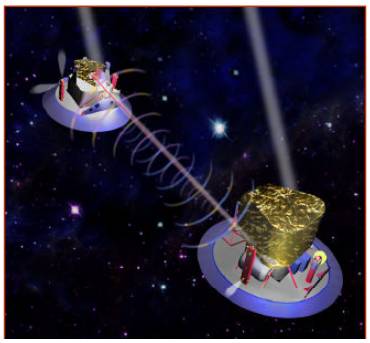
An Overview of the StarLight Mission



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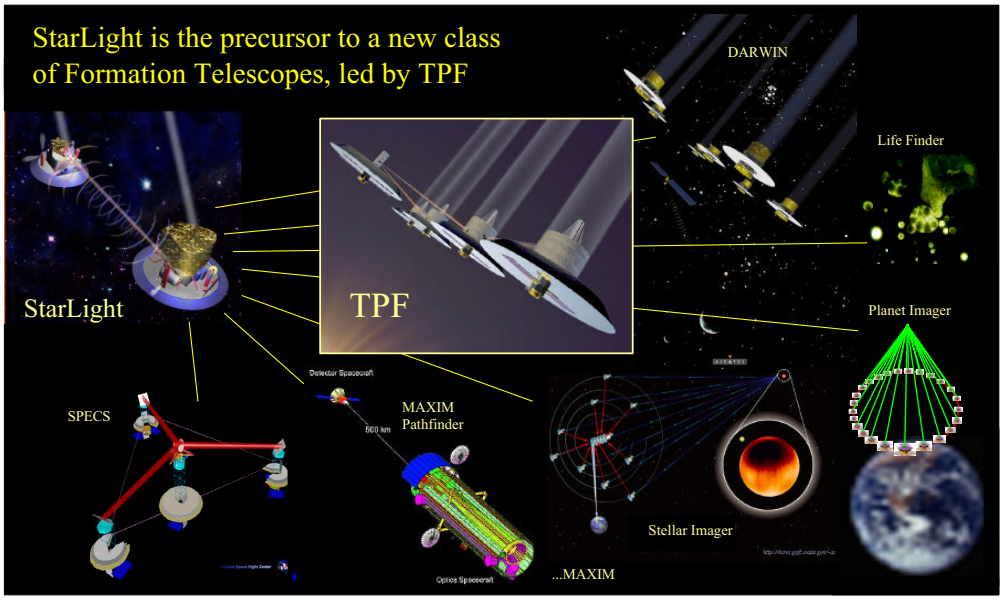
StarLight and Formation Telescopes



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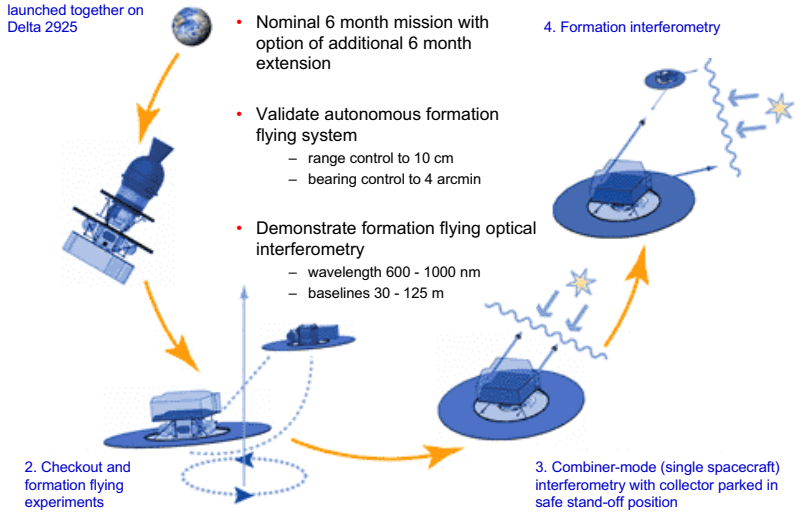
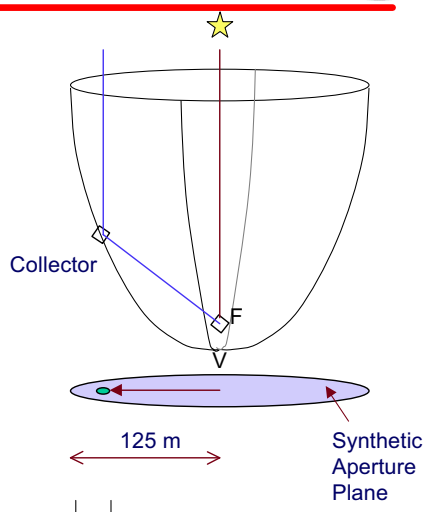
StarLight mission summary

