Laboratory Measurements of Calibration Sources for X-shooter

F. Saitta[1], F. Kerber[1], P. Bristow[1], H. Dekker[1], S. D'Odorico[1], C. Dupuy[1], J.-L. Lizon[1], A. Norup Sorensen[2], J. Vernet[1]

1 European Southern Observatory, Germany, 2 Copenhagen University Observatory, Denmark

We report on simulations and laboratory measurements to characterize the spectral output and operational properties of a selection of pen-ray lamps containing the noble gases Ne, Ar, Kr, and Xe as well as a Th-Ar hollow cathode lamp. Testing is taking place at ESO using a commercial Fourier Transform Spectrometer (FTS). The results of the laboratory work will determine the combination of lamps to be used as calibration sources for the near-IR arm (1000-2500 nm) of the X-shooter spectrograph.

Introduction - X-shooter

X-shooter is a single target spectrograph for the Cassegrain focus of one of the VLT UTs covering in a single exposure the spectral range from the UV to the K band (320 -2500 nm). It is designed to maximize the sensitivity in this spectral range through the splitting in three arms (UVB, VIS and NIR) with optimized optics, coatings, dispersive elements and detectors. X-shooter will be a unique instrument on 8m class telescopes in that it is capable of recording - over such a large wavelength range - the spectrum of an astronomical target in a single exposure. It operates at intermediate resolutions (R=4000-14000, depending on wavelength and slit width) sufficient to address quantitatively a vast number of astrophysical applications while working in a background-limited S/N regime in the regions of the spectrum free from strong atmospheric emission and absorption lines. The instrument is currently under construction and commissioning is scheduled for 2008.
The following table lists the main characteristics of X-shooter:

Spectral Format	Prism cross-dispersed echelle (order separation ≥ 12")
Wavelength range	300-2500 nm, split in 3 arms by dichroics
Resolution	4000-7000 for 1" slit
Slit configuration	long slit (~12"); widths: 1" (standard), 0.6" (high resolution), 5" (flux calibration); IFU 1.8" x 4" input area
Detectors	2k x 4k CCDs (UV and Visual-Red arms), 2k x 2k (1k x 2k used) Hawaii LPE MCT (IR)
Auxiliary functions	Calibration Unit; acquisition and guide unit with 1' x 1' field and filter set; ADC for the UV and Visual arms.

Wavelength Calibration Sources for X-shooter

To realize the potential of X-shooter excellent wavelength calibration across all three arms is essential. For UVB and VIS, Th-Ar hollow cathode lamps have been chosen as calibration sources following the successful operations of such lamps in e.g. FEROS, SINFONI, UVES and HARPS. For the NIR arm the situation is less clear cut and we are conducting a dedicated program to select the best combination of calibration sources for this wavelength region which traditionally has relied on atmospheric features for wavelength calibration. Recently, ESO has gained significant experience with NIR wavelength standards as part of the CRIRES project (see Kerber et a;. P17, this conference). As part of the X-shooter study we will use ESO's laboratory FTS (Fig. 1) to investigate the spectral output and operational characteristics of a variety of pen ray lamps and the Th-Ar hollow cathode lamp.

Pen Ray Lamps

These lamps are called "Pencil" lamps because of their size and shape. They are made of double bore quartz tubing with two electrodes at one end sealed into a handle. These lamps produce narrow, intense lines from the excitation of various rare gases and metal vapors. They are commercial products widely used for wavelength calibration of spectroscopic instruments such as monochromators, spectrographs, and spectral radiometers e.g. in industrial and chemical analysis applications.
For X-shooter we are studying the properties of pen ray lamps with a noble fill gas, Ne, Ar, Kr or Xe. In the calibration unit the light from up to four of the lamps will be combined in a 6-inch integrating sphere with Spectralon surface before being fed to the NIR arm.
One main goal of the study is to find out what combination of the four possible lamps will give a composite spectrum best suited for calibration of X-shooter in terms of line density and dynamic range. For this we need to establish relative intensities of the lines and the lamps relative to each other.

