TEXAS TECH UNIVERSITY

# Observability of Intermediate mass BHs

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From bestplaces.net

Image courtesy Buddy Holly Center

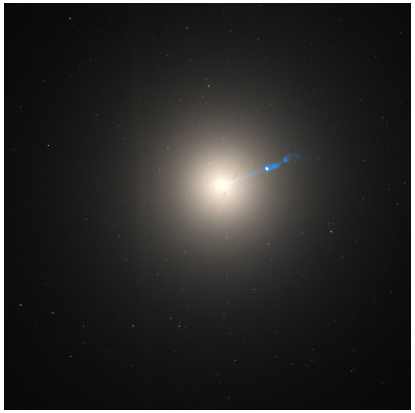
Greater than a single star can produce, less than an AGN?

Reasonable characteristics might be:

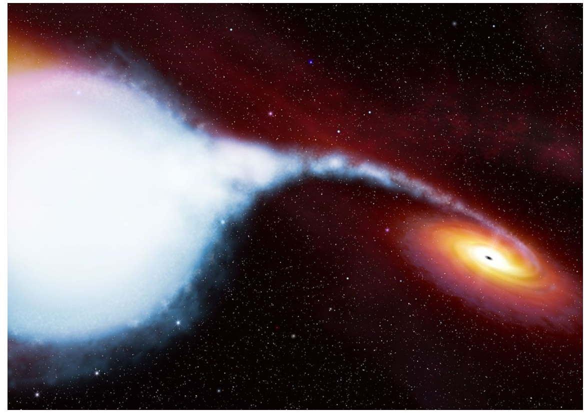
$$100 - 10^6\, M_\odot$$

and not in the center of a galaxy

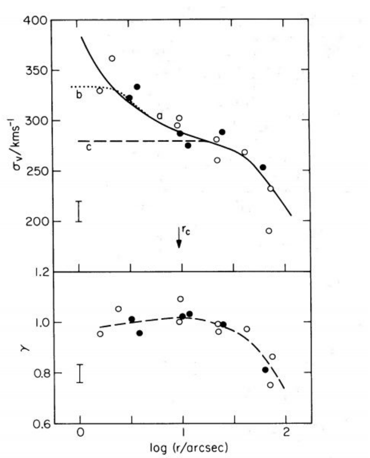
# How we find supermassive and stellar mass black holes



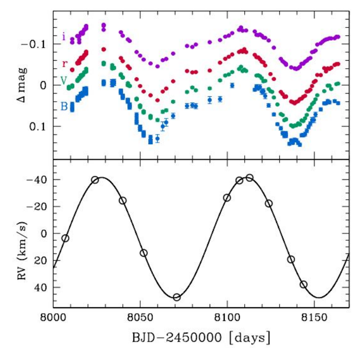
Jets: Curtis 1918; Edge et al. 1959



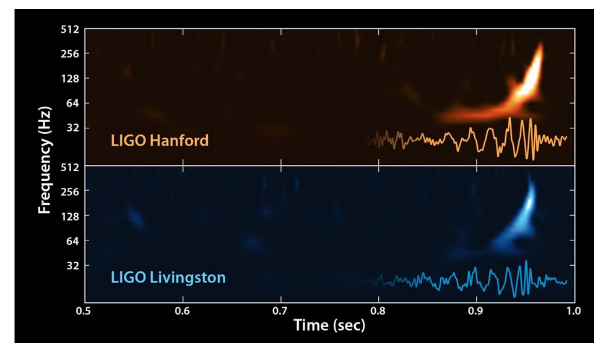
Accretion disks: Bowyer et al. 1965




Statistical probes of dynamics - e.g. Sargent et al. 1978



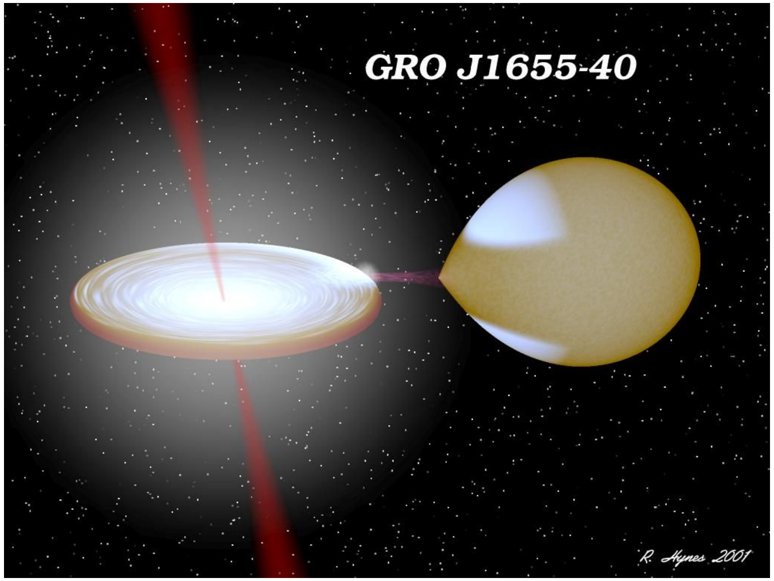

Ordered orbits of a single star:
Trimble & Thorne (1969);
Thompson et al. (2019)

