Precision Radial Velocity

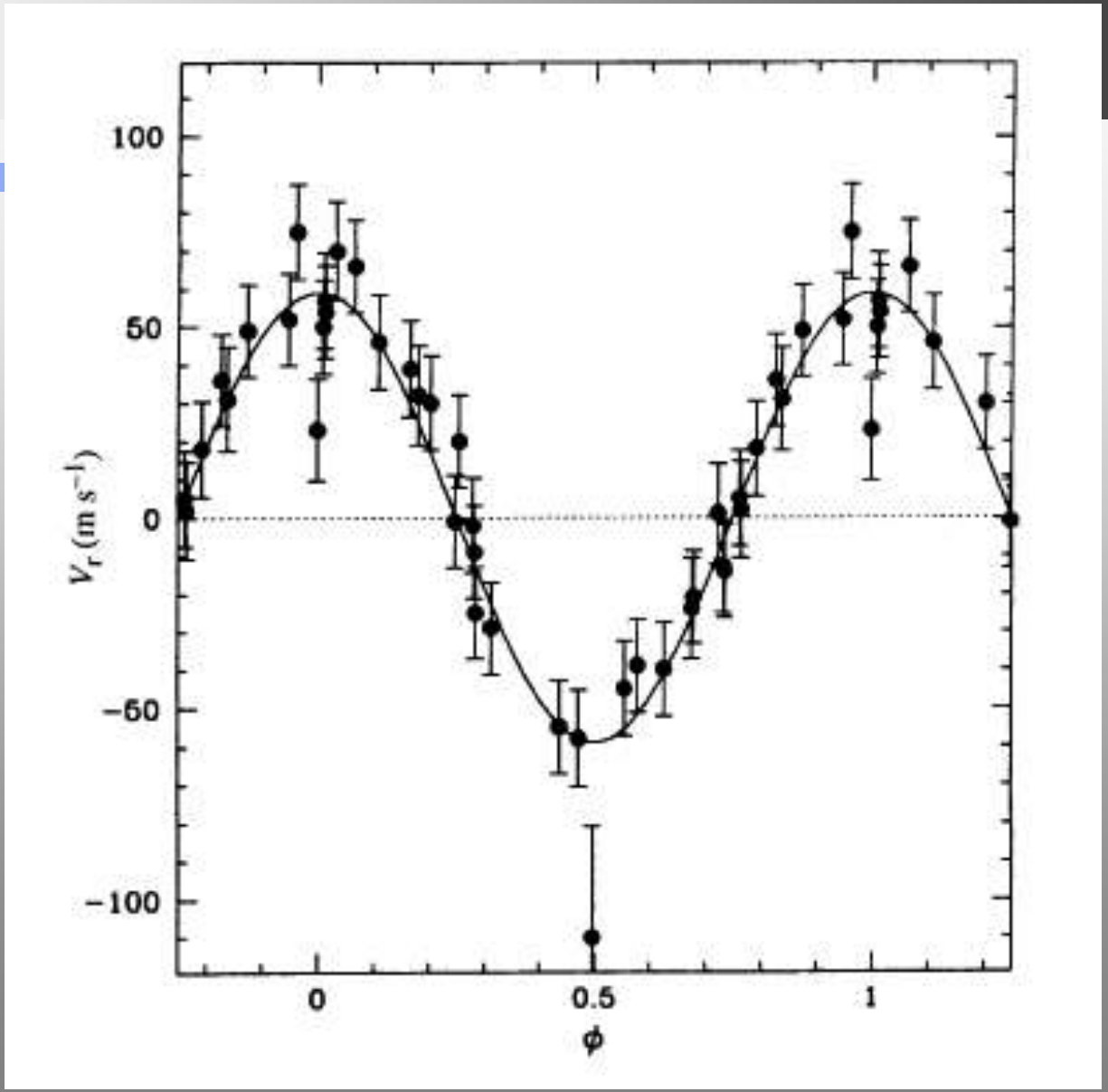
Lamps and some aspects of spectrograph calibration

F. Kerber, G. Lo Curto, G. Nave (NIST) et al.

Outline

- **Observing as measuring process**
- **Calibration Lamps and their properties**
- **Calibration Reference Data**
- **Light injection**
- **Fibre Scrambling**
- **Summary**

- **51 Peg (Mayor & Queloz)**



Observing: Top Level Requirements

1. **Calibration needs to be able to remove all relevant signatures imprinted on the light from the target throughout its journey to the detector readout.**
2. **Astronomical observations shall be treated as a process of experimental physics by a measuring apparatus. The observatory shall make all efforts required to properly describe, understand and minimize all statistical and systematic errors associated with the measuring process.**

Astronet Roadmap 2009

"As a core fundamental element, and as a guide, it is recommended that funding provision for laboratory astrophysics be included in the planning of all astronomical and space mission research programmes at a level of the order of 2% of overall budget, with each programme taking "ownership" and peer-review of this part of the project."

Astronet Roadmap, p.132

Decadal survey 2010

"Missions and facilities … that will require significant amounts of new laboratory data to reach their scientific goals should include within their program adequate funding for the necessary experimental and theoretical investigations."

Decadal Survey, 5-24

Calibration Requirements: Lamps

- **The lines should be sharp to allow highly accurate measurement of their wavelength**
- **The wavelengths should be traceable to laboratory standards (calibration reference data)**
- **The wavelengths should be constant under all operating conditions**
- **The spectrum should have many evenly spaced lines in the wavelength range of interest, with a density appropriate for the type of instrument and spectral resolution used**

(cf Stanley & Dieke 1955)

Calibration Requirements: Lamps

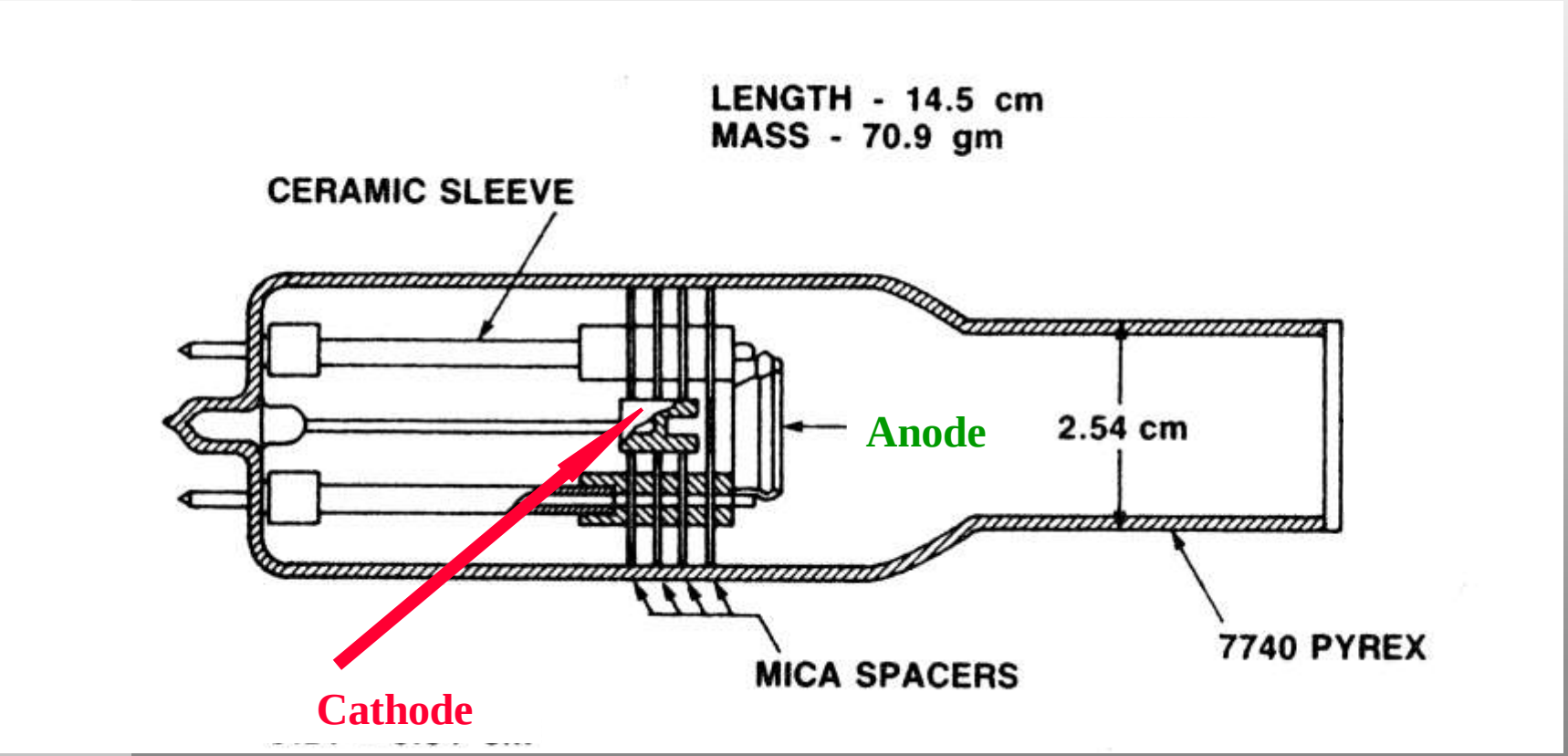
- **The spectrum should show only minimal variation over the lifetime of the lamp**
- **The spectrum should be highly reproduceable from one lamp to another**
- **The lamp should be simple and easy to operate**
- **The light source should be safe to operate without supervision and should be long-lived**
- **The lamp and supporting equipment should be readily available at a low cost and be inexpensive to operate**

