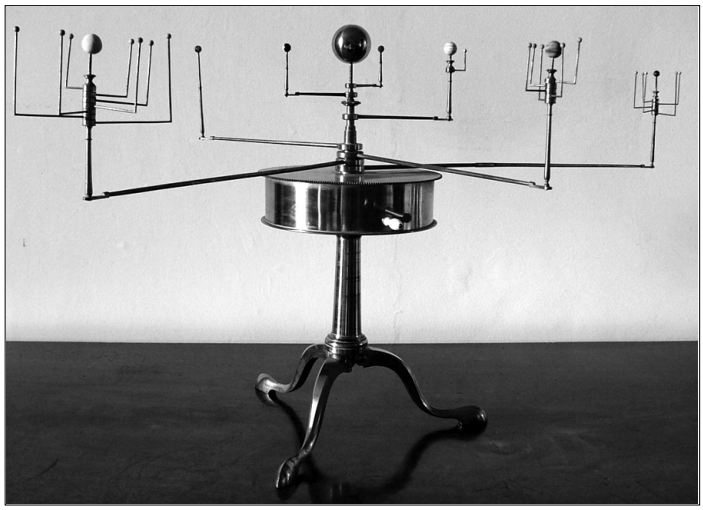
ASTR 310 Tutorial 1: A Human Orrery

An orrery is a mechanical model of the Solar System. When you turn a crank, the planets and moons orbit the Sun at correctly-scaled distances with correctly-scaled periods.



In this tutorial, you and your classmates build a scale model of the Solar System by marking the locations of the visible planets, Mercury, Venus, Earth, Mars, Jupiter and Saturn, at regular intervals of time. Later, when you and your classmates step from location to location, you'll reproduce the motion of the planets – a human orrery!

Part I: Construction

The scale of this model is 1 metre per AU (astronomical unit, the distance from the Earth to the Sun). Since 1 AU is 150 million km, this model is 150 *billion* times smaller than the real Solar System. Each planet's orbit is approximated as circular so it can be built using a piece of string scaled to the planet's orbital radius (semi-major axis). Markers show each planet along its orbit at 16-day intervals for Mercury, Venus, Earth and Mars, and 160-day intervals for Jupiter and Saturn. The marker shows only the location of planet: the planet's themselves are much, much smaller.

Planet	Orbital Radius			Period	
	km	AU	Scaled	Actual	Scaled
Mercury	57 900 000	0.39	39 cm	88 days	11 16-day intervals
Venus	108 200 000	0.72	72 cm	226 days	14 16-day intervals
Earth	150 000 000	1.00	1 m	1 year	23 16-day intervals
Mars	227 900 000	1.52	1.52 m	1.88 years	43 16-day intervals
Jupiter	778 400 000	5.20	5.20 m	11.86 years	27 160-day intervals
Saturn	1 427 000 000	9.54	9.54 m	29.42 years	67 160-day intervals

In groups of three, you will build one section of the orrery. Your TA will give your group a set of "blueprints" and materials.

To locate each marker, first loop the string over the post at the center of the orrery (representing the Sun) and pull the string straight. Then, have one partner stand near the center and read the angles off the giant protractor. At each specified angle, stick the correct numbered marker to the ground.

When you're finished, unhook your string from the Sun, neatly wind up the string and put it back in the bag with the blueprints, and give it back to the TA. Check with the TA to see if there are any more sections to build.

Part 2: The Human Orrery

Your TA will explain how the orrery works with students playing the roles of the planets.

Name _____ ID No. _____ Tutorial Day/Time _____

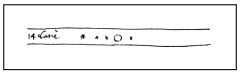
Part 3: Questions Please answer these questions. Each student should hand in his or her own paper.

Stand on the orbit of Saturn. Saturn is about 10 times farther from the Sun than Earth is. Compared to Earth, how many times farther does Saturn travel to orbit the Sun? _____

The Saturn markers show its location every 160 days while the markers for the inner Solar System show the planets' locations every 16 days. If we used 16-day markers for Saturn, too, about how many centimetres apart would the markers be? _____ How many centimetres apart are the Earth markers? _____ Which planet is travelling slower, Earth or Saturn? _____ Approximately how many times slower? _____

Can you combine these facts to explain why Saturn takes about 30 years to orbit the Sun?

