Project Management of DAG: Eastern Anatolia Observatory

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ABSTRACT

The four meter DAG (Eastern Anatolia Observatory in Turkish) telescope is not only the largest telescope in Turkey but also the most promising telescope in the northern hemisphere with a large potential to offer scientific observations with its cutting edge technology. DAG is designed to be an AO telescope which will allow both infrared and visible observations with its two Nasmyth platforms dedicated to next generation focal plane instruments. In this paper, status updates from DAG telescope will be presented in terms of; (i) in house optical design of DAG, (ii) tender process of telescope, (iii) tender process of enclosure, and (iv) tender process of the observatory building. Also status updates from the focal plane instruments project and possible collaboration activities will be presented.

Keywords: Project Management, Telescope, Enclosure, Observatory Building

1. INTRODUCTION

1.1 Telescope Mount Coordinate System

The telescope mount coordinate system is a fixed coordinate frame, which is aligned about the azimuth axis on the defined park position, and has its origin at the intersection of the Altitude and Azimuth axes of the telescope. It is used for dimensioning all non-moving parts of the telescopes.

The telescope coordinates have axis labels X, Y and Z. The XY plane is horizontal. The X-axis points towards the defined park position, the Y-axis is rotated 90 deg, and the Z-axis points toward the Zenith. The rotational angles about the X, Y and Z axes are designated α, β and γ respectively. The zero points for the α and γ axes are in the direction of the Y-axis.

The zero point for the β axis lies in the directions of the Z-axis. In cases where confusion might arise between telescope coordinates and the movable coordinate frames for the telescope tube and enclosure, the telescope mount coordinates axes are appended with a subscript -M to indicate the frame referred to (i.e. X_M, Y_M, Z_M, α_M, β_M, γ_M, etc.). The arrangement of the telescope axes is shown in the figure below.

1.2 Enclosure Coordinate System

The enclosure coordinate system is fixed with the rotating enclosure and aligned with its observing slit. When in park position, the coordinate system is consistent with the telescope mount coordinate system described in Figure 1.

The direction of the enclosure parking position is looking south, with the slit directed toward the service building (TBC). The local Z axis always points towards the vertical. The local Y axis always points toward the center of the enclosure observing slit.

In cases where confusion might arise between telescope mount coordinates and the movable coordinate frames for the telescope tube and enclosure, the optical tube coordinates axes are appended with a subscript -E to indicate the frame referred to (i.e. X_E, Y_E, Z_E, γ_E).
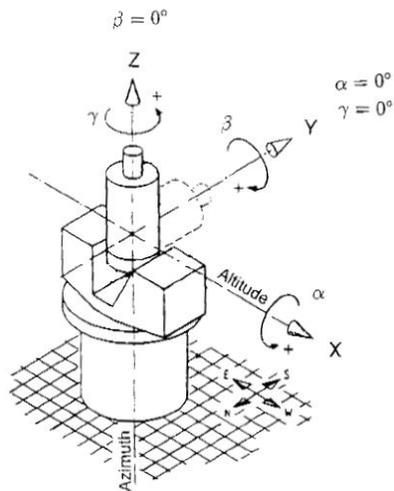
Figure 1. Orientation of the telescope coordinates

2. TELESCOPE REQUIREMENTS

2.1 Optical Tube Coordinate System

The optical tube coordinate system applies to the telescope tube, which is the main body of the telescope holding the primary (M1), and secondary (M2) mirrors and such. When in park position, the coordinate system is consistent with the telescope mount coordinate system described in Figure 1.

The local Z axis always points towards the line of sight. As the telescope is pointed off-zenith towards zenith angle of 90 degrees (or an elevation angle of zero, horizon pointing), the positive Y axis points up (to zenith for a horizon pointing telescope). The Z axis then points towards the horizon in the direction of the telescope pointing as the telescope moves toward horizon pointing (elevation angle of zero). This provides the local coordinates used by the M1, M2 and M3 assemblies and any other items mounted to the telescope tube.

