Model Based Calibration

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Calibration Support Group/Instrumentation

ESO Calibration Workshop,
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Instrumentation
- CRIRES & X-Shooter teams

CRIRES

Michael Rosa

Pascal Ballester

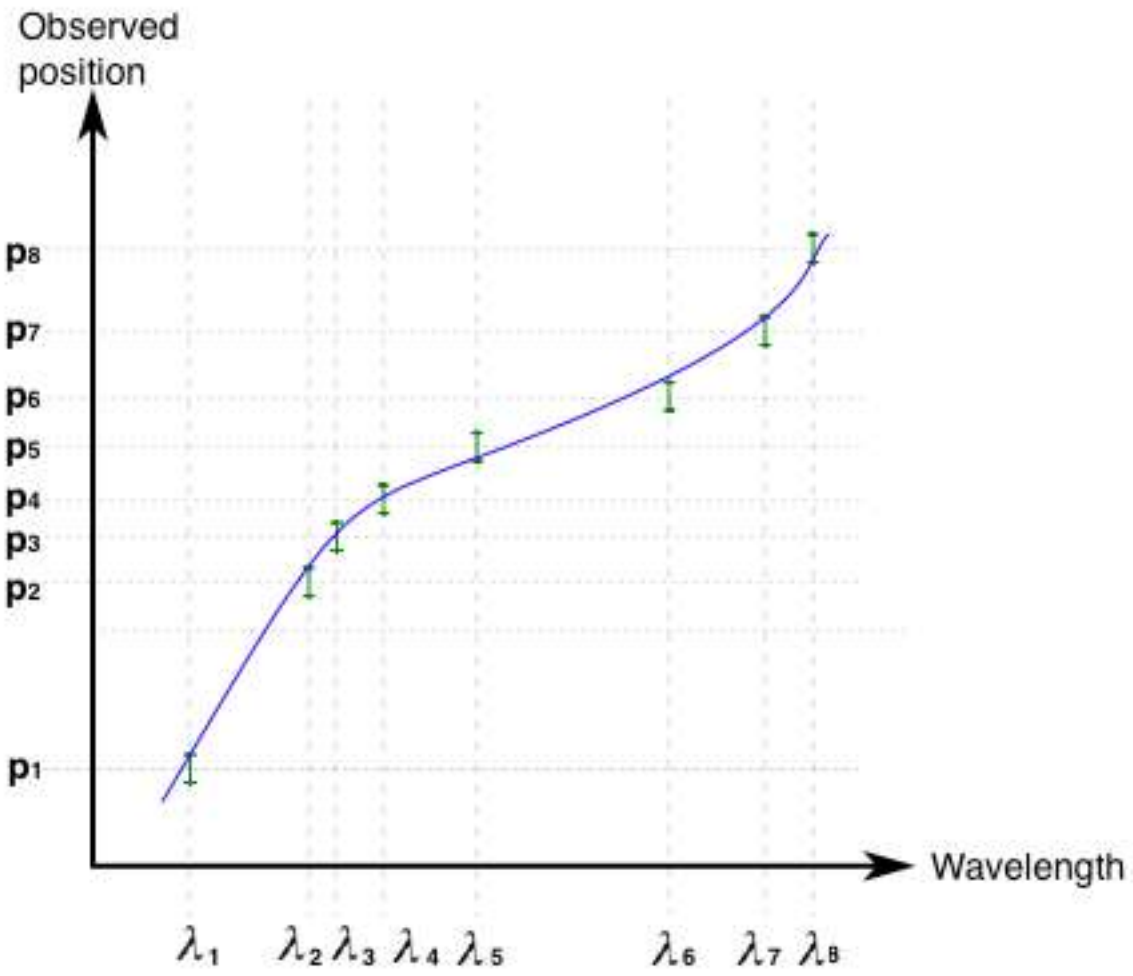
Yves Jung
DFS/Pipeline development

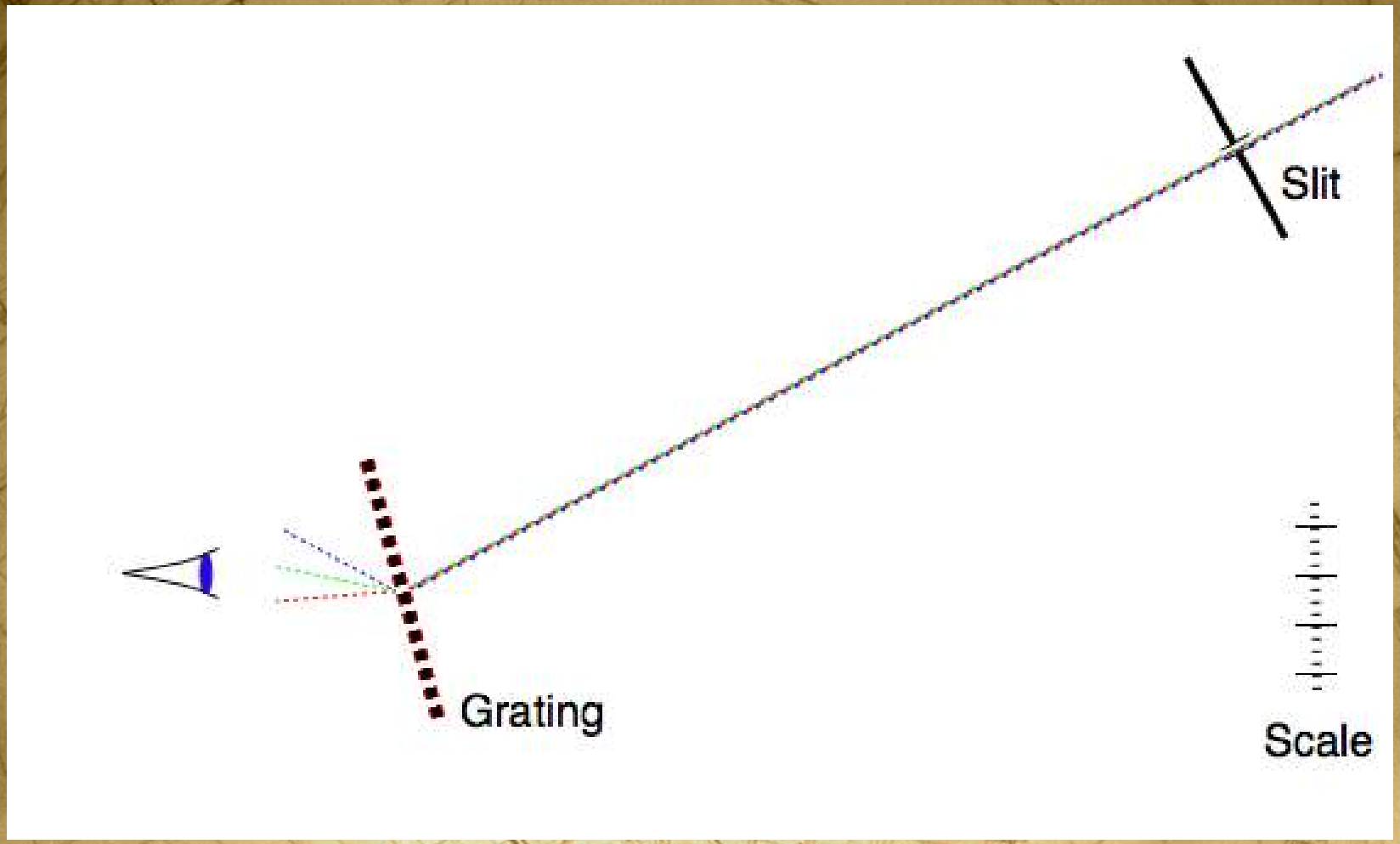
