Study of the Output Mode Cleaner Prototype using the Phasecamera

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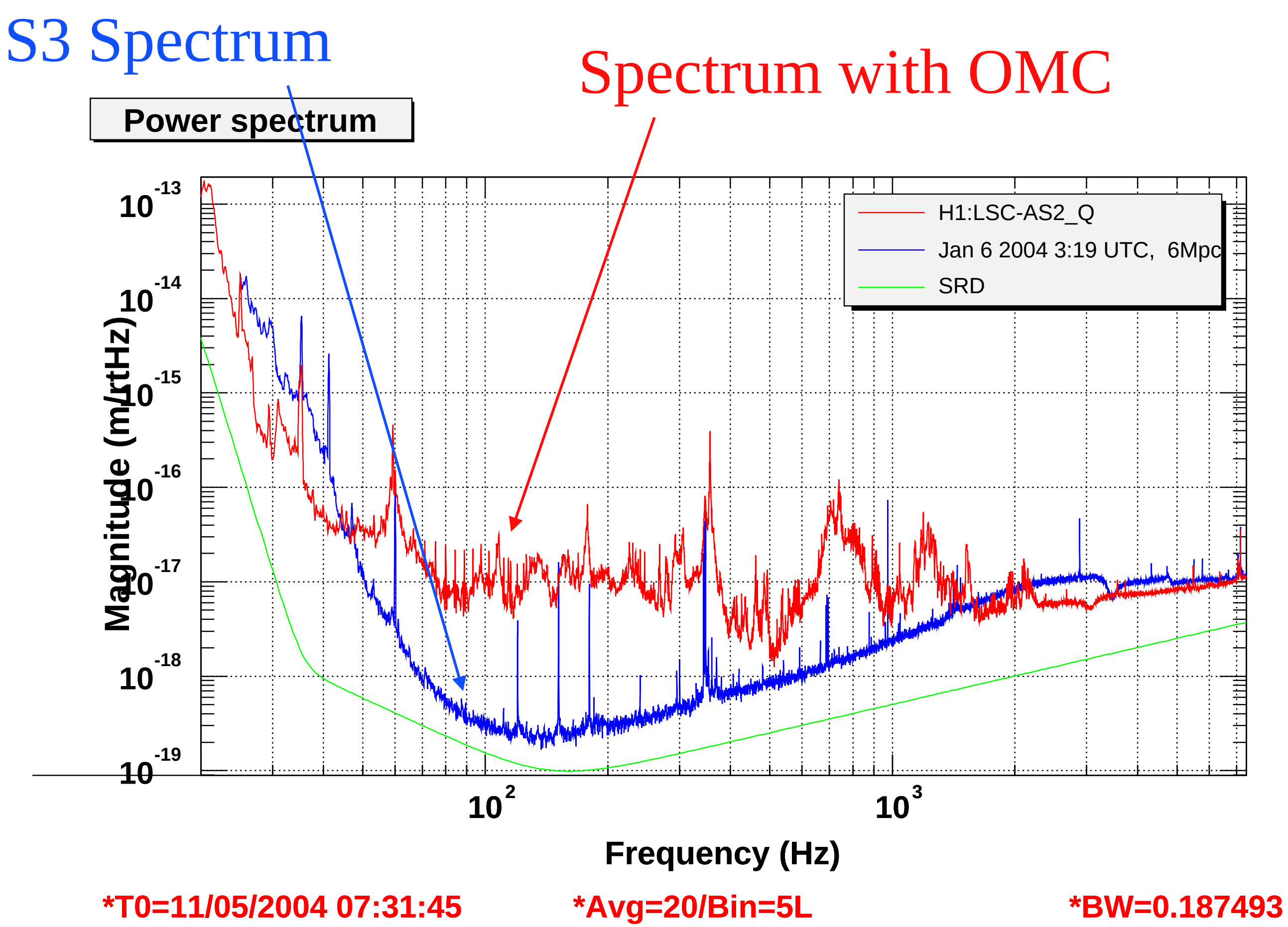
The Problem:
H1 with and without the OMC



