Kinematical evidence for an intermediate-mass black hole in M54

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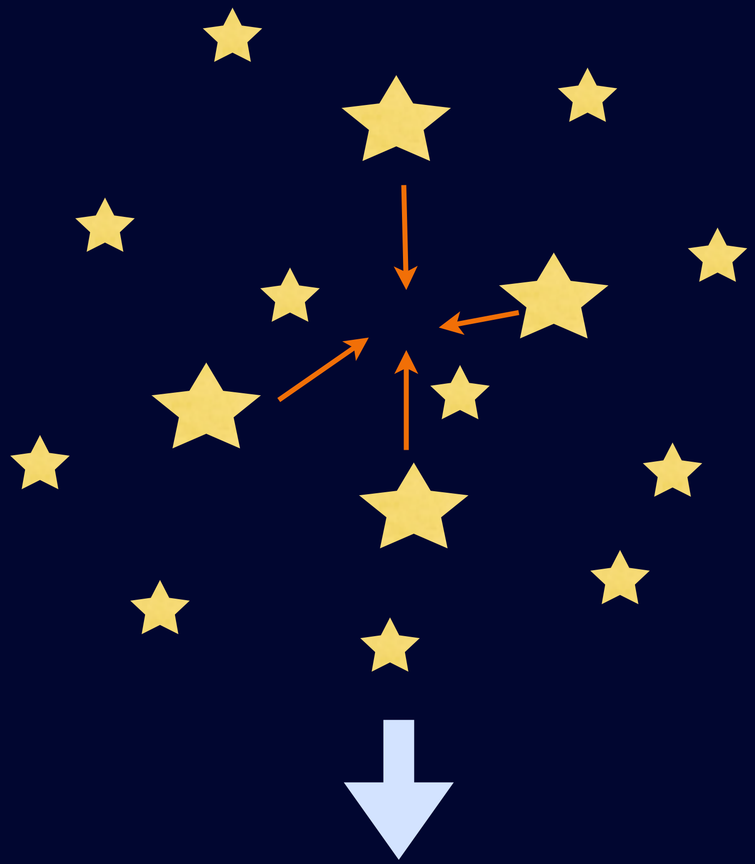
History and motivation for finding IMBHs in GCs

- X-ray sources (Silk & Arons, 1975)
- Analytical models from Bahcall & Wolf (1976)
- Small sphere of influence, only resolved until recently
- Seeds necessary to form SMBHs
- Possible extension of M_{BH}-sigma relation
- Possible sources for gravitational wave detectors

