WORLD COPERNICAN CONGRESS

Sizes, Distances, and Order: Celestial Reckoning in Late Medieval Islam

Copernicus and Astronomy:

Continuity, Reform, and Dissemination Conference

at the World Copernican Congress

Toruń, September 2023

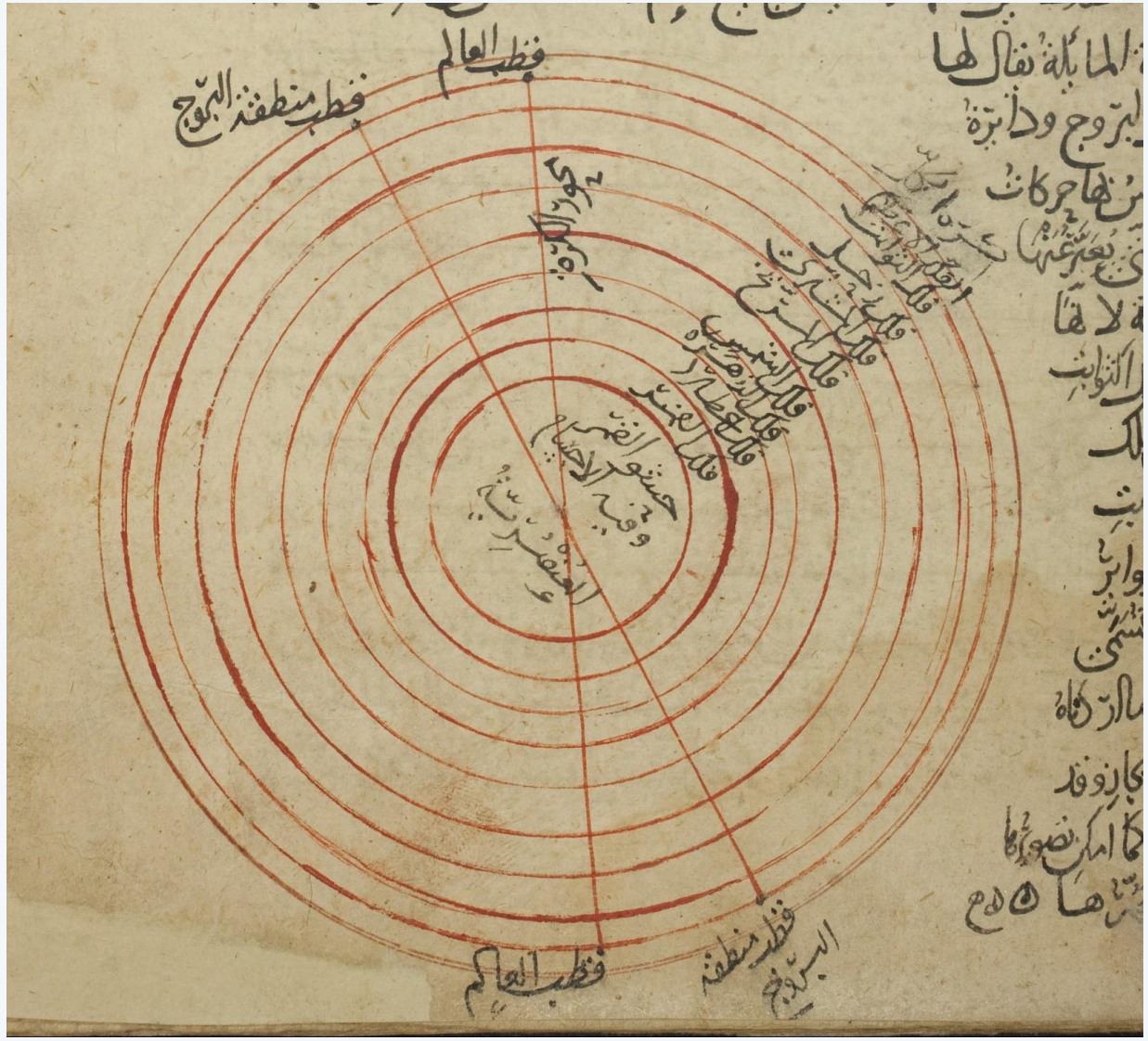
Sally P. Ragep

Sizes, Distances, and Order:
Celestial Reckoning in Late Medieval Islam

- **Celestial Order**
- The ʿUrḍī/Shīrāzī Challenge to Ptolemy
- The Aftermath of the ʿUrḍī/Shīrāzī Recalculation
- Kāshī Reconciles ʿUrḍī with Ptolemy: Crisis Averted?
- Or Not Resolved? Reactions to Kāshī

ʿAbd al-Jabbar al-Kharaqī's *Muntahā al-idrāk*

(in Arabic; completed 1132-3 CE)



Sizes, Distances, and Order:
Celestial Reckoning in Late Medieval Islam

- Celestial Order
- **The ʿUrḍī/Shīrāzī Challenge to Ptolemy**
- The Aftermath of the ʿUrḍī/Shīrāzī Recalculation
- Kāshī Reconciles ʿUrḍī with Ptolemy: Crisis Averted?
- Or Not Resolved? Reactions to Kāshī

