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Exploring the Long-term Average Spectra of the Persistent BHCs GRS 1758-258 & 1E 1740.7-2942

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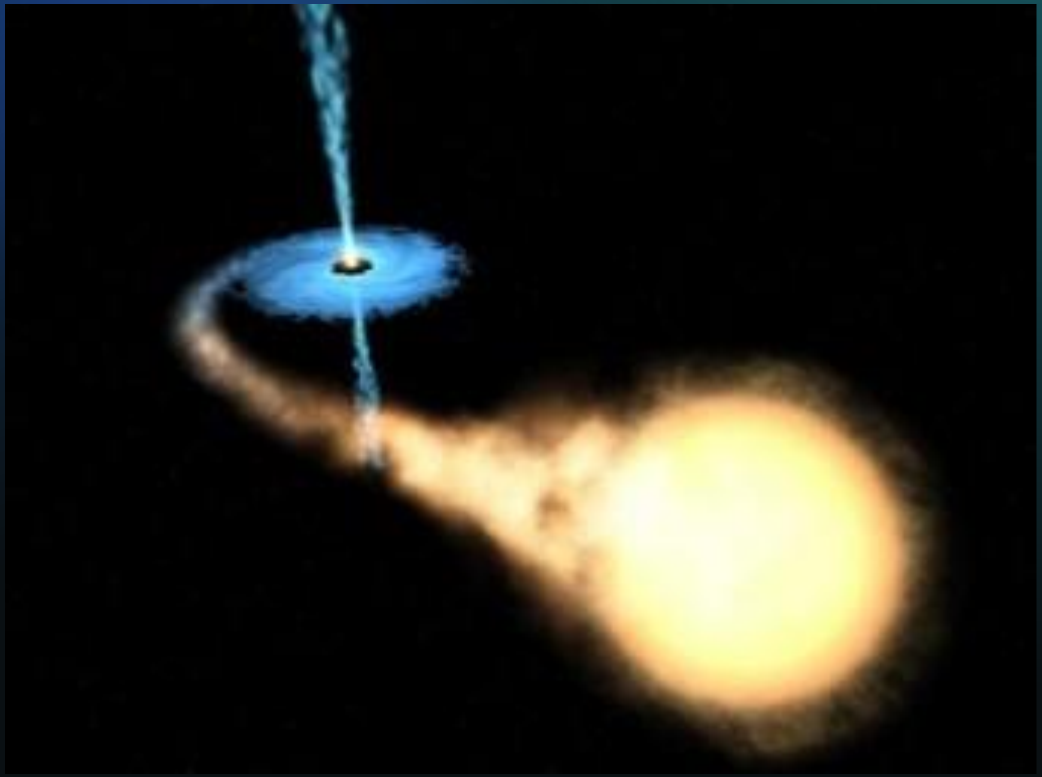
Outline

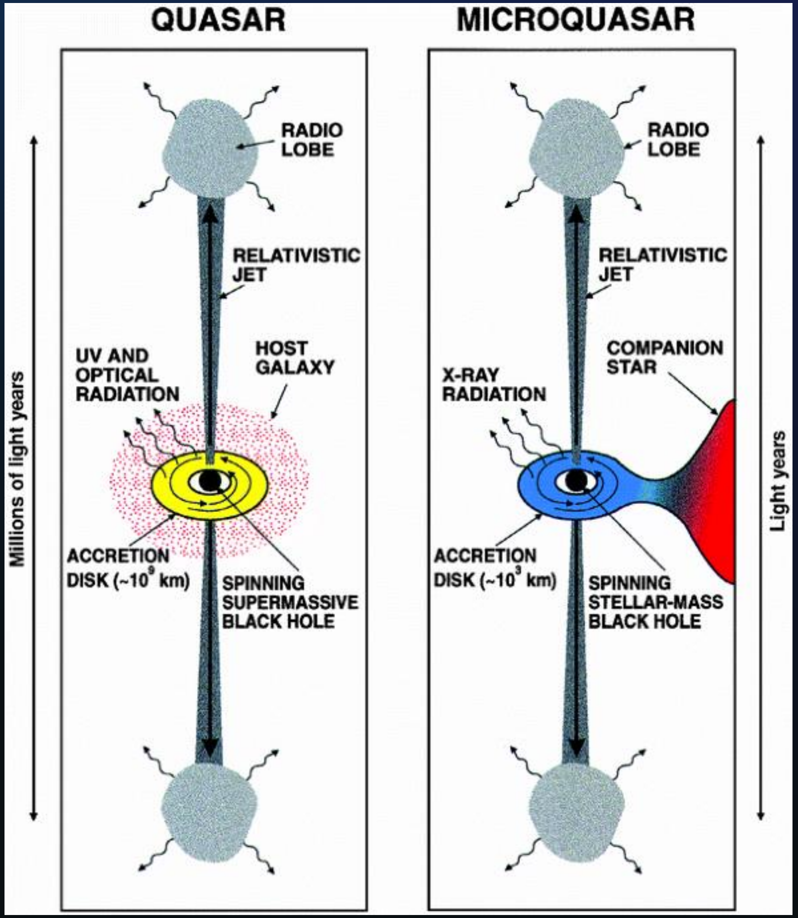
- Micro-quasars
- GRS 1758 & 1E 1740
  - LC's
  - Spectra
    - High-Energy Results
- Conclusions



