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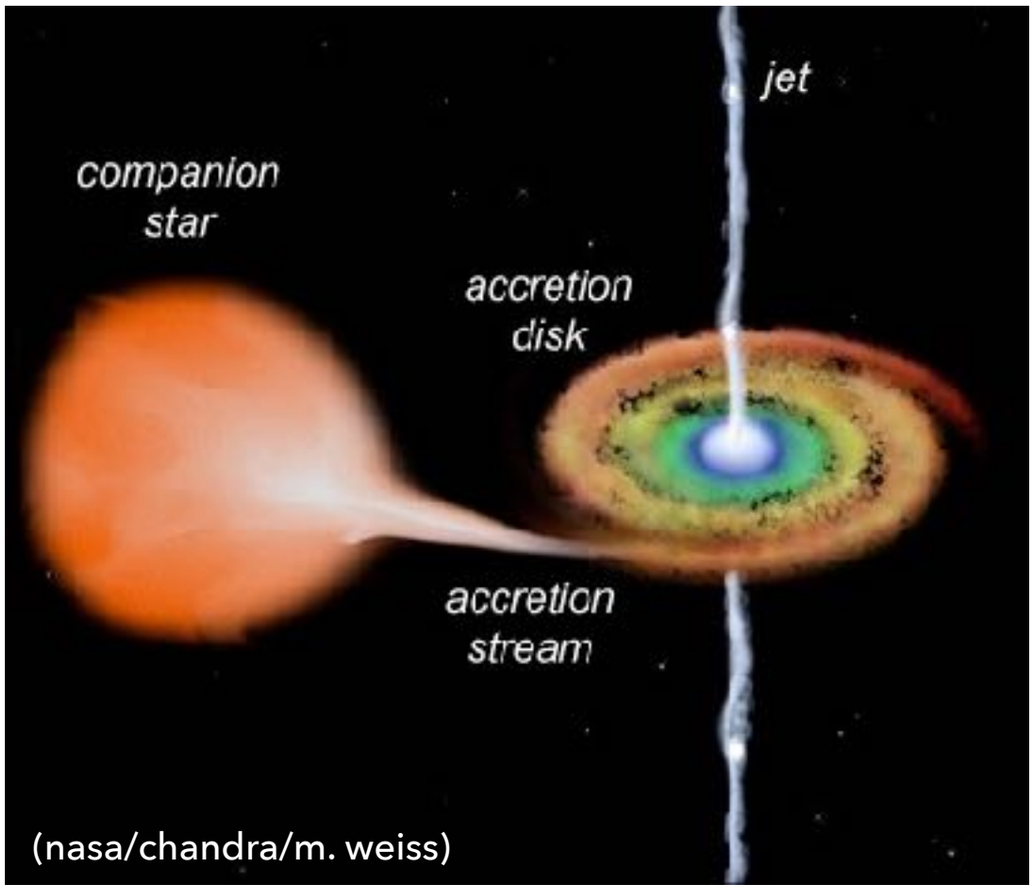
THE MAVERIC SURVEY: BLACK HOLES IN GLOBULAR CLUSTERS

COMPACT OBJECTS & GLOBULAR CLUSTERS



Dense clusters of ~10^5–10^6 stars

~ 10 Gyrs old

~20 bright NS LMXBs in GCs

— Much more common than field LMXBs (per mass)

No BHs though!

BLACK HOLES IN GLOBULAR CLUSTERS?

No GC black holes? Explained by mass segregation, and violent 3-body + 4-body interactions ejecting BHs from the clusters

More recent candidate discoveries and theoretical predictions cast doubt

LIGO discoveries of BH-BH merger events have renewed interest in the frequency of BHs in GCs

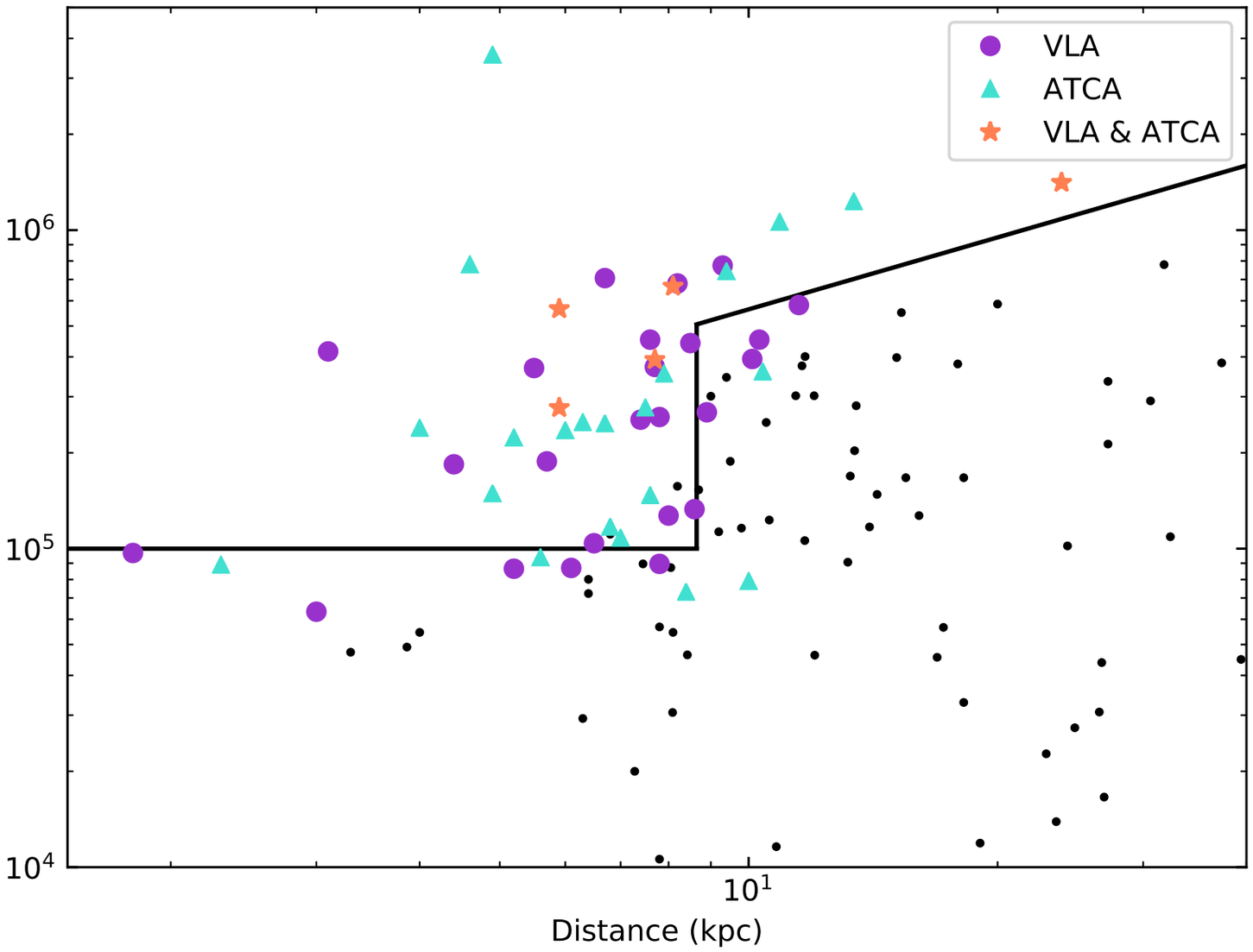
WHO CARES?

Maybe we can find more BHs!

