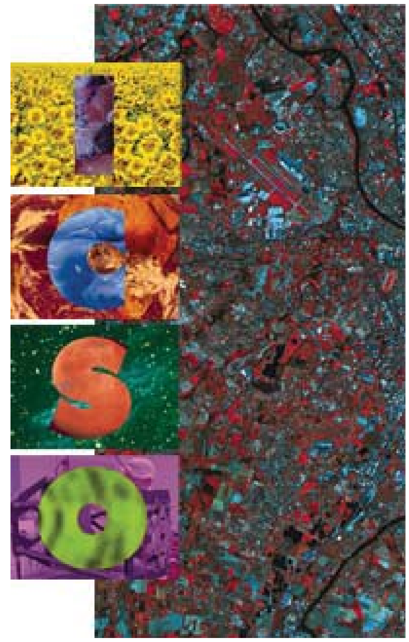
International Conference on Space Optics—ICSO 2000

Toulouse Labège, France

5–7 December 2000

Edited by George Otrio



Prospects for the design of an ultraviolet imaging Fourier transform spectrometer

Philippe Lemaire

International Conference on Space Optics — ICSO 2000, edited by George Otrio, Proc. of SPIE Vol. 10569
1056913 · © 2000 ESA and CNES · CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307873

PROSPECTS FOR THE DESIGN OF AN ULTRAVIOLET IMAGING FOURIER TRANSFORM SPECTROMETER

Philippe LEMAIRE

Institut d'Astrophysique Spatiale, Université de Paris XI, Bât. 121, 91405 Orsay Cedex (FRANCE)

ABSTRACT – *Recent results from solar observations in the far and extreme-ultraviolet (FUV/EUV) obtained from SOHO (SOlar and Heliospheric Observatory) and TRACE (Transition Region Camera) show the extreme variability of the solar atmosphere. Within the limited resolution of the instruments (1-2 arcseconds) horizontal and vertical velocities up-to 100 to 400 km s^{-1} have been measured. With an horizontal velocity of 100 km s^{-1} an one arsecond structure crosses the one arcsecond slit width of a classical slit spectrometer in less than 10 seconds. In the future, with higher angular resolution (e.g. 0.1 arcsecond), the capability to study small structures will be greatly reduced by a classical slit spectrometer.*
To be able to characterize the small scale solar atmospheric structures formed in the 10^4 K to 10^6 K temperature range (which emit in the 30 to 180 nm wavelength range) a spectrometer without slit (or with wide slit) is required. At the same time to obtain an accurate measurement of the doppler velocity an high spectral resolution is needed. The two requirements, high spectral resolution and large slit, are difficult to be simultaneously fulfilled with a classical slit spectrometer within the limited volume of a space instrumentation. Also, we propose to use an Imaging Fourier Transform Spectrometer (IFTS) to provide simultaneously a bidimensionnal field and an accurate determination of line profiles and positions.
The development of Fourier Transform Spectrometers (FTS), although popular in the infrared, has been very limited in the UV/FUV by the lack of very high quality beam splitter. Since 10 years, the use of diffraction gratings as beam splitters has been suggested and few intruments have been built ([Chak 94]; [Clea 92]; [File 00]). These instruments illustrate some applications in the new wavelength domain opened by using a beam splitter grating, but do not yet provide the full capabilities of an FTS.
In this paper we present several optical schemes which can provide the full capabilities of a complete IFTS in the FUV/EUV spectral range.

