Interferometry of Close Binaries
Technical Considerations

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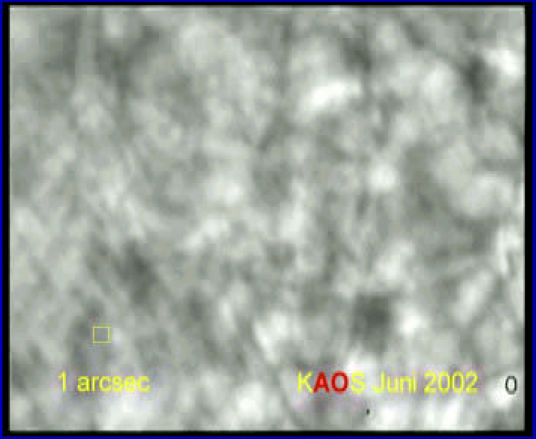
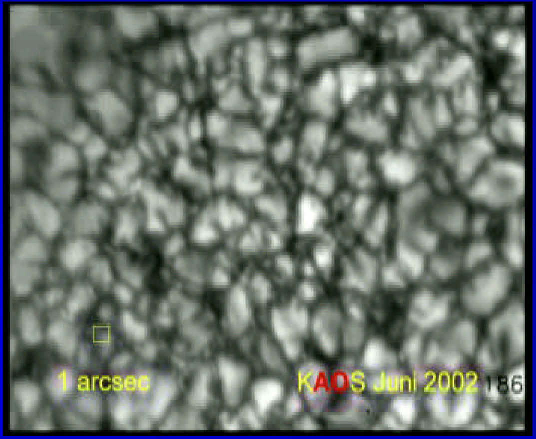
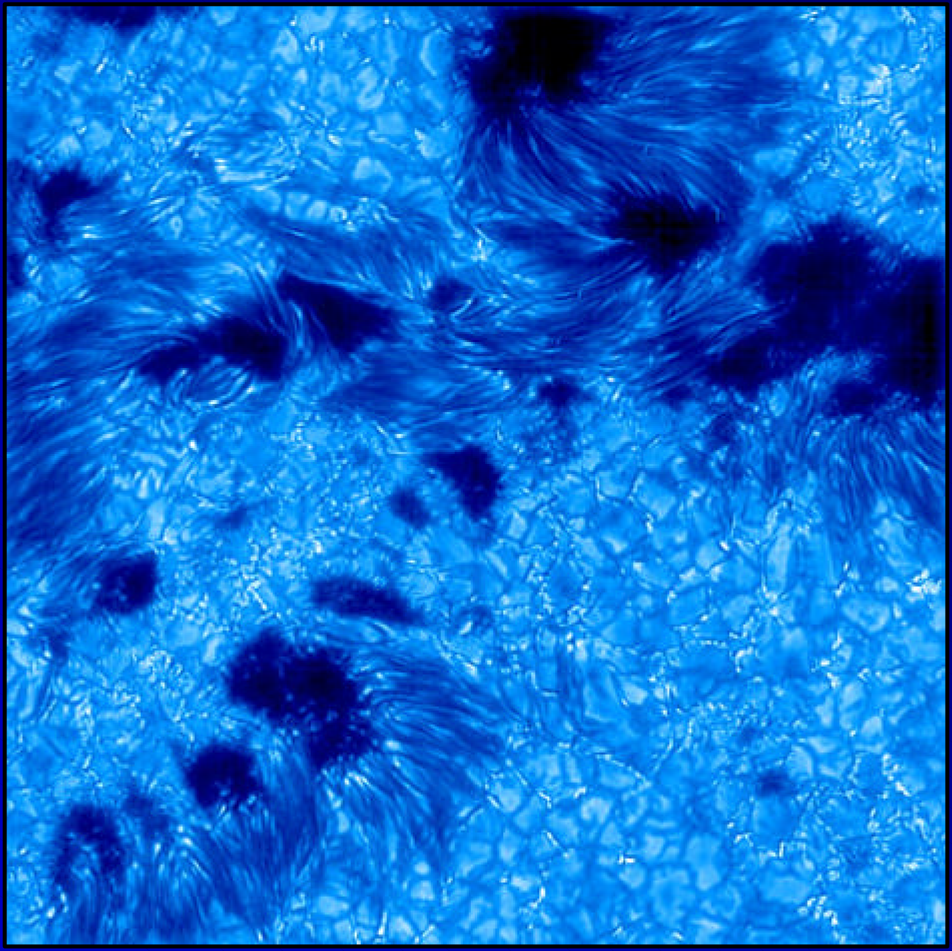
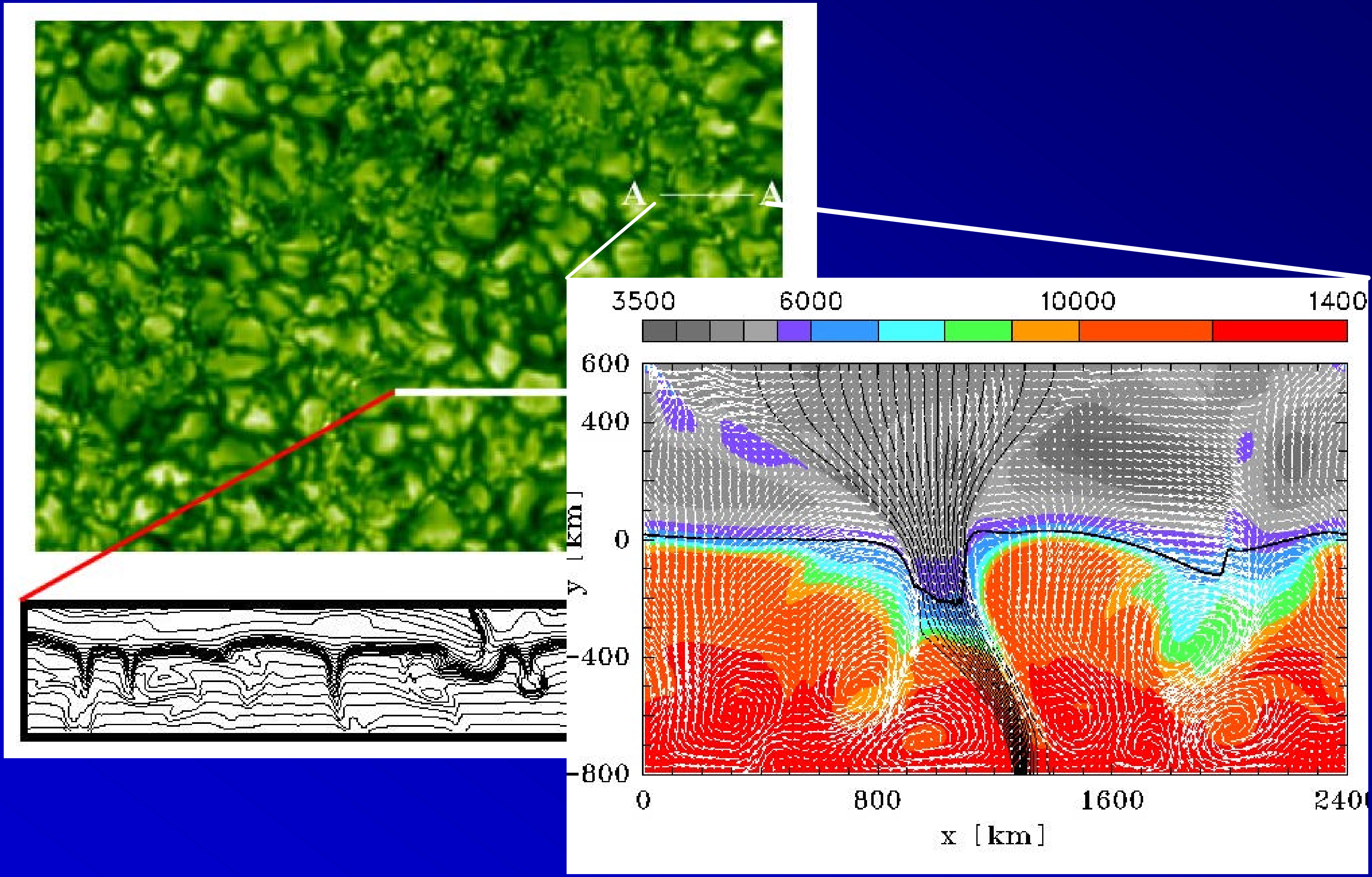

