Photon noise limited Doppler measurement with a Fourier transform seismometer

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Abstract

The photon noise limited performances of a Fourier transform seismometer for ground-based asterosismological observations are computed. Simulations are conducted for a set of stars of type close to solar, with V magnitude equal to 4, and $v \sin i$ from 0 to 40 km s^{-1}.

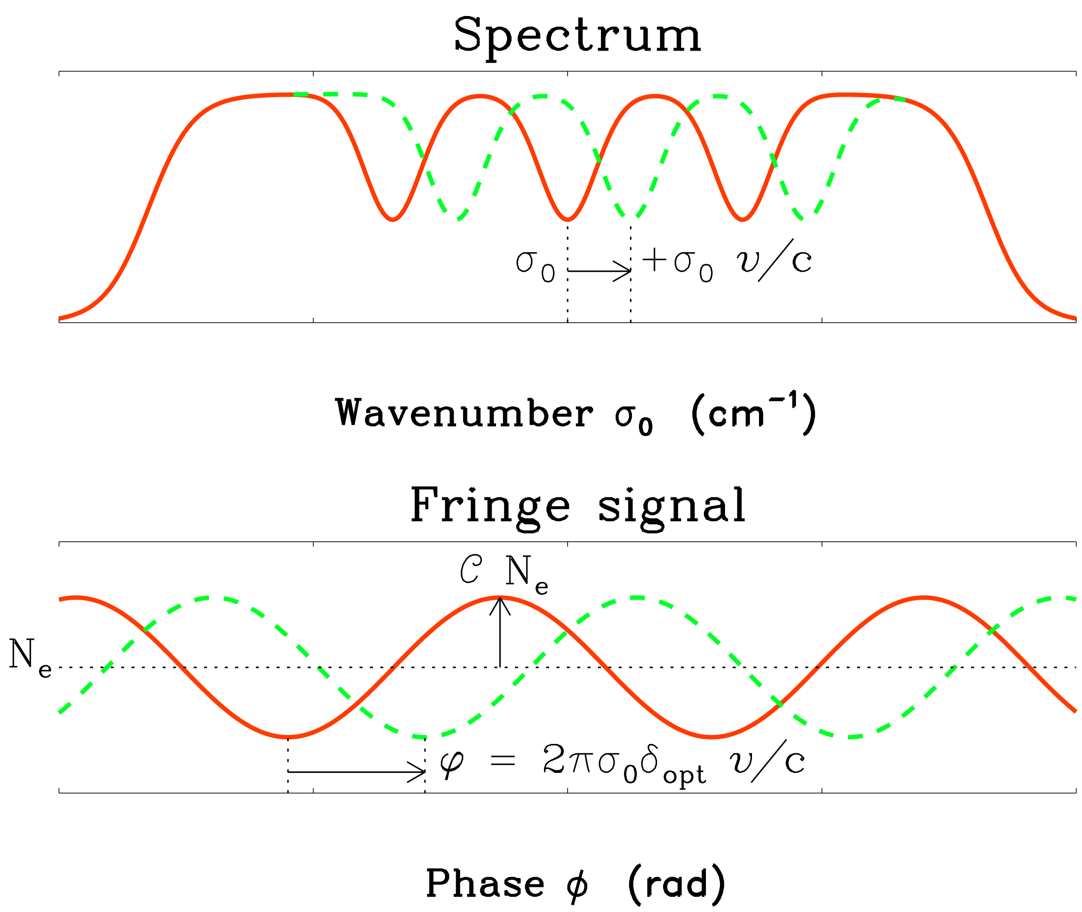
The best instrumental configuration includes a low-resolution post-disperser, which covers a large portion of the visible domain. The final results are presented as the ratio of the performances of the FT seismometer to the minimum radial velocities obtained with a grating spectrometer, on the same stellar targets. This ratio varies roughly between 1 and 2.

The FT seismometer can make a challenging solution, for a network dedicated to asteroseismology. Such a network is intended to provide ground based spectrometric asteroseismic measurements, complementary to photometric measurements provided by incoming space missions as Corot or Eddington.

Due to the fact that the instrumental principle is simple, stable, monolithic, and does not involve moving parts, space applications are possible.

