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MOSAIC TELESCOPES TECHNOLOGY AND SCIENCE

FROM TINY REFLECTING TILES TO LARGE ASTRONOMICAL MIRRORS IN HONOR OF GUIDO HORN D'ARTURO

26 | 27 JAN 2026

AULA PRODI
SAN GIOVANNI IN MONTE, 2
BOLOGNA - ITALY

CTAO | CTA | ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

An Excursus of Large Telescopes with Segmented Mirrors

Tom Herbst, MPIA Heidelberg

Mosaic Telescopes Technology and Science
Bologna, 26 January 2026

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OED: *excursus (noun):* A detailed discussion of a point or question…

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Wikipedia: Often, excurses have nothing to do with the matter being discussed… and are used to lighten the atmosphere…

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What is a Segmented Mirror / Mosaic Telescope?

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(usually to simplify manufacture)

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Including:
- Independent Telescope Arrays
- Independent Telescopes on a Common Mount
- Random Subapertures on a Common Primary
- Dense Segmentation of a Common Primary

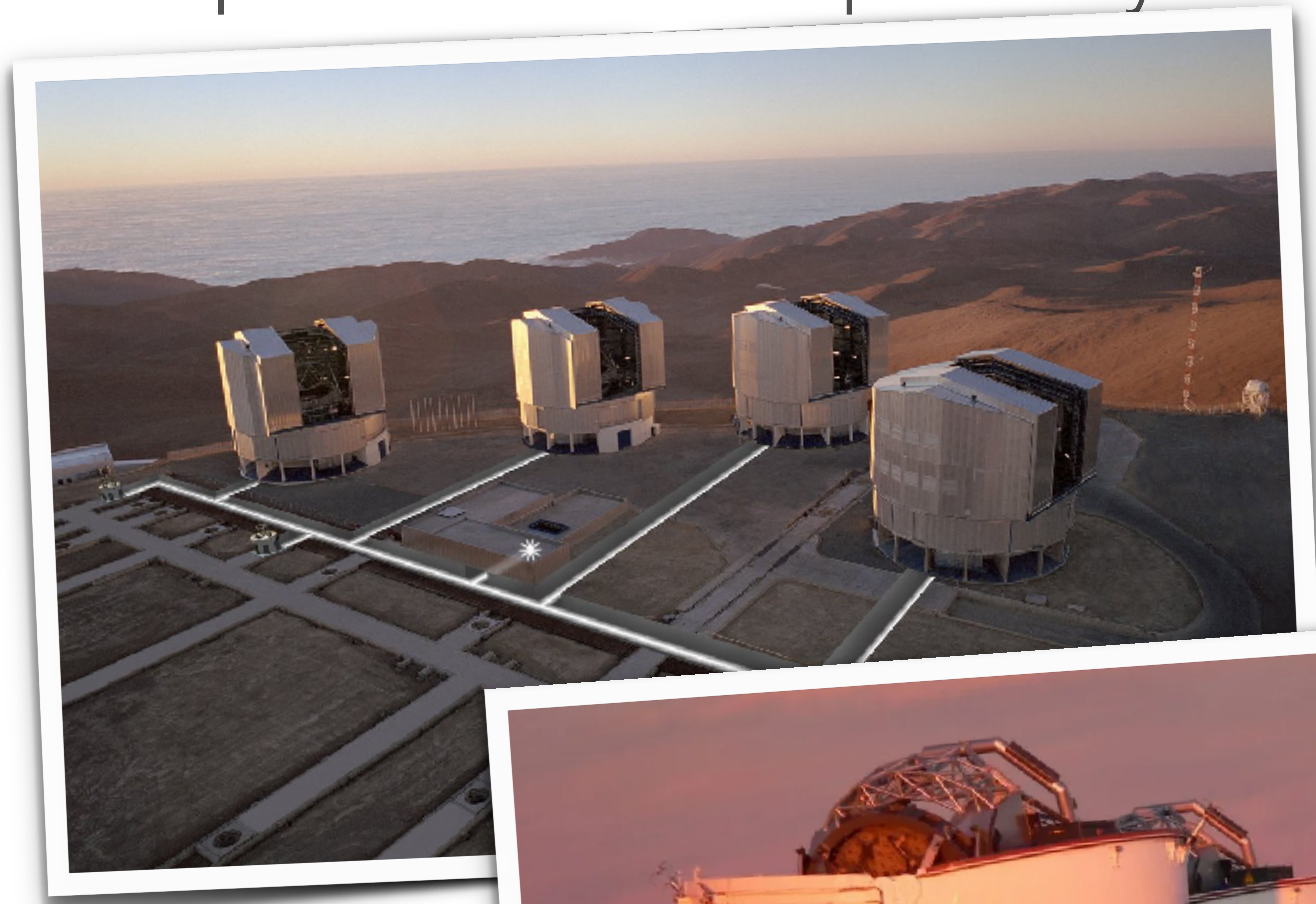
Independent Telescope Arrays

Independent Telescopes on a Common Mount

Random Subapertures on a Common Primary

Dense Segmentation of a Common Primary

Independent Telescope Arrays



Independent Telescopes on a Common Mount

Random Subapertures on a Common Primary

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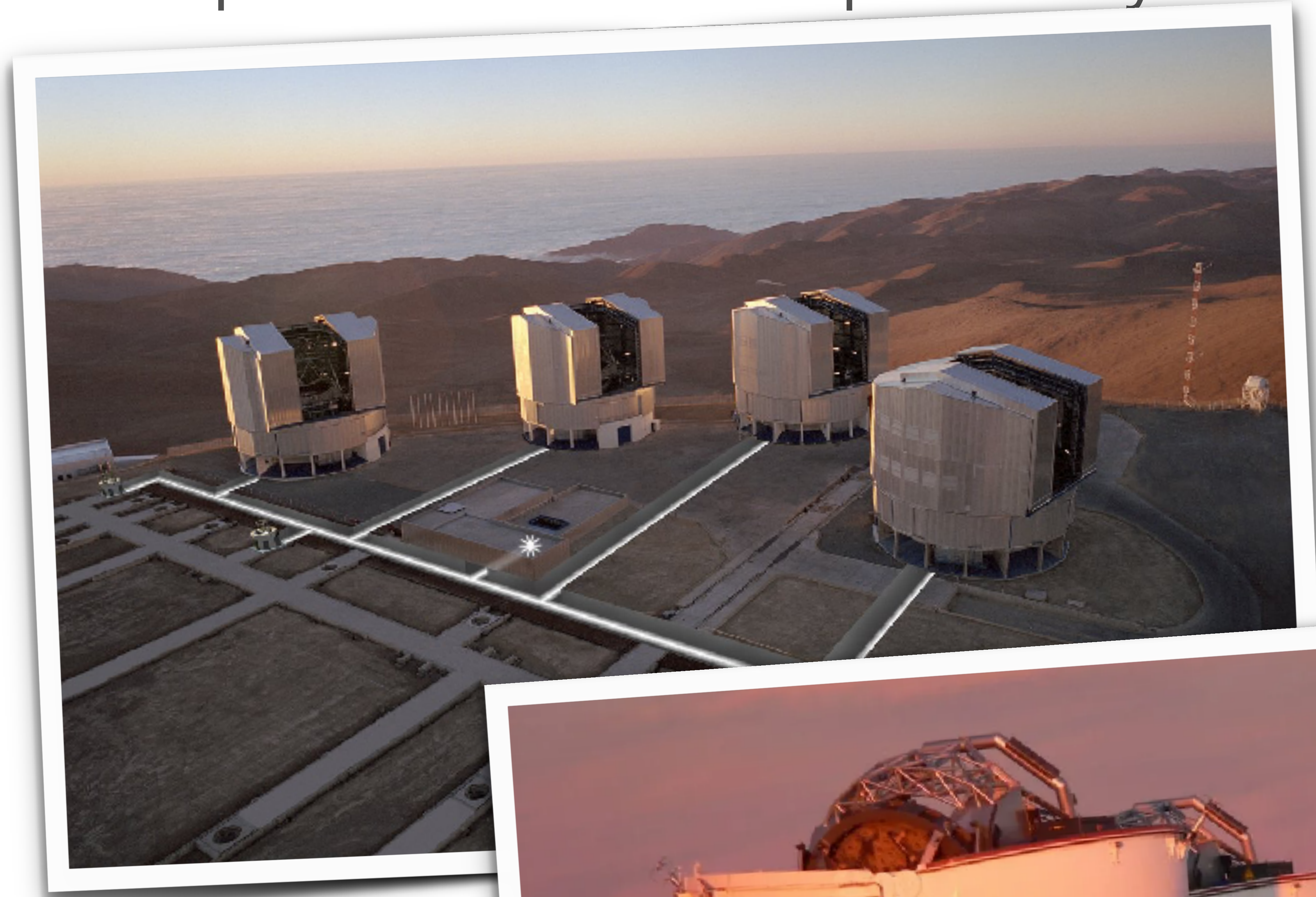

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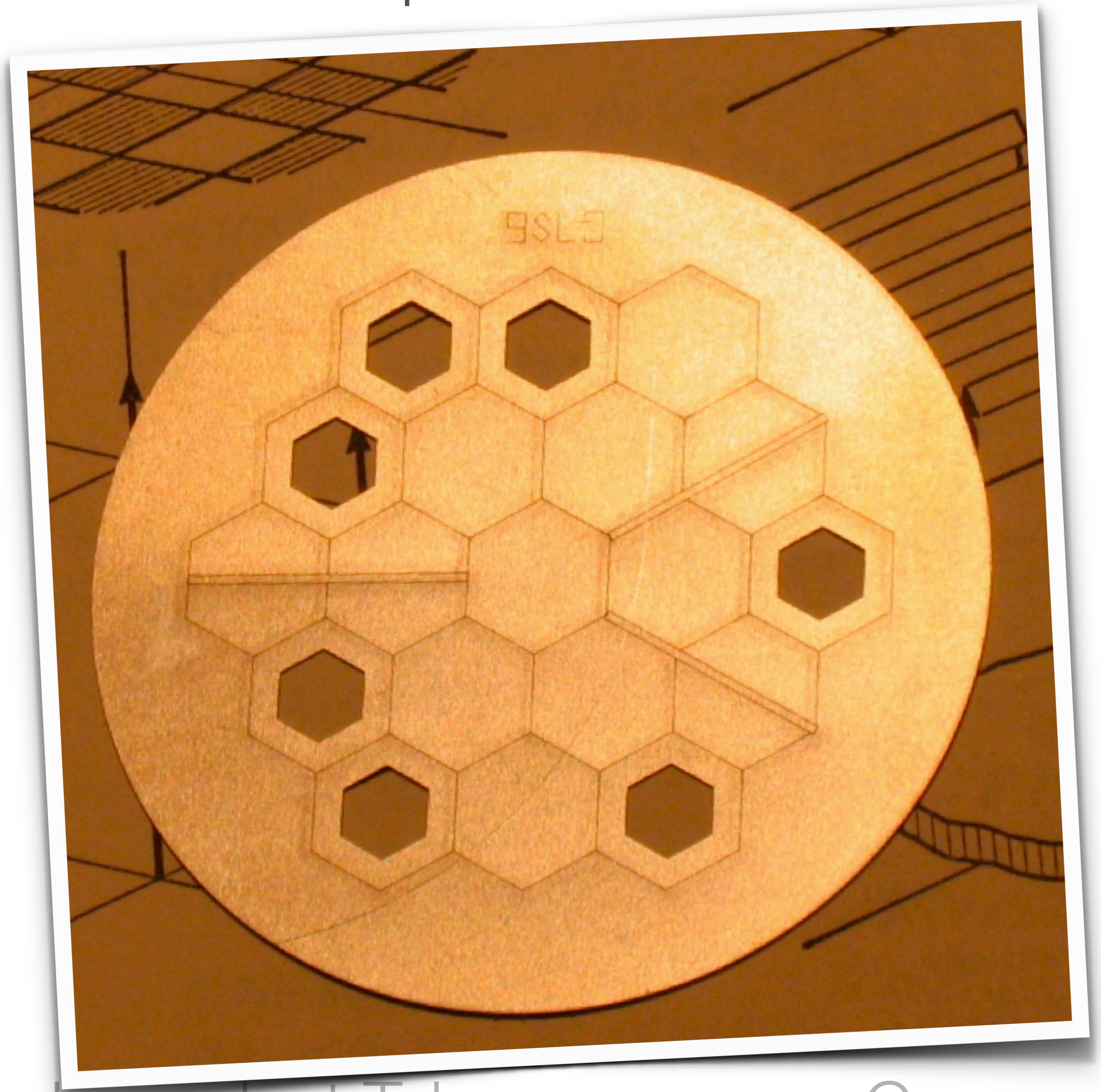

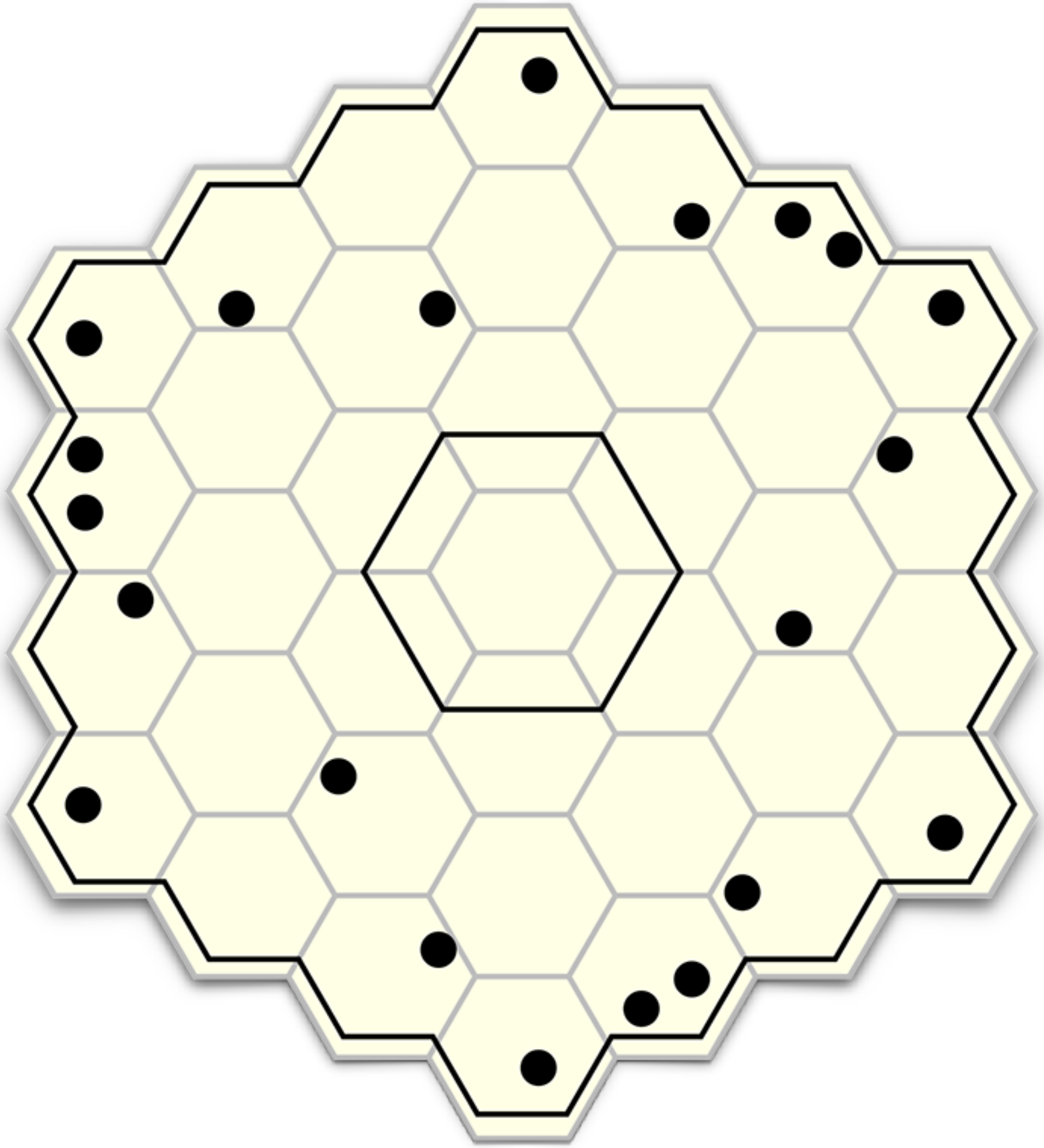

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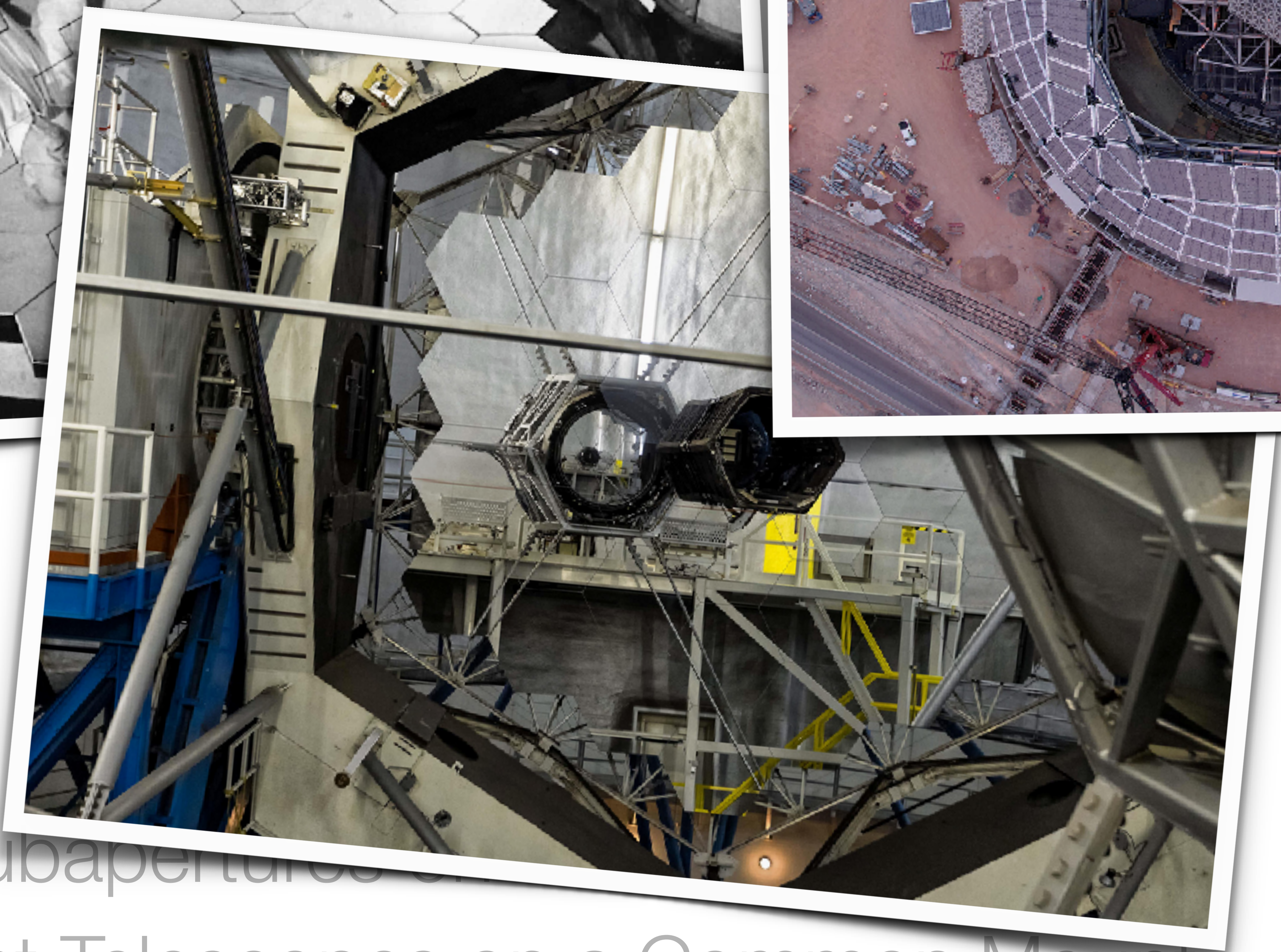


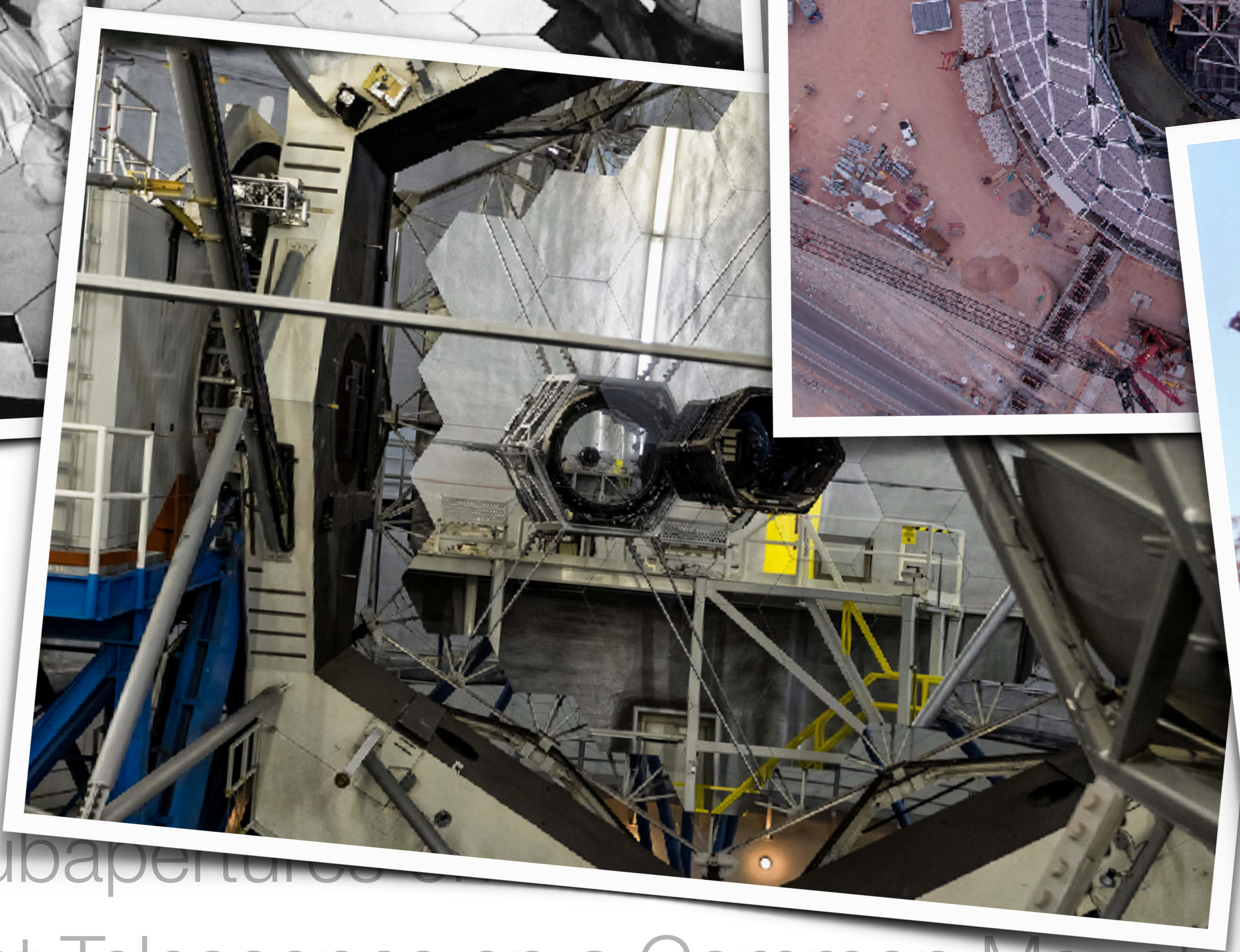
…and many more

Random Subapertures

Independent Telescopes on a Common Mount

Independent Telescope Arrays

Dense Segmentation of a Common Primary



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Random Subapertures o

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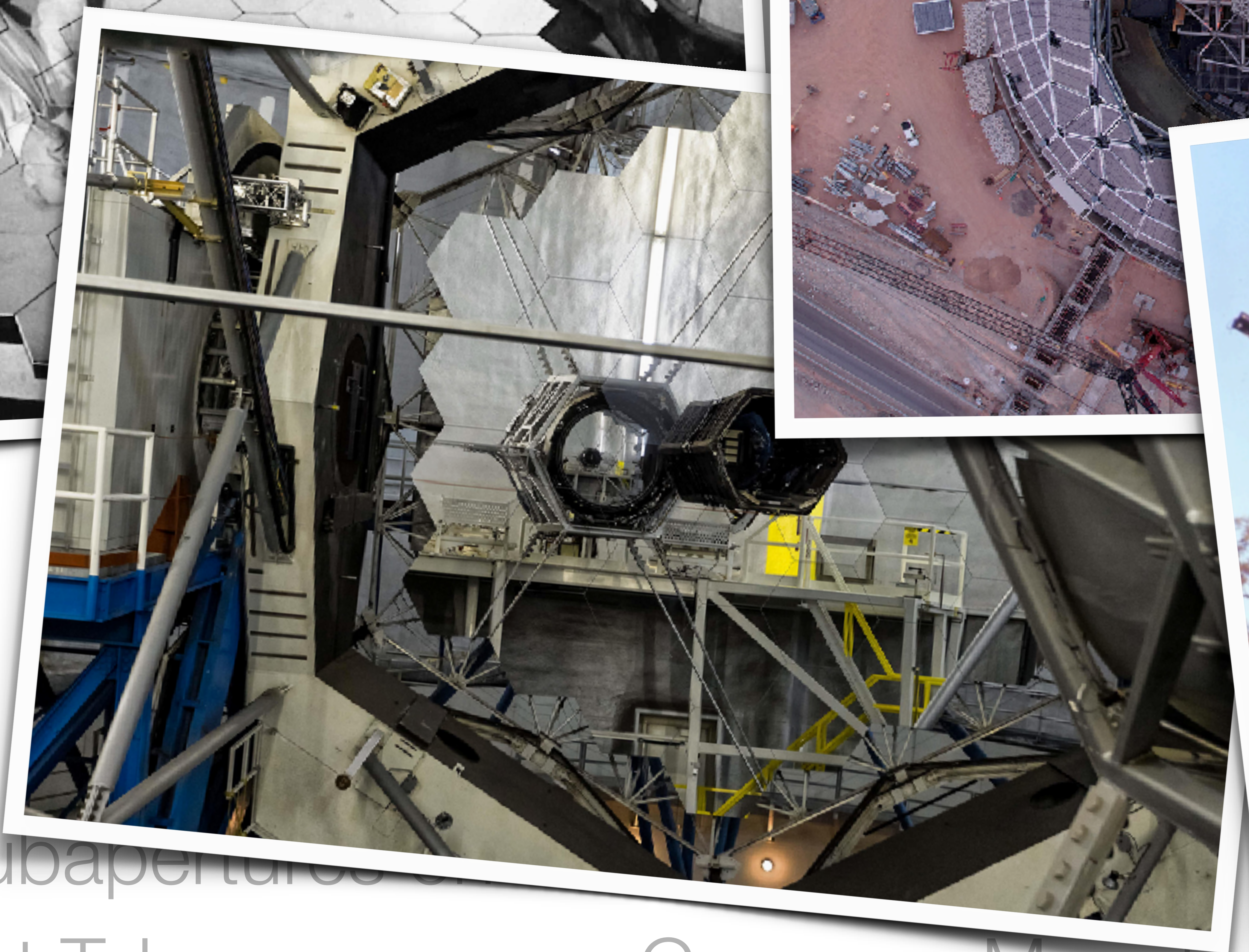


Random Subapertures

Independent Telescopes on a Common Mount

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Why Dense Segmentation ?

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Monoliths:

- Availability, cost of blanks
- Breakage cost enormous
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- Off-axis polishing
- Alignment and active control
- Diffraction, thermal effects of edges
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(more later…)

A Brief History of Segmented Mirrors

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Guido Horn d'Arturo
1879-1967

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Jerry Nelson
1944-2017

A Brief History of Segmented Mirrors

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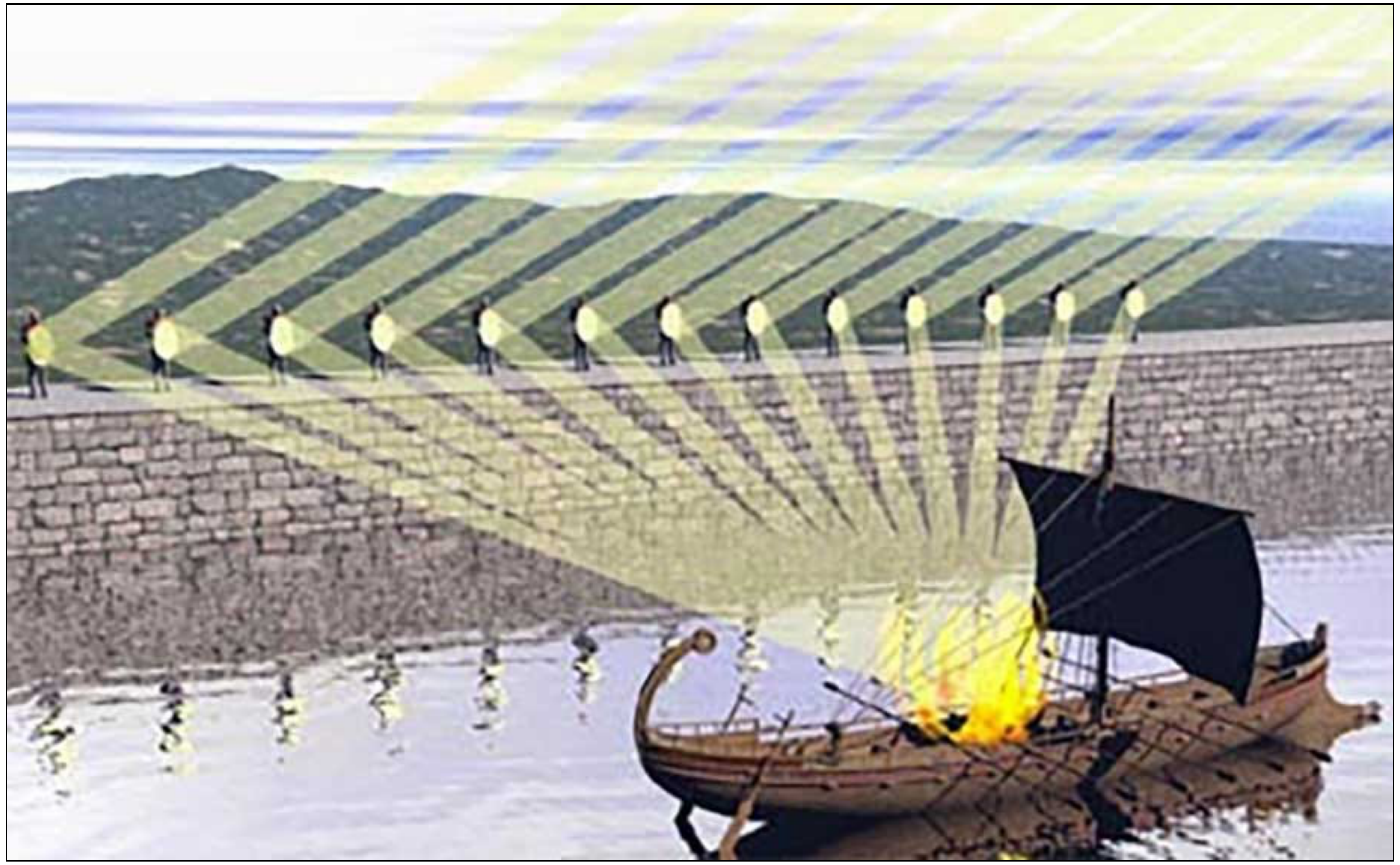
Archimedes of Syracuse
287-212 BCE

Jerry Nelson
1944-2017

Archimedes “Death Ray” 212 BC



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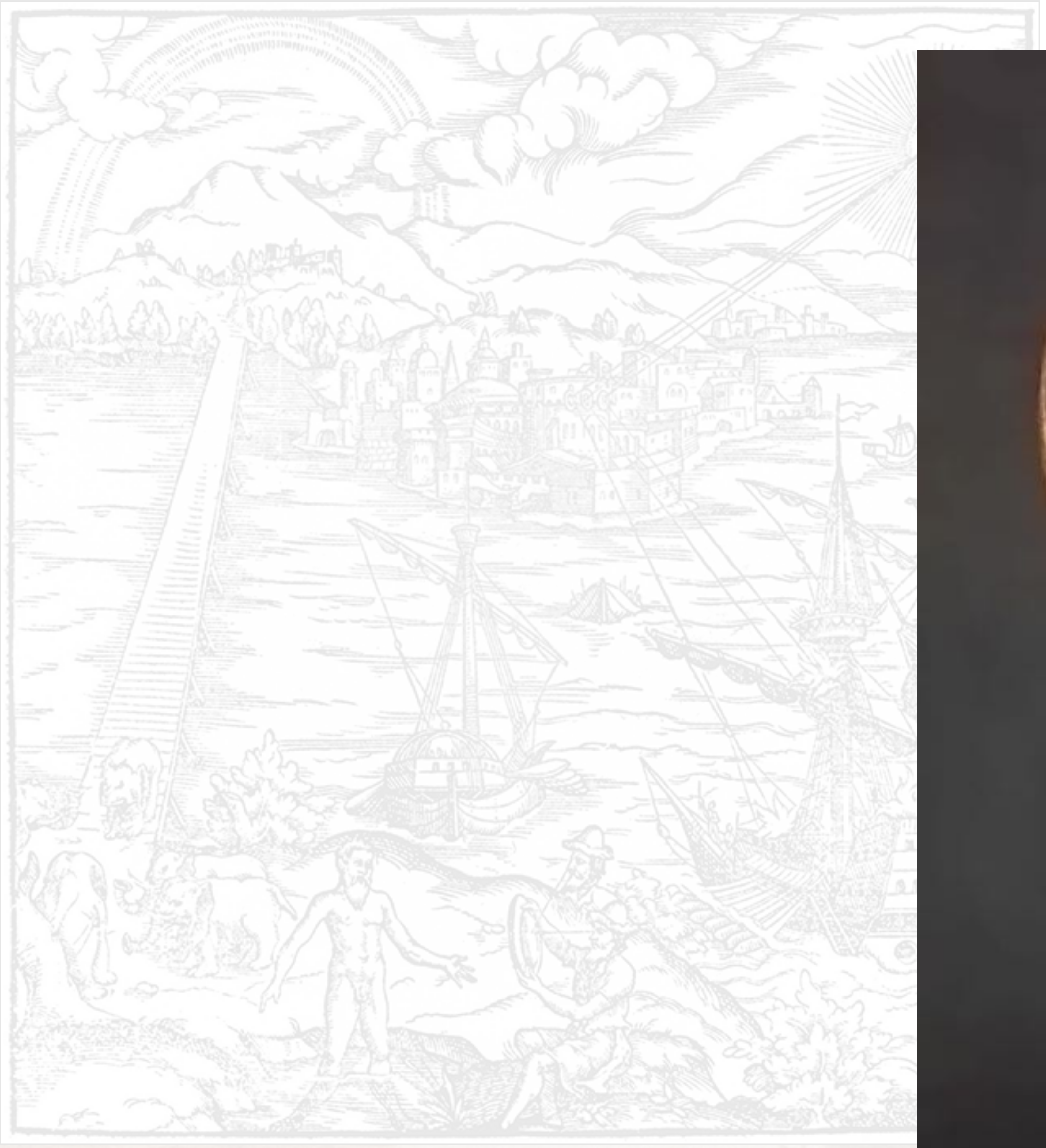
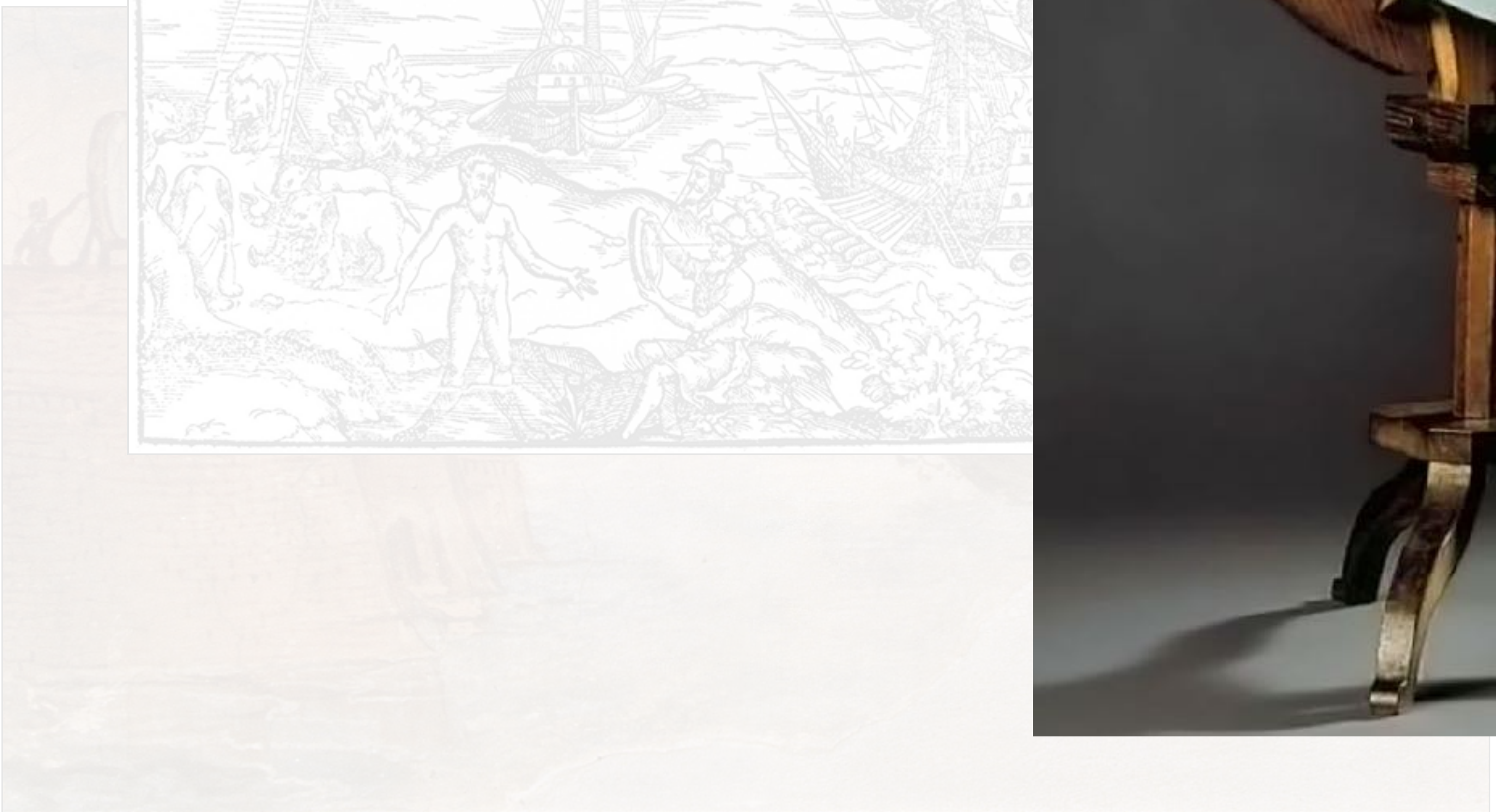
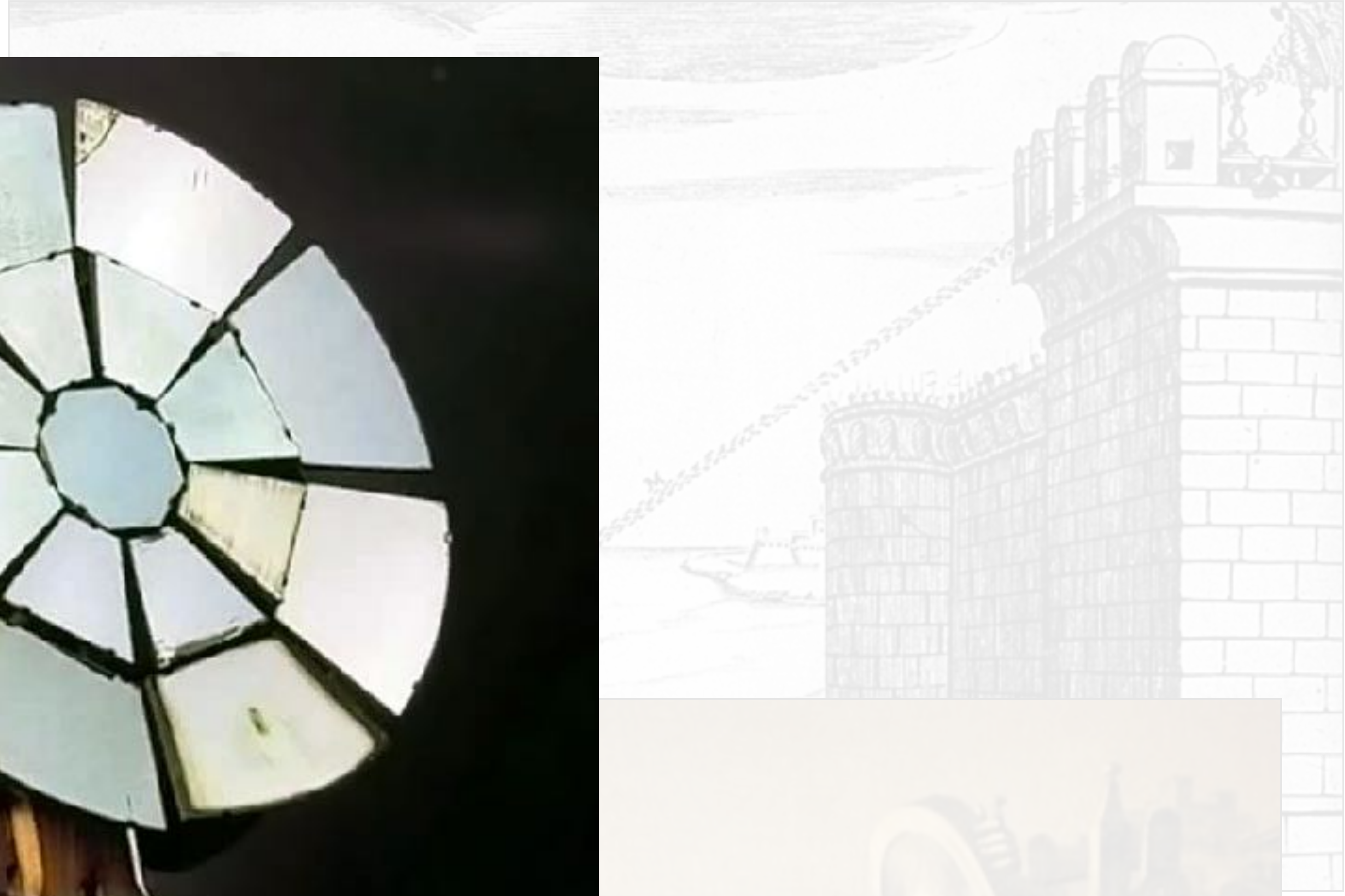




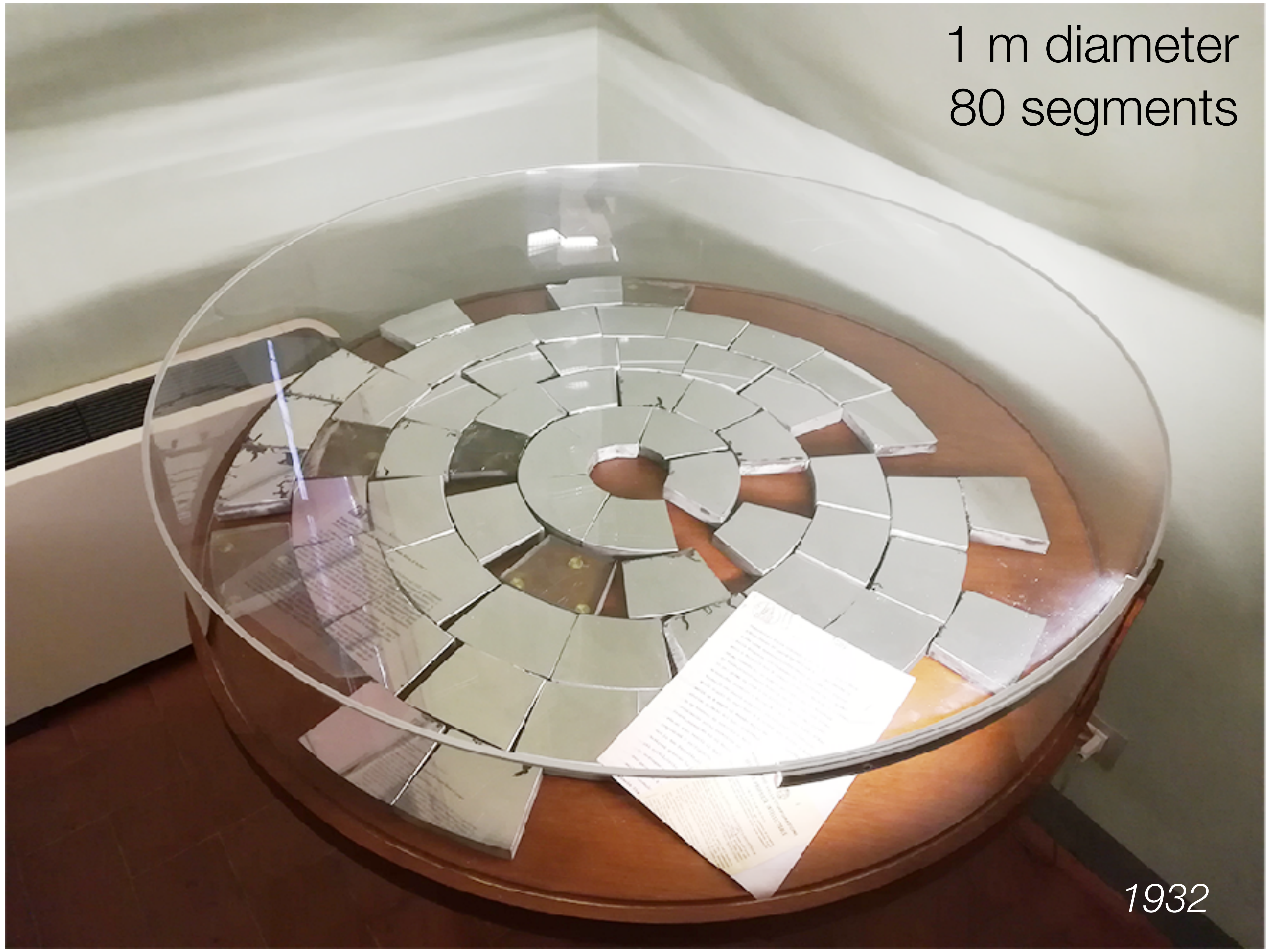
Archimedes “Death Ray” 212 BC

Myth Busters, 2006

Guido Horn d’Arturo

Guido Horn d’Arturo
1879-1967

Guido Horn d'Arturo



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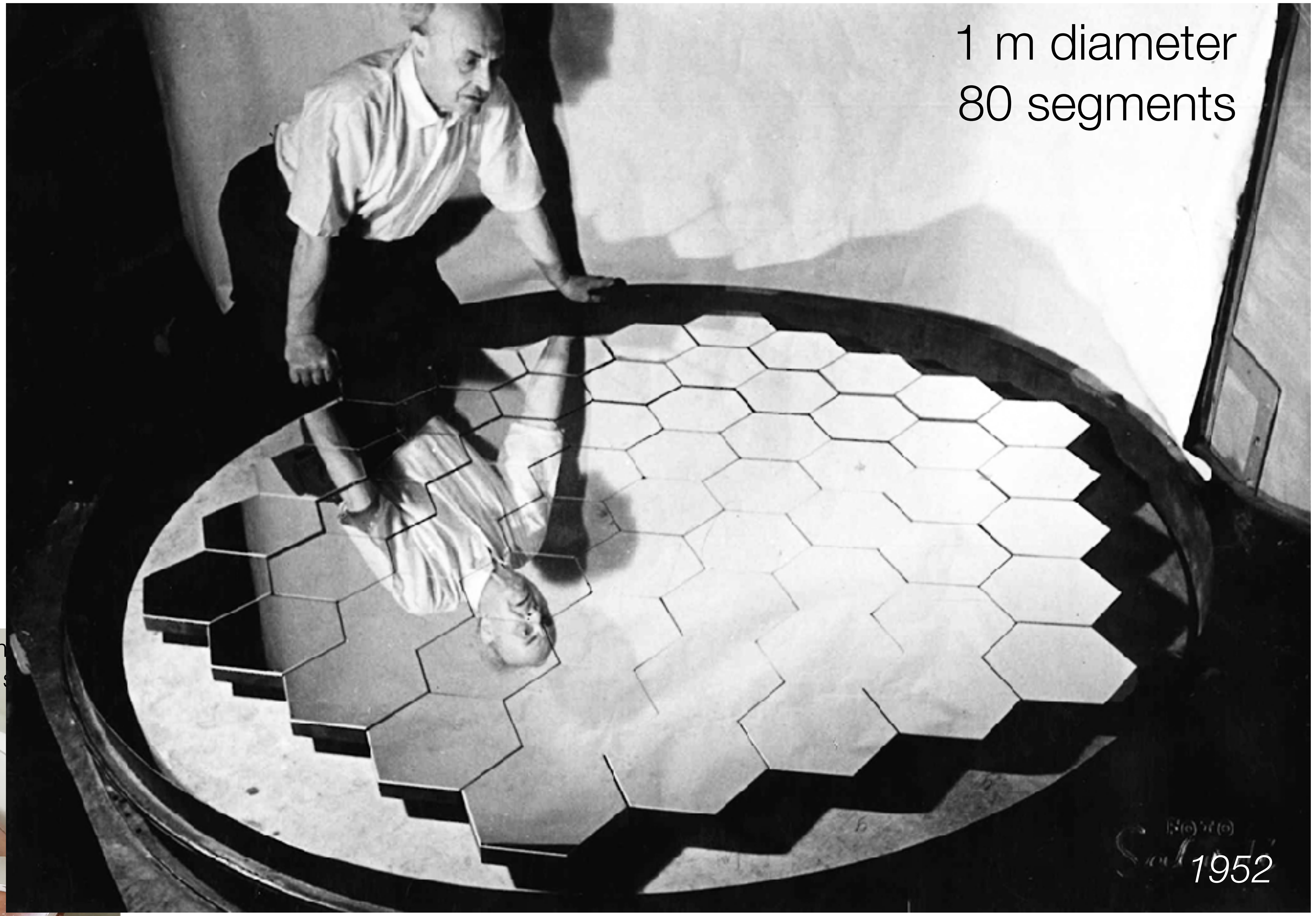

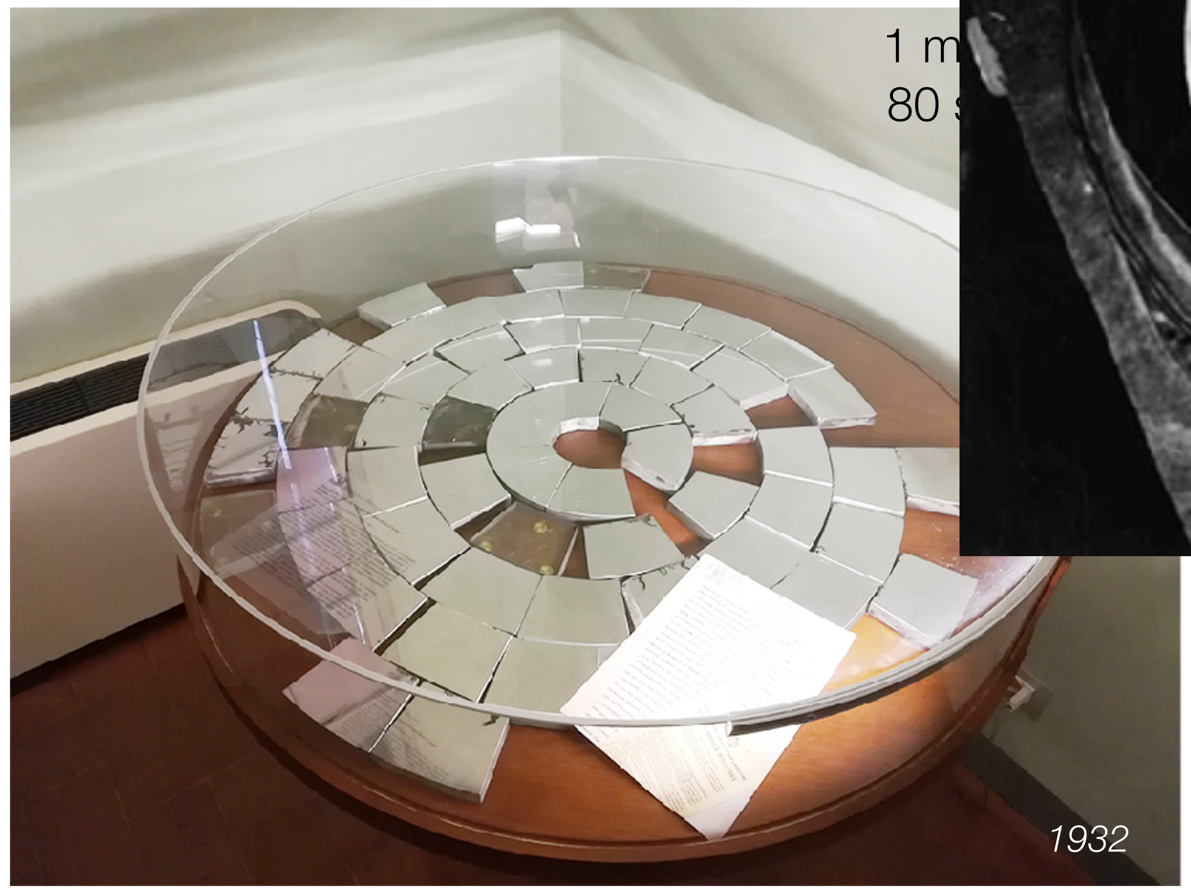

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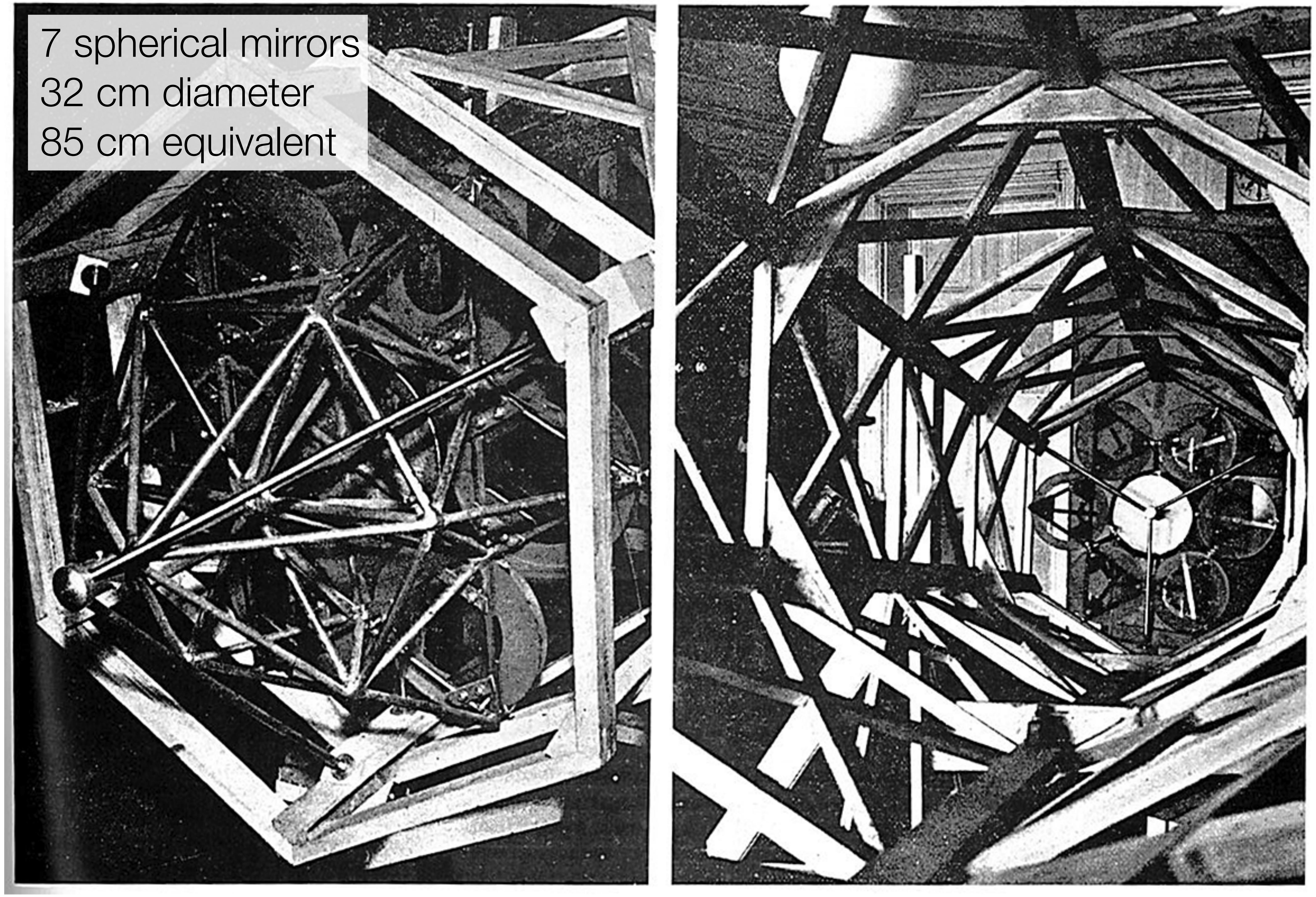
Contemporaries

Yrjö Väisälä
1891-1971

Contemporaries



Yrjö Väisälä
1891-1971

"In the spring of 1949, I began to build a trial telescope,
a miniature model for immense telescopes…"

Contemporaries

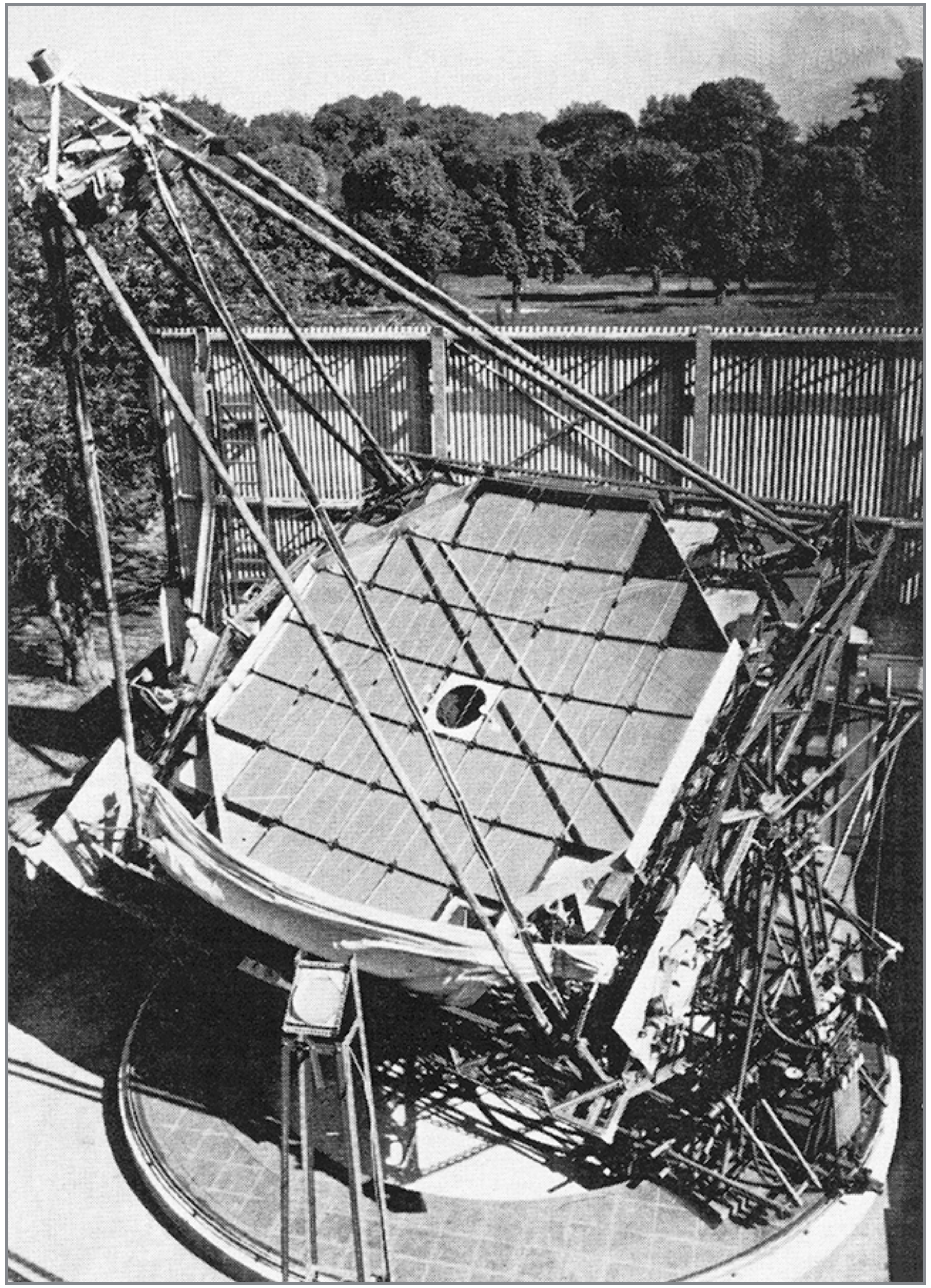
Pierre Connes
1928-2019

Contemporaries

Near Infrared Astronomical Light Collector (1974)

Observatoire de Paris

- 36 identical square segments
- 60 x 60 cm 4.2 m equivalent
- Polished to common sphere



Pierre Connes
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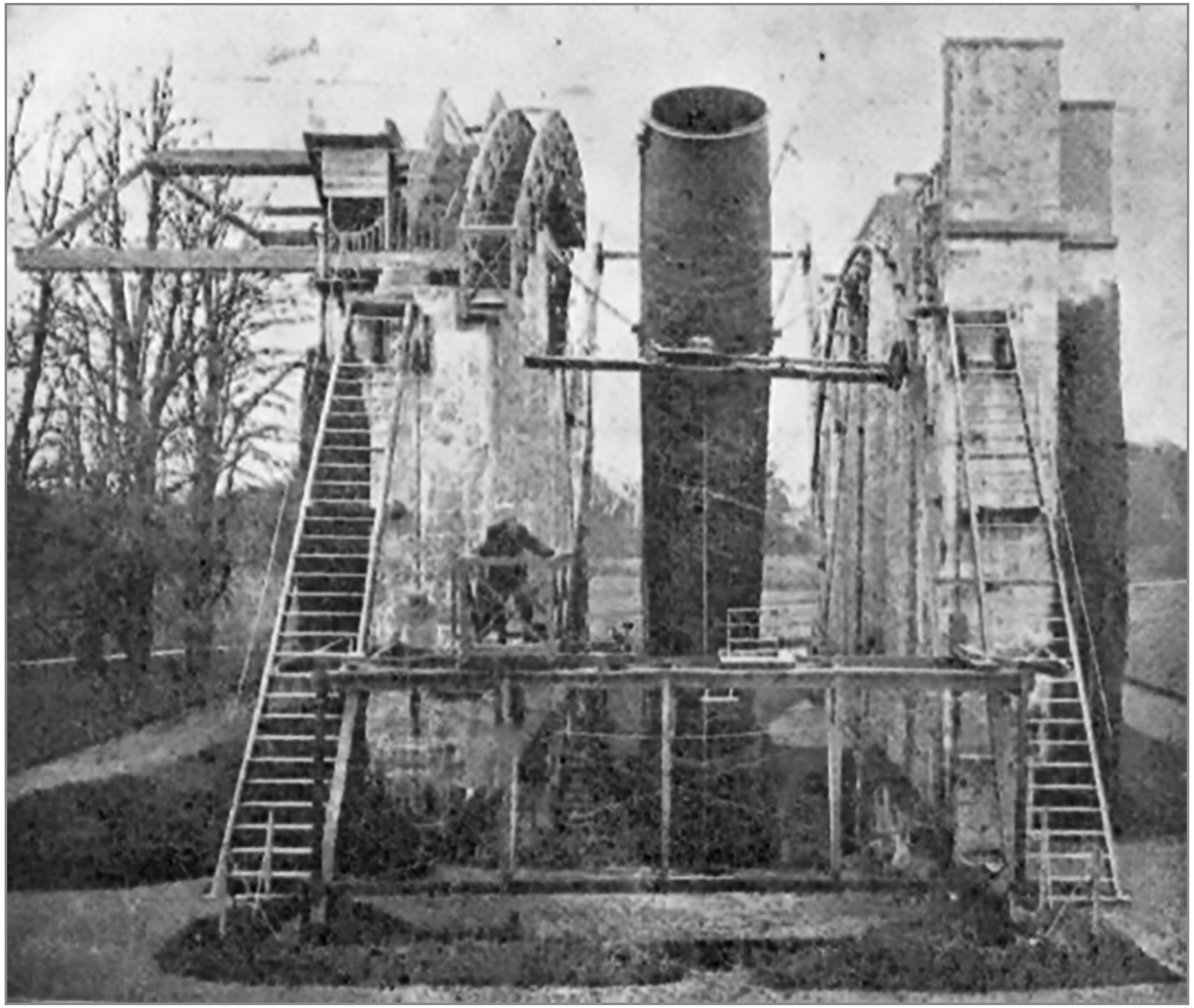
Less Well Known…

William Parsons
3rd Earl of Rosse
1800-1867

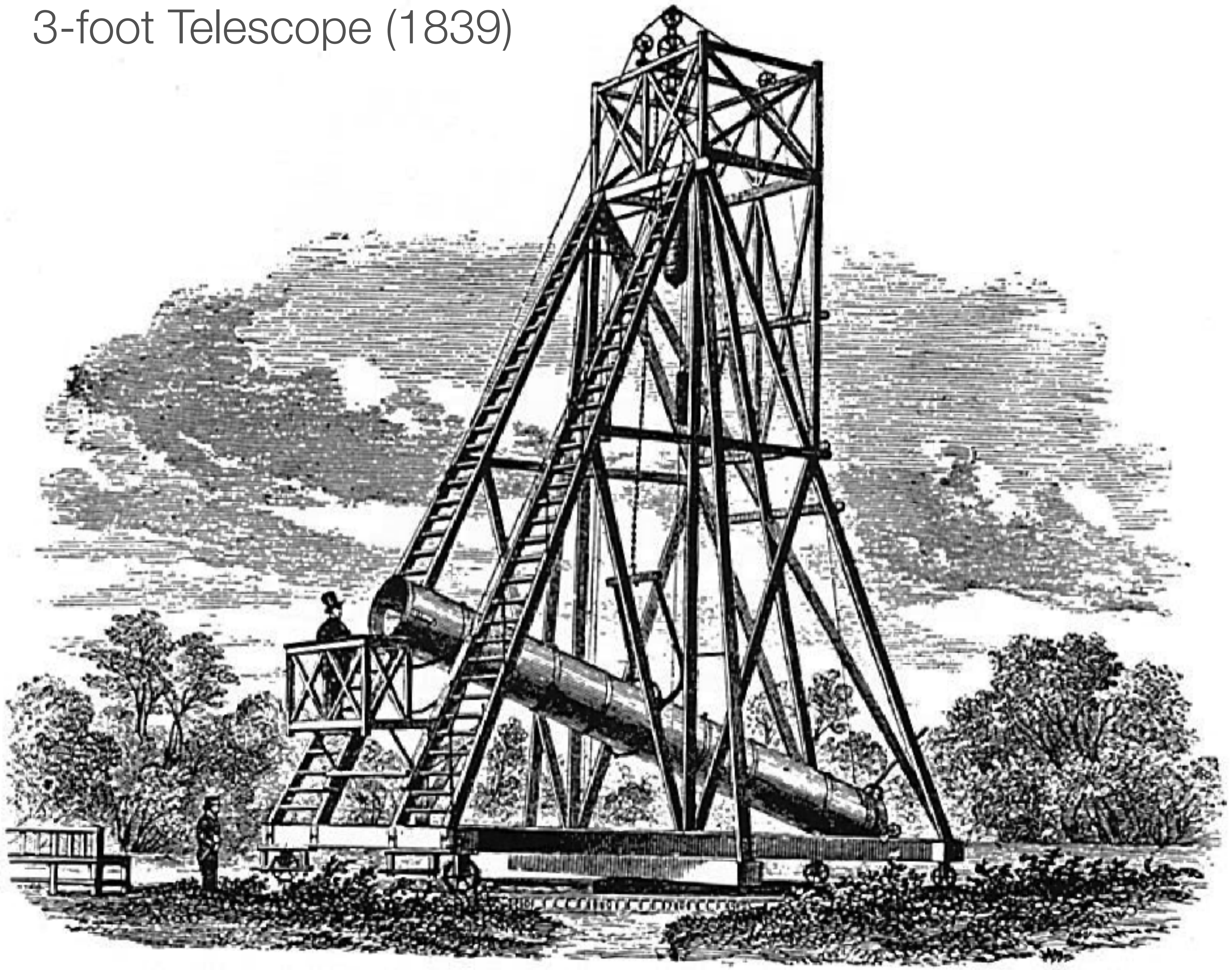
Less Well Known…



“Leviathan of Parsontown” 1.83 m Diameter (1845)

