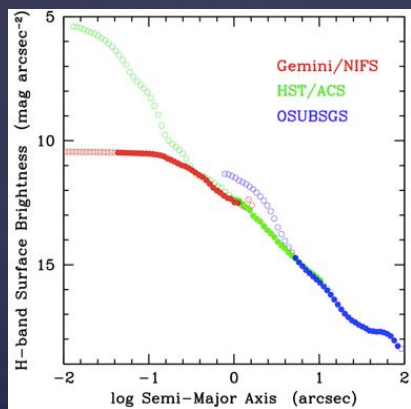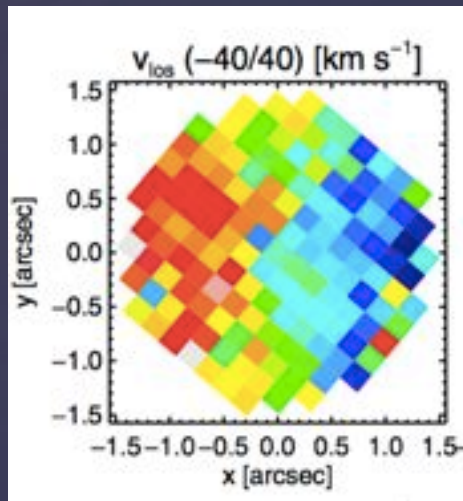# Comparison of Stellar Dynamical Modeling & Reverberation Mapping for AGN

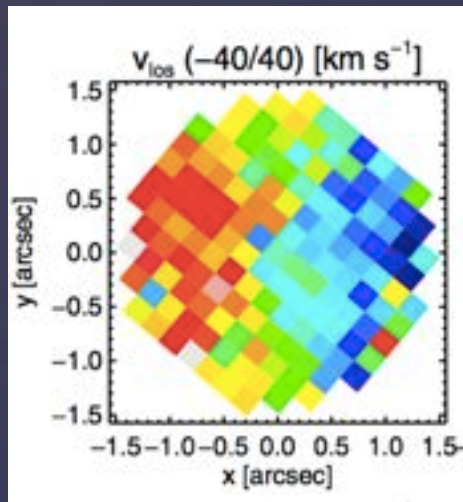Caroline A. Roberts
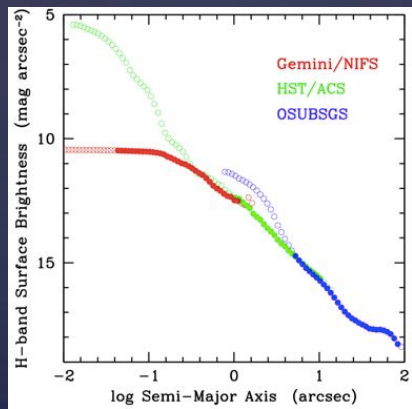Misty Bentz

Stellar Dynamical (SD) Modeling

Step 1

Stellar Dynamical (SD) Modeling

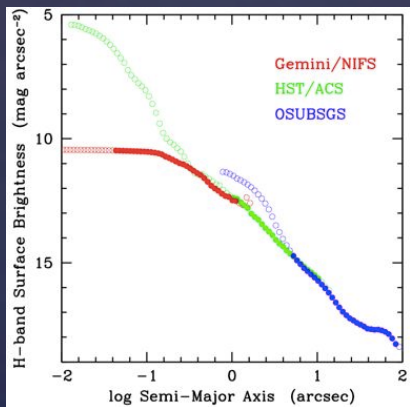luminosity $*$ Υ_H $\sim$ stellar mass distribution   distribution

