

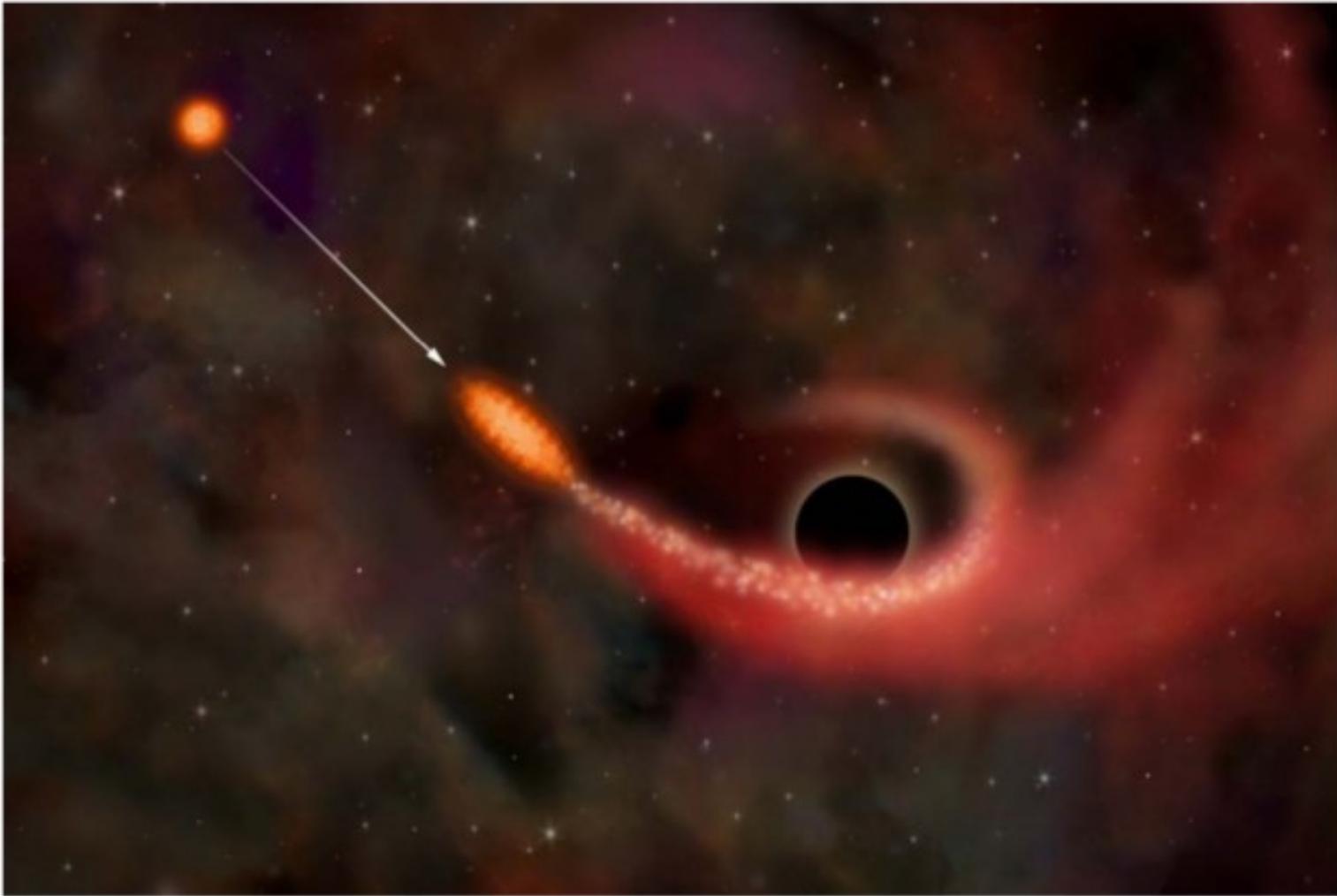
Optical/UV to X-ray Echoes following a Tidal Disruption Flare ASASSN-14li

By
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Collaborators:

**Brad S. Cenko (NASA/GSFC), Aleksander Sadowski (MIT), James Guillochon
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Cannizzo (NASA/GSFC)**

What is a Tidal Disruption Flare?



Credit: CXO

Why study?

Among many other things:

- They can allow us to understand the properties of hidden black holes, viz., masses, spins, jets, etc
- They also allow us to understand how stellar debris settles into a `disk' around a supermassive black hole in real time

e.g., Rees 1983; Strubbe & Quataert (2009); Kochanek (1995); Zauderer et al. (2011); Berger et al. (2011).

Some open questions

- How and when does material circularize?
- Does the circularized material form an accretion disk (of what kind)?
 - Tied to the origin of the optical and UV emission from TDFs:
 - Optical/UV direct from an accretion disk?
 - Optical/UV from tidal stream interaction?
 - Optical/UV from X-ray re-processing?

Some References: Shiokawa et al. (2015); Bonnore et al. 2016; Svirski et al. (2016); Hayasaki et al. (2016); Piran et al. (2015); Dai et al. (2016); Franchini et al. (2016); Lodato & Rossi (2011) and more

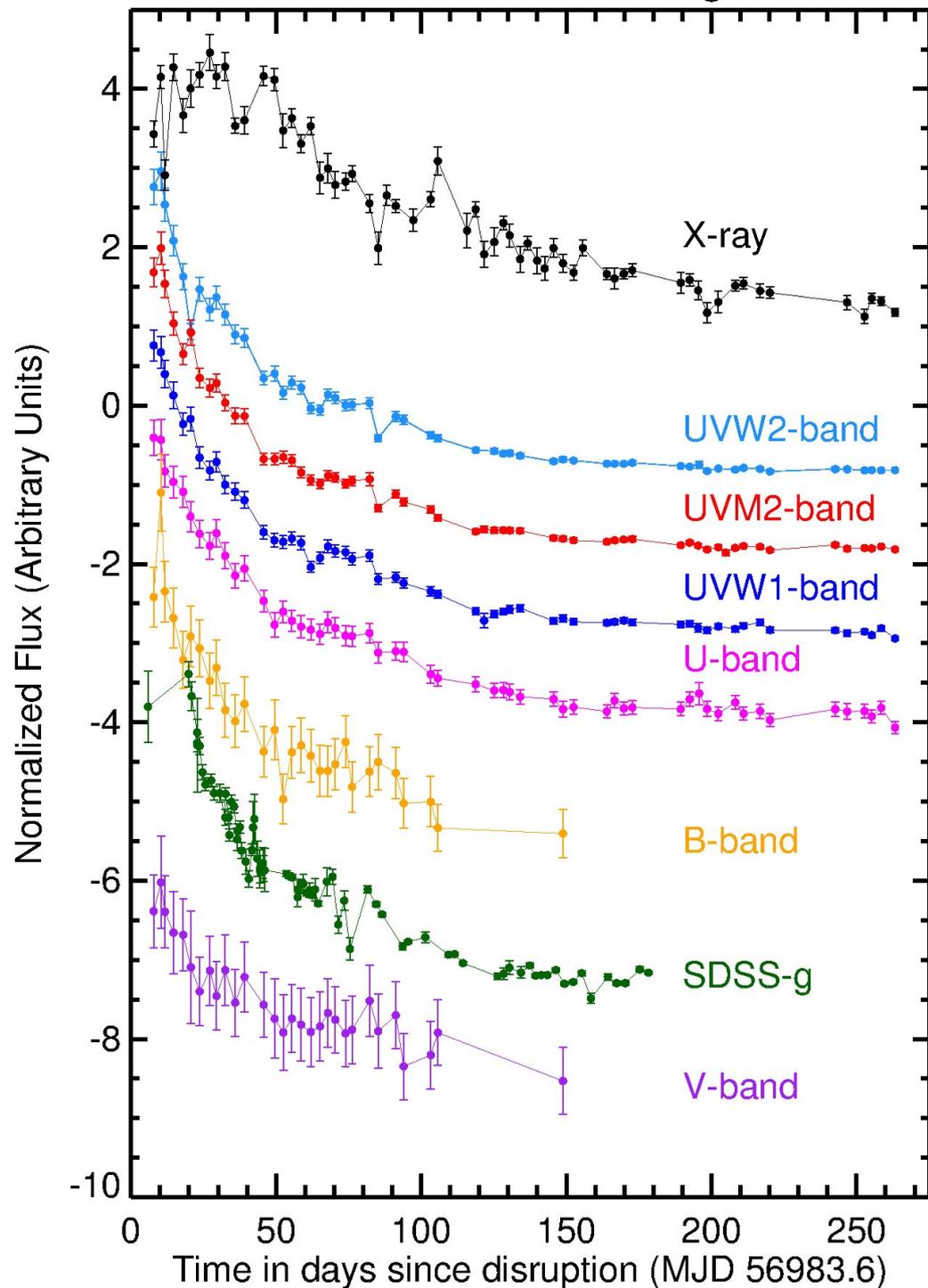
ASASSN-14li: A TDF Poster Child

- Why a TDF?
 - Spatial position
 - Blue optical spectra with broad H α and He emission lines
 - A constant optical color unlike Sne
- A flare that shined in X-ray, UV, optical and radio: a true multi-wavelength TDE

Holoien et al. (2016); Miller et al. (2015); van Velzen et al. (2016); Krolik et al. (2016); Alexander et al. (2016), Arcavi et al. (2014), etc

