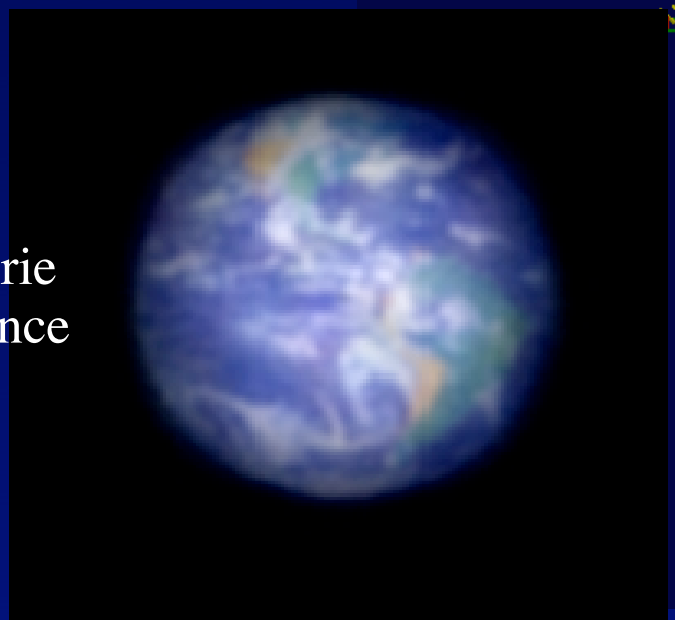
Search for Earth-Like and Living Exoplanets



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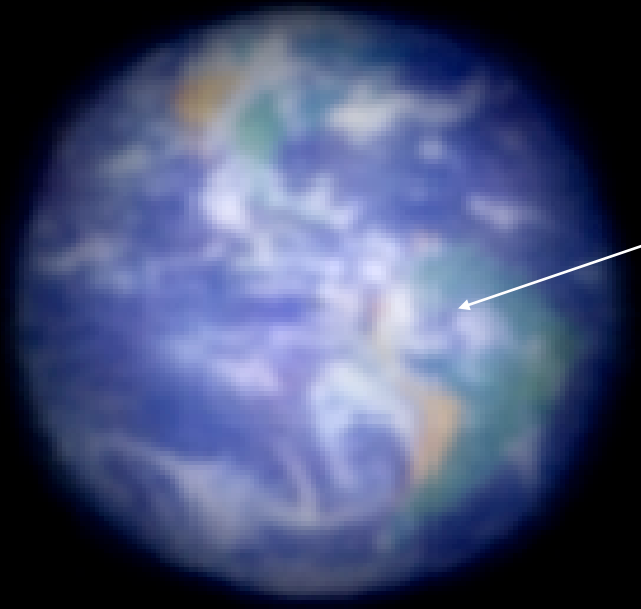
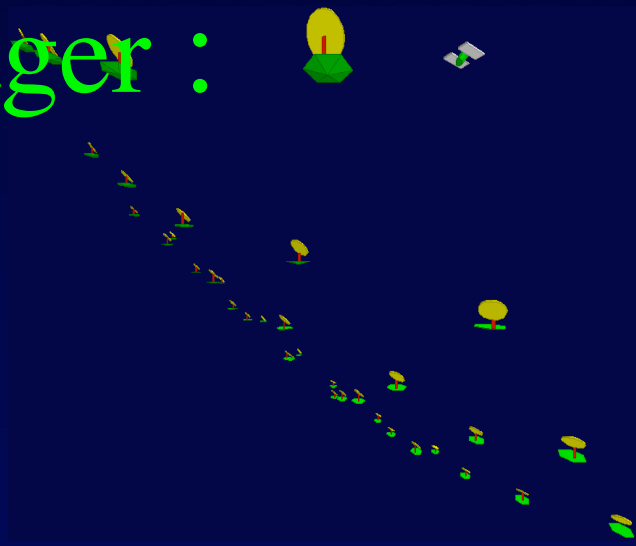
Towards an Exo-Earth Imager :

hypertelescope with coronagraph





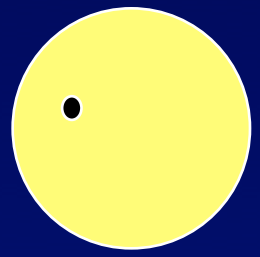
- Simulation with 150 mirrors of 3 m
- 150 km array
- Exo-Earth at 3 pc , 30 mn exosure

Methods for detecting exo-Earths

- **Visible**: extreme coronagraphy with telescope > 2m
  (Bonneau et al. 1975, Moutou et al. 1998 , Nisenson et al.2002)
- **Infra-red** :
  - Nulling interferometer (DARWIN, TPF)
  - Coronagraphic imaging interferometer (coronagraphic hypertelescope)

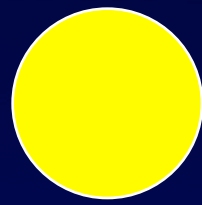
Or:

- Transits:
  - photometry with small aperture
  - imaging of resolved star with Exo-Earth Discoverer



- Doppler spectroscopy and astrometry of star 's reflex orbit (Mayor & Queloz 1997, Shao et al. 1997)
- Gravitational lensing: 2 candidate events, not confirmable

