# TURKEY'S NEXT BIG SCIENCE PROJECT: DAG THE 4 METER TELESCOPE


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## INTRODUCTION

- **DAG project**:
  "Eastern Anatolia Observatory" in Turkish.
- Launched in **2012.**
- Fully funded by Turkish Government.

| | |
|---|---|
| Location: *Erzurum, Turkey* | Optics: *Ritchey-Chretien;* |
| Altitude: *3170 m* | *Diffraction Limited with aO+AO* |
| Mount: *Alt-Az* | *f. 56m* |
| Diameter: *4 m* | FoV: *30 arcmin* |

- The low order figuring errors (optical train of M1-M2-M3) are defined in terms of **Zernike coefficients** and referred to the M1 surface area.
- The high order figuring errors are defined using the **phase structure functions**.
- **GLAO** (ground layer adaptive optics) design is developed concurrently with the telescope.

## DESIGN REQUIREMENTS

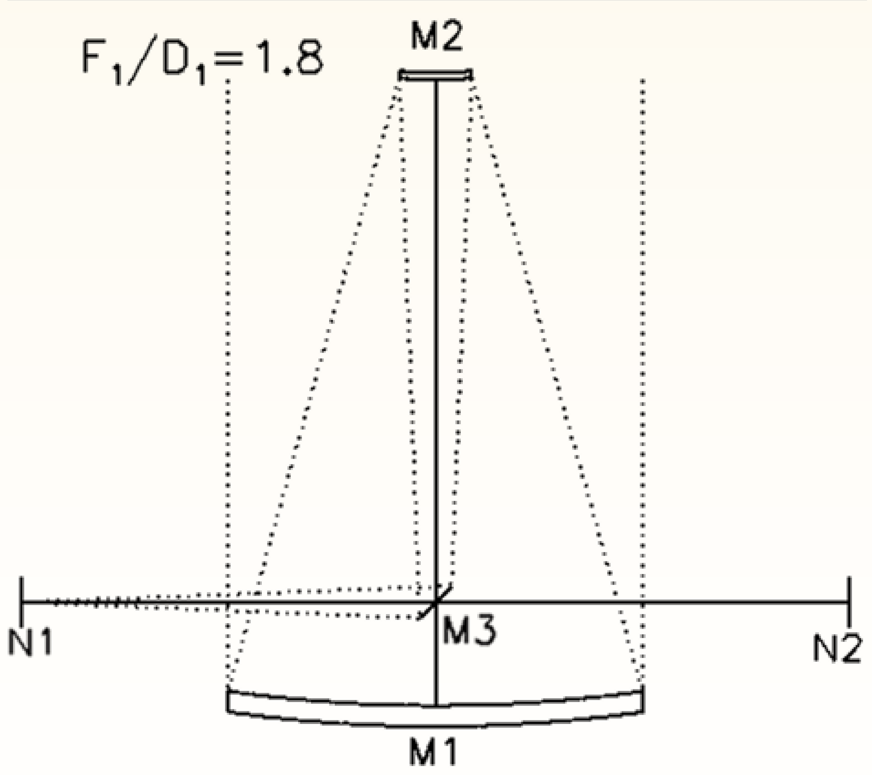
- **Telescope Central Obscuration**
  *Target: 20-30%, Goal: <20%*
- **Ritchey-Chrétien Optical Configuration**
  *to cancel off-axis coma & sperical abbreation*
- **Nasmyth Focal Plane**
  *M1 + AO + post-AO* ➔ *d*(M3F) = 5 m
- **Normalized Parameters for Two Mirror Telescope**

$$\begin{pmatrix} k & \text{ratio } D_2/D_1 \text{ when the telescope FoV is } 0^\circ \\ m_2 & \text{ratio } F_T/F_1 \text{, M2 lateral magnification} \\ \rho & \text{ratio of the radius of curvature of the mirrors } R_2/R_1 \\ \beta & \text{back focal distance (M1 vertex to focal plane) in units of } F_1 \end{pmatrix}$$

