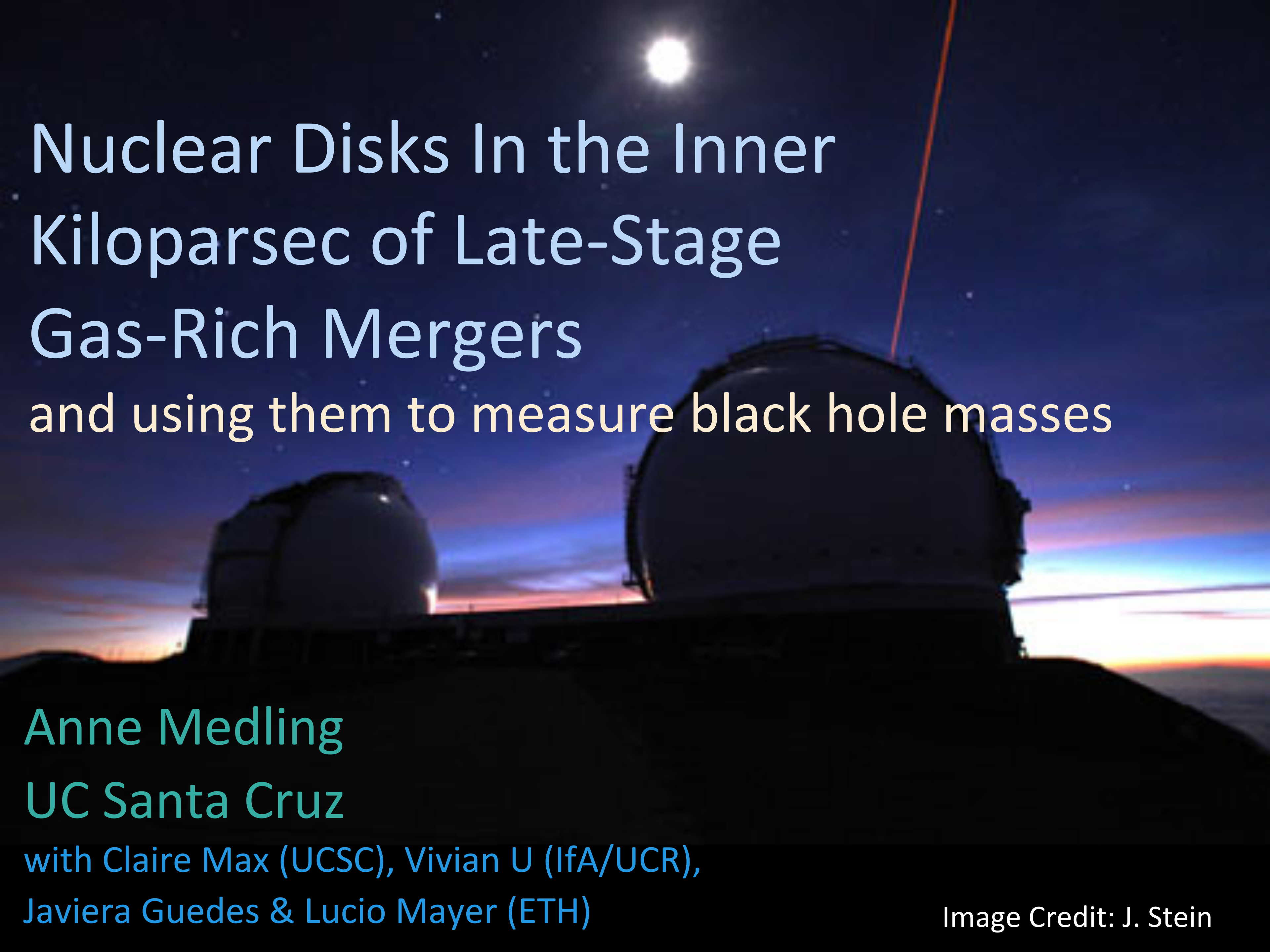

Nuclear Disks In the Inner Kiloparsec of Late-Stage Gas-Rich Mergers

and using them to measure black hole masses

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UC Santa Cruz
with Claire Max (UCSC), Vivian U (IfA/UCR),
Javiera Guedes & Lucio Mayer (ETH)

Image Credit: J. Stein

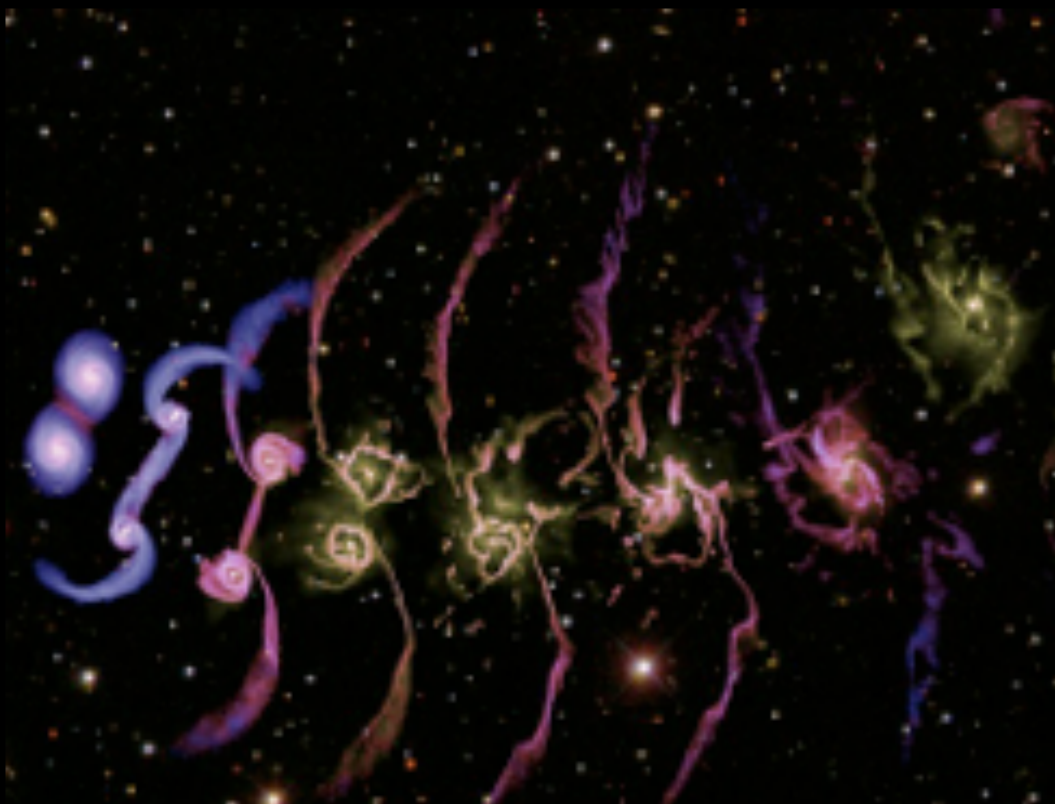
Where are we going with this?

