The UV Fresnel imager

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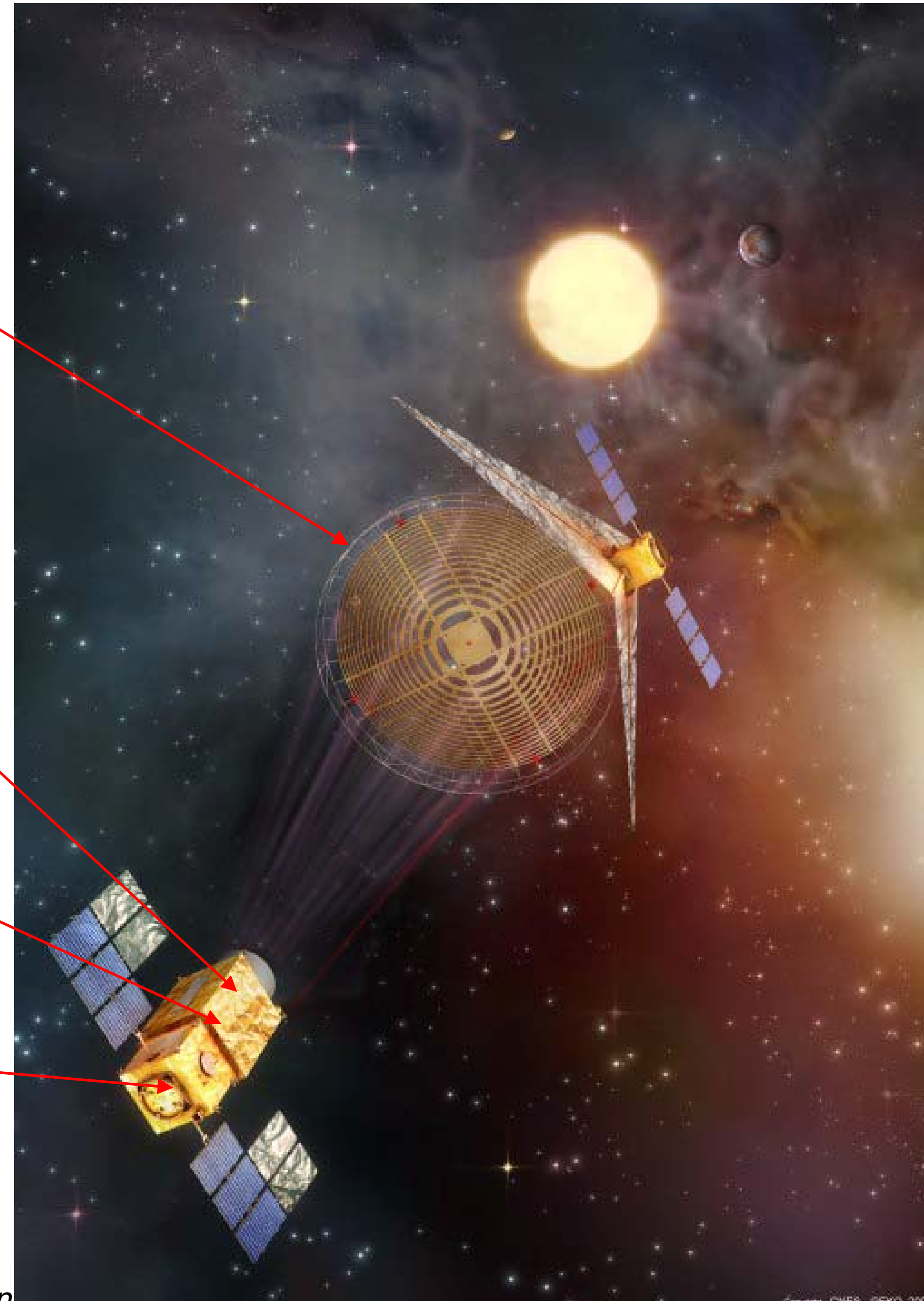
The UV "Fresnel imager" for astrophysics

Fresnel Array: thin membrane
6 to 15 meter diameter,
diffraction limited, apodized.

Field optics telescope:
50 cm diameter.

Chromatic correction system:
Blazed concave grating,
10 to 30 cm diameter

focal Instrumentation:
UV Spectro-imagers



Outline

I. Optical concept

II. Validation tests

III. Going to UV

III. Space mission science cases

I. Diffraction focusing

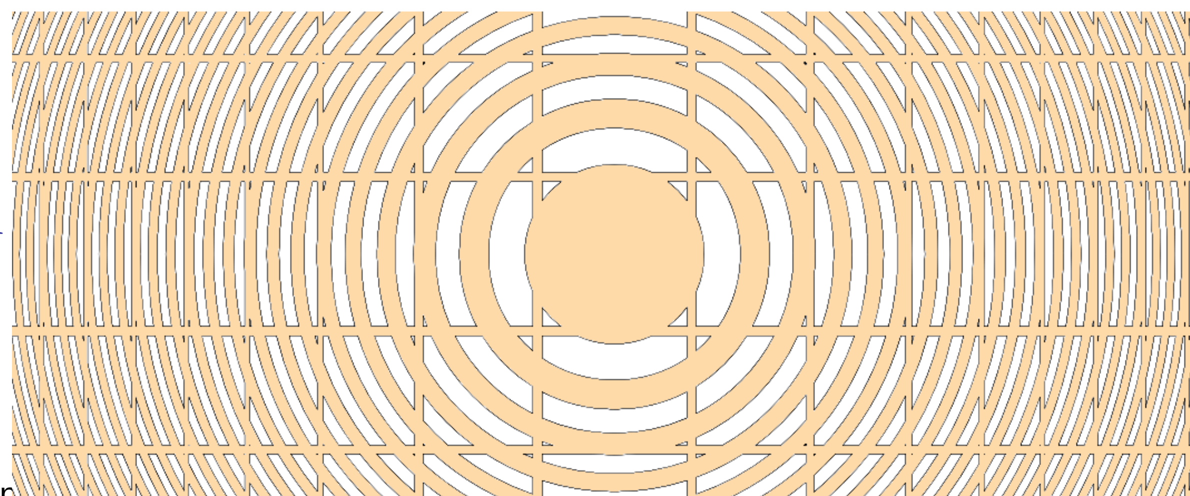
Fresnel lenses

One name, two types

Refractive: low resolution

no cophasing between sectors,

This is not diffraction focusing.



Diffractive: high resolution

cophasing:

Diffraction focusing.

