Central supermassive black holes from SINFONI observations

R.P Saglia, MPE

with

R.Bender, N.Nowak, P. Erwin, J. Thomas

Gas and stars in Galaxies – A Multi-Wavelength 3D Perspective
Garching, 10th June 2008
Outline

- Introduction: status of present direct (dynamical) SMBH mass measurements
- Near-IR integral-field observations of galactic nuclei with SINFONI
- What can we measure at the diffraction limit
- Dynamical Modeling
- The $M_{\text{BH}} - \sigma$ relation
- Conclusions
Supermassive black holes

• All galaxies with a massive (classical) bulge component host a SMBH. The mass of the SMBH correlates with the velocity dispersion and the luminosity/mass of the bulge
• strong link between bulge formation and black hole growth
Classical- and pseudo-bulges

- Two different bulge-types:
  - *classical bulges*: mini-ellipticals, formed by mergers
  - *pseudobulges*: disk-like characteristics (e.g. rapid rotation), formed by secular evolution

M81: classical bulge

NGC1512: pseudobulge
Status

- few dynamical SMBH mass measurements (~40), mostly normal, massive E
- low-σ (<120km/s) and high-σ (>300km/s) regime not very well constrained
- very few non-E’s (pure disks, pseudobulges)
- few core ellipticals
- very few merger remnants and AGN
- Goals:
  - constrain $M_{\text{BH}}$-σ slope by measuring low- and high-σ range
  - measure $M_{\text{BH}}$ for “special” galaxies
Problems

• direct (dynamical) $M_{BH}$ measurements require a very high spatial resolution to resolve the sphere of influence (usually $<<1''$)
• high S/N (>30 per pixel) required (high surface brightness)
• strong dust obscuration in most disks, pseudobulges, AGN and merger galaxies
• in AGN: non-stellar emission dilutes spectral signatures
• dynamical modelling difficult if non-axisymmetries (bars) are present
SINFONI

- NIR-AO:
  - high spatial resolution <0.1"
  - less affected by dust
  - non-stellar contribution less strong (in AGN)
- SINFONI@VLT:
  - integral-field spectrograph SPIFFI+adaptive optics module MACAO
  - near-IR (1-2.5μm): J, H, K and H+K
  - FOV: 0.8” (25mas), 3.0” (100mas) and 8.0”
  - (250mas)
  - 32x64 spatial resolution elements
  - Spectral resolution in K: ~50 km/s
  - PARSEC: Na line laser, bright reference
  - “star” for AO observations
### Observed galaxies

**GTO time for SINFONI detectors and OmegaCam – R. Bender**

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>D (Mpc)</th>
<th>0.1'' pc</th>
<th>$\sigma$ (km/s)</th>
<th>$d_{soi}$ (’’’)</th>
<th>resolution (’’’)</th>
<th>Type</th>
<th>nucleus</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC1398</td>
<td>18</td>
<td>9</td>
<td>200</td>
<td>SBab</td>
<td>0.34</td>
<td>0.19..0.32</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC3368+</td>
<td>10</td>
<td>5</td>
<td>128</td>
<td>SBB</td>
<td>0.22</td>
<td>0.15..0.25</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC3627+</td>
<td>10</td>
<td>5</td>
<td>115</td>
<td>SABb</td>
<td>0.19</td>
<td>0.15/0.088</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC4501</td>
<td>13</td>
<td>6</td>
<td>161</td>
<td>SBA</td>
<td>0.33</td>
<td>0.13</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC4569</td>
<td>16</td>
<td>8</td>
<td>117</td>
<td>SABab</td>
<td>0.11</td>
<td>0.15</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC4579</td>
<td>16</td>
<td>9</td>
<td>154</td>
<td>SABb</td>
<td>0.23</td>
<td>0.15</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC4699</td>
<td>19</td>
<td>9</td>
<td>215</td>
<td>SABb</td>
<td>0.37</td>
<td>0.13</td>
<td>pseudo</td>
</tr>
<tr>
<td>NGC3412</td>
<td>11</td>
<td>5</td>
<td>101</td>
<td>SB0</td>
<td>0.11</td>
<td>0.13</td>
<td>low-σ</td>
</tr>
<tr>
<td>NGC3489</td>
<td>12</td>
<td>6</td>
<td>105</td>
<td>SAB0</td>
<td>0.12</td>
<td>0.08</td>
<td>low-σ</td>
</tr>
<tr>
<td>NGC4486a*</td>
<td>16</td>
<td>8</td>
<td>110</td>
<td>dE</td>
<td>0.13</td>
<td>0.10</td>
<td>low-σ</td>
</tr>
<tr>
<td>NGC5102</td>
<td>4</td>
<td>2</td>
<td>65</td>
<td>SA0</td>
<td>0.10</td>
<td>0.12/0.07</td>
<td>low-σ</td>
</tr>
<tr>
<td>Fornax A</td>
<td>18</td>
<td>9</td>
<td>228</td>
<td>E pec</td>
<td>0.44</td>
<td>0.12/0.08</td>
<td>core?</td>
</tr>
</tbody>
</table>

