# Solid State Astrophysics and/with the RGS

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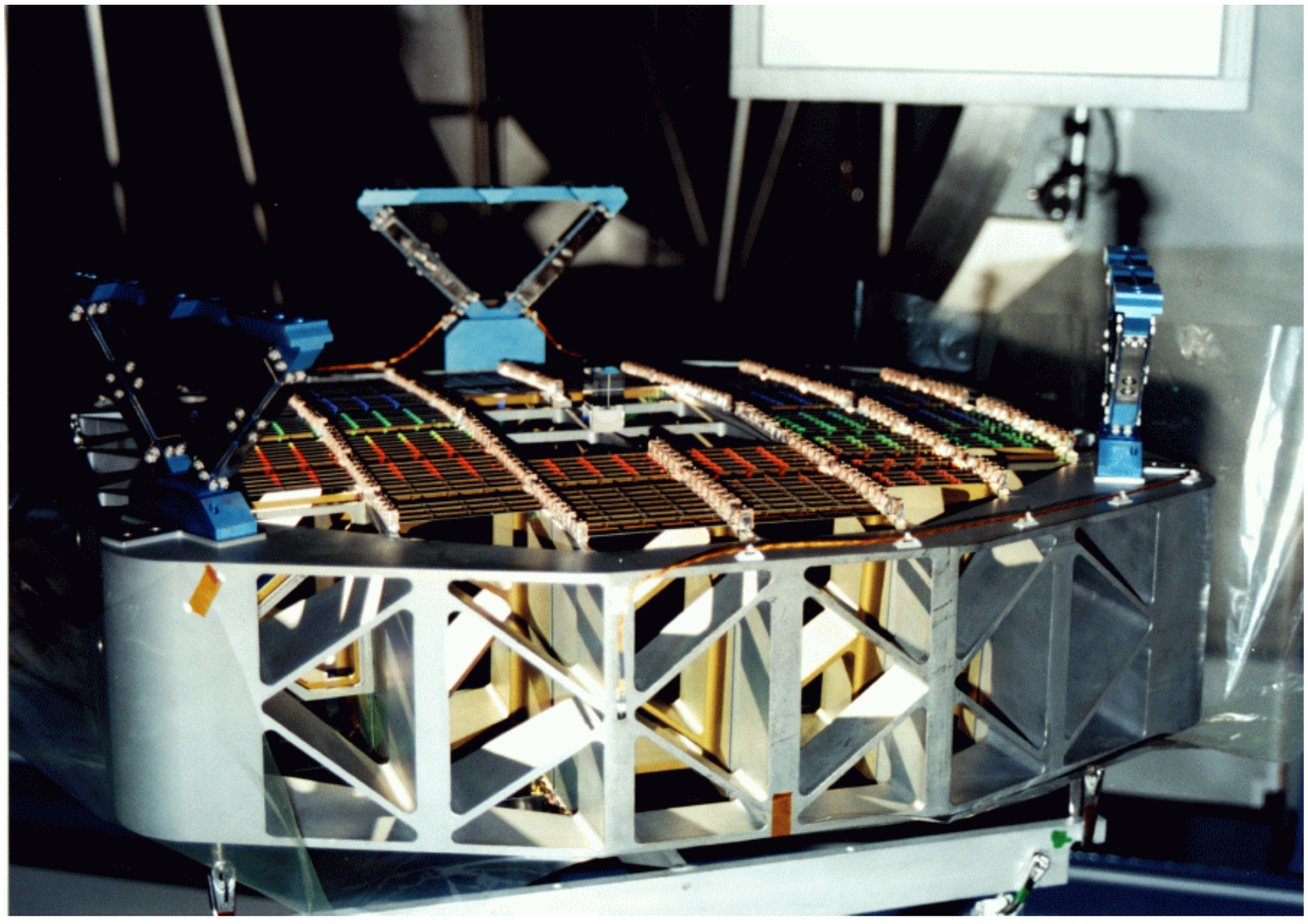
Columbia Astrophysics Laboratory

XMM-*Newton* 20th Anniversary Symposium
GSFC, October 21-22, 2019

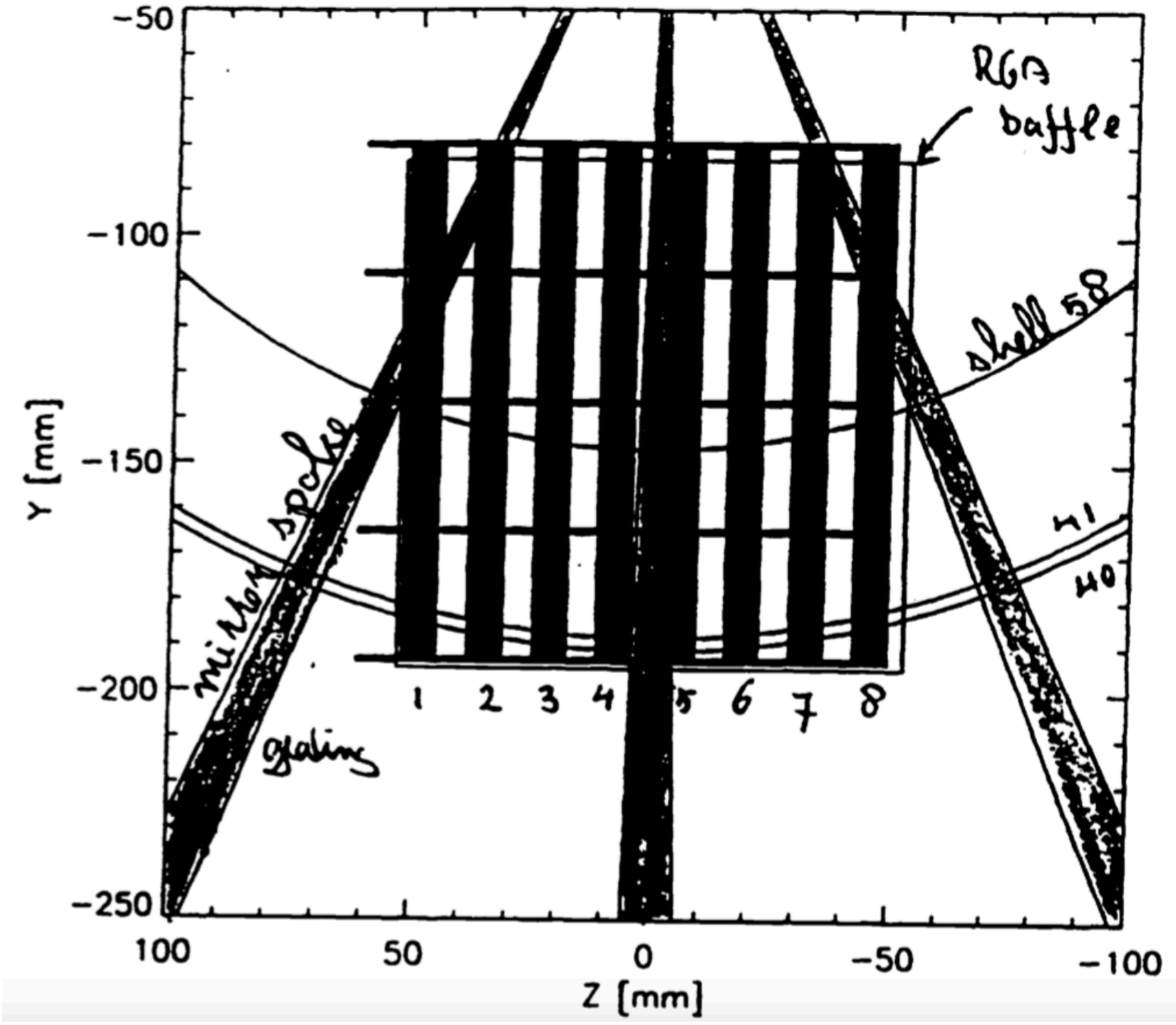
courtesy of Steve Kahn, Andy Rasmussen, Jean Cottam, John Peterson, Josh Spodek, Masao Sako, Marcela Stern, Todd Decker, Bill Craig, Jay Bixler, Chris Mauche, Chuck Hailey; Bert Brinkman, Jan Willem den Herder, Cor de Vries, Ton den Boggende, Rolf Mewe, Jelle Kaastra; Christian Erd; and Herr Bräuniger, Herr Burkert

