Thermal Compensation System Servo and required heating for H1

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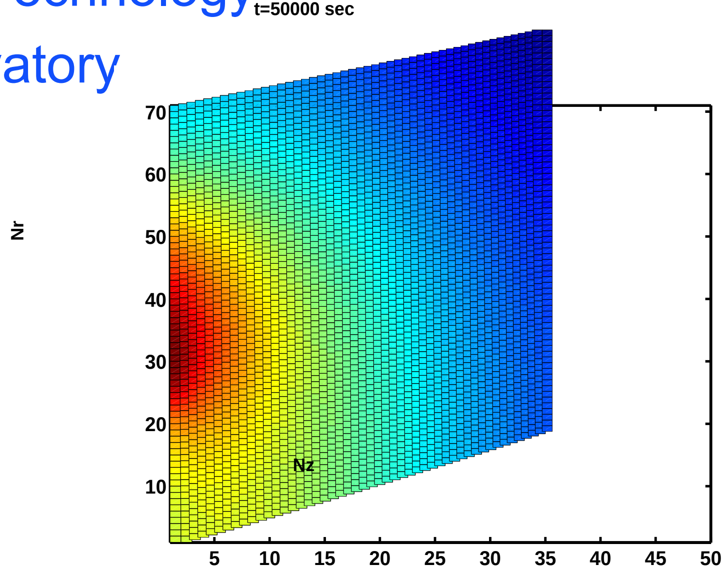


Outline

- Part 1:
  - Thermal Compensation System Servo
- Part 2:
  - How does the required TCS power depend on the 1064nm Laser Power?

Part 1:
The Problem

Experimental observations:

- With TCS Annulus heating we achieved optimal PRC build-up
  - H1 Inspiral Range up to 8.5Mpc (back in Aug 2004)

- BUT:
  - The optical gain always plummeted after ~30min.
  - It was usually possible to tweak it up again (patience required!)
  - The IFO was never stable for more that ~90min

- What's going on?