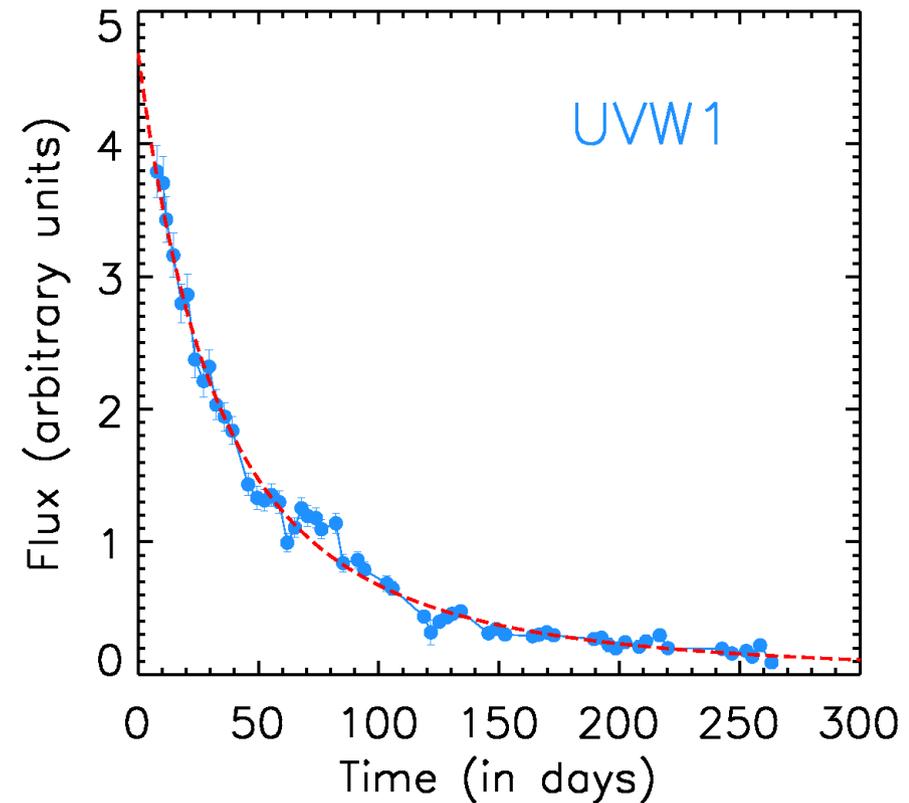
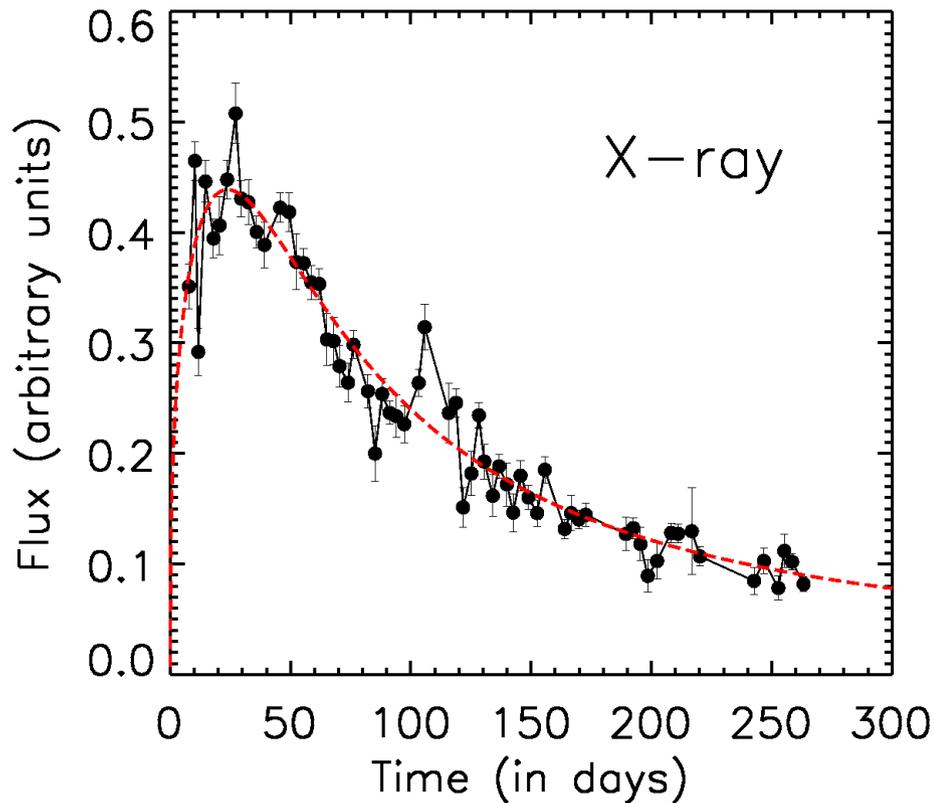
Part 1: What we did?

ASASSN-14li's Multiband Light Curves



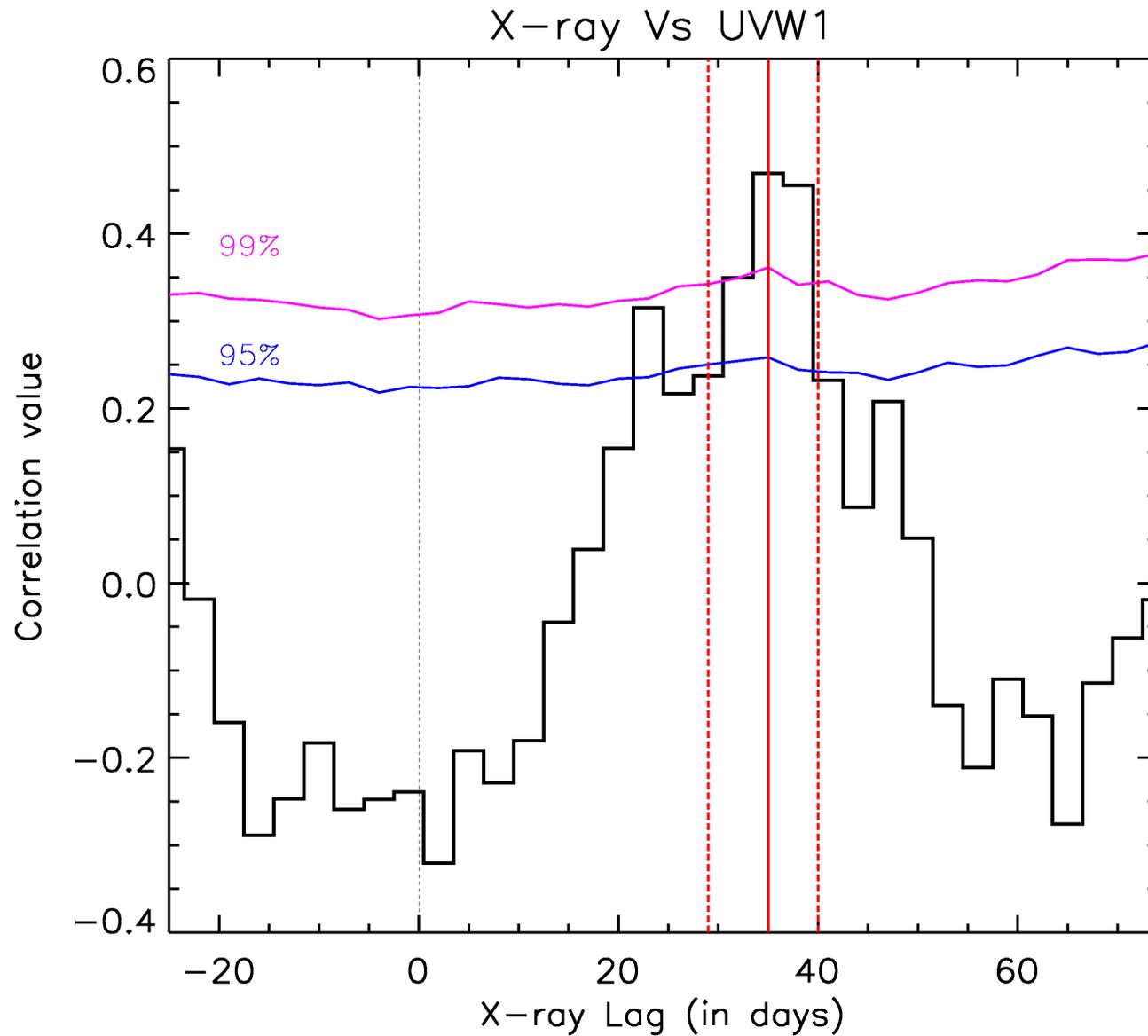
ASASSN-14li: Optical/UV and X-ray Monitoring Campaign with Swift