# 1. Test Early, Test Often



first representative test: Electro-Optical Bread Board (EOBB, 12/1993):
8 flight-grade replicated gratings
in flight-design mounting, correctly aligned
behind four mirror shells, at Panter Long Beam

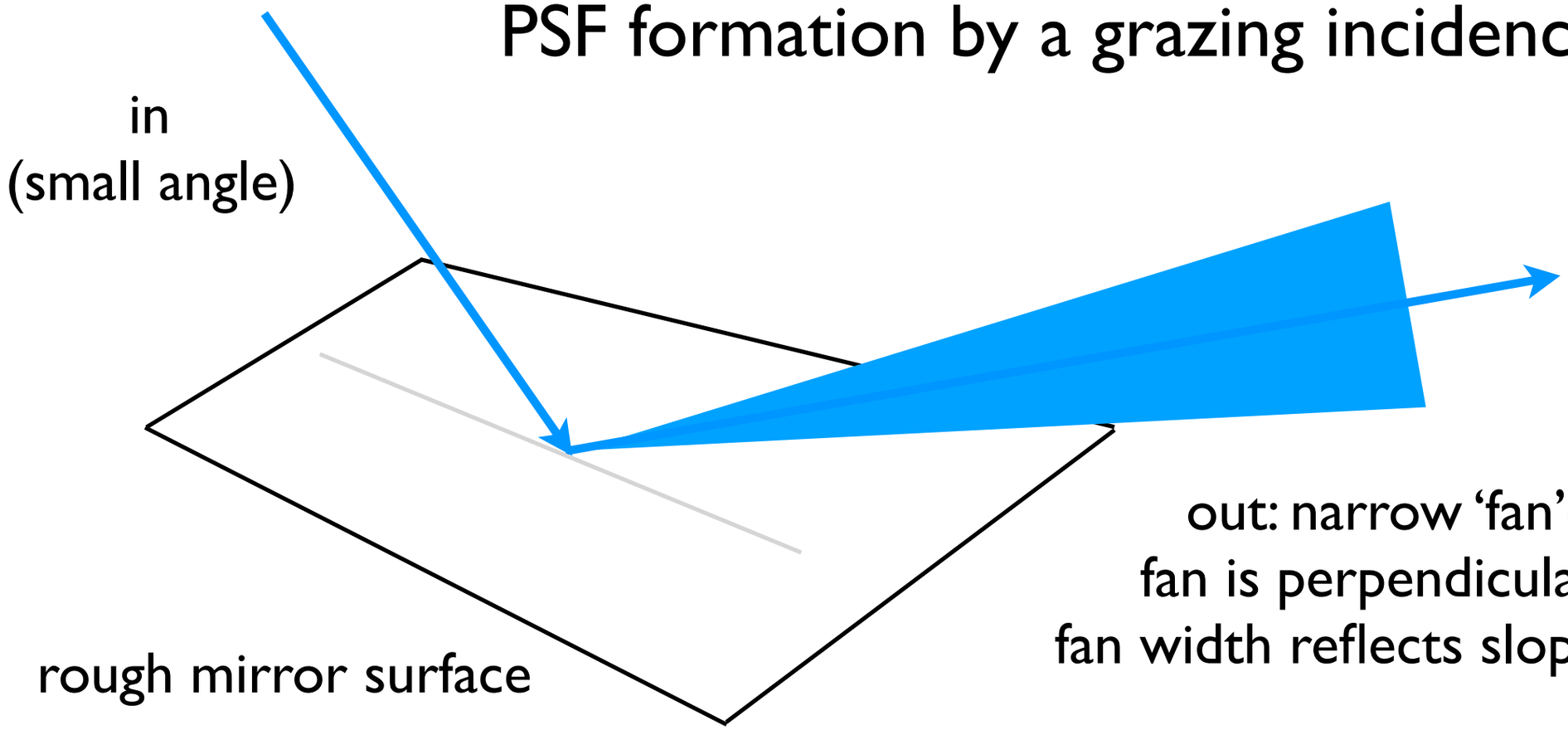
# RGS at Panter: EOBB




8 gratings, 4 mirror shells

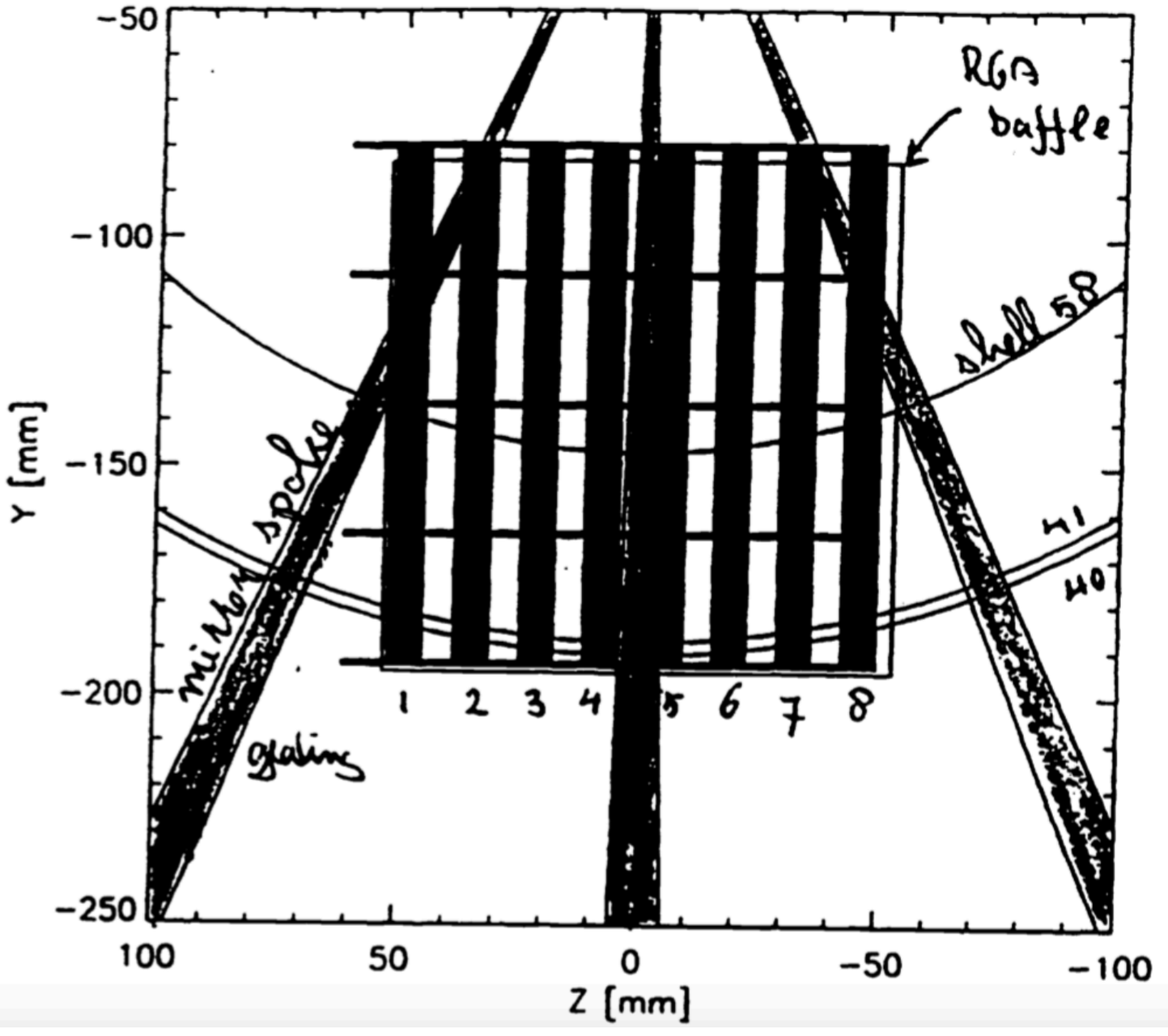
Reflection Grating Module in “6 o’clock position”

# PSF formation by a grazing incidence mirror




a narrow mirror sector contributes a