1 arcsec
KAOS Juni 2002
0


1 arcsec
KAOS Juni 2002
186



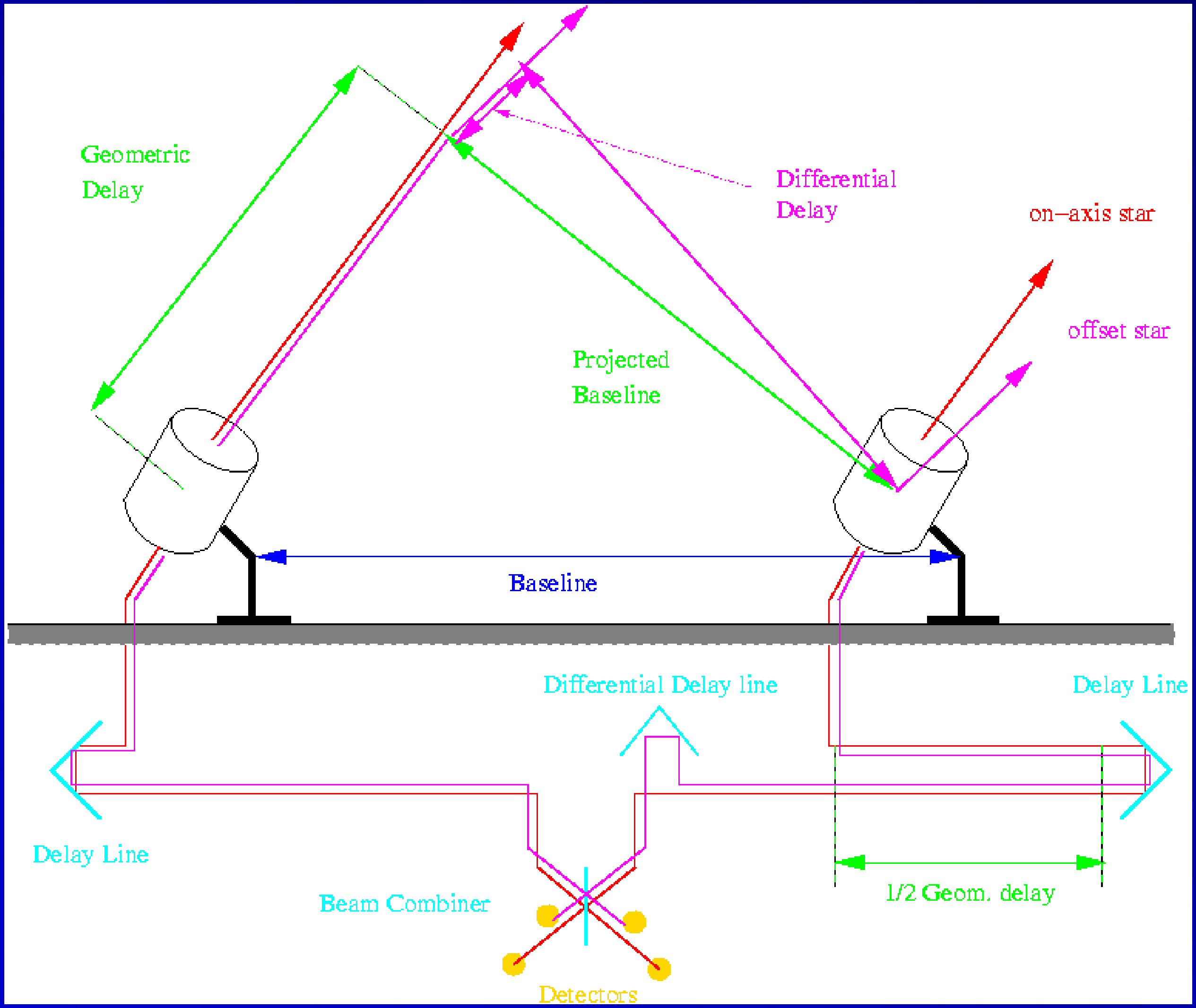

A
A
3500
6000
10000
1400
600
400
0
-400
-800
y [km]
0
800
1600
240
x [km]

Why Double Stars?

- Simplest source of scientific interest
- Ideal probe to test / demonstrate the characteristics of a two-beam interferometer
- Particular emphasis on extended field issues

Scenario

- Two late type main sequence stars somewhere in the FOV of MIDI
- Spectral types K0 … L0, characterized by T_{eff}
- Spectral regime N band with various settings of the spectral resolution R_{λ}

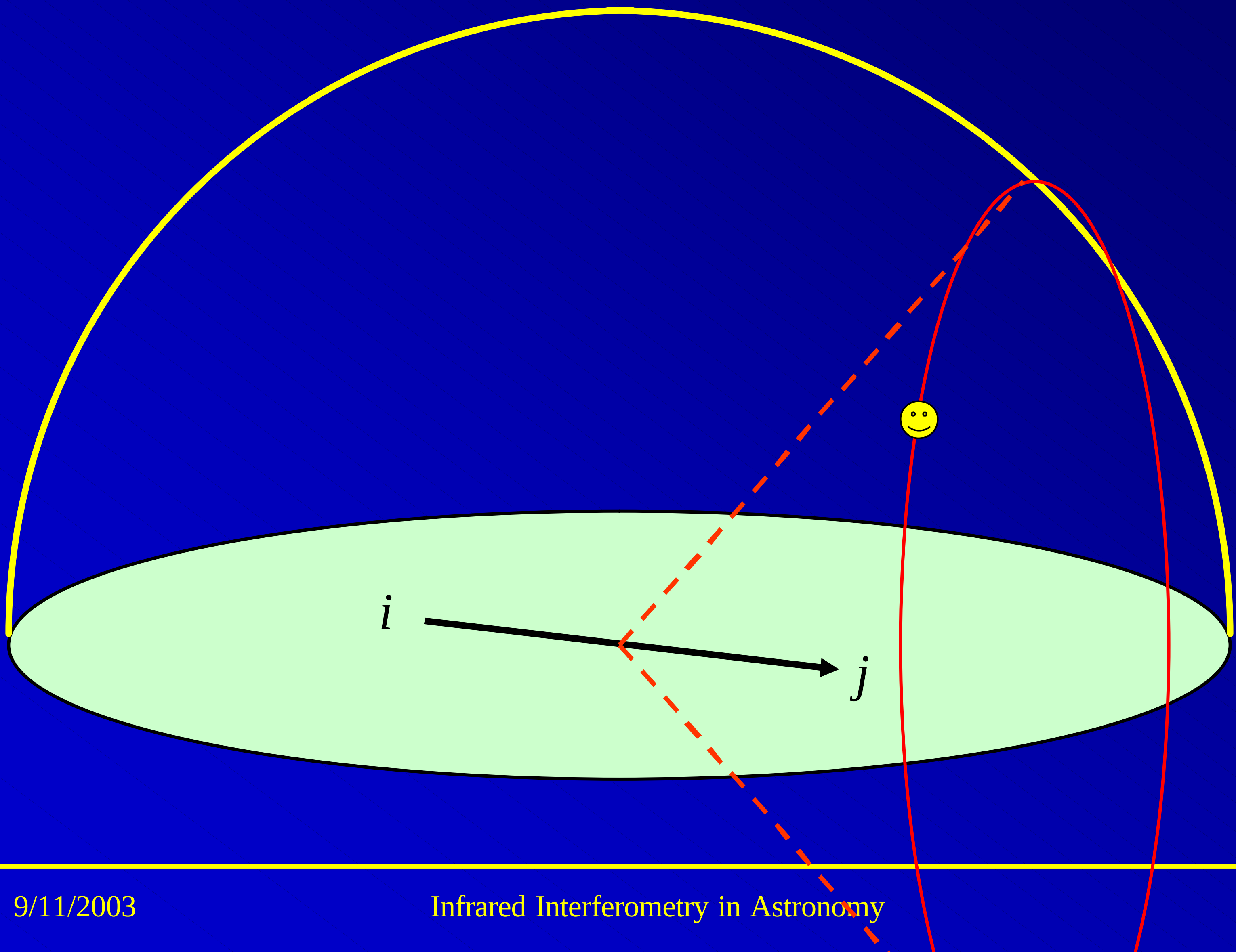

Geometric
Delay
Differential
Delay
on–axis star
offset star
Projected
Baseline
Baseline
Differential Delay line
Delay Line
Delay Line
Beam Combiner
1/2 Geom. delay
Detectors

Interferometer Basics

- Projected baseline:

$$\overline{\mathbf{B}}_{ij} = \begin{pmatrix} u_{ij} \\ v_{ij} \\ w_{ij} \end{pmatrix} (d, h)$$

