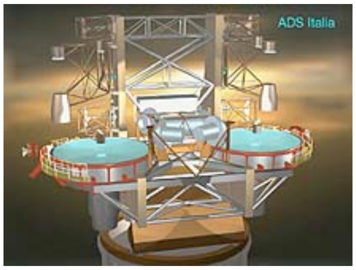

LBT PROJECT 2×8.4m TELESCOPE
Doc.No. : 002s105 Issue : b Date : 22 Jan 2010

LBT PROJECT

2 × 8.4m OPTICAL TELESCOPE

LBTO Coordinate

System Description

	Signature	Date
Prepared	Douglas Miller	22 Jan 2010
Reviewed		
Approved		

1. Revision History

Issue	Date	Changes	Responsible
a	30 June 09	First draft	Douglas Miller
b	22 Jan 10	Added AO Coordinate System Description	Douglas Miller

2. Table Of Contents

3. About this document

3.1. Purpose

The purpose of this document is to describe the coordinate systems used at the LBTO, how they are defined and how to transform between them.

First the mechanical coordinate systems of the telescope, the coordinate systems used at the telescope focal stations, the coordinate system of the AGw guide probe and the coordinate system used by the Adaptive Optics system will be described.

Second, the transformations between these coordinate systems used at the focal stations will be described that are needed to properly denote positions and directions from the AGw unit, the AO and the science instrument's points of view. Not all of the detailed transformation between these coordinate systems will be given in this document, but the relevant document will be referenced

Finally, he mounting orientation of the AGw unit and the science instrument at each focal station will be described. This mounting has three general steps:

1. Set the telescope instrument rotator to its central position. This is usually a rotator position of 180 degrees, which will allow the rotator to move ± 270 degrees.
2. Mount the AGw unit on the movable part of the instrument rotator such that the +Y direction of the guide/active optics probe is aligned with the +Y direction of the PCS_XY coordinate system. (See section 5)
3. Mount the science instrument to the AGw at the appropriate orientation such that positive Declination (North) is up. (See section 9)

Once the three step listed above are complete, the rotator "Zero" position is set by adjusting the offset value, (eg LEFTZEROPOINT, see section ??) so that Declination motions (North-South) are aligned with the columns of the science instrument. With this orientation defined then the transformation between the other coordinate systems must be determined on-sky (eg PSC_XY to AGw guide probe coordinates).

3.2. Reference Documents

[RD1] 002s101 Telescope and Enclosure Coordinate System Definitions, Dave Ashby, 10 November 2007
[RD2] 481x200a Telescope Pointing Kernel Users Guide, David Terrett, 20 December 2005

4. Mechanical Coordinate System

4.1. Telescope Coordinate Systems

The definition of the mechanical coordinate system of the telescope can be found in the CAN document 002s101a [RD1]. Included below are figures 1 and 2 of this document.

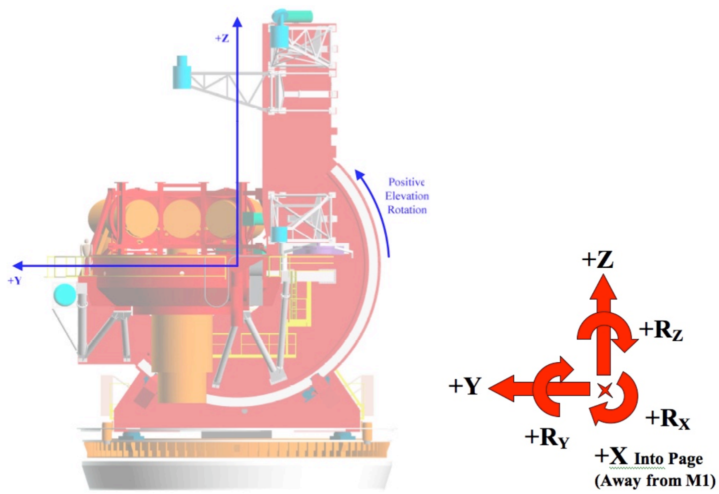

Figure 1: The mechanical coordinate system of the telescope. Note: the positive elevation direction is in the negative R_X direction.

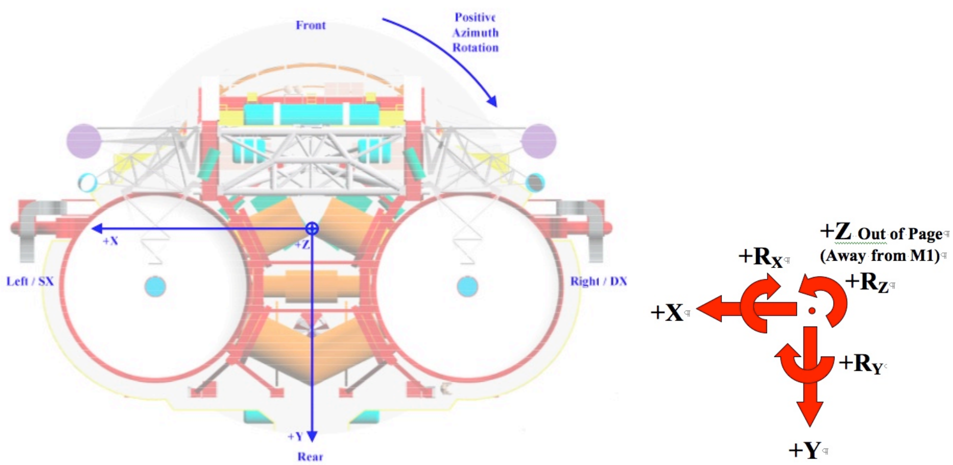

Figure 2: The mechanical coordinate system of the telescope looking down at a zenith pointing telescope. Note: the positive azimuth direction is in the negative R_Z direction.

A simple way to image this coordinate system is, if the telescope is horizon pointing and you are standing behind the primary mirrors, the positive Z-Axis is the direction the telescope is pointing, the positive Y-Axis is up and the positive X-Axis is to your left. This is the standard right-hand-rule.

4.2. Primary Mirror Coordinate System

The mechanical coordinate systems of the primary mirrors are the same as that of the telescope.

4.3. Hexapod Coordinate System

The coordinate systems defined below are the coordinates seen if looking from the primary mirror (M1) towards the hexapod (and towards the sky: +Z).