(cf Stanley & Dieke 1955)

Hollow cathode lamp (HCL)

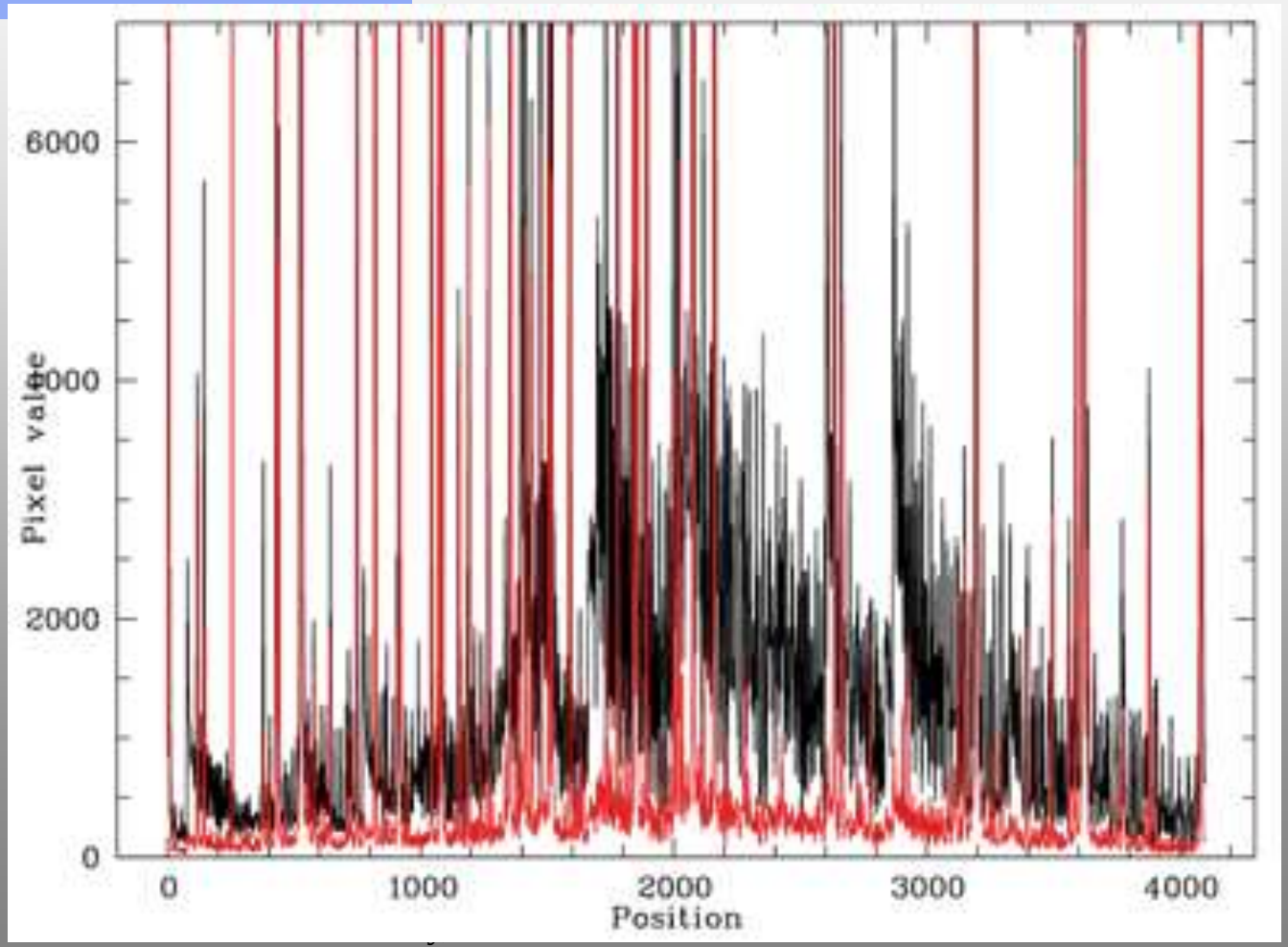
- **Paschen (1916): hyperfine structure work**
- **A. Walsh (1950s): atomic absorption spectroscopy**
- **Getter removes impurities/outgassing**
- **Commercial product for chemical analysis**
  - **Over 50 elements available**
  - **Combinations of up to 6 elements in a single cathode**
- **Space: IUE, several spectrographs on HST**
- **Ground: many instruments, RV work**

Hollow Cathode Lamp (HCL)



