WAET

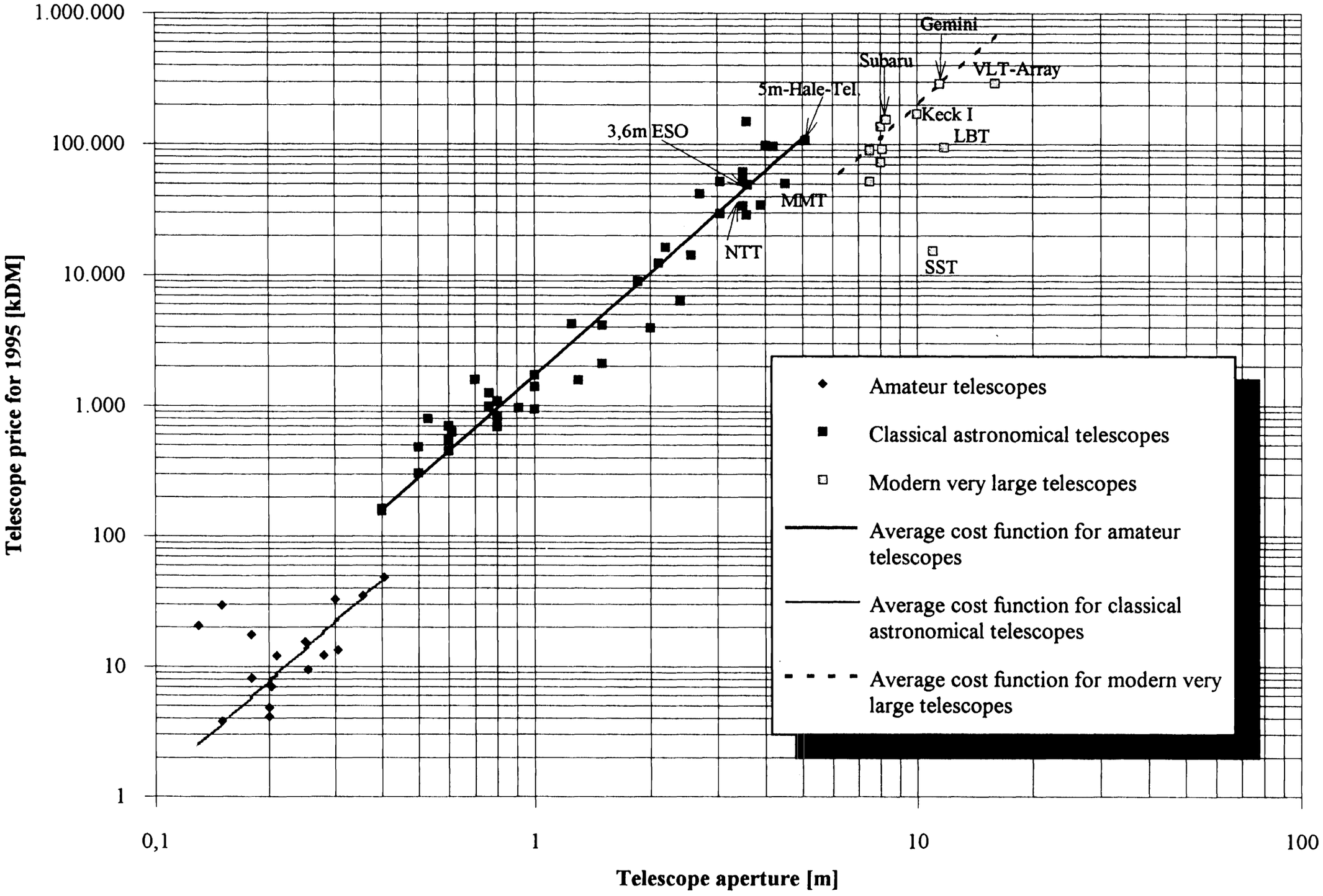
Wide Aperture Exoplanet Telescope

Ben Monreal
CWRU Physics

arxiv:1801.00822

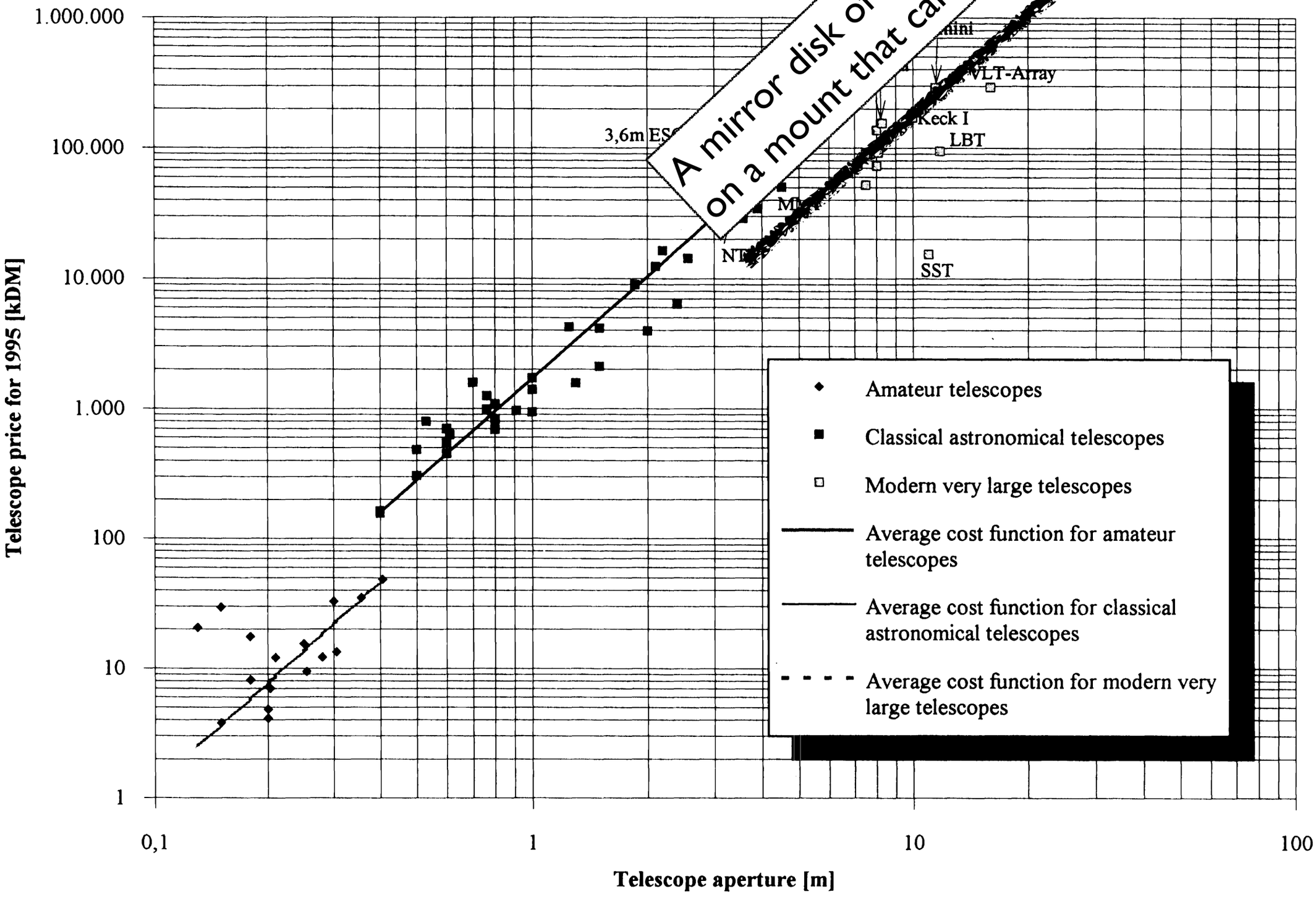
with:
Rob Halliday (thermal engineering, optics)
and:
Ama Carney (mechanical)
Christian Rodriguez (UCSB) (planet populations)
Mingyuan Wang (Zemax/optical)

Cost estimation



Schmidt-Kaler & Rucks, SPIE 2871 (1997)

Cost estimation



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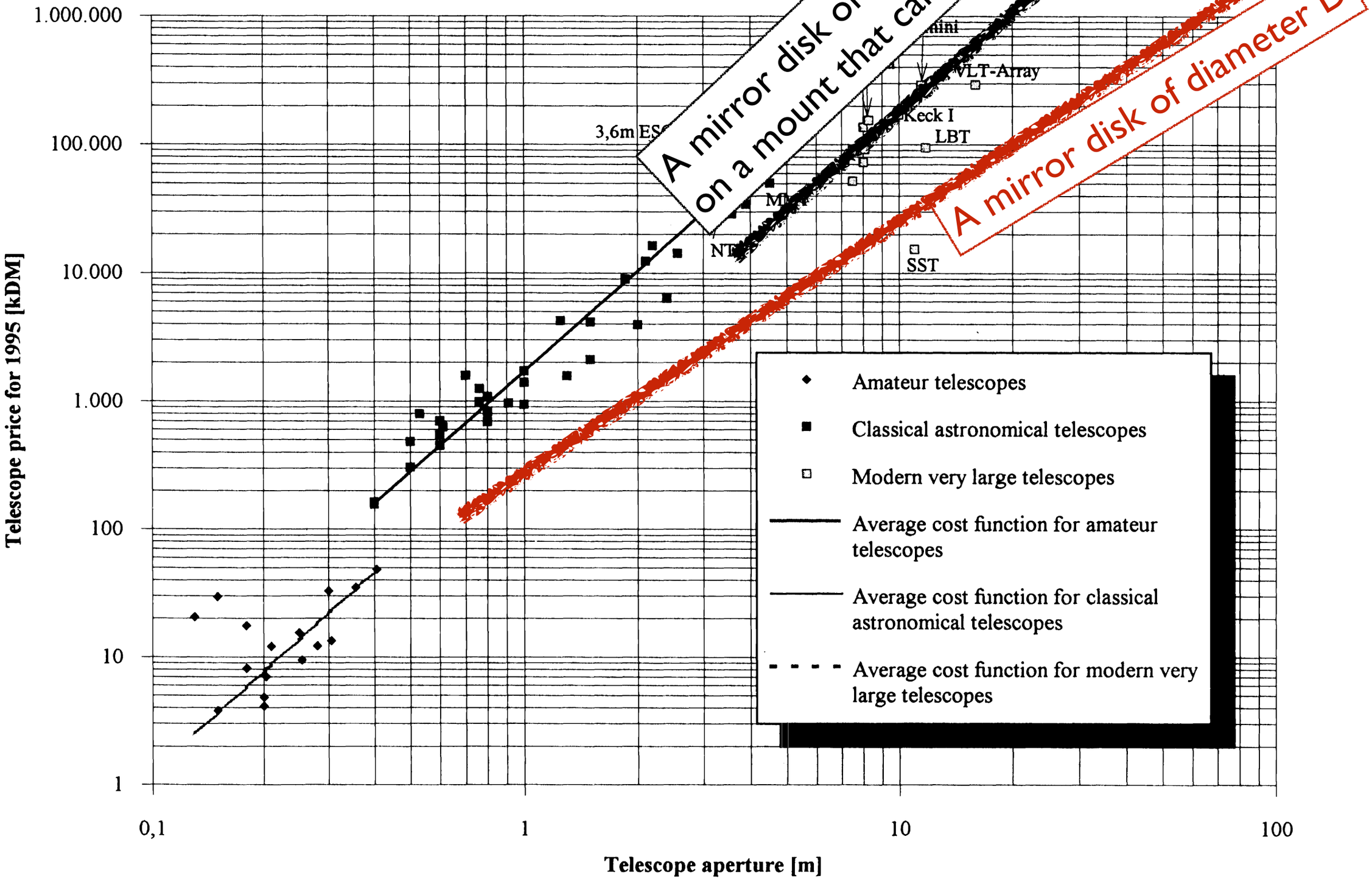

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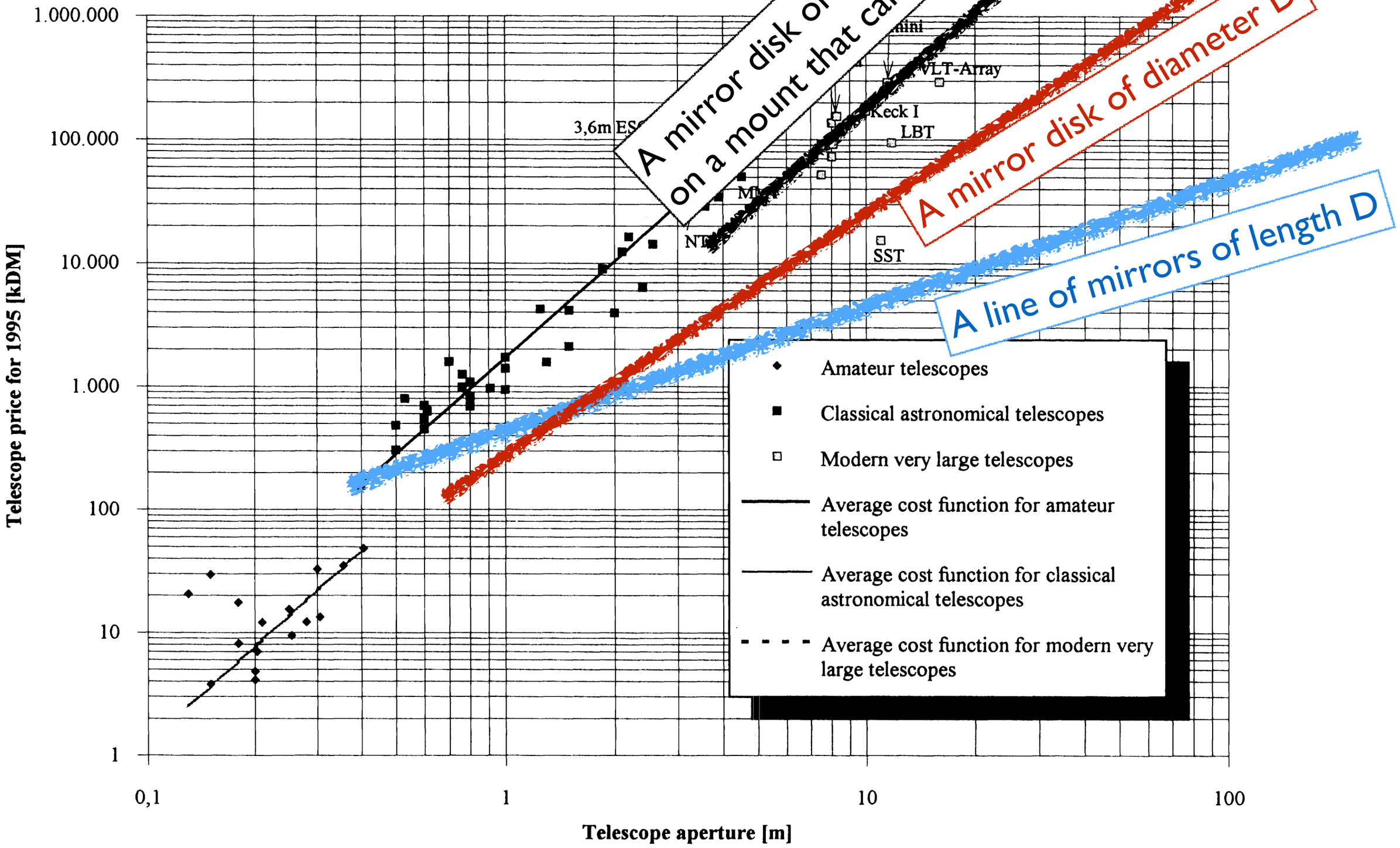

