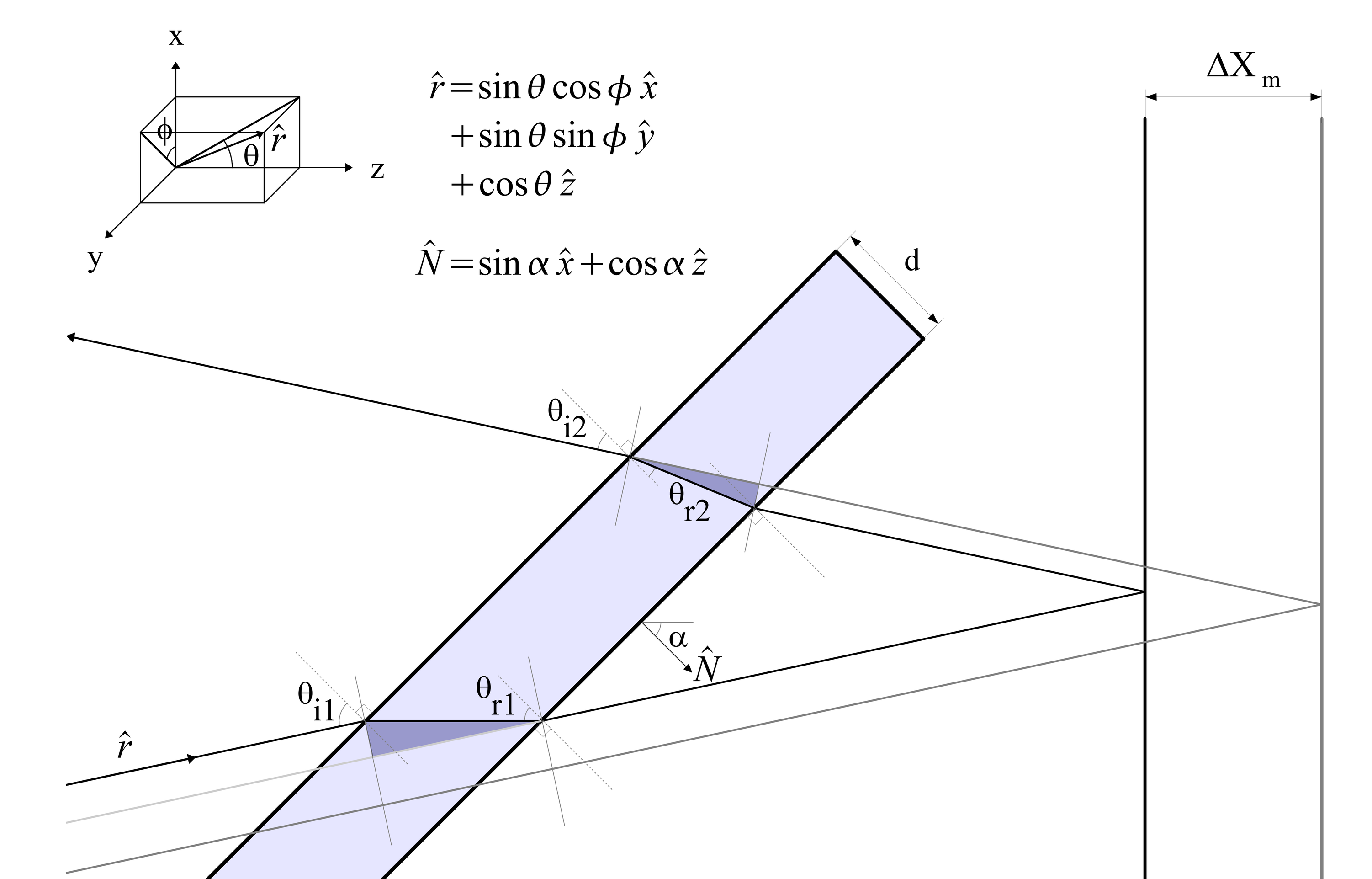
Field Widening Effects on Modulation Efficiency and ILS Resulting From the Use of Uncompensated Beam Splitter

Raphaël Desbiens*, Pierre Tremblay*, Vincent Farley**, Jean-François Legault**, Martin Chamberland**

* Centre d'optique, photonique et laser, Université Laval
Pavillon Adrien-Pouliot, Québec, Québec, G1K 7P4, Canada

** Telops Inc., 4940 rue Pierre-Georges-Roy,
Saint-Augustin-de-Desmaures, Québec, G3A 1V7, Canada



OPD calculation scheme

The wavefront going through an inclined plate is compared to the wavefront in free space.

