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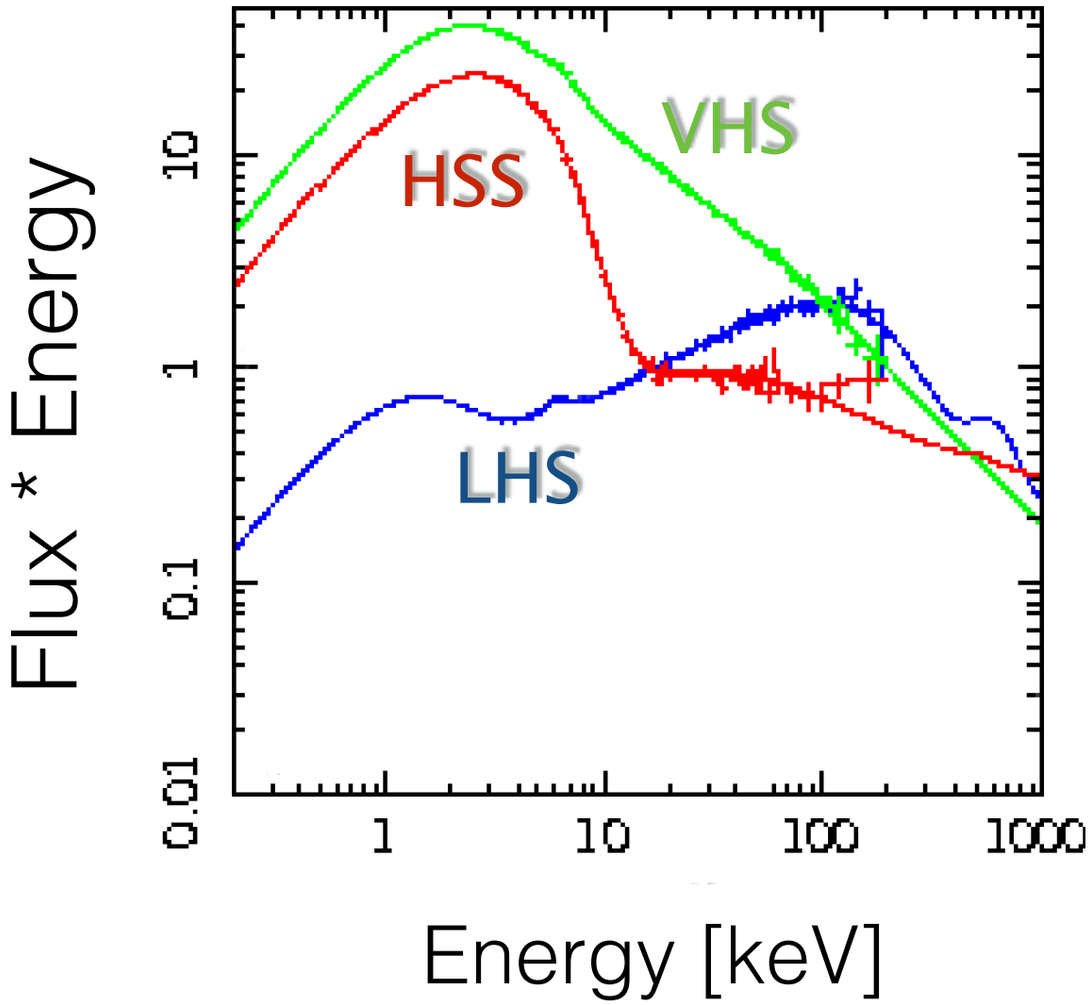
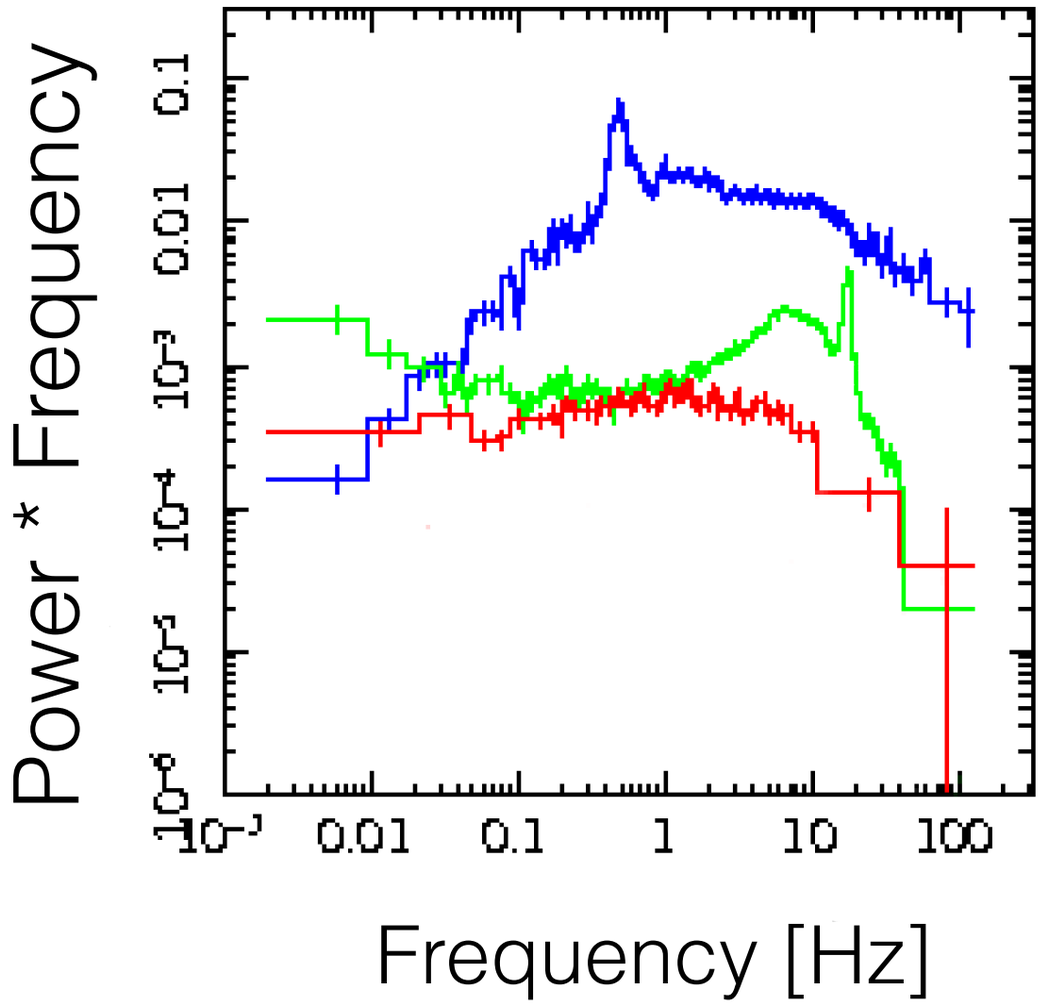
Quantitative tests of *propagating mass accretion rate fluctuations*: achievements and challenges

Stefano Rapisarda
Adam Ingram
Michiel van der Klis

University of Amsterdam



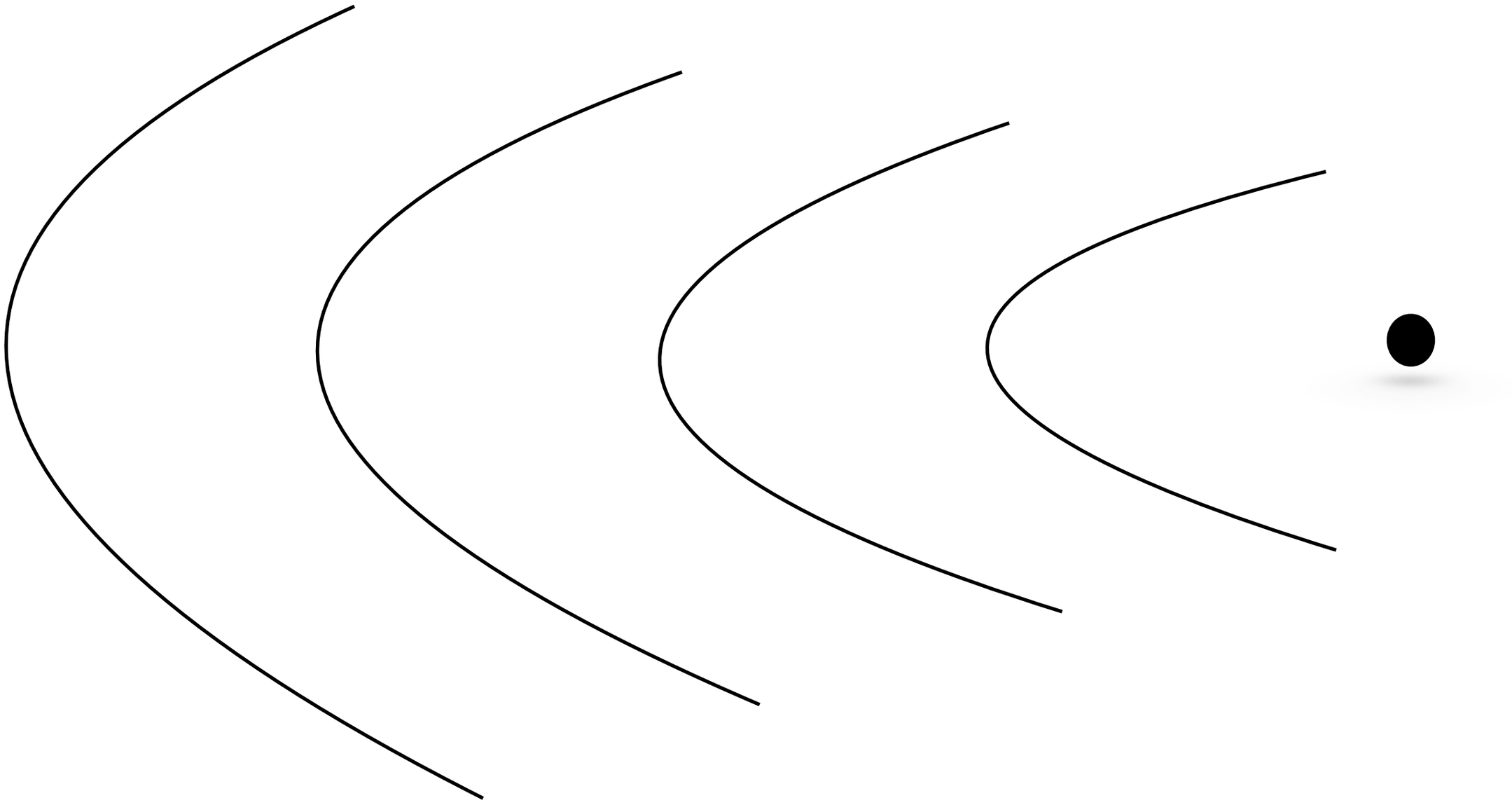


VHS Very-High State

HSS High-Soft State

LHS Low-Hard State

(Done 2010)



Propagating fluctuations: ingredients for the recipe

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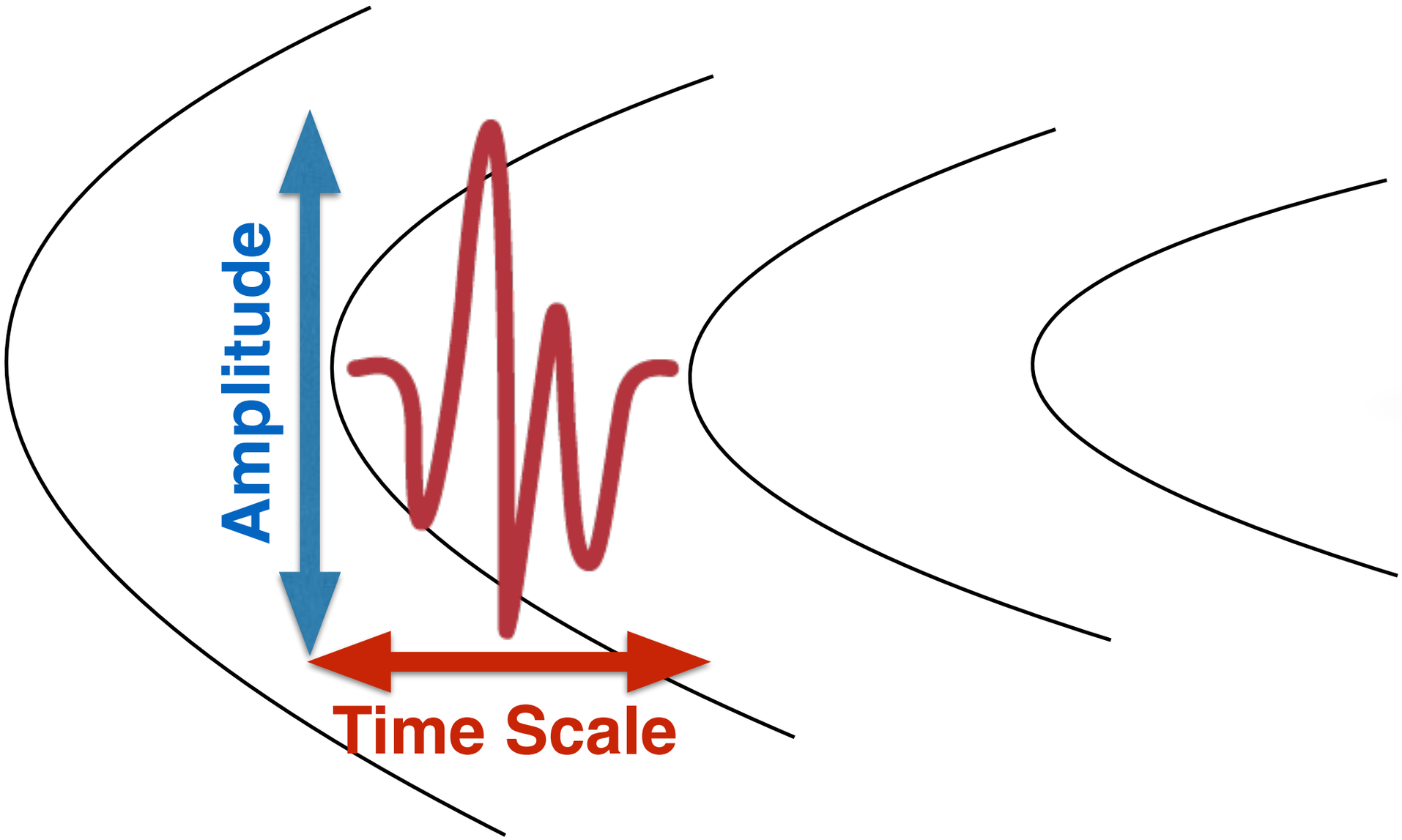

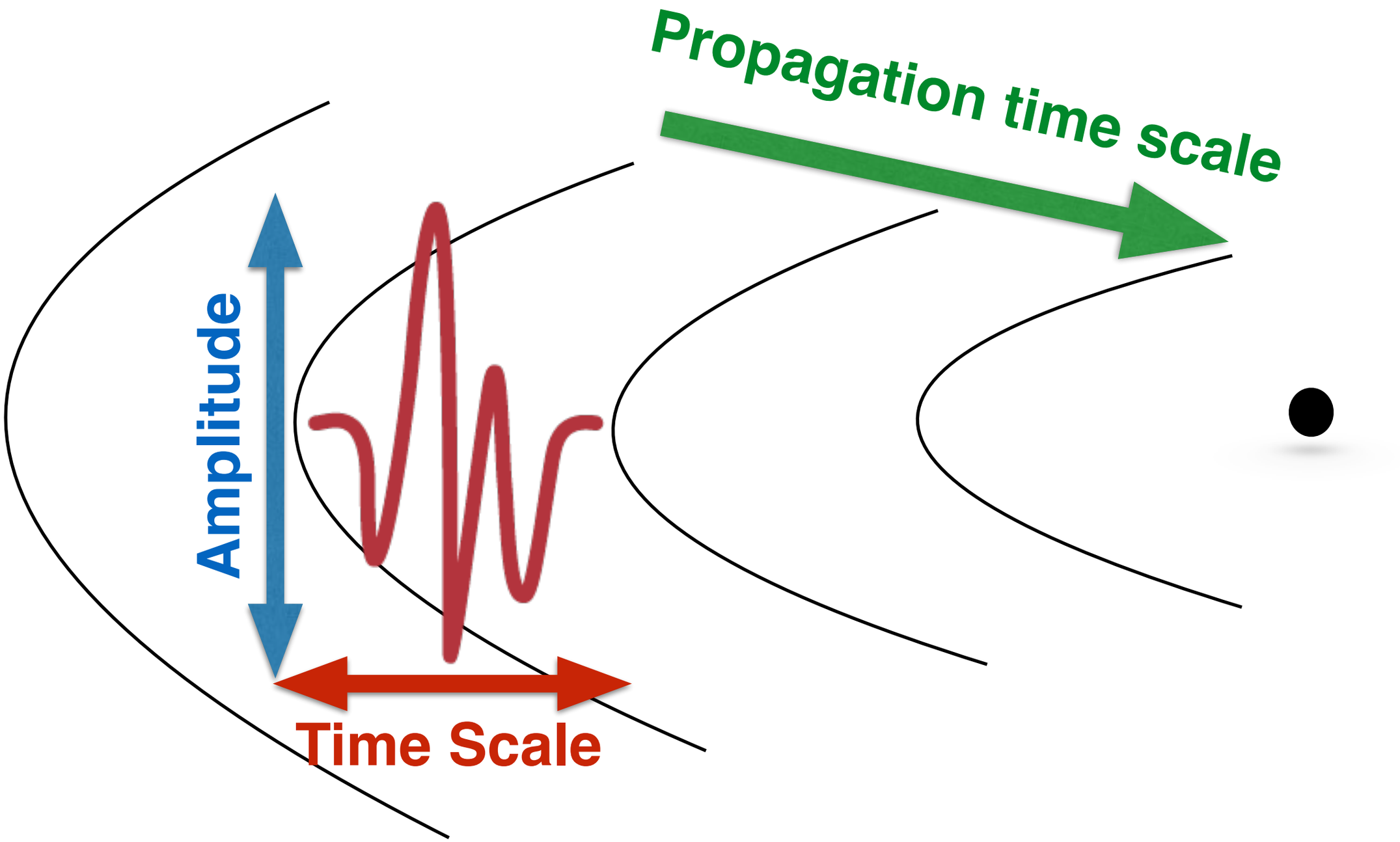
Propagation time scale
Amplitude
Time Scale

Propagating fluctuations: ingredients for the recipe

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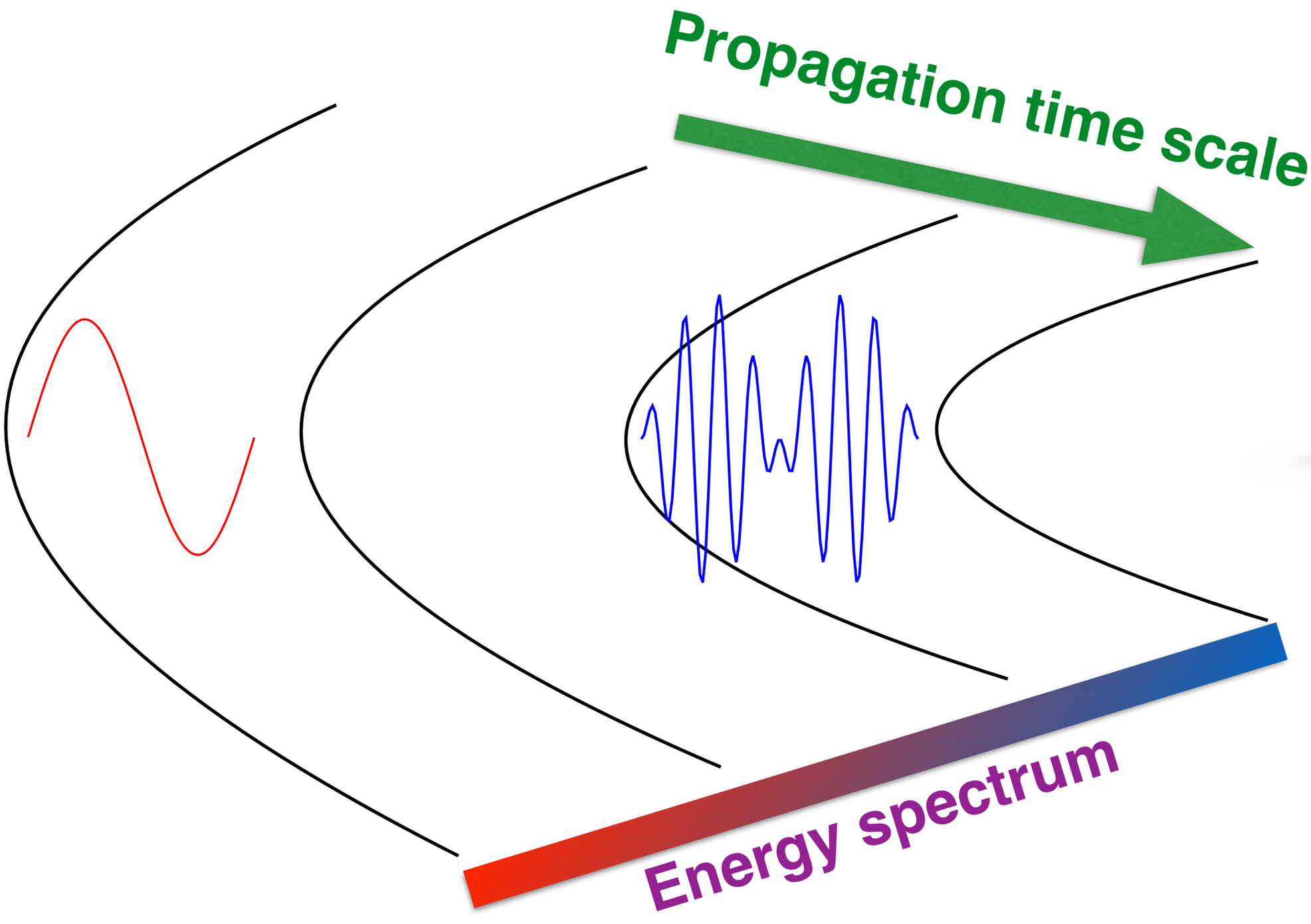

Propagating fluctuations: ingredients for the recipe

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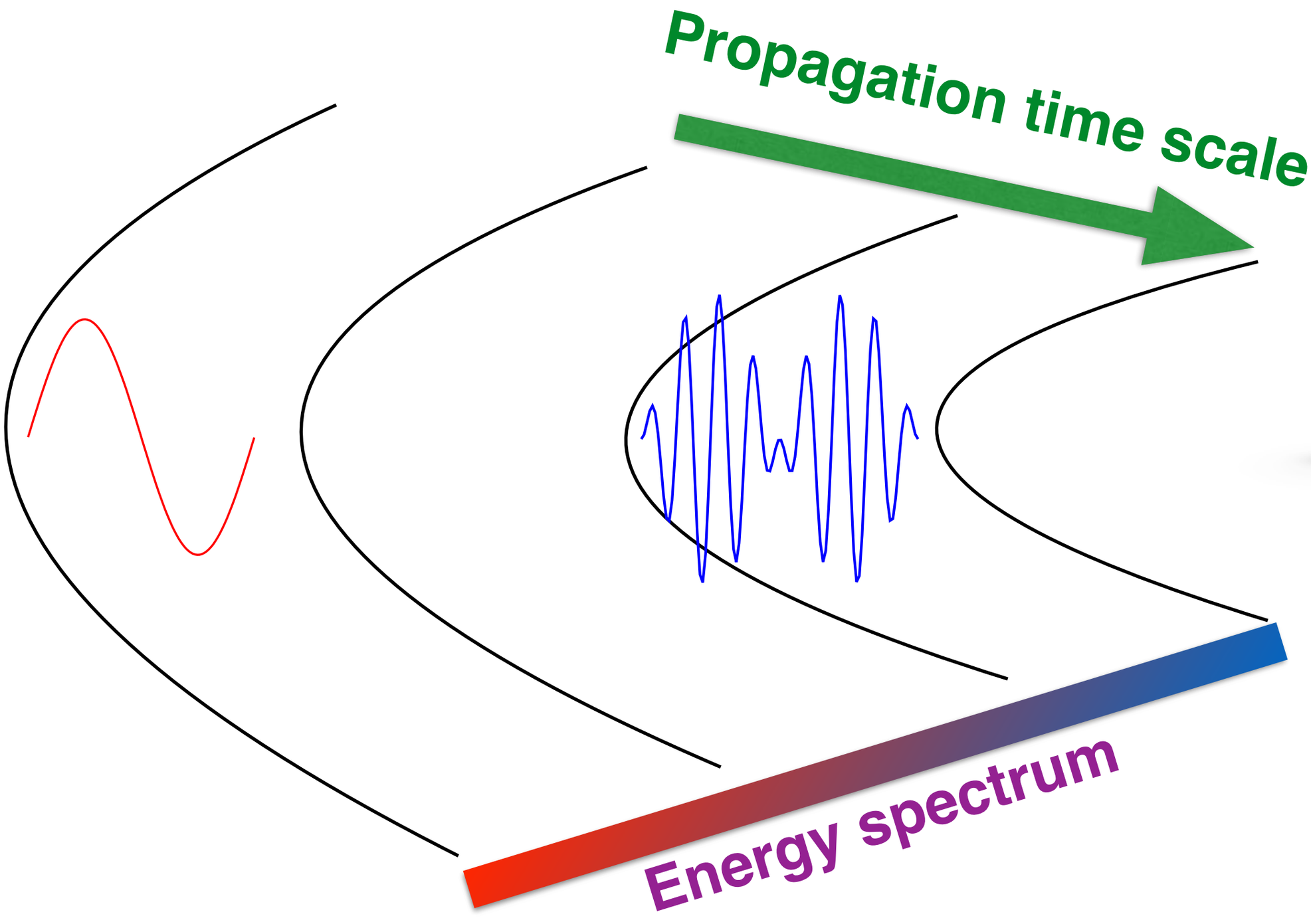
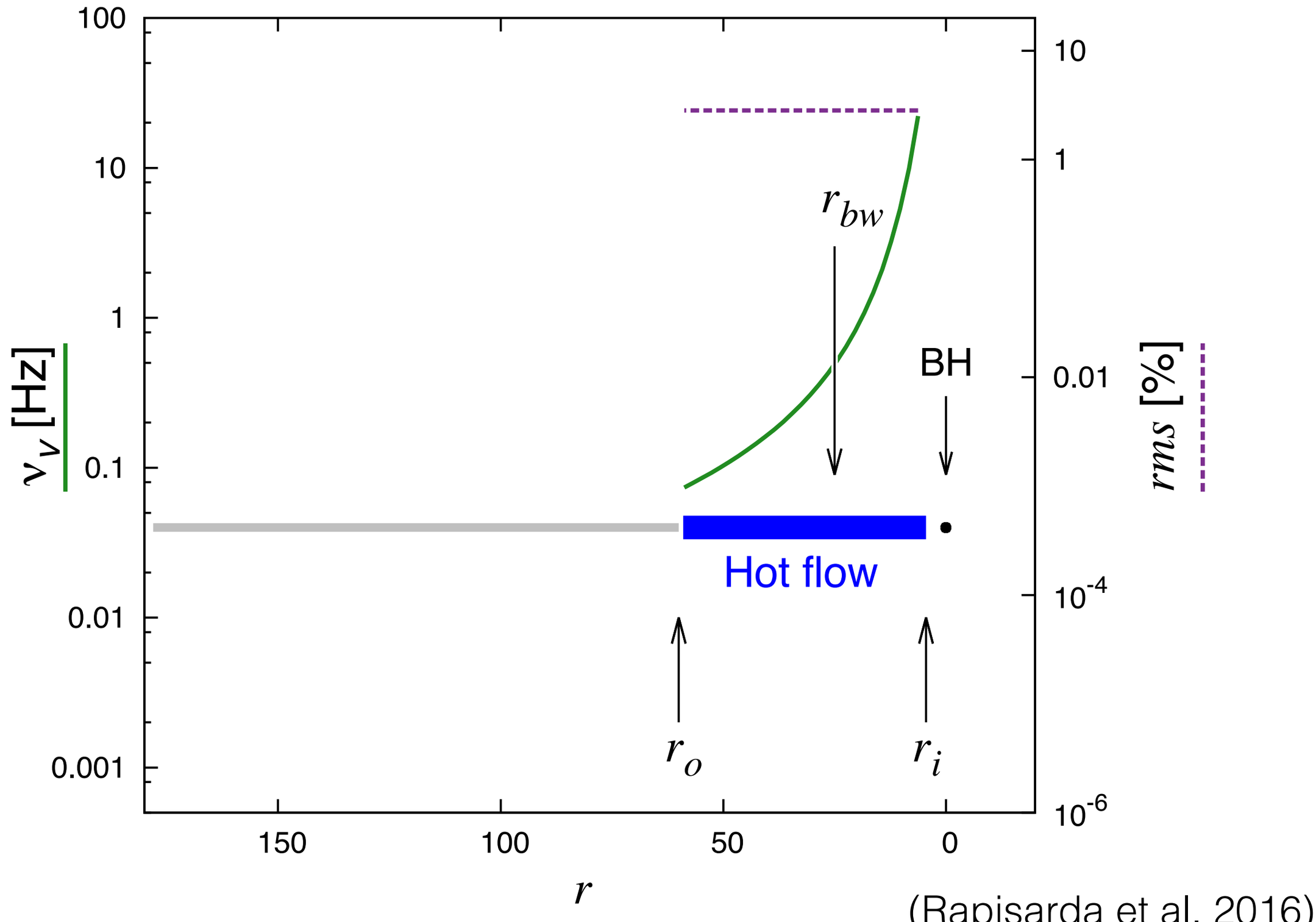


