Viewing the Molecular Torus in AGN

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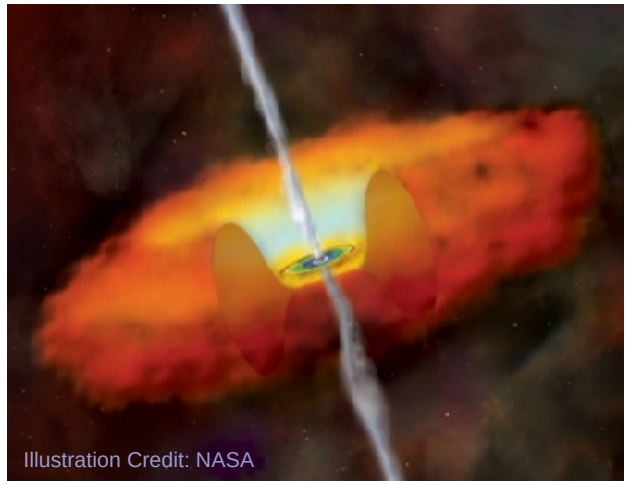
Is there a Torus of Molecular Hydrogen?

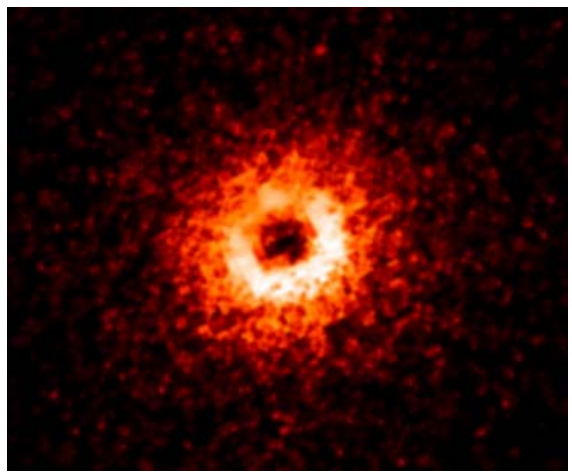
Three main characteristics of H_2

- Size scale of the gas distribution
- Kinematics: velocity and velocity dispersion
- Column density of the gas

The latest torus models (e.g. a clumpy torus) predict:

- Size scales of 10-60 pc
- Column densities of at least $10^{21\text{-}22}$ cm^{-2}
- Disk scale heights of 10s of pc