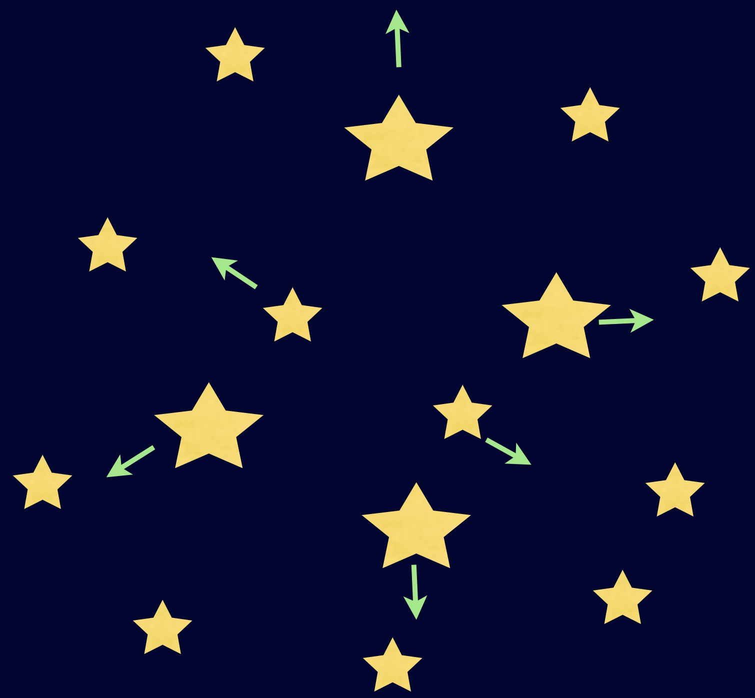
Basic facts of star cluster dynamics

Two-body relaxation



Core Collapse

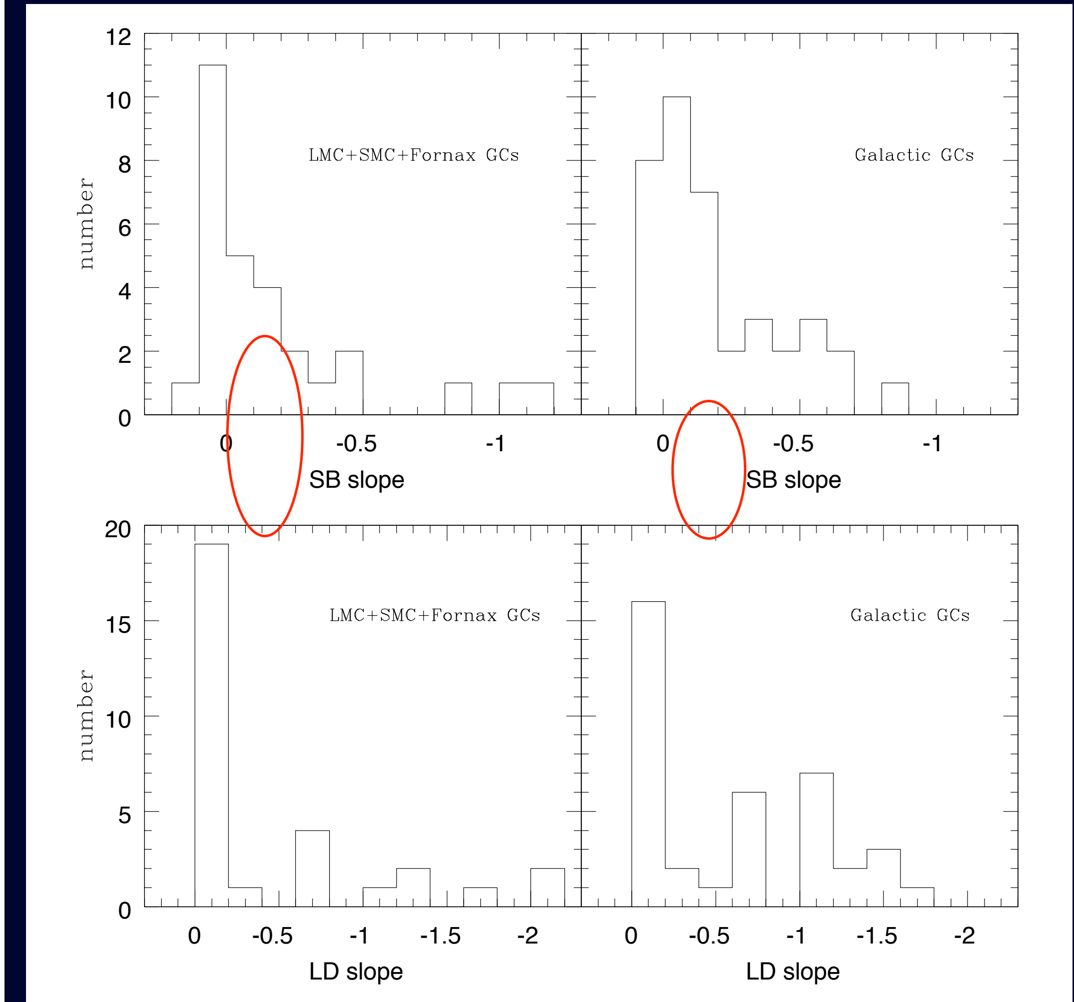
Heating mechanism



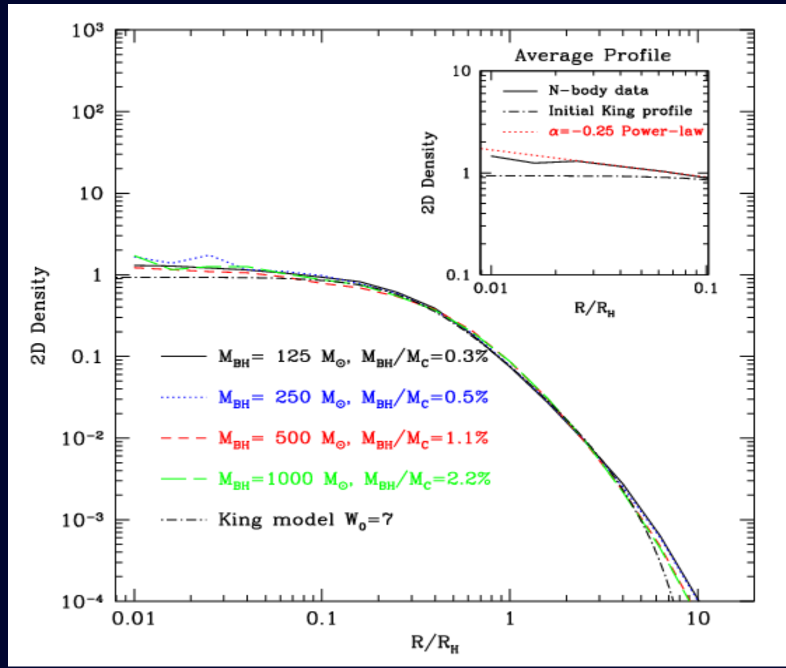
- Binaries
- Stellar mass black holes
- Stellar mass loss
- White Dwarf kicks
- Intermediate mass black hole

SB slopes distributions

~20% of HST-based SB profiles have central slopes matching N-body models with central BHs



Noyola & Gebhardt, 2006, 2007



Baumgardt et al (2005)

N-body simulations of star clusters containing central black holes predict a central shallow cusp of slope ~-0.2 in surface density.

