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# Development of space-based diffractive telescopes



**Key words:** Membrane diffractive optical elements; Diffractive telescope; Super large aperture

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# Space telescope progress

- Looking at the history of the development of large-aperture space telescopes, it takes nearly three decades to upgrade the optical system from 3.8 to 6.5 m.

| Year | Event |
|---|---|
| 1990 | The Hubble Space Telescope was launched into space, with an aperture of 2.4 m. |
| 1992 | Many KH-12 space reconnaissance cameras have been put into orbit, with the maximum diameter being 3.8 m. |
| 2002 | The launch of the James Webb Space Telescope System in 2011 was post-poned to 2021 because of difficulties in manufacturing and adjustment. The aperture of the primary lens was also reduced from the original 8 to 6.5 m. |

# Tendency and challenges

- As it is difficult to develop a large-aperture spatial optical remote sensor using the conventional reflective optics, three methods have been developed to solve this problem.

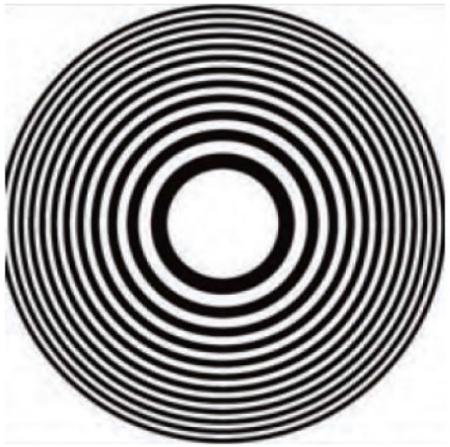
| No. | Method |
|---|---|
| 1 | Space block self-assembly technology |
| 2 | Technology for optical interference synthetic-aperture imaging |
| 3 | Diffractive telescope imaging technology |



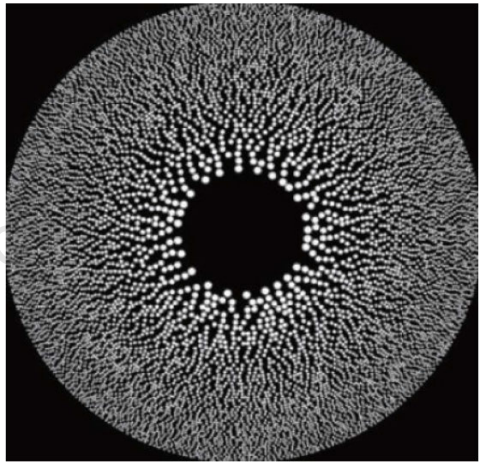
Diffractive telescope imaging technology is currently the only proven engineering application of large-aperture or super-large-aperture optical systems in space.

