# X-ray Detection of a Nova in the Fireball Phase


König et al., Nature 605, 7909, 2022


## Ole König

together with J. Wilms, R. Arcodia, T. Dauser, K. Dennerl, V. Doroshenko, F. Haberl, S. Hämmerich, C. Kirsch, I. Kreykenbohm, A. Malyali, M. Lorenz, A. Merloni, A. Rau, T. Rauch, G. Sala, A. Schwope, V. Suleimanov, P. Weber, K. Werner


**RICAP22** (Rome, Thursday 8th September, 2022)


FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

eROSITA

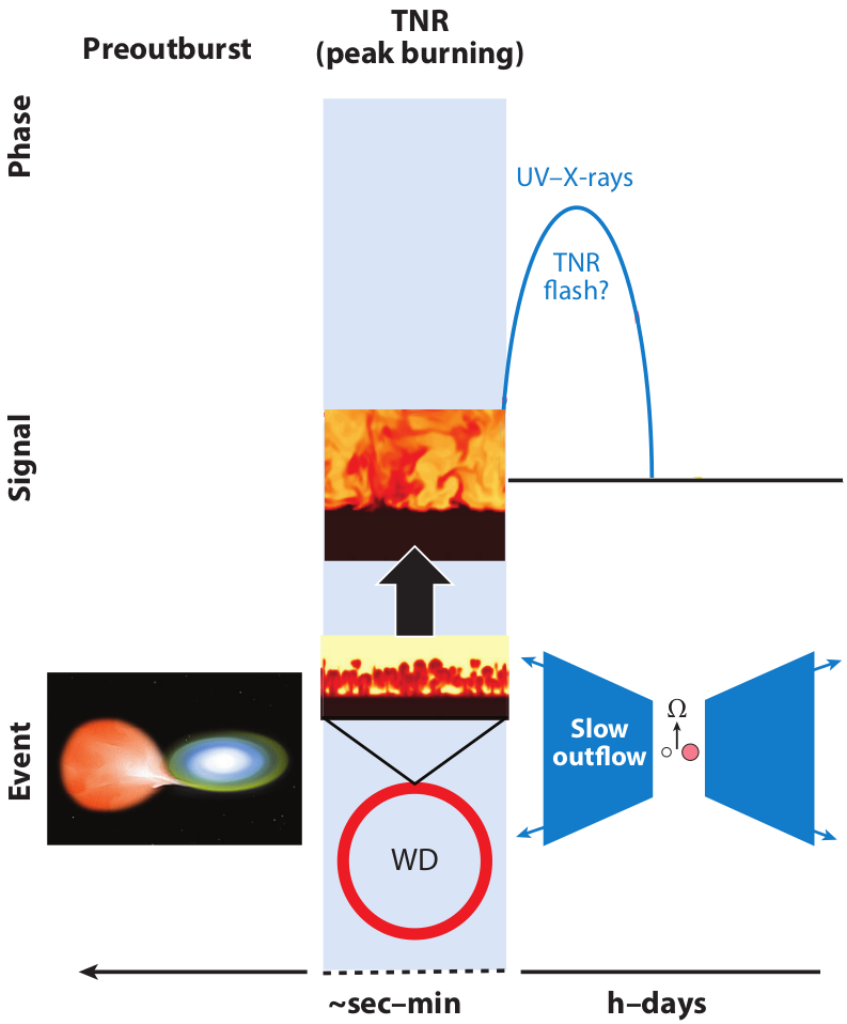
# Introduction to Novae


Kraft (1959)

- First nova eruption detected $\sim$2000 years ago

Chomiuk et al. (2021)

# Introduction to Novae




- First nova eruption detected ∼2000 years ago

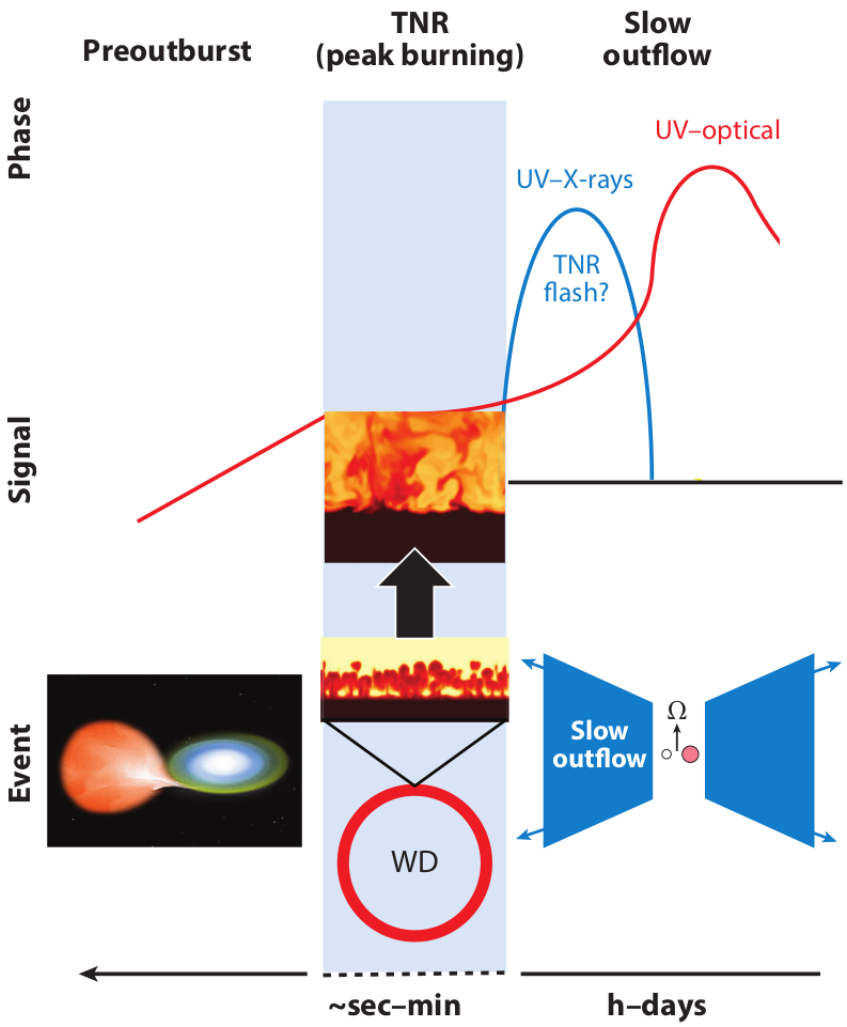
The X-ray flash should be detectable...

- ... as a short and very soft transient
- ... at the Eddington luminosity

Chomiuk et al. (2021)

Starrfield et al. (1990); Hillman et al. (2014); Morii et al. (2016); Kato et al. (2016)

# Introduction to Novae




- First nova eruption detected ∼2000 years ago

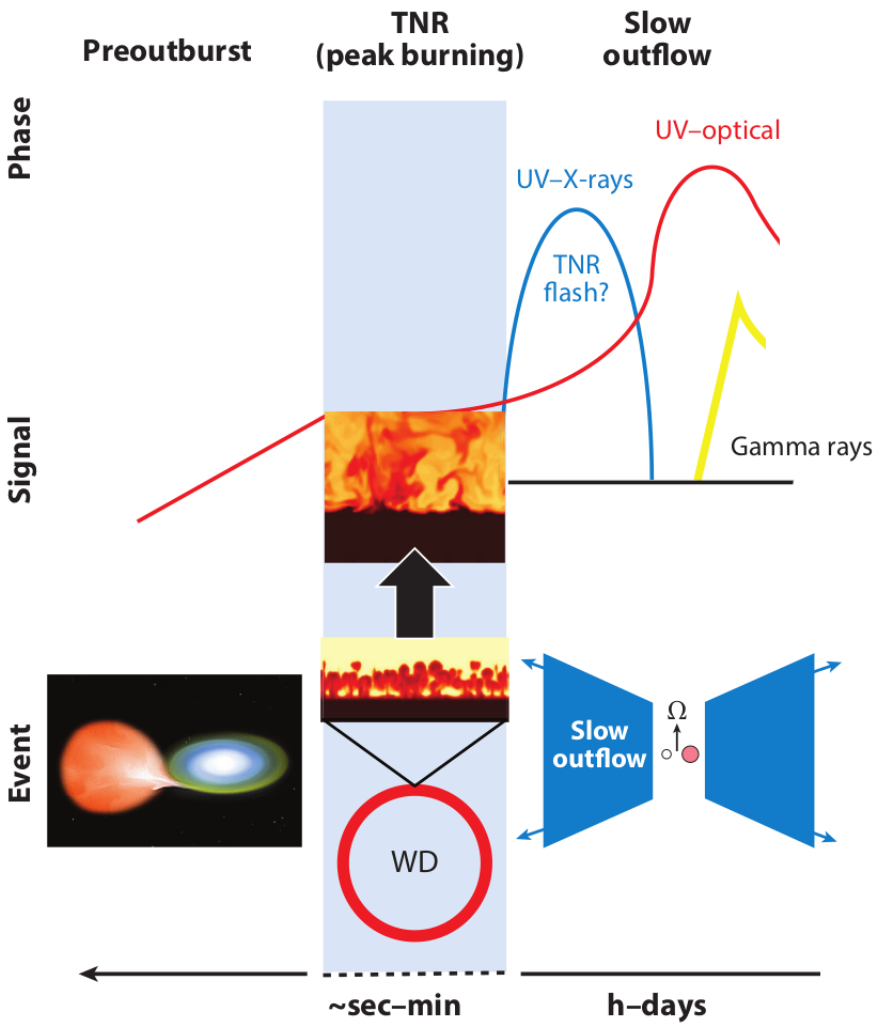
The X-ray flash should be detectable...