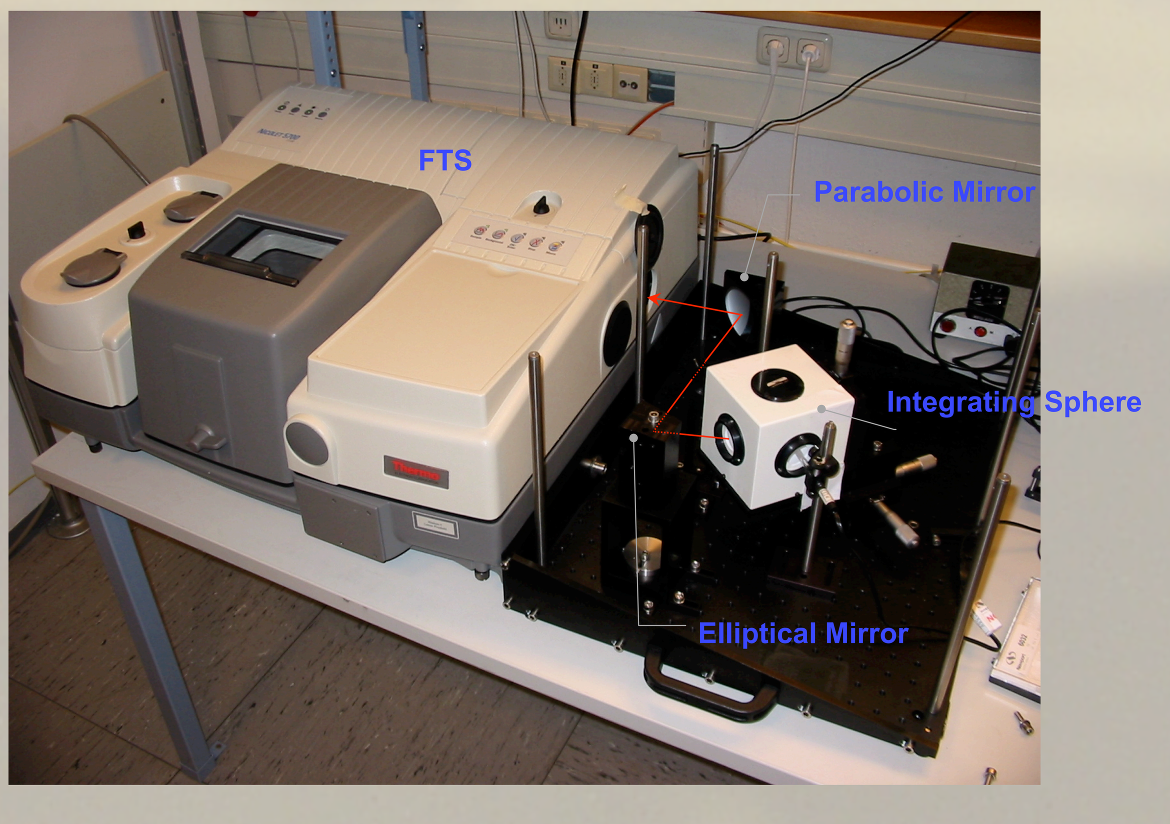

Figure 1: Fourier Transform Spectrometer with permanent set-up for measuring external sources in the ESO IR laboratory.