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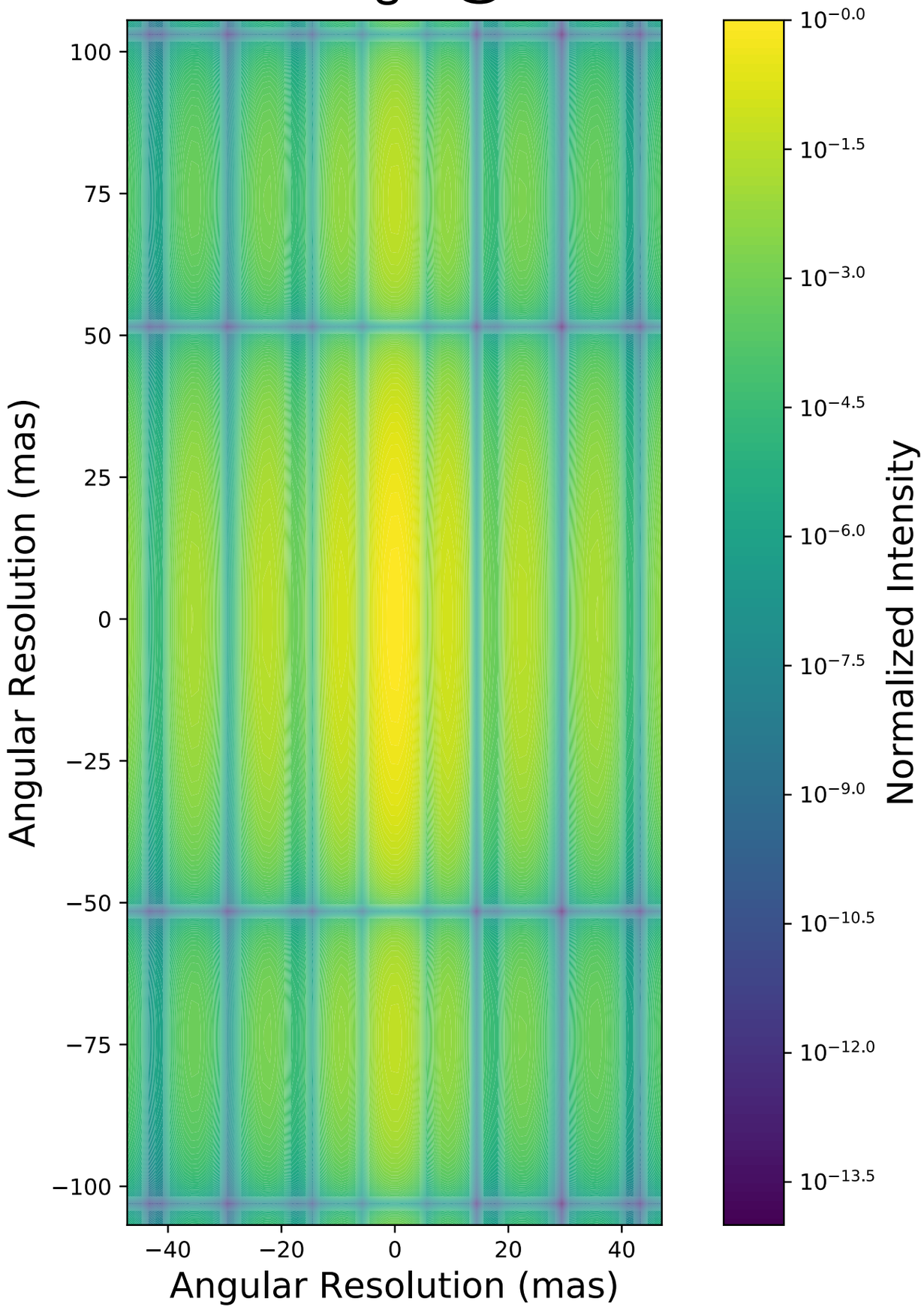
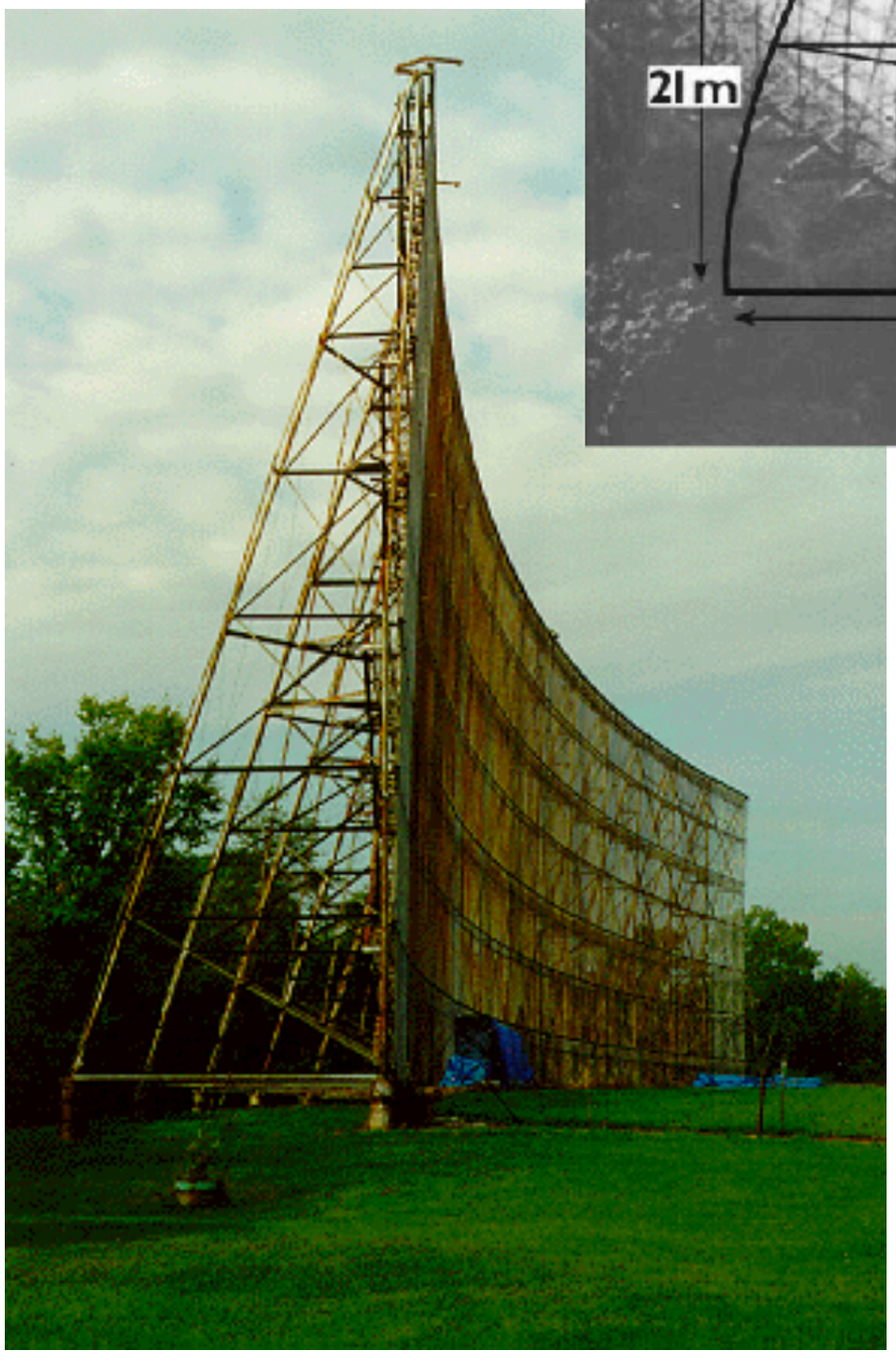
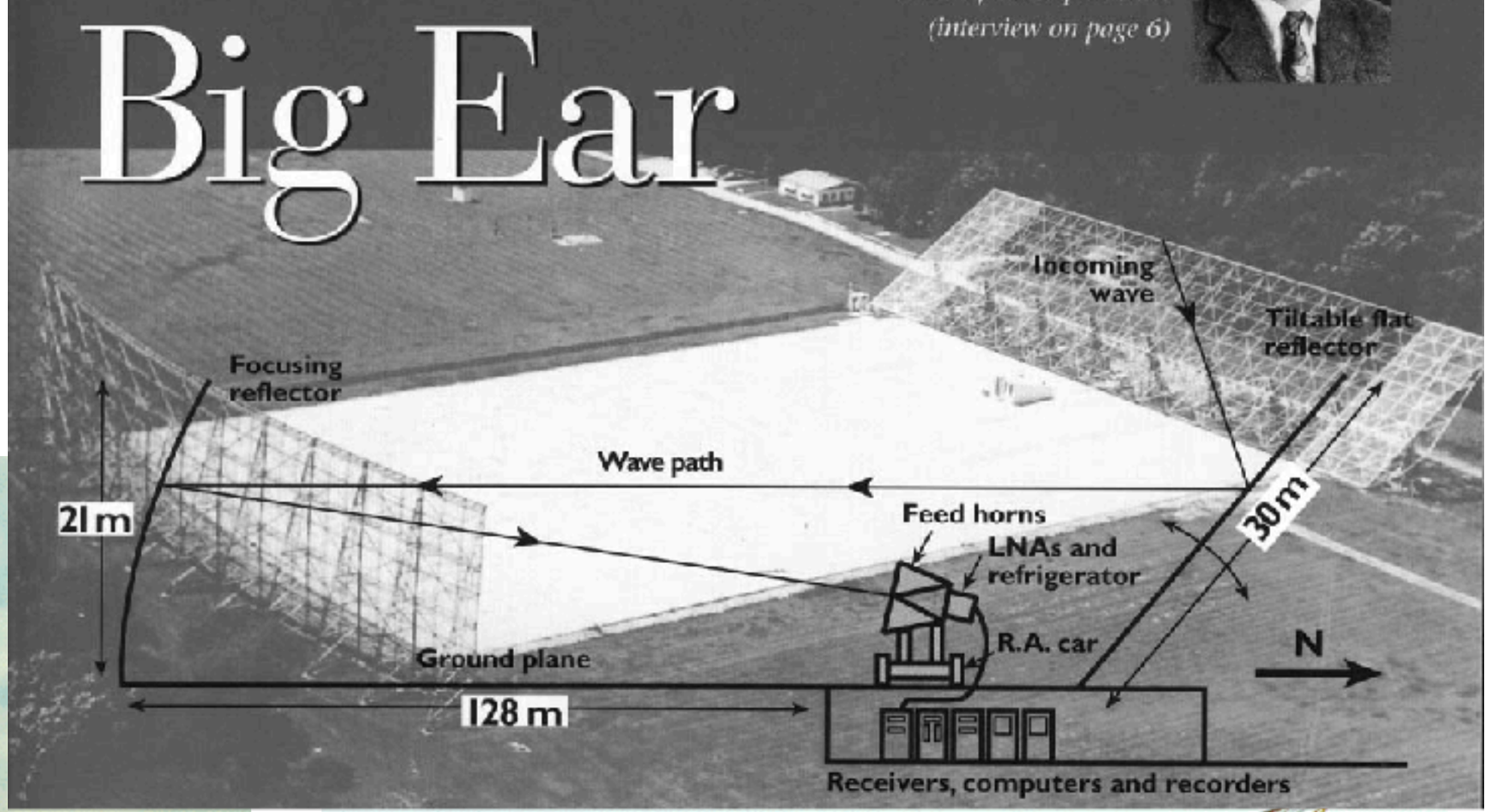


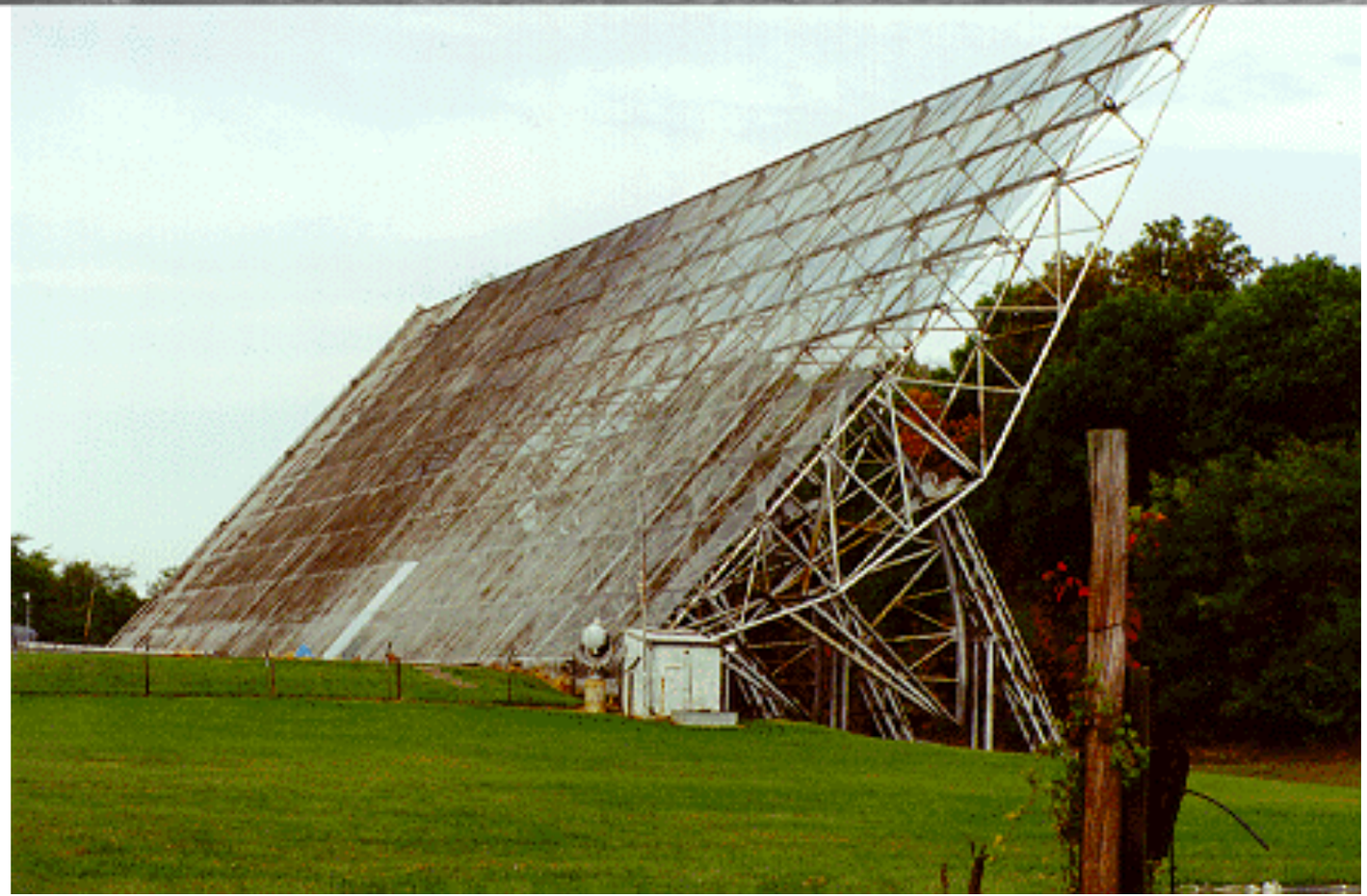
Very asymmetric PSF

- Not necessarily able to do all high-resolution science
- Fine for exoplanets
  - Systems randomly oriented on sky
  - *most* systems move into in high-res separation *some* of the time

