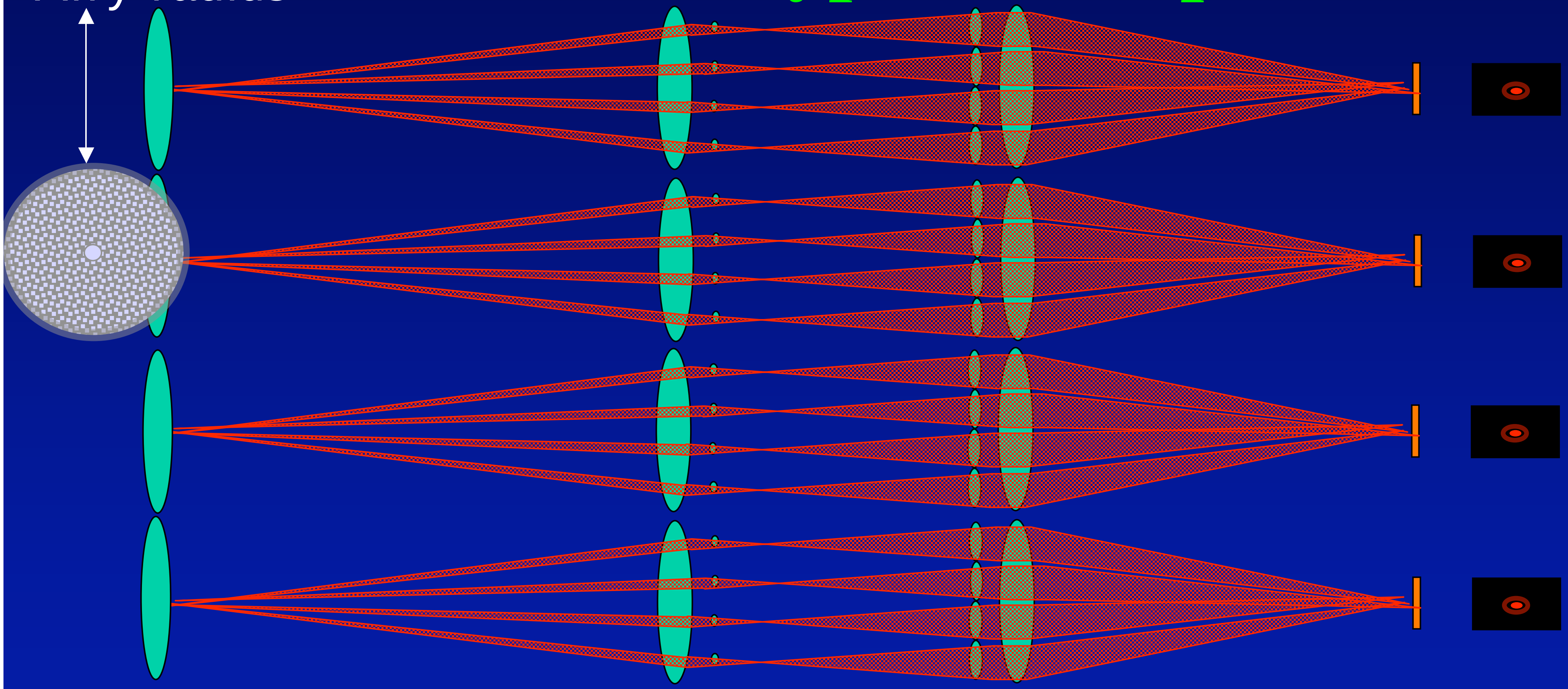
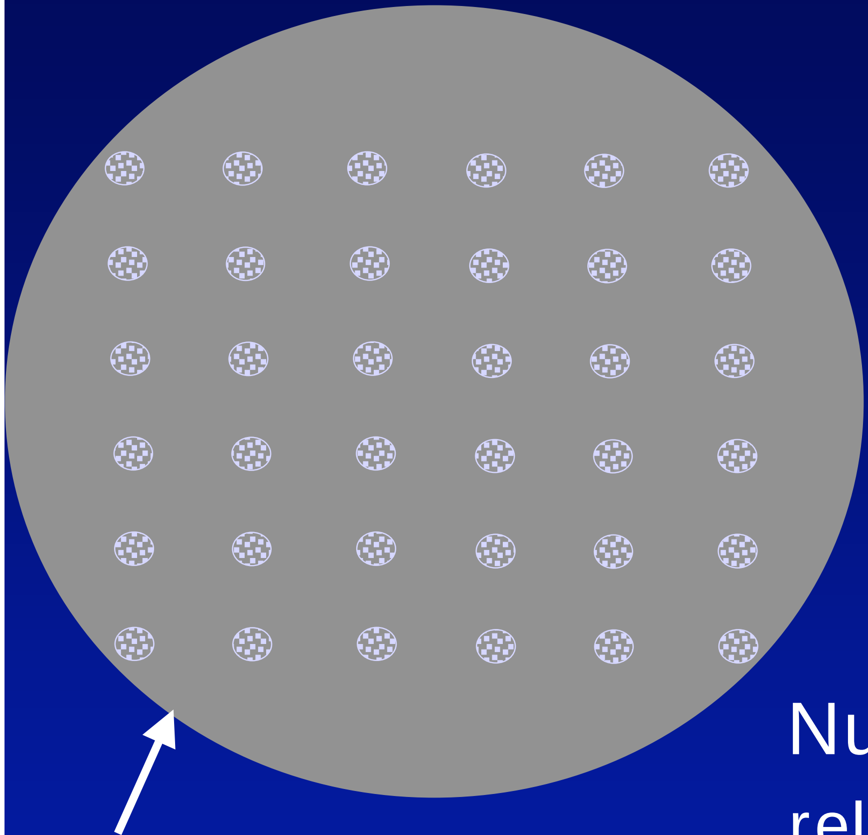
Multi-field Imaging

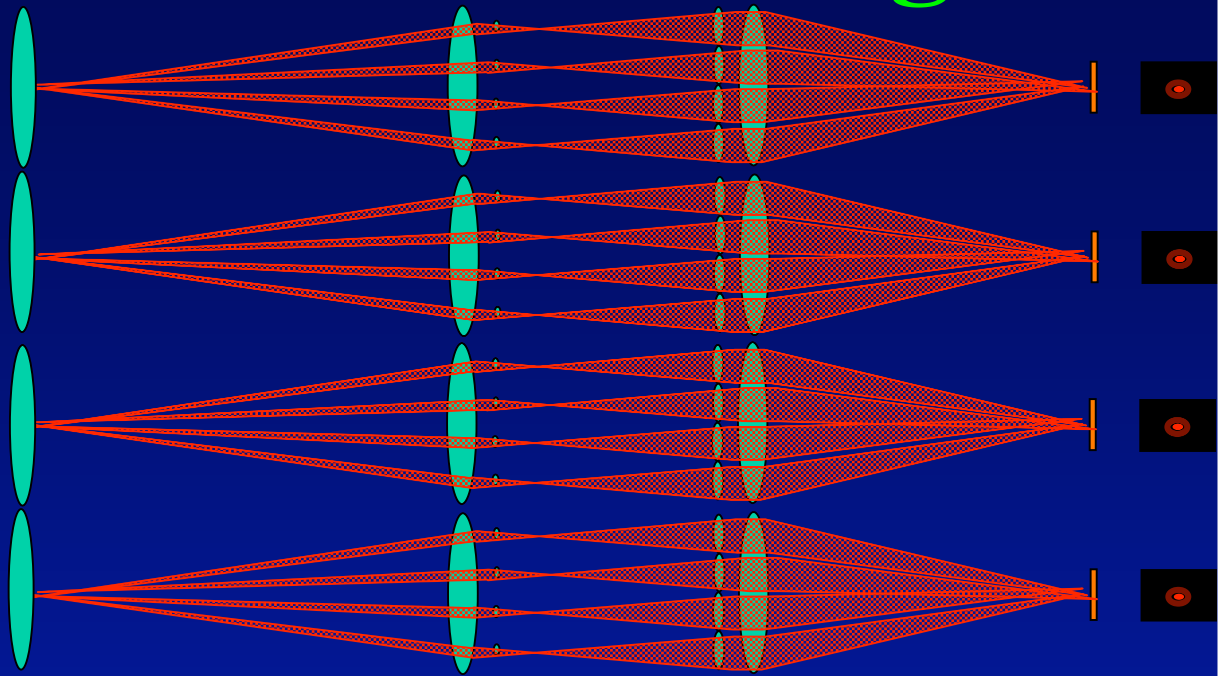
with Hypertelescope



Coverage of Multi-field Image



corrected Fizeau field
(size F on sky)



