Radiative Cooling Thermal Compensation

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LIGO-G080543-00-Z

Advanced High Power Detectors

- An absorption level ~ 0.3-0.4 ppm is done currently on FP mirrors HR-Ti doped Ta_2O_5 coatings.

- In advanced high power detectors almost a MW standing power will impinge the HR coating of FP mirrors over a gaussian spot of ~6 cm radius:

  → Expected heating power up to ~ 0.5 W

- For a 6 cm radius spot over the mirror surface at room temperature (293 K):
  - Fused silica emissivity ~ 0.93, (Wien law → $\lambda \sim 10\mu m$)
  - Emissive power $E = \sigma\varepsilon T^4 \sim 389\ W/m^2$

  → Mirror spot emispheric emitted power P ~ 4.4 W

- **At equilibrium the same amount is absorbed from the environmental thermal bath**

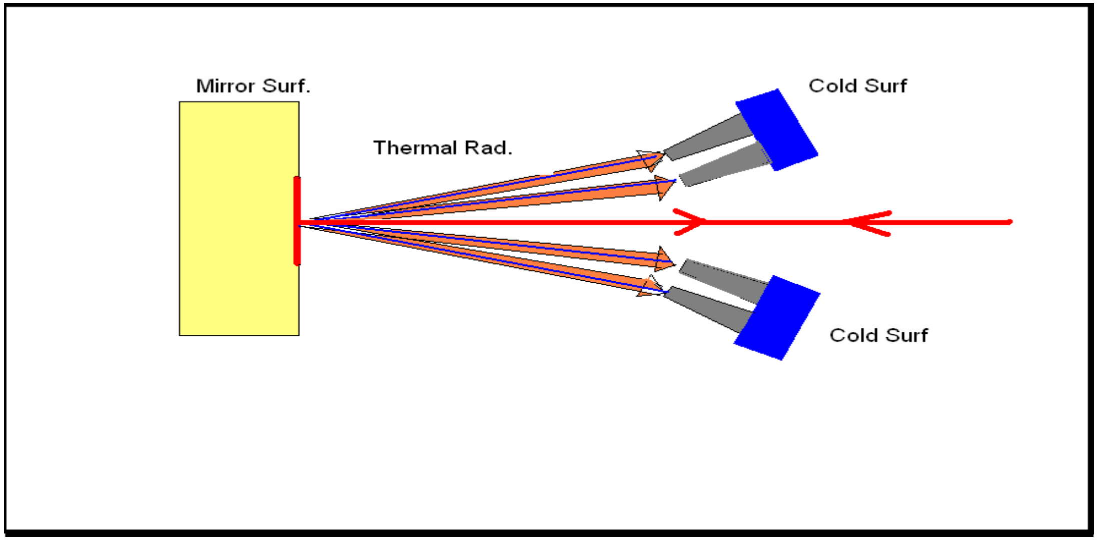
Principle of Directional Radiative Cooling (DRC)

- Establish thermal radiation heat exchange between a cold surface (masking partially the environment to the mirror) and the mirror hot spot surface

- **The cold target could be a Li-N_2 surface:**
  - higly efficient ~99.6%
  - emits only 0.4% thermal radiation than a room temperature body

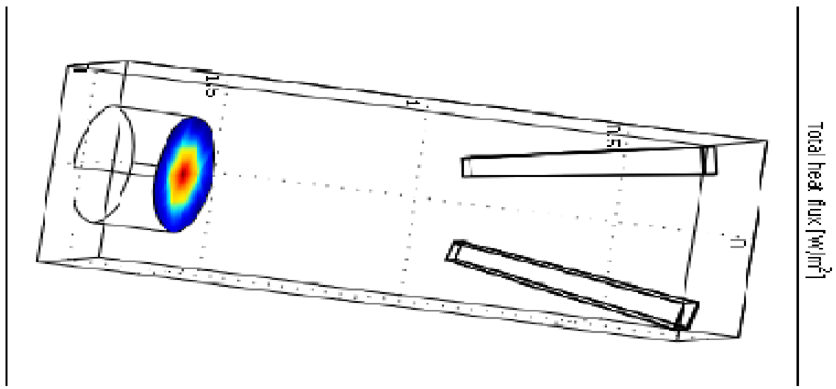
Driving thermal radiation

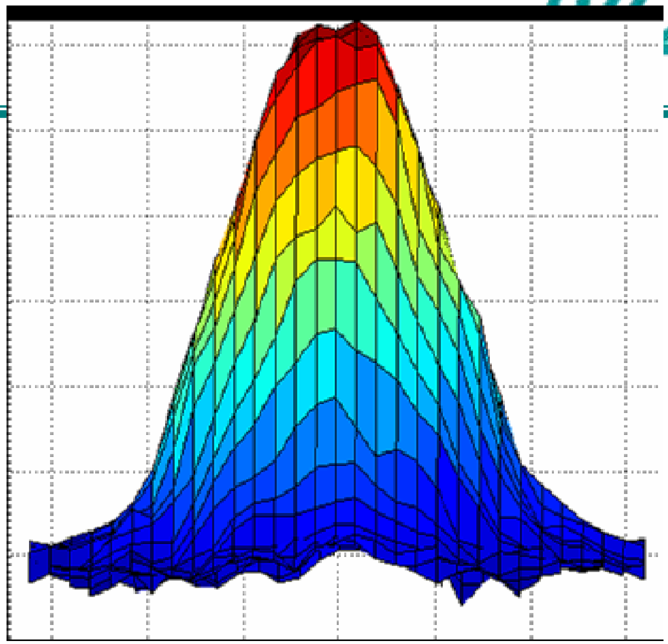
- **Proximity cooling**
- **Imaging cooling**
- **Baffled cooling**