ABSTRACT — Our presentation deals with the behavior of Fourier-transform spectrometers (FTS) using an uncompensated beam splitter. As expected, the lack of compensation results in strong dispersion over the spectral band, spreading the zero-path difference (ZPD) region of the interferograms. In fact, the exact position of the ZPD varies with wavenumber.

It is very insightful to notice that operating with an uncompensated beam splitter is similar to some field-widening configurations. The latter enables to achieve an infinite Haidinger fringe pattern for a given non-zero optical path difference (OPD). This configuration involves necessarily that fringes are observed at ZPD.

Symmetrical operation about ZPD therefore suffers increased limitations due to the tighter fringe pattern resulting from supplementary phase accumulation into the beam splitter substrate. The fringe pattern integration over the instrument field of view (FOV), for single pixel as well as for imaging detectors, results in apparent loss of modulation efficiency. In fact, global impact on instrument line shape (ILS) (or equivalent self-apodization) is expected, with both contributions to the ILS phase and amplitude.

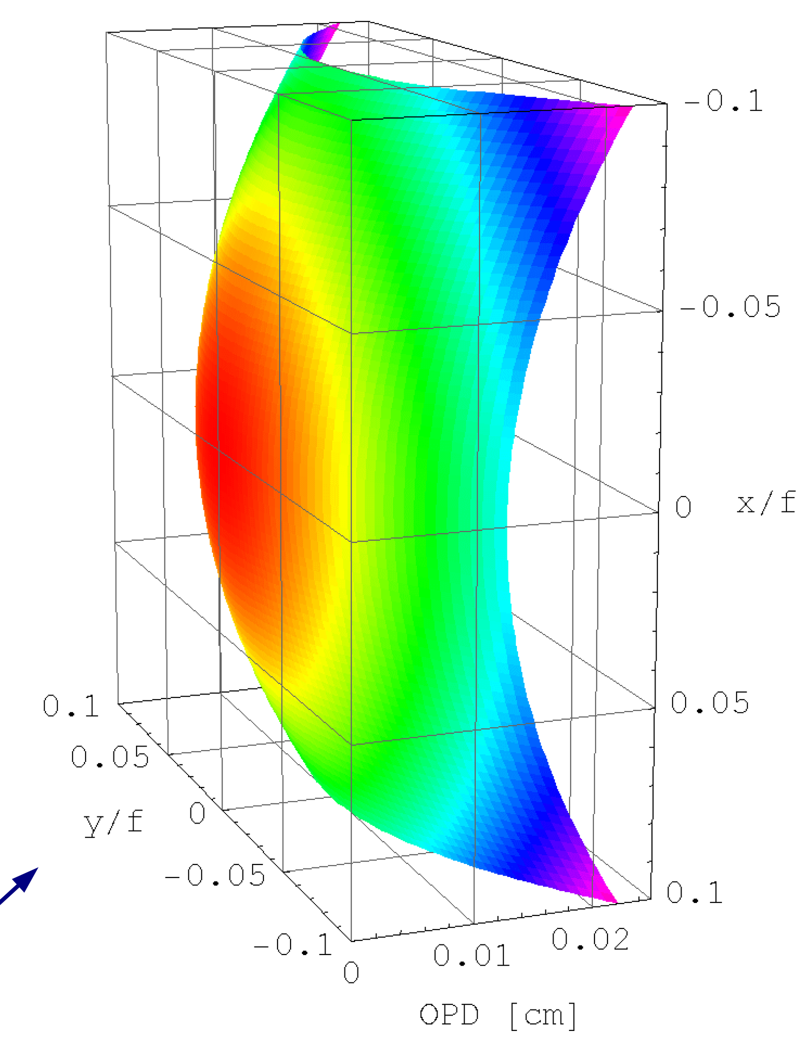
3D MODEL

— The Optical Path Difference (OPD) resulting from an inclined plate (beam splitter plate or compensating plate) in one of the FTS arms, is given by