William Parsons
3rd Earl of Rosse
1800-1867

Less Well Known…


3-foot Telescope (1839)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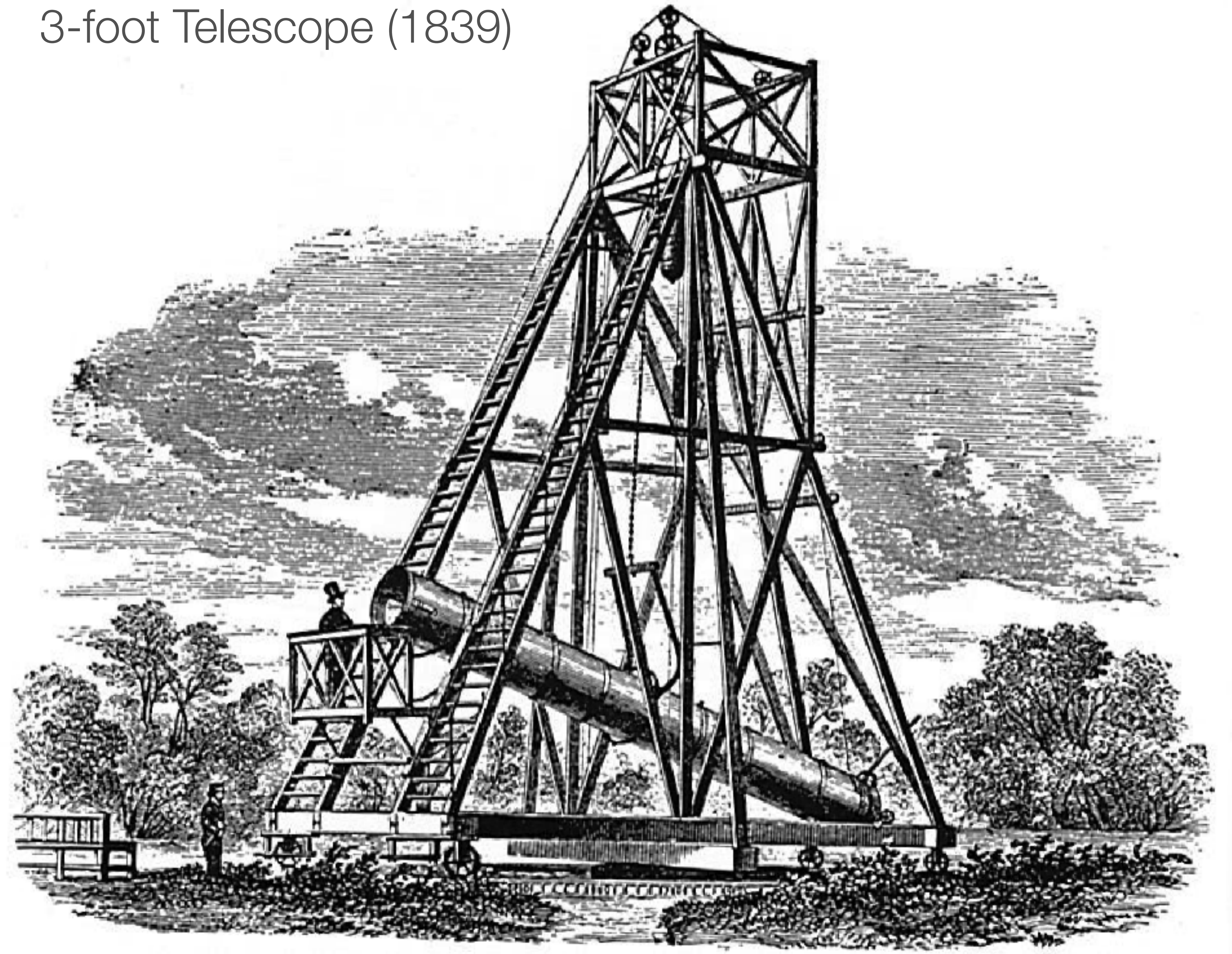

William Parsons
3rd Earl of Rosse
1800-1867

"Six pieces of the highest speculum metal were then prepared one quarter of an inch thick, and fitted so as to make, when put together, a complete circular disc…"

Edinburgh Journal of Science, 1830

Less Well Known…

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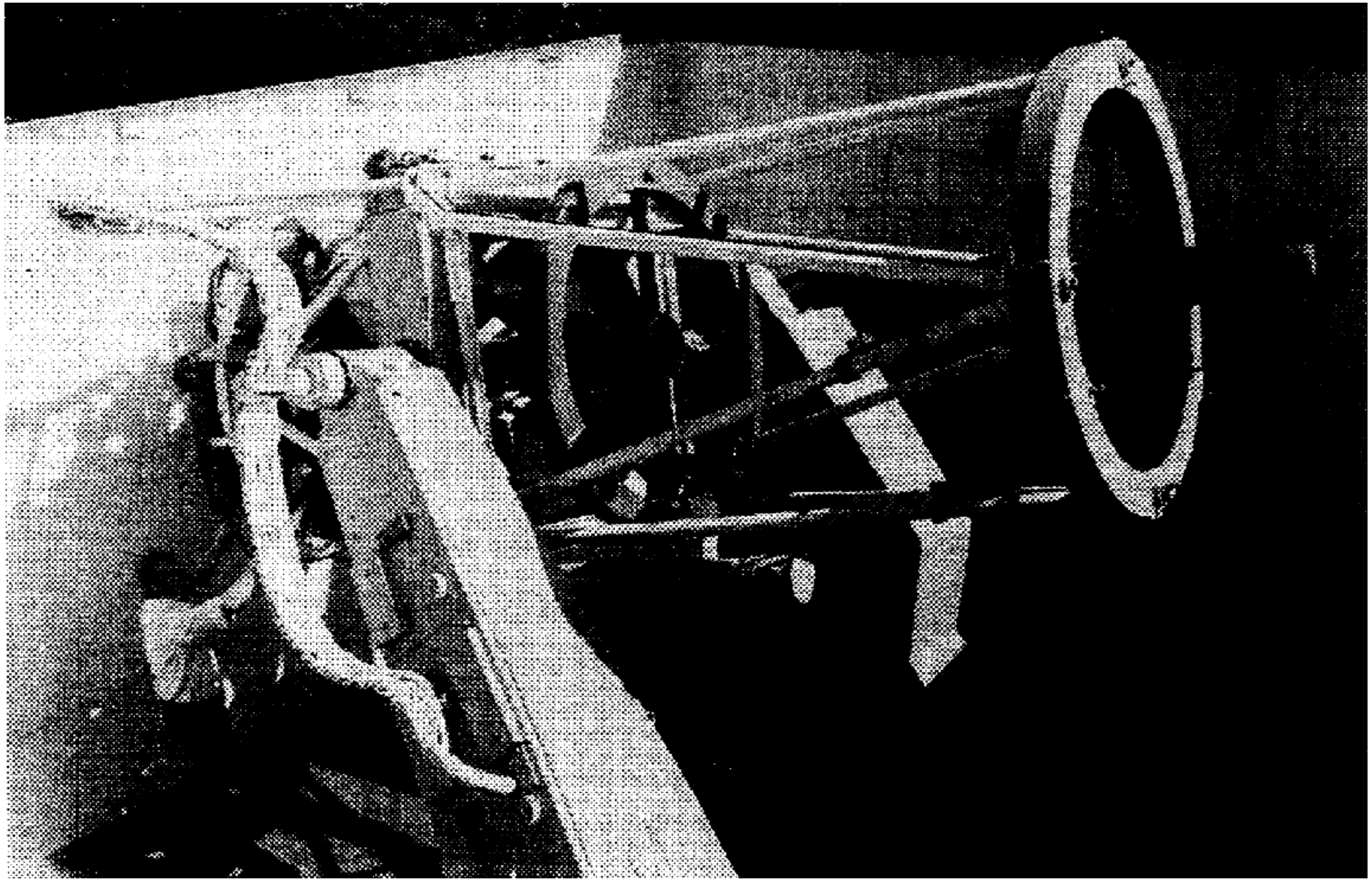
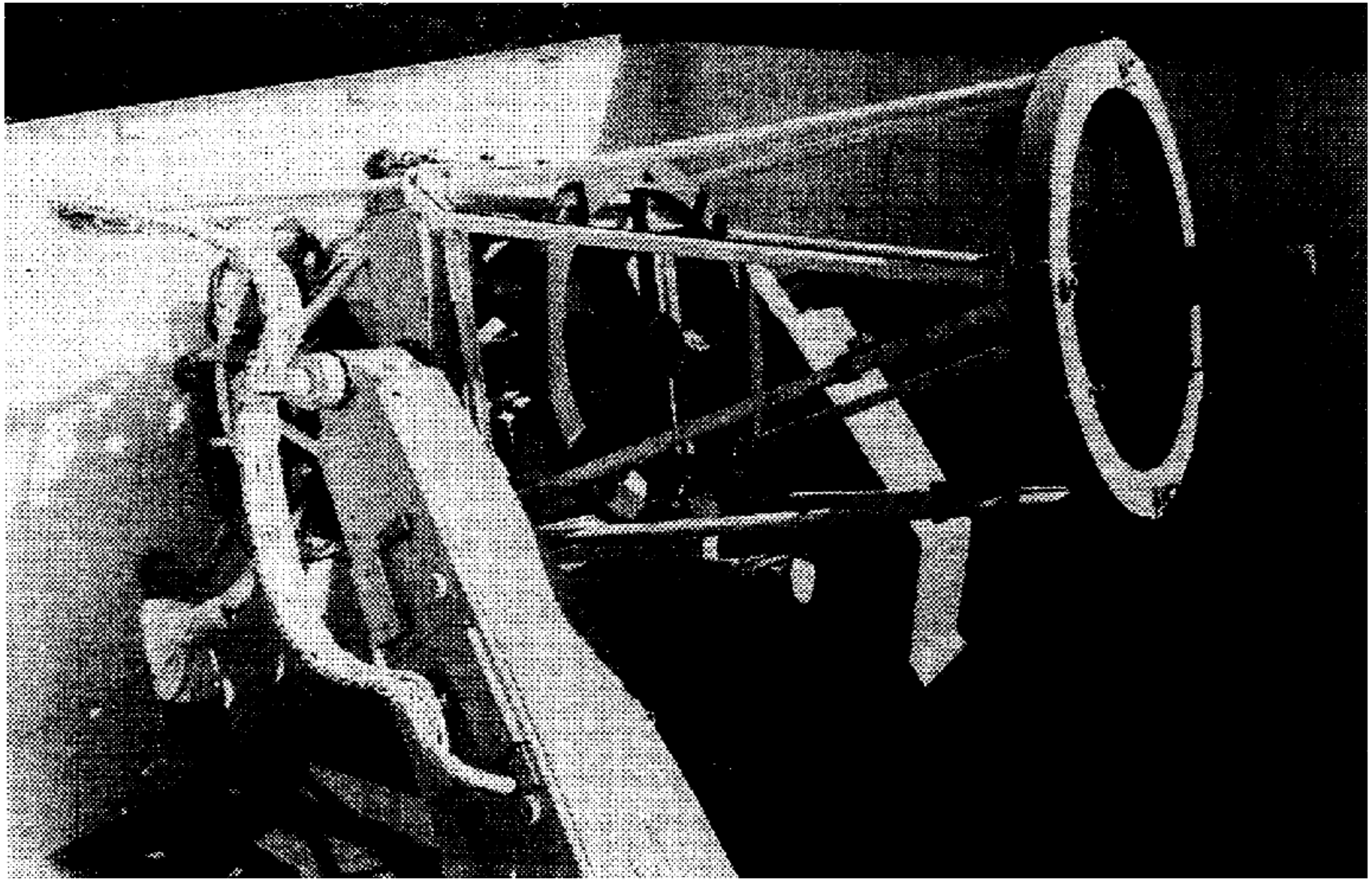


AST-1200 (1978)

Crimean Astrophysical Observatory

- 7 hexagonal segments
- 45 cm point-point,
- 1.2 m equivalent
- not phased…

Less Well Known…



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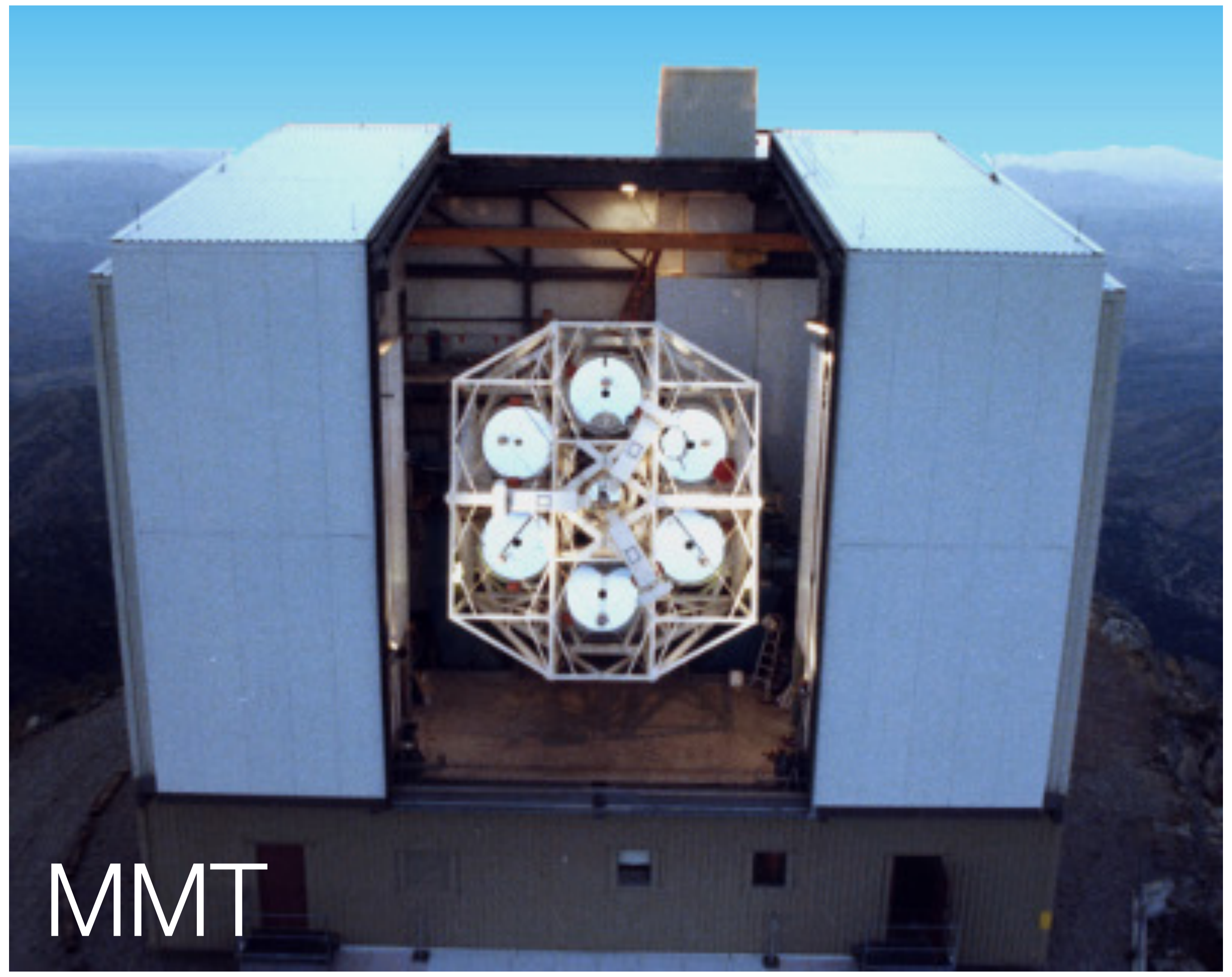
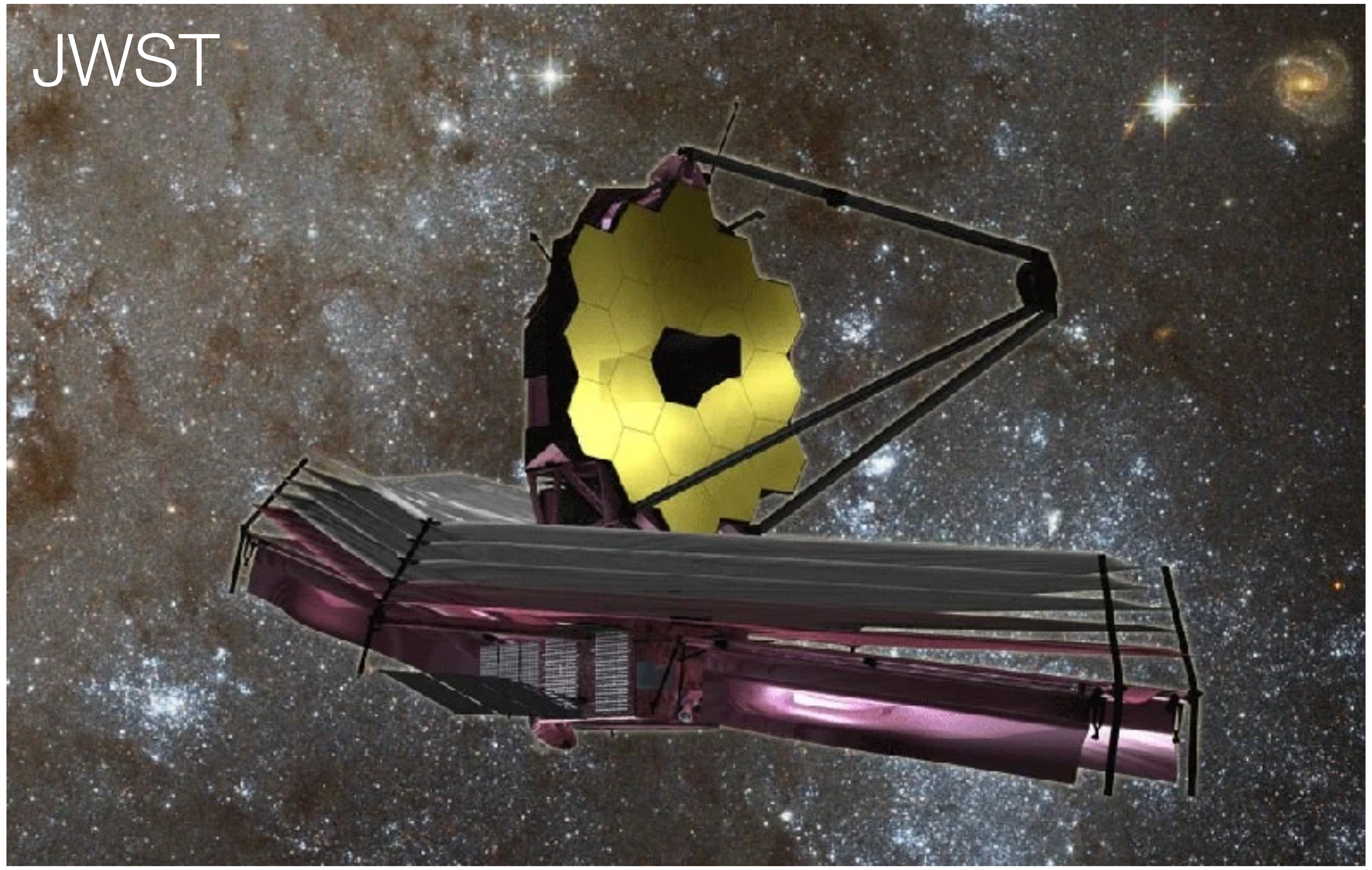
and since?

Legacy





Legacy – Telescopes with Segmented Mirrors

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Other / Concepts

- JWST 2021

- NNTT 1980's
- CELT, VLOT, GSMT late 1990's
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notice anything weird?

Curiosities

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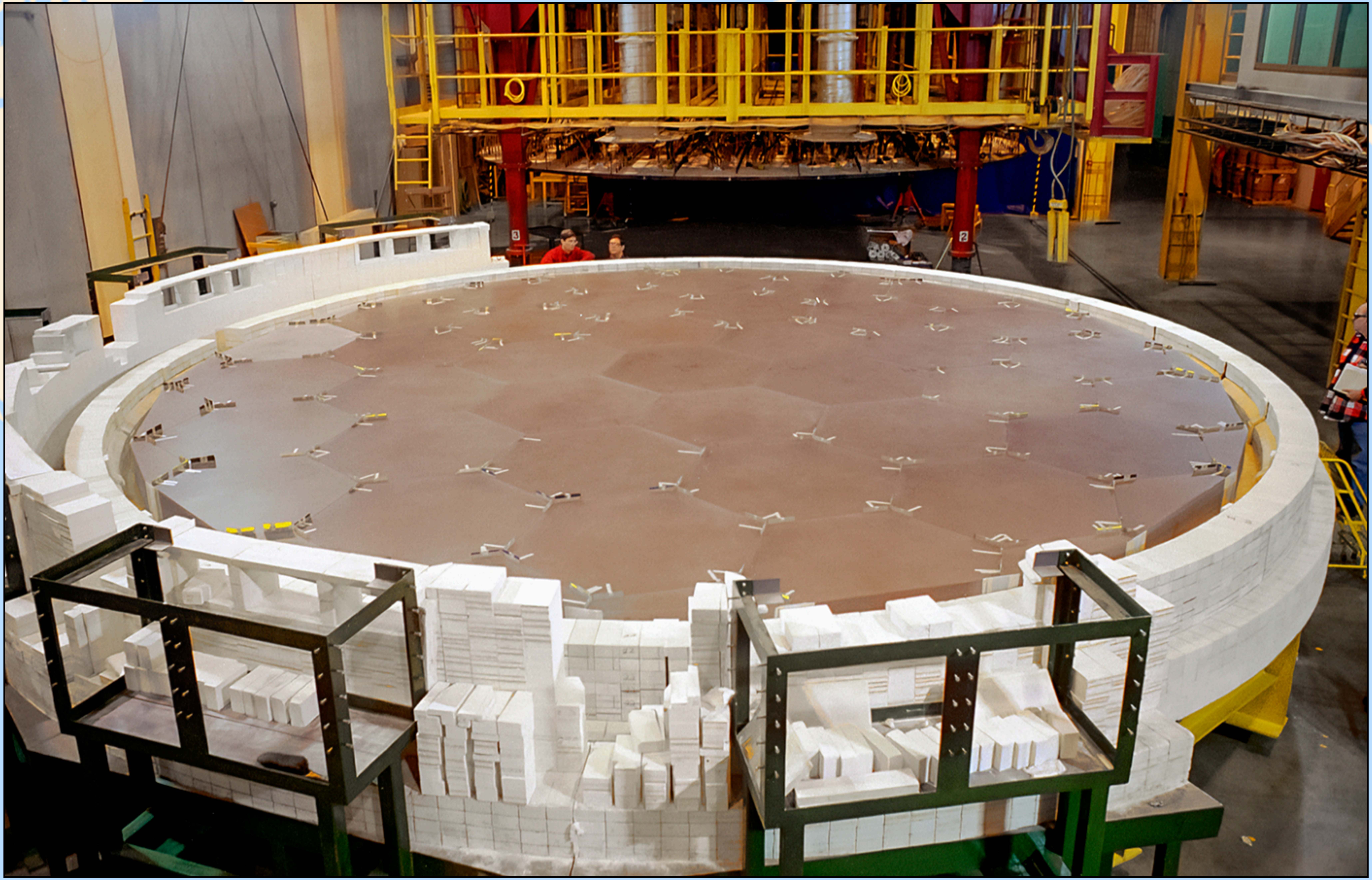

Gemini North 1999

Curiosities

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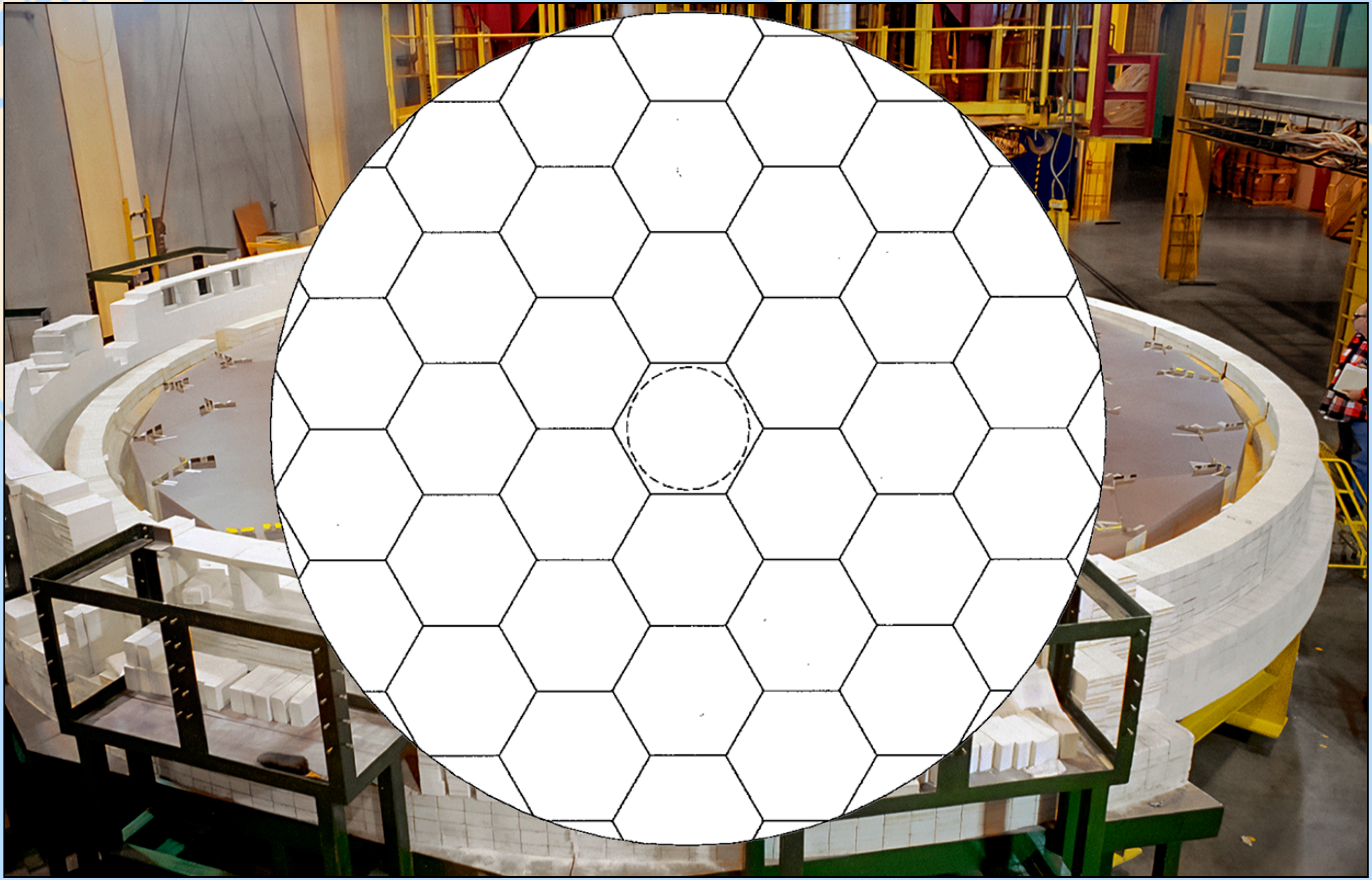

Curiosities

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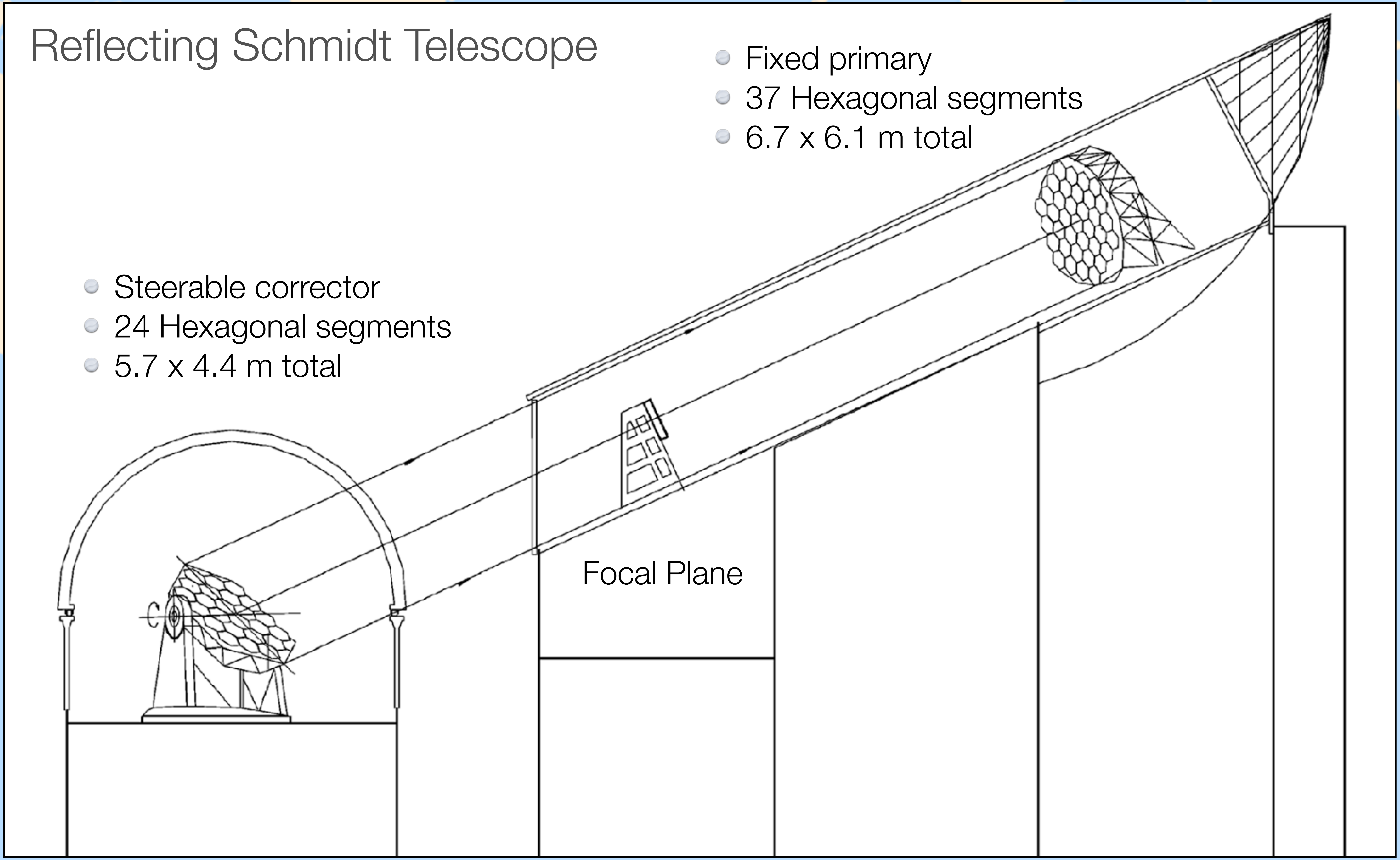
Curiosities

Reflecting Schmidt Telescope

- Fixed primary
- 37 Hexagonal segments
- 6.7 x 6.1 m total

- Steerable corrector
- 24 Hexagonal segments
- 5.7 x 4.4 m total



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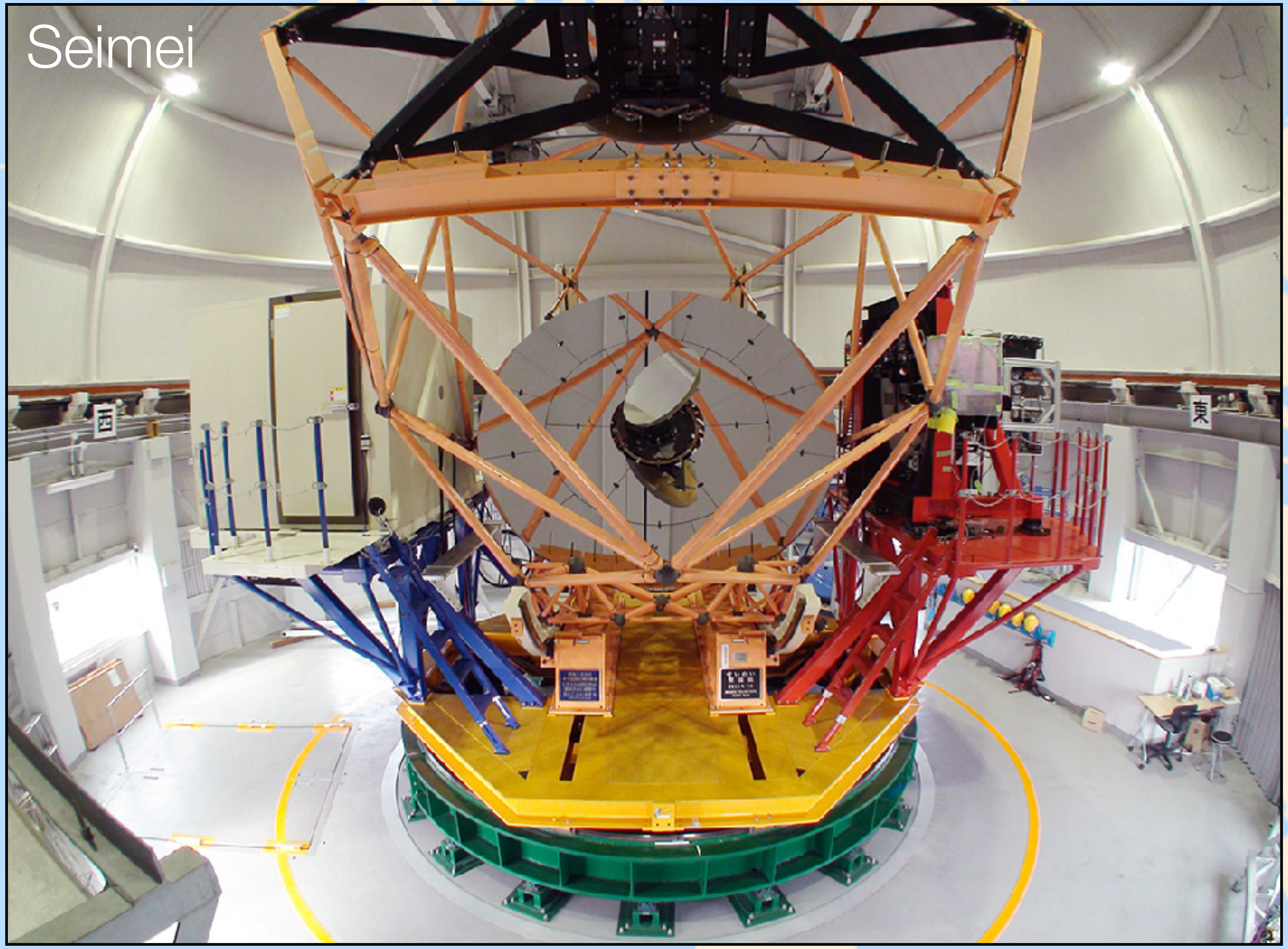
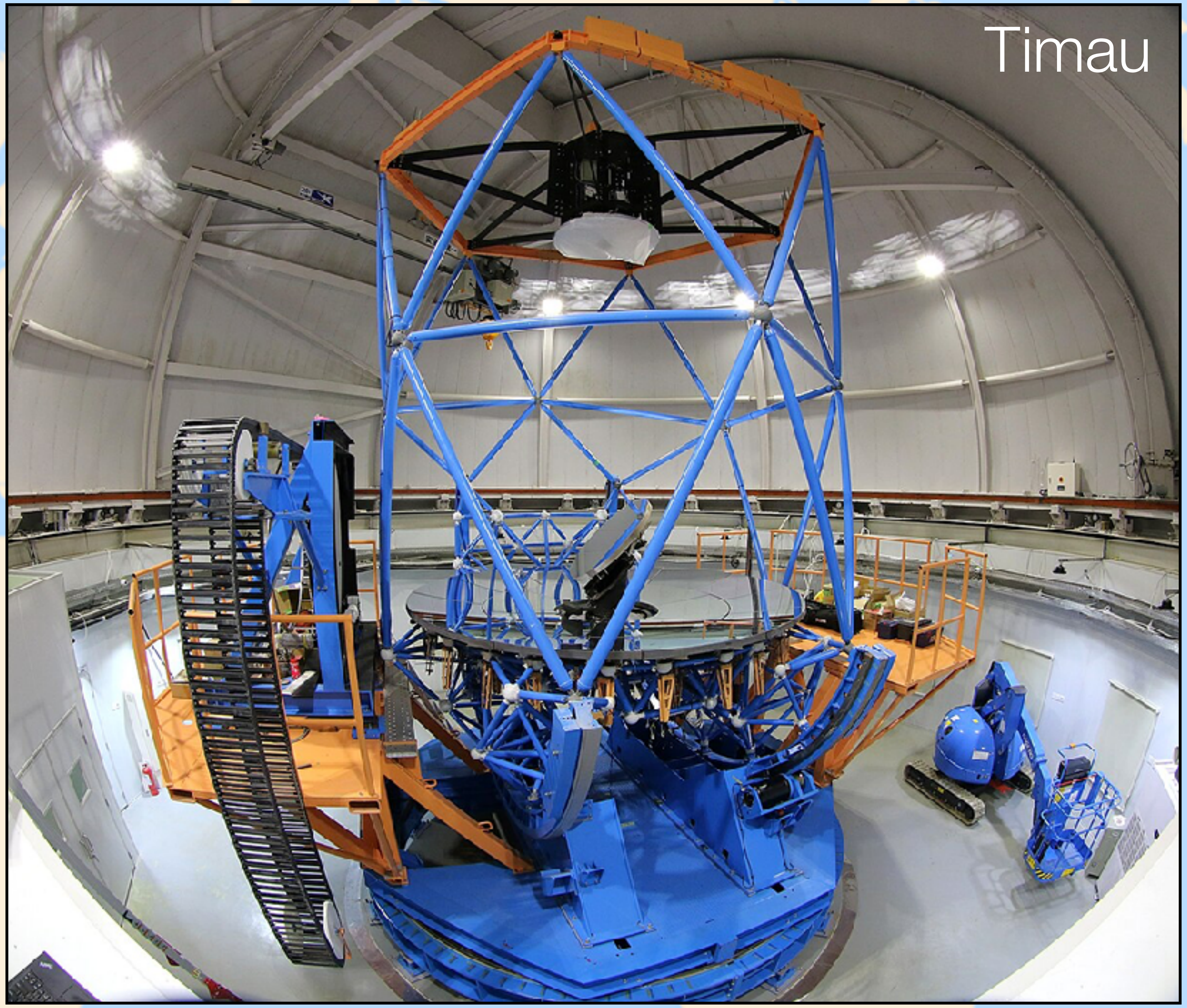
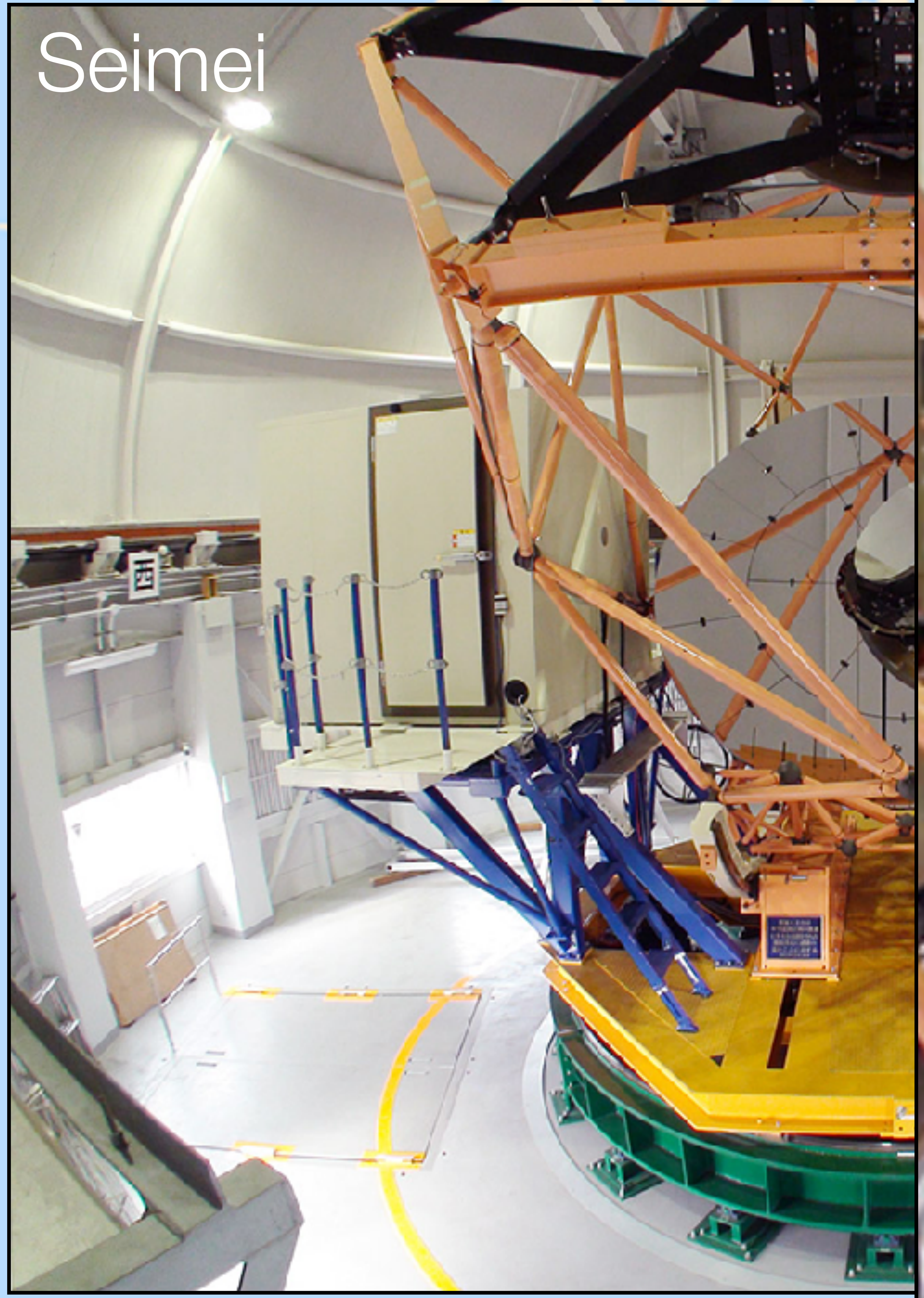
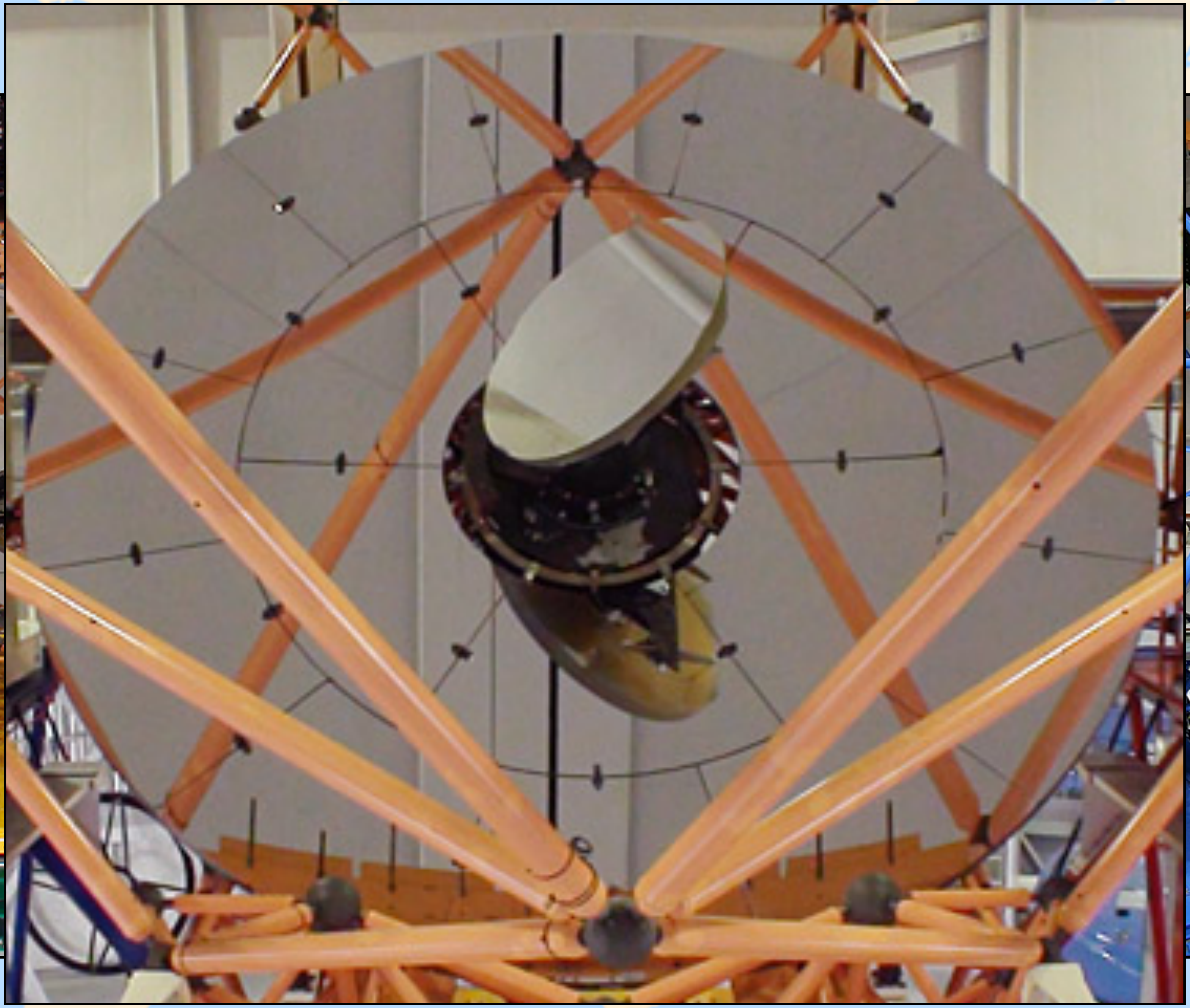




Primary Mirror:
- 3.8 m Aperture
- 18 Segments
- Annular segmentation

Curiosities





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Let’s design a (densely) segmented mirror telescope…

Tesselation…

Tesselation…

Assumption: All (or many) segments should have the same general size and shape

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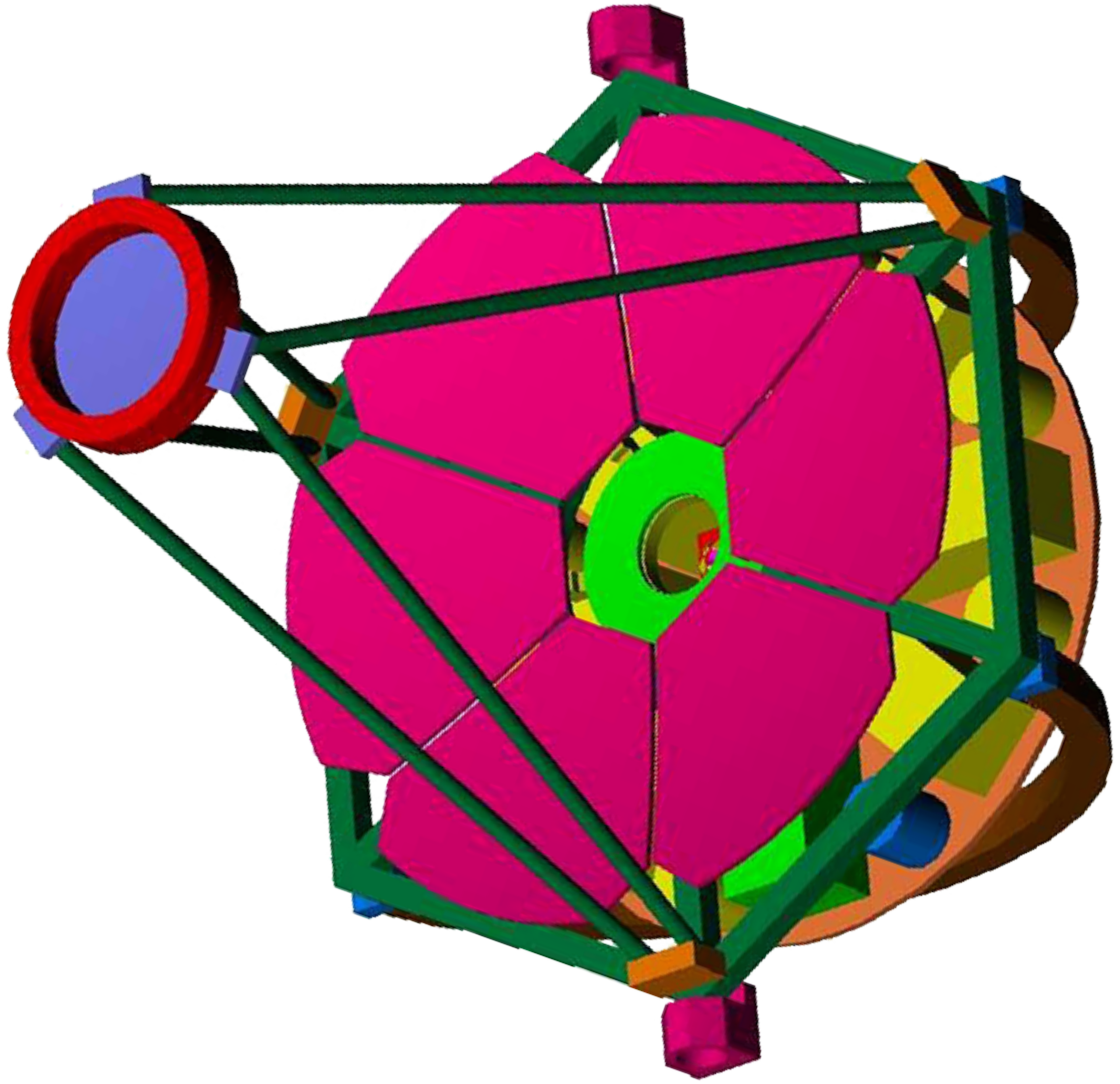
Options:
- Petals

Large Petal Telescope



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Options:
- ~~Petals~~
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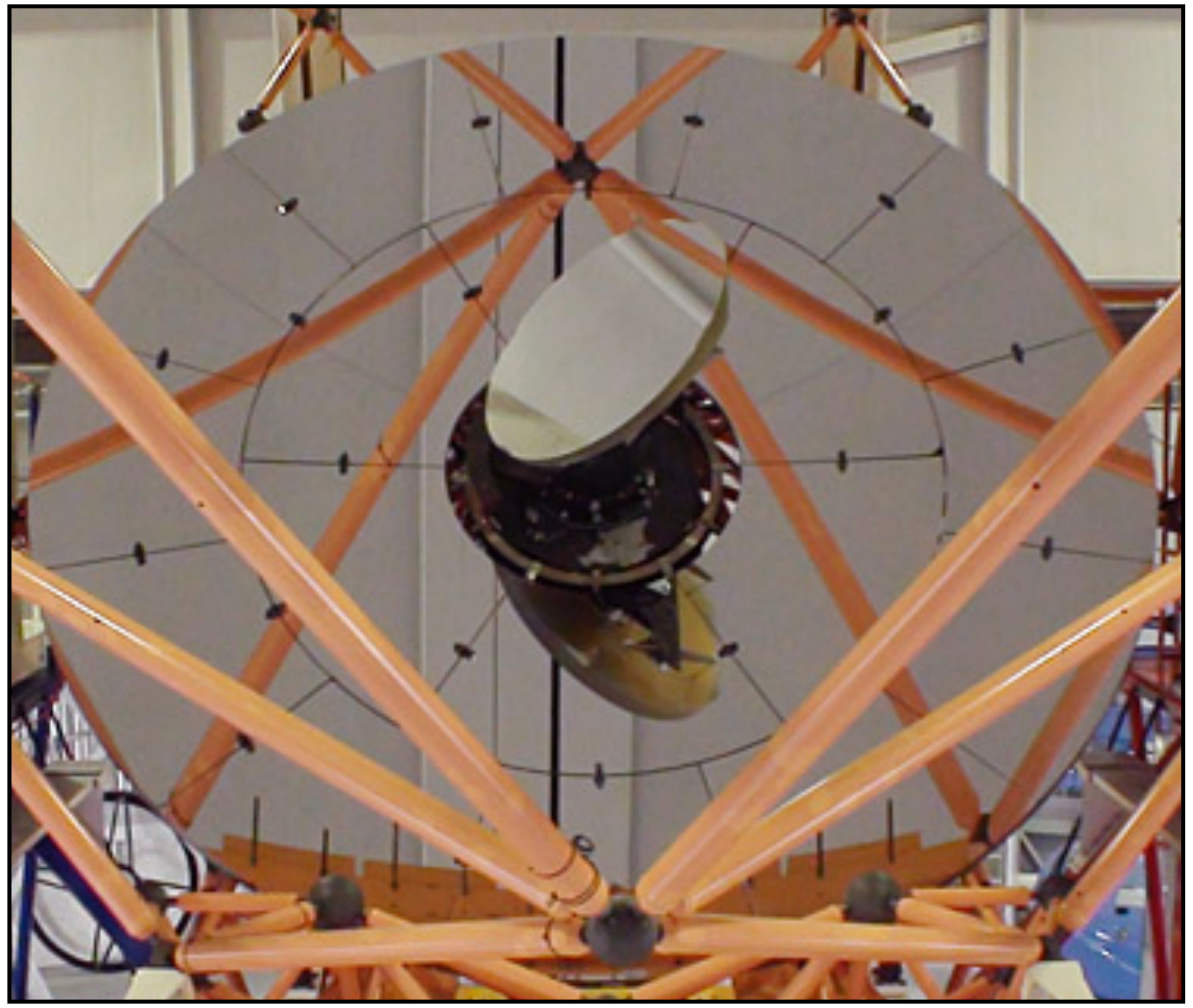
Seimei



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Assumption: All (or many) segments should have the same general size and shape

Options:

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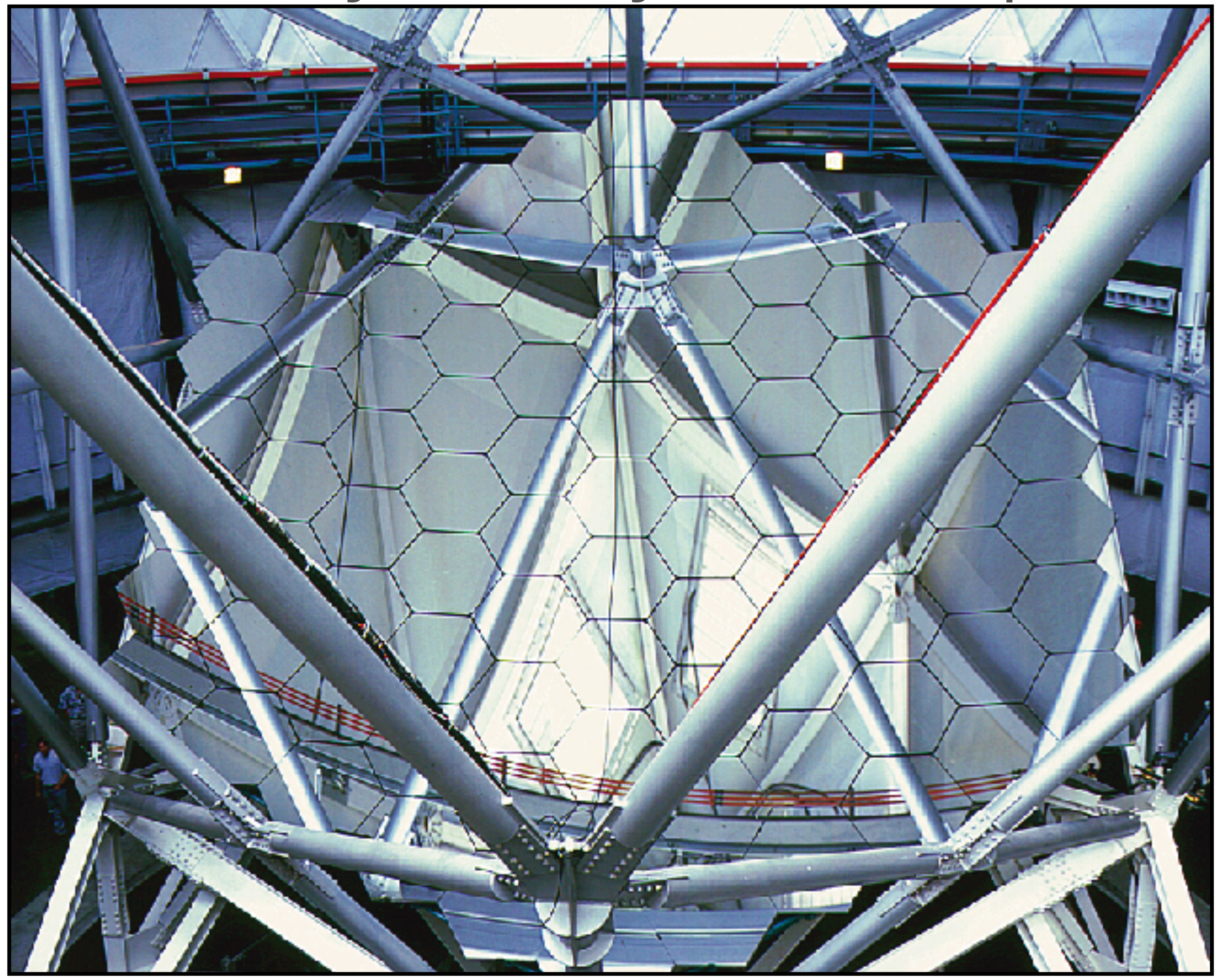
- Annuli
- Polygons

Hobby-Eberly Telescope



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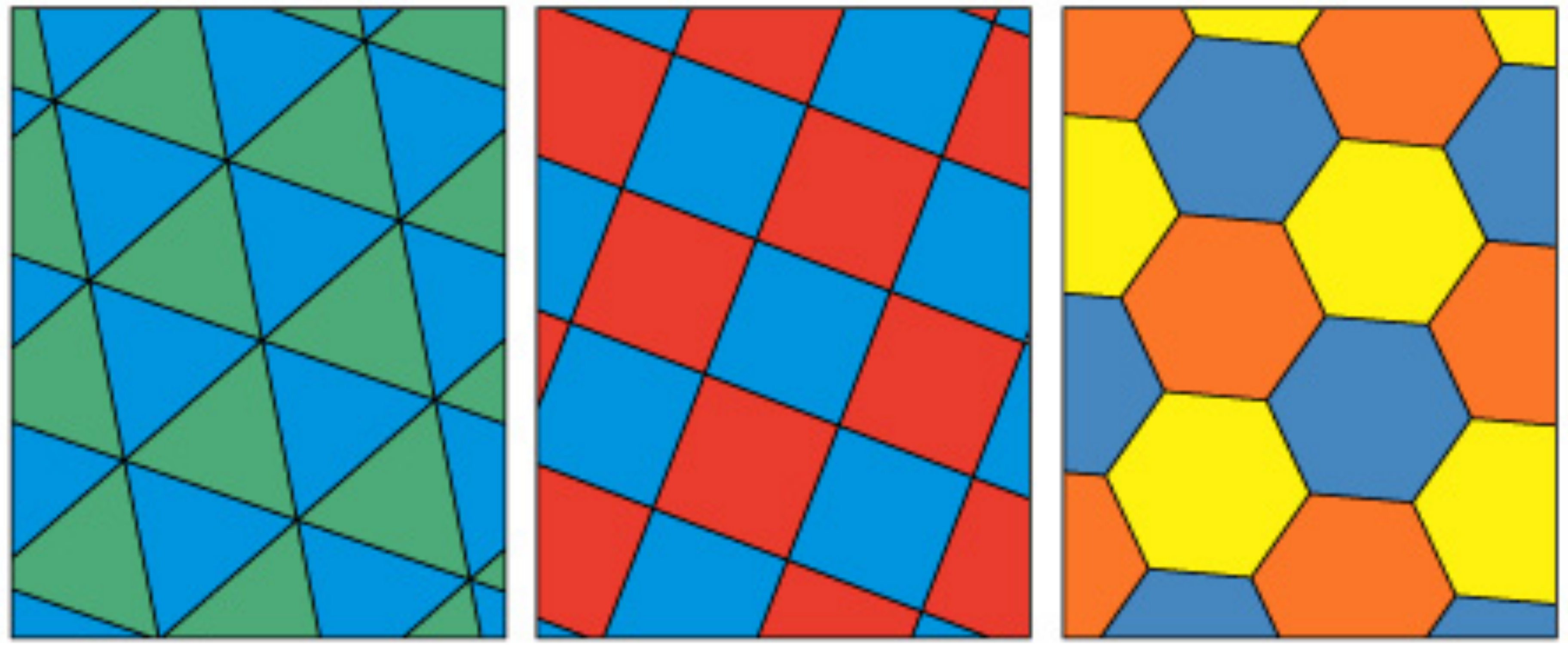
"The only regular polygons that can tesselate the plane are the equilateral triangle, the square, and the hexagon"



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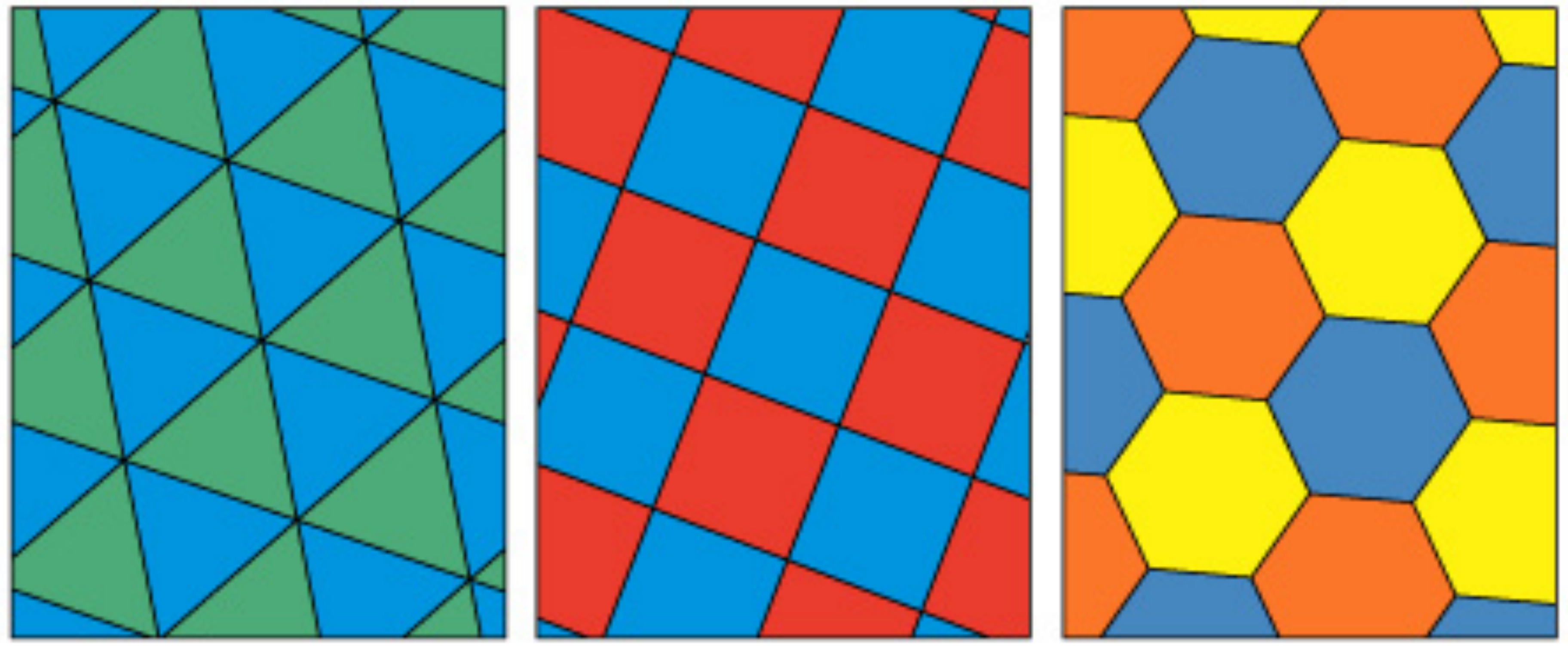
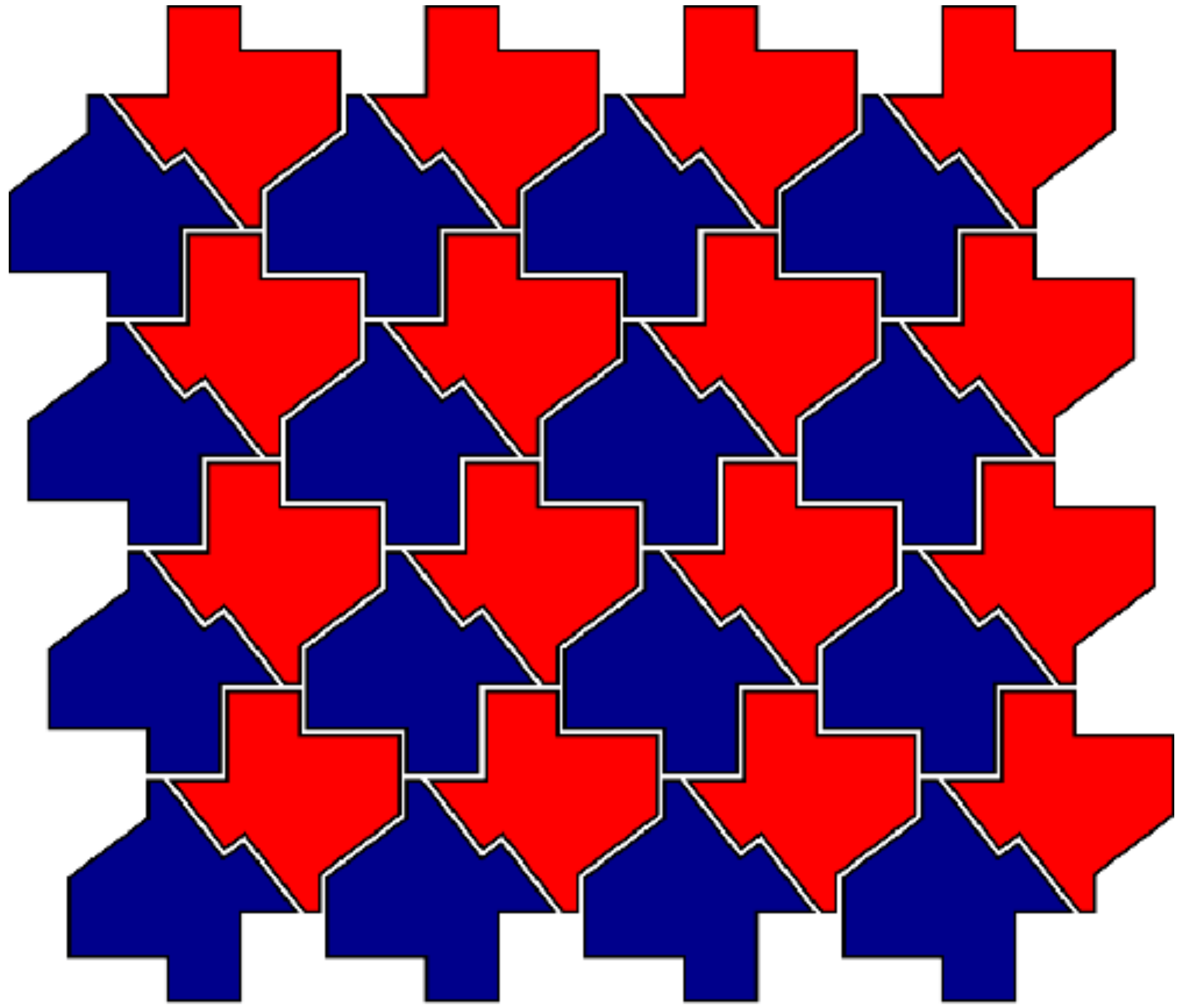
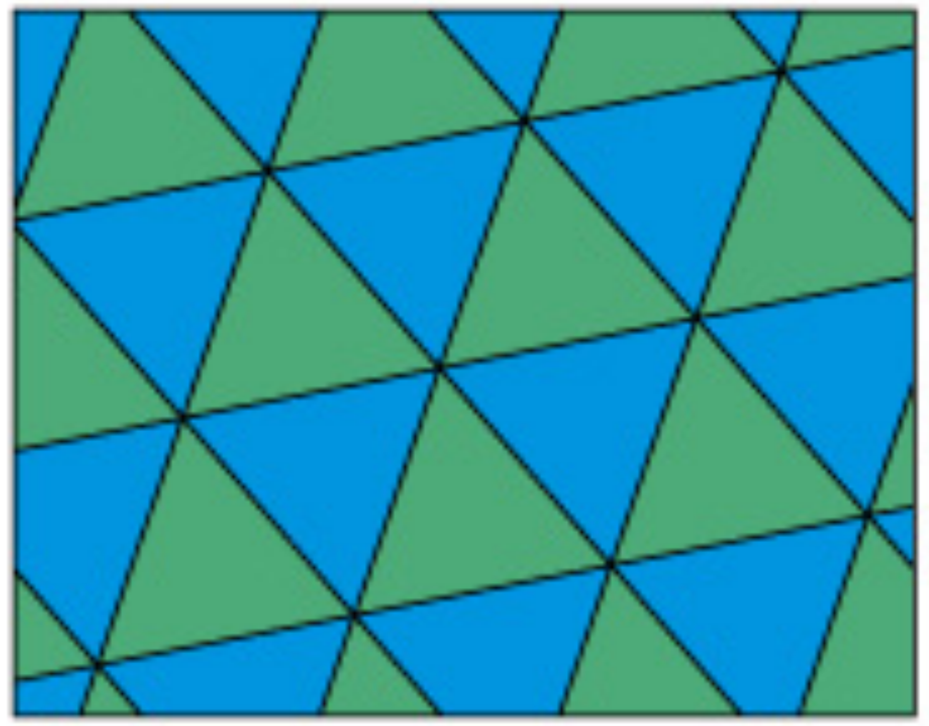
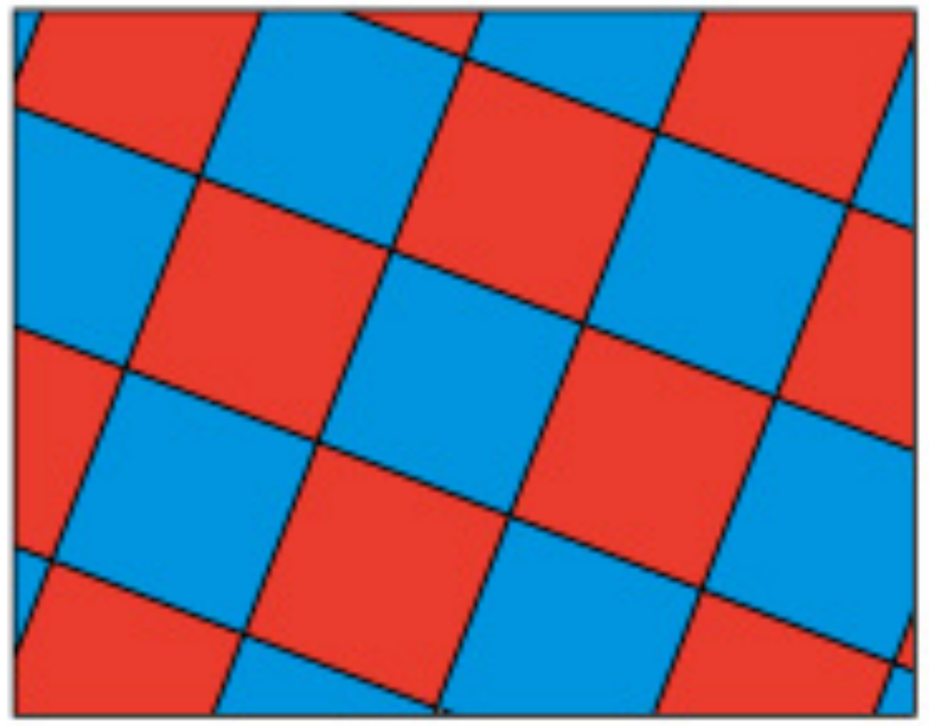


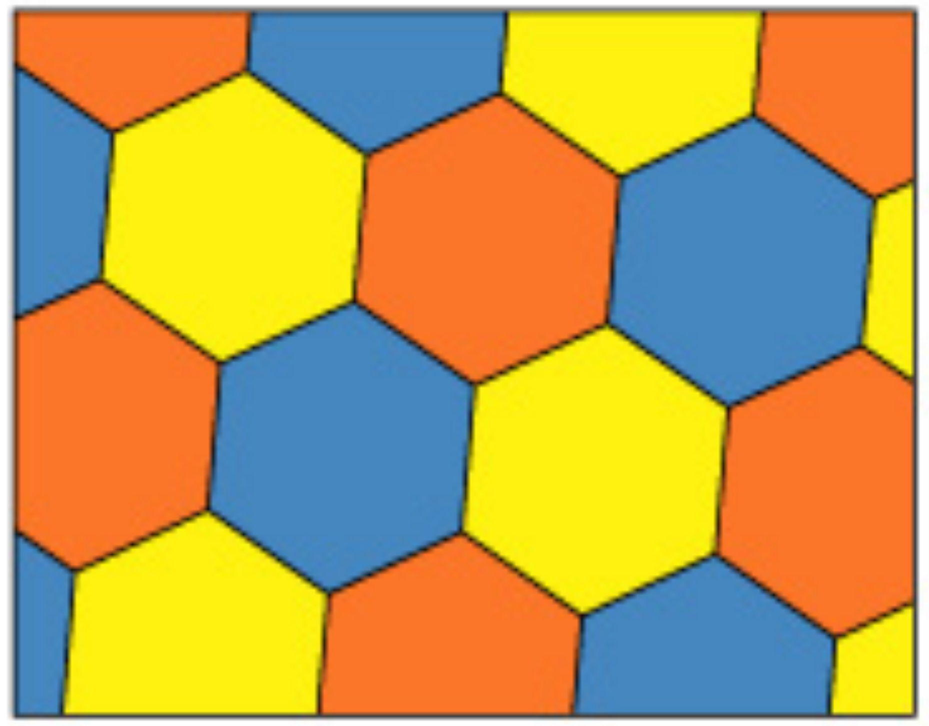
Texellation



Which (Regular) Polygonal Tesselation?







