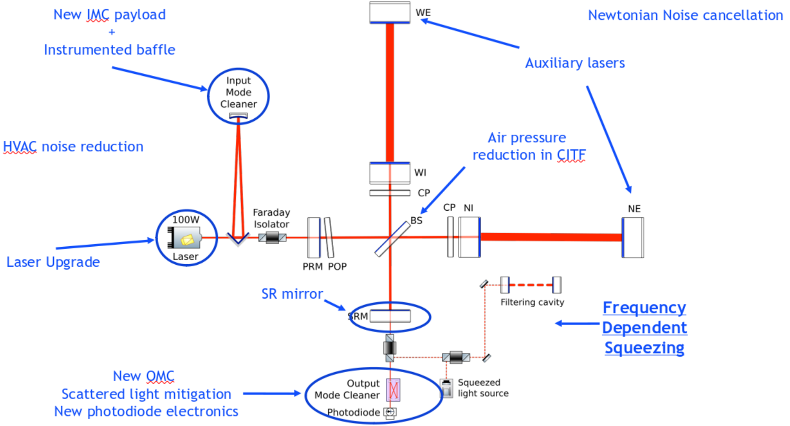
AdV+ Commissioning

Michał Wąs on behalf of the Virgo colloboration
ILANCE workshop

LAPP/IN2P3 - Annecy

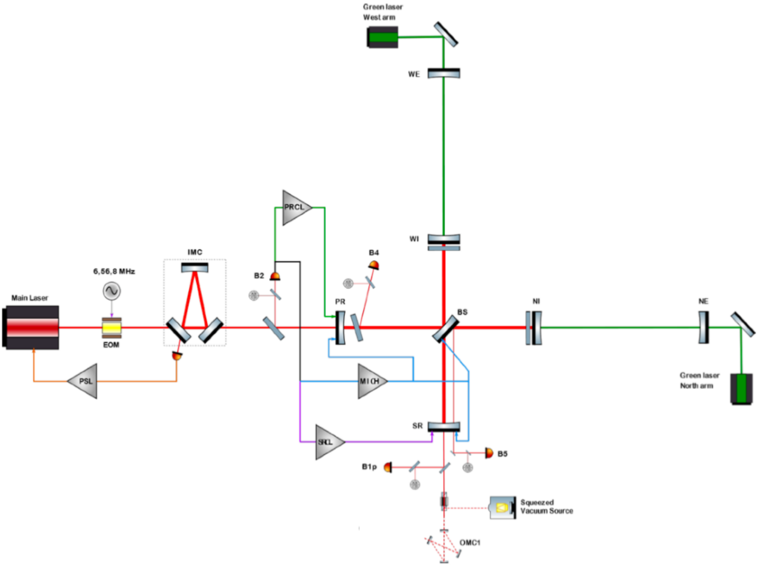
Lots of new equipment to make work



Interferometer commissioning highlights

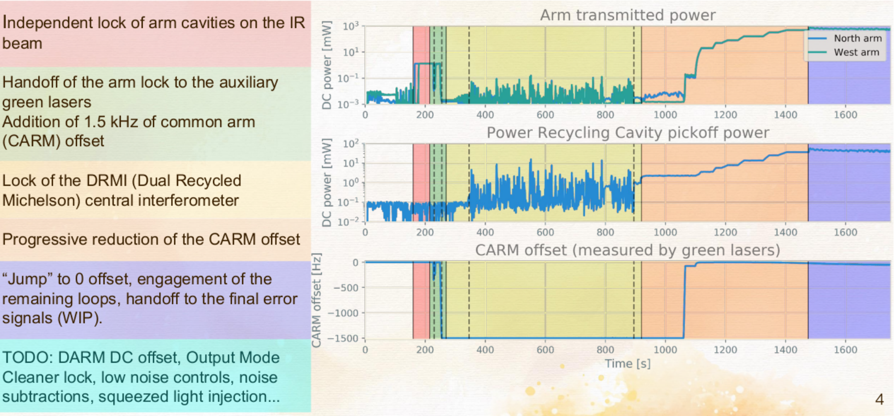
- Upgrade sensors on optical bench suspensions
  - Scattered light pushed below 12 Hz
- Injection & Laser system robustness
  - 10 year old stability issues resolved
    $\Rightarrow$ Installed fiber EOM actuator with $\times$10 larger dynamic ($\sim$ 20 rad)
  - losses slowly increasing
- Achieved lock acquisition at 25W and then at 40W, then reduced input power to 33W
- Thermal compensation enabled, CO2 laser actuator aligned
- Arm Fabry-Perot cavities optical characterization
- New output mode cleaner locked, and interferometer in DC read-out