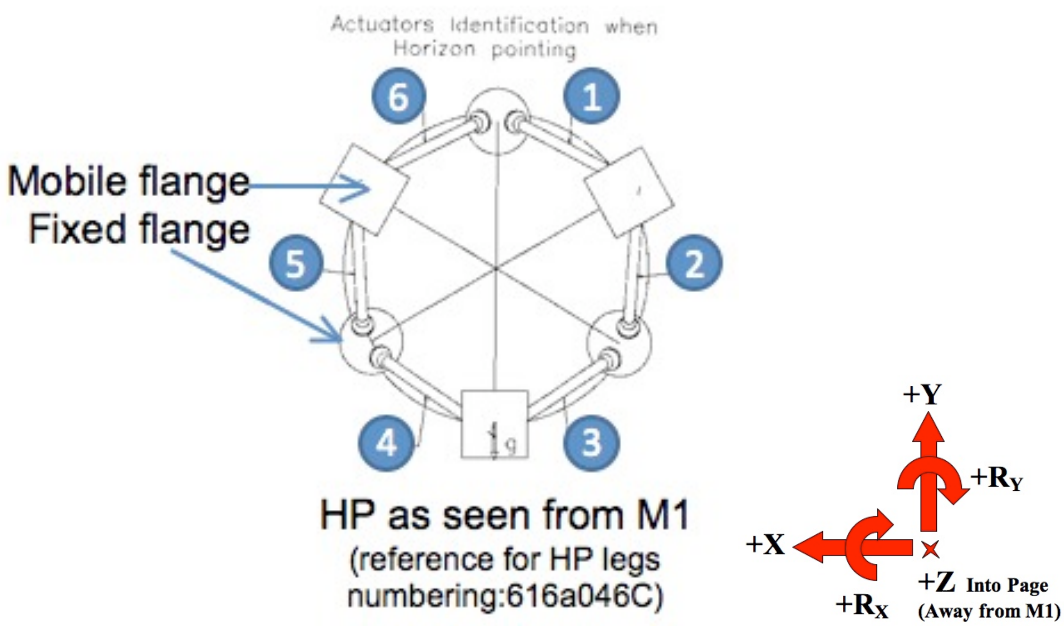

Figure 3: The coordinates of the secondary hexapod in the telescope mechanical coordinate system. This view is from the primary mirror, if the telesope is horizon pointing (from April 2, 2009 email from A. Riccardi).

4.3.1. UMAC: Software Coordinates

The internal coordinate system used by the firmware of the UMAC hexapod controller is rotated by 180 degrees around the Z-Axis from the telescope's mechanical coordinate system.

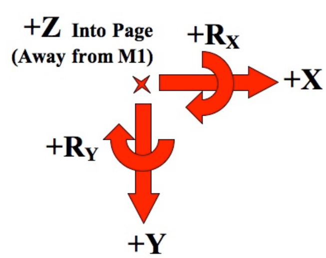

Figure 4: The coordinate system used by the UMAC that controls the M2 hexapod

The units of the position requests are in microns, and units of angle requests are in arc-seconds.

4.3.2. OSS: Software Coordinates

The coordinate system of the OSS subsystem of the TCS uses the telescope coordinate system. Note, this is the same coordinate systems as is used by the PMC subsystem of the TCS for movement of the primary mirror. Thus, a +X position change of 100 microns will move the primary mirror and secondary mirror in the same direction.

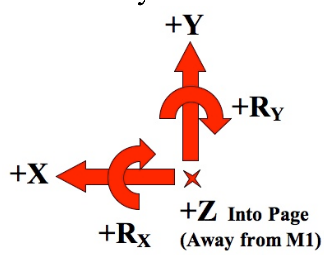

Figure 5: The coordinate systems used by the OSS, which is the same as the telescope's mechanical coordinate system

The units of position the OSS expects, through either the OSS Gui, PSF Gui or IRC request (which are actually all related) are millimeters and the units of angle are arc-seconds. When the position and angle values of the hexapod are retrieved from the UMAC by the OSS, the x, y and z coordinates are all divided by 1000 (unit change) and the sign of the x, y, R_x (apha) and R_y (beta) values are changed (conversion from UMAC to OSS coordinates). When a request for hexapod motion is received by the OSS the opposite conversion occurs just before the move request is sent to the UMAC.

5. PCS_XY Coordinates

The PCS_XY Coordinates is the coordinate system used at the LBT to describe a position inside the movable part of the rotator and the AGw structure. The name PCS_XY is derived from the TCS subsystem that determines these coordinates, the PCS, or Pointing Control Subsystem.

The PCS, using software called "the pointing kernel", is responsible for instructing the telescope mount where to point. In addition, PCS instructs the appropriate instrument rotator to move a specific position and possibly how to move (depending on the rotator mode of the observation).

TCS subsystems that control the guiding and active optics (GCS) and adaptive optics (AOS) will need to know the physical position of target stars to properly position various probes and cameras. This physical position inside the AGw structure will be provided by the PCS, in PCS_XY coordinates, via function calls. The requesting subsystem (GCS or AOS), or their "subsystems", will be responsible for transforming the retrieved PCS_XY coordinates into the coordinate system needed to properly position the appropriate probe or camera for each focal station.

This section will describe the definition of PCS_XY coordinates and the retrieval of these values from PCS.

5.1. Illustration of PCS_XY Coordinates

Each focal station of the telescope will have its own PCS_XY coordinate system. To understand each of these PCS_XY coordinate systems, it is easiest to describe them in terms of other coordinate systems used at the telescope, Sky Coordinates and Telescope Coordinates. The three useful coordinate systems are:

- Sky Coordinates: Declination (North) and Right Ascension (East)
- Telescope Coordinates: Elevation and Azimuth of the telescope mount
- PCS_XY Coordinates: A physical position inside each rotator

At each focal station, the thee coordinate systems listed above all have a common origin where the mechanical rotation axis of the moveable part of the rotator intersects the telescope focal plane. The orientation of the coordinate systems axes depend on the position of the focal station, the rotator angle and the telescope's position.

The relative orientations of the Sky, Telescope and PCS_XY coordinate systems are easiest to visualize with the telescope horizon pointing toward the South, on the meridian. At this telescope position, an observer looking at the sky from behind the telescope, in the direction the telescope is pointing, will see Dec up and RA to the left, and will see positive elevation direction up and positive azimuth to the right.

To visualize the orientations of the Sky, Telescope and PCS_XY coordinate systems at each focal station, the position of an observer is defined as:

- Bent Gregorian: The observer is standing on the central instrument platform, looking through the rotator structure, toward the tertiary, secondary and primary mirrors and out at the sky.
- Direct Gregorian: The observer is standing behind the telescope, which is horizon pointing, looking through the rotator structure, toward the secondary and primary mirrors and out at the sky.

With the telescope pointing South at the horizon, as described above, the Sky and Telescope coordinates for each focal station are orientated according to what the observer would see looking through the rotator structure. The PCS_XY coordinates are now defined with +Y pointing in the direction of Dec and +X pointing in the direction of RA. These three coordinate systems are shown for all the LBT focal stations in the subsections below.

The orientation of the PCS_XY coordinate system is locked to the rotating part of the rotator structure. As the telescope changes position and the rotator turns, the Sky and Telescope coordinates will change their orientation relative to each other and relative to the PCS_XY coordinates, but the PCS_XY coordinates do not move relate to the AGw structure. With this definition, the instruments inside the AGw (guider and wavefront sensor cameras) have a stationary coordinate system with a known (albeit changing) orientation relative to the Sky and Telescope coordinates. The transformation from Sky coordinates to PCS_XY coordinates is a "service" provided by the PCS (see section 5.2 below).