- ... as a short and very soft transient
- ... at the Eddington luminosity
- ... shortly before the optical peak
- ... and it has never been observed despite dedicated search campaigns

Chomiuk et al. (2021)

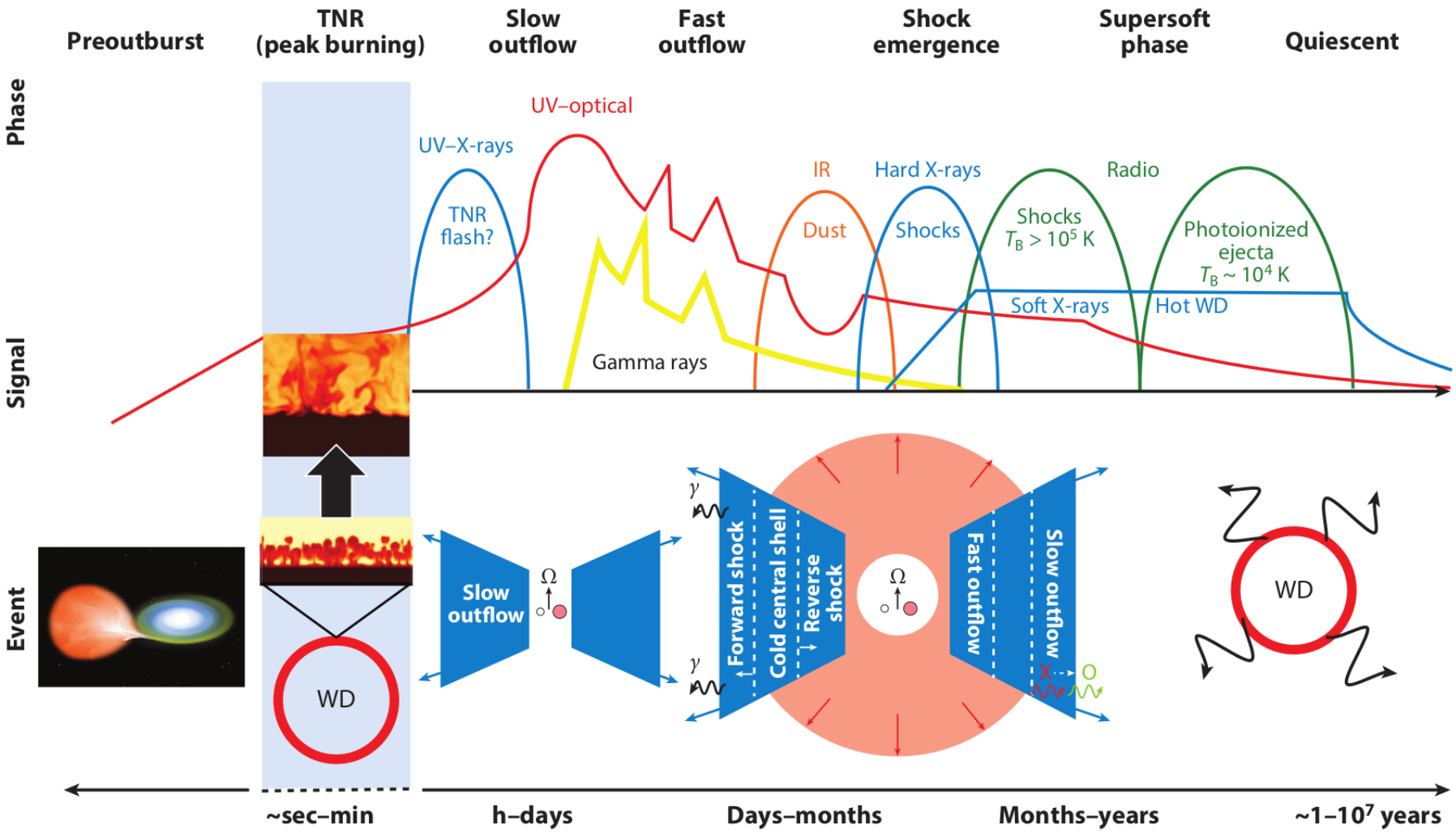
Starrfield et al. (1990); Hillman et al. (2014); Morii et al. (2016); Kato et al. (2016)

# Introduction to Novae




Chomiuk et al. (2021)

# Introduction to Novae

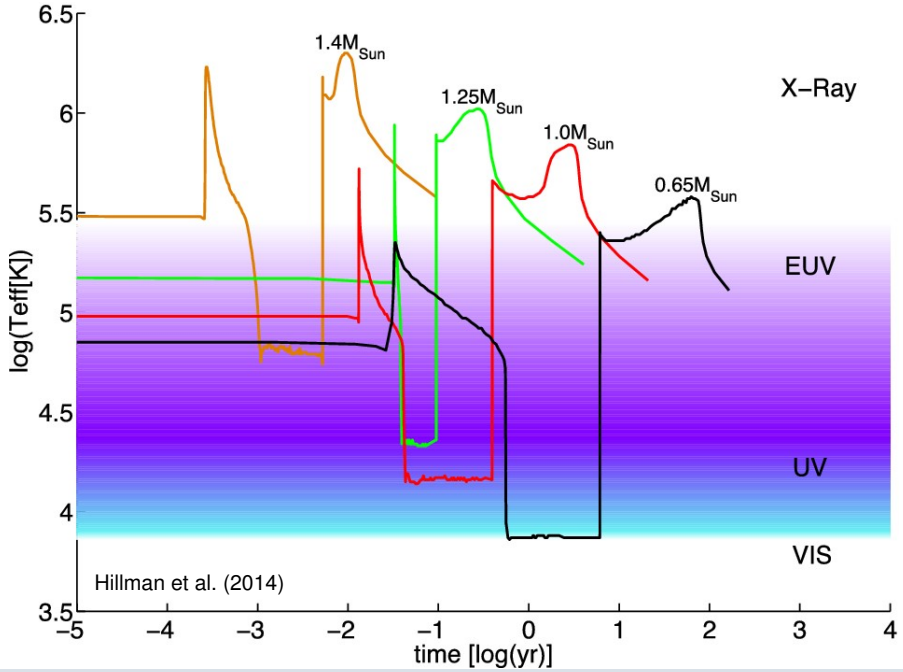



Chomiuk et al. (2021)

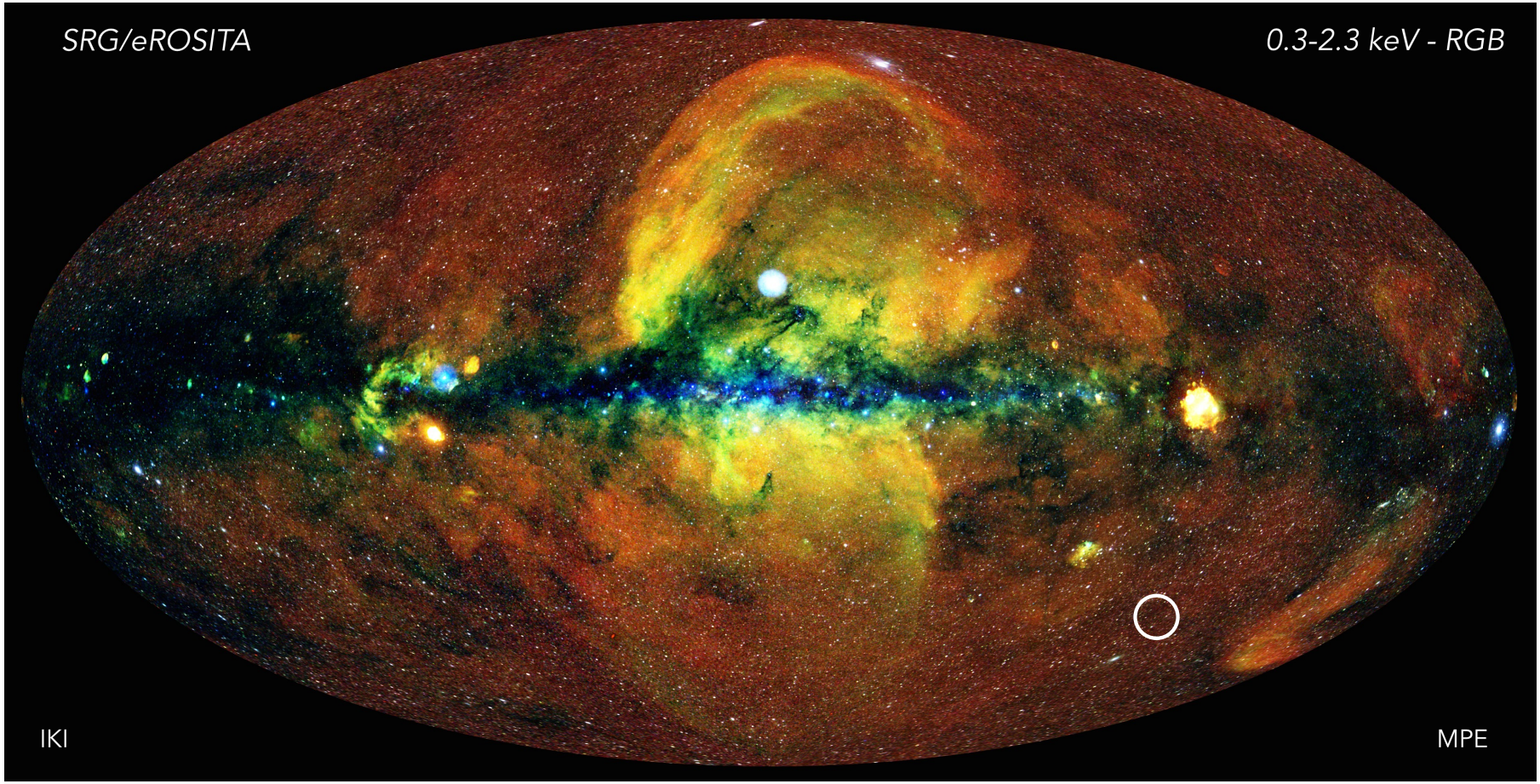
# Why is detecting the X-ray flash so interesting?