- Comparing gas and stellar kinematics on 20-80pc scales
  - Can nuclear disks help binary black holes merge?
- Looking for AGN activity (or lack thereof) in the cores of gas-rich mergers
  - Seeing dual black holes vs. dual AGN
- How do mergers fall on BH scaling relations (and what will it tell us about BH-host coevolution)?

mergers - (U)LIRGs - adaptive optics

INTRO

Gas-rich mergers can trigger AGN and starbursts



- As gas funnels to the center, fuels AGN or star formation
- Feedback and winds then may blow out the rest of the gas at some time

T. Di Matteo

Gas-rich mergers can trigger AGN and starbursts

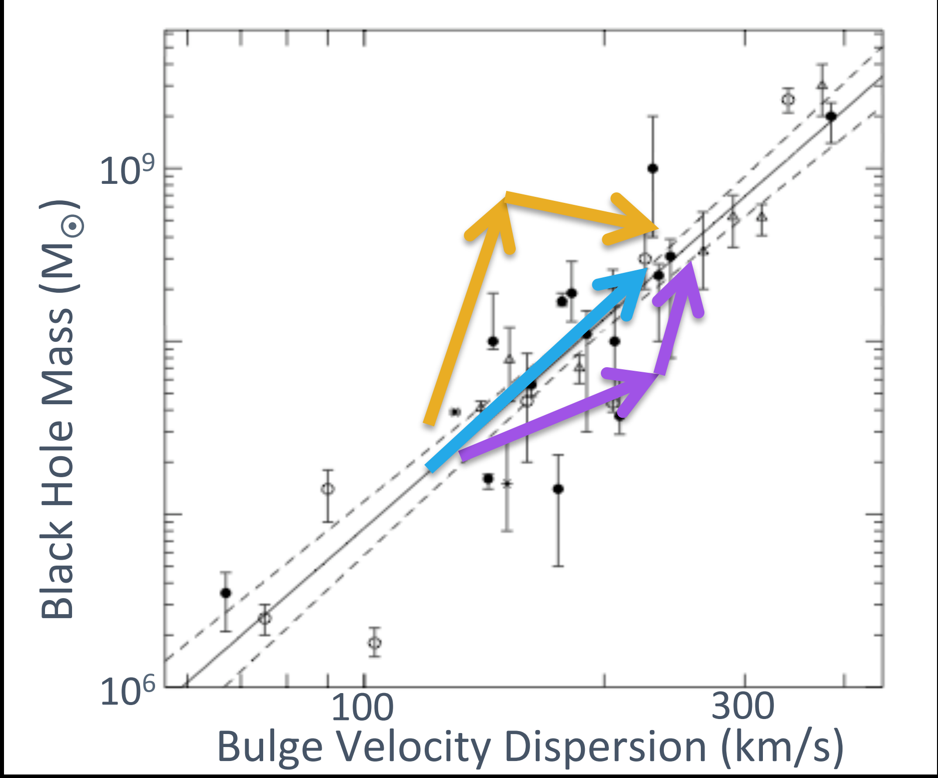
Open questions:

- When do we see two AGN?
- What dictates amount of star formation vs. AGN activity?
  - Which uses up or destroys the gas reservoir?

Hubble Heritage Image

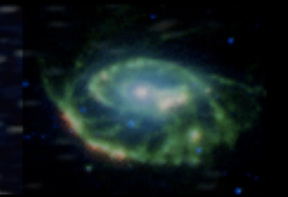
BH-host scaling relations

Tremaine et al. 2002



- Galaxy and BH both grow during a merger; properties track each other
- But what do they look like during a gas-rich merger?
- (It's hard to measure these quantities during a merger though)

GOALS Great Observatory All-sky LIRG Survey



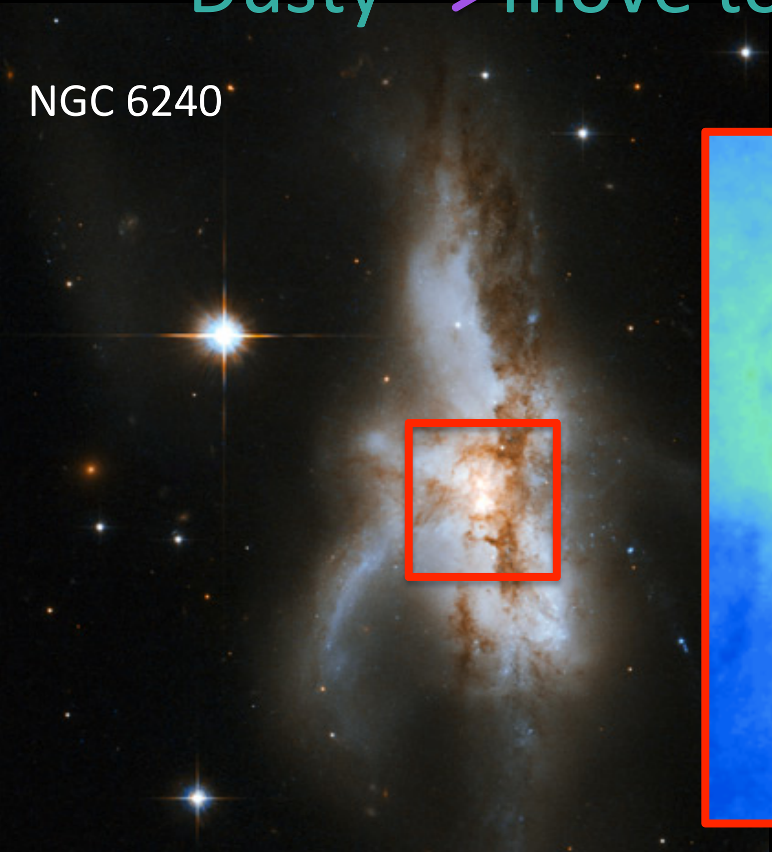
We pull our sample from GOALS:

- 200+ brightest IR-selected galaxies
  - (Ultra-) Luminous InfraRed Galaxies - (U)LIRGs
- Redshift <0.1
- Generally bright in the IR because of either starburst or AGN heating dust (or both)
- Span all nuclear spectral types and merger stages -> we select late-stage mergers

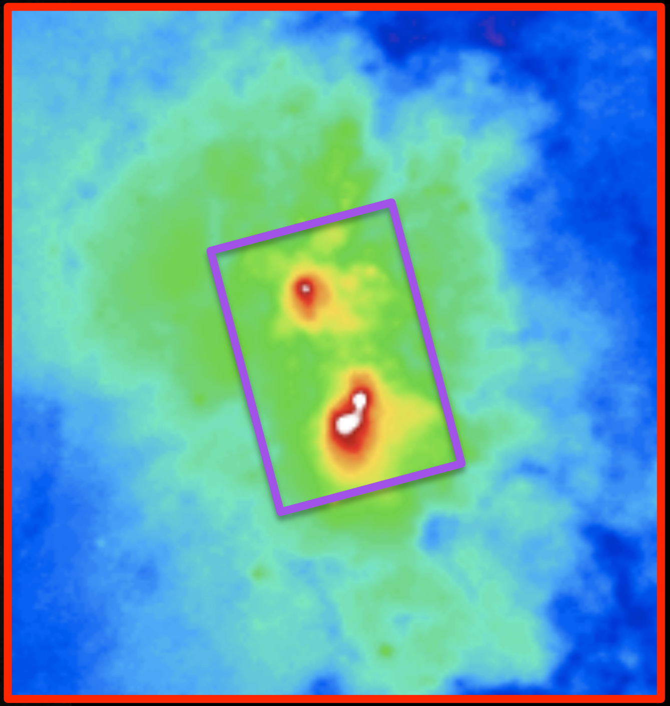
e.g. Armus et al. 2009, PASP, 121, 559A

Understanding Cores in (U)LIRGs: High Spatial Res is Key!

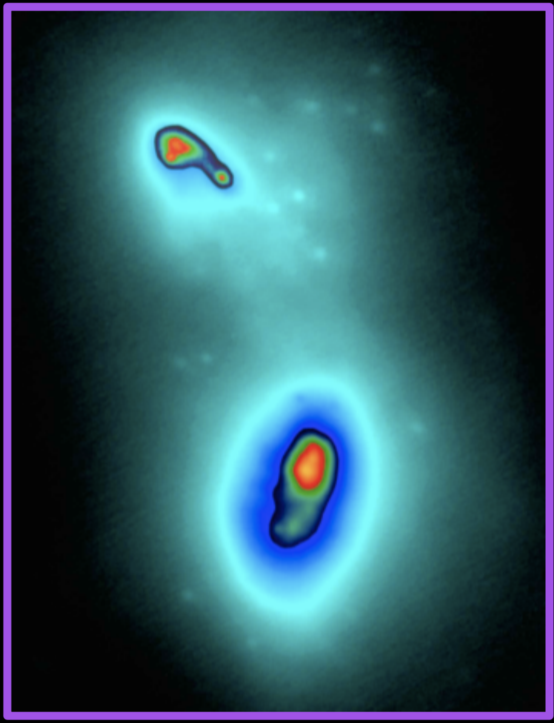
- Resolution of HST ~ .05”; Keck AO matches this
- Dusty → move to NIR