- Cancel geometric delay w_{ij} by delay line for position (δ,h) in sky



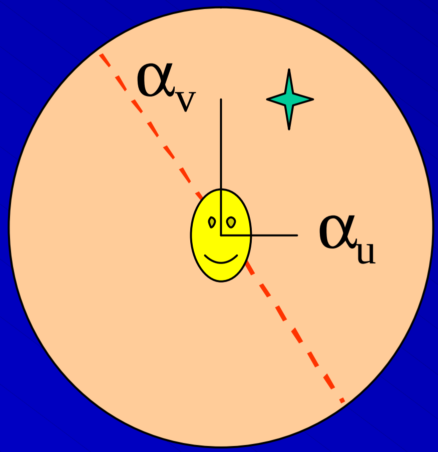
i
j

Single Baseline Differential Delay

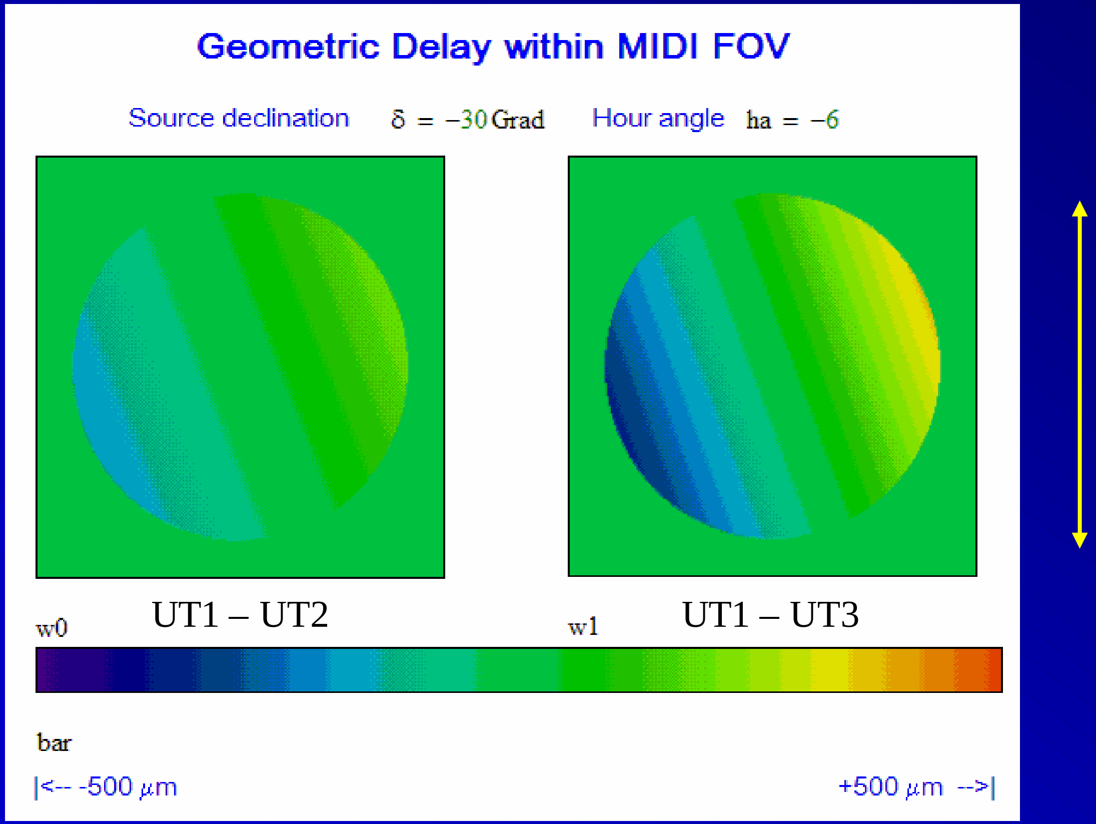
- Differential delay *dw* depends on offset angle *a* from tracking cone

$$dw = \overline{\mathbf{B}}_{ij}\,\tilde{a}$$

$$\tilde{a} = \begin{pmatrix} a_u \\ a_v \\ 0 \end{pmatrix}$$

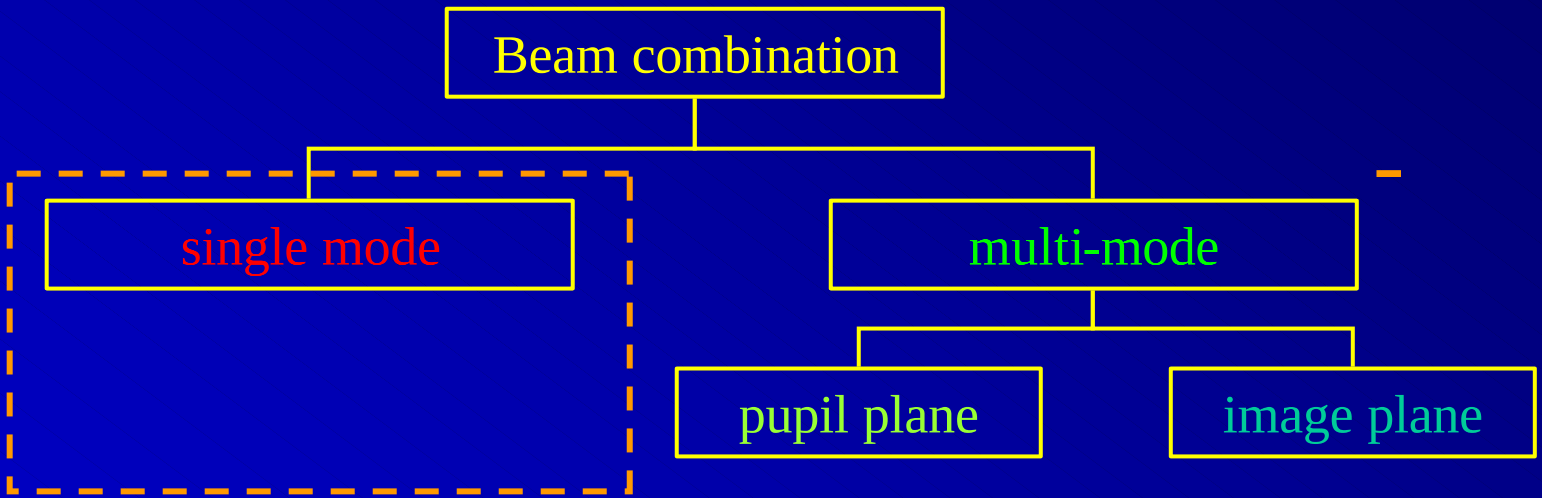


Differential Delay for MIDI FOV



2.6 arcsec

Methods of beam combination

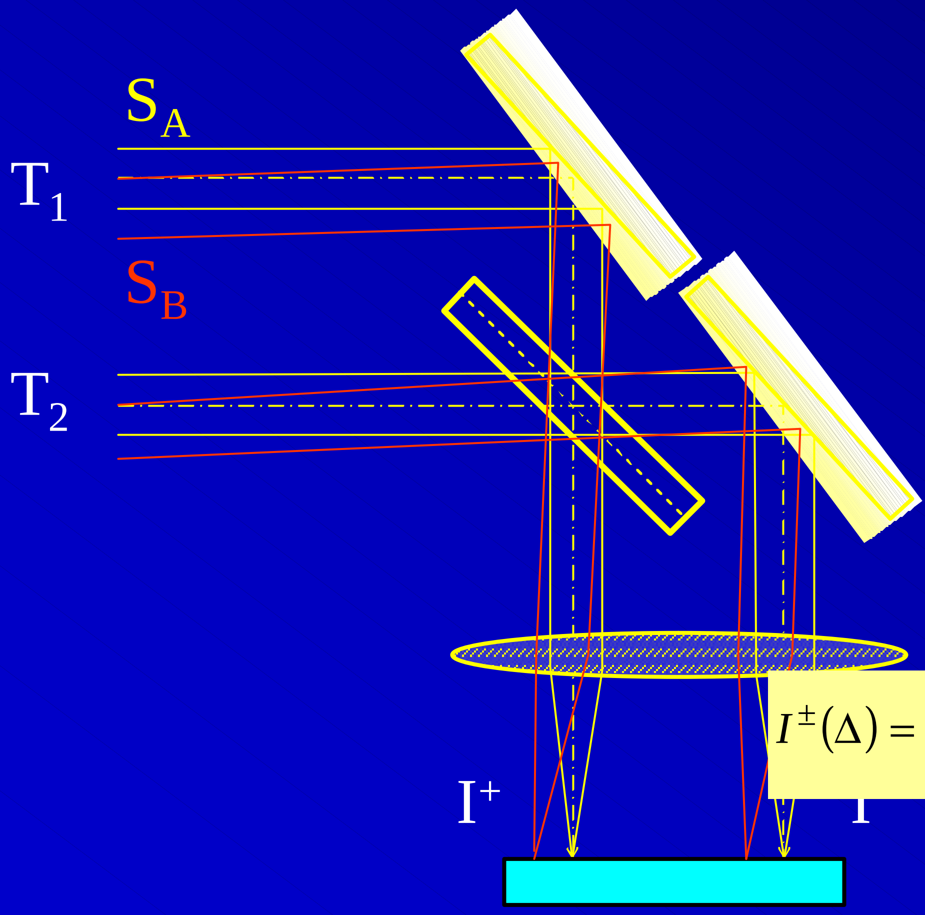


The detected field of view is equivalent to the Airy disk of an array element

The detected field of view exceeds the Airy disk of an array element.

Beam combination takes place in the plane of a transferred pupil or an image.

