Prospects for observing dynamically formed stellar mass black hole binaries with gravitational waves

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UTRGV

Motivation

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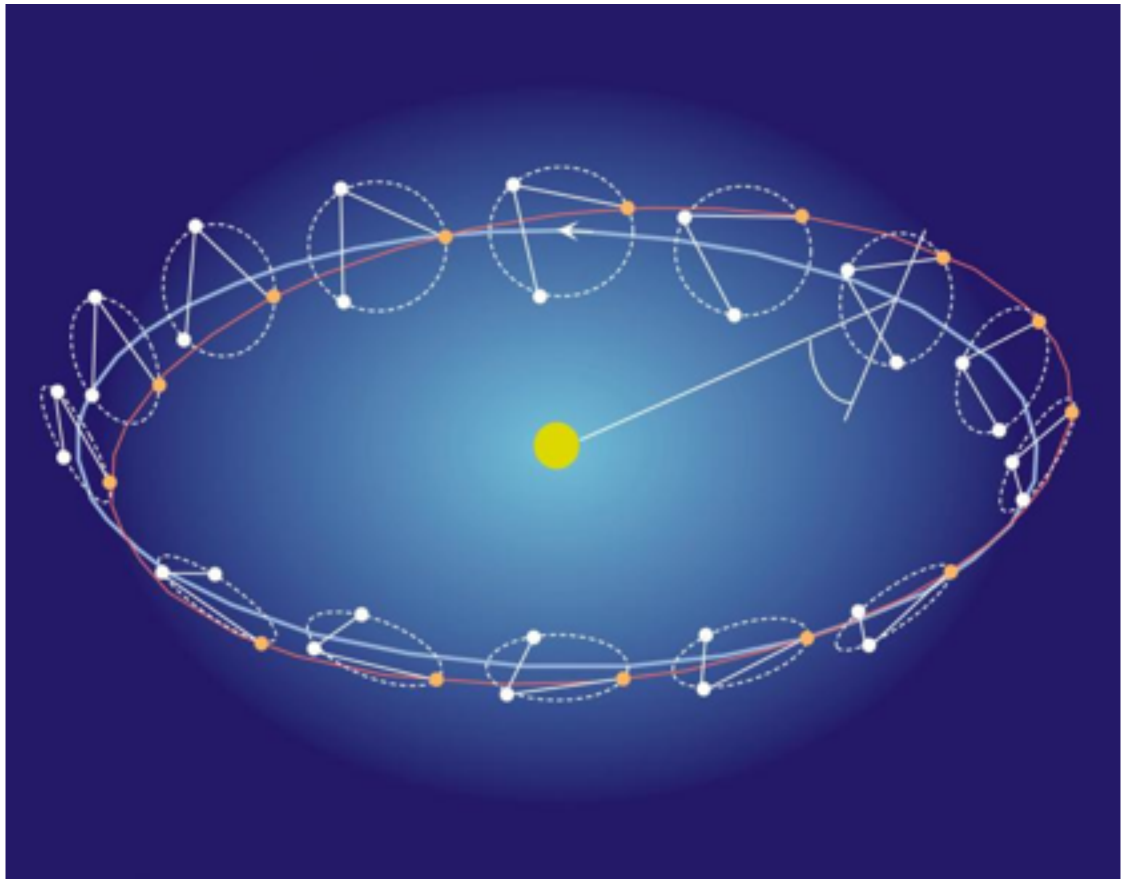
- Most stellar mass object sources have been considered to be limited to the Galaxy
- Higher mass black holes may be detectable at extragalactic distances.
- What can we learn from gravitational wave observations of these objects?

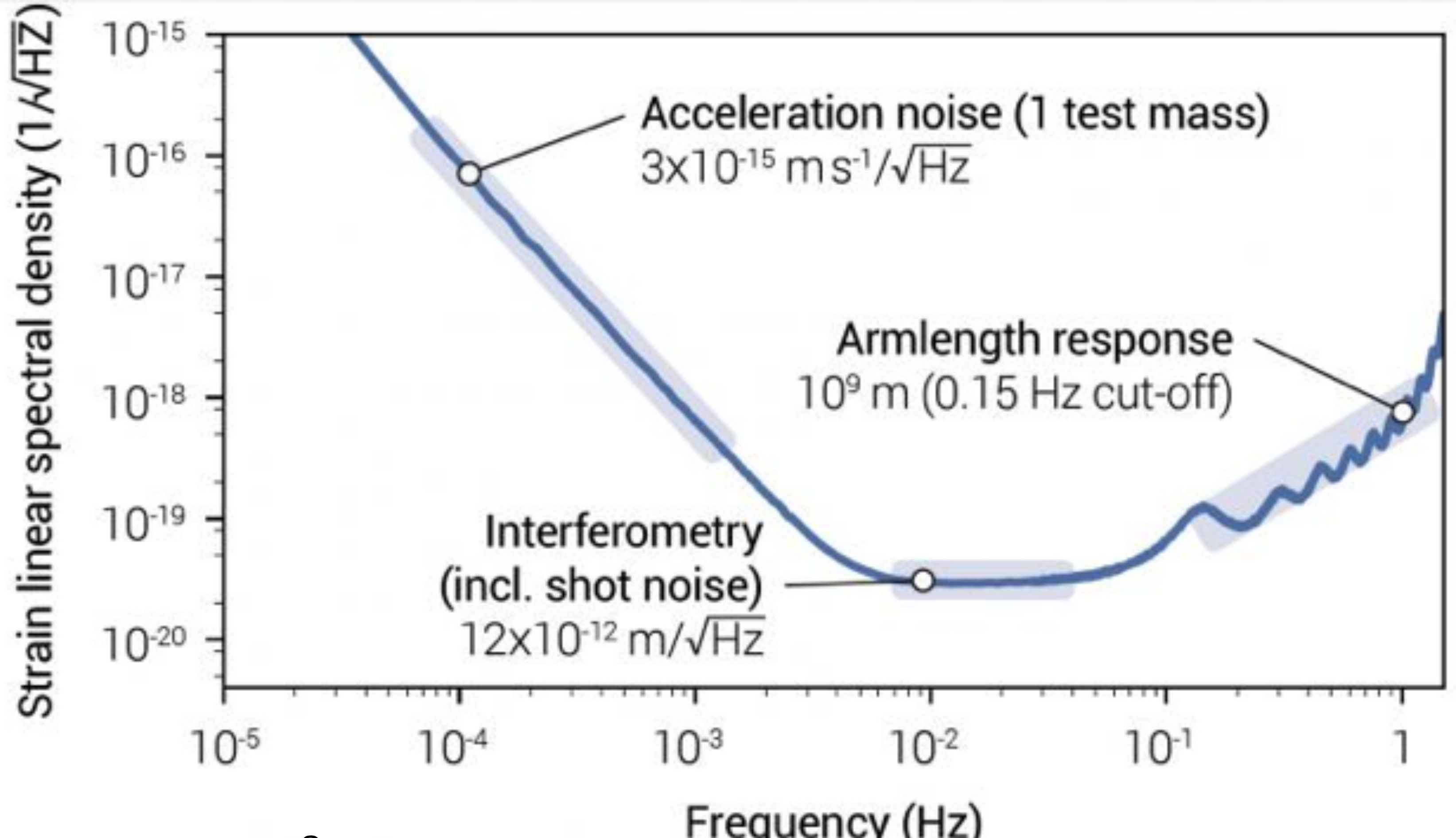


Quick Summary of eLISA

- Three spacecraft in solar orbit
- Laser links between two pairs
- 10^6 km armlengths

ESA L3 Mission

Scheduled launch: 2034



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        - Simple, Continuous, Small frequency shift

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Determining Distances

The measured gravitational wave strain:

$$h = \frac{G^{5/3}}{c^4}\frac{\mathcal{M}_c^{5/3}\omega^{2/3}}{d}$$

is proportional to the square root of the "apparent magnitude" in gravitational waves, while the chirp:

$$\dot{\omega} = \frac{96}{5}\frac{G^{5/3}}{c^5}\mathcal{M}_c^{5/3}\omega^{11/3}$$

Is proportional to the power lost by the binary, or the "absolute magnitude" in gravitational waves. Thus we can find the distance through:

$$d = \frac{5c\dot{\omega}}{96h\omega^3}$$

Stellar Mass Black Holes

- Brightest (in GW) sources from stellar evolution.
- Likely to be chirping
- Hard to make in large numbers in the field
- Not so hard to make dynamically in dense stellar systems
- Likely to be more massive if formed at low metallicity
- Globular clusters!

