Intermediate-mass black holes with HARMONI

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Black holes

What, where, how?

- stellar mass $\sim 10^1\, M_\odot$
- supermassive $10^6\, M_\odot - 10^{10}\, M_\odot$
- intermediate (IMBH) $10\, M_\odot - 10^6\, M_\odot$

Black holes

What, where, how?

- stellar mass $\sim 10^1\, M_\odot$
  - we know both where and how they form (stars $\gtrsim 20\, M_\odot$)
- supermassive $10^6\, M_\odot - 10^{10}\, M_\odot$
  - know where, not how (AGN)
- intermediate (IMBH) $10\, M_\odot - 10^6\, M_\odot$
  - where? how?
  - supermassive BHs start off as IMBHs?

IMBHs

How to make an IMBH?

- Remnants of Pop III stars?
- Runaway growth from stellar collision in dense star cluster?
- Progenitors of supermassive BHs?

What would we like to probe?

- What are the masses $M_\bullet$ of these IMBHs?
  - show that at least one exists
- their mass function? Any correlations with host?
- environment around IMBH.

How to detect IMBHs

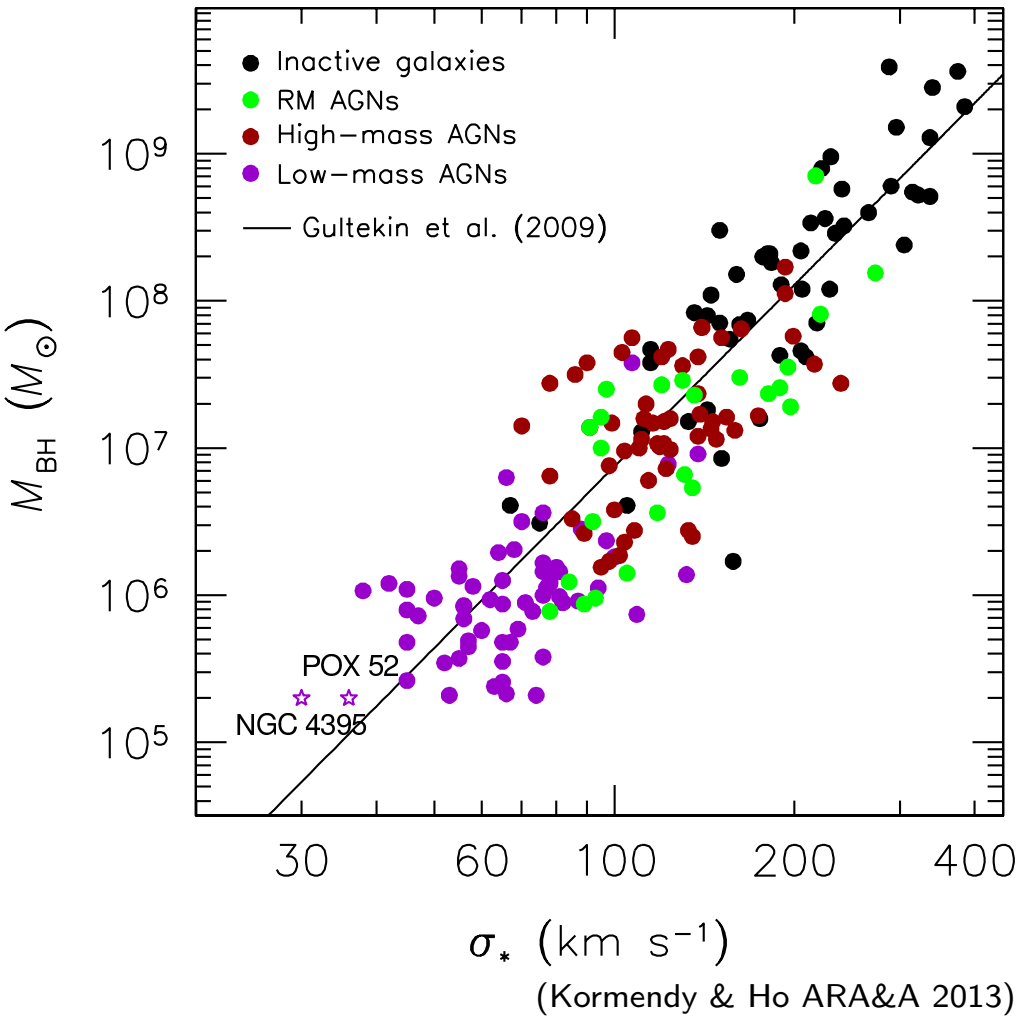
1. ~~Gravitational waves~~
   - detect merger of IMBH with stellar-mass BH...?
2. ~~Microlensing~~
   - look for long-duration events, but v_{sky}? distances?
3. ~~ULX~~
   - ...

