Compact object astrometry with the NGVLA

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With great thanks for many discussions to Walter Brisken, James Miller-Jones, and Laura Chomiuk.

Motivations

Understand distances and kick velocities for X-ray binaries

Window on the supernova process

Compact object masses, spins, kick velocities and gravitational waves are the key insights to supernovae apart from the explosions and remnants

Spin-orbit misalignment

Accuracy of spin estimates

Understand the processes of binary evolution

Why NGVLA

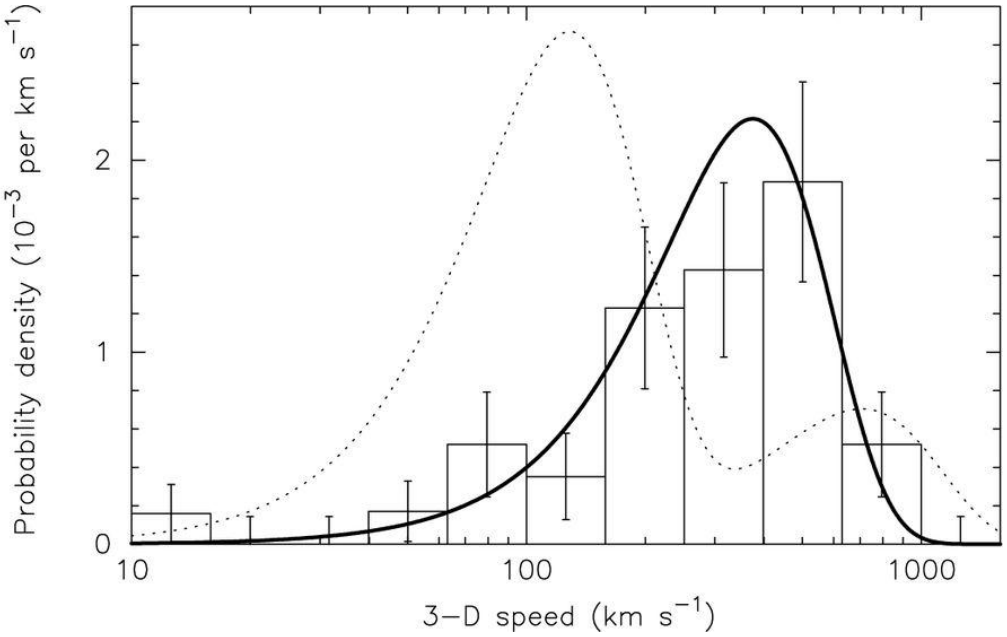
GAIA: confusion and sensitivity problems for reddened objects in Plane

VLBA- lacks sensitivity in general

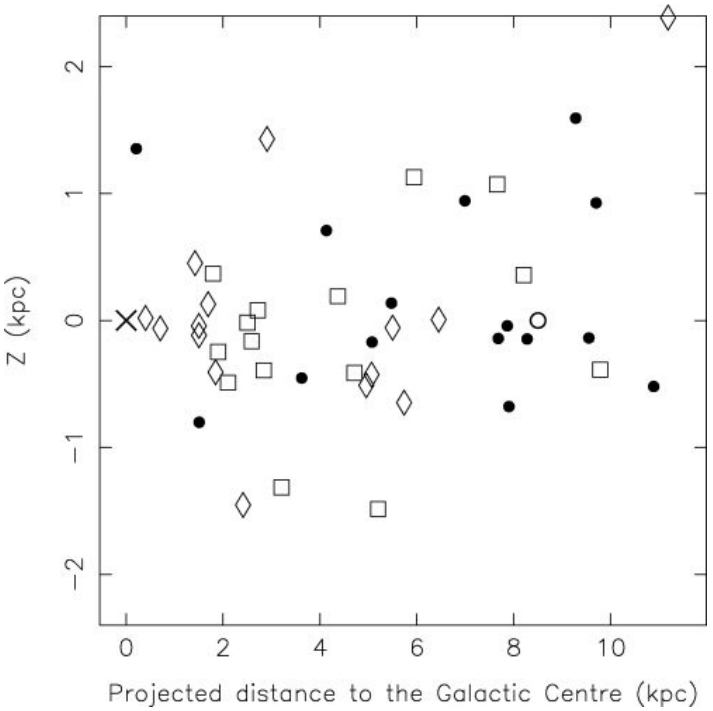
X-ray binary populations are small, so not enough objects within GAIA horizon distance

Faintest accretors are flat spectrum sources, so high frequency and high sensitivity go together

Kicks to compact objects



Pulsars: Hobbs et al. 2005



Black hole binaries (solid), neutron star binaries (open); Jonker & Nelemans 2004

