High Gain Antenna Pointing on the Mars Exploration Rovers

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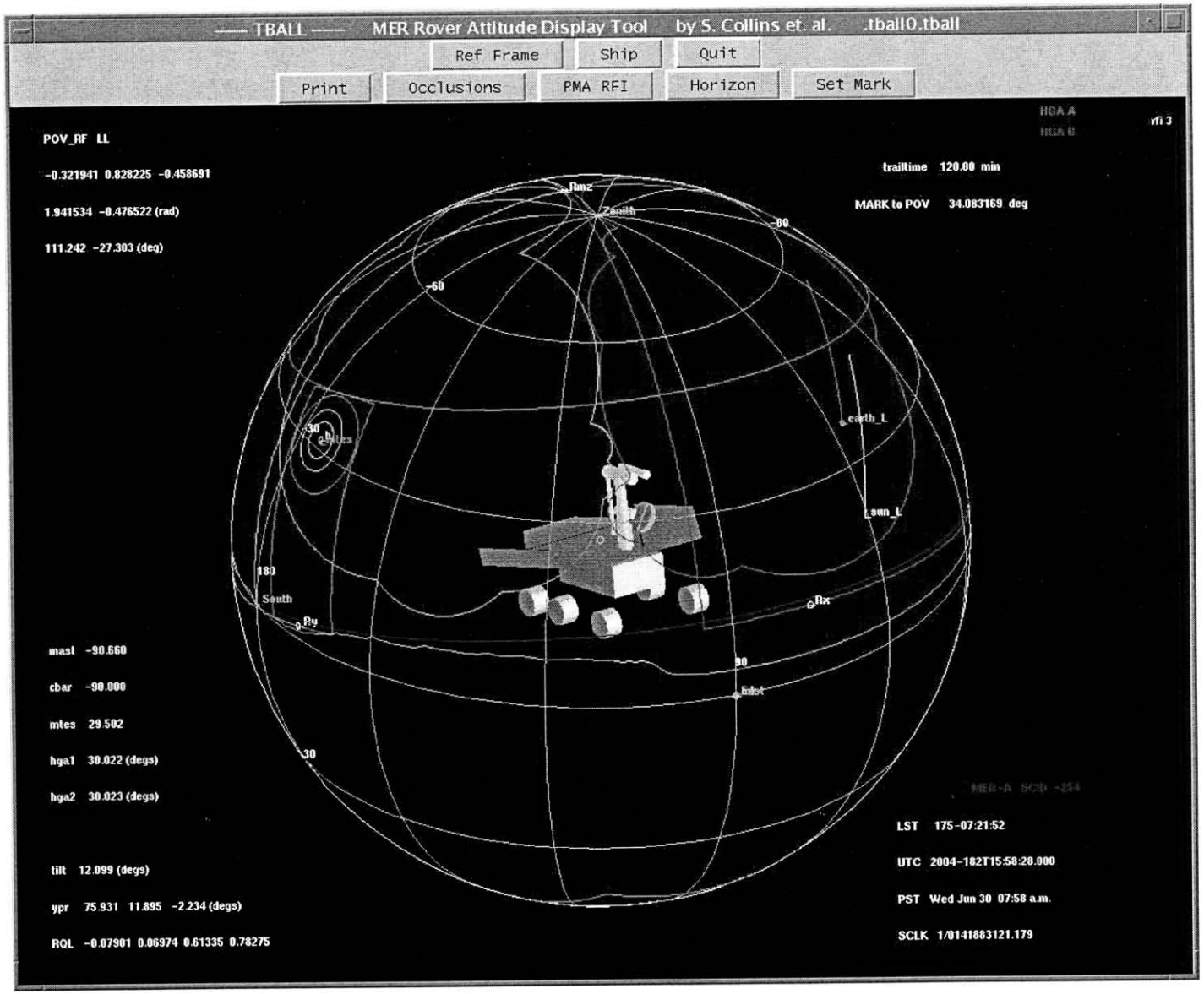
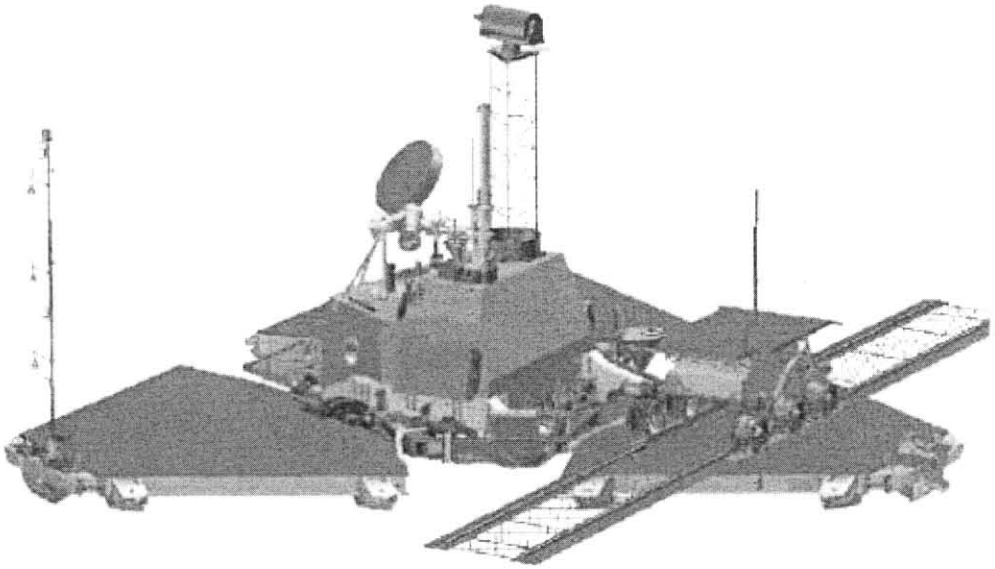
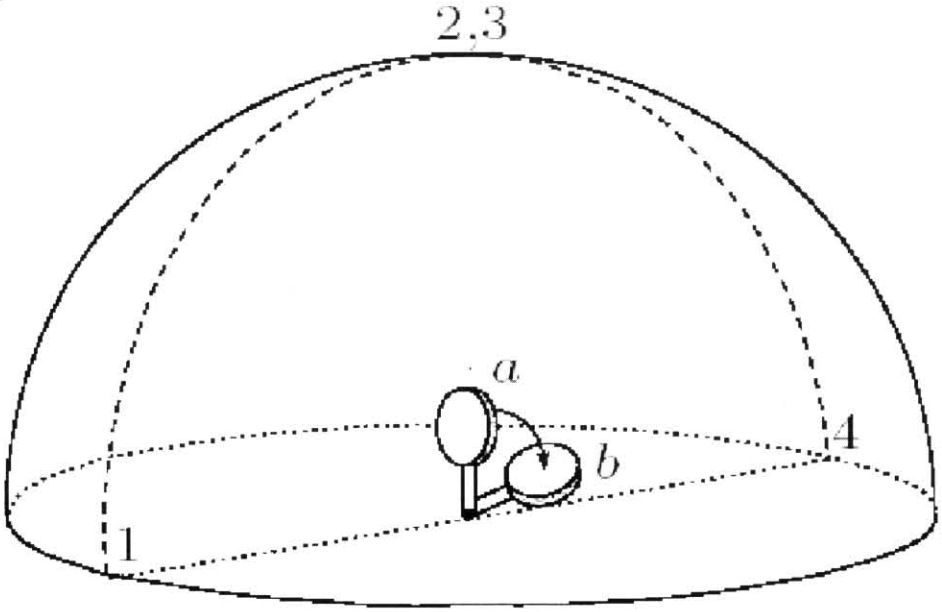
The Rover within the Celestial Sphere