Hubble Heritage Image



ACS I-band

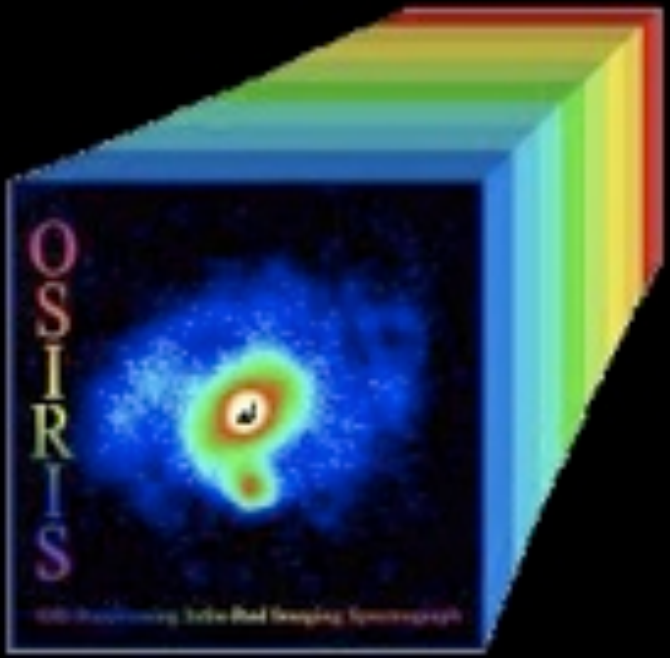


Keck K-band w/LGS AO

15 (U)LIRGs - IFU spectroscopy - near-IR

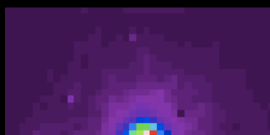
SAMPLE & DATA

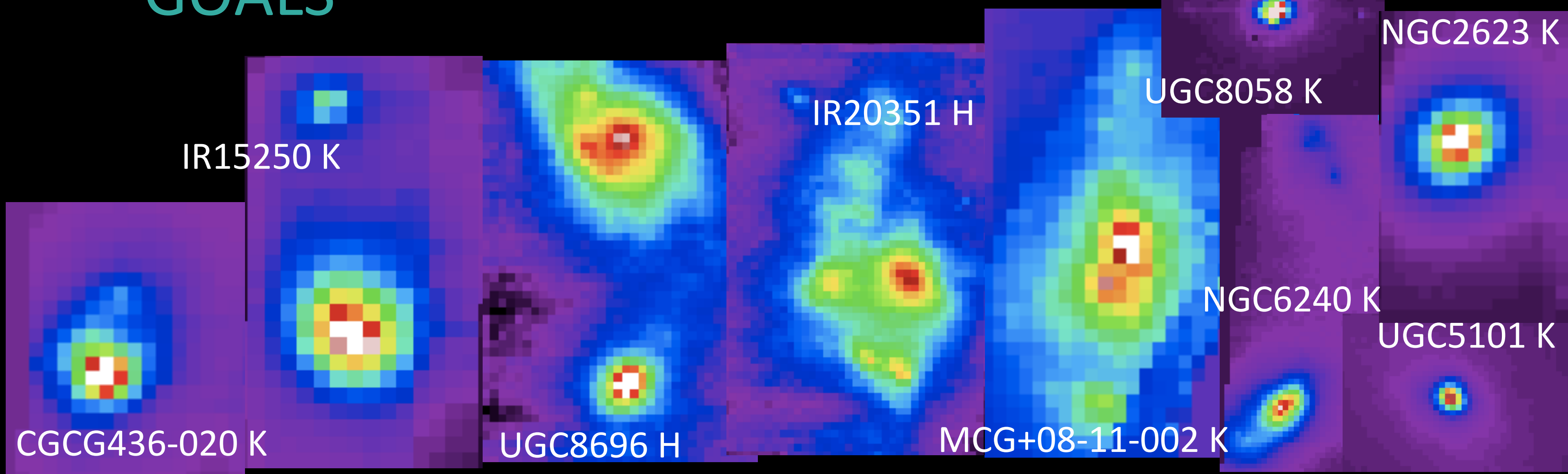
Observing Program



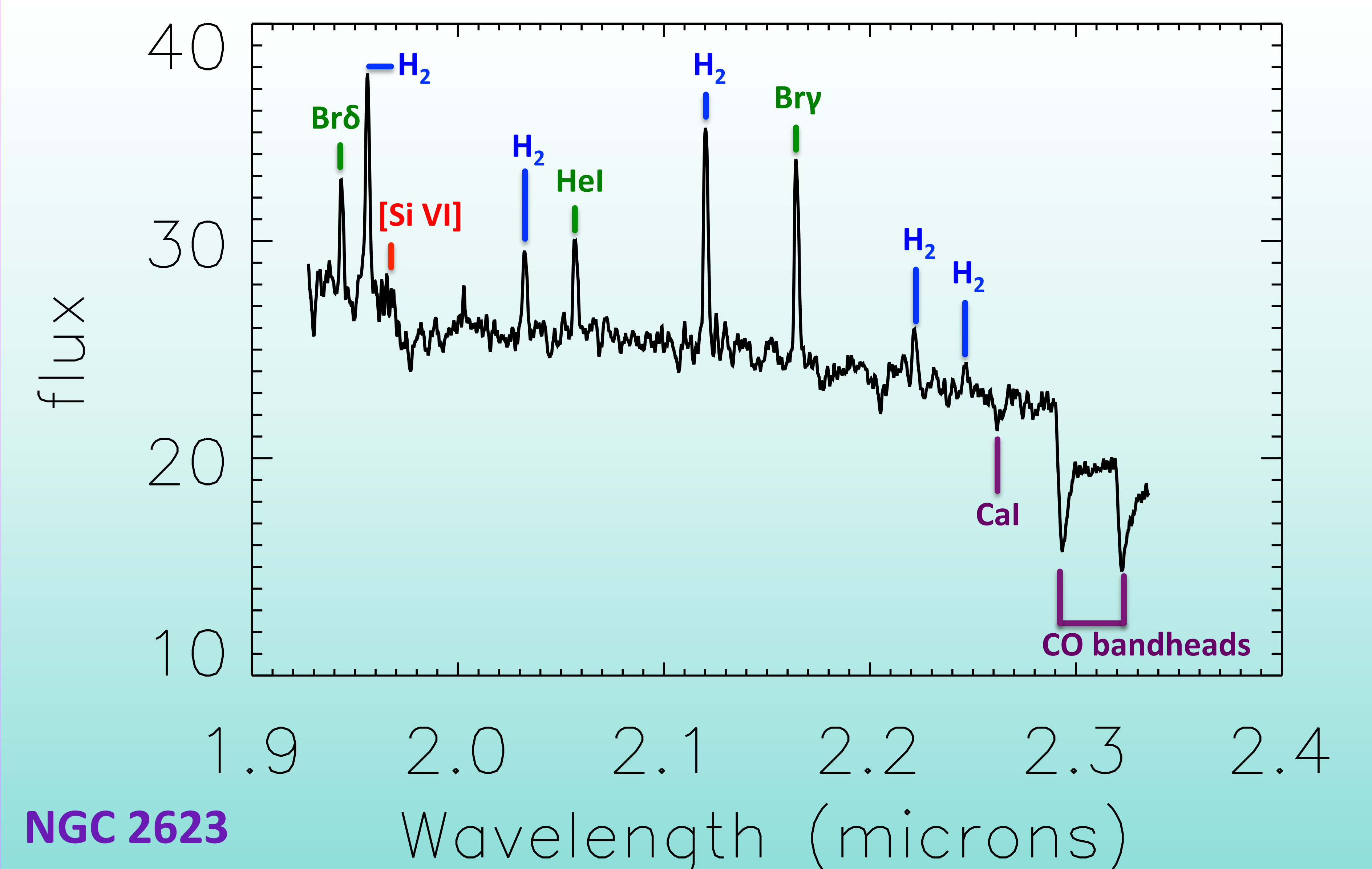
OSIRIS + Keck LGS AO

- High spatial resolution IFU spectroscopy at 0.035 and 0.1 "/pixel scales)
- 15-20 late-stage mergers from GOALS