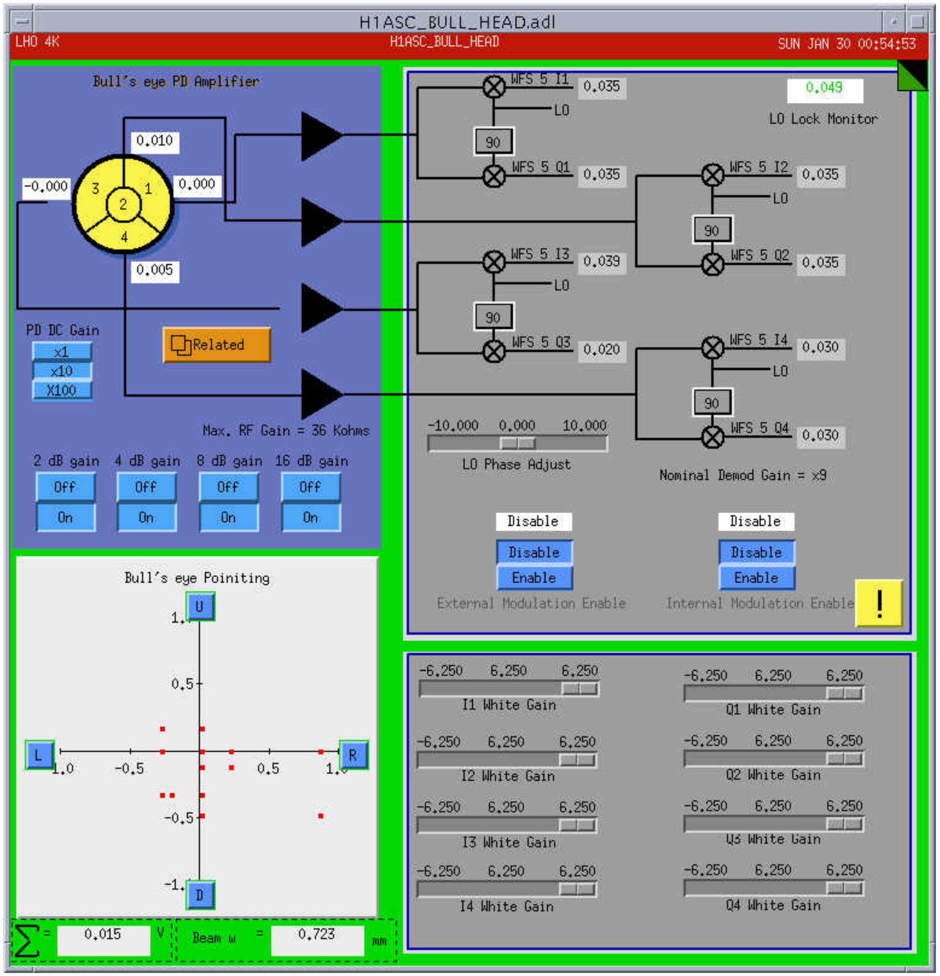
The approach: The TCS servo

- Need a servo to keep the recycling gain at it’s optimal point:
  - 2 DoF’s (TCSX, TCSY)
    → Need 2 error signals
- AS_I – an orphan error signal
  - Works just fine for differential TCS - shown by Hiro
- For the common TCS we need a signal that is linear across the maximum recycling gain point:
  - The common TCS directly affects the wave front curvature difference between carrier and sidebands, i.e. the radial mode matching
    → We need a radial WFS, or Bull’s Eye detector

- We actually had an (almost working) Bull’s eye detector form LIGO’s prehistoric times on site…

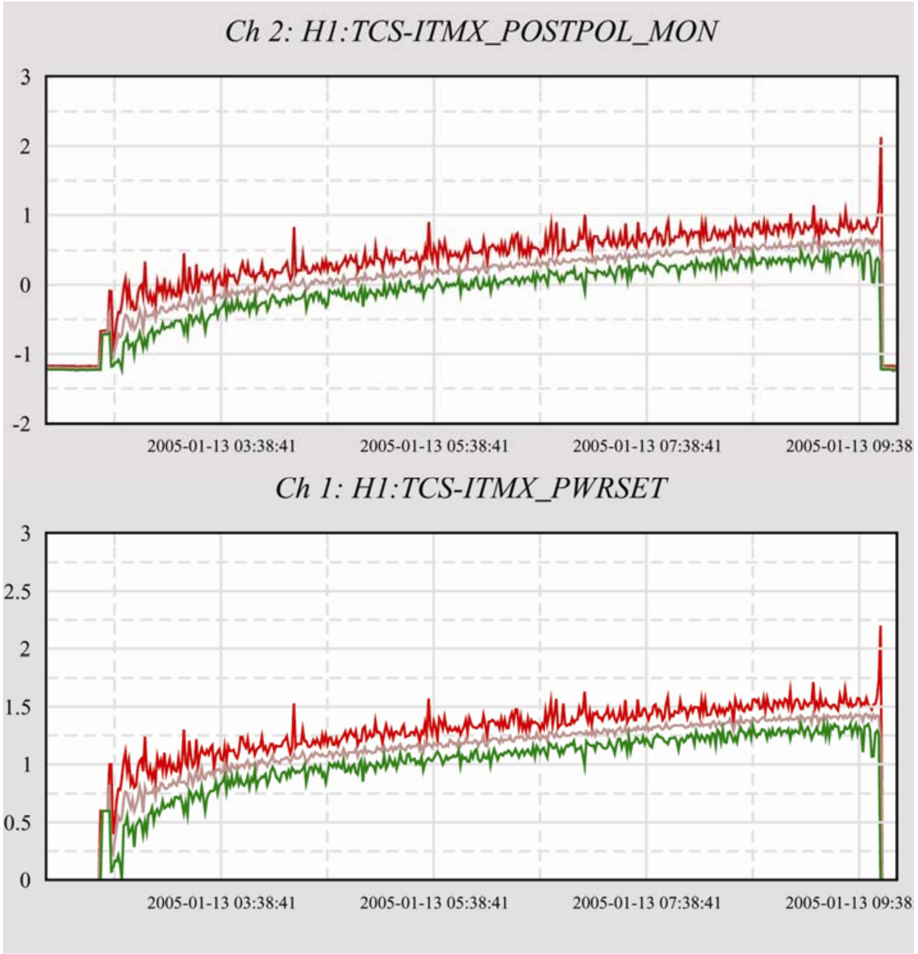
The Bull's eye

- Bull's eye PD installed in POB beam
  - Inner Segment has r_0=1mm
  - Node of 1st Laguerre polynomial $(1-2r^2/w^2)$ at r_0 → w=1.4mm
- TCS servo loop shaping:
  - Sampling rate: 1Hz
  - Pole at 0Hz (Integrator)
  - Zero at 1/(10min) to compensate the thermal pole
  - Roll-off pole at 0.1Hz
- Optimal recycling gain requires a small offset

