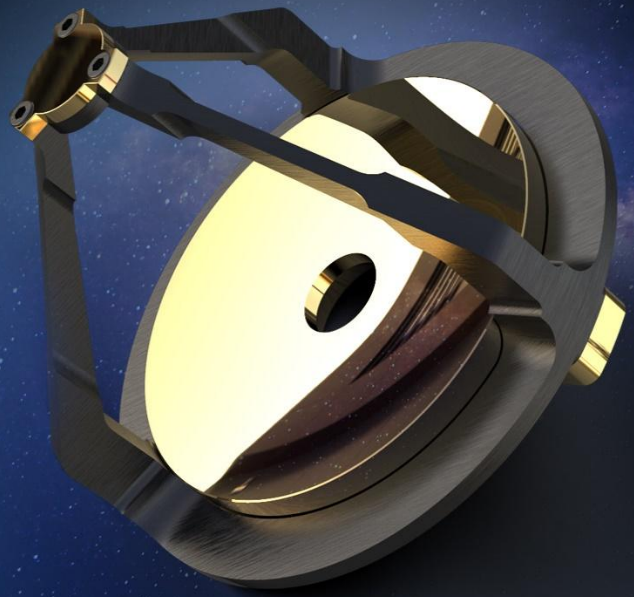
# Aluminum Mirrors for LaserCom: Opportunities and boundaries


Presented by

Clemens Dicke, Head of Sales & Technology

Edmund Optics son-x GmbH


Palaiseau, April 9, 2025



EPIC Technology Meeting on Disruptive Optics at Thales

Palaiseau, April 08-09, 2025

Edmund optics | worldwide

Edmund Optics® is a leading, global provider of
optical technology solutions that has served a variety of markets since 1942

