The High Energy X-ray Probe (HEX-P) perspective on AGN: from accretion physics to supermassive black hole growth and feedback

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Overview

HEX-P is a probe-class mission concept that will combine high spatial resolution X-ray imaging (<10 arcsec FWHM) and broad spectral coverage (0.1-150 keV) with an effective area far superior to current facilities (including XMM-Newton and NuSTAR), enabling pioneering new insights into a variety of important astrophysical problems. The unique capabilities of HEX-P in observing active galactic nuclei (AGN) will enable breakthrough discoveries, connecting the extreme environment around the event horizons of supermassive black holes to downstream feedback, jets and winds, in particular ultrafast outflows (UFOs). These observations will revolutionize our understanding of supermassive black hole growth and the important effect that these objects have on their host galaxies and the formation of structure in the Universe. HEX-P will (1) provide a detailed view of the inner regions of the accretion flow; (2) enable precision black hole spin measurements and extend our census of supermassive black hole spins beyond the local Universe, constraining supermassive black hole growth; (3) probe particle acceleration mechanisms in the vicinity of black holes and probe the physics of the X-ray emitting corona; and (4) make detailed measurements of ejection physics, including the launching of relativistic jets and ultrafast outflows, a key mechanism by which AGN can impart significant kinetic power into their surroundings.

Supermassive black hole spins: tracing their growth and accretion history

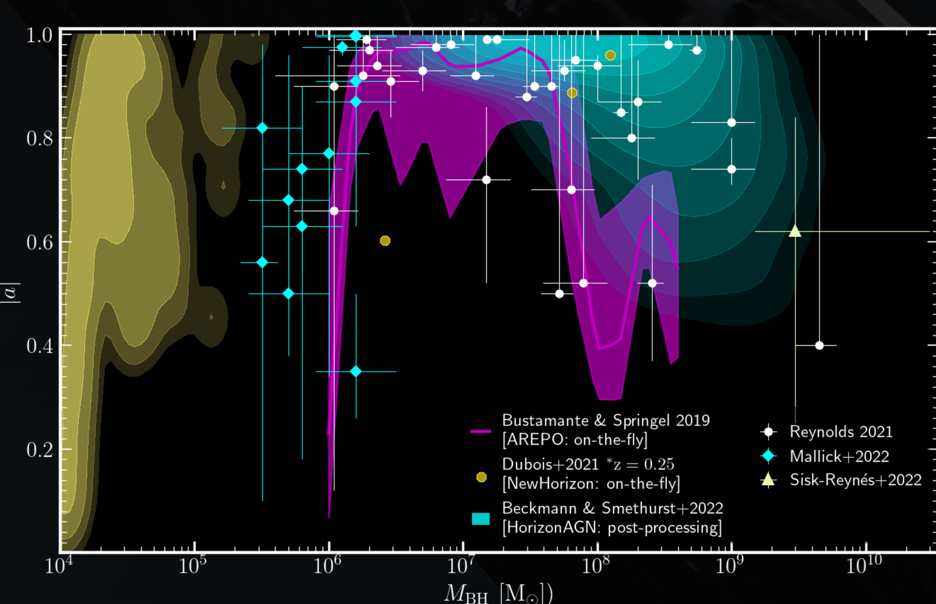
See Poster 100.41 (J. Piotrowska) for more information

One of the biggest questions in astrophysics and cosmology is exactly how supermassive black holes formed, and how they grew along with their host galaxies (e.g. Volonteri et al. 2021).

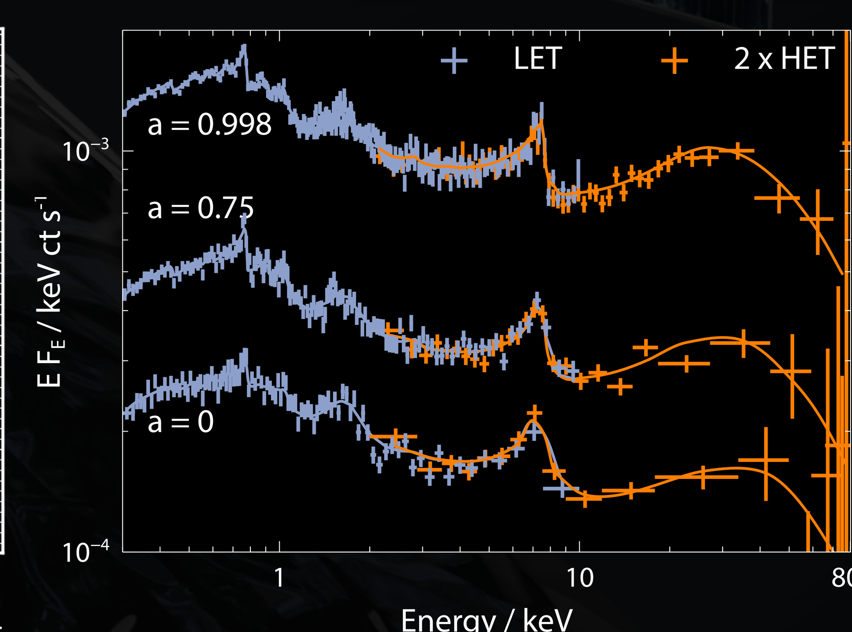
The growth history of supermassive black holes is encoded in their spin distribution (Reynolds 2021, Berti et al. 2008): black holes that grow through ordered accretion will spin up as angular momentum is transferred onto the black hole, while growth by chaotic accretion or mergers will produce less rapidly spinning black holes. Up to 40% of the rest mass energy of a black hole can be stored within its spin.

