DARWIN

x-Array Aperture Configuration in Planar or Non-Planar Spacecraft Formation for DARWIN/TPF-I Candidate Architectures

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SPIE Optics+Photonics

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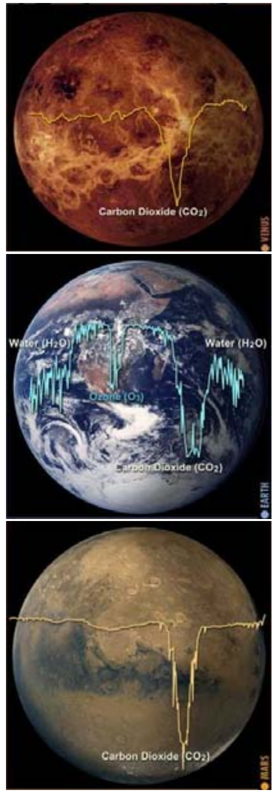
Introduction – DARWIN/TPF-I Mission Goals

- Detection of terrestrial planets within the habitable zones of nearby stars
- Characterization of the detected Earth-like exo-planets
    - physical parameters
    - presence of an atmosphere (signs of biological activity)
- Aperture synthesis imaging for general astrophysics



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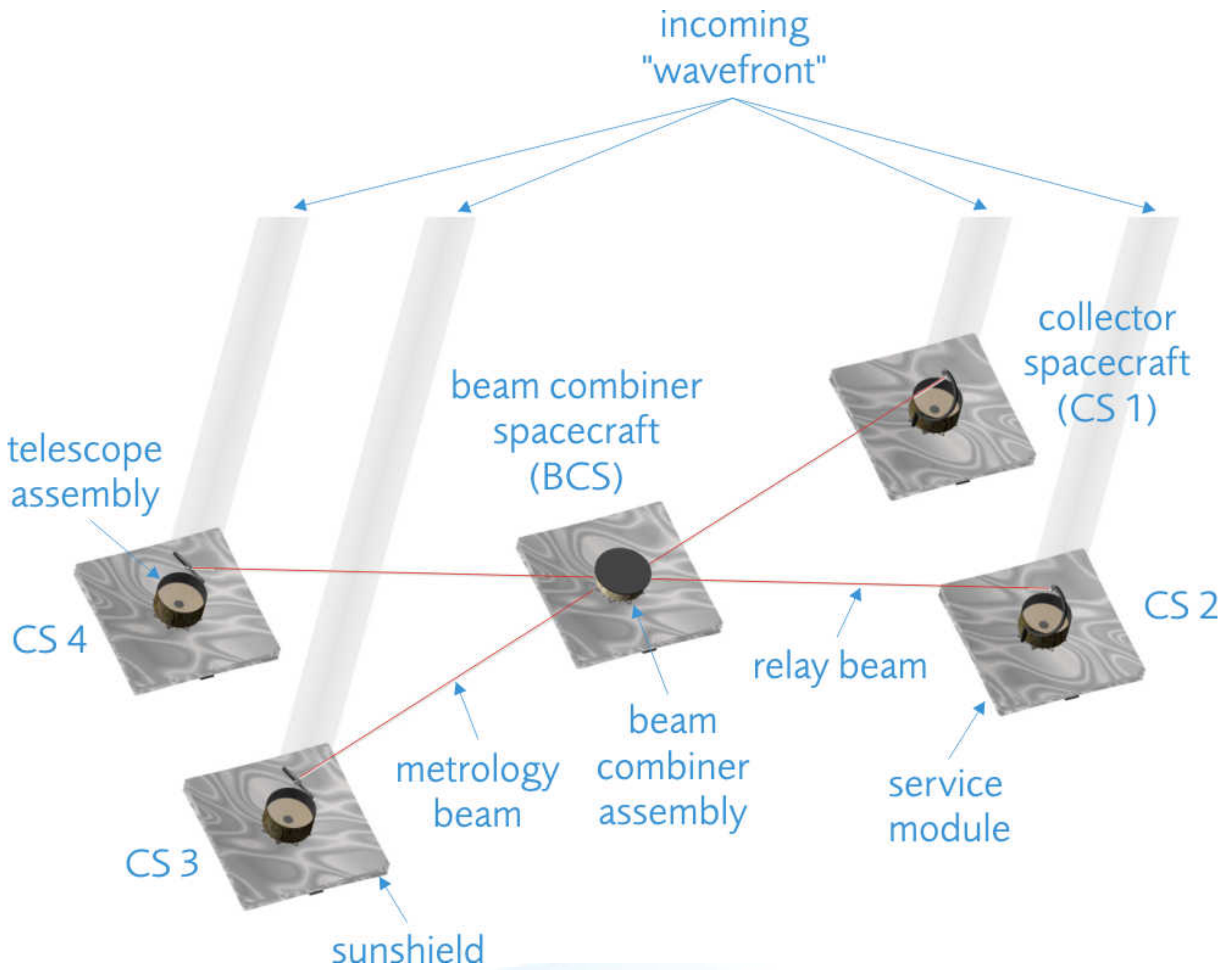
Introduction – DARWIN/TPF-I Mission

- Space-borne nulling interferometer
- Operational orbit at L2
- Operates in the mid-infrared wavelength regime from 6.5 to 20 micrometers
- Instrument is distributed over 5 spacecraft which fly in a closely-controlled formation
- Baselines are adjustable up to several hundred meters