Number of fields = $(F\,d\,/\lambda)^2$

relative coverage of sky area =N $(d/D)^2$

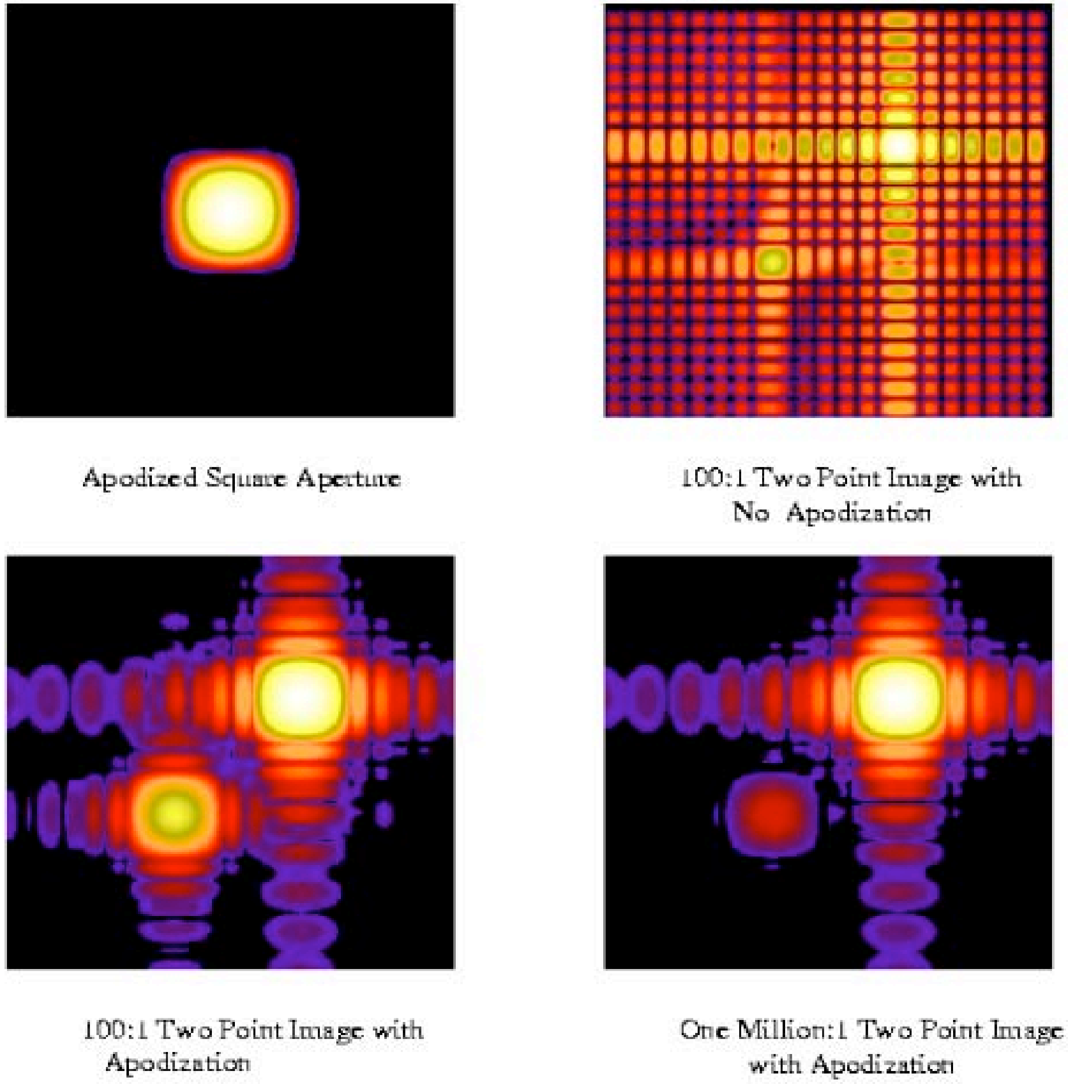
Example: “exploded OWL”

N=10,000; d=1m; D=1km

gives 10,000 fields and 1% coverage

A square aperture with and without apodization

- **Here is a square aperture with crossed Sonine apodization.**
- **Next to it is the two point image (100:1 contrast) with square aperture but no apodization.**
- **On the lower row, the 100:1 image with apodization and then 10^6:1 ratio with apodization.**
- **Apodization narrows the aperture and degrades the resolution, with a *significant* increase in dynamic range.**



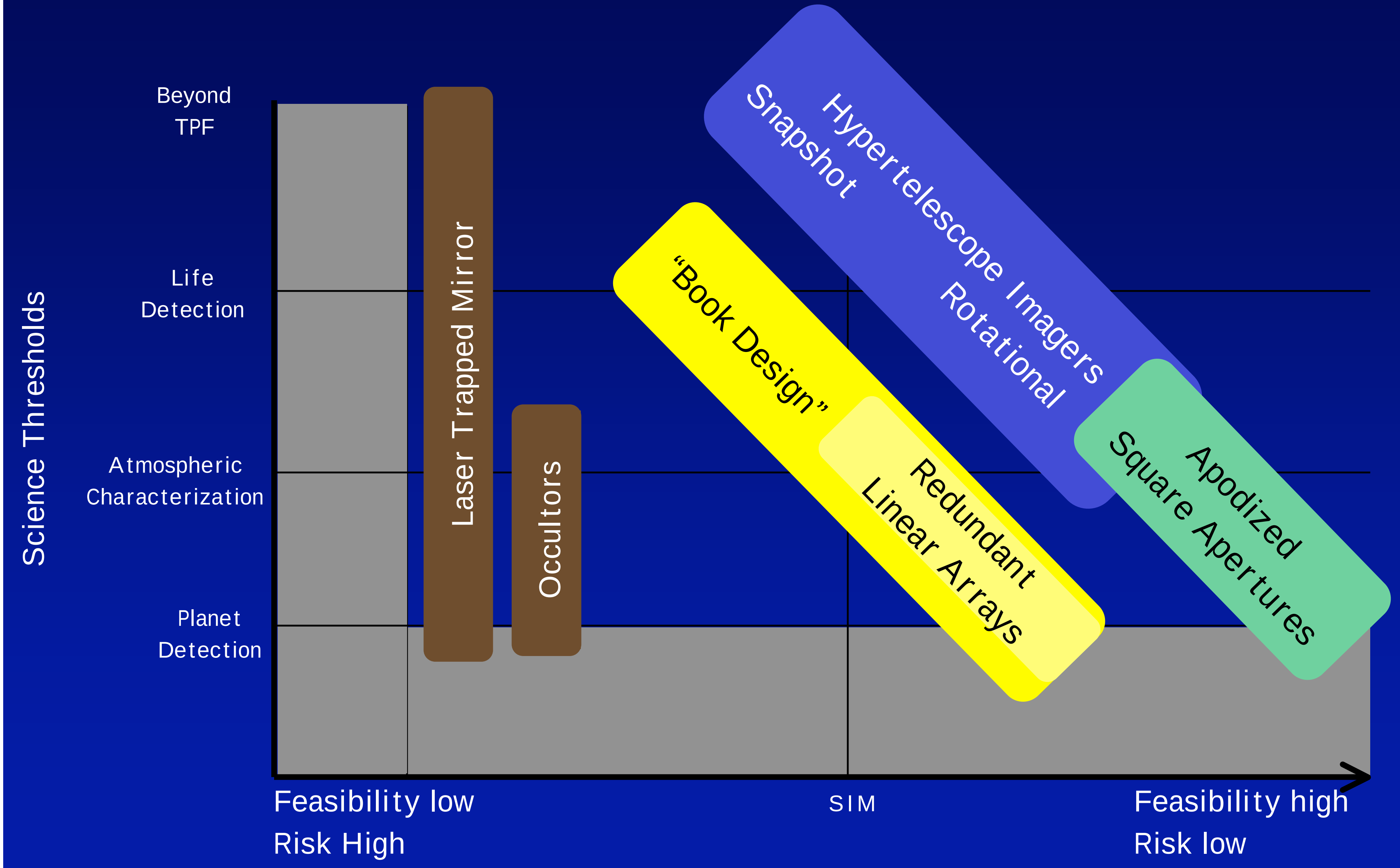
Apodization with Square Aperture

Science Scoring – Results

(Planetary sci: 75% Astrophys: 25%)

	Planetary Sci	Astrophys	Weighted total
Densified Pupil Hypertelescope	455/500	412/550	444
Laser Trapped Mirror	400/500	550/550	437
Book Design	365/500	371/550	366
Redundant Linear Array	300/500	287/550	297
ASA	300/500	340/550	310
Occulters	250/500	520/550	317

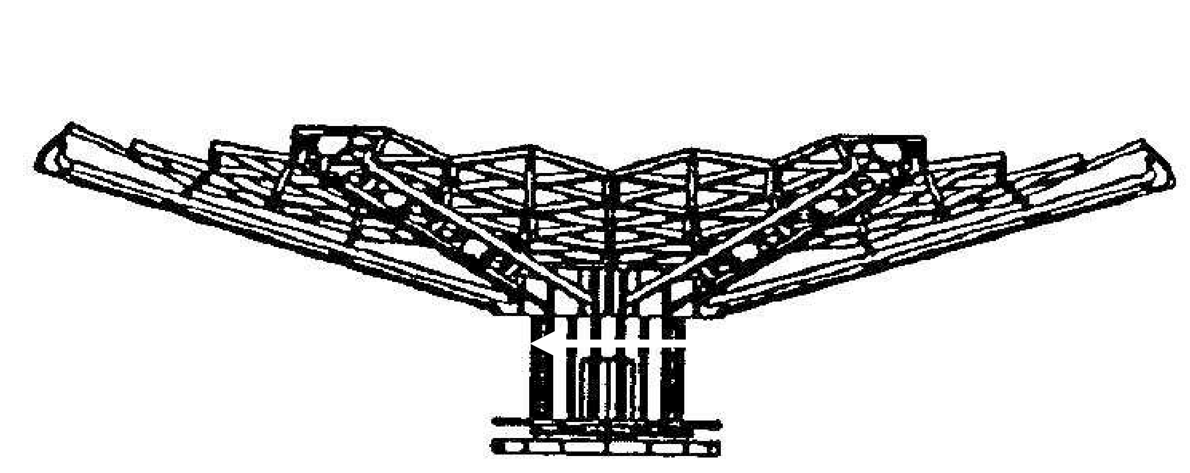
Comparison of Concepts



Conclusions and Recommendations

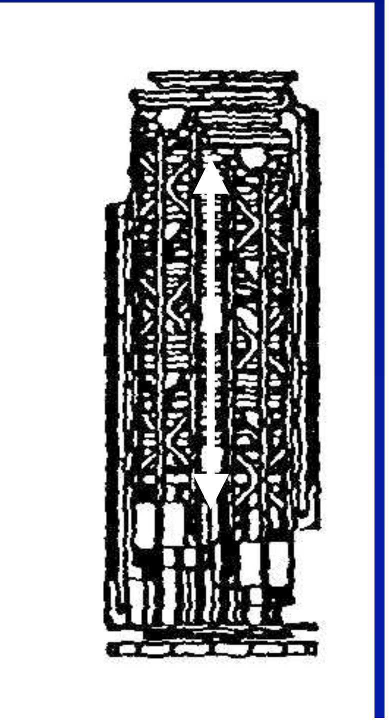
- Develop Apodized Square Aperture architecture on several possible scales - in visible and infrared - as potentially quickest, cheapest TPF realization.
- Develop Hypertelescope Imager architectures, as most promising for eventual very high resolution TPF realizations, scalable to Life Finder and Planet Imager.
- Define earth frequency through precursors.
- Develop mini-TPF options as TPF alternatives.
- Continue investigation of Laser Trapping as enabling technology for future ultra-large apertures.