Cross-Correlation Analysis



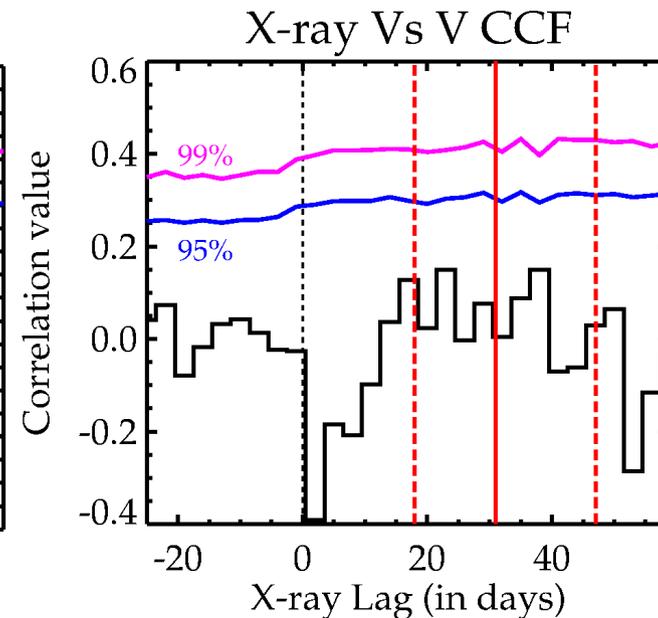
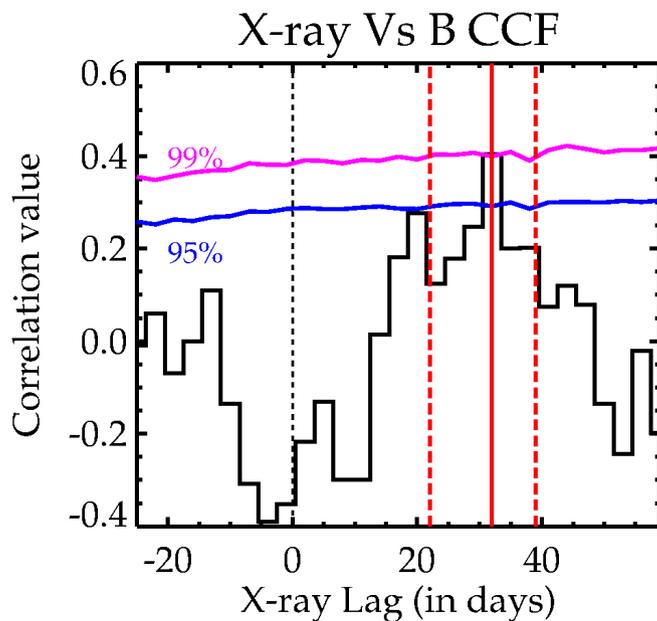
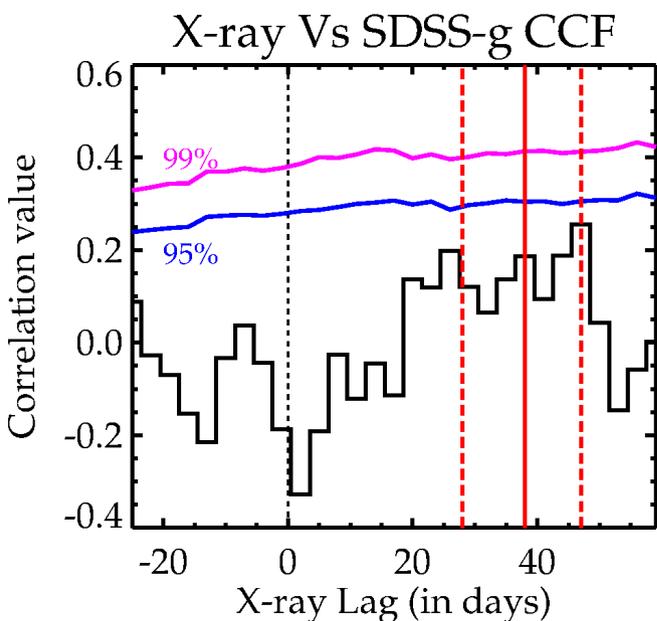
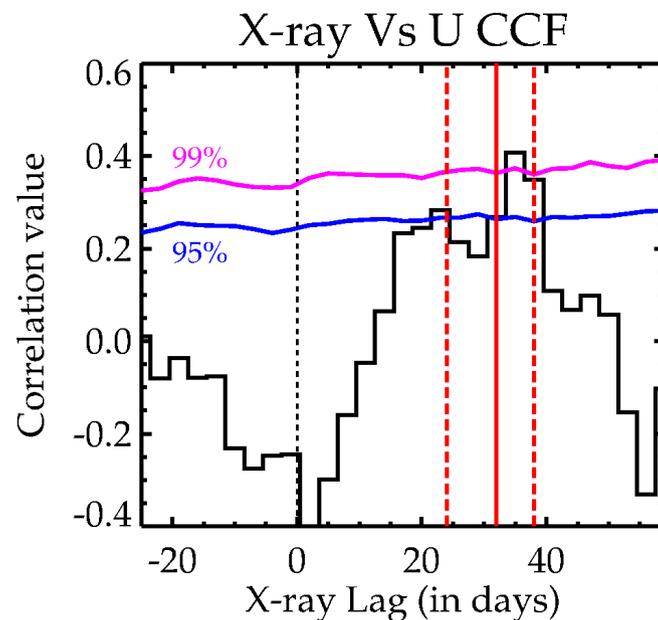
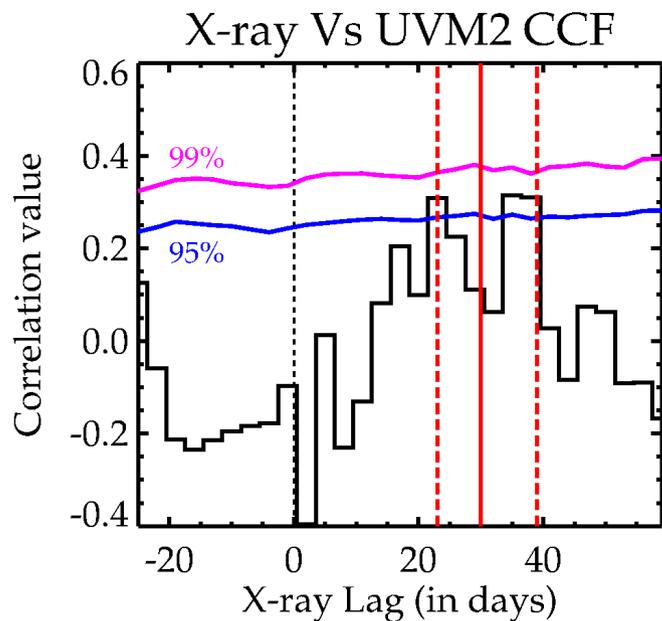
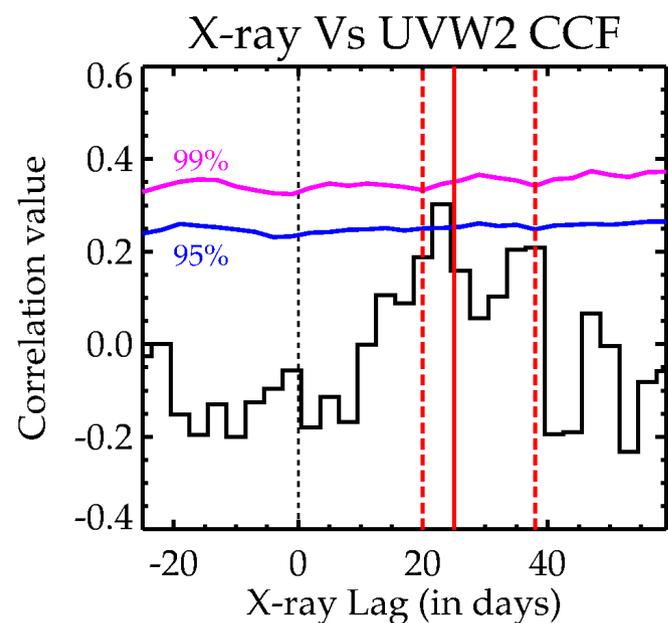
**De-trended and extracted the
interpolated cross-correlation function
(ICCF)**