$$OPD = d\,n(\sigma_o)\cos\theta_{r1} + d\,n(\sigma_o)\cos\theta_{r2} - d\cos\theta_{i1} - d\cos\theta_{i2} - (\Delta X + \Delta X_{ZPD})\cos\theta$$

The origin may be set to the ZPD position at a given wavelength of the on-axis ray.

$$OPD = d\sqrt{n^2(\sigma_o) - 1 + (\cos\theta\cos\alpha + \sin\theta\sin\alpha\cos\phi)^2} + d\sqrt{n^2(\sigma_o) - 1 + (\cos\theta\cos\alpha - \sin\theta\sin\alpha\cos\phi)^2} - 2d\cos\theta\cos\alpha - (\Delta X + \Delta X_{ZPD})\cos\theta$$



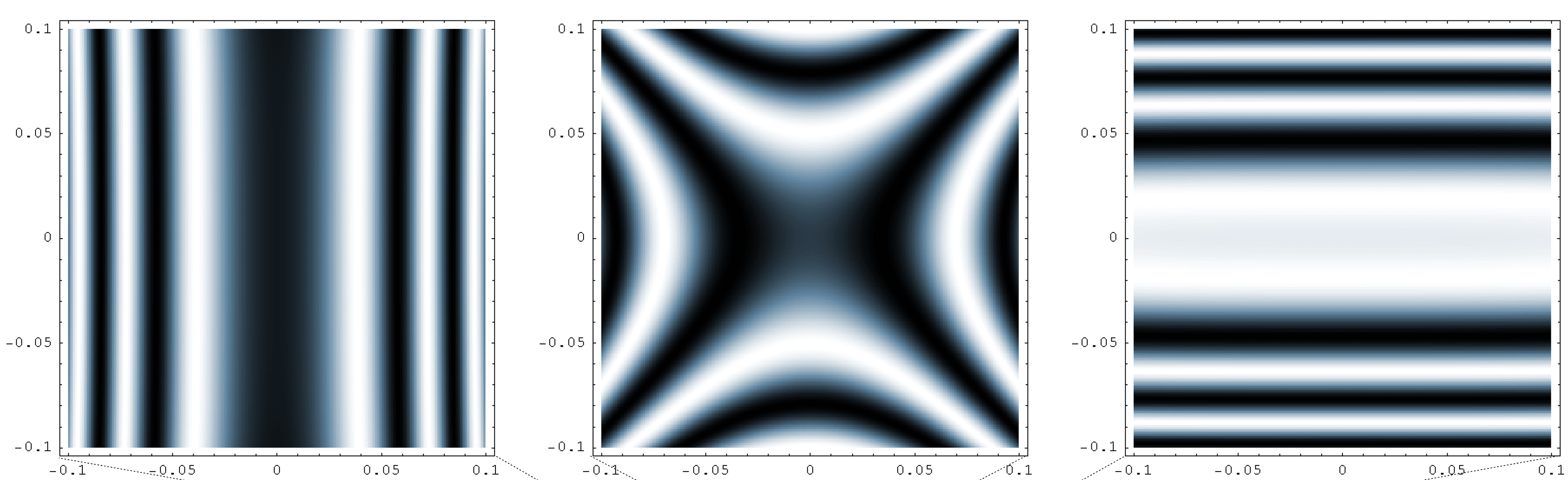
Surface of the ZPD position in the field of view