HCL: Not all lamps are equal

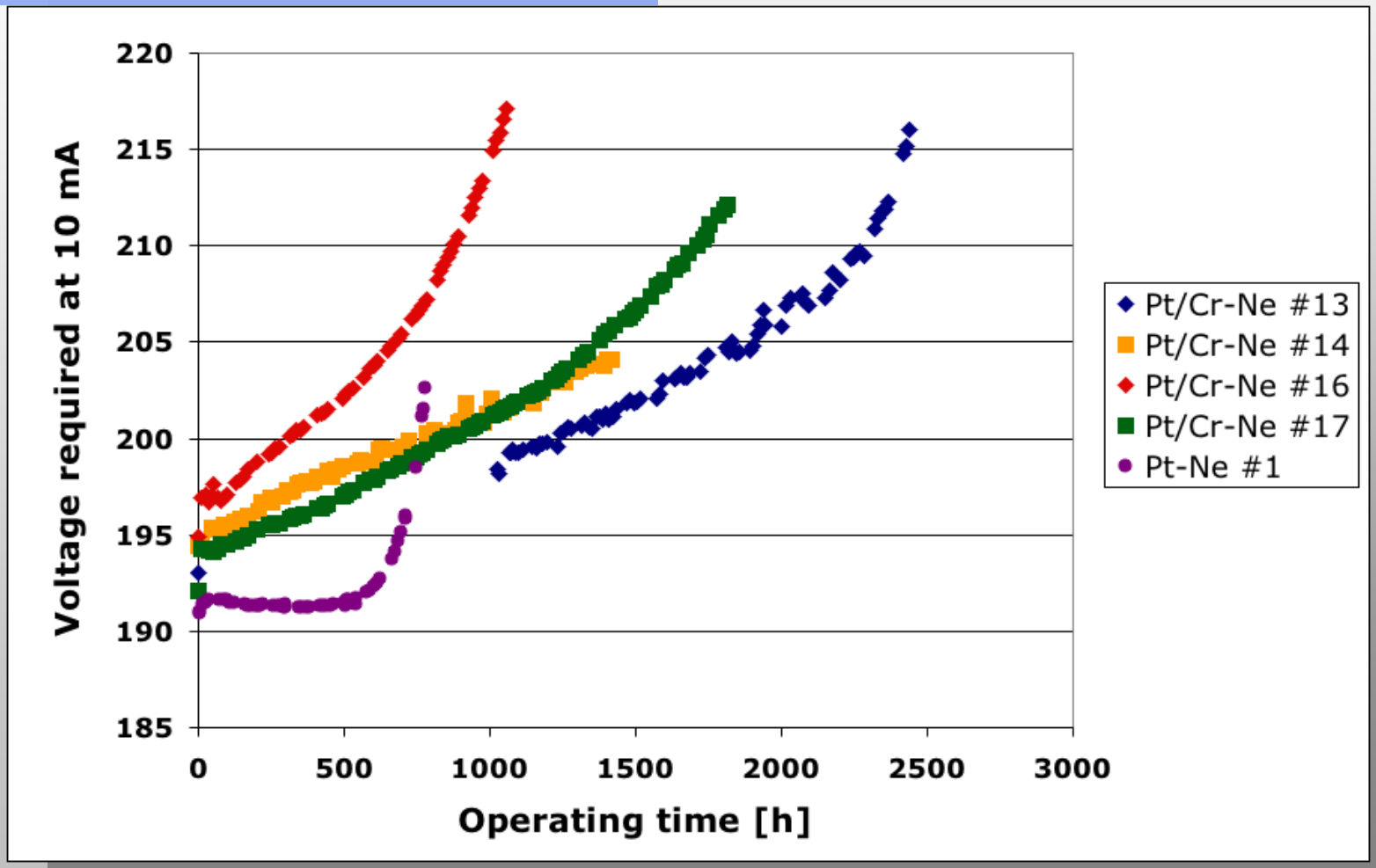
- Contaminated Th-Ar HCL

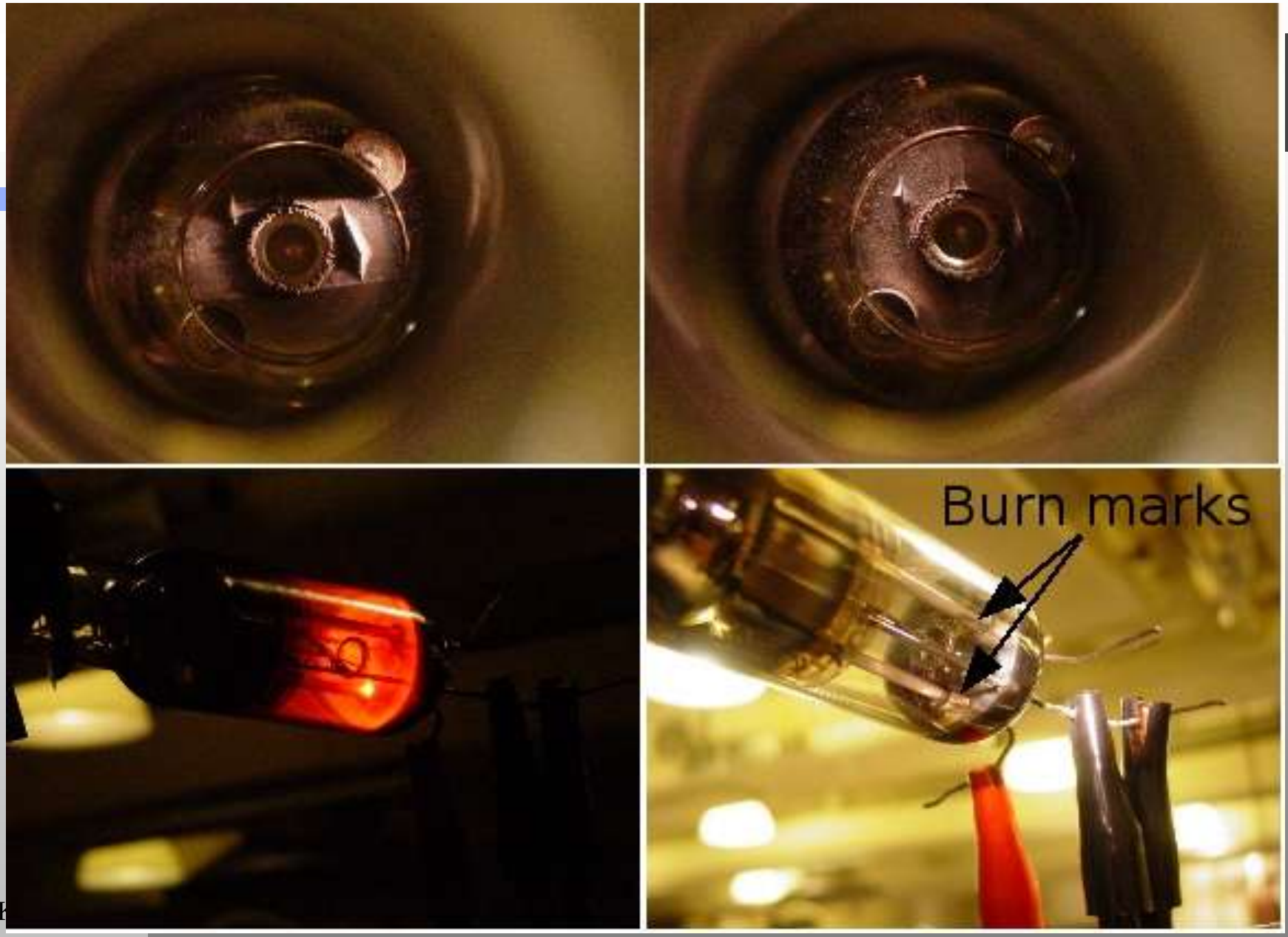


HCLs: Lamps are not forever …

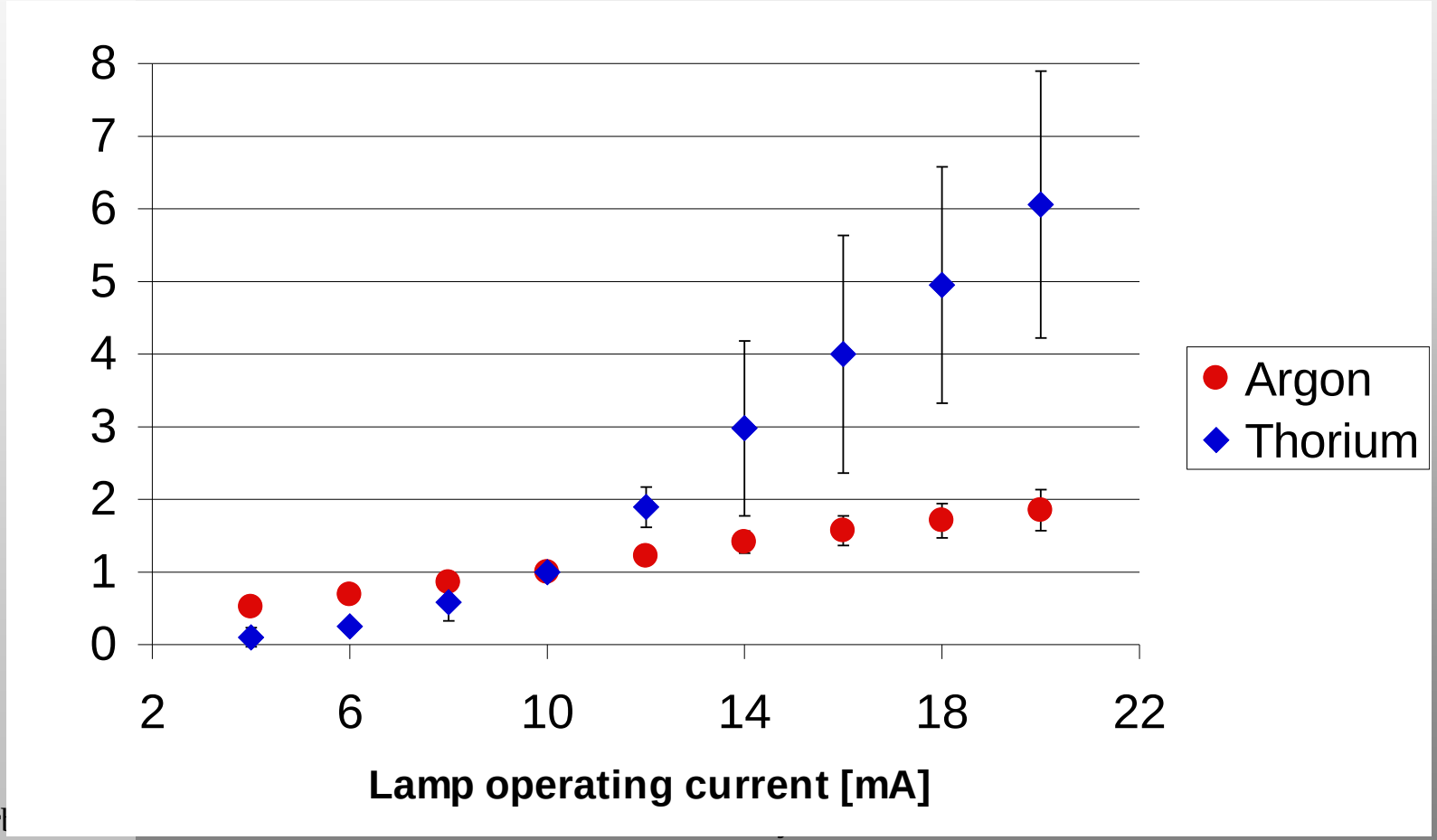
- **Lifetime about 10 Ah (1000 h at 10 mA)**
- **Aging**
- **Spectrum (operating current)**
- **Pressure shifts**
- **Loss of fill gas (clean-up)**
- **Sputtering losses - widening of cavity**