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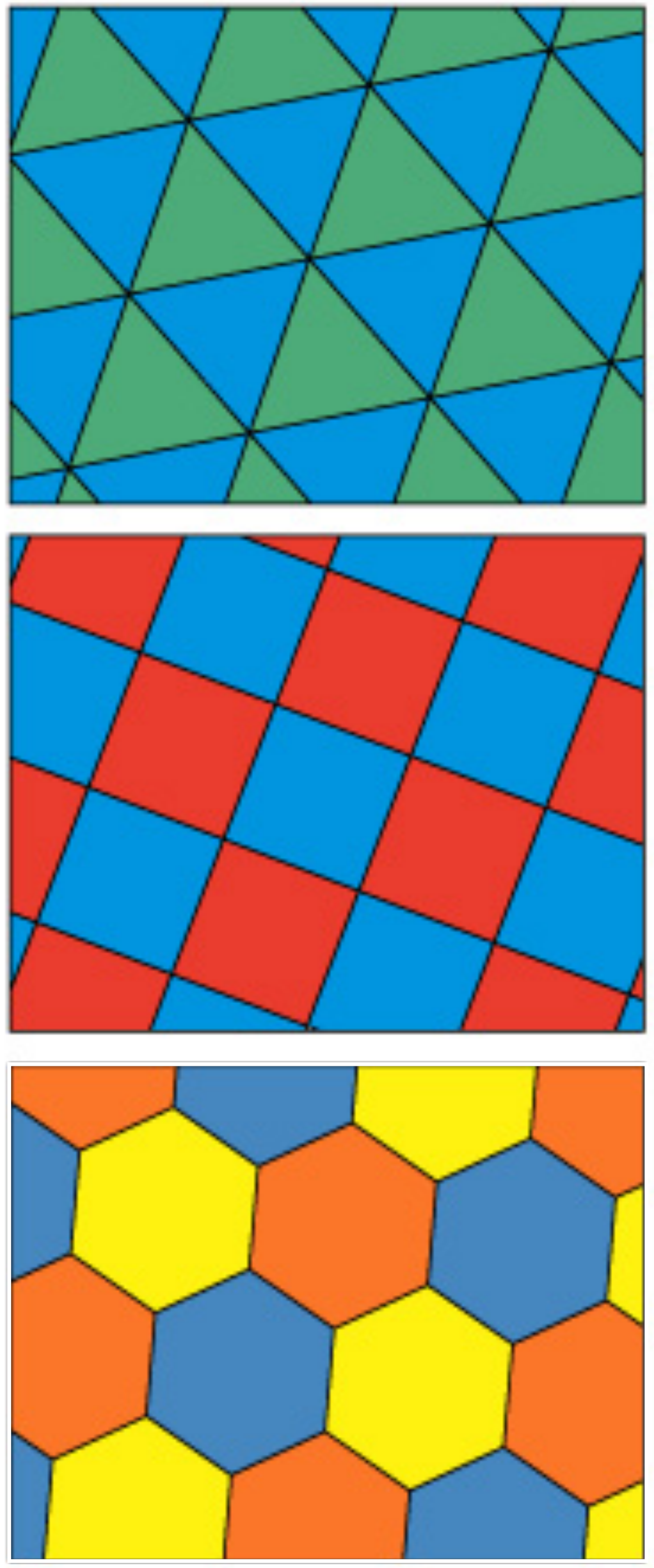
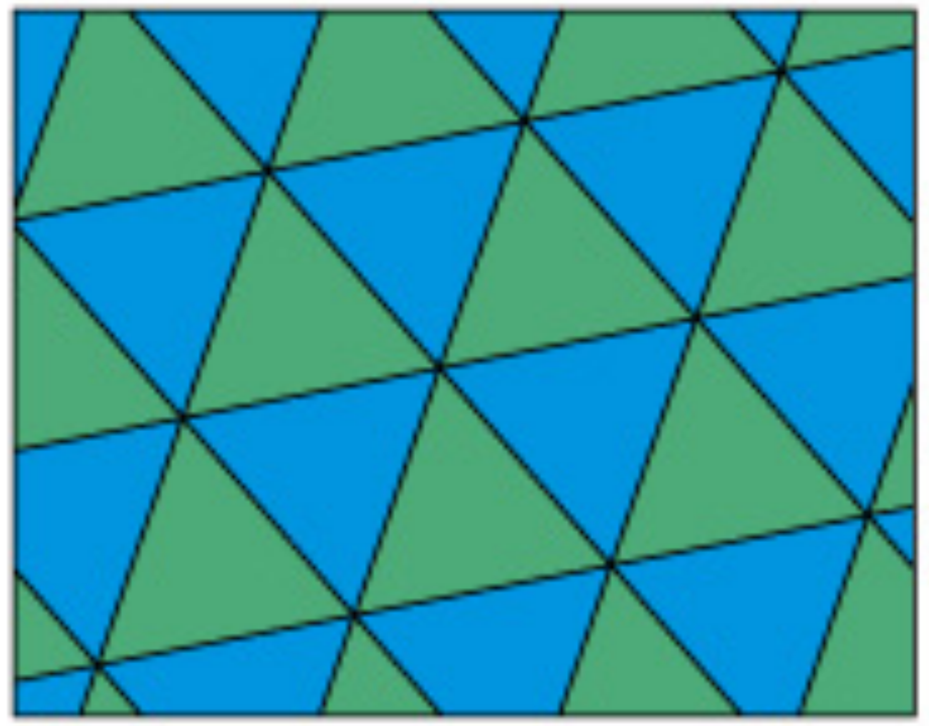
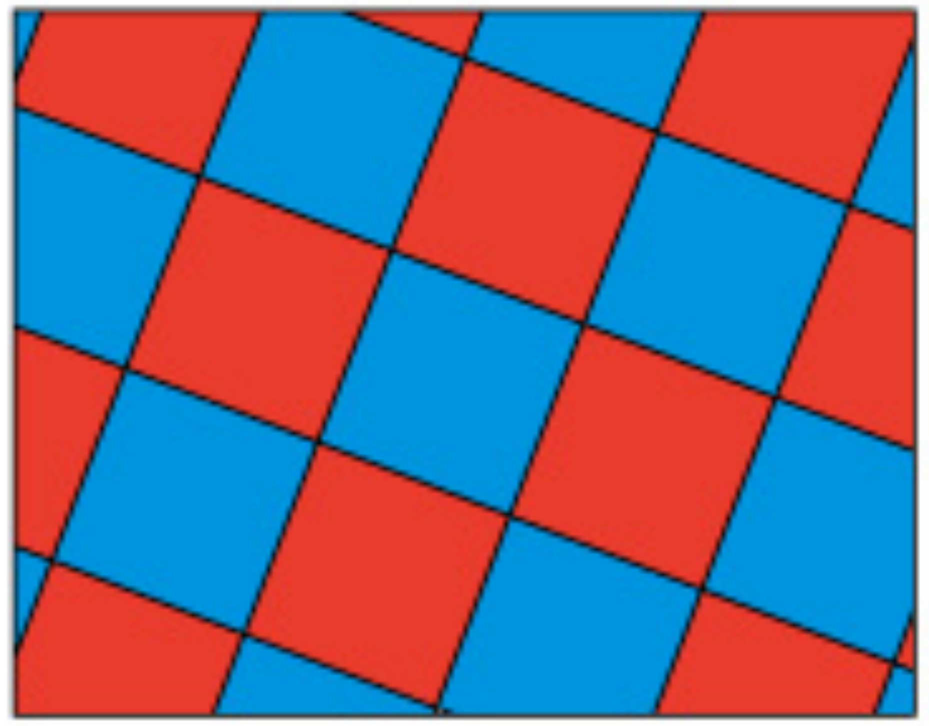


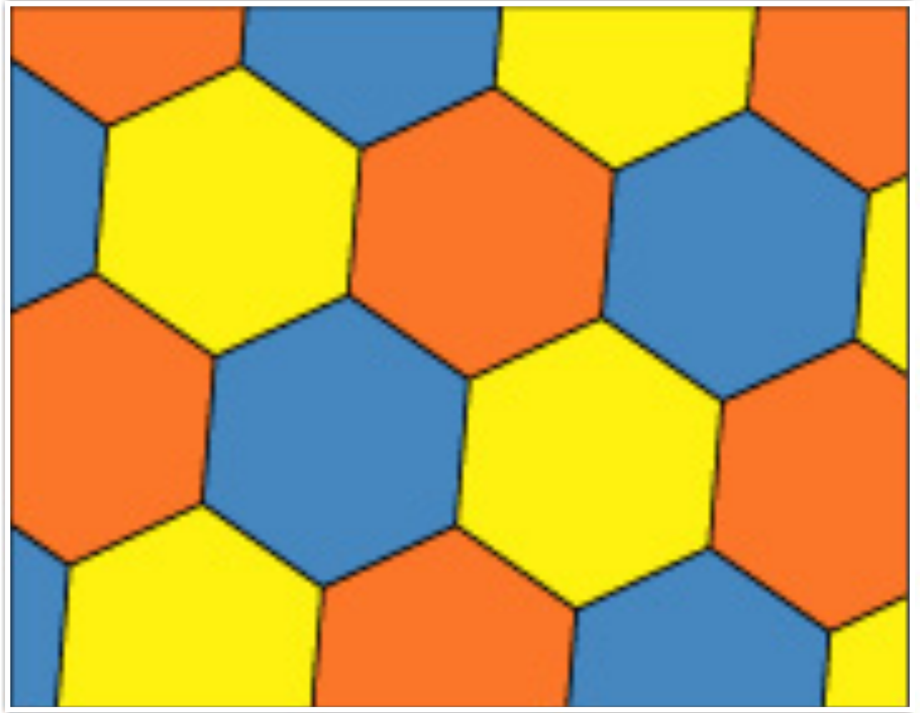
Short answer: Hexagons

- fewest edges per unit area
- smallest perimeter per unit area
- no sharp corners
- manageable diffraction
- closest to (circular) blank

Which (Regular) Polygonal Tesselation?







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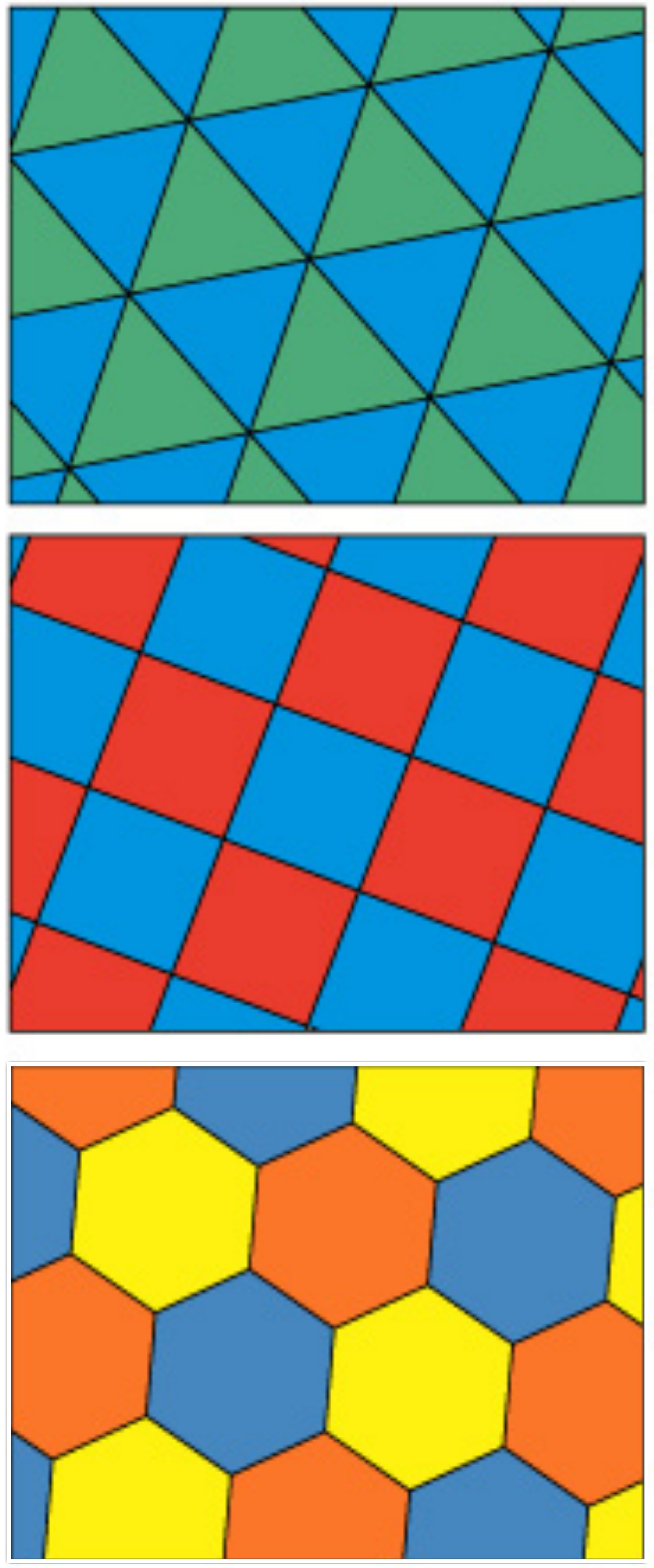
- fewest edges per unit area
- smallest perimeter per unit area
- no sharp corners
- manageable diffraction
- closest to (circular) blank

Which (Regular) Polygonal Tesselation?



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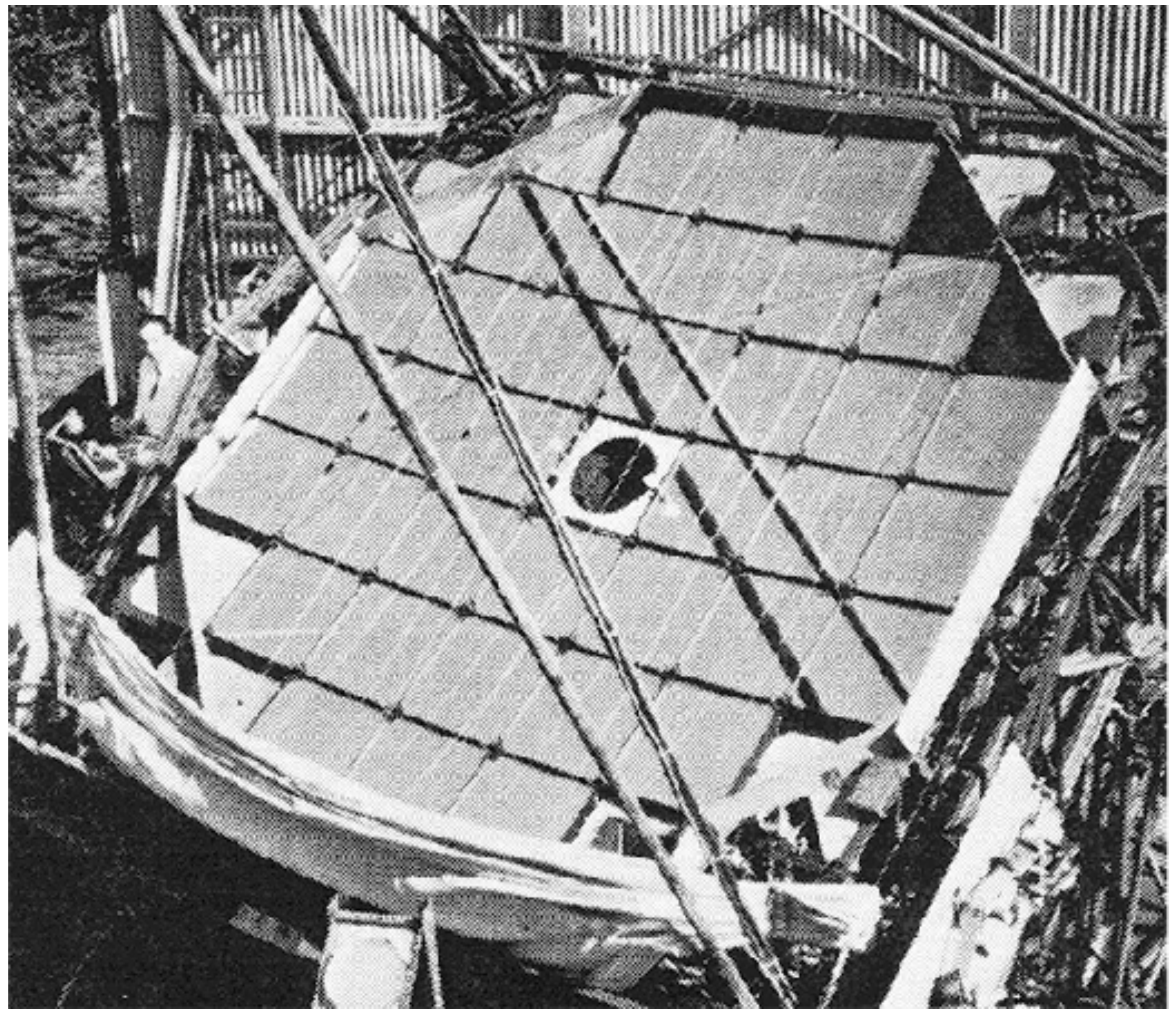

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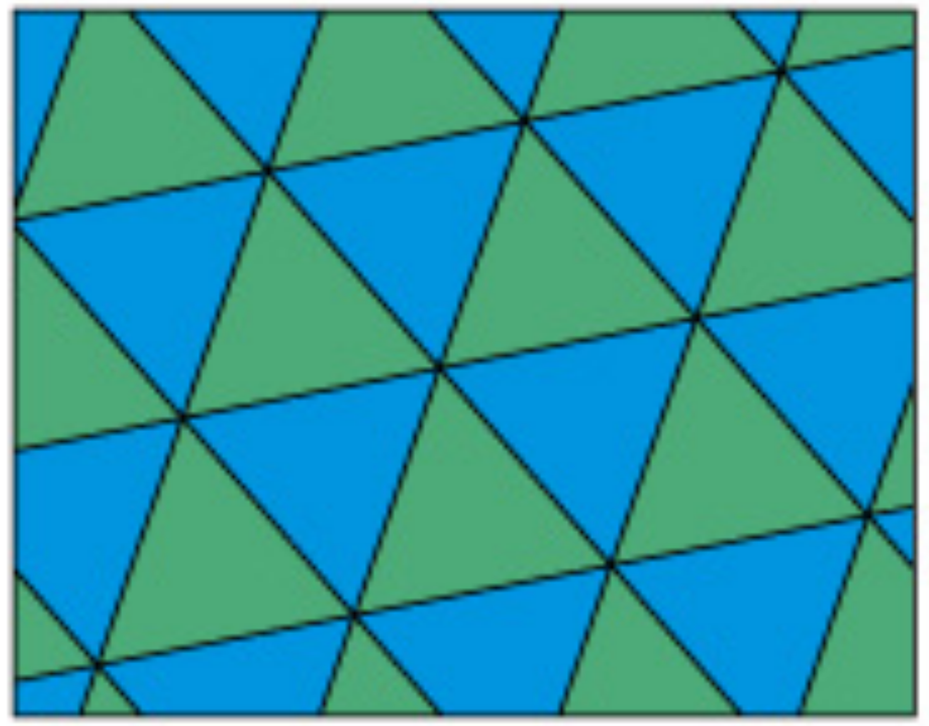

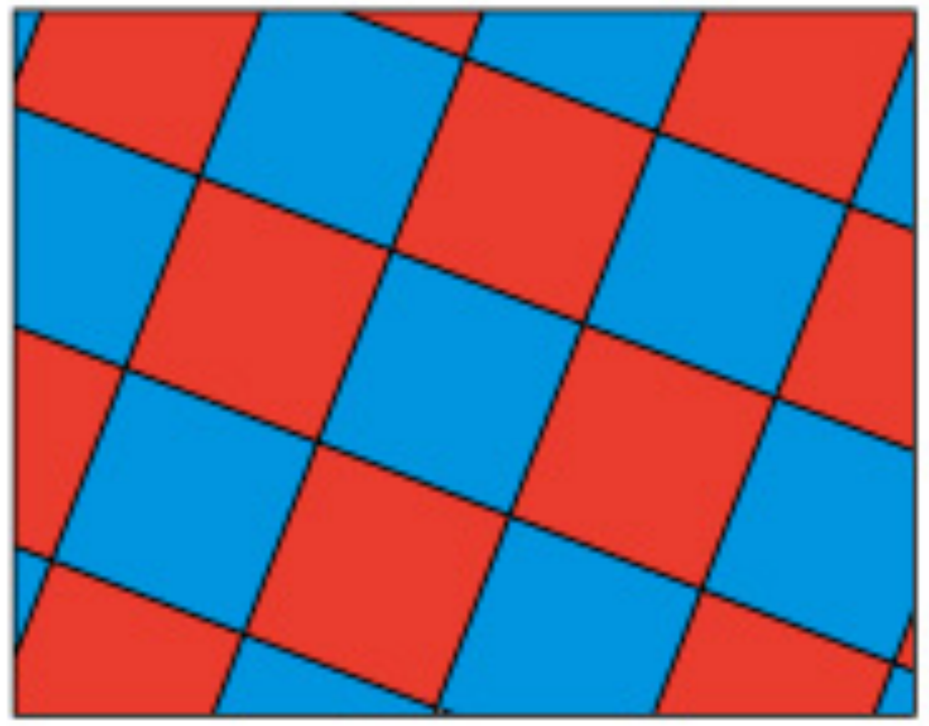

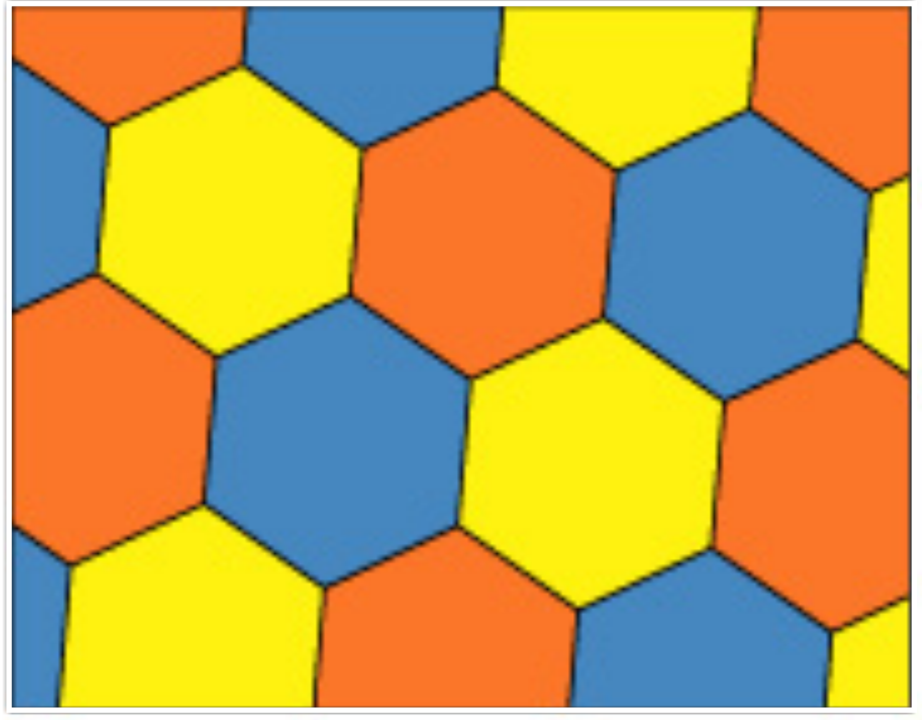

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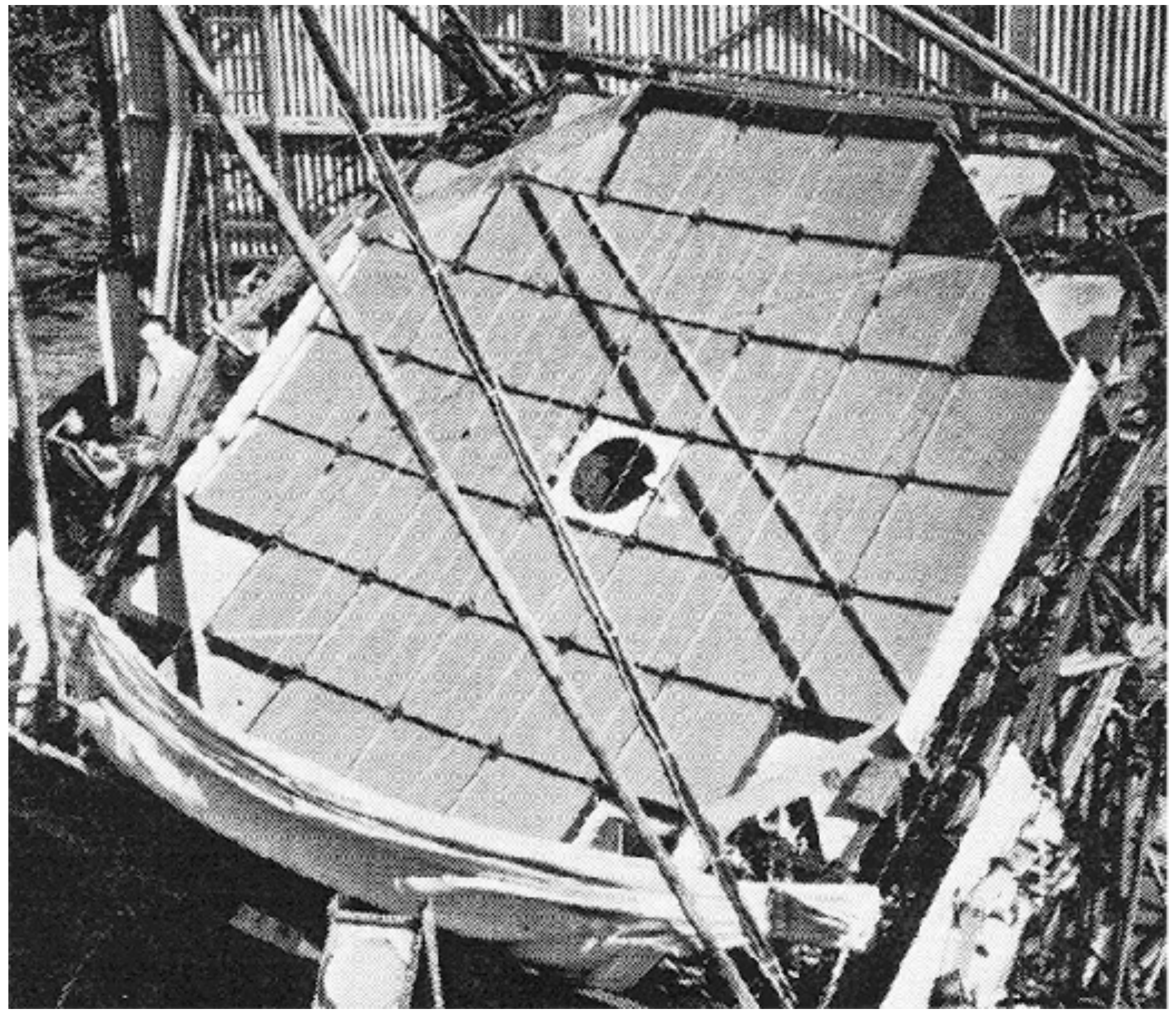

but…


Everton
F.C.
Liverpool
F.C.

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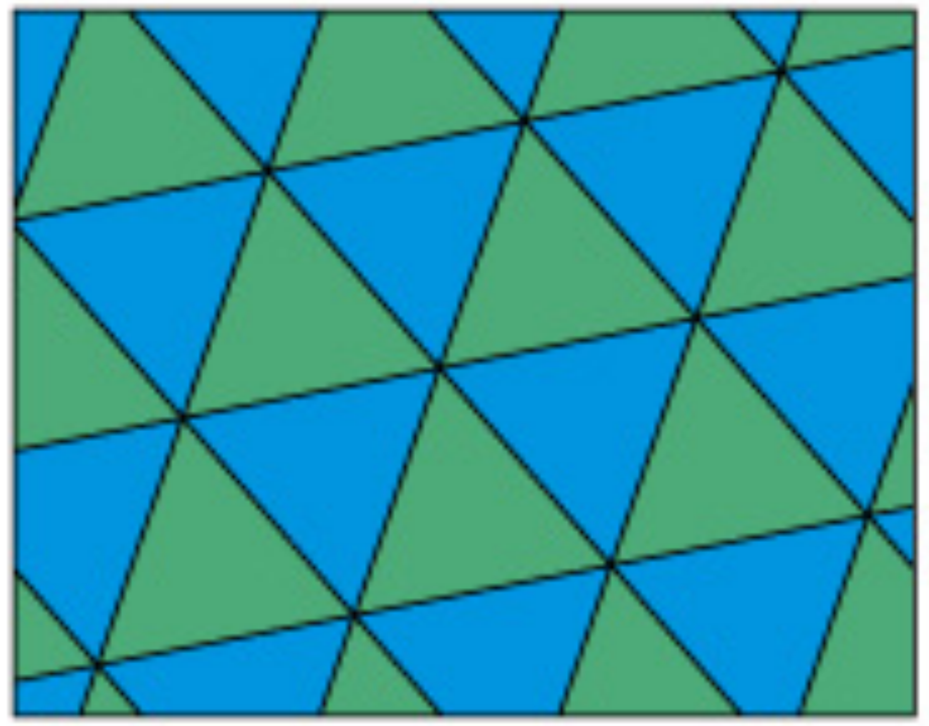

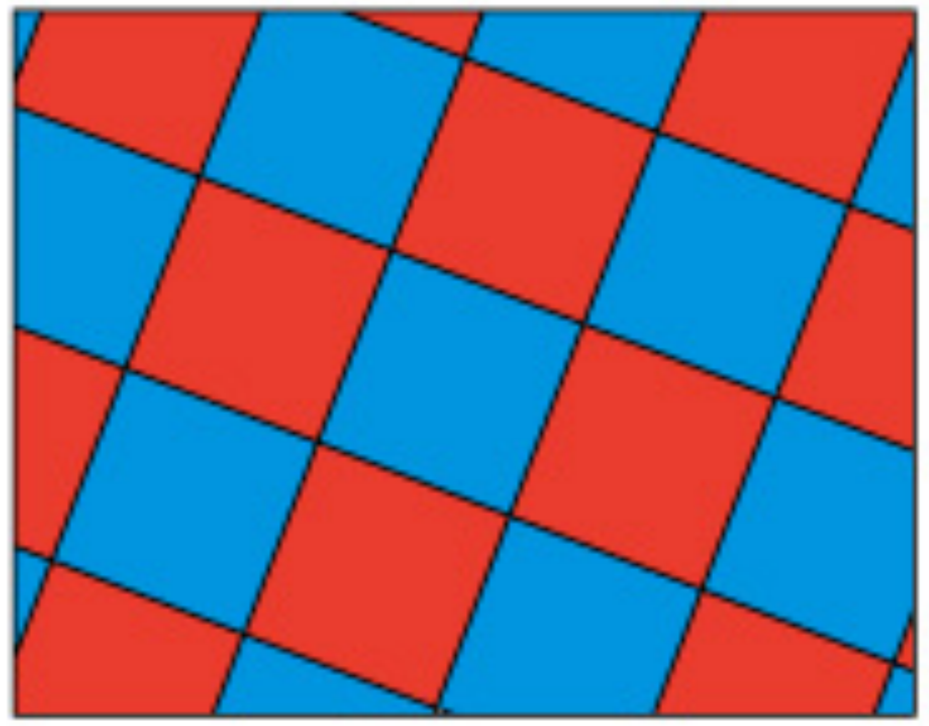

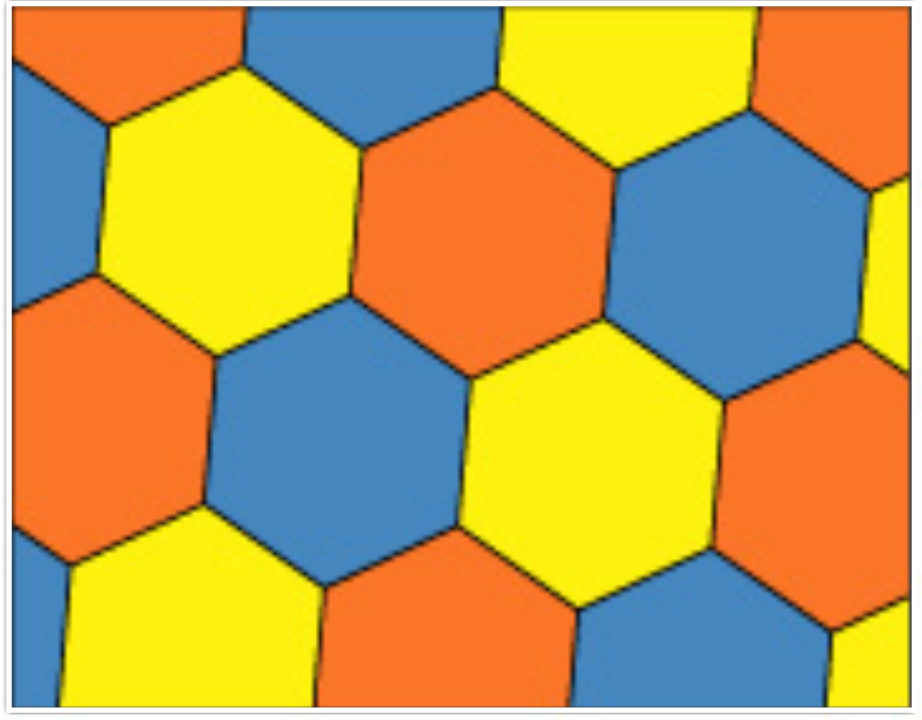

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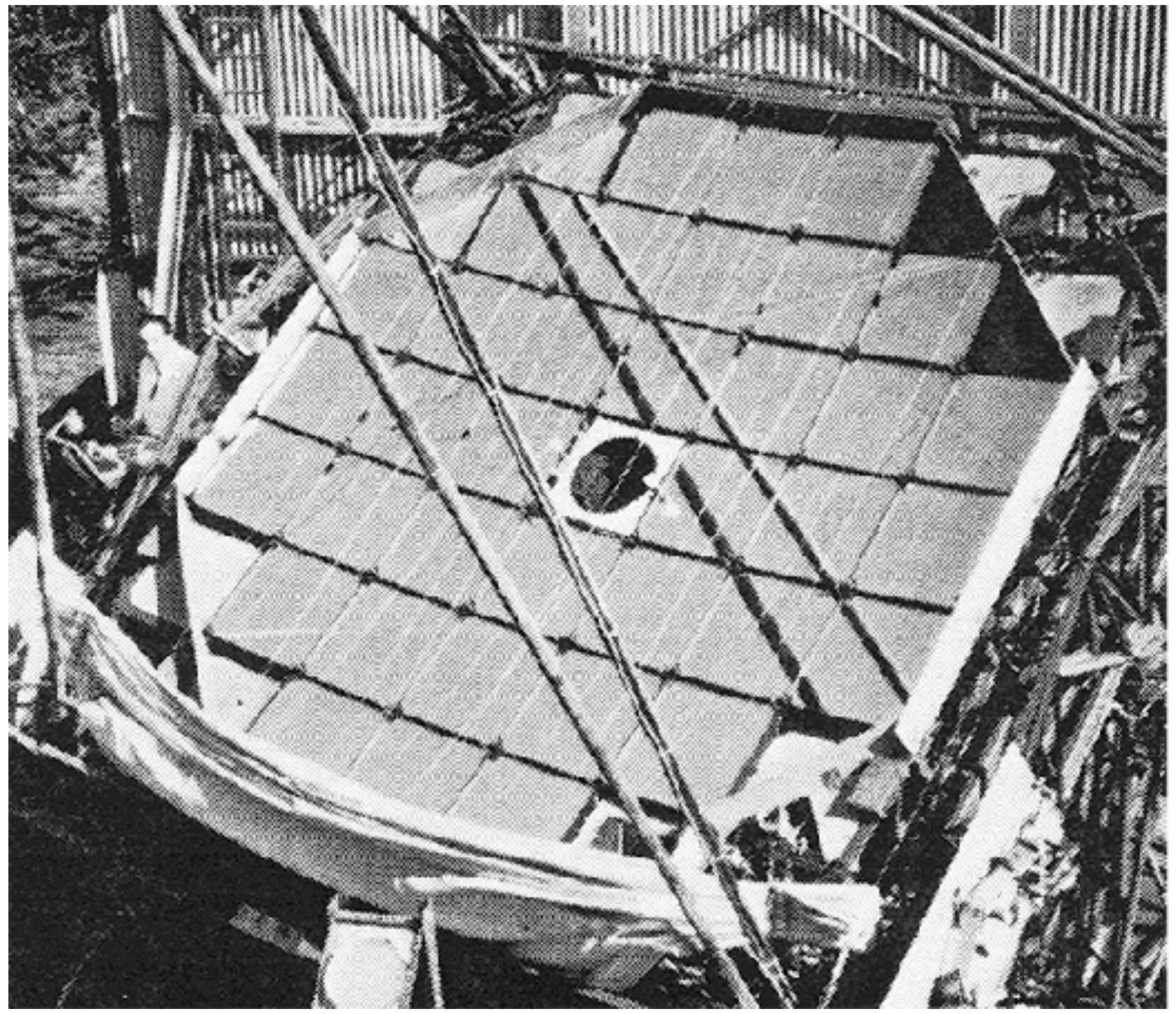

but…

How Many Segments?

How Big Should the Segments Be?

Good question… it's complicated…

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(Almost) all since: ~1.5 m (point to point)

Annular Rings or Hexagonal?   Let’s Experiment…

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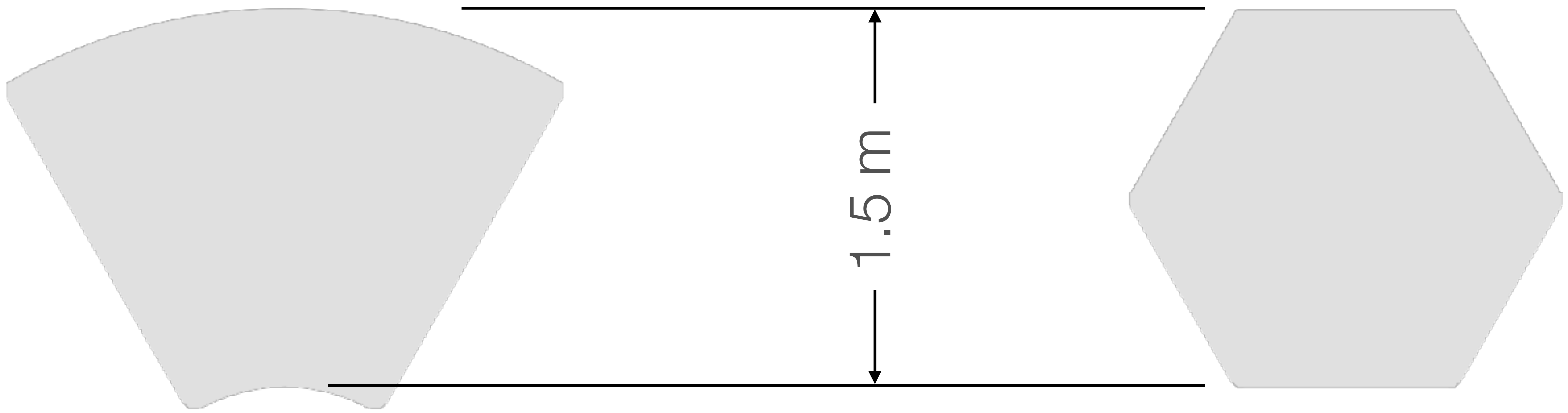
Assumption: Individual segments are 1.5 meters "across"



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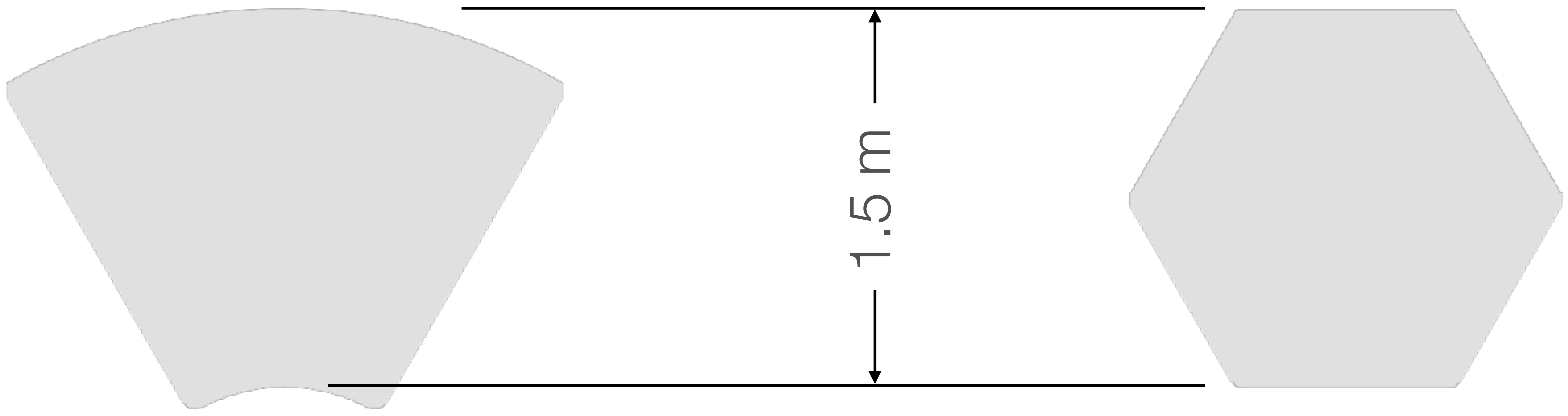
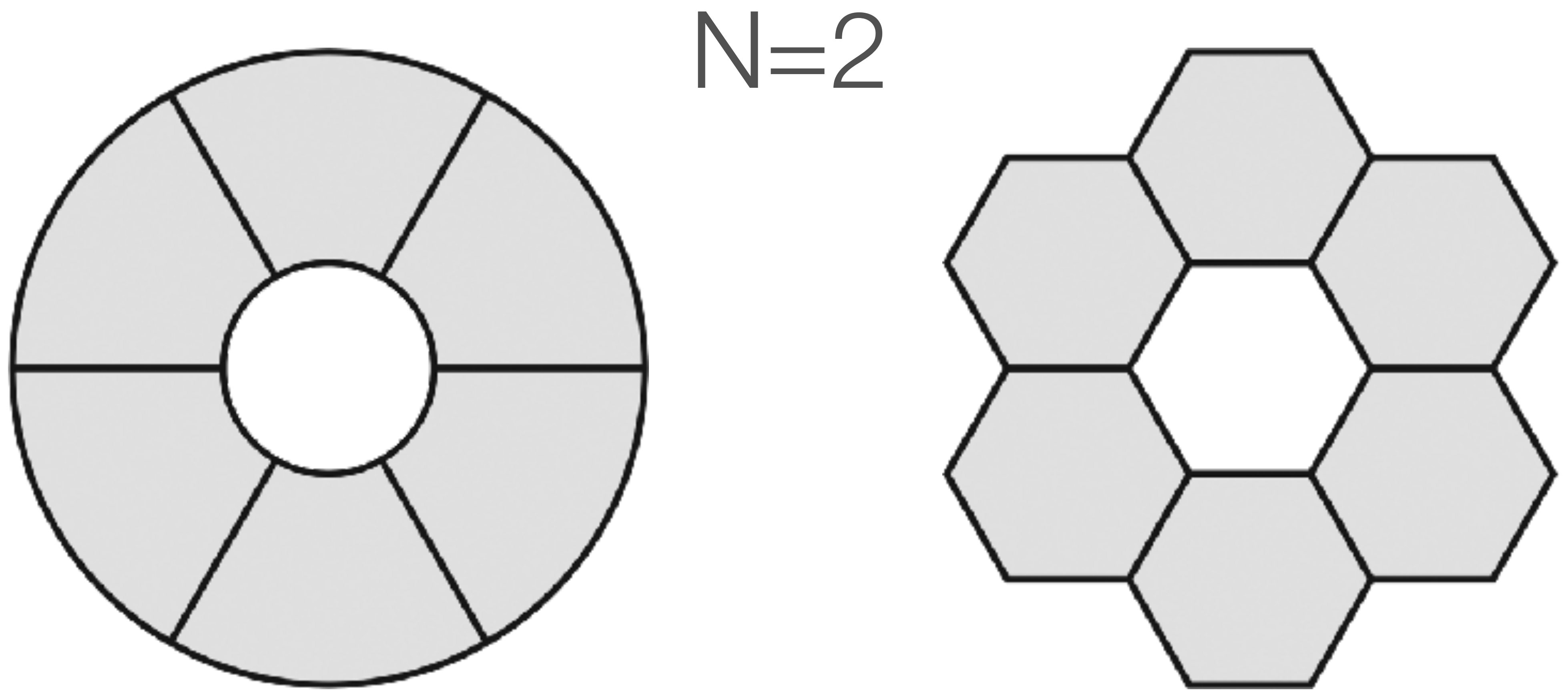
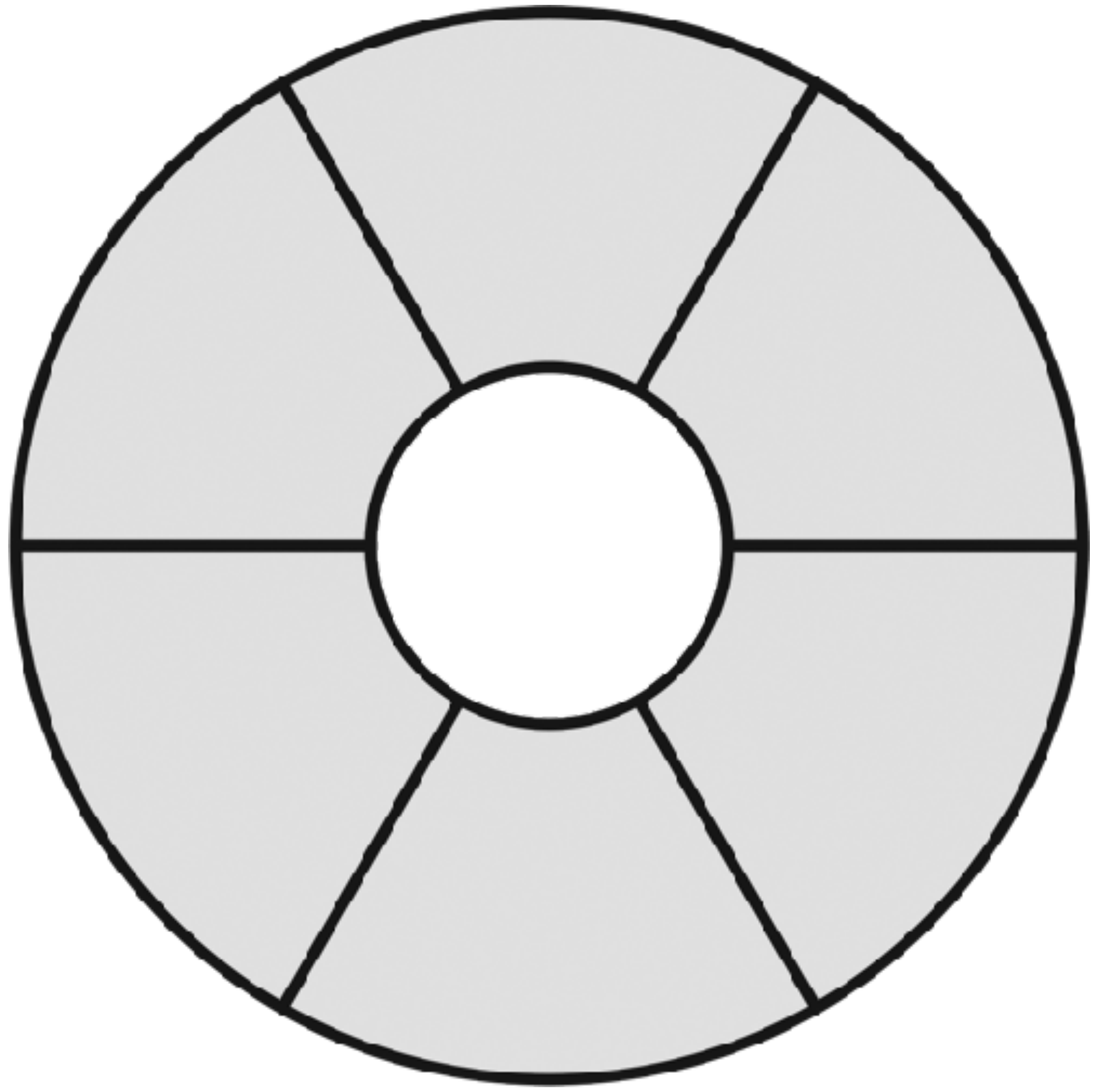
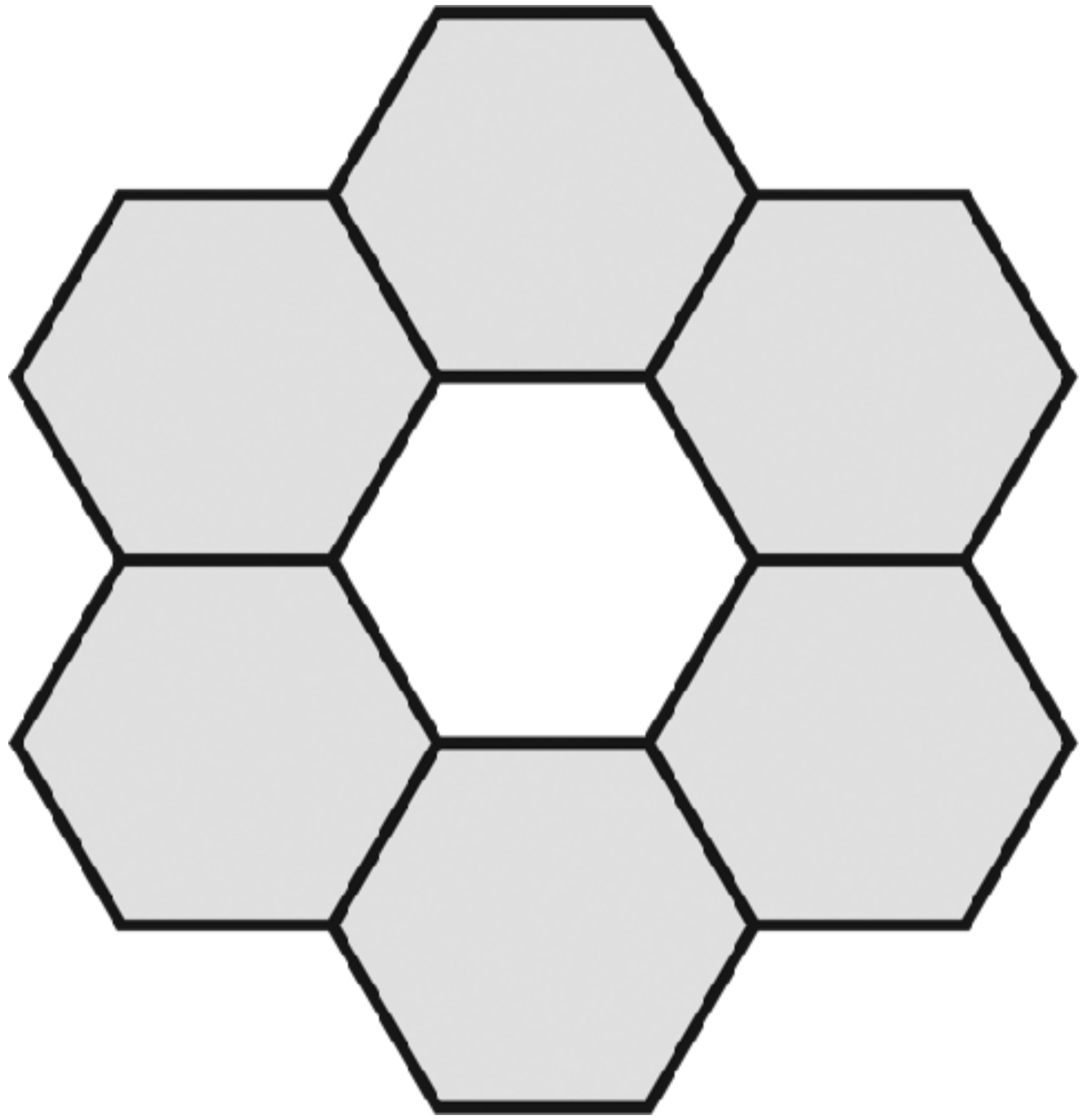