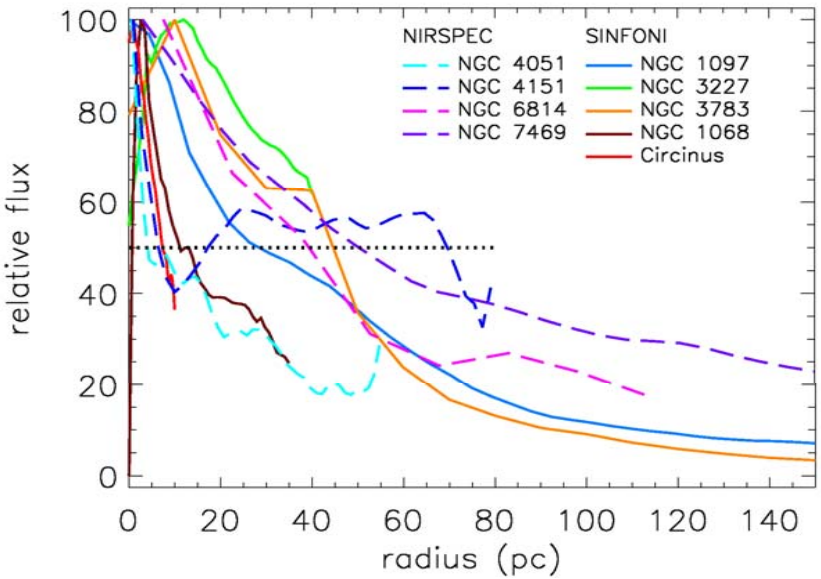


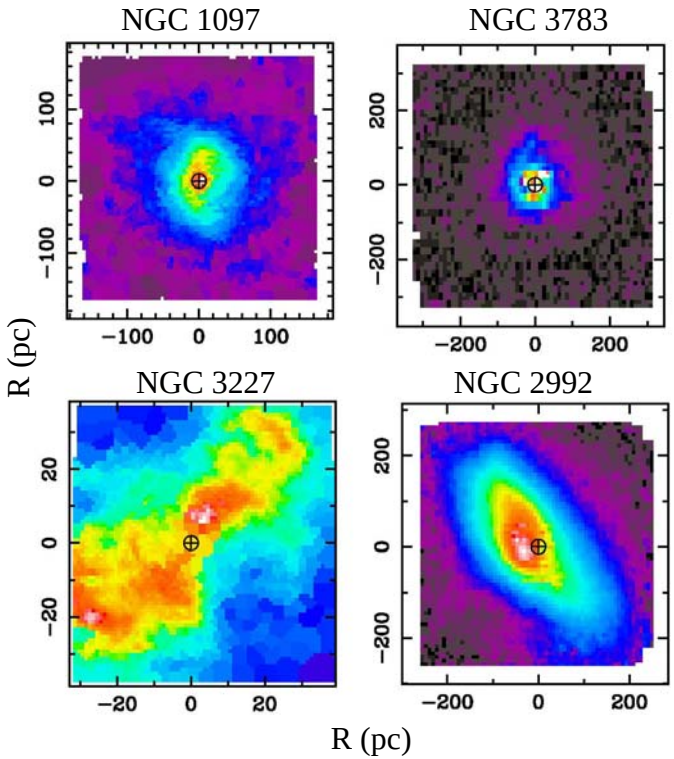


(Hönig et al. 2006)

Spatial Distribution of H_2 2.1218 μm

- The half-width-half-maximum is generally less than 50 pc
- Sérsic fits suggest disk-like distributions

