Signatures of concealed Super-Eddington accretion

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Ultraluminous X-ray Sources (ULXs)

An extreme form of X-ray binary (XRB)

- XRBs are binary stars where a normal star donates mass to a black hole or a neutron star
- Naively, their brightness is limited by the Eddington luminosity, past which radiation pressure wins over gravity
- In other galaxies, we see point sources with apparent luminosities past the Eddington limit, these are called ULXs

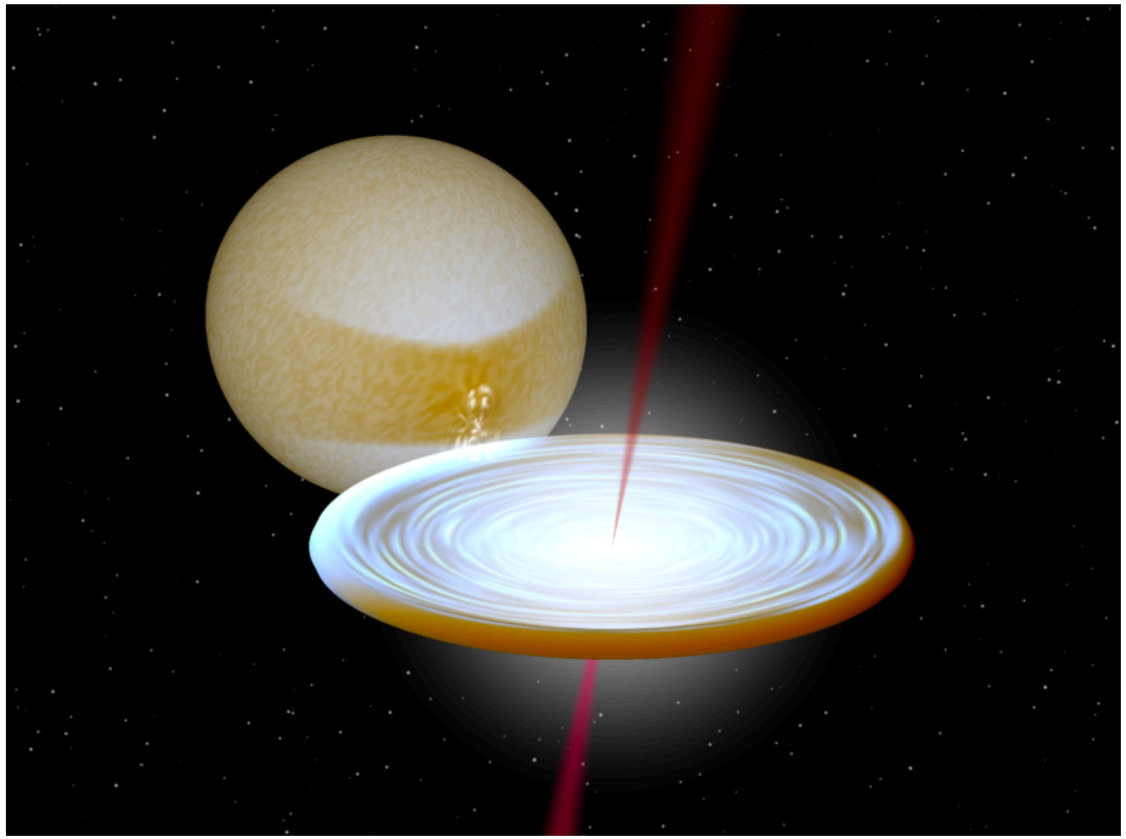


Image made with binsim, a program by Robert Hynes

Why are ULXs that bright?

