Principles of AMBER Data Reduction

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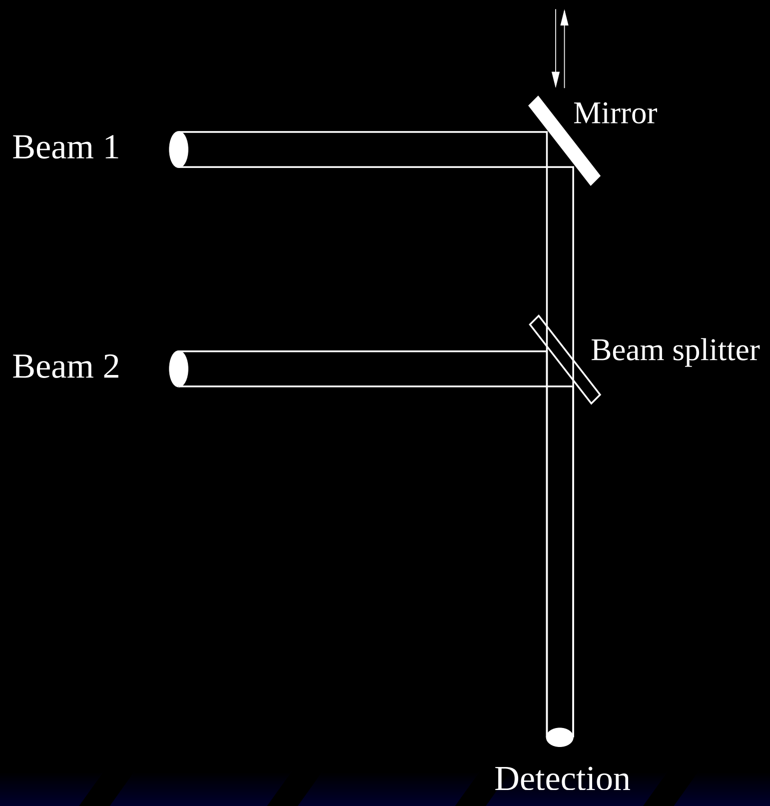
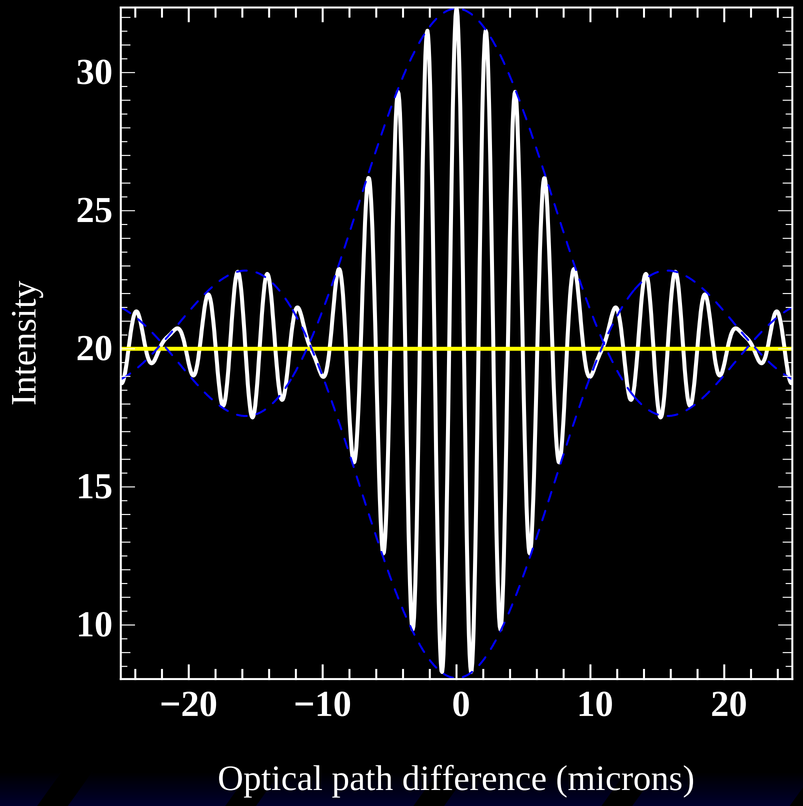
Basics in interferometry

- The generic interferometric equation (2 telescopes)

$$I(z) = I_1(z) + I_2(z) + 2\sqrt{I_1(z)I_2(z)}q(z)V_{12}cos(\Phi(z) + \Phi_{12} + \phi^p_{12})$$

$\hookrightarrow$ Temporal coding ($z \equiv t$, $\Phi(z) = 2\pi\nu_{12}t$)