narrow fan-shaped spot to the PSF

# RGS at Panter: EOBB



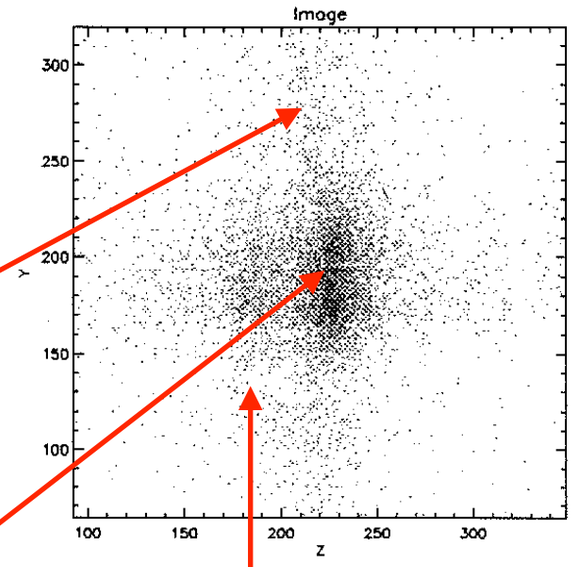

In the "6 o'clock" or "noon" positions wrt. to the mirror, the gratings make a narrow spot in dispersed light, perpendicular to the dispersion direction.
At EOBB, we had effective resolving power ~ 3000!

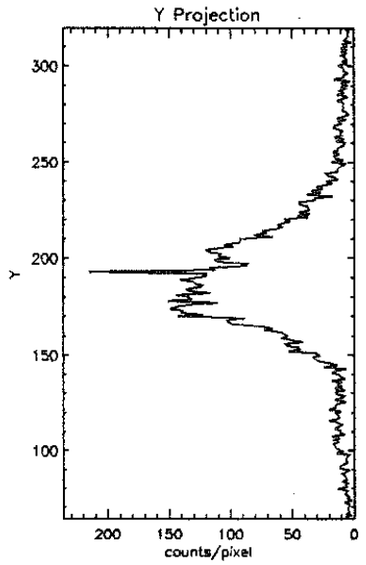
# Sample RGS EOBB image: Al Kα *m* = −1

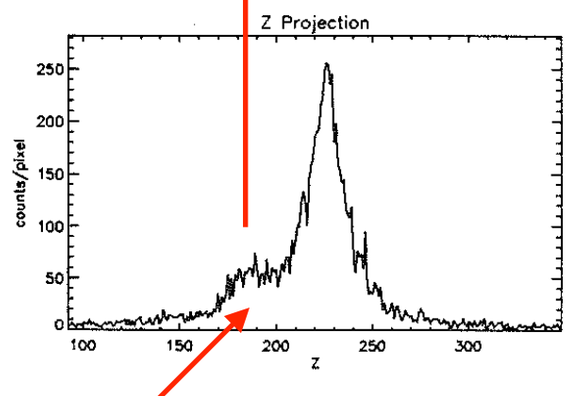
You can kind of see the individual gratings

