SIM astrometric demonstration at the 150 picometer level using the MAM testbed.

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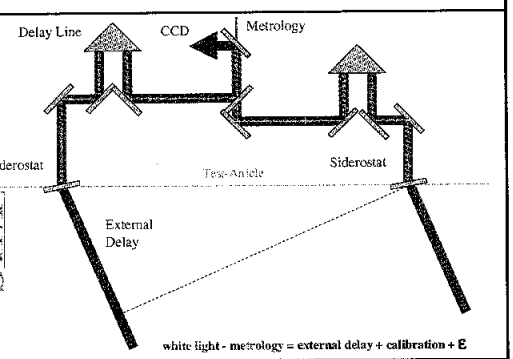
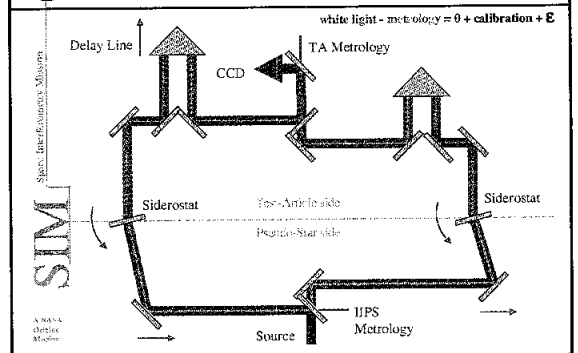
Outline

- MAM Simplified Layout.
- Chopping Scenario.
- Data Analysis Tools.
- Static test (Field Independent).
- 3 Star test (Field Dependent).
- Lessons learned
- Conclusion.

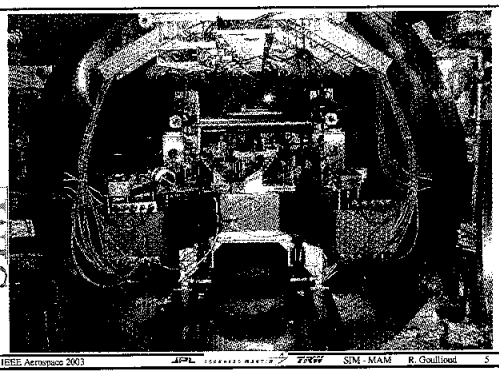
SIM Simplified Layout



MAM Simplified Layout: IIPS Slew

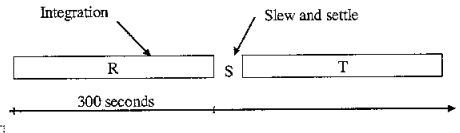


The MAM experiment in the vacuum chamber.

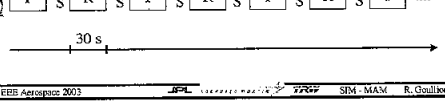


Chopping Scenario

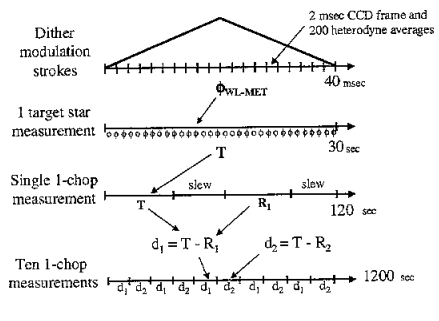
- Instead of staring at the Target star for 300 seconds.



- We stare 30 seconds at a time and chop back and forward between the Target and Reference stars 10 times.

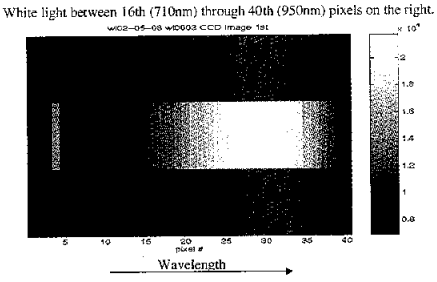


Time scales



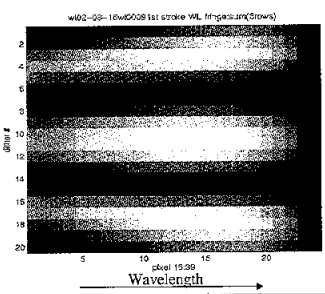
Dispersed fringe image on the CCD camera

- 500 Hz CCD frame rate.
- HeNe fringe on the left centered on 4th pixel
- White light between 16th (710nm) through 40th (950nm) pixels on the right.