https://www.media.inaf.it/2016/03/01/v404-cygni/

Micro-quasars

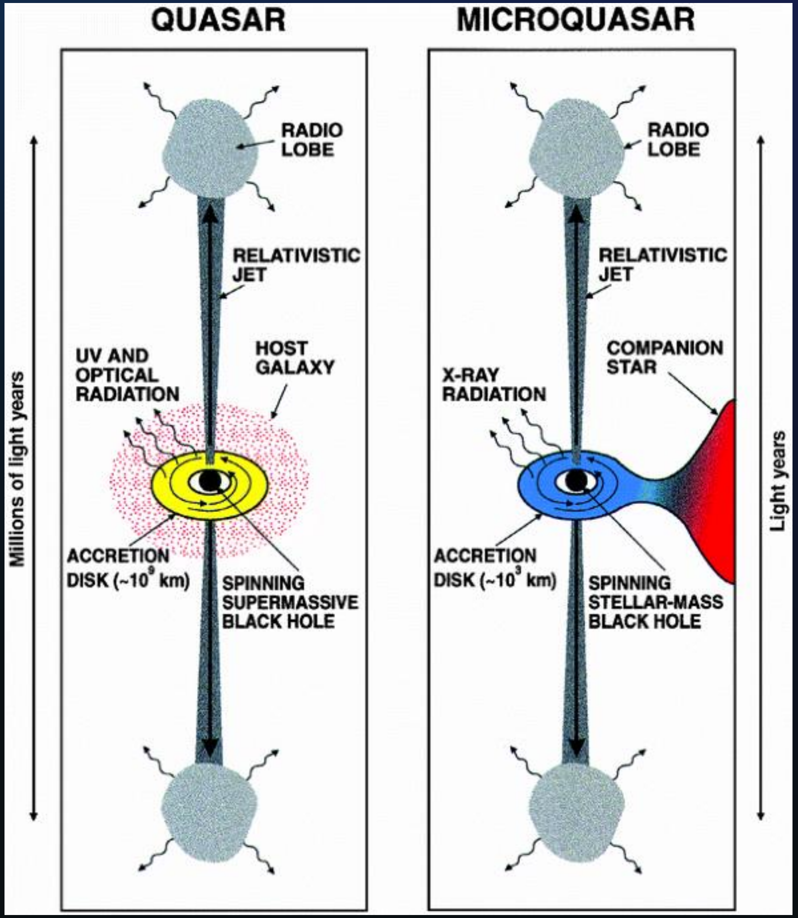
- What is a micro-quasar?
  - Accreting stellar-mass BH with radio jets reminiscent of radio-loud AGNs
  - Evolves on shorter timescale so possible to study accretion on BHs and jets
  - Most MQs are transient, but some persistent
  - First ones discovered: 1E 1740 & GRS 1758 in 1990s



https://www.nature.com/articles/33603

Micro-quasars

- What is a micro-quasar?
  - In hard state, hard X-ray spectra modeled by thermal Comptonization
  - >~200 keV spectra often show excess; “hard tail”
  - Origin of tail debated
    - Hybrid thermal/non-thermal Comptonization in corona
    - Synchrotron emission from jet
    - Others…



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GRS 1758 & 1E 1740

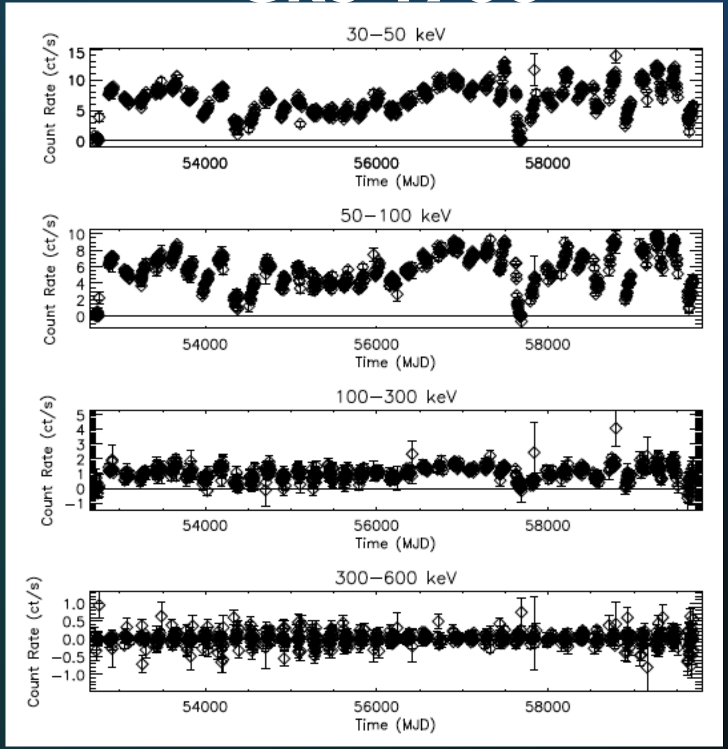
- **GRS 1758**:
- Discovered by GRANAT/SIGMA
- LMXB with BH
- Galactic Center; distance ~ 8 kpc
- Persistent
- Typically in hard state
- Early INTEGRAL papers
  - Pottschmidt et al. (2006)

- **1E 1740**:
- Discovered by Einstein Observatory
- LMXB with BH
- Galactic Center; distance ~ 8 kpc
- Persistent
- Typically in hard state
- Early INTEGRAL papers
  - Del Santo et al. (2005); Bouchet et al. (2009); Natalucci et al. (2014)

