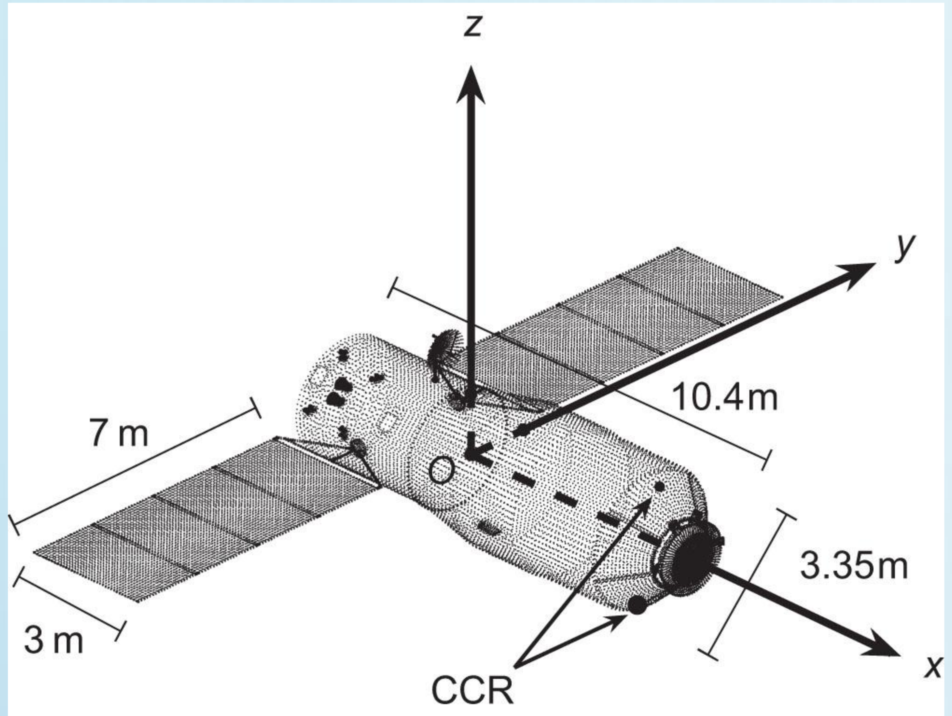
SLR OBSERVATION OF TIANGONG-1

HOU-YUAN LIN[1], TING-LEI ZHU[1], ZHI-PENG LIANG[2], CHANG-YIN ZHAO[1*], DONG WEI[1], WEI ZHANG[1], XING-WEI HAN[2], HAI-FENG ZHANG[3], ZHI-BIN WEI[4], YU-QIANG LI[5]

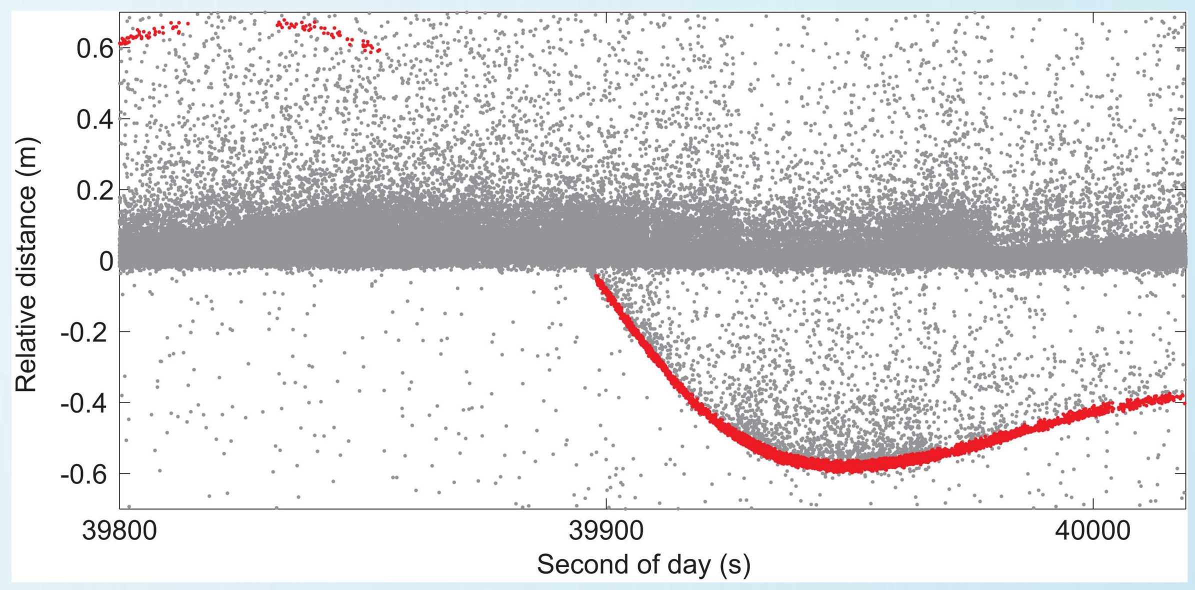
[1]PURPLE MOUNTAIN OBSERVATORY, CAS, NANJING 210034, CHINA.
[2]CHANGCHUN OBSERVATORY, NATIONAL ASTRONOMICAL OBSERVATORIES, CAS, CHANGCHUN 130117, CHINA.
[3]SHANGHAI ASTRONOMICAL OBSERVATORY, CAS, SHANGHAI 200030, CHINA.
[4]CHINESE ACADEMY OF SURVEYING AND MAPPING, BEIJING 100830, CHINA.
[5]YUNNAN OBSERVATORIES, CAS, KUNMING 650216, CHINA.