The picture on the right is taken from a notebook Galileo wrote in 1610. It's his observation of Jupiter surrounded by its four largest moons, Io, Europa, Ganymede and Callisto (now known at the Galilean moons). The picture has been shrunk so Jupiter is at the right scale for our model of the Solar System.



Have one partner stand on Jupiter's orbit and hold up the picture while the others go to Earth. From Earth, can you see the dot of Jupiter in the picture? yes no

Why is it so easy to see Jupiter at night?

Can you see the moons? yes no

If they're so small, how did Galileo see the moons?

On January 7, 1610, almost exactly 400 years ago, Galileo's used his new telescope to see the moons of Jupiter for the first time in history.

One partner stand on an Earth marker and another partner stand on the nearest Mars marker. The moment when Earth and Mars are lined up on the same side of the Sun is called opposition (because seen from Earth, the Sun and Mars are on opposite sides of the sky.) In our scaled model, it takes light 8 minutes to travel 1 metre. How how long does it take to send a radio signal from Earth to one of the spacecraft on Mars? _____

Send your partner to the Mars marker on opposite sides of the Sun from Earth. This moment is called conjunction because seen from Earth, the Sun and Mars are together ("conjoined") in the sky. Now how long does it take to send a radio signal to Mars? _____

Approximately how many times farther from Earth is Mars when the two planets are on opposite sides of the Sun, compared to when they line up on the same side of the Sun? _____

The nearest star to our Solar System is called Proxima Centauri. It's 267 800 AU away. If we want to include it in our model, in which of these places should we put it?

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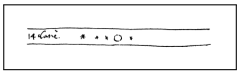

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Send your partner to the Mars marker on opposite sides of the Sun from Earth. This moment is called conjunction because seen from Earth, the Sun and Mars are together ("conjoined") in the sky. Now how long does it take to send a radio signal to Mars? _____

Approximately how many times farther from Earth is Mars when the two planets are on opposite sides of the Sun, compared to when they line up on the same side of the Sun? _____

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Send your partner to the Mars marker on opposite sides of the Sun from Earth. This moment is called conjunction because seen from Earth, the Sun and Mars are together ("conjoined") in the sky. Now how long does it take to send a radio signal to Mars? _____

Approximately how many times farther from Earth is Mars when the two planets are on opposite sides of the Sun, compared to when they line up on the same side of the Sun? _____

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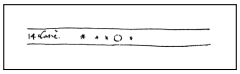