# Tendency and challenges

- Binary optics elements



Fresnel zone plate



Photon sieve

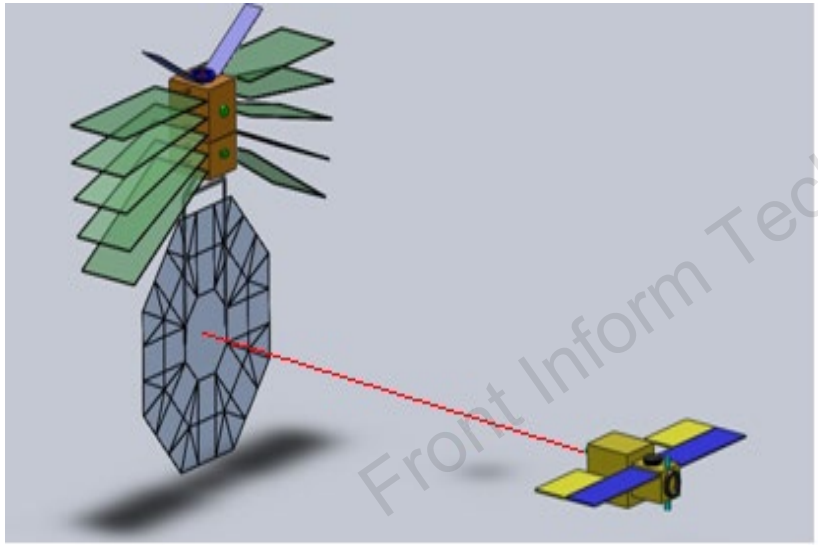


For the direct writing techniques of continuous relief micro-optics

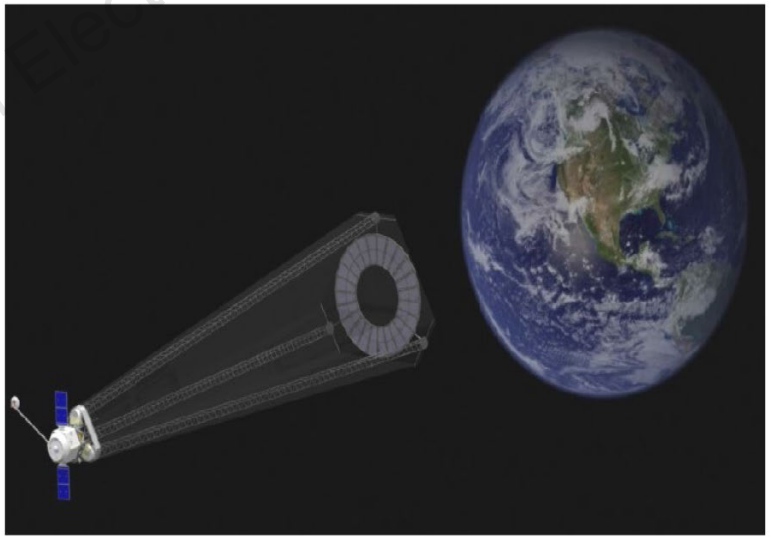
| No. | Technology |
|---|---|
| 1 | Single point diamond turning |
| 2 | Electron beam direct writing |
| 3 | Laser direct writing |

# Future space-based diffractive telescope

- A large-aperture space telescope system employing a diffractive optical element is composed of a diffractive primary lens and a corrector.



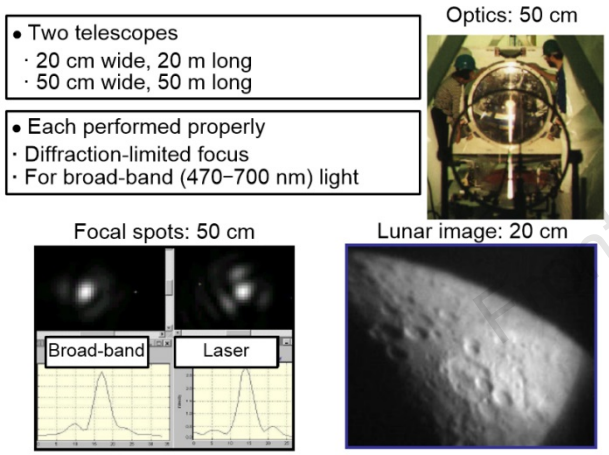
Double-star cooperative spatial diffraction telescope system



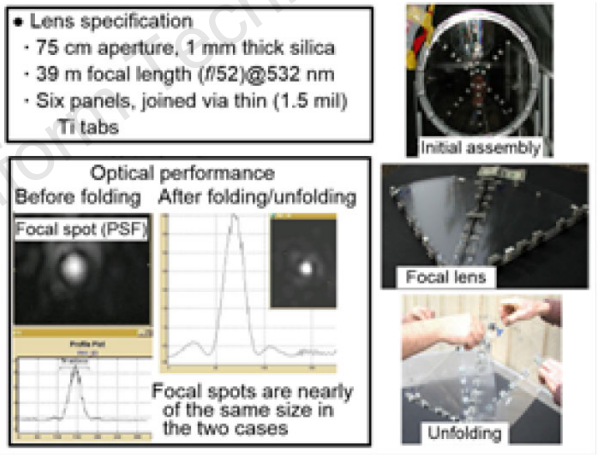
Single star soft connection space diffraction telescope mirror system

# State of development outside China

- In 1998, a space-based diffractive telescope program called "Eyeglass" was launched by the Lawrence Livermore National Laboratory (LLNL) in the USA.
- The system was made up of two satellites several kilometers away from each other, which comprised the diffractive primary lens and the corrector, respectively.