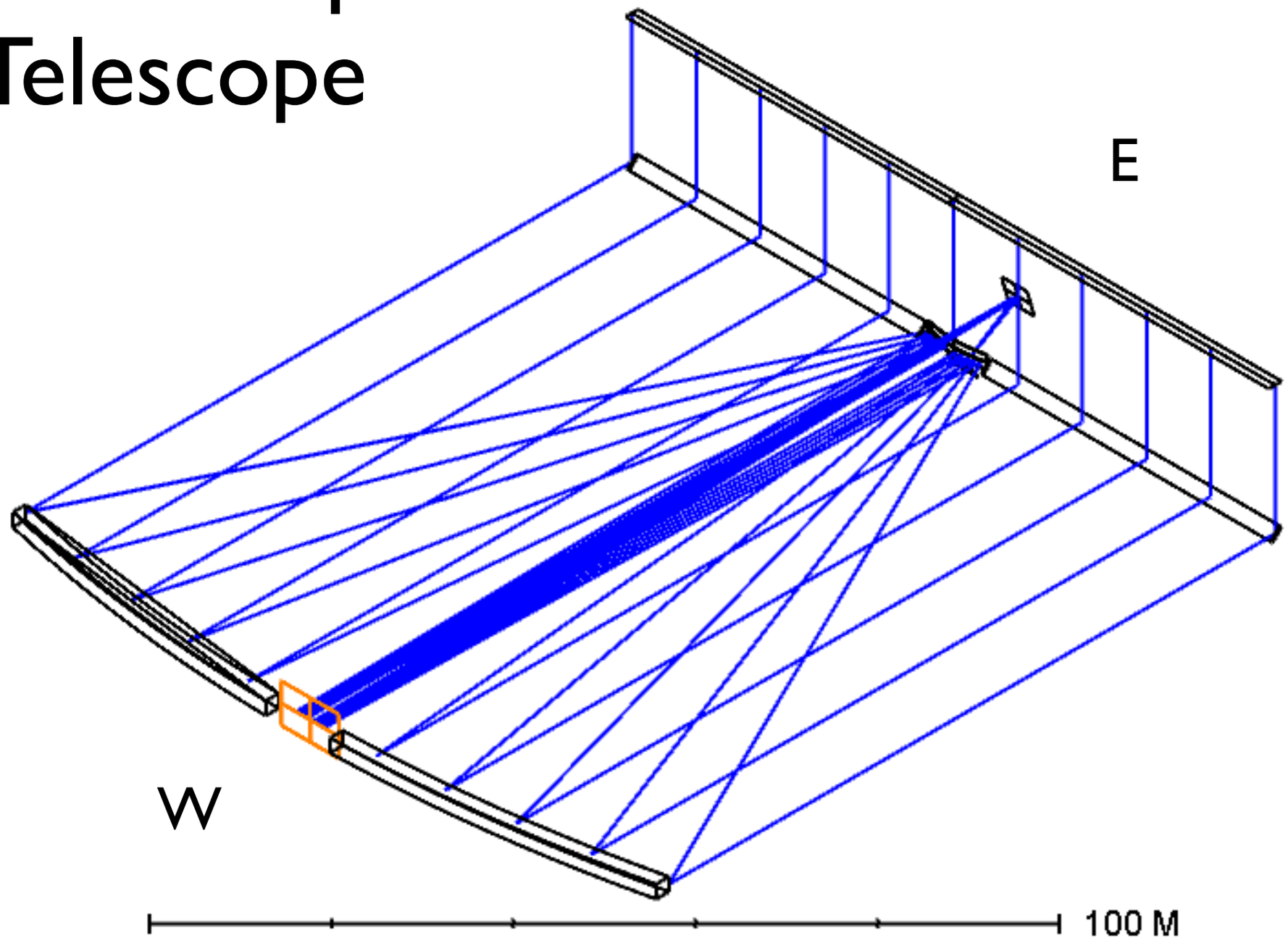
Kraus -type



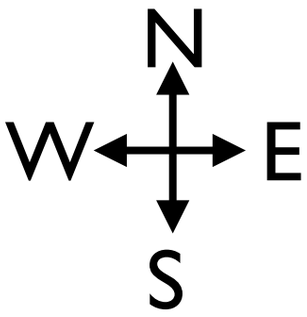

Big Ear
(interview on page 6)
Incoming wave
Tiltable flat reflector
Focusing reflector
Wave path
21 m
Feed horns
LNAs and refrigerator
30 m
R.A. car
N
Ground plane
128 m
Receivers, computers and recorders



WAET: Wide Aperture Exoplanet Telescope

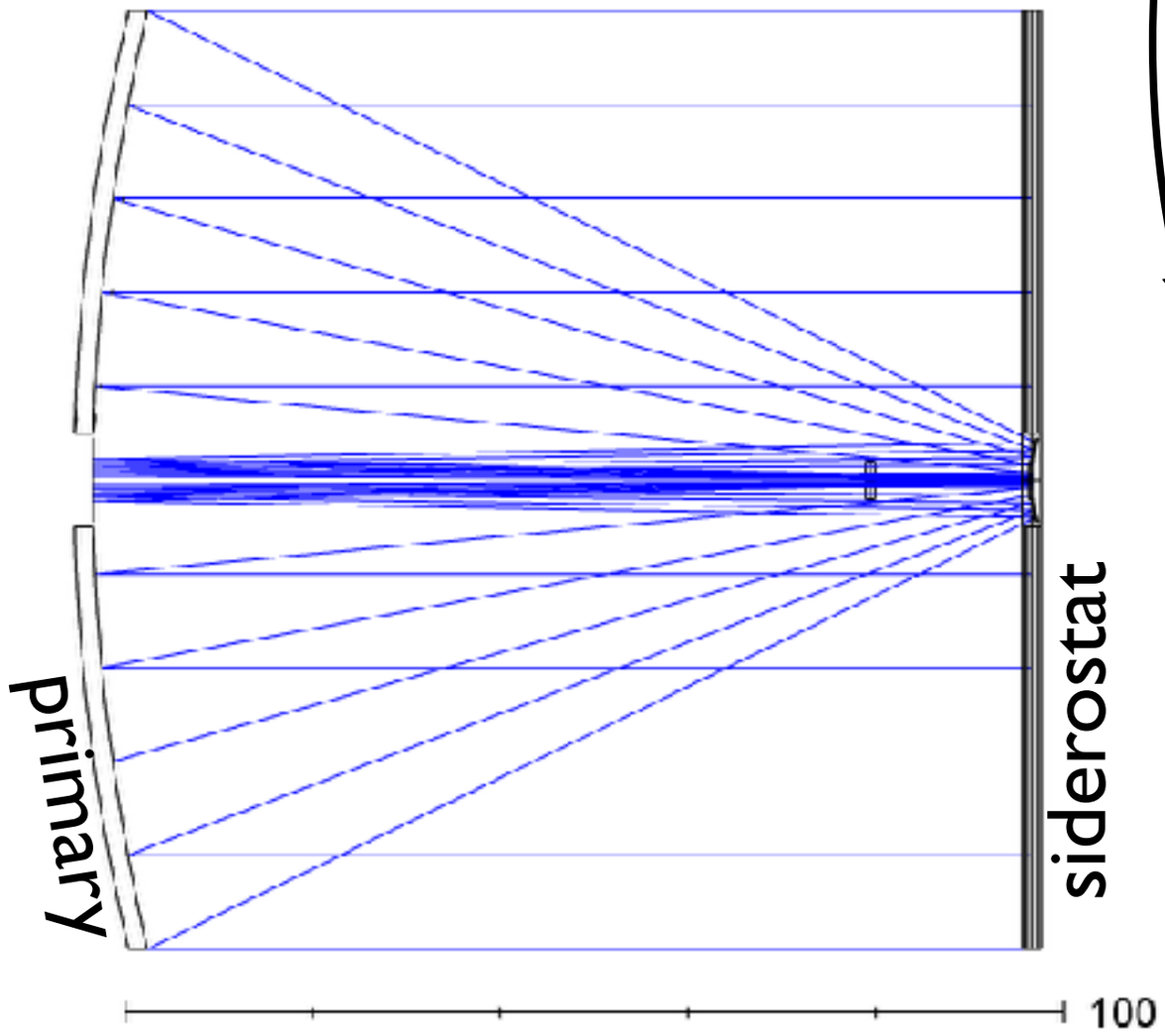


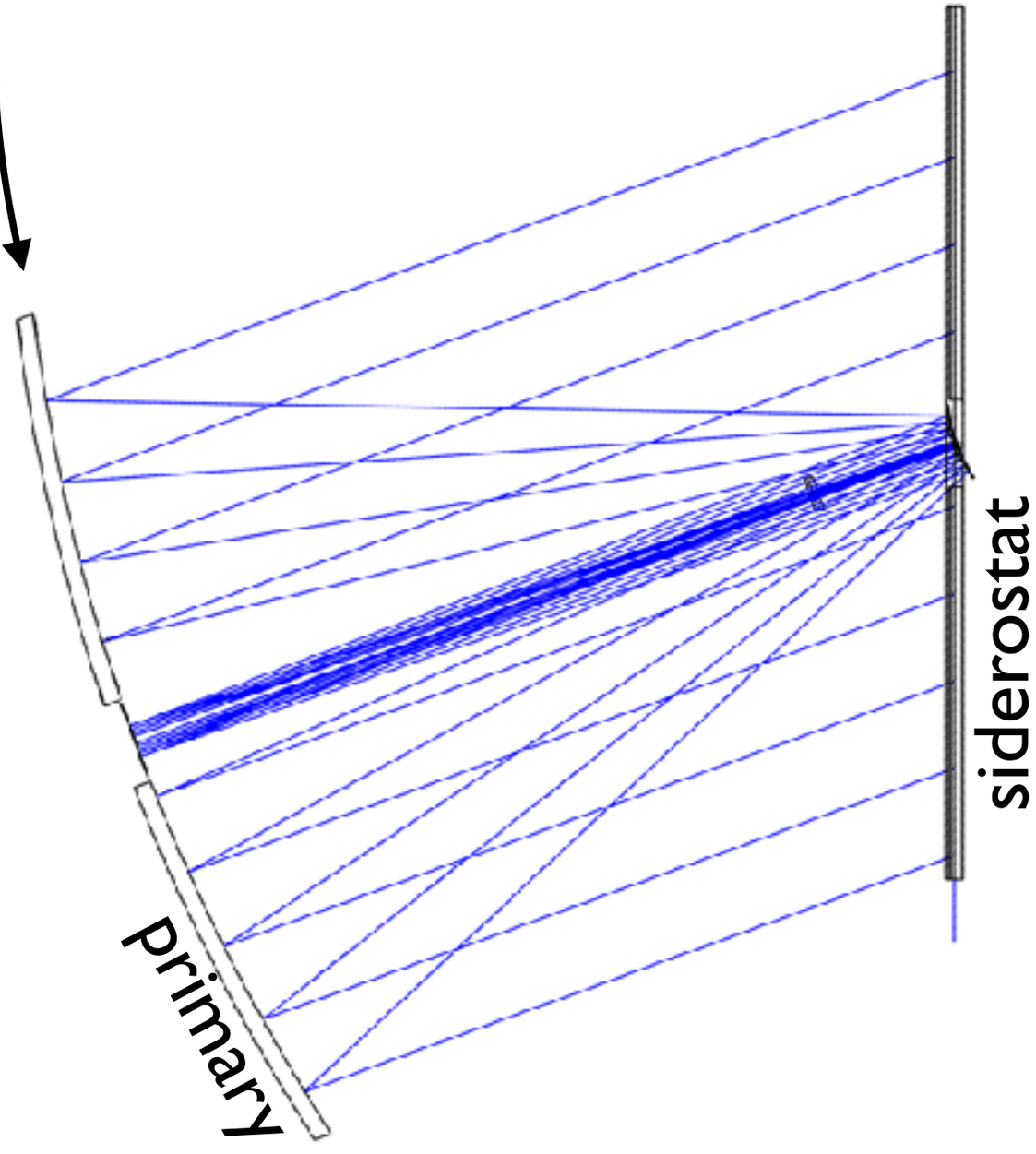
Zemax model by Mingyuan Wang



top view

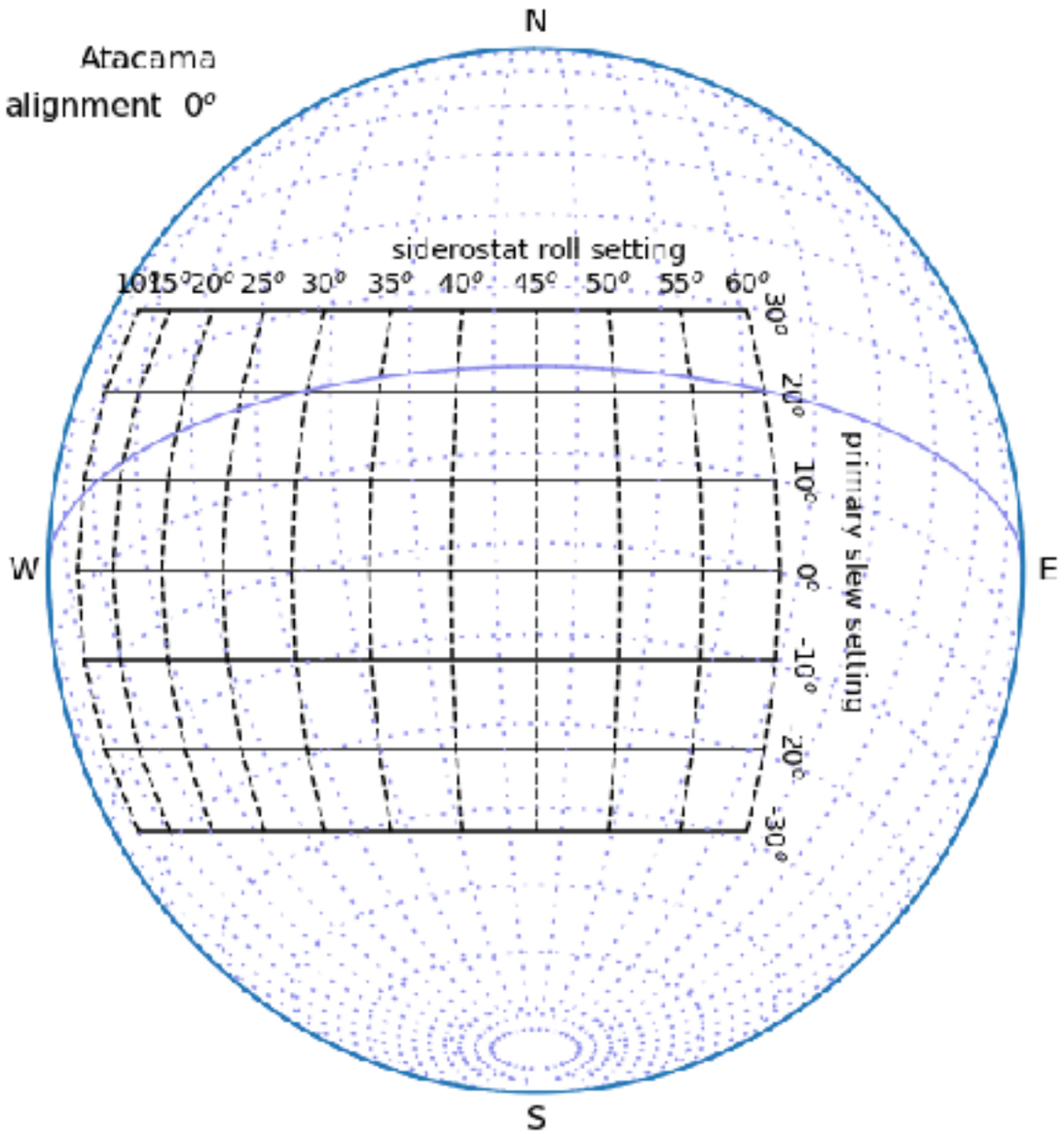
Primary "slew" motion
= slide along ground

