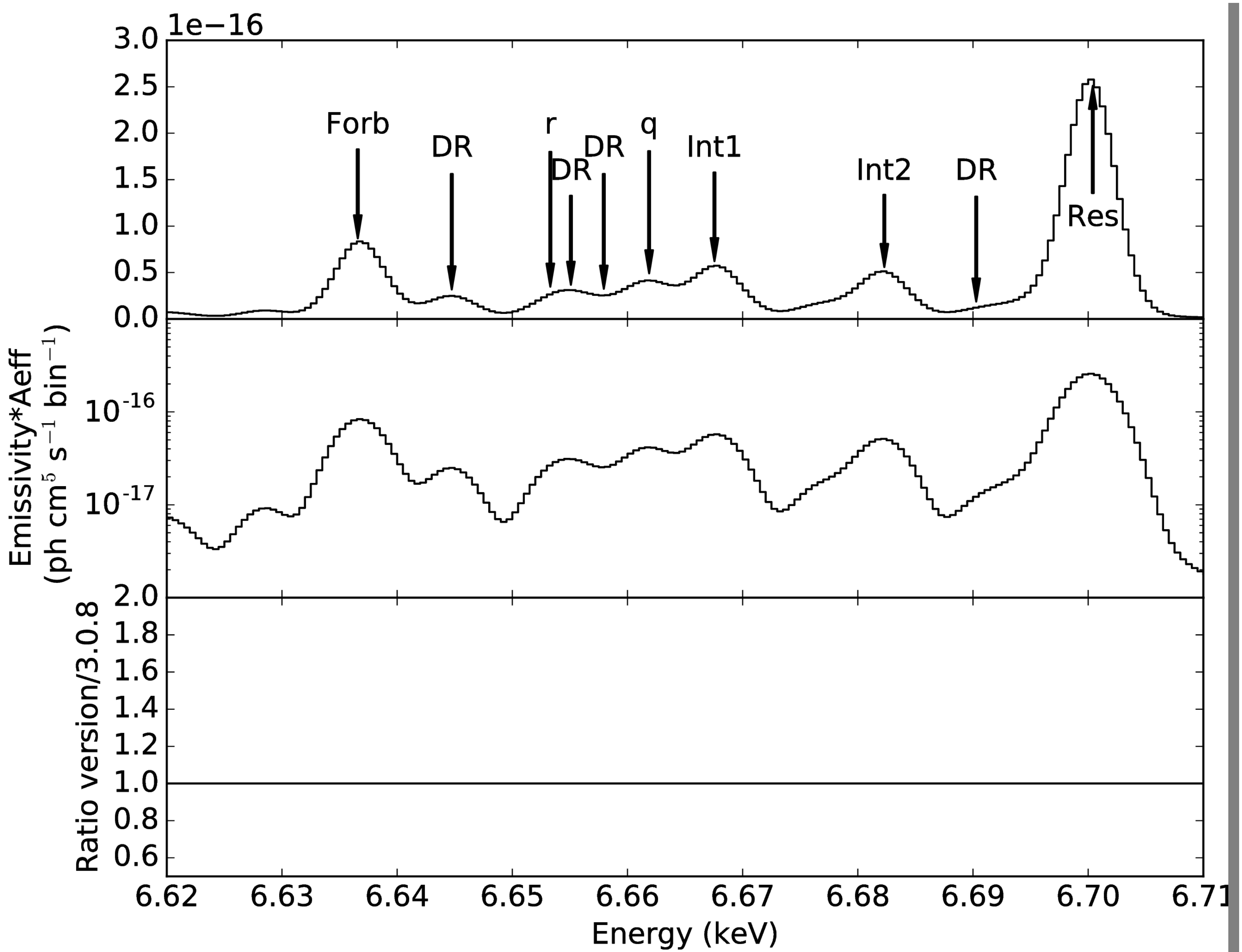
What we learned we don't know from Hitomi

Adam Foster for the Hitomi Perseus Atomic Team

L. Gu, J. Kaastra, H. Odaka, R. Smith, M. Sawada, S. Nakashima, N. Ota, G. Brown, J. de Plaa & more


1e−16
Forb
DR
r
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Int1
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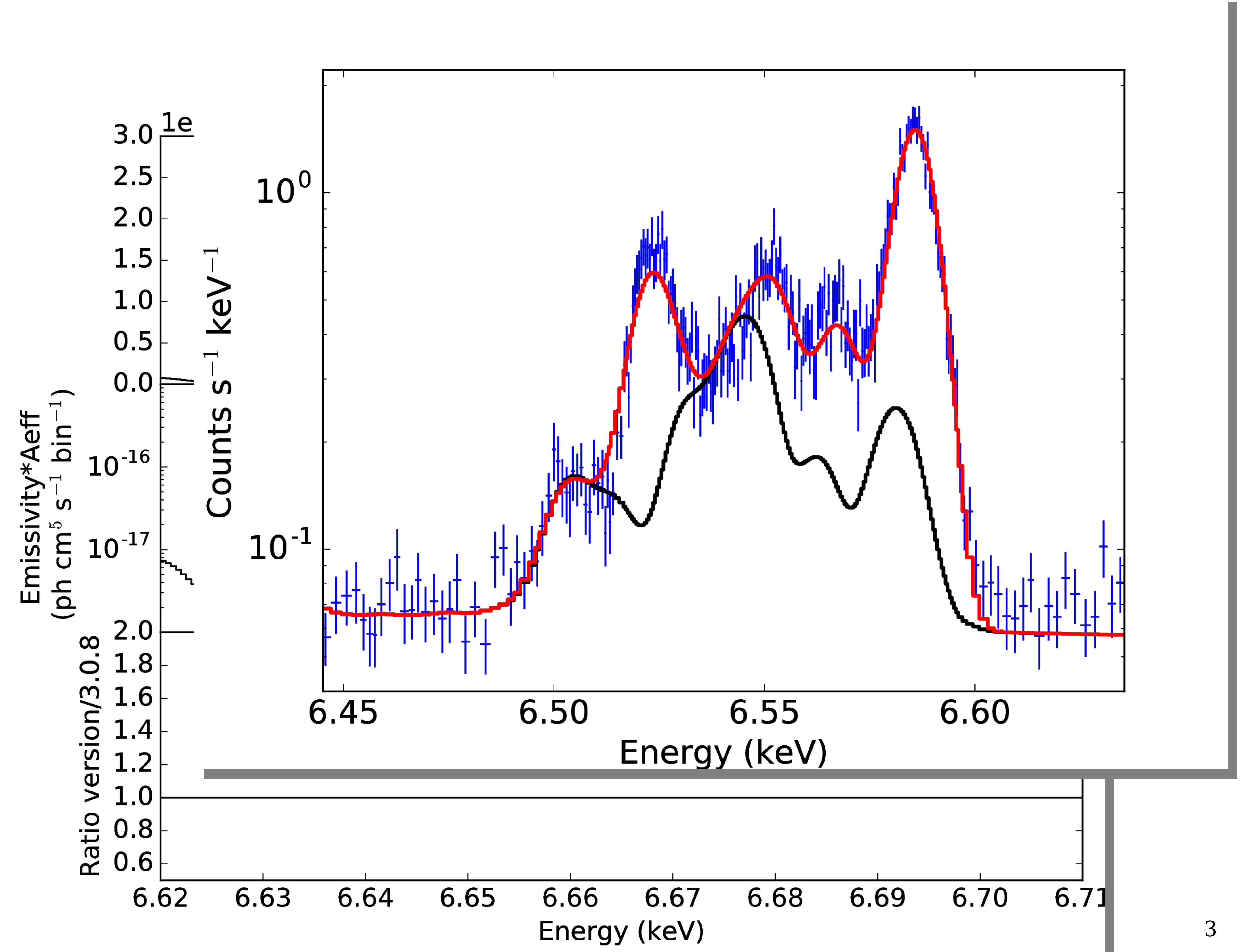
Res
Emissivity*Aeff
(ph cm^5 s^{-1} bin^{-1})
Ratio version/3.0.8
Energy (keV)