Outline

Aperture configuration

- x-Array

Spacecraft formation

- Planar formations
- Non-planar formations

Critical items and design drivers

DARWIN/TPF-I Instrument Implementation

Instrument implementation is determined by

- Aperture configuration
- Spacecraft formation

Aperture configuration

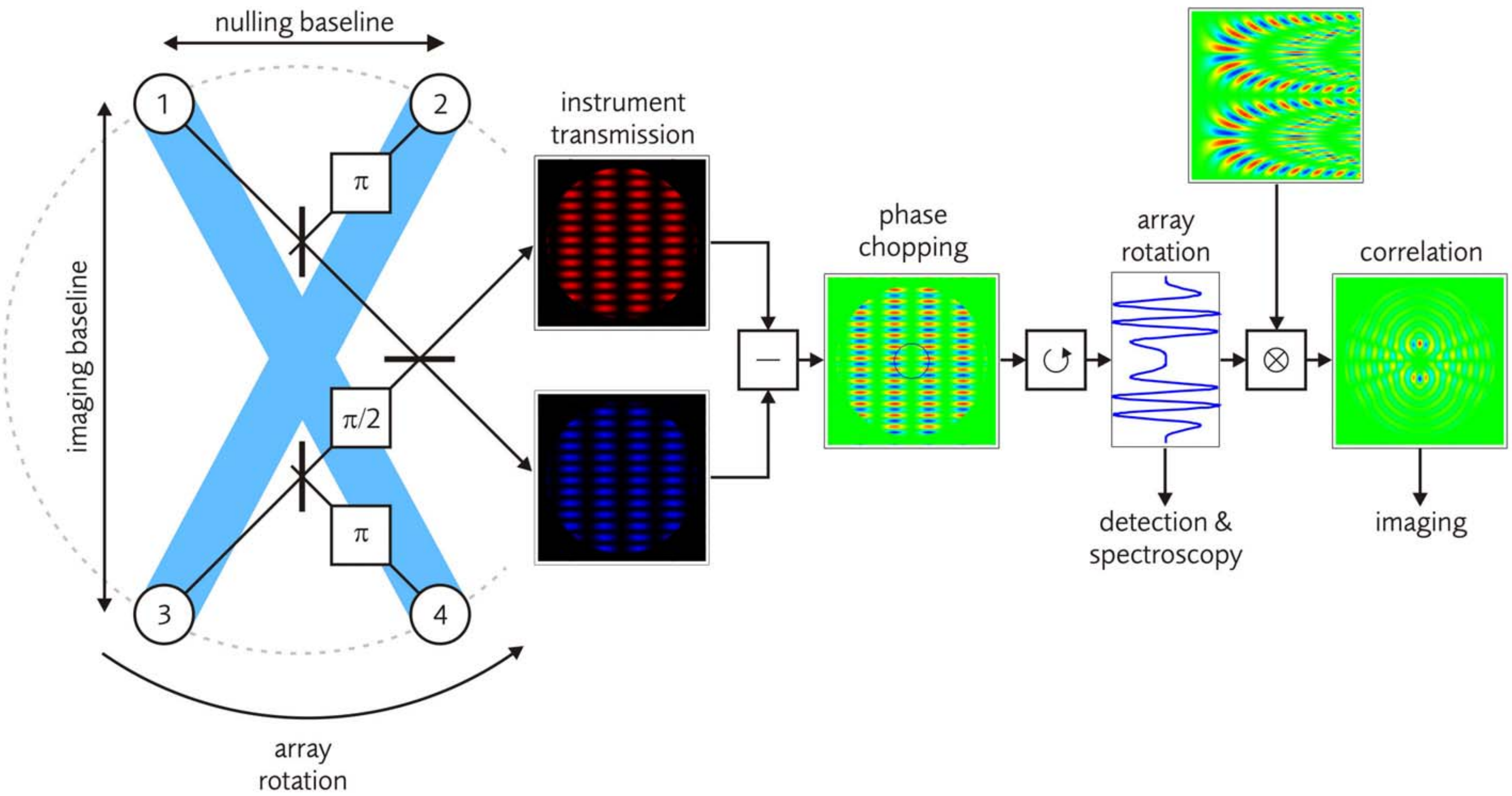
- Arrangement of the collector spacecraft relative to each other
- Defines the angular selectivity of the interferometer
- Determines the theoretical performance
- x-Array is a highly optimum aperture configuration