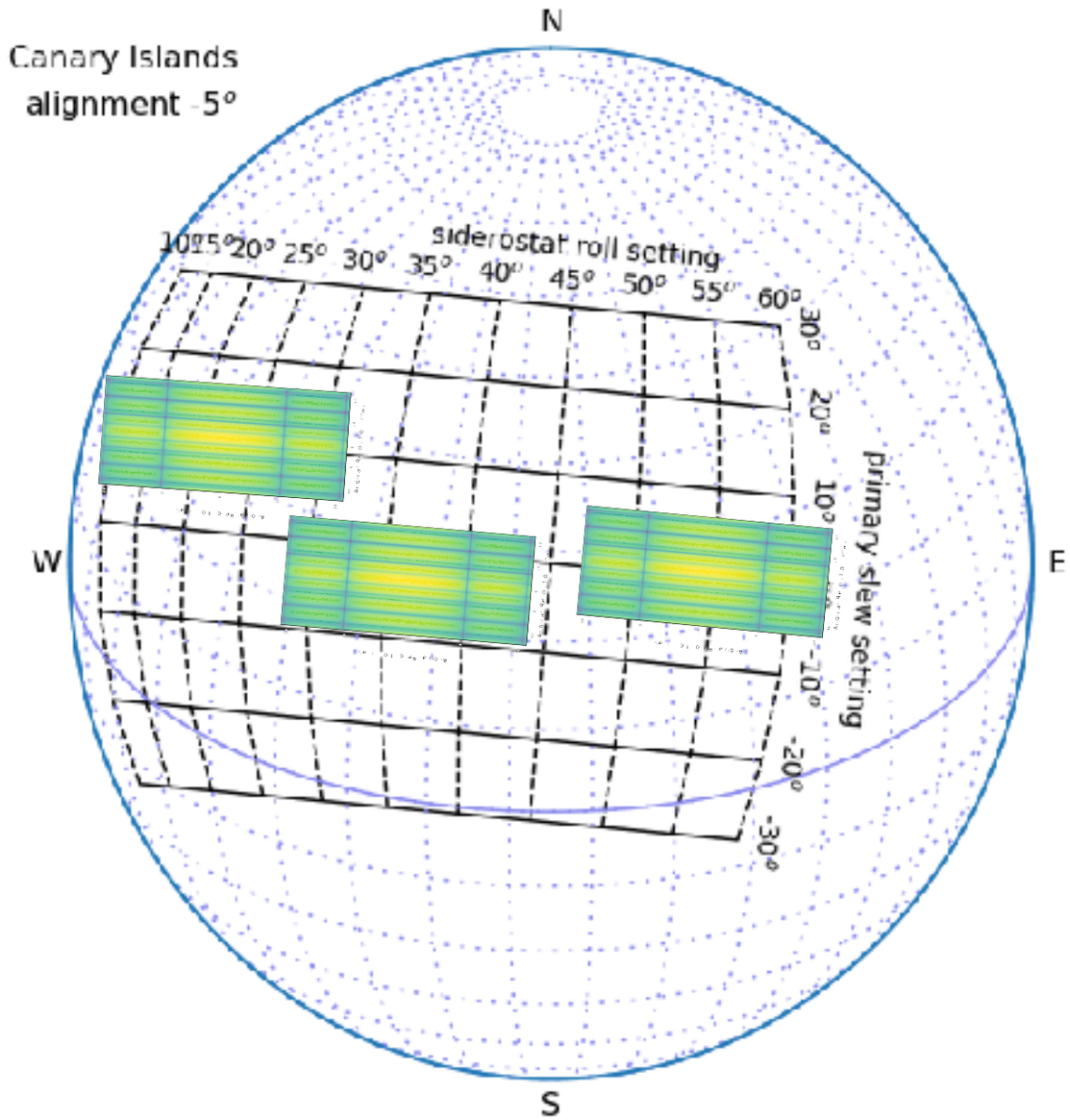


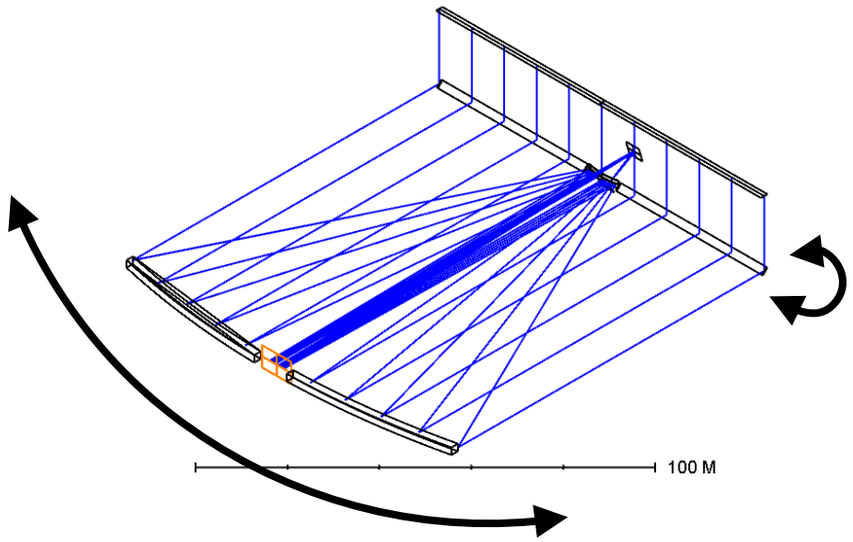


Sky coverage

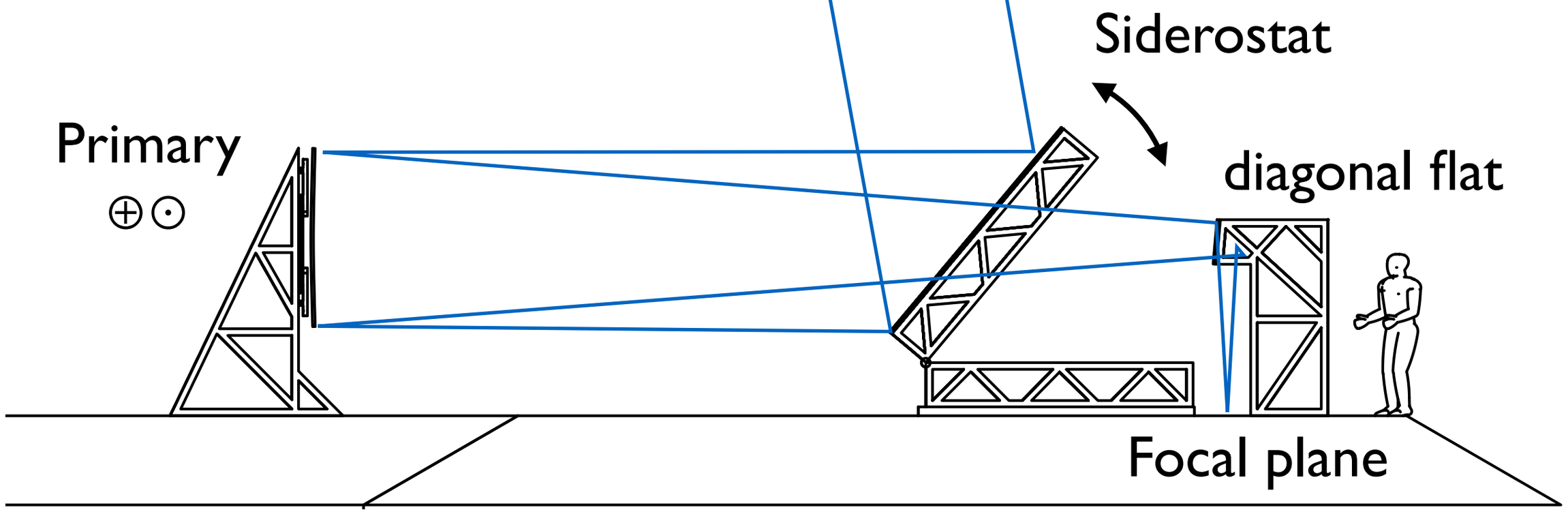
- Siderostat axis not necessarily N-S
- Minimize field rotation?

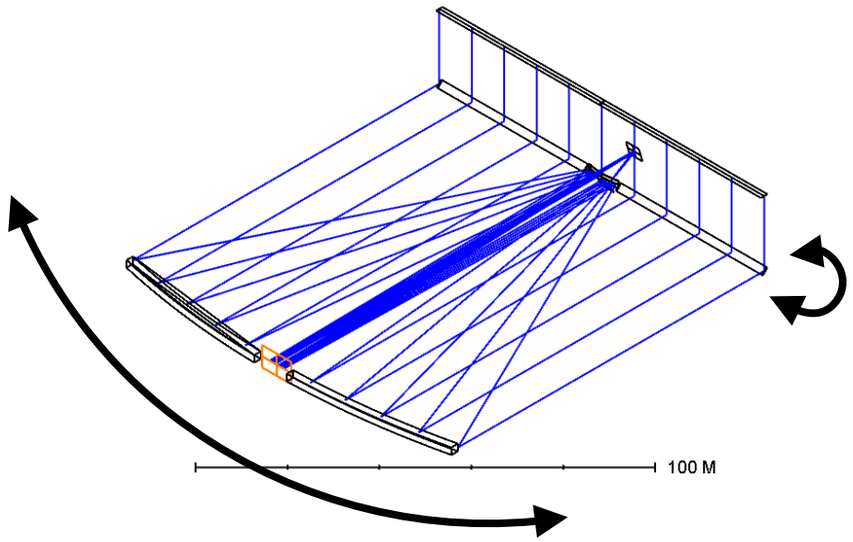






- WAET geometry fits any prescription (Newtonian, RC, spherical)
- Tolerates long focal lengths
- Large refractive optics possible





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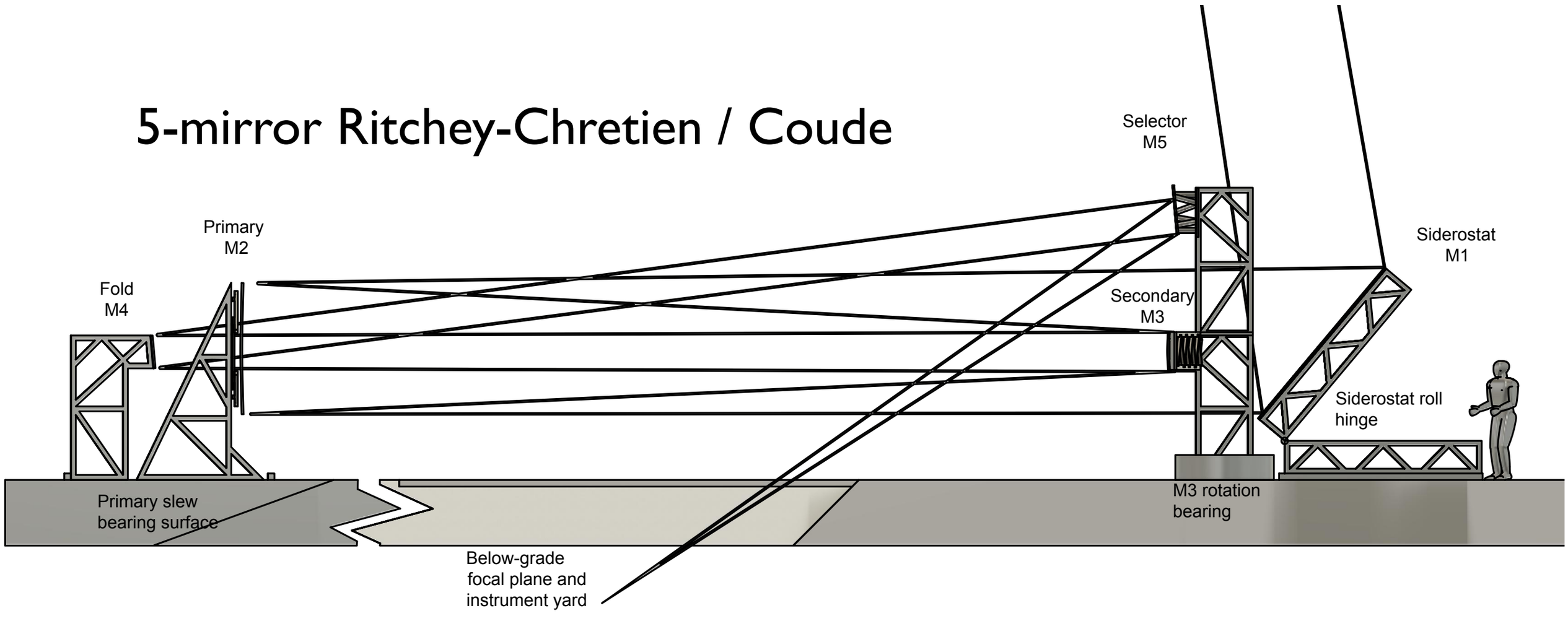
5-mirror Ritchey-Chretien / Coude