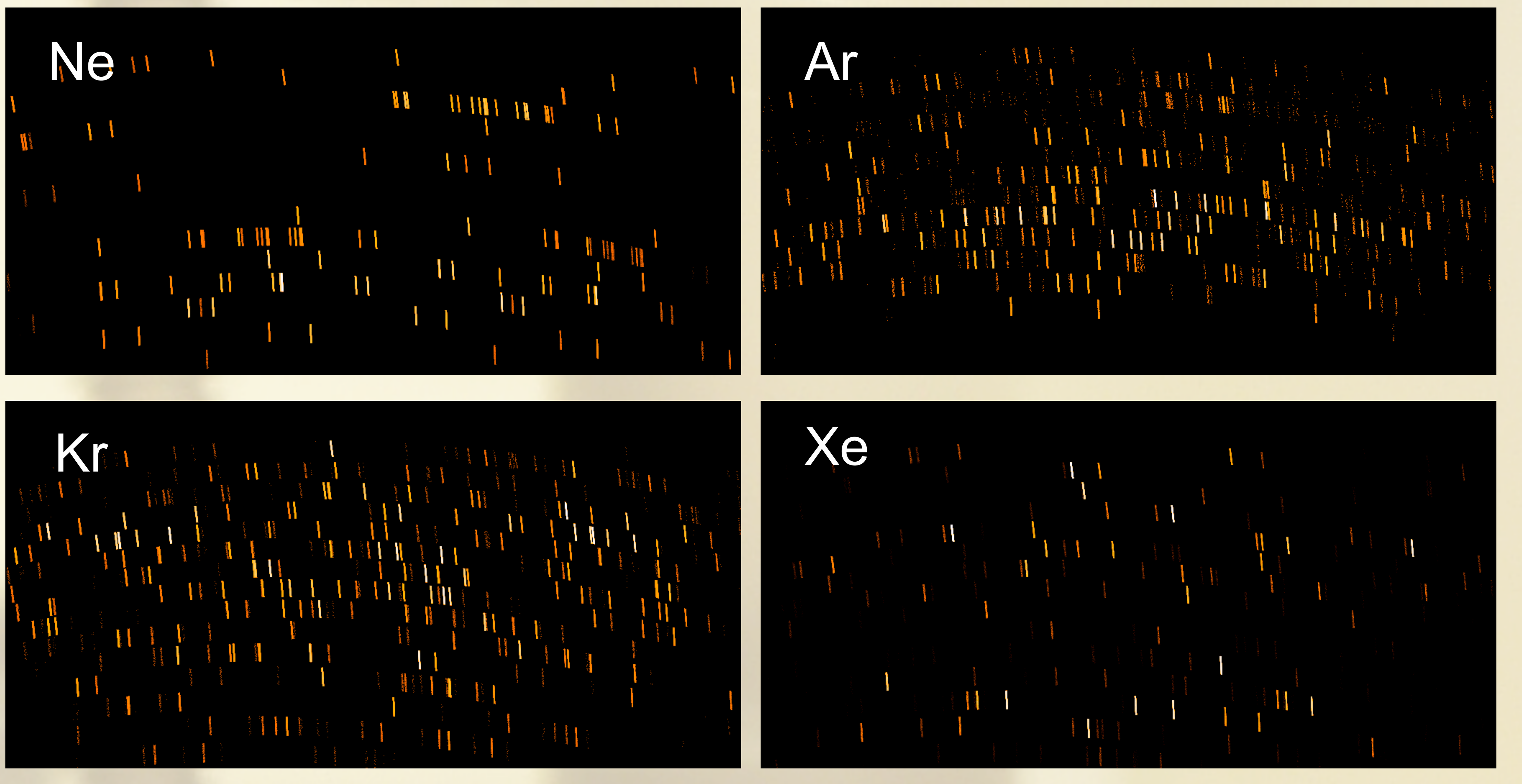

Figure 2: Simulated Spectra of Ne , Ar , Kr , Xe in the X-shooter spectral format for the NIR arm. The 2-D echellograms are produced by means of a physical model of X-shooter developed at ESO. Details of this method are described in the talk by P. Bristow. As input published lists of emission lines for each element are provided. Note: The relative intensities of lines of a given element are reasonably well know. In contrast the intensities of the lamps relative to one another are not known and will be determined by the laboratory measurements. Hence these simulations are for illustration purposes only, at this point.

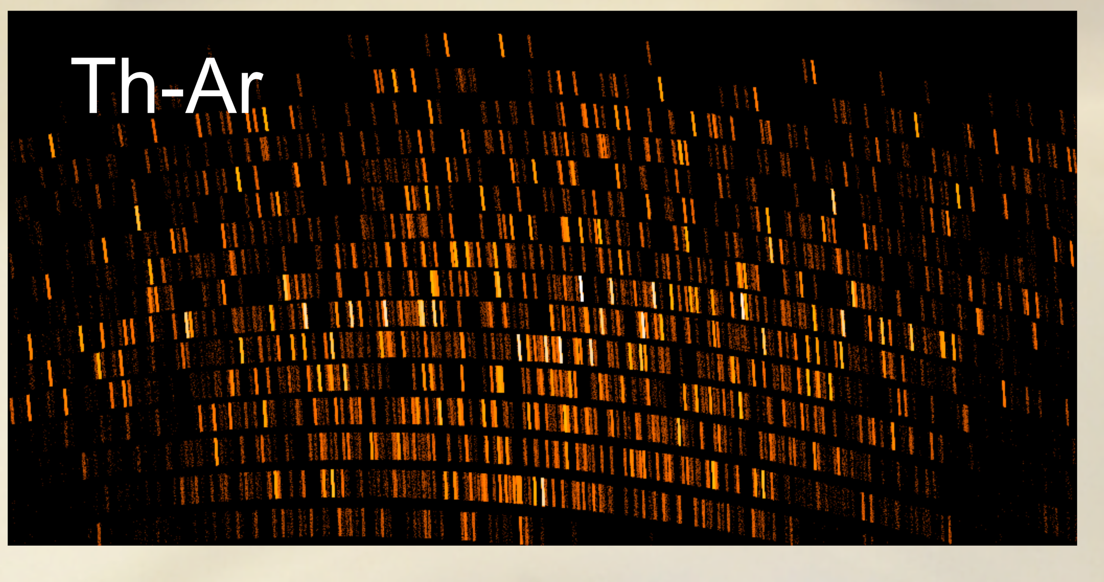

Figure 3: Simulated Spectra of Th-Ar in the X-shooter spectral format for the NIR arm. The echellogram as produced by means of a physical model of X-shooter developed at ESO. The input list of emission lines from a Th-Ar is a product of laboratory work done in a collaboration of ESO and NIST for the CRIRES project.

