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Two stellar-mass black holes in the globular cluster M22

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Strader et al. (2012a), Nature, 490, 71
Strader et al. (2012b), ApJ, 750, L27

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Overview

- A search for the accretion signature of IMBHs in GCs:
  - No evidence found
  - IMBHs either rare in GCs or extremely radiatively inefficient

- Serendipitous detection of two flat-spectrum radio sources:
  - Interpreted as stellar-mass black holes
  - Challenges our understanding of GC dynamical interactions
  - Possibly more massive than ‘field’ sMBHs

Black holes in globular clusters

- Intermediate-mass black holes (IMBHs):
  - $50\text{-}10^6$ solar masses
  - Possible explanations for the most luminous ULXs?
  - Best candidate to date is HLX-1 (*Farrell et al. 2009*)
  - Should be formed efficiently in GCs (*Miller & Hamilton 2002; Portegies Zwart et al. 2004*)
  - Should be located at the cluster centre

- Stellar-mass black holes (sMBHs):
  - 3-35 solar masses
  - Hundreds form from massive stars early in cluster history
  - A few known in extragalactic GCs (*Maccarone et al. 2007*)
  - More massive than field sMBHs?
  - Should be located close to cluster centre

Survival of sMBHs in GCs

- Most massive objects sink to the centre by dynamical friction
  - Exchange energy with stars
  - Come into energy equipartition
  - Slow down
  - Sink to core

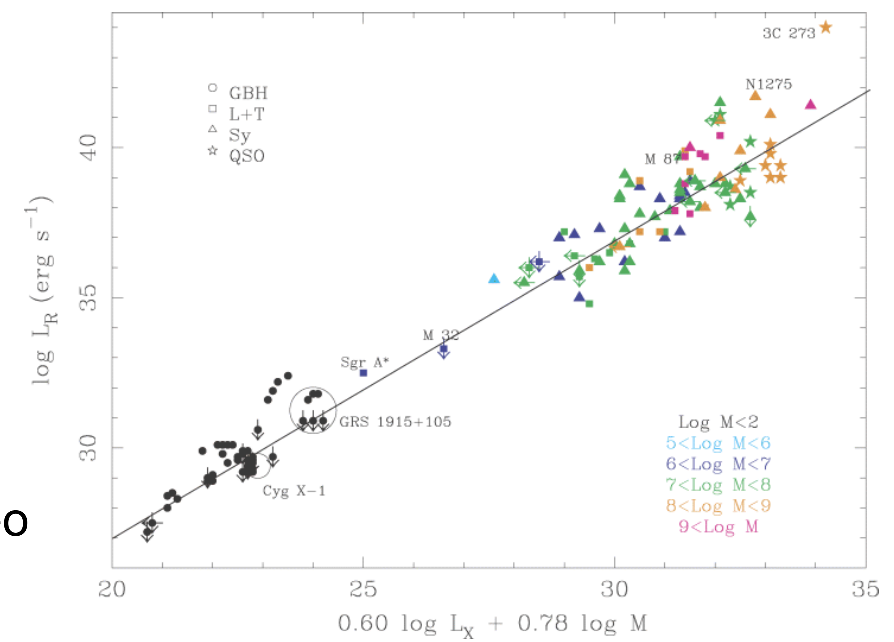
- Core BHs interact with one another
  - Form binaries, ejecting a third
  - Repeated encounters build up recoil velocity
  - Binaries eventually ejected (*Kulkarni et al. 1993*)
  - Single BH or BH binary remains
  - Some may remain in the halo (*Sigurdsson & Hernquist 1993*)

Accretion signatures of IMBHs in GCs

- Search for B-H accretion signatures at cluster centre
  - X-rays (accretion flow): can be superposed NSs
  - Radio (jets): BHs much brighter than NSs
- Fundamental Plane of Black Hole Activity

$$\log L_R = 0.60 \log L_X + 0.78 \log M_{BH} + 7.33$$

- Radio emission brighter for higher black hole mass
- More effective probe than X-rays (*Maccarone 2004*)



Merloni, Heinz & di Matteo (2003)