Study low luminosity accretion physics

Massive BH–BH binaries formed dynamically? If GCs retain BHs, likely that some BH–BH systems form dynamically

CLUSTER SURVEY



VLA survey of ~31 Milky Way GCs

ATCA survey of ~26 southern Milky Way GCs

50 total (some VLA/ATCA overlap)

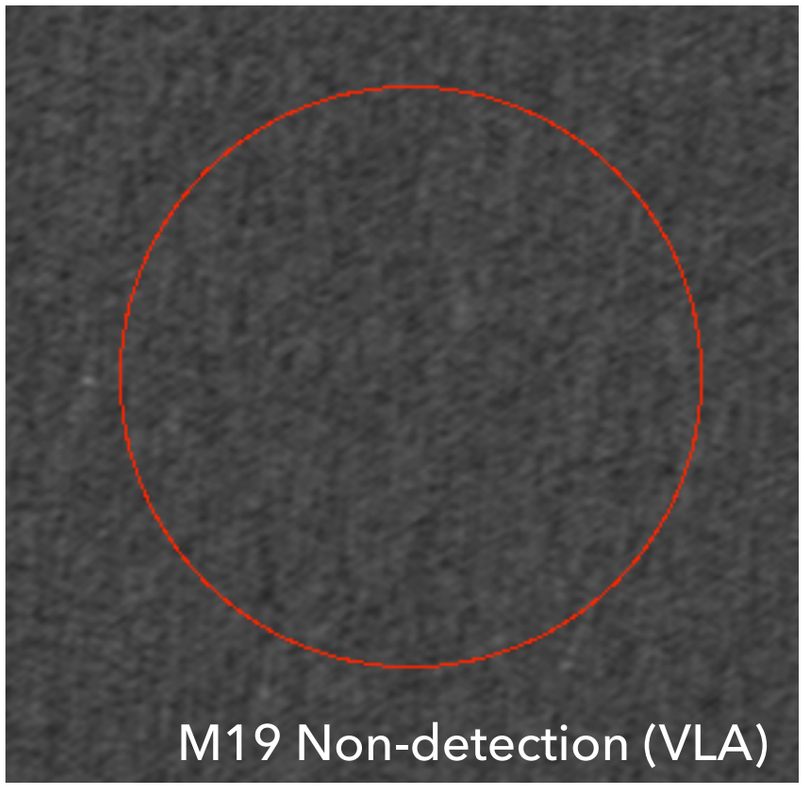
Want massive (enough)and close (enough) clusters!

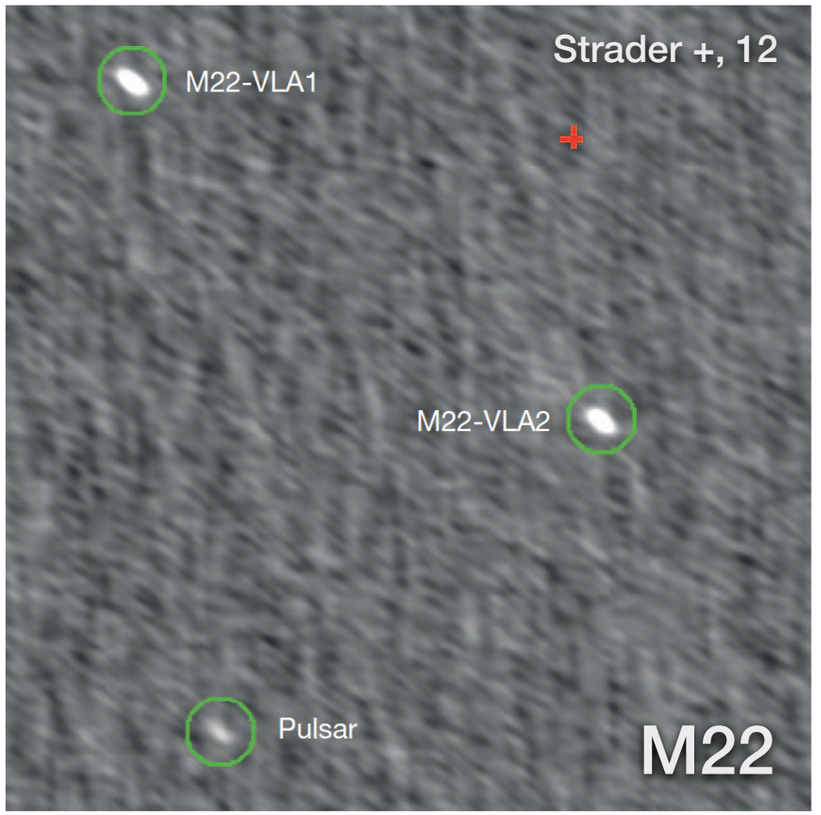
FINDING BLACK HOLES

Image cluster cores looking for unresolved significant radio sources and spectral indices

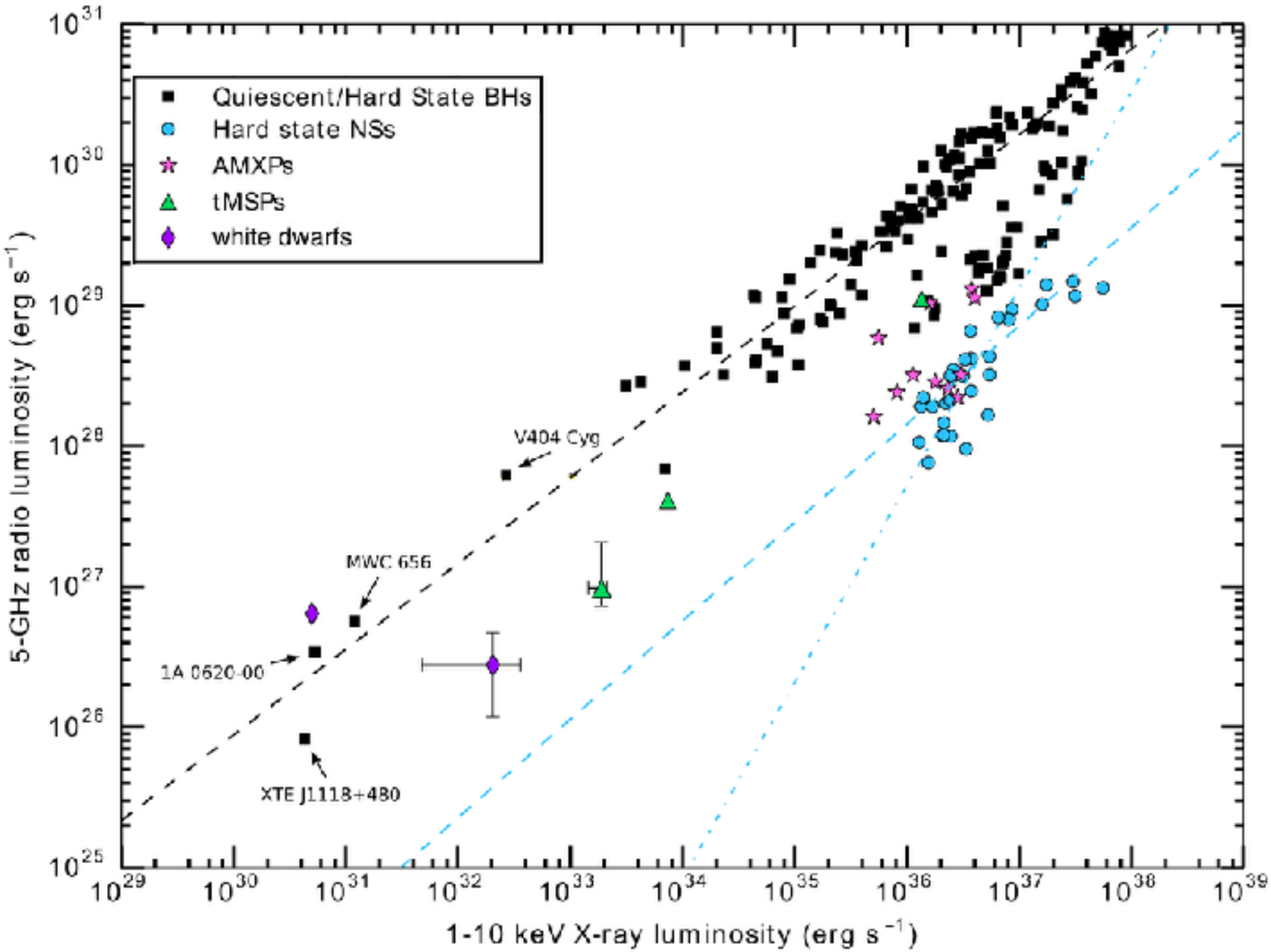
$$S \propto \nu^{\alpha}$$

Candidates should have α = 0 (or close to it) due partially self-absorbed synchrotron