1.1 - Principle

The Doppler signal is searched in the interferogram of a stellar spectrum limited by a filter (bandwidth $\Delta\sigma$). The observable is the phase shift φ



1.2 - Performances / photon noise

The photon noise velocity performance $\delta v_{\rm rms} = \dfrac{c}{Q\sqrt{N_{\rm e}}}$ depends on :

- The quality factor : $Q = \sqrt{2}\pi\ \sigma_0\delta_{\rm opt}\ \mathcal{C}$

– the wavenumber σ_0 and optical path difference (opd) $\delta_{\rm opt}$ are related to the stellar line width Δv : $\sigma_0\ \delta_{\rm opt}\ \propto\ 1/\Delta v$

– $\mathcal{C}$ is the fringe contrast at opd $\delta_{\rm opt}$

- The number of detected photoelectrons $N_{\rm e}$:

– depends on luminosity of the instrument

– increases with the filter bandwidth $\Delta\sigma$

Hiatus: when $N_{\rm e}\ \nearrow$ because $\Delta\sigma\ \nearrow$, then $\mathcal{C} \searrow$ and $Q \searrow$

Solution: Fourier Interferometer + Post-dispersion

2.1 - Simulations

Simulations :

from synthetic spectra of dwarf stars	$T_{\rm eff}$ 5000 to 7000 K
range	380 - 680 nm (14700 - 26300 cm^{-1})

Parameters :

V magnitude	0 to 6
rotational velocity $v \sin i$	0 to 80 km s^{-1}

Conditions :

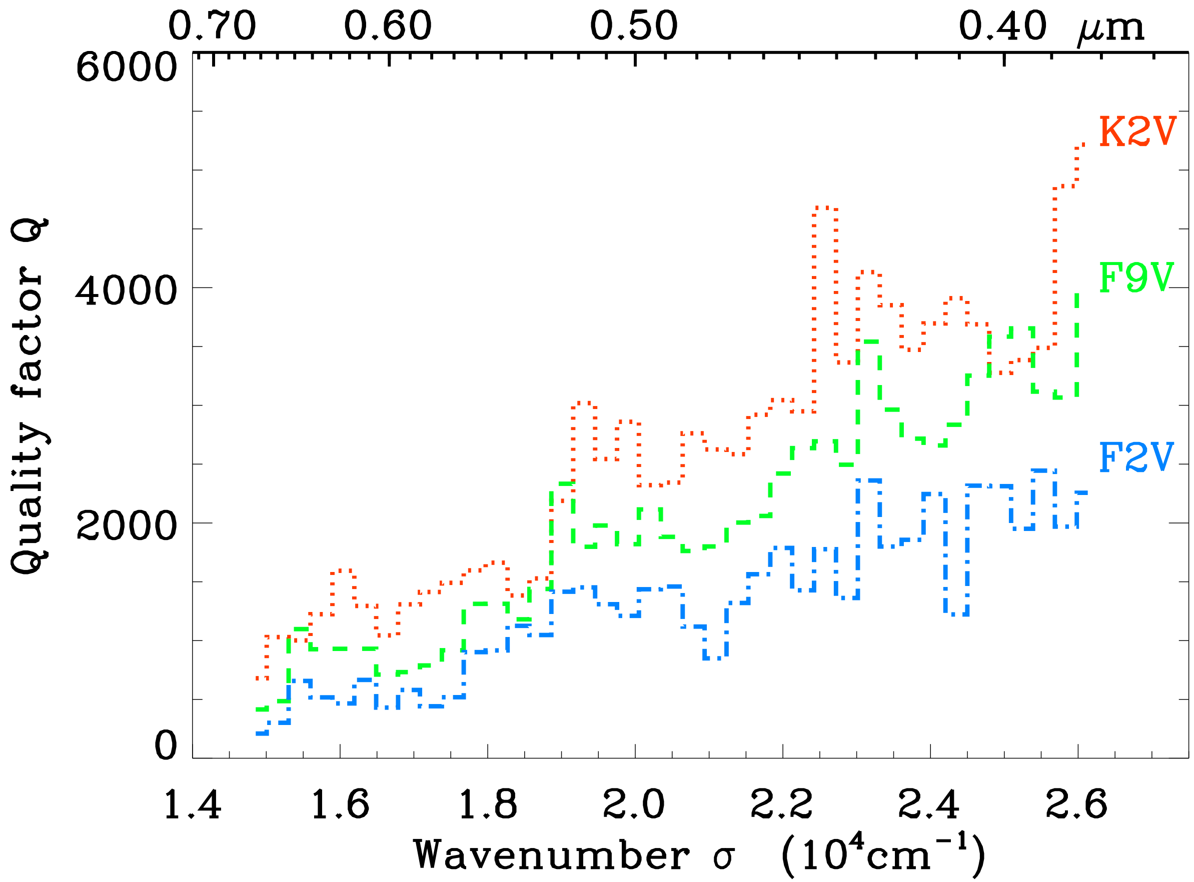
2-m class telescope; conservative duty-cyle =50%