Spacecraft formation

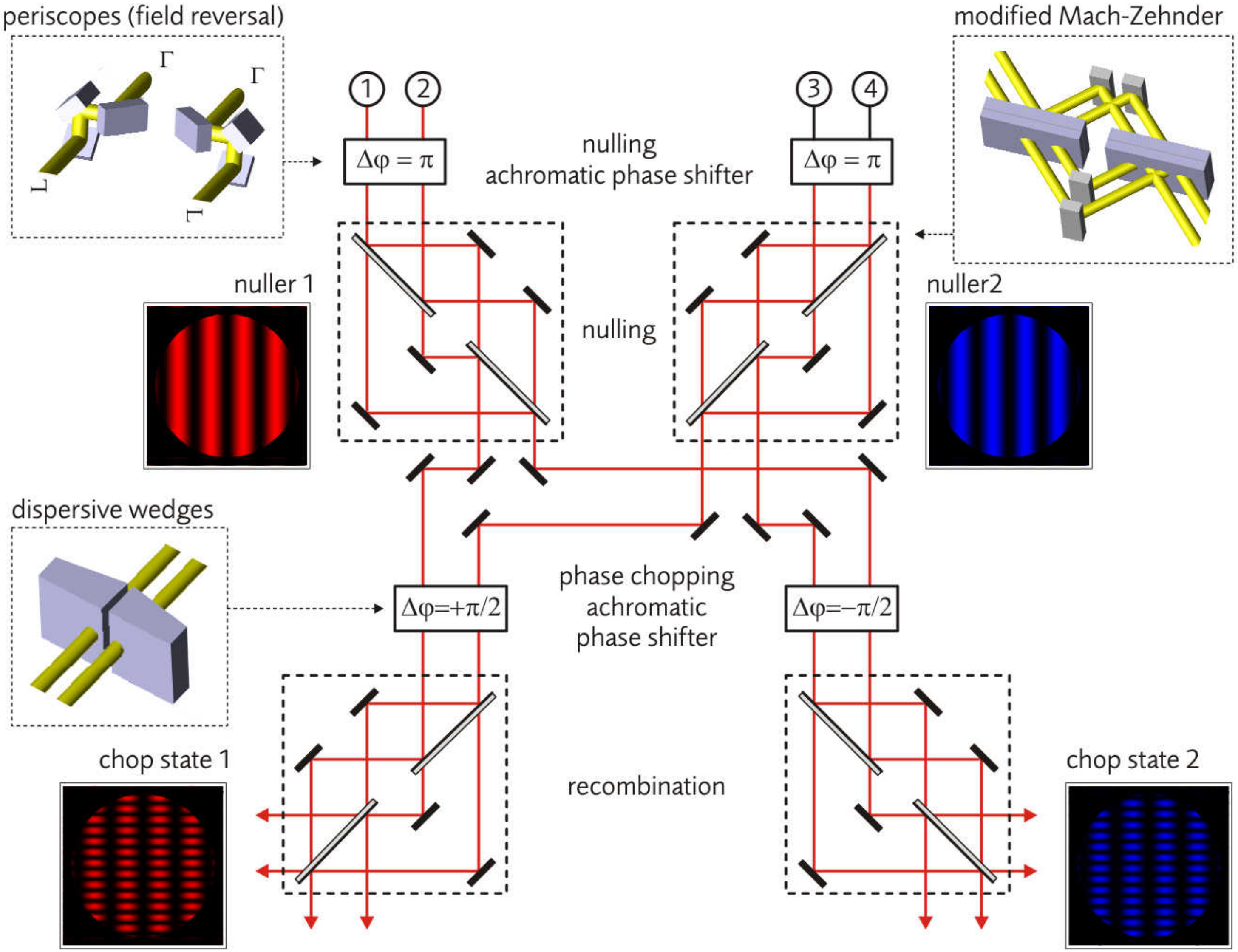
- Arrangement of the beam combiner spacecraft relative to the collector spacecraft
- Independent of the aperture configuration
- Planar (in plane) formations and non-planar (out of plane) formations

Wallner et.al., "DARWIN mission and configuration trade-off", Proc. SPIE 6268 (2006)

x-Array Aperture Configuration – Principle of Operation



x-Array Aperture Configuration – Interferometer Core



x-Array Aperture Configuration – Key Features

Decoupling of nulling and imaging properties

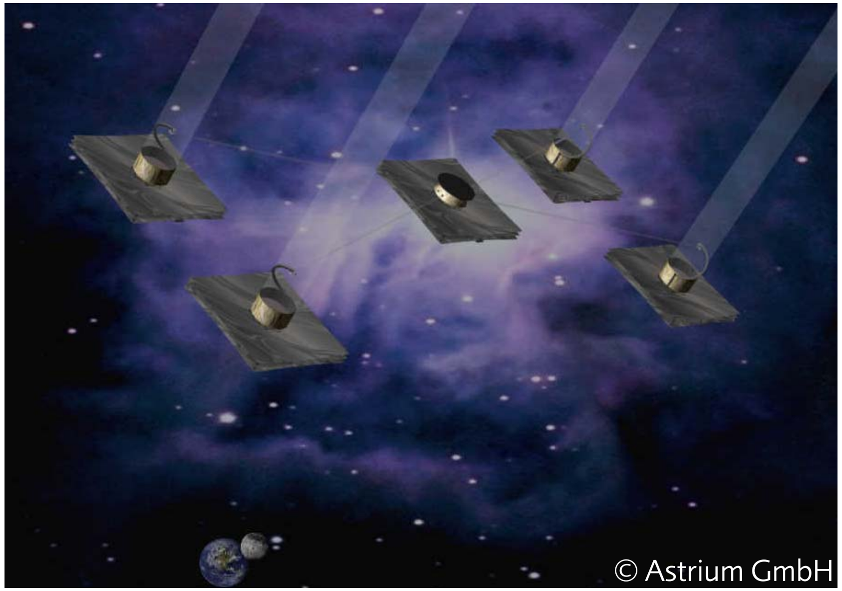
- Instrument implemented as cascaded two-telescope nullers
- Short nulling baseline for strong rejection of the on-axis star
- Long imaging baseline for high angular resolution

Perfectly symmetric and extremely efficient instrument implementation

- Perfect symmetry (polarisation, optical path length, transmission)
- Perfectly efficient co-axial beam recombination (100% efficiency)
- Periscope achromatic phase shifters for nulling (π)
- Phase chopping phase shifters ($\pm\pi/2$) with relaxed requirements