The sample

- Use FP to predict Bondi accretion rate from cluster gas
- Six GCs at δ>-30^o, with predicted S(6 GHz)>5μJy/beam
- Select the brightest (M22, M19, at 17, 12μJy/beam)
- M15 (6 μJy/beam) due to claimed IMBH from stellar kinematics

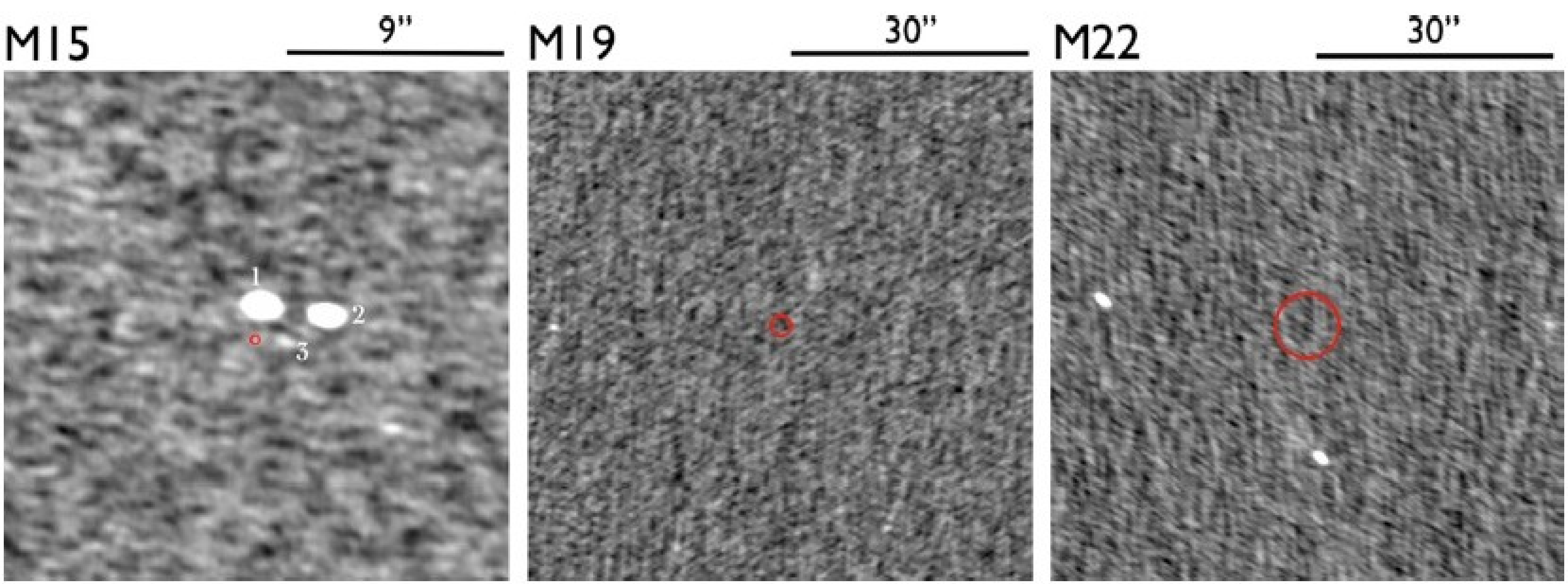
Image credit: ESA, Hubble, NASA

Image credit: J.C. Cuillandre, Hawaiian Starlight, CFHT