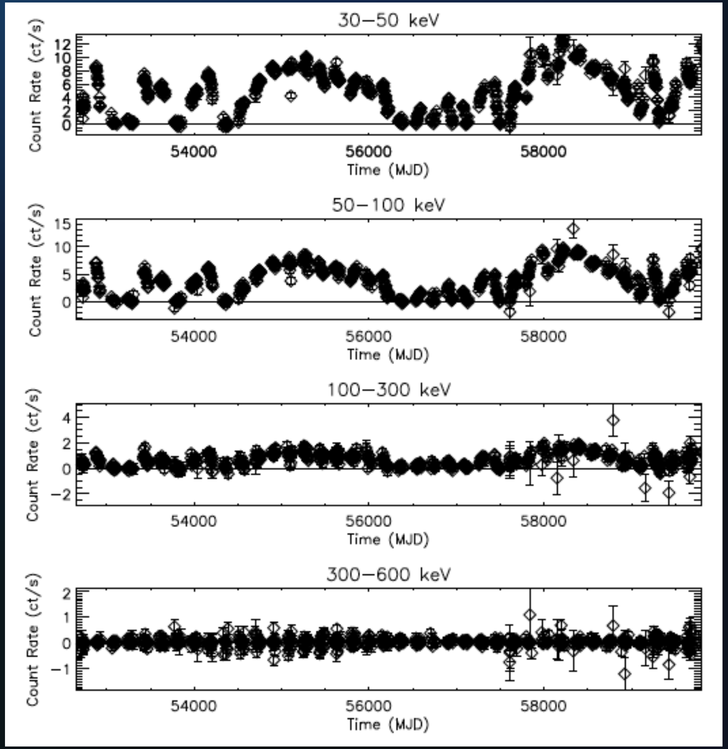
ISGRI Light Curves

- **GRS 1758**
- ~22.3 Ms
- Det sig up to 300 keV
- Marginal 300-600 keV: 4.8σ

GRS 1758



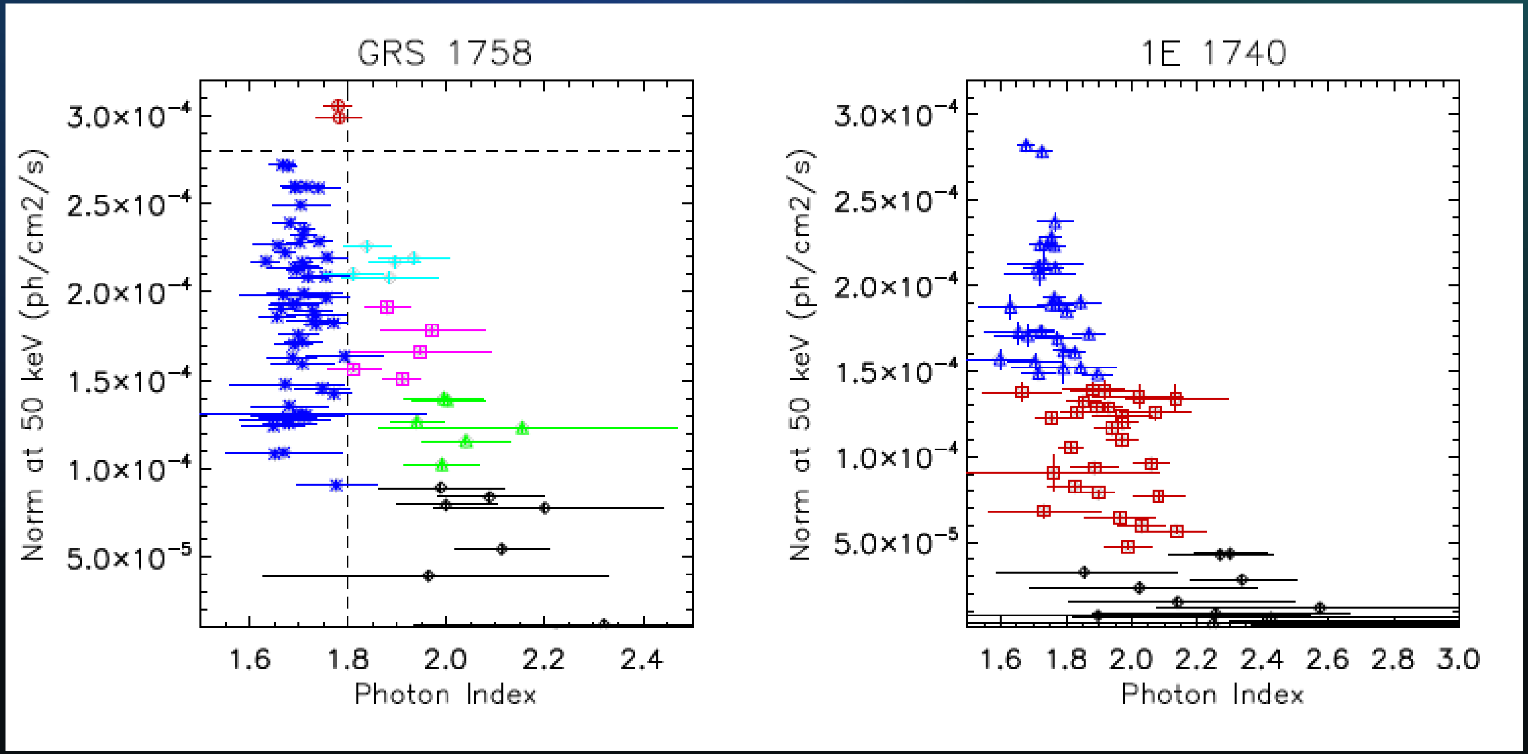
1E 1740



- **1E 1740**
- ~23.8 Ms
- Det sig up to 300 keV
- Not sig in 300-600 keV: 2σ, but in quiescent for >4Ms

