Tunable Filters Basics

Outline

- ***What is a Tunable Filter and why we need it?***
- ***The Fabry-Perot interferometer: Historical background***
- ***Basic Principles***
- ***Practical Implementation***
- ***The etalon implemented as a Tunable Filter***
- ***Instruments with Tunable Filters***

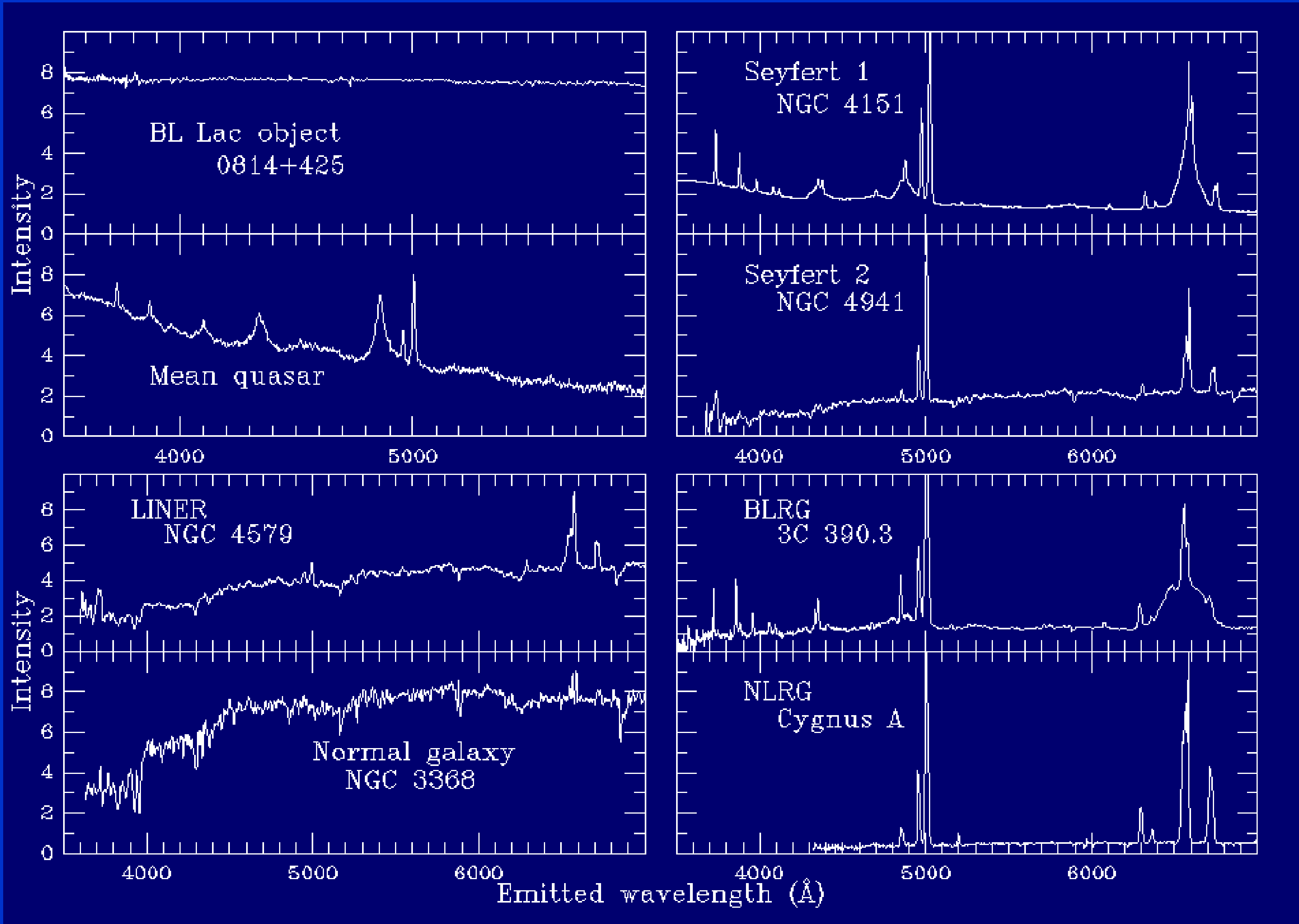
What is an ideal Tunable Filter

- ***The ideal tunable filter is an imaging device which can isolate an arbitrary spectral band at an arbitrary wavelength over a broad, continuous spectral range, preferably with a response function which is identical in form at all wavelengths.***

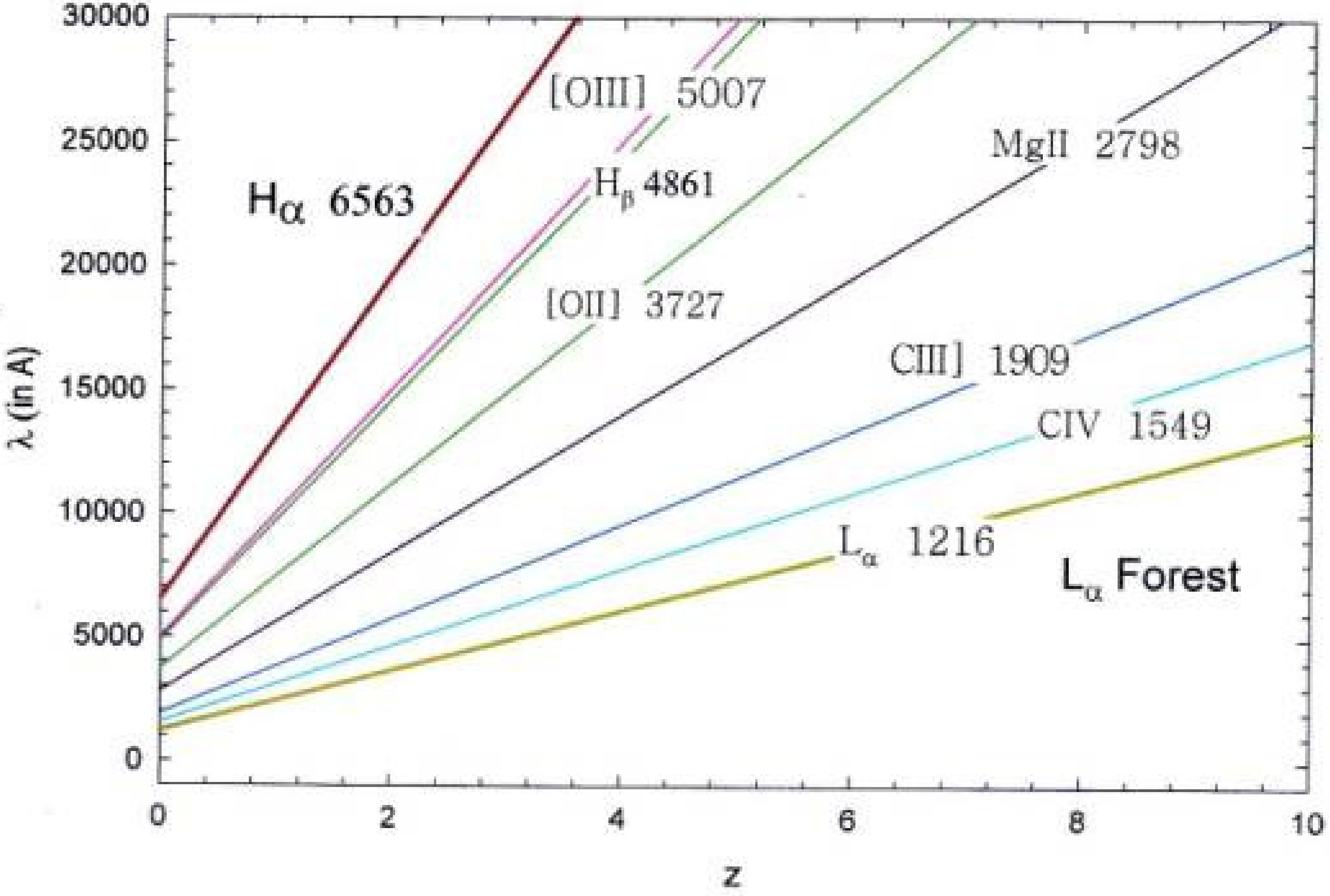
Tunable Filter Ideal Specifications

- *Image quality, high throughput, stable*
- *Widest possible field of view*
- *Monochromatic band (phase free)*
- *Tunable, identical, square profile*
- *Broad spectral coverage, fast response*
- *Large span in resolving power*
- *Minimal reflectance phase*
- *Minimal stray light*

Spectra of emission Line objects

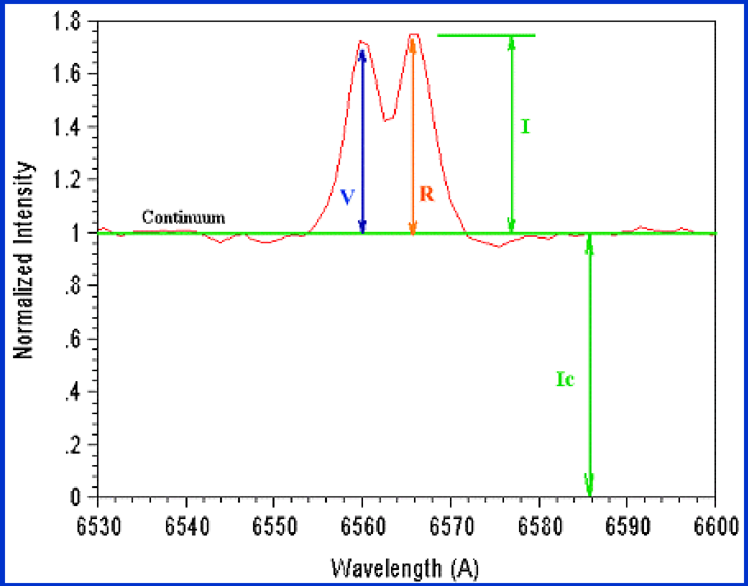


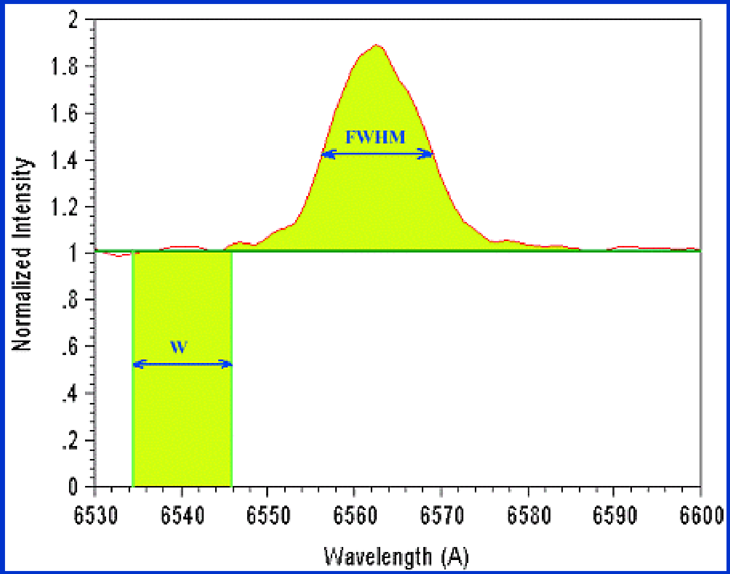
Wavelength vs. Z



Selecting objects with narrowband filters

There are several advantages to selecting objects through narrowband imaging. The sky background, the most significant limitation to the detection of faint objects in broadband images, is greatly reduced in narrowband images.