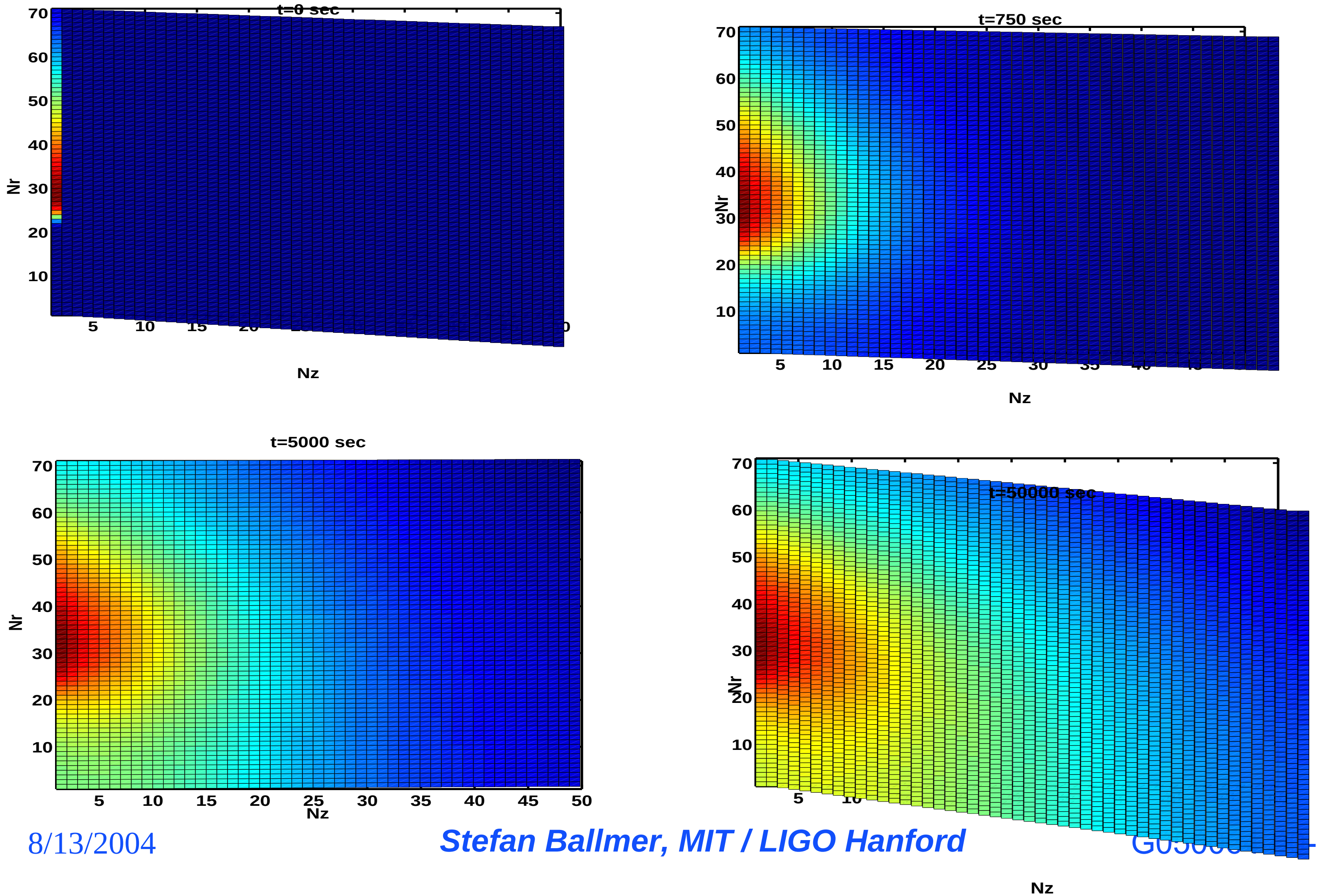


Is H1 recycling gain stable now?

- At 3.35 Watts into MC:
  - O(12h) locks with constant recycling gain
- BUT:
  - We observe a very slow increase in required TCSX annulus power
  - 1/e time = O(couple hours)
- At 4 Watts we simply run out of TCSX range after 90min