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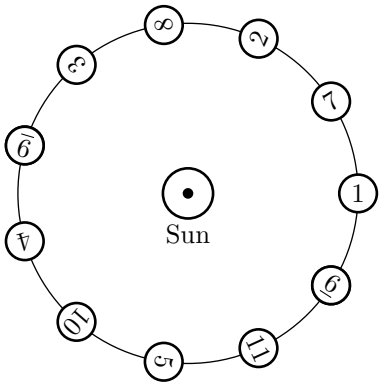
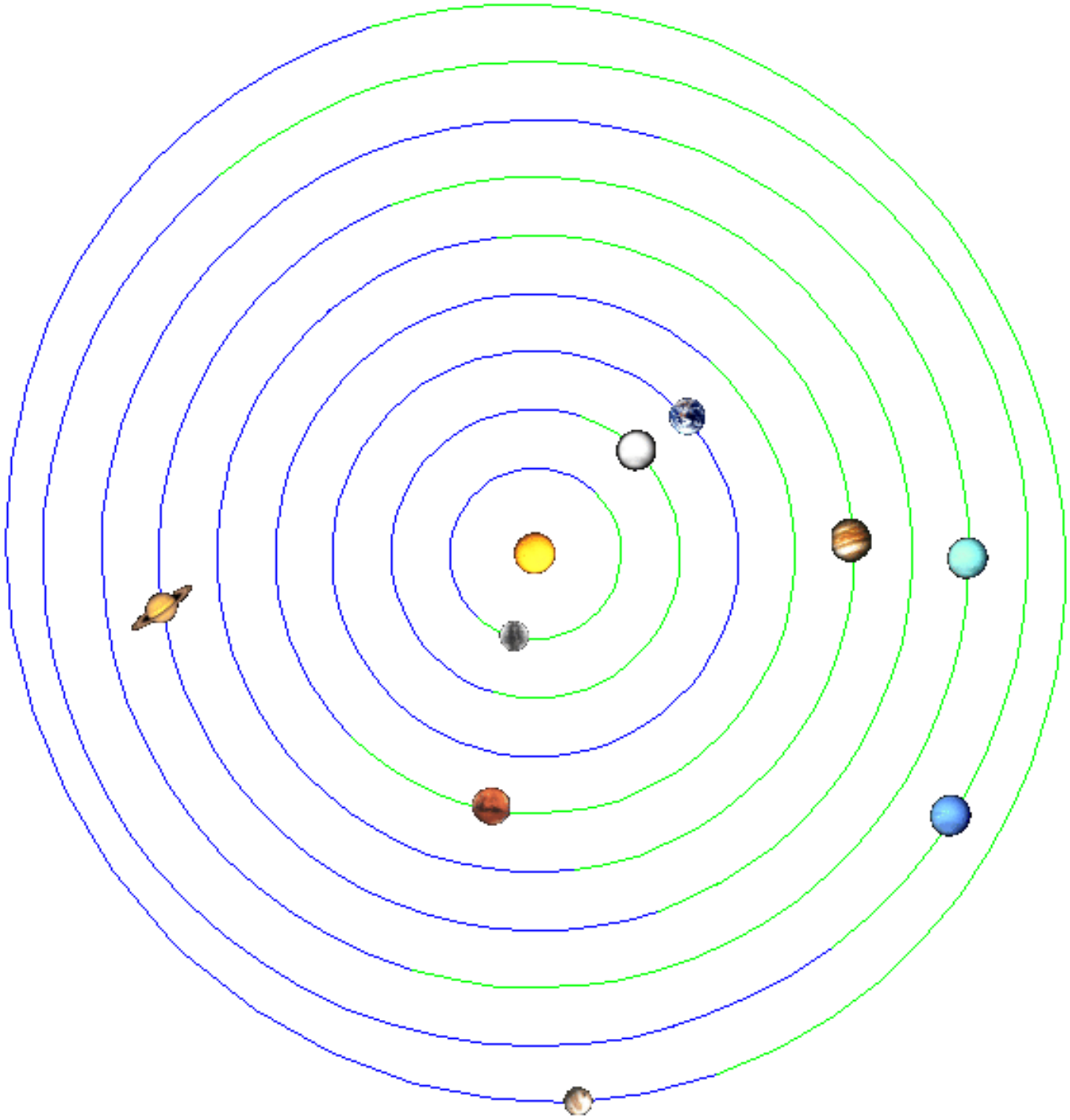
Human Orrery Blueprint

Inner planets shown at 16-day intervals; Jupiter and Saturn shown at 160-day intervals.
Use this blueprint to select to locations matching the planets' current positions (maps available at `www.fourmilab.ch/solar`.) The orbital radii are not to scale in this diagram.





Planet: Mercury

Markers: M1 – M11
Orbital radius: 0.39 metres

Location Angles	
Marker	Angle
M1	0
M2	65
M3	131
M4	196
M5	262
M6	327
M7	33
M8	98
M9	164
M10	229
M11	295

Planet: Venus

Markers: V1 – V14
Orbital radius: 0.72 metres

Location Angles	
Marker	Angle
V1	0
V2	26
V3	51
V4	77
V5	103
V6	129
V7	154
V8	180
V9	206
V10	231
V11	257
V12	283
V13	309
V14	334

Planet: Earth 1

Markers: E1 – E12
Orbital radius: 1.00 metres

Location Angles	
Marker	Angle
E1	0
E2	16
E3	31
E4	47
E5	63
E6	78
E7	94
E8	110
E9	125
E10	141
E11	157
E12	172

Planet: Earth 2

Markers: E13 – E23
Orbital radius: 1.00 metres

Location Angles	
Marker	Angle
E13	188
E14	203
E15	219
E16	235
E17	250
E18	266
E19	282
E20	297
E21	313
E22	329
E23	344

Planet: Mars 1

Markers: M1 – M15

Orbital radius: 1.52 metres

Location Angles	
Marker	Angle
M1	0
M2	8
M3	17
M4	25
M5	33
M6	42
M7	50
M8	59
M9	67
M10	75
M11	84
M12	92
M13	100
M14	109
M15	117

Planet: Mars 2

Markers: M16 – M30

Orbital radius: 1.52 metres

Location Angles	
Marker	Angle
M16	126
M17	134
M18	142
M19	151
M20	159
M21	167
M22	176
M23	184
M24	193
M25	201
M26	209
M27	218
M28	226
M29	234
M30	243