1 – INTRODUCTION

Spectrometry is a powerful tool to analyze and characterize laboratory, atmospheric and astrophysical plasmas. Low density, high temperature plasmas (greater than few thousand degrees) have strong emission lines in the ultraviolet (UV) wavelength range (from 200 nm down to 0.1 nm, far ultraviolet –FUV-to x-ray range) and the study of the plasma properties (density, temperature, velocity,…) requires the use of specific instrumentations.
The observations of the upper solar atmosphere are currently done by a set of instruments on SOHO and by TRACE (Transition Region And Coronal Explorer). The SOHO spectrometers (SUMER, [Whil 97] and [Lema 97]; CDS, [Harr 97]) and imager (EIT, [Mose 97]) have shown that the solar atmosphere is strongly structured and in continuous agitation. This has been confirmed and extended by the TRACE high resolution images ([Schr 99]). With angular resolutions ranging from 1-2 arcsec (SUMER) and 2-3 arcsec (CDS) the average line Doppler shifts are below 15 km s^{-1}, but in several locations (mainly along the bright chromospheric network and in active regions) very high velocity short duration events (up-to several hundred km s^{-1} [Inne 97]) or continuous flows (several ten km s^{-1} [Brek 97]) have been detected. The horizontal velocities measured on the solar surface, from EIT and TRACE images, give also very high values (several hundred km s^{-1}, [Mose 97] and [Schr 99]) in some locations.
In a classical spectrometer with an entrance slit (which defines the spectral resolution) it is necessary to keep the slit width as small as possible, e.g. the nominal slit widths in SUMER and CDS are 6.3 μm (1 arcsecond on the solar image) and 25 μm (2 arcseconds) respectively. At 72 km s^{-1} an event crosses the SUMER slit in 10 seconds and the CDS slit in 20 seconds, making difficult to obtain information on its properties (acceleration, slow down, shocks,..). In the future, the angular resolution will be increased to separate the filamentary components of the transition region and coronal loops; very high velocities events will emerge from the velocities averaged over 1 arcsecond and will cross a smaller angular slit width (to keep up with the angular resolution). A classical slit spectrometer has limited capabilities to cope with the new observational constraints in the FUV and extreme UV (EUV) wavelength ranges.
An imaging Fourier transform spectrometer (IFTS) has the capability to make simultaneous spectral analysis of bi-dimensional images (on a 2-D array). This capability begins to be used in the infrared owing to the development of fast detectors and computers needed to record and to reduce the data [Mail 95].
The application of the classical FTS (with semi-transparent beam splitter) has been done in laboratory down to the cut-off of fused silica (150 nm). Further downward there is no transparent material of optical quality good enough to be used as a beam splitter and few attempts have been done to build FTS with either the wave front division or the grating amplitude division but with limited imaging capability.
After a presentation of the status of to-day UVFTS we give some typical requirements for a solar UVIFTS and the resulting critical parameters. Then, we present and discuss several possible optical schemes able to fulfill the requirements.

2. FTS USING GRATING BEAM SPLITTER.

Since the realization of gratings the splitting of the incident beam into several orders has been used as a tool to develop specific spectrometer [Baru 11].
In 1959 P. Connes [Conn 59] has proposed an FTS using a grating to split and to recombine the beam. The FTS was proposed for the far infrared, where at the time no beam splitter was existing, and was optimized for one wavelength and a complicated motion of the mirrors was performed to make the scan.
In 1972, the description of an all-reflection Michelson interferometer using 3 gratings (one as a beam

splitter and 2 to cancel the dispersion) has been done ([Krug 72]). More details on the instrument have been published later ([Krug 73]) with the application to infrared Fourier spectroscopy ([Fonc 78]). This set of papers can be used as a reference for the instruments proposed in the ultraviolet.
Cleary [Clea 92] has built an all-reflection Michelson interferometer using a concave grating in the Rowland mounting to split and to recombine the beam. To separate the input and output beams on the grating, the grating is used off-plane and the size of the aberrations (with large astigmatism) precludes to make good images.
An interesting concept of an FTS without moving part was proposed and built ([Roes 90], ([Wels 91], [Chak 94]). The diffracted beams from the grating +1 and –1 orders come back as –1 and +1 to recombine on the grating. The interference fringes are imaged on the detector (resolution limited by the detector size) and every point in the entrance aperture contributes to any point in the interferogram. The mix-up between the x and y axes of the input image can be only disentangle by a rotation of the interferometer and a tomographic reconstruction [Smit 95].
One can also use the 0 and 1 grating orders to split and recombine the beam ([File 00]). This provides an ad hoc solution to very small wavelength interval, with nearly monochromatic source and very coarse angular resolution.
These late optical scheme have limited capacity to make 2-D imagery ought to the asymmetry introduced by the grating. Hereafter we take advantage of the Kruger ([Krug 72]) scheme to overcome this difficulty.
The general grating equation is:

$$\cos\varphi\,(\sin\alpha + \sin\beta) = n\,k\,\lambda\;\;10^{-6} \qquad (2.1)$$

where φ is the off-plane incident angle (the reference plane is perpendicular to the ruling axis),
α and β are the incident and diffracted angle in the reference plane,
n and k are the number of lines/mm and grating order respectively,
λ is the wavelength expressed in nm.