Detecting light from exo-Earths

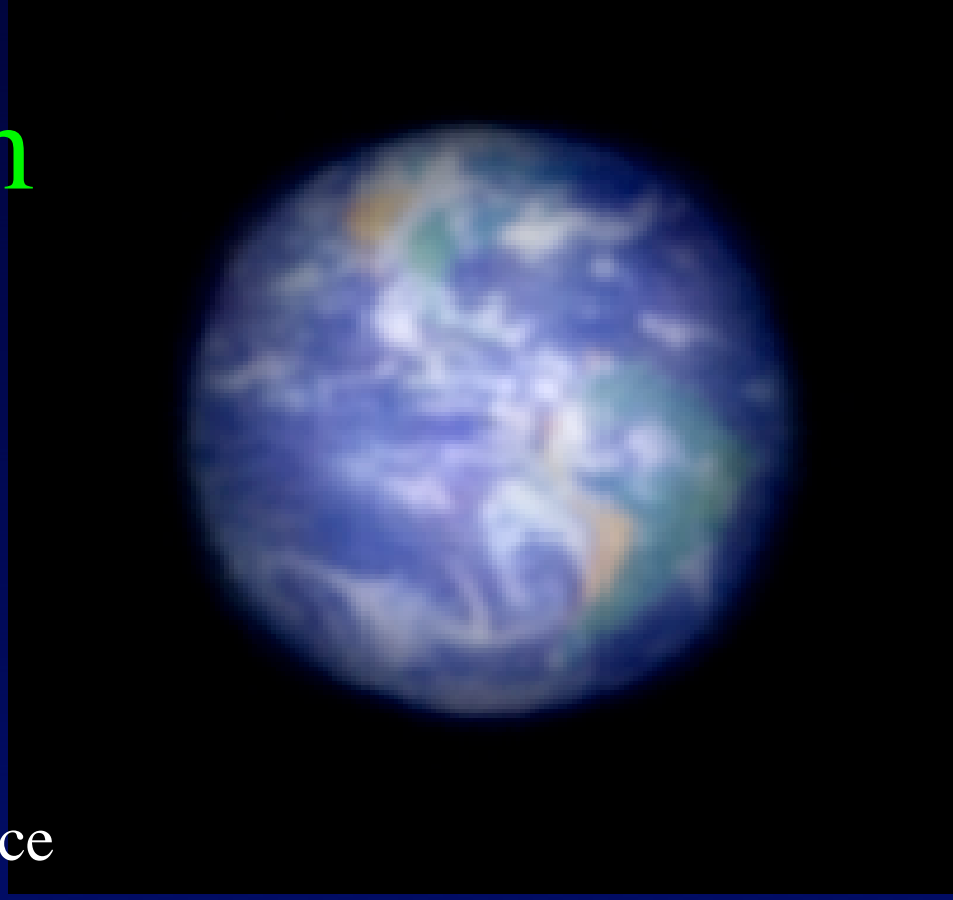


- Essential for spectroscopic search of life, but difficult
  - Weak luminosity with respect to parent star
    - 10^{-9} to 10^{-11} in the visible
    - 10^{-6} in the thermal infra-red (10 microns) (Bracewell 1978)
- But enough planet photons with a few square meters of collecting aperture
- Feasible in the visible with « extreme coronagraphy »

Atmospheric spectral features
indicative of life

- O_2, O_3, CO_2, H_2O
- How conclusive ? O_2 can be produced from H_2O by photo-dissociation, under mineral catalysis

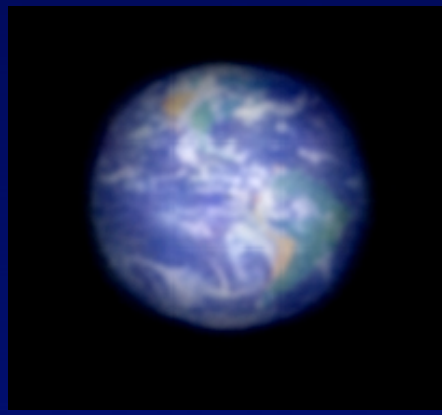
Detecting life from « green spots »



- Can be any color
- seasonal variations discriminate against mineral colors: phase advance of annual photosynthetic cycle with respect to temperature cycle
- Correlation with clouds

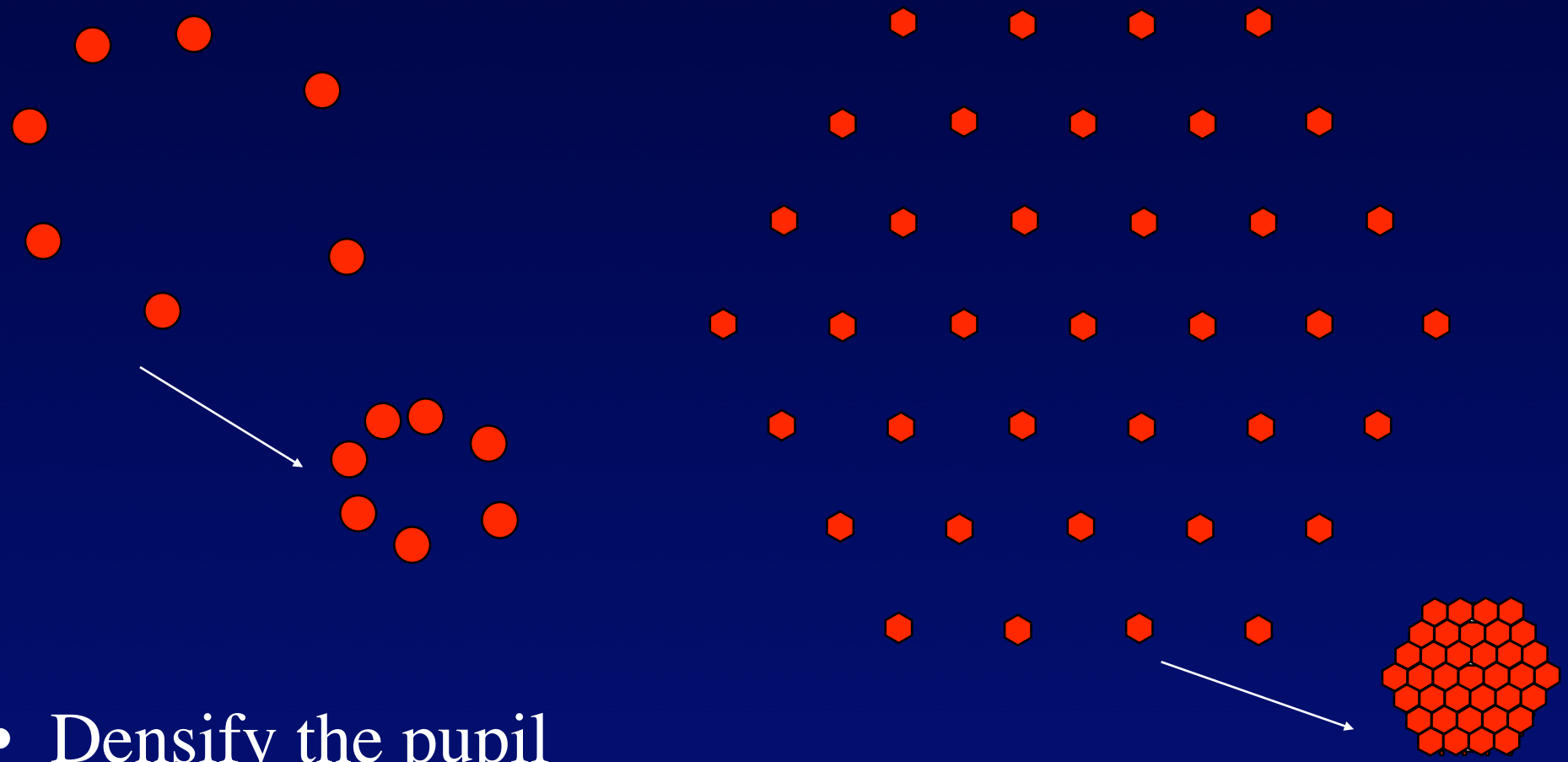
What ’s a hypertelescope ?

