Hypertelescope Optical Observatory

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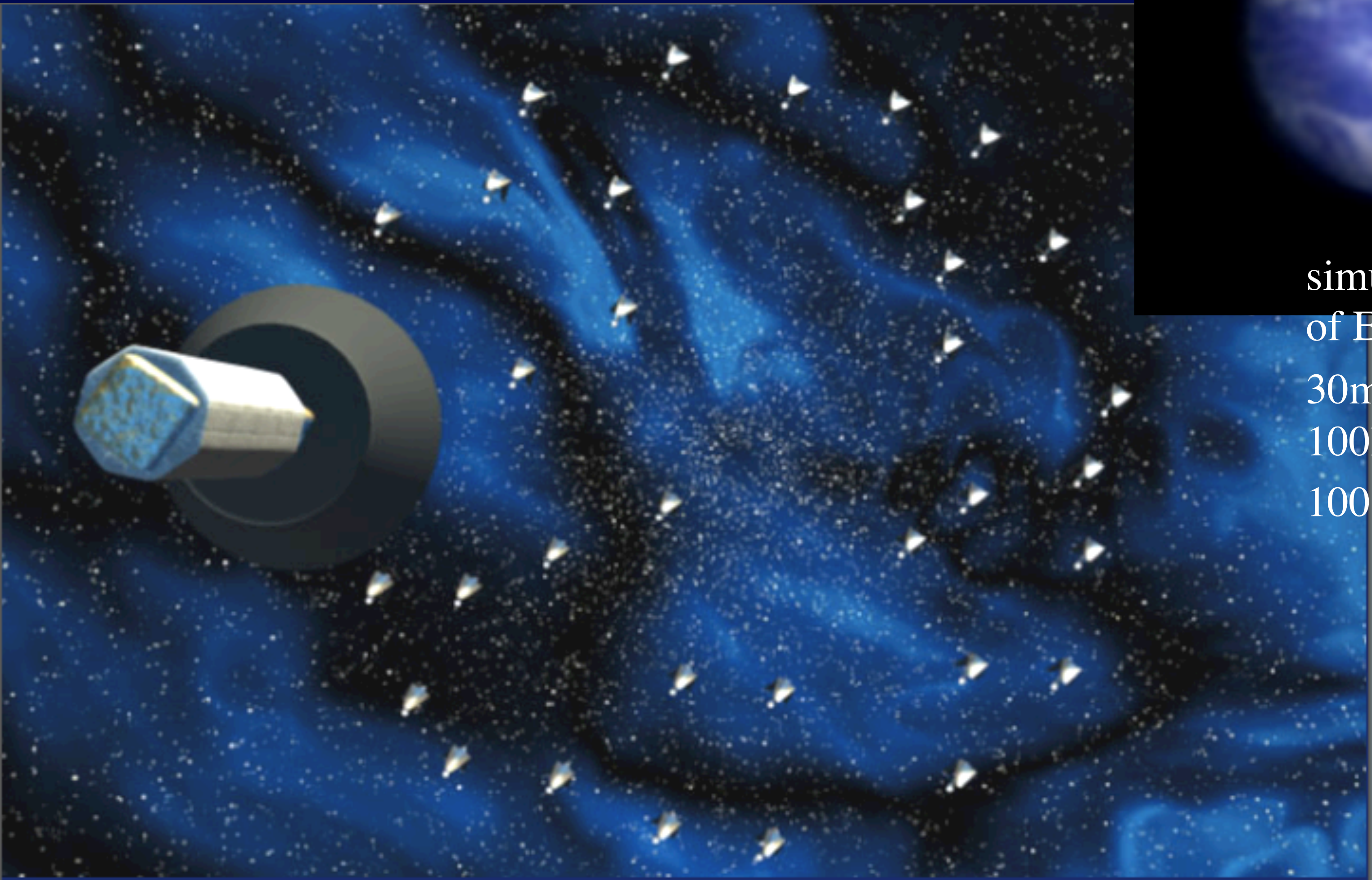
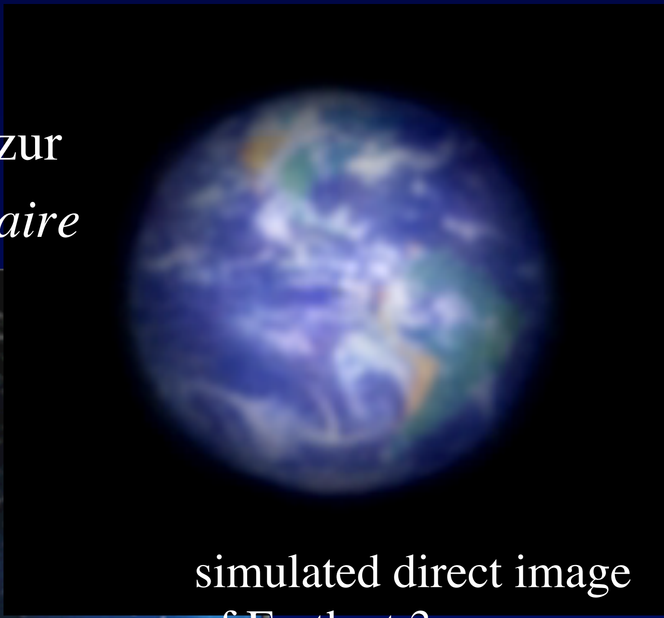




simulated direct image of Earth at 3 pc

30mn exposure with 100km hypertelescope, 100 sub-apertures

We build a hypertelescope

multi-aperture imaging interferometer

- has more future in space...
- ...beyond 100,000 km size
- 1 to 100km proposed now