Two ways of using diffraction

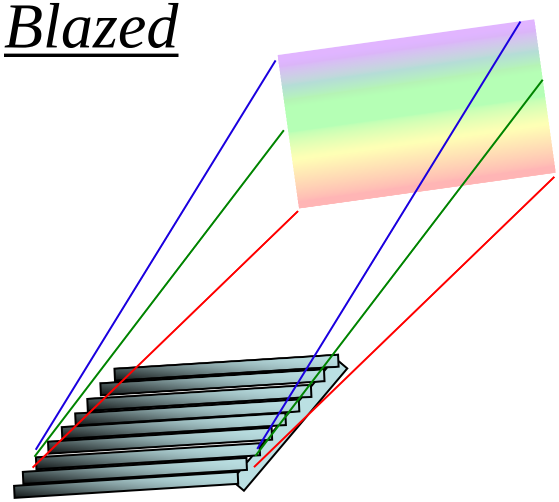
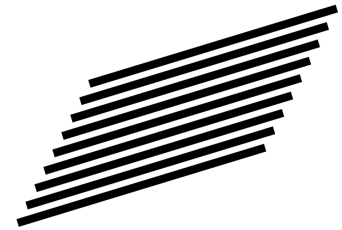
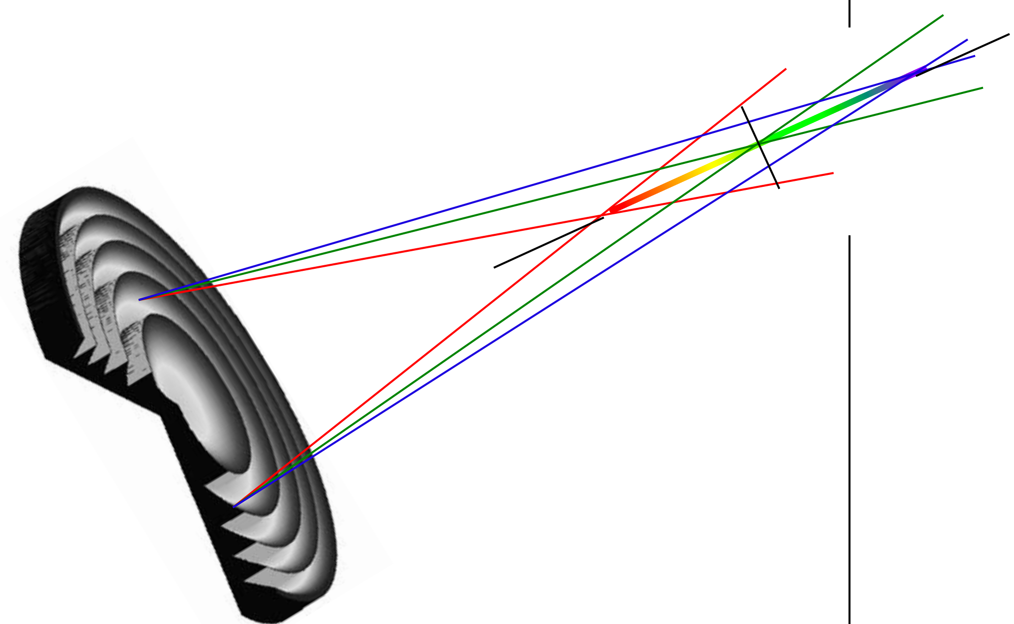
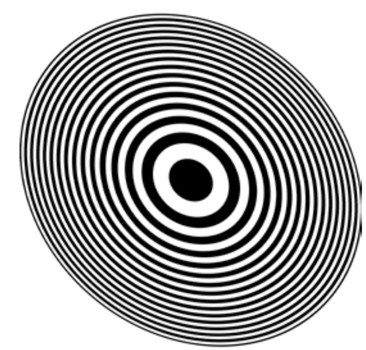
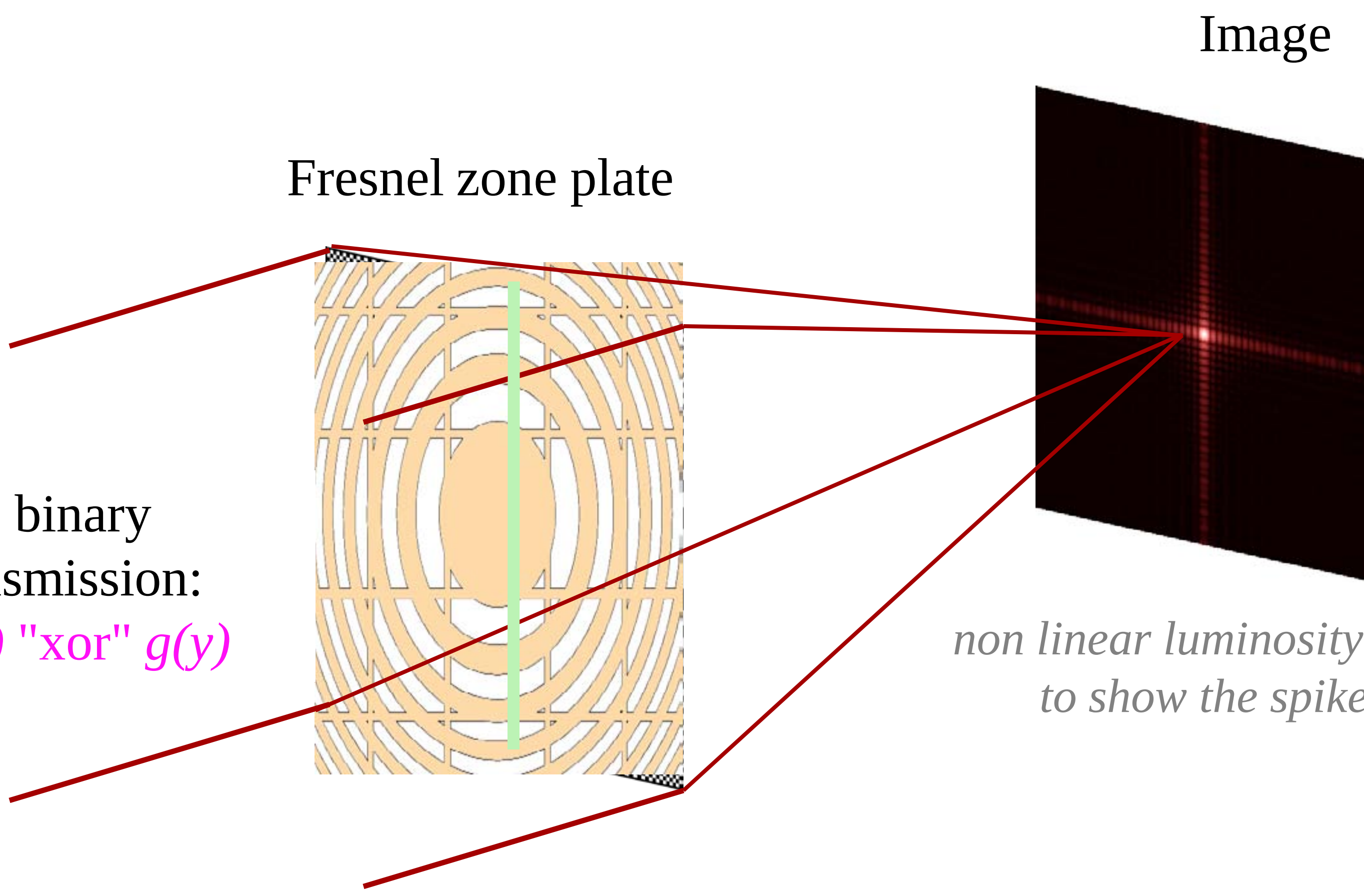
	Blazed	*Binary:* Transmission $g(x) = 1$ or 0
gratings		
Fresnel zone plates		

Image formation

Can light travel in vacuum all the way from source to image?



Quasi no stray light except in four spikes.

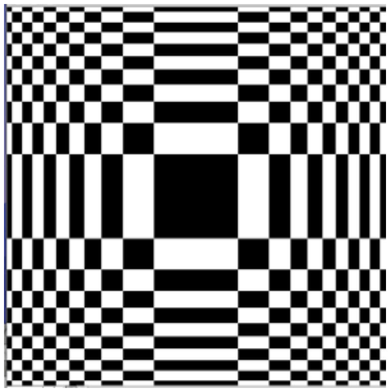
2-D binary transmission:
g(x) "xor" *g(y)*

non linear luminosity scale, to show the spikes.

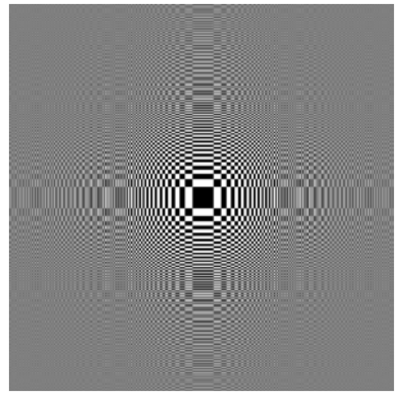
Fresnel arrays compared to solid apertures

Images of a point source by:

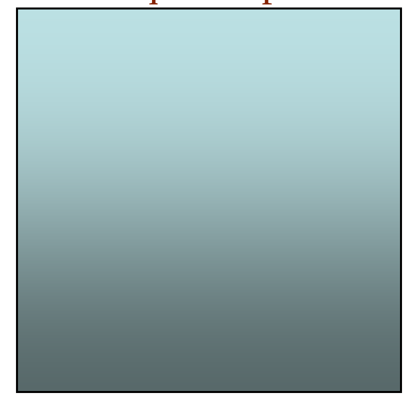
300 Fresnel zones

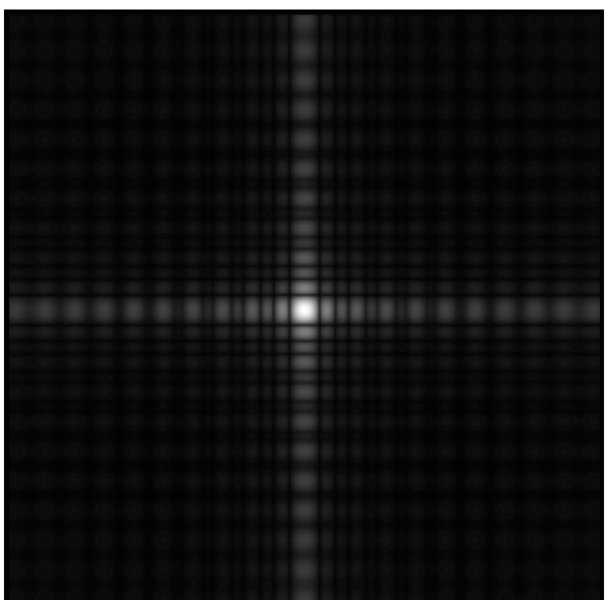


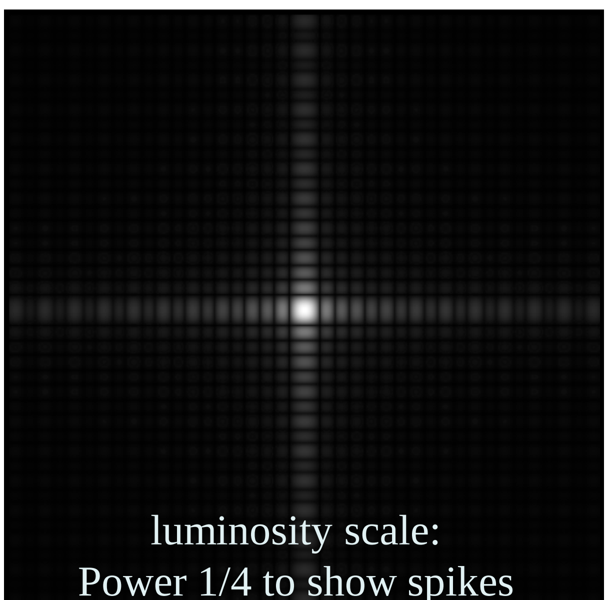
3000 Fresnel zones

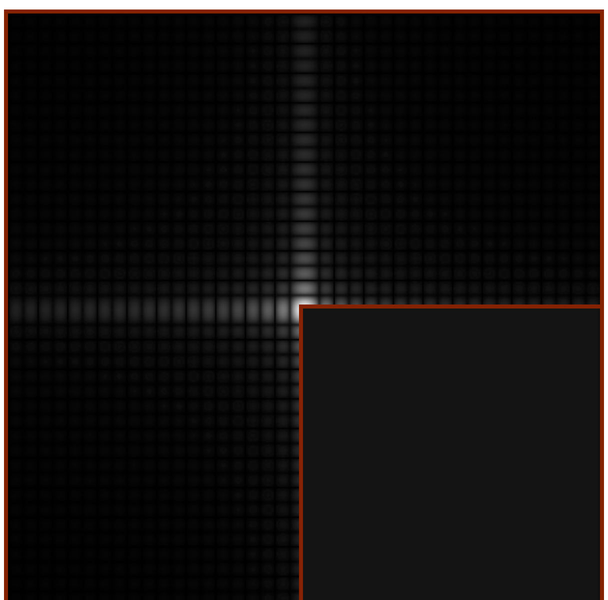


Solid square aperture





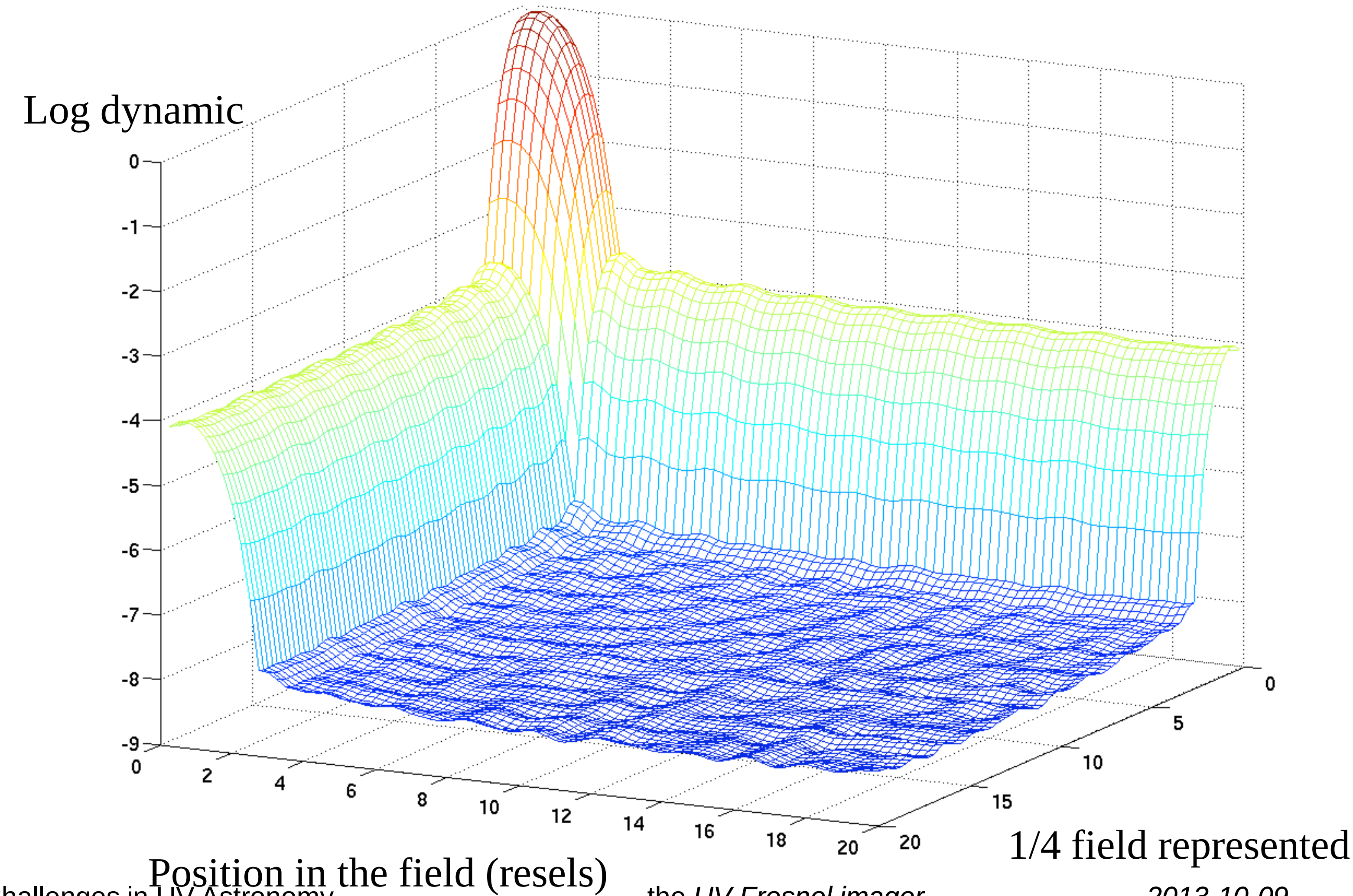




Fresnel arrays: *Dynamic range & resolution*
PSF for 300 zones (720 000 apertures)

Numerical Fresnel propagation

apodized prolate,
order 0 masked



"pro":

Focus with an ultralight mesh: 200g for a 6m square, 1.2 kg for 15m

Light passes through holes =>broad spectral domain: λ = 90nm (UV) to 25 µm (IR)

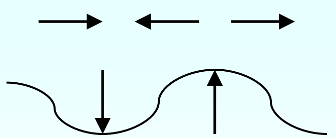
Get accurate wavefronts, allow approximate manufacturing & positioning:

The tolerance is wavelength independent:

a 15 m Fresnel array yields a λ/50 wavefront at tolerances:

50 µm holes position error in the plane of the mesh,

1 cm membrane position error perpendicular to plane



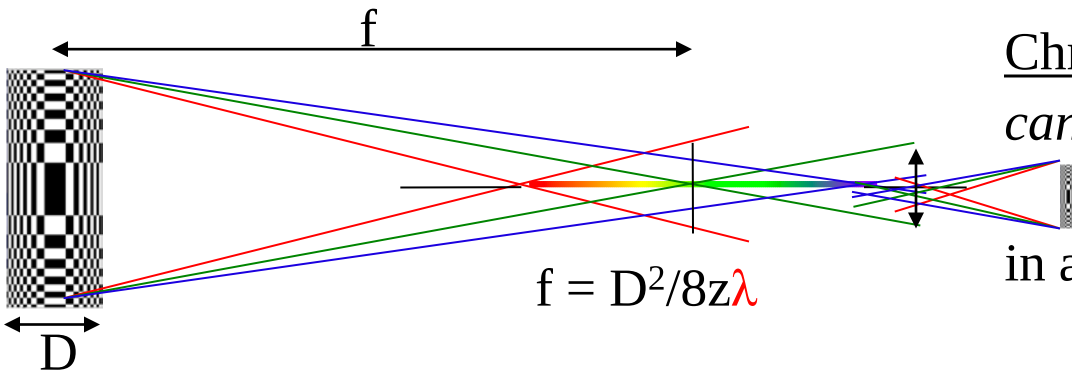
Open the way to large apertures in space, at short wavelengths.

Reach high angular resolution: *same as diffraction limited optics of equal size*,

Reasonable field : ~1000 times the resolution.

Obtain high contrasts on compact objects.

"Against":



Chromatism:

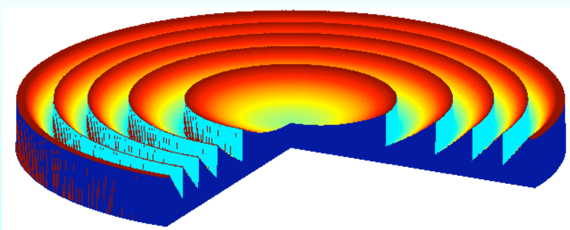
can be canceled by order -1 diffraction

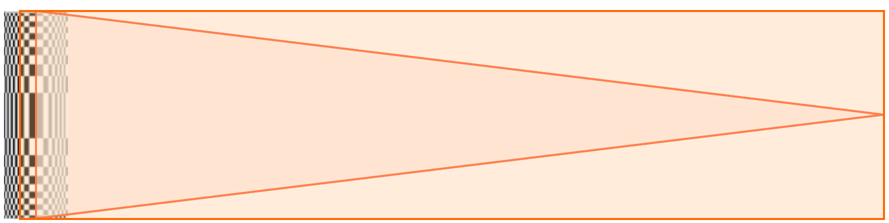
in a pupil plane.

Requires chromatic correction optics

of small size, but with Δλ/λ < 30%

causes field limitations.