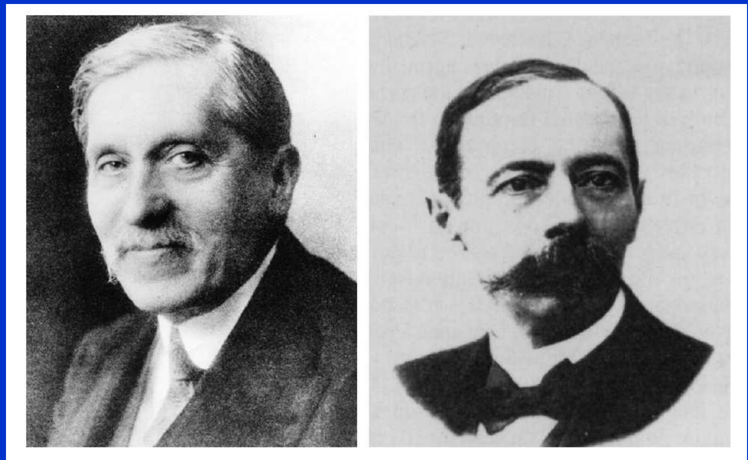


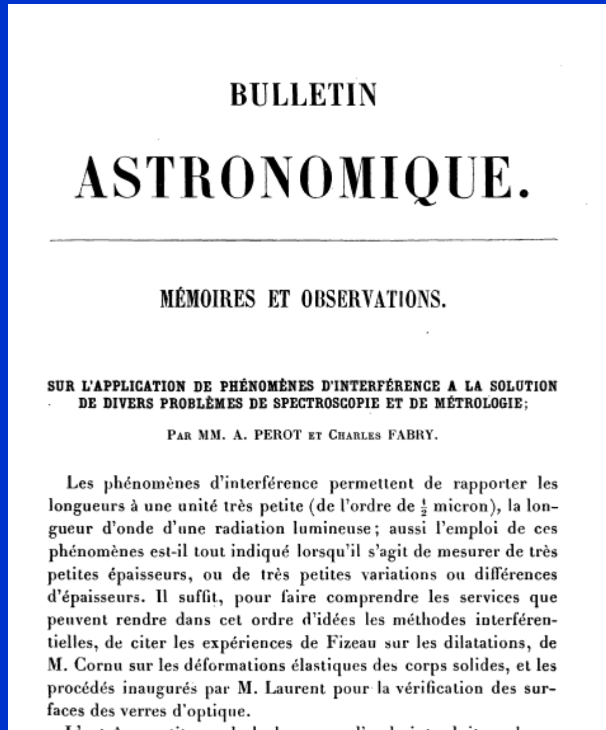


Techniques available for TF

- *Fabry-Perot interferometer*
- *Linear or circular variable filter*
- *Multilayer dielectric filter*
- *Michelson interferometer*
- *Acousto-optic filter*
- *Solid etalon filter*
- *Solid Michelson filter*
- *Generalized resonant grating filter*
- *Lyot-Ohman filter*
- *Generalized Lyot filter*
- *Liquid crystal filter*
- *Volume phase holographic grating filter*

The Fabry-Perot interferometer





BULLETIN

ASTRONOMIQUE.

MÉMOIRES ET OBSERVATIONS.

SUR L'APPLICATION DE PHÉNOMÈNES D'INTERFÉRENCE A LA SOLUTION DE DIVERS PROBLÈMES DE SPECTROSCOPIE ET DE MÉTROLOGIE;

PAR MM. A. PEROT ET CHARLES FABRY.

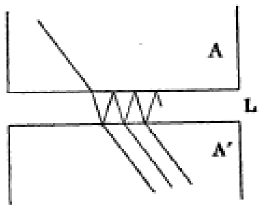
Les phénomènes d'interférence permettent de rapporter les longueurs à une unité très petite (de l'ordre de $\frac{1}{2}$ micron), la longueur d'onde d'une radiation lumineuse; aussi l'emploi de ces phénomènes est-il tout indiqué lorsqu'il s'agit de mesurer de très petites épaisseurs, ou de très petites variations ou différences d'épaisseurs. Il suffit, pour faire comprendre les services que peuvent rendre dans cet ordre d'idées les méthodes interférentielles, de citer les expériences de Fizeau sur les dilatations, de M. Cornu sur les déformations élastiques des corps solides, et les procédés inaugurés par M. Laurent pour la vérification des surfaces des verres d'optique.

In 1899 Fabry and Perot described an interferometer which enabled high resolution observation of spectral features. First reported the use of a scanning FP for astronomy in 1914.

The Fabry-Perot interferometer

Un phénomène de ce genre peut se produire dans certains appareils interférentiels, grâce aux réflexions multiples que la lumière peut y subir. Soit, par exemple, une mince couche d'air L limitée par deux surfaces transparentes A et A′ (*fig.* 2). Une onde inci-

Fig. 2.



dente donnera lieu à une infinité d'ondes émergentes ayant subi respectivement 0, 2, 4, ..., 2*n*, ... réflexions, et présentant, par

from 0.25 cm to 12 cm. Fig. 3 represents a 1 cm standard made by M. Jobin. It consists of a steel plate *A* pierced by a circular opening in which are fastened three small steel screws *P*, the ends of which are carefully rounded and polished. Against these three curved surfaces plates of plane silvered glass *L*, *L′*, are held by Brunner spring clamps, and are thus maintained at a fixed distance. By carefully scraping the steel pins the silvered plates are brought to perfect parallelism. Experience has shown that after dismounting and replacing the glass plates their parallelism is preserved and the thickness of the standard does not change.

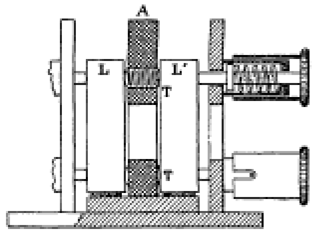


FIG. 3.

"We must emphasize the simplicity of the apparatus used and the ease with which it can be mounted at the telescope. When the silverings have been carefully selected, the interferencial apparatus does not cause the loss of much light and permits the study of objects of very feeble brightness". (C Fabry and A Perot. Ann.Chim.Phys. 16, p115, 1899)

Basic Principles

A Fabry-Perot interferometer or etalon (from the French etalon, meaning 'measuring gauge' or 'standard') is typically made of a transparent plate with two reflecting surfaces, or two parallel highly-reflecting mirrors.

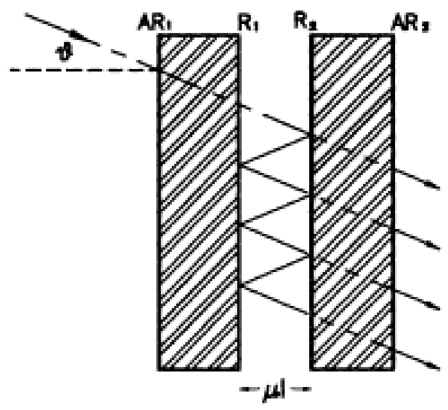
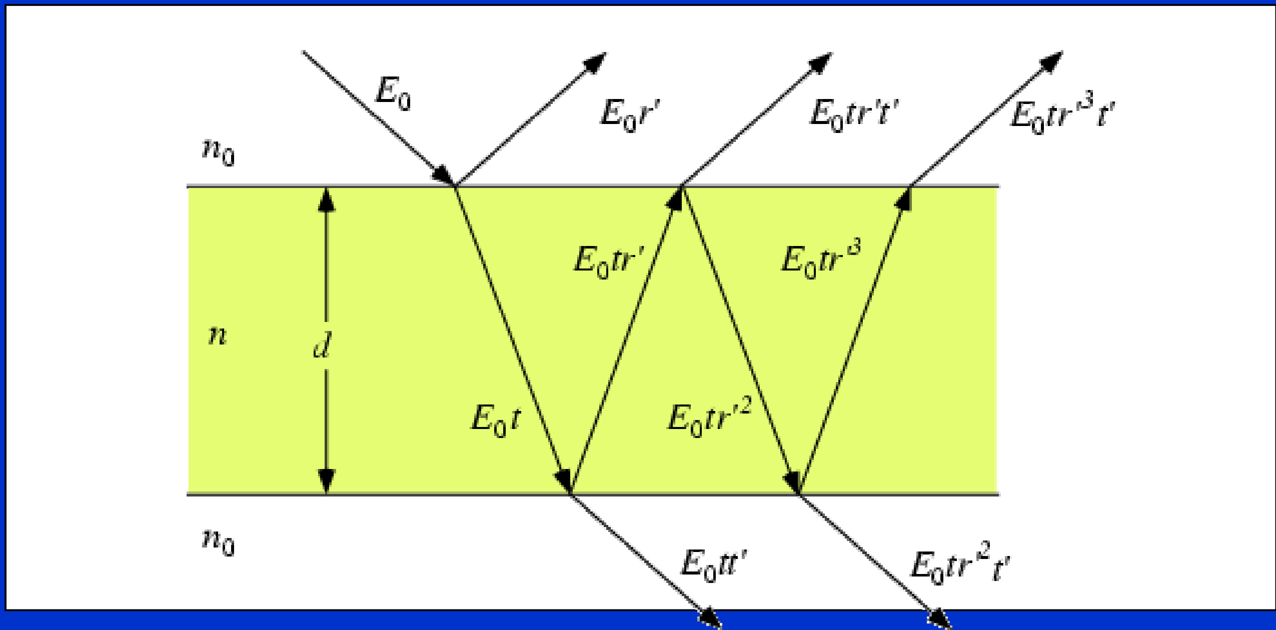


Figure 1. A Fabry-Perot etalon comprising two glass plates with highly reflective interior surfaces, $\mathcal{R}_1$ and $\mathcal{R}_2$, and anti-reflective exterior coatings, $\mathcal{AR}_1$ and $\mathcal{AR}_2$.