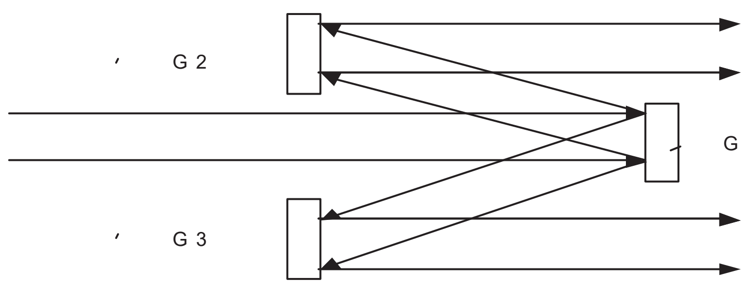


Fig.1: A grating beam splitter using +/- 1 grating orders in subtractive dispersion. In this case G1, G2, G3 gratings have the same lines/mm number.

In case of an in-plane grating G1 with $\alpha = 0$ incident angle, the diffracted beam (with an angle β) is collected on grating G2 (same ruling density as G1, parallel and facing G1) with β incident angle and gives a diffracted beam on its normal with zero dispersion. The combination of the 2 gratings is equivalent to an optical filter with a wavelength pass-band (with a trapezoidal profile) which is a function of the ruling density, the distance between the 2 gratings and the size of each grating. The central wavelength of the filter can be selected by adjusting the distance between the 2 gratings.
A collimated input beam on the first grating gives a collimated beam parallel to the input beam ([Murt 74]). The first grating can be used in orders +1 and –1 (beam splitter) with two second gratings (Fig.1) to provide two parallel output beams as we will use in following mounting schemes.
As an example, a set of gratings with the following parameters:

- 3600 lines/mm, optimized for 120 nm,
- 60 mm distance between G1 and the G2/G3 planes,
- 20 mm width of G1 (and 25 mm width of G2 and G3)

provides a 20 nm pass-band width. Increasing the 60 mm distance to 74.5 mm changes the central wavelength to 100 nm (49.2 mm distance gives 140 nm) with nearly the same pass-band width.
The G1 beam splitter grating must have similar efficiency in +1 and –1 orders to obtain the highest contrast in the interference fringes. To optimize the efficiency G2 and G3 gratings must be blazed for the central wavelength of the interferometer useful pass-band.

3. SOLAR REQUIREMENTS FOR AN UVIFTS

From the experience gained on SOHO, we can put some guidelines for the development of an UVIFTS:

- resolving power from 20,000 to 40,000 to obtain emission lines profiles of element species at several stage of ionization. The accuracy of the line position (to determine Doppler velocities down to 1 km s^{-1}) is compatible with this resolving power.
- simultaneous 2-D imaging of a 30 arcsecond diameter field, corresponding to an average supergranular cell on the solar image. 0.1 arsecond angular resolution (objective to be fulfilled at Sun-Earth distance, one astronomical unit, 1 AU).
- scanning time of a 10-20 nm spectral range in 10-20 seconds to follow the evolution of fast events with 1 minute lifetime.
- image stigmatism all across the field. A goal of 0.1 arsecond angular resolution (objective to be fulfilled at Sun-Earth distance, 1 AU) seems realizable.

From the requirements we can derive some critical parameters for a 120 nm reference wavelength and 20 nm pass-band width.

- The scanning range (L) or total path difference is related to the resolving power (R) by

$$L = (\lambda\ R) / 2 \qquad (3.1)$$

With the above parameters we obtain L = 1.2 (2.4) mm or, using a scanning mirror which doubles the path difference, we have 0.6 and 1.2 mm respectively.

