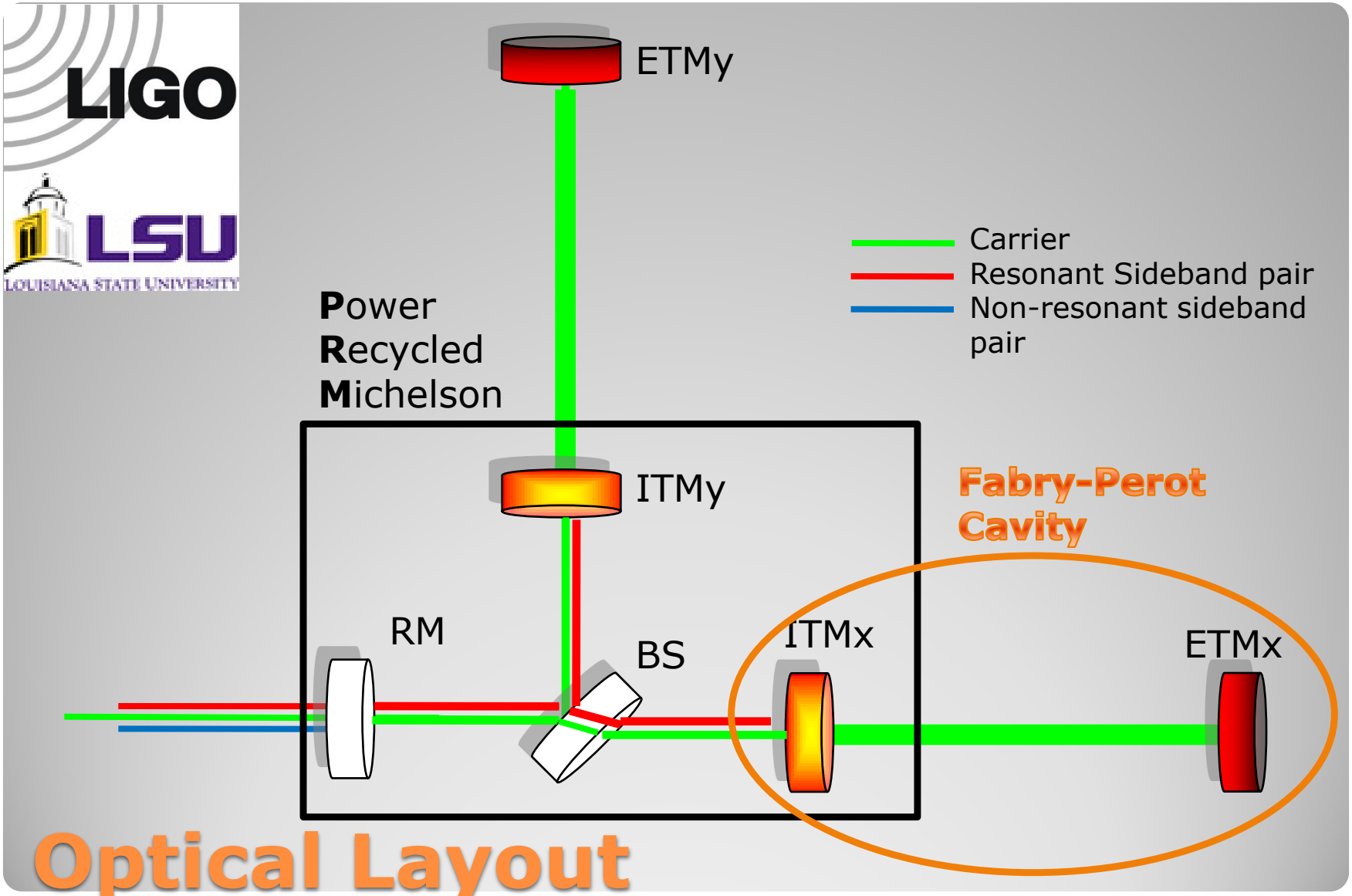
# Thermal Compensation in LIGO

Rupal S. Amin



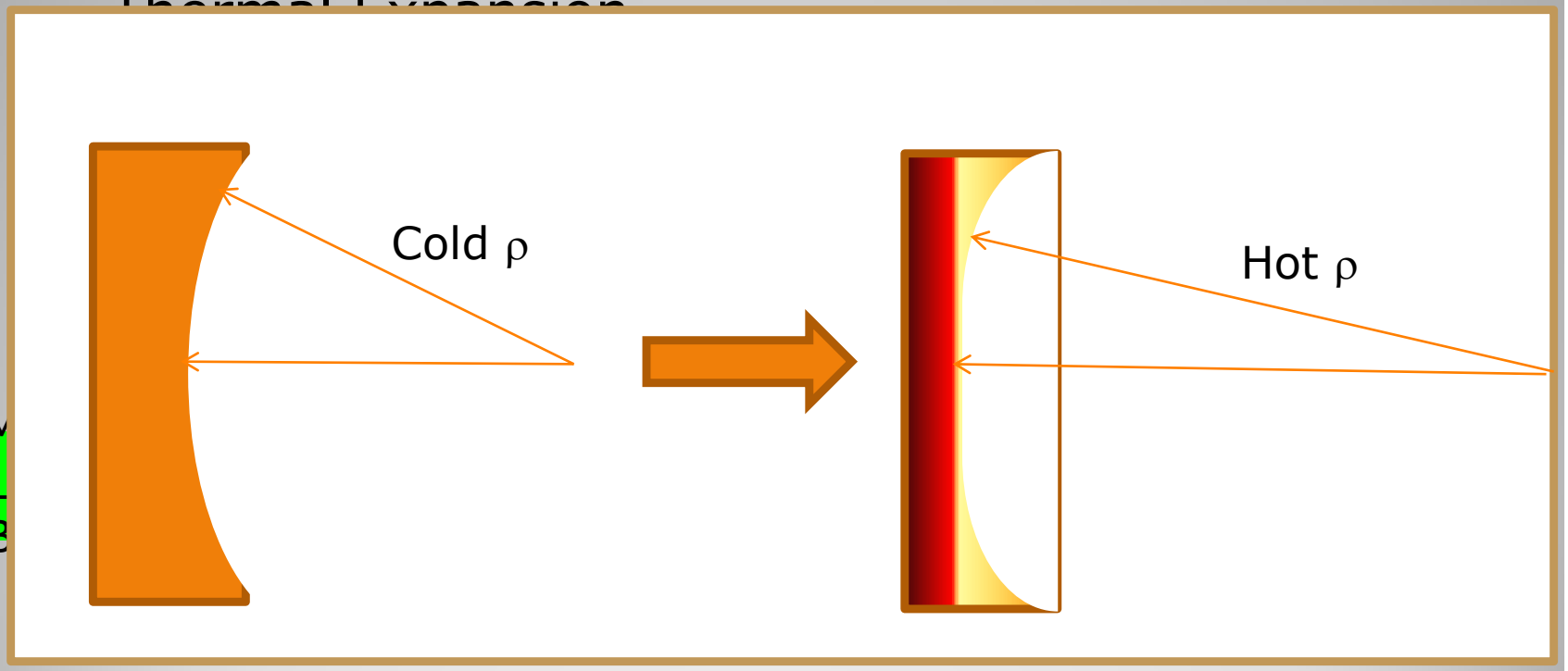
# Outline

- LIGO Layout
- Thermal Aberrations
- Thermal Issues
- Compensation Systems
- Model
- Closing Remarks