Making BBH in Globular Clusters

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Birth

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Mass Segregation

Making BBH in Globular Clusters

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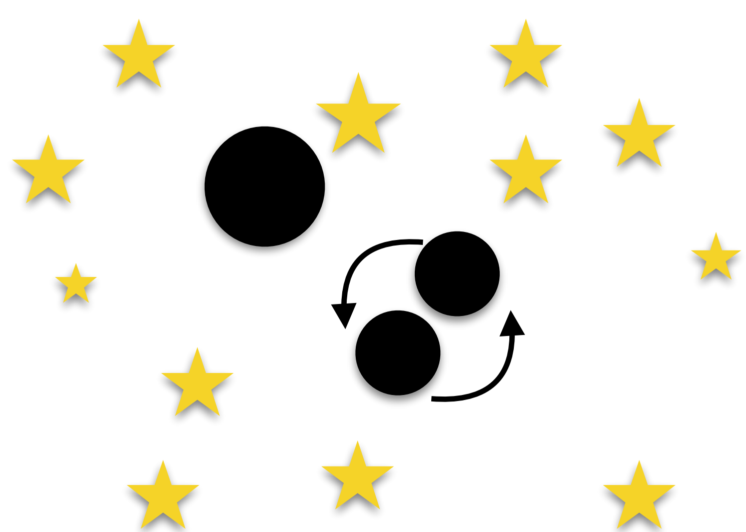
Exchange Interactions



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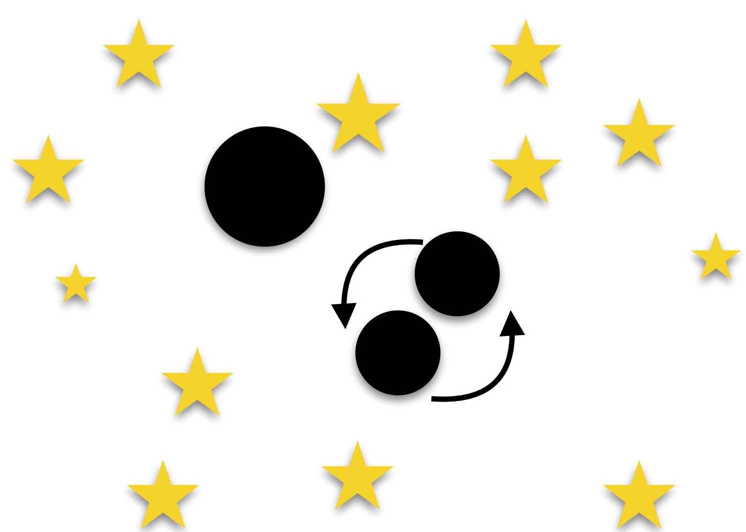
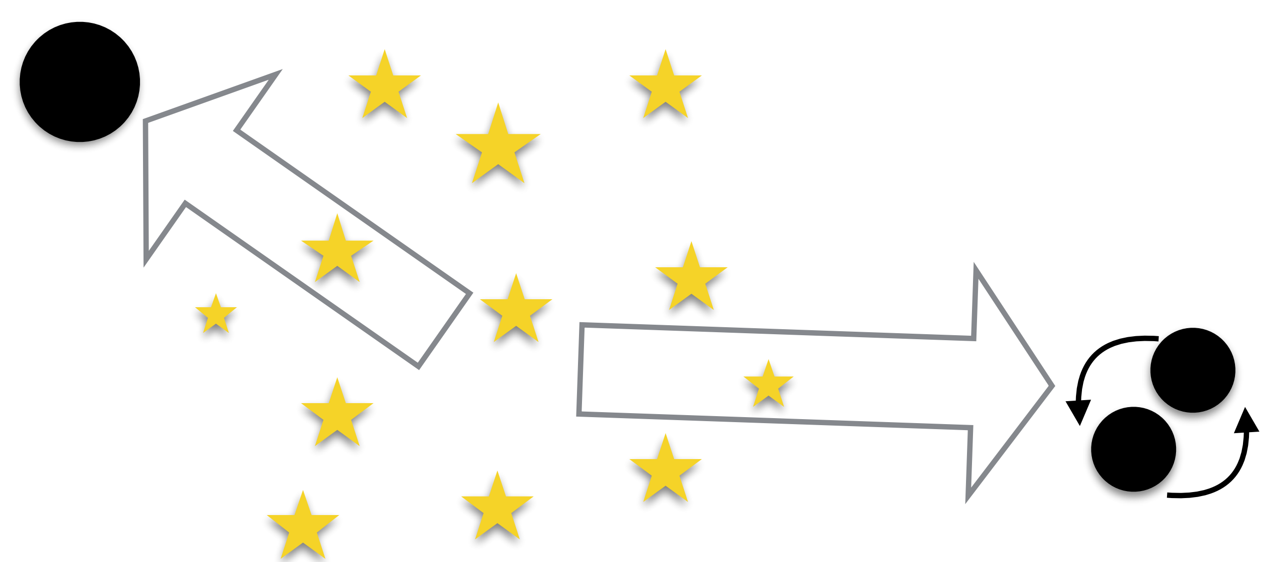
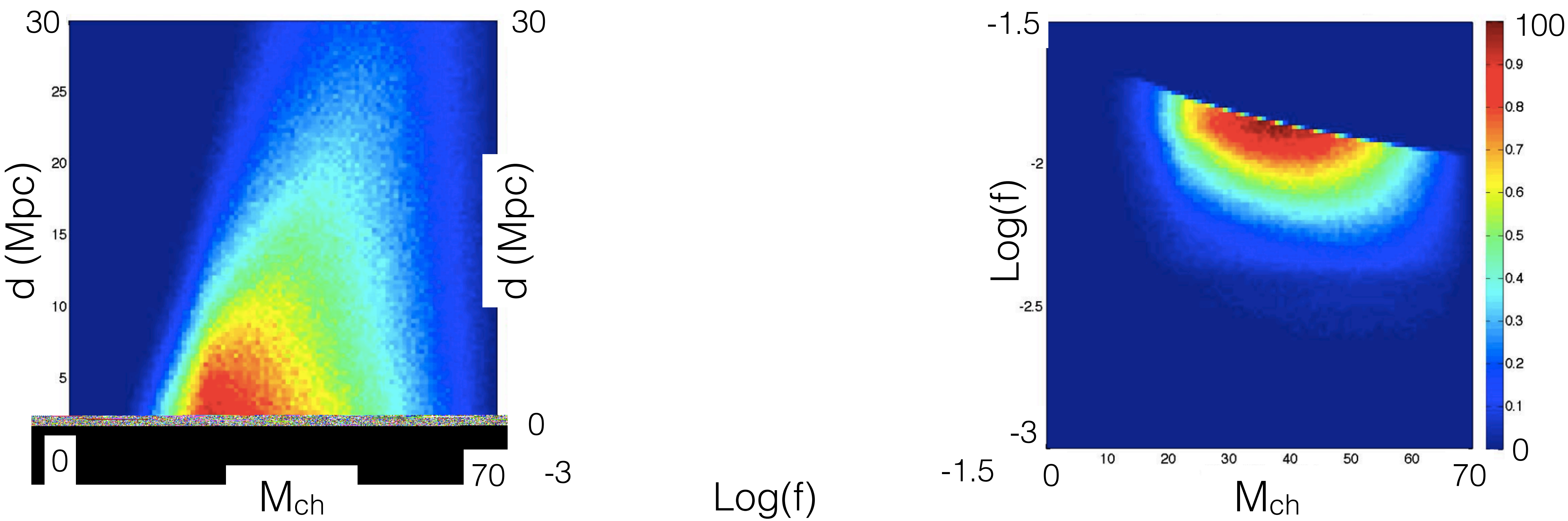


Dynamical Ejection



So, how distant can the detectable binaries be?

