How Well Can SIM-Lite Measure Parameters of Neutron Star and Black Hole Binaries?

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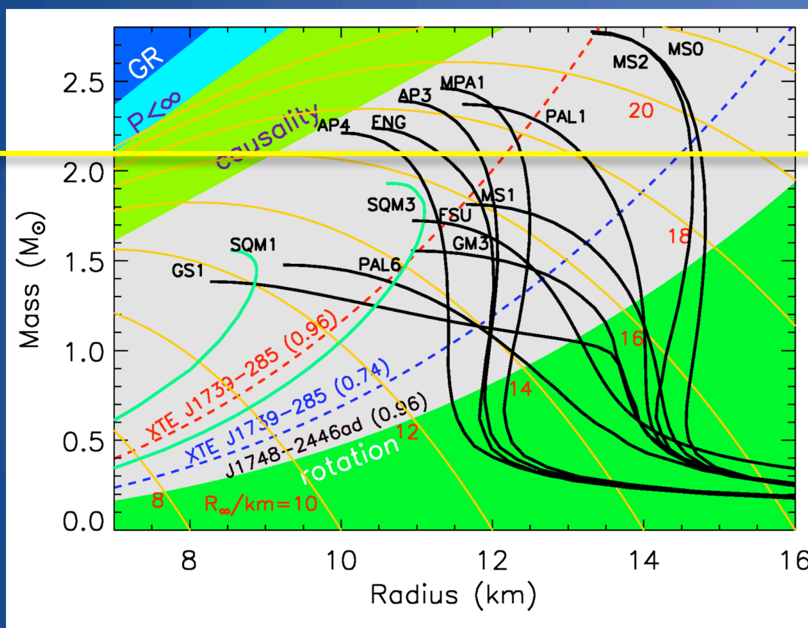
Motivation: What Parameters? Masses, Binary Inclinations, and More



Mass-Radius Relationships for different
Neutron Star Equations of State
(Lattimer & Prakash 2007)

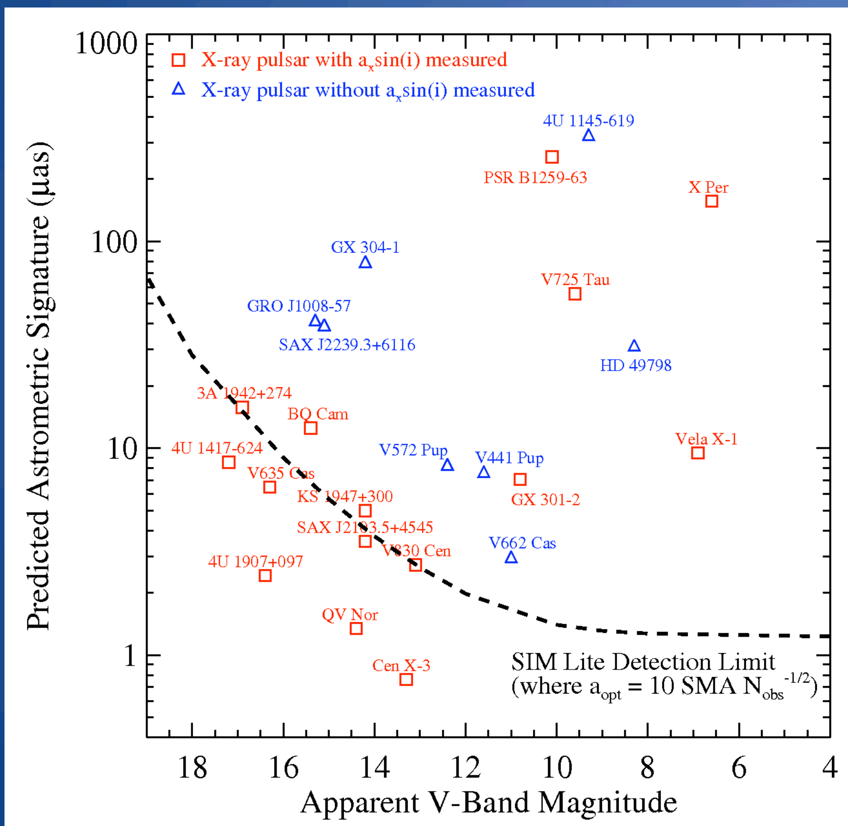
- Measurement of even a single NS with a high mass can rule out soft EOSs and Strange Quark Matter EOSs

