大型成像大气契伦克夫望远镜(LIACT)光学设计初步

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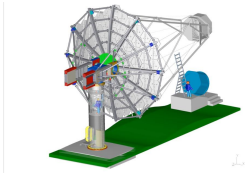
第二届LHAASO合作组会议 ▪ 昆明 ▪ 2017-01-18

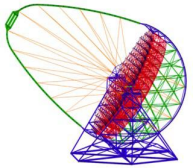
内容提要

1. 大型成像大气契伦克夫望远镜的研制现状
2. LIACT的光学设计目标与要求
3. 设计方案初步

1. 大型成像大气契伦克夫望远镜的研制现状

	口径D (m)	焦距f (m)	f/D	视场	子镜数目	子镜尺寸	反射面积	反射镜面型
Whipple 	10	7.3	0.7	3~4°	248		75m^2	Davies– Cotton
VERITAS 	12	12	1.0		350	35cm (六边形)	110m^2	
H.E.S.S.(I) 	12	15	1.2		382	60cm (圆形)	108m^2	
CTA(MST) 	12	16	1.35	7~8°	84	120cm (六边形)		

（续）

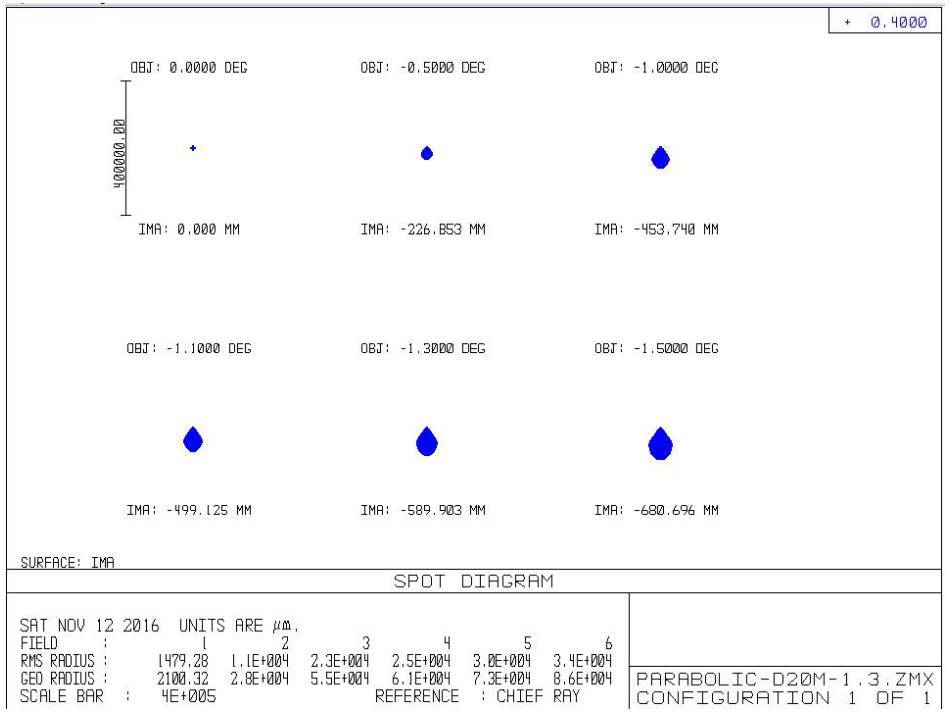
	口径D (m)	焦距f (m)	f/D	视场	子镜数目	子镜尺寸	反射面积	反射镜面型
MAGIC 	17	17.5	1.03	2°	956	50 cm × 50 cm	236m^2	Paraboloid
H.E.S.S.(II) 	28	36	1.3		875	90 cm (六边形)	614m^2	
CTA(LST) 	23	31	1.35	4.4°	207	151 cm (六边形)	390m^2	
LIACT	20			3°				

1.1 反射镜面型

（1）抛物面型特点：

- 消除球差，使近轴区域的成像质量更佳
- 成像视场不可能太大

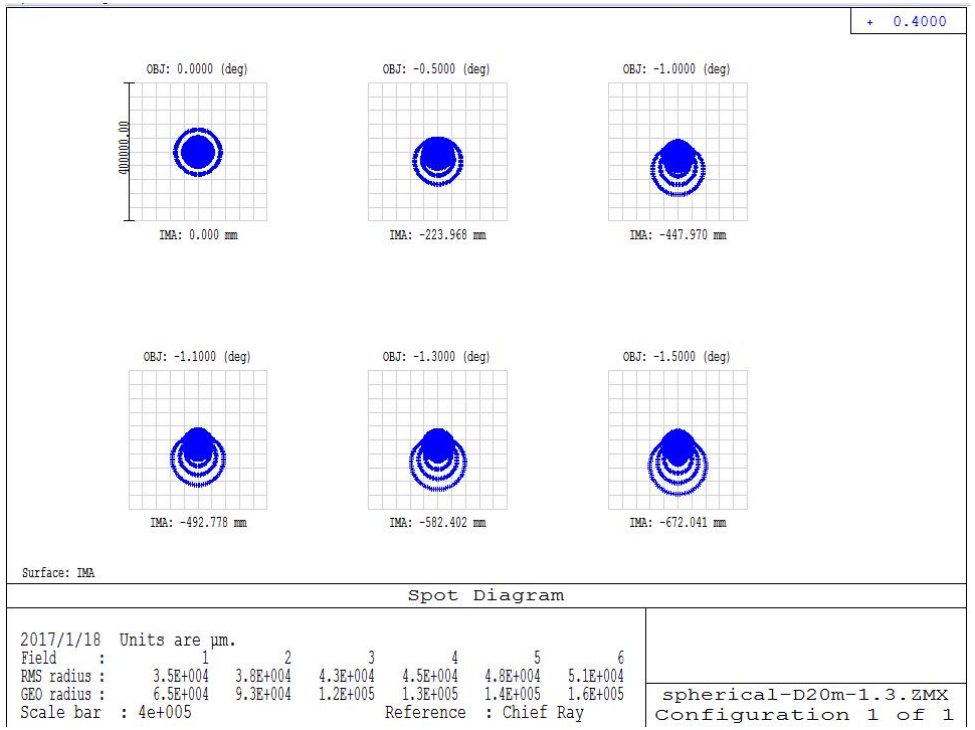
困难：子镜的曲率半径随其位置而变化。



抛物面反射镜成像(R=52m)