- Confirm $>$ 30 years of theoretical work on novae

  e.g., Starrfield et al. (1990); Krautter (2008); Hillman et al. (2014); Morii et al. (2016); Kato et al. (2016); Chomiuk et al. (2021)
- Constrain the timing of the thermonuclear runaway
- Constrain the amount of pre-existing circumbinary material
- Energy conservation?
- Constrain the white dwarf mass



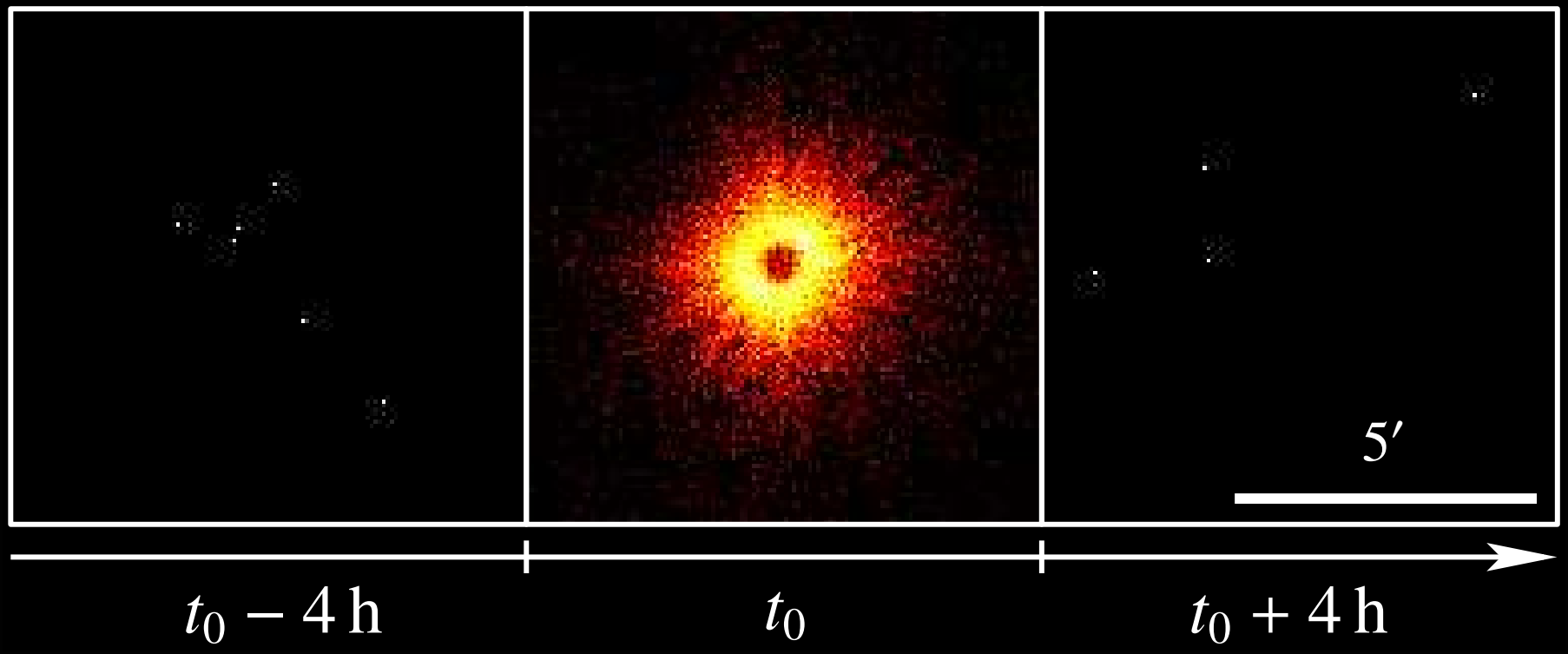
# The *eROSITA* mission



The Eye was rimmed with fire, but was itself glazed, yellow as a cat's, watchful and intent, and the black slit of its pupil opened on a pit, a window into nothing.

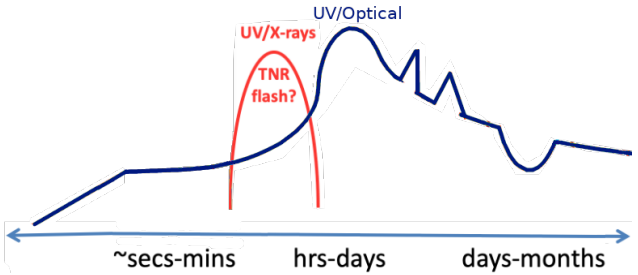
Frodo seeing Sauron in the mirror of Galadriel, The Fellowship of the Ring

# YZ Reticuli: An extremely bright new X-ray transient

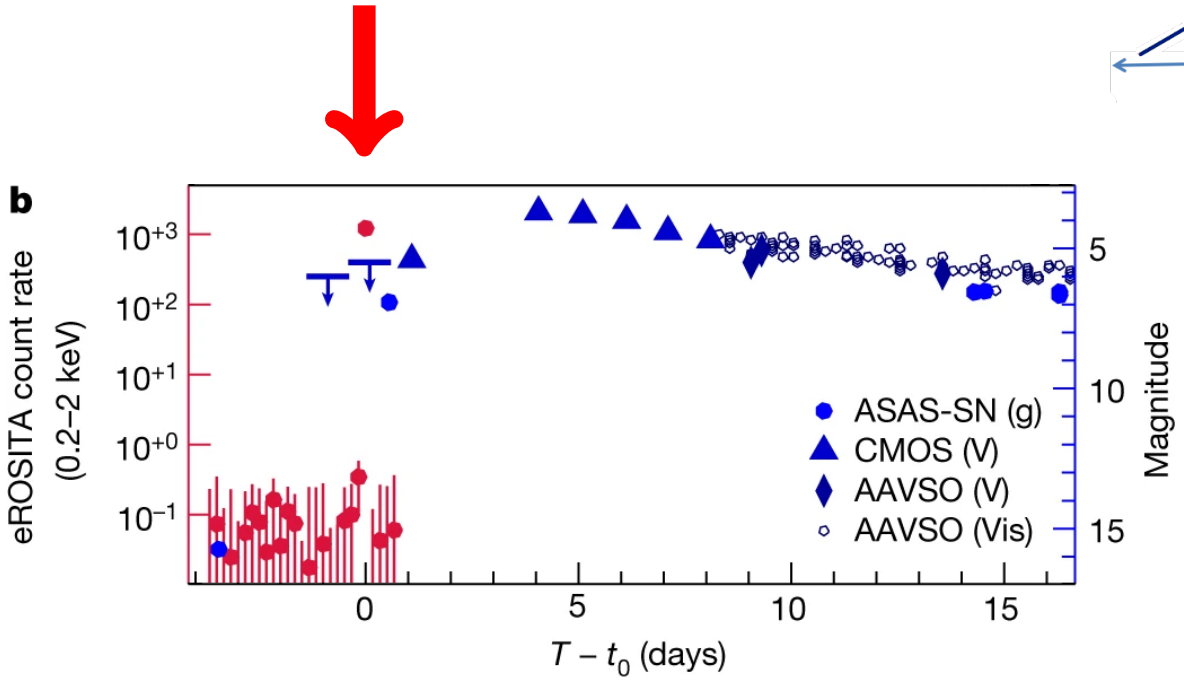



König et al., Nature, 2022

# YZ Reticuli: Lightcurve

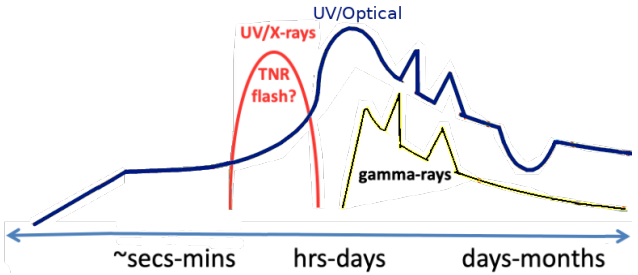



Modified from Chomiuk et al. (2021)