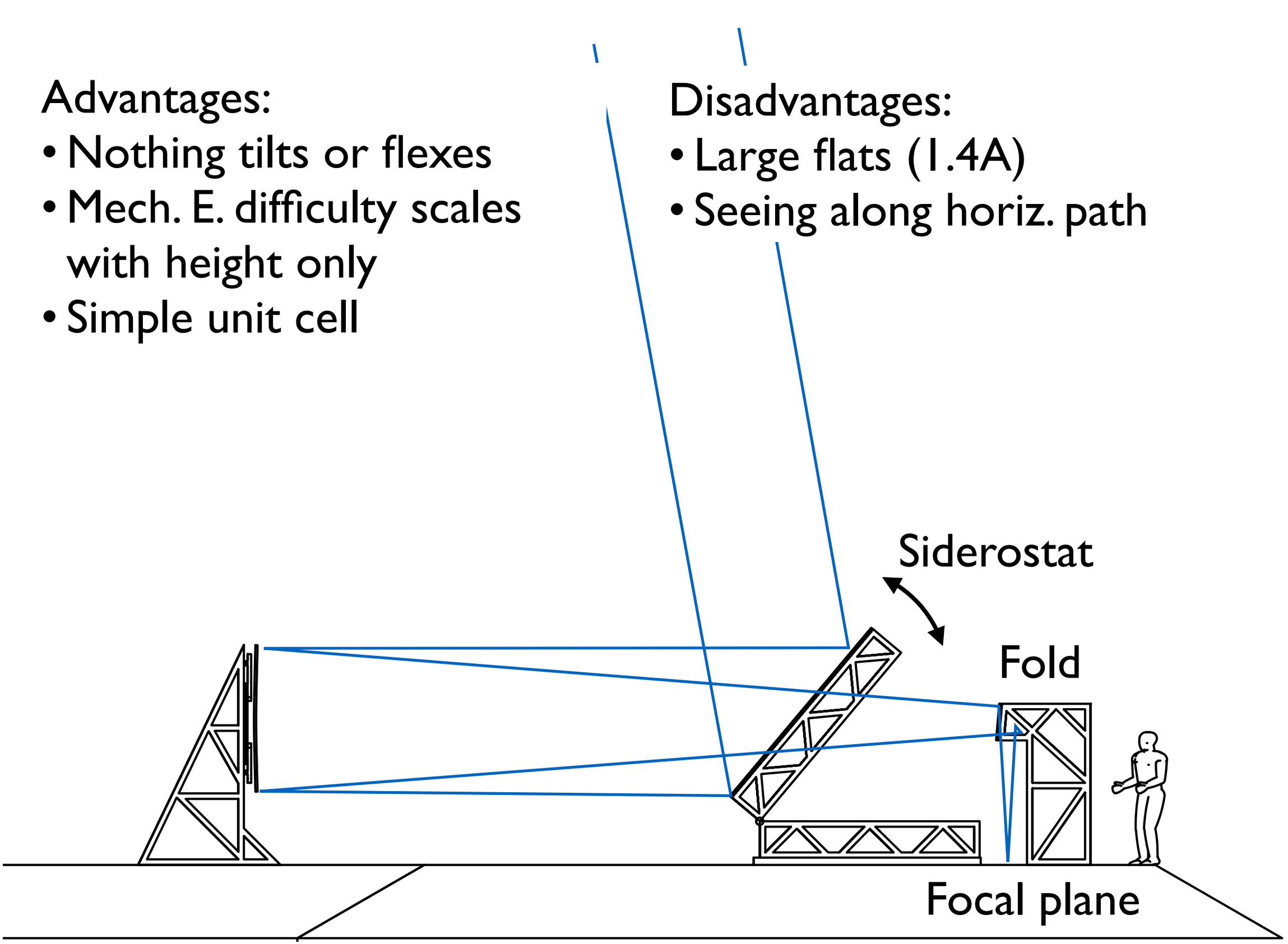


Advantages:

- Nothing tilts or flexes
- Mech. E. difficulty scales with height only
- Simple unit cell

Disadvantages:

- Large flats (1.4A)
- Seeing along horiz. path



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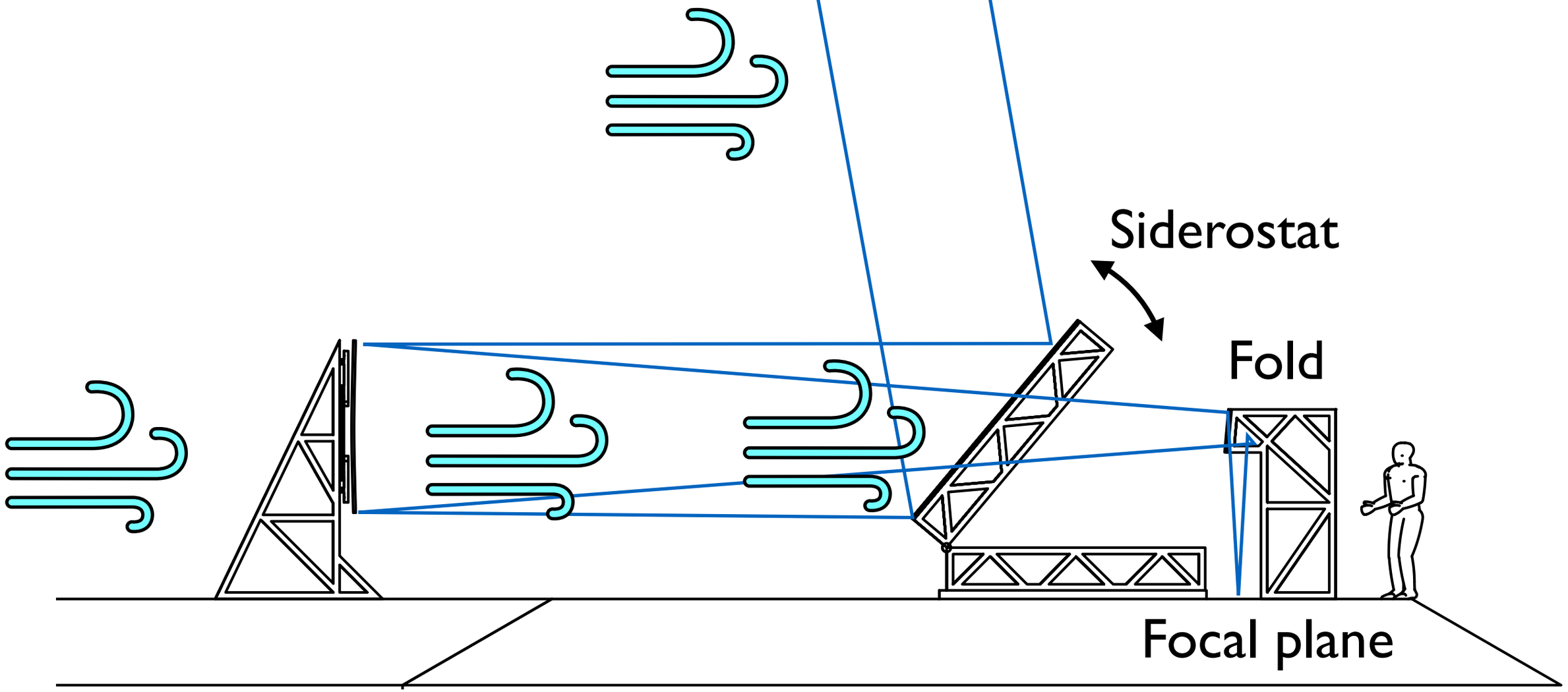

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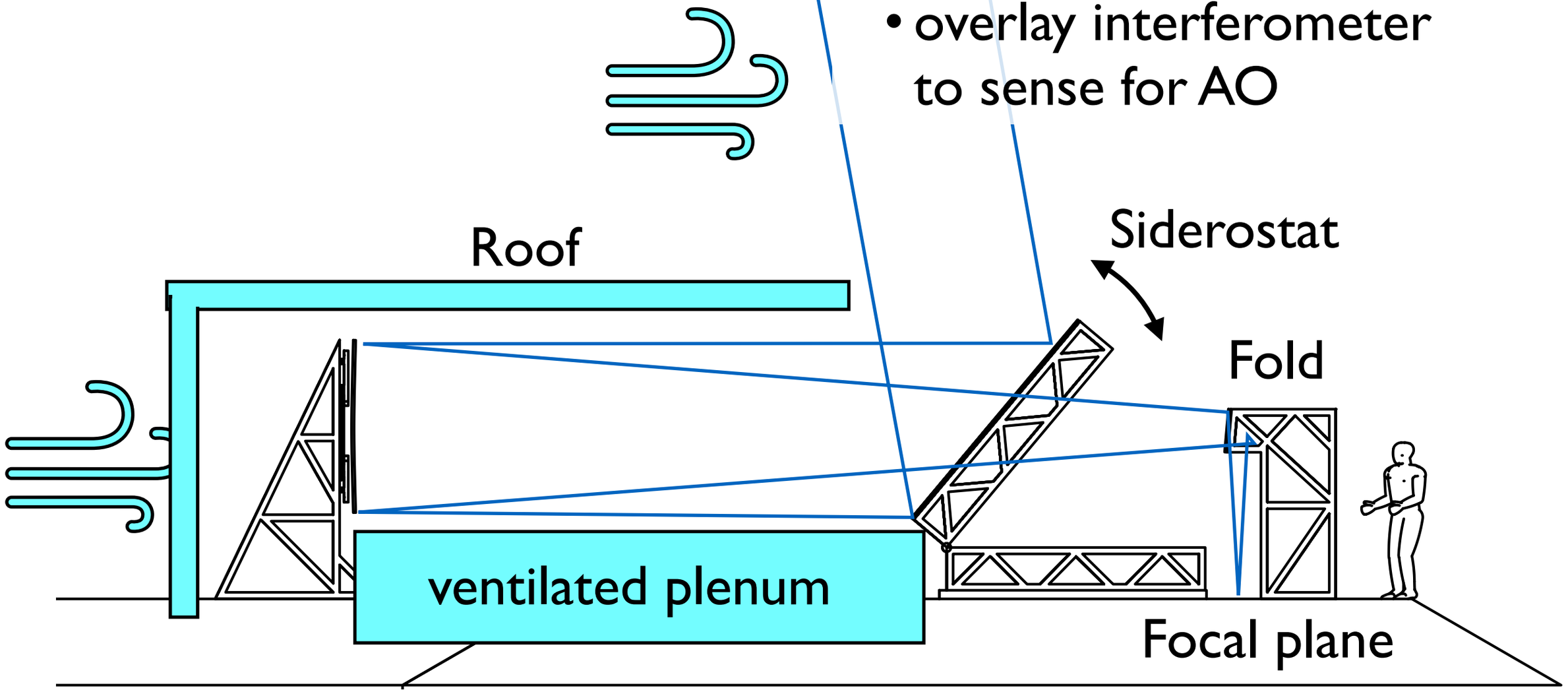
  - roof
  - overlay interferometer to sense for AO



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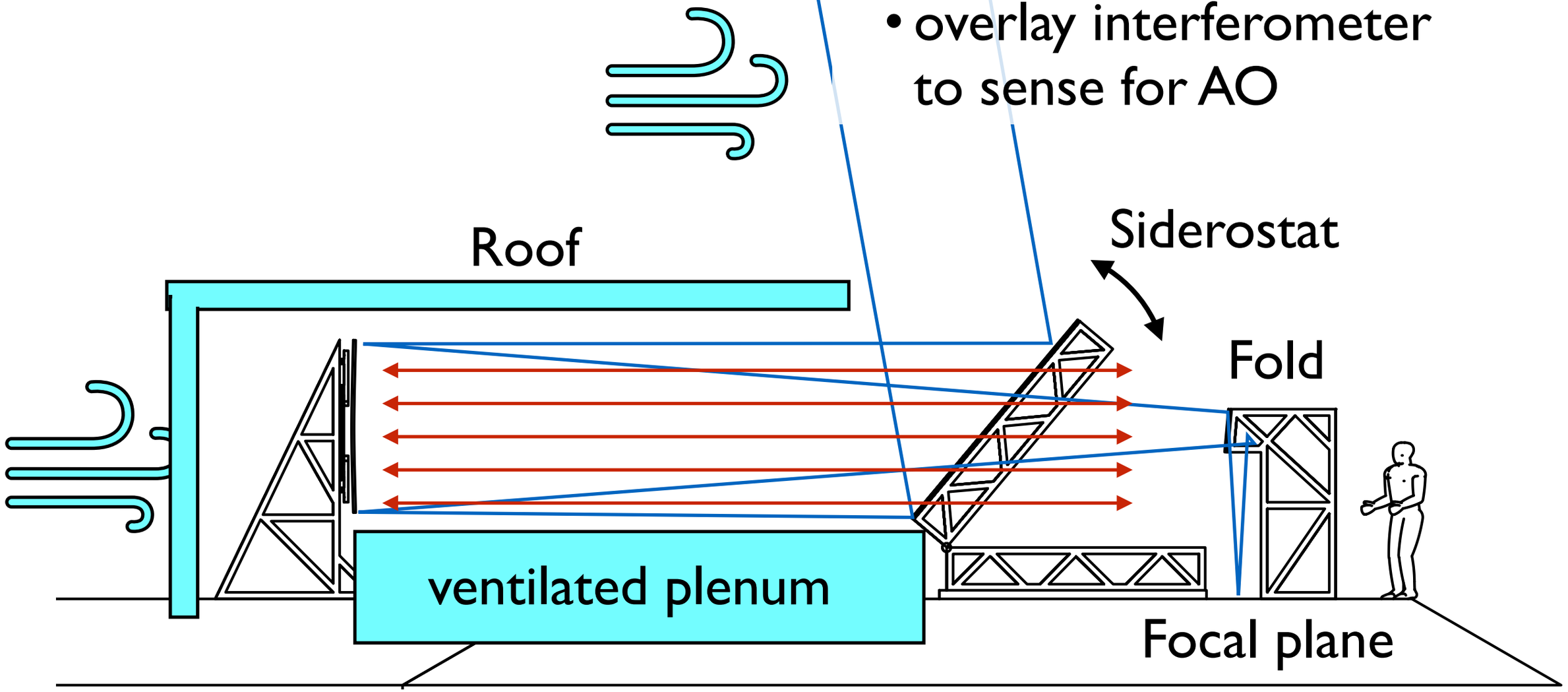
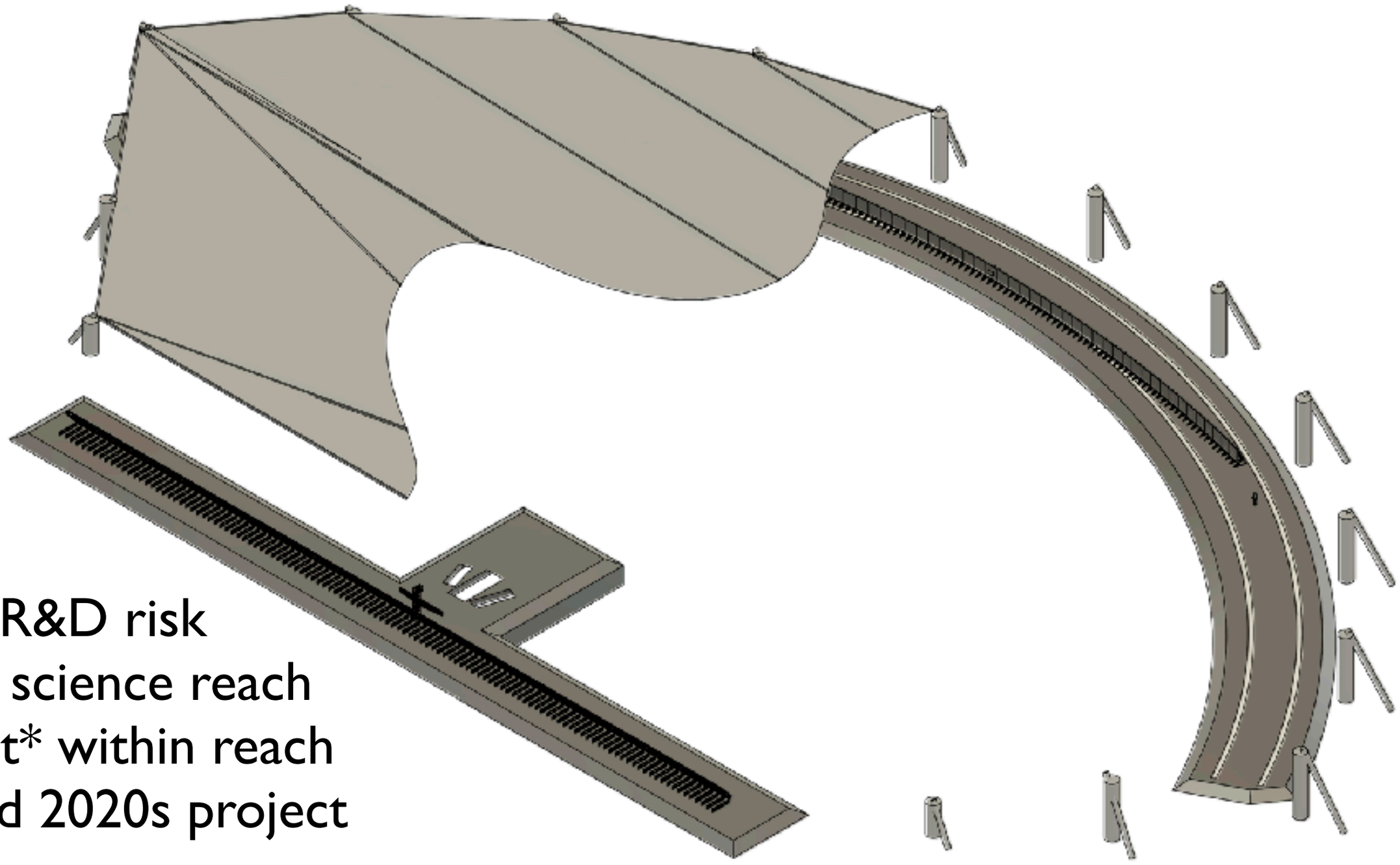