Basic Principles

Light entering the cavity undergoes multiple reflections. At the resonant wavelengths, the resultant reflected beam interferes destructively with the light reflected from the first plate cavity boundary and all the incident energy, in the absence of absorption, is transmitted.



Basic Principles

A scheme of an imaging Fabry-Perot interferometer comprising of (a): interference filter; (b) focal plane; (c) field lens; (d) collimator lens; (e) Fabry-Perot etalon; (f) camera lens; (g) Dewwar housing; (h) CCD.

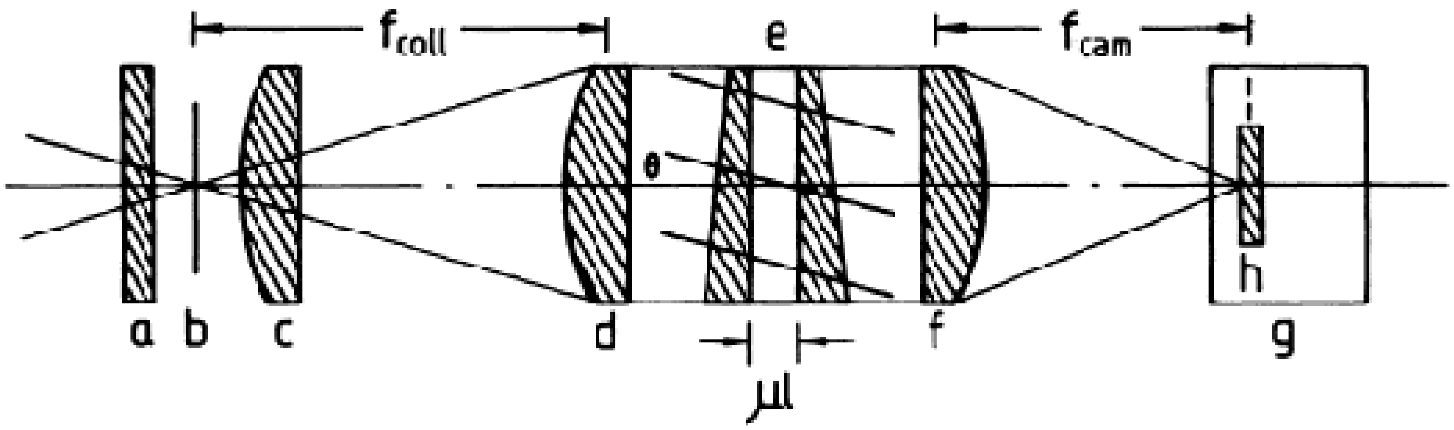
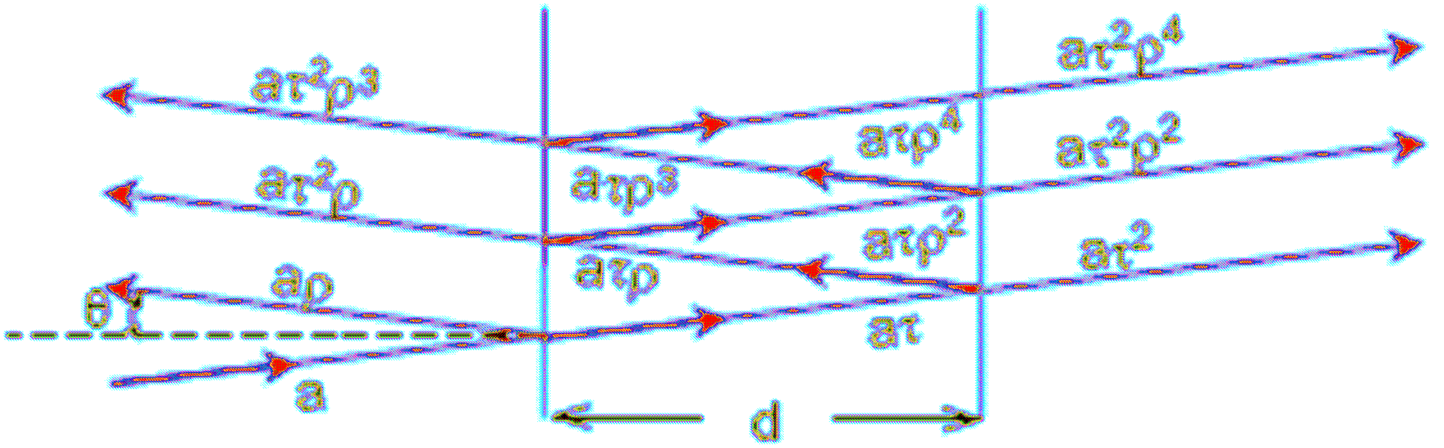


FIG. 1. Schematic drawing of an imaging Fabry–Perot interferometer comprising (a) interference filter, (b) focal plane, (c) field lens, (d) collimator lens, (e) Fabry–Perot etalon, (f) camera lens, (g) Dewar housing (h) CCD.

Interference Path

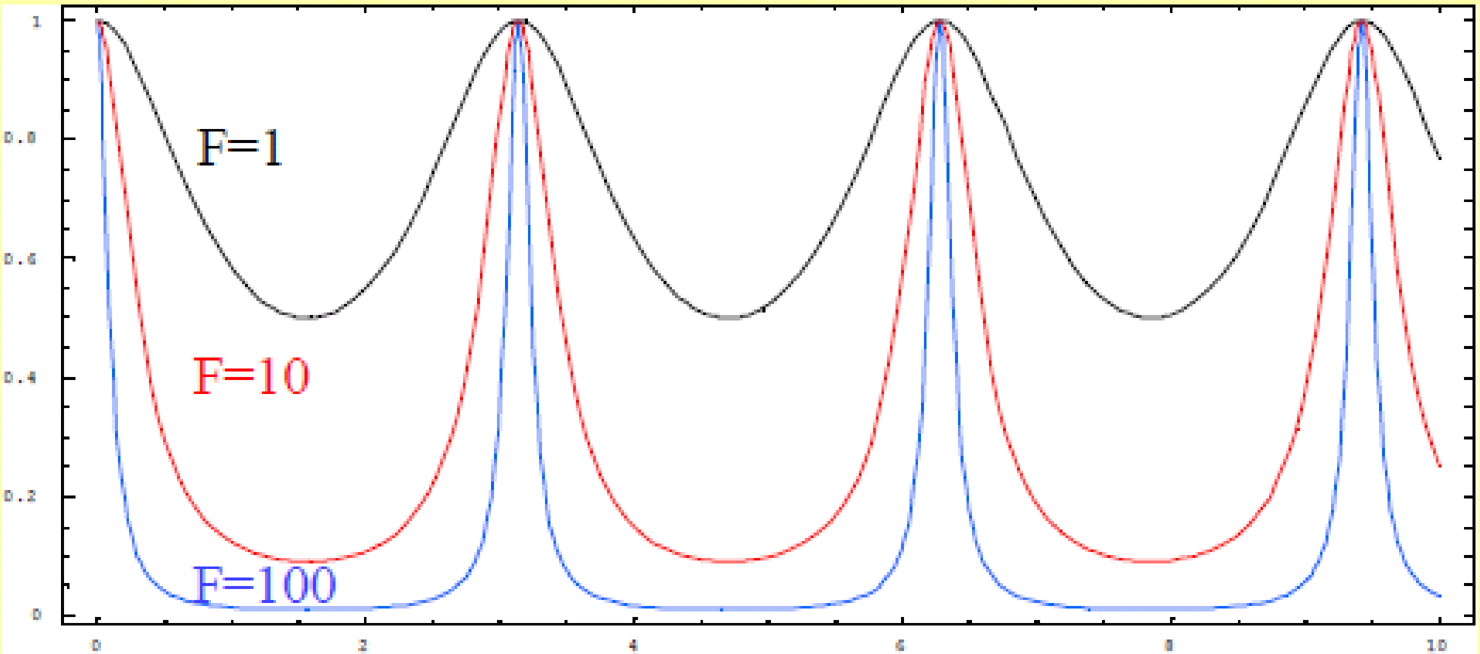


d = spacing between the mirrors

τ = amplitude transmissivity

ρ = amplitude reflectivity

The Airy Function



The Airy Function

If both surfaces have a reflection coefficient R, the transmission function of the etalon is given by the Airy Function:

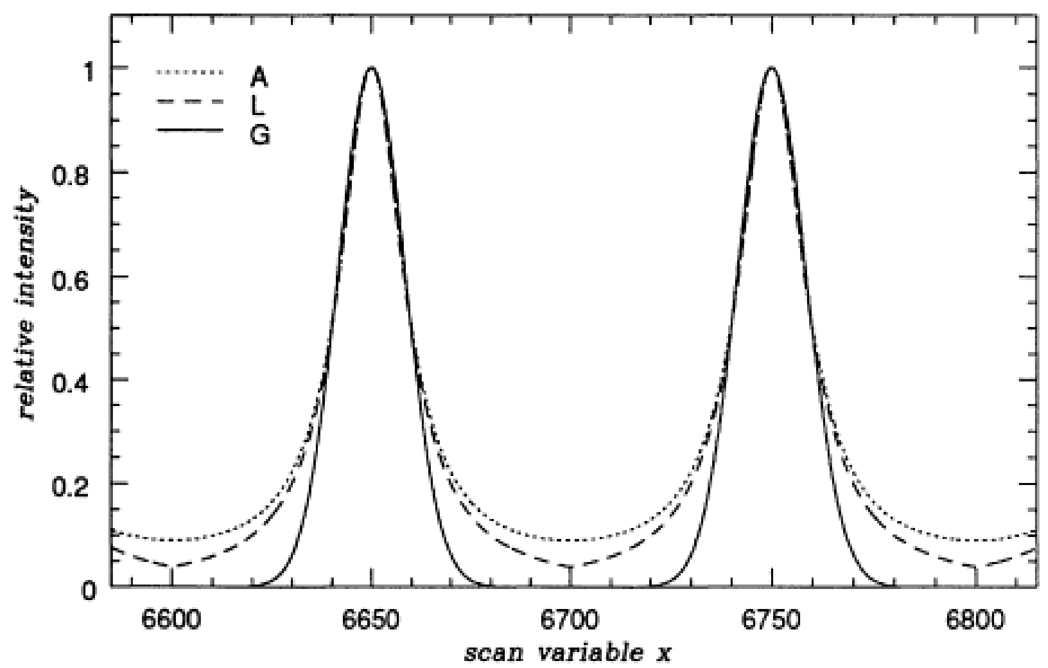
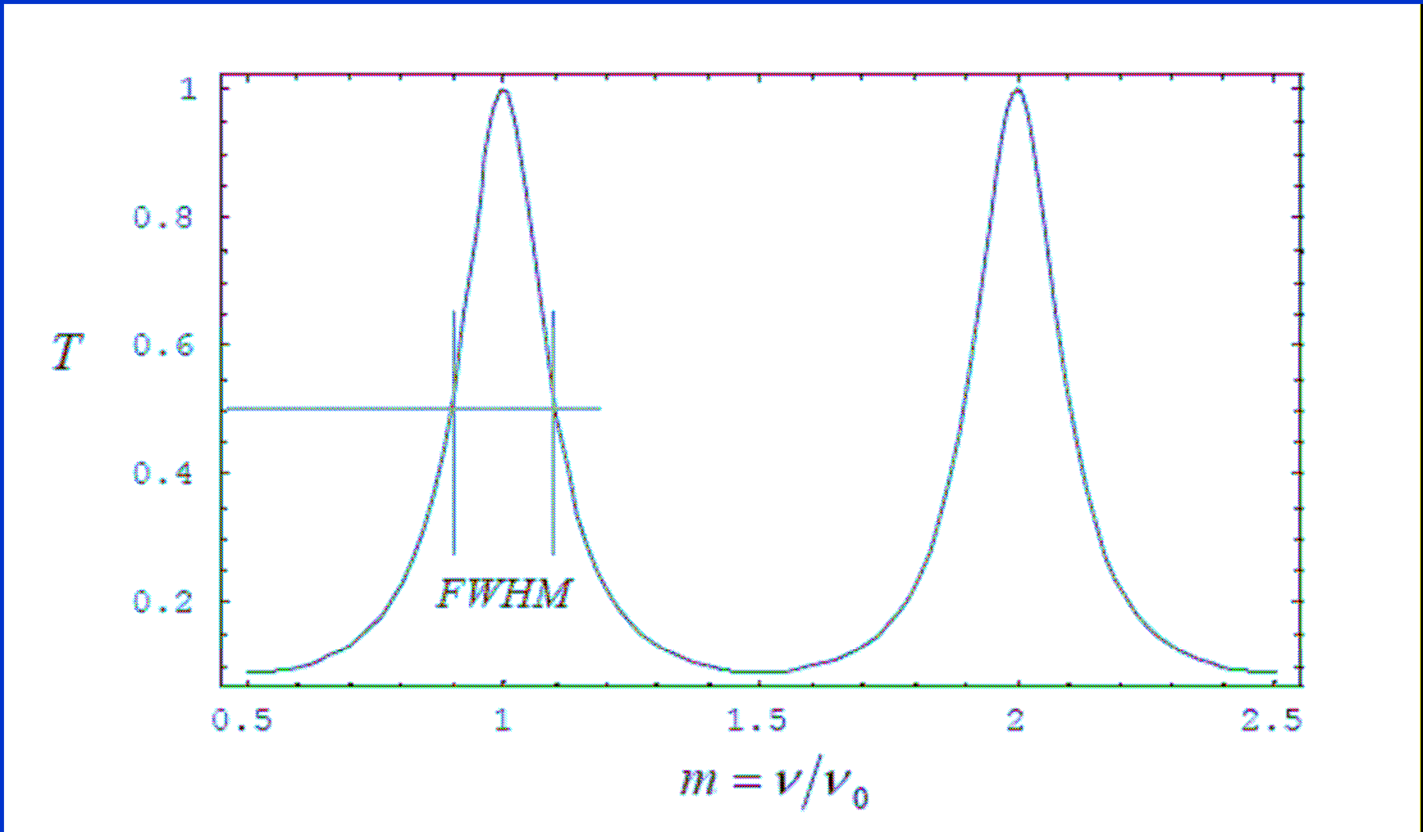
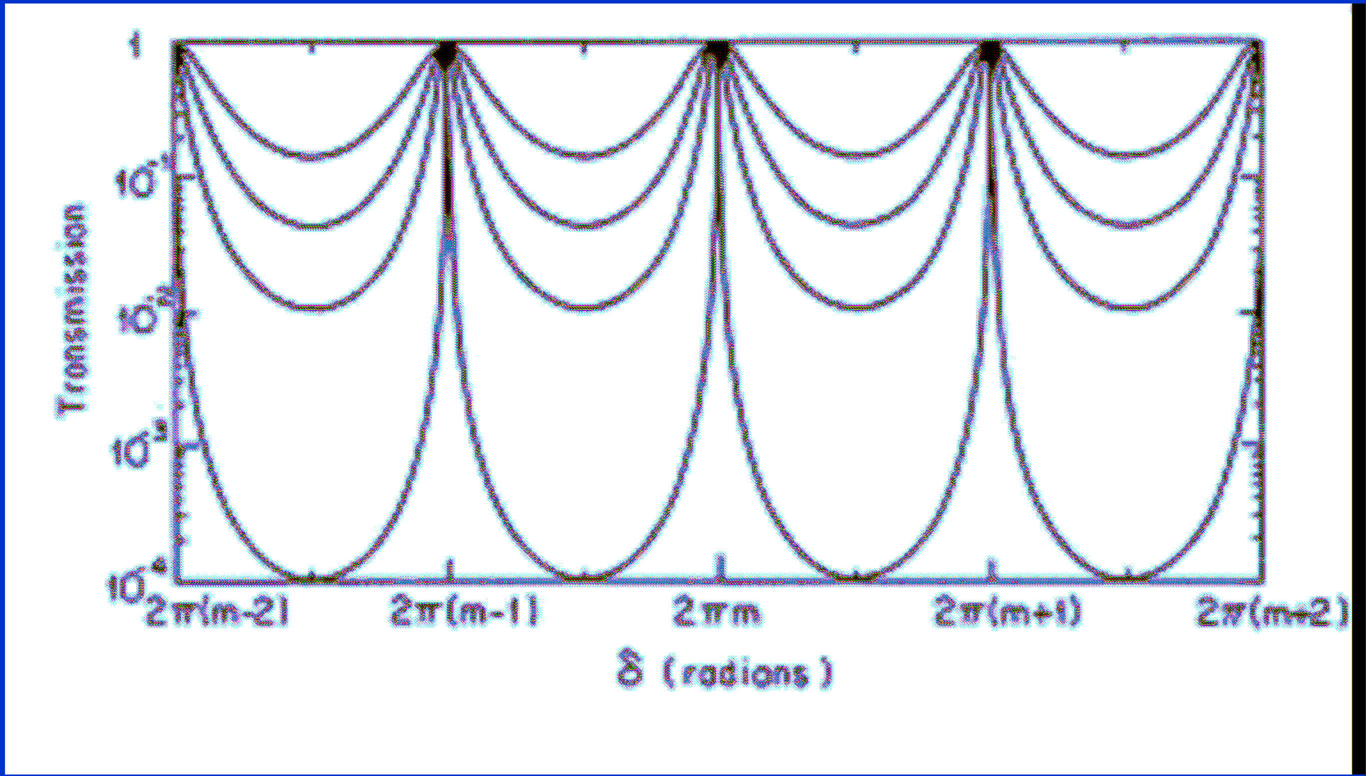


Figure 2. Three cyclic functions listed in Table 1 (column 2) shown at low finesse to emphasize their differences.