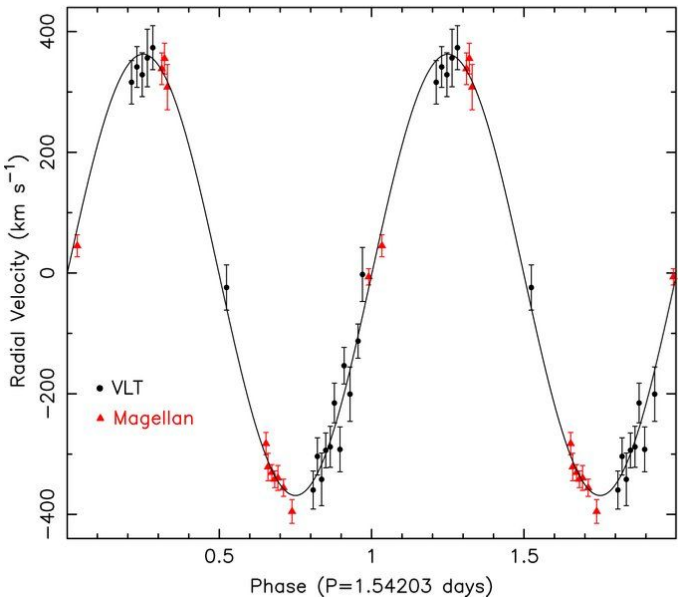



Abbott et al. (2016)

# How we estimate masses of stellar black holes

**Standard approach**
Measure radial velocity amplitude of donor star
Estimate *inclination angle*, and mass ratio of binary -- Casares & Jonker (2014) for a review
Emission line widths and double peak separations can give indirect tracers (Casares 2015,2016)



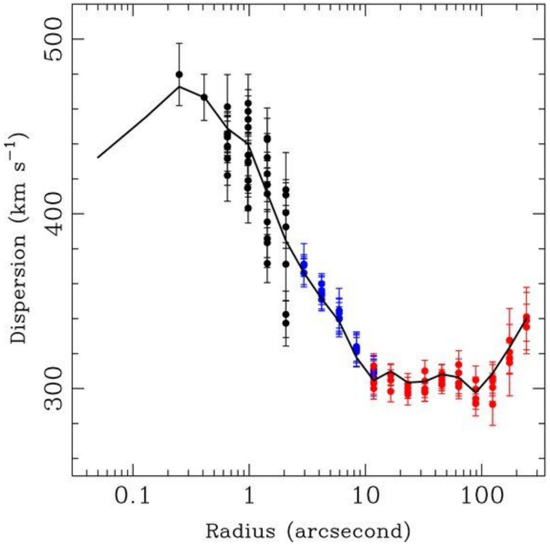




From Rob Hynes' binsim image gallery, see Rob Hynes' web page at Louisiana State University

Orosz et al. 2011

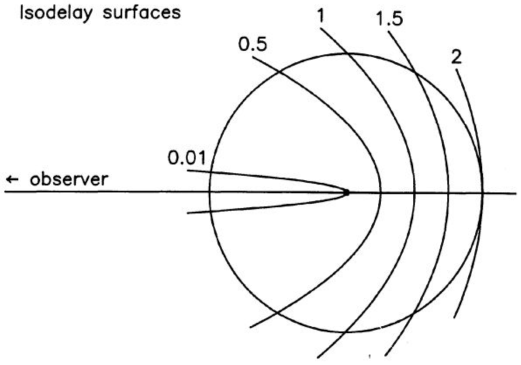
# How we estimate masses for supermassive black holes