FINDING BLACK HOLES



Gallo +, 06

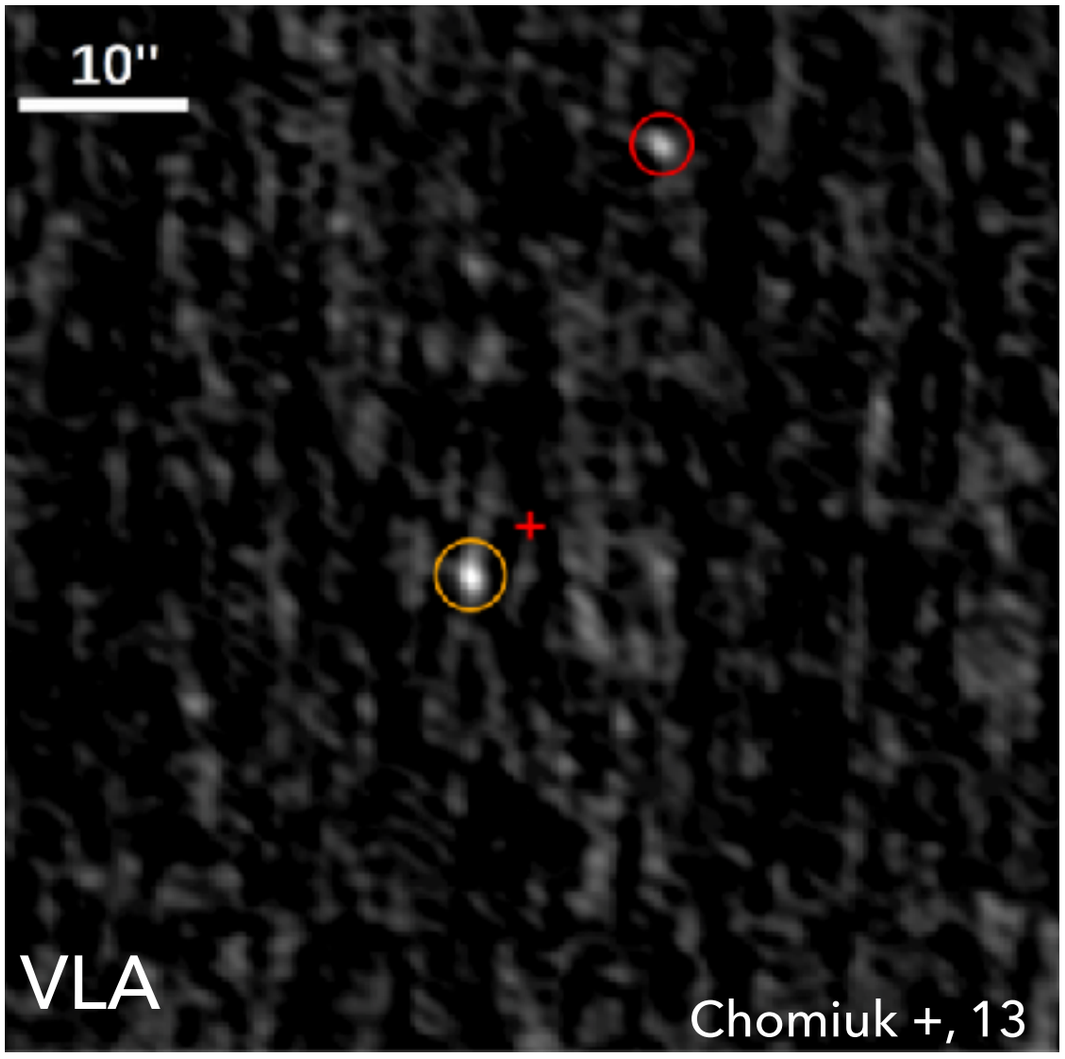
Migliari & Fender, 06

Kording +, 08,11

Tetarenko +, 16

Get X-ray data for the candidate (ideally simultaneous) to help rule out neutron star or accreting white dwarf – then get mass estimate!

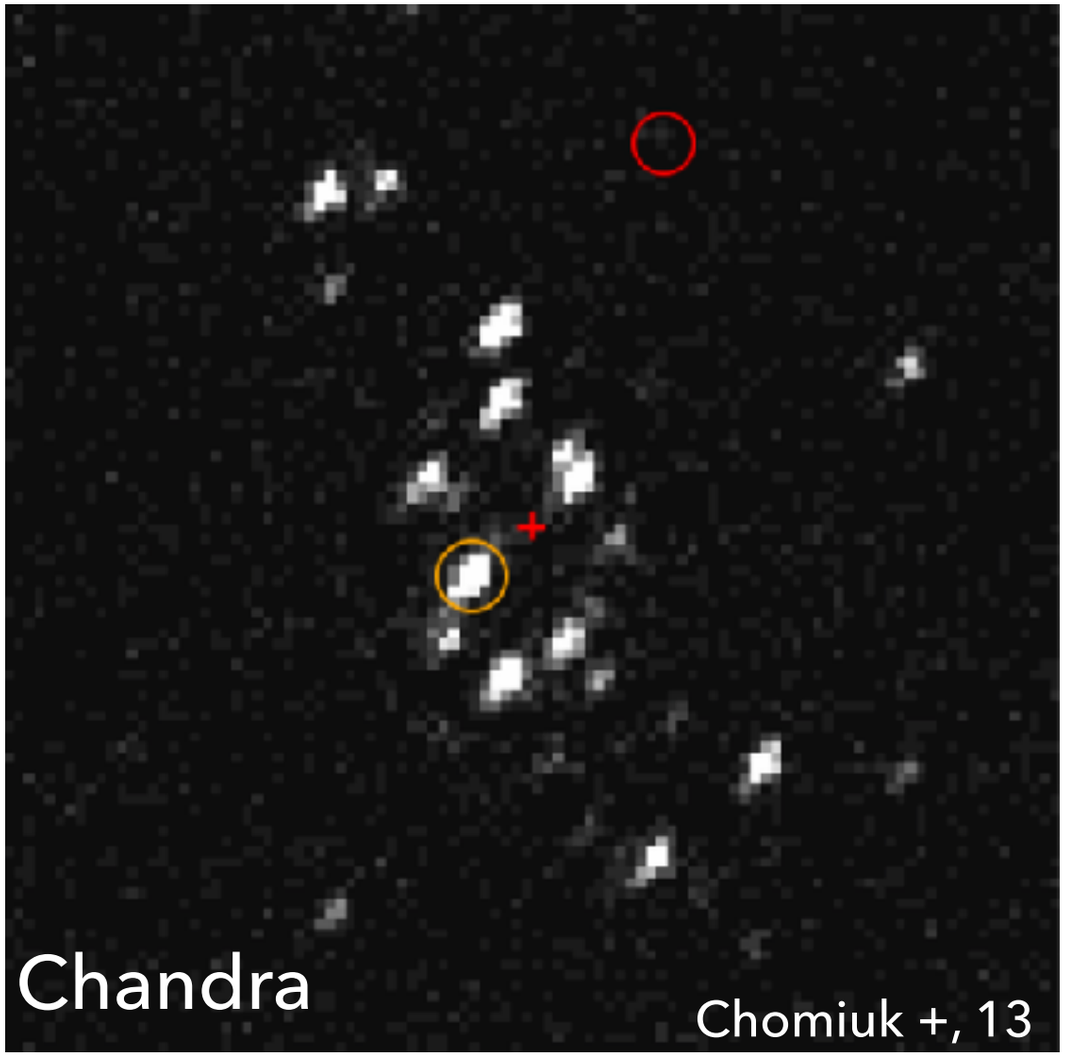
M62 IN RADIO & X-RAY



19.9 +/- 3.2 μJy (5 GHz)

18.1 +/- 2.3 μJy (7.4 GHz)