1e
3.0
2.5
2.0
1.5
1.0
0.5
0.0
10-16
10-17
Emissivity*Aeff
(ph cm5 s−1 bin−1)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
Ratio version/3.0.8
6.62
6.63
6.64
6.65
6.66
6.67
6.68
6.69
6.70
6.71
Energy (keV)
10^0
10^-1
Counts s−1 keV−1
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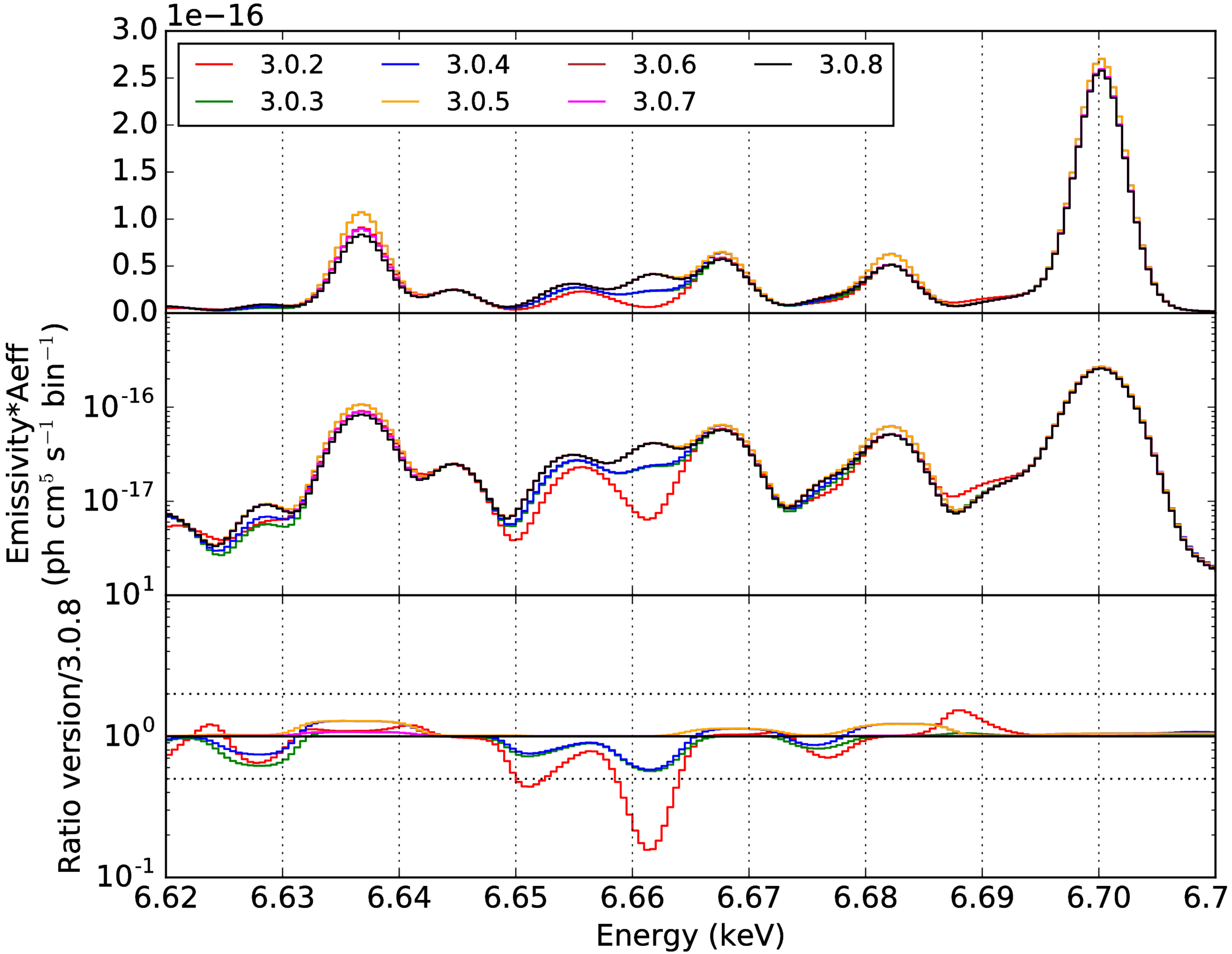
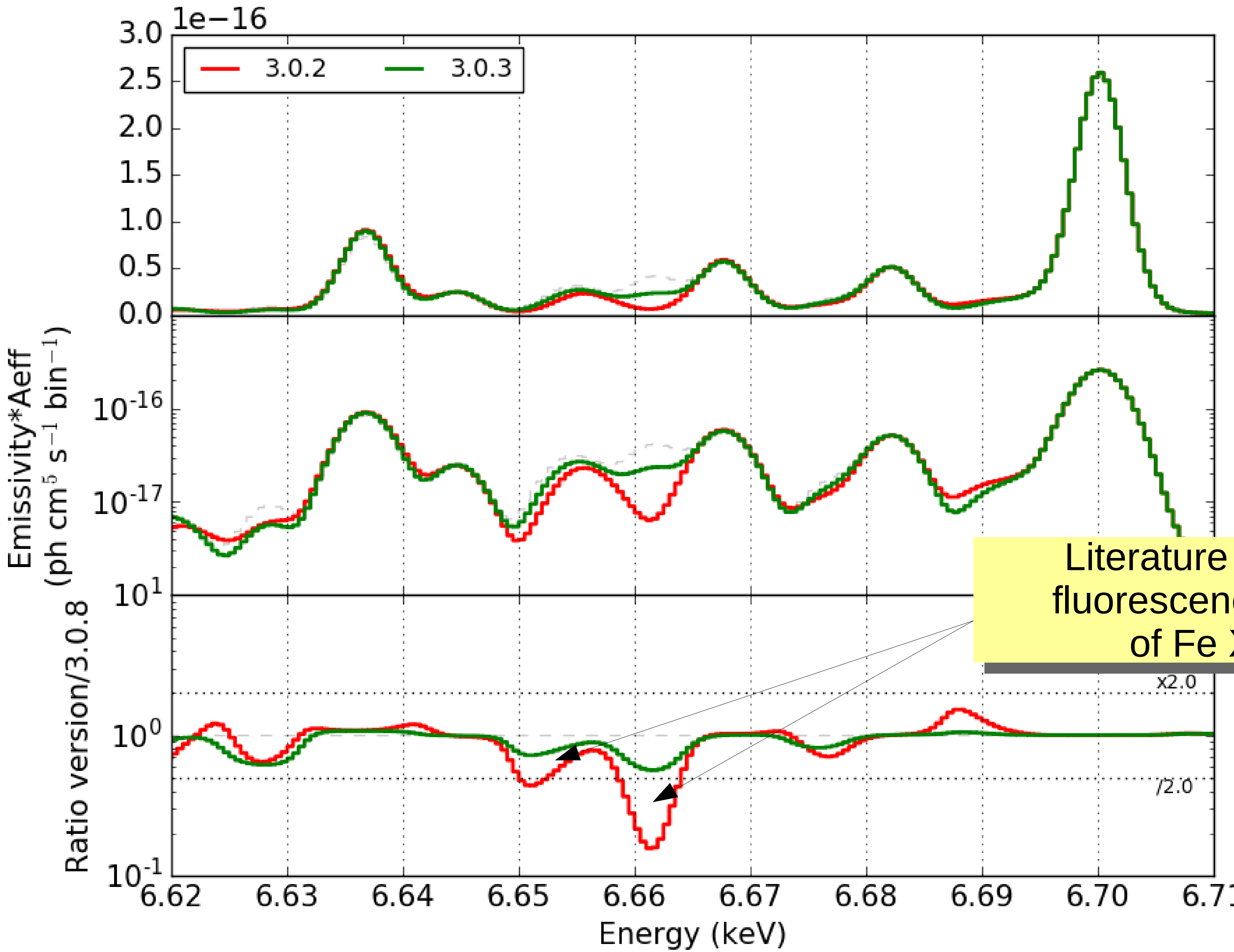
6.50
6.55
6.60
Energy (keV)


1e−16
3.0.2
3.0.3
3.0.4
3.0.5
3.0.6
3.0.7
3.0.8
Emissivity*Aeff
(ph cm^5 s^{-1} bin^{-1})
Ratio version/3.0.8
Energy (keV)