*CORRESPONDENCE TO: CYZHAO@PMO.AC.CN

•Observations

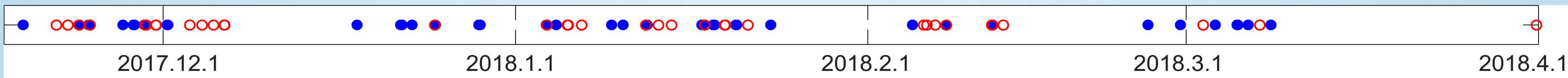


- The main body of Tiangong-1 is 10.4 m in length with a maximum diameter of 3.35 m and a weight of 8.5 t. A body-fixed coordinate system is established with the center of mass as the origin O. The three coordinate axes are along the principal axes of inertia I_x, I_y, I_z.
- Tiangong-1 is equipped with **two corner cube reflectors** (CCR) on the docking interface, which can be used for satellite laser ranging (SLR).

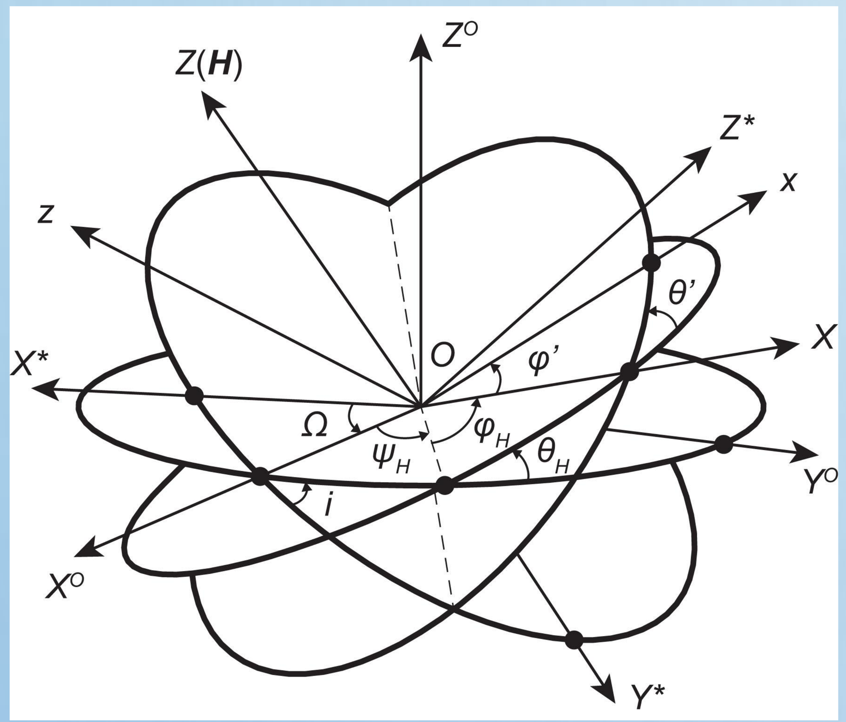


- An example of SLR data of Tiangong-1 on January 18, 2018 at UTC 11.1 h. **The abscissa** is the second of day and **the ordinate** is the relative distance ΔP from the large CCR to the small one. **The gray data** are measured from the large CCR with background noise. **The red** marks the signals from the small CCR. **This change in distance is due to the combined effect of changes in the observation direction and the satellite attitude.**

