

# Astrometry of Black Hole X-ray Binaries with Gaia DR2: Implications for their formation and distribution

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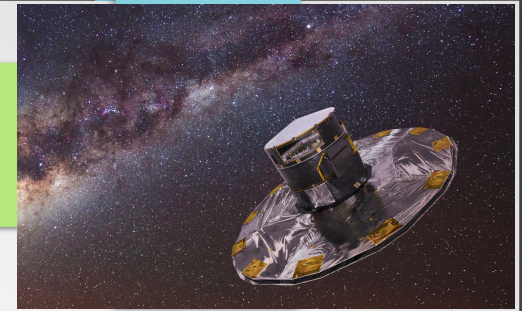
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Poshak Gandhi  
Christian Knigge  
Michael A.C. Johnson  
John A. Paice  
Tom J. Maccarone  
Nathan Leigh  
Douglas Boubert

# Astrometry of Black Hole **X-ray** Binaries (BHXRBS)

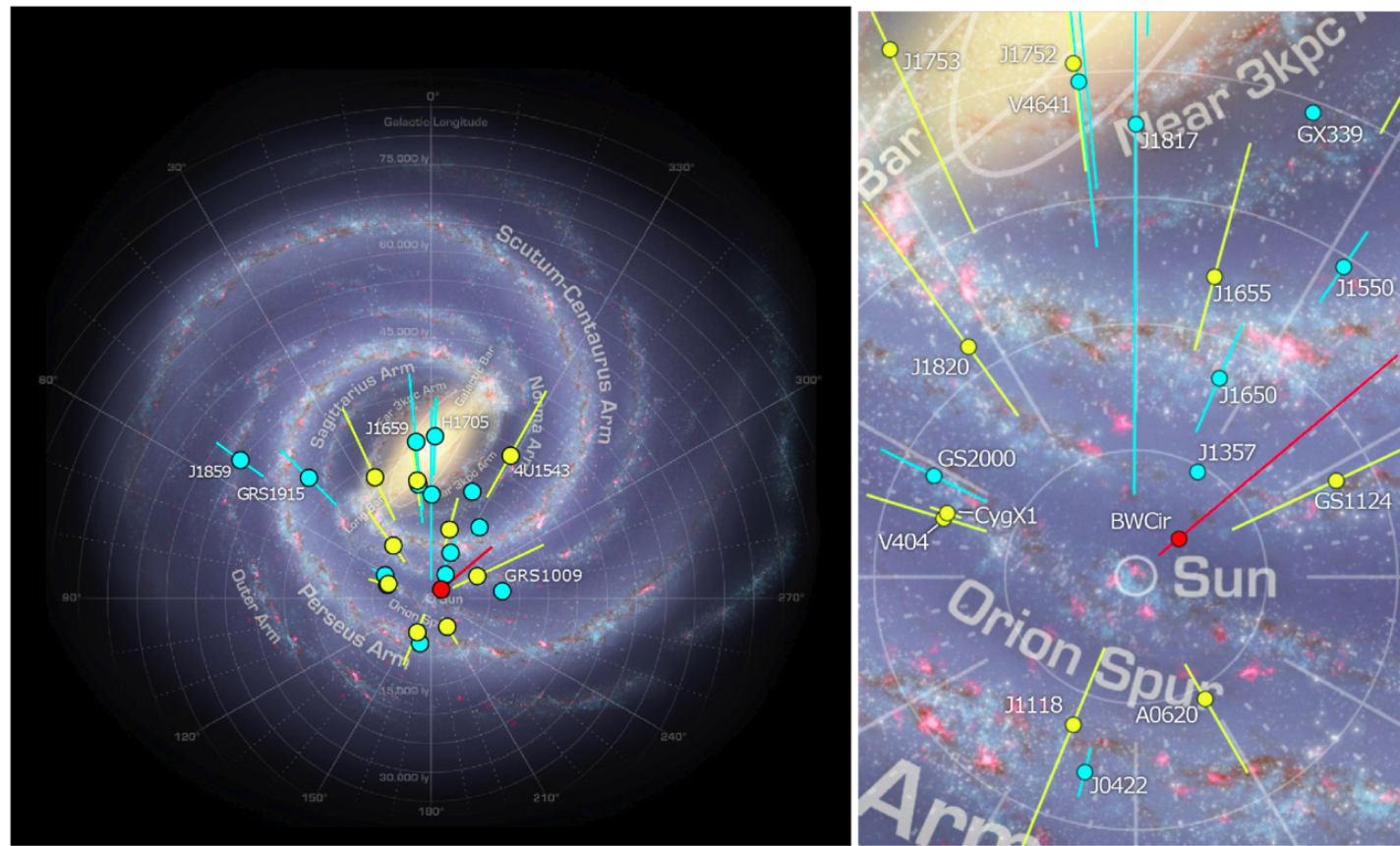
- *Astrometry (Parallax, Proper Motion => distance and kinematics)*
- *Important:*
  - to confirm photometric/spectroscopic distance and luminosity estimates
  - to compute space velocities
  - to understand formation scenarios
  - spins, etc..
- *Challenging:*
  - Need monitoring over years
  - Faint counterparts in quiescence :  $G_{\text{mag}} > 18$
  - Many are transient in nature
  - Large distances  $> 1$  kpc
- **Virtually no optical astrometry** of BHXRBS before *Gaia*