Th-Ar Hollow Cathode Lamp

Modern commercial hollow cathode lamps (HCLs) are sealed-off glass tubes that contain a metal cathode, a metal anode and a fill gas at a defined pressure. The lamp is operated by applying a voltage of a few hundred volts across cathode and anode. As a result, a discharge is formed in the low pressure (few hundred Pa) fill gas and positive ions of the plasma are accelerated towards the cathode where they release matter through sputtering. As a result a HCL emits a rich spectrum of narrow emission lines from both the gas and metal atoms and ions in the plasma. The Th spectrum was studied from 278 nm to about 1000 nm at high resolution more than 20 years ago by Palmer & Engleman (1983, LANL Report LA-9615). Its emission lines are very narrow and the spectrum is rich over a wide wavelength range. In nature Th has only one isotope, ^{232}Th, which has zero nuclear spin. Thus the use of Th for calibration lines avoids complex and asymmetric line profiles attributable to isotopic or hyperfine structure.

Two valuable studies of the Th-Ar spectrum in the near IR have recently been published, but neither is directly applicable to the operation of X-shooter:

- Hinkle et al. (2001, PASP, 113, 548) produced an atlas of the Th-Ar spectrum covering selected regions in the range 1000 nm to 2500 nm. Their list of about 500 lines contains significant gaps in wavelength coverage.
- More recently, a fundamental analysis of the Th-Ar spectrum was provided by Engleman, Hinkle & Wallace (2003, JQSRT, 78, 1). Their list contains more than 5000 lines. Their high current source is very different from low current commercially available lamps and is not well-suited for operation at an astronomical facility. Although the spectrum from the high current lamp is significantly different from commercial Th-Ar lamps, the line list is highly valuable for identification of the lines in low current spectra.

The spectrum of low current Th-Ar HCLs has been studied extensively by a collaboration (Kerber et al. 2006, SPIE 6269, 2O) of ESO and the US Institute of Standards and Technology (NIST) in preparation for ESO's high resolution IR echelle spectrograph (CRIRES). See the poster by Kerber et al. P17 for details. X-shooter will benefit directly from this experience.

Goals of the Laboratory Measurements

For the wavelength calibration of X-shooter's near-IR arm either a Th-Ar HCL or a combination of Ne, Ar, Kr, Xe pen ray lamps will be employed. The individual lamps are going to be used in parallel and their light is going to be combined by means of an integrating sphere (customised Labsphere 6-inch sphere, with Spectralon surface; granulated PTFE). Additional measurements of these lamps are required in order to fully understand their operational characteristics and to verify their suitability for X-shooter calibration.

ESO's IR laboratory is equipped with a state of the art commercial FTS. We have built a permanent set-up which replicates part of the optical train of the FTS (Fig. 1). This allows us to use an external light source for our FTS measurements.

The main goals of the measurements are:

- to measure the spectra of commercially available pen ray lamps filled with Ne, Ar, Kr, Xe (Fig. 2 shows simulated X-shooter spectra of the four gases),
- to determine line density and intensity ratios of each lamp,
- to determine the relative intensities of the four lamps,
- to select a suitable combination of one to four pen ray lamps and verify the usefulness of the composite spectrum.,
- to compare such a composite gas spectrum to the spectrum of a Th-Ar hollow cathode lamp (Fig. 3 shows a simulated X-shooter spectrum),
- to analyse for the number of unblended lines,
- to study issues related to the operation of the calibration lamps, such as stability, lifetime, optimal operating current etc.

Summary

We reported here on the plan for selecting the calibration sources for the NIR arm of X-shooter. To this end we have performed simulations of X-shooter echelle spectra using a physical model of X-shooter and line lists of Ne, Ar, Kr, Xe available from the literature and provided by colleagues at NIST.

In the next step we will conduct laboratory measurements of Ne, Ar, Xe and Kr pen ray lamps and a Th-Ar hollow cathode lamp in the range 900 - 2500 nm. In particular we are interested in the relative intensities of the lamps in order to find a suitable combination of them that can be used in an integrating sphere to form a composite spectrum.
Based on these studies we will then select the best calibration source in terms of number density of lines, number of unblended lines and dynamical range.

To support this work we have built a permanent set-up at the external port of the FTS in the ESO IR laboratory and we are now ready to begin the measures on these lamps.

Acknowledgements: We would like to thank all members of the X-shooter team for their dedicated effort. Special thanks go to C.J. Sansonetti, G. Nave (NIST) for providing some of their results prior to publication.