In cases where confusion might arise between telescope coordinates and the movable coordinate frames for the telescope tube and enclosure, the optical tube coordinates are appended with a subscript -T to indicate the frame referred to (i.e. XT, YT, ZT).

2.2 Reference to Optical Design

The principle optical schematics of the telescope is illustrated in Figure 2. The telescope shall provide two Nasmyth foci but no Cassegrain focus. Table 1 gives the nominal design of the telescope configuration, for three values of the primary mirror f-number specification range, and a primary mirror diameter of 4 m. These numbers are indicative of the final optical configuration.

1. Radius of curvature and distances between mirrors vertex are given in absolute value.
2. Distances are defined along optical axis, from vertex to vertex
3. Entrance pupil of the telescope is the primary mirror.
4. Primary mirror thickness is indicative and values given here ensure that lateral supports contact points, collocated with the plane of the center of gravity of the mirror. Lateral support contact points are at the mid height between the height of the vertex and the height of the meniscus, on the mirror edge. In this configuration lateral supports need only to apply forces in the mirror plane and not in the axial direction as well.

2.3 Optical System Requirements

Specifications were derived assuming that M1 is a thin mirror controlled in shape and position by an active optics (aO) system, consisting of a number of axial and lateral actuators. It nonetheless also applies to other mirror types (segmented, semi-rigid, etc.).

Table 1. Nominal design of the DAG telescope configuration

Parameters constant to all designs - units [mm]

F_T/D_1	F_T	D_1	A_3	B_3	M1M3	M3F
14 [-]	56000	4000	425	300	–1000	4200

Primary mirror

F_1/D_1	1.6	1.7	**1.8**	1.9	2.0	–
F_1	6400	6800	**7200**	7600	8000	[mm]
R_1	-12800	-13600	**-14400**	-15200	-16000	[mm]
K_1	-1.004750	-1.005585	**-1.006512**	-1.007535	-1.008658	–

Secondary mirror - mirror diameter is for an unvignetted FoV of 30'

F_2/D_2	1.7	1.8	**1.9**	2.0	2.2	–
D_2	662.643	686.835	**710.720**	734.305	757.596	[mm]
F_2	-1111.663	-1232.458	**-1359.618**	-1493.217	-1633.333	[mm]
R_2	-2223.325	-2464.916	**-2719.236**	-2986.434	-3266.667	[mm]
K_2	-1.627157	-1.680976	**-1.737038**	-1.795454	-1.856341	–
ϵ	0.166	0.172	**0.178**	0.184	0.189	–

Mirrors separations

$\overline{M1M2}$	-5415.385	-5717.197	**-6015.190**	-6309.434	-6600.000	[mm]
$\overline{M2M3}$	4415.385	4717.197	**5015.190**	5309.434	5600.000	[mm]

Normalized parameters

k	0.153846	0.159236	**0.164557**	0.169811	0.175000	–
m_2	8.750000	8.235294	**7.777778**	7.368421	7.000000	–
ρ	0.173697	0.181244	**0.188836**	0.196476	0.204167	–
β	0.500000	0.470588	**0.444444**	0.421053	0.400000	–

Specifications also consider the presence of an adaptive optics (AO) system – not part of the telescope delivery – which may be able to correct residual static errors, to some extent (as determined by the AO actuators stroke). Nevertheless, specifications are made such that the telescope will be a seeing limited telescope when operating in seeing limited mode, and a diffraction limited telescope when operating in AO correction mode.
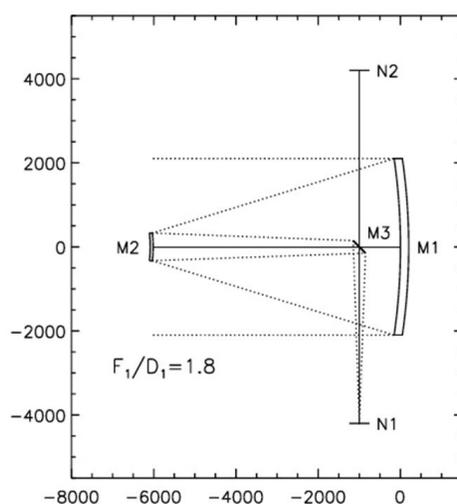
Figure 2. The actual optical schematic is defined in accordance to requirements

