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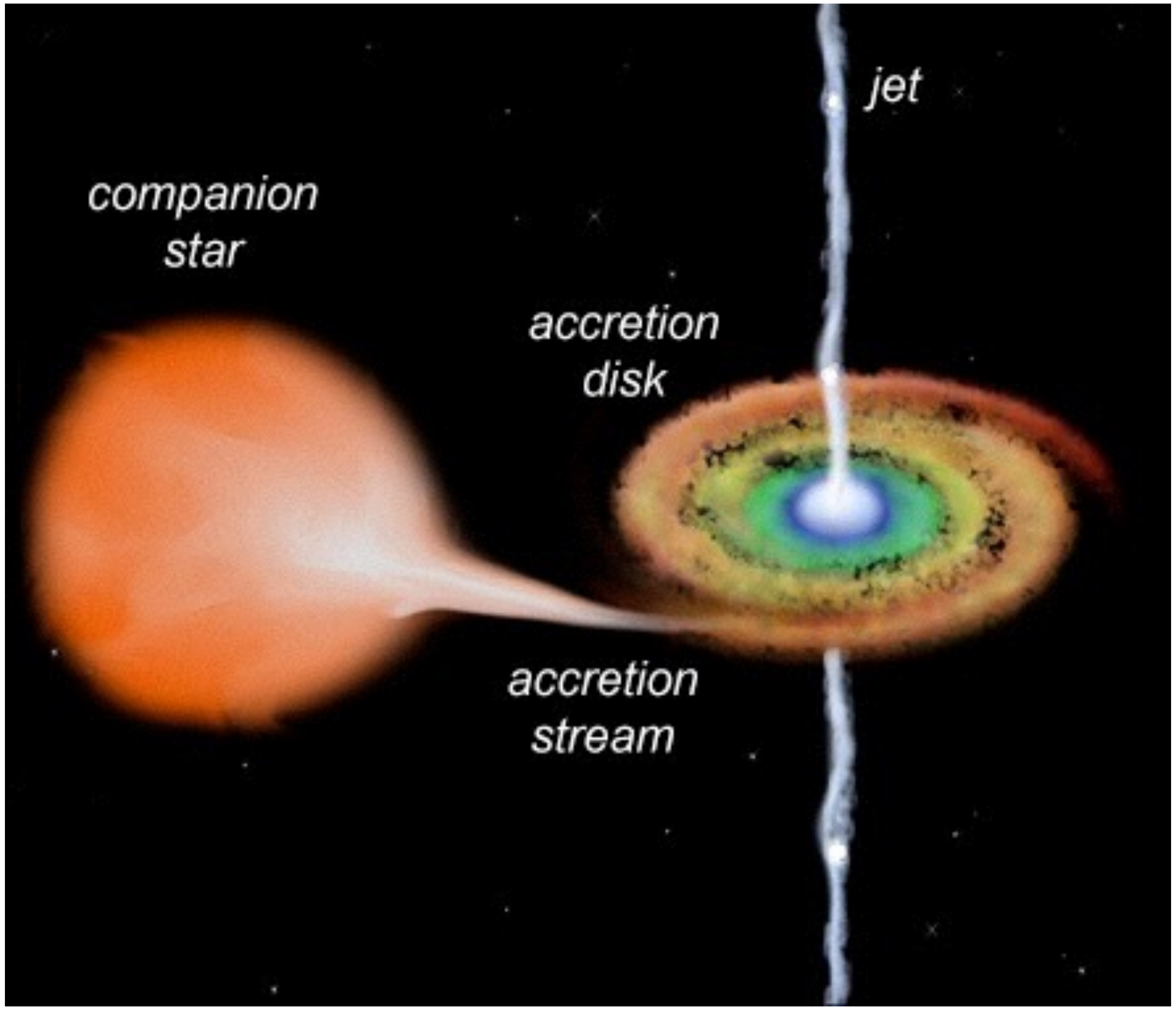
A RADIO SEARCH FOR BLACK HOLES IN THE MILKY WAY GLOBULAR CLUSTER M10

X-RAY BINARIES



(nasa/chandra/m. weiss)

BH, NS, or WD with mass transferring companion

Accretion rate controls the energetics of the binary

High accretion rates = lots of X-rays!

Low accretion rates = quiescence, more radio bright

Most LMXBs are in quiescence

GLOBULAR CLUSTERS

Dense clusters of ~10^5–10^6 old stars

Galactic GCs ~ 10 Gyr

LMXBs ~100 times more common due to frequent stellar encounters

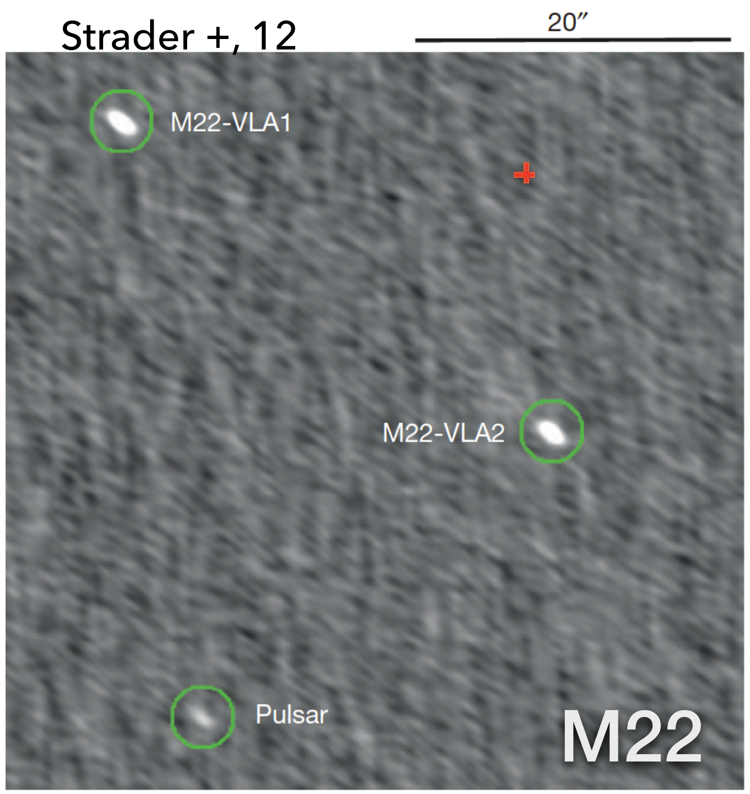
(apod/j.c. cuillandre)

