MSL Coordinate Systems for Science Instruments

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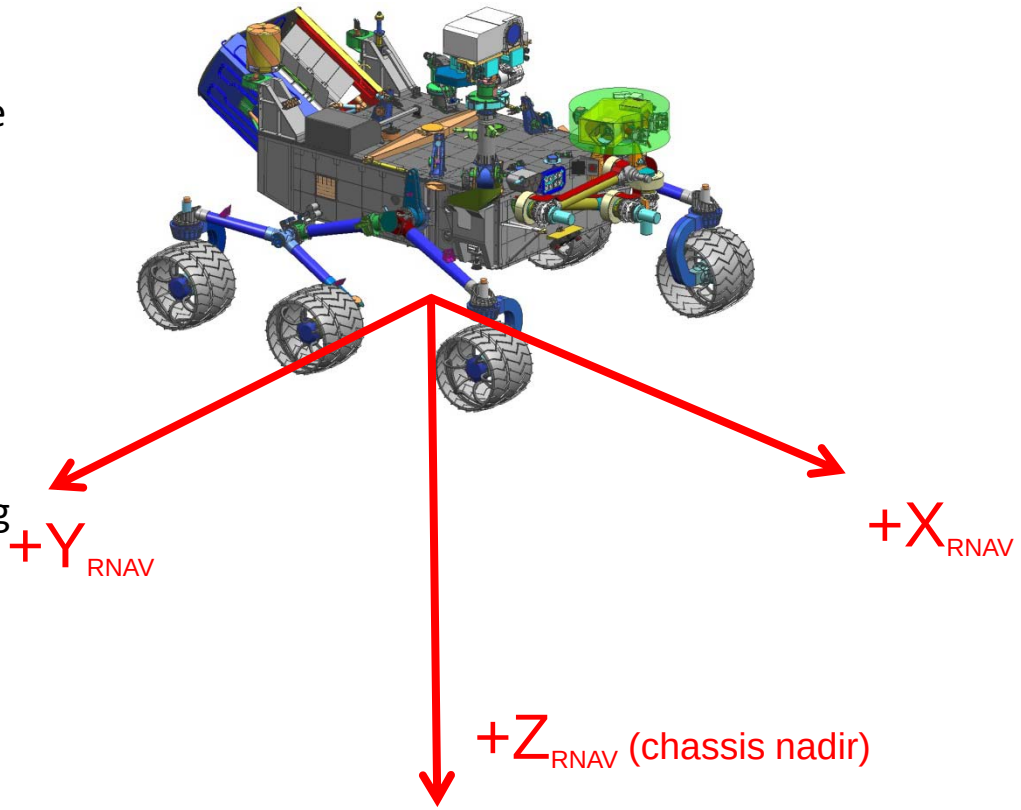
Primary Rover Operations Coordinate Frames

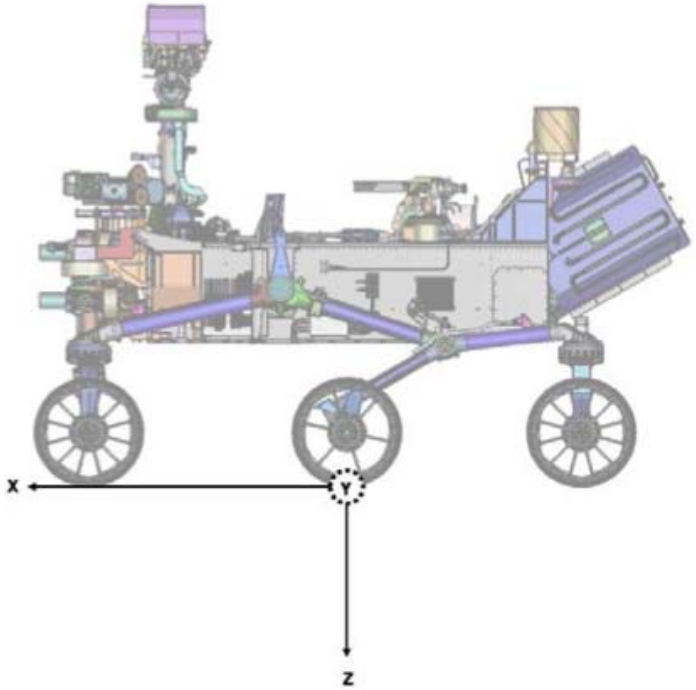
Frame Name	Description	Origin Type	Direction Type	Location of Origin	+X Direction	+Y Direction	+Z Direction	Typical use case
SITE	**Site Frame**	Mars fixed	Mars fixed	Frame origin is attached to Mars, sits on the nominal Martian surface. New sites are declared by a command sent by the Rover Planners, typically at the end of a drive, usually associated with an accompanying Navcam 360-degree panorama.	North	East	Nadir	Targeted remote sensing (XYZ), target designation, driving. This is the most commonly used frame in operations.
RNAV	**Rover Navigation Frame**	Rover fixed	Rover fixed	Frame origin is fixed relative to the rover, located at the nominal Martian surface, centered under the rover turn-in-place rotation axis.	Forward drive direction	Starboard direction	Down (chassis nadir)	Pointing cameras to fixed locations relative to the rover body (usually used in special cases only).
LL	**Mars Local Level Frame**	Rover fixed	Mars fixed	Frame origin is fixed relative to the rover, located at the nominal Martian surface, centered under the rover turn-in-place rotation axis.	North	East	Nadir	Untargeted remote sensing (az/el), for example, drive direction imaging, general terrain imaging, cases where accurate XYZ position is unknown