Data type	Experiment	Theory
Fluorescence yields	Some, as check	Y



Literature data for fluorescence yields of Fe XXIV

Palmeri et al

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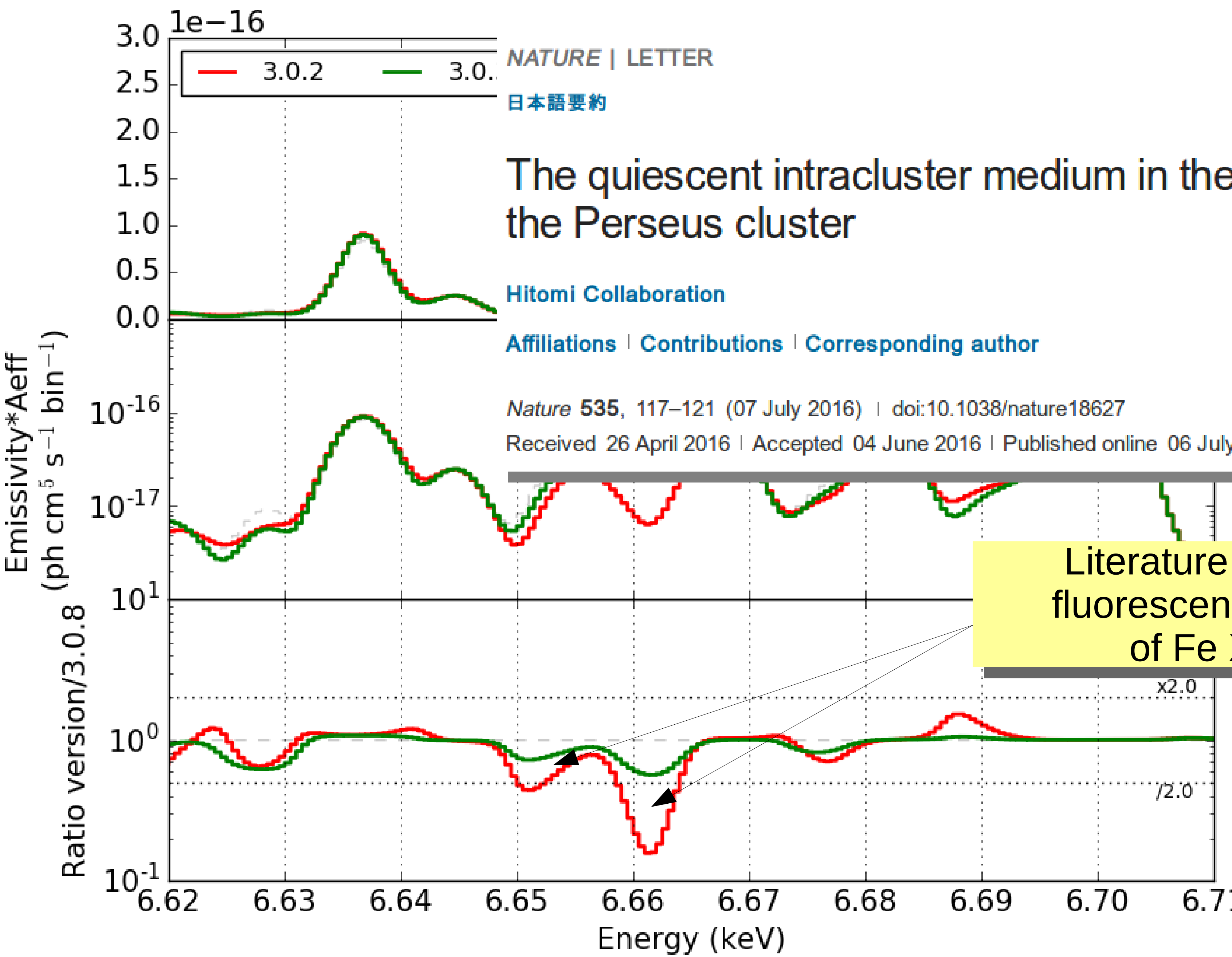

NATURE | LETTER

日本語要約

The quiescent intracluster medium in the core of the Perseus cluster

Hitomi Collaboration

Affiliations | Contributions | Corresponding author

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Literature data for fluorescence yields of Fe XXIV

Palmeri et al

Data type	Experiment	Theory
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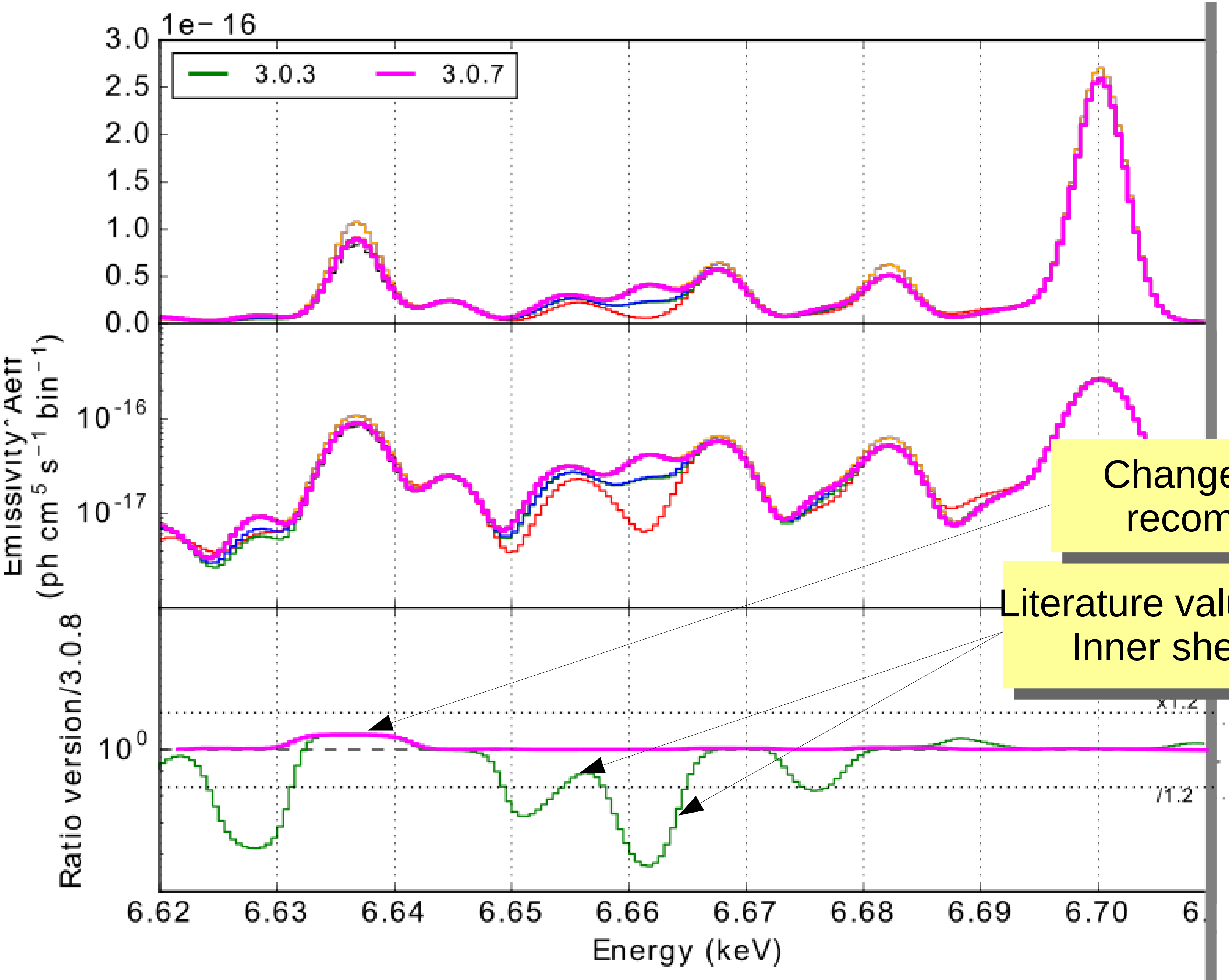
Ioniz & Recomb rates	~ Y	Y