Bandpass width

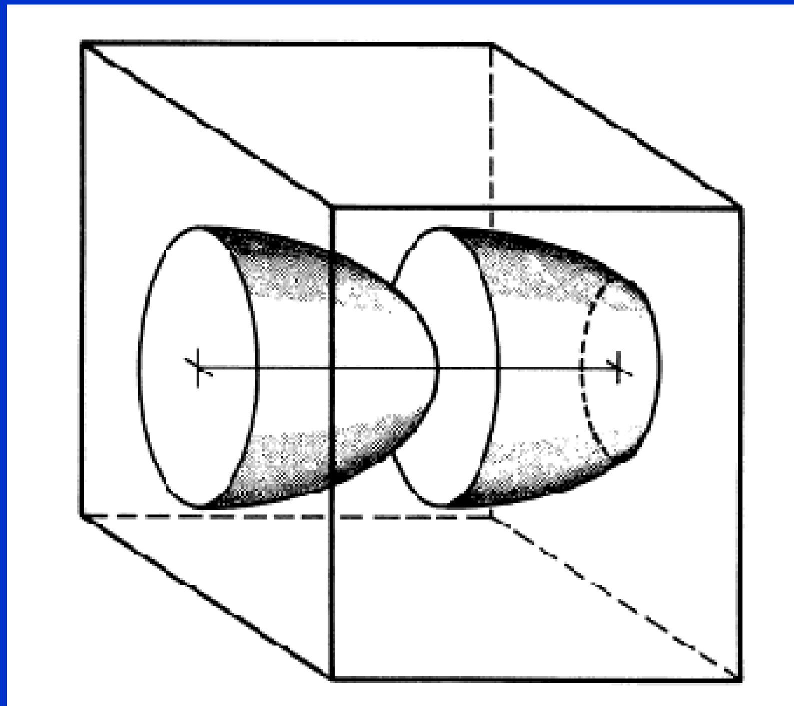


Contrast



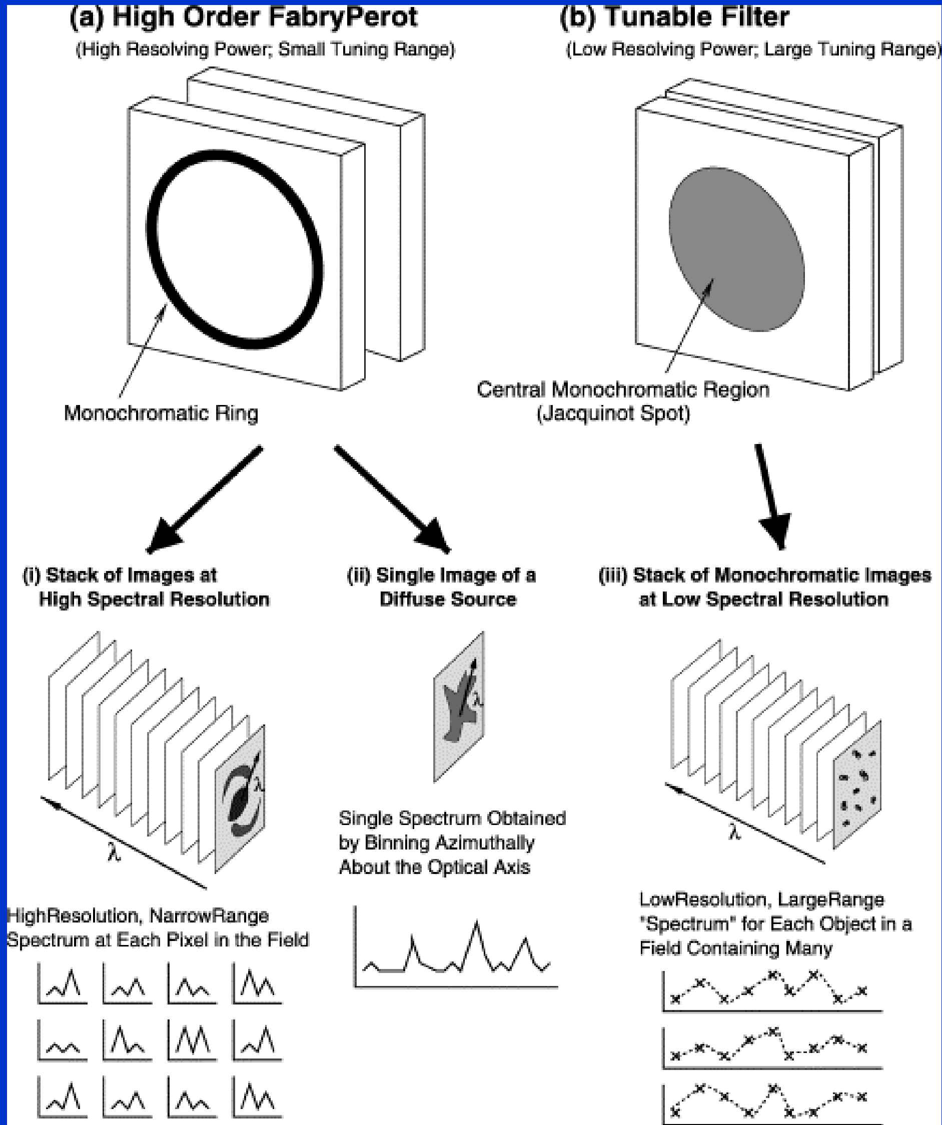
Transmission
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$2\pi(m-2)$
$2\pi(m-1)$
$2\pi m$
$2\pi(m+1)$
$2\pi(m+2)$
δ (radians)

Phase Surface

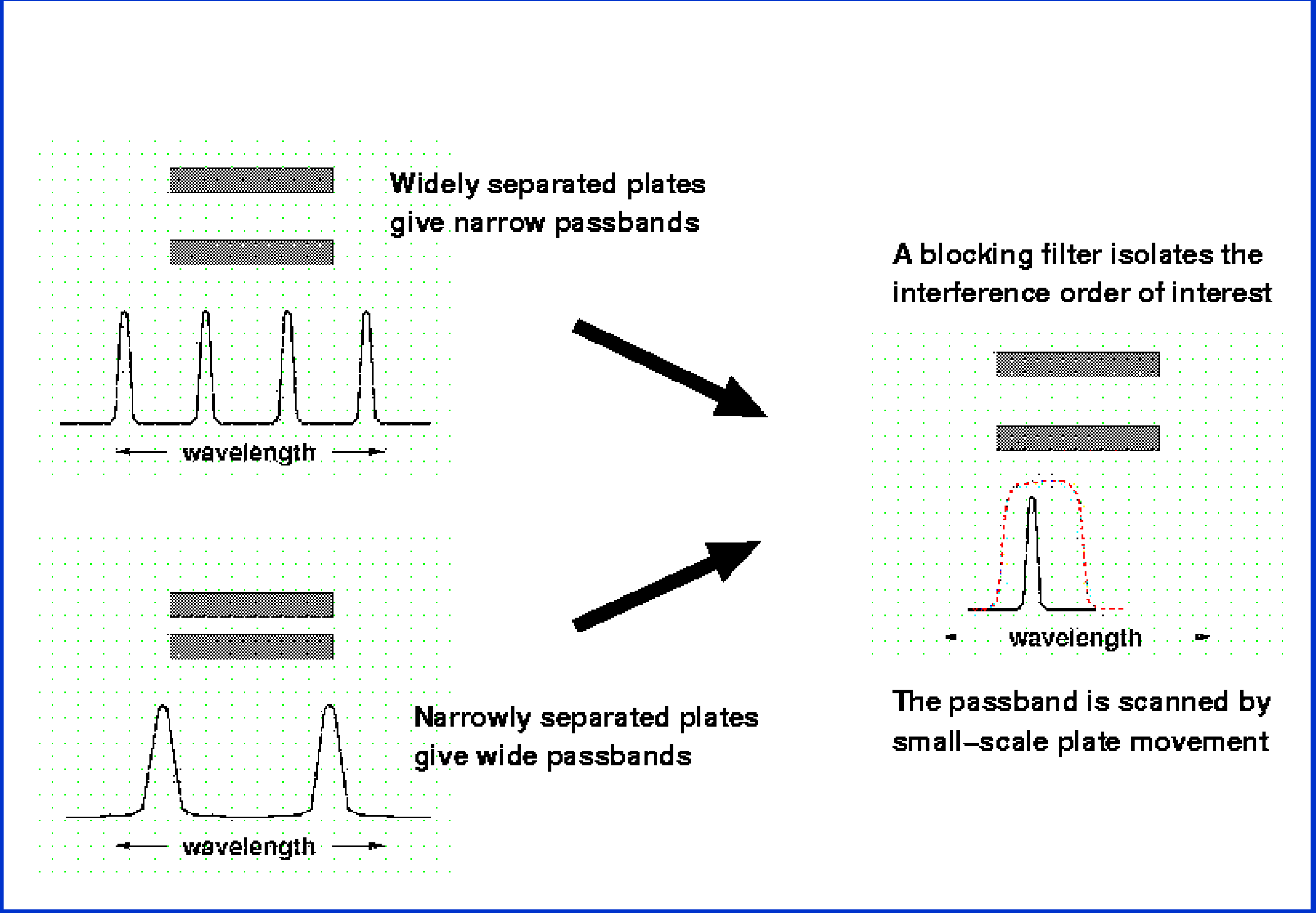


Constant-phase surface. The horizontal direction is the scan direction. The truncated Airy surfaces of maximum transmission for monochromatic light are illustrated throuth almost two orders, where the curvature has been groslly exaggerated.

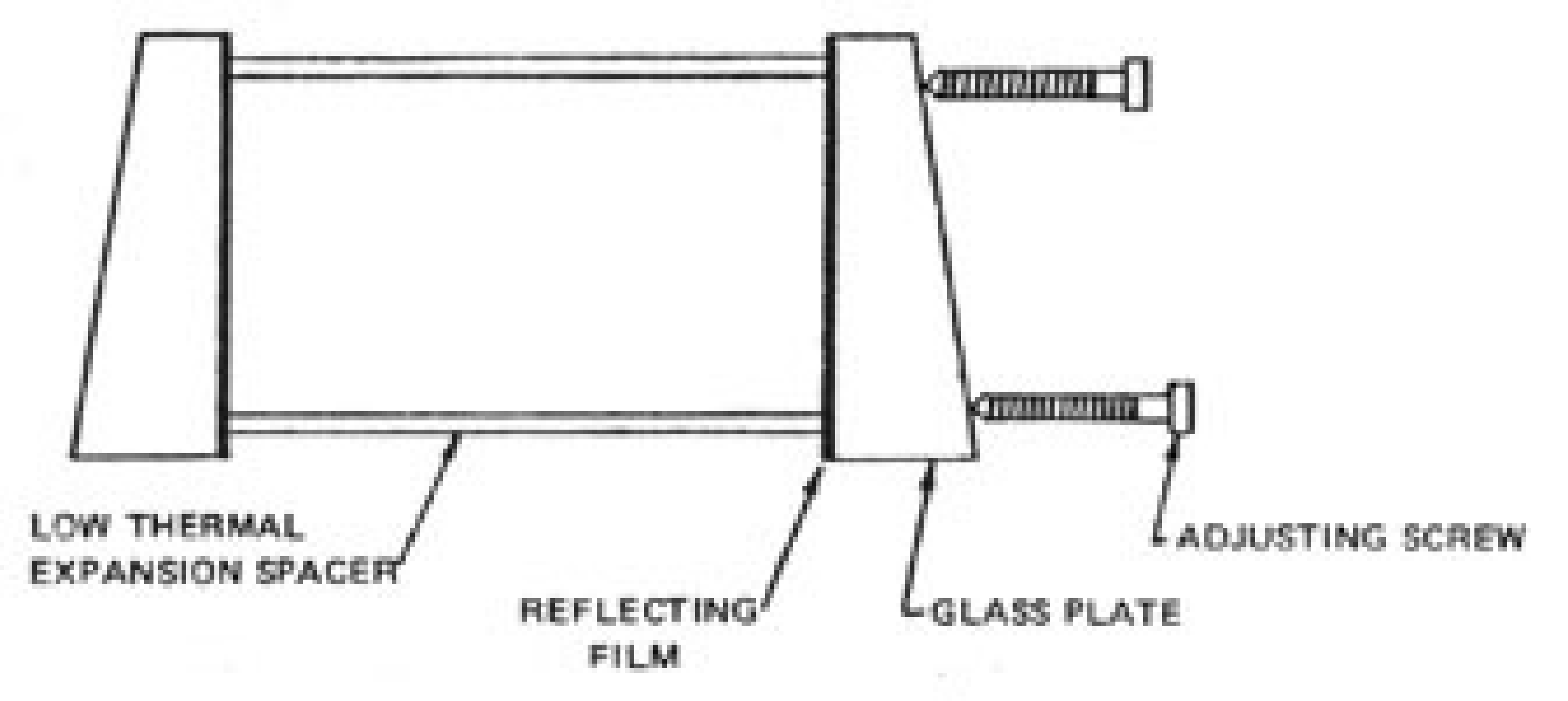
The Fabry-Perot etalon as a tunable filter