HCL: accelerated aging test

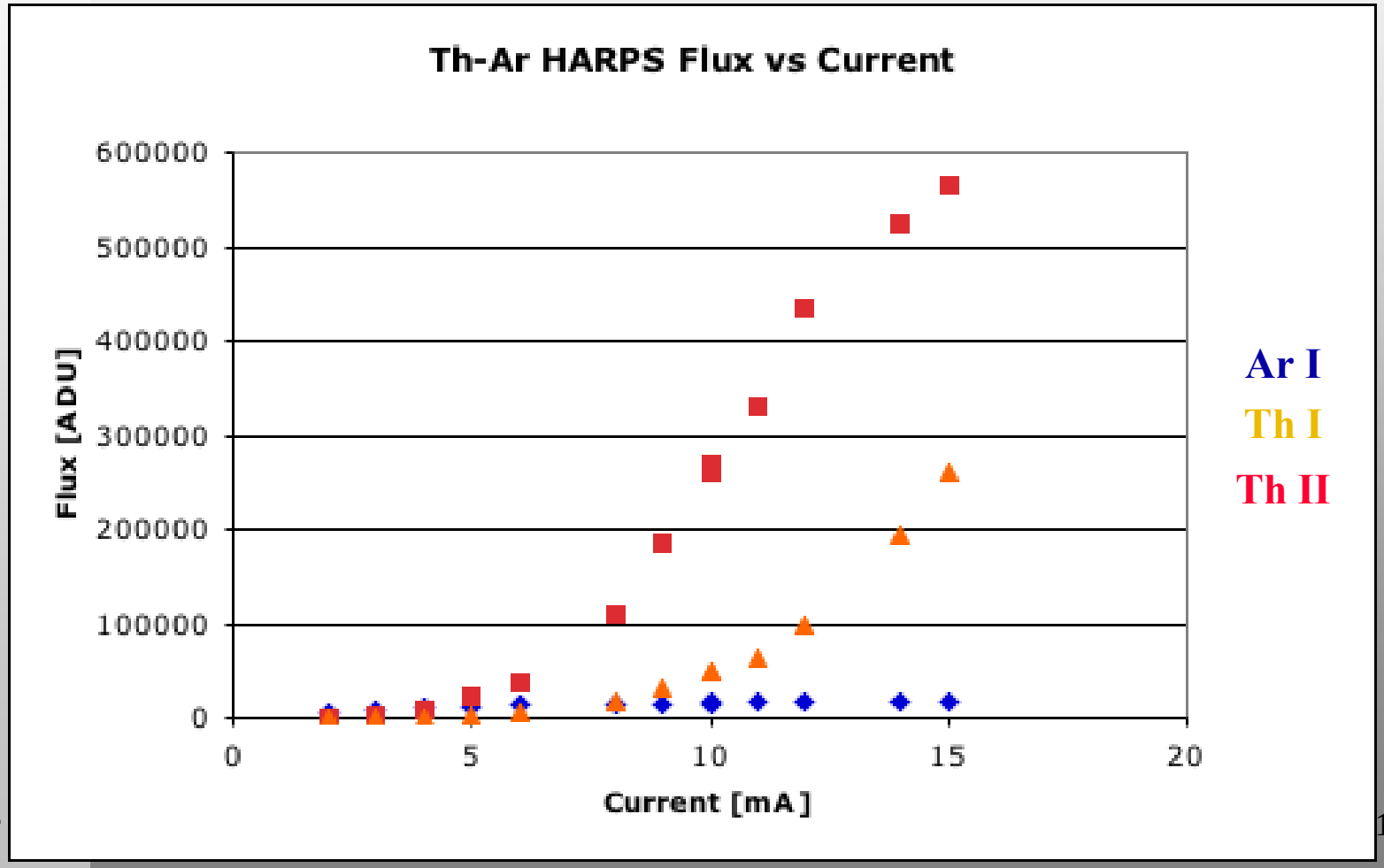


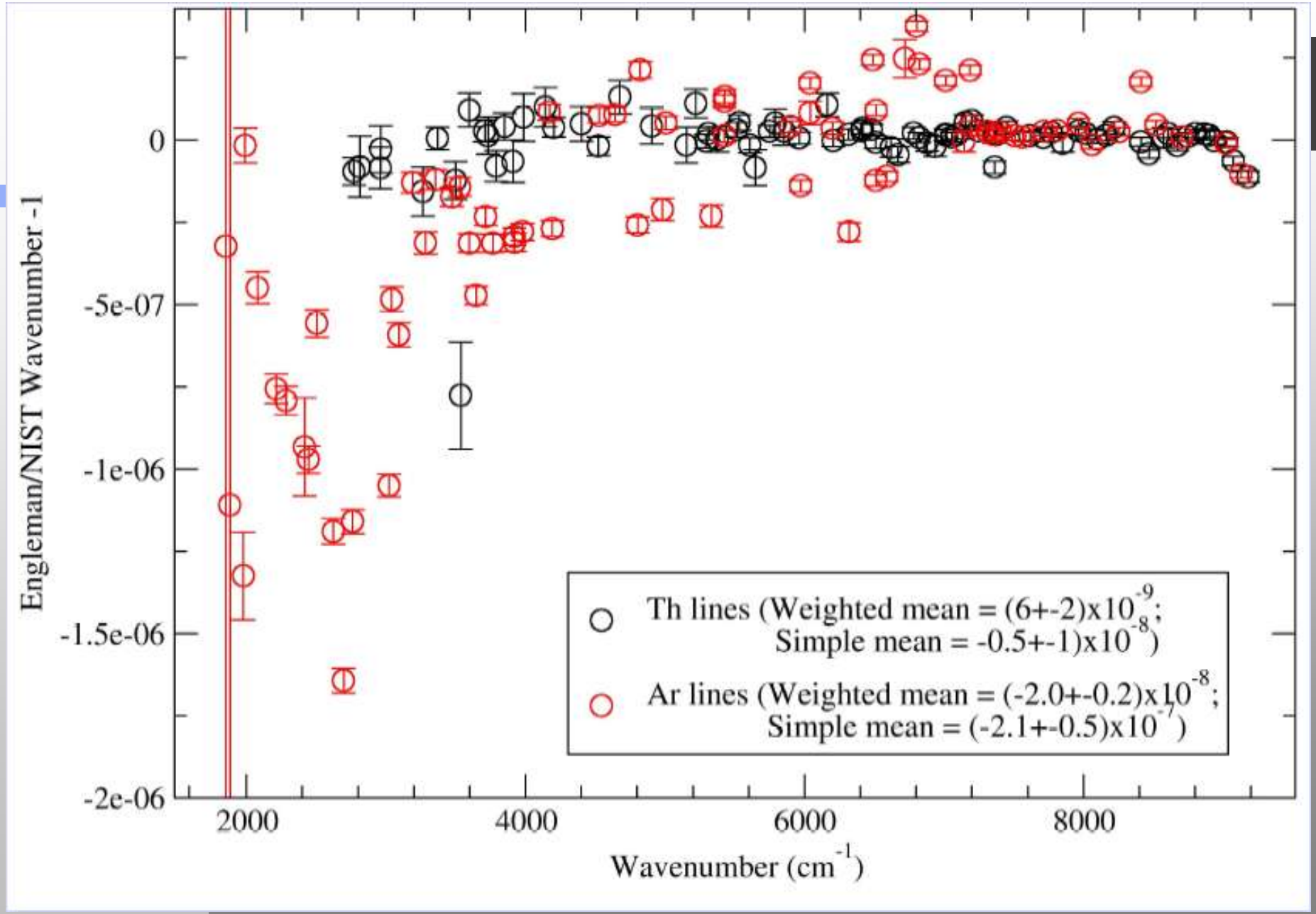

Burn marks

Spectrum - Operating Current



Spectrum - Operating Current



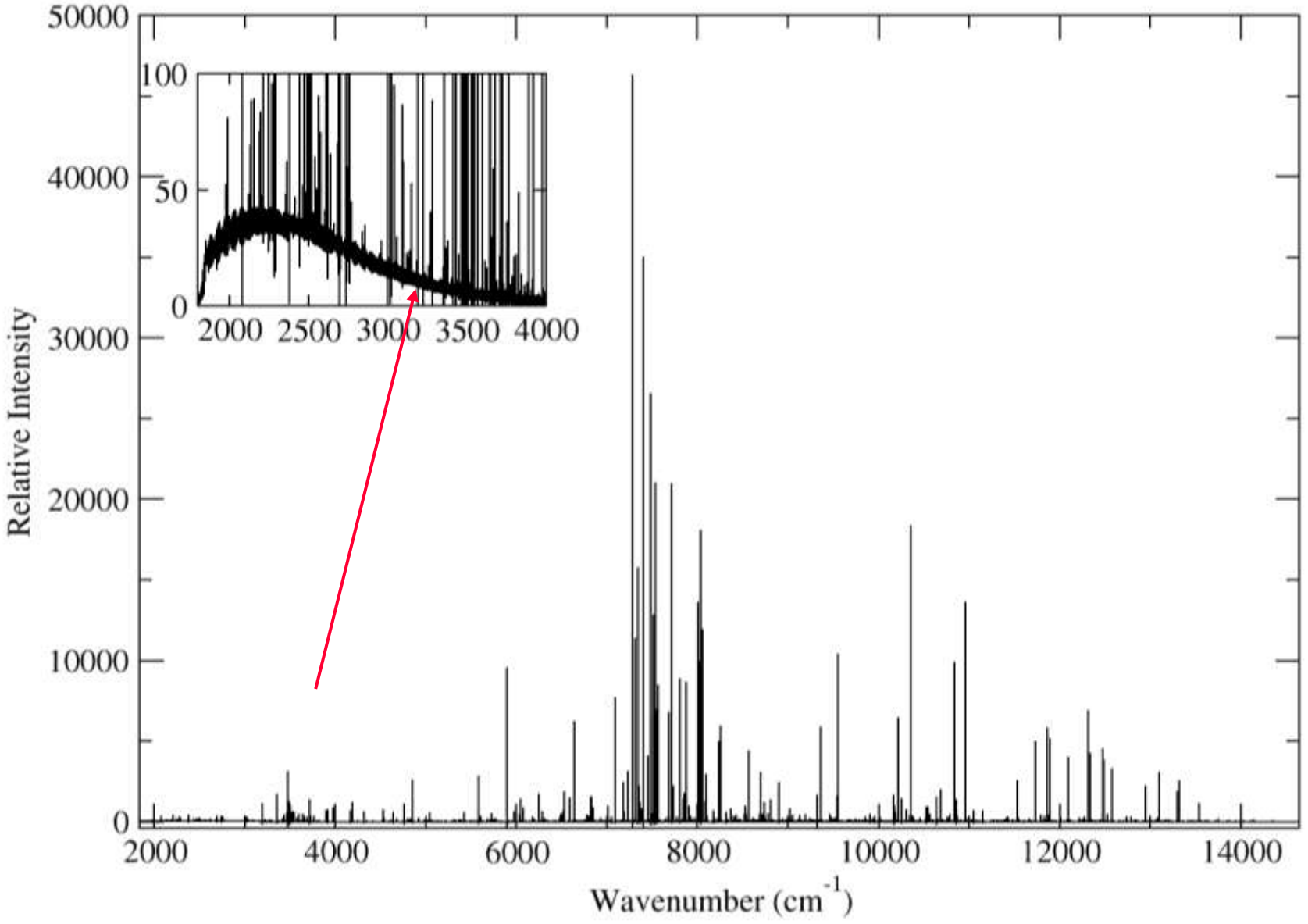

Engleman/NIST Wavenumber -1
0
-5e-07
-1e-06
-1.5e-06
-2e-06
2000
4000
6000
8000
Wavenumber (cm-1)
Th lines (Weighted mean = (6+-2)x10-9; Simple mean = -0.5+-1)x10-8)
Ar lines (Weighted mean = (-2.0+-0.2)x10-8; Simple mean = (-2.1+-0.5)x10-7)

Calibration Reference Data

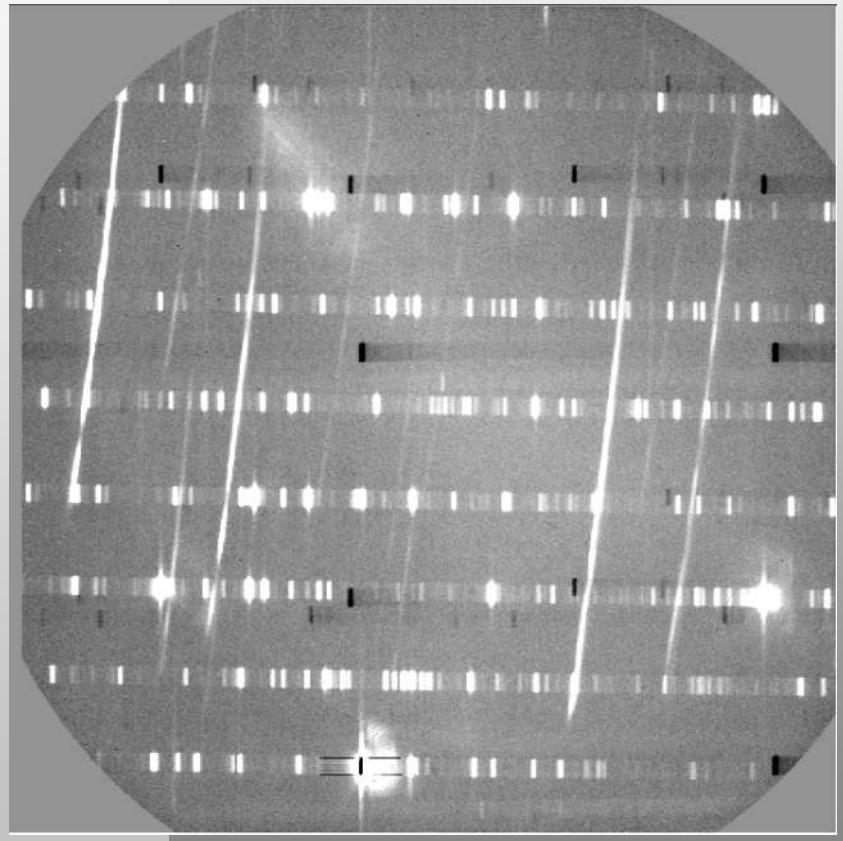
- **Traceable to laboratory standards >> "ground truth"**
  - **For wavelength CRD link to frequency/time**