$\alpha = -0.24 +/- 0.42$

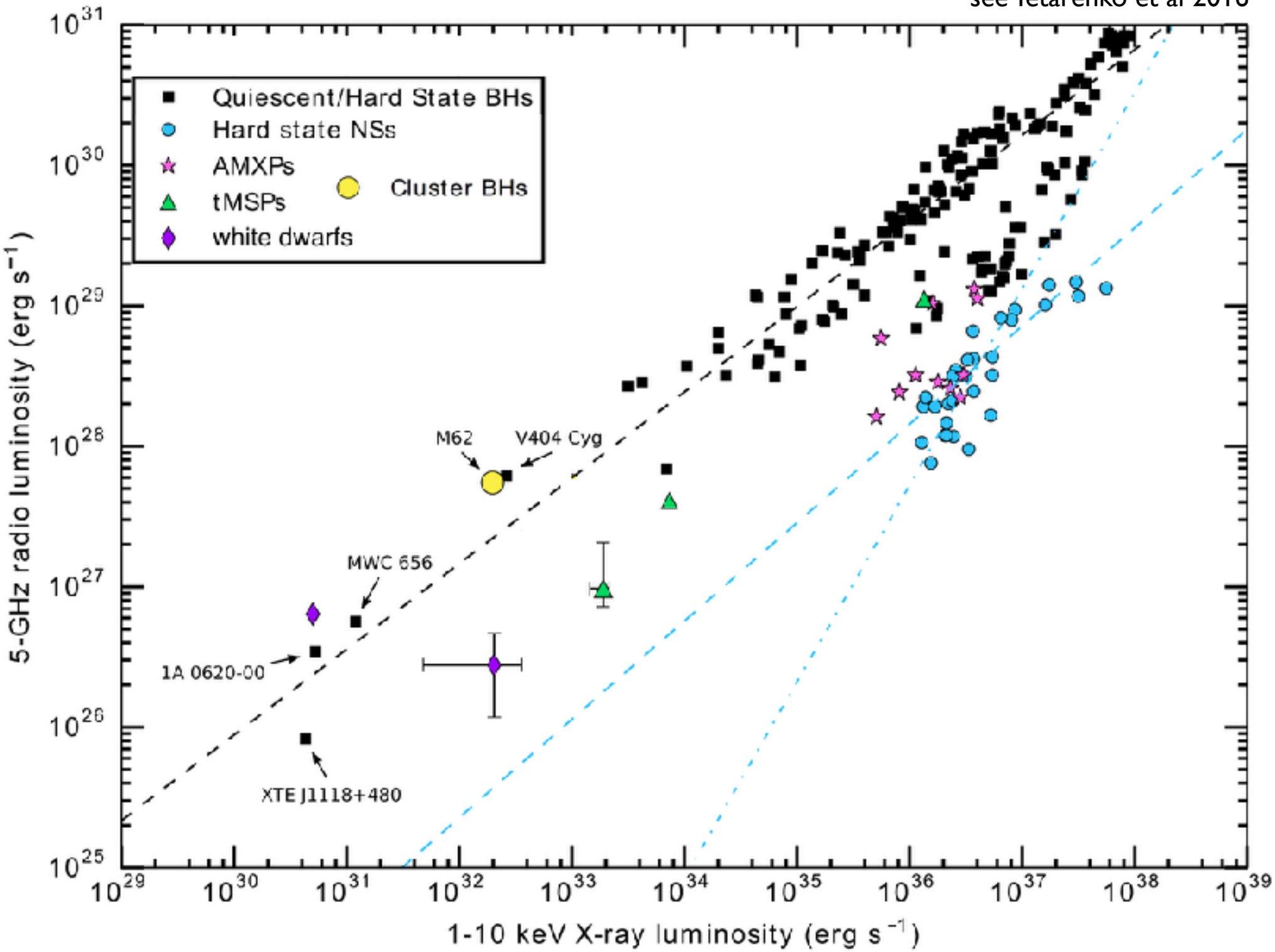


Unabsorbed $L_X = 5 \times 10^{32}$ erg/s

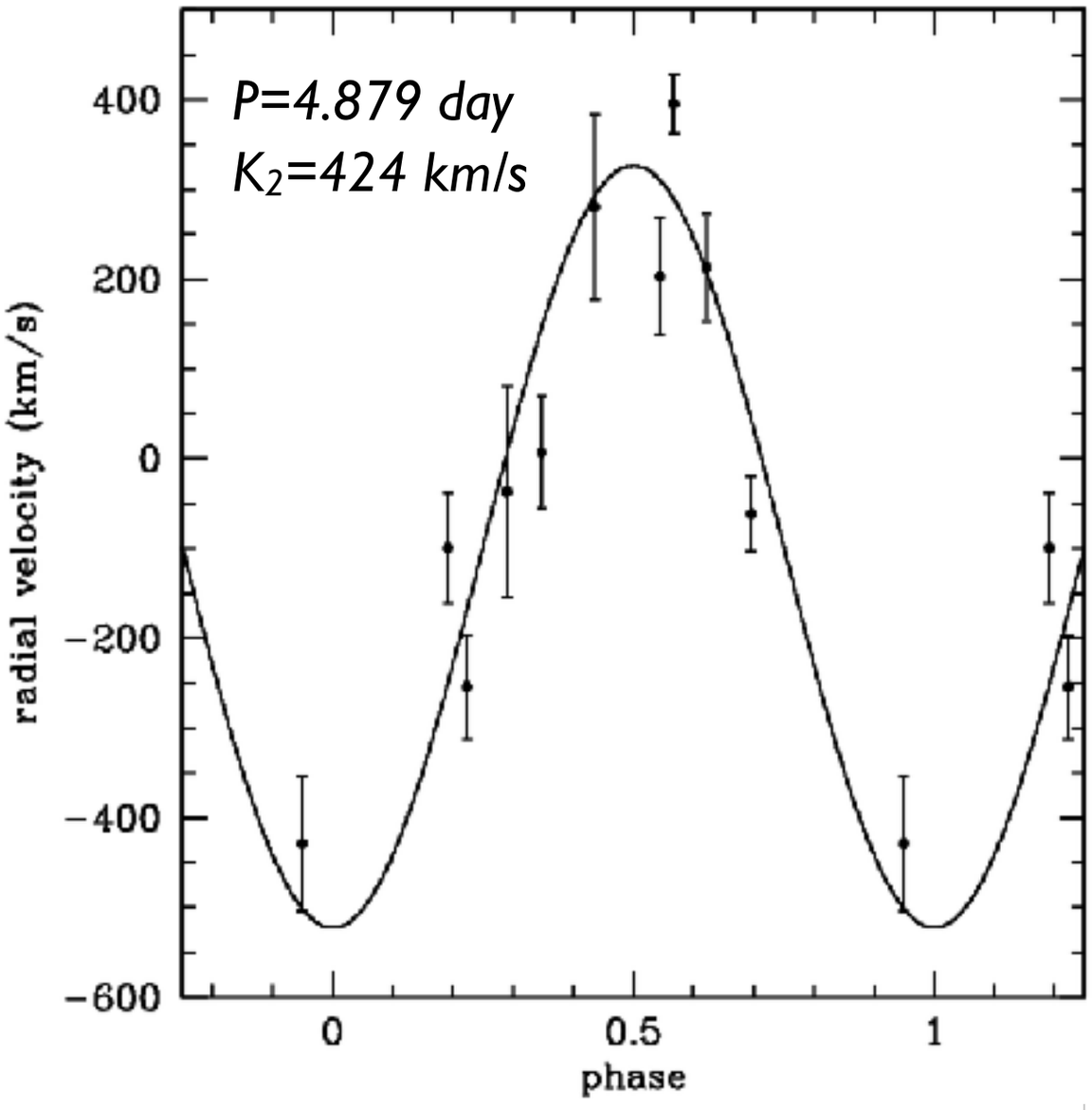
0.5 - 10keV

M62 RADIO/X-RAY CORRELATION

see Tetarenko et al 2016



M62 OPTICAL SPECTROSCOPY



$$f(M) = \frac{PK_2^3}{2\pi G} = \frac{M_1\,(\sin i)^3}{(1+q)^2}$$

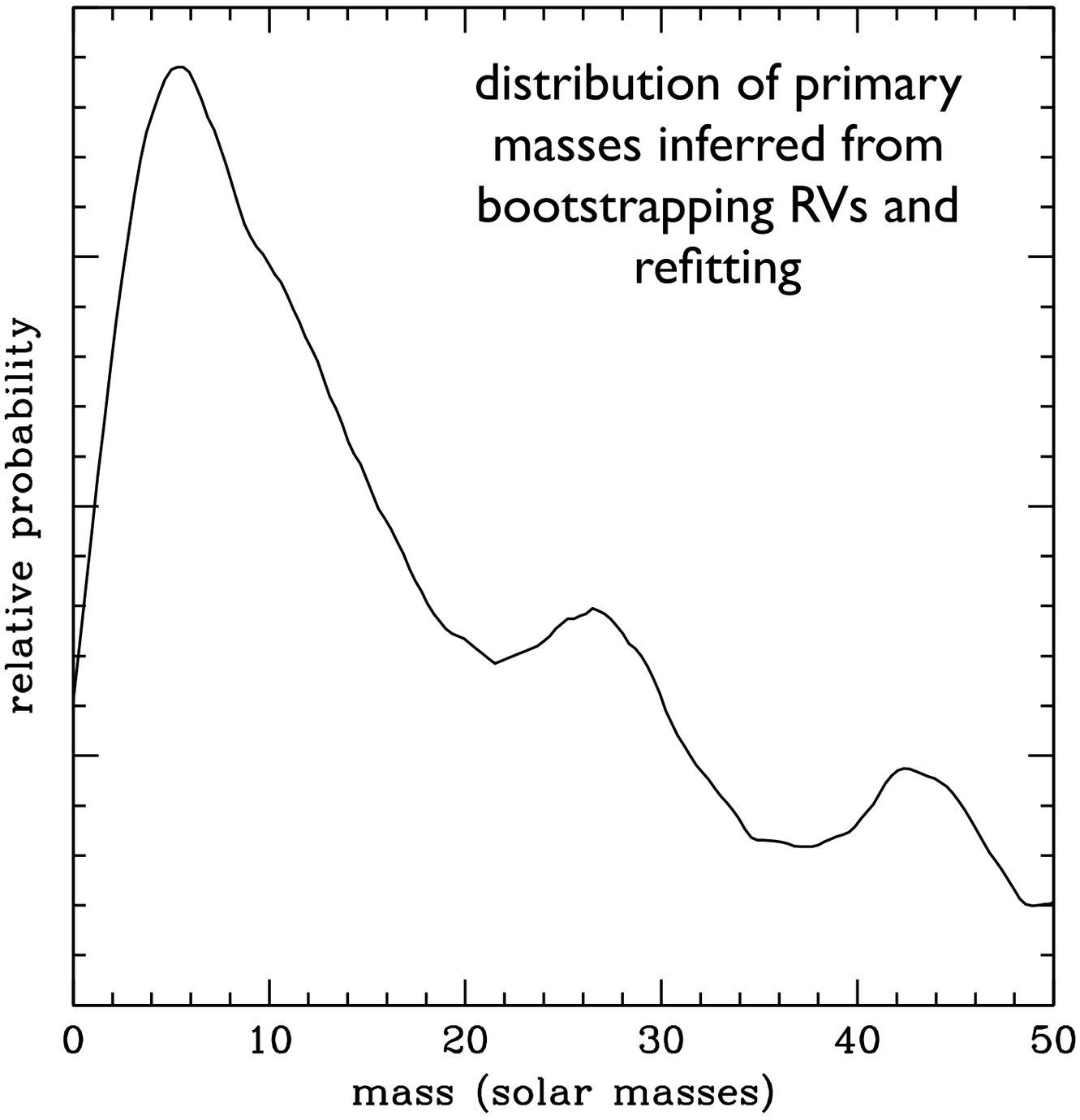
Optical source at radio/X-ray position

Giant with blue and H-alpha excess, double peaked

HST spectral observations of counterpart recently completed!