- Lyubarskii 1997 → first analytical model
- Kotov et al. 2001 → phenomenological model
- Arevalo & Uttley 2006 → computational model
- *Ingram & Done 2012* → PROPFLUC
- Ingram & van der Klis 2013 → analytical solutions
- Rapisarda et al. 2014
- Rapisarda et al. 2016

→ Model implementations
First systematic applications

PROPFLUC: the main assumptions



(Rapisarda et al. 2016)

PROPFLUC single hump power spectrum

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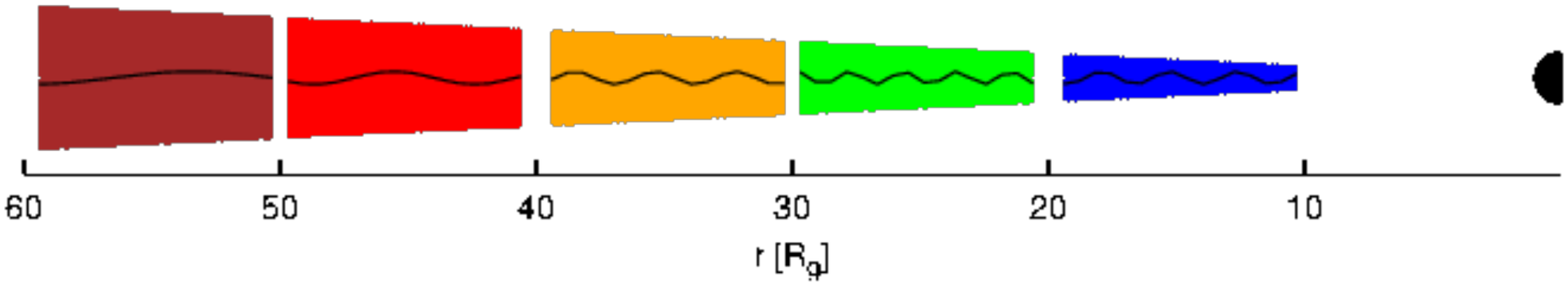

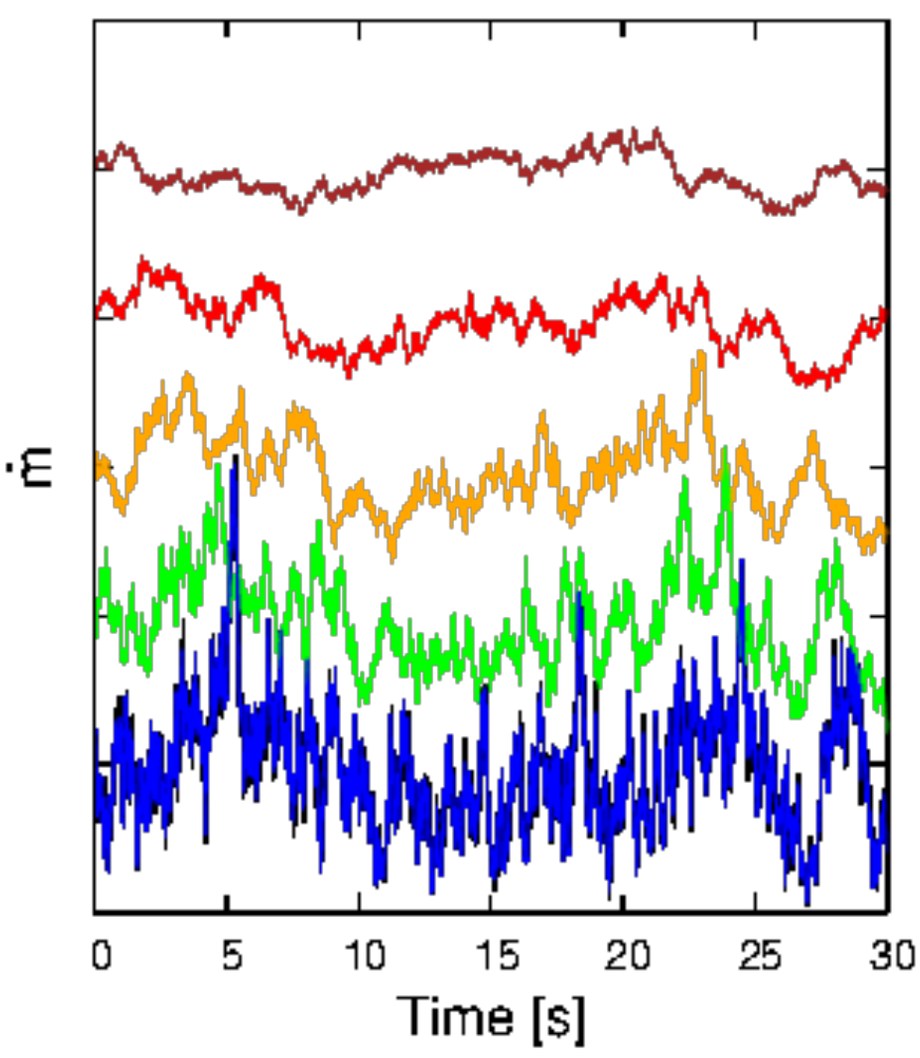

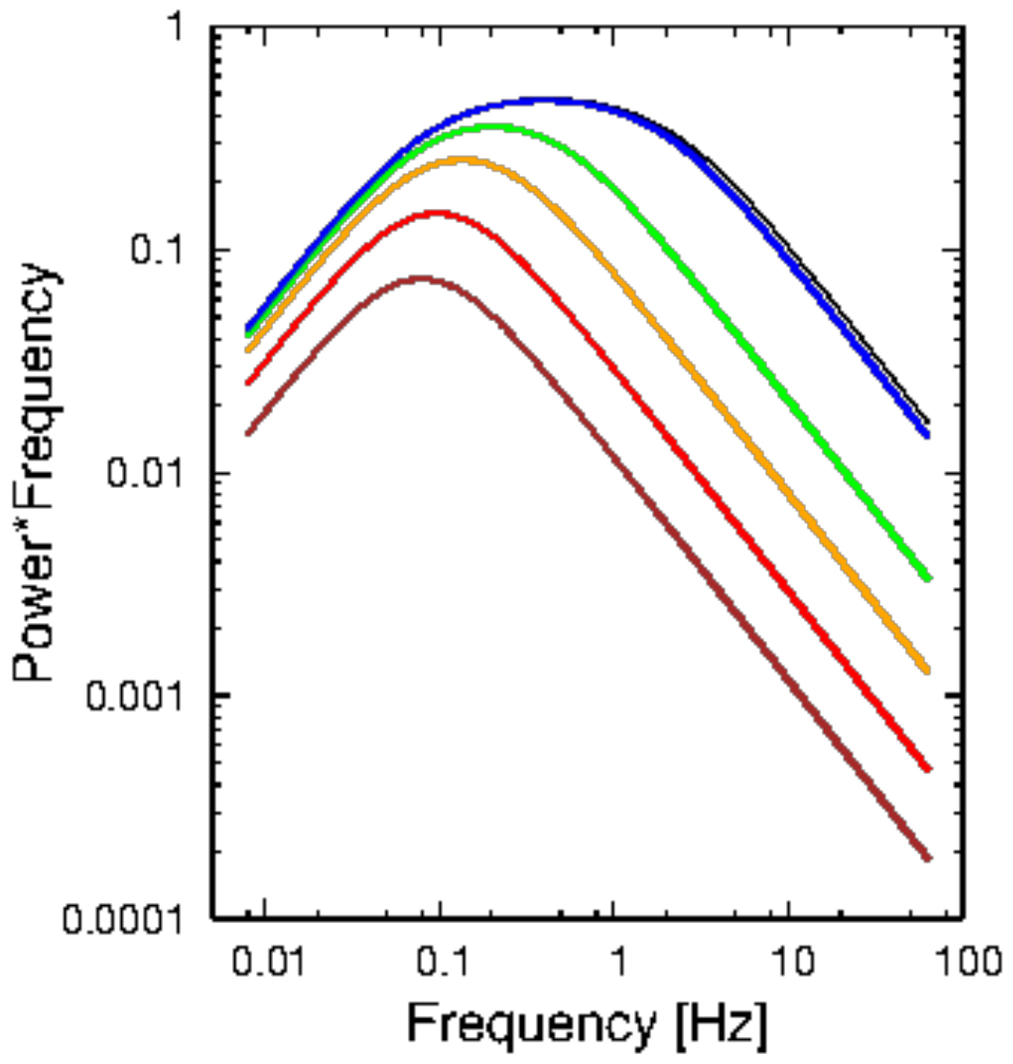

Introducing PROPFLUC

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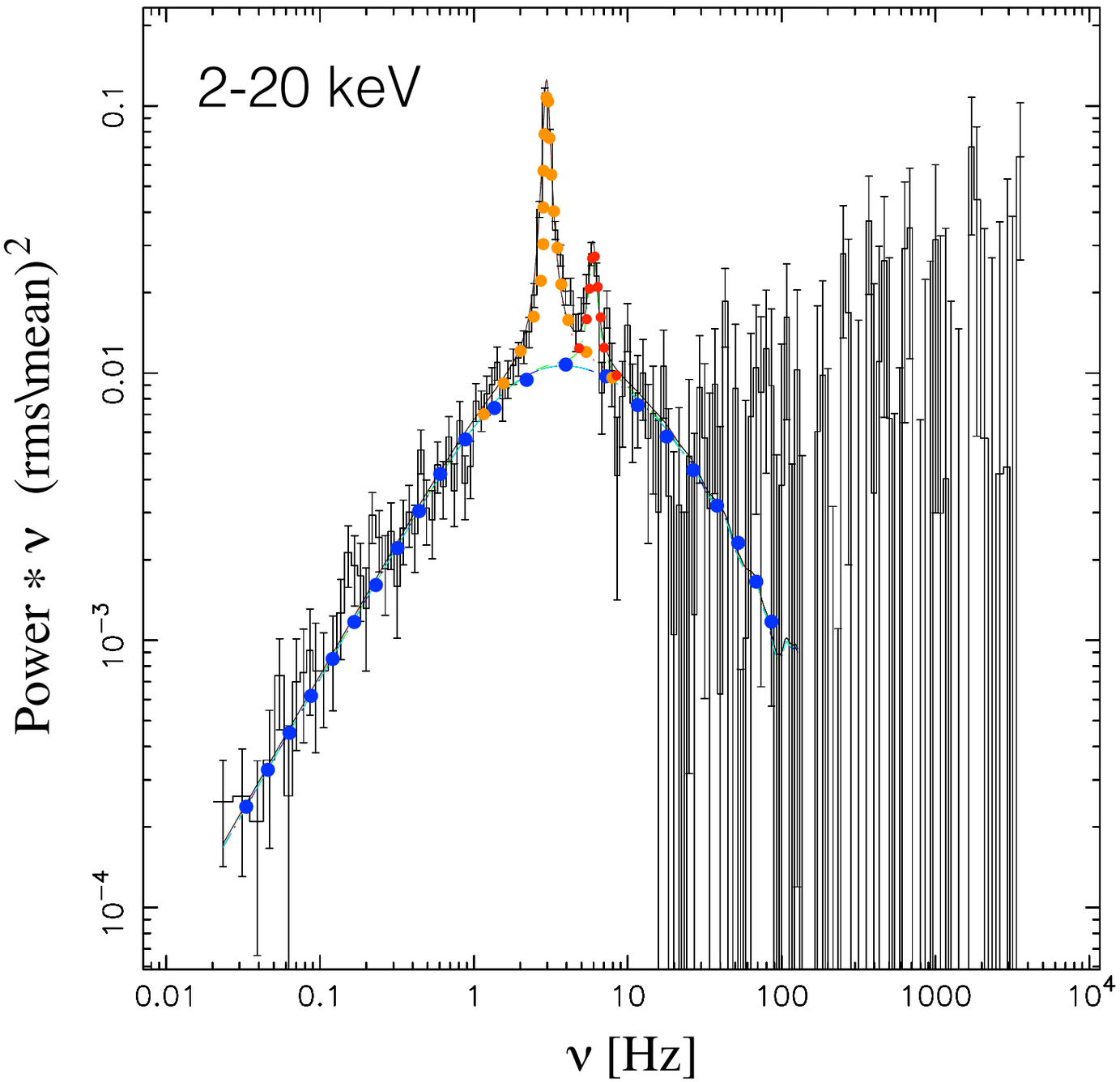

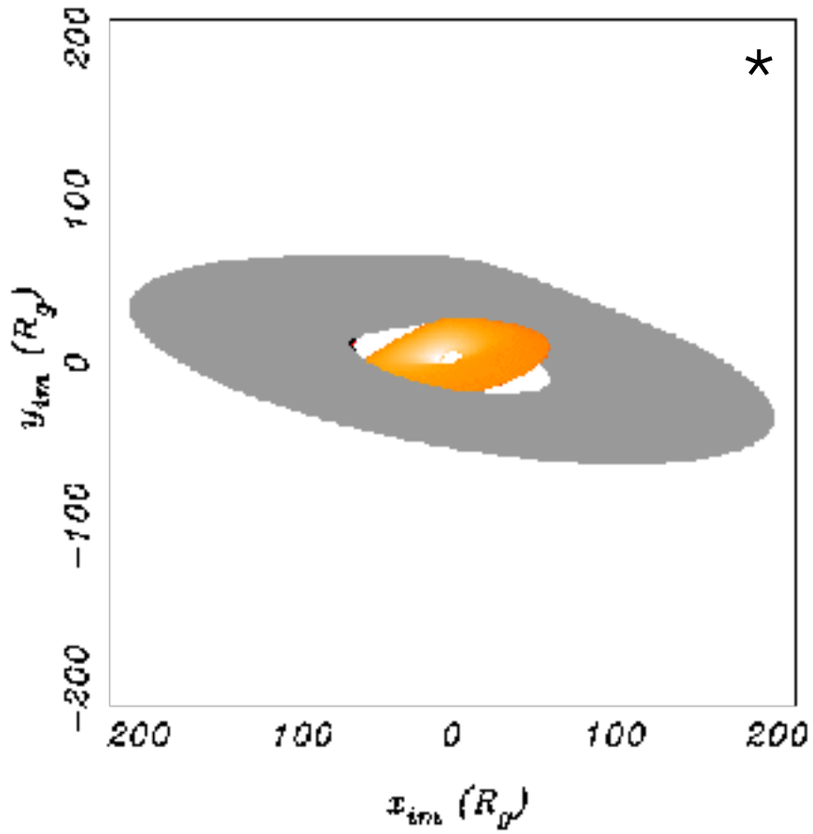

- Propagating fluctuations
- Precession of the inner flow

Figure courtesy of A. Ingram (*)

Propagating fluctuations: the main assumptions

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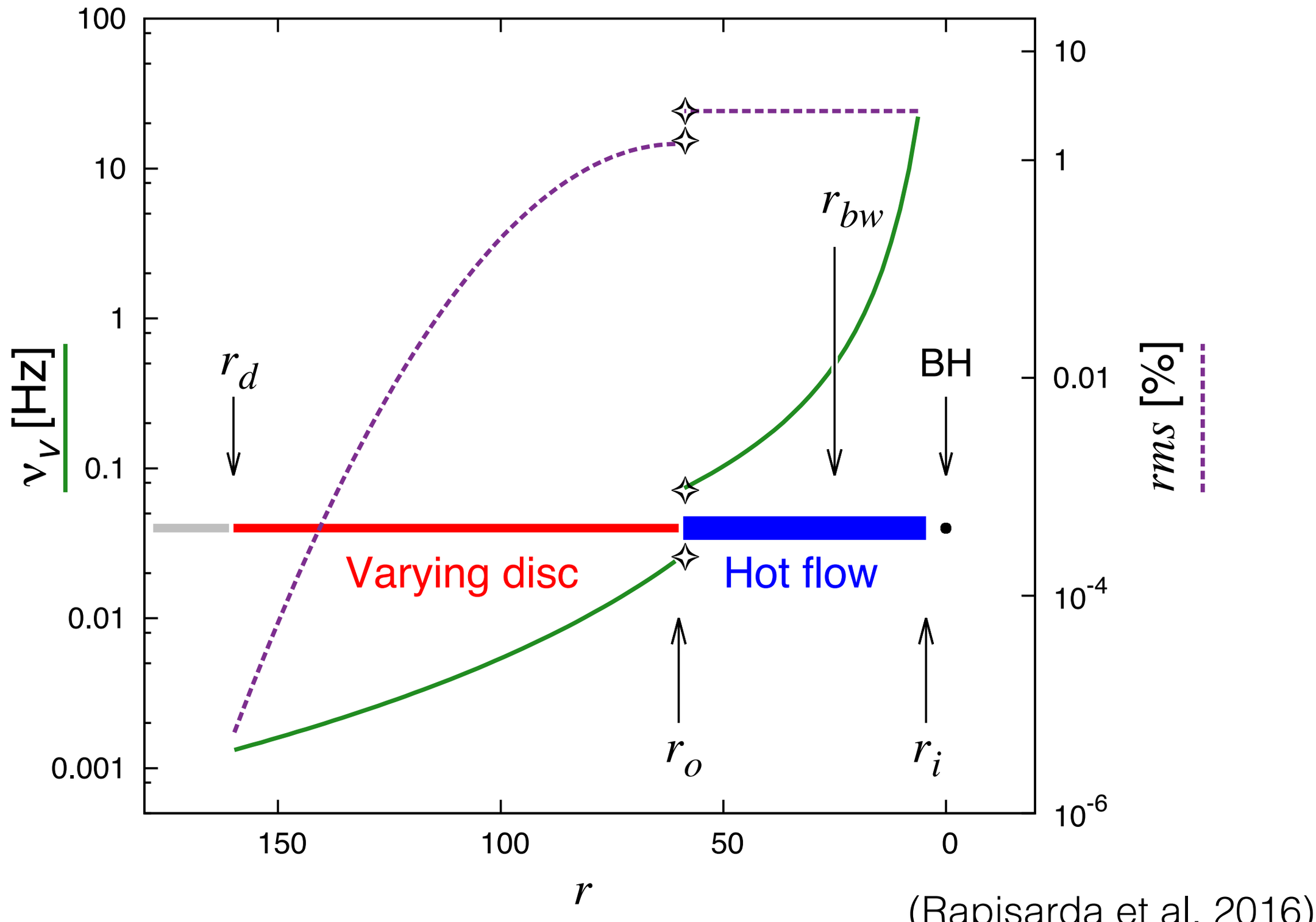

(Rapisarda et al. 2016)

Propagating fluctuations: the main assumptions

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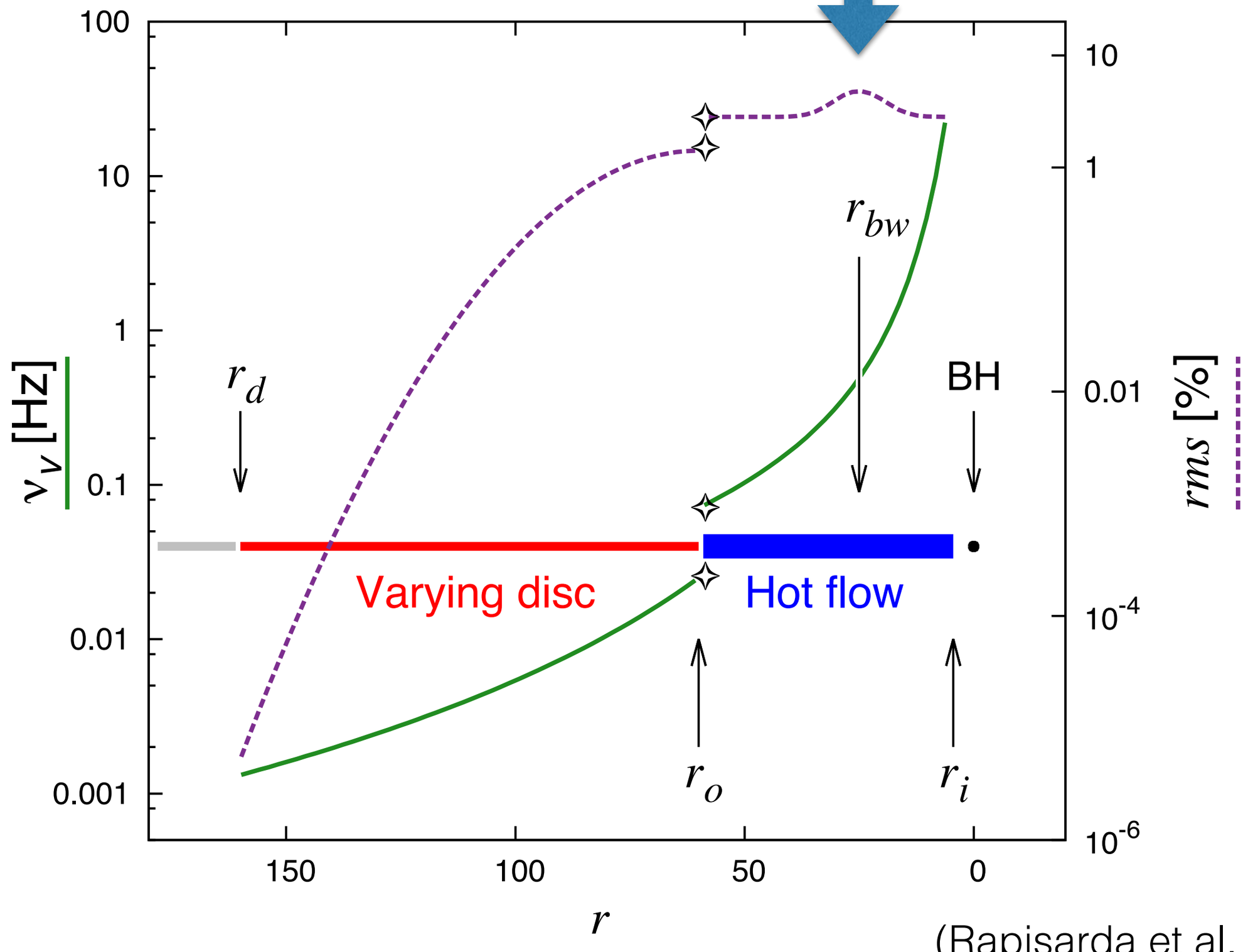

(Rapisarda et al. 2016)

Propagating fluctuations: three hump power spectrum

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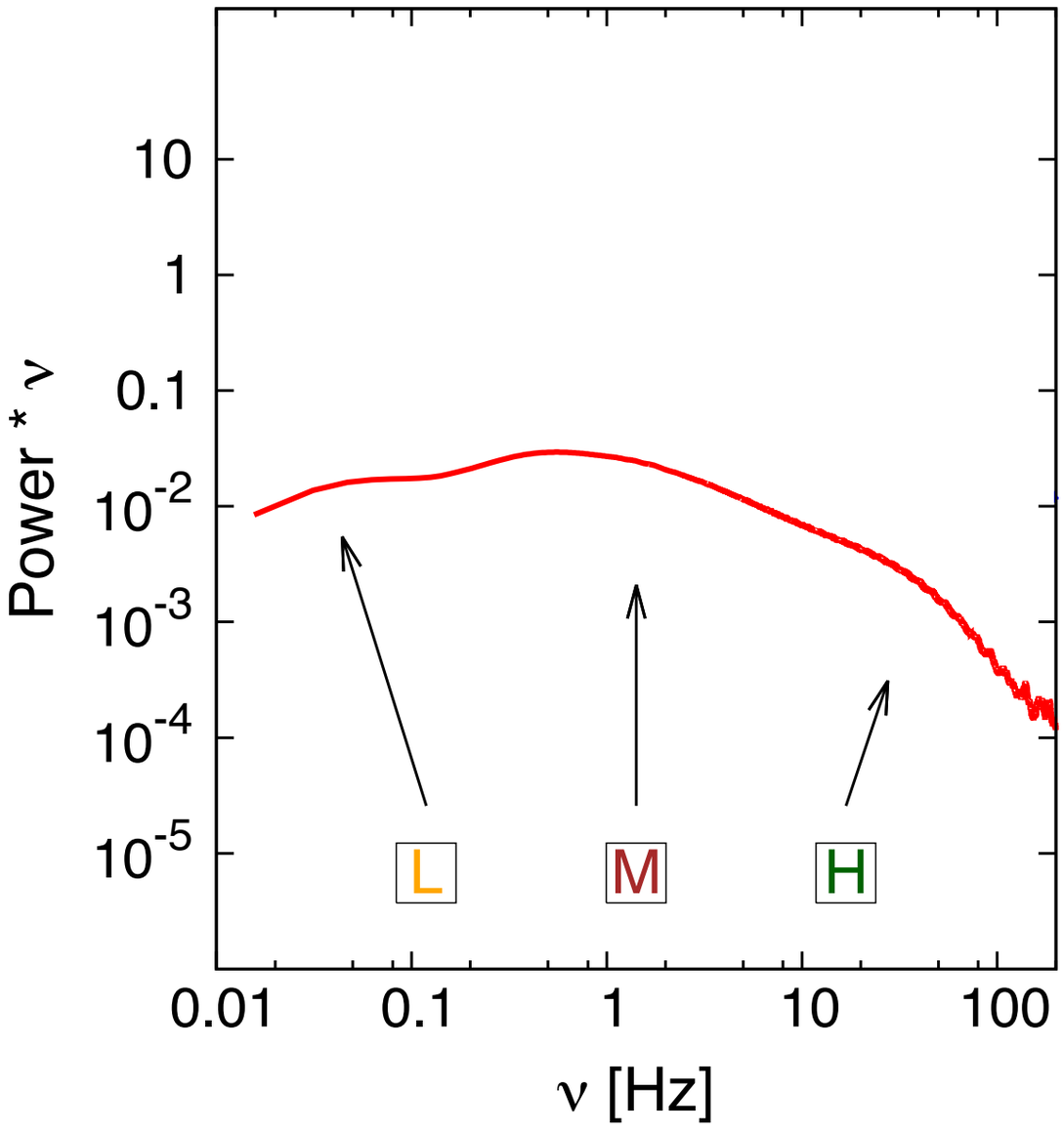