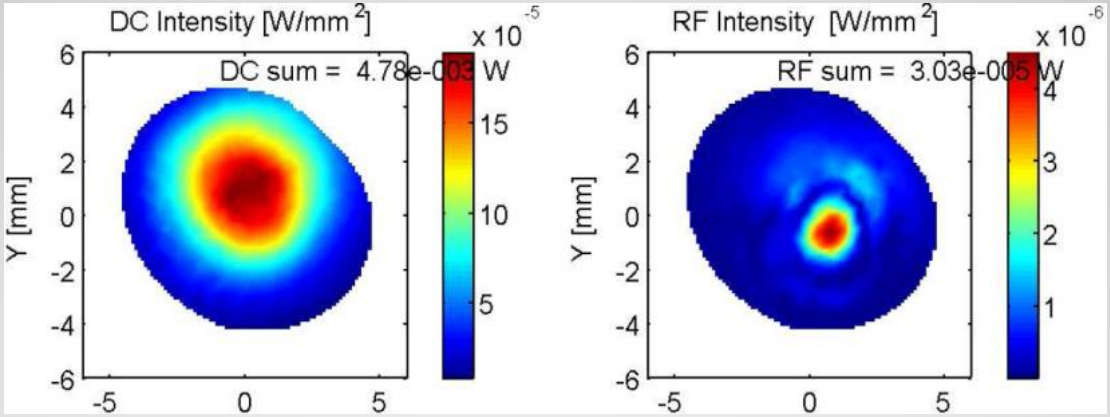

# Optical Layout

- Causes
- HEAT GRADIENT
  - Thermal Lensing
  - Thermal Expansion
- Effects
  - Differential Expansion