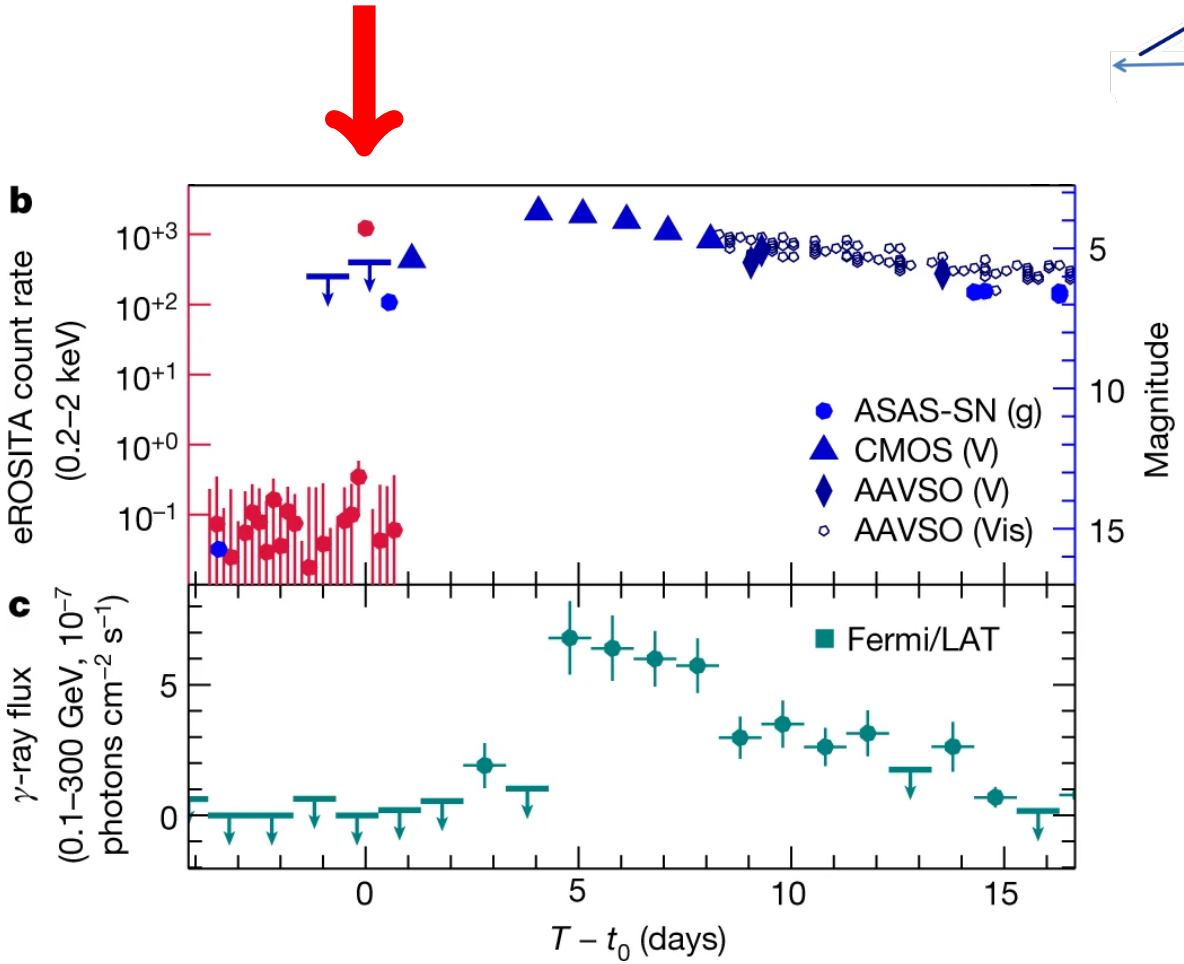



König et al., Nature, 2022

# YZ Reticuli: Lightcurve

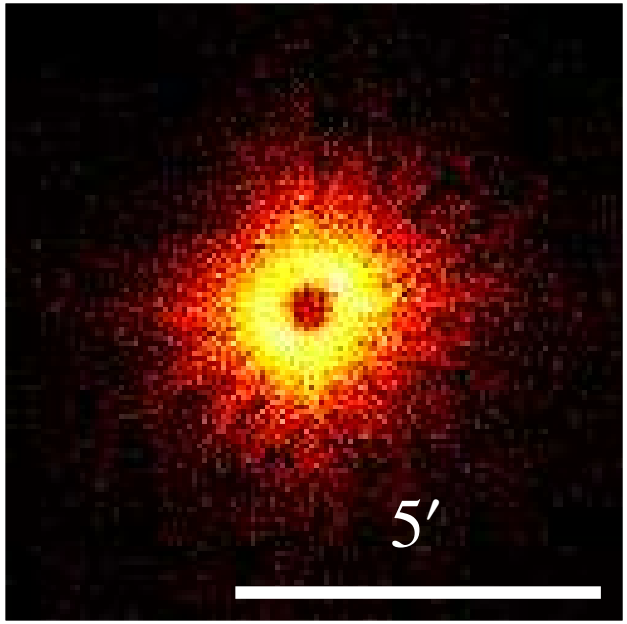


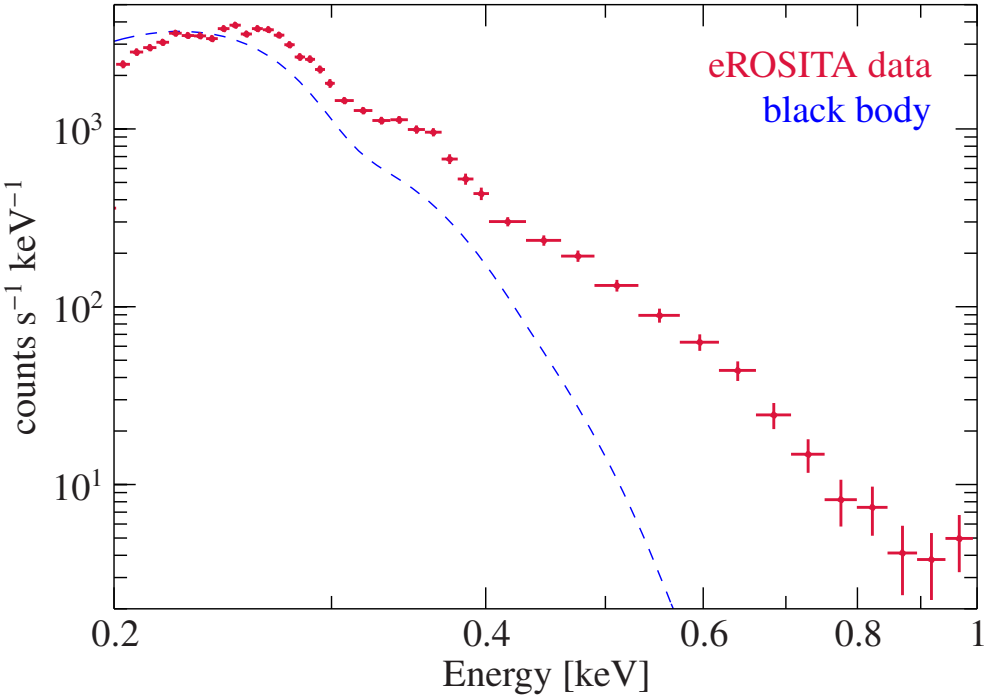

Modified from Chomiuk et al. (2021)




König et al., Nature, 2022

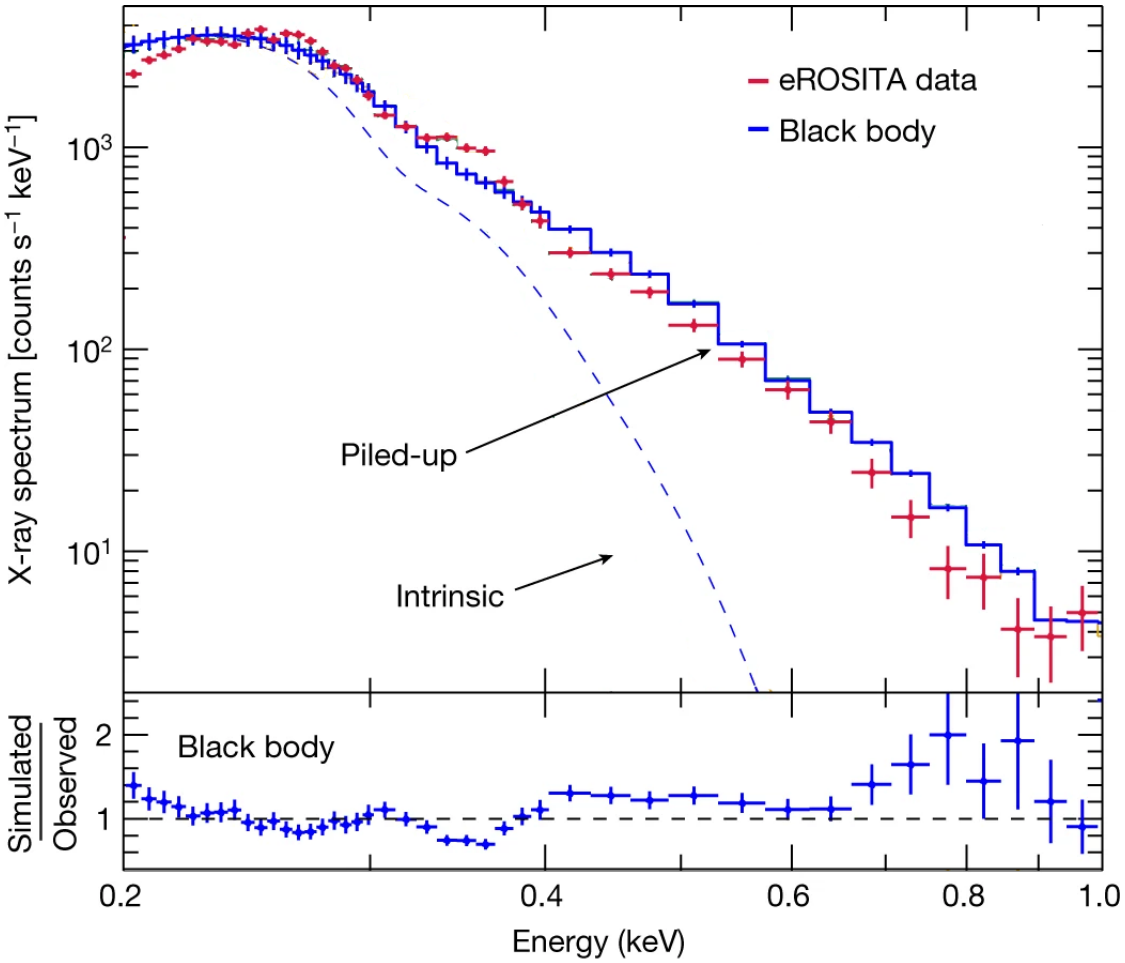
# Problem: The data show severe pile-up




→ How do we estimate the spectrum and brightness?

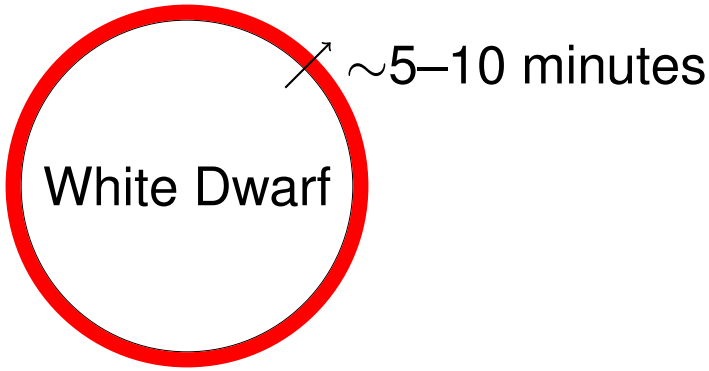
# Fitting the observation through SIXTE simulations




- Severe spectral distortion due to high photon rate
- Simulations show: Consistent with ≈30 eV black body