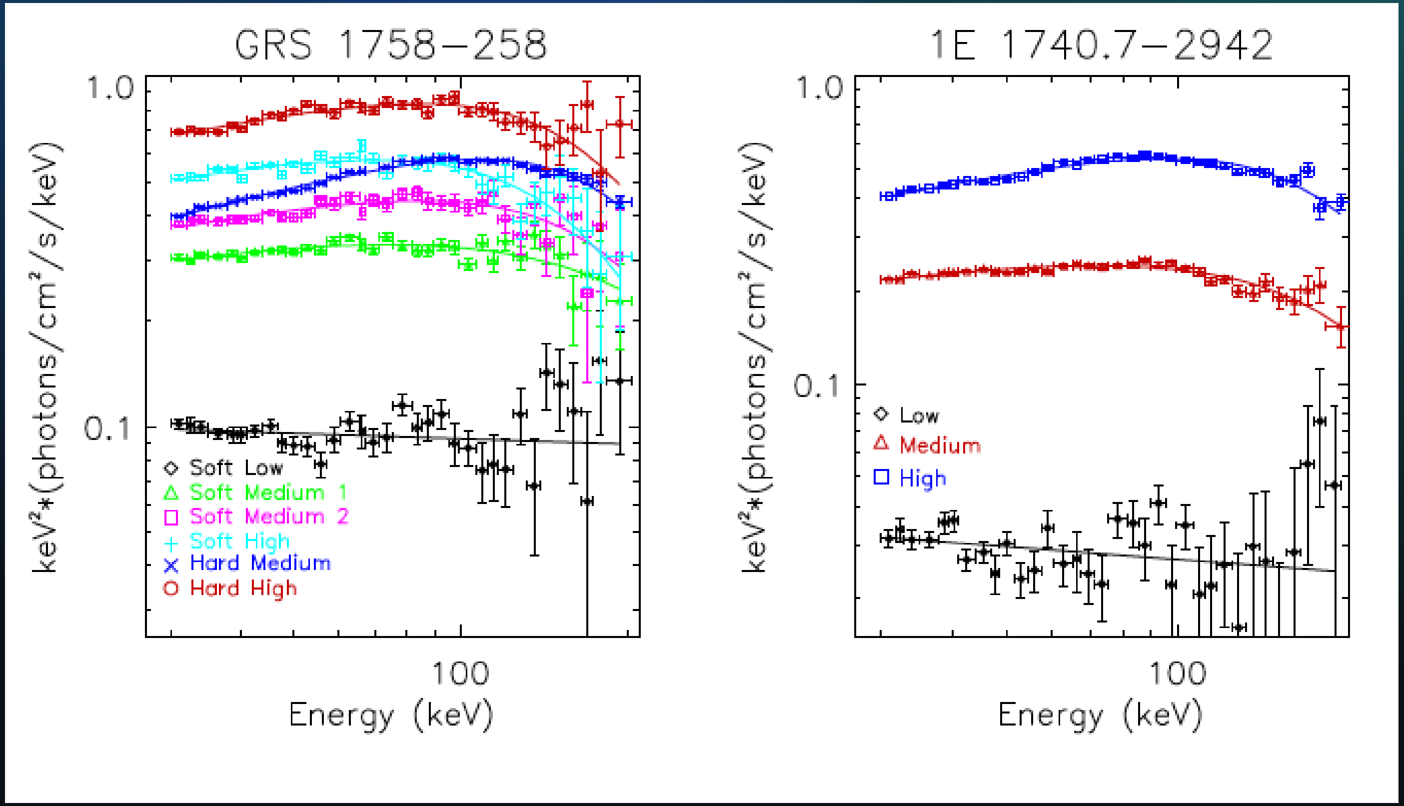
Spectral Groups

- Grouped revs close in time & rate
- Fit 30 – 90 keV spec to po-law
- Plot **Γ**/50 keV norm
- GRS 1758:
  - Flux independent **Γ** state
  - Flux dependent **Γ** states
- 1E 1740:
  - Flux dependent **Γ** states



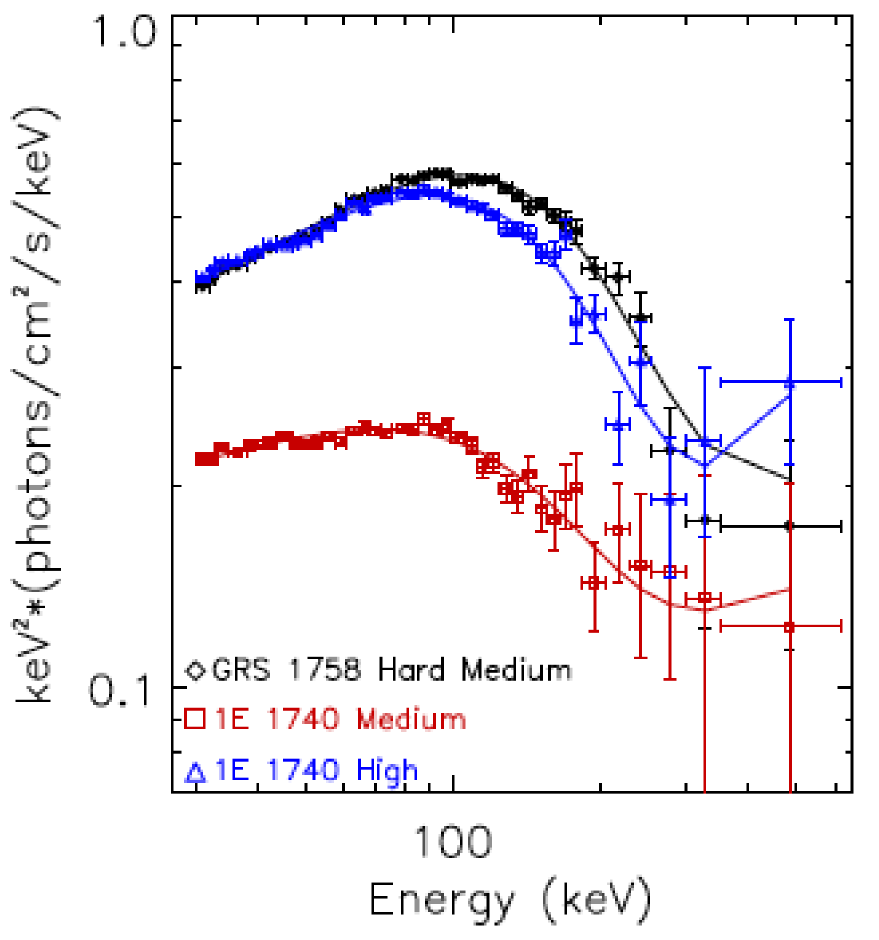
Average Spectra

- Avg group spectra and fit 30– 210 keV
- GRS 1758:
  - Low flux (black): **Γ** ~2.1
  - Higher fluxes: CompTT - kT_e~35 – 60 keV, **τ**~0.8 – 1.6
- 1E 1740:
  - Low flux (black): **Γ** ~2.1
  - Higher fluxes: CompTT - kT_e~40–47 keV, **τ**~1.1 – 1.5