- A « multi-element imaging interferometric array »
- Uses « densified-pupil » imaging to provide direct image
- Usable for coronagraphy



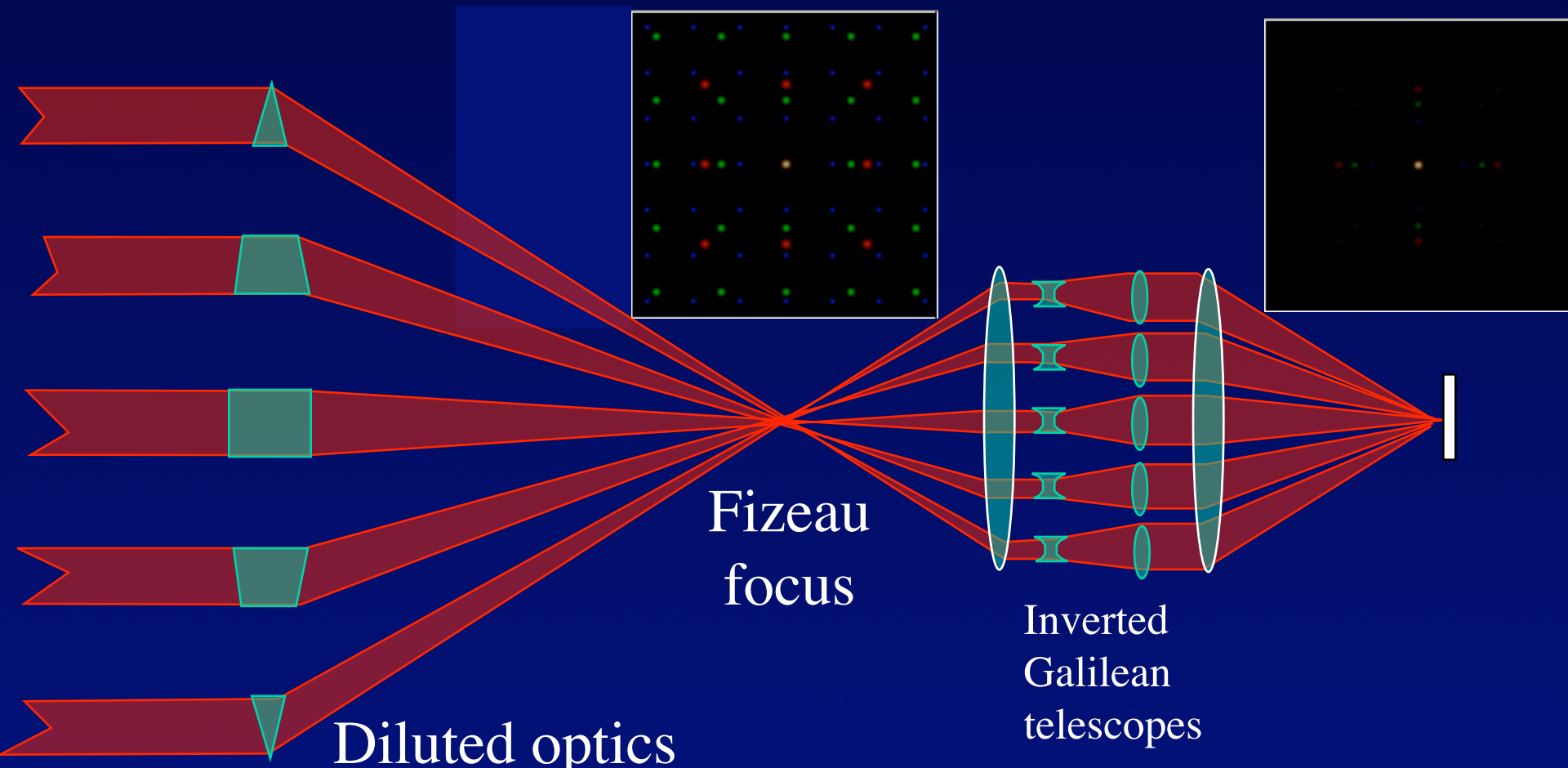
Principle of hypertelescopes

(Labeyrie A&A, 1996)



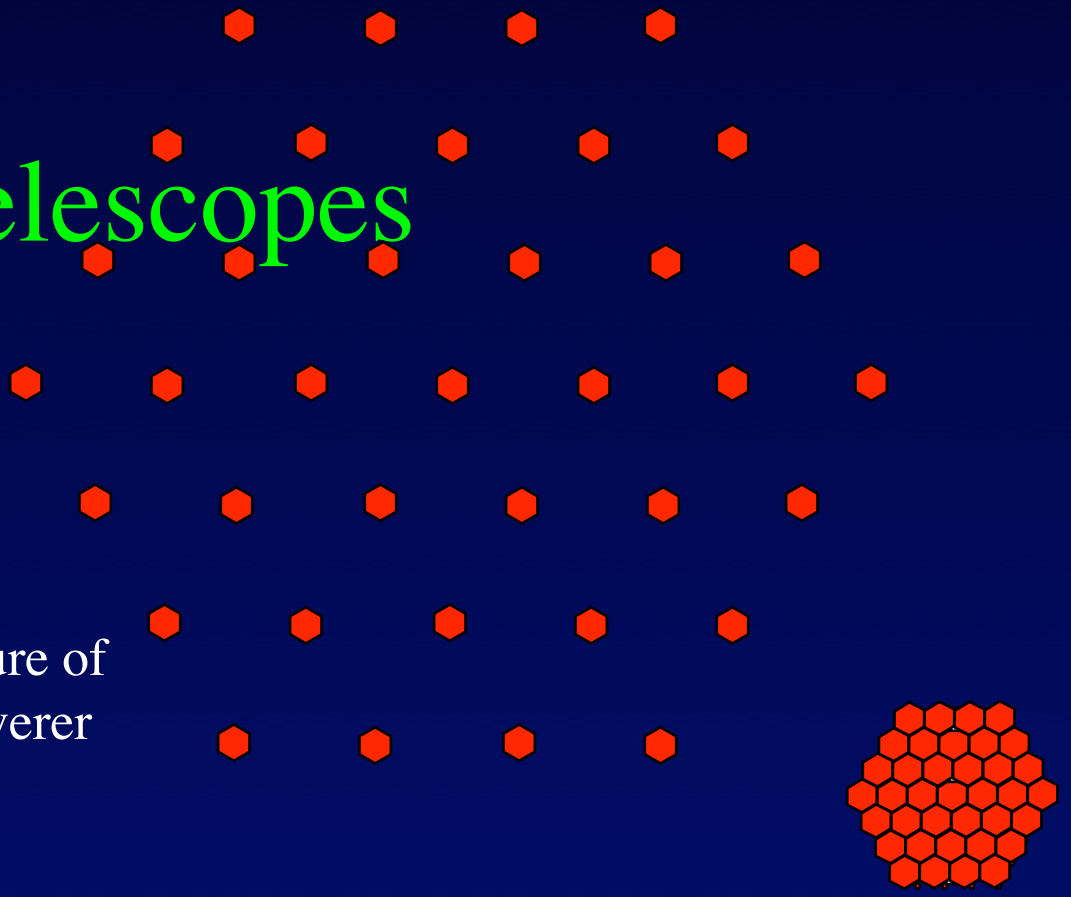
- Densify the pupil
- Preserve the center ’s pattern