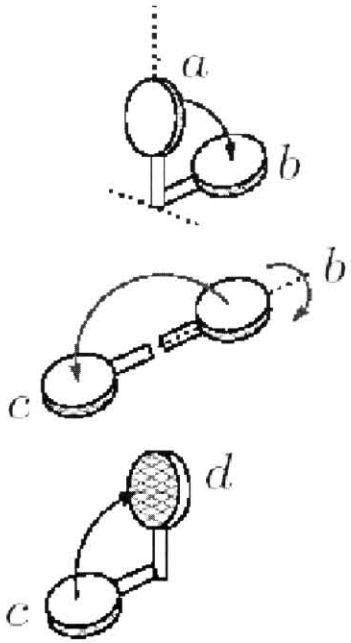
Mars Exploration Rover



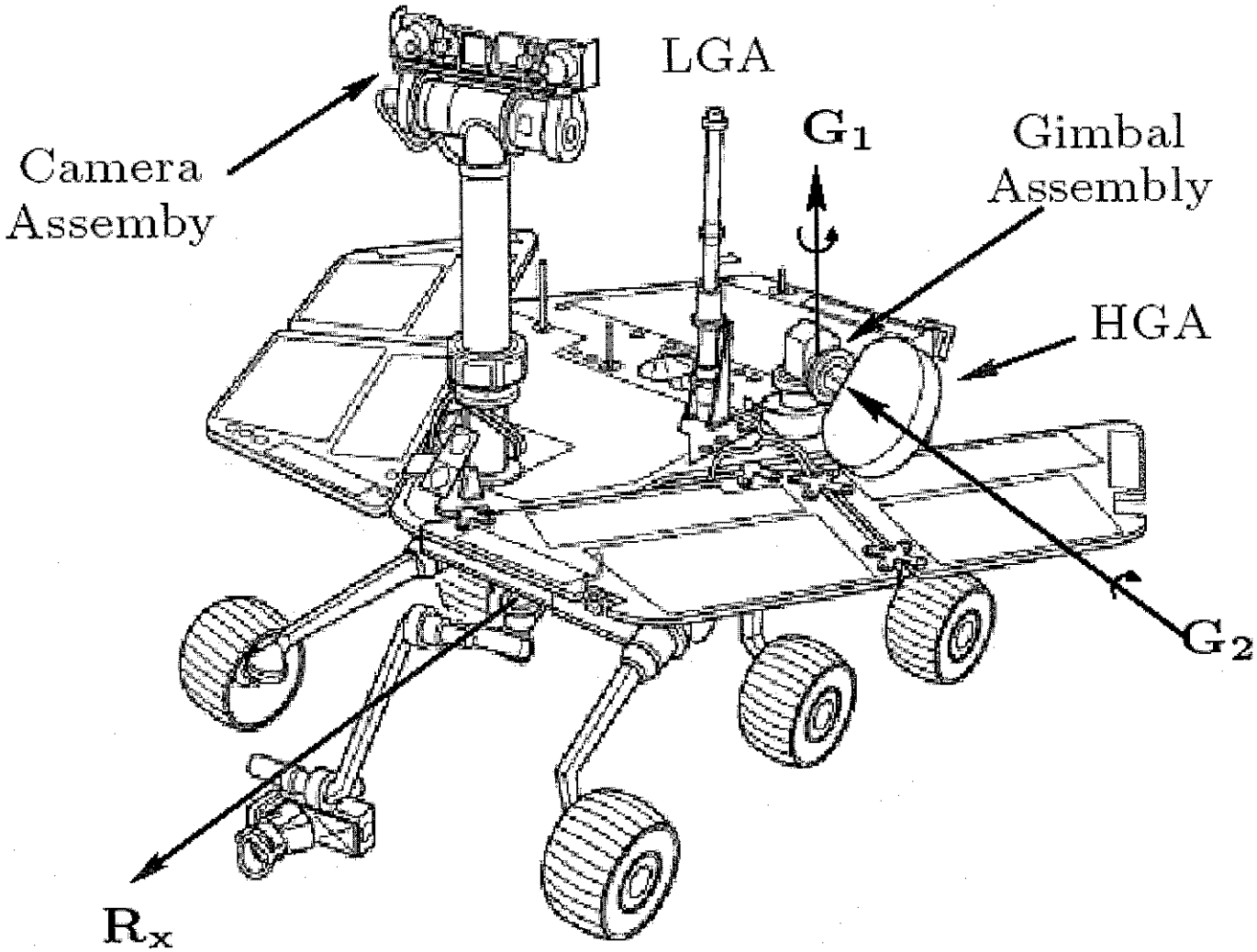
A Overview of Flops on Mars Pathfinder



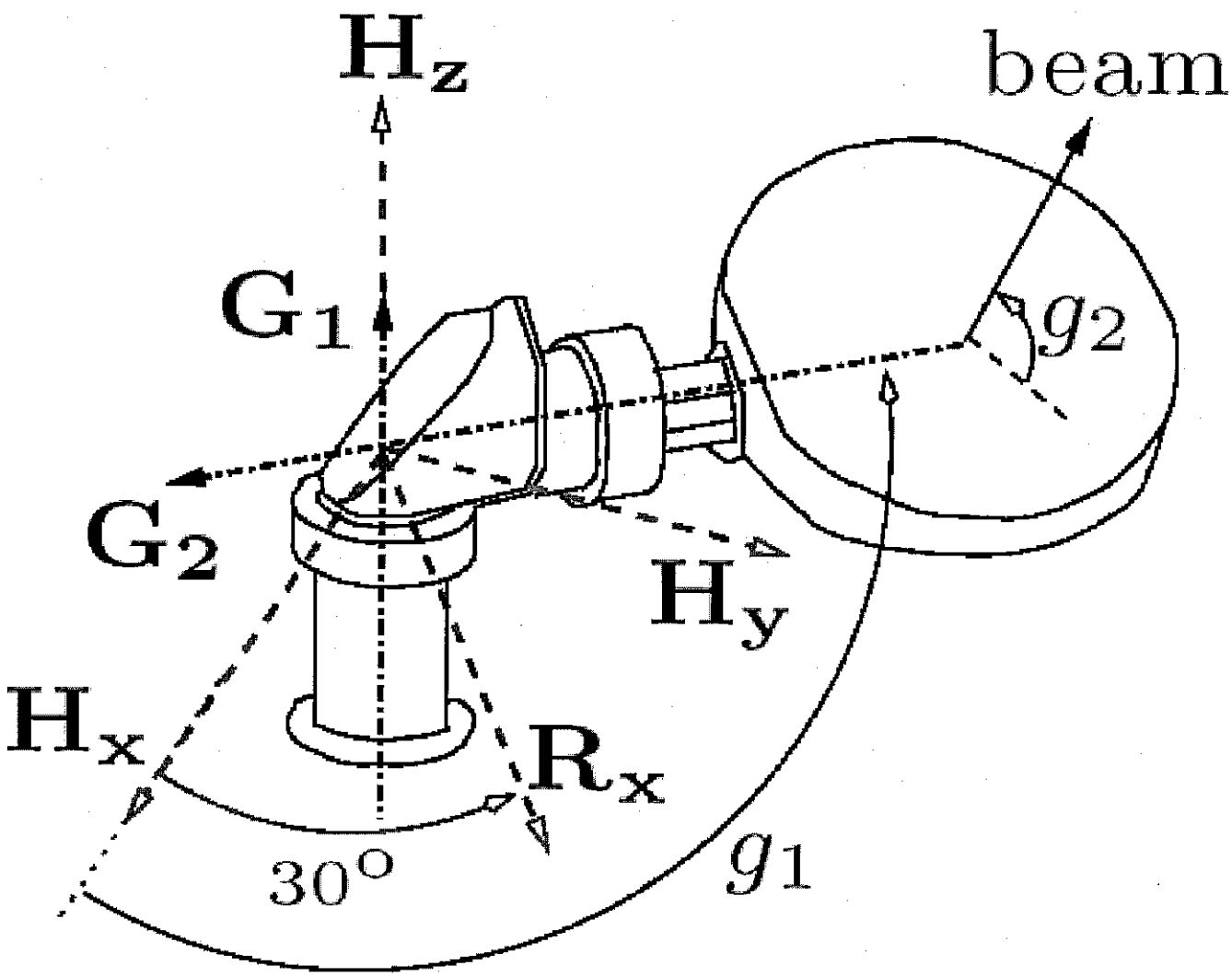




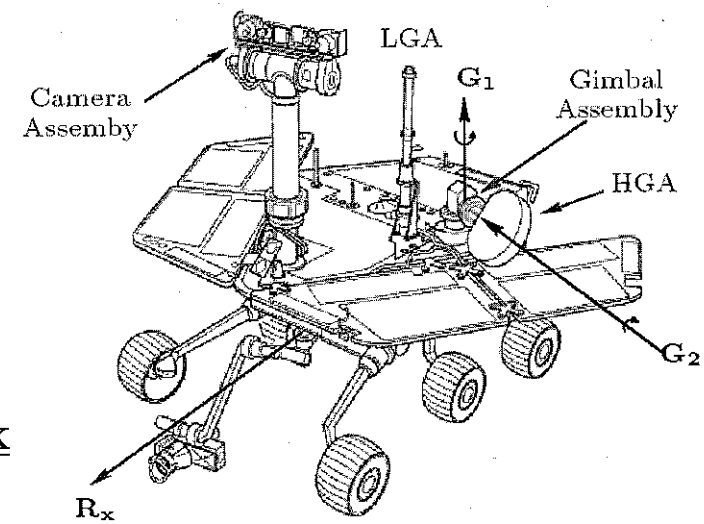
Mars Exploration Rover



