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Large corner-cube retroreflector & laser ranging for Chang'E-4 relay satellite

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Outline

1. Motivation
2. Goals
3. Large Hollow CCR
4. LR Station
5. Schedule

1、Motivation

Only a few regular LLR stations
None in China so far



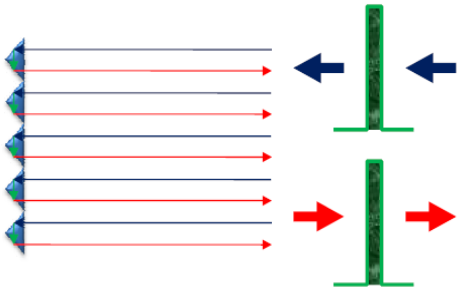

Station	(USA) McDonald	(USA) Apache Point	(France) GRASSE	(Italy) Matera
Telescope	Diameter : 0.76m Common path	Diameter : 3.5m Common path	Diameter : 1.54m Common path	Diameter : 1.5m Common path
Laser	Nd:YAG Energy:150mJ Width : 200ps λ : 532nm R.R. : 10Hz	Nd:YAG Energy : 115 mJ Width : 90 ps λ : 532 nm R.R. : 20Hz	Nd:YAG Energy : 220mJ Width : 70ps λ : 532nm R.R. : 10Hz	Nd:YAG Energy : 200mJ Width : 40ps λ : 532nm R.R. : 10Hz

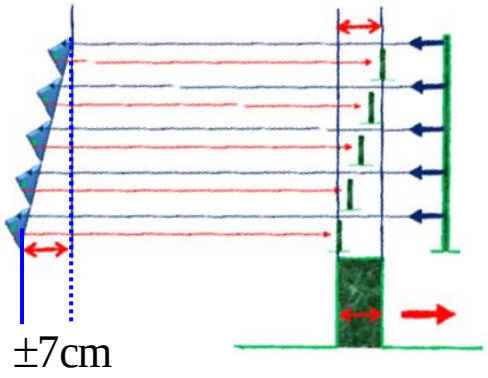
Scientific Objectives of LLR

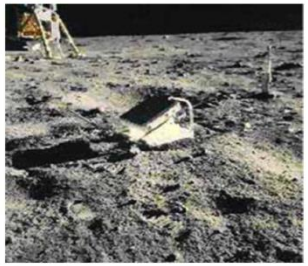
	Current status	LLR precision 1mm
Weak E.P.	$\Delta a/a < 10^{-13}$	10^{-14}
Strong E.P.	$\eta = 4\beta-\gamma-1 < 4\times10^{-4}$	3×10^{-5}
Time-variation of G	$\dot{G}/G < 9\times10^{-13}\ \mathrm{yr}^{-1}$	$5\times10^{-14}\ \mathrm{yr}^{-1}$
Inverse square law	$\alpha < 3\times10^{-11}$	10^{-12}
PPN parameters	$\beta-1 < 10^{-4}$	10^{-5}
Earth-Moon system	Moon : inner structure, orbit, levitation, deformation, inertial moments, etc. Earth : atmosphere (1~50mm) 、 tides (2mm) 、 rotation (2.6mm) 、 precession (1.9mm) , etc.	

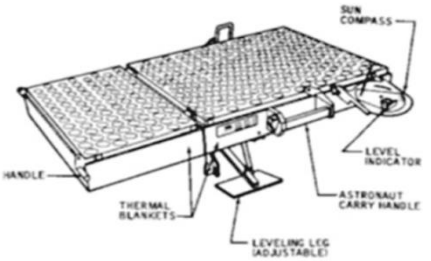
Problems of Current CCRs

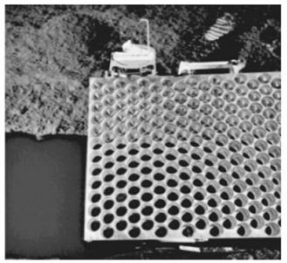
Name	Size	CCR Number
Apollo 11	3.8 cm	100
Apollo 14	3.8 cm	100
Apollo 15	3.8 cm	300
Lunakhod 1	11 cm	14
Lunakhod 2	11 cm	14