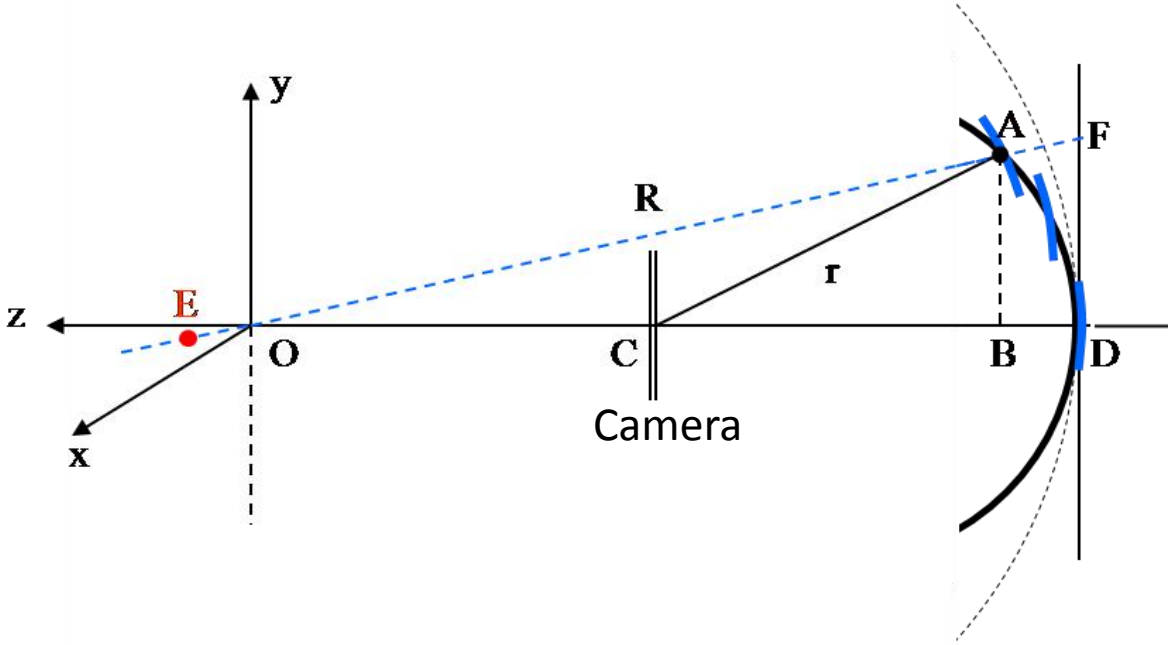
400mm 400mm

Scale bar



球面反射镜成像(R=52m)

（2）Davies– Cotton结构



- O 是坐标原点及中央子镜的球心，其它子镜的球心随其位置而变。
- 子镜的曲率半径： R
  焦距：$f=R/2$

- 光学支撑结构（OSS）曲率半径： $r=f$
  C 是 OSS 的球心

$$R = 2r$$

- 特点：（1）光学成像性能类似于抛物面；
  （2）子镜是球面镜，且曲率半径相同。

问题：

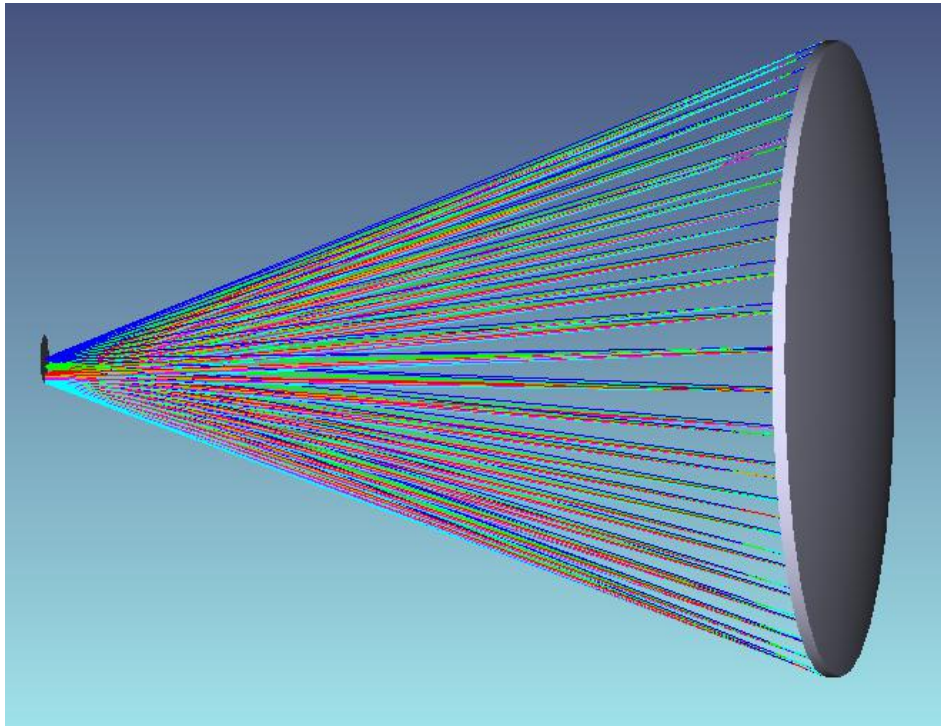
- D-C 结构的缺点：经反射镜后，光子到达探测器不同步
- [*Astroparticle Physics 21 2004-149*]：
  - For 10 GeV gamma showers detected by 20 m IACTs, the width of Cherenkov pulse in the instruments focal plane becomes 15–20 ns for spherical reflector instead of the intrinsic 5–8 ns, which would be detected by parabolic telescopes.
  - It is shown that the spherical reflector substantially widens the pulse of collected Cherenkov photons, while the design induced additional widening is negligibly small for the parabolic reflector.