Principle of hypertelescopes



For coronagraphy:

periodic hypertelescopes fully densified



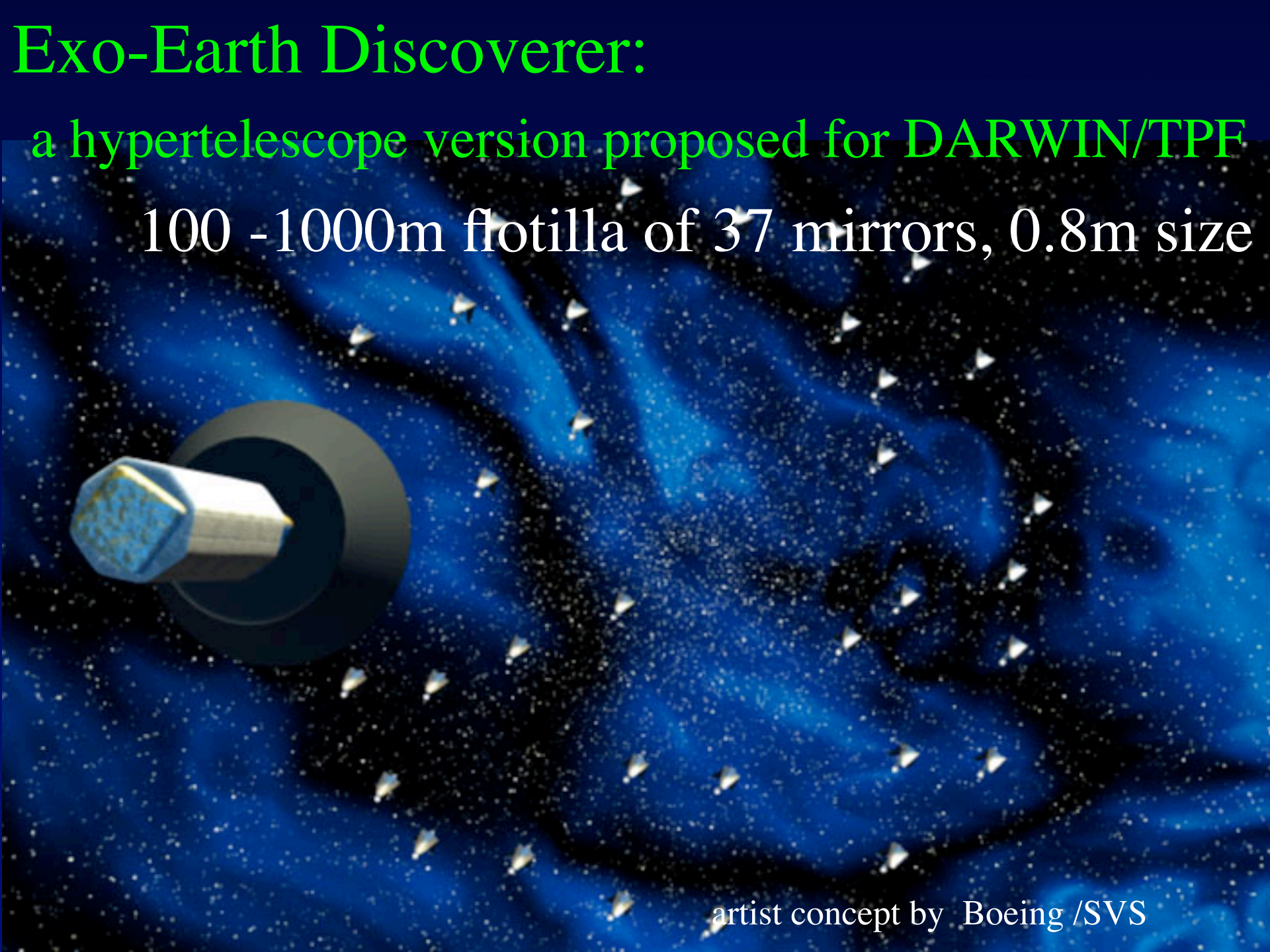
37 element aperture of
Exo-Earth Discoverer

- Filled exit pupil , behaves like a conventional aperture
- Strong redundancy, improves dynamic range of image and coronography

Exo-Earth Discoverer:

a hypertelescope version proposed for DARWIN/TPF

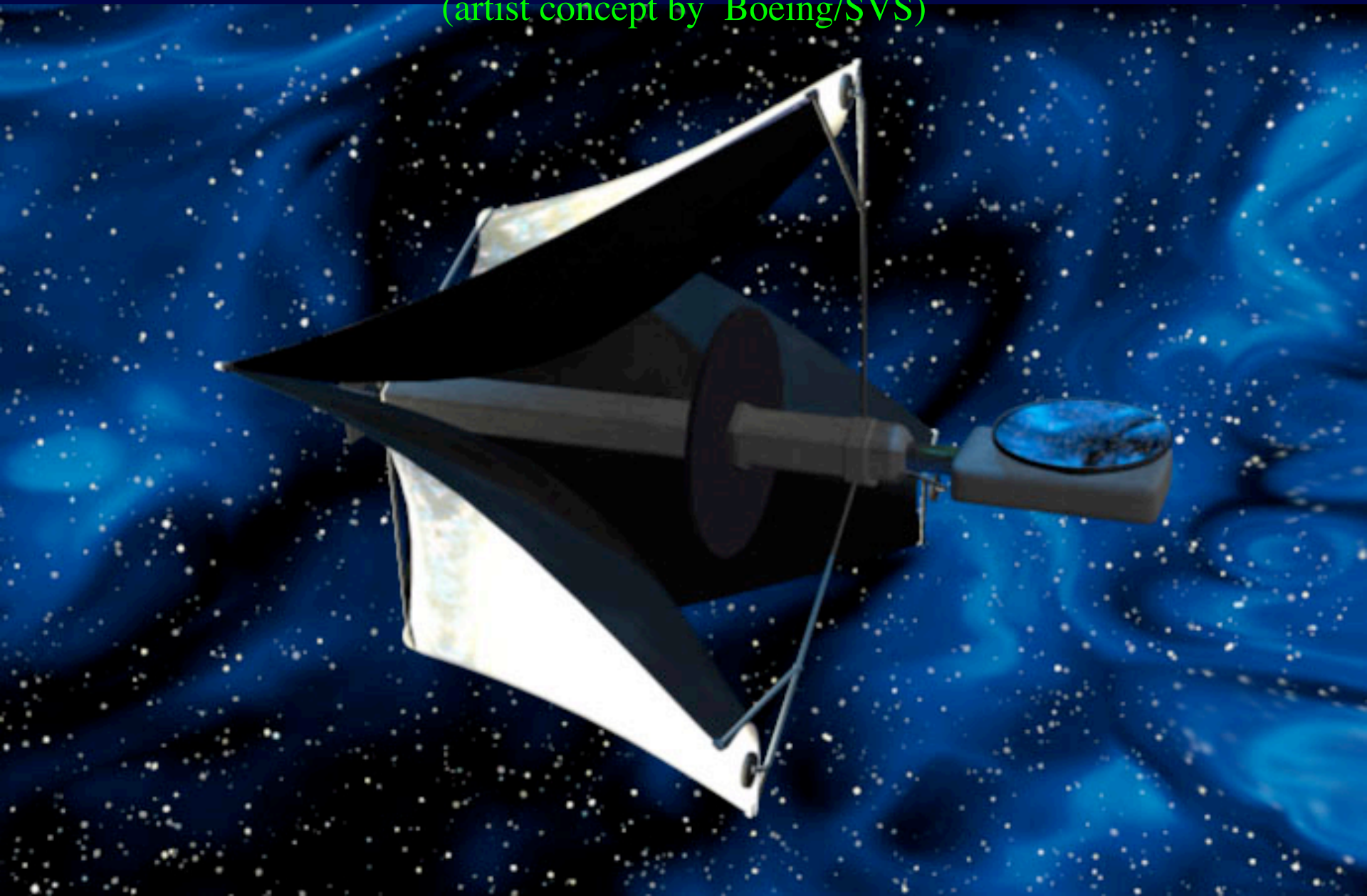
100 -1000m flotilla of 37 mirrors, 0.8m size