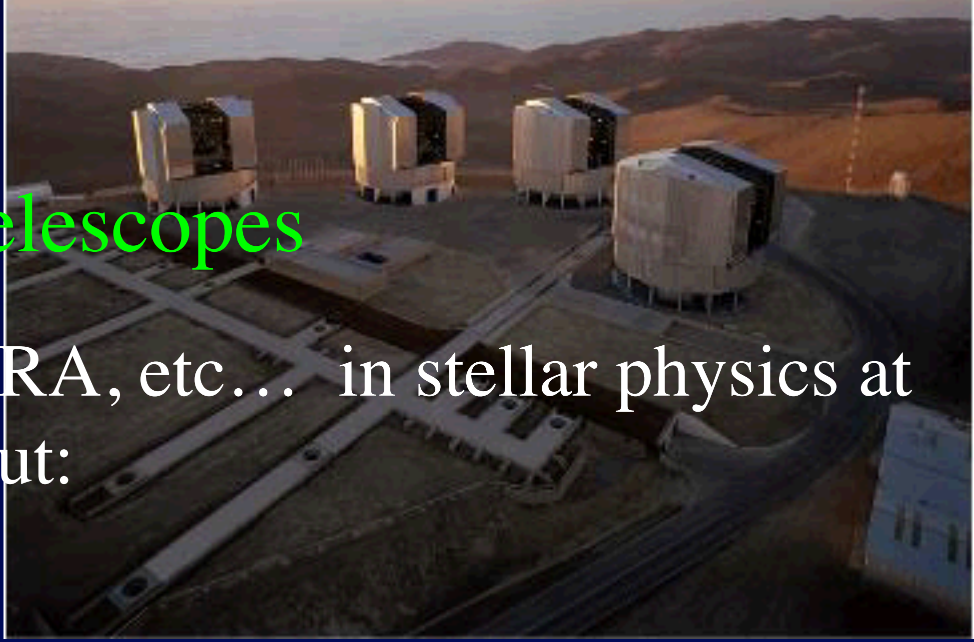
details at:
https://lise.oca.eu/

Technical heritage from three decades of study

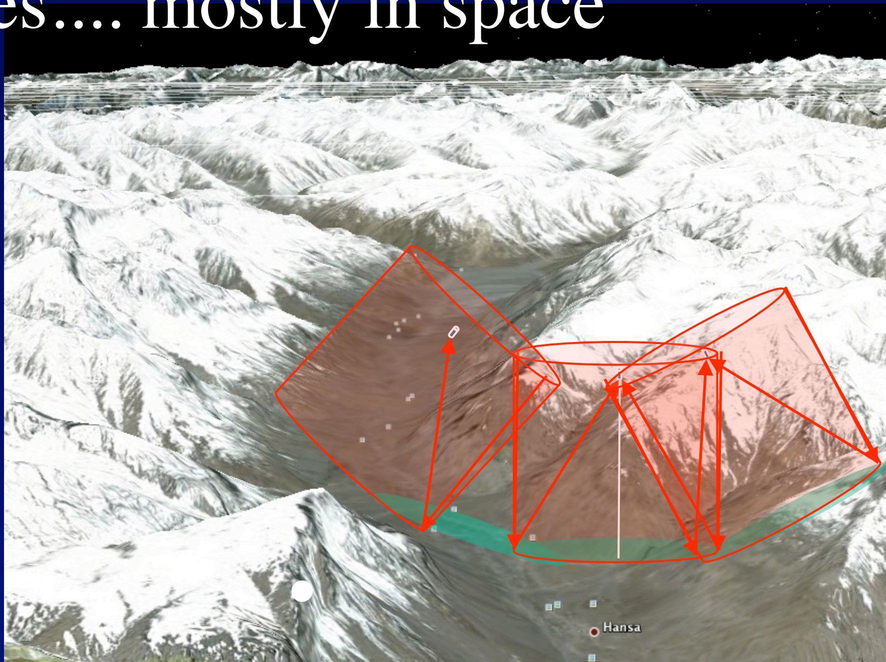
since the TRIO, DARWIN, EED, LUCIOLA, etc.. proposals to ESA and NASA

- ground-based interferometers and prototype hypertelescopes
- lab model of micro-solar-sail design
- lab testing of laser-trapped mirror in high vacuum
- PRISMA testing of formation flight , with different thruster types and sensors

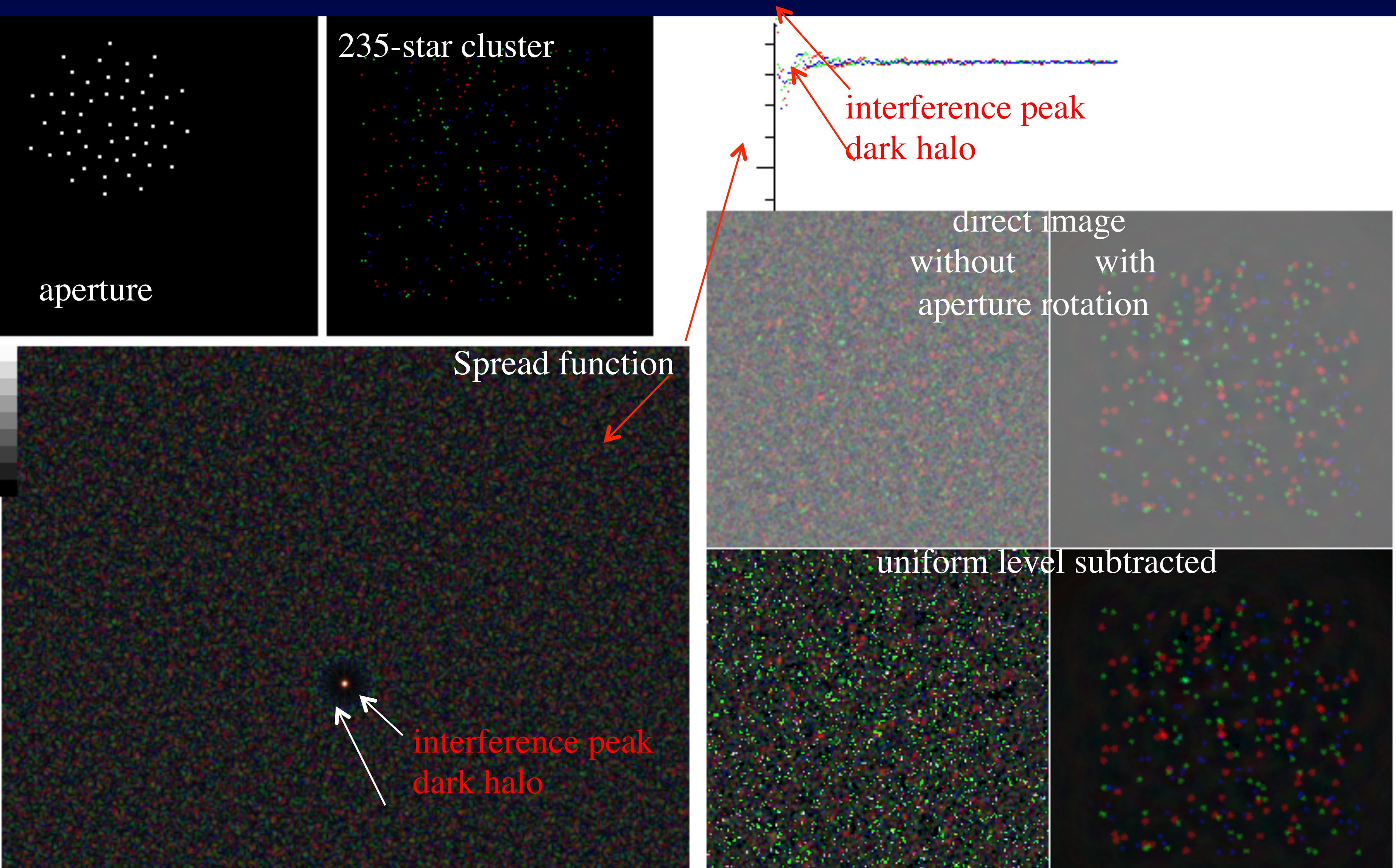
Limits of ground-based interferometers and hypertelescopes



