Central Heating Radius of Curvature Correction System (CHRoCC) used in Virgo

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Virgo Collaboration

CHRoCC: Motivations

Virgo+ end mirrors have larger RoC asymmetry than Virgo's (3300m & 3410m)

- Common noise cancellation is reduced.
- Reduction in recycled power.
- Increased risk of noise due to diffused light.

End mirror RoC's are close to HOM degeneracy

- Increased clipping losses due to HOM's excited by mirror roughness.
- Same HOM's can increase noise on alignment signals.

Many solutions for changing RoC for GEO, AdV Ligo, AdV Virgo

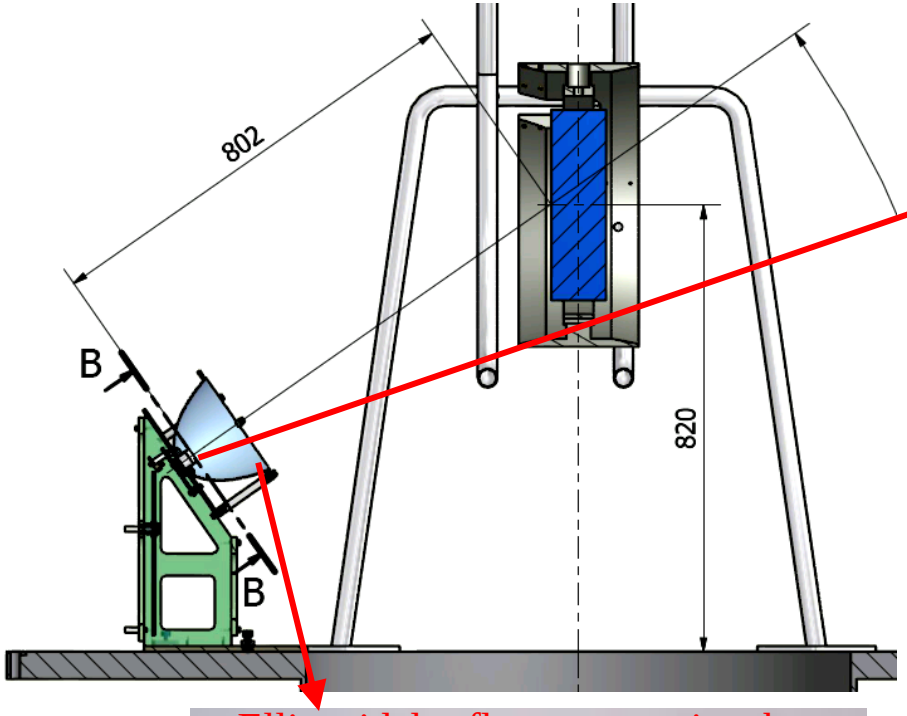
- Not very power efficient → using peripheral heating
- Reduces RoC, whereas we need to increase RoC

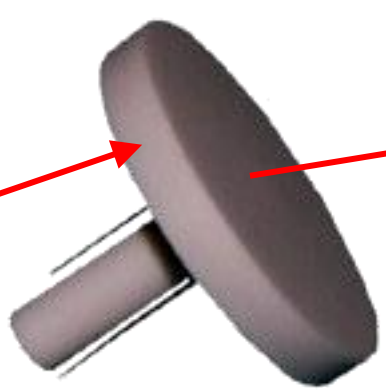
So we proposed **C**entral **H**eating **R**adius **o**f **C**urvature **C**orrection

Increase RoC of end mirrors by projecting heat pattern onto center of mirror HR surface. Heat source is a blackbody emitter.

- Mirror absorbs less power by about a factor 10 compared to alternative solutions
- Installation is low risk.

In-vacuum projector made of off-the-shelf components:

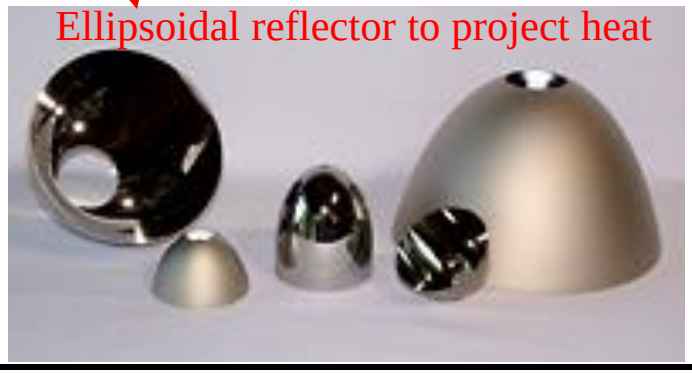




Blackbody heat source

Mounted inside heat shield

Ellipsoidal reflector to project heat



Heat source:

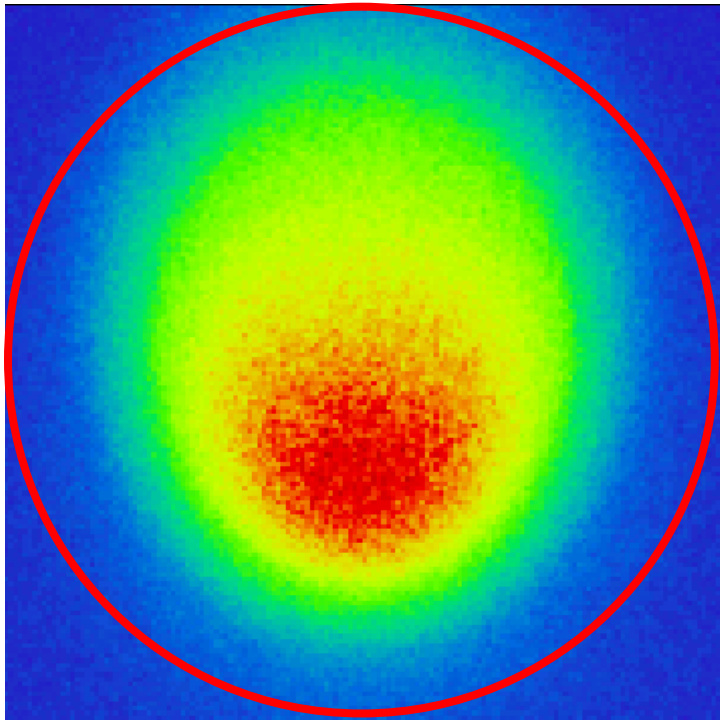
- Supplier: HeatWave Labs
- Al2O3 (Alumina) substrate (1 inch diam)
- UHV compatible.
- Maximum temperature 1200 °C.