CHARMS, GSFC

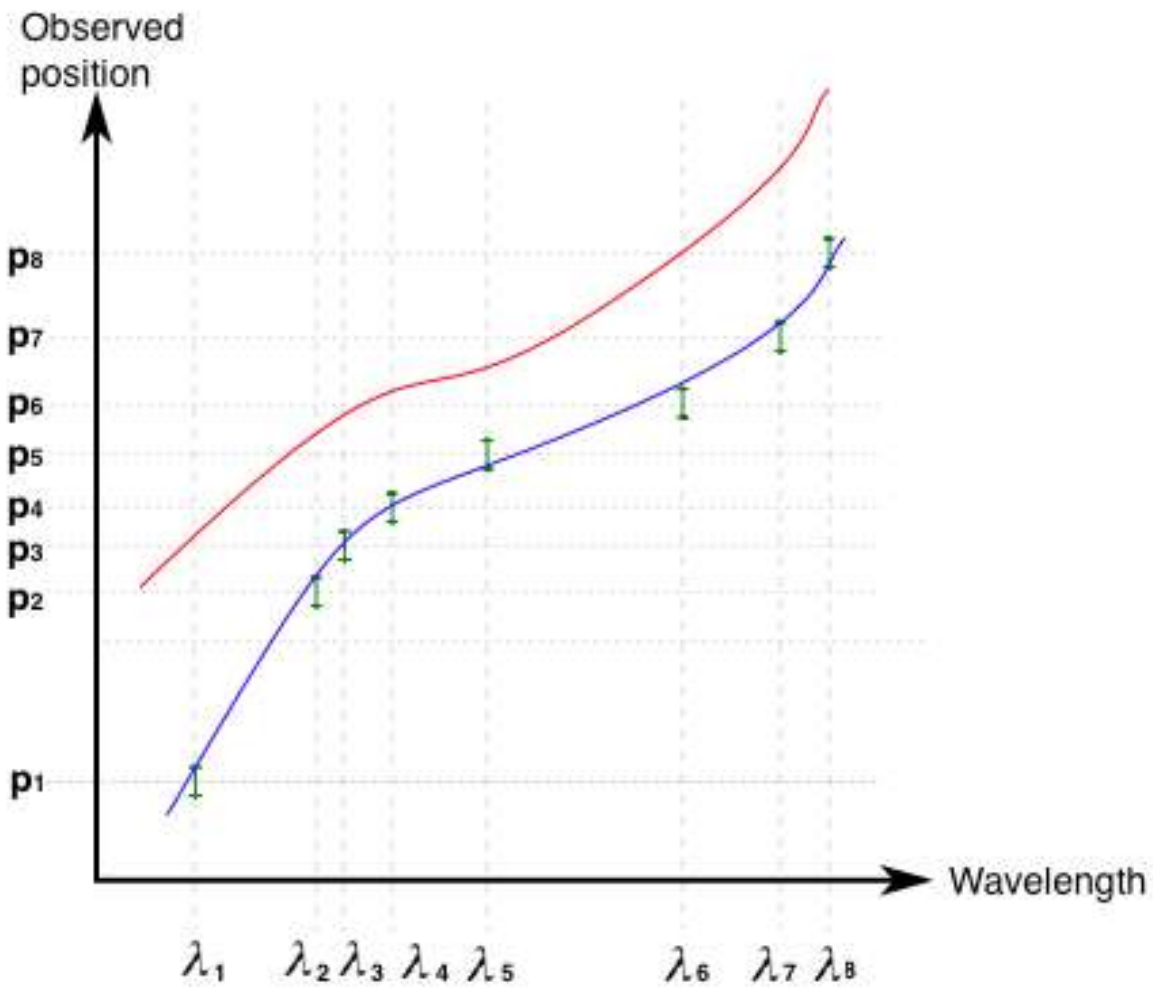
Atomic Spectroscopy Group (NIST)

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*"


Observed position
p8
p7
p6
p5
p4
p3
p2
p1
Wavelength
λ1
λ2 λ3 λ4 λ5
λ6
λ7 λ8


Slit
Grating
Scale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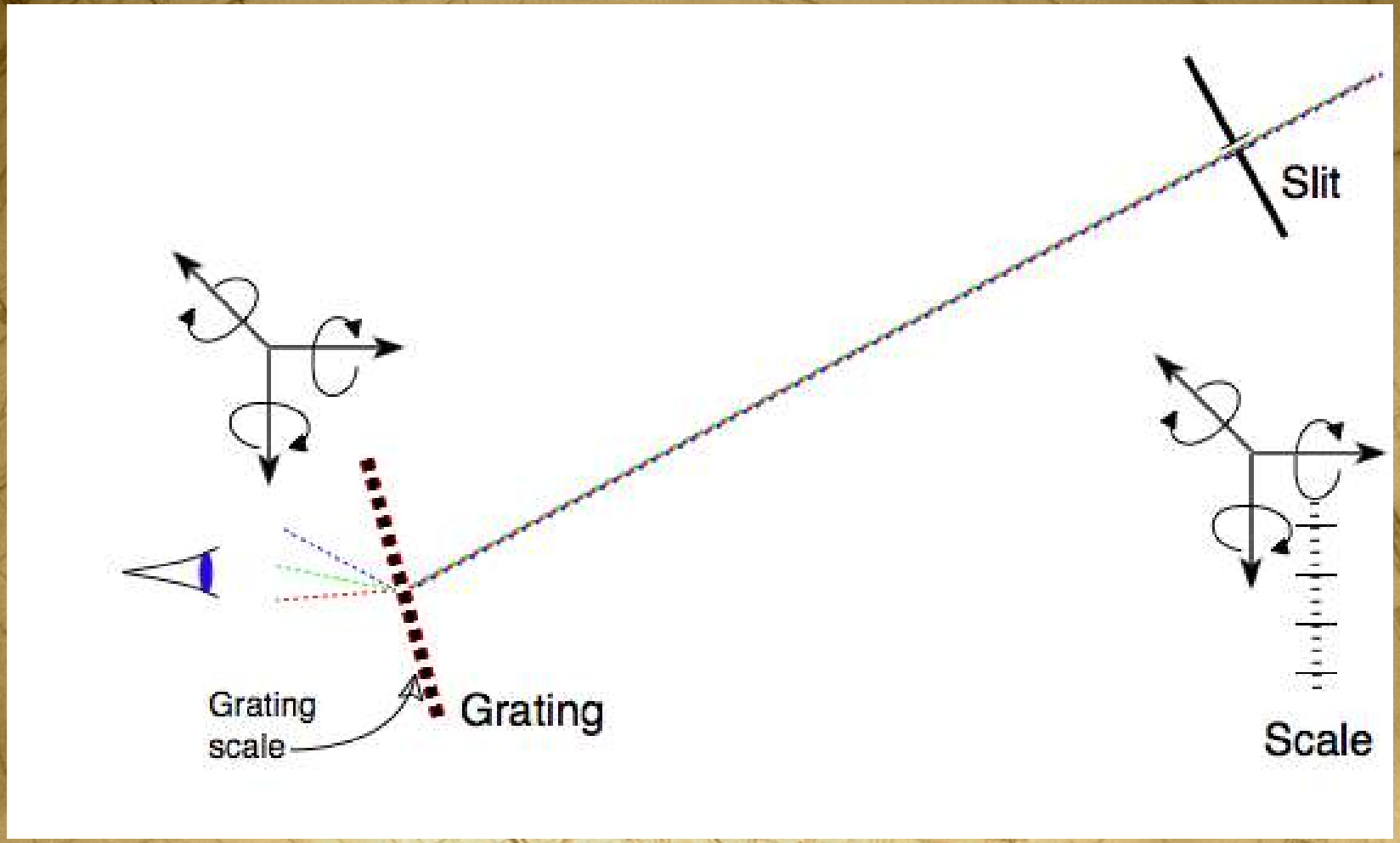
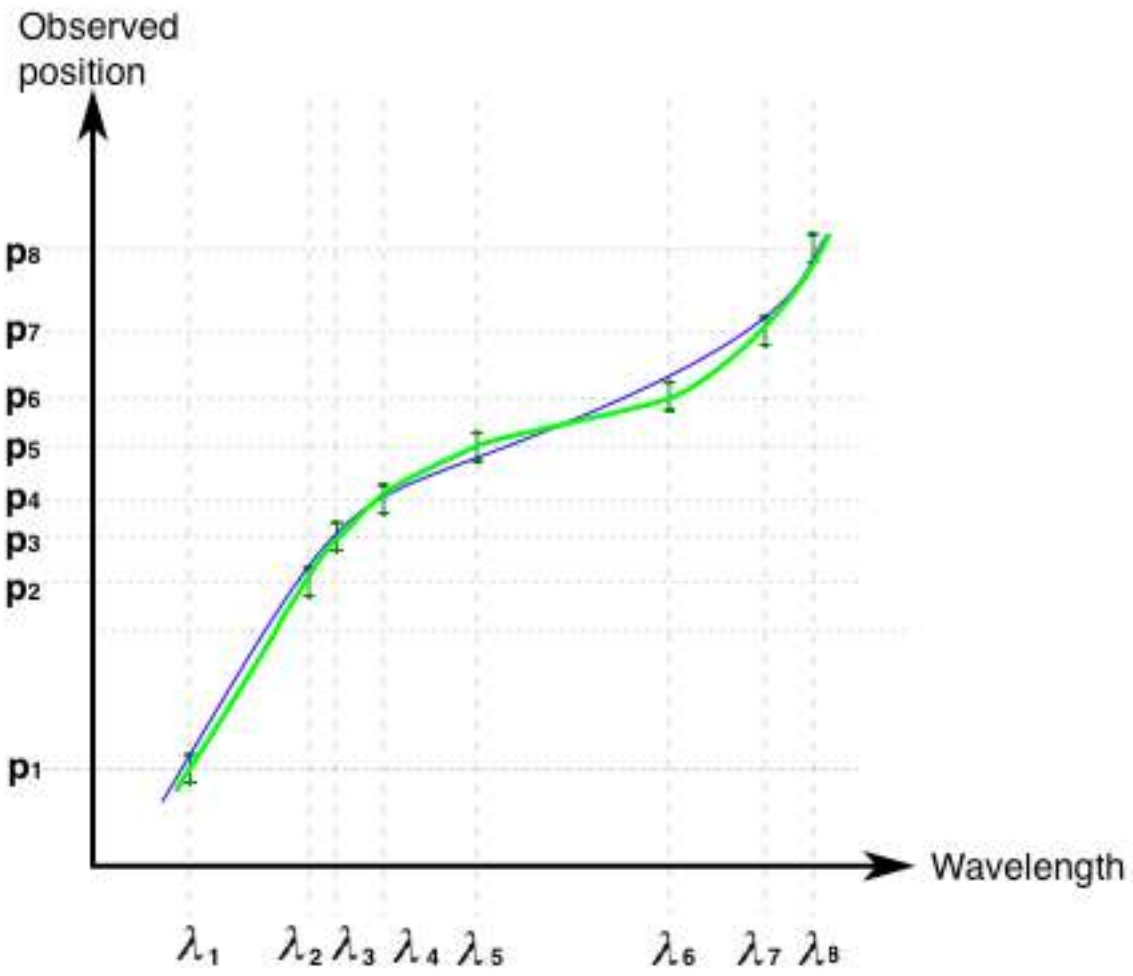