Kinematic evidences for black holes in GCs

M15

- Evidence for central black hole is inconclusive
- 3400 $M_\odot$ inside 0.05 pc
- Possible central rotation
- SB fits models for post core-collapse bounce

van den Bosch et al., 2006;
McNamara et al., 2003;
Gerssen et al., 2002

G1

- 20,000 $M_\odot$ central black hole from orbit-based models
- Alternative model fits kinematics. Requires two merging clusters
- Central rotation detected
- Flat central core in SB
- Central X-ray and radio emission detected

Gebhardt et al., 2005;
Baumgardt et al., 2003
Pooley & Rappaport, 2006;
Ulvestad et al., 2007

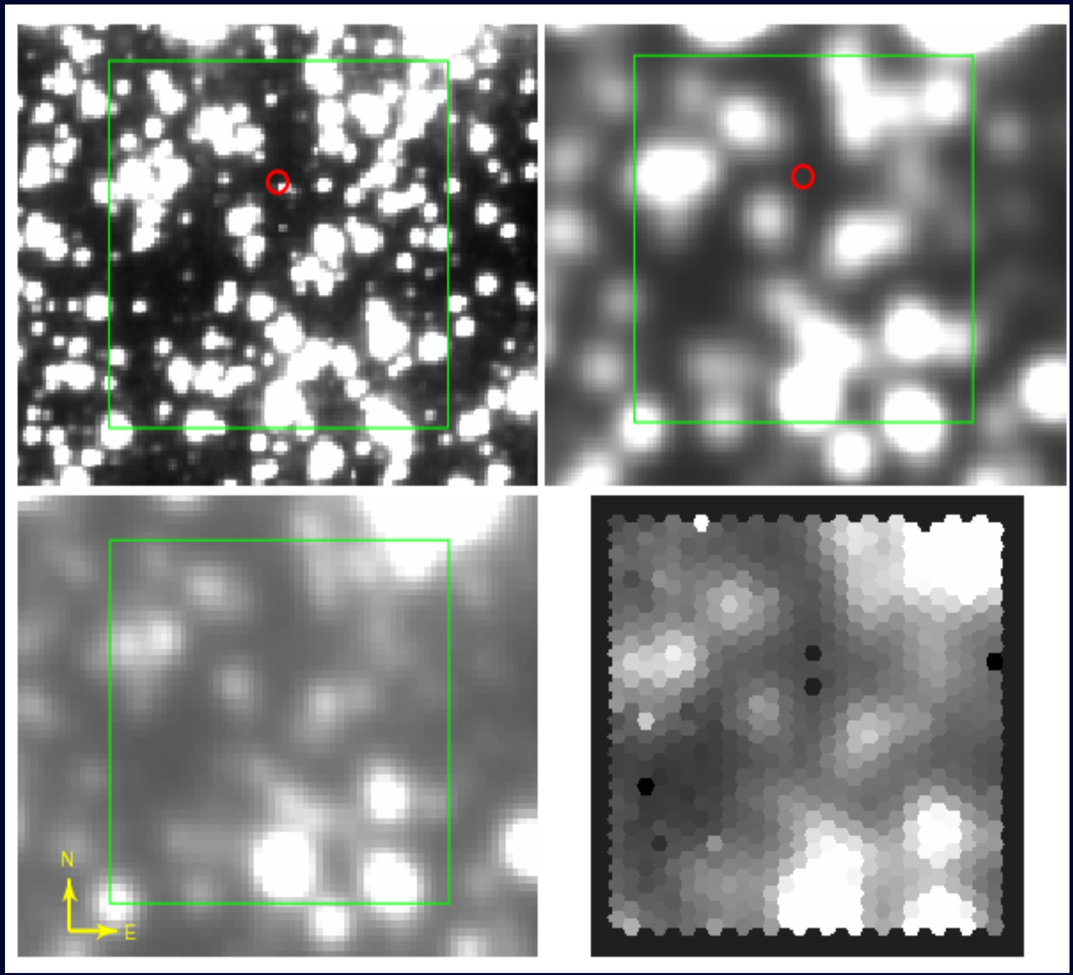
NGC 6752

- Unusual millisecond pulsar population
- Measured central M/L implies 1000-2000 $M_\odot$ inside 0.08 pc
- Configuration could come from single or double black hole of 200-500 $M_\odot$