M_{BH} + stellar mass distribution $\sim$ $V \propto \dfrac{U}{m}$

Step 2

Stellar Dynamical (SD) Modeling
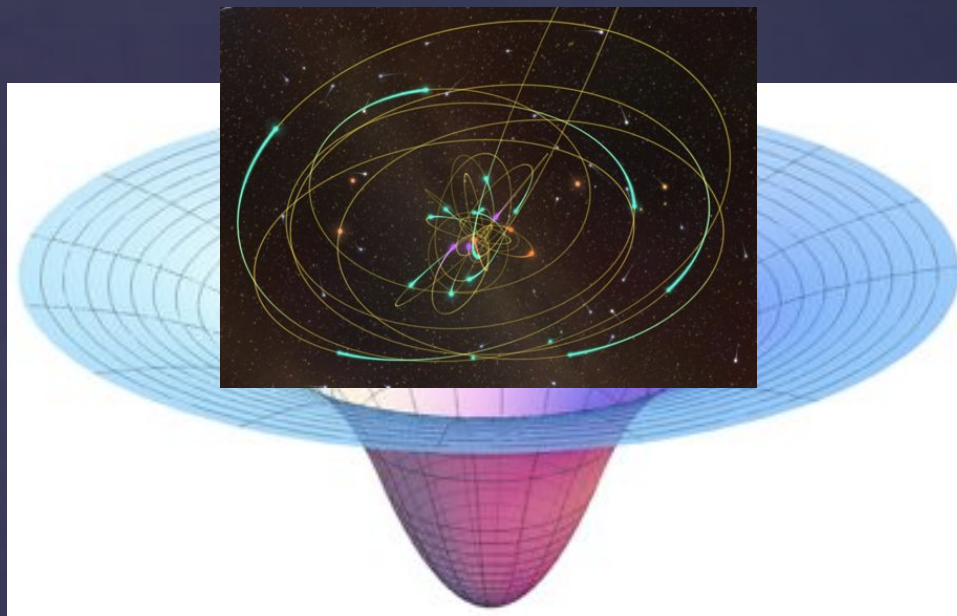
Step 2

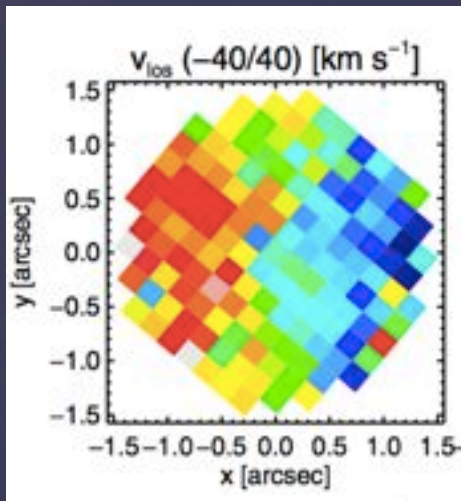# Stellar Dynamical (SD) Modeling
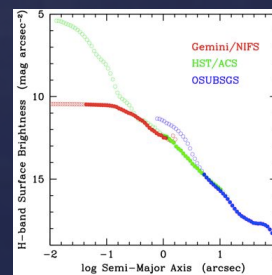
Step 3