Slit
Grating
scale
Grating
Scale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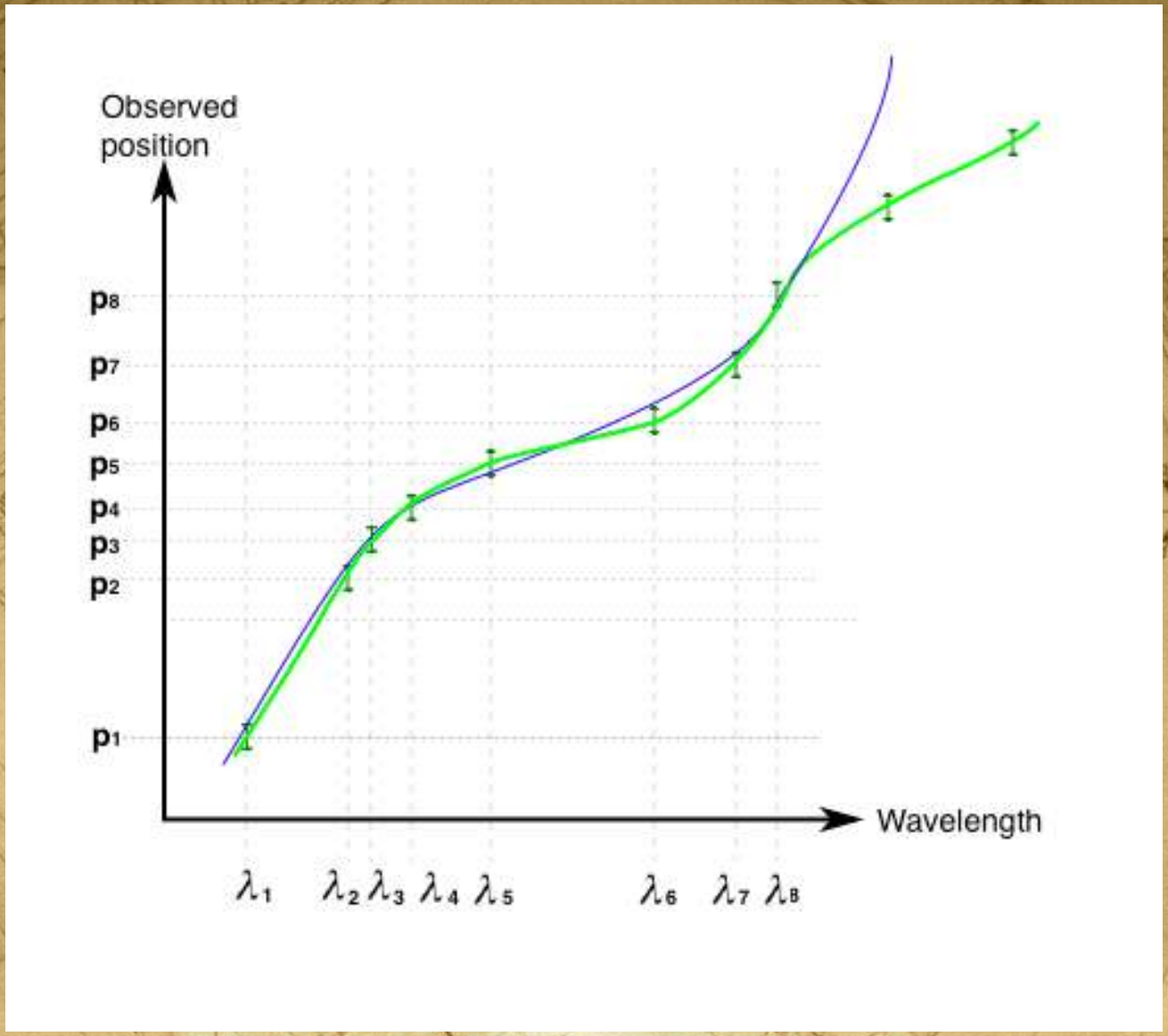