- The minimum sampling interval is given by

$$\Delta x \leq \lambda_{min} / 2 \qquad (3.2)$$

with λ_{min} = 100 nm, $\Delta x \leq 50$ nm gives the 25 nm mirror step.

- The accuracy of the scanning must be a fraction of the step or few nanometers.

4. SOME OPTICAL SCHEMES

4.1 Amplitude division

We present 2 schemes with similar parameters for a solar UVIFTS observing the Sun at one AU with 0.1 arcsecond angular resolution.
An off-axis parabola (2 m focal length) provides a solar image on the 30 arcsec entrance hole (0.29 mm diameter) of the spectrometer. The throughput beam is collimated by a small off-axis parabola (size 18 x 24 mm^2, 160 mm focal length) and diffracted by the grating and beam splitter G1 (3600 l/mm). The +1 and –1 orders are collected by the G1 and G2 gratings which cancel the dispersion (3600 l/mm). Then one beam is folded by a fixed plane mirror, while the other one is folded by a scanning plane mirror which provides the optical path difference. The two folded beams are either send back (Fig. 2) in reverse to the grating assembly to be recombined and refocused (off-axis parabola, 2 m focal length) or directly recombined at the off-axis parabola focus (Fig. 3). The 25 m total equivalent focal length provides a stigmatic image with a scale of 12.5 µm / 0.1 arcsec in the detector plane (computations performed with ZEMAX™).

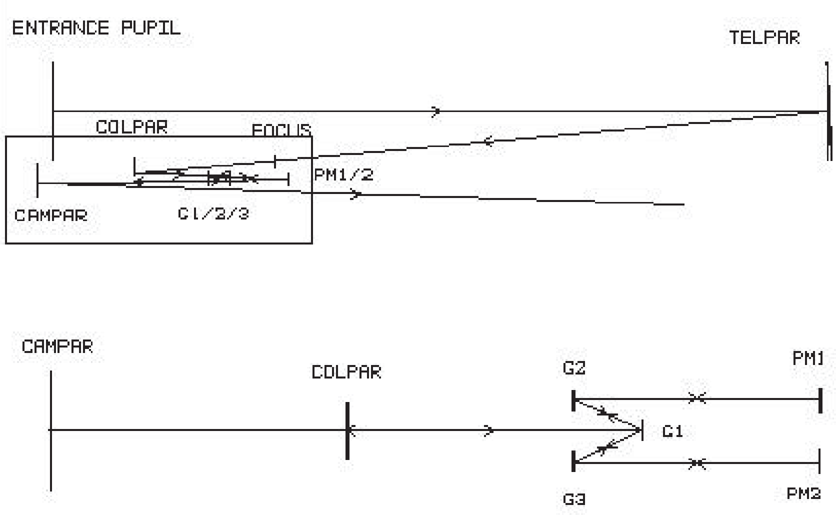


Fig. 2: Optical scheme with double passage through a subtractive tandem grating.
Top: the full instrument with telescope (off-axis paraboloid: TELPAR), focus (FOCUS), collimator (off-axis paraboloid: COLPAR), plane grating set (G1,G2,G3), plane mirror set (PM1,PM2) and camera mirror (off-axis paraboloid: CAMPAR).
Bottom: top box enlargement at 90 degrees with collimator output beam diffracted on G1, dispersion cancelled on G2 and G3, reflected on PM1 (moving mirror) and PM2 (fixed mirror), dispersed again in G2 and G3, recombined with cancelled dispersion on G1, and then focused by CAMPAR.