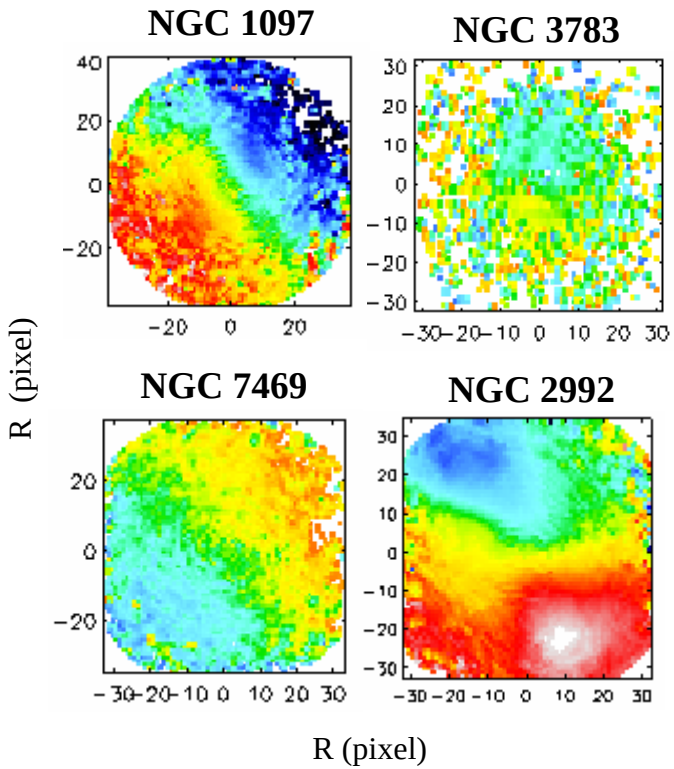




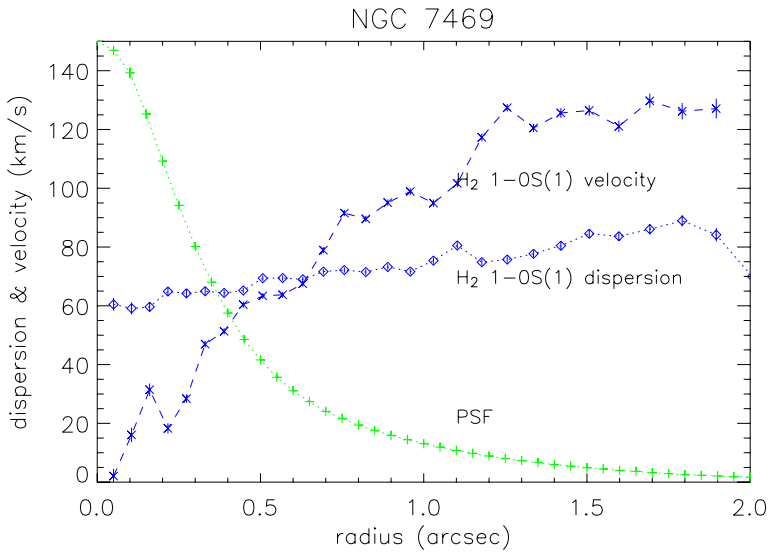
NIRSPEC Sample - Hicks & Malkan 2007

SINFONI Sample - Davies et al. 2007

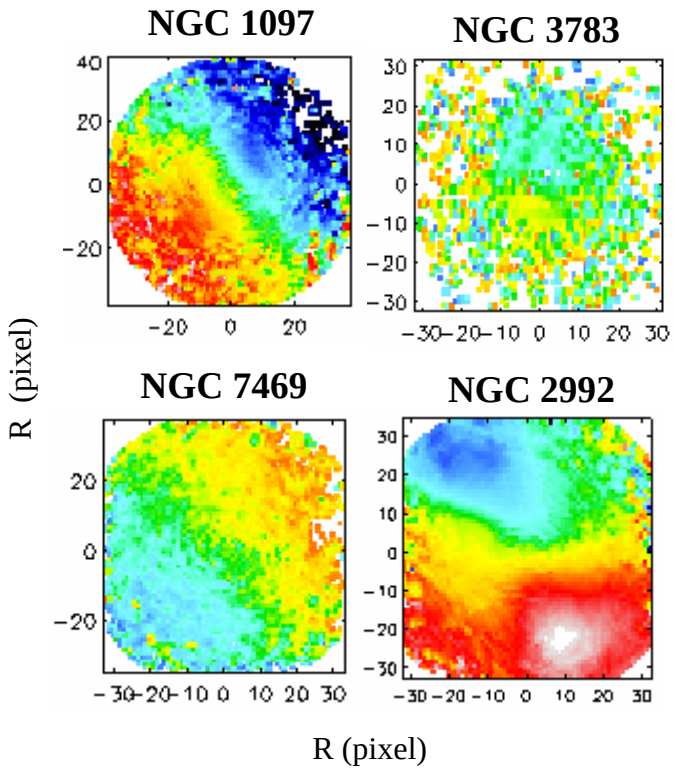
H_2 Kinematics: Velocity & Velocity Dispersion



- Ordered velocity field suggests disk rotation



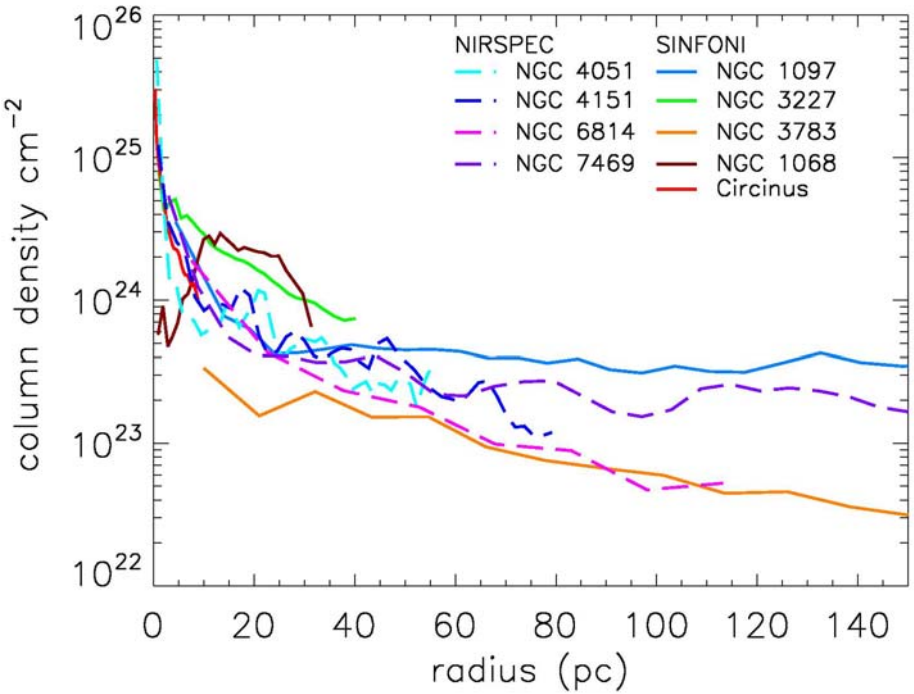
H_2 Kinematics: Velocity & Velocity Dispersion