- June 2006 launch to heliocentric orbit
- Nominal 6 month mission with option of additional 6 month extension
- Validate autonomous formation flying system
  - range control to 10 cm
  - bearing control to 4 arcmin
- Demonstrate formation flying optical interferometry
  - wavelength 600 - 1000 nm
  - baselines 30 - 125 m

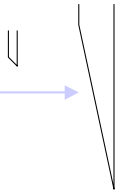


2 spacecraft parabolic geometry

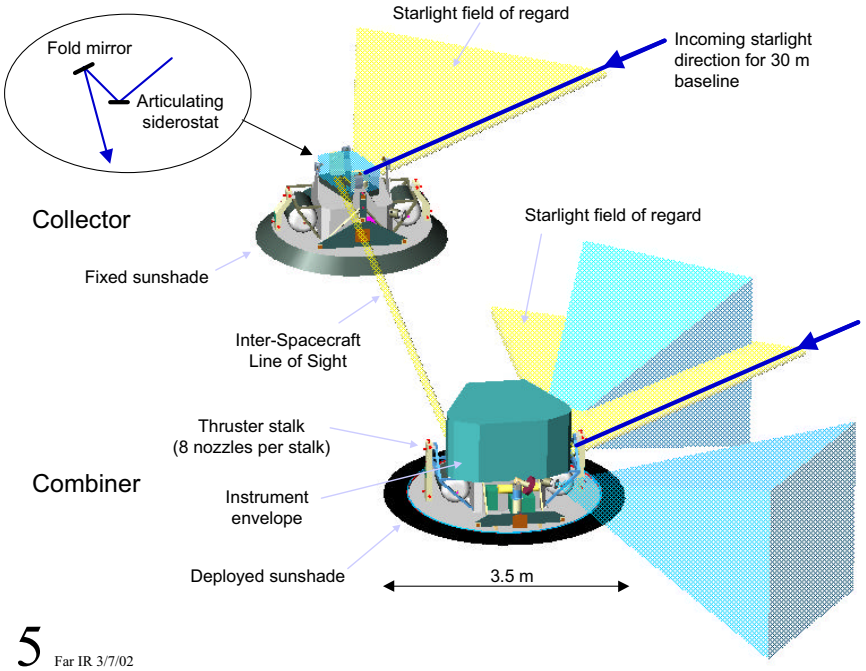
- Original 3 spacecraft design did not fit the budget
- 2 spacecraft concept demonstrates all key areas of formation flying interferometry
- Collector flown on the surface of a virtual paraboloid, with combiner at the focus
- Gives a baseline of 125 m with a fixed delay of only 14 m