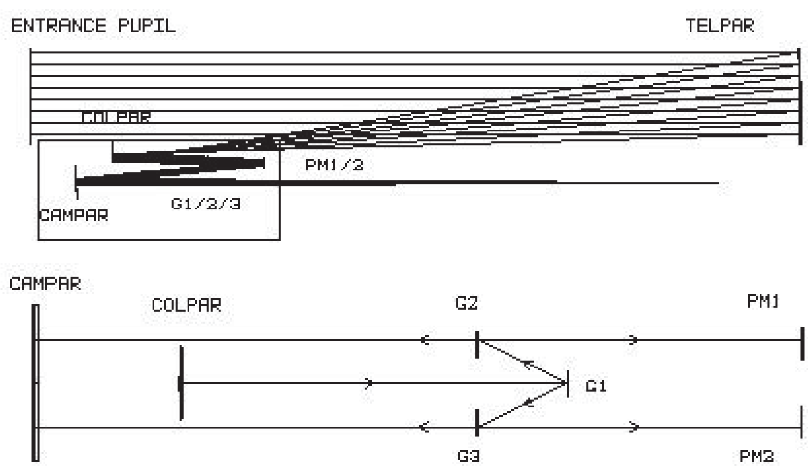


Fig. 3: Optical scheme with single passage through a subtractive tandem grating.
Top: the full instrument with telescope (off-axis paraboloid: TELPAR), focus (FOCUS), collimator (off-axis paraboloid: COLPAR), plane grating set (G1,G2,G3), plane mirror set (PM1,PM2) and camera mirror (off-axis paraboloid: CAMPAR).
Bottom: top box enlargement at 90 degrees with collimator output beam diffracted on G1, dispersion cancelled on G2 and G3, reflected on PM1 (moving mirror) and PM2 (fixed mirror), recombined and focused by CAMPAR.

The maximum spectral resolution of an FTS matched to a telescope is given by ([Mail 95])

$$R = 8 / \phi^2 \; (d / D)^2 \qquad (4.1)$$

with ϕ the total angular field on the sky, D the telescope diameter and d the diameter of the beams in the FTS. Using the selected parameters (ϕ = 30 arcsec, D = 300 mm and d = 24 mm) the resolving power is limited to 2.4 10^6 well above the required resolving power. For the specified resolving power (4 10^4) the theoretical field is limited to 10 degrees; it is evident that the telescope and the FTS aberrations will be the main limitation of the field (e.g the telescope is a section of a F = 3 parabola which has a 0.1 arcsec coma at 15 arcsec from the center of the field).

In such optical schemes the quality of the optical surfaces is critical since the interference of the 2 beams must be better than $\lambda/4$ at the wavelength of measurement ($\approx \lambda/16$ at 500 nm). The advantage of the small beam size in the spectrometer makes it possible to realize flat optical surfaces with very good optical quality ($\approx \lambda/100$ at 500 nm).

The smoothness and the range of the scan can be provided by piezoelectric devices which give nanometer accuracy. The parallelism of the mirror displacement has to be kept within 0.1 arcsec (within the capability of tip/tilt nanomechanisms). Accurate linear motions for soft x-ray interferometry have already been produced ([Duar 97]).

4.2 Wave-front division

For some specific case it can be interesting to split the beam at the telescope entrance and to work with a wave-front division FTS. This scheme has been developed to look at interference fringes (Young experiment, Fresnel mirrors, …) or to measure the optical path difference between two mediums with different refractive indices (Rayleigh interferometer). One recent application in the Michelson stellar interferometer is the measurement of angular dimensions of sources. The same Michelson interferometer can combine spatial and spectral resolutions ([Stee 95]).

Some types of wave-front division interferometers have been described by Möller ([Möll 95]). A recent measurement made at 1.25 keV (about 1 nm) has shown the capability to produce interference fringes in grazing incidence ([Cash 00]).

A wave-front division scheme can be attractive in the case of the observations that will be performed on board the Solar Orbiter (a solar probe studied by ESA to make observations down to 0.2 AU from the Sun). At 0.2 AU distance an advantage is the improvement of spatial resolution: the 72 km resolution on the solar surface (near disk center) corresponds to 0.5 arcsec (instead of 0.1 arcsec at 1 AU), but the disadvantage is the increase (factor 25) of solar flux on the telescope mirror. In this case a small collecting surface with reduced field and focal length can provide similar resolution to a larger telescope at 1 AU.

The proposed scheme is shown in Fig.4.

