# The High Energy X-Ray Probe (HEX-P)

## *Resolving the nature of X-ray binaries, Sgr A* flares and particle accelerators in the Galactic Center*

Shifra Mandel[1], Kaya Mori[1], Arash Bodaghee[2], Benjamin Coughenour[3], Jonathan Grindlay[4], JaeSub Hong[4], Roman Krivonos[5], Ekaterina Kuznetsova[5], Samaresh Mondal[6], Melania Nynka[7], Gabriele Ponti[6,8], John Tomsick[3], Shuo Zhang[9], Javier Garcia[10], Brian Grefenstette[10], Bret Lehmer[11], Kristin Madsen[12], Giovanni Stel[6,13], Daniel Stern[14] & the HEX-P Team

## Galactic Center (GC) science with HEX-P

As the next-generation X-ray observatory, HEX-P will boast

- an unprecedented broad **energy range**, combined with
- superb **spatial resolution**, and
- an **effective area** far superior to
- current facilities'.

These capabilities will allow us to detect, identify, and study various types of X-ray sources in the crowded Galactic center by constraining their spectral properties.

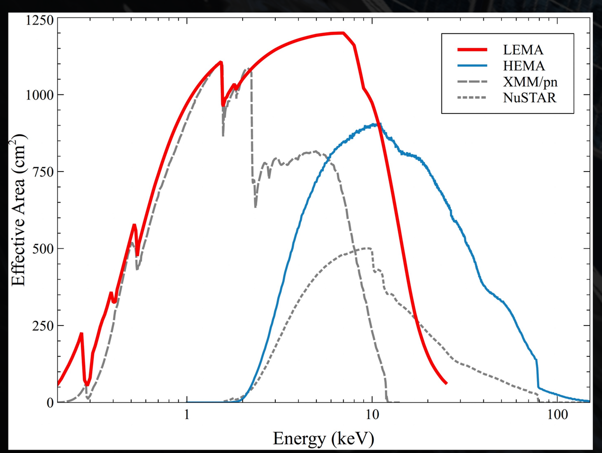


Fig 1. The effective area of HEX-P compared to current X-ray observatories.

## Sgr A* X-ray flares: "hiccups" from the supermassive black hole

- Sgr A* emits X-ray flares due to **particle acceleration** around the supermassive BH
- Particle acceleration and emission mechanisms: **Synchrotron** or **SSC**? [1,2]
- HEX-P can constrain particle acceleration during flares by detecting **spectral cut-off** (see figure below)
- Statistical studies: Does the X-ray photon index **evolve** with time? [3]
- Multi-wavelength studies with HEX-P, EHT, Gravity, etc. will constrain the SED evolution and time lags during flares ⇒ are they **relativistically expanding**?

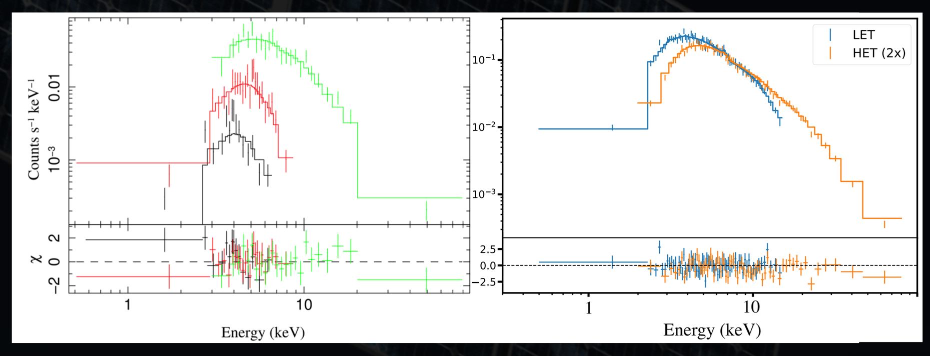

Fig 5. Left: NuSTAR (green) and Chandra (red & black) spectra of a Sgr A* flare[3]. Right: simulated HEX-P 10x weaker flare; spectral cut-off at 30 keV.