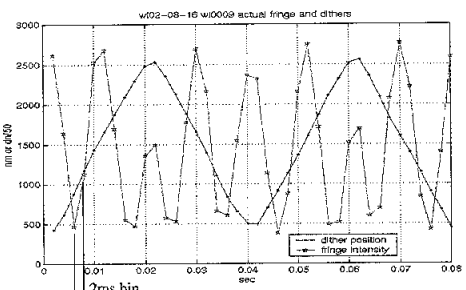


White light fringes

- We displayed only one full dither stroke (20 images), as a function of the spectral channel along the horizontal axis



Actual fringe and dither positions observed in MAM testbed.



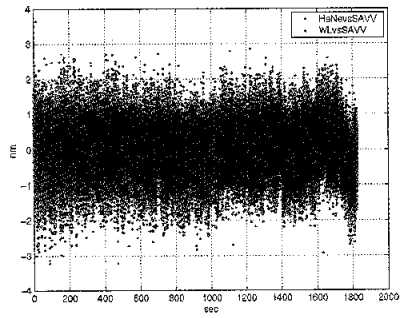
The interference intensity model we used in our algorithms

- For a given dither stroke:

$$I_{il}^{data} = I_l\{1 + V_l \cos(k_l x_i + C_l)\},$$

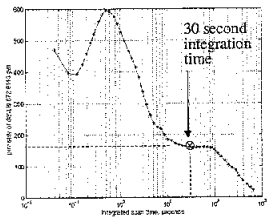
- i is the index for dither positions (bin) within the stroke.
- l is the index for spectral pixels, for white light, l=16,...39, which is the spectral pixel index on CCD.
- I_{il}^{data} is the CCD intensity measured at each spectral channel l for each dither postion (bin) i.
- x_i is the dither position for each bin measured by the metrology.
- I_l, V_l and k_l are fitted intensity, visibility and wave number, respectively, all assumed to be constant over a given dither stroke, i.e. over all dither positions x_i at given wavelength l.
- C_l is the value of interest: the fitted phase (or delay * wave number) between the interference fringe from the spectral channel l and the dither cycle wave. It is assumed to be constant over a given dither stroke.

Example of optical path difference between starlight and metrology



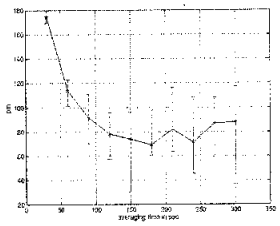
RT Allan deviation of the optical path difference between white light and SAVV

- RT Allan deviation: $\sigma_{OPD}^{RT}(\tau) = \mathrm{std}(\ \Delta OPD_n(\tau)\ )$ for the integration time τ.
- $\Delta OPD_n(\tau) = \{OPD_{n+1}(\tau) - OPD_n(\tau)\}$ is the nth RT chop.
- $OPD_n(\tau) = \mathrm{mean}(C_{ji} / k_i)$ for dither cycles j for the interval of time τ (Reference).
- $OPD_{n+1}(\tau) = \mathrm{mean}(C_{ji} / k_i)$ for dither cycles j within the next interval of time τ (Target).
- Maximum overlapping.



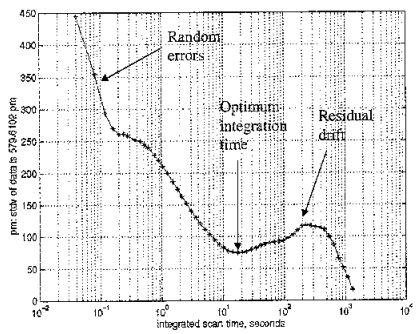
Chop deviation of optical path difference between white light and SAVV

- $\sigma_{OPD}^{chop}(m) = \mathrm{std}(\ \mathrm{mean}_m(\ \Delta OPD_n\ )\ )$
- $\mathrm{mean}_m(\ \Delta OPD_n\ )$ is the mean value of m chop values ΔOPD_n.
- $\Delta OPD_n = \{\ OPD_{n+1}(30s) - OPD_n(30s)\ \}$.
- No overlapping between the averaged chops.

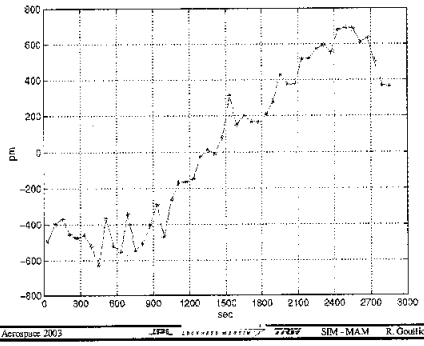


Lab Results

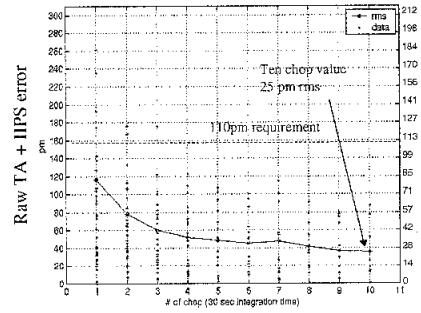
RT Allan variance after the precision alignment, September 20, 2002.