- Past this limit, the excess mass supply is ejected
- The wind forms an opaque “funnel” that only allows the light to escape through a narrow solid angle (geometric beaming)
- A face-on observer sees an extremely bright source

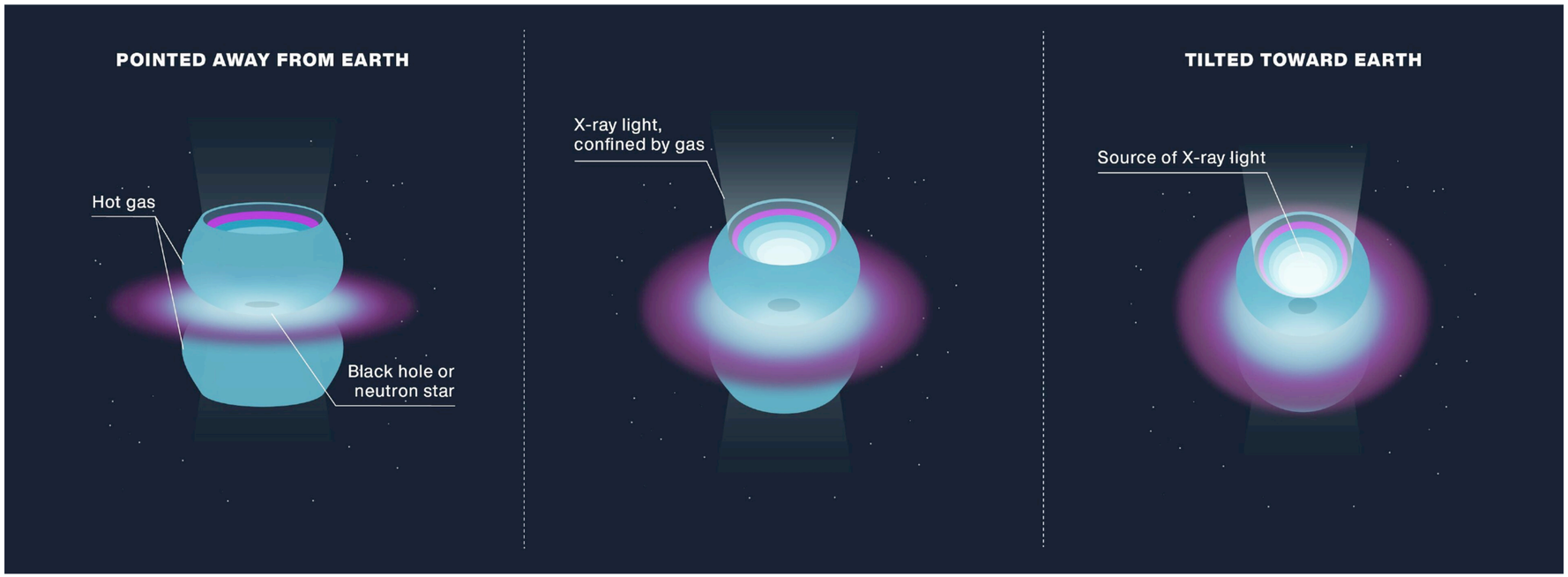


Image: NASA/JPL-Caltech

Obscured ULXs in the Milky Way

- Some sources in the Milky Way may be ULXs pointed away from us (most famously SS 433)
- Reflection and scattering tend to polarize light depending on the scattering direction

Image: Andrew Norman

- X-ray polarimetry became possible with the launch of IXPE
- Cygnus X-3 was found to be very strongly polarized
  - An obscured ULX!