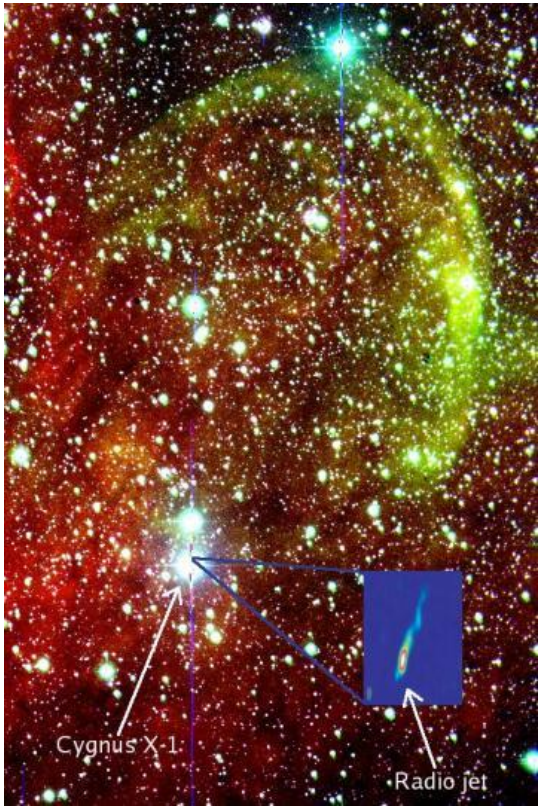
Kick mechanisms

Blaauw: mass loss in supernovae + conservation of momentum

Natal kicks: asymmetric supernovae, or more exotic mechanisms

The difference is crucial:

One misaligns the black hole spin, and the other does not



Cyg X-1: small space velocity,aligned jet? Gallo et al. 2005. Also does not show “geometric” oscillations!

Proper motions: easy, but kick speeds require distances

1 masec/yr = 10 km/sec at 2 kpc, so this can be done even with the VLA/ATCA for bright sources

Distances and radial velocities also needed

Geometric parallaxes at 5 kpc will be 0.2 masec.

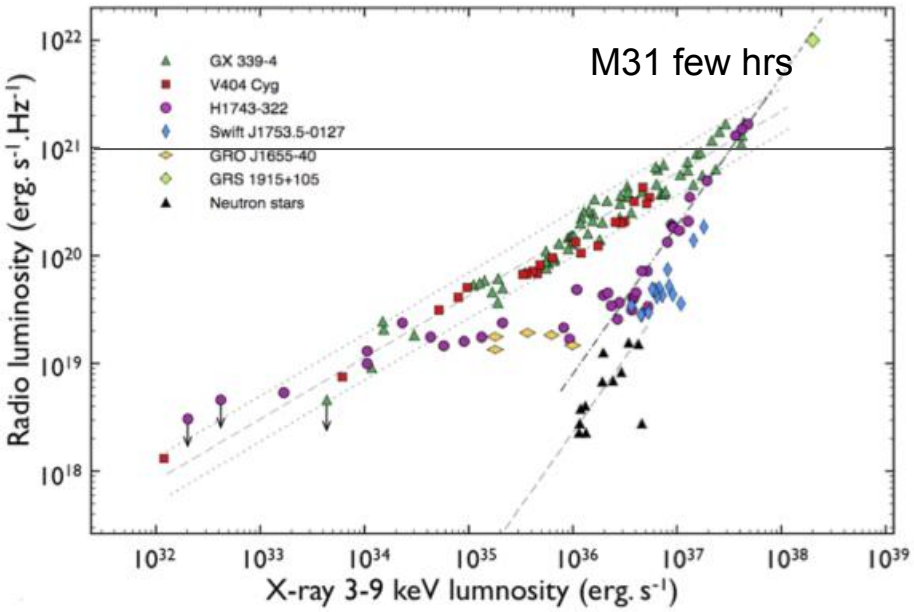
Quiescent black holes: 50-1000 microJy at a few kpc