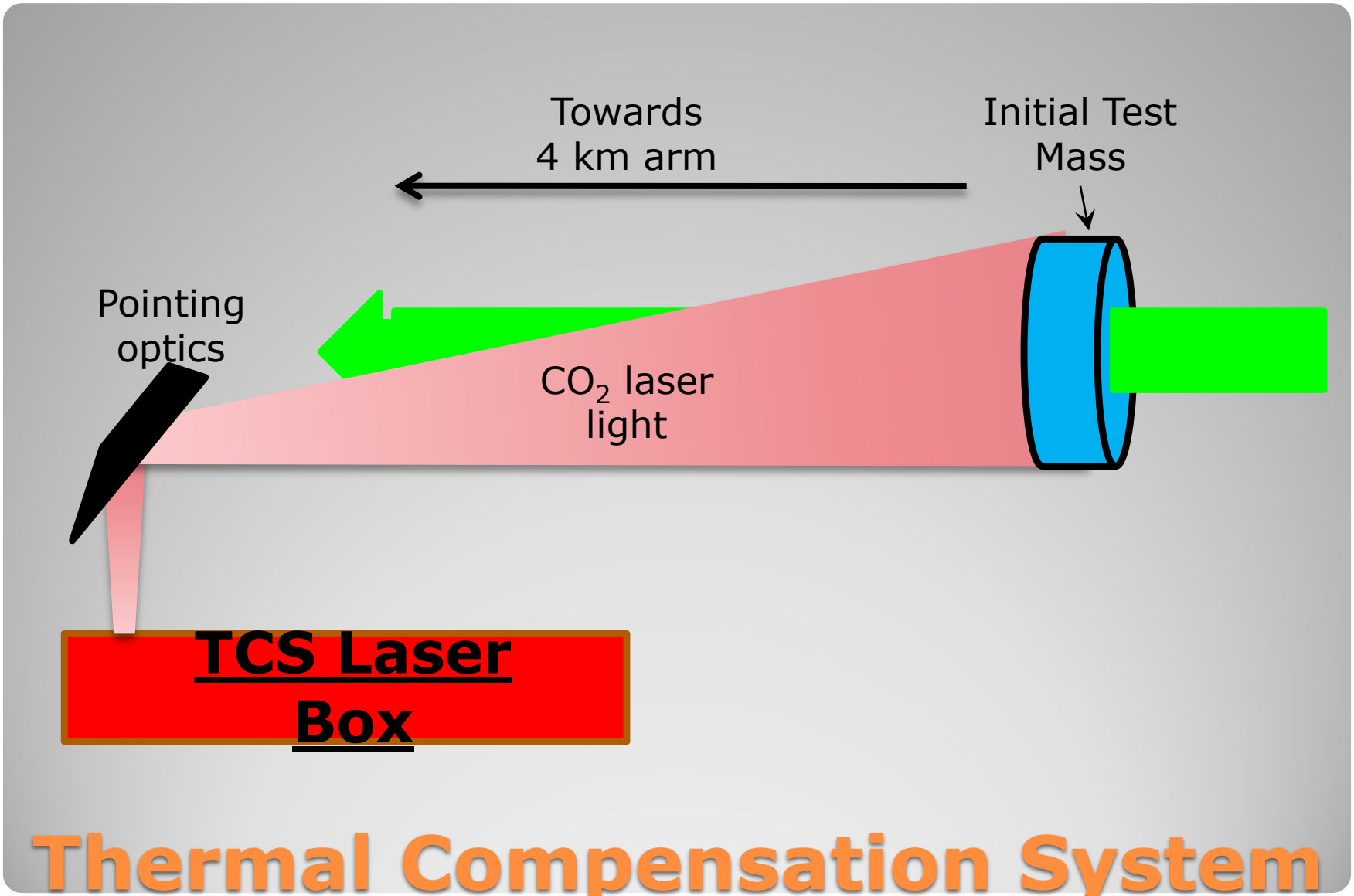



# Thermal Aberrations

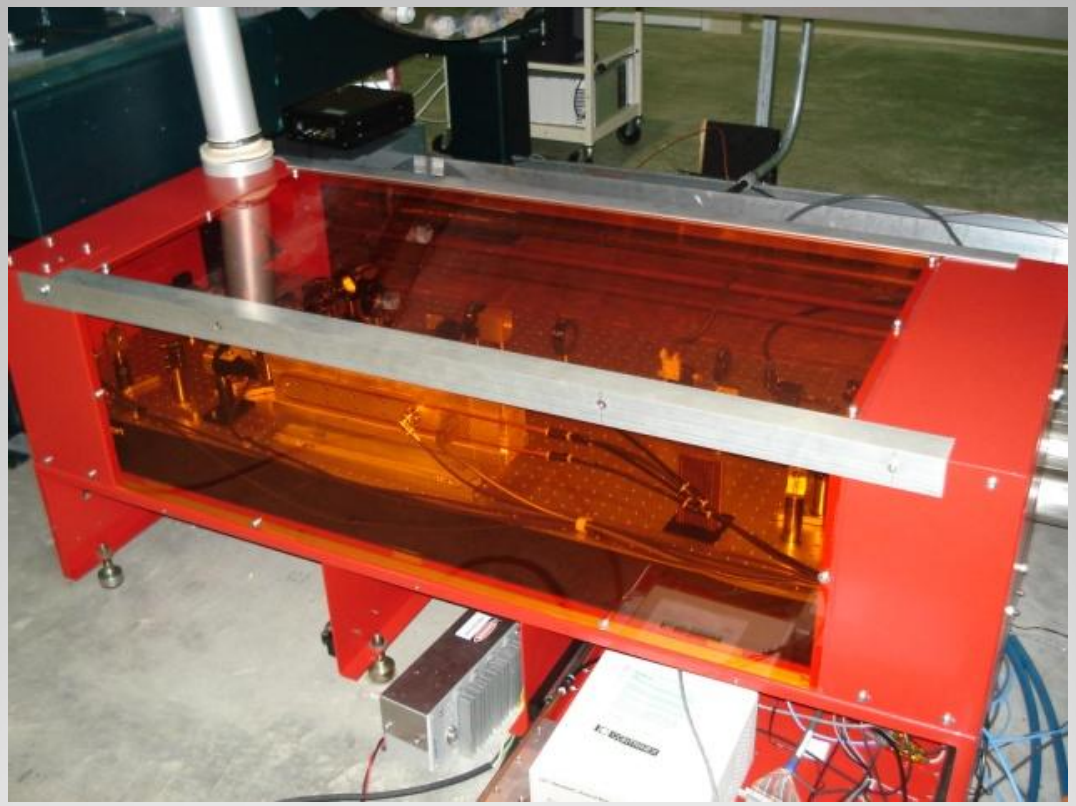
- PRM Stability Issues
  - Not stable for RSB
  - Cavity g-factor > 1
  - No containment in cold state
- Contrast Defect
  - Imbalanced thermal lenses increases junk light output




# Thermal Issues: eLIGO




# Thermal Compensation System

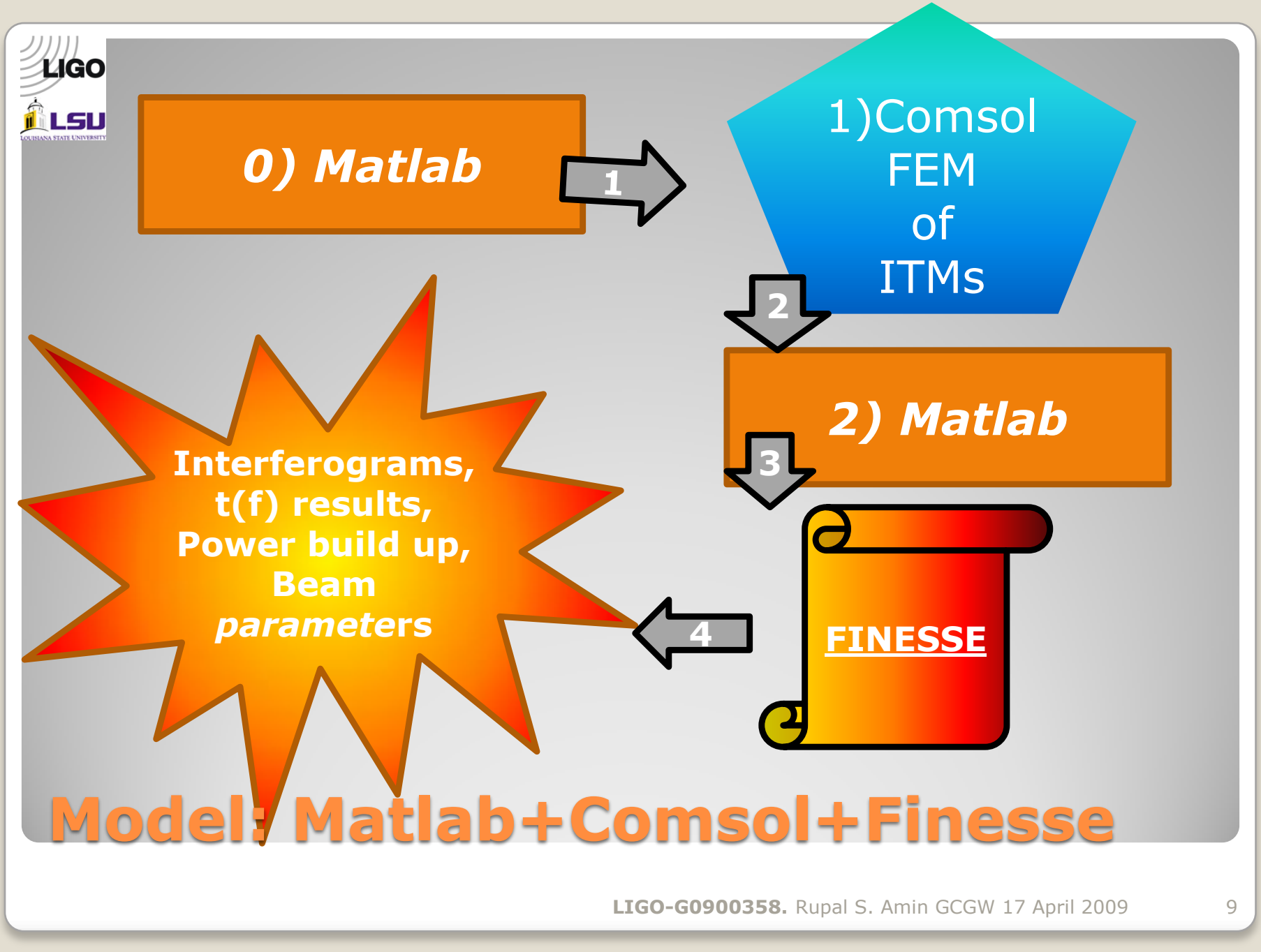


# TCS Hardware

# Need a thermal model of the INTERFEROMETER

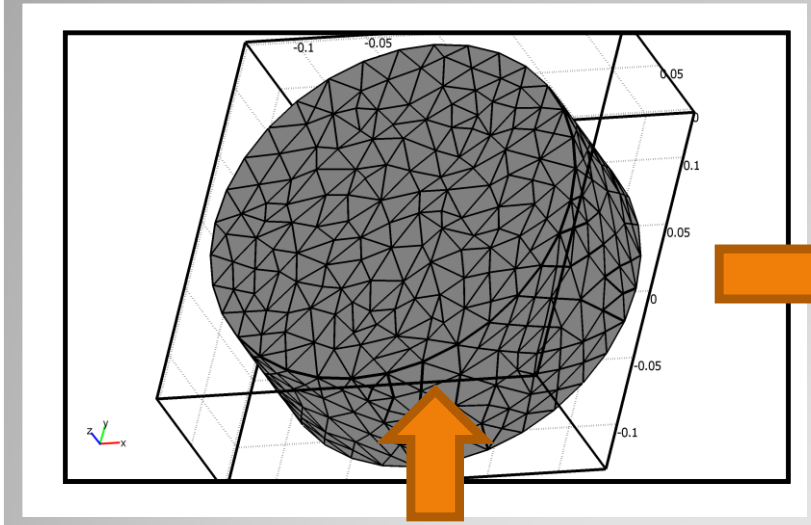
(Dramatic music)