Multi-Mode Pupil Plane Beam Combination



- Quasi-monochromatic: $dw < l\ R_l$
- Detected intensity:

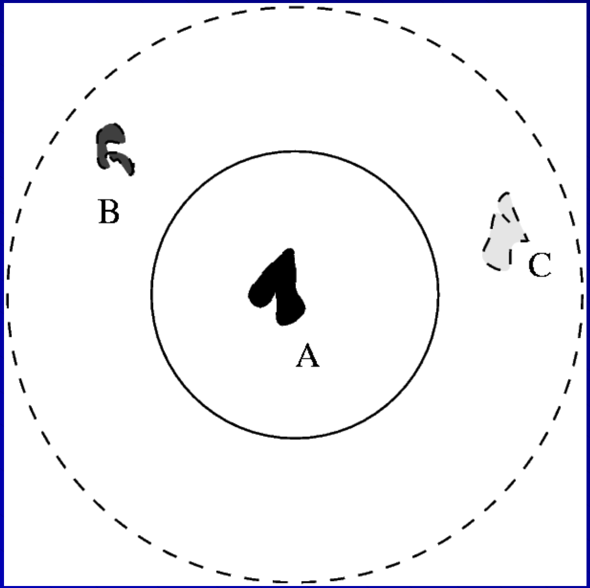
$$I^{\pm}(\Delta) = F_A\left[T_1^2 + T_2^2 \pm 2T_1T_2 \sin\left(2pi\left(\frac{\Delta + dw_A}{l}\right)\right)\right.$$
$$\left. + F_B\left[T_1^2 + T_2^2 \pm 2T_1T_2 \sin\left(2pi\left(\frac{\Delta + dw_B}{l}\right)\right)\right.\right.$$

- General intensity distribution:

$$I^{\pm}(\Delta) = \iint_{\text{Field}} F(\mathbf{a})\left[T_1^2 + T_2^2 \pm 2T_1T_2 \sin\left(2pi\left(\frac{\Delta + dw_A}{l}\right)\right)\right] d\mathbf{a}$$

Multi-Mode Pupil Plane Beam Combination

- Quasi-monochromatic: business as usual!
- Fourier relation between measured fringe visibility and object distribution is preserved under quasi-monochromatic conditions, even if detected with a single pixel detector!
- What counts is the intensity of the sources which are permitted to propagate to the detector.
- Use field stops to reject unwanted sources.



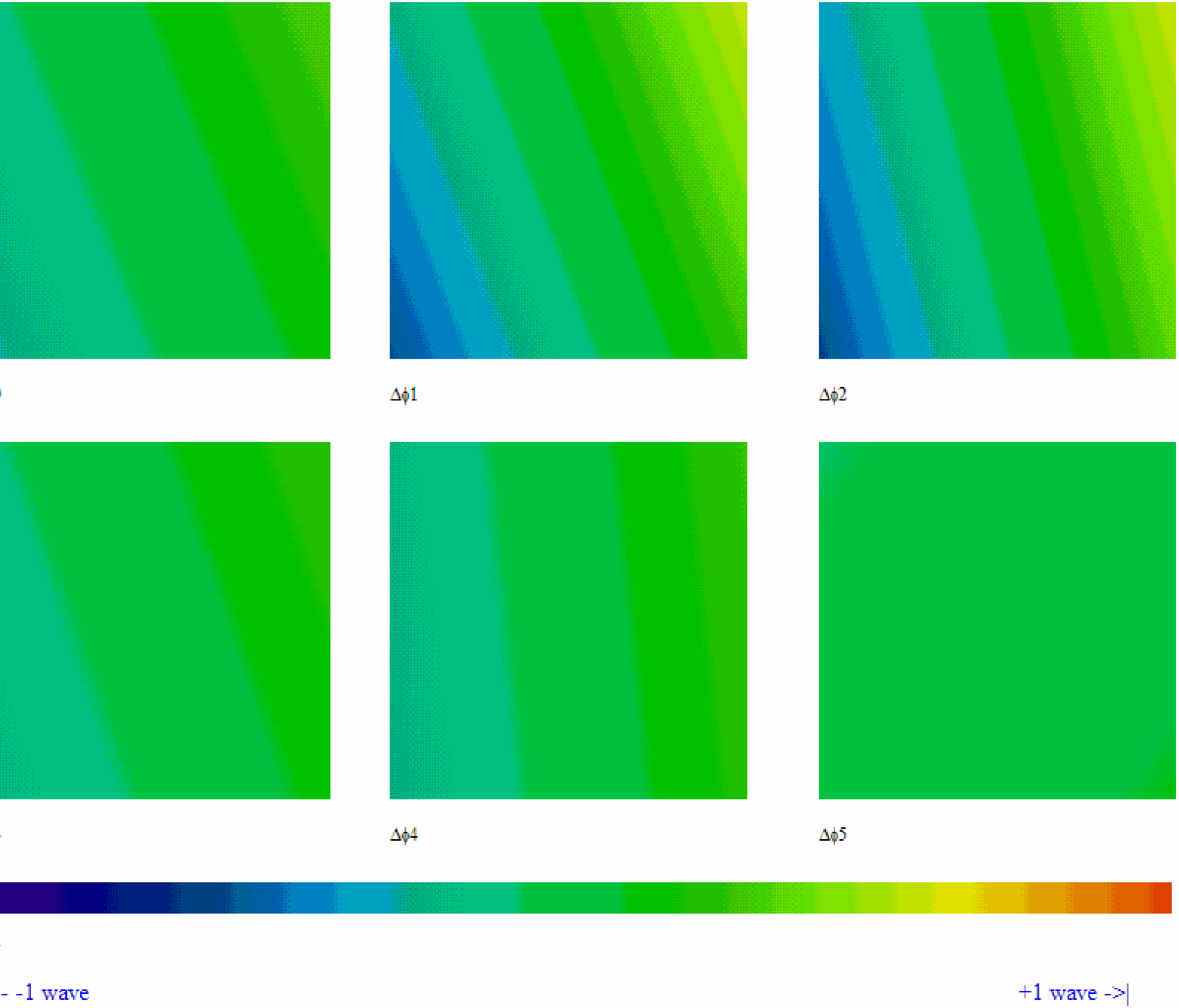
Polychromatic Conditions

- Spectral distribution F_λ of source
- Spectral sensitivity E_λ of instrument
- Measured intensity is a complicated mixture of spatial and spectral information if differntial delay approaches coherence length and sources are not separated!

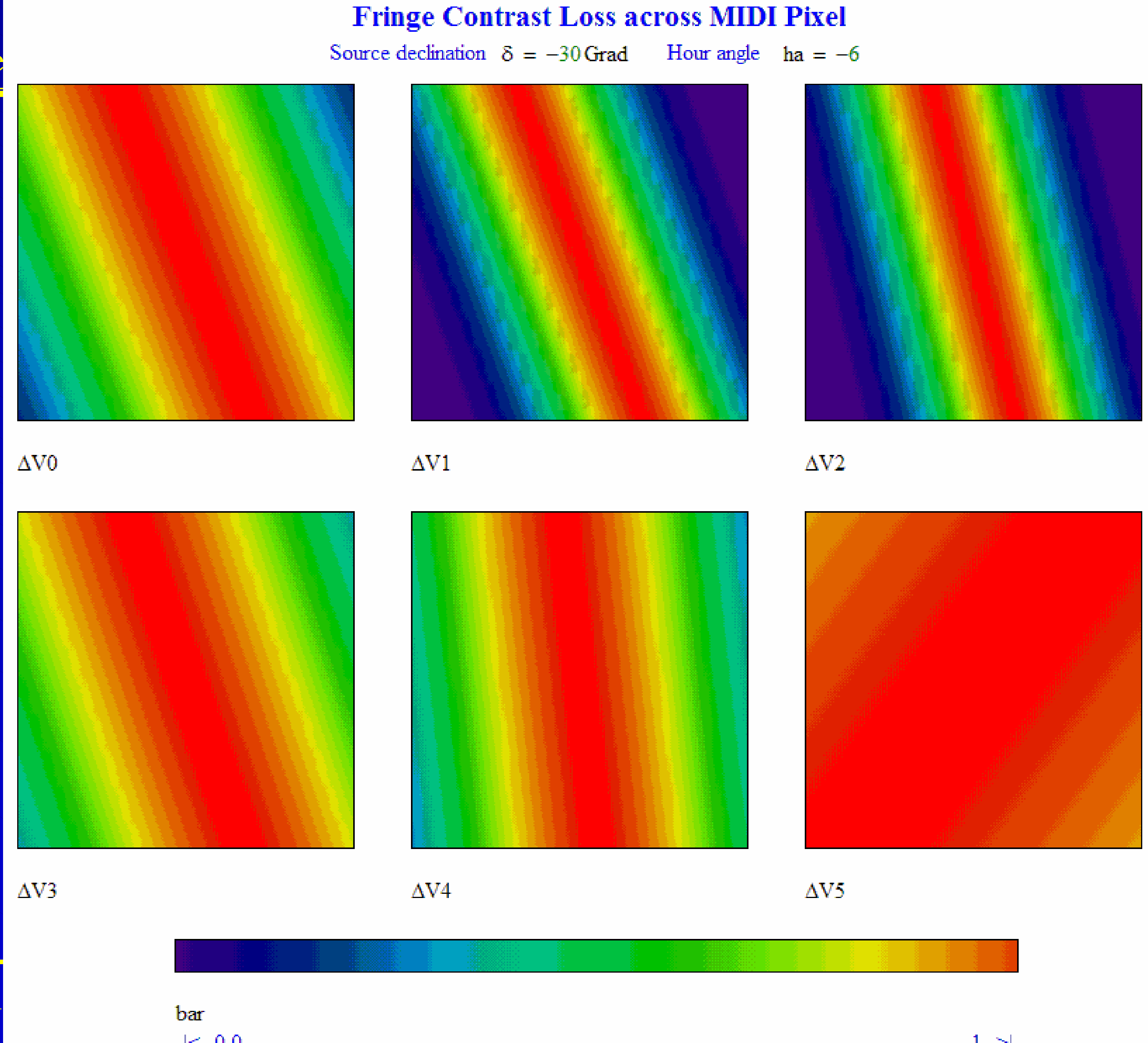
$$I^{\pm}(\Delta) = \int E_l F_{l,A}\left[T_1^2 + T_2^2 \pm 2T_1T_2 \sin\left(2pi\left(\frac{\Delta + dw_A}{l}\right)\right)\right] dl$$
$$+ \int E_l F_{l,B}\left[T_1^2 + T_2^2 \pm 2T_1T_2 \sin\left(2pi\left(\frac{\Delta + dw_B}{l}\right)\right)\right] dl$$

