Model Based Calibration

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Instrumentation
- CRIRES & X-Shooter teams

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CRIRES
SDD
DFS/Pipeline development

NASA
NIST
ESO
Space Telescope
Calibrating the QAS
(“Quantitative Analysis” Spectroscope)

“Looking through the spectroscope at a fluorescent lamp… one violet line at 4360Å and one green line at 5460Å. If the lines are not exactly in place, the difference must be added or subtracted respectively in all determinations”
From Concept to Application

- M. Rosa: Predictive calibration strategies: The FOS as a case study (1995)
- Bristow, Kerber, Rosa: four papers in HST Calibration Workshop, 2006
- UVES, SINFONI, FOS, STIS
ESO's real instruments are a bit more complex than QAS…
CRIRES Simplified

- Model must take into account
  - Prism
    - 15° ZnSe Pre-disperser: \( n(T, \lambda) \)
    - Adjustable
  - Echelle grating
    - Adjustable
  - Focussing optics
  - Detector array
    - 4 x 1024x512pix
    - ~300 pix gaps
Not so simple…

- ~40 parameters
- Not all orthogonal - some degeneracy
- Constrained by design
- Different slit positions to sample 2D
- Multiple prism and grating angles
- Optimisation algorithm required => Simulated Annealing
Prism refractive index \((T,\lambda)\)

Spectral atlas for calibration lamp, eg. high quality Th-Ar hollow cathode data.

Initial “first guess” configuration file

Simulated Annealing

CRiRES model kernel

Output

Predicted positions of spectral features (pixels on detector array)

Matched

Measured feature positions (pixels) from deep calibration lamp exposure (wavecal)

Compare lists and compute metric which describes how well they match

Satisfactory match? No Change configuration

Simulated Annealing

Yes

Master configuration
CRIRES Products

- Optimisation provides optimal configuration of *fixed* parameters
- In collaboration with Yves Jung:
  - **Static library**
    - Uses header values for Prism and Grating settings
    - *Settings* \(\Rightarrow\) *angles* - via best fit from optimisation
    - Accuracy in \(~1\) pixel domain *across all wavelengths*
  - **Dynamic Library (in development)**
    - Requires on-the-fly wavecal exposure
    - Optimises prism and grating angles while keeping others fixed
    - Potentially in the 0.1 pixel domain *across all wavelengths*
CRIRES Summary

- Wavelength range 1-5μm
- Maps to ~200 exposures
- ~800 polynomial fits (1 per chip) would be required
- At some wavelengths these exposures will have very few calibration features
- Via the physical model approach we get a solution that can be extrapolated/interpolated to all wavelengths.
- See poster P15 by Yves Jung “The CRIRES Data Reduction Challenges”
X-Shooter (300nm-2.5µm)

- Model for **UVB, VIS** & **NIR** arms quickly adapted from CRIRES template
  - Same model kernel
  - Independent configuration files
- Cross dispersed
- Single mode (no moving components)
- Larger wavelength coverage per detector
- Flexure
Calibration Reference Data

- Whatever the method of calibration - *better reference data will help*
- CRIRES - Sky does not provide sufficient calibration features at high resolution
  - Th-Ar *NIST* collaboration - Kerber et al *P17*
- CRIRES, X-Shooter - Performance dependent upon $n(\lambda,T)$ prisms
  - *CHARMS* Optical properties collaboration
Wavelength Standards

- Th-Ar: standard source in VIS for FEROS, FLAMES, HARPS, UVES
- Project to establish NIR wavelength standards
- UV/VIS/IR 2m Fourier Transform Spectrometer, NIST
- > 2000 lines as wavelength standards: 900 – 4500 nm
- Insight into the properties of Th-Ar lamps

Saitta et al. Poster P27 compares Th-Ar, Ne, Ar, Kr & Xe spectra for X-Shooter

Th-Ar hollow cathode lamps - a standard source for wavelength calibration for near IR astronomy

CRIRES N 2O gas cell (poster P17) - characterization with ESO FTS
Refractive Index Measurements

ZnSe $n(\lambda, T)$

from CHARMS,
(GSFC, NASA)
Leviton & Frey, 2004

- ZnSe refractive index data for CRIRES
  - Model accurately predicts CRIRES behaviour as a function of temperature
- Measurements for X-Shooter prisms in progress
Conclusions

- Physical model approach:
  - Physically meaningful
  - Predictive power
  - Past CASPEC, UVES, FOS, STIS
  - Current CRIRES - Implementation delivered, fine tuning
    X-Shooter - prototype ready

- Calibration Reference Data (laboratory measurements)
  - Wavelength Standards
  - Optical Materials

- Future E-ELT