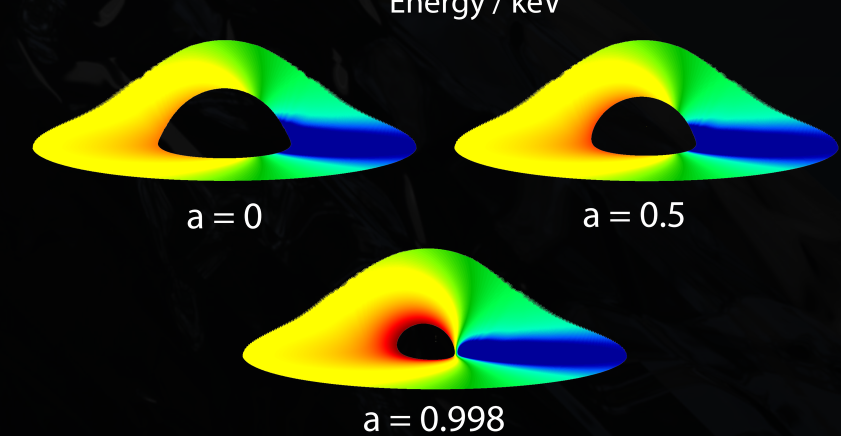
The details of angular momentum transfer from the accretion flow onto the black hole, however, depend upon the state of the accretion disk and whether angular momentum is transported away in jets and outflows, thus our understanding of accretion physics and the cosmological growth of black holes go hand-in-hand.

By measuring the distribution of supermassive black hole spins as both a function of mass and redshift, in addition to the physics of the accretion process, HEX-P will constrain cosmological models of supermassive black hole growth.



▲*Census of measured supermassive black hole spins (Reynolds 2021, low mass measurements: Mallick et al. 2022, and high mass: Sisk-Reynés et al. 2022), compared to predictions of the spin distribution as a function of black hole mass derived from cosmological simulations and semi-analytic models (credit J. Piotrowska).*





(Top) Simulated 200 ks HEX-P observations of nearby ($z = 0.025$) AGN with maximum, intermediate and slowly spinning black holes, with equivalent mass accretion rates. (Bottom) The extremal redshift of the broad iron K line is used to infer the inner radius of the accretion disk, from which the spin of the black hole is inferred. ▶

The unique capabilities of HEX-P will enable precision measurements of the spins of a broad sample of black holes, as well as the structure of the inner accretion flow, by detecting X-rays that are reflected and reprocessed by the innermost radii of the accretion disk (Brenneman et al. 2006). Current samples are biased towards the more rapidly spinning black holes due to their greater accretion luminosities, but the sensitivity of HEX-P will push the sample down to lower spins.

Broadband spectral coverage, using both the low and high energy telescopes (LET and HET) enables precision measurements of the relativistically broadened iron K line, the Compton hump, and the soft X-ray spectrum. This will enable the reflection to be separated from other emission and absorption components in the spectrum.

Accurate measurements of black hole spin require an understanding of how the inner accretion disk is illuminated by the corona (Fabian et al. 2014). Only with simultaneous, precision measurements of both the reflection spectrum and reverberation time lags is it possible to measure the location and structure of the corona, to eliminate an important systematic in the measurement of black hole spin (e.g. Alston et al. 2020).

Do you have ideas for how HEX-P would revolutionize your science? Get in touch!

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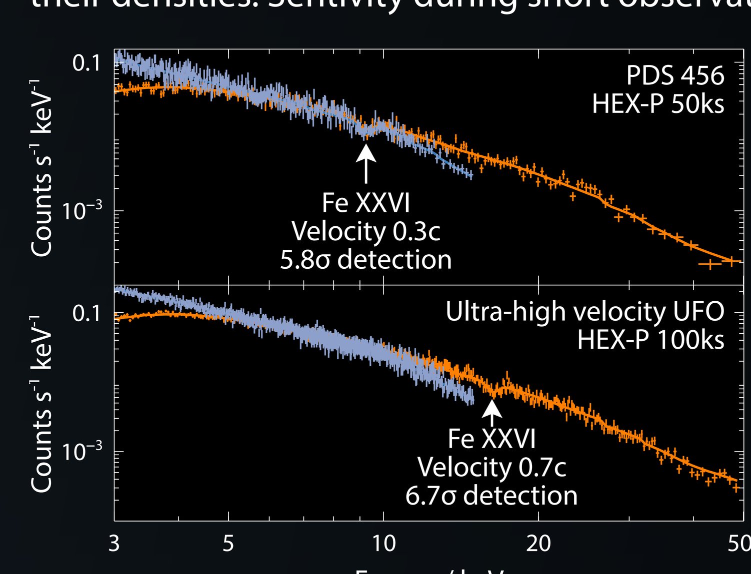
Ejection physics and AGN feedback via ultrafast outflows (UFOs)

Another important question is how the growth of the supermassive black hole in the center of a galaxy influences the growth of that galaxy by AGN feedback.