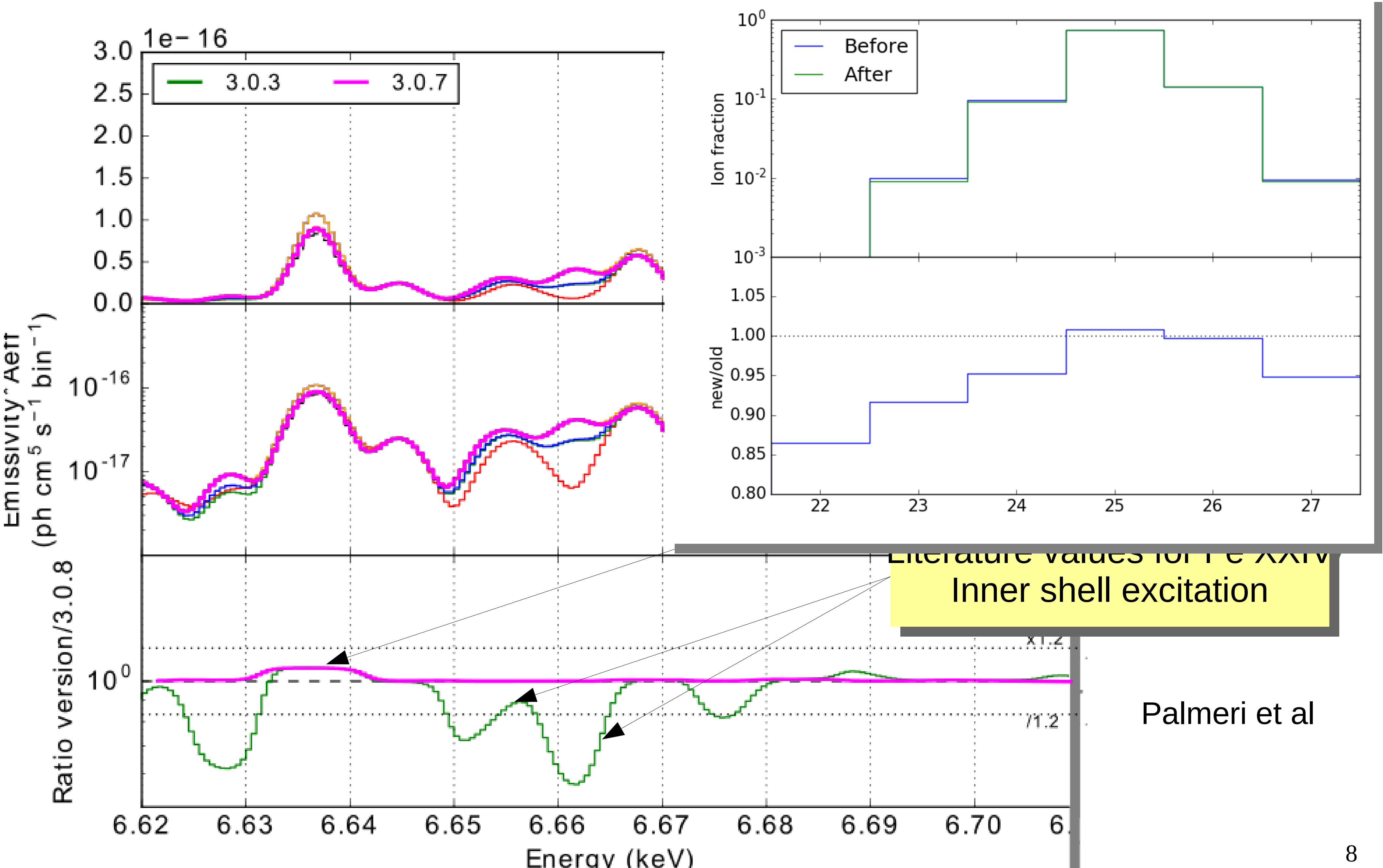


Change ionization and recombination rates

Literature values for Fe XXIV Inner shell excitation

Palmeri et al

Data type	Experiment	Theory
Fluorescence yields	Some, as check	Y
Ioniz & Recomb rates	Mostly Near Neutrals	Y