Transmission efficiency to focus < 10%

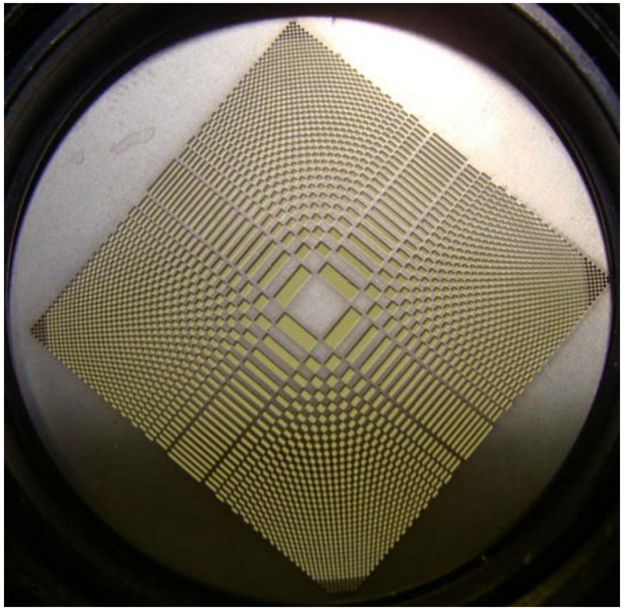
can be compensated by large apertures.

Achieved at present : 6.8%

Long focal lengths: *requires formation flying in space, (7500 fields in 7 years)*

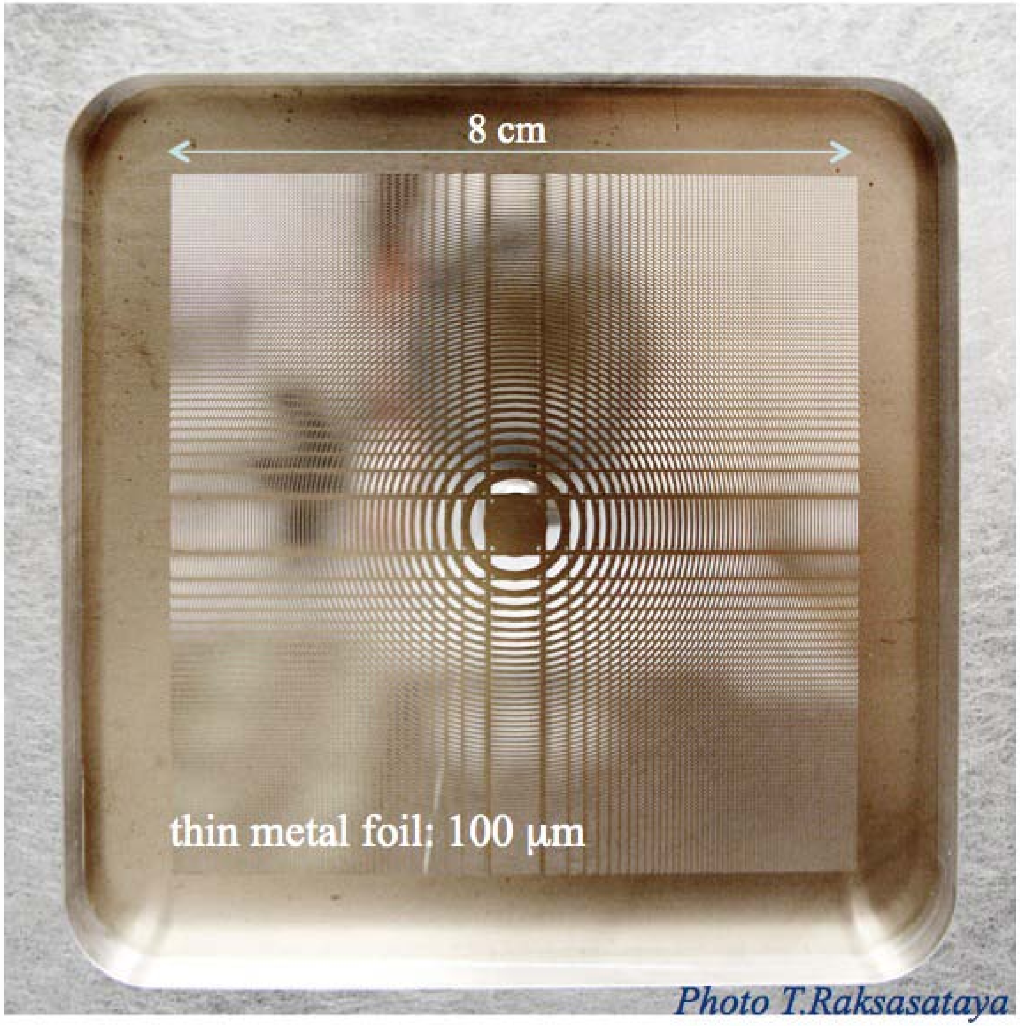
$f = D^2/8z\lambda$

II. Validation tests



- Getting achromatic images
- Getting high contrasts
- Going to UV

8 cm Fresnel array, lab tests, visible (2005-2008)



116 Fresnel zones
26680 apertures.

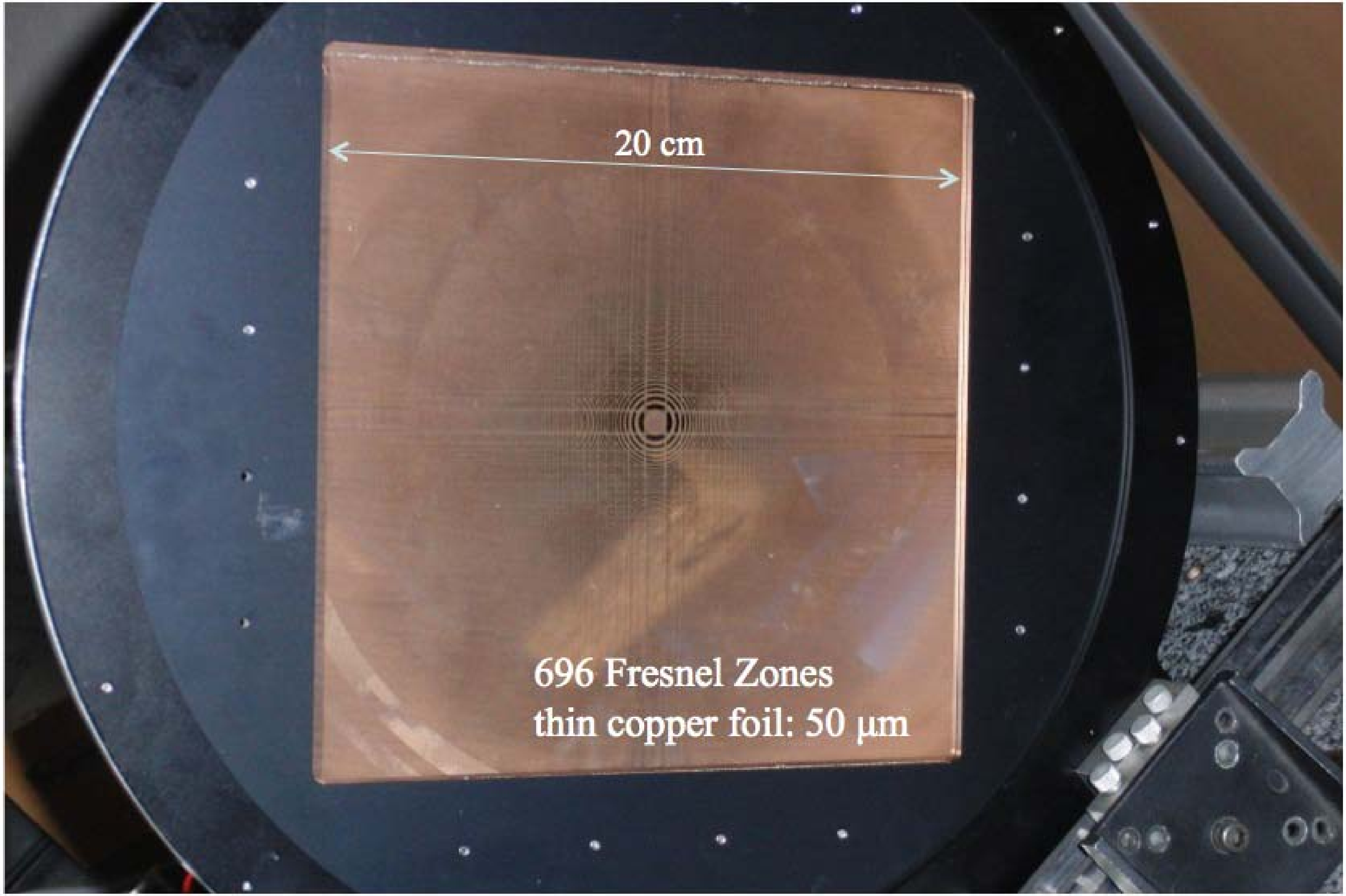
f= 23 meters at λ= 600 nm

Precision: 5µm on holes positioning
=> λ/70 wavefront quality.