Dynamics of:

4. low-luminosity AGN in dwarf galaxies
   - e.g., NGC 4395 (Filippenko & Ho 2003),
   - POX 52 (Barth et al 2004)
5. Globular clusters
6. Nuclear stellar clusters, esp late-type spirals

IMBHs in active galaxies?

(e.g., Barth, Greene, Ho 2004)



(Kormendy & Ho ARA&A 2013)

Purple: $M_\bullet \sim rv^2/G$, taking

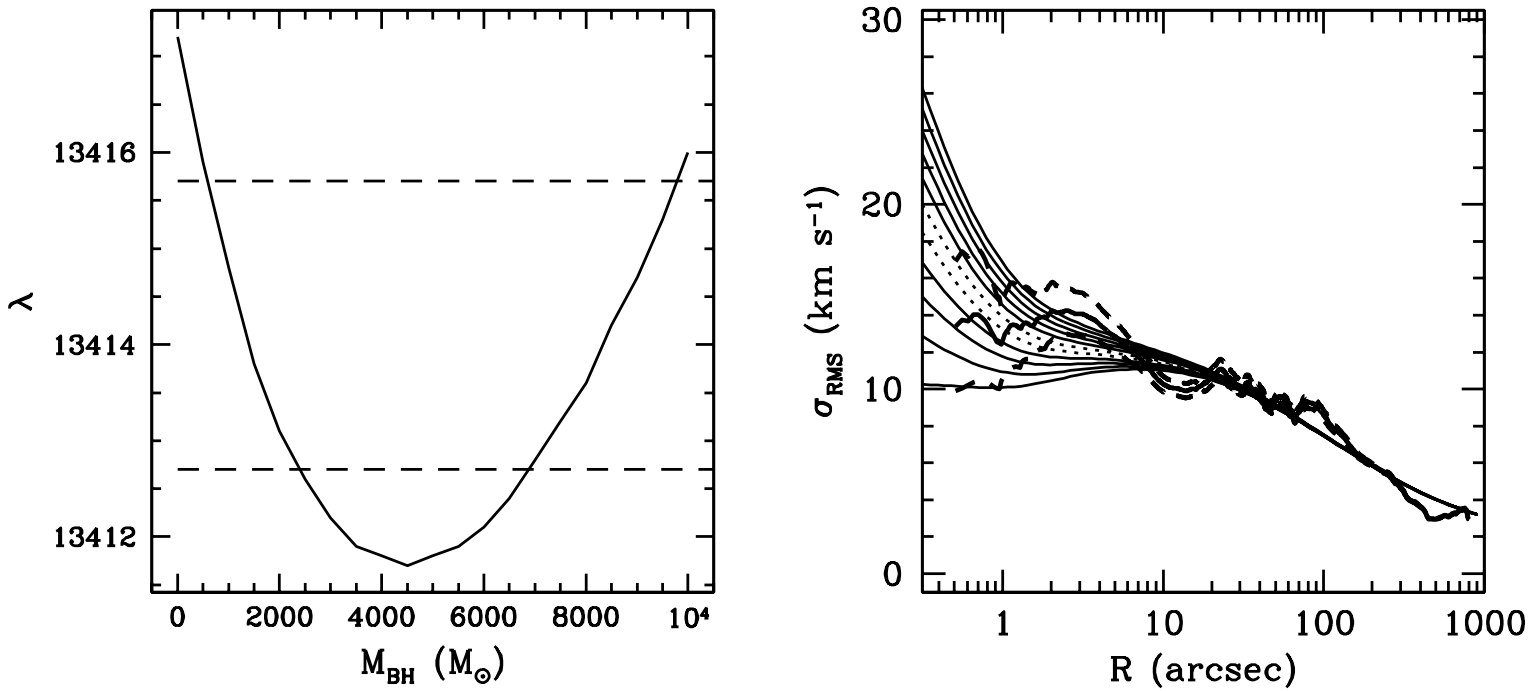
- r from extrapolation of $r_{\rm BLR}$–$L_{\rm AGN}$ correlation,
- v from Hα linewidth.