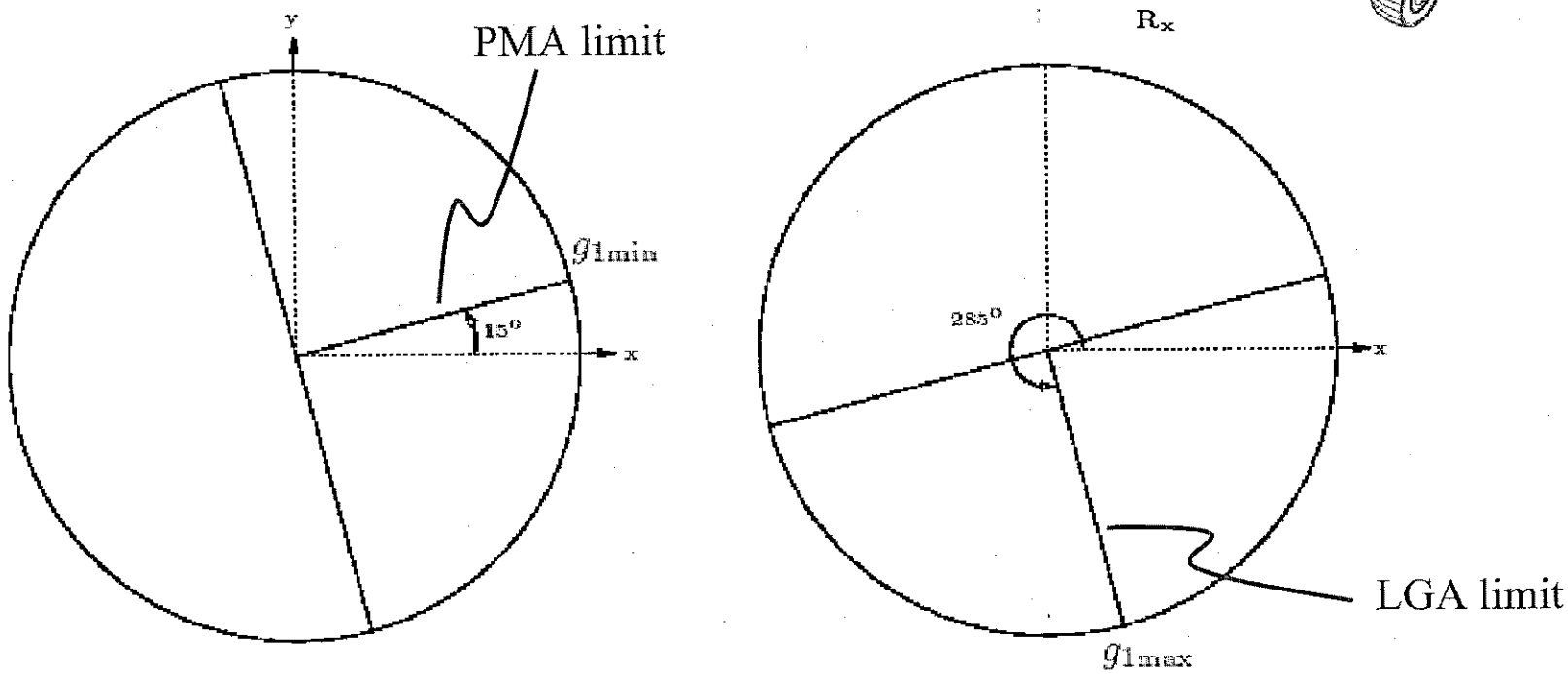
High Gain Antenna Assembly



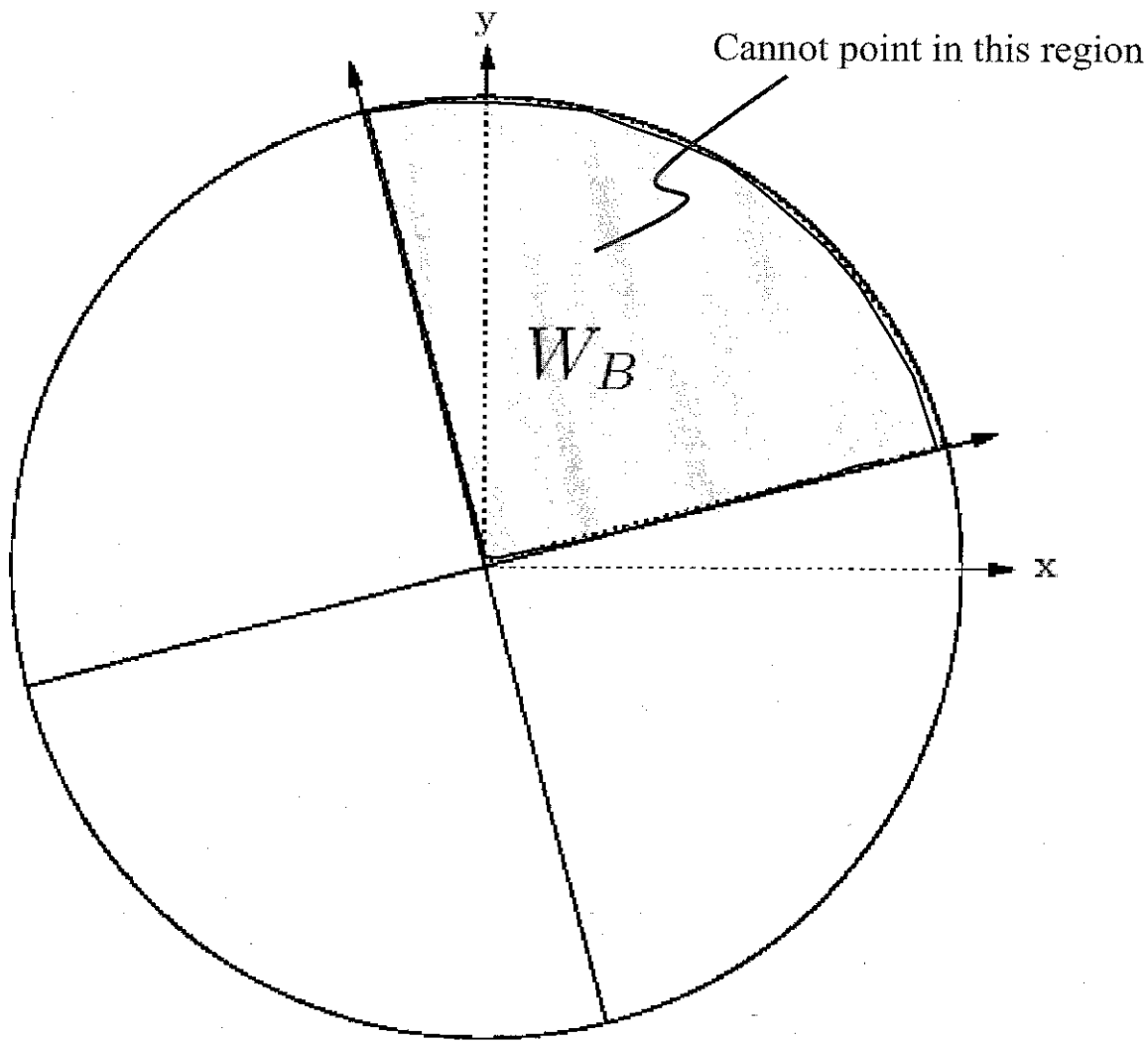
HGA Azimuth ("pan") Motion Limits



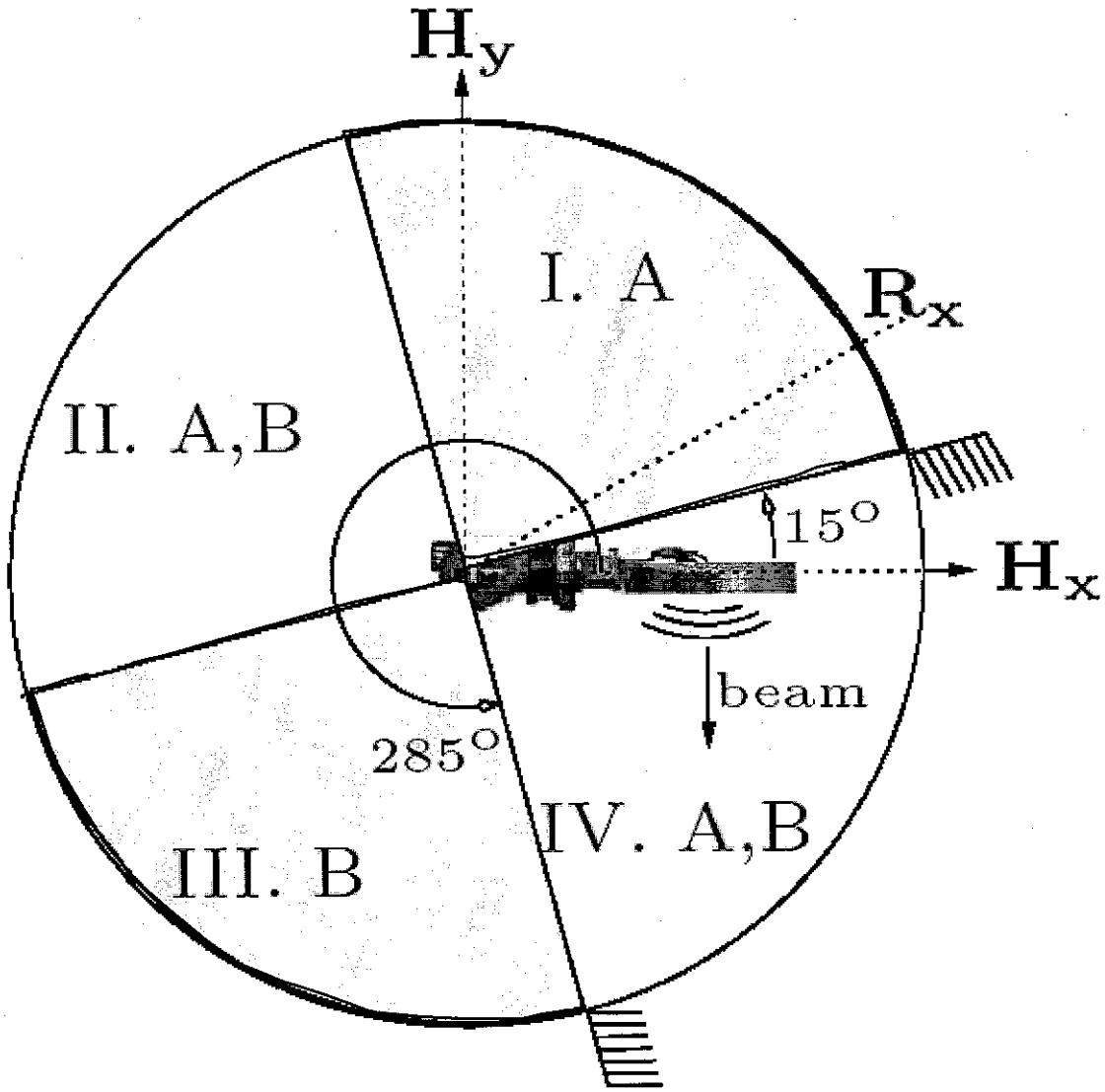
Limits on Azimuth motion as seen from above the rover deck