Definition of the RNAV Frame

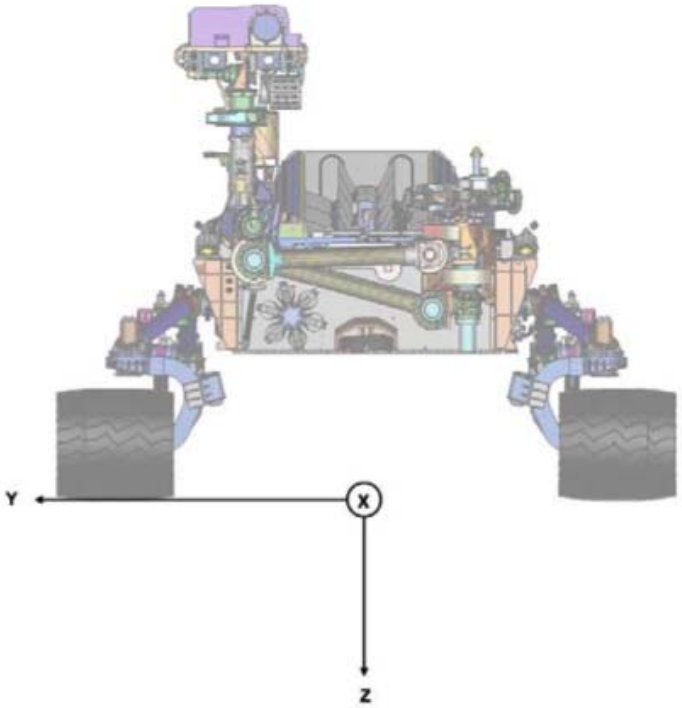
- The RNAV origin is located on the nominal (flat) surface of Mars, beneath the rover, centered on the turn-in-place axis of rotation.
  - When the rover turns in place, the RNAV origin stays fixed
- The $+Z_{RNAV}$ axis points downward (relative to the rover chassis) and is perpendicular to the X_{RNAV}/Y_{RNAV} plane.
- The $+X_{RNAV}$ axis points in the forward drive direction.
- The $+Y_{RNAV}$ axis points towards the starboard side of the rover (i.e, to the right when facing forward).
- The RNAV coordinate system is right-handed, orthogonal, and defined by axes X_{RNAV} Y_{RNAV}, and Z_{RNAV} (shown in red, below).



Definition of the RNAV Frame (cont.)