Preliminary Deployment Analysis

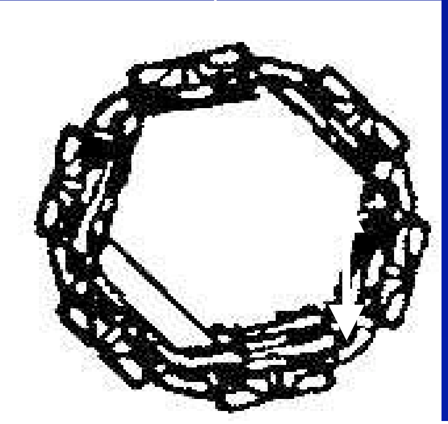


- Three rings of segments, 36 reflector panels
- Areal density 15 kg/m2
- Maximum panel diameter 3.8 m
  - (1) Maximum reflector diameter 23 m
  - (2) Packaged height 14.8 m
  - (3) Packaged cross-sectional diameter 4.9
- Packaged volume 283.4 m^3
- Reflector mass 5200 kg

(2)

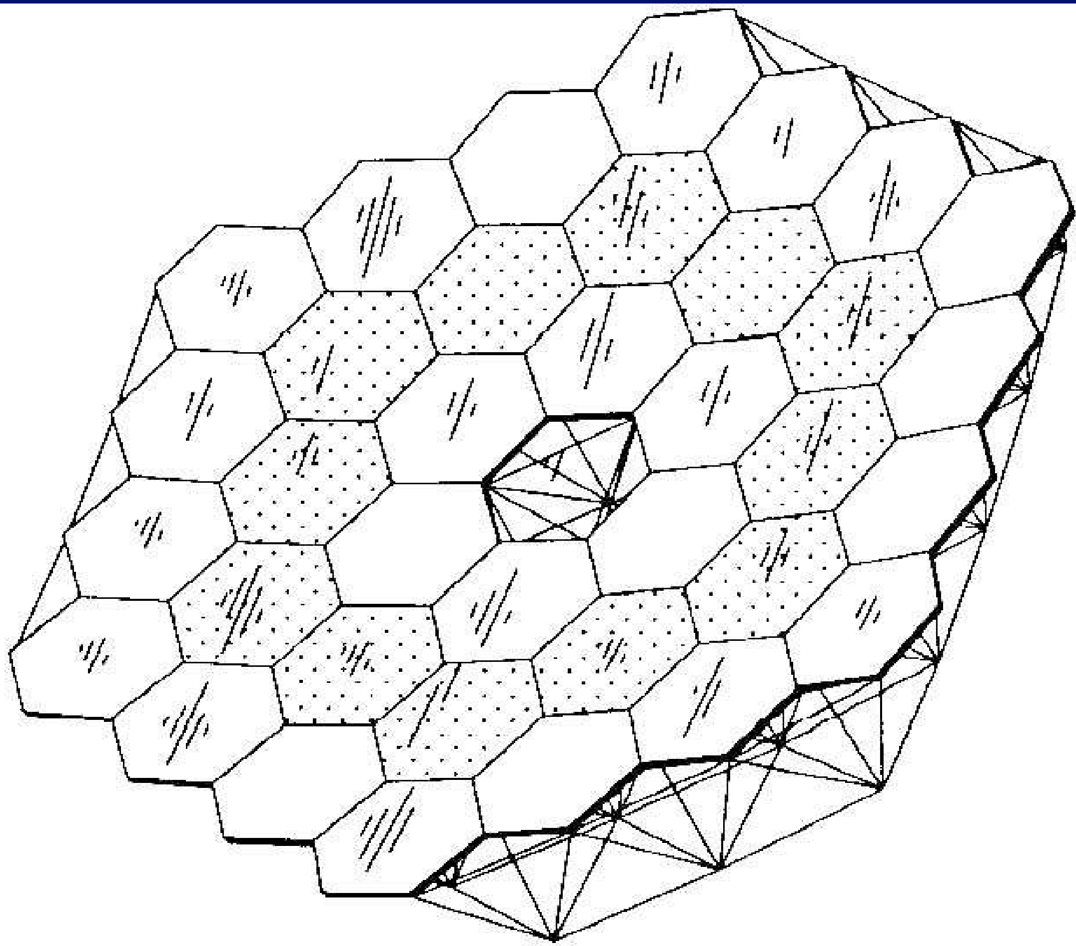


(3)



Erectable Segmented Reflector

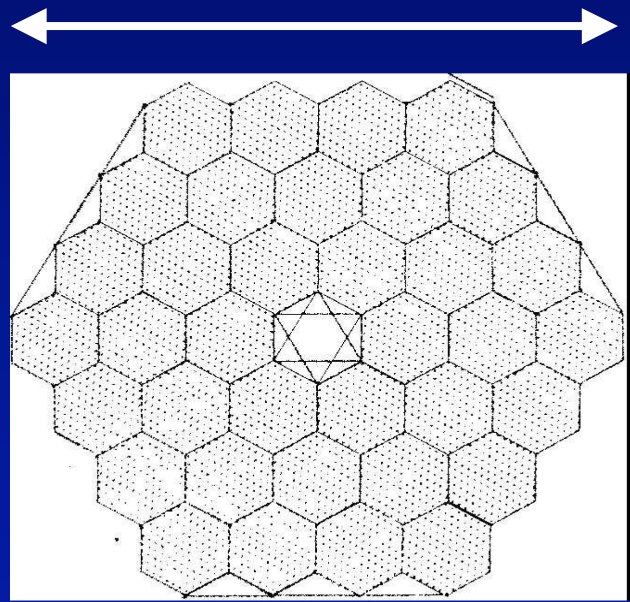
- Advantages:
  – Can be packaged efficiently
  - 1^{st} Frequency ~10 Hz
- Disadvantages:
  – Cost and time associated with on orbit construction
  – Associated orbital transfer loads (LEO to L2) applied to the structure



Assembled reflector : 3 ring

- (1) Maximum diameter 24.3 m
- Reflector mass 3470 kg
- Reflector surface area 374 m^2
- Moment of inertia 130,850 kg m^2

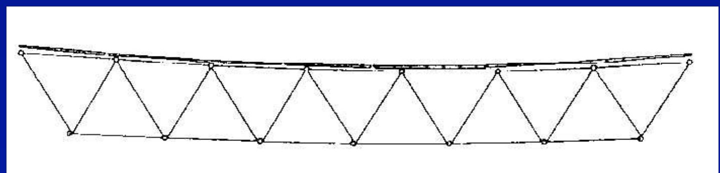
(1)

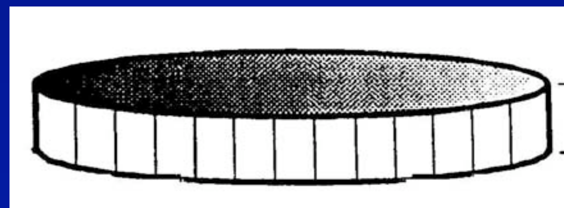


Frequency analysis: 3 ring

- To a first approximation, the erectable reflector can be considered as flat circular sandwich plate. (Curvature effects are negligible in the determination of the lowest natural frequency)

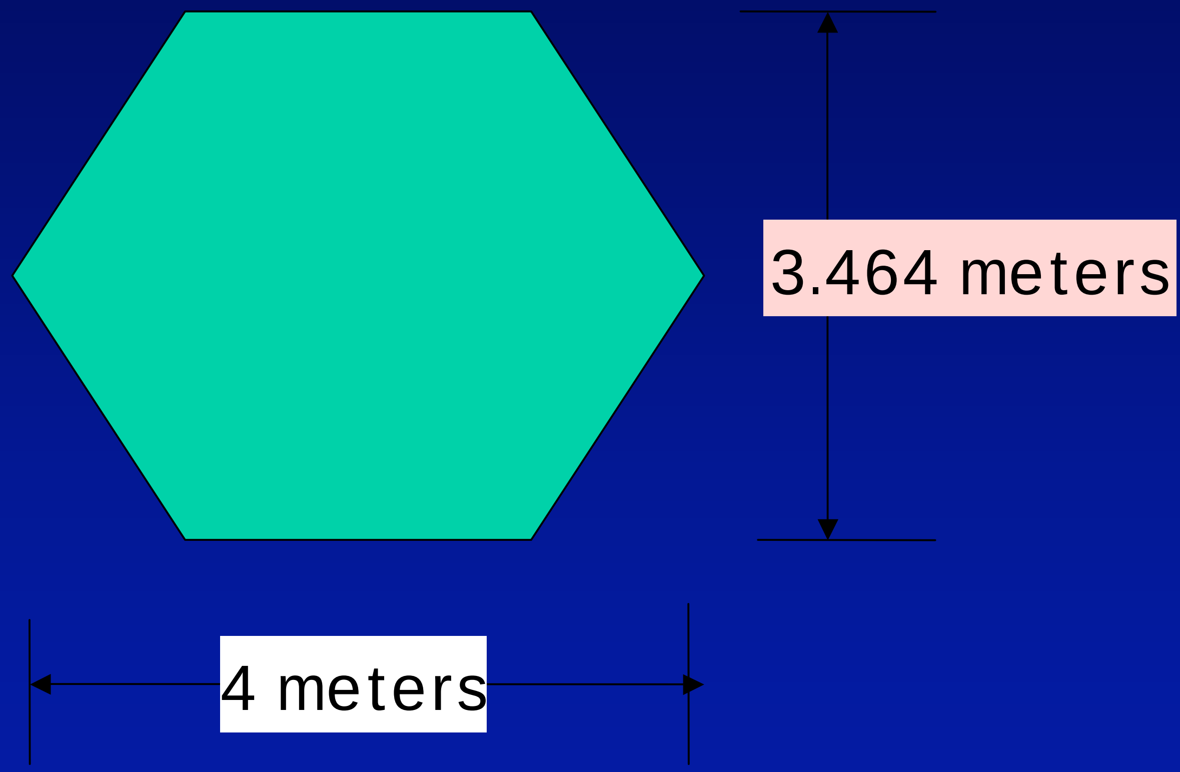
Approx. 1st resonant frequency ~19 Hz **





** Tower truss and secondary mirror not included

ASA 30 Configuration (3 of 5)



Assume SiC material.