Baseline	Separation	Bearing angle
30 m	40 m	46 deg
125 m	600 m	12 deg



Observing configuration



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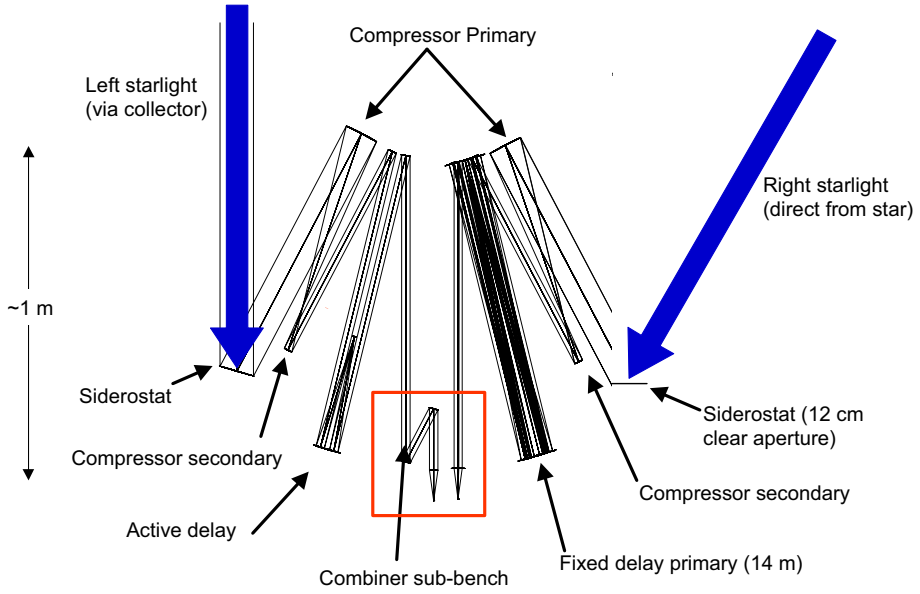
Combiner instrument optics (unfolded)



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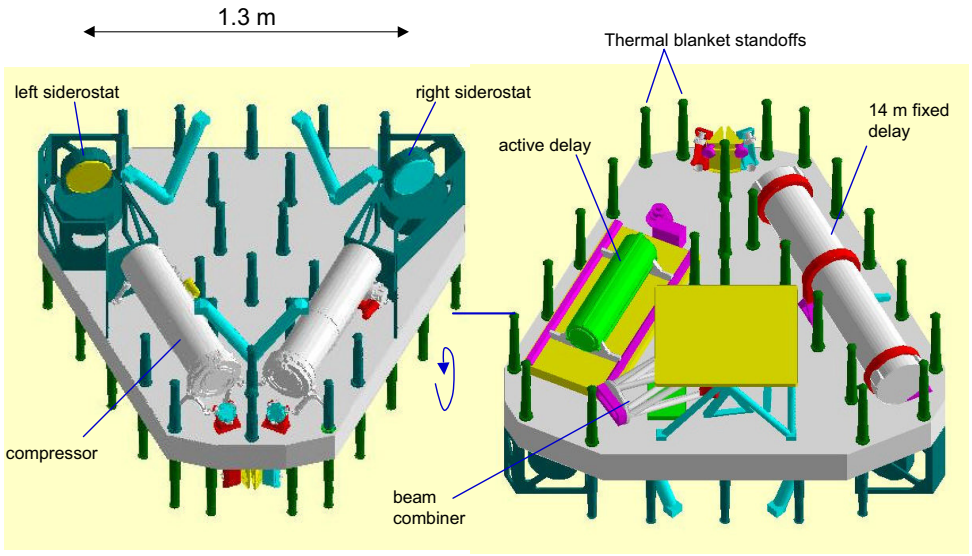
Combiner instrument layout



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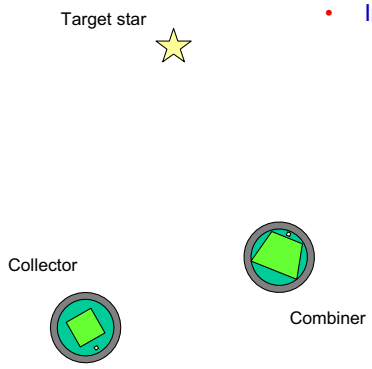
Acquisition and Observation Sequence

1. Move spacecraft
2. Acquire right starlight
3. Acquire metrology
4. Acquire left starlight
5. Estimate delay & delay rate; trim formation
6. Find fringe
7. Track & Measure fringe



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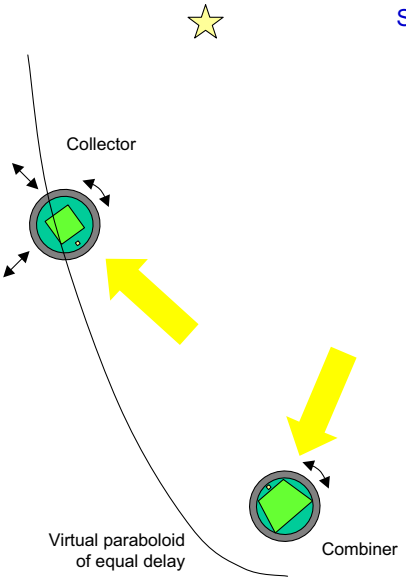
Move spacecraft