Is this expected?
Time domain FEM model

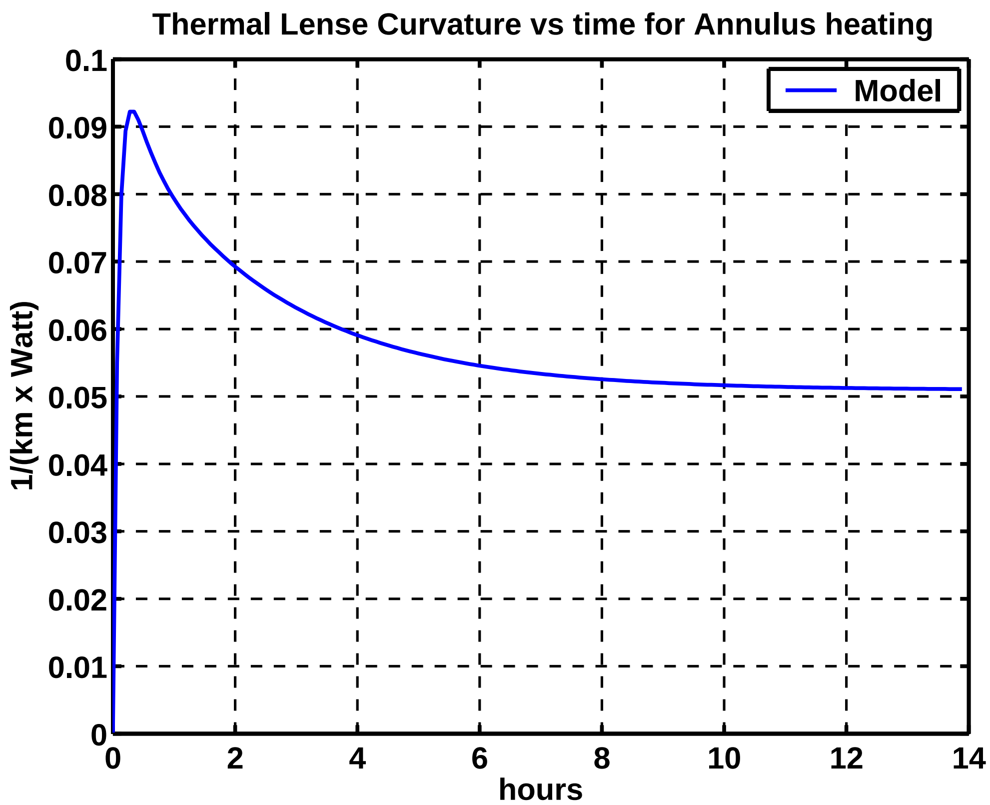


Thermal Lens Curvature vs. Time for constant Annulus heating

- Efficiency loss of almost 50%!
- 1/e time constant =4.3h

- Reason:
  - Heat propagates along optical axis and to the center
  - Deeper inside the optic the annulus structure of the temperature field is lost → opposite sign effect!

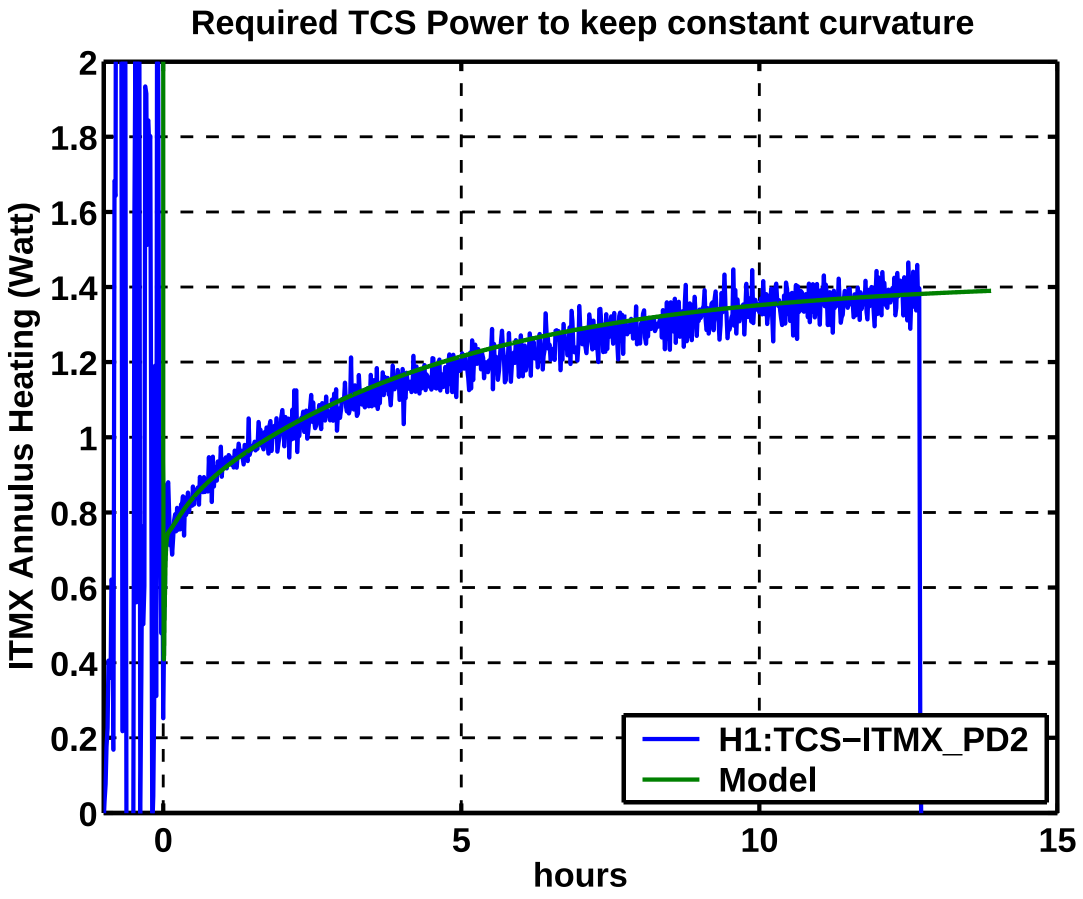
- No such dramatic effect for central heating