- Population of 10^7 BH binaries
- Uniform distribution in a 30 Mpc sphere
- Uniform distribution in masses from 10-80 M_{sun}
- Uniform distribution in orbital periods below 2000 s
- Uniform distribution in orientation
- Run through LISA simulator and determine detection
- SNR > 8



MB, Hinojosa, Mata, Belczynski 15

- Next, look to see if there is a population with these properties. Focus on field binaries to start. (Undergrad project: Jesus Hinojosa)

- Use the gravitational wave galaxy catalog (White, Daw & Dillon 11, 12) to determine galaxy type and position out to 30 Mpc.

- Use SyntheticUniverse.org to produce field binaries.

- Populate the galaxies in the catalog.

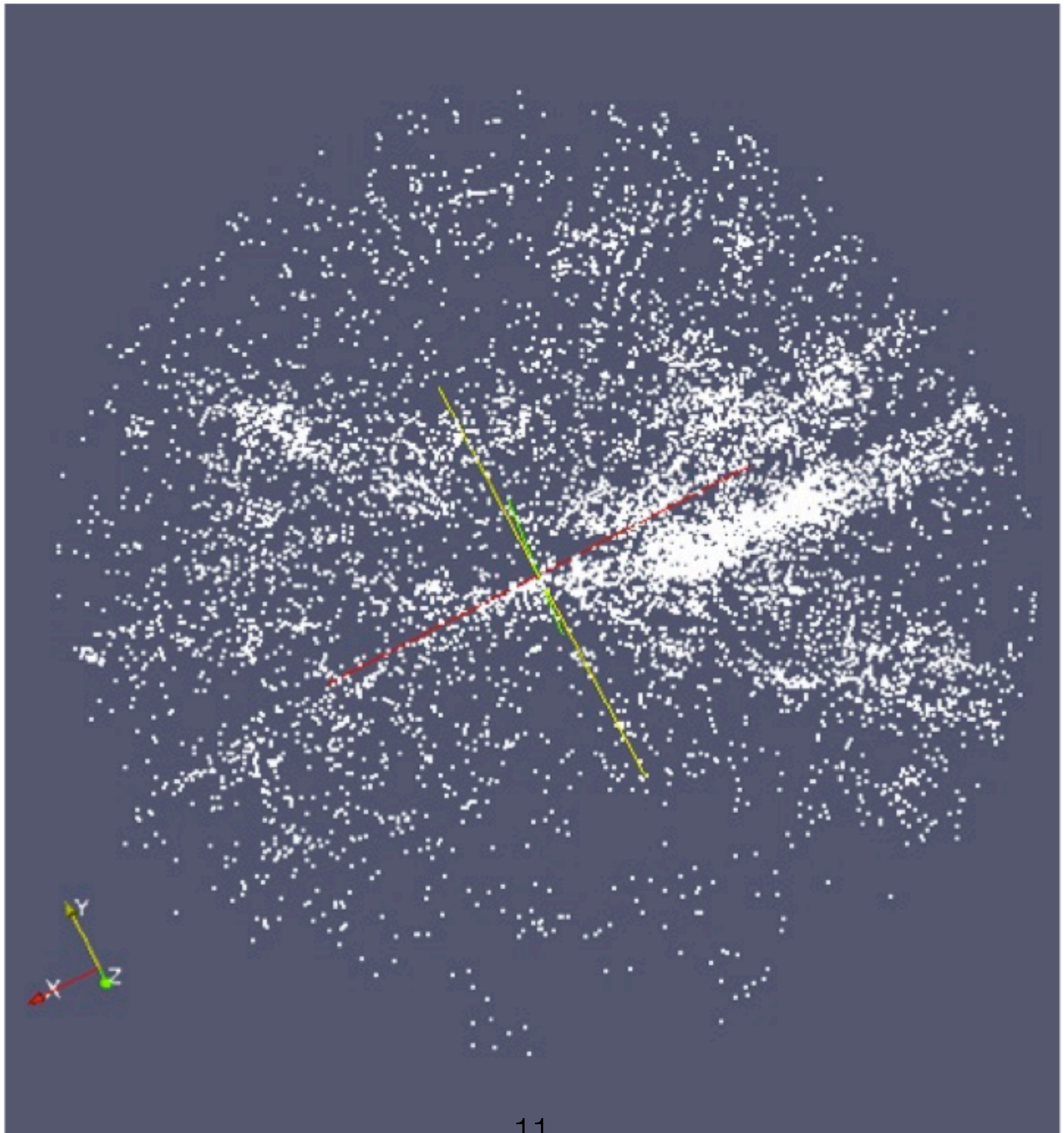


Table 2: Probability of Detection from BBH systems Results

	Elliptical	Spiral	Irregular
Probability of Detection (%)	0	89.58	51.11
		1.70	2.05
		0.30	2.05
		2.17	17.22
		2.17	9.69
Total	0	95.93	82.12

- Field binaries were from solar metallicity
- Lower chirp masses
- Elliptical galaxies produce their binaries early

Black Hole Binary Production in Globular Clusters

- There have been many studies of black hole binary production in globular clusters.