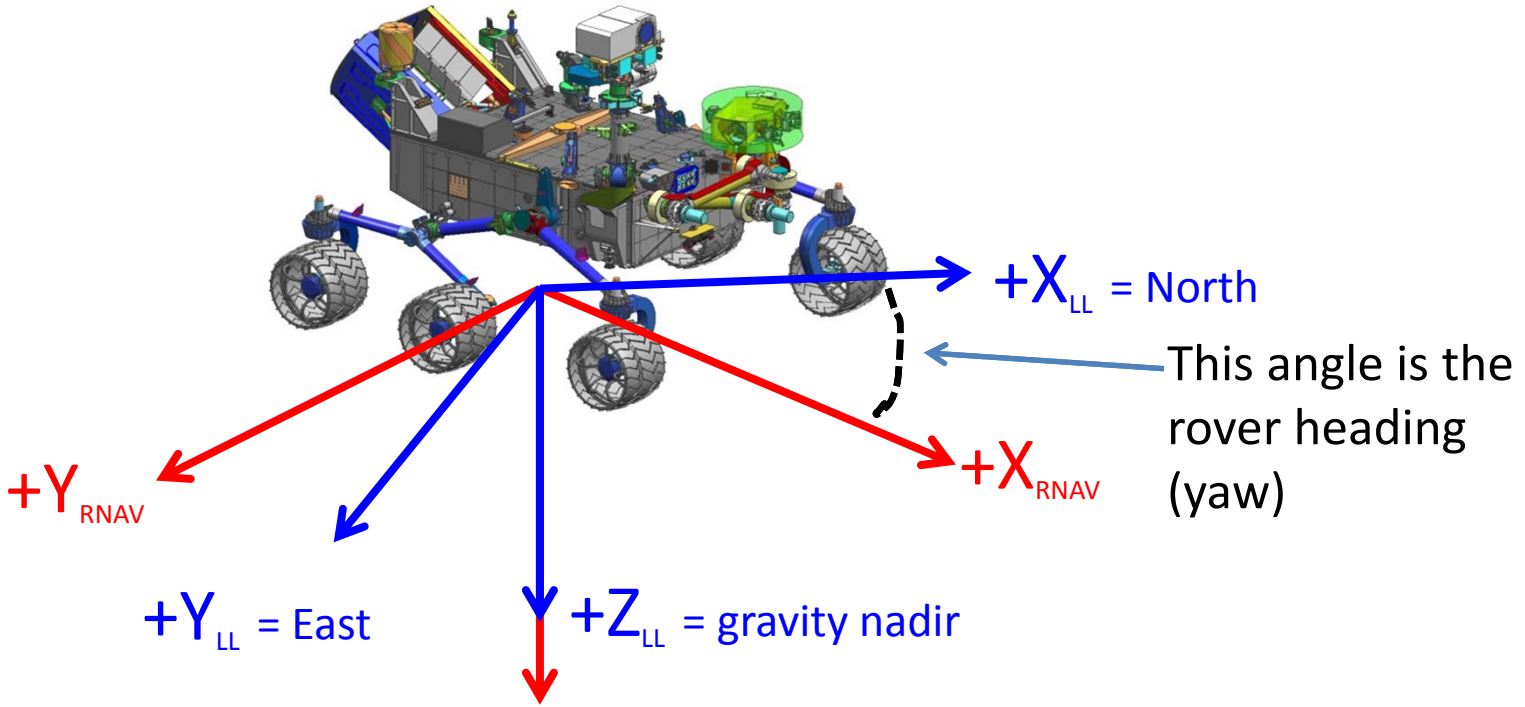
RNAV Frame Side View



RNAV Frame Front View

Definition of Mars Local Level Frame

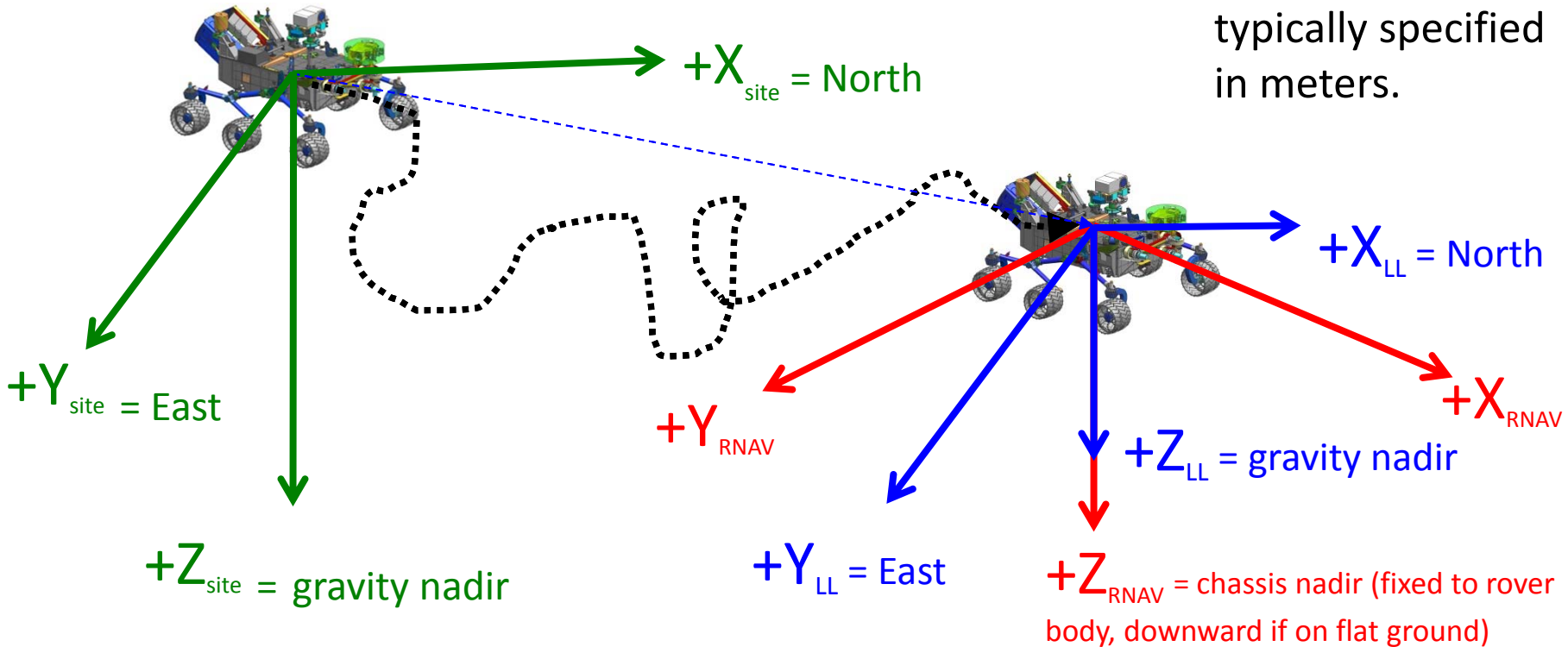
- The Mars Local Level Coordinate Frame (LL Frame) is right handed, orthogonal, and defined by axes X_{LL}, Y_{LL}, and Z_{LL} (shown in blue, below).
- It is a North (X_{LL}) East (Y_{LL}) Nadir (Z_{LL}) frame.
- When a site frame is declared, the LL frame origin is coincident with the RNAV frame.
- The frame origin is attached to the rover, but the directions of the axis are Mars fixed.
  - Can be thought of as a compass



Definition of Site Frame

A site frame is a LL frame that is attached to the Martian surface whenever the site index is incremented (shown in green, below).

1. Declare a site frame
2. Drive
3. The rover position in site frame is given by (X_{LL},Y_{LL},Z_{LL}), typically specified in meters.