It is important to note that the "handedness" of the PCS_XY coordinates for all focal stations are the same. Specifically, if the +Z direction is defined to be towards the sky, the PCS_XY coordinate system is right handed (see section 5.2 below). This means, for example, the AGw and GCS does not need to know which focal station (Bent or Direct Gregorian) it is mounted. The returned PCS_XY coordinates for an off-axis guide star will depend on the focal station for which they are requested. The GCS and AGw can simply place the guide probe and wavefront sensor camera at the returned PCS_XY position (of course with the proper rotation and translation into the AGw motors' coordinate system). As an example, if a guide star is North of the pointing position of the telescope, then the returned PCS_XY coordinate values (0,y) will be the same for both Bent and Direct Gregorian. If the guide star is East of the pointing position of the telescope, then the returned PCS_XY coordinate values (x,0) will have positive x value for Direct Gregorian and negative x value for Bent Gregorian. Note: I have NOT checked the PCS_XY orientation with the MCSPU Simulator.

The only dependence of the PCS_XY coordinates on the Science Instrument is the rotator offset value (LEFTZEROPOINT parameter in PCSInstrument.conf) needed to orient the sky properly on the Science detector, specifically setting North as up. The mounting position of each instrument on the movable part of the rotator should be optimized such that, for the correct image orientation (North up), the instrument rotator is in the center of its travel (see section 9 below).

5.1.1. SX (Left) Bent Gregorian Focal Stations

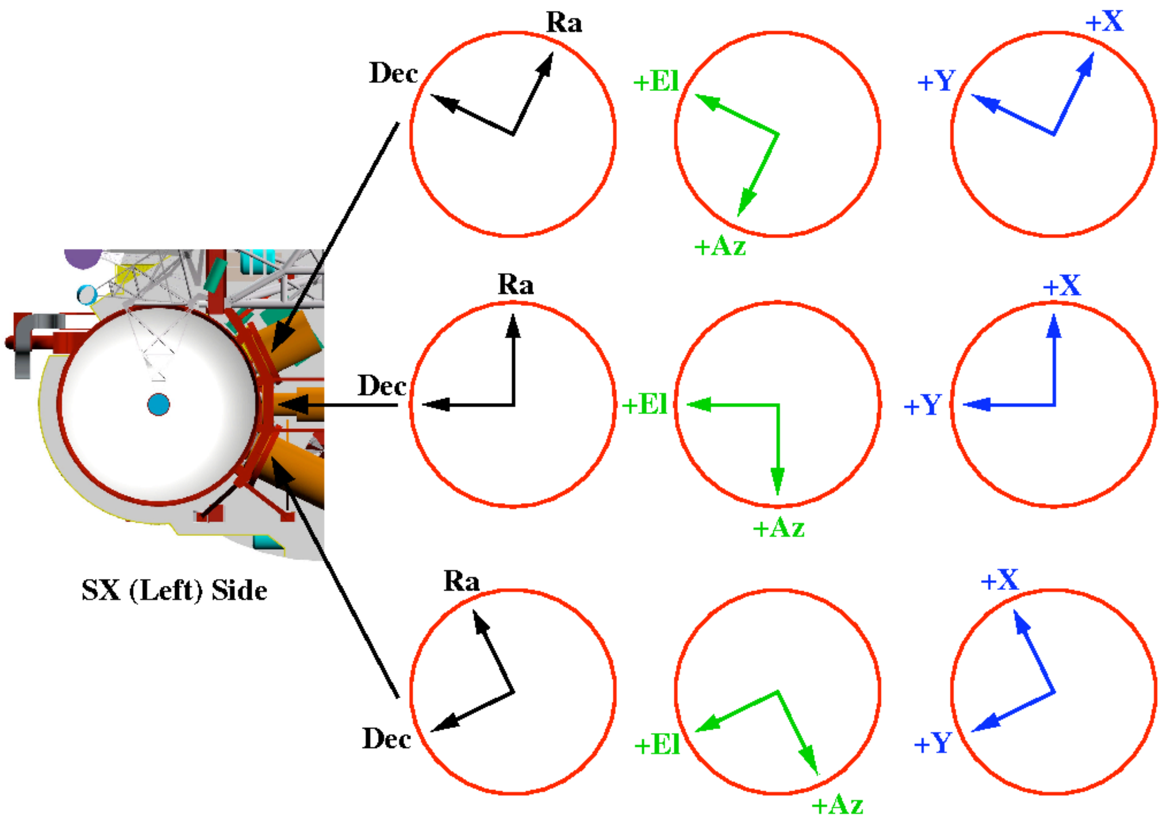

Figure 6: Illustration of PCS_XY coordinate system for the SX (Left) Bent Gregorian focal stations with the telescope horizon pointing toward the South. Note: I have checked the PCS_XY orientation with the MCSPU Simulator (30Jul09)

5.1.2. SX (Right) Direct Gregorian Focal Station

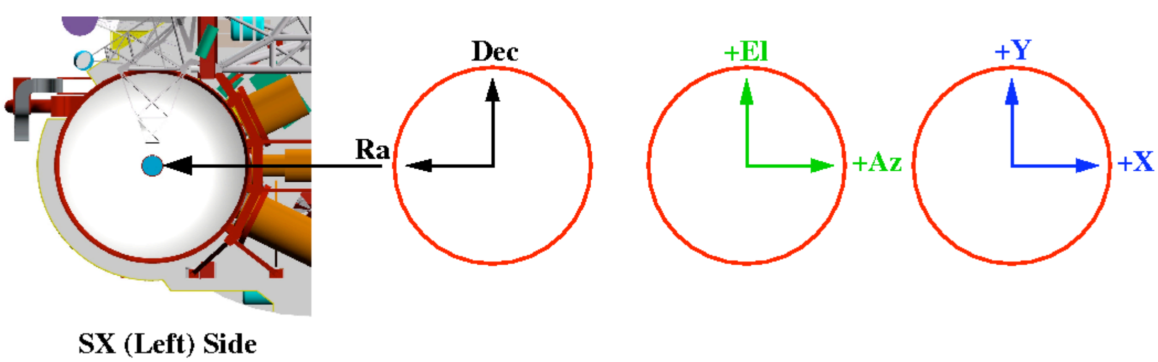

Figure 7: Illustration of PCS_XY coordinate system for the SX (Left) Direct Gregorian focal station with the telescope horizon pointing toward the South. Note: the observer is behind the primary. Note: I have NOT checked the PCS_XY orientation with the MCSPU Simulator