- **Meta Data describing "what and how"**
- **Error information**
- **Documented by original data provider**
- **Published**

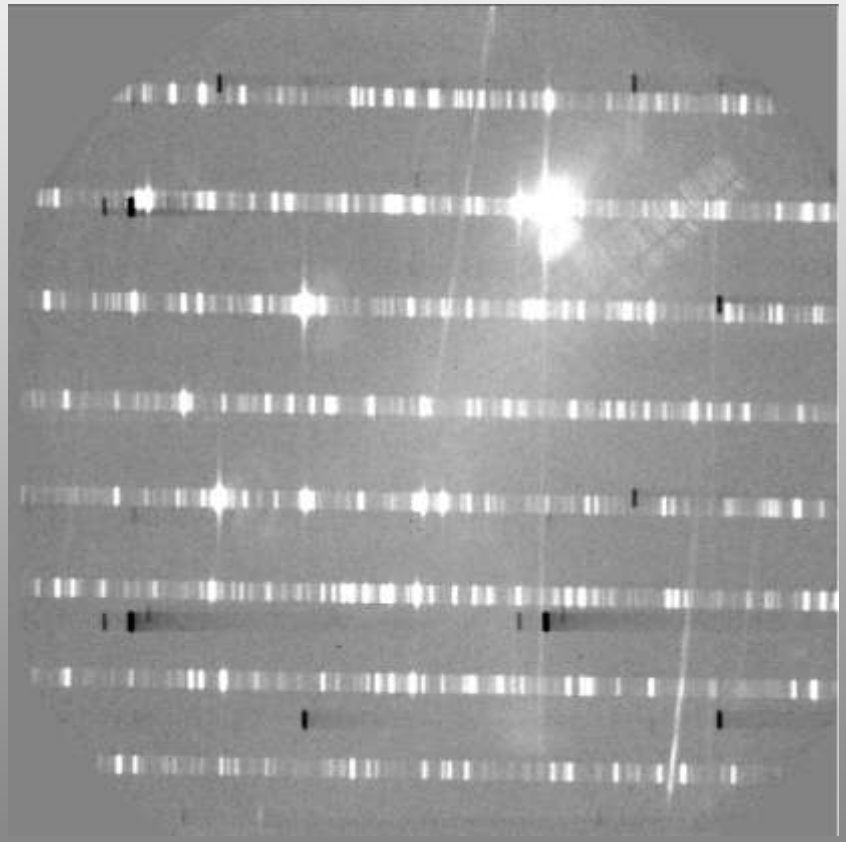
Th-Ar Reference Data

- **Why Thorium ?**
  - **Single isotope, zero nuclear spin**
- **Total ~2400 lines between 750 nm and 4800 nm**
  - **accuracy ~ 0.001 cm^{-1} for strong lines**
  - **Kerber, Nave, Sansonetti 2008, ApJS 178, 374, atlas at http://physics.nist.gov/PhysRefData/ThArLampAtlas/ThArLampAtlas.html**
- **Calibration accuracy in wavelength: ~1.4 x 10^{-8}**
  - **calibration using laser measurements of Th lines (DeGraffenreid & Sansonetti 2002)**
  - **5 x 10^{-8} ≅ 1/100 of a pixel in CRIRES**