Distances to Mercury and Venus according to Ptolemy's *Almagest*

MERCURY

$$\frac{91;30\ (\text{farthest distance [R=60]})}{33;04\ (\text{nearest distance [R=60]})} = \frac{x\ (\text{farthest distance [in earth-radii; e.r.=1]})}{64;10\ \ (\text{nearest distance [in earth-radii; e.r.=1]})}$$

x ≈ 177½ (Mercury's farthest distance in earth-radii; e.r.=1)
(*Planetary Hypotheses*: x=166)

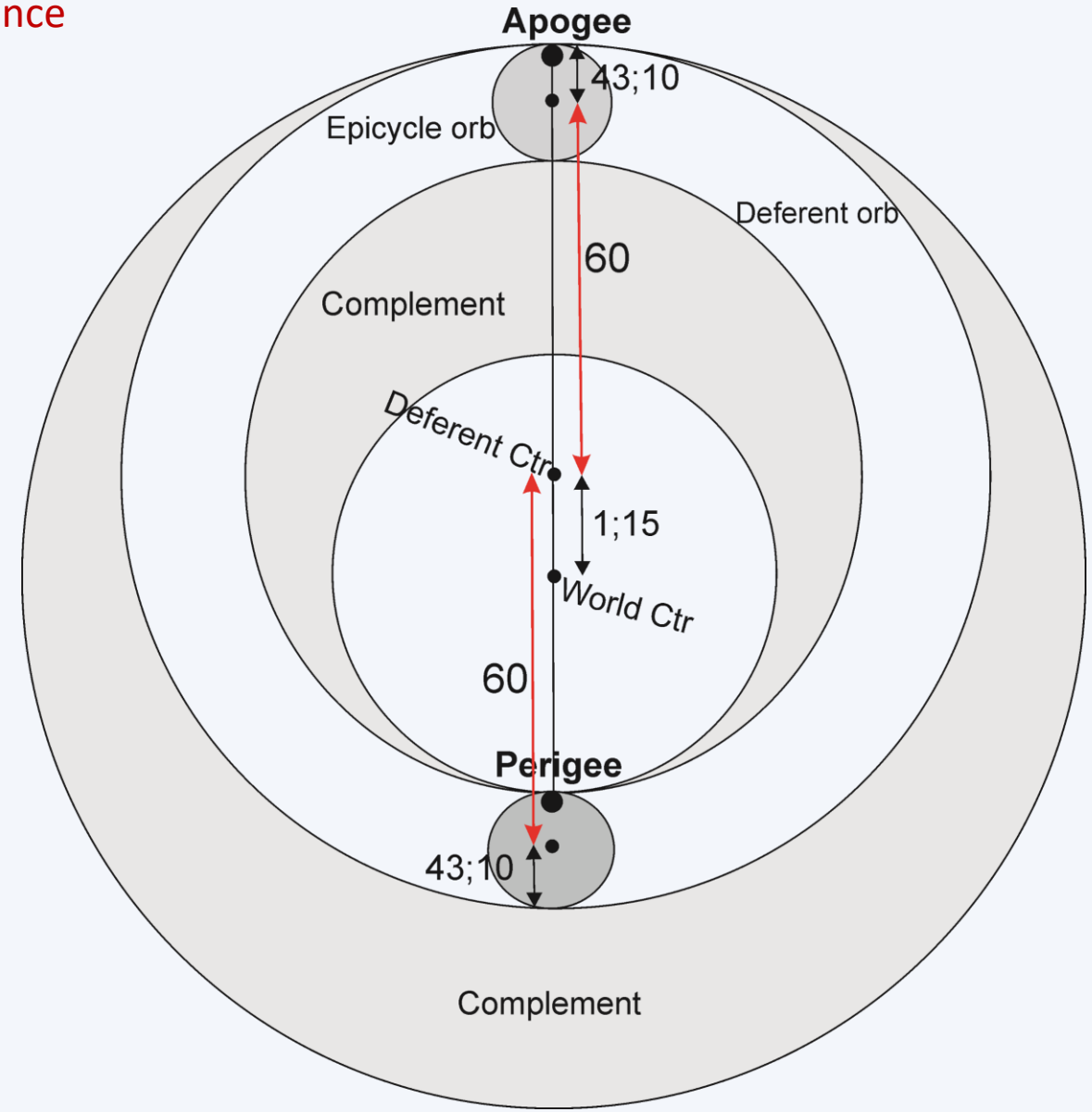
VENUS

$$\frac{104;25\ (\text{farthest distance [R=60]})}{15;35\ (\text{nearest distance [R=60]})} = \frac{x\ (\text{farthest distance [in earth-radii; e.r.=1]})}{177;30\ \ (\text{nearest distance [in earth-radii; e.r.=1]})}$$

x ≈ 1189 (Venus's farthest distance in earth-radii; e.r.=1)
(*Planetary Hypotheses*: x=1079)