A Sample Cross-Correlation Function



Positive lag ==> X-rays lag

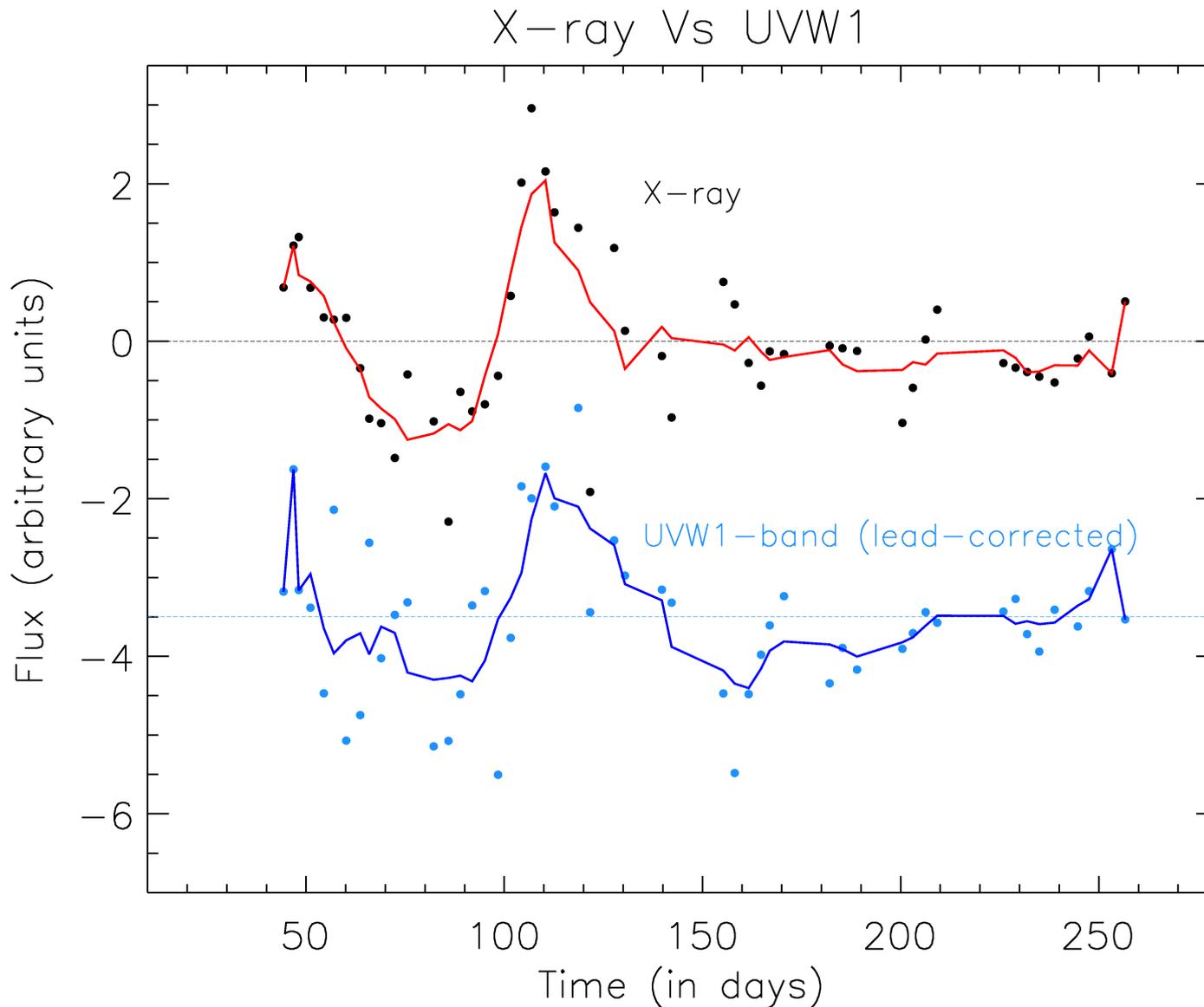
The rest of the CCFs



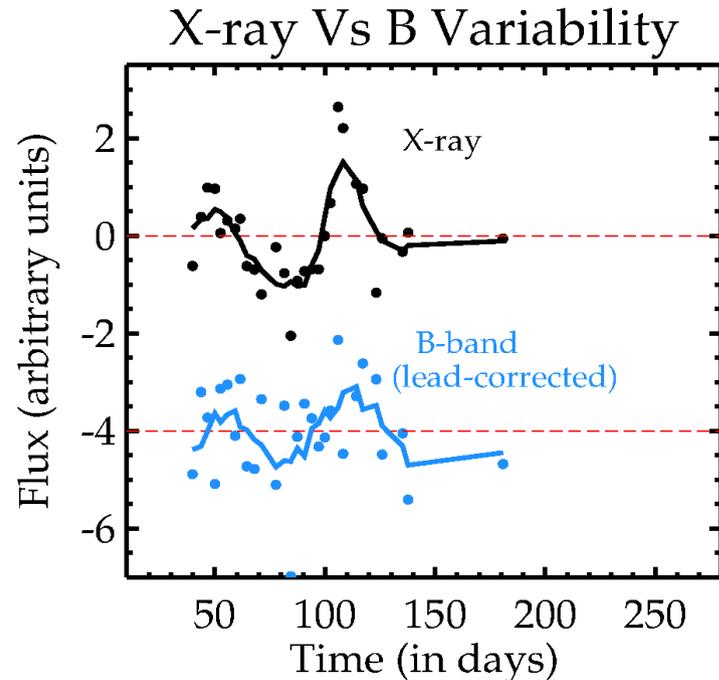
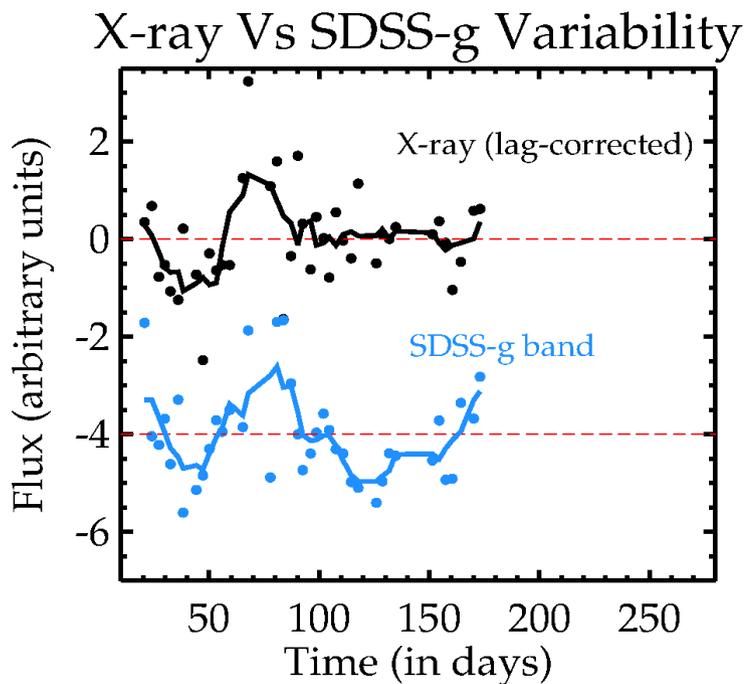
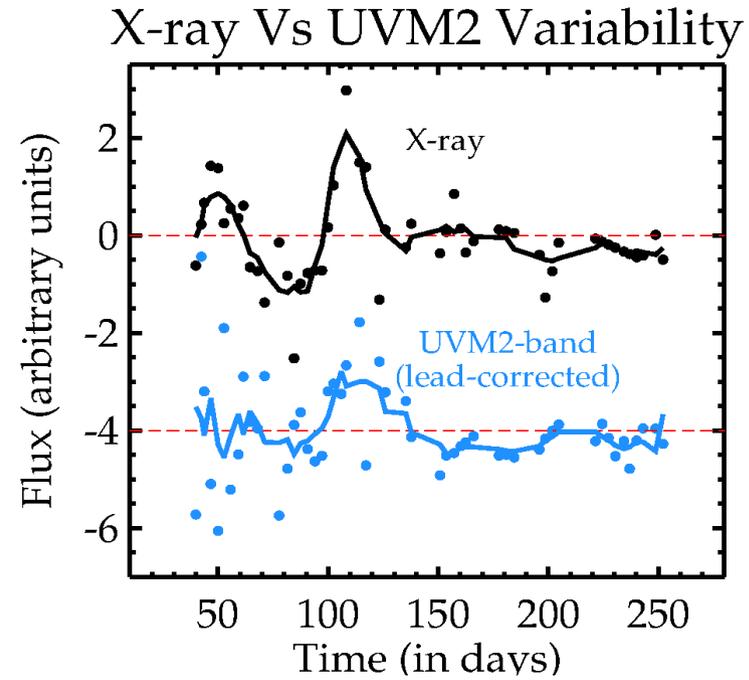
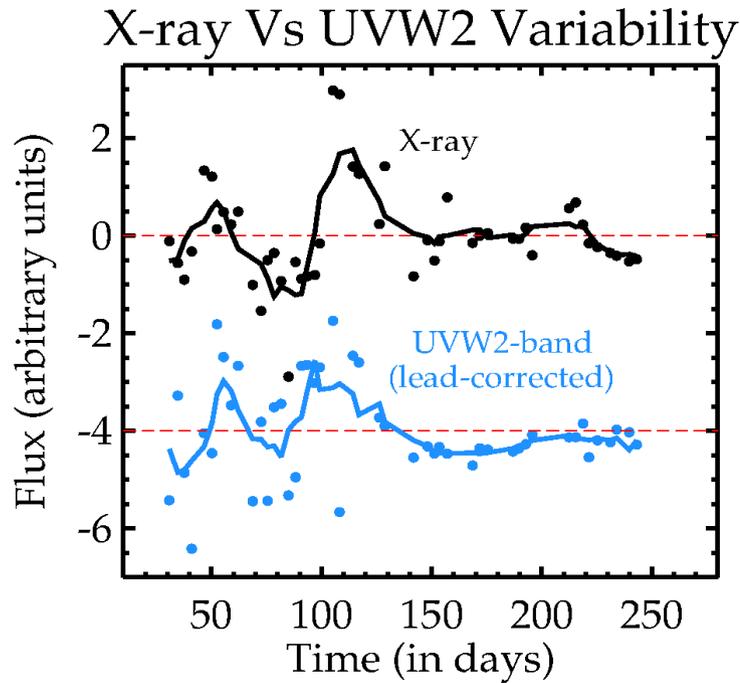
Positive lag ==> X-rays lag