1. **Move spacecraft**
2. Acquire right starlight
3. Acquire metrology
4. Acquire left starlight
5. Estimate delay & delay rate; trim formation
6. Find fringe
7. Track & Measure fringe



- Formation & Attitude Control System (FACS)
  - Fusion of sensors inputs:
    - startrackers (~ 5 arcsec)
    - gyros
    - AFF sensor
    - (laser metrology)
  - Actuators
    - Reaction wheels (not used for interferometry)
    - Cold gas thrusters
      - 16 per spacecraft
      - 7 mN thrust
      - 74 μN-s minimum impulse
  - Master/Slave architecture
  - Functions:
    - collision avoidance
    - sun avoidance
    - fuel balancing
    - minimize thruster plume impingement
  - Performance:
    - +/- 10 cm range
    - +/- 4 arcmin bearing
    - +/- 3 arcmin spacecraft attitude

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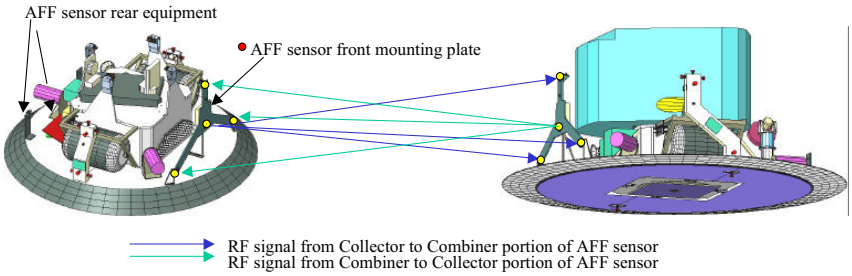
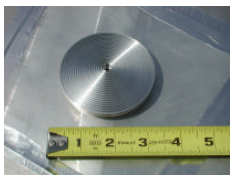
Autonomous Formation Flying sensor

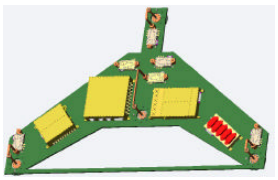


- Ka band system (30 GHz)
- 2 Tx and 4 Rx per spacecraft
- Ranging codes based on NAVSTAR GPS
- Relative bearing from carrier phase difference
- Symmetric between spacecraft
- 2 cm range, 1 arcmin bearing (1 σ)

Prototype Ka-band Antenna with choke rings



Electronics mounted on back of mounting plate



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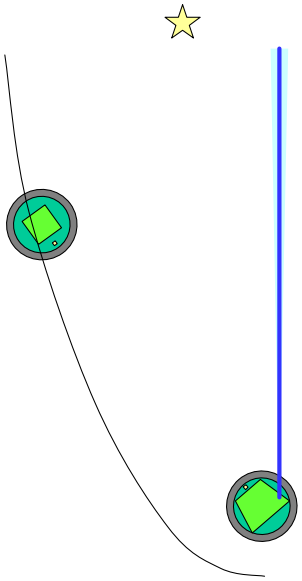
Acquire right starlight

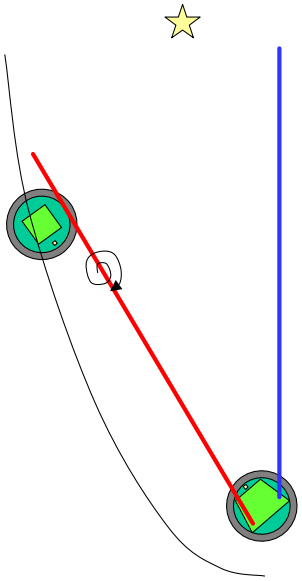
1. Move spacecraft
2. **Acquire right starlight**
3. Acquire metrology
4. Acquire left starlight
5. Estimate delay & delay rate; trim formation
6. Find fringe
7. Track & Measure fringe