Phase Difference across MIDI Pixel over Spectral Band

Source declination $\delta = -30$ Grad Hour angle $ha = -6$

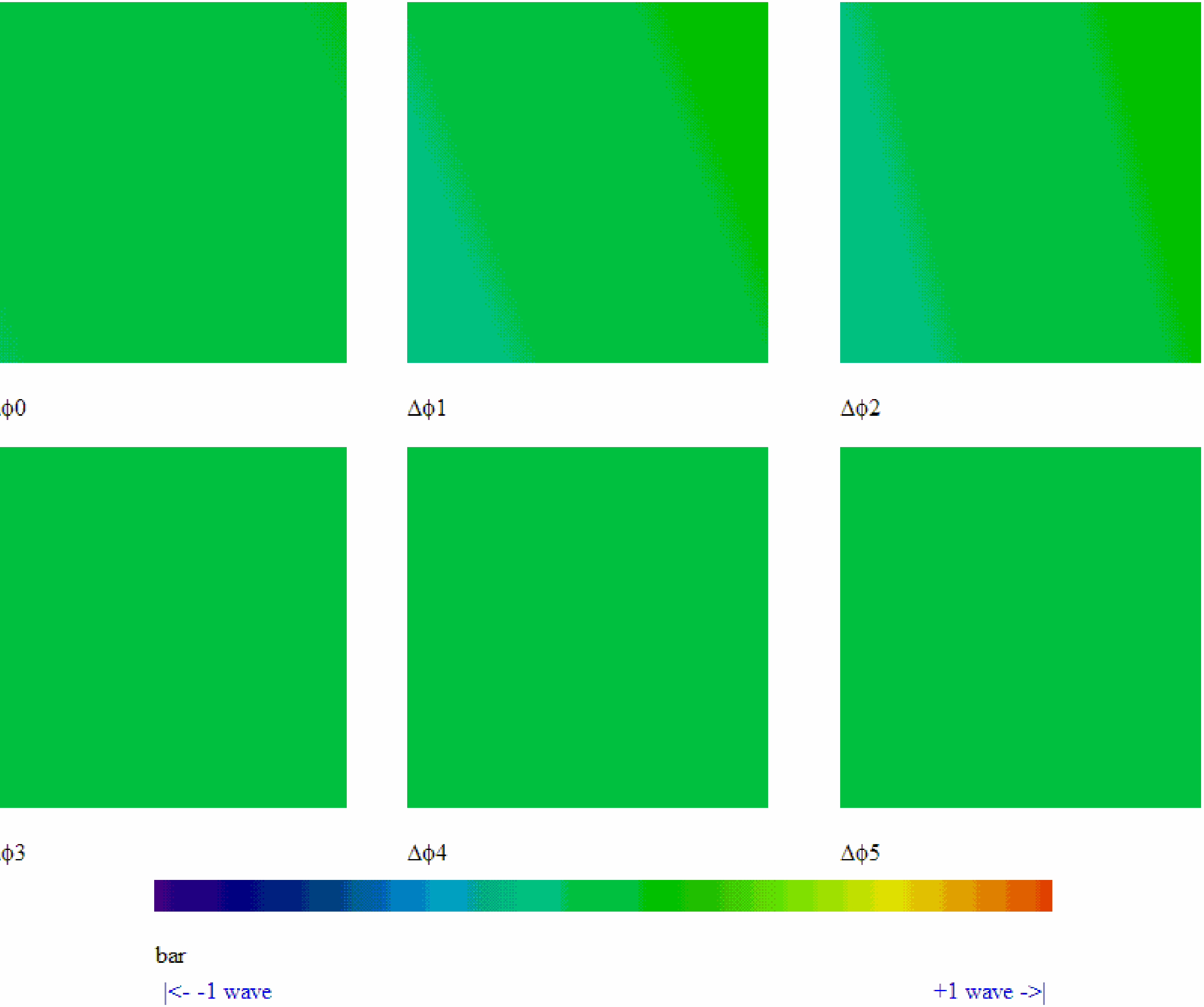


$R_{\lambda} = 2.5$


Fringe Contrast Loss across MIDI Pixel
Source declination δ = −30 Grad
Hour angle ha = −6
ΔV0
ΔV1
ΔV2
ΔV3
ΔV4
ΔV5
bar

Phase Difference across MIDI Pixel over Spectral Band

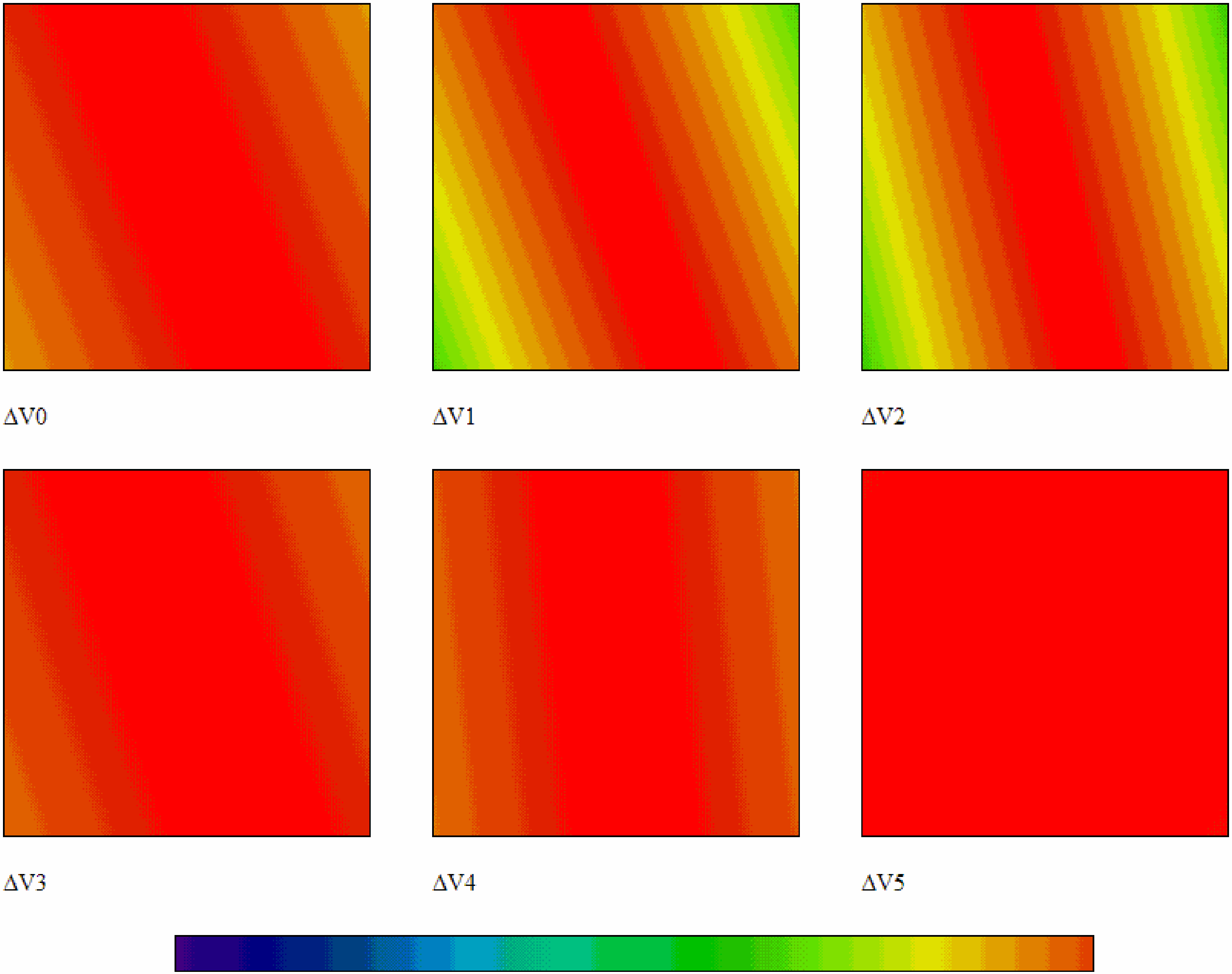
Source declination $\delta = -30$ Grad   Hour angle $ha = -6$ Spectral resolution $R_S = 10$