Literature values for Fe XXIV
Inner shell excitation

Palmeri et al

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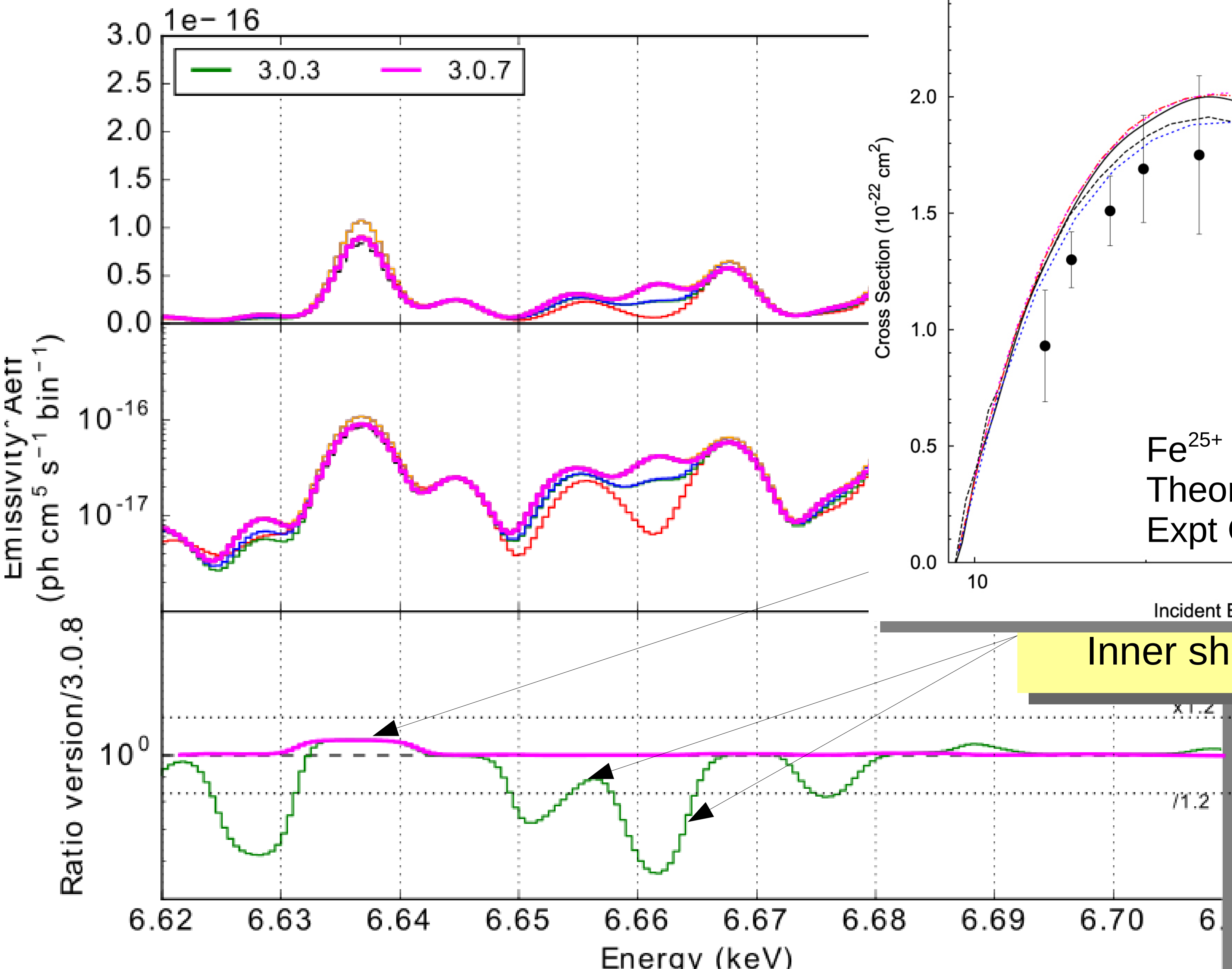
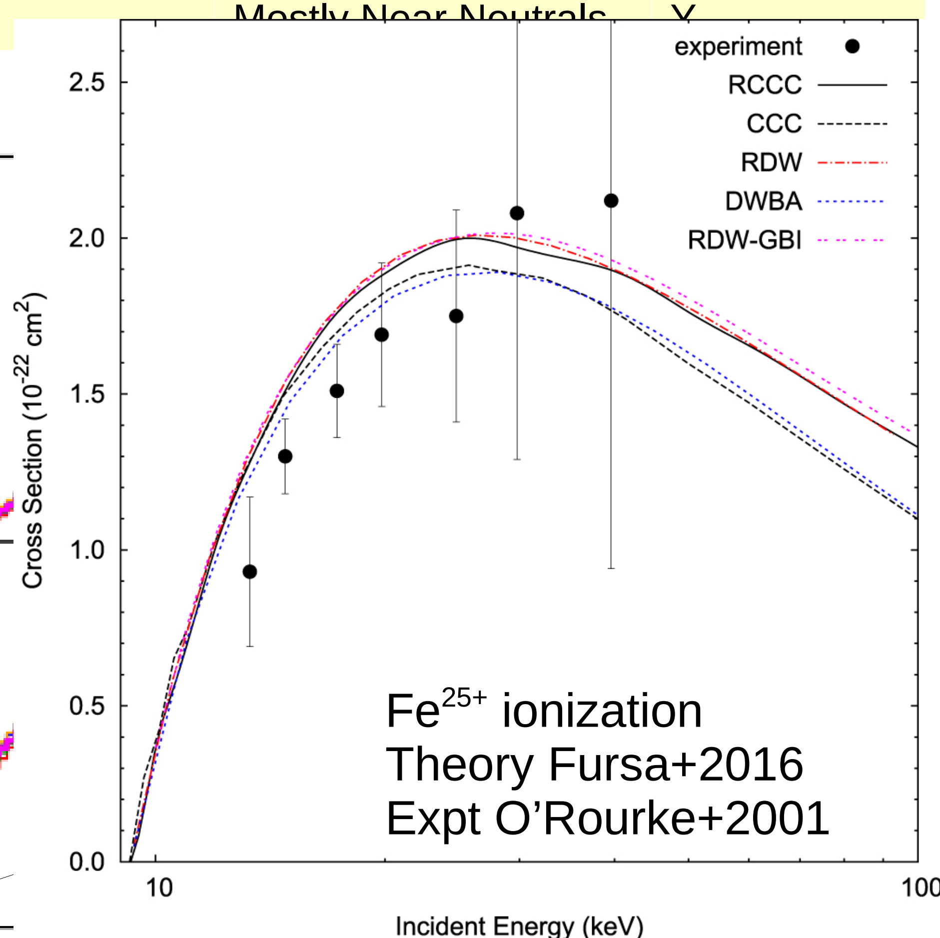
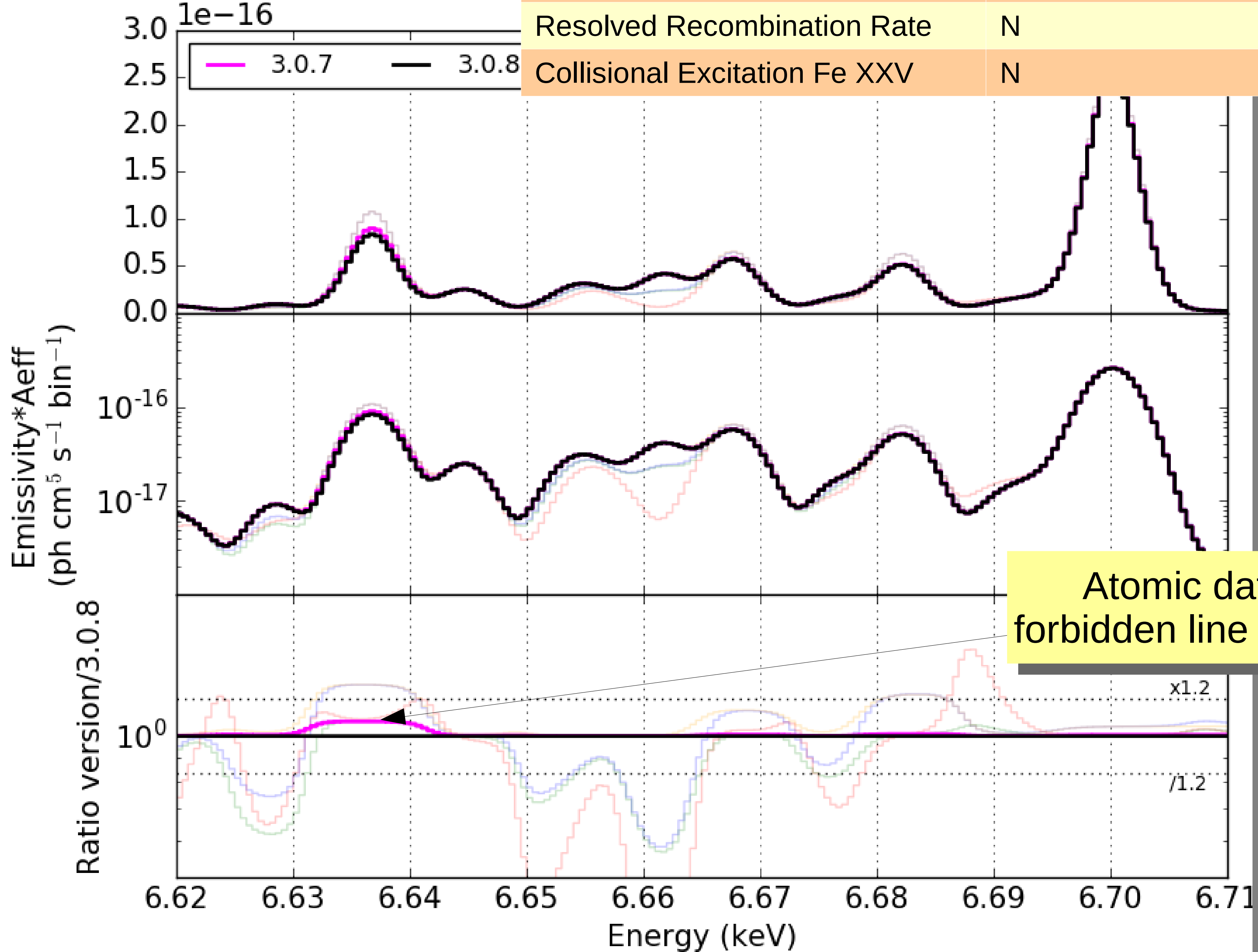




Inner shell excitation

Palmeri et al

Data type	Experiment	Theory
Fluorescence yields	Some, as check	Y
Ioniz & Recomb rates	Mostly Near Neutrals	Y
Collisional Excitation Fe XXIV	N	Y
Resolved Recombination Rate	N	Y
Collisional Excitation Fe XXV	N	Y



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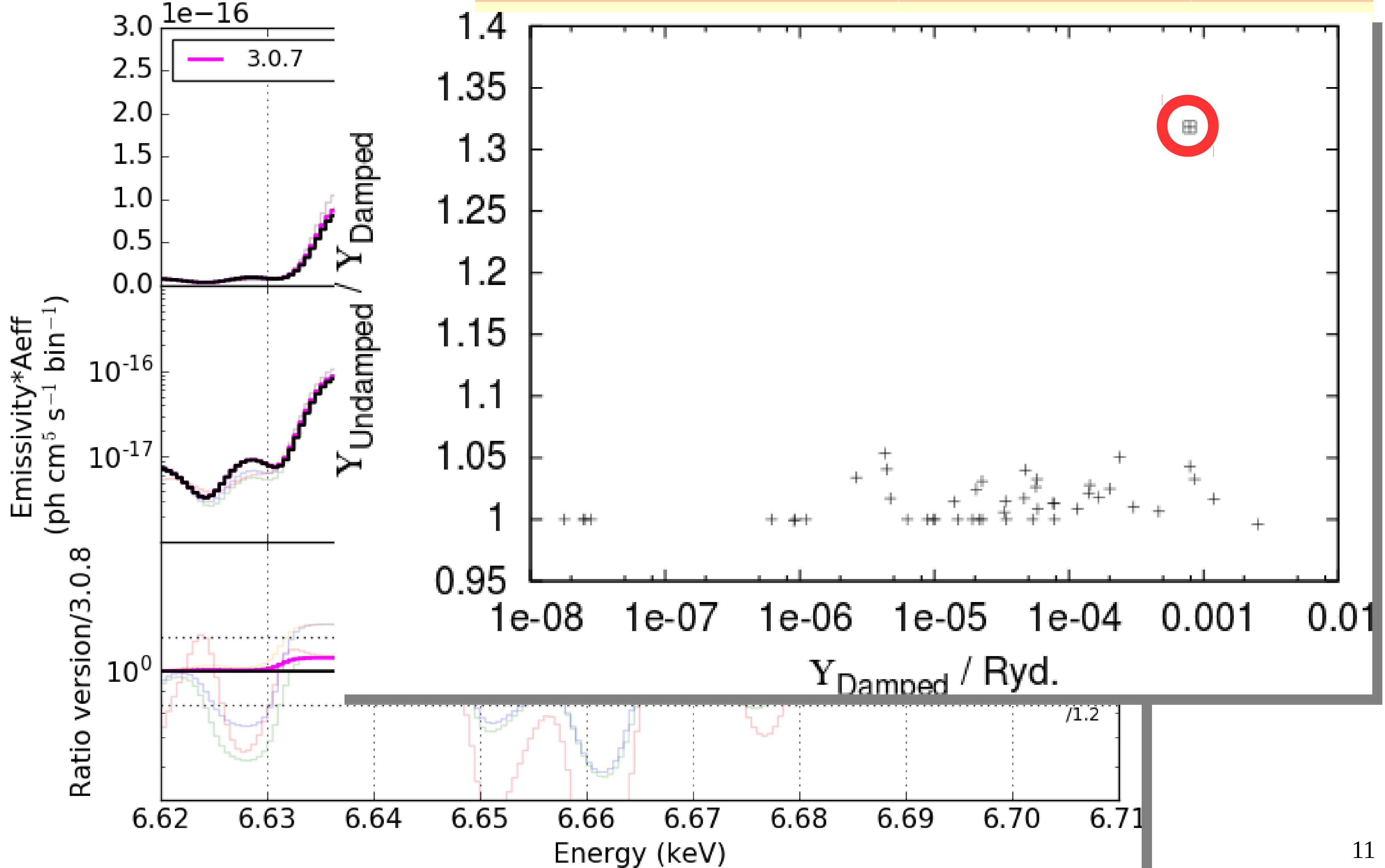