## 3
### Generations Devoted to Optics
Norman Edmund (1916 – 2012)
Robert Edmund
Mari Edmund

## 1,250+
### Employees
Across 18 Global Locations
Engineering Support Available 24/7

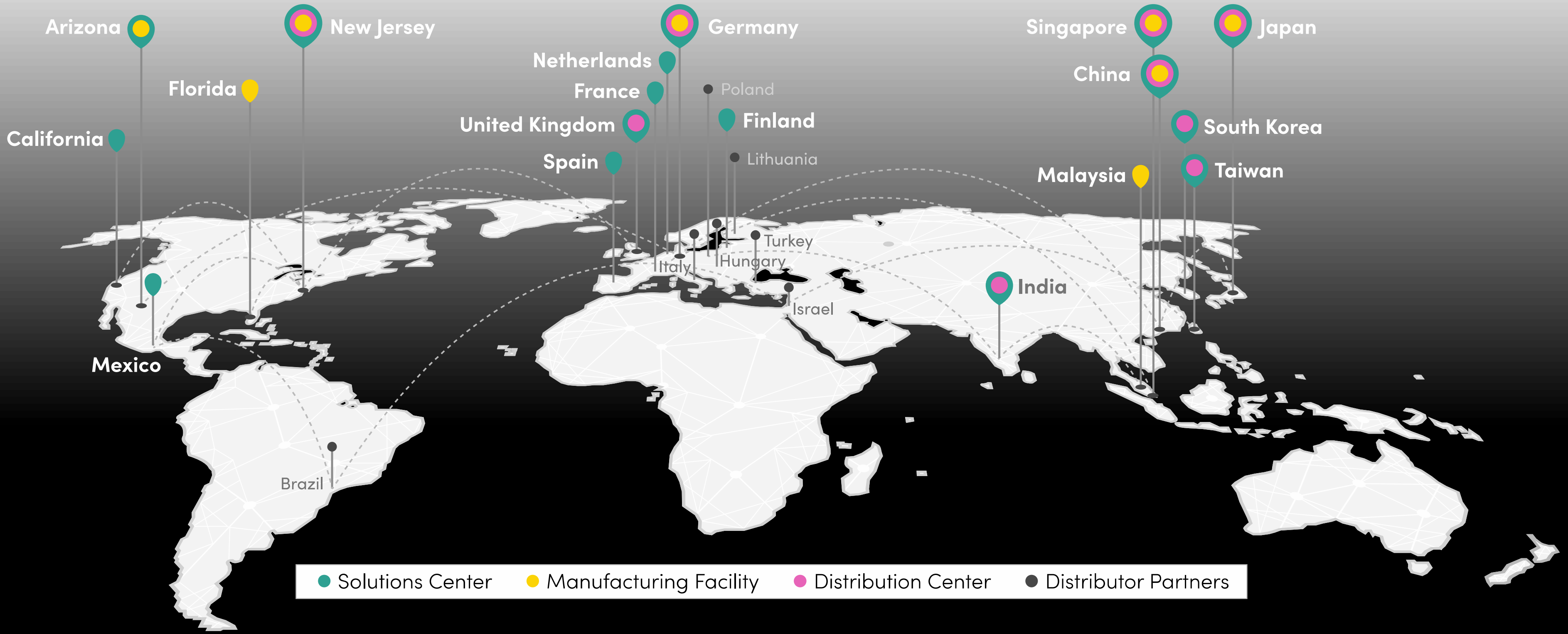
## 24/ 7
### Technical Support

## 6
### Warehouses

## 34,000+
### Optical Components
Nearly **2 Million** Components In Stock, Ready to Ship
from the Industry's Most Trusted Brands

## 8
### Manufacturing Facilities
Over **2.5 Million** Optical Components Made Each Year
Over **175 Thousand** Optical Assemblies Made Each Year

# Global Footprint



Edmund optics | worldwide

## Servicing Our Customers through

# SPECIALIZED SOLUTIONS

### Marketplace

One-stop shop for the best brands and products in optics and photonics

### Manufacturing Services

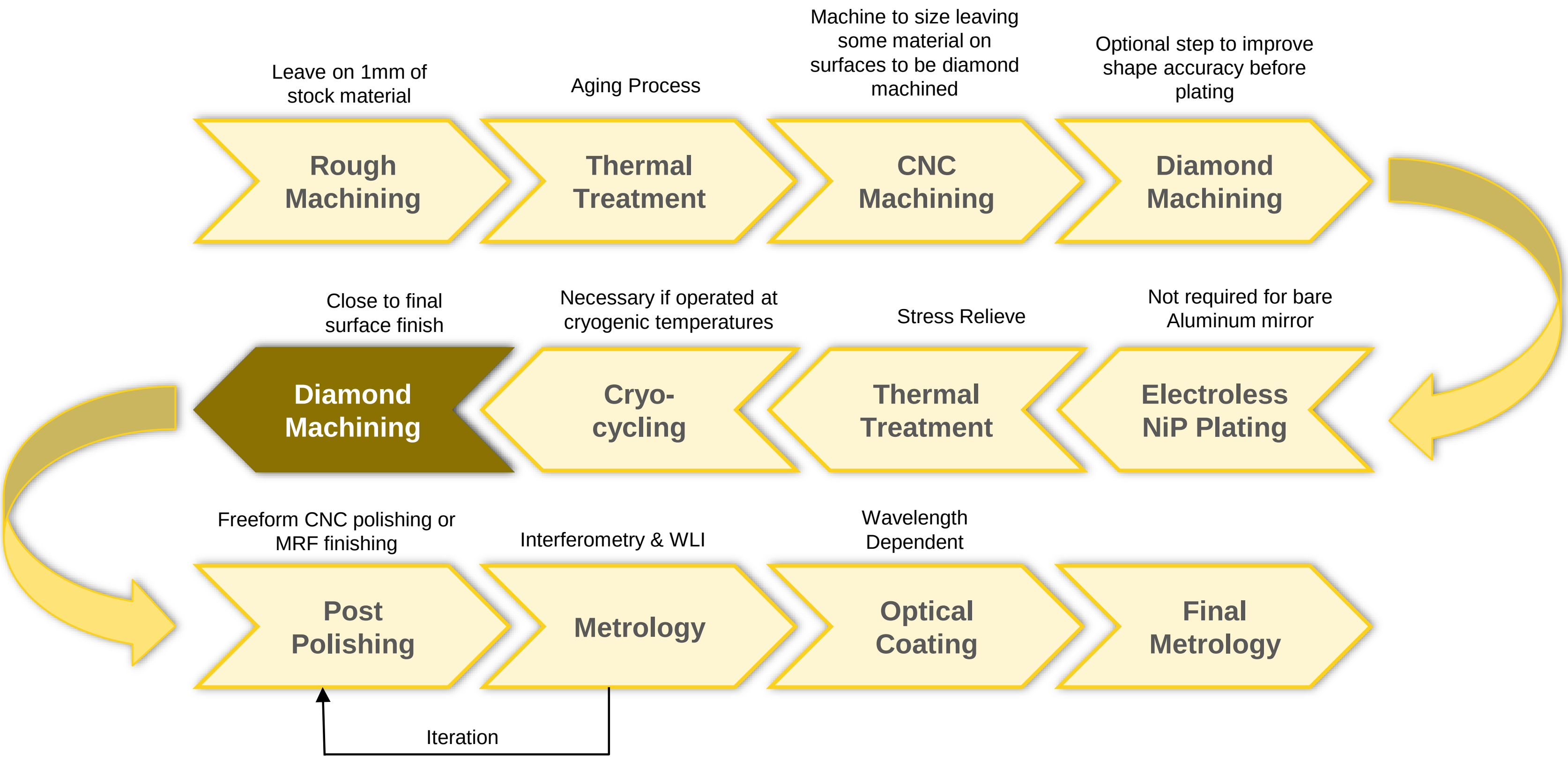
Custom and volume manufacturer of precision optical components, imaging assemblies, and systems