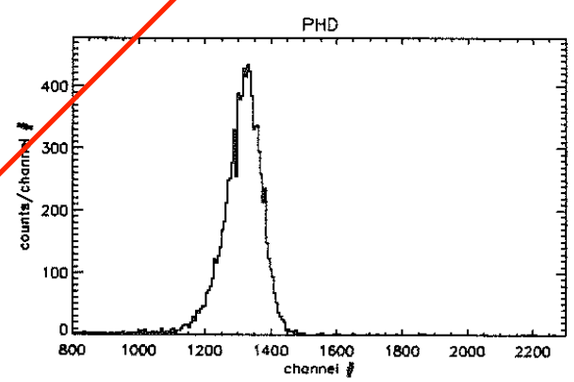
The spot is roughly elliptical, as expected (mirror dominates over grating flatness and alignment errors); *but fuzzier than expected!*

And *what* is *this*??




| | |
|---|---|
| Total: | 9310.00 |
| Z_Median: | 217.75223 |
| Z_Sigma: | 35.456290 |
| Z_HEW: | 33.000000 |
| Z_Skew: | −0.21933417 |
| Z_Kurt: | 2.2758877 |
| Y_Median: | 189.16433 |
| Y_Sigma: | 39.967922 |
| Y_HEW: | 39.000000 |
| Y_Skew: | 0.13250532 |
| Y_Kurt: | 1.5435235 |

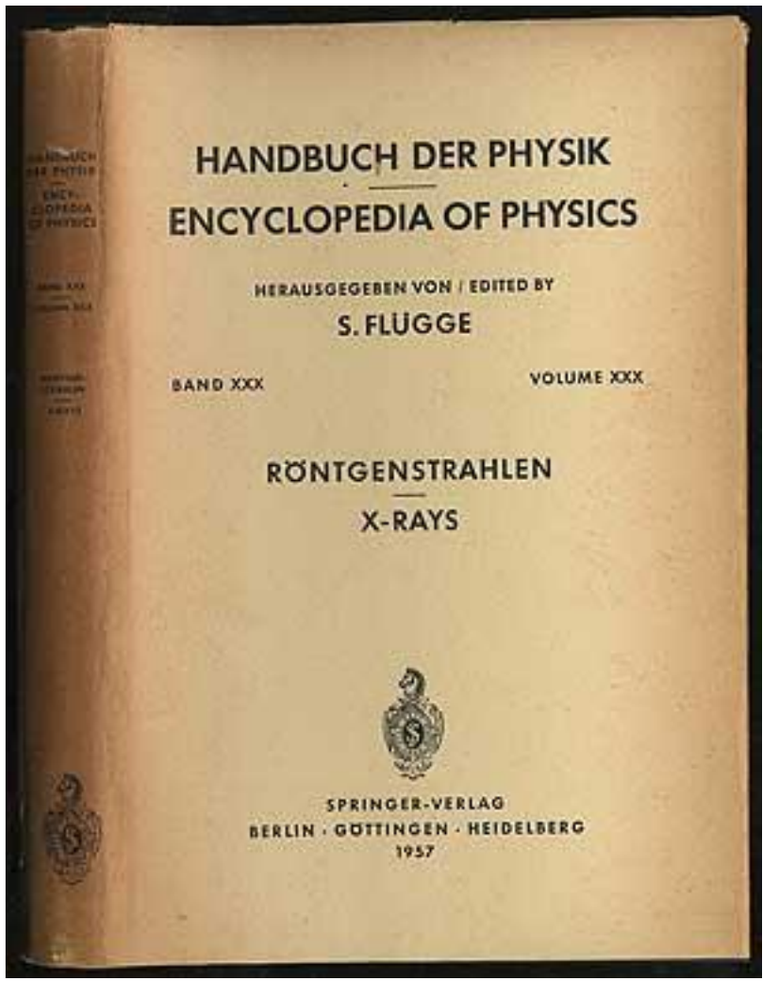
| | |
|---|---|
| Order: | −1 |
| Wavelength: | 0.00000 |
| Box Config: | 6 oclock |

| | | | |
|---|---|---|---|
| MDM_TZ: | 0 | RFC_TY: | 0 |
| BENCH_RY: | 0 | RFC_RY: | 0 |
| BENCH_RZ: | 0 | | |
| RGA_TX: | 0 | PSPC_TX: | 0 |
| RGA_TZ: | 0 | PSPC_TY: | 0 |
| RGA_RY: | 0 | PSPC_TZ: | 0 |
| FOCUS_TX: | 0 | PSPC_RY: | 0 |
| FOCUS_TZ: | 0 | PSPC_RZ: | 0 |

Directory: /home/imager6/panter/data

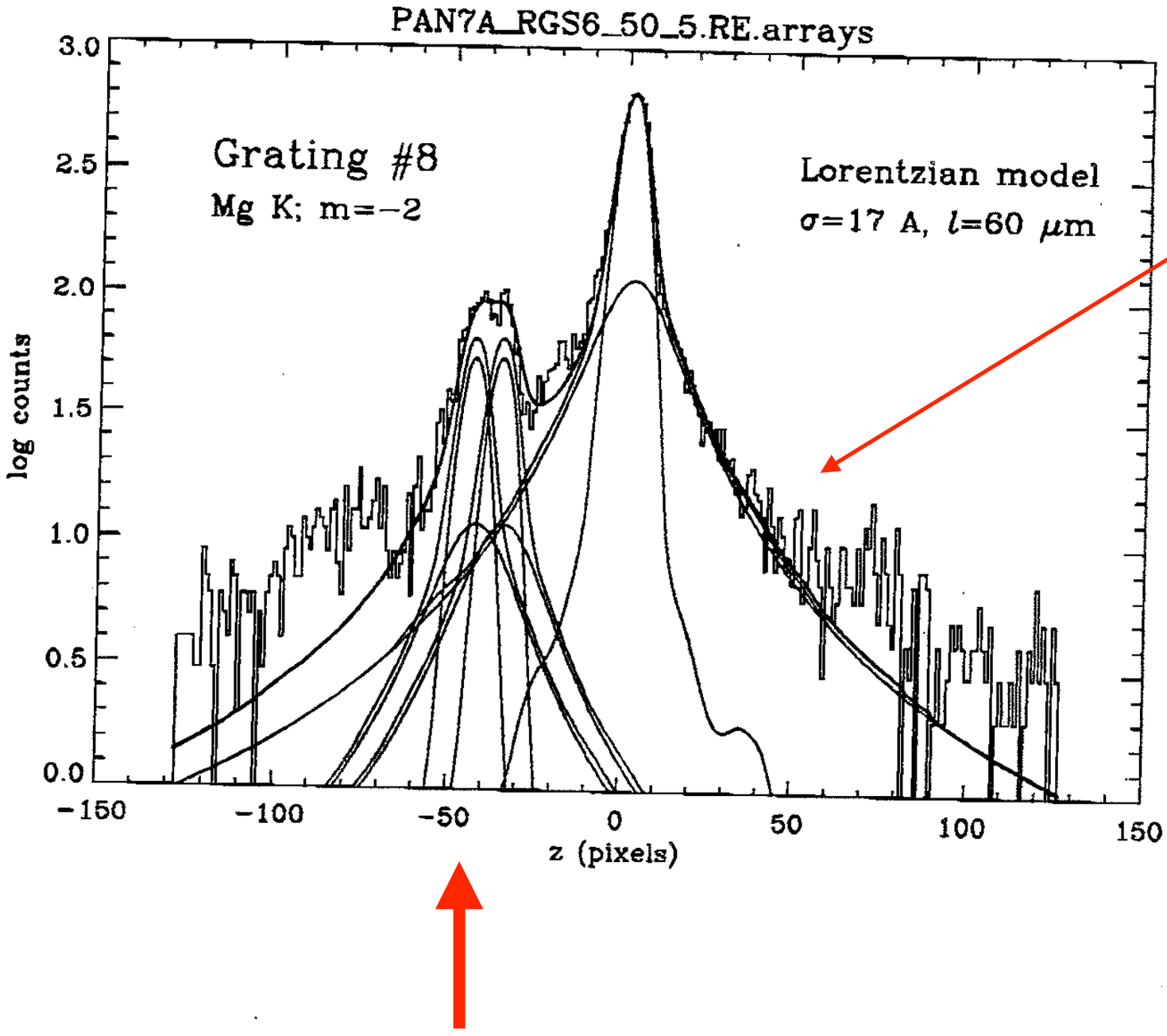
The secondary spot was always there in orders $m \neq 0$,
at wavelength slightly *shorter* than Kα