None of these LMXBs contained a stellar-mass BH, despite high LMXB frequency, 100–1000 BHs originally in cluster

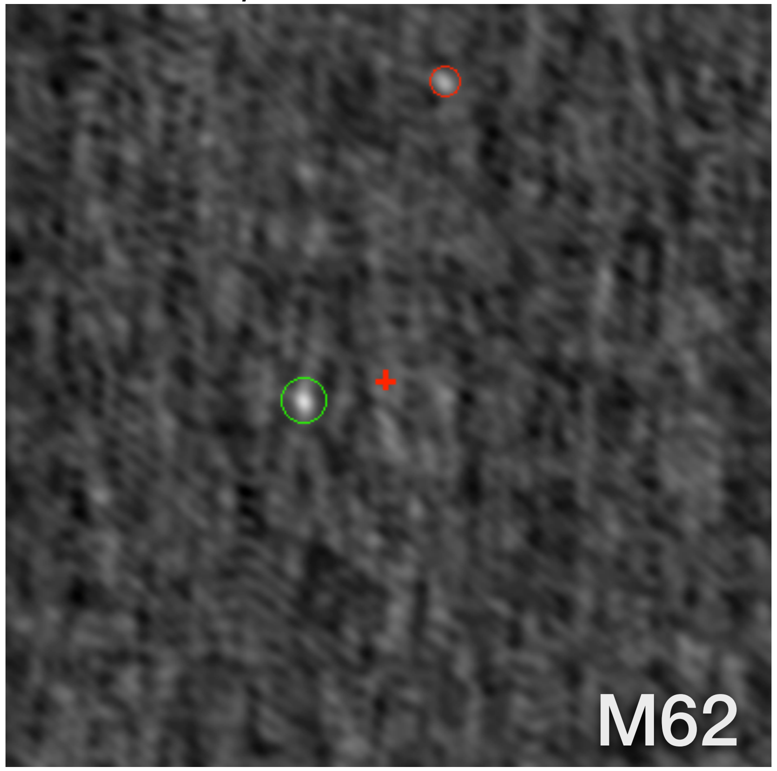
Only ~ 1 in 100 GCs expected to still have a BH at 10 Gyr

BLACK HOLES IN GLOBULAR CLUSTERS?

Strader +, 12



Chomiuk +, 13



In 2012 VLA survey of 5 Milky Way GCs, 3 BH candidates discovered

Other promising candidates had also been found in extragalactic GCs (not by us)

Revisited by theorists, recent simulations show GCs can retain many BHs at 10 Gyr

WHO CARES?

<u>Finding more black holes would be easier!</u>

Only 20 – 30 confirmed black holes —— now we would know right where to look, and how to look

The currently known BHs are all in the field, with large uncertainties in distance, but GCs have accurate distance measurements

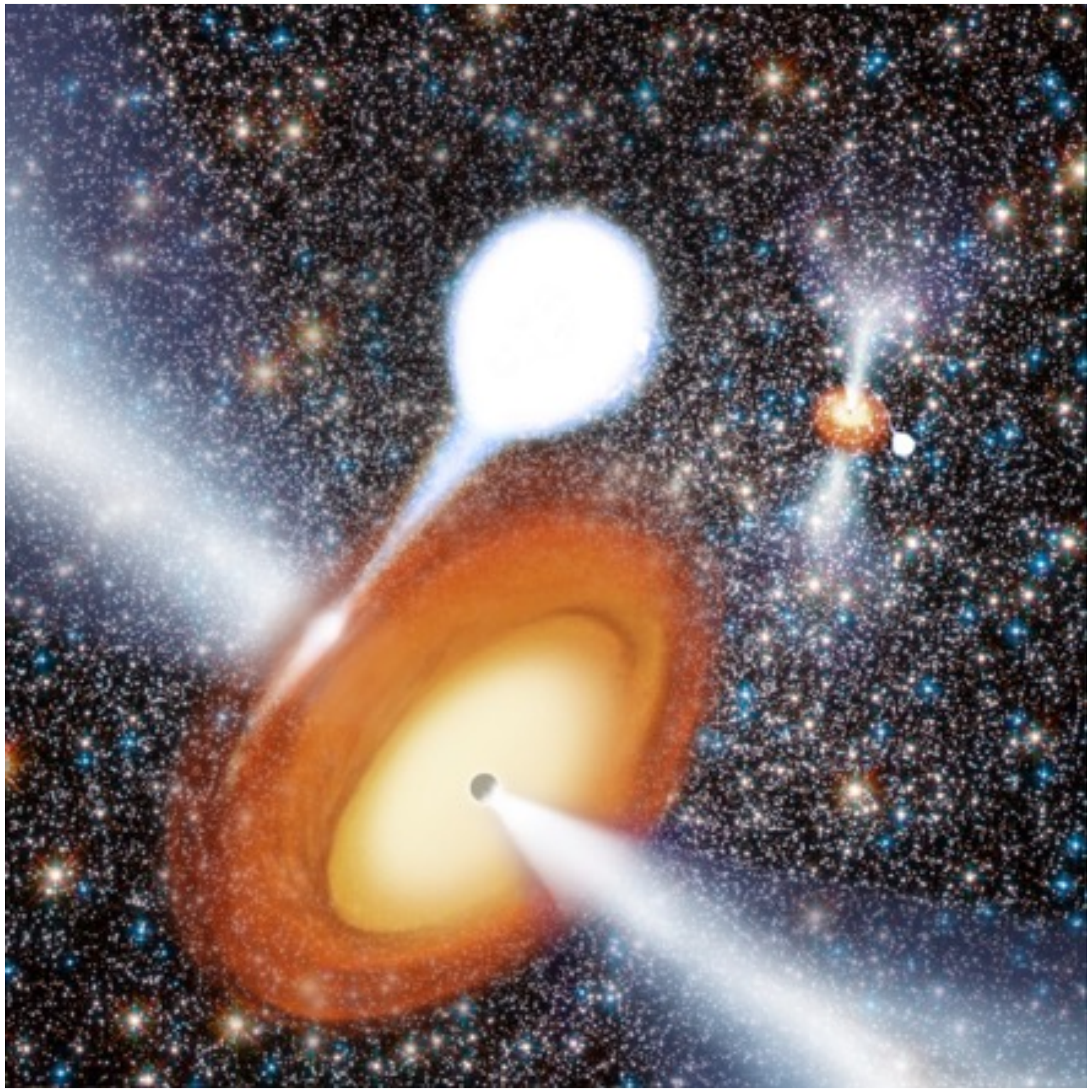
More accurate study of BH LMXBs!

