The UV side of galaxy evolution with FRESNEL imagers

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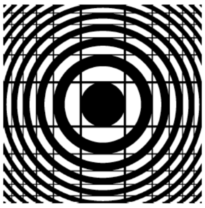
Optical Principle

A Fresnel imager is a space telescope that uses a Fresnel array as primary optics, akin to a Soret zone plate. While having the resolution and imaging capabilities of large mirrors, no optical material is involved in the focusing process: just **vacuum** and a thin **opaque** foil punched with specially shaped holes. This layout of numerous **void** subapertures focuses light by **diffraction**. Light forms directly an image while having traveled entirely in vacuum: there is no optically active element in the light path that could degrade the wavefront or limit the bandpass, although small size optical elements are present after the primary focus.

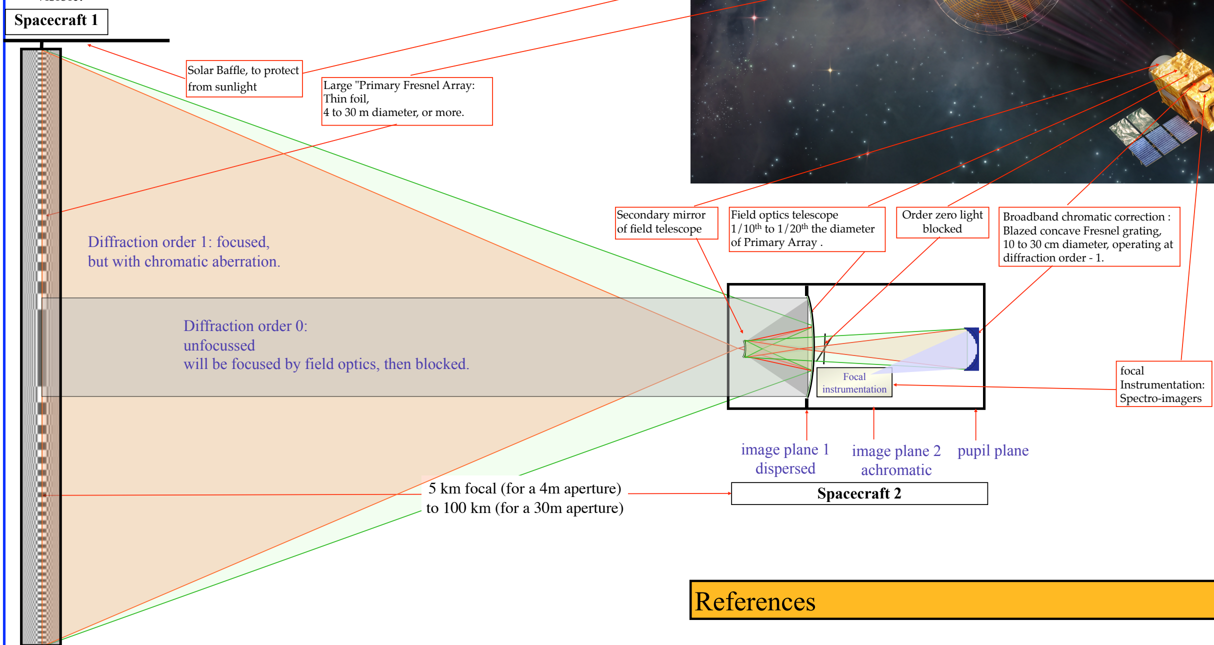
- A Fresnel array focuses up to 10% (theoretically) of the incident light: 6% to 7% efficiencies have been achieved in our lab prototypes (see Serre et al. 2009).
- In a Fresnel array, Fresnel rings are held together by a set of orthogonal bars, which follow a precise positioning law. Bars contribute also to focalization.
- The main aperture is square and apodized, thus allowing high dynamic range: up to 10^8 in the raw image.
- High Dynamic Range imaging requires a high optical grade outgoing wavefront. The wavefront quality is driven by the precision of the focusing optics. In the case of a Fresnel array, this corresponds to the precision in positioning of the subapertures (logical complement of rings and bars) in the plane of the array. This precision is broadly relaxed compared to a mirror surface requirement: a factor of 200 or more, depending on the f-ratio of the Fresnel array. The optical quality, and the light transmission efficiency to focus are wavelength independent.



Example of a Fresnel array. Black is opaque material, white is void holes. Bars contribute optically to image formation, and hold the rings.