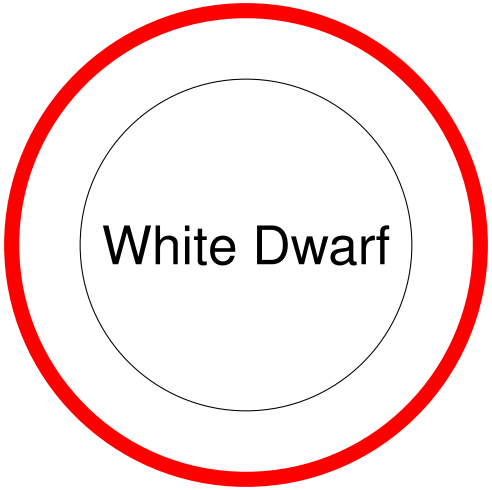
König et al., Nature, 2022

# What can we say about the system?



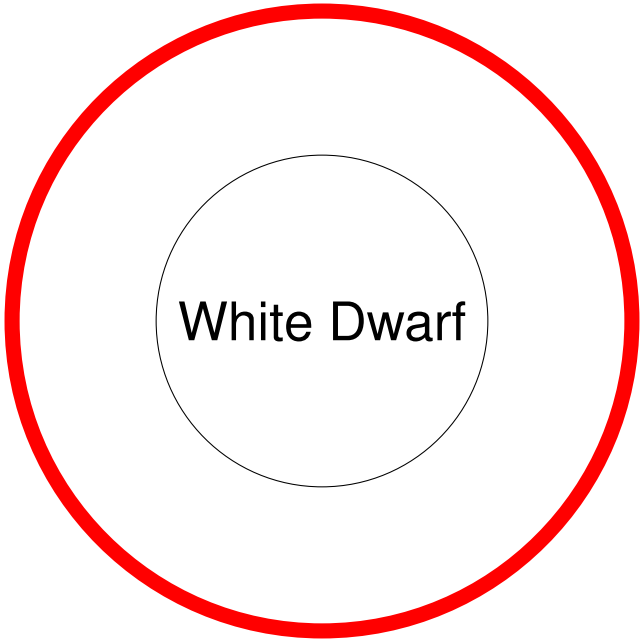

- Thermonuclear runaway in WD atmosphere
- Quick convection through envelope

# What can we say about the system?



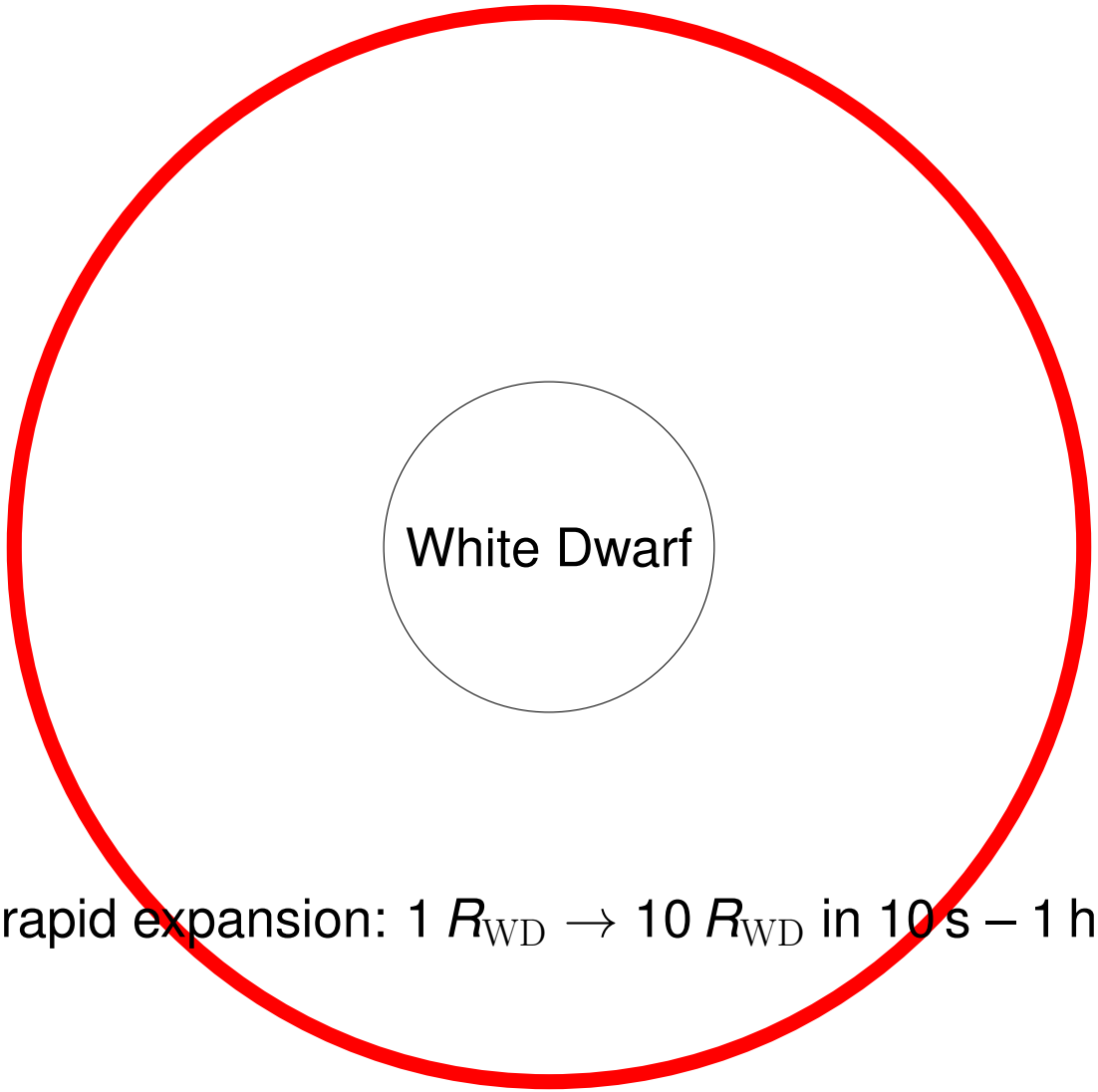

rapid expansion: 1 $R_{\mathrm{WD}} \rightarrow 10\, R_{\mathrm{WD}}$ in 10 s – 1 h

# What can we say about the system?



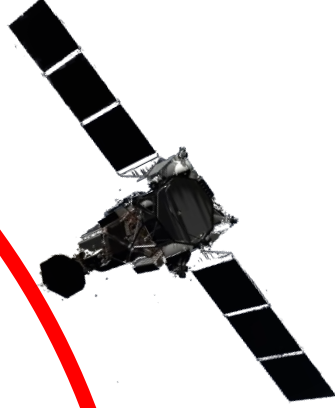

rapid expansion: 1 $R_{\mathrm{WD}} \rightarrow 10\, R_{\mathrm{WD}}$ in 10 s – 1 h

# What can we say about the system?




rapid expansion: 1 $R_{\mathrm{WD}} \rightarrow 10\ R_{\mathrm{WD}}$ in 10 s – 1 h

# What can we say about the system?



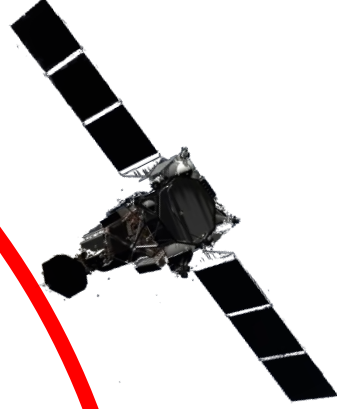
$R_{\mathrm{photosphere}} \approx 50\,000\,\mathrm{km}$

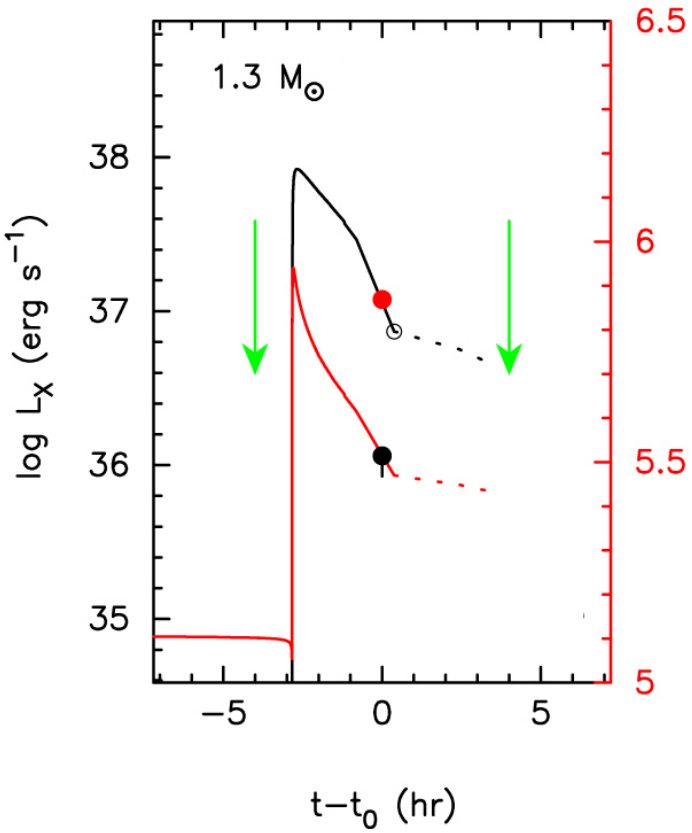
$kT_{\mathrm{BB}} \approx 28\,\mathrm{eV}$