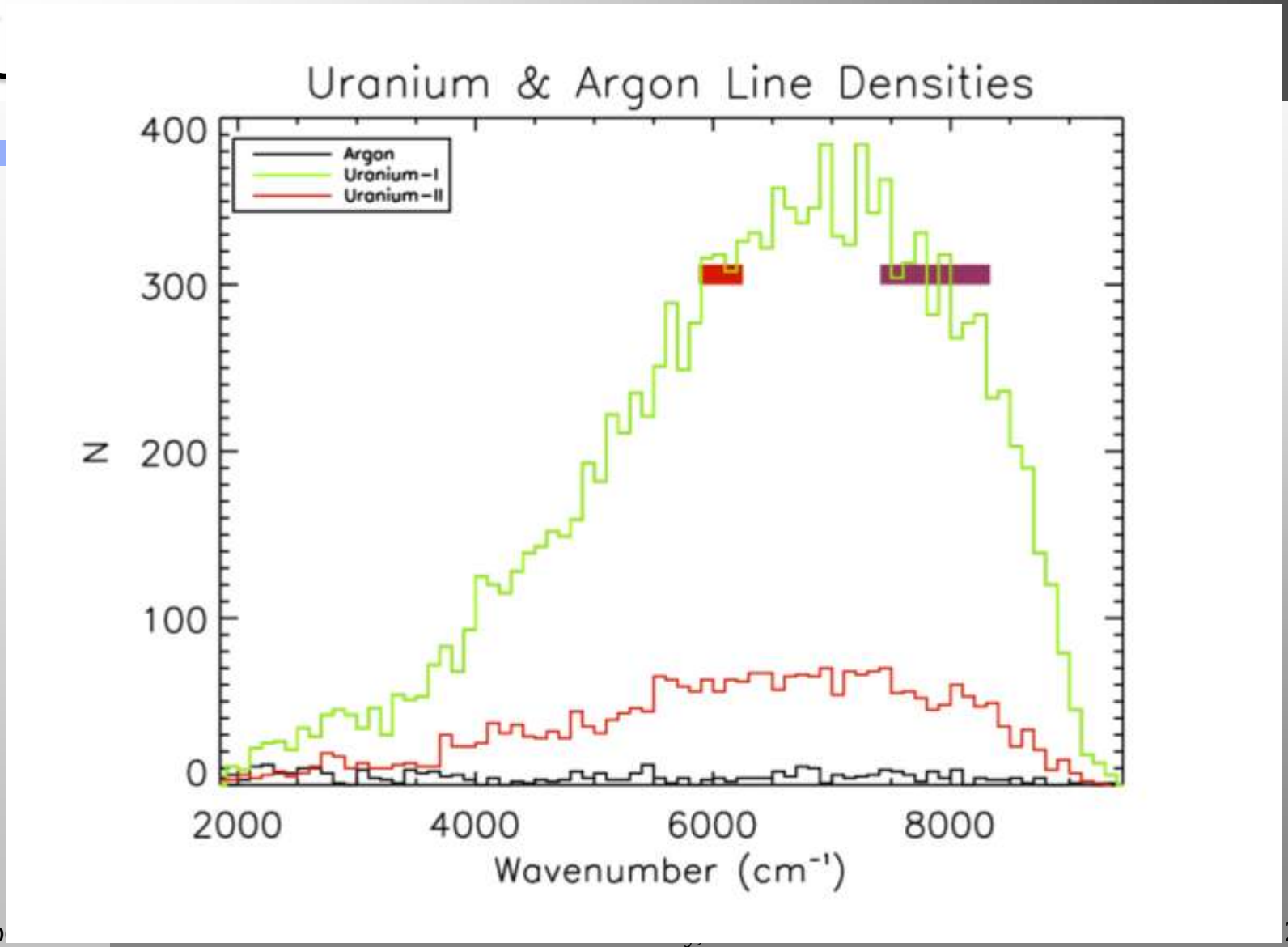

50000
40000
30000
20000
10000
0
Relative Intensity
2000
4000
6000
8000
10000
12000
14000
Wavenumber (cm-1)
100
50
0
2000 2500 3000 3500 4000

U-Ne (poster by Redman et al.)



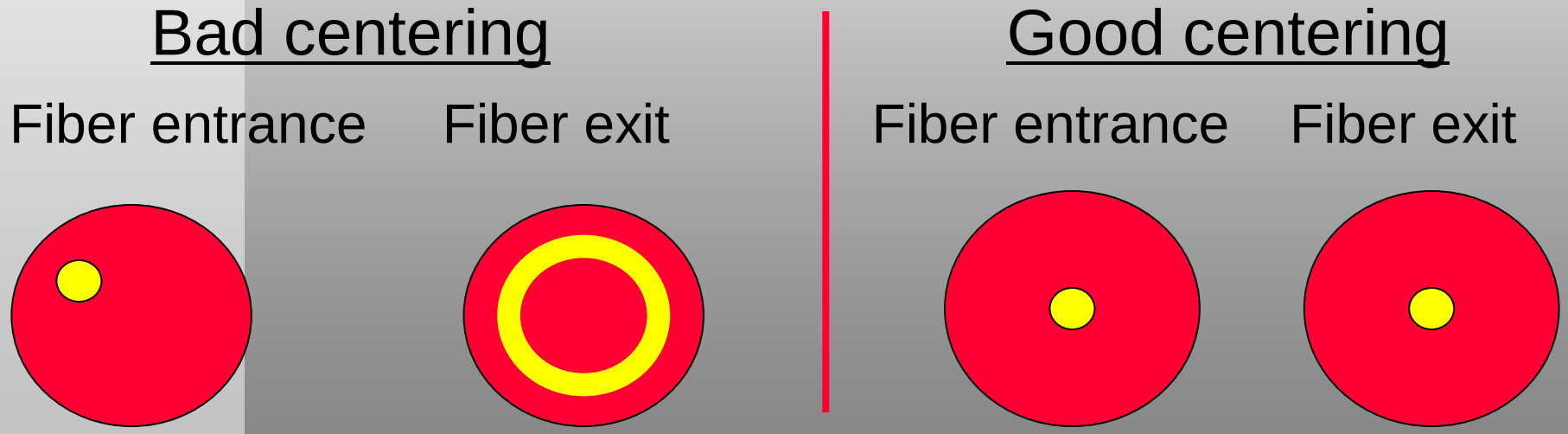


U

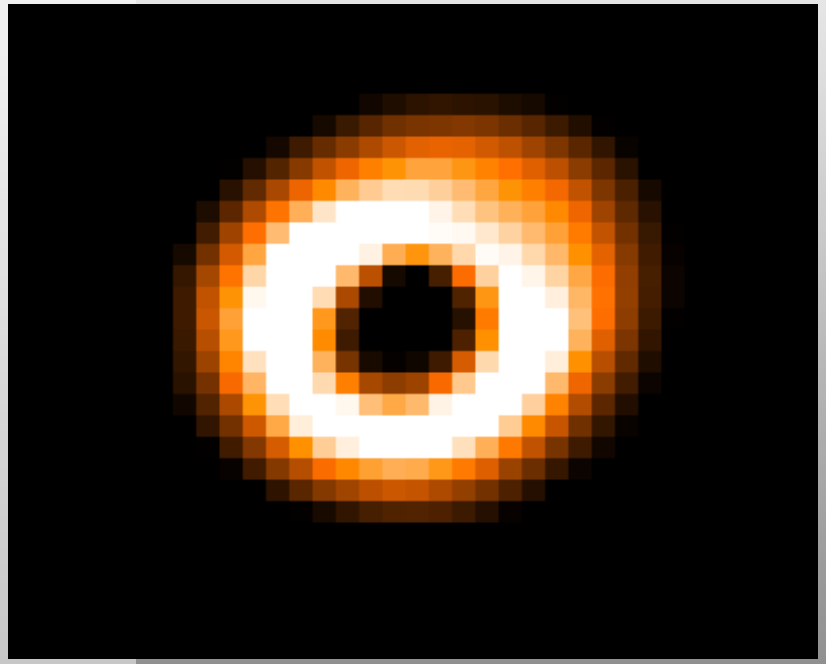

Uranium & Argon Line Densities
Argon
Uranium-I
Uranium-II
N
400
300
200
100
0
2000
4000
6000
8000
Wavenumber (cm⁻¹)