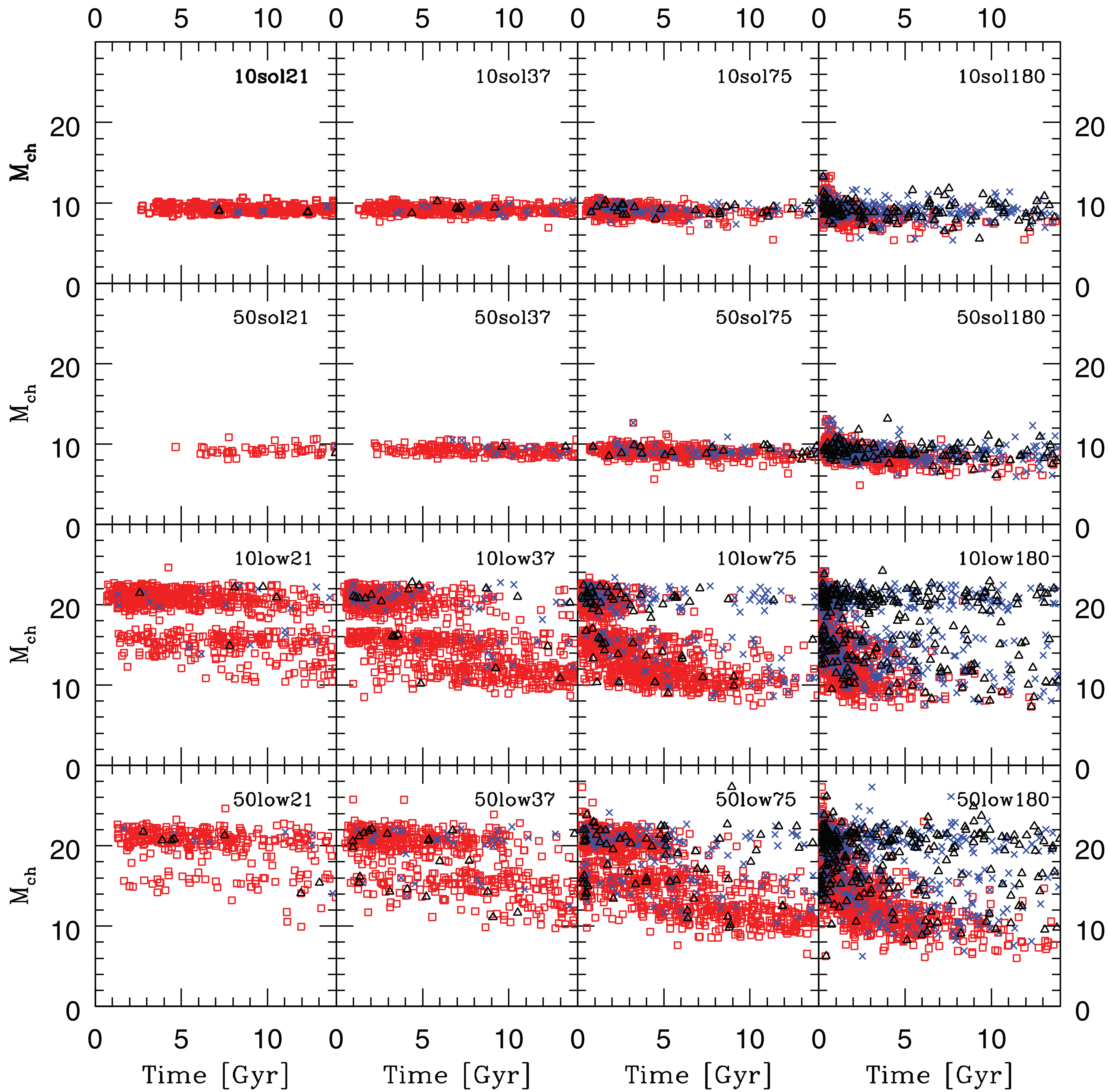
Portegies Zwart & McMillan 2000
Miller & Hamilton 2002
MB 2002
O'Leary + 2006
O'Leary, O'Shaughnessy, & Rasio 2007
Sadowski + 2008
Moody & Sigurdsson 2009
Downing, MB, Giersz, & Spurzem 2010
Downing, MB, Giersz, & Spurzem 2011
Morscher, Umbreit, Farr, Rasio 2013
Bae, Kim, & Lee 2014

Black Hole Binary Production in Globular Clusters

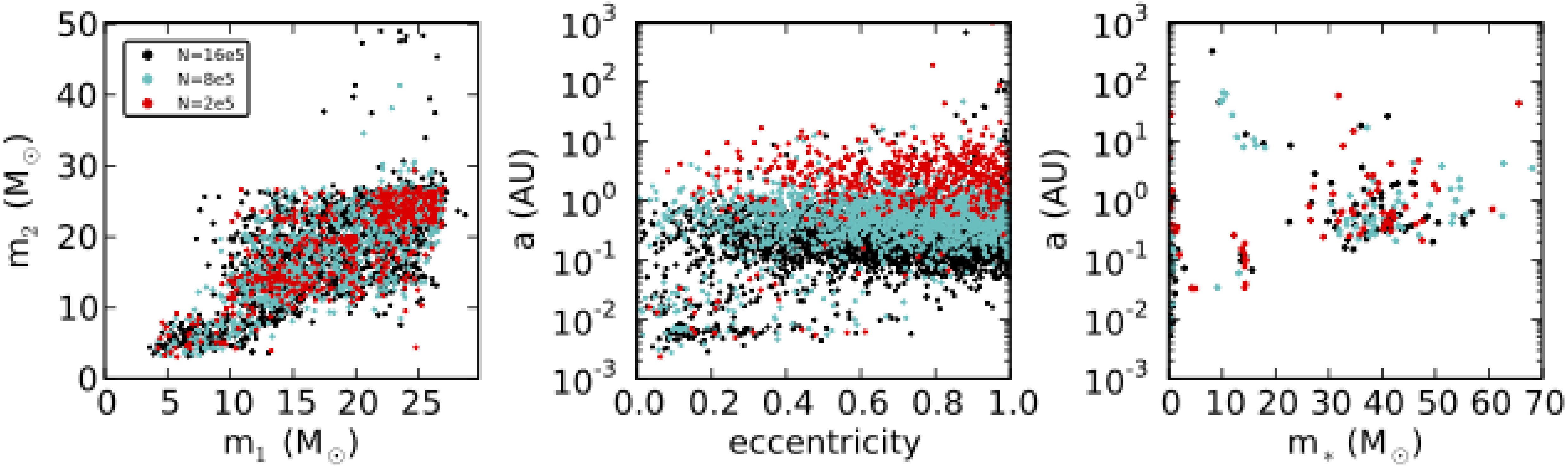
- There have been many studies of black hole binary production in globular clusters.
- Expected aLIGO sources.
- Downing + 2011 found that the more massive BH ejected binaries could be detected by LISA at Mpc distances.
- Confirmed with a parameter study.

- Low metallicity leads to larger chirp masses
- Higher chirp mass gives larger search volume

Downing + 11



- Recent work shows black hole binaries are produced (and ejected) over a longer timescale.