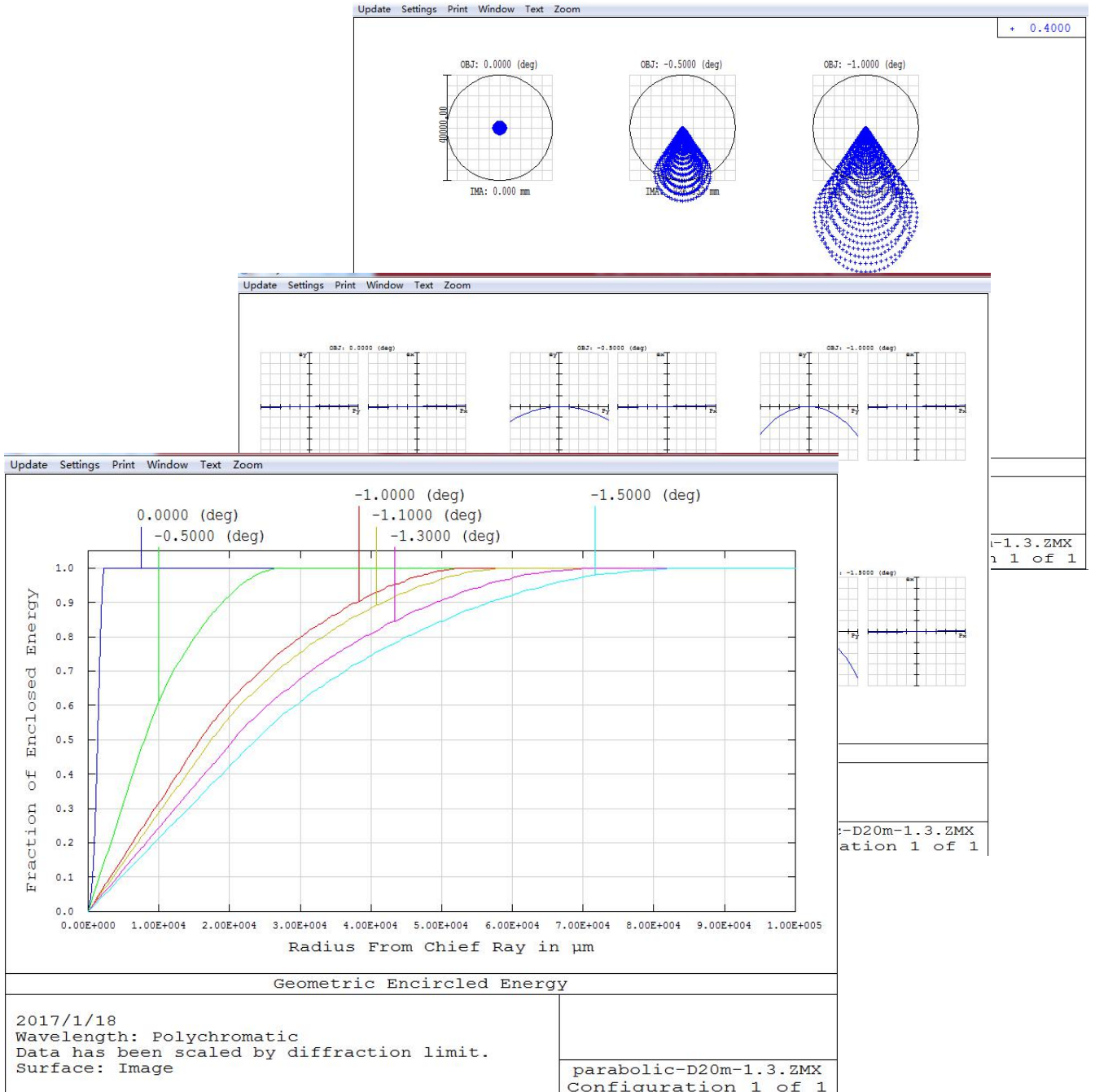
2. LIACT的光学设计目标与要求：

- （1）望远镜视场：3.0 degree×3.0 degree；
- （2）口径：20m
- （3）Davies Cotton结构
- （4）角度分辨率：0.1 degree
- （5）光电倍增管尺寸：PMT 38～40mm 圆形
- （6）用于拼接的矩形子镜单块最大对角尺寸为1.8m，长宽可自选。
- （7）镜片重量为： 13kg/m^2