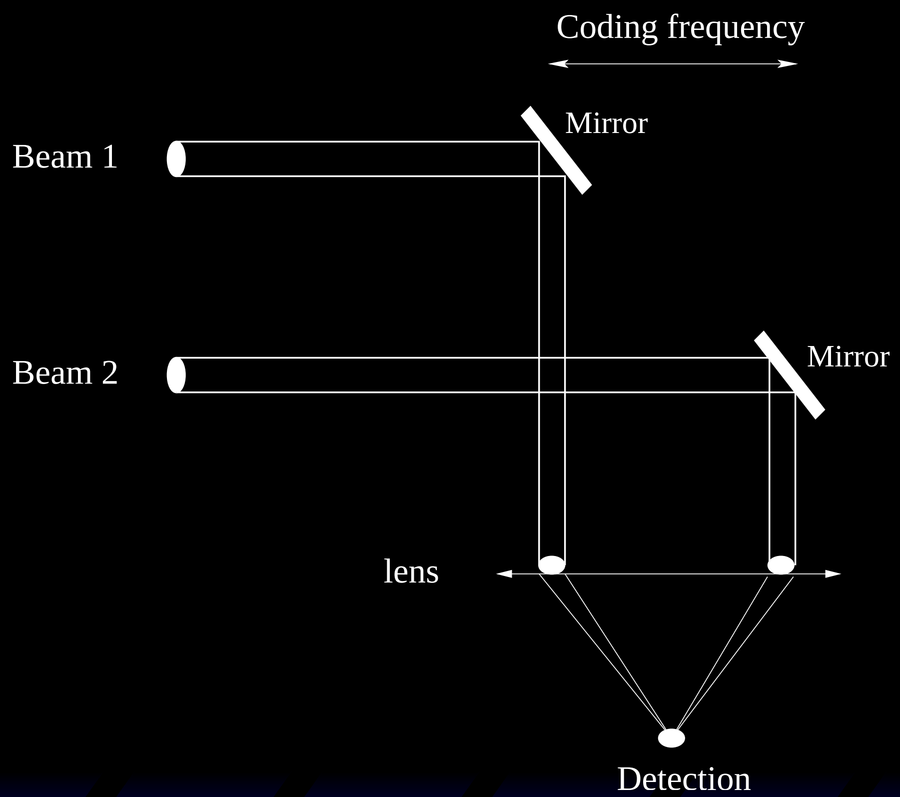


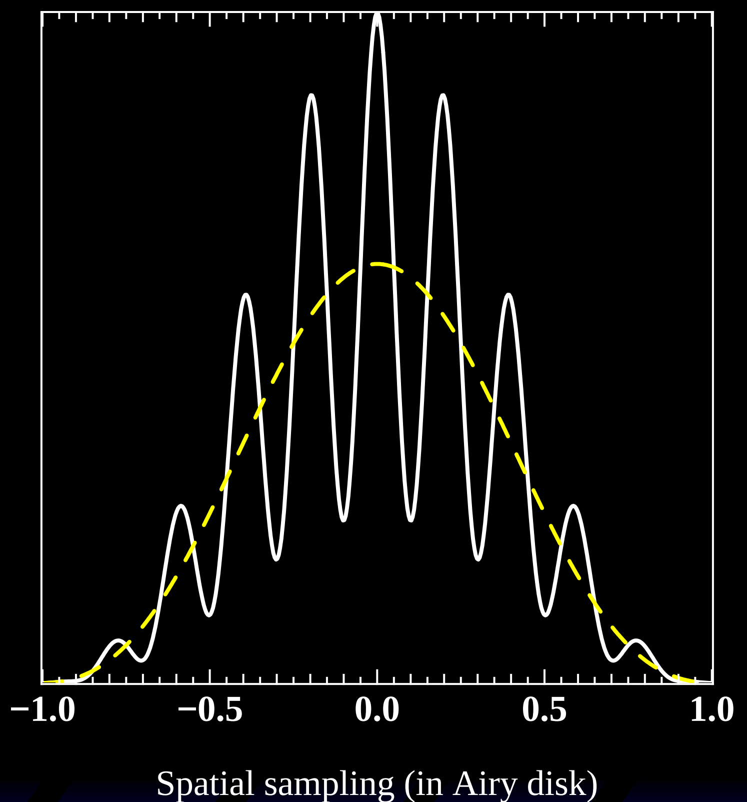
Basics in interferometry

- The generic interferometric equation (2 telescopes)

$$I(z) = I_1(z)+I_2(z)+2\sqrt{I_1(z)I_2(z)}q(z)V_{12}cos(\Phi(z)+\Phi_{12}+\phi^p_{12})$$

$\hookrightarrow$ Multiaxial coding ($z \equiv \alpha$, $\Phi(z) = 2\pi\alpha f_{12}$)