A Typical K-band Spectrum

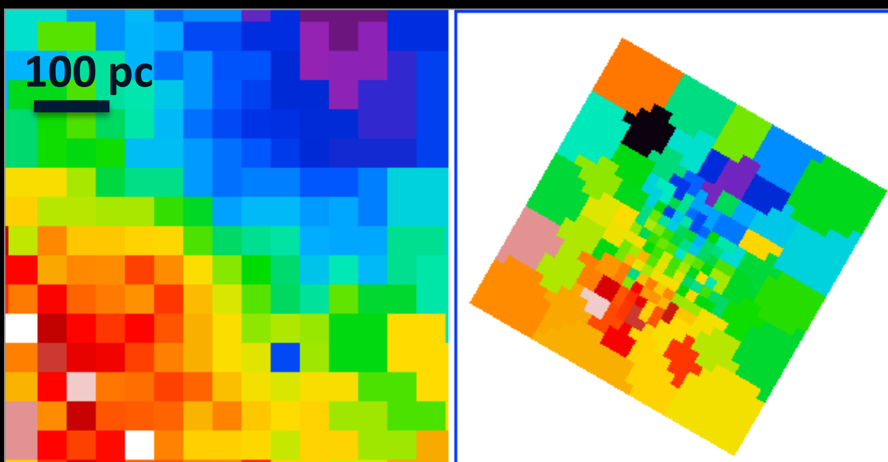


ubiquitous - stars and gas - predicted by simulations

NUCLEAR DISKS

We see lots of strong rotation!