Stellar Dynamical (SD) Modeling

Step 4

Onken et al. 2014

Supermassive Black Hole
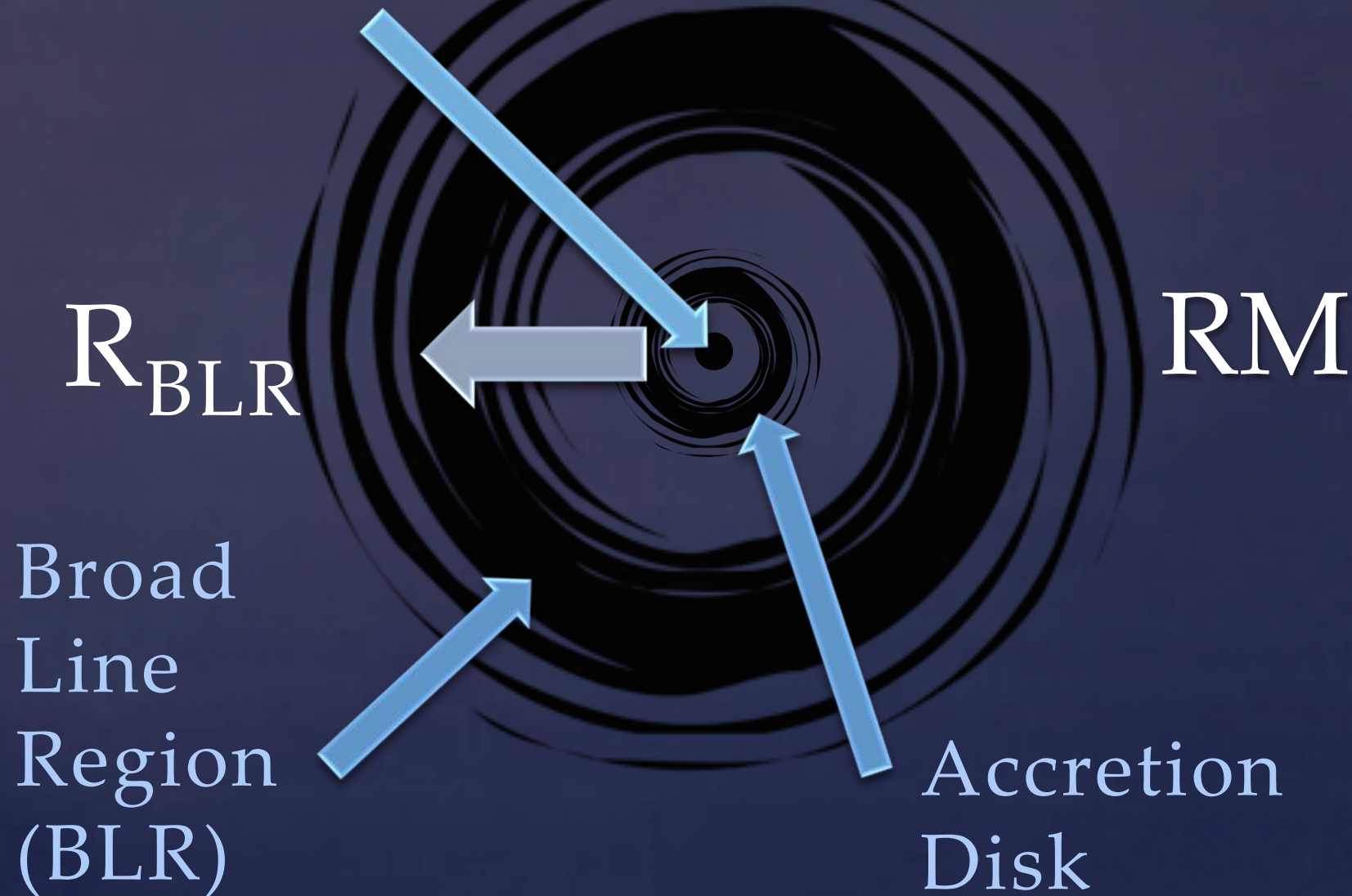
R_{BLR}

RM

Broad Line Region (BLR)