Model vs. H1

- Invert the impulse response
  → required power for constant curvature

- Only gain adjusted to mach data

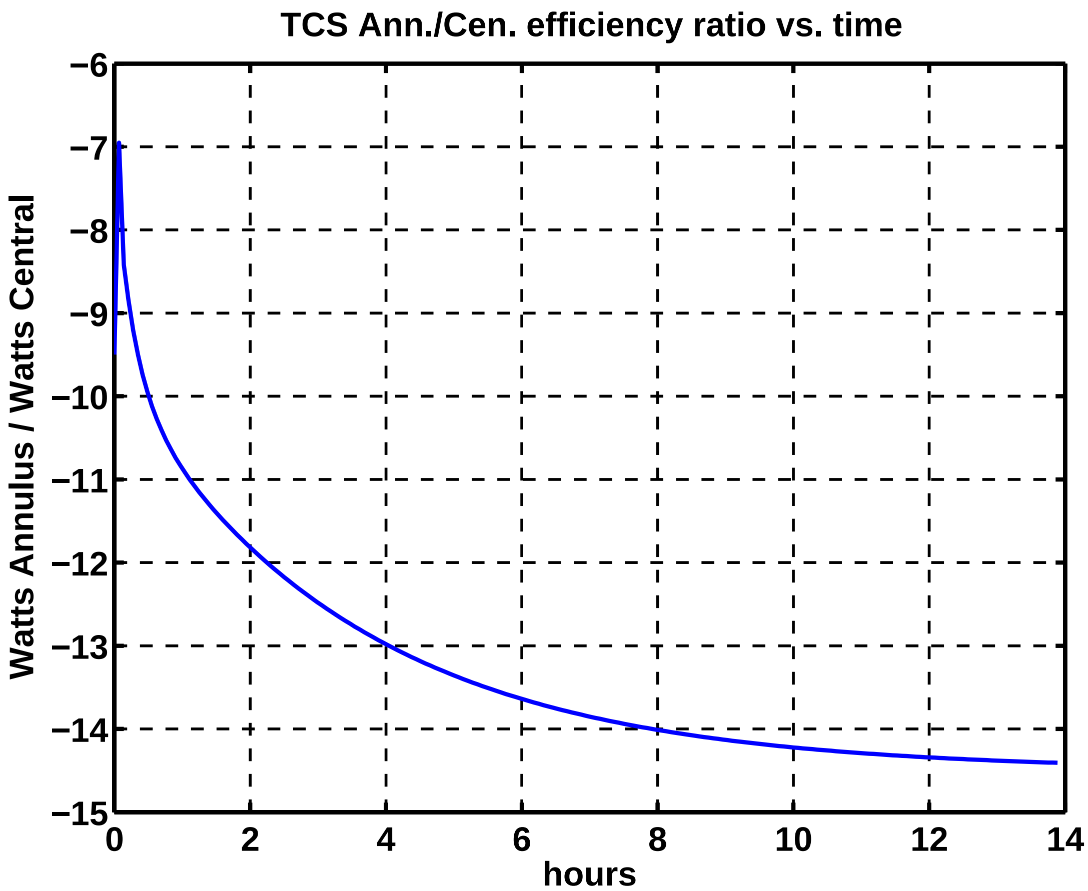


Central vs. Annulus heating: Efficiency

- Question:
  - How much more Power do we need for Annulus heating compared to Central Heating to get the same curvature change?