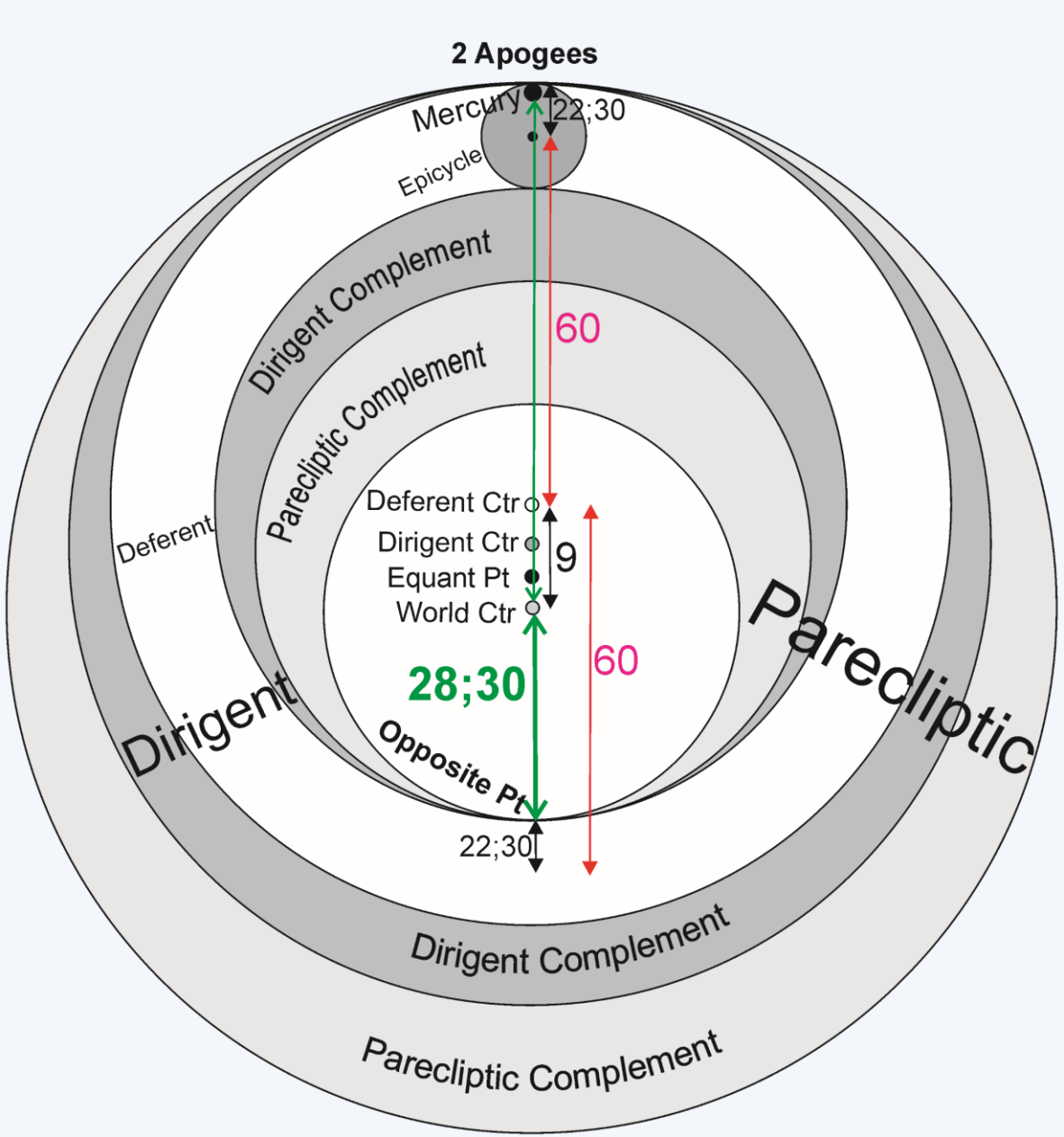
Venus's Distances

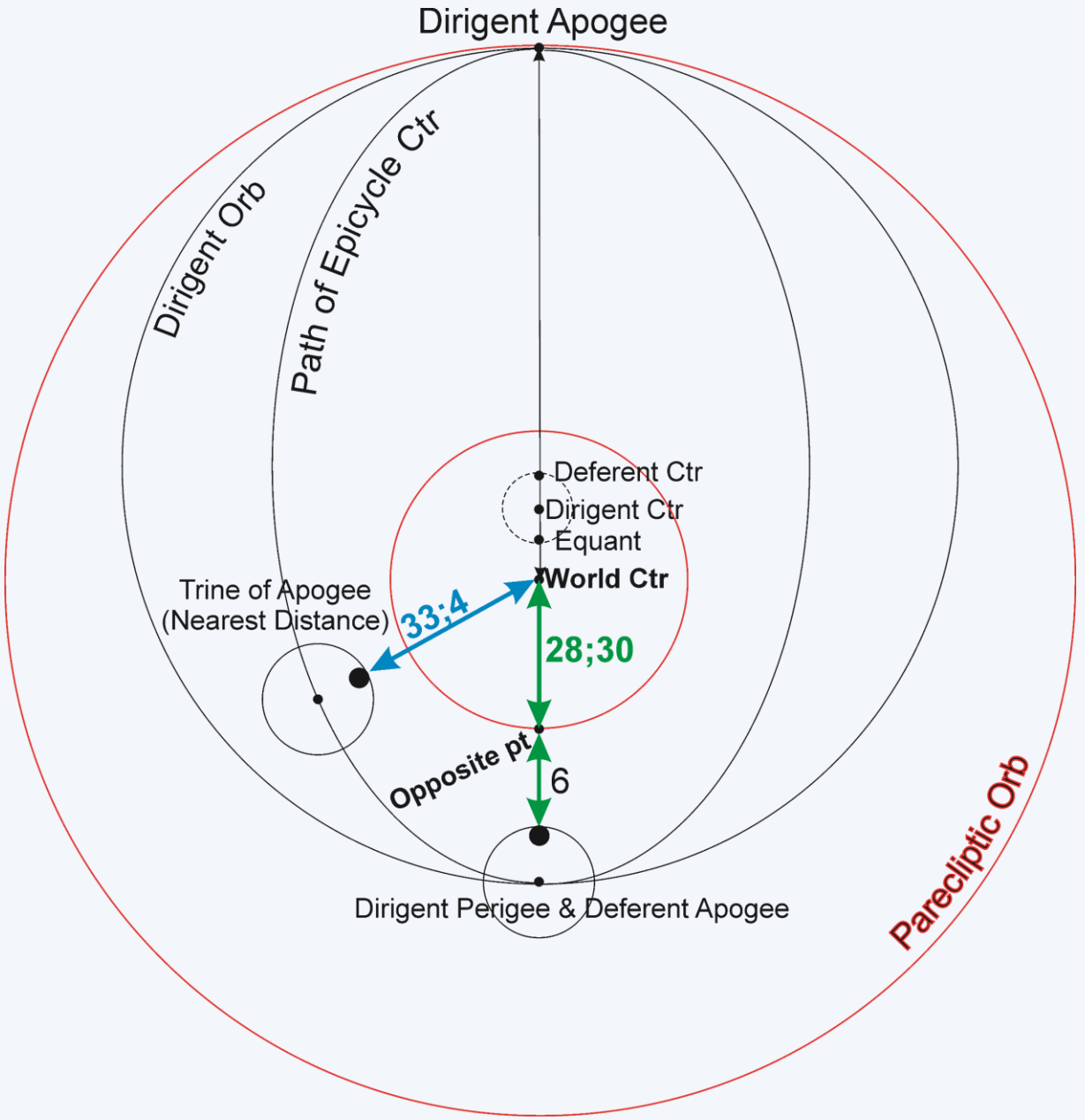
Venus's farthest distance (at apogee): **104;25**



Venus's nearest distance (at perigee): **15;35**

Mercury's Distances (according to ʿUrḍī)





Distances to Mercury and Venus according to ʿUrḍī

MERCURY

$$\frac{91;30\ (farthest\ distance\ [R=60])}{28;30\ (nearest\ distance\ [R=60])} = \frac{x\ (\text{farthest distance [in earth−radii; e.r.=1]})}{64;30\ \ (\text{nearest distance [in earth−radii; e.r.=1]})}$$

x ≈ 207;5 (Mercury's farthest distance in earth-radii; e.r.=1)
(*Planetary Hypotheses*: x=166)