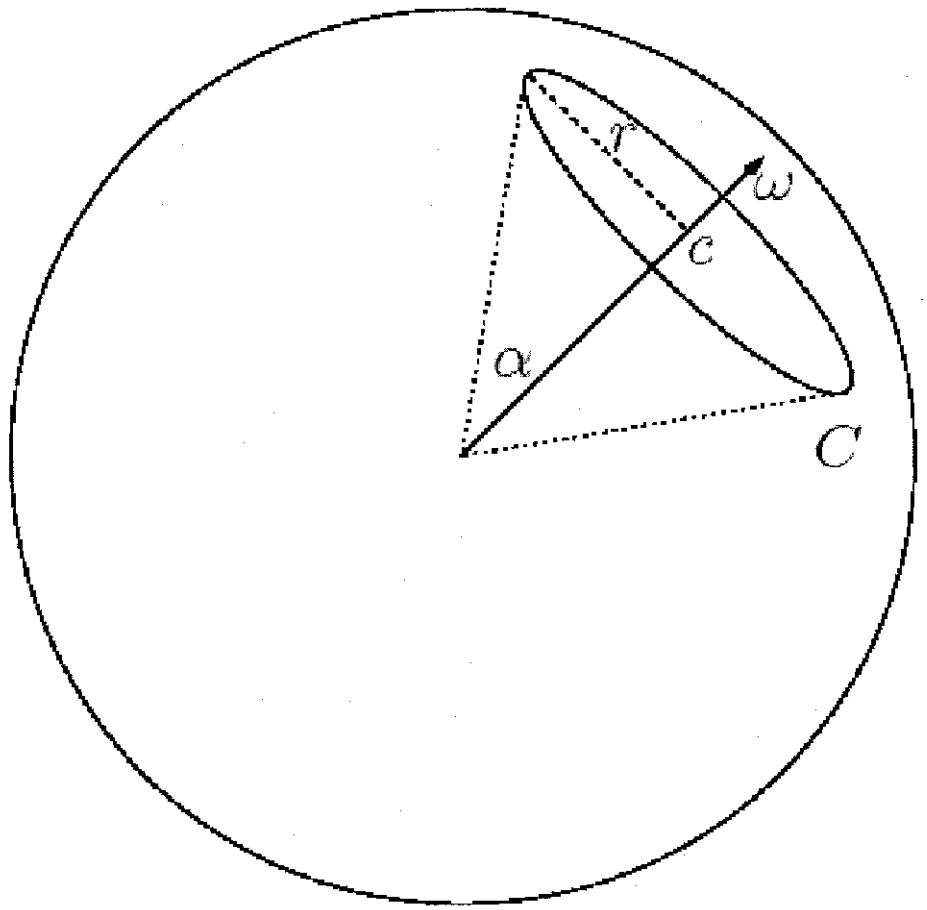
Inadmissible Region "B"



