The structures and impact direction of the South Pole-Aitken Basin. Jingwen Liu[1,2,3], Jianzhong Liu[1,3], Dijun Guo[4], Jingyi Zhang[1,2,3], 4, Kai Zhu[1,3,] Li Zhang[1,3]. [1]Center for Lunar and Planetary Science, Institute of Geochemistry, Chinese Academy of Sciences, 99 Lincheng West Road, Guiyang 550051, China, Email: liujianzhong@mail.gyig.ac.cn. [2]University of Chinese Academy of Sciences, Beijing 100049, China. [3]Center for Excellence in Comparative Planetology, Chinese Academy of Sciences, Hefei 230031, China. [4]Beijing University, Beijing, China

Introduction: The South Pole-Aitken (SPA) basin is the oldest and largest preserved impact structure on the Moon [1, 2]. It is undoubtedly that larger or older impact events occur during planetary accretion, most indications were erased through subsequent impact bombardment and viscous relaxation [3]. Consequently, analysis of the SPA structure can provide clues about the early lunar evolution, even the early history of the solar system.

However, none of previous conclusions [4-6] can explain why the boundary line near the Apollo Basin is close to a perfect arc, rather than an elliptical arc. Examining the inner structures of several other lunar basins reveals that oblique impact can enough explain the anomaly ellipse structures without low velocity or other conditions. Alternatively, the annular structures and impact direction of SPA are prosed in this paper.

Ellipses structures of Lunar Basins: In the central parts of typical multi-ring basins --- Orientale Basin and Mendel-Rydberg Basin, we find a similar elliptic structure as SPA. Using LOLA DEM and WAC image data, we can distinguish the circular structure of the Orientale Basin. According to the elevation and FeO, we can obtain an elliptical structure of the Orientale Basin. The long axis direction is northeast-southwest, has 14° offset with the long axis of their ellipse structure. And the short axis is shorter than the diameter of the inner Rook ring. Using the same method, we obtained the circular and elliptical structures of the Mendel-Rydberg Basin. The long axis direction is northwest-southeast, and the short axis and long axis both are shorter than the innermost ring of the Mendel-Rydberg Basin, has 5° offset with the long axis of their ellipse structure.

Annular structures of SPA: Using the WAC image and LOLA DEM data, we have drawn two circular rings of SPA (**Figure 1a**). The area near the Apollo Basin is the most well-preserved ejecta formation of the SPA Basin [7]. This position is more like a perfectly circular arc than an ellipse arc from the image callout with black arrows. Both the inner and outer rings show undulations closer to perfect circles. As shown in **Figure 1b**, the most various circular and ellipse structures are located near the Planck Basin. The topography, gravity, and FeO content characteristics are not obvious in individual research, but the curve of the circle will emerge intermittently, fusing these data. Combined with the internal characteristics of the multi-ring basin, it is originally from the SPA impact. As shown in **Figure 1d**, the South Pole is the most challenging region to identify. Our results may be closer to the reality according to remote sensing data marked by the black arrows. As shown in **Figure 1 a, e, f**, the inner ring's interior is relatively homogeneous. The terrain is low and may be filled by basalts. The outer ring is the highest area of the basins, and as you can see from **Figure 1 f**. There are radiation stripes outside.

The impact direction of SPA: The gray data obtained can more clearly identify the ejecta patterns of the Orientale Basin generated by oblique impacts [8] (white lines in **Figure 2 a**). Mendel-Rydberg basin is visible in LRO WAC image but overprinted with ejecta from the Orientale Basin [9]). To distinguish its geological structure, we fused a variety of remote sensing data. Like the Orientale Basin, this direction line does not coincide with the major axis of the ellipse structure, and the radial texture in the impact line downstream is closer to the center of the basin (**Figure 2 b**).

With gravity gradient data the background, the radiative structures of SPA impact are obvious (the white lines in **Figure 2c**). According to the distribution of the radiation structures and the arc gravity gradient distribution in the center, the impact direction of the SPA is southeast-northwest. In the downstream of the impact direction, similar to Orientale and Mendel-Rydberg, the radial patterns are closer to the SPA center.