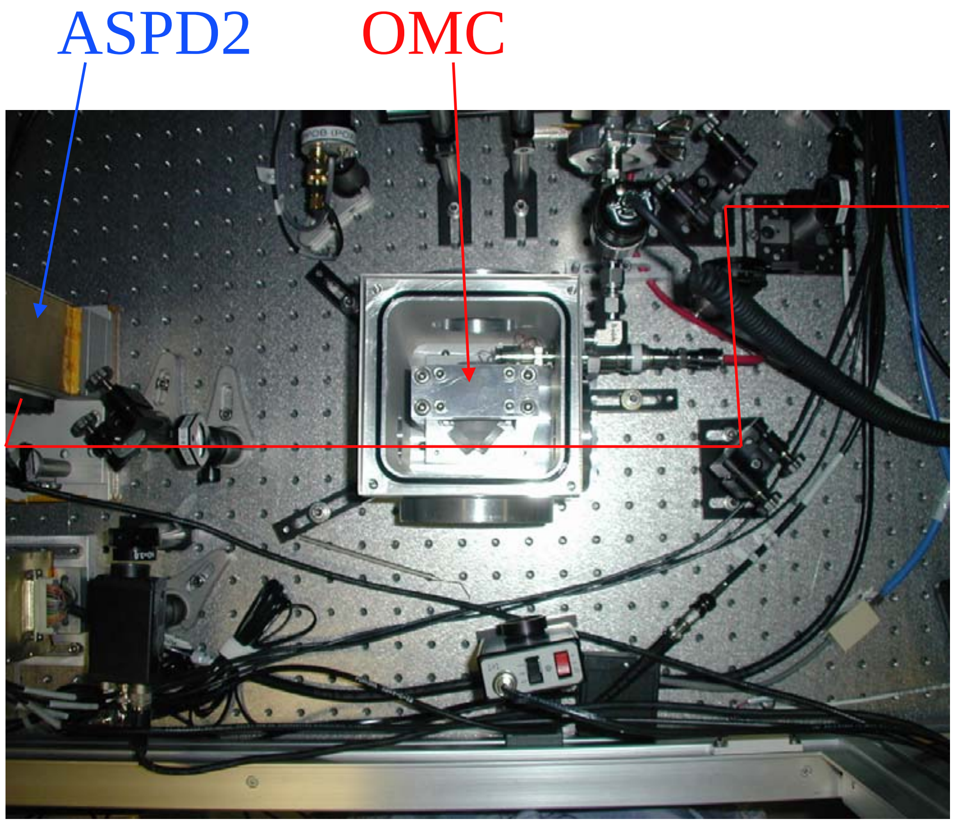
Peter F and Stefan, May 11

Understanding the OMC

- Difficulty in tracking down the noise in detect and common mode
- It would be useful to see the spatial map of the light incident on the AS PD, to look at the modal content
- Consider a simple case of a bright Michelson lock (or straight shot off an ITM into the AS port) so we only have TEM00 mode incoming
- Create a simple model with all information at hand (astigmatic beam, OMC parameters)
- Compare the modal content of the experiment and model and see if there's a difference in this simplified case

Experimental Setup: OMC

- ASPD 2 on transmission of OMC
- OMC kept on resonance by 3 methods
  - » Dither locking (maximization of total transmission)
  - » 2-Omega locking (maximization of sideband throughput)
  - » ASI locking (equalization of upper and lower sidebands)
- Noise was high with all 3 methods

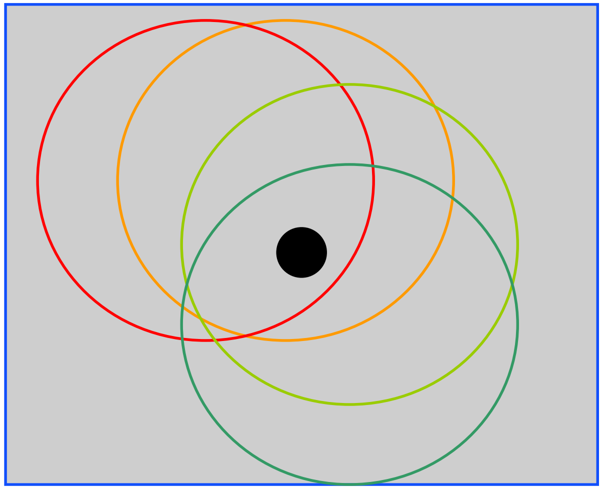


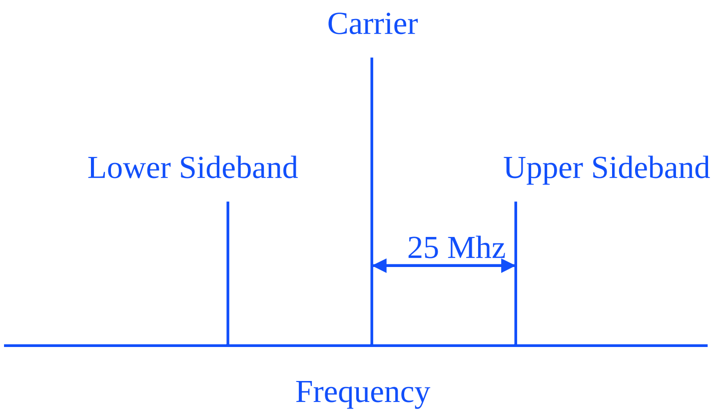
Experimental Setup: Antisymmetric Port Light