To Confirm the Correlation and lags

Compare the light curve directly



To Confirm the Correlation and lags



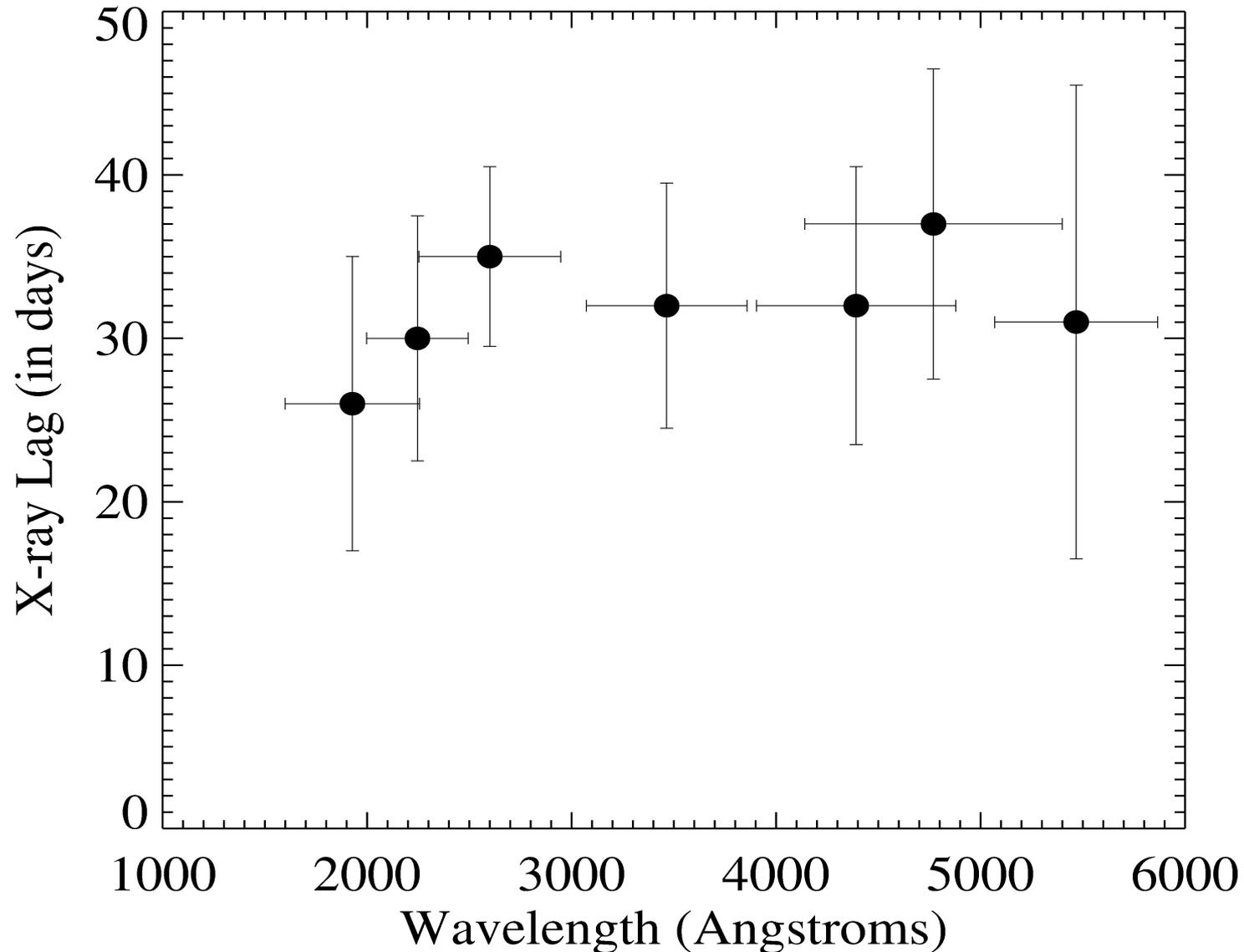
What is the statistical significance of the optical/UV leading the X-ray emission?

CCF peak $> 95\%$ in 5 out of 7 CCFs

Using Binomial distribution formula,

Global Significance $> 4.4\sigma$

In summary, ASASSN-14li's optical and the UV emission appears to **lead** the X-ray emission by 20-40 days



Part 2: What conclusions?

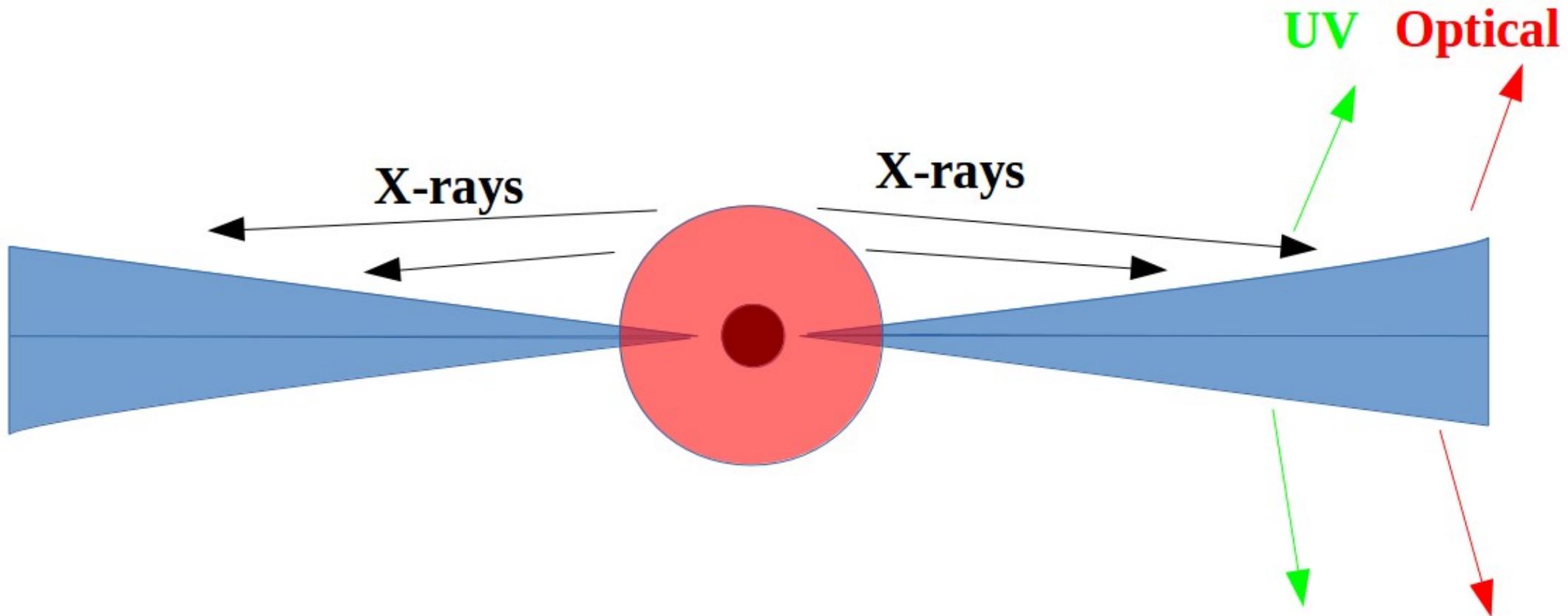
Some of the open questions

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Some References: Shiokawa et al. (2015); Bonnore et al. 2016; Svirski et al. (2016); Hayasaki et al. (2016); Piran et al. (2015); Dai et al. (2016); Franchini et al. (2016) and more

(1) What can we conclude from this?

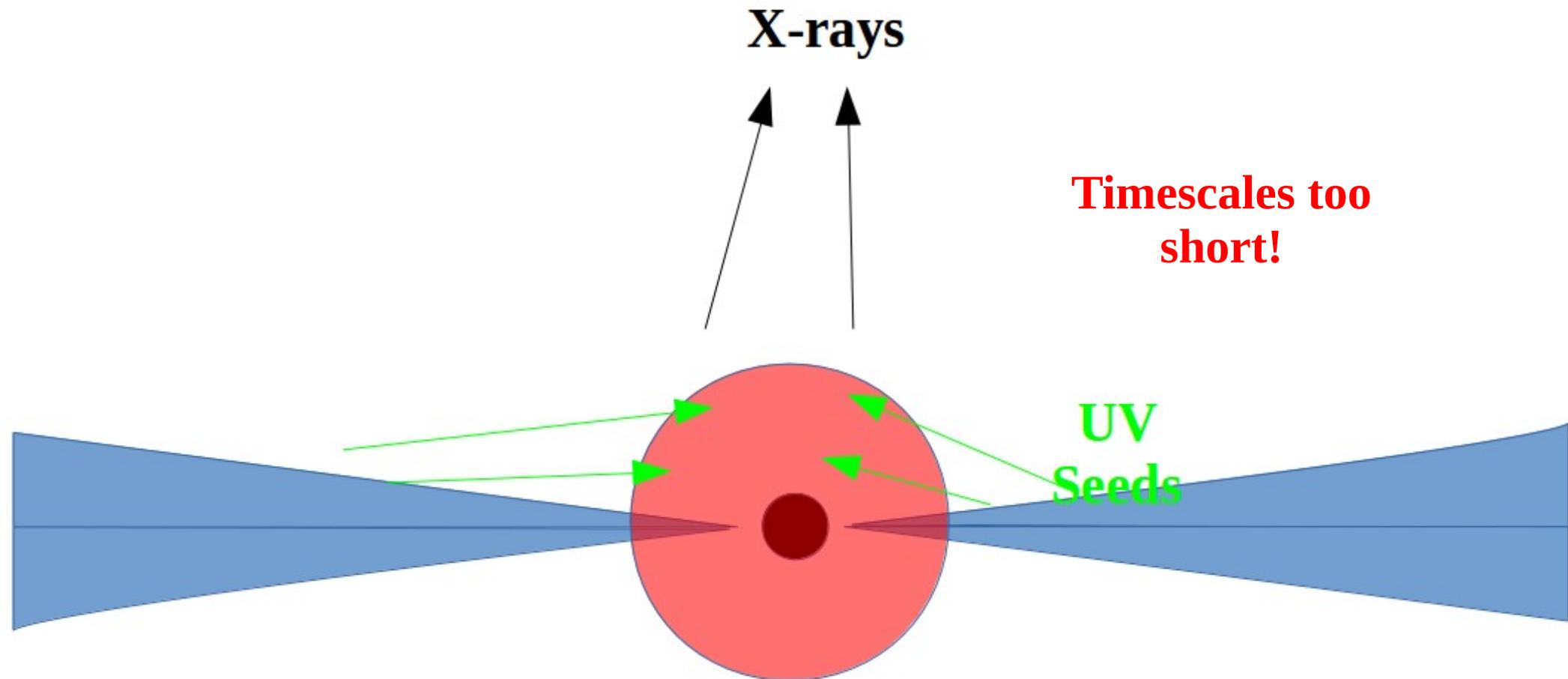
- The optical and the UV emission is not from **PURE** X-ray reprocessing



Optical/UV “leads” X-ray!