NGC2623 H_2 velocity, stellar velocity

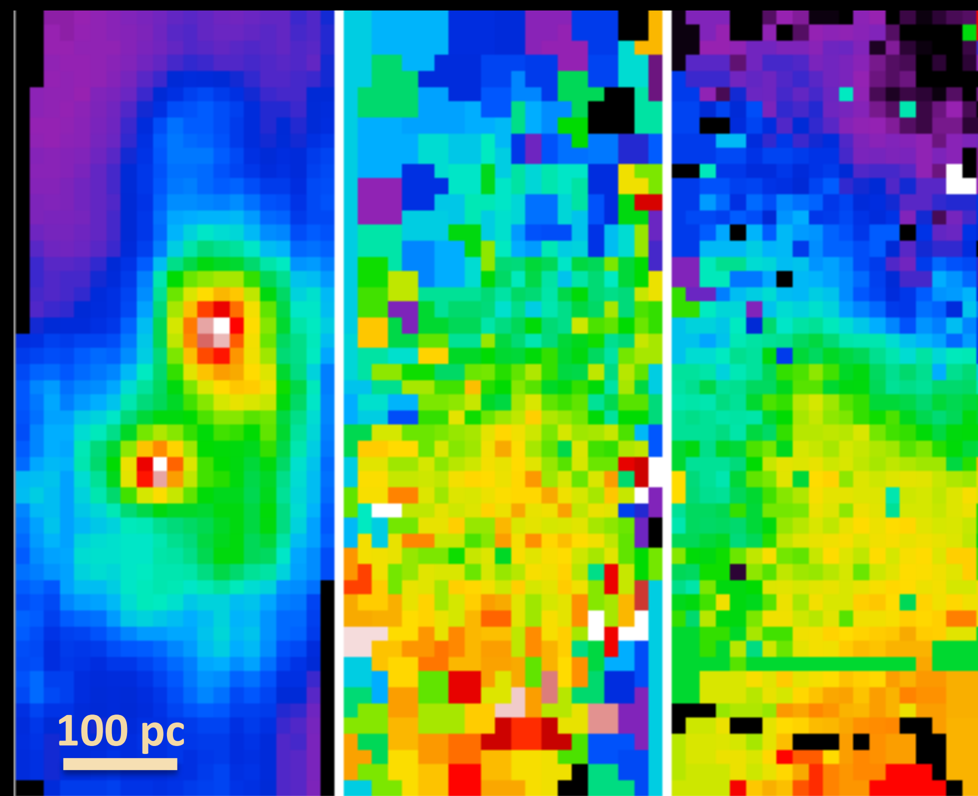


Velocity colorbar = [-400,-100] km/s

Gas and stars both show similar rotation

MCG+08

continuum flux, Brγ velocity, stellar velocity

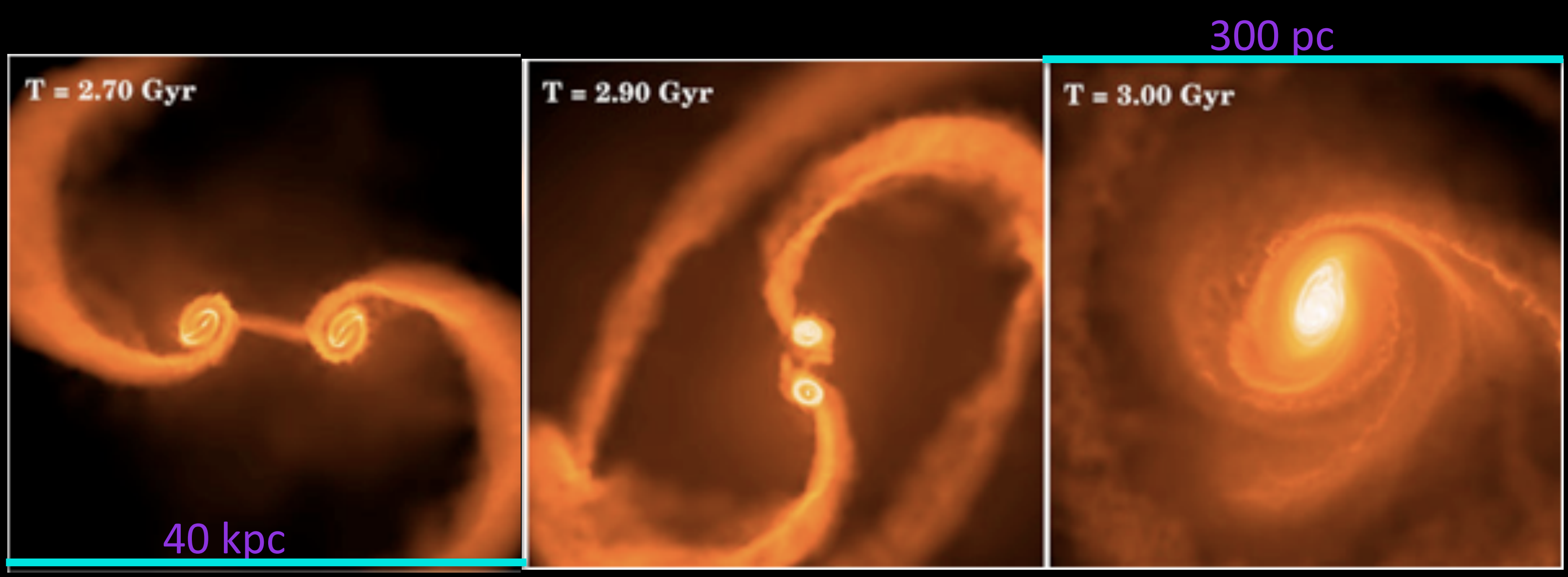


Velocity colorbar = [-150,300] km/s

see AMM+13 in prep

Nuclear Disks in Simulations

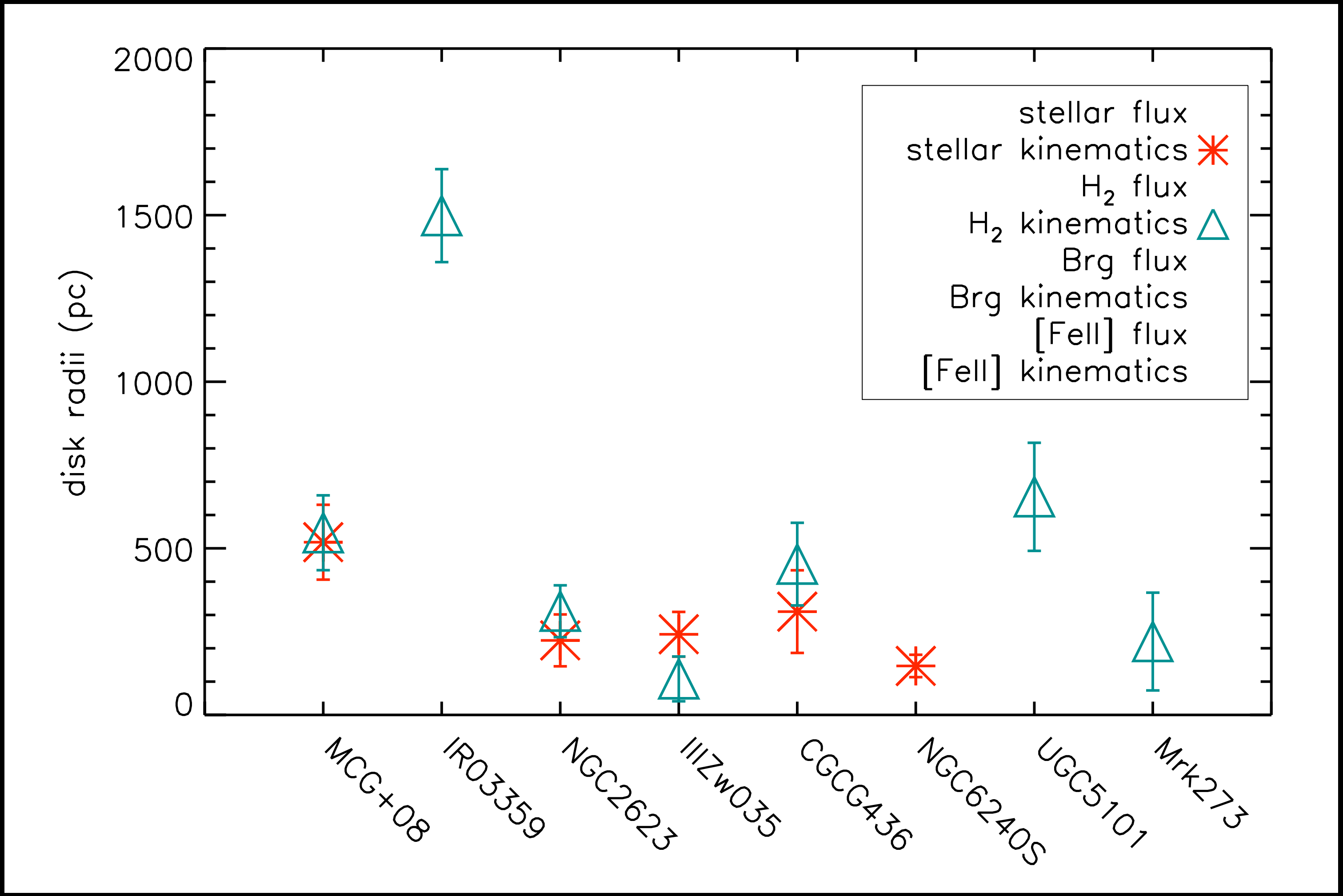
- ~300 pc scale disks seen in major merger simulations (e.g. Mayer+07)
- Plausibly important for merging of binary BHs



L. Mayer

Preliminary

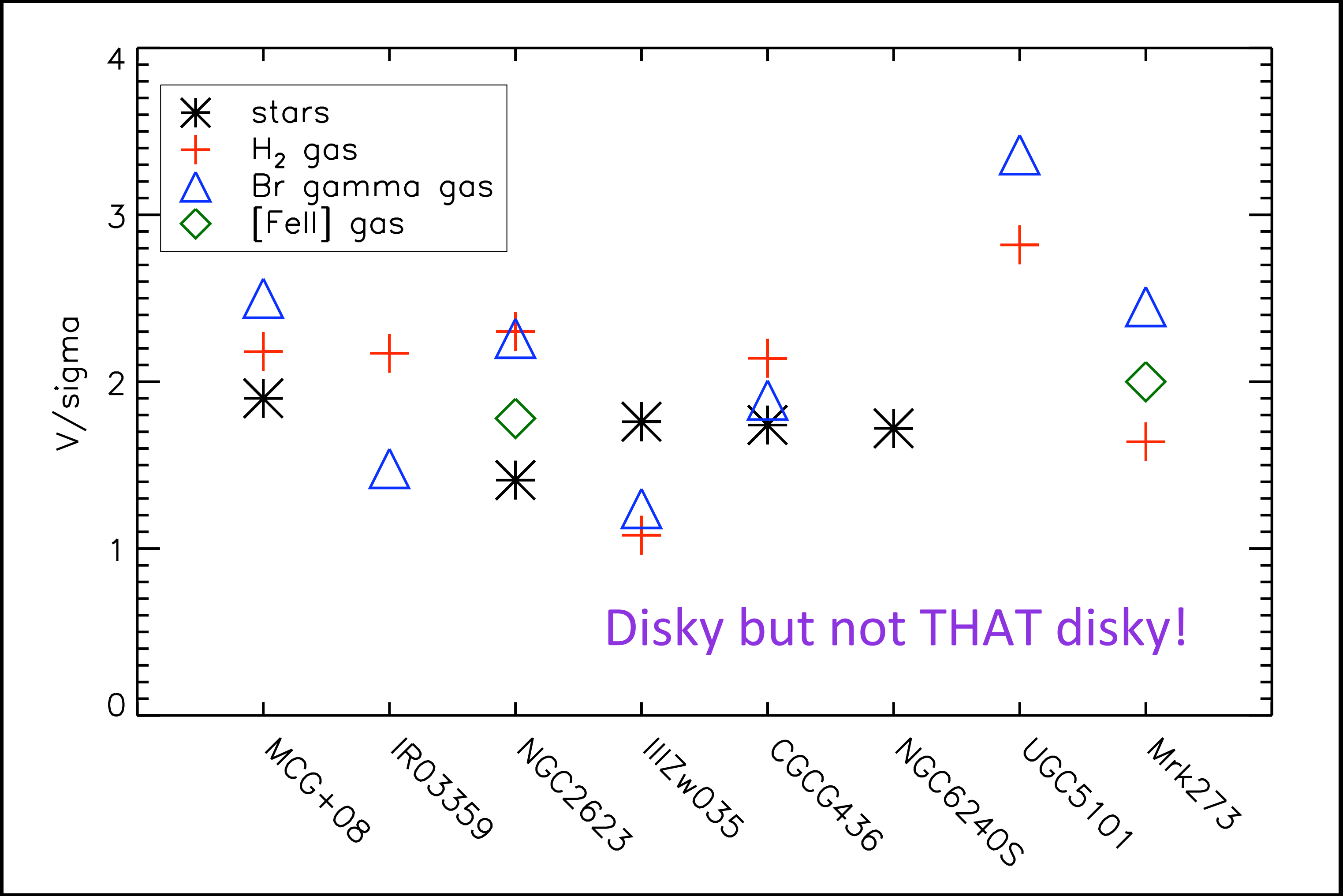
Disk Sizes



see AMM+13 in prep

Preliminary

V/σ of Disks



see AMM+13 in prep

We see disks in every system

- These gas disks seem to form stars (and stars seem to stay in disks)
- Simulations show that disks form, disrupt and reform
  - Following gas and stellar disk sizes and v/sigma can indicate formation/history of disk
- Plan to compare sizes and other parameters across a wider range of merger phase