Achievements on lab sources:

- *Diffraction limited*
- *Broad band imaging (450-850nm)*
- *10^{-6} dynamic range.*

20 cm Fresnel array (2009-2012)



20cm Fresnel array, lab tests

- Angular resolution
- Field
- Contrast

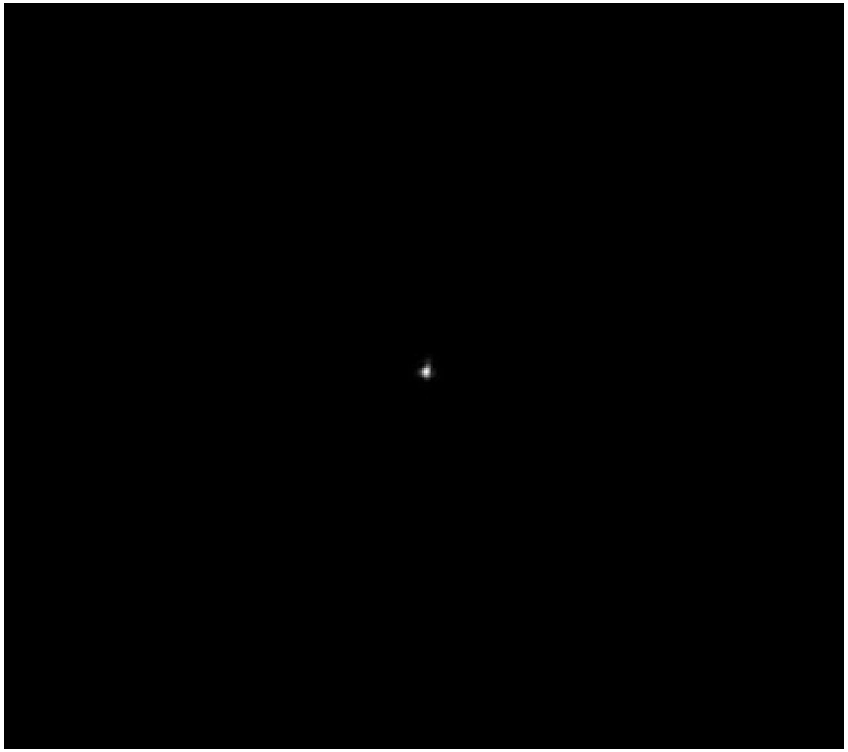
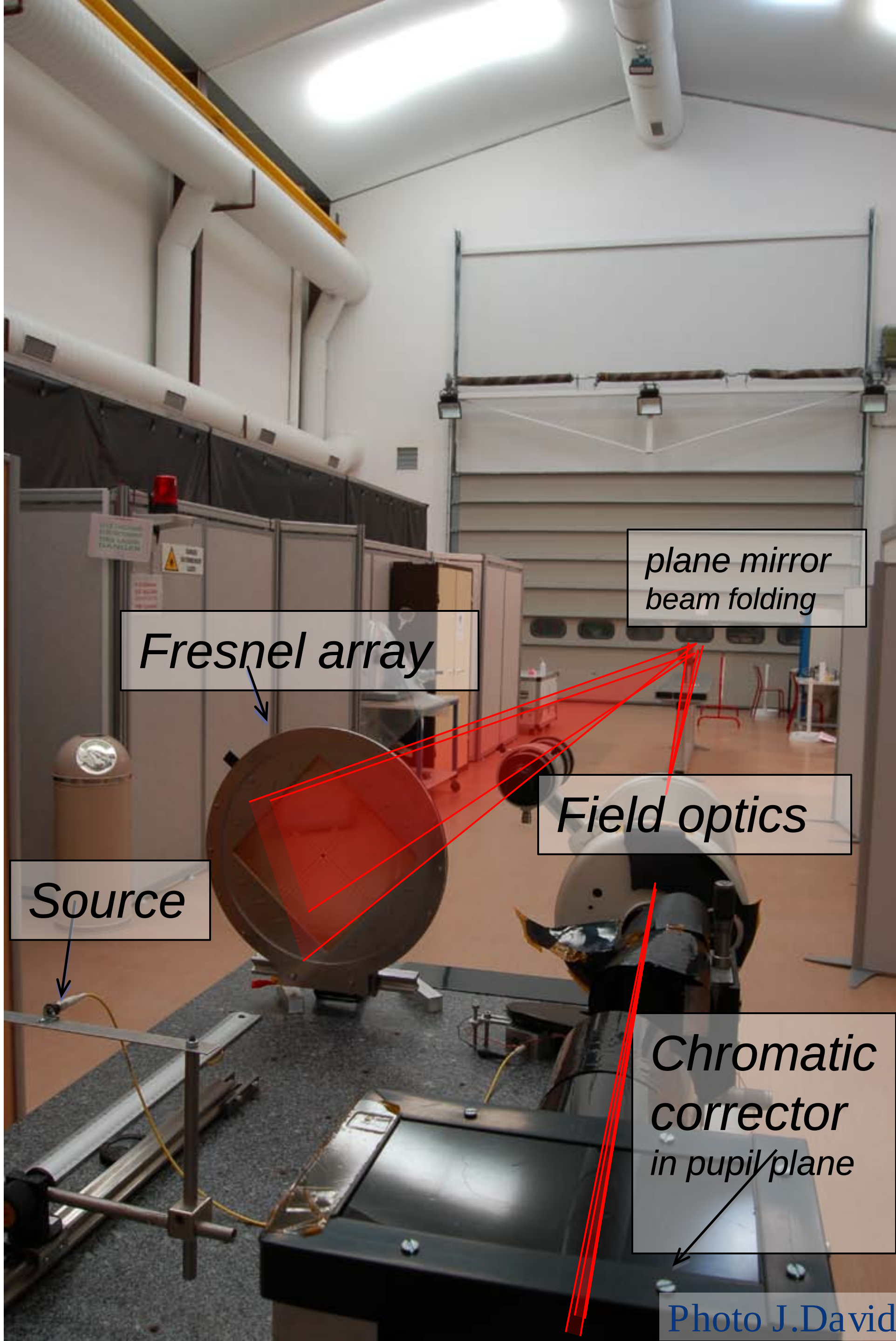


Image of a point source



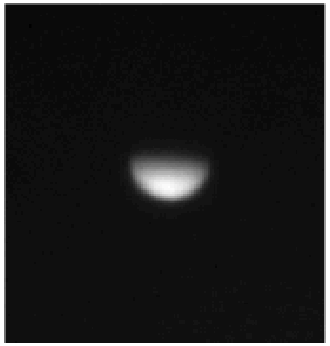
20 cm Fresnel array, sky tests

Moon, 20 cm Fresnel array, visible and NIR

λ = 650 to 900 nm

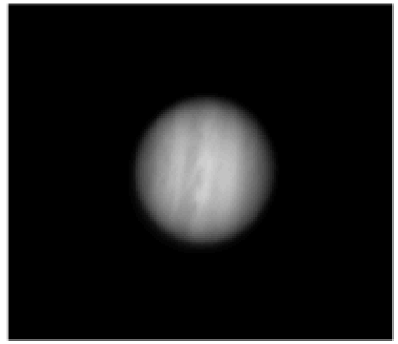
20 cm Fresnel array, various sky sources

