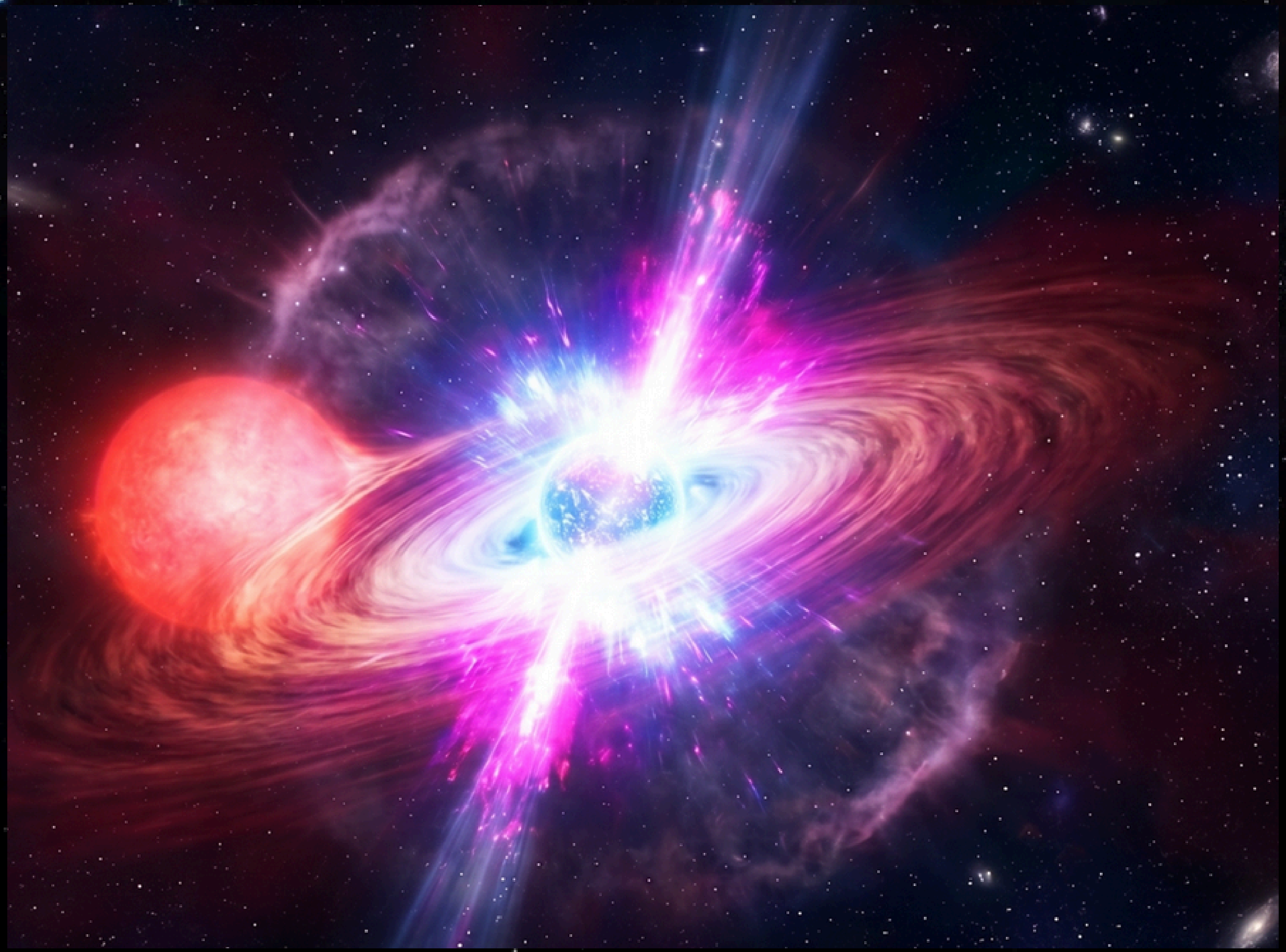
UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

The effect in the X-ray light-curves and spectra of Radiative Winds in thermonuclear X-ray bursts

Daniel Muñoz-Vela
Gloria Sala
Barbara de Marco
Jordi José
Yago Herrera



UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Type I X-ray Bursts

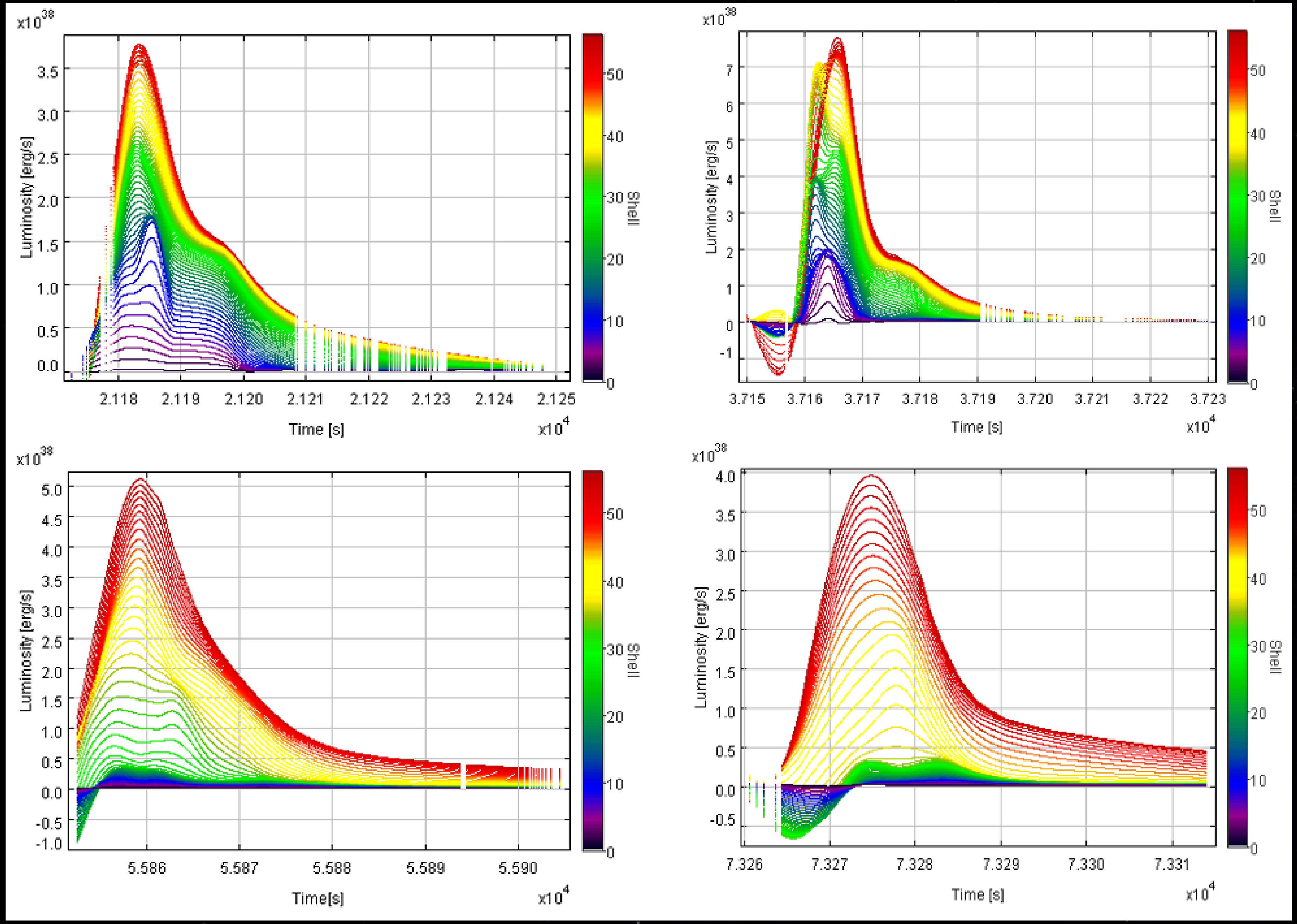
- Explosive nuclear burning of accreted H/He on a neutron star surface.
- Sudden rise and long exponential decay (S. Guichandut et al. 2023)
- Elements synthesized. Should remain trapped on the star's surface?

Stellar winds

- Outward pressure (from gas, magnetic fields or radiation).
- Mass ejected $\propto$ mass NS
- Extreme radiation drives optically thick winds, expelling material and heavily modifying the observed X-ray emission.

Bridging models

XRB hydrodynamic models



XRB	$\tau_{rec}(hours)$	$\tau_{burst}(s)$	$T_{peak}(10^9 K)$	$L_{peak}(10^5 L_\odot)$	α
XRB-1	5.9	75.8	1.06	0.97	60
XRB-2	4.9	55.4	1.26	2.1	34
XRB-3	6.4	62.3	1.15	1.7	40
XRB-4	5.1	75.5	1.12	1.2	36

$M_{NS} = 1.4 M_\odot$

$R_{NS} = 13.1$ km

Accretion rate: $1.75 \times 10^{-9} M_\odot / yr$

Metallicity: $Z = 0.02$

The Astrophysical Journal Supplement Series, 189:204–239, 2010 July doi:10.1088/0067-0049/189/1/204