Indirect!

Something for high-contrast HARMONI?

M15: a core collapsed globular cluster
(Gerssen et al 2002)

HST WFPC+STIS provide $I(R)$, $\sigma(R)$ (dashed below).



Solid curves on RHS: models for different $M_\bullet$

Equipartition $\Rightarrow$ heavier bodies sink to centre.
Stars move in potential $\Phi_\star(r) + \Phi_{\rm dark}(r) + \Phi_\bullet(r)$.
What to take for $\rho_{\rm dark}(r)$?

Rely on conversations with Messrs Fokker, Planck and colleagues.

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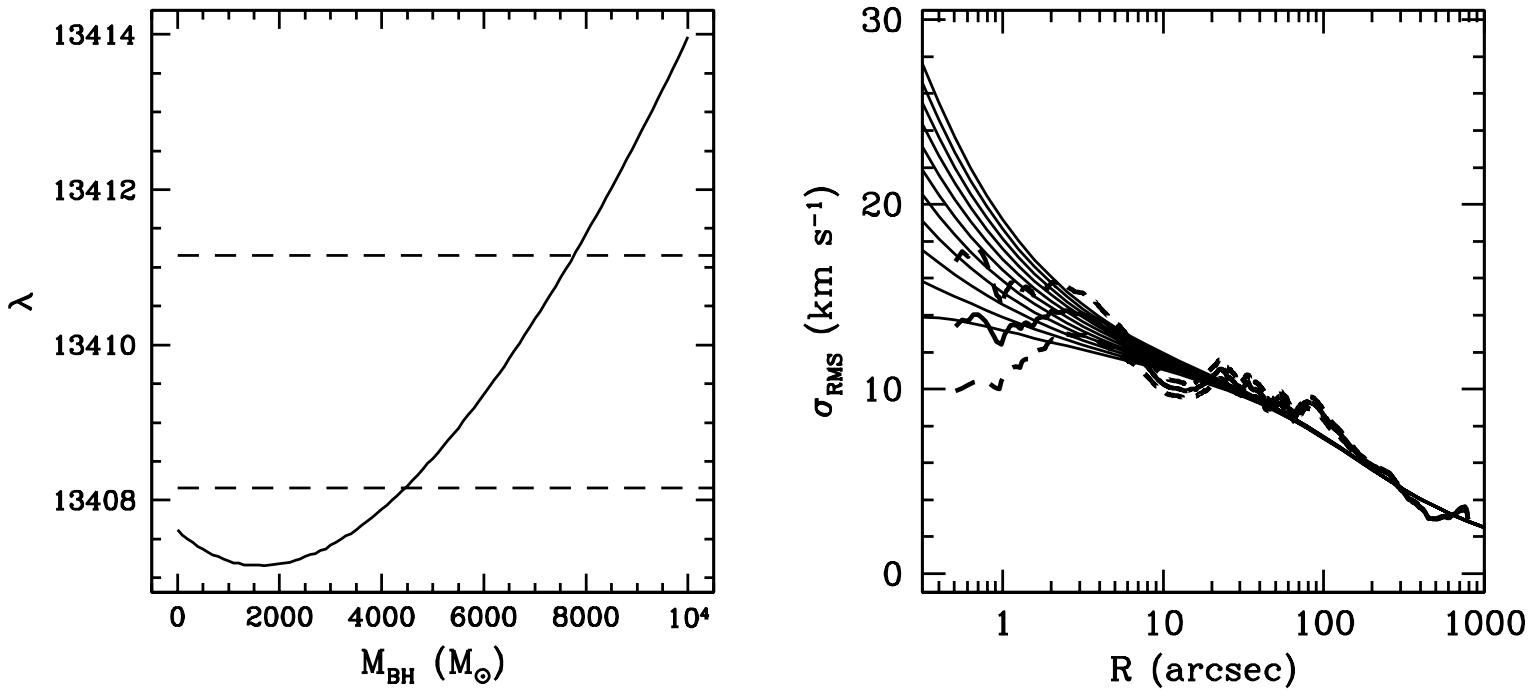