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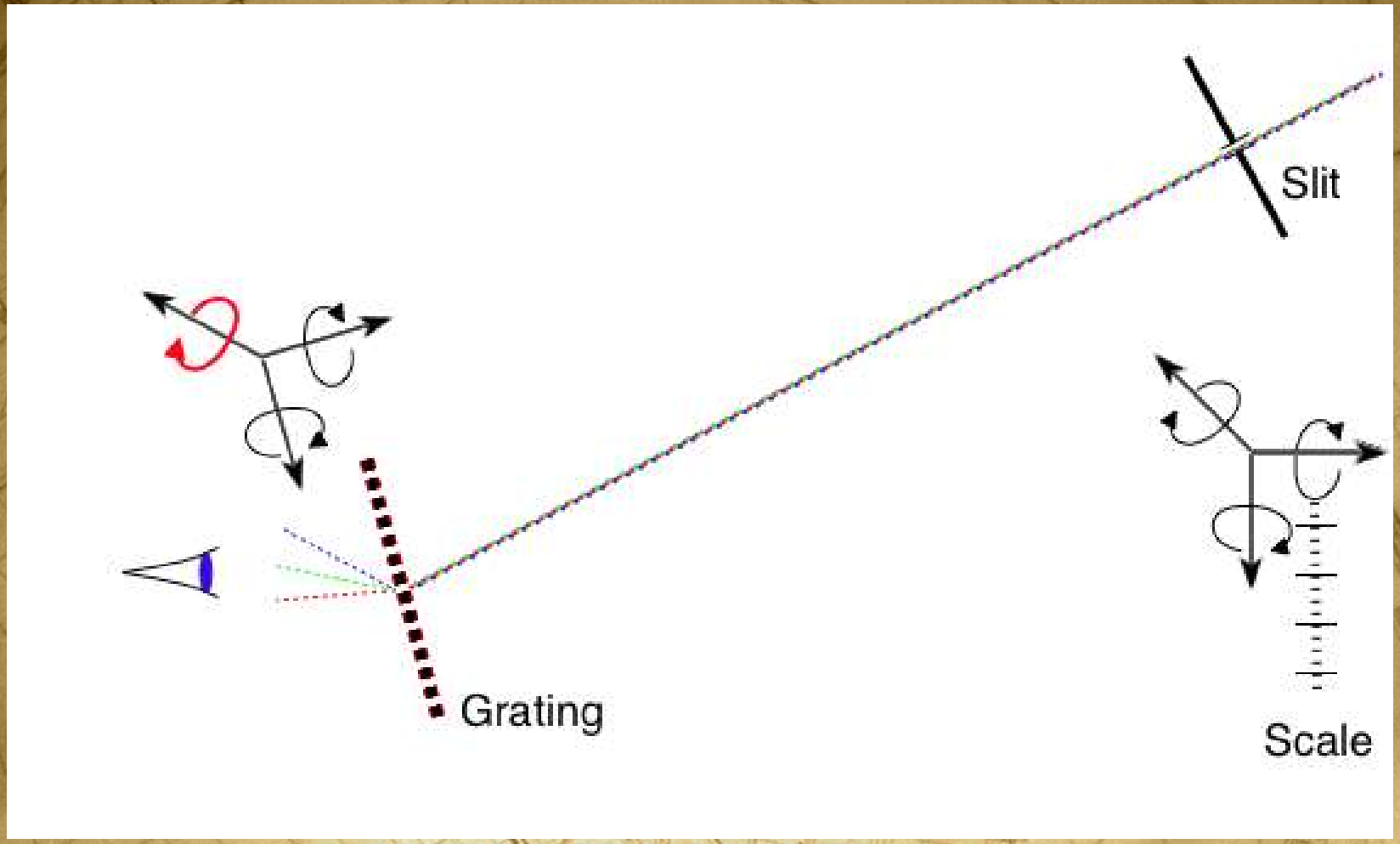
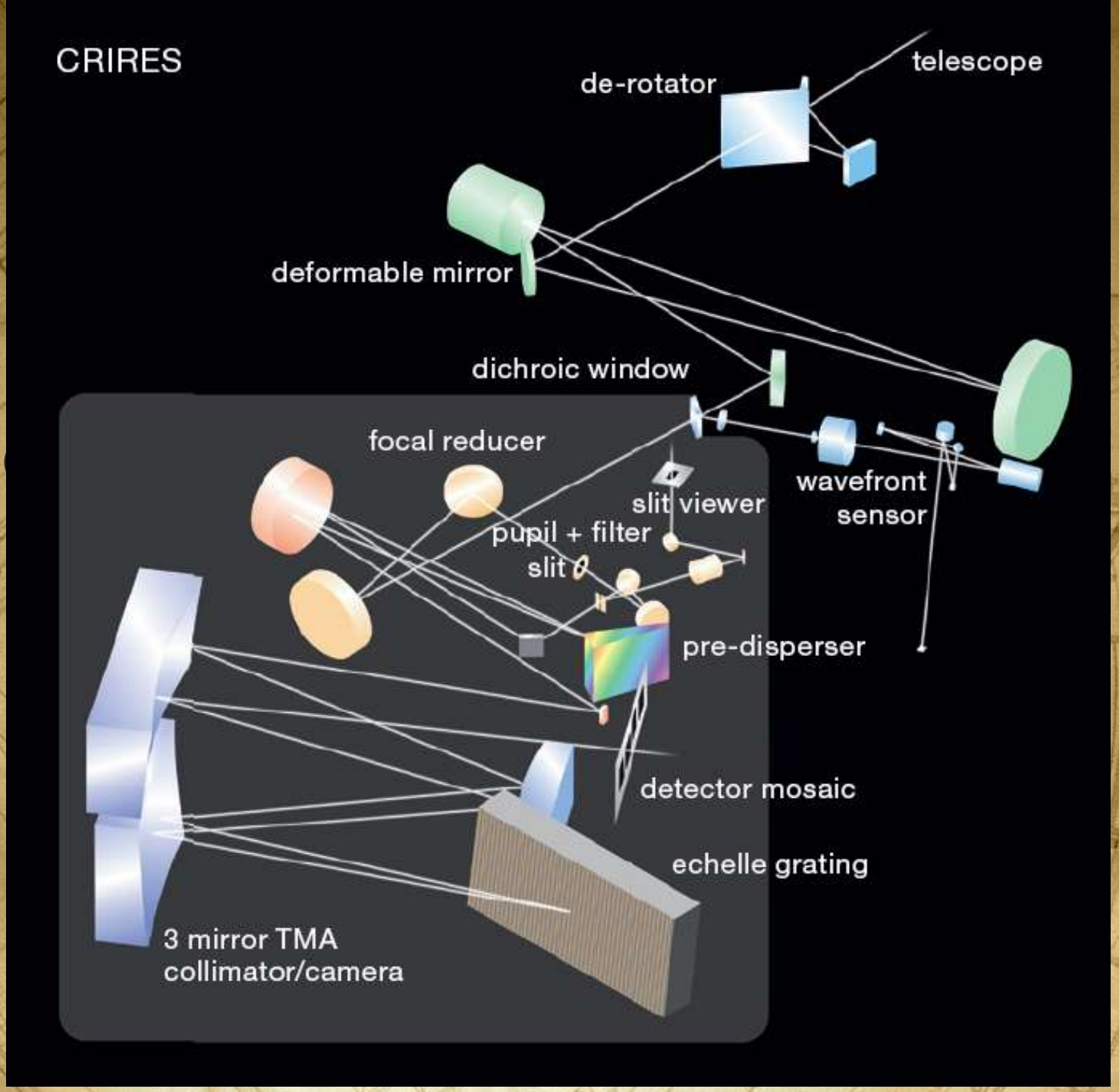