…and we count **rings:**

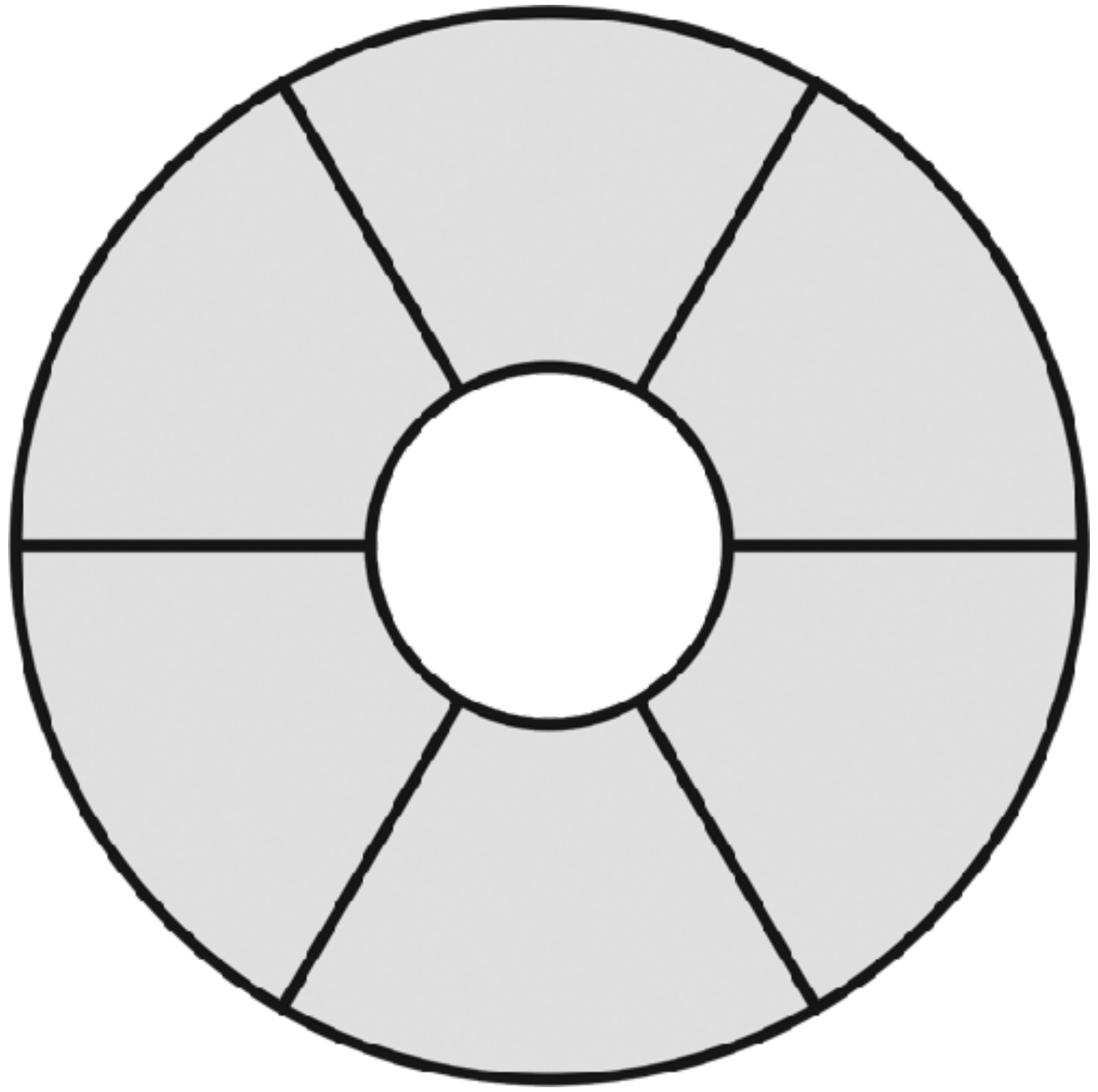


Annular vs Hexagonal N=2

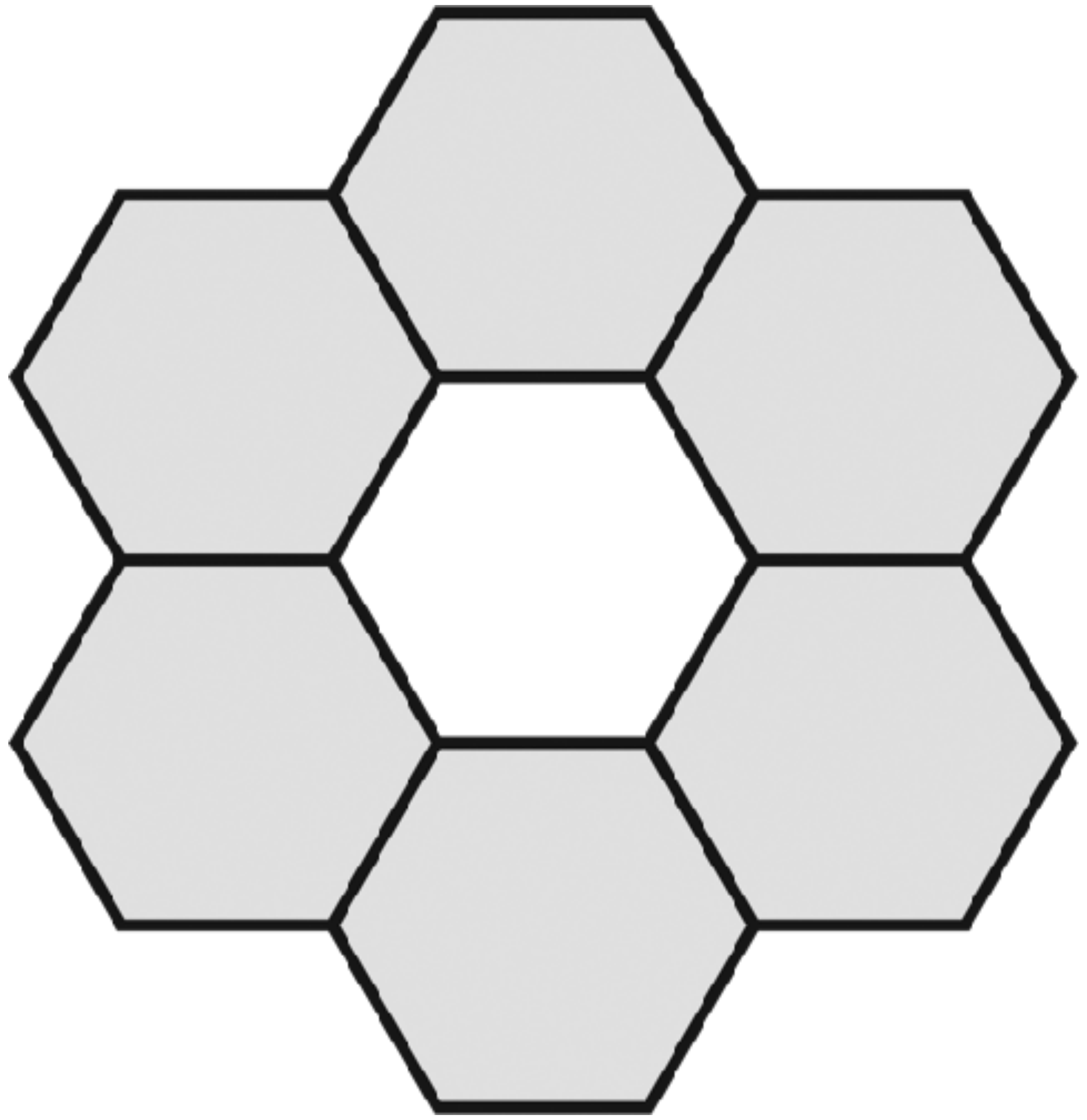




Annular vs Hexagonal N=2

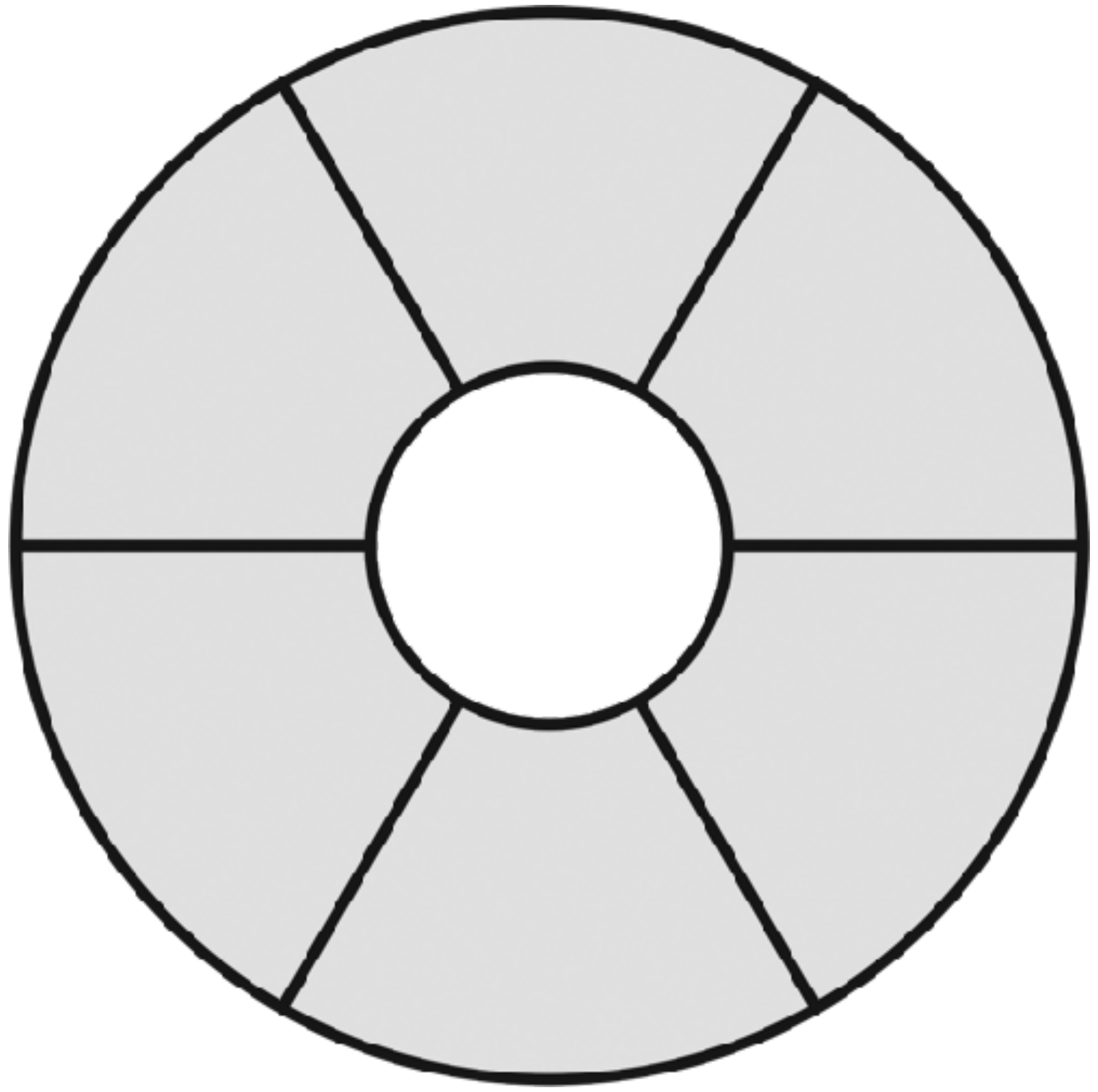


6 Segments
Diameter: 4.5 m
Area: 14.1 m^2
6 Edges
1 Spare required



6 Segments
Diameter: 4.5 m
Area: 11.7 m^2 (1.2 segments less)
6 Edges
1 Spare required

Annular vs Hexagonal



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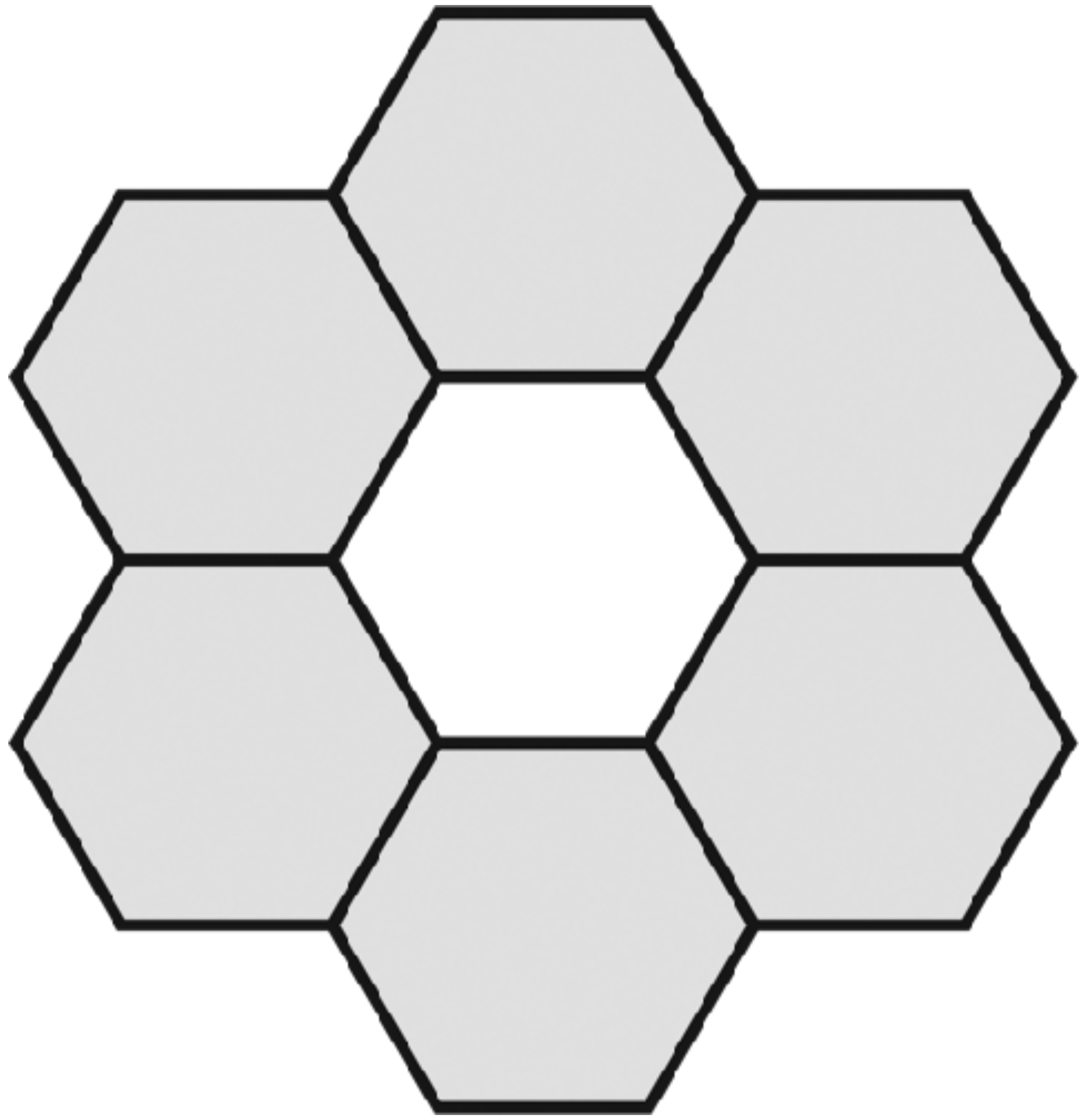

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Annular vs Hexagonal N=3

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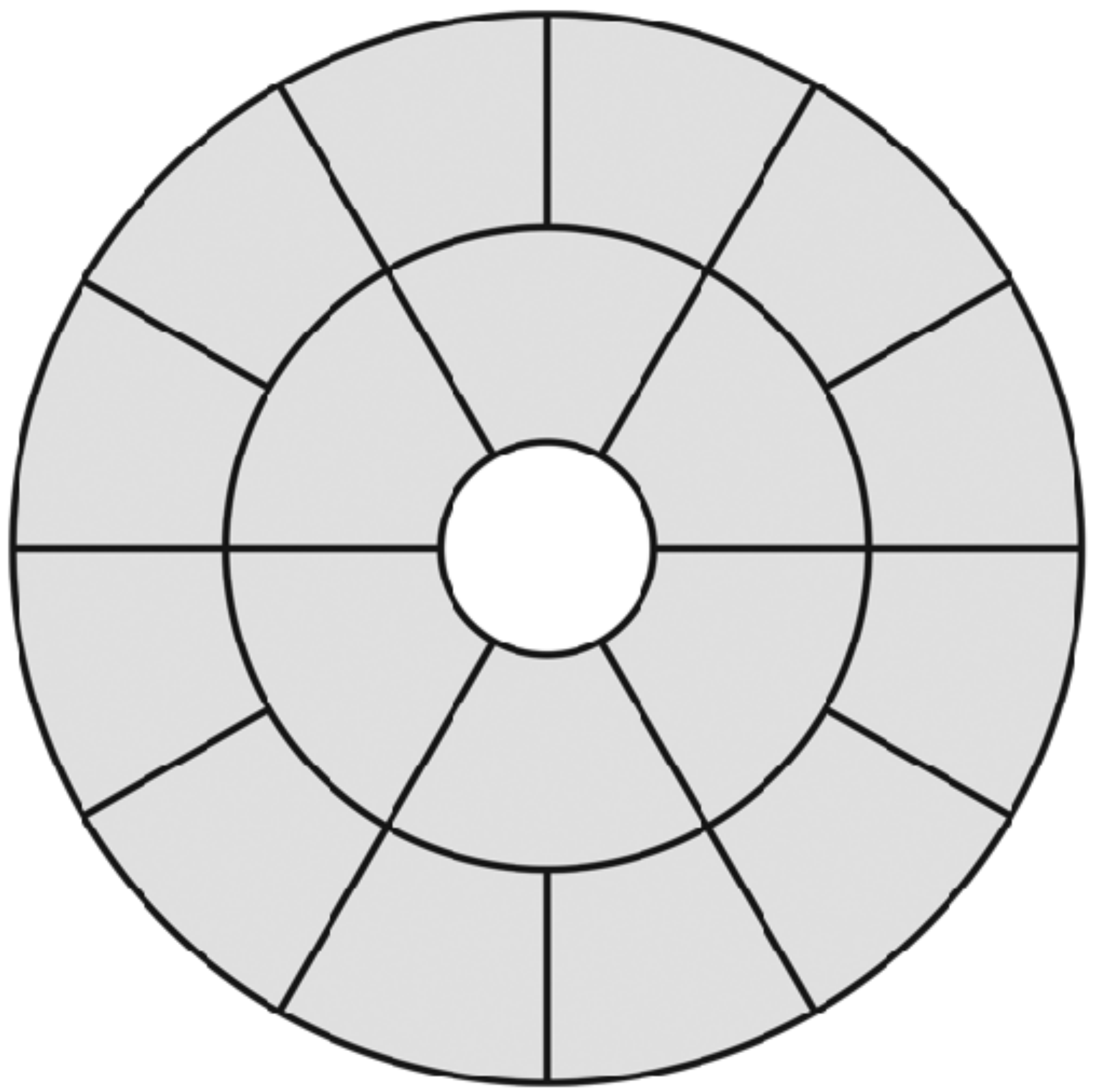
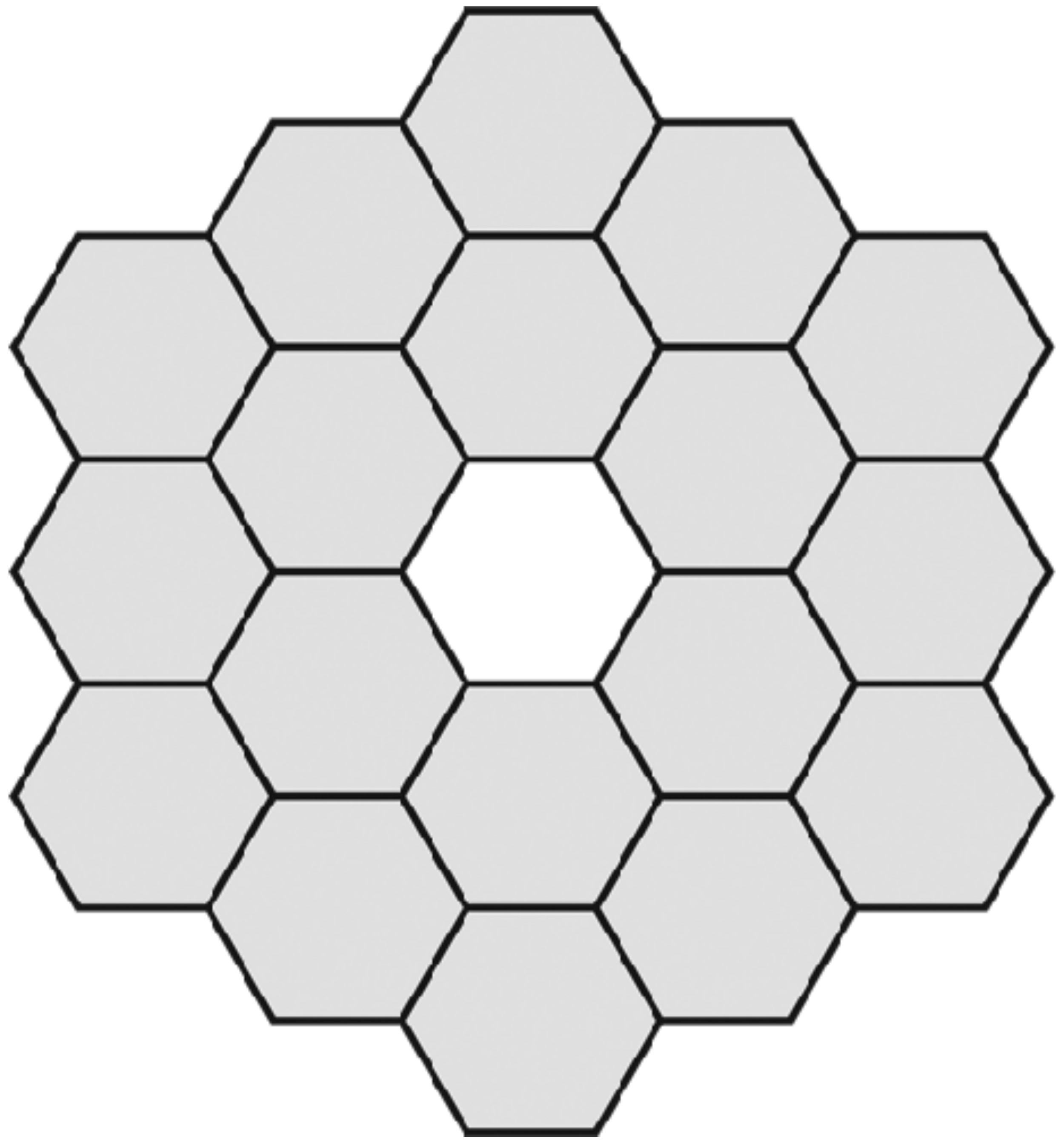
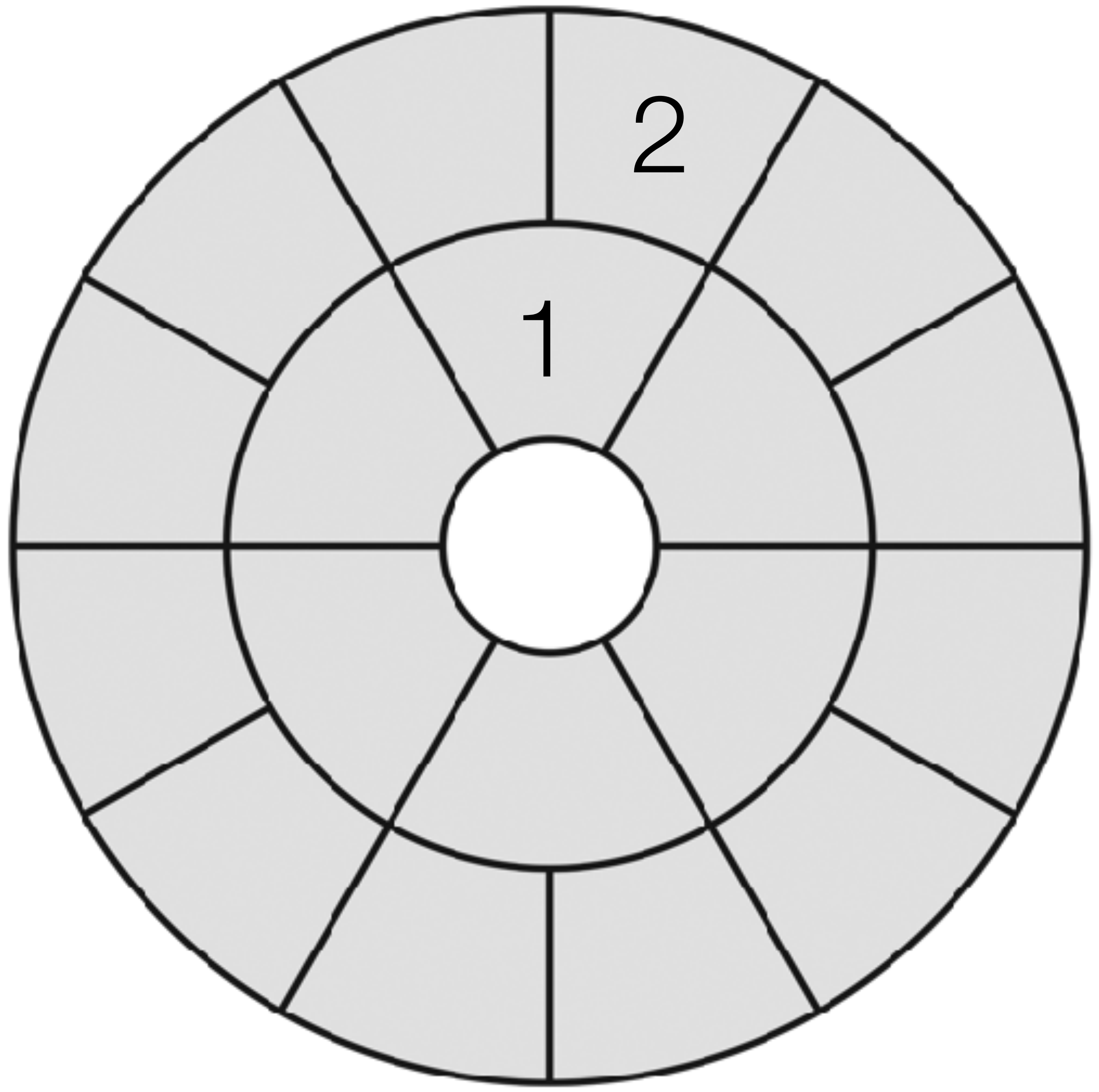


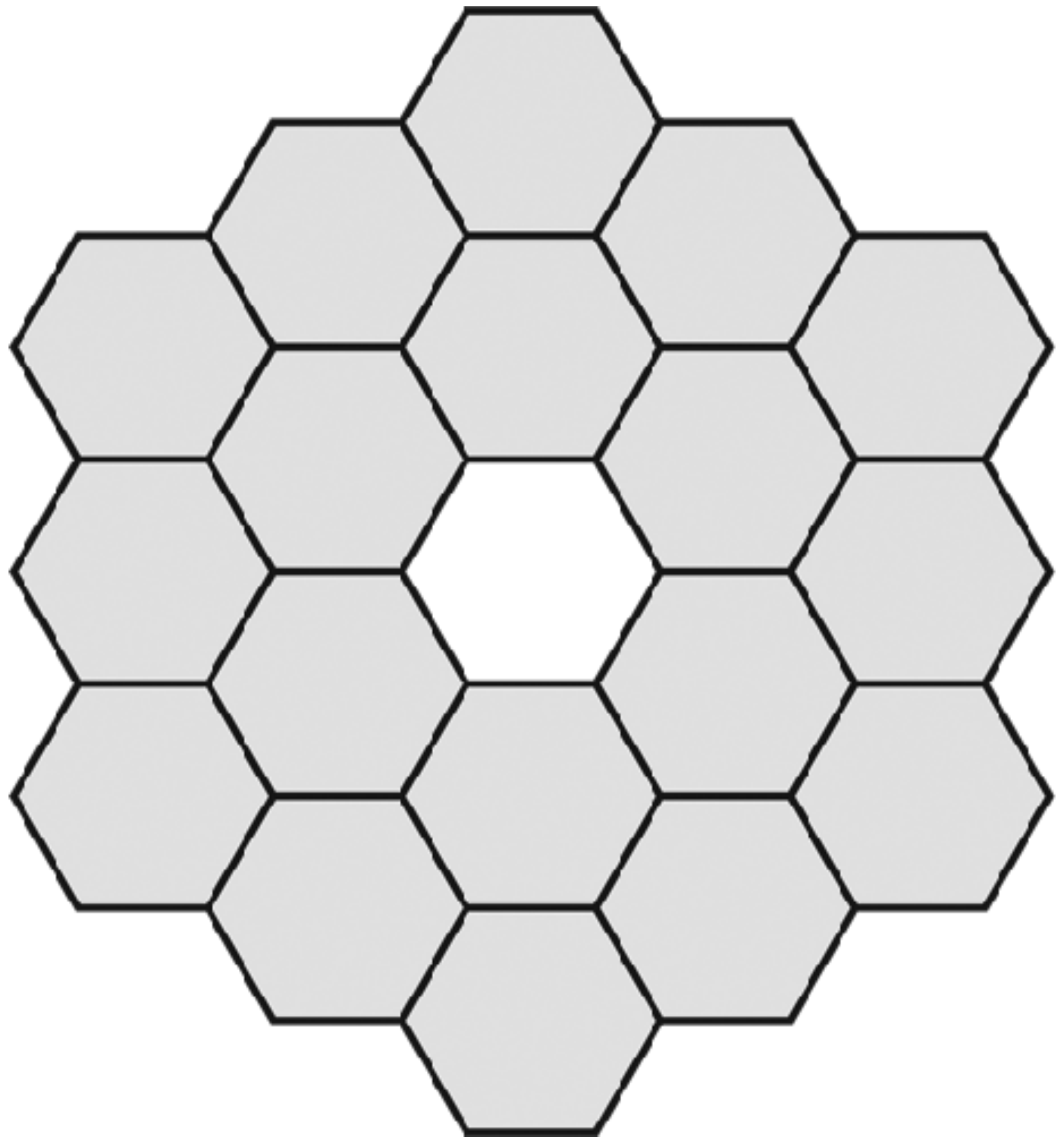
18 Segments
Diameter: 7.5 m
Area: 42.4 m^2
30 Edges
2 Spares required



18 Segments
Diameter: 7.5 m
Area: 35.1 m^2 (4 segments less)
36 Edges
3 Spares required

Annular vs Hexagonal N=3





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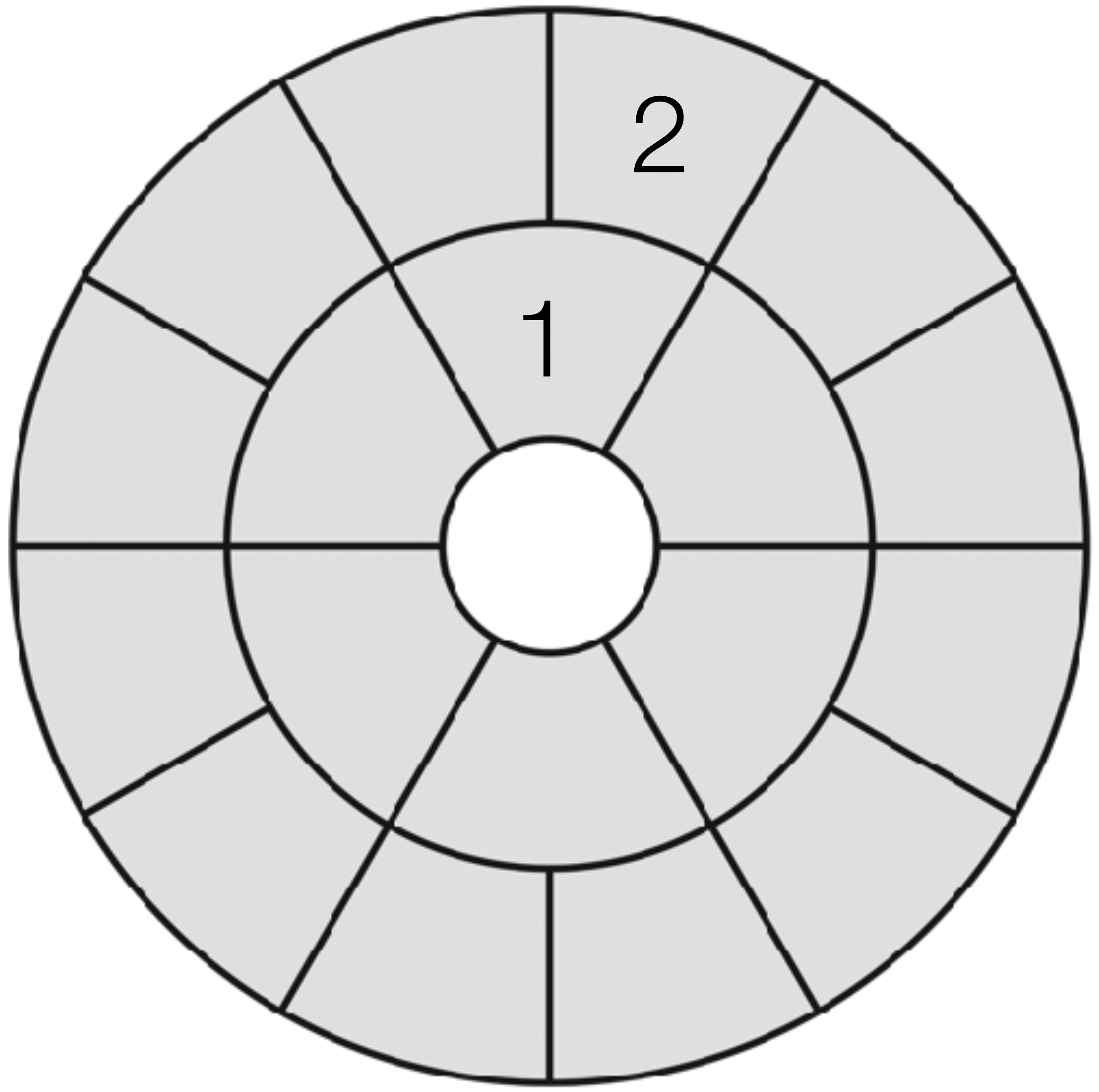

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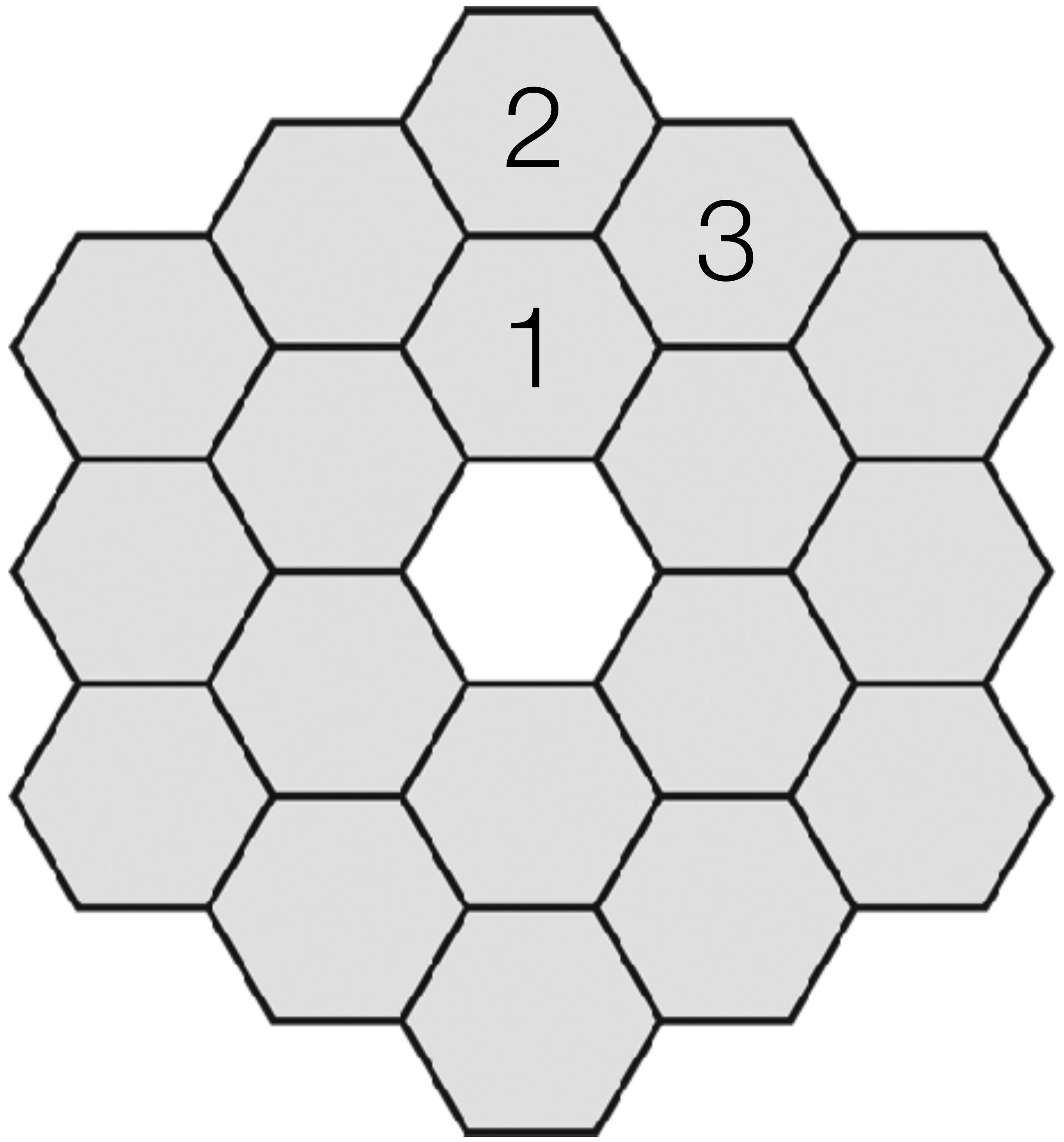

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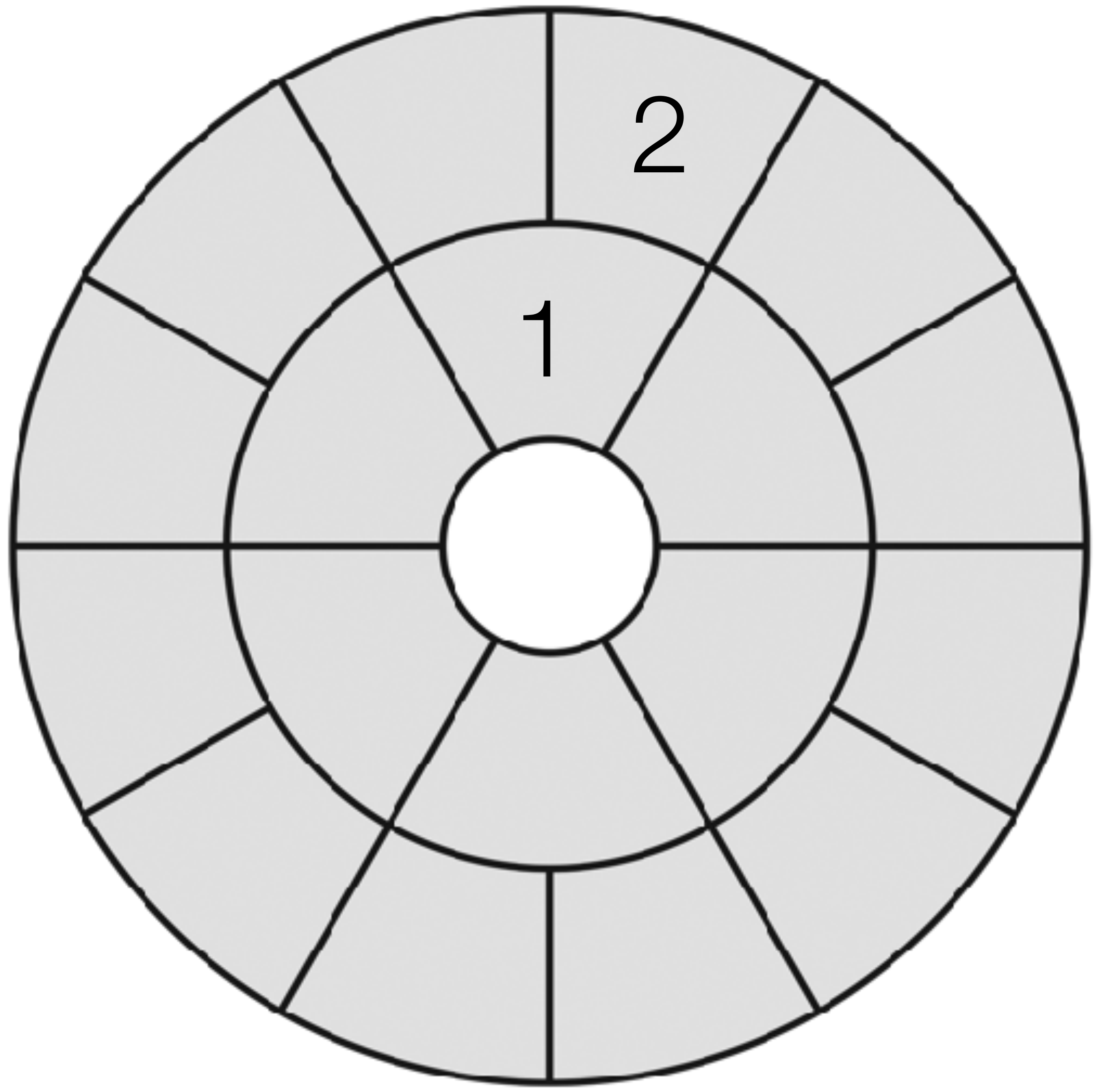

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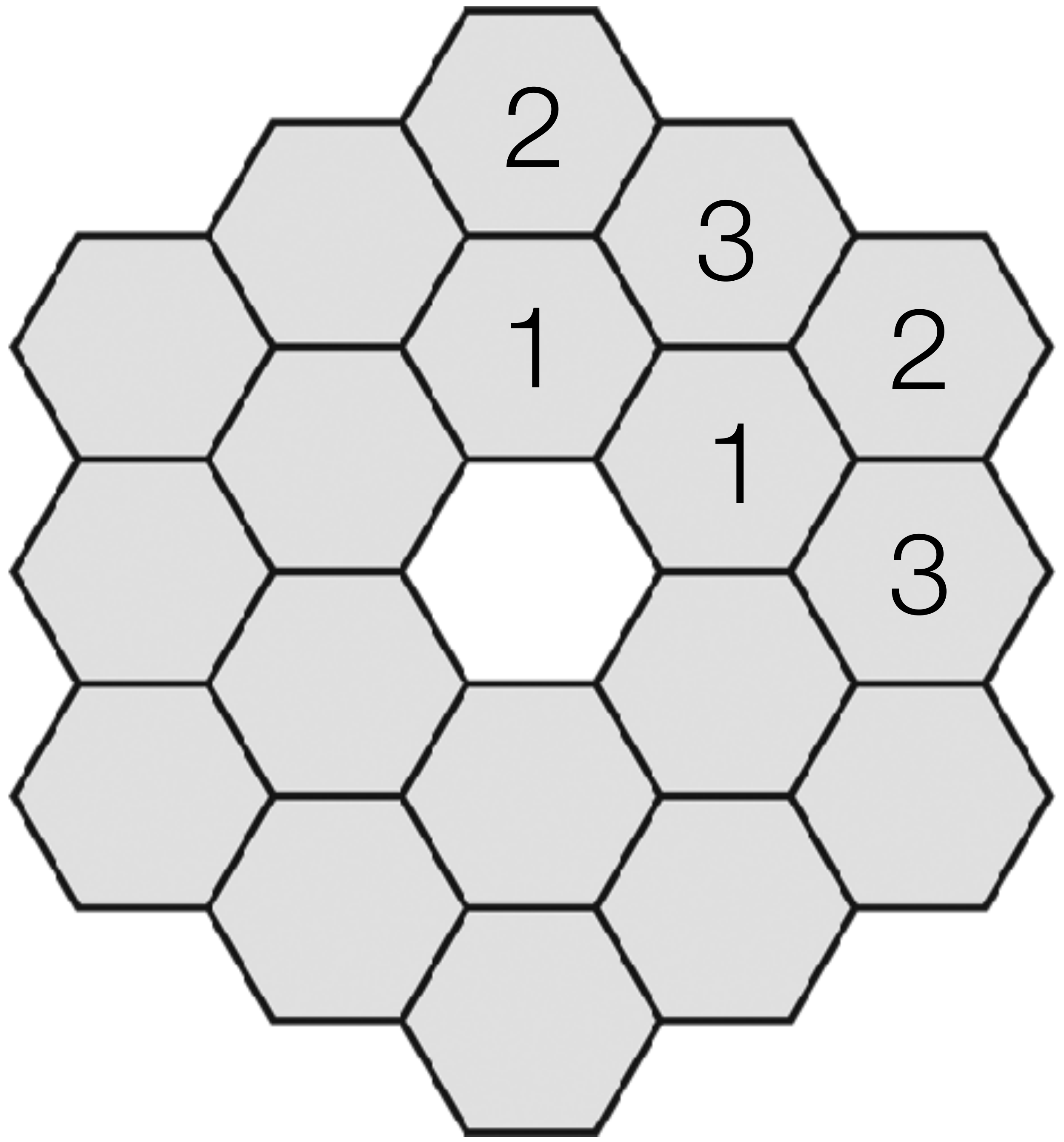

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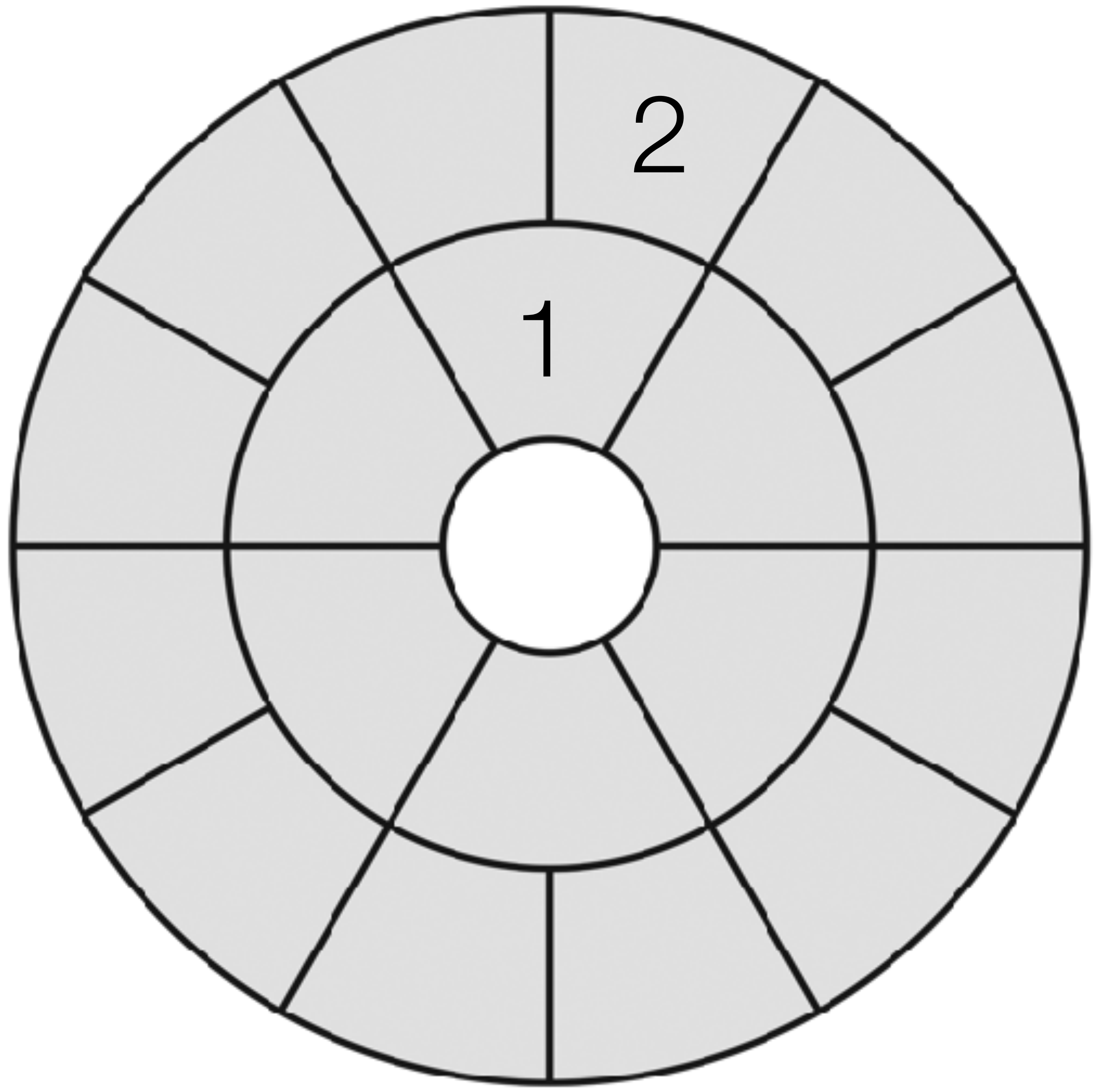

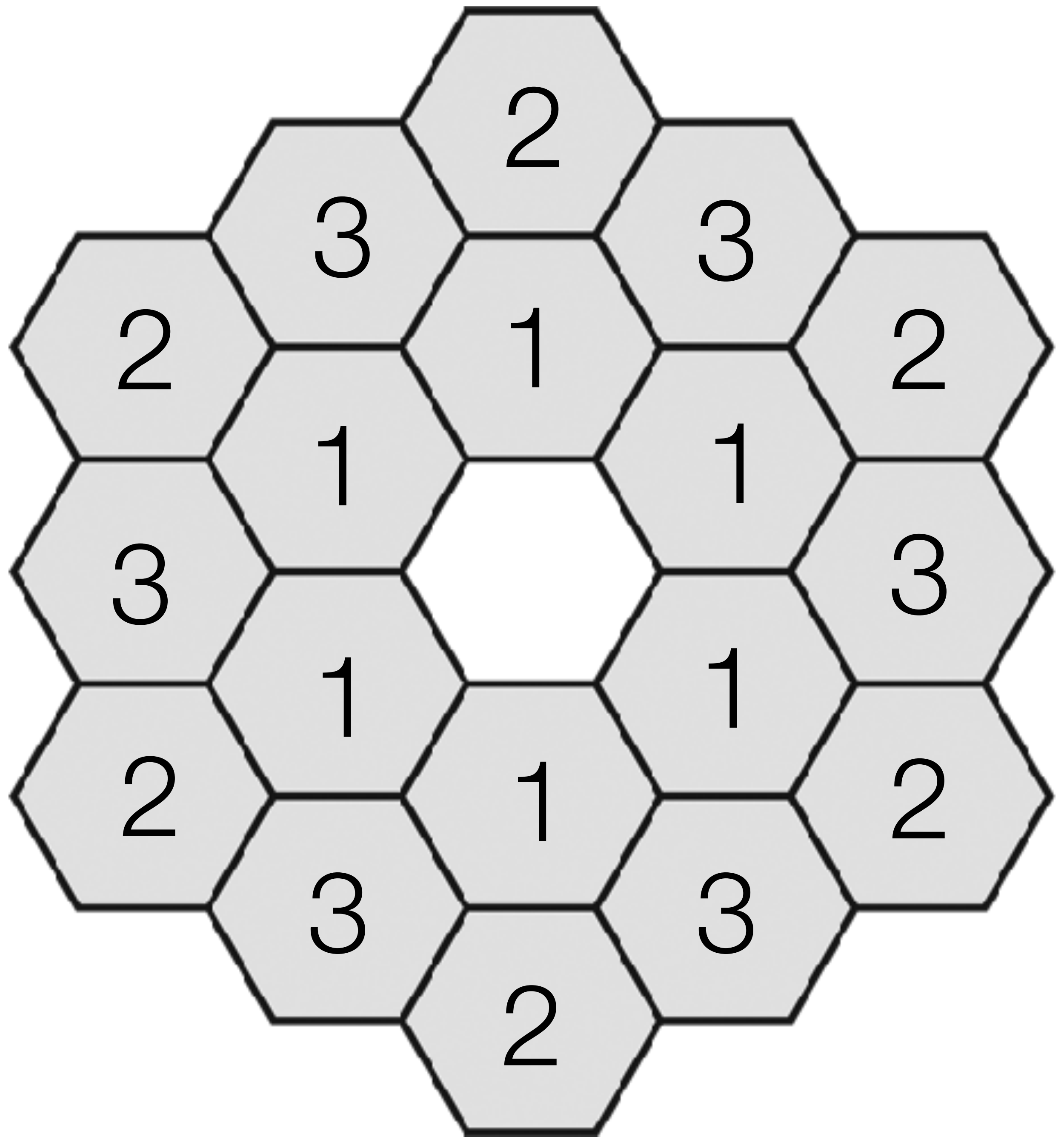

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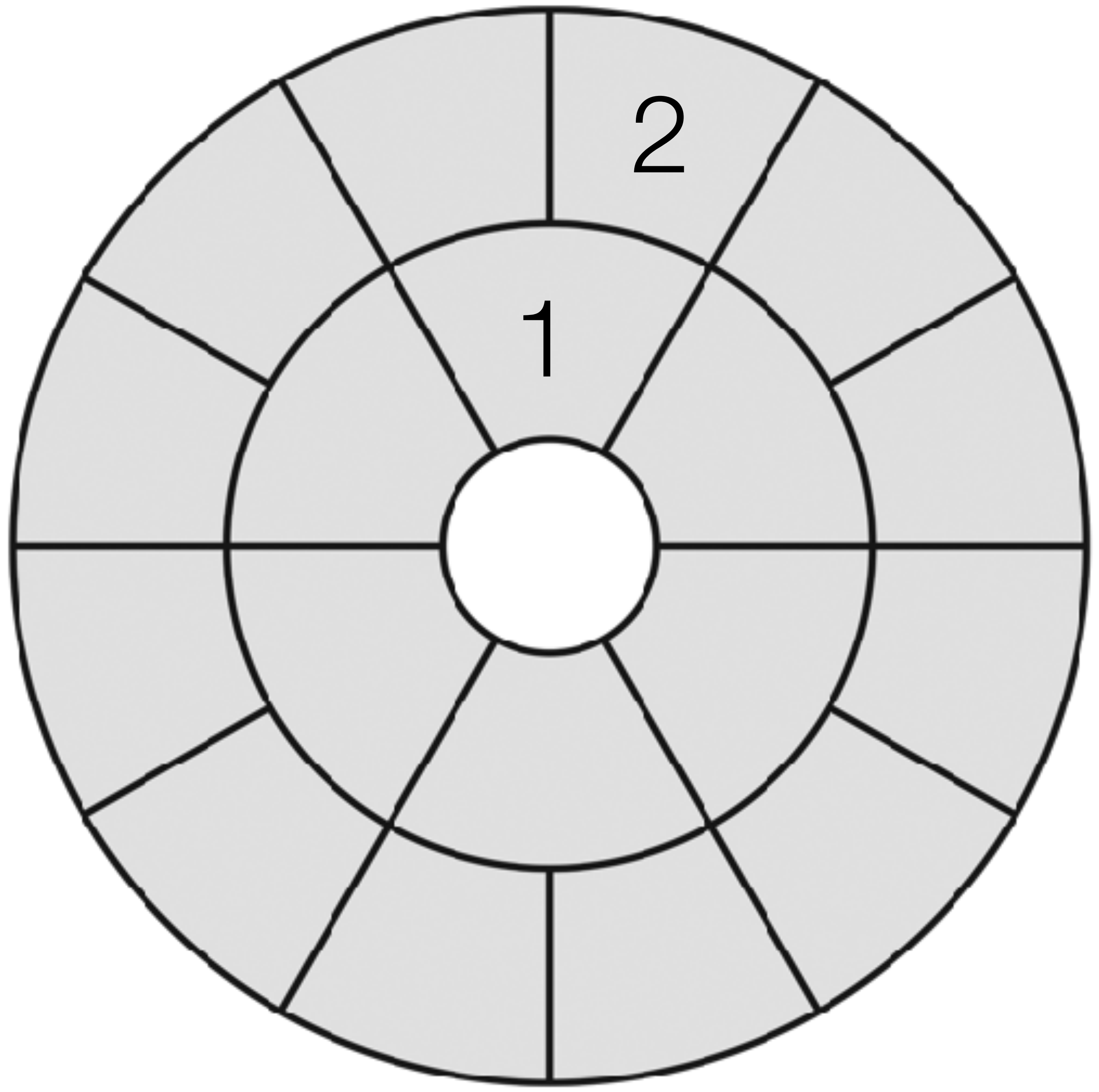
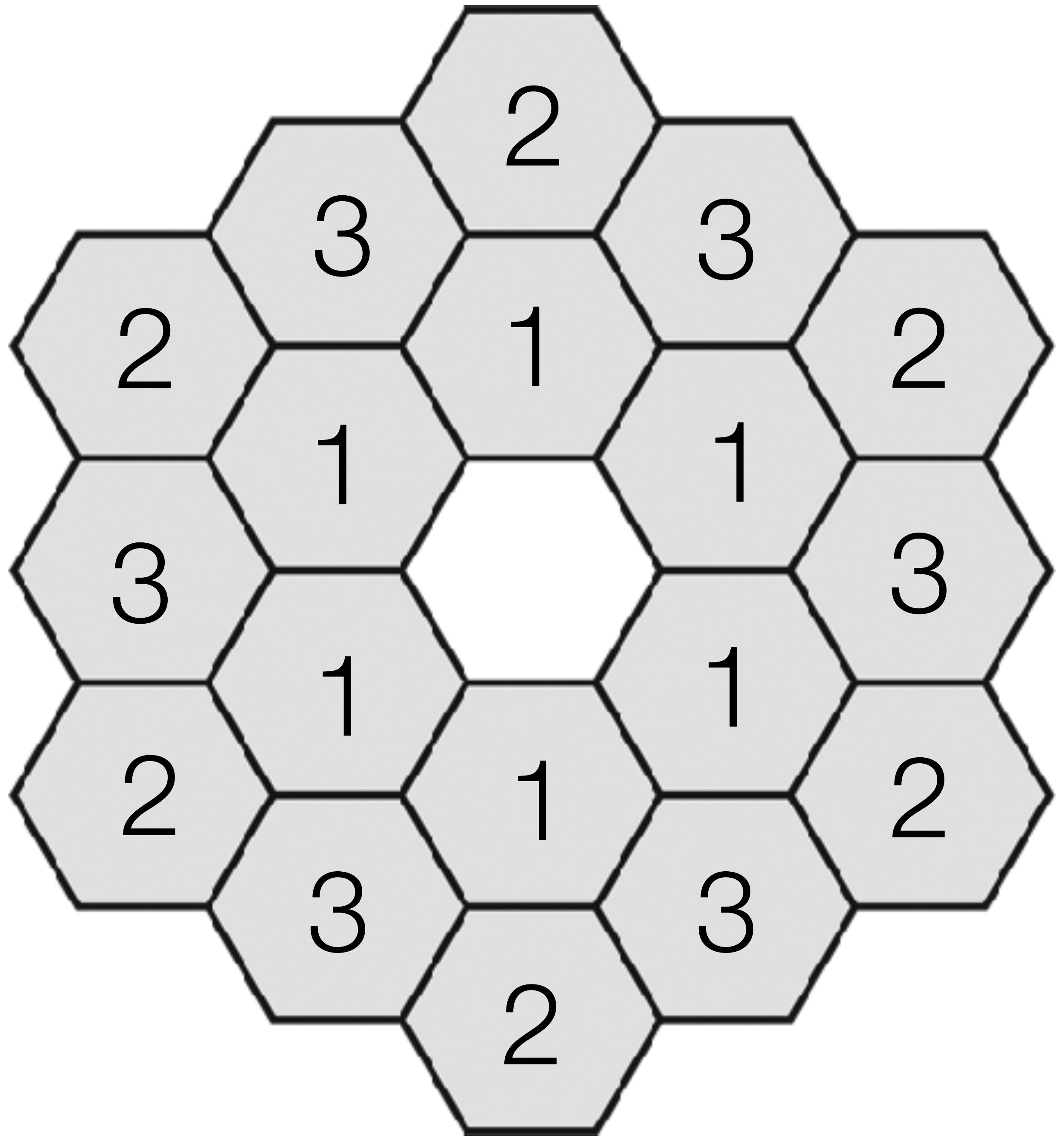
Annular vs Hexagonal





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Annular vs Hexagonal N=4

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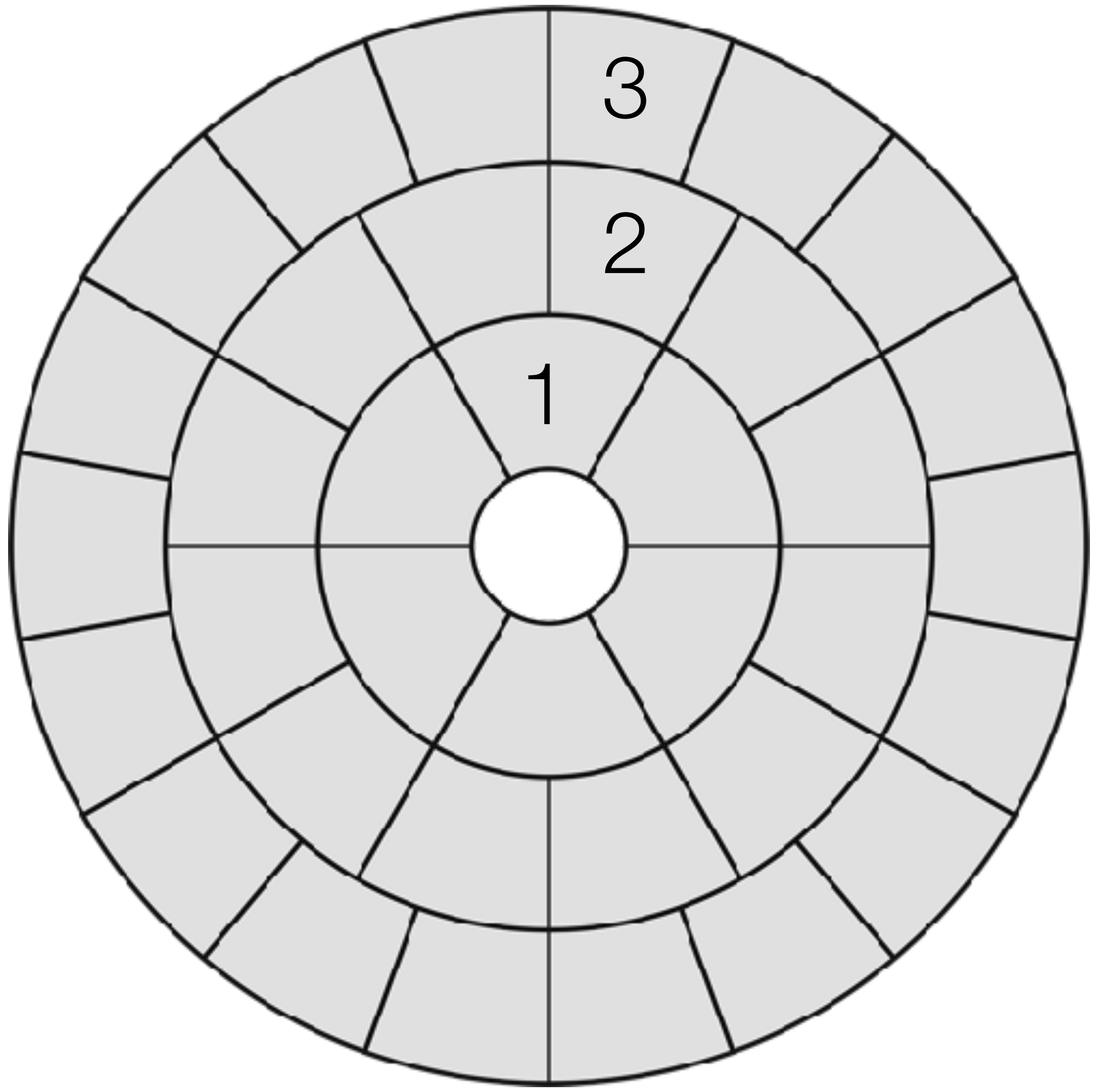
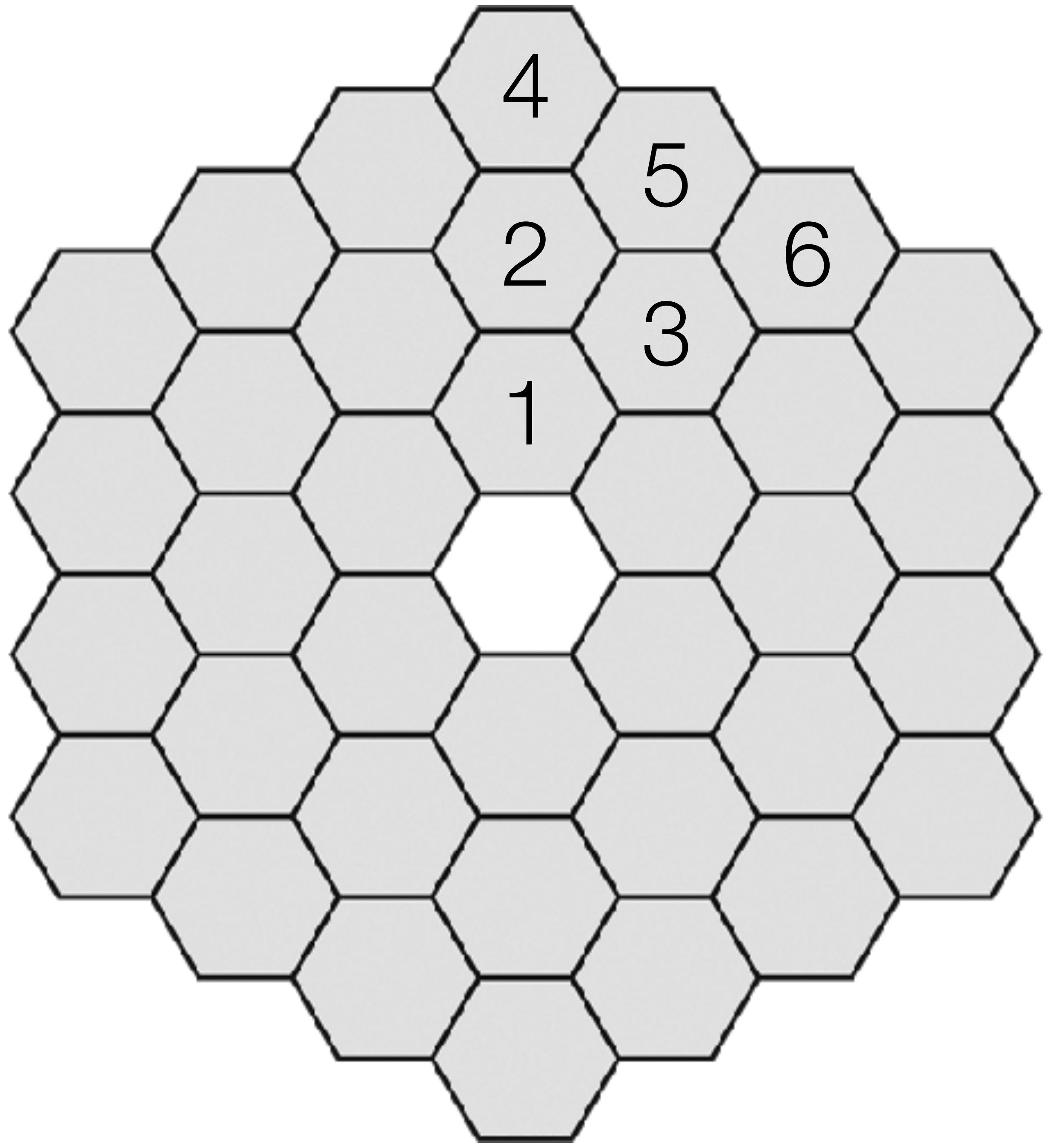
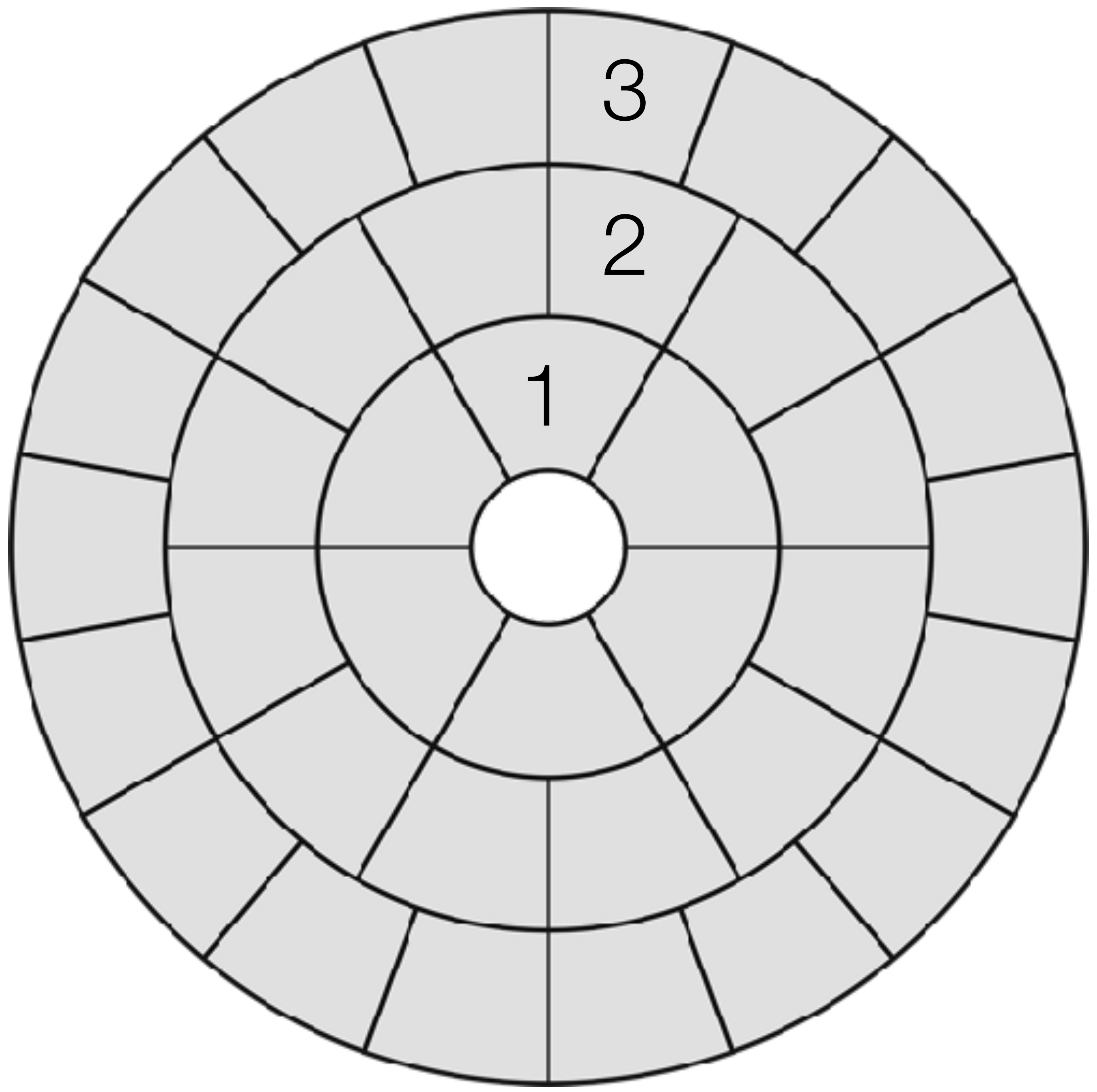