VENUS

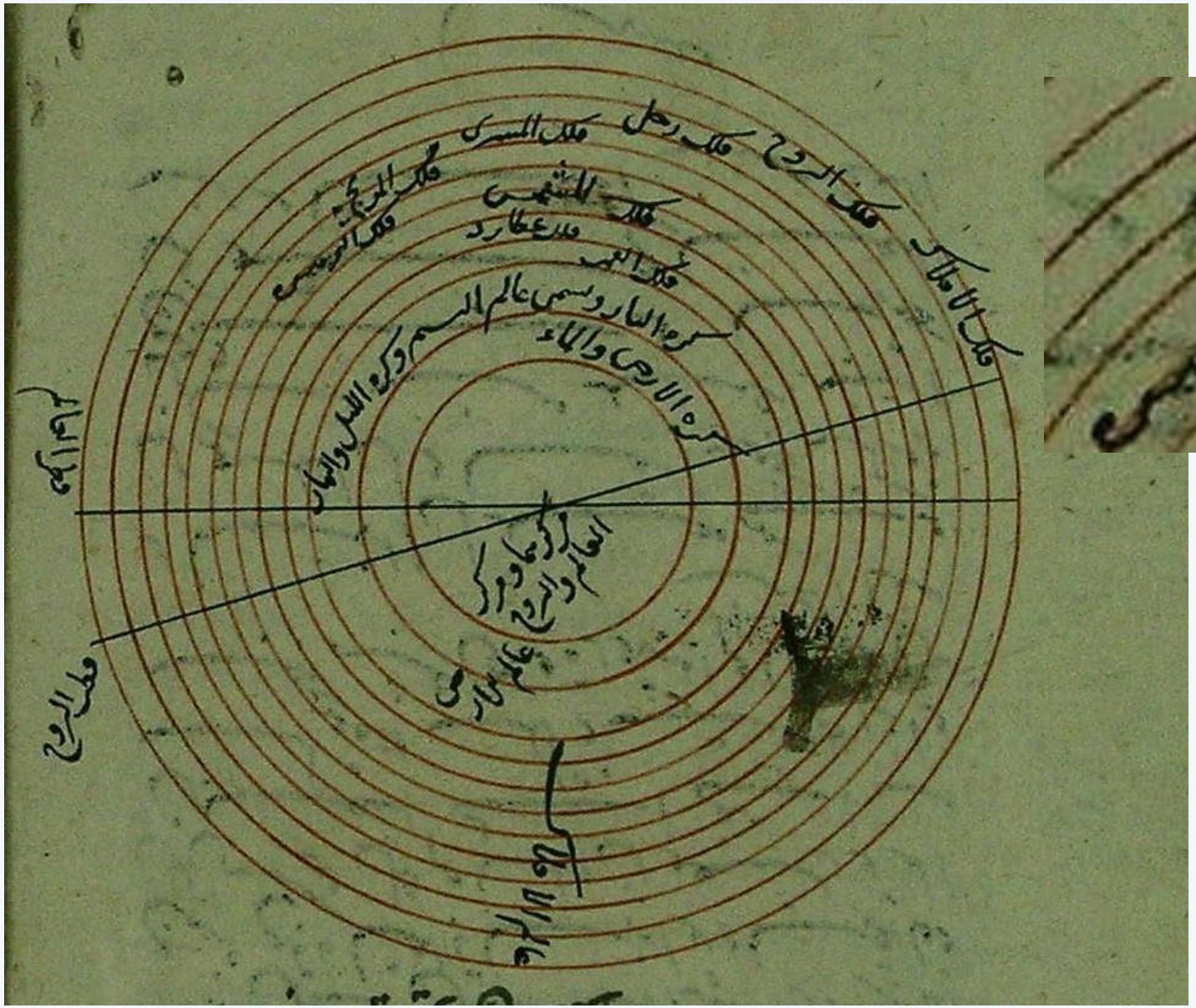
$$\frac{104;25\ (\text{farthest distance [R=60]})}{15;35\ (\text{nearest distance [R=60]})} = \frac{x\ (\text{farthest distance [in earth−radii; e.r.=1]})}{207;5\ \ (\text{nearest distance [in earth−radii; e.r.=1]})}$$

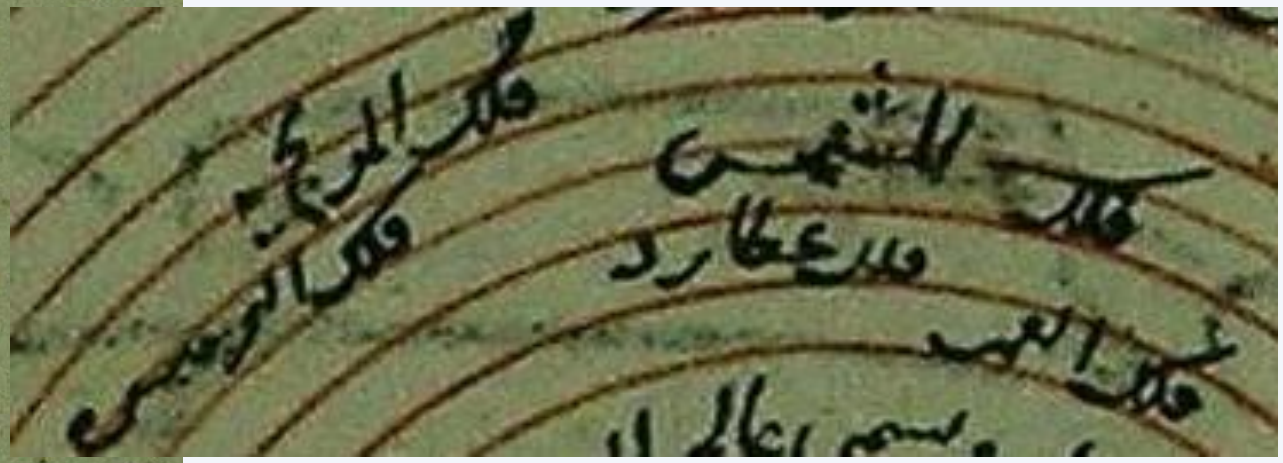
x = 1387;34 ≈ 1388 (Venus's farthest distance in earth-radii; e.r.=1)
(*Planetary Hypotheses*: x=1079)

Sizes, Distances, and Order:
Celestial Reckoning in Late Medieval Islam

- Celestial Order
- The ʿUrḍī/Shīrāzī Challenge to Ptolemy
- **The Aftermath of the ʿUrḍī/Shīrāzī Recalculation**
- Kāshī Reconciles ʿUrḍī with Ptolemy: Crisis Averted?
- Or Not Resolved? Reactions to Kāshī