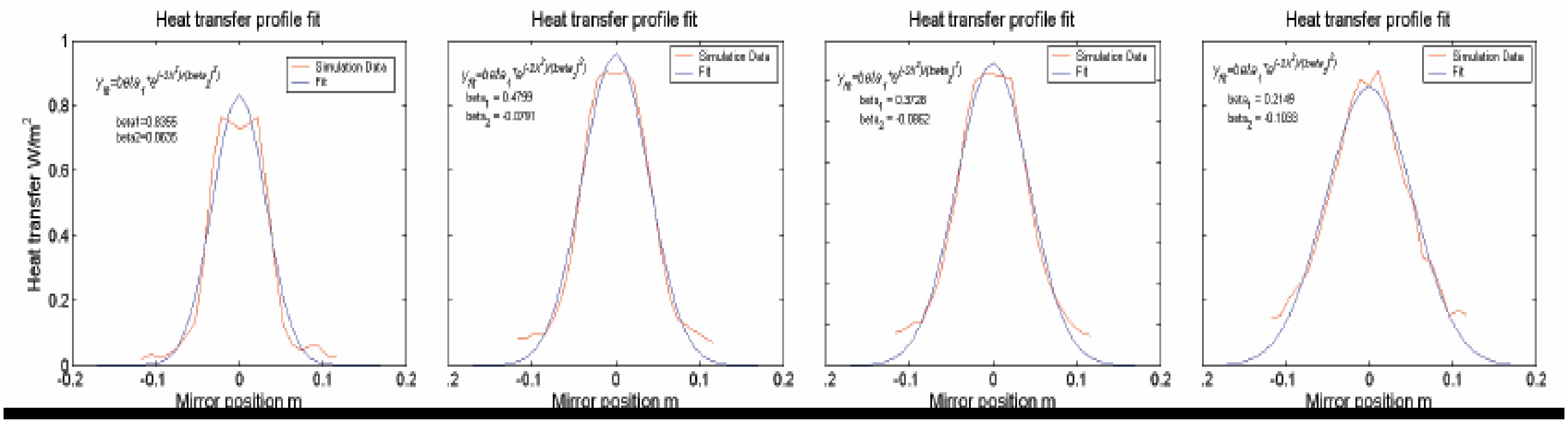


Baffled DRC De-Focussing

- Defocused spot mimic gaussian profile

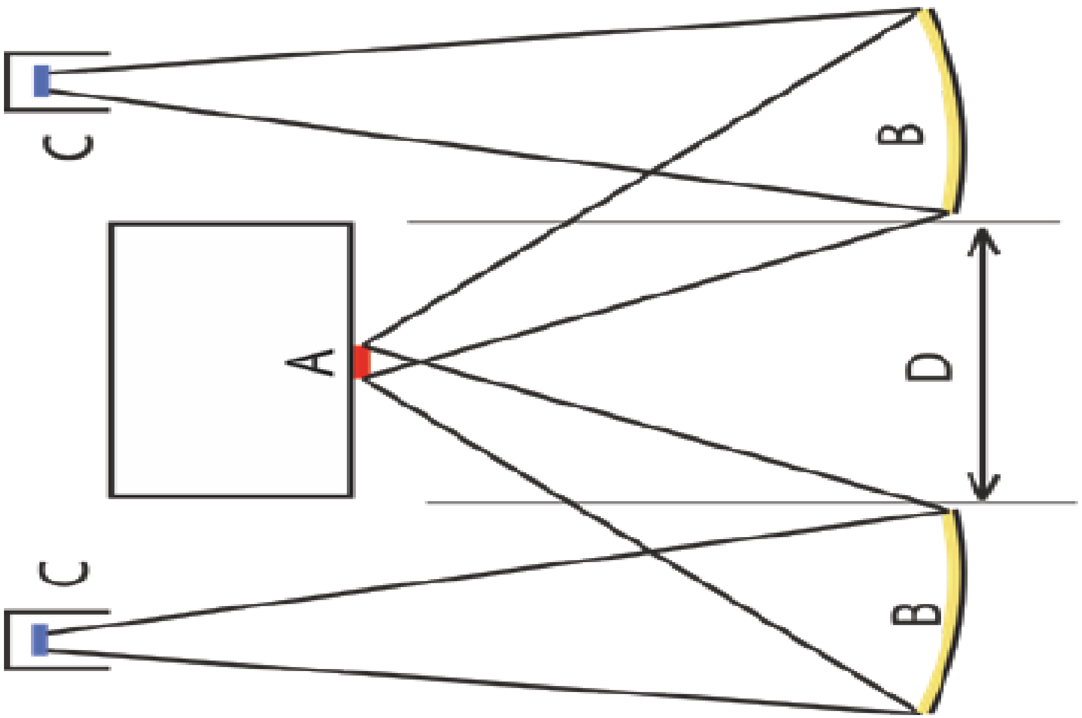






Mirror Focused DRC

- Liquid nitrogen cold targets focused with Au plated parabolic mirrors on stored beam spot
- Mimic Gaussian spot profile by moving cold targets out of focus

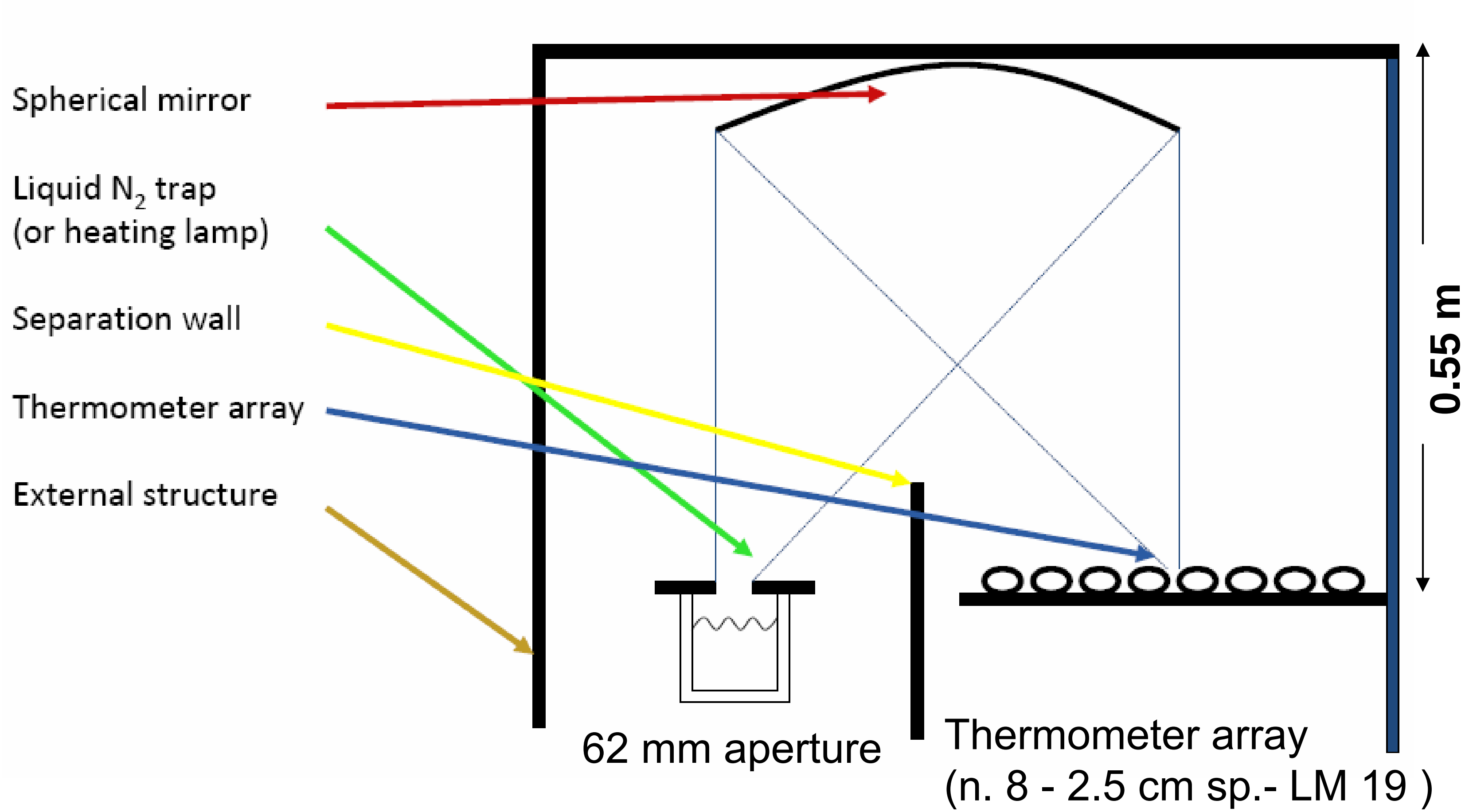


First Experimental Results

Measurement of the cooling power of a LN_2 cold target focused on a linear array of temperature probes in air

(August 2008 - Caltech Lab.)

Experimental Apparatus: Schematics

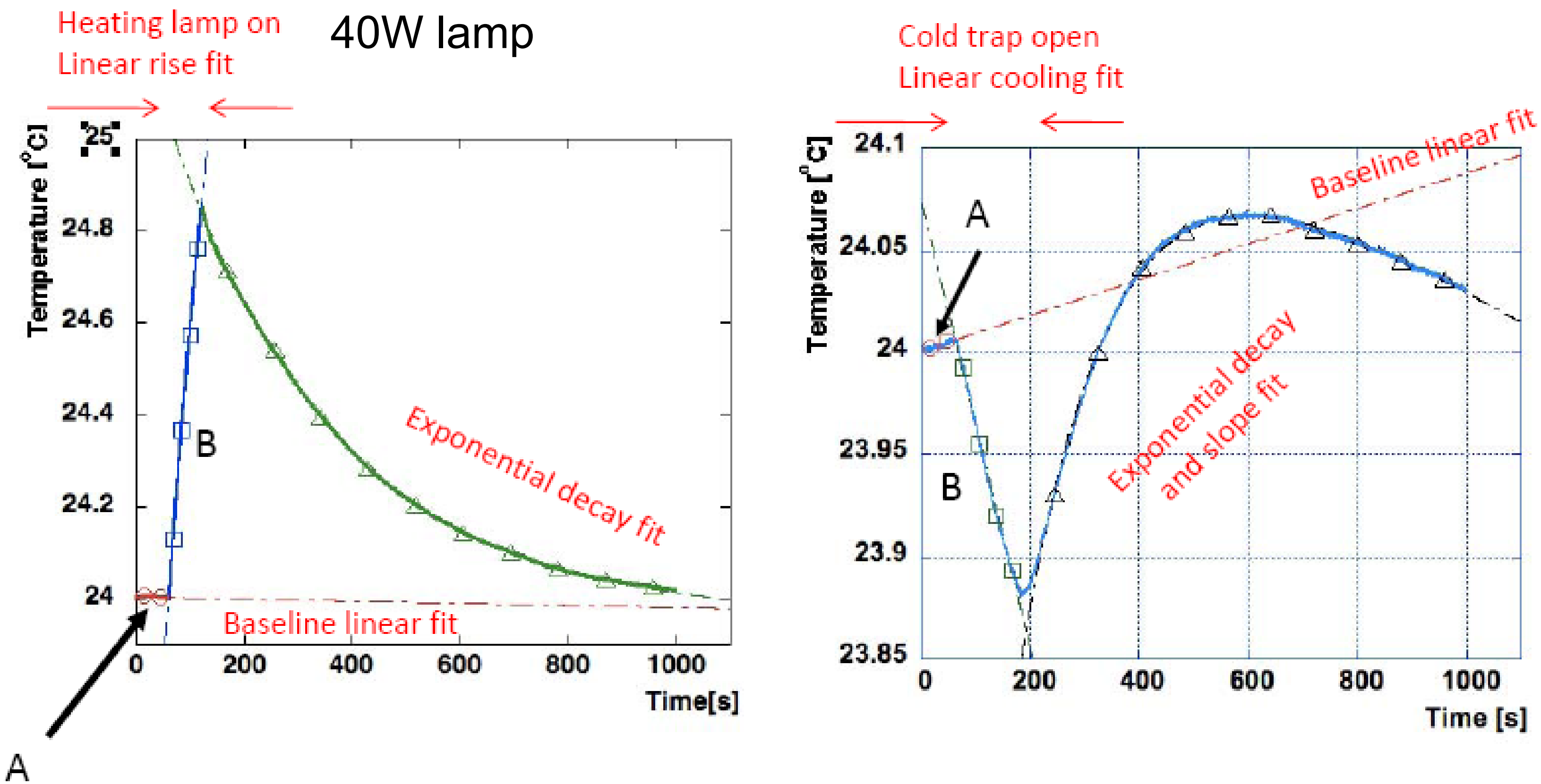


J. Kamp , H. Kawamura, R. Passaquieti, and R. DeSalvo:

Radiative cooling TCS , LIGO-G080414-00-R Pasadena 12 August 2008 (article inpreparation)