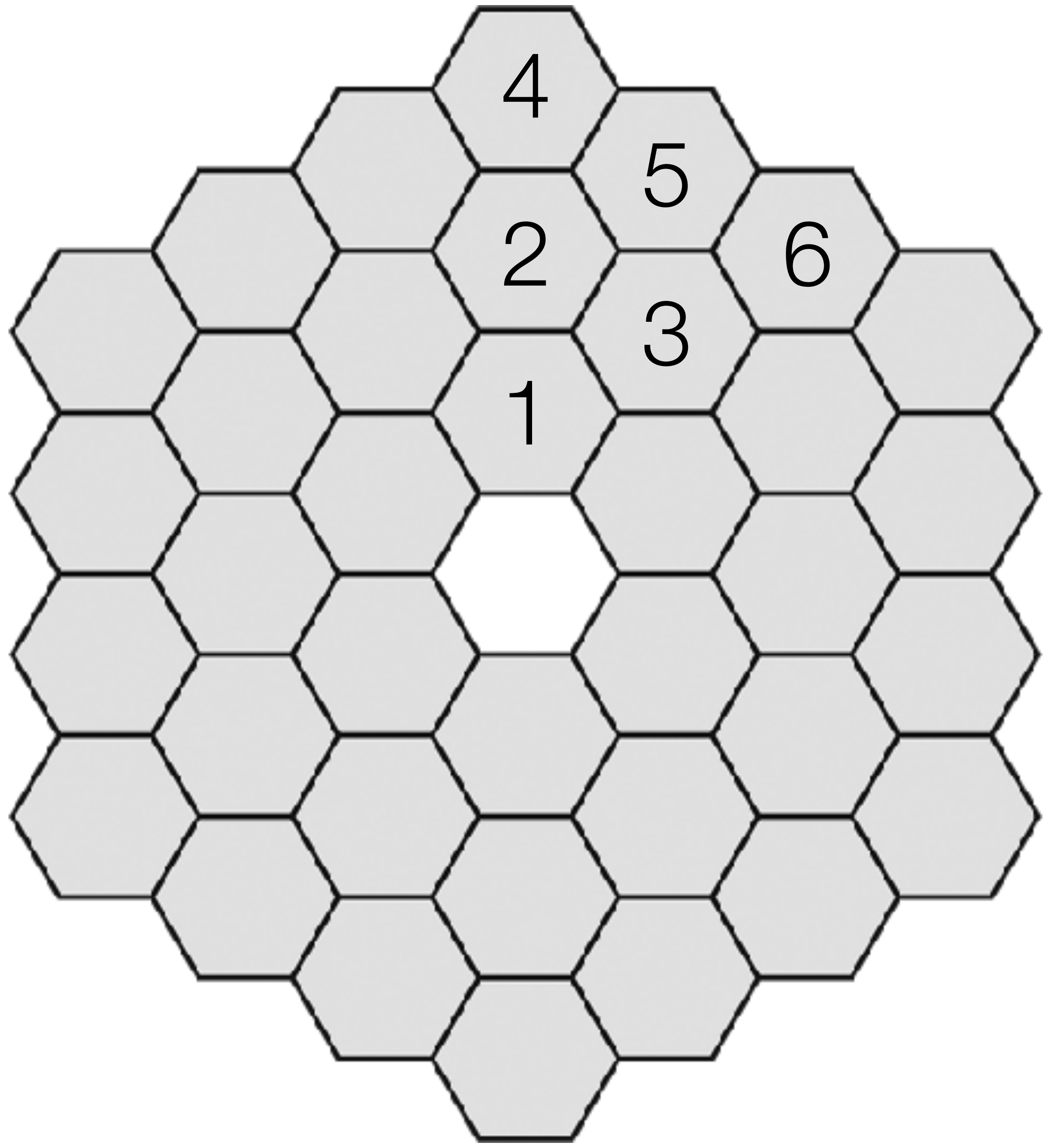


36 Segments
Diameter: 10.5 m
Area: 84.8 m^2
72 Edges
3 Spares required

36 Segments
Diameter: 10.5 m
Area: 70.1 m^2 (8 segments less)
84 Edges
6 Spares required

Annular vs Hexagonal N=4





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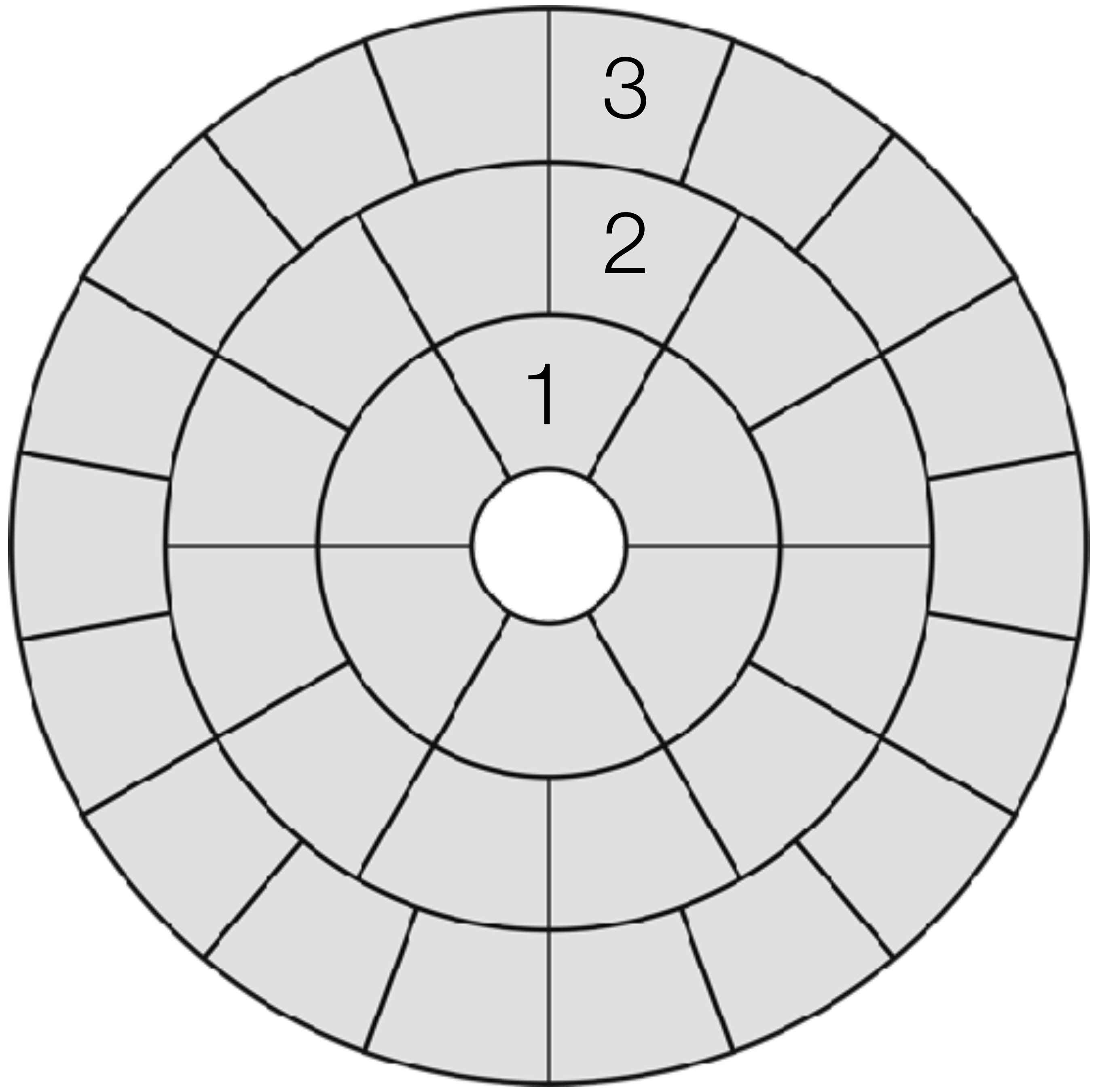
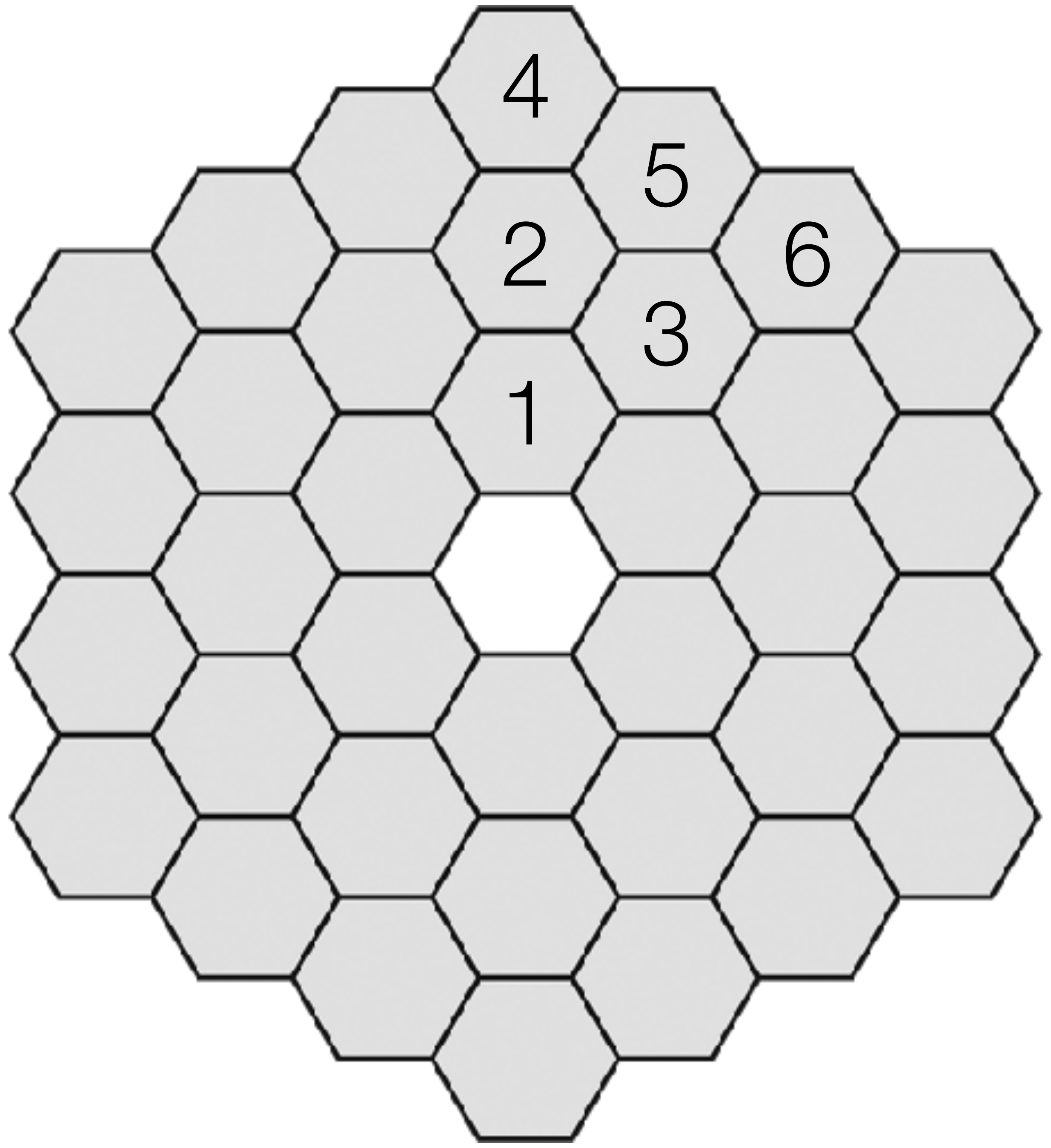
Annular vs Hexagonal





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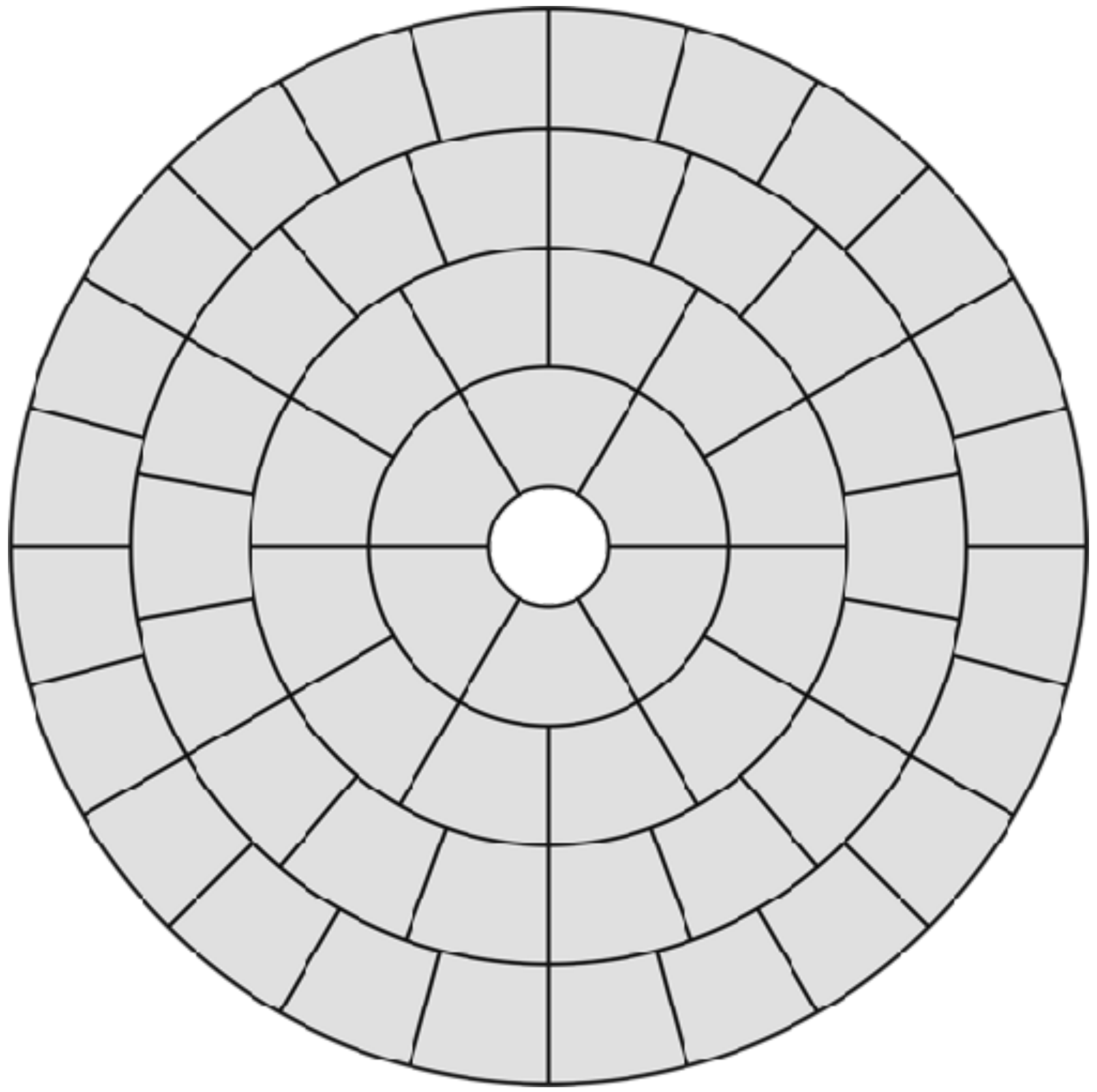
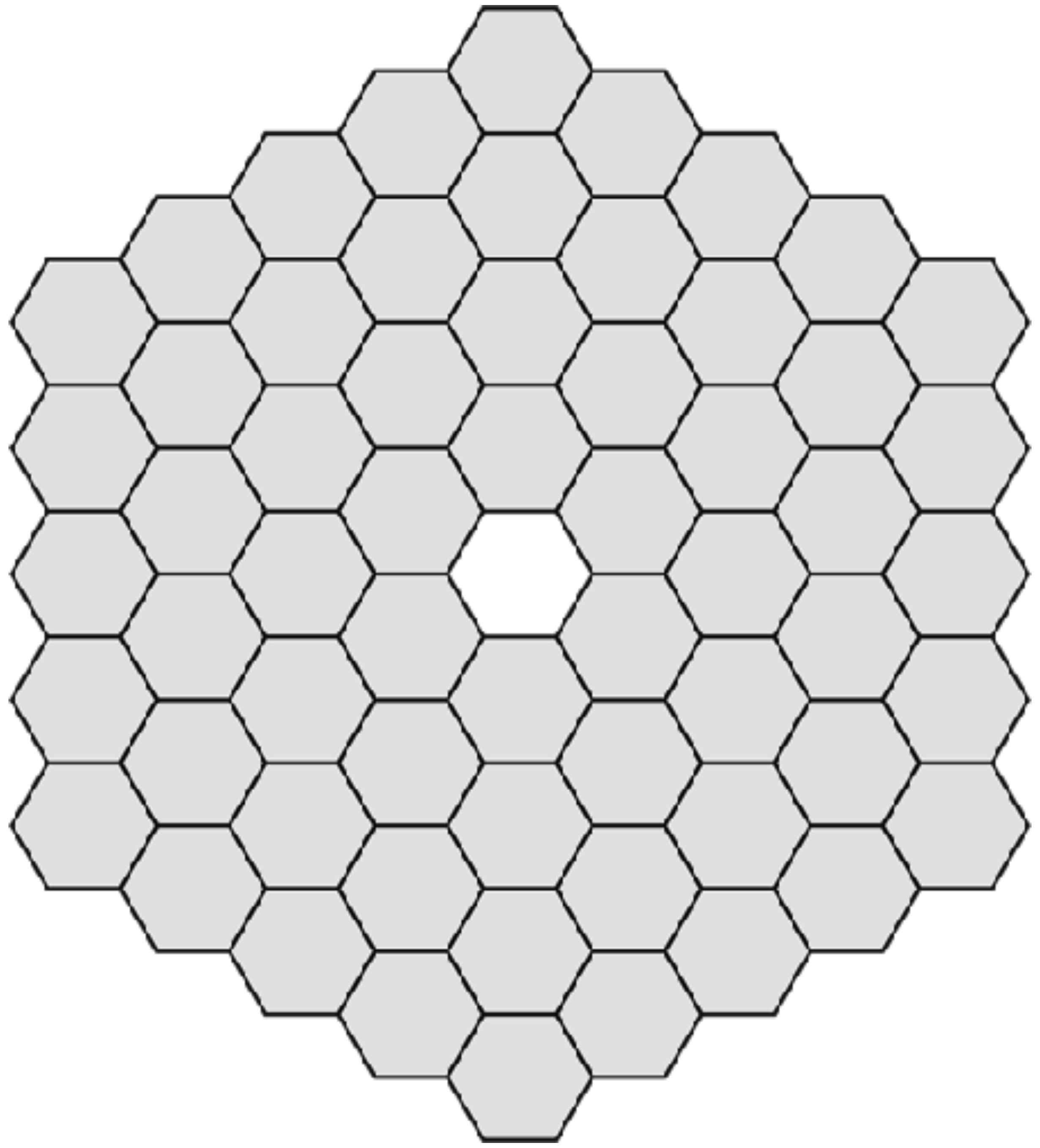
Annular vs Hexagonal N=5

Annular vs Hexagonal N=5

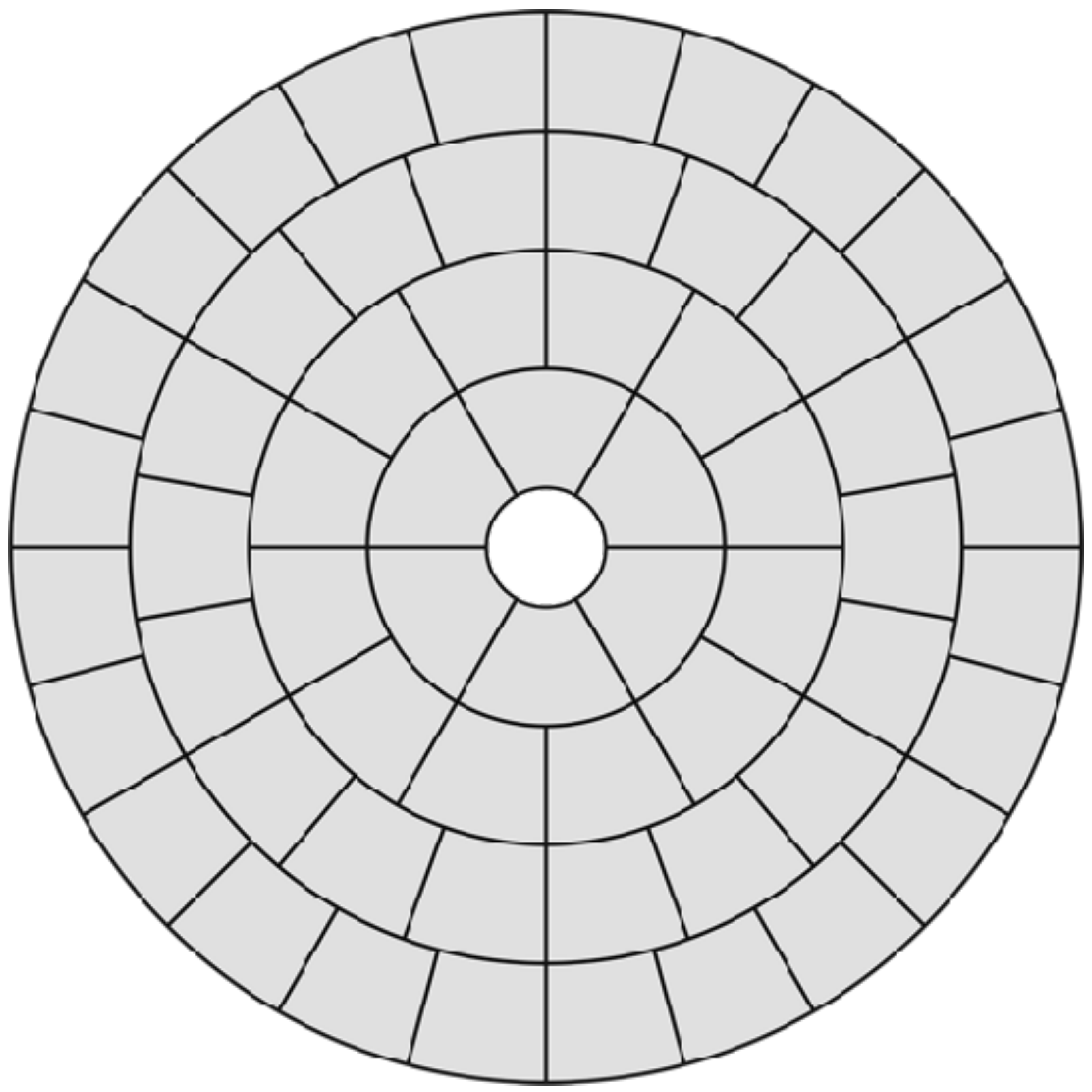


60 Segments
Diameter: 13.5 m
Area: 141.4 m^2
132 Edges
4 Spares required



60 Segments
Diameter: 13.5 m
Area: 116.9 m^2 (13 segments less)
150 Edges
10 Spares required

Annular vs Hexagonal N=5



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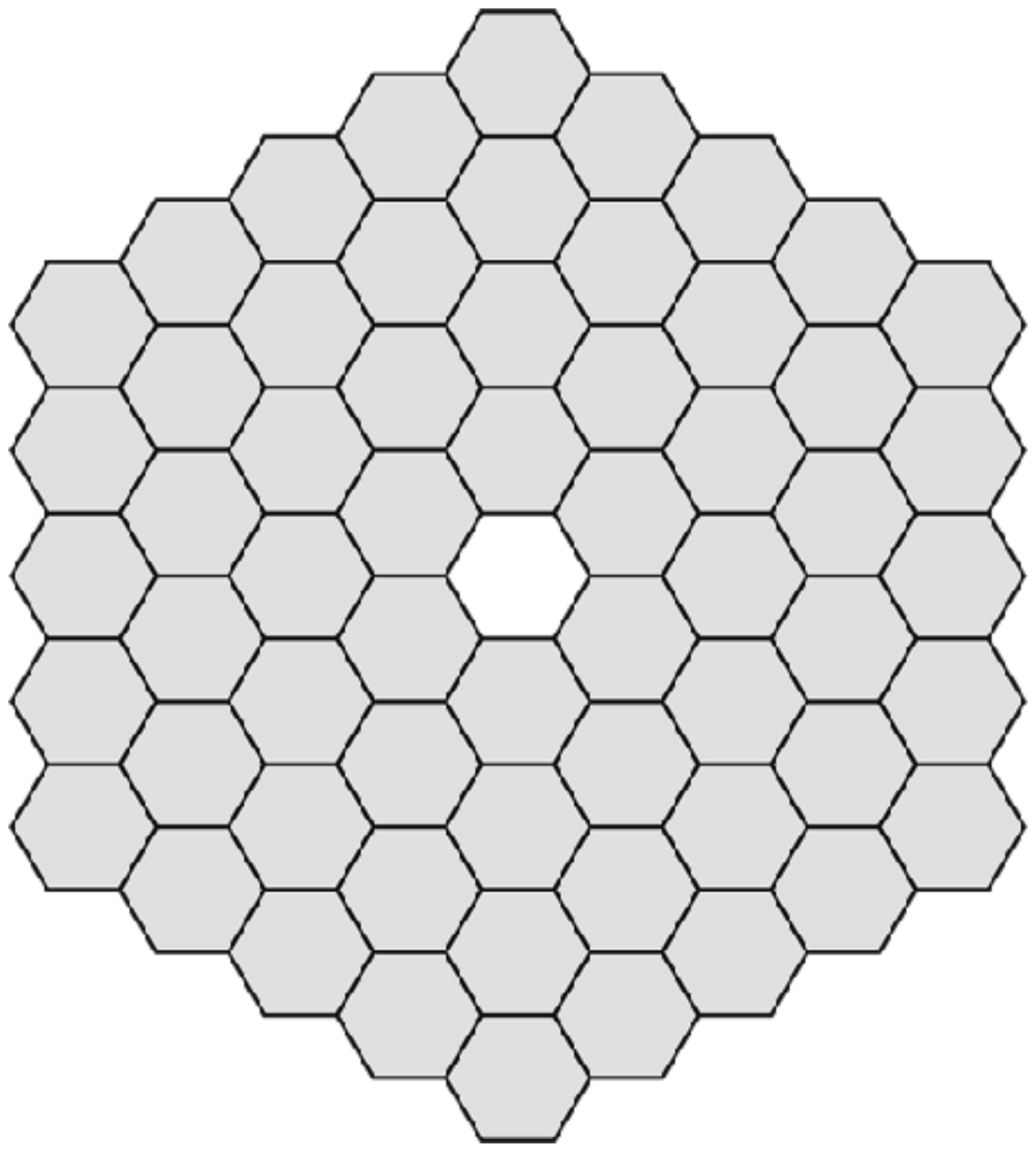

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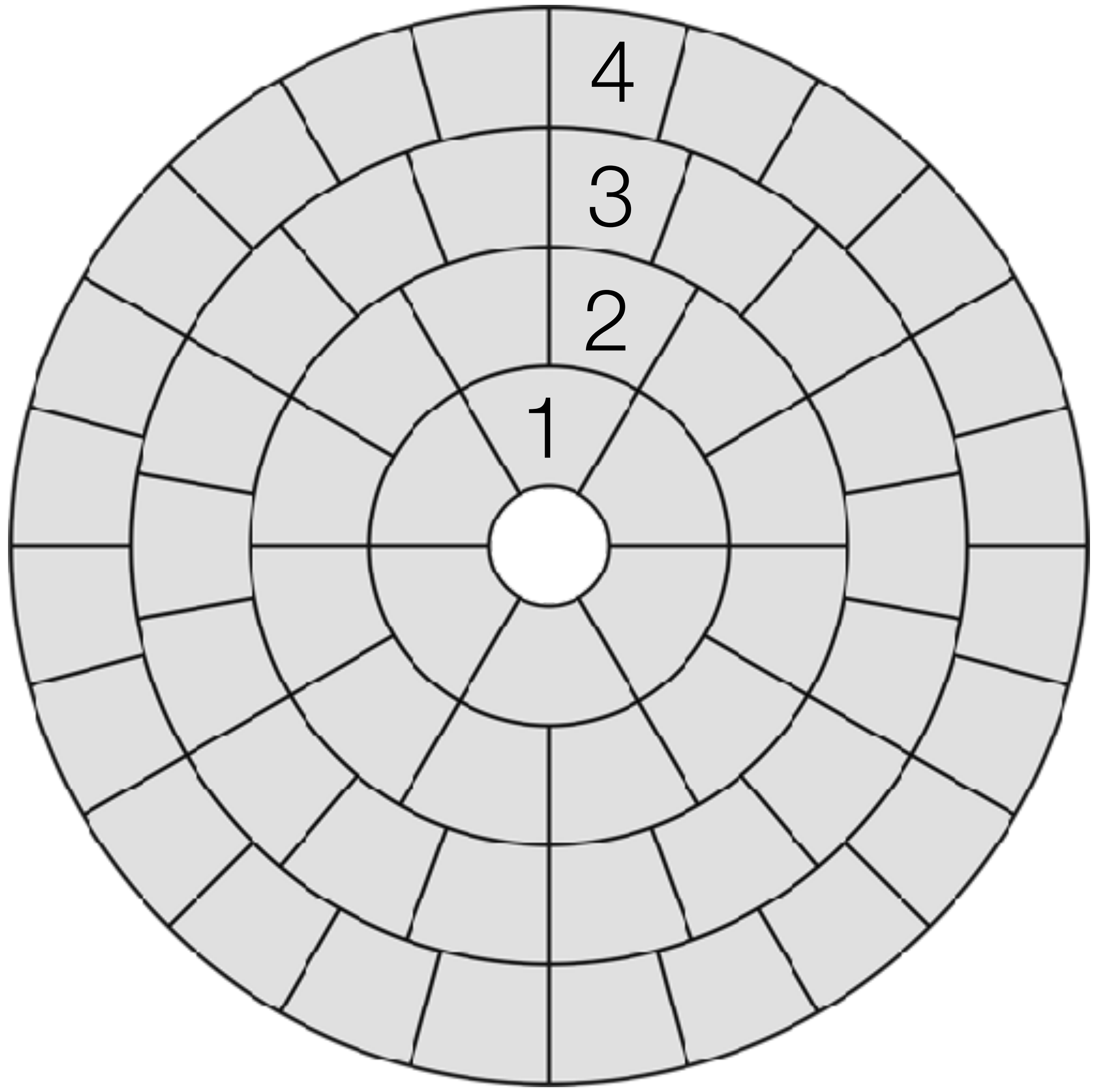

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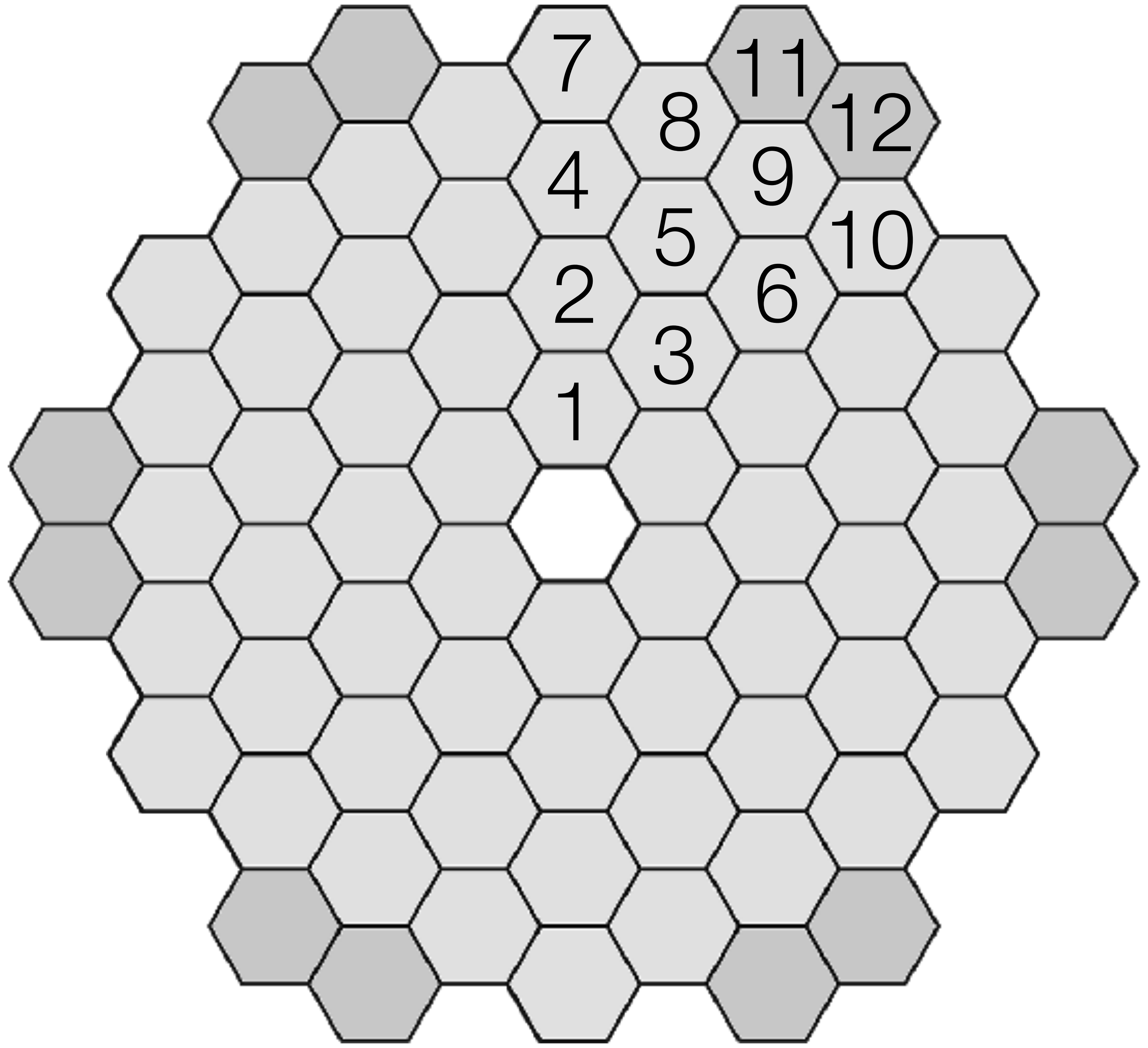
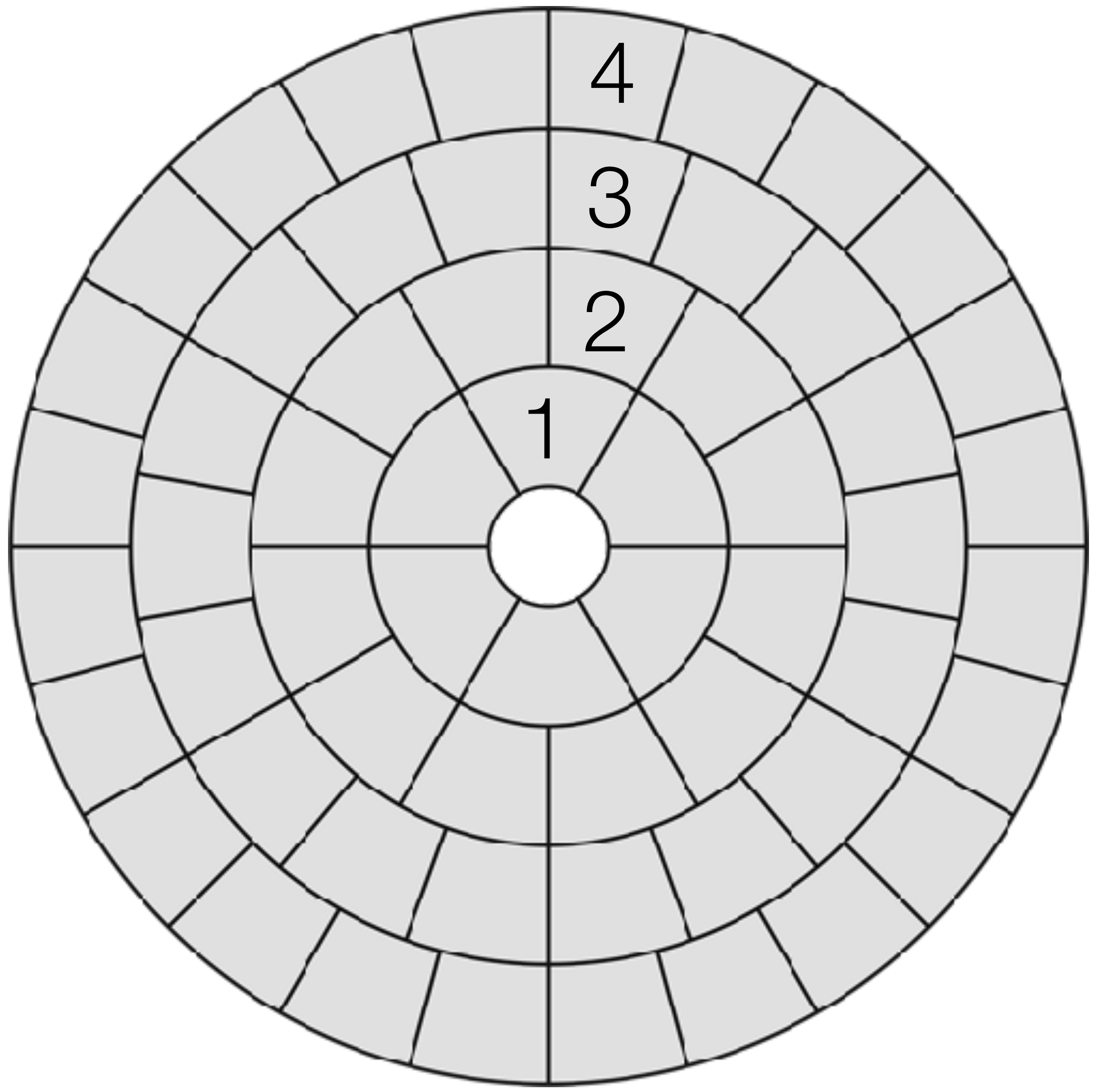


72 Segments
Diameter: 14.8 m
Area: 140.3 m^2
180 Edges
12 Spares required

Annular vs Hexagonal N=5



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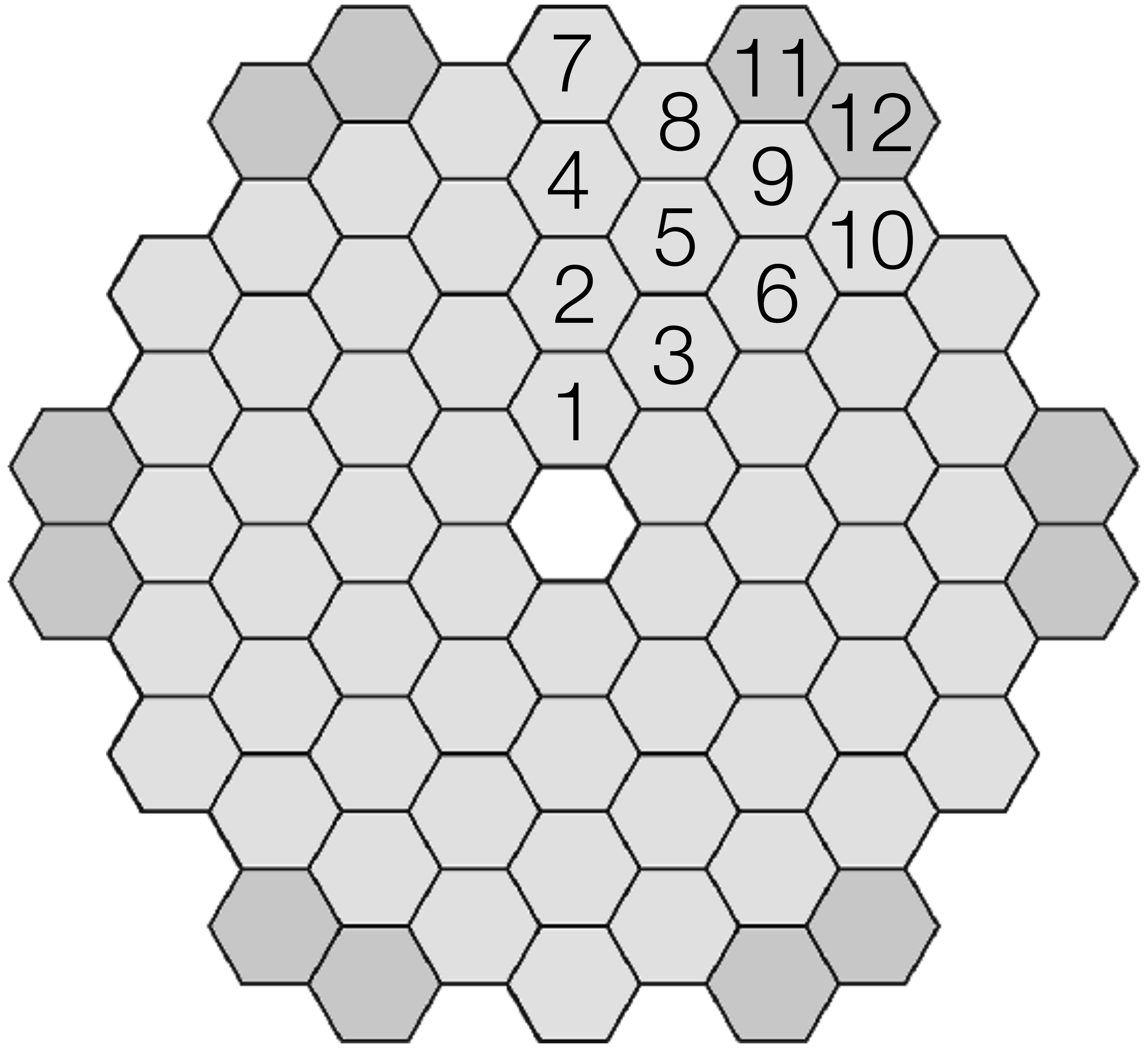

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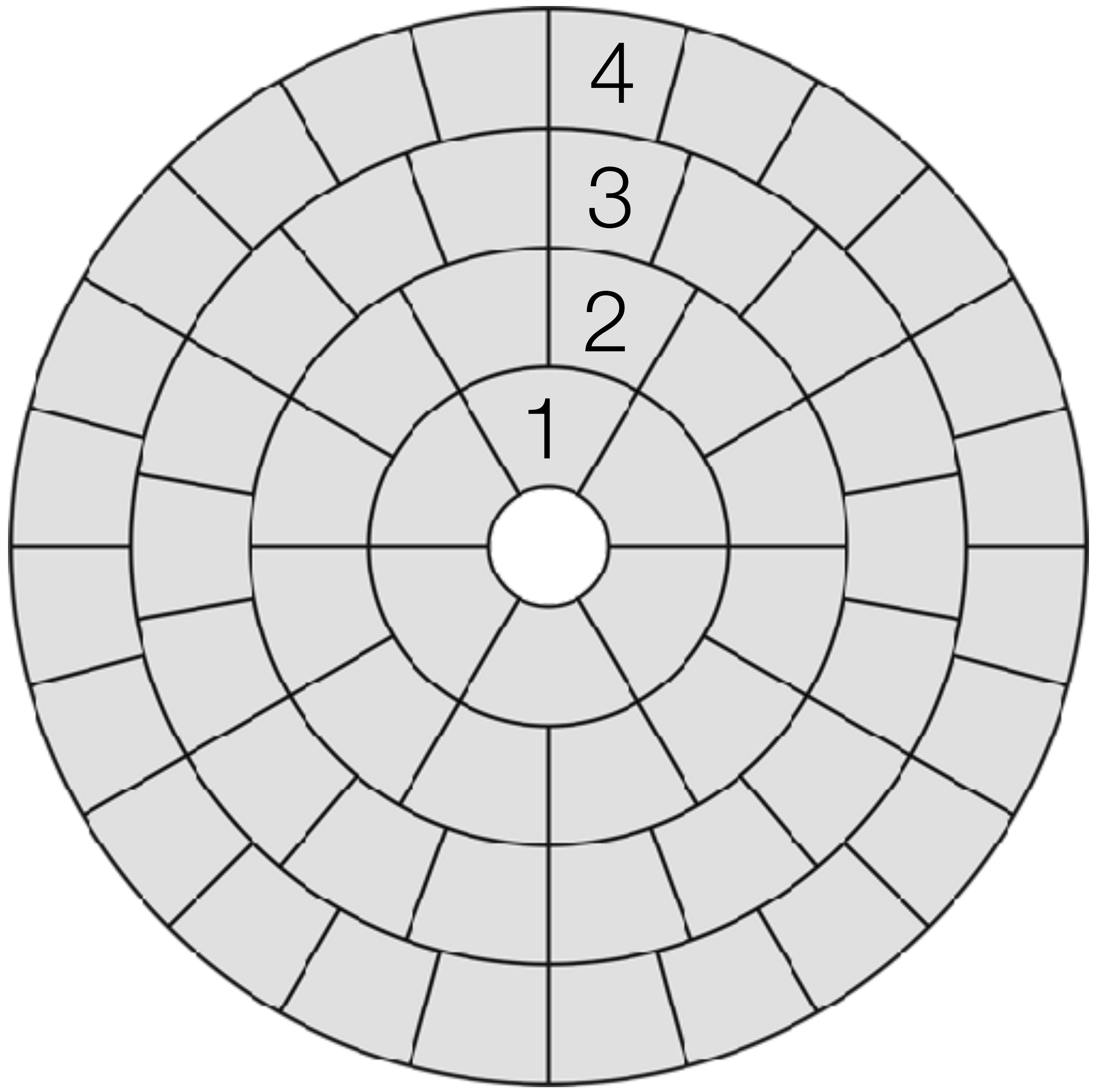
Diameter: 14.8 m
Area: 140.3 m²
180 Edges
12 Spares required

Annular vs Hexagonal



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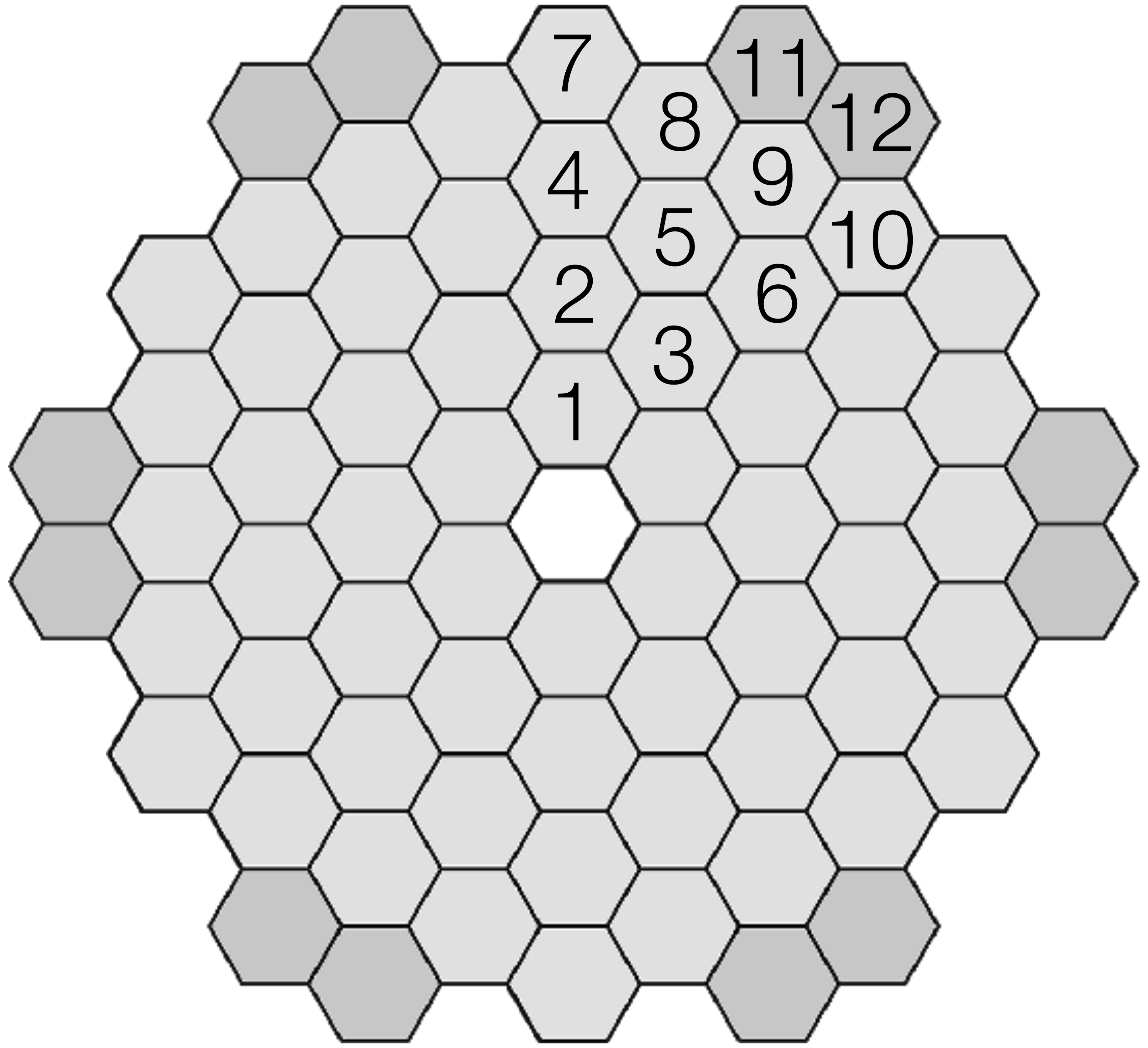
4 Spares required



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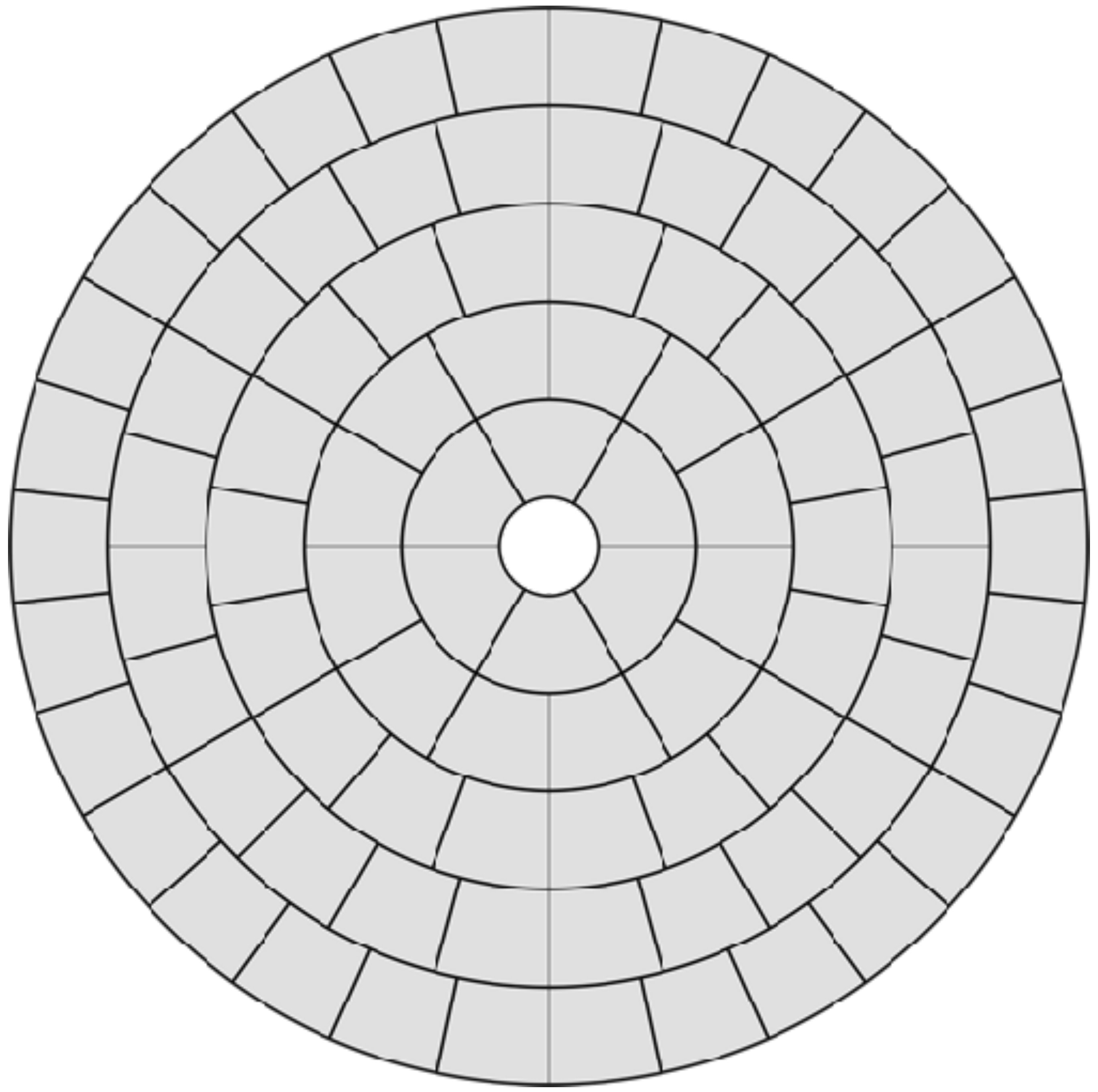
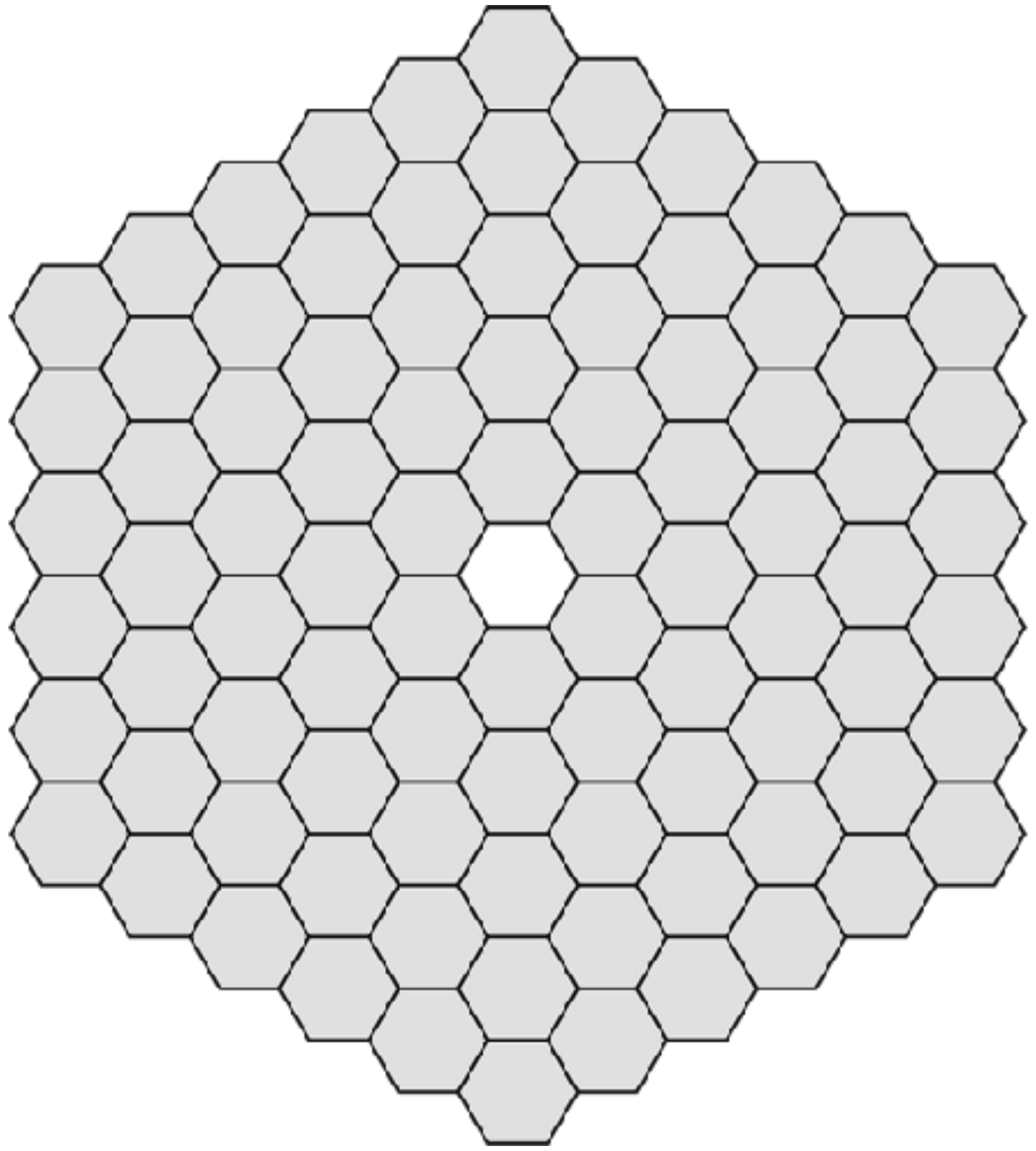
Annular vs Hexagonal N=6

Annular vs Hexagonal N=6

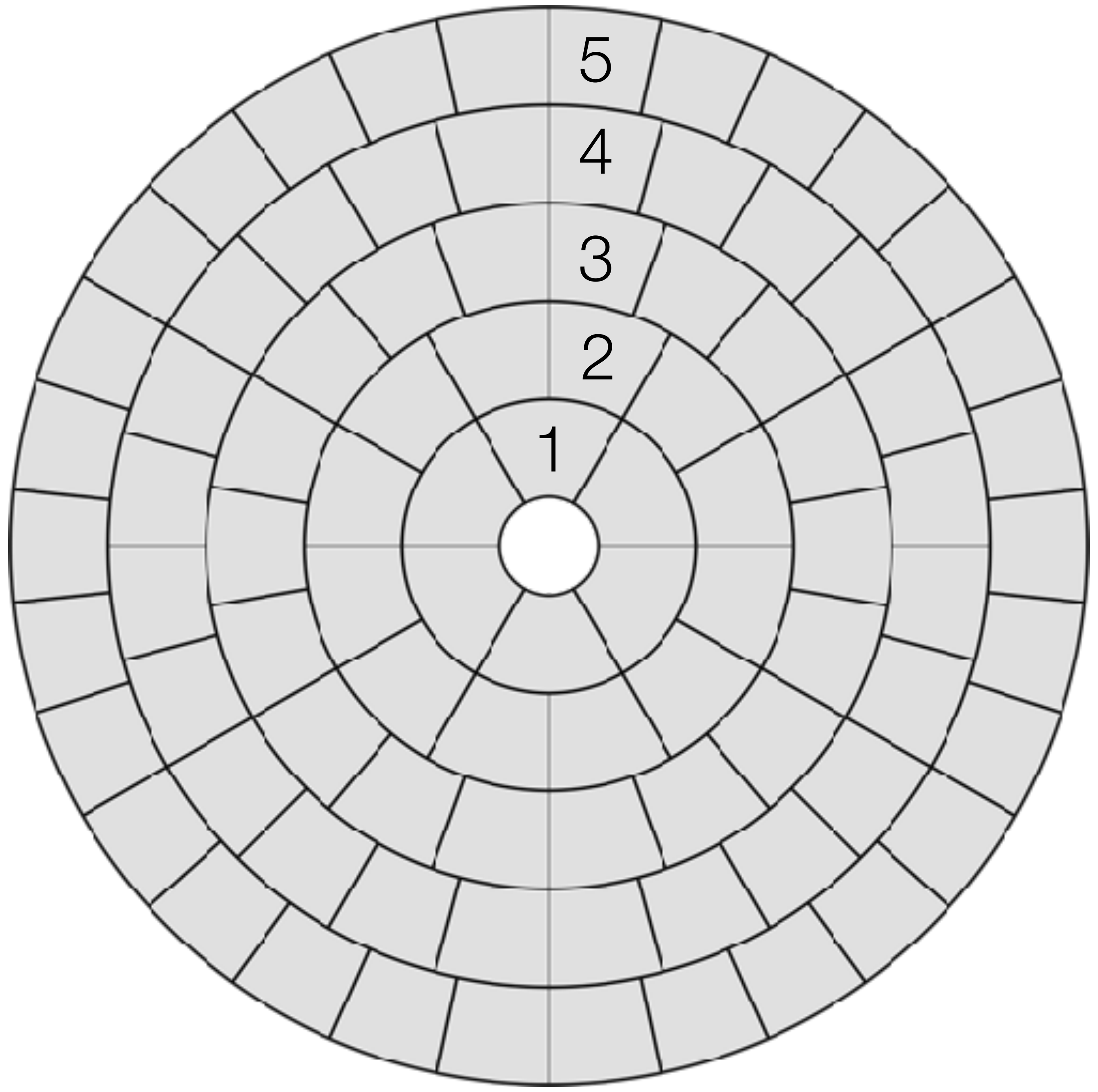


90 Segments
Diameter: 16.5 m
Area: 212 m^2
210 Edges
5 Spares required



90 Segments
Diameter: 16.5 m
Area: 175 m^2 (19 segments less)
234 Edges
15 Spares required

Annular vs Hexagonal N=6



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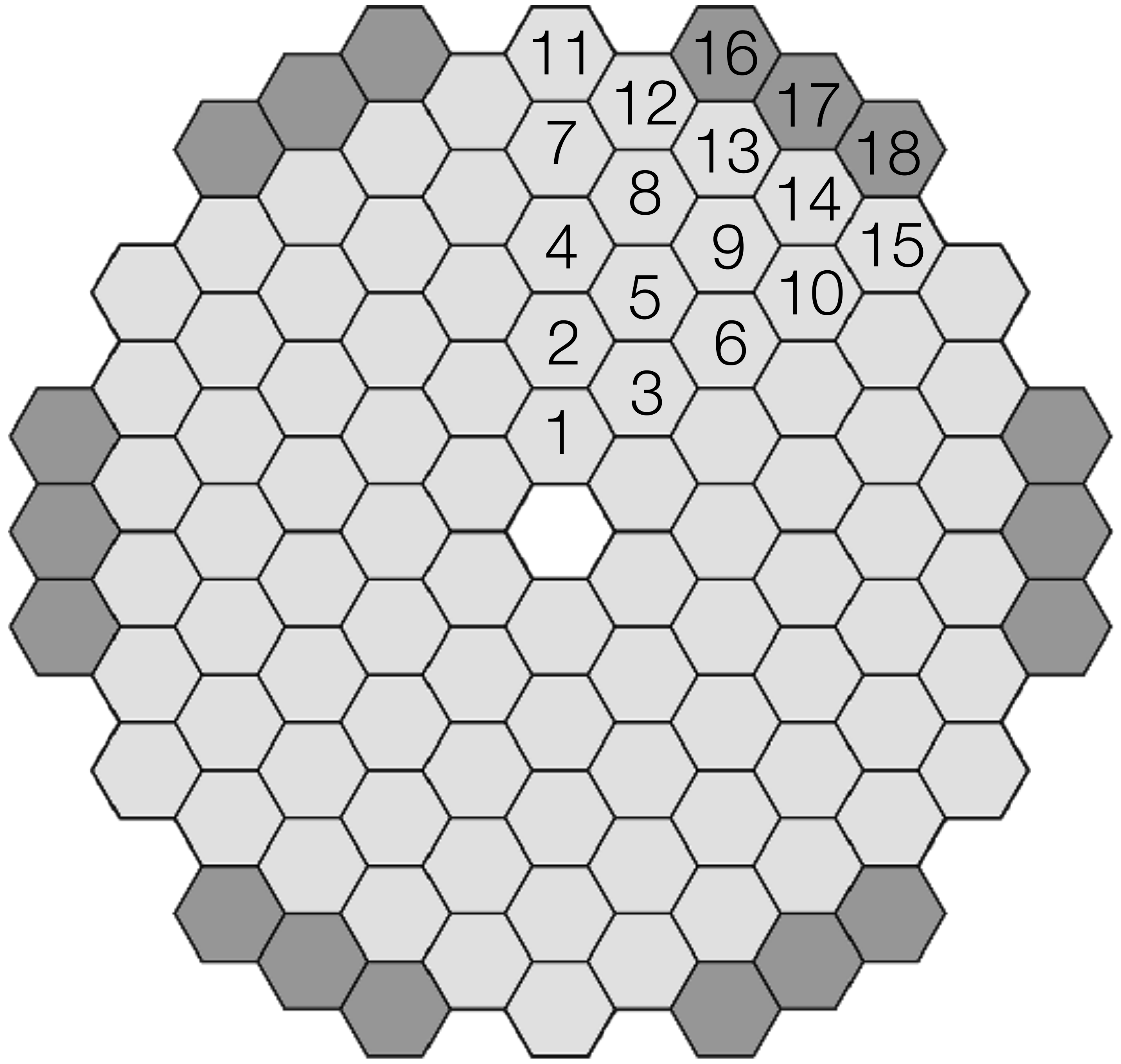
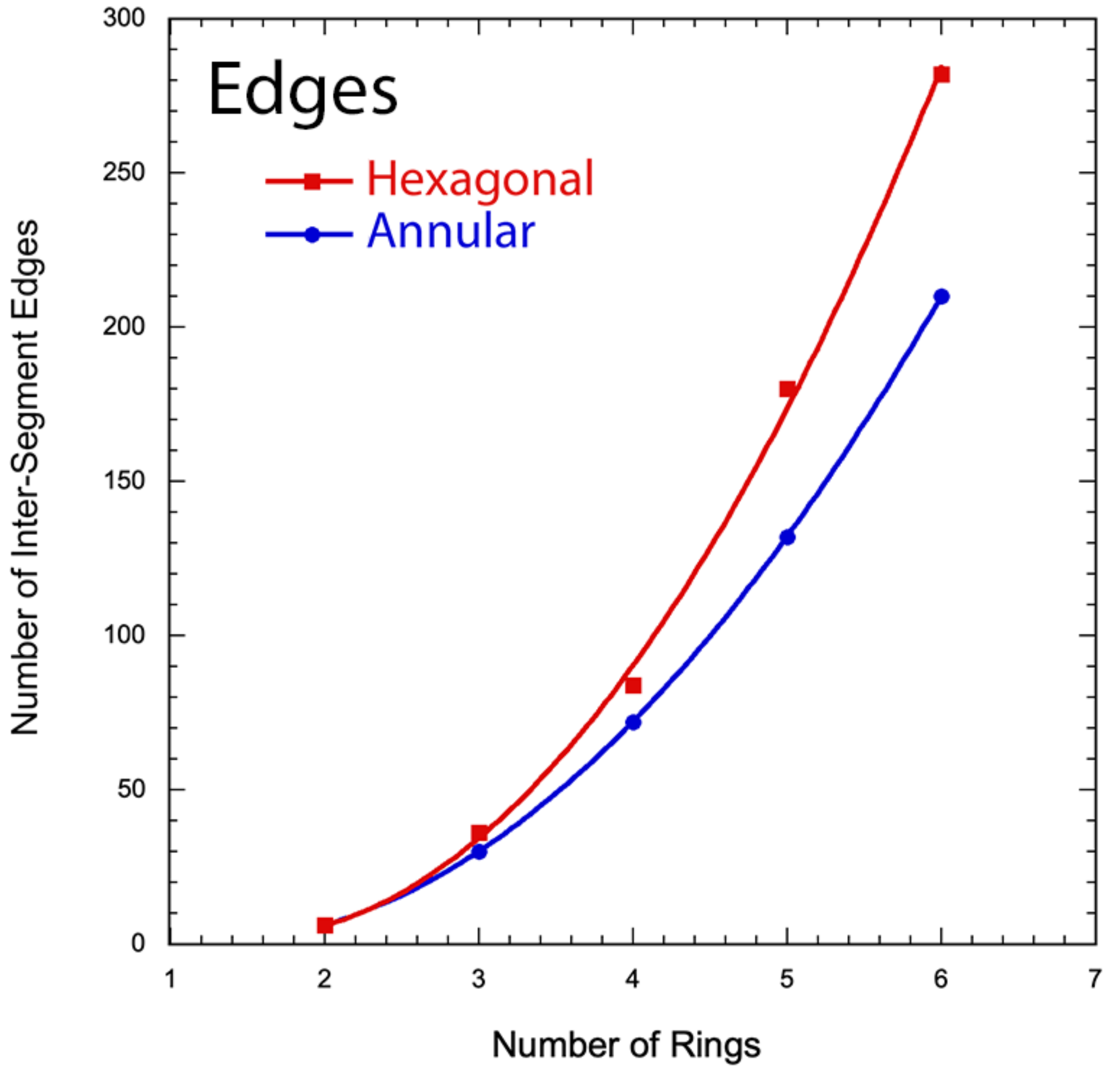
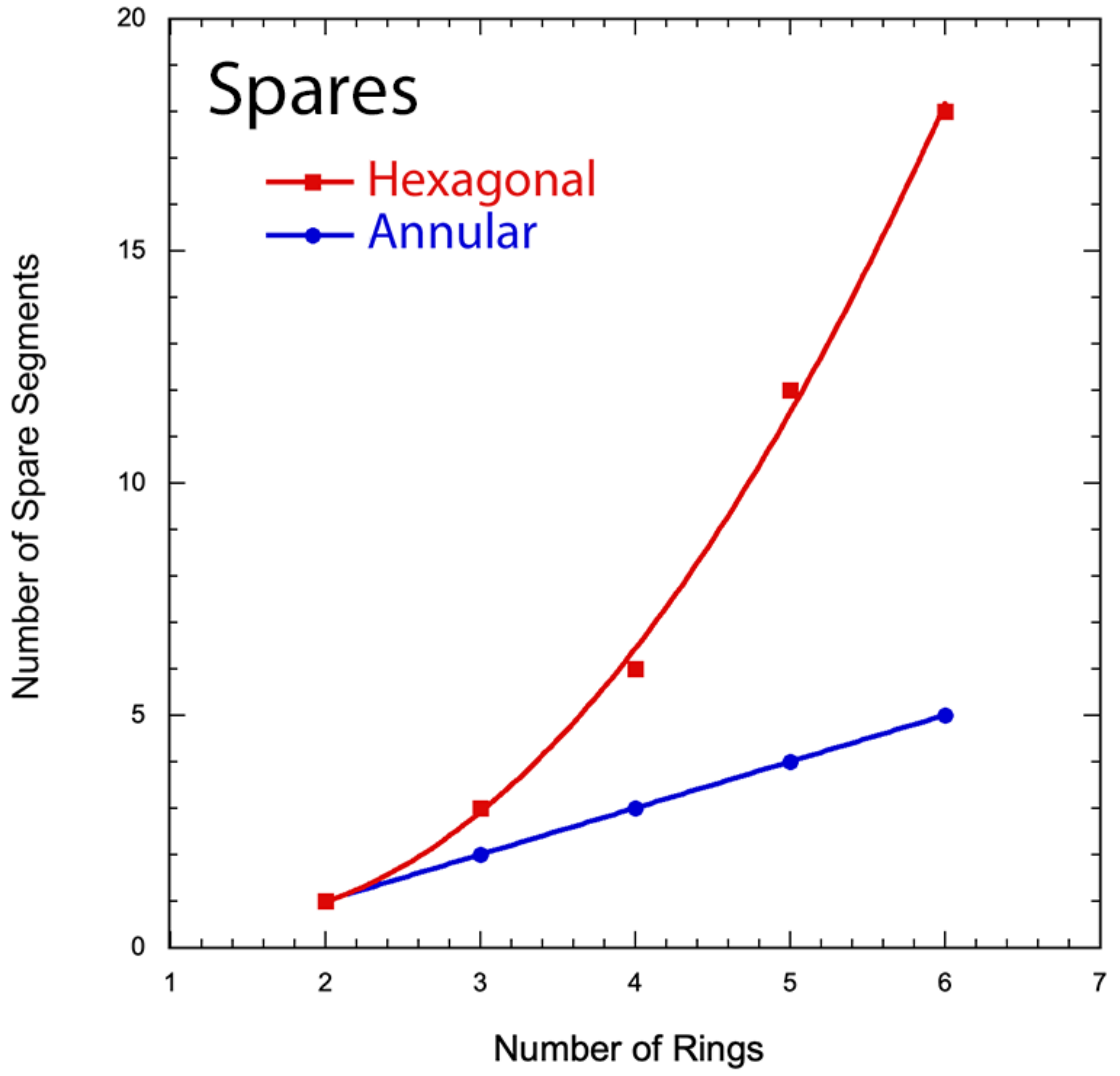