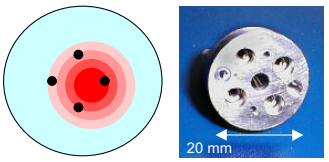
- Instrument has single CCD for acquisition, angle tracking and fringes
- Acquisition field of view = 1 arcminute
- Once acquired, control loop tracks out changes of combiner inertial attitude

Acquire metrology

1. Move spacecraft
2. Acquire right starlight
3. **Acquire metrology**
4. Acquire left starlight
5. Estimate delay & delay rate; trim formation
6. Find fringe
7. Track & Measure fringe



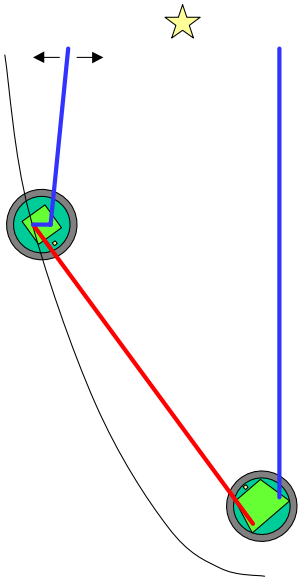
- Outgoing 1.3 μm metrology beam is coincident with left combiner boresight
- Collector fold mirror houses 4-diode Metrology Pointing Sensor
- AFF sensor gives combiner - collector bearing angle
- Left combiner siderostat performs spiral search to acquire laser signal
- With metrology pointing loop locked, system can resolve 10 μm/s transverse motion @ 600 m
- Dual target linear metrology monitors external and internal paths simultaneously with one beam to 10 nm



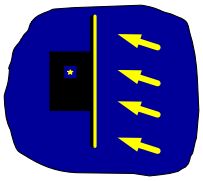
Metrology Pointing Sensor

Acquire left starlight

1. Move spacecraft
2. Acquire right starlight
3. Acquire metrology
4. **Acquire left starlight**
5. Estimate delay & delay rate; trim formation
6. Find fringe
7. Track & Measure fringe



- Left starlight boresight is locked to center of collector optics
- Collector siderostat executes a small search until star appears in combiner focal plane
- Left angle tracking control and metrology pointing loop form a coupled control system, distributed across both spacecraft
- Stray light from collector sunshade is an issue:



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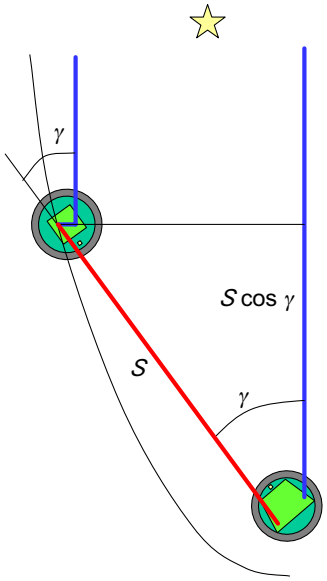
Estimate delay & delay rate

1. Move spacecraft
2. Acquire right starlight
3. Acquire metrology
4. Acquire left starlight
5. **Estimate delay & delay rate; trim formation**
6. Find fringe
7. Track & Measure fringe



Delay offset = Left path – Right path

$$\approx S - \left(S\cos\gamma + D_{fixed}\right)$$

$$\approx S\left(1-\cos\gamma\right) - D_{fixed}$$

Delay (10 mm)

- S → AFF sensor (20 mm)
- γ → Angular metrology (10")

Delay rate (20 μm s^{-1})

- S → Linear metrology (25 μm s^{-1})
- γ → Angular metrology (15 mas s^{-1})

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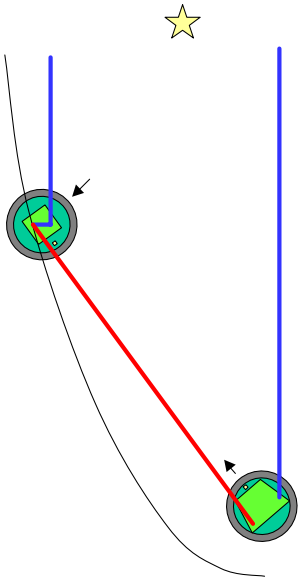
Trim formation