Admissibility Map from Motion Limits

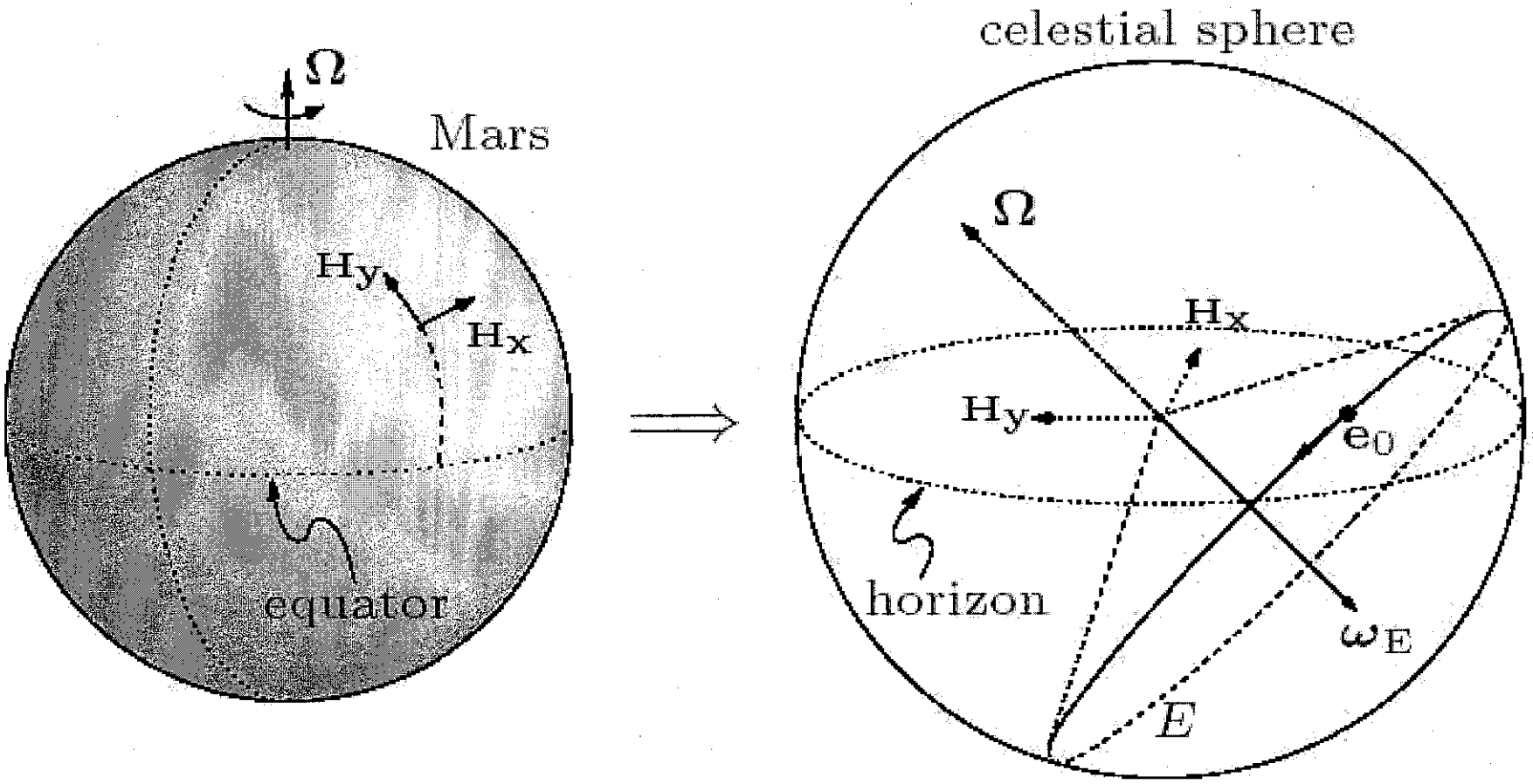


Basic Spherical Circle - Notation

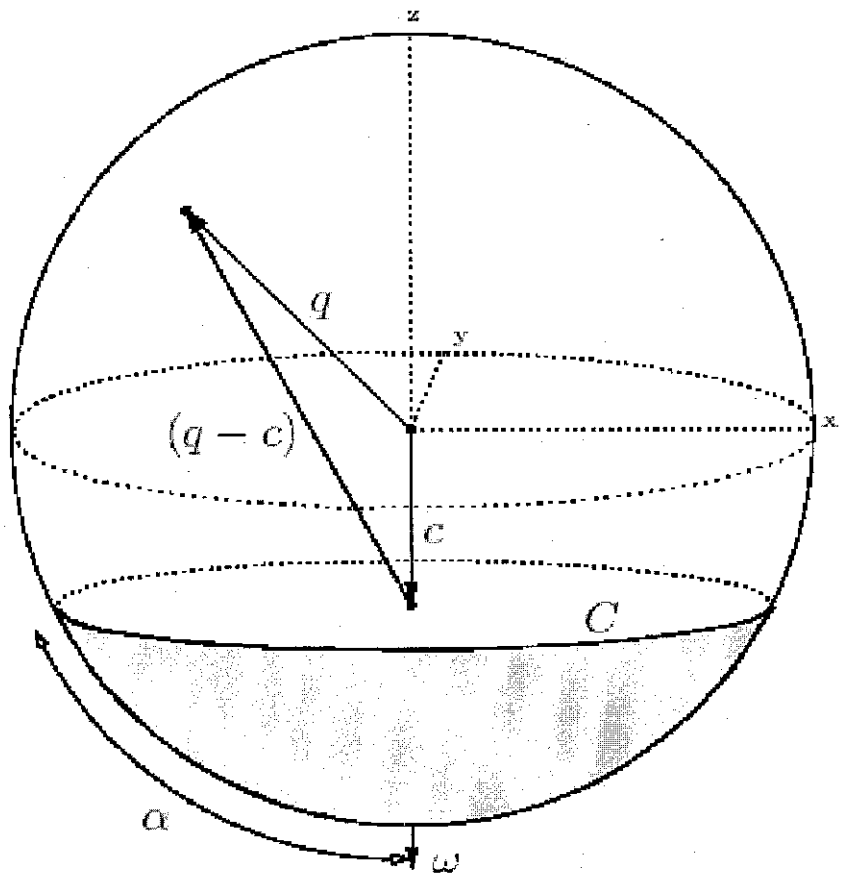


Circle C with axle ω and half-angle α

Earth Trajectory as seen from Rover POV



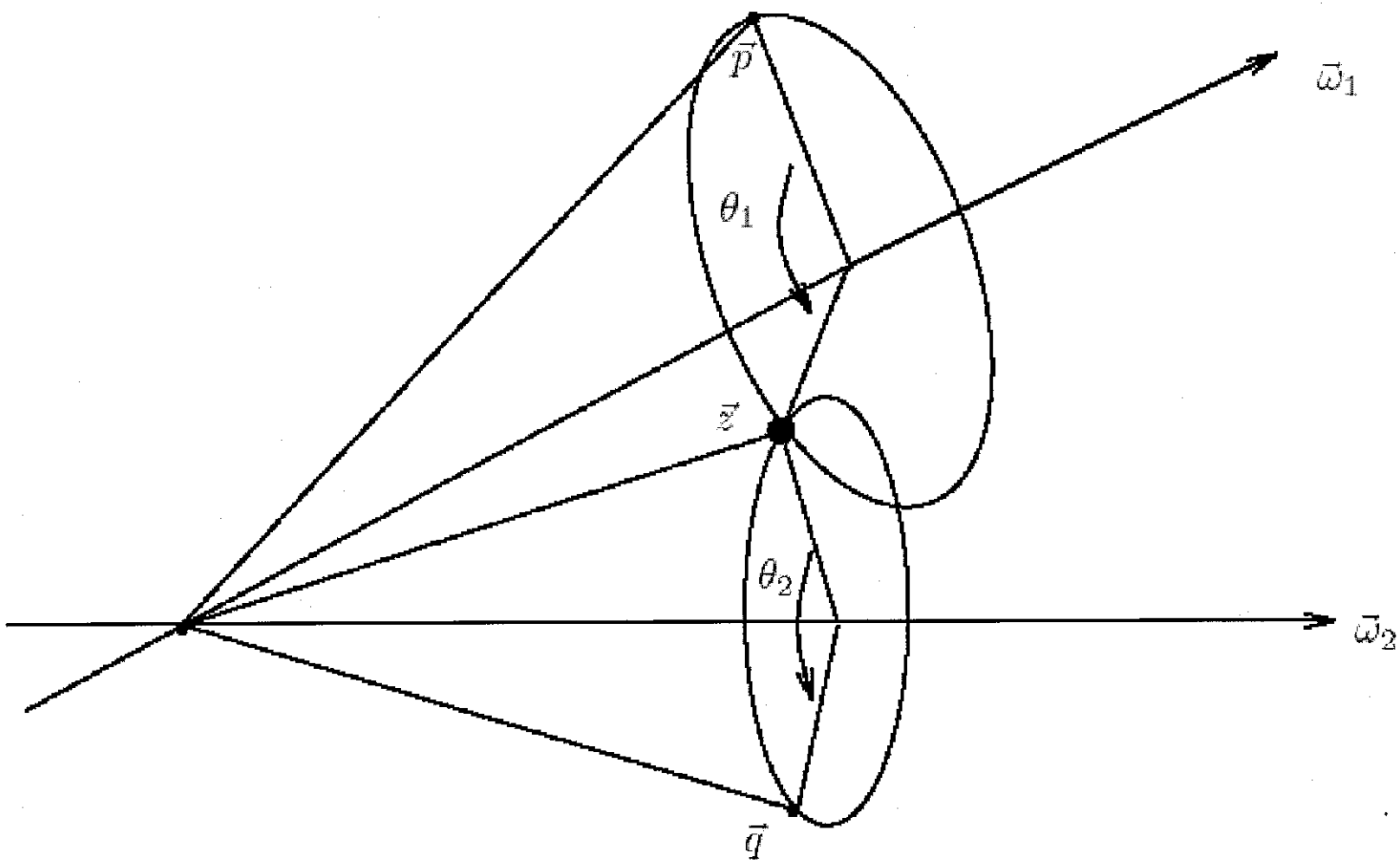
Basic Occlusion Definition



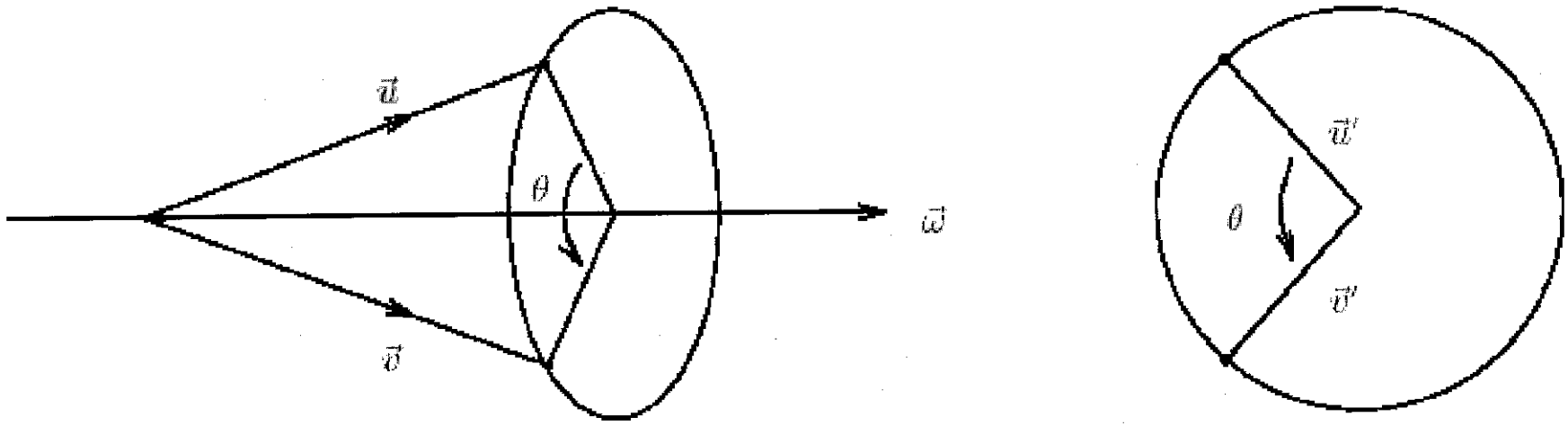
Occlusion circle C with test point q.

$$(q-c)\cdot\omega \geq 0 \Rightarrow q \text{ is inside } C.$$
$$(q-c)\cdot\omega < 0 \Rightarrow q \text{ is outside } C.$$