Photon sieve diffraction telescope with aperture of 200 mm

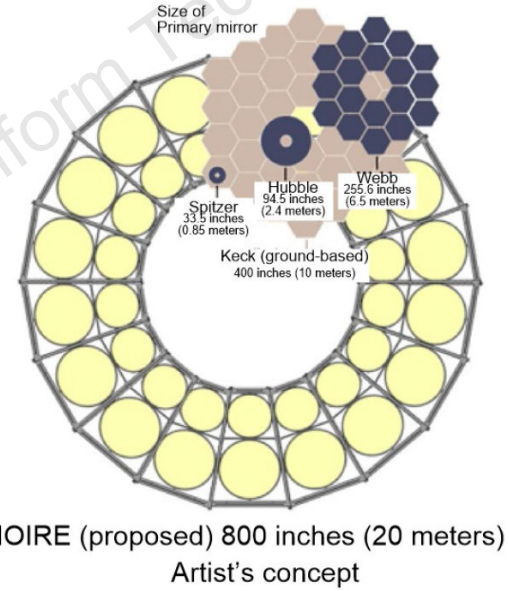



Photon sieve splicing primary mirror with aperture of 800 mm


Foldable diffraction main mirror with aperture of 5 m

# State of development outside China

- In 2010, DARPA in the USA issued a Broad Agency Announcement (BAA) (No. 10-51) soliciting industry proposal for the MOIRE program.
- The announcement required participants provide designs with the potential for a 20 m aperture system, which can provide continuous imaging services with resolution better than 2.5 m, imaging time less than 1 s, a field of view greater than 10 km×10 km, and a coverage area over 155 km$^2$.

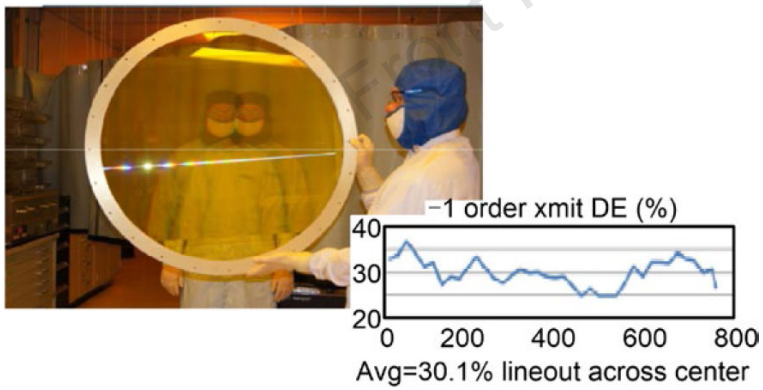



MOIRE film diffraction main mirror

# State of development outside China

Design proposals for the MOIRE project need to address the following important technical issues:
(1) provide a large aperture, low cost, light weight, and deployable diffractive membrane optical system for GEO orbital imaging;
(2) possess near real-time imaging stability and high precision in image localization;
(3) make the spectrum of the imaging system wider;
(4) solve the stability and dynamic problems of large-scale structures in GEO orbits.






Diffraction film with aperture of 80 cm

Diffraction film with aperture of 20 foot

# Research and development status in China

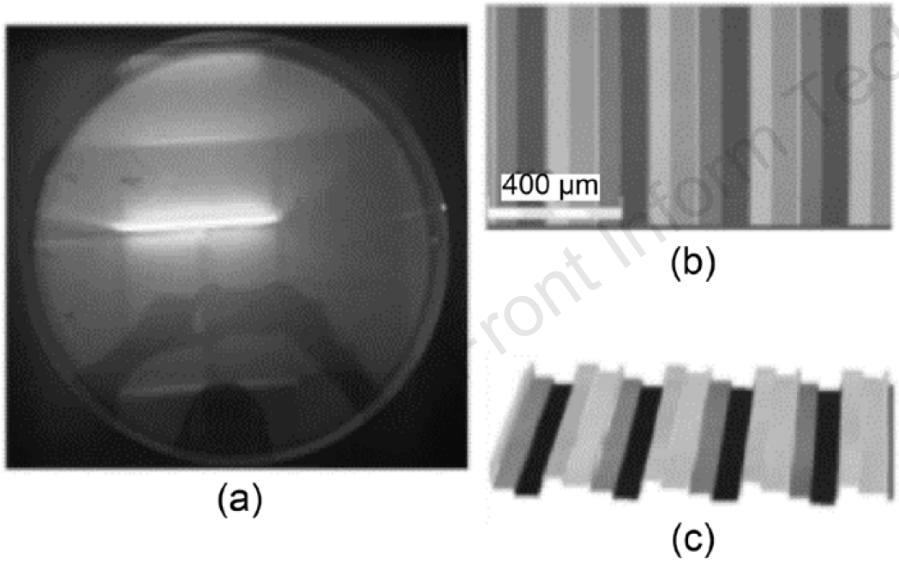
Research work on the diffraction imaging technology of CIOMP

| Date | Event |
| --- | --- |
| Since 1990 | Research on diffractive optics and its applications has been carried out, and the first laser-based direct writing device for the production of diffractive elements with an aperture of up to 200 mm was developed. |
| Since 2010 | Diffractive optics telescope systems have been studied. |
| To date | The preliminary design and analysis of a super-large-aperture optical system has been finished.<br>Research on the processing technology for a membrane photon sieve has been conducted, and the stitching errors have been simulated and analyzed. |