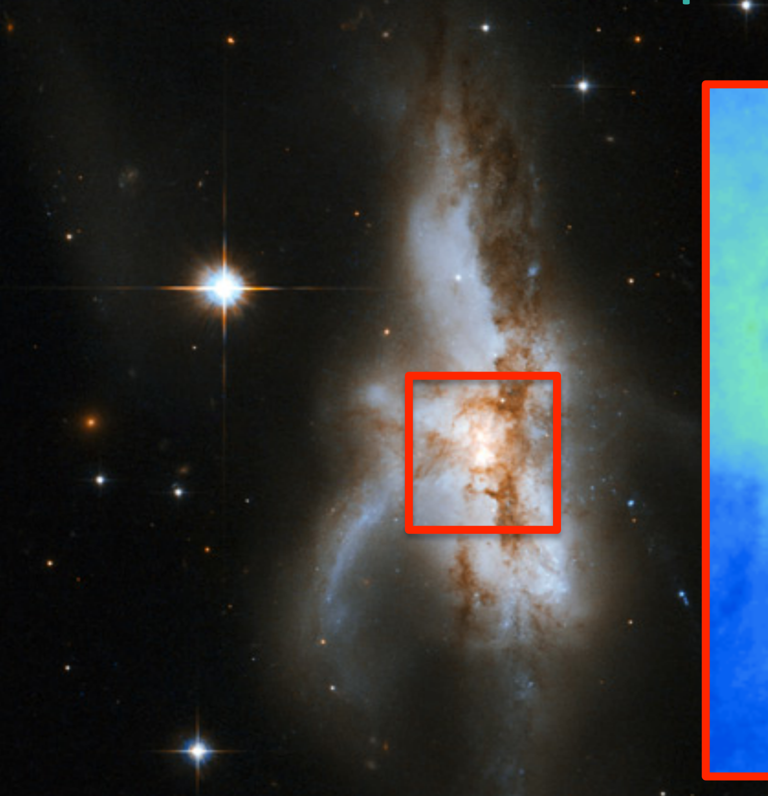
see AMM+13 in prep

dynamical masses - scaling relations

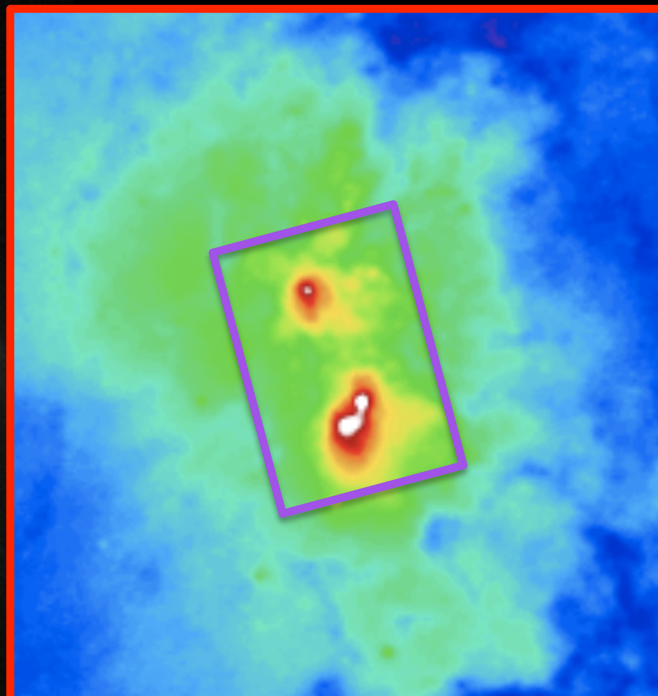
BH MASSES

NGC 6240

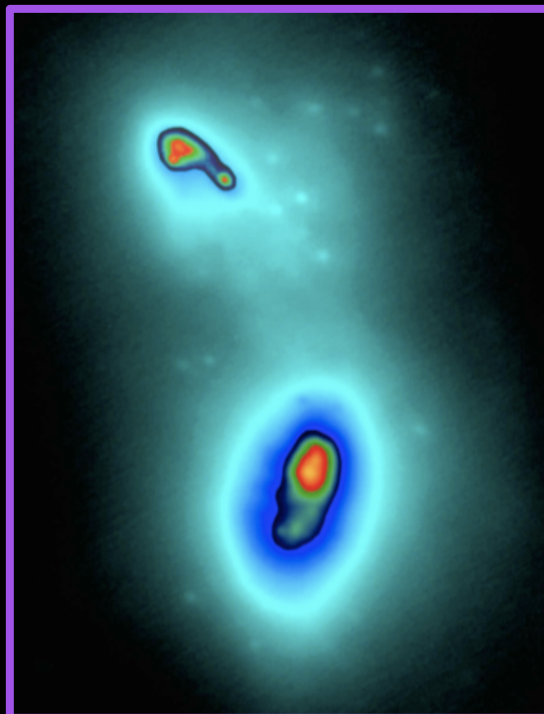
- X-ray confirmed dual AGN (Komossa+03)
- 2 nuclei ~ 700pc apart



Hubble Heritage Image



ACS I-band

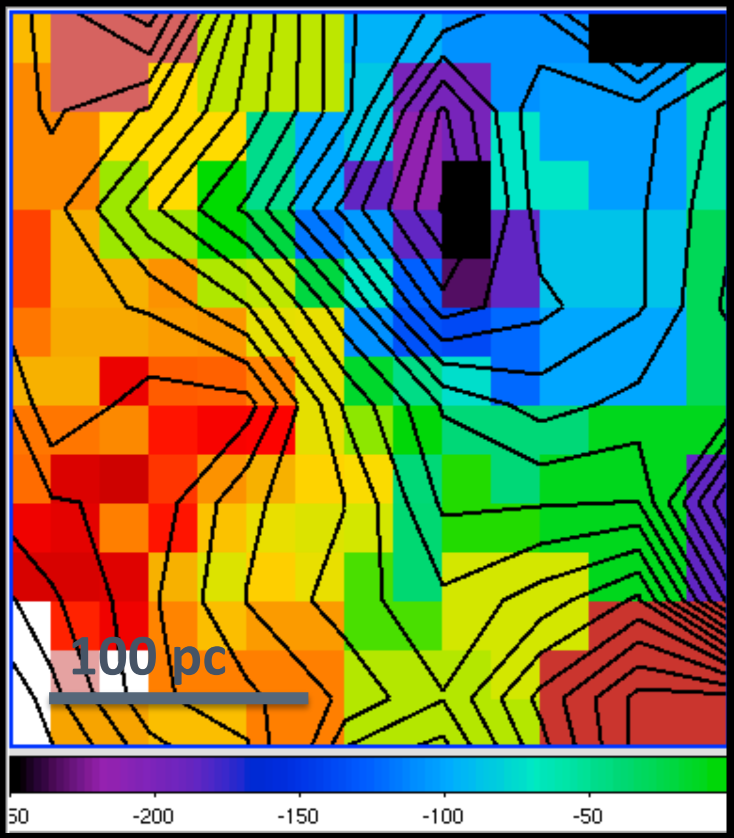


Keck K-band w/LGS AO

See AMM+11

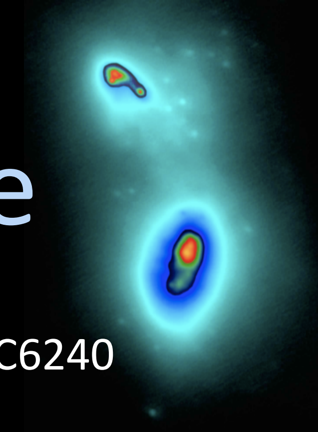
Steep velocity gradient in stars

- Keplerian rotation?
- Use two BH mass measurement methods as a test of assumptions
  - Assume thin disk for lower mass limit
  - Incorporate dispersion (assume virialized) for upper limit