Planet: Mars 3

Markers: M31 – M43

Orbital radius: 1.52 metres

Location Angles	
Marker	Angle
M31	251
M32	260
M33	268
M34	276
M35	285
M36	293
M37	301
M38	310
M39	318
M40	327
M41	335
M42	343
M43	352

Planet: Jupiter 1

Markers: J1 – J14

Orbital radius: 5.20 metres

Location Angles	
Marker	Angle
J1	0
J2	13
J3	27
J4	40
J5	53
J6	67
J7	80
J8	93
J9	107
J10	120
J11	133
J12	147
J13	160
J14	173

Planet: Jupiter 2

Markers: J15 – J27
Orbital radius: 5.20 metres

Location Angles	
Marker	Angle
J15	187
J16	200
J17	213
J18	227
J19	240
J20	253
J21	267
J22	280
J23	293
J24	307
J25	320
J26	333
J27	347

Planet: Saturn 1

Markers: S1 – S17
Orbital radius: 9.54 metres

Location Angles	
Marker	Angle
S1	0
S2	5
S3	11
S4	16
S5	21
S6	27
S7	32
S8	38
S9	43
S10	48
S11	54
S12	59
S13	64
S14	70
S15	75
S16	81
S17	86

Planet: Saturn 2

Markers: S18 – S34
Orbital radius: 9.54 metres

Location Angles	
Marker	Angle
S18	91
S19	97
S20	102
S21	107
S22	113
S23	118
S24	124
S25	129
S26	134
S27	140
S28	145
S29	150
S30	156
S31	161
S32	167
S33	172
S34	177

Planet: Saturn 3

Markers: S35 – S51
Orbital radius: 9.54 metres

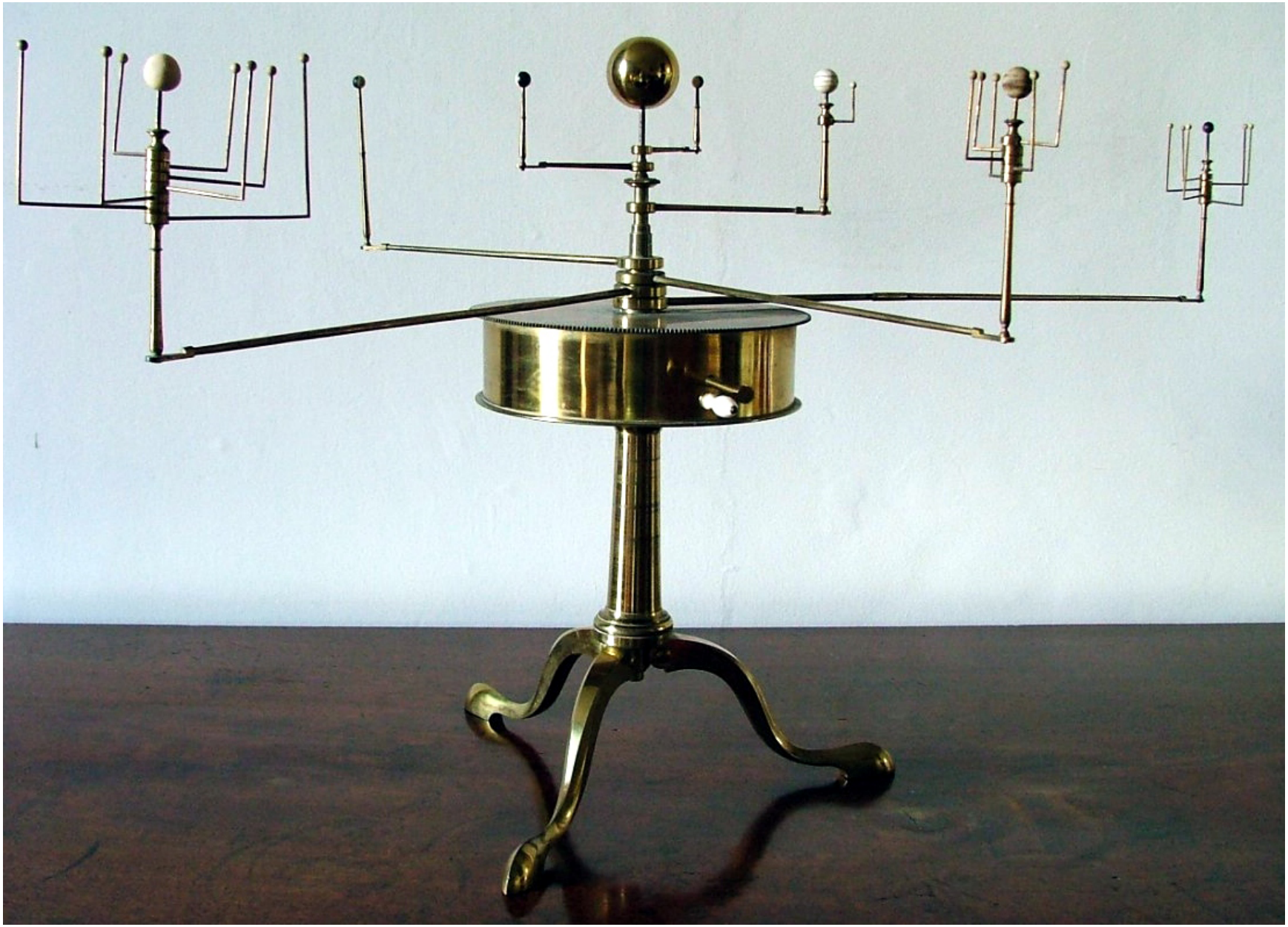
Location Angles	
Marker	Angle
S35	183
S36	188
S37	193
S38	199
S39	204
S40	210
S41	215
S42	220
S43	226
S44	231
S45	236
S46	242
S47	247
S48	253
S49	258
S50	263
S51	269