3. 设计方案初步

单个抛物面反射镜：





3. 设计方案初步

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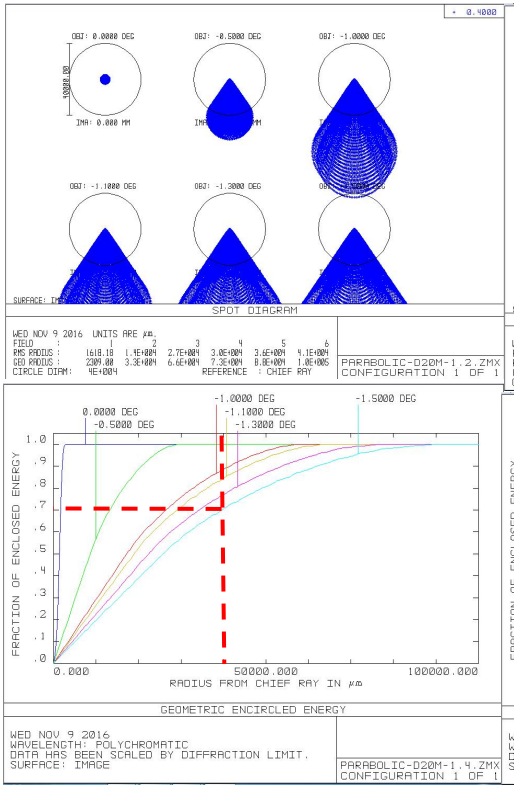
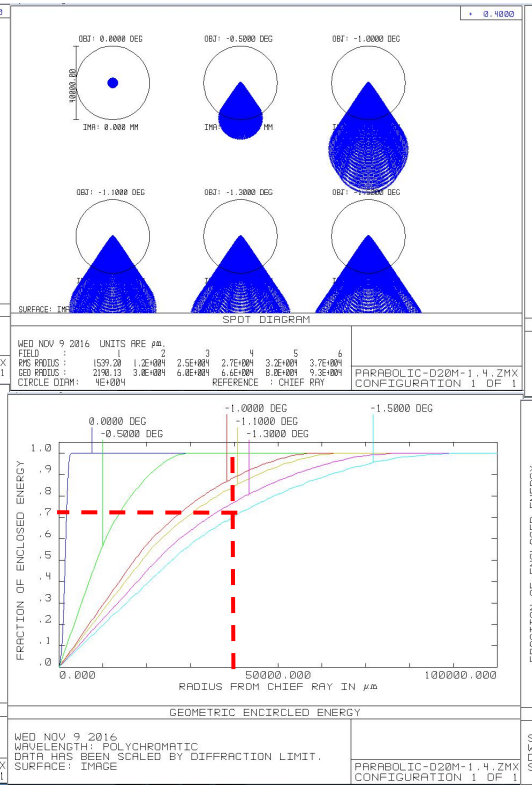
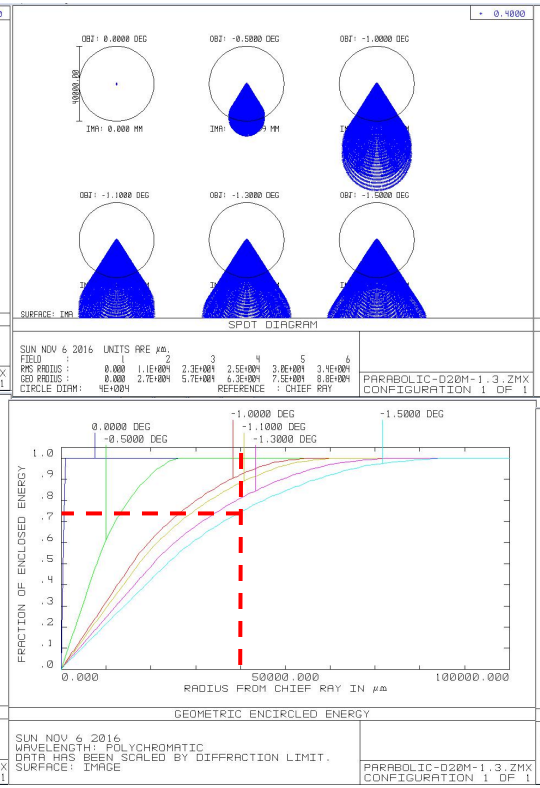