$M_{X,VelaX-1} = 1.86 \pm 0.16\ M_{sun}$

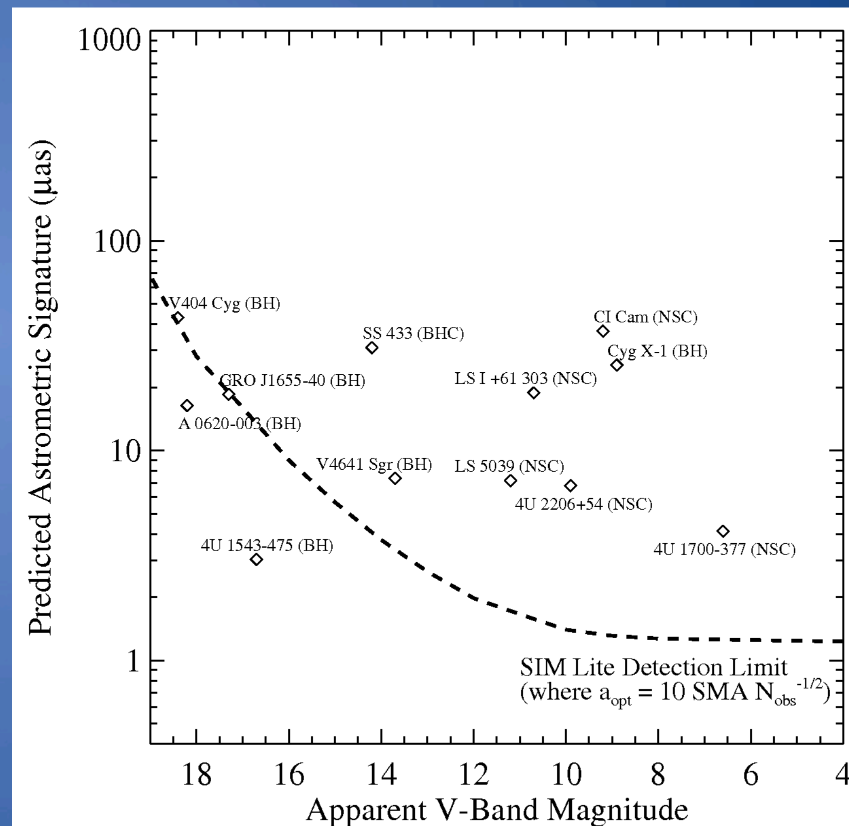
$M_{X,4U1700-377} = 2.44 \pm 0.27\ M_{sun}$

- Black Holes
  - Masses interesting for stellar evolution and BH formation.
  - Binary inclinations are important for interpreting the X-ray emission that comes from the accretion disk.

Predicted Astrometric Signatures for Neutron Star and Black Hole Binaries

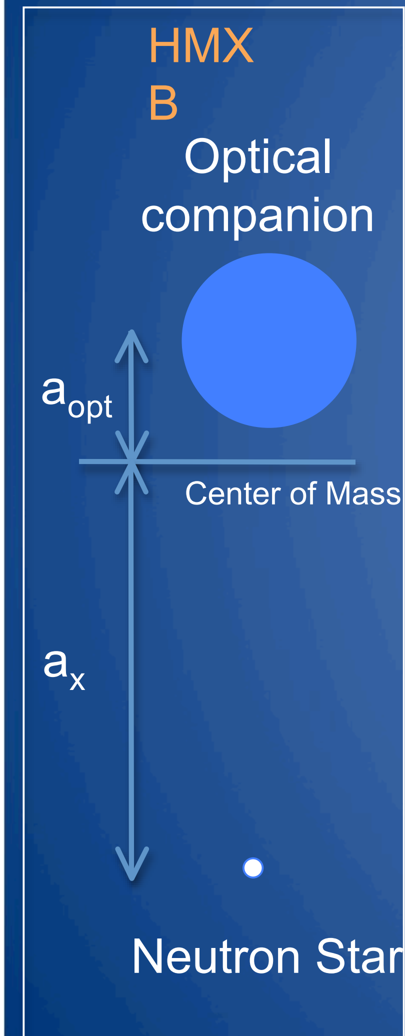


X-ray Pulsars



Black Holes, BH and NS Candidates

Measuring Masses of Neutron Stars in High-Mass X-ray Binaries



- For X-ray pulsars with orbital time delay measurements (i.e., $a_x \sin(i)$ measured), SIM Lite will be able to obtain a direct neutron star mass measurement (M_{NS}) according to:

$$M_{NS} = (4\pi/GP_{orb})\ [d\tan(a_{opt})/\sin^2 i]\ [a_x \sin(i) + d\tan(a_{opt})\sin(i)]^2$$

where

P_{orb} = Binary orbital period (previously known)

$a_x \sin(i)$ = Projected size of NS orbit (previously known)

d = source distance (measured by SIM Lite – Wide Angle)

a_{opt} = angular size of optical companion's orbit (measured by SIM Lite – Narrow Angle)

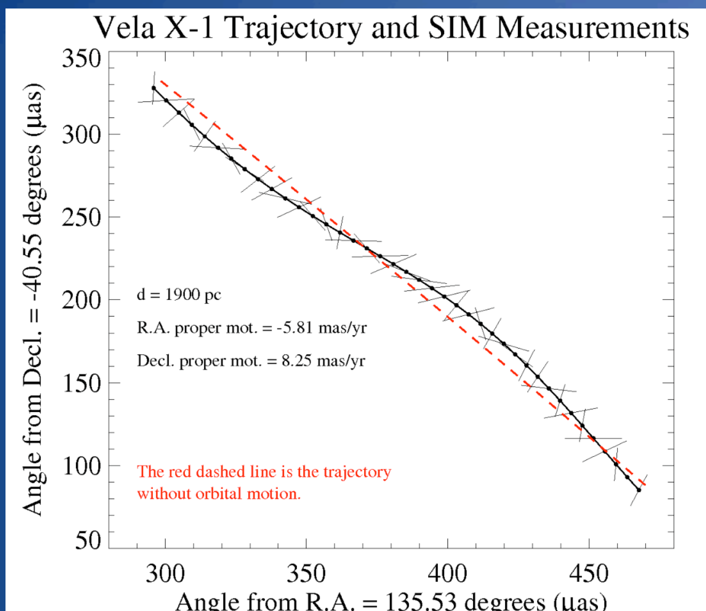
i = binary inclination (measured by SIM Lite – Narrow Angle)

Orbital Parameters for HMXBs

Primary Goal of the Project: Use simulations to determine how well SIM Lite will measure the compact object masses for these 10 systems.

Source Name	P_{orb} (days)	$a_x\sin(i)$	Ecc.	M_{opt}/M_{sun}	M_{NS}/M_{sun}
Vela X-1	8.964368(40)	113.89(13)	0.0898(12)	24	1.86(16)
V725 Tau	110.3(3)	267(13)	0.47(2)	15	?
GX 301-2	41.498(2)	368.3(37)	0.462(14)	55	?
X Per	250.3(6)	454(4)	0.111(18)	15	?
PSR B1259-63	1236.724(1)	1296.3(1)	0.86989(1)	10	?
Cyg X-1 (BH)	5.599829(16)	-	<0.05	20	10
4U 1700-377 (NSC)	3.411581(27)	-	0.22(4)	58	2.44(27)
LS I +61 303 (NSC)	26.4960(28)	-	0.72(15)	10	?
LS 5039 (NSC)	3.90603(17)	-	0.35(4)	23	$3.7^{+1.3}_{-1.0}$
SS 433 (BHC)	13.08211	-	<0.05	12	4.3(8)