Spacecraft Formations

Planar spacecraft formations



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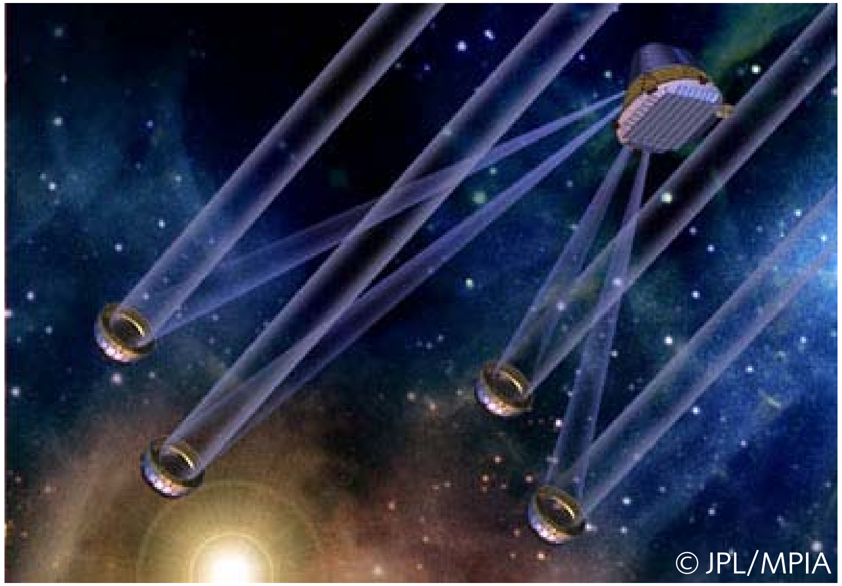
- All spacecraft form a virtually stiff truss
- Sky access: 71%
- Simpler scientific instrument

⇒ Instrument drives the spacecraft design

Non-planar spacecraft formations ("EMMA")



© JPL/MPIA

- Spacecraft do not form a virtually stiff truss (collector spacecraft rotate around beam combiner spacecraft)
- Sky access: 95%
- Simpler spacecraft

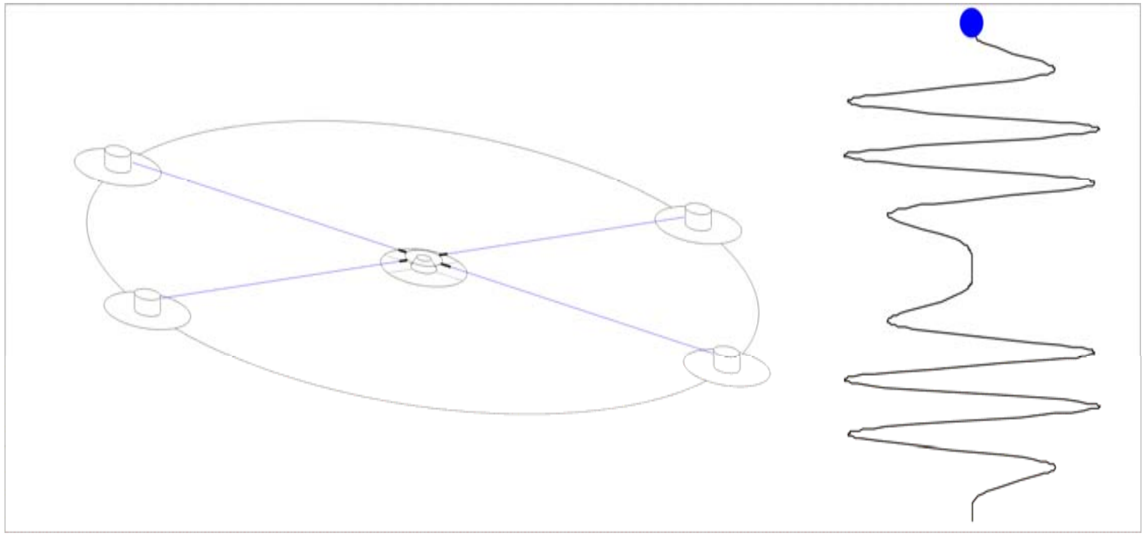
⇒ Spacecraft drives the instrument design!

Planar Spacecraft Formations – Formation Flying

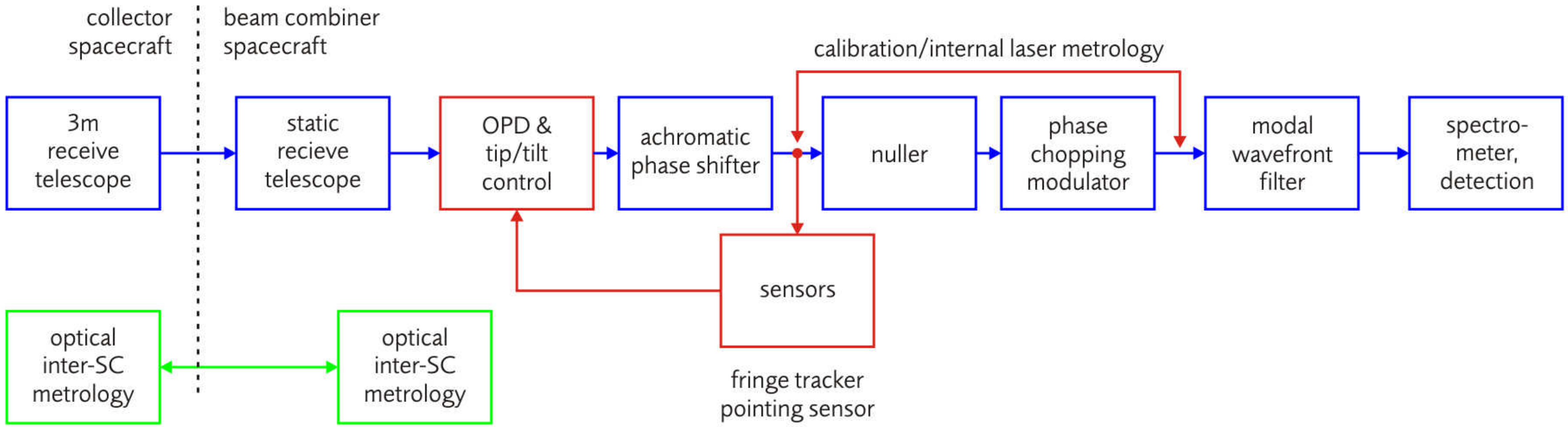
- All spacecraft form a virtual stiff truss