(2) What can we conclude from this?

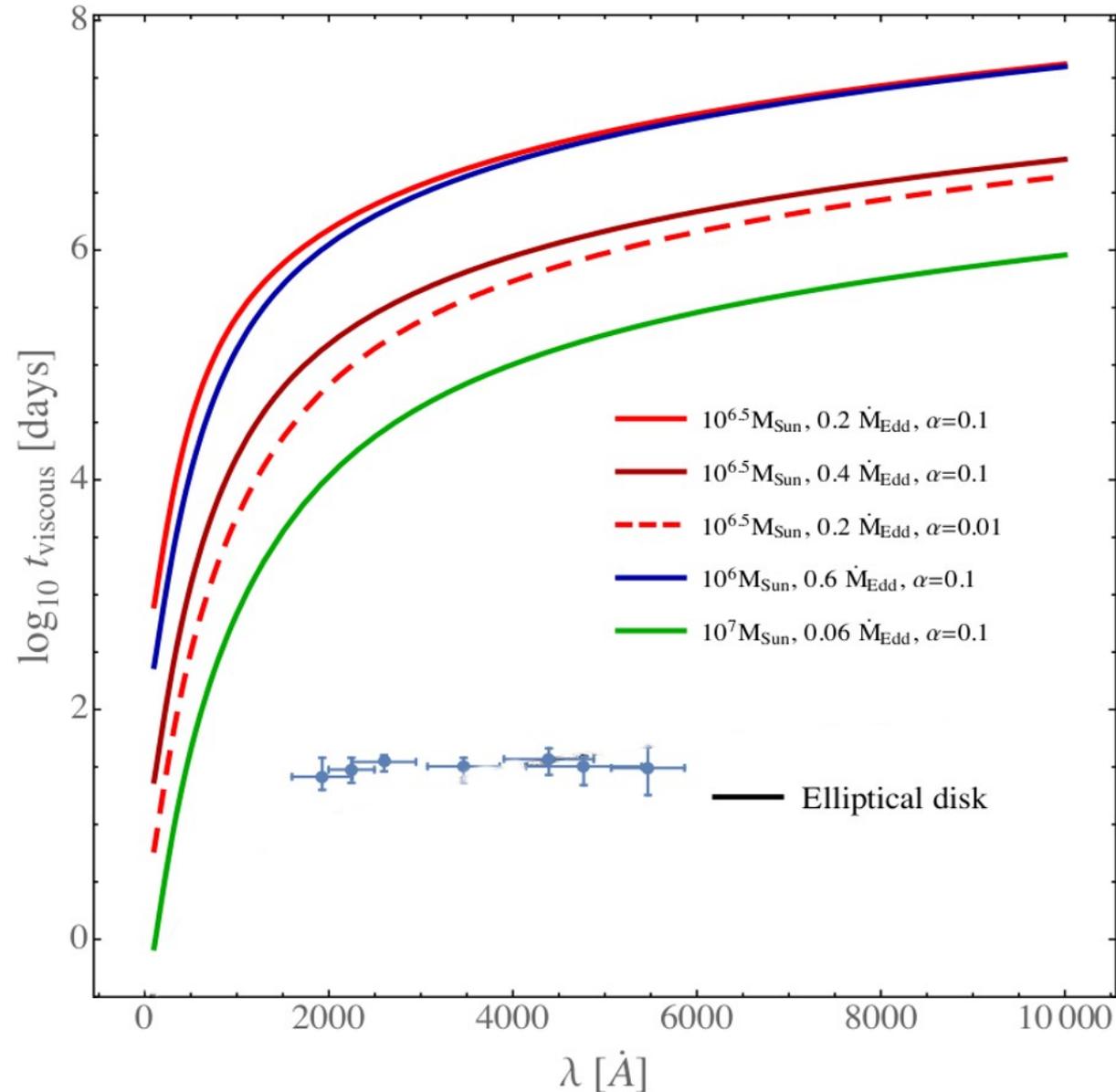
- **Optical and UV emission NOT from PURE seed photons**



(3) What can we conclude from this?

Cannot be due to **JUST** viscous propagation in a standard disk

Shakura & Sunyaev
(1973)

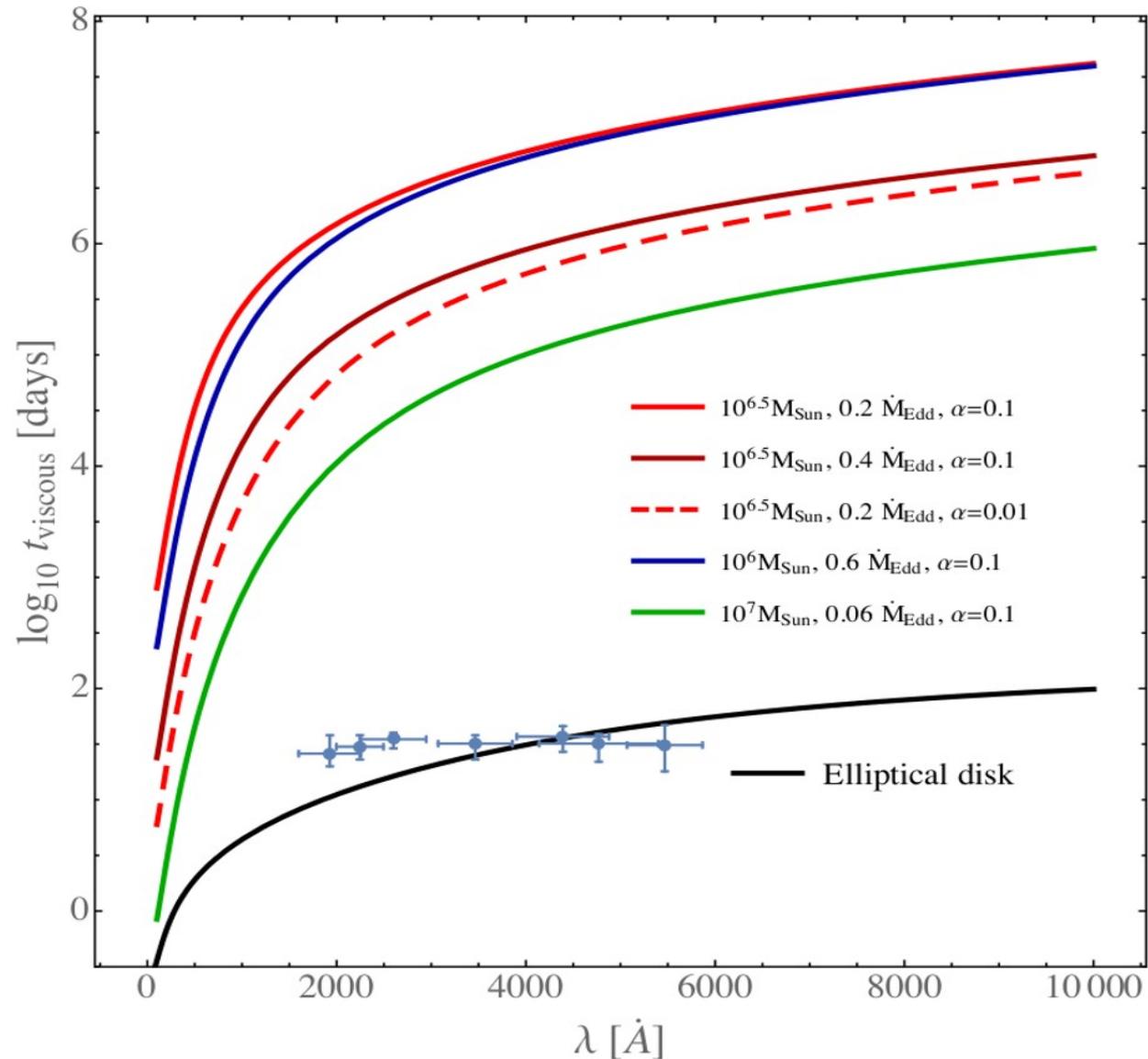


(3) What can we conclude from this?