WHO CARES?

Study of low luminosity accretion physics

Known BHs all discovered in X-ray outburst or from the bright X-rays produced during rapid accretion

Most cluster BHs expected to be in quiescence —– new sample for low luminosity accretion study



WHO CARES?

Caltech

<u>GCs are favorable environment for the formation of BH-BH and BH-NS binaries</u>

Possible sources of gravitational waves for detections by aLIGO

Massive BH-BH binaries formed dynamically? If so, GCs could be even more likely source of gravitational waves

CLUSTER SURVEY

BHs have always been found via very luminous X-ray emission — but this is rare. Most BHs are in quiescence

Quiescent BHs emit in the radio because of synchrotron jets, which are brighter than X-ray emission at low accretion rates

New method — Do radio search to detect the large BH population in quiescence!

50 total close and massive clusters with VLA and ATCA

Goal to establish statistics on the frequency of BHs in GCs

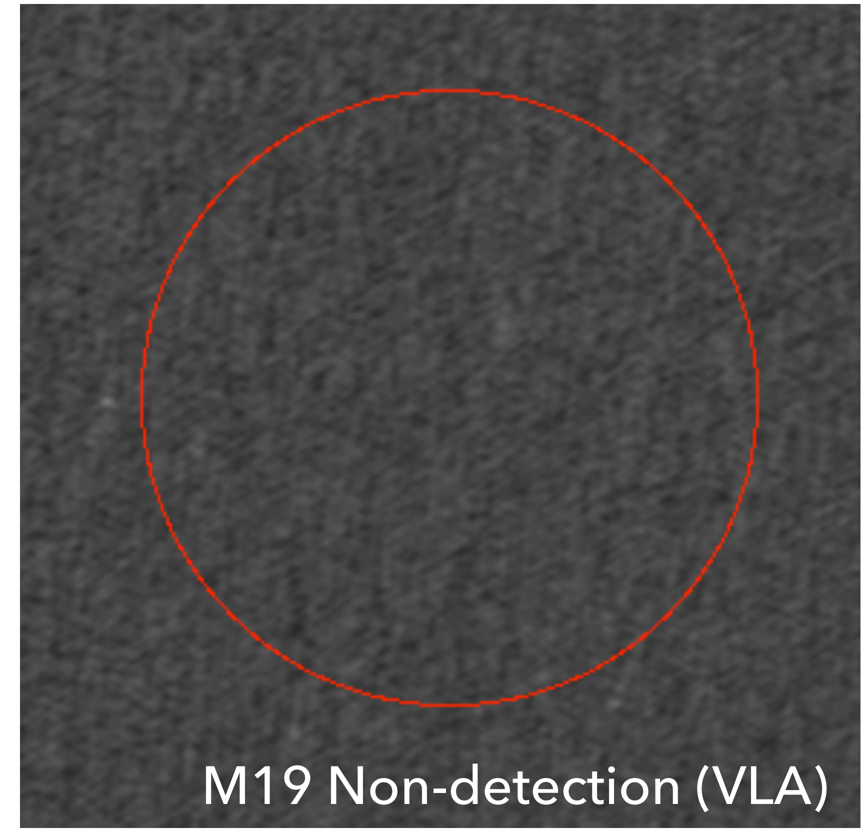
FINDING BLACK HOLES

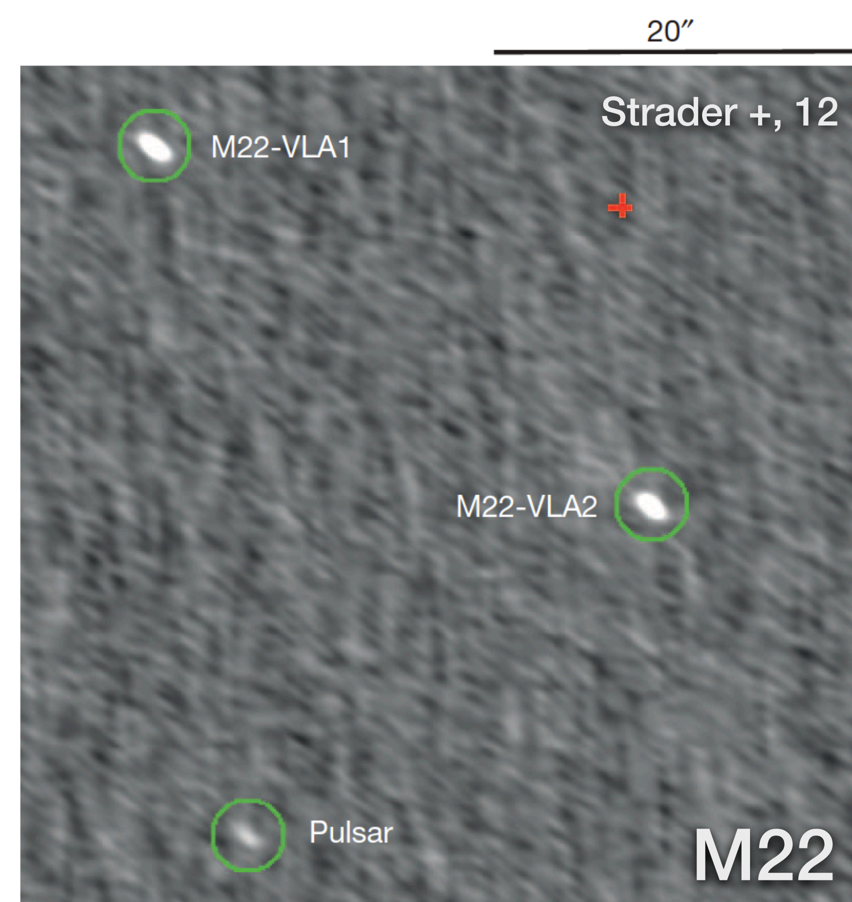
Image cluster cores looking for unresolved significant radio sources

Changes in flux density (S) are related to changes in frequency (ν) by the spectral index (α).

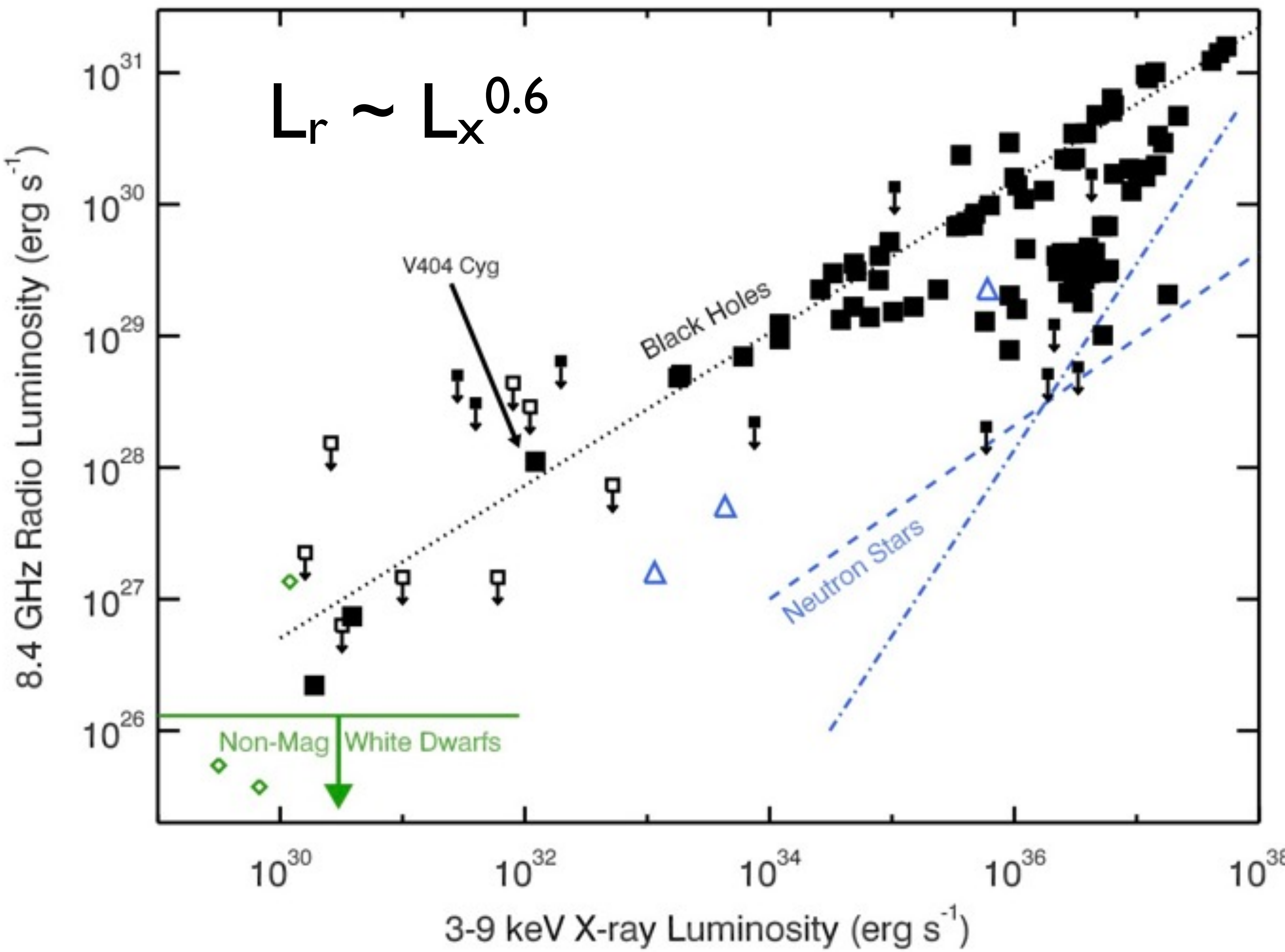
$$S \propto \nu^{\alpha}$$

Candidates should have $\alpha = 0$ (or close to it)