artist concept by Boeing /SVS

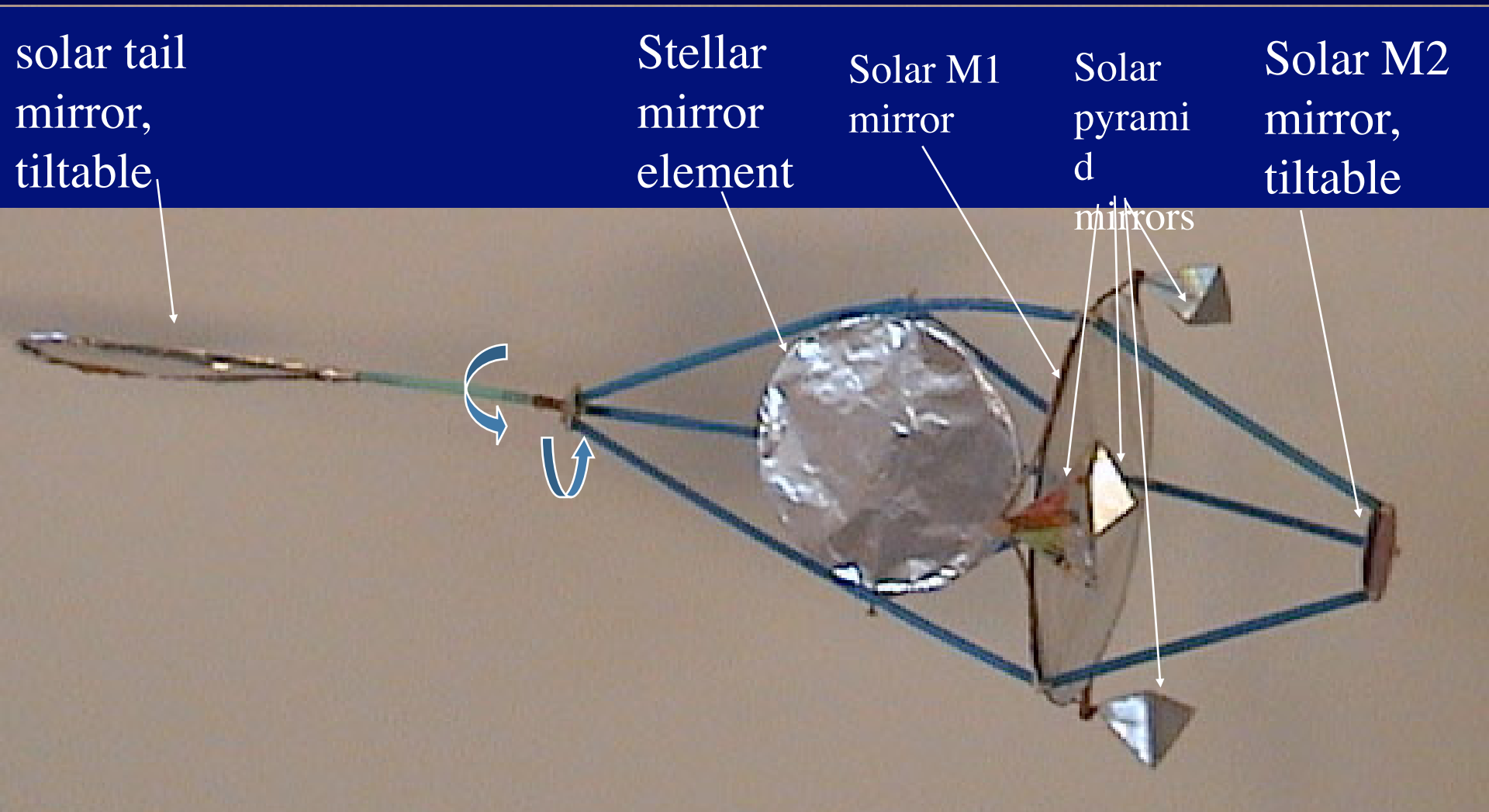
Free-flyer element

(artist concept by Boeing/SVS)