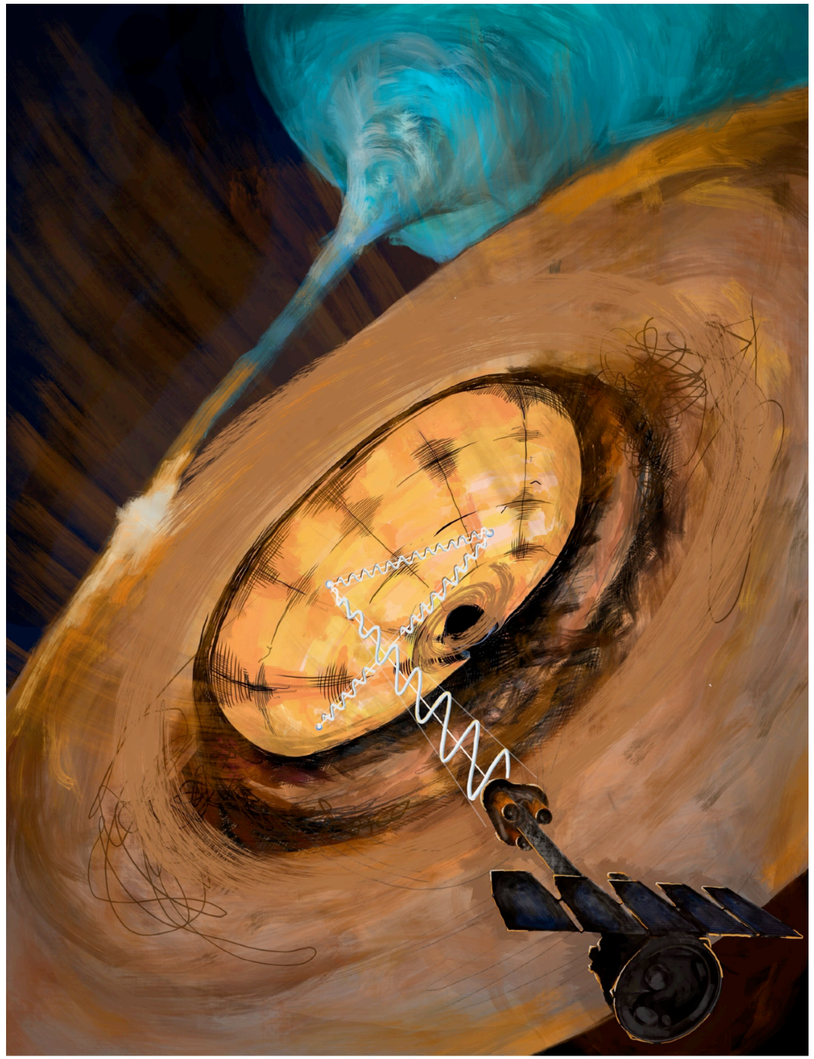


Image: Alexander Mushtukov

Modeling polarization from obscured ULXs

Cygnus X-3 as a case study

- We performed Monte-Carlo simulations of the radiative transfer in the funnel.
- The polarization of Cygnus X-3 changes drastically with the X-ray spectrum, i.e., the scattering direction changes