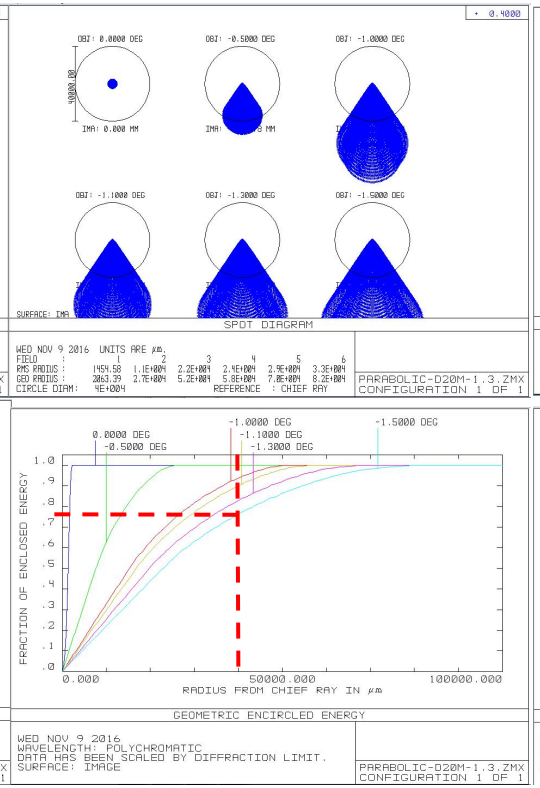
f/D=1.1



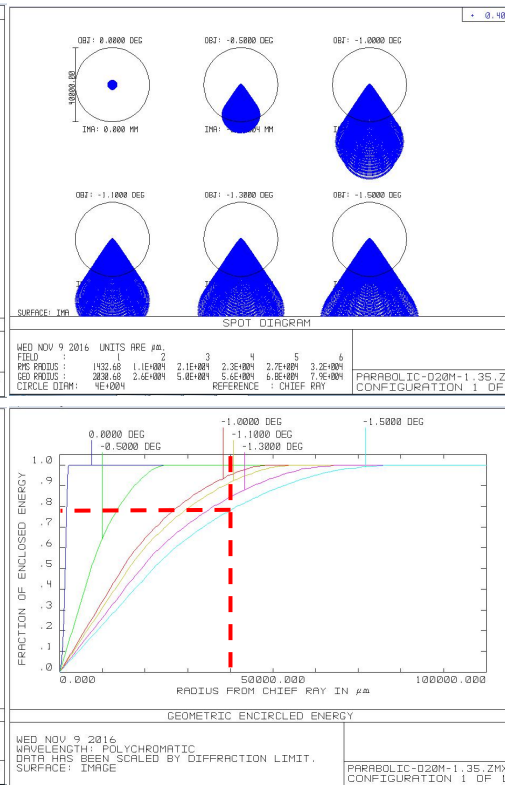
f/D=1.2



f/D=1.3



f/D=1.35



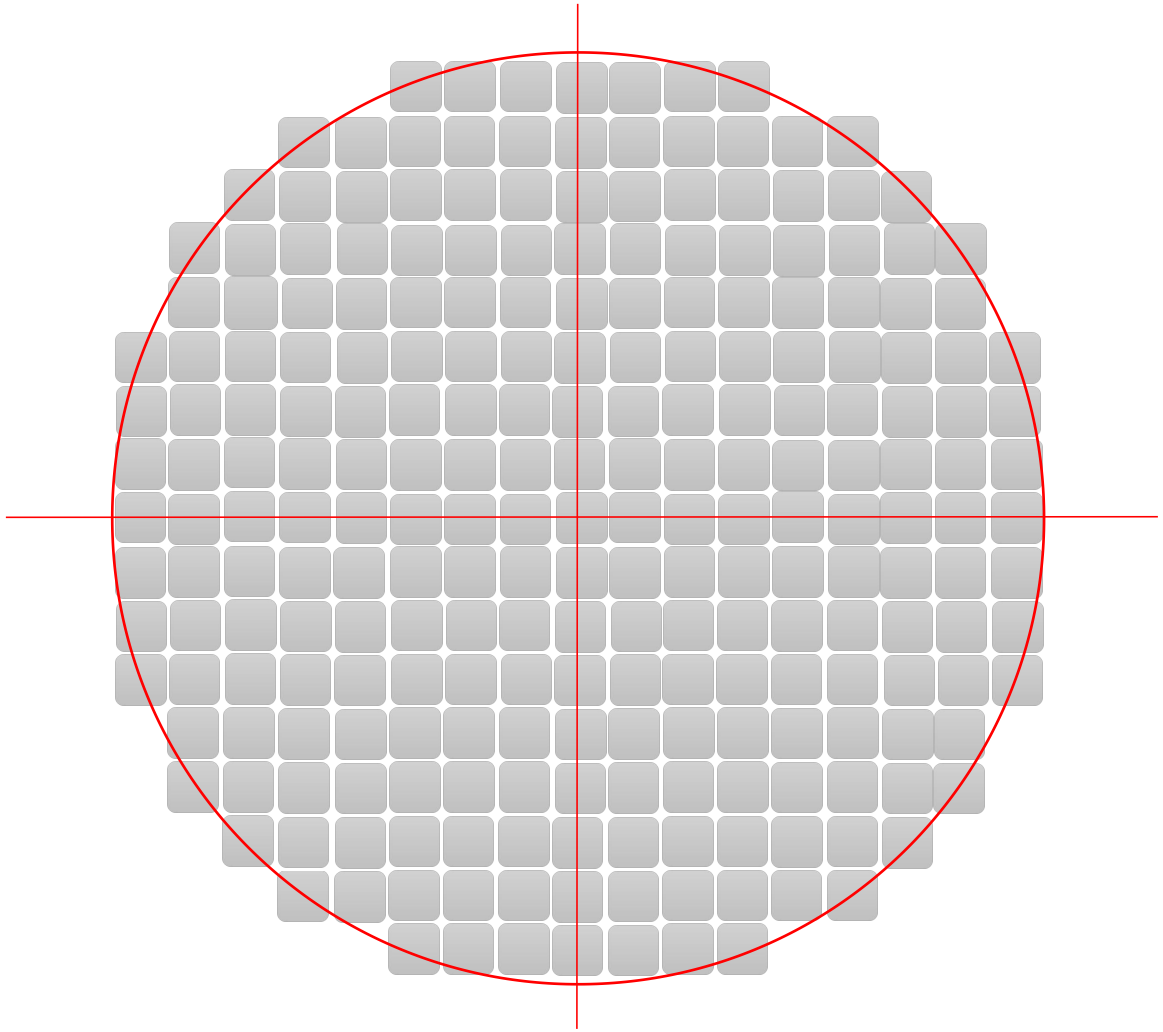
f/D=1.4

D=20m，ω=1.5°										
	f/D=1.1		f/D=1.2		f/D=1.3		f/D=1.35		f/D=1.4	
f	22m		24m		26m		27m		28m	
r	44m		48m		52m		54m		56m	
Φ(IMA)	1.36m		1.44m		1.53m		1.58m		1.6m	
Half FOV	0°	1.5°	0°	1.5°	0°	1.5°	0°	1.5°	0°	1.5°
RMS Spot Radius(mm)	1.62	41	1.54	37	1.48	34	1.45	33	1.43	32
Encircled Energy within 40mm		>70%		>72%		>74%		>75%		>78%

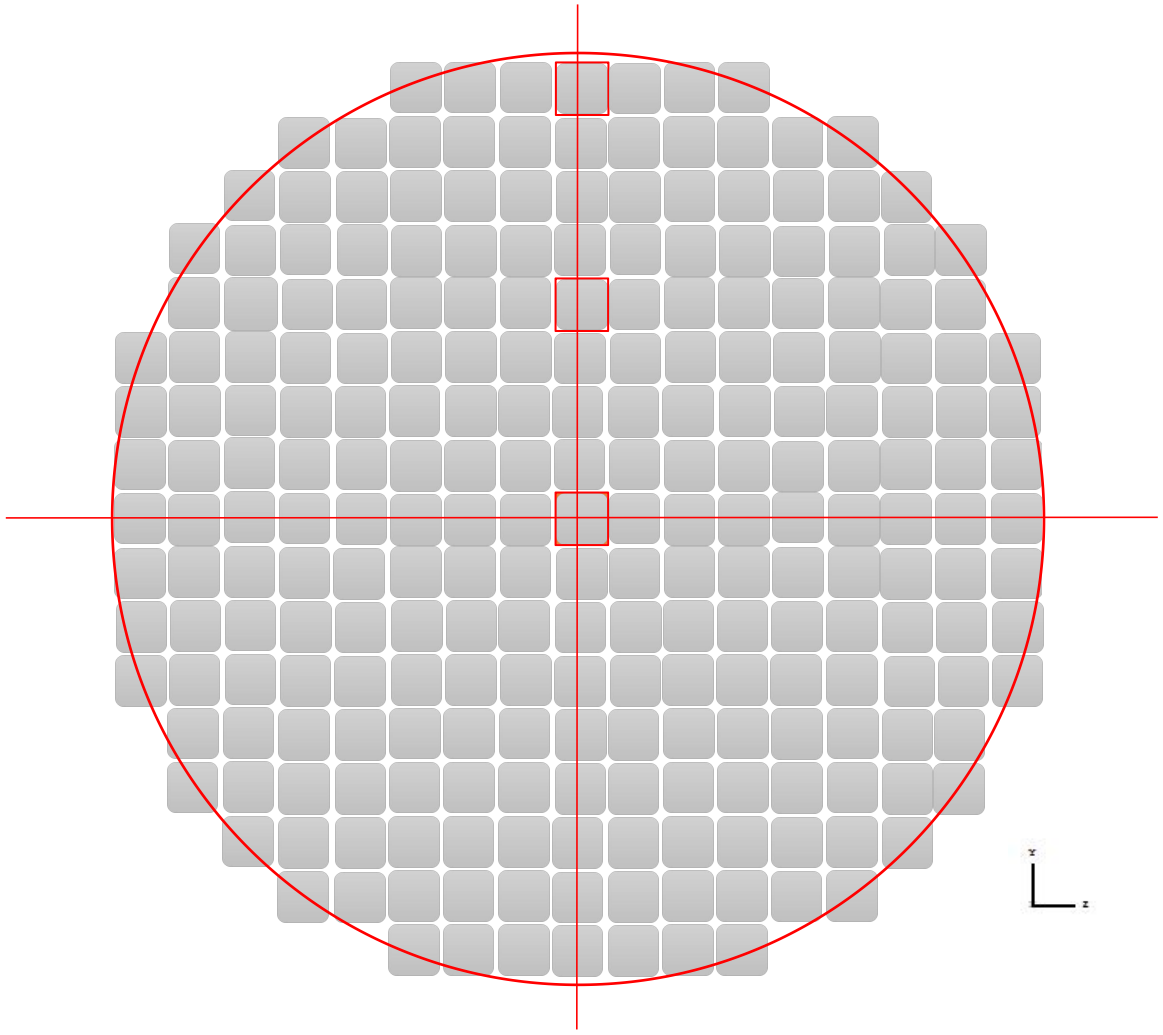
- LIACT初始光学结构：
  - Davies-Cotton 结构
  - 口径：20m
  - 反射镜曲率半径：52m
  - 焦距：26m
  - 焦比：1.3
  - 像面尺寸：1.5m