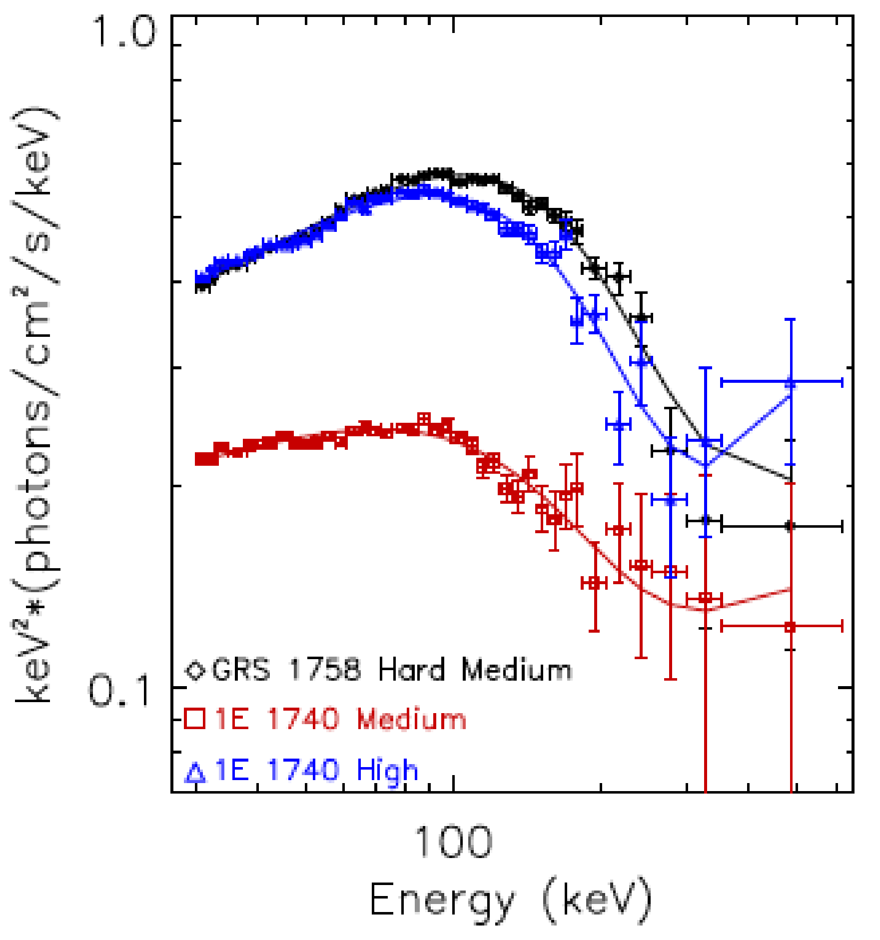
High-Energy Spectra

- Extended E-range for states with >8Ms to 30- 610 keV
- CompTT fits have excess > 200 keV
- CompTT+po-law improves fit
- GRS 1758:
  - Γ = 1.9 +/- 0.2; F-test sig: ~ 4σ
- 1E 1740:
  - Γ = 1.6 +/- 1.3; F-test sig: ~ 2.8σ for **med**
  - Γ = 1.5 +/- 0.9; Required for good fit for **high**



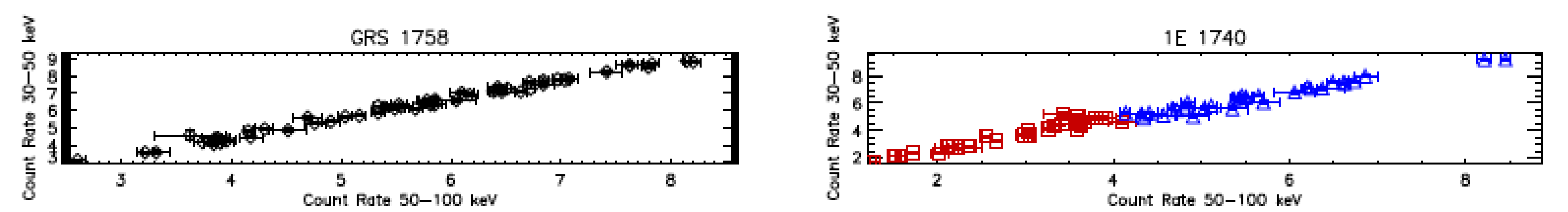
High-Energy Spectra

- Fit hybrid thermal/non-thermal model, Eqpair
- All fits had sig. power to non-thermal particles
  - $l_{nt}/l_h > 0.50$
- Suggesting hard tail present in each spectrum
- Well fit with both Eqpair and po-law (jet) models
- How to differentiate between scenarios?
  - Hybrid corona → photons from same region
  - Jet → hard X-ray/soft γ-ray photons from diff regions
  - Count-rate correlations vs energy



Count-rate Correlations

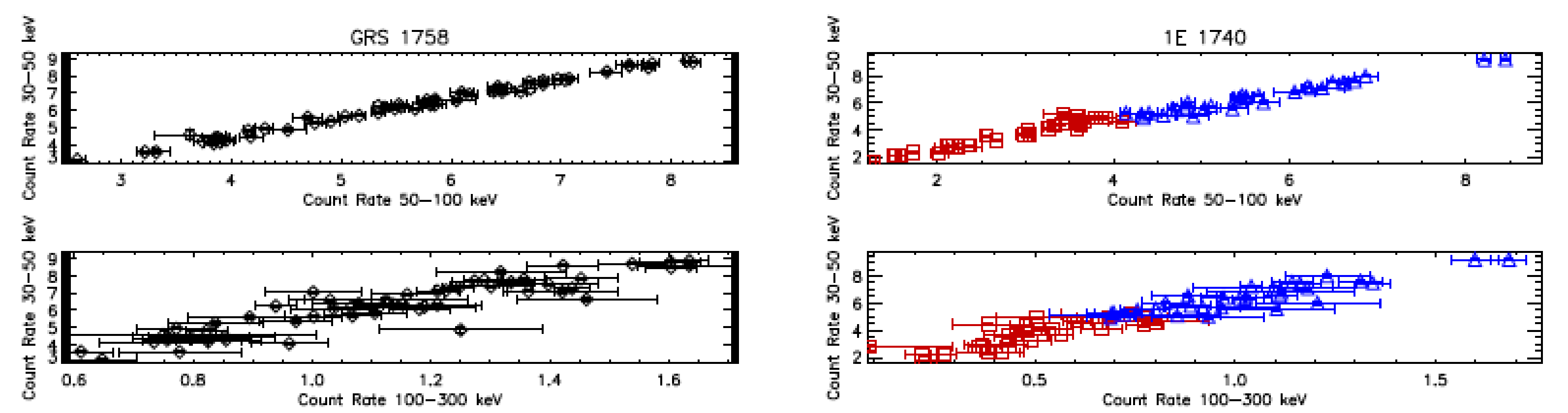
- Spearman correlation 30 – 50 keV to higher-E bins
    - 50 – 100 keV:
        - GRS: 0.99 (7.3σ)
        - 1E: 0.93 (4.3σ); 0.95 (5.2σ)