Stability of the light injection

A de-centering of 0.5” generates an offset of 3m/s in RV

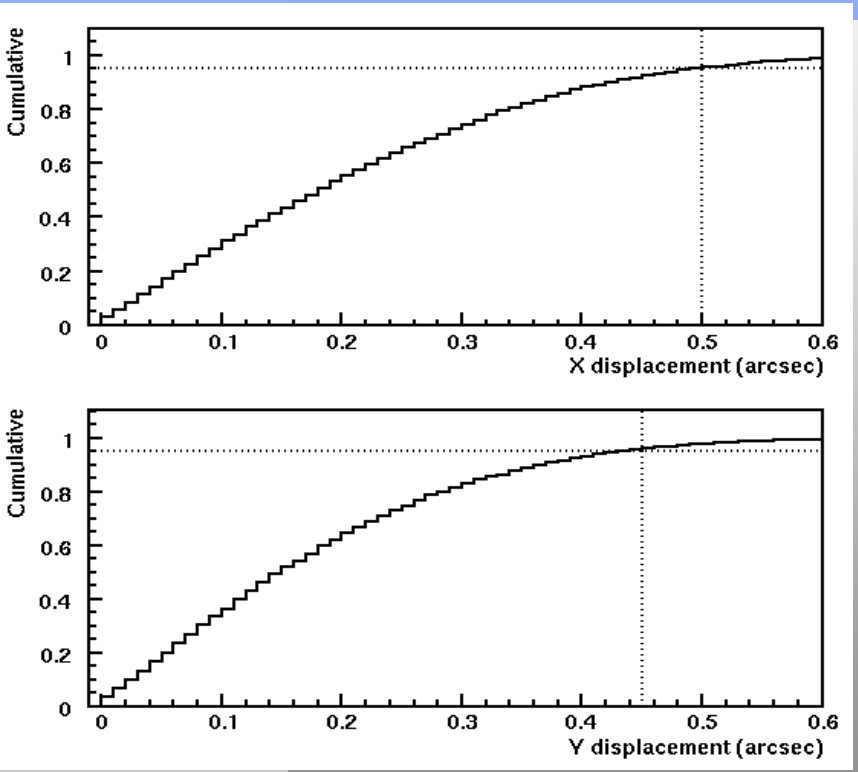


Light Injection, guiding

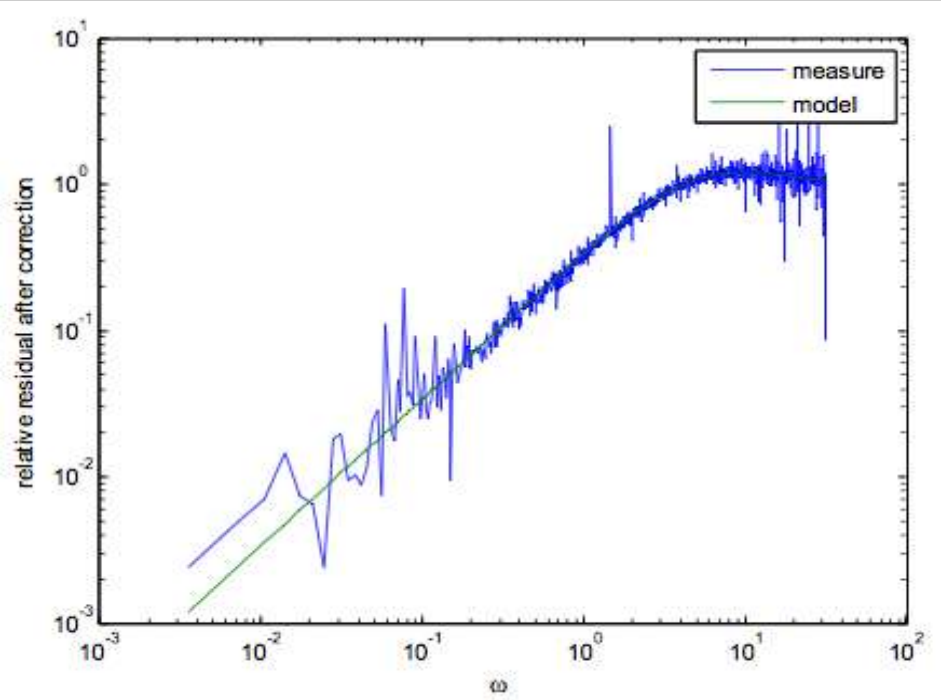


“Good” guiding, 0.1” RMS,
~30 cm/s contribution to RV

Light Injection, guiding

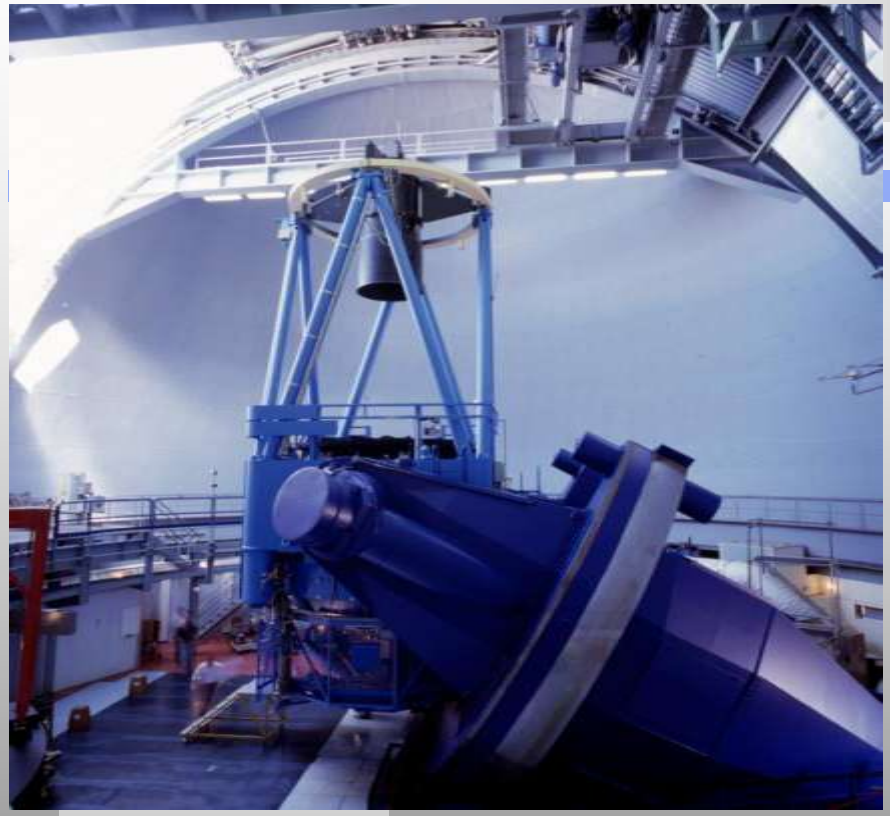


<5% of the corrections are higher than 0.5”



Effective dumping up to 0.3Hz, with a 10Hz correction frequency

New concept: guiding at 3.6m



200 tons telescope

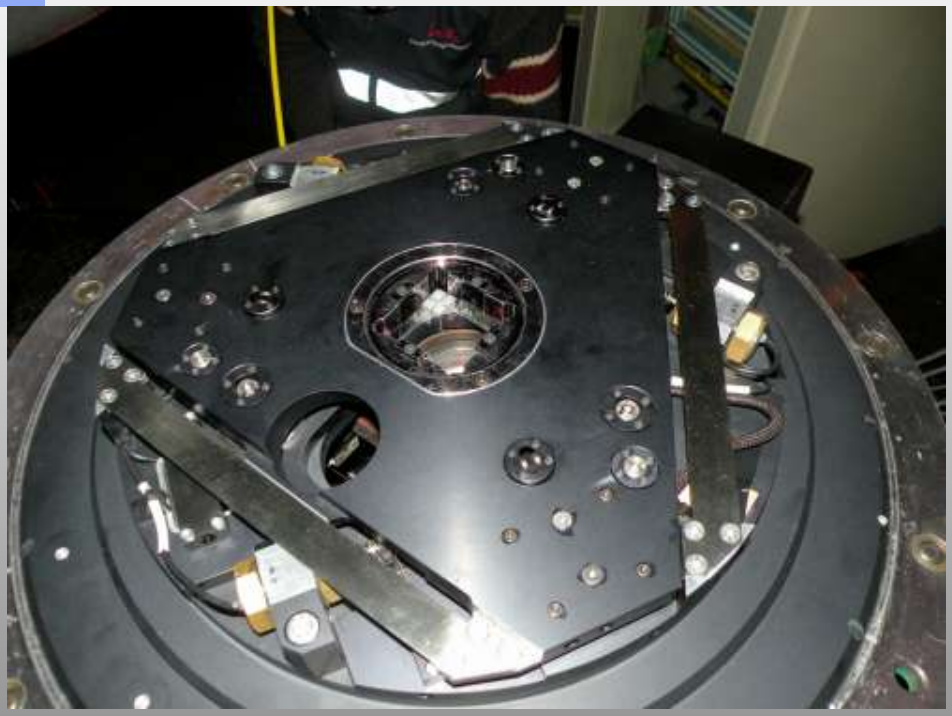
2 kg tip-tilt table

Increase: accuracy, speed

Correct for “slow” perturbations (mechanics, wind)

New concept: secondary guiding

- **Glass doublet: 32mm thick in a tip-tilt table**
- **Operate up to 10 Hz**
- **Correct up to 1.5” before offload**
- **Precise to 10 µm =>0.01”**