**Stellar dynamics**



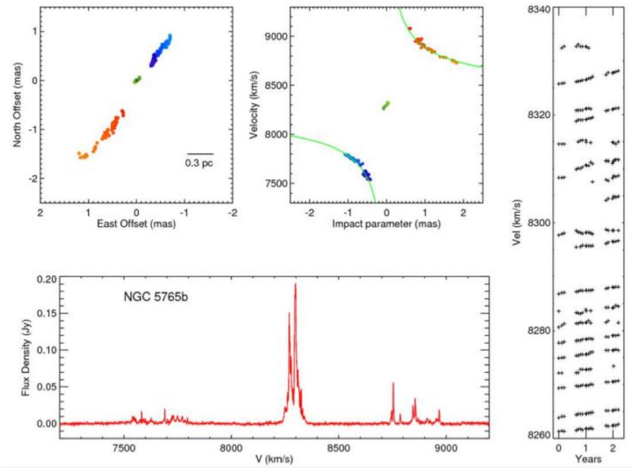

Gebhardt et al. 2011

**Reverberation mapping**




Bahcall et al. 1972; Peterson et al. 1993; Bentz et al. 2016

**Masers**




Braatz et al., ngVLA Science Book

Other approaches: gas dynamics (e.g. Boizelle et al. 2019) - growing in importance with ALMA, could grow further with Next Generation VLA

Imaging black hole shadow (EHT Collaboration, 2019) - extremely precise, but limited to very small number of objects

# Searches versus confirmation and mass estimation

- Jets: discovered in 1918, appreciated in late 1950s, led to black hole hypothesis in early 1960s (Salpeter 1964;Zel'dovich 1964)
    - Never led to precise mass estimates
- X-rays from stellar mass black holes
    - First discovered in in 1969
    - Never led to precise mass estimates, but can give crude ones
- Dynamical searches for black holes, masers - must know where to look, but can give precise masses

# Where should we look?  (Should trust Marta more than me on this!)

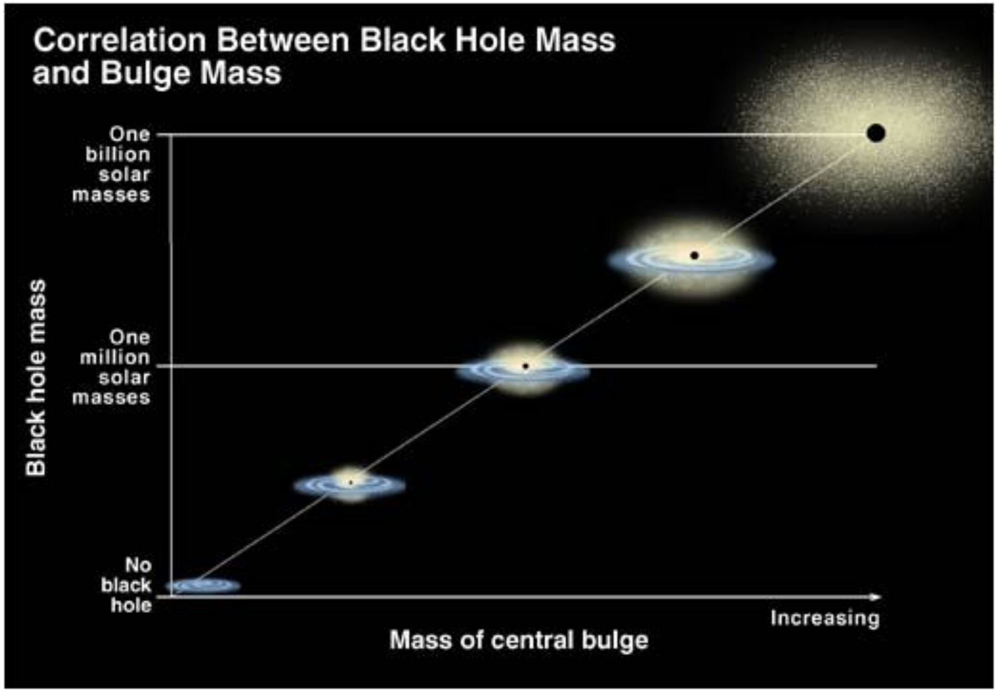



Figure: Cordes & Brown, STScI

M-sigma (Gebhardt et al. 2000; Ferrarese & Merrit 2000)
M_bulge -M_BH relation (Magorrian et al. 1998)

Do these relations hold up for low mass systems like dwarf galaxies and globular clusters?