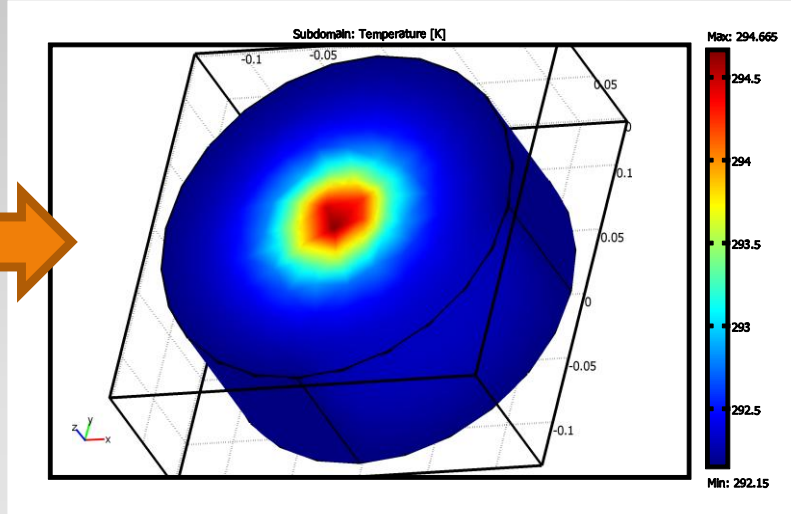
# Solution for eLIGO


0) Matlab
1
1)Comsol FEM of ITMs
2
2) Matlab
3
FINESSE
4
Interferograms, t(f) results, Power build up, Beam parameters
Model: Matlab+Comsol+Finesse

- Comsol Finite Element Analysis

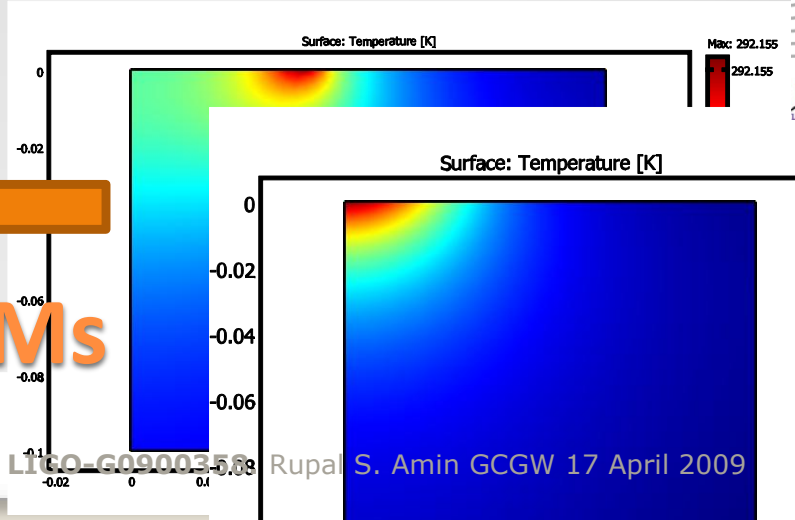
- Simulate mirror heating patterns with and without TCS






Inputs: Boundary Conditions
Substrate Materials

Outputs: Deformed Surface
Thermally Dependent n





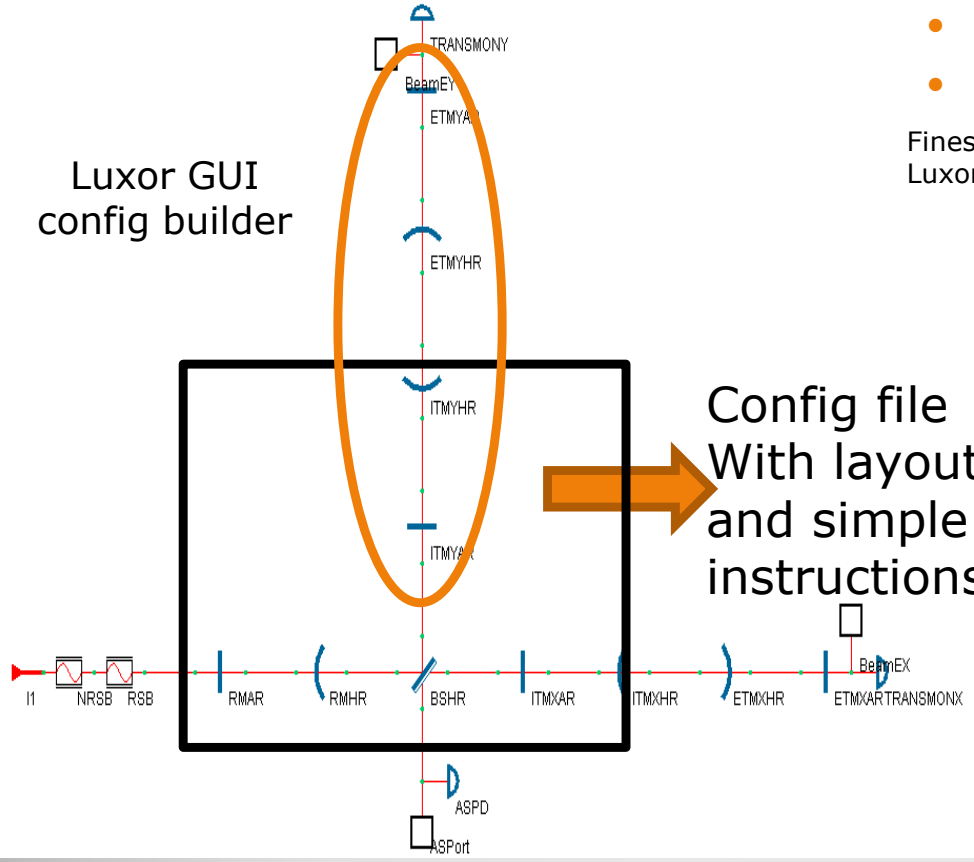


# Step 1: FEM of ITMs

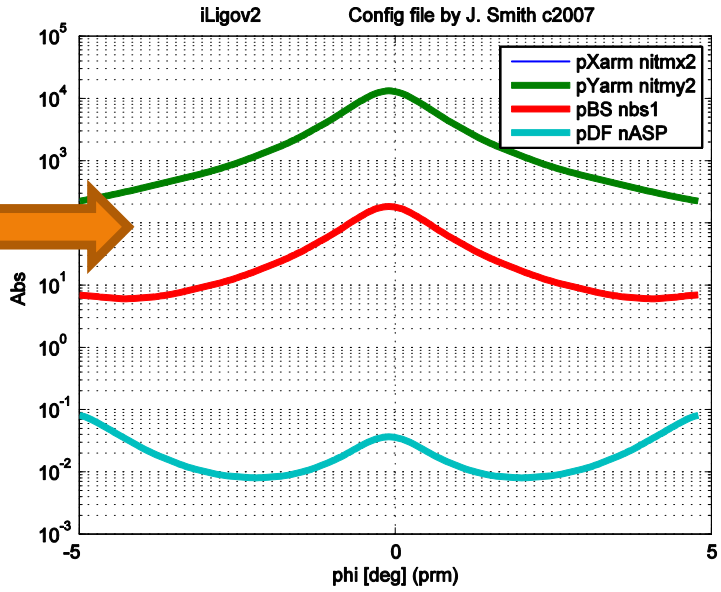
- Optical interaction only
- No mechanical interactions
- No radiation pressure