- Many results of VLTI, CHARA, etc… in stellar physics at milliarcsecond resolution, but:
- Modest limiting magnitude
- Modest « reconstructed » images with the few baselines
- Improvable with hypertelescopes…. mostly in space
  - rich direct imagery
  - resolution gain with large flotilla
  - high limiting magnitude
  - UV to IR



Example: simulated direct image of stars with 50 sub-apertures (Fizeau mode)



Interferometer and hypertelescope:

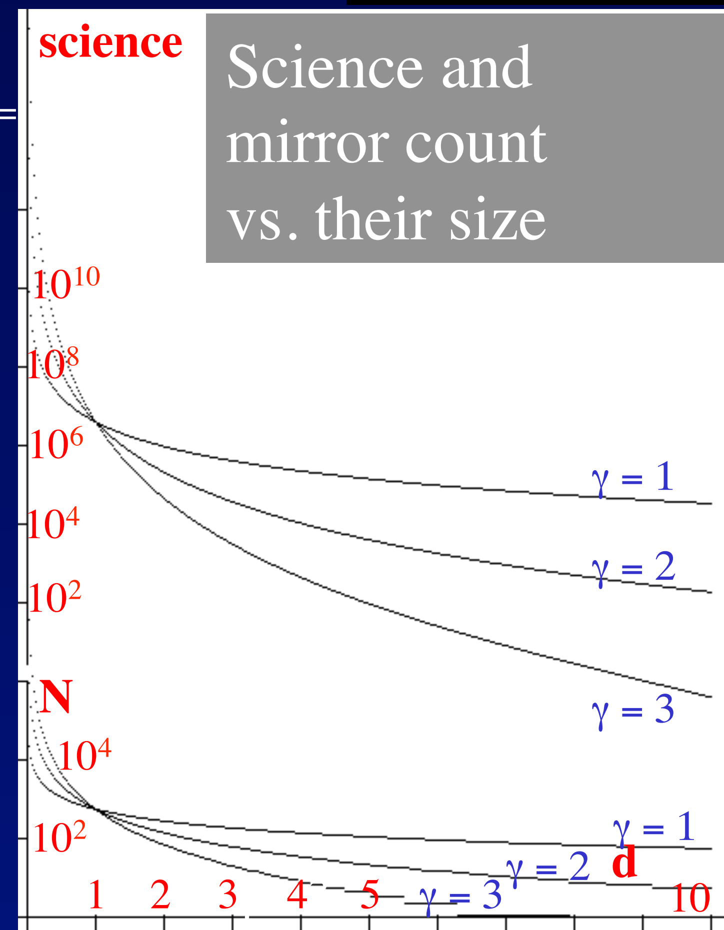
The science gain with smaller sub-apertures at given collecting area

(Labeyrie et al., Exp. Astronomy, 2009, Labeyrie et al., 2010)

- crowded fields : the tolerable number of stars grows as N^2
- The size of the "Direct Imaging Field » (or « Clean Field ») is λ/s (s is the sub-aperture spacing)
- Science vs. mirror size d , at given cost $C_{pa} = N\, d^{\gamma}$, where γ = 2 to 3

$$Sc = C_{pa}^{\,2}\; d^{-2\gamma}\ \{(7/4)\log_2 C_{pa} + (1-7\gamma/4)\log_2 d\}$$

- Huge gain in science with smaller d
- 1000x more science with d=10cm than 1m
- … but minimal mirror size : a few centimeters for tolerable diffractive spreading in the Fizeau focal plane
- Example of " Laser Trapped Hypetelescope Flotilla" : 40,000 mirrors of 3cm matching the collecting area of JWST



Hypertelescope Optical Observatory (HOO):