hWAET

100 m x 2 m
2 mas @ 1μm

	hWAET	Keck	TMT	OWL
Area	200 m^2	2.5x	1/3 x	1/40x
L	100 m	10x	3x	1x
Cost	$150M	1x	1/8 x	1/10x

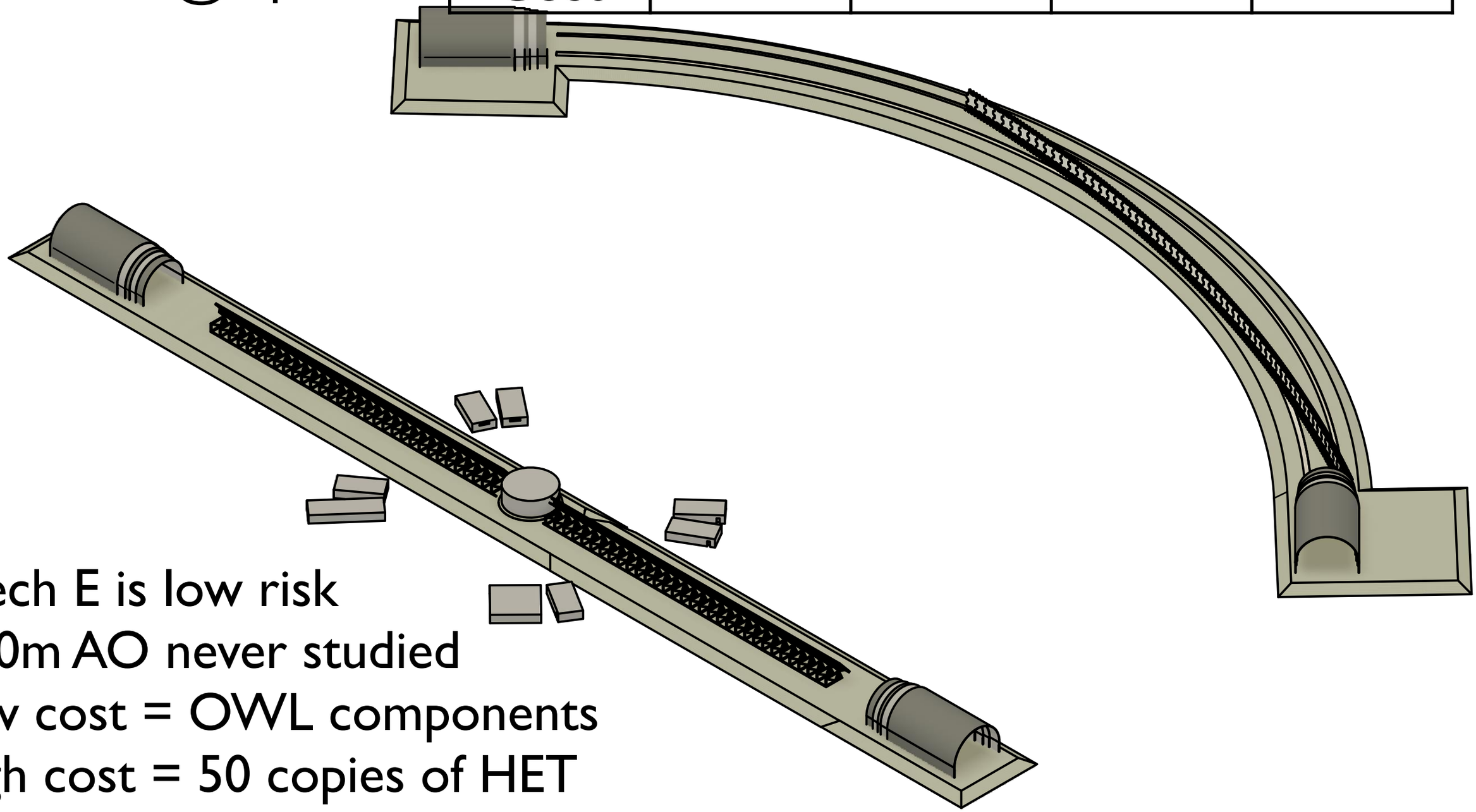


Low* R&D risk
New* science reach
Budget* within reach
= good 2020s project

kWAET

300 m x 5 m
0.7 mas @ 1μm

	kWAET	Keck	TMT	OWL
Area	1500 m^2	20x	2x	1/5
L	300 m	30x	10x	3x
Cost	$250-950M	more	less	less



Mech E is low risk
300m AO never studied
low cost = OWL components
high cost = 50 copies of HET

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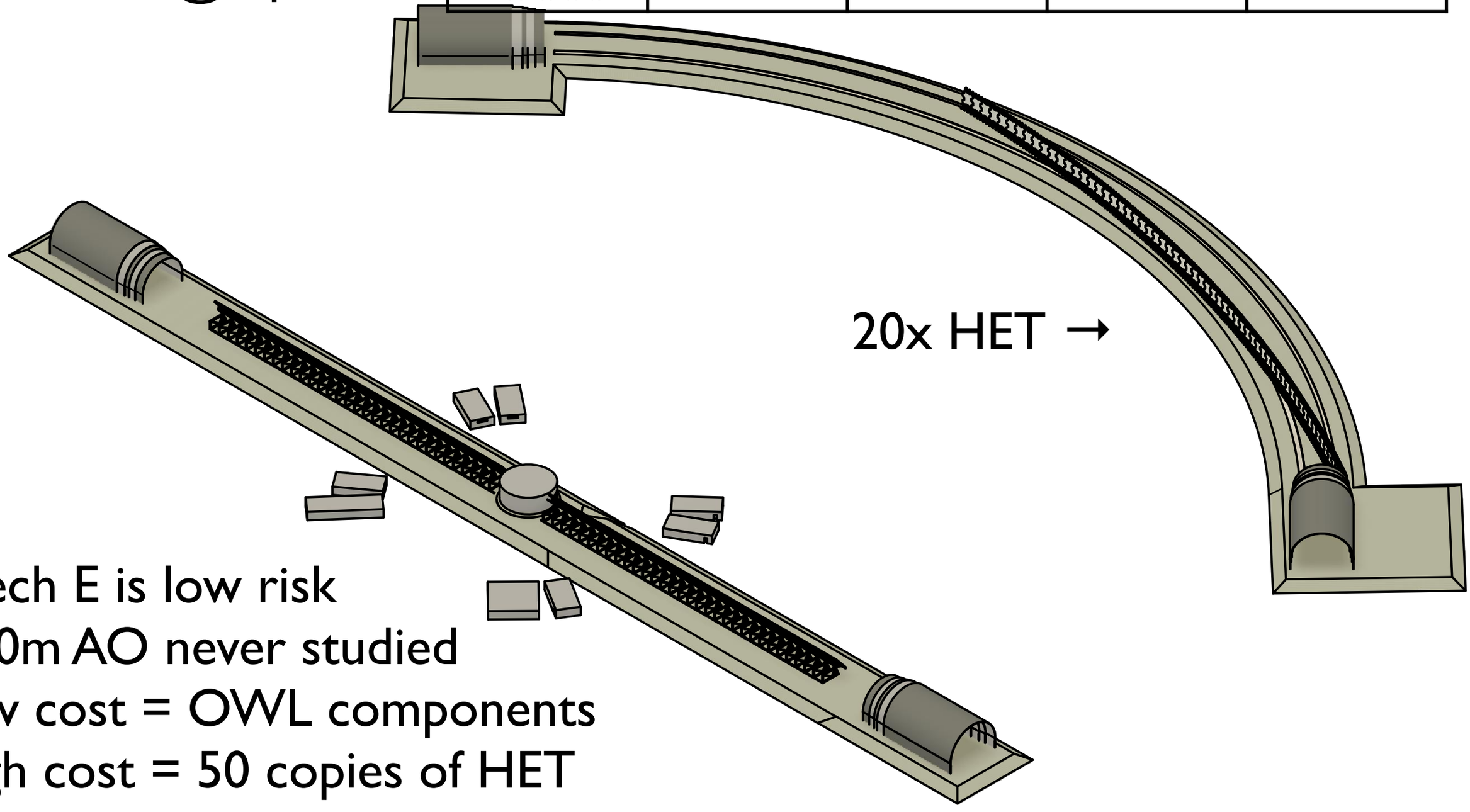

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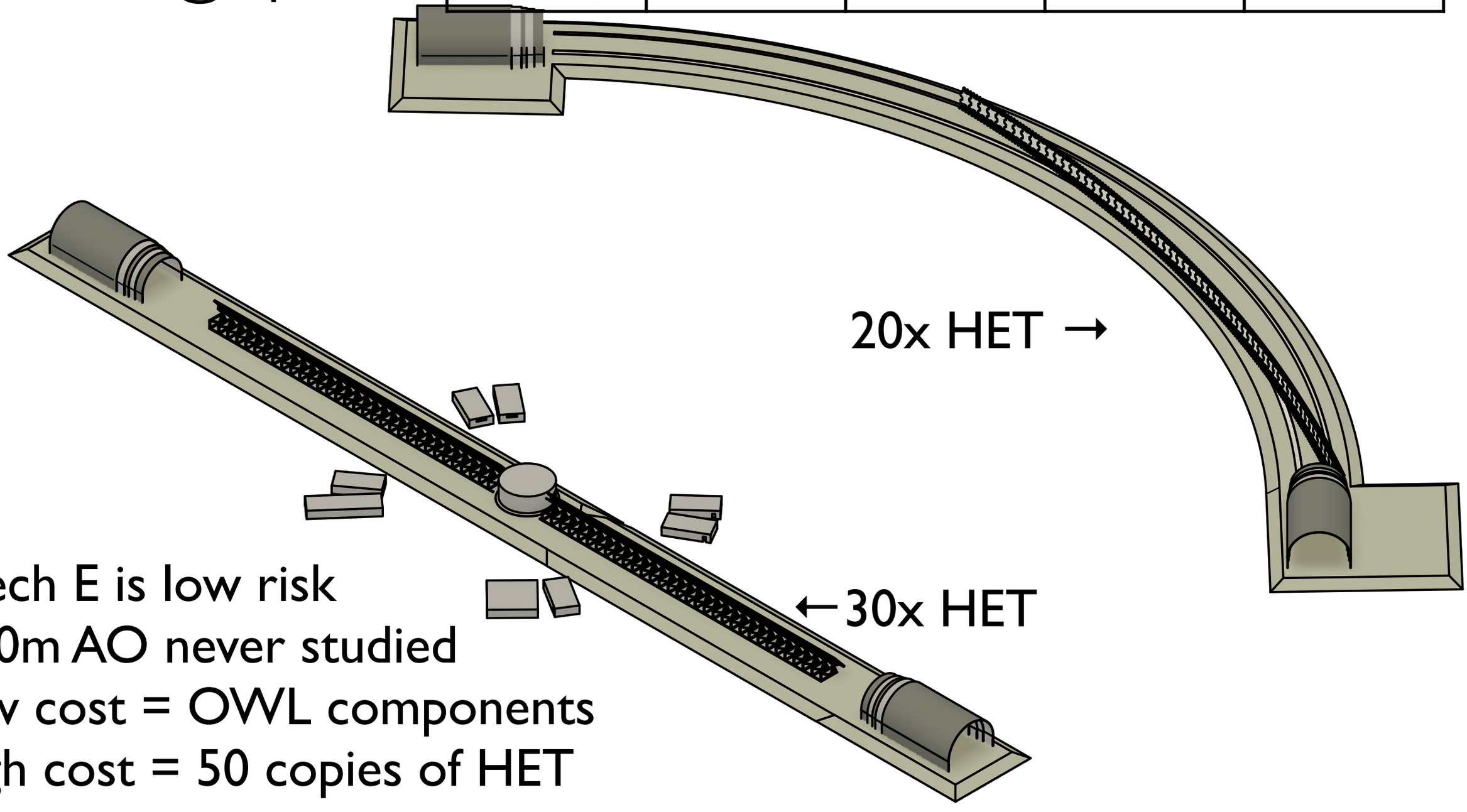

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Conclusions and path forward