HYDRODYNAMIC MODELS OF TYPE I X-RAY BURSTS: METALLICITY EFFECTS

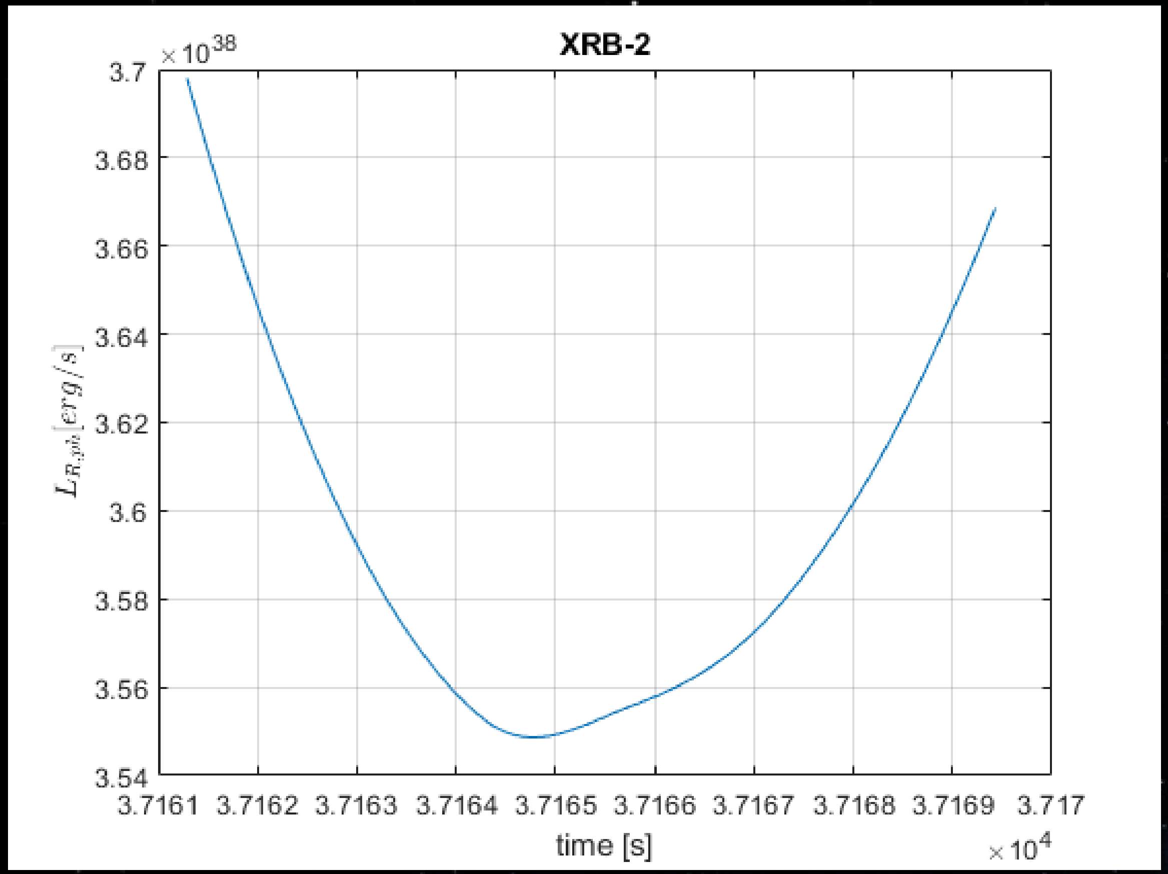
Jordi José[1,2], Fermín Moreno[1], Anuj Parikh[3], and Christian Iliadis[4,5]
[1] Departament de Física i Enginyeria Nuclear, EUETIB, Universitat Politècnica de Catalunya, C./ Comte d'Urgell 187, E-08036 Barcelona, Spain; jordi.jose@upc.edu, moreno@ieec.fcr.es
[2] Institut d'Estudis Espacials de Catalunya (IEEC), Ed. Nexus-201, C/ Gran Capità 2-4, E-08034 Barcelona, Spain
[3] Physik Department E12, Technische Universität München, James-Franck-Strasse, D-85748 Garching, Germany; anuj.parikh@ph.tum.de
[4] Department of Physics and Astronomy, University of North Carolina, Chapel Hill, NC 27599-3255, USA; iliadis@unc.edu
[5] Triangle Universities Nuclear Laboratory, Durham, NC 27708-0308, USA

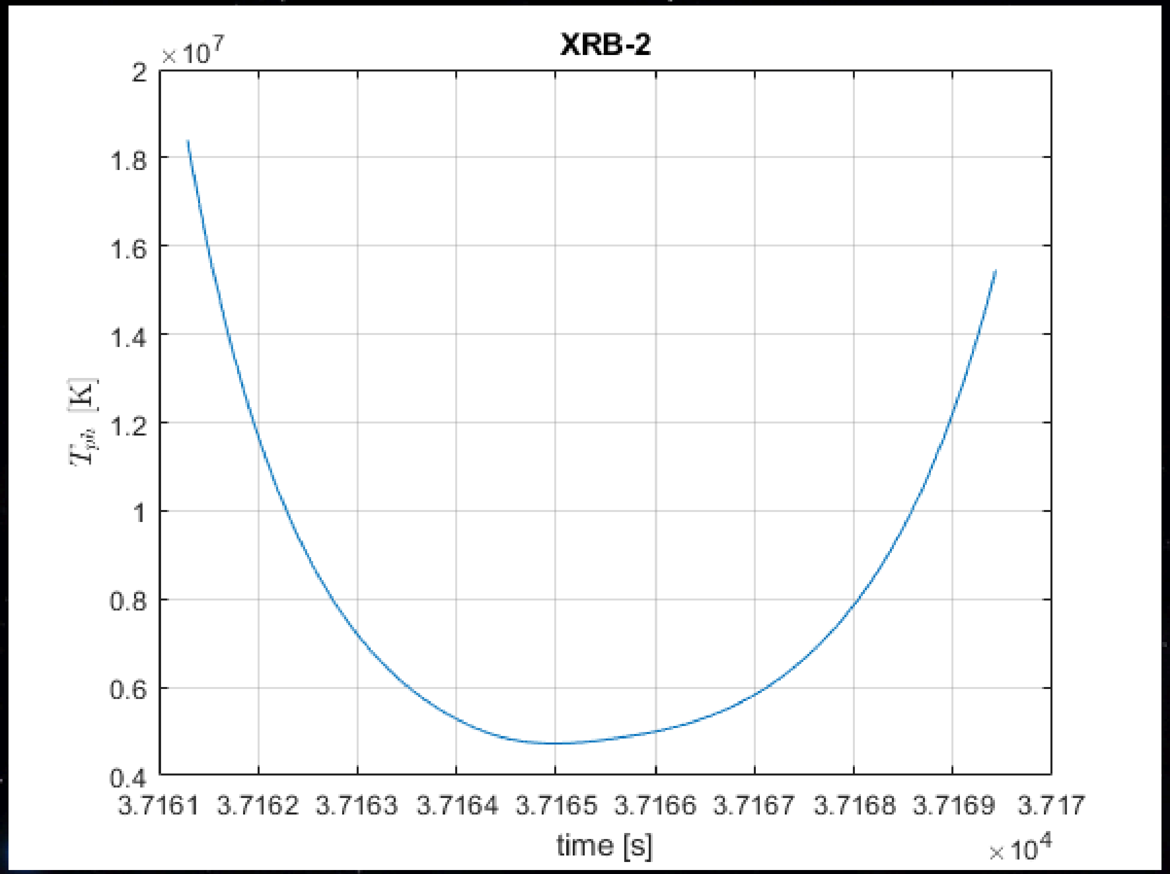
Received 2009 December 16; accepted 2010 May 24; published 2010 June 30

Bridging models

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Stellar wind model





- Stationary, radiation-driven winds.
- Very small changes in luminosity ~ 3.6x10^{38} erg/s.
- Minimum at peak of photospheric expansion.


A&A 638, A107 (2020)
https://doi.org/10.1051/0004-6361/201936895
© ESO 2020

Astronomy & Astrophysics

Simulations of stellar winds from X-ray bursts

Characterization of solutions and observable variables

Y. Herrera[1,2], G. Sala[1,2], and J. José[1,2]

[1] Departament de Física, EEBE, Universitat Politècnica de Catalunya, c/Eduard Maristany 16, 08019 Barcelona, Spain
e-mail: gloria.sala@upc.edu
[2] Institut d'Estudis Espacials de Catalunya, c/Gran Capità 2-4, Ed. Nexus-201, 08034 Barcelona, Spain

Bridging models

UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

- Not well-defined photosphere in XRB models.
- Assumption: Photospheric luminosity ≈ luminosity in last layer of XRB (3.52×10^{38} erg/s)

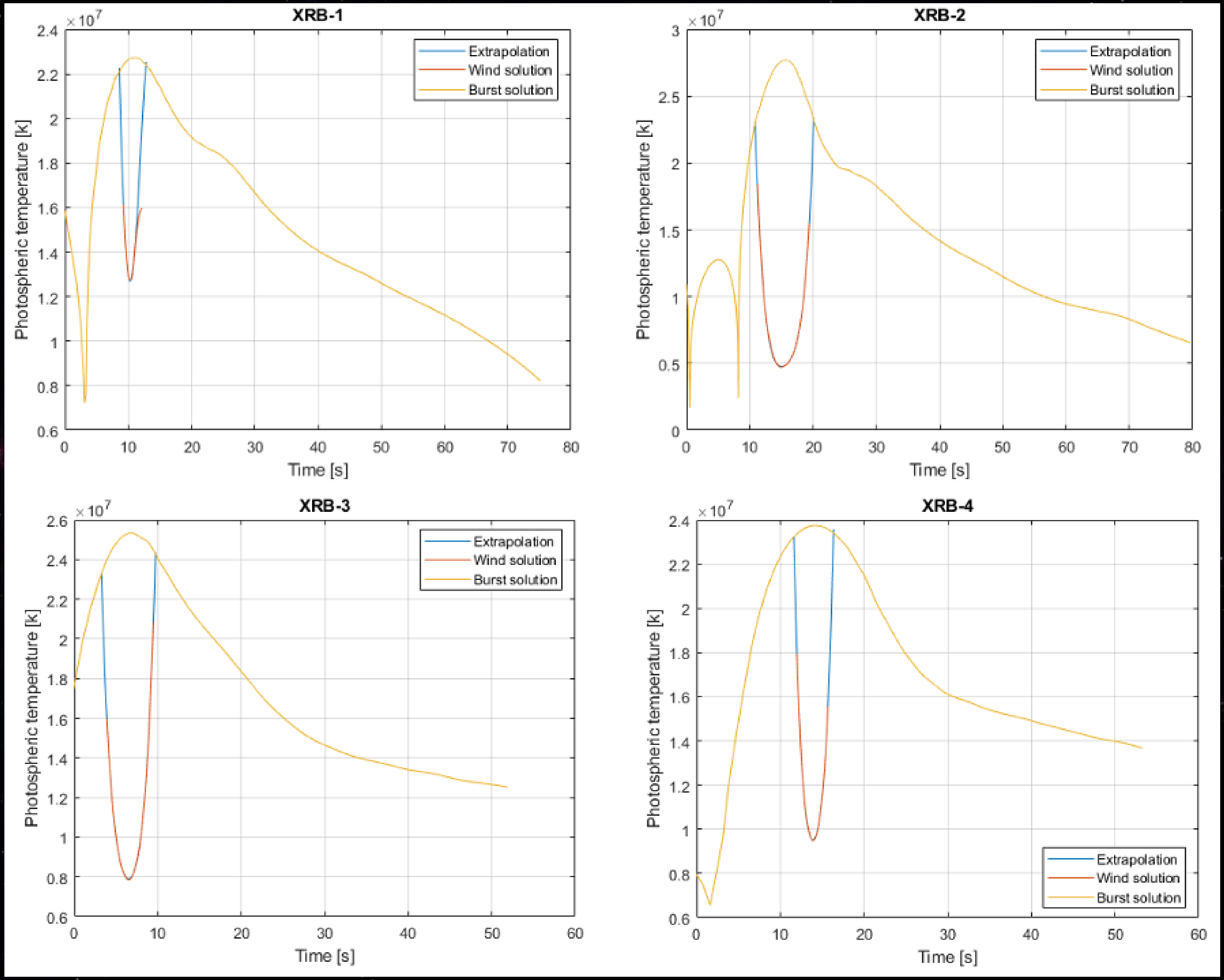
$$\tau^* = 8/3$$
$$y = m \cdot r_{ph} + n \;\Rightarrow\; r_{ph} = (\ln(8/3) - n)/m$$