Colpi et al., 2003;
D’Amico et al., 2002

Omega Centauri

ACS **convolved ACS**



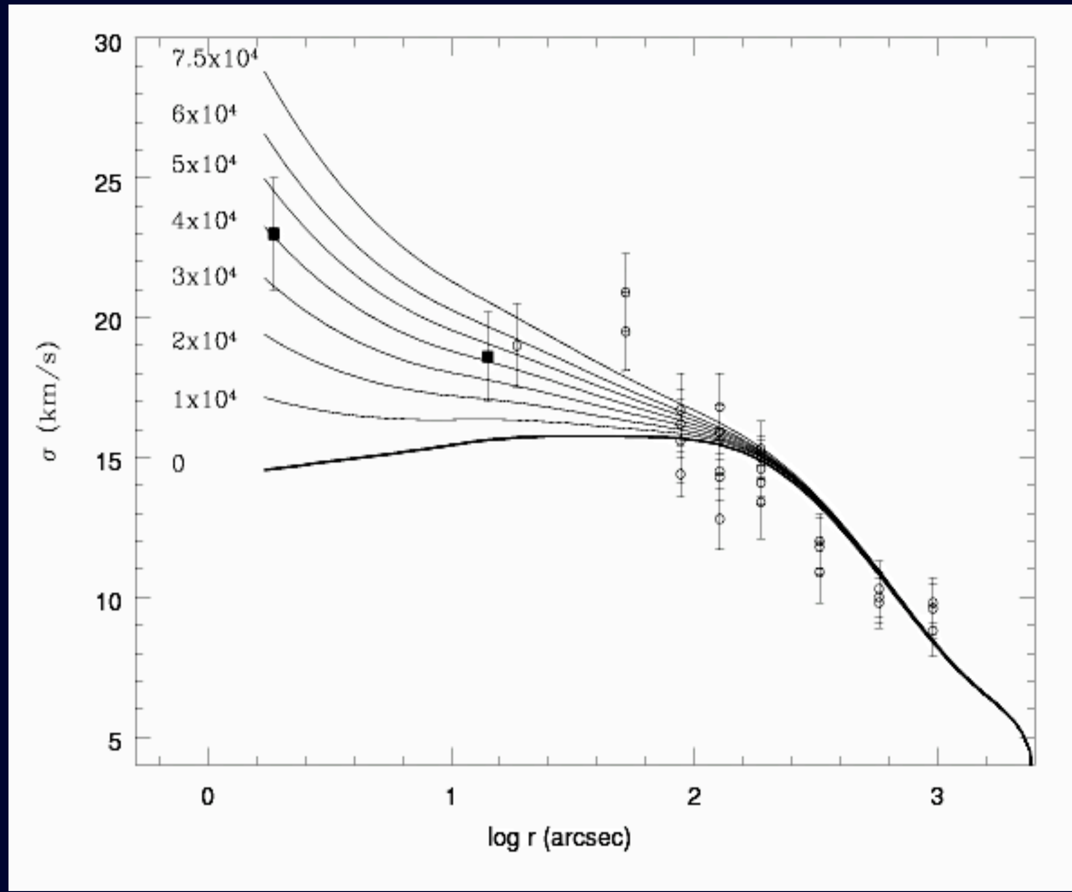
GMOS acquisition **GMOS**

Noyola, Gebhardt & Bergmann 2008

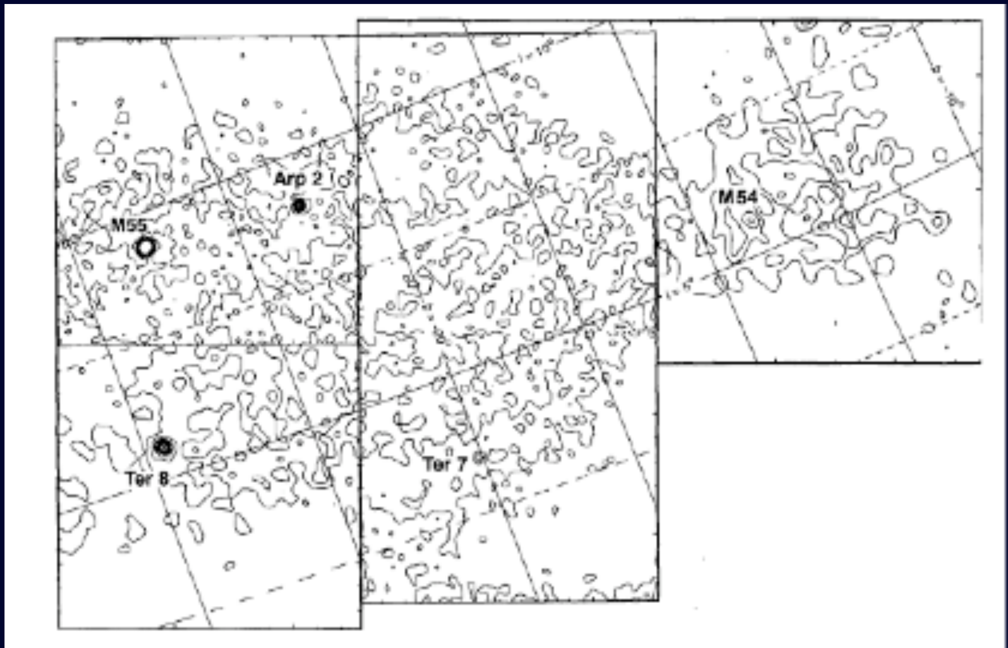
- Kinematics from Gemini-GMOS IFU
- Use Calcium triplet region
- Velocity dispersion measured from integrated spectra in two 5”×5” fields
- Velocity dispersion rise detected between the fields at 14” (18.6 km/s) and the central field (23.0 km/s)