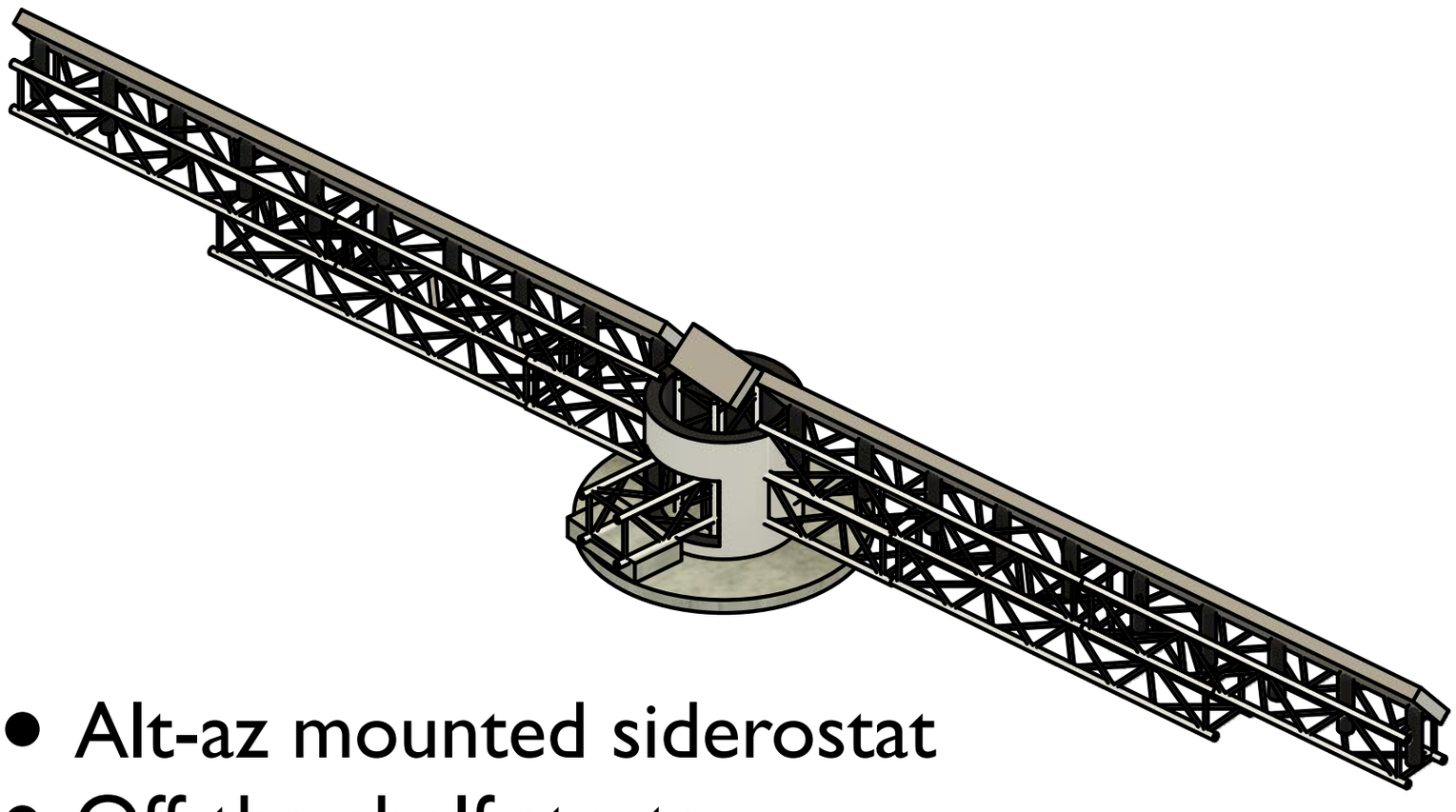
- hWAET (100x2 m) has attractive cost/scope/schedule
- #1 need: a real fluid + thermal + AO model
  - First candidate for showstopper problems
    - Science case? If xAO → rocky planet reflected light
- Specific plea:
  - help!
- General plea:
  - publish your management data!! (costs, effort, etc.)

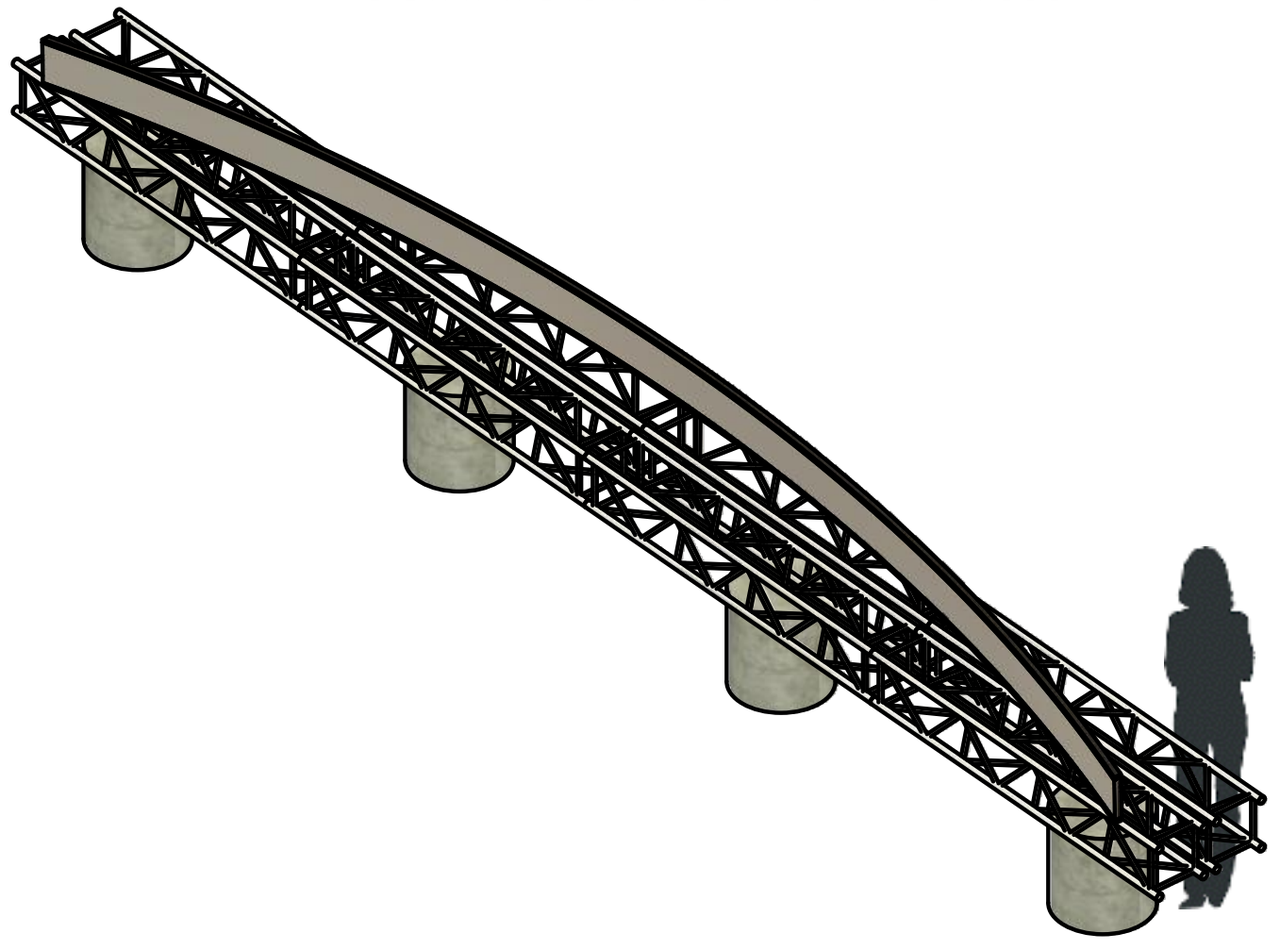
Backup slides

dWAET

10 m x 30 cm
20 mas @ 1μm

- Area (and cost?) of a 2m
- Resolution of a 10m





- Alt-az mounted siderostat
- Off-the-shelf struts
- Whole system fits in a 40’ truck or container

Three example configurations			
	dWAET	hWAET	kWAET
Length (m)	10.0	100	300
Width (m)	0.30	2.0	5.0
Aperture (m^2)	3.0	200	1500
λ/d @1μm (as)	21m	2.1m	690μ
Cost estimates ($)			
Primary mirror	1.50M	100M	450M
Siderostat mirror	760k	51M	380M
Supports	43000	2.8M	21M
Foundation/sheds	15000	760k	5.1M
Thermal	4000	10.0M	18.0M
Total	2.3M	153M	850M
Cost/m^2	770k	770k	560k

Cost estimation

Cost scaling estimates			
Component	Version		Scaling estimate
Steel framework		\$2k	$L \times W$
Air bearings		\$2k	$L \times W$
Mirror cells		\$10k	$L \times W$
Enclosures		\$2k	$L \times W^{0.5}$
Siderostat mirror		\$150k	$L \times W$
Primary mirror	Aspheric	\$450k	$L \times W$
	HET-like	\$200k	$L \times W$
	OWL-like	\$80k	$L \times W$
Slab and bearing	Primary-slew	\$250	$L^{1.6}$
	Siderostat-pivot	\$150	L^2
Thermal control	Ground cover	\$40	L^2
	Roof (flat)	\$200	L^2
	Roof (tension)	\$1k	L^2

Cost estimation

Cost scaling estimates

Component	Version	Scaling estimate
Steel framework		\$2k L×W
Air bearings		\$2k L×W
Mirror cells		\$10k L×W
Enclosures		\$2k $L \times W^{0.5}$
Siderostat mirror		\$150k L×W
Primary mirror	Aspheric	\$450k L×W
	HET-like	\$200k L×W
	OWL-like	\$80k L×W
Slab and bearing	Primary-slew	\$250 $L^{1.6}$
	Siderostat-pivot	\$150 L^2
Thermal control	Ground cover	\$40 L^2
	Roof (flat)	\$200 L^2
	Roof (tension)	\$1k L^2

Ama Carney 100m engineering model

Christian Rodriguez went to Caltech archives for Keck project records

derivable from the literature

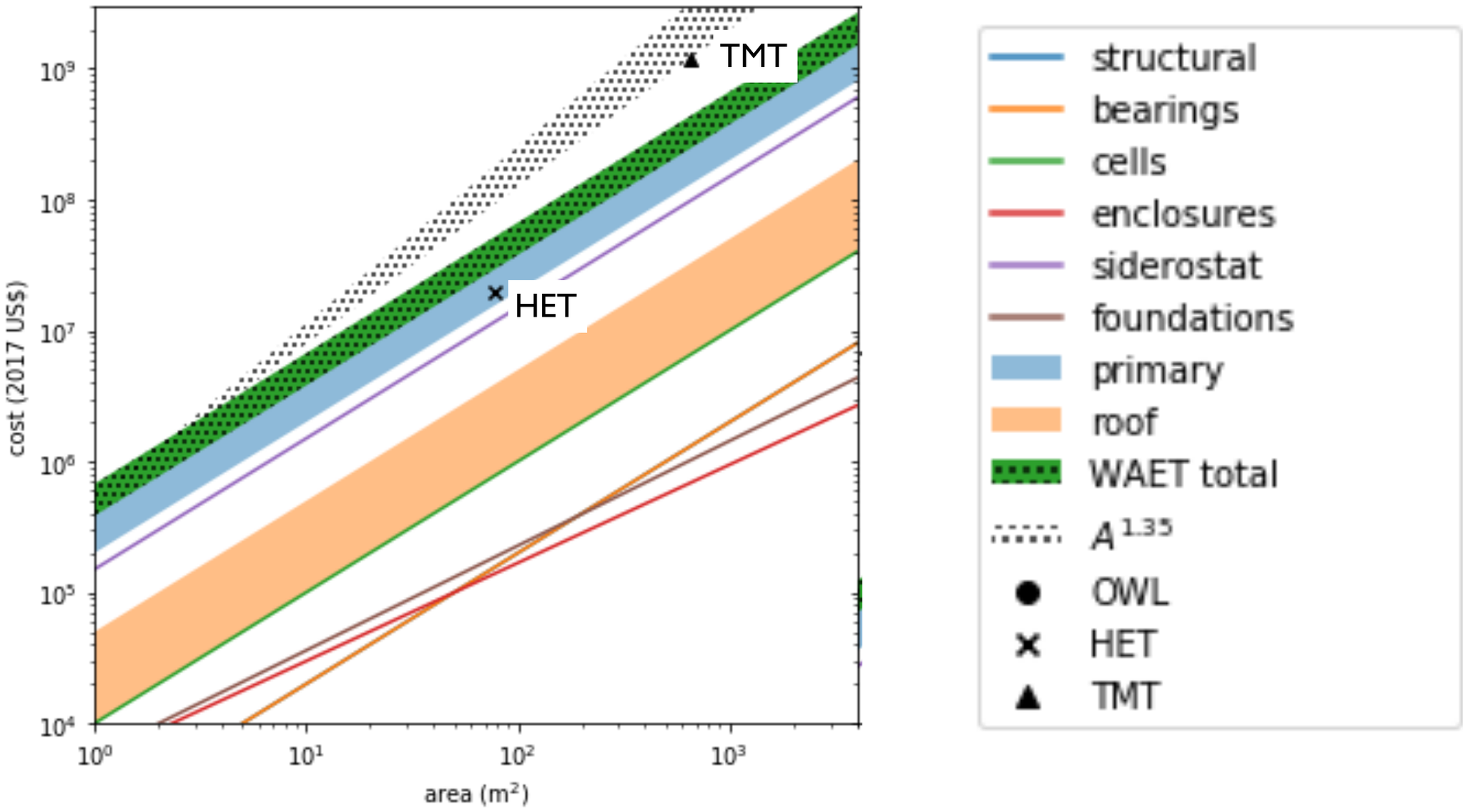
Wikipedia, TBH

Gilmozzi et. al.