1994ApJ...437..802K

THE ASTROPHYSICAL JOURNAL, 437:802–826, 1994 December 20

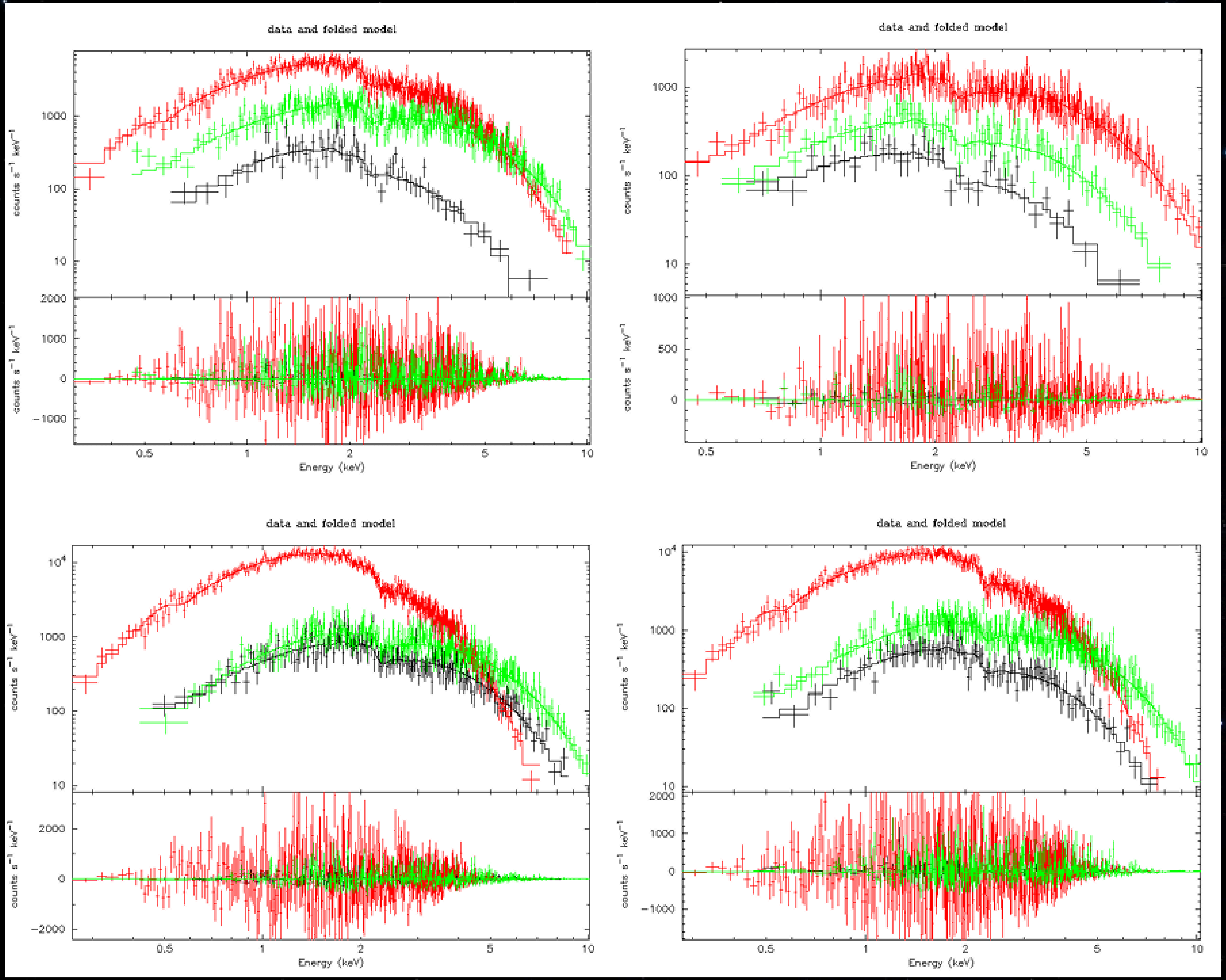
OPTICALLY THICK WINDS IN NOVA OUTBURSTS

MARIKO KATO
Department of Astronomy, Keio University, Hiyoshi, Kouhoku-ku, Yokohama 223, Japan;
mariko@educ.cc.keio.ac.jp
AND
IZUMI HACHISU
Department of Earth Science and Astronomy, College of Arts and Sciences, University of Tokyo, Komaba, Meguro-ku, Tokyo 153, Japan;
hachisu@kyohou.c.u-tokyo.ac.jp
Received 1994 February 7; accepted 1994 June 28



Simulating X-ray spectra

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

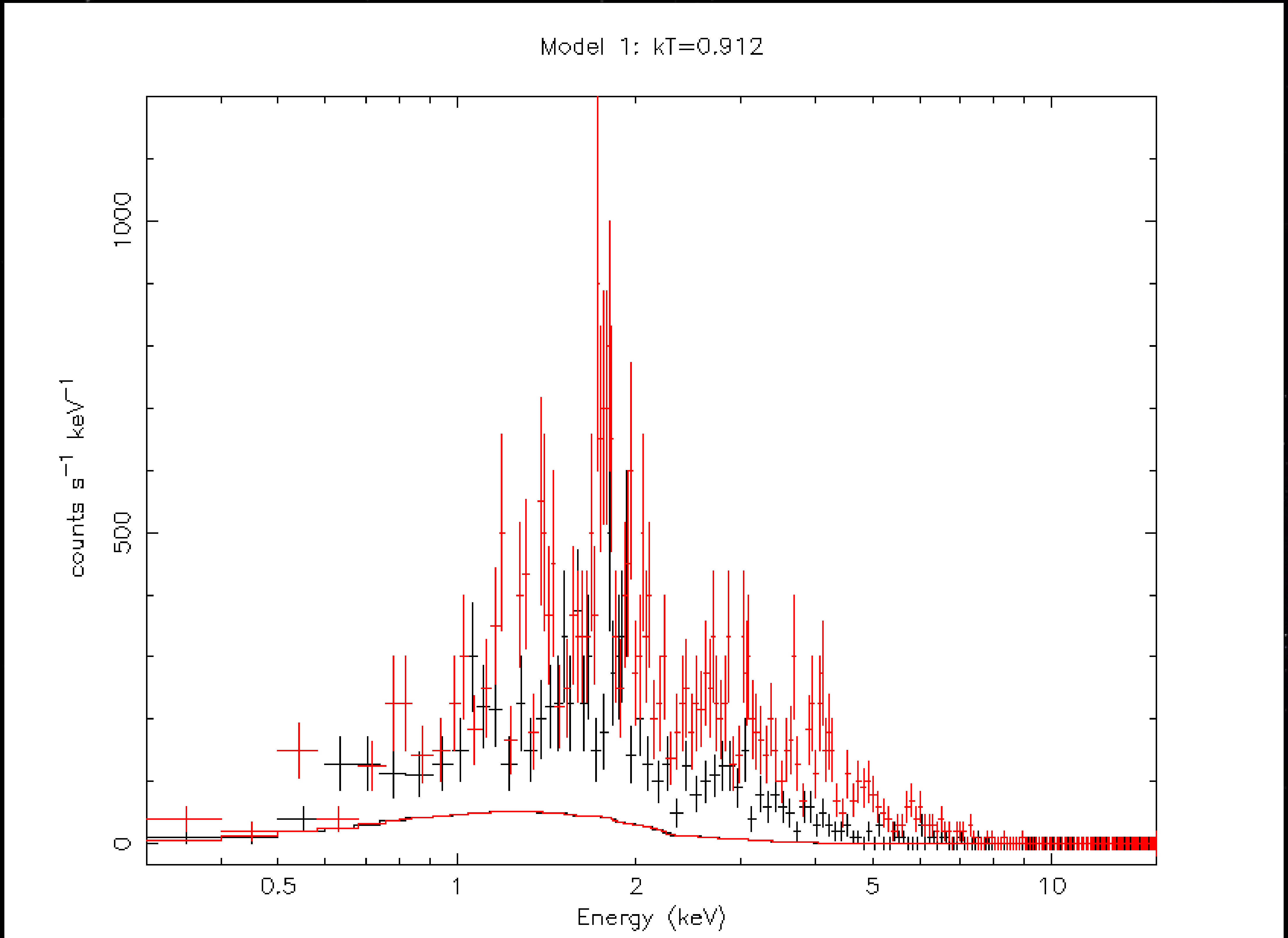


- **Model:** TBabs×bbody
- Norm: Kbb = L_{39}/D_{10}^2
- D ≈ 7 kpc
- Abs = $1.33\text{x}10^{21}$ cm^{-2} (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