$\lambda =$ 650-900 nm

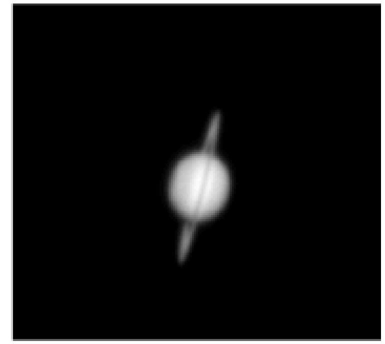


Venus

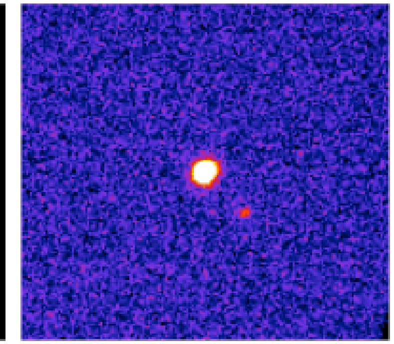
Mars



Jupiter

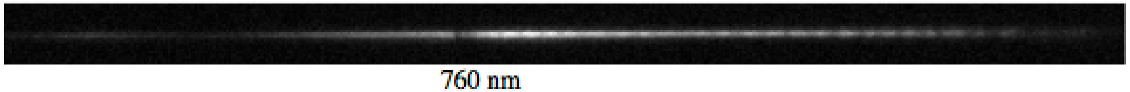


Saturn

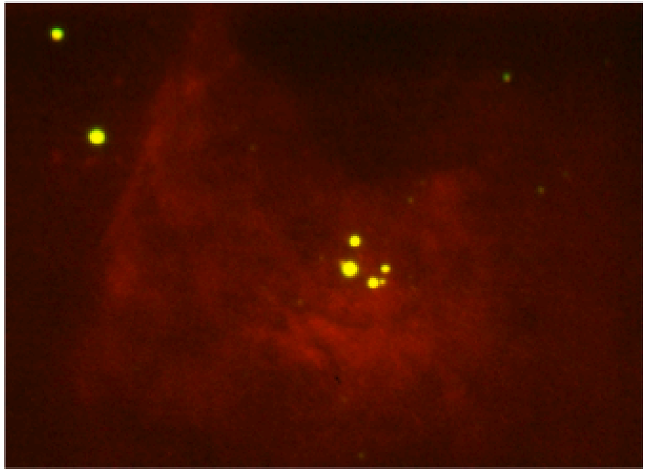


Neptune + triton

ε Lyr



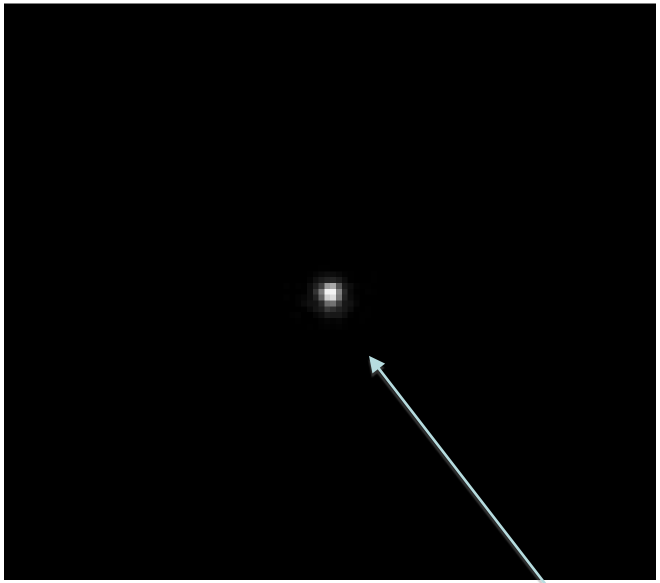
spectrum of α Cyg, obtained by displacing the chromatic corrector

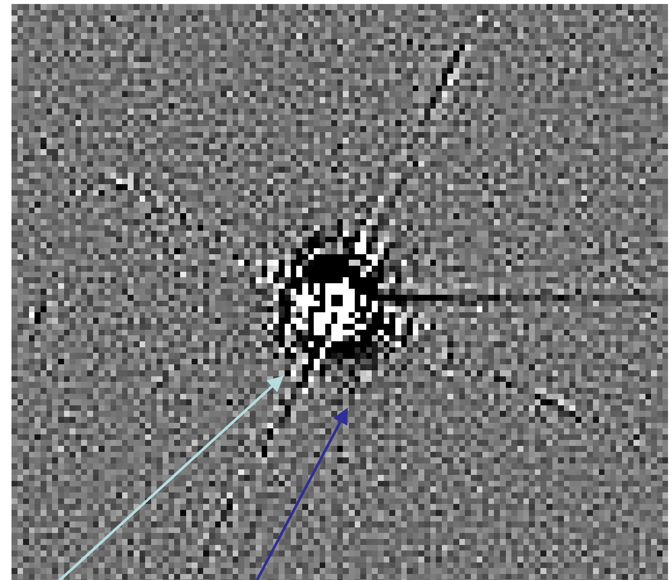


θ Ori in M42 (combined Hα + continuum 650-900 nm)

20 cm Fresnel array, Sirius

λ = 640-740 nm



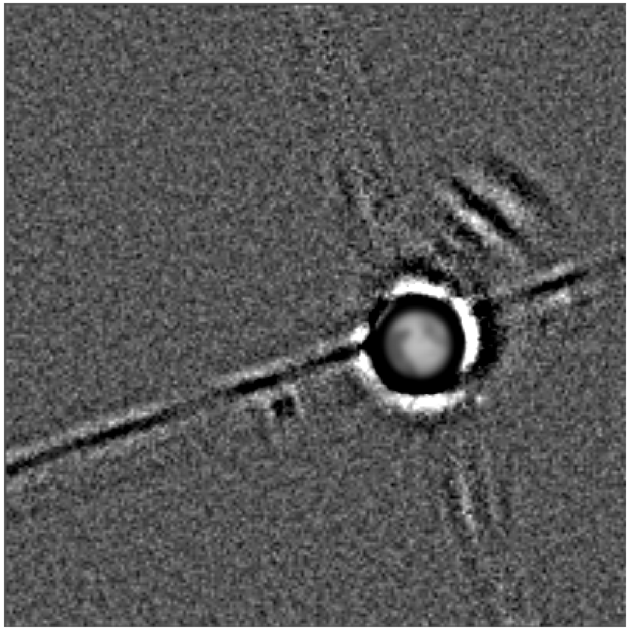


Sirius A and Sirius B
Separation 6''

Magnitudes -1.5 and 8.5 in spectral band V
brightness ratio at λ = 690 nm: ~ *26000*

20 cm Fresnel array, Mars

contrast tests on Phobos



650-740 nm band-pass, averages of 200 exposures, 1s each.

III. And now: go to UV!

Why this wavelength domain ?

- High angular resolution;
- Efficient focusing compared to classical optics:

  expected dynamic range = 10^8

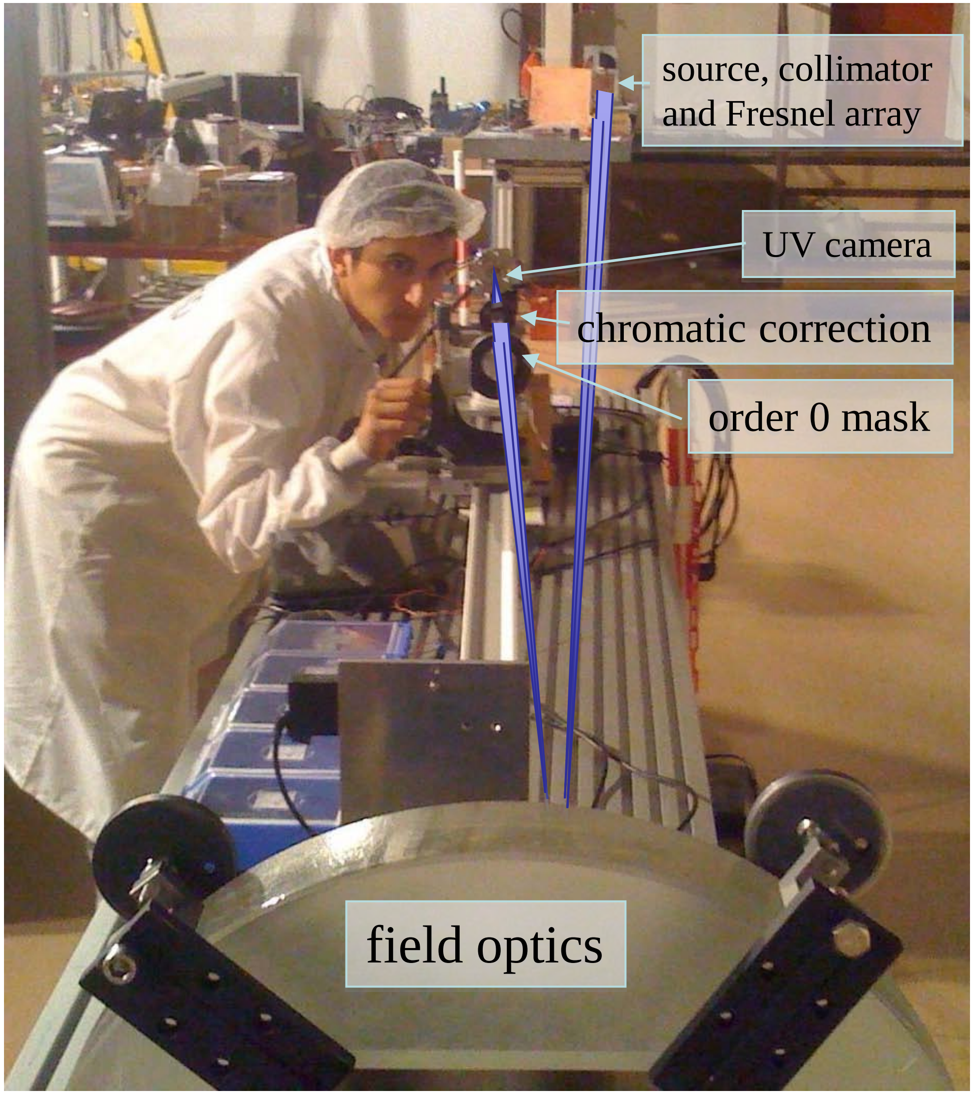
- 7000 different fields reachable in a 7-year mission with 400 ms^{-1} ergol;
- at *121 nm:* 1.7 to 4.2 *mas* resolution, 2 to 5 *arc seconds* fields;
- at *250 nm: 10 mas* reslution, 10 *arc seconds* fields.

Need to validate a space Fresnel imager in UV ?