50 – 100 keV

Count-rate Correlations

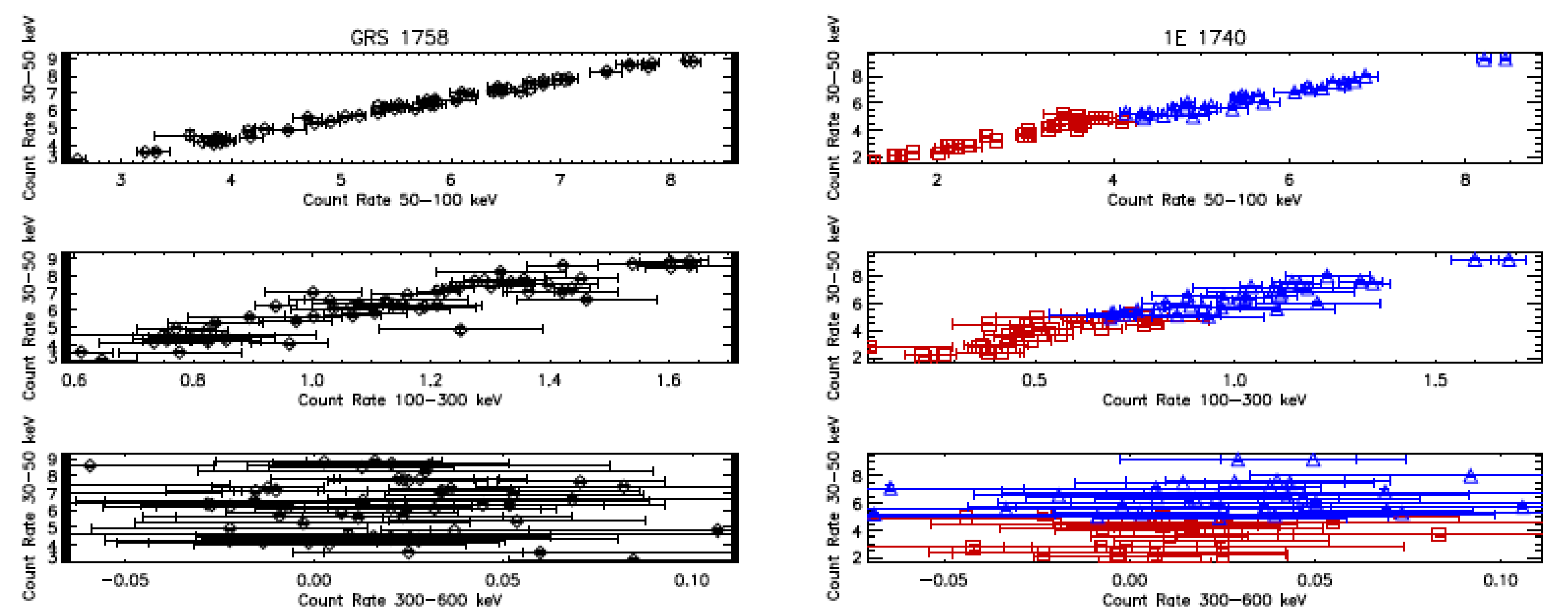
- Spearman correlation 30 – 50 keV to higher-E bins
  - 50 – 100 keV:
    - GRS: 0.99 (7.3σ)
    - 1E: 0.93 (4.7σ); 0.95 (5.2σ)
  - 100 – 300 keV:
    - GRS: 0.91 (6.7σ)
    - 1E: 0.85 (4.3σ); 0.85 (4.7σ)