Simulating X-ray spectra

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

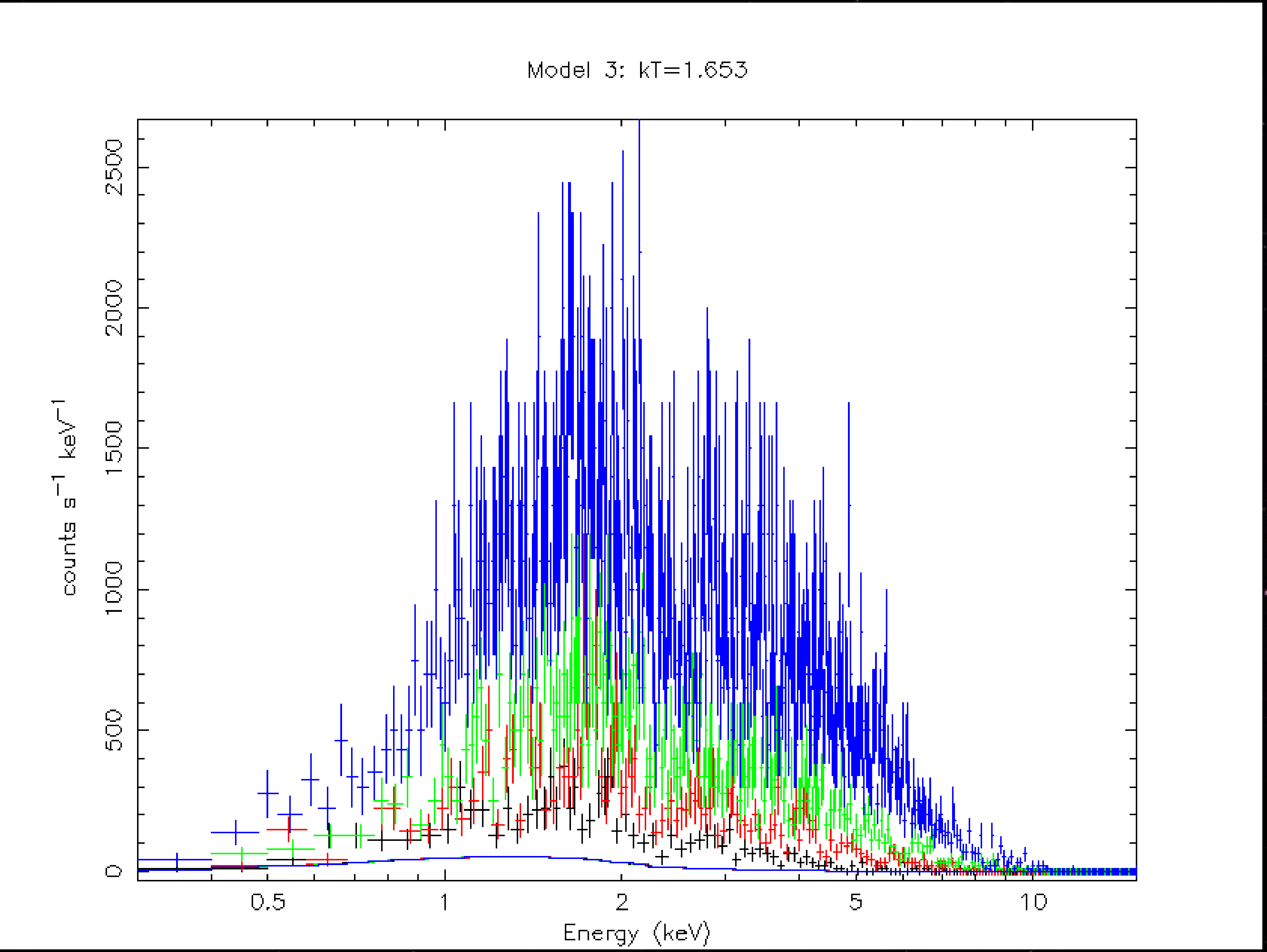


- **Model:** TBabs×bbody
- Norm: Kbb = L_{39}/D_{10}^2
- D ≈ 7 kpc
- Abs = $1.33\text{x}10^{21}\text{cm}^{-2}$ (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

Simulating X-ray spectra

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

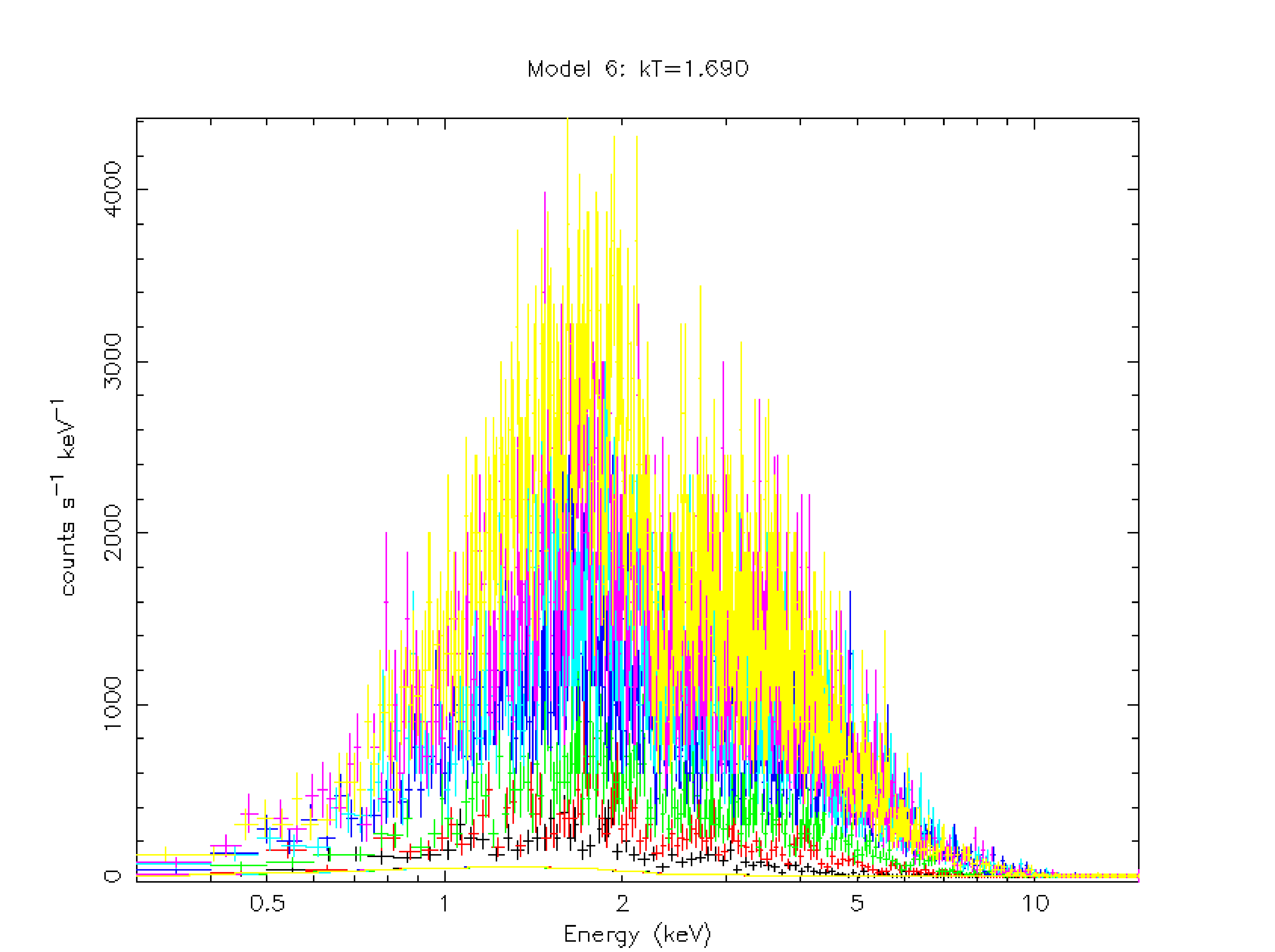


- **Model:** TBabs×bbody
- Norm: Kbb = L_{39}/D_{10}^2
- D ≈ 7 kpc
- Abs = 1.33x10^{21} cm^{-2} (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

Simulating X-ray spectra

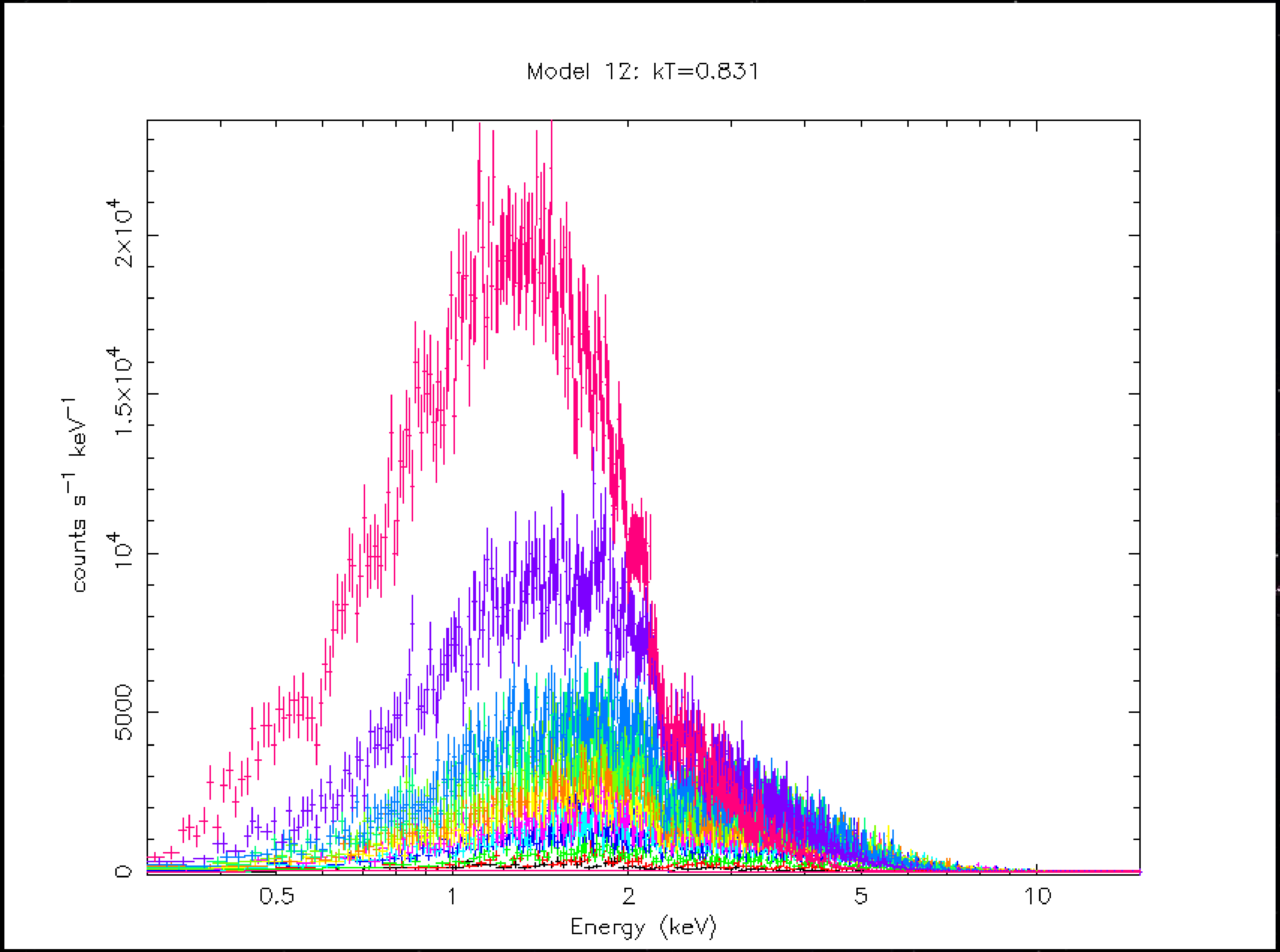
UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH



- **Model:** TBabs×bbody
- Norm: $K_{bb} = L_{39}/D_{10}^2$
- D ≈ 7 kpc
- Abs = 1.33×10^{21} cm^{-2} (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