Propagating fluctuations: three hump power spectrum

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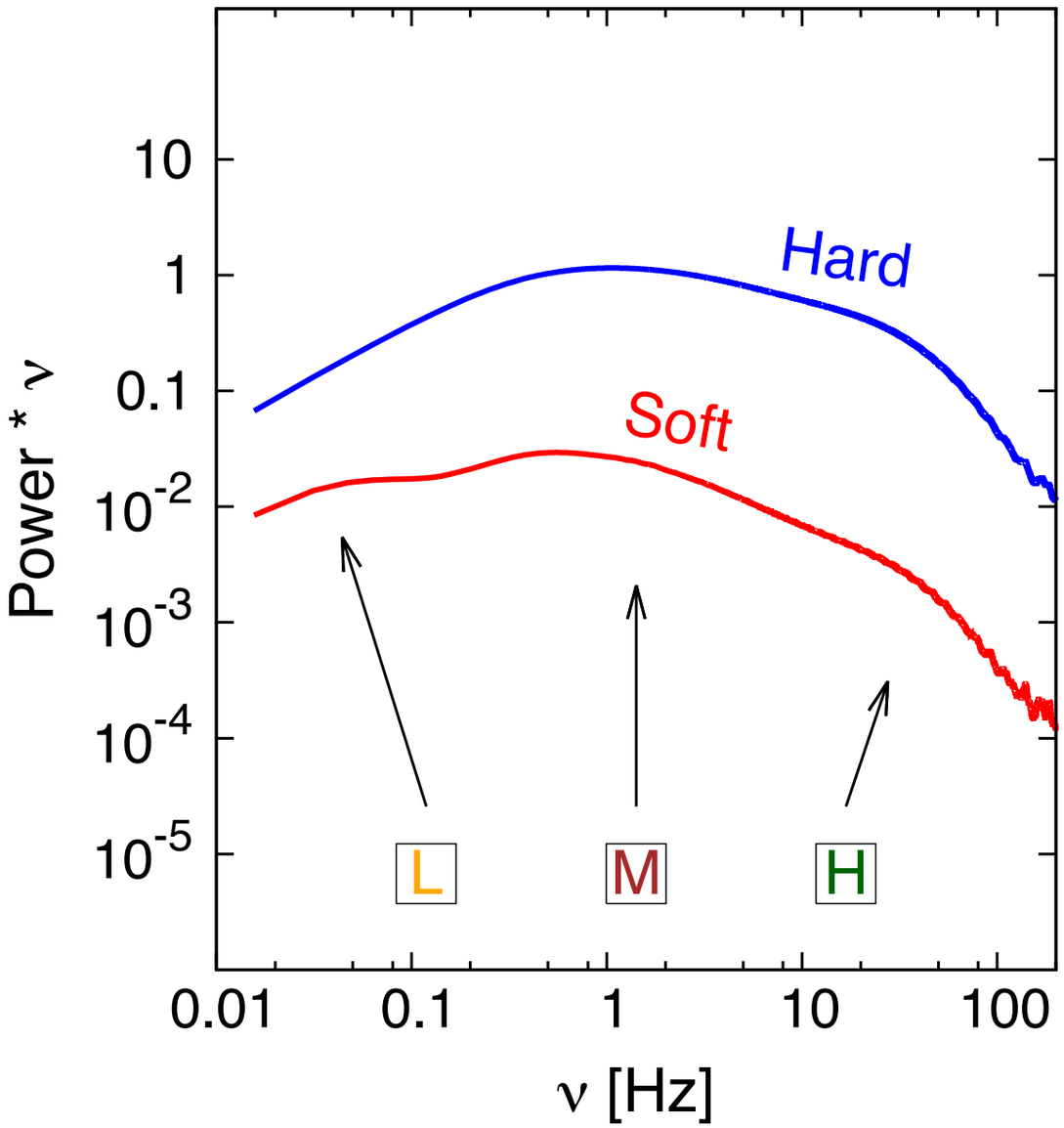
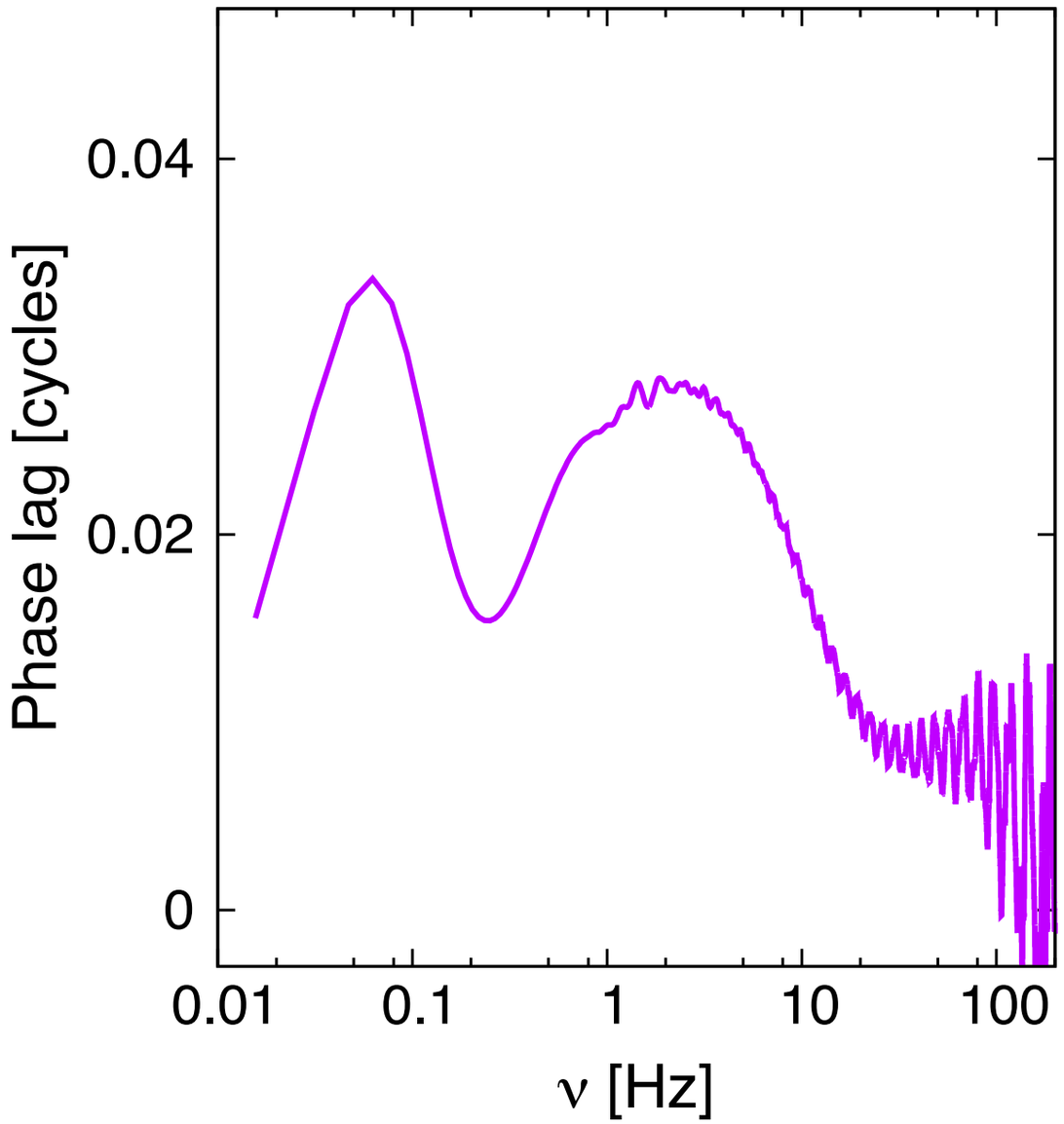
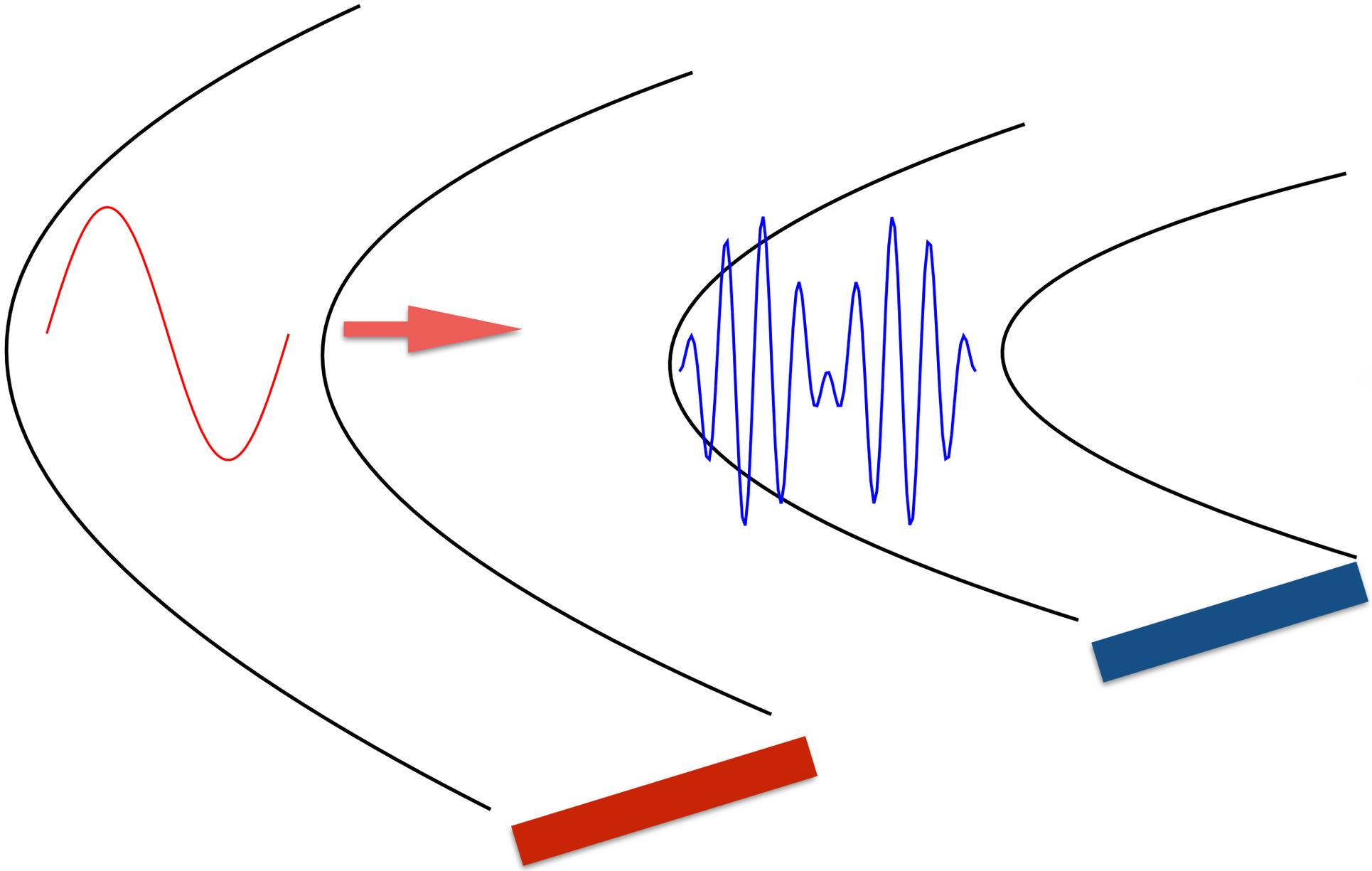
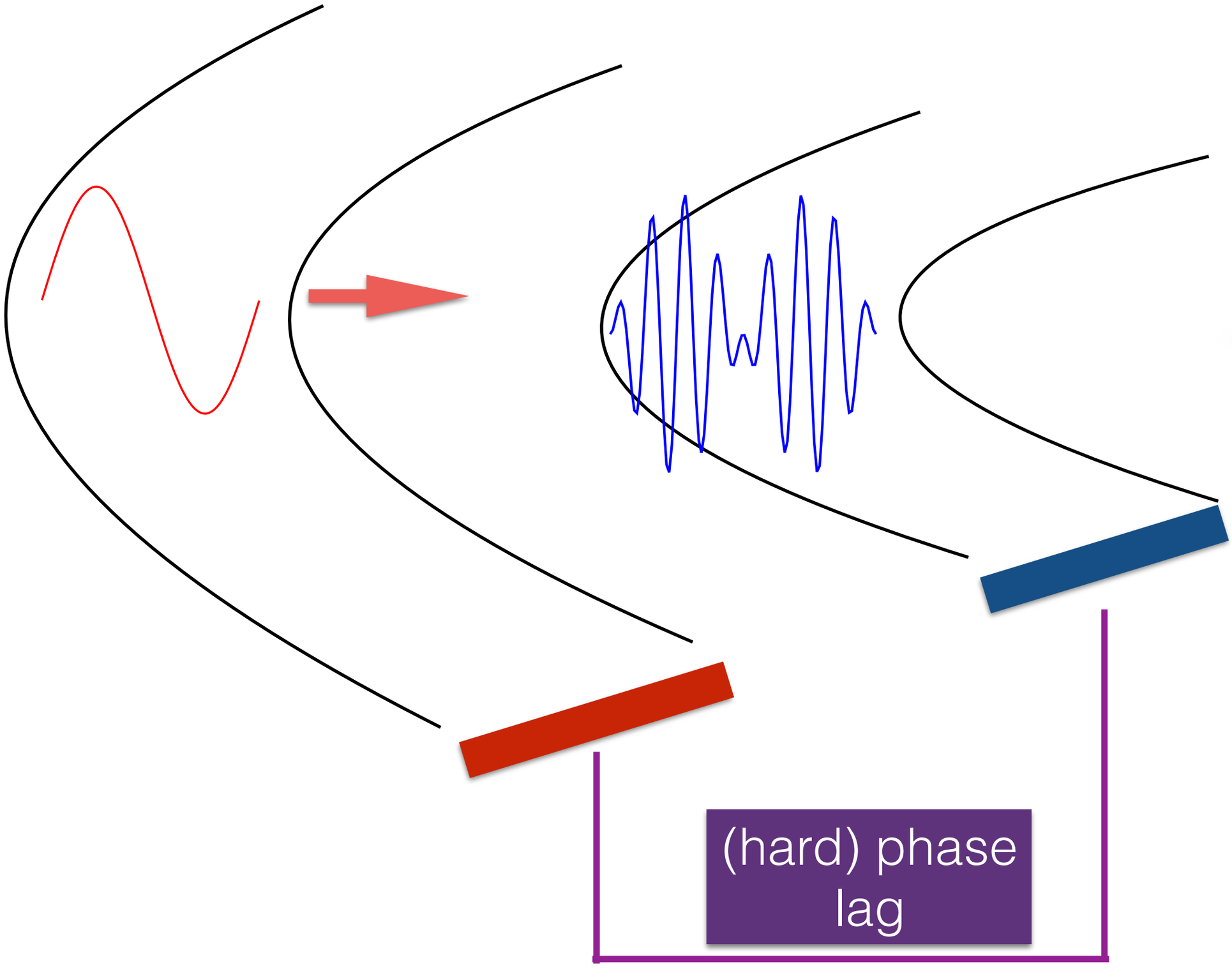




Propagating fluctuations: ingredients for the recipe



Propagating fluctuations: ingredients for the recipe



- Lyubarskii 1997

- Kotov et al. 2001 → phenomenological model
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- Ingram & Done 2011/12 → PROPFLUC
- Ingram & van der Klis 2013 → analytical solutions

- Rapisarda et al. 2014
- *Rapisarda et al. 2016* → MAXI J1659-152 Swift data

Results: XTE J1550-564, 1998 LHS, obs. 1

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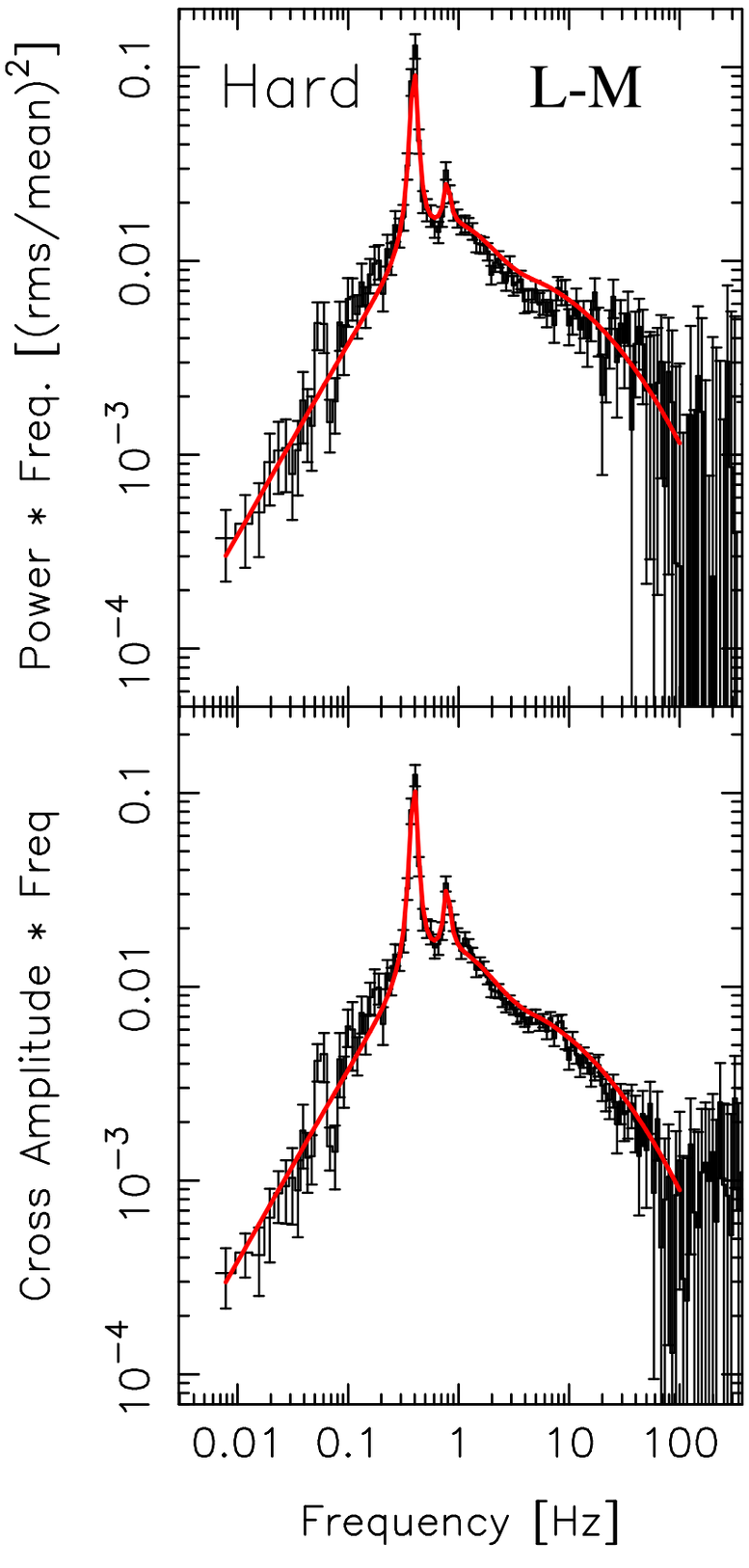

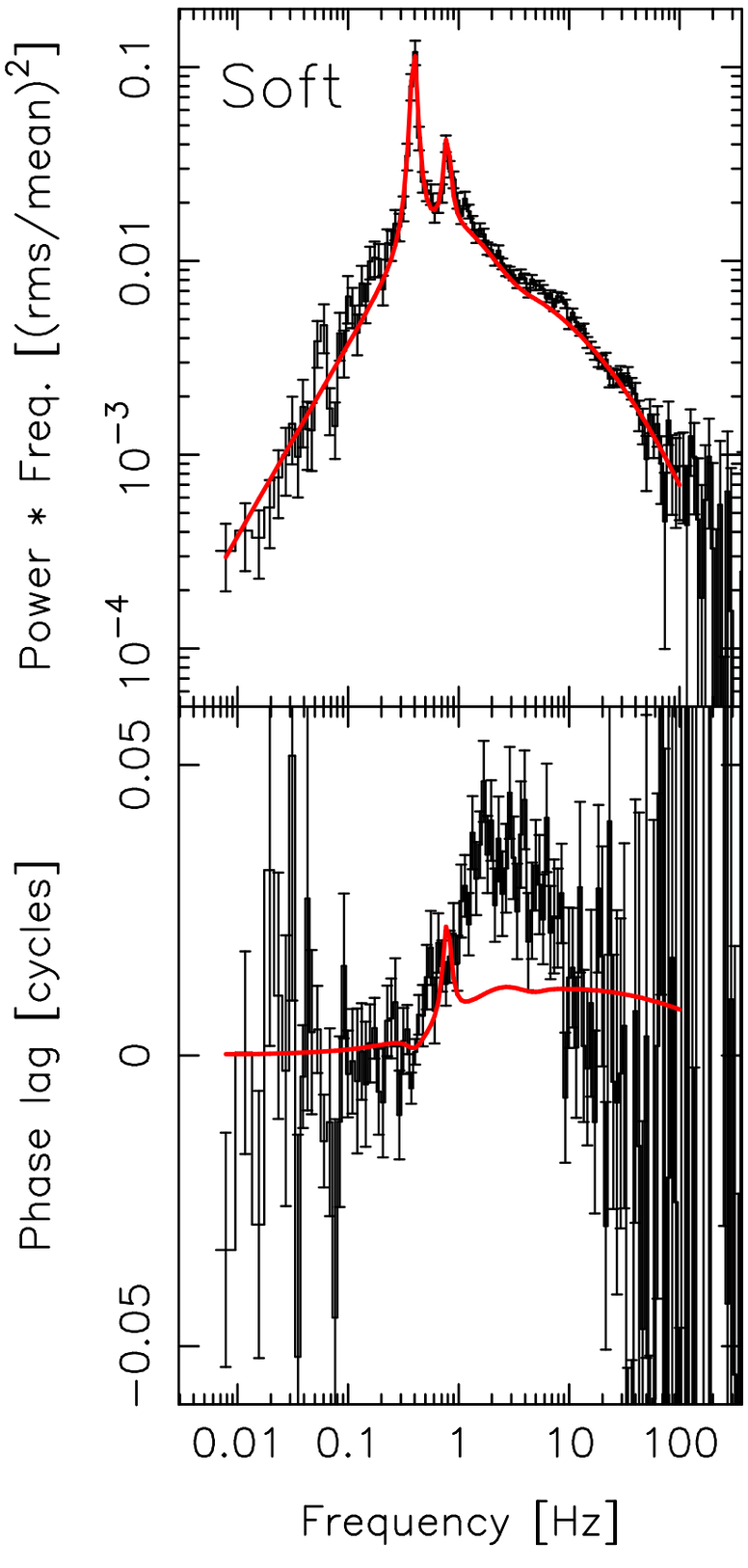

Results: XTE J1550-564, 1998 LHS, obs. 1

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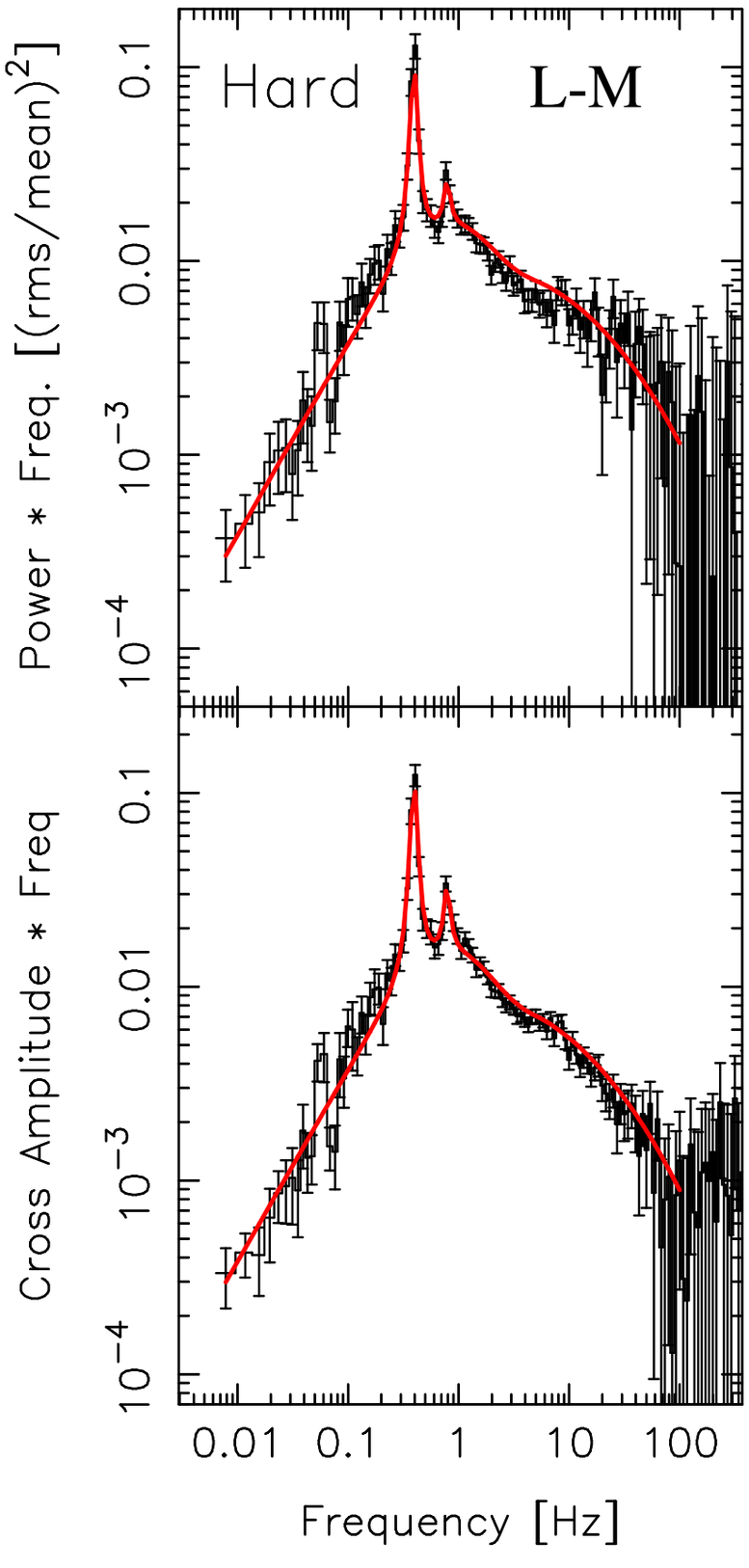

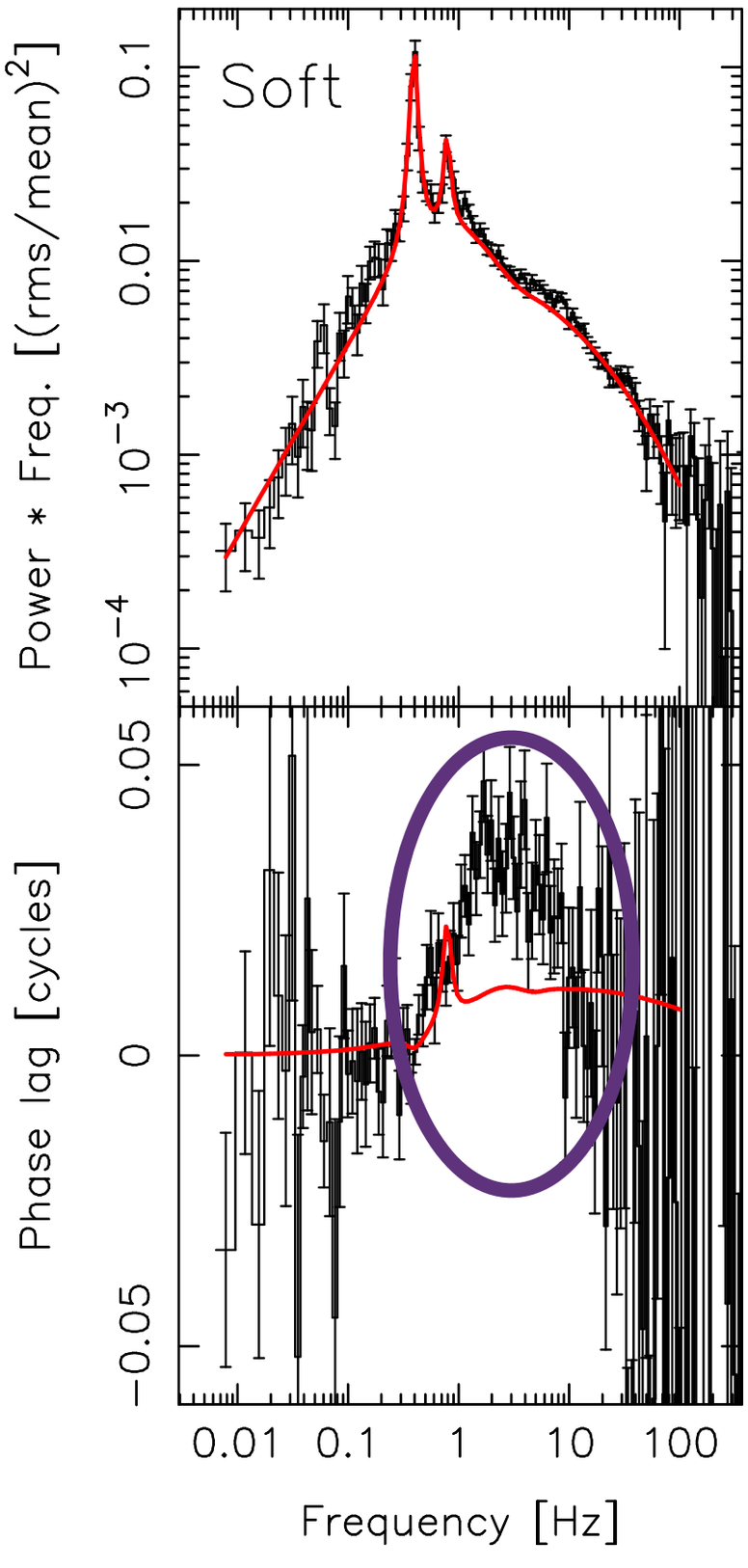

Results: XTE J1550-564, 1998 LHS, obs 2

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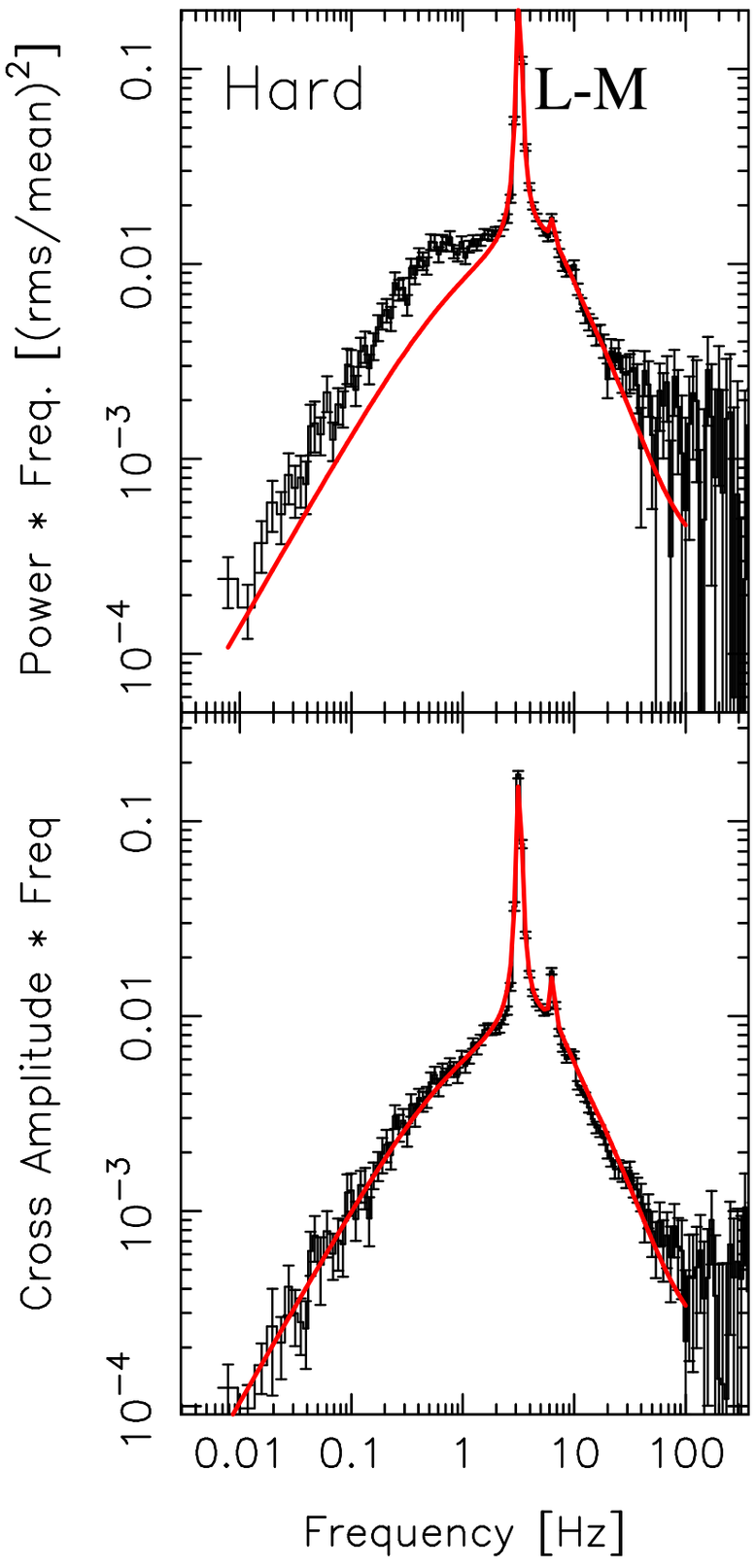