- Ordered velocity field suggests disk rotation
- Estimate the dynamical mass by taking into account the velocity dispersion:

$$M_{dyn} = (v^2+3\sigma^2)\ R / G$$

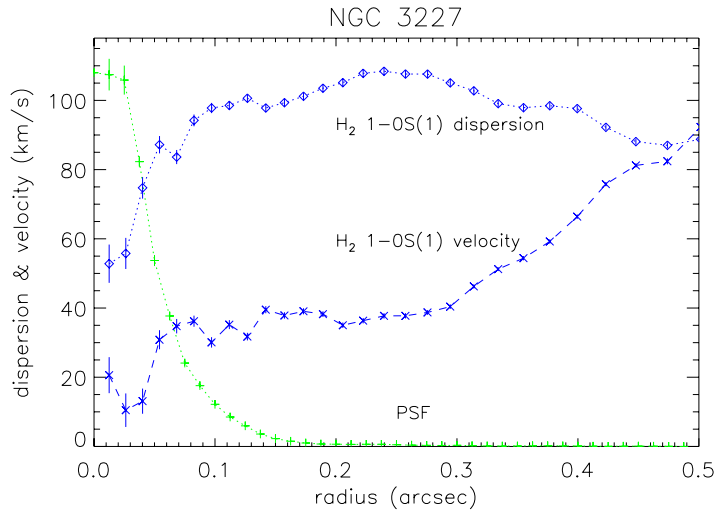
H_2 Column Densities

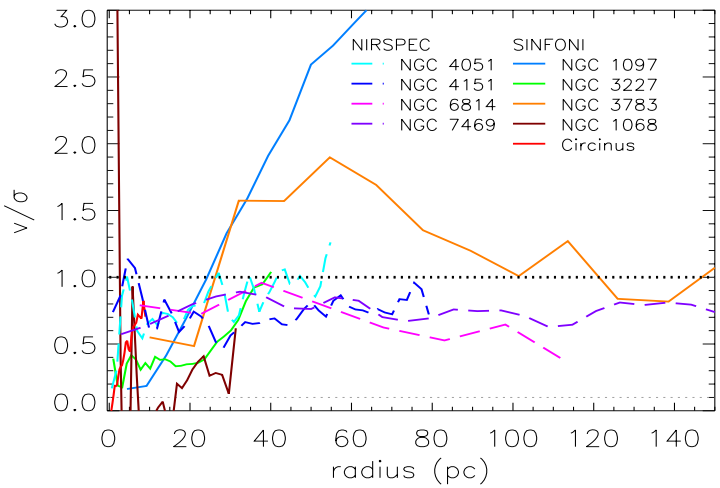


- At least 10^{23} cm^{-2} when using a 10% gas fraction
- If a more probable gas fraction of 30% is used then the column densities are even higher

Thickness of the H_2 Disk

- Velocity dispersion is equal to or greater than the velocity speeds
  - Shocks can only account for a dispersion up to 70 km s^{-1}
  - Remaining dispersion due to bulk motion of the gas, i.e. a thick disk
  - Heating from a nuclear starburst and/or the AGN can maintain the vertical structure