Lock acquisition



LIGO-G2101957, M. Tacca

Lock acquisition



- Only first step in red is the same as during O3
- Rest completely changed because of signal recycling installation

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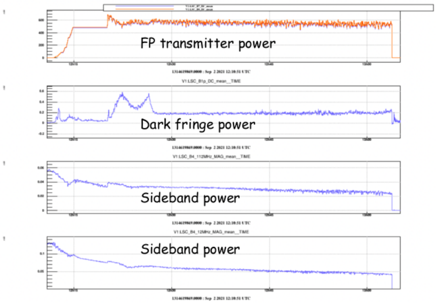
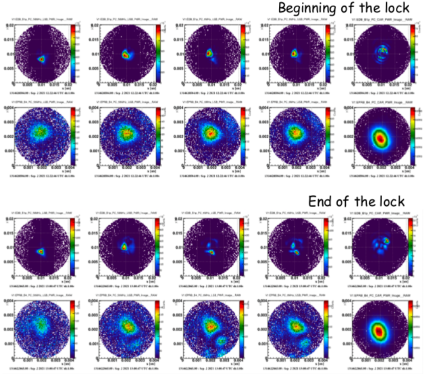
LIGO-G2101934, M. Valentini

Interferometer thermal tuning

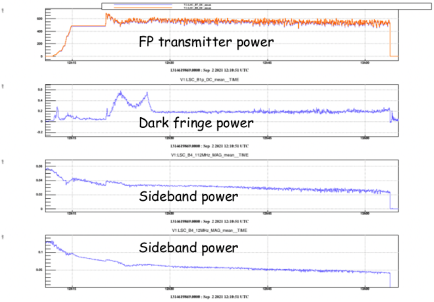


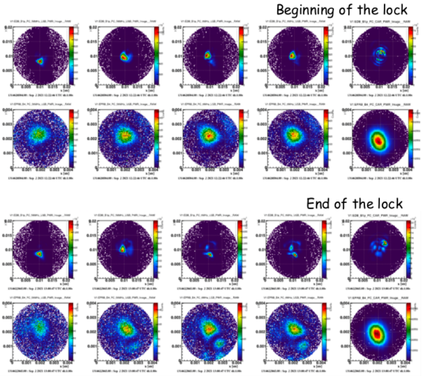


- O4 goal is to have 200kW in arm cavities (880mW in transmission of end mirrors)
- With 40W input power locking with 160kW and quickly decaying to 120kW
- Dark fringe power is ~ 10 times higher than during O3

VIR-0716A-21, I. Nardecchia

Interferometer thermal tuning

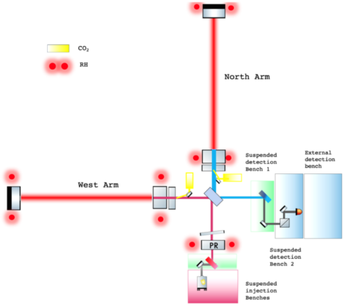




- O4 goal is to have 200kW in arm cavities (880mW in transmission of end mirrors)
- With 40W input power locking with ~~160kW~~ 190kW and quickly decaying to ~~120kW~~ 170kW
- Dark fringe power is $\sim$ ~~10~~ 5 times higher than during O3
- Improvement after enabling end mirror ring heaters, but very short locks