Two sections (40 x 60 mm^2) of the 1000 mm focal length off-axis parabola telescope illuminated by the solar flux provide the solar image on a 0.72 mm hole (corresponding to 30 arcsec seen from Earth – 1 AU). The throughput beams are collimated by a small off-axis parabola (150 mm focal length) and folded by a fixed plane mirror (PM2 , 6 x 9 mm^2) and a scanning plane mirror (PM1, 6 x 9 mm^2) which provides the optical path difference. The two beams are focused and recombined by a small off-axis parabola (1000 mm focal length). The 6.66 m equivalent focal length gives a stigmatic image with a scale of 16 μm/0.5 arcsec at 0.2 AU (or 16 μm/0.1 arcsec at 1 AU).

Another version of this optical scheme is the introduction of a set of gratings with single passage to define the pass-band and to recombine the two beams before the camera mirror.

With the proposed scheme the telescope aberration (equivalent to the expected angular resolution at the edge of the field) will be the limiting factor. The criticality of the paraboloid shape has to be carefully investigated.

The simplicity of the optical scheme without gratings makes it very much appealing, but it is important to limit the pass-band to few hundred nanometers. This may be done partly by a selection of the mirror

coating and detector photocathode, but a specific study of a reflective filter made of multi-layers deposits on a mirror may be required.
Although with more optical surfaces, the introduction of a set of gratings to recombine the beams before the camera mirror has the advantage to provide the flexible pass-band. Also the surface quality required on the telescope, the collimator, the plane mirrors and the gratings is relaxed onto the camera mirror.

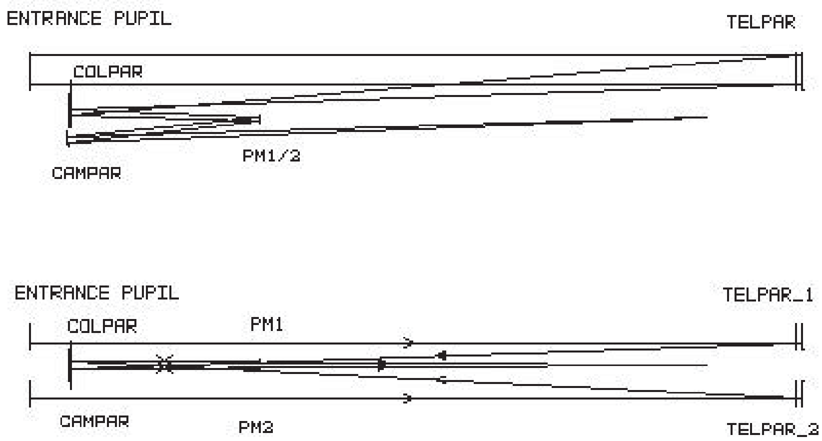


Fig. 4: Optical scheme with wave-front division on the off-axis parabola telescope.
Top: The full instrument with telescope (off-axis paraboloid: TELPAR), collimator (off-axis paraboloid: COLPAR), plane mirror set (PM1/2)and camera mirror (off_axis paraboloid: CAMPAR).
Bottom: view at 90 degrees; two equal sections (symmetrical) of the telescope are illuminated , then the beams combine to form an image at the focus and illuminate two sections of the collimator. The collimated beams are folded by a moving plane mirror (PM1) and a fixed plane mirror (M2), and are recombined by the camera mirror.

This kind of optical scheme with the potential use on a future space experiment merits to be studied in further details.

5. Conclusion

In this paper we have briefly reviewed the status of the development of the FTS in the UV to explore the possibility of making an UVIFTS.
With the goal of developing a solar UVIFTS we have looked at several optical schemes based either in amplitude division or in wave-front division. For each scheme two sets of optical path have been proposed and discussed.
This analysis shows that the building of an UVIFTS is realistic if enough care is given in the design and the study of the constraints. All the elements needed to reach this goal, although at the edge of to-day technology, are within hands:

- optical quality of mirrors is still rapidly improving,
- accurate nanomechanisms are available (reduction of size may be needed),
- accurate position controls (based on laser or capacitance) can be used,

An important component of the realization of an UVIFTS is the collection of photons (detector) and the analysis of the data. This was not the purpose of this paper, but it can be noted that fast UV detector arrays already exist, although there is still some possibility of improvement in quantum efficiency, speed, solar blindness …Also the fast development of small computer speed combined with the capacity of very large memory makes realistic the collection and processing of the huge amount of data which is produced during a spectral scan.