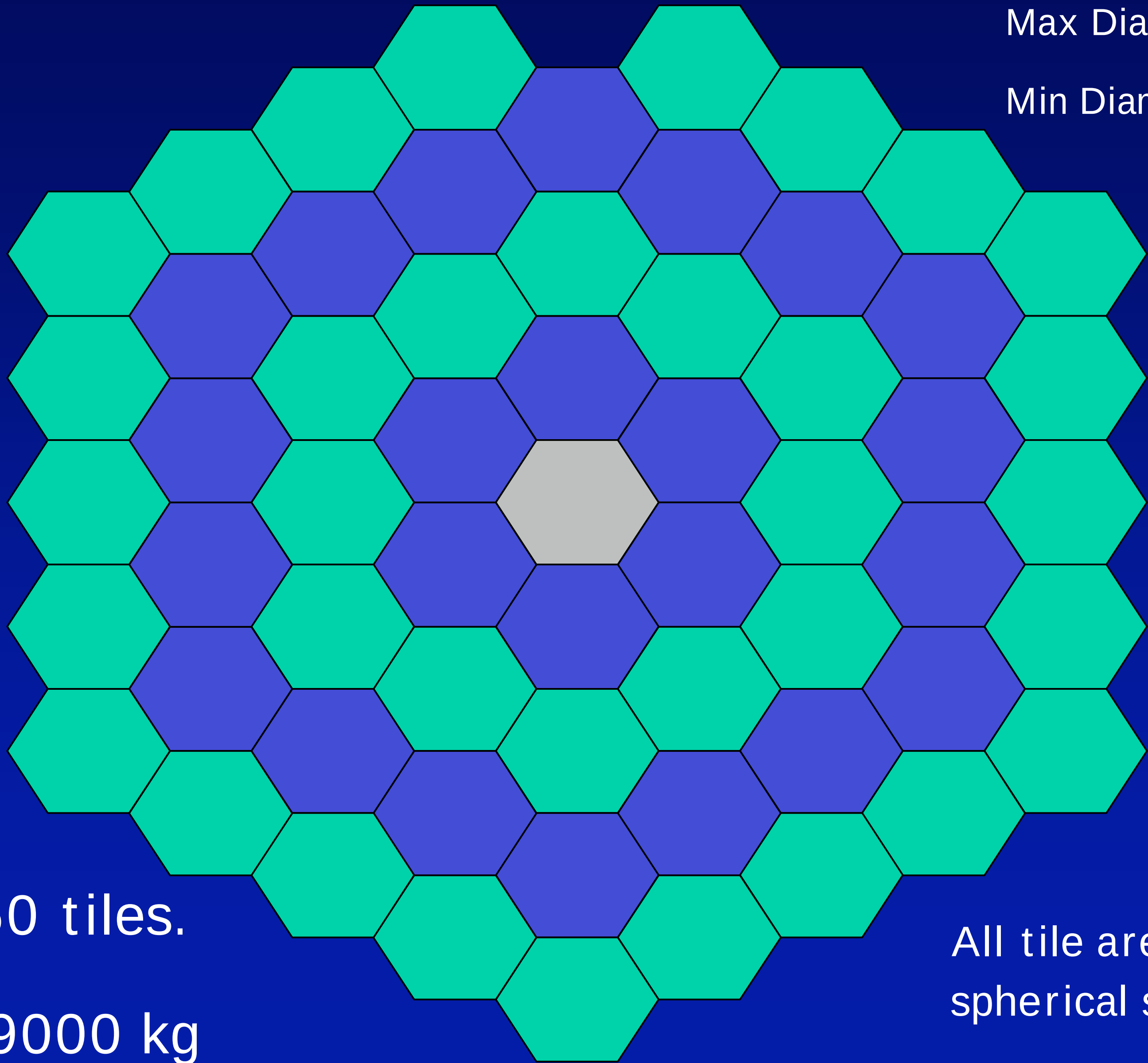
Estimated weight = 150 kg.

Spherical shape

ASA 30 Configuration (4 of 5)

Max Diameter = 31.4 m

Min Diameter = 28 m



Requires 60 tiles.

Weight = 9000 kg

All tile are identical spherical shapes.

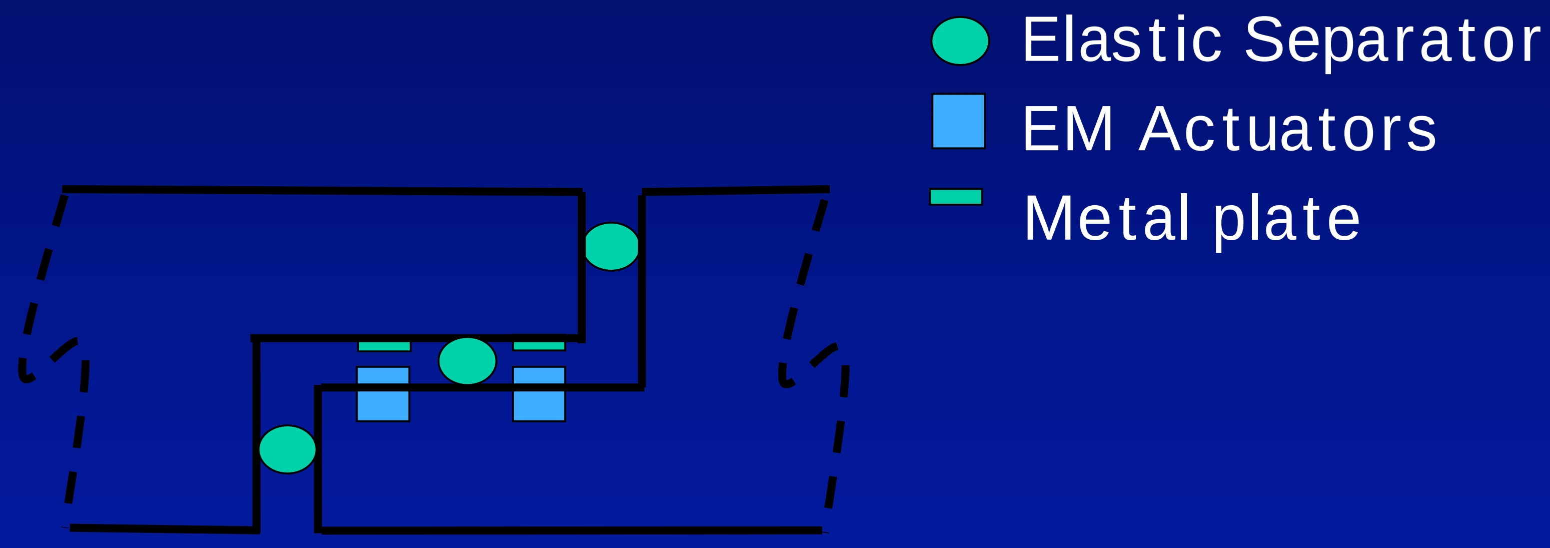
UMBRAS/Occulters Update Oct. 2000 (2 of 2)

- Additional concept reviewed: SCODOTEP, J. Schneider
    - Less mature than either UMBRAS/BOSS
    - Considers both artificial disks & Moon as a possible occulters
- Feasibility issues with all concepts
    - Relative position (telescope-occulter) severely limits flexibility in selecting targets (or else requires frequent repositioning)
    - Good metrology required to maintain occultation (solvable)
    - The occulter is a complete spacecraft, requiring development, launch, and operations, yet only half an instrument
    - Null depth only to 10^{-4} with 100m dia. occulter
        - → BUT, Could be used with other methods
- Questions
    - Could L_2 dynamics help with occulter trajectory management?