radiates at $L_{\mathrm{Edd}}$

**Massive**
White Dwarf
**because** $t_{\mathrm{flash}} < 8\,\mathbf{h}$

# What can we say about the system?



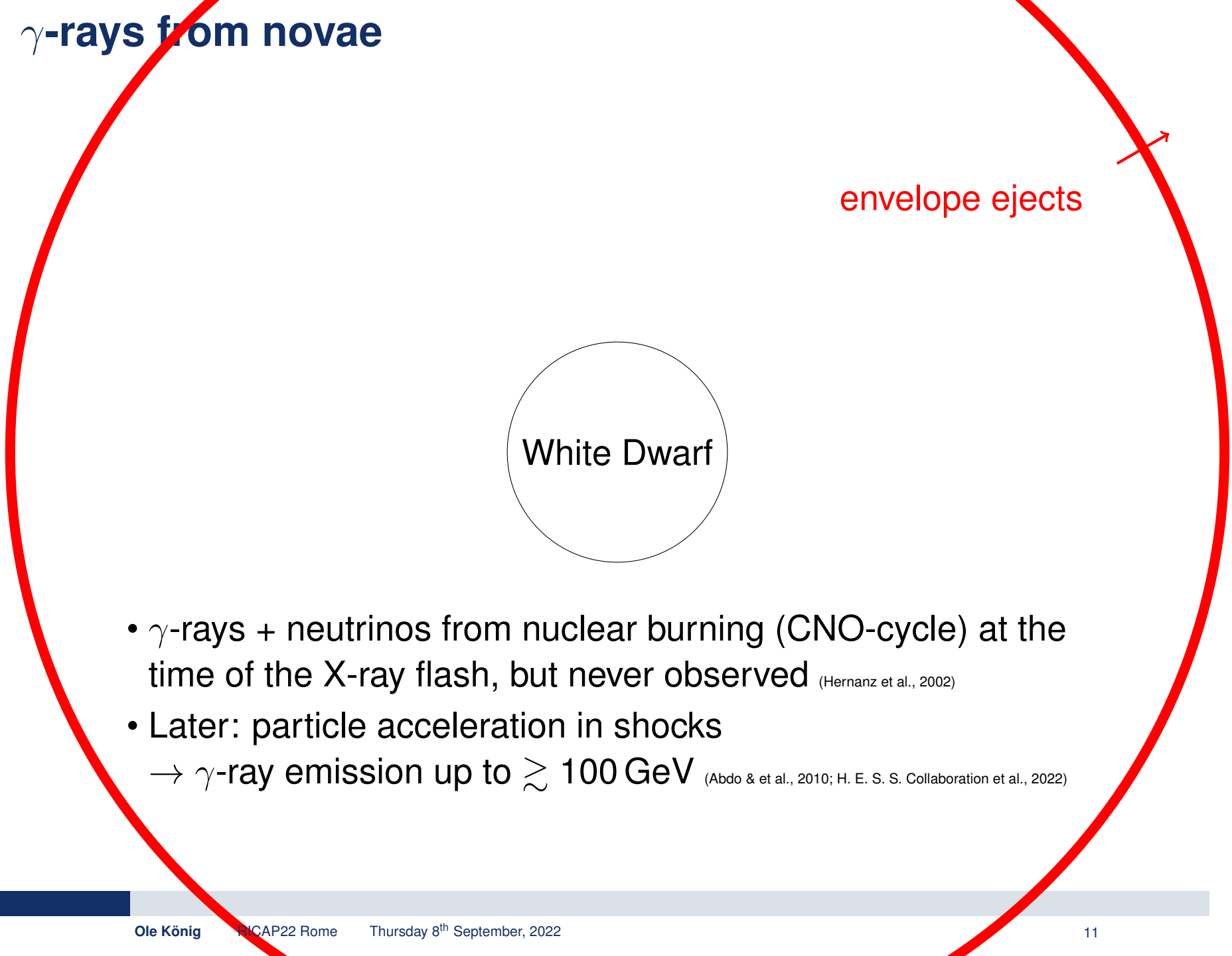



Modified from Kato et al. (2022)

**Massive**
White Dwarf
**because** $t_{\rm flash} < 8\,\mathbf{h}$

- Mass may be close to Chandrasekhar limit
- X-ray flash terminates when wind is launched

# $\gamma$-rays from novae

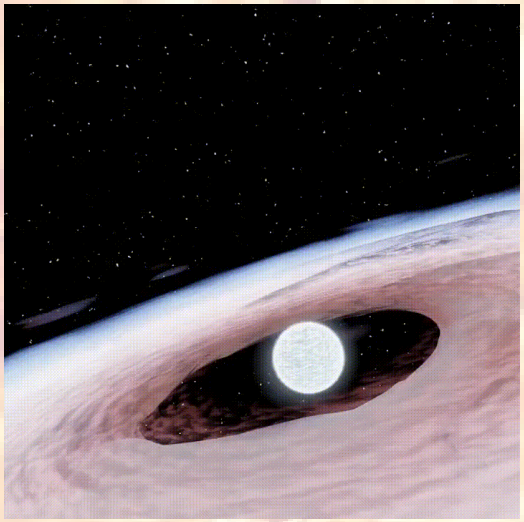



- $\gamma$-rays + neutrinos from nuclear burning (CNO-cycle) at the time of the X-ray flash, but never observed (Hernanz et al., 2002)
- Later: particle acceleration in shocks
  $\rightarrow$ $\gamma$-ray emission up to $\gtrsim$ 100 GeV (Abdo & et al., 2010; H. E. S. S. Collaboration et al., 2022)

# Summary

## Starrfield et al. (1990):

**“It is possible that [an X-ray flash] could be detected by a very sensitive all sky survey”**



## Take Home Message

- ***eROSITA*** detected the **first X-ray flash** from a **nova**
- $\gamma$**-rays predicted** during fireball phase, but not yet observed
- Likely **no cosmic rays** from fireball phase (but later from shocks!)

# Bibliography


Abdo A.A., et al. 2010, Science 329, 817

Chomiuk L., Metzger B.D., Shen K.J., 2021, Annu. Rev. Astron. Astrophys. 59

H. E. S. S. CollaborationAharonian F., Ait Benkhali F., et al., 2022, Science 376, 77

Hernanz M., Gómez-Gomar J., José J., 2002 46, 559

Hillman Y., Prialnik D., Kovetz A., et al., 2014, Mon. Not. R. Astron. Soc. 437, 1962

Kato M., Saio H., Hachisu I., 2022, ApJL 935, L15

Kato M., Saio H., Henze M., et al., 2016, Astrophys. J. 830, 40

Kraft R.P., 1959, Astrophys. J. 130, 110

Krautter J., 2008, In: Evans A., Bode M.F., O'Brien T.J., Darnley M.J. (eds.) RS Ophiuchi (2006) and the Recurrent Nova Phenomenon, Vol. 401. Astron. Soc. Pacific Conf. Ser., Astron. Soc. Pacific, San Francisco, p. 139

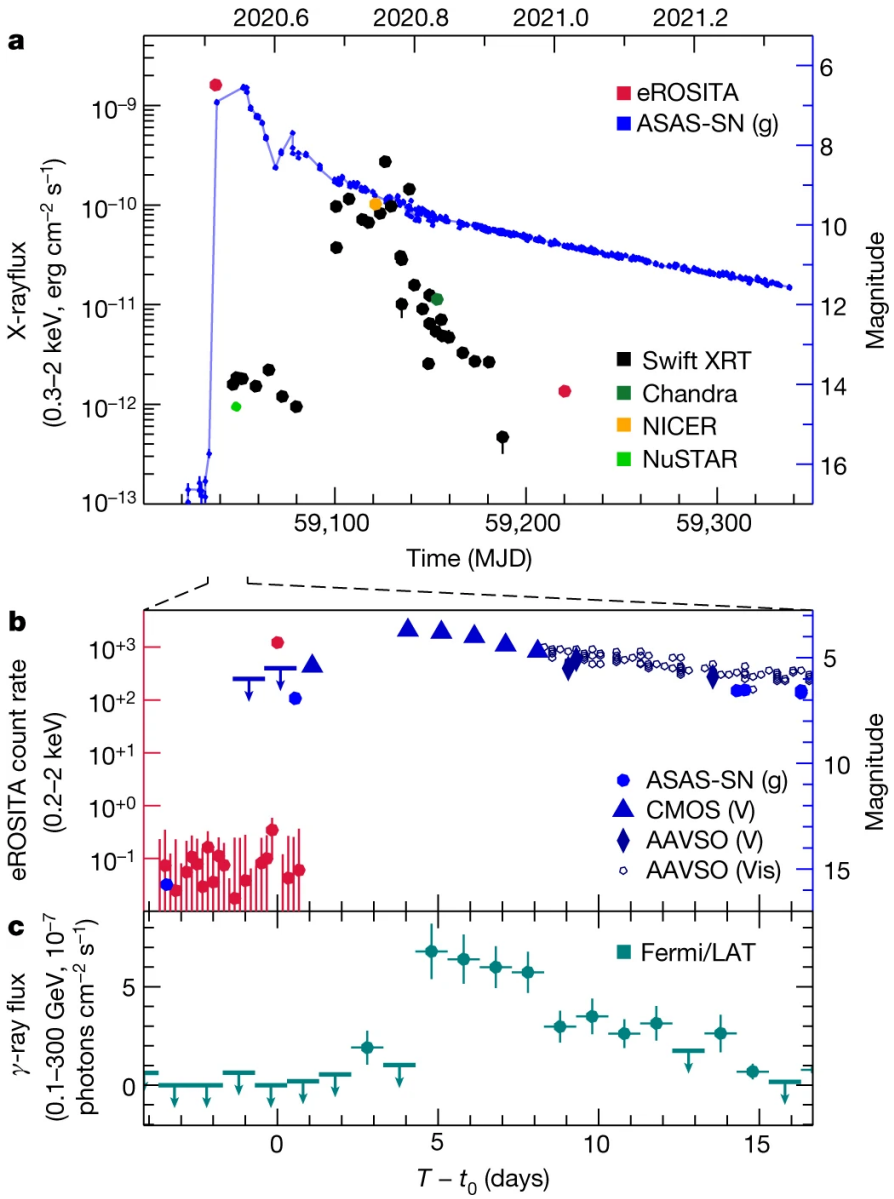
Metzger B.D., Finzell T., Vurm I., et al., 2015, MNRAS 450, 2739

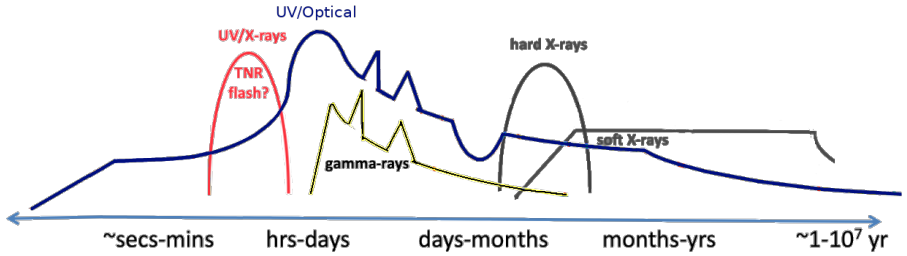
Morii M., Yamaoka H., Mihara T., et al., 2016, Publ. Astron. Soc. Japan 68, S11