Morscher + 15

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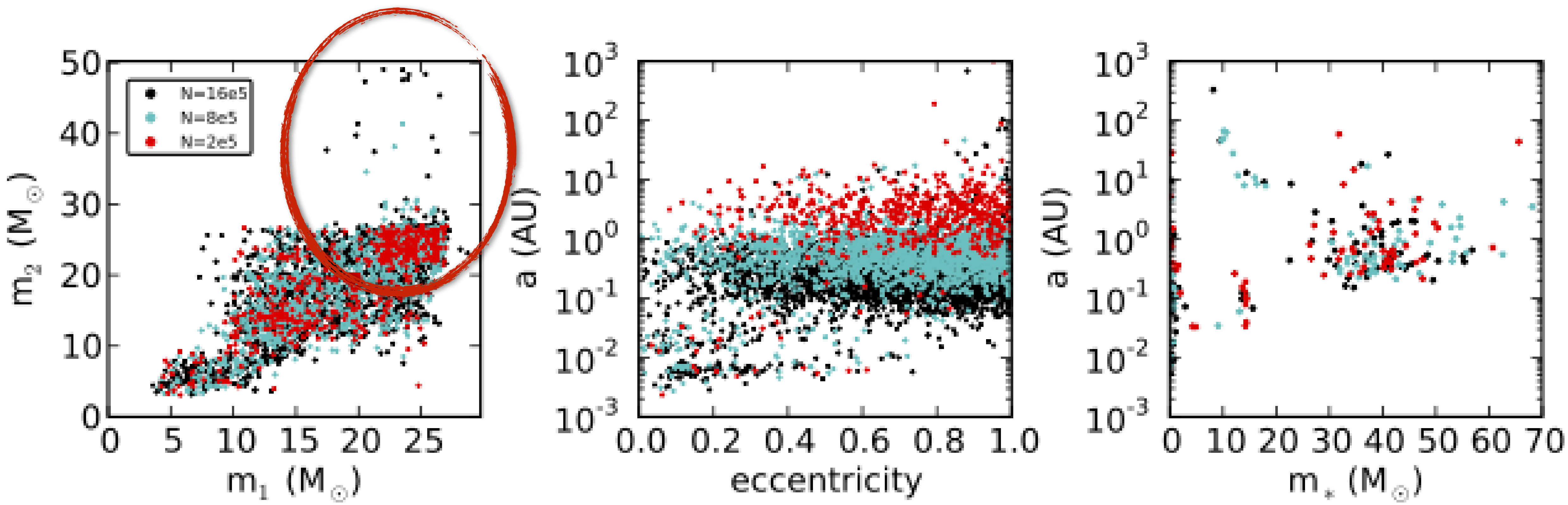
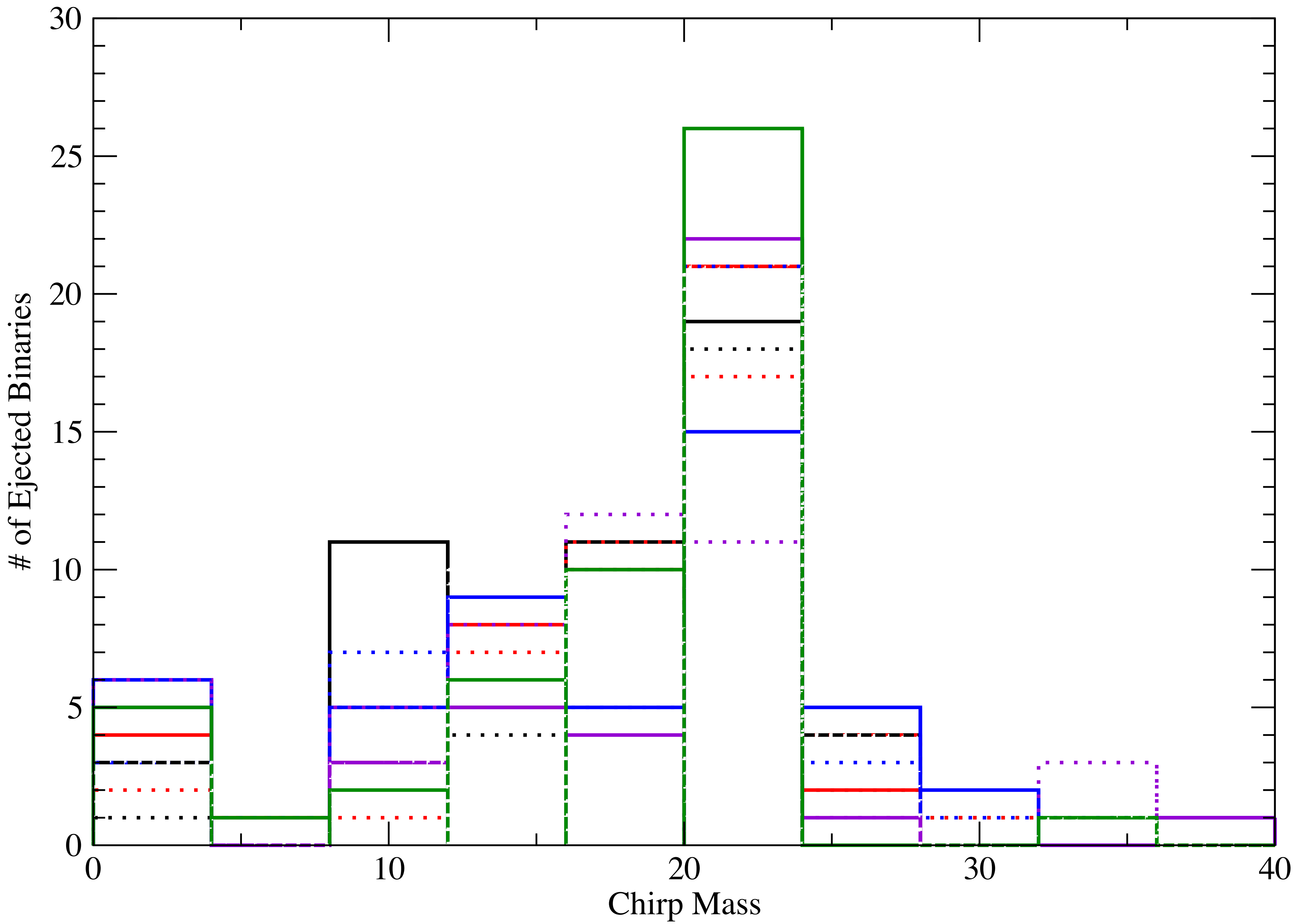
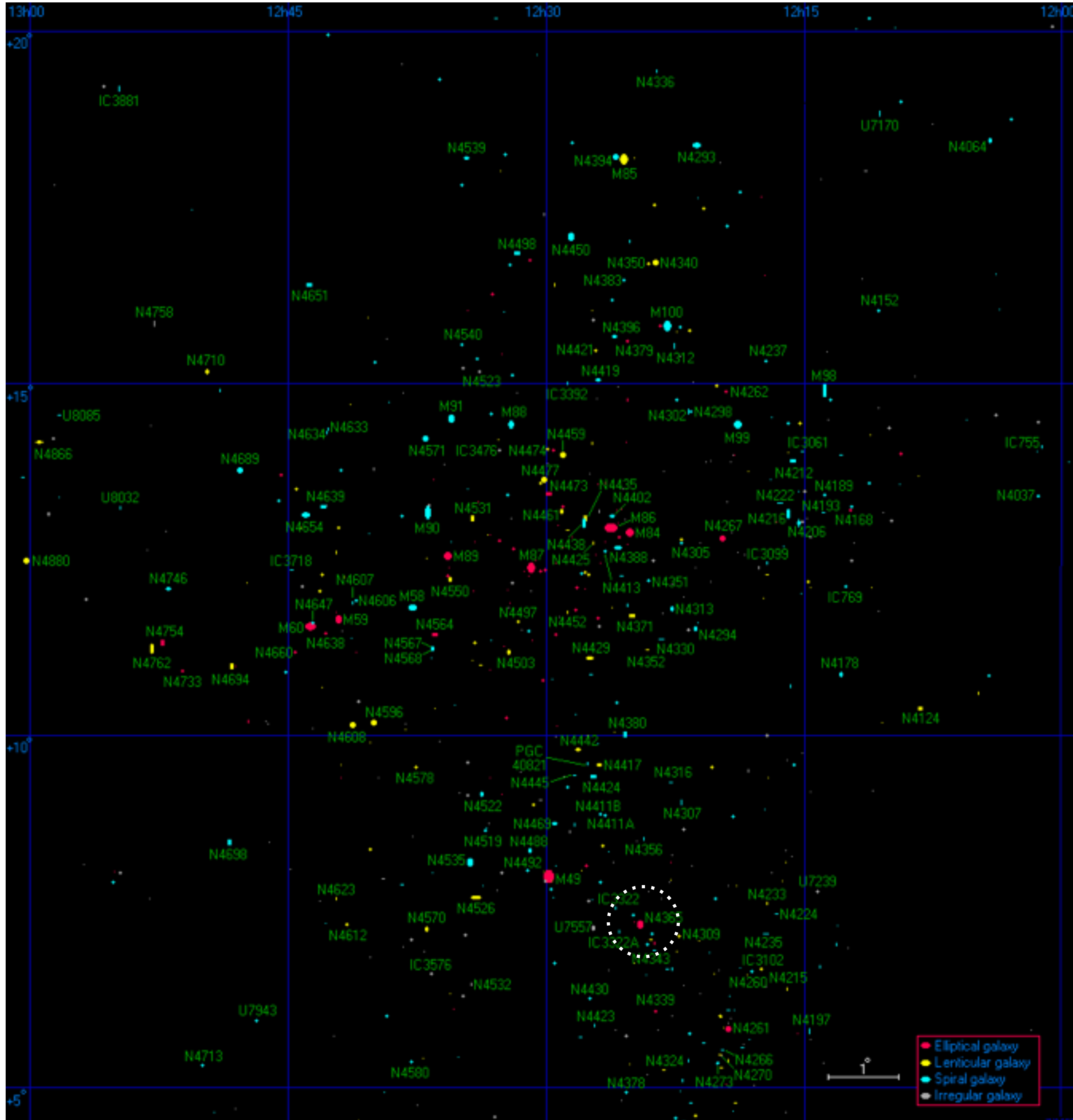