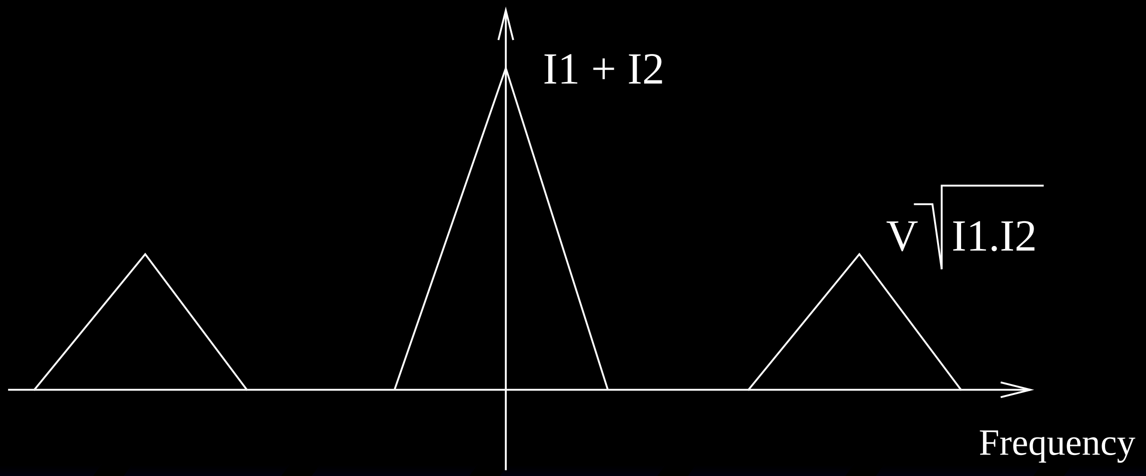


Basics in interferometry

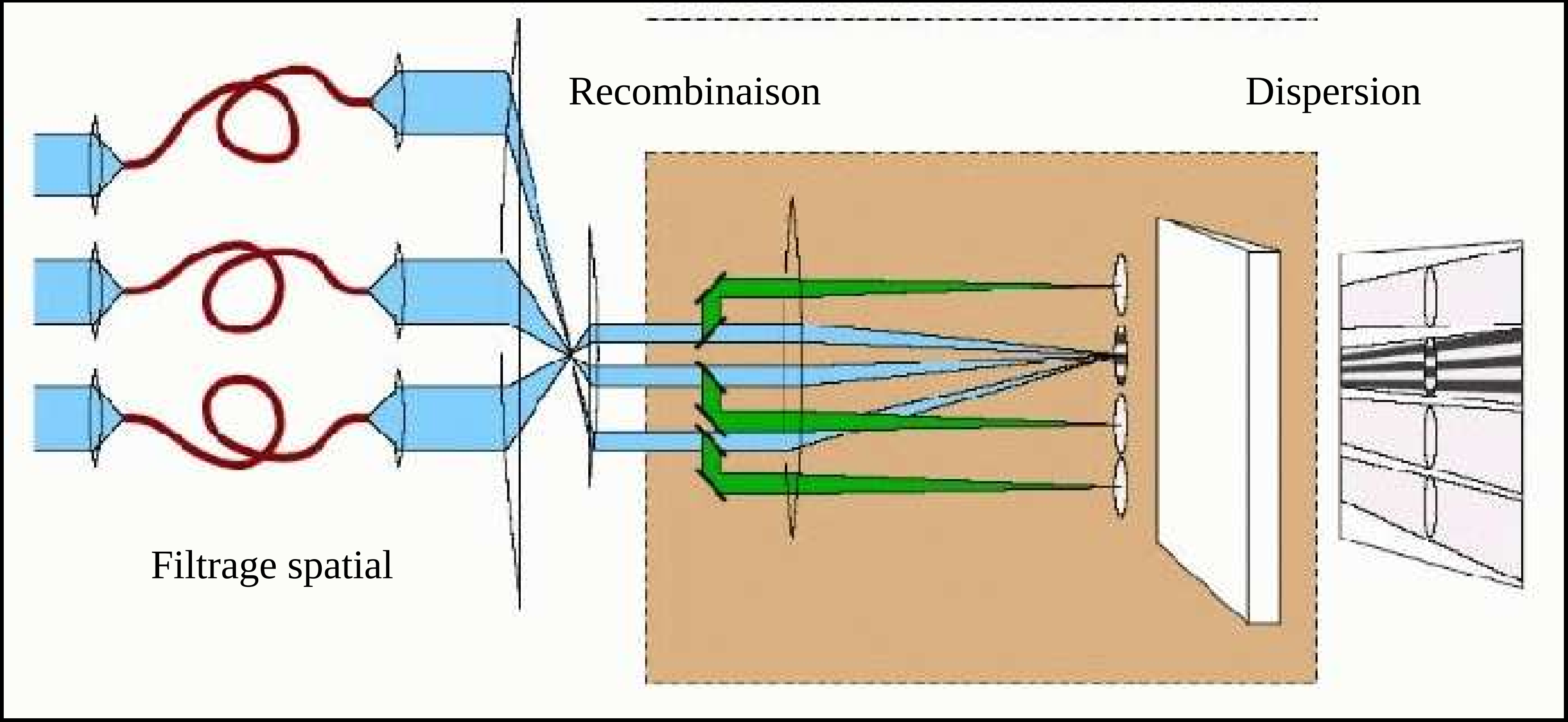
- The generic interferometric equation (2 telescopes)

$$I(z) = I_1(z)+I_2(z)+2\sqrt{I_1(z)I_2(z)}q(z)V_{12}cos(\Phi(z)+\Phi_{12}+\phi_{12}^p)$$