Ellipsoidal Reflector:

- Supplier: Phoenix Electroforms
- Nickel substrate.
- UHV compatible.

Zemax simulation made of projection system

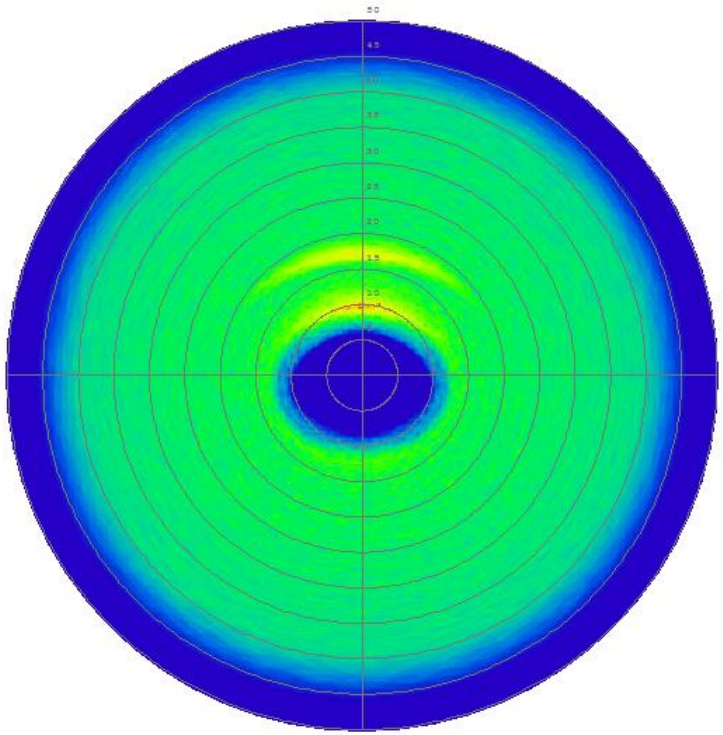
Intensity pattern on test mass



Asymmetry due to angle of incidence

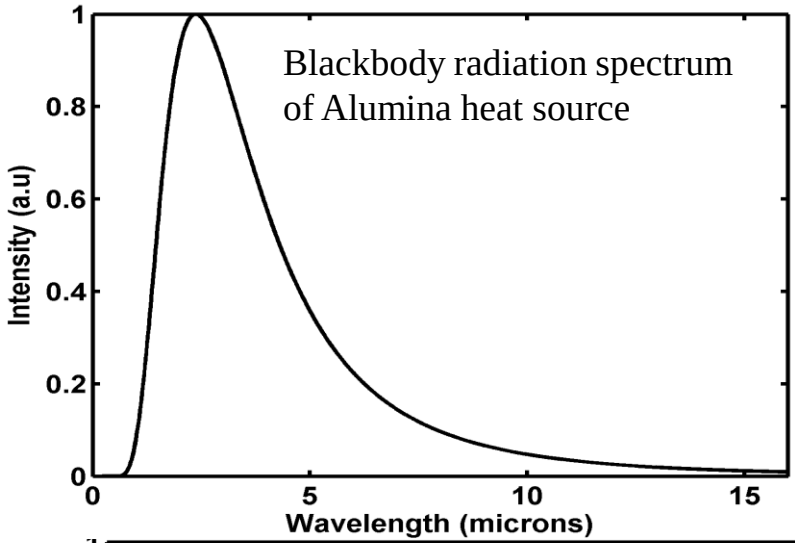
56% of heat hits mirror

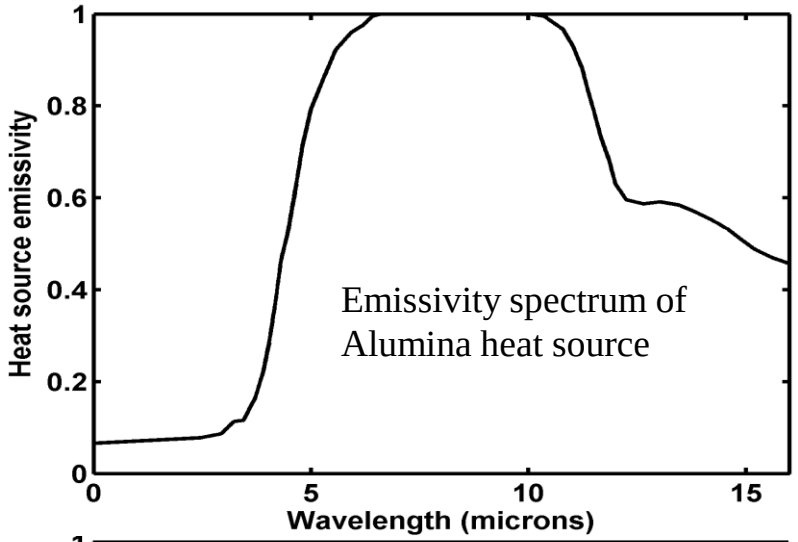
Angular distribution (0 to 50 deg)
Intensity "missing" test mass