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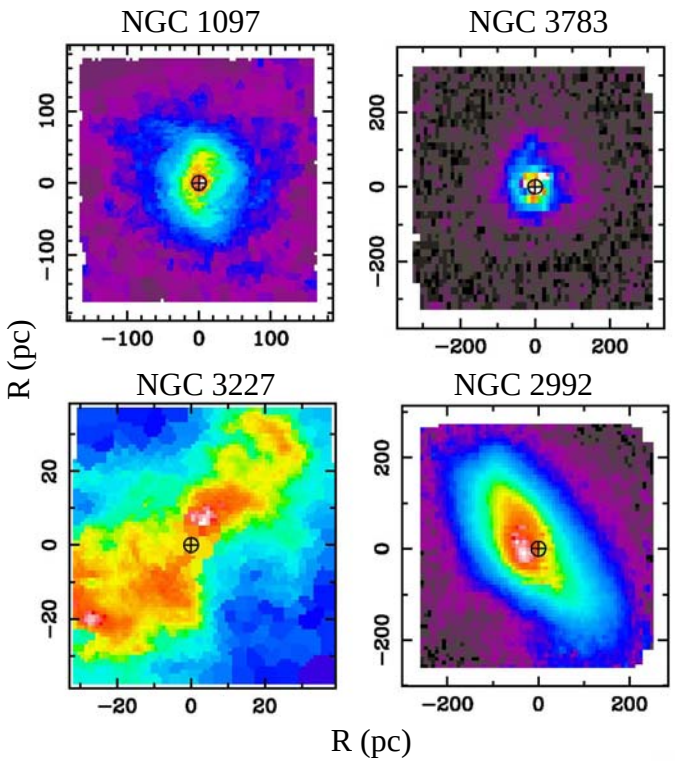
Is there a Torus of Molecular Hydrogen?

- Yes - evidence that there is an obscuring *torus-like* structure of molecular hydrogen in the AGNs observed includes:
  - Spatial distribution of a few 10s of parsecs
  - Column densities high enough to obscure the AGN
  - High velocity dispersion that is most likely a result of bulk motion suggesting a thick disk



Relevant Papers

- NIRSPEC 2-D data for a sample of Seyfert 1s:

  Hicks & Malkan 2007 ApJS, submitted

  Circumnuclear Gas in Seyfert 1 Galaxies: Morphology, Kinematics, and Direct Measurement of Black Hole Masses

- SINFONI 2-D data for a sample of Seyfert 1s & 2s:

  Davies et al. 2007 ApJS, submitted (astro-ph 0704.1374)