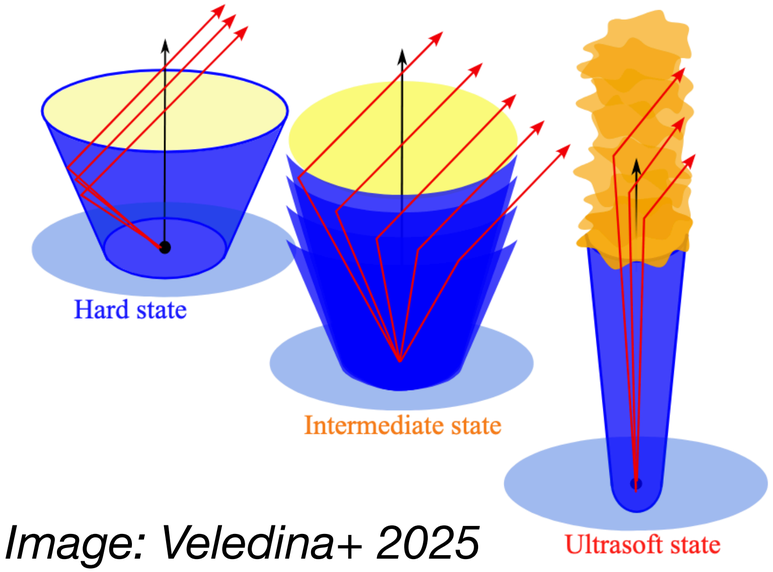
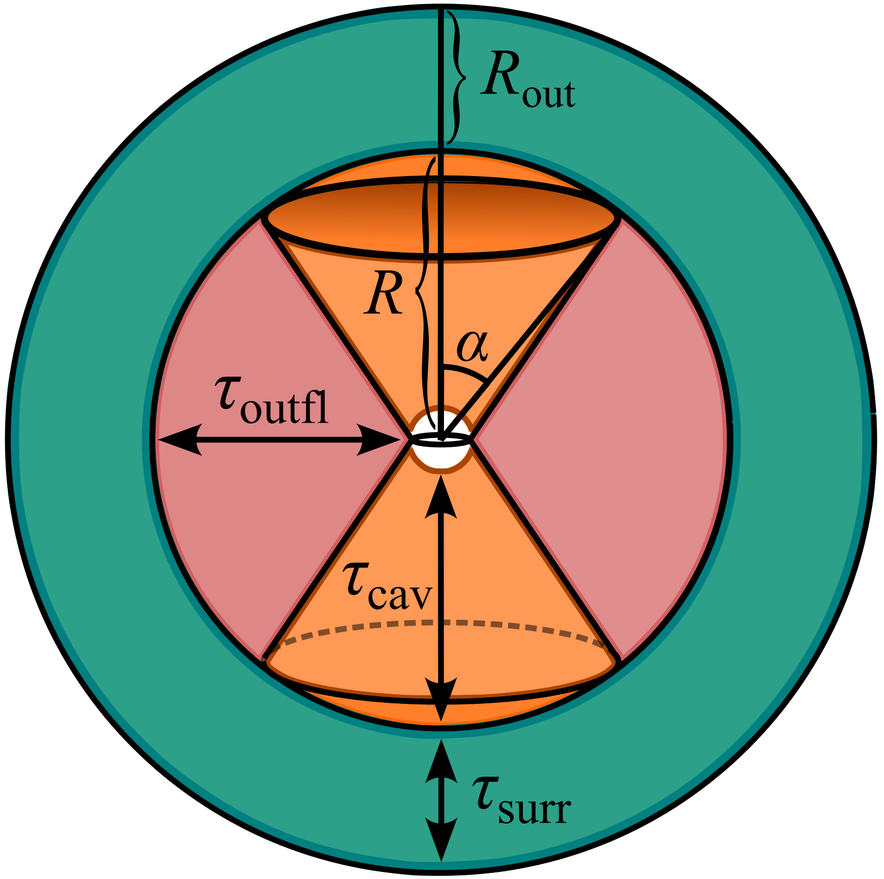
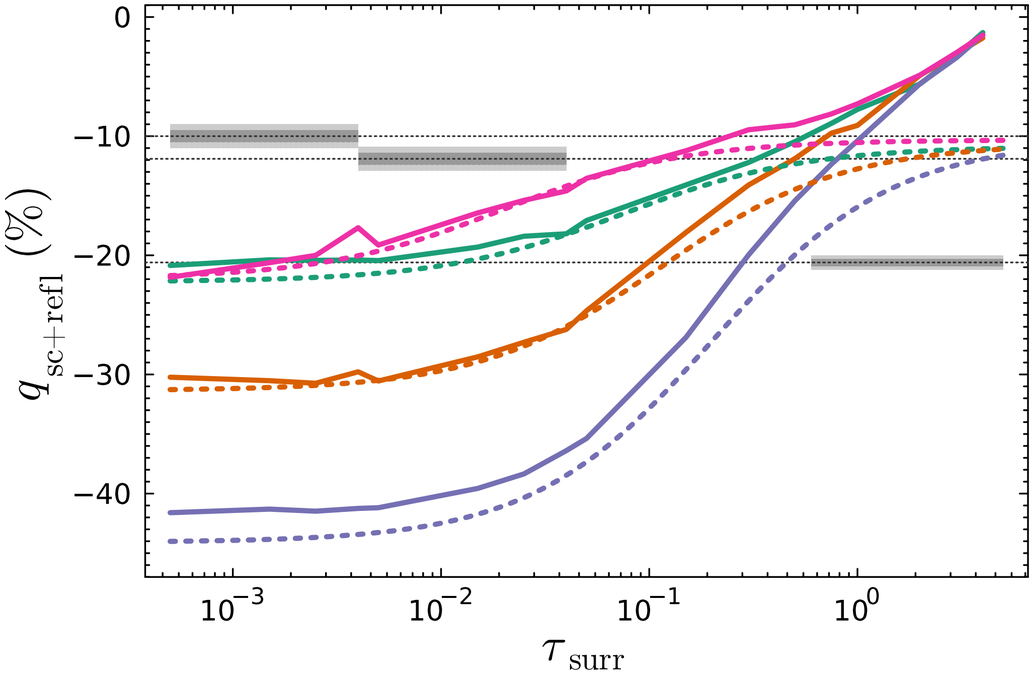