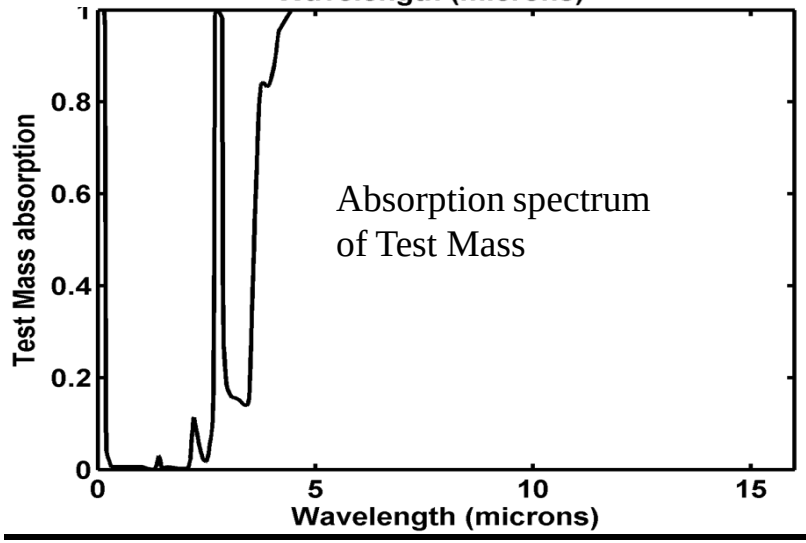


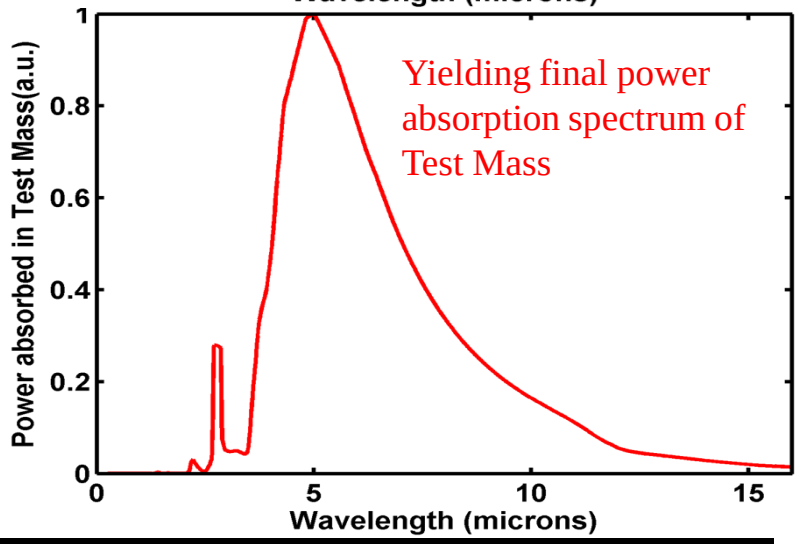
44% of heat goes "elsewhere"

Power actually absorbed by Test Mass depends on many parameters:



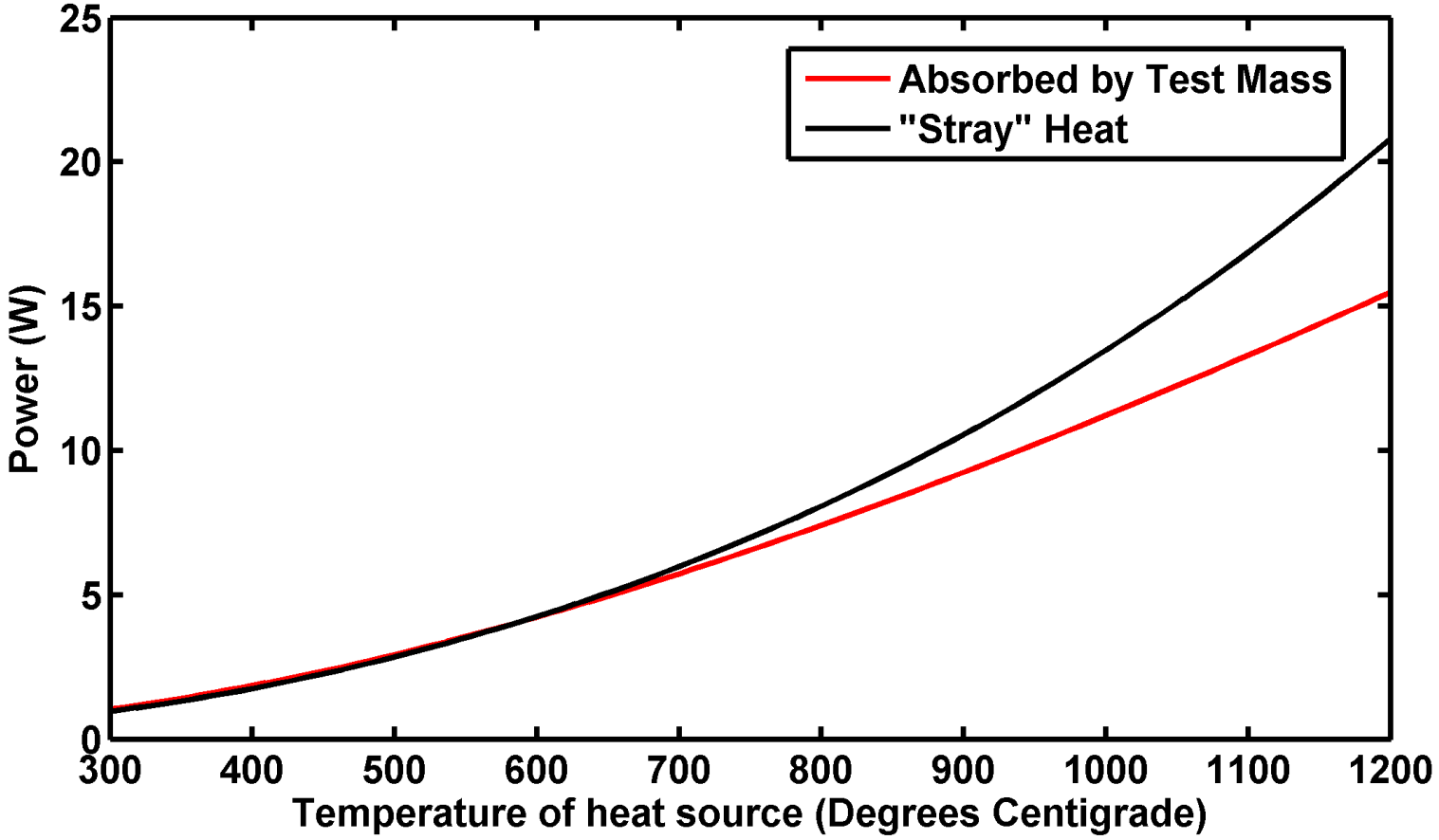






CHRoCC: Heat absorbed

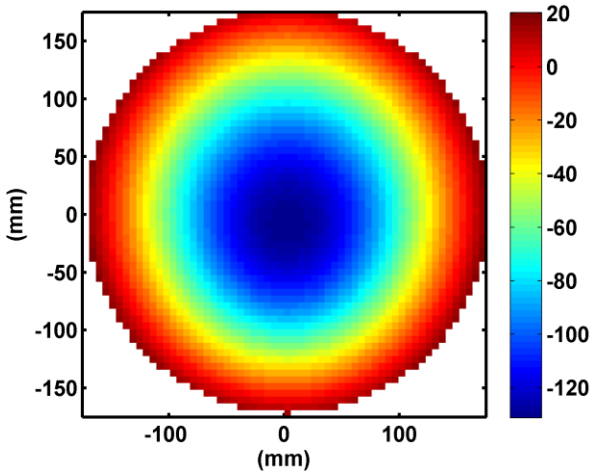
Calculate total power absorbed by Test Mass vs. temperature of heat source.

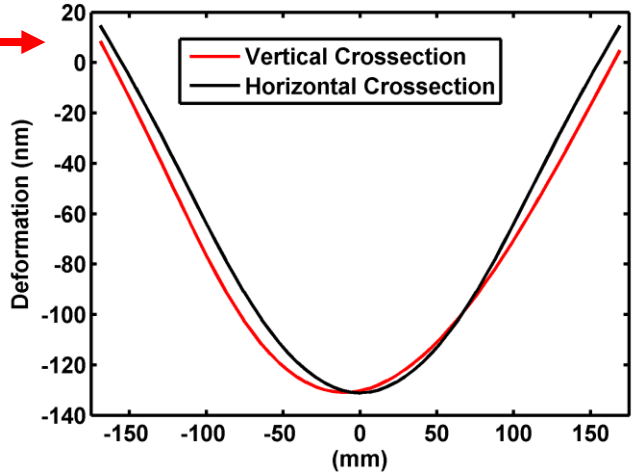


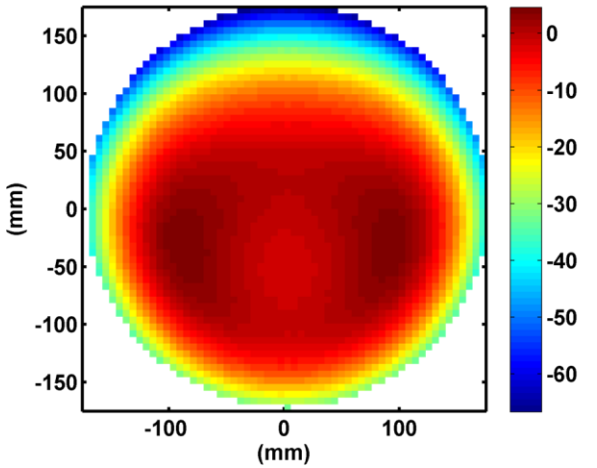
Maximum absorbed power is 15W.