Slit
Grating
Scale

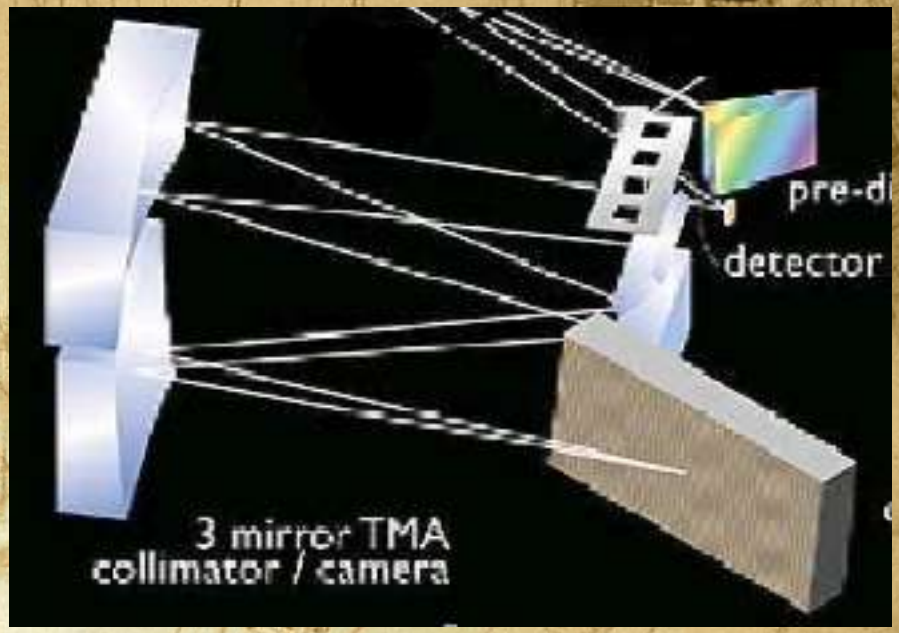
From Concept to Application

- M. Rosa: Predictive calibration strategies: The FOS as a case study (1995)
- P. Ballester, M. Rosa: Modeling echelle spectrographs (A&AS 126, 563, 1997)
- P. Ballester, M. Rosa: Instrument Modelling in Observational Astronomy (ADASS XIII, 2004)
- Bristow, Kerber, Rosa: four papers in HST Calibration Workshop, 2006
- UVES, SINFONI, FOS, STIS


CRIRES
telescope
de-rotator
deformable mirror
dichroic window
focal reducer
wavefront
sensor
slit viewer
pupil + filter
slit
pre-disperser
detector mosaic
echelle grating
3 mirror TMA
collimator/camera

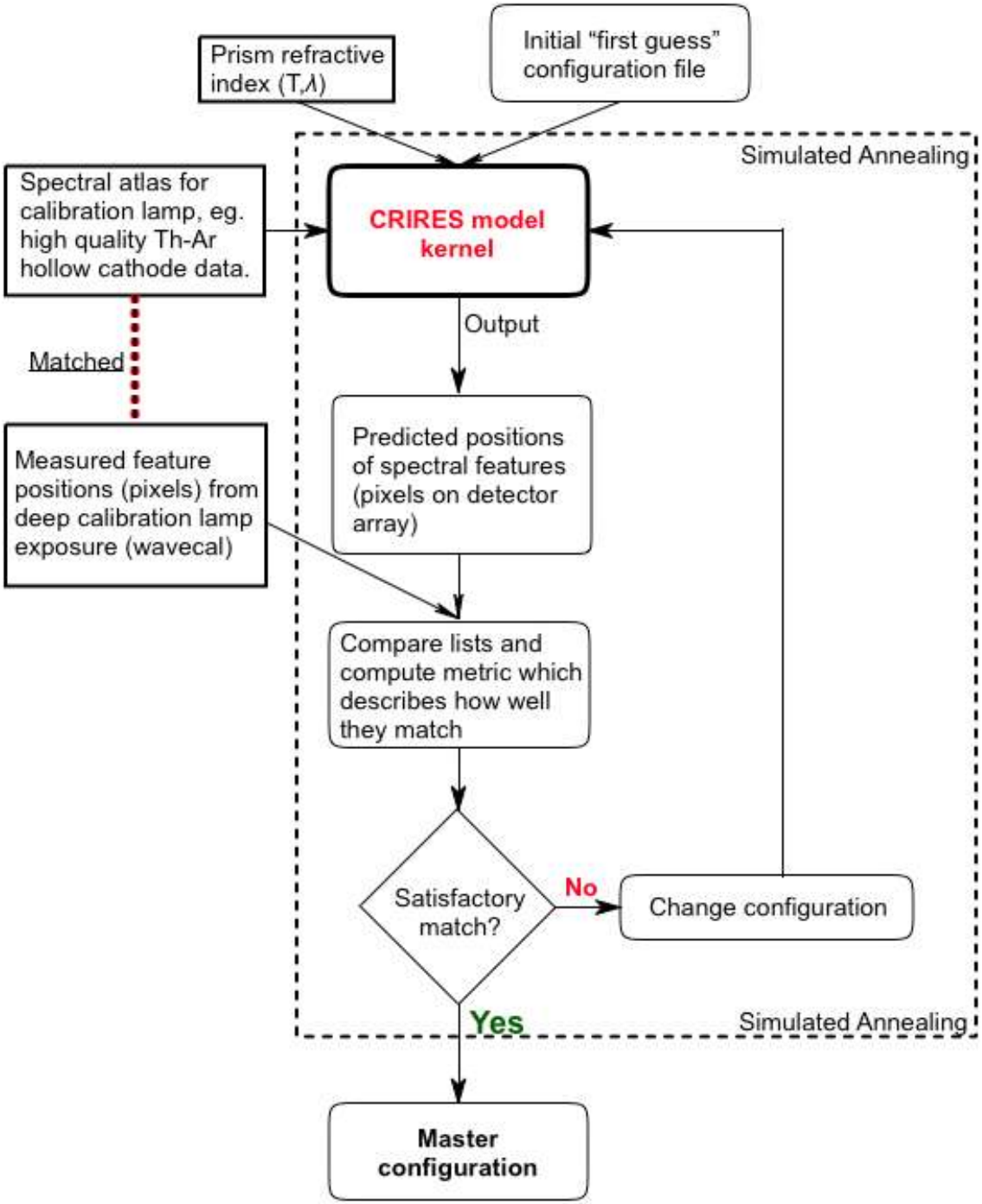
CRIRES Simplified

- 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,λ)
Initial "first guess" configuration file
Simulated Annealing
Spectral atlas for calibration lamp, eg. high quality Th-Ar hollow cathode data.
CRIRES model kernel
Output
Matched
Predicted positions of spectral features (pixels on detector array)
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
Yes
Simulated Annealing
Master configuration