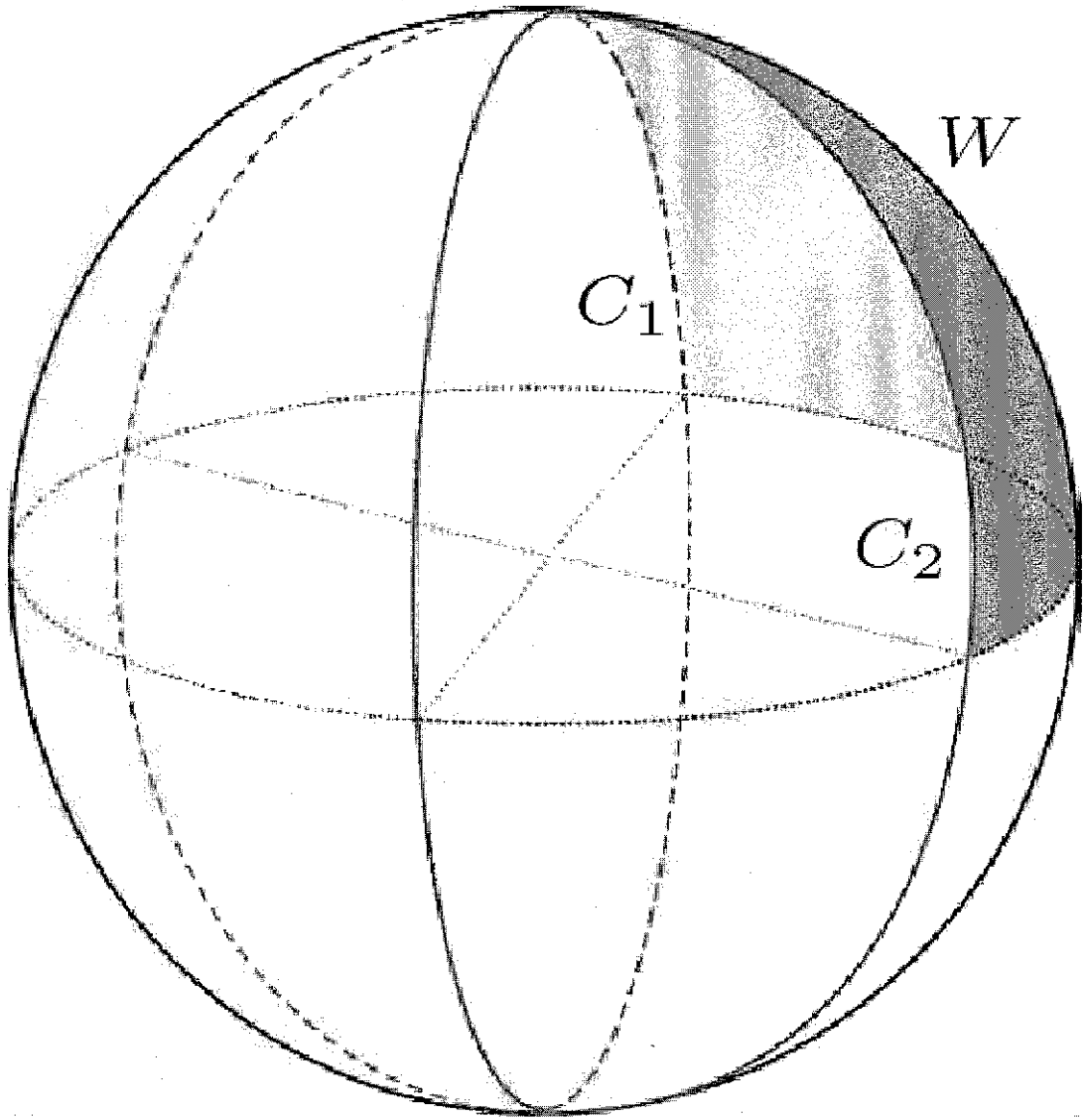
Paden-Kahan Solution #2 - illustrated



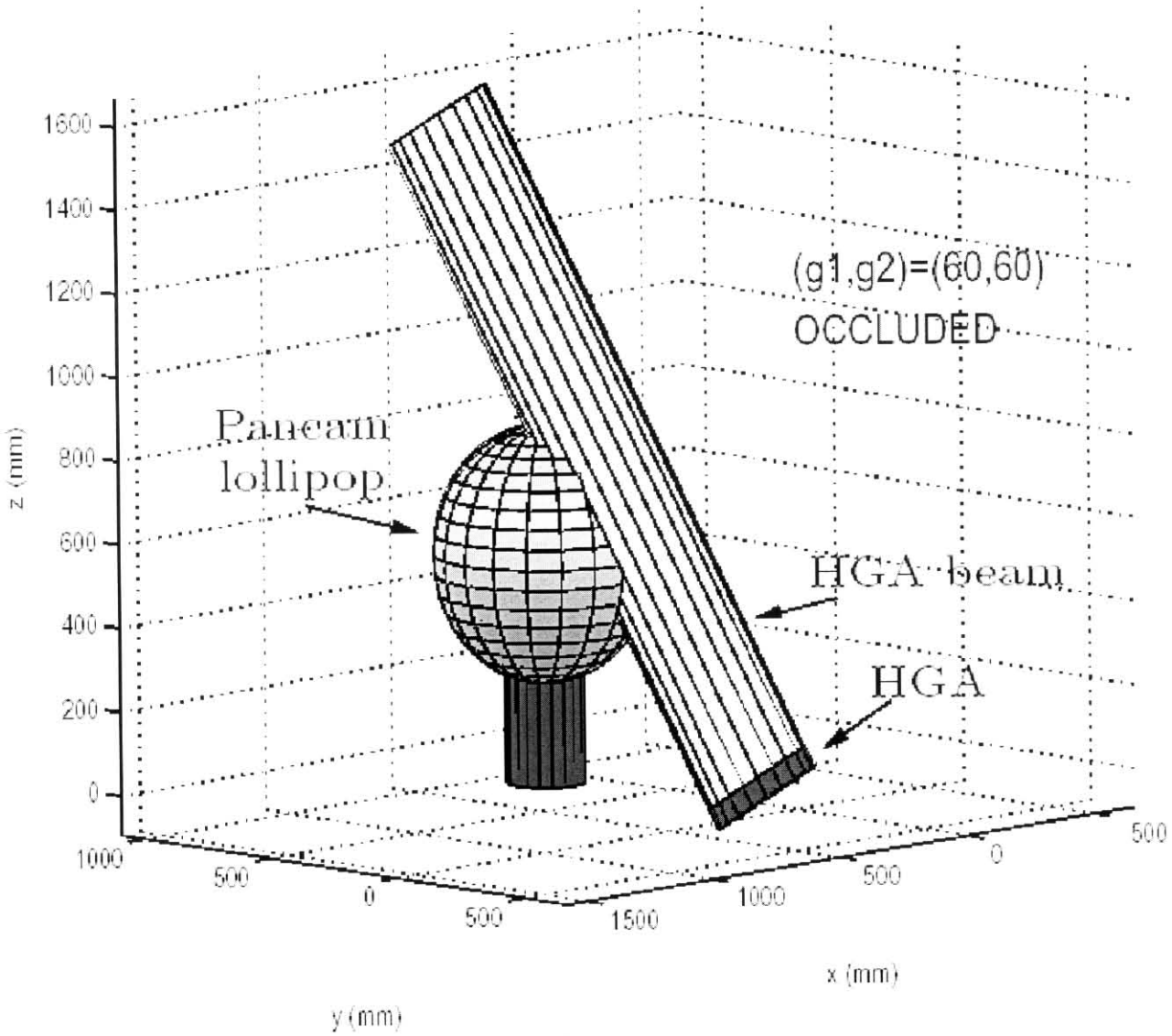
Paden-Kahan Solution #1 - Illustrated



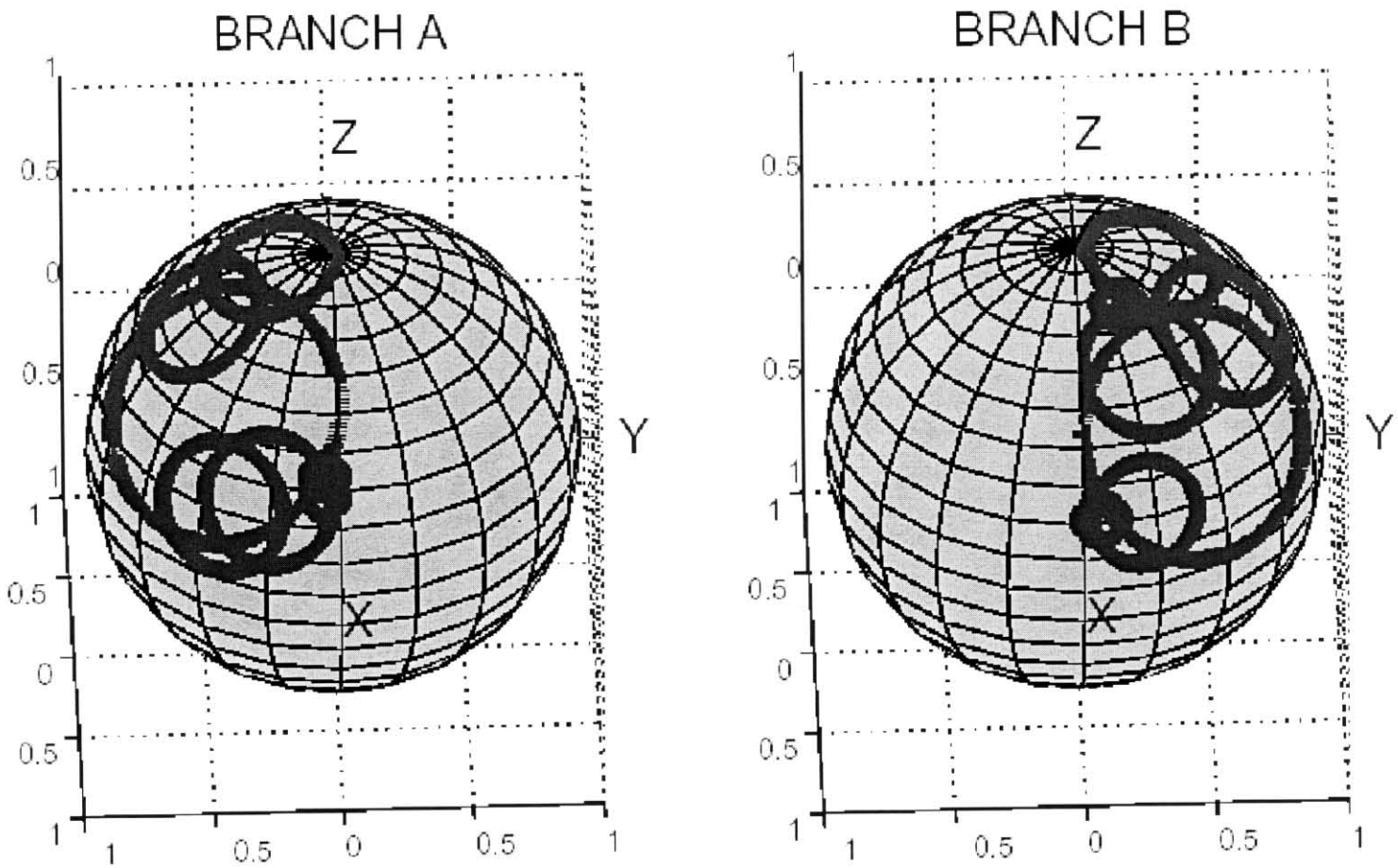
Wedge Occlusion



Constructing the PMA Meld Occlusions



PMA Meld Occlusions



Branch Selection Logic

At the beginning of a communication session, the HGA pointing algorithm computes the incursion times for each of the occlusions and then computes the overall incursion time for each branch using

$$\begin{aligned} t_{\mathrm{A}} &= \min(t_{\mathrm{T}}, t_{\mathrm{D}}, t_{\mathrm{HA}}, t_{\mathrm{PA}}), \\ t_{\mathrm{B}} &= \min(t_{\mathrm{T}}, t_{\mathrm{D}}, t_{\mathrm{HB}}, t_{\mathrm{PB}}). \end{aligned}$$

The algorithm selects whichever branch provides the longest possible time until incursion, and begins tracking the Earth using that branch.