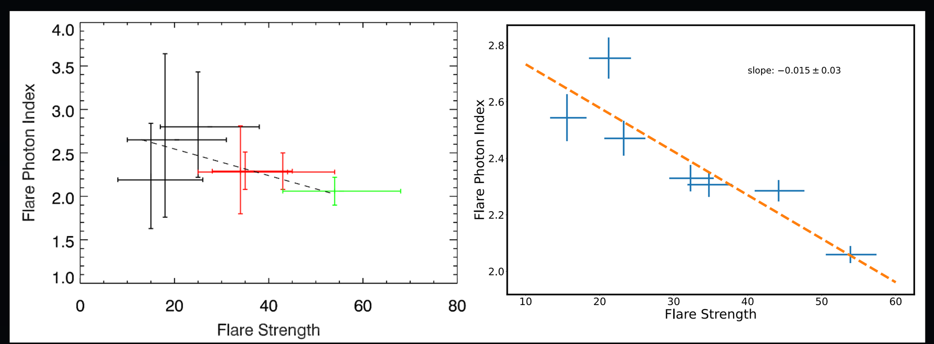

Fig 6. Left: best-fit spectral index vs flux relation for Sgr A* flares[3]. Right: HEX-P will allow us to constrain the flux/photon index relation.

## HEX-P will resolve sources in crowded regions, like the GC

The GC is home to many exotic X-ray point sources (Fig 3), like cataclysmic variables (CVs) and black hole (BH) & neutron star (NS) low-mass X-ray binaries (LMXBs).

- **Chandra** observatory: able to *resolve* individual point sources in the crowded GC region (above), but lacks the energy range required to constrain their *spectra*
- **NuSTAR**: broadband capabilities to measure *spectra* of different X-ray sources, but lacks the spatial resolution required to *resolve* point sources in the crowded GC
- **HEX-P**: both the **broadband energy** capabilities and **angular resolution** required to a) resolve individual GC X-ray sources, **and** b) measure their spectral properties
- Differentiate between thermal & non-thermal sources ⇒ identify individual sources as **LMXBs**, **CVs**, or millisecond pulsars (**MSPs**)

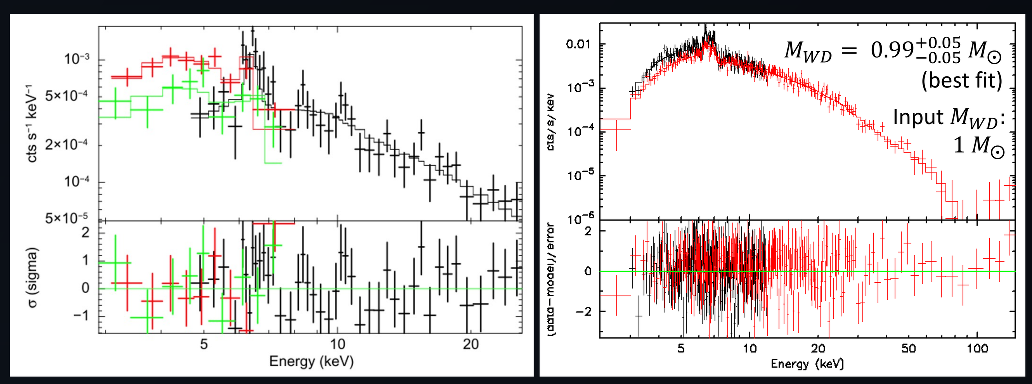

Fig 2. Left: Chandra (red), XMM-Newton (green) and NuSTAR (black) spectra of a CV candidate in the GC (~343 ks NuSTAR exposure; Hong et al. 2016). Right: simulated HEX-P LET (black) and HET (red) spectra of the same source (100 ks exposure) demonstrates HEX-P's ability to accurately measure and constrain $M_{WD}$ in CVs.