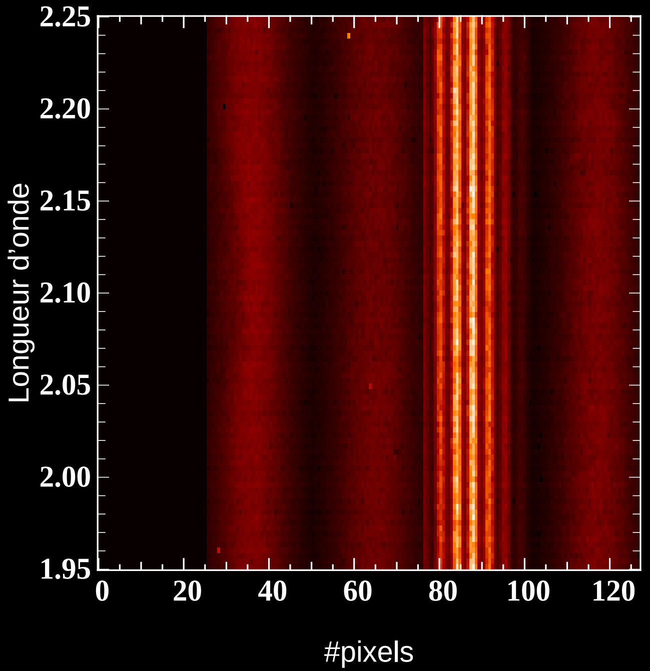
- Usual visibility estimations:
  - $\hookrightarrow$ Contrast computation: $\dfrac{I_{max}-I_{min}}{I_{max}+I_{min}}$
  - $\hookrightarrow$ Fourier transform:

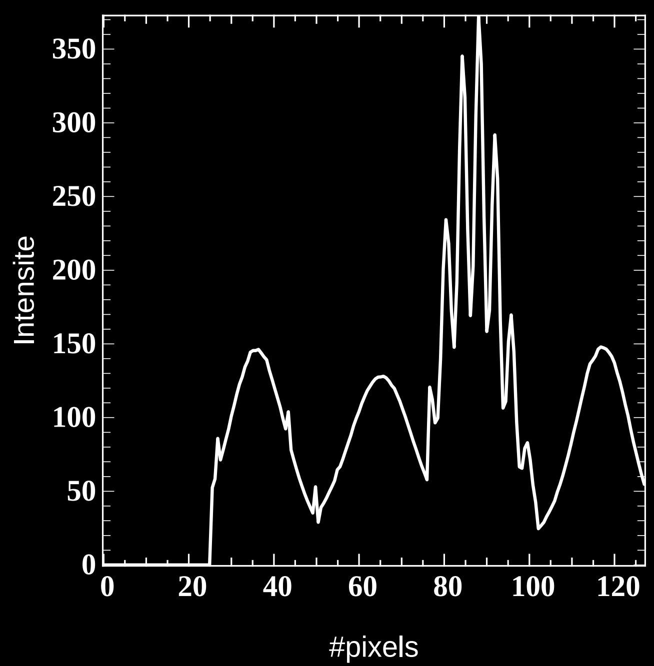


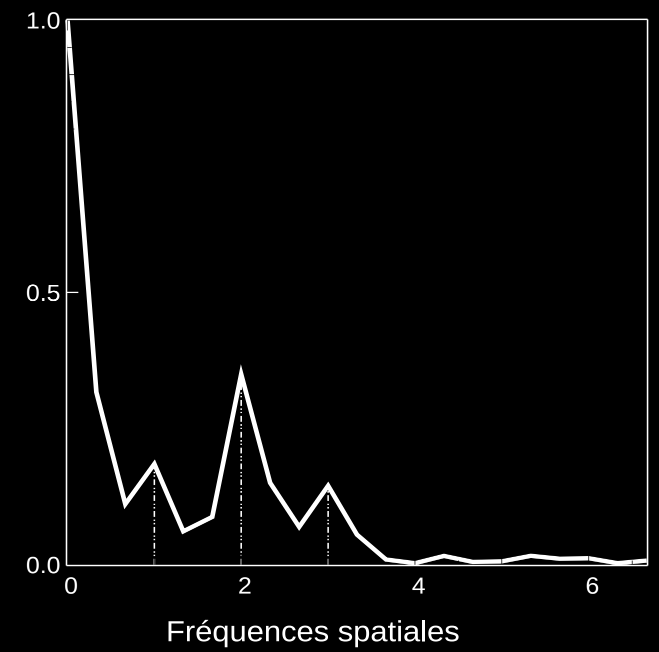
AMBER: principle



AMBER: the interferometric signal







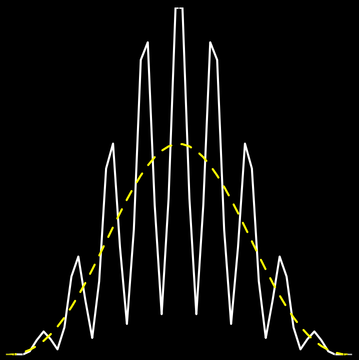
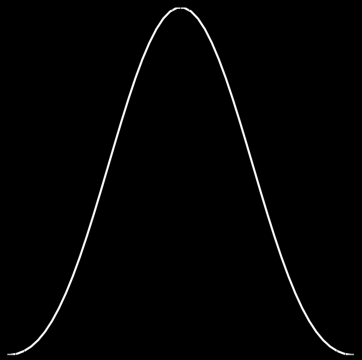
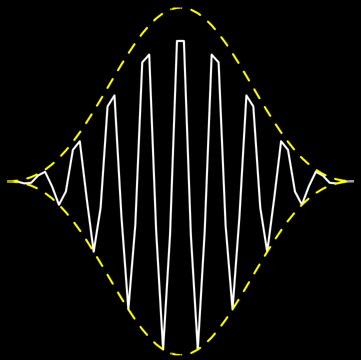
$$i_k = \sum_{i}^{N_{tel}} N t_i a_k^i + 2 \sum_{i<j}^{N_{tel}} N \sqrt{t_i t_j} \sqrt{a_k^i a_k^j} V_{ij} \cos(2\pi \alpha_k f_{ij} + \phi_{ak}^{ij} + \Phi_{ij} + \phi_{ij}^p)$$

t_i: transmission of telescope number i

a_k^i: Intensity profile at the output of the fiber number i

AMBER: the interferometric signal

Interferogram = Continuum + Fringes

$$N t_1 a_k^1 + N t_2 a_k^2$$

$$P_i v_k^i = N t_i a_k^i$$

$$\sqrt{a_k^1 a_k^2} V_{12} \cos(2\pi \alpha_k f_{12} + \phi_{ak}^{12} + \Phi_{12} + \phi_{12}^p)$$

$$c_k^{(1,2)} = \sqrt{\frac{a_k^1 a_k^2}{\sum_k a_k^1 a_k^2}} \cos(2\pi \alpha_k f_{12} + \phi_{ak}^{12})$$

$$d_k^{(1.2)} = \sqrt{\frac{a_k^1 a_k^2}{\sum_k a_k^1 a_k^2}} \sin(2\pi \alpha_k f_{12} + \phi_{ak}^{12})$$

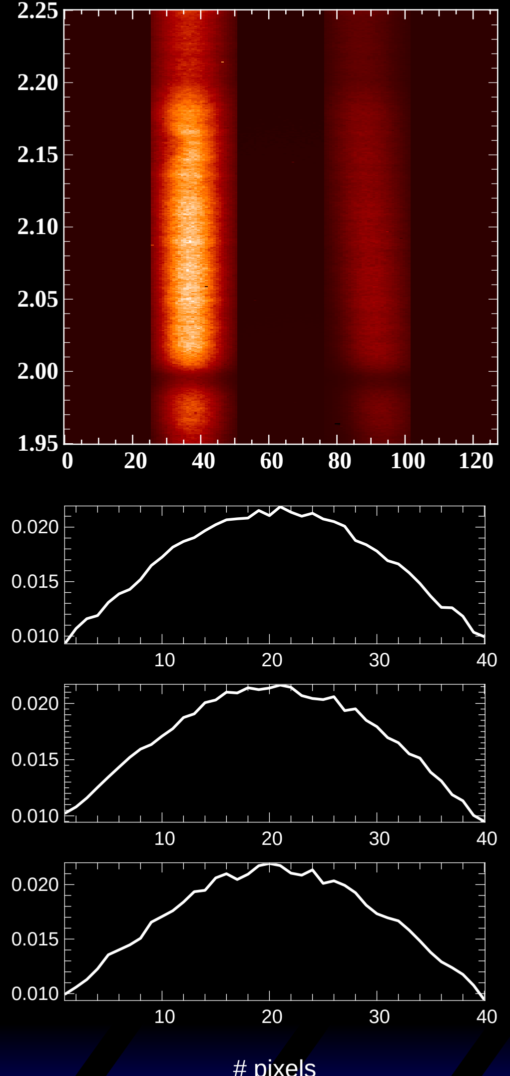
AMBER Data Reduction

- Optimized processing: Modelling of the signal in the detector plane
- 4 phases:

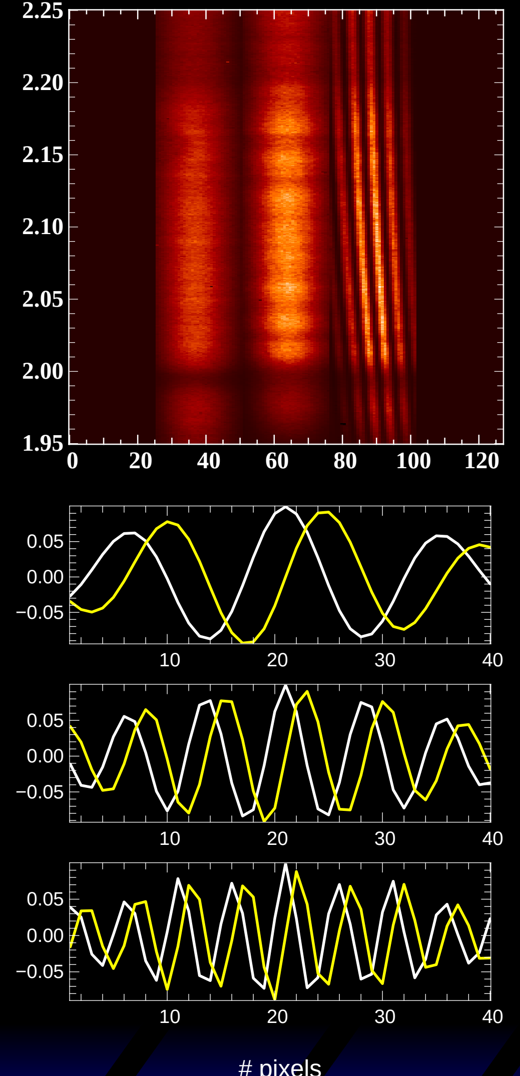
1. Cosmetic
2. Calibration of the instrument:
   - $\hookrightarrow$ flux ratio v_k^i
   - $\hookrightarrow$ carrying waves $c_k^{(i,j)}$, $d_k^{(i,j)}$
3. Observables estimation:
   - $\hookrightarrow$ Square visibility
   - $\hookrightarrow$ Closure phase
   - $\hookrightarrow$ Differential phase
4. Biases correction

Calibration of the instrument

Calibration of v_k^i



Calibration of $c_k^{(i,j)}$, $d_k^{(i,j)}$

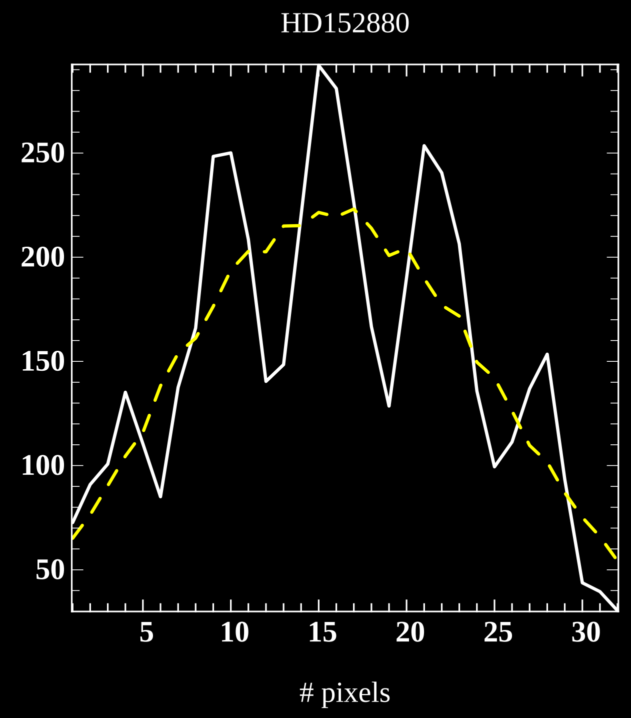


Continuum subs traction

$$i_k = \sum_{i}^{N_{tel}} N t_i a_k^i + 2 \sum_{i<j}^{N_{tel}} N \sqrt{t_i t_j} \sqrt{a_k^i a_k^j} V_{ij} \cos(2\pi \alpha_k f_{ij} + \phi_{ak}^{ij} + \Phi_{ij} + \phi_{ij}^p)$$