5.1.3. DX (Right) Bent Gregorian Focal Stations

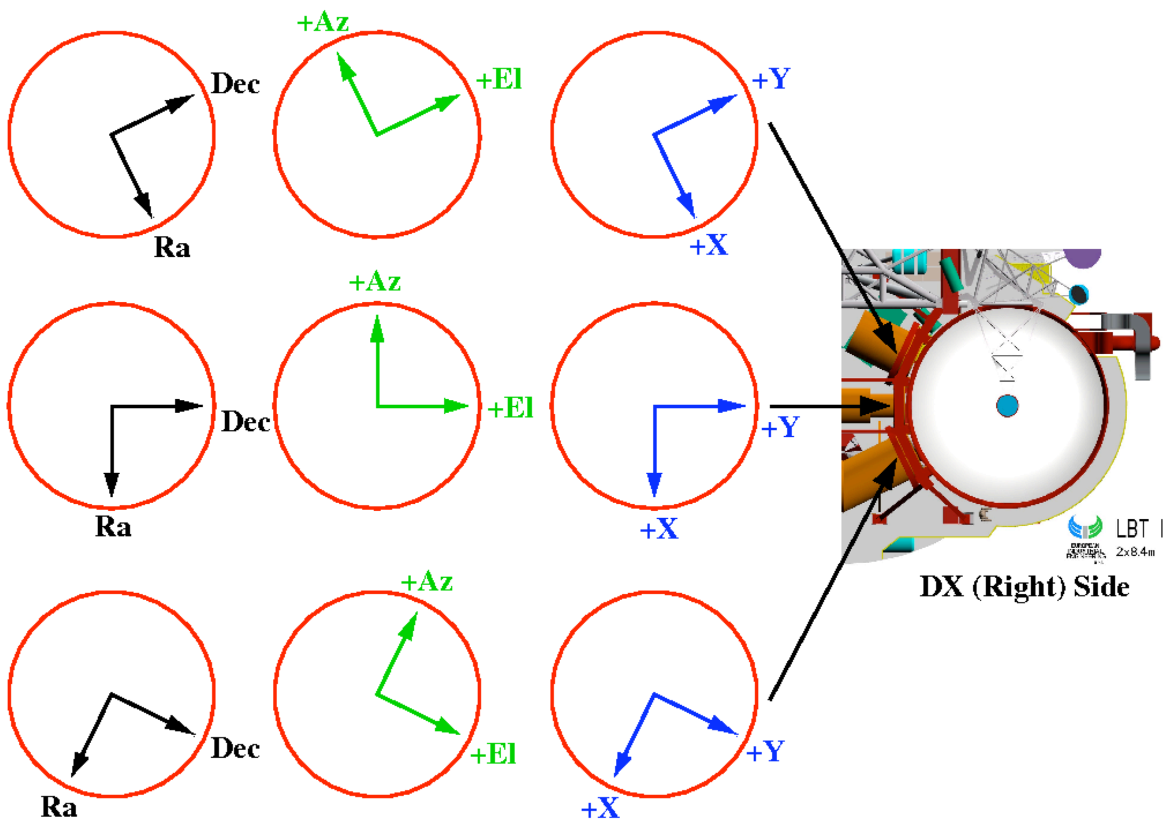

Figure 8: Illustration of PCS_XY coordinate system for the DX (Right) Bent Gregorian focal stations with the telescope horizon pointing toward the South. Note: I have NOT checked the PCS_XY orientation with the MCSPU Simulator

5.1.4. DX (Right) Direct Gregorian Focal Station

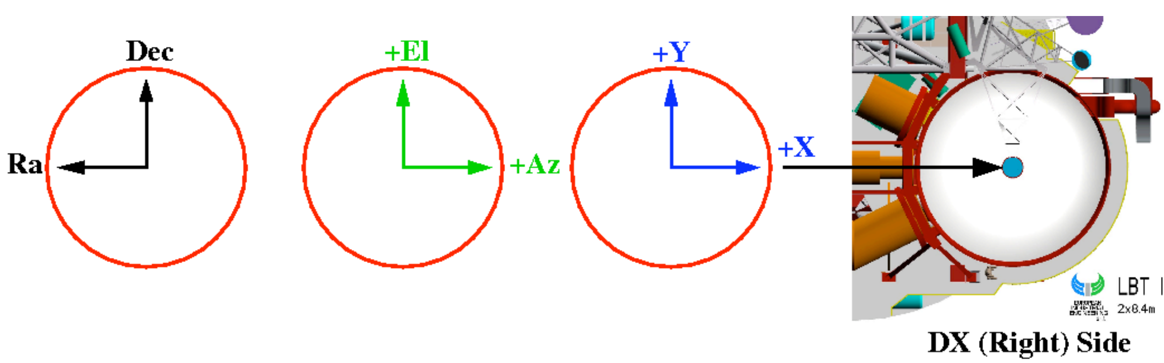

Figure 9: Illustration of PCS_XY coordinate system for the DX (Right) Direct Gregorian focal station with the telescope horizon pointing toward the South. Note: the observer is behind the primary. Note: I have NOT checked the PCS_XY orientation with the MCSPU Simulator

5.2. Calculation of PCS_XY Coordinates

The TCS, specifically the PCS, can be requested to calculate the PCS_XY coordinates for a specific object. Once the telescope is in position (tracking or holding), a subsystem of the TCS, for example the GCS or AOS, can request the PCS to calculate the PCS_XY position of a provided position on the sky. The on-axis position of the target star (or object), defined by the center of rotation of the rotator structure, is defined as PCS_XY position (0,0). The physical position of a guide star needed by GCS or a reference star needed by AOS, is determined by calling a PCS function[1] with Ra and Dec in sexadecimal notation in the argument "position". The (X,Y) position in millimeters in PCS_XY coordinates will be returned.

The call to the PCS routine in turn makes a call to the pointing kernel (see [RD2]) which has all the information needed to determine the PCS_XY coordinates of the given position on the sky. The kernel uses the current on-axis position (the coordinates where the telescope is pointing), the position for which the PCS_XY coordinates are requested, the current rotator and position angles and a pair of "sign" parameters that depends on the focal station (Bent verses Direct Gregorian). These "sign" flags are needed to denote how many reflections (eg +X to –X or visa-versa) of the PCS_XY coordinate system are required due to reflections of the incoming light on mirror surfaces. For the LBTO, there is one additional reflection at the tertiary mirror for the Bent Gregorian focal stations relative to the Direct Gregorian focal stations and thus the X "sign" flag is false for Bent Gregorian stations and is true for Direct Gregorian stations. These flips are defined in

/home/telescope/TCS/Configuration/PCS/PCSInstrument.conf

as LEFTXYFLIP and RIGHTXYFLIP. For Bent Gregorian focal stations, both these parameters are set to "false false" for no flips for X or for Y. For Direct Gregorian they are set to "true false" for an X flip. These parameters show that the image flip of the sky due to the tertiary mirror requires only the x-axis to be flipped in the PCS_XY coordinate system relative to the Direct Gregorian PCS_XY coordinates. These "sign" flags are not passed from the subsystem, GCS or AOS, to PCS, but are part of the PCS configuration for the current authorized focal station.

A byproduct of the flipping of the PCS_XY x-axis for the Direct Gregorian focal stations so that they have the same "handedness" as the Bent Gregorian focal stations is that the rotation direction of the instrument rotation must be flipped. These rotation direction flags are defined also defined in PCSInstrument.conf as LEFTSCALE and RIGHTSCALE. These parameters are set to +1.0 for the Bent Gregorian focal stations and to -1.0 for Direct Gregorian[2].

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[1] GCS calls the function computeKFPCoordinates(int side, Position star) to get the PCS_XY coordinates of a guide star from the PCS.

[2] Doug and Michelle need to empirically check that this description is correct. (14Jan10)

The (X,Y) PCS_XY position returned by the PCS function call can be used to position the acquisition and guiding camera and the active optics wavefront sensor (GCS) or to position the adaptive optics wavefront sensor (AOS). Note, the PCS function does not check if the returned (X,Y) position is in range of motion of any stages in the AGw. These checks must be performed by the calling subsystem. Also, any calibration of the positioning of camera stages, such as rotations or translations from PCS_XY coordinates to stage motion coordinates, nonlinear stage motion, focal plane curvature etc, must be performed by the subsystem.