# Company Profile

- Shop floor space of 700 m²
  - Incl. 200 m² highly temperature-controlled
- Office Space of 400 m²

- son-x GmbH founded in 2011 as a spin-off from Fraunhofer
- Based in Aachen, Germany
- Focus on ultra precision manufacturing
  - Ultrasonic Tooling Systems (UTS)
  - Ultra Precision Machining
- Optical component manufacutring:
  - Mirrors
  - Mould inserts
  - Plastic lenses
  - Infrared Lenses
- DIN ISO 9001 certified
- **Jan 16, 2025: Part of Edmund Optics**

# Metal Mirror Production Process Chain

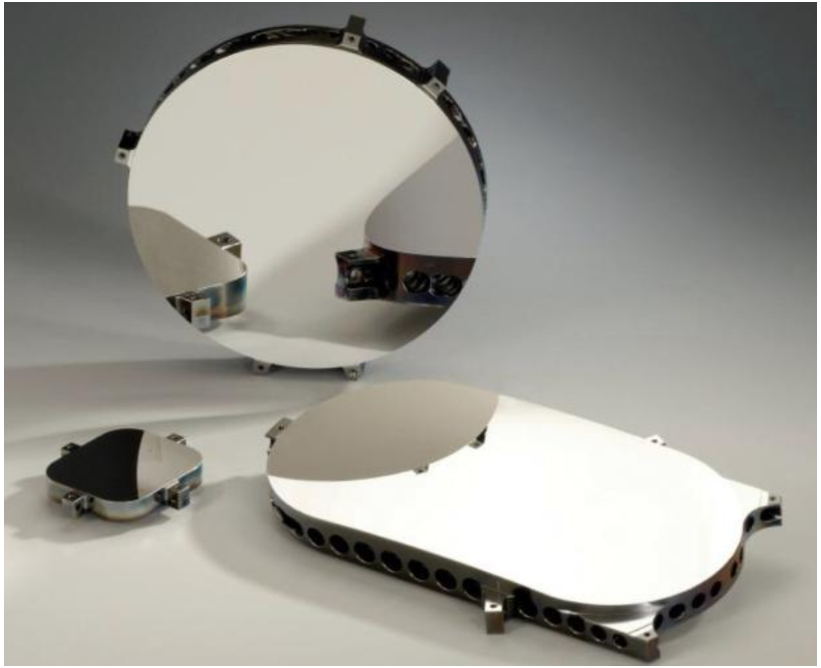


# Ultraprecision mirrors for space

# Typical Substrate Materials and their Characteristics

| | Glass | Glass Ceramic | Ceramic | Metal |
|---|---|---|---|---|
| **Material** | $SiO_2$ | Zerodur | Silicon Carbide | Aluminum |
| **Density** | low | medium | high | medium |
| **Strength** | medium | medium | high | medium |
| **Thermal stability** | medium | high | high | low |
| **Machinability** | poor | poor | very poor | excellent |