We tried everything: rogue reflections? reflection off the 'ribs'?
Maybe double ionization? Read *Handbuch der Physik* on X-ray spectroscopy? (desperate form of lab astrophysics!!)




Heinrich Bräuniger alterted us to 'satellite lines' listed in HdP-
but to us, that suggested "satellite lines" in highly ionized plasmas, which always appear at *longer* wavelengths than their 'parent line'…

MAR 21 '94 11:06 FROM LLNL LEA PAGE.027



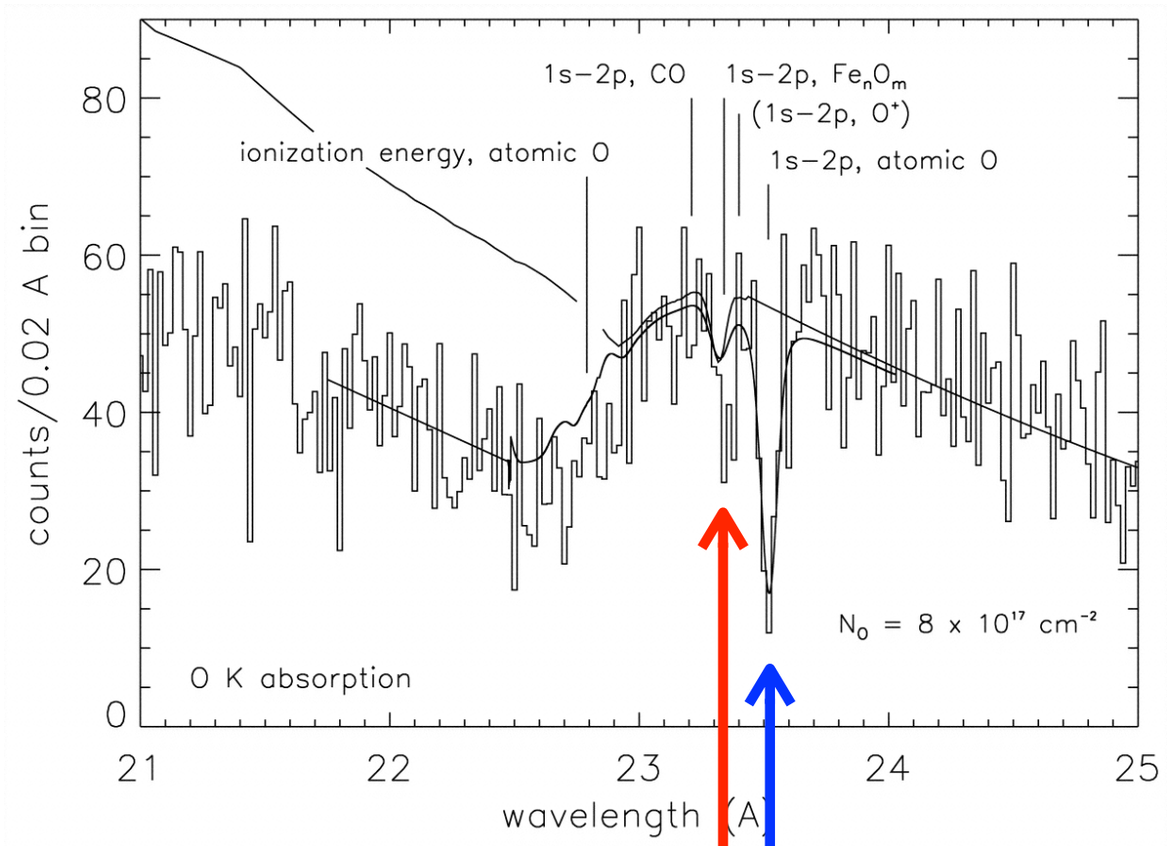

Also note these large scattering wings: sign of unauthorized tinkering with manufacturing process by vendor *(byproduct: a very nice scalar theory of scattering applied to diffraction gratings, worked out by Steve Kahn)*