Image credit: D. Williams, N. Sharp, AURA, NOAO, NSF

Results

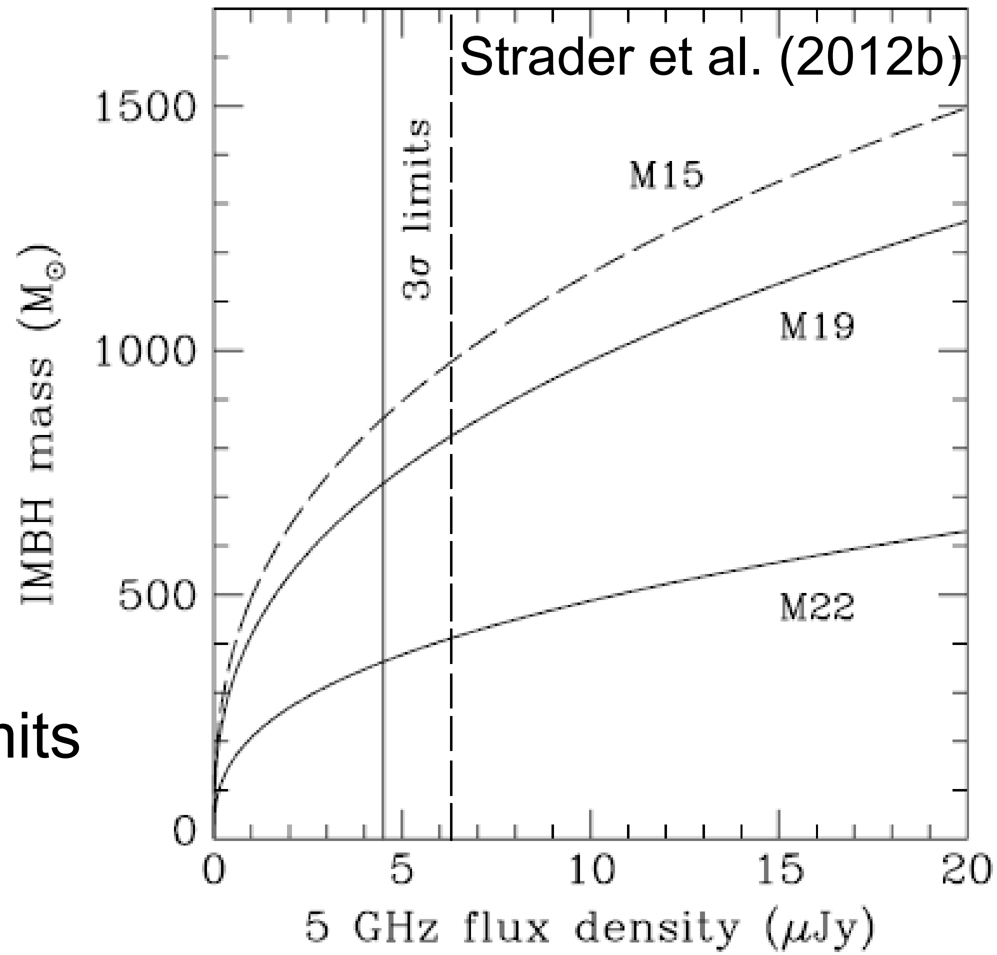
- Search within Brownian radii
  - Encounters with passing stars perturb IMBH from GC centre
  - 4, 1.3, 0.2” for M22, M19, M15
- No radio emission from cluster centres ($3\sigma < 6.3$ μJy/beam)



Strader et al. (2012b)