- Calculation of the best photon noise limited performances
- Comparison with a grating spectrometer (Bouchy et al. 2001, A&A 374, 733)

2.2 - Quality factor

Q / spectral type

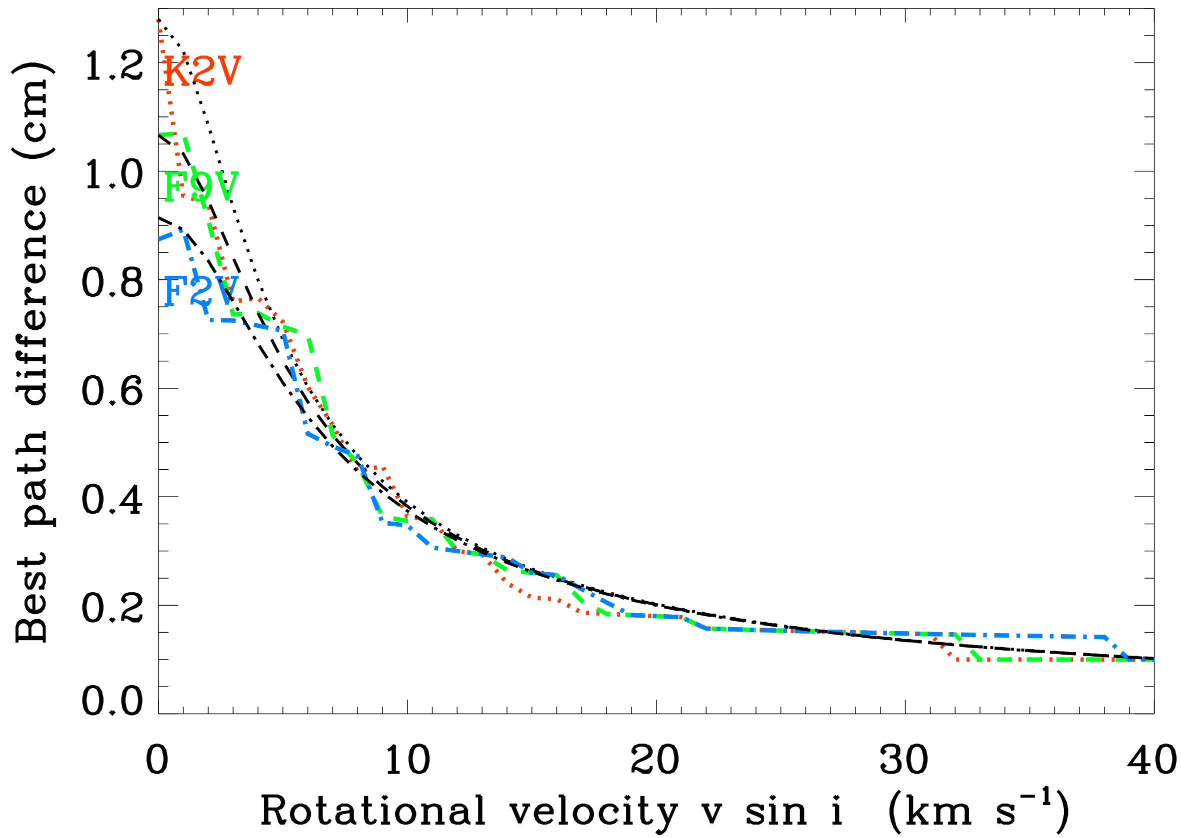
High values of C, hence Q, are obtained in the blue part of the stellar spectra