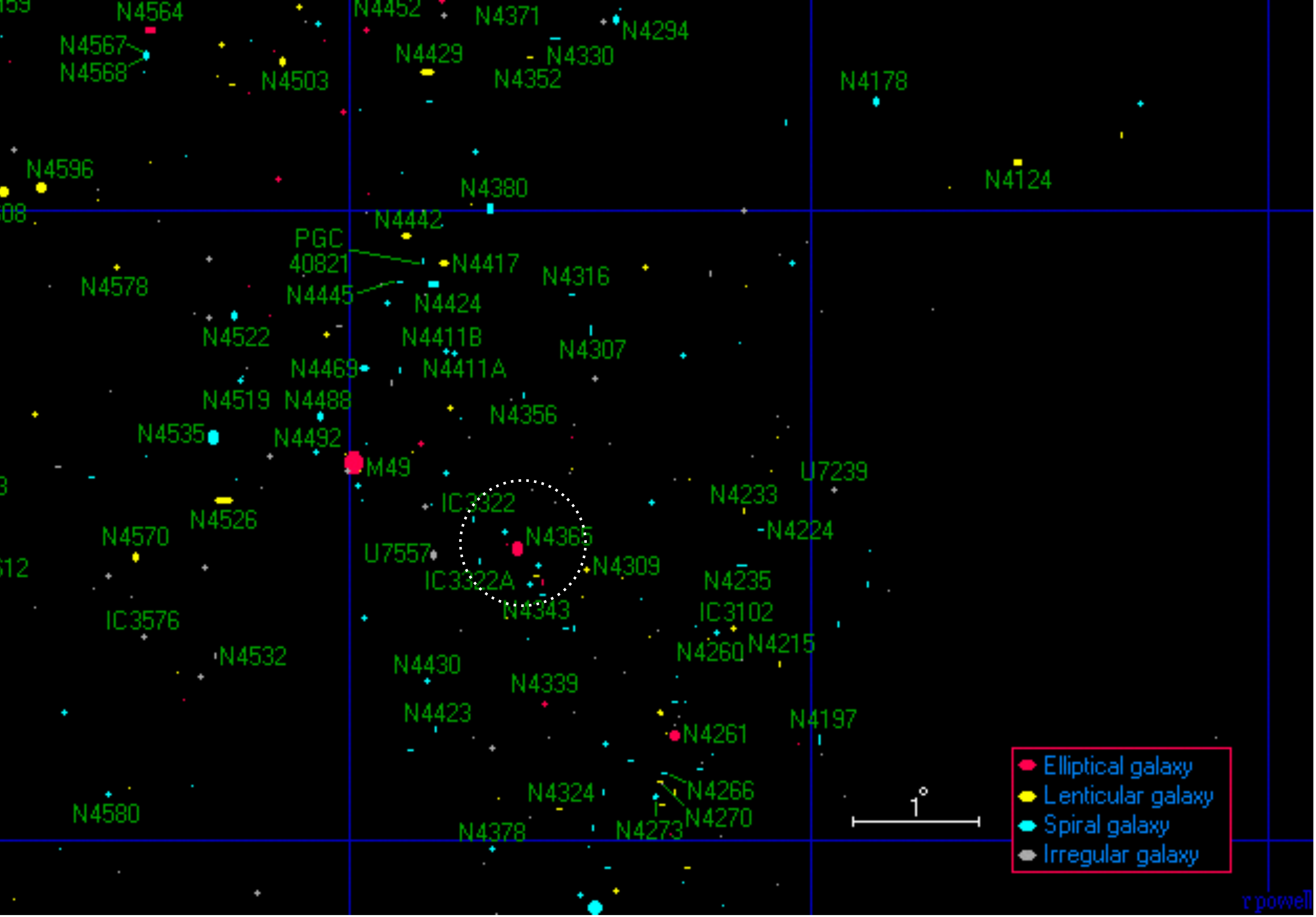
Morscher + 15

Monte Carlo Models–Work in Progress
(Dongming Jin)



eLISA error box superimposed on a chart of the Virgo cluster, centered on NGC 4365 for a typical BBH signal.





N4564
N4452
N4371
N4294
N4567
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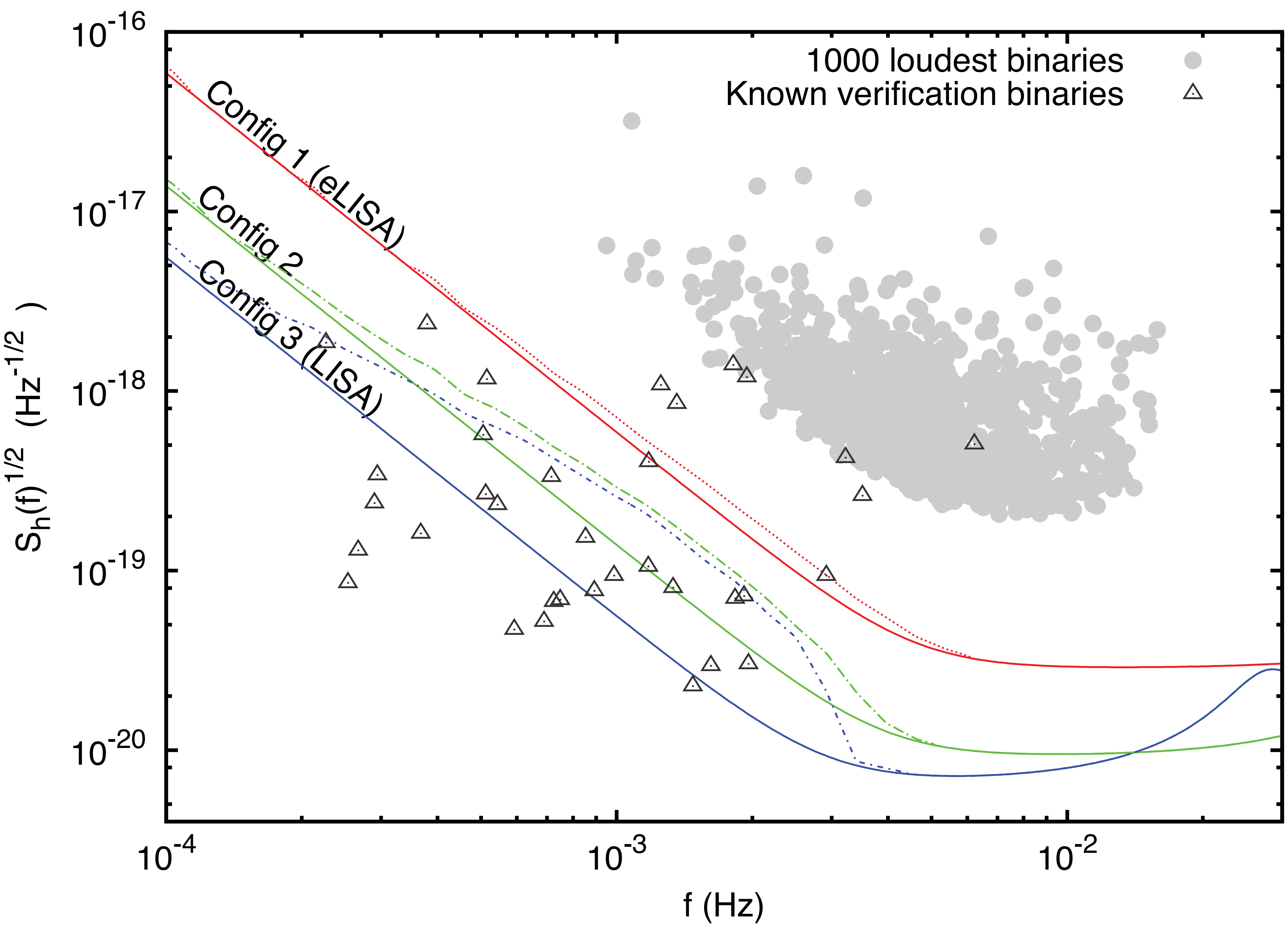
N4429
N4330
N4503
N4352
N4178
N4596
N4380
N4124
N4442
PGC
40821
N4417
N4578
N4316
N4445
N4424
N4522
N4411B
N4307
N4469
N4411A
N4519
N4488
N4356
N4535
N4492
M49
U7239
IC3322
N4233
N4526
N4224
N4365
N4570
U7557
N4309
IC3322A
N4235
N4343
IC3102
IC3576
N4215
N4260
N4532
N4430
N4339
N4423
N4197
N4261
N4266
N4324
N4580
N4270
N4378
N4273
1°
Elliptical galaxy
Lenticular galaxy
Spiral galaxy
Irregular galaxy
r.powell