some other industries are better about public cost estimation info

hangar and stadium projects

Cost estimation



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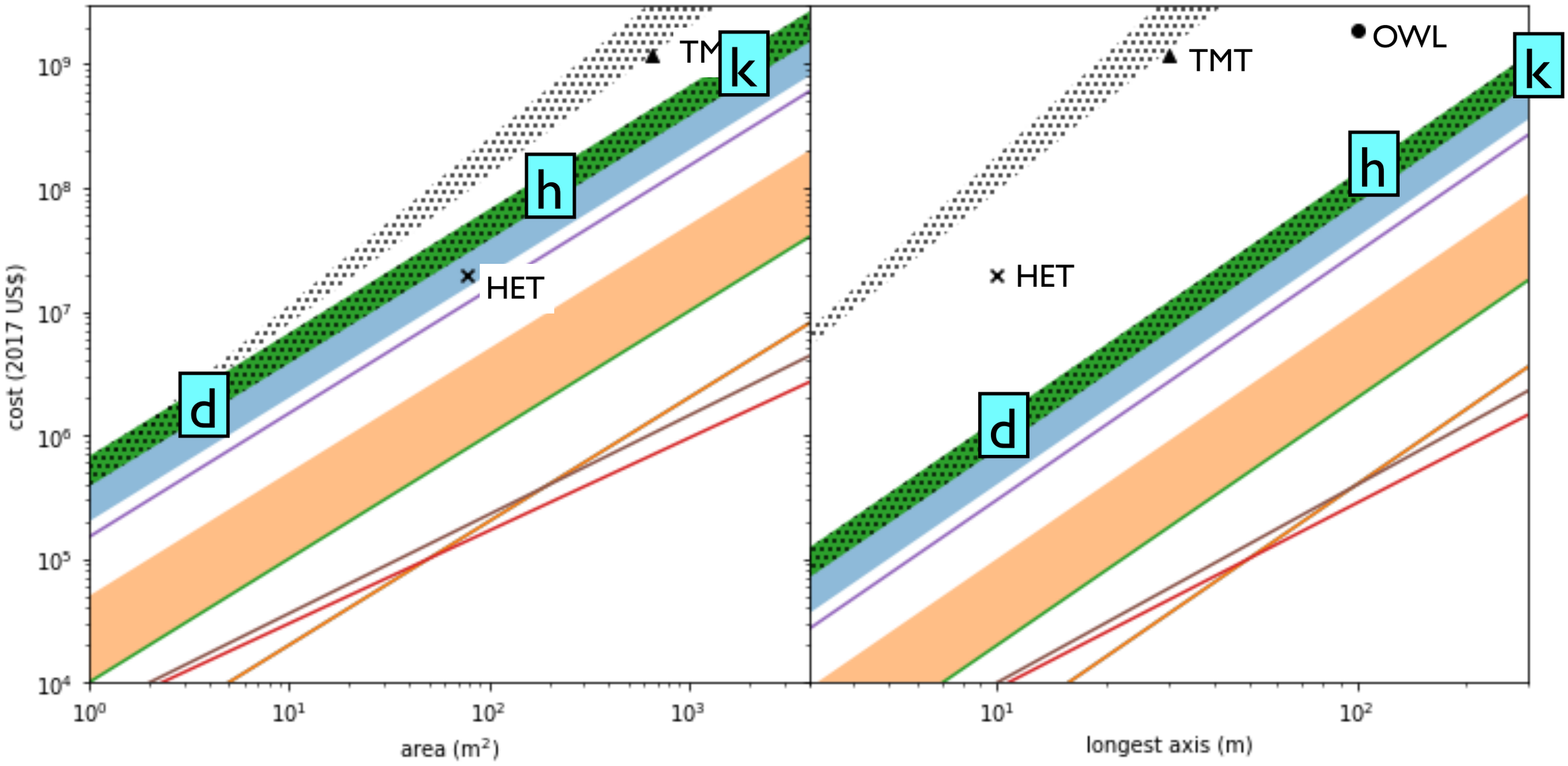

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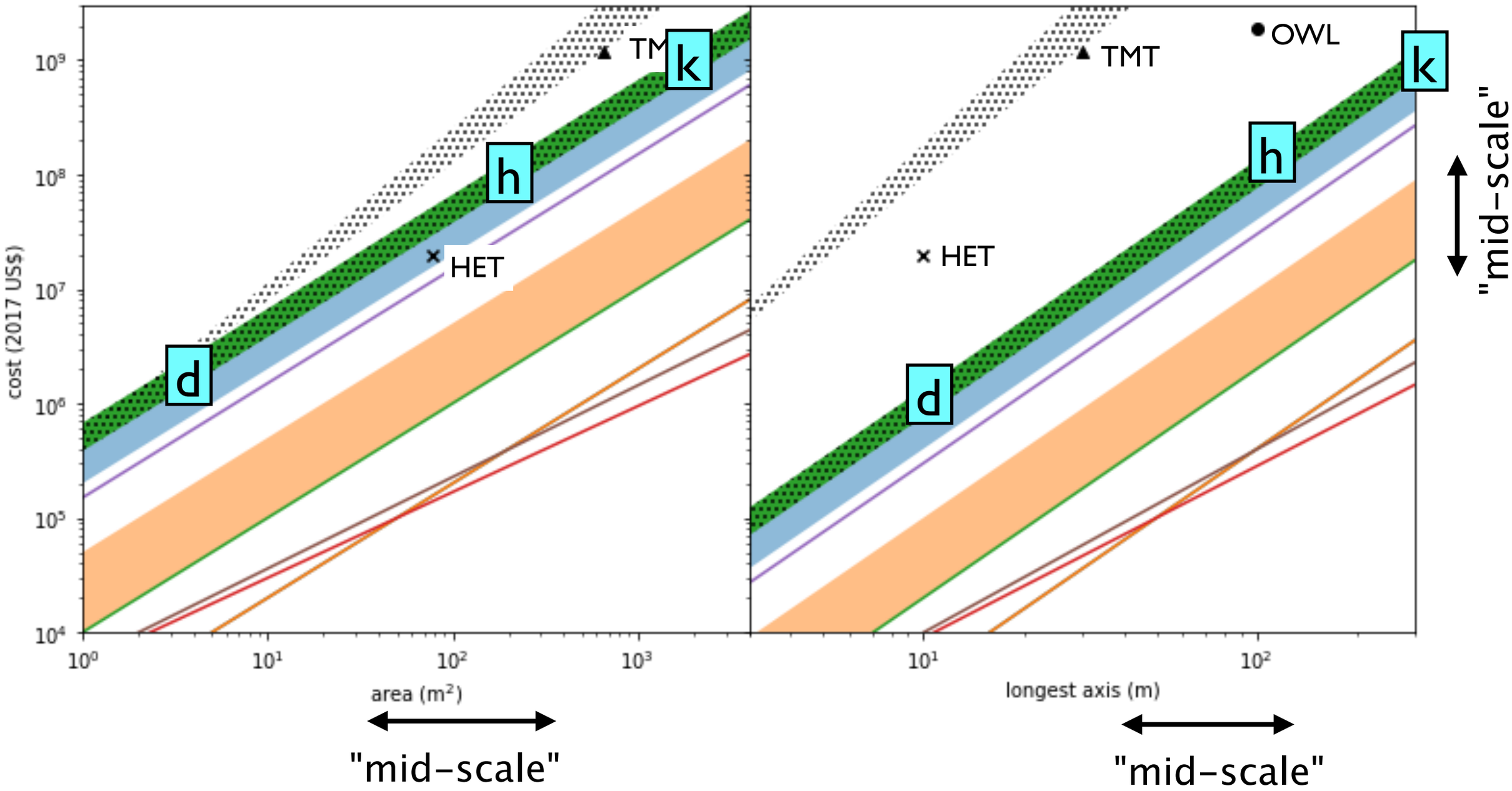


kWAET cost particularly uncertain

- What do mirrors really cost at this scale?
  - "Standard scaling" = $850M
  - 20 copies of entire HET = $600M
  - Gilmozzi et. al. published OWL cost estimator (virtually the only public domain literature at this detail)
    - Zerodur, shipping, slicing, etc..
    - OWL: $1.2B and kWAET : $150M (!?)

Conclusions

- No showstoppers yet; many questions
- My wish list:
  - More people involved
  - Fluid / AO model for hWAET, kWAET
  - Optical design constraints for hWAET
  - Mirror cost model
  - Engineering design of roof
  - Big wish: decadal survey
  - Bigger wish: actually build it

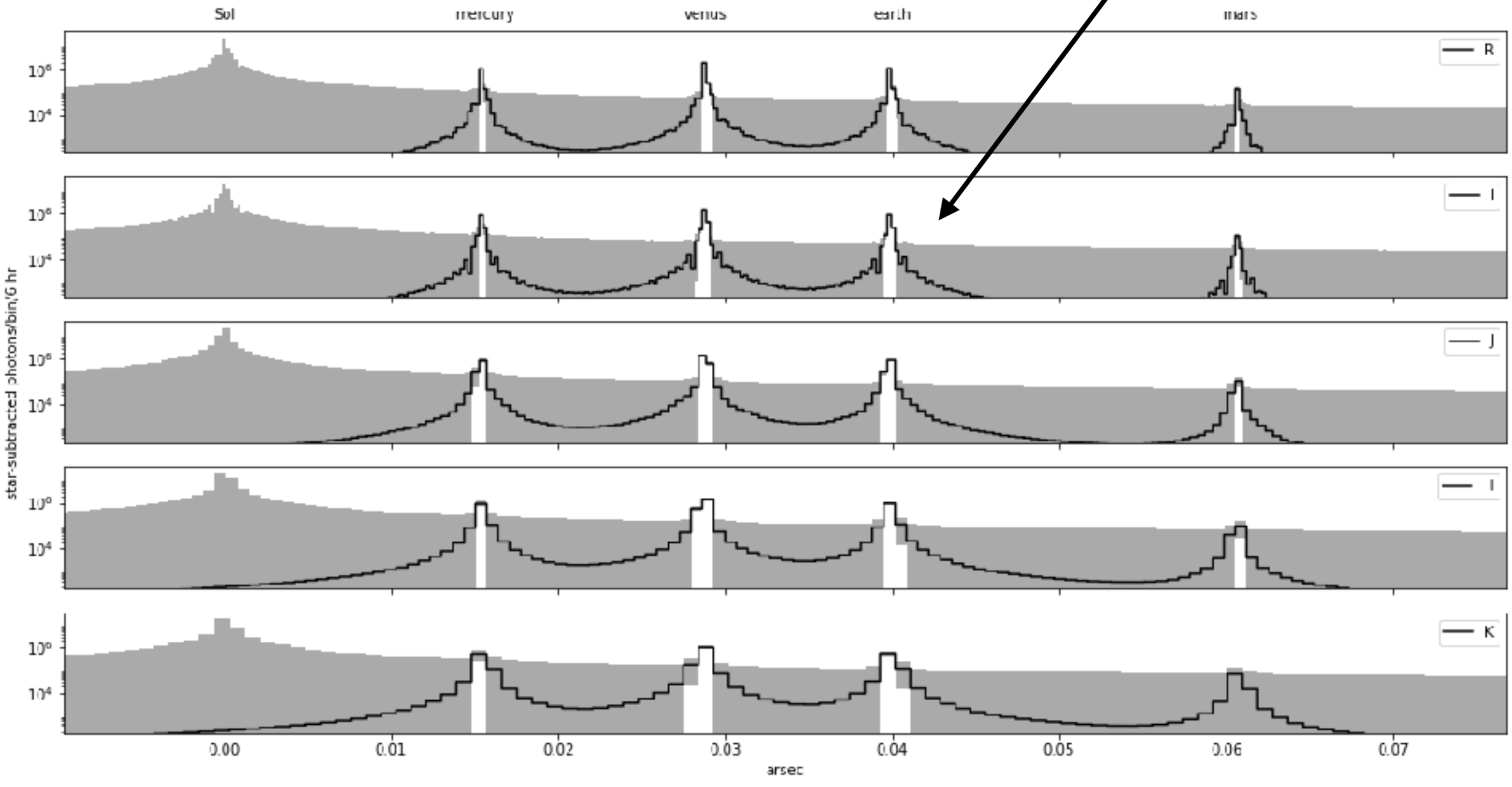
Thanks:
Rob Halliday
Ama Carney
Christian Rodriguez
Mingyuan Wang

kWAET

300 m x 5 m

the solar system
seen from 25pc
(rectangular aperture!)
(no coronagraph!)
(all albedos = 1.0)

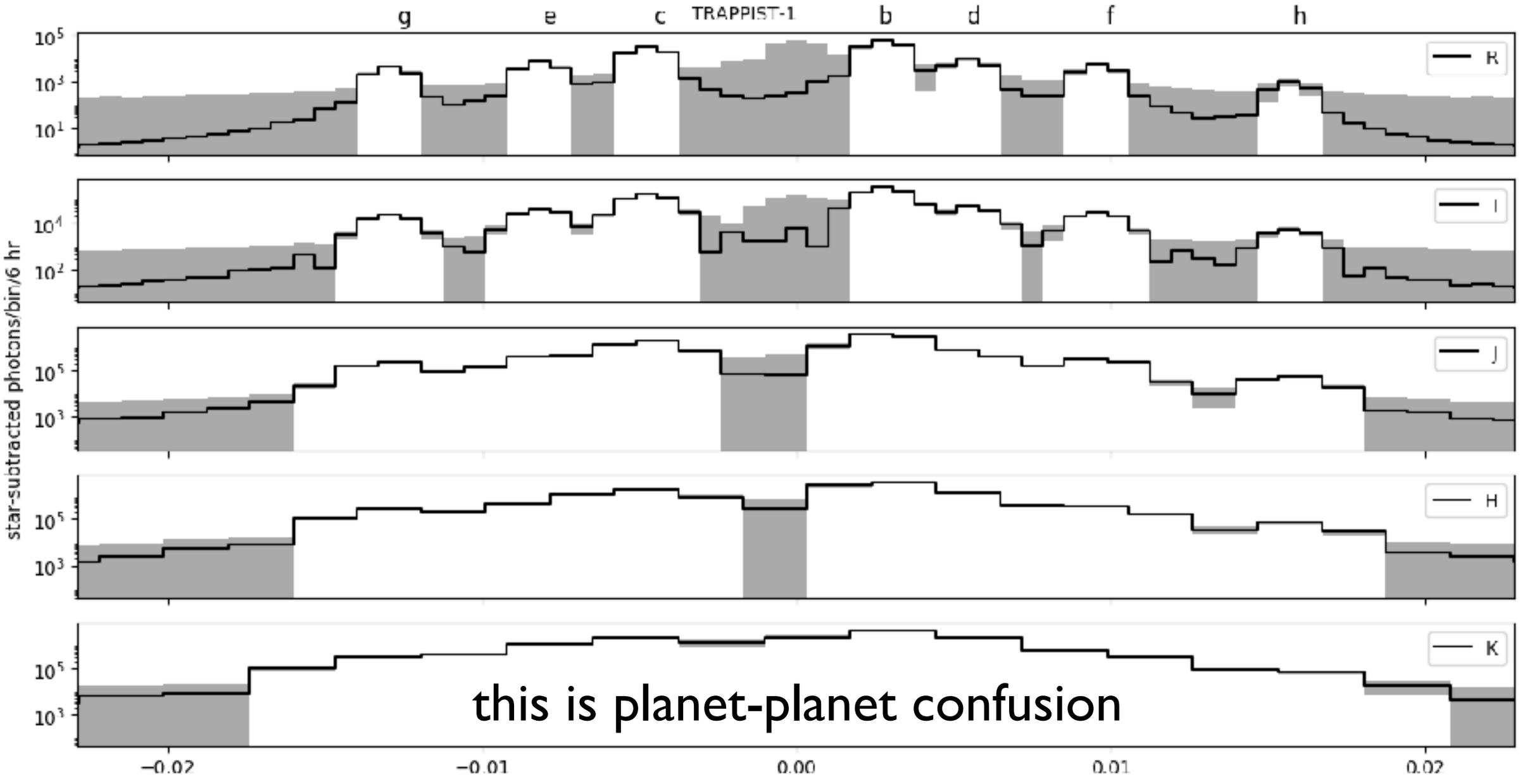
~20 sigma
detection of Earth



hWAET

100 m x 2 m

Trappist-1 system in reflected light
five bands, 6h exposure
all albedos 1.0
star subtraction, no coronagraph



this is planet-planet confusion

PSFs by Rob Halliday