Dynamical models

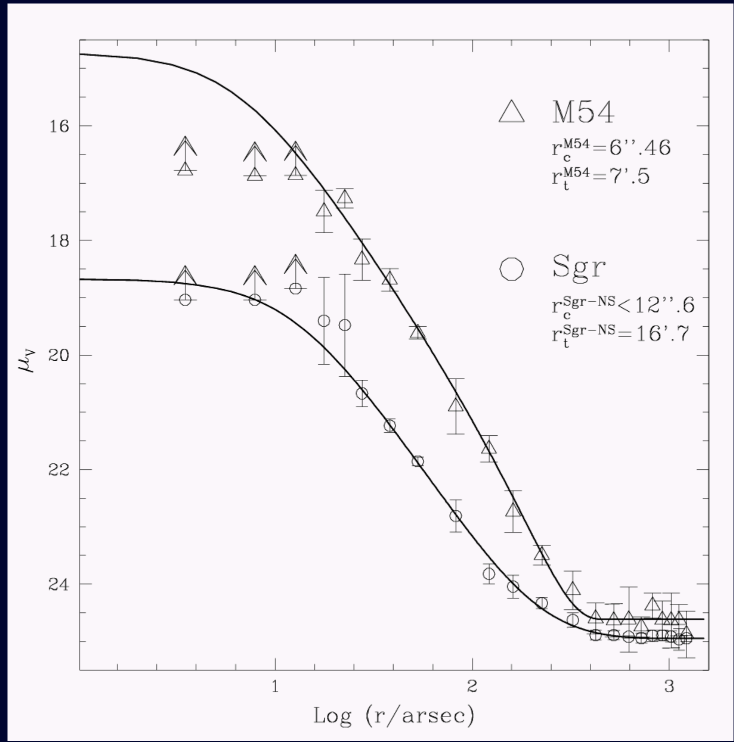
- Central kinematics from GMOS, outer points from individual radial velocities
- Spherical dynamical models assuming a constant M/L ratio and various black hole masses
- Spherical models consistent with a black hole of $4\pm1\times10^4$ $M_\odot$