- A summary of all observations before re-entry. **Blue dots** contain two reflector data, and **red hollows** have single reflector data.



•Rotational state estimation methods

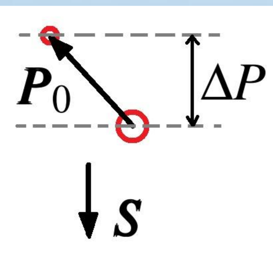


- Based on the rotational motion model with 6 unknown parameters H, ψ_H, ϑ_H, φ_H, ϑ', and φ' (Lin et al., 2016), and the known orbital elements, we can establish the transformation between **the body-fixed coordinate system** and **the inertial coordinate system**.

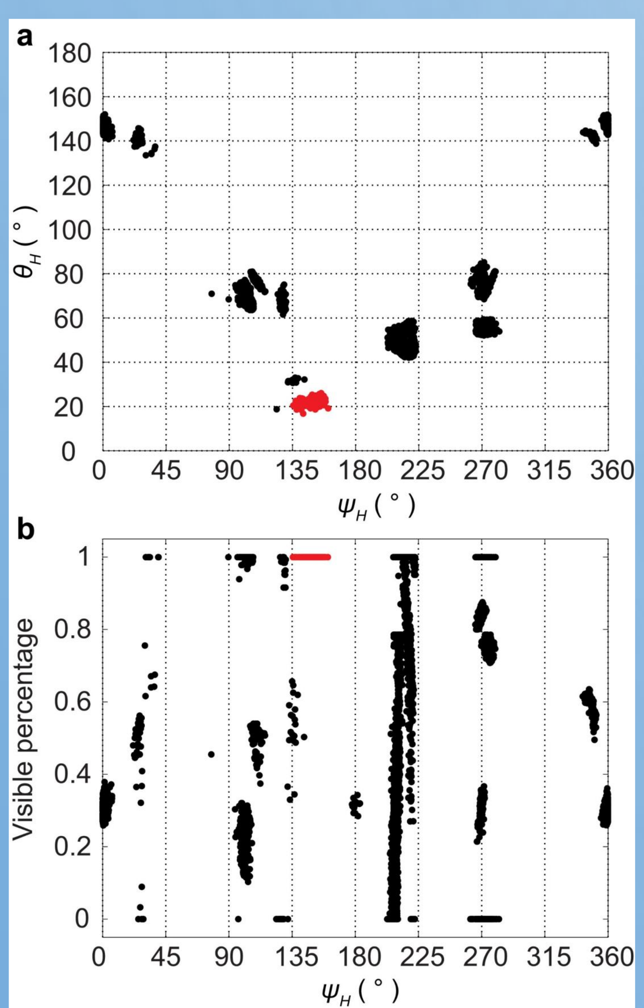
- Then the relative distance of the two CCRs is written as

$$\Delta P = -\boldsymbol{S} \cdot \boldsymbol{P}_0$$

where $\boldsymbol{P}_0$ is the relative vector from the large CCR to the small one, $\boldsymbol{S}$ is the unit vector to the observation station.