⇒ Spacecraft formation rotates around common line of sight

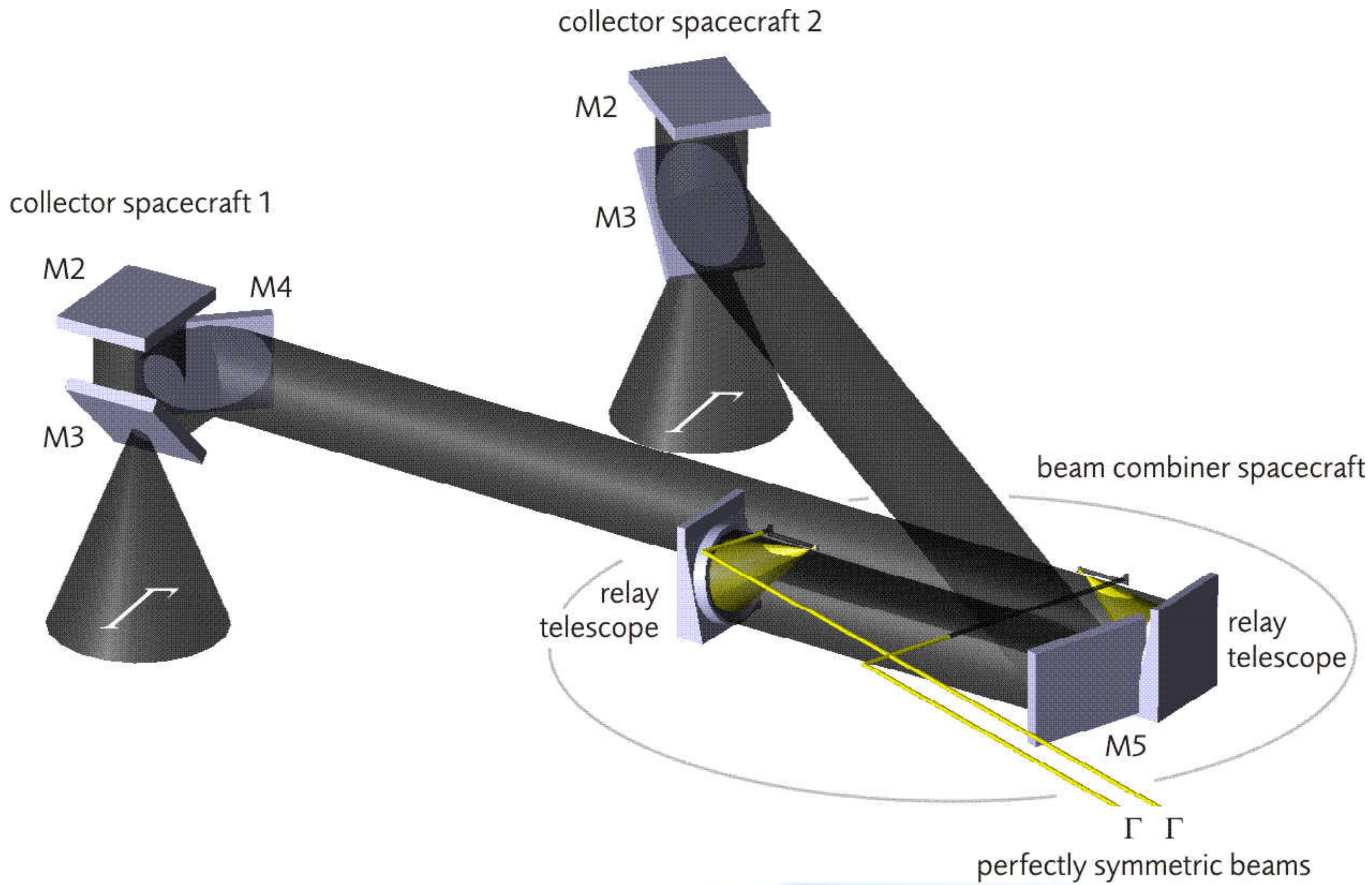
- Fixed geometry for beam relay and inter-spacecraft metrology
- Simplified acquisition procedure at small baseline
- On ground verification feasible



Planar Spacecraft Formations – Science Payload



Planar Spacecraft Formations – Symmetric Beam Routing



Planar Spacecraft Formations – Critical Issues

- Size of spacecraft stack not compatible with today launchers (Ariane 5, Delta IV Heavy)

Launcher constraints on science payload

- Receive telescopes with deployable secondary mirror assembly
- Deployment and alignment mechanism
- Once after launch (potentially recalibration)

Launcher constraints on spacecraft

- Deployable sunshields
- Complexity driven by the telescope size
- Heritage from JWST and GAIA

