Measuring the throughput in spectrographs

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The spectrograph throughput is one of the most important features for astronomy observations. However, its measurement is difficult and usually is calculated by extrapolation of individual component efficiencies. We propose a simple method of measuring the overall efficiency at single wavelength by using a laser based device. We demonstrate it on a fiber linked Echelle spectrograph.
The optical efficiency of an optical system is defined as the rate of optical energy through the system, divided by the energy coming directly from the source:

\[ \eta = \frac{E_i}{E_o} \times 100\% \]
Basic Echelle design

- Full parabola as collimator
- Output fibre end
- 9°
- CCD
- Tele-objective
- X-disperser
- Échelle
Echelle spectrograph efficiency

The efficiency includes:
- Fibre link: telescope-fibre coupling, fibre transmission and fibre-collimator coupling
- Collimator
- Echelle
- Cross-disperser (Prism or Grating)
- Camera
- CCD
Fibre link efficiency (1)

- Pinhole – seeing ratio
- Pinhole – lens/fibre misalignment
- F/# matching and misalignment
- Polishing quality
- Fresnel, input and output lenses
- Lenses misalignment errors and aberrations
- Internal fibre transmission
- Focal ratio degradation (FRD)
Pinhole - seeing ratio
Fibre link efficiency (2)

Typical values

- Pinhole – seeing (when seeing = Ø fibre) 50%
- Polishing quality 95%
- Fresnel, input and output lenses 92%
- Lenses misalignment errors 98%
- Internal fibre transmission (length) 96%
- Focal ratio degradation (FRD) 60-95%

- Total (not including seeing) 49-78%
Telescope – fibre coupling - FRD
Telescope – fibre input coupling
Fibre coupling

With 1x grin-lens

With 2x grin-lenses
Fibre output – collimator coupling

F/3 f 5mm F/20

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Collimator mirror reflectivity

- Edmund-Optics coatings for mirrors:
Echelle grating efficiency

- The maximum efficiency of echelles is maintained near the Littrow condition (when angle of incidence equals angle of diffraction)
- Within each order, the efficiency will be maximum at the middle of the order. Typically reaching 50 to 75%. It drops to about one-half these values at the crossover points (free spectral range)
- Out of Littrow configuration, the echelle reflectivity reduces rapidly (shadowing effect)
Echelle orders efficiency

Peak efficiency (100%)
Green laser 532nm (94%)

Correction coefficient: 1.064
Shadowing effect

Graph showing the relationship between relative efficiency and grating angle, indicating a decrease in efficiency as the grating angle increases.
Échelle out of Littrow

The “grating angle” should be as small as possible in order to approach the Littrow configuration where the efficiency is the maximum. In our FLECHAS design, we found that 9° was the best compromise between the size of the camera objective and the optical table.
FLECHAS Spectrograph

- Parabola: f 444 mm, Ø 75 mm, Edmund Optics
- Collimator beam: F/18
- Pupil: 25 mm
- Échelle: 79 li/mm 63º 25×50×9, Thorlabs
- X-disperser: Prism N-F2 60º 60x60x60mm
- Objective: f 200 F/2.8, Canon
- CCD Atik 11000: 4008×2672×9 µm (24×35)
Fibre link

- **Fibre**: ø 50 µm and 10 m long, Polymicro FIP
- **Fibre Injection F#**: F/3
- **Fibre Output F#**: F/3
- **Output lens**: Doublet \( f = 5 \text{ mm}, \, \varnothing 3 \text{ mm}, \) Linos
- **Collimator F#**: F/18.5
- **Beam projection at the collimator (pupil)**: \( \varnothing 24 \text{ mm} \)
- **Fibre image at the collimator (slit equivalent)**: \( \varnothing 308 \mu \text{m} \)
Optical efficiency
according to manufacturer

- Parabolic Mirror 95 %
- Échelle 55 %
- Echelle vignetting 95 %
- Prism 92 %
- Canon objective 90 %

- Fibre efficiency 49%-78 %
- Spectrograph only 41%
- Spectrograph + Fibre 20%-32%
Fibre efficiency

Fibre transmission (internal) in 20 m. FLECHAS uses the FBP type.
Parabolic mirror reflectivity
Lab measurements

Reflectivity Enhanced Aluminium

Transmission (%) vs Wavelength (nm)
X-disperser. Transmission grating efficiency
Lab measurements

X-disperser Newport

Transmission (%)

Wavelength (nm)

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X-disperser. Prism efficiency
Lab measurements

Prism N-F2 60 60x60x60mm

Transmission (%)

Wavelength (nm)
Measuring prism efficiency
Camera efficiency
Lab measurements

Canon 200mm F/2.8 EF

Transmission (%) vs. Wavelength (nm) for a Canon 200mm F/2.8 EF lens.
Measurement of the reference flux (100%)
Measurement of the flux through fibre

- Laser
- 3 X objective
- 0.5 mm pinhole
- Iris
- 16 X objective
- F/3
- Fibre
- Iris
- Integrating sphere
- F/3
- Photo diode
- I/V transducer
Integration sphere

incident beam
entrance aperture
photodetector

“first strike spot”
sidewalls with high average reflectivity
Measurements
Measurements

- Injection in fibre F/3
- Laser wavelength 532 nm
- Peak correction coefficient 1.064

\[ \eta = \frac{E_i}{E_o} \times 100 \, (\%) \]

- Fibre efficiency 82.4%
- Spectrograph only 39.7% 42.2% (*)
- Spectrograph + fibre 32.7% 34.8% (*)

(*) After applying peak correction coefficient
Conclusions

- The efficiency of an instrument is a feature as important as any other (resolution, wavelength range, etc.).
- Most critical component: the fibre. A bad FDR could cause you loosing 30% of the light (imagine you need a telescope 30% bigger!).
- Efficiency measurements can be easily performed with lasers (blue, green and red).