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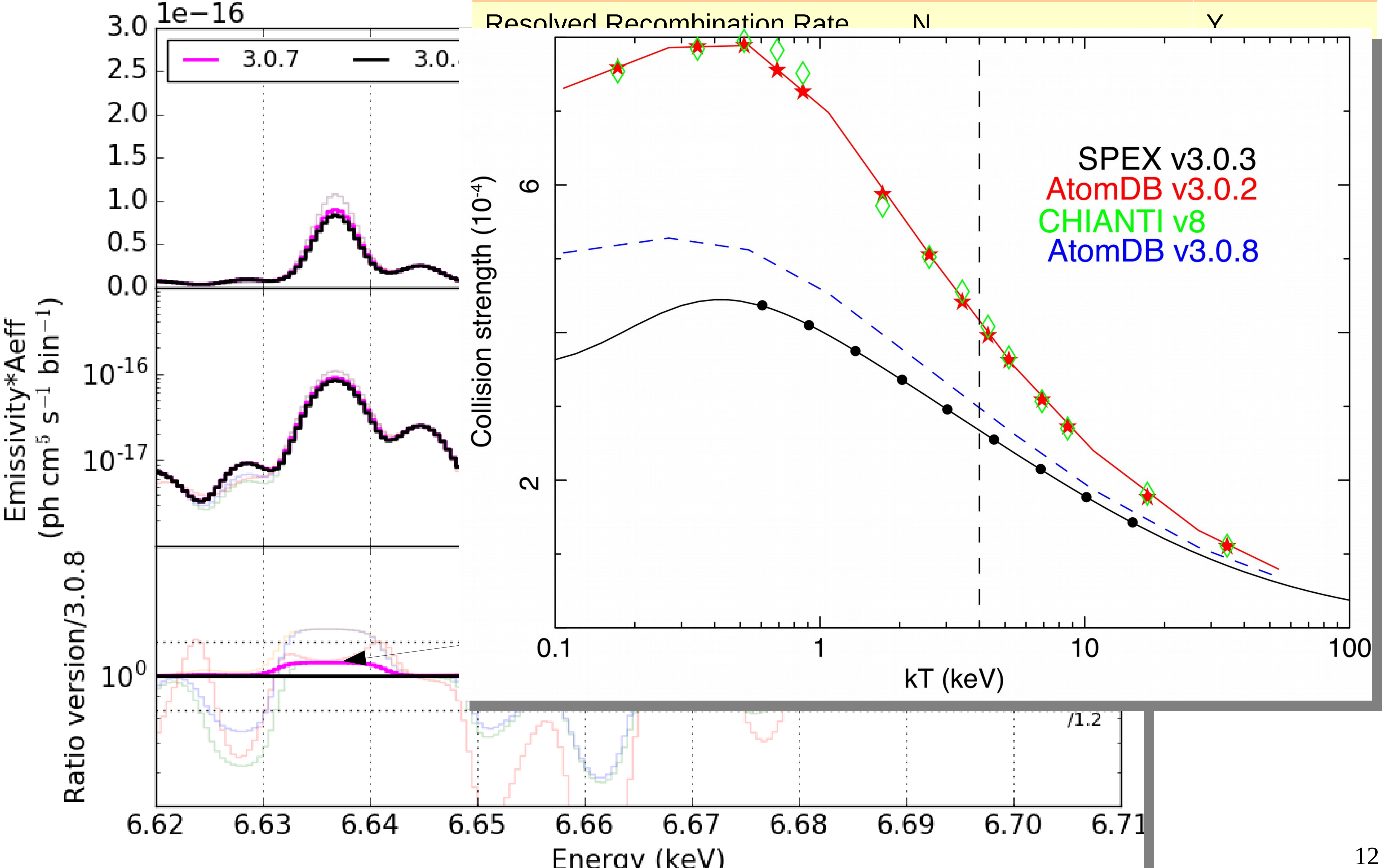