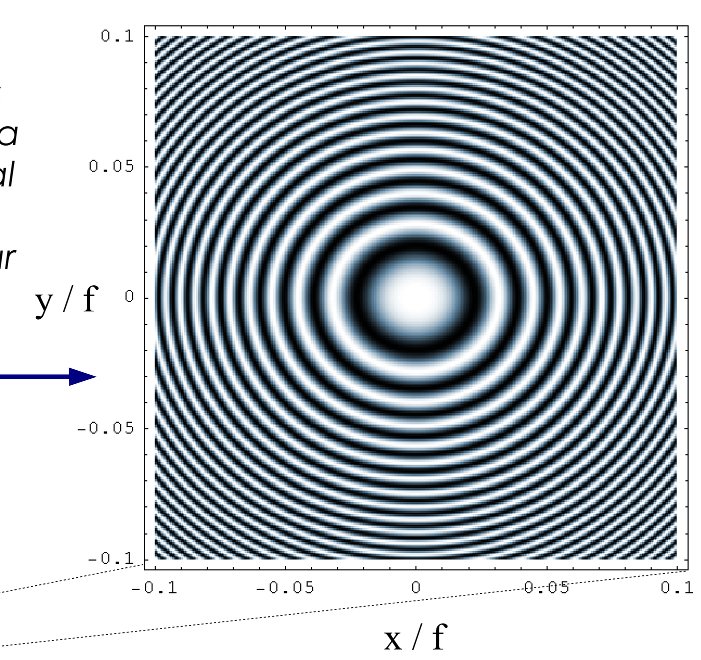
The ZPD position depends on the ray angle. It is not a flat plane due to spherical aberration. That is the reason why fringes appear in the on-axis ZPD plane.