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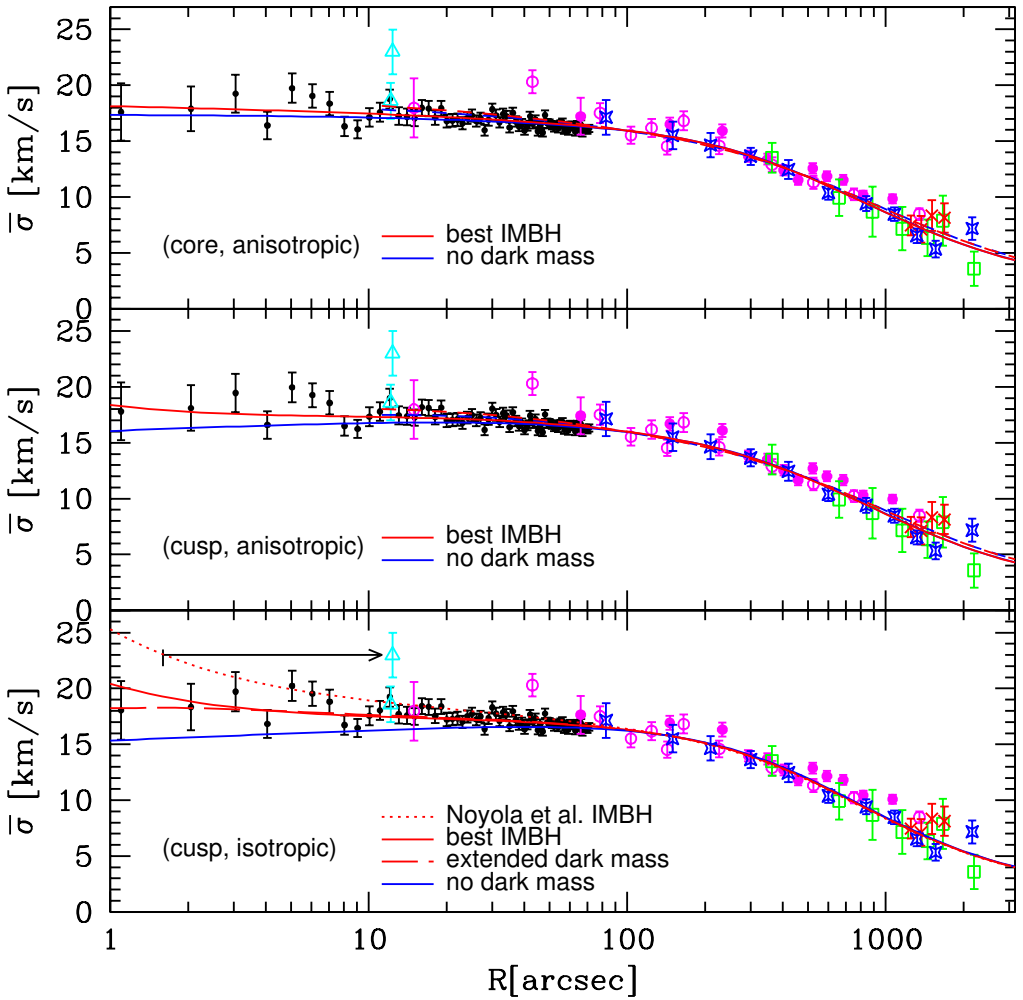
An IMBH in the globular cluster/dwarf nucleus ω Cen?

van der Marel & Anderson 2010



σ_R, σ_ϕ from 50,000 PMs.