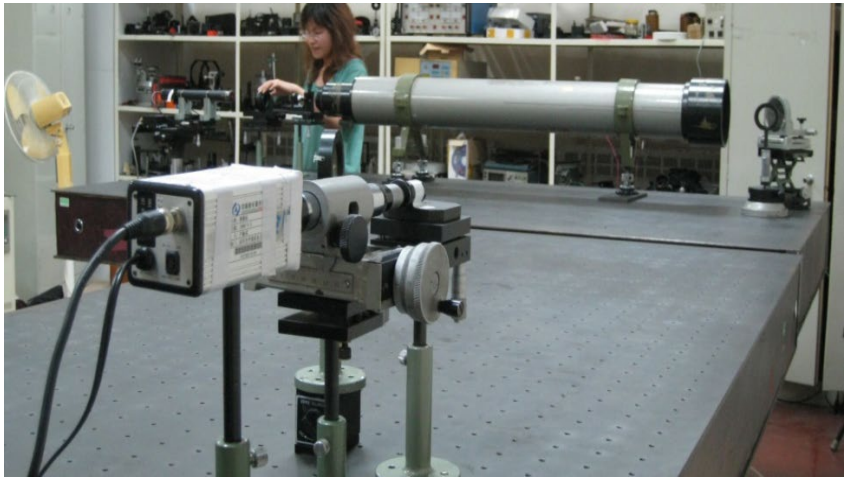
# Research and development status in China

Research work on the diffraction imaging technology of CIOMP

| No. | Technology |
|---|---|
| 1 | Design and development of a large-aperture diffractive-optics imaging system |
| 2 | Establishment of the image quality analysis model for the diffractive optical system |




A four-step diffraction objective lens



The compound eye diffractive telescope and optical system detecting device

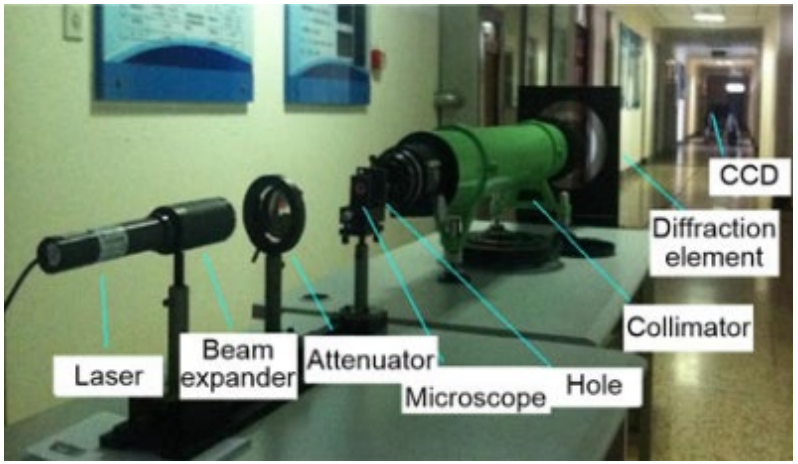
# Research and development status in China

Research work on the diffraction imaging technology of CIOMP

| No. | Technology |
|---|---|
| 3 | Verification and development of the principles for the diffractive compound eye imaging system |
| 4 | Preparation of the membrane diffractive element |



Membrane photon sieve




The compound eye diffractive telescope and optical system detecting device

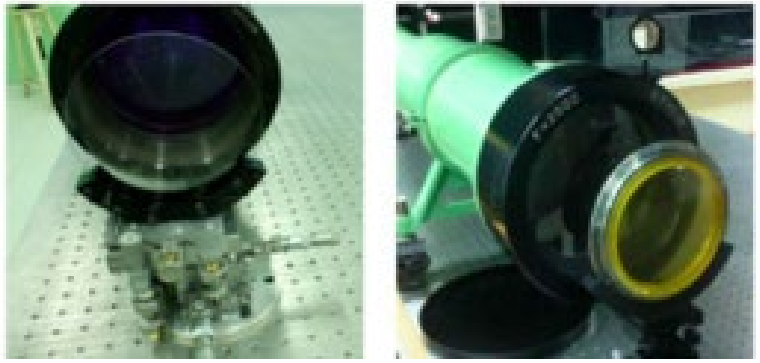
# Research and development status in China