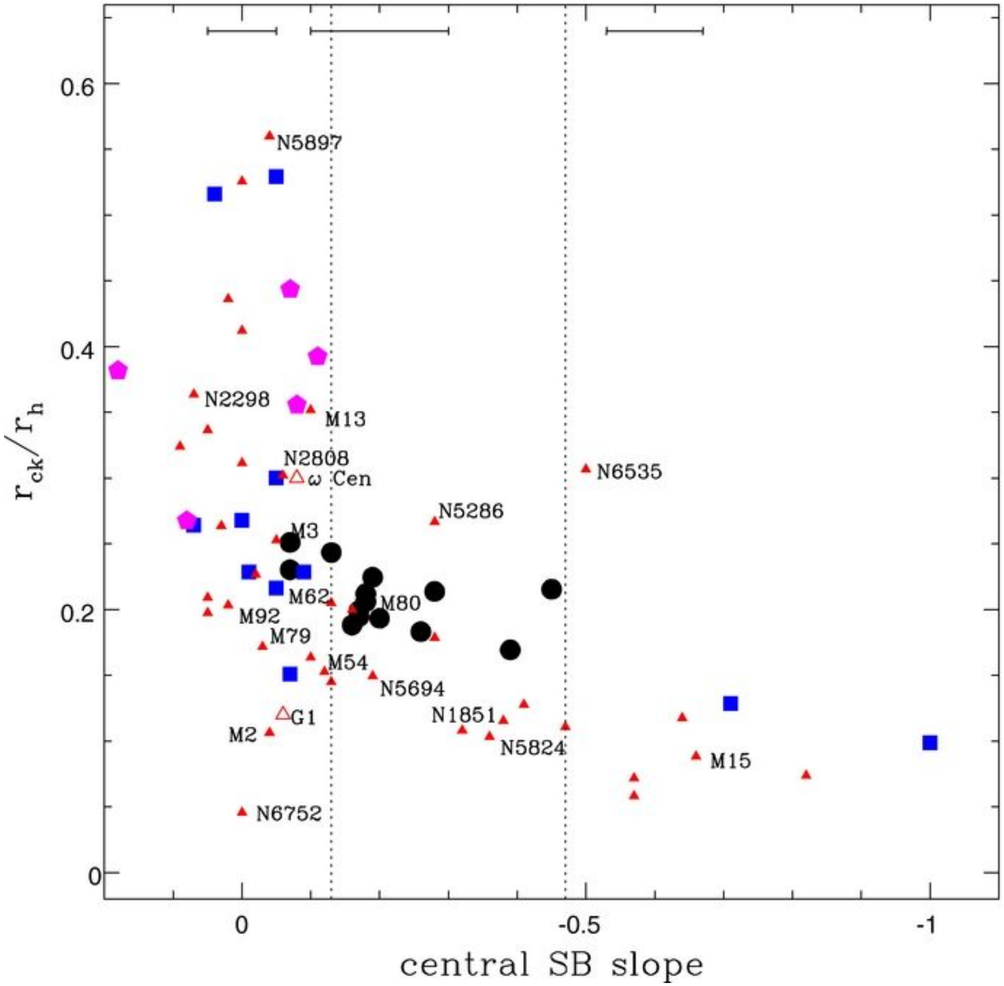
# Where do we look?

?

# Cluster bulk properties?

Bahcall-Wolf cusps?

“Heating” of cluster core by interactions with IMBH




Noyola & Baumgardt (2011)

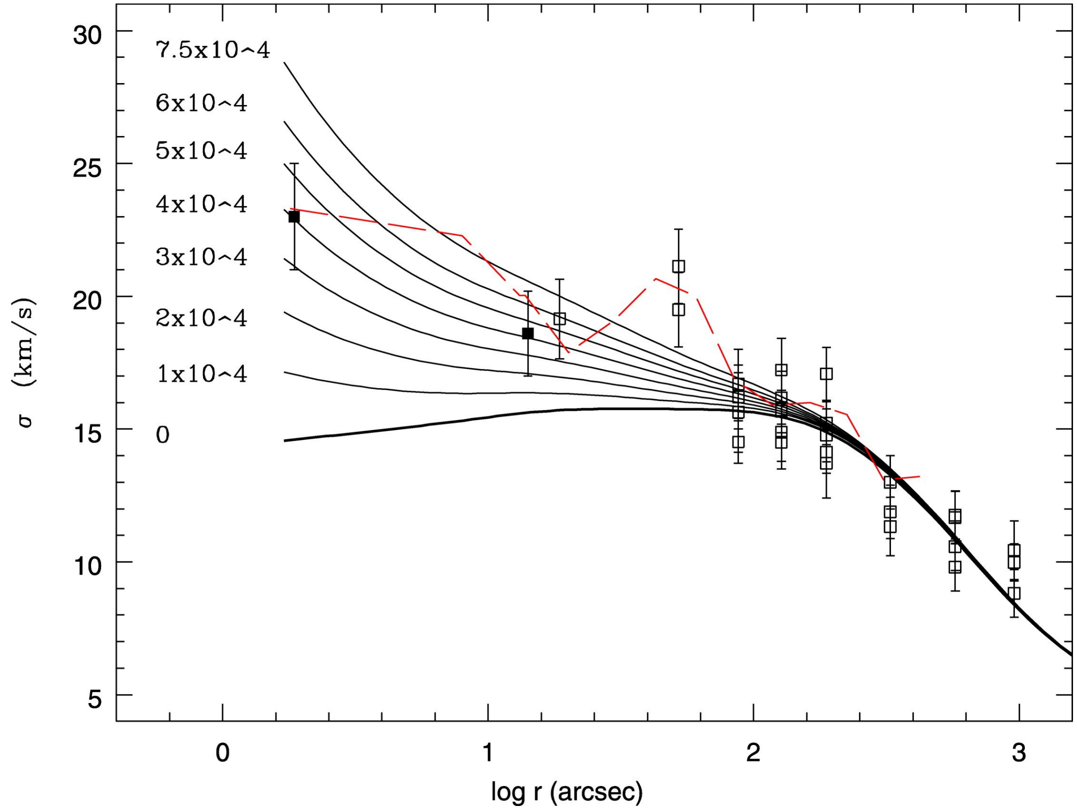
# Stellar dynamics: dispersional stellar dynamics also dangerous