Table 2. Optical System Requirements of DAG Telescope

Primary mirror clear aperture (D1):	4.0 m;
Primary mirror focal ratio (f1):	1.8
Configuration:	Ritchey-Chretien (RC) M1 and M2 are hyperboloids with conic constants matched to cancel off-axis coma and spherical aberration.
Focal Planes	Two Nasmyth foci. No Cassegrain focus
Effective focal length:	56 m
Operational waveband:	350 to 3000 nm
Unvignetted FOV (diameter):	30 arcmin available at the Nasmyth foci
Primary science FOV:	10 arcmin
Number, location of Nasmyth foci:	Two foci, located 4.2 m after M3

The AO system foreseen for the DAG telescope has a deformable mirror with an inter-actuator distance (ΛAO) of 0.4 m, as projected in the entrance pupil plane (M1). According to Nyquist/Shannon sampling theorem, wavefront errors at spatial scales shorter than twice the inter-actuator distance, i.e. 0.8 m, cannot be corrected. The AO system cutoff spatial frequency is therefore defined as the spatial frequency associated to the inter-actuator sampling, $1/(2\Lambda$AO$)$.

Because the deformable mirror actuators grid is generally square, the AO correction domain in the spatial frequency space also has a square shape. Wavefront aberrations which can be described with spatial frequencies inside the square are defined as low order WFE, while wavefront aberrations that are located outside this domain are designed as high order WFE. It is clear that low order WFE could in principle be seen and then corrected by the AO system wavefront sensor (WFS), while the high order ones could not.

This being said, because it is not certain that the future AO system geometry will be square, and because it simplifies specifications, we will assume here that the low frequency corrected domain is circular, therefore the cutoff frequency will be defined for all directions inside the pupil, not only for two given orthogonal directions.

In this respect, demonstration of the low order and high order residual wavefront errors specifications are met regardless of the direction of measure inside the entrance pupil.

2.4 Secondary Mirror

The secondary mirror M2 will be a convex mirror controlled in five degree of freedom: decentering, piston, and tip-tilt relative to the vertex. The alignment mechanism will have the following requirements:

Table 3. Alignment mechanism requirements of DAG telescope

	Focus (Δz)	Decenter (Δx, Δy)	Tip-tilt (θx, θy)
Absolute Accuracy	10 μm	20 μm	20 arcsec
Incremental accuracy referred to a 20 μm focus move	2.5 μm	5 μm	5 arcsec

The range along all degrees of freedom are adequate to ensure at the Nasmyth foci the image optical quality specified in terms of WFE, under all applicable gravity and thermoelastic deformations experienced by the telescope.

On-axis aberrations generated by M2 misalignment within the specified incremental accuracy, as seen from the focal plane (defocus, astigmatism, 3rd order coma and spherical) is expected to be significantly smaller than the on-axis WFE budget. Off-axis aberrations generated by M2 misalignment as seen from the focal plane will be significantly smaller than the expected off-axis astigmatism for the Ritchey-Chretien configuration, over the 10' science FOV.

2.5 Tertiary Mirror

The tertiary mirror M3 will be a flat, elliptical mirror, inclined at 45 deg with respect to the telescope optical axis. It will be actively aligned along piston (telescope axis) and tip-tilt. The range along all degrees of freedom are adequate to ensure at the Nasmyth foci the image optical quality specified in terms of WFE, under all applicable gravity and thermoelastic deformations experienced by the telescope. The M3 mechanism shall have the following requirements:

Table 4. M3 mechanism requirements of DAG telescope

	Piston (aligned along the ZT axis)	Tip-tilt (Rx, Ry)
Absolute Accuracy	10 μm	20 arcsec
Incremental accuracy referred to a 20 μm focus move	2.5 μm	5 arcsec