- Use the simplest case: Bright Michelson lock
- TEM00 Astigmatic beam
- Major and minor axes rotated 25 degrees counterclockwise relative to OMC
- Two waists of 137um and 107um
- Spacing of 6.6cm between waists
- OMC mode matched by maximizing transmission

Experimental Setup: Phasecamera

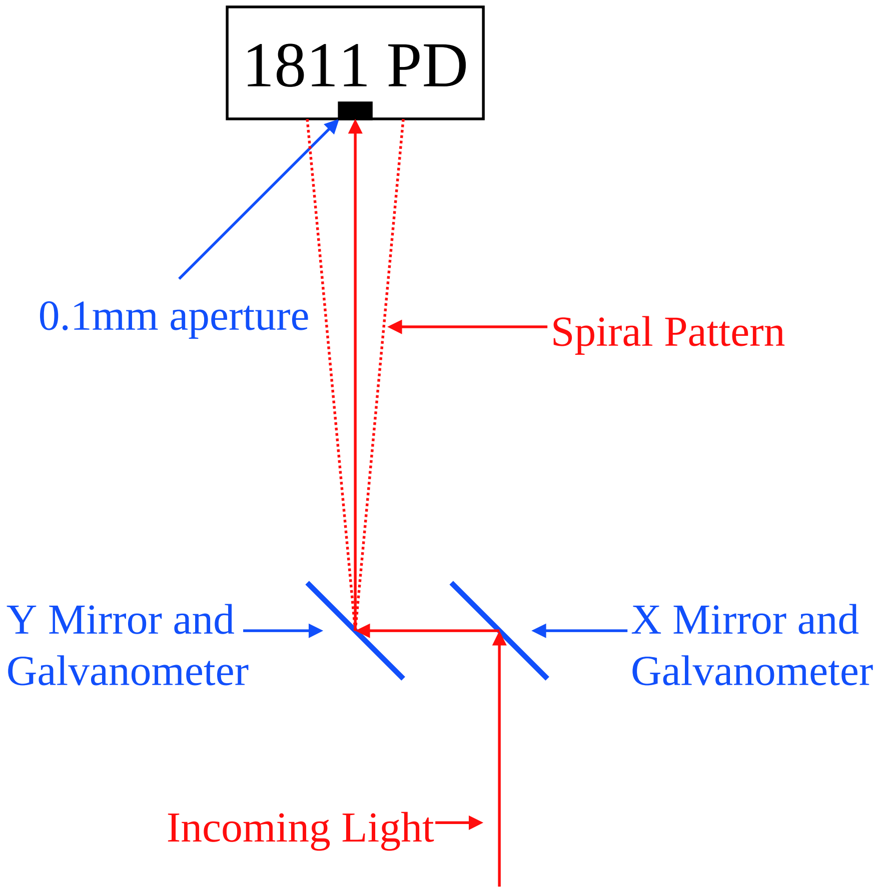
- The purpose of the phase camera is to spatially resolve the RF components of the incoming light field
- Take a small aperture and move the much larger beam around capturing data from a small section of the light at a time
- In this case we want to measure the beat between the carrier and sideband





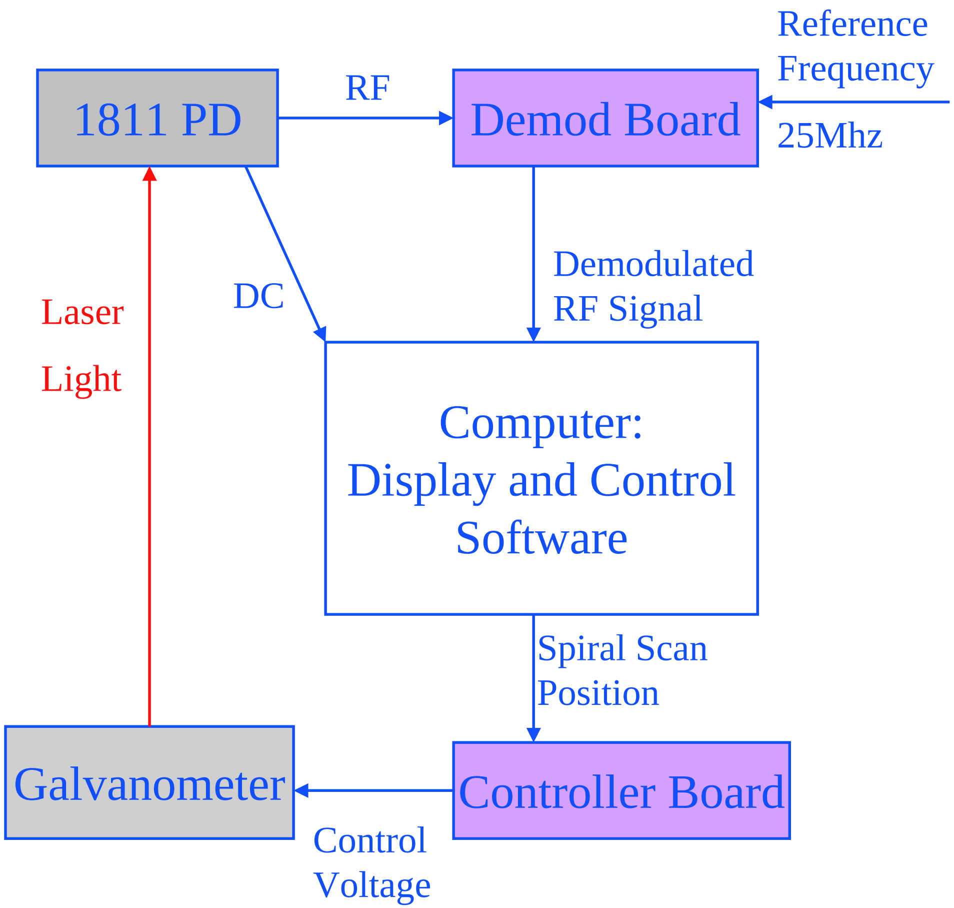
Experimental Setup: Phasecamera (continued)