- Ground based UV prototype;
- intermediate step for space

Validation tests in UV, 2013

Lab tests at λ = 260 nm, Δλ = 10 nm

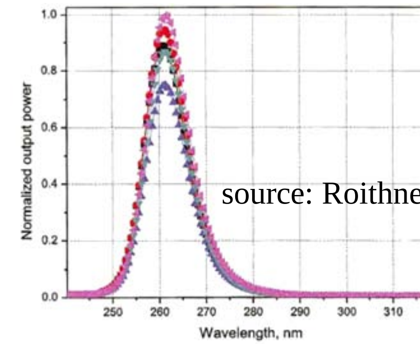


Light sources:

LEDs, λ = 260 nm, and 285, 310 nm

Δλ (fwhm) = 10 nm.

UV LED spectrum



Source objects:

10 to 200 μm circular diaphs,
USAF target (carved into copper)

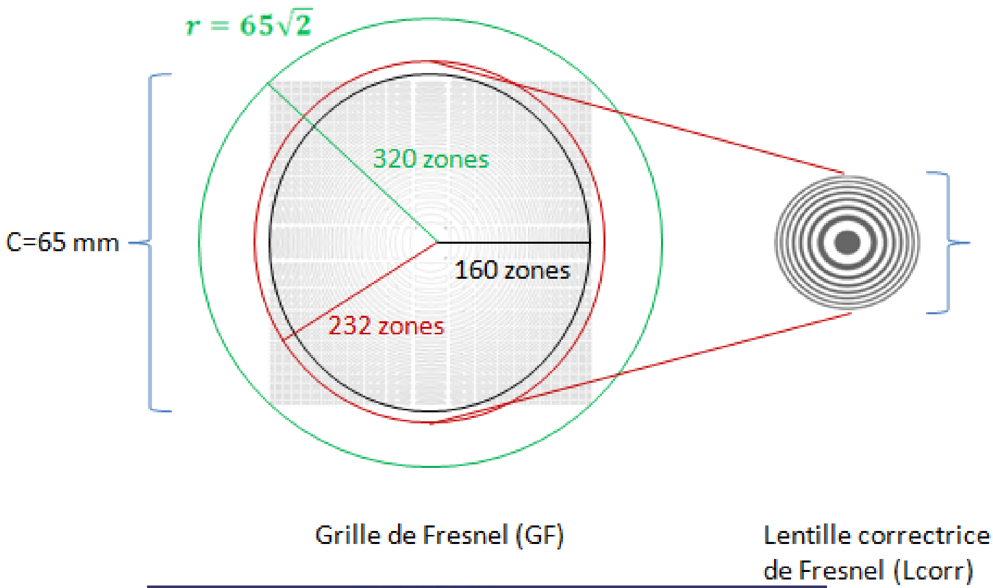
Fresnel array:

square 6.5 x 6.5 cm,
320 Fresnel zones,
f = 12.7 m @ λ = 260 nm.

UV camera:

developed by Thales
320 x 256, 30 μm square pixels
peak sensitivity 265 nm

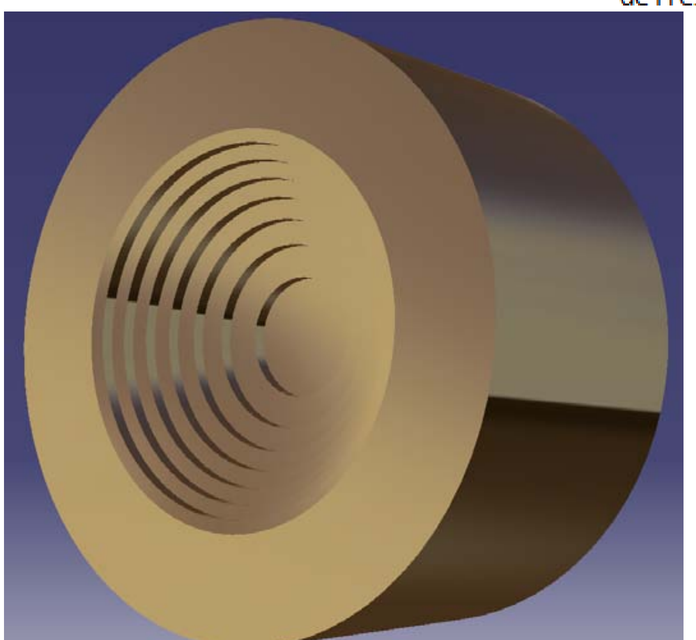
Chromatic correction config in UV



Tested chromatic correction in lab:
chromatic correction at order -2:
232 zones Fresnel lens,
D = 16 mm.

D= 16 mm
116 zones à l'ordre 1
232 zones à l'ordre 2

in fused silica,
blazed for λ = 600 nm at order -1,
used at order -2 => 300 nm.



Planned chromatic correction in space:
chromatic correction at order -1:
concave and blazed Fresnel mirror,
carved by ion etching
+ magnetorheology,
then coated for UV reflectivity.

one reflecting surface, three actions:
dechromatism + focusing + fine guiding.

Tests at λ= 260nm Δλ= 10 nm

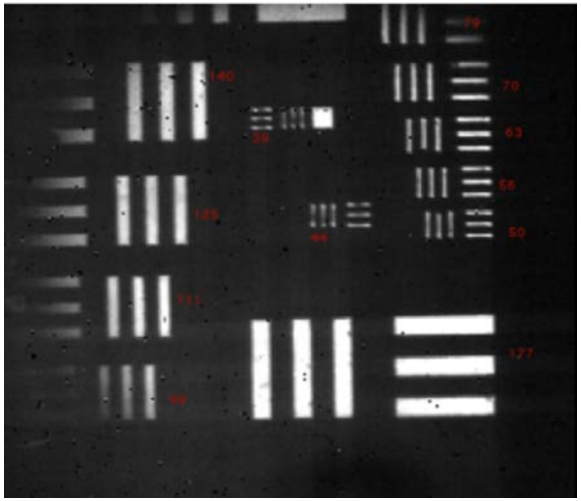


image of USAF target,
at λ = 260 nm

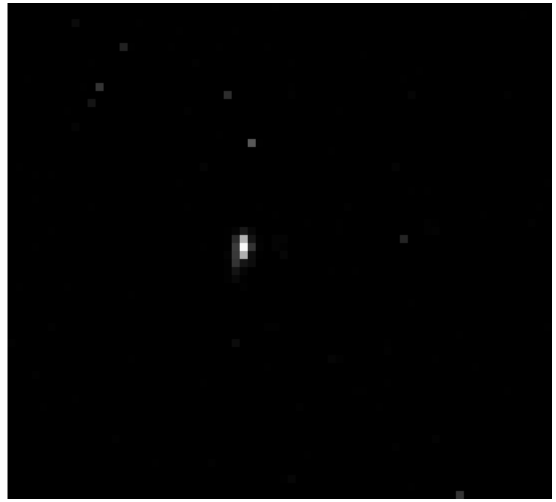


image of 10 µm diaph,
at λ = 260 nm

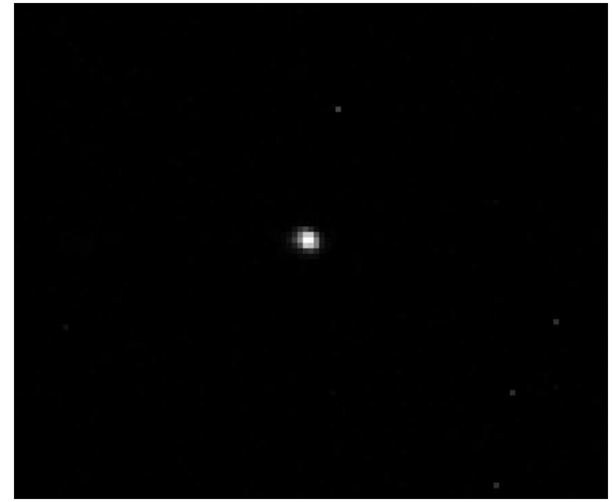
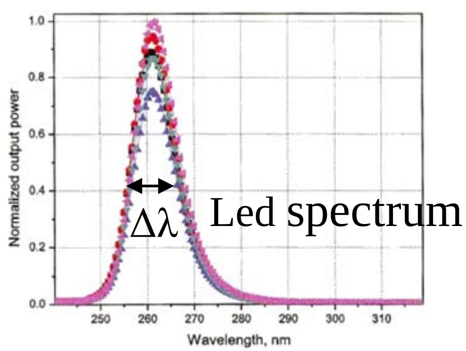
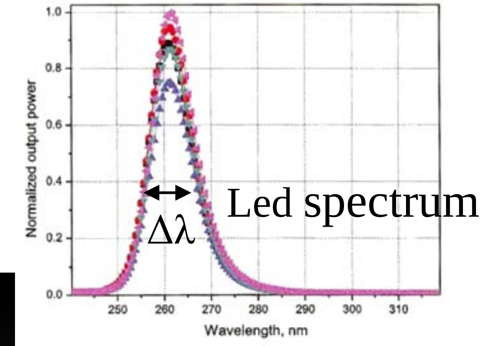
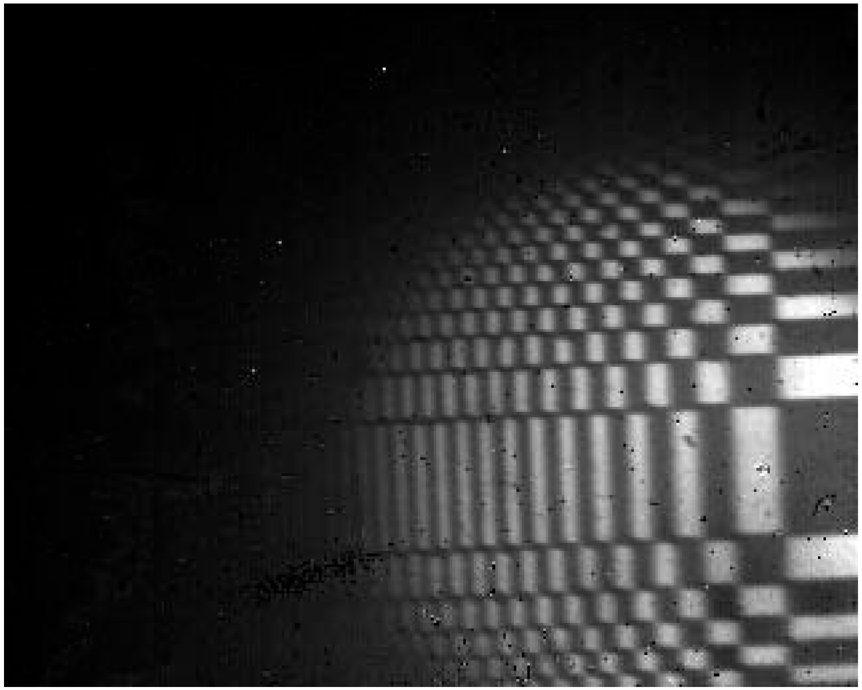