2.6 General Applicable Requirements for M1, M2 and M3

Table 5. General applicable optical requirements of DAG telescope

Micro roughness	Micro roughness shall be lower than 2 nm rms (goal 1 nm rms). The assumption is that micro roughness for the three mirrors add in quadrature, totalizing to 3.5 nm (1.7 nm goal).
Optical surface	Scratches, pits and digs according to DIN3140: 5/6x0.4; K2x0.025
Reflectivity (coated optical surface):	Aluminum coating; 90% in [350-700 nm], 85% in [700-950 nm], 90% in [950-1050 nm], 95% in [1050-1300 nm], 97% in [1300-1800 nm], 98% in [1800-3000 nm].

2.7 Mechanical Requirements

Table 6. Mechanical requirements of DAG telescope

Mounting:	Altitude-Azimuth
Zenith blind spot (ZBS):	≤ 1 deg Zenith angle
Azimuth range	>= ± 270 deg
Altitude range (in maintenance mode)	$\alpha M = -90$ to $+90$ deg
Altitude range (in observing mode)	Zenith Angle = ZBS to 70 deg
"Locked" system (structural) eigenfrequencies	> 8 Hz
Slew speed	2 deg/sec + 8 second settling time
Pointing accuracy, absolute (blind pointing error)	< 2 arcsec for any point in the sky with Zenith angle < 70 deg,
Pointing accuracy, incremental	< 0.1 arcsec for a 10 arcmin offset in any direction
Tracking accuracy, open loop	rms < 0.1 arcsec for one minute
Tracking accuracy, closed loop with	rms < 0.1 arcsec for one hour under maximum telescope wind

autoguider	load • Maximum mean wind speed: U = 4 m/s • Turbulence intensity: σu/U = 0.2 • Turbulence scale: L = 2 m • Wind power density according to the Von Karman spectrum: $$\frac{nS_u}{\sigma_u^2} = \frac{4x}{(1 + 70.8x^2)^{5/6}}$$ with n = frequency (Hz), $x = nL/U$
Secondary mirror alignment	The support mechanism will provide fine alignment along 5 degrees of freedom: piston, tip-tilt, x- and y-center.
Tertiary mirror flip and alignment	The mechanism will provide the following functions: • Switching the light beam to alternate Nasmyth foci • Fine alignment along 3 degrees of freedom: piston (ZT axis), tip-tilt
Instrument Nasmyth flanges (Figure 3)	Load capability: 2000 kg located 1.7 m from the flange and attached to it, plus 2000 kg as equipment laying on the platform itself, with center of gravity at its center.
Instrument envelope (Figure 3)	Load capability: 2000 kg located 1.7 m from the flange and attached to it, plus 2000 kg as equipment laying on the platform itself, with center of gravity at its center.
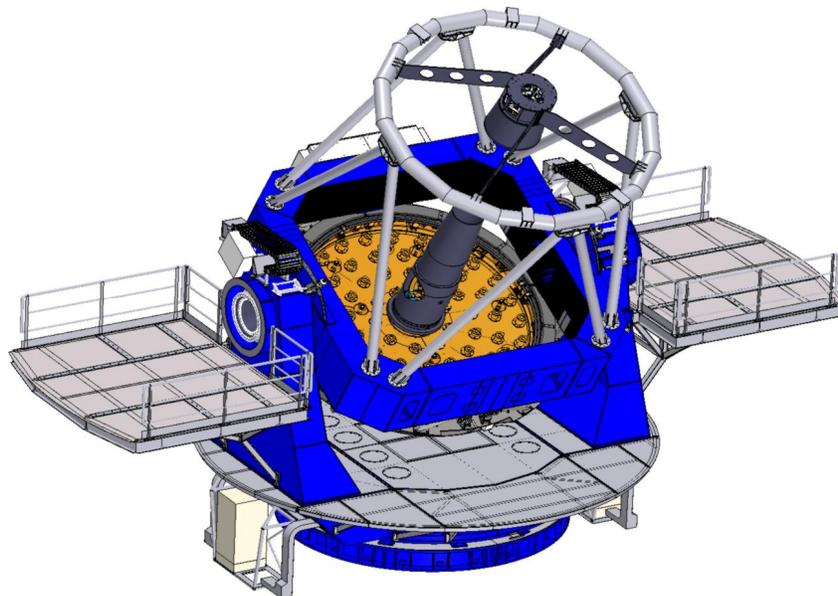
Figure 3. DAG telescope design