Disagree with GMOS σ_z (Noyola+2008).

Where is the centre?

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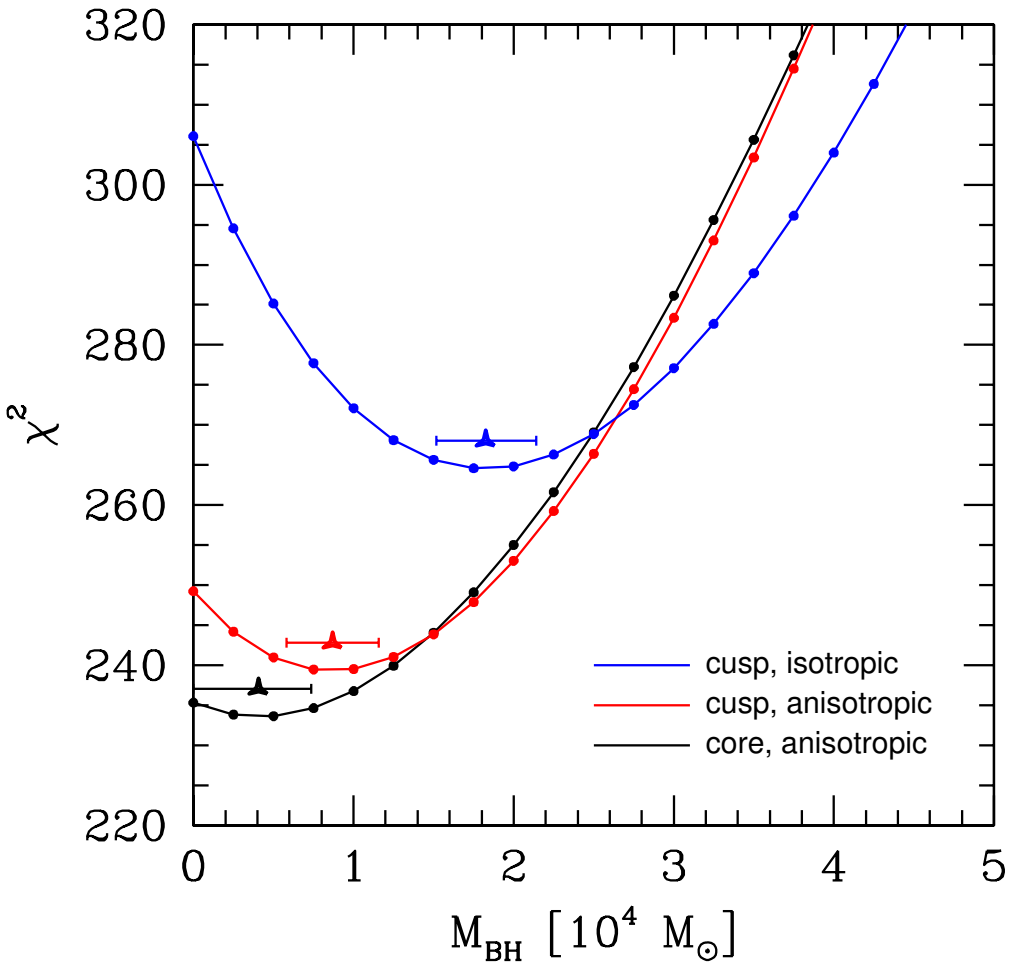