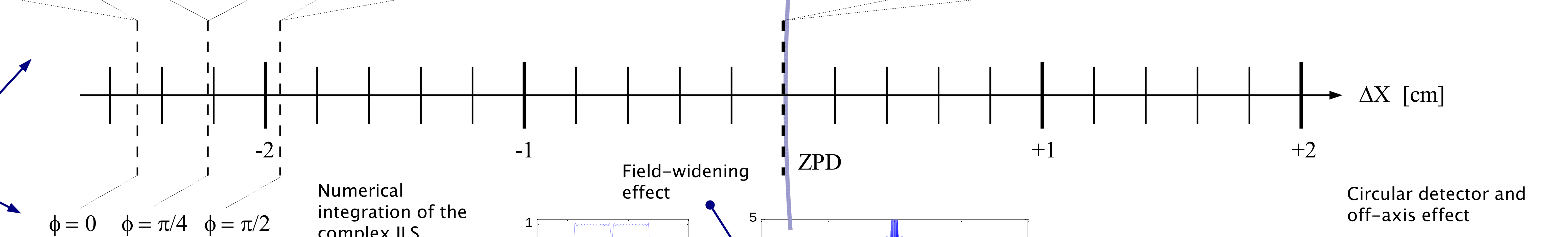
Instrument parameters

substrate :
KBr at α = 45°
d = 10 mm

wavenumber :
σ_o = 1000 cm^{-1}
$n(\sigma_o)$ = 1.5242







"Infinite" fringe planes in the FOV

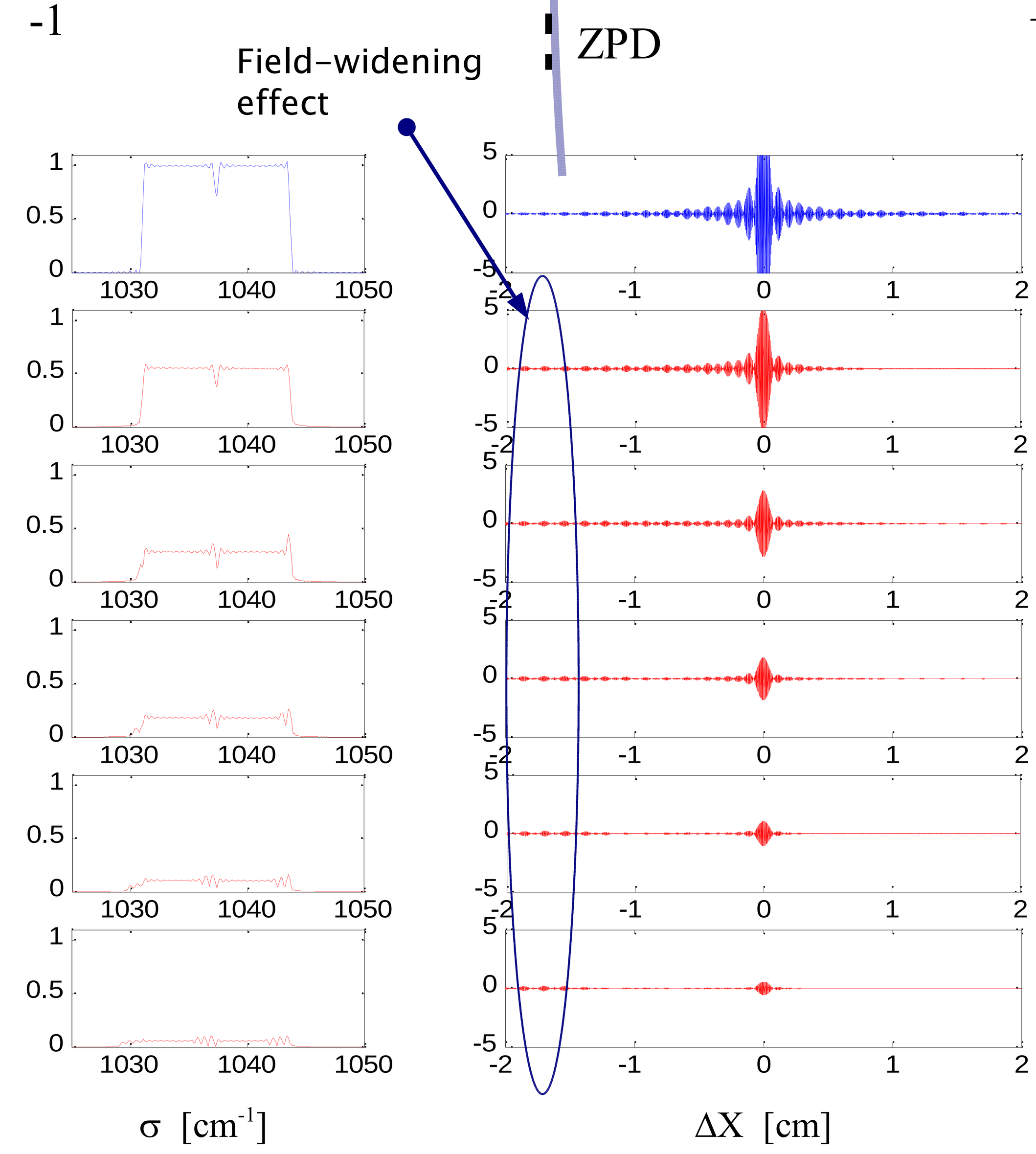
Due to astigmatism, the plane where the fringe curvature vanishes depends on the azimuthal angle ϕ. We can see that fringes are infinite in the x or y dimension for the rays with angle ϕ = 0 and ϕ = π / 2 respectively. When the plate angle is α = 0, there is no more astigmatism and a single plane of infinite fringes is observed in the field of view.

Numerical integration of the complex ILS

Simulation of the spectra of a FTS with a 1-cm-thick KBr plate introduced in one arm with no angle.

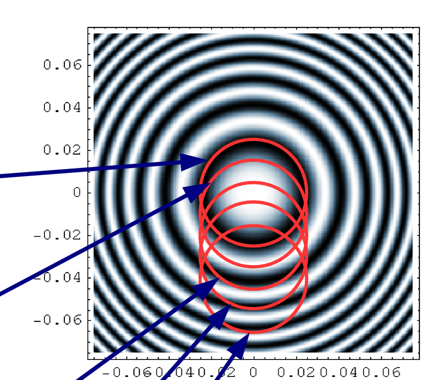
The spectrum is flat from 1031.25 to 1043.75 cm^{-1} with an absorption line at 1037.5 cm^{-1}.