Finesse: http://www.rzg.mpg.de/~adf/
Luxor: http://www.aei.mpg.de/~jah/luxor.html

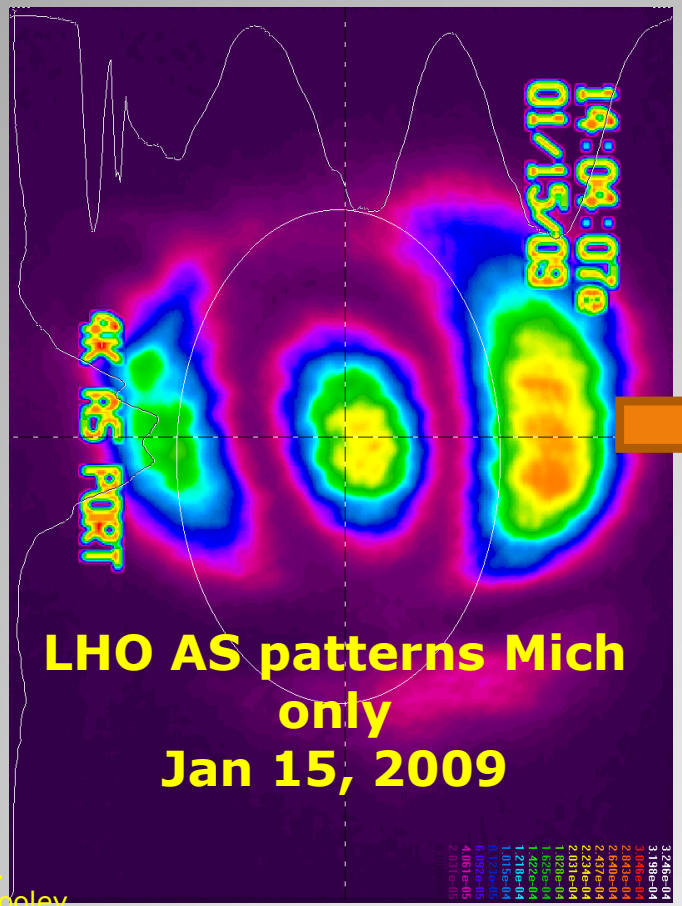
Luxor GUI config builder




Config file With layout and simple instructions

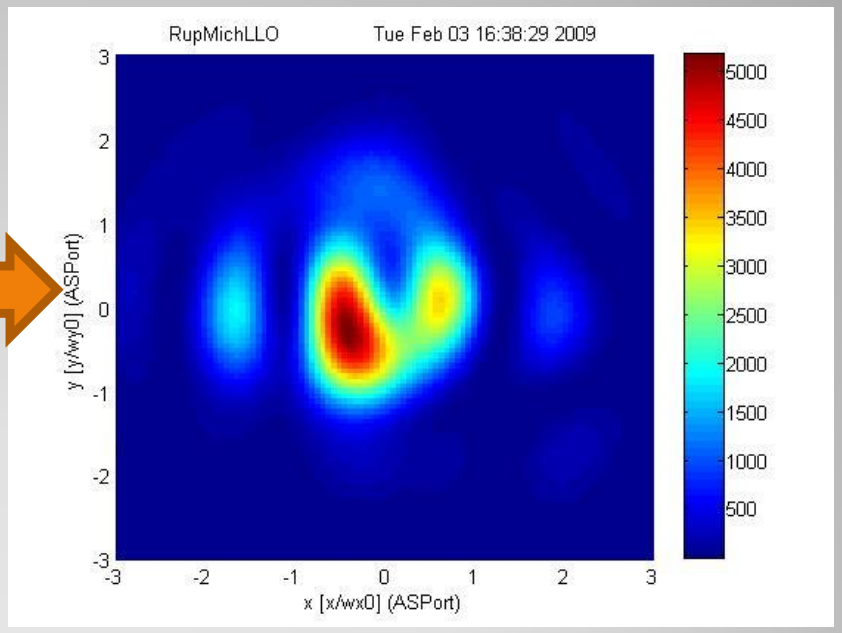



# Step 2: In-house sim. code




**LHO AS patterns Mich only Jan 15, 2009**

K. Dooley ilog LHO




Simulated Interferogram

# Step 3: FEM + Simulation

- Interferometers require thermal compensation to maintain stability at high power
- Thermal model construction in progress
- Sensible control signals are needed
- Cannot assume that new TCS behave exactly like old TCS