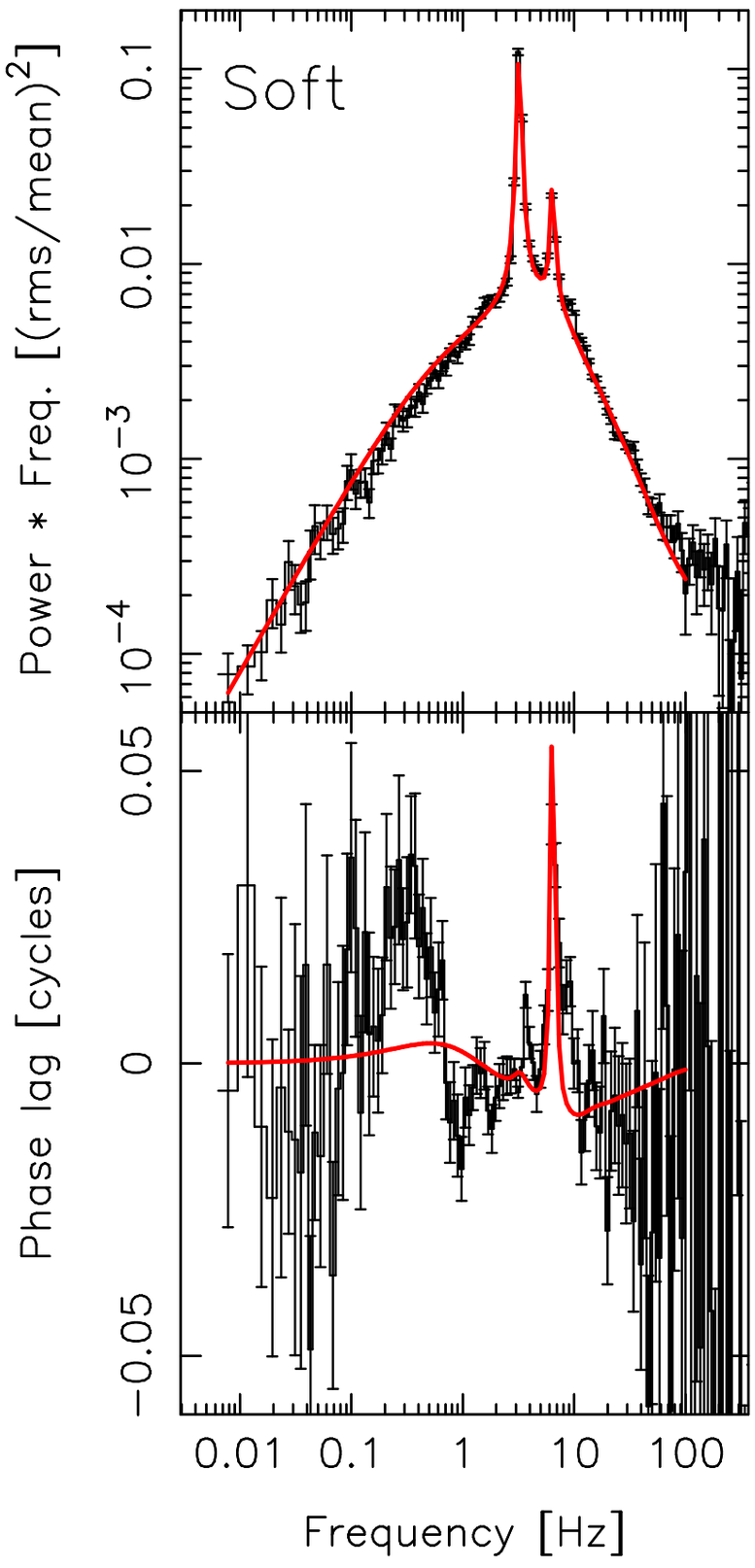

Results: XTE J1550-564, 1998 LHS, obs 2

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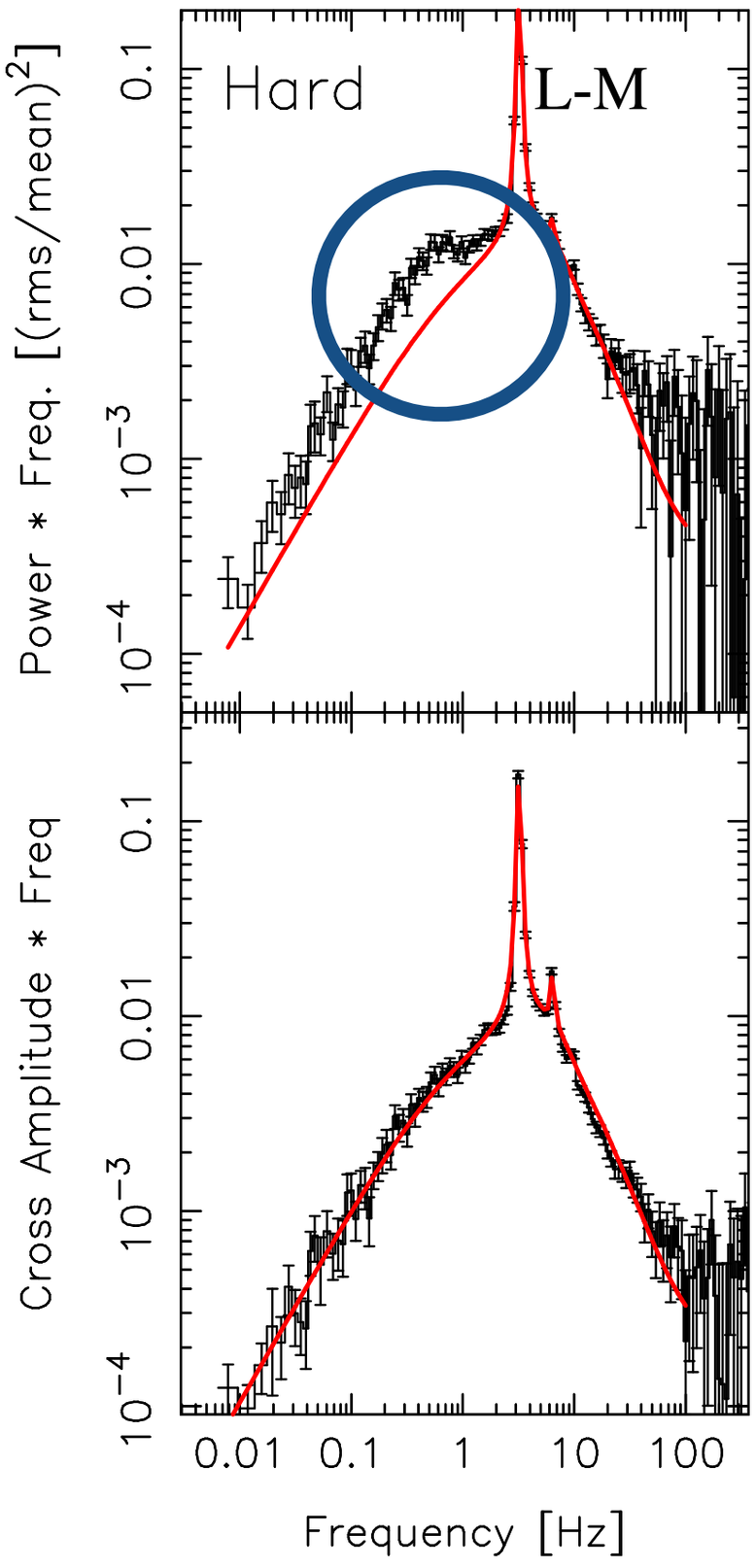

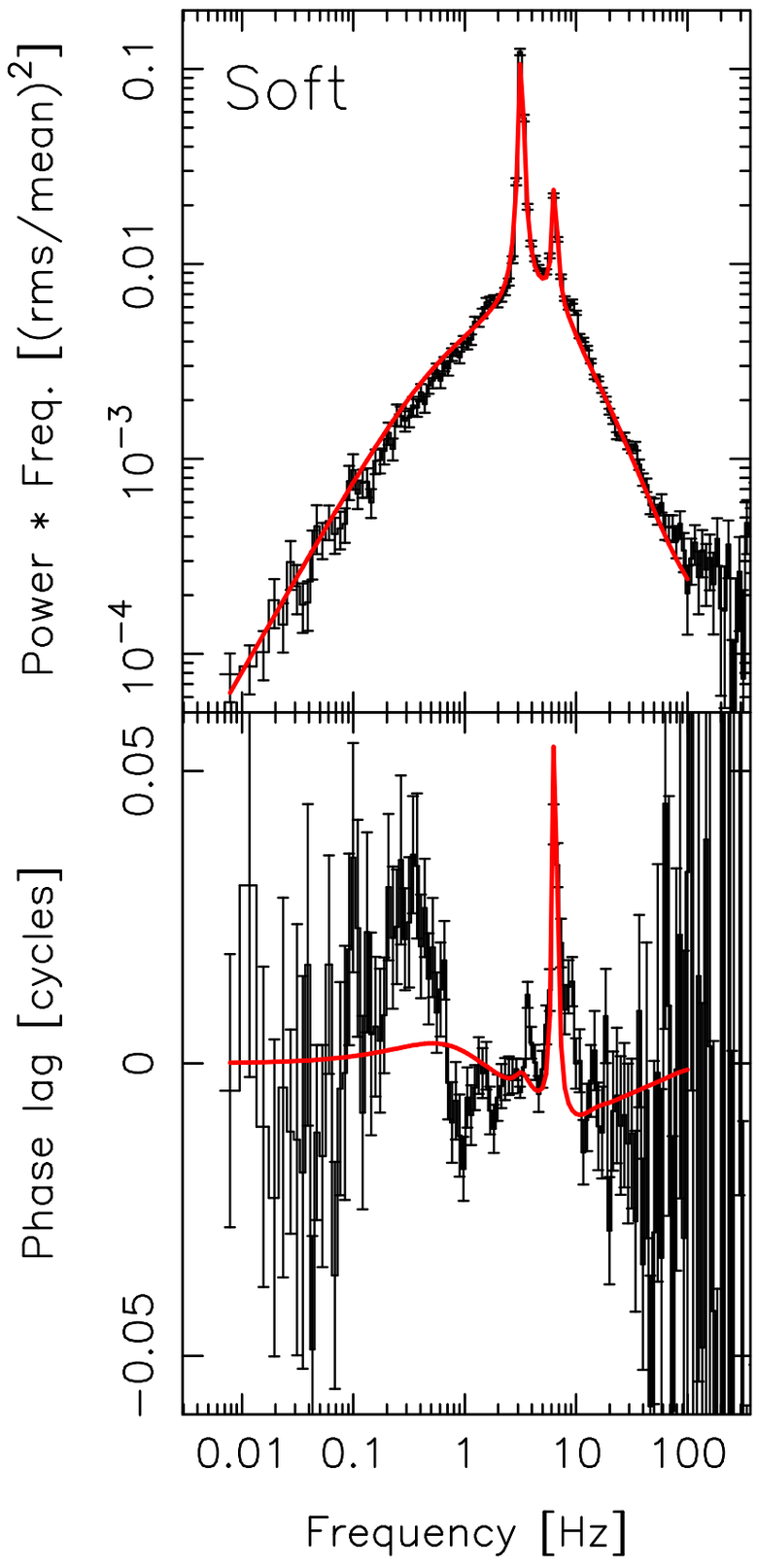

Results: XTE J1550-564, 1998 LHS, obs 2

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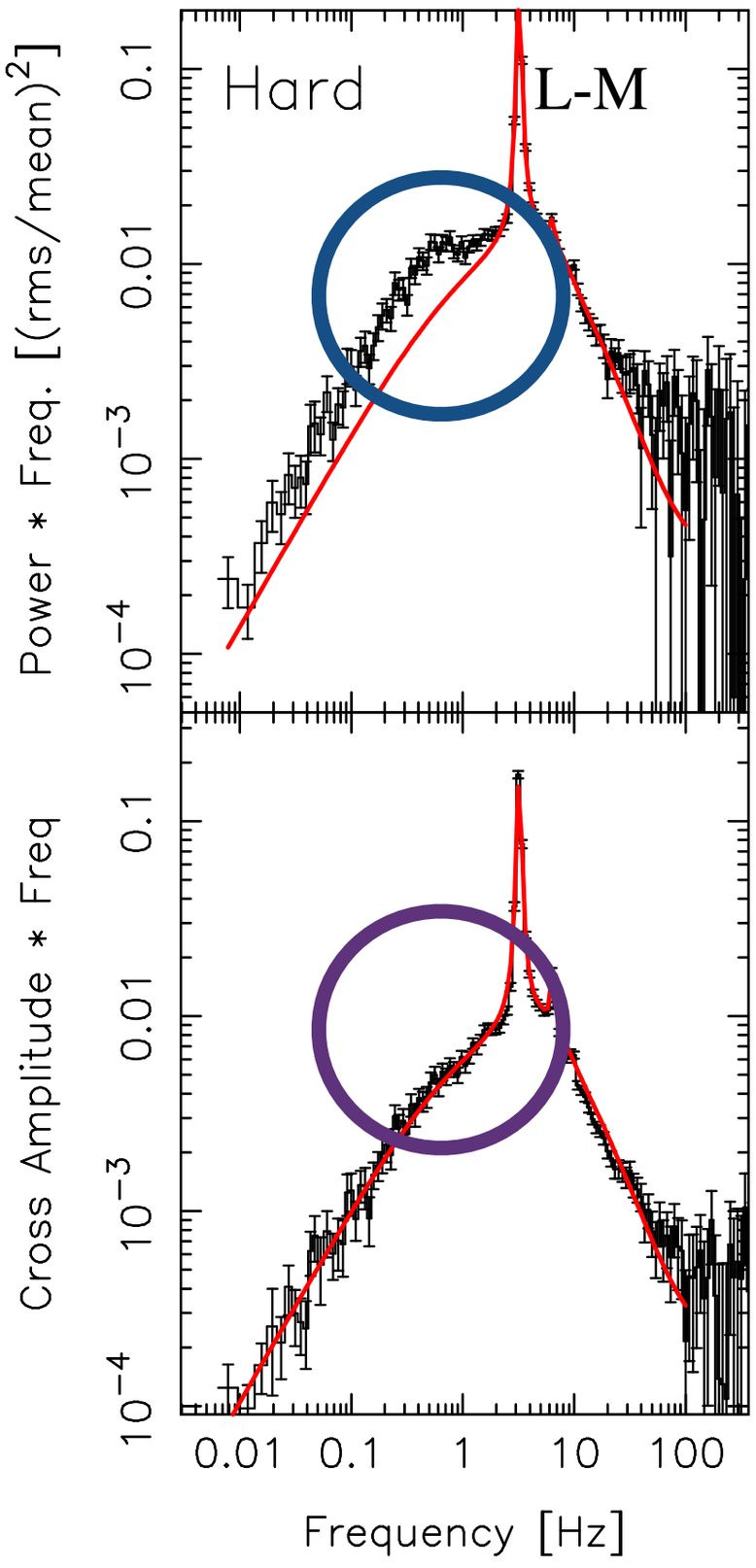

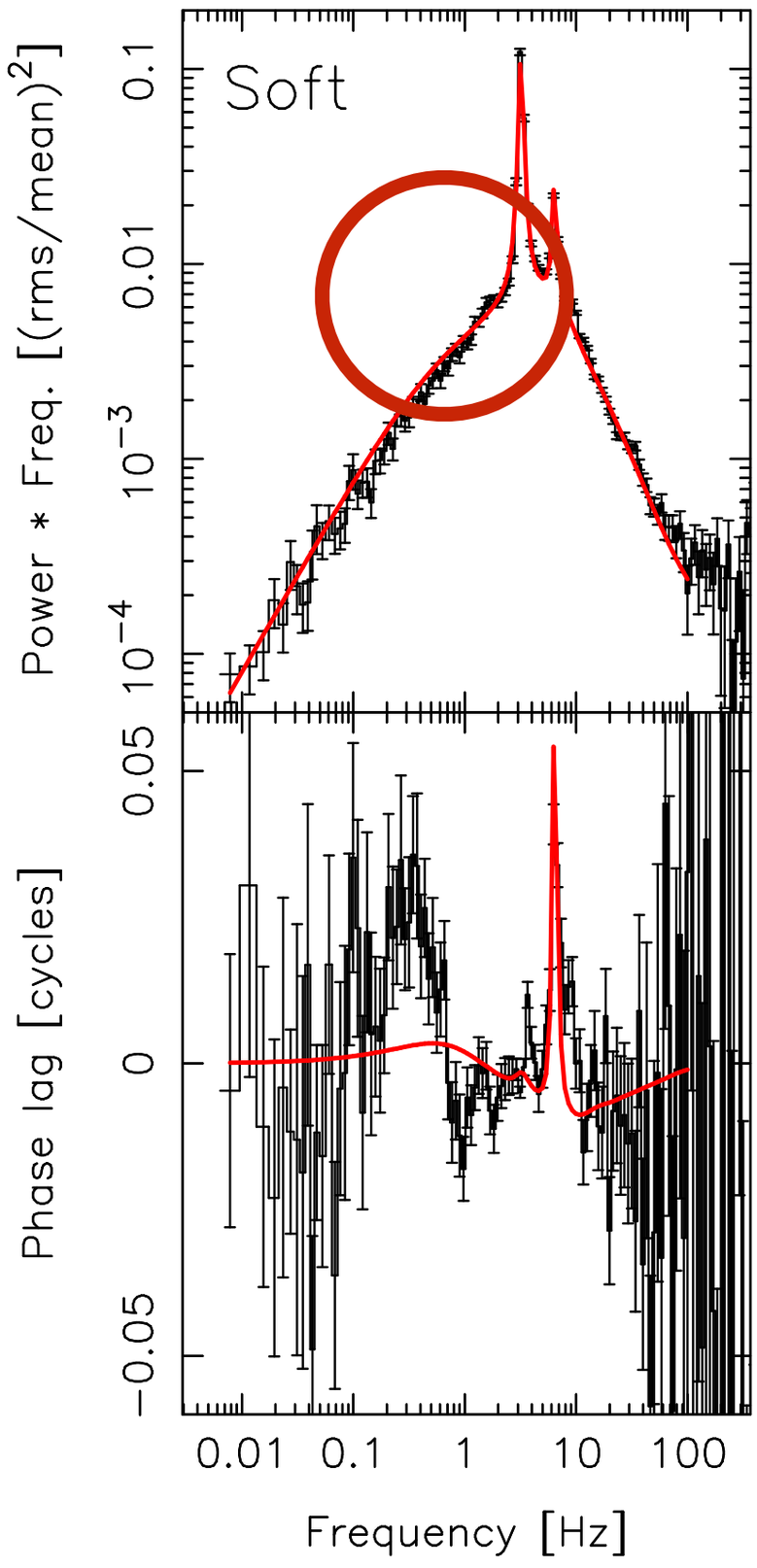

Results: XTE J1550-564, 1998 LHS, obs 2

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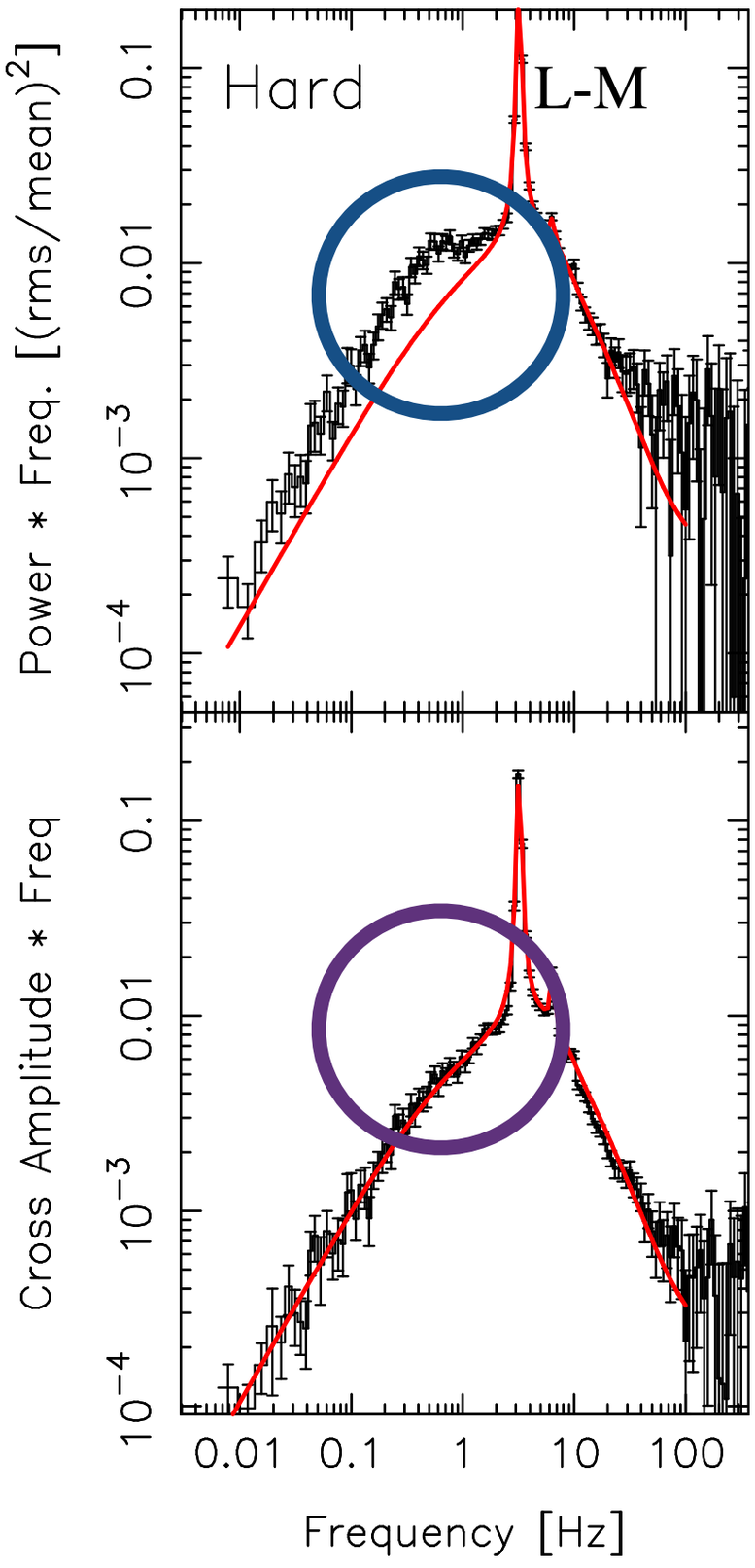

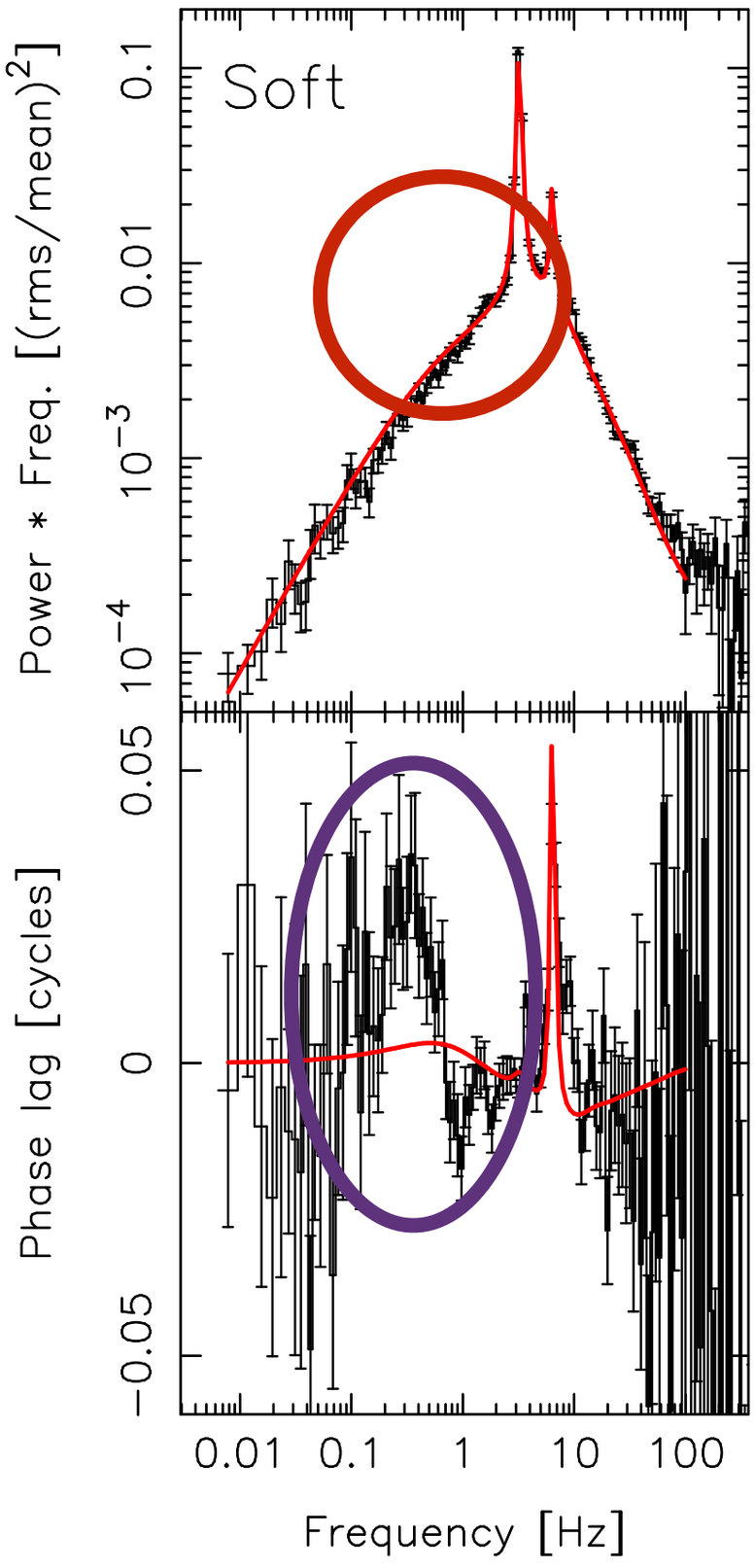

However…

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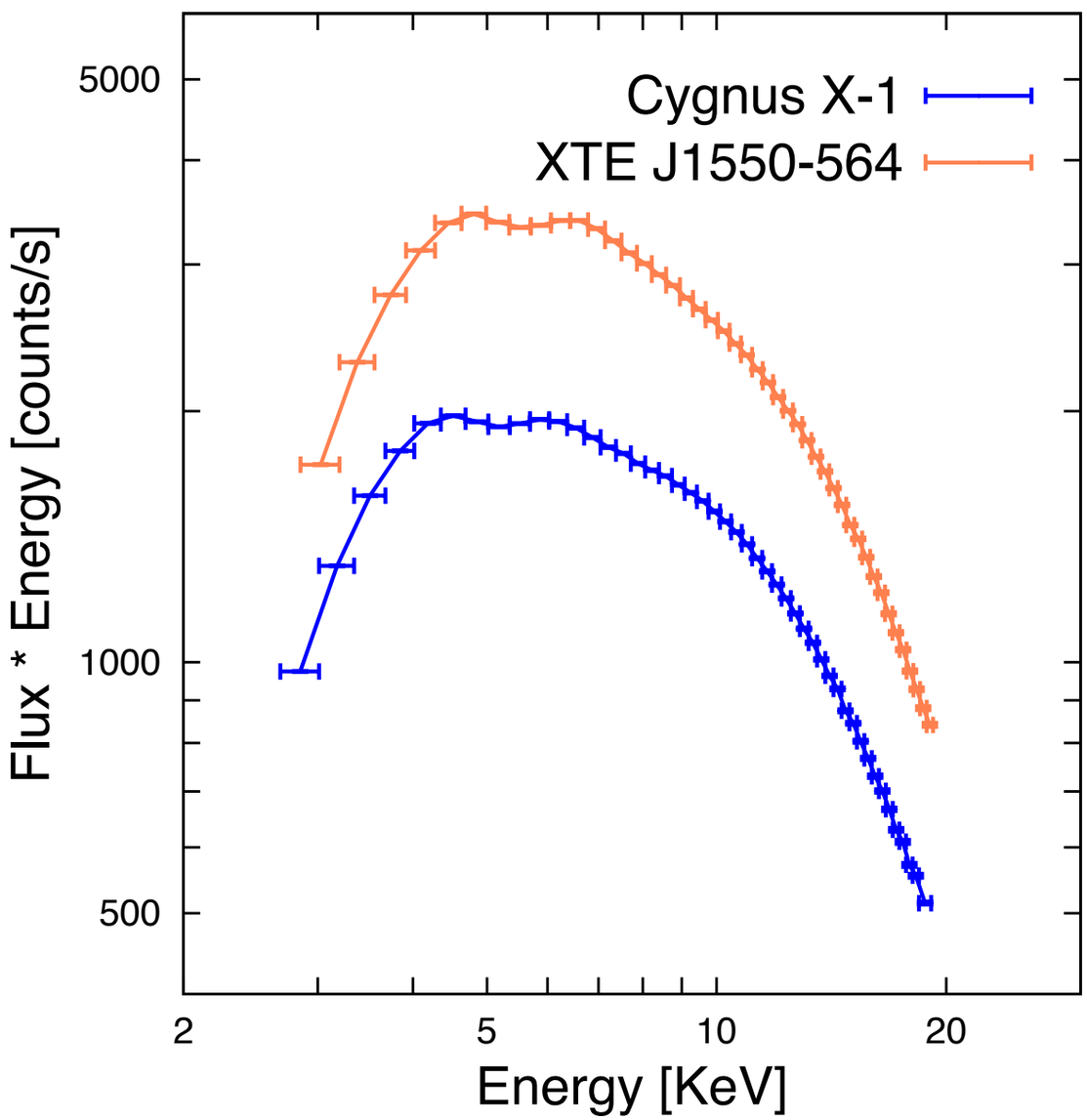