More epochs needed to determine orbit

M62 OPTICAL SPECTROSCOPY



Mode ~ 5 M_{sun}

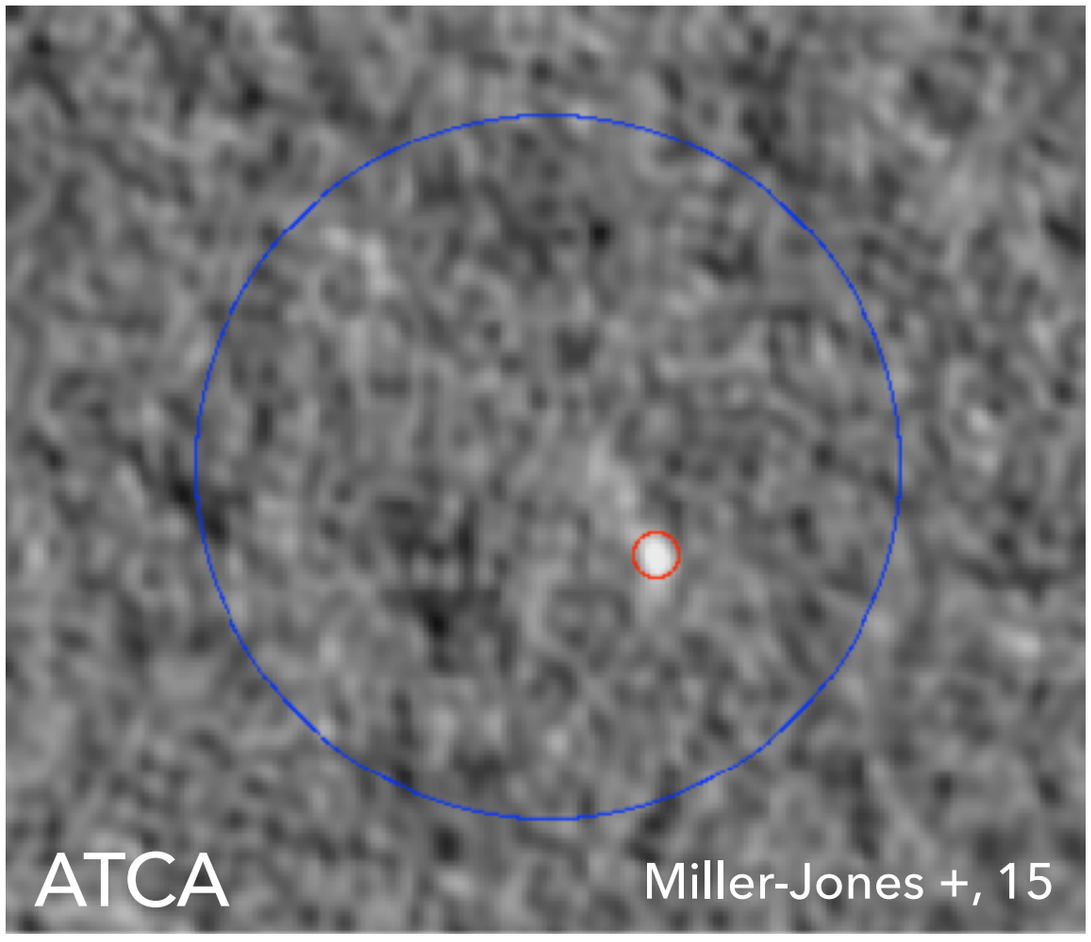
Median mass ~ 17 M_{sun}

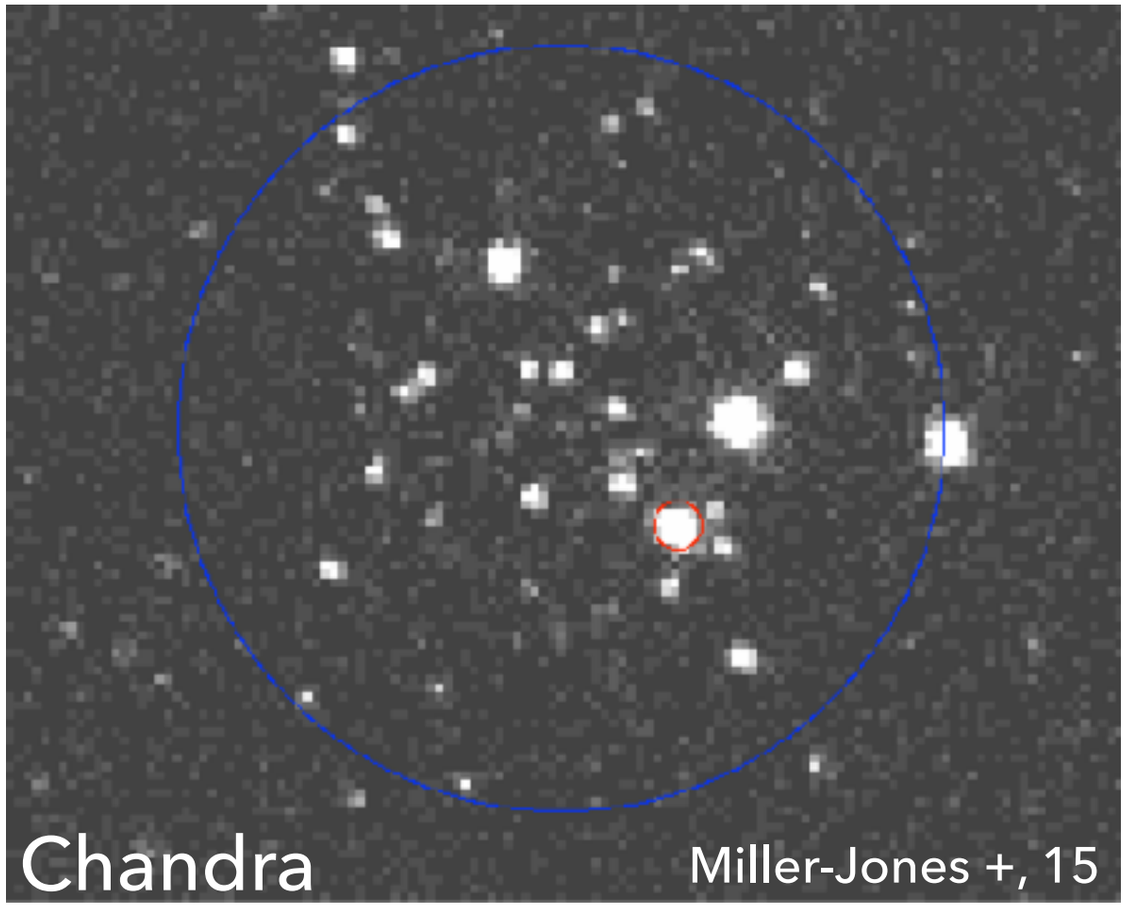
1/3 chance of Mass > 25 M_{sun}

Ligo-esque source

More RV measurments upcoming with MUSE — Approved for 15 1hr epochs in 2018A (4 completed already)

47 TUC IN RADIO & X-RAY





27.2 +/- 7.2 μJy (5.5 GHz)

30.7 +/- 8.9 μJy (9 GHz)