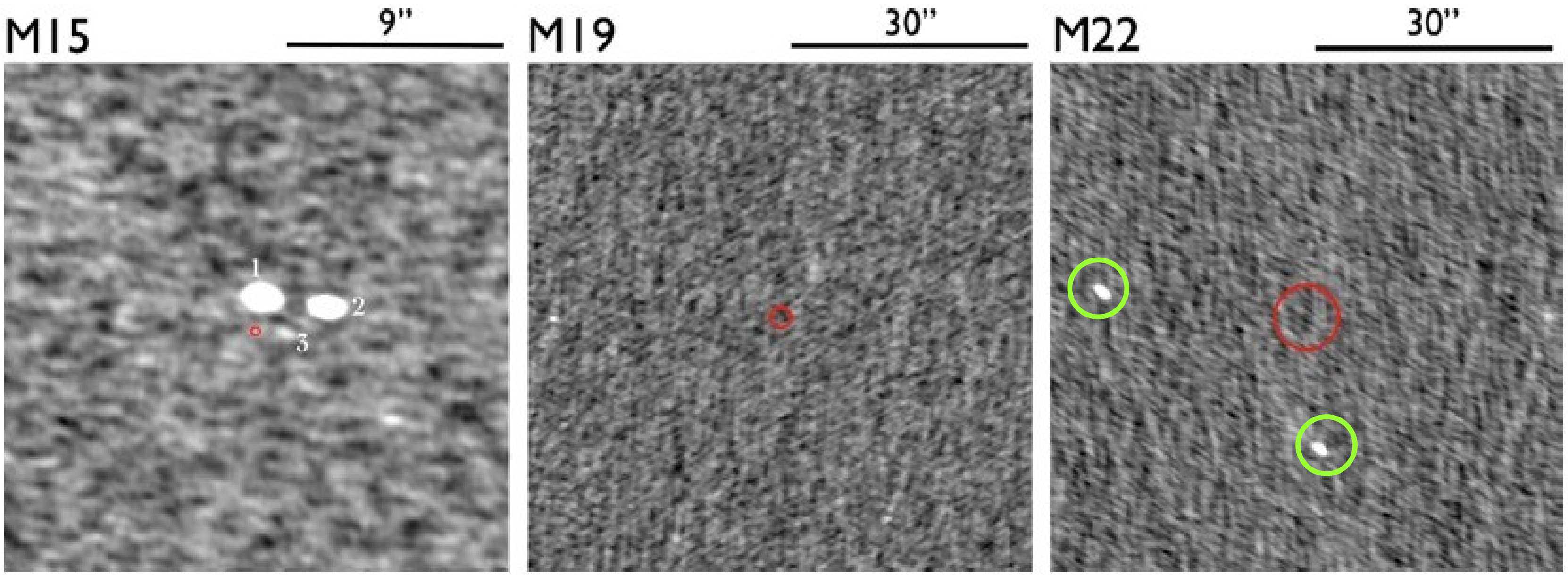
IMBH upper limits

- Mass constraints
  - M15: <980 M_0
  - M22: <360 M_0
  - M19: <730 M_0
- No convincing accretion signatures of IMBHs
- All existing dynamical "detections" an order of magnitude above radio limits
- Possibilities:
  - Low gas densities
  - Extremely inefficient accretion (<10^{-9} Eddington)
  - IMBHs >10^3 M_0 rare in GCs



Spin-off science

- Two flat-spectrum sources (α=0.0 - 0.2) in M22
- 55-58 μJy/beam
- 0.4, 0.25 pc from cluster centre (core radius 1.24 pc)



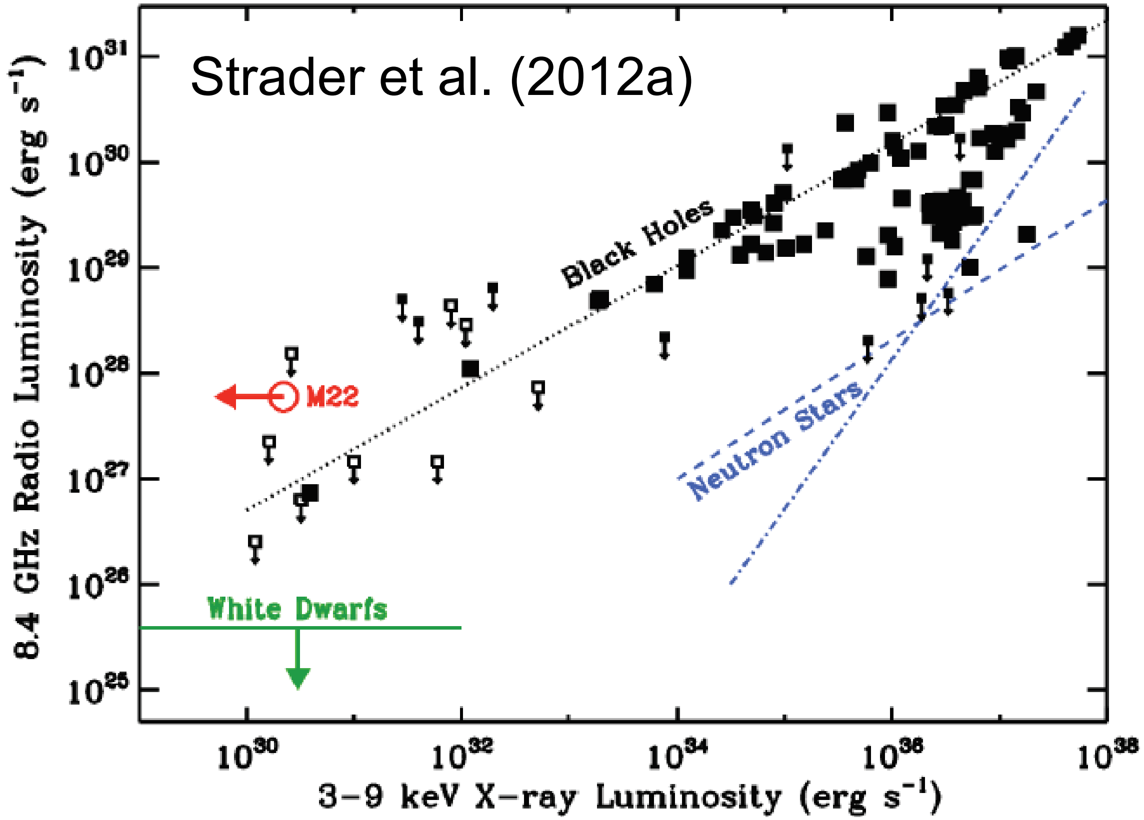
Strader et al. (2012b)