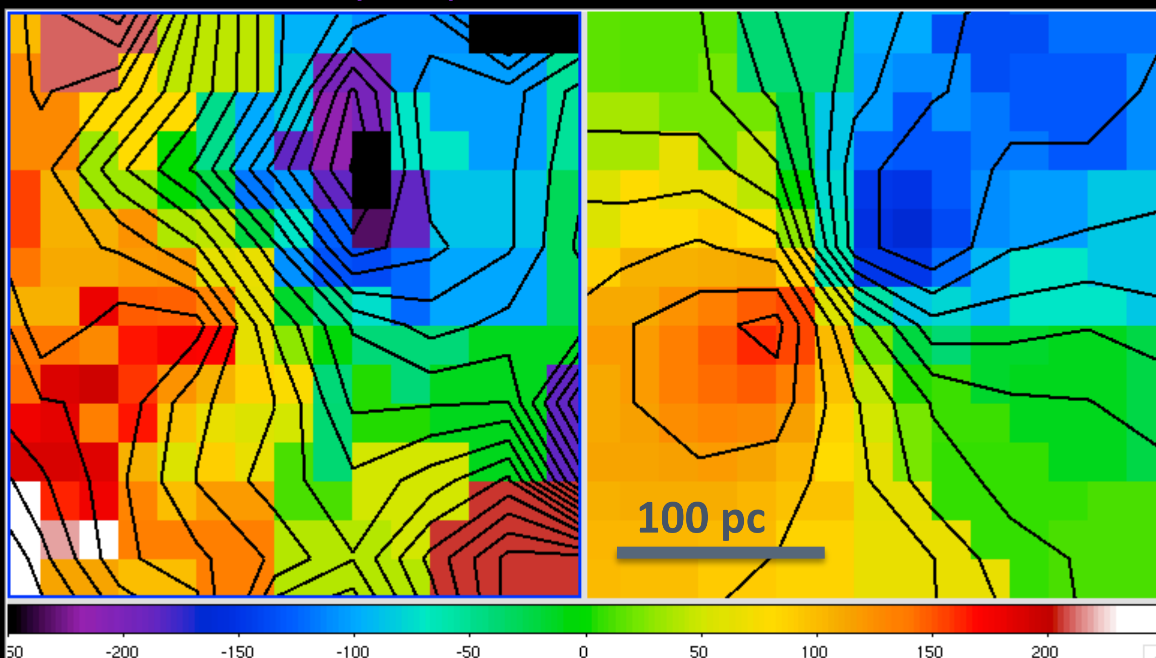


See AMM+11

NGC 6240's south black hole



Observed velocity map　　Model velocity map



Stellar velocities from OSIRIS in 2-d region around BH

Model:

$$v = \sqrt{\frac{GM_{encl}(r)}{r}}$$

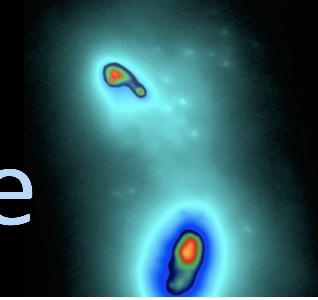
$$M_{encl}(r) = M_{BH} + \rho_0 r^{\gamma}$$

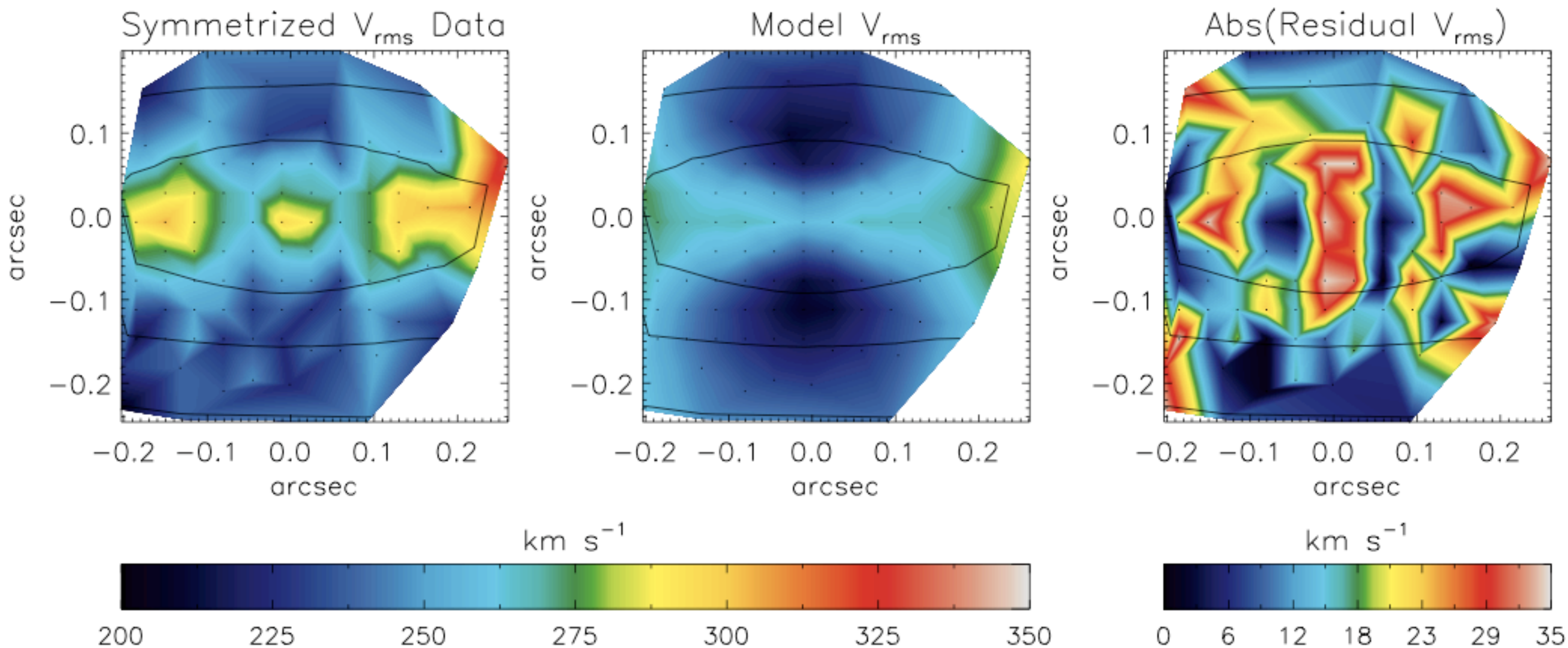
$M_{BH} = 8.7 \pm .3 * 10^8\, M_\odot$

(lower limit)

See AMM+11

NGC 6240's south black hole





JAM Modeling (Cappellari 2008)

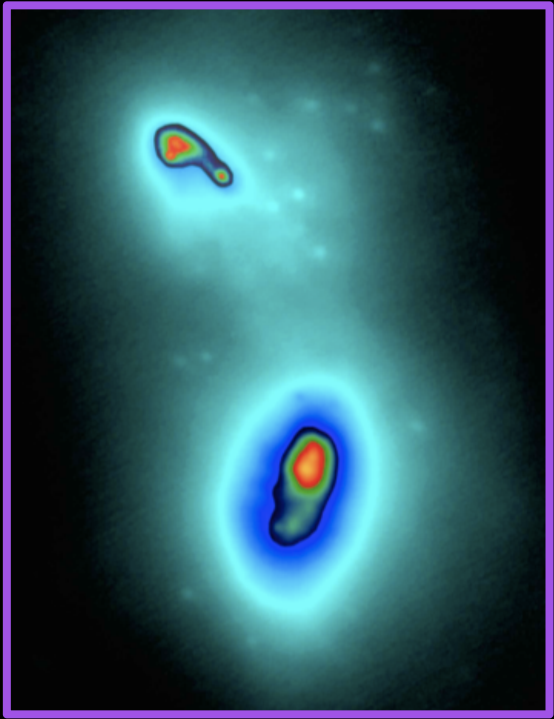
$$v_{rms} = \sqrt{v^2 + \sigma^2}$$

$M_{BH} = 2.0 \pm 0.2 * 10^9 M_\odot$

(upper limit)

