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

<table>
<thead>
<tr>
<th>gratings</th>
<th>Blazed</th>
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<tbody>
<tr>
<td><em>Fresnel zone plates</em></td>
<td><img src="image" alt="Blazed Fresnel zone plates" /></td>
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| Binary: 
Transmission |
<table>
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<tr>
<td>$g(x) = 1 \text{ or } 0$</td>
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![Binary: Transmission](image)
Can light travel in vacuum all the way from source to image?

2-D binary transmission:
\[ g(x) \text{ "xor" } g(y) \]

Quasi no stray light except in four spikes.

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

luminosity scale: Power 1/4 to show spikes
Fresnel arrays: Dynamic range & resolution
PSF for 300 zones (720 000 apertures)

Numerical
Fresnel propagation

apodized prolate,
order 0 masked

Position in the field (resels)
1/4 field represented

Log dynamic
"pro":

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

Get accurate wavefronts, allow approximate manufacturing & positioning:

The tolerance is wavelength independent:

a 15 m Fresnel array yields a \( \lambda/50 \) wavefront at tolerances:

- 50 \( \mu m \) 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 : \( \sim 1000 \) 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 $\Delta \lambda / \lambda < 30\%$ causes field limitations.

Transmission efficiency to focus $< 10\%$ can be compensated by large apertures. Achieved at present: 6.8%
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 \( \lambda = 600 \text{ nm} \)

Precision: \( 5 \mu m \) on holes positioning
\( \Rightarrow \lambda/70 \) wavefront quality.

**Achievements on lab sources:**

- Diffraction limited
- Broad band imaging \((450-850\text{nm})\)
- \( 10^{-6} \) dynamic range.
20 cm Fresnel array (2009-2012)

696 Fresnel Zones
thin copper foil: 50 μm
20cm Fresnel array, lab tests

- Angular resolution
- Field
- Contrast

![Image of a point source](image.jpg)

ESO/NUVA/IAG Workshop on Challenges in UV Astronomy
20 cm Fresnel array, sky tests

- Pupil plane control
- Field optics
- Order 0 mask
- Chromatic correction
- Beam splitter Pupil/Science
Moon, 20 cm Fresnel array, visible and NIR

\[ \lambda = 650 \text{ to } 900 \text{ nm} \]
20 cm Fresnel array, various sky sources

$\lambda = 650-900 \text{ nm}$

Venus

Mars

Jupiter

Saturn

Neptune + triton

$\varepsilon$ Lyr

spectrum of $\alpha$ Cyg, obtained by displacing the chromatic corrector

$\theta$ Ori in M42 (combined H$\alpha$ + continuum 650-900 nm)
20 cm Fresnel array, Sirius

\[ \lambda = 640-740 \text{ nm} \]

Sirius A and Sirius B
Separation 6"

Magnitudes -1.5 and 8.5 in spectral band V
brightness ratio at \( \lambda = 690 \text{ nm} \): \( \sim 26000 \)
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 resolution, 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 $\lambda = 260$ nm, $\Delta \lambda = 10$ nm

Light sources:
- LEDs, $\lambda = 260$ nm, and 285, 310 nm
  - $\Delta \lambda$ (fwhm) = 10 nm.

Source objects:
- 10 to 200 $\mu$m circular diaphs,
- USAF target (carved into copper)

Fresnel array:
- square 6.5 x 6.5 cm,
- 320 Fresnel zones,
- $f = 12.7$ m $\@ \lambda = 260$ nm.

UV camera:
- developed by Thales
- 320 x 256, 30 $\mu$m 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,
$D = 16 \text{ mm}$.

- 232 zones Fresnel lens, $D = 16 \text{ mm}$.
- 116 zones à l’ordre 1
- 232 zones à l’ordre 2

in fused silica,
blazed for $\lambda = 600 \text{ nm}$ at order -1,
used at order -2 $\Rightarrow 300 \text{ nm}$.

**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 $\lambda = 260\text{nm}$ $\Delta\lambda = 10\text{ nm}$

image of USAF target, at $\lambda = 260\text{ nm}$

image of 10 $\mu$m diaph, at $\lambda = 260\text{ nm}$

image of 25 $\mu$m diaph, at $\lambda = 260\text{ nm}$
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.
Challenges in UV Astronomy

Siderostat mirror to orient and stabilize the beam

Fixed Fresnel array

Chromatic correction and detectors

IV. Space mission science
Full Fresnel mission themes

Themes addressable in UV @ High Dynamic Range Spectro-Imaging

- Solar system objects: planet auroras, multiple asteroids;
- Exoplanets: 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, Δλ= 40 nm & 80 nm
- 2 instruments: Imaging 4000*4000 + spectro-imaging 10*20*2000