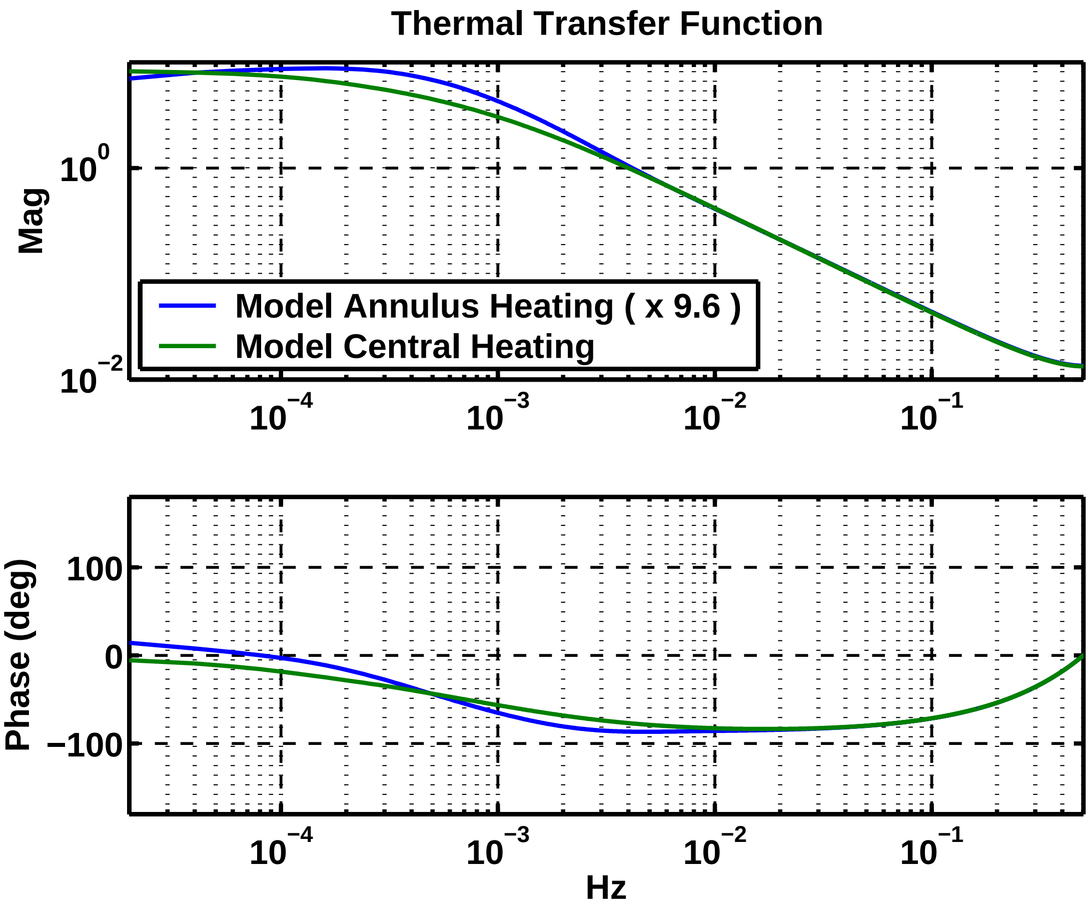
- Answer depends on time since lock acquisition!

- Caution:
  - Central heating temperature profile is not a pure parabola -> fit not great



Central vs. Annulus heating: Thermal Transfer Function

- TCS Power → curvature Transfer Function (arbitrary units)