CRIRES Products

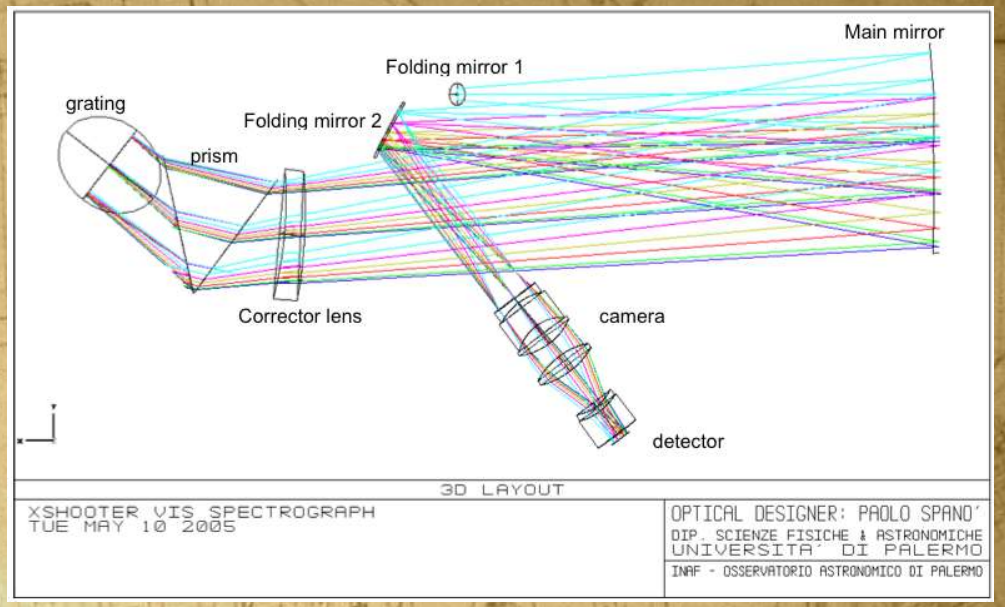
- Optimisation provides optimal configuration of *fixed* parameters
- In collaboration with Yves Jung:
  - **Static library**
    - Uses header values for Prism and Grating settings
    - *Settings => angles* - via best fit from optimisation
    - Accuracy in ~1 pixel domain *across all wavelengths*
  - **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*

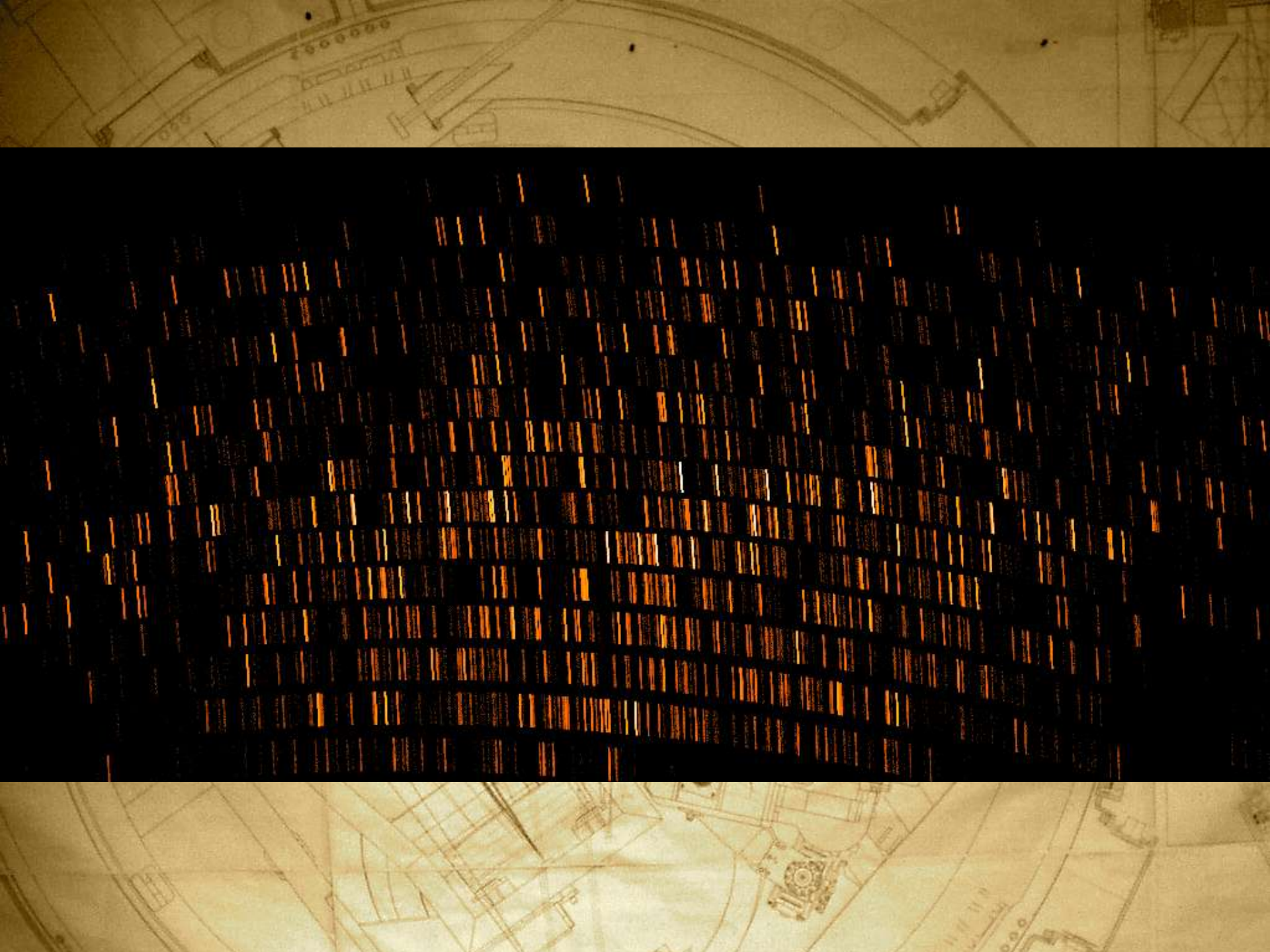
CRIRES Summary

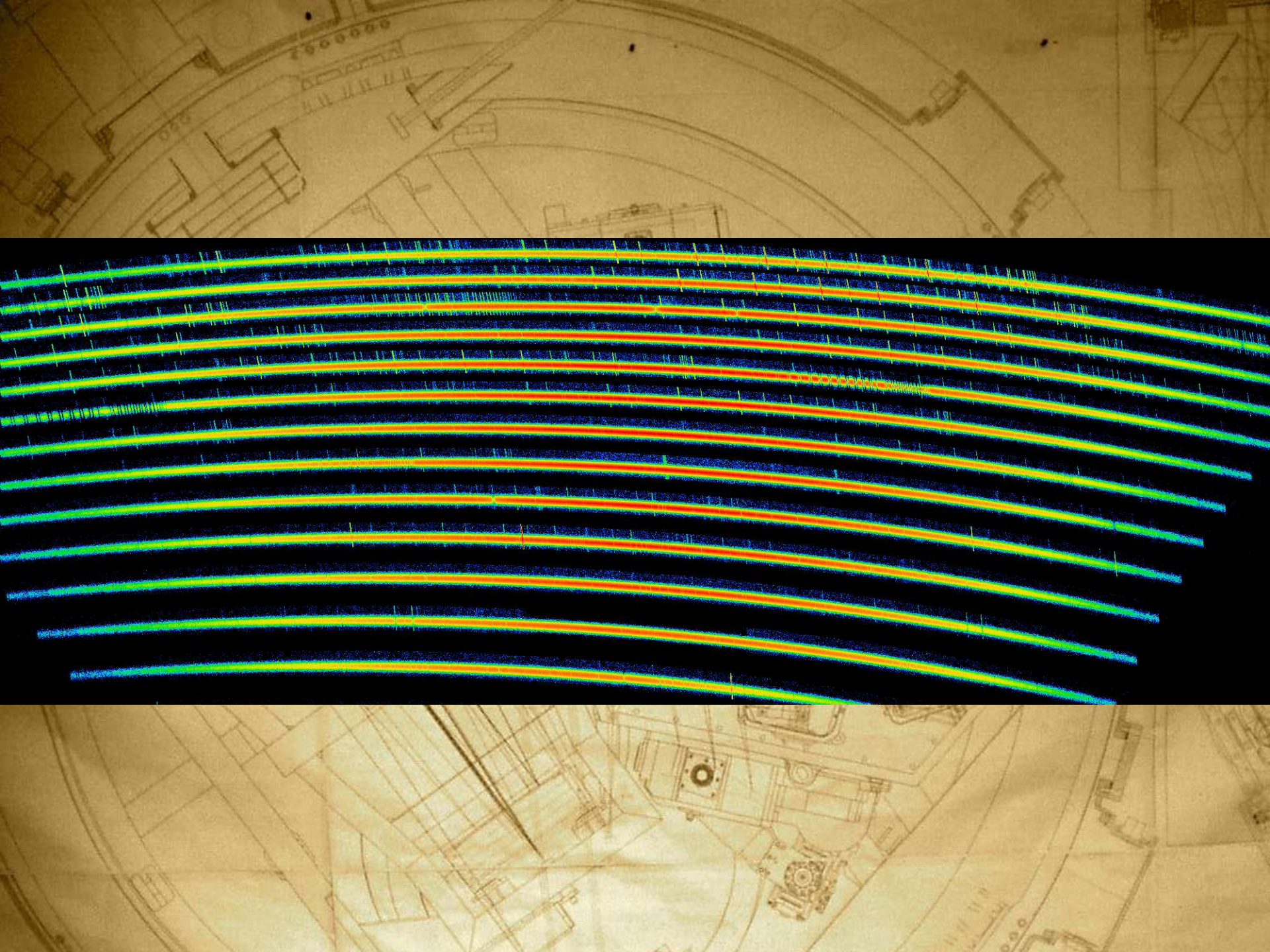
- Wavelength range 1-5μm
- Maps to ~200 exposures
- ~800 polynomial fits (1 per chip) would be required
- At some wavelengths these exposures will have *very* few calibration features
- **Via the physical model approach we get a solution that can be extrapolated/ interpolated to all wavelengths.**
-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