Simulating X-ray spectra

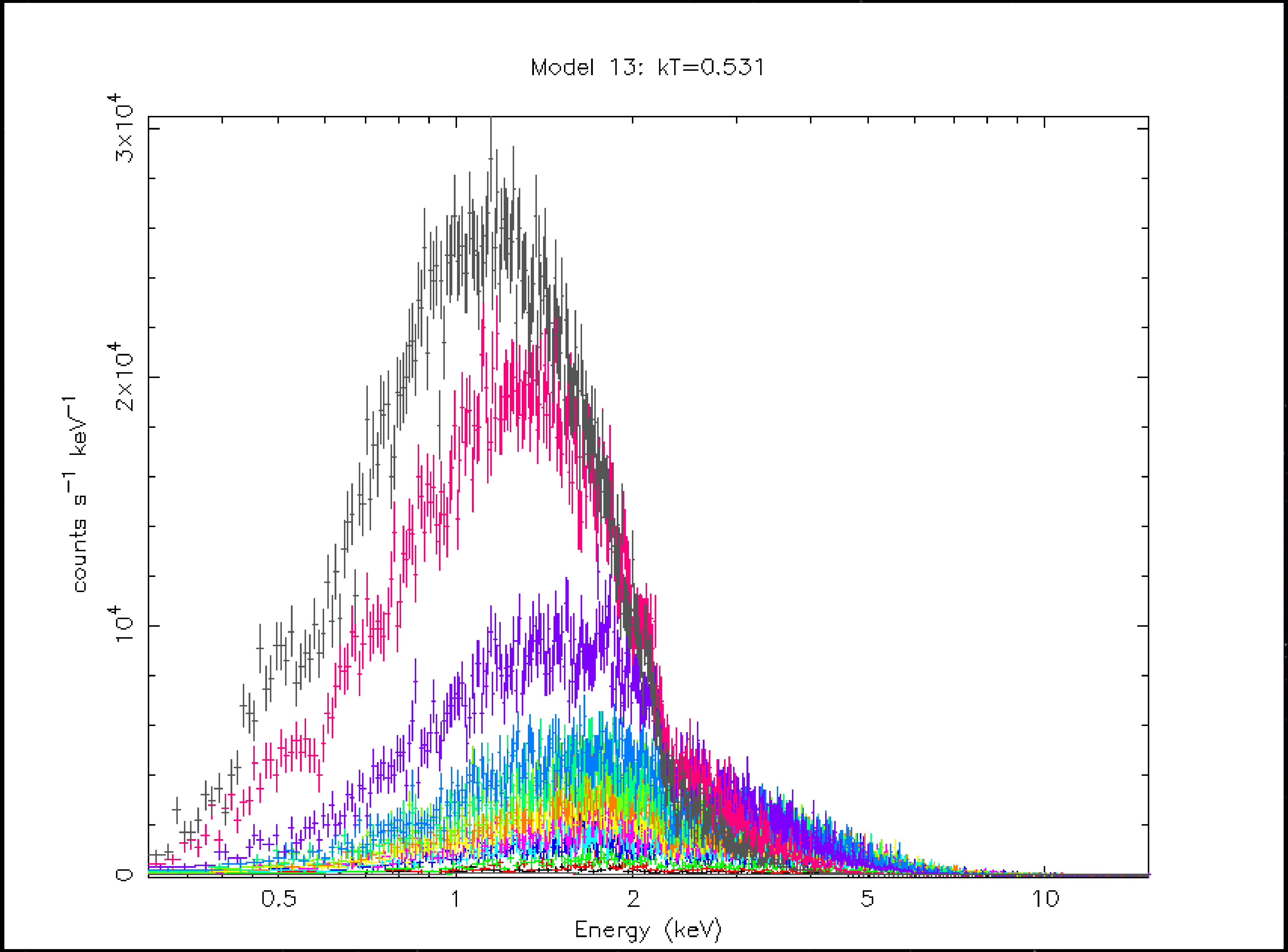


- **Model:** TBabs×bbody
- Norm: $K_{bb} = L_{39}/D_{10}^2$
- D ≈ 7 kpc
- Abs = 1.33×10^{21} cm^{-2} (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

Simulating X-ray spectra

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

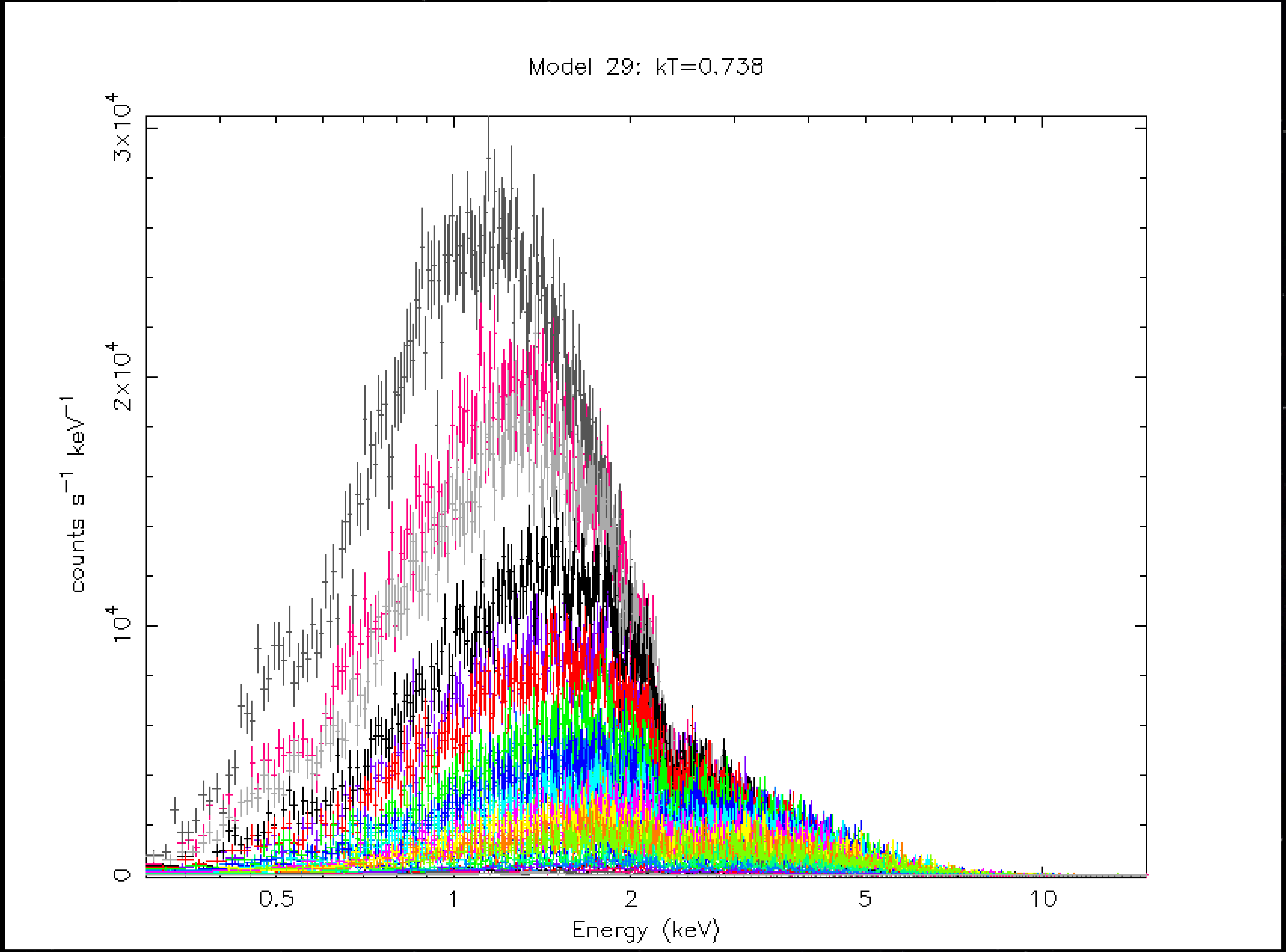


- **Model:** TBabs×bbody
- Norm: $K_{bb} = L_{39}/D_{10}^2$
- D ≈ 7 kpc
- Abs = 1.33×10^{21} cm^{-2} (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