Caveats:

1) Cluster center must be well known
2) Mass segregation means that high mass to light ratio is not enough
3) Statistical significance of most dynamics claims not sufficient
4) Distances must be known precisely (compare e.g. Kiziltan, Baumgardt & Loeb 2017 for 47 Tuc with e.g. Freire et al. 2017)

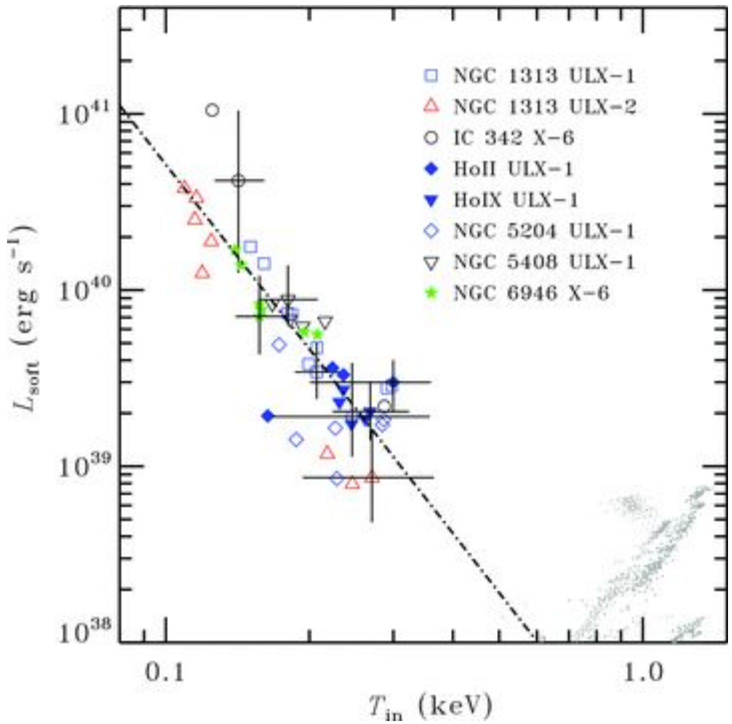
What may work better:

Individual fast stars may work, but do not appear to be present in Omega Cen (e.g. Baumgardt et al. 2019)




Noyola, Gebhardt & Bergmann (2008) - Omega Cen

# Accretion I: High luminosities and characteristic behaviors: maybe, but caution is advised!

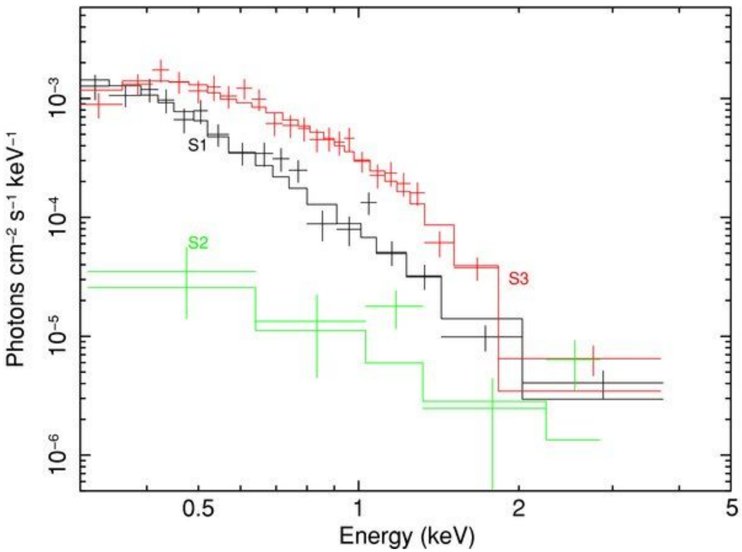



Kajava & Poutanen (2009)