# Aluminum Mirrors – Properties and Advantages



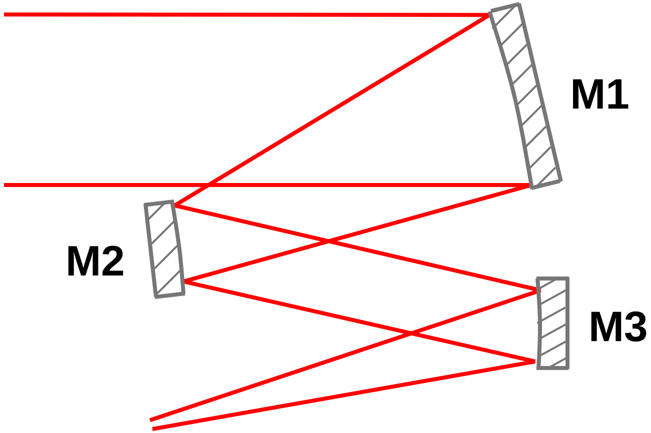
*Source: Fraunhofer IOF*

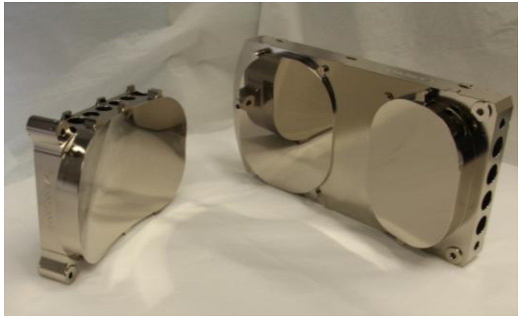
- Relatively inexpensive materials and ease of blank manufacture
- Direct integration of mounting and reference features
- Ability to add heating/cooling channels and relatively high thermal conductivity
- High percentage of light weighting possible
- Material matching between mirror and mounting structure

# Aluminum mirrors in TMA / Cassegrain Telescopes: Oportunities and boundaries

# Telescope Designs – TMA*

*TMA = Three Mirror Anastigmat

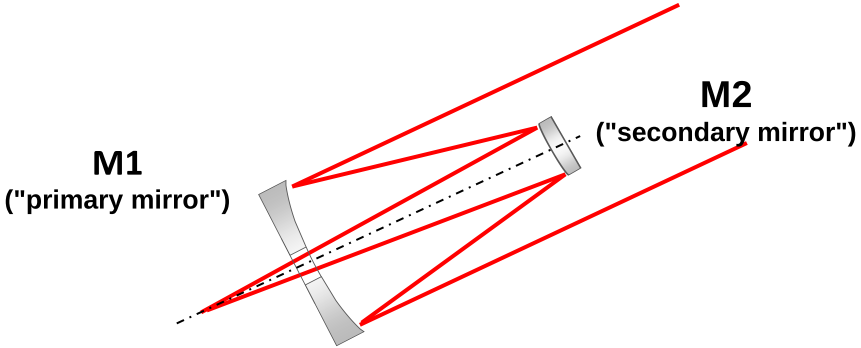


*Source: Fraunhofer IOF*

- Using 3 curved mirrors enabling to minimize all three main optical aberrations – spherical aberration, coma, and astigmatism
- Enables both a wide field of view and relatively small geometrical dimensions of the telescope
- Individual mirror geometries off-axis (freeform)

# Telescope Designs – Cassegrain




*Source: Edmund Optics son-x IOF*

- Incoming light captured by a concave parabolic main mirror ("primary mirror")
- Reflected light captured by a convex hyperbolic "secondary mirror"
- Allows compact designs
- Individual mirror rotational symmetric

# Aluminum mirrors for space: Parameter

# Typical Aluminum Alloys their Characteristics

Roughness **RMS** – a rough estimation

| Material | 6061 T6 / T651 | RSA 6061 / 905 | Al with NiP |
|---|---|---|---|
| **Roughness RMS** | 5nm – 10nm | < 3nm | < 2nm |

**S**urface **F**orm **E**rror (SFE) – a rough estimation

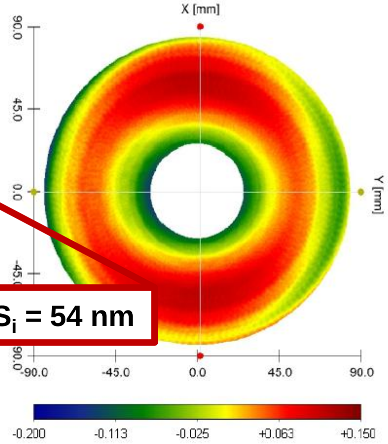
| Diameter | Ø < 20mm | Ø < 80mm | Ø < 160mm | Ø 500mm - 1000mm |
|---|---|---|---|---|
| **PVi*** | < λ/10 @633nm (< 60nm) | < λ/8 @633nm (< 80nm) | < λ/4 @633nm (< 160nm) | ~ 1µm – 6µm |
| **RMSi*** | < λ/50 @633nm (< 12nm) | < λ/40 @633nm (< 16nm) | < λ/20 @633nm (< 30nm) | ~ 500nm – 3µm |