TPF Mission Architectures

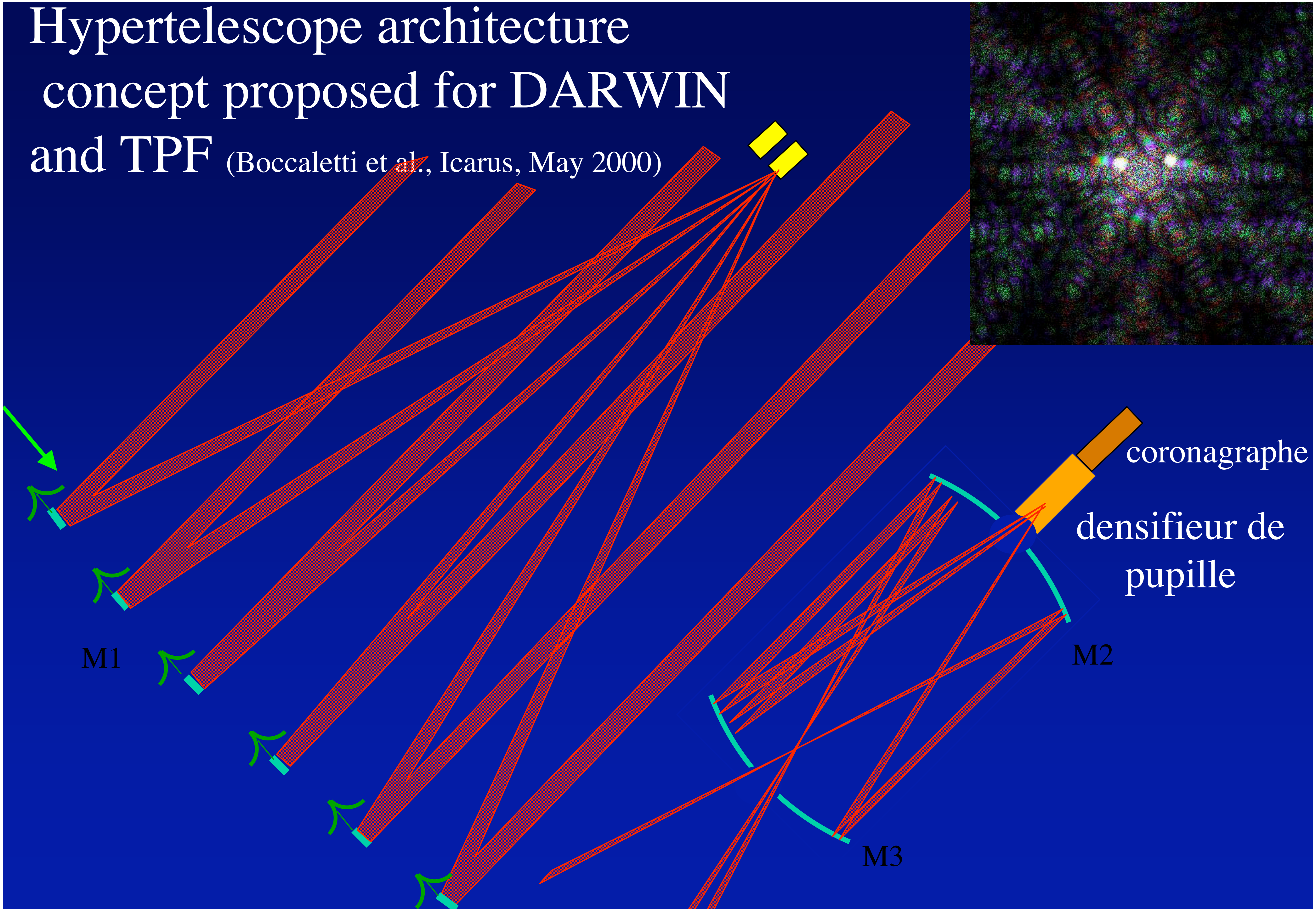
ASA 30 Configuration

Detail of dove-tail fitting &
Actuator control



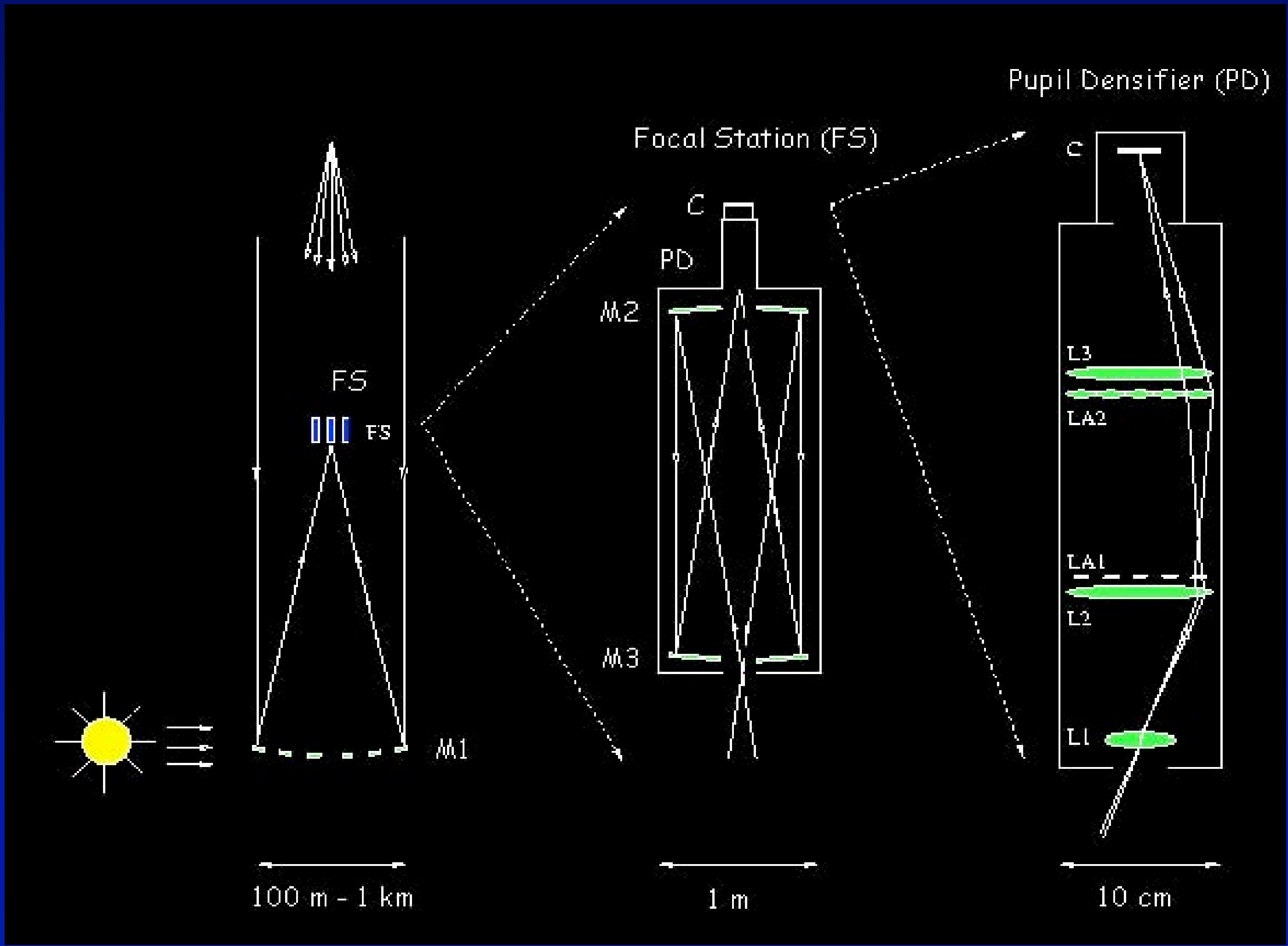
Electromagnetic actuators have some permanent magnetism for holding tiles in place, and are used for both piston and tilt corrections.

Hypertelescope architecture concept proposed for DARWIN and TPF (Boccaletti et al., Icarus, May 2000)

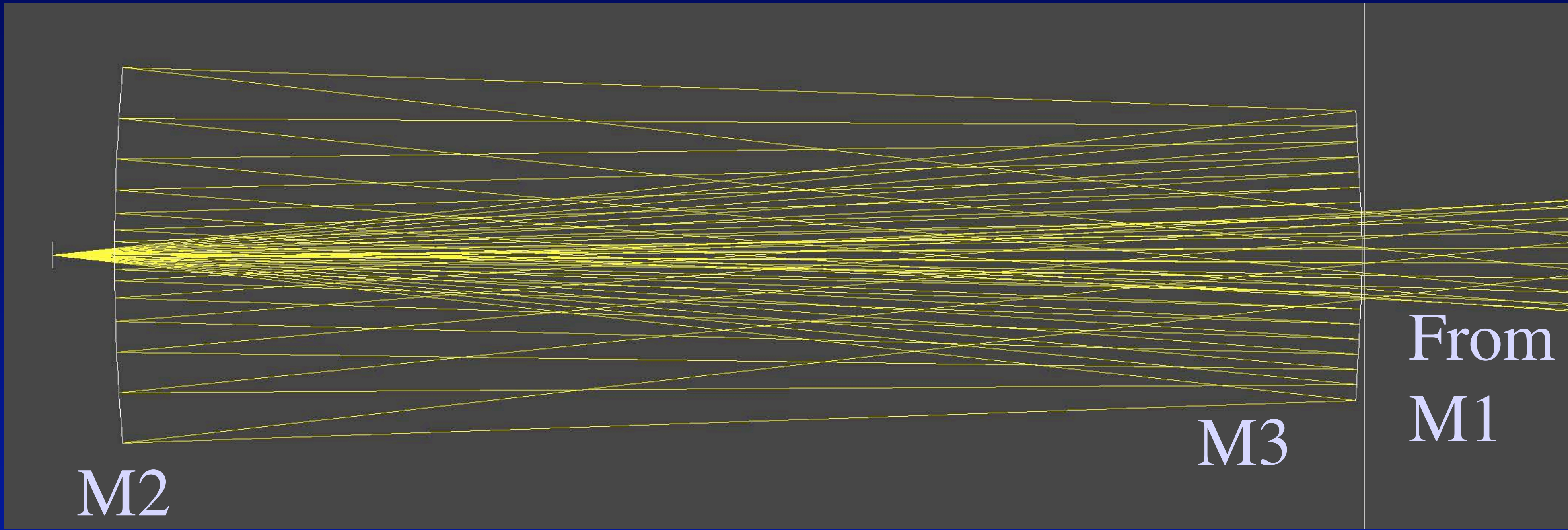


Beam Combiner

- Fizeau stage + densifier
- Corrector of spherical aberration and coma
- Pupil densifier: micro-lenses or micro-mirrors
- Usable primary median field size is D/2F (7,2° if F/4 aperture)