Non-Planar Spacecraft Formations – Formation Flying

- Spacecraft do not form a virtual truss

⇒ Beam combiner spacecraft has fixed orientation relative to Sun

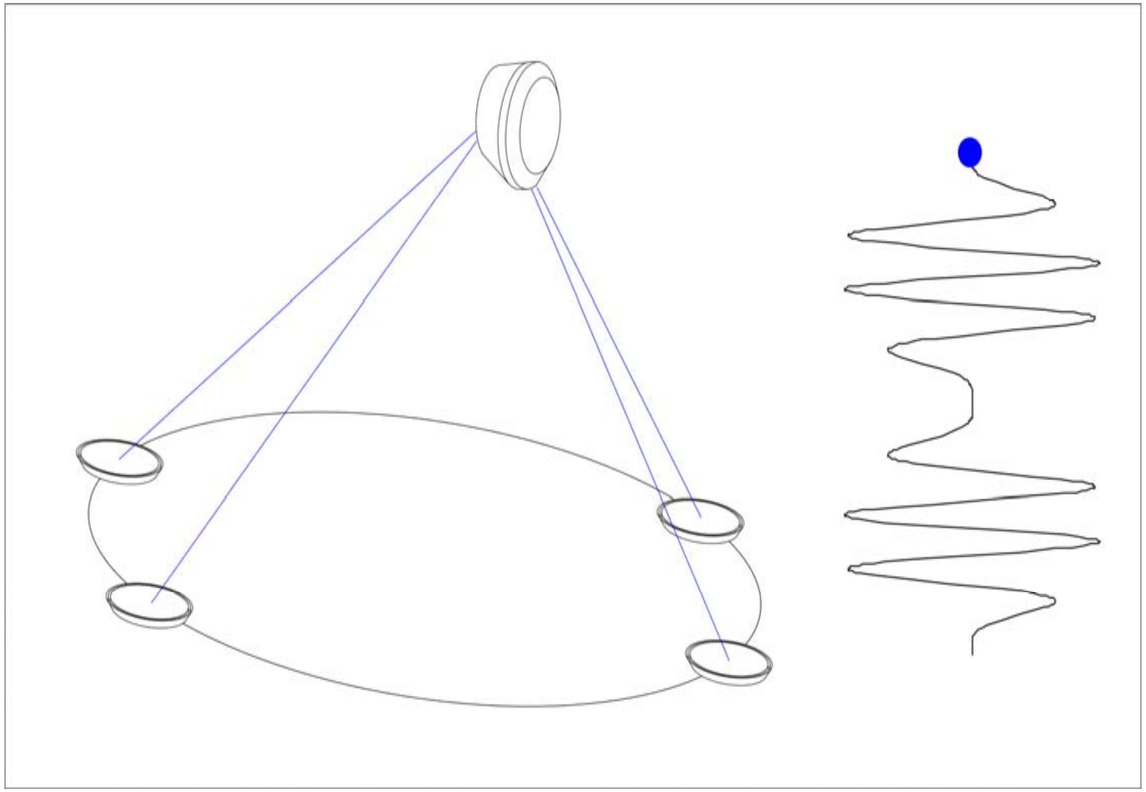
⇒ Collector spacecraft rotate around common line of sight

⇒ Collector spacecraft tumble

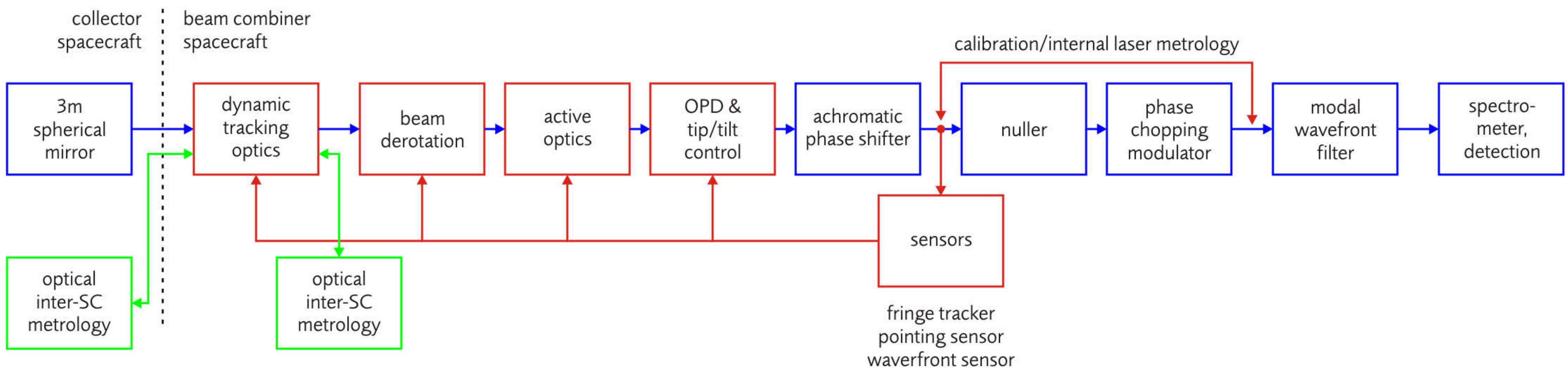
- Variable geometry for beam relay and inter-spacecraft metrology

⇒ Tracking for science and metrology beams

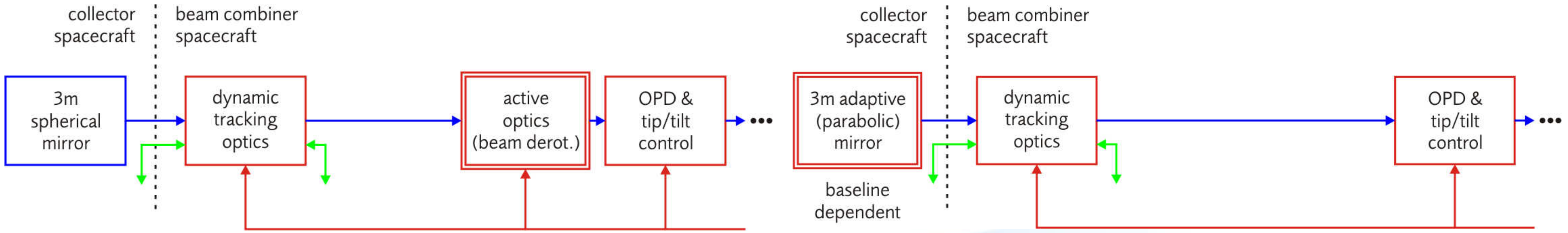
- Acquisition critical
- On ground verification not possible