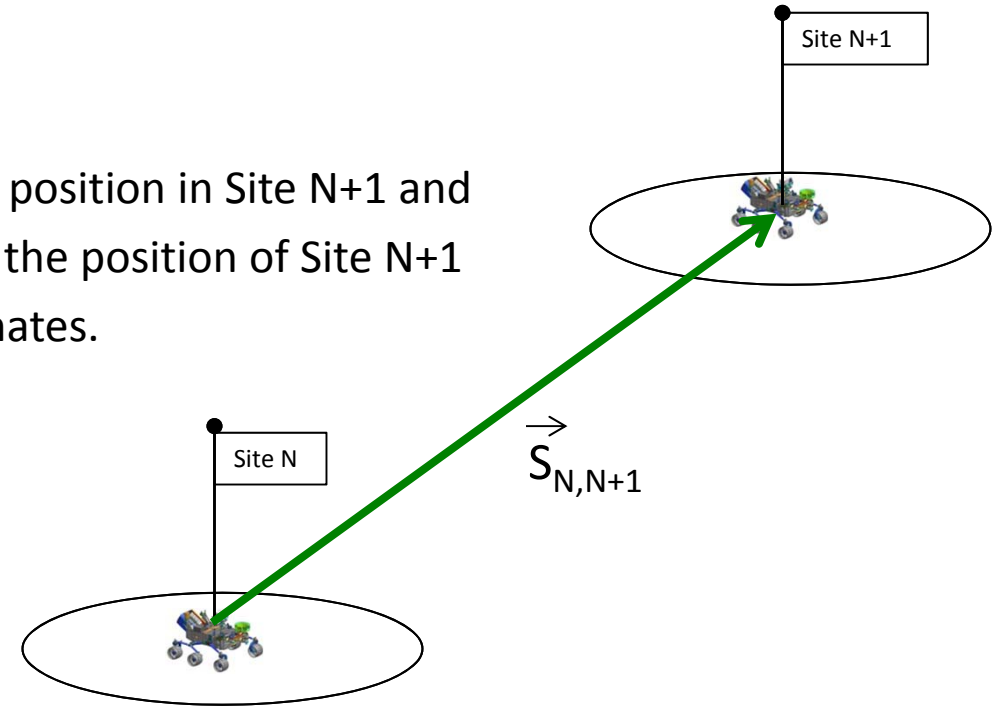


Site to Site Translations

Given two site frames, S_N and S_{N+1}, the rover position expressed in site N coordinates is given by:

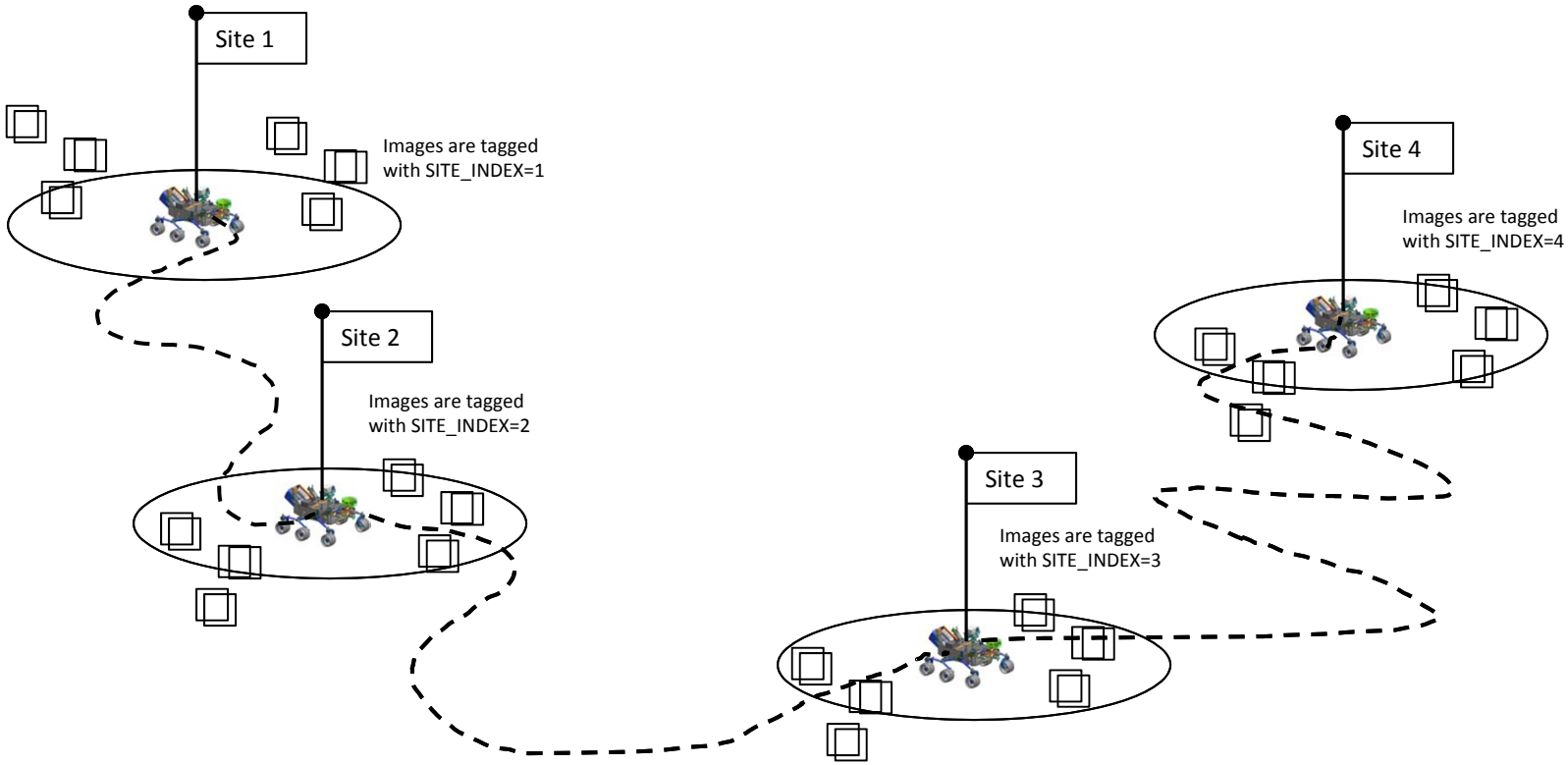
$$(X_{N+1},Y_{N+1},Z_{N+1}) + S_{N,N+1},$$