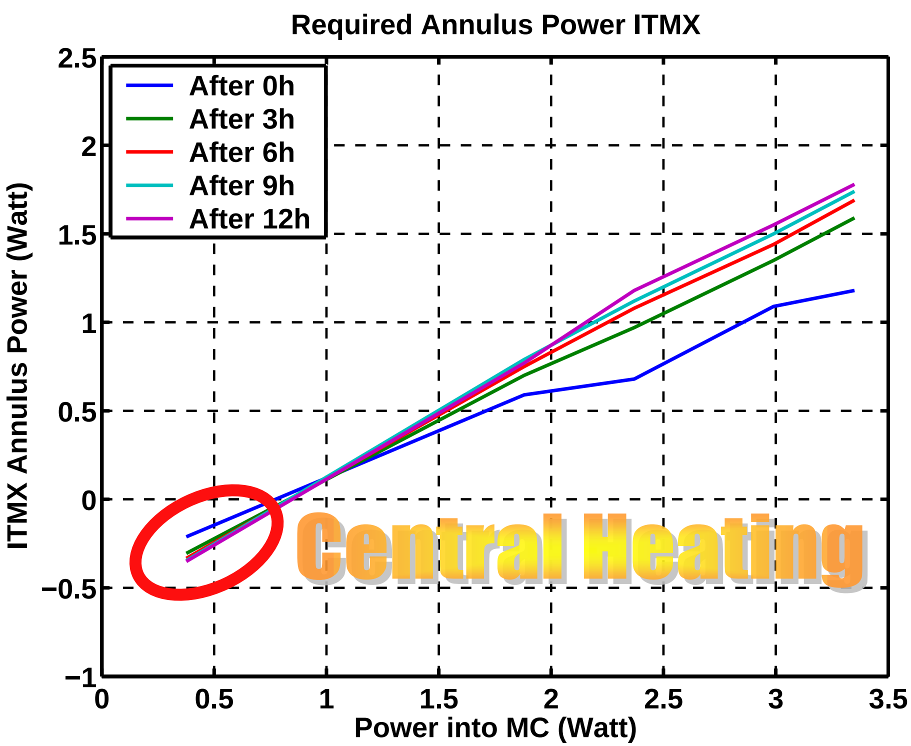


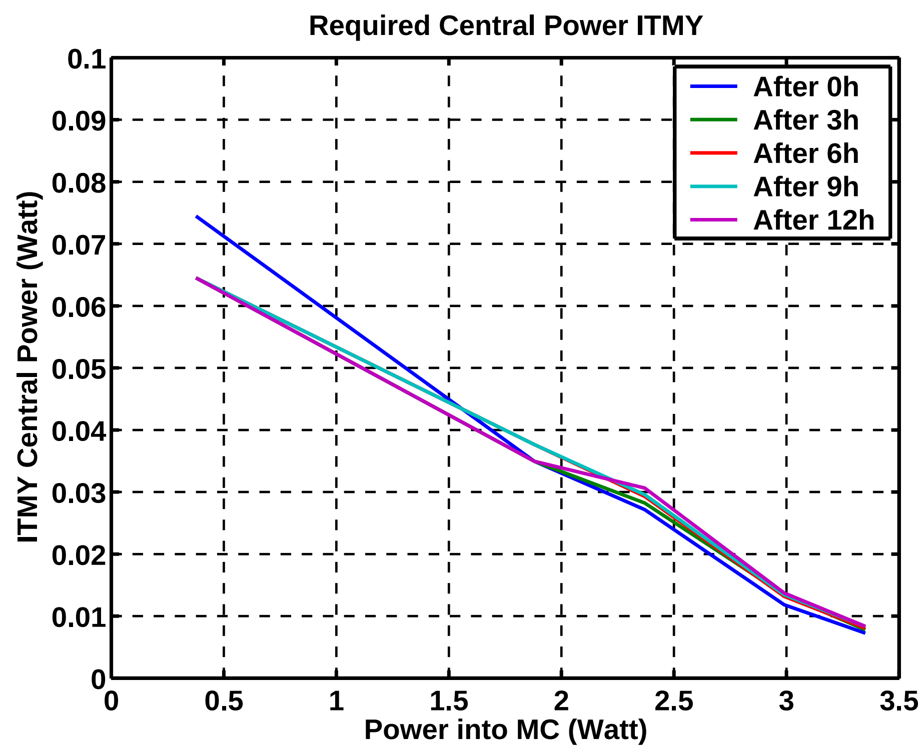
Part 2:
The Power Measurement

- With the TCS servo running we ran H1 at 5 different power levels:
  - 0.38, 1.9, 2.4, 3.0 and 3.4 Watt
  - Each lock lasted ~12hours
  - Read out the required TCSX and TCSY power at 0, 3, 6, 9 and 12 hours into the lock.
  - The also automatically chose whether it need Annulus or Central heating.

- Words of caution:
  - The measurement error is O(20%)
    - The λ/2 plate actuators are not very linear, especially at small transmission powers
    - The CO2 laser output can drift – mode-hops have been observed
    - We have a back-reflection problem from the masks at high transmission powers. This causes both DC Laser power changes and increased intensity noise.