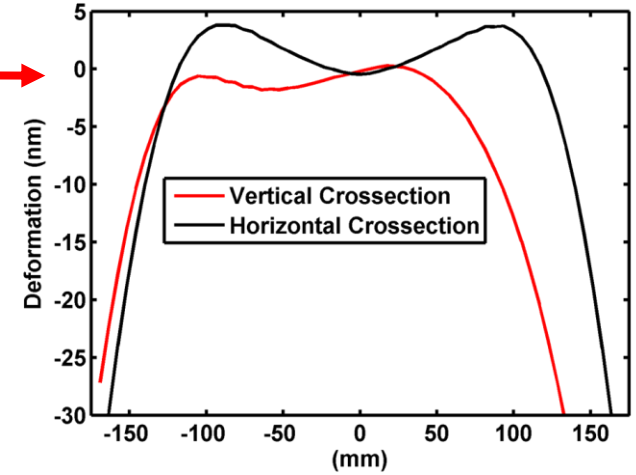
CHRoCC: Effect on RoC

ANSYS thermal simulation to determine effect of 3W absorption









Induced RoC change 125m

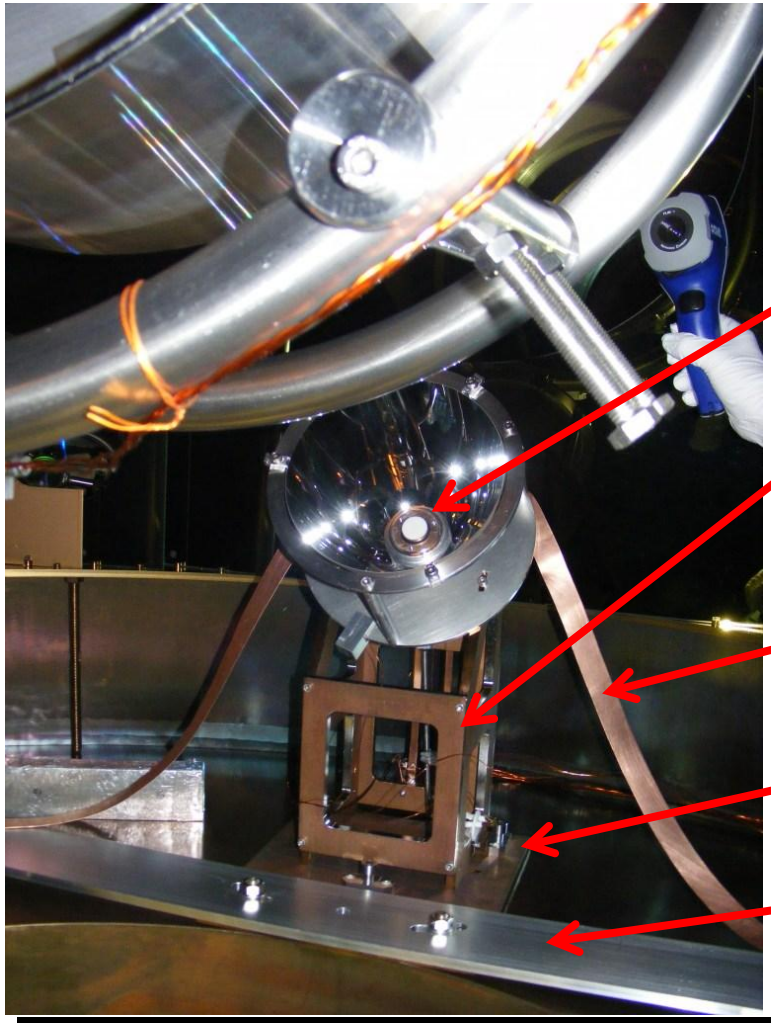
Remove RoC

Residual rms 1.1 nm

CHRoCC has required dynamic range for required correction

Power and heating spot size could be increased to reduce residual rms

Installation of first CHRoCC completed on 17th December 2010



CHRoCC installed in tower

High thermal time constant of ceramic should minimize risk of noise coupling

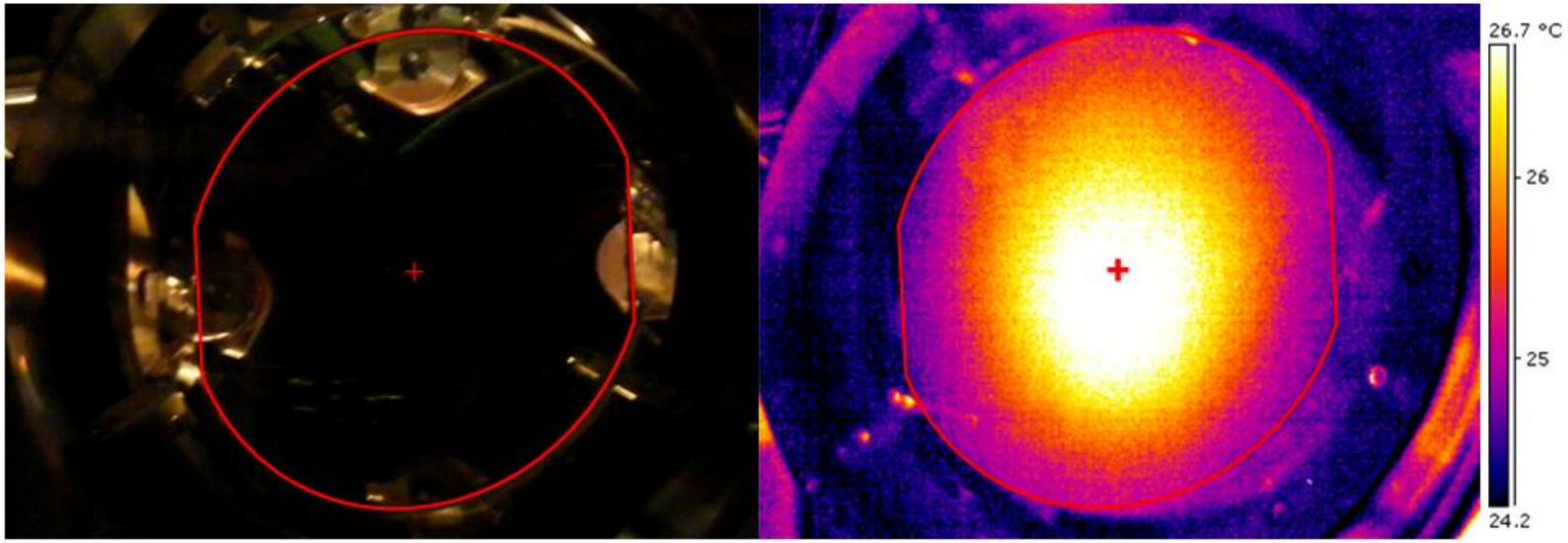
Heat treated steel frame to increase emissivity and increase dissipation by radiation