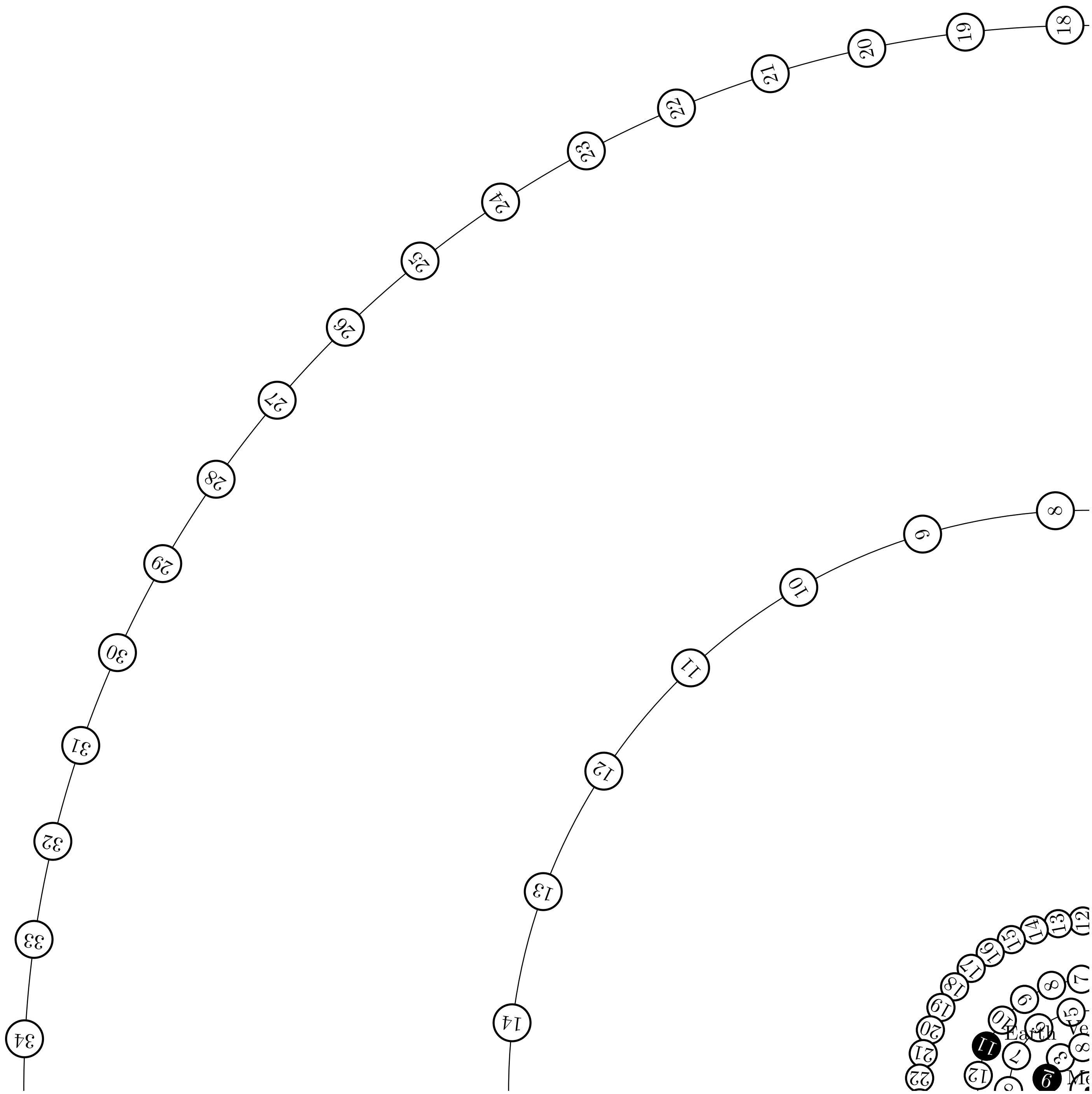
Planet: Saturn 4

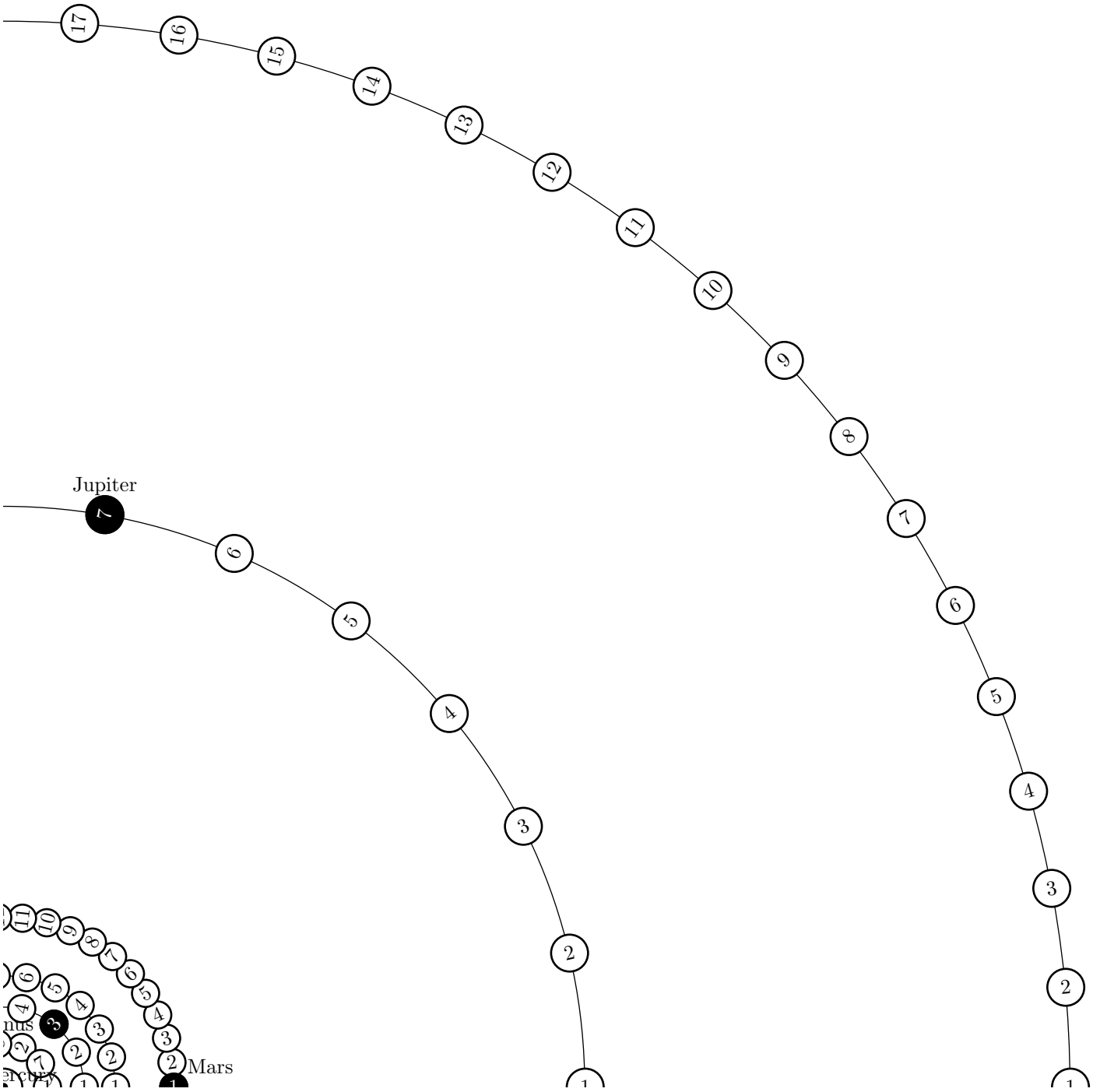