3. ENCLOSURE REQUIREMENTS

3.1 General Applicable Requirements of DAG Enclosure

Table 7. General requirements of DAG enclosure

Free inner volume:	a. Half sphere centered at X,Y,Z=0 with radius (upward)=7.0 m b. Cylinder below this half sphere of radius=7.0 m and height=3.065 m c. Cylinder centered at X=0, Y=5.6 m, with radius (directed along Y) =2.5 m, top not lower than Z=3 m, free volume all the way downward. This free volume shall be provided for one particular angular position of the rotating enclosure. d. The overall free height shall include all margins required by the hook of the overhead crane to access all points of the above defined volume.
Azimuth track	Circular azimuth track centered on the telescope azimuth axis
Height (position) of azimuth track	–4 m from Z=0 level
Slit width	4.5 m
Minimum free elevation angle of view of telescope for a 4-m diameter light beam centered at X,Y,Z=0	10.5 deg
Minimum free elevation angle of telescope for maintenance.	0.0 deg

3.2 Mechanical Requirements of DAG Enclosure

Table 8. Mechanical requirements of DAG enclosure

Rotation range	± 275 deg
Maximum rotation (slew mode) speed	adjustable up to 2 deg/sec + 8 second settling time
Rotation accuracy, absolute (blind pointing error)	< 1 deg
Rotation accuracy, incremental	< 0.1 deg for a 5 deg offset in any direction
Rotation accuracy, closed loop with feedback signal	< 0.05 deg for one hour (with a smooth operation)
Slit doors opening/closing time	< 2 minutes
Overhead crane travel	Along YE axis: YE from –7.0 m to +7.0 m Along XE axis: XE from –2 m to +2 m
Overhead crane load	6.5 metric tons
Lifetime profile	30 azimuth revolutions at maximum speed per day

4. PIER INTERFACE REQUIREMENTS

The pier characteristics are defined by the telescope manufacturer (AMOS) to withstand the followings:

- With the telescope dummy fixed on the pier with 24 points, with only translational constraints, the first three eigenfrequencies of the system is higher than: (i) 8.07Hz bending in X direction; (ii) 8.22Hz rotation around Z axis; (iii) 9.71Hz bending in Y direction.
- The minimum local stiffness values under each mechanical jack are: (i) Vertical stiffness: 1.5e9 N/m; (ii) Lateral stiffness: 2.0e8 N/m
- total vertical load: 858kN (dead load), 1950kN (survival), -236kN (upward, survival)

- total lateral load applied at 1836mm above the pier interface: 3kN (due to wind), 1250kN (survival due to seism and wind simultaneously)
- total torsion torque applied on the top pier: 14kNm (due to the azimuth telescope motor)

5. OBSERVATORY REQUIREMENTS

5.1 Enclosure Support Building

Table 9. Enclosure support building requirements

Main functions:	3-floor building surrounding the telescope pier: 1. Pier floor: access to pier 2. Base floor: access to building, maintenance labs 3. Observing floor: access to telescope and instruments 4. Topped by the rotating enclosure circular support slab Thermal control of telescope volume by forced ventilation.
Enclosure support top surface (interface with anchorages the enclosure support track):	Circular slab of - outer diameter 16 m - inner diameter 14 m, with a 5-m wide hatch in correspondence with the slit in parking position. Located 2 m below reference origin (altitude axis)
Observing floor	Circular slab of - outer diameter 16 m - inner diameter 7 m Located 4 m (TBC) below reference origin (altitude axis)
Pier height from foundation slab imbedded in solid ground	3 m
Building foundation	Separate from pier foundation