The instrument has to be optimized for the blue part of the spectrum

2.3 - Best path difference

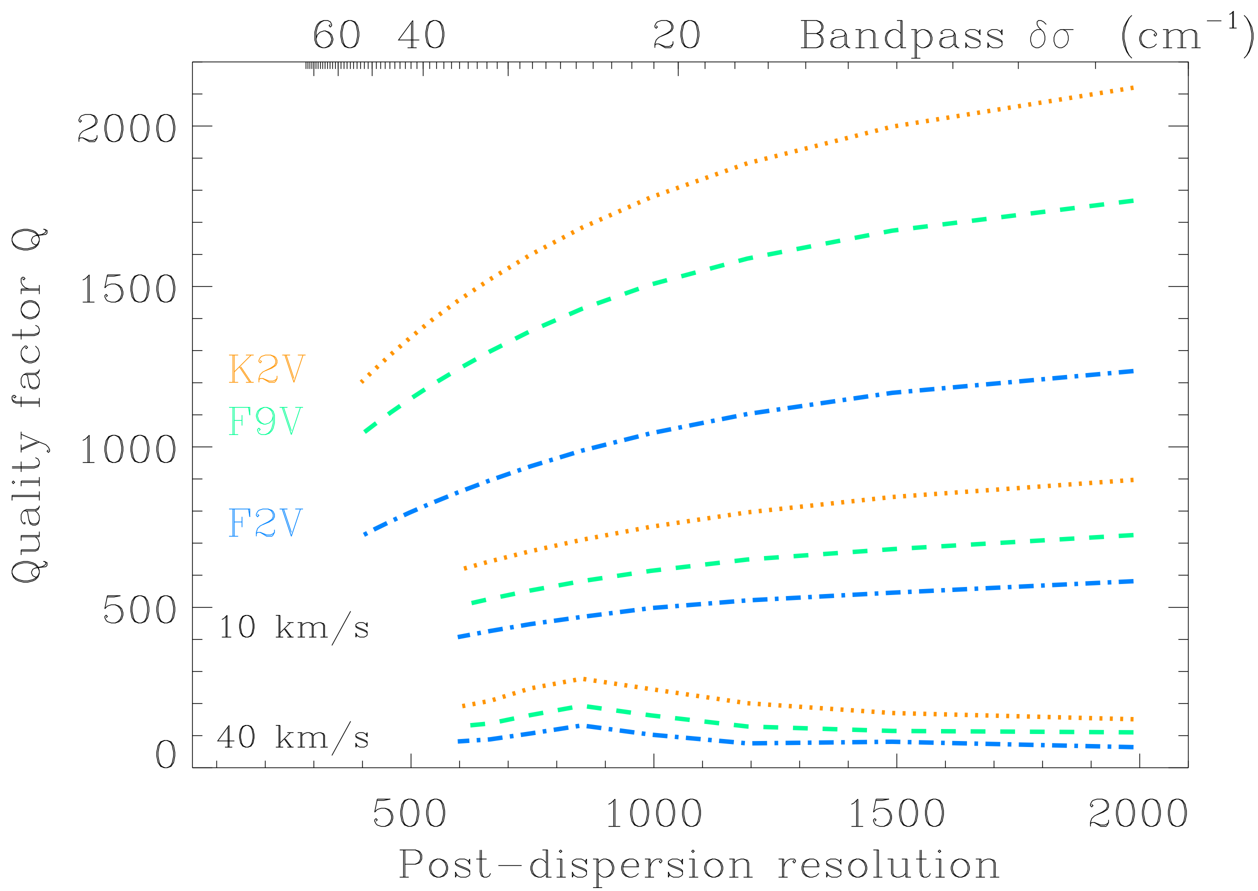
Best opd δ_{opt} / type spectral and rotation.
Performances remain efficient in a large domain of δ around the best opd value.