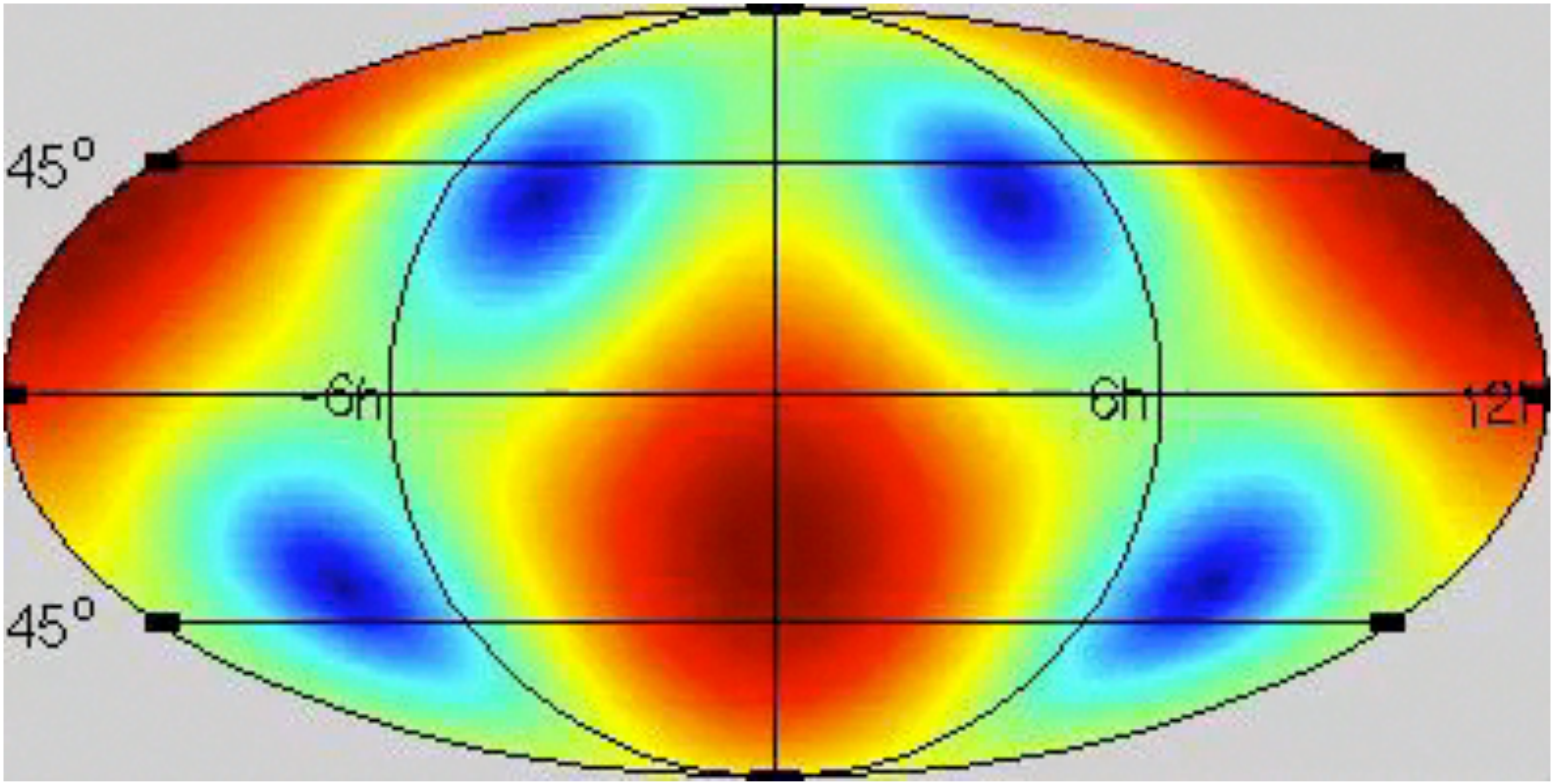
Fig. 7.— A three color (gri) Suprime-Cam image of NGC 4365, with its globular cluster (GC) candidates marked by small circles. This image is a zoom-in at $\sim 18' \times 17'$ ($\sim 120 \times 110$ kpc) of the original, which is three times the area. An *HST*/Advanced Camera for Surveys image mosaic was also used to select GCs out to $\sim 4'$ from the galactic center. Blom et al. (2012a) determined that NGC 4365 has 6450± 110 GCs and that its GC system extends beyond 9.5 galaxy effective radii.