6. AG/w Coordinates (Guiding and Active Optics)

This section describes the mounting orientation of the AGw unit and the general relationship between the coordinate systems involved. As listed in section 3.1 the AGw unit is mounted on the movable part of the instrument rotator such that the -Y direction of the guide probe is aligned with the +Y direction of the PCS_XY coordinate system. The orientation of the PCS_XY coordinate system for each focal station are illustrated in section 5.1 above.

The mounting of the AGw unit on the movable part of the rotator is not exact, nor is the mounting of the guide probe stages, nor the mounting of the guide and wavefront sensor cameras on the guide probe stages. This results in the X,Y axes of the AGw guide probe and PCS_XY coordinate systems not being exactly aligned, but should be within a degree or two of parallel and only a few millimeters offset. To solve this slight misalignment, a transformation between these coordinate systems must be empirically determined.

Once the AGw unit has been mounted and the rotator "Zero" position set by adjusting the offset value, LEFTZEROPOINT, the transformation between the PSC_XY and AGw guide probe coordinates must be determined on-sky. For the AIP AGw units at LFBG and LDG, the determination of these transformations were performed by AIP staff, with assistance from LBTO staff.

6.1. SX (Left) Focal Stations

6.1.1. Front Bent Gregorian

The mounting orientation of the AGw unit at the Left Front Bent Gregorian focal station is shown in Figure 10. This orientation is applicable at the telescope position described in section 5.1. This aligns the –Y direction of the guide probe coordinate system with the +Y direction of the PCS_XY coordinate system. The origin of the AGw coordinate system is not at the rotation center of the LFBG rotator, as is the PCS_XY coordinate system, but at the pivot point of the guide probe arm. This pivot point is located at approximately at (0,612) millimeters in the PCS_XY coordinate system (upper left of Figure 10)

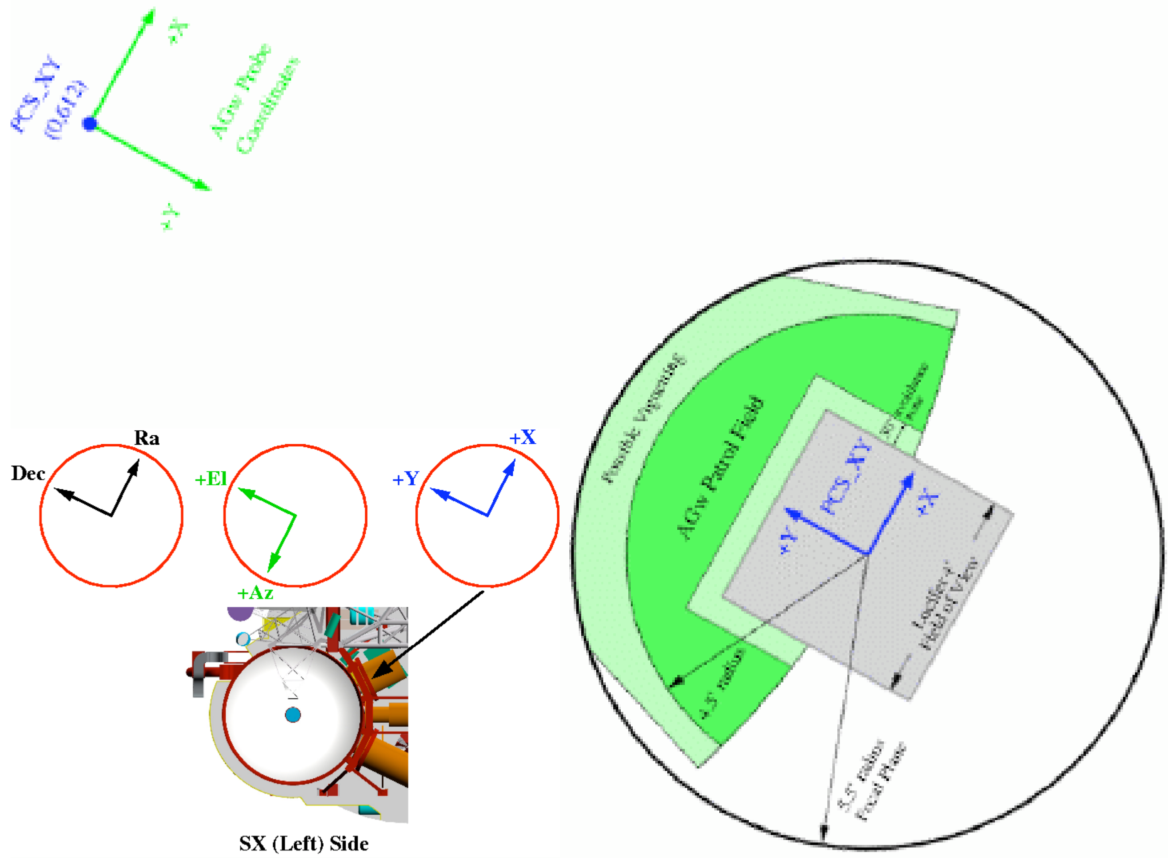

Figure 10 AGw mounting orientation at Left Front Bent Gregorian. . This view is for an observer standing on the Gregorian platform looking into the LFBG port with the telescope and rotator position described in section 5.1.1

6.2. DX (Right) Focal Stations

6.2.1. Front Bent Gregorian

The mounting orientation of the AGw unit at the Right Front Bent Gregorian focal station is shown in Figure 11. This orientation is applicable at the telescope position described in section 5.1. This aligns the –Y direction of the guide probe coordinate system with the +Y direction of the PCS_XY coordinate system. The origin of the AGw coordinate system is not at the rotation center of the LFBG rotator, as is the PCS_XY coordinate system, but at the pivot point of the guide probe arm. This pivot point is located at approximately at (0,612) millimeters in the PCS_XY coordinate system (upper right of Figure 12)