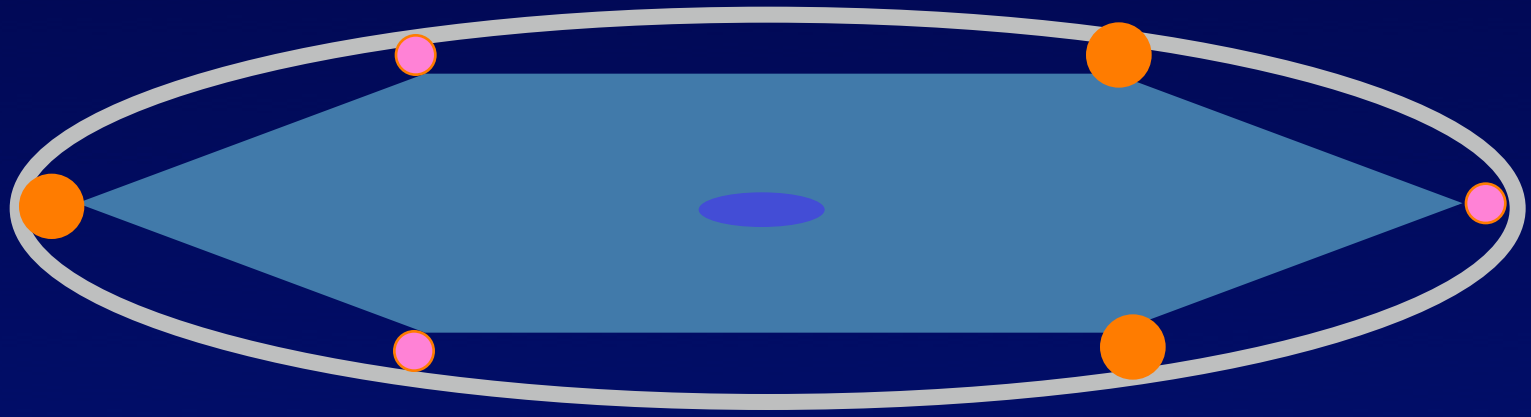
Model of ultra-low mass free-flyer

controlled by solar radiation pressure



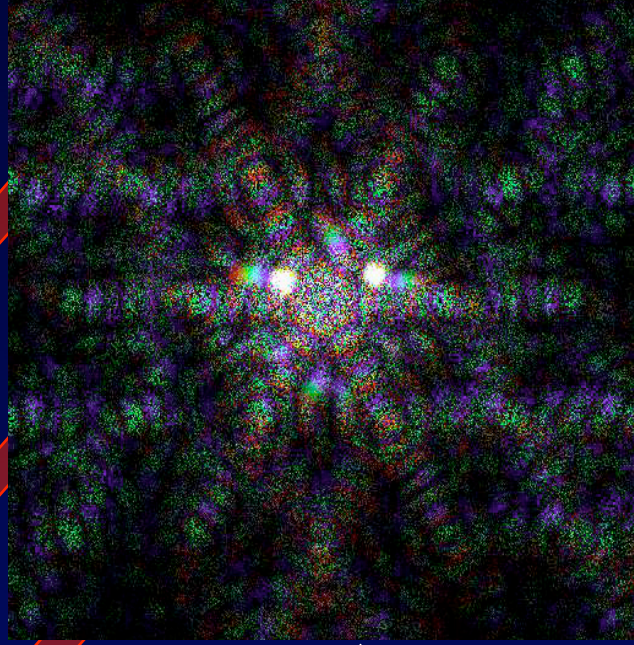
Stretched membrane mirrors

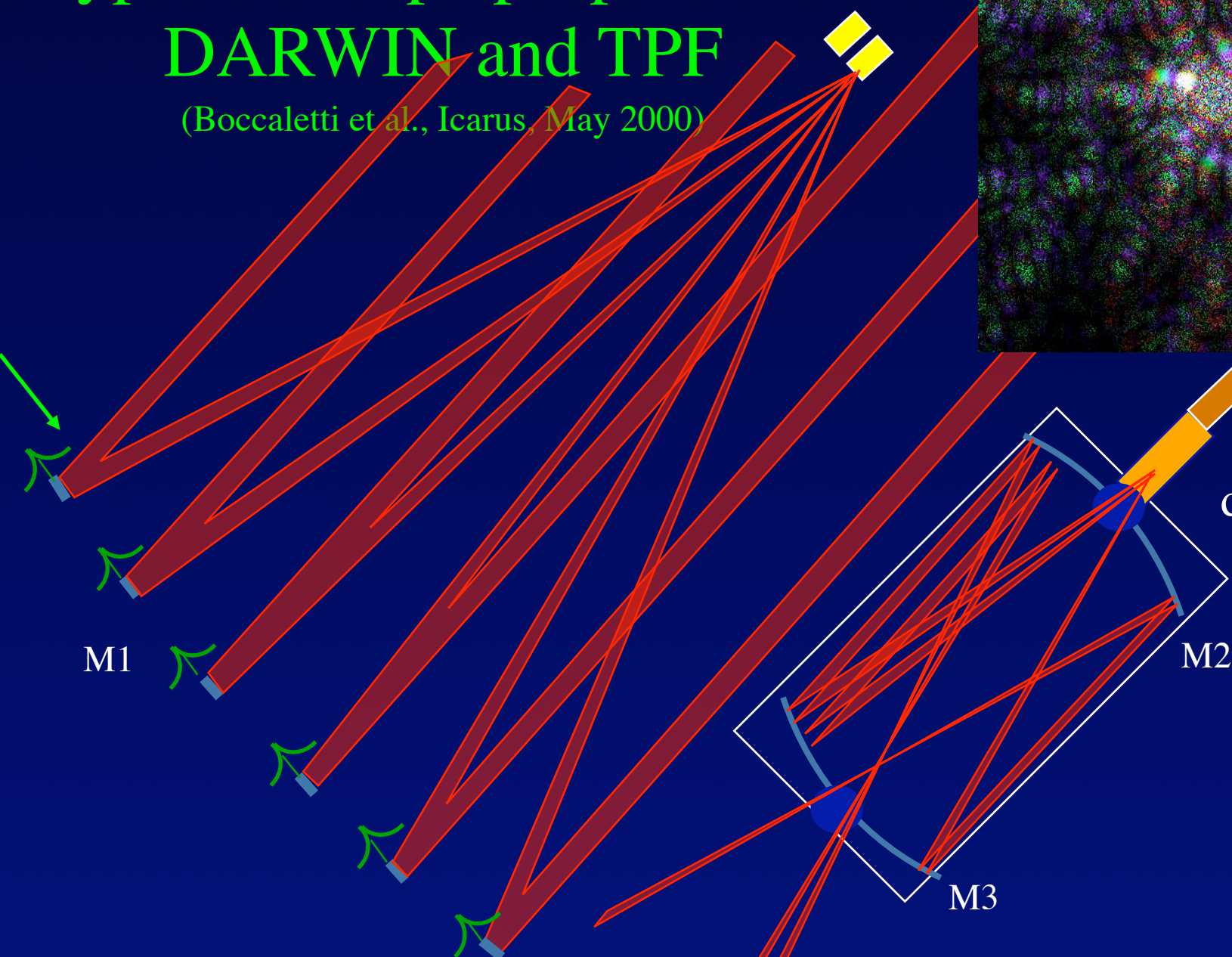
(Angel et al.)



Hypertelescope proposed for DARWIN and TPF

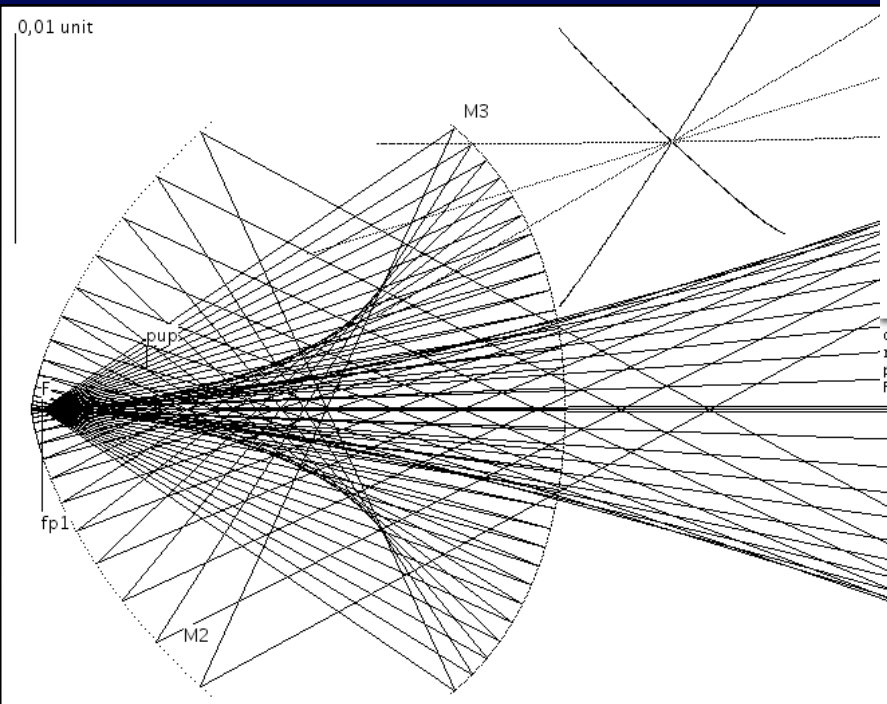
(Boccaletti et al., Icarus, May 2000)