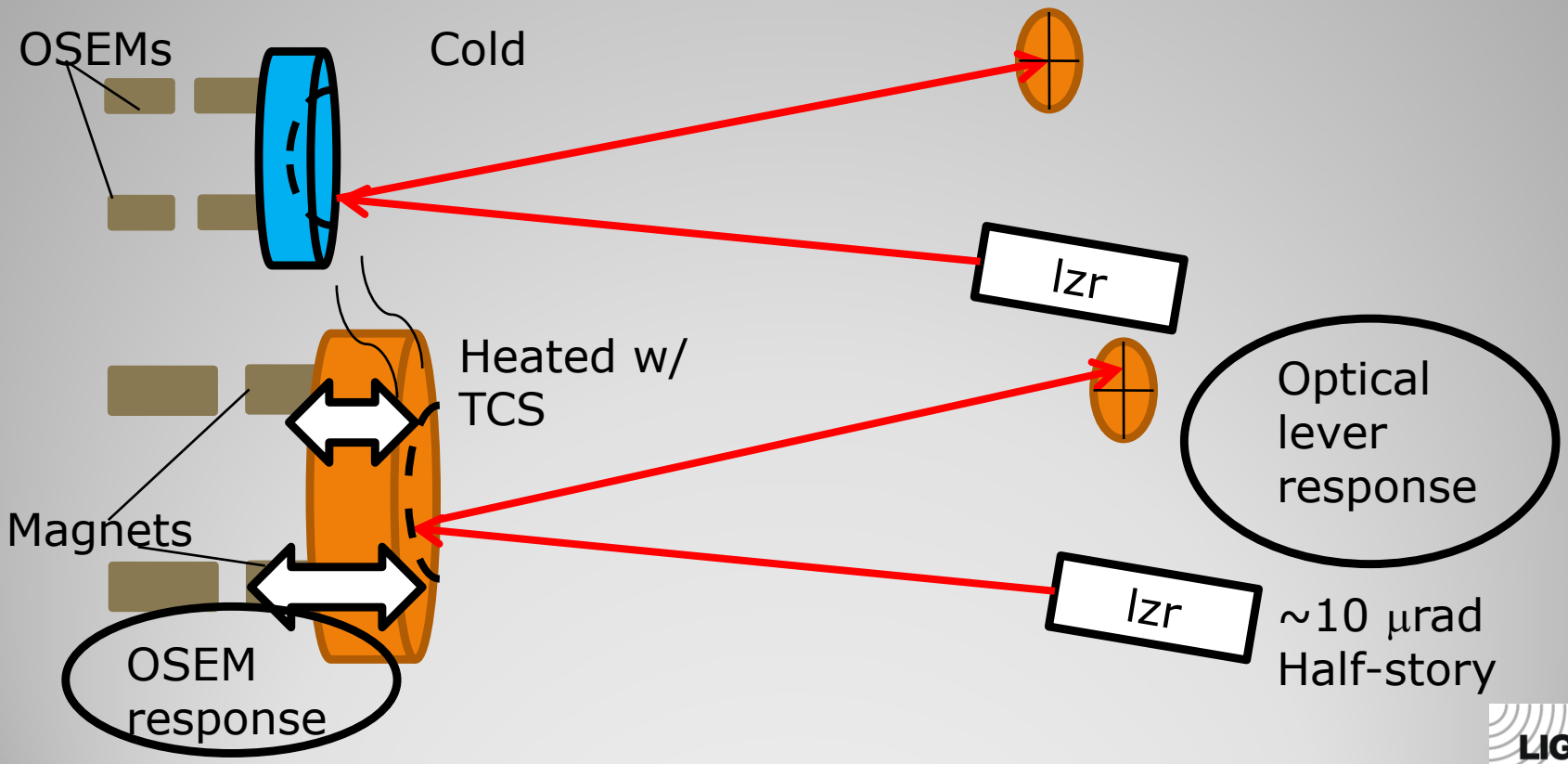
# Closing

# Thanks to…


- Special Thanks to
- J. Giaime LSU Associate Prof. of Physics
- Phil Willems TCS Group Leader CIT
- Aidan Brooks
- Cheryl Vorvick
- Carl Adams
- Viginio Sannibale
- Mohana Mageswaran

- NSF grant number:
  - NSF-PHY-0605496

- Unexpected TCS induced ASC signals
  - Due to surface expansion and mirror expansion

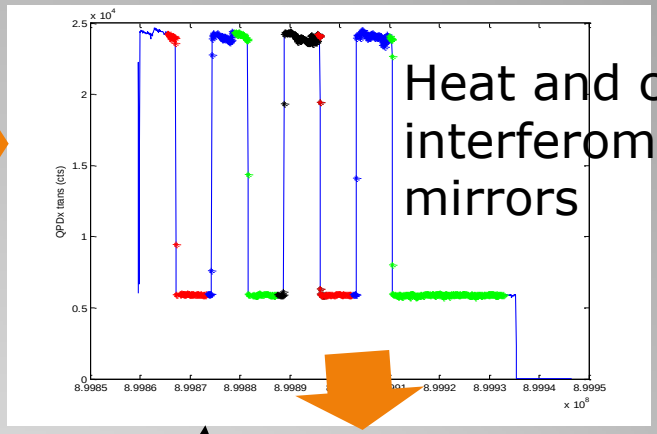



# Problems with cut and paste

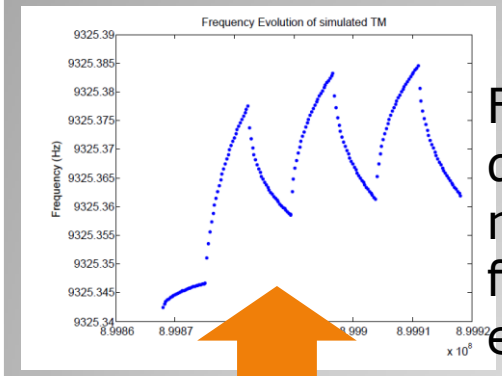
| | Common | Differential |
|---|---|---|
| **iLIGO** | Sideband power build-up | AS_I In-phase demodulation |
| **eLIGO** | Sideband power build-up? | **Working on it** |

**Problems with cut and paste**

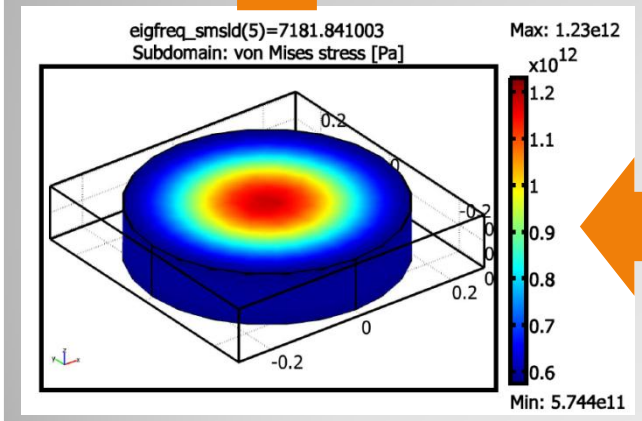
- Need to measure mirror absorption ratios