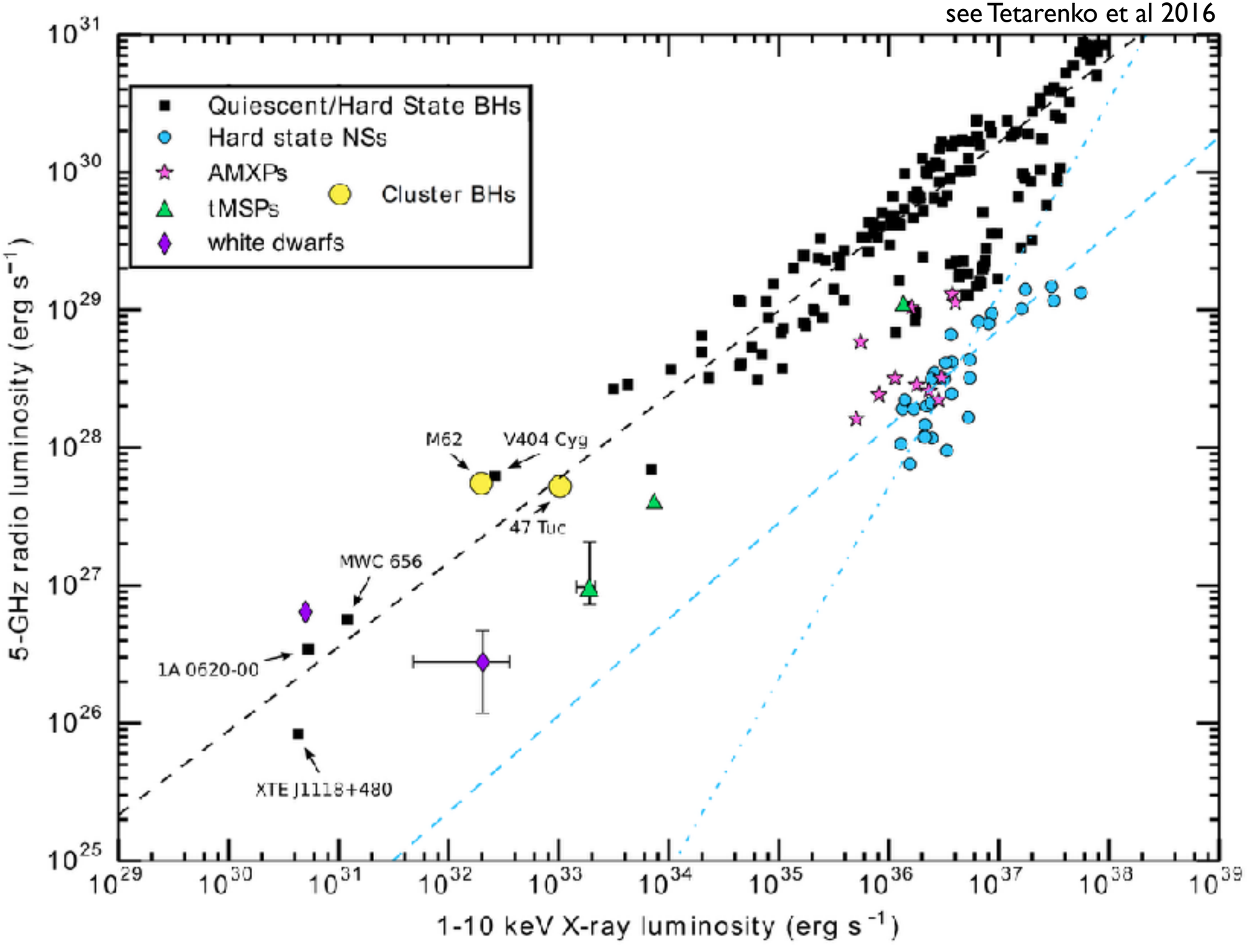
$\alpha = 0.2 +/- 0.8$

$L_X \sim 10^{33}$ erg/s

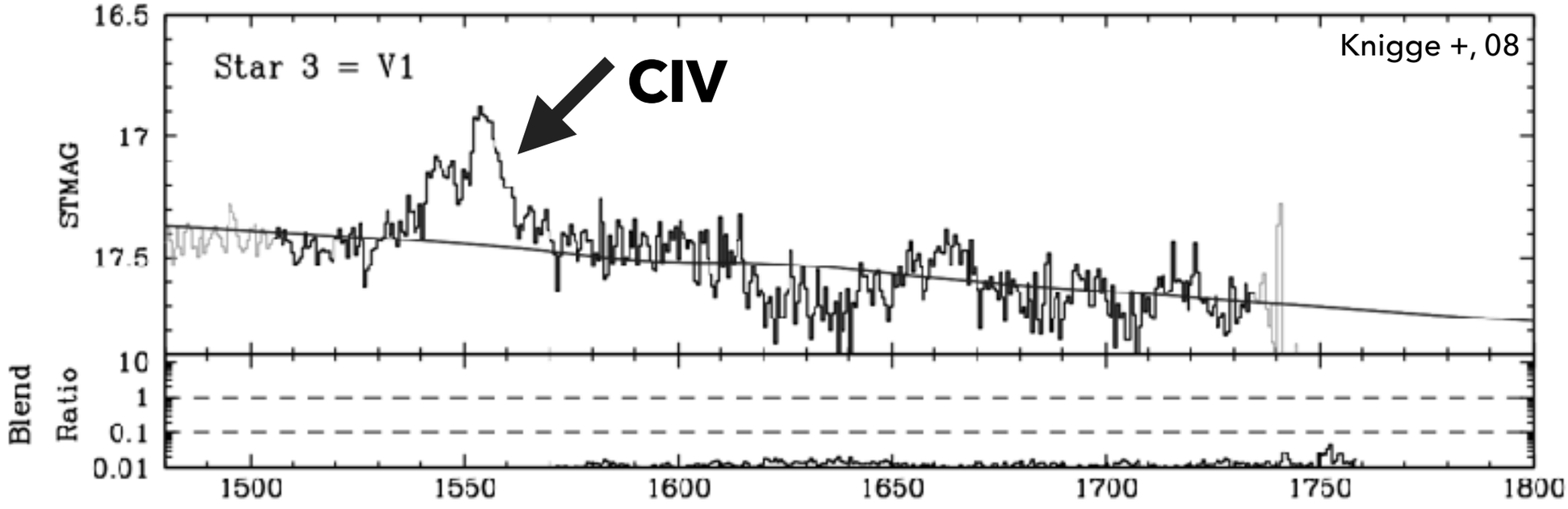
1 - 10 keV

X9 RADIO/X-RAY CORRELATION

see Tetarenko et al 2016