108 Segments
Diameter: 17.6 m
Area: 210 m^2
282 Edges
18 Spares required

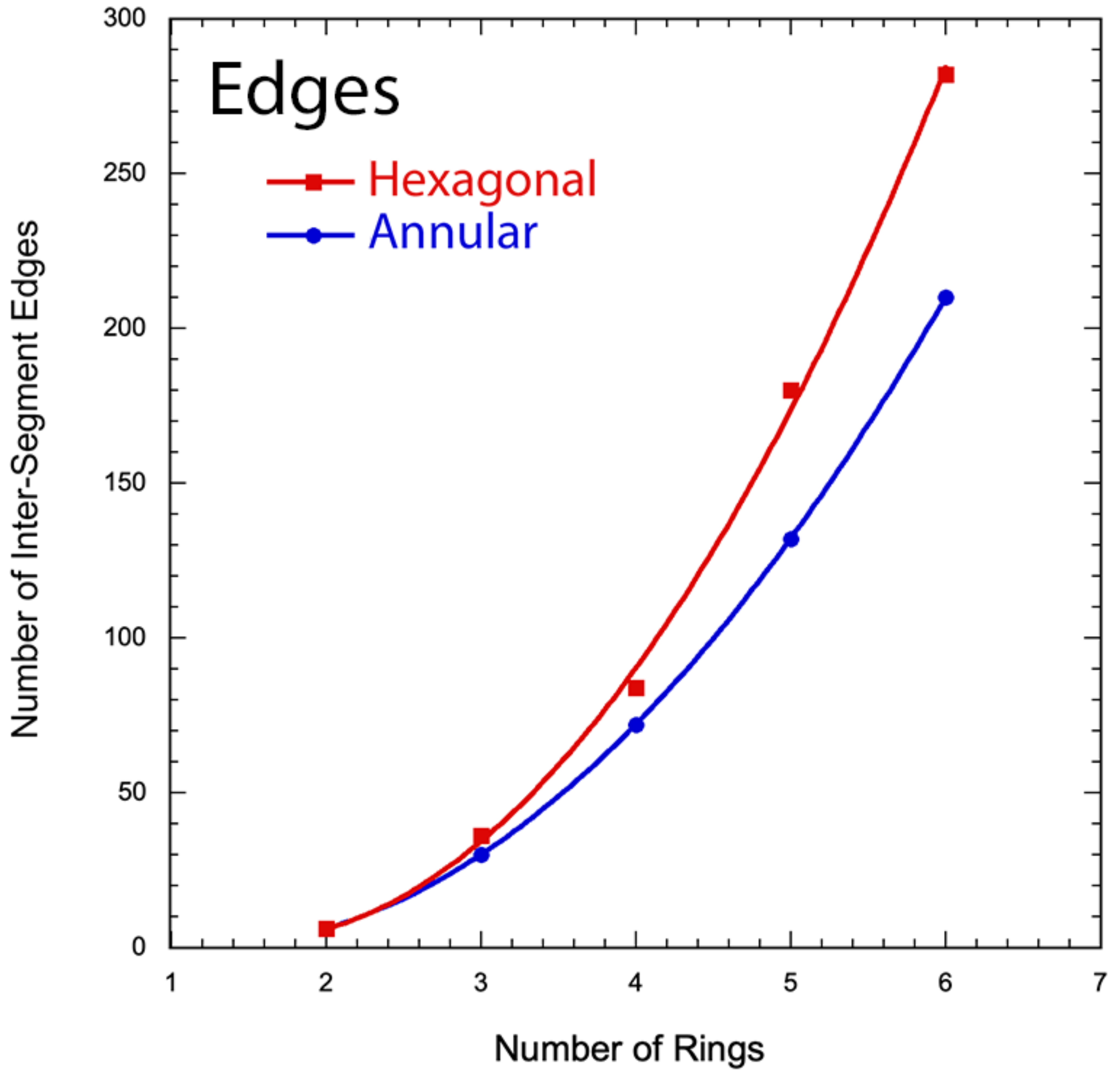
Edges and Spares…

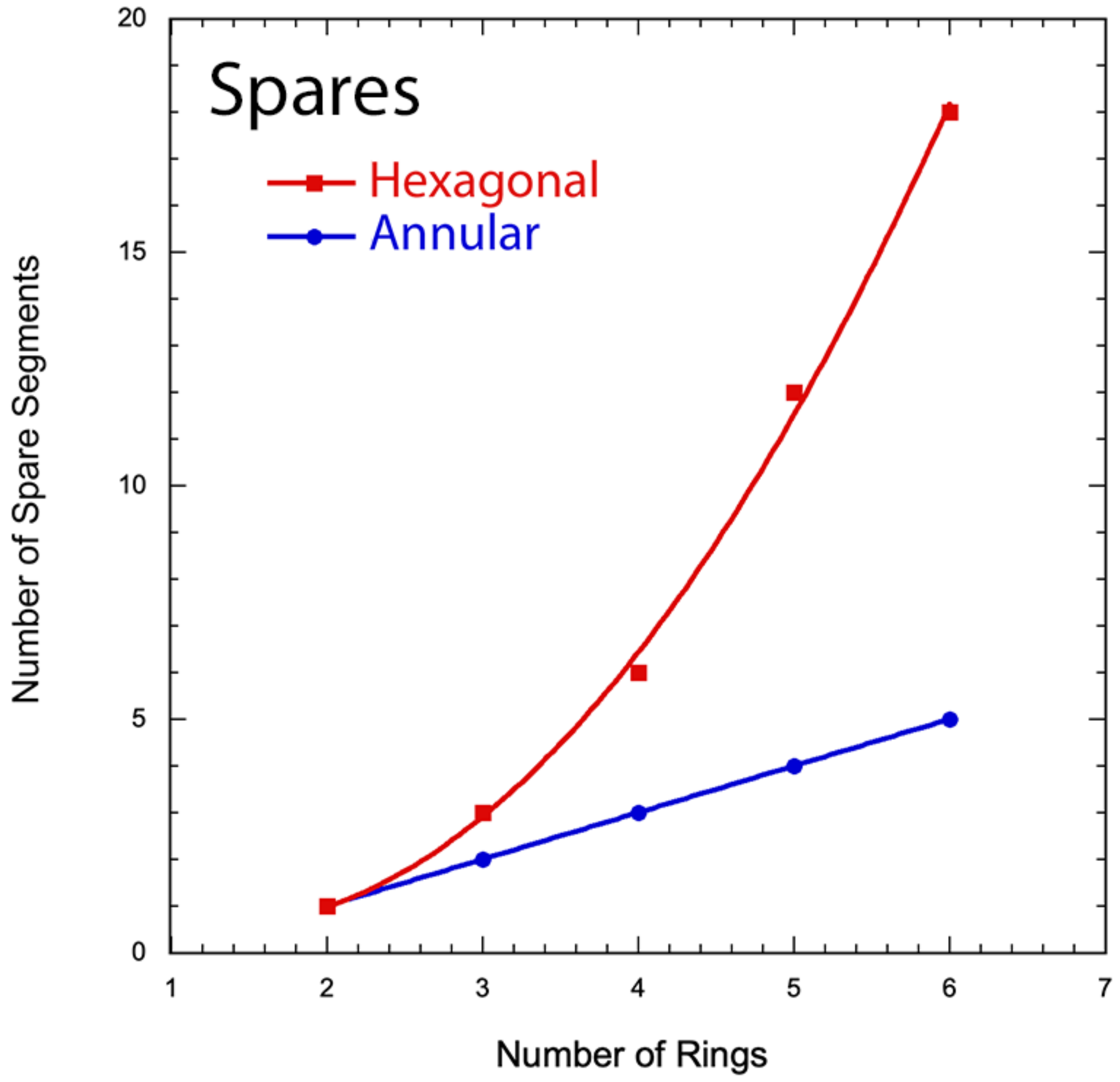
Edges and Spares…





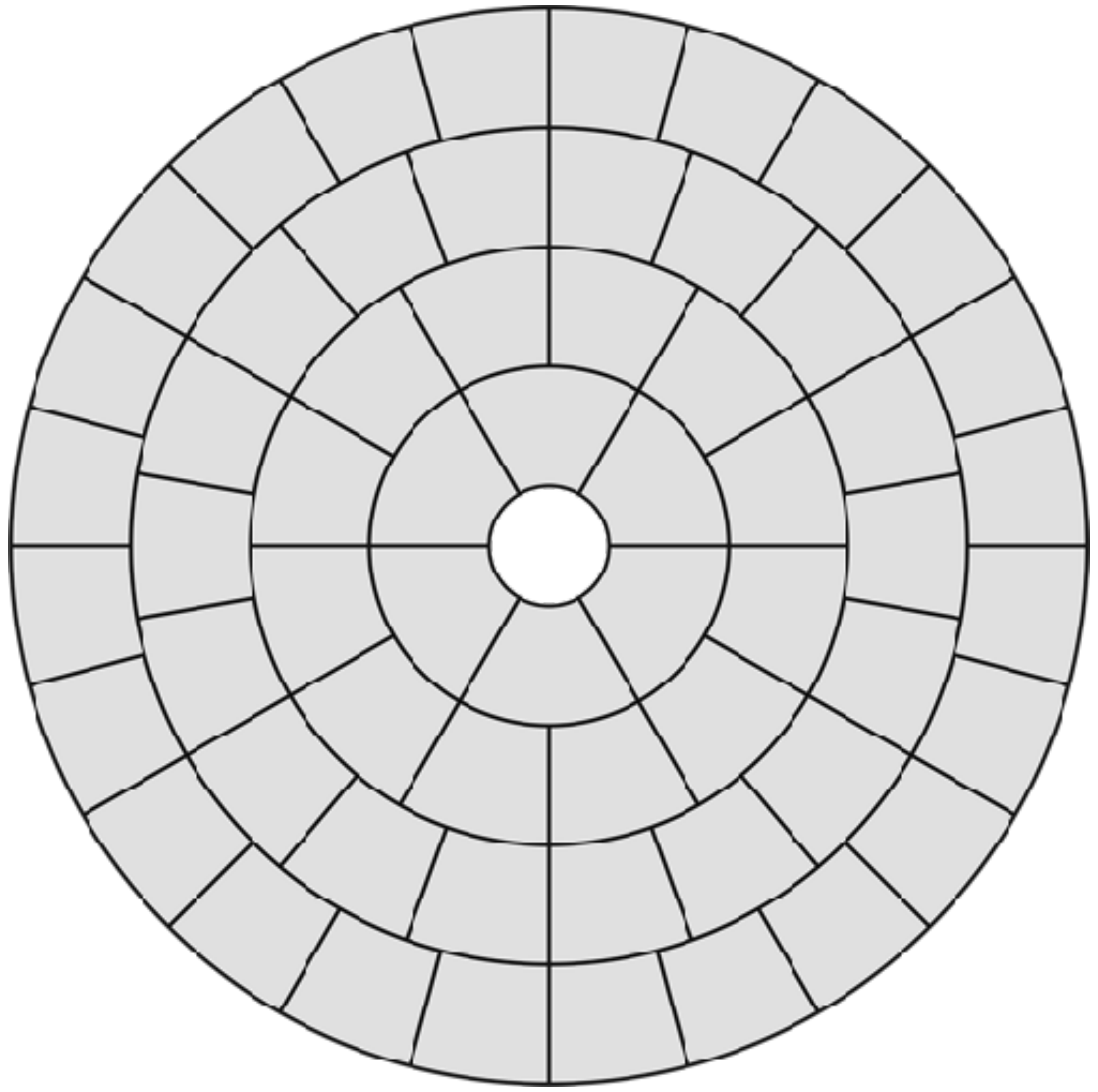
Edges and Spares…





and ELT?

Annular vs Hexagonal N=5



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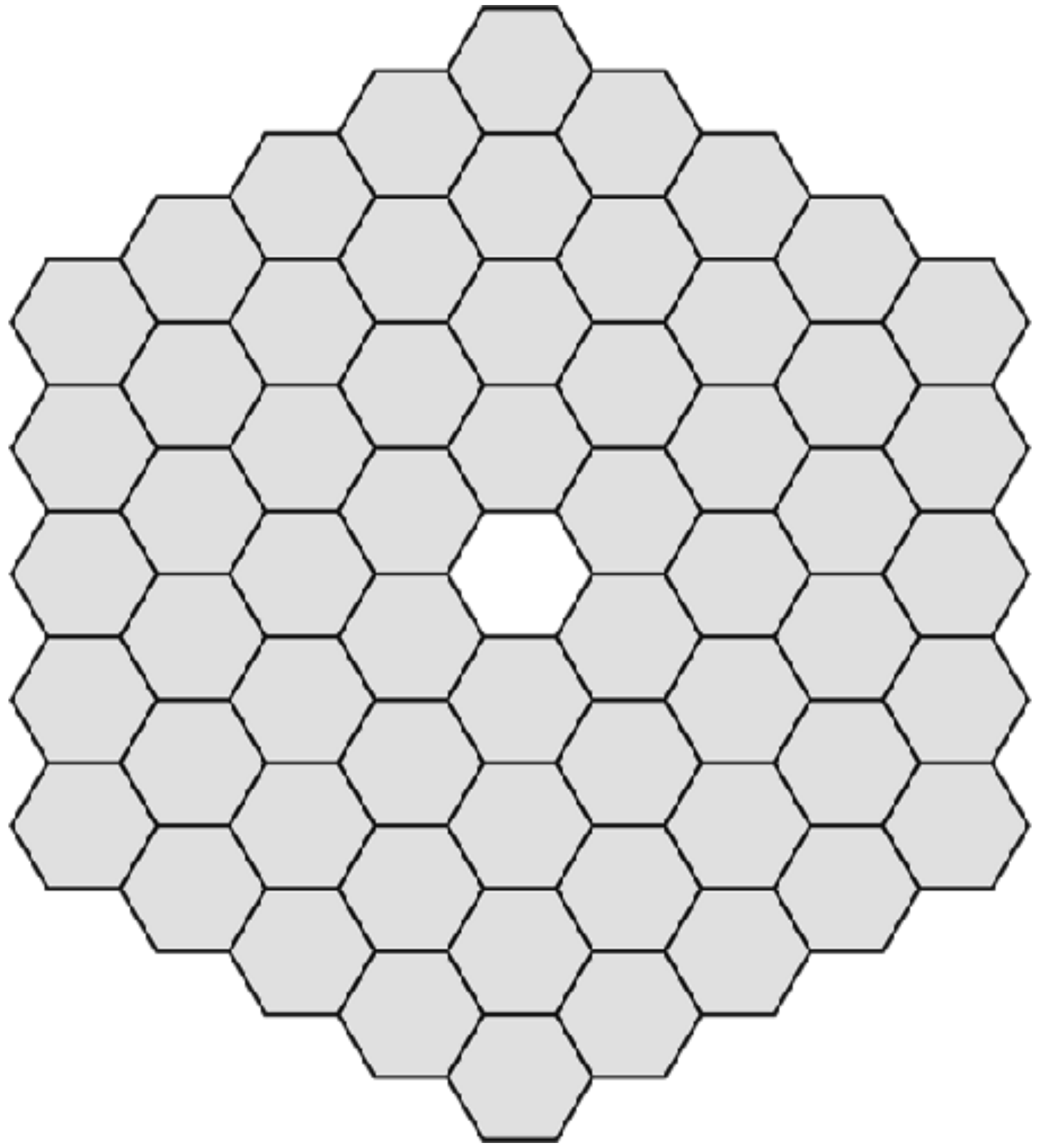
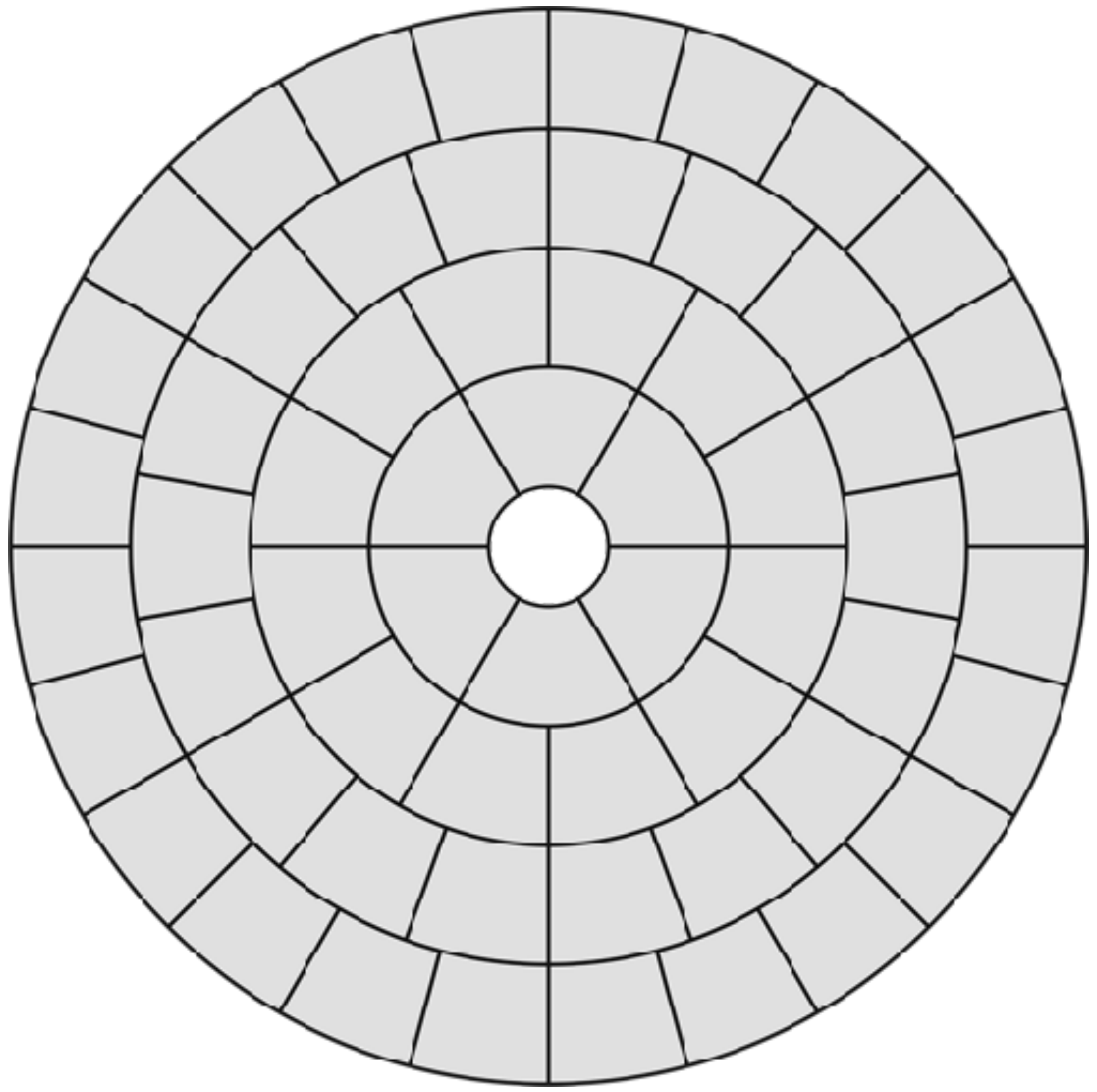
132 Edges
4 Spares required

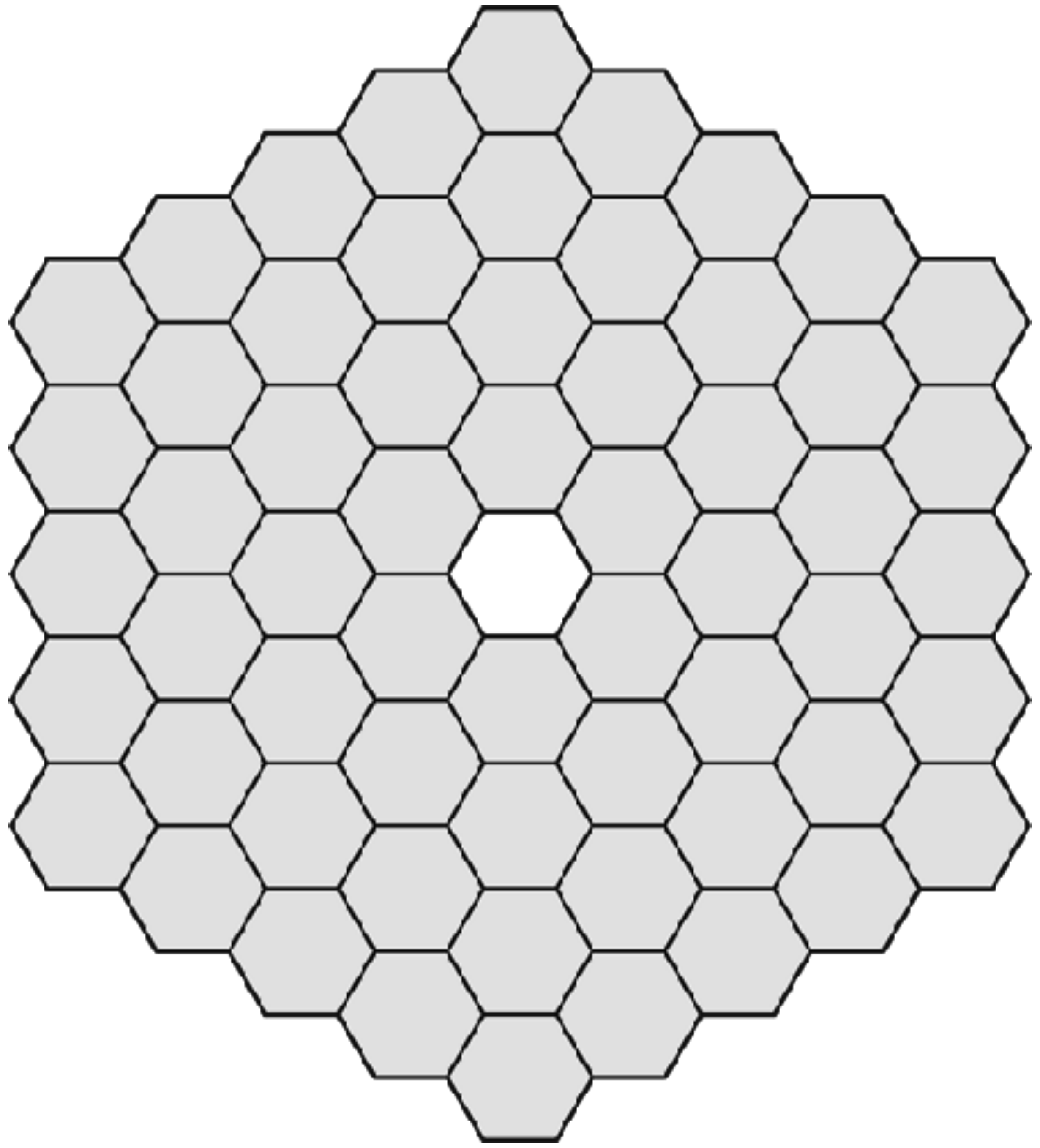


60 Segments
Diameter: 13.5 m
Area: 116.9 m^2
150 Edges
10 Spares required

Annular vs Hexagonal N=5

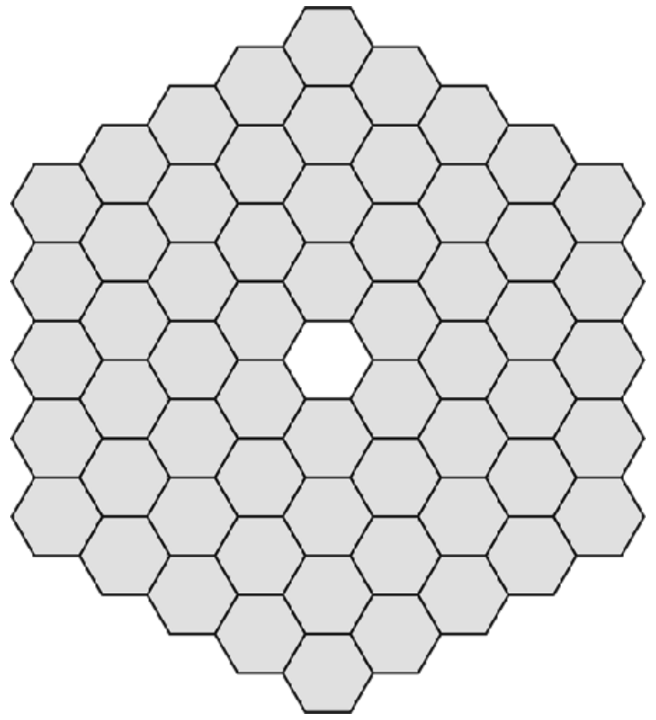


60 Segments
Diameter: 13.5 m
Area: 141.4 m²
132 Edges
4 Spares required

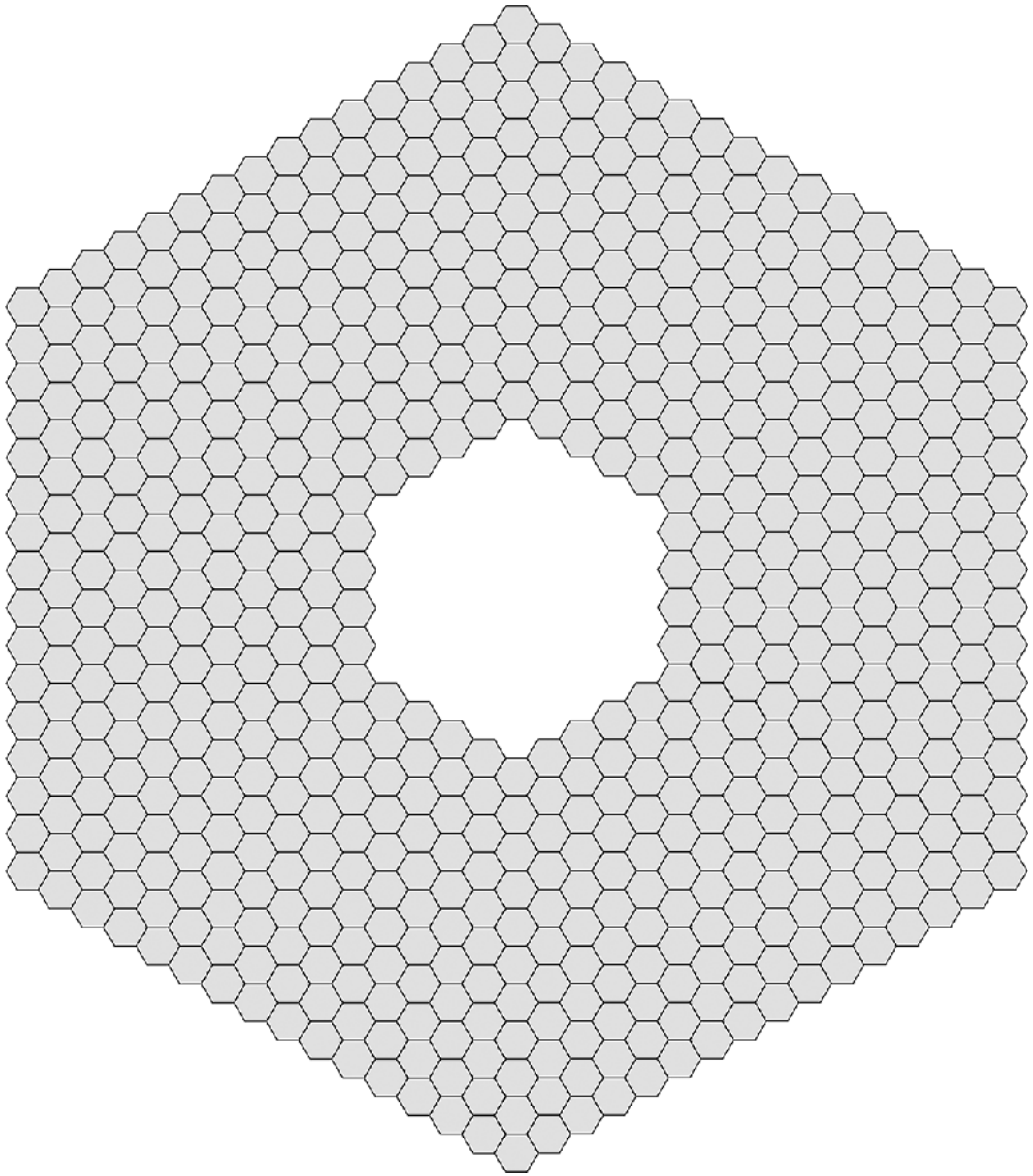


60 Segments
Diameter: 13.5 m
Area: 116.9 m²
150 Edges
10 Spares required

…and ELT…

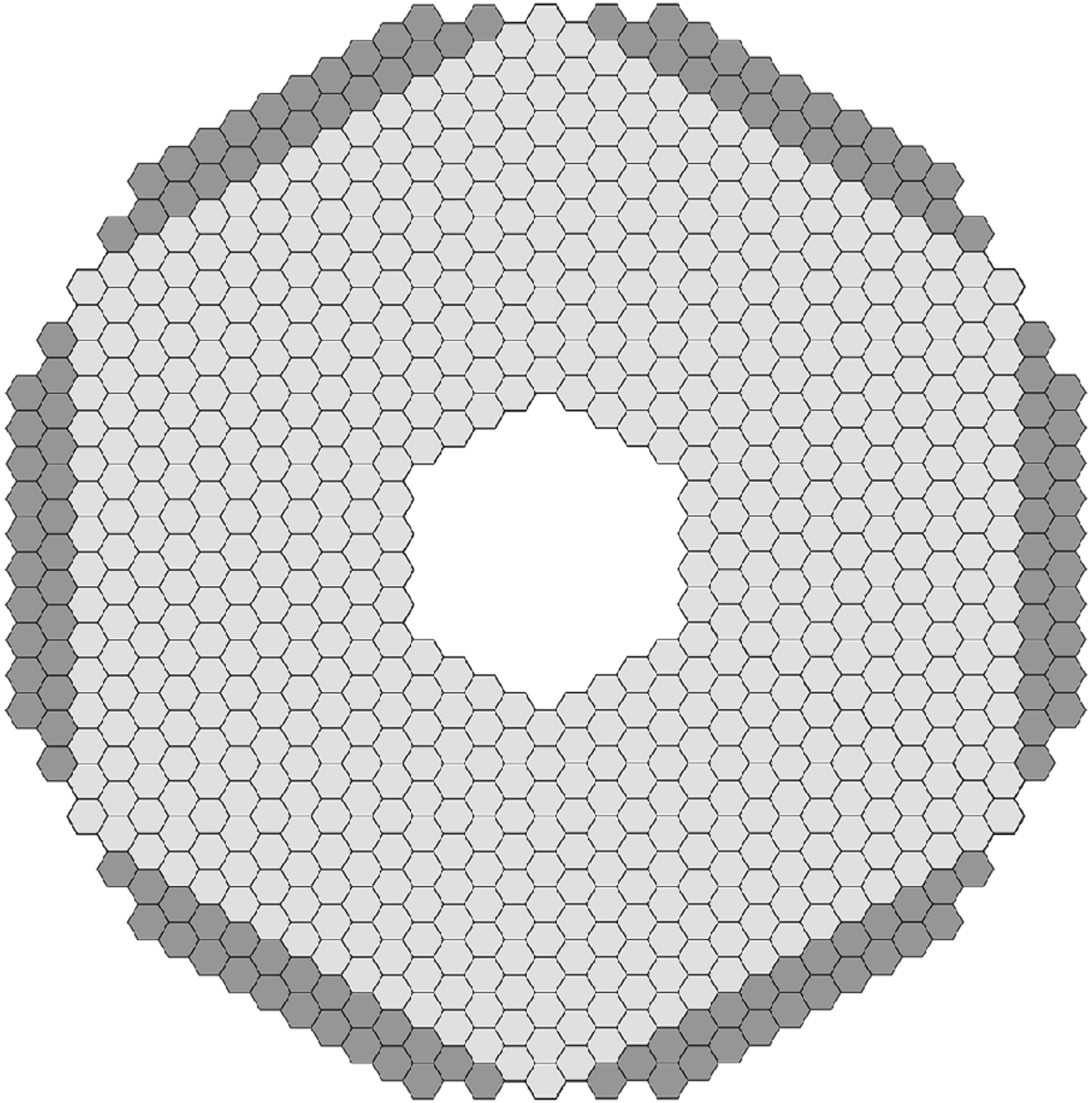


…and ELT…



N=16

…and ELT…



N=16

798 Segments
Diameter: 39.3 m
Area: 978 m^2
2304 Edges
133 Spares required

So…Annular Rings or Hexagonal?

So…Annular Rings or Hexagonal?

	Annular	Hexagonal
Packing efficiency:		
Number of spares:		
Total number of edges:		
Number of edges / segment:		
Regular neighbour geometry:		
Shape close to mother blank:		
Circular mosaic:		
Manufacturing difficulty:		
Diffraction pattern / PSF:		
Big telescope heritage:		

So…Annular Rings or Hexagonal?

	Annular	Hexagonal
Packing efficiency:	✔	✔
Number of spares:	✔	
Total number of edges:	✔	
Number of edges / segment:		✔
Regular neighbour geometry:		✔
Shape close to mother blank:		✔
Circular mosaic:	✔	
Manufacturing difficulty:		✔
Diffraction pattern / PSF:	✔	
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	Annular	Hexagonal
Packing efficiency:	✔	✔
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Shape close to mother blank:		✔
Circular mosaic:	✔	
Manufacturing difficulty:		✔
Diffraction pattern / PSF:	✔	
Big telescope heritage:		✔

Edges and Segment Control

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More edges: more sensors, but greater “stiffness” and robustness to failure

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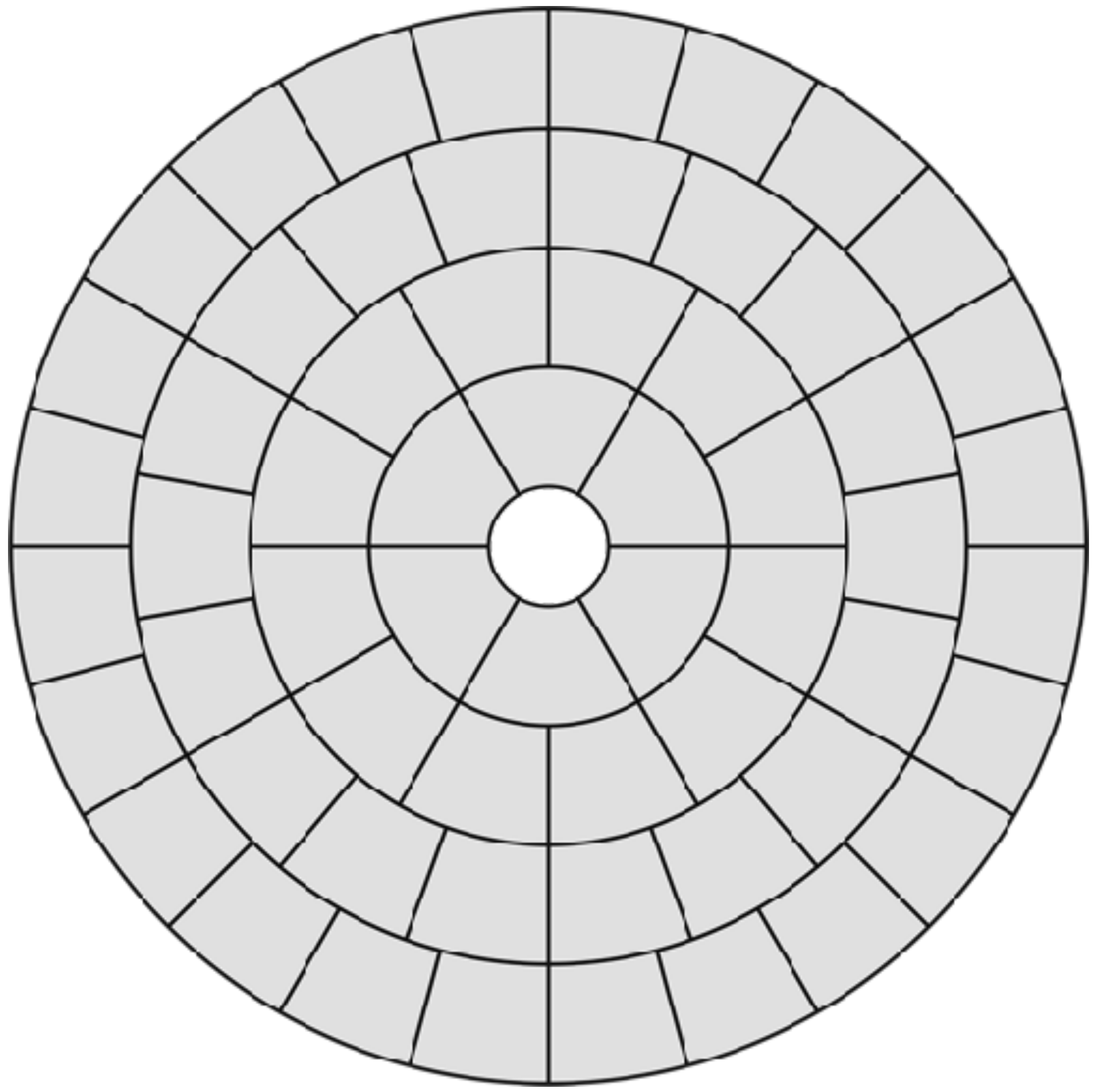
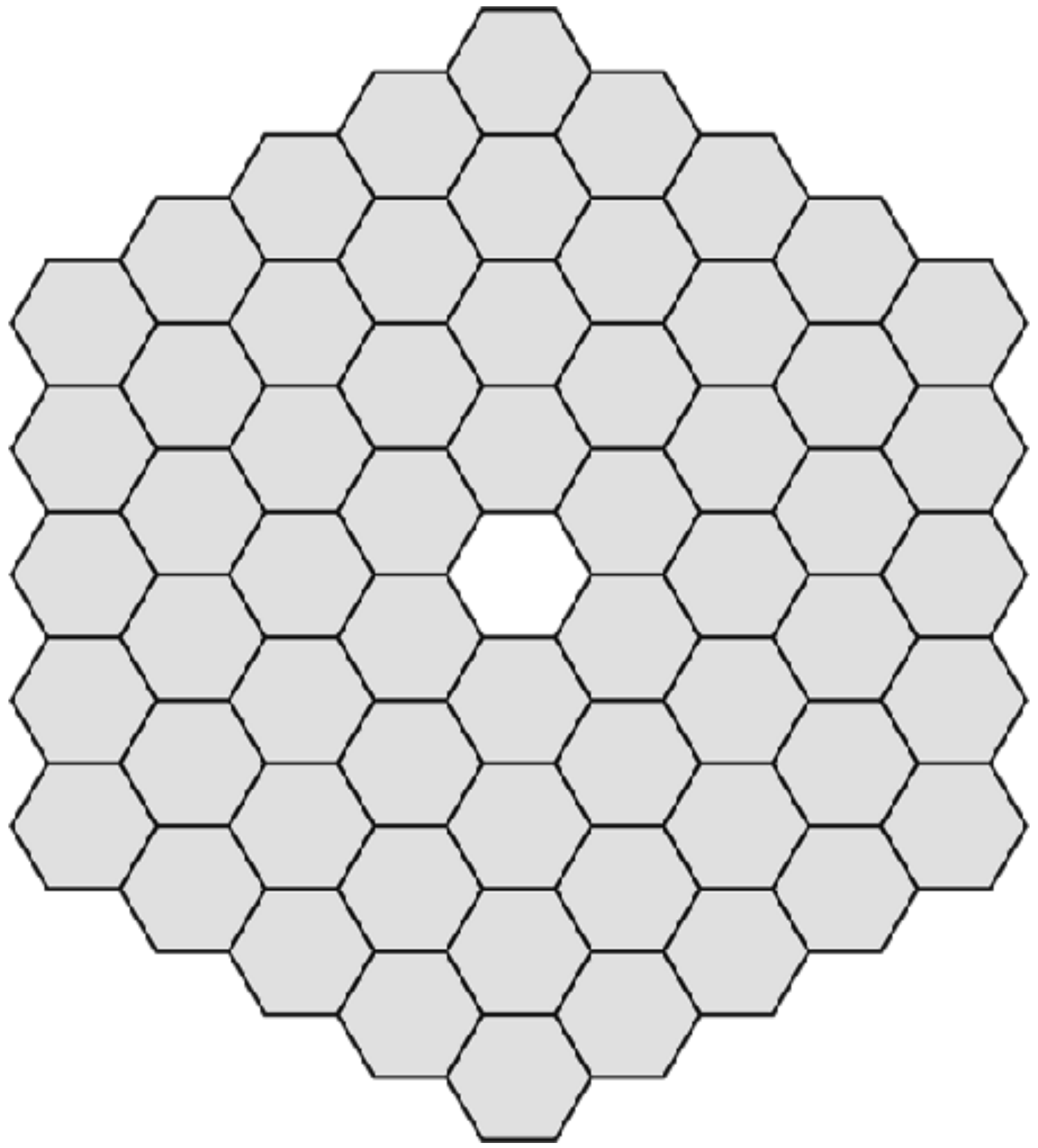
Neighbour geometry:





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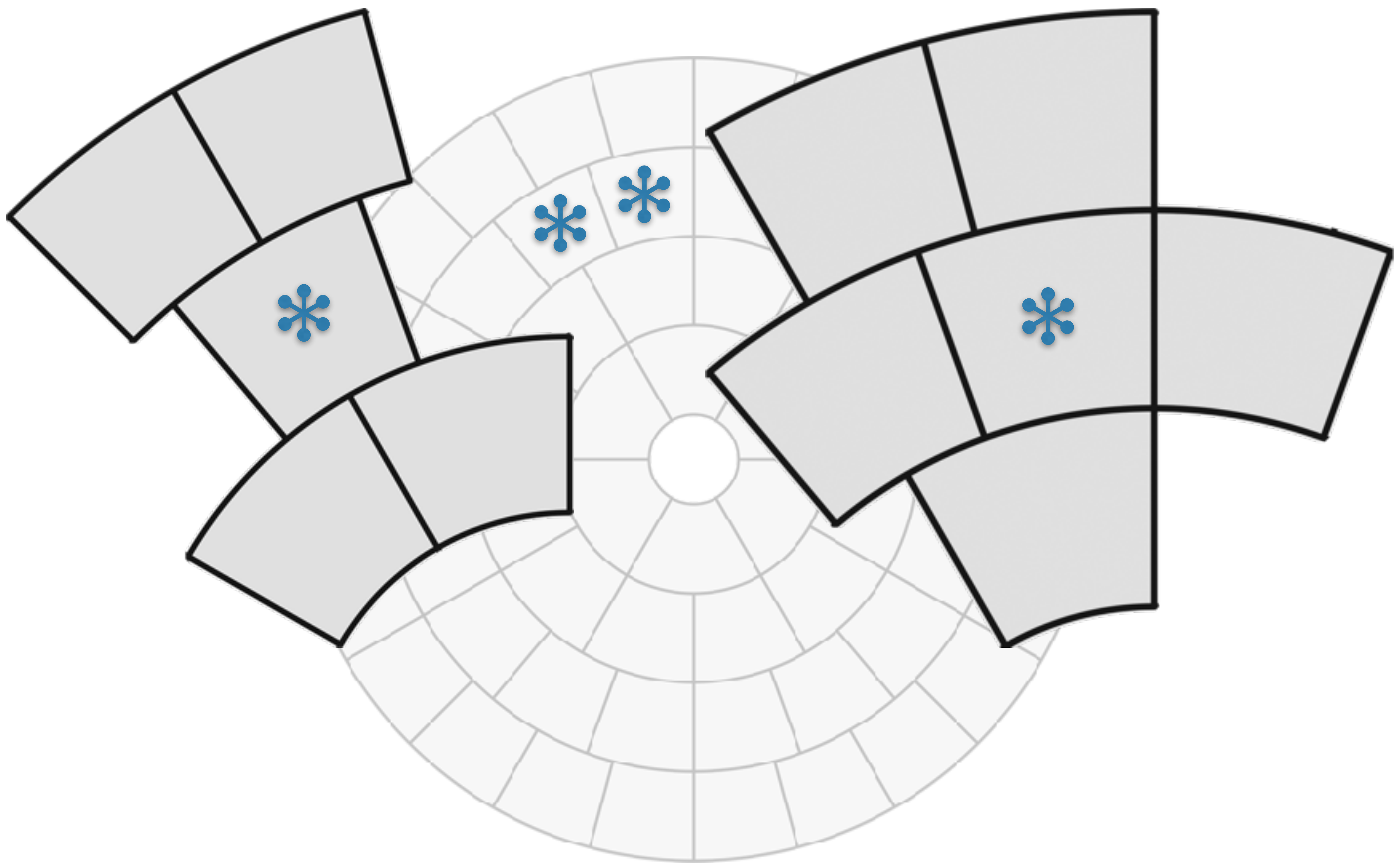

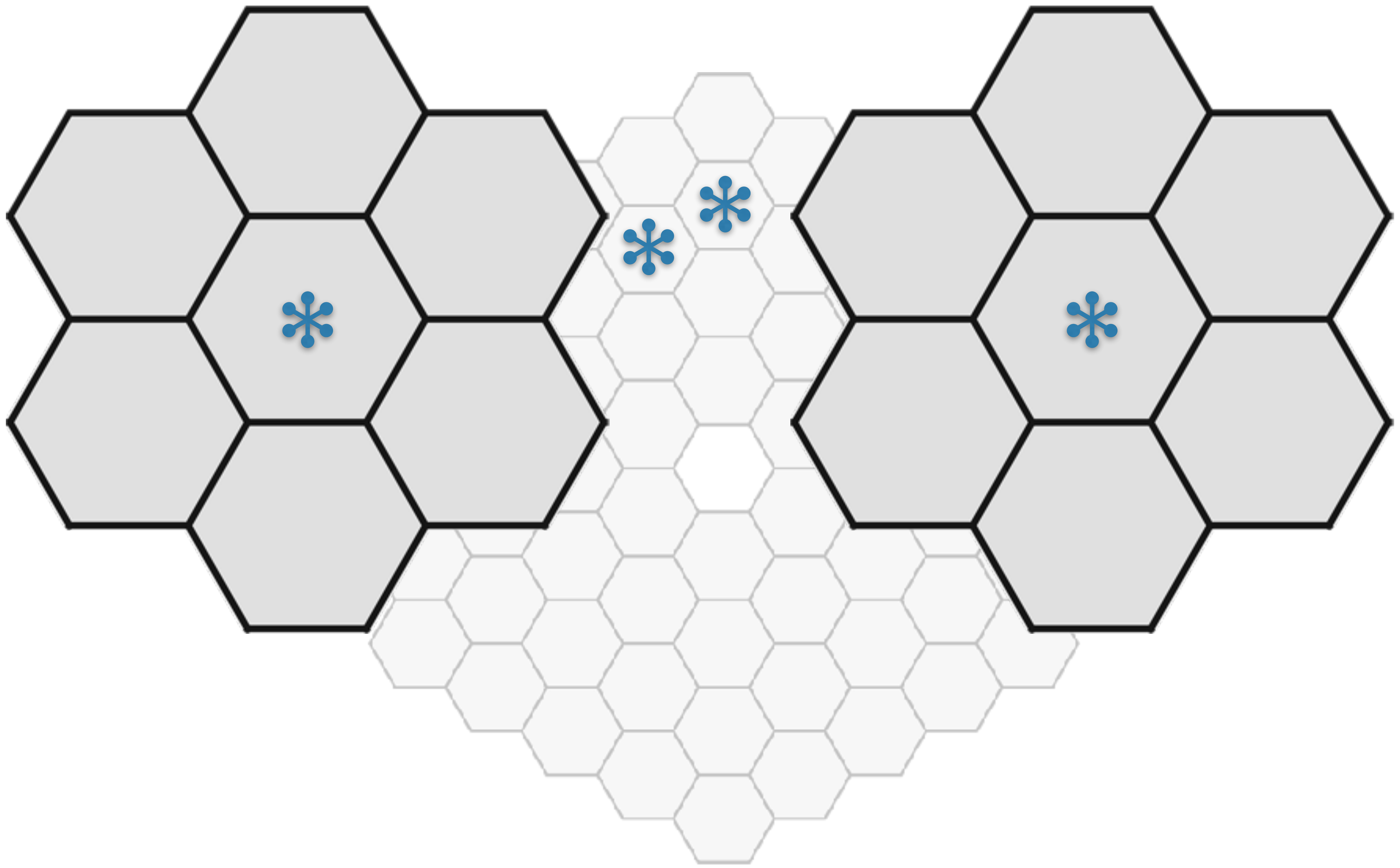

So…Annular Rings or Hexagonal?

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Packing efficiency:	✔	✔
Number of spares:	✔	
Total number of edges:	✔	
Number of edges / segment:		✔
Regular neighbour geometry:		✔
Shape close to mother blank:		✔
Circular mosaic:	✔	
Manufacturing difficulty:		✔
Diffraction pattern / PSF:	✔	
Big telescope heritage:		✔

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Packing efficiency:	✔	✔
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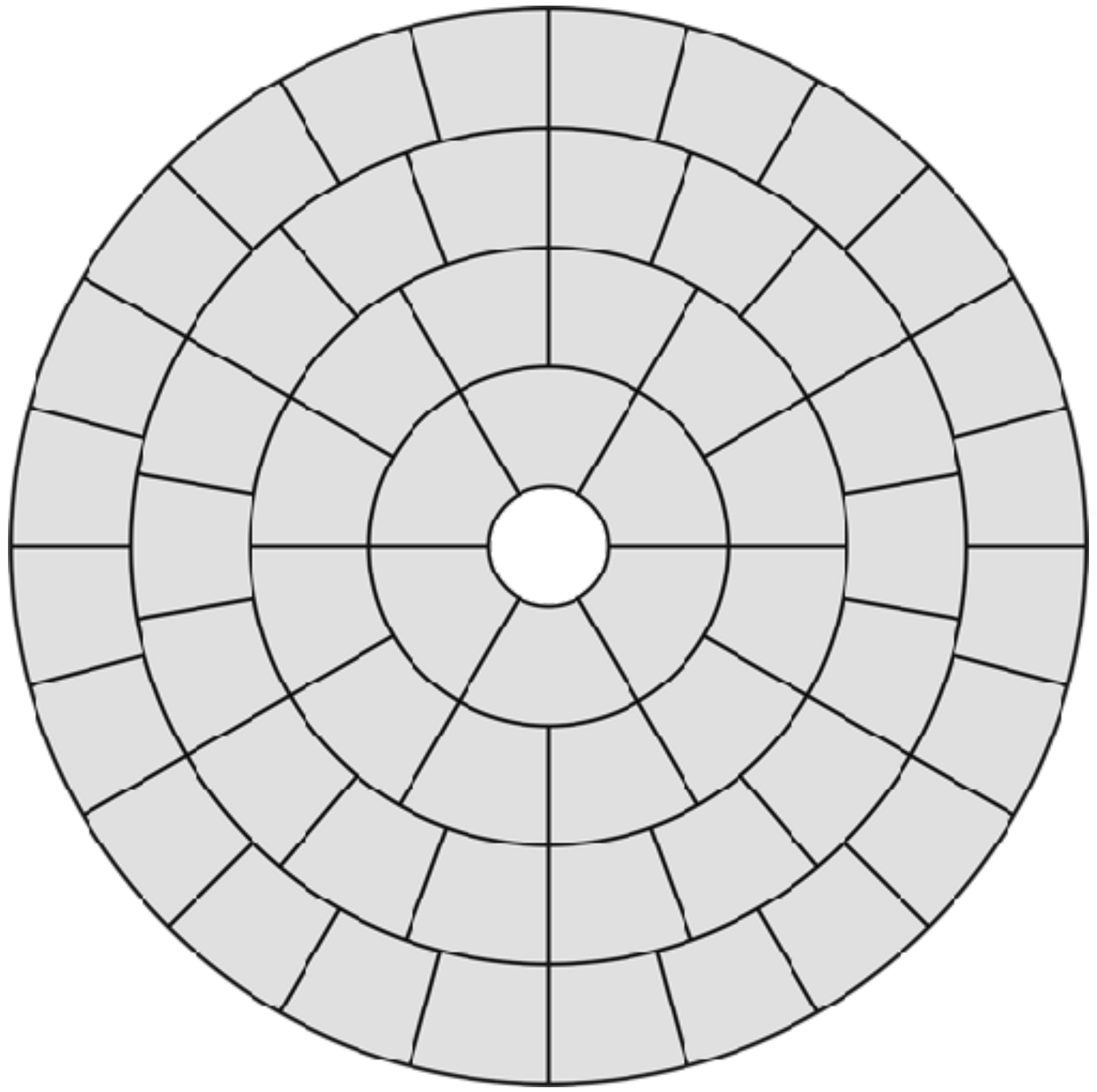
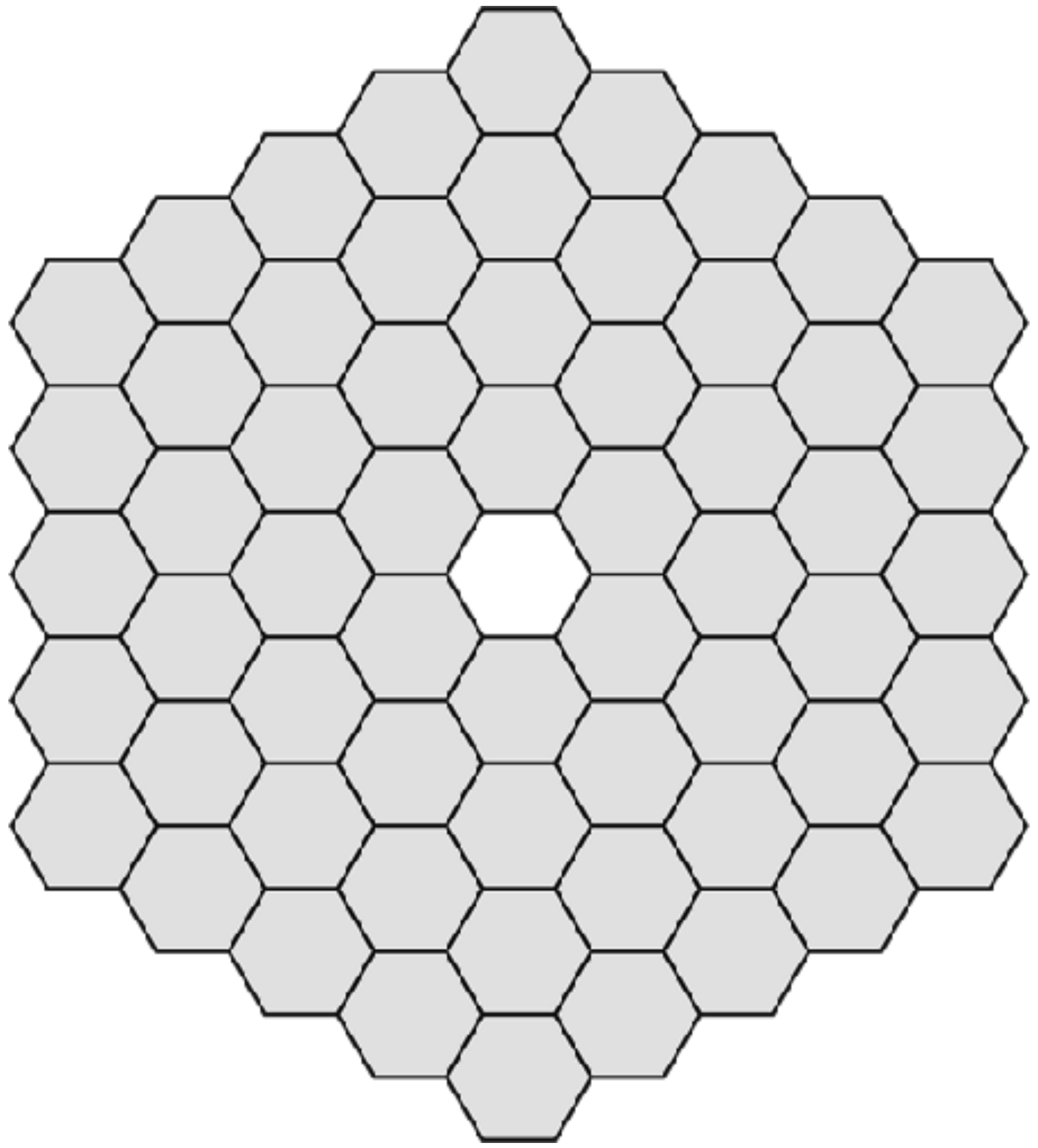
Edges and Diffraction…

Edges and Diffraction…

More (aligned) edges: more “spikes”





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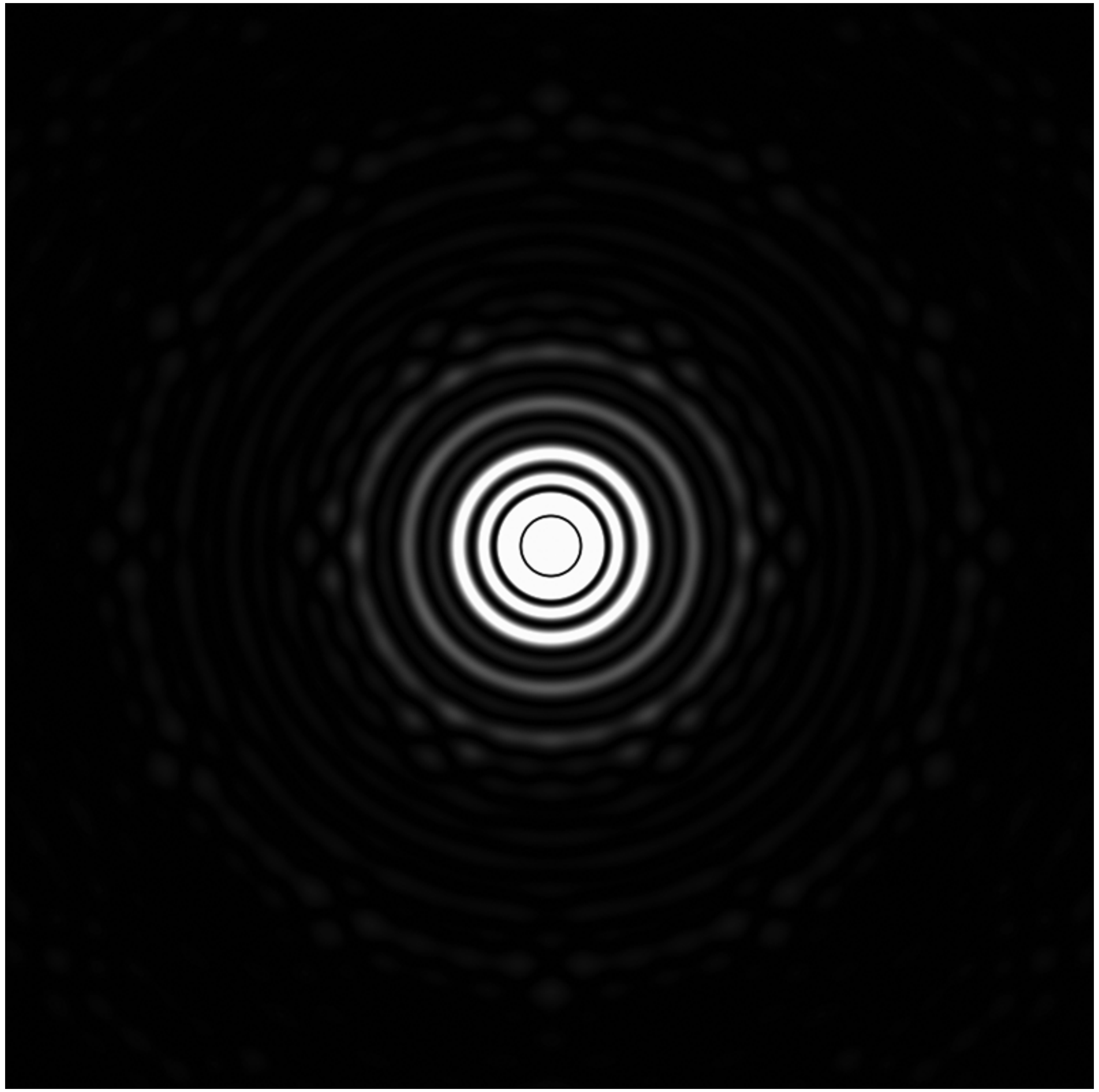

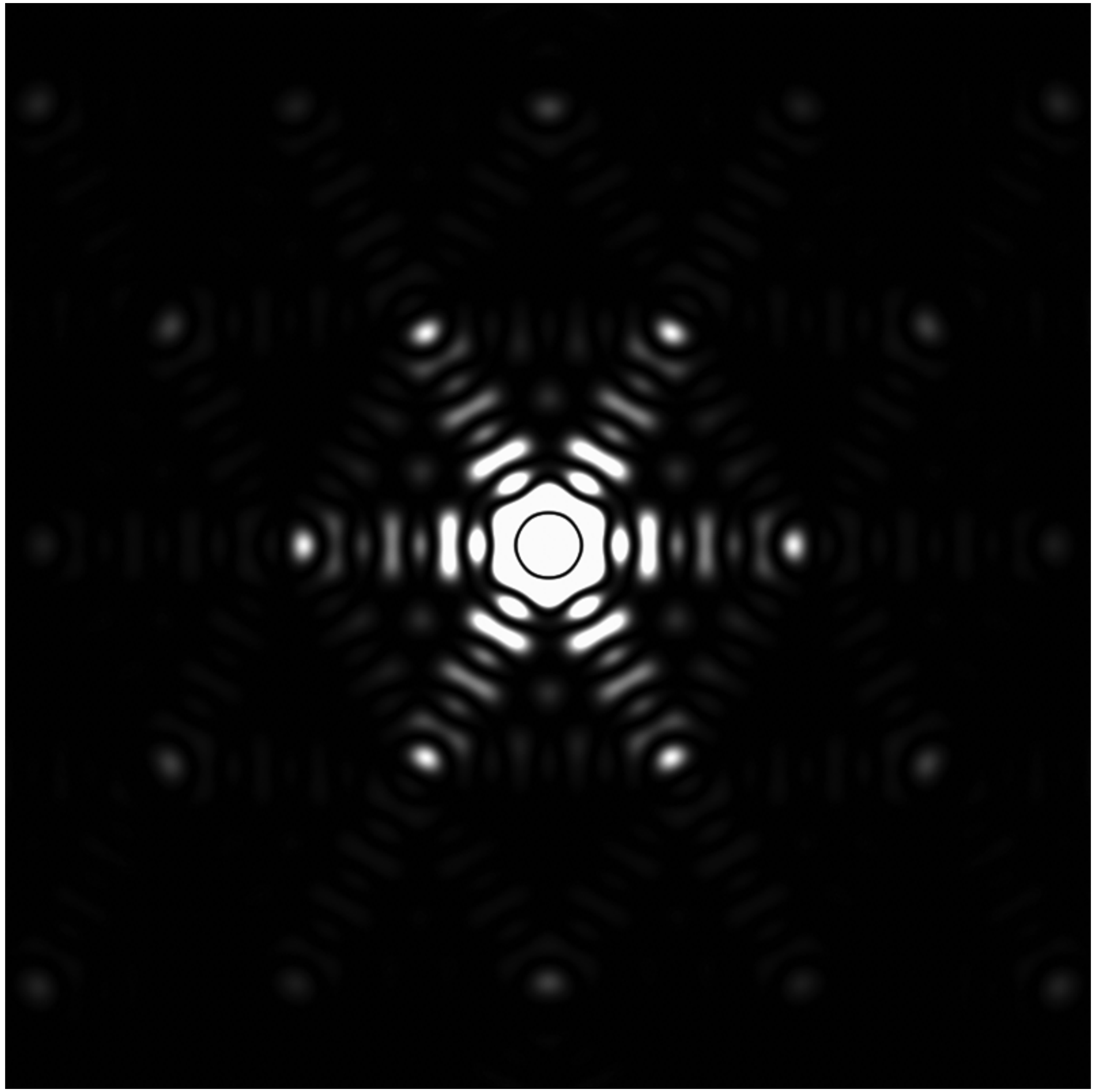

So…Annular Rings or Hexagonal?

	Annular	Hexagonal
Packing efficiency:	✔	✔
Number of spares:	✔	
Total number of edges:	✔	
Number of edges / segment:		✔
Regular neighbour geometry:		✔
Shape close to mother blank:		✔
Circular mosaic:	✔	
Manufacturing difficulty:		✔
Diffraction pattern / PSF:	✔	
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Shape close to mother blank:		✔
Circular mosaic:	✔	
Manufacturing difficulty:		✔
Diffraction pattern / PSF:	✔	
Big telescope heritage:		✔

Consensus…(?)