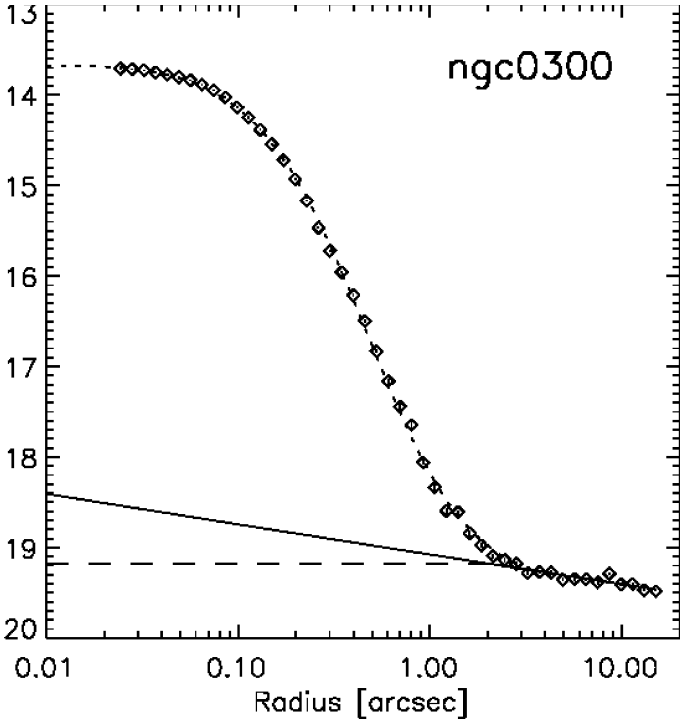
Present models rely on :

1. an assumed geometry + centre location
2. assumed $\Sigma(R)$ profile
3. assumed anisotropy profile
4. binned velocities

Other GCs: G1 (Gebhardt+05), NGC 5286 (Feldmaier+13), M3, M13, M92 (Kamann+14).

Nuclear stellar clusters (NSCs)

(e.g., van der Marel et al. 2007)



Present in $> \frac{1}{2}$ of early- and late-type spirals, dEs, low-L Es.
Only "hot" component in late-type spirals. Best studied there.

Gross properties of NSCs

Size $r_{\rm h} \sim 3\,{\rm pc}$.

Luminosity $L \sim 10^{6-7}\,L_{\odot}$

Dispersion $\sigma \sim 20 {\rm km\,s}^{-1}$

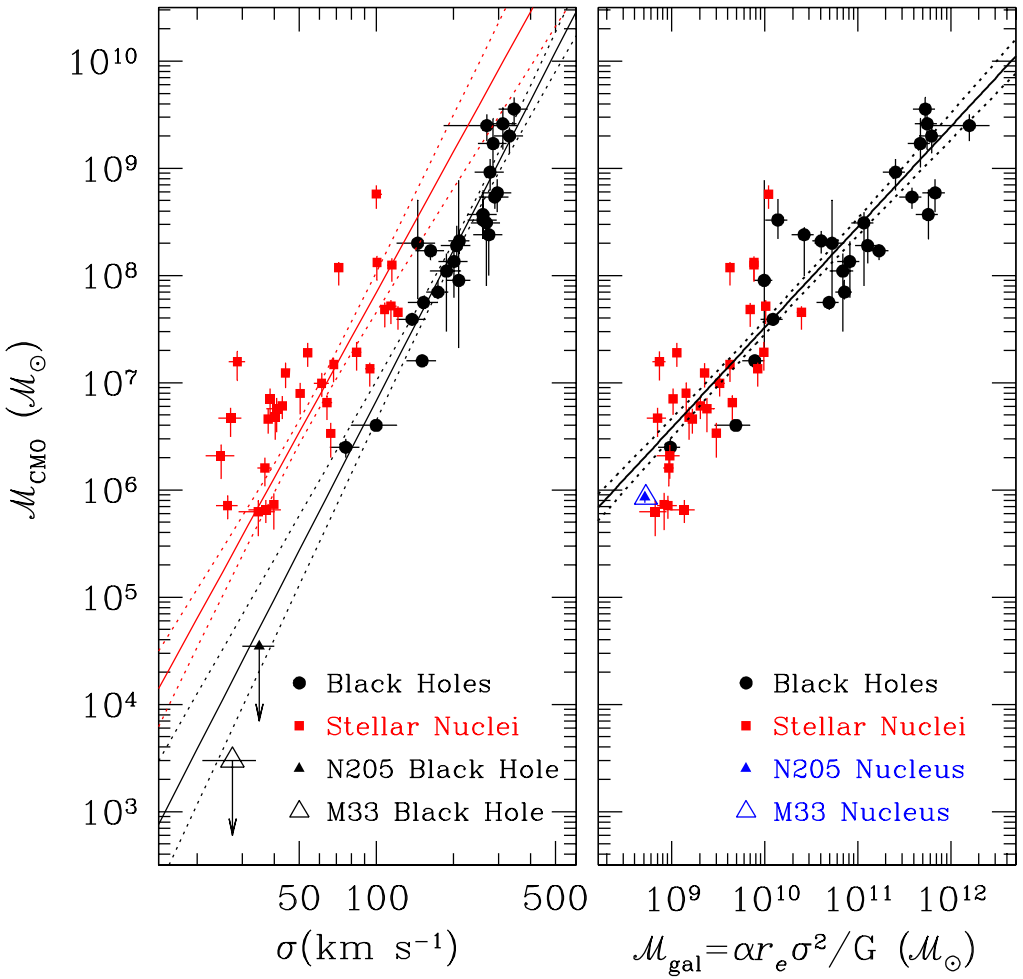
Overlap with large GCs (G1, ω Cen). Similar to UCDs.