5.2 Maintenance and Control Building

Table 10. Maintenance and control building requirements

Main functions:	Multi-functional building adjacent to the enclosure building, providing 1. In/outlet of telescope optical units (M1, M2, M3) by an elevator, providing access to enclosure base and observing floors. 2. Storage, cleaning and coating plant for telescope optics. Handling crane for all M1, M2, M3 operations. 3. Observatory control room 4. Vehicle storage (garage) for a middle size van. 5. Workshop 6. Living facilities: dorms, canteen, infirmary
Building foundation	Separate from enclosure foundation
Optics handling requirement	Defined by M1 cell: 5x5x2 m, 10 tons
Volume for optics storage, cleaning and coating plant	At least 12x8x4 m, with direct access to the outside. The height specified is meant under the hook of the crane.
Control room	25 m2
Workshop	30 m2
Vehicle storage	25 m2, with direct access to the outside
Living facilities	Dorms: 4 rooms, each 20 m2 Canteen: 30 m2 Infirmary: 20 m2

6. CURRENT STATUS

6.1 Telescope

- Telescope FDR has been successfully passed with compliance to technical specifications.
- M1 mirror blank is to be delivered by mid-August 2016.
- Procurement of the main orders by AMOS is undergoing.

6.2 Enclosure

- Enclosure PDR passed with compliance to technical specifications.
- FDR will take place by mid-July 2016.
- Manufacturing of the embedded plates is expected by the first week of August 2016.

6.3 Pier

- The pier design proposed by GUNARDA and PROMER has been checked by EIE and AMOS about the local stiffness at the interface level with the mechanical jacks and about the dynamical behavior.
- The local stiffness requirements are fulfilled.
- Pier manufacturing will be finalized by September 2016.

6.4 Observatory Building

- FDR of the observatory building been successfully passed with compliance to technical specifications.
- Groundworks is expected to be finalized by September 2016.
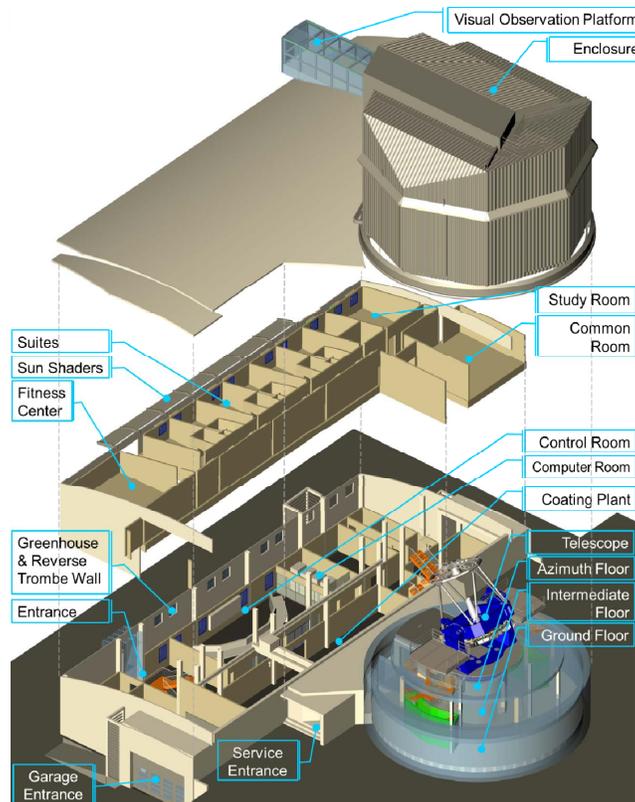
Figure 4. Exploded drawing of DAG observatory with the enclosure and telescope