FINDING BLACK HOLES



Gallo +, 06

Migliari & Fender, 06

Kording +, 08,11

Get X-ray data for the candidate (ideally simultaneous) to rule out neutron star or accreting white dwarf

FINDING BLACK HOLES

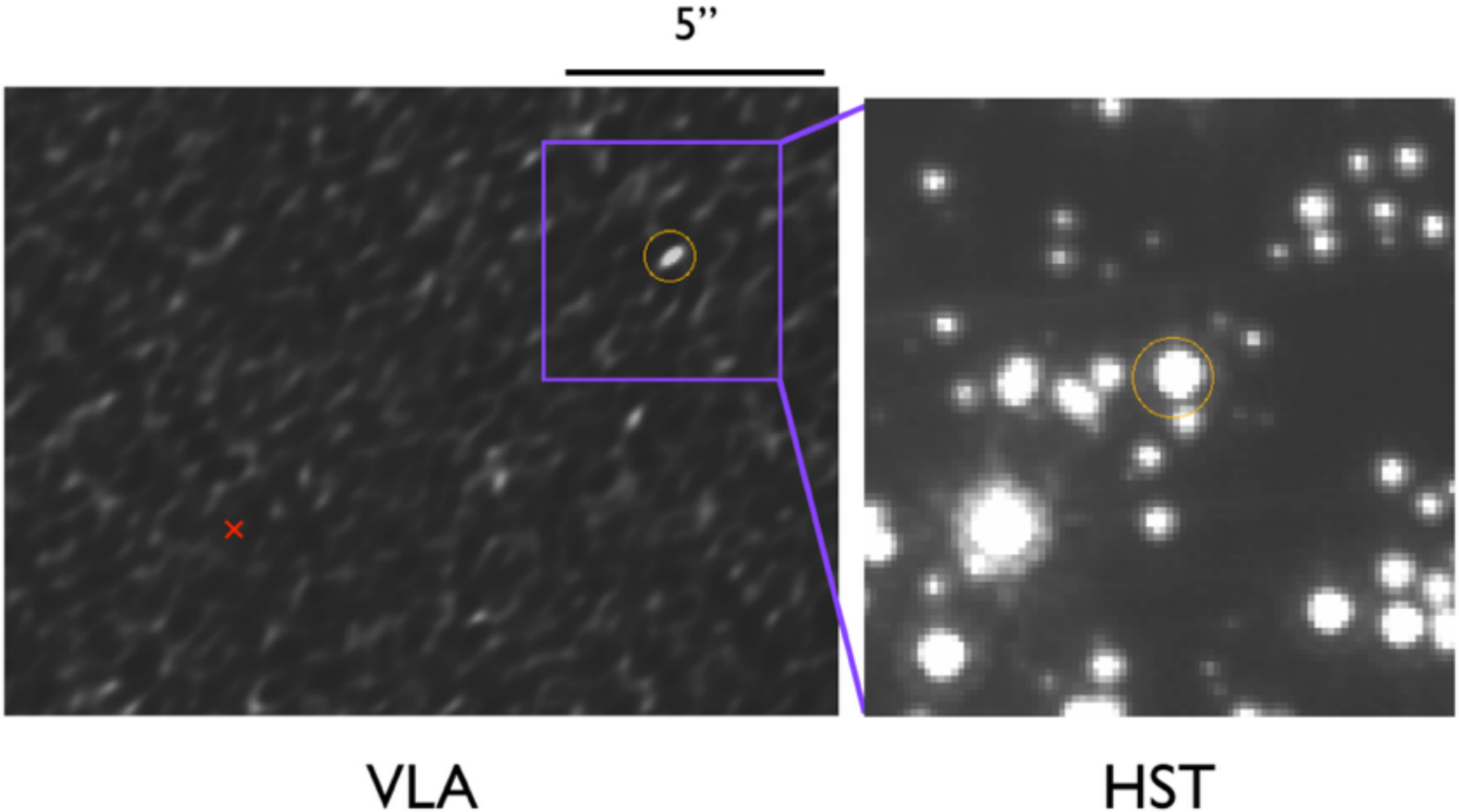
What we really need is a mass limit for the candidate! Mass limits of compact objects more established than fundamental plane

Use optical spectroscopy of binary companion to find its period and semi-amplitude of radial velocity curve

$$f(M) = \frac{P_{\rm orb}}{2\pi G}(K_2)^3 = \frac{M_1 \sin^3 i}{(M_1 + M_2)^2}$$

But… mass limits depend on the binary inclination, which is unknown (we will deal with this later)

M10 RADIO



Observed in five 2hr epochs in early 2014, candidate detected 10" from cluster center (r_c = 46")

Only detected in first epoch! Another variable source

M10 RADIO

In epoch of detection, flux is

18 +/- 5 μJy (5 GHz)