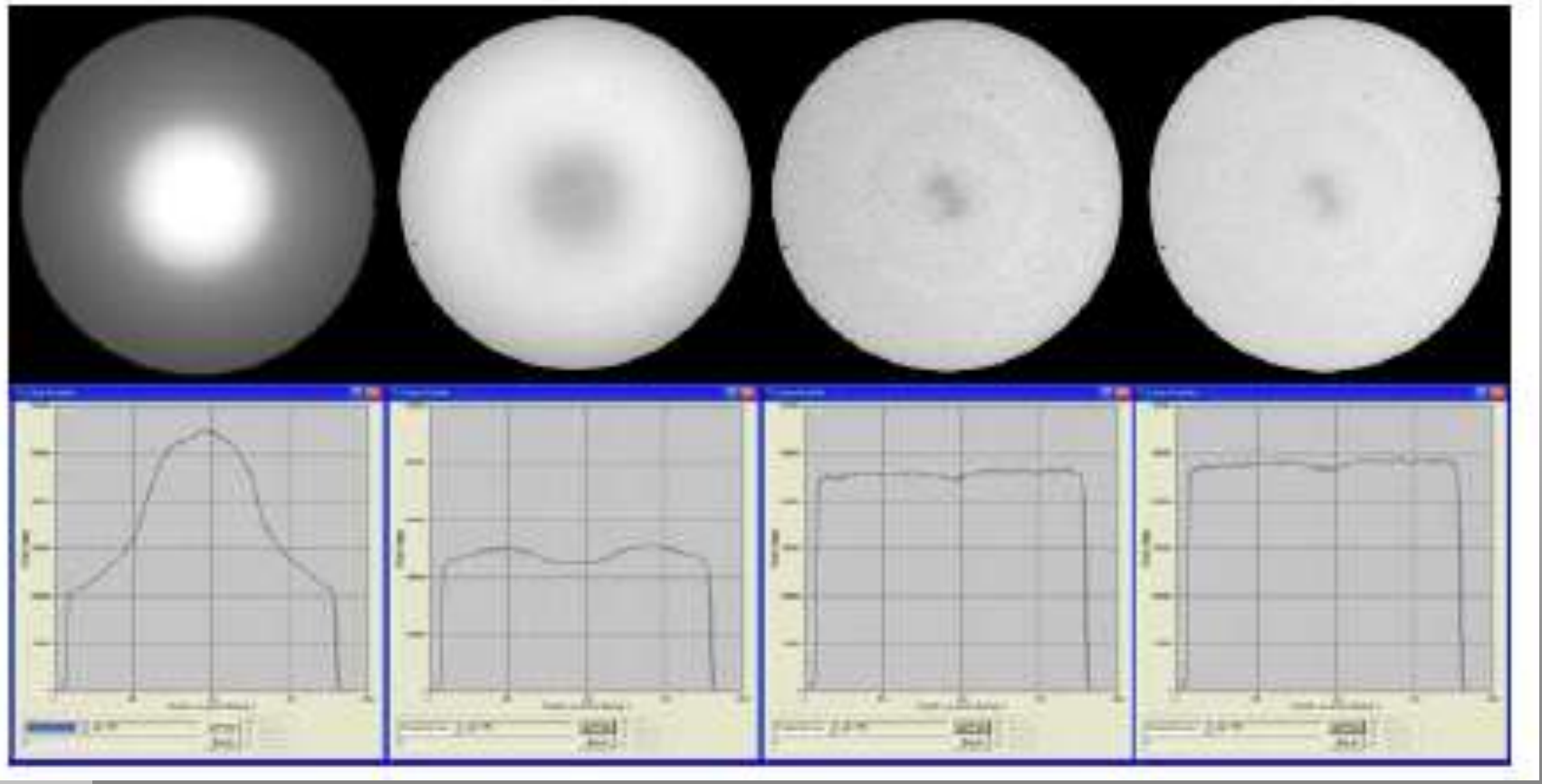


Glass:
Cemented LLF1-PSK3 doublet
Transmission > 98%

Secondary Guiding: status

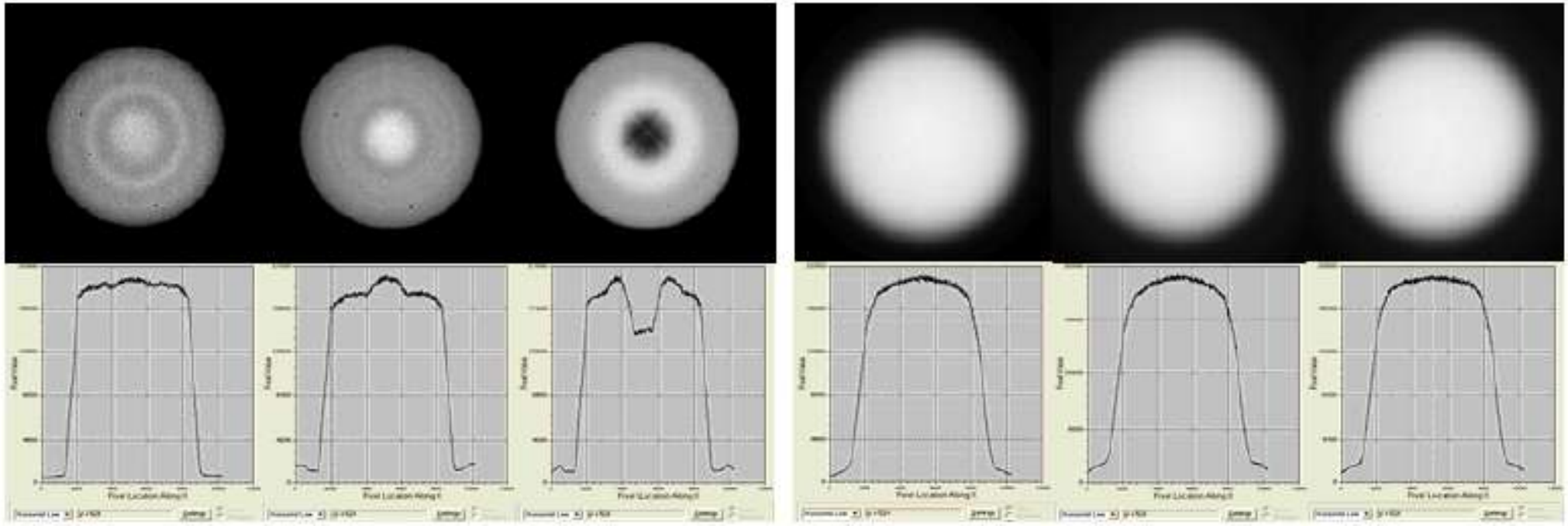
- **Laboratory tests: all technical requirements met**
- **System successfully integrated at the telescope**
- **Remote control tested**
- **Scientific verification: November 2010**
- **Expect the system in operation starting 2011.**
- **More tests at the telescope Friday night.**

Scrambling: Near Field



G. Avila

Scrambling: Far Field

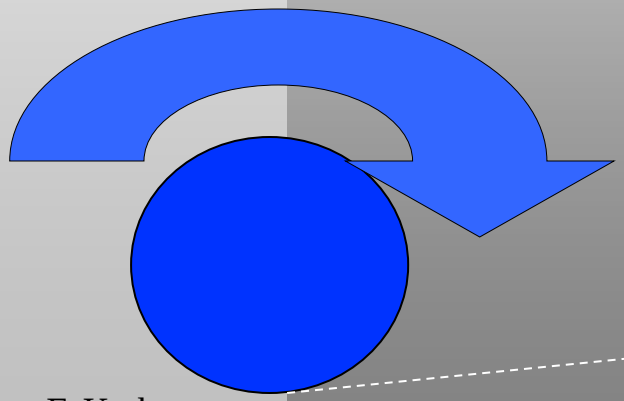


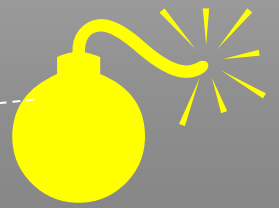
Square fiber: 200x200 μm, Spot size 150 μm, illumination central, +50 μm, -50 μm

Precise timing of the photo-center

The rotational velocity of Earth is V_r~450m/s. In one minute the projection of this velocity along a given direction changes by ~ 2m/s.

Observing through Cirrus >> Flux meter





RV: need for accuracy ?

- **Science case demands it**
- **Compare across instruments**
- **Compare across long time base (instrument stability)**

RV: need for accuracy ?

	Wavelength range [nm]	Global accuracy	Local accuracy	Global repeatability	Local repeatability
Physical constants	400 - 700	$< 10^{-9}$	$< 10^{-9}$	$< 10^{-9}$	$<10^{-9}$
Exoplanets	300 - 2500	$< 10^{-6}$	$< 10^{-6}$	$< 10^{-10}$	$< 10^{-9}$
Expansion of Universe	300 - 800	$< 10^{-11}$	$< 10^{-11}$	$< 10^{-11}$	$< 10^{-11}$
Asteroseismology	400 - 700	NA	NA	$< 10^{-10}$	$< 10^{-10}$
Isotopic ratios	400 - 700	NA	$< 10^{-7}$	NA	$< 10^{-7}$
Absolute radial velocities	400 - 700 (- 900)	$< 10^{-9}$	$< 10^{-9}$	$< 10^{-9}$	$< 10^{-9}$

FP7 Networks of Nodes of Expertise Task 6003 Ultra-accurate Wavelength Calibration Techniques of Cosmic Sources Spectra

Summary

- **RV work is experimental physics**
  - **Control the environment**
  - **Understanding calibration sources**
  - **Use calibration reference data**
  - **Understanding errors and limits**
- **Progress in light injection and scrambling**