Accretion Disk

Resolvable r_h:
SD Modeling candidates

MW

Overlap
population

AGN: RM candidates

NGC 4151 & 3227

- **z = 0.0033**
- **2006 – Bentz et al.**
  - **RM mass**
  - $M_{BH} = 4.57^{+0.57}_{-0.47} \times 10^7 \, M_{Sun}$ (**$\langle f \rangle = 5.5$**)
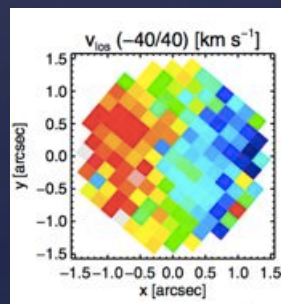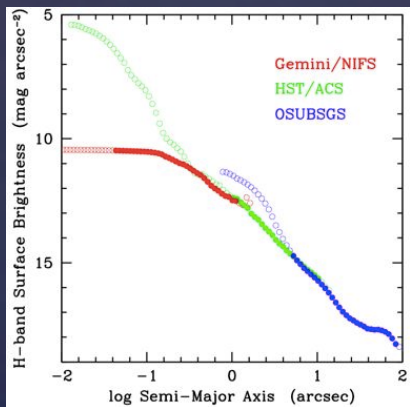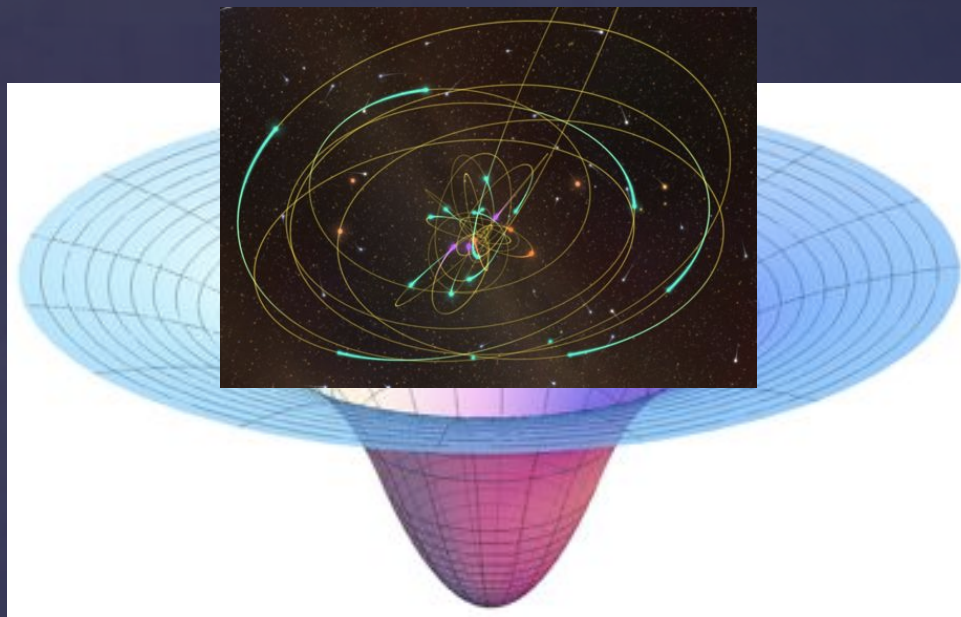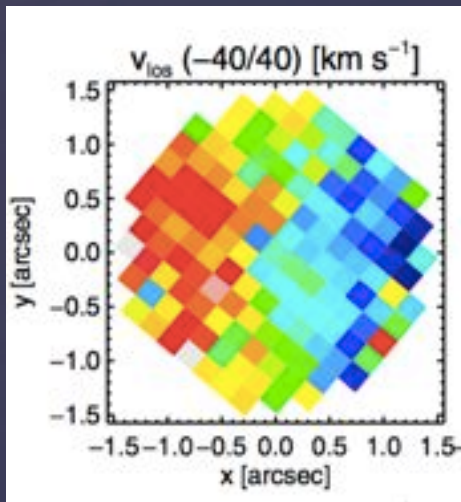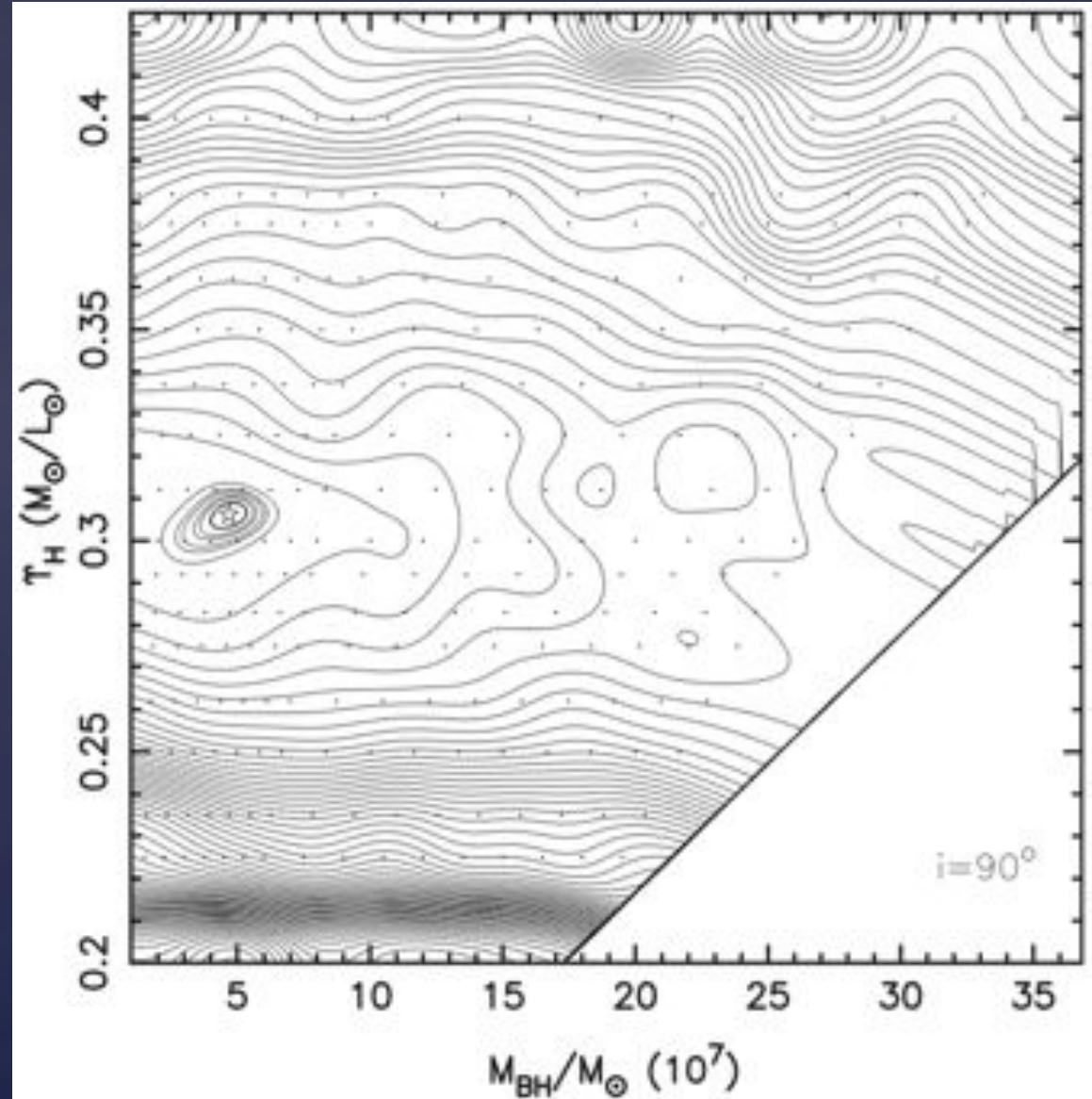- **2014 – Onken et al.**
  - **SDM Mass (improved)**
  - $M_{BH} = 3.760^{+1.150}_{-1.150} \times 10^7 \, M_{Sun}$
- **2019**
  - **SDM Mass (improved)**
  - **Bar-optimized code (Valluri)**
  - **No data binning**