Shīrāzī's Ordering of the Planets in the *Tuḥfa*





orb of Mars

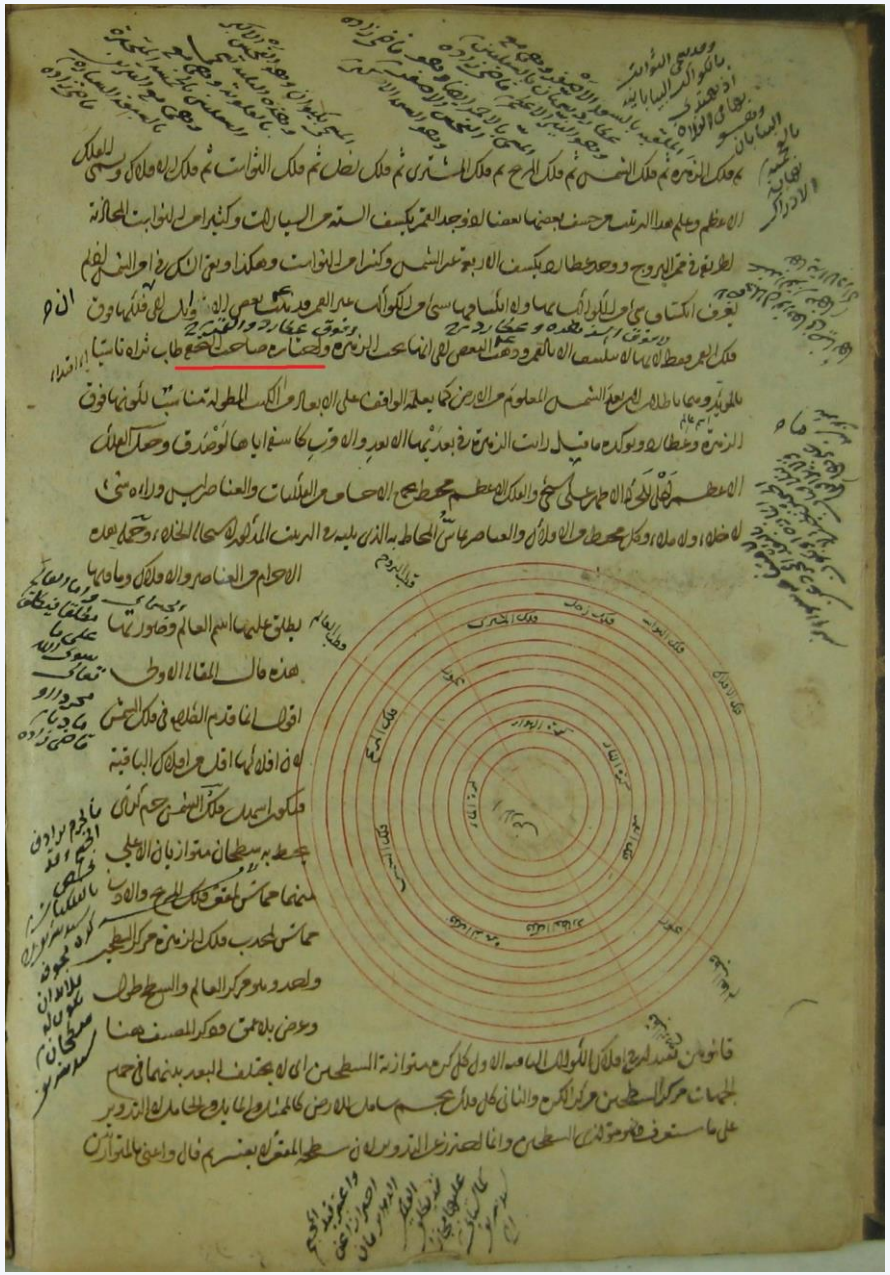
orb of Venus

orb of the Sun

orb of Mercury

orb of the Moon

‘Ubaydī’s Ordering of the Planets





orb of the Sun

orb of Venus

orb of Mercury

Ṭūsī on the Celestial Order

"They placed the Sun in the medial orb between the [upper planets] and the [lower planets] … deeming this the most elegant arrangement and the most excellent structure inasmuch as the 6 [other planets] were connected to it—the upper [planets] in a certain way, the lower in another and the Moon in yet another. In addition, the known distance of the [Sun] from the Earth corresponded to this positioning." (*Tadhkira*, II.2)

Sizes, Distances, and Order:
Celestial Reckoning in Late Medieval Islam

- Celestial Order
- The ʿUrḍī/Shīrāzī Challenge to Ptolemy
- The Aftermath of the ʿUrḍī/Shīrāzī Recalculation
- **Kāshī Reconciles ʿUrḍī with Ptolemy: Crisis Averted?**
- Or Not Resolved? Reactions to Kāshī