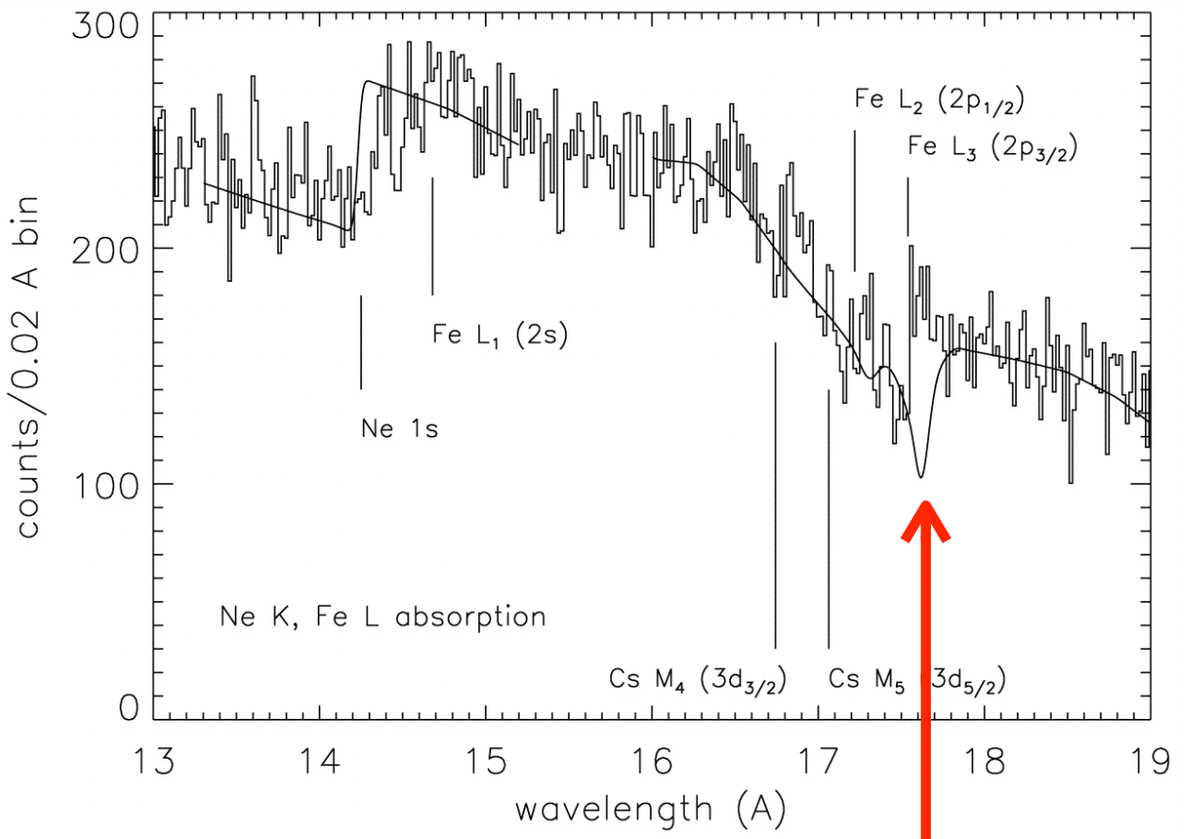
Finally, Bill Craig and I scanned the source radiation with a monochromator: *the lines are indeed intrinsic to the source!* Likely mechanism: *excitation in oxides!*

# 2. The ISM

this 'chemical shift' must also be happening in molecules in interstellar space, and in dust particles (silicates, oxides, C compounds)! *Resolvable with RGS and Chandra!*

X0614+091 *Chandra* LETGS




1s-2p in oxide

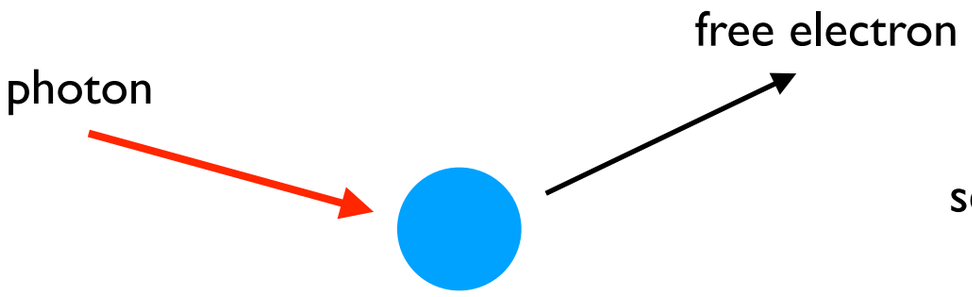
1s-2p in atomic O (not consistent with lab data!)