Basic Example (no PMA)

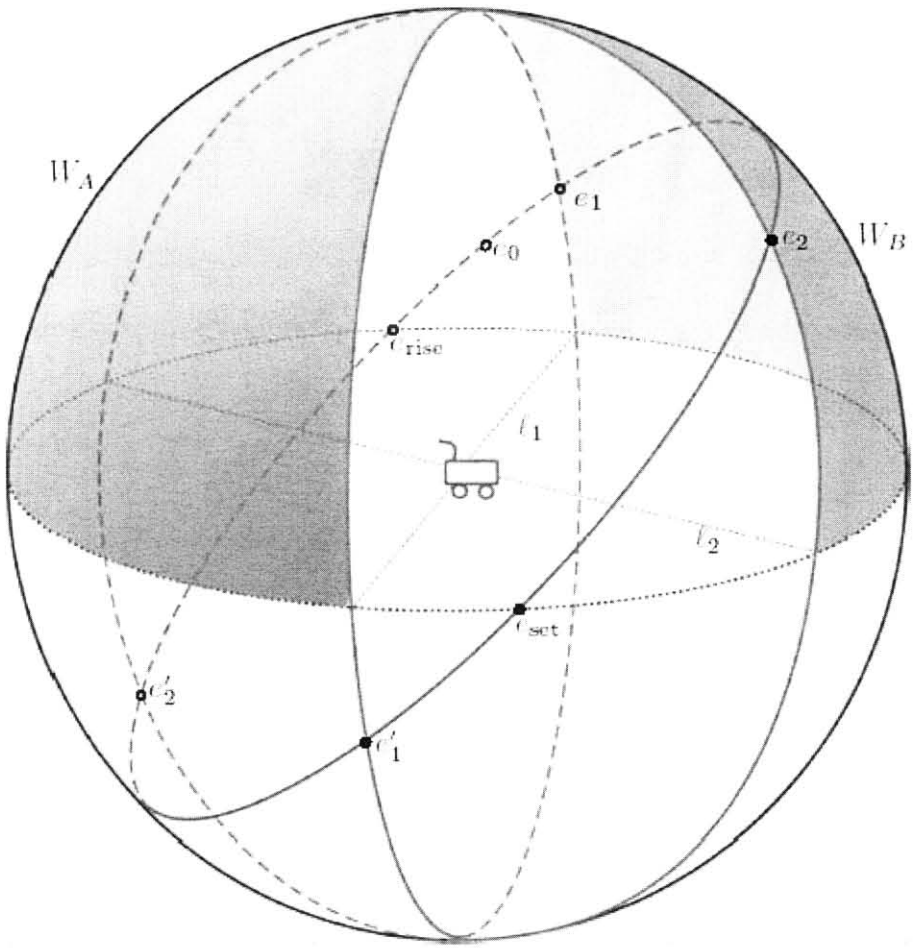


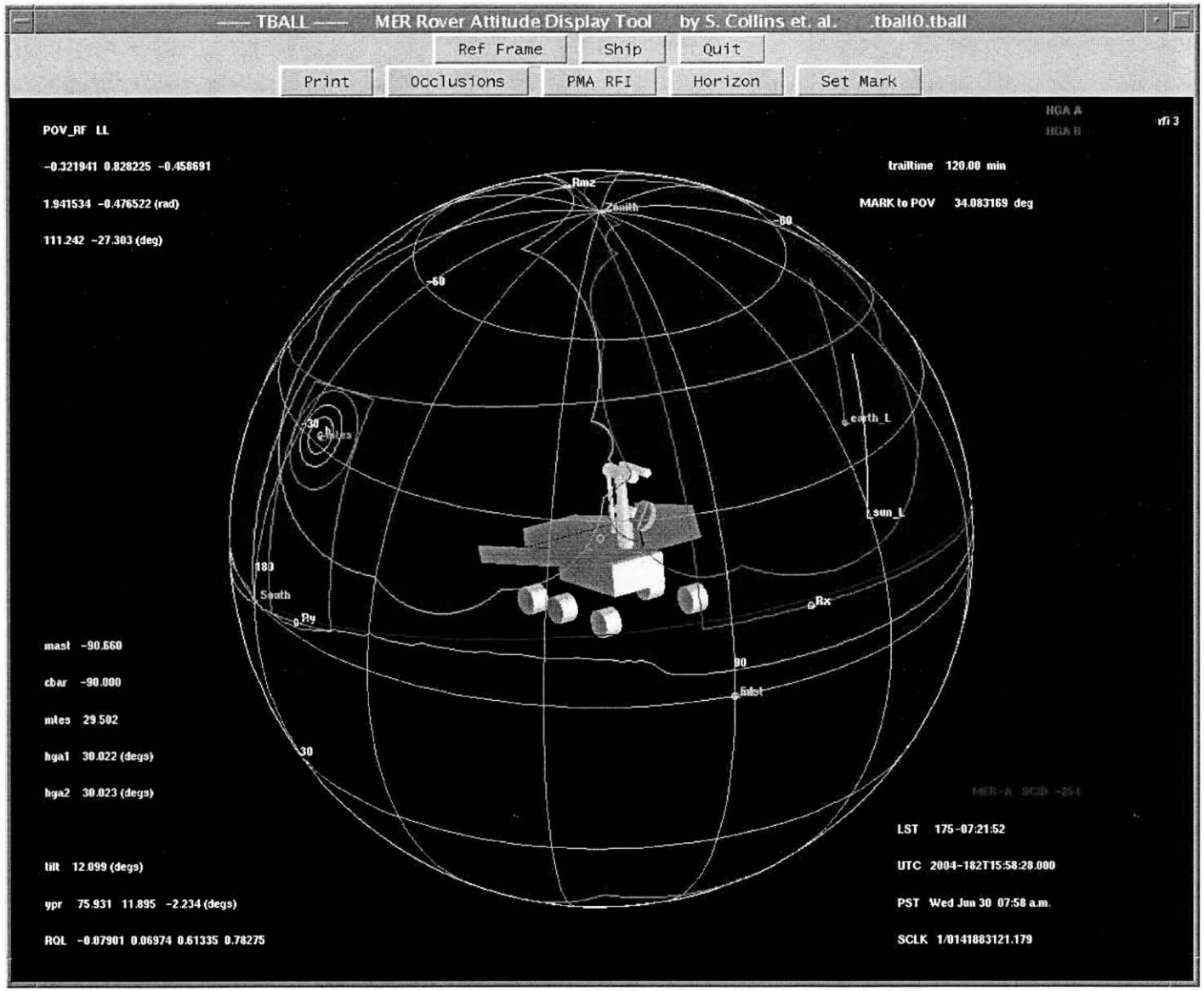
Figure 6: The hardstops create two wedges (indicated as red and green shadows on the sphere between lines ℓ_1 and ℓ_2). The earth trajectory as a function of time is shown starting at position e_0 at time t_0, entering wedge W_B at e_1 and exiting at e_2. For this example, the earth sets before entering the wedge W_A.

Handling Occlusions in Midtrack

If the current branch does become occluded during the course of the track, then the algorithm takes one of the following actions, depending on which occlusion is encountered.

- **Terrain or Deck Occlusion:** The communication session is immediately terminated.
- **Hardstop Occlusion:** The algorithm performs a flop to the alternate branch.
- **Pancam Occlusion:** Rather than flop, for operational reasons the algorithm continues to track but alerts the communications manager to send only realtime health and status data. When the Pancam Occlusion is cleared, the HGA algorithm informs the communications manager that it may resume its normal transmission behavior.

The Complete Occlusion Set



Acknowledgements

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References

[1] C. Anthony Vanelli, *Autonomous Reorientation of a Maneuver-Limited Spacecraft Under Simple Pointing Constraints.* Ann Arbor, Michigan: University Microfilms, 1997.

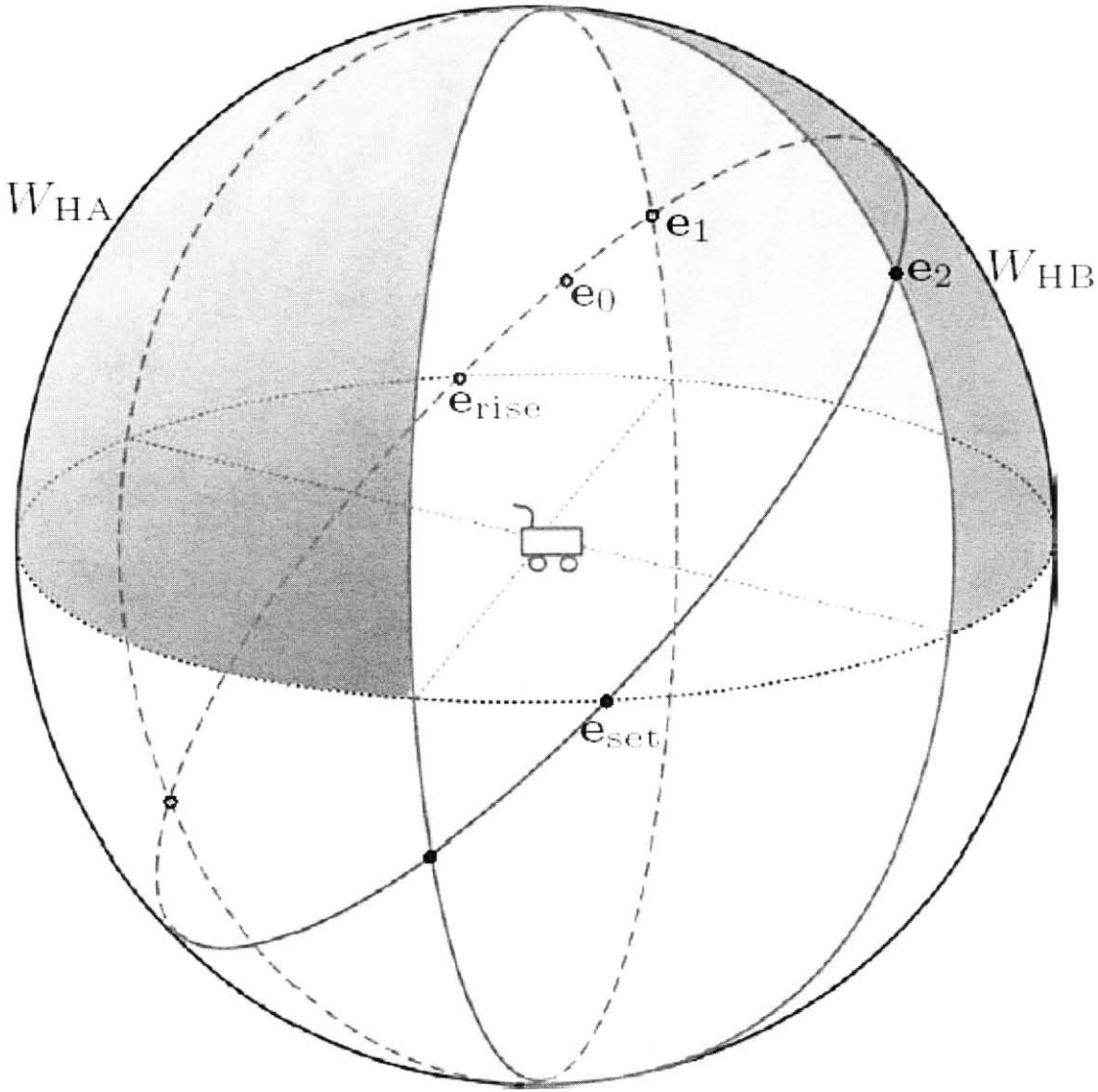
[2] Richard M. Murray, Zexiang Li, S. Shankar Sastry, *A Mathematical Introduction to Robotic Manipulation*, CRC Press, Ann Arbor, 1994.