Maximum opd < 1.2 cm $\Longrightarrow$ small instrument size

2.4 - Resolution of post-disperser

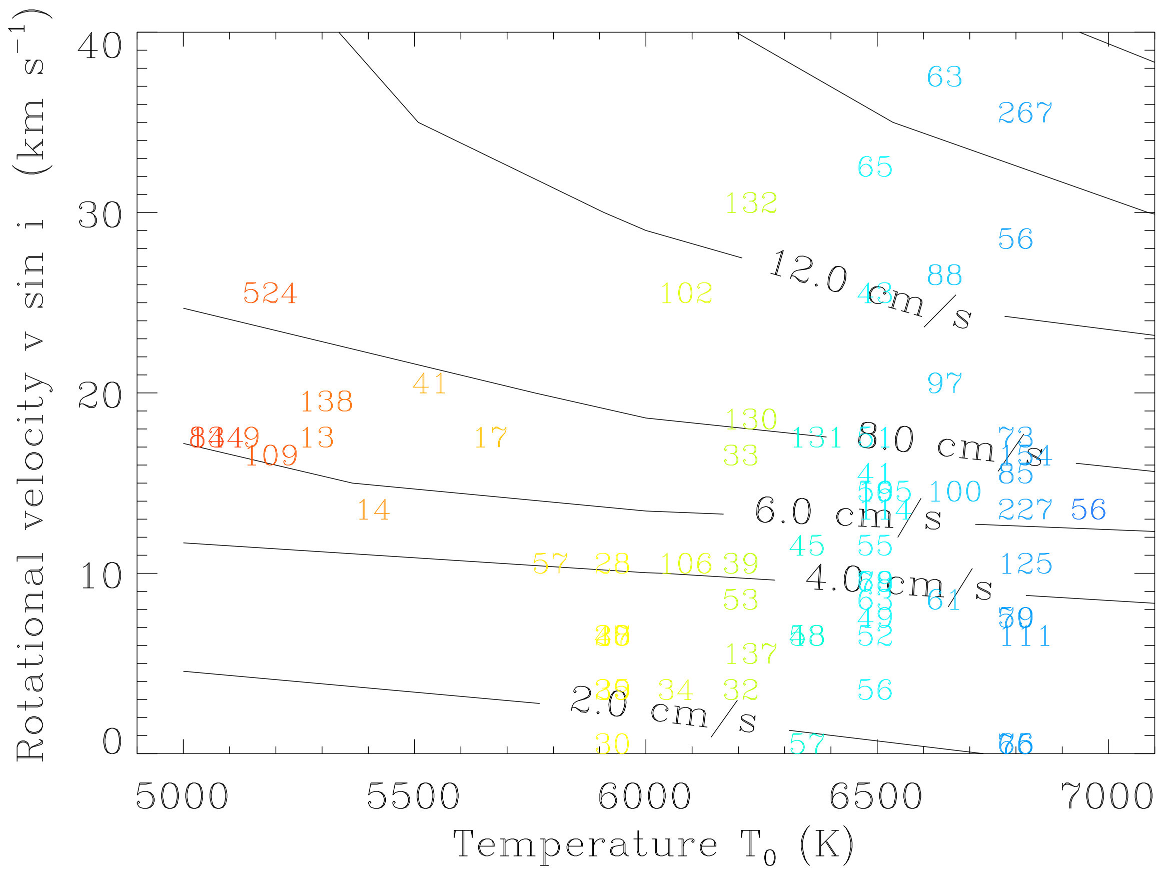
Quality factor of the stellar spectrum as a function of the resolution of the post-disperser