*Radius tolerance approx. ±0.1%

# SFE correction (SPDT)

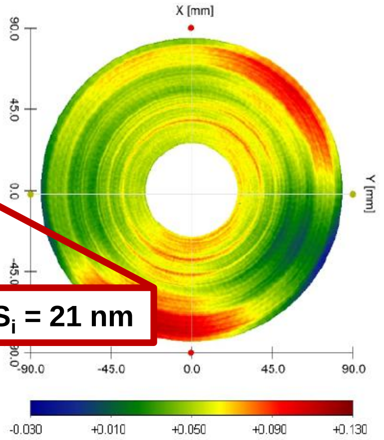
## Iteration '0'

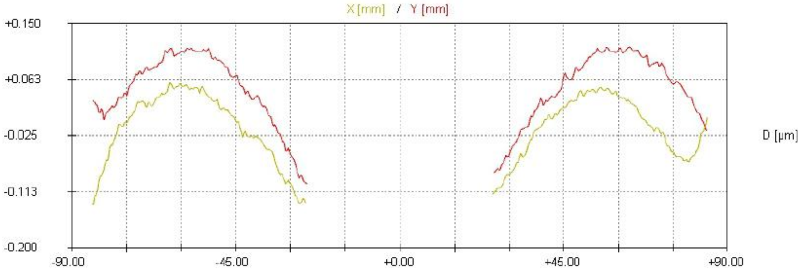
| | |
|---|---|
| | 170.0 / 1.0 |
| Aspheric radius optimization | compensated |
| Deviation | orthogonal |
| Optimized base radius [mm] (c) | -319.50479 |
| Power deviation [µm] (c) | 1.067 |
| PV total / irregularity [µm] | 1.148 / 0.287 |
| PV99 total / irregularity [µm] | 1.066 / 0.238 |
| RMS total / irregularity [µm] | 0.281 / 0.054 |
| Slope error ave / rms ["] | 1.8 / 1[illegible] |
| Slope error max ["] (X,Y) | 9.9 (-8[illegible].34 , 7.46) |
| Slope error 95 ["] | 3.8 |
| Zernike PV [µm] | 0.256 |
| Astigmatism [µm] | 0.109 |
| Coma [µm] | 0.001 |
| 3rd order aberration [µm] | 0.214 |
| 3/ A(B/C) [µm] | 1.067 (0.287 / 0.186) |
| 3/ PV [µm] | 1.148 |
| 3/ RMSt [µm] | 0.281 |
| 3/ RMSi [µm] | 0.054 |
| 3/ RMSa [µm] | 0.028 |
| 3/ PVr [µm] | 0.275 |
| 3/ dS (F/G/H) ["] | (10 / 1 / 0.339) |
| 3/ RMS dS (K/L/M) ["] | (1 / 1 / 0.339) |