VIR-0716A-21, I. Nardecchia

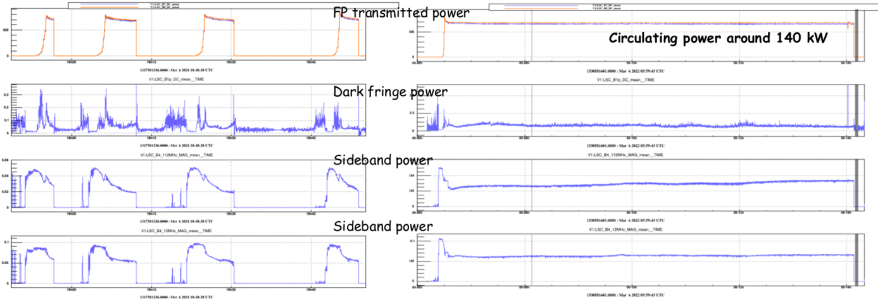
Interferometer thermal tuning



- Several actuators
  - Ring Heater - change curvature of mirrors
  - Central heating - CO2 laser keeping mirrors hot when intereferometer unlocked
  - Double Axicon - CO2 laser with doughnut shaped beam correcting for main YAG laser central heating
  - Beam spot on mirrors to avoid point absorbers
  - Input mirror temperature to change their reflectivity (Etalon)
- Several observables
  - Carrier and side-band power at different port of interferometer
  - Beam shape from cameras, sideband shape from phase-camera
  - Mode decomposition with output mode cleaner
  - Laser frequency noise coupling
  - Scattered light noise coupling
- How to relate observables to action on actuators?

  $\Rightarrow$ Lots of room to improve understanding and simulations

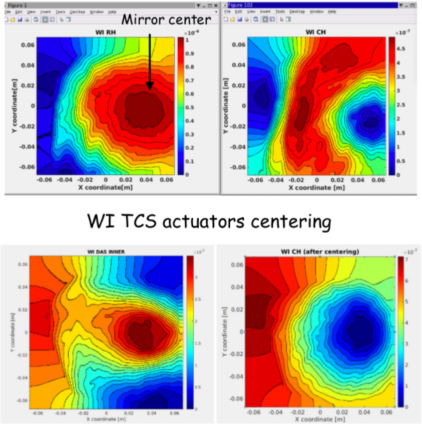
Reduced input power to 33 W

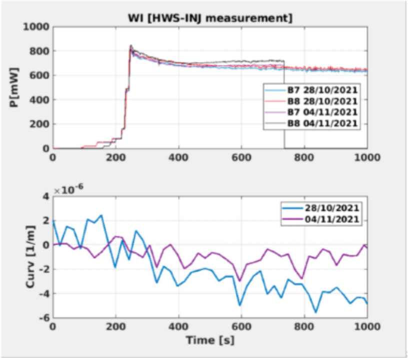


- Reduced power gave few minutes long locks allowing rough adjustment of TCS
- Unexpected effects
  - Optical spring at much higher frequency than expected, $\sim 30\,\mathrm{Hz}$
  - Interferometer working point jumps / mode hoping

LIGO-G2200494, M. Tacca

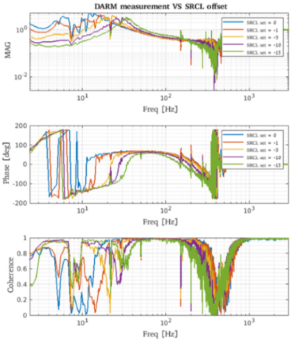
TCS alignment and power tuning

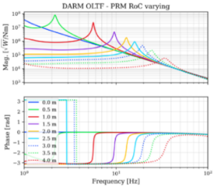


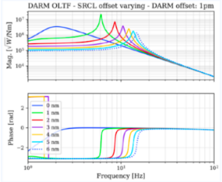


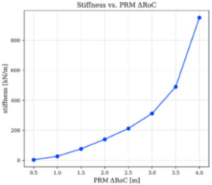
- Using Hartman sensors as probe of mirror curvature
- Differential measurement between TCS actuator on and off
- Adjusted CO_2 laser alignment to center on deformation due to ring heater
- Adjusted power to keep same curvature as power in arms increases

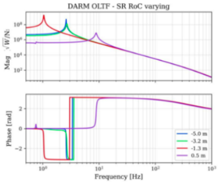
Optical spring







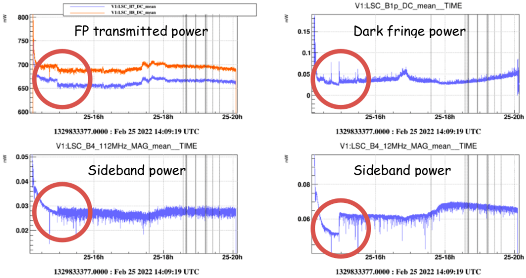


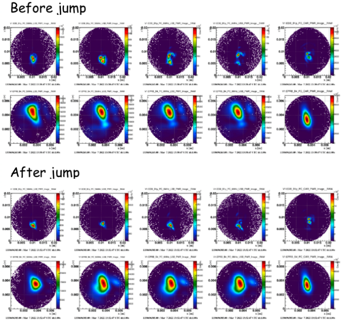


- Optical spring should be at $\sim$ 5 Hz for 33 W of input power
- Measured spring of $\sim$ 30 Hz would be expected for 200 W of input power
- Campaign of simulations shows that many defects can create a stiffer optical spring
  - PR/SR radius of curvature
  - SRCL offset
  - SR alignment