- First the incoming light is focused such that the radius of the light is much larger than the pinhole of the photodetector
- As the “galvos” move the steering mirrors, a different “pixel” of the light becomes incident on the photodetector
- Spiral scan pattern is used to increase scan speed
- A full scan of 4000 points takes ~0.5 seconds



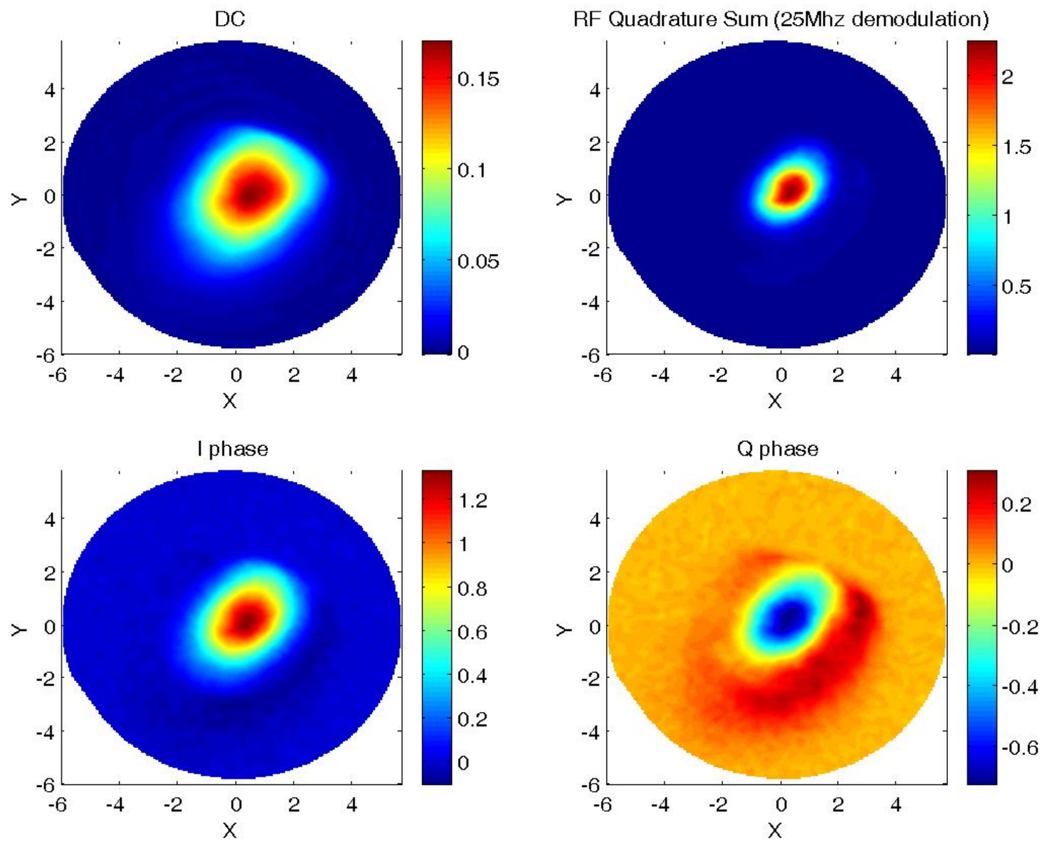
Experimental Setup: Phasecamera (continued again)

- For each point in a scan, the RF signal is demodulated at 25Mhz and recorded, along with the DC signal
- After each point of data is collected, the computer sends the next position to the "galvo" controller and the process repeats
- Once a full scan is complete, displays the data as a phasemap in "real time"
- Raw data can be saved to an ASCII text file for later analysis