- Accurate measurements of CV spectra (above) ⇒ determine well-constrained white dwarf masses (**$M_{WD}$**)
- Significant implications for studies of **galaxy evolution** and **gravitational wave events**

## The Galactic Center: a cornucopia of energetic X-ray sources

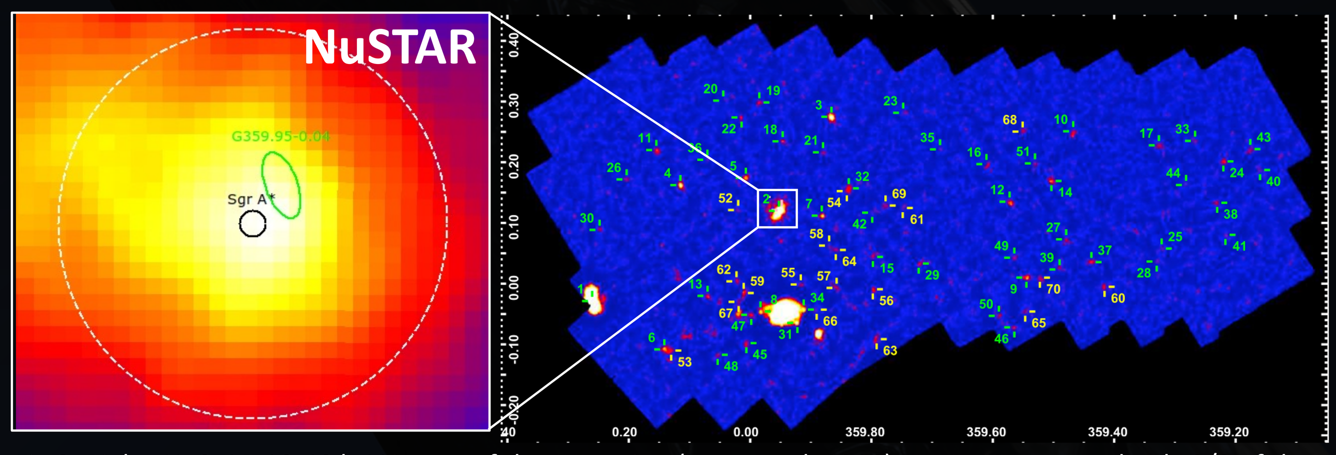


Fig 3. Right: NuSTAR 10-40 keV image of the GC region (Hong et al. 2016). NuSTAR surveyed only 2/3 of the larger (2x0.8 deg) Chandra (Wang/Muno) GC field; stray-light background (SLB) contamination prevented observation of the remaining areas. HEX-P will not be susceptible to SLB, and will therefore be able to cover the entire GC region. Left: inset showing the central pc of the Galaxy. The bright PWN G359.95-0.04 dominates the hard X-ray emission and no other sources can be resolved.