Desirable features of hypertelescope flotilla

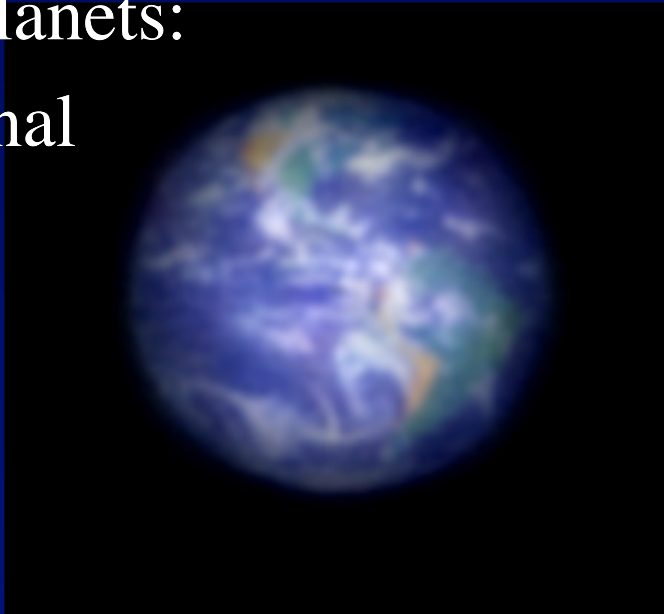
- General purpose observatory with:
- very high resolution
- high limiting magnitude
- *Pointable*
- Expandable to tens of kilometers and conctractible
- Upgradable with additional sub-apertures and focal instruments

The broad science of hypertelescopes: some examples

- accretion disks and black-holes in AGNs
- gravitational lensing
- cosmology : morphology of remote galaxies
- optical counterparts of gammay-ray bursts
- direct search for life on resolved exo-planets:

  the « indian summer » signal

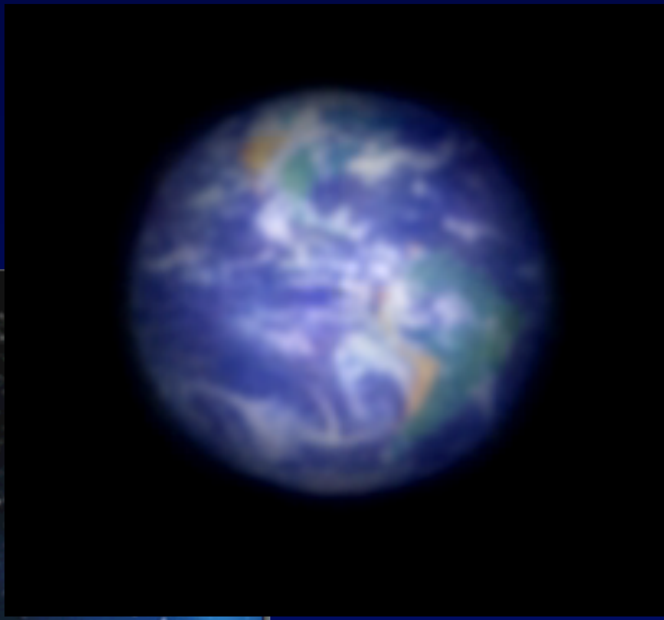
  of seasonal color changes

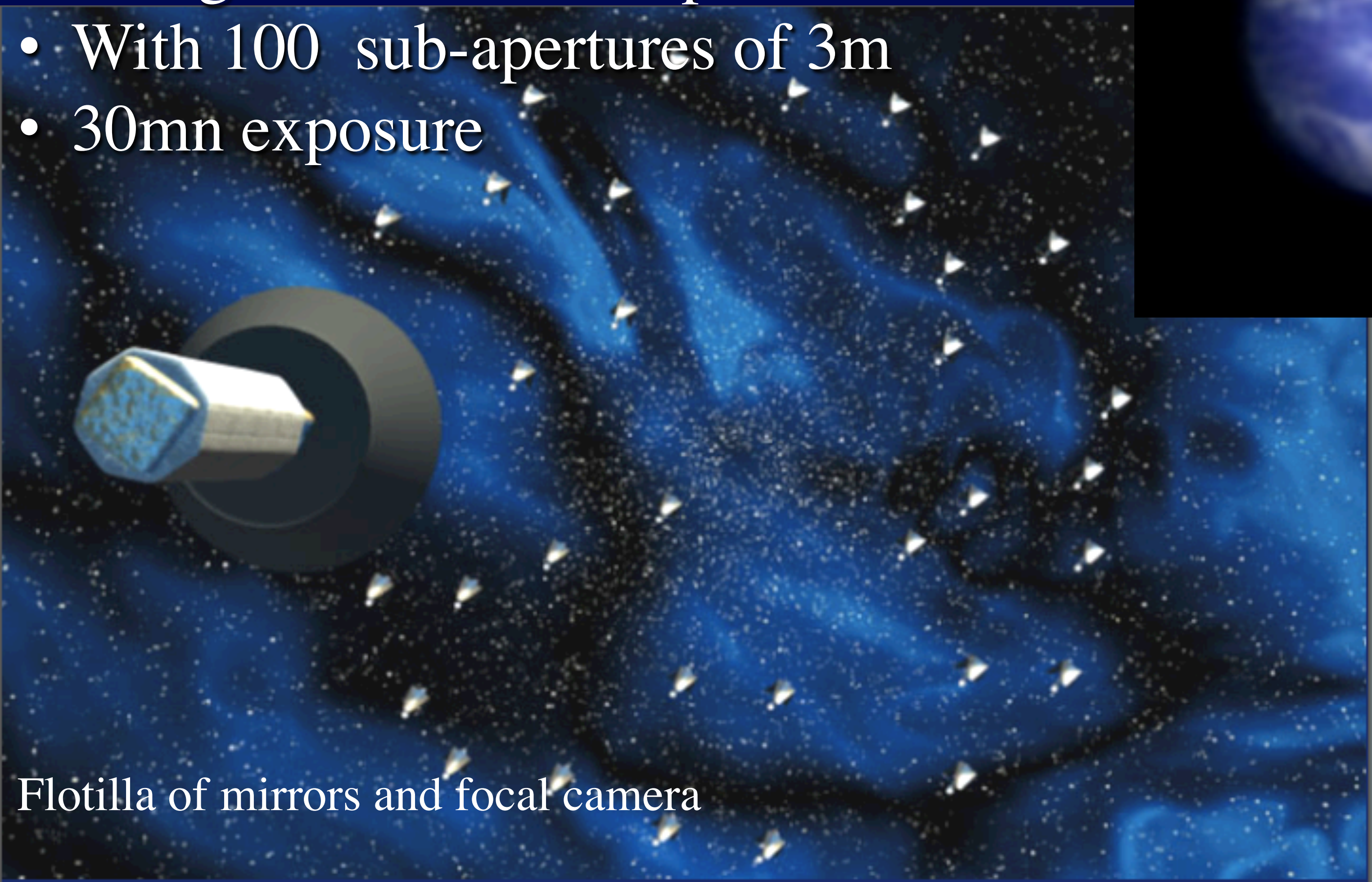


Space hypertelescope for searching life

Simulated direct image of Earth at 3 parsecs

- Using a 100km meta-aperture
- With 100 sub-apertures of 3m
- 30mn exposure

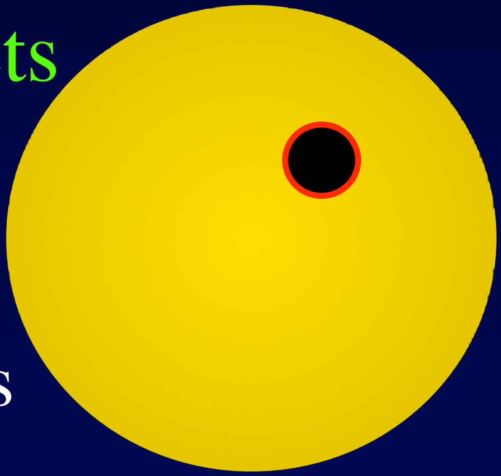




Flotilla of mirrors and focal camera

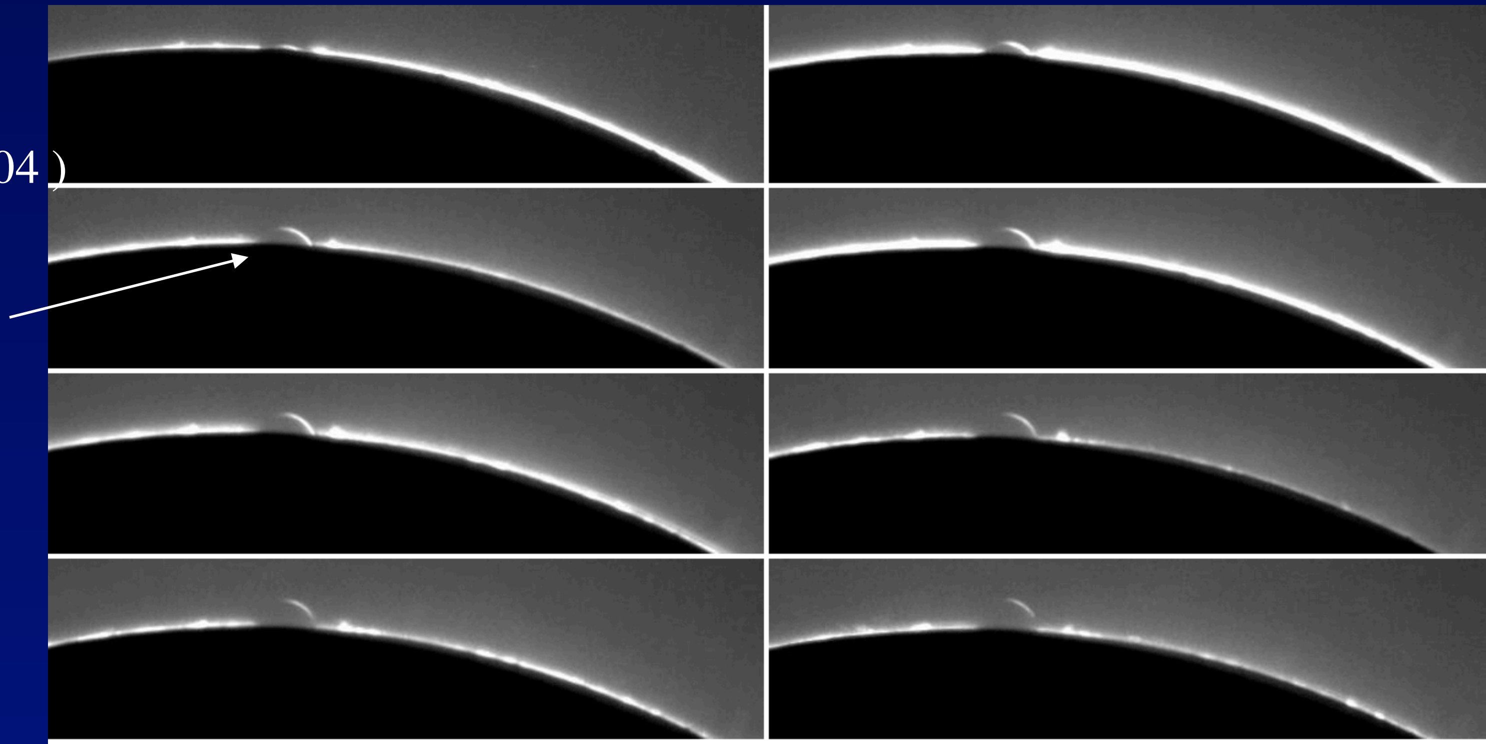
Resolved imagery of transiting exoplanets

(Labeyrie 2013)

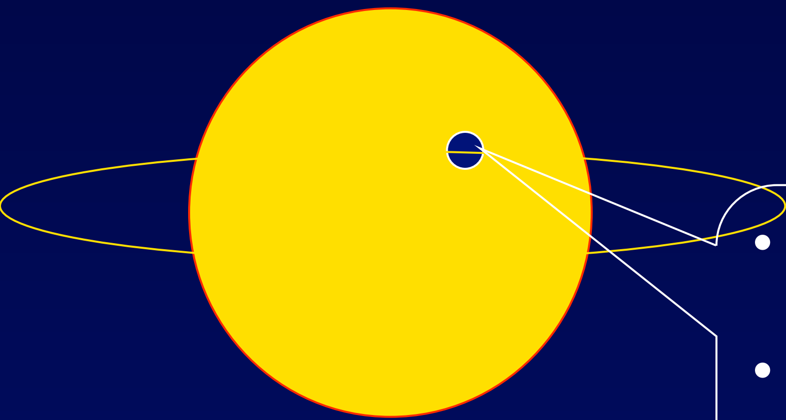


- Easier during transit and egress: spectra of refraction arc for searching bio-marker lines
- extreme coronagraph needed otherwise