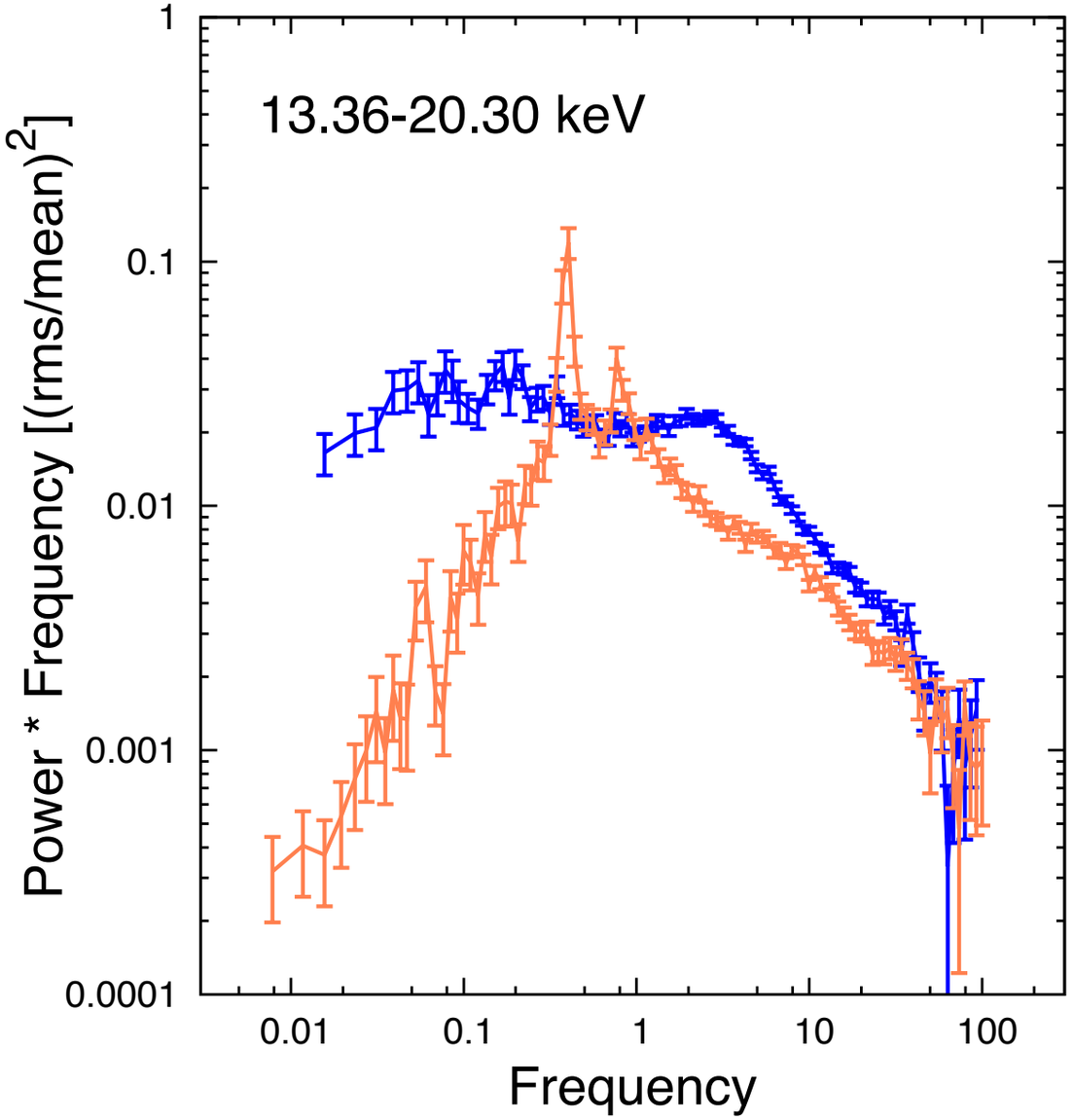

(Rapisarda et al. in prep II)

Results: Cygnus X-1, 1997, LHS

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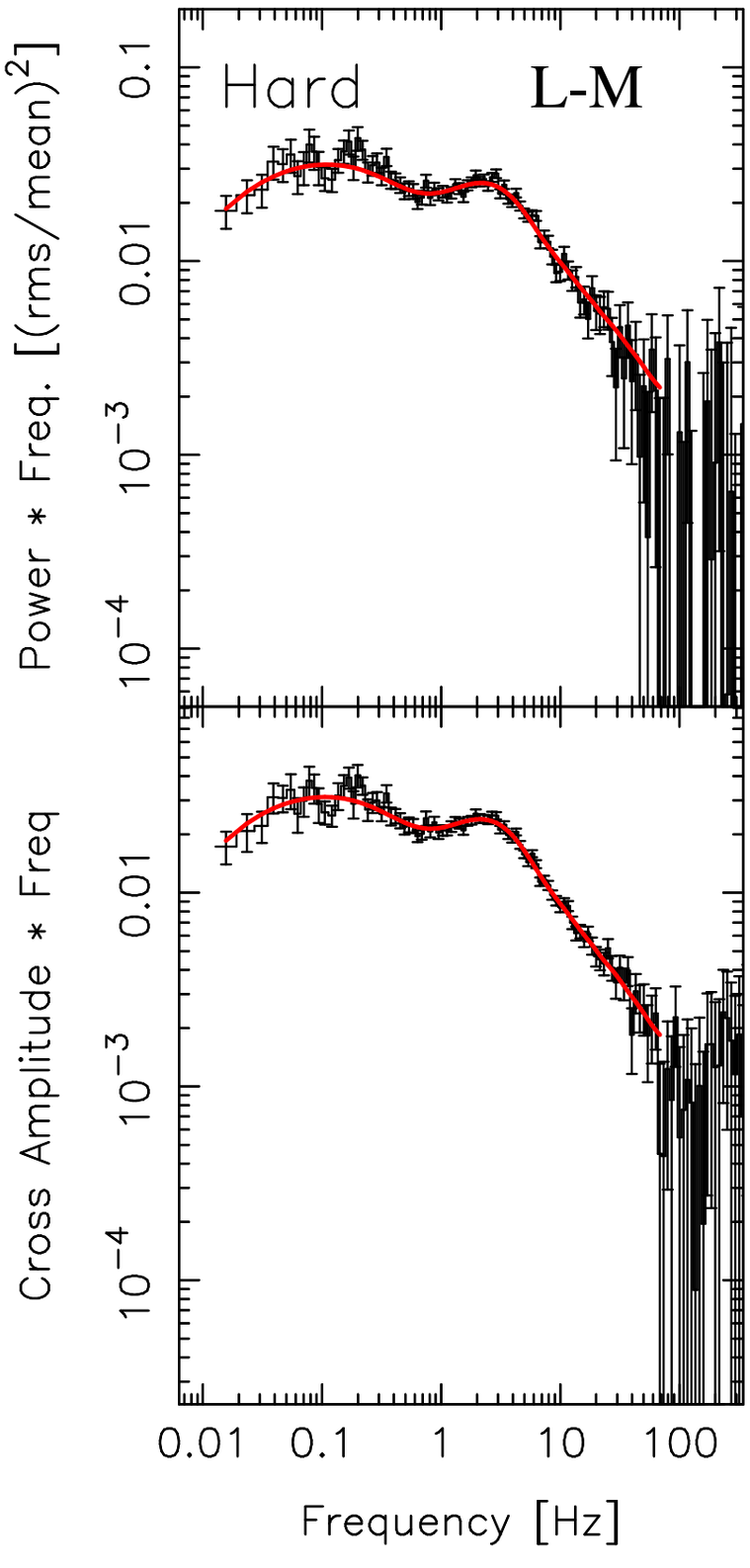

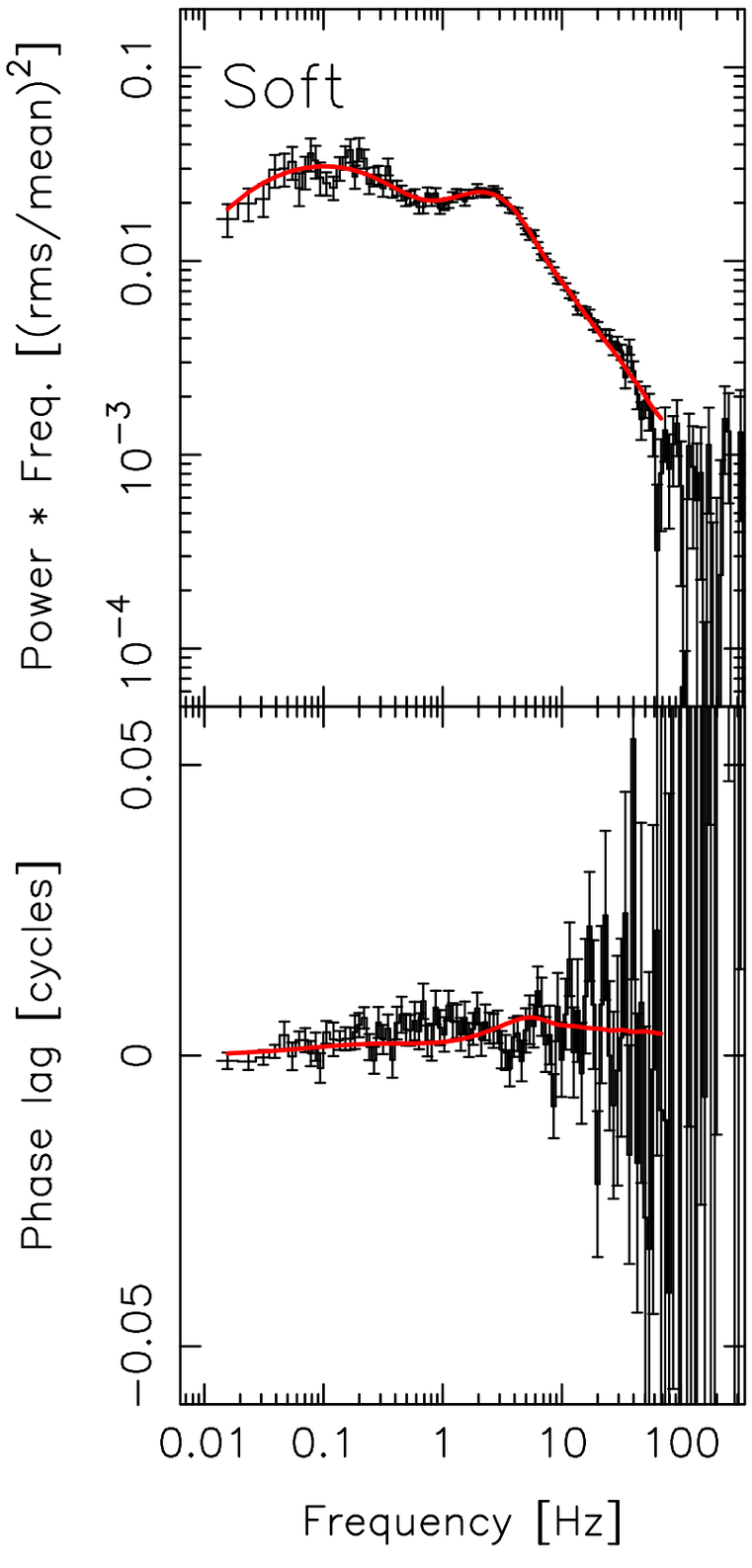

Summary

- We jointly fitted the *power spectrum* in a *soft* and *hard* band, and the *cross-spectrum* between these two bands, with a **propagating fluctuations model** *for the first time;*
- We found *quantitative* and *qualitative* discrepancies between model predictions and data;
- We need to implement the code and to extend our sample to the largest variety of sources, states, and energy bands;
- **eXTP** would give us the opportunity to work on high s/n data (fundamental for our joint fit) and to use the additional polarization information to investigate the origin of the variability.

Thanks

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What we are doing:

jointly fitting
the *power spectrum* in a *soft* and *hard* band, and the
cross-spectrum between these two bands,
with a **propagating fluctuations model**
for the first time.

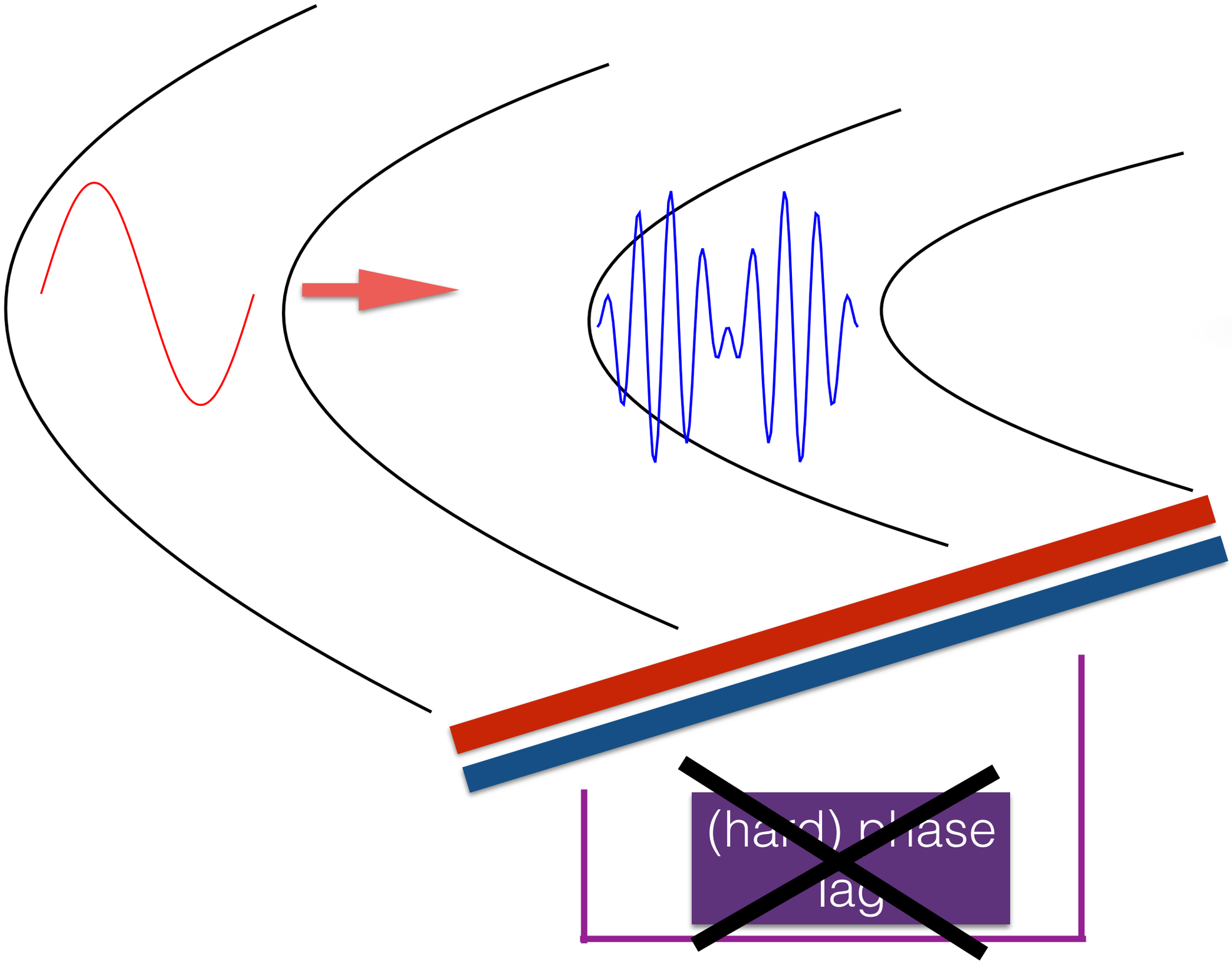
What we found:

propagating fluctuations *not always* reproduce the characteristics of the rapid variability in BHBs

What we need:

implementing the code
extending our sample (high quality observations)
constraining the model parameters with additional information (polarization)

Propagating fluctuations: ingredients for the recipe



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LT Precession of the inner hot flow

Truncated disc geometry

Propagating mass accretion rate fluctuations

PROPFLUC

Power spectrum, cross spectrum (phase lags)

Direct link between PS features and system physical parameters

Testing propagating fluctuations hypothesis

Outburst description using model physical parameters

Results: MAXI J1659-152

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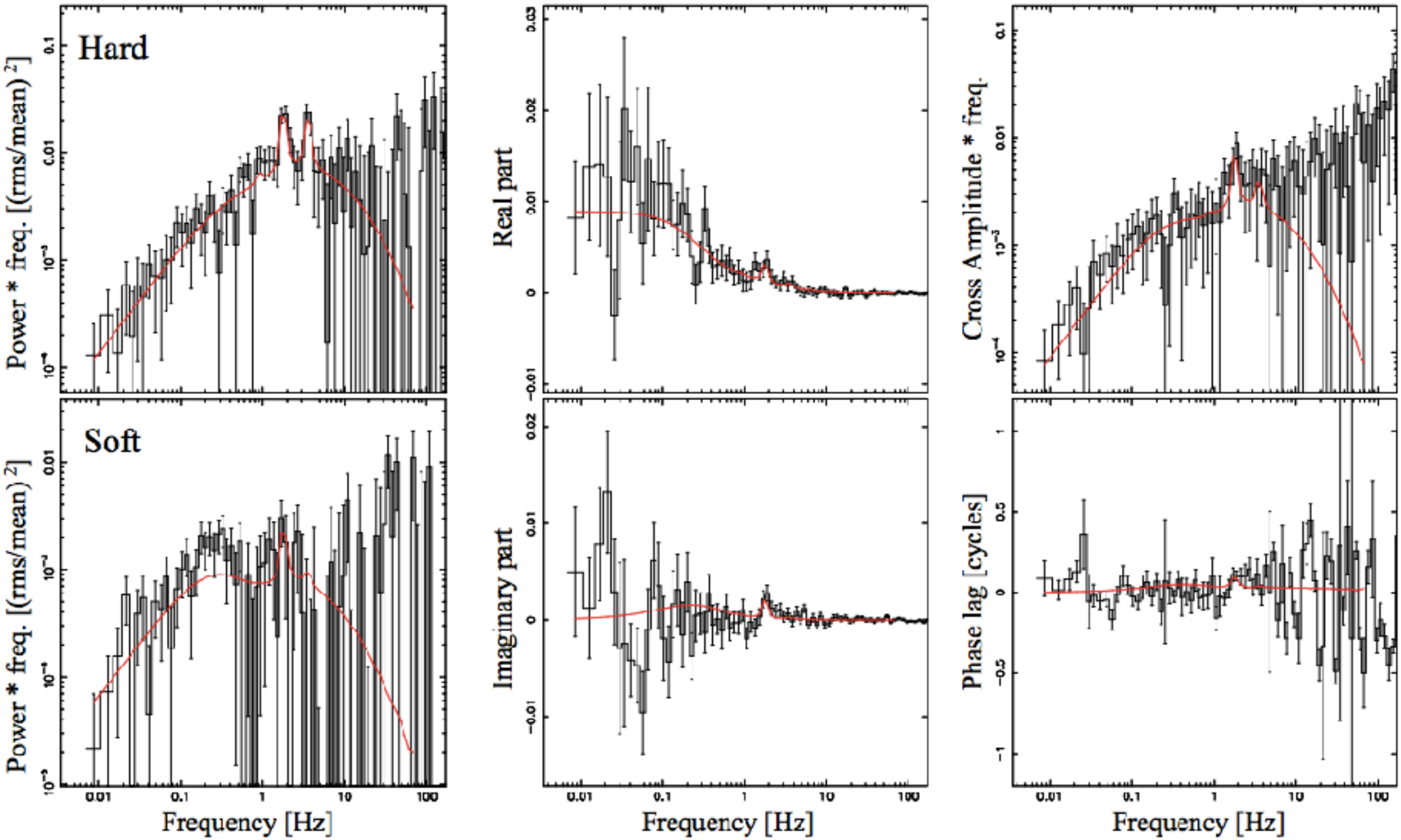

Results: MAXI J1659-152

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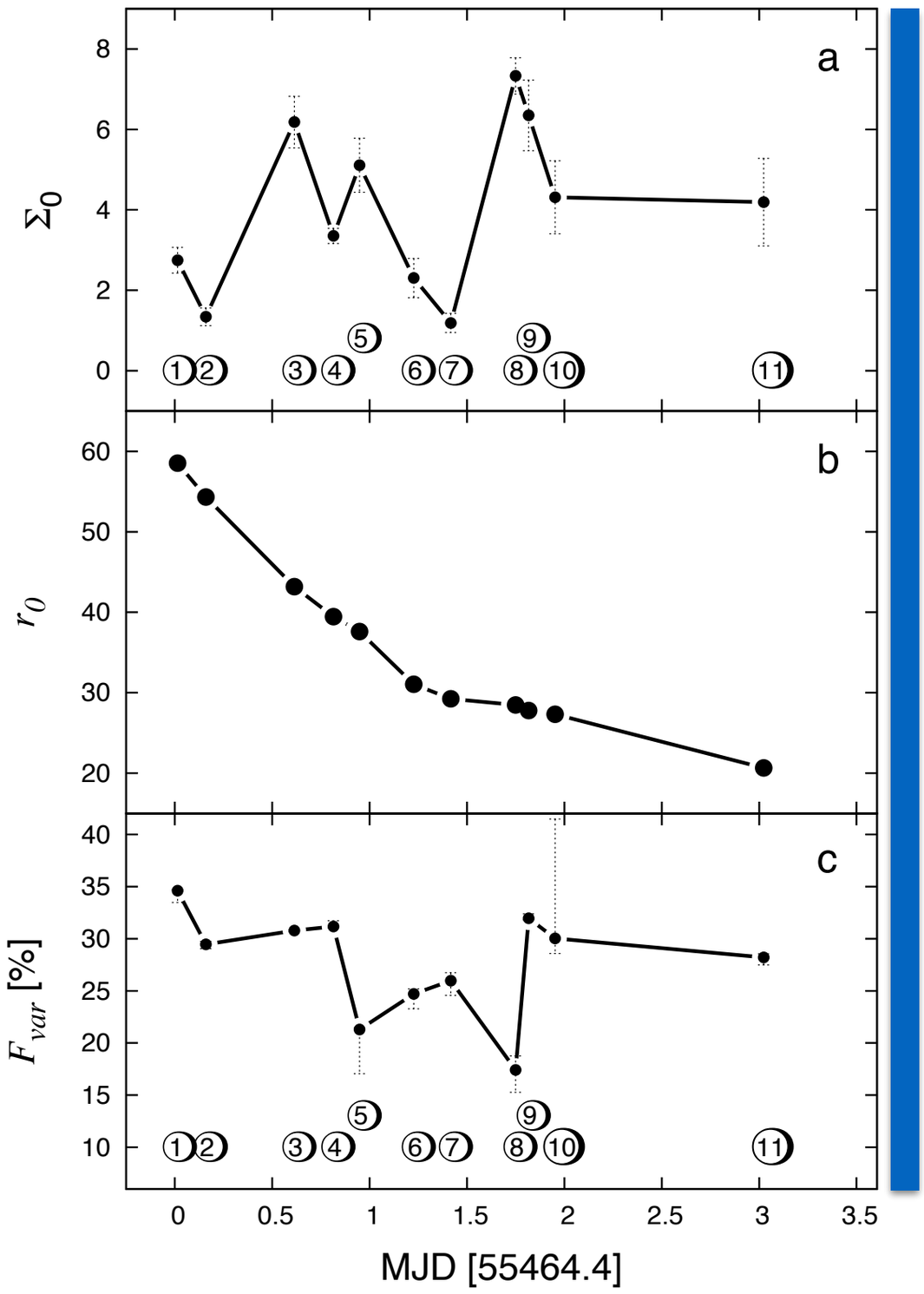
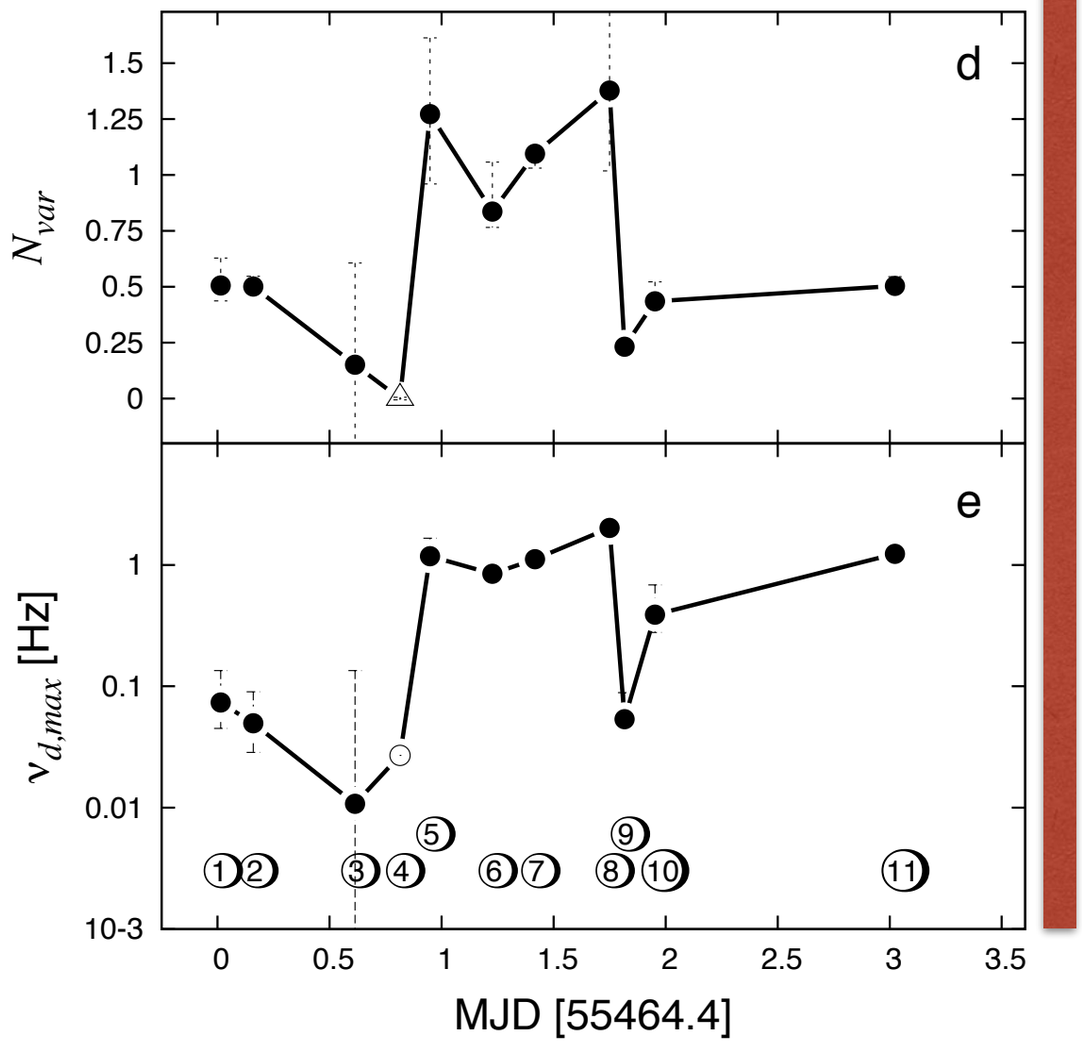
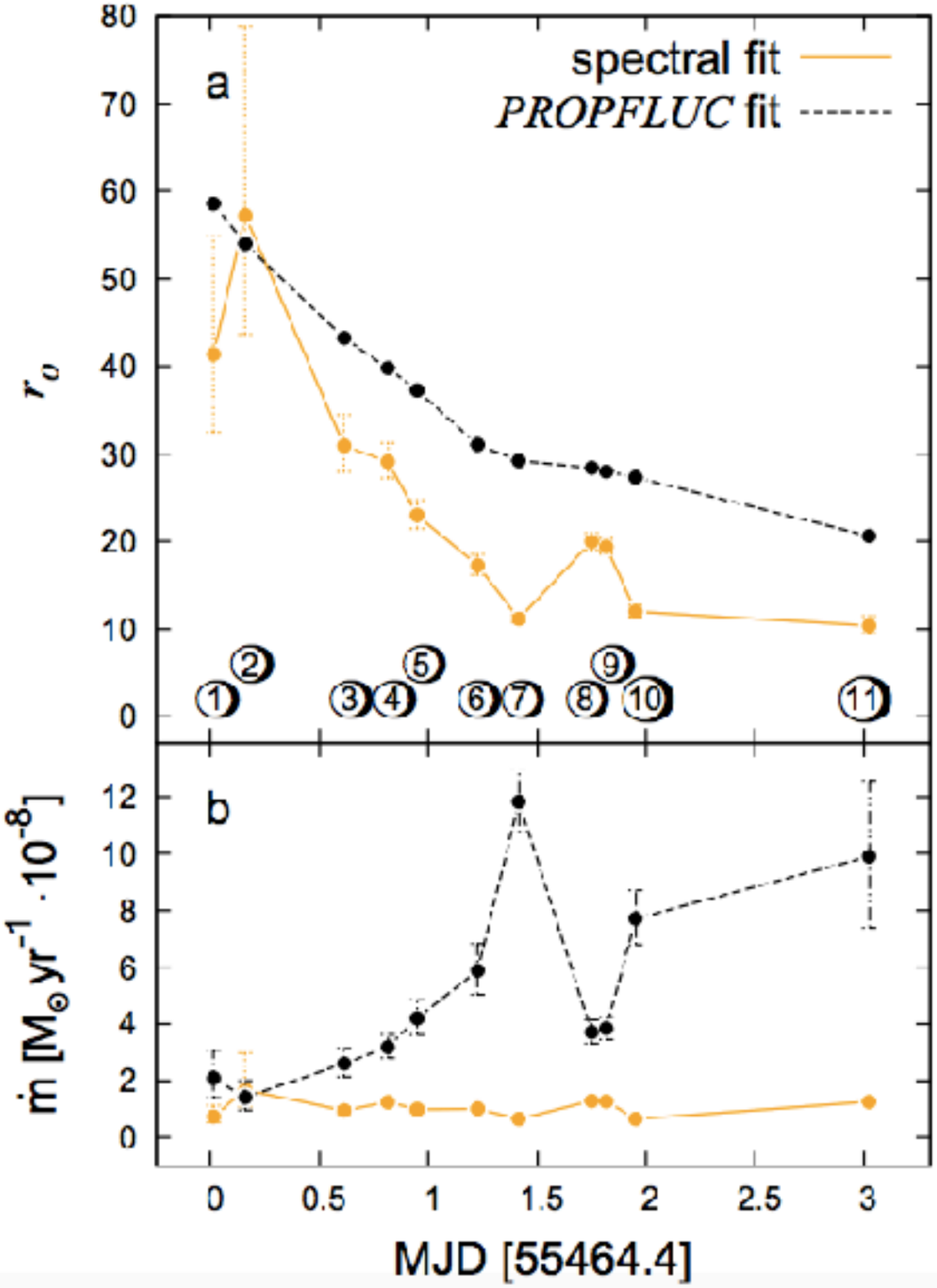
Hot flow