X9 OPTICAL/UV SPECTROSCOPY



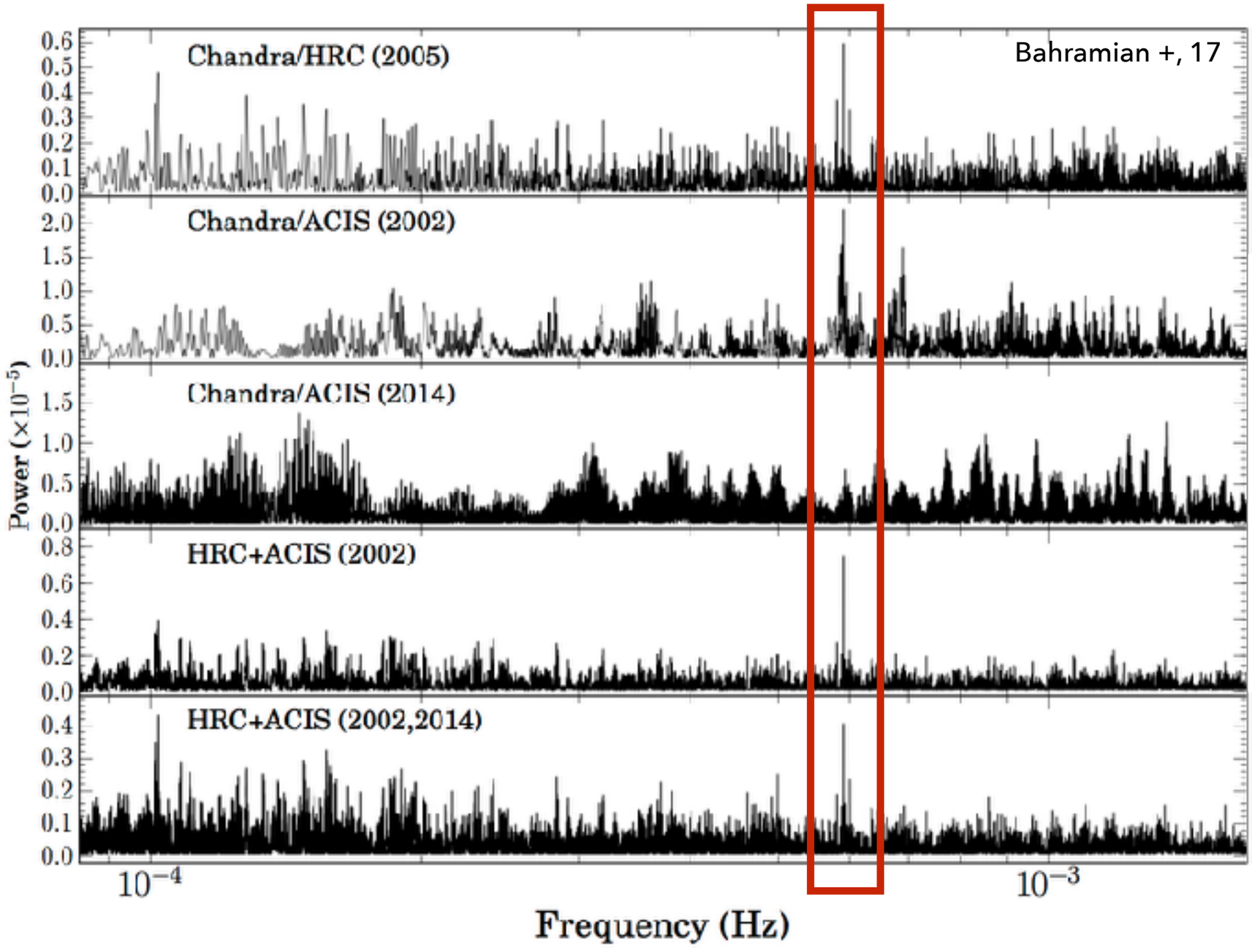
Double peaked CIV – Carbon accretion?

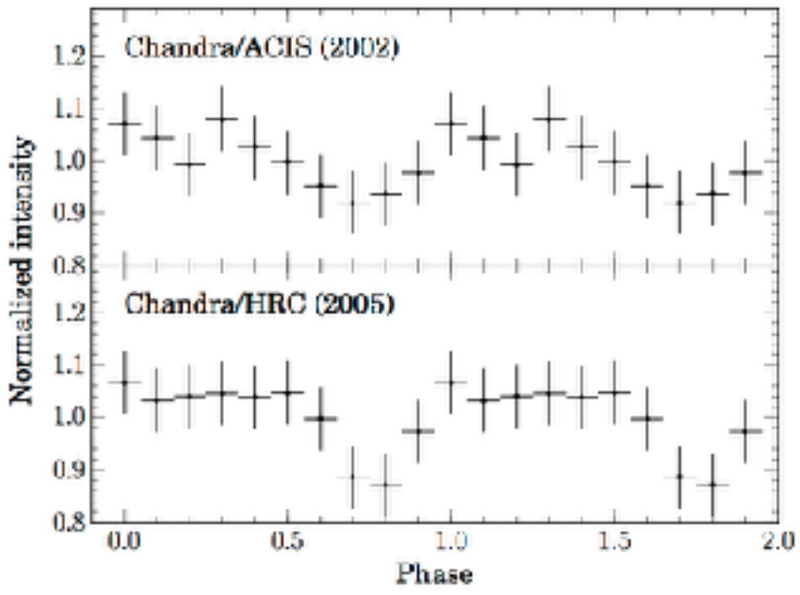
Oxygen abundance in X-rays

No H or He emission!

A CO white dwarf companion!