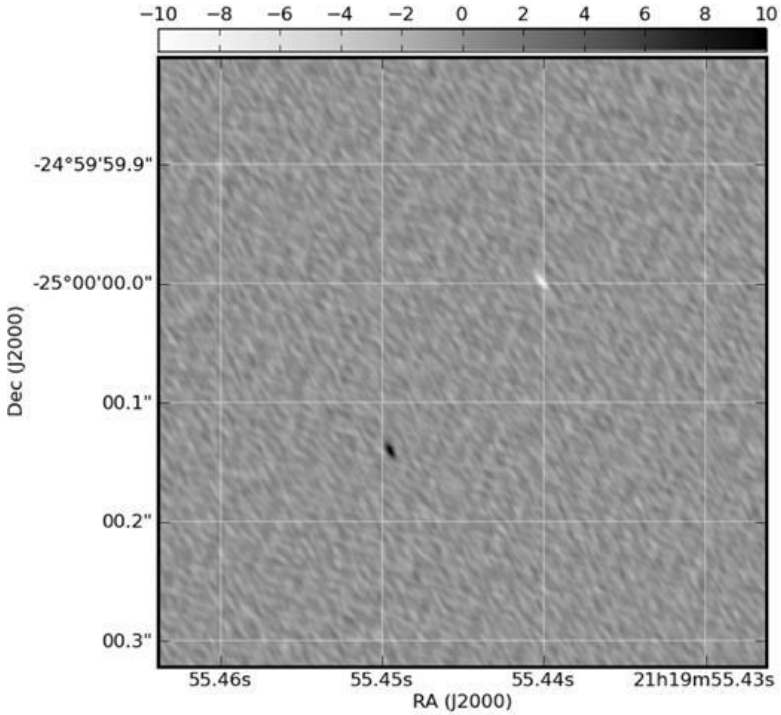
So, can expect ~100 sigma detections, so astrometry to uncertainty of ~50 microarcsec = about 4 sigma parallax -- somewhat longer baselines would help immensely here, but can be offset by long observations

Distances also feed into compact object masses, inclination angles, the other big constraint for understanding supernovae

Can also survey for these with astrometry!

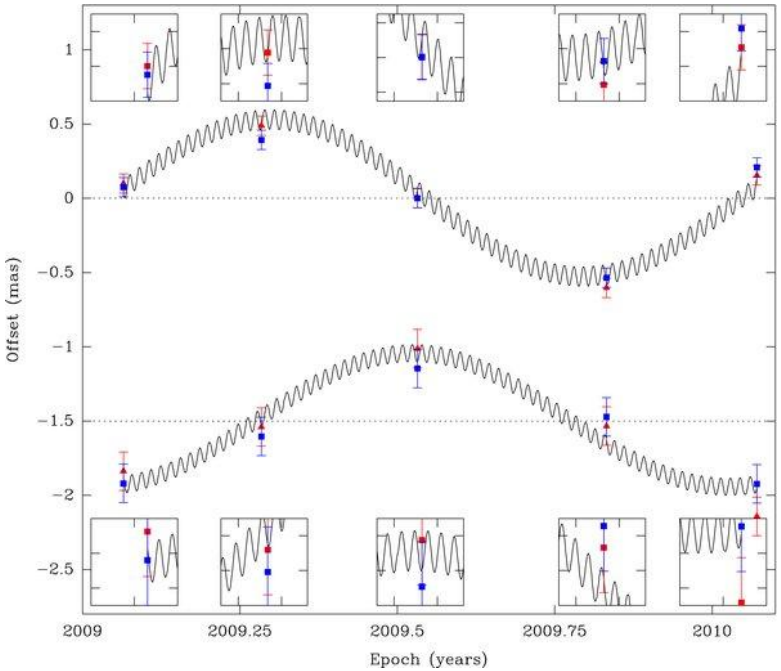
Astrometric searches for quiescent and isolated black holes