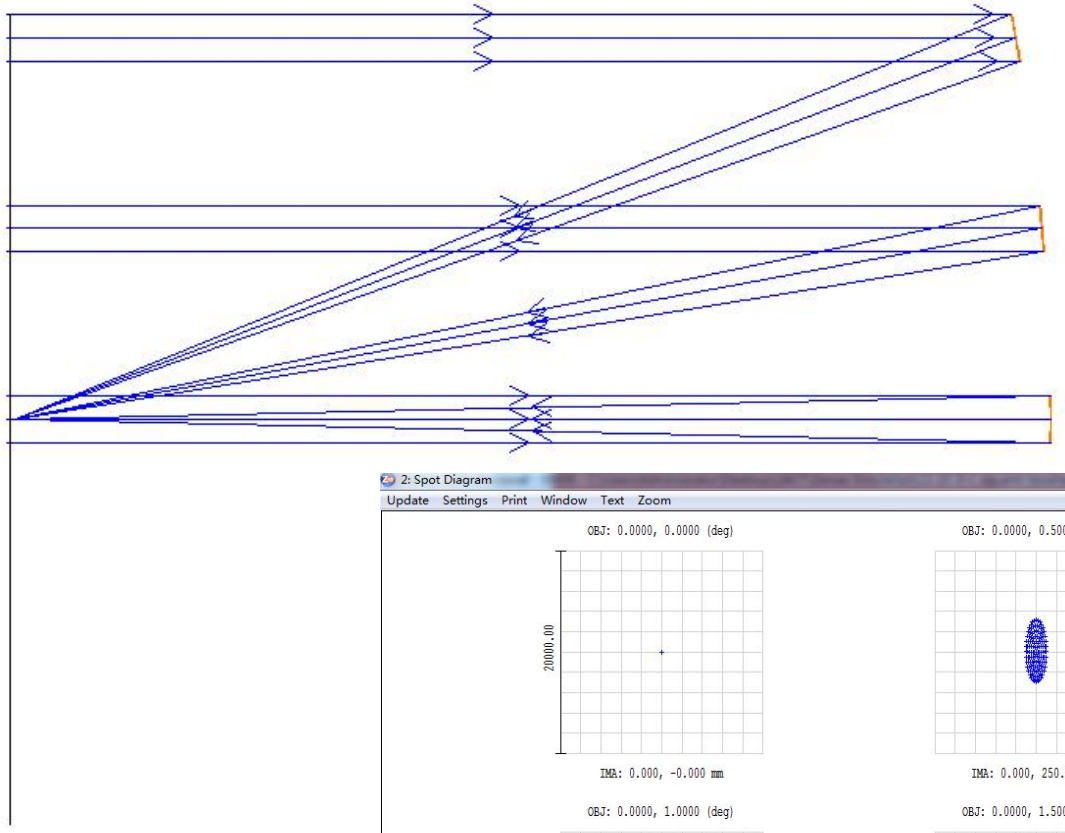
  - 子镜数目：241 块
  - 子镜形状：方形
    边长：1.175m
    对角线长：1.662m
    厚度：20mm

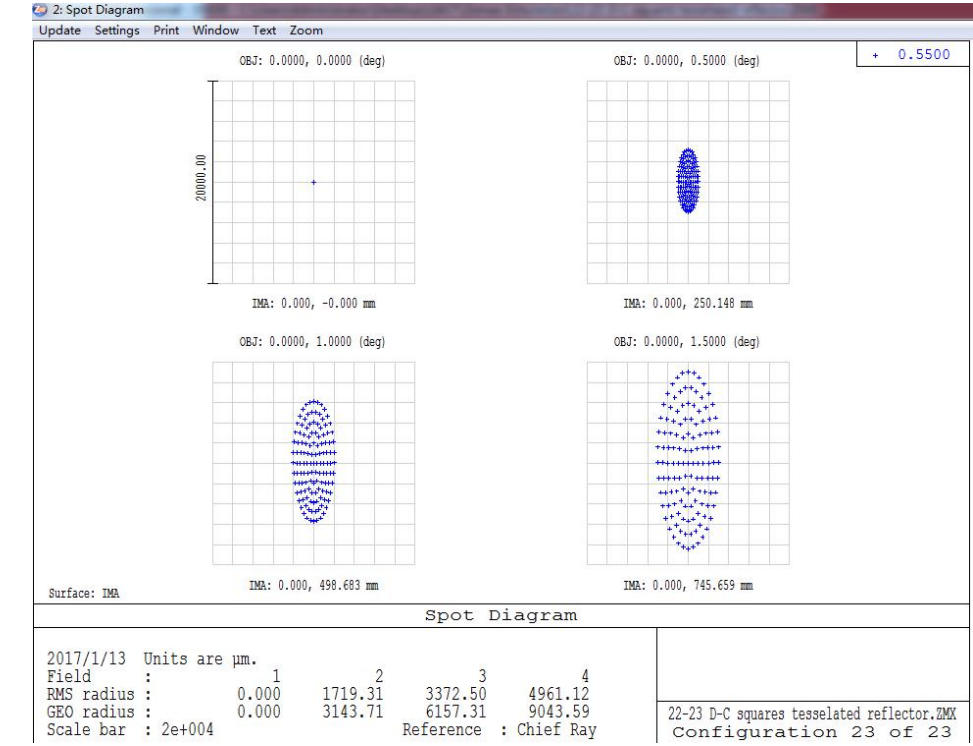
  - 总反射面积：333m^2
  - 子镜重量：~18kg
  - 反射镜总重量：~4333kg