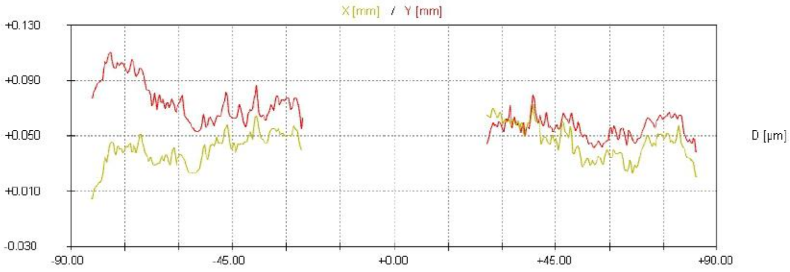



## Iteration '3'

| | |
|---|---|
| | 170.0 / 1.0 |
| Aspheric radius optimization | compensated |
| Deviation | orthogonal |
| Optimized base radius [mm] (c) | -319.55536 |
| Power deviation [µm] (c) | -0.645 |
| PV total / irregularity [µm] | 0.691 / 0.158 |
| PV99 total / irregularity [µm] | 0.629 / 0.114 |
| RMS total / irregularity [µm] | 0.168 / 0.021 |
| Slope error ave / rms ["] | 1.4 / 0[illegible] |
| Slope error max ["] (X,Y) | 10.1 (2[illegible].43 , -7.45) |
| Slope error 95 ["] | 3.2 |
| Zernike PV [µm] | 0.137 |
| Astigmatism [µm] | 0.072 |
| Coma [µm] | 0.001 |
| 3rd order aberration [µm] | 0.001 |
| 3/ A(B/C) [µm] | -0.645 (0.15[illegible]) |
| 3/ PV [µm] | 0.691 |
| 3/ RMSt [µm] | 0.168 |
| 3/ RMSi [µm] | 0.021 |
| 3/ RMSa [µm] | 0.019 |
| 3/ PVr [µm] | 0.154 |
| 3/ dS (F/G/H) ["] | (10 / 1 / 0.339) |
| 3/ RMS dS (K/L/M) ["] | (1 / 1 / 0.339) |