Copper ribbons to increase dissipation by conduction

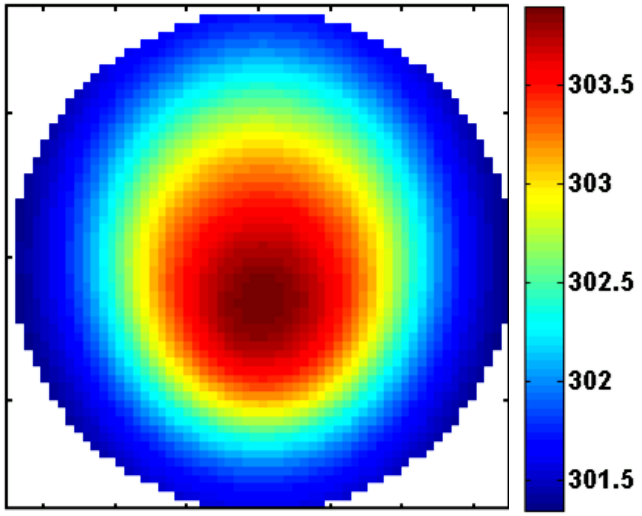
Stand “sitting” on floor using 3-point contact

Reference plate to position CHRoCC in tower

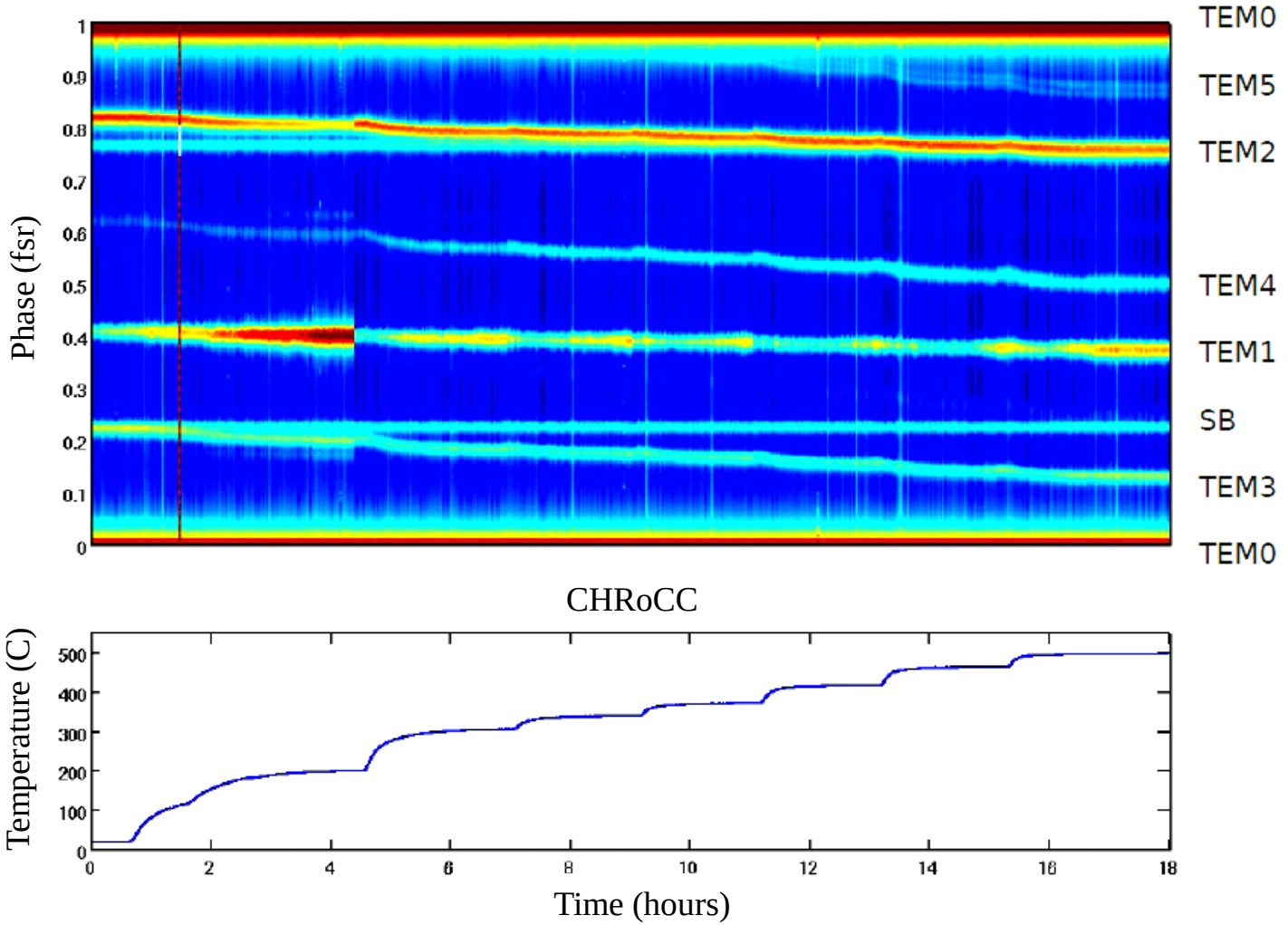
CHRoCC: In-tower check



- Heater set to 500 degrees
- Temperature pattern clearly seen on Test mass
- Temperature gradient about 2 degrees
- Good agreement with simulation →