# Astrometry of BHXRBs with *Gaia*

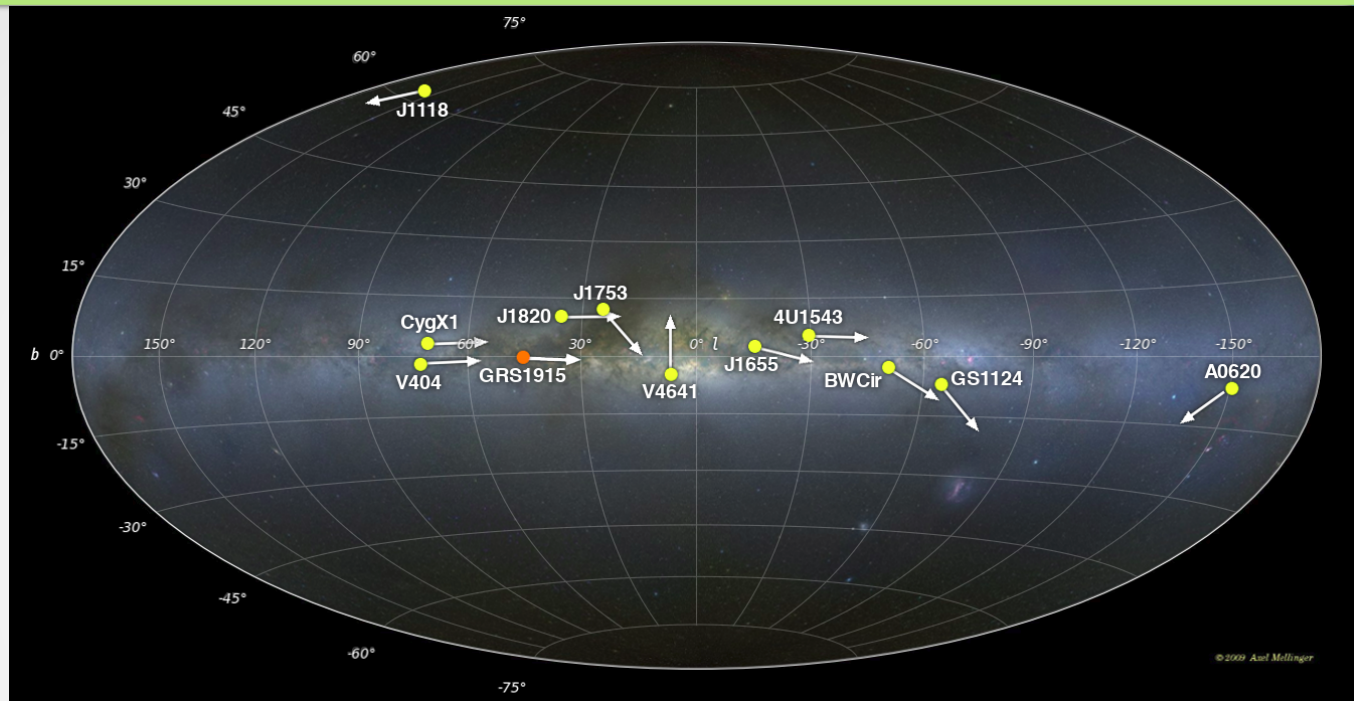


<https://www.cosmos.esa.int/web/gaia/the-mission>

About 24 dynamically confirmed BHXRBs from *BlackCAT* (Corral-Santana et al. 2016)