Markers: S52 – S67

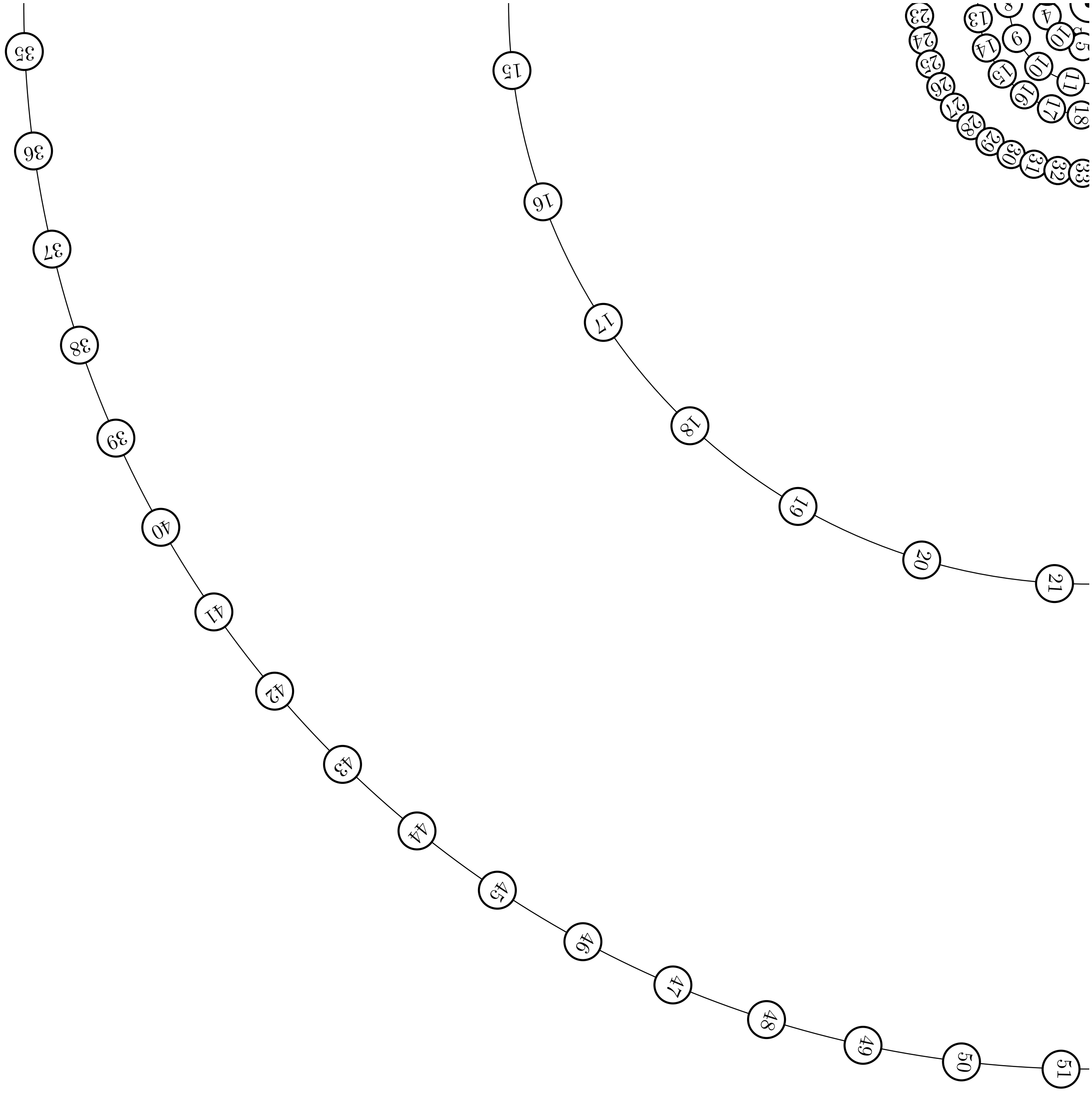
Orbital radius: 9.54 metres

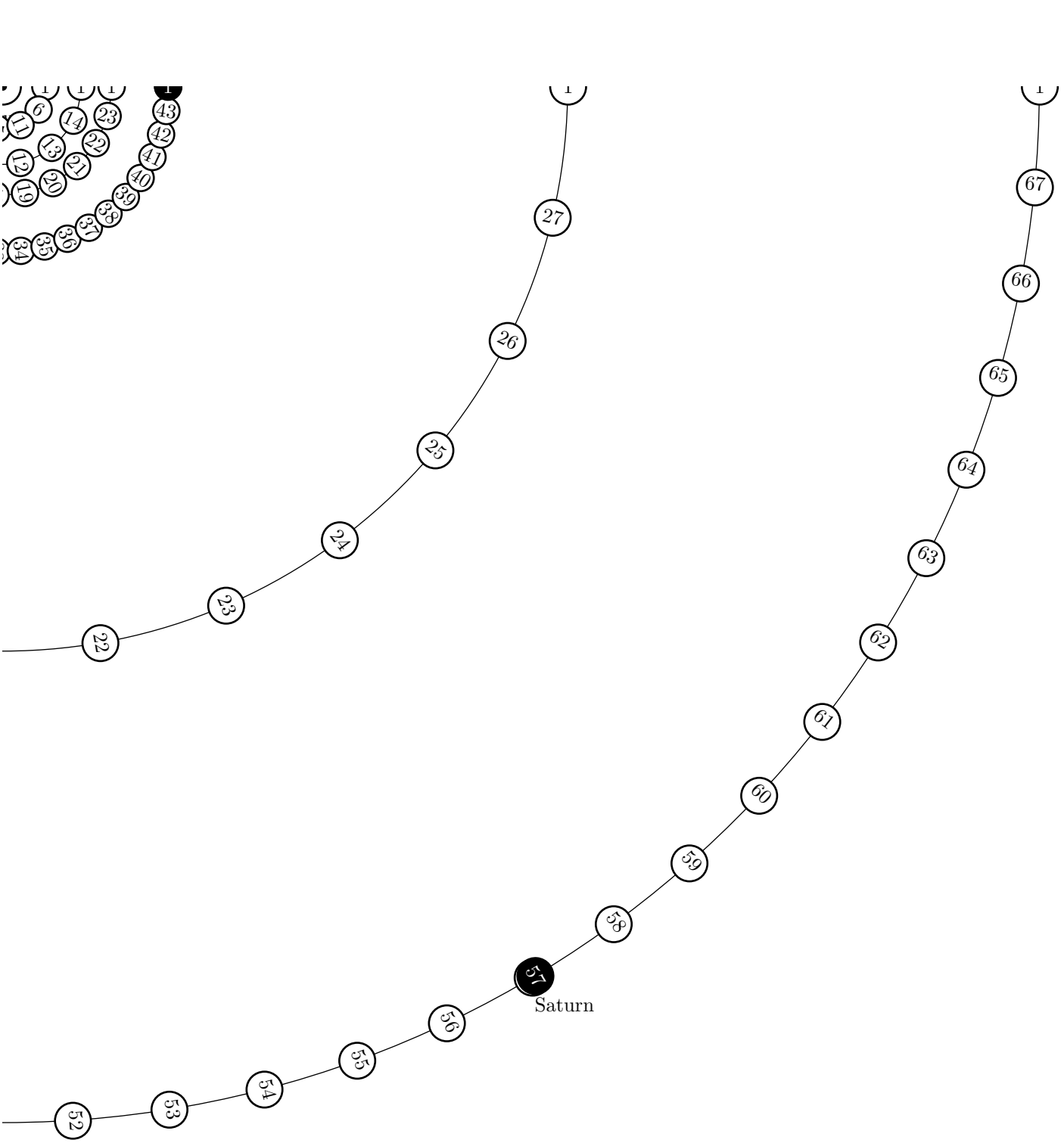
Location Angles	
Marker	Angle
S52	274
S53	279
S54	285
S55	290
S56	296
S57	301
S58	306
S59	312
S60	317
S61	322
S62	328
S63	333
S64	339
S65	344
S66	349
S67	355




Earth


Jupiter
Mars




Saturn