variability in appearance of Fe L

FP *et al.*, *ApJ*, 2001

# 3. Finally, the Solid State: Absorption by Astrophysical Dust

photoelectric absorption by isolated atom

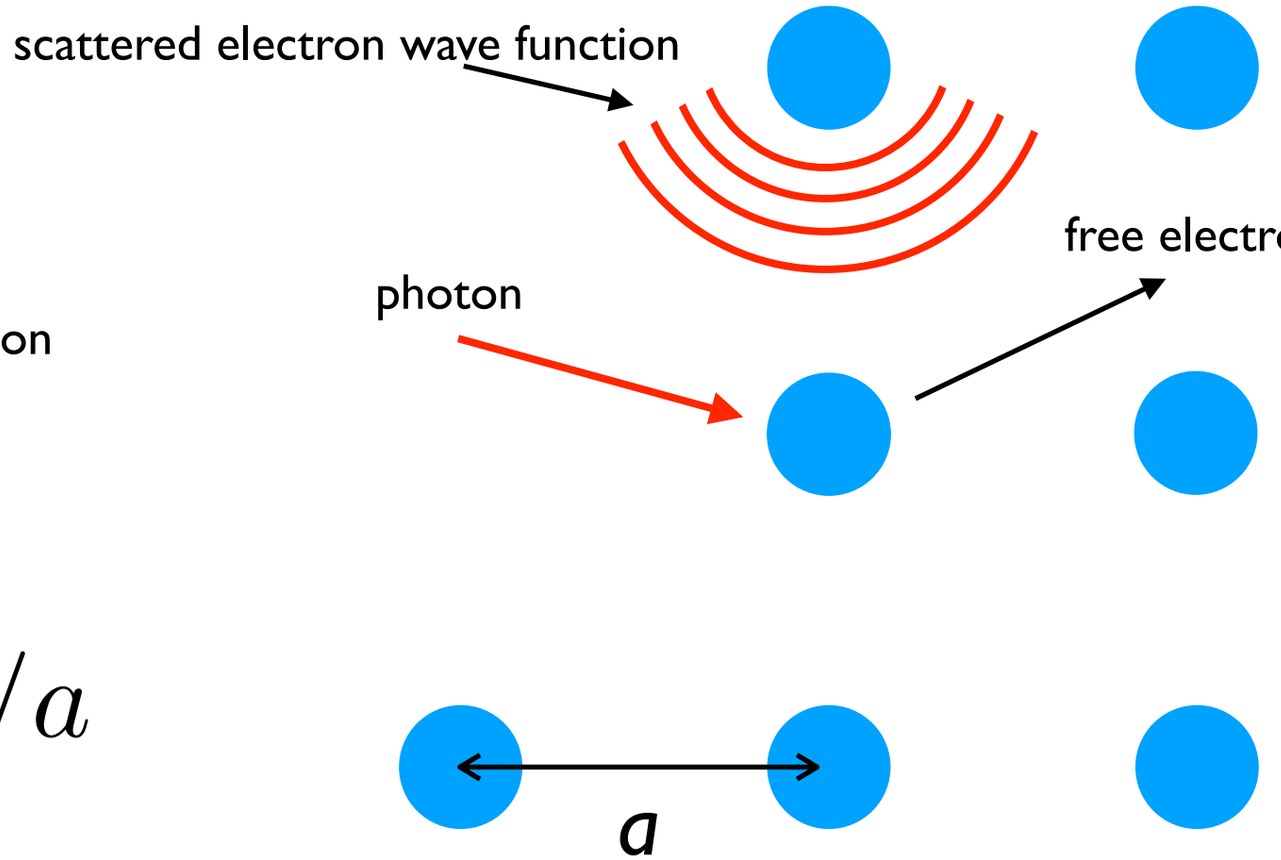



free electron wave function

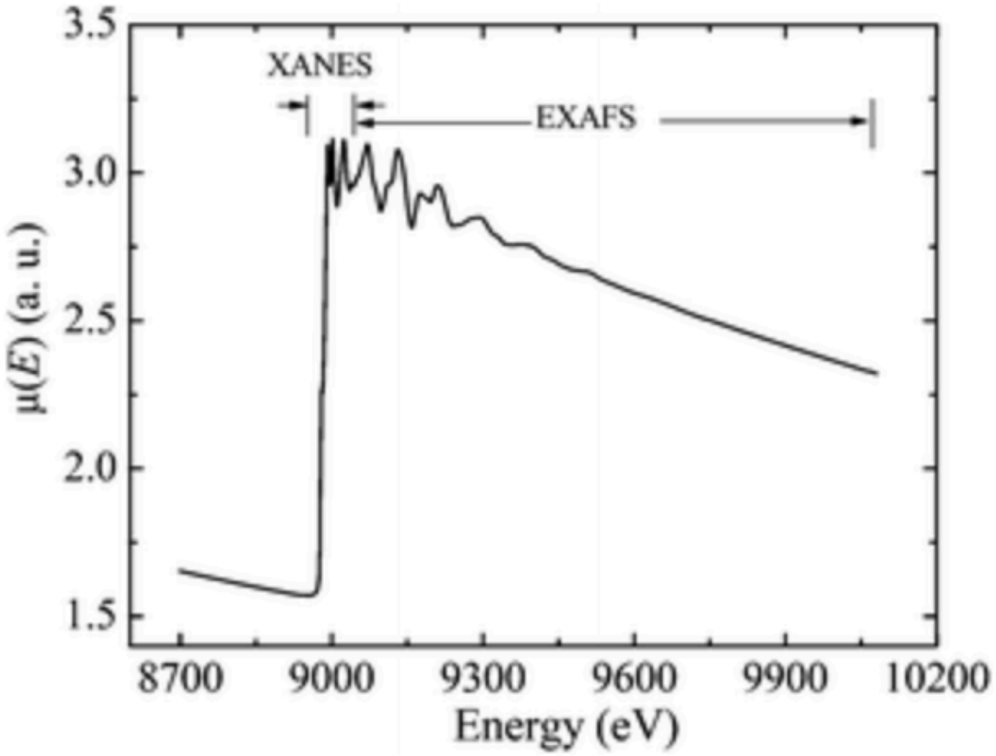
$$p = \hbar k; \;\; k \sim n\pi/a$$

$$E_\gamma = \chi + n^2 \frac{h^2}{8 m_e a^2}$$

atom surrounded by other atoms, in regular structure ('short-range order')



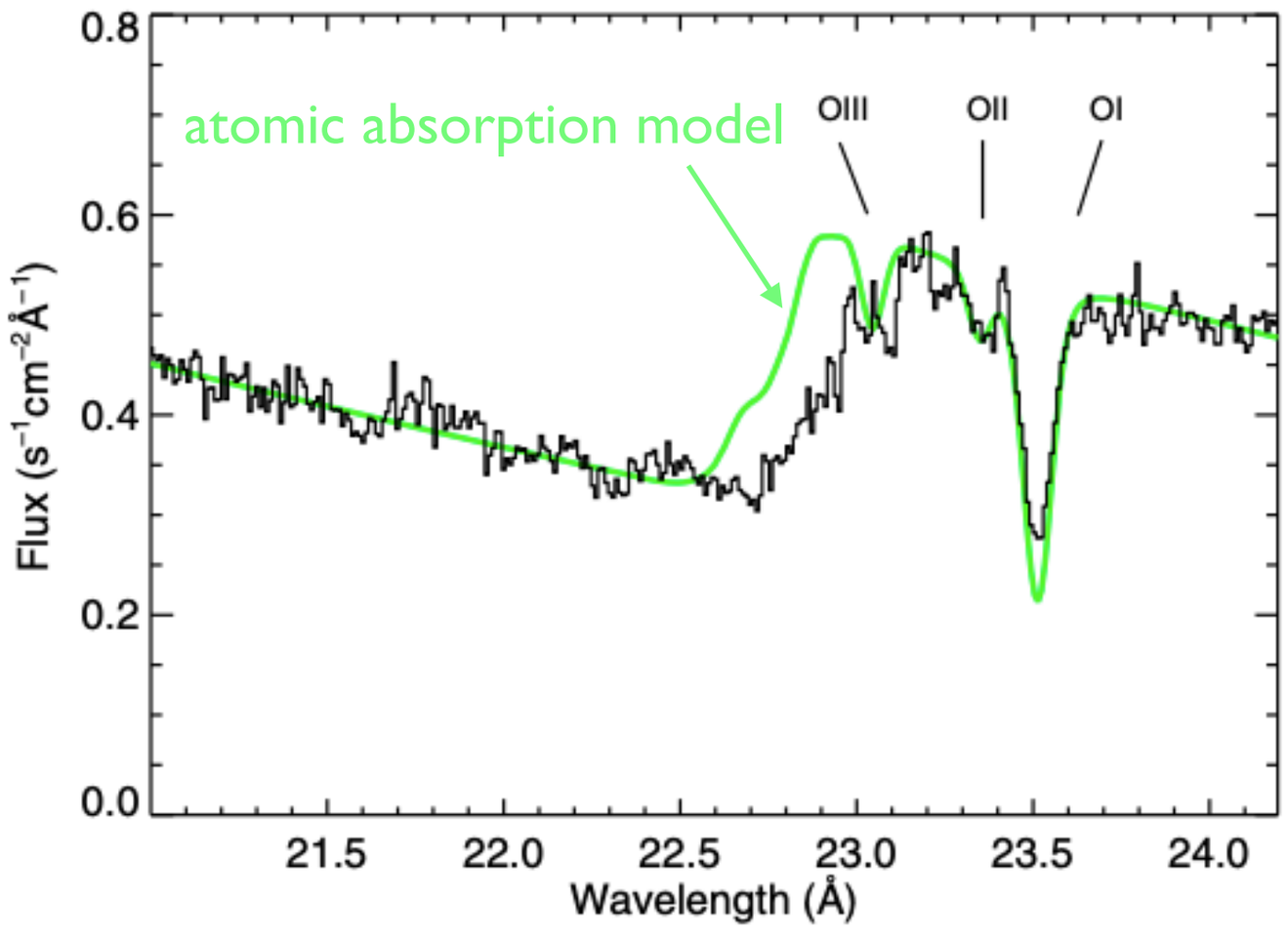

'XAFS'