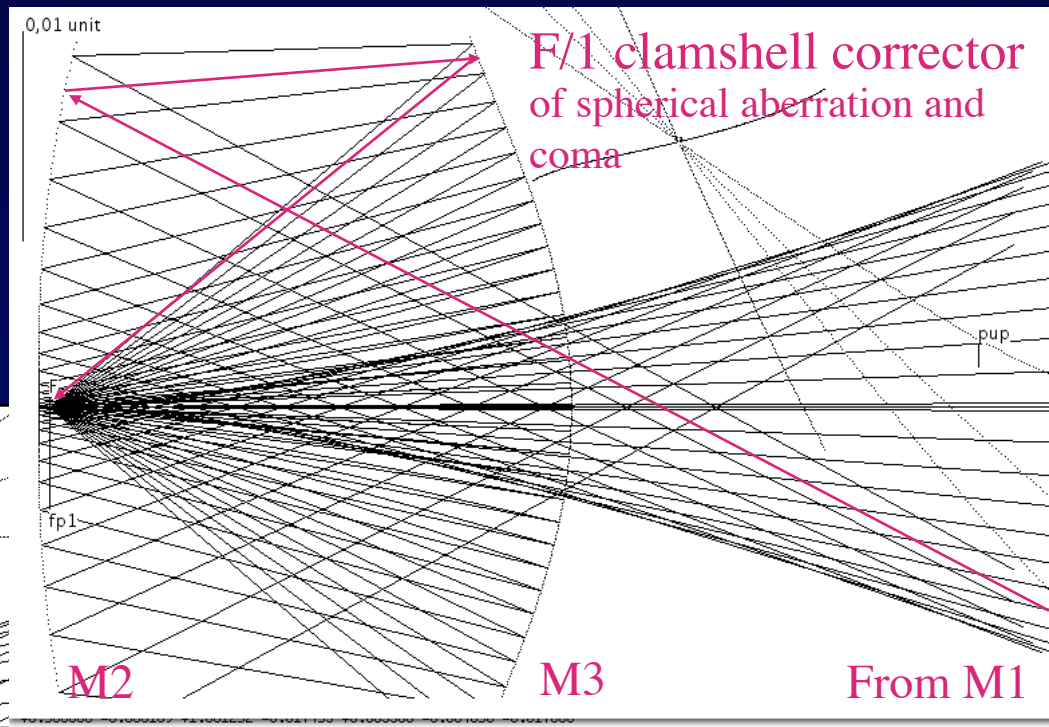
Correcting the aberration of a spherical mirror in the beam combiner

Two types of clamshell correctors



diametres: M1 -1 M2 -0.02738 M3 0.027
rayon M1: R=2 hauteur incidence HM=-0
position approchee M3: XD=1.025 chemir
F/D(M1)=1 sortie=0.720741 deltafocus

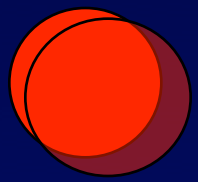
Diameter 2.7% of M1 at F/1



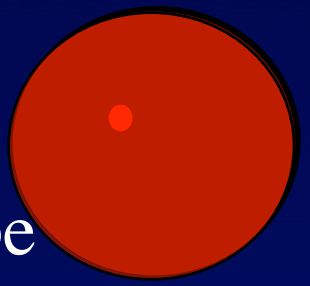
diametres: M1 -1 M2 -0.034905 M3 -0.03536 soit %M1 = 3.536038
rayon M1: R=2 hauteur incidence HM=-0.5 sinus sortie SM=-0.66
position approchee M3: XD=1.025 chemin optique PL=3.051 focale resultante=0.82449
F/D(M1)=1 sortie=-0.569141 deltafocus =-2.500000E-03 mic = 6 champ ref =-1.010000E-04

Suitable for the Exo-Earth Discoverer

Infra-red detection: the sensitivity gain with hypertelescope coronagraphy (Boccaletti et al., Riaud et al., 2003)