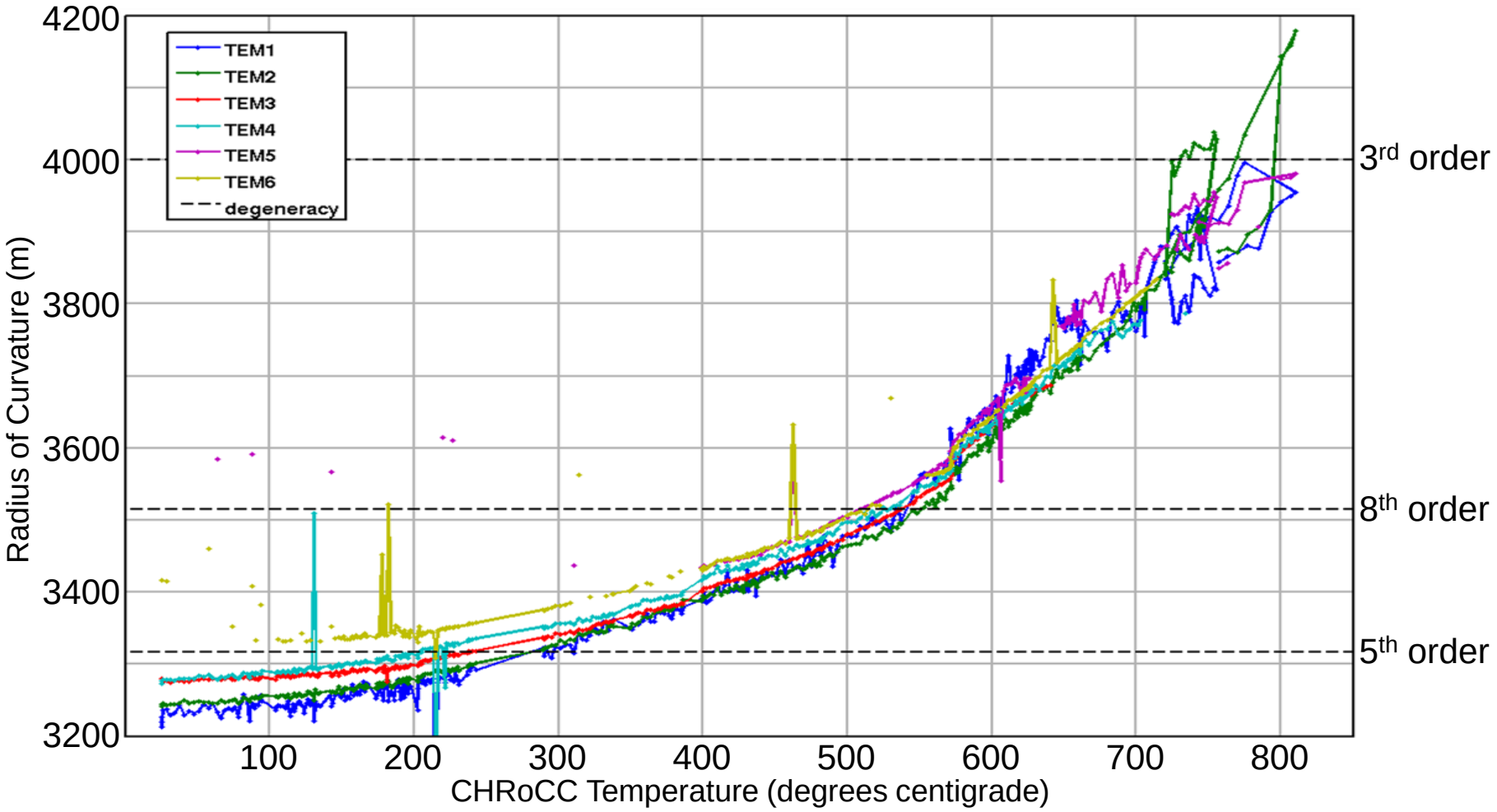
Use FP arms as Scanning Fabry-Perot while changing CHRoCC temperature.



Phase of HOM's gives information about end mirror RoC

CHRoCC: Characterization

Calculate RoC change with CHRoCC temperature from HOM phase measurements



CHRoCC meets expectations, having extremely large actuation range

CHRoCC: Present & Future

The performance and use of CHRoCC was described by R. Gouaty on Monday:

Increased recycling gain
- Power on dark fringe reduced
- Lower average losses in arm cavities

- HOM's no longer generate noise in alignment signals
- No way to further reduce intrinsic losses asymmetry

Virgo is now robust and obtained a record sensitivity using CHRoCC

CHRoCC was originally just a patch but works very well

Could there be a use for such a device in advanced GW detectors ?

Here are a few ideas:

Fine tuning of Advanced mirror RoC's

RoC specifications for Advanced detectors will be much more stringent

CHRoCC could be a very useful tool for the fine tuning of RoC's

→ Could relax extreme tolerances on mirror RoC's

→ However, creates lensing in transmissive optics

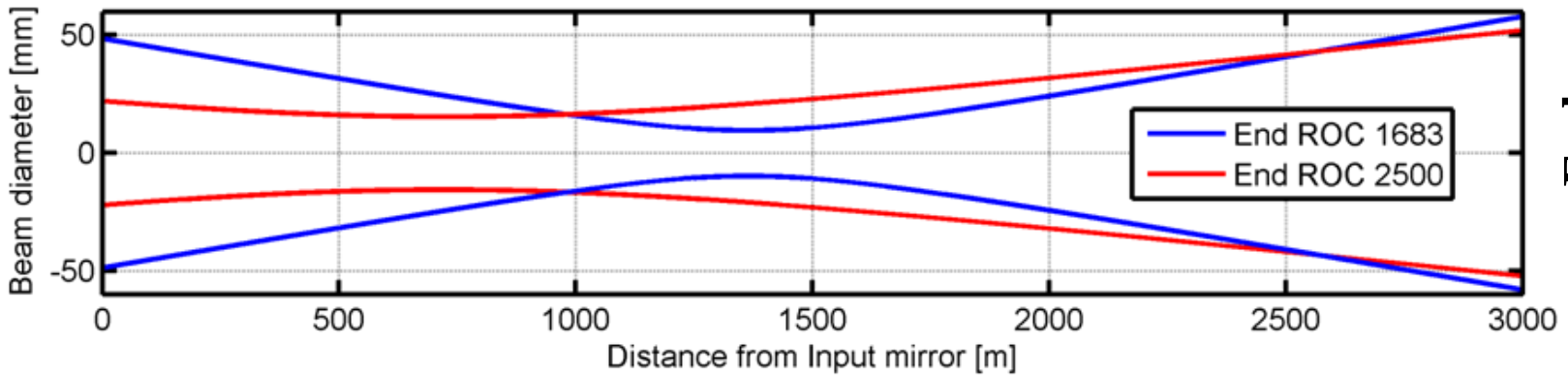
Variable recycling cavity beam radius

Using a marginally stable recycling cavity for Advanced leads to concerns.
→ (see R. Ward's talk on Friday)