Temperature of BH disks should scale as $M^{-1/4}$

Soft excesses may indicate IMBHs, but can have other causes

Many ULXs are *pulsars* (Bachetti et al. 2014)




Farrell et al. (2009); Godet et al. (2009)

“HLX-1” -- peaks at about $10^{42}$ erg/sec

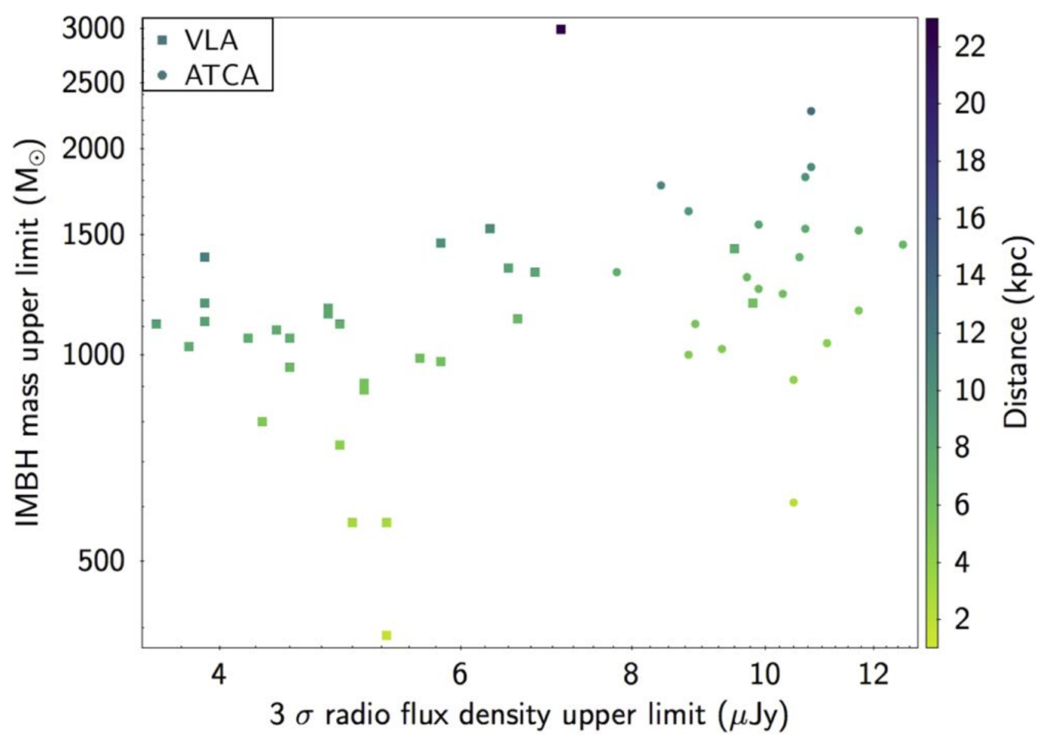
Appears to make state transitions between disk-like and power law states. This happens at 2% Eddington (Maccarone 2003; Vahdat Motlagh et al. 2019) for stellar mass BHs, and probably for AGN (Maccarone, Gallo & Fender 2003)

Radio peaks at state transitions (Webb et al. 2012)

# Accretion II: ISM accretion in clusters and dwarf galaxies: should work but no detections!

Caveats:

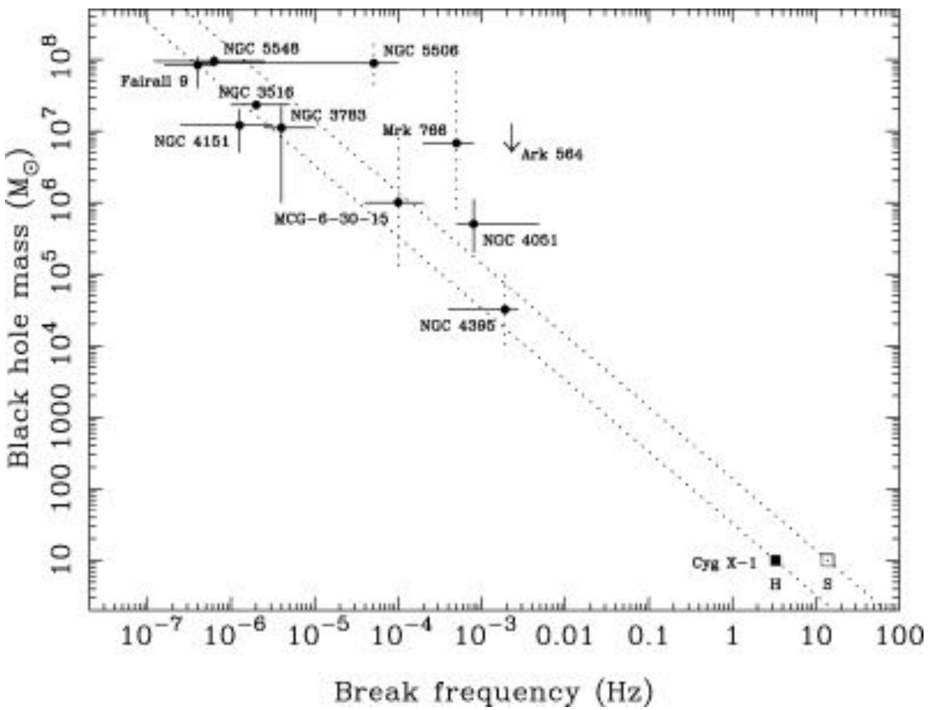
- Fraction of Bondi-Hoyle rate?
  - (assumed similar to Pellegrini 2005 for AGN)
- Gas inhomogeneities? (only a few good measurements - e.g. Freire et al. 2001)



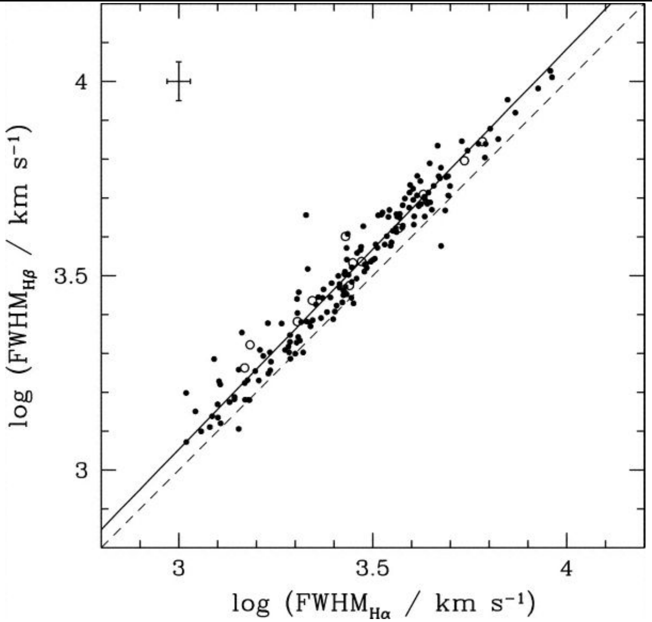

Tremou et al. (2018)

Ensemble measurements in nearby galaxies open more parameters space (e.g.Wrobel, Nyland & Miller-Jones 2015), but also no detections yet