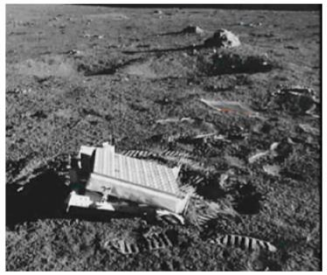


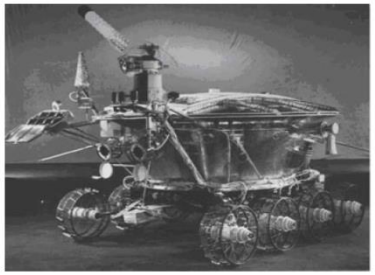


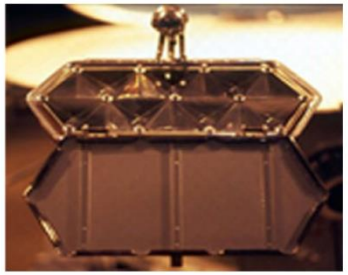












- **Aging after 45 years;**
- **Uncertain reflection position of CCR array coupling with lunar levitation causes a random error of about 7 cm.**

CCR Array is the Bottleneck

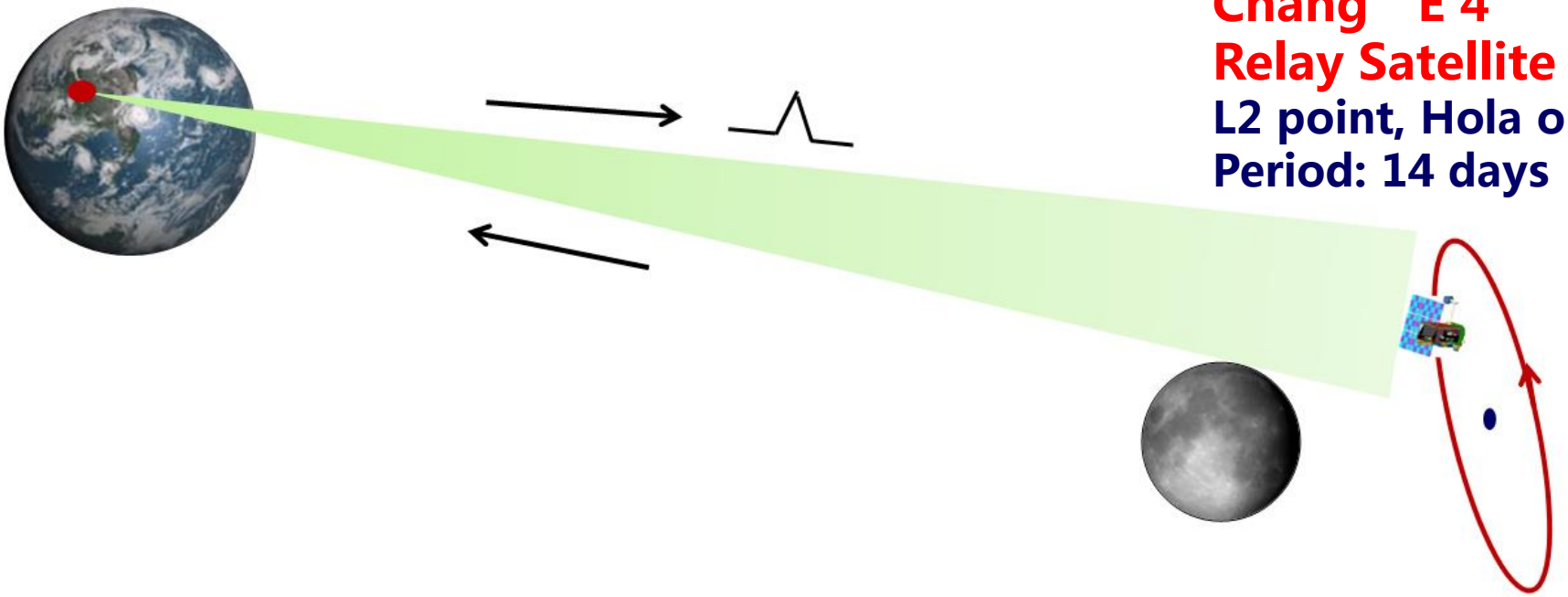
Random error of LR system of Apache Point

Error Source	One way error (mm)
APD jitter	7.5
Pulse width	7.5
TDC jitter	3.8
Freq. reference	1
APO system total	11
CCR array	12~35
Total random error (single photon)	16~36

Max. error

2、Goals

1. Next-generation CCR（Single large CCR），carried by Chang’E 4 relay satellite；
2. Advanced LR stations in China（Lunar & Relay satellite laser ranging）.