Ultrafast outflows (UFOs) are highly ionized winds launched from the inner accretion disk at revelativistic velocities up to 0.3c (Tombesi at al. 2010). They can carry significant kinetic energy and momentum into the host galaxy (Nardini et al. 2015) and therefore represent an important potential channel for AGN feedback. Much remains unknown, however, about the mechanisms by which UFOs are launched, how they vary and how their output is governed over cosmic time.

The unique combination of a broad bandpass, collecting area above 10 keV, and spectral resolution will enable HEX-P to detect blueshifted absorption lines from UFOs, measuring the velocity and ionization of the outflows and constraining their densities. Sentivity during short observations lets us probe their variability.



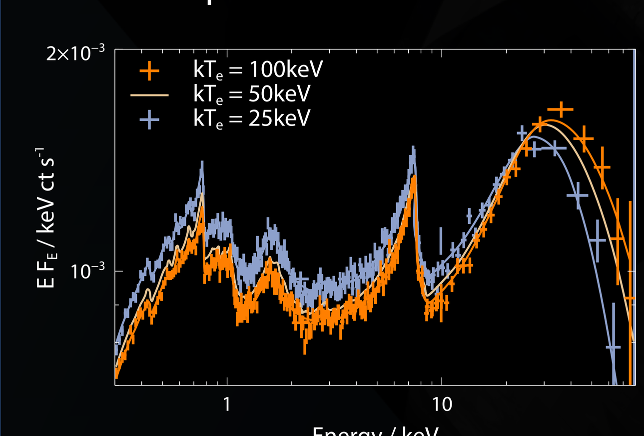
With sensitivity above 10 keV, HEX-P will constrain the maximum velocities that UFOs can reach, placing important constraints on the physical processes by which the outflows are accelerated.

◀ *Simulation of UFO absorption lines in HEX-P observations of AGN. Two cases are shown, a UFO similar to that detected in PDS 456, and an ultra-high velocity outflow, showing the capability of HEX-P to constrain the maximum UFO velocities (credit: E. Nardini).*

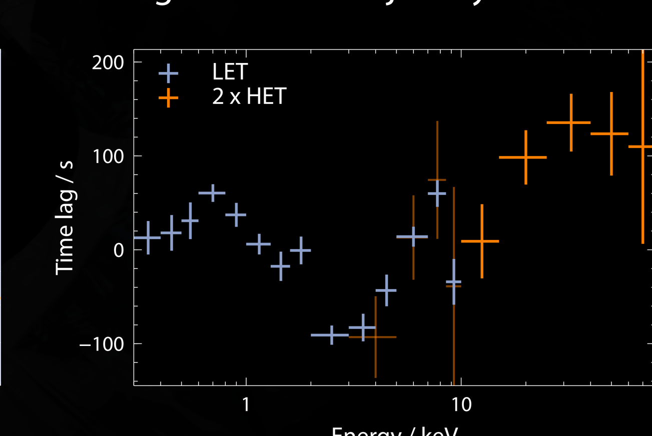
Probing the physics of the corona and the environment just outside the event

With radiation providing a crucial part of the feedback between an accreting supermassive black hole and its host galaxy, understanding the conversion of gravitational energy to radiation is vital. Aside from the accretion disk, the X-ray corona plays a key role in this. Yet, our knowledge of the location, geometry and inner structure of the corona, as well as how it is energized, is incomplete.

HEX-P will address important questions regarding the corona, such as the nature of the electron distribution (Fabian et al. 2017) and geometry. HEX-P will be able to obtain coronal temperatures and map the black hole environment for a much larger sample of accreting supermassive black holes, obtaining a better picture of how much diversity there is and study any redshift trends, while comparing radio-loud and radio-quiet AGN to understand the launching of relativistic jets by black holes.



▲*Simulated 500 ks HEX-P spectra of AGN in which the temperature of the corona is 100 keV and 25 keV, in addition to the model for a 50 keV corona, showing how HEX-P will be able to measure the coronal temperature.*



▲*Simulated measurement of the X-ray reverberation time lag as a function of energy from a 500 ks HEX-P observation of a typical nearby AGN, probing the location and structure of the corona and inner accretion disk.*

HEX-P
HIGH ENERGY X-RAY PROBE

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