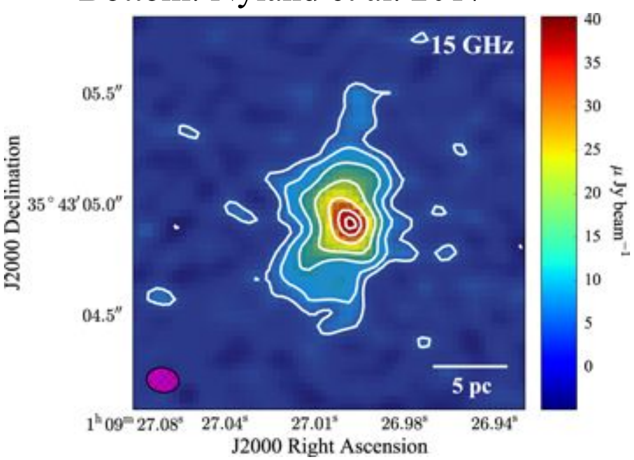
# The smallest AGN



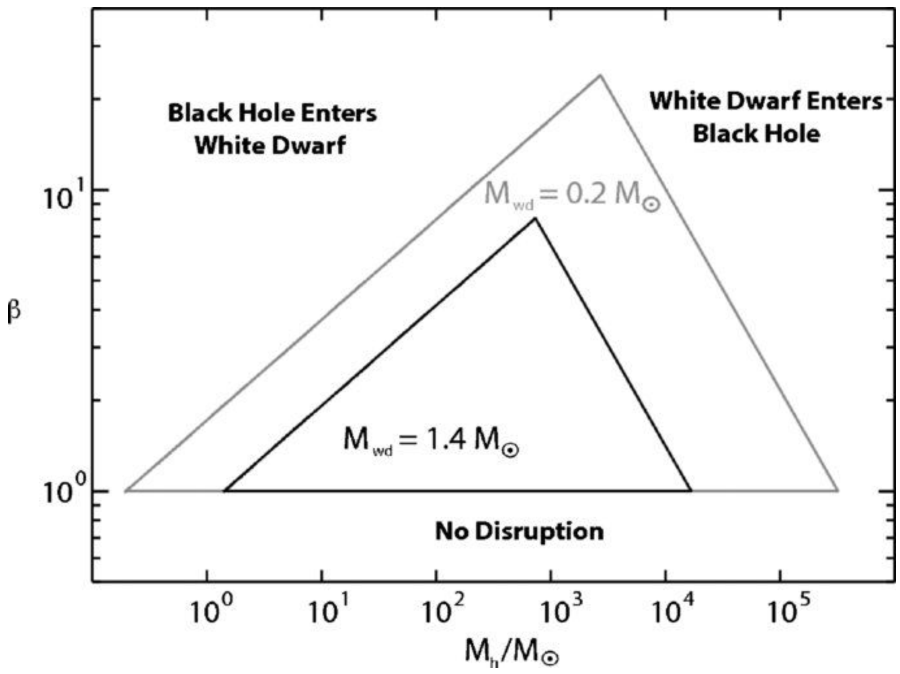

Vaughan et al. (2005)
Timing plane even better now (McHardy et al. 2006), about same scatter as M-sigma relation

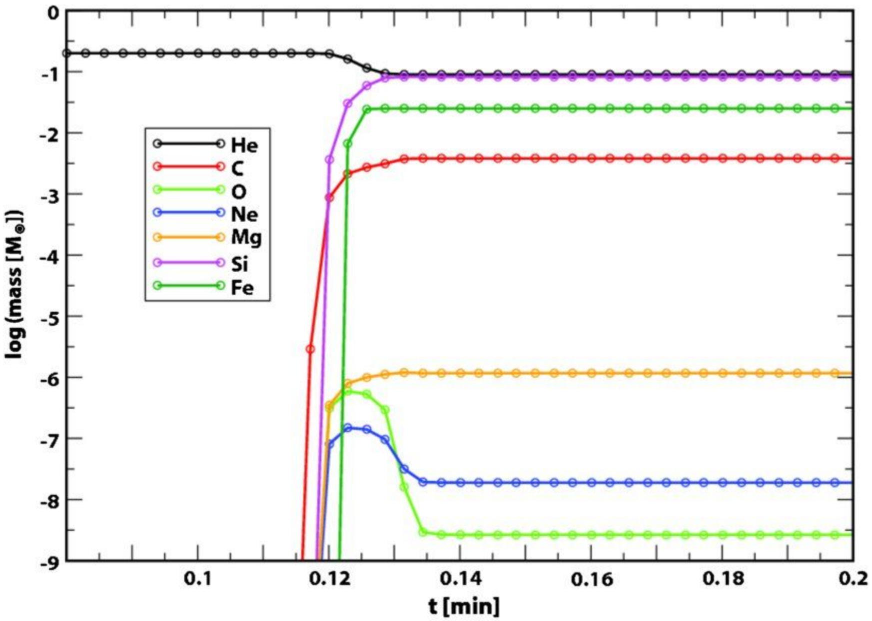



Top: Greene & Ho (2005)
Bottom: Nyland et al. 2017



# Tidal Disruptions: TDEs of white dwarfs and off-nuclear TDEs




Rosswog et al. (2009)

Tidal ignition -- could produce Ca gap transients, but no X-rays seen so far (Sell et al. 2018)

See also suggestions of having seen WD TDEs from Irwin et al. (2010), Perley et al. (2019)

Everything we've seen so far has a more mundane alternative explanation, but there could be clear signatures from this!

# The future

- Gravitational waves:
  - LISA could detect lots of these mergers
  - Maybe pulsar timing if Sgr A* has IMBH companion as suggested by Naoz et al (2020)
  - At low mass end of IMBHs, harmonics could creep into LIGO band
- X-rays:
  - Better collecting area to do timing (e.g. STROBE-X or Lynx) for low mass AGN
  - Spectral state determinations in nearby galaxies (FORCE)
- Optical/IR:
  - Better astrometry, do mass measurements on smaller scales in AGN
  - IR nebular lines (Cann et al. 2020)
- Radio
  - Nearby/globular clusters: look for fainter sources, wandering black holes using proper motions
  - Better pulsar measurements