M54 and the Sag dwarf



Ibata et al, 1997

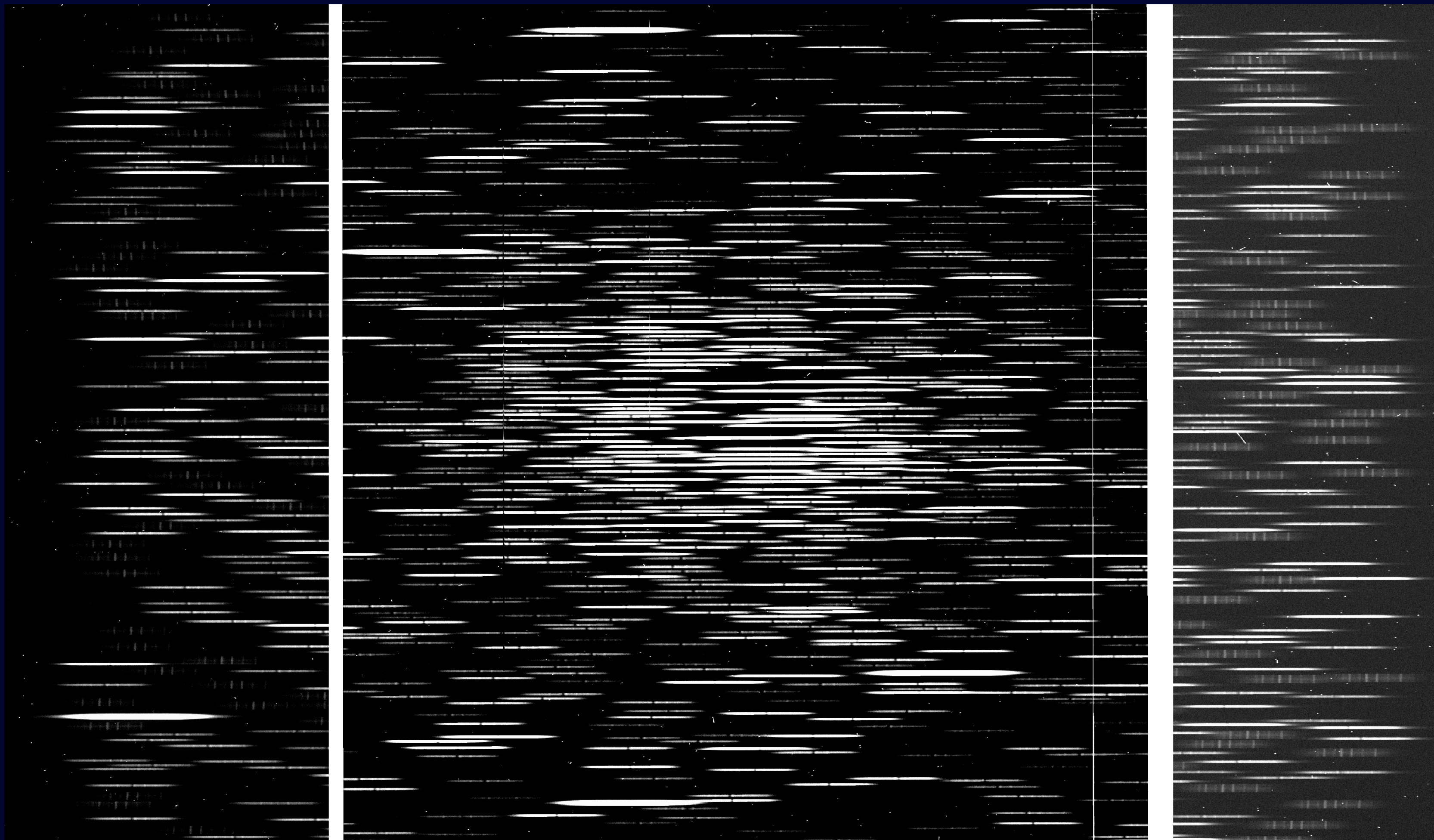


Monaco et al, 2005

M54 could be the nucleus of the Sag dwarf galaxy

GMOS data for M54

GMOS



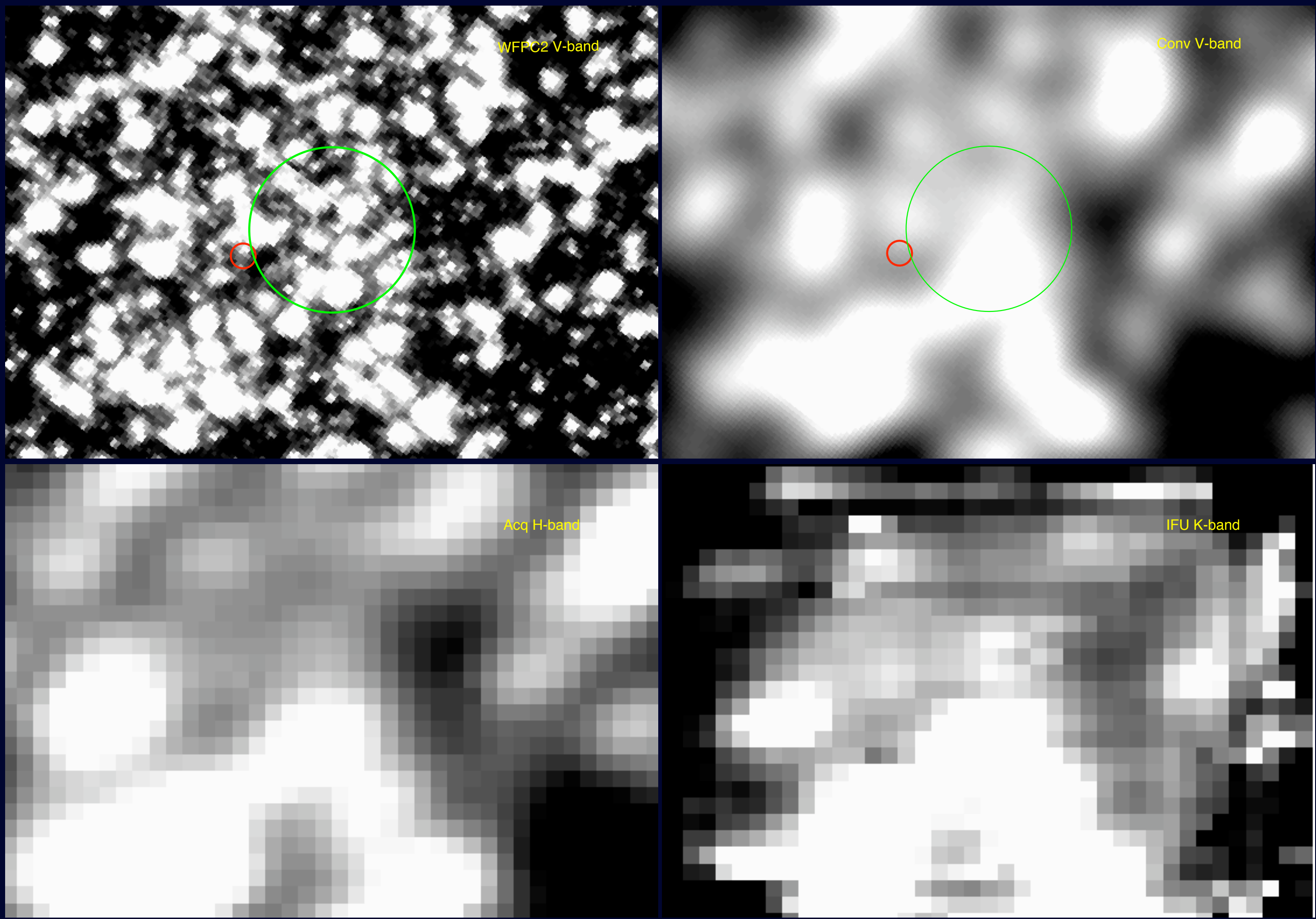
H-alpha filter; ~700 velocities

Noyola, Gebhardt & Bergmann., 2009, in prep

GNIRS data for M54

WFPC2 V-band

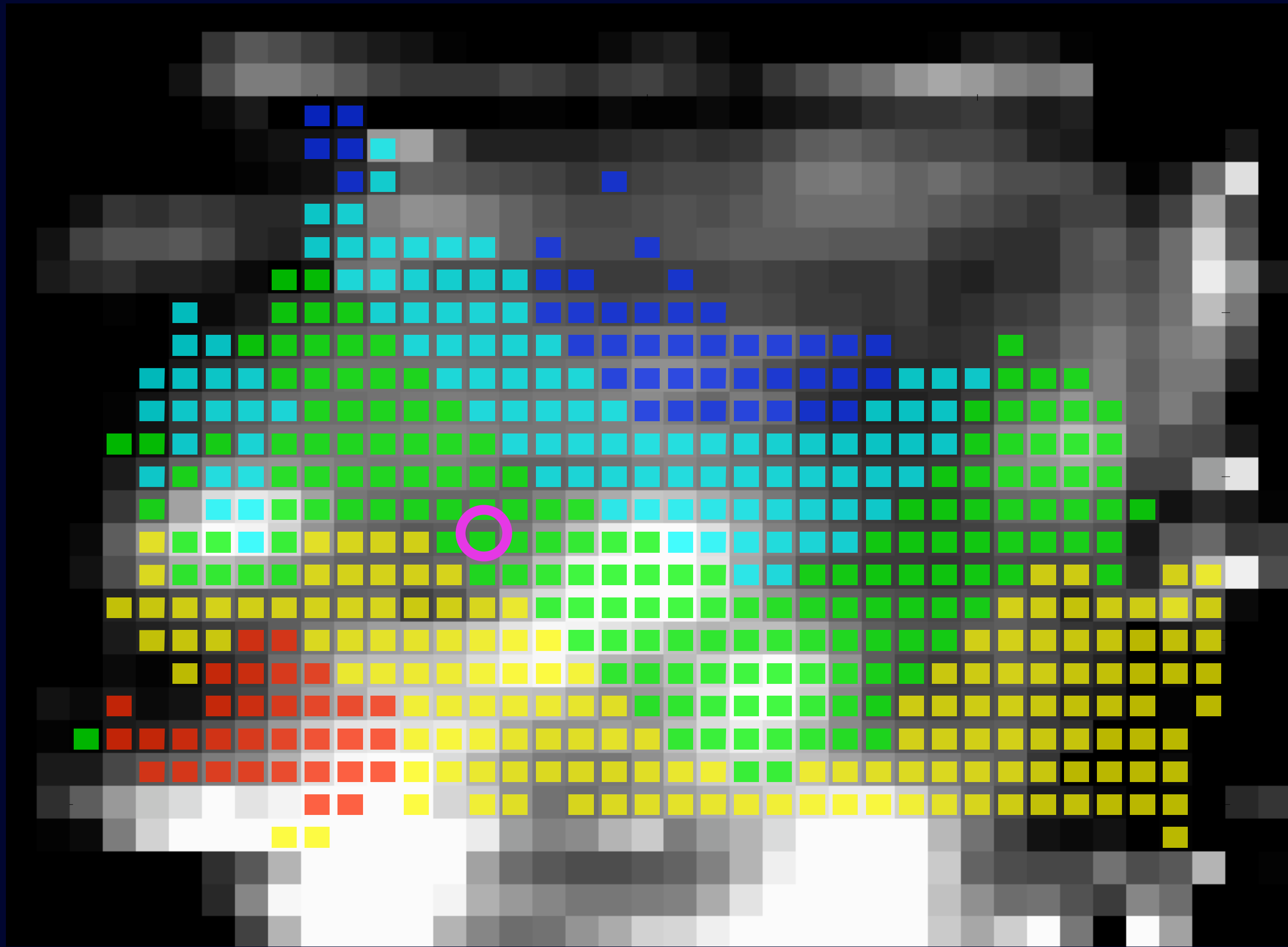