Solar transit of Venus (Rondi, 2004)



Example of hyperteleseope science with direct imaging: exo-planets transiting across the resolved parent star

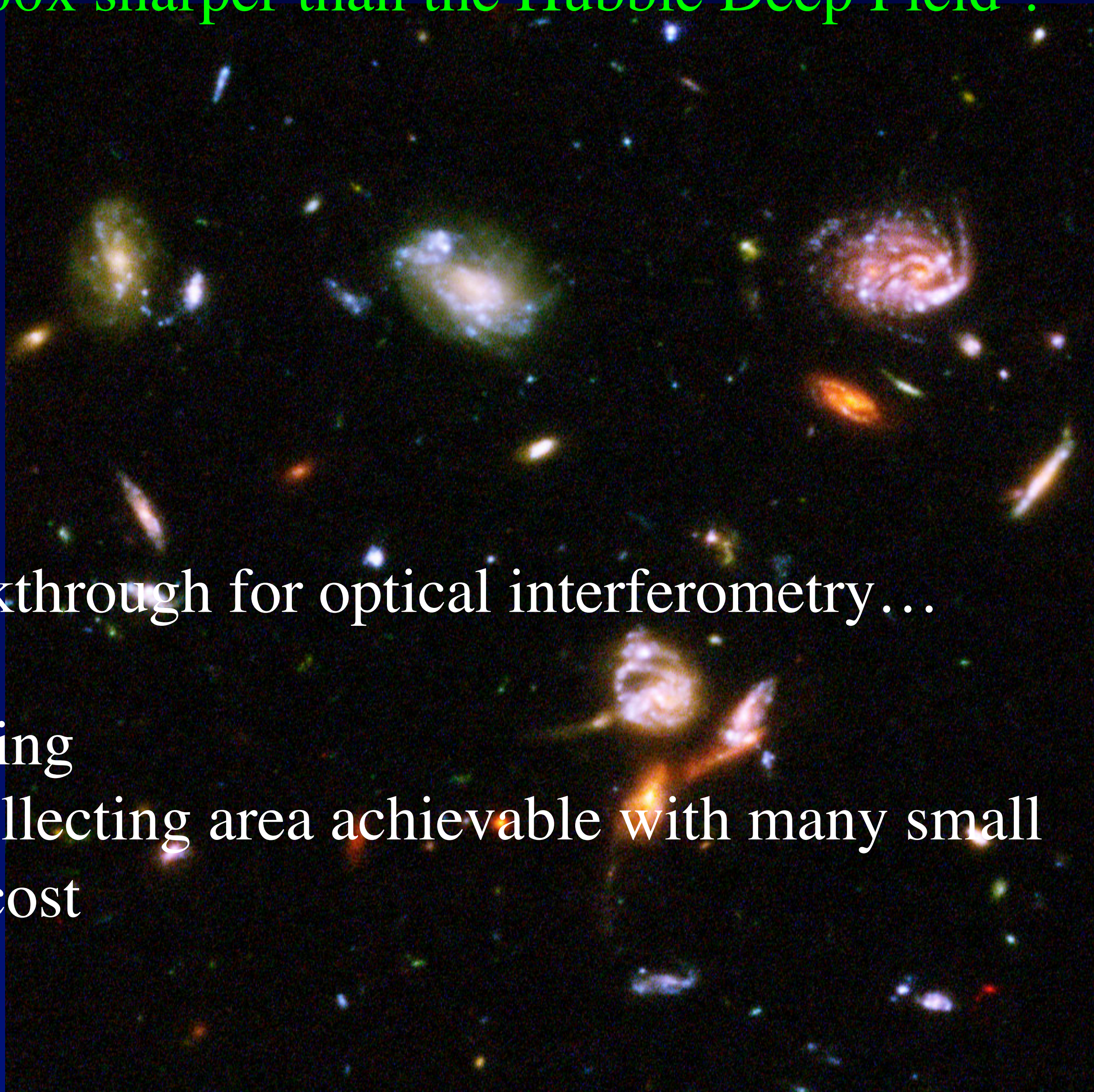


- the size of a Jupiter at 10pc is just resolved with a 1km hypertelescope
- many apertures are required for low sidelobes in the interference function
- then provides a contrasted dark spot

- a transiting Earth is detectable with a 10km flotilla and more apertures (simulations needed)
- usable for spectroscopy of planet's extended atmosphere
- requires a snapshot imaging interferometer with high dynamic range :

hypertelescope

Hypertelescope for cosmology:
See fainter and 400x sharper than the Hubble Deep Field ?



- a potential breakthrough for optical interferometry…
- … resulting from:
  - direct imaging
  - the large collecting area achievable with many small mirrors ... at lower cost

Hypertelescope flotilla concept: a dilute optical form of the Arecibo radio-télescope

- modular, flexible, expandable geometry
- operable with multiple focal spaceships...
- ... specialized... from UV to IR... coronagraphy, etc...
- ... for parallel science
- same limiting magnitude as HST, JWST, ELTs if equal collecting area
- three driving options with micro-thrusters for the mirror flotilla:
  1. chemical, as demonstrated by the PRISMA test of formation flying
  2. solar sail
  3. laser trapping

Hypertelescope Optical Observatory (HOO):

How feasible ? 3 driving options for flotilla

1. ion thrusters, etc…
2. micro-solar sails (Luciola proposal Labeyrie et al. , 2009)
3. laser trapping (Labeyrie et al., 2010)

simplifies ? tiny mirrors , lower cost ?