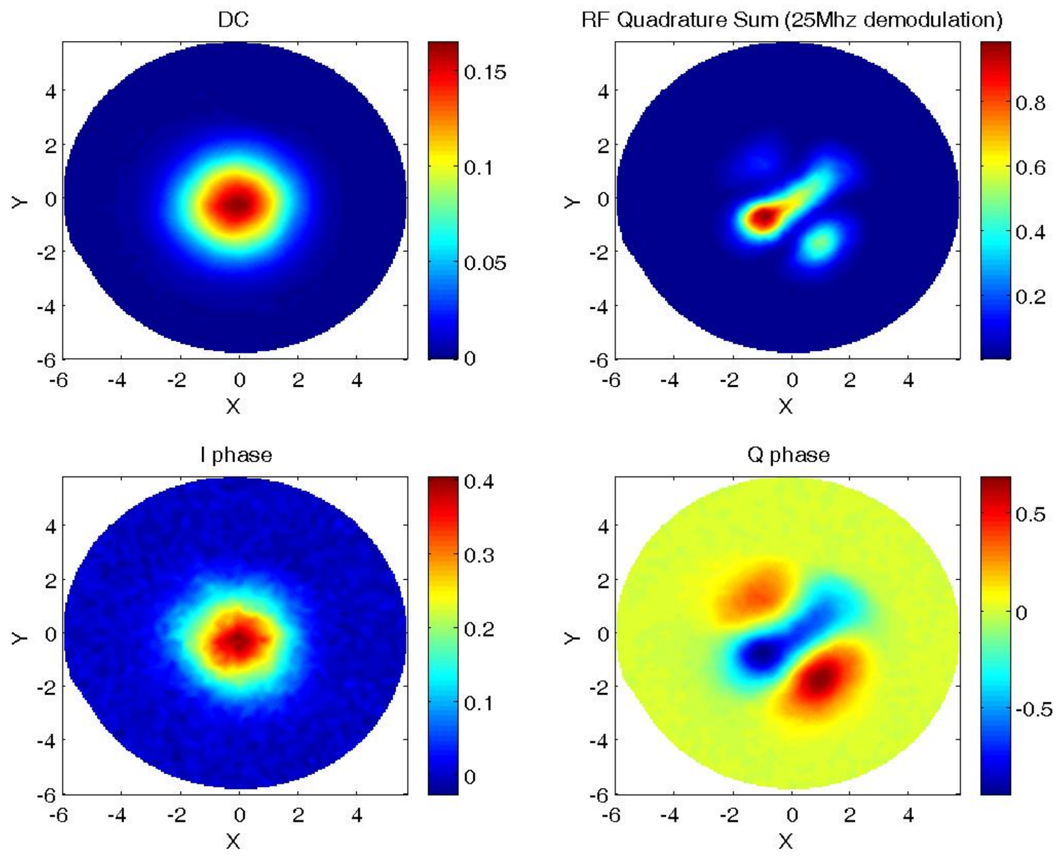
Bright Michelson Lock without the OMC (astigmatic light)

- Phasecamera data from the AS port
- Sideband imbalance and/or amplitude modulation is present, as indicated by the TEM00-ish mode
- This effect is unaffected or decreased by the OMC, depending on the locking scheme



Phasecamera image from Bright Michelson State with OMC

- Images are on transmission of the OMC
- Phase demodulation chosen so all the junk is in the Q phase
- Note the distinct TEM11 mode structure
- Amplitude modulation or sideband imbalance is still present, although ratio of RF to DC TEM00 is less