Recycling cavity of AdV will be more sensitive to aberrations due to large beam
→ 49mm for AdV compared to 21mm for Virgo

Possible strategy for initial commissioning:
→ Reduce beam size by using CHRoCC on End mirror

Input



End

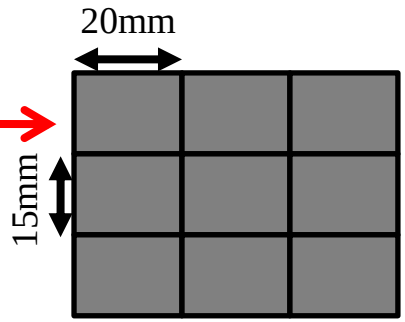
A double CHRoCC setup is capable of recovering Virgo type beam sizes in RC

Work in known configuration while commissioning the compensation systems

CHRoCC correcting Higher order aberrations of surface figure

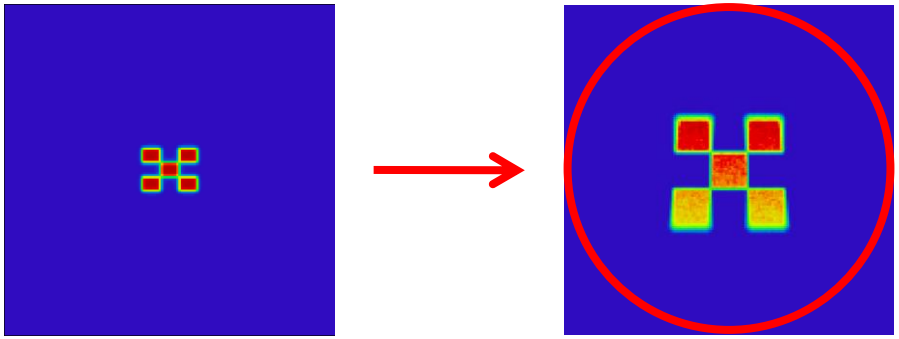
Original CHRoCC sends single heat spot onto mirror
→ Can only correct RoC

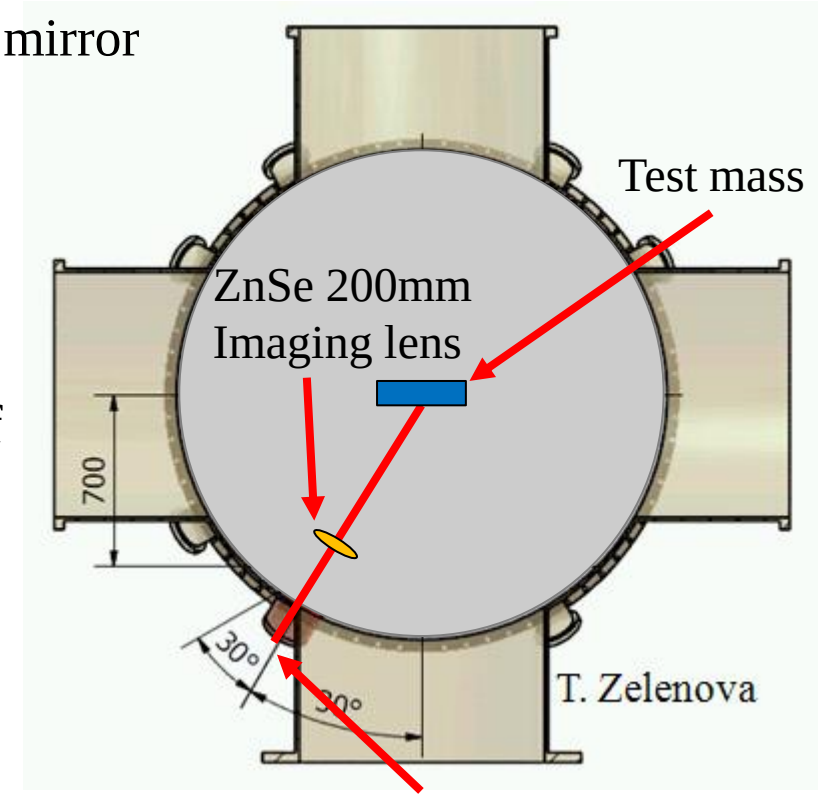
Require a heater array with independent actuators



And an imaging system

Zemax simulation shows good reproduction of heating pattern on Test Mass:





System less power efficient but adequate for higher order aberration correction

System is beginning to look like adaptive optics for GW detectors

CHRoCC: Conclusions

- A new approach to RoC correction by central heating has been presented
  - Power efficient
  - Very high dynamic range
- System fully simulated with Zemax and Ansys
- Installed in End towers of Virgo+ and characterized
- Worked as expected and permitted recovery of Virgo+ interferometer
- CHRoCC works well and provides an extra degree of liberty that could be important for Advanced Virgo
- Imaging of heater arrays onto mirrors could be a useful tool in the fight against aberrations in Advanced Gravitational Wave Detectors