Bursty SFH, SF detectable within last $10^8\,{\rm yr}$.

Some have AGN (Seth+2008; Graham & Spittler 2009).

Aside: Scaling of NSCs in *early-type* Virgo galaxies

(e.g., Wehner & Harris 2006; Côté et al 2006)



(How to subtract underlying component?)

$L \sim 10^6 L_\odot$, $r \propto L^{0.5}$

Masses of NSCs in late-type spirals
(Neumayer & Walcher 2012)

- only $\sim 10^1$ dynamical mass measurements of NSCs
- zillions from pop synth
- both methods give broadly consistent answers.

Most of the virial $M_{\rm cluster}$ estimates (and bounds on $M_\bullet$):

Galaxy	Type	σ (km/s)	Dist (Mpc)	M_{BH} $(M_\odot)$	M_{NC} $(M_\odot)$	Sersic n	M_{Bulge} $(M_\odot)$	Ref
group 1				×		×		
NGC 300	SAd	13 ± 2	2.2	$< 1 \times 10^2$	$1{\times}10^6$	1.1	–	1
NGC 428	SABm	24.4±4	16.1	$< 3 \times 10^4$	$3{\times}10^6$	1.05	–	1
NGC 1042	SABcd	32±5	18.2	$< 2.5 \times 10^4$	$3{\times}10^6$	1.15	–	1
NGC 1493	SBcd	25±4	11.4	$< 2.5 \times 10^5$	$2{\times}10^6$	2.36	–	1
NGC 2139	SABcd	17±3	23.6	$< 1.5 \times 10^5$	$8{\times}10^5$	1.53	–	1
NGC 3423	SAcd	30±5	14.6	$< 1.5 \times 10^5$	$3{\times}10^6$	1.20	–	1
NGC 7418	SABcd	34±5	18.4	$< 1.5 \times 10^5$	$6{\times}10^7$	–	–	1
NGC 7424	SABcd	16±2	10.9	$< 1.5 \times 10^5$	$1{\times}10^6$	0.91	–	1
NGC 7793	SAd	25±4	3.3	$< 5 \times 10^3$	$8{\times}10^6$	1.27	–	1

All based on *single* central σ per galaxy.

What can HARMONI do for NSCs?

Toy NSC model based on NGC 7424 (Walcher et al 2005):

- Total mass $10^6 M_\odot$,
- scale radius 2 pc, with
- central I-band sb 16 mag/arcsec^2.
- $M_\bullet = 3 \times 10^4 M_\odot$.

Major simplification

- All stars in model have same K-band spectrum.
- ...and we ignore discreteness effects...

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Simulated observations – really, really overidealised