1. Move spacecraft
2. Acquire right starlight
3. Acquire metrology
4. Acquire left starlight
5. **Estimate delay & delay rate; trim formation**
6. Find fringe
7. Track & Measure fringe



- Need to get within the range and rate capabilities of the active delay line
- Instrument laser metrology provides precision range rate and bearing data to FACS
- Small thrusts to trim the delay and delay rate
- Iterative process until requirements met
- When complete we have a stabilized optical structure:
  - Tip/tilt stabilization:
    - 3 pointing loops locked (left & right stellar angle tracking, metrology beam to collector)
  - Path stabilization:
    - active delay line tracks out jitter sensed by dual target linear metrology

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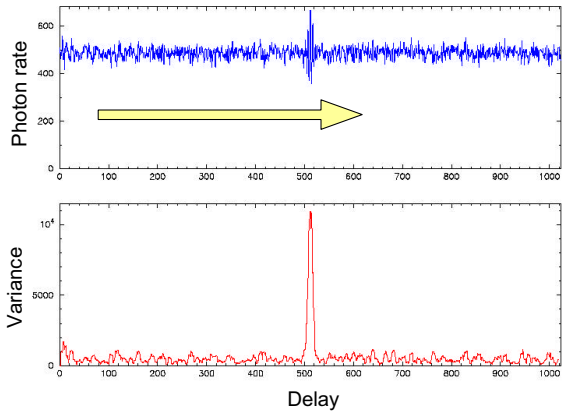
Find fringe

1. Move spacecraft
2. Acquire right starlight
3. Acquire metrology
4. Acquire left starlight
5. Estimate delay & delay rate; trim formation
6. **Find fringe**
7. Track & Measure fringe



- Delay uncert ~ 10 mm (1 σ)
- Delay rate uncert ~ 20 μm s^{-1} (1σ)
- Search 50 mm in delay at 100 μm s^{-1}
- Scan the delay line across the search range
- Fringes give increased variance in detected photon rate

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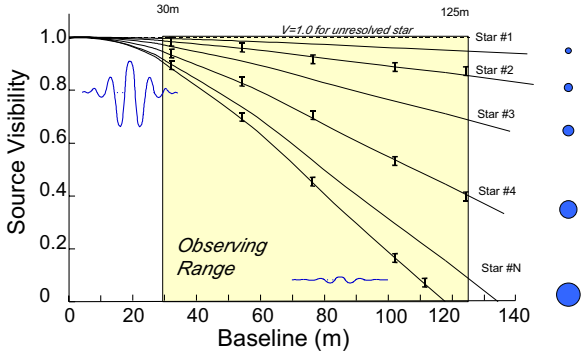
Track & measure fringe

1. Move spacecraft
2. Acquire right starlight
3. Acquire metrology
4. Acquire left starlight
5. Estimate delay & delay rate; trim formation
6. Find fringe
7. **Track & Measure fringe**

- StarLight measures visibility amplitude at each of 5 baselines (30 - 125 m)
- White light and 4-channel dispersed fringe outputs, sampled at 500 Hz
- Inherit algorithms from Keck Interferometer
- The interferometer performance will be characterized by observations of ~ 20 known stars of different size and brightness, down to about 5th magnitude



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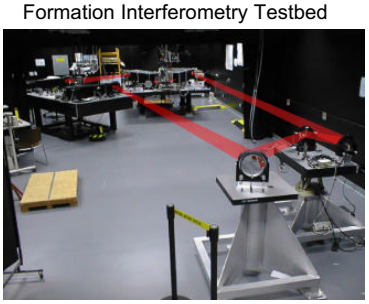
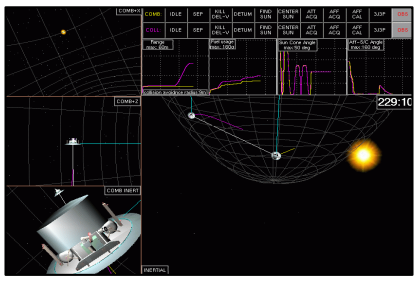
Technology development