# Proper Motion and Peculiar Velocities of BHXRBs



Gandhi, Rao et al. (2019), MNRAS, 485

- *First estimates of peculiar velocities for 7 BHXRBs*

## Consistent results for

|               |           |
|---------------|-----------|
| Cyg X-1       | ~20 km/s  |
| GRO J1655-40  | ~140 km/s |
| XTE J1118+480 | ~140 km/s |
| V404 Cyg      | ~ 45 km/s |

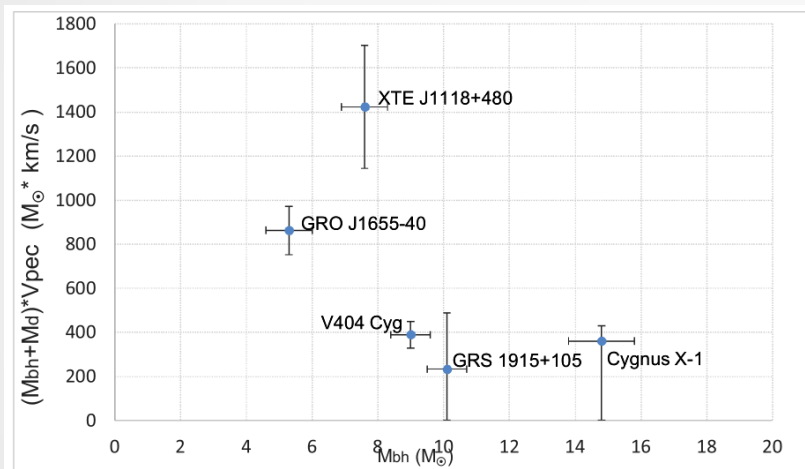
## New results

|                  |            |
|------------------|------------|
| 1A 0620-00       | ~ 40 km/s  |
| SAX J1819.3-2525 | ~ 70 km/s  |
| MAXI J1820+070   | ~ 60 km/s  |
| BW Cir           | ~ 100 km/s |



# Peculiar Velocities of BHXRBs

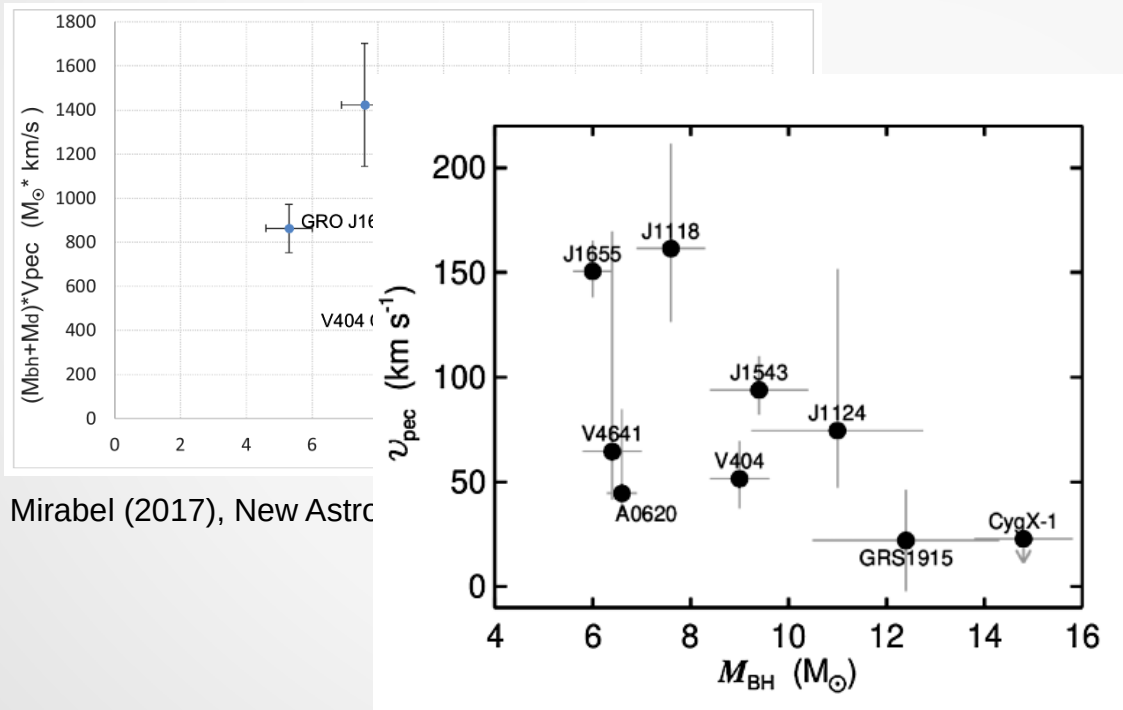
- Peculiar velocities are high for most BHBs ( $> 30$  km/s)
- The median peculiar velocity is **65 km/s**
- KE due to peculiar motion is  **$\sim 0.05\%$**  of typical supernova explosion energies