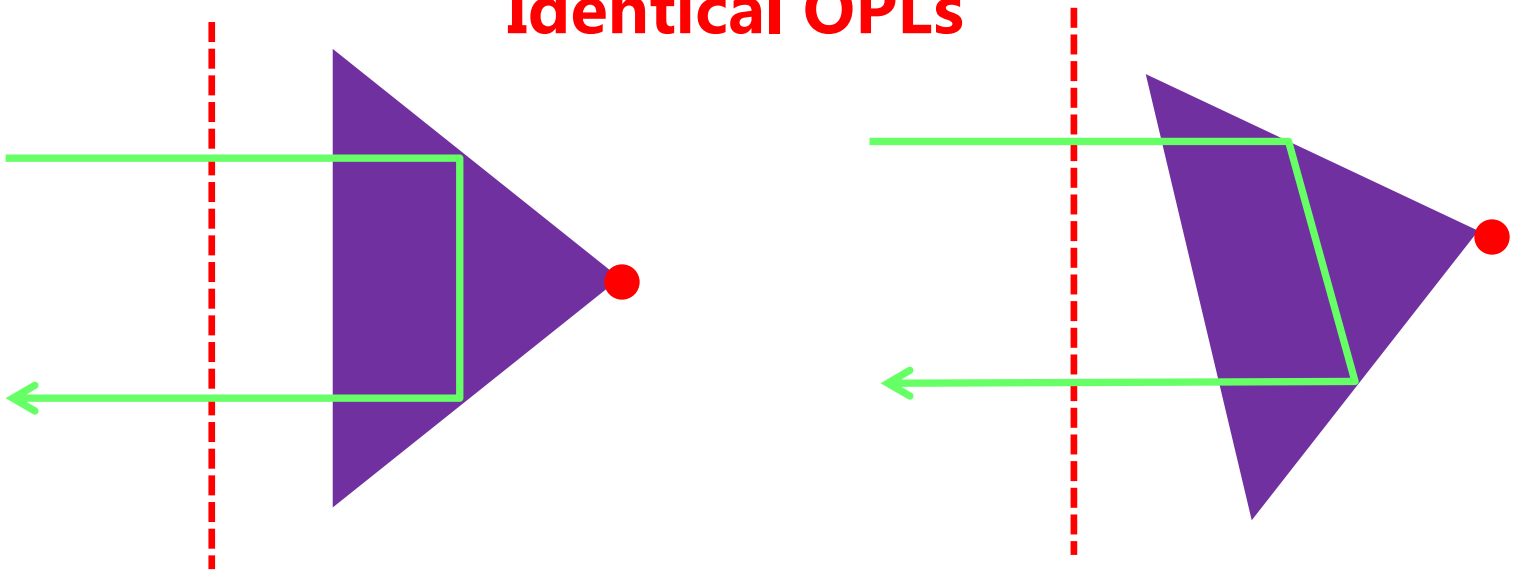


3、Large Hollow CCR

Merits：

1. Single & exact reflection point

Identical OPLs

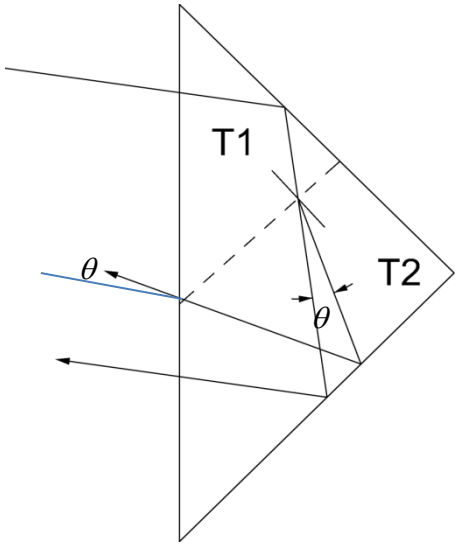


Normal incident **Inclined incident**

Issue on Thermal Effect

Merits :