0.5-10 keV
Swift

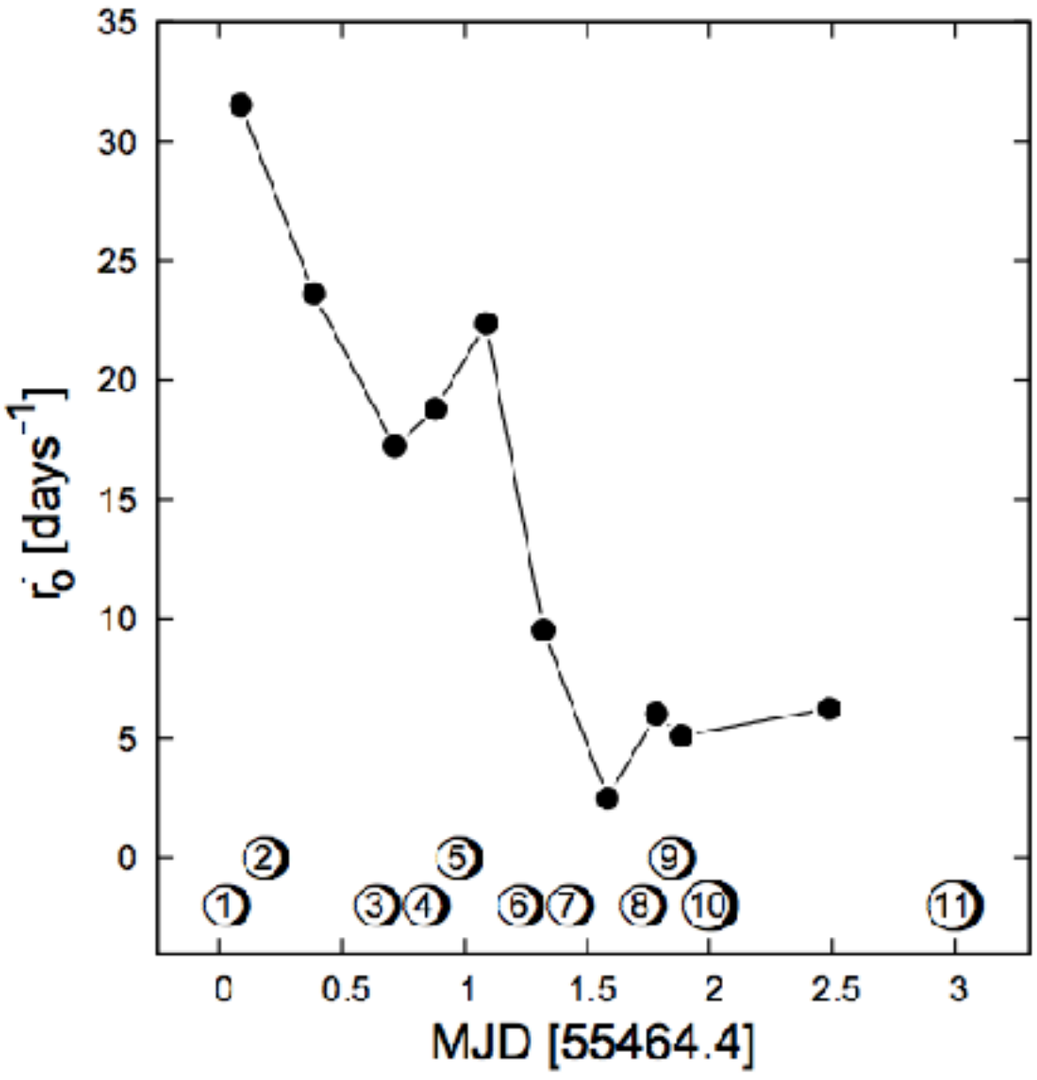
Disc







$$\dot{M} = \frac{8\pi\sigma}{3GM_{BH}} r_o^3 T_{max}^4$$



Double “hump” power spectrum

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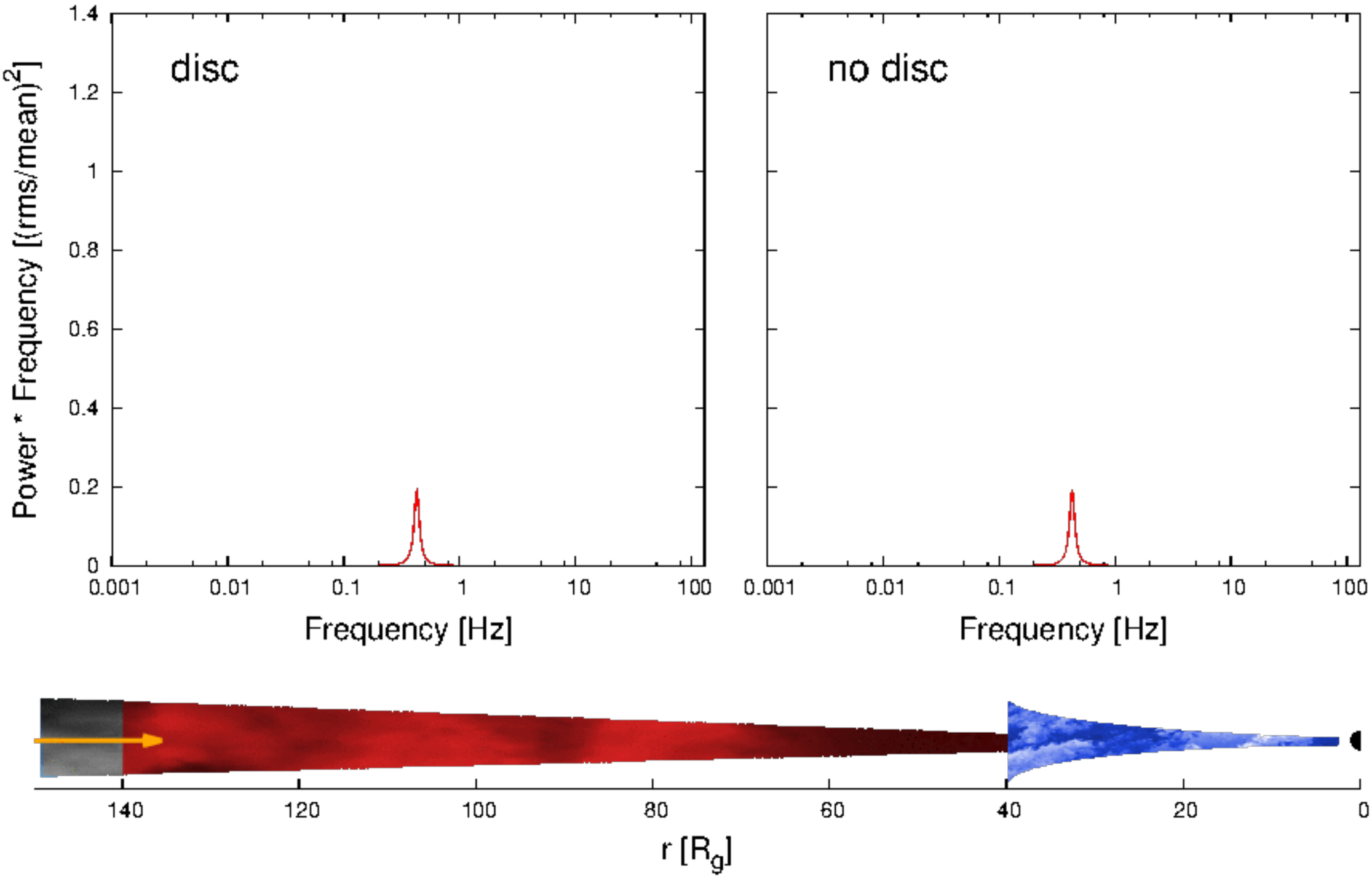

Double “hump” power spectrum

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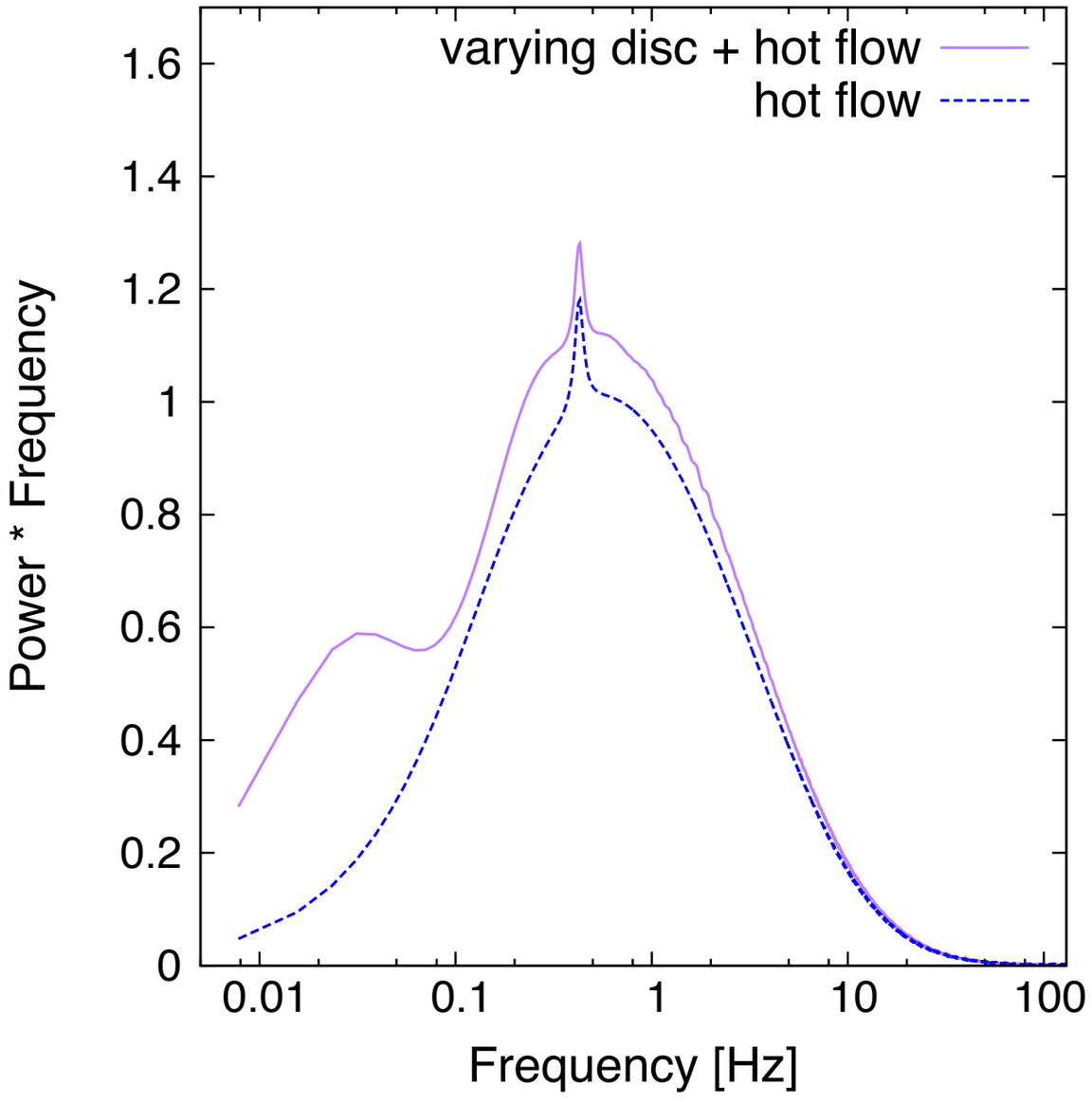

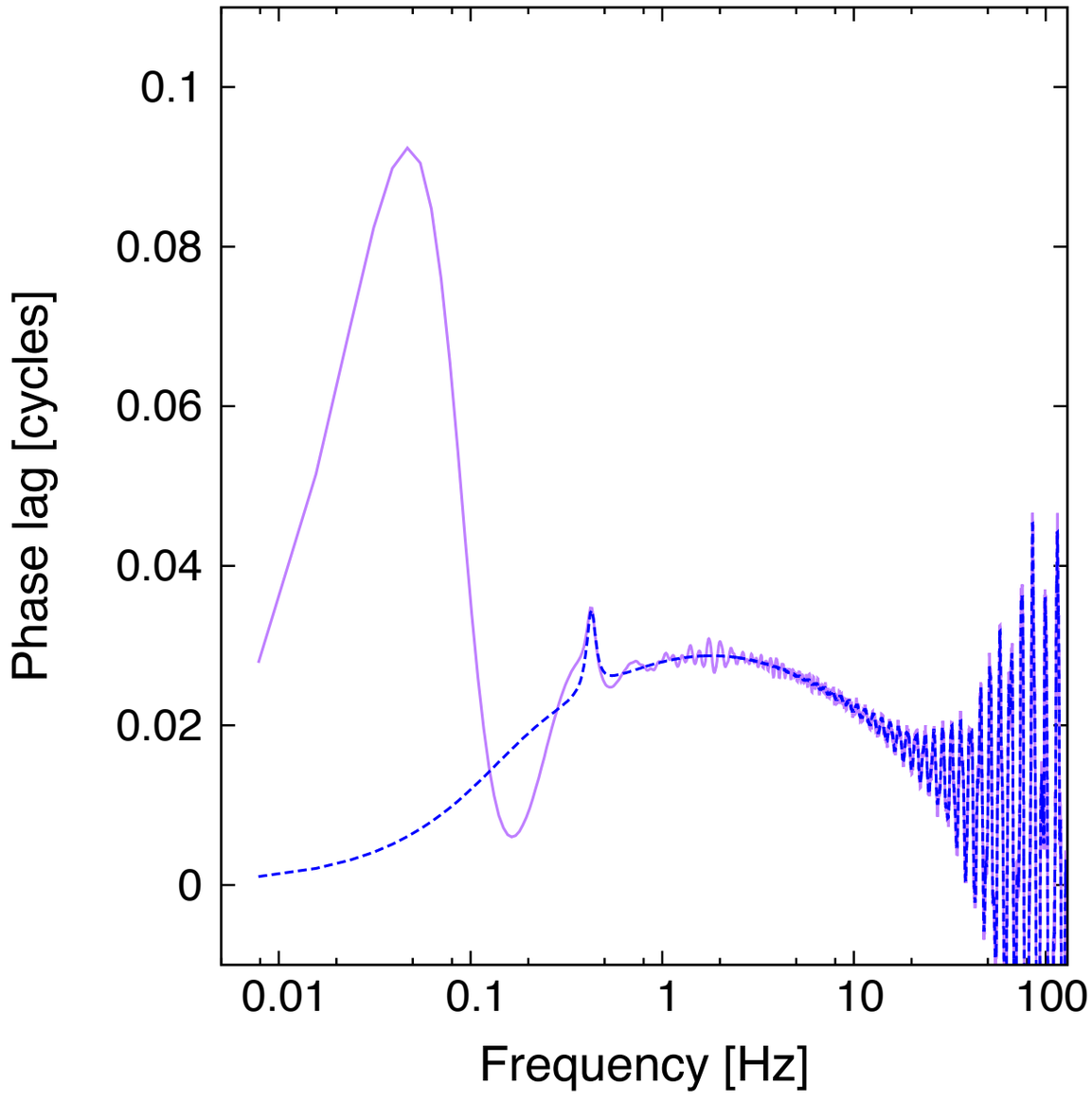

MAXI J1659-152, timing Vs spectral fitting

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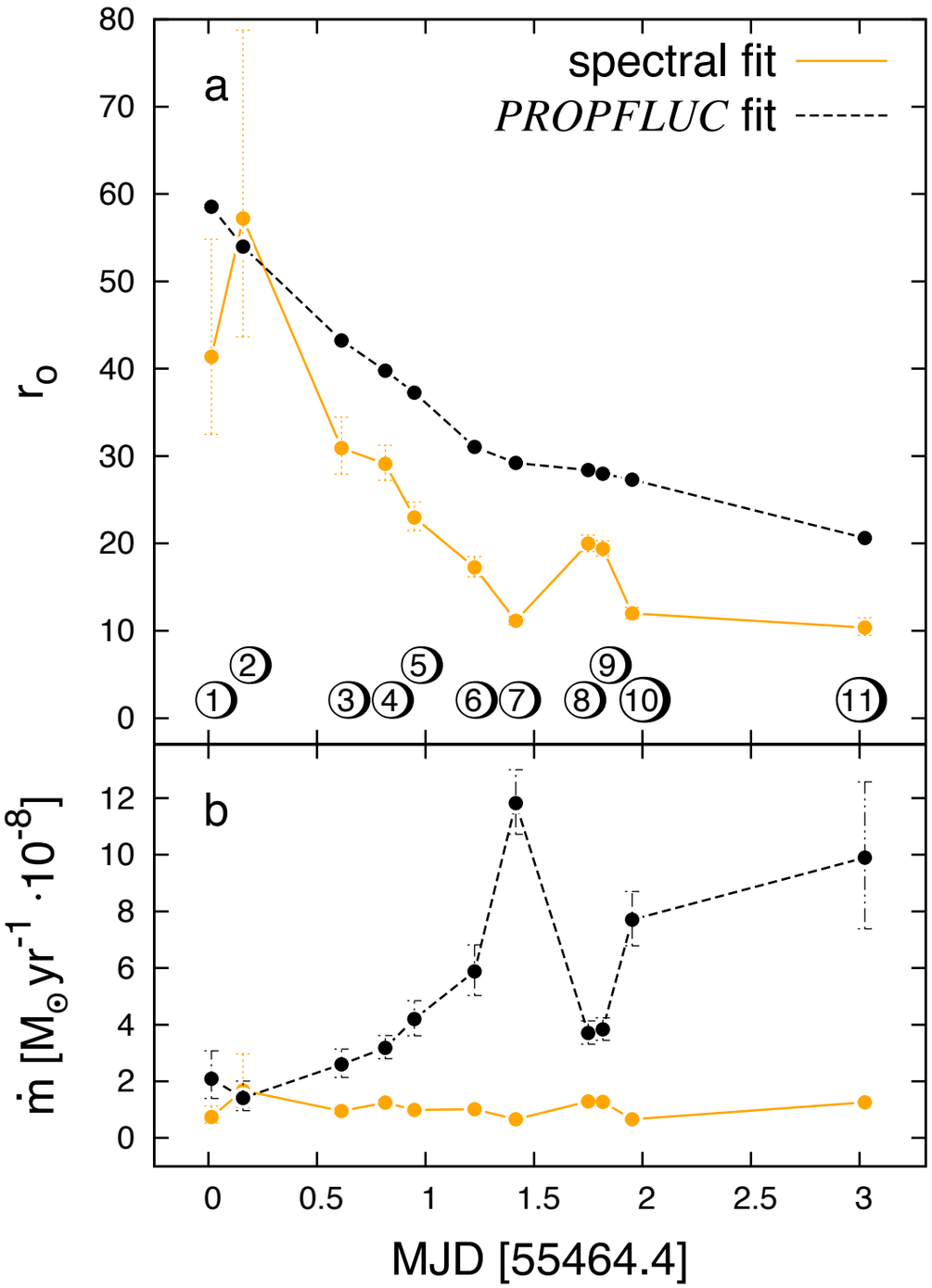
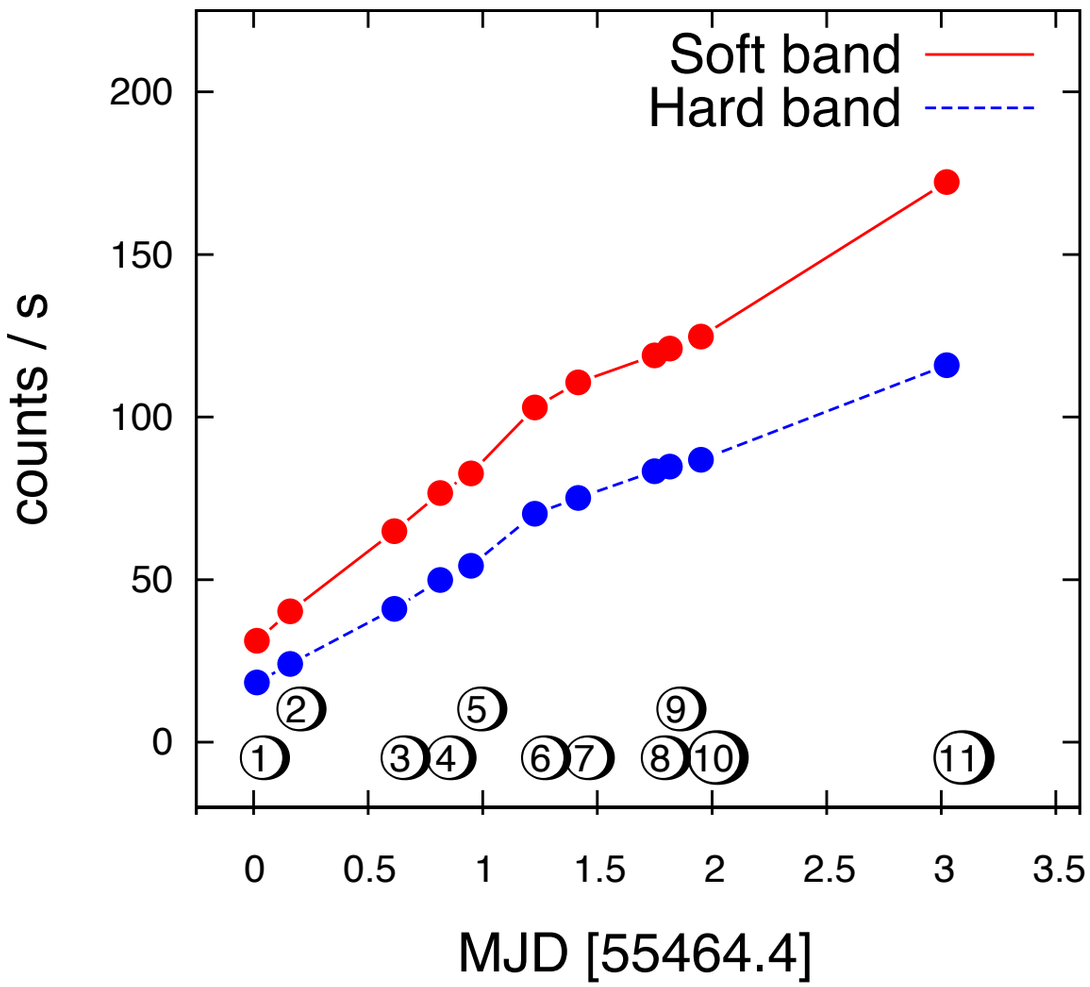
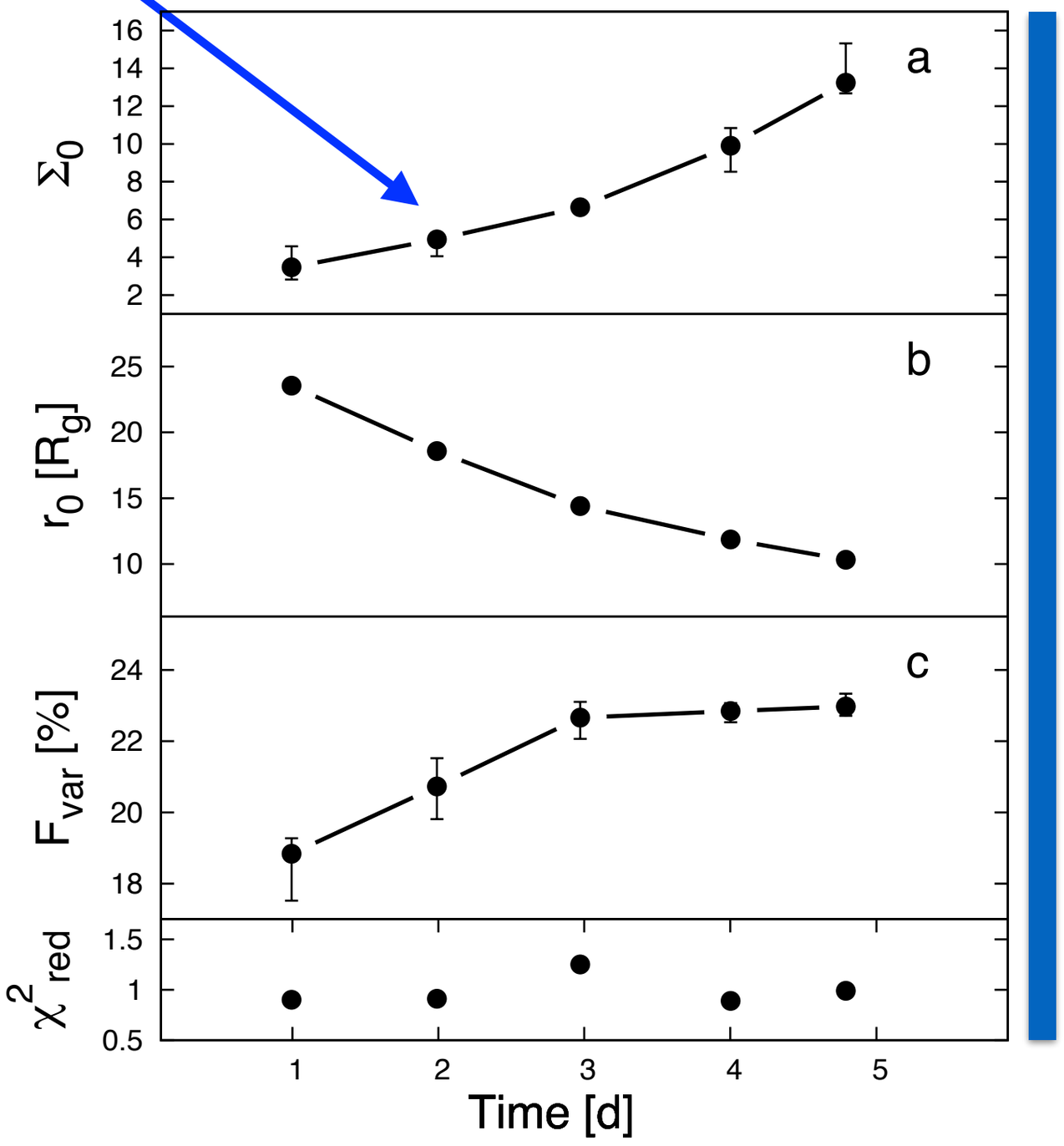




$$\Sigma_0 \propto \frac{\Sigma(r)}{\dot{m}(r)}$$

MAXI J1543-564

- 2-20 keV
- Power spectra in the rising phase the outburst
- Inner flow surface density profile and BH parameters <u>fixed</u>



(Rapisarda et al. 2014)