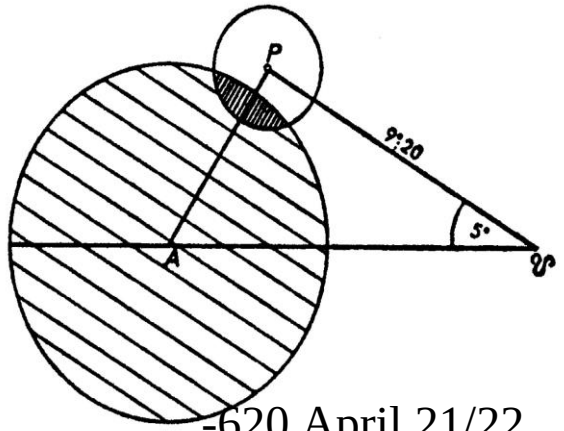
Kāshī Reconciles ʿUrḍī with Ptolemy

1) Kāshī tells us that he "**redid the calculations presented in the *Almagest*** in a way that seconds and even thirds were not ignored in order to obtain fractions that others did not take into account…and I incorporated them into the calculations."
2) Kāshī **did not rely on new observations**. To determine the distance to the Sun **he used the 2 Babylonian lunar eclipses that Ptolemy presented in the *Almagest***.
3) Kāshī **determined that what was between the two orbs of the luminaries was extensive enough for the orbs of Venus and Mercury. In other words, he determined that the concavity of the Sun's orb was** one thousand, four hundred and fifty-three and two-thirds of one-fifth times the Earth's radius **[1453 + 2/3(1/5)],** which was large enough to accommodate Venus and Mercury. Recall ʿUrḍī and Shīrāzī's result for the farthest distance of Venus's orb was about **1388 e.r.**.
4) There was **no void** because **Kāshī took the radii of the planets and the thickness of the Moon's *jawzahar* orb into account** in his calculations.
5) **Taking into account the radii of the planets and using precise figures rather than approximations resulted in small differences between his figures and Ptolemy's. But the most significant of Kāshī's recalculations was related to the 2 Babylonian eclipse observations.**

The 2 Babylonian Eclipse Observations

When the Moon's center P is 9 1/3° from the node along the inclined circle, for Ptolemy (*Almagest*, V.14) it is 48 ½′ from the ecliptic along the great circle drawn through it at right angles to the inclined circle

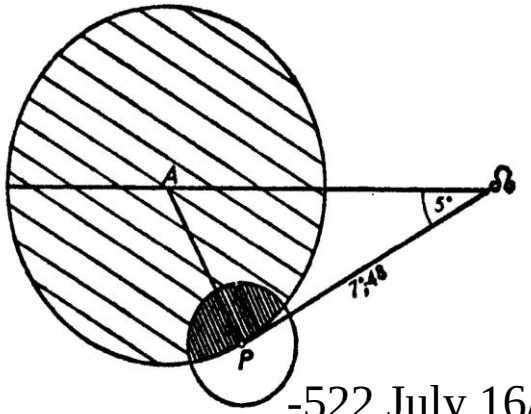
¼ Moon's diameter eclipsed



-620 April 21/22

When the Moon's center P is 7 4/5° from the node along the inclined circle it is 40 2/3′.