1. **Single & exact reflection point**
2. **Insensitive to thermal effect**



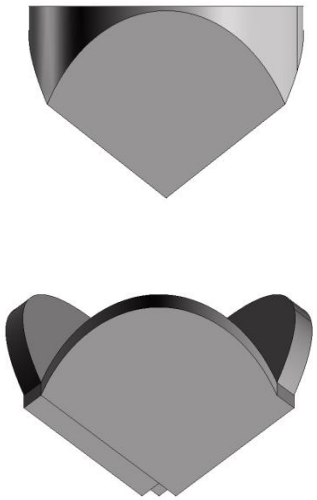
Thermal coeff. Refractive index~10^{-5}/K
Grad. T ~ 0.1K/mm

- **Solid CCR: deformation of 90° > 10”**
- **Hollow CCR: negligible if mounting properly**

Issue on Mass

Merits :

1. **Single & exact reflection point**
2. **Insensitive to thermal effect**
3. **Lighter mass**

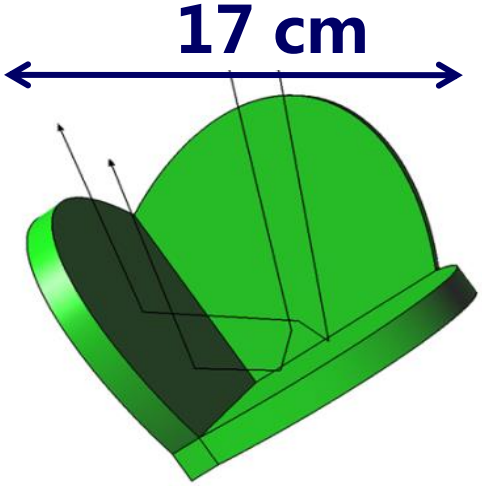


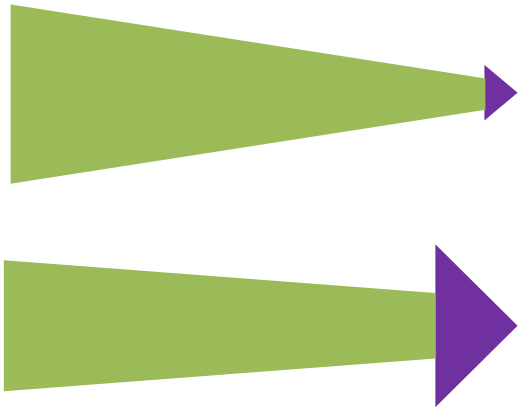
17-cm Aperture CCR	mass(g)
Solid	3070
Hollow	1584

Issue on Divergence Angle

Merits :

1. Single & exact reflection point
2. Insensitive to thermal effect
3. Lighter mass
4. Smaller divergence angle





	D (cm)	# CCR	Reflectivity
Single	17	1	0.6
Apollo 15	3.8	300	0.9

17-cm single CCR ≡ Apollo-15 CCR array

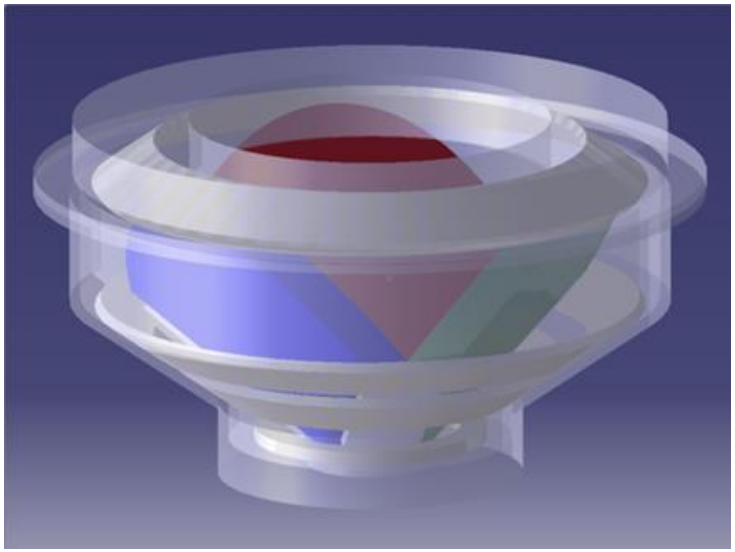
$$\theta_{div} \propto \frac{\lambda}{D}$$