6.5 Schedule

- Whole schedule is given in Figure 5.
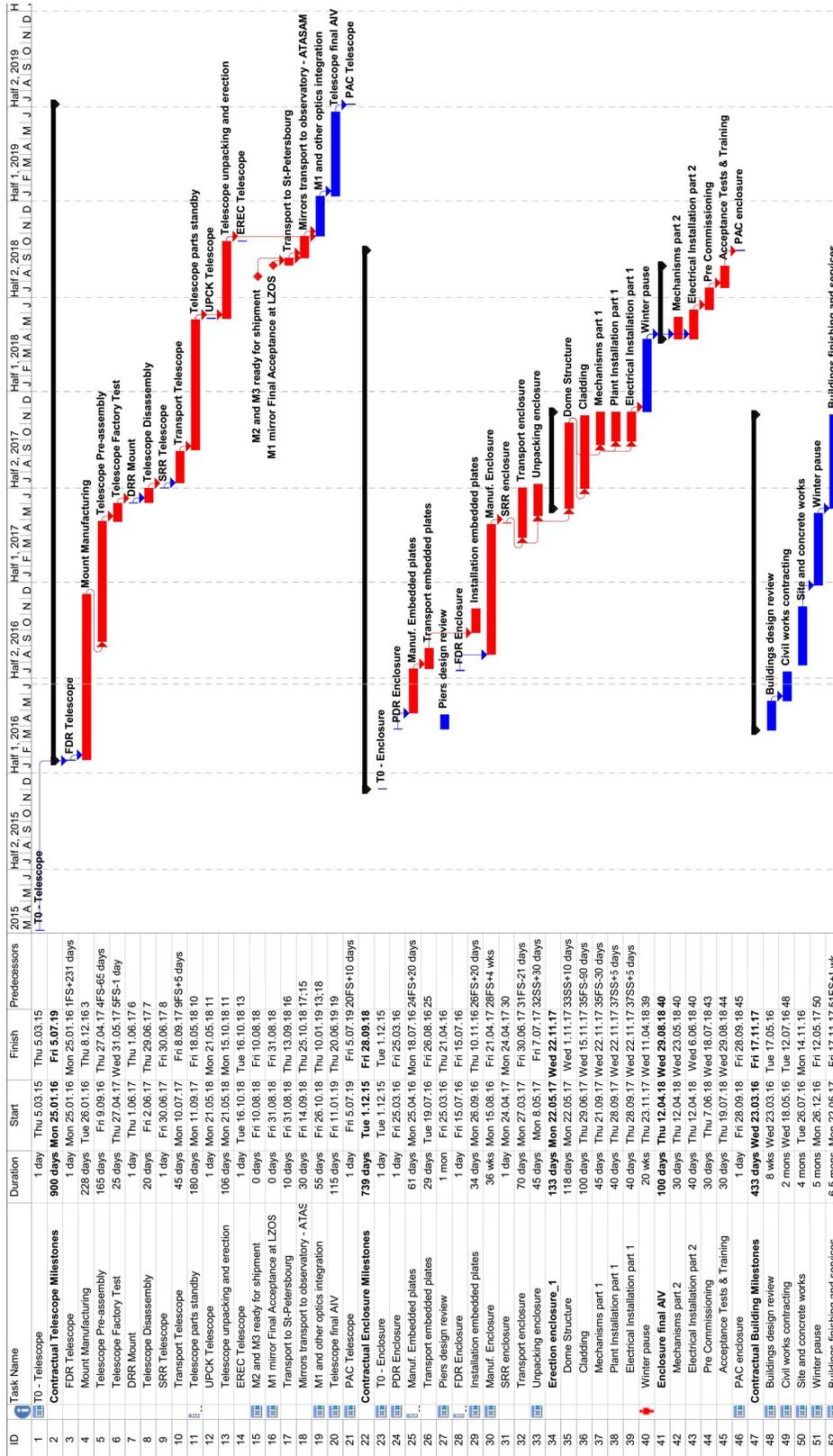
Figure 5 Gantt Chart of the whole DAG Project