- **z = 0.0039**
- **2006 – Davies et al.**
  - **SDM mass**
  - $M_{BH} = 7 \times 10^6 - 2 \times 10^7 \, M_{Sun}$
- **2010 – Denney et al.**
  - **RM Mass**
  - $M_{BH} = 7.63^{+1.62}_{-1.72}$
    $\times 10^6 \, M_{Sun}$ (**$\langle f \rangle = 5.5$**)
- **2019**
  - **SDM Mass (improved)**
  - **Bar-optimized code (Valluri)**
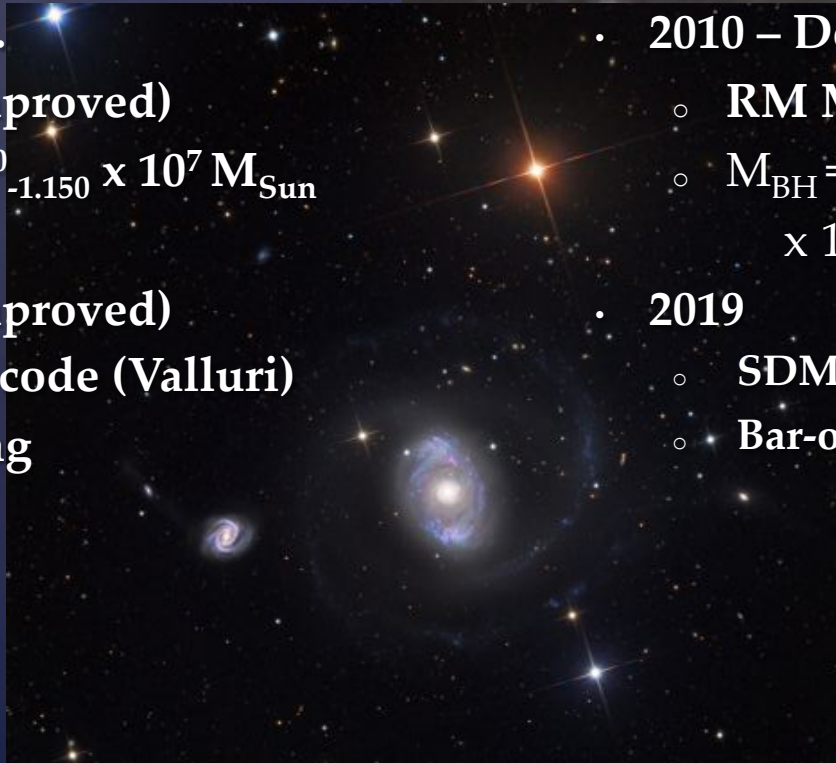
Bar-Optimized Code

- Monica Valluri and Eugene Vasilieve; adaptation of Valluri's 2004 code for:
  - IFU data
  - Non-axisymmetric kinematics (2017)

- An orbit library of 1000s stars for each of the models

- Integrated for ~100 orbits

- Dozens of models run for each study

- H-band w/ AO
- R ~ 5000
- Spatial resolution: 0".05
- FOV: 3" x 3"
- 2008 February 16-17, 19-24
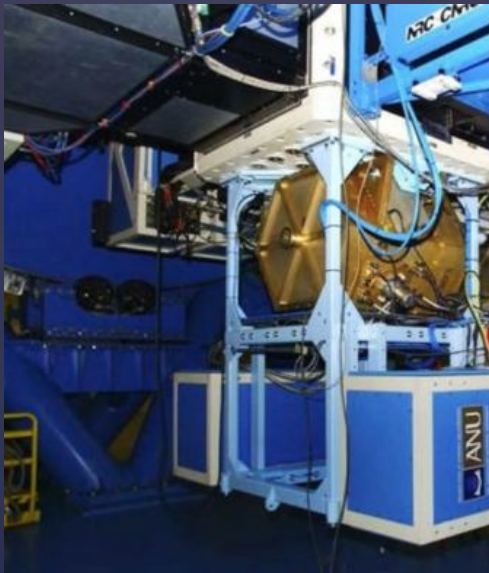
- K-band w/ AO
- R ~ 4300
- Spatial resolution: 0".085
- FOV: 0".80 x 0".80
- 2004 December 21