The potential of IFTS is very large and its extension in the UV may prove to be essential not only to study astrophysical plasma but also laboratory plasma.

REFERENCES:

[Baru 11] C. Barus: “The Interferometry of Reversed and Non-Reversed Spectra”, *Publ.* 149, Part I (Carnegie Institute, Washington, D. C., 1911).

[Brek 97] P. Brekke, O. Kjeldseth –Moe, R. A. Harrison: “High- Velcity Flows in an Active Region Loop System Observed wilth the Coronal Diagnostic Spectrometer (CDS) on SOHO”, *Solar Phys.* 175, pp.511-521 (1997).

[Cash 00] W. Cash, A Shipley, S. Osterman, M. Joy: “ Laboratory detection of X-ray fringes with a grazing incidence interferometer”, *Nature* 407, pp.160-162 (2000).

[Chae 98] J. Chae, H. S. Yun, A. I. Poland: “ Temperature Dependence of Ultraviolet Line Average Doppler Shifts in the Quiet Sun”, *Astro.Phys.J.Suppl.Ser.* 114, pp.151-154 (1998).

[Chak 94] S. Chakrabarti, D. M. Cotton, J. S. Vickers, B. C. Bush : “Self-compensating, all- reflection interferometer”, *Applied. Opt.* 33, pp.2596-2607 (1994).

[Clea 92] D. D. Cleary, J. W. Nichols, D. S. Davis: “Design for an all-reflection Michelson interferometer”, *Applied. Opt.* 31, pp.433-435 (1992).

[Conn 59] P. Connes :”Principe et réalisation d’un nouveau type de spectromètre interferentiel”, *Revue d’Optique* 38, pp.157-201, pp.416-441 (1959).

[Duar 97] R. Duarte, M. R. Howells, Z. Hussain, T. Lauritzen, R. McGill, E. Moler, J. Spring: ” A linear motion machine for soft x-ray interferometry“, *SPIE* 3132, pp.224-232 (1997).

[File 00] J. Filevich, K. Kanizay, M. C. Marconi, J. L. A. Chilla, J. J. Rocca: “Dense plasma diagnostics with an amplitude-division soft-x-ray laser interferometer based on diffraction gratings”, *Optics Letters* 25, pp.356-356 (2000).

[Fonc 78] R. J. Fonck, D. A. Huppler, F. L. Roesler, D. H. Tracy, M. Daehler : “All-reflection Michelson interferometer: analysis and test for far ir Fourier spectroscopy”, *Applied Opt.* 17, pp.1739-1747.

[Harr 97] R. A Harrison, A. Fludra, C. D. Pike, J. Payne, W. T. Thompson, A. I. Poland, E. R. Breeveld, A. A. Breeveld, J. L. Culhane, O. Kjeldseth_Moe, M. C. E. Huber, B. Aschenbach: “High-Resolution Observations of the Extreme Ultraviolet Sun”, *Solar Phys.* 170, pp.123-141 (1997).

[Inne 97] D. E Innes, P. Brekke, D. Germerott, K. Wilhelm:“Bursts of Explosive Events in the Solar Network“, *Solar Phys.* 175, pp.341-348 (1997).

[Krug 72] R. A. Kruger, L. W. Anderson, F. L. Roesler: “All-Reflection Interferometer for Use as a

Fourier-Transform Spectrometer", *J.Opt.Soc.Amer.* 62, pp.938-945.

[Krug 73] R. A. Kruger, L. W. Anderson, F. L. Roesler: "New Fourier Transform All-Reflection Interferometer", *Applied Opt.* 12, pp.533-540.

[Lema 97] P. Lemaire, K. Wilhem, W. Curdt, U. Schühle, E. Marsch, A. I. Poland, S. D. Jordan, R. J. Thomas, D. M. Hassler, J.-C. Vial, M. Khüne, M. C. E. Huber, O. H. W. Siegmund, A. Gabriel, J. G. Timothy, M. Grewing: "First results of the SUMER telescope and spectrometer on SOHO: II. Imagery and Data Management", *Solar Phys.* 175, pp.105-122 (1997).