Maccarone 2005; Fender, Maccarone & Heywood (2013); Tetarenko et al. 2016

Astrometric wobble of black holes



Reid et al. 2011

Can already, with VLBA, distinguish clockwise versus counterclockwise orbit

Wobble for Cyg X-1 should be ~50 microsec, and would be doable with NGVLA

Wider, fainter black hole X-ray binaries' masses could be measured this way

Jet inclination angles and position angles

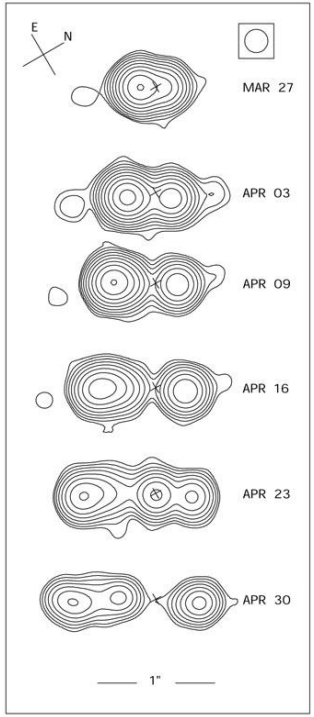
Imaging a jet: gets position angle

Compare with wobble or X-ray polarization position angles

Two-sided proper motions for a jet plus distance: gets inclination angle

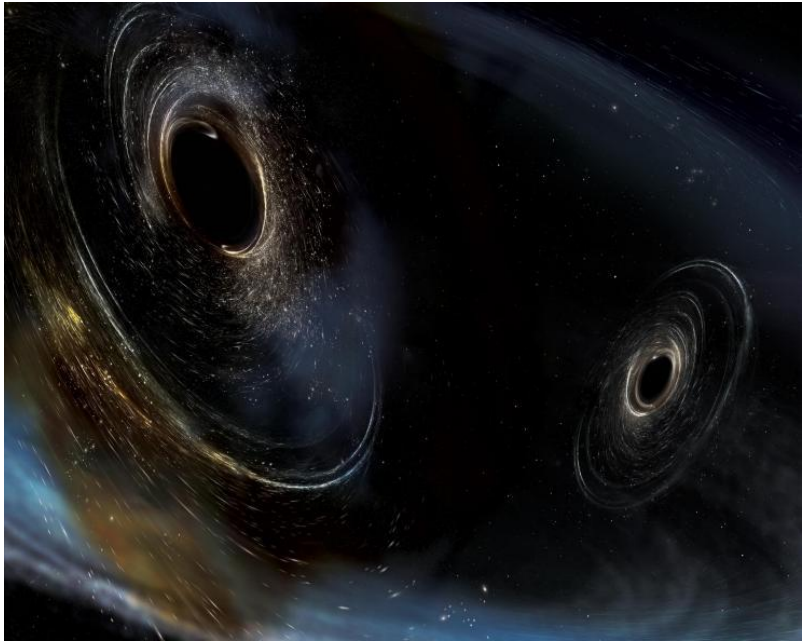
Presently: only a handful of objects with imaged jets

This is often sensitivity limited, especially for single sided jets



Mirabel & Rodriguez 1994

Need for these angles



Aurore Simonnet, LIGO team

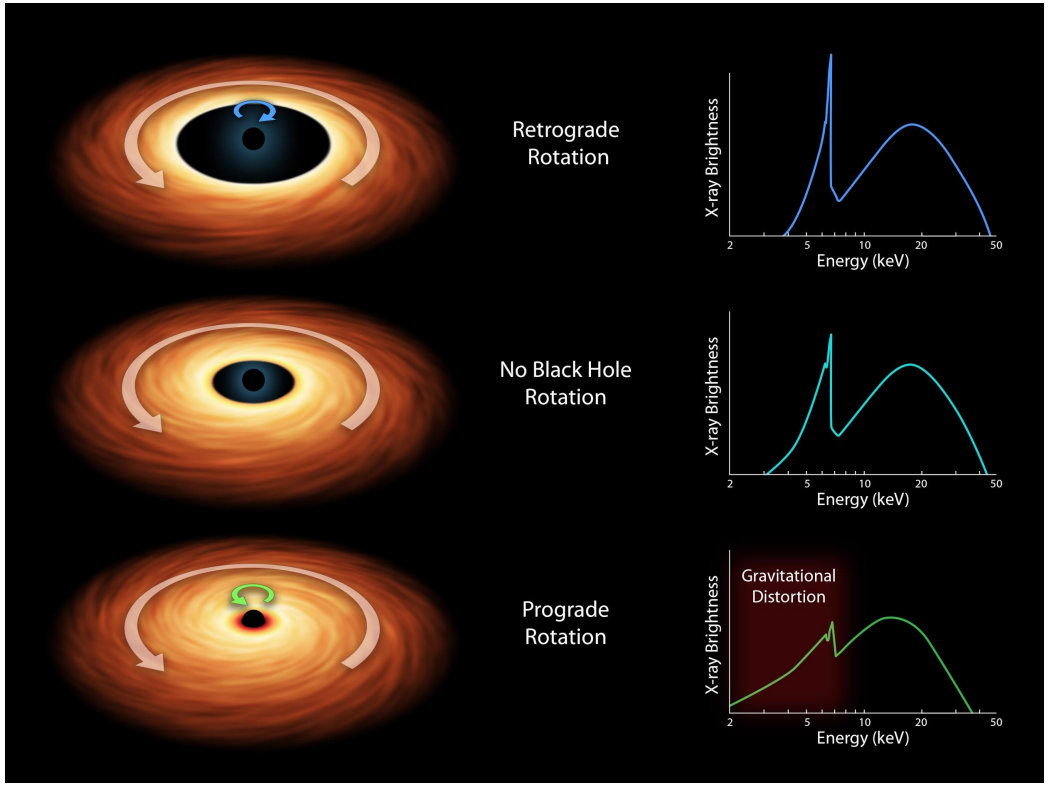


Figure from NuSTAR mission team

Conclusions

Radio observations at high resolution and sensitivity have important implications for understanding formation and evolution of compact objects, including LIGO event formation mechanisms

Maximizing the NGVLA resolution is of real value to these studies