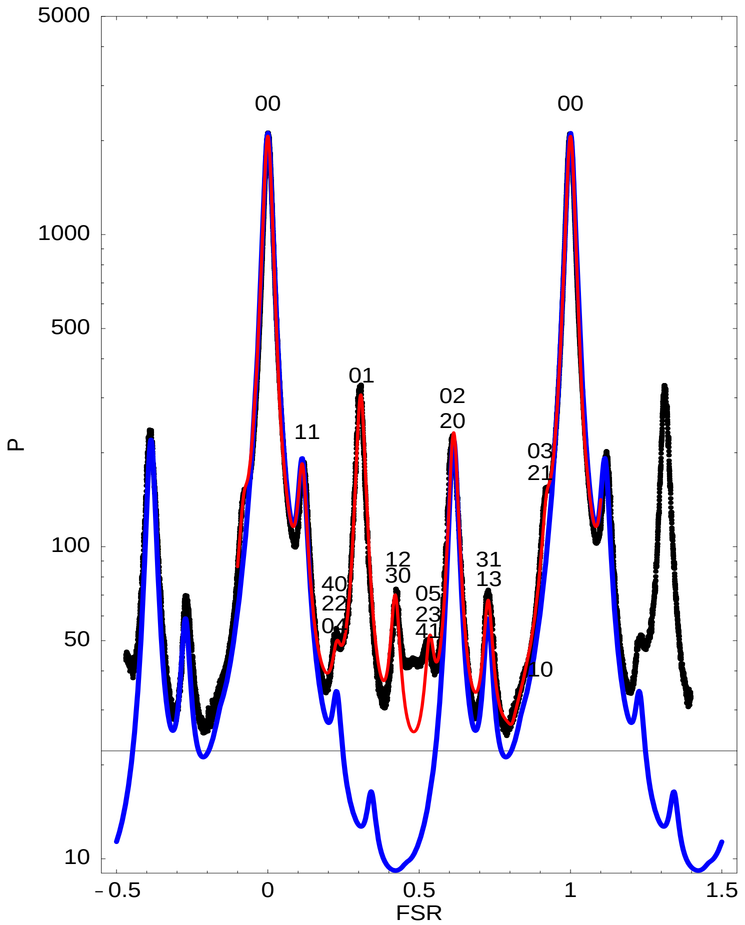


Modeling: Decomposition of the Light

- Light inside OMC can be represented in the Hermite Gaussian basis, restricted by boundary conditions
- Astigmatic Light isn't perfectly mode matched to the OMC, so higher order modes are created and transmitted even though incoming light is only "TEM00"
- Simply take the inner product of the astigmatic field with the individual modes in the OMC basis to find amplitude

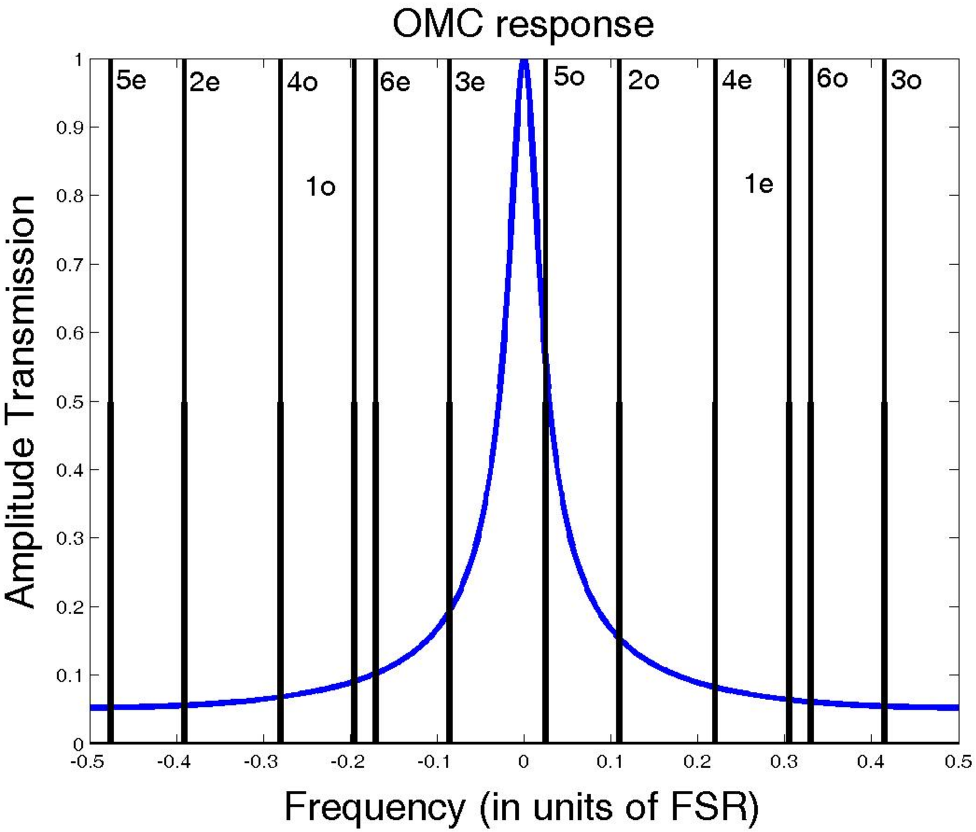
Modeling:
OMC scan versus OMC model

- Scanned incoming light by changing length of OMC, going through a full Free Spectral Range
- Provides an experimental decomposition of the astigmatic light
- Black curve is the scan data, Blue is the model decomposition, Red is a numerical fit to the data