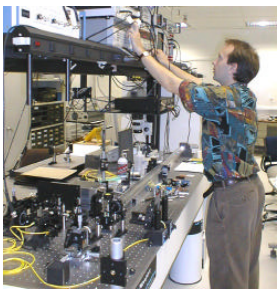
Formation Interferometry Testbed



Formation Flying Simulations



Autonomous Formation Flying Sensor tests



Linear and angular metrology

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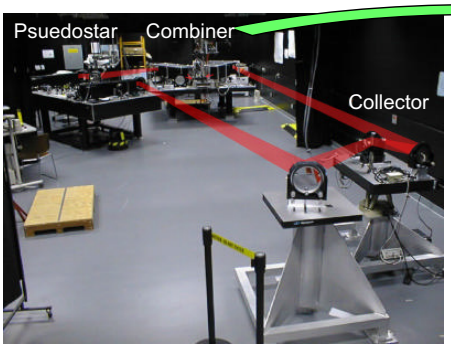
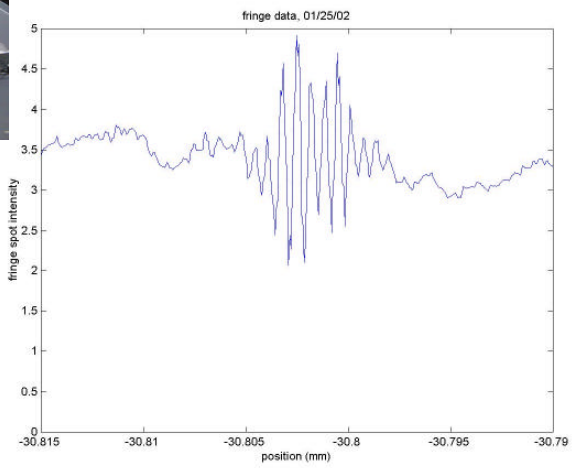
Formation Interferometer Testbed



Located at JPL



- **Recently achieved white light fringe tracking**
  - **Instrument visibility ~40% (matches the predicted value)**
  - **All control loops operating simultaneously**
  - **Performancelimited by:**
    - **20m airpatheach arm**
    - **50 Hz camera**

Key performance metrics

Performance metric	*StarLight*	*TPF Planet-finding*	*TPF Astrophysics*	*StarLight Technology*	*TPF need*
1 Wavelength band (fringes)	600 - 1000 nm	7 - 20 μm	3 - 30 μm		
2 Baselines	30 - 125 m *	75 - 200 m	75 - 1000 m	2-spacecraft parabolic geometry	angular resolution for astrophysics
3 Separation	40 - 600 m *	25 - 70 m	25 - 330 m		
4 Range control (+/-)	10 cm *	5 cm	5 cm	AFF sensor, angular metrology, formation-flying algorithms, low impulse thrusters	sizes delay lines
5 Bearing control (+/-)	4 arcmin *	1 arcmin	0.2 arcmin		
6 Range knowledge (1 σ)	2 cm	1 cm	1 cm	AFF sensor	formation control ; fringe search limiting magnitude; delay line range
7 Range rate knowledge (1 σ)	< 1 μm / s	35 μm / s	1 μm / s	Dual target linear metrology system	
8 Inertial Bearing knowledge (1 σ)	10 arcsec	10 arcsec	2 arcsec	Angular metrology system	
9 Bearing rate knowledge (1 σ)	30 milliarcsec / s	40 milliarcsec / s	0.2 milliarcsec / s	Angular metrology system	
10 Path length stabilization (1 σ)	35 nm	3.5 - 70 nm	70 nm	Dual target linear metrology system	nulling
11 Tip/tilt stabilization (1 σ)	0.1 λ/D	0.025 λ/D	0.05 λ/D	Angular metrology system, distributed control loops	nulling

* nominal performance; limits to be pushed on orbit


The universe
through FIR-
submm "glasses":
A FIR-submm
number count
model