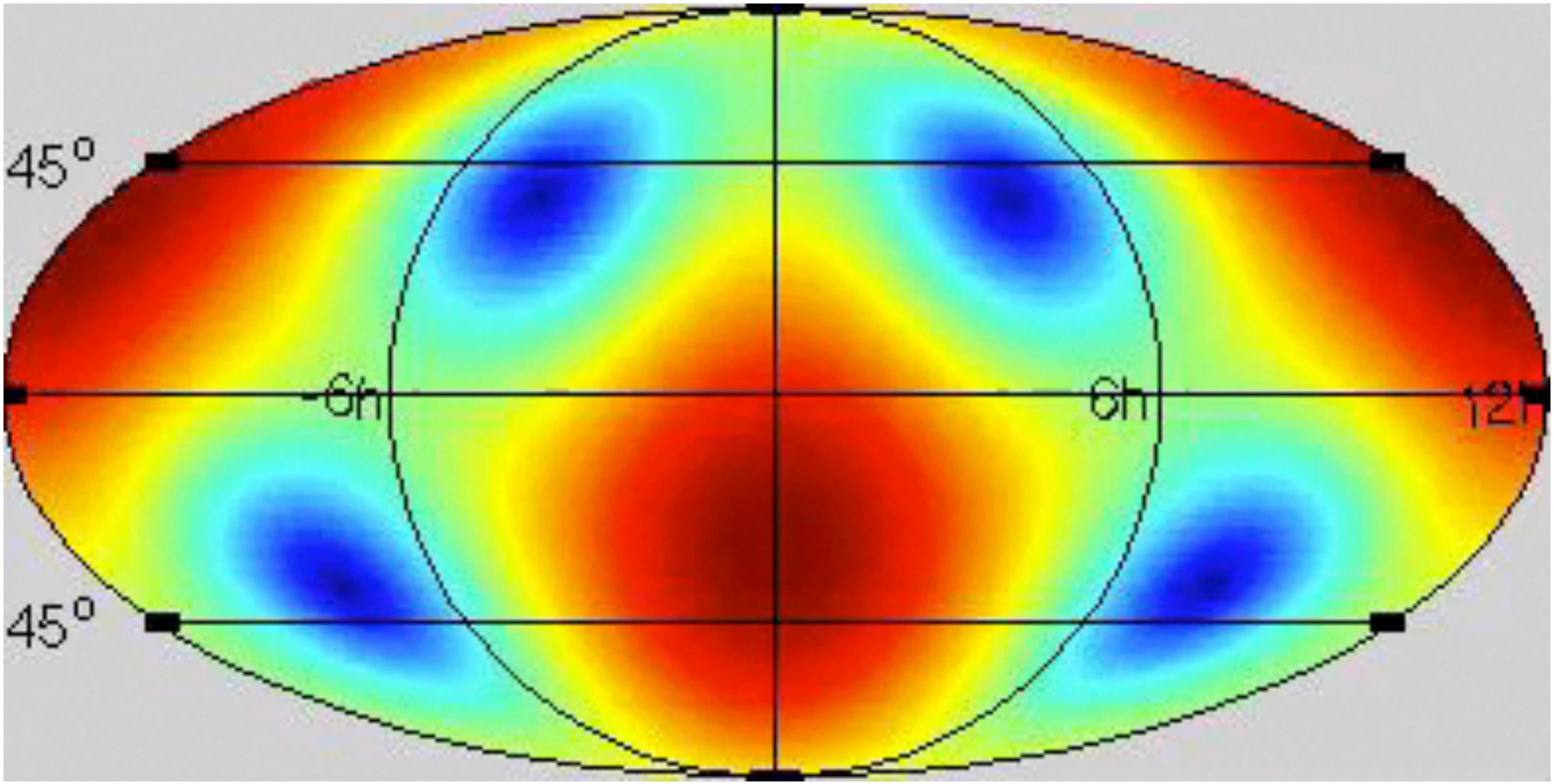
Brodie + 14

At the low frequency end, the Galactic population of compact object binaries will provide a confusion-limited noise above instrument noise

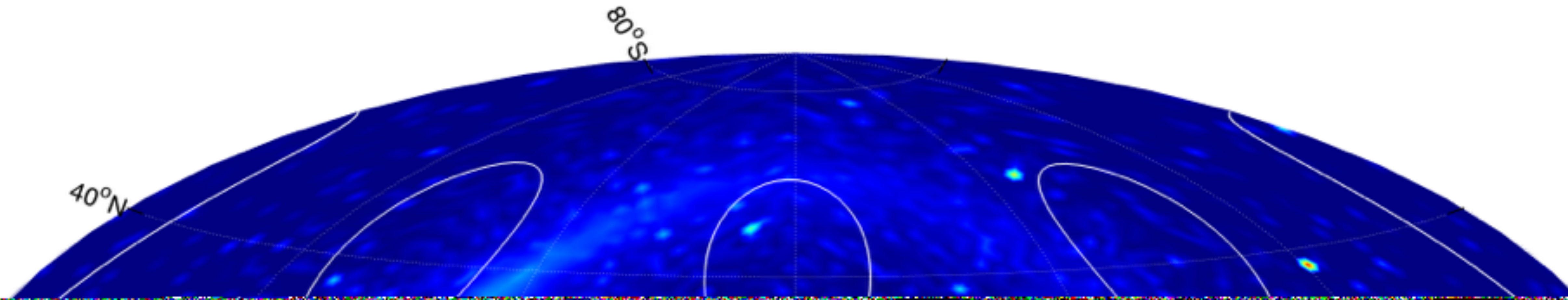


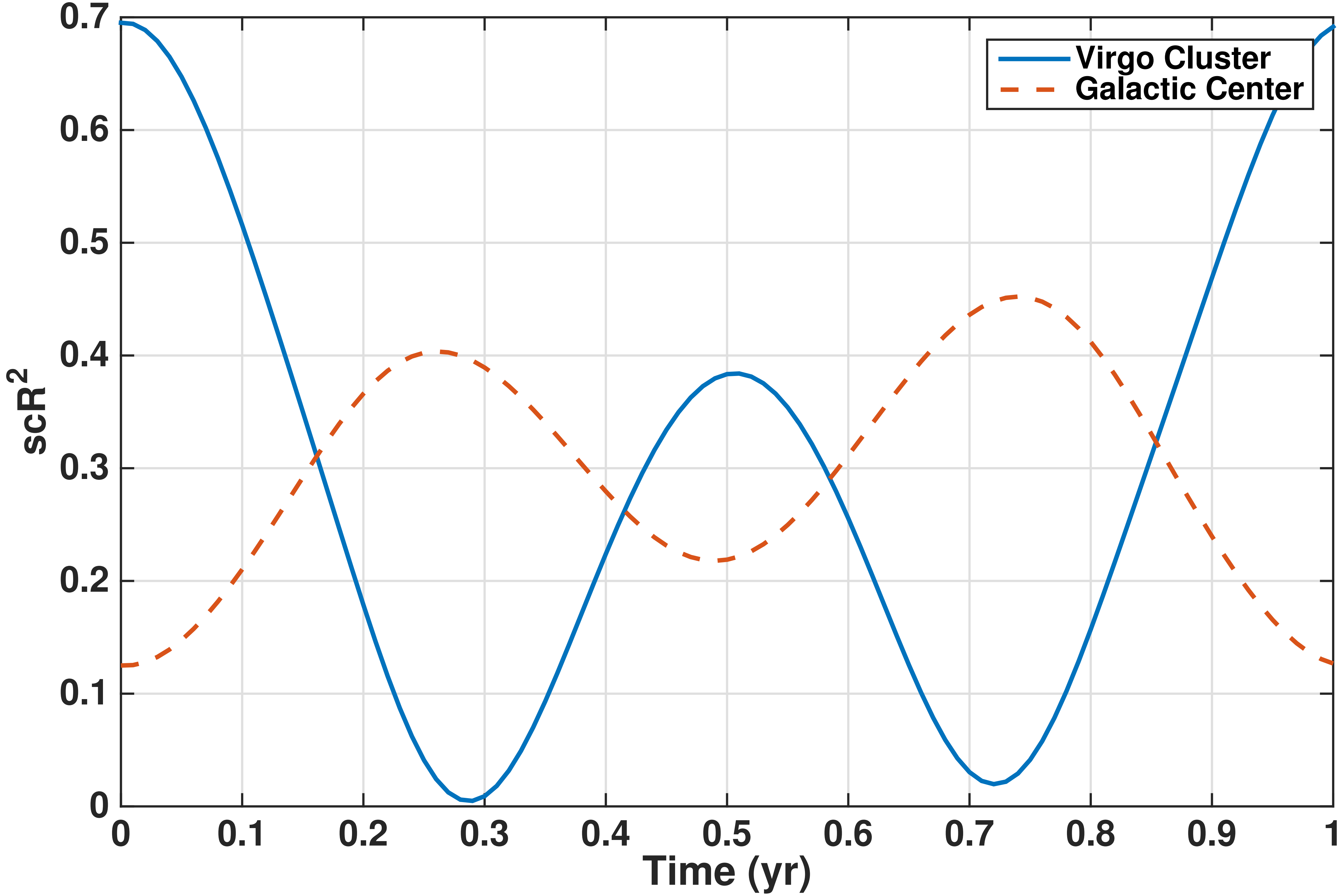
Littenberg + 13


45°
-6h
6h
12h
45°


45°
-6h
6h
12h
45°

Choose the orientation of eLISA to reduce the foreground





0.7
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0.4
0.3
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0.1
0
scR^2
0
0.1
0.2
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0.4
0.5
0.6
0.7
0.8
0.9
1
Time (yr)
Virgo Cluster
Galactic Center

Science Payoff

- Possibly identify host galaxies (not host globular clusters)
- Identify possible globular cluster properties that enhance binary production
- Identify mass distributions
- Get distances to individual cluster member galaxies

Thank you