- **A rotational motion mode can be obtained using a genetic algorithm that satisfies the changes in ΔP in the observation data .**



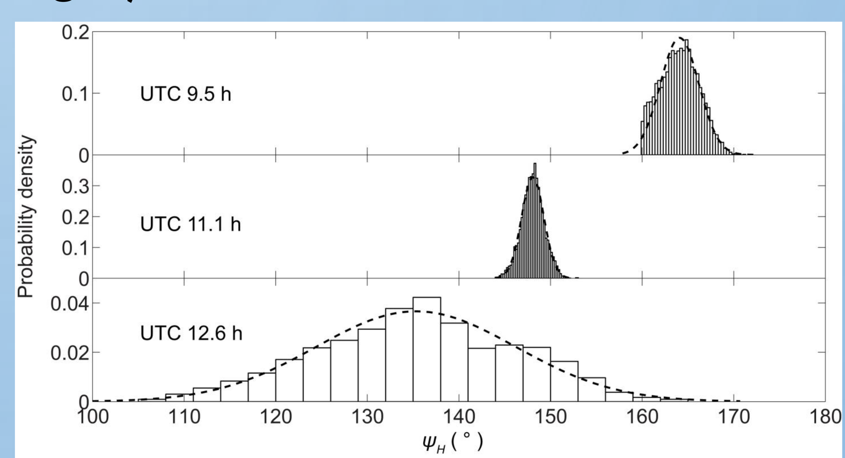
- Usually, multiple possible solutions are obtained for the data from a single pass. **Fig. a** shows the solutions for two main parameters ψ_H and ϑ_H, which are the spherical coordinates of the self-spin angular momentum $\boldsymbol{H}$ in the orbital plane system. Hence, we need to screen all solutions to eliminate false ones, including inspecting the visibility of the CCRs in the observation geometry (**Fig. b**) and comparing the results from other adjacent passes. This process eventually yielded a certain orientation of the angular momentum (**red region**).

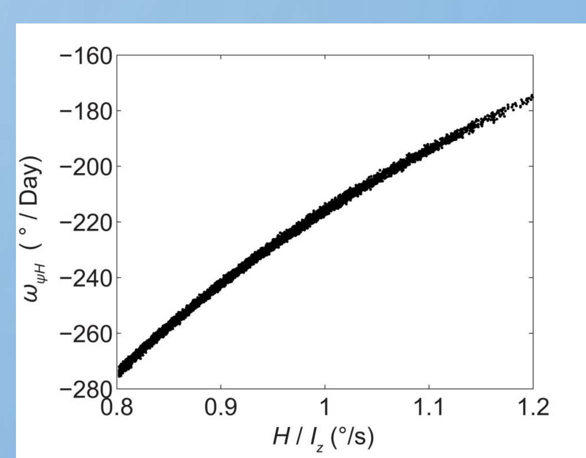
- **Determining the exact angular momentum magnitude H is another problem.** Directly solving the rotational speed is extremely difficult because the valid observation duration in a single pass is much smaller than the rotation period of Tiangong-1, the time interval between adjacent passes is much larger than this rotation period, as well as the large dimension of the algorithm making ΔP not sensitive to the changes in H.

- However, it is possible to accurately determine the direction of the angular momentum (ψ_H, ϑ_H) in a single pass, and the solution in each pass is a mutually independent process (**the lower left**). Due to the influence of the gravity gradient torque, the angular momentum precesses around the normal of the orbital plane. Variations in ψ_H can be reduced to a first-order secular linear change and a second-order periodic change (Lin et al., 2016). For a triaxial ellipsoid model, the linear change rate of ψ_H can be approximated as

$$\omega_{\psi_H} = -\cos i \cdot \dot{\Omega} + \frac{3GM}{4R^3 H} \cos \bar{\theta}_H \left(I_x(1 - 3\sin^2 \bar{\theta}' \sin^2 \bar{\varphi}') + I_y(1 - 3\sin^2 \bar{\theta}' \cos^2 \bar{\varphi}') + I_z(1 - 3\cos^2 \bar{\theta}') \right)$$

Therefore, the magnitude of the angular momentum can be obtained by numerically solving the ψ_H—H correlation (**the lower right**).





•Results

- The angular momentum of Tiangong-1and its evolution in both the body-fixed system and the inertial system are well estimated. Its rotational speed is found to increase.
- Due to the fact that this work is currently under preparation for a referee publication, we will not discuss it in more detail here.

Reference

- Lin, H.-Y., Zhao, C.-Y. & Zhang, M.-J. Frequency analysis of the non-principal-axis rotation of uniaxial space debris in circular orbit subjected to gravity-gradient torque. *Adv. Sp. Res.* **57**, 1189–1196 (2016).
- Lin, H.-Y., et al. Tiangong-1's accelerated self-spin before re-entry. Under review.