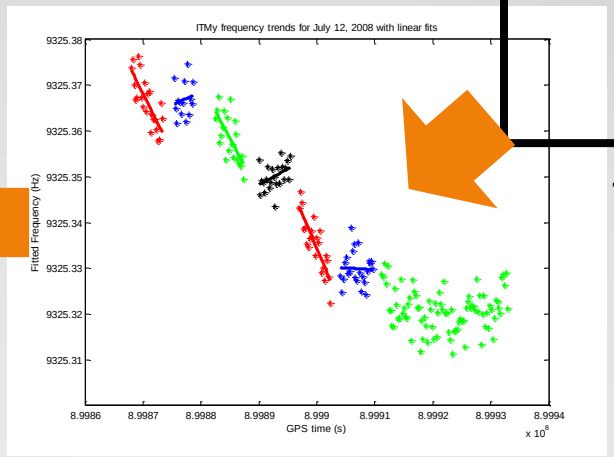


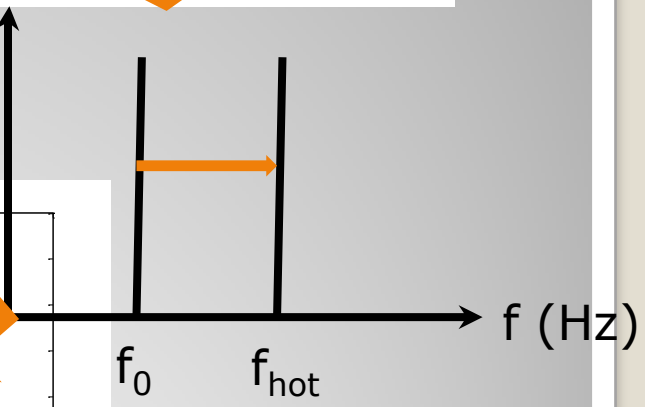

Heat and cool interferometer mirrors




FEM of drumhead mode freq. evolution

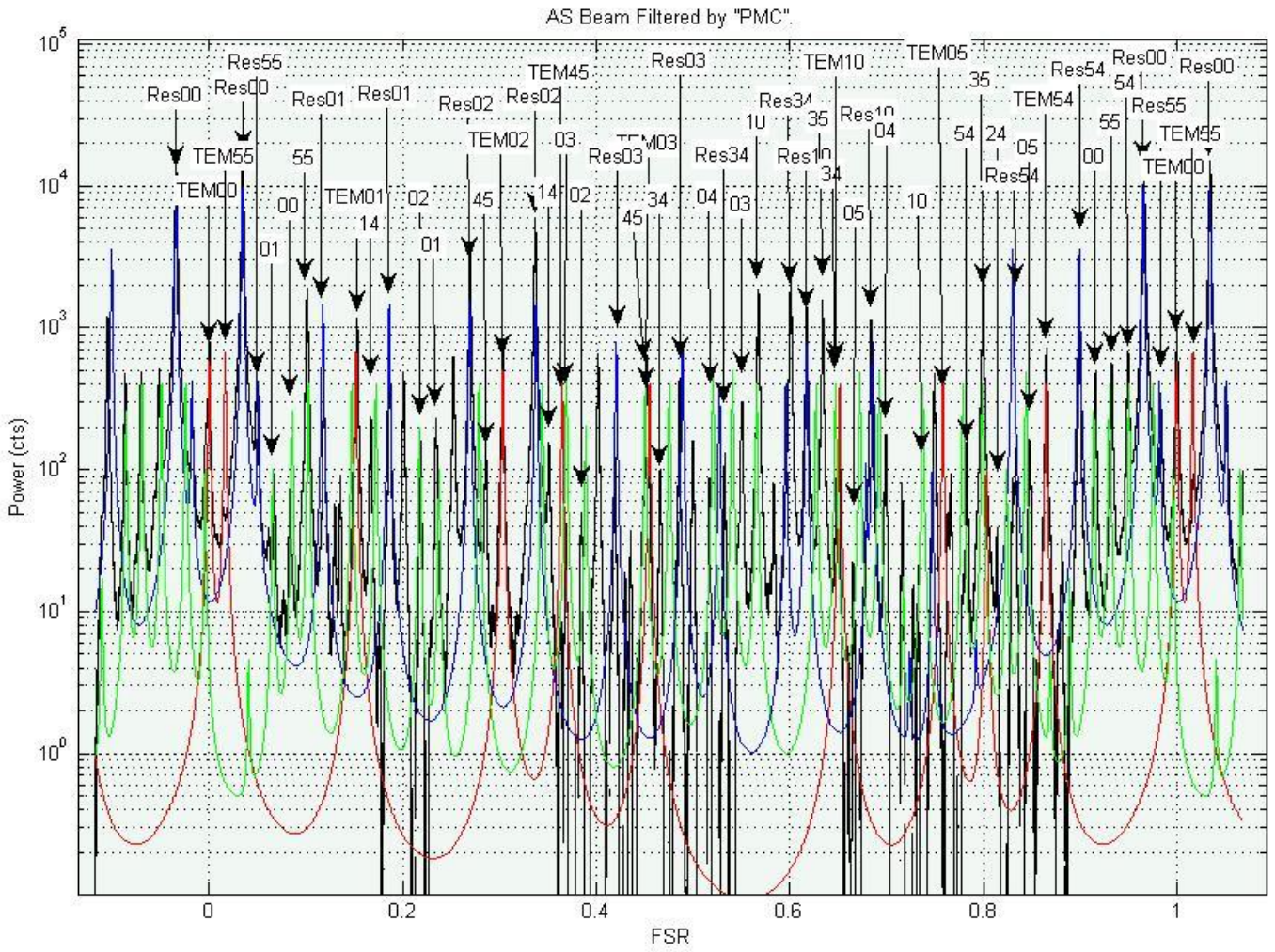


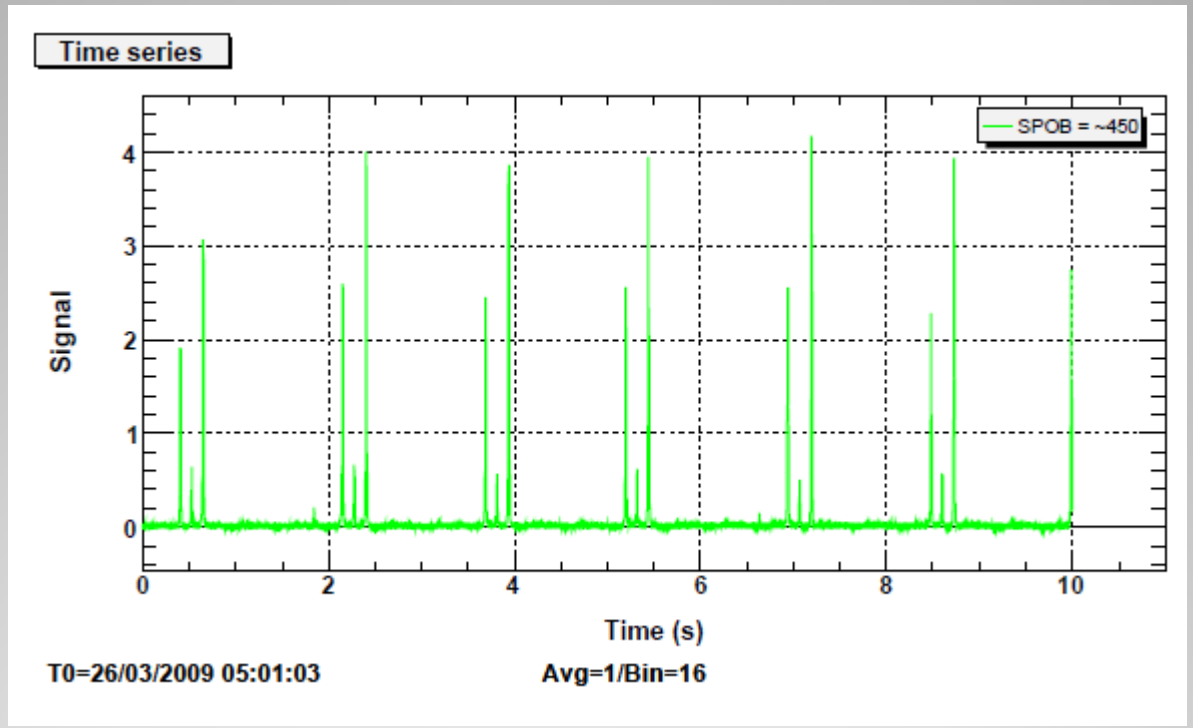




Results in frequency shifts

# Step 1: Model actual heating




# Thermal issues: eLIGO




Resonant Sideband Imbalance Still Here

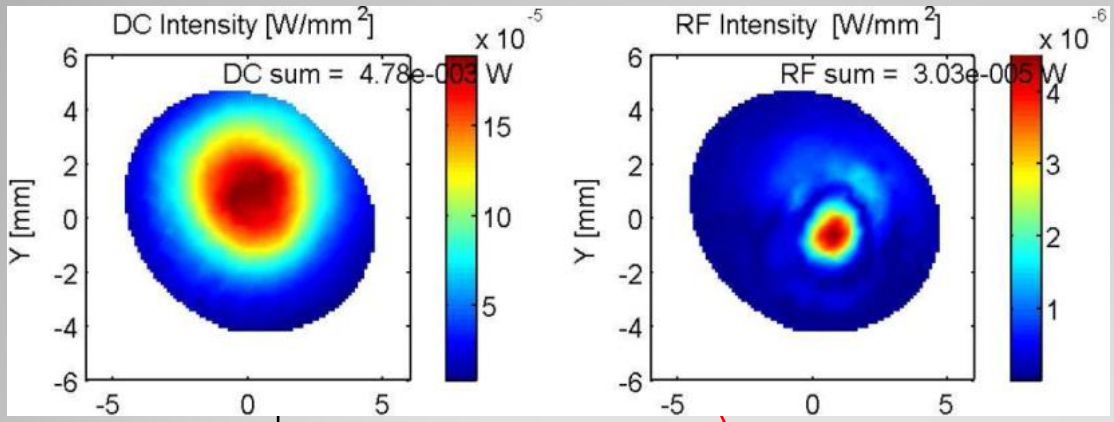
# Problems with cut and paste

# Resonant Sideband Build-up

- -2003-2004 LHO ilog
- Indicate poor power build-up PRIOR to mirror replacement
- Due to excessive thermal lensing

Sideband overlap and imbalance NOT controlled

-LLO Phase Cam. (A. Gretarsson LLO ilog 2004)




Pwr in