Mirabel (2017), New Astronomy Reviews

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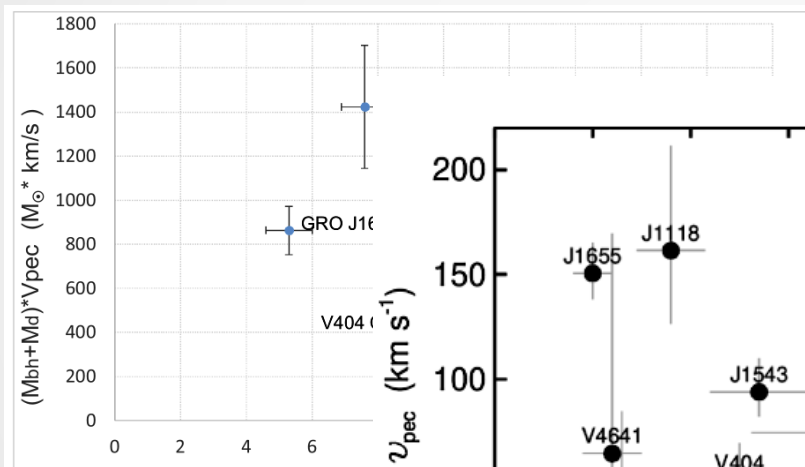


Mirabel (2017), New Astron

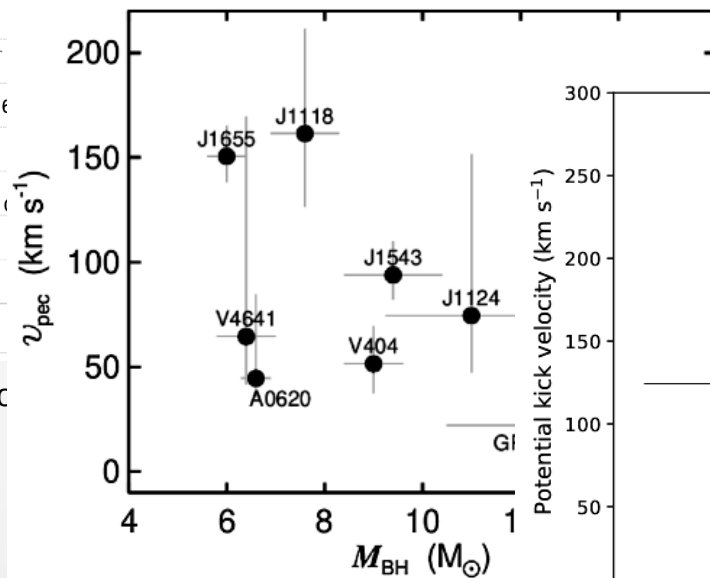
Gandhi, **Rao** et al. (2019), MNRAS, 485