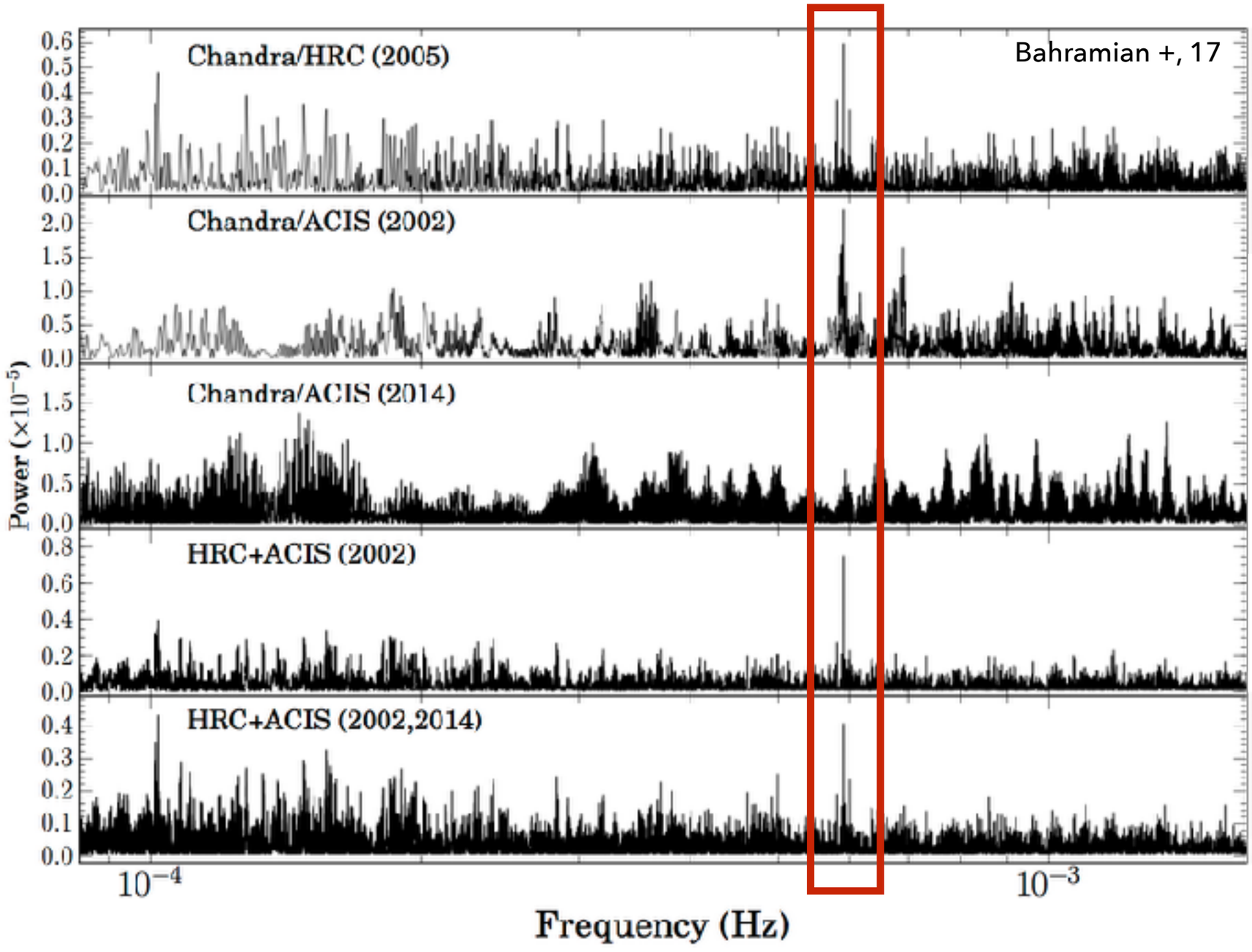
X9 X-RAY TIMING

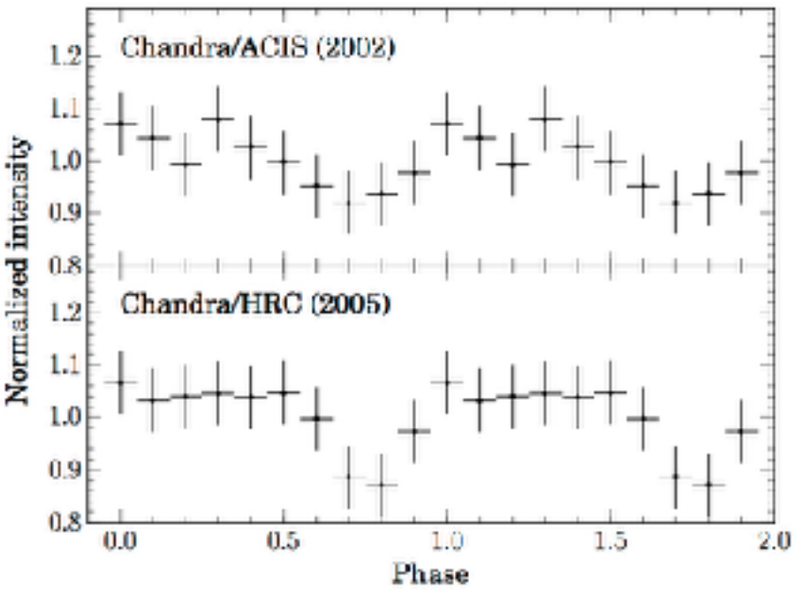




Peak in power spectrum at 28.2 min, strongest around oxygen emission lines

X9 X-RAY TIMING

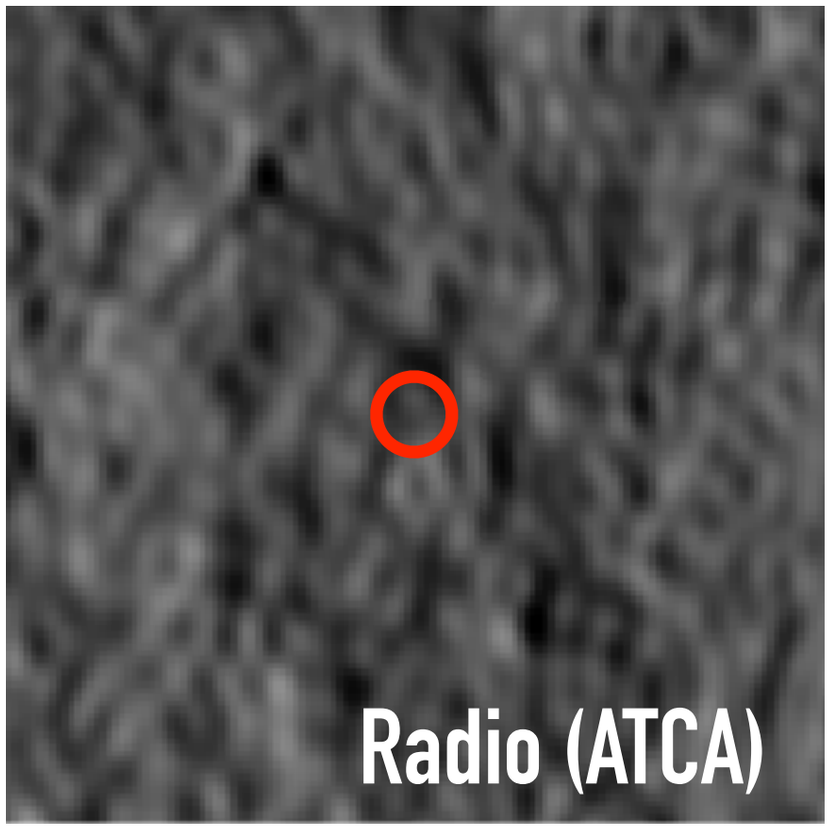


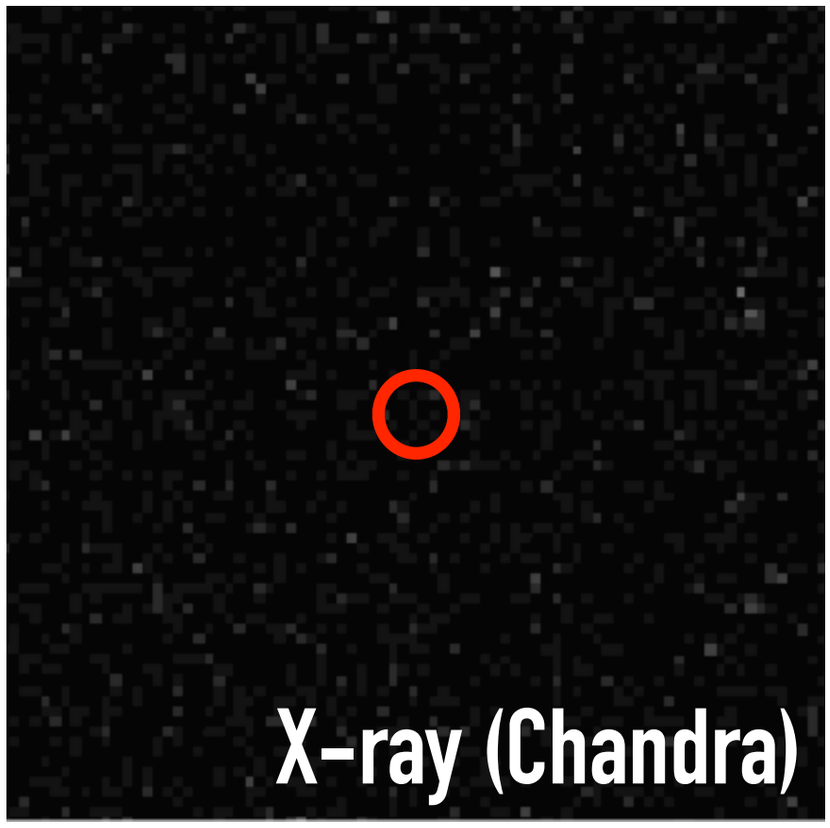


NS or BH??

See Miller-Jones +,15; Bahramian +, 17; Tudor +, 18

BLACK HOLE IN NGC 3201





Discovered in MUSE radial velocity survey, see Giesers et al. 2018

Minimum mass = $4.58 \pm 0.18 M_\odot$

Most likely = $6.1^{+10.2}_{-1.4} M_\odot$

First dynamical confirmation of BH in GC — we know they are out there!

OTHER CANDIDATES AND FUTURE!

12 new candidates found out of the 50 clusters surveyed — more expected

Continue with multi-wavelength follow up

Problems: Variability, cluster crowding, inclination

Other interesting objects found – tMSPs, MSPs

Survey also producing IMBH mass limits (Tremou +, 18), GC radio source counts, and more!