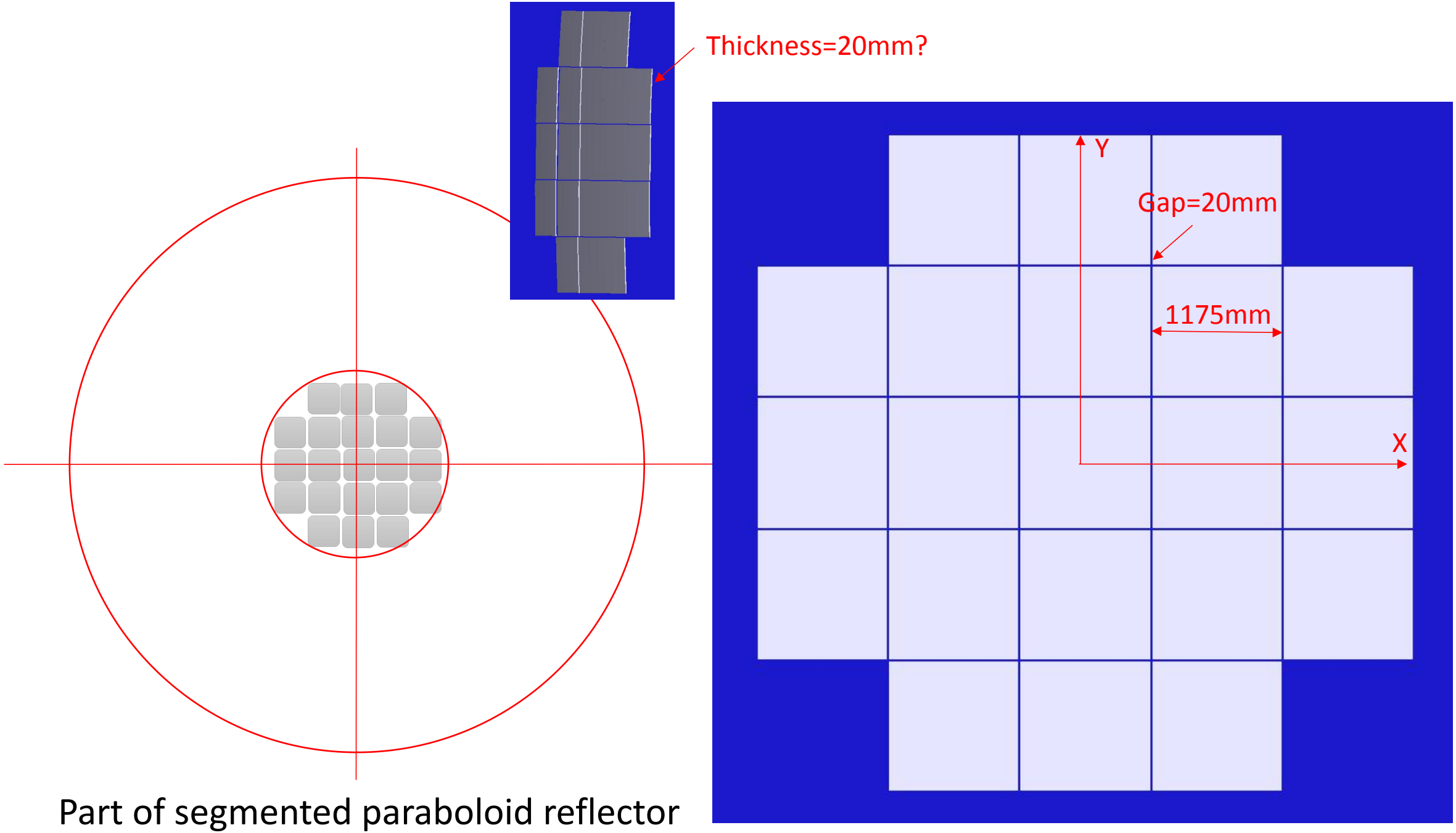


Part of segmented D-C reflector

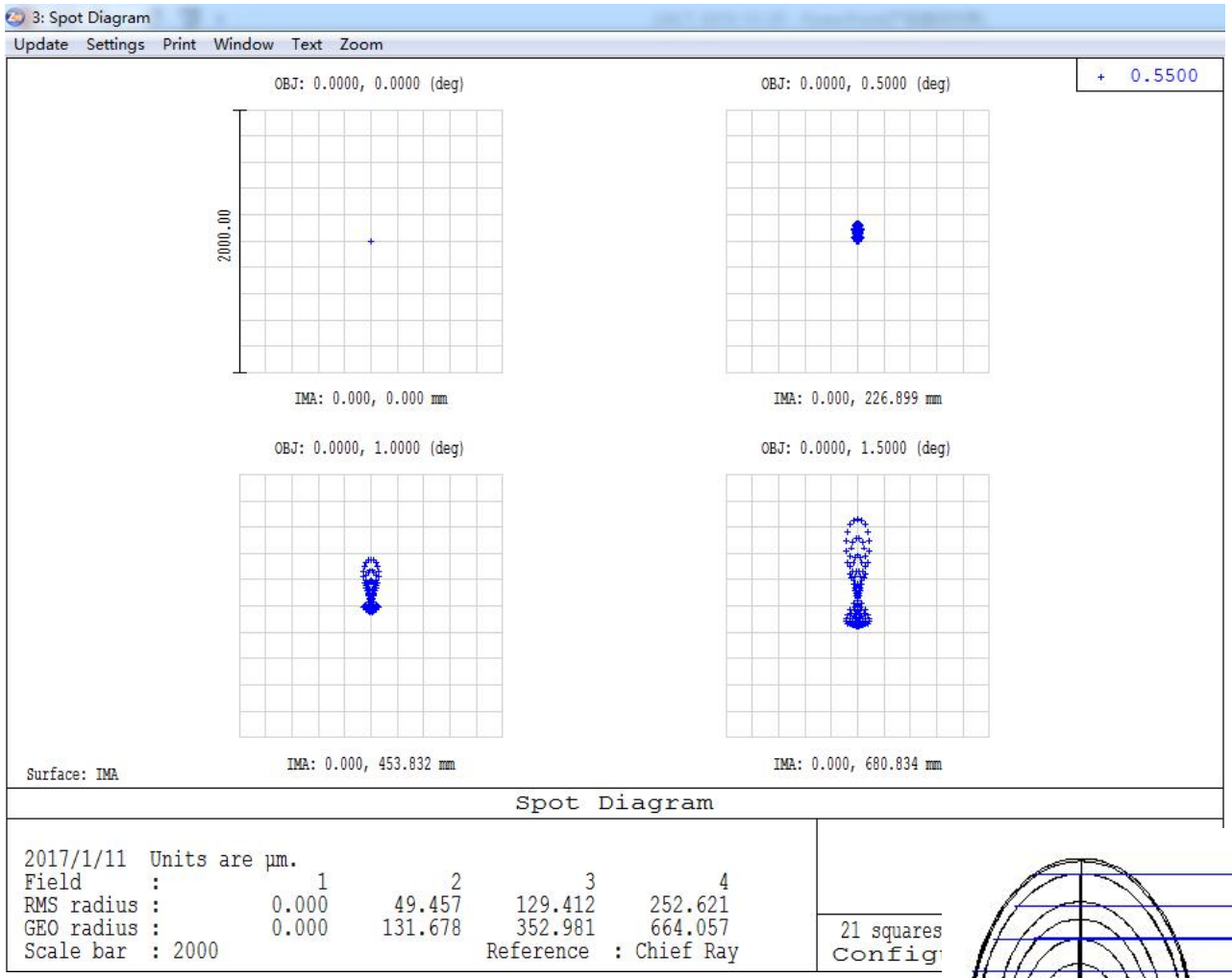




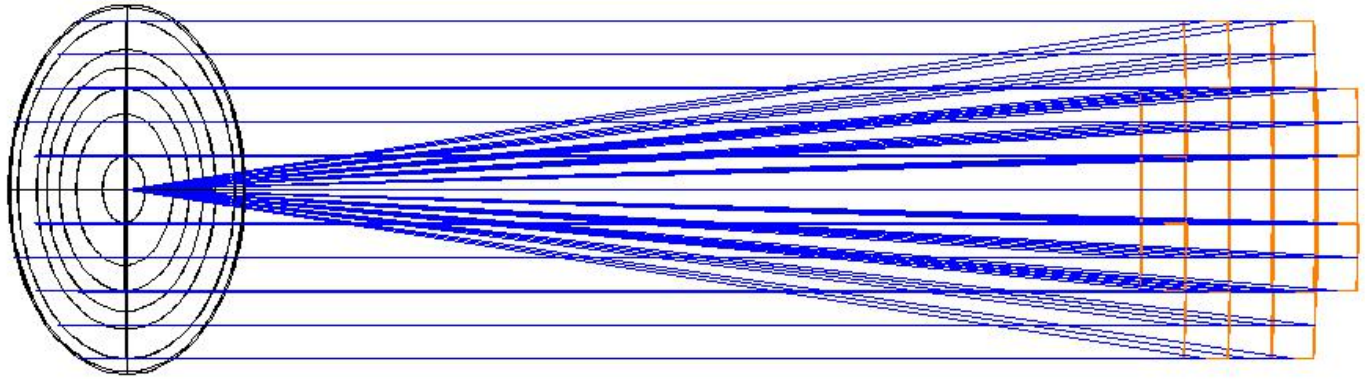




Part of segmented paraboloid reflector



Part of segmented paraboloid reflector



- Tolerance

Tolerance of a single-piece paraboloid:

Worst offenders:

Type			Value	Criterion	Change
TETX	1	1	-0.20000000	15.91786550	0.32569624
TETX	1	1	0.20000000	15.91786550	0.32569624
TETY	1	1	-0.20000000	15.91786550	0.32569624
TETY	1	1	0.20000000	15.91786550	0.32569624
TIRR	1		-0.20000000	15.59225411	8.4847E-005
TRAD	1		0.20000000	15.59223315	6.3886E-005
TEDX	1	1	-0.20000000	15.59216929	2.8544E-008
TEDX	1	1	0.20000000	15.59216929	2.8544E-008
TEDY	1	1	-0.20000000	15.59216929	2.8544E-008
TEDY	1	1	0.20000000	15.59216929	2.8544E-008

Tolerance of a segmented paraboloid:

Worst offenders:

Type			Value	Criterion	Change
TETX	6	6	-0.20000000	0.01408788	0.01408788
TETY	6	6	0.20000000	0.01408788	0.01408788
TETX	6	6	0.20000000	0.01408788	0.01408788
TETY	6	6	-0.20000000	0.01408788	0.01408788
TTHI	6	7	0.20000000	1.6690E-011	6.9877E-014
TTHI	6	7	-0.20000000	1.6672E-011	5.2212E-014
TEDY	6	6	0.20000000	1.6671E-011	5.1121E-014
TEDY	6	6	-0.20000000	1.6670E-011	4.9499E-014
TEDX	6	6	0.20000000	1.6666E-011	4.6436E-014
TEDX	6	6	-0.20000000	1.6655E-011	3.5219E-014

- Sensitivity: Tilt、 z position、 Radius, irregularity、 Decenter
- So, the OSS should allow each facet to be accurately aligned.

后续工作:

- 模拟 241 片子镜拼接 D-C 反射镜、抛物面反射镜，分析比较并确定最终选型；
- 优化方案
- 公差分析

敬请指正！

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