Simulating X-ray spectra

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

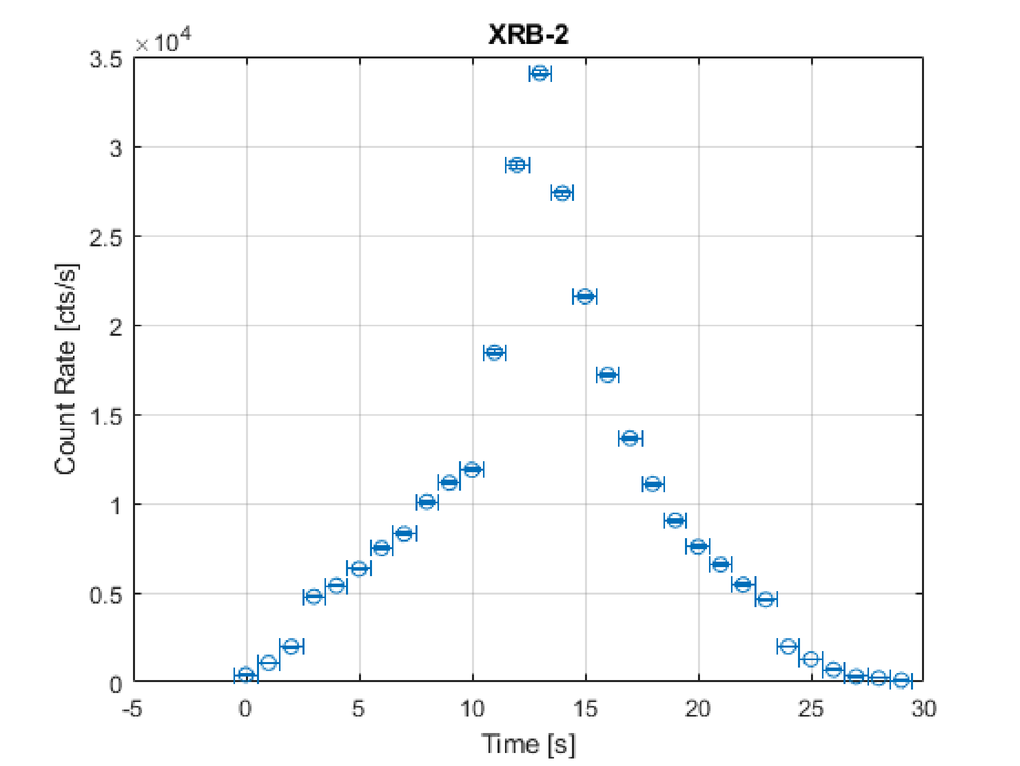


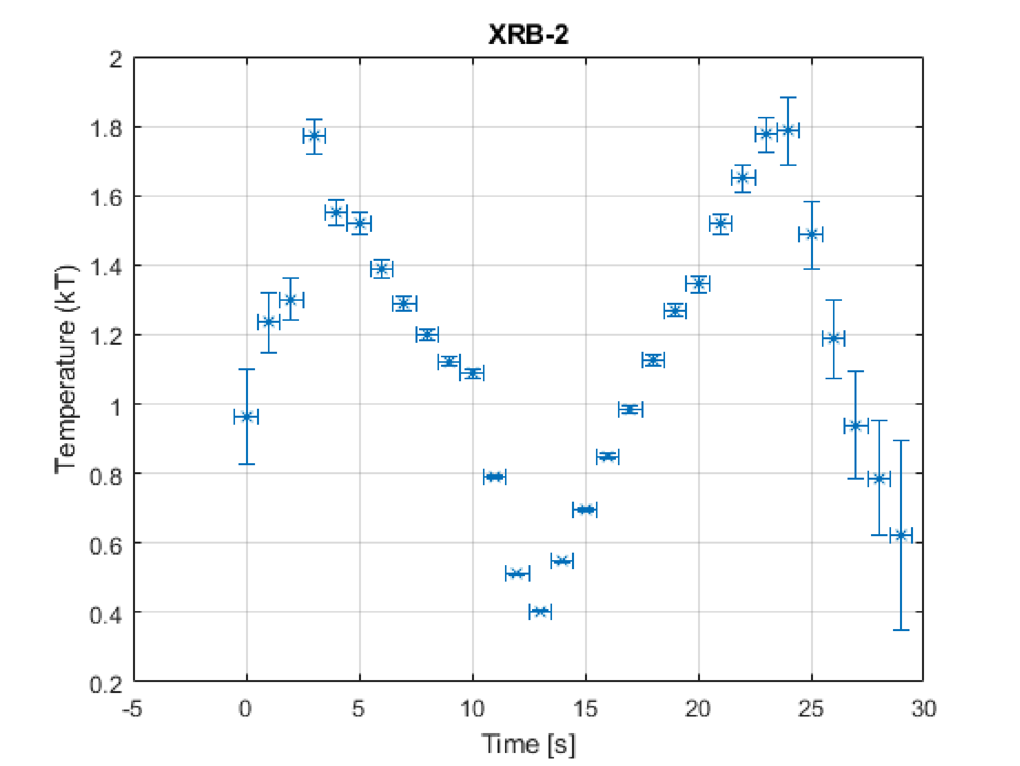
- **Model:** TBabs×bbody
- Norm: Kbb = L_{39}/D_{10}^2
- D ≈ 7 kpc
- Abs = 1.33×10^{21} cm^{-2} (4U 1820–30)
- Rising; Peak; Decaying

Model	kT [keV]	χ^2	Bins	χ^2/N
1	0.88264	71.76	66	1.087
	1.10238	493.98	483	1.023
	1.96279	341.14	359	0.950
2	1.02401	35.28	40	0.882
	2.05262	277.17	342	0.810
	1.45376	94.99	107	0.888
3	1.53698	174.38	200	0.872
	0.66798	400.00	418	0.957
	2.07232	291.86	319	0.915
4	1.17299	102.66	122	0.841
	0.80110	441.45	446	0.989
	1.96647	290.41	335	0.867

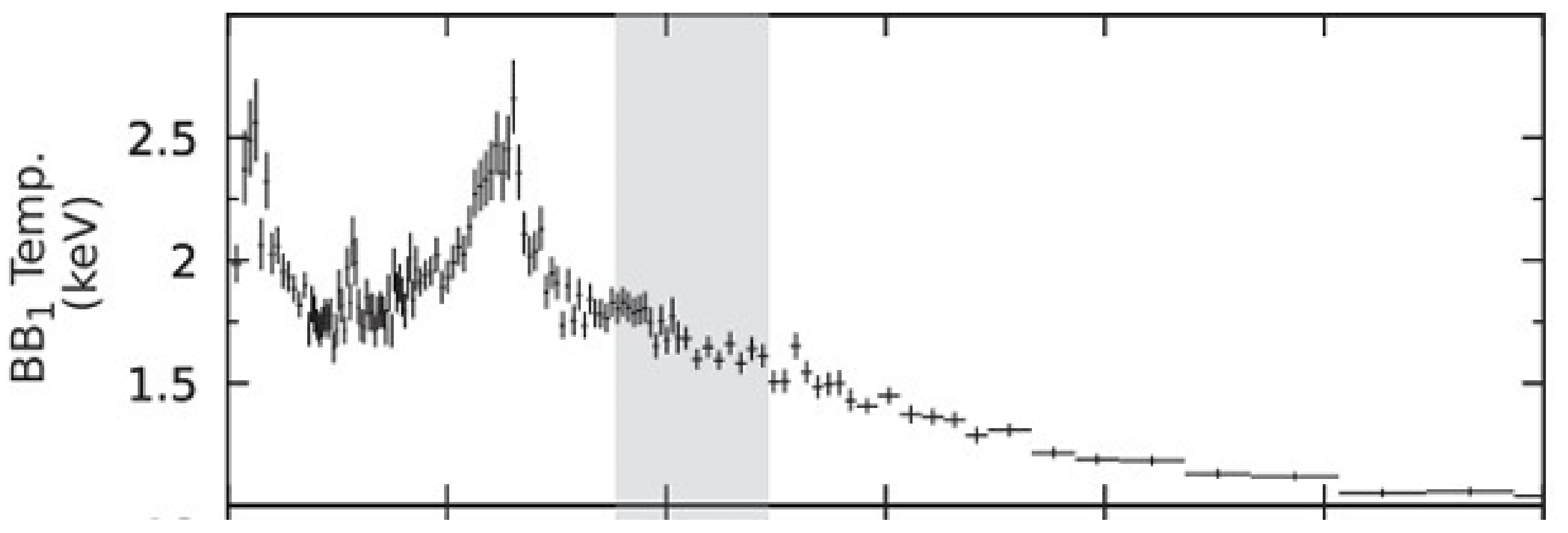
Simulating X-ray spectra

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

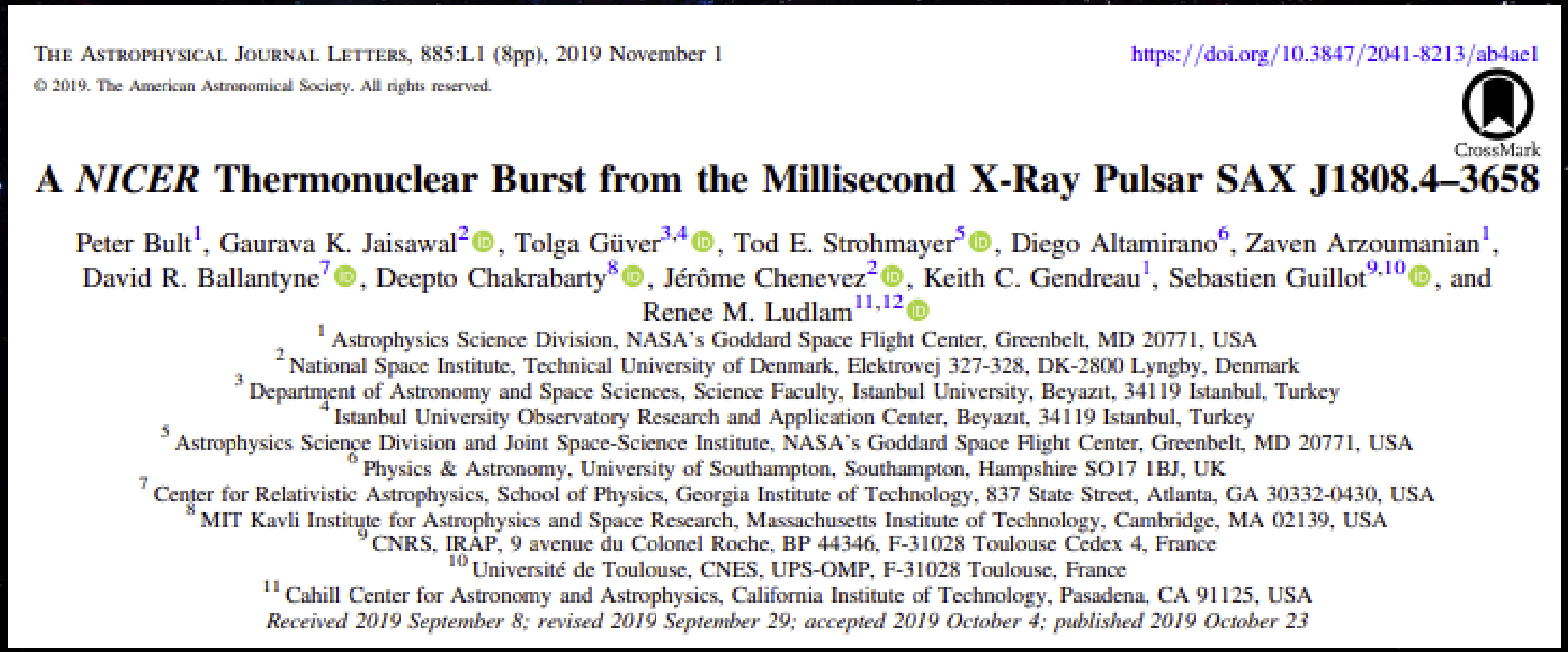




- Temperature decrease by a factor of 2.
- Consistent temperature evolution and decrease factor.



Peter Bult et al. Time-resolved spectroscopy of the X-ray burst using a double blackbody model.