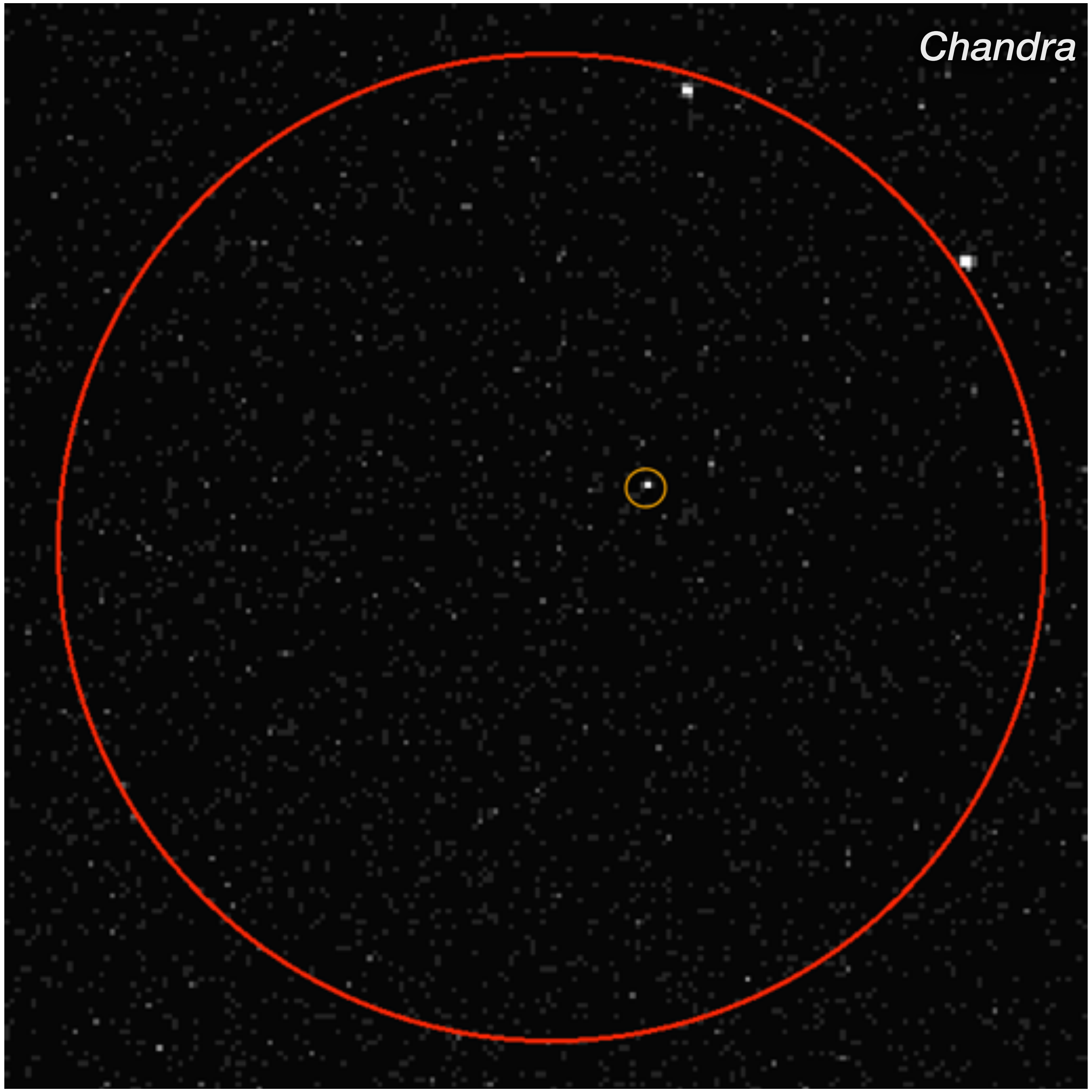
26 +/- 4 μJy (7.4 GHz)