Warming and Cooling Cycles

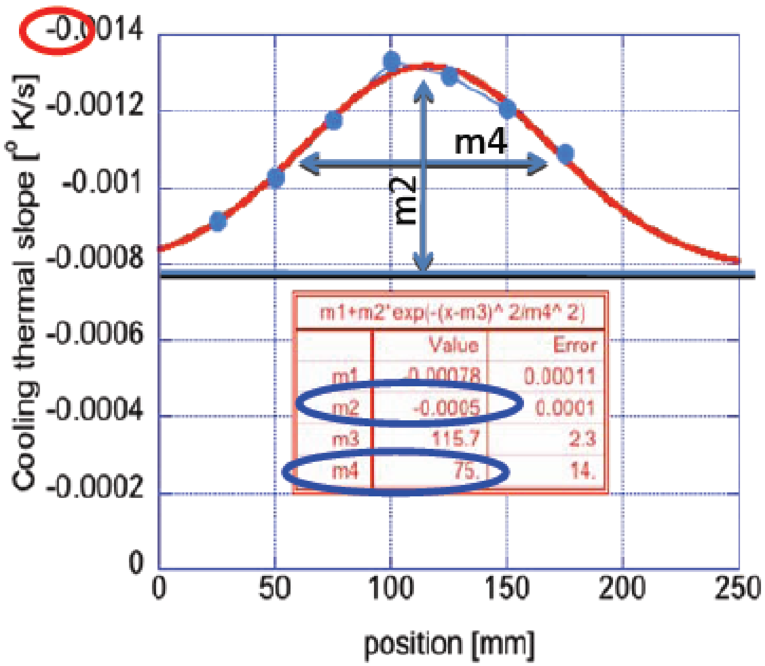
40W lamp



Thermal Power= slopeA - slopeB [oC/s]

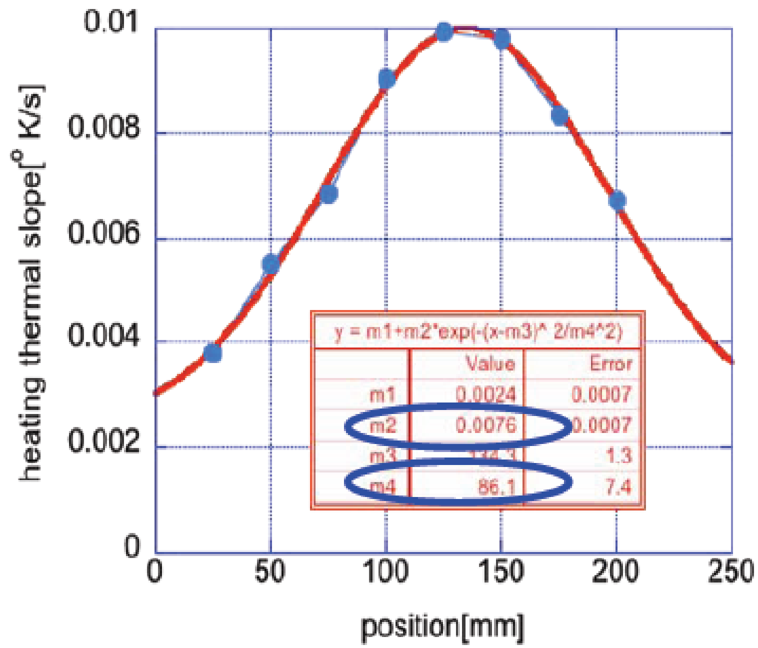
Power Deposition/Extraction: Results

cooling



heating

40W lamp



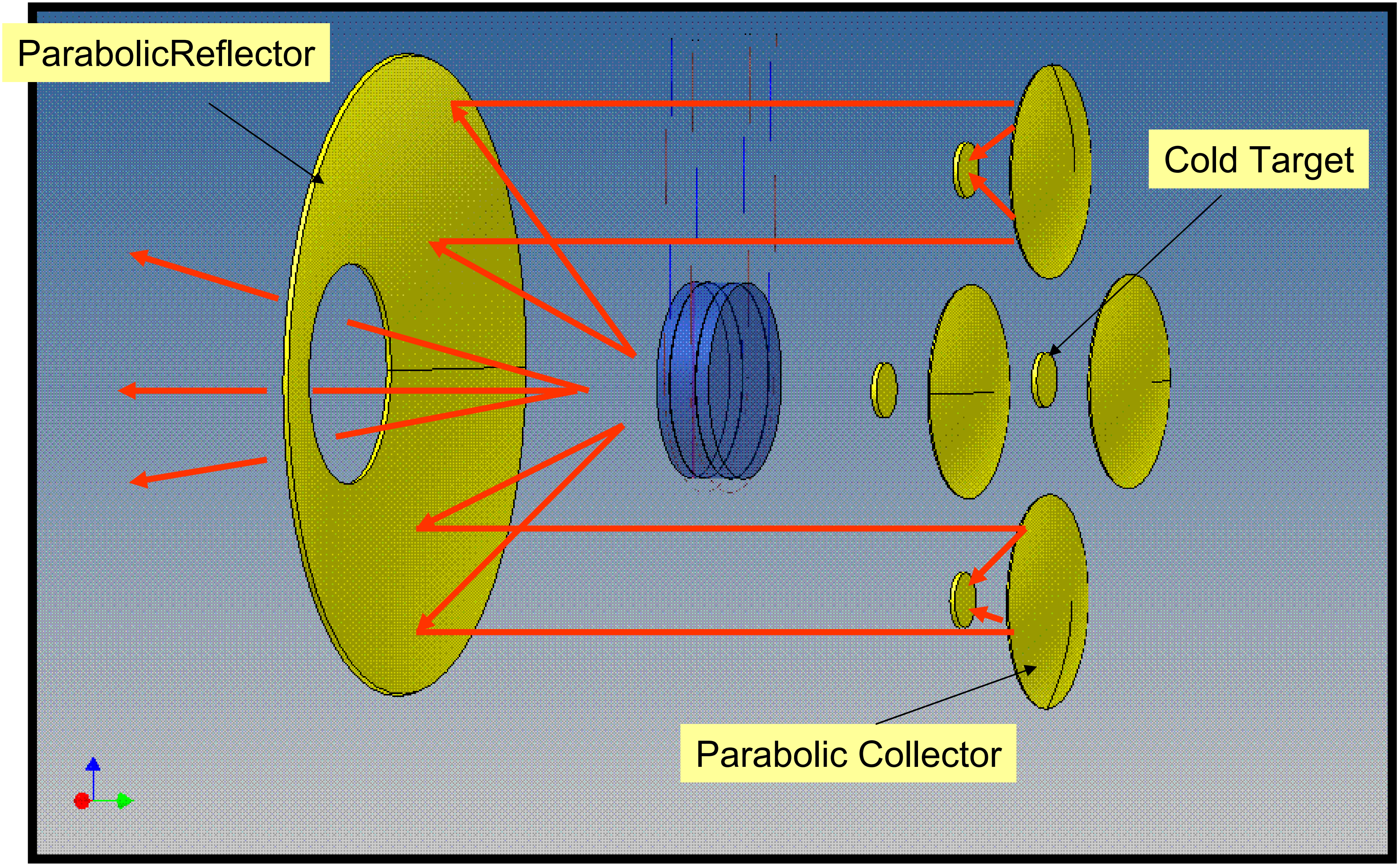
Exchanged power = Gaussian spot surface S = m2*m4

Result:
measured cooling power ~155 ±78 ±39 mW (average over 6 meas.)
(max theor. cooling power ~ 260 mW)