Resolution of the post-disperser can be limited to 1200

3.1 - Performances

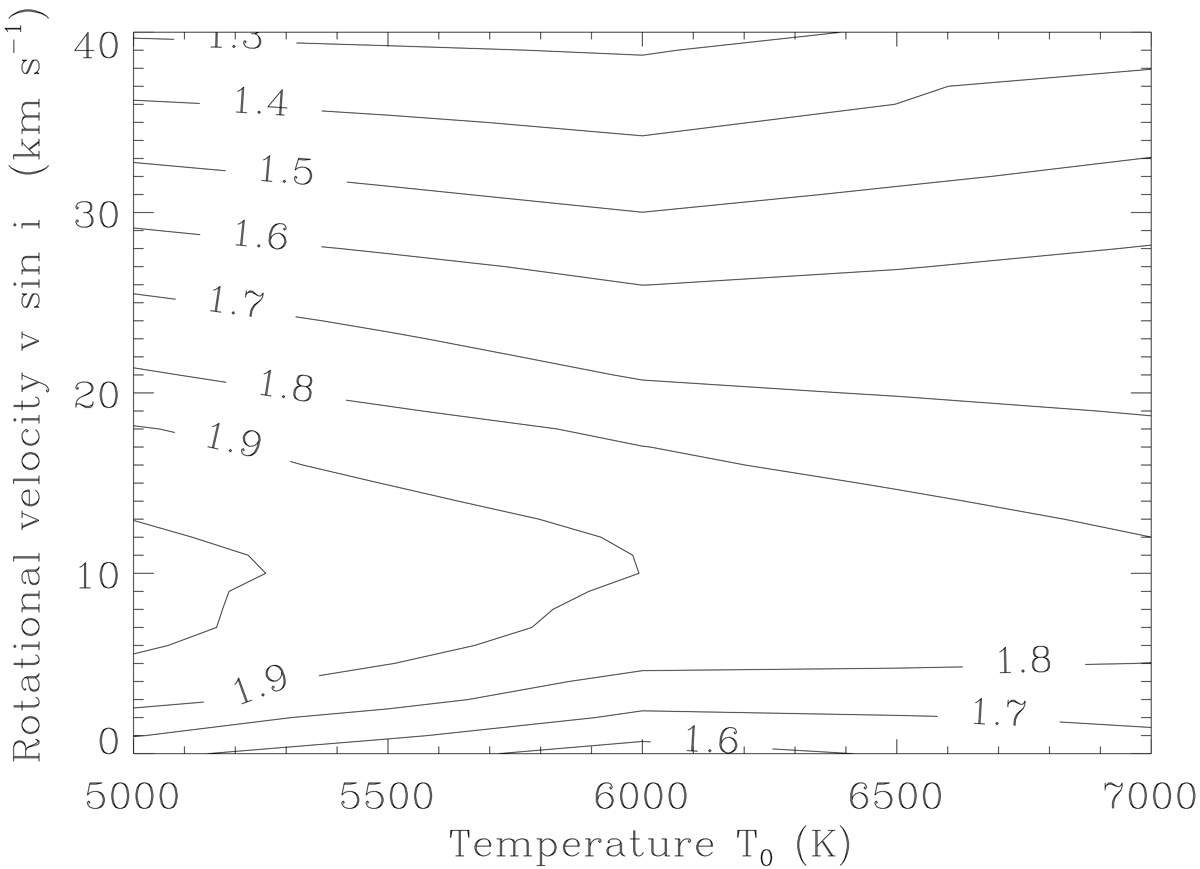
Performances (2-m class telescopes, 5 nights observation, duty cycle of 50%, and V=4 star), compared to expected p-mode amplitudes of seismic targets (class IV and V)



More than 80 IV or V class stars can be measured with the FTS ; > 300 including red giants (as ξ Hya, Frandsen et al. 2002, A&A 394, L5)

3.2 - FTS / GS (grating spectrometer)

Ratio $\delta v_{\mathrm{FTS}}/\delta v_{\mathrm{GS}}$; performances obtained with the FTS (R=1200) and a grating spectrometer (R=88000) as Harps (Bouchy et al. 2001, A&A 374, 733)