Spectral index $\alpha = 1.3$ +/- 1.0

Flux does NOT vary during the two-hour observation

No flares during other epochs

M10 IN X-RAY

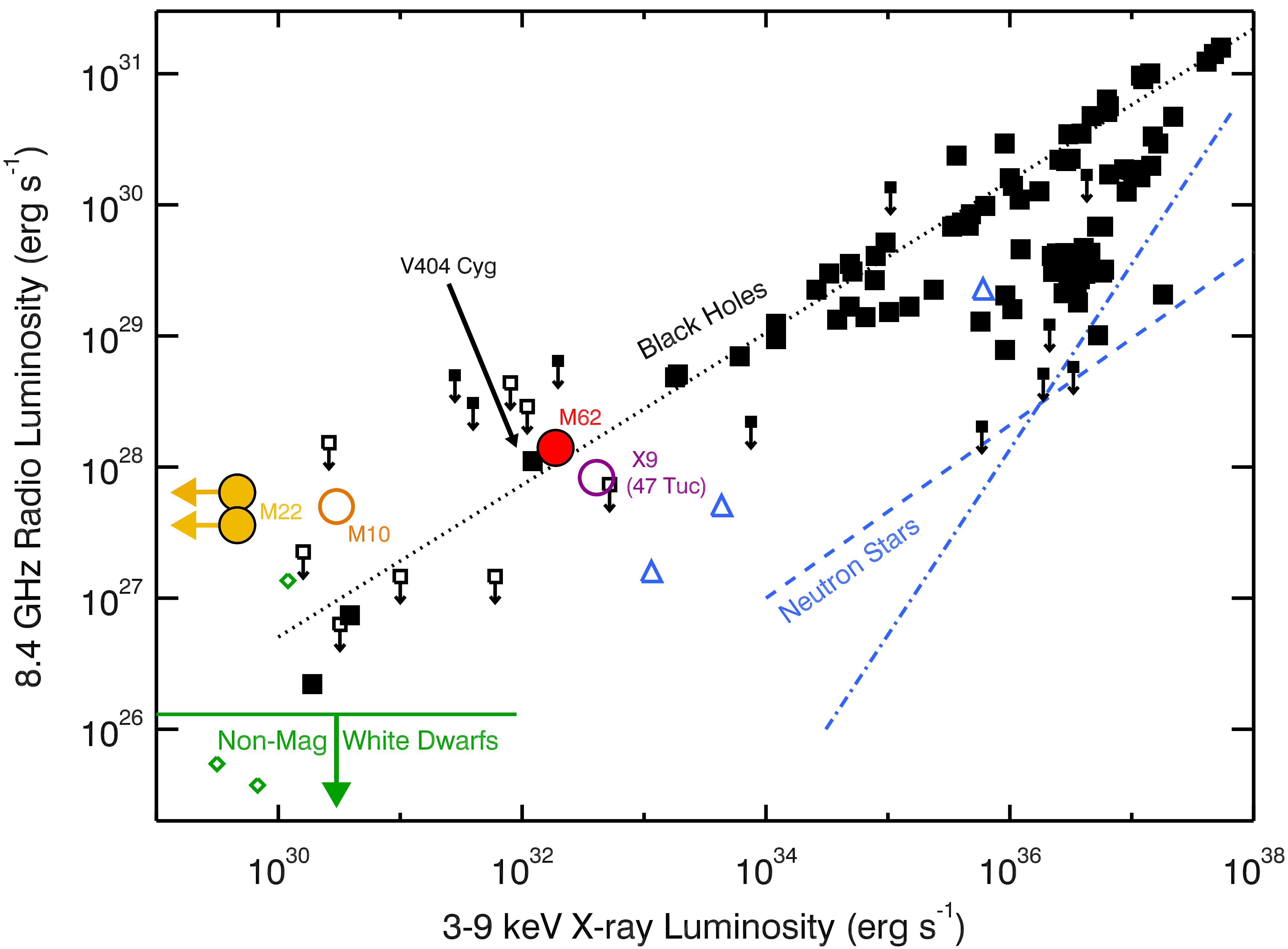


Got 33 ks Chandra observation with source detection

Only ten net counts over background

Unabsorbed $L_X = 5 \times 10^{32}$ erg/s

M10 RADIO & X-RAY CORRELATION



NOT SIMULTANEOUS

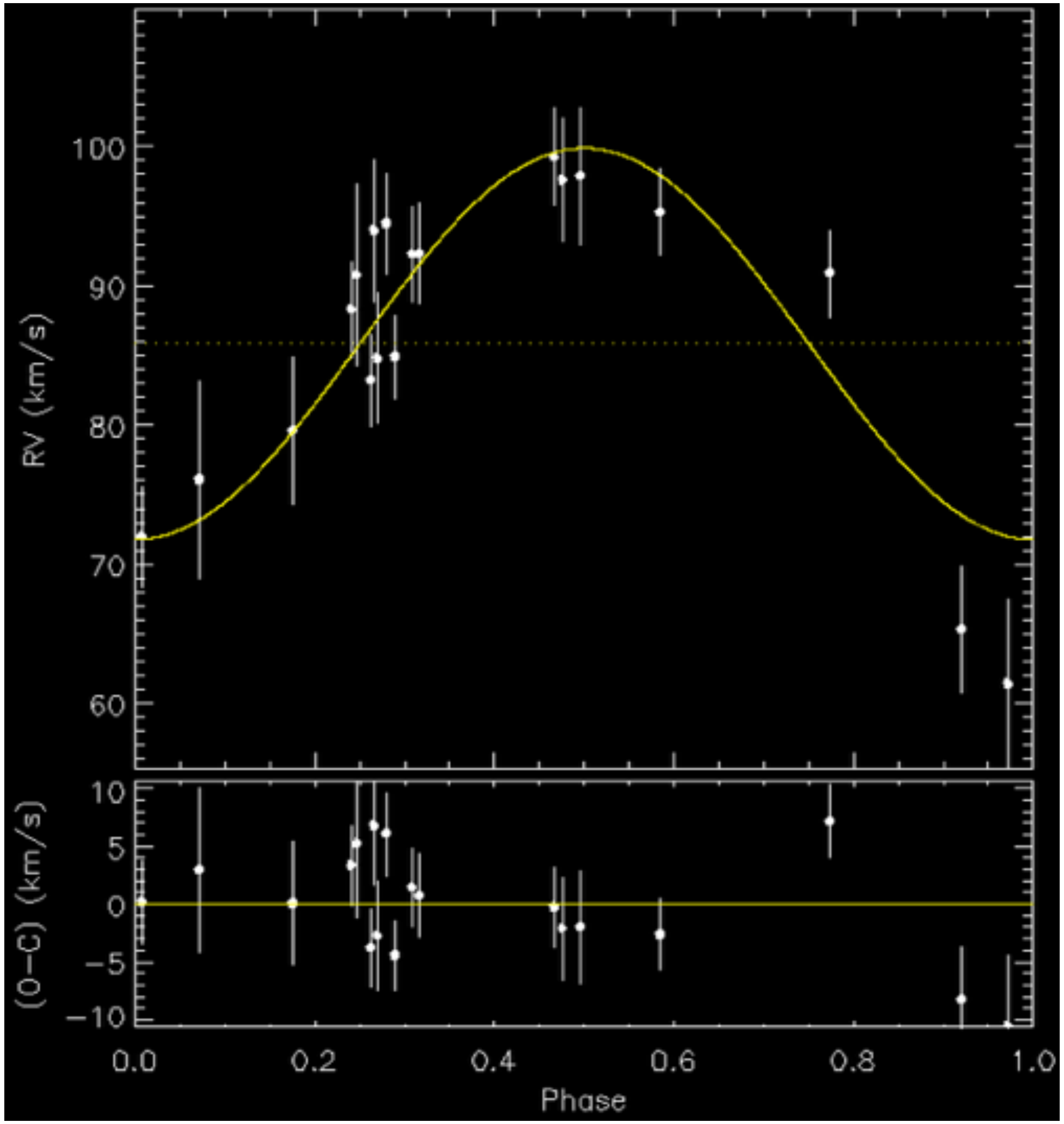
M10 OPTICAL SPECTROSCOPY WITH SOAR

H-alpha emission, sometimes double peaked - accretion!