The Astrophysical Journal Letters, 885:L1 (8pp), 2019 November 1
https://doi.org/10.3847/2041-8213/ab4ae1

CrossMark

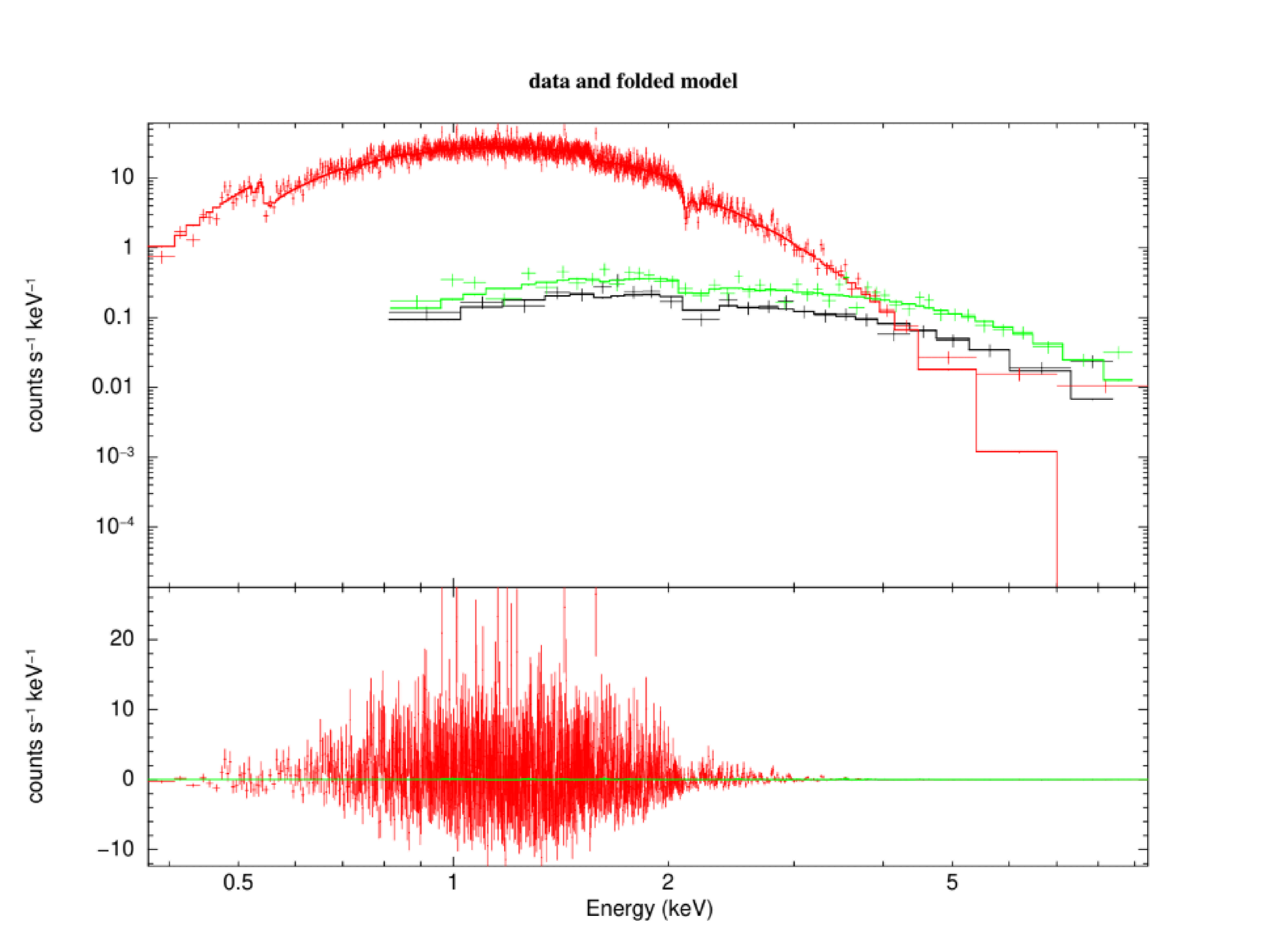
A *NICER* Thermonuclear Burst from the Millisecond X-Ray Pulsar SAX J1808.4–3658

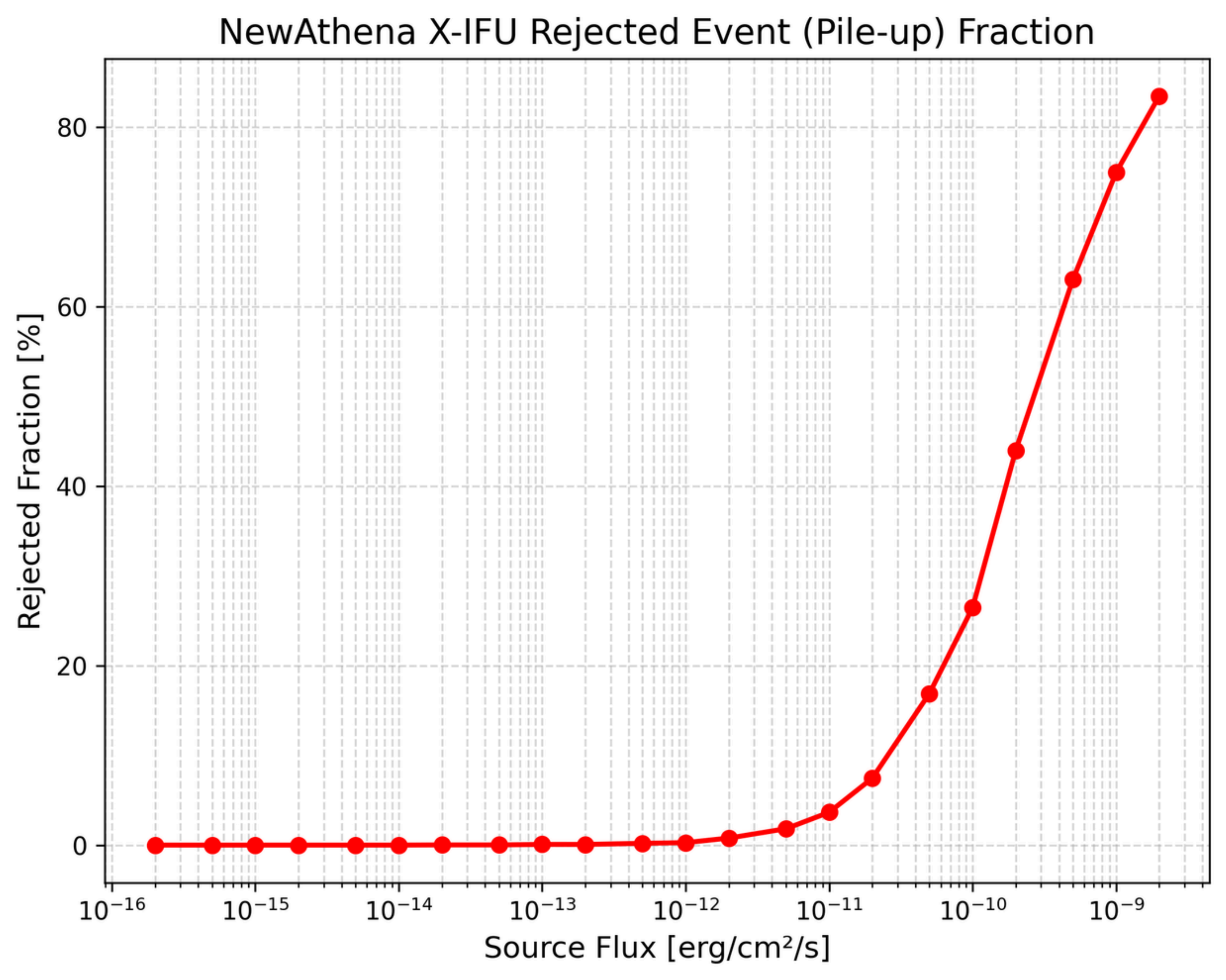
Peter Bult[1], Gaurava K. Jaisawal[2], Tolga Güver[3,4], Tod E. Strohmayer[5], Diego Altamirano[6], Zaven Arzoumanian[1], David R. Ballantyne[7], Deepto Chakrabarty[8], Jérôme Chenevez[2], Keith C. Gendreau[1], Sebastien Guillot[9,10], and Renee M. Ludlam[11,12]
[1] Astrophysics Science Division, NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA
[2] National Space Institute, Technical University of Denmark, Elektrovej 327-328, DK-2800 Lyngby, Denmark
[3] Department of Astronomy and Space Sciences, Science Faculty, Istanbul University, Beyazıt, 34119 Istanbul, Turkey
[4] Istanbul University Observatory Research and Application Center, Beyazıt, 34119 Istanbul, Turkey
[5] Astrophysics Science Division and Joint Space-Science Institute, NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA
[6] Physics & Astronomy, University of Southampton, Southampton, Hampshire SO17 1BJ, UK
[7] Center for Relativistic Astrophysics, School of Physics, Georgia Institute of Technology, 837 State Street, Atlanta, GA 30332-0430, USA
[8] MIT Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[9] CNRS, IRAP, 9 avenue du Colonel Roche, BP 44346, F-31028 Toulouse Cedex 4, France
[10] Université de Toulouse, CNES, UPS-OMP, F-31028 Toulouse, France
[11] Cahill Center for Astronomy and Astrophysics, California Institute of Technology, Pasadena, CA 91125, USA
Received 2019 September 8; revised 2019 September 29; accepted 2019 October 4; published 2019 October 23

SIXTE simulations: Athena X-IFU

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Focused simulation - Optical filter





Distance set: D = 708 kpc

SIXTE simulations: Athena X-IFU

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Focused simulation - Optical filter

Parameter	Phase 1 (rise)	Phase 2 (peak)	Phase 3 (tail)
Physical input			
L (10^{38} erg/s)	0.62	3.60	2.00
F (10^{-12} erg/cm^2/s)	1.03	6.00	3.29
Temperature: kT (keV)			
Input	1.29	0.41	1.72
Output (fit)	1.58 ± 0.09	$0.404 \pm 3 \times 10^{-3}$	1.95 ± 0.09
% Difference	**+23%**	**-2%**	**+13%**
Normalization (10^{-5})			
Input	1.2	7.2	3.9
Output (fit)	2.2 ± 0.2	25.1 ± 0.2	6.2 ± 0.6
% Difference	**+83%**	**+249%**	**+59%**
Goodness of fit			
Total χ^2/d.o.f. = 1298.6/1195	χ^2_ν = **1.09**	(Prob = 0.019)	

Fitting models to the simulated spectra:

- Model: TBabs×bbody

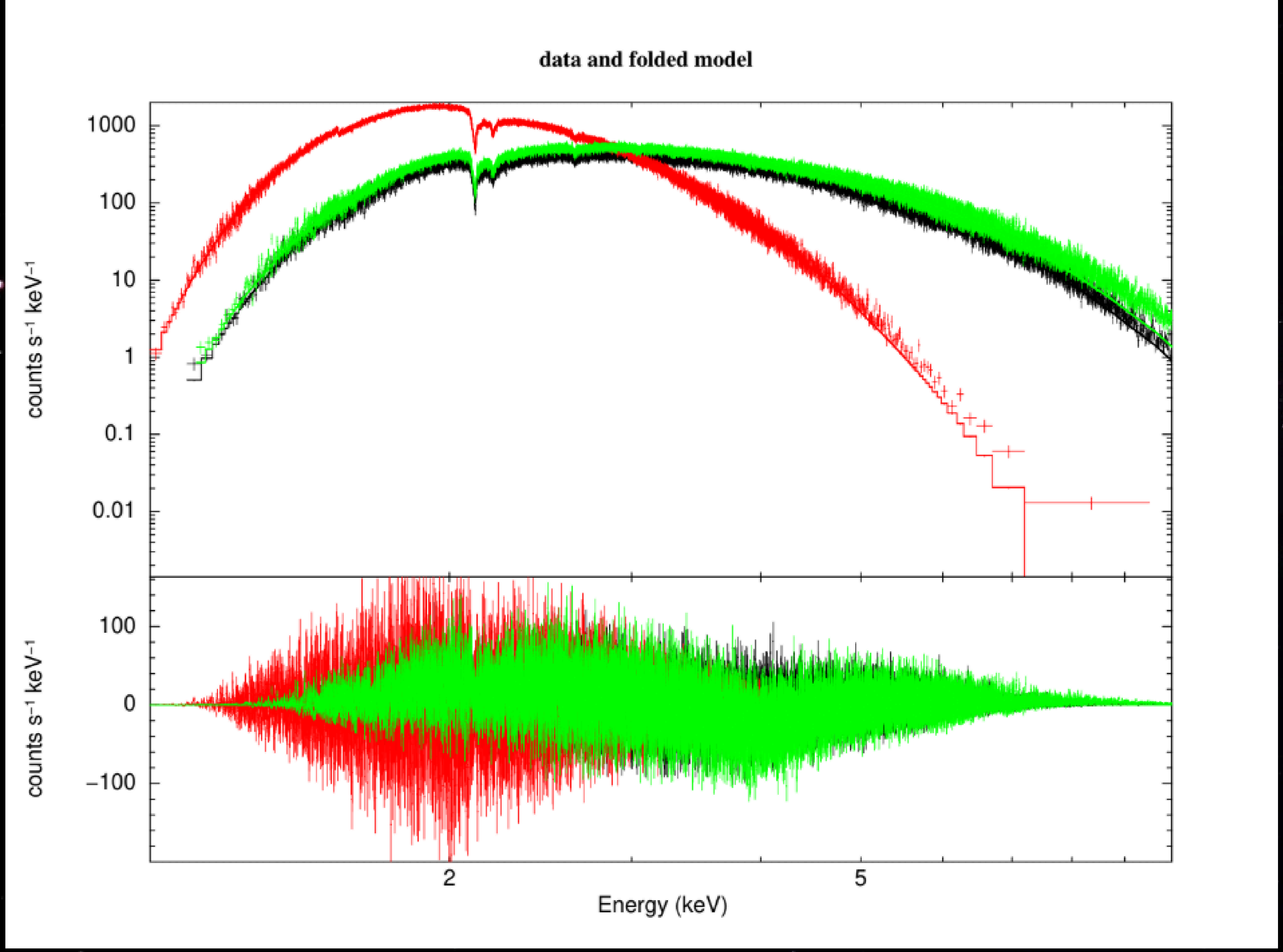
Difficulty of galactic observations.

Can perform extragalactic observations (Andromeda).

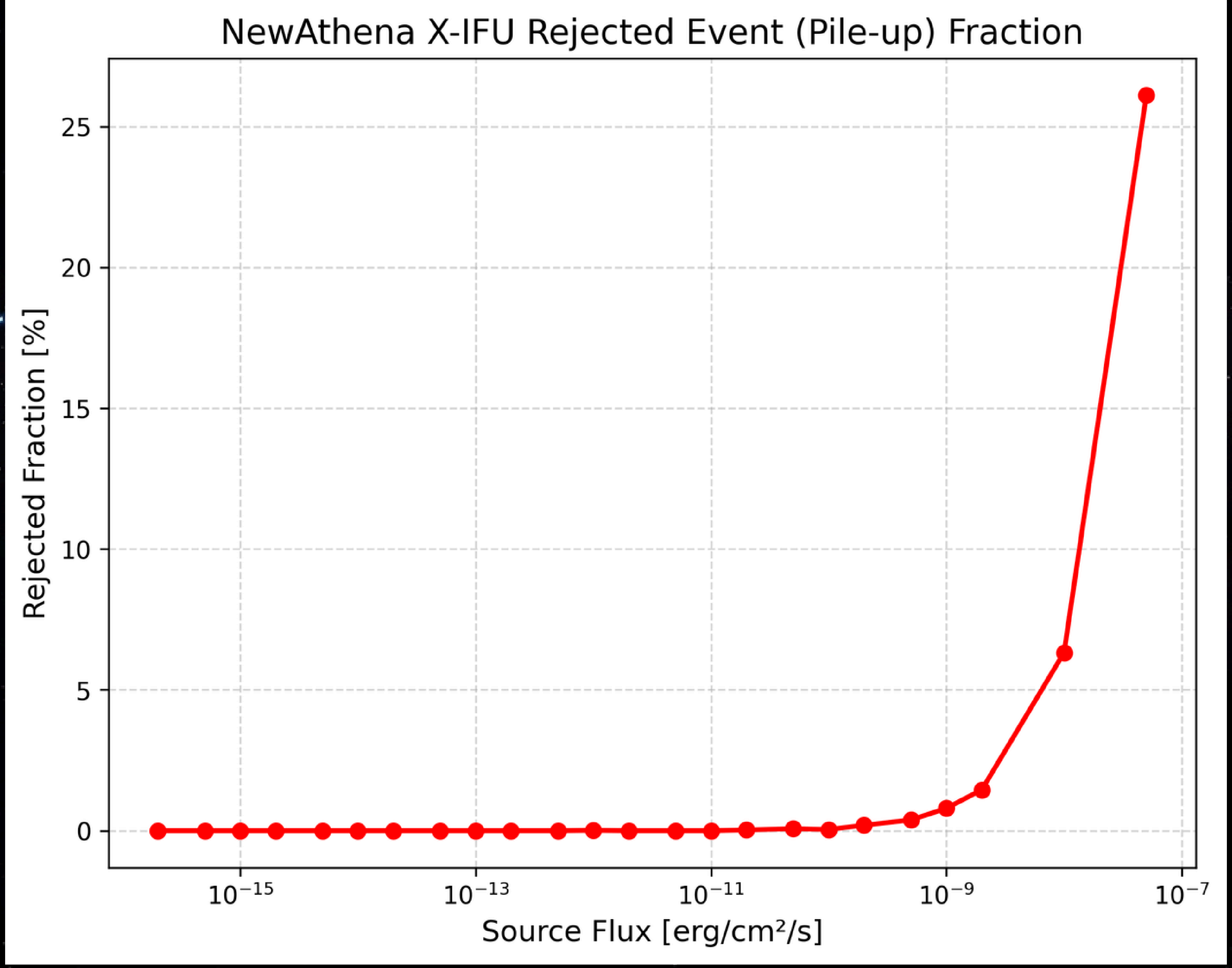
SIXTE simulations: Athena X-IFU

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Defocused simulation



Distance set: D = 7.46 kpc



SIXTE simulations: Athena X-IFU

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

Defocused simulation

Parameter	Phase 1 (Rise)	Phase 2 (Peak)	Phase 3 (Tail)
Physical input			
L (10^{38} erg/s)	0.62	3.60	2.00
F (10^{-8} erg/cm^2/s)	0.93	5.40	2.96
Temperature: kT (keV)			
Input	1.29	0.41	1.72
Output (fit)	$1.143 \pm 1 \times 10^{-3}$	$0.3675 \pm 3 \times 10^{-4}$	$1.183 \pm 1 \times 10^{-3}$
% Difference	**-12%**	**-10%**	**-31%**
Normalization (10^{-2})			
Input	11.1	64.7	35.4
Output (fit)	6.14 ± 0.01	18.24 ± 0.08	8.00 ± 0.01
% Difference	**-45%**	**-72%**	**-77%**
Goodness of fit			
Total χ^2/d.o.f. $= 32533.1/25844$	$\chi^2_\nu = \mathbf{1.26}$	(Prob $= 2.3 \times 10^{-163}$)	

- Fitting models to the simulated spectra: TBabs×bbody
- Extraction: Filtered for surviving High-Resolution (GRADING==1) photons.
- Standard XSPEC pipeline uses a "canned" ARF (Ancillary Response File).

SIXTE simulations: Athena X-IFU

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

Defocused simulation

Parameter	Phase 1 (Rise)	Phase 2 (Peak)	Phase 3 (Tail)
Physical input			
L (10^{38} erg/s)	0.62	3.60	2.00
F (10^{-8} erg/cm^2/s)	0.93	5.40	2.96
Temperature: kT (keV)			
Input	1.29	0.41	1.72
Output (fit)	$1.143 \pm 1 \times 10^{-3}$	$0.3675 \pm 3 \times 10^{-4}$	$1.183 \pm 1 \times 10^{-3}$
% Difference	**-12%**	**-10%**	**-31%**
Normalization (10^{-2})			
Input	11.1	64.7	35.4
Output (fit)	6.14 ± 0.01	18.24 ± 0.08	8.00 ± 0.01
% Difference	**-45%**	**-72%**	**-77%**
Goodness of fit			
Total χ^2/d.o.f. $= 32533.1/25844$ $\quad \chi^2_\nu = \mathbf{1.26}$ $\quad$ (Prob $= 2.3 \times 10^{-163}$)			

- Fitting models to the simulated spectra: TBabs×bbody
- Extraction: Filtered for surviving High-Resolution (GRADING==1) photons.
- Standard XSPEC pipeline uses a "canned" ARF (Ancillary Response File).

The defocused observations of bright sources with *Athena*/X-IFU

E. S. Kammoun[1,2], D. Barret[1], P. Peille[3], R. Willingale[4], T. Dauser[5], J. Wilms[5], M. Guainazzi[6], and J. M. Miller[7]

[1] IRAP, Université de Toulouse, CNRS, UPS, CNES, 9 Avenue du Colonel Roche, BP 44346, 31028 Toulouse Cedex 4, France, e-mail: ekammoun@irap.omp.eu
[2] INAF – Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, 50125 Firenze, Italy
[3] Centre National d'Études Spatiales (CNES), 18 Avenue Edouard Belin, 31400 Toulouse Cedex 4, France
[4] Department of Physics and Astronomy, University of Leicester, Leicester, UK
[5] Dr. Karl Remeis-Observatory and Erlangen Centre for Astroparticle Physics, Sternwartstr. 7, 96049 Bamberg, Germany
[6] ESA European Space Research and Technology Centre (ESTEC), Keplerlaan 1, 2201 AZ, Noordwijk, The Netherlands
[7] Department of Astronomy, University of Michigan, 1085 South University Avenue, Ann Arbor, MI 48109, USA

Received 22 March 2022 / Accepted 29 April 2022

Conclusions

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

- XRB and stellar wind models bridged and validated against real NICER observations.
- Extension stellar wind model (avoid extrapolation).
- Athena's defocused mirrors successfully protect the microcalorimeters from 2.25 Crab bursts.
- Standard canned calibration completely fails, creating unphysical temperature inversions and massive residuals. Need of development of dynamic, pixel-by-pixel ARF reconstruction software.