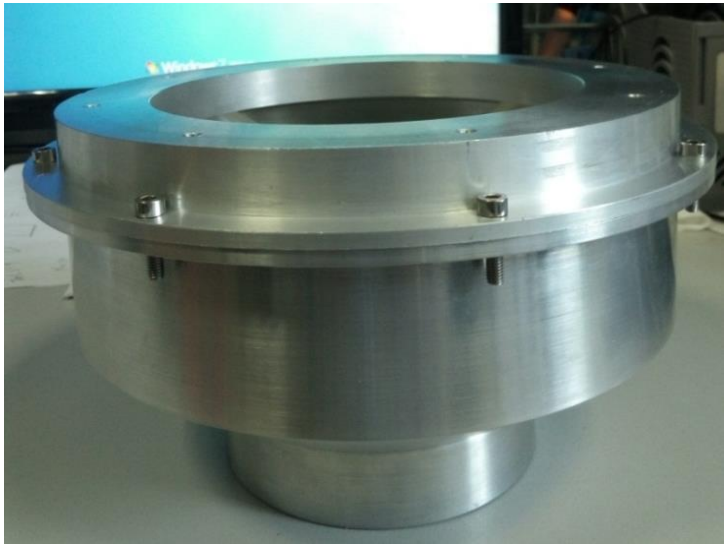
Demerits of Large Hollow CCR

1. Precision of angle:
   - difficult to manufacture from monolithic piece
   - silicate bonding
2. Mechanical Rigidity:
   - weaker than that of solid one
   - high-efficiency vibration isolation devices
3. Coating:
   - sensitive to radiation & thermal effect
   - Ag or dielectric coating

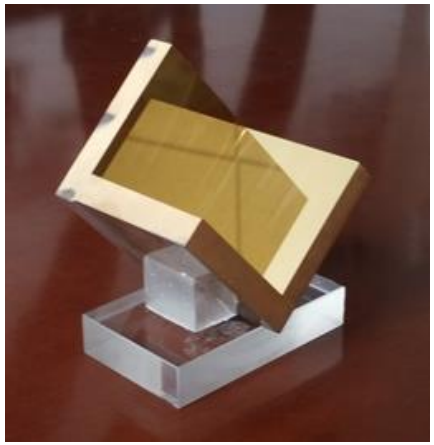
Structure of CCR Retro-Reflector

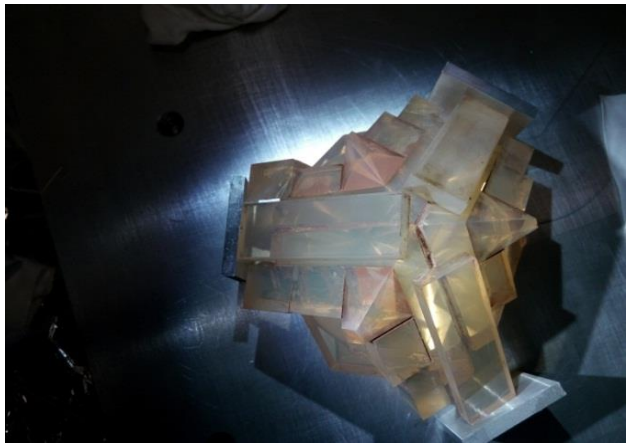
- Envelop：Φ240mm×300mm
- Inner components：CCR、housing（mounting & protection, minimizing temp. grad.）、vibration isolation device、window