Fit to RV curve of companion gives P = 3.3380 +/- 0.0012 days

Semi-amplitude K_2 = 14.1 +/- 1.6 km/s

With these parameters we can see what inclination gives M consistent with BH



M10 OPTICAL SPECTROSCOPY WITH SOAR

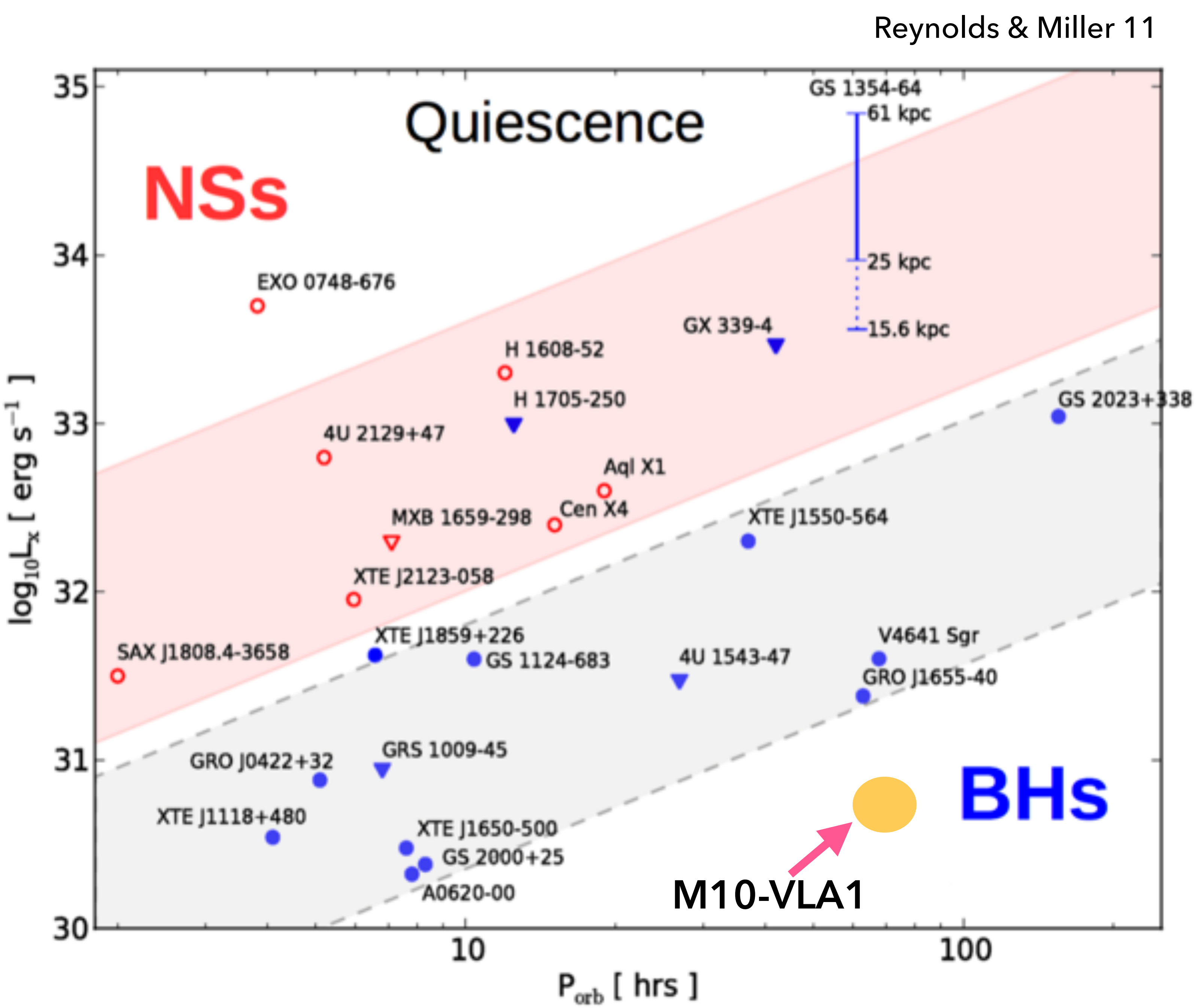
Binary must be almost face on to have mass consistent with BH, i less than 6 degrees

Even to have white dwarf primary, i must be less than 12 degrees

Doesn't look good for BH scenario, but if you buy that it must be a compact object, a BH is much more likely

Need a good photometric light curve to try to detect ellipsoidal variations, this will constrain i

M10 PERIOD-LUMINOSITY RELATION



For same orbital period BHs have lower X-ray luminosity (event horizon?)

WDs not here, but very short period systems

WDs also could be more massive in GCs

M10 SUMMARY

Radio detected candidate, variable on long-ish timescales, flat/inverted spectrum

X-ray detected

Optical spectrum shows H-alpha, which is double peaked at some epochs

RV curve of companion make BH binary less likely (but assumptions can change this)

Really must get a good measurement for the inclination —— efforts are in progress. Preferentially finding face on BHs?

Long period and X-ray luminosity consistent with BH