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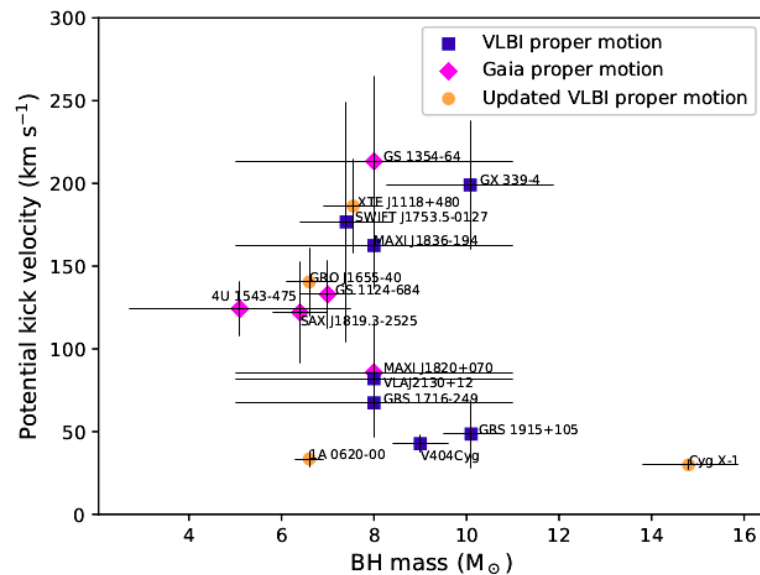
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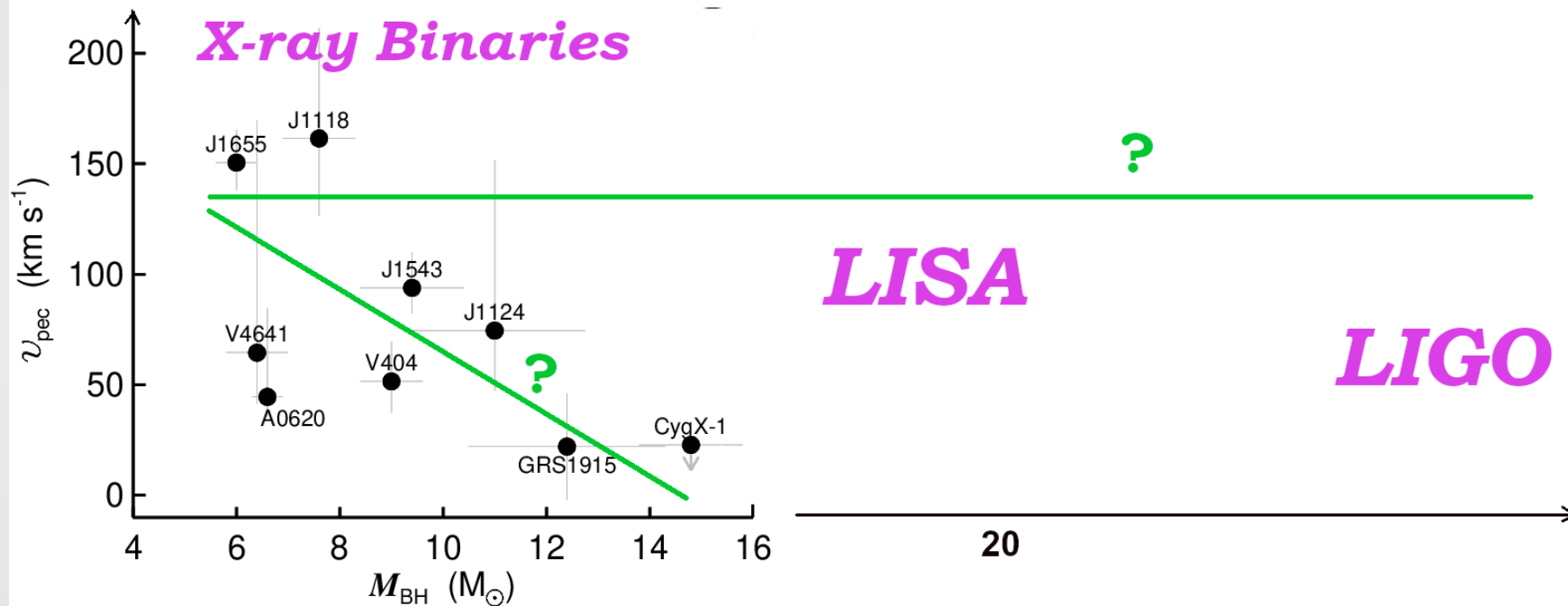