Image: Veledina+ 2025

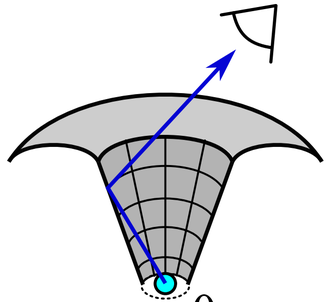
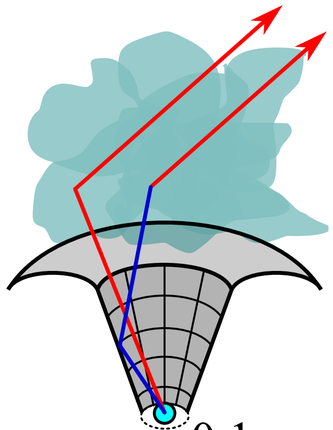
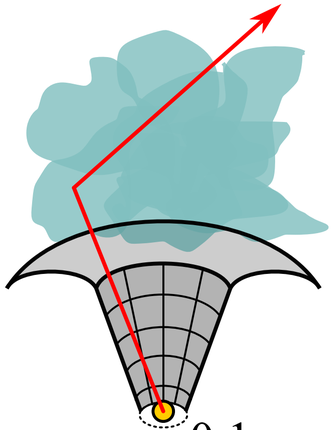


Results: polarization

- The polarization changing with the spectra can be fully explained by the optically thin medium