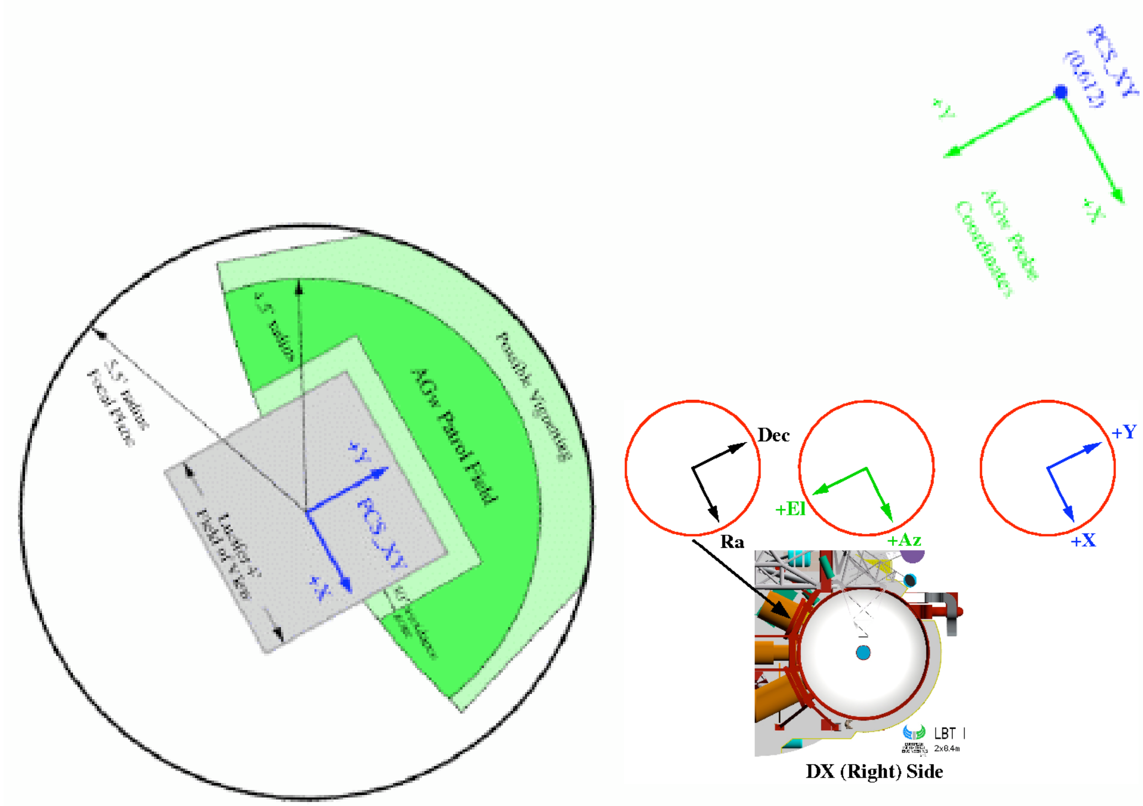

Figure 11 AGw mounting orientation at Right Front Bent Gregorian. This view is for an observer standing on the Gregorian platform looking into the RFBG port with the telescope and rotator position described in section 5.1.3

7. AG(Big)W Coordinates (Adaptive Optics)

This section describes the mounting orientation of the AG(Big)W unit and the general relationship between the coordinate systems involved. As listed in section 3.1 the AIP AGw unit is mounted on the movable part of the instrument rotator such that the -Y direction of the guide probe is aligned with the +Y direction of the PCS_XY coordinate system. This mounting position then defines the orientation of the (Big)W unit's coordinate system to the PCS_XY coordinate system, which is that both the +X and +Y axes of these coordinate systems are aligned. The orientation of the PCS_XY coordinate system for each focal station are illustrated in section 5.1 above.

The mounting of the AGw/W unit on the movable part of the rotator is not exact, nor is the mounting of the pyramid sensor stages and camera. This results in the X,Y axes of the AG(Big)W and PCS_XY coordinate systems not being exactly aligned, but should be within a degree or two of parallel and only a few millimeters offset. To solve this slight misalignment, a transformation between these coordinate systems must be empirically determined.

Once the AGw/W unit has been mounted and the rotator "Zero" position set by adjusting the offset value, LEFTZEROPOINT, to align the science instrument's rows and columns with North and East, the transformation between the PCS_XY and (Big)W coordinates must be determined on-sky.

7.1. SX (Left) Focal Stations

7.1.1. Front Bent Gregorian

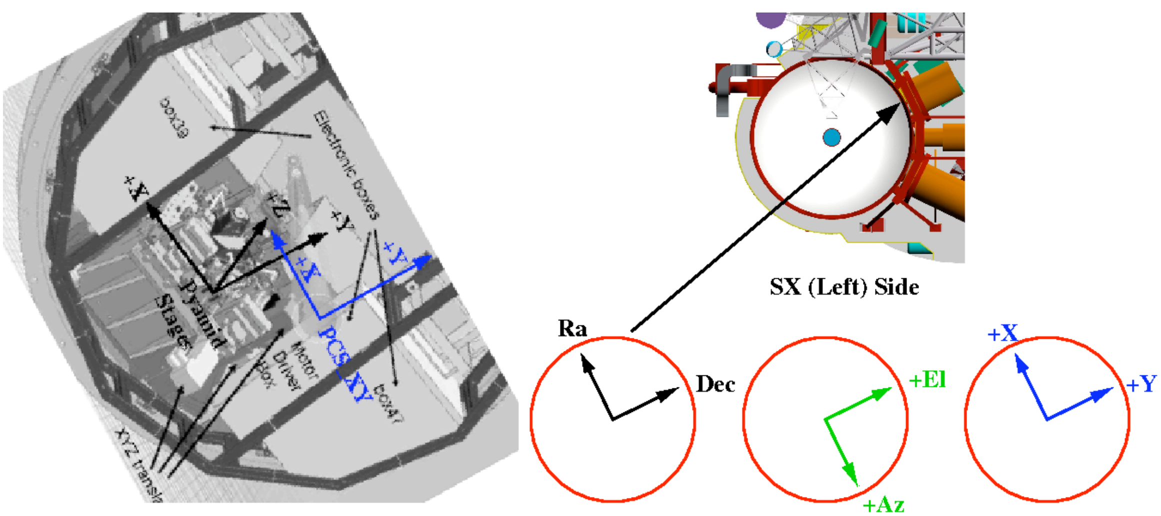

Figure 12: The coordinate systems of the AG(Big)W at Left Front Bent Gregorian. In the image on the left, the **Black** coordinate system describes the motion of the Pyramid Sensor stages and the **Blue** coordinate system shows the PCS_XY directions. This view is for an observer standing on Primary Mirror looking into the LFBG port with the telescope and rotator position described in section 5.1.1.

7.2. DX (Right) Focal Stations

7.2.1. Front Bent Gregorian

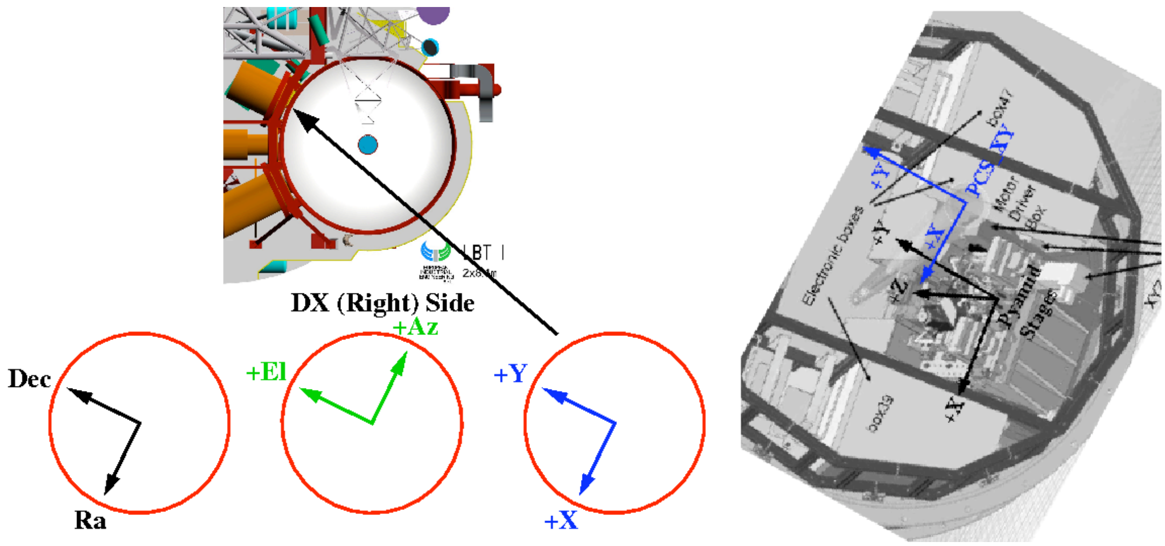

Figure 13: The coordinate systems of the AG(Big)W at Right Front Bent Gregorian. In the image on the right, the **Black** coordinate system describes the motion of the Pyramid Sensor stages and the **Blue** coordinate system shows the PCS_XY directions. This view is for an observer standing on the Primary Mirror looking into the RFBG port with the telescope and rotator position described in section 5.1.3