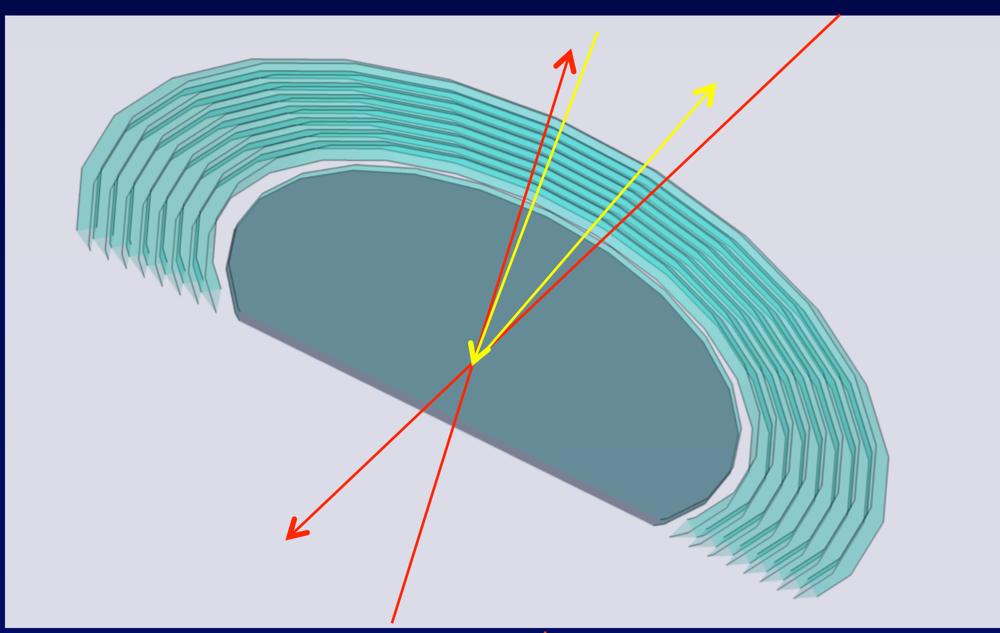
Laser-Trapped Hypertelescope Flotilla

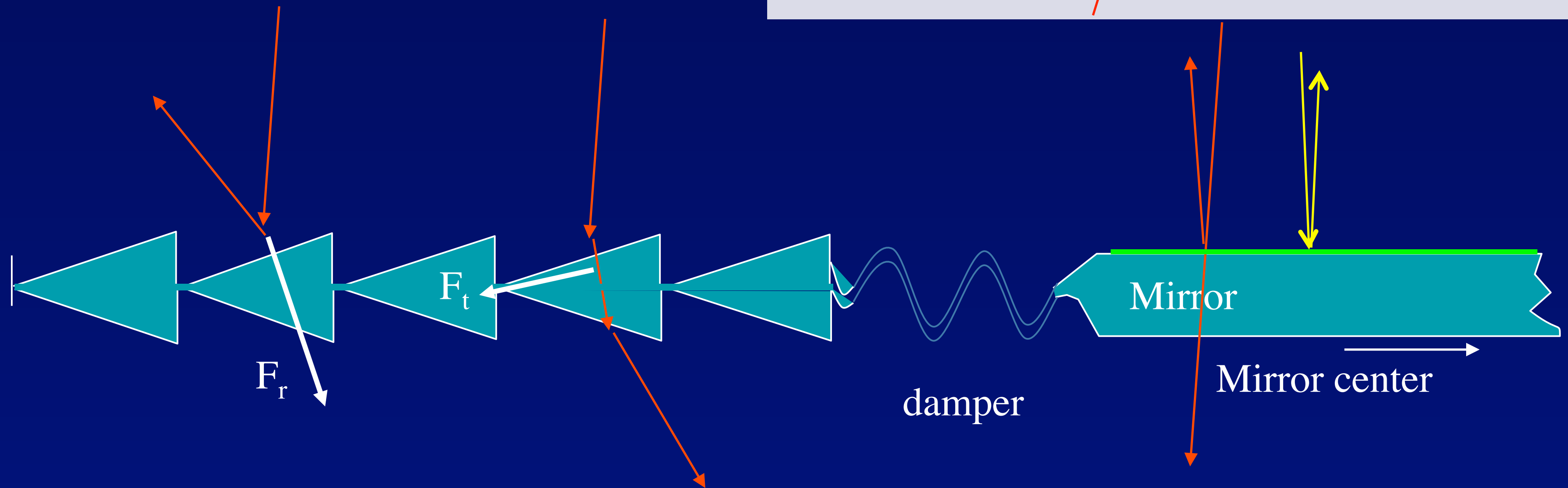
(Labeyrie et al., 2009, Labeyrie et al., 2010)