where $(X_{N+1},Y_{N+1},Z_{N+1})$ is the rover position in Site N+1 and $S_{N,N+1}$ is the vector that describes the position of Site N+1 expressed in Site N frame coordinates.



Multiple Site Frames

- As the rover drives across the Martian surface, it accumulates errors in its position with respect to the local site frame origin.
- When these accumulated errors become large enough (or whenever it is convenient), the rover drivers declare a new site frame by executing a command onboard the rover.
- When a new site frame is declared, the rover position becomes (0,0,0) in the current site frame.
- Often a new site will be declared when acquiring a Navcam 360-degree panorama.



Cartesian (XYZ) versus Angles (az/el)

There are 2 common methods of pointing the cameras within the RNAV and Local Level/Site:

- Cartesian 3-D points (X,Y,Z)
  - Referenced from the coordinate frame origin
- Azimuth and Elevation Angles
  - Referenced from +X axis (azimuth) and X/Y plane (elevation)

Coordinate Type: XYZ

Site Frame (LL) XYZ:

+X is North

+Y is East

-X is South

-Y is West

+Z is down

-Z is up

RNAV XYZ:

+X is Forward

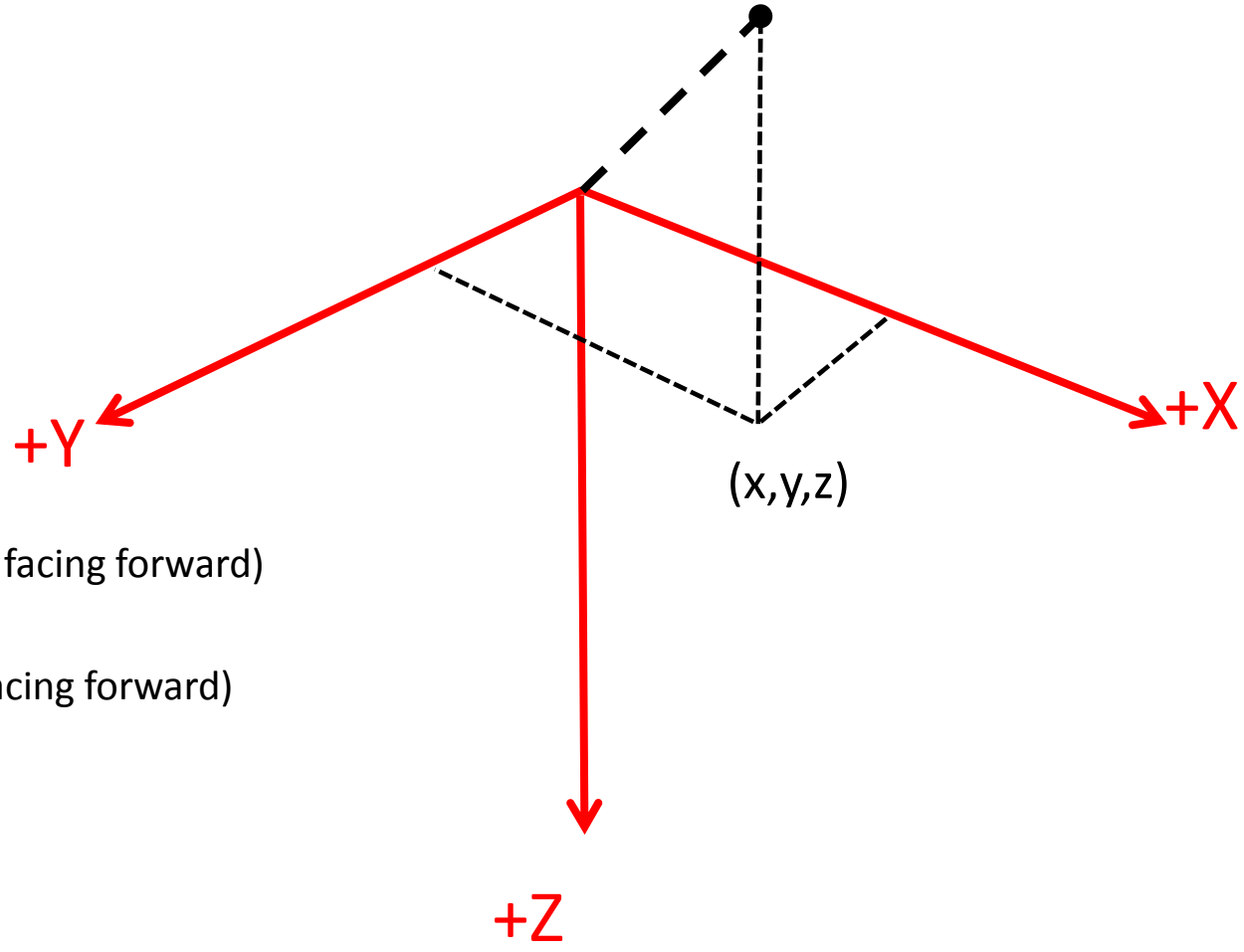
+Y is to the right (when facing forward)