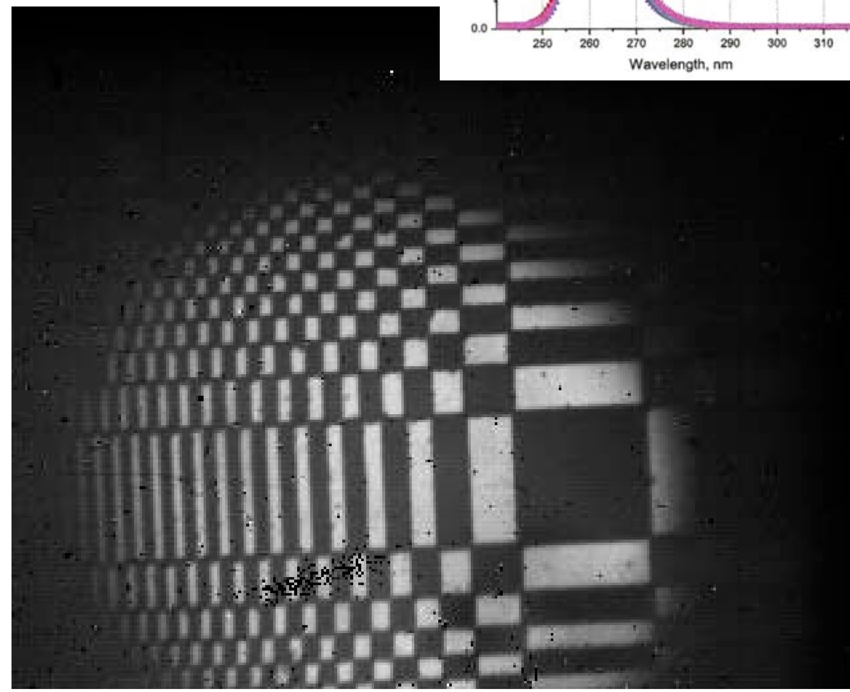
image of 25 µm diaph,
at λ = 260 nm



Chromatic effects in UV







diffractive lens displaced horizontally:
bad correction

diffractive lens aligned
with pupil of Fresnel array:
good chromatic correction

How to increase the TRL ?

ISS proposal

Get support from CNES, to apply for a ROSCOSMOS mission;

Aperture will be limited to 15 cm for Ly-α;

=> bright sources only

=> resolution limited to 0.17" (in Ly-α)

ISS is not stable, not oriented => siderostat mirror required;

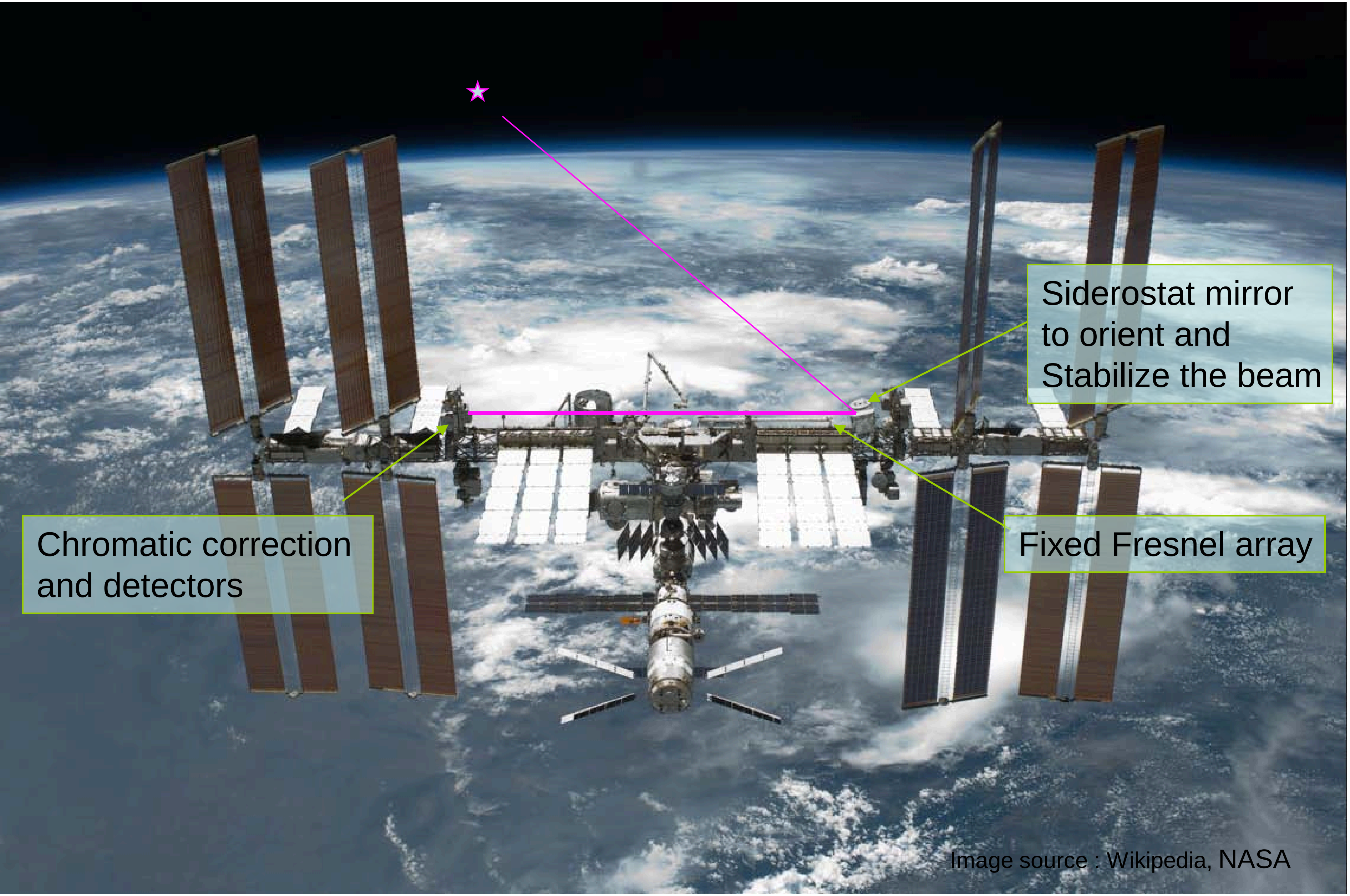
ISS environment is polluted due to gas: where & to what extent?

Agencies will require scientific goals!

in addition to tech tests, some science is possible:

- Moon surface,
- Jupiter auroras,
- UV spectroscopy on M stars;

Let's start by building an interest group: volunteers welcome.


Siderostat mirror
to orient and
Stabilize the beam
Chromatic correction
and detectors
Fixed Fresnel array
Image source : Wikipedia, NASA

IV. Space mission science

Full Fresnel mission themes

Themes addressable in UV @ High Dynamic Range Spectro-Imaging

- Solar system objects: planet auroras, multiple asteroids;
- Exolanets: imaging=>orbits, soil & atmosphere spectra;
- Stellar physics: T Tauri, stellar disks, M stars, White dwarfs;
- Astrochemistry in gas and dust cloud boundaries;
- Reflection nebulae;
- Clusters: chemical evolution, stellar populations;
- Galaxies, star formation, AGN, cosmology.

Configuration proposed

- Primary array 6 m to 15 m => resolution 4.2 to 1.7 mas in Ly α
- Two UV channels centered on 125 & 250 nm, $\Delta\lambda$= 40 nm & 80 nm
- 2 instruments : Imaging 4000*4000 + spectro-imaging 10*20*2000