Starrfield S., Truran J.W., Sparks W.M., et al., 1990, In: Cassatella A., Viotti R. (eds.) Physics of Classical Novae., Springer Verlag, Berlin, Heidelberg, p.306

# Sublementary slides

# YZ Reticuli: Lightcurve with supersoft source state

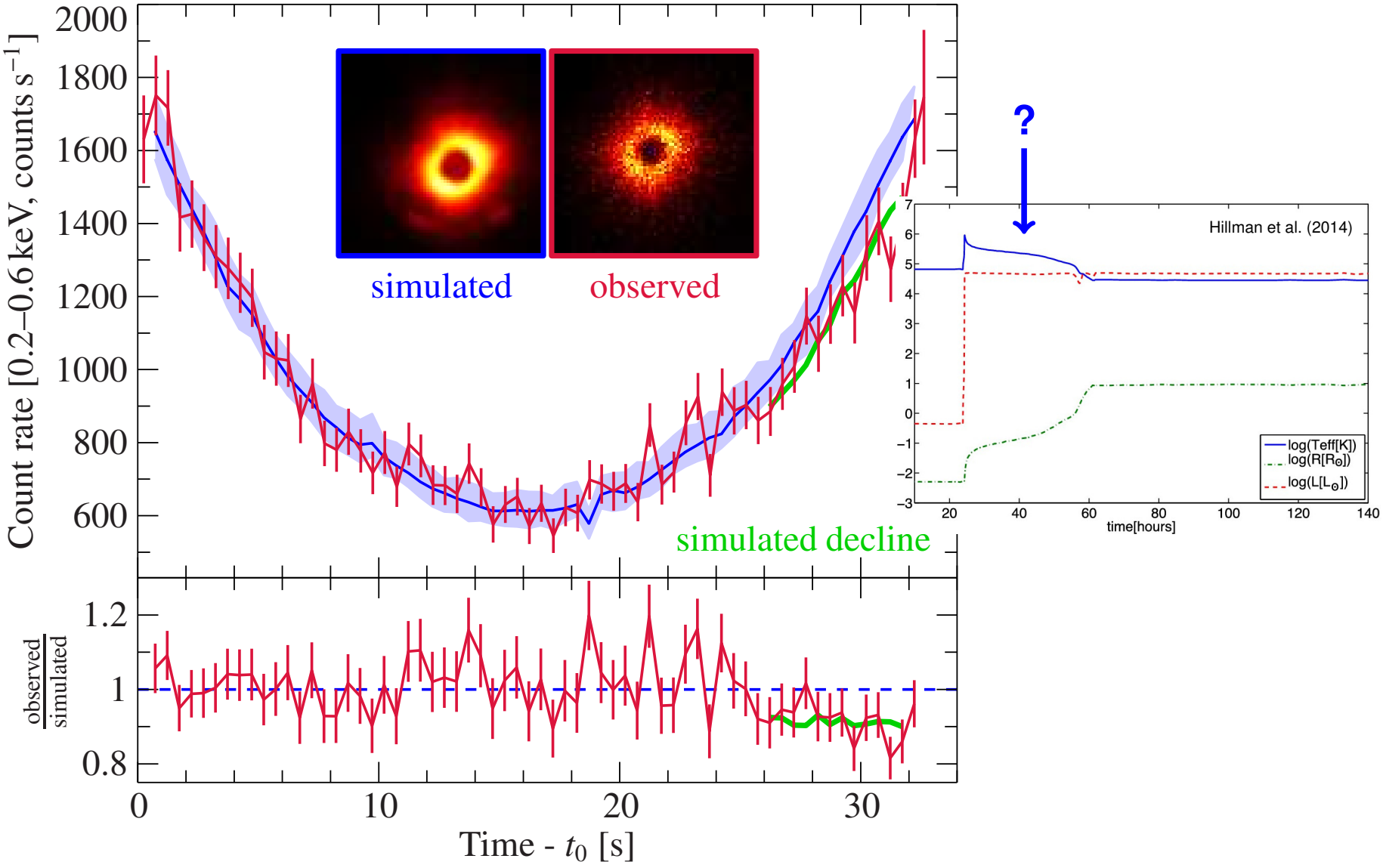


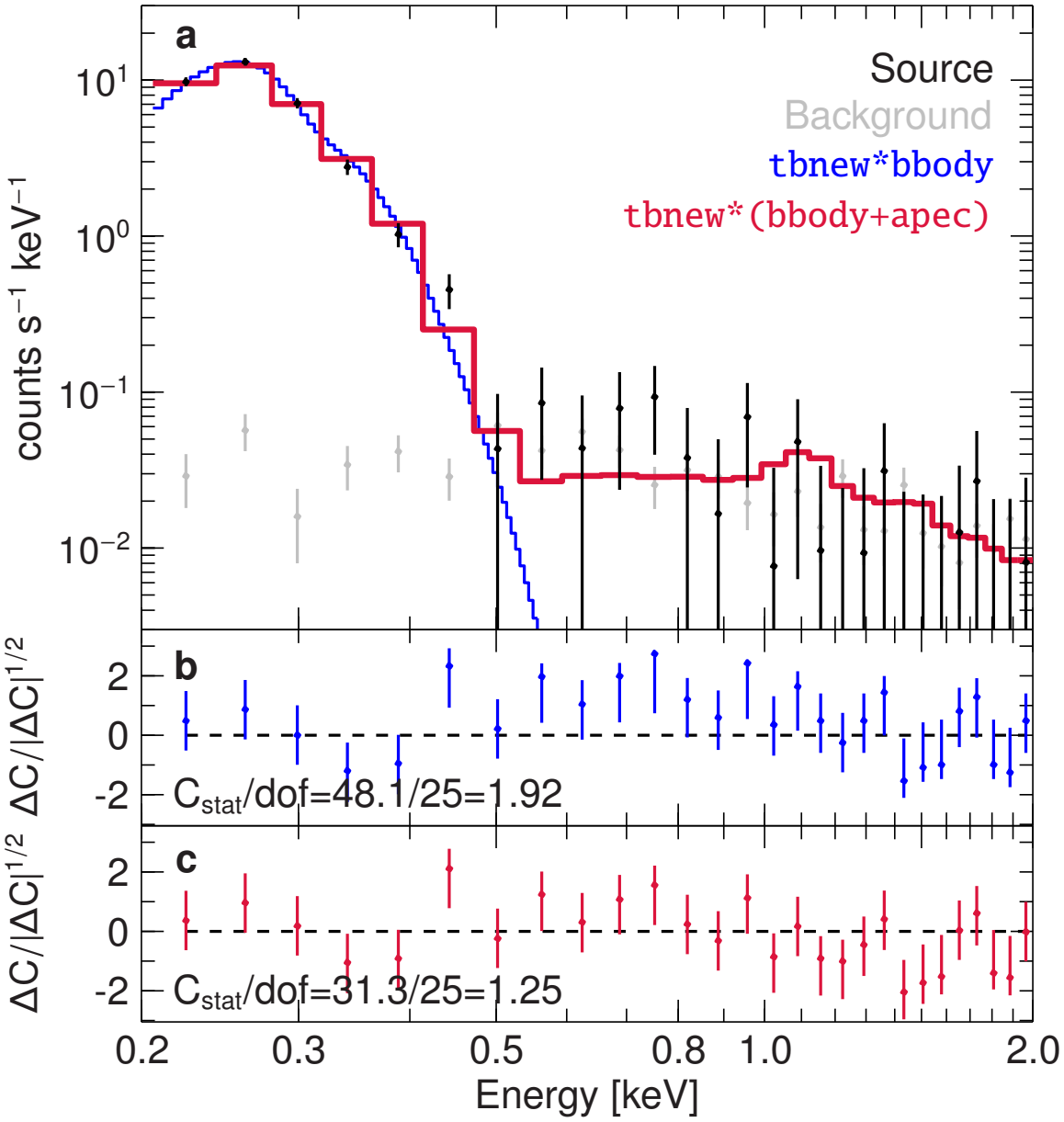

Modified from Chomiuk et al. (2021)

König et al., Nature, 2022

# Reconstructed slew lightcurve and image



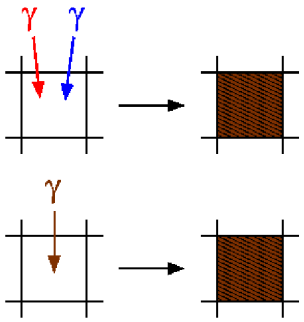
# Supersoft Source with *eROSITA*



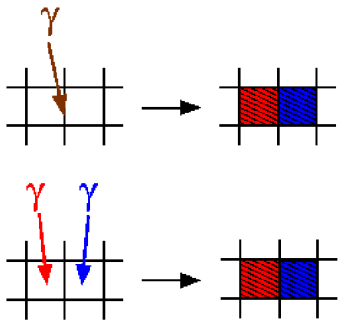
# Simulation of X-ray Telescopes (SIXTE)

- Generic **end-to-end** Monte Carlo simulator
- Designed to be mission independent ($\rightarrow$ Athena, XMM, **eROSITA**,...)
- Simulates vignetting, PSF, charge cloud, read-out, **pile-up**,...