8. Adaptive Optics System Coordinates

8.1. Adaptive Secondary

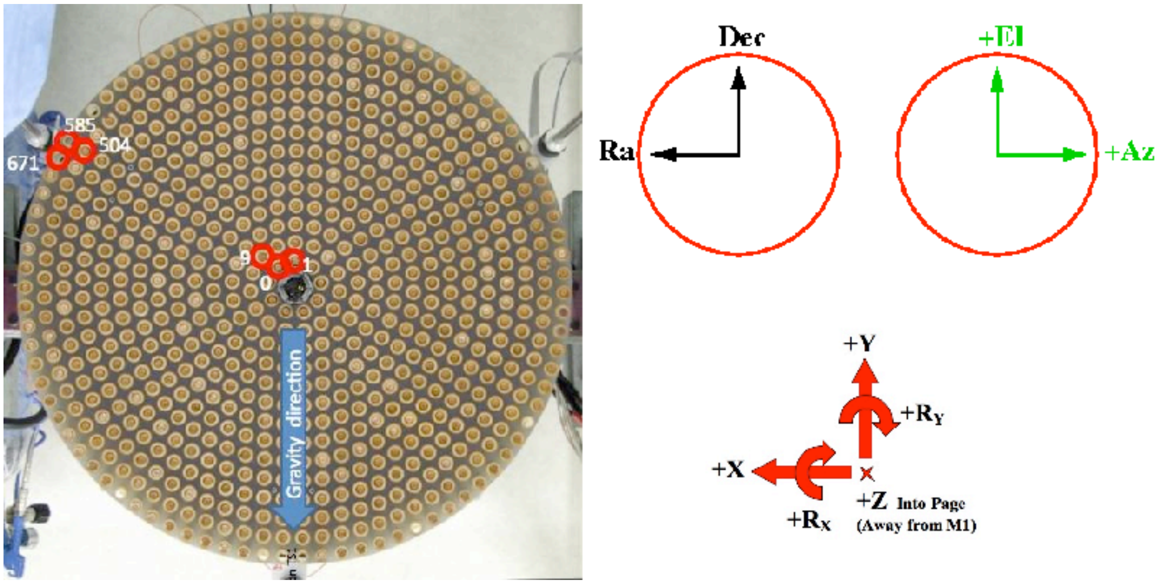

Figure 14: The Adaptive Secondary orientation and coordinate systems as viewed from the primary mirror with the telescope in the position described in section 5.1. The **Red** arrows describe the mechanical coordinate system of the telescope. The actuator numbering of LBT672a is also displayed.

8.2. Pyramid WaveFront Sensor

Screen shots from the AO Engineering GUI will be inserted here along with coordinates. (DLM 14Jan10)

8.3. Technical Viewer

Screen shots from the AOS GUI will be inserted here along with coordinates. (14Jan10)

8.4. Solar Tower to Telescope Coordinates

The Adaptive Secondary was mounted in the Arcetri Solar Tower test stand to have the same orientation as it will have at the Telescope. This means the Adaptive Secondary was mounted in the Zenith pointing Solar Tower such that its gravity direction pointed South. Thus, if the Solar Tower were laid over to horizon pointing toward the South, with the telescope position described in section 5.1, the Adaptive Secondary would have the orientation shown in Figure 14.

The AG(Big)W unit was mounted at the bottom Solar Tower such that the Pyramid Sensor was positioned to the South. The AO re-rotator was positioned to ??? degrees, the Interaction Matrix was acquired and the Reconstructor Matrix calculated. Thus, with the orientation at the telescope of the AGw/W at RFBG determined by the orientation of the PCS_XY coordinate system (see discussion in sections 5.1.3 and 7.2.1), the AO re-rotator position must be changed so that the relative orientation of the Pyramid sensor to the Adaptive Secondary from the Solar Tower is replicated at the telescope.

In addition, the Bent Gregorian focal stations there is an additional reflection it the optical path at the Tertiary Mirror. The Adaptive Optics System must compensate for this additional reflection at the telescope.

The AG(Big)W coordinate systems, relative to the Adaptive Secondary, in the Solar Tower are the same as those at the telescope if the AG(Big)W were to be mounted at a Direct Gregorian focal station (ie no additional Tertiary Mirror reflection). Figure 15 shows the relative position of the Pyramid Sensor stage coordinates and the telescope mechanical coordinates as seen in Figure 14. Note the X axis has been flipped because we are viewing the AG(Big)W from the Adaptive Secondary's point of view.

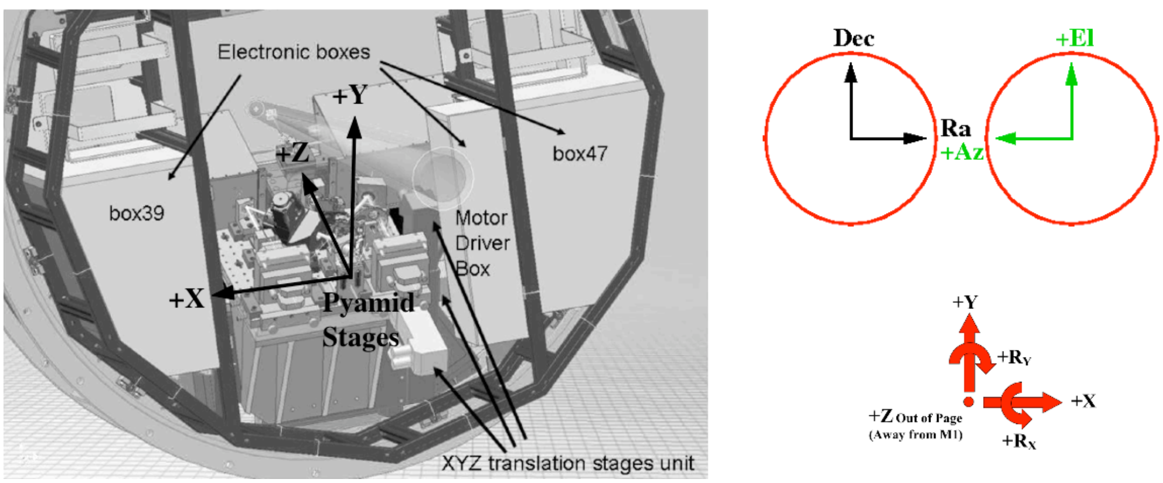

Figure 15: The orientation of the (Big)W unit in the Solar Tower (Direct Gregorian at the telescope) relative to coordinate systems used at the telescope, with the Solar Tower (telescope) in the position described in at the beginning of section 8.4. The observer is at the Secondary Mirror looking through the AGw/W interface ring (DG port). The Red arrows describe the telescope's mechanical coordinate system.