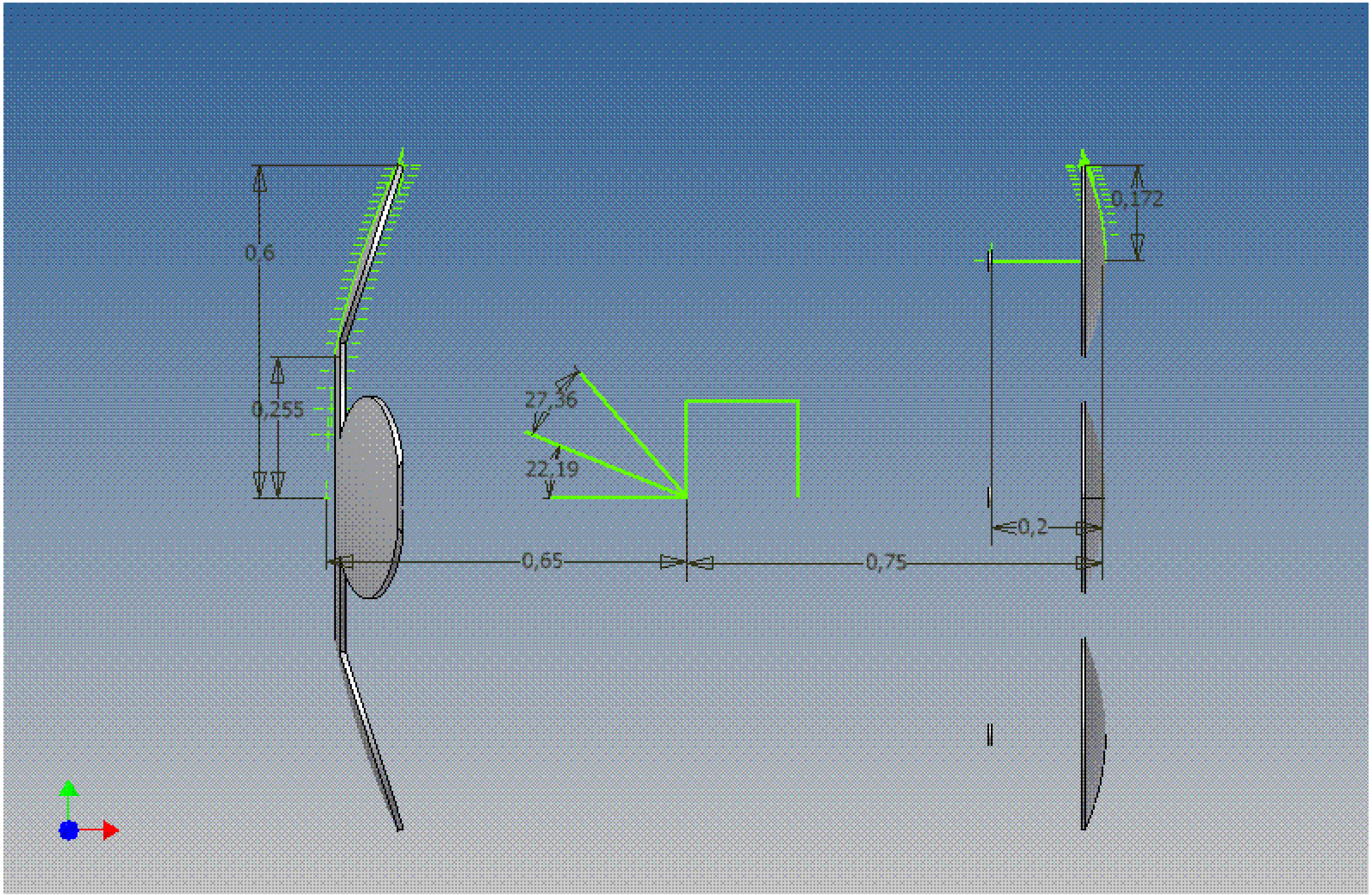
A Preliminary Case Study: Design and Simulation

Mirror DRC focused system dimensionally compatible with the actual Virgo vacuum chamber

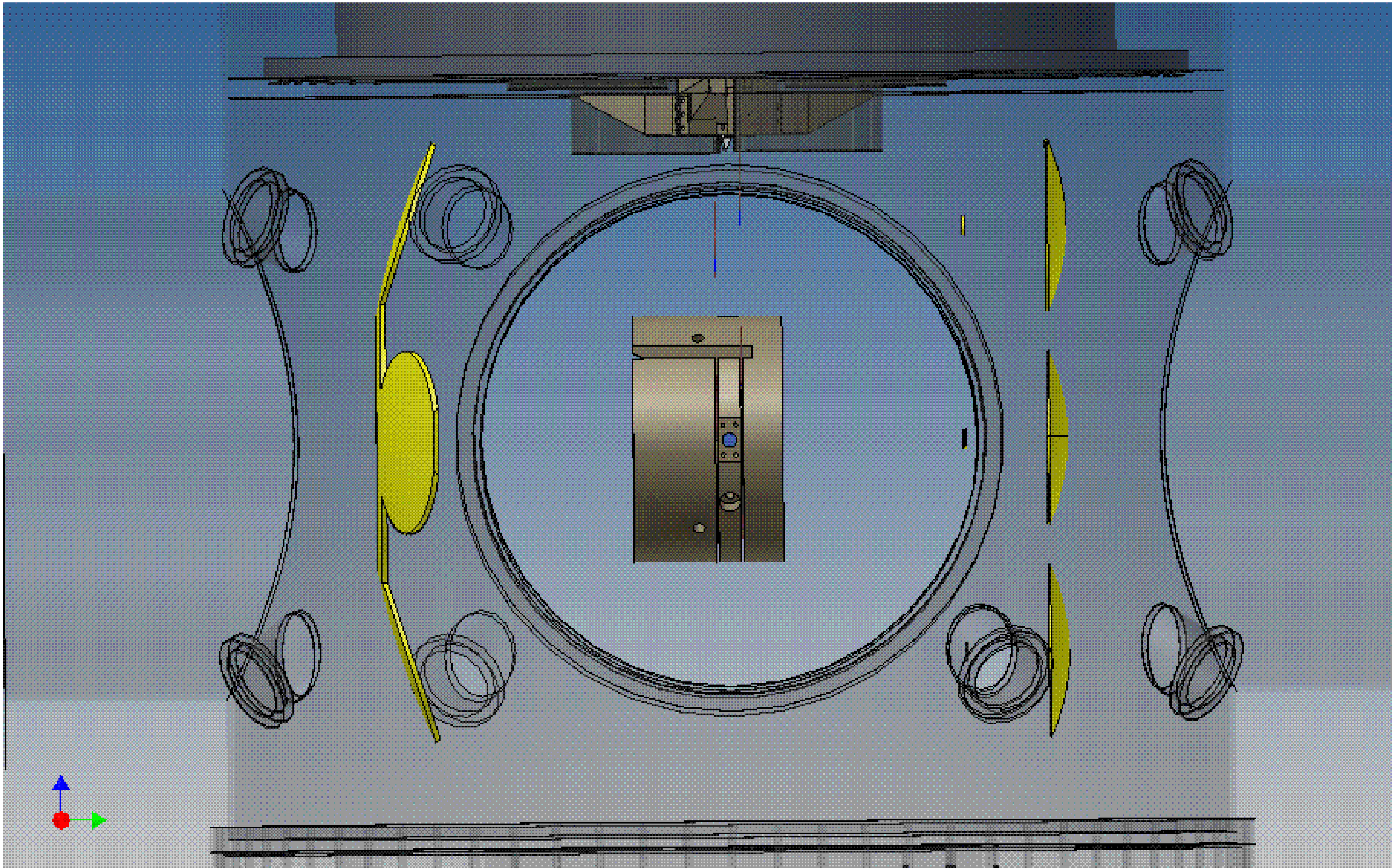
Model: Implementation of Parabolic Collectors