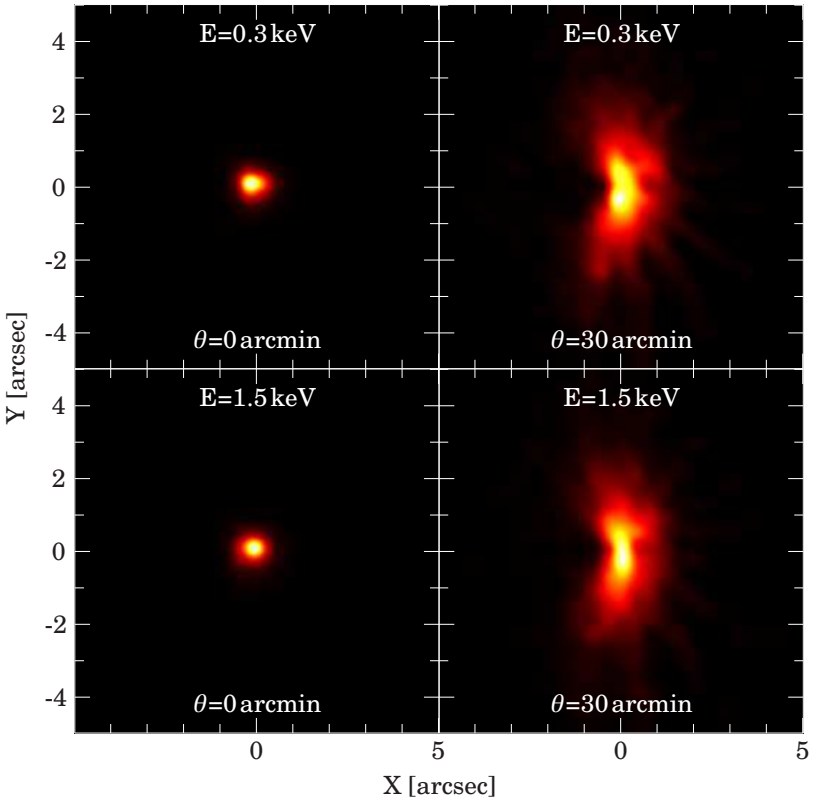
**Energy** pile-up:




**Pattern** pile-up:

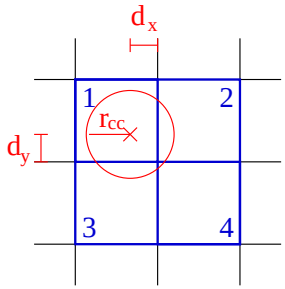


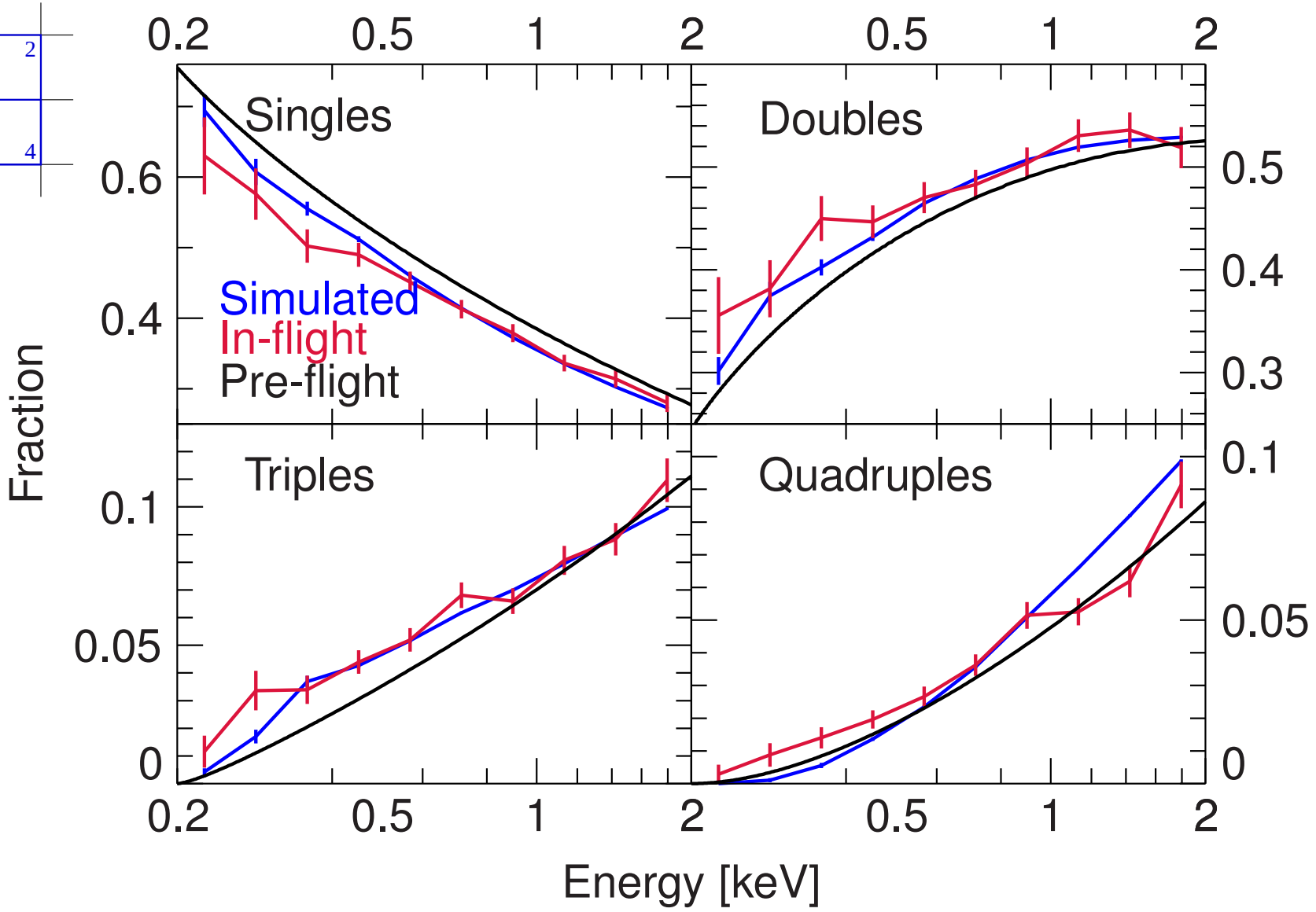

eROSITA PSF




https://www.sternwarte.uni-erlangen.de/research/sixte/

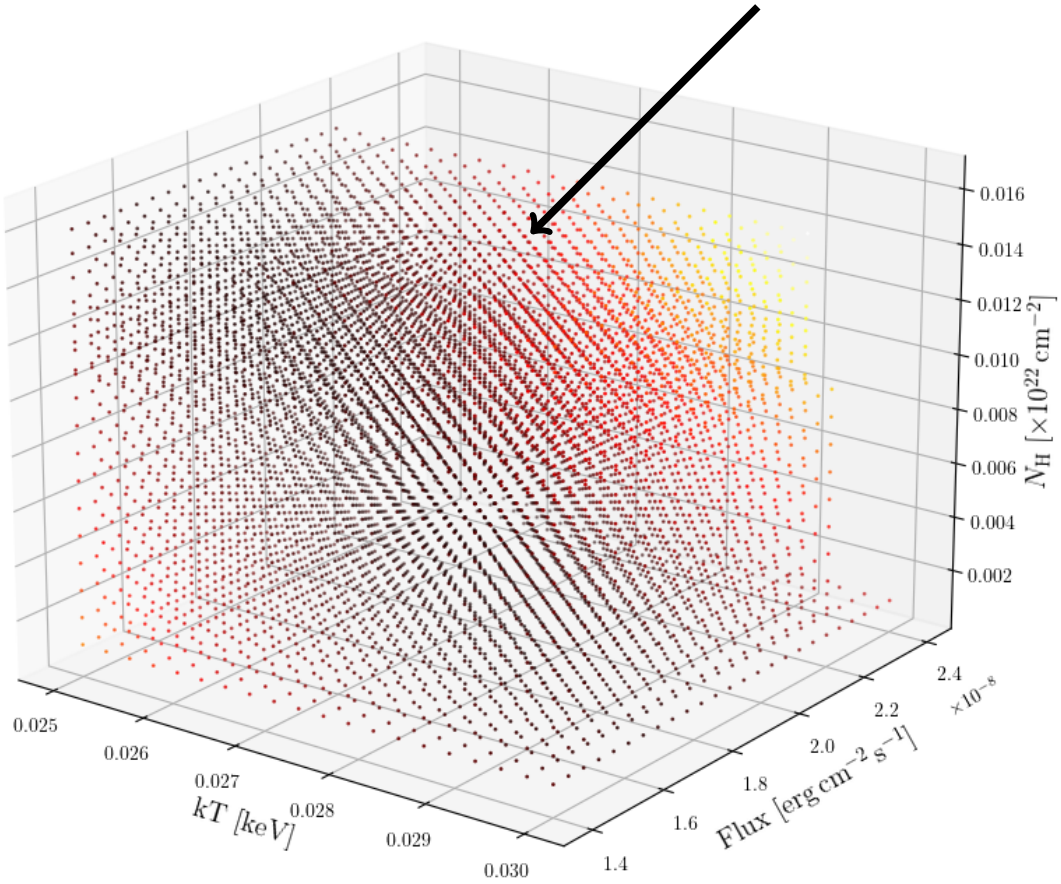
# Pattern fractions to calibrate charge cloud in SIXTE

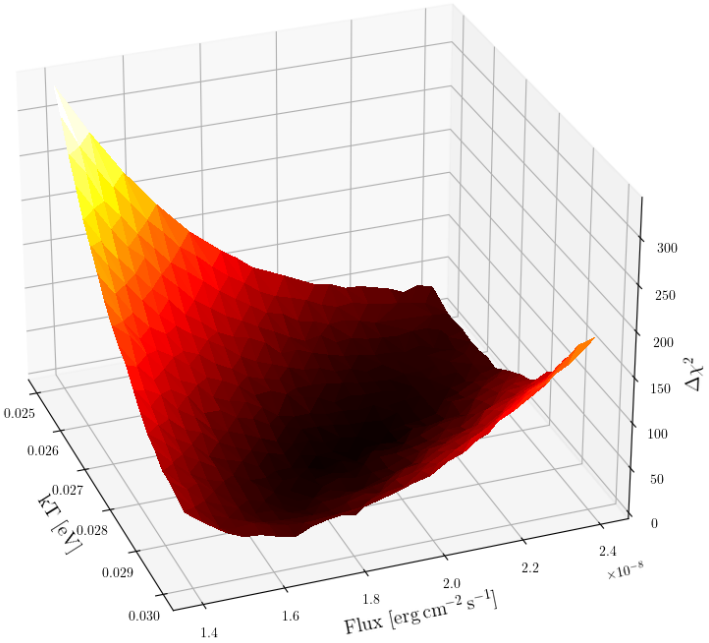


# Estimating the uncertainties

- Each point: 1000 averaged slews $\hat{=}$ 36 ks
- $\sim$8000 gridpoints, $\sim$50 000 CPU hours



# Estimating the uncertainties