The blue curve is obtained from an on-axis detector without the plate, and the red curves show the plate influence for different detector positions.



Circular detector and off-axis effect

The interferograms correspond to a circular detector of 0.025f radius centered at 0, 0.01f, 0.02f, 0.03f and 0.04f of the optical axis in the image plane, where f is the focal length.



INSTRUMENT LINE SHAPE

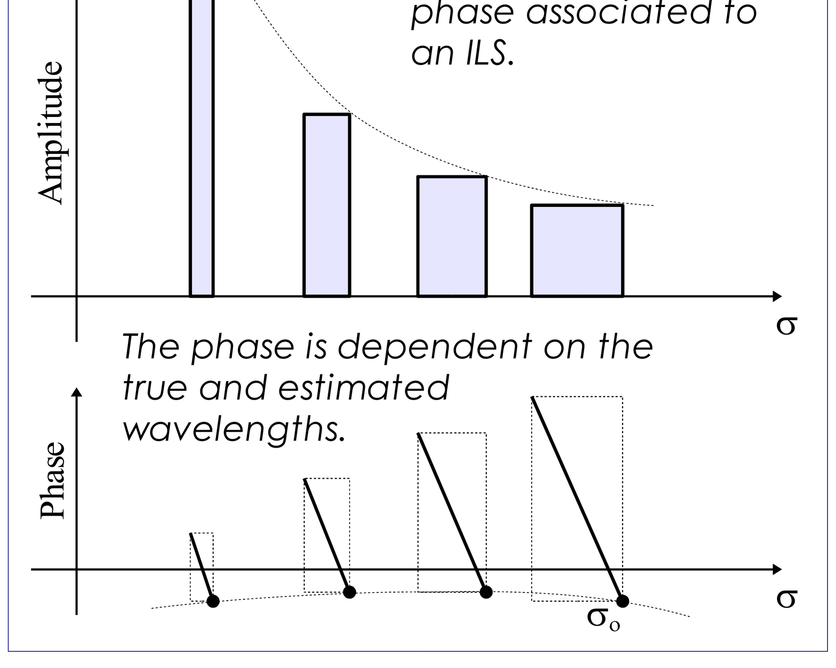
— An FTS with an uncompensated beam splitter (or a field-widened interferometer) results not only in a dispersed interferogram, but it also produces asymmetrical modulation efficiency losses. Theses effects, which are wavelength dependent and off-axis angle dependent, can be taken into account by a *complex instrument line shape* (ILS). An uncompensated plate changes slightly the ILS amplitude, however the ILS phase undergoes a much more dramatic effect. Such large phase changes over the ILS extent result in interferences between nearby line shapes. These interferences are the spectral counterpart of the modulation efficiency losses.

The slight effect of an uncompensated plate on the ILS amplitude is due to the astigmatism, or the ϕ angle dependence, which is usually weak. In the case of a non inclined plate (α = 0), the ILS amplitude is not changed by the dispersive plate. Therefore, ILS models can be used directly with a phase added to include dispersive and field-widening effects.

The ILS phase is dependent on both true wavelengths of the source (optical wavelengths) and estimated wavelengths of the measurement (Fourier domain). It is not a multiplicative effect on the spectrum due to spherical aberration.

ILS scheme

Illustration of the phase associated to an ILS.



CONCLUSION

— The use of an uncompensated beam splitter produces effects already known in field-widened interferometers. Theses effects are modeled on the instrument line shape by adding a phase which is dependent on both the true wavelengths of the source and the estimated wavelengths of the measurement. The concept of complex ILS leads to consistent results when integrated with numerical algorithms to synthetic spectra.

Our future work includes :
- Evaluating the compensation required to ensure these problems are not present;
- The impact of complex ILS on existing phase correction and complex calibration algorithms;
- Analyzing the impact of nearby lines interference on retrieval.

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