100 - 300 keV

Count-rate Correlations

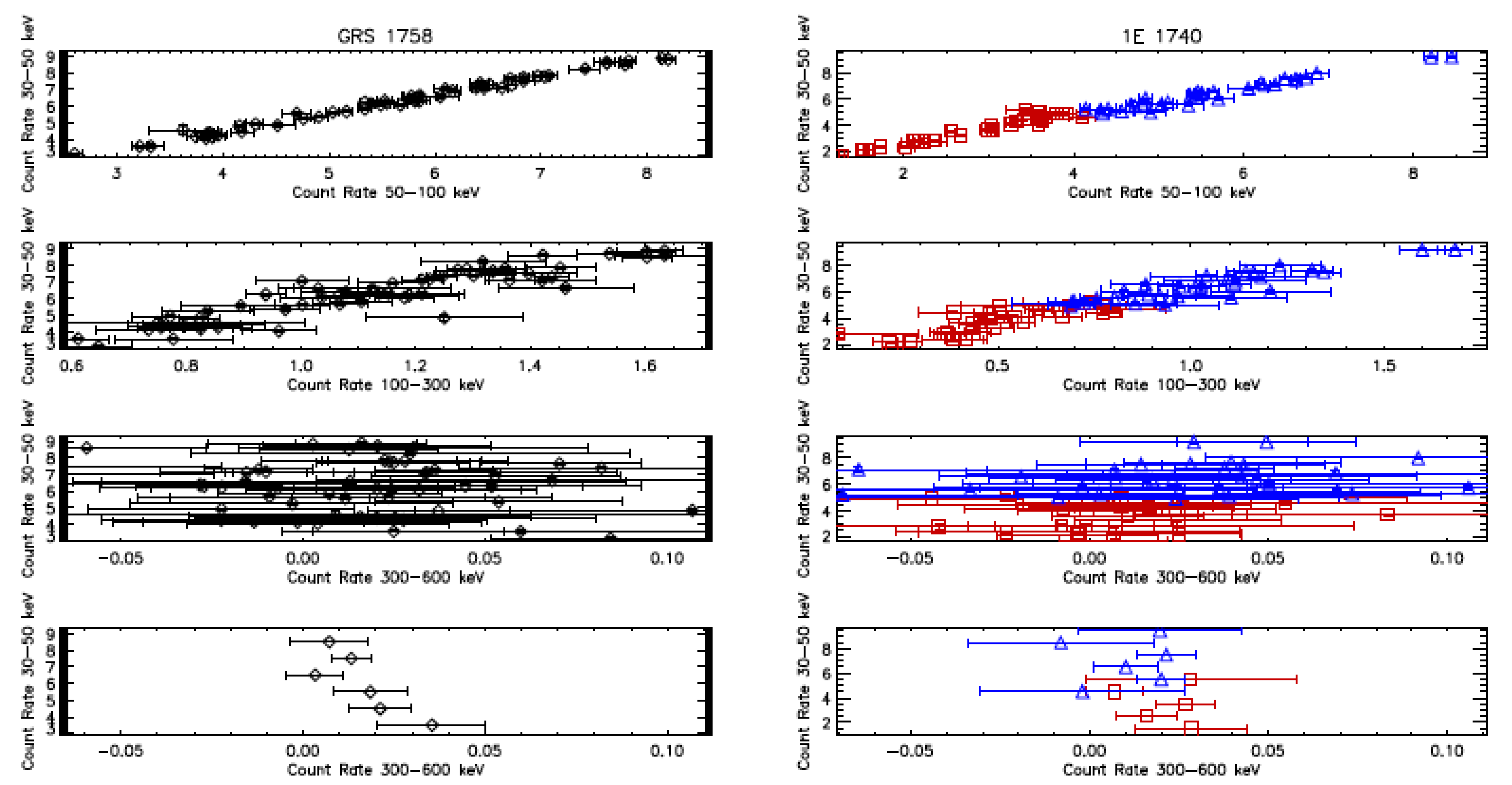
- Spearman correlation 30 – 50 keV to higher-E bins
  - 50 – 100 keV:
    - GRS: 0.99 (7.3σ)
    - 1E: 0.93 (4.7σ); 0.95 (5.2σ)
  - 100 – 300 keV:
    - GRS: 0.91 (6.7σ)
    - 1E: 0.85 (4.3σ); 0.85 (4.7σ)
  - 300 – 600 keV:
    - Low statistics/lots of scatter so rebinned



300 - 600 keV

Count-rate Correlations

- Spearman correlation 30 – 50 keV to higher-E bins
  - 50 – 100 keV:
    - GRS: 0.99 (7.3σ)
    - 1E: 0.93 (4.7σ); 0.95 (5.2σ)
  - 100 – 300 keV:
    - GRS: 0.91 (6.7σ)
    - 1E: 0.85 (4.3σ); 0.85 (4.7σ)
  - 300 – 600 keV:
    - GRS: -0.83 (1.9σ)
    - 1E: -0.30 (0.6σ); 0.03 (0.1σ)

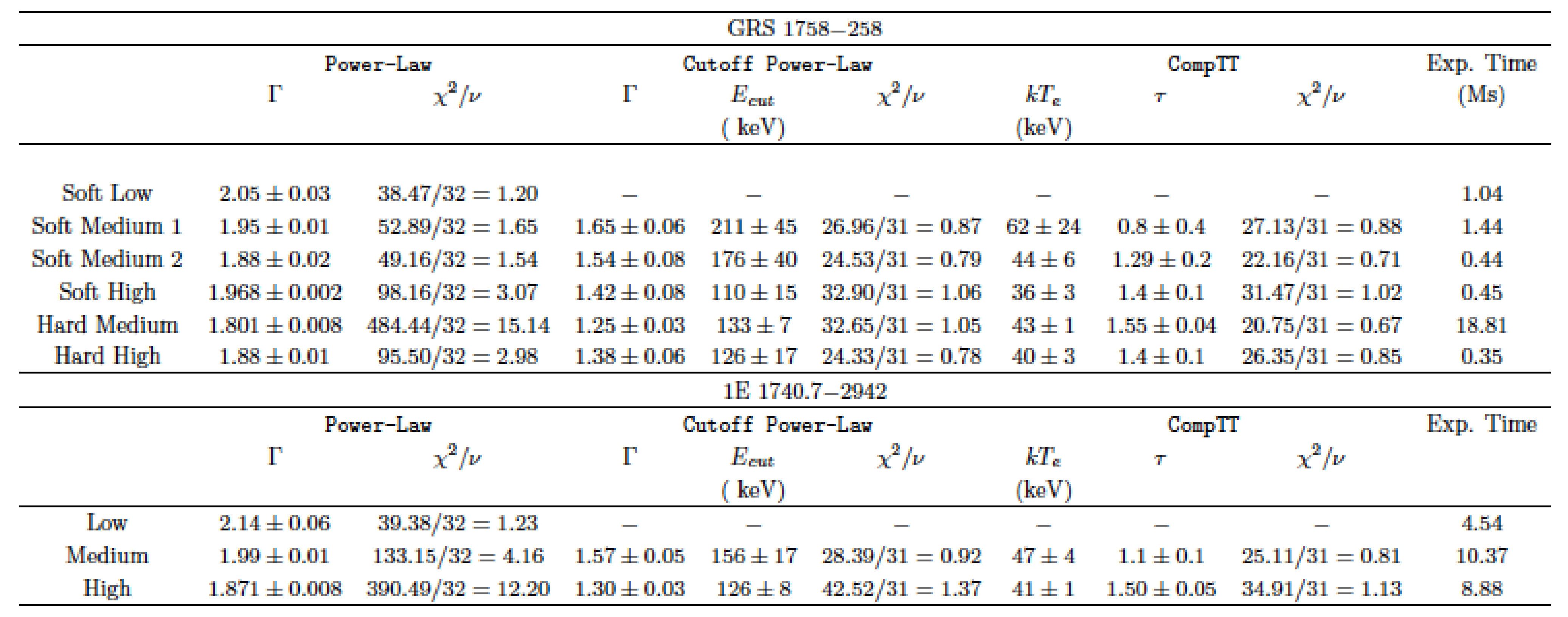


300 – 600 keV

Conclusion

- Studied the long-term behavior of GRS 1758 and 1E 1740 with ISGRI
  - GRS ~ 22 Ms; 1E ~ 23 Ms exp time
- Sources predominately in Comptonized spectral state
- States with > 8 Ms show excesses above CompTT
  - 1E high → significant; GRS → marginal; 1E med → not required
- Eqpair (hybrid) & po (jet) models provide good descriptions of spectra
- Differentiate scenarios via count-rate correlations
  - Strong correlations below 300 keV (CompTT component)
  - Anti-correlation/no correlation >300 keV → photons different origin
  - Disfavors hybrid scenario compared to jet scenario