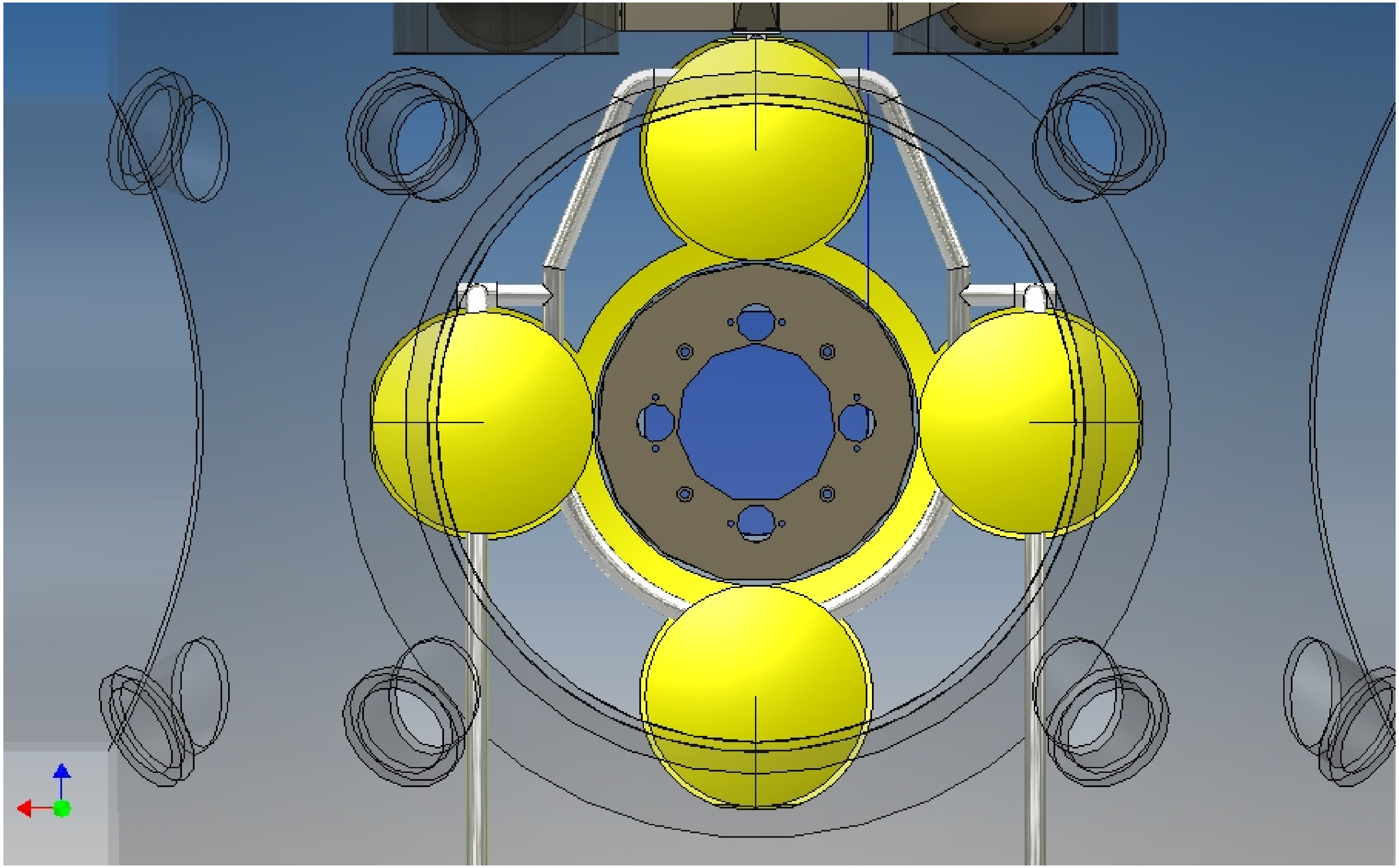
Model Geometry



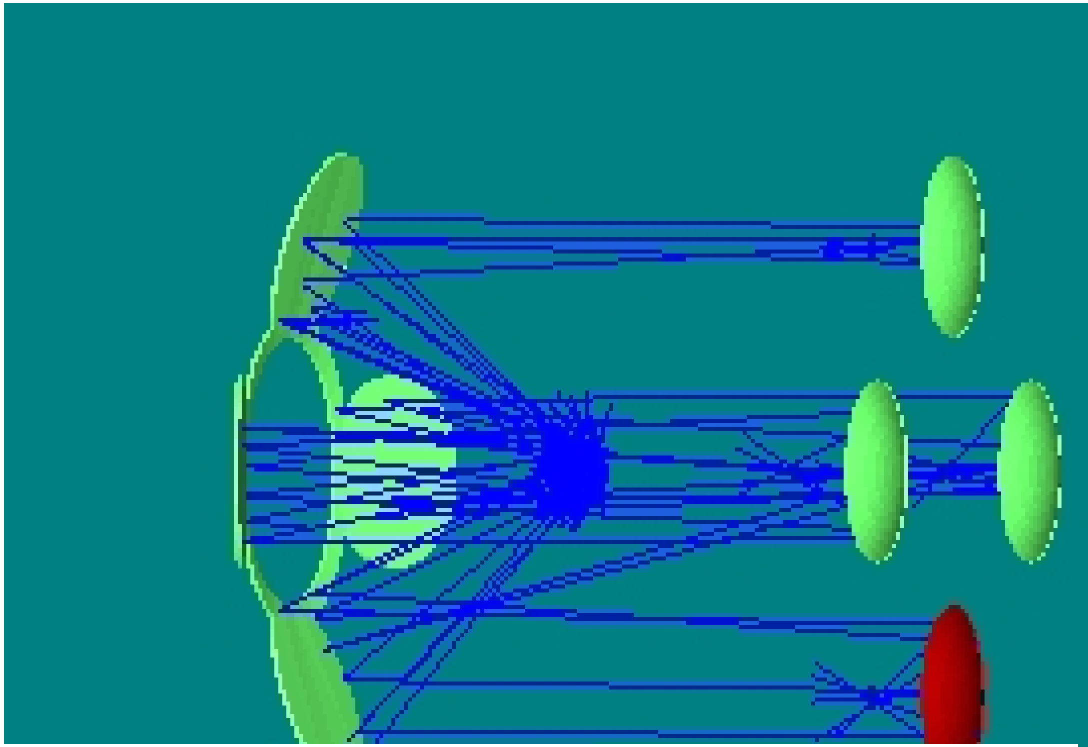
Model Implementation in Virgo (4/5)



Model Implementation: Problems



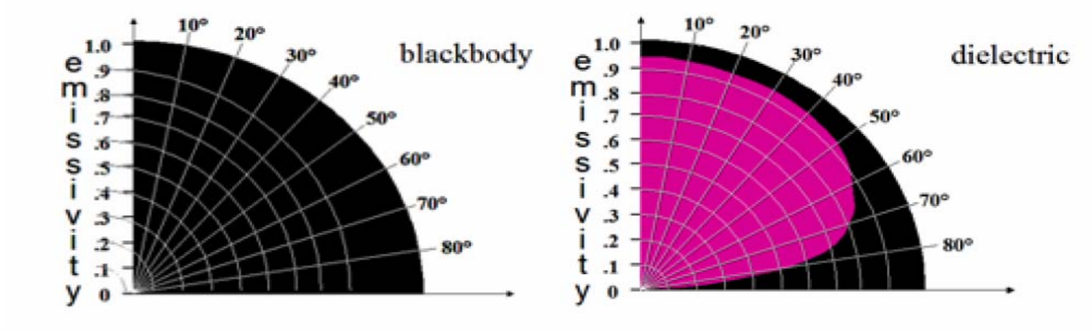
ZEMAX IR Simulation Set Up



Source:
- Disc radius=6 cm
- T=293 K ($\lambda \sim 10\ \mu m$)
- ε =0.93
- Flux= 4.4 W (100000 rays)

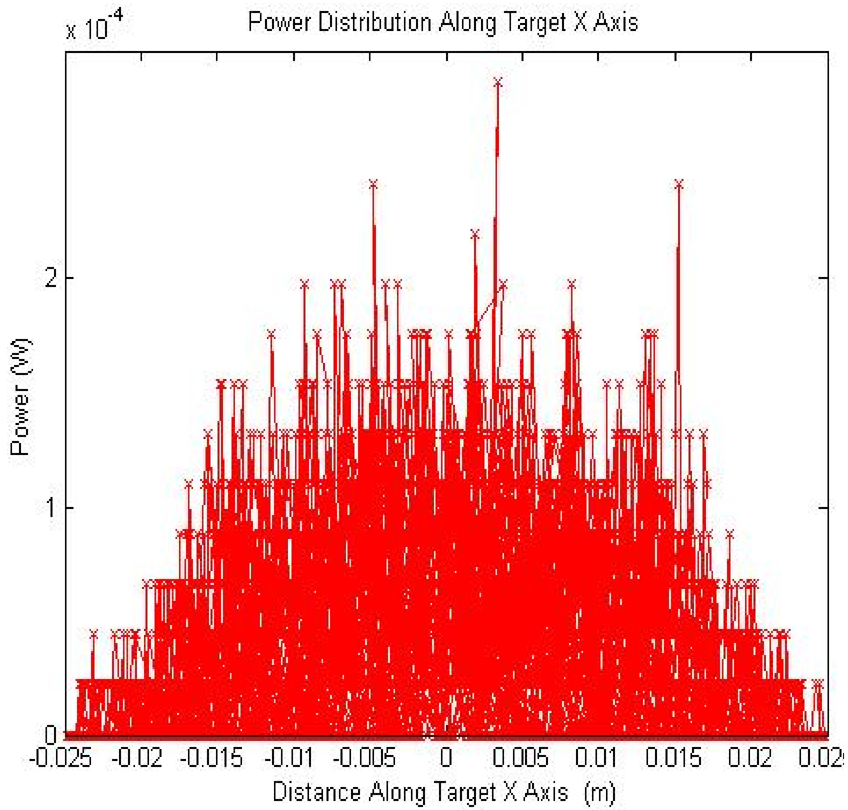
Angular cosine distribution:
$I = I_0 \cos(\theta)$