Tunable Filter Observation



A simple Etalon



First Queensgate Etalon

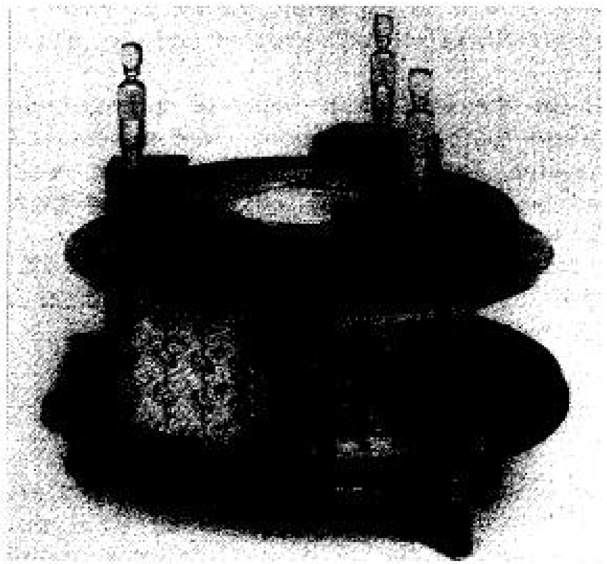
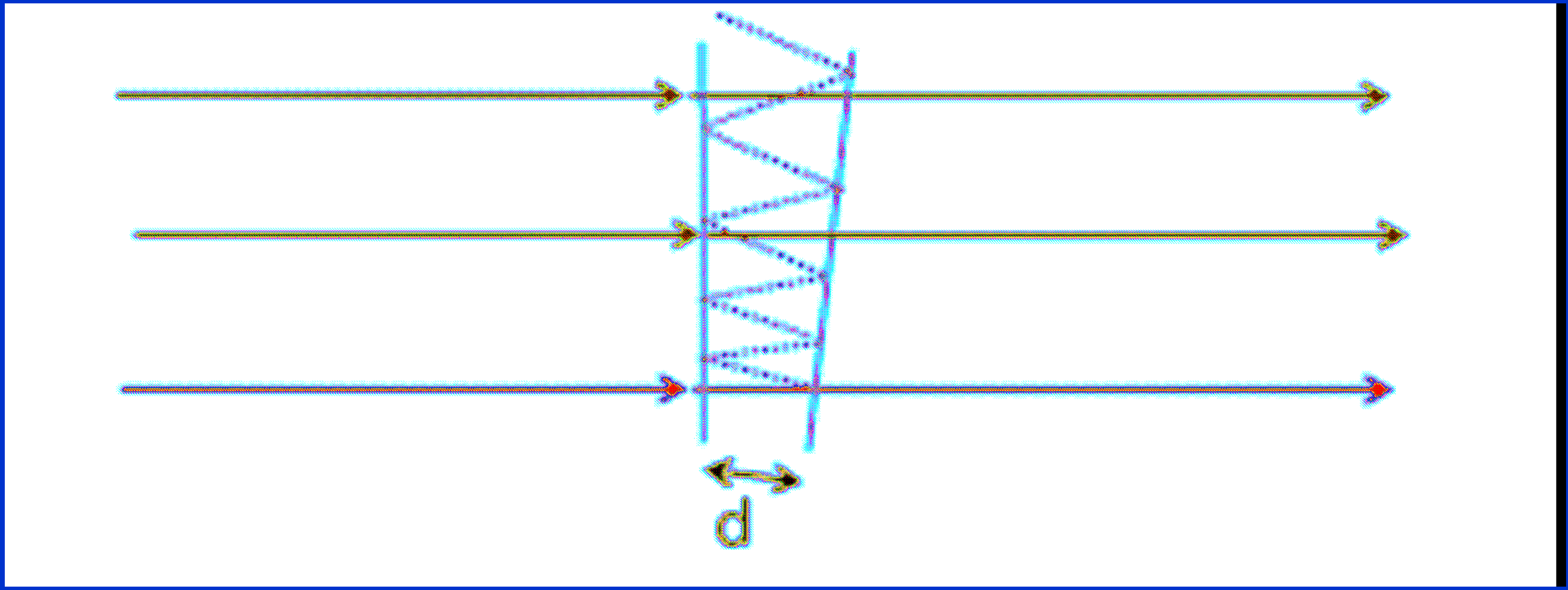


Figure 2: The CasFPer servo-stabilised FP, Mark I

CasFPer, the first prototype serv-stabilised FP tested at the 2.5m INT at Herstmonceux, Sussex, and used to study the [OIII] lines of planetary nebulae. This first generation device was piezo-tuned,capacitatively stabilized, and mechanically aligned.

Mirror Parallelism



Queensgate Etalon Operation

Schematic arrangement of the capacitors and PZT stacks in the ambient temperature ET-series etalons. The X and Y channels control parallelism,and the capacitor is referenced to a fixed value capacitor to control mirror spacing.

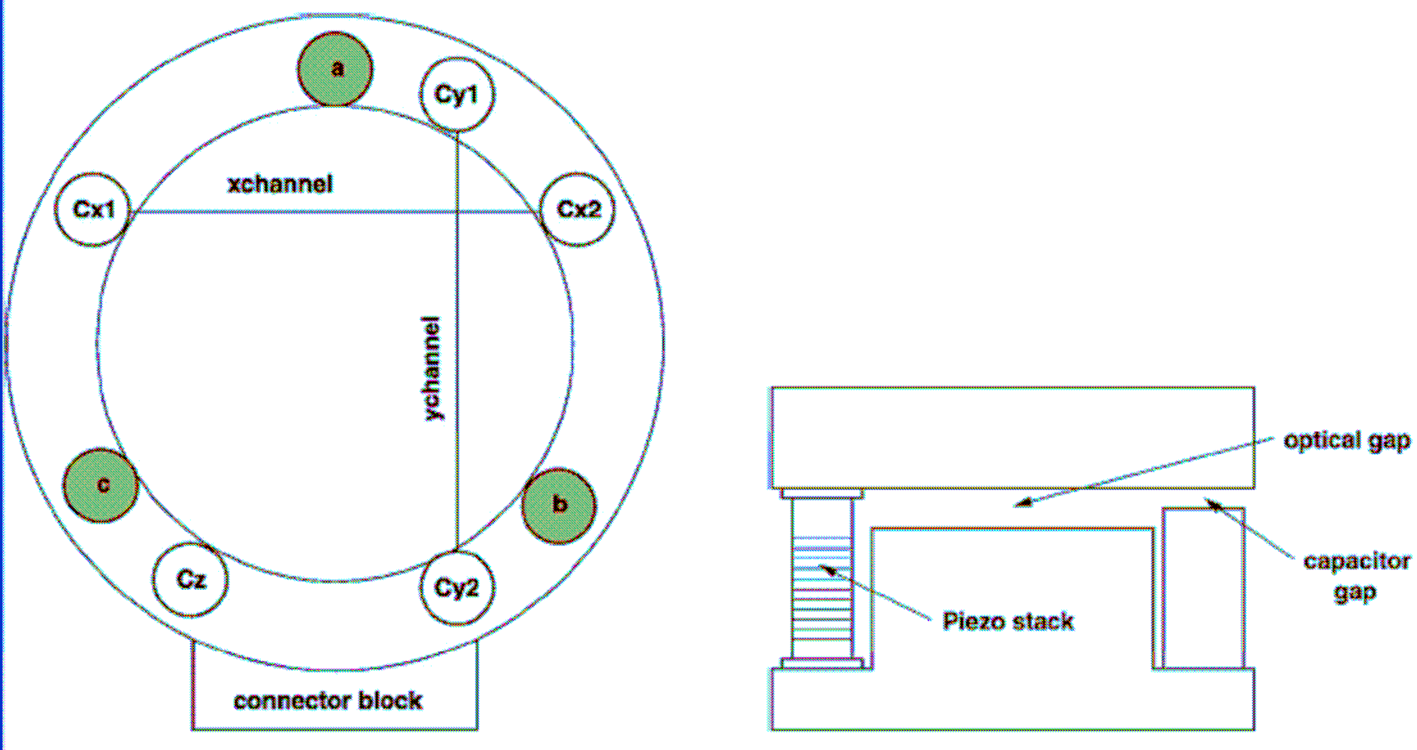
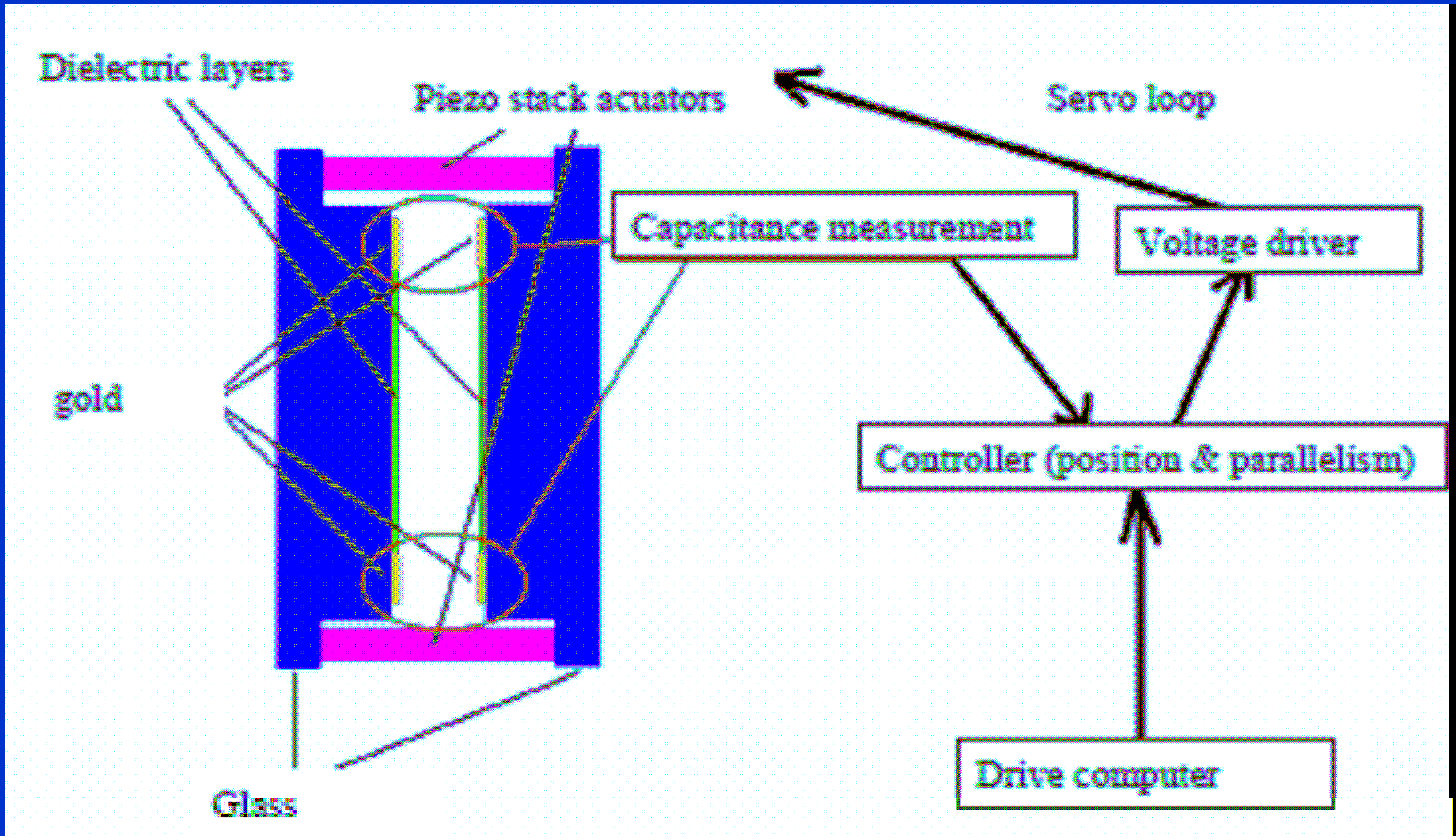


FIG. 7.—Schematic view of the Fabry-Pérot etalon. *Left*: Location of the piezoelectric actuators (*a*, *b*, and *c*) and the capacitance sensors (Cx_1, Cx_2, Cy_1, Cy_2, and *Cz*). *Right*: Cross-section illustrating the operation principle of the Fabry-Pérot.