Atri et al. (2019), arxiv: 1908.07199

**Are BHs formed in momentum-conserving kicks in SN explosions?**

# Natal kicks and formation scenarios

- XRBs give insight on the first natal kicks in binaries, which strongly influences GW merger rates.

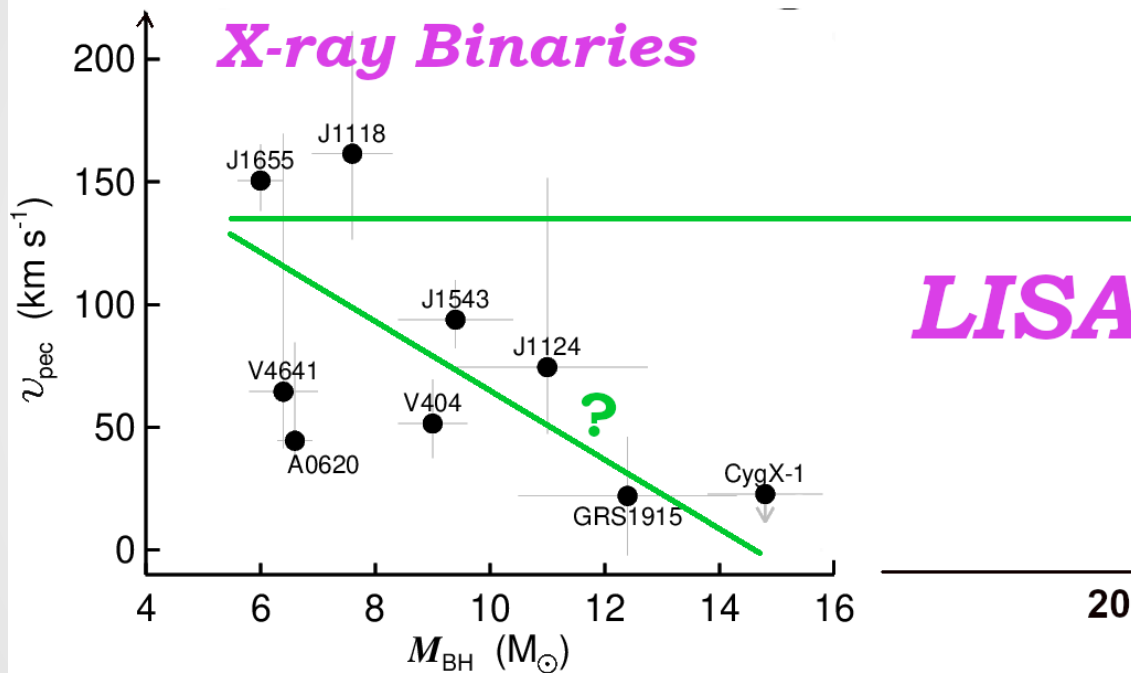


Gandhi, Rao et al. (2019), MNRAS, 485

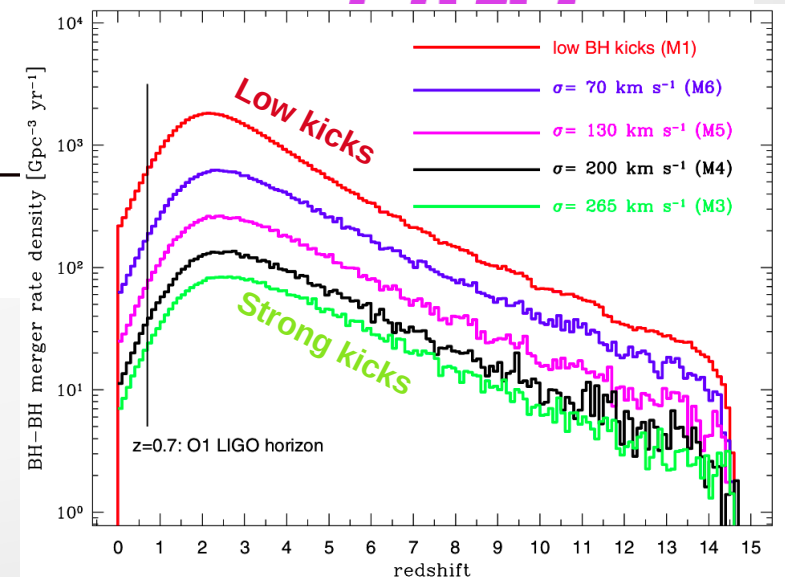


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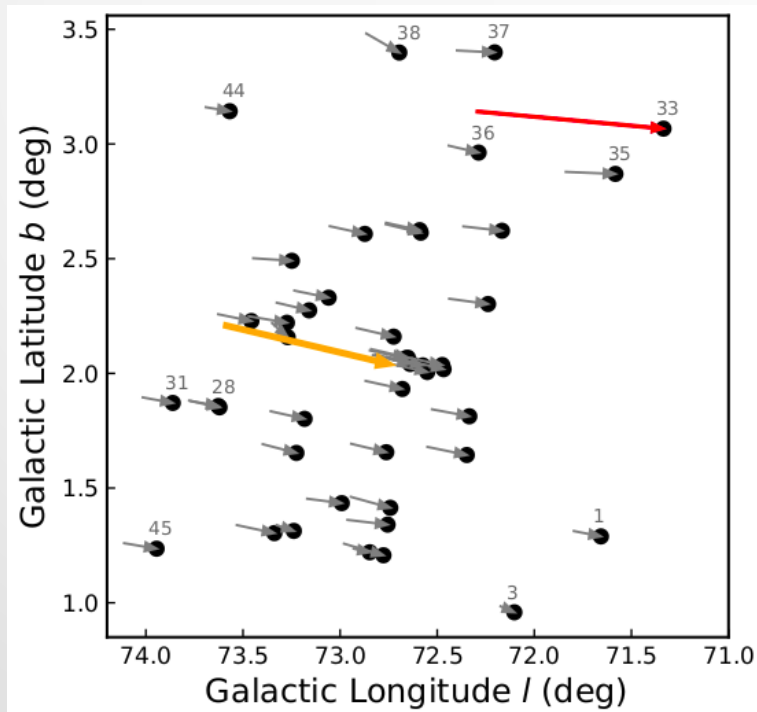
Gandhi, Rao et al. (2019), MNRAS, 485