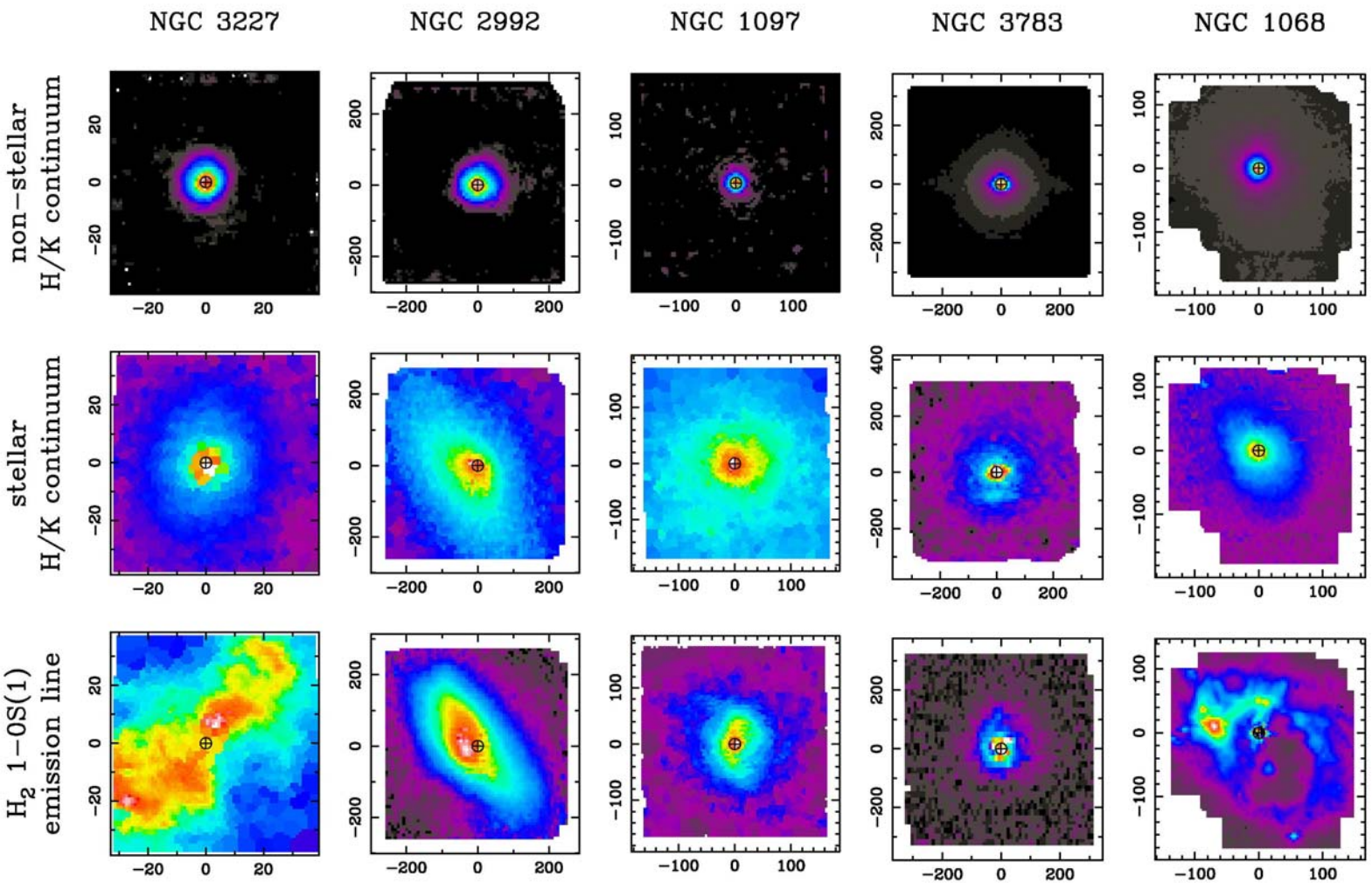
  A Close Look at Star Formation around Active Galactic Nuclei

SINFONI AGN Sample

Object	Classification	D (Mpc)	Resolution	
NGC 1097	LINER, Sy1	18	0.245”	21pc
NGC 2992	Sy1	33	0.30”	48pc
NGC 3227	Sy1	17	0.085”	7pc
NGC 3783	Sy1	42	0.18”	37pc
NGC 7469	Sy1	66	0.085”	27pc
NGC 1068	Sy2	14	0.085”	6pc
Circinus	Sy2	4	0.22”	4pc
Mkn 231	ULIRG, Sy1, QSO	170	0.176”	145pc
IRAS 05189–2524	ULIRG, Sy1	170	0.12”	100pc

- Nine Seyfert galaxies
- Logarithmic mean resolution of 22 pc
- Integral Field Spectrometer with NGS AO

Examples of SINFONI Data



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NIRSPEC AGN Sample

Object	Classification	D (Mpc)	Resolution	
NGC 3227	Sy 1	17	0.10"	7 pc
NGC 3516	Sy 1	35	0.15"	26 pc
NGC 4051	Sy 1	9	0.11"	5 pc
NGC 4151	Sy 1	13	0.12"	8 pc
NGC 4593	Sy 1	36	0.08"	14 pc
NGC 5548	Sy 1	70	0.07"	25 pc
NGC 6814	Sy 1	21	0.07"	7 pc
NGC 7469	Sy 1	66	0.11"	35 pc
Ark 120	Sy 1	132	0.11"	70 pc

- Nine Seyfert 1 galaxies, all with M_{BH} estimates from reverberation mapping
- Logarithmic mean resolution of 15 pc
- Constructed 2-D Maps from single slit observations with NGS AO