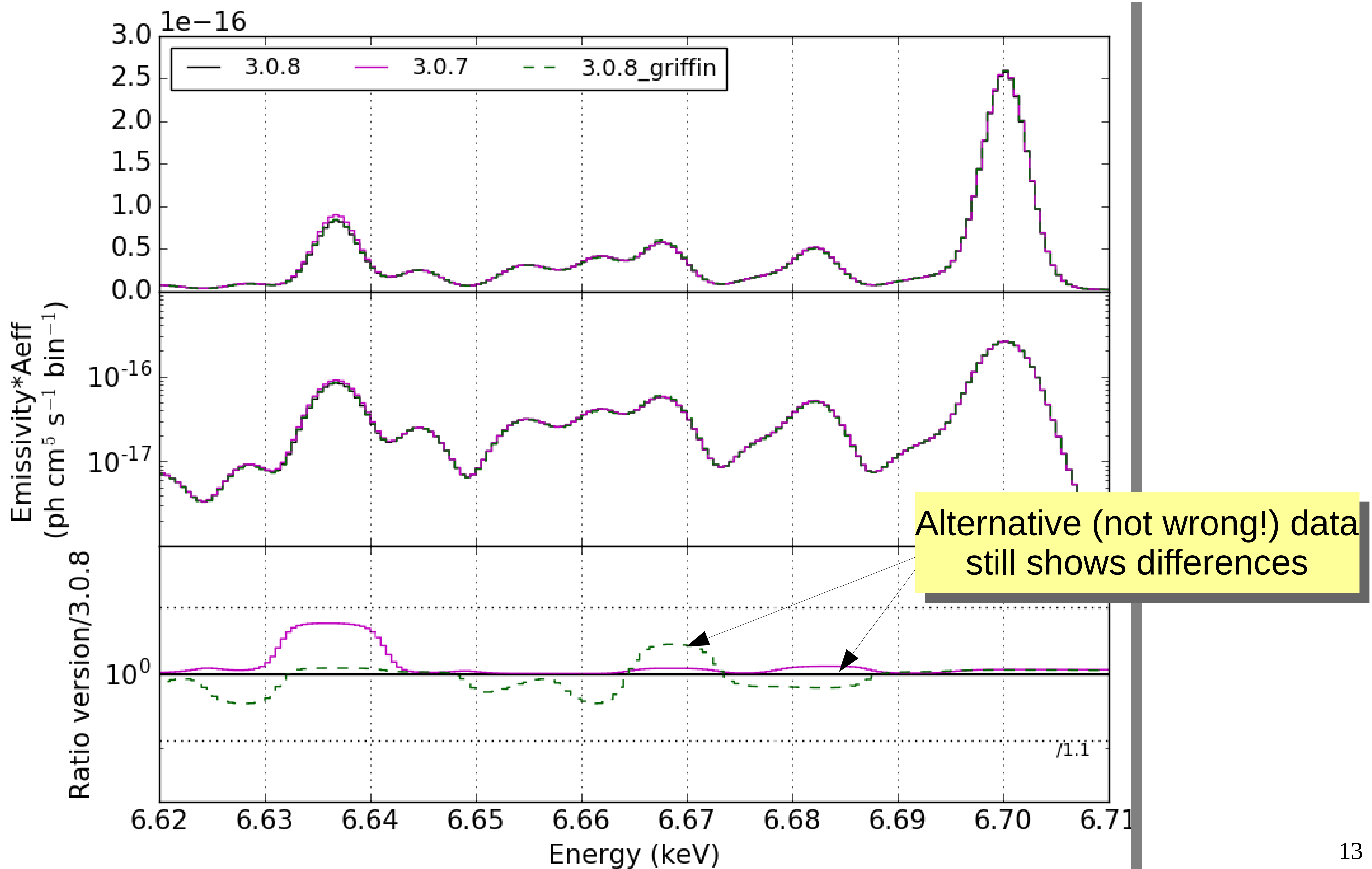

1e−16
3.0
2.5
2.0
1.5
1.0
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3.0.8
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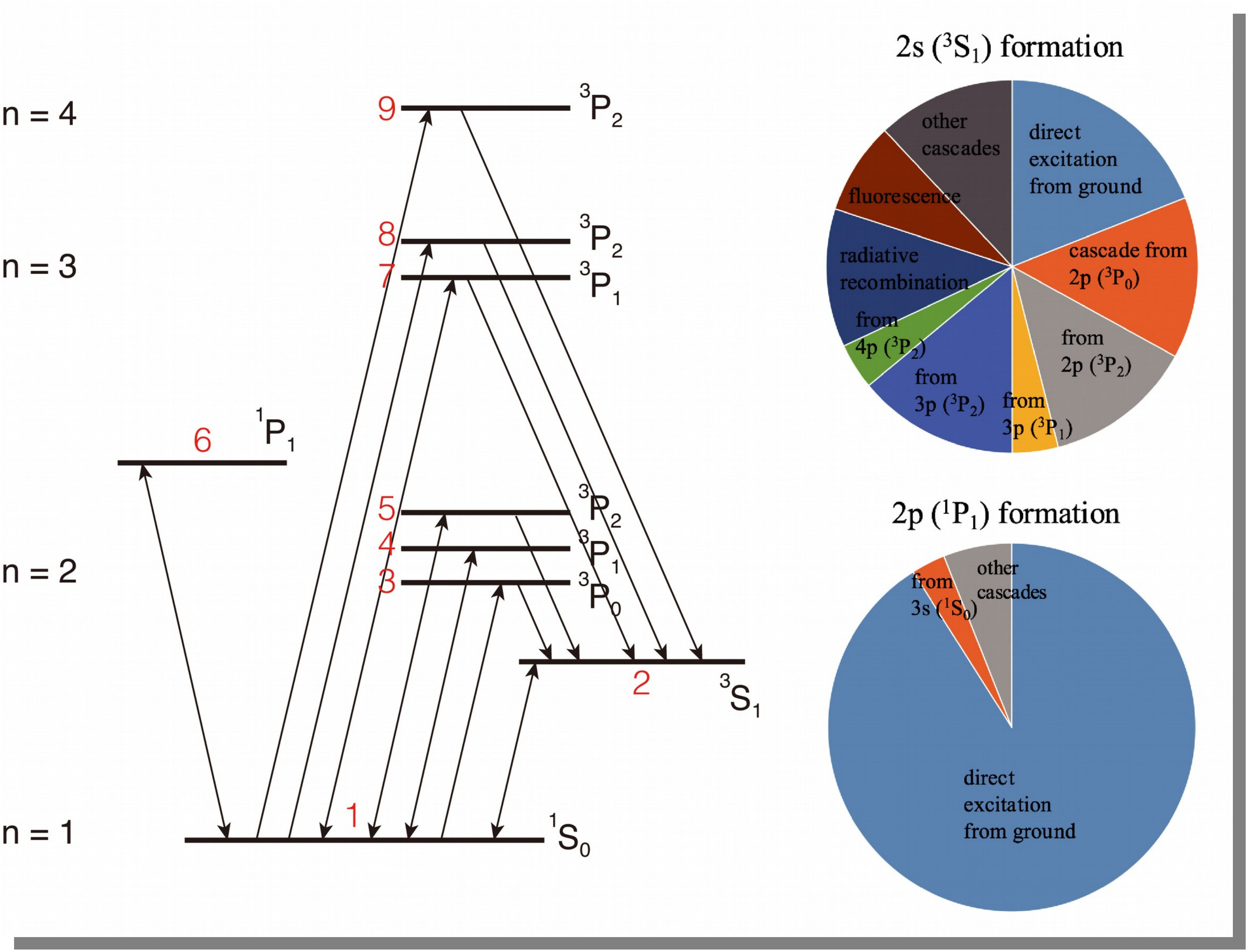
3.0.8_griffin
Emissivity*Aeff
(ph cm^5 s^{-1} bin^{-1})
10^{-16}
10^{-17}
Ratio version/3.0.8
10^0
/1.1
6.62
6.63
6.64
6.65
6.66
6.67
6.68
6.69
6.70
6.71
Energy (keV)
Alternative (not wrong!) data
still shows differences

Line Ratio Diagnostics



Diagnostics lines at 4keV

Line	Iron				Sulphur			
	$\varepsilon_{\mathrm{SPEX}}$	$\varepsilon_{\mathrm{AtomDB}}$	$\varepsilon_{\mathrm{CHIANTI}}$	%	$\varepsilon_{\mathrm{SPEX}}$	$\varepsilon_{\mathrm{AtomDB}}$	$\varepsilon_{\mathrm{CHIANTI}}$	%
Lyα_2	0.100	0.106	0.114	13.2	0.580	0.707	0.684	18.6
Lyα_1	0.209	0.207	0.212	2.4	1.160	1.393	1.370	17.0
Heα_z	0.826	0.908	0.758	18.2	0.084	0.098	0.061	44.0
Heα_y	0.544	0.545	0.516	5.3	0.026	0.031	0.021	38.5
Heα_x	0.491	0.510	0.472	7.7	0.012	0.014	0.010	33.3
Heα_w	2.568	2.513	2.440	5.1	0.294	0.299	0.269	10.2
G ratio	0.725	0.781	0.716	9.0	0.415	0.478	0.342	32.8
R ratio	0.798	0.861	0.767	11.7	2.211	2.178	1.968	11.1
Lyα/Heα_w	0.120	0.125	0.134	10.7	5.918	7.023	7.636	24.5

A SPEX 4keV G-ratio → 9.1keV in AtomDB

A Chianti 4keV G-ratio → 11keV in AtomDB

In flight calibration: Hitomi Atomic Data Paper

Model	kT	Si	Fe
Baseline	2.74	0.91	0.828
Pre-launch SPEX	0.263	0.03	-0.243
Pre-launch APEC	-0.039	-0.24	-0.047
APEC V3.0.8	0.071	-0.10	-0.134
2CIE	–	-0.12	0.024
no AGN	0.523	-0.01	-0.206
No gain correction	0.01	-0.13	-0.008