- Big: hexagonal
- Small: annular

There's More to Shape than Outline…

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"The primary mirror of every modern two-mirror telescope is either hyperbolic or parabolic…"

There’s More to Shape than Outline…

“The primary mirror of every modern two-mirror monolithic telescope is either hyperbolic or parabolic…”

There’s More to Shape than Outline…

“The primary mirror of every modern two-mirror monolithic telescope is either hyperbolic or parabolic…”

But…

Aspheric segments are:

- difficult to fabricate
- difficult to test
- difficult to align
- (many) more spares

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"The primary mirror of every modern two-mirror monolithic telescope is either hyperbolic or parabolic…"

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On the other hand… Aspheric segments:

- give excellent image quality
- simplify downstream optics
- are a proven technology

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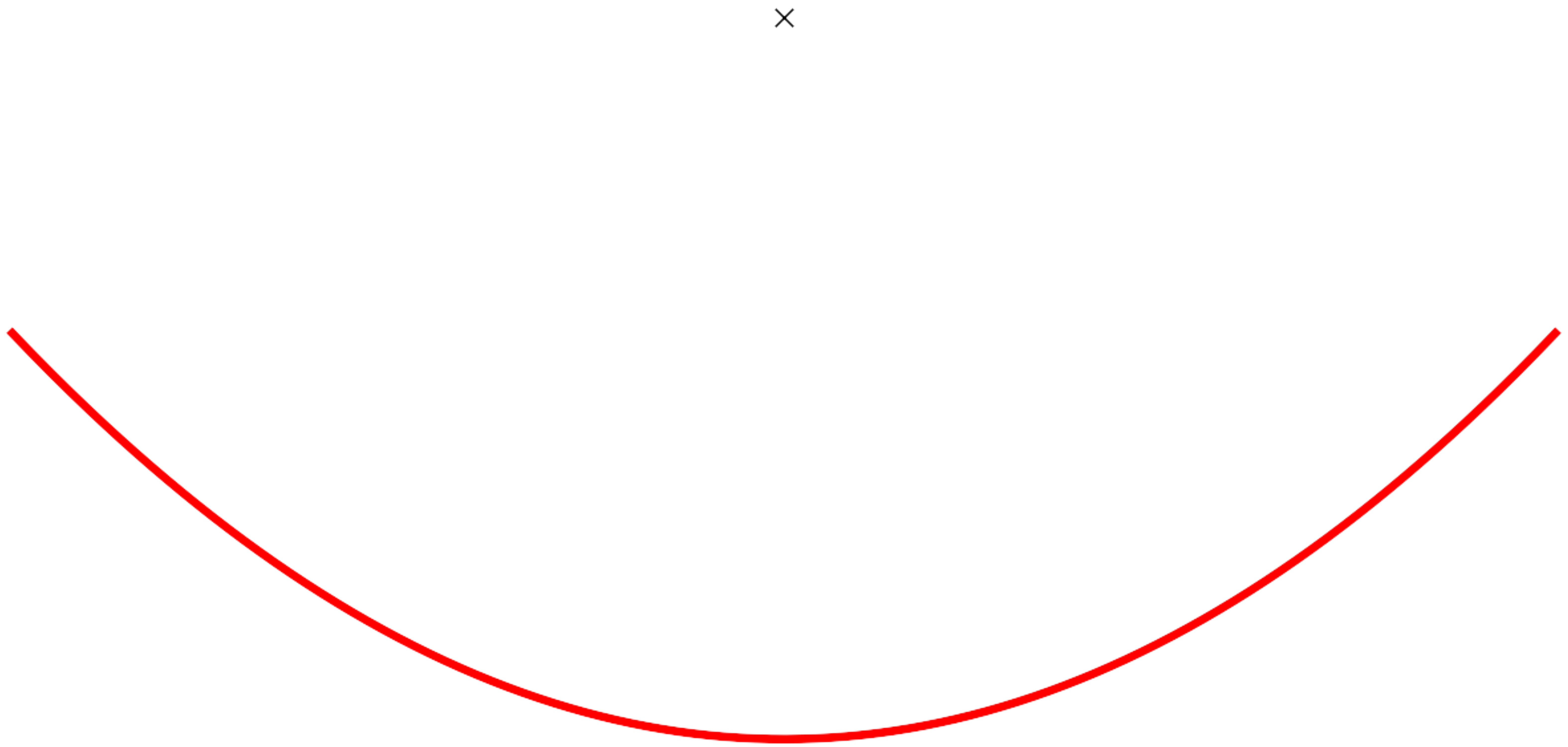
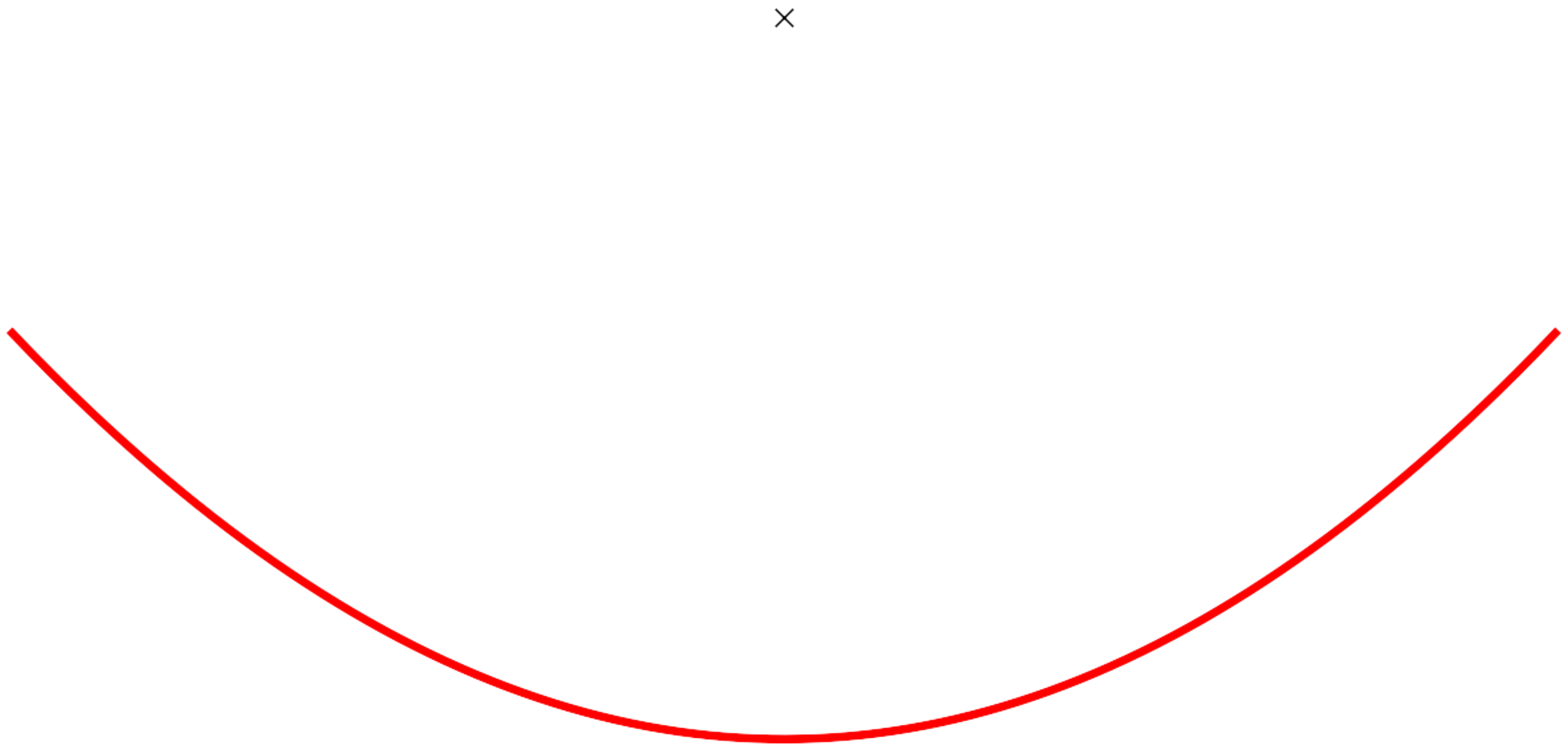
A Seidel Sidebar (and some history)



A Seidel Sidebar (and some history)

Parabola



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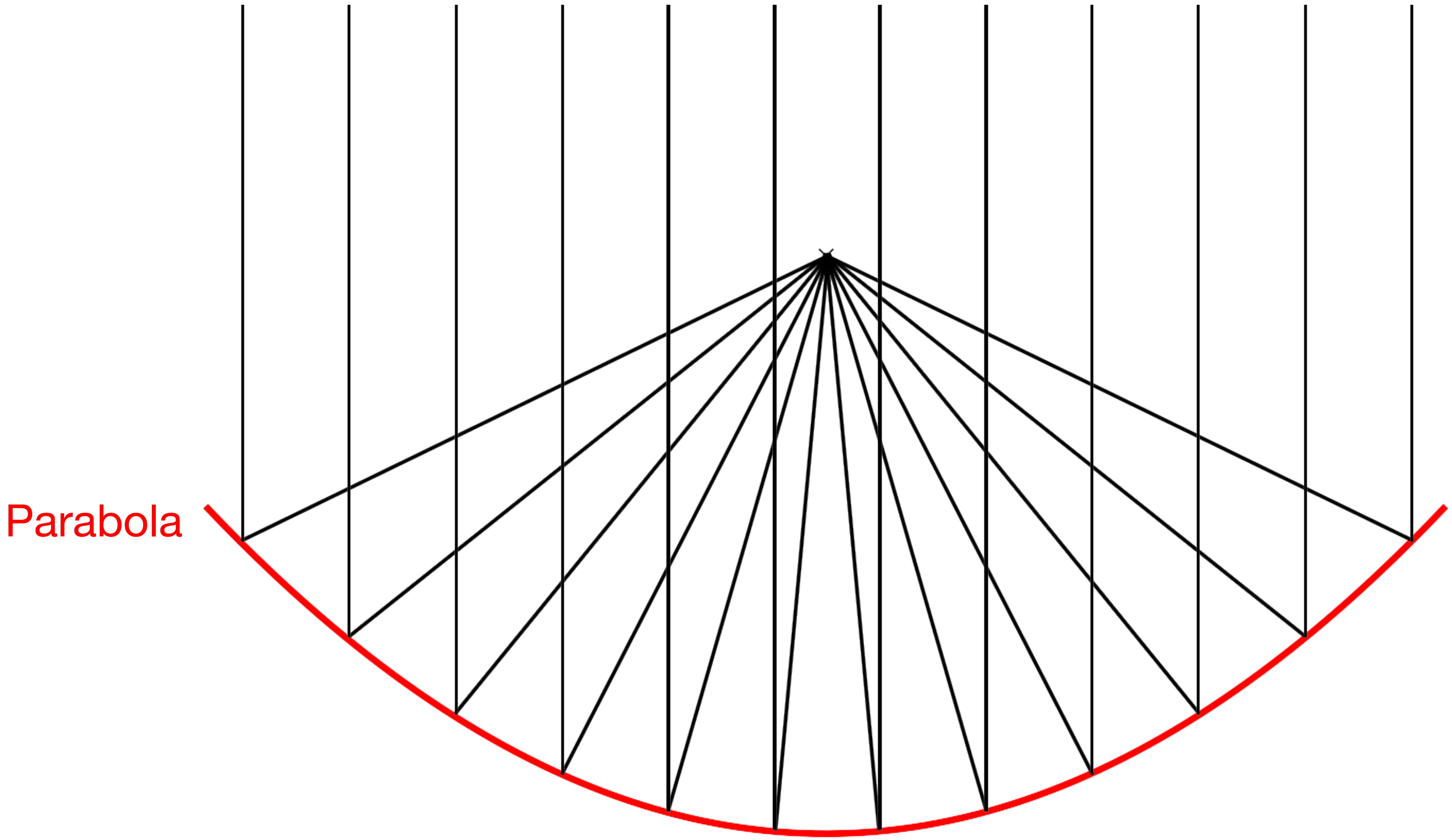
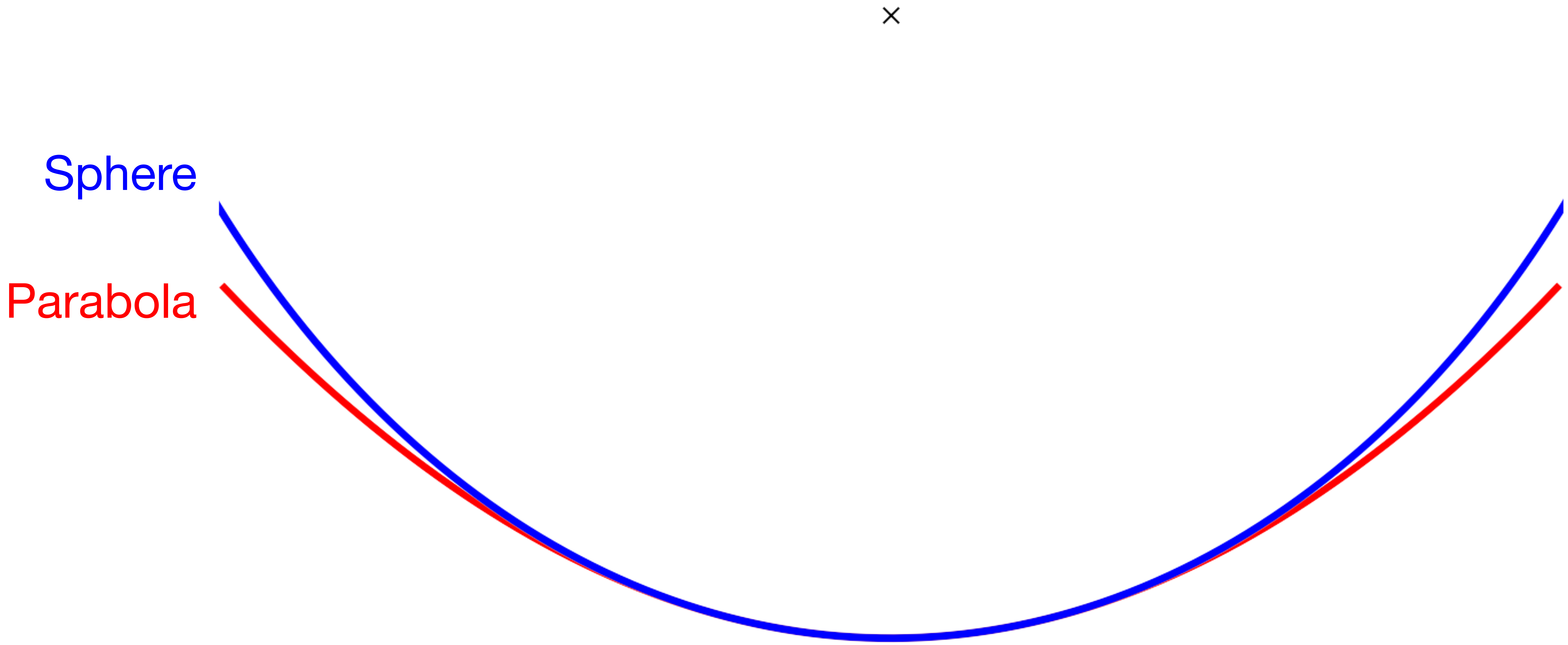


A Seidel Sidebar (and some history)



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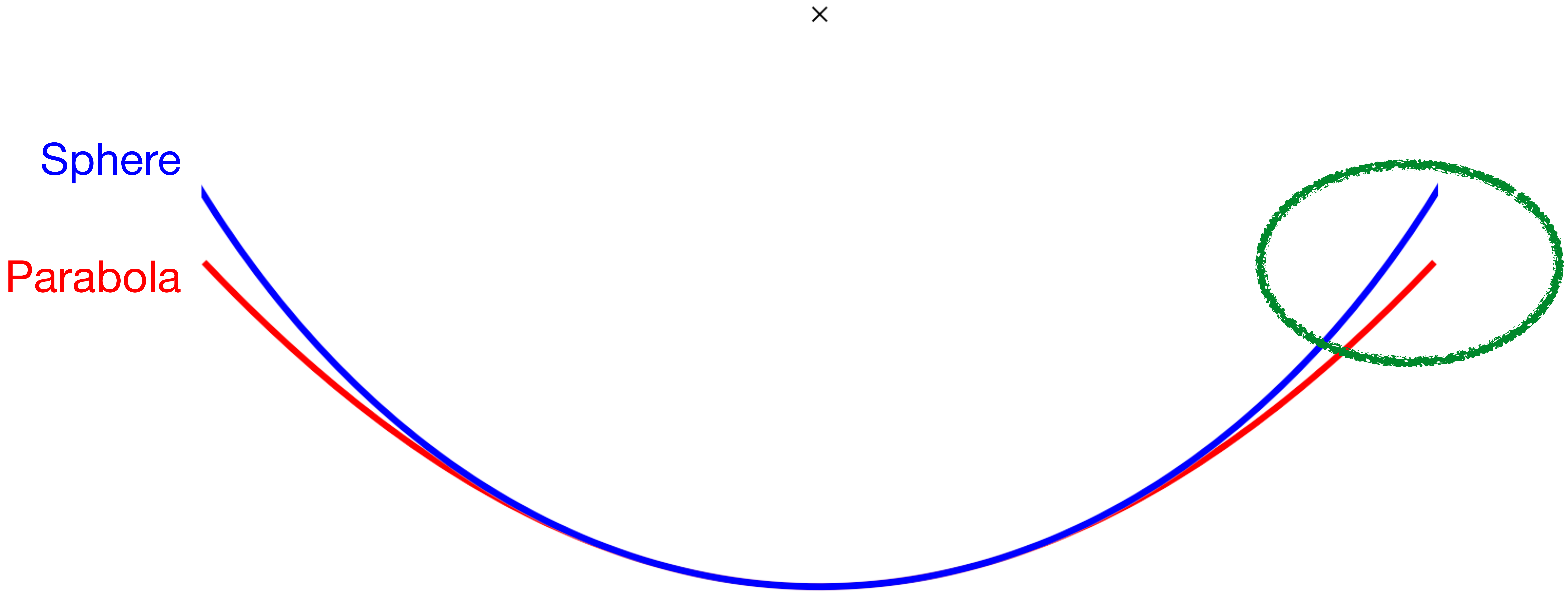

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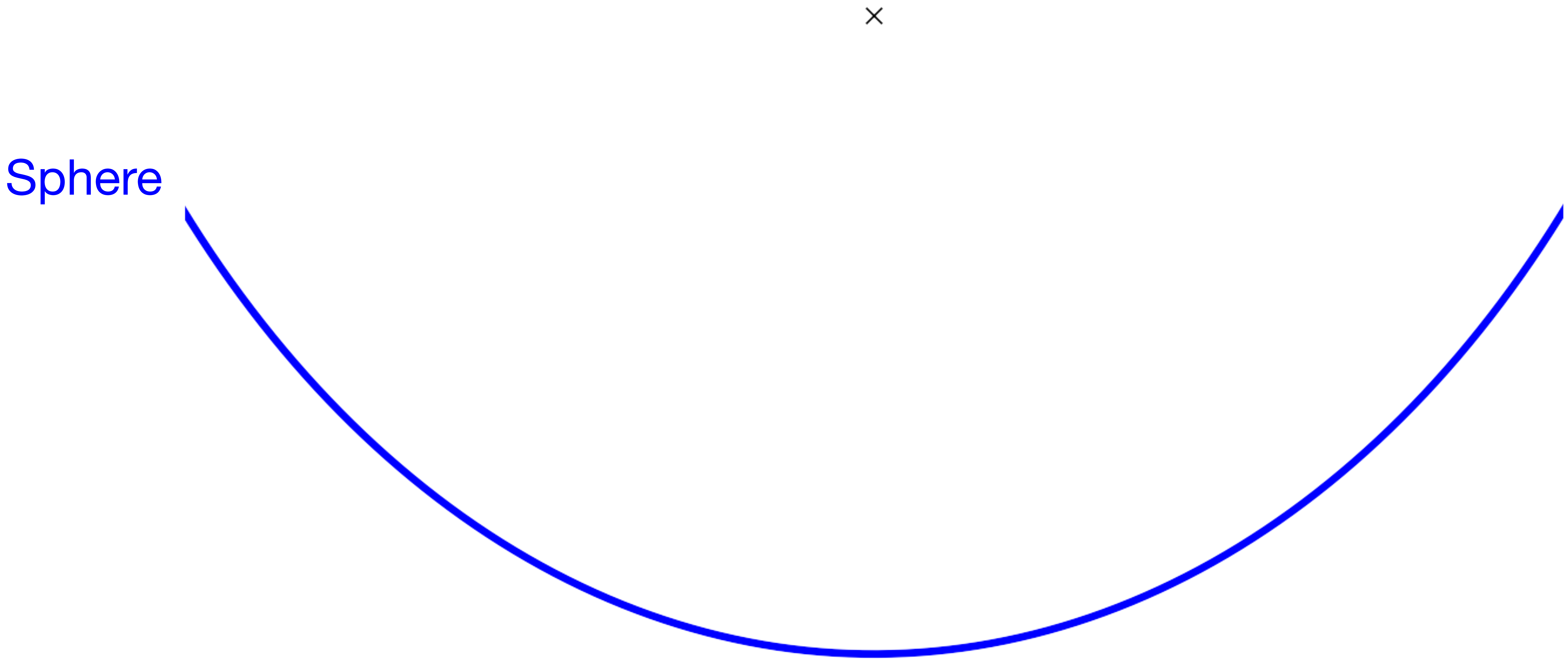
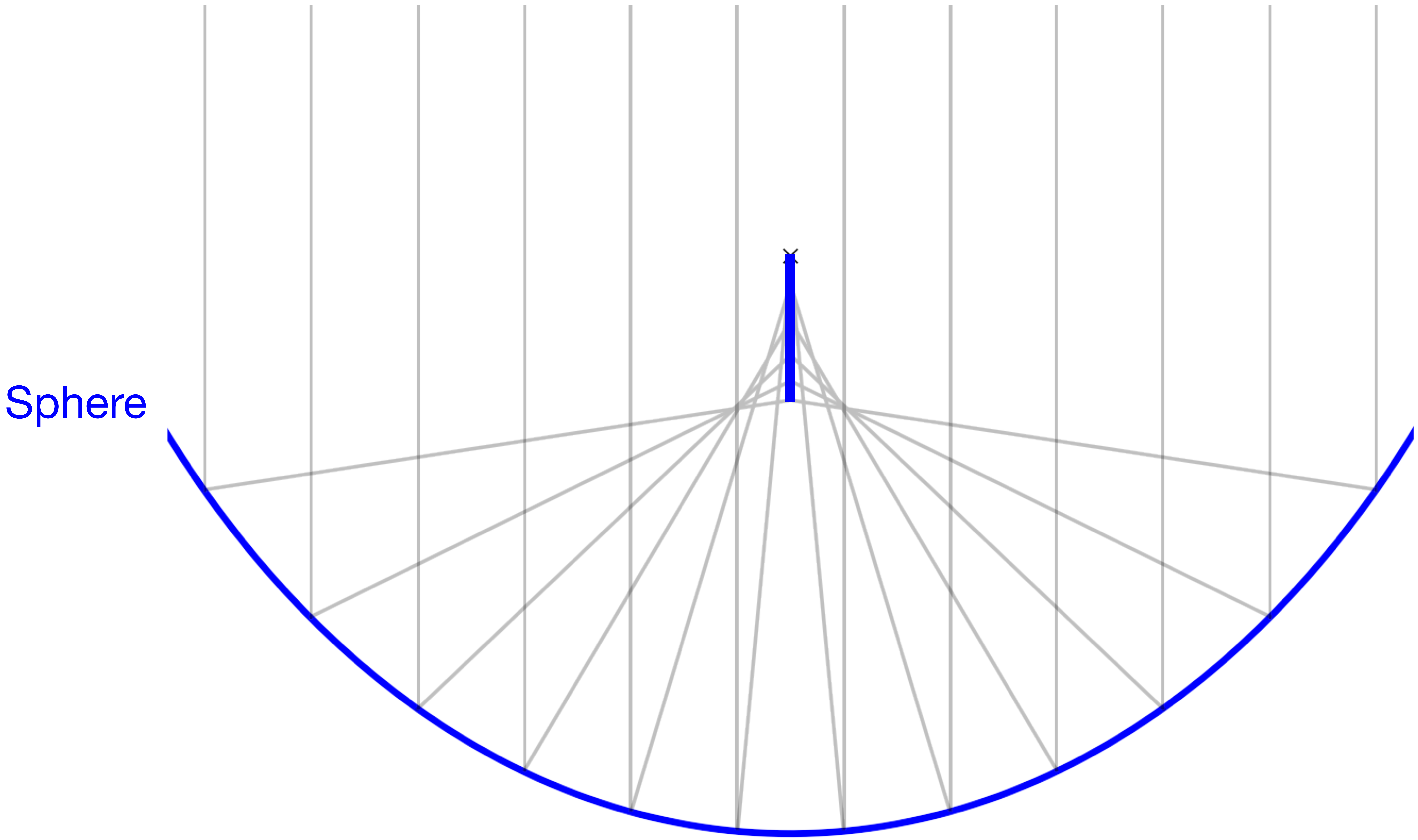


A Seidel Sidebar (and some history)

Spherical Aberration (edge of mirror has shorter focal length)



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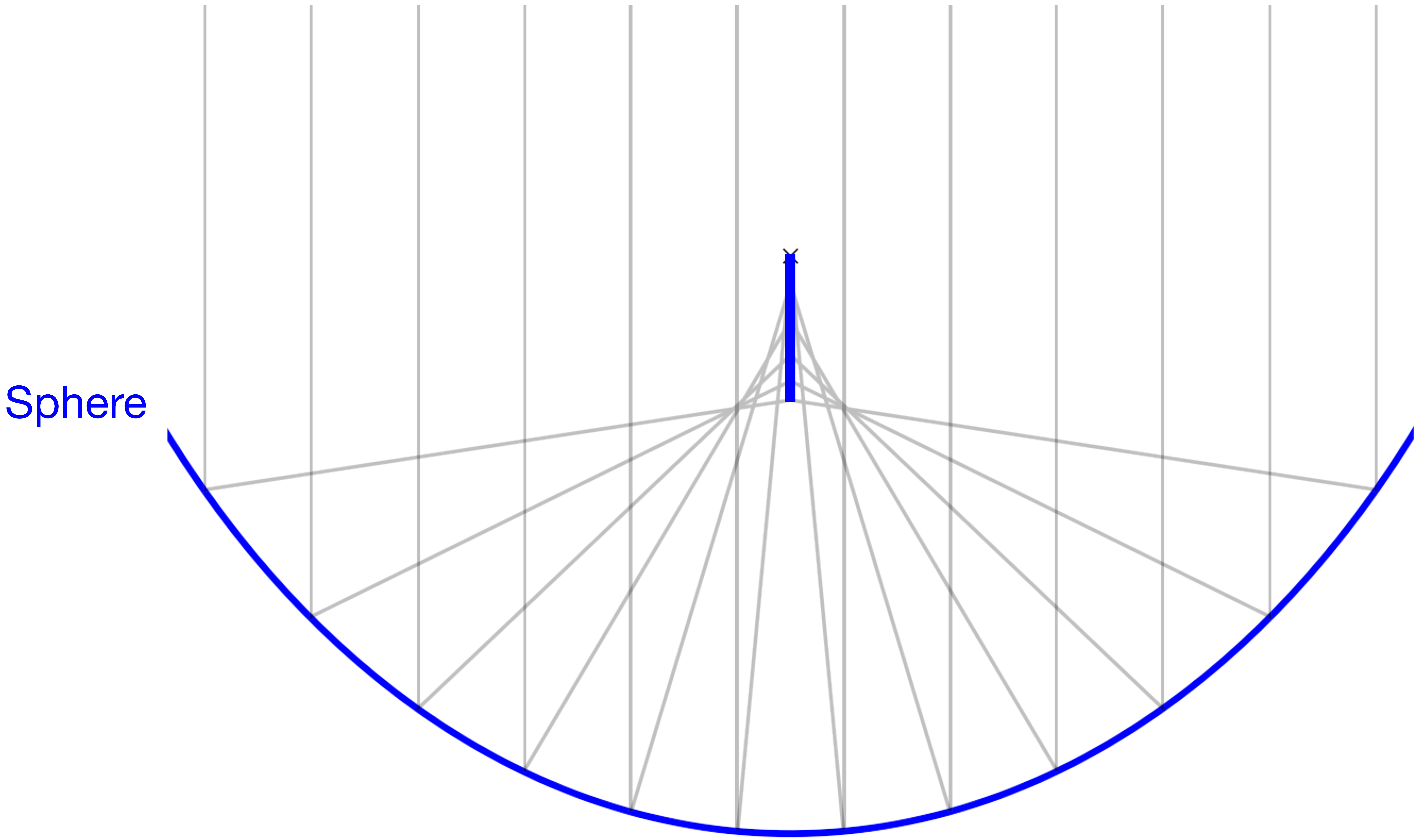

What to do?

Correcting Spherical Aberration…

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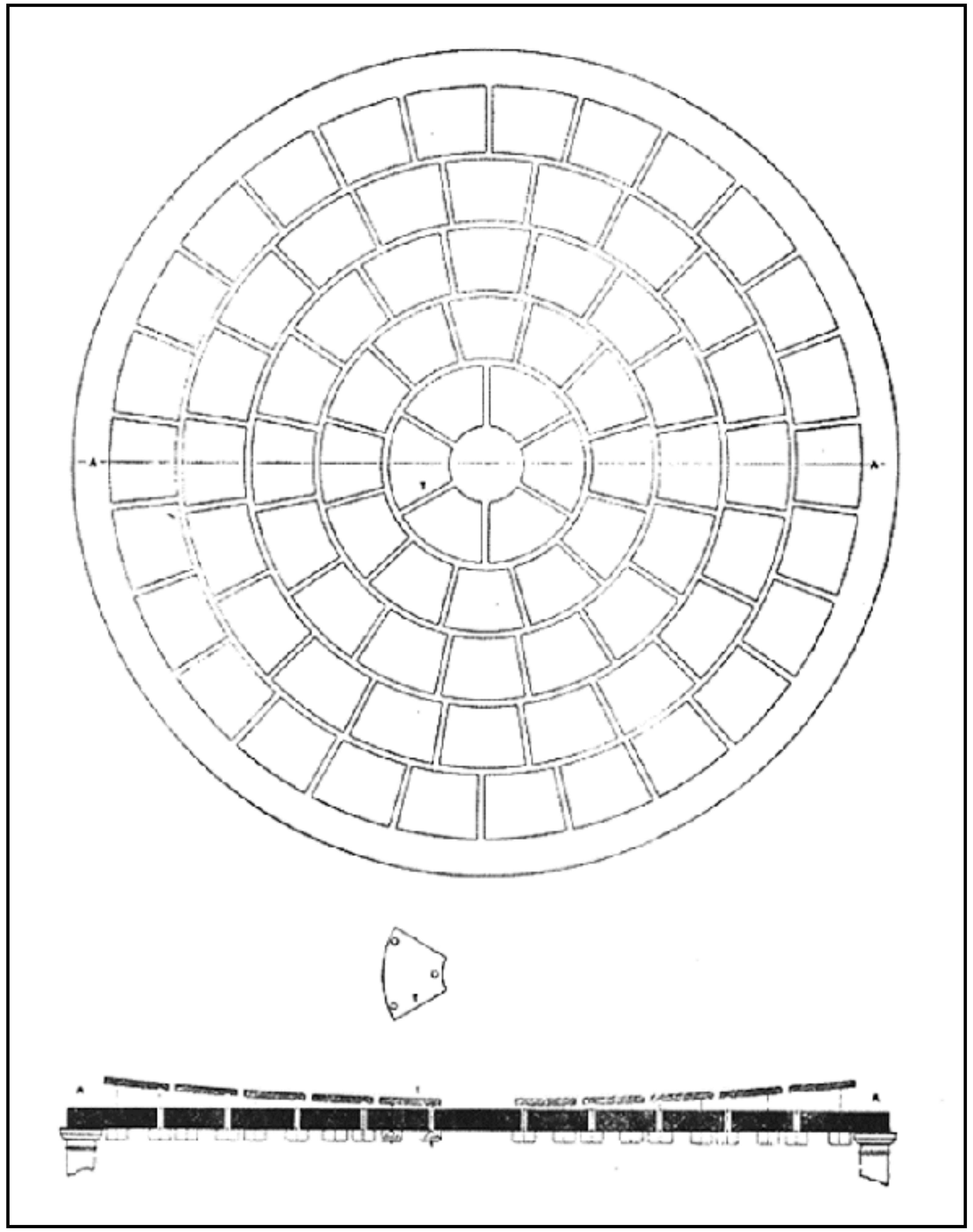
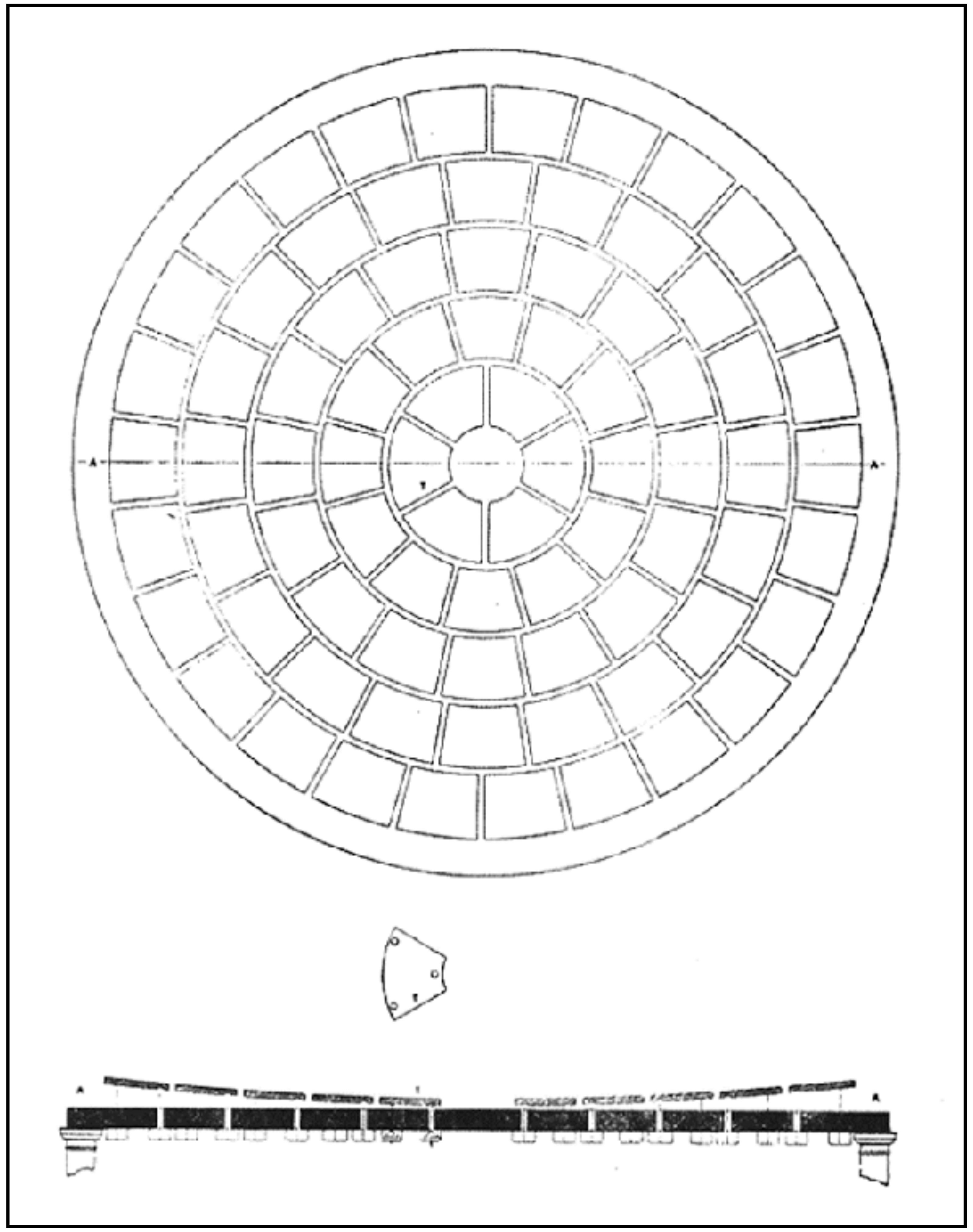
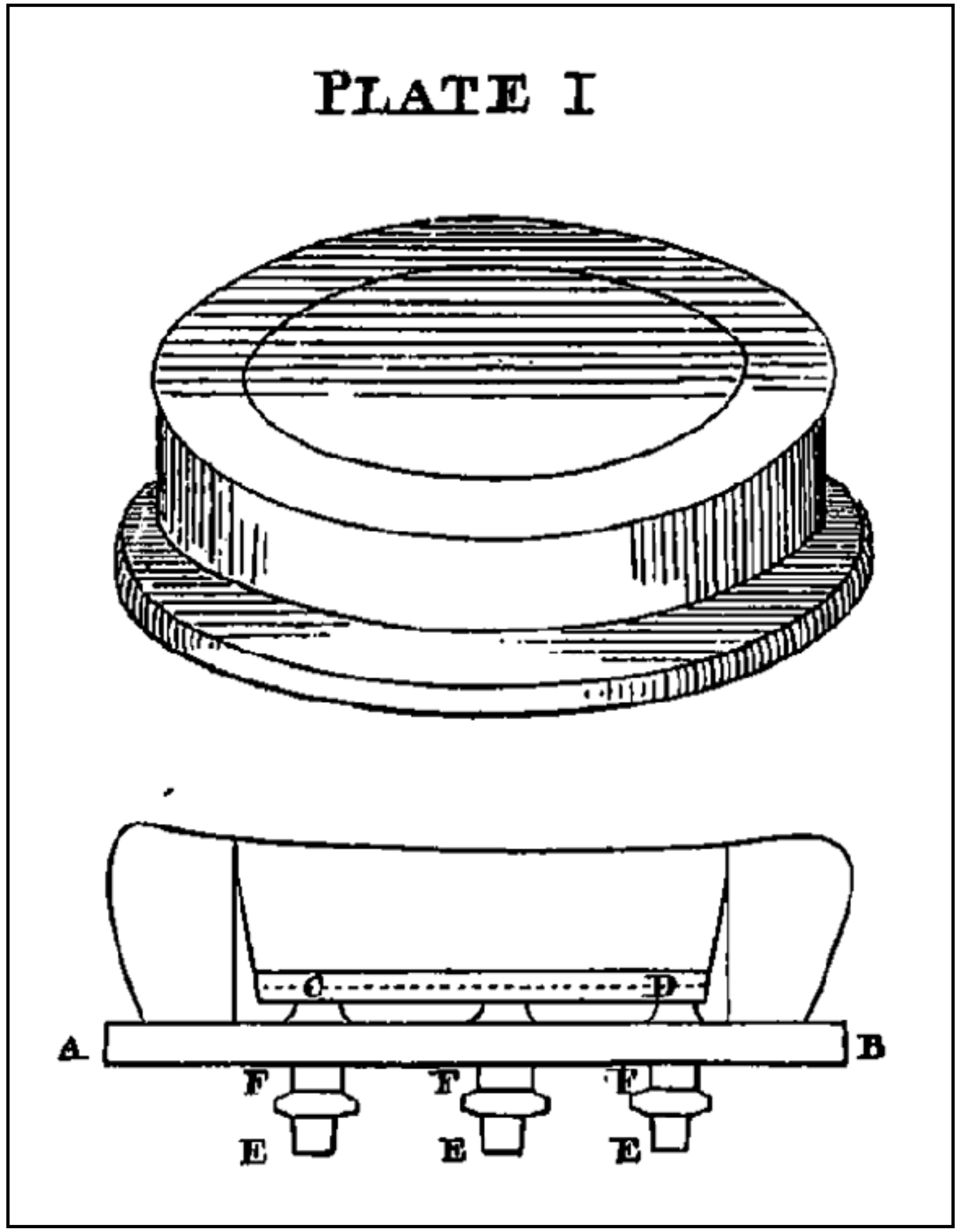


Correcting Spherical Aberration…





There's More to Shape than Outline…

"The primary mirror of every modern two-mirror monolithic telescope is either hyperbolic or parabolic…"

But… Aspheric segments are:

- difficult to fabricate
- difficult to test
- difficult to align
- less interchangeable

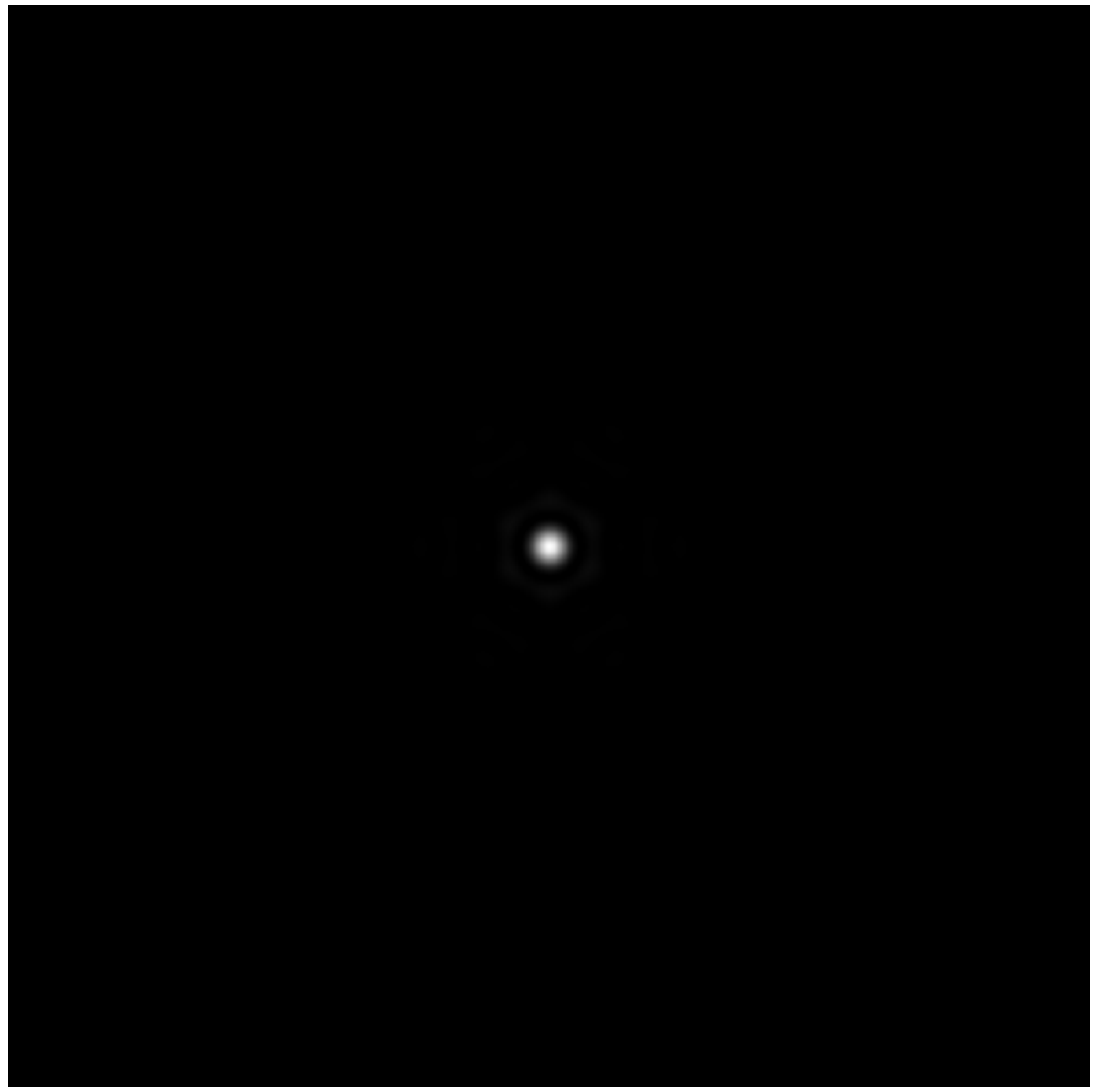
On the other hand… Aspheric segments:

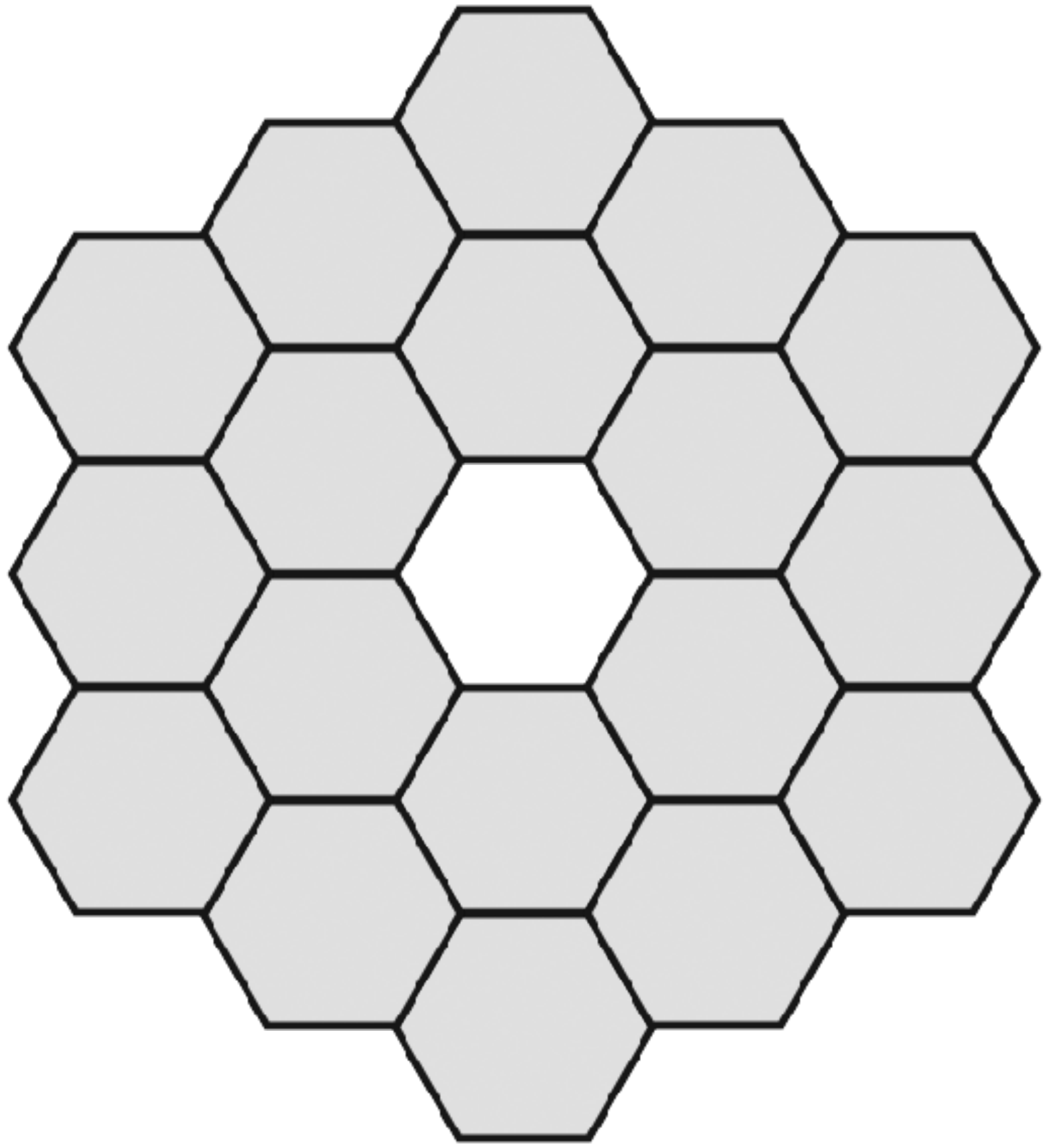
- give excellent image quality
- simplify downstream optics
- are a proven technology

Phasing…

Phasing…

Co-Phased





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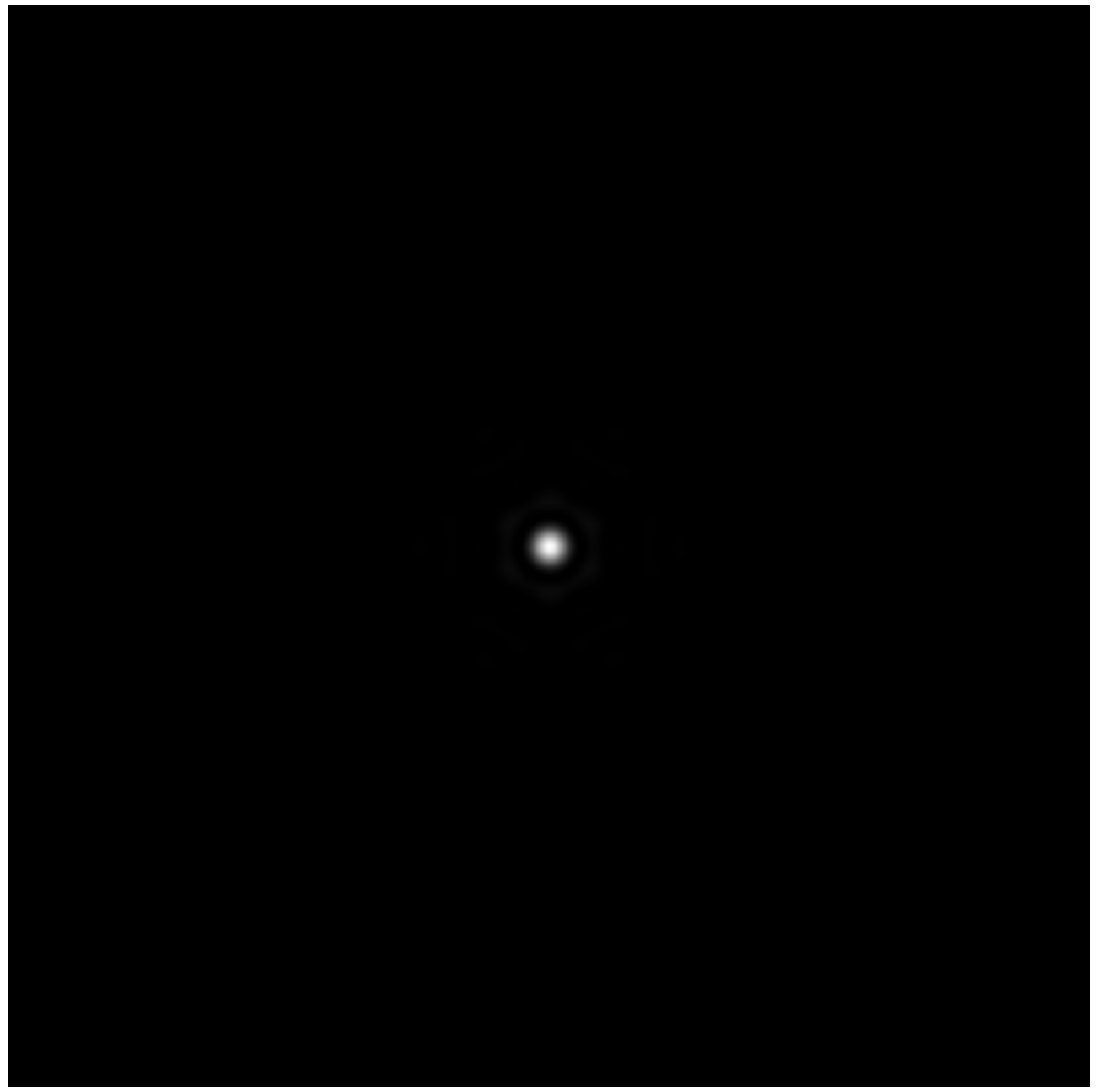
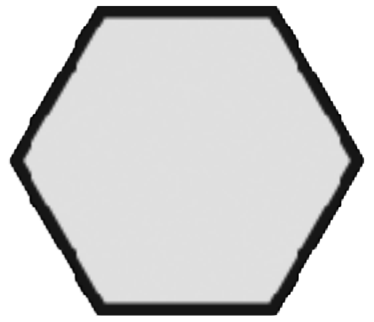
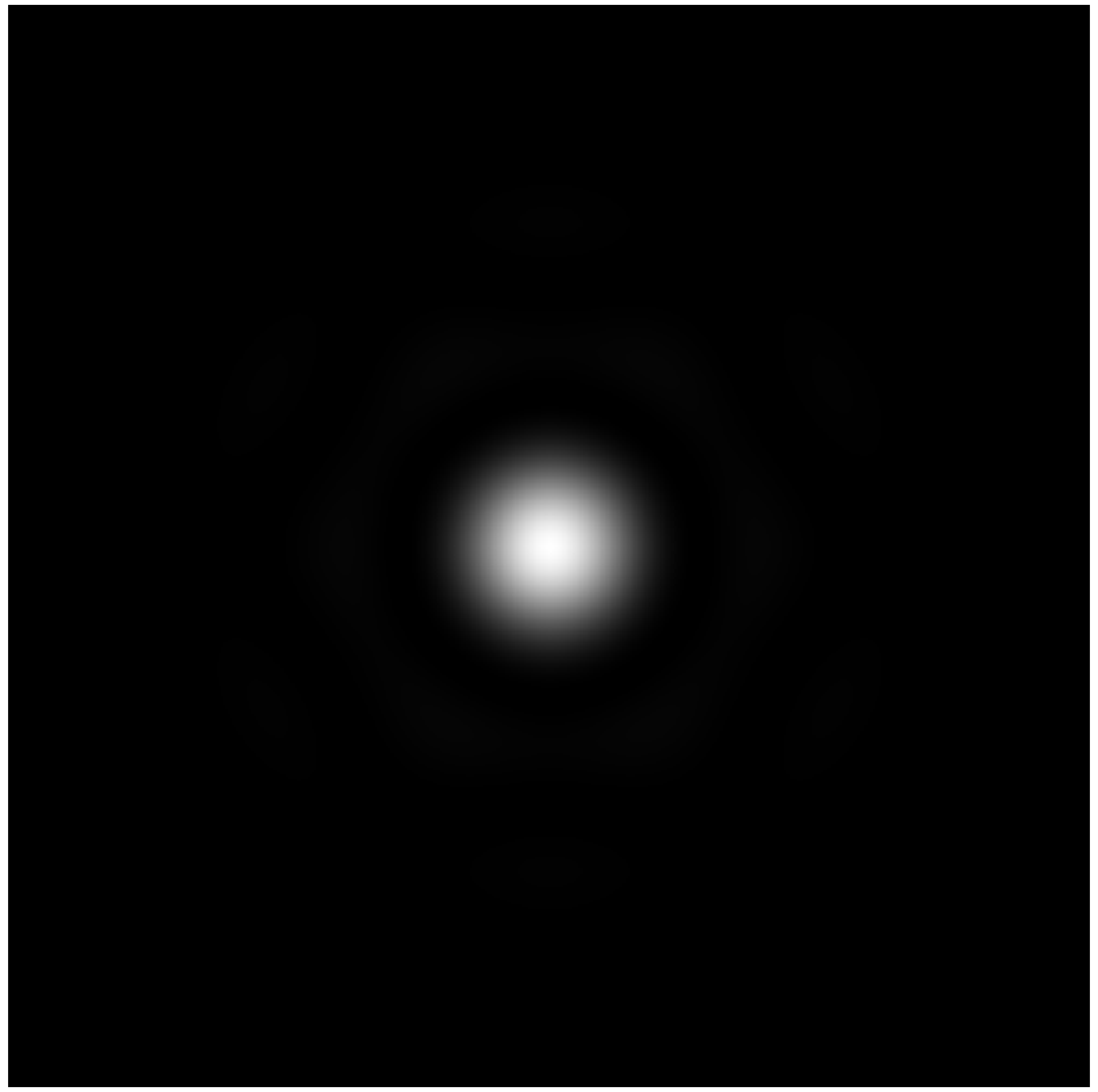
Co-Phased





Un-Phased



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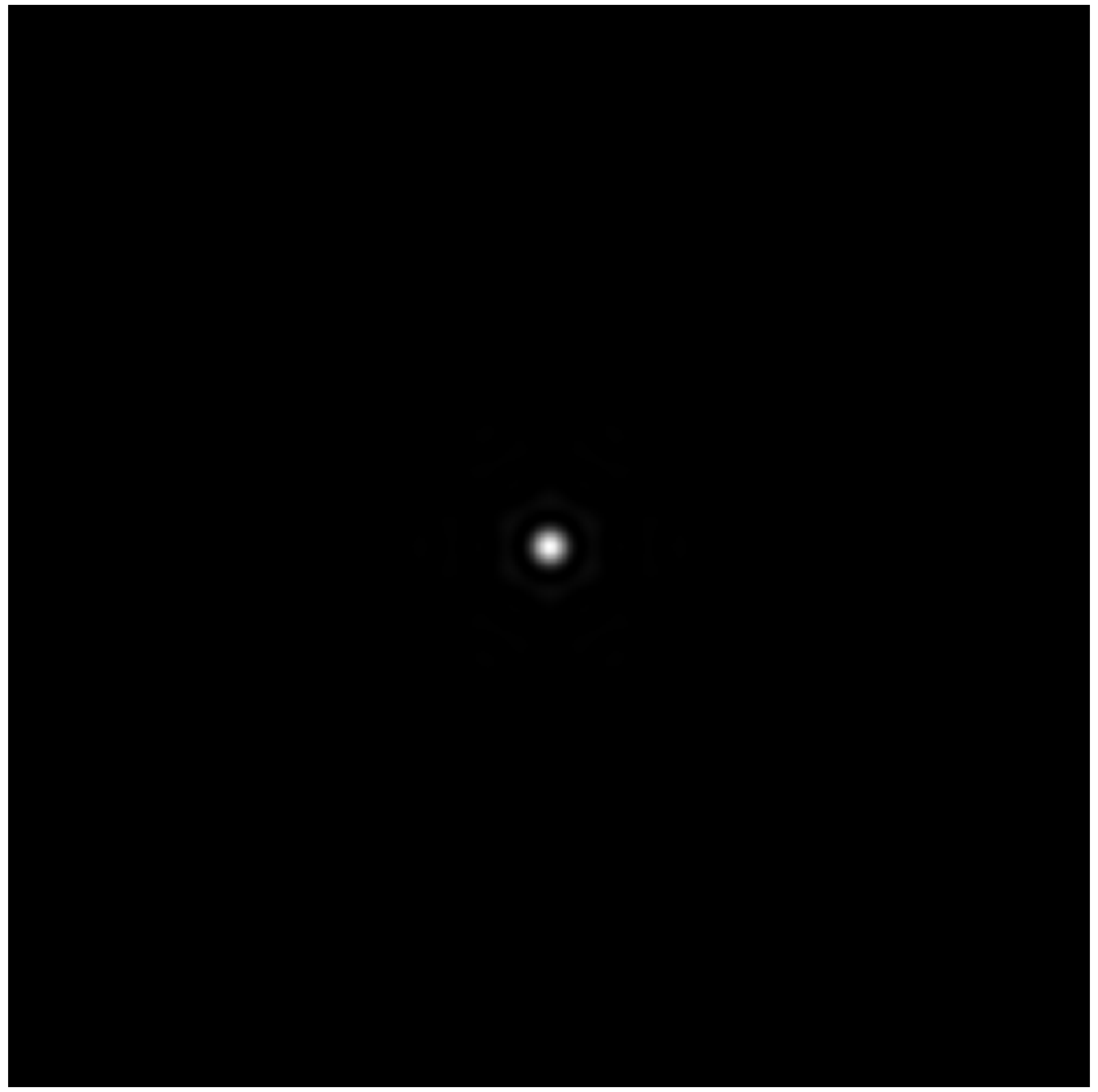

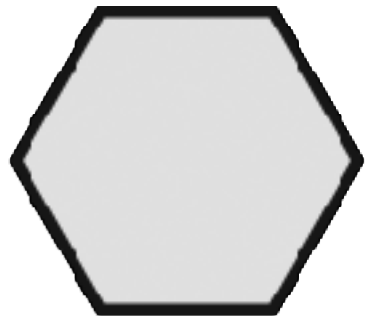

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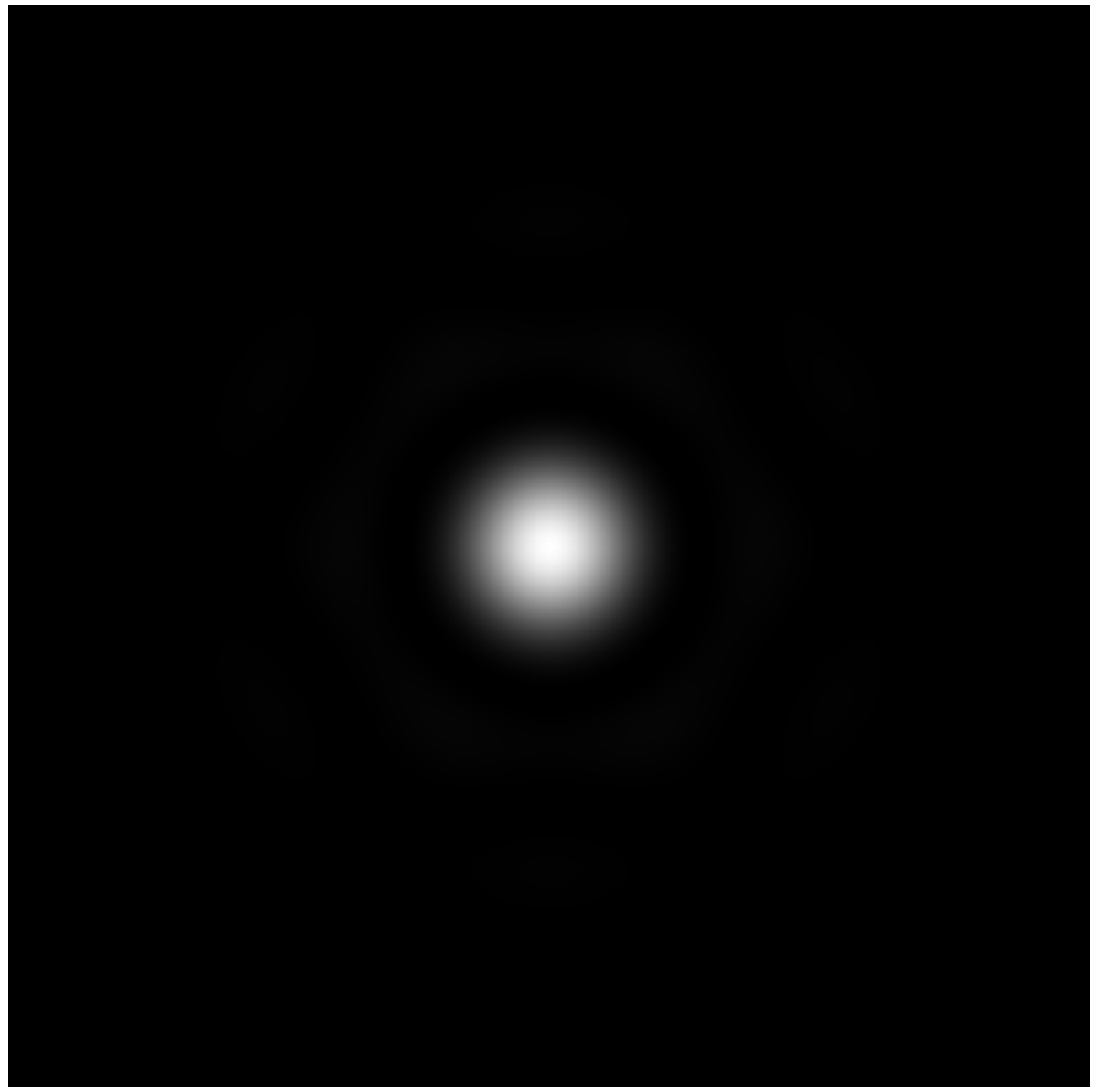
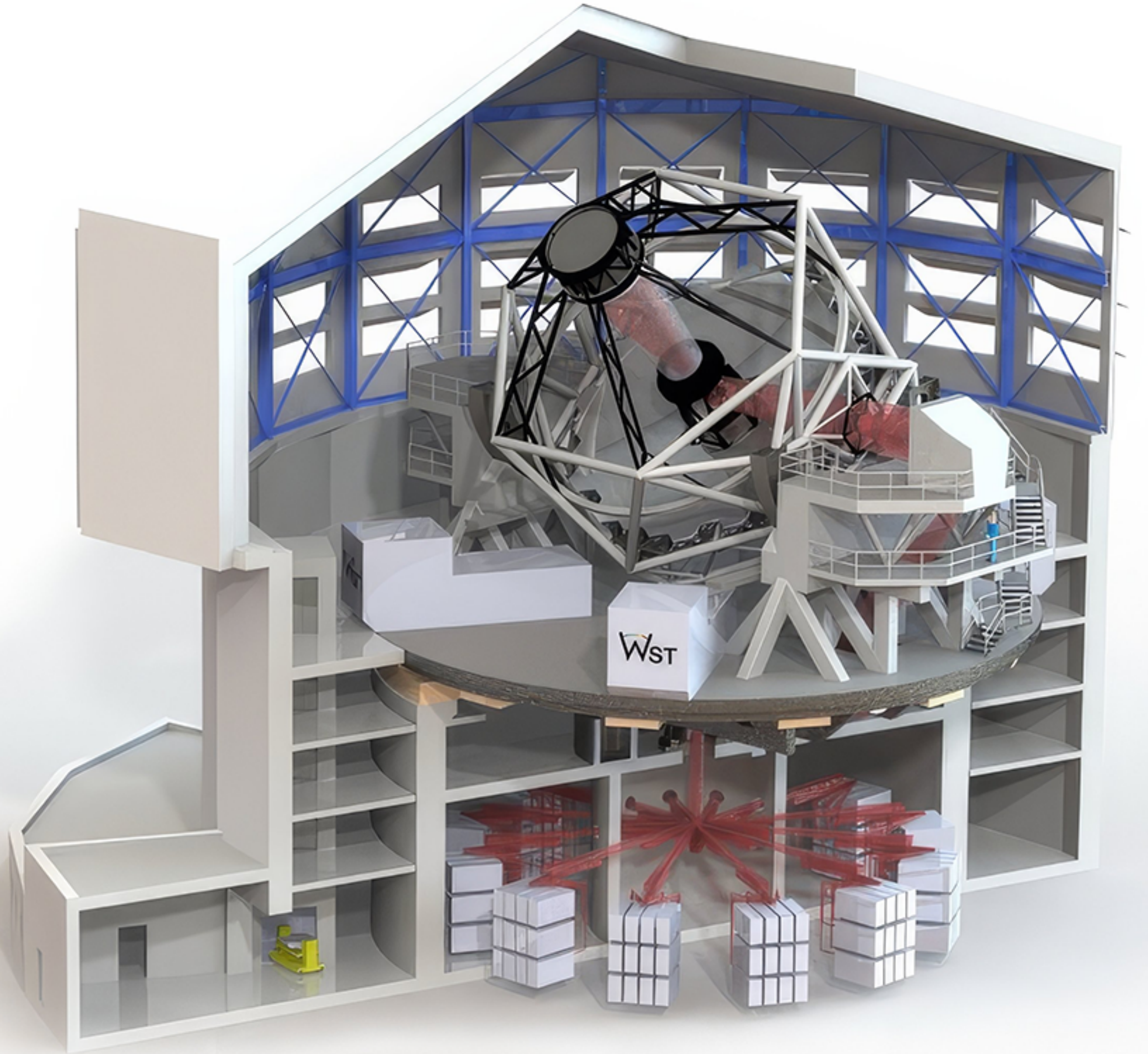


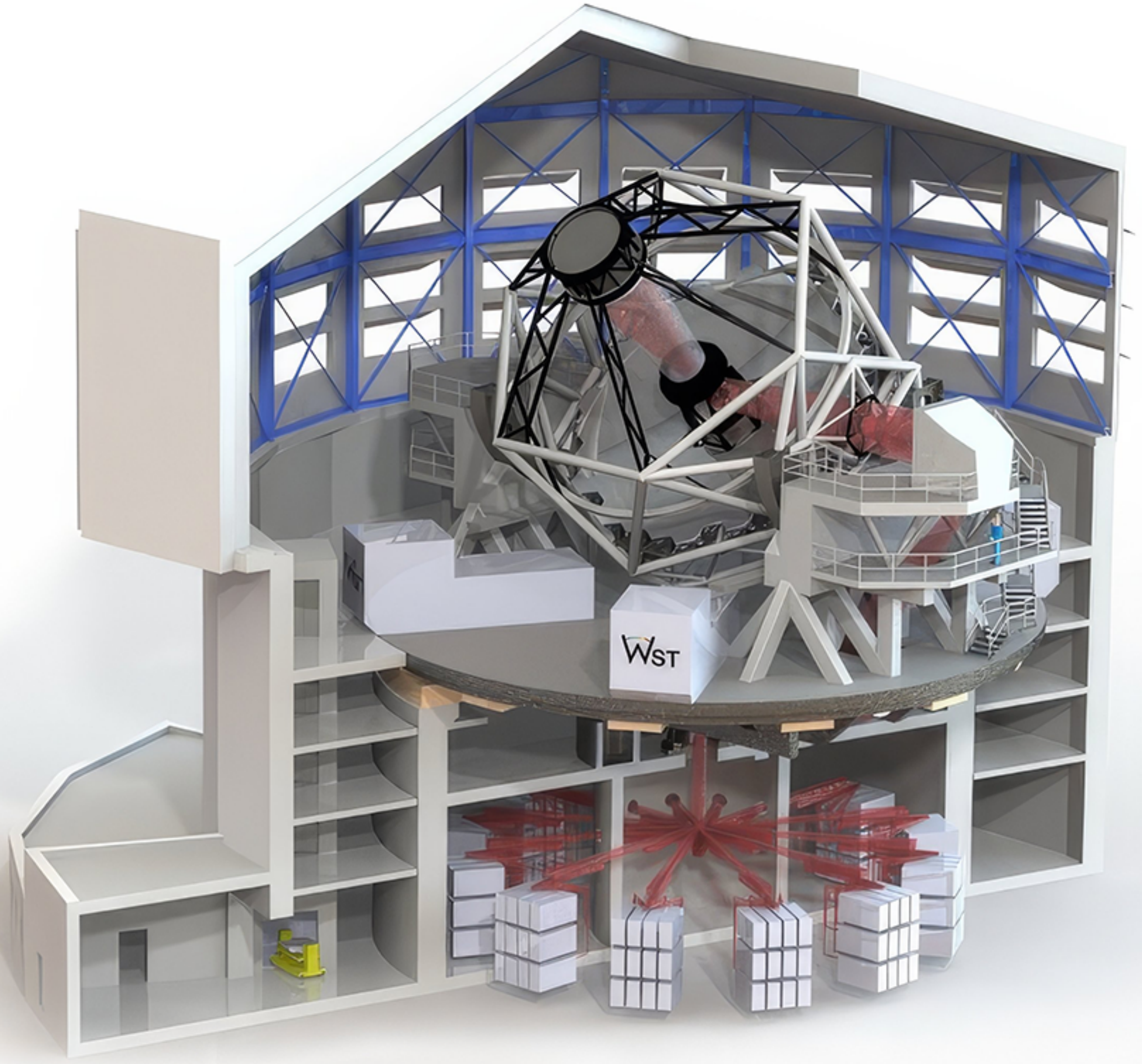
and the future?