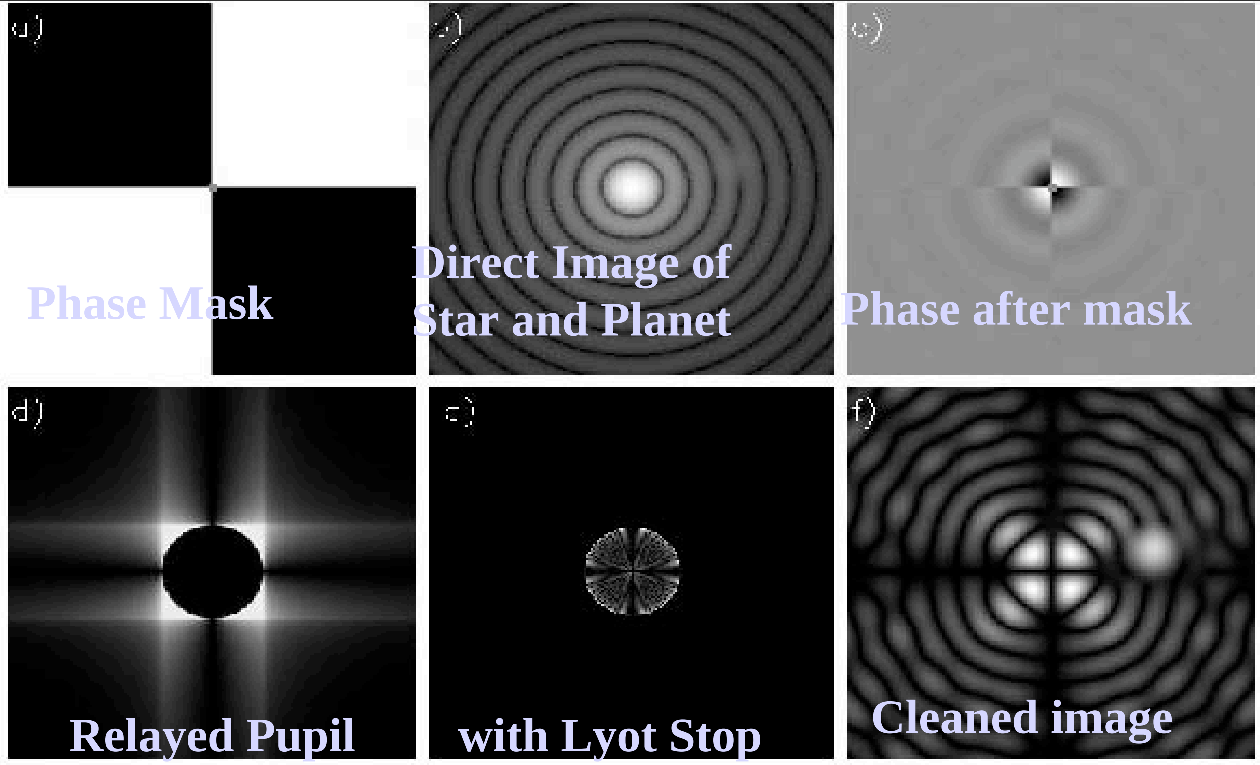
Corrector of Spherical Aberration and Coma from F/4 Spherical Array



- 0.21 m diameter, 1.34 m length for 100 m array at F/4
- 25 % central obscuration, reducible by increasing size
- Pupil obscuration up to 10% tolerable for Rouan coronagraph : possible with larger (3x) corrector

Densified Pupil Imaging w/ Coronagraphy

- Four-quadrant phase-mask in the focal plane (Rouan 2000)
- High dynamic range ⇒ 20 mag. with perfect optics
- Resolution unaffected
- Broad-band operation with achromated phase mask
- Exit pupil must be circularized
- Affected by guiding errors (null width ∝ θ^2)



Coronagraphy simulations

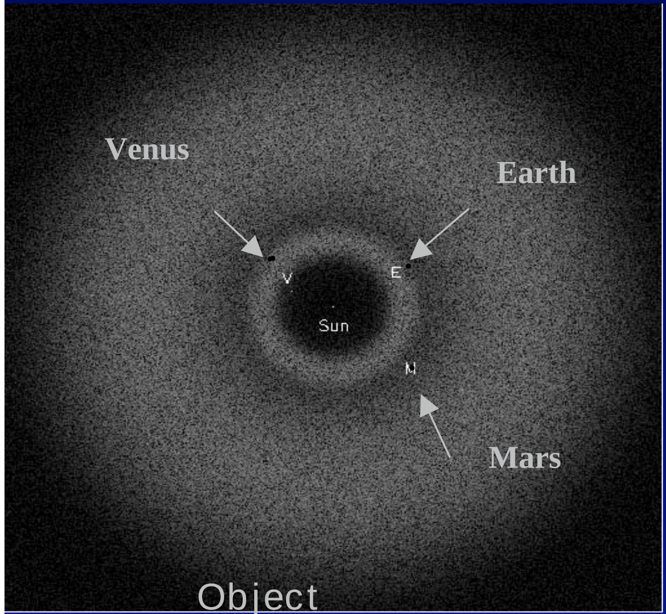


Image of a solar system (G2V star, Venus, Earth, Mars) at 20 pc for 100 m baseline

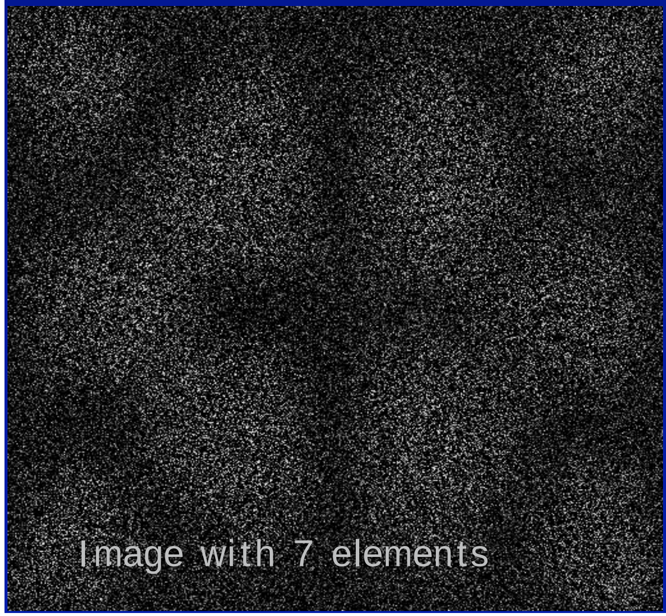
Lz = 12.7 mag/arcsec_

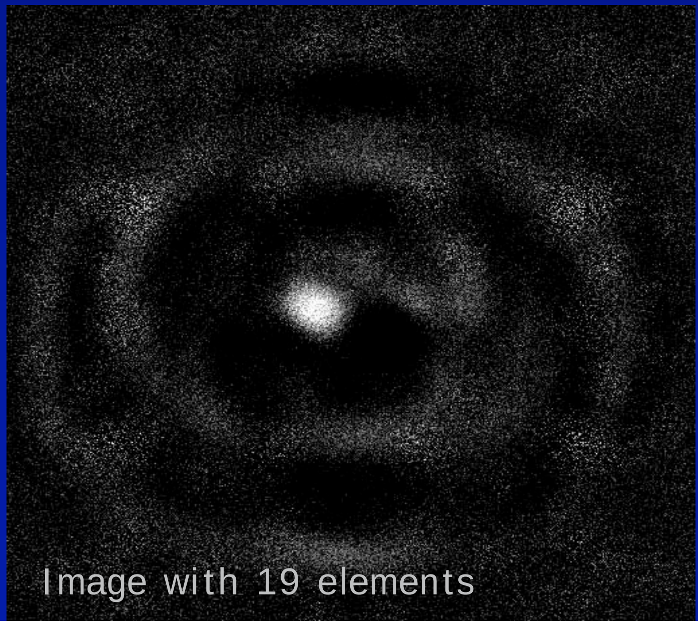
Lez = 10 Lz

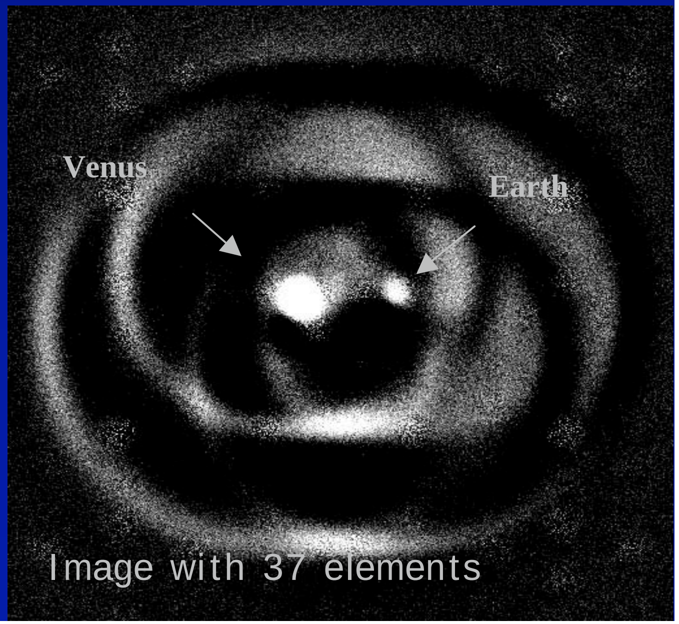
Wave error : λ/170 rms

Exposure : 10 h in N band (10.2 ± 2.6 µm) with 20 square meters of aperture , in 37 elements