-X is Rearward

-Y is to the left (when facing forward)

+Z is down

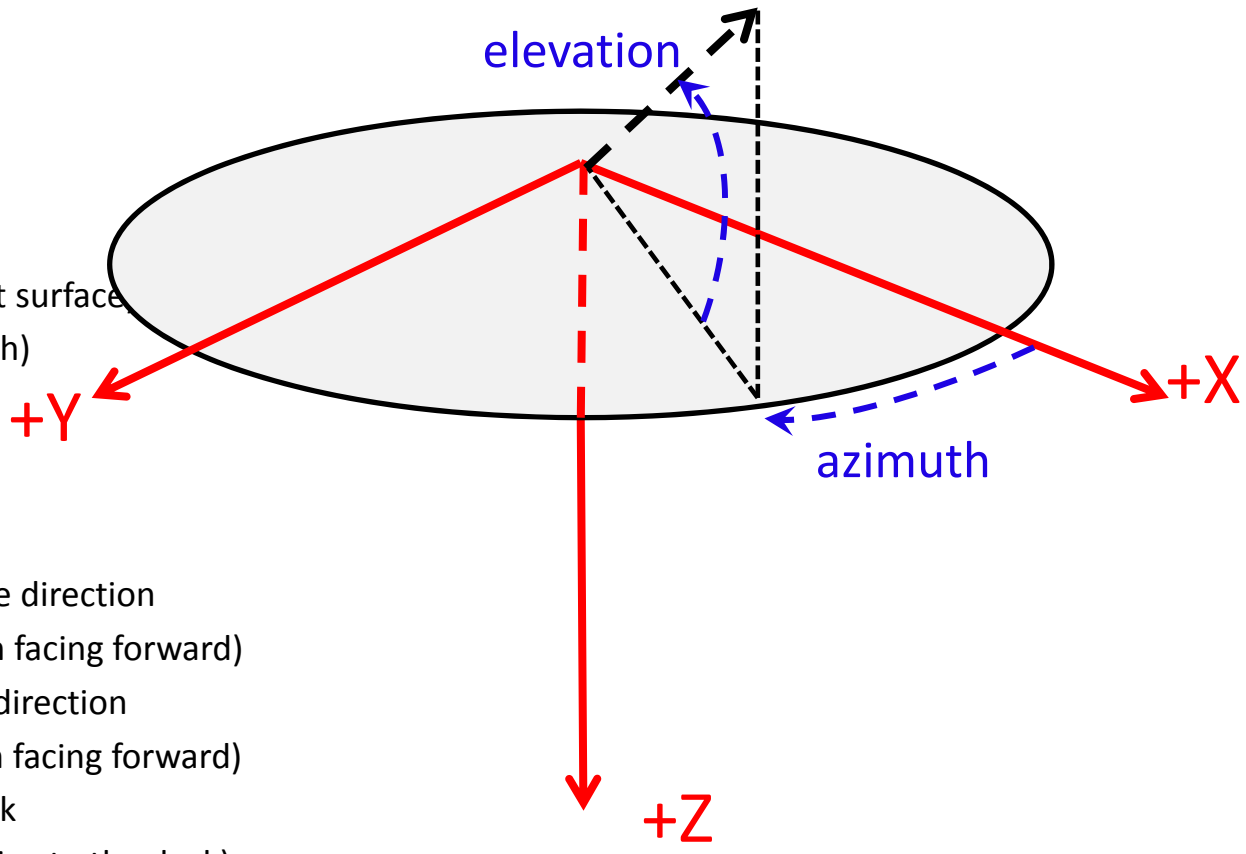
-Z is up



Azimuth/Elevation Angle Definitions

LL az/el pointing:

Azimuth 0 is North
Azimuth 90 is East
Azimuth 180 is South
Azimuth 270 is West
Elevation 0 is at the horizon (flat surface)
Elevation 90 is straight up (zenith)
Elevation -90 is straight down*



RNAV az/el pointing:

Azimuth 0 is in the forward drive direction
Azimuth 90 is to the right (when facing forward)
Azimuth 180 is in the rearward direction
Azimuth 270 is to the left (when facing forward)
Elevation 0 is parallel to the deck
Elevation 90 is straight up (relative to the deck)
Elevation -90 is straight down* (relative to the deck)

*Note: The RSM can only point down to approximately -85 degrees in the RNAV frame.

Note: When using az/el pointing, the boresights are positioned so that they are *parallel* to the corresponding coordinate frame vectors. For example, an LL elevation angle of 0 places the boresight parallel to the LL X/Y plane.

Other coordinate types

In addition to XYZ and AZ/EL absolute pointing, there are other options available:

- AZ/EL RELATIVE pointing can move the camera boresights relative to their current position
  - Example: If the camera is pointed North, a relative azimuth move of +90 degrees will point the camera to the East.
- JOINT Frame pointing (absolute and relative) allows pointing of the cameras using Remote Sensing Mast (RSM) joint angles (measured relative to the RSM joint hardstops)