$R_\lambda = 10$

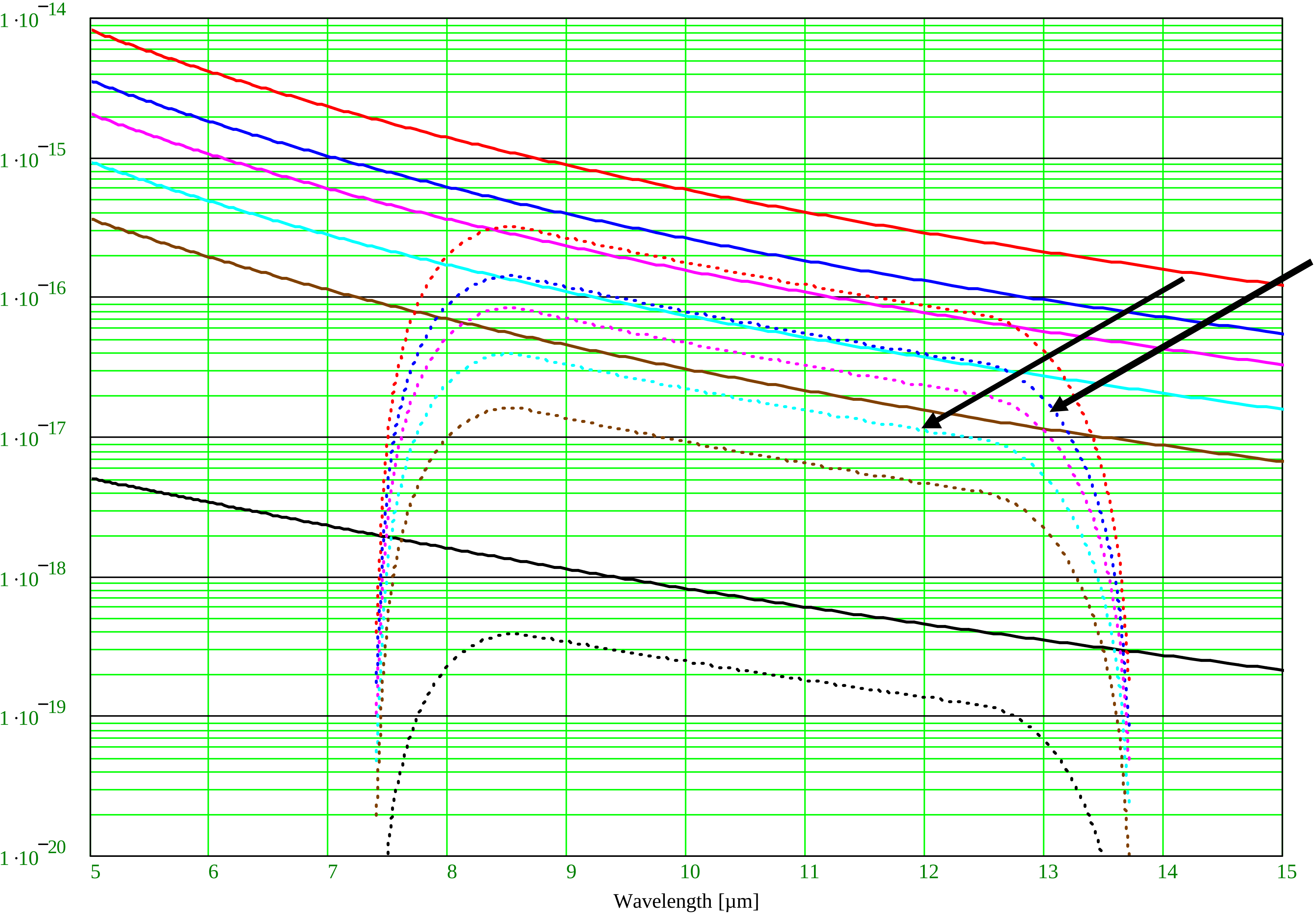
Fringe Contrast Loss across MIDI Pixel

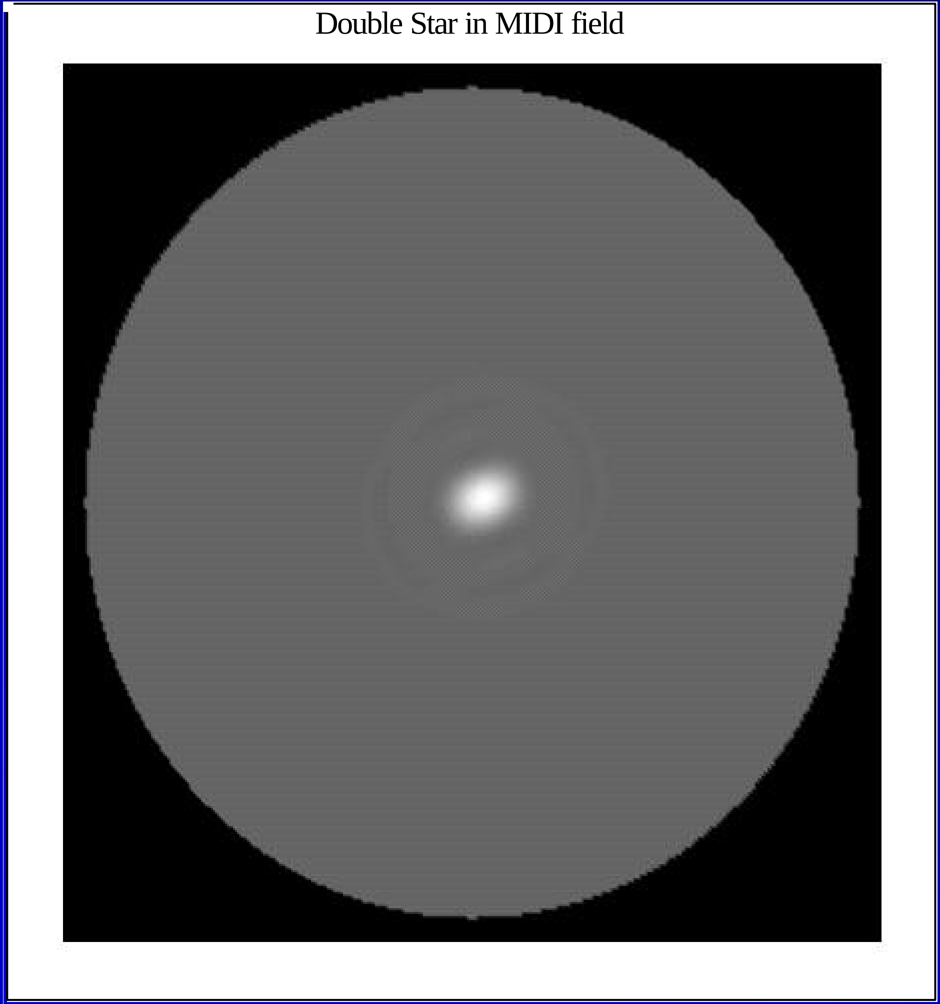
Source declination $\delta = -30$ Grad   Hour angle $ha = -6$ Spectral resolution $R_S = 10$



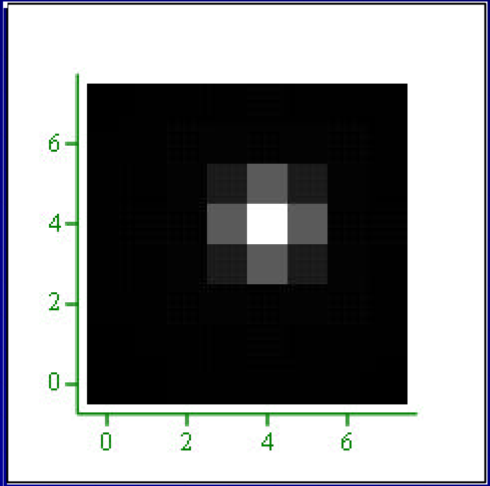
Close Binary Illustrations

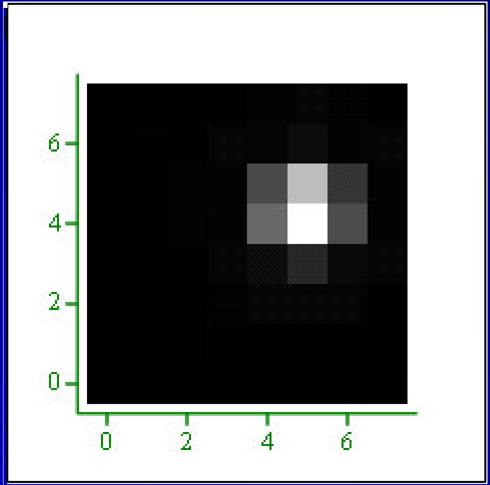
- Two stars at position $\delta = -30°$, $h = 0$
- Distance 50 pc
- Relative positions $(\alpha,\delta)_A = (0,0)$ and $(\alpha,\delta)_B = (0.08,0.03)$ arcsec from CoF
- Separation 0.085 arcsec (about 1 pixel!)
- Star A: K5V, Star B: M5V
- Rayleigh-Jeans law spectra in N Band
- N Flux ratio 1 / 0.28