Queensgate Etalon Operation



Capacitance Micrometry

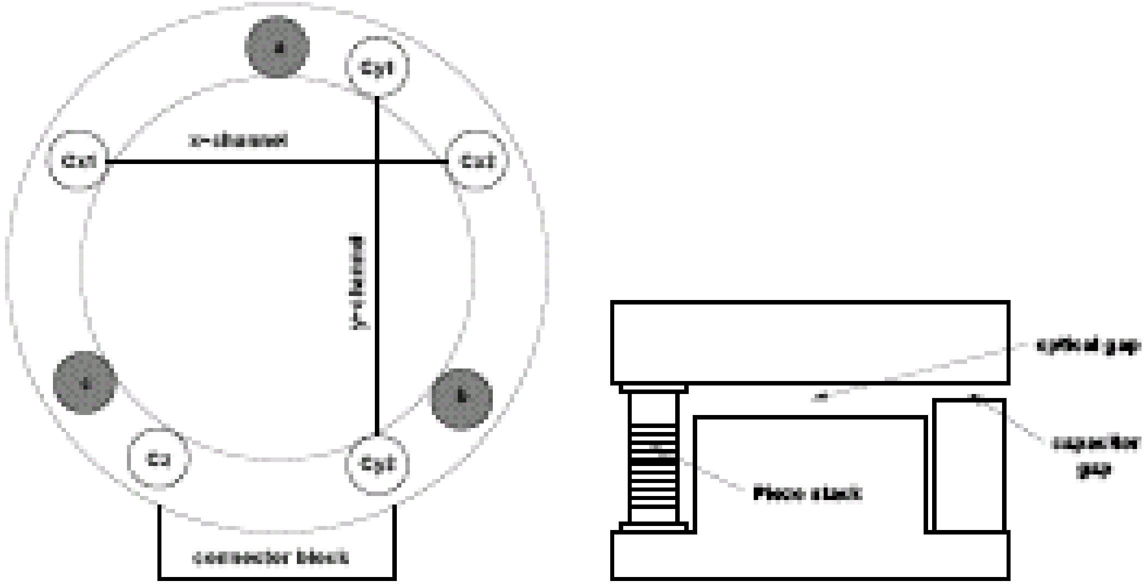
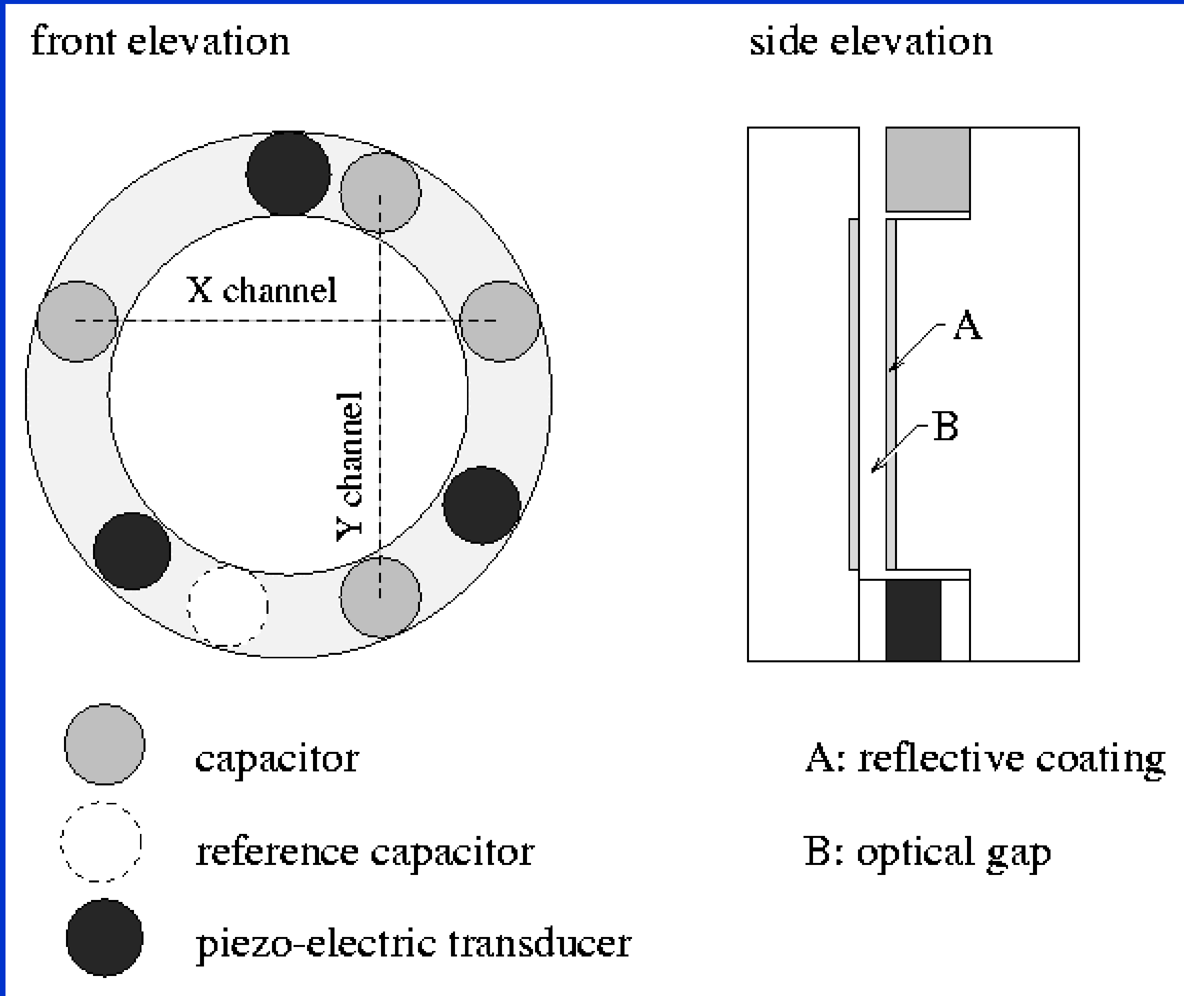
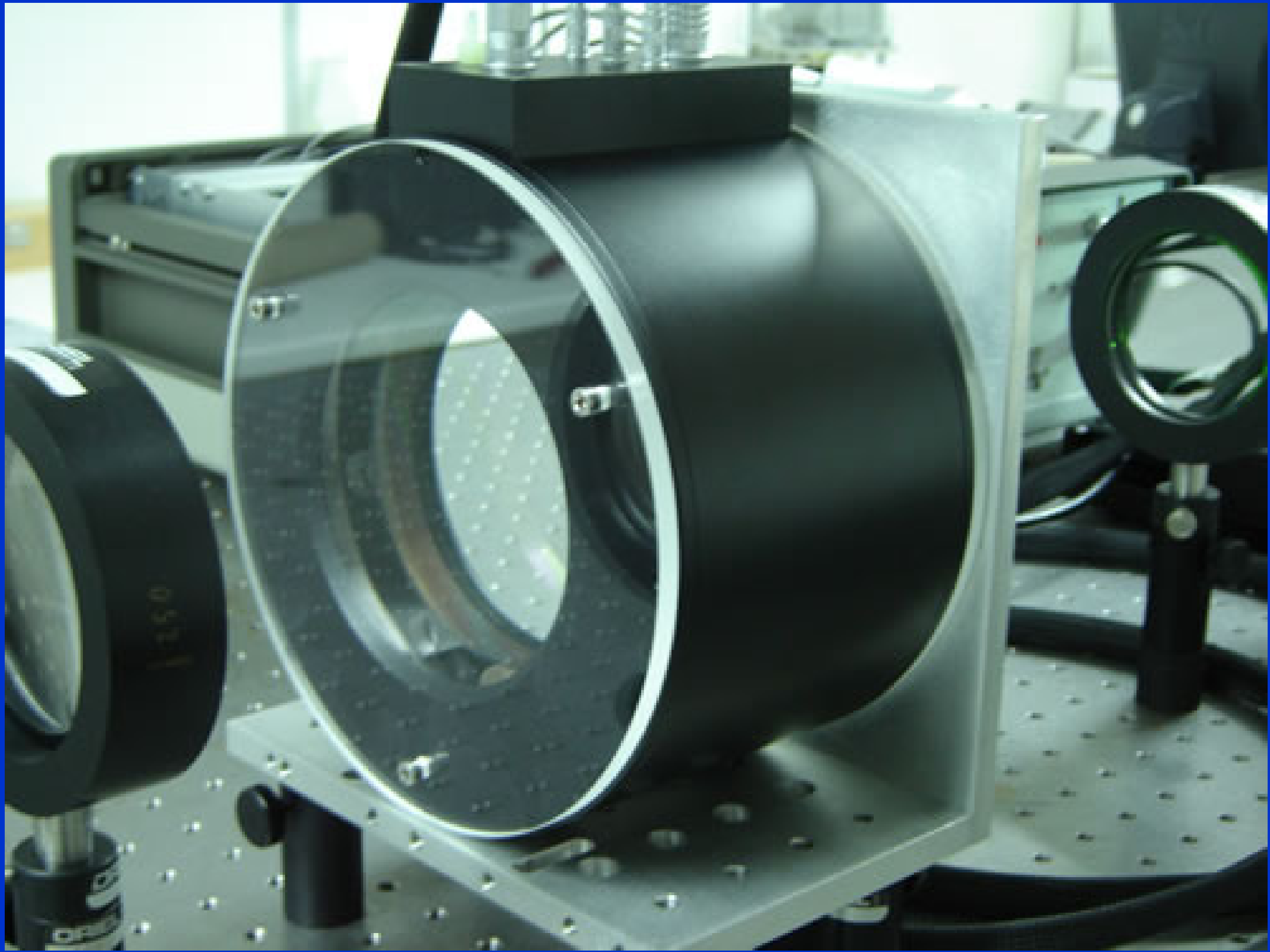


Fig. 7.— Schematic view of the Fabry-Pérot etalon. *Left:* Location of the piezo-electric actuators (a, b, and c) and the capacitance sensors (Cx_1, Cx_2, Cy_1, Cy_2, and Cz). *Right:* Cross section illustrating the operation principle of the Fabry-Pérot.