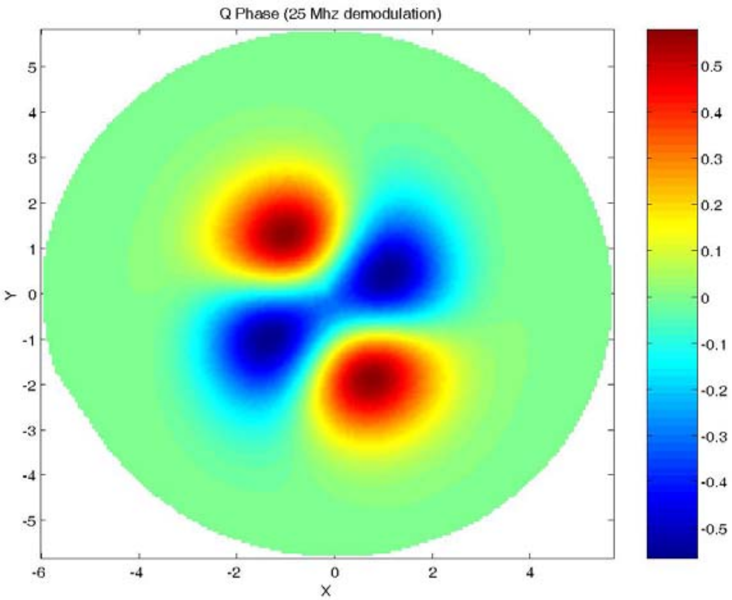
Modeling: OMC response function

- Transmission through the OMC is controlled by reflectivity of mirrors and losses in the cavity
- Assuming no losses in the cavity or through the back mirror, we get the transmission curve shown
- Note high transmission (~50%) of “5 odd” mode
- Apply this transmission to the initial modal content to get transmitted modal content



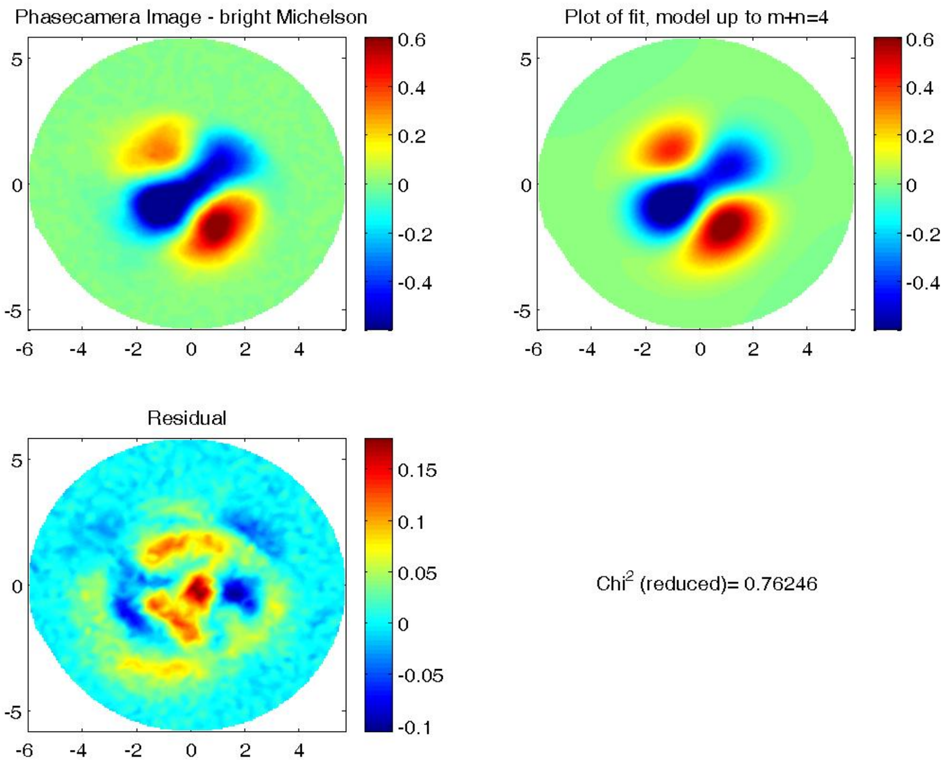
Modeling: Prediction for the Phasecamera

- Model prediction assuming the incoming light is perfectly aligned to the OMC
- Shows the beating between the carrier and sidebands (25 Mhz demodulation)
- “Demodulation” phase chosen such that all the junk light is in the phase shown
- Other phase is empty
- Looks like the phasecamera images



Comparing Phasecamera Data and the Model

- Use a least squares nonlinear fitting algorithm to fit the OMC model to the Phasecamera data
- With variations of +/-20% in the predicted modes from model (non-misalignment modes)
- $\chi^2(reduced)$ of ~1