Prototype Testing





No. prototype	Testing date	Angle ccuracy
YJ001 (silicate bonding)	2016-03-03	28″ , 20″ , 11″
YJ002 (thermal cycle) (-15~+50°C)	2016-03-21	3″ , 8″ , 11″
	2016-03-27	8″ , 8″ , 8″
YJ003 (optical test) ZYGO interferometer	2016-05-05	1″ , 1″ , 6″
	2016-05-10	3″ , 1″ , 11″
	2016-06-15	2.9″ , 2.8″ , 7.8″

4、LR Station

- **Upgrade 1.2-m telescope :**

  less time & funding are needed

- **Two phases :**

  1st phase: 3J/pulse, 10ns, 10Hz laser
  (to obtain returned signal)
  2nd phase: 100mJ/pulse, 60ps, 1kHz laser
  (to increase precision)

Kunming station

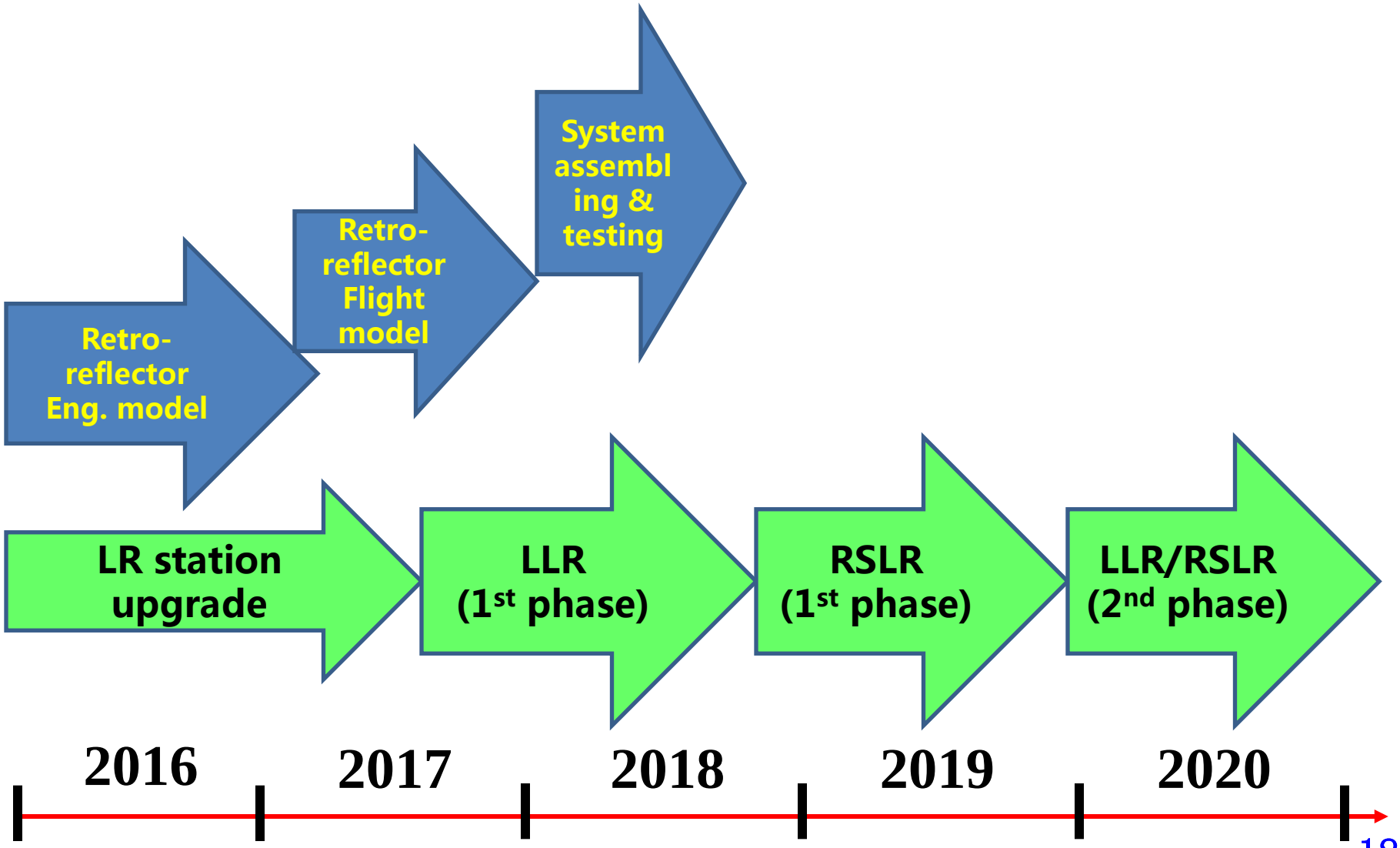
Received Photon Number

Target	1st Phase		2nd Phase	
	Apollo 15 retroreflector	RS CCR	Apollo 15 retroreflector	RS CCR
Pulse energy	3	3	0.1	0.1
Telescope diameter	1.06	1.06	1.06	1.06
Div. Angle of laser (arcsec)	2	2	2	2
Div. angle of CCR (arcsec)	8	2	8	2
Opt. efficiency (emitting)	0.4	0.4	0.4	0.4
Opt. efficiency (receiving)	0.2	0.2	0.2	0.2
Transmission of atmosphere	0.6	0.6	0.6	0.6
Reflectivity of CCR	0.9	0.6	0.9	0.6
Area of CCR (m^2)	0.34	0.0227	0.34	0.0227
Distance ($\times 10^4$km)	38.4	45.0	38.4	45.0
Antenuation	0.1	0.1	0.1	0.1