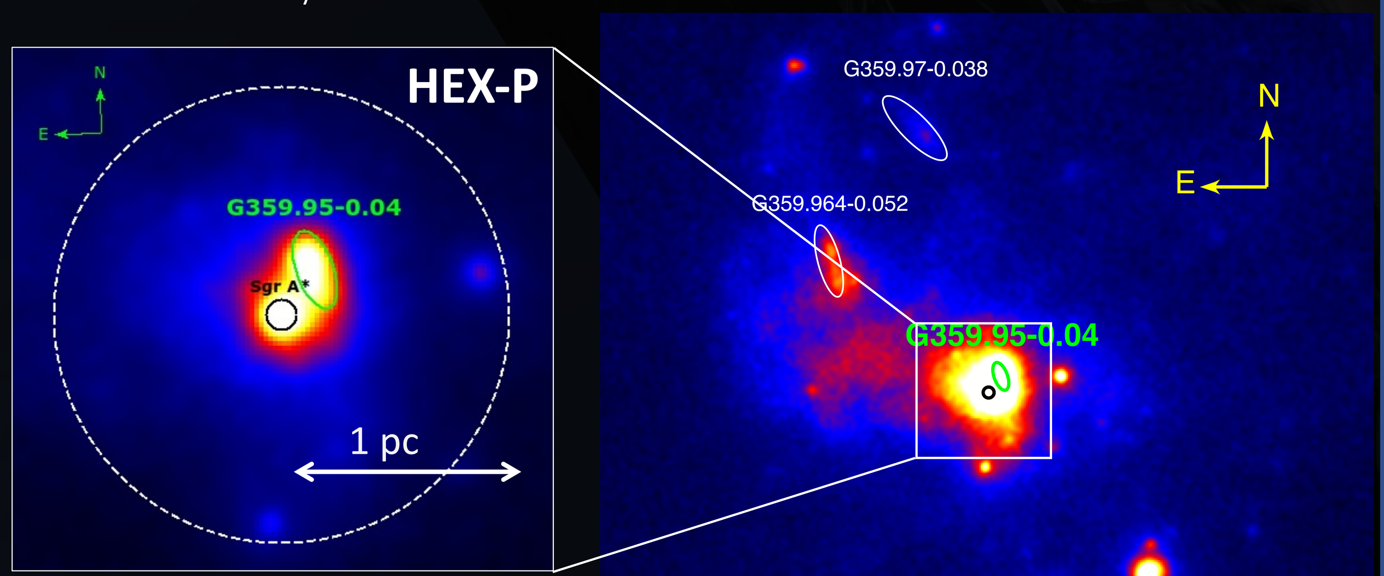


Fig 4. Right: HEX-P image of the GC in the 1-150 keV band, simulated using a 500 ks observation. The yellow circle has a radius of 1 arcmin. The inset on the left shows the central pc. Sgr A* and the PWN G359.95-0.04 are distinguishable, as are a number of other sources that are unresolved in the NuSTAR image (cf. Fig 3 above).

## GC X-ray sources to probe with HEX-P

### Point sources:

- Quiescent **BH LMXBs** (non-thermal)
- **CVs** (thermal; the source of CHXE?)
- **Pulsars** (source of GeV excess?)
- **Sgr A*** flares (particle acceleration and emission mechanisms)

### Diffuse sources:

- **PWNe/SNRs/star clusters** (PeVatron candidates)
- **X-ray filaments** (probing TeV-PeV electrons)
- **Molecular clouds** (cosmic ray distribution and/or reverberation of Sgr A* outbursts in the past)

## GC PeVatrons: a new and exciting frontier

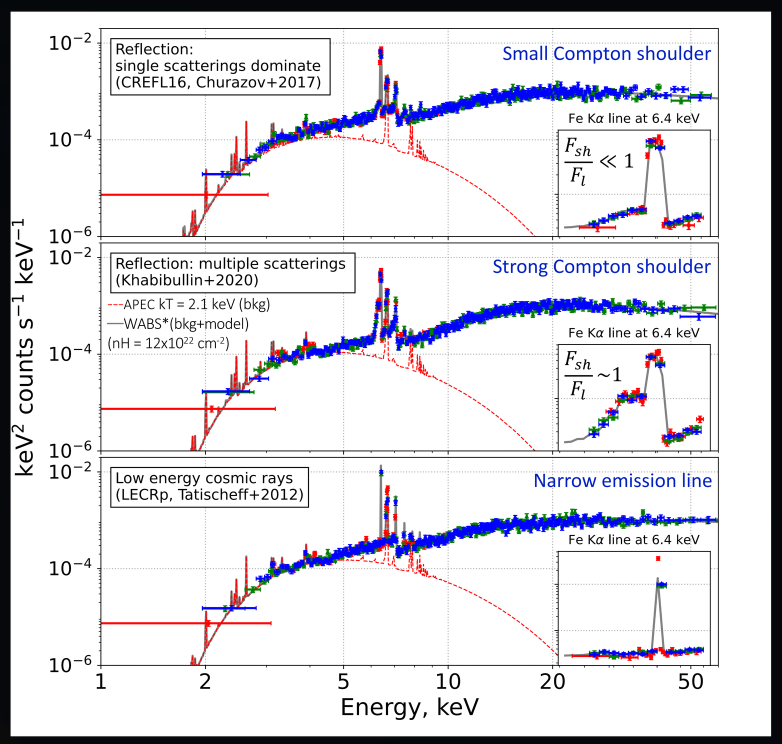


Fig 7. Simulations of HEX-P LET (red) and HET (blue & green) spectra demonstrate the ability of HEX-P to decipher the origin of high-energy X-rays from the giant GC molecular cloud Sgr B2. Possibilities include single- (top panel) or multiple- (center panel) scattering Compton reflection from inside the molecular cloud, or excitation by low-energy cosmic rays (bottom panel). Simulation exposure: 500 ks.