Pupil nulling

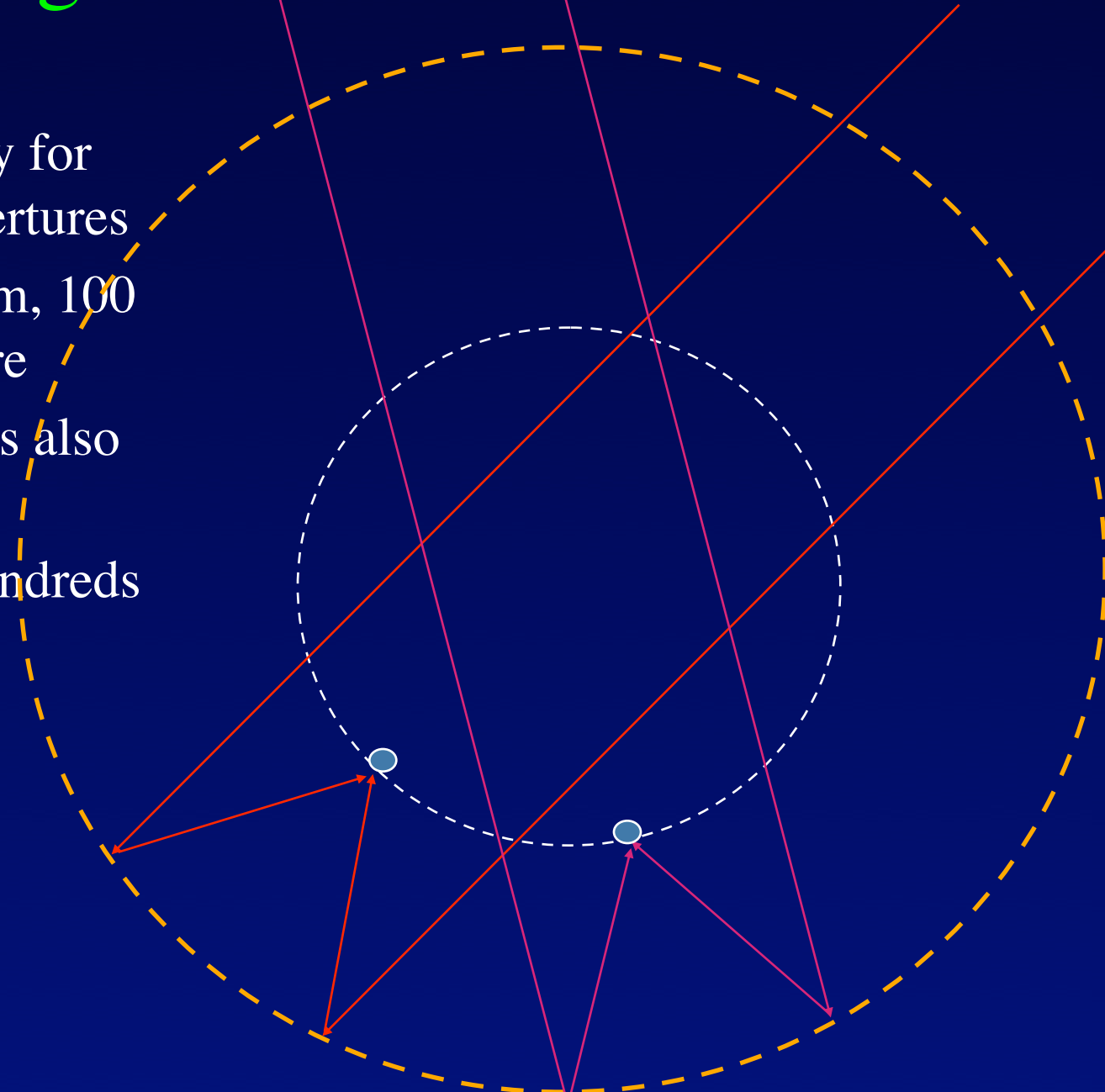


Hypertelescope coronagraphic image

- Pupil « nulling » mixes emission of λ/d sky patch with planet on the single detector pixel
- Image has sky and planet on distinct pixels in the hypertelescope case

Exo-Earth Imager in bubble form

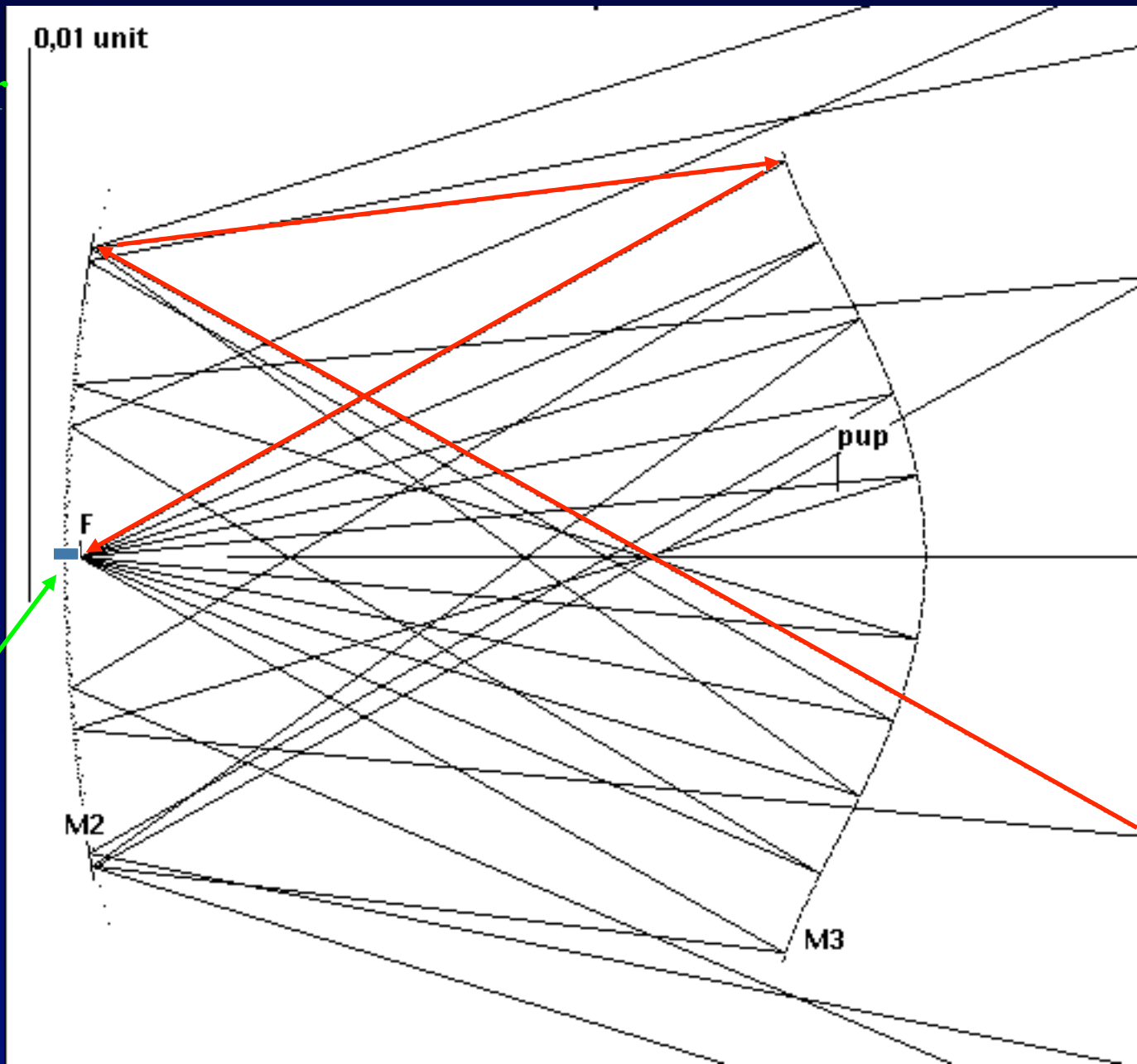
- 400 km bubble array for 100km effective apertures
- 10,000 mirrors of 3m, 100 per effective aperture
- 1-km diluted flotillas also as focal correctors
- Static observing, hundreds of exo-Earths simultaneously



Diluted clam shell corrector, 1 km diameter

for a 100 km Exo-Earth Imager

- Mirror elements smaller than 1m
- Correction of spherical aberration and coma

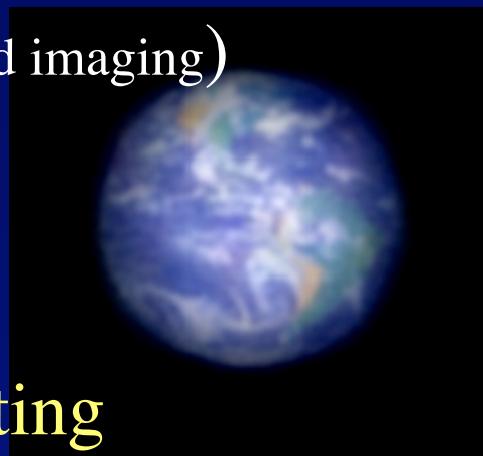


DARWIN, TPF or hypertelescope version? Pros and cons

- snapshot image improves rejection of infra-red background : exposures 10 to 100 times shorter
- Direct high-resolution image with hypertelescope
- Hypertelescope has more mirrors, of smaller size
- but 6 can suffice with scheme of Roddier & Guyon
- Detailed comparison needed

Conclusion: proposed steps for detecting exo-Earths and life

- Optional visible coronagraphic telescope , 2 to 6m
- And/or DARWIN-TPF **or** visible -IR hyperterlescope (Exo-Earth Discoverer, for general purpose imaging and exo-Earth coronagraphy)*
- Then (2015 ?): 100-km imaging interferometer (Exo-Earth Imager , also for general micro-arc-second imaging)



– * selection requires detailed study and testing