Possibilities

- Background sources
  - No optical/X-ray counterpart, expect <0.1 in central 30”
- Pulsars
  - Radio spectra not steep enough
- Pulsar wind nebulae/SNRs
  - High luminosity, short lived, large sizes, radio polarization, found in dense regions: unlikely
- Planetary nebulae
  - No [O III] nebulosity
- Foreground ultracool dwarfs
  - No strong circular polarization, no optical/IR counterparts; must be 50-100pc

Accreting compact sources

- No Chandra counterparts
- $L_X < 2.2 \times 10^{30}$ erg/s
- $\log (L_R/L_X) > -2.6$
- NS, WD inconsistent unless strongly variable
- Relatively massive BHs (10-20 M_0)?



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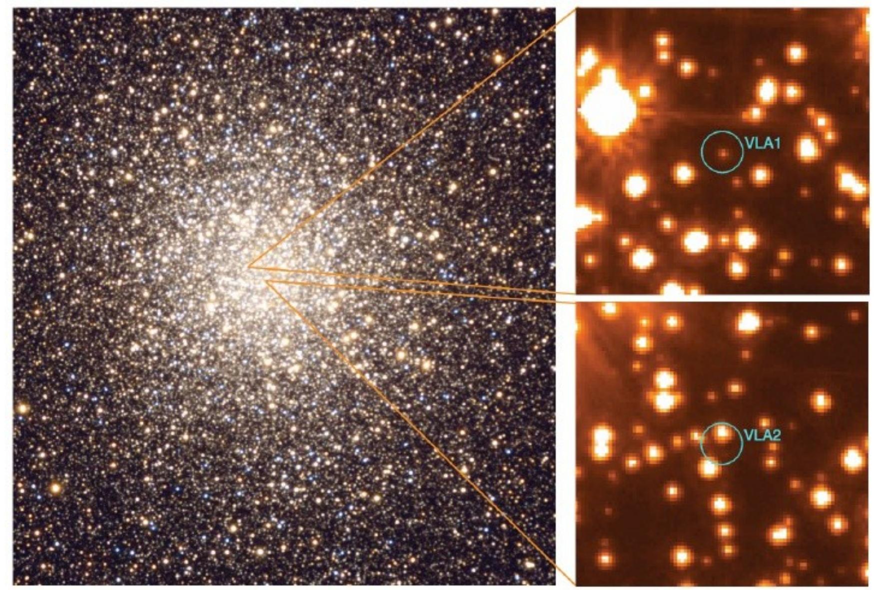
Nature of the systems