GEMINI/NIFS & VLT/SINFONI

TIMELINE
NGC 4151

Step	Status/Completion Date
Re-reduction of the data cubes	Completed
pPXF analysis	In progress
Beginning the modeling	September 2017
Analysis completion, begin writing	December 2017
NGC 3227	
Begin re-reduction of the data cubes	January 2018
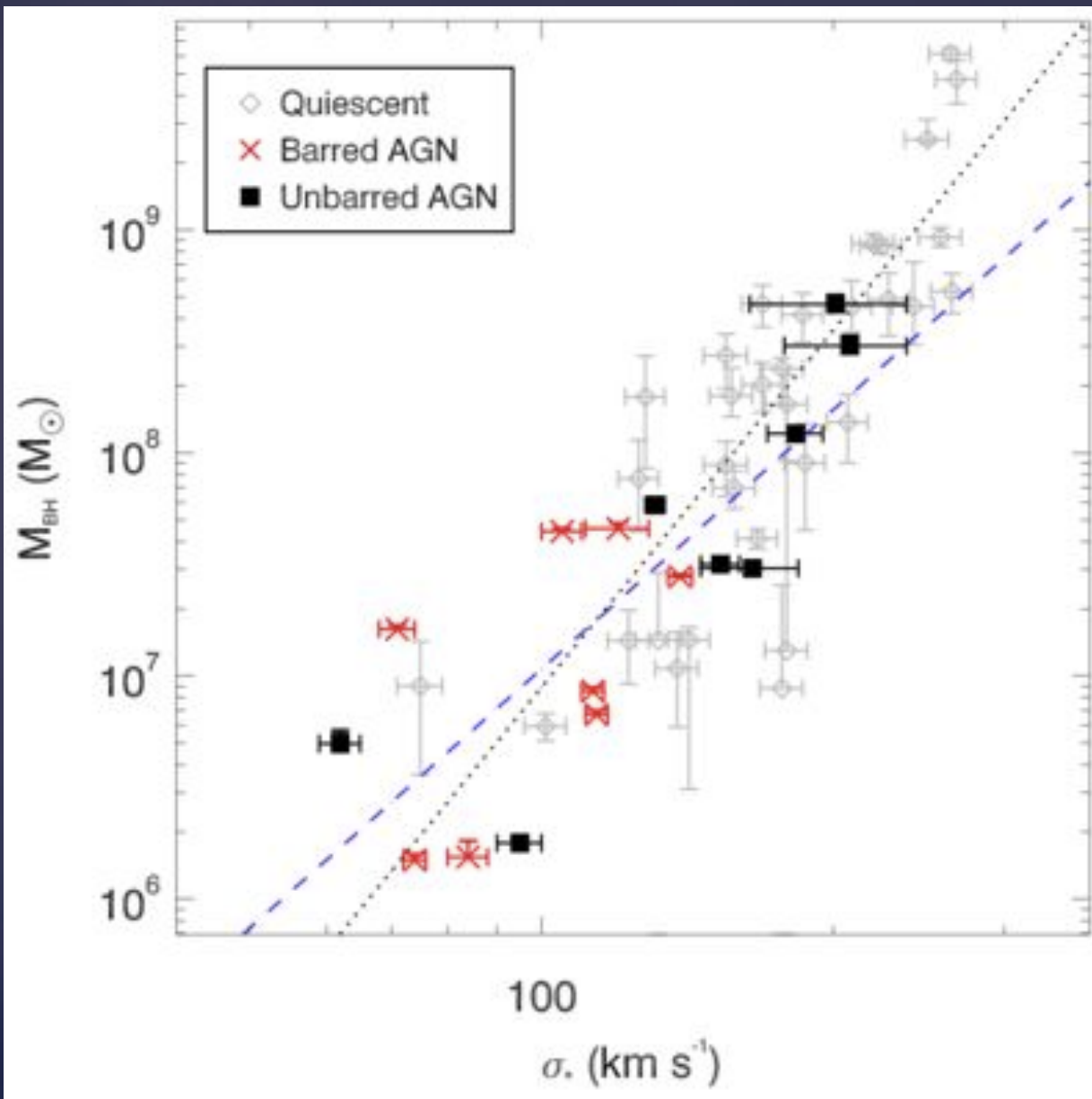
M-σ∗ considerations:

- Quality and definition of r_e
- Definition of σ_*
- Assumption of a quiescent, AGN relation
- Morphological dependence (pseudo bulges, bars (65% of late type, most near AGN))