# XAFS example: Cu K edge

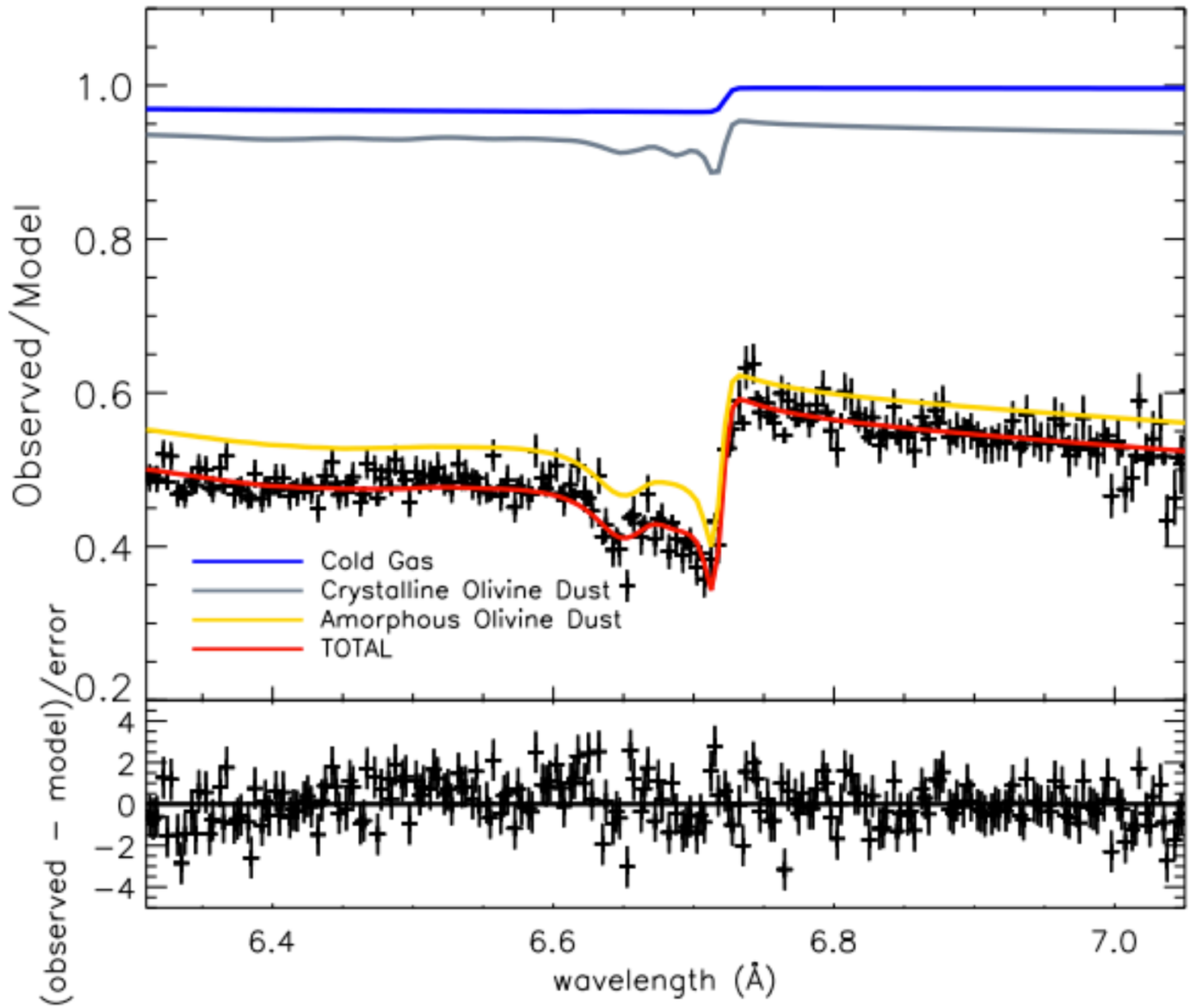
dedicated RGS observation of Sco X-1: O K edge (de Vries & Costantini 2009):

*amorphous water ice XAFS !??*



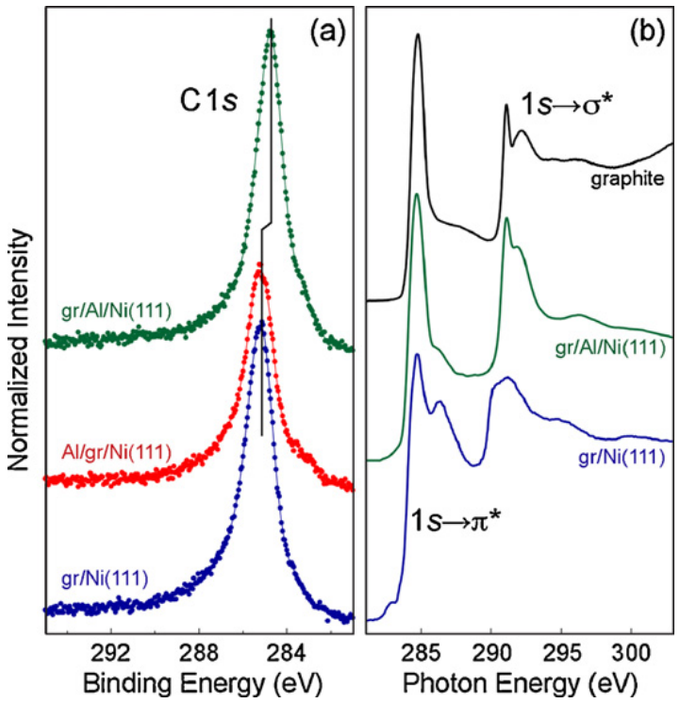
# Si K edge in GX5-1/ *Chandra* HETGS

XAFS probes
*short range order!*
*Not* the full crystal lattice!
(that's IR)




Sascha Zeegers *et al.* 2019

Generalov *et al.* 2013




# Try the interstellar Carbon K edge!

Graphene XAFS

1ES1553+113
*Chandra* LETGS
work with John Staunton (Columbia); in progress