Model and Fit Data

Normalized the TEM00 mode amplitude to 1 and phase to 0 for clarity

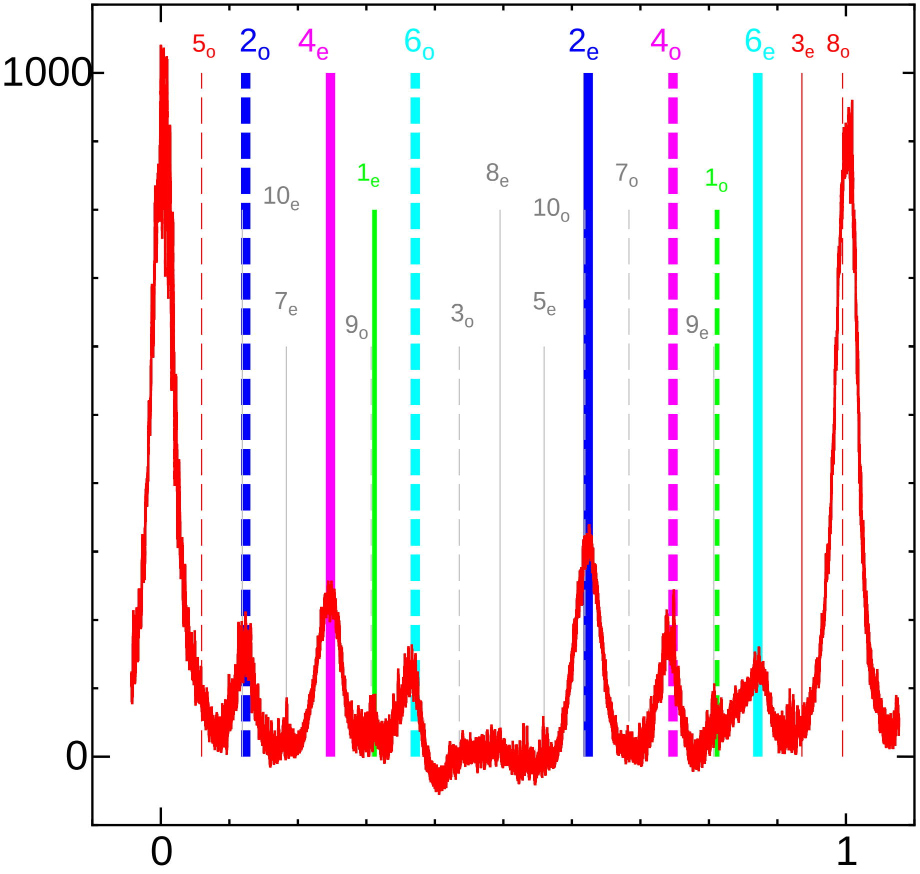
Mode	Model		Misaligned Model		Bright Mich		Straight Shot	
	Amplitude	Phase In Degrees	Amplitude	Phase In Degrees	Amplitude	Phase In Degrees	Amplitude	Phase In Degrees
χ^2	-	-	-	-	0.802	-	3.889	-
(normalized A)	-	-	-	-	258	-	99	-
00	1	0	1	0	1	0	1	0
01	-	-	0.28	-155	0.43	71	0.50	62
10	-	-	.13	25	0.044	-15	0.066	2
02	0.23	-57	0.22	-43	0.30	-44	0.30	-72
11	0.26	80	.23	87	0.256	100	0.20	100
20	0.21	31	0.22	32	0.27	11	.27	11
03	-	-	0.11	153	0.023	12	0.03	12
12	-	-	0.12	-63	0.09	-70	0.04	62
21	-	-	0.05	-172	0.06	-17	0.06	-38
30	-	-	0.05	57	0.080	59	0.12	34
04	0.07	-113	0.06	-86	0.02	-90	0.02	-90
13	0.11	23	0.09	43	0.127	129	0.11	175
22	0.02	176	0.003	-161	0.03	191	0.03	191
31	0.10	111	0.09	117	0.10	131	0.08	91
40	0.06	62	0.061	64	0.04	82	.04	82

Implications

- Amplitude of misalignment modes (TEM01, TEM10) is consistent with a displacement or angular misalignment of order the waist size or divergence angle
- In the simple case of a bright Michelson, higher order modes on transmission of the OMC are at most 4% of the TEM00 mode amplitude
- Transmission of the OMC can be explained with just astigmatic beam and misalignment, no additional “hidden” effects

Back to the noise in Detect and Common Mode

- However, in the case of detect or common mode, the incoming light is not just a TEM00
- Much more energy in higher order modes
- The "5 odd" modes (50,32,14) transmit well through the OMC (~50% transmission in amplitude)
- Any "5 odd" mode present in the incoming light or created through misalignment from "4" or "6" modes will reach the AS photodetector, adding to the noise



Summary

- Created a very simple model which predicts the phasecamera data on transmission of the OMC which only needs the following as input parameters:
  - » Astigmatic nature of the light
  - » Length of OMC and curvature of mirrors inside the OMC
  - » Finesse of the cavity
- Successful use of the Phasecamera and analysis of the associated data