$$P_i v_k^i = N t_i a_k^i$$

$$m_k = i_k - \sum_{i=1}^{N_{tel}} P_i v_k^i$$



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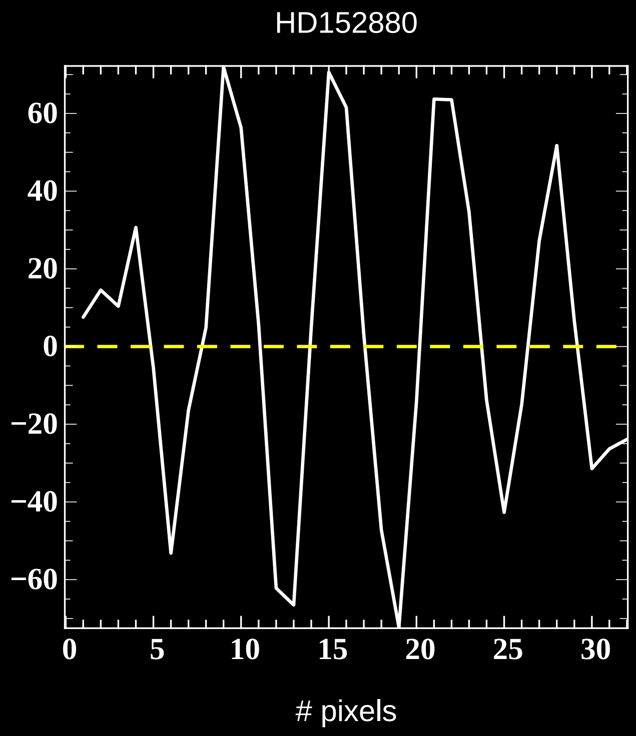

Estimation of the coherent flux

$$m_k = 2\sum_{i<j}^{N_{tel}} N\sqrt{t_i t_j}\sqrt{a_k^i a_k^j}V_{ij}\cos(2\pi\alpha_k f_{ij} + \phi_{ak}^{ij} + \Phi_{ij} + \phi_{ij}^{p})$$

Estimation of the coherent flux

$$mk = 2\sum_{i<j}^{N_{tel}} N\sqrt{t_i t_j}\frac{\sqrt{a_k^i a_k^j}}{\sqrt{\sum_k a_k^i a_k^j}} V_{ij}[\cos(\Phi_{ij}+\phi_{ij}^p)c_k^{(i,j)} - \sin(\Phi_{ij}+\phi_{ij}^p)d_k^{(i,j)}]$$

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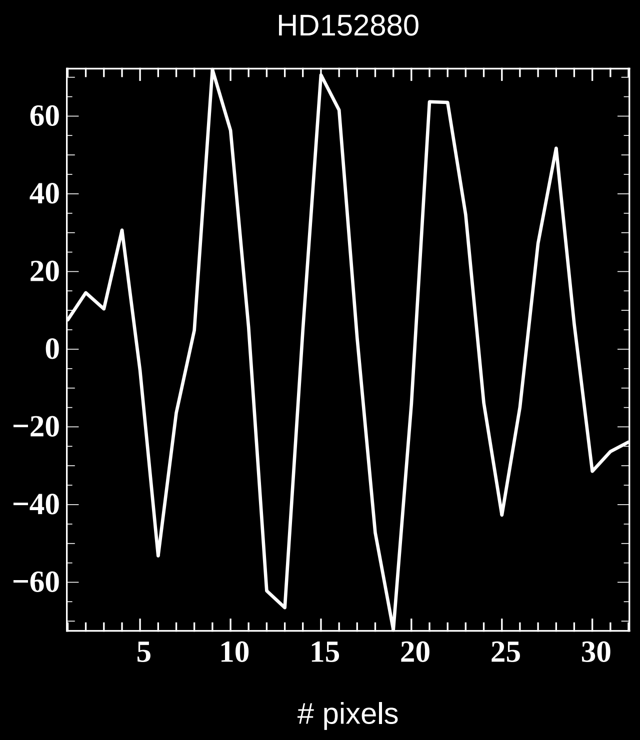
$$mk = R_{ij}c_k^{(i,j)} - I_{ij}d_k^{(i,j)}$$

$$R_{ij} = 2N\sqrt{t_i t_j}\sqrt{\sum_k a_k^i a_k^j} V_{ij}\cos(\Phi_{ij}+\phi_{ij}^p)$$

$$I_{ij} = 2N\sqrt{t_i t_j}\sqrt{\sum_k a_k^i a_k^j} V_{ij}\sin(\Phi_{ij}+\phi_{ij}^p)$$

