Nuclear dynamics of a nearby Seyfert with NIRSpec integral field spectroscopy

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Summary

- Observe the nuclear region of a nearby Seyfert galaxy NGC 4151 with NIRSpec IFU;
- Obtain stellar kinematic maps;
- Construct dynamical models to measure the mass of the central black hole;
- Compare with other methods for black hole mass determination.

Methods for measuring the black hole mass

- Reverberation mapping (few dozen AGNs);
- Gas dynamics ($\sim$ a dozen of galaxies);
- Stellar dynamics (Jeans, Schwarzschild, M2M models – few dozen);
- Maser emission (NGC 4258);
- Individual stellar orbits (Milky Way).

Black hole dominates the gravitational potential

inside the radius of influence: $r_{\rm infl} \equiv \dfrac{G\,M_{\rm BH}}{\sigma^2}$.

This is typically $\lesssim 1''$!

Reverberation mapping

Time delay τ between the continuum emission of the AGN and the flux from the broad emission-line region $\Longrightarrow$ size of the BLR

$R = c\tau$;

Emission line width V $+$

virial theorem $\Longrightarrow$

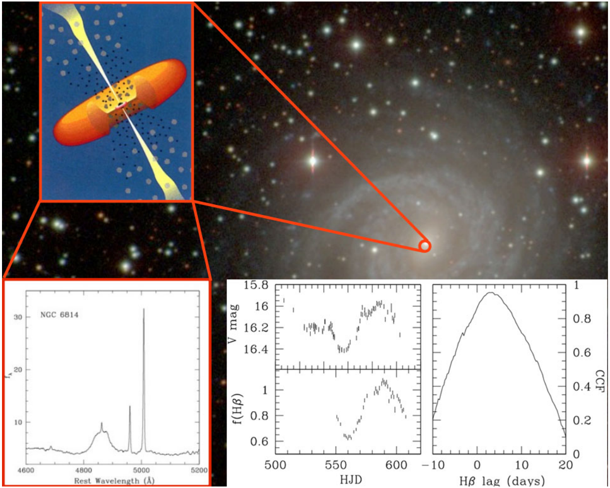
black hole mass

$GM_{\mathrm{BH}} = f\, R\, V^2$

geometric factor

$f \sim \mathcal{O}(1)$

(calibrated externally)



Gas dynamics

Velocity profiles of circumnuclear gas along several long slits;

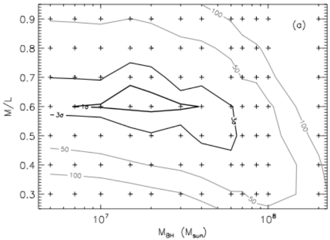
stellar surface brightness profile

+

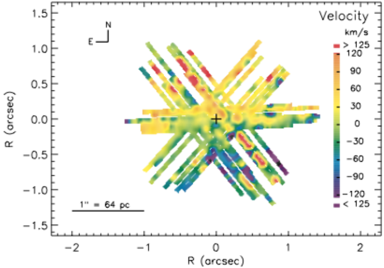
model parameters (M_{BH}, i, PA, M/L)

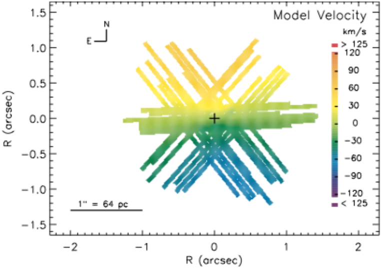
$\Downarrow$

comparison of 2d velocity fields



(assuming circular motion in a thin disk)

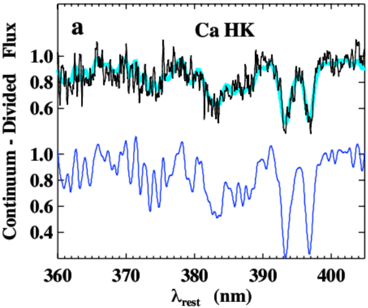


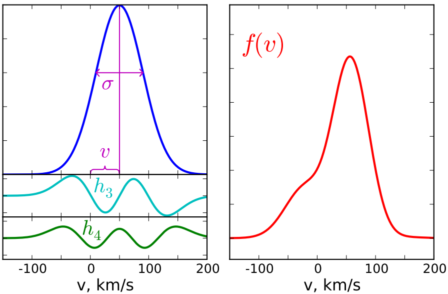


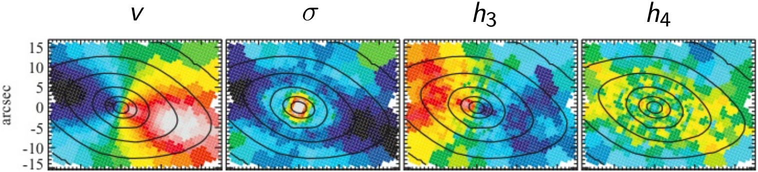
NGC4151, [Hicks&Malkan 2008]

Stellar dynamics: data

IFU spectroscopy $+$ template stellar spectra $\Longrightarrow$
2d kinematic maps with Gauss–Hermite parametrization of LOSVD
(need high S/N and velocity resolution to measure $h_3, h_4, \ldots$)