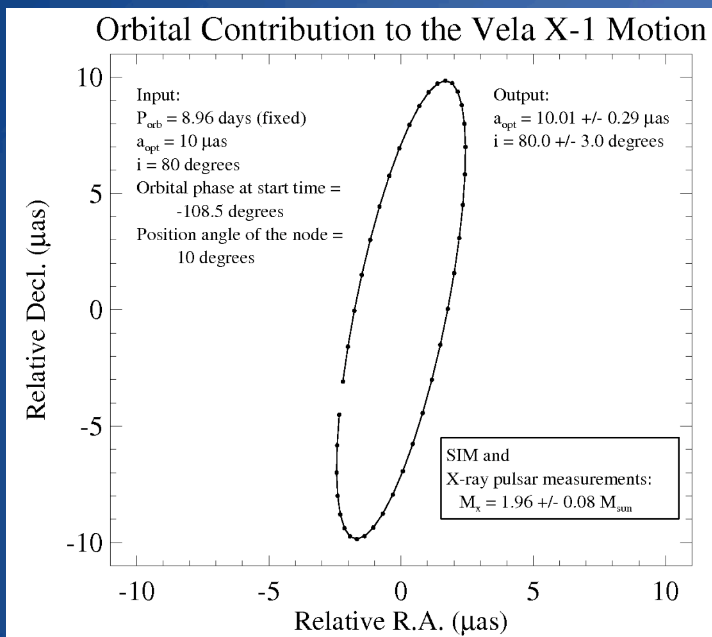
Approach to Simulations: Observing Scenario and Data Stream

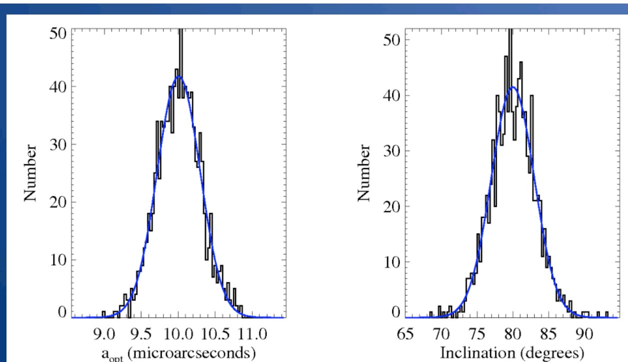


Tomsick et al. 2005, AAS presentation

- Calculate actual positions of the target (with orbital, parallax, and proper motion) and N_{ref} reference stars (with parallax and proper motion) vs. time, t.
- Randomly choose a SIM Lite baseline angle (θ) for each of the N_{obs} visits to the target.
- Simulate 1-d differential measurements between the target and each of the N_{ref} reference stars. (The "noise" estimates come from tables or websites provided by the SIM project.)
- A data set consists of: N_{obs} timestamps, N_{obs} θs, and N_{ref} x N_{obs} measurements of target/reference star angles.

Approach to Simulations: Fitting and Results for Vela X-1





- χ^2 fitting with the same functional form that was used in simulating the data stream
- Vela X-1 work done with N_{ref} = 4. The function has 24 free parameters:
  - 4x5 non-orbital parameters: x_{0k}-x_{0T}, y_{0k}-y_{0T}, u_{xk}-u_{xT}, u_{yk}-u_{yT}, and π_k-π_T, k = 1-4
  - 4 orbital parameters: a_{opt}, i, t_{ref}, and Ω (position angle of the line of nodes)
- Result: 4% measurement of M_{NS} in 40 hours of mission time.

Plan for this Study

- Compare simulation results for my code and the code developed for the planet studies (Muterspaugh "orbit-fitting" code)
- Improvements to my code:
  - two more orbital parameters: e and ω
  - optimize observing strategy (e.g., N_{obs} vs. T_{obs}, more observations at periastron, N_{ref})
  - more realistic (e.g., non-random baselines, reference star wobble, SIM-Lite rather than SIM numbers)
- Optimize and check simulation code and obtain results for the 10 systems (5 X-ray pulsars, 1 BH, 3 NSCs, 1 BHC)

Summary

- Science:
  - M_{NS} and constraining Neutron Star EOSs
  - M_{BH} and i: Stellar evolution, BH creation, accretion physics
  - BHC/NSC: Masses can constrain BH/NS nature
- Targets:
  - HMXBs are best: Large orbits and the optical light is dominated by the one component (companion)
  - X-ray pulsars give the most direct mass measurement
- This Study:
  - Cross-check and improvement of simulation code
  - Detailed paper on simulation results for 10 HMXBs