Queensgate Etalon Operation



OSIRIS: etalon



Why we use two etalons?

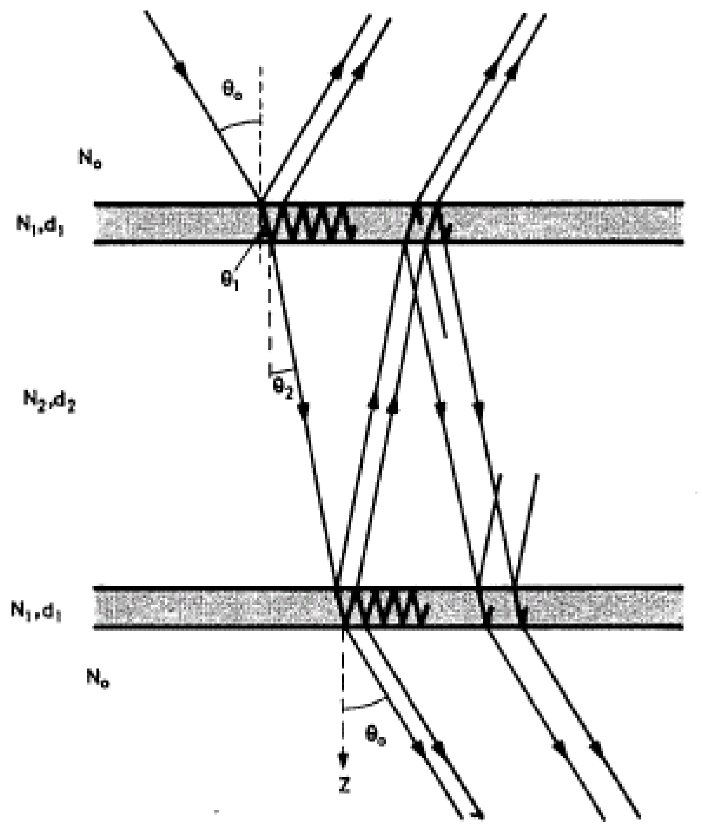
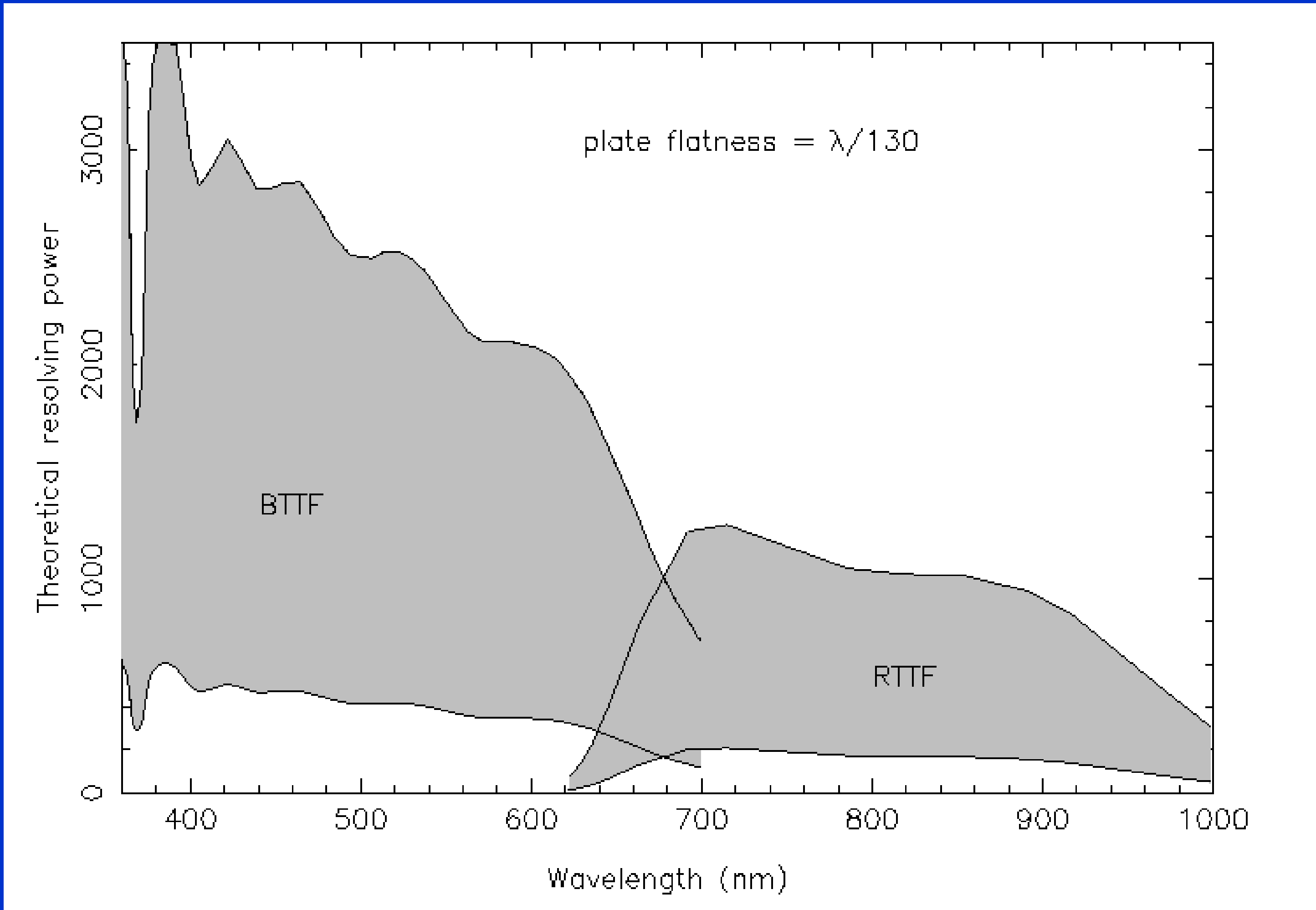


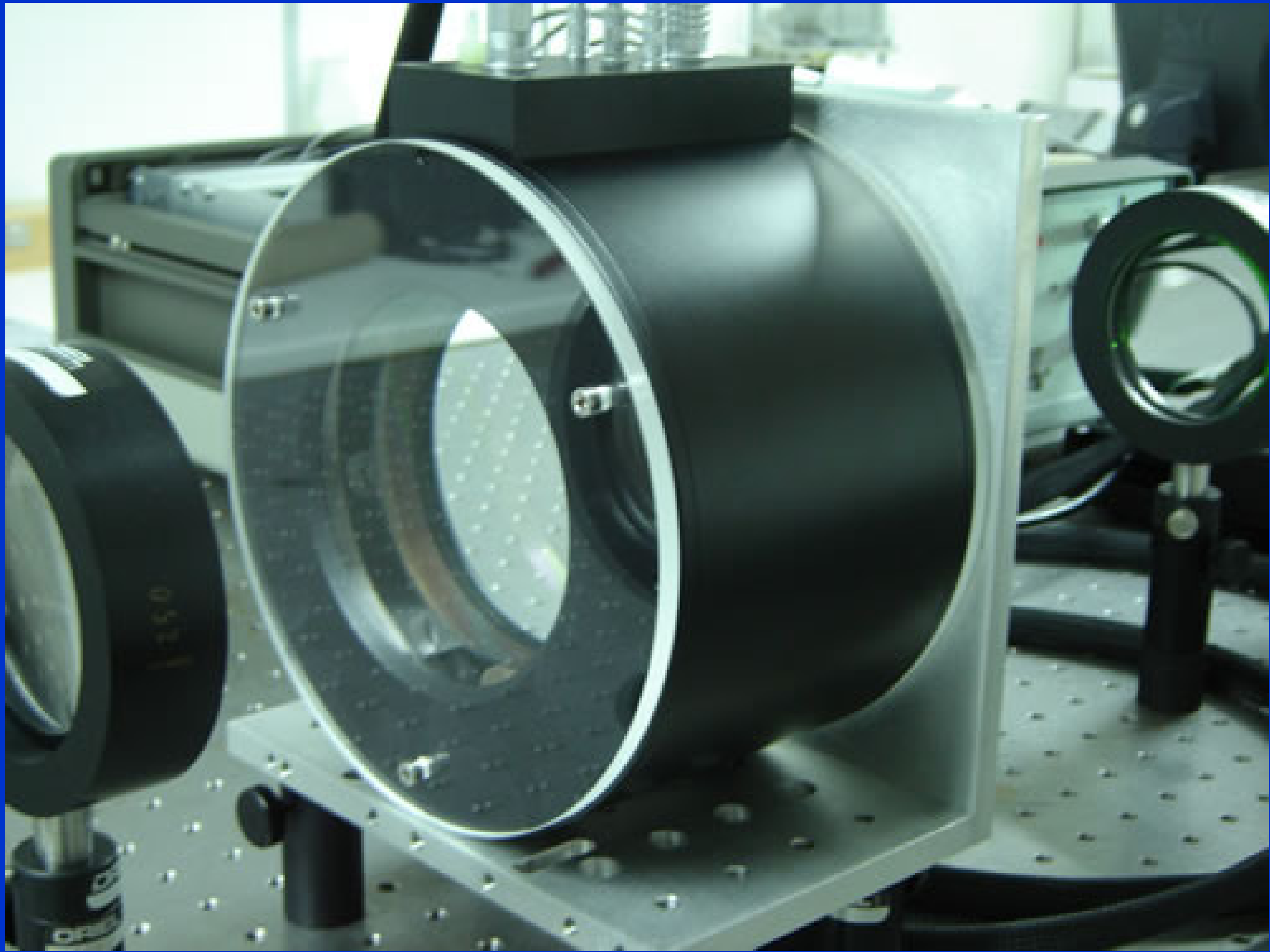
Fig. 1. Reflection and transmission of a plane wave in a FP when the coatings are considered as two thin films with parallel-plane boundaries.

Why we use two etalons?



Instruments width Tunable Filters

- Goddard Fabry-Perot Imager
- Kyoto Tridimensional Spectrograph
- Calar Alto Fabry-Perot Spectrometer
- Taurus Tunable Filter (AAT)
- Maryland-Magellan Tunable Filter
- PFIS/SALT
- OSIRIS



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