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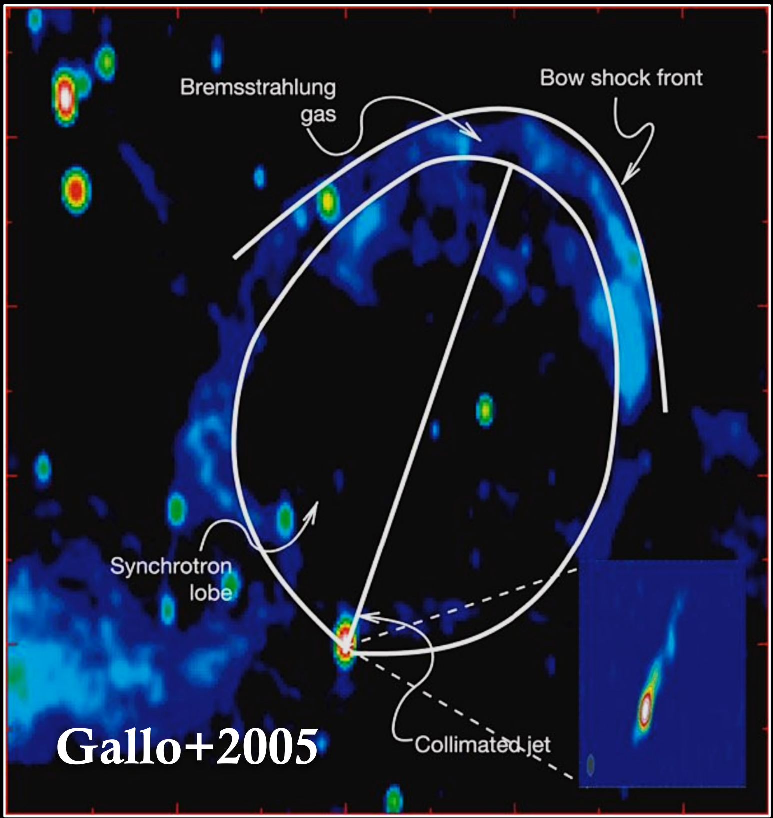
Outflows in X-ray Binaries

Nathalie Degenaar
University of Amsterdam

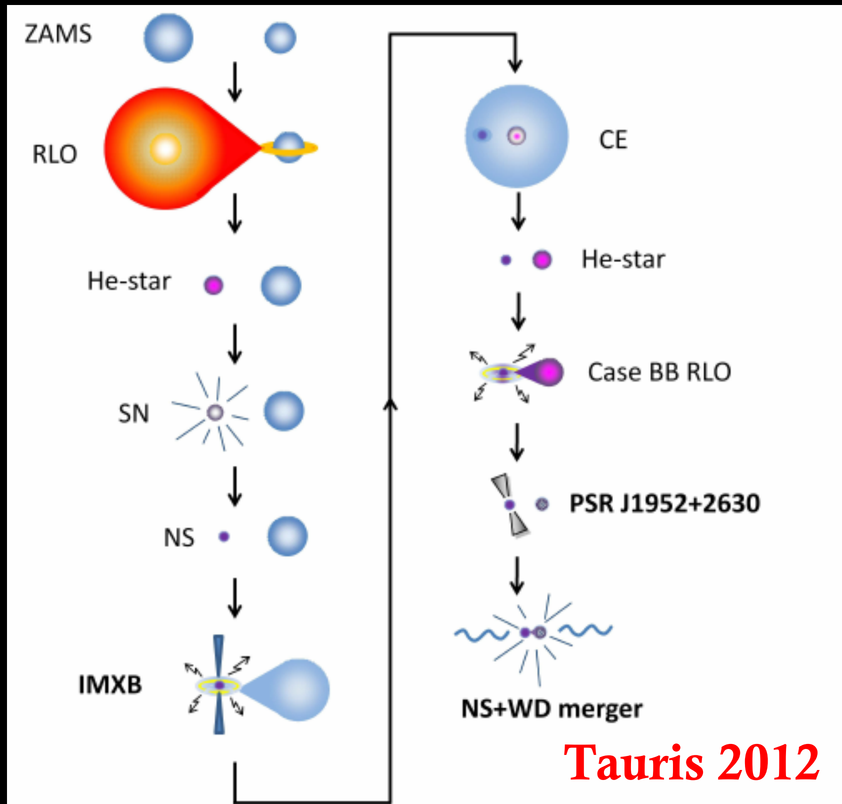
Boston *Accretion in Stellar Systems* August 2018

Importance of Outflows

Integral part of accretion flows: Accretion physics
Impact on environment: Heat ISM, turbulence, …
Non-conservative mass-transfer: Binary evolution



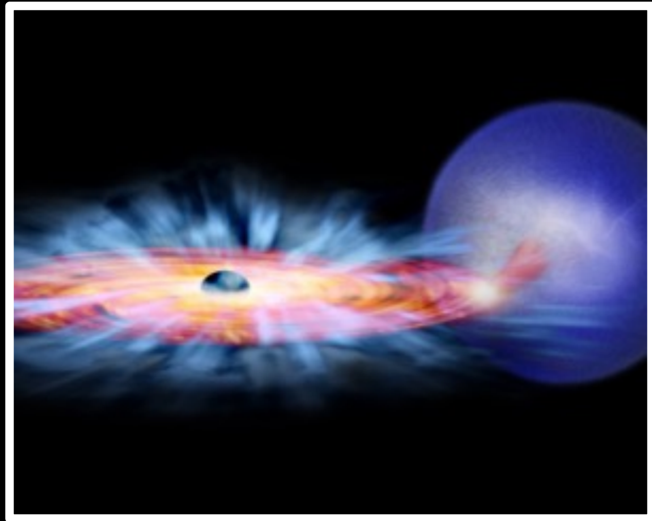
Gallo+2005



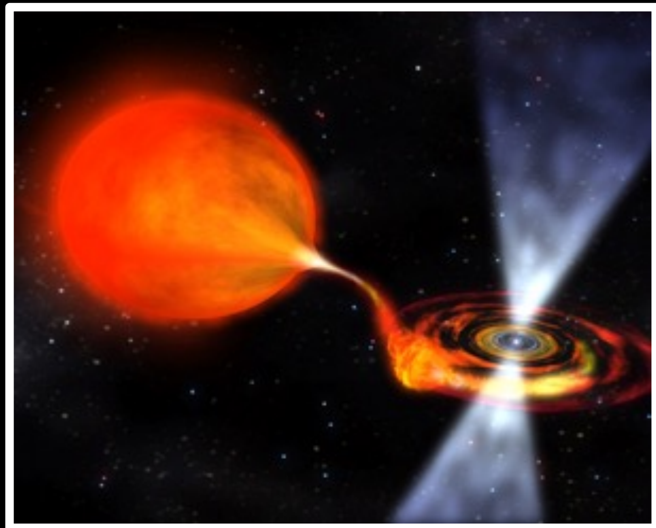
Tauris 2012

Topics

✧ Connection outflows & accretion
✧ Jets past & present
✧ Winds past & present

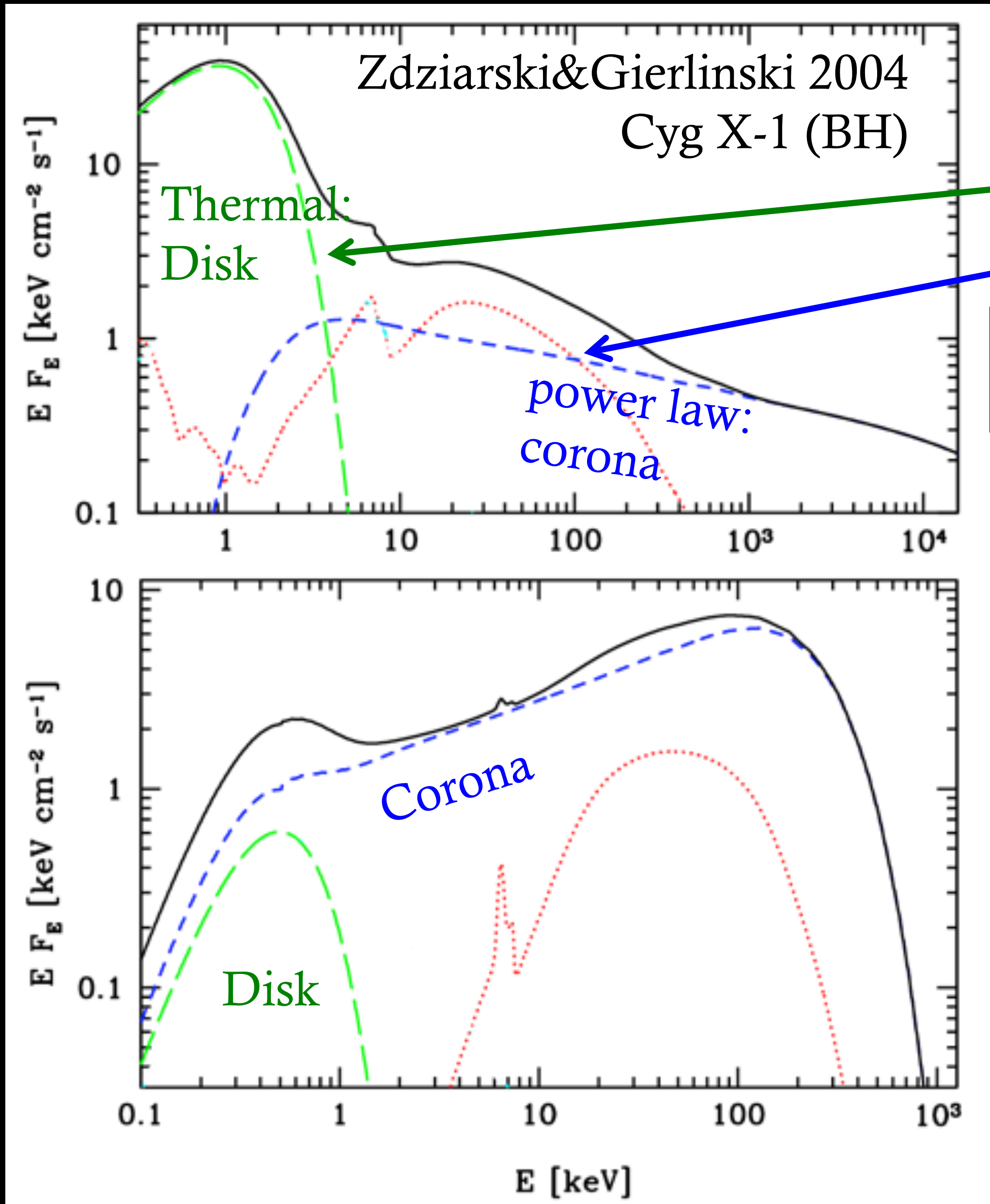


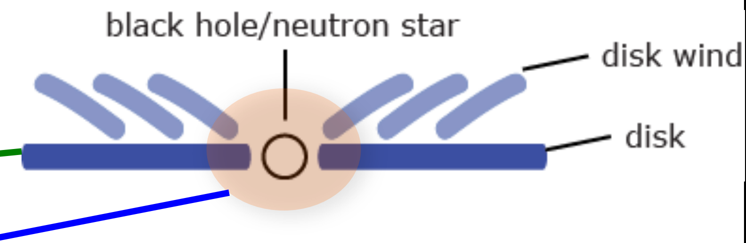
✧ Highlight: Thermonuclear X-ray bursts as a probe of outflows
✧ Highlight: Jets from neutron stars with high magnetic fields



Accretion States

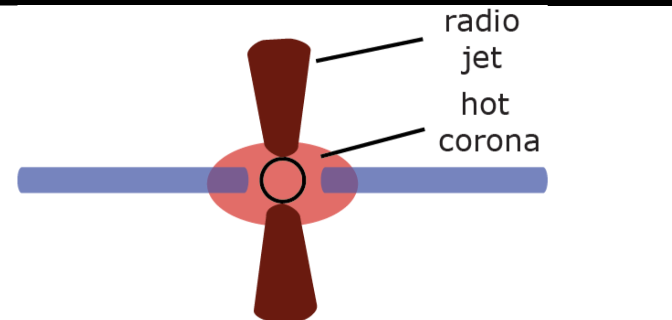
Accretion States





Soft State

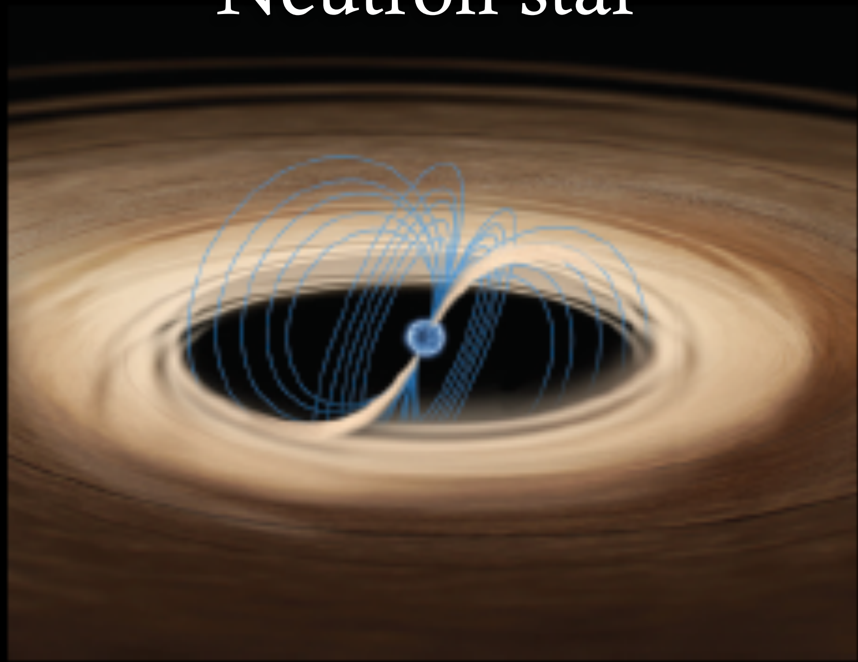
Hard State



Black Holes versus Neutron Stars

Black hole

Neutron star



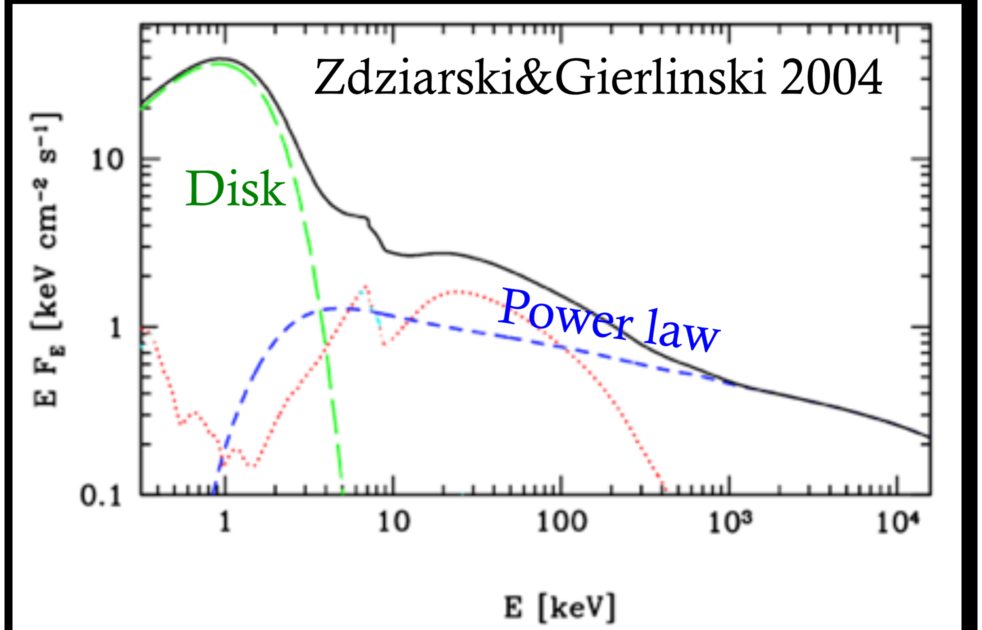
Companion stars + accretion disks similar

But: neutron stars have a solid surface + magnetic field

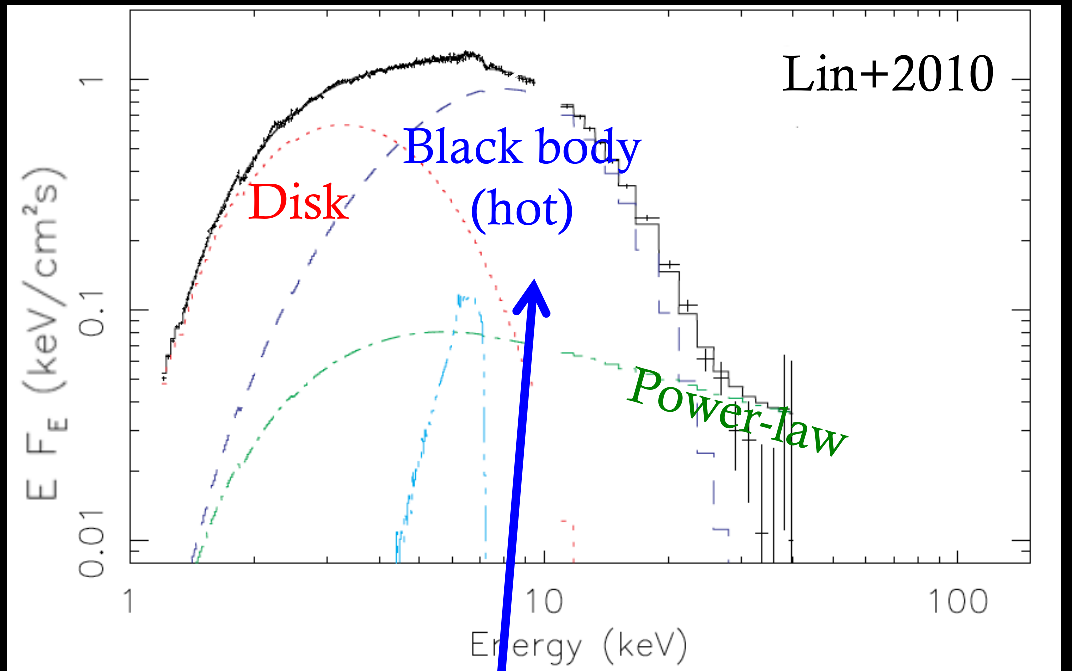
→ Can truncate inner disk, extra source of soft photons

Black Holes versus Neutron Stars

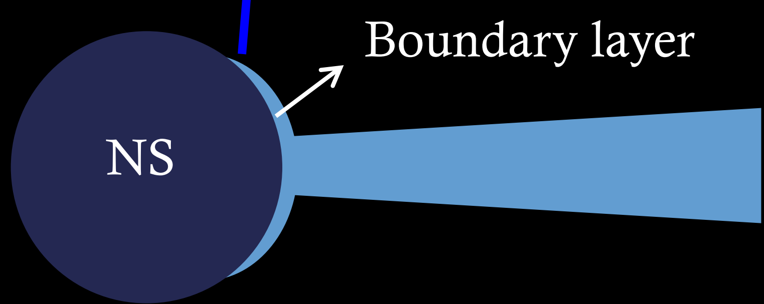
Black hole



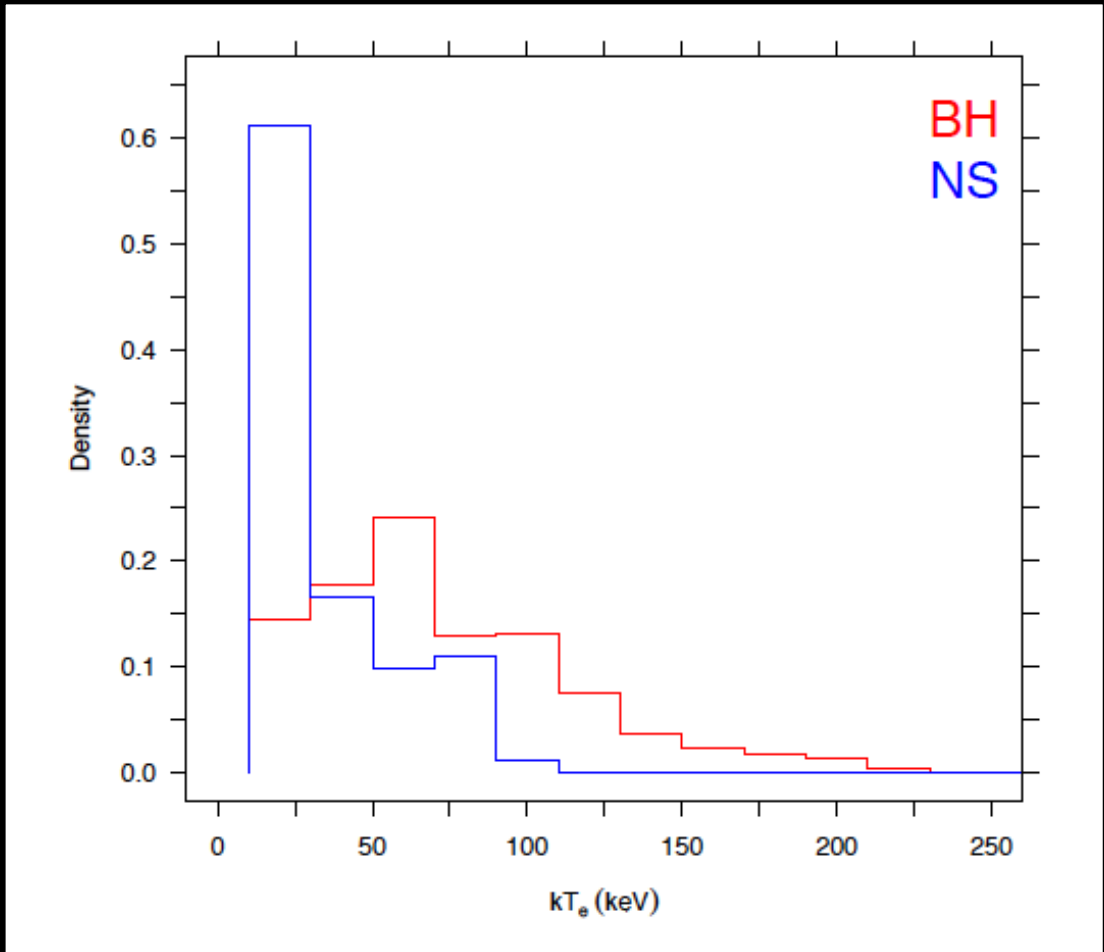
Neutron star



Solid surface / boundary layer produces soft (thermal) emission



Black Holes versus Neutron Stars

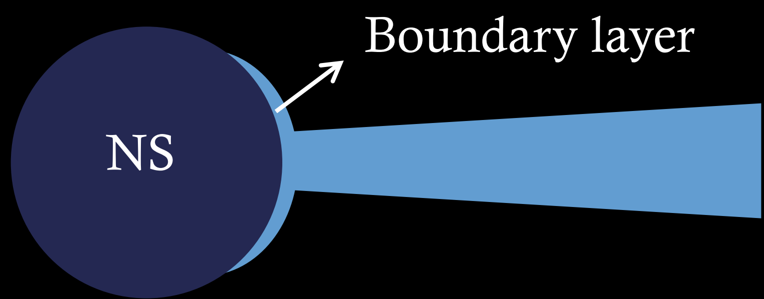


Systematic study of RXTE data; 8 black holes, 4 neutron stars (hard states)

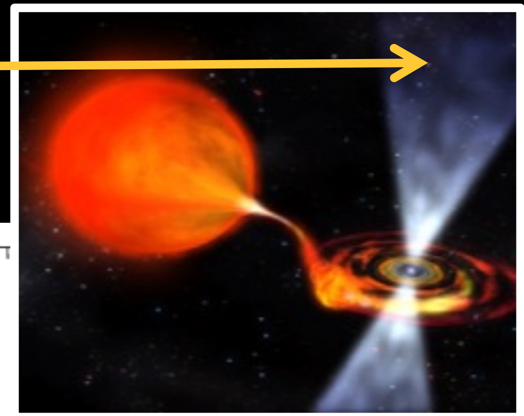
Burke+2017

Neutron stars have cooler coronae than black holes

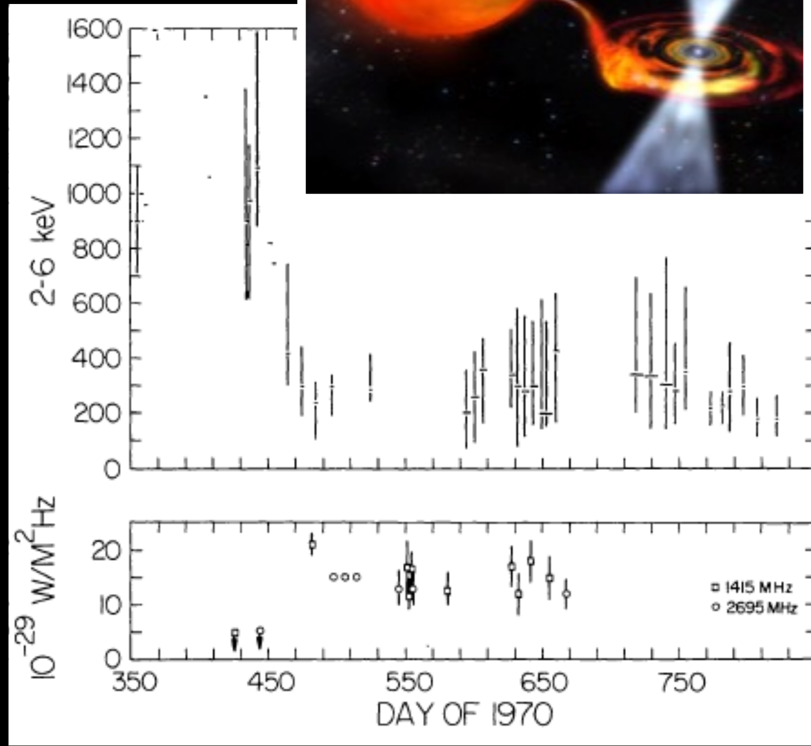
Coronae cooled by extra source of soft photons?



Linking Outflows to Accretion States



Some History:
Jets & Accretion states



- ✧ Tananbaum+1972 (Cyg X-1)

  Connection radio and X-rays

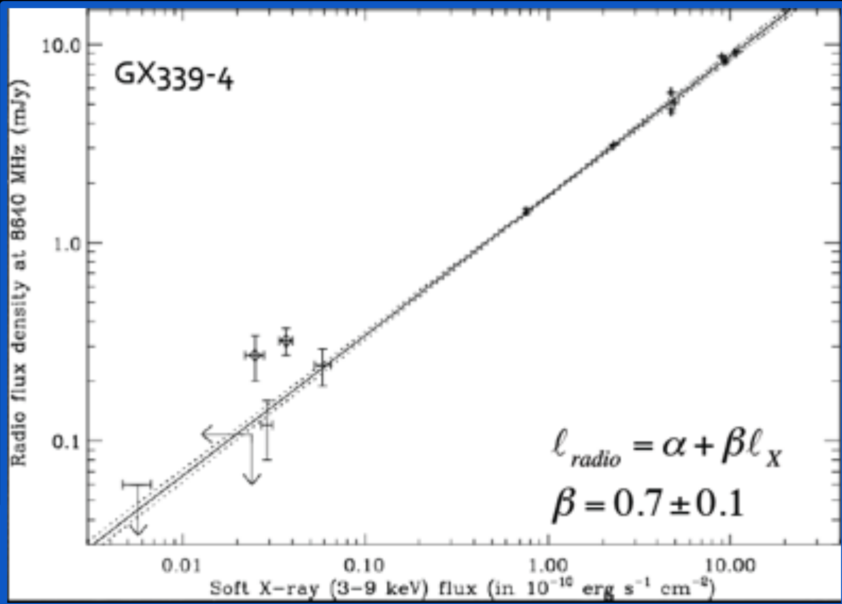
- ✧ Fender 2001 (black holes)

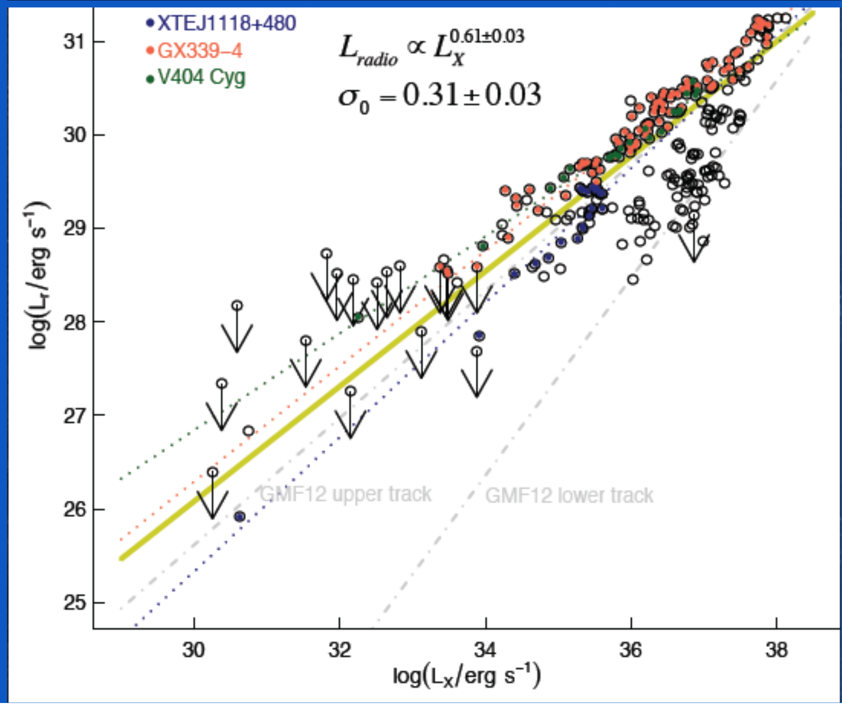
  Radio emission only in hard X-ray states

- ✧ Fender+2004 (black holes)

  Framework linking accretion states to jets

Jet-Accretion Connection





Corbel+2003

Tight X-ray/radio correlation GX 339-4 (multiple outbursts)

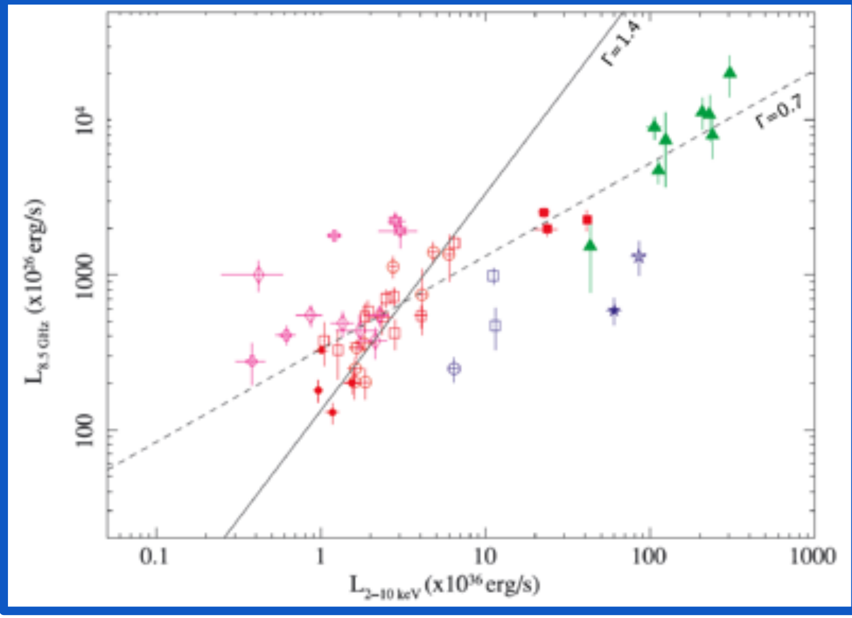
Gallo+2014

Confirms relation for 24 black holes, broader Lx range

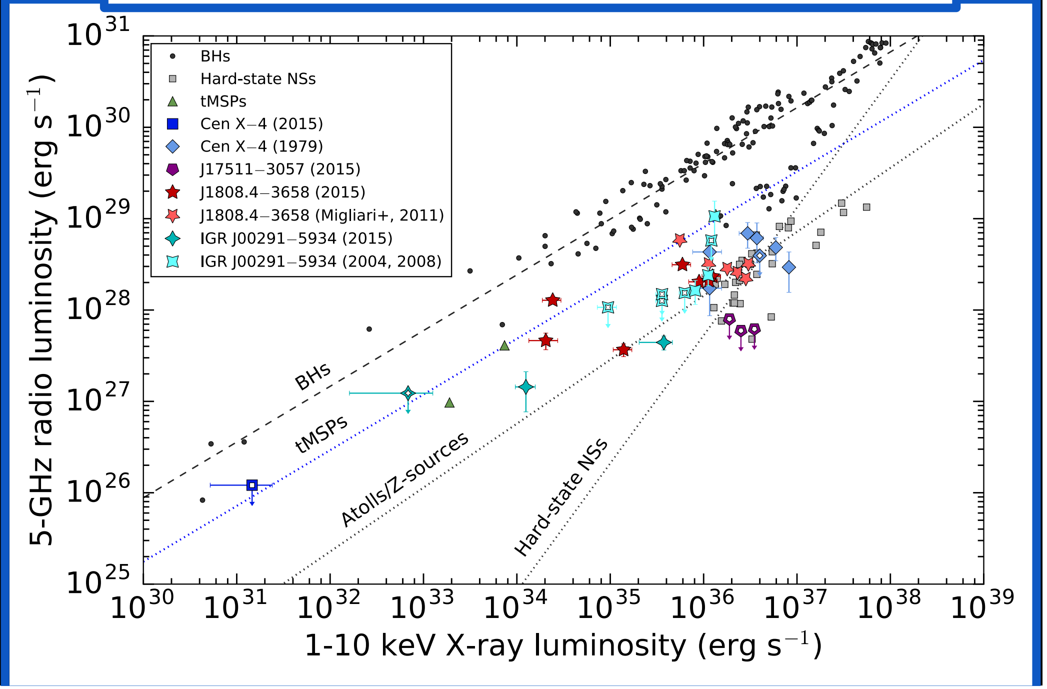
See also Hannikainen+1998; Corbel+2000, 2008, 2013; Gallo+2003, 2012; Jonker+2010; Coriat+2011; Miller-Jones+2011

Jet-Accretion in Neutron Stars

Migliari & Fender 2006
Different couplings NSs?
Less radio bright than BHs
Limited Lx range sampled



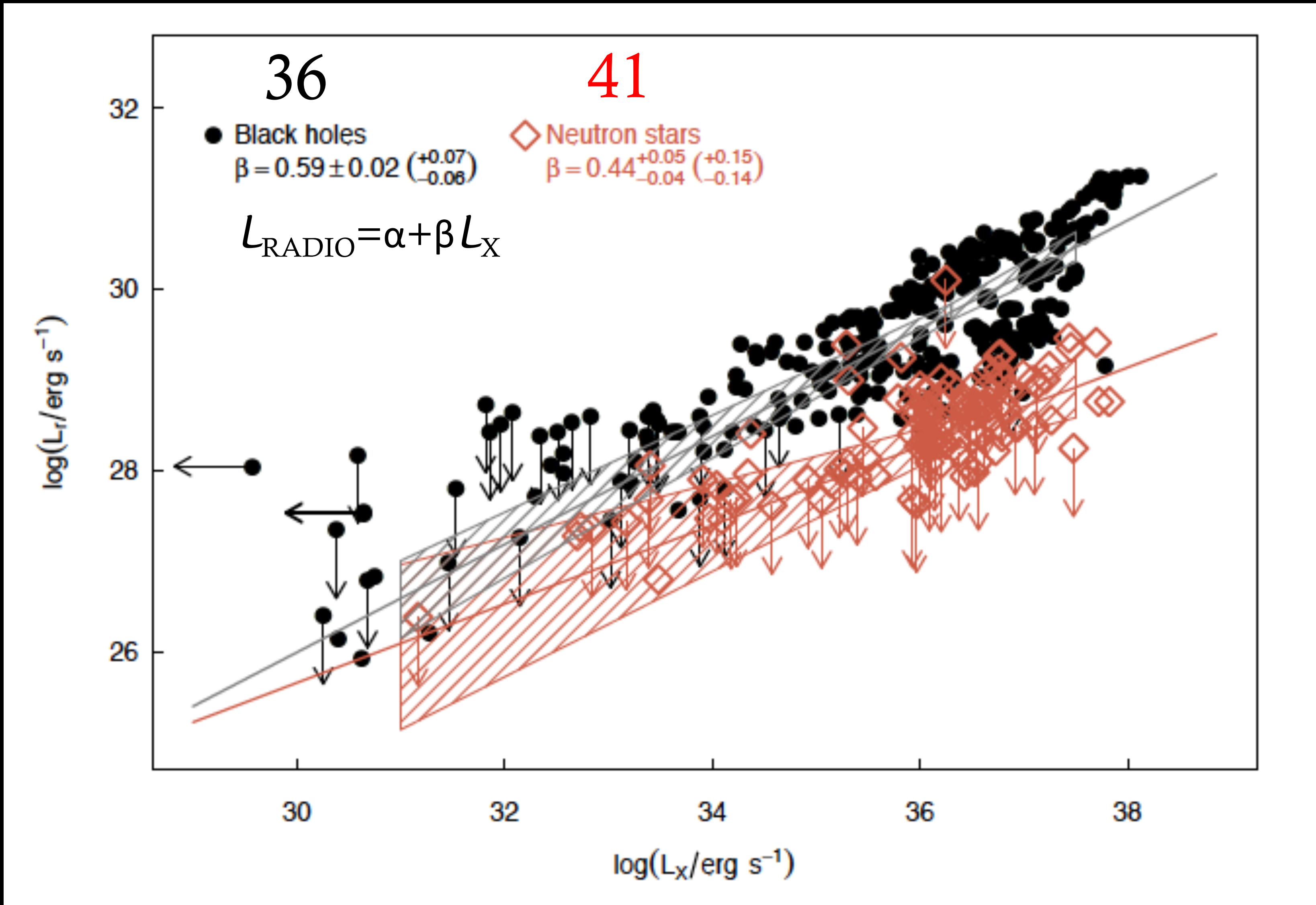
Tudor+2017
No universal correlation?



See also Fender & Hendry 2000; Fender & Kuulkers 2001; Miller-Jones+2009; Tudose+2009; Migliari+2011, 2012; Deller+2015; DeMartino+2015; Gusinskaia+2017; Tetarenko+2017

Jet-Accretion Connection Latest

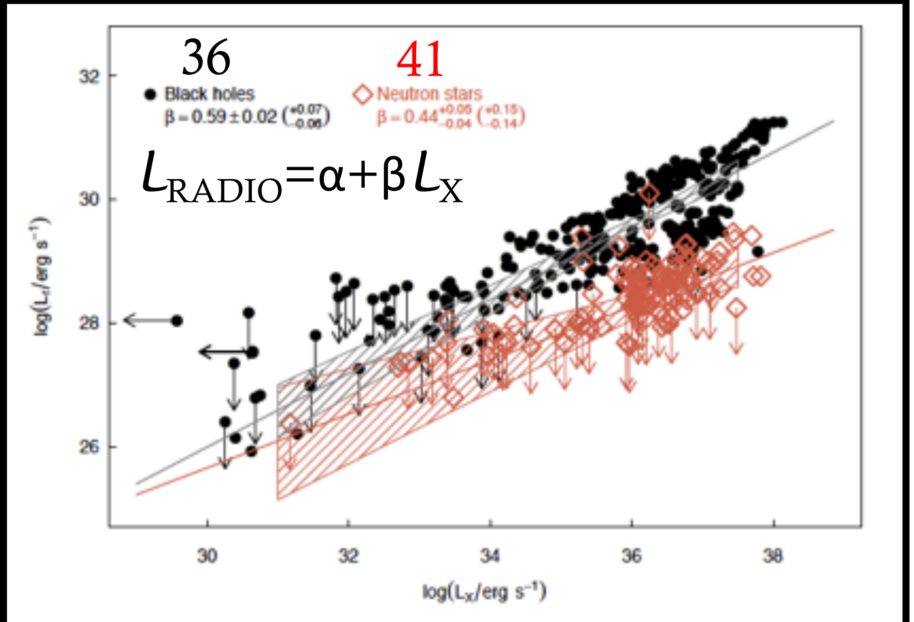
Gallo, Degenaar & van den Eijnden 2018



Jet-Accretion Connection Latest

Gallo, Degenaar & van den Eijnden 2018

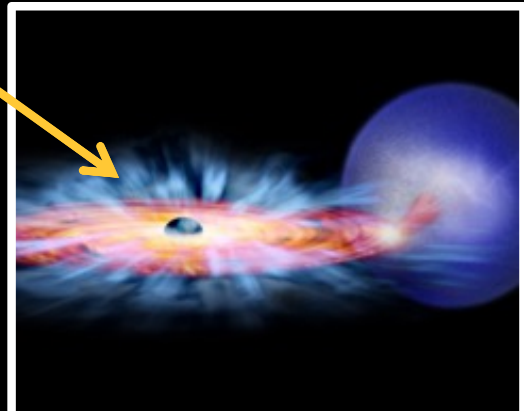
- ✧ Similar coupling indices for NS and BH sample
- ✧ NS less radio-loud than BHs

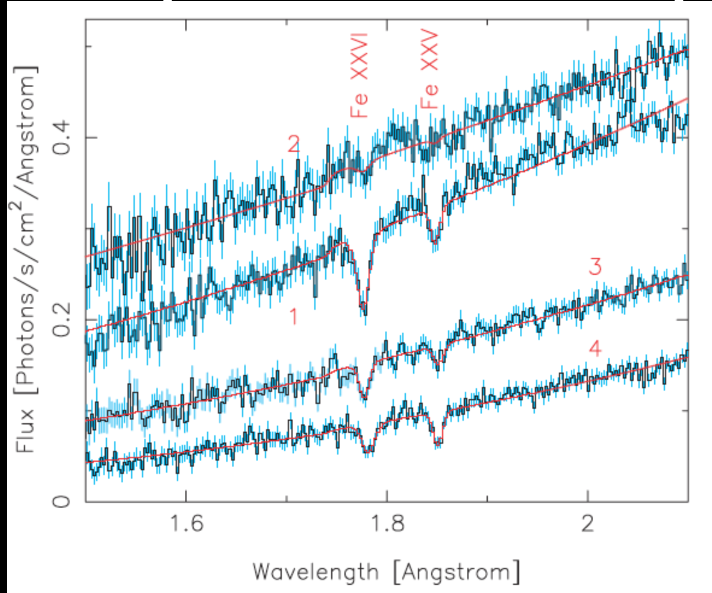


- ✧ NSs <u>not</u> more scattered than BHs
- ✧ NSs <u>not</u> under-represented compared to BHs

Some History: Winds & Accretion states

Absorption (emission) narrow lines





- ✧ Miller+2006/2008 (H1743-322/GRO J1655-40)

  Winds stronger in soft states

- ✧ Neilsen & Lee 2009 (GRS 1915)

  Anti-correlation winds and jets; state dependence

- ✧ Ponti+2012 (sample of BHs)

  Global link between winds and accretion state

Current Status on Winds

Diaz Trigo & Boirin 2016 (review)

Ionized emission/absorption in 19 sources (8 BHs)

Since then: ~5 more (1 BH)

(Degenaar+2015; Miller+2016; King+2016; van den Eijnden+2017; Raman+2018)

Source	P_{orb}	N_H^{Gal} 10^{21} cm^{-2}	NS	Dips	i (°)	log ξ < 3	log ξ ≥ 3	Flow	References on the warm absorbers
XB 1916−053	0.83 h	2.3	NS	D		x	x	atm	Boirin04, Juett06, Díaz Trigo06, Iaria06, Zhang14
1A 1744−361	1.62 h	3.1	NS	D			x	atm	Gavriil12
4U 1323−62	2.93 h	12	NS	D			x	no grat.	Boirin05, Church05, Bałucińska-Church09
EXO 0748−676	3.82 h	1.0	NS	D		x	x	atm	Díaz Trigo06, van Peet09, Ponti14
XB 1254−690	3.93 h	2.0	NS	D			x	atm	Boirin03, Díaz Trigo06/09 , Iaria07
MXB 1658−298	7.11 h	1.9	NS	D		x	x	atm	Sidoli01, Díaz Trigo06
XTE J1650−500	7.63 h	4.2			> 50	?[a]	?[b]	?[c]	Miller02/04
AX J1745.6-2901	8.4 h	12	NS	D			x	no grat.	Hyodo09, Ponti15
MAXI J1305−704	9.74 h[d]	1.9		D		x		in	Shidatsu13, Miller14
X 1624−490	20.89 h	20	NS	D			x	atm	Parmar02, Díaz Trigo06, Iaria07b, Xiang09
IGR J17480−2446	21.27 h[e]	6.5	NS	D			x	out	Miller11
GX 339−4	1.76 d	3.6			> 45[f]	x		?[g]	Miller04, Juett06
GRO J1655−40	2.62 d	5.2		D			x	out	Ueda98, Yamaoka01, Miller06b/08, Netzer06, Sala07, Díaz Trigo07, Kallman09, Luketic10, Neilsen12
Cir X−1	16.6 d	16	NS	D		x	x	out	Brandt00, Schulz02, , D'Aí07, Iaria08, Schulz08
GX 13+1	24.06 d	13	NS	D			x	out	Ueda01/04, Sidoli02, Díaz Trigo12, Madej14, D'Ai14
GRS 1915+105	33.5 d	13		D			x	out	Kotani00, Lee02, Martocchia06, Ueda09/10, Neilsen09/11/12
IGR J17091−3624	>4 d[h]	5.4			> 53[i]		x	out	King12
4U 1630−47		17		D			x	out	Kubota07, Díaz Trigo13/14, King13/14, Neilsen14
H 1743−322		6.9		D			x	out	Miller06a

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GX 13+1	24.06 d	13	NS	D			x	out
GRS 1915+105	33.5 d	13		D			x	out
IGR J17091−3624	>4 d[h]	5.4			> 53[i]		x	out
4U 1630−47		17		D			x	out
H 1743−322		6.9		D			x	out

Outflow: 100% BHs, 30% NSs

Velocities ~200-3000 km/s

Extreme cases: ~ 0.04 c

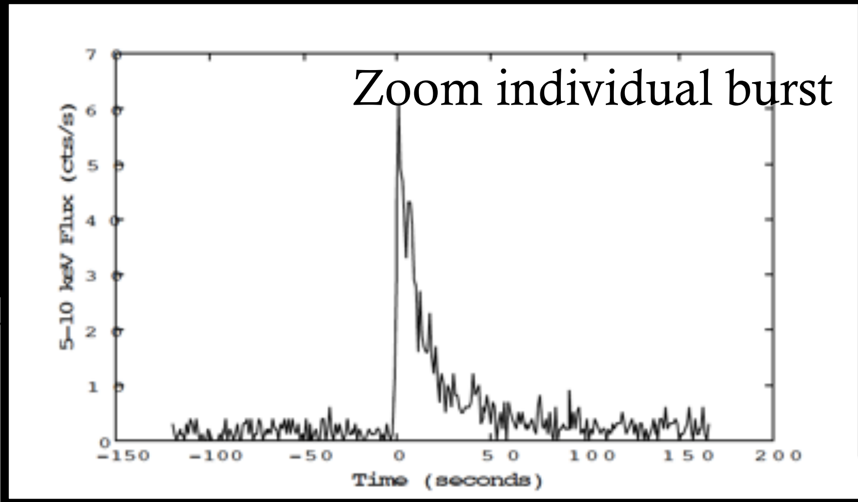
Highlight I:

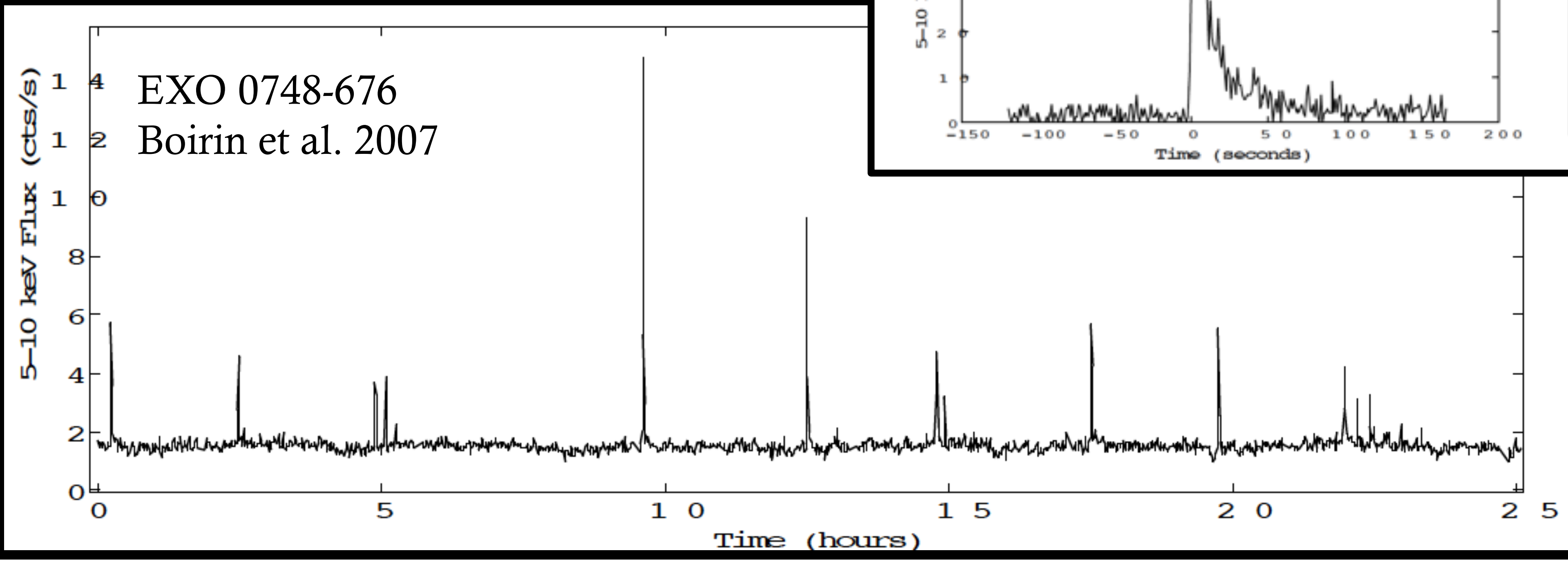
Thermonuclear X-ray Bursts as a Probe of Outflows

Thermonuclear X-ray Bursts

Thermonuclear fusion on the surface of a neutron star
(Grindlay+1978; Belian+1978)

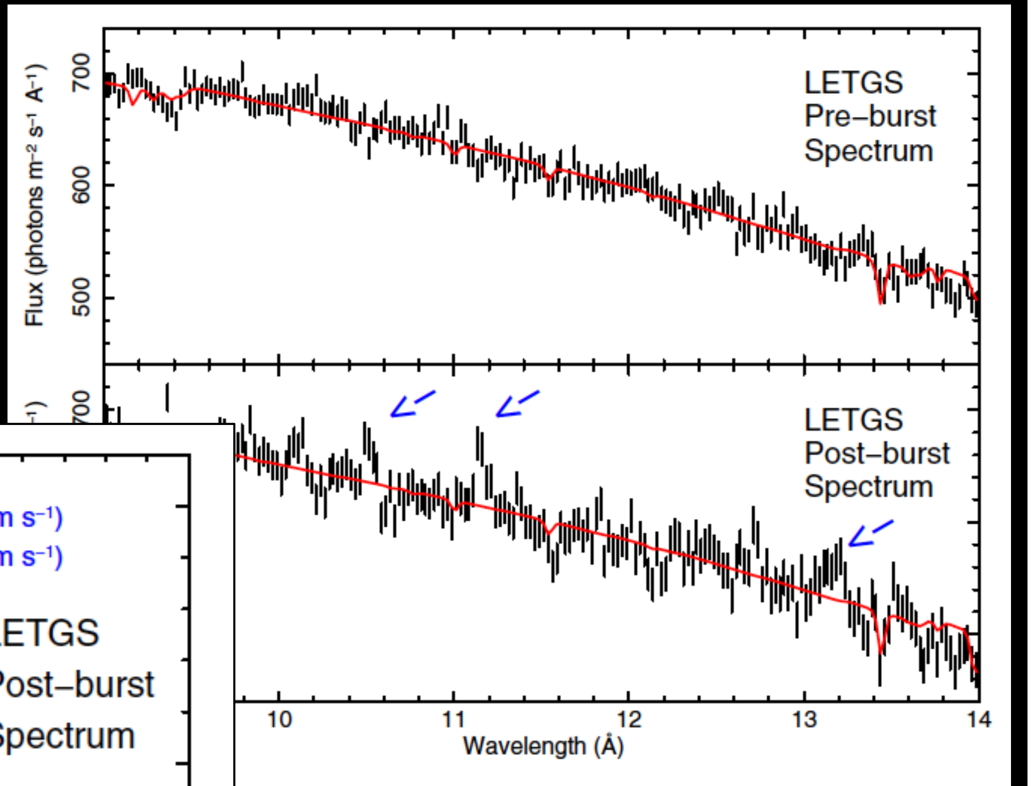
Emission peak: Eddington limit
Repetition rate: hours-days
X-ray bursters known: ~125

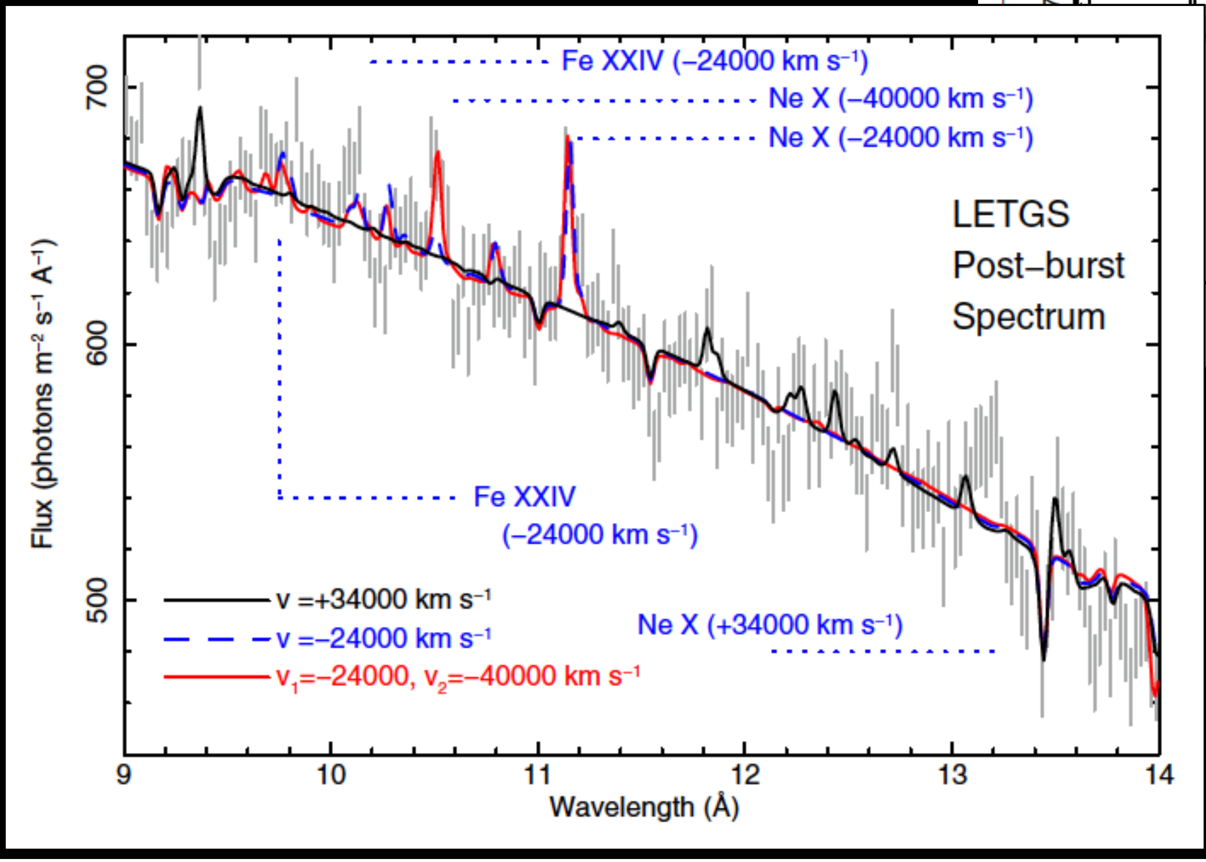




Winds Induced by X-ray Bursts

Pinto+2014
Chandra/LETG detection of wind *after* a bright X-ray burst (SAX J1808.4-3658)





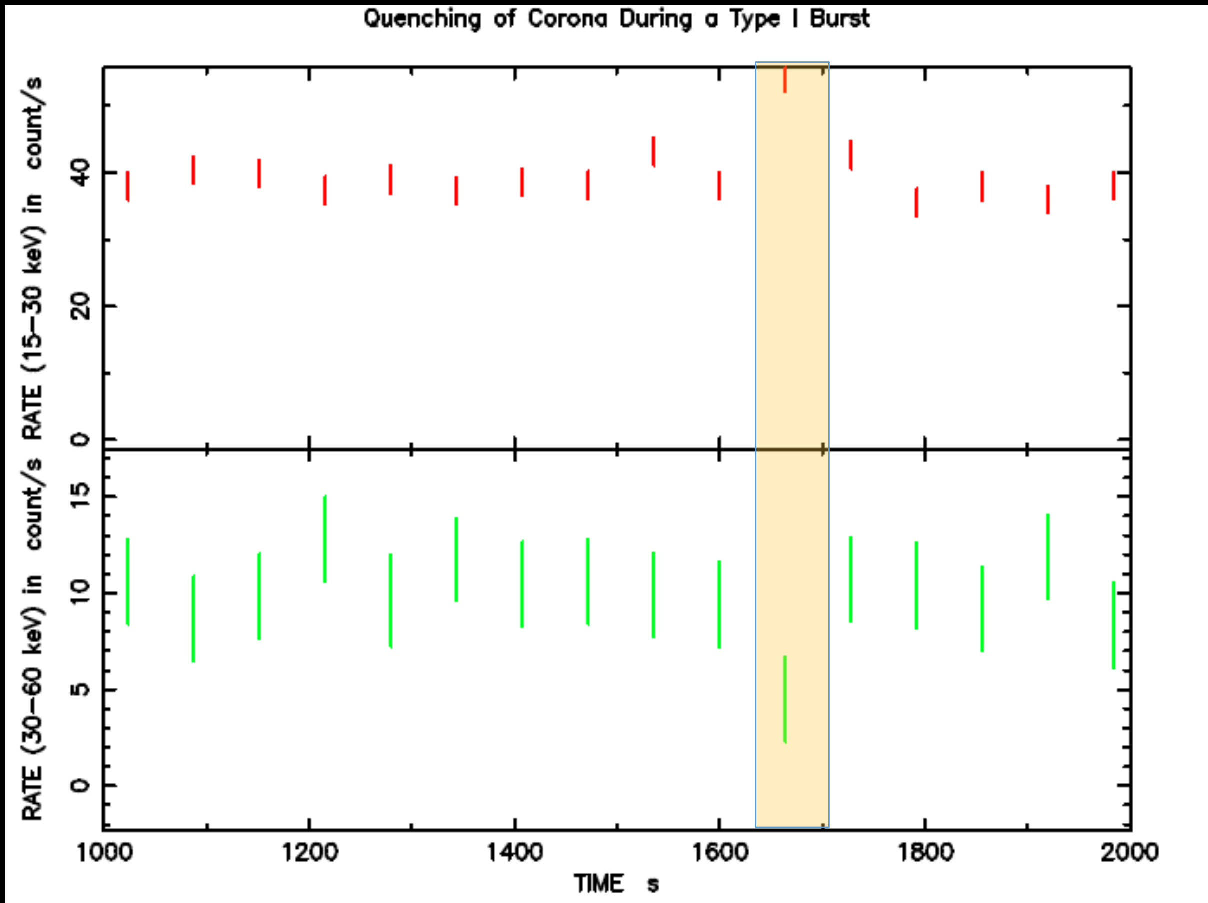
See also
Ballantyne & Everett 2005;
Degenaar+2013; Keek+2014

Corona Cooling by X-ray Bursts

Maccarone & Coppi 2003 (Aql X-1)

Dip in >30 keV emission during X-ray burst peak

Cooling of corona due to injection soft photons?



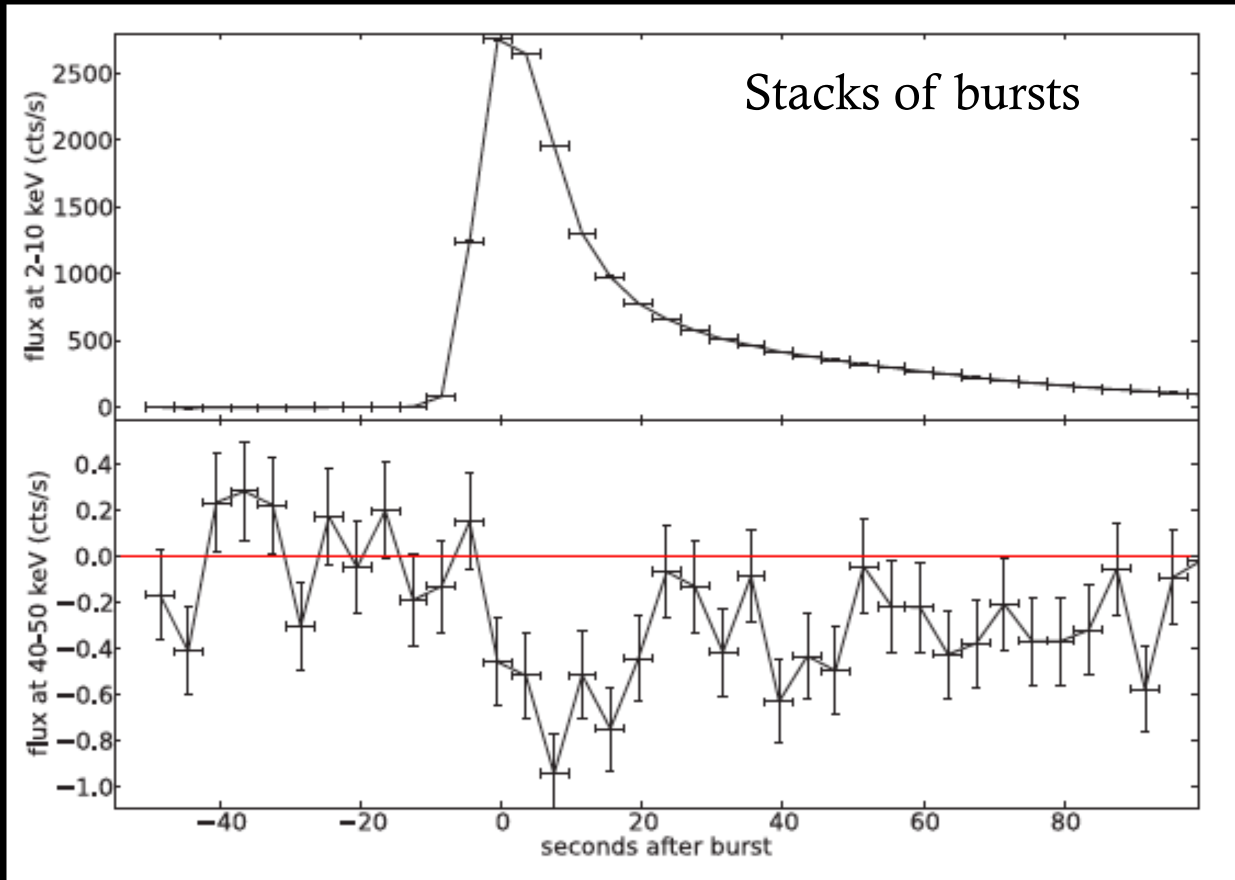
Single burst

Effect of X-ray Bursts on Coronae

Chen+2013 (Aql X-1)

Confirm reduction >30 keV emission during X-ray bursts

See also Chen+2012; Ji+2013, 2014ab; Kajava+2017

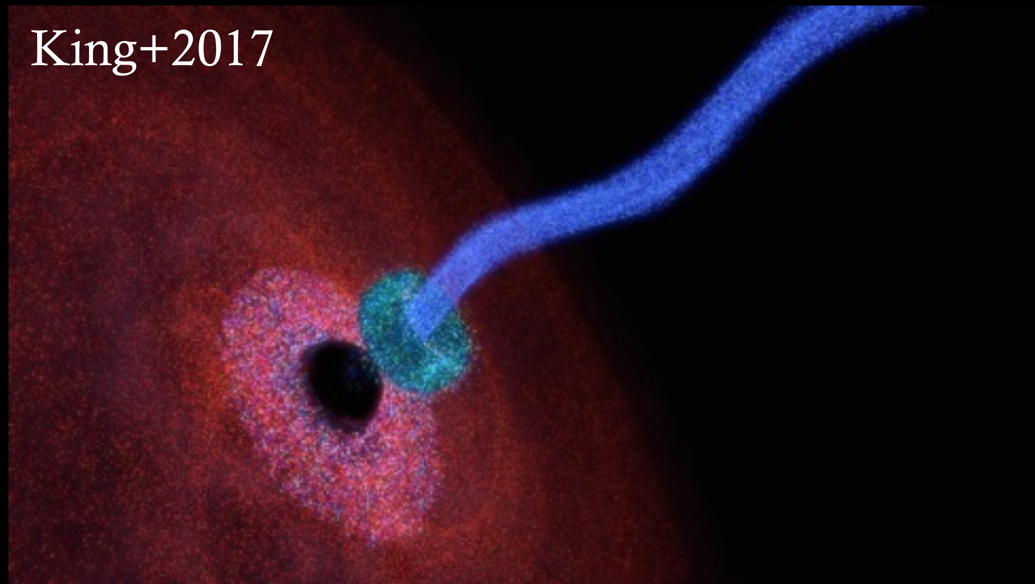


Can X-ray Bursts Affect Jets?

Jets are linked with coronae (base of jet?)

Degenaar+2017
If X-ray bursts lead to coronae cooling can the jet be affected?

Can be tested: bursters bright enough in radio and high repetition rate



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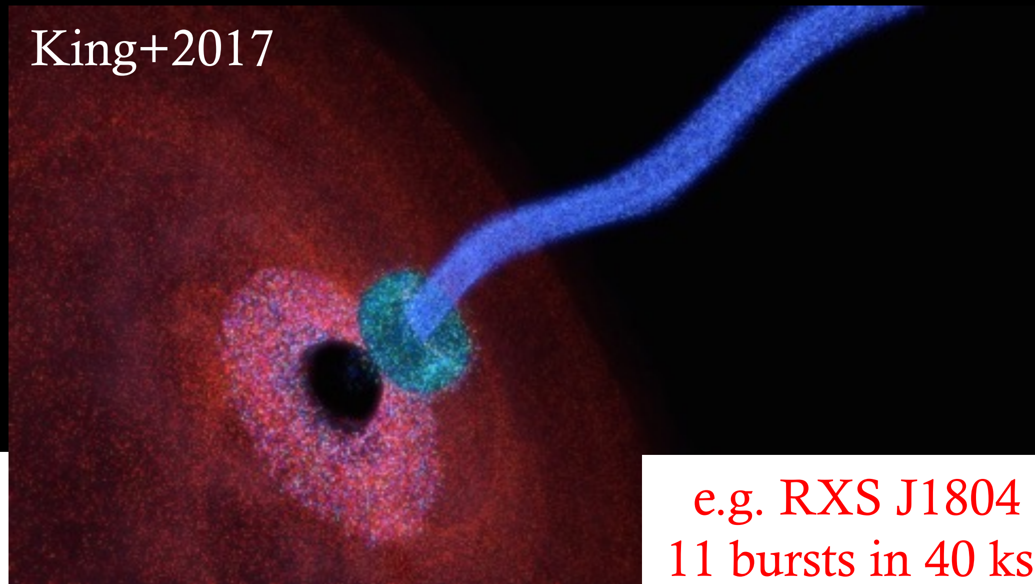
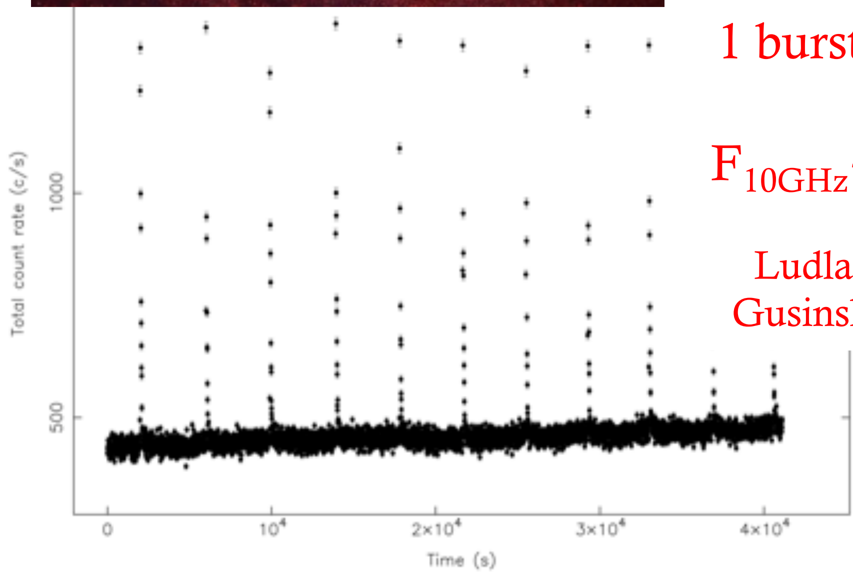


e.g. RXS J1804
11 bursts in 40 ks:
1 burst per 1 hr

F_{10GHz}~200 μJy

Ludlam+2016;
Gusinskaia+2017



X-ray Bursts to Probe Outflows

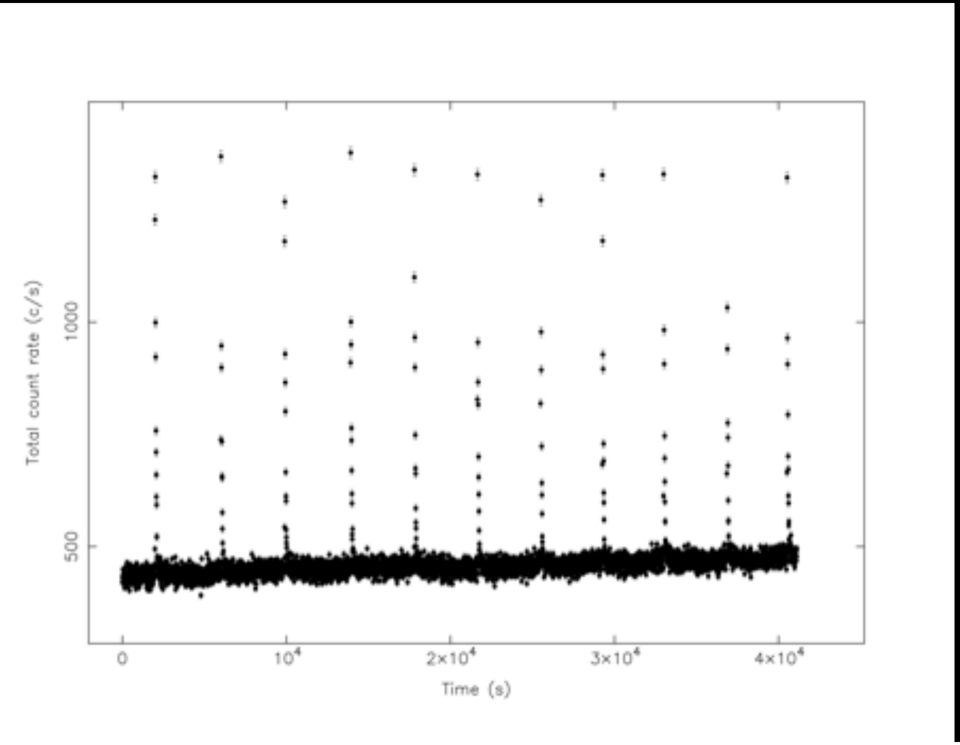
X-ray bursts may affect accretion disks and corona

Also affect winds and jets

Disk + corona repeatedly disrupted/restored

Direct probe of internal dynamics accretion process

Great potential for further study



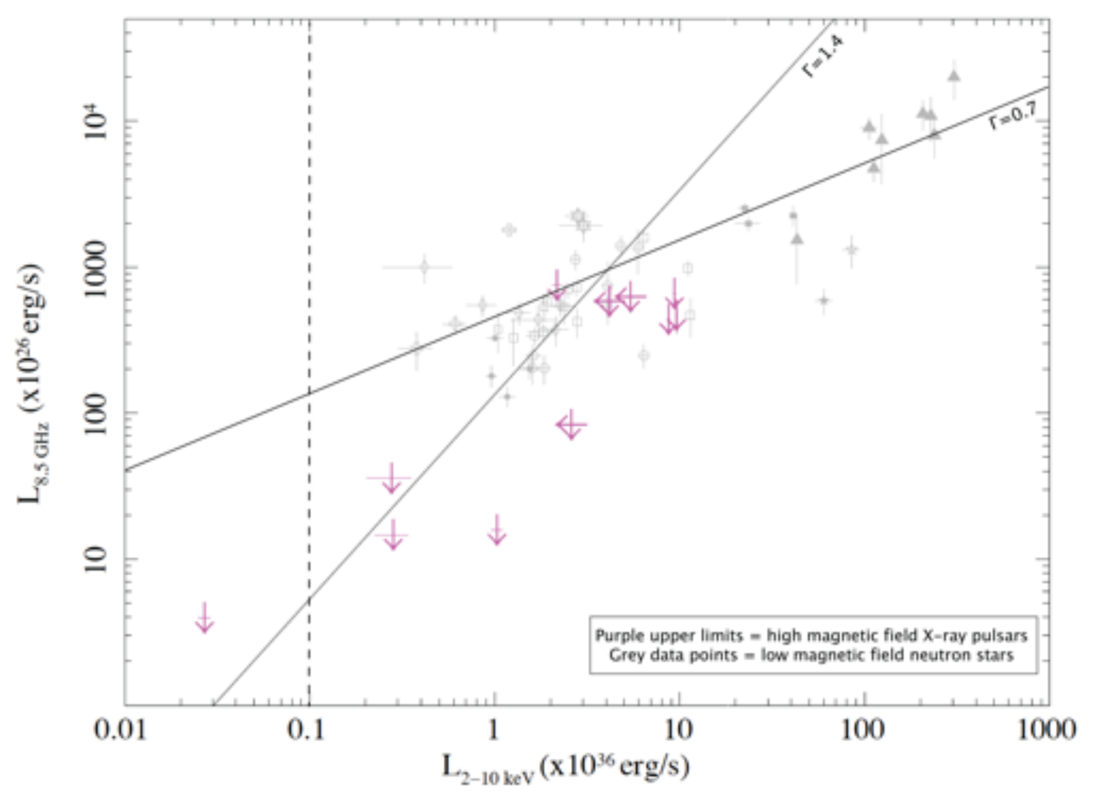
Highlight II:

Jets from Neutron Stars with High Magnetic Fields

Jets from High-B Neutron Stars

Migliari+2012

Compilation of new + old work: No radio detections of neutron stars with high magnetic fields ($B>10^{10}$ G)



Observational paradigm

Strong magnetic fields prevent jet formation

Supported by theory

Massi & Kaufman-Bernado 2008

See also Fender & Hendry 2000; Migliari+2006

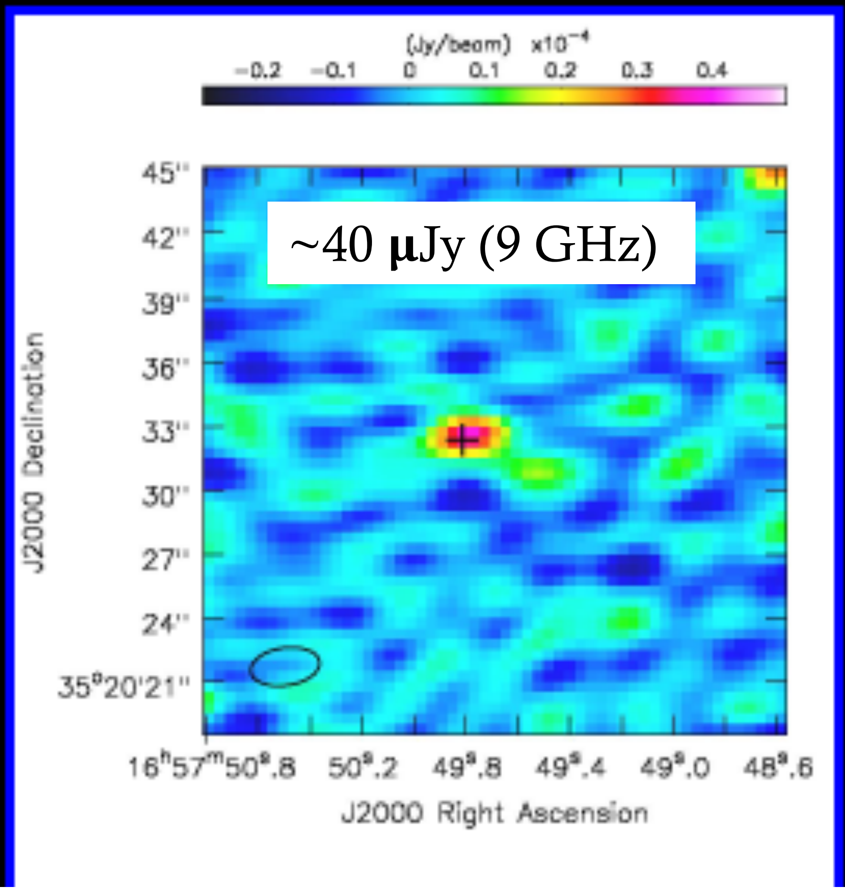
Radio Detections High-B NSs

Van den Eijnden+2018 ab

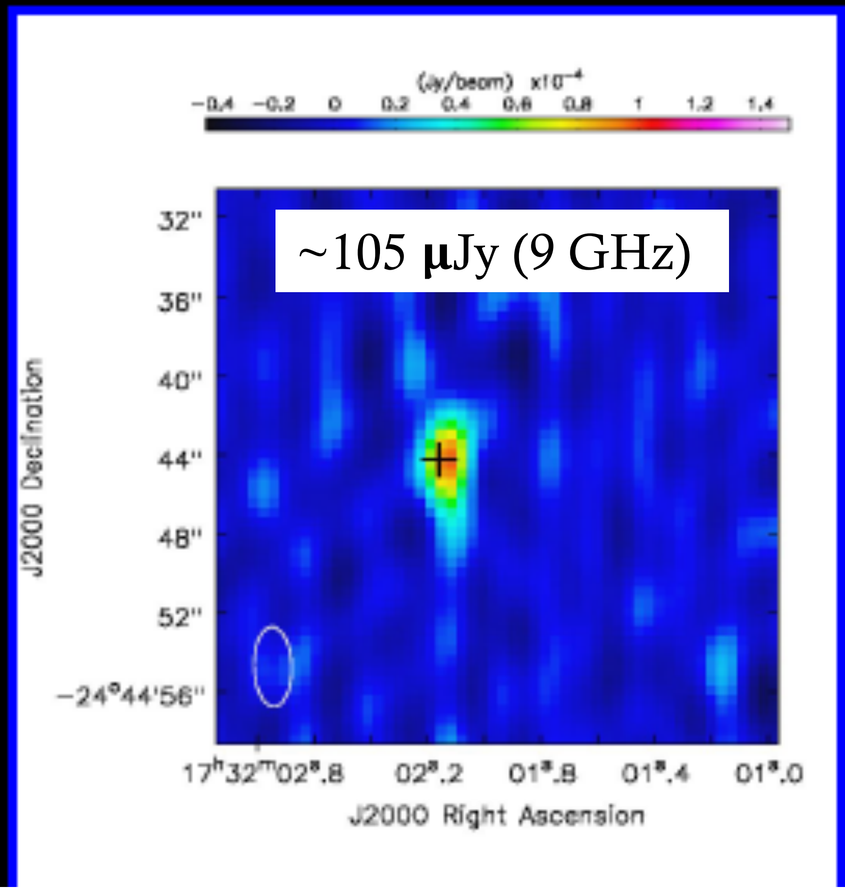
Radio detections of 2 neutron stars with $B \sim 10^{11}$-10^{13} G

Single band/epoch: Jet possible, but not conclusive

Her X-1



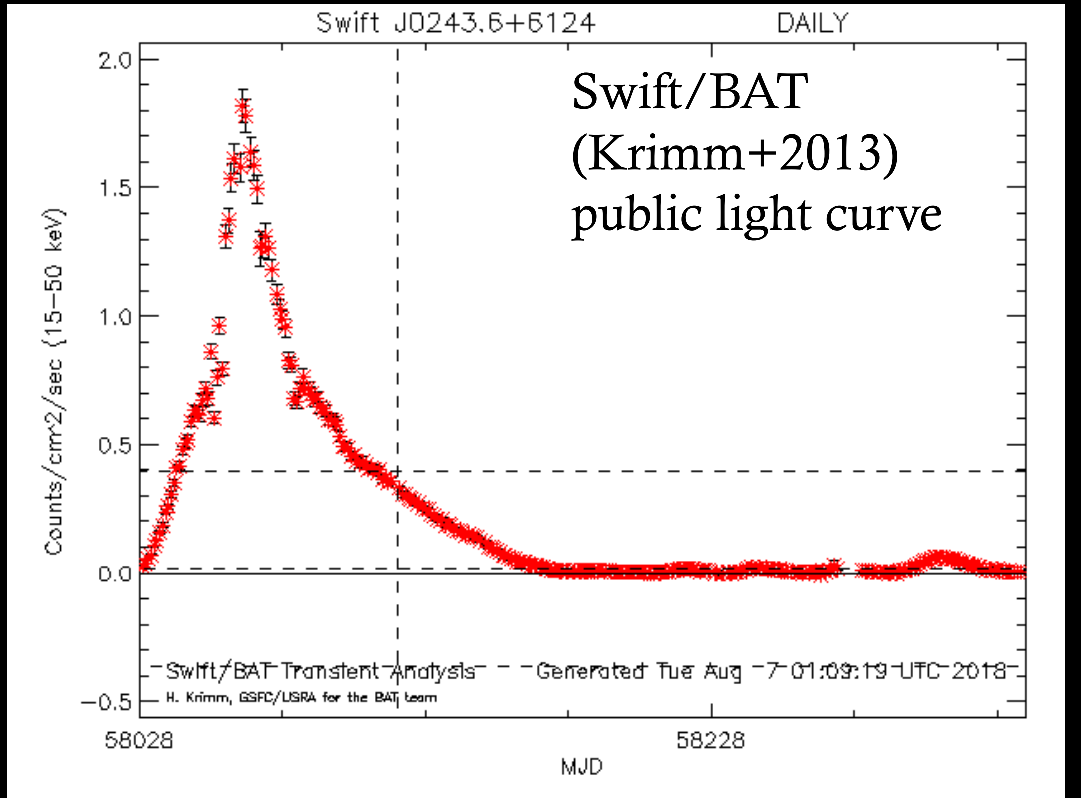
GX 1+4



A New Super-Eddington Pulsar

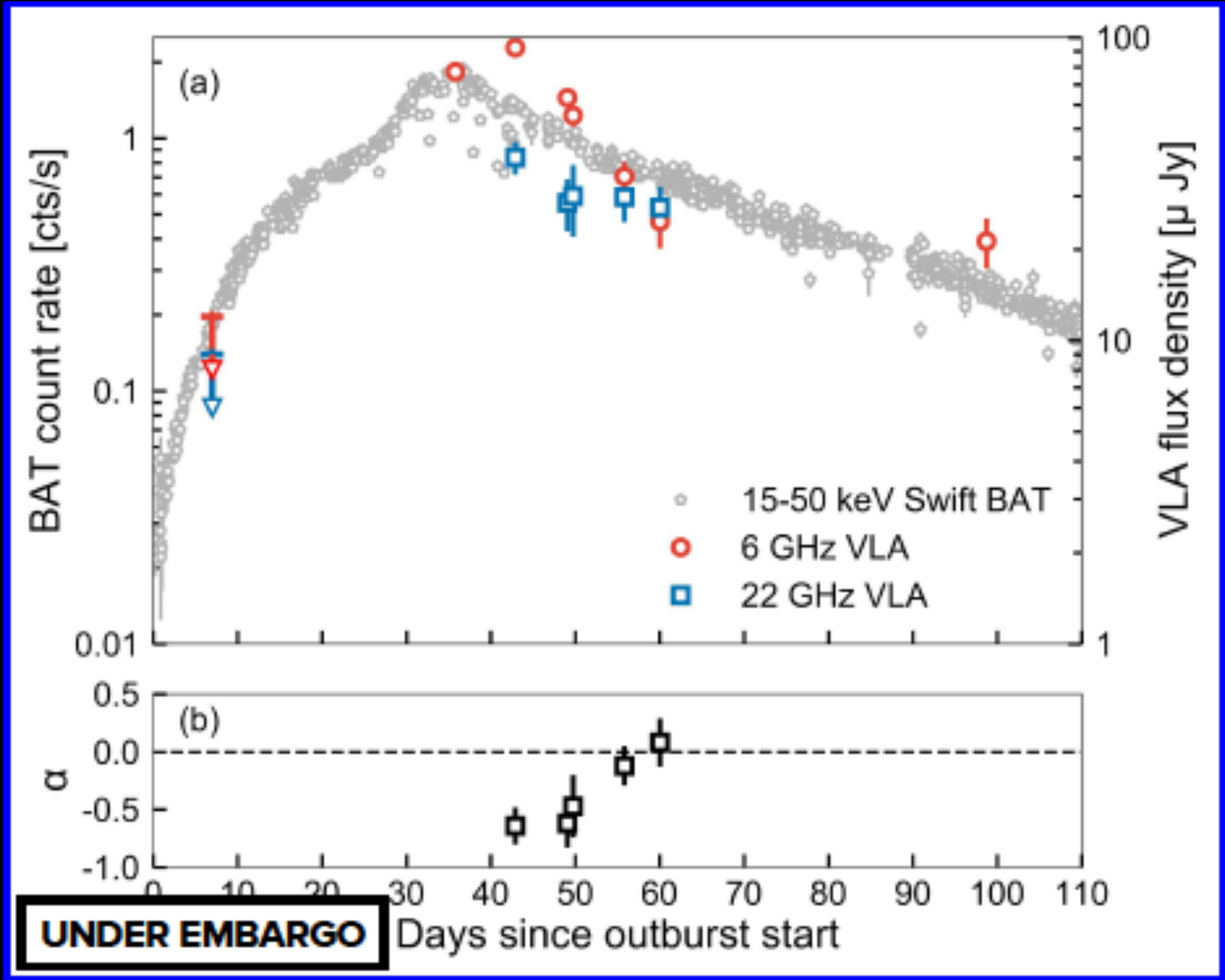
Swift J0243.6+6124
9.8 s spin period
Magnetic field ~10^{12} G

Be-star companion
Orbital period 27.6 days



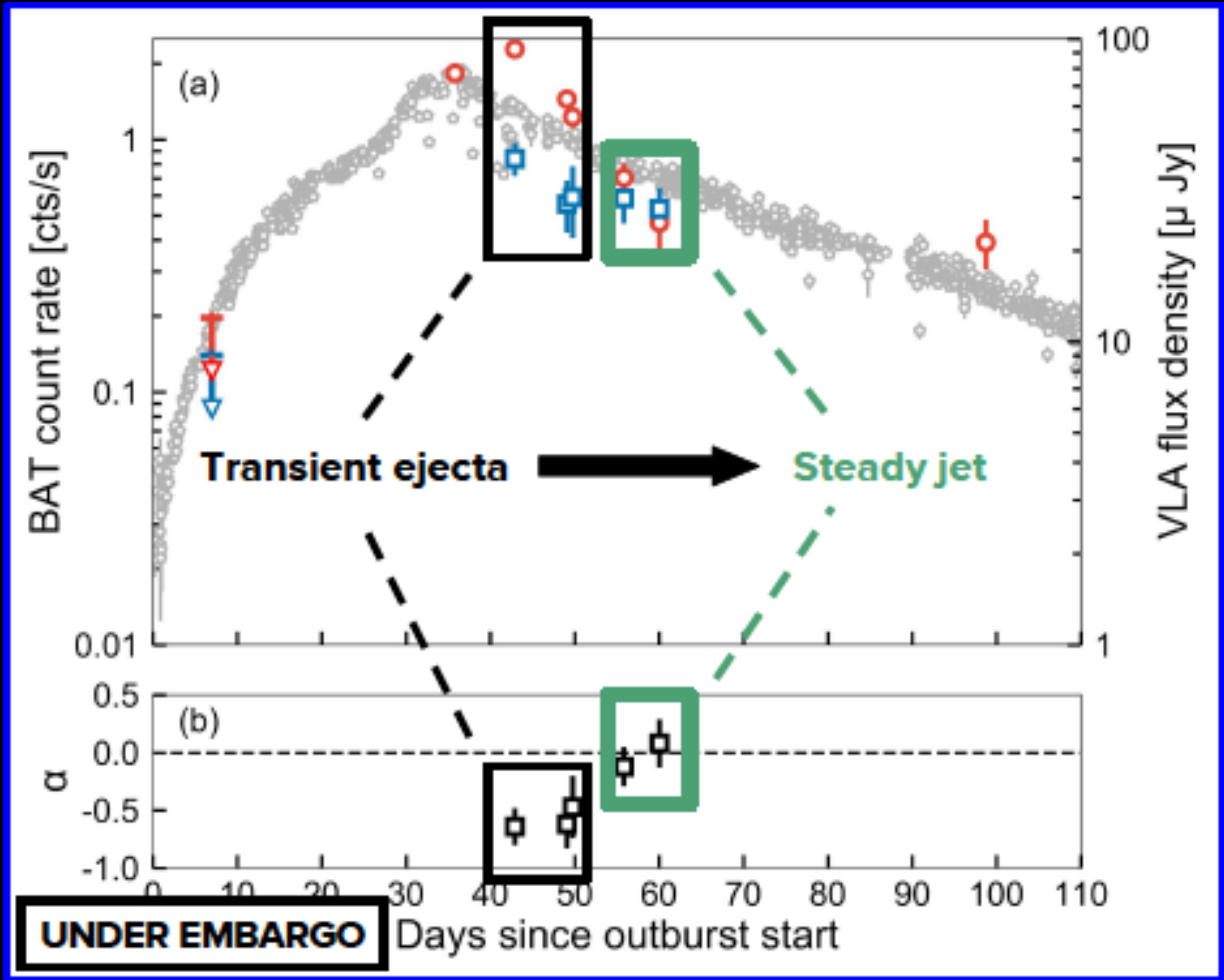
Distance >5 kpc (Gaia DR2)
Outburst peak >10^{39} erg/s → Super-Eddington

Radio Jet Emission High-B NS



Van den Eijnden et al., Nature accepted

Radio Jet Emission High-B NS



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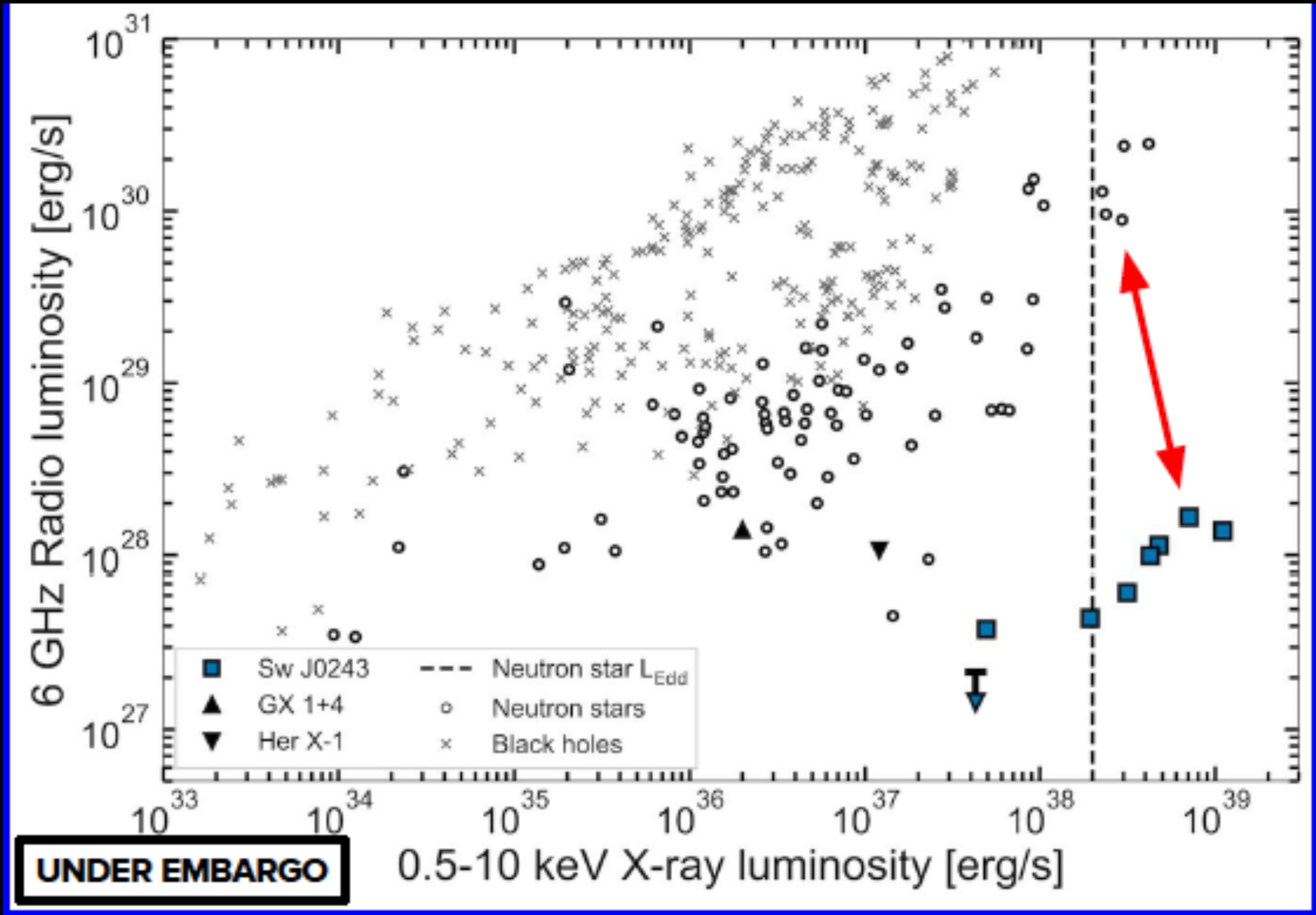

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Implications of Jet Detection

- Jet launching mechanisms neutron stars
  Classical jet model (Blandford-Payne) ruled out
  ``Blandford-Znajek type'' model (Parfrey+2016, 2017)

- Test parameters that may determine jet power
  Spin dependance (~5-1000 s!), spin up vs spin down

- Accretion geometry in Be/X-ray binaries
  Jets during type-I outbursts (periastron)?

- Super-Eddington accretion regime
  ULX pulsars can launch jets

Summary: News & Questions

✧Power and mass-loss rates of winds and jets?
Impact environment, binary evolution

✧Link between winds and jets?
Exist together at high and low accretion rate?

✧X-ray bursts as repeating probes of outflows
May destruct jets, launch winds

✧Neutron stars with strong B fields produce jets
Study jet formation + accretion coupling

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Netherlands Organisation for Scientific Research

July 1-3, 2019:
Outflows in Amsterdam

Focused workshop on
"Outflows in black holes, neutron stars and white dwarfs"
Jets, winds, magnetic propellers, accretion regimes

SOC & LOC: Nathalie Degenaar, Thomas Russell
Juan Hernández Santisteban, Jakob van den Eijnden