At the telescope the first Adaptive Optics System will be mounted on the DX (Right) side of the telescope with the WaveFront Sensor mounted at the Right Front Bent Gregorian focal station. At this focal station there is an additional reflective surface, the Tertiary Mirror, which results in a flip of the mechanical coordinate system (see Figure 17). Similarly, the second Adaptive Optics System will be mounted on the SX (Left) side, with the same mechanical coordinate system flip (see Figure 16).

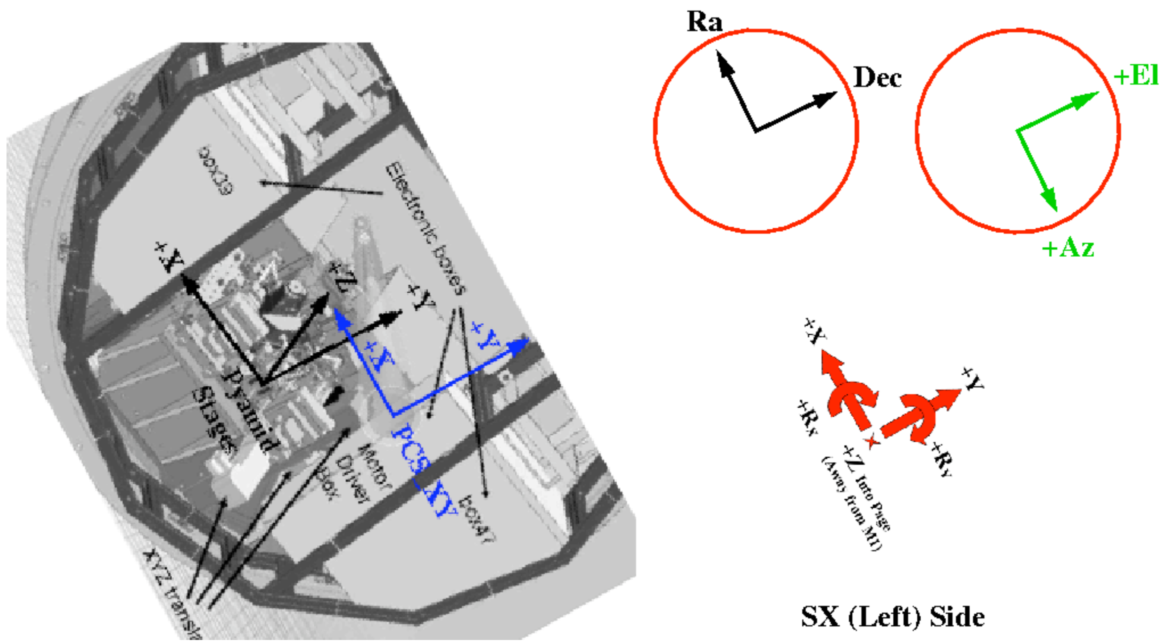

Figure 16: The orientation of the (Big)W unit at the Left From Bent Gregorian relative to with the telescope in the position described in section 5.1. The observer is standing on the Primary Mirror looking through the LFBG port. The Red arrows describe the telescope's mechanical coordinate system.

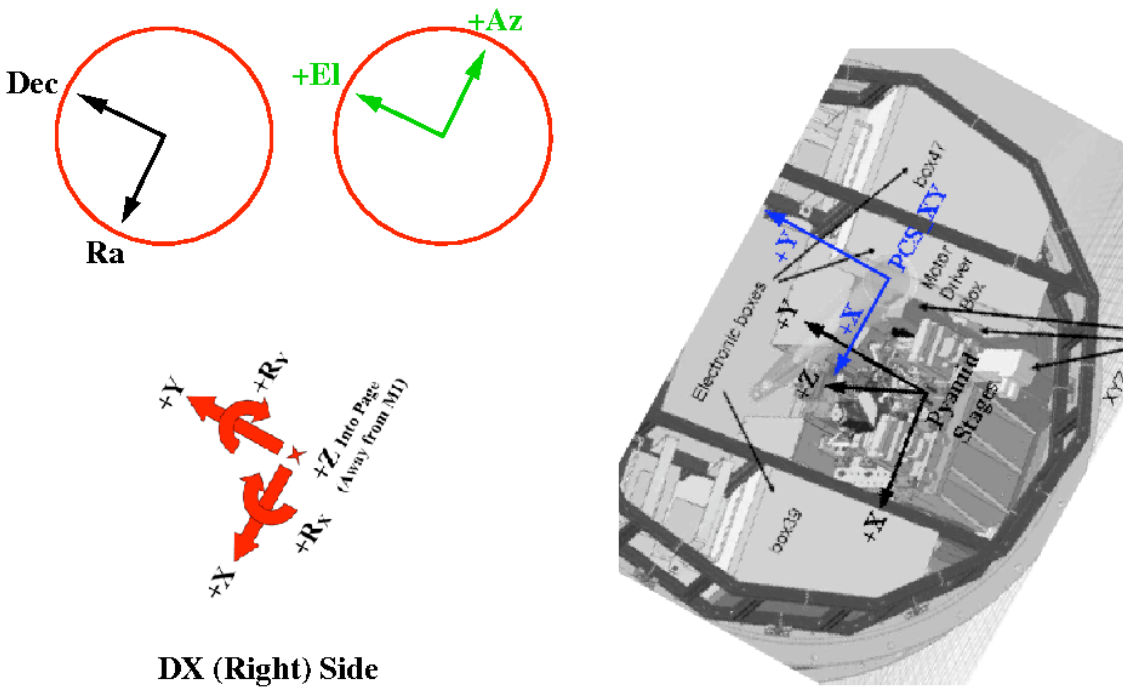

Figure 17: The orientation of the (Big)W unit at the Right From Bent Gregorian relative to with the telescope in the position described in section 5.1. The observer is standing on the Primary Mirror looking through the RFBG port. The Red arrows describe the telescope's mechanical coordinate system.

Comparing Figure 16 and Figure 17 to Figure 15, it can be seen that the mechanical coordinate systems of the (Big)W will be mounted at the telescope with only a flip of the Pyramid Sensor images about the +Y axis compare to the coordinate system used in the Solar Tower. Thus, the re-rotator angle used in the Solar Tower will also be used at the telescope. The flipping of the Pyramid Sensor image can be corrected several way (flip the Pyramid Sensor image before processing slopes, flipping the Interaction Matrix before inversion, flipping the Reconstructor Matrix, etc). How is Arcetri planning on implementing this flip? What is the current re-rotator angle?

9. Instrument Mounting Positions

More Later (DLM 15Jan10)

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Document Type: Report
Source: Steward Observatory
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Revised by:
Date_of_Revision: 2010-01-22
Checked by: Douglas Miller
Date_of_Check:
Accepted by:
Date_of_Acceptance:
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