Expandable to a 100km flotilla and beyond

Laser-trapped mirror element

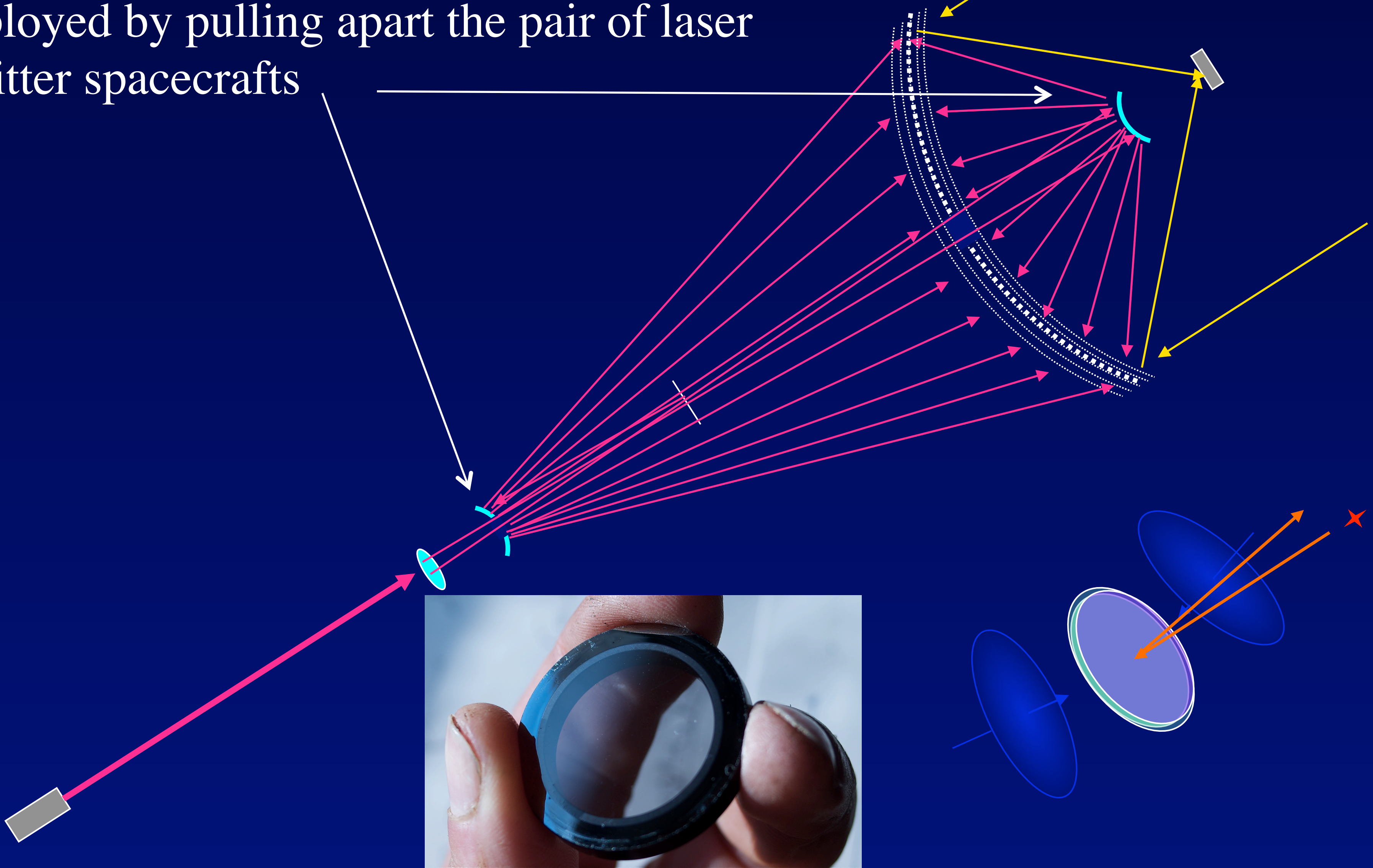
- coarse alignment by laser radiation pressure on peripheral Fresnel lens
- fine alignment and cophasing by standing waves





Laser-induced deployment: from package to kilometric flotilla

deployed by pulling apart the pair of laser emitter spacecrafts



Hypertelescope Optical Observatory (HOO):

Why laser-trapped mirrors ?

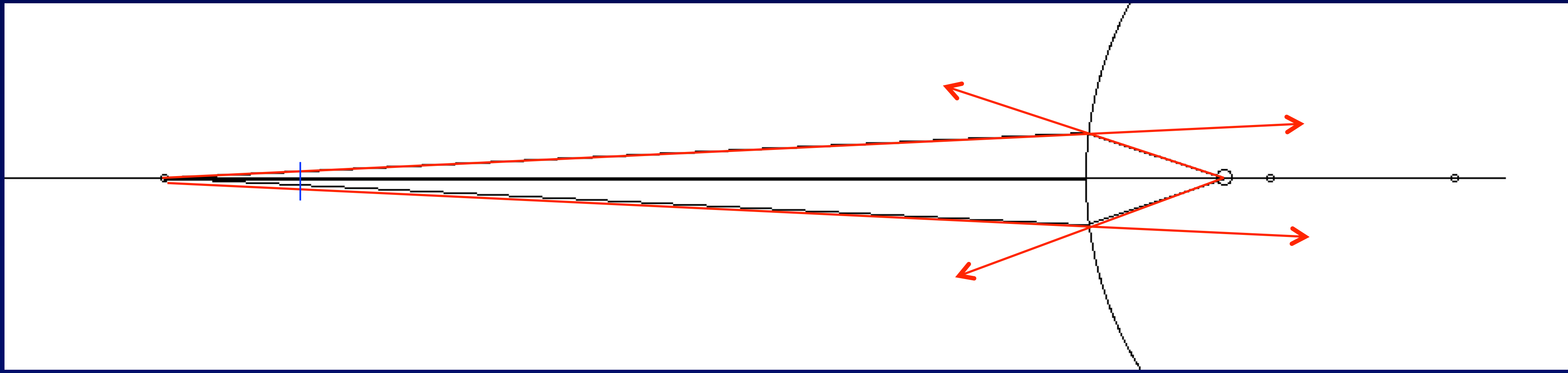
- Already used for manipulating atoms, bacterias, etc…
- Well suited for accurately positioning tiny mirrors in micro-gravity reduction of mass, cost
- enhanced imaging performance with the numerous mirrors
- Self-aligning with sub-wavelength accuracy

Hyperteléscope as laser-trapped flotilla: a case of disruptive technology ?

- at given total area, a subdivided aperture is better for imaging performance
- mirrors as small as 30mm are ideal …
- … and reduce the total mass, cost, failure risk
- cophasing achieved by laser trapping in a single standing wave

example:

Sizing of a 100km laser-trapped flotilla



Suggested road map toward hypertelescopes in space

1. Pursue laboratory testing of the laser trapping option initiated in high vacuum by S.Residori and U.Bortolozzo
2. if justified: ISS/Columbus test of trapping design
3. select option for flotilla driving (chemical , solar or laser drive)
4. launch expandable flotilla : aperture from 1 to 100km ,mirror count: 20 to 100 and more
5. early science: exoplanet transits, AGNs, cosmology
6. Upgrades: size, mirror count, focal spaceships