$$R_{ij}^2 + I_{ij}^2 = 4N^2 t_i t_j \sum_k a_k^i a_k^j V_{ij}^2$$

$$C_{ij} = R_{ij} + iI_{ij} \propto V_{ij}\exp(i[\Phi_{ij}+\phi_{ij}^p])$$



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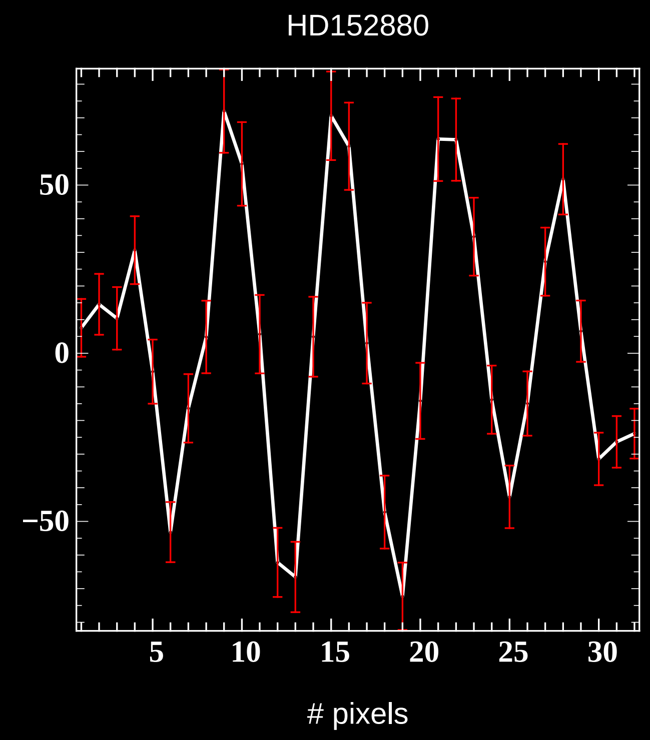
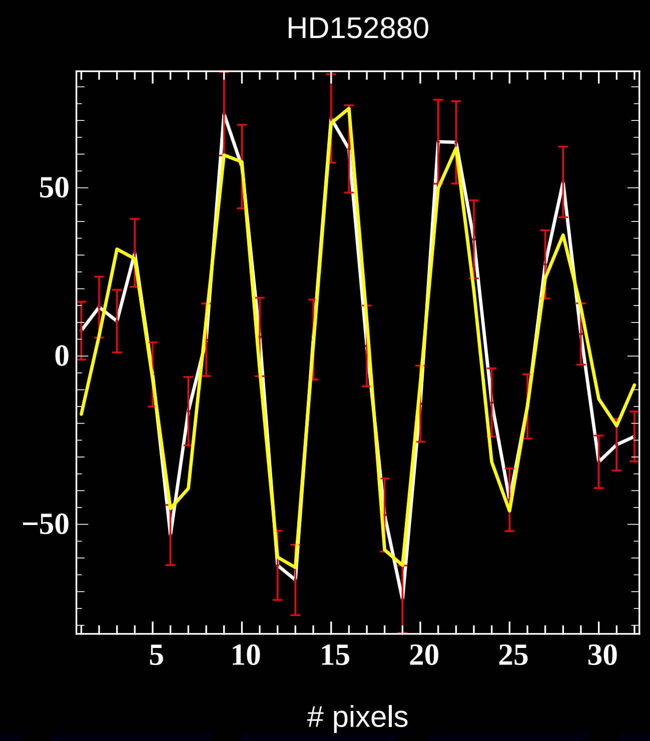


Estimation of the coherent flux

$$mk = 2\sum_{i<j}^{N_{tel}} N\sqrt{t_i t_j}\frac{\sqrt{a_k^i a_k^j}}{\sqrt{\sum_k a_k^i a_k^j}} V_{ij}\left[\cos(\Phi_{ij} + \phi_{ij}^p)c_k^{(i,j)} - \sin(\Phi_{ij} + \phi_{ij}^p)d_k^{(i,j)}\right]$$

$$mk = R_{ij}c_k^{(i,j)} - I_{ij}d_k^{(i,j)} = \left[c_k^{(i,j)}, d_k^{(i,j)}\right]\begin{bmatrix} R_{ij} \\ I_{ij} \end{bmatrix}$$



$$R_{ij} = 2N\sqrt{t_i t_j}\sqrt{\sum_k a_k^i a_k^j} V_{ij}\cos(\Phi_{ij} + \phi_{ij}^p)$$

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$$R_{ij}^2 + I_{ij}^2 = 4N^2 t_i t_j \sum_k a_k^i a_k^j V_{ij}^2$$

$$C_{ij} = R_{ij} + iI_{ij} \propto V_{ij}\exp(i[\Phi_{ij} + \phi_{ij}^p])$$

Estimation of the observables

- Square visibility: $\widetilde{V_{ij}^2} = \dfrac{< R_{ij}^2 + I_{ij}^2 >}{4 < P_i P_j > \sum_k v_k^i v_k^j}$
- Closure phase: $\arg[\widetilde{B}_{123} =< C_{12} C_{23} C_{13}^* >]$
- Differential phase: $\arg[\widetilde{W}_{ij} =< C_{ij,\lambda} C_{ij,\lambda_{ref}}^* >]$

- Biases on the visibility
  - $\hookrightarrow$ Quadratic estimation
  - $\hookrightarrow$ Contrast loss because of :
    - Jitter (HF OPD fluctuations)
    - Non zero OPD (Loss of spectral coherence)