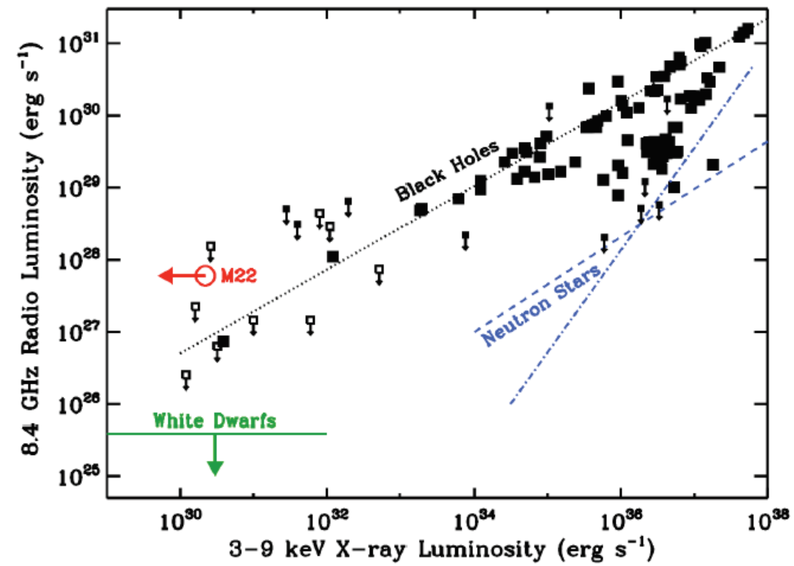
- Little interstellar gas: probably RLOF rather than Bondi accretion
- VLA1:
  - 0.05” from 0.34 M_0 M-dwarf
  - P(chance) ~ 2%
- VLA2
  - 0.17” from 0.62 M_0 MS star
  - P(chance) ~ 26%
- Why not exchanged out?
  - WD companion?
  - Low core density?

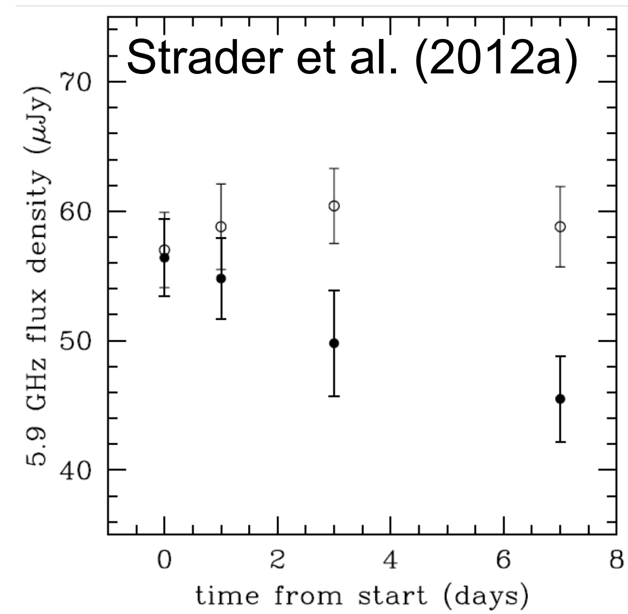


Strader et al. (2012a)

Massive sMBHs?

- X-ray emission should be detected
- Scatter on correlation?
- Variability?
  - 2.6σ-level only
- Massive BHs?
  - Low metallicity
    - Less wind mass loss
  - No binary formation
    - No CE stage
  - Exchange/tidal capture
- Estimate 15 M_0 from location and thermalization





How could they be retained?

- Core heating by the black holes reduces cluster density
  - Reduces interaction rate
  - Significant fraction of BHs remains bound for several Gyr
  - Simulations done for star clusters in Magellanic Clouds
  - Supported by core radius (fifth largest in massive MW GCs)
    - Black hole heating?
- Cluster still in core contraction phase?
- Merging of two smaller clusters
  - Spread in [Fe/H] may support this
  - One retained BH from each could still be present

Conclusions

- No good evidence for radiative signatures of accretion onto IMBHs
- IMBHs are either rare in globular clusters, or extremely radiatively inefficient
- Two stellar-mass black hole candidates detected in M22
- Challenges theoretical models of BH ejection
- Follow-up observations underway
  - Deeper Chandra X-ray observations to constrain L_R/L_X
  - Further radio data (variability, better spectral constraints)
  - Astrometry (proper motion to confirm cluster association)