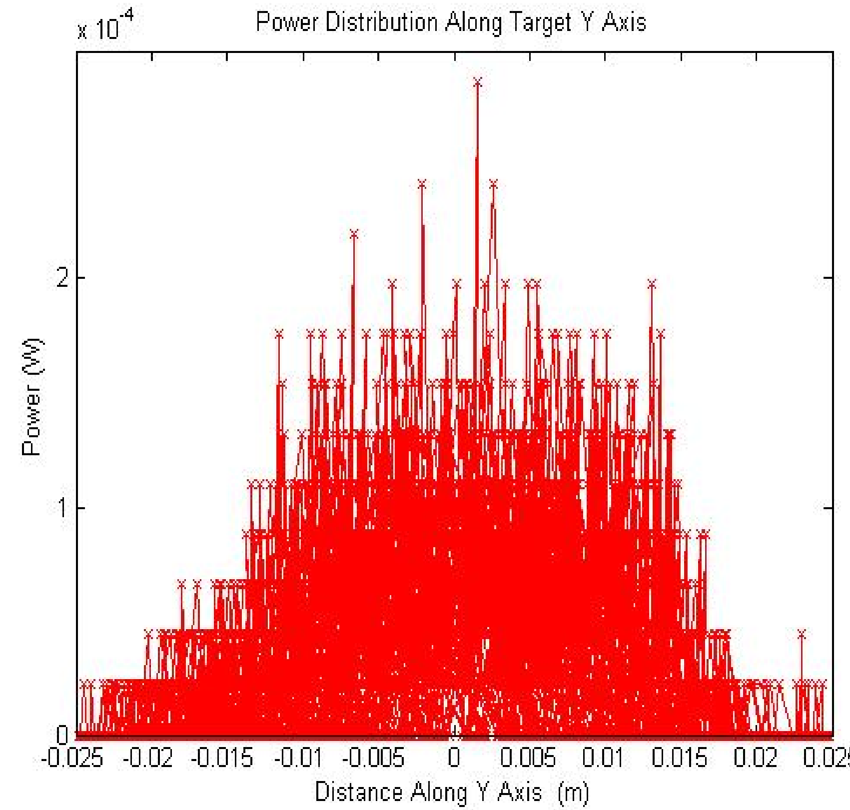
Target :
BB Disc Detector (diam.= 5 cm)

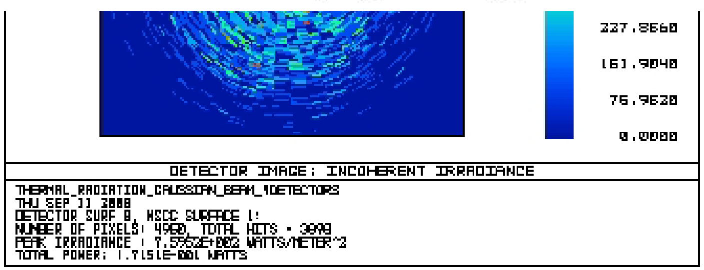


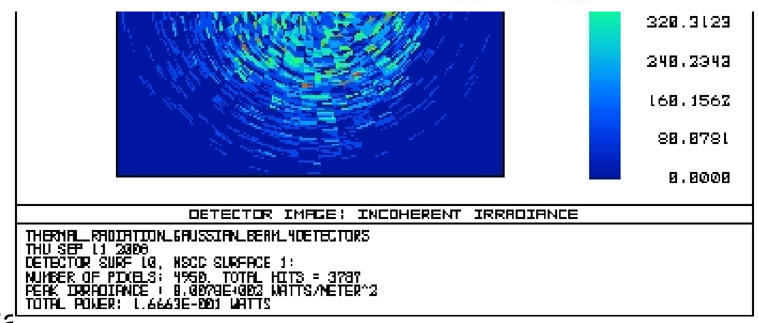
igure 1. Emissivity Variation with Angle, Perfect Blackbody, Real Body. (Source Infrared Training Center)

Target Power Distribution

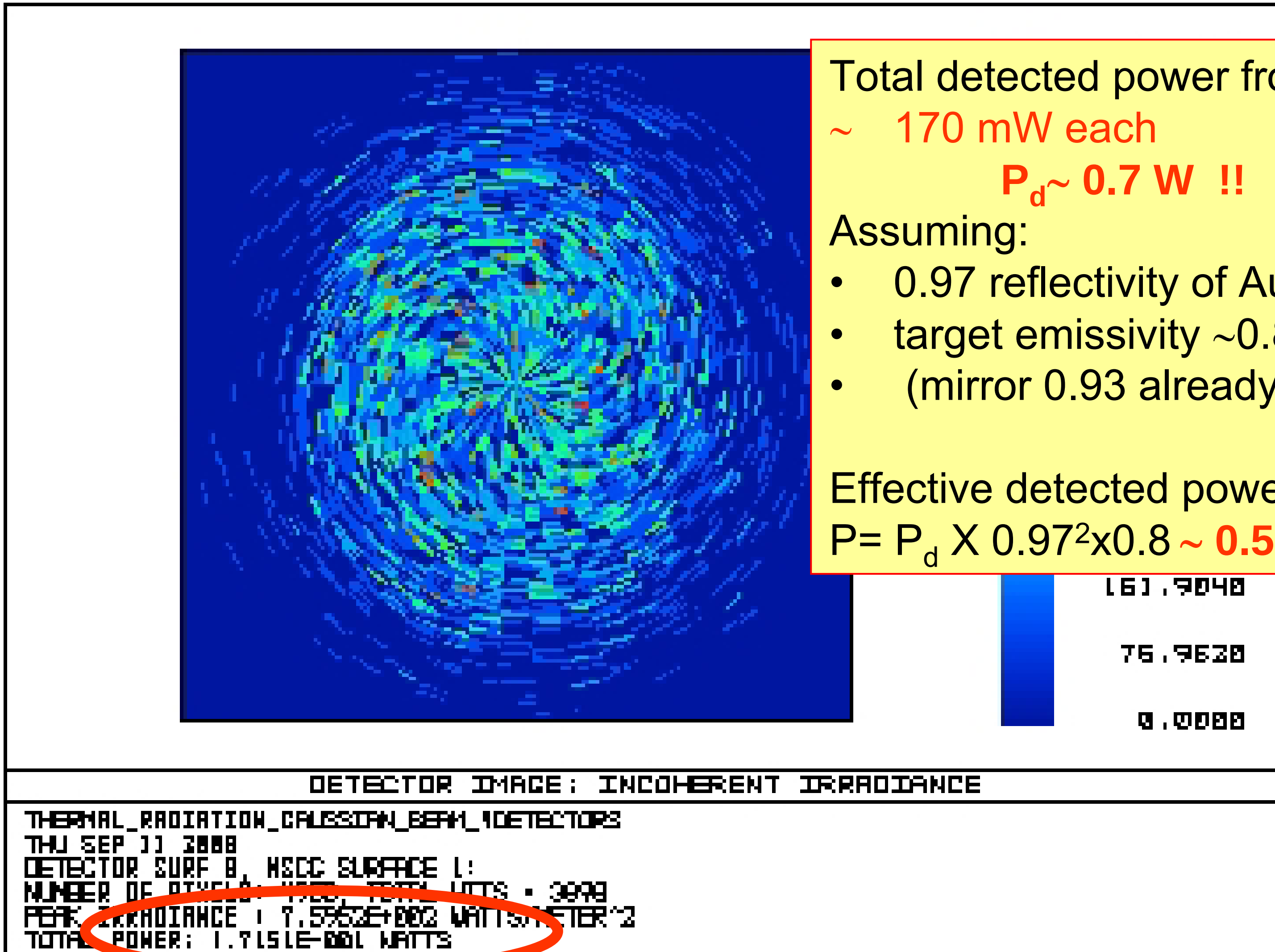








Detected Power on the Targets



Total detected power from 6cm radius spot:

~ 170 mW each

P_d~ 0.7 W !!