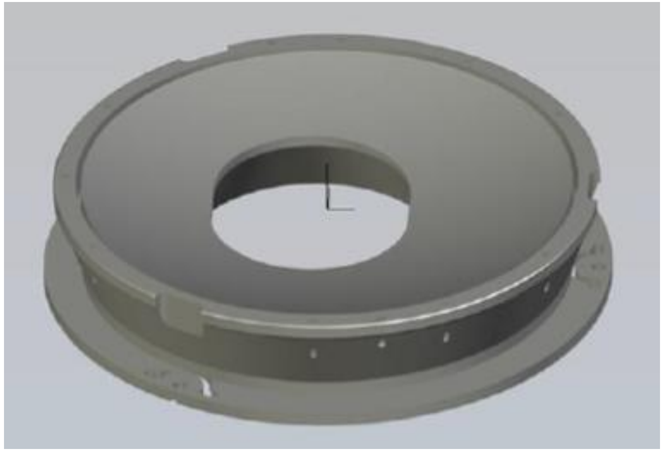


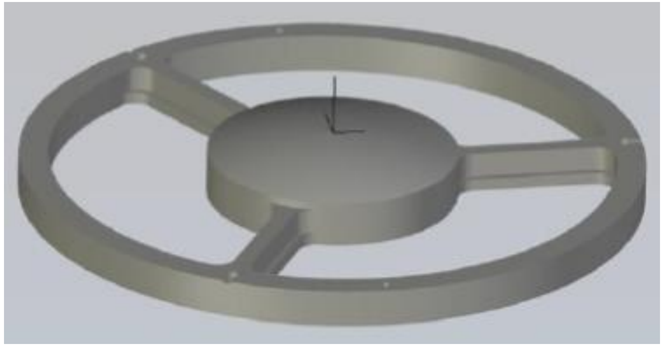



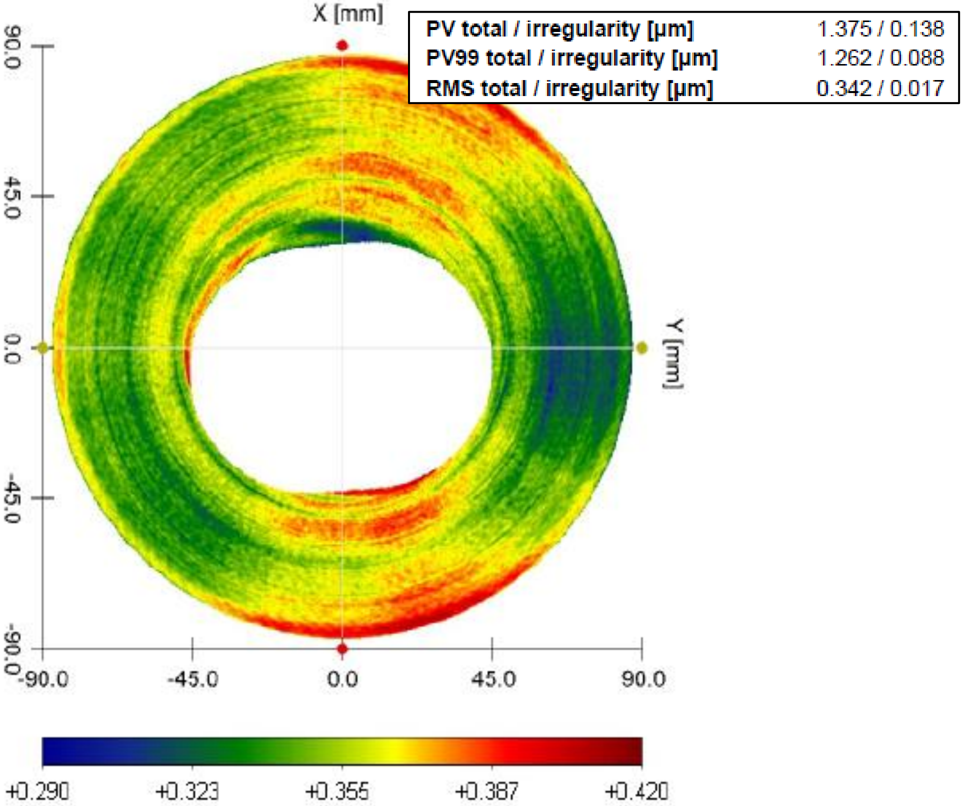



# Examples

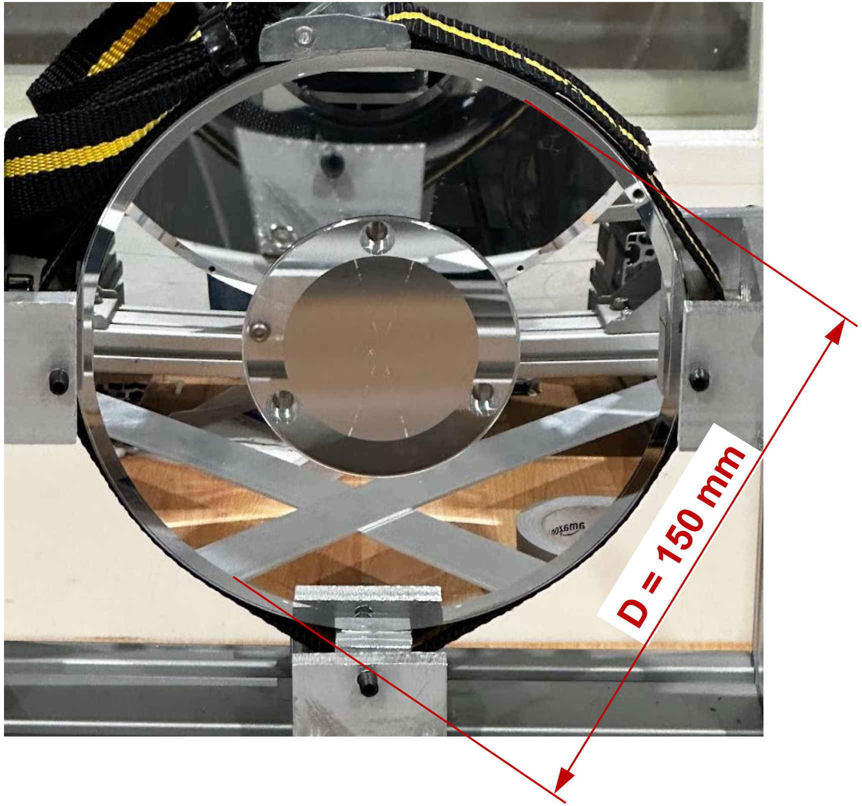
# Example I – Mirror for Wendelstein 7-X Stellarator