7. FUTURE WORK

As the largest telescope project moves forward, the additional FPI project has just been funded by the Ministry of Development of Turkey. DAG team, within this short time scale and in collaboration of four national universities, has started the FPI project. The Project will be coordinated by Ataturk University Astrophysics Research and Application Centre (ATASAM) which was founded in 2012 and is responsible for most of the astrophysical, and electro-optical research funded by the Ministry of Development. There will be three supporting laboratories which will be established within the framework of the DAG-FPI project. These laboratories will be established at the following universities: i) FMV Isik University (for AO and DR research and development); ii) Orta Dogu Teknik Universitesi/METU (calibration laboratory); iii) Istanbul University (MKID).

Currently, desired type of instruments for the DAG telescope is given in Table 11. At the moment, there expected to be one AO supported focus at the telescope. However, DAG team is investigating the possibilities for building a second AO system for the other focus as well. This, in principle, is possible as the AO system (including DR) will be built in Turkey at FMV Isik University.

Table 11. DAG FPI Instruments

Focus	Instrument No	Wavelength	Type	Local Contribution (%)	Int. Contribution (%)
N1/N2		-	DR	50	50
N1		-	AO	90	10
N1	A	VIS	IMG	95	5
N1	B	NIR	IMG	95	5
N1	C	VIS+NIR	NT	-	100
N2	A	VIS	SPEC	80	20
N2	B	NIR	SPEC	80	20
N2	C	?	?	?	100?

N1: AO hosting focus; **N2:** Non-AO focus; **DR:** Derotator; **AO:** Adaptive Optics; **NIR:** Near-IR; **IMG:** Imaging; **SPEC:** Spectroscopy; **MOS:** Multi-object Spectroscopy; **NT:** New technology detectors

The main purpose of the DAG-FPI project is to obtain first generation instruments for the DAG telescope. This includes optical and near-infrared detectors and both for imaging and for spectroscopy. Since the national observatory of Turkey has been operational, Turkish astronomical community is well familiar with FOSC instruments built by the Copenhagen University. This kind of instruments (FOSC series, FORS2@VLT etc) are generally the workhorses of observatories. In this respect, a multi purpose instrument for optical and its equivalent in near-infrared are desired. These two instruments most likely will be installed at the Nasmyth-2 focus where the AO system will not be operational. But depending on the discussions that will undergo before the commissioning and even during the building of the instruments, these multi purpose instruments can be installed at the Nasmyth-1 focus. The need for AO both for imaging and spectroscopy is driven mainly by the scientific rationale of the DAG project, and broad research interests of the Turkish astronomical community.

The design of the telescope is made so that each Nasmyth focus can hold three instruments up to a total weight of 2000 kg. N1 will be equipped with an AO system for the moment. A brief overview of the expected instrument distribution for the two foci is given below:

N1-a: An imager (can be metal oxide semiconductors) for the optical wavelengths where high resolution imaging is needed.

N1-b: A NIR imaging detector. Depending on science cases this instrument can be used with or without AO given the typical field-of-view of such detectors are quite small already.

N1-c: A microwave kinetic inductor detector as a new technology instrument will likely be placed. This will be operated around at temperatures of 100 mK and allow observing from optical to near-infrared wavelengths.

N2-a: DAG Project team has decided to obtain a spectrograph which willl operate between 350-1000 nm with resolutions between 100-3000. This instrument is expected to be a workhorse for the Turkish astronomical community.

N2-b: As DAG will be the first and largest telescope to operate in the near-IR in Turkey, spectroscopy will be very crucial. This instrument will enable Turkish astronomers to work in the wavelength range of $0.9 - 2.5$ microns.

N2-c: Although it is desired to have a multi-object spectrograph (if not possible with N2-a), this instrument slot can be reserved for future collaborations.

This ambitious project will not only serve to national but also to the international astronomical communities. At this stage, all kind of scientific and technical collaborations are very welcome and expected.

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