Assuming:

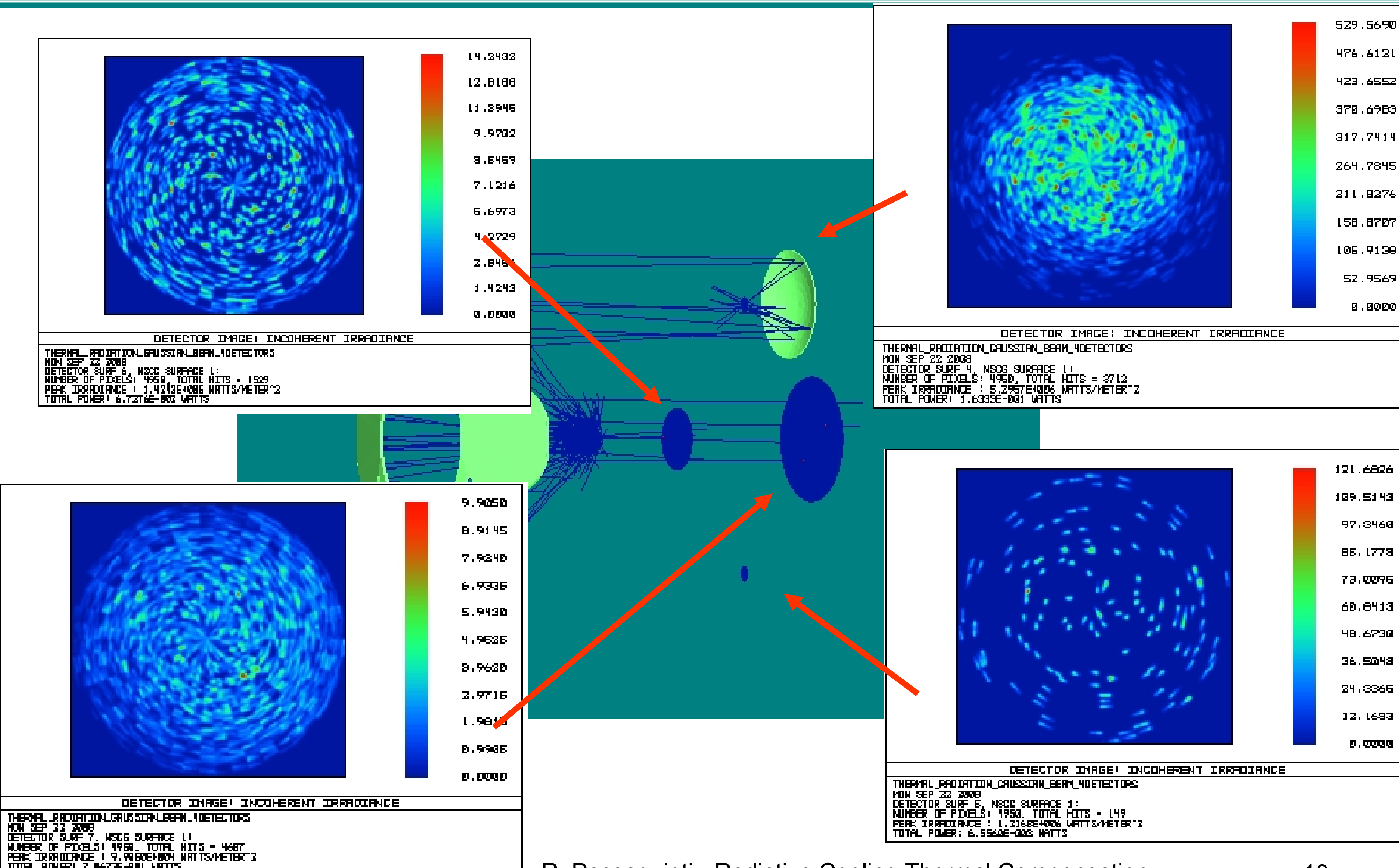
- 0.97 reflectivity of Au plated surfaces
- target emissivity ~0.8
- (mirror 0.93 already considered)

Effective detected power

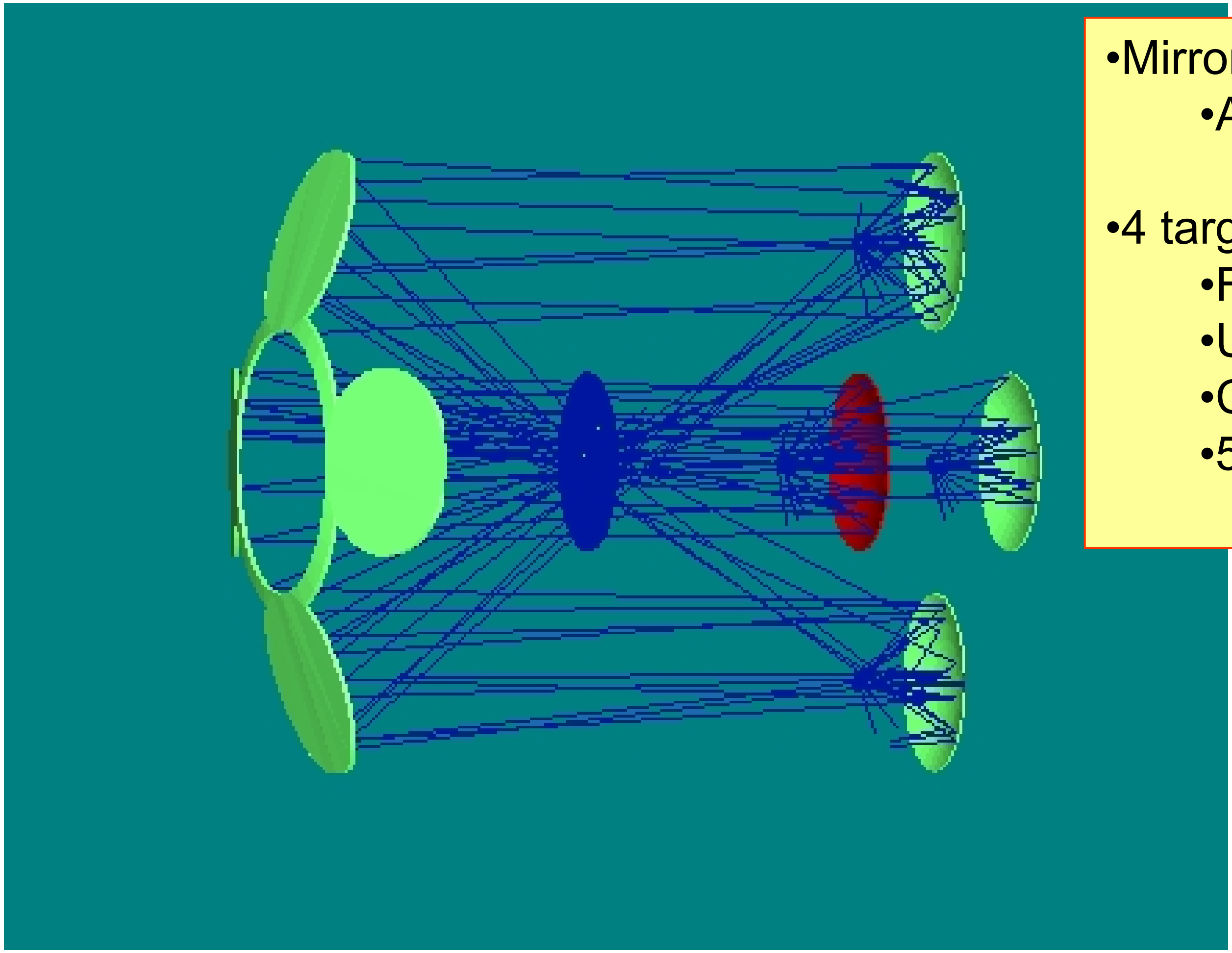
$P = P_d \times 0.97^2 x 0.8$ **~ 0.5 W**