Batiste et al. 2017

- Enhances confidence in inherent assumptions made for each method

- Independent measurements of f

- Refines and enhances the M-σ relation

- Improves galaxy formation and evolution models

Method Comparison

Brown et al. 2013
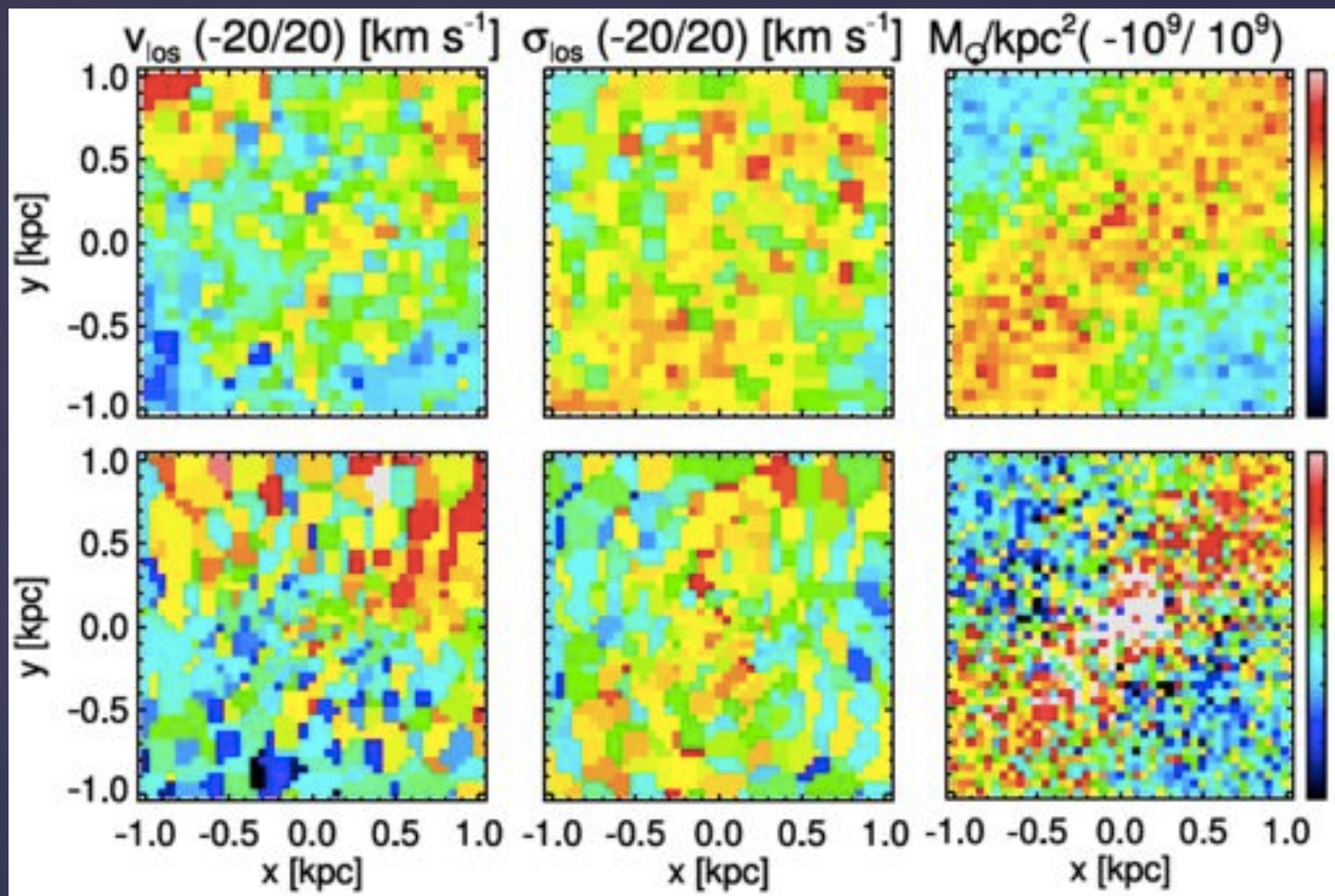
M_{SMBH} Overestimation with Axisymmetric SD Modeling Code