Repetition rate (Hz)	10	10	1000	1000
QE of detector (%)	60	60	60	60
Received photons/pulse	1.98	0.74	0.26	0.1

Error Budget

	Error Source	1st Phase	2nd Phase
Random Errors	C-SPAD jitter	3 mm	3 mm
	Pulse width	1500 mm	9 mm
	TDC jitter	3 mm	3 mm
	Frequency reference	1 mm	1 mm
	Hollow CCR	negligible	negligible
Grand Total (single photon)		1.5 m	9.2 mm

5、Schedule


Retro-reflector Eng. model
Retro-reflector Flight model
System assembling & testing
LR station upgrade
LLR (1st phase)
RSLR (1st phase)
LLR/RSLR (2nd phase)
2016
2017
2018
2019
2020

Conclusion

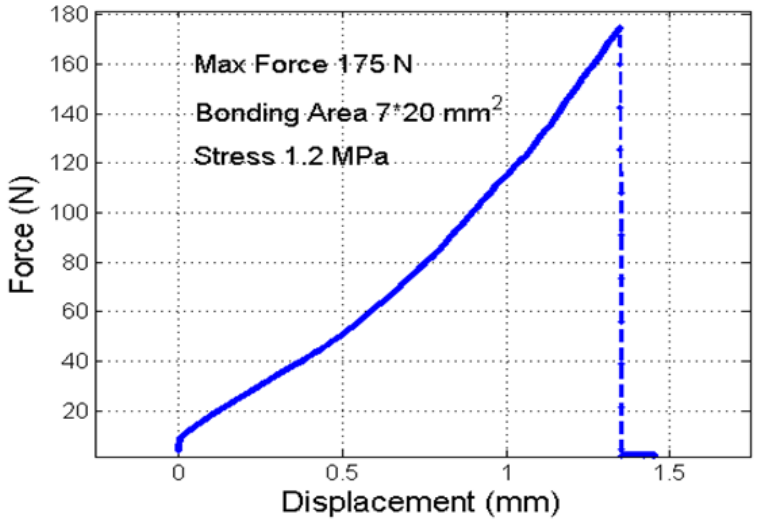
Lunar & Relay-Satellite LR

- A 17-cm hollow CCR will be installed on Chang'E 4 relay satellite, and LLR & RSLR will be carried out in 2018.
- Accomplish the 1st step of LLR in China
  - To prove the validity of large hollow CCR
  - To enhance the LR capability in China

Thanks for your attention

Mechanical Analysis

order	Natural frequency (Hz)
1	652.18
2	802.
3	935.
4	1063.5
5	1315.6



Bonding strength : 1.2MPa

Acceleration direction	Max. applied force (MPa)	
	200g	300g
⊥ Bonding interface	4	6.1
⊥ Mirror plane	8.9	**13**