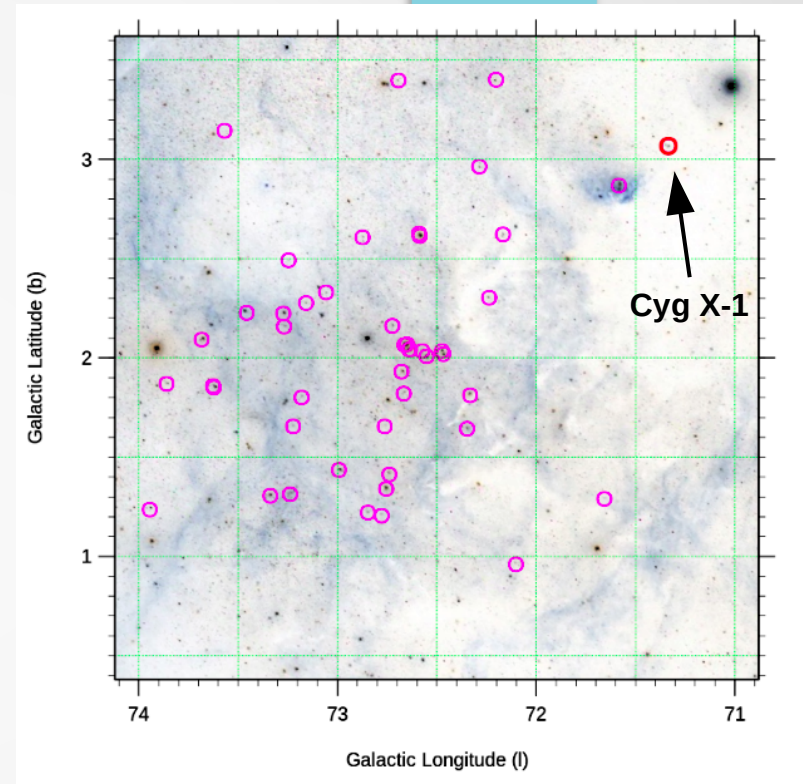
Belczynski et al. 2016, Nature, 512

# Tracing the origin of *high mass* BHXRBS

- Parent association of Cyg X-1
- Studied Cyg OB3 region with Gaia astrometric solution of 45 stars in the region
- Similar distance, proper motion and peculiar velocities of Cyg OB3 and Cyg X-1

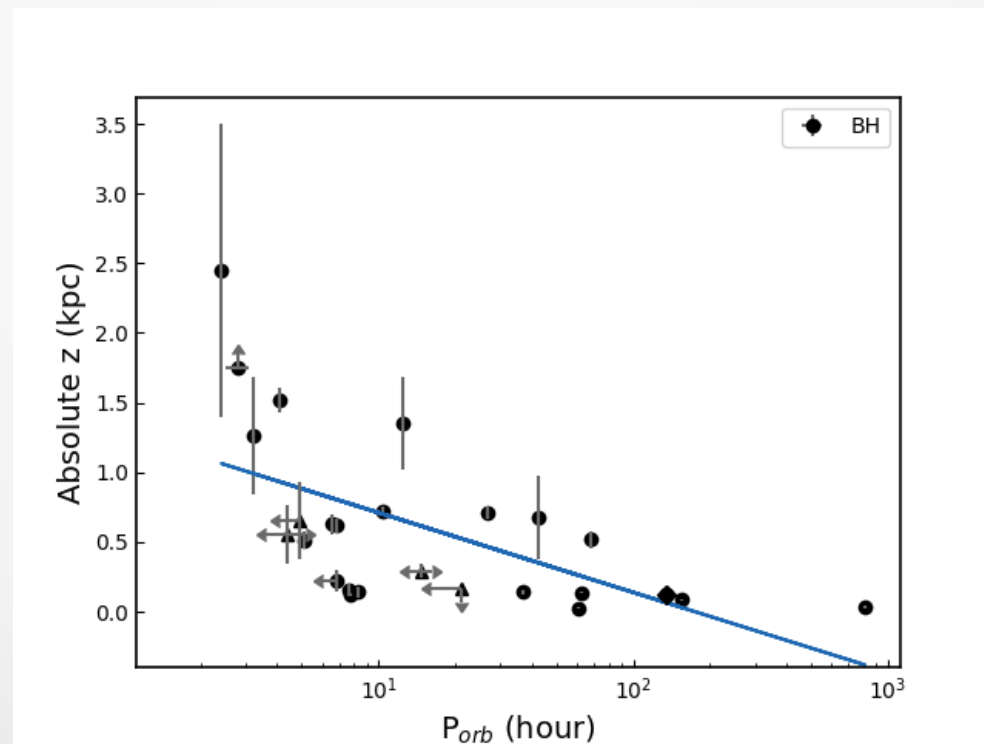


- Proper motion over past 0.1 Myr
- Cyg X-1 : over past 0.5 Myr
- Median Cyg OB3: over past 0.5 Myr



# Spatial Distribution of BHXRBs

- $z$ -heights from the Galactic disk
- Significant correlation with orbital period of BHXRBs



# Summary

- Astrometry for BHXRb population in optical is available for the first time with *Gaia*
- Precise distance measurement and peculiar velocity measurements.
- Potentially capable of contributing to
  - Momentum conserving natal kicks
  - Black hole formation scenarios
  - Origin of BHXRbS in Galactic disk or halo
  - Origin of BHXRbS in Globular clusters
- Further investigation will need:
  - Full astrometric solution for a larger sample of black hole binaries
  - Better precision in parallax and proper motion measurements
  - EDR3, DR3, DR4 and more..