Widefield Spectroscopic Telescope (WST)



Widefield Spectroscopic Telescope (WST)

WST:
- 12 m class dedicated facility
- 3 square deg field
- 30,000 multiplex
- “After ELT”



Widefield Spectroscopic Telescope (WST)

WST:
- 12 m class dedicated facility
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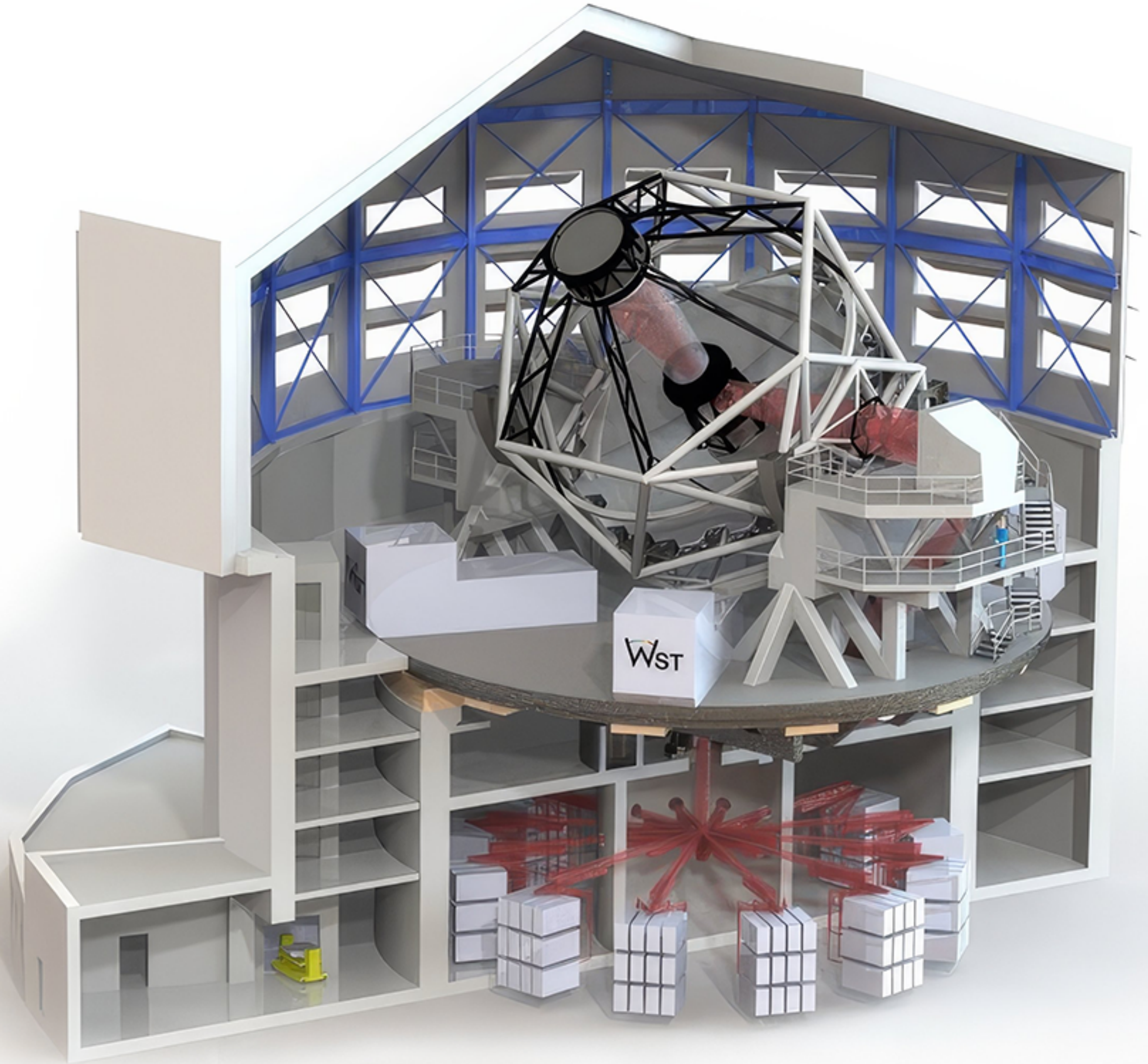
- 30,000 multiplex
- “After ELT”

Primary:
- 78 hexagonal segments
- 99 m^2 area
- ELT segments



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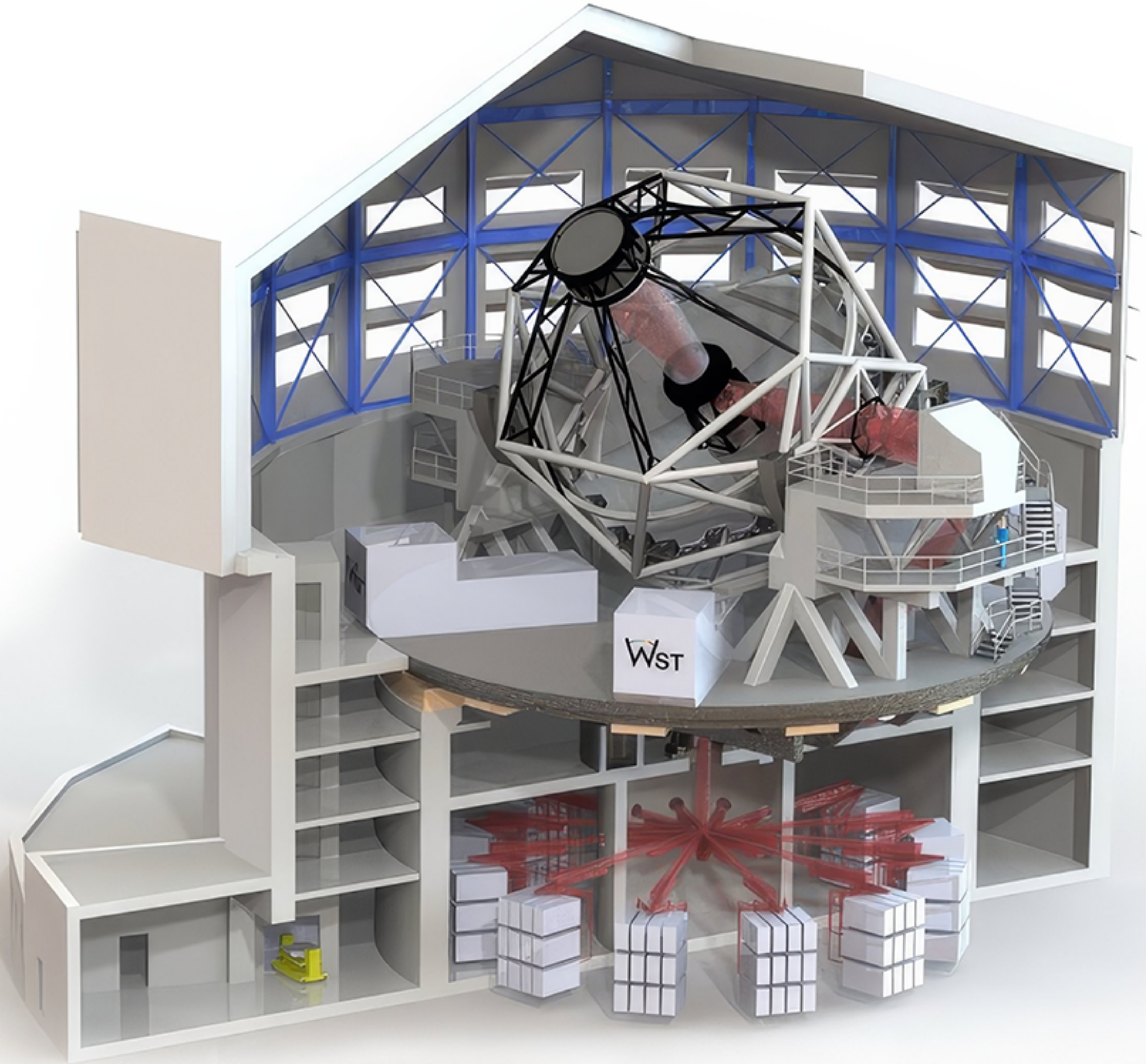
- ELT segments

but:
- unphased
- no AO (seeing limited)



WST Segmented Primary Mirror

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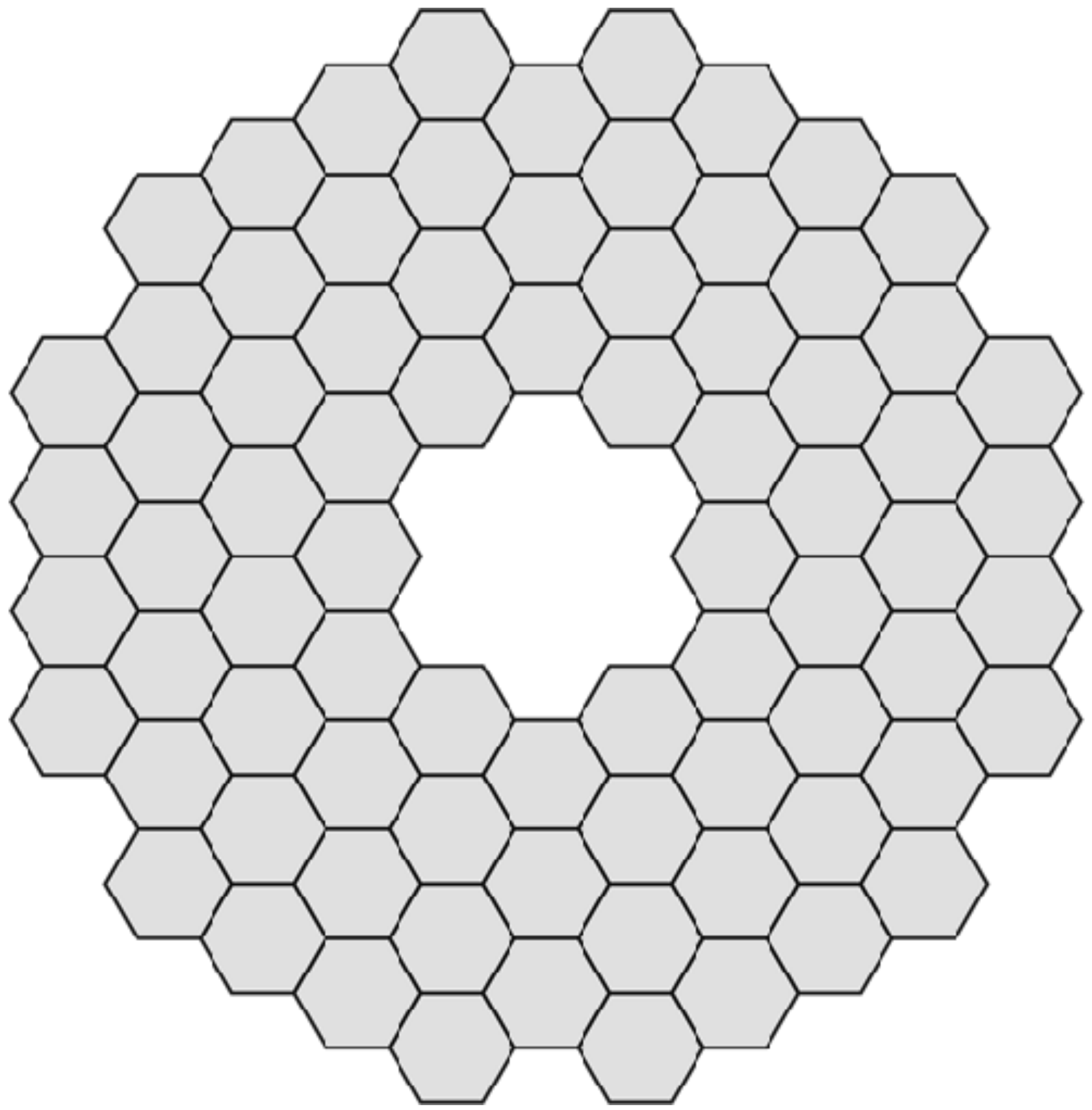
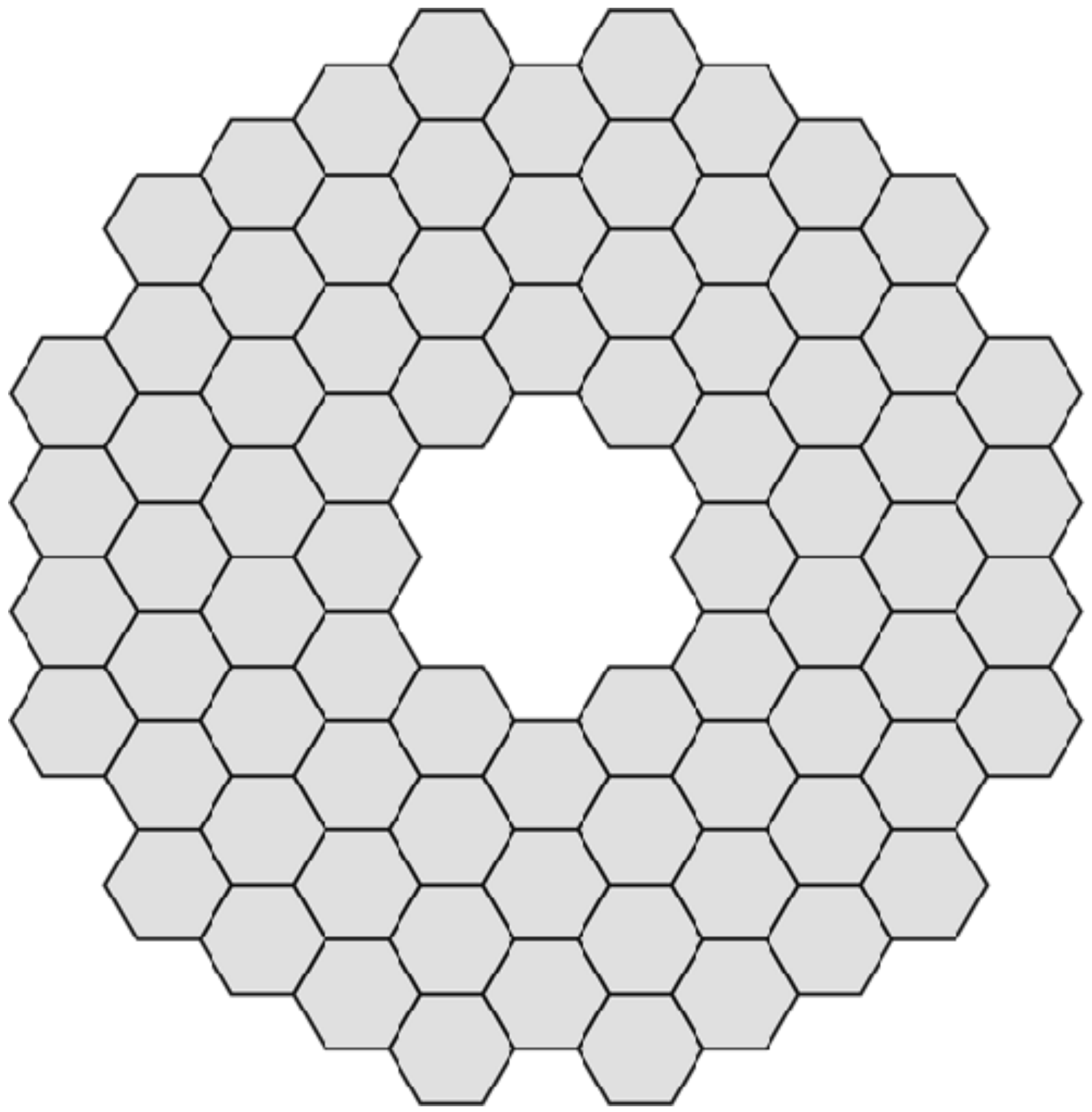


78 Segments
Diameter: 12.1 m
Area: 99 m^2
186 Edges
13 Spares required

WST Segmented Primary Mirror



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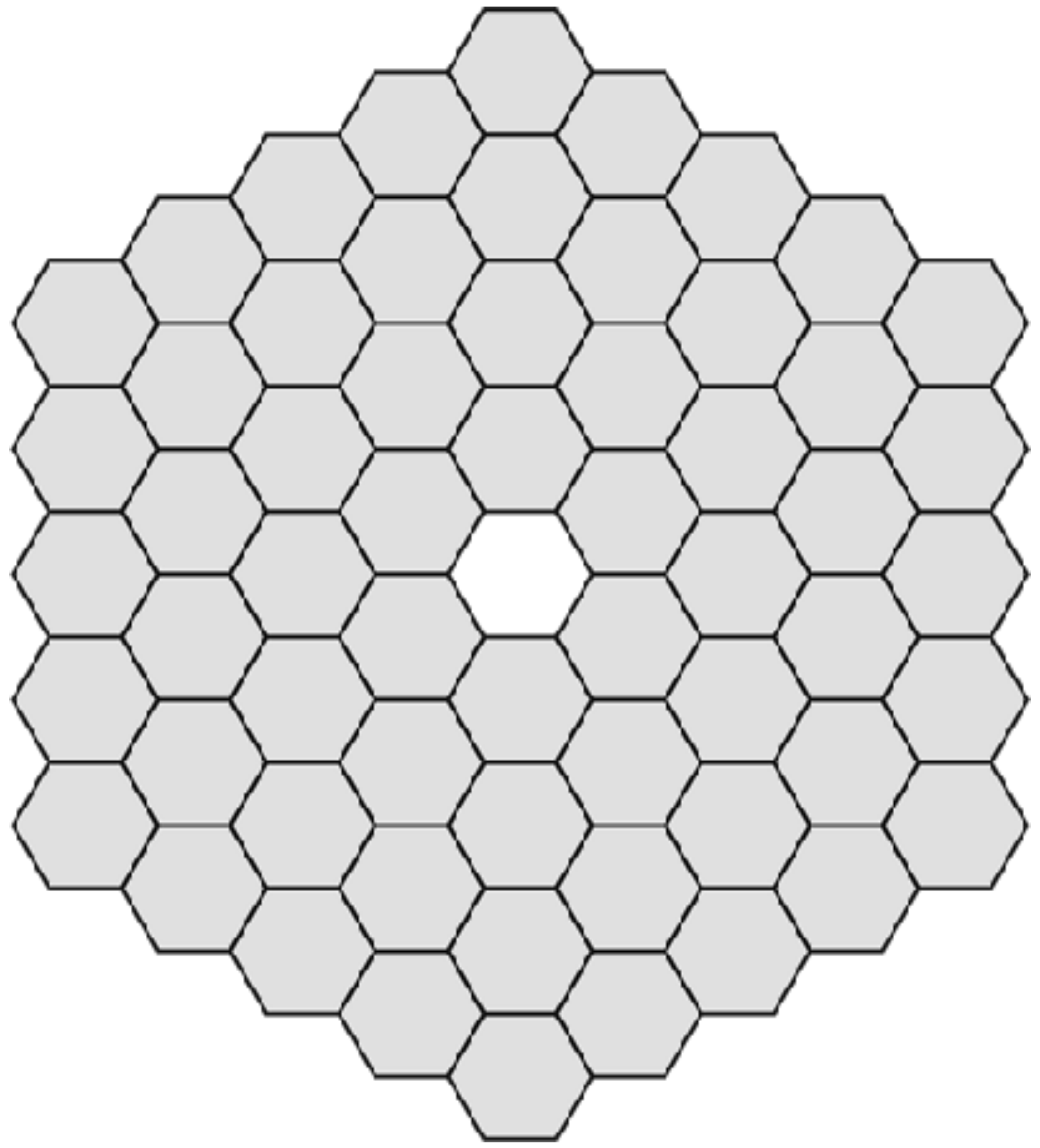
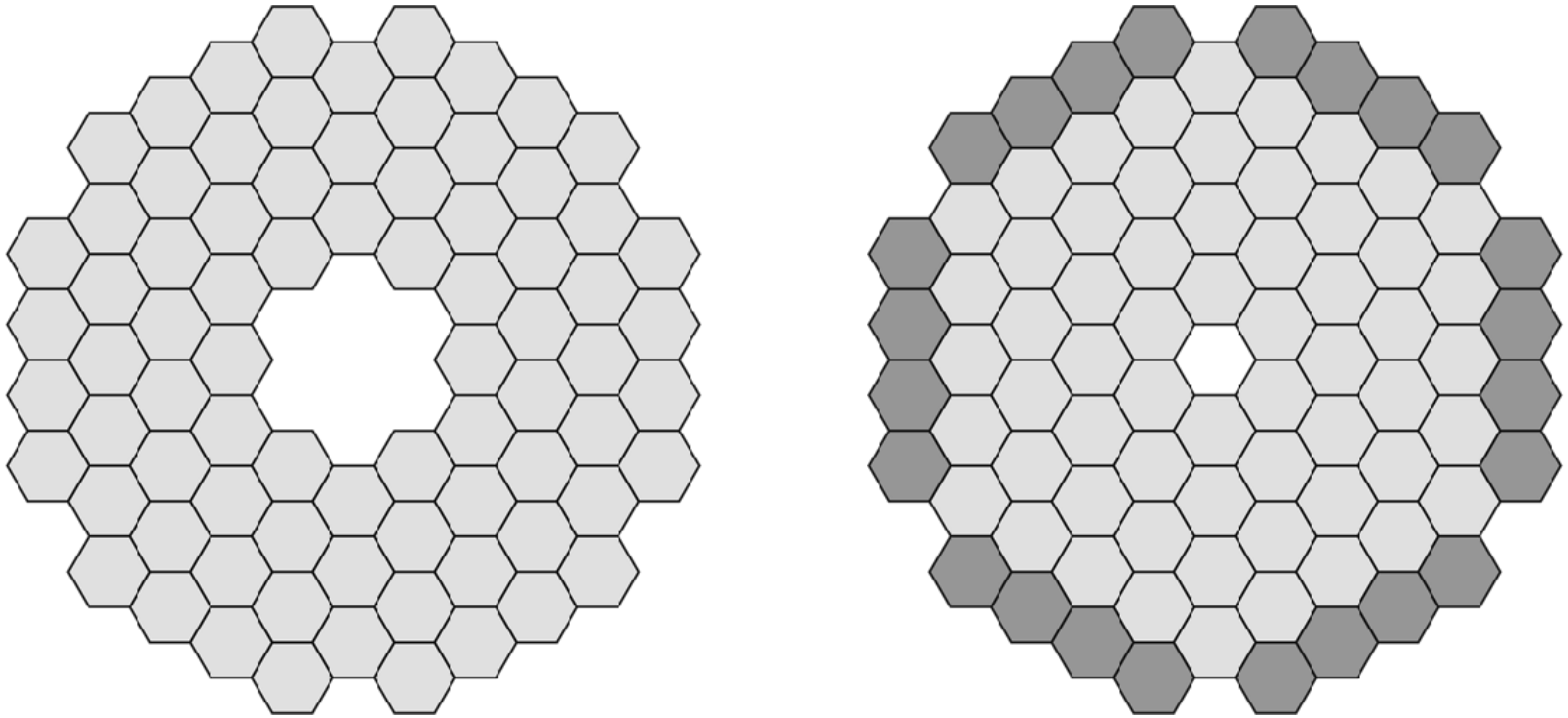


N=5

WST Segmented Primary Mirror



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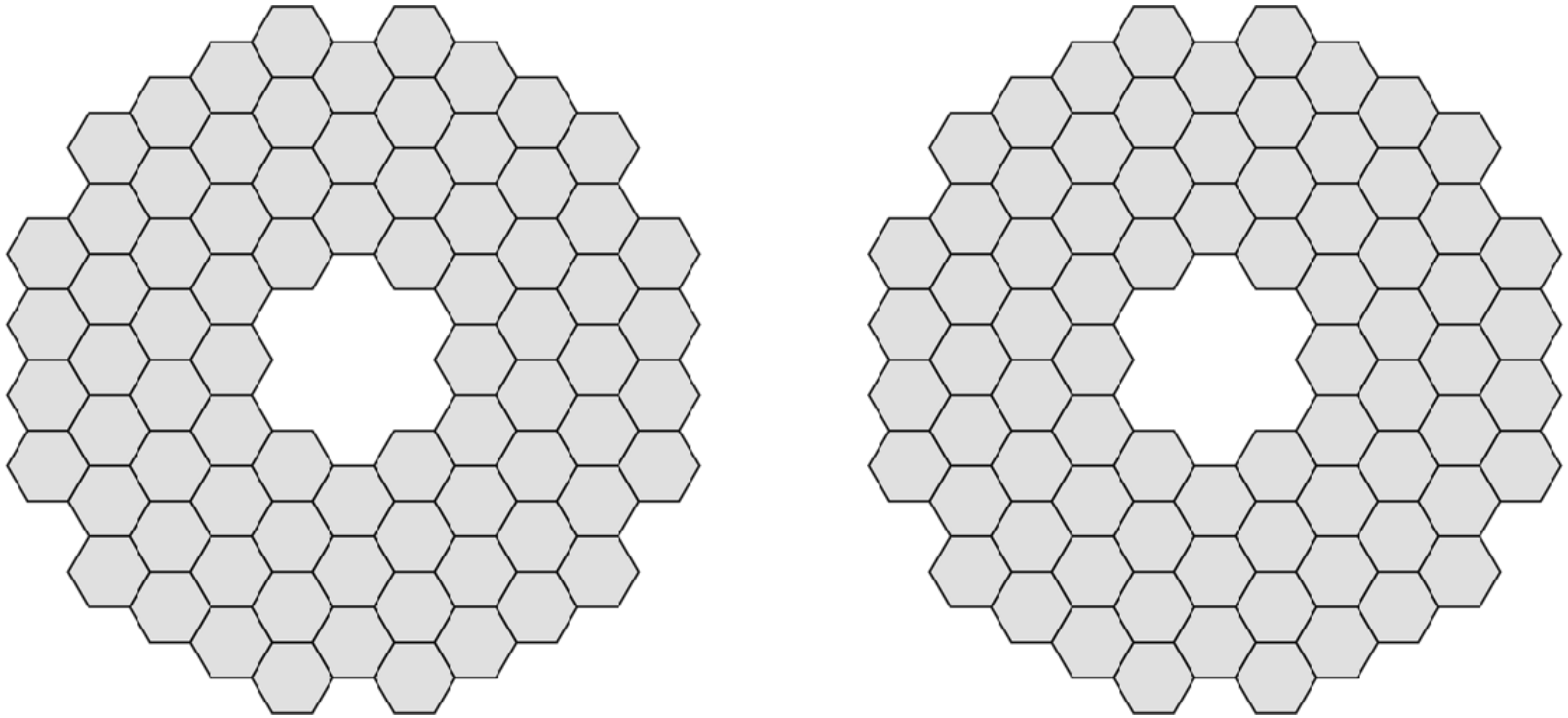
WST Segmented Primary Mirror



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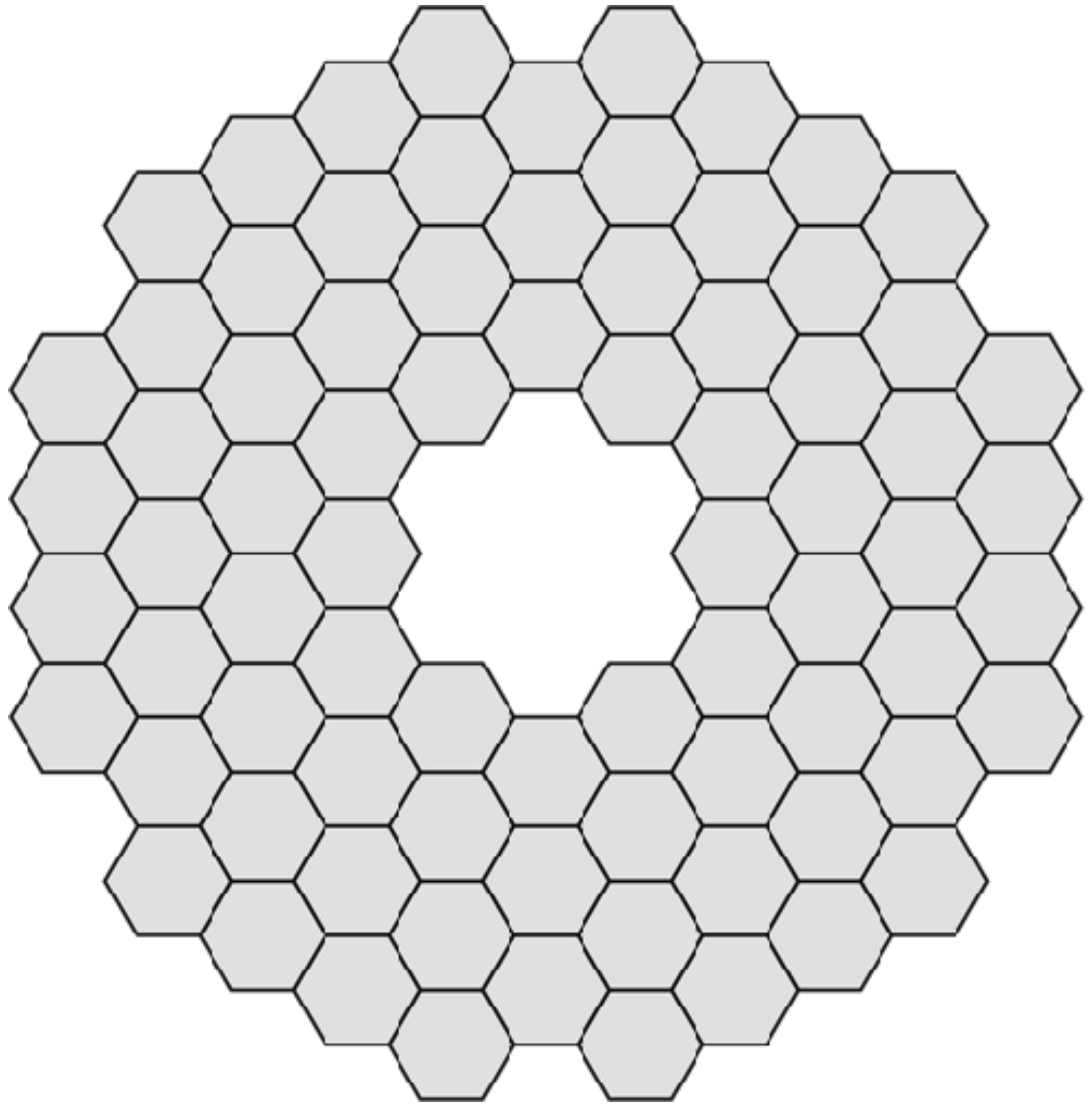
WST Segmented Primary Mirror



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Diameter: 12.1 m
Area: 99 m^2
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A Better Way?

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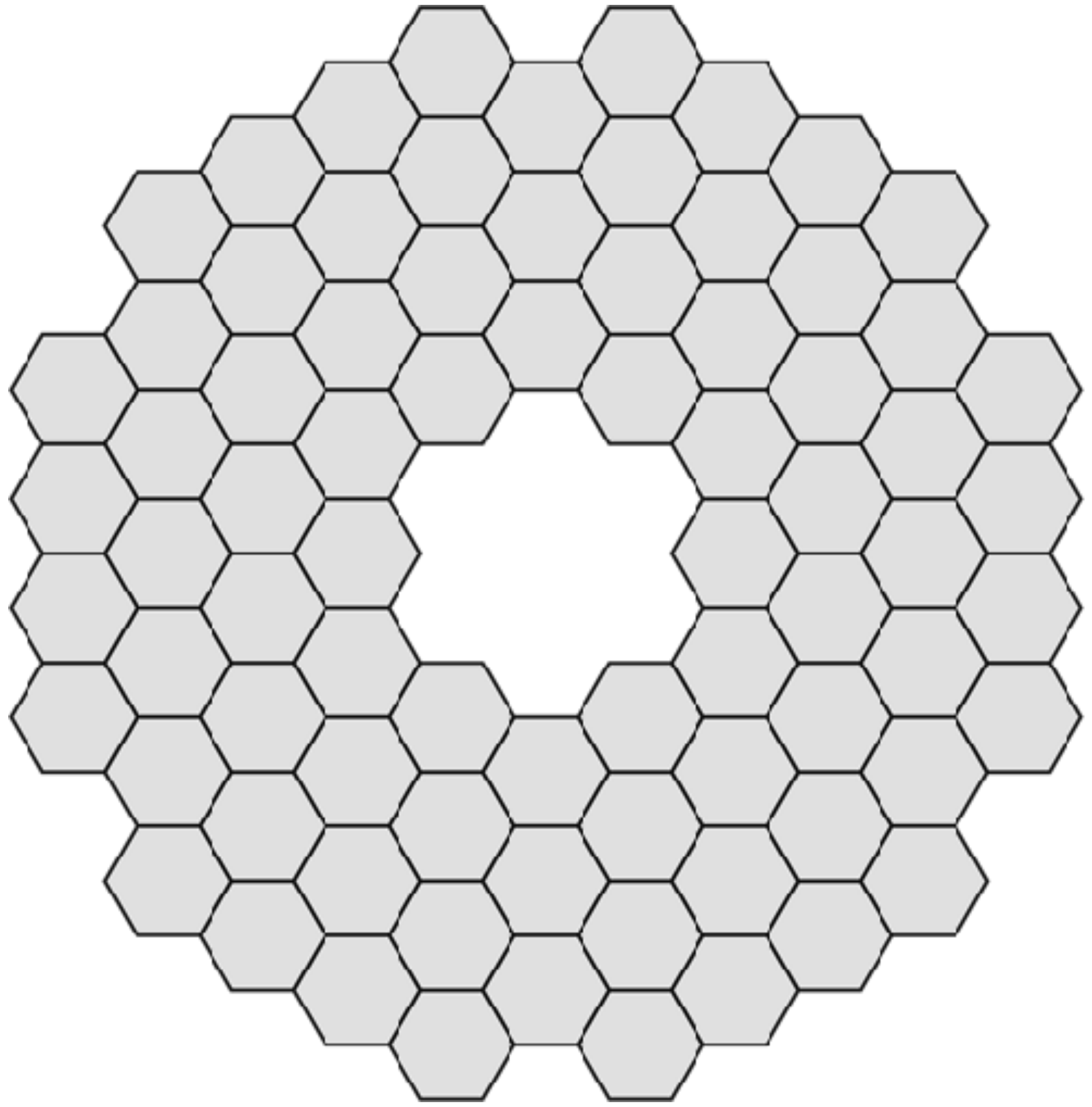

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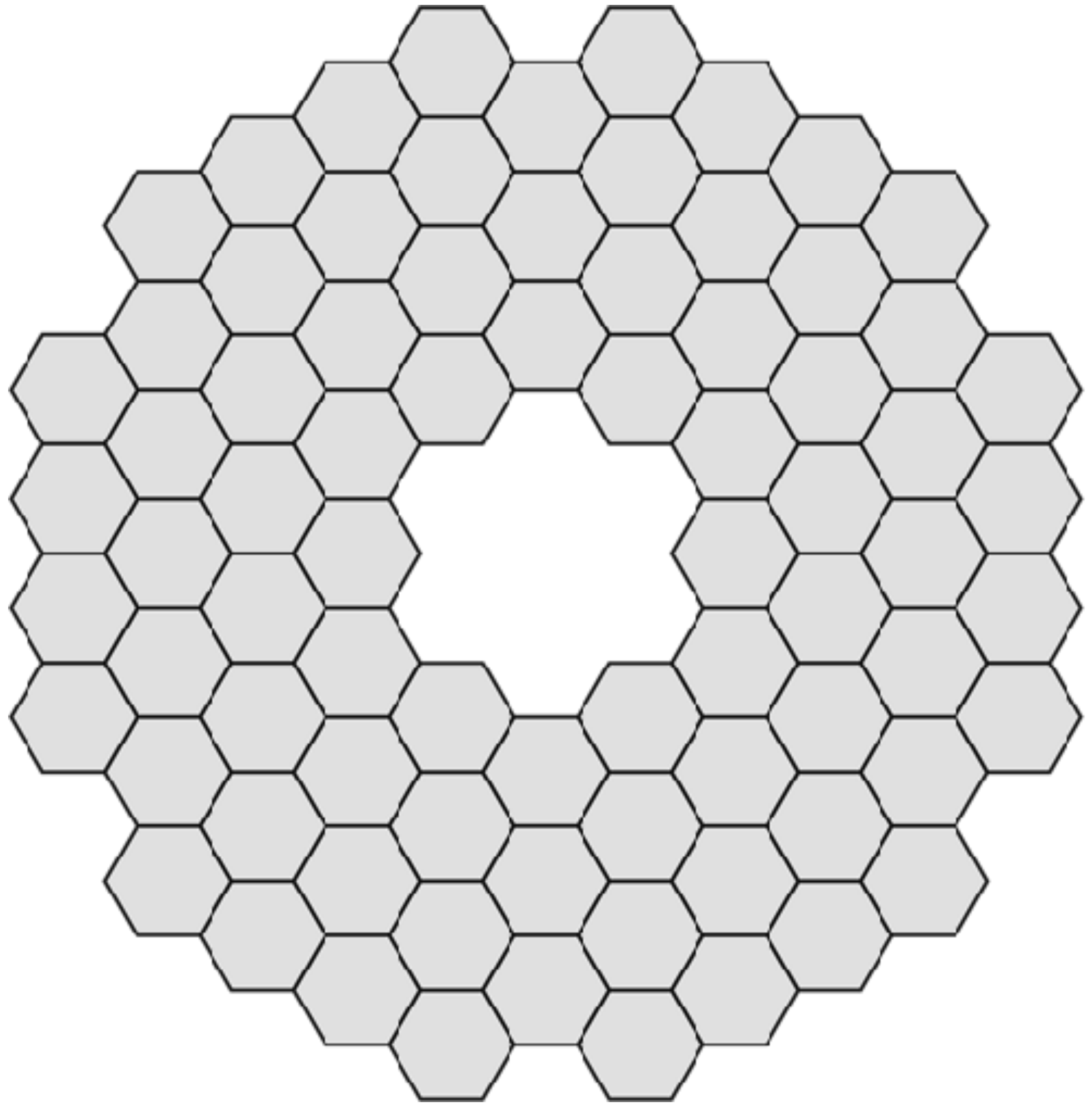
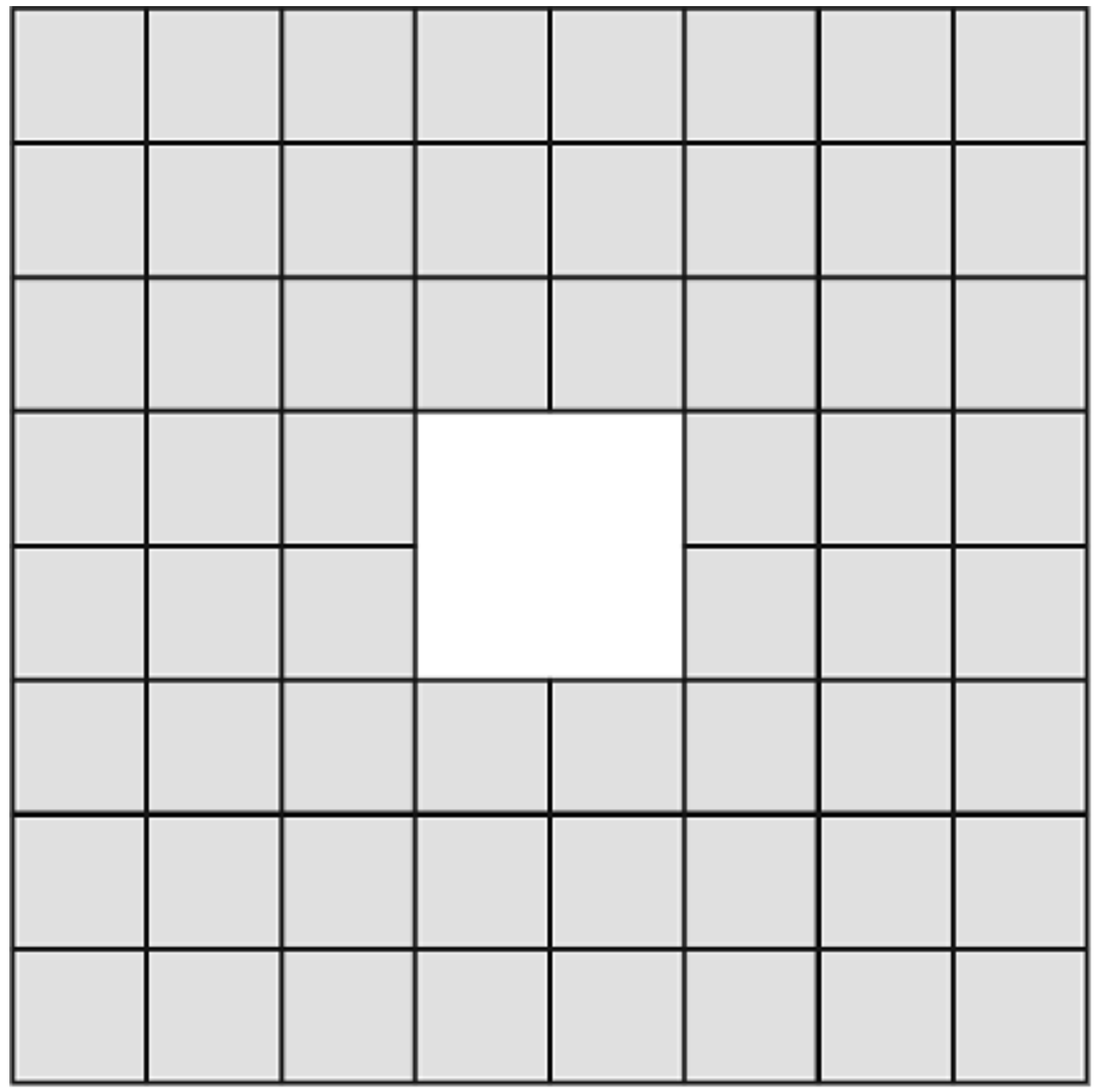
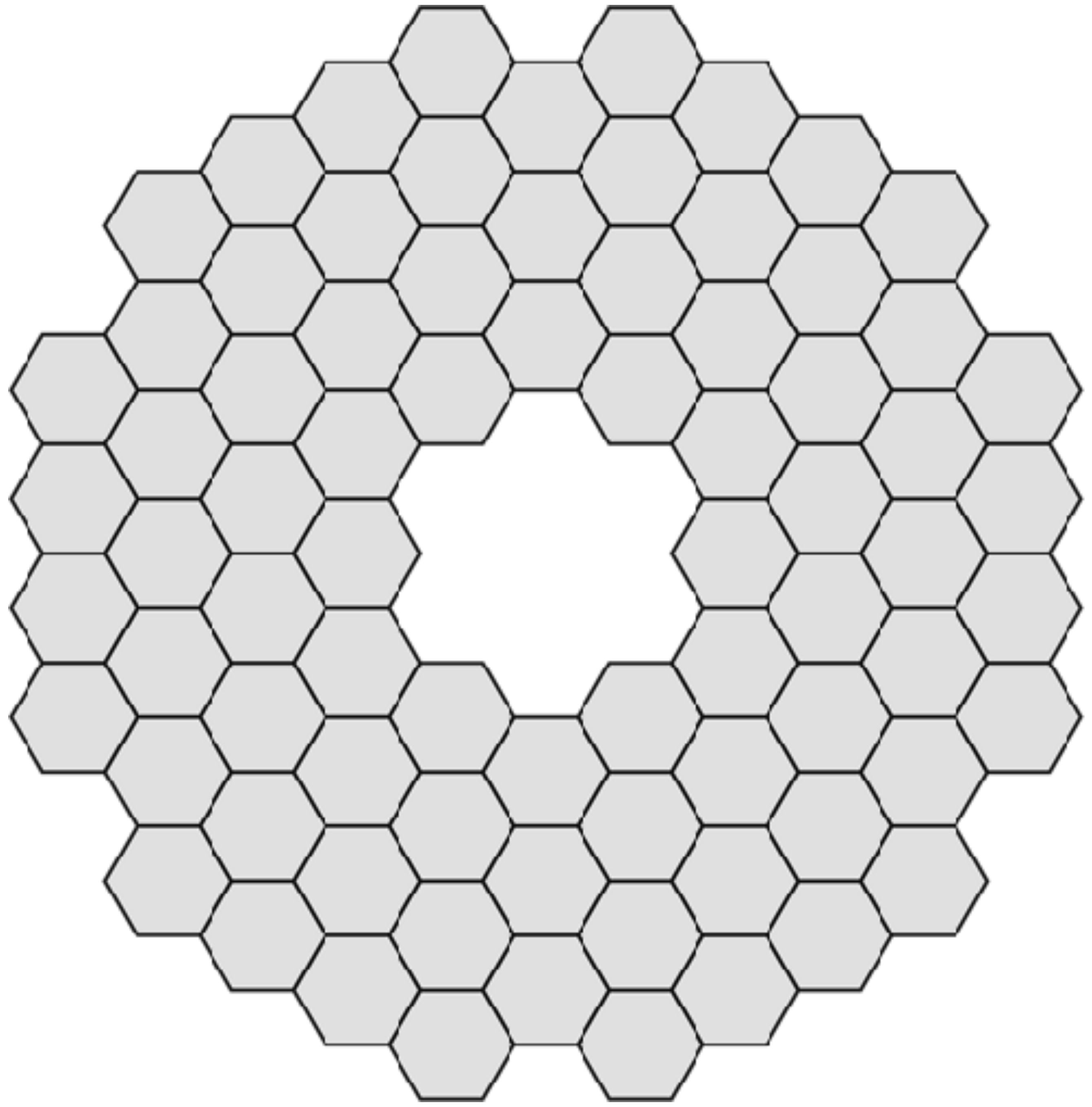


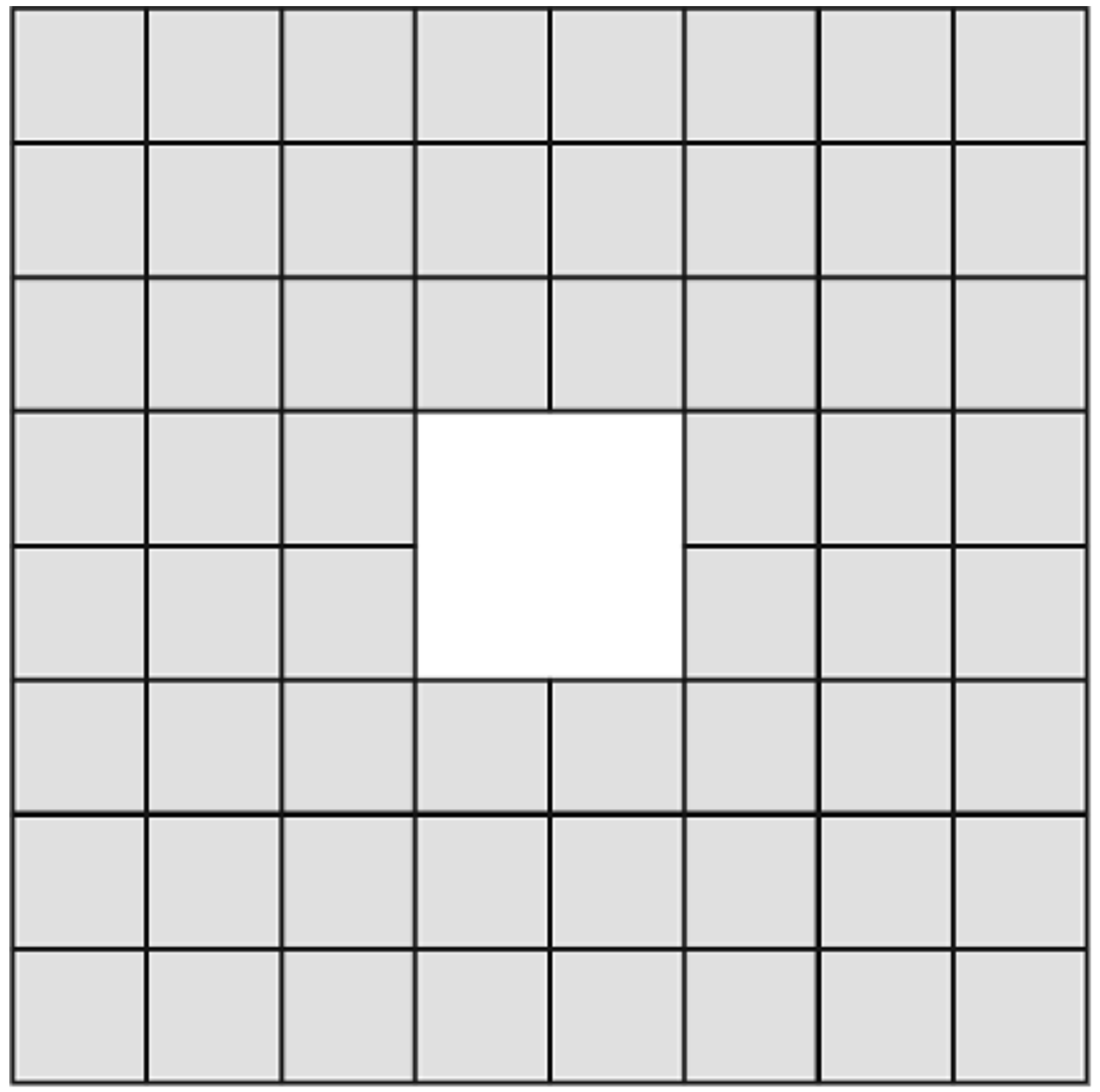


- 60 segments
- 1.3 m square
- same area

A Better Way?



Recall:
- ELT segments
- unphased
- no AO (seeing limited)



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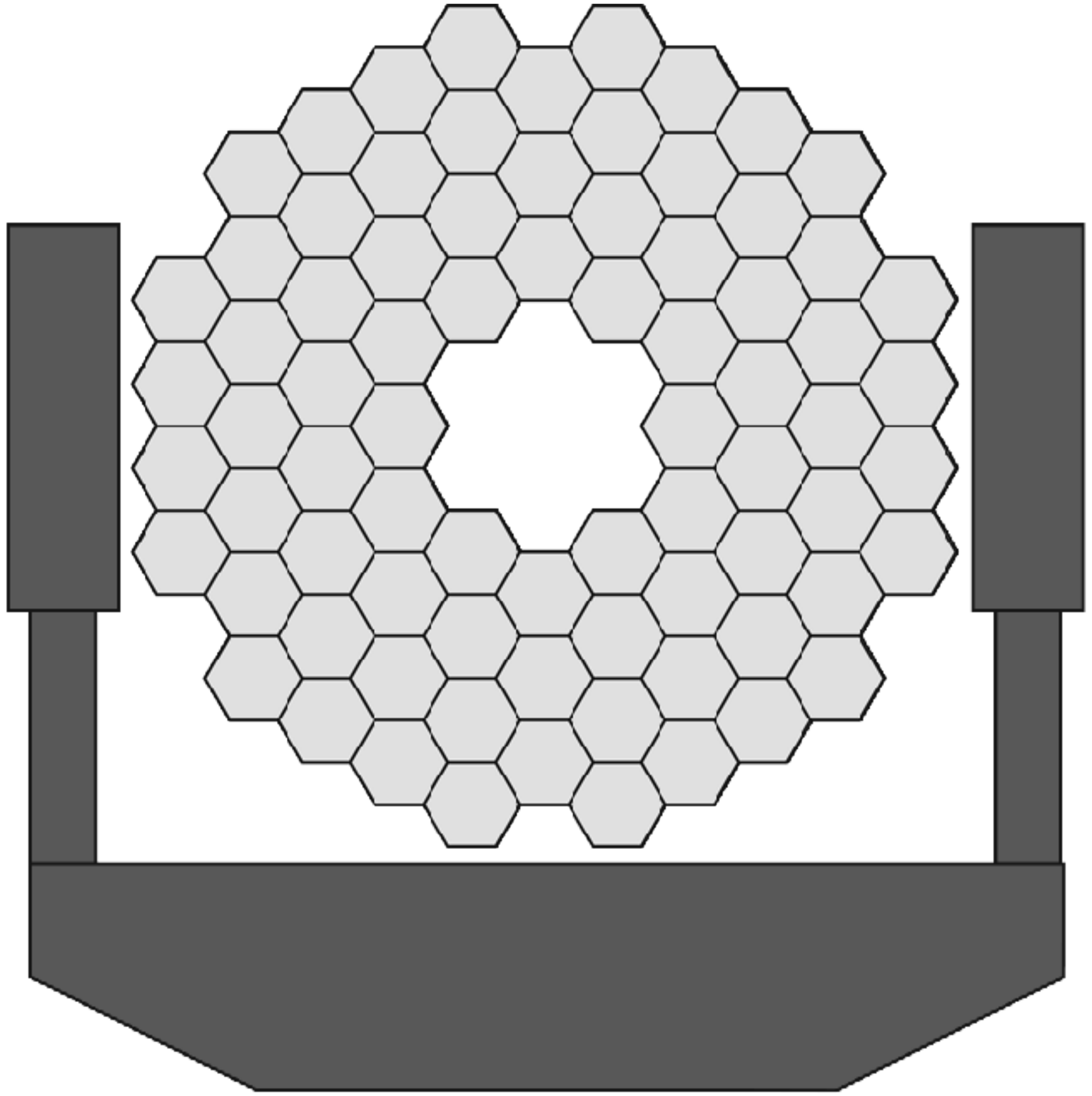
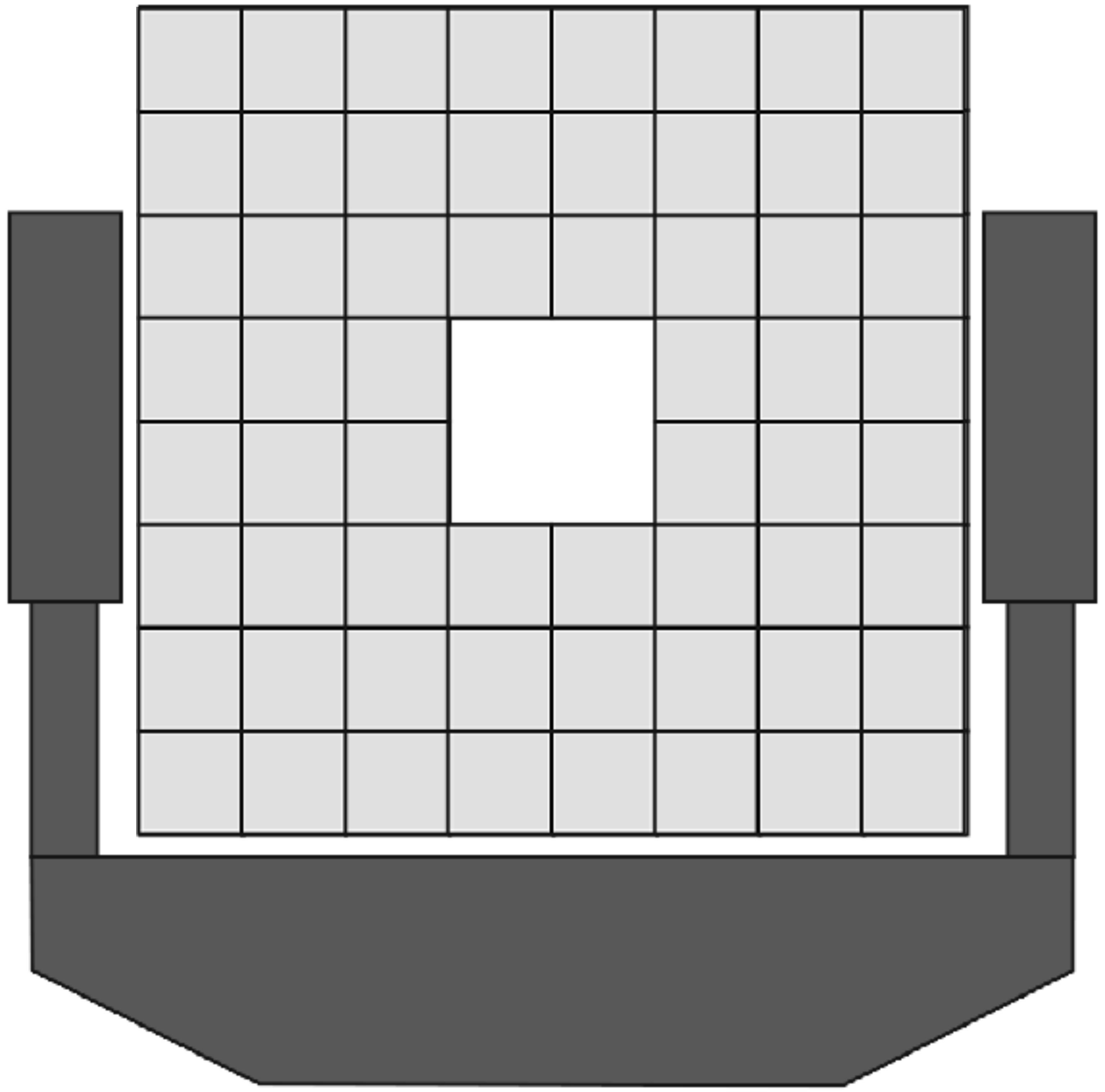
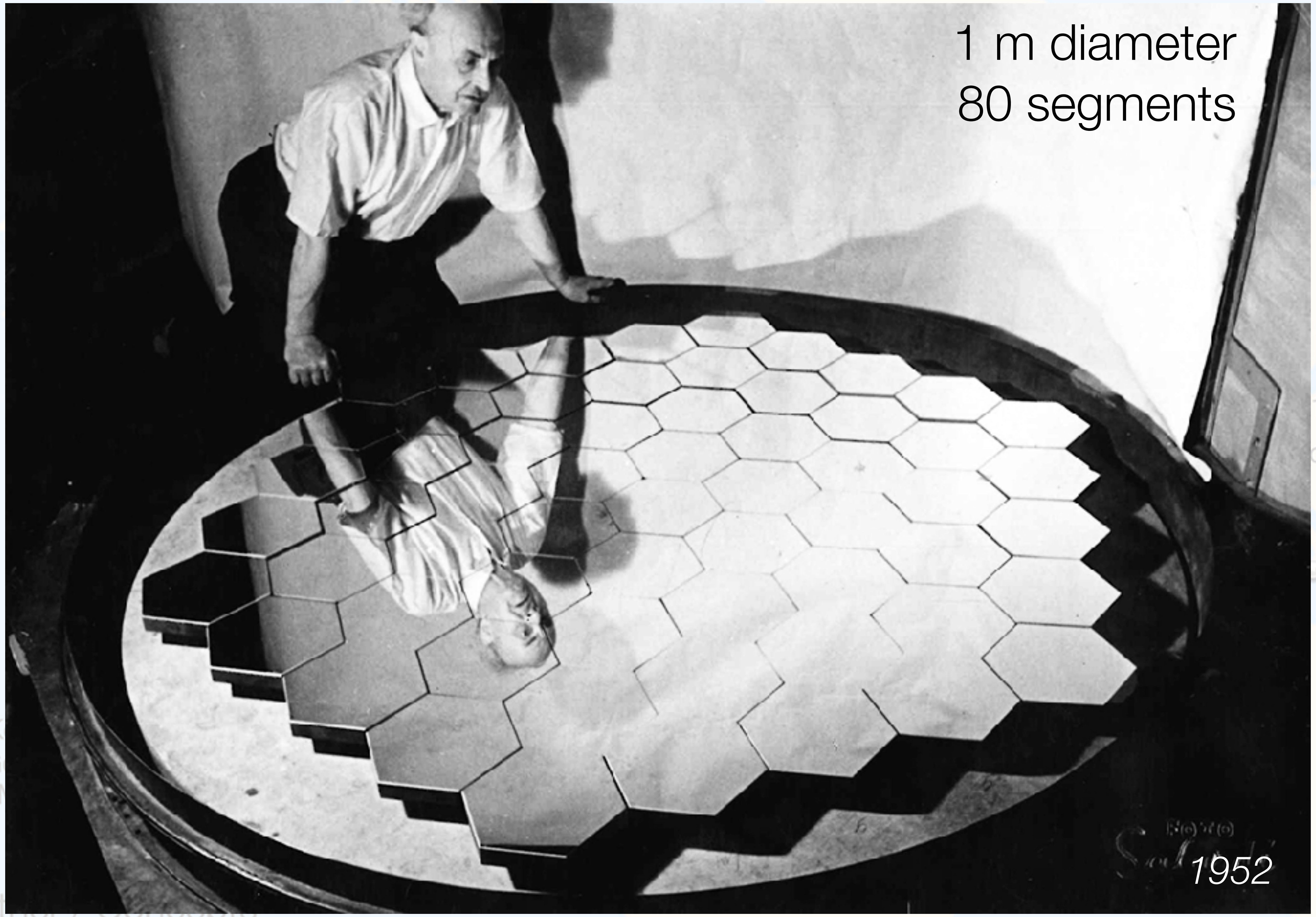
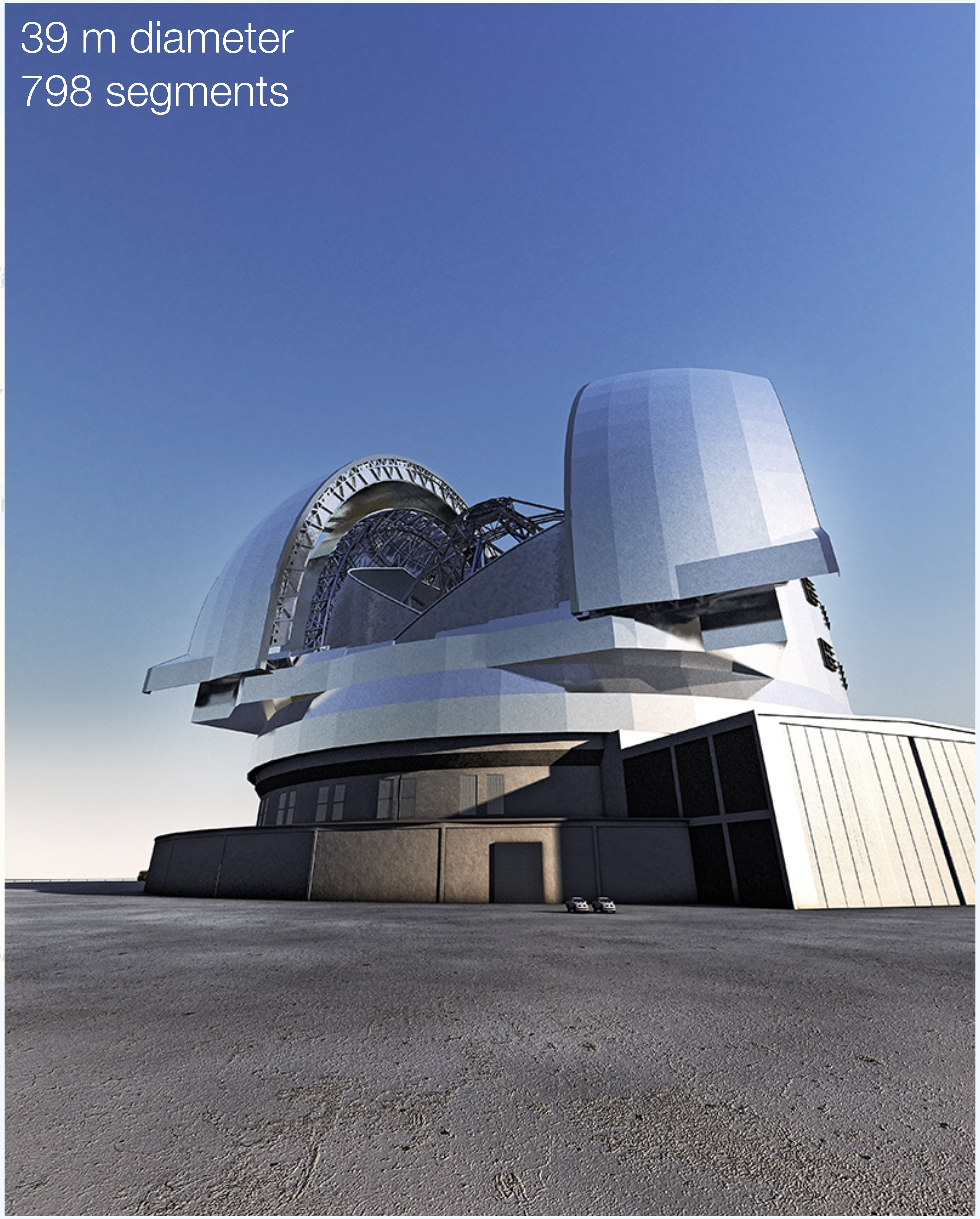




- 13% less width
- 45% less volume


Väisälä 1949
Parsontown 1830
Meudon 1977
Guido Horn d'Arturo
AST-1200 1978
JUST 2026
LAMOST 2008
Seimei 2019
Archimedes 212 BCE
MMT 1982
HET 1997
GTC 2007
TMT 2035?
Keck 1993, 1996
Gemini North 1999
TMT 2035?
Timau 2026
ELT 2030
GMT 2033?
Gemini South 2000
Rubin 2025
SALT 2005
Other / Concepts
JWST 2021
NNTT 1980's
CELT, VLOT, GSMT late 1990's
Euro50 late 1990's
OWL late 1990's
Large Petal Telescope
High Dynamic Range Telescope
Maunakea Spectroscopic Explorer
Wide-field Spectroscopic Telescope





Segmented mirror telescopes are here to stay…

Thanks!

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MOSAIC TELESCOPES TECHNOLOGY AND SCIENCE

FROM TINY REFLECTING TILES
TO LARGE ASTRONOMICAL MIRRORS
IN HONOR OF GUIDO HORN D'ARTURO

26 | 27 JAN 2026

AULA PRODI
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