½ Moon's diameter eclipsed

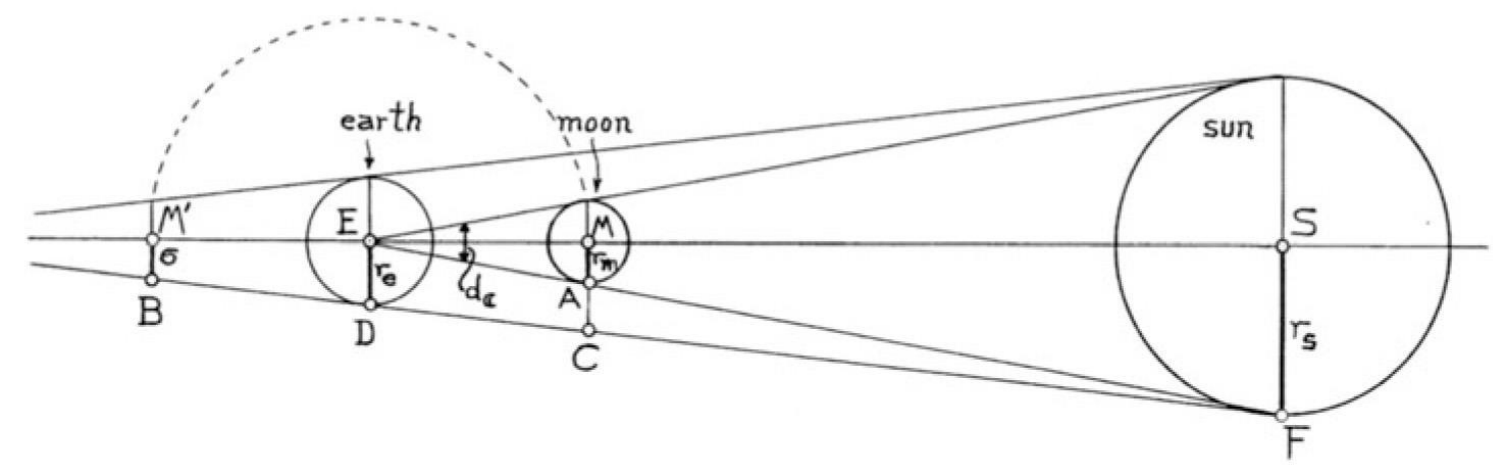


-522 July 16/17

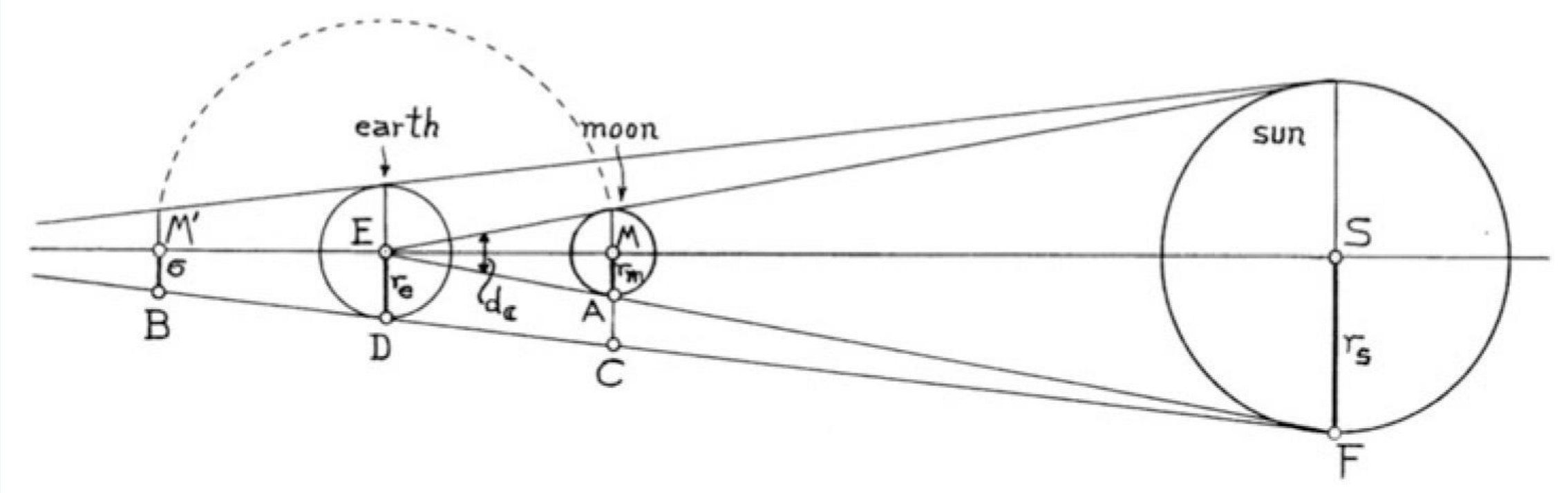
These figures are from Olaf Pedersen's *Survey of the Almagest*.

Calculating the Sun's Distance

	Ptolemy	Kāshī's Recalculation
First eclipse latitude	0;48,30	0;48,34
Second eclipse latitude	0;40,40	0;40,48
Latitude difference	0;07,50	0;07,46
Moon's apparent radius at farthest distance	0;07,50x2=0;15,40	0;07,46x2=0;15,32
Moon's farthest distance (EM)	64;10 r_e	63;34,15 r_e
Moon's actual radius (AM= r_m)	0;17,33 r_e	0;17,14 r_e
Ratio of Earth's shadow radius to Moon's radius	2;35,44=>2;36 or 2 3/5	2;37,35,47
Earth's Shadow radius at Moon's farthest distance (MC)	2 r_e – 2;36 r_m = 1;14,22 r_e	2 r_e – 2;37,35,47r_m = 1;14,44 r_e
AC = MC–AM	**0;56,49** r_e	**0;57,29,47** r_e



Calculating the Sun's Distance **(ES)**



$$ES = \left(\frac{EM}{r_e - AC}\right) r_e = \frac{64;10}{1-0;56,49} r_e \approx \mathbf{1210} r_e \text{ (Ptolemy)}$$

$$ES = \left(\frac{EM}{r_e - AC}\right) r_e = \frac{63;34,15}{1-0;57,29,47} r_e \approx \mathbf{1523;30}\, r_e \text{ (Kāshī)}$$

Sizes, Distances, and Order:
Celestial Reckoning in Late Medieval Islam

- Celestial Order
- The ʿUrḍī/Shīrāzī Challenge to Ptolemy
- The Aftermath of the ʿUrḍī/Shīrāzī Recalculation
- Kāshī Reconciles ʿUrḍī with Ptolemy: Crisis Averted?
- **Or Not Resolved? Reactions to Kāshī**

Some Skeptical Views of Sizes and Distances (from Jurjānī's Commentary on the *Tadhkira*)

"The majority of people upon hearing that the distance between one of the planets and the Earth is so many parasangs, and that the size of its body is such and such, 'roll their eyes' (لوّوا رؤوسهم) [lit., turn their heads] and say this is all invented lies. This is due to the lack of their study of the rules of geometry and optics, and their belief that there is no way to determine these except by ascending and getting near those bodies and measuring them firsthand, just as we do with things around us."

"He is best who says that human power is limited for perceiving the distances of the celestial bodies and their sizes according to what they are in reality. Indeed, no one knows that except their Creator."

WORLD COPERNICAN CONGRESS

Thank you

Dziękuję!

Minister of Education and Science
Republic of Poland

NICOLAUS COPERNICUS UNIVERSITY IN TORUŃ

JAGIELLONIAN UNIVERSITY IN KRAKÓW

UNIVERSITY OF WARMIA AND MAZURY IN OLSZTYN

PAN HN POLISH ACADEMY OF SCIENCES
L. & A. Birkenmajer
INSTITUTE FOR THE HISTORY OF SCIENCE