  - Only used in special circumstances.

Other Rover Operations Coordinate Frames

Frame Type	FRAME	Description
Mobility	WHEEL_LF	Left front wheel
	WHEEL_RF	Right front wheel
	WHEEL_LM	Left middle wheel
	WHEEL_RM	Right middle wheel
	WHEEL_LR	Left rear wheel
	WHEEL_RR	Right rear wheel
	NAV_GOAL	Current rover navigation goal
	NAV_VTT	Visual Target Tracking target
	WHEEL_RR	Right rear wheel
Remote Sensing Mast (RSM)	RSM_BASE	RSM base
	RSM_HEAD	RSM head
	RSM_JOINTS	Joint-space (coordinate type must be JOINTS_ABS)
	NCAML	Left Navcam on active rover computer
	NCAMR	Right Navcam on active rover computer
	RMI	ChemCam Remote Micro Imager
	MCAML	Left Mastcam
	MCAMR	Right Mastcam
	CCAM_CAL	ChemCam calibration target
	MCAM_CAL	Mastcam calibration target
Inertial Vectors	SUN	Sun
	Earth	Earth
	Phobos	Phobos
	Deimos	Deimos

Frame Type	FRAME	Description
SA/SPaH	ARM	Robotic arm base
	TURRET	Robotic arm turret
	MAHLI	MAHLI
	SCOOP_TIP	Scoop tip
	SCOOP_TCP	Scoop tool control point
	PORTION	CHIMRA portioner
	APXS	APXS
	DRILL	Drill
	DRT	Dust removal tool
	ARM_TGT	Arm target
	ARM_GUARDED	Last arm guarded move
	DROPOFF	CHIMRA dropoff frame
	SAM1	SAM inlet 1
	SAM2	SAM inlet 2
	CHEMIN	Chemin inlet
	OCM1, OCM2, etc.	Indexed Organic Check Material
	TRAY	observation tray
Other Body Mounted	RAD	RAD instrument on the rover deck
	REMS_UV	REMS UV sensor on the rover deck
	REMS_BOOM1	REMS Boom 1
	REMS_BOOM2	REMS Boom 2
	HCAML	Left Hazcam on active rover computer
	HCAMR	Right Hazcam on active rover computer
	FIDUCIAL	Indexed fiducials