Introducing PROPFLUC

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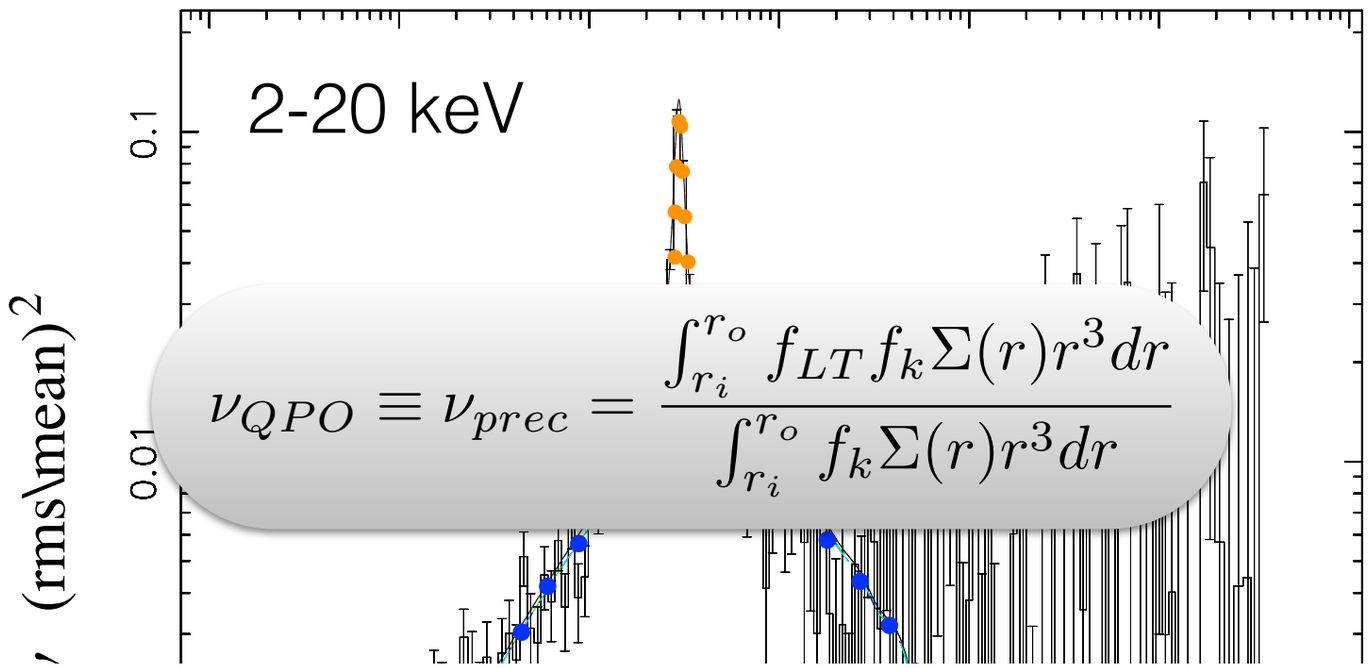

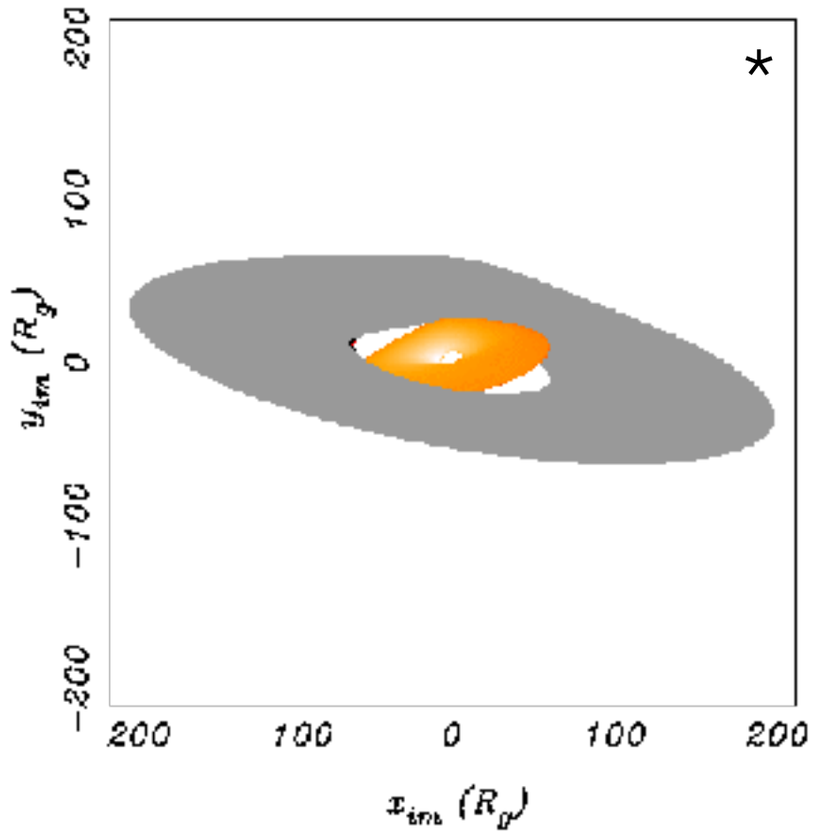

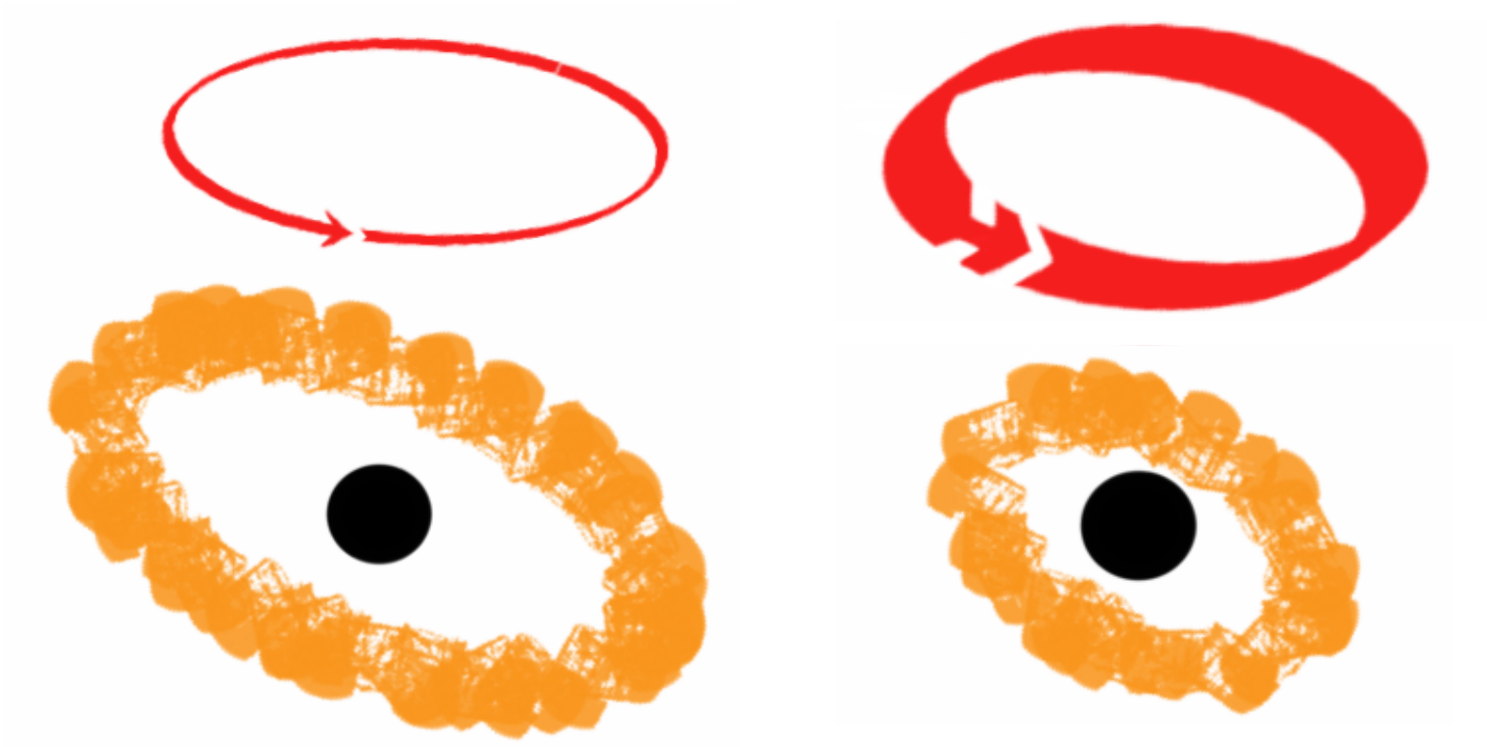

- Propagating fluctuations
- Precession of the inner flow

Figure courtesy of A. Ingram (*)

Timing analysis: introducing power spectrum features

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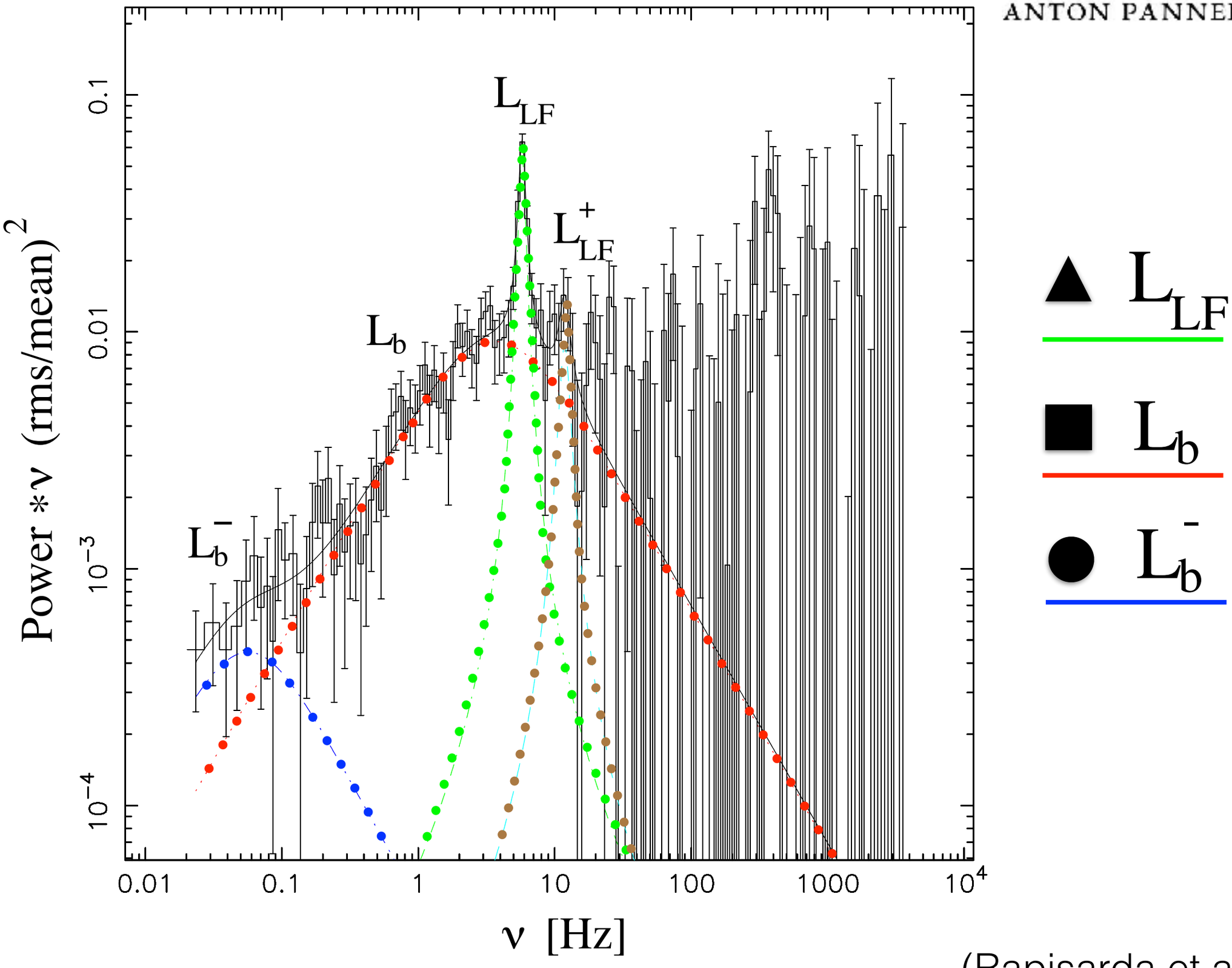

(Rapisarda et al. 2014)

rms evolution

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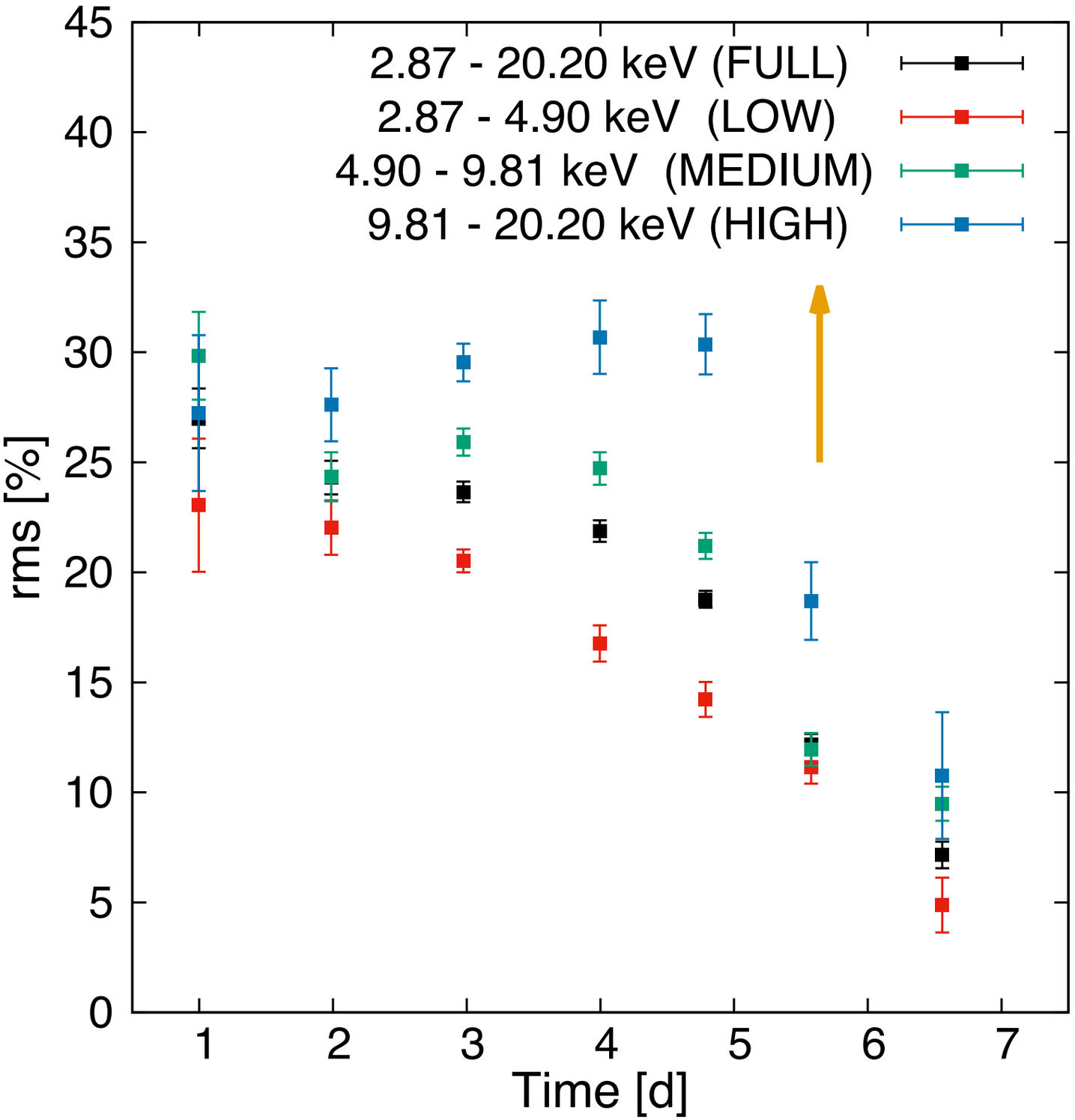

Radio emission: Miller-Jones et al. 2011

A physical interpretation of MAXI J1543-564 rising phase

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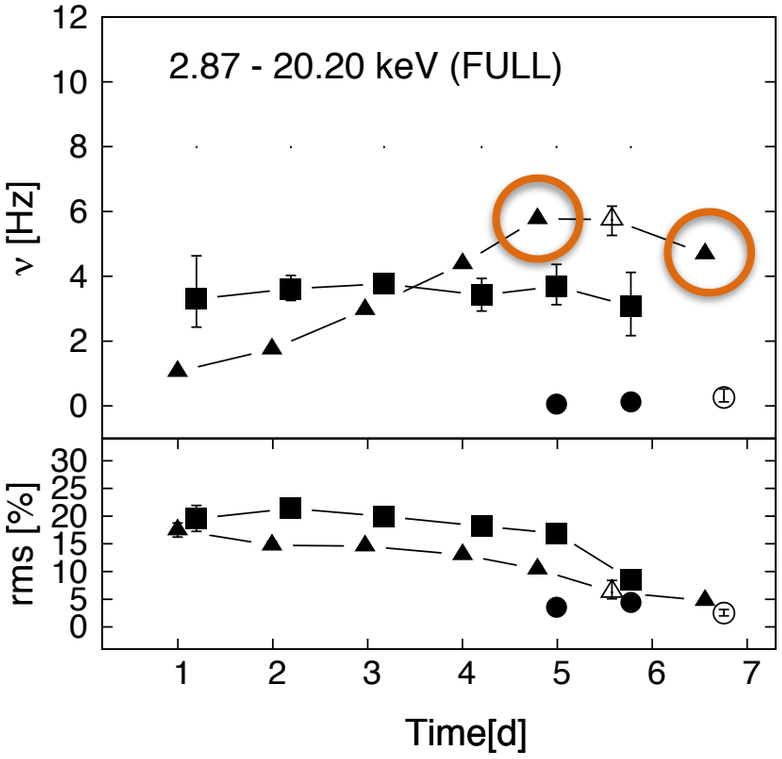
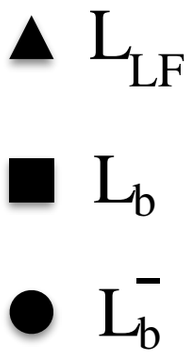
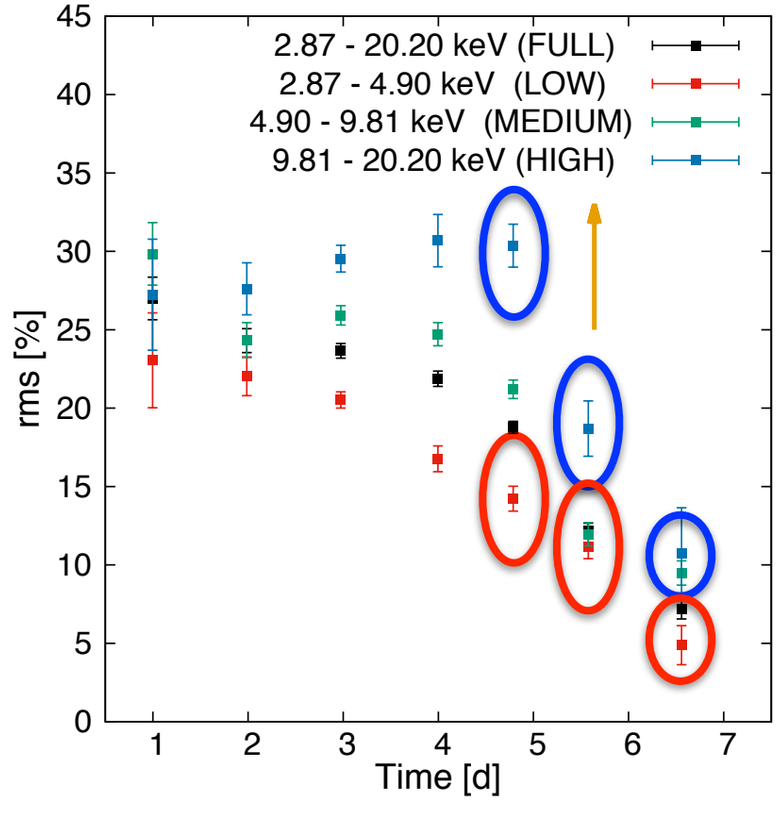
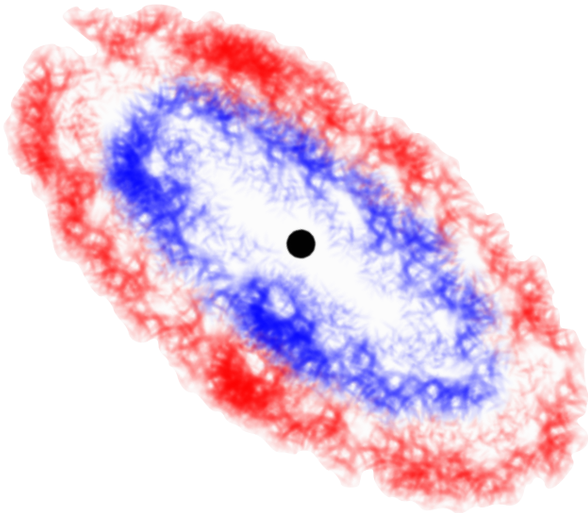
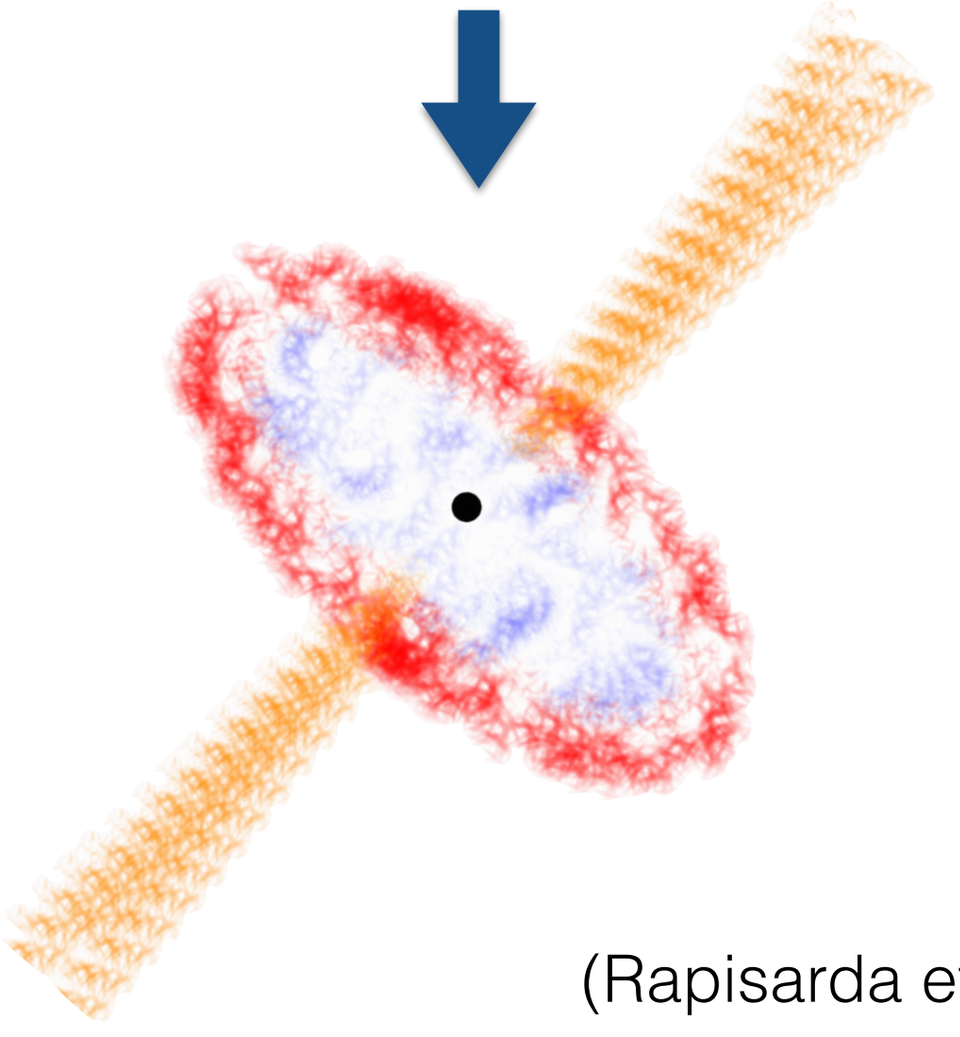


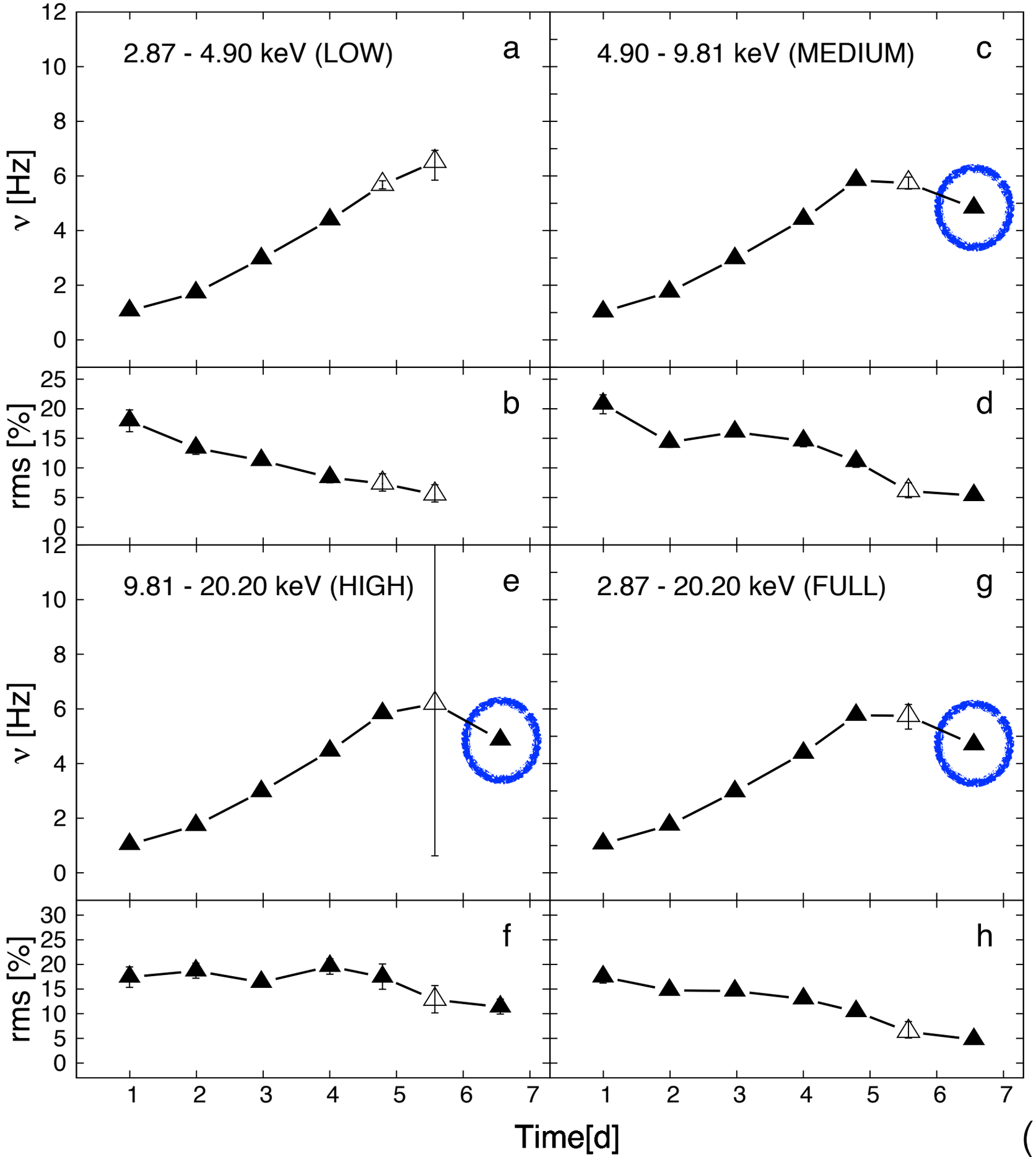


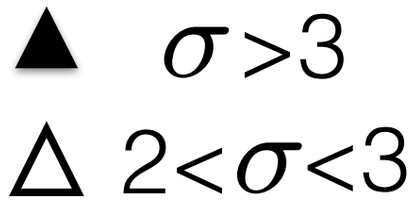






(Rapisarda et al. 2014)





(Rapisarda et al. 2014)

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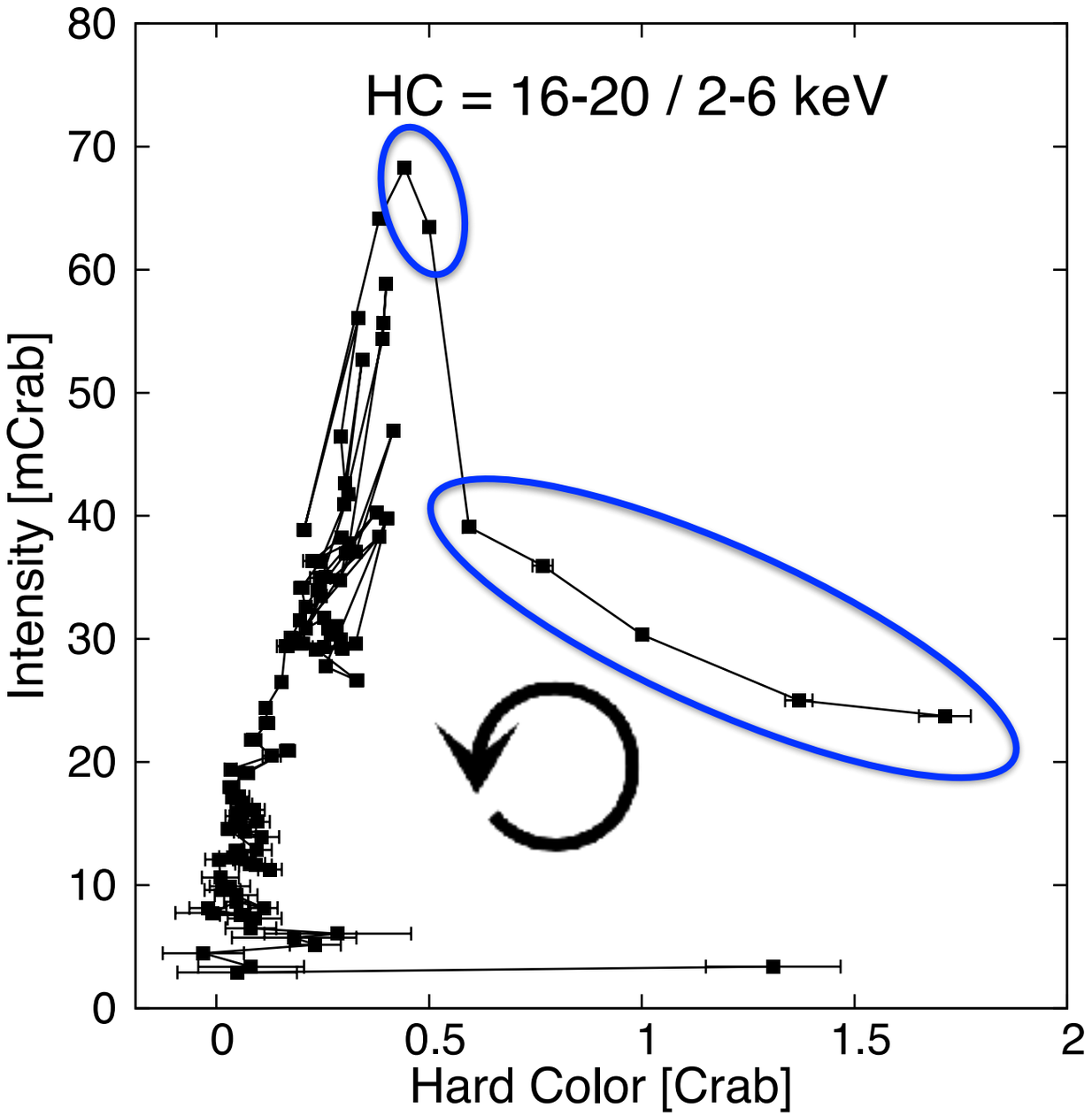
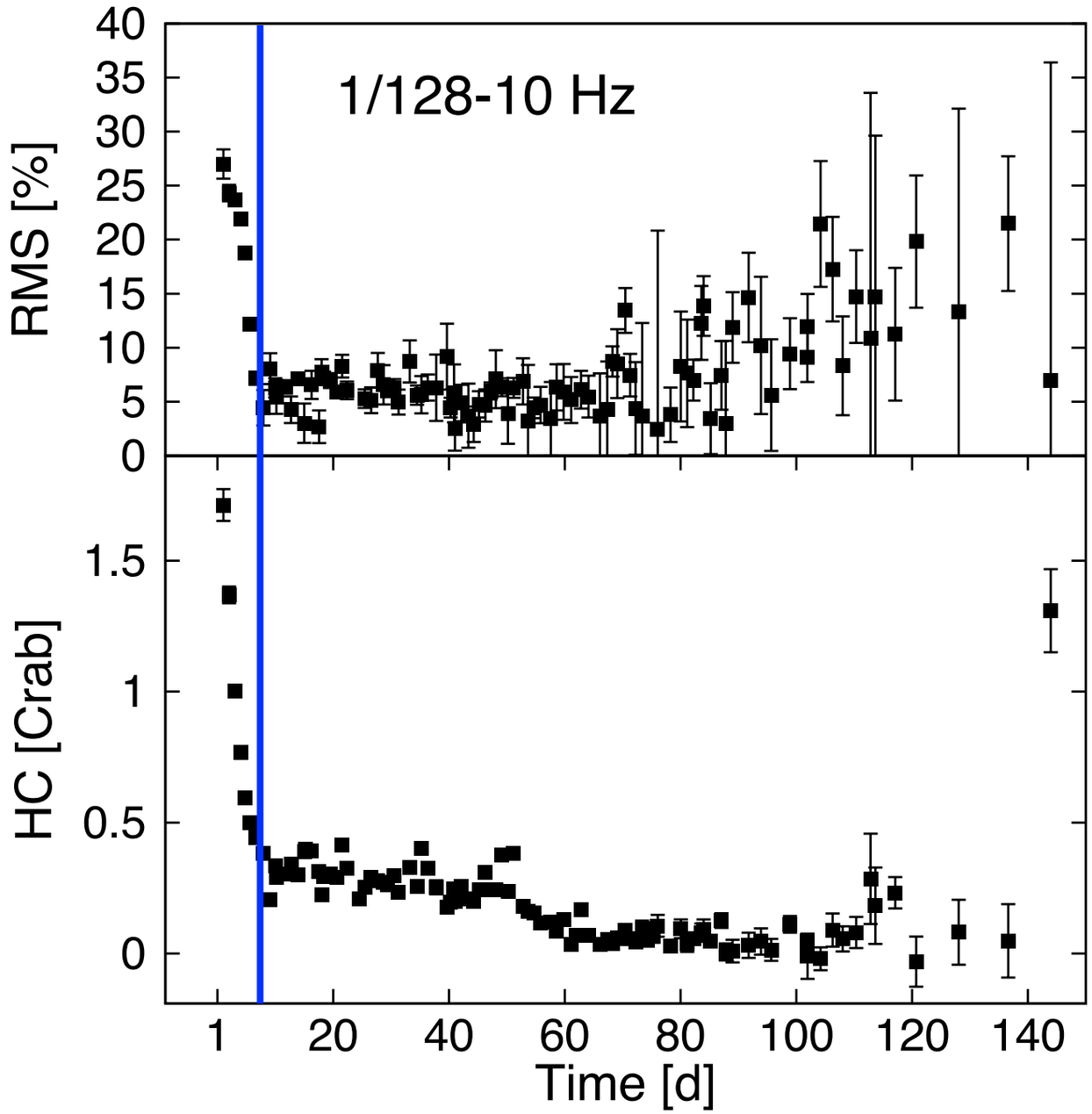
MAXI J1543-564





(Rapisarda et al. 2014)

A propagating region in the inner disc

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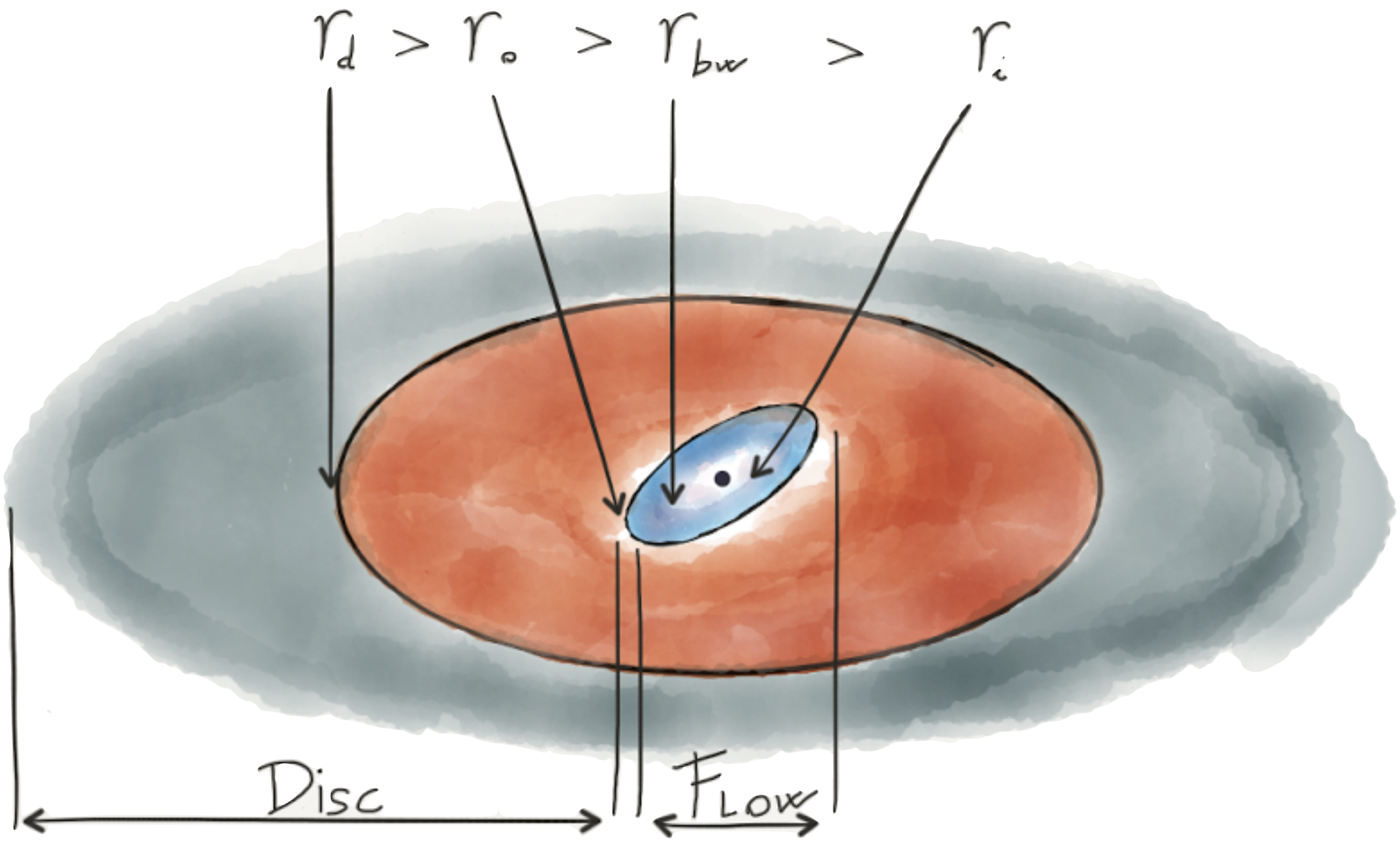

PROPFLUC computations

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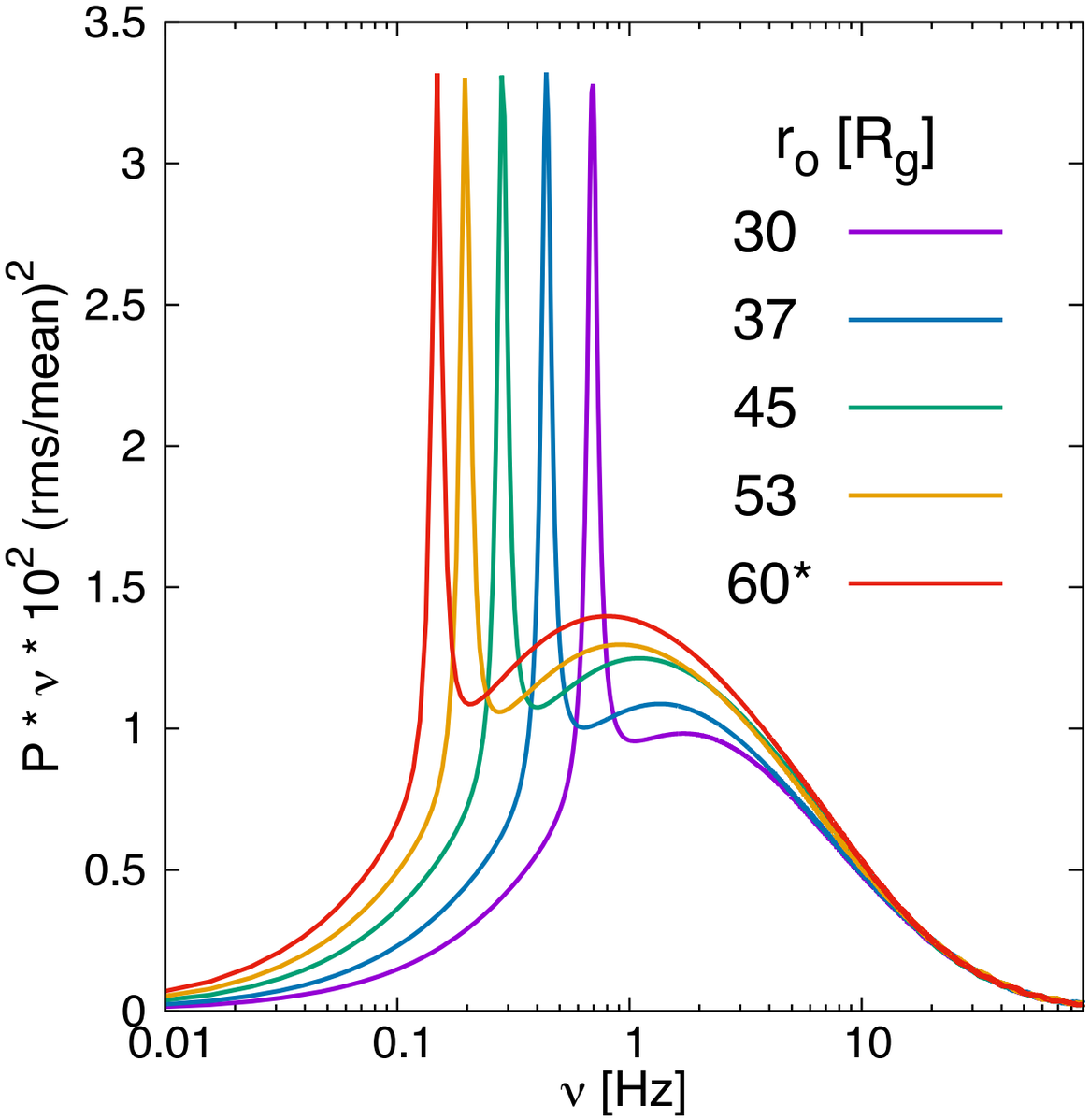

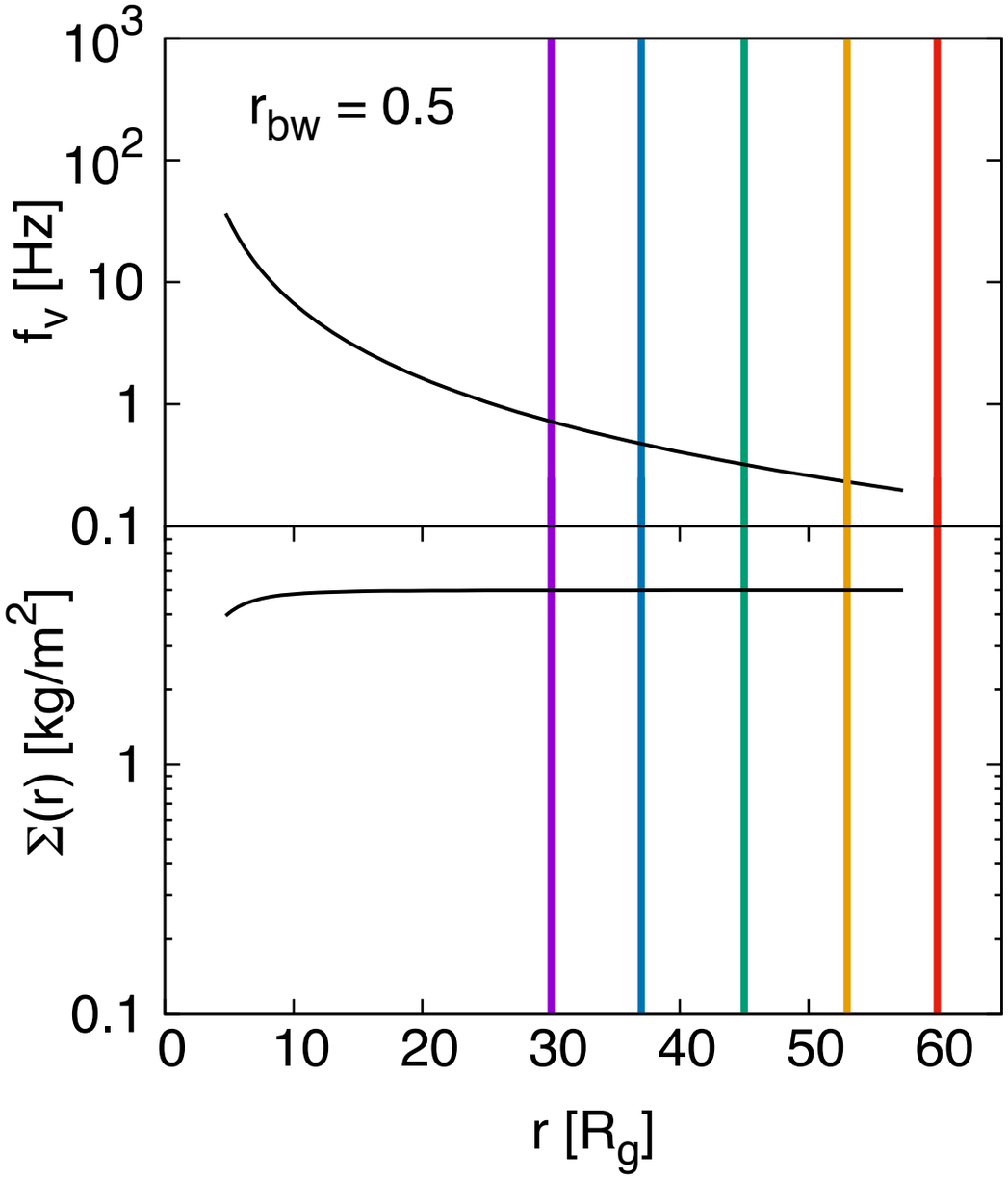

(Rapisarda et al. 2014)

PROPFLUC computations

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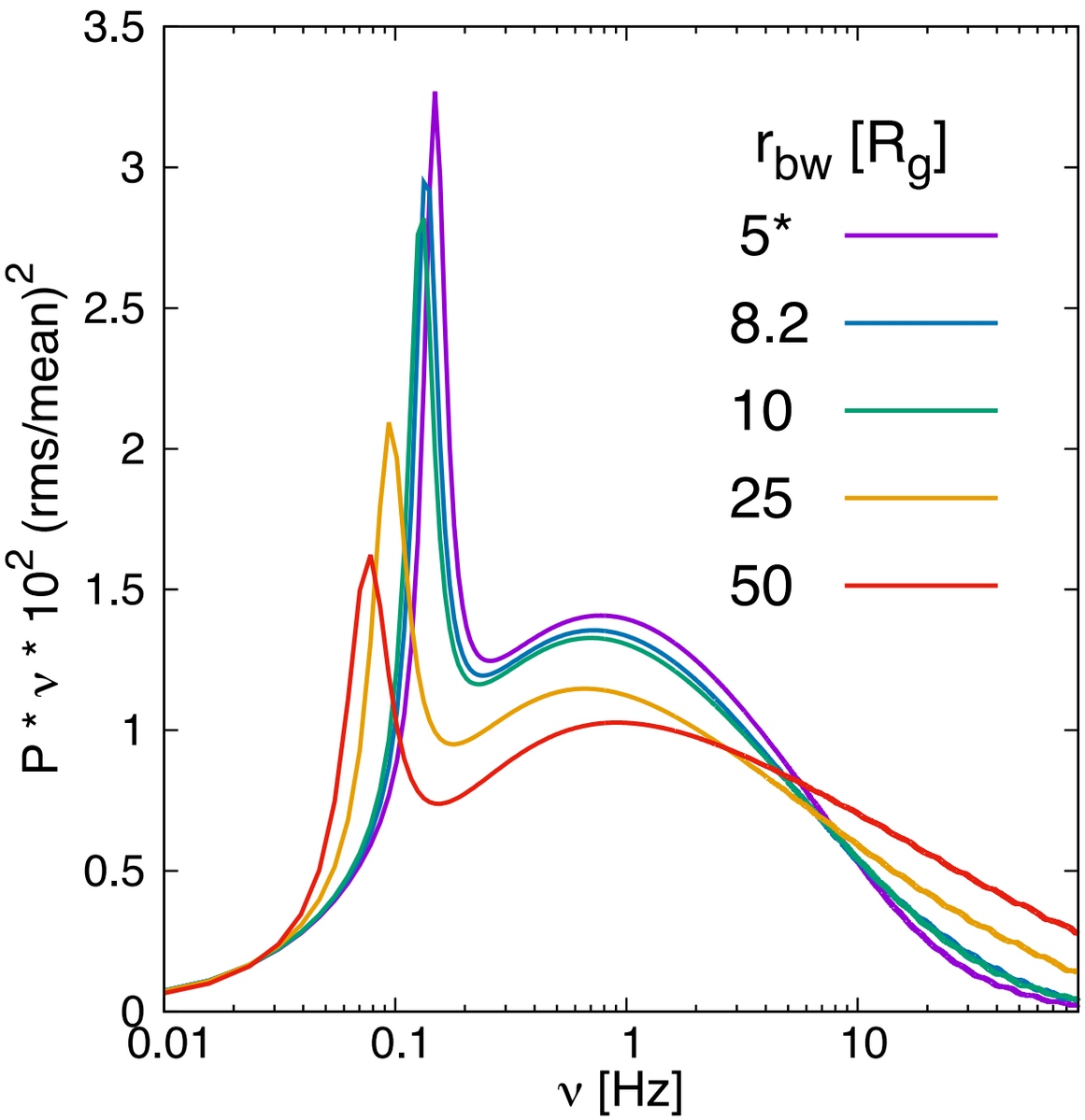

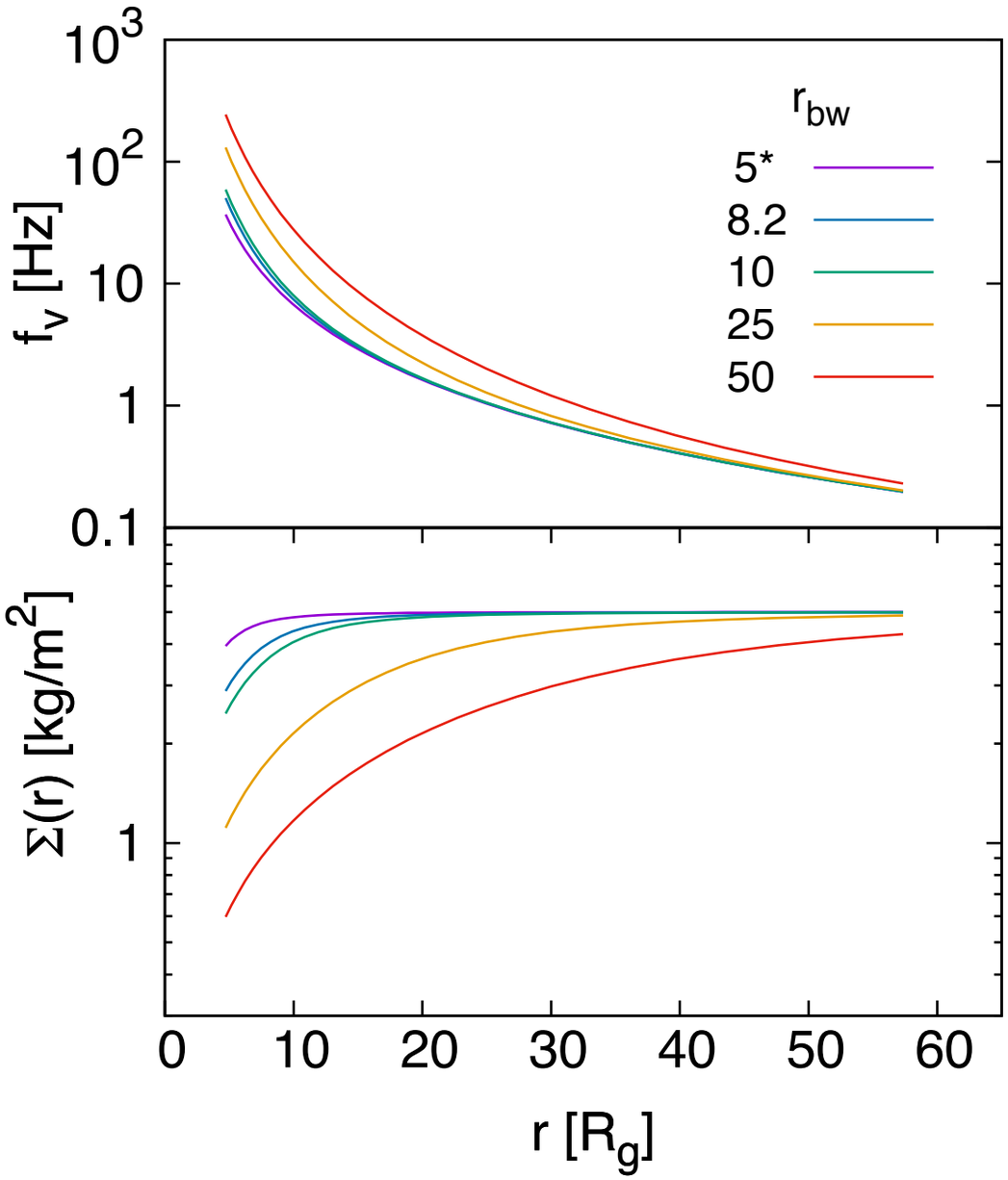

(Rapisarda et al. 2014)

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$$\Sigma(r) = \frac{\Sigma_0 \dot{M}}{cR_g} \frac{x^\lambda}{(1+x^\kappa)^{(\zeta+\lambda)/\kappa}}$$

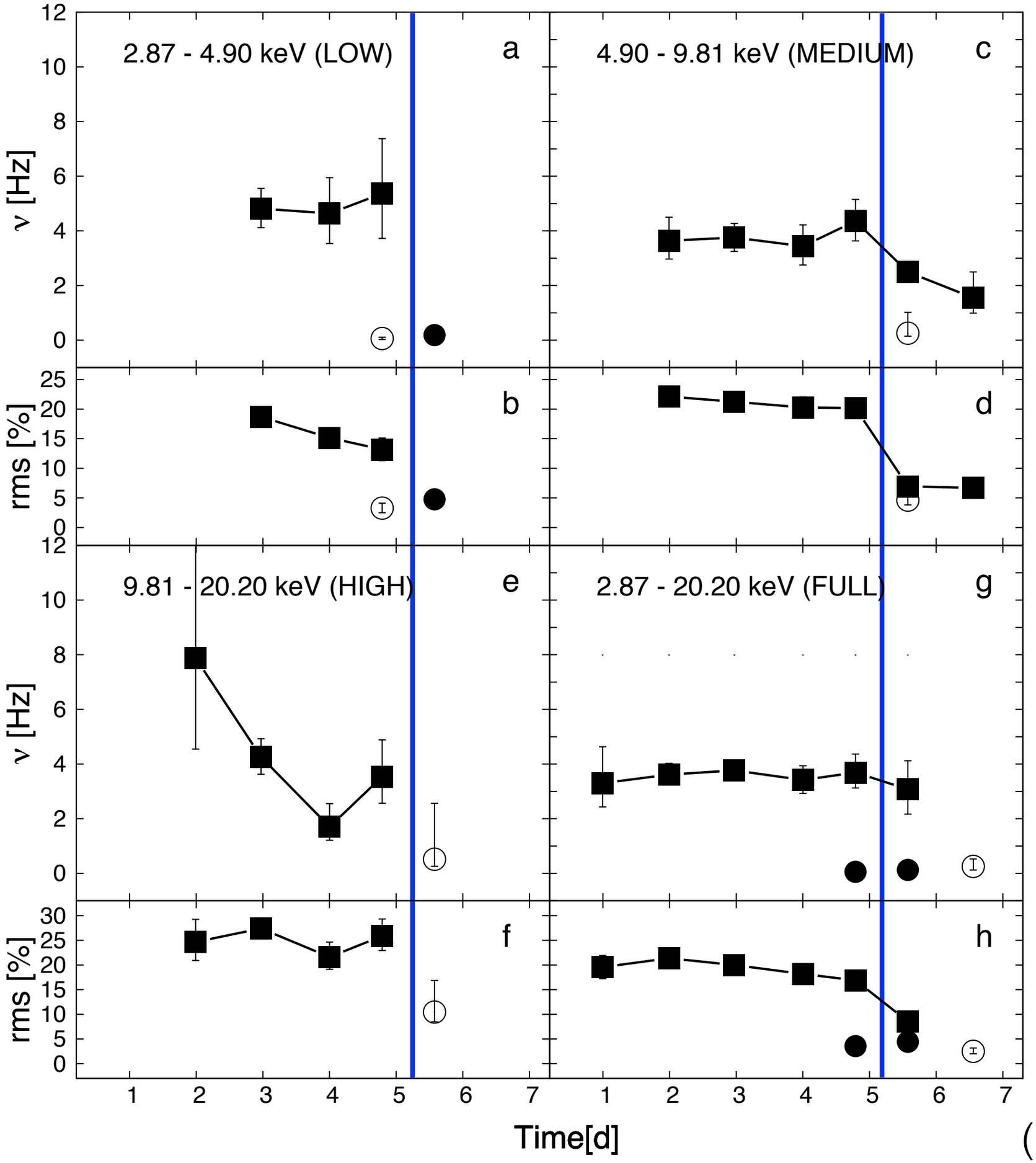
Surface density

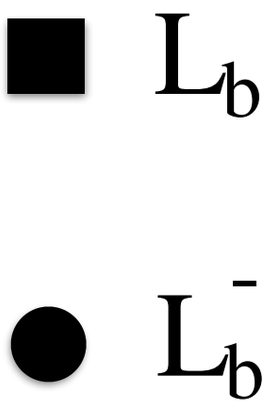
$$\nu_{QPO} \equiv \nu_{prec} = \frac{\int_{r_i}^{r_o} f_{LT} f_k \Sigma(r) r^3 dr}{\int_{r_i}^{r_o} f_k \Sigma(r) r^3 dr}$$

QPO frequency

$$r_{bw} = 3(h/r)^{-4/5} a_*^{2/5}$$

Bending wave radius





▲ $\sigma > 3$

△ $2 < \sigma < 3$

(Rapisarda et al. 2014)

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MAXI J1659-152

- Transient black hole binary
- Discovered on 25 September 2010 by Negoro et al. (2011)
- Shortest orbital period BHB (2.41 h)
- Observations collected between 25 September and 22 October 2010 by Swift

Dips or not dips, that is the question

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