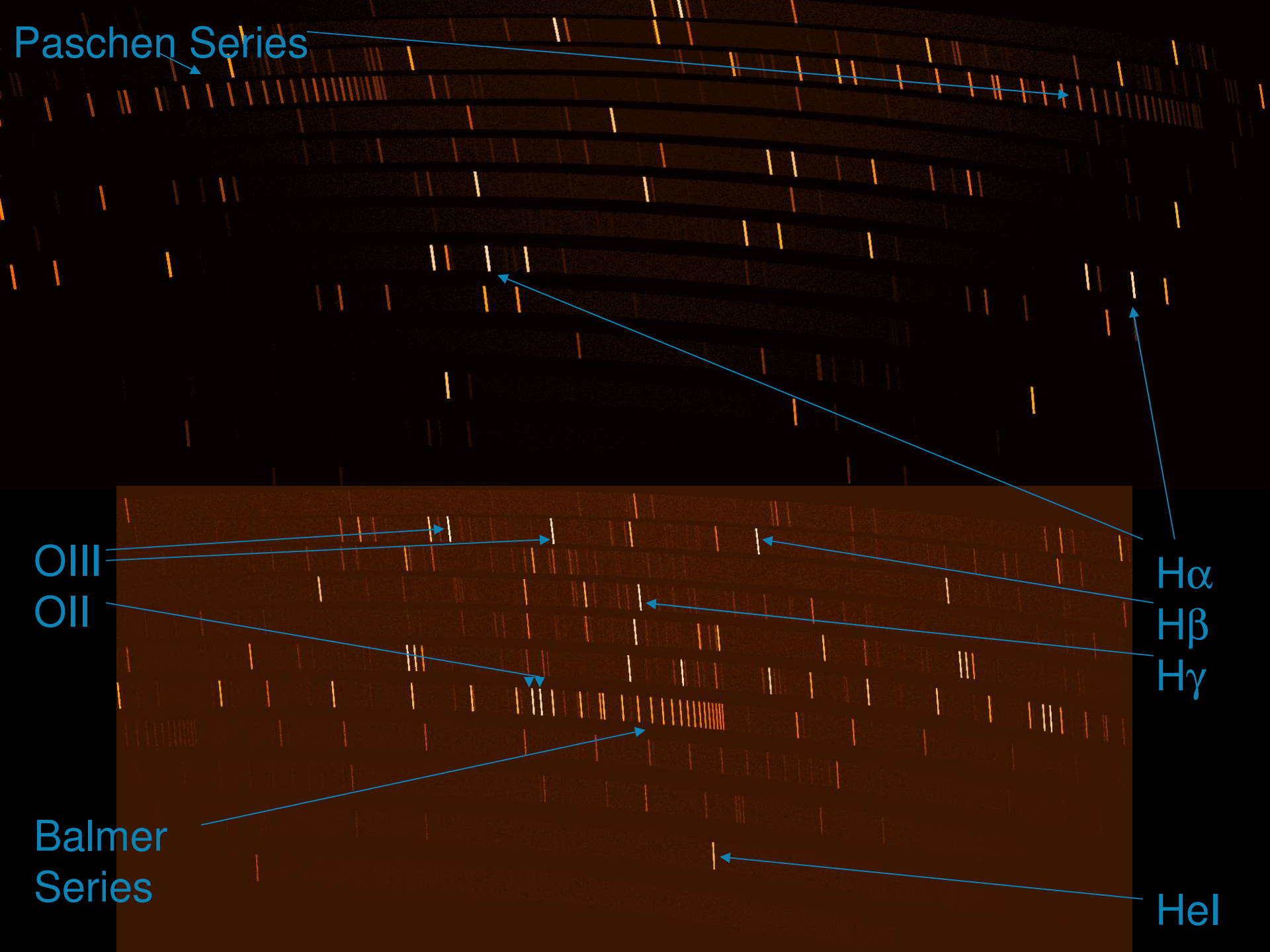
X-Shooter (300nm-2.5µm)

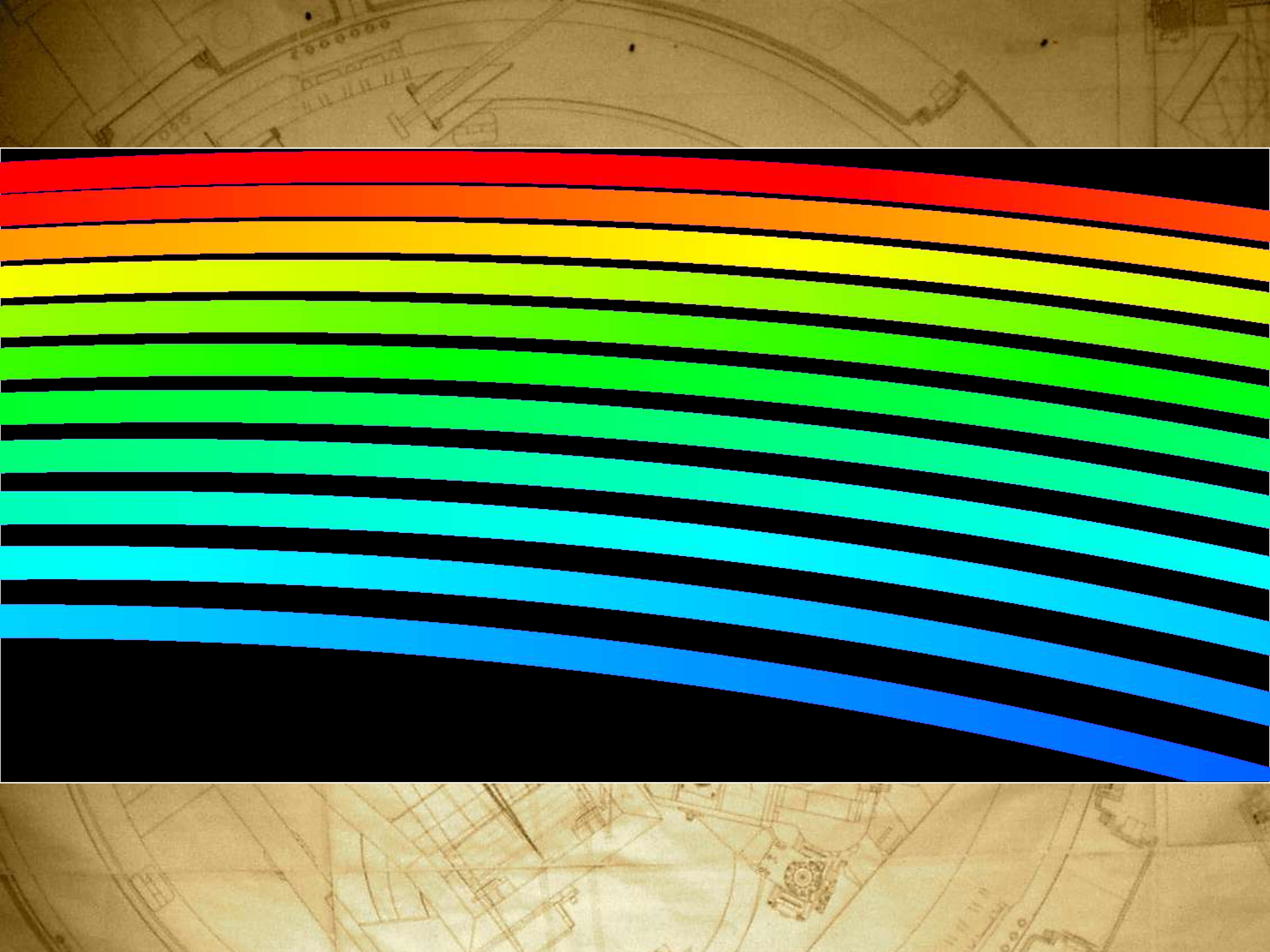
- Model for UVB, VIS & NIR arms quickly adapted from CRIRES template
  - Same model kernel
  - Independent configuration files
- Cross dispersed
- Single mode (no moving components)
- Larger wavelength coverage per detector
- Flexure