1·10^−14
1·10^−15
1·10^−16
1·10^−17
1·10^−18
1·10^−19
1·10^−20
5
6
7
8
9
10
11
12
13
14
15
Wavelength [μm]



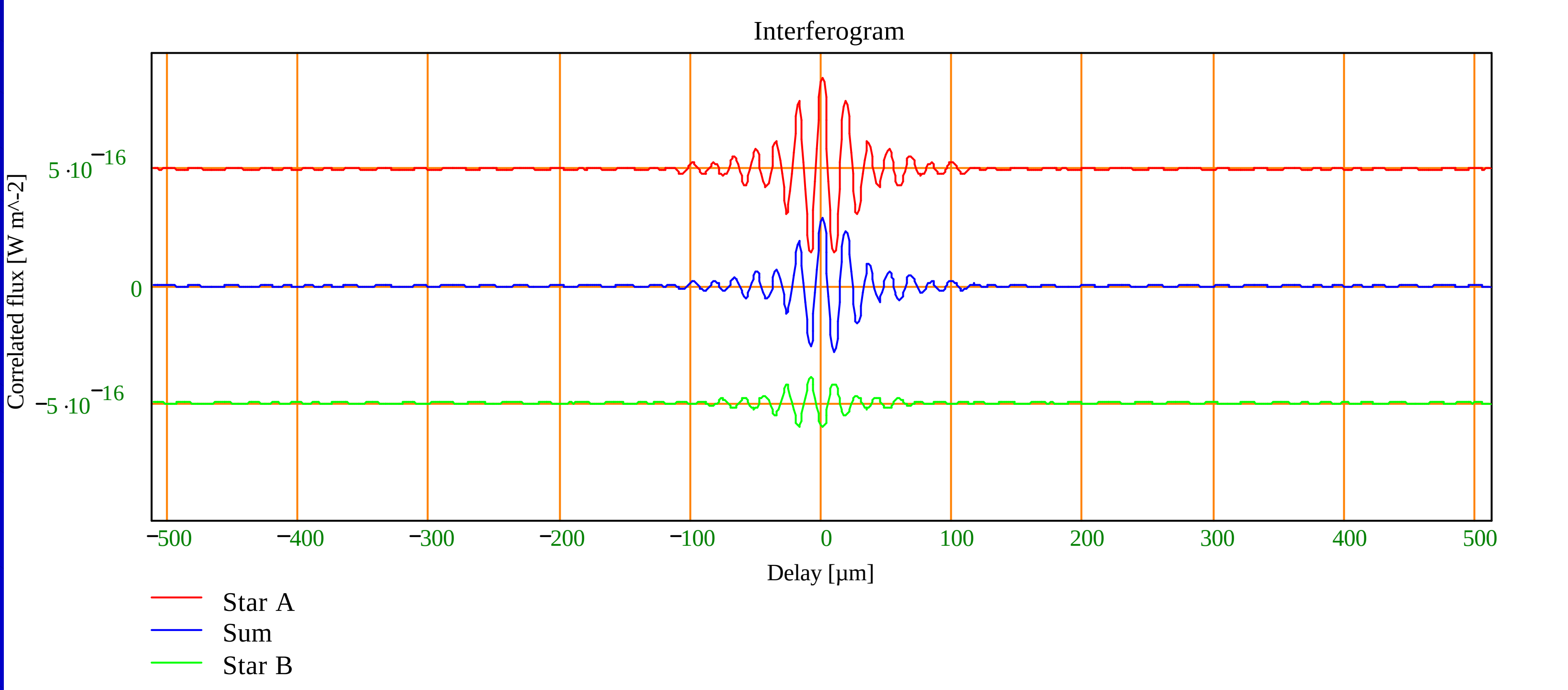
P raw





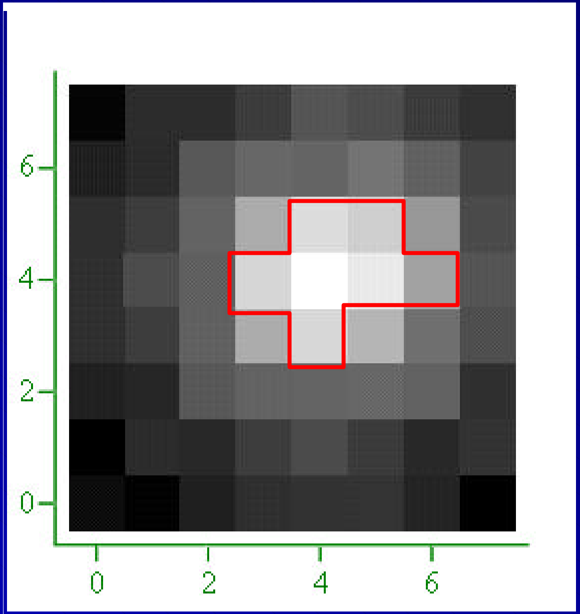
P2 B

Full field interferograms

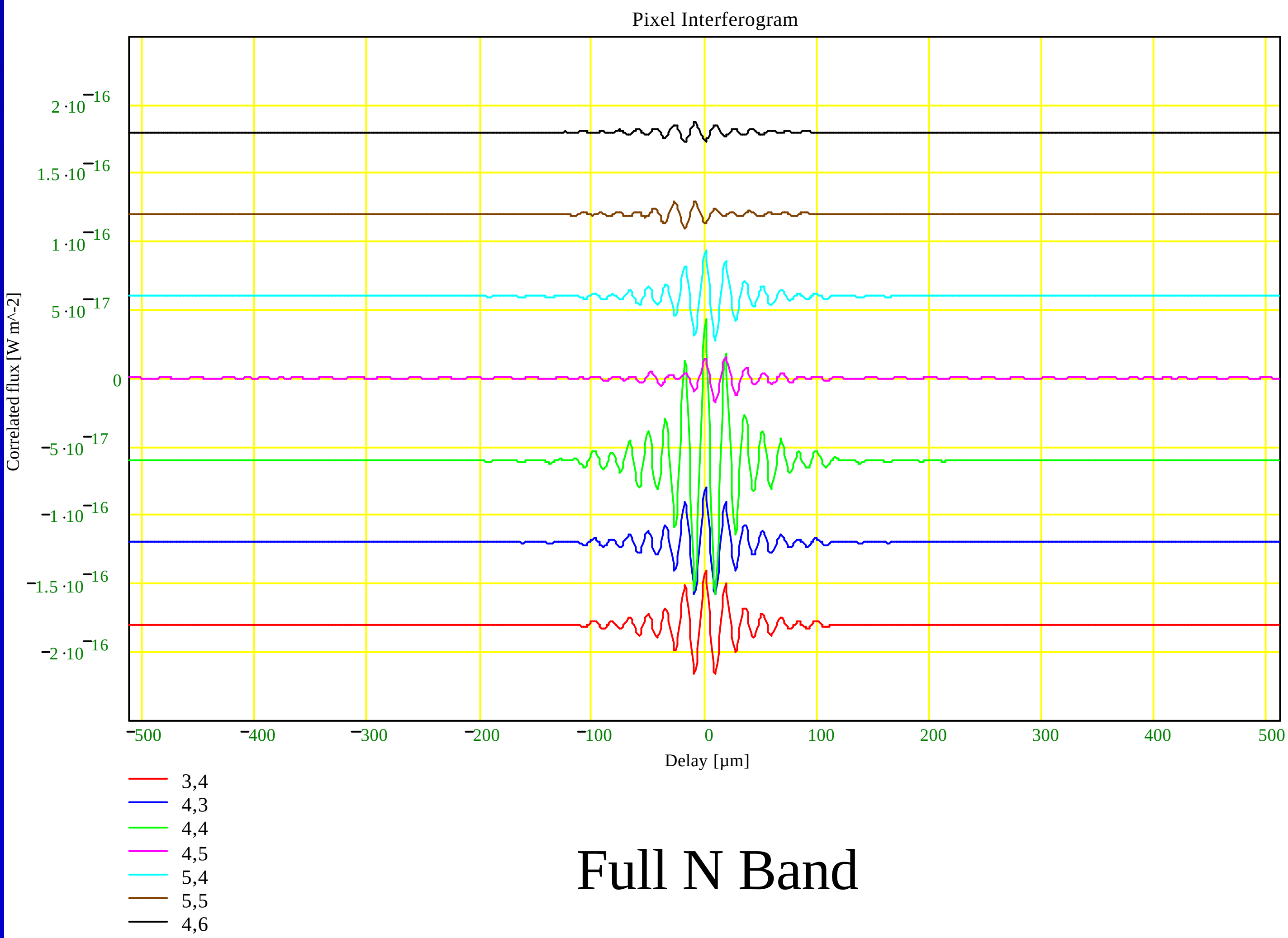


Detected Flux

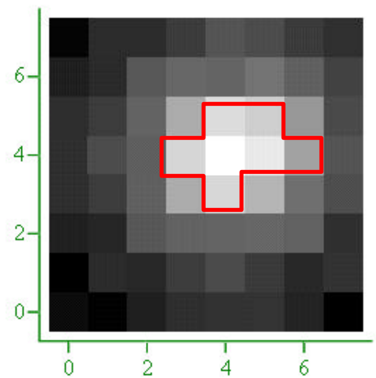
- Log Intensity
- Select seven brightest pixels
- Extract individual interferograms