- NSC placed at 10 Mpc.
- Viewed through 4mas spaxels + E-ELT-ish psf, and
- range of different spectral resolutions.
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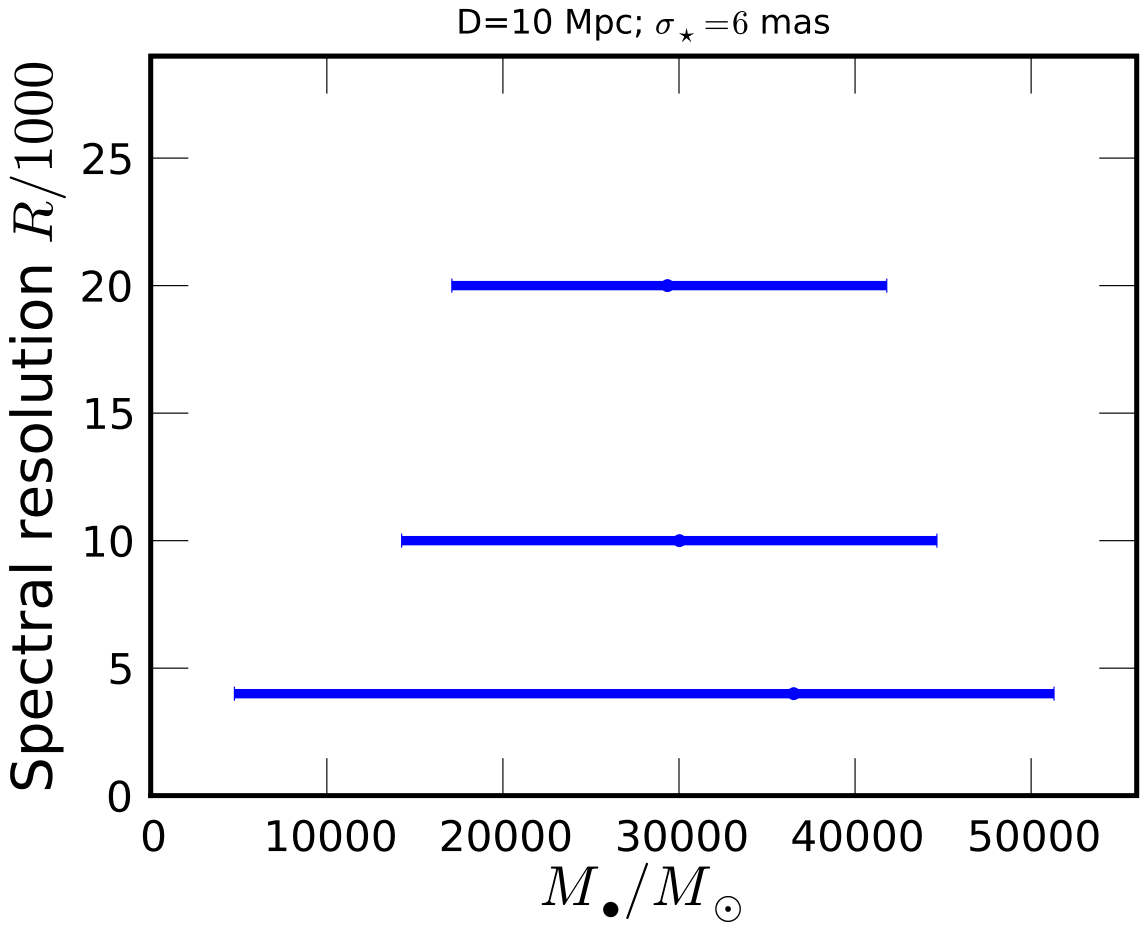
Modelling: Fit Schwarzschild models directly to spectra.
Single free parameter: $M_\bullet$. (No systematics.)

NSCs with E-ELT

How securely could we detect an IMBH?



Better test: discrete models → HSIM → Jeans.

Summary

HARMONI will extend BH MF to $M_\bullet < 10^6 M_\odot$

– just point it at nearby LLAGN, GC, NSCs.

How low we go depends on our modelling tools.

Challenge: "semi-resolved" stellar pops

Two sorts of modelling needed:

1. need psf fitting; per-spaxel deblending
   - synergy with MICADO
   - want E-ELT Pampelmuse++ (Kamann+13,14)
2. Dynamical modelling of these spectra
   - model spaxel-by-spaxel without further binning,
   - or assumptions about $\Sigma(R)$ profile.
   - Still need to guess location of centre, $\Phi_{\rm dark}(r)$

Payoff – just $M_\bullet$? Meh!

Probe phase-space distribution of different stellar pops:

- better constraints on Φ (Battaglia; Walker & Peñarrubia)
- test NSC formation scenarios