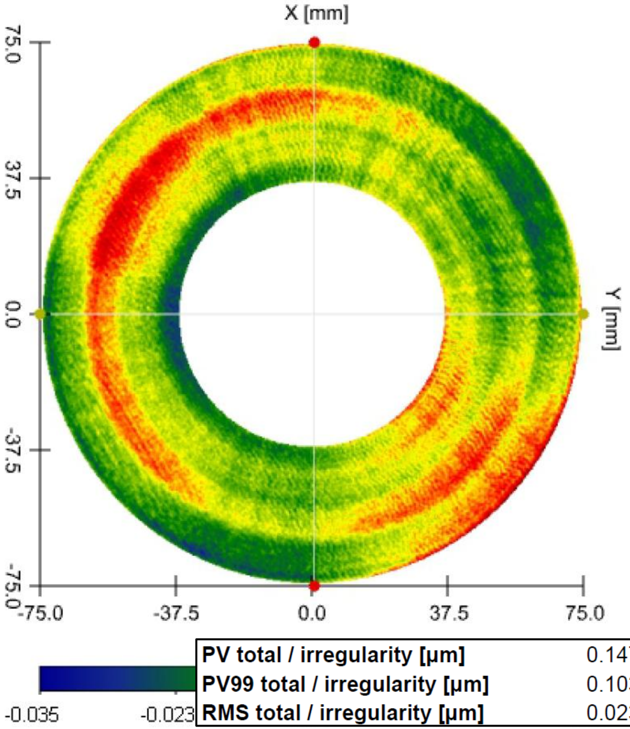




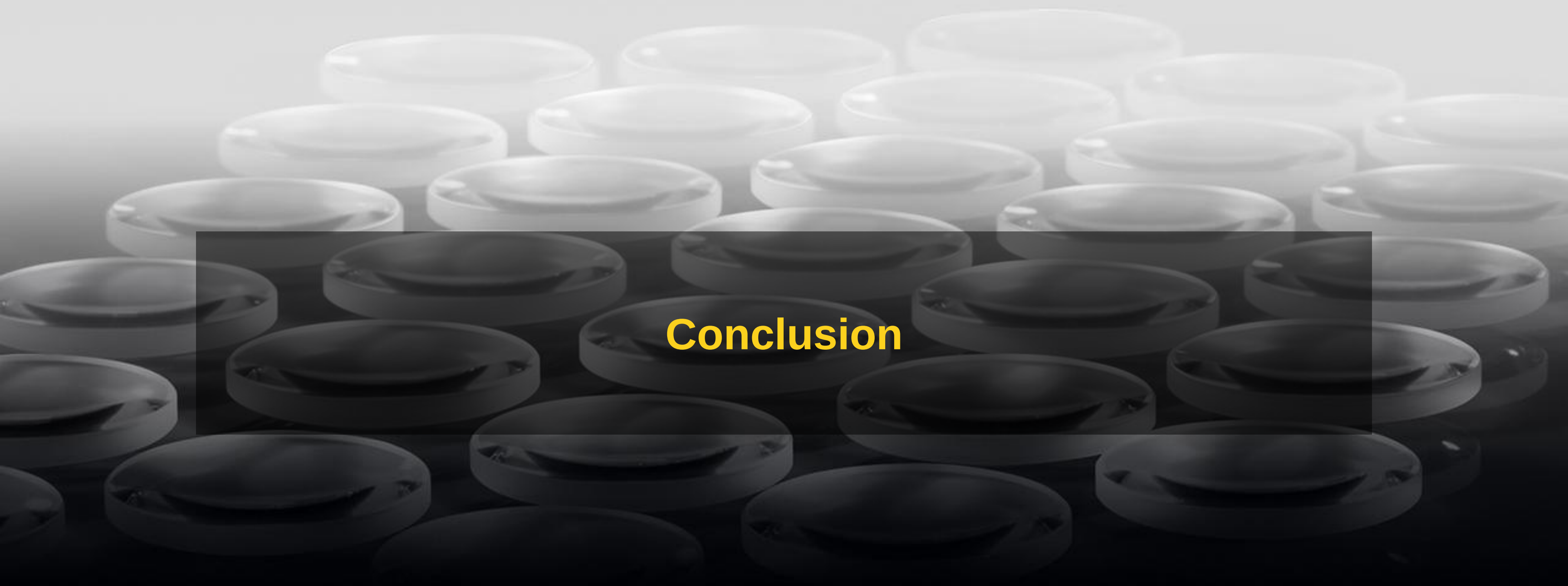


# Example II – Test Mirror (Edmund Optics son-x)




| | |
|---|---|
| **PV total / irregularity [µm]** | 0.147 / 0.070 |
| **PV99 total / irregularity [µm]** | 0.103 / 0.034 |
| **RMS total / irregularity [µm]** | 0.0235 / 0.0069 |



# Conclusion

# Opportunities and boundaries

| | | | | Ø ~ 200mm |
|---|---|---|---|---|
| **Diameter** | Ø < 20mm | Ø < 80mm | Ø < 160mm | Ø 500mm - 1000mm |
| **Material** | RSA 6061 / 905 | | | Al with NiP |
| **Process** | Single Point Diamond Turning (SPDT) | | | Post polishing |
| **Reflected WFE RMSi*** | < λ/25 @633nm (< 24nm) | < λ/20 @633nm (< 30nm) | < λ/10 @633nm (< 63nm) | < λ/10 @633nm (> 63nm) |

*Radius tolerance approx. ±0.1%

**Feasible for series production in SPDT** **Frontier** **TBD**

# The Future Depends on Optics®

- Safety / Security
- Health / Nutrition
- Communications
- Sustainability
- Productivity
- Mobility