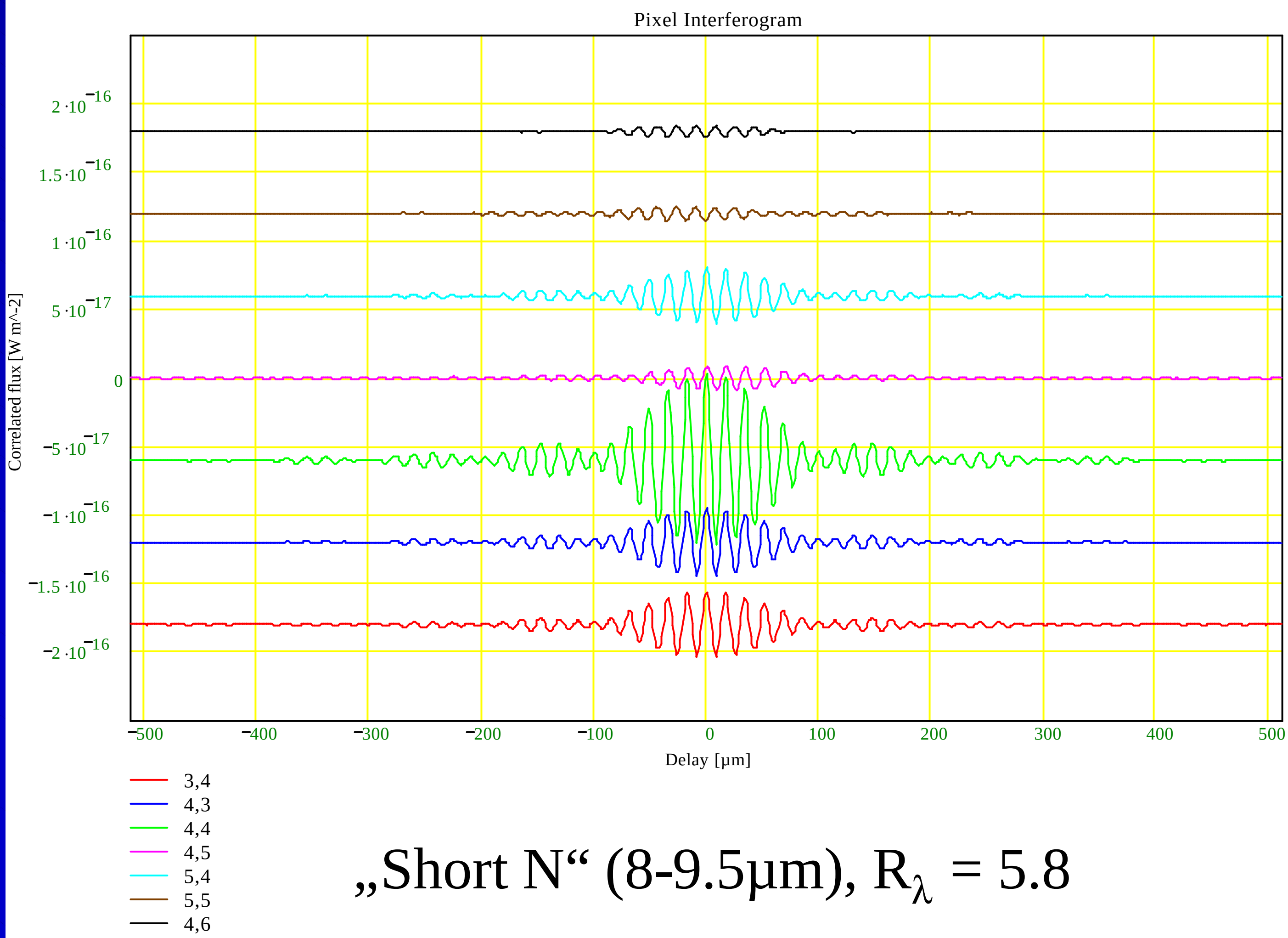
P_{Sum}



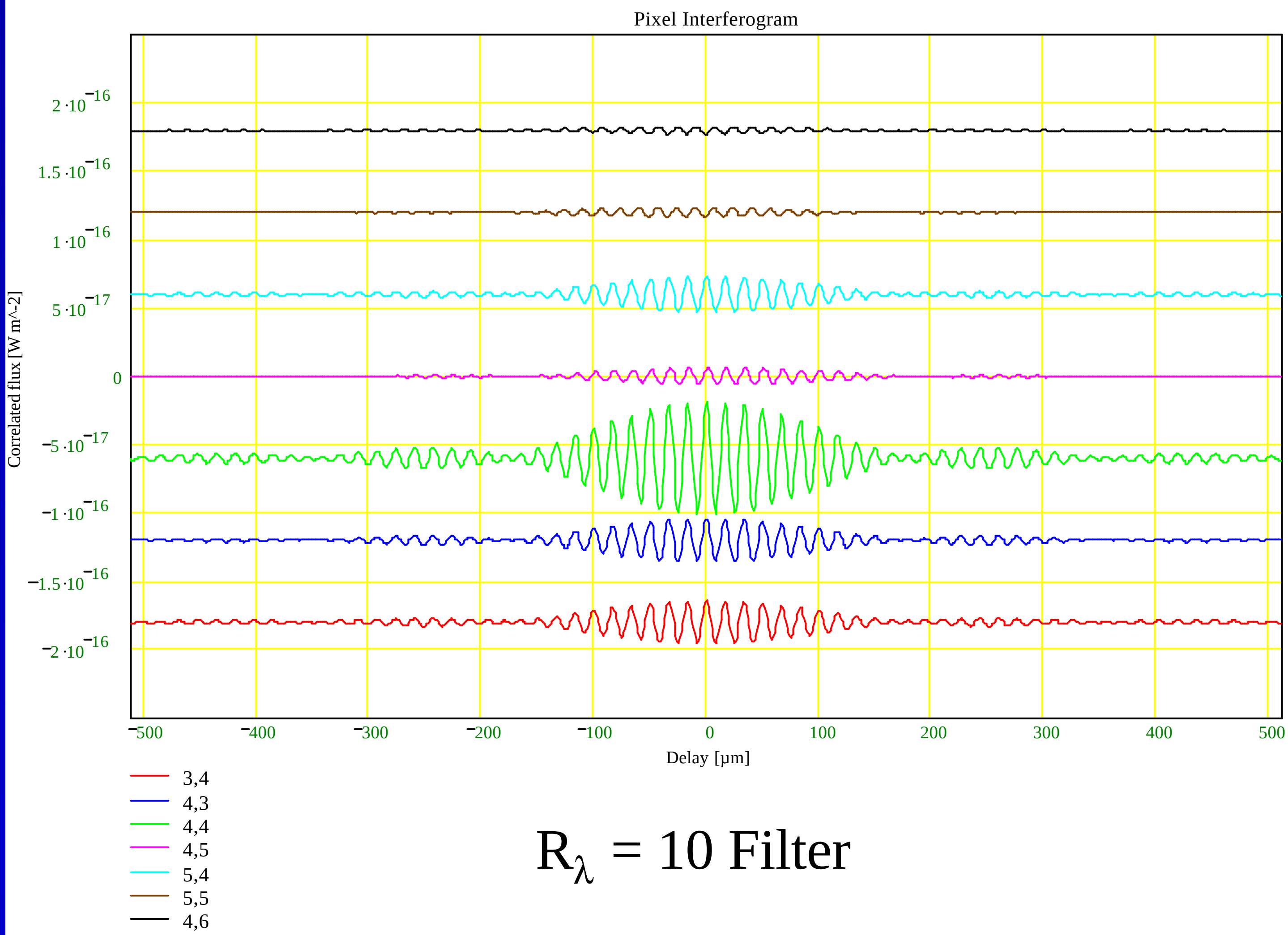
Full N Band



P Sum



„Short N“ (8-9.5µm), R_λ = 5.8



$R_\lambda = 10$ Filter

Conclusions and Observations

- Very low R_λ (<< 10) measurements of MIDI should be analyzed with careful consideration of bandwidth effects
- There is no need to be concerned about differential delay in the MIDI FoV for higher R_λ
- Long stroke scanning (several 100 µm) enables quasi-simultaneous detection of fringes in an extended field („instantaneous mosaicing“)
- Single mode additions (pinholes, fibers) may just conceal problems