An abnormally high value of elevation occurs in downstream of the impact direction (the red area of the DEM in **Figure 2d**), indicating that this area has the same high terrain as the northeast position of SPA. Simultaneously, we superimpose the basin ring data larger than 200km (the black rings in **Figure 2d**) and basalt data (the black areas in **Figure 2d**) on the background. Given the observed correlation between the topography to outside the basins and basalt, the distribution of basins and basalt is the most reasonable control on the topology anomaly. The higher topography in the northeast area results from the dense distribution of basins in this area; the lowest topography in the

southwest of the SPA results from the two large-scale basin impact events of the Austral and Austral North Basin the basalt after the collisions. Therefore, we believe that the Gravity Gradient results are more accurate than Melosh et al. [10], which do not consider the influence of these factors**.**

Conclusions: The results in our study indicate that the Orientale, Mendel-Rydberg, and the oldest SPA basin all have an elliptic shape in the center. SPA has annular structures of SPA in its outside as other basins.

The impact direction of Orientale, Mendel-Rydberg have 14°and 5° offset with the long axis of their ellipse structure. Alternatively, the impact direction of the SPA is tilted 45° northwest with the major axis of its ellipse. But this phenomenon does not exist in small impact events [11]. Maybe with the increase of impact scale, the possibility that the major axis of the ellipsoid structure deviates from the impact direction is larger.

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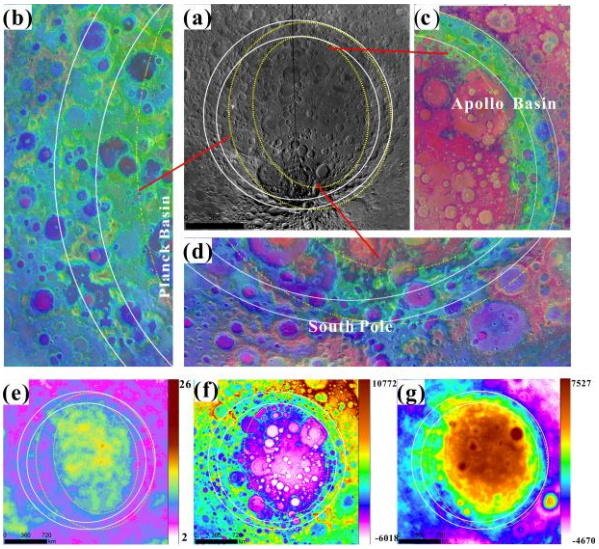

Figure 1 The circular rings of SPA. a circular rings(white line) and elliptic shape(yellow line) of SPA layered with WAC. b circular rings near the Planck Basin layered with DEM and WAC. c circular rings near the Apollo Basin layered with DEM, GRGM900C and WAC. d circular rings near the Sothe poar layered with DEM, GRGM900C and WAC. e circular rings and elliptic shape of SPA laryerd with FeO distributions. f circular rings and elliptic shape of SPA laryerd with LOLA. e circular rings and elliptic shape of SPA laryerd with GRGM900C.

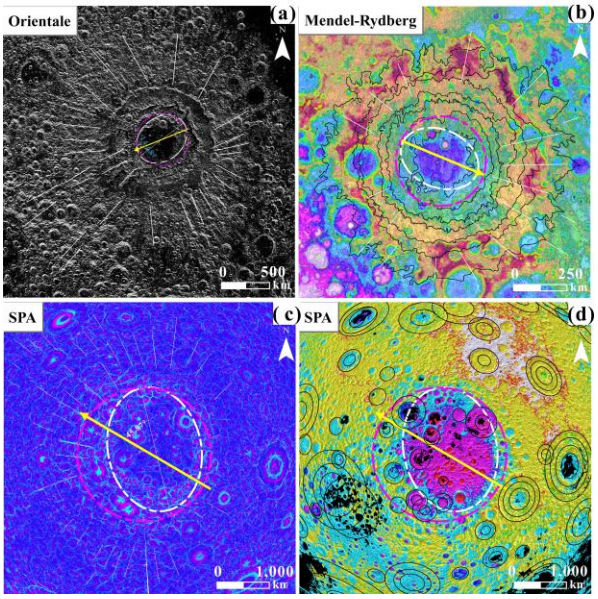

Figure 2 The impact direction of SPA. a. the impact direction (yellow line) and elliptic shape(purple line) of the Orientale Basin. b. the impact direction and elliptic shape of Mendel Rydberg c. the impact direction and elliptic shape(purple line) of the SPA layered with Gravity Gradient data .d the impact direction and elliptic shape of the SPA layered with DEM and basalts(black area)