LIGO-G2200501, R. Maggiore

Working point jumps / mode hoping

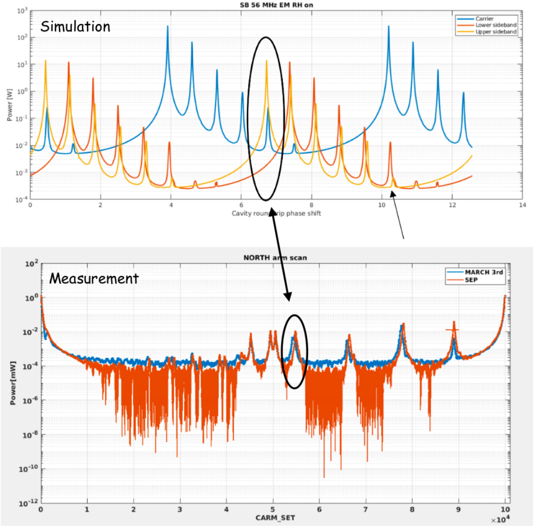




- A change in PR vertical alignment (pitch)
- Lower power in arms
- Higher power on dark fringe
- Higher sideband power
- Improved stability
- Cause ?
  - ⇒ Sideband HOM co-resonant with carrier TEM00 in the arms
  - ⇒ Carrier and sideband are clearly not superposed in PRC

LIGO-G2200494, M. Tacca

Sideband HOM coresonance

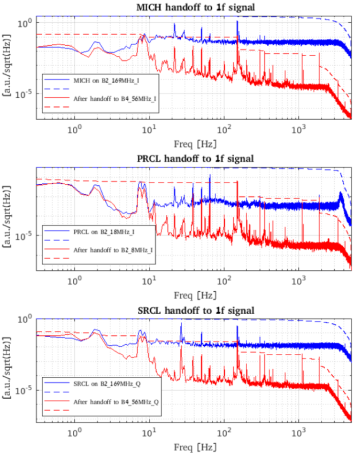


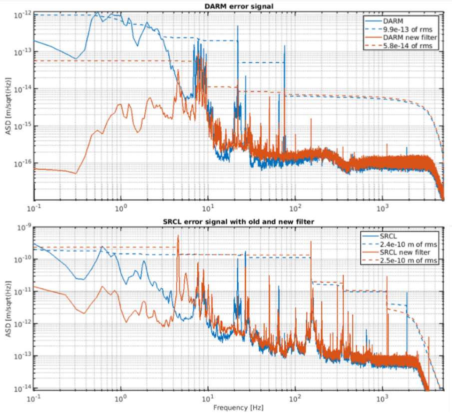
- Sideband order 4 HOM close to co-resonating with carrier fundamental mode
- Adjusted arm cavity end mirrors to reduced overlap
- This reduced the occurrence of jumps, but not completely resolved

$\Rightarrow$ Recenter beam on PR to attempt improving carrier vs sideband ovevrlap in PRC

LIGO-G2200494, M. Tacca

Switching length control to final configuration

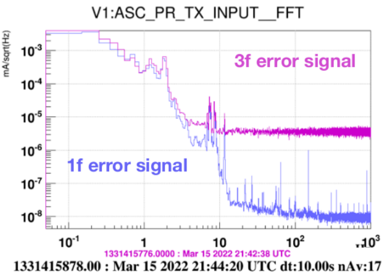


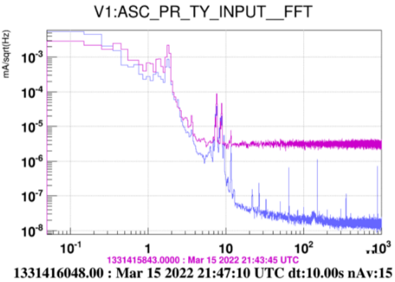


- Changing
  - from 3f signals (beat between side-band and side-band harmonic)
  - to 1f signals (beat between side-band and carrier)
- Increase loop precision (high gain at low frequency)

VIR-0356A-22, M. van Dael

Switching angular control to final configuration

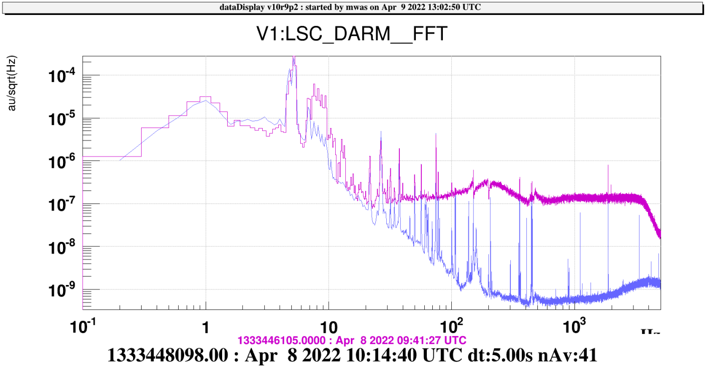




INJ Shift	INJ tilt	PR	BS	SR	DIFF+	COMM+	DIFF-	COMM-
Not controlled	B2 8 MHz	B4 6 MHz	B1p 50 MHz I	B1p 50 MHz Q	B1p 56 MHz	B5 DC ?	Oplev/ centering	Oplev/ centering
	Drift control	Full bandwidth	Drift control	Drift control	Full bandwidth		Drift control	Drift control

- Changing
  - from 3f signals (beat between side-band and side-band harmonic)
  - to 1f signals (beat between side-band and carrier)
- Searching for good error signals for several degrees of freedom
- Many loops use wavefront sensors only with $< 100\,\mathrm{mHz}$ bandwidth
  - $\Rightarrow$ Need to increase their bandwidth to 2–3 Hz

DC read-out

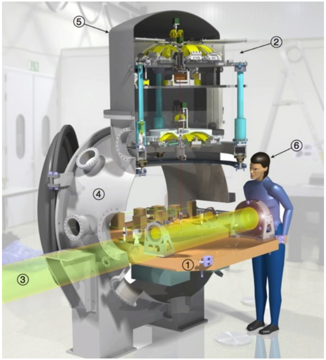


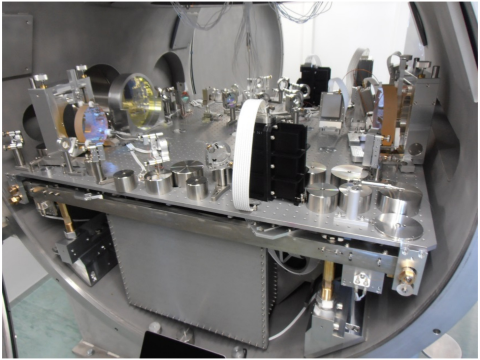
- Lock OMC
  - PZT malfunctioning, using thermal control only, limits bandwidth to 0.5 Hz (instead of 3 Hz)
- DC read-out: use OMC transmission to control DARM
  - Interferometer LSC/ASC control not accurate
  - ⇒ Using high dynamic / high noise photodiodes
- Limited at all frequencies by other length degrees of freedom (MICH, SRCL, laser frequency)

Conclusion

- Achieved first full DC read-out lock
- Several not understood surprises limit good operations
  - Stiffer optical spring
  - Interferometer mode jumps
  - Sideband not overlapped with carrier
- Good ideas of potential solutions
  - Center input beam on PR (currently 4 mm off-center)
  - Adjust SR radius of curvature
- Diagonalize length control using feed-forward techniques to reduce control noise coupling by more than $\times 100$
- Investigate any remaining excess noise in sensitivity curve

Scattered light from suspended end benches





- Receiving beam transmitted by end mirrors
- 7 m behind end mirrors, suspended in separate vacuum chamber
- Tracking mirror position by pushing on the bench suspension point

⇒ No scattered light noise above 10 Hz in normal conditions

  - But west end bench suspension misbehaving during O3