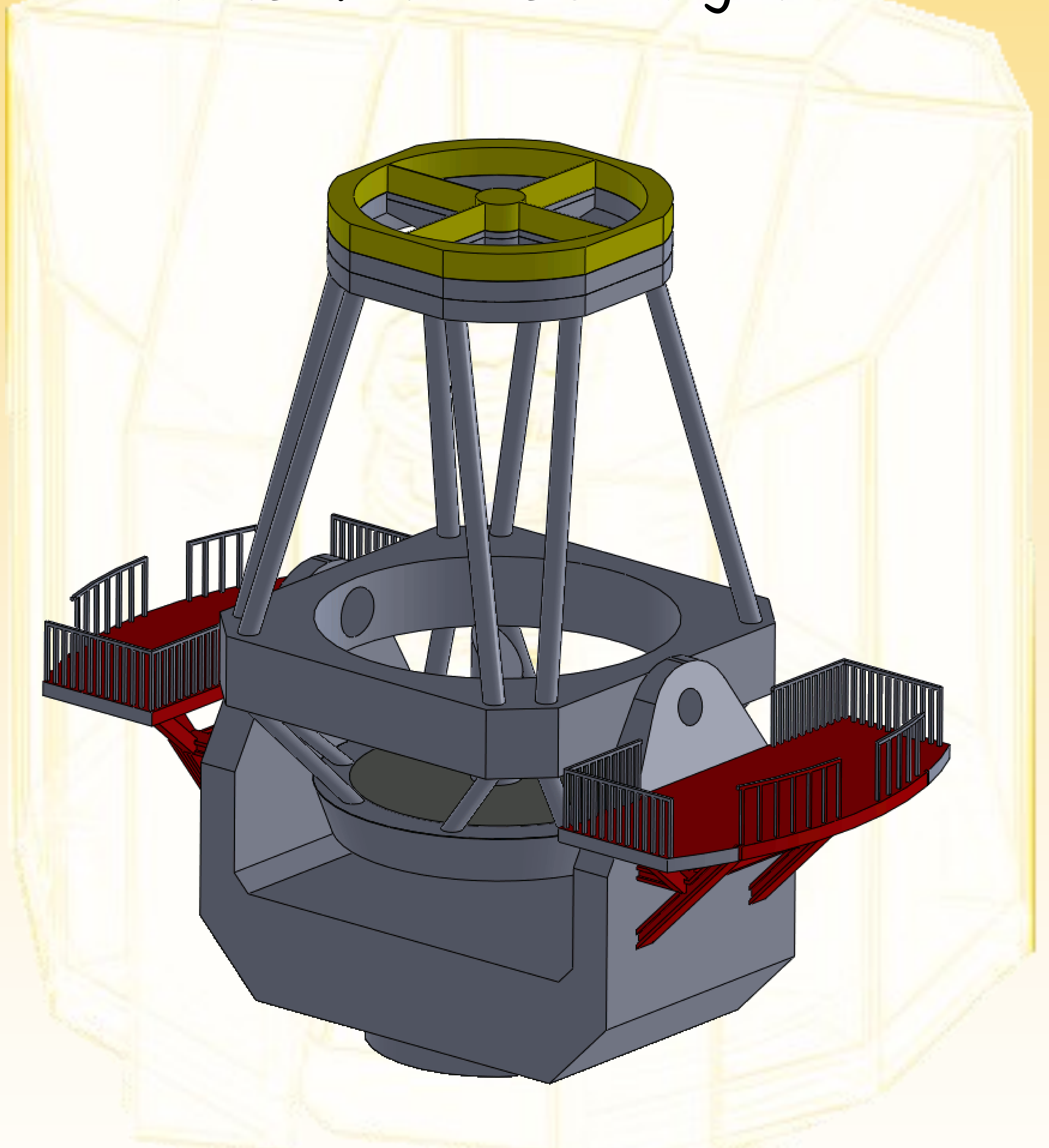
$$\beta = \frac{1}{F_1}\left(\overline{M3F} + \overline{M1M3}\right), \quad m_2 = \frac{F_T}{F_1}, \quad k = \frac{1+\beta}{1+m_2}, \quad \rho = \frac{m_2 k}{m_2 - 1}$$

- **Single Guide Star Diffraction Limited AO mode**
  *Isoplanatic diameter is used :* $FoV_{SSAO}[''] = \frac{6546}{\langle h \rangle w_0}$
  ***w0** : local seeing*
  ***<h>**: turbulent layer altitude*
  ➔ FoV = 0.27—2.7 mm (40-400 pixels @7μm)
- **Improved Seeing Mode — GLAO**
  *Assumed a corrected FoV of 5' (10' at most)*
- **Seeing Limited Imaging Mode**
  *FoV= 10'/20'(target/goal) w/seeing=0.5"@500nm*

## TELESCOPE OPTICAL DIMENSIONS




## Years of dreams coming true...



## WAVEFRONT ERROR BUDGETING

- **M1** : a thin modern monolithic mirror with aO.
- **M2** : controlled mirror: decentering and tip-tilt; stiffness will be ensured by thickness;
- **M3** : an elliptical mirror; inclined 45 degrees; stiffness will be ensured by thickness;
- **N1** : a GLAO system for seeing = 0.2" over FoV = 4'
- **GLAO + deformable mirror + WF sensors** :
  ➔ a single conjugate natural guide star (SCAO)
  ➔ high angular resolution AO system
- **N2 (non-AO)** : seeing limited large FoV instruments
- **aO** : cannot compensate aberrations due to optical turbulence; because time scale ~1 - 10 ms (much faster than the aO system loop rate).