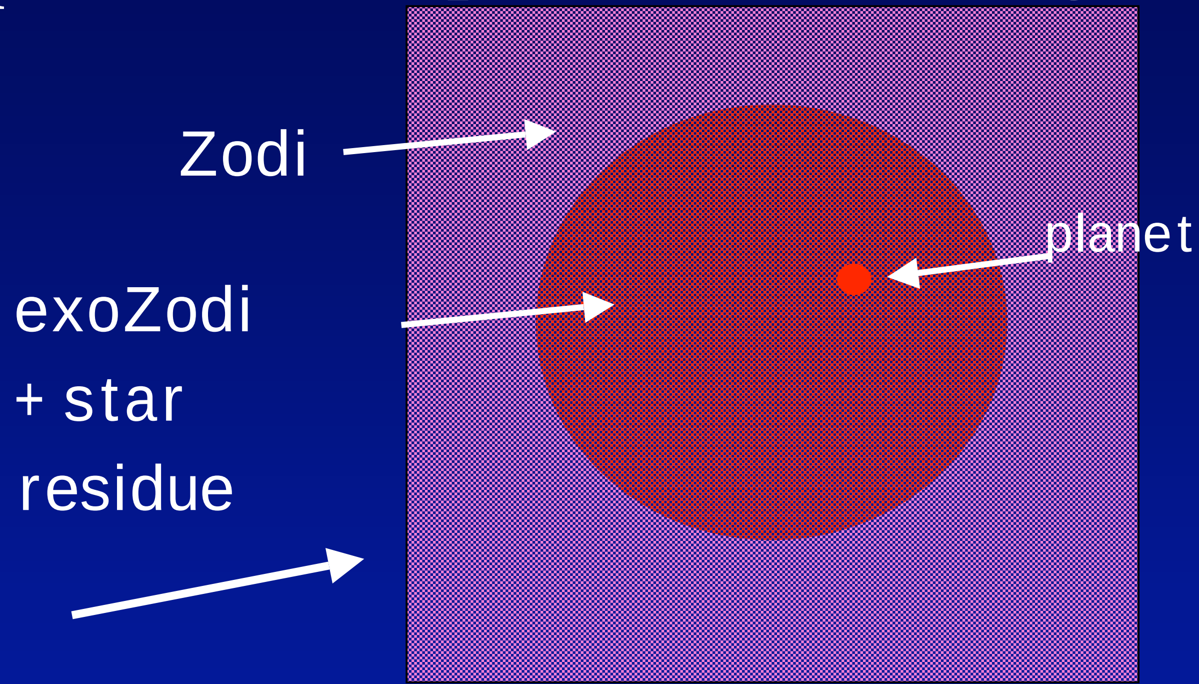
Opposite quadrant subtracted







The theoretical contrast advantage of hypertelescopes with respect to "Book Design"

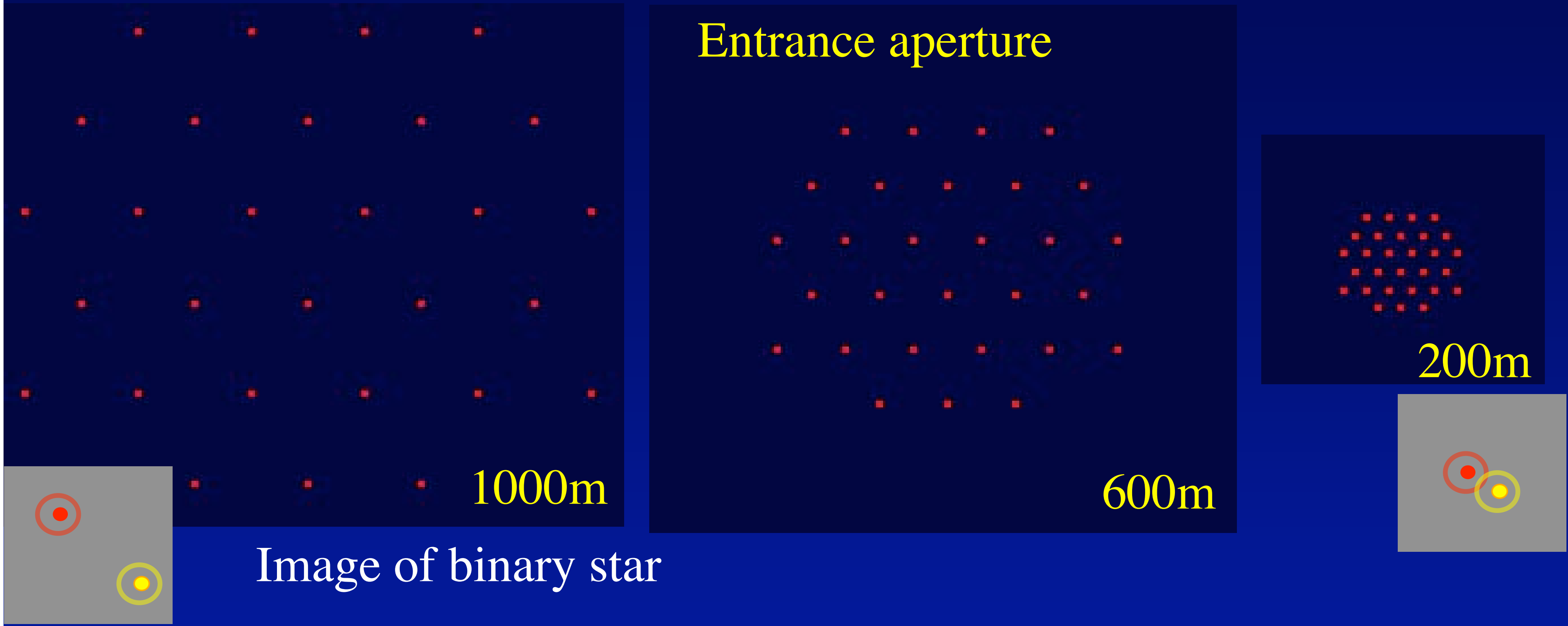


Direct image

- Image separates the planet's peak from most zodi & exoZodi collected by the sub-apertures in a l/d sky patch.
- No such separation in Bracewell interferometry
- Planet contrast improves as N if star residue is negligible