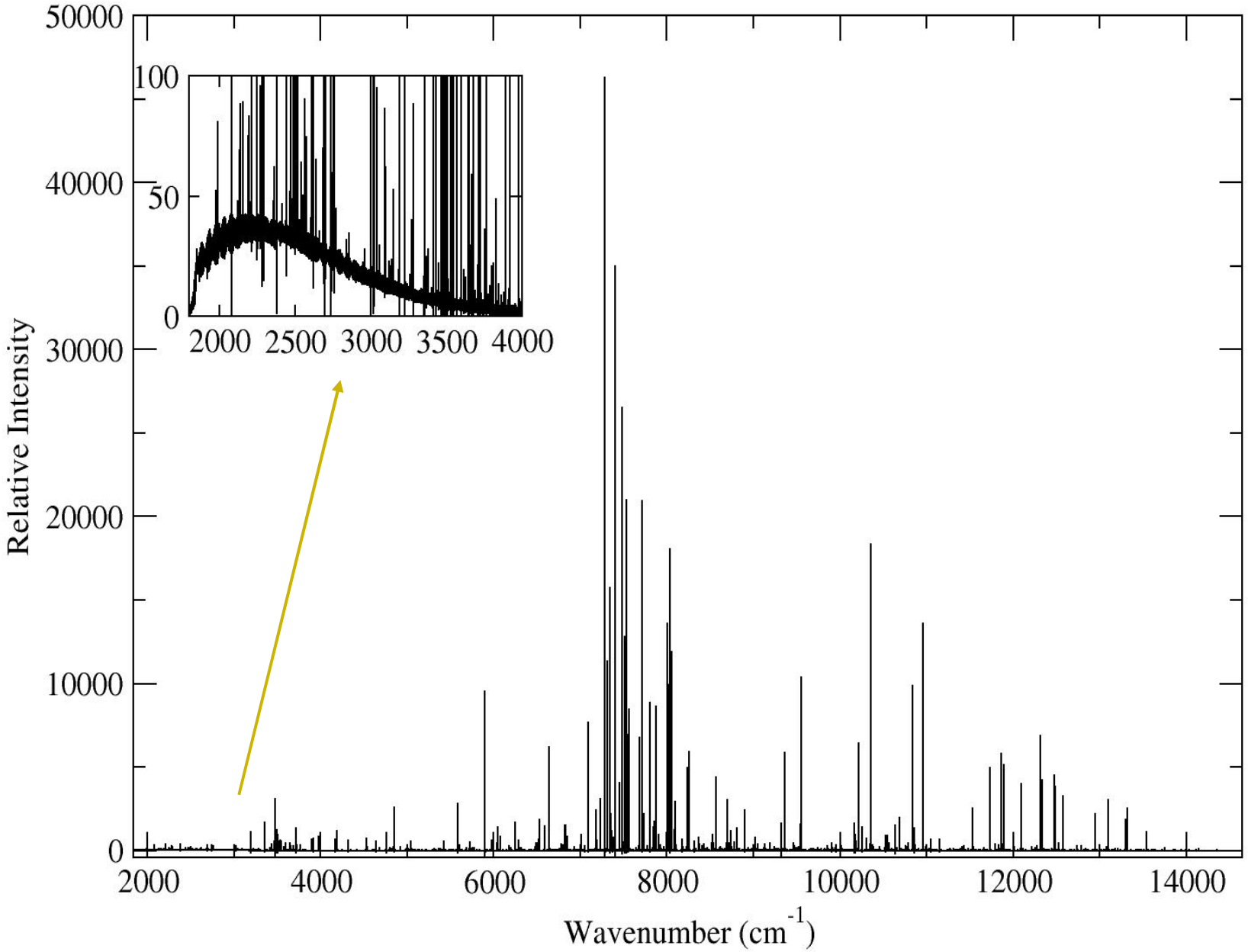



Paschen Series
OIII
OII
Balmer Series
Hα
Hβ
Hγ
HeI



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

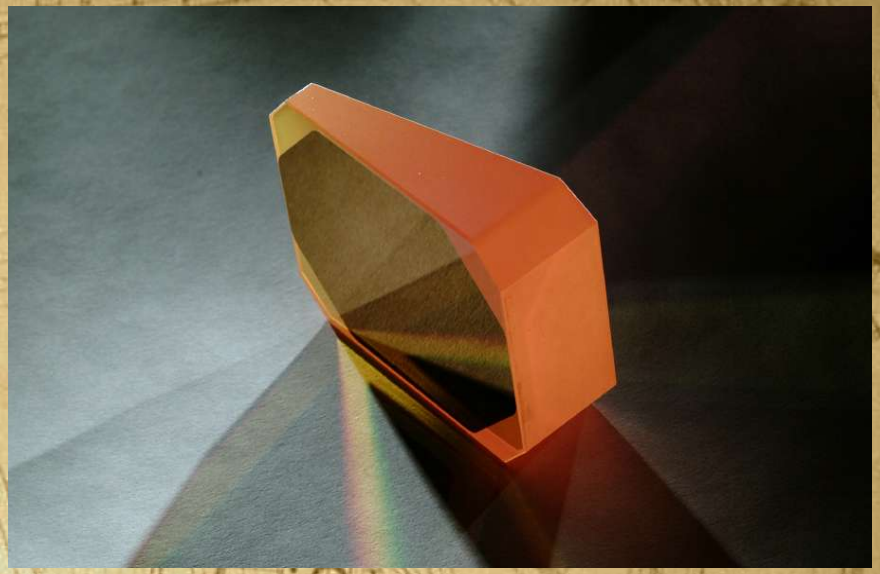

50000
40000
30000
20000
10000
0
Relative Intensity
2000
4000
6000
8000
10000
12000
14000
Wavenumber (cm-1)
100
50
0
2000 2500 3000 3500 4000

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