- The instruments focal plane receives **aberrations** as a combination of **(1)** optical turbulence aberrations (residual if AO is on), **(2)** aO-corrected telescope pseudo or slow varying static aberrations and **(3)** instruments internal optics aberrations.
- The AO system will be **dimensioned** to compensate for optical turbulence aberrations.
- But as **residuals** will be seen by the AO system,
- they will be **compensated** up to the AO system's cut-off frequency

## ERROR BUDGET METRICS

- The basic metrics:
  a) the WFE standard deviation (or RMS),
  b) the Strehl ratio,
  c) the FWHM of the PSF, and
  d) the energy proportion within a given aperture shape.
- Thus, using the WFE and the Strehl metrics for budgeting is sufficient and practical as the WFE can be measured during manufacturing.

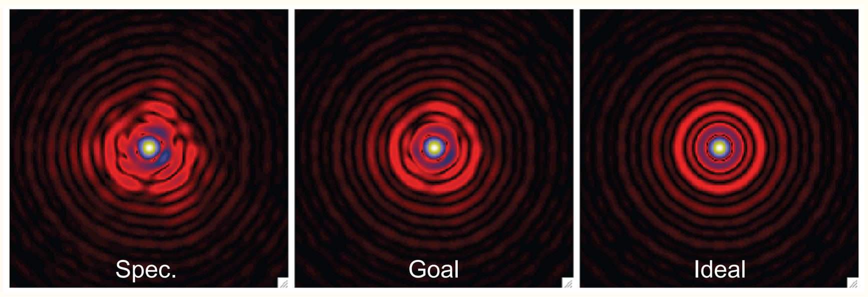
## MIRROR MANUFACTURING ERROR BUDGET

- An AO system is able to correct wavefront aberrations, up to the AO cutoff spatial frequency
- It separates WFE into low and high order components.
- The best DM actuator pitch for DAG AO is 40 cm, and
- Therefore phase aberrations **>2 $\lambda_{AO}$ (80 cm)** are partially corrected.

**Low Order WFE:**

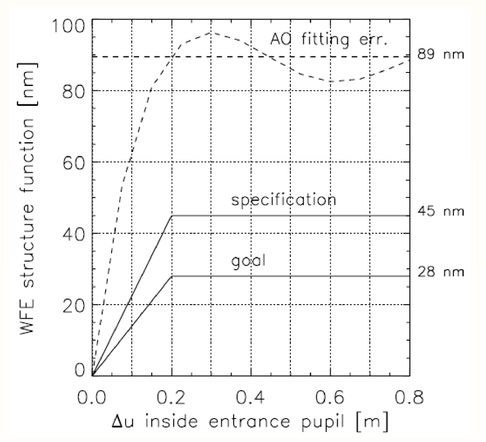
- A pitch $\lambda_{AO}$ = 40 cm
  ➔ allows ~80 actuators.
  ➔ compansate all Zernike Poly. up to $j_{max}(80)=79$ or radial order $n=11$.
- Maréchal's law (@500 nm)
  ➔ Strehl ratio = 86% for spec.
  ➔ Strehl ratio = 96% for goal.
  The first value is easily achievable,
  The second is more challenging.

| N | j-indexes | \|*aj*\| spec | nm goal |
|---|---|---|---|
| 2 | 5-6 | 14.6 | 7.3 |
| 3 | 7-10 | 7.5 | 3.8 |
| 4 | 11-15 | 4.7 | 2.4 |
| 5 | 16-21 | 3.3 | 1.7 |
| 6 | 22-28 | 2.5 | 1.2 |
| Quadratic Sum to $a_{29}$ to $a_{78}$ | | | |
| 7-11 | 29-78 | 9.3 | 4.7 |
| Total Error (nm): | | 31 | 15 |




**High Order WFE:**

- The performance of the AO is limited by the fitting error.
- Consider: 0.5" seeing, DM pitch of 0.4 m
  ➔ fitting error of 68 nm.
- Strehl decrease should be **< 0.95** (goal 0.98) @ J-band (1.25 μm).




## CONCLUSION

- Total length is kept under 10m; d(M1M2) is 6.5m.
- FoV=10' in seeing limited mode (cannot be larger in RC systems)
- Corresponding CCD array size is about 2400 pixels @typical seeing of 0.5"
- Mosaic CCD arrays with curvature adjusted installations might increase FoV
- In GLAO, FoV=6' limited more by turbulent isoplanatic patch, which is in principle smaller than this, then by off-axis defocus.

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