12% change in S abundance

14% change in Fe abundance

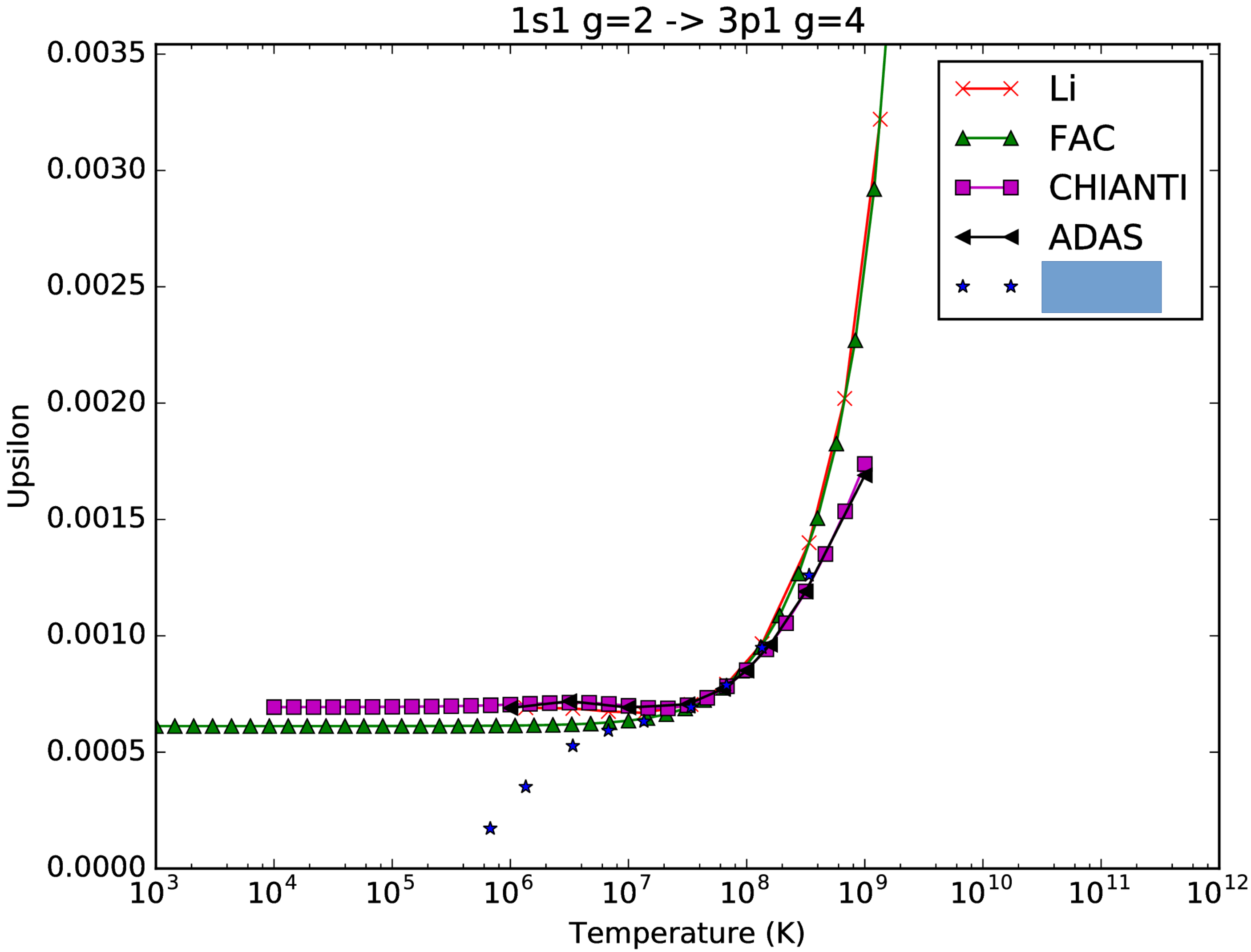
Also studied the effects of:

- Different models
- Line shapes
- Fixing Line Ratios
- Collision Strengths

- Atomic code, astrophysical modelling, and instrumental calibration have overall similar contribution to the error budget.
- Atomic code improved dramatically after the launch (some key updates triggered by the atomic paper itself).
- Still the uncertainty on collisional excitation is 10-20%@4 keV (might be larger at lower- or higher- energies).
- Laboratory work needed.

This was the easy stuff

H-like and He-like Fe are the simplest systems!



This is the easy stuff!

H-like and He-like Fe are the simplest systems!

Lurking below 2keV/in longer observations:

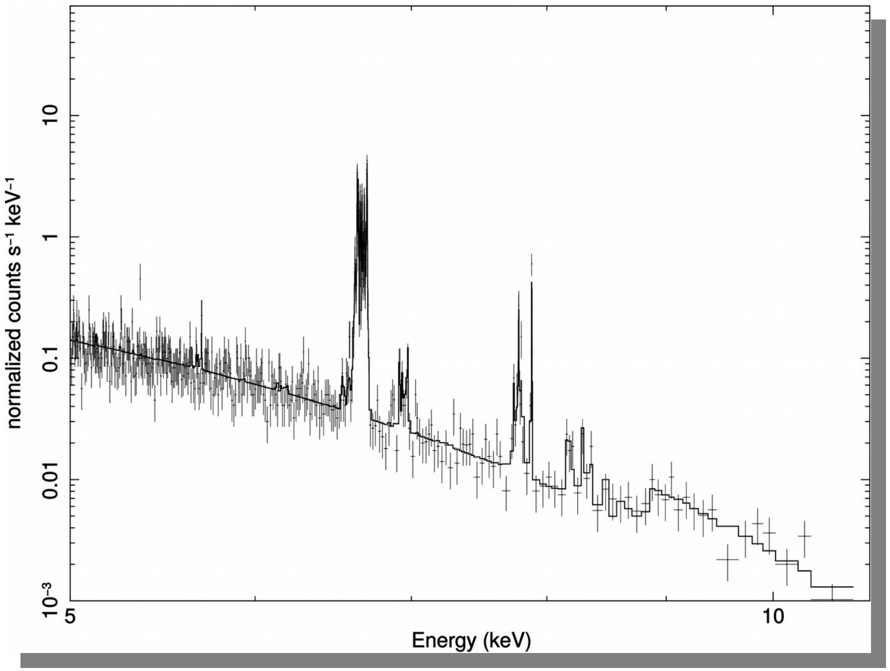
- Fe L-shell lines (wavelength, intesity, identification)
  - Ionization balance?
  - Line identification?
  - Driving processes?
  - Dielectronic satellite lines (wavelength, intensity)

We need significant Ground Calibration for Atomic Data!

Summary: What don't we know

- Ionization rates, esp. at high energies
- Collisional excitation of strong diagnostic lines
- Inner-shell excitation and fluorescence yields
- All of the above * lots for non-Fe
- Dielectronic Satellite lines – wavelength, flux

Lorentz Workshop



APEC → Reduced CSTAT: 1.4
KT = 1.5keV

SPEX → Reduced CSTAT: 1.2
KT = 1.3keV

```
Dear Adam,

We have been analyzing our spectrum and your model is worse than SPEX. [Why] is
your code wrong?

Yours,
Baffled Scientist
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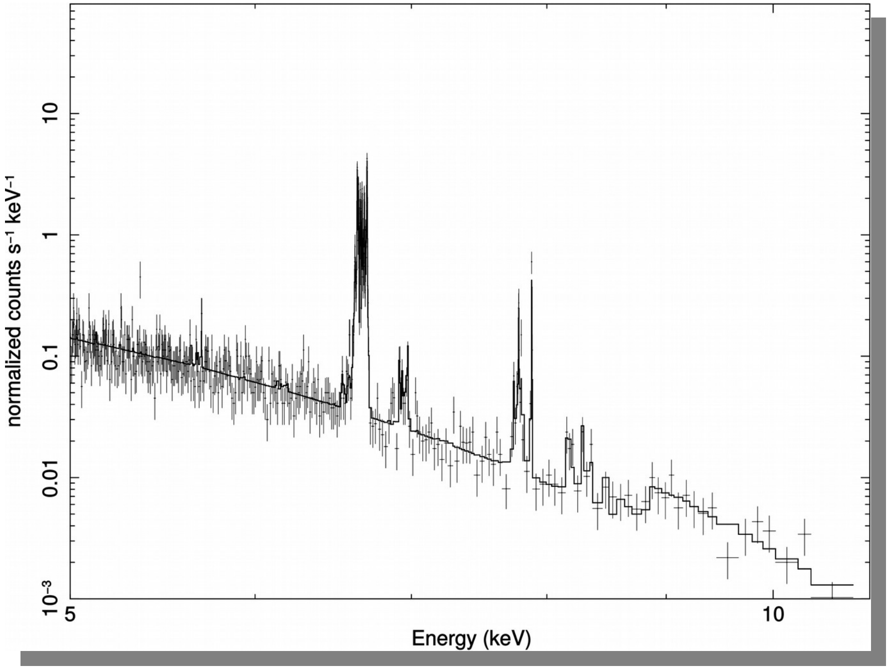
Lorentz Workshop



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Dear Adam,

We have been analyzing our spectrum and your model is worse than SPEX. Your code is wrong.

Yours,
Angry Scientist

- Produce series of easily comparable outputs:

CIE Plasma	NEI plasma	Photoionized Plasma
Charge State Distribution	Charge State Distribution	Charge State Distribution
Radiated X-ray Power	Strong Line List	Strong Lines
Strong Line List	Continuum Spectrum	Heating and Cooling Rates
Line Populating Processes		Absorption Spectrum

- Post in simple ASCII formats for users to access