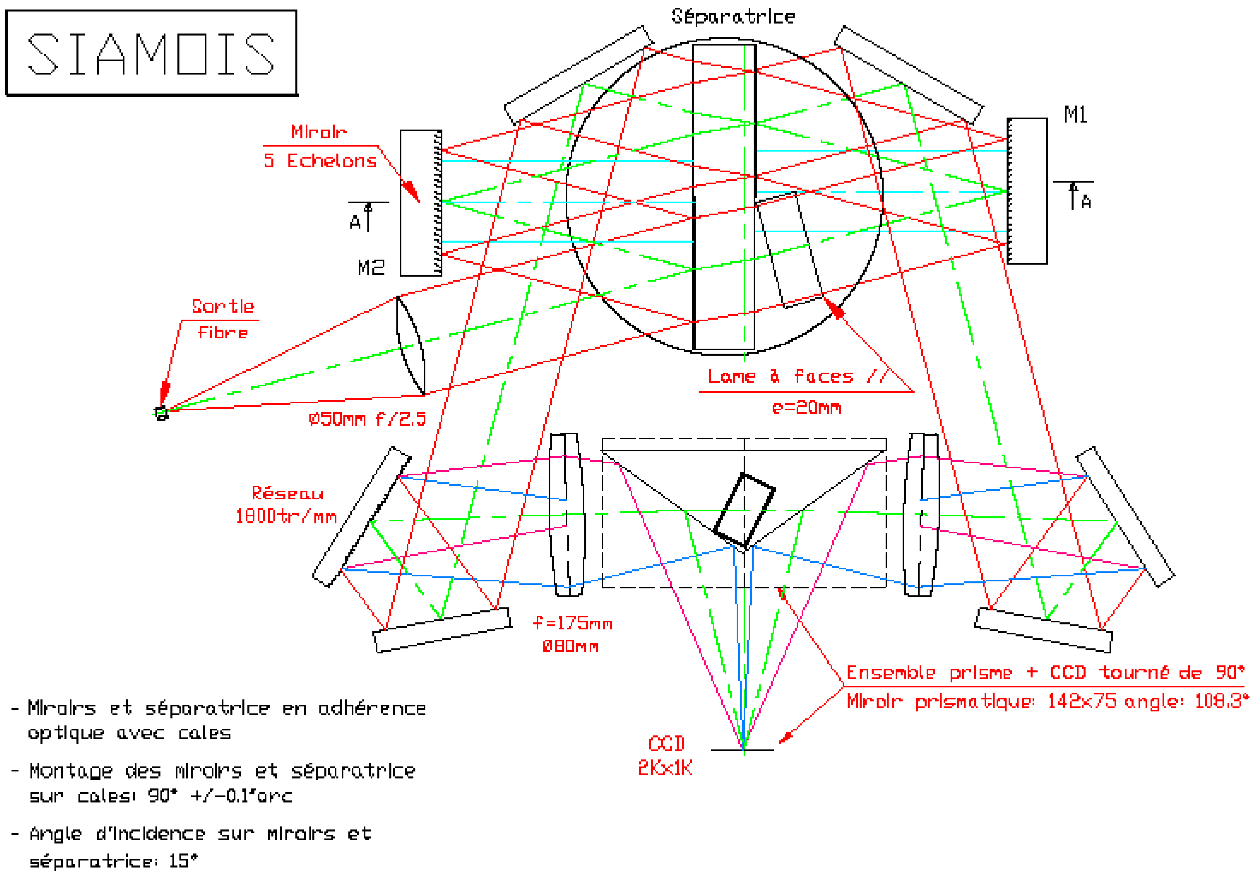
FTS less efficient than GS, but very similar photon noise limited performances: $\delta v_{\mathrm{FS}}/\delta v_{\mathrm{GS}} < 2$

4.1 - Concept

- feeding of the instrument from the telescope by optical fiber
  a single 60μm fiber, 1.5” on the sky
- an optical fiber adapter $f/2.5$ — stabilization of star image
- fixed o.p.d — by a parallel plate in one arm
- sampling of a fringe — by 5 points
- one mirror of the interferometer — 5 steps of depth = $\lambda_0/10$
- post-dispersion by two low-resolution gratings — R=1200
- two folding mirrors for cross-separation of the 5 channels

4.2 - Design

no adjustment;
no servo-system;
no electronics control;
no moving parts



High stability, simplicity, small size, reduced cost

Conclusion

- Efficient performances
- Possible solution for a network (2-m class telescope)
- Efficient for stellar magnitudes up to 6, $v \sin i$ up to 40 km s^{-1}
- Small, simple and monolithic instrument
- Space applications possible

Photon noise limited Doppler asteroseismology with a Fourier transform seismometer I. Fundamental performances

Mosser, B., Maillard, J.P., & Bouchy, F. 2003, PASP