S. Ballmer (MIT thesis, 2006)

## Thermal Issues: iLIGO


## Effects on Strain Sensitivity

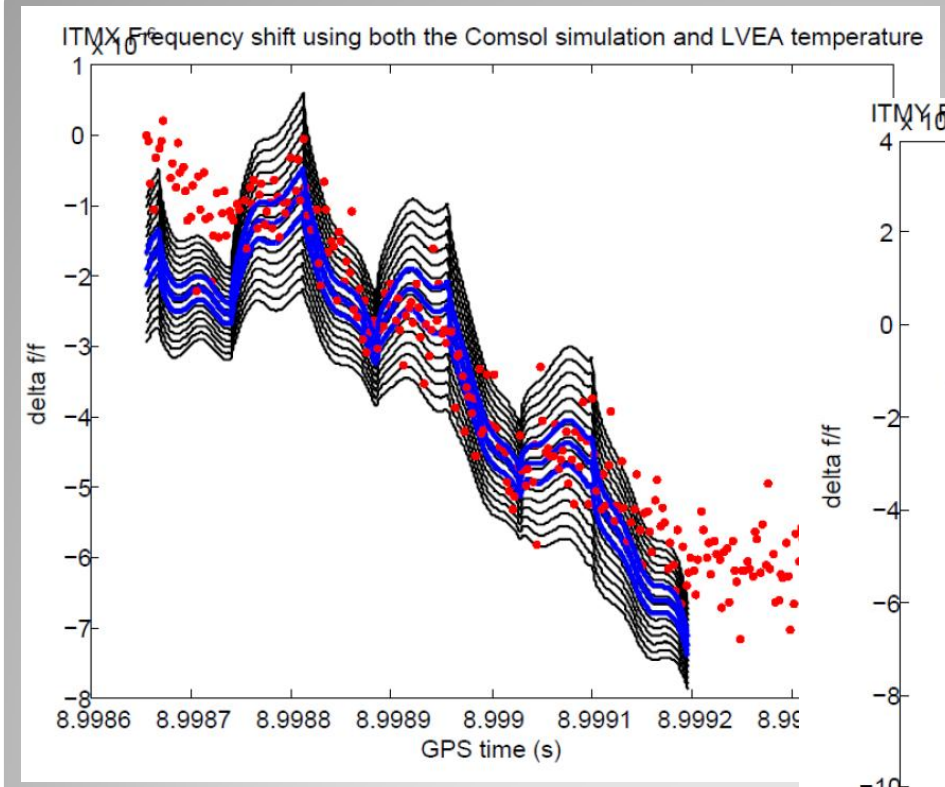
- Decrease arm cavity gain → Arm length sensing
- Decrease PRM carrier gain → Shot noise
- **Decrease PRM SB gain → Locking and alignment precision**
- Increase total carrier contrast defect → Shot noise

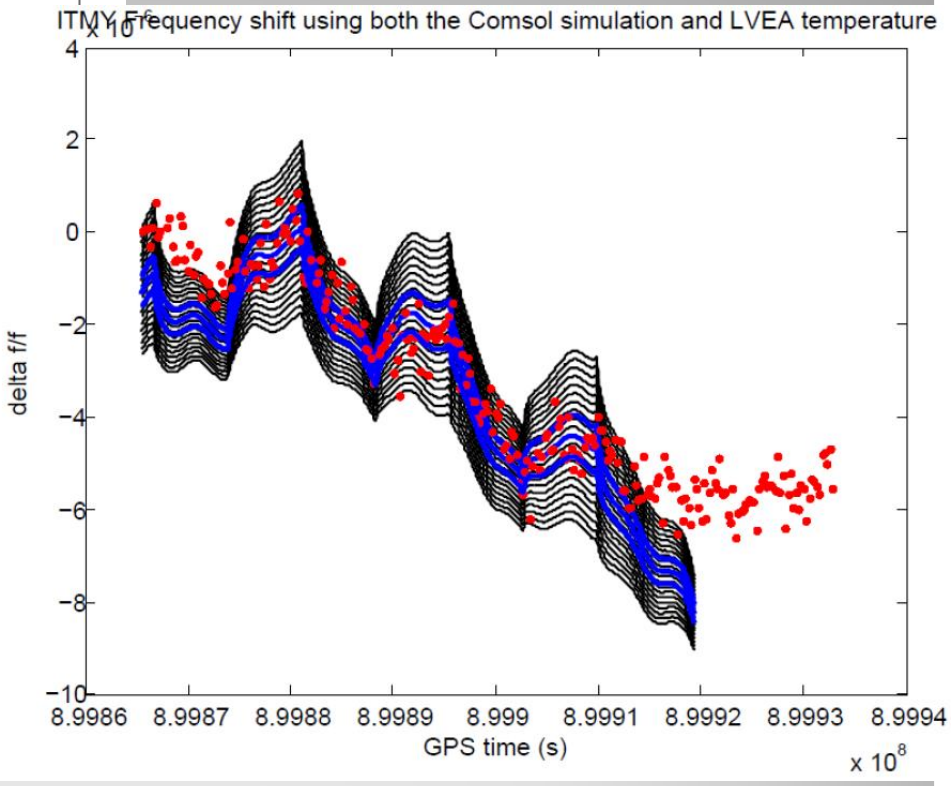
R. Lawrence (MIT Thesis, 2003)

# Thermal issues: iLIGO

# Thermal Compensation System

- Objective
- Control thermal aberrations with auxiliary lasers
  - Reduce optical noise
  - Improve high frequency sensitivity
  - Reduce down time with pre-heating




Result:
Absorption ratio for ITMX = 3.5 ppm
ITMY = 5 ppm +/- 10%

# Step 1: Result