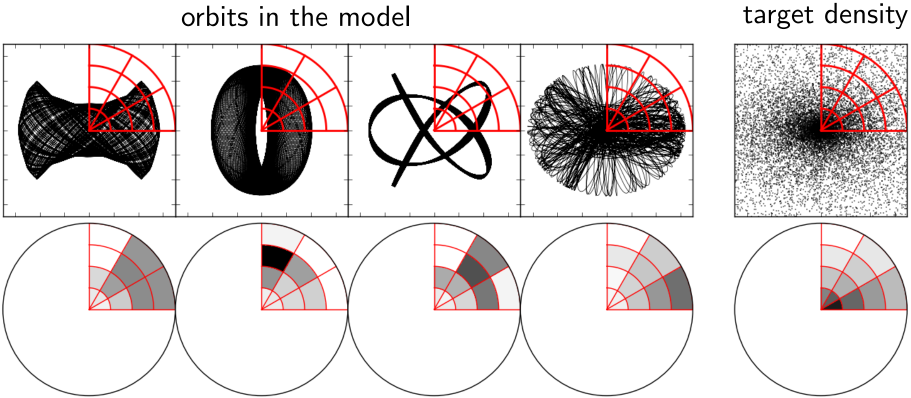




[from Cappellari+2007]

Stellar dynamics: Schwarzschild orbit-superposition models

1. For each choice of model parameters ($M_{\rm BH}$, i, M/L, ...) construct a library of possible orbits in the given potential.
2. Assign orbit weights to reproduce target density and kinematics.
3. Evaluate the quality of fit and repeat with different parameters.

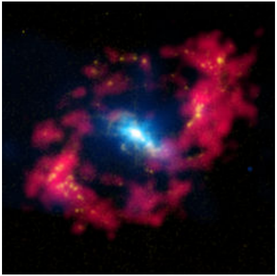


Choice of target: why NGC 4151?

- One of the best-studied Seyfert galaxies;
- $D \simeq 15$ Mpc, $\sigma \simeq 90 - 120$ km/s;
- $M_{\rm BH} \sim 4 \times 10^7\, M_\odot$, radius of influence $\sim 12 - 20$ pc $\sim 0.2'' - 0.3''$.

[A.Block]

[J.Schmidt]



[Wang+2010]

NGC 4151: a testbed for black hole mass determination

Black hole mass has been measured with different methods:

- Reverberation mapping:
  $M_{BH} = (4.1 \pm 0.7) \times 10^7\, M_\odot$ [Metzroth+2006],
  $M_{BH} = (4.6^{+0.6}_{-0.5}) \times 10^7\, M_\odot$ [Bentz+2006],
  using the geometric factor $f = 5.5$ [Onken+2004], or
  $M_{BH} = (3.6^{+0.5}_{-0.4}) \times 10^7\, M_\odot$ using the value $f = 4.3$ [Grier+2013].

- Gas dynamics:
  $M_{BH} = (3.0^{+0.8}_{-2.0}) \times 10^7\, M_\odot$ (AO long-slit) [Hicks & Malkan 2008].

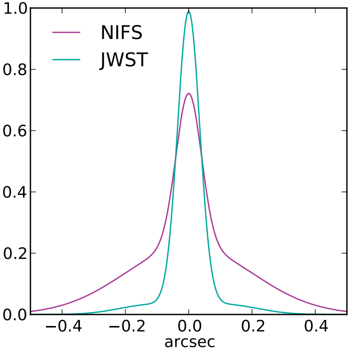
- Stellar dynamics:
  $M_{BH} = (4 - 5) \times 10^7\, M_\odot$ (non-AO long-slit) [Onken+2007],
  $M_{BH} = (3.8 \pm 1.2) \times 10^7\, M_\odot$ (AO IFU – NIFS) [Onken+2014];

  Currently we are reanalyzing the same data using a better pipeline and a different implementation of the Schwarzschild method for barred galaxies.

Choice of instrument: why JWST/NIRSpec?

NIFS (AO IFU on Gemini North)

- $3'' \times 3''$ FOV;
- $0.1'' \times 0.043''$ pixel size;
- Core–halo PSF: $0.09'' - 0.5''$;
- Spectral resolution $R \sim 5000$;



NIRSpec (IFU on JWST)

- $3'' \times 3''$ FOV;
- $0.1''$ pixel ($4\times$ dithered to $0.025''$);
- Sharper PSF: FWHM $\sim 0.08''$;
- $R \sim 2700$ at $\lambda = 2.4\,\mu$m;

\+ Much lower background;

\+ Cleaner AGN subtraction;

\+ Higher sensitivity:
1.5h exposure to reach S/N=50 for aperture size 0.025" vs. 8h on NIFS;

− Lower spectral resolution:
may be difficult to determine higher Gauss–Hermite moments of LOSVD.

Planned observations

- Use NIRSpec in IFU mode;
- G235H+F170LP grating and filter ($1.66 - 3.17\,\mu$m);
- CO and OH absorption features at $2.3 - 2.5$, $2.8 - 3.0\,\mu$m;
- $3'' \times 3''$ region centered on the AGN;
- 4-point dither strategy ($\Rightarrow$ $0.025'' \times 0.025''$ pixel size);
- 8 exposures with total time of 1.5h;
- Additionally observe 4 giant stars ($M_K \sim 10$) for 90s each to serve as templates in pPXF spectral fitting;
- Estimate the PSF from the (unresolved) AGN and these stars;
- Total requested time: 8.5h.

Expected science products

- Characterize the NIRSpec IFU PSF

  (test the spatial resolution and efficiency of galaxy–AGN separation);
- Explore the accuracy of LOSVD extraction

  (including higher-order Gauss–Hermite moments);
- Obtain template stellar spectra

  (may be used to for kinematic studies of other galaxies);
- Construct new kinematic maps for stars and gas in NGC 4151;
- Provide an independent estimate of black hole mass.