### Molecular clouds:

- Imprints of past Sgr A* outbursts in X-ray reflection
  - Compton hump
  - Fe fluorescence line; photo-absorption edge
- X-ray emission from cosmic-ray (CR) bombardment:
  - Low energy CRs ⇒ non-thermal bremsstrahlung
  - High energy CRs ⇒ synchrotron radiation

### X-ray filaments:

- More than two dozen radio filaments (i.e. bundled magnetic flux tubes) detected in the X-ray band [4]
- Synchrotron hard X-ray emission ⇒ explore the spatial & energy distributions of TeV-PeV electrons in the GC
  - SED (radio/X-ray/TeV, in synergy with CTA):
    - B-field strength
    - Constrain electron energy distribution
  - High energy spectral cutoff ⇒ max electron energy

### Particle accelerators in the GC:

- Supermassive black hole: Sgr A*
- Pulsar wind nebulae: G359.95-0.04, G0.9+0.1, G0.13-0.11
- Supernova remnants: Sgr A East, G1.9+0.3 (very young SNR; ideal for Titanium 44 line detection)
- Star clusters: Arches, Quintuplet, nuclear star cluster

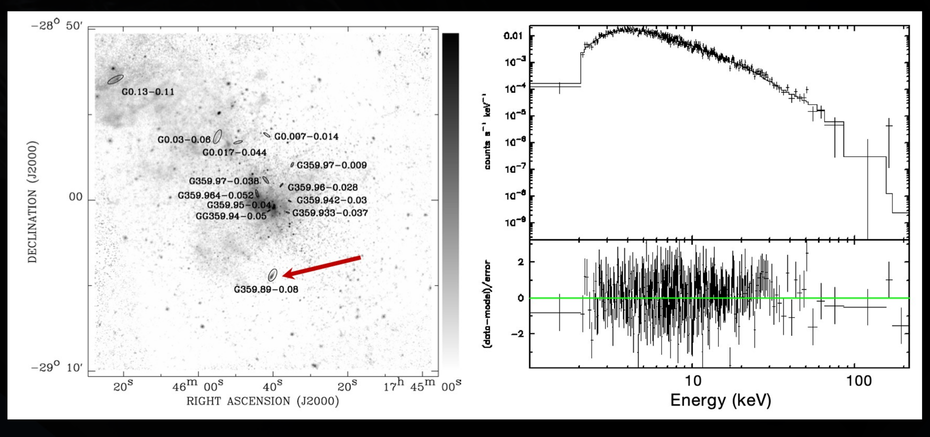

Fig 8. Left: Chandra GC image; arrow indicates filament G359.89-0.08, a.k.a. Sgr A-E (Johnston et al. 2009). Right: simulated HEX-P HET spectrum of the source extends past 100 keV.

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

ss5018@columbia.edu

hexp.org

@HEXP_Future

**HEX-P**
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[1]Columbia University, New York, NY [2]Georgia College & State University, Milledgeville, GA [3]University of California, Berkeley, Berkeley, CA [4]Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA [5]Space Research Institute (IKI): Moscow, Russia [6]INAF Observatorio Astronomico di Brera, Merate, Italy [7]MIT, Cambridge, MA [8]Max-Planck-Institut für extraterrestrische Physik, Garching, Germany [9]Bard College, Annandale-on-Hudson, NY [10]California Institute of Technology, Pasadena, CA [11]University of Arkansas, Fayetteville, Fayetteville, AR [12]Goddard Space Flight Center, Greenbelt, MD [13]University of Insubria, Como, Italy [14]Jet Propulsion Laboratory, Pasadena, CA

References: [1]Ponti et al. (2017) [2]Gravity Collaboration (2021) [3]Zhang et al. (2017) [4]Zhang et al. (2014)