Part 2:
The Data

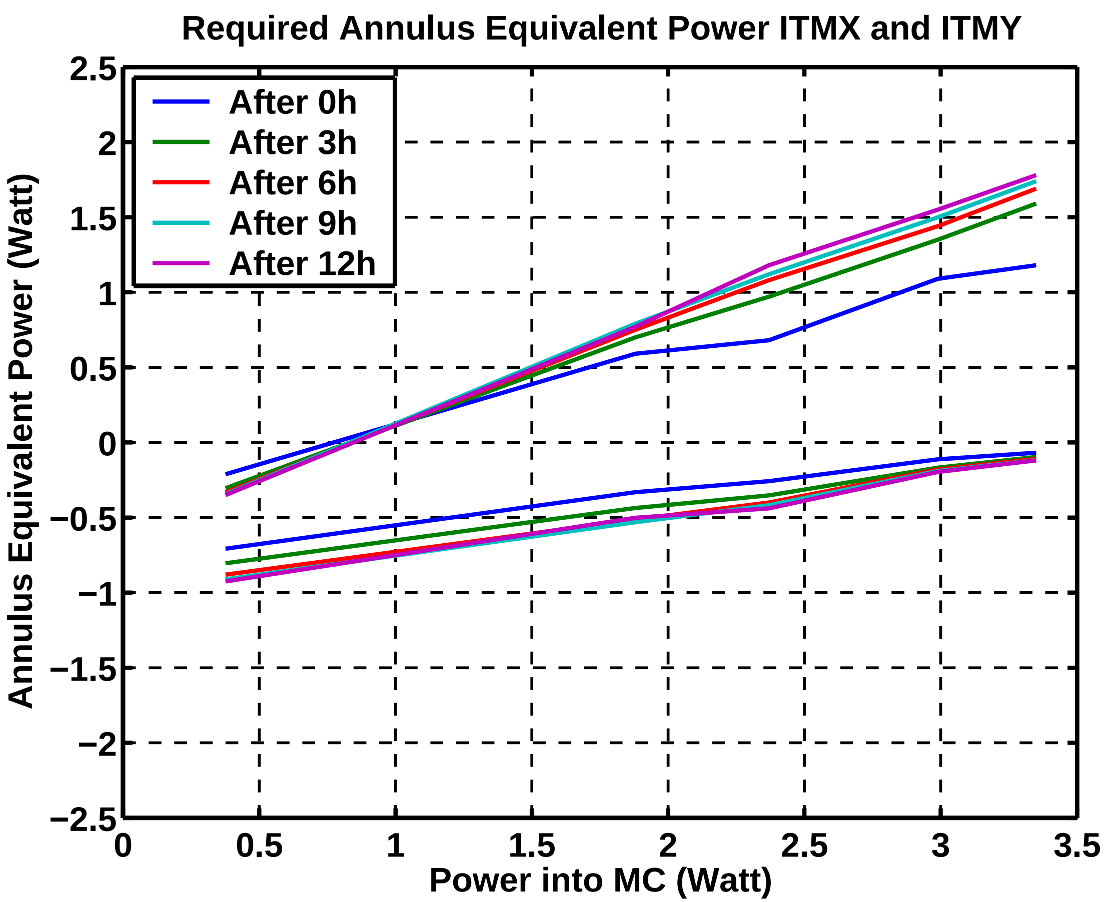




Part 2:
The Thing about apples and oranges…

- Converted all Central Heating data points to Annulus power using the curve on slide 10

- Large differential offset
- Slope ratio ~2:1
  - Can we trust it? (Uncertainty in C→A conversion)



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The raw data

- 0.376 Watt into MC:

hours	PDraw	PDcal (W)		Set X (W)	Set Y (W)
0	N/A	N/A		0.083	0.277
3	N/A	N/A		0.091	0.240
>3	N/A	N/A		const	const

- 1.88 Watt into MC:

hours	PDraw	PDcal (W)	Set X (W)	Set Y (W)	
0	0.25	0.3136		0.59	0.13
3	0.31	0.4096		0.7	0.13
6	0.35	0.4736		0.75	0.14
9	0.36	0.4896		0.79	0.14
12	0.36	0.4896		0.77	0.13

- 2.37 Watt into MC:

hours	PDraw	PDcal (W)	Set X (W)	Set Y (W)	
0	0.32	0.4256		0.68	0.101
3	0.5	0.7136		0.97	0.105
6	0.57	0.8256		1.08	0.109
9	0.61	0.8896		1.12	0.110
12	0.64	0.9376		1.18	0.114

- 2.99 Watt into MC:

hours	PDraw	PDcal (W)	Set X (W)	Set Y (W)	
0	0.85	1.2736		1.09	0.044
3	1.05	1.5936		1.35	0.05
6	1.12	1.7056		1.44	0.049
9	1.18	1.8016		1.5	0.05
12	1.21	1.8496		1.55	0.051

- 3.35 Watt into MC:

hours	PDraw	PDcal (W)	Set X (W)	Set Y (W)	
0	0.89	1.3376		1.18	0.027
3	1.19	1.8176		1.59	0.029
6	1.27	1.9456		1.69	0.03
9	1.31	2.0096		1.74	0.031
12	1.33	2.0416		1.78	0.031