The 3D datacube

NGC 4486a Data Reduction: spred/gasgano
Stellar continuum

NGC1398  NGC3368  NGC3627  NGC4501
NGC4569  NGC4579  NGC4699  NGC3412
NGC3489  NGC4486a  NGC5102  NGC1316
Stellar Kinematics

- Maximum penalized likelihood method (Gebhardt et al. 2000): non-parametric fit of template spectra convolved with line-of-sight velocity distribution (LOSVD)
- Strongest spectral features in $K$ band: CO bandheads

In the following: Gauss-Hermite Parametrization $V, \sigma, h_3, h_4$
Stellar velocity fields

NGC 3368

NGC 3489

NGC4486a
Kinematics of NGC1316

Nowak et al. almost submitted

- $v$
- $\sigma$
- $h_3$
- $h_4$
NGC 5102: $\sigma \sim 65$ km/s
• near-IR ($K$ band) indices: Na I (2.21$\mu$m), Ca I (2.26$\mu$m), Fe I (2.23$\mu$m), CO (2.29$\mu$m)
• spectral synthesis models not yet available, but soon?

Credit: Silva, Kuntschner, Lyubenova
Gas emission

No flux calibration done yet, do not ask for gas masses!

$H_2 \ 1-0 \ S(1) \ \lambda \ (\mu \text{m})$
Gas maps

$H_2\ 1-0\ S(1)$

No emission detected in NGC 1398, NGC3412, NGC3489 NGC4486a, NGC4501, NGC4699, NGC 5102
Gas Kinematics: NGC 3627

Gas might not trace the gravitational potential

Stellar Velocity Field

H2 Velocity Field
Counterrotating gas in NGC 3368
Stellar dynamical modelling

• Schwarzschild (1979) orbit superposition technique (Gebhardt et al. 2003, Thomas et al. 2004/5):
  • gravitational potential (from light distribution of stars) + assumed mass-to-light ratio $M/L$ + assumed $M_{\text{BH}}$
  • generate orbit library (~2x7000 orbits)
  • find weighted superposition of orbits that reproduce light distribution and best fits the LOSVDs
  • repeat with systematically varied $M/L$ and $M_{\text{BH}}$
  • best-fitting $M/L$ and $M_{\text{BH}}$ follow from $\chi^2$ analysis
Photometry and longslit data

dust-corrected SOFI and NICMOS images

NGC 1316

Siding Spring 2.3m, CaT region
Best-fit model

NGC4486a
Black hole masses

NGC 4486a

NGC 1316

8 more to come in the next months!

<table>
<thead>
<tr>
<th>Galaxy</th>
<th>$M_\bullet$ (10^8 M_☉)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGC 1316</td>
<td>$1.5^{+0.25}<em>{-0.80} \times 10^8 M</em>☉$</td>
</tr>
<tr>
<td>NGC 3368</td>
<td>$6.3 \times 10^6 M_☉$</td>
</tr>
<tr>
<td>NGC 3489</td>
<td>$6.8 \times 10^6 M_☉$</td>
</tr>
<tr>
<td>NGC 4486a</td>
<td>$1.5^{+0.75}<em>{-0.79} \times 10^7 M</em>☉$</td>
</tr>
</tbody>
</table>
The $M_* - \sigma$ relation
Conclusions

• SINFONI delivers diffraction-limit 2D spectra that probe well the central regions of local galaxies
• 12 galaxies with low $\sigma$ and/or pseudo/classical bulges and/or merger remnant/AGN observed with SINFONI
• Stellar (and gas) kinematics measured to constrain
  • the mass of the central supermassive black hole
• Gas emission detected in 5 galaxies
• Modeling of 4 galaxies confirms predictions of the $M_\bullet - \sigma$ relation
• From Period 82 on: observations of local giant Es with $\sigma>$300 km/s and/or cores.