Fits 1



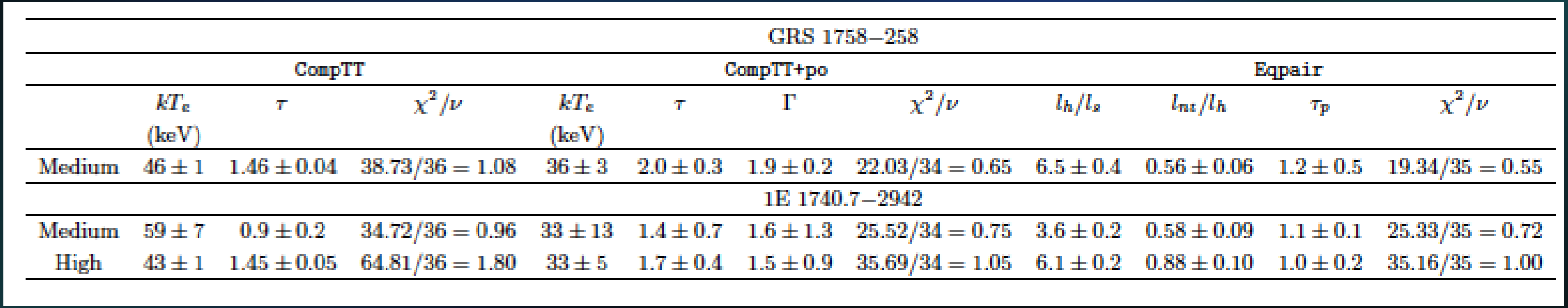
GRS 1758–258

	Power-Law		Cutoff Power-Law			CompTT			Exp. Time (Ms)
	Γ	χ^2/ν	Γ	E_{cut} (keV)	χ^2/ν	kT_e (keV)	τ	χ^2/ν	
Soft Low	2.05 ± 0.03	$38.47/32 = 1.20$	–	–	–	–	–	–	1.04
Soft Medium 1	1.95 ± 0.01	$52.89/32 = 1.65$	1.65 ± 0.06	211 ± 45	$26.96/31 = 0.87$	62 ± 24	0.8 ± 0.4	$27.13/31 = 0.88$	1.44
Soft Medium 2	1.88 ± 0.02	$49.16/32 = 1.54$	1.54 ± 0.08	176 ± 40	$24.53/31 = 0.79$	44 ± 6	1.29 ± 0.2	$22.16/31 = 0.71$	0.44
Soft High	1.968 ± 0.002	$98.16/32 = 3.07$	1.42 ± 0.08	110 ± 15	$32.90/31 = 1.06$	36 ± 3	1.4 ± 0.1	$31.47/31 = 1.02$	0.45
Hard Medium	1.801 ± 0.008	$484.44/32 = 15.14$	1.25 ± 0.03	133 ± 7	$32.65/31 = 1.05$	43 ± 1	1.55 ± 0.04	$20.75/31 = 0.67$	18.81
Hard High	1.88 ± 0.01	$95.50/32 = 2.98$	1.38 ± 0.06	126 ± 17	$24.33/31 = 0.78$	40 ± 3	1.4 ± 0.1	$26.35/31 = 0.85$	0.35

1E 1740.7–2942

	Power-Law		Cutoff Power-Law			CompTT			Exp. Time
	Γ	χ^2/ν	Γ	E_{cut} (keV)	χ^2/ν	kT_e (keV)	τ	χ^2/ν	
Low	2.14 ± 0.06	$39.38/32 = 1.23$	–	–	–	–	–	–	4.54
Medium	1.99 ± 0.01	$133.15/32 = 4.16$	1.57 ± 0.05	156 ± 17	$28.39/31 = 0.92$	47 ± 4	1.1 ± 0.1	$25.11/31 = 0.81$	10.37
High	1.871 ± 0.008	$390.49/32 = 12.20$	1.30 ± 0.03	126 ± 8	$42.52/31 = 1.37$	41 ± 1	1.50 ± 0.05	$34.91/31 = 1.13$	8.88

Fits 2



	CompTT			CompTT+po				Eqpair			
	kT_e (keV)	τ	χ^2/ν	kT_e (keV)	τ	Γ	χ^2/ν	l_h/l_s	l_{nt}/l_h	τ_p	χ^2/ν
GRS 1758−258											
Medium	46 ± 1	1.46 ± 0.04	$38.73/36 = 1.08$	36 ± 3	2.0 ± 0.3	1.9 ± 0.2	$22.03/34 = 0.65$	6.5 ± 0.4	0.56 ± 0.06	1.2 ± 0.5	$19.34/35 = 0.55$
1E 1740.7−2942											
Medium	59 ± 7	0.9 ± 0.2	$34.72/36 = 0.96$	33 ± 13	1.4 ± 0.7	1.6 ± 1.3	$25.52/34 = 0.75$	3.6 ± 0.2	0.58 ± 0.09	1.1 ± 0.1	$25.33/35 = 0.72$
High	43 ± 1	1.45 ± 0.05	$64.81/36 = 1.80$	33 ± 5	1.7 ± 0.4	1.5 ± 0.9	$35.69/34 = 1.05$	6.1 ± 0.2	0.88 ± 0.10	1.0 ± 0.2	$35.16/35 = 1.00$