Comparisons of Dynamical and Reverberation M_{SMBH}
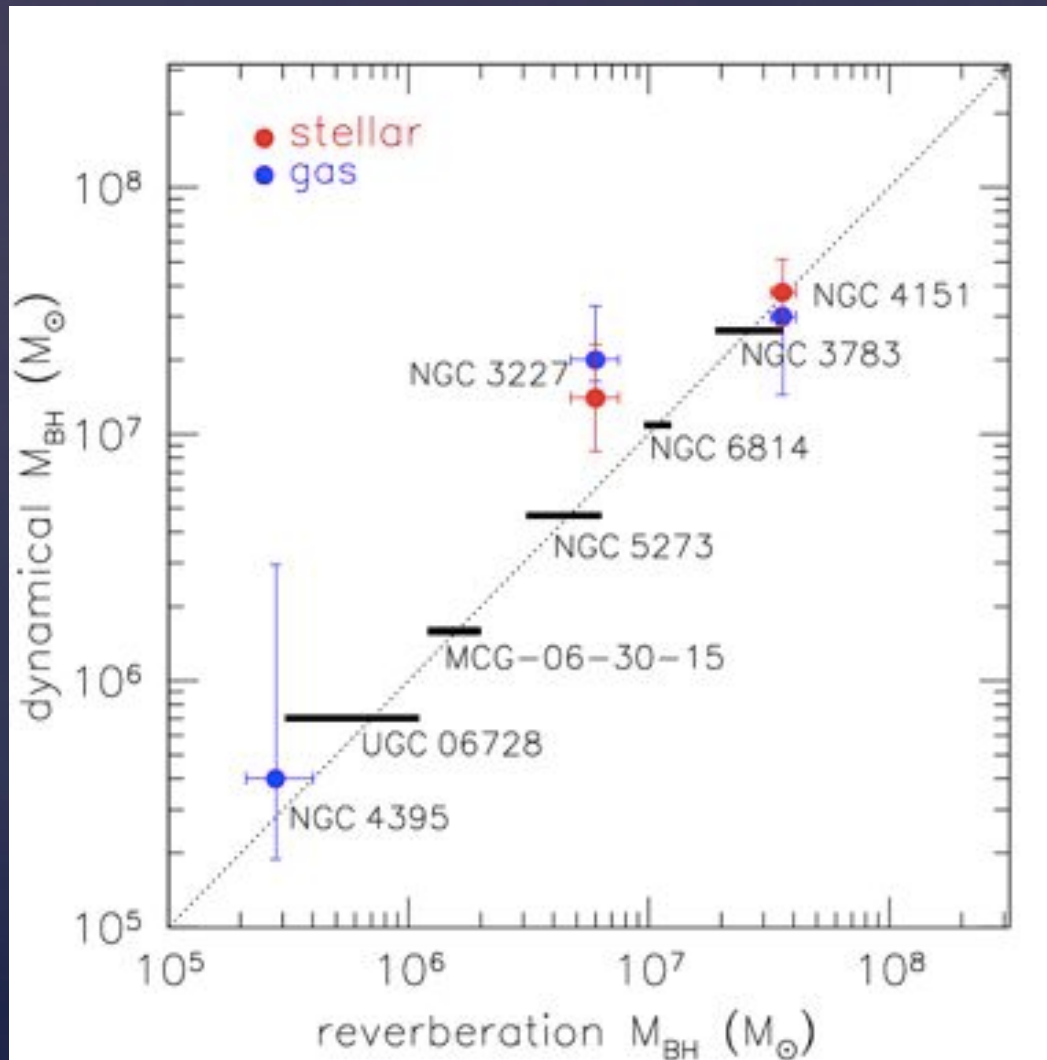

Bentz

AGN	Morphology	RM	SD	SDBO
NGC 4151	Weakly barred	● [1]	● [8], [9]	⊙ (This work)
NGC 3227	Weakly barred	● [7]	● [6]	
NGC 6814	Weakly barred	● [2]	⊙ (Batiste)	
NGC 5273	Unbarred early type	● [3]	⊙ (Batiste)	⊘
NGC 4395	Unbarred late type	● [10]	⊘	⊘
MCG-06-30-15	Unbarred late type	● [4]	○ (Bentz)	⊘
UGC06728	Bar unknown, late type	● [5]		
NGC 3783	Strongly barred	⊙ (Bentz)		

M$_{SMBH}$ Comparisons

[1] Bentz+ 06, ApJ, 651, 775
[2] Bentz+ 09, ApJ, 705, 199
[3] Bentz+ 14, ApJ, 796, 8
[4] Bentz+ 16, ApJ, 830, 136
[5] Bentz+ 16, ApJ, 831, 2

[6] Davies+ 06, ApJ, 646, 754
[7] Denney+ 10, ApJ, 721, 715
[8] Onken+ 07, ApJ, 670, 105
[9] Onken+ 14, ApJ, 791, 37
[10] Peterson+ 05, ApJ, 632, 799

● Completed
⊙ In progress
○ In prep
⊘ Not Possible/ Necessary

Thank You!