Research on diffractive-optics imaging technology by IOE

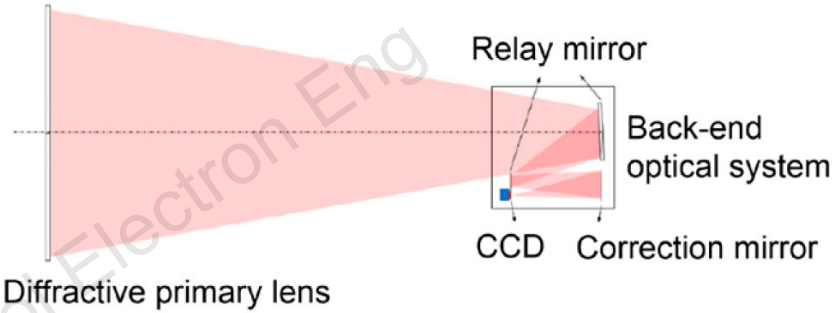
| Year | Technology |
|---|---|
| 2008 | A micro-structured silicon-based infrared imaging prototype with an aperture of 80 mm was completed. |
| 2011 | A membrane primary lens with a quartz substrate and polyimide membrane primary lens was developed. |
| 2012 | A membrane prototype with an aperture of 80 mm was tested in an outdoor field, and a stitching testing of the mirrors with an aperture of 200 mm was performed. |
| 2014 | A membrane diffractive telescope with an aperture of 400 mm, a waveband of 0.49–0.68 μm, and a Fresnel zone plate surface microstructure was first realized in China |
| 2015 | The wideband achromatic model from Schupmann was applied to the design of a large-aperture diffractive-optics imaging system, and an astronomical scope with a 5 m aperture primary lens was designed. |

# Research and development status in China

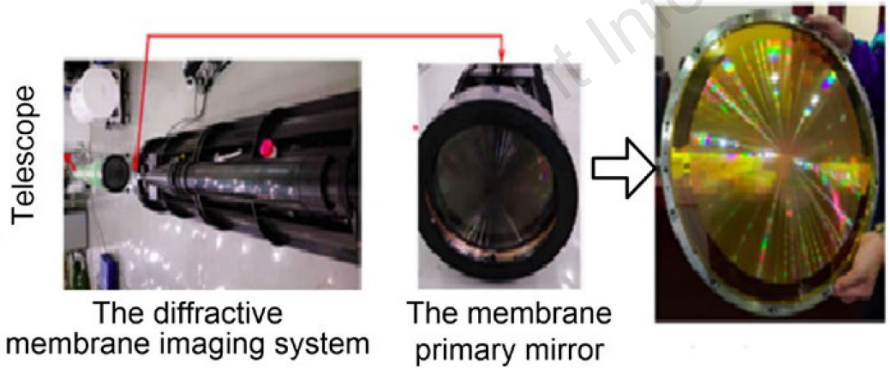
Research on diffractive-optics imaging technology by IOE



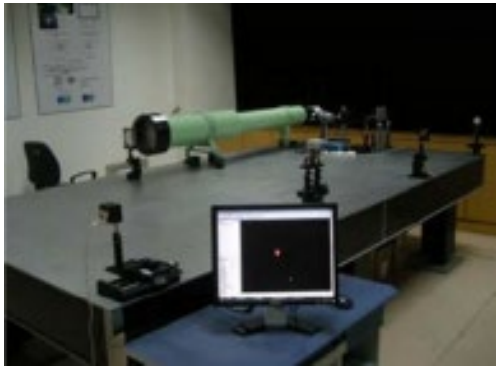
Membrane primary lens with quartz substrate




Schematic of a space telescope based on the planar diffractive lens




Membrane telescope bar with 400 mm in diameter and a complex scene target imagery



Experimental setup for the broadband imaging performance test

# Development trends

| No. | Outlook |
| --- | --- |
| 1 | Optical design for chromatic aberration correction |
| 2 | Processing of membrane diffractive optical elements |
| 3 | Stitching and unfolding technology |
| 4 | Realization of the relative spatial position for two parts of the diffractive telescope system |