Formation flying spacecrafts

- The long focal lengths of Fresnel arrays require formation flying of two spacecrafts, at L2 Lagrangian point, one spacecraft holding the Fresnel array, the other holding the focal instrumentation.
- The Fresnel array is baffled form sunlight and can point targets in a +/- 20° meridian band, perpendicular to the sun direction.
- The chromatism intrinsic to diffractive focusing by Fresnel arrays is canceled by one or several small compensative diffraction elements in a pupil plane after prime focus, yielding one or several $\Delta\lambda > \lambda = 0.2$ bandpasses for different channels in the "receiver" spacecraft. The optical elements and detectors are specific to each channel, and can be optimized according to the central wavelength of each.
- In the receiver spacecraft, the beam encounters three reflecting surfaces: one is common to all spectral channels (field optics telescope primary mirror) the second and third one can be specific to each spectral bandpass and switched when changing channels. There will be 2 to 4 different channels, with imagers and specto-imagers, covering partially the spectrum from Lyman α to the visible.



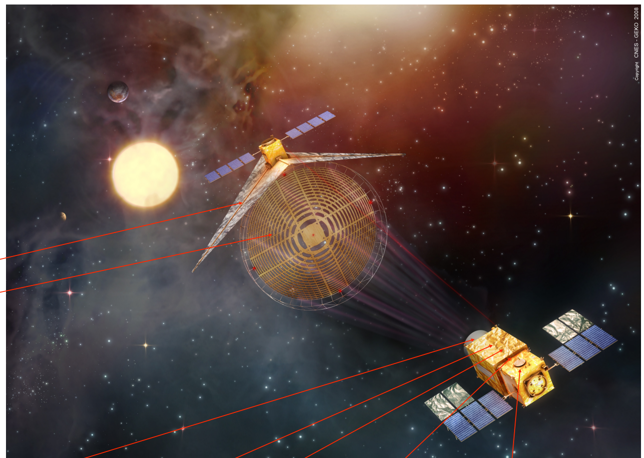
Constraining the star-formation history of Galaxies

The first version of the Fresnel Imager has been designed to probe the efficiency of the concept in the UV spectral domain, with a relatively large spectral coverage. Hence, the Fresnel Imager should be an ideal instrument to **study the evolution of the star-formation activity traced by rest-frame UV, in particular around Lyman alpha emission**, in different ways:

- The spatial resolution achieved (i.e. 0.006-0.008" in the far UV) is enough to resolve the typical size of an HII region all the way between z~1 and the local universe. This capability could be further improved by the use of lensing clusters, taking advantage from the magnification induced on the background population of galaxies. An unprecedented resolution could be achieved in the study of the physical properties of star-forming regions by combining the 3D spectroscopic information corresponding to the ISM and stars in these regions.
- Understanding the relationship between Lyman α emission and other physical properties in relatively low-z (z<1) spatially resolved galaxies, such as the age of the stellar population, dust absorption and kinematics, is crucial when using Lyman α as a cosmological probe in higher redshift studies (see e.g. Kunth et al. 2003, Atek et al. 2008), in particular when deriving the SFR and SFR density from Lyman alpha emission. The Fresnel Imager should provide a unique tool to calibrate these quantities in a variety of galaxy types and environments, all the way from z~0 to 1.
- The high dynamic range achieved by the Fresnel Imager could provide a new insight on the relationship between AGN and starburst activity in the central regions of galaxies, with important implications on the process of galaxy assembly across the cosmic time.

The next generation of Fresnel Imager after the demonstrator mission, with enhanced FOV and spectral coverage towards the near-IR, should provide a unique tool for the **study of the first galaxies** (see Koechlin et al. 2009 for a review).

Artist view of the two spacecraft, all elements based on a phase zero study by CNES. The distance between spacecraft is not at scale, and the number of Fresnel zones (rings) has been reduced for visibility. The main aperture will be apodized by modulation of the Fresnel array pattern (position phase and aspect ratio) and optical devices at the pupil planes.



Conclusion

With a 4 meter aperture, the Fresnel Imager concept achieves 6 to 8 mas angular resolution in Lyman α and 10^6 to 10^8 dynamic range imaging in the UV and visible, with 1000x1000 resolution elements fields. The concept has been successfully tested in the visible, and will be tested in the UV during the following months (research funded by RTRA-STAE). An international interest group is being formed, with specialists of the different science cases. A proposal for a 2025-2030 mission will be submitted to the next ESA Cosmic Vision call.

References

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