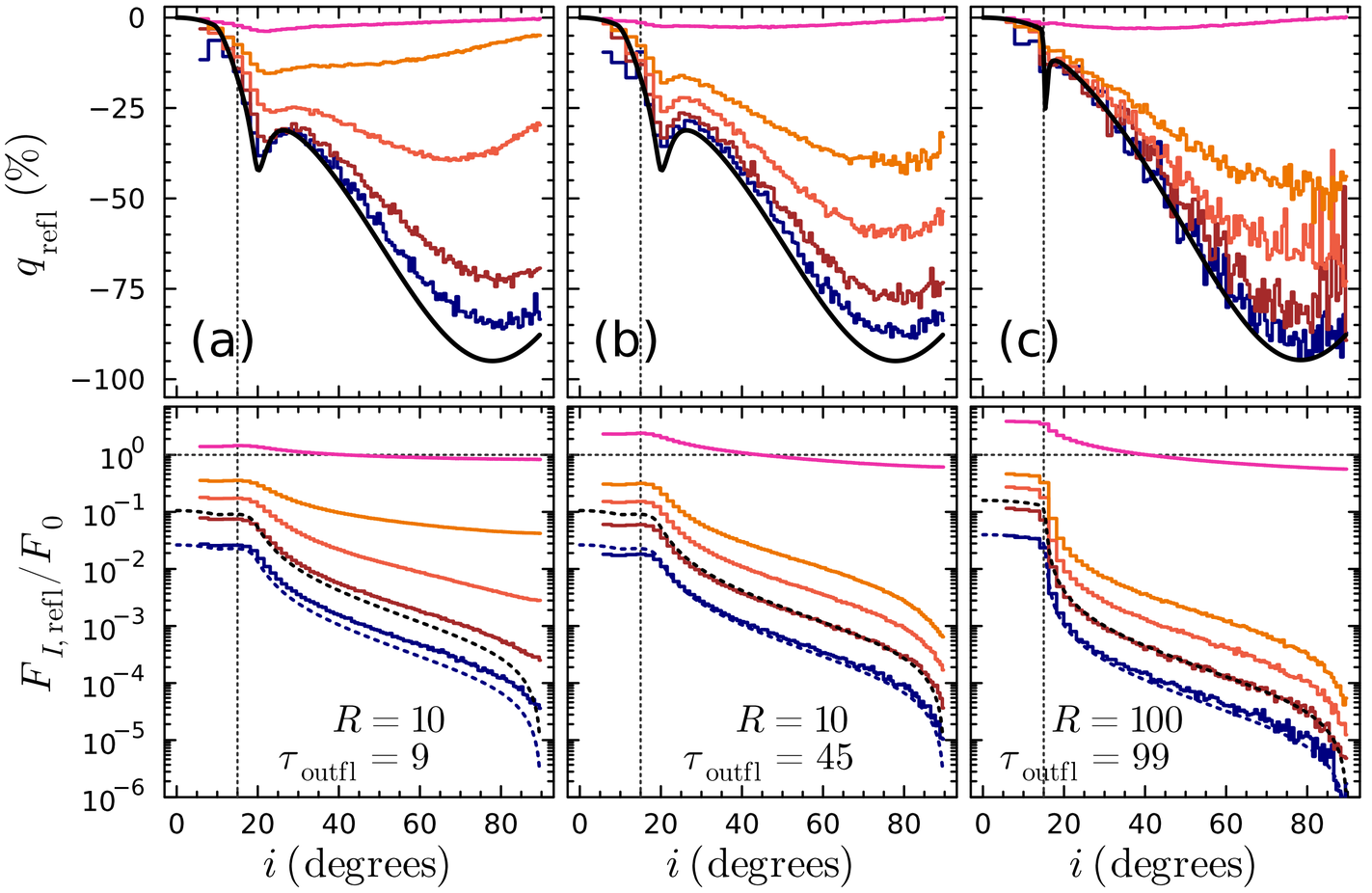


$\lambda << 1, \quad \tau_{\rm outfl} >> 1, \quad \tau_{\rm cav} = 0$

Hard	Intermediate	Ultrasoft
- Reflection spectrum - PD ~ 20% - PD dips at 6-8 keV - PD dips at < 3 keV	- Softer refl. spectrum - PD ~ 10% - Flux increases - PD ~flat with energy	- Blackbody spectrum - PD ~ 10% - Flux increases - PD flat with energy
- Unpolarized Fe line is produced in the funnel - Another component at < 3 keV?	- Fe line etc. is scattered, thus polarized	- Softer incident spectrum => no refl.
		
$\tau_{\rm surr} = 0$	$\tau_{\rm surr} \sim 0.1$	$\tau_{\rm surr} \sim 0.1$

Results: beaming

- Geometric beaming is less efficient than we expected
- Funnel must be strongly absorbing to explain the strong polarization
- The beaming in Cygnus X-3 cannot be caused purely by reflection!



Summary

- ULXs appear impossibly bright, but their emission is not isotropic
- The X-ray polarization of obscured ULXs can reveal their shape
- The changing polarization in Cygnus X-3 shows a changing geometry
- Large factors of geometric beaming may be difficult to achieve

Thank you!

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