Pathlength error between starlight and metrology averaged down to 30 second single numbers (chop observation time).



Error between white light and metrology paths as a function of the number of 30 second chops averaged together for the field independent test



Three-star field dependent test sequence

T s R1 s T s R2 s T s R1 s T ....

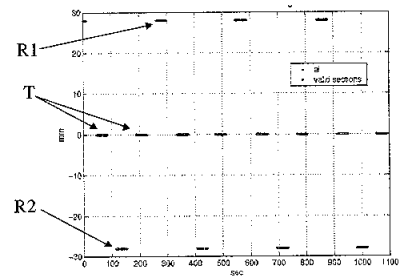
30 s

R1 T R2

-0.5degree 0 +0.5degree Field position

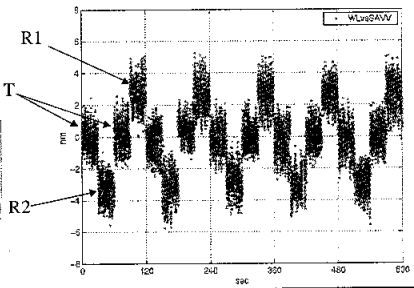
Delay line position as measured by the metrology during the 3 star field dependent test.

- The valid part of the data after each slew is highlighted in red.
- One can see the two reference stars on each side of the target one.



White light versus metrology OPD for the three star field dependent test after removal of the slew.

- The first star of the sequence is the target star.
- The two reference stars are located on each side of the target one.



"TRT" chopping

ε_1 ε_2

$\overline{D}_{T1}$ $\overline{D}_{T2}$ $\overline{D}_{T1}$ + ...

up down up down up down

$\overline{T}$ $\overline{R}_1$ $\overline{T}'$ $\overline{R}_2$ $\overline{T}''$ $\overline{R}_1$ $\overline{T}'''$

30s 30s 30s 30s 30s 30s 30s

Chopping Equations

- Single "TRT" chop:

$$\overline{D}_{T1} = \langle (\overline{R}_1 - \overline{T}), (\overline{R}_1 - \overline{T}') \rangle = \overline{R}_1 - \langle \overline{T}, \overline{T}' \rangle$$

$$\overline{D}_{T2} = \langle (\overline{R}_2 - \overline{T}), (\overline{R}_2 - \overline{T}') \rangle = \overline{R}_2 - \langle \overline{T}, \overline{T}' \rangle$$

- Multiple star chop:

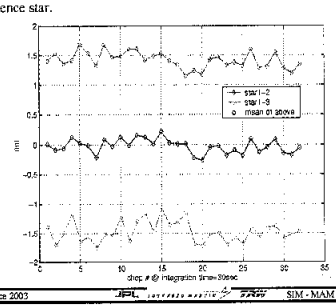
$$\varepsilon = \langle \overline{D}_{T1}, \overline{D}_{T2} \rangle$$

$$\varepsilon = \langle (\overline{R}_1 - \langle \overline{T}, \overline{T}' \rangle), (\overline{R}_2 - \langle \overline{T}', \overline{T}'' \rangle) \rangle$$

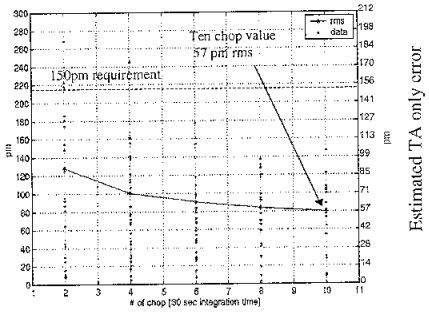
$$\varepsilon = \langle \overline{R}_1, \overline{R}_2 \rangle - \langle \overline{T}, \overline{T}', \overline{T}', \overline{T}'' \rangle$$

Relative position of the three stars in term of error between starlight and metrology for the field dependent test.

- One can see the 1.5 nm field dependent error between the target and each reference star.



Error between white light and metrology paths as a function of the number of chops averaged together for the field dependent test.



Future Tests

- Repeat NA for other star spacing.
- Repeat NA for the other axis.
- Increase the slew speed of the pseudo-star for WA.
- Built new siderostats with no backlash.
- Demonstrate WA basic performance (30 µas).
- Demonstrate field independent performance at the goal.
- Demonstrate WA calibration (10 µas).
- Drive NA performance to the goal (10 µas).
- Drive WA performance to the goal (4 µas).