[3] Erwin Kreyszig, *Advanced Engineering Mathematics,* John Wiley & Sons, New York, 1967.

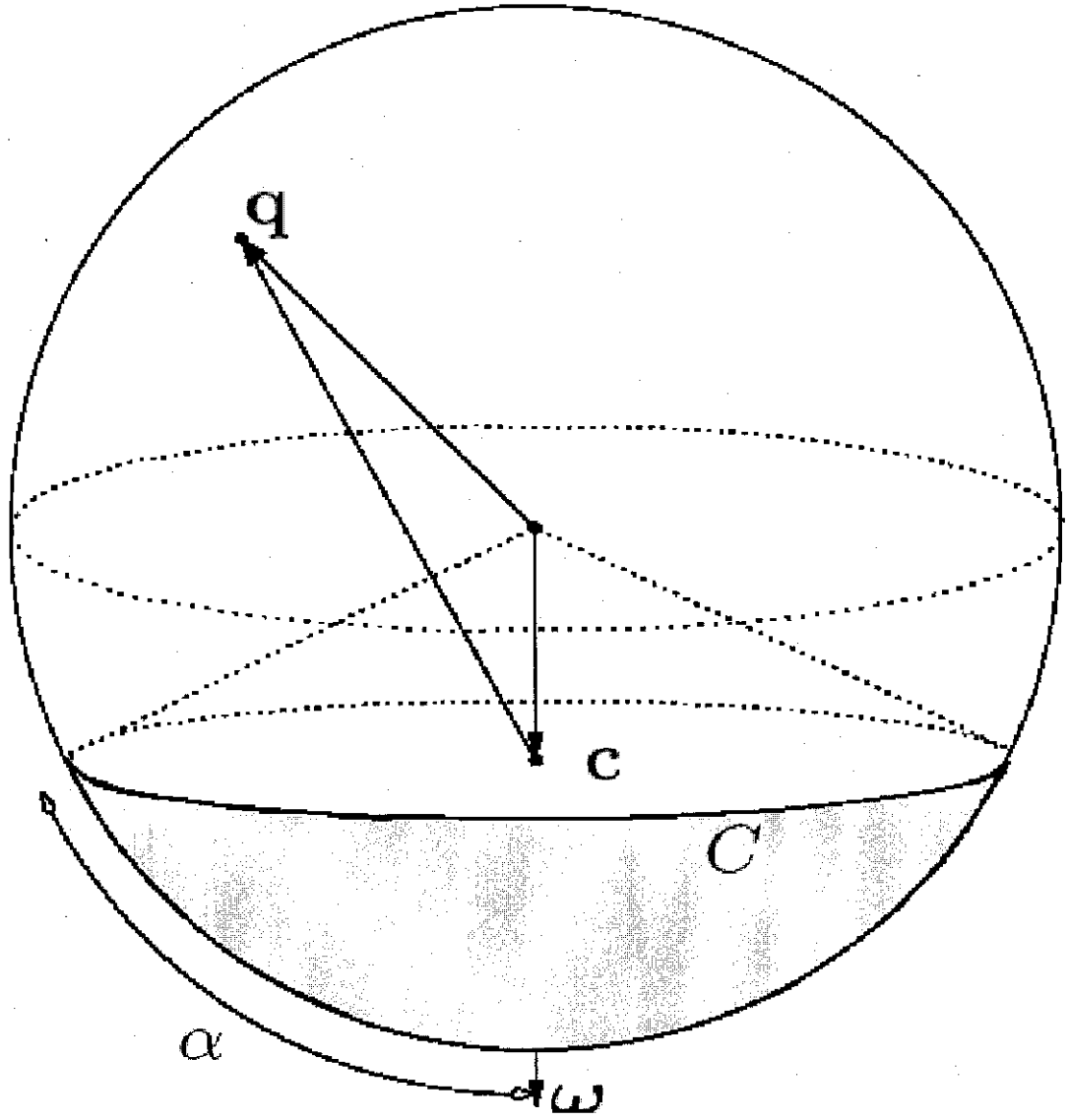
[4] Peter C. Hughes, *Spacecraft Attitude Dynamics,* John Wiley & Sons, New York, 1986.

Backup Slides

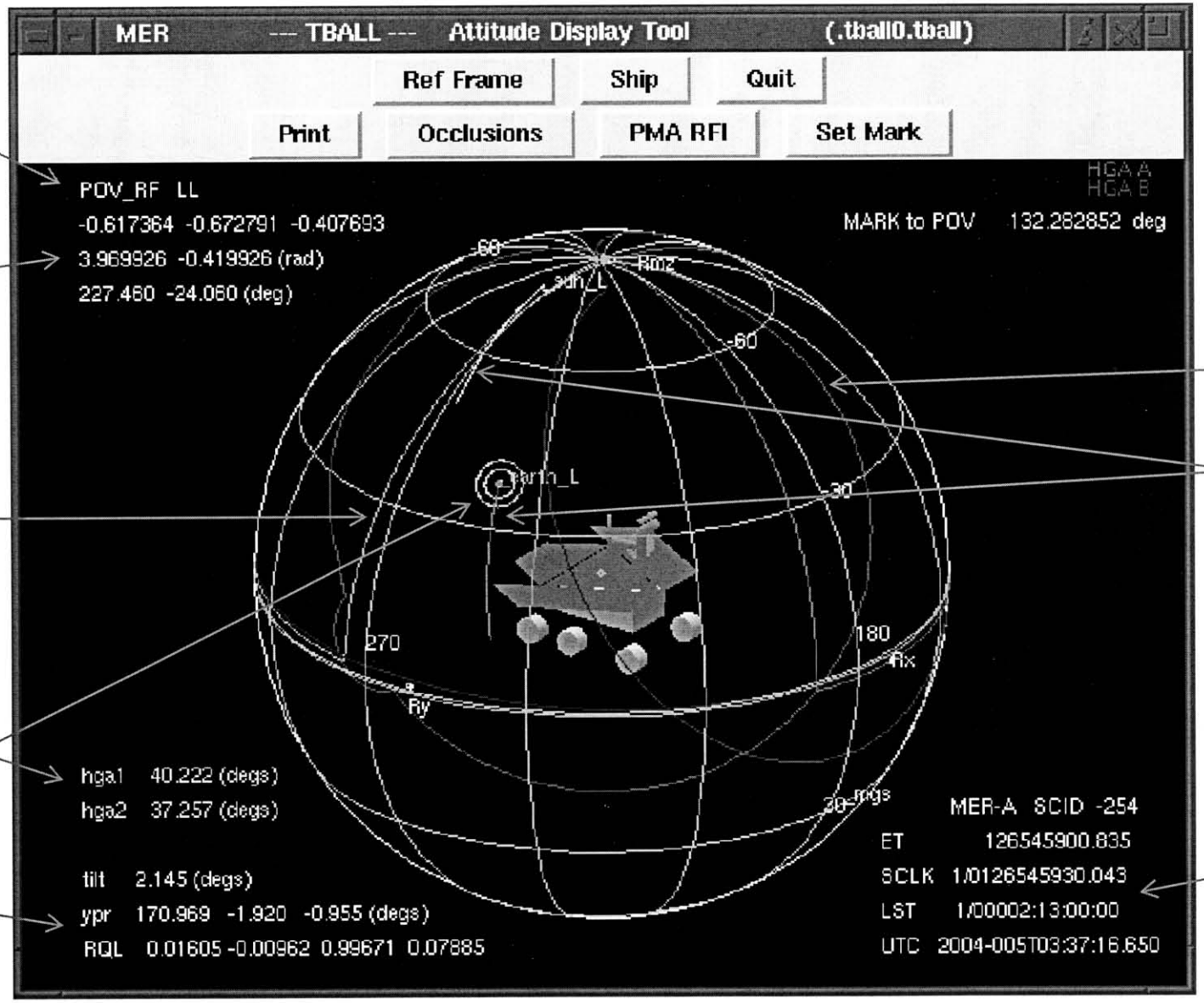
Backup - Example



Backup



TBALL - MERA SOL2 HGA geom



Crude mapping of PMA RFI

Sun, Earth plotting, with future trajectory

(Note earth obscured by PMA)

HGA hardstop limits for each HGA pointing solution ("branch")

HGA boresight and gimbal angles

Attitude knowledge

Times in all the useful timebases