WFPC2 convolved



Gemini aqc

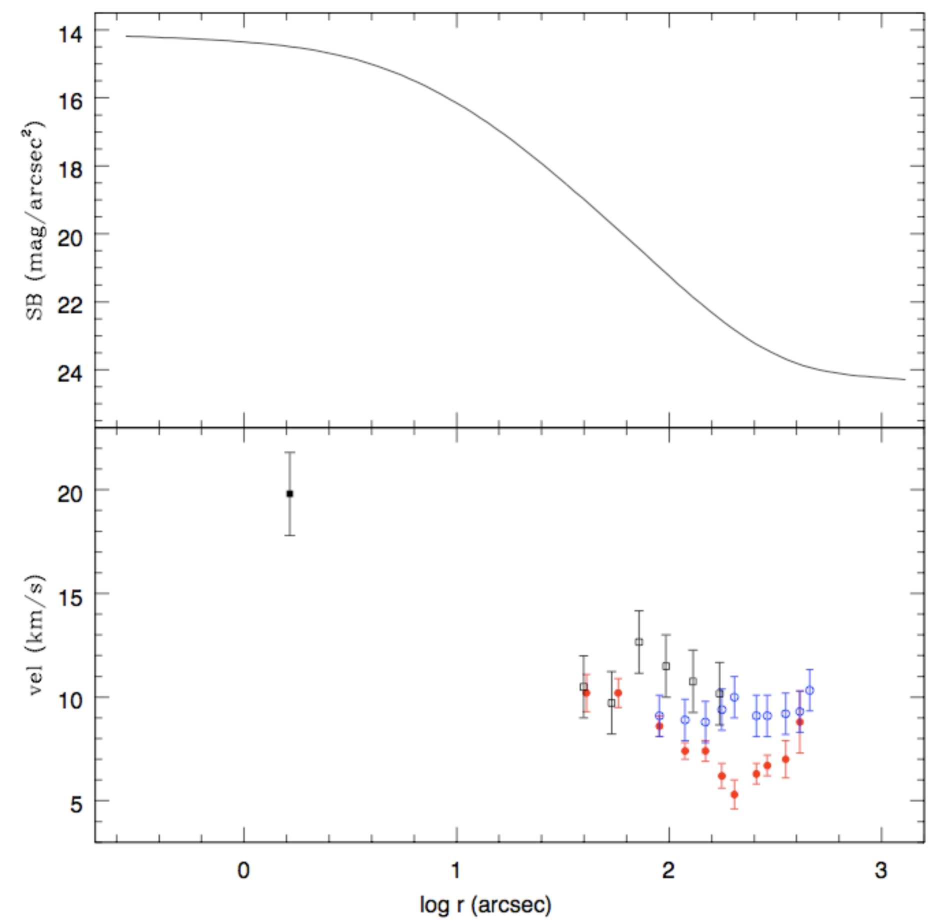
GNIRS reconst.

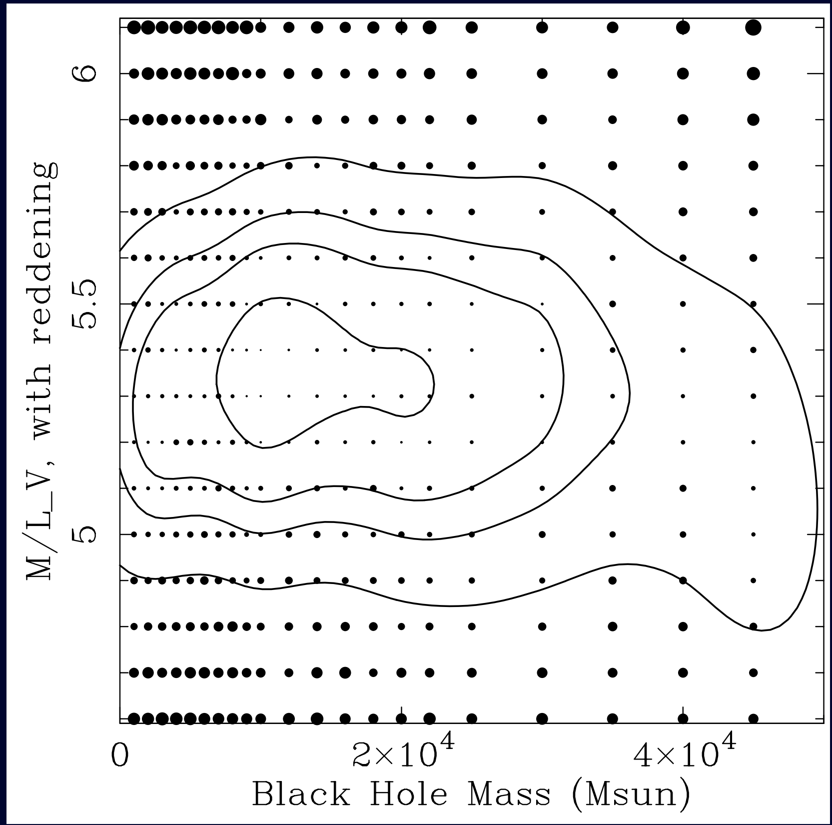
Velocity map



- Use CO bandhead to measure kinematics
- Detect rotation pattern with 13 km/s amplitude, $\sigma = 15$ km/s

Models





- Density and velocity inputs completed with other data

Bellazzini et al., 2008; Monaco et al., 2005

- Best fit model has BH mass of 10^4 $M_\odot$
- No BH model requires some radial anisotropy

Conclusions

- M54 shows a shallow central density cusp
- GMOS data provides ~500 individual radial velocities outside the core
- GNIRS data shows clear rotation at the center
- Best fit model for M54 requires a $10^4\ M_\odot$ central BH
- Stability tests are crucial to evaluate alternative scenarios