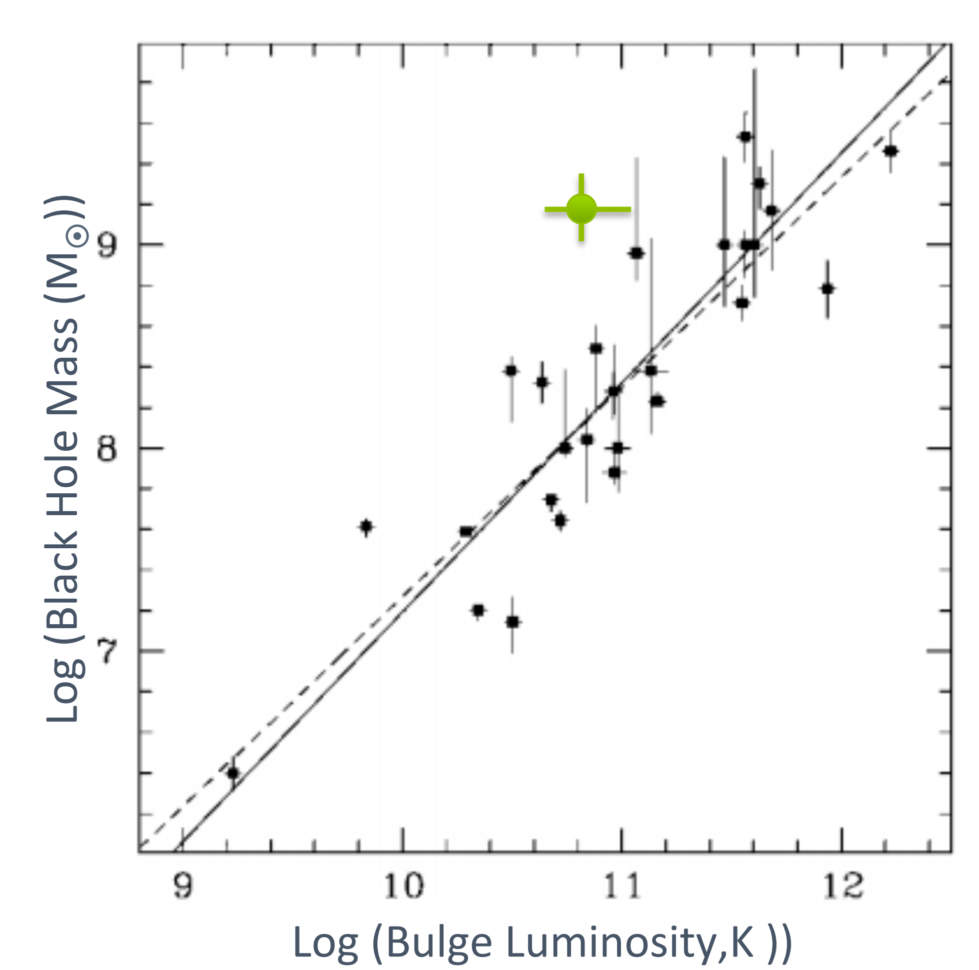
Finding Dual Black Holes

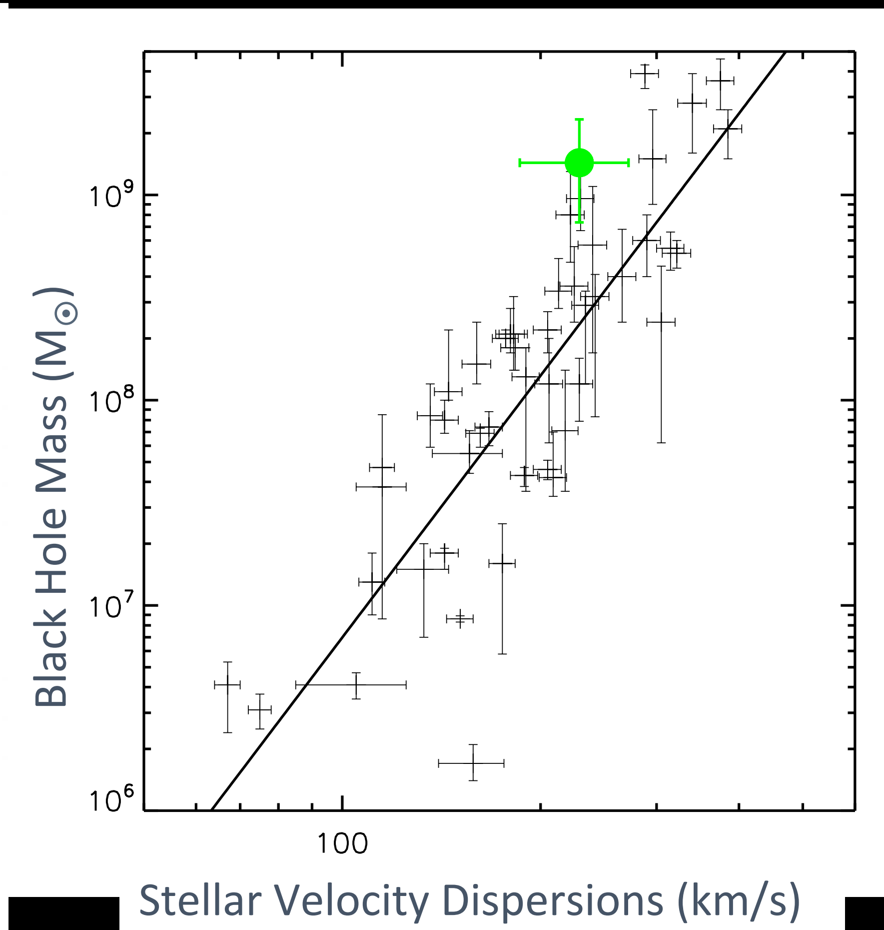
- NGC 6240 is an X-ray confirmed dual AGN (Komossa+03)
- But – with AO we can use kinematics to locate the black holes independent of whether or not they are AGN!



Keck K-band w/LGS AO

BH-host scaling relations



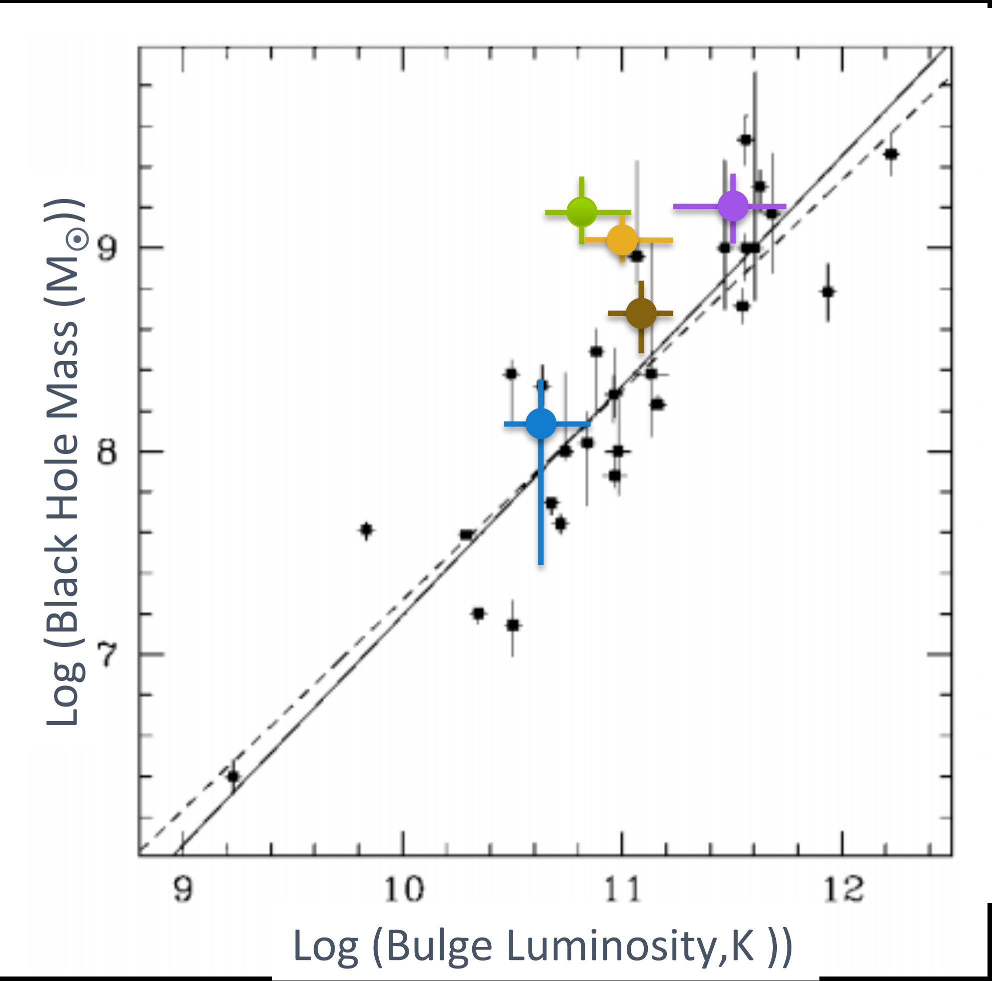