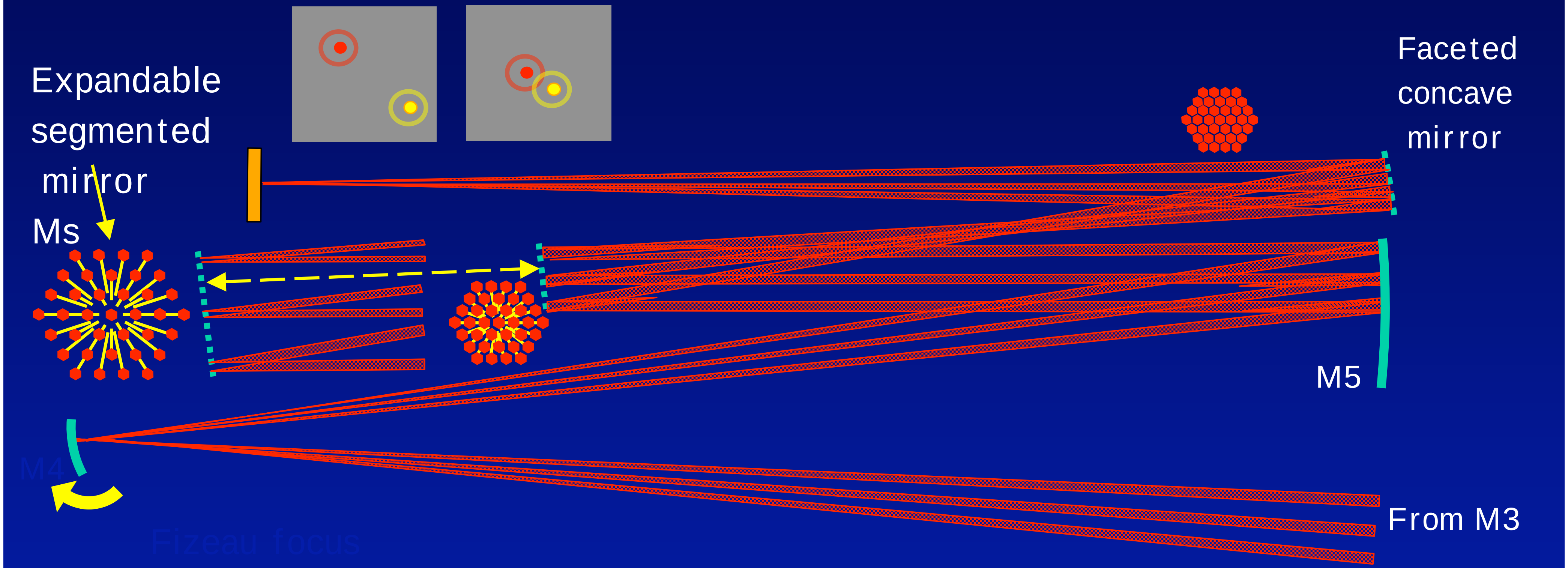
So: large sensitivity gain

Array expansion/contraction



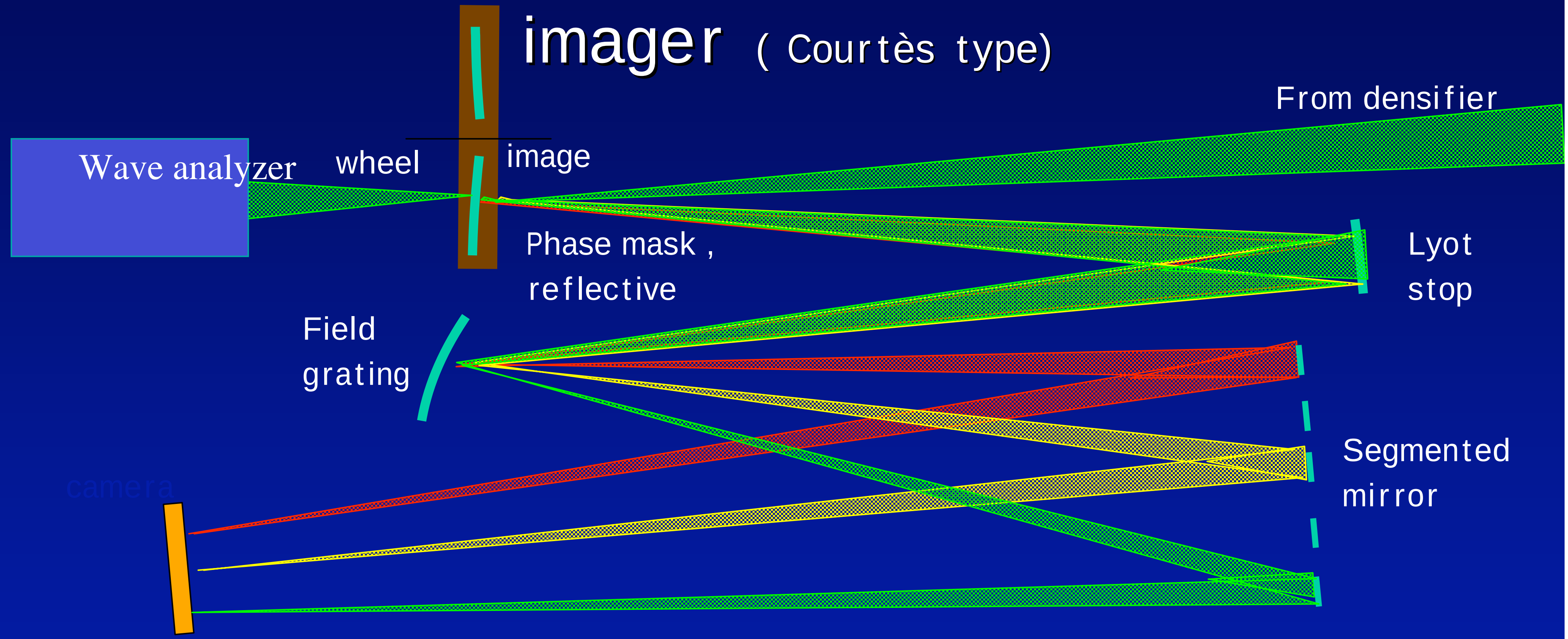
- Needed to match resolution to object ?
- Achieved by sliding elements on M1 spherical locus
- Requires simultaneous adjustment in the pupil densifier using expandable segmented mirror
- Achieves zooming in the direct image.
- Compatible with coronagraph, the exit pupil being invariant

Adjustable array size ?:
Option of Zoomable Pupil densifier



- Zoomable pupil densifier accommodates array expansion, achieved by sliding elements on M1 spherical locus
- Resolution proportional to aperture size
- Compatible with coronagraph, the exit pupil being invariant

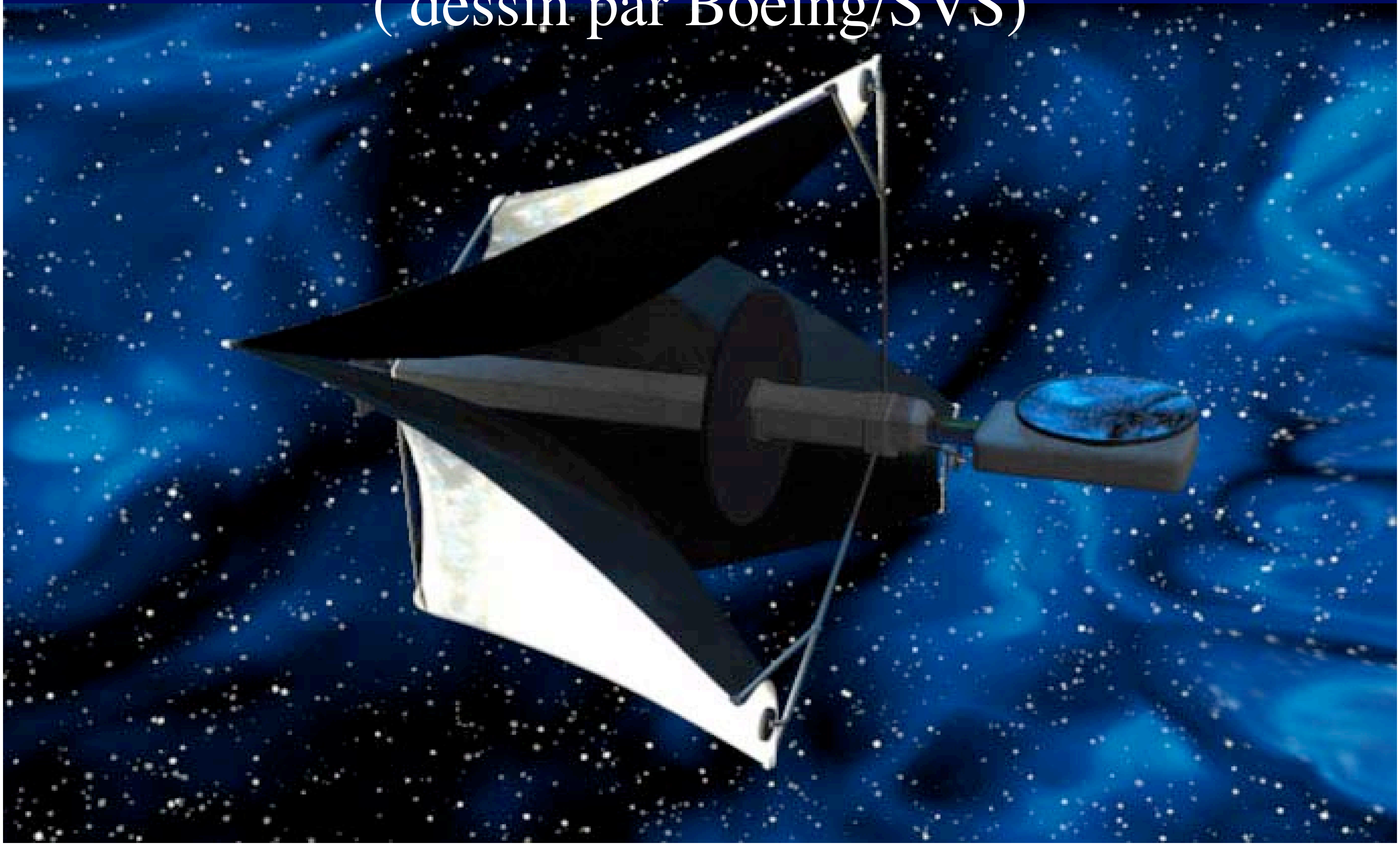
Spectroscopy:
Coronagraph with multi-spectral imager (Courtès type)



- Produces array of 10-100 monochromatic images
- Also white image on direct camera accessed by wheel
- design usable for visible and IR

Element d'hypertélescope

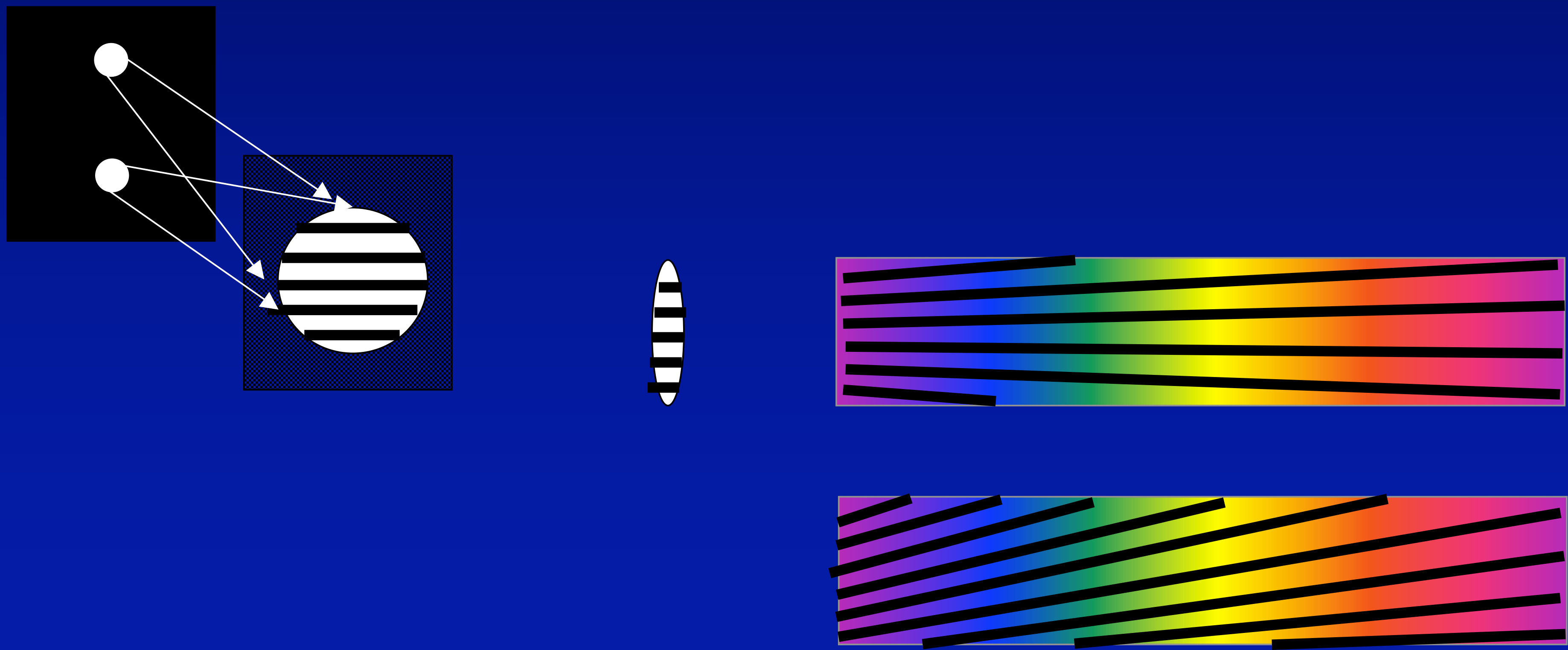
(dessin par Boeing/SVS)



Réglage des interféromètres:

Recherche de franges à N faisceaux

- Généraliser la méthode de Michelson ?



Conclusions

- L ’architecture hypertélescope est retenue pour la poursuite de l ’ étude NASA

- Mentionnée par NASA et ESA comme la solution pour le long terme