[Mail 95] J.P. Maillard: "3-D Spectroscopy with a Fourier Transform Spectrometer", in 3D Optical Methods in Astronomy, G. Comte and M. Marcelin eds., *ASP Conference Series* 71, pp.316-327 (1995).

[Mose 97] D. Moses, F. Clette, J.-P. Delaboudinière, G. E. Artzner, M. Bougnet, J. Brunaud, C. Carabetian, A. H. Gabriel, J. F. Hochedez, F. Millier, X. Y. Song, B. Au, K. P. Dere, R. A. Howard, R. Kreplin, D. J. Michels, J. M. Defise, C. Jamar, P. Rochus, J. P. Chauvineau, J. M. Marioge, R. C. Catura, J. R. Lemen, L. Shing, R. A. Stern, J. B. Gurman, W. M. Neupert, J. Newmark, B. Thompson, A. Maucherat, F. Portier-Fozzani, D. Berghmans, P. Cugnon, E. L. Van Dessel, J. R. Gabryl: "EIT Observations of the Extreme Ultraviolet Sun", *Solar Phys.* 175, pp.571-599 (1997).

[Murt 74] M. V. R. K. Murty: "Theory and Principles of Monochromators, Spectrometers and Spectrographs", *Opt. Eng.* 13, pp.23-39 (1974).

[Möll 95] K. D. Möller : " Wave-front-dividing array interferometers without moving part for real-time spectroscopy from the IR to the UV", *Applied Opt.* 34, pp.1493-1501 (1995).

[Roes 90] F. L. Roesler, J. Harlander: "Spatial Heterodyne Spectroscopy: Interferometric Performance at any Wavelength Without Scanning", *Optical Spectroscopic Instrumentation and Techniques for the 1990s, SPIE* 1318, pp.234-243 (1990).

[Schr 99] C.J. Schrijver, A. M. Title, T. E. Berger, L. Fletcher, N. E. Hurlburt, R. W. Nightingale, R. A. Shine, L. Golub, J. A. Bookbinder, E. E. Deluca, R. A. Mcmullen, H. P. Warren, C. C. Kankelborg, B. N. Handy, B. De Pontieu: " A New View of the Solar Outer Atmosphere by the Transition Region And Coronal Explorer", *Solar Phys.* 187, pp.261-302 (1999).

[Smit 95] P. L. Smith, A. P. Thorne, W. H. Parkinson: "A comparison of Imaging Fourier Transform with Grating Spectrometry for Tridimensional Spectroscopy", 3D Optical Spectroscopic Methods in Astronomy", G. Comte and M. Marcelin eds., *ASP Conference Series* 71, pp.328-331 (1995).

[Stee 95] Ph. Stee, D. Bonneau, P. Lawson, F. Morand, D. Mourard, I. Tallon, F. Vakilii: "Michelson-Spectro-Interferometry (MSI) of Be stars envelopes with the GI2T Interferometer", 3D Optical Spectroscopic Methods in Astronomy", G. Comte and M. Marcelin eds., *ASP Conference Series* 71, pp.365-368 (1995).

[Wels 91] B. Y. Welsh, S. Chakrabarti: "Prospect of space-based interferometry at EUV and soft x-ray wavelengths", *Multilayers and Grazing Incidence X-Ray/EUV Optics, SPIE* 1546, pp.108-116 (1991).

[Wilh 95] K. Wilhelm, P. Lemaire, W. Curdt, U. Schühle, E. Marsch, A. I. Poland, S. D. Jordan,R. J.

Thomas, D. M. Hassler, M. C. E. Huber, J.-C. Vial, M. Kühne, O. H. W. Siegmund, A. Gabriel, J. G. Timothy, M. Grewing, U. Feldman, J. Hollandt, P. Brekke: "First results of the SUMER telescope and spectrometer on SOHO: I Spectra and Radiometry", *Solar Phys*. 175, pp.75-104 (1997).