LIGO

Target Geometry Optimization

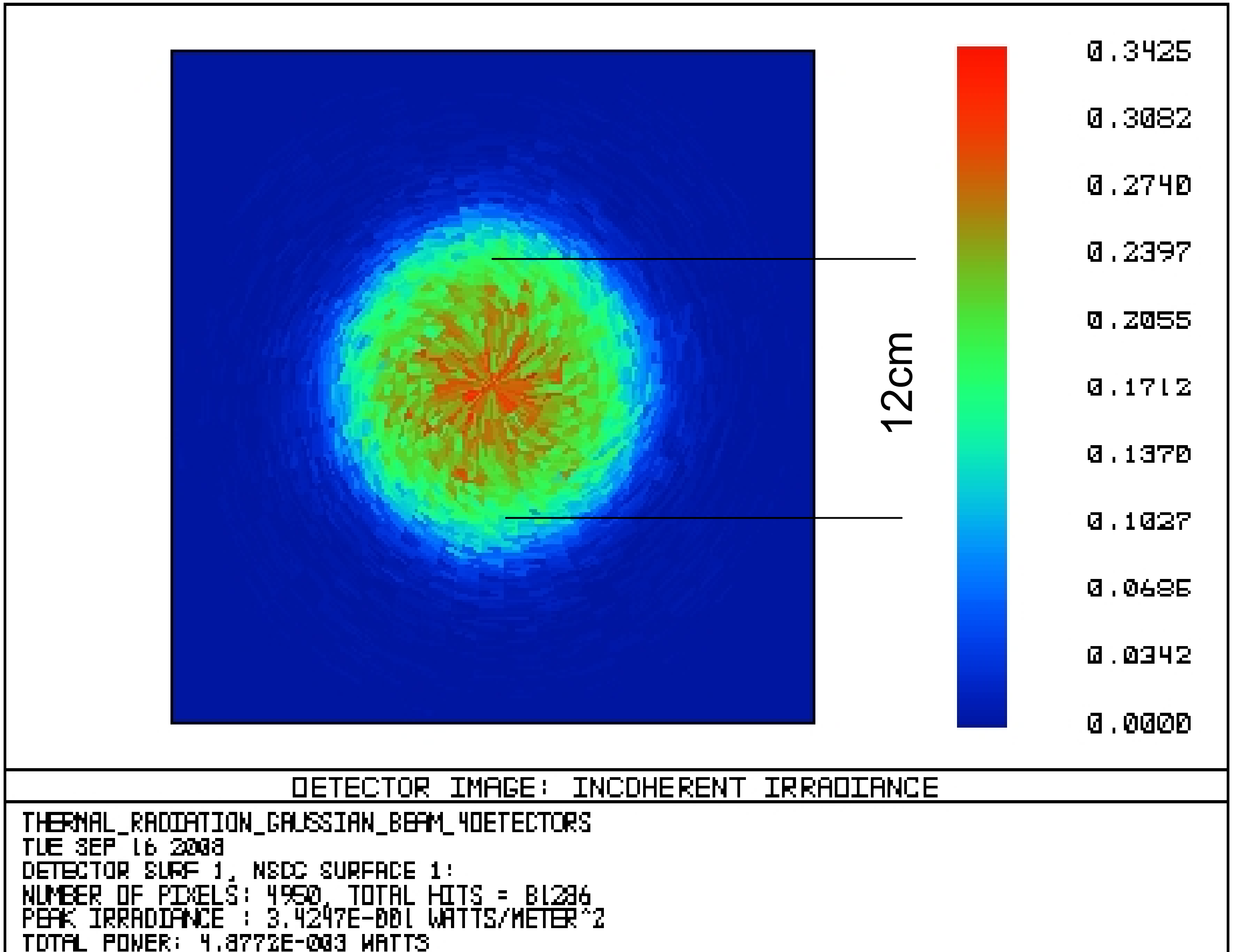


Back-Radiation from 77 K Targets to Mirror



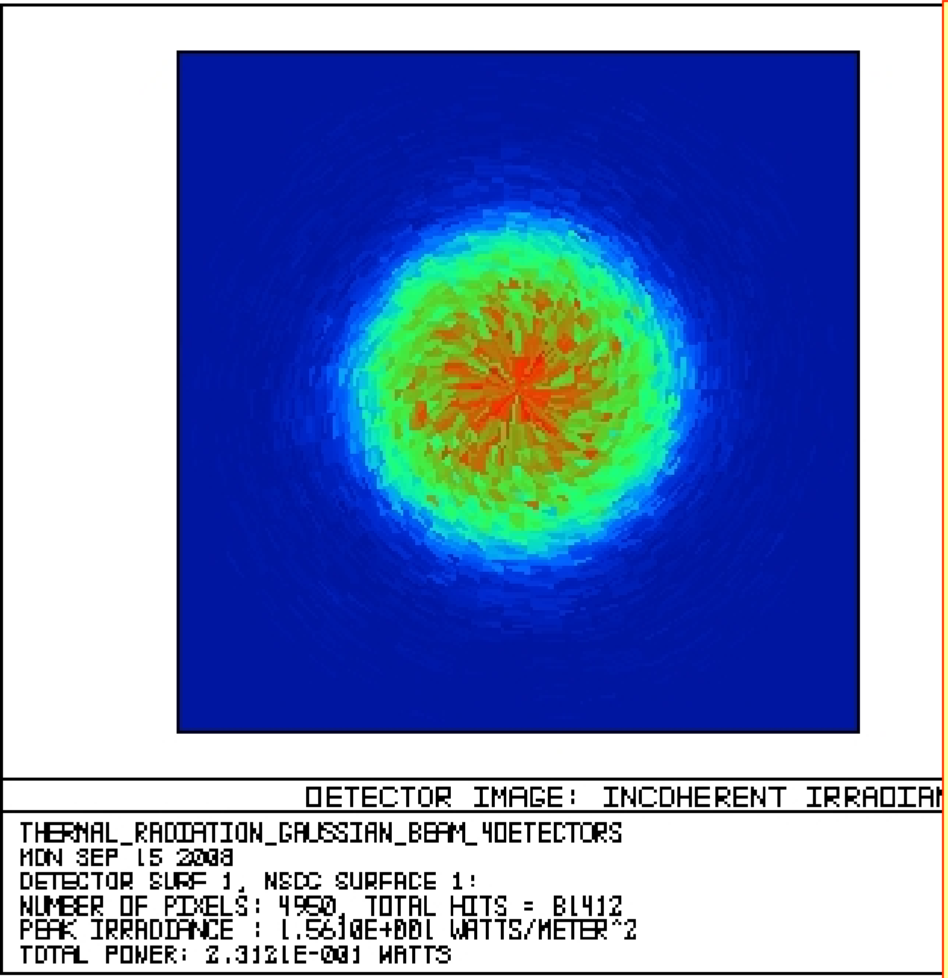
- Mirror:
  - A BB detector of 35cm diam.
- 4 targets at 77K:
  - Flux= 3mW each (λ~38 μm)
  - Uniform distrib. On surface
  - Cos angular distrib
  - 50000 rays each

Back-Radiation Power Distribution on Mirror



Total power ~5mW
Effective power ~4mW

Back-Radiation from 200 K Targets to Mirror



- Mirror:
    - A BB detector of 35cm diam
- 4 targets at 200 K:
    - Flux~ 140mW each(λ~14 μm)
    - Uniform distrib. on surface
    - Cos angular distrib
    - 50000 rays each

Total Flux over the mirror ~ 230mW

Considering:

- Target collector reflect. ~ 0.97
- Mirror reflector reflect. ~ 0.97
- Mirror emissivity ~0.93

Total effective power on the mirror

Pback_refl ~ 200 mW

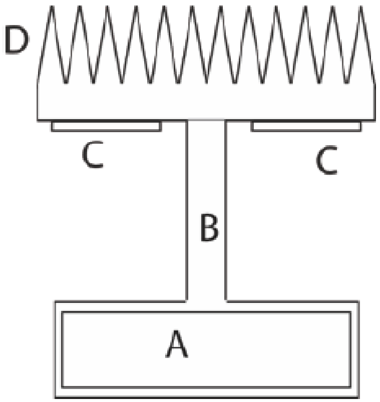
Simulation Summary

- Thermal Radiation exchanges:
  - Thermal radiation from 6 cm radius mirror spot to 4 targets (5 cm diam) ~ 0.5 W
  - Thermal radiation from 4 cold targets (5 cm diam) to mirror:
    - 77 K : ~ 4 mW
    - 200 K: ~ 200 mW

  - Net radiation flux from mirror 6cm radius spot to targets at 77 K: ~ 500 mW
    - Use of LN_2 or low noise refrigerators (pulse-tube)
  - Net radiation flux from mirror 6cm radius spot to targets at 200 K: ~ 300 mW
    - Possible use of peltier cells (multilayer $\Delta T \sim 90$ K)

Other Radiation Cooling Control Methods

- Iris control:
  - An iris placed in front of each target tuning the sink surface
  - Require remote adjustment and moving parts in vacuum



- Target temperature control
  - A resistor heater (C) tuning the target (D) temperature
    - Reaction time depends on target heat capac.
- Hot resistor power balance
  - Shielded resistor heater and cold target both focussed on the mirror
    - Fast
    - Useful during unlock
- Remote driving of peltier-cells (if implementable)

Conclusions

- The feasibility of DRC has been recently tested and demonstrated with an experiment in air:
  - an experiment in vacuum is required
  - even better if performed with a silica bulk in a full 1:1 scale geometry set-up.

- Preliminary ZEMAX IR simulation of a case study model, fitting the Virgo payload geometry, has shown the interesting result of 0.5 W to 0.3 W heat power extraction from a mirror beam spot of 6cm radius.
    - need to be optimized,
    - reflector surface scattering need to be considered,
    - target surface geometry need to be modified to mitigate scattered beams
    - Noise sources need to be studied (cooling profile on mirror, alignment specs. refrig. specs., seismic attenuation specs., ...)

- This system can be tuned to match the laser heat power released on the mirror beam spot
- Thermal lensing could be at least mitigated without major modification of the payloads
- Cold surfaces Cryopumping of organics impurities

- **DRC has been recently presented in Virgo. No decision has been taken at the moment by the Virgo Collaboration about future plans for DRC in AdV.**