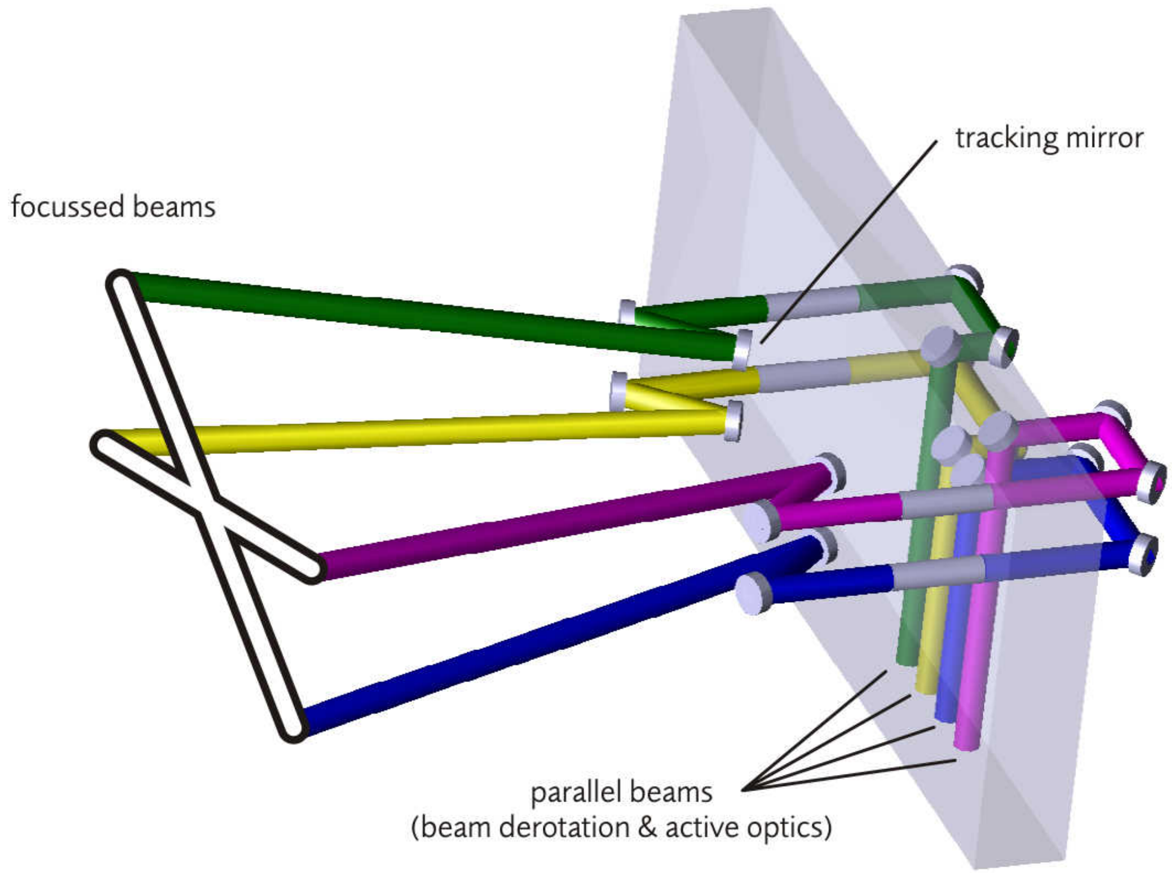
Non-Planar Spacecraft Formations – Science Payload

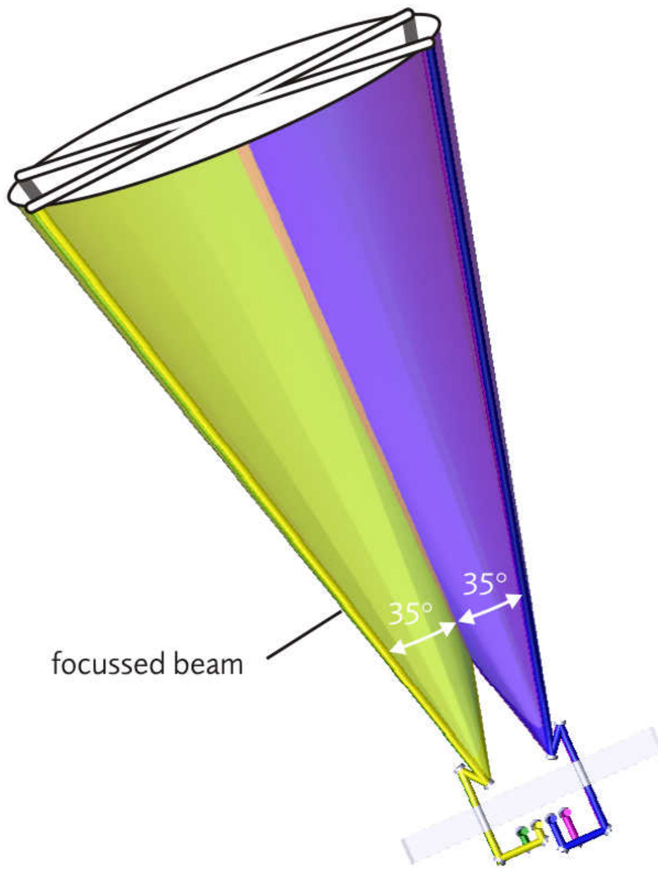


Alternatives:



Non-Planar Spacecraft Formations – Receive Optics





Non-Planar Spacecraft Formations – Critical Issues

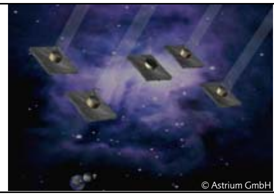
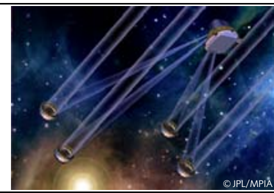
Formation flying mode

- Acquisition critical
- High performance star trackers ($\ll$ 1 arcsec stability)
- Synchronous tracking of laser metrology beams
- On ground verification not feasible

Science mode

- Rotation of collector spacecraft relative to the beam combiner spacecraft
- Synchronous tracking of science beams and metrology beams
- Active science beam actuators (tracking, derotation, wavefront correction)
- Perturbations at rotation frequency due to residual control errors

Spacecraft Formations – Key Issues and Design Drivers

	Planar spacecraft formations 	Non-planar spacecraft formations 
Beam symmetry	• perfectly polarisation symmetric	• inherently polarisation asymmetric
Science beam actuators	• OPD, fine pointing	• OPD, fine-pointing • synchronous beam tracking • synchronous active wavefront correction
Receive optics	• secondary mirror deployment • ground testing possible	• mirrors with ≈ 2 km curvature radius • no ground testing possible
Formation flying	• virtually rigid instrument • on-ground verification possible	• metrology acquisition critical • synchronous metrology beam tracking • on-ground verification not possible
Imaging mode	• dual feed imaging for faint objects possible	• only for bright objects
Spacecraft design	• deployable sunshields required • equal solar pressure on all spacecraft	• fixed sunshields • different solar presser on spacecraft

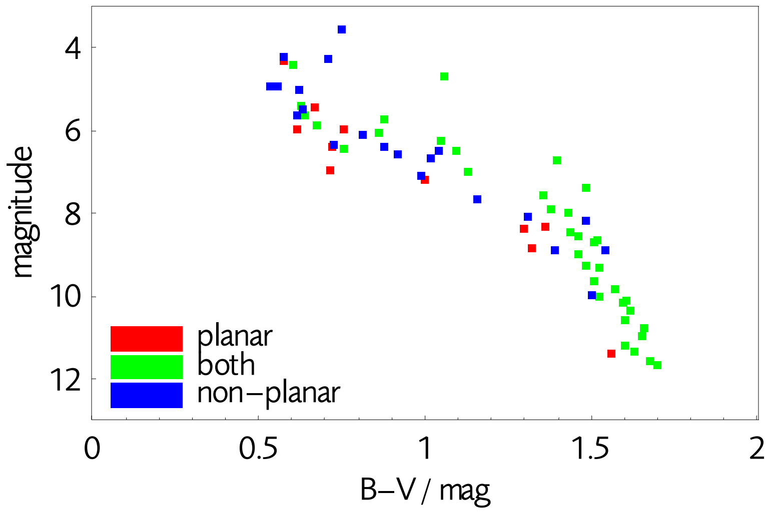
Conclusions – Aperture Configuration

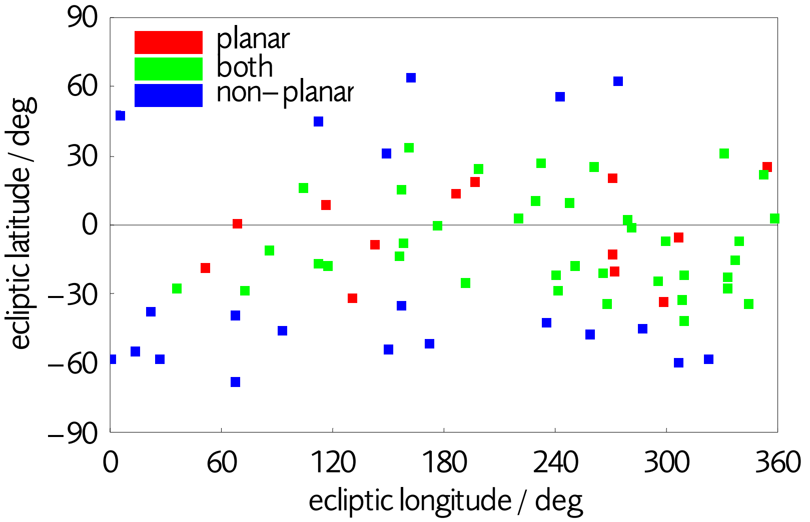
x-Array represents a highly optimum aperture configuration

- Decoupling of nulling and imaging properties
- Perfectly symmetric and extremely efficient implementation by cascaded two-telescope nullers

⇒ Instrumental and observational advantages

⇒ Outstanding scientific performance





Conclusions – Spacecraft Formation

Planar formations

- Allow for an optimum scientific instrument at the cost of a complex spacecraft
- Suffer from the reliability of the deployment mechanisms

Non-planar formations

- Simplify the spacecraft but require beam tracking and active wavefront correction synchronous to array rotation
- Suffer from accuracy and reliability of science beam actuators
- Suffer from synchronous instrumental errors

Conclusions

Development of key technologies and subsystems required

- Deployable sunshield and secondary mirror assembly for planar formations
- Receive mirror and synchronous tracking and wavefront correction optics for non-planar formations

Status of analysis

- Formation flying, opto-dynamics, science performance
- Different level for planar and non-planar formation