GEO 600: Advanced Techniques in Operation

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for the GEO team
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GEO600 – German-British Observatory – Located near Hannover, Germany
GEO600

- Michelson interferometer with power- and signal-recycling
- Folded 600 m arms
- No arm cavities

P = 2 kW

30W @ 1064 nm
Historical perspective

- **1994** Joint German-UK proposal for GEO600
- **1995** Construction begins
- **2001-2007** Joint science runs with LIGO and Virgo
- **2007-2009** GEO600 operates in Astrowatch mode during Enhanced LIGO upgrades
- **2009 to present** GEO-HF upgrades + Astrowatch
Pathfinder for advanced techniques

As of early 2000s:
- monolithic multi-chain suspensions + reaction chain
- signal recycling
- electro-static drives
Pathfinder for advanced techniques

As of today:
– squeezed light injection

Now considered as a high priority upgrade for Advanced LIGO
Projects at GEO 600

- Astrowatch
- Sensitivity improvement
  - Mid-frequency noise
  - Higher power
- Research for Advanced Detectors
  - Thermal compensation
  - Squeezing integration
  - Output mode cleaner control
Astrowatch team

- Christoph Affeldt
- Holger Wittel
- Emil Schreiber
- Hartmut Grote
- Jonathan Leong
- Kate Dooley
- Michael Weinert
- Volker Kringel
- Marc Brinkmann

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Astrowatch

Science duty cycle:

- 2011: 60%
- 2012: 62%
- 2013: 62%

Recent: Supernova at 3.5 Mpc, but time unknown

GEO SN range is 100 pc with 5 sec. time window
Towards higher laser power

- Nominal Astrowatch operation uses 3 W at mode cleaner input; 2 kW at BS

High power not always stable... only sometimes
Baffles

- Installed baffles around 3 mirrors to block small angle scattered light
- Scattered light reduced by factor 1.5 to 3 in 3 chambers
Baffle noise projection

- Use sensors and actuators to make noise projection

- Baffle noise at least 2 orders of magnitude below strain sensitivity
Side heaters

- Segmented thermal compensation
- Compensates astigmatism in end mirror

Class. Quantum Grav. 31 (2014) 065008. Holger Wittel et al.
BS thermal lens

- The GEO beam splitter substrate transmits the full circulating power

Thermal image of BS

65mK temp increase w.r.t. ambient @ 3.2kW

reflection of cooled imaging sensor
Indirect BS thermal compensation

- Ring heater at end mirror partially compensates for BS thermal lens
Indirect BS thermal compensation

Project image of array of platinum heaters onto the BS using IR optics

Full 12x12 array is built...
Indirect BS thermal compensation

...and the hardware is tested!
Squeezing integration

- Beam splitter
- Arm
- squeezer
- Detection PD
Vacuum (zero-point) fluctuations

– Even when the average electro-magnetic field amplitude is 0, the variance still remains.

– Vacuum fluctuations enter the interferometer at all ports where no classical field exists

Phasor diagram of coherent vacuum.
Squeezed light

Phasor diagrams of:

Coherent state of light

Squeezed state of light

There is a minimum uncertainty product, but noise can be redistributed.
Squeezed light in GW detectors


Figure courtesy L. Barsotti
Squeezing performance

Science time squeezed:
2012: 90% (205 days)
Squeezing performance

Science time squeezed:
2012: 90% (205 days)
2013: 80% (175 days)
Record to date: 3.7 dB

Detectable squeezing level limited by optical losses (36%)
Squeezing upkeep

The GEO600 squeezer has been in operation for more than 4 years.

Photo-chemical reaction of green light with vacuum grease contamination.
Squeezing upkeep

The GEO600 squeezer has been in operation for more than 4 years.

Damaged OPA crystal

Today: new OPA
4 years ago

Summer 2013

mode out of OPA
Squeezer alignment

Principle:

- Use wavefront sensing
- Feedback to steering mirror PZTs

from interferometer

wavefront sensors

Squeezer + IFO RF sidebands

from squeezer

PZTs
Squeezer alignment

- We have good alignment sensors and actuators
- 3 Hz unity gain frequency
- 4/4 degrees of freedom tested; and it works!
Squeezing outlook

- Replace SHG (housing + cavity)
- Commission permanent use of 4/4 degrees of freedom squeezer alignment (current is 2/4)
- Continue paving the way for more squeezing to be observed:
  - Replace Faraday PBS
  - Refine the loss budget (currently 36% losses)
– GEO600 is collecting science data (nights and weekends)
– GEO600 continues to research advanced technologies
  – Thermal compensation
  – Long-term squeezing and integration
– ...
Live noise budget