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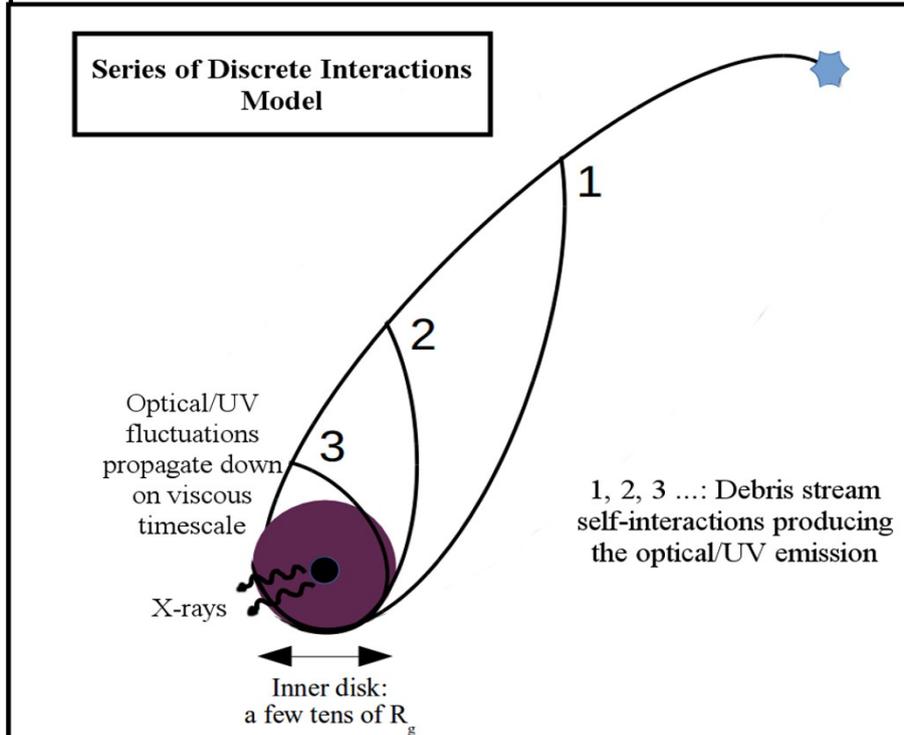
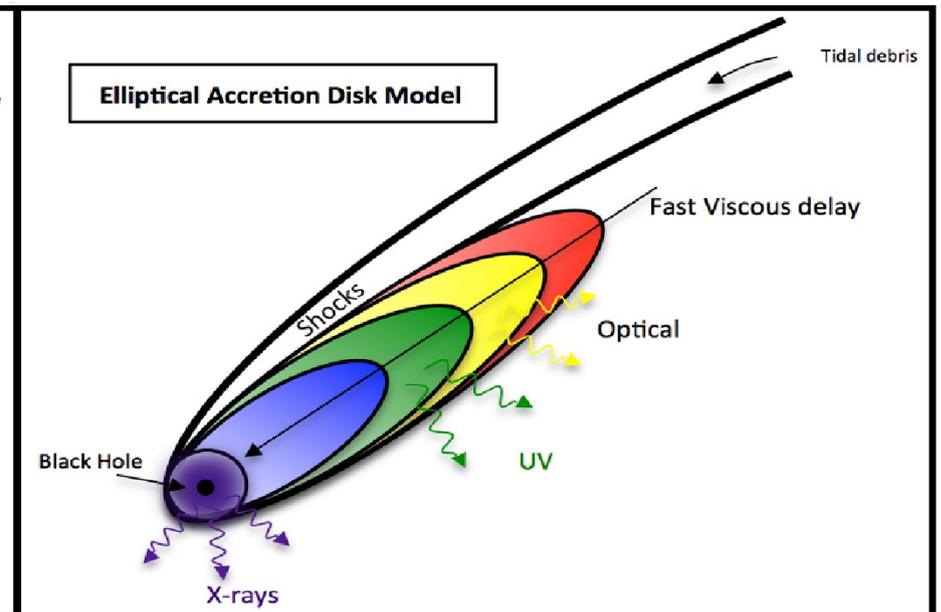
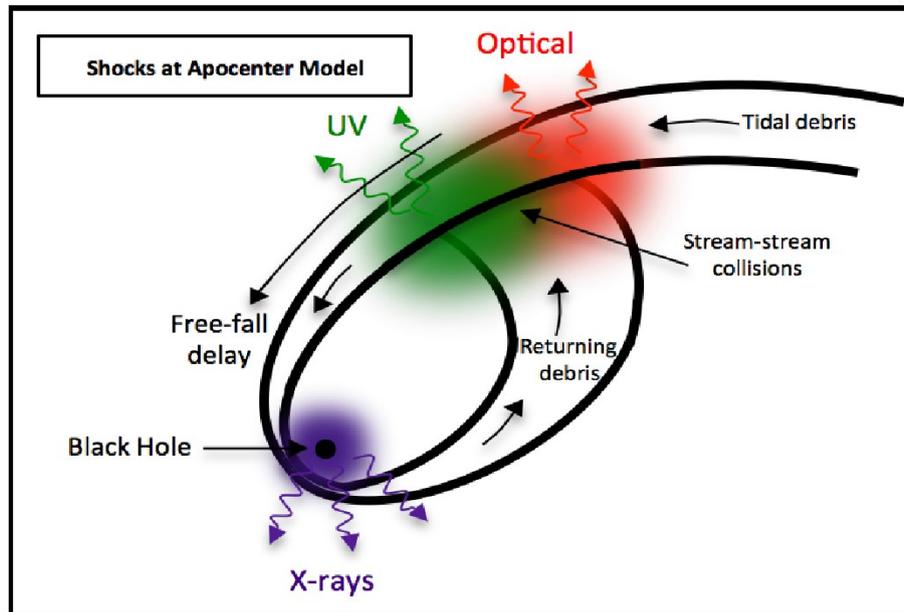
Shakura & Sunyaev
(1973)

Guillochon et al.
(2014)



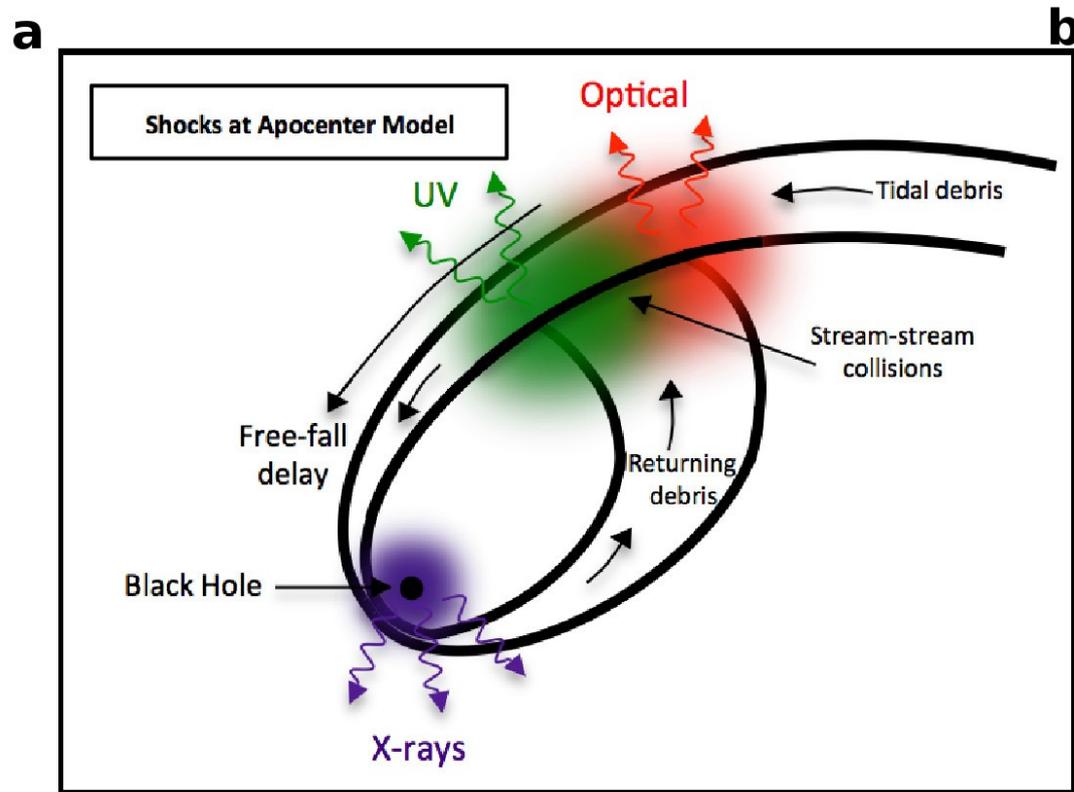
**Stream Self-interaction models
can explain the Lags**

Three models seem consistent with these lags



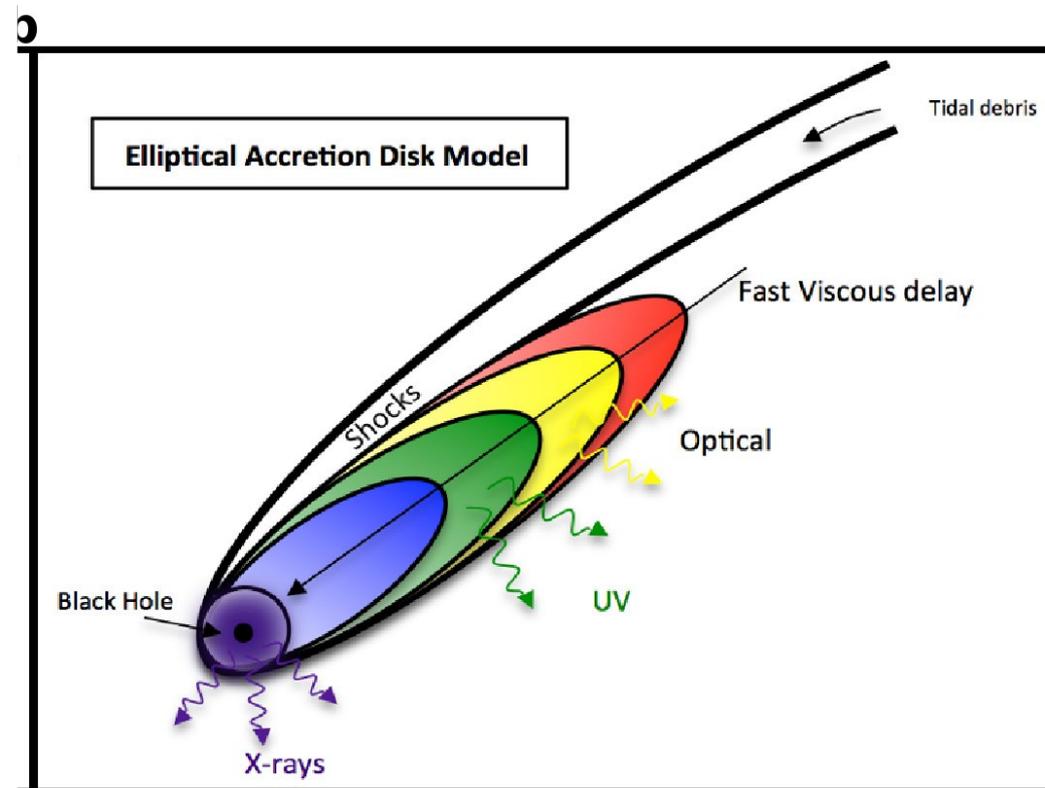
Piran et al. 2015 (but with modifications)
Guillochon et al. 2014
Bonnerot et al. 2017

Shocks at Apocenter Model



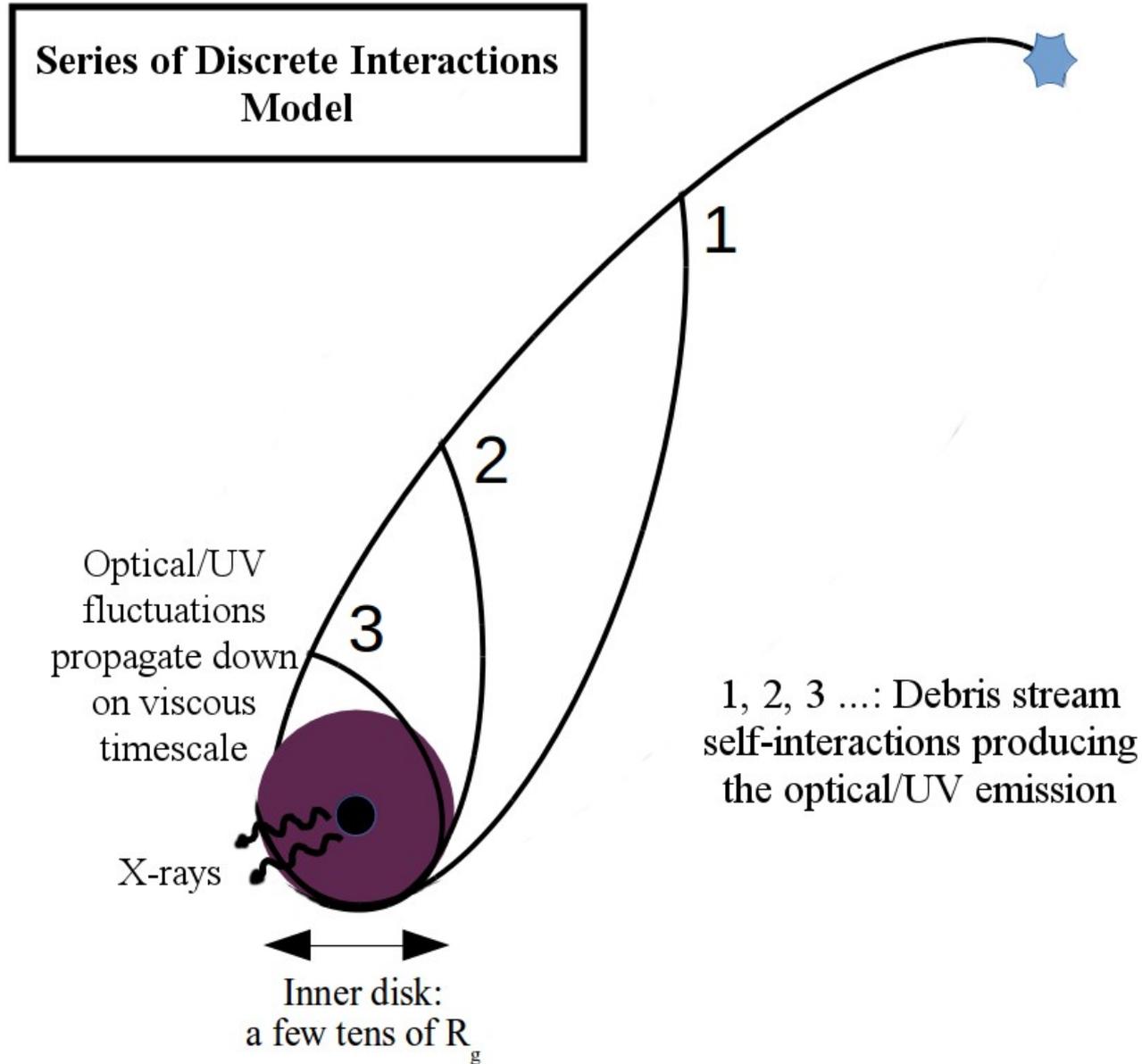
Piran et al. 2015 (but with modifications)

Extended Elliptical Disk Model



Guillochon et al. 2014

Series of Discrete Interactions Model

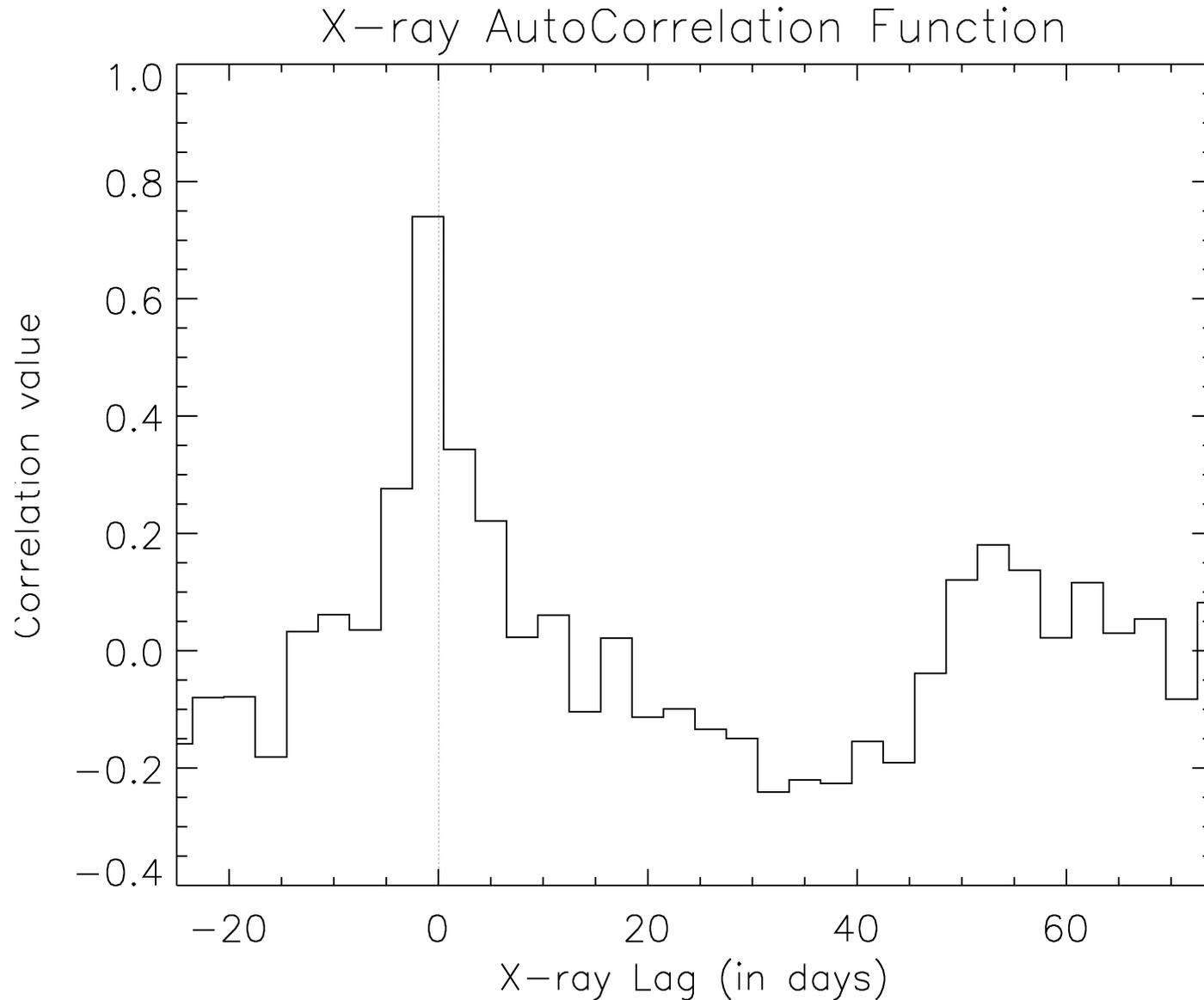


Take away points

- In ASASSN-14li, optical and UV emission leads the X-rays by ~ 35 d
- **Compelling evidence against a disk instability driven AGN outburst**
- **ASTROSAT: Simultaneous X-ray and UV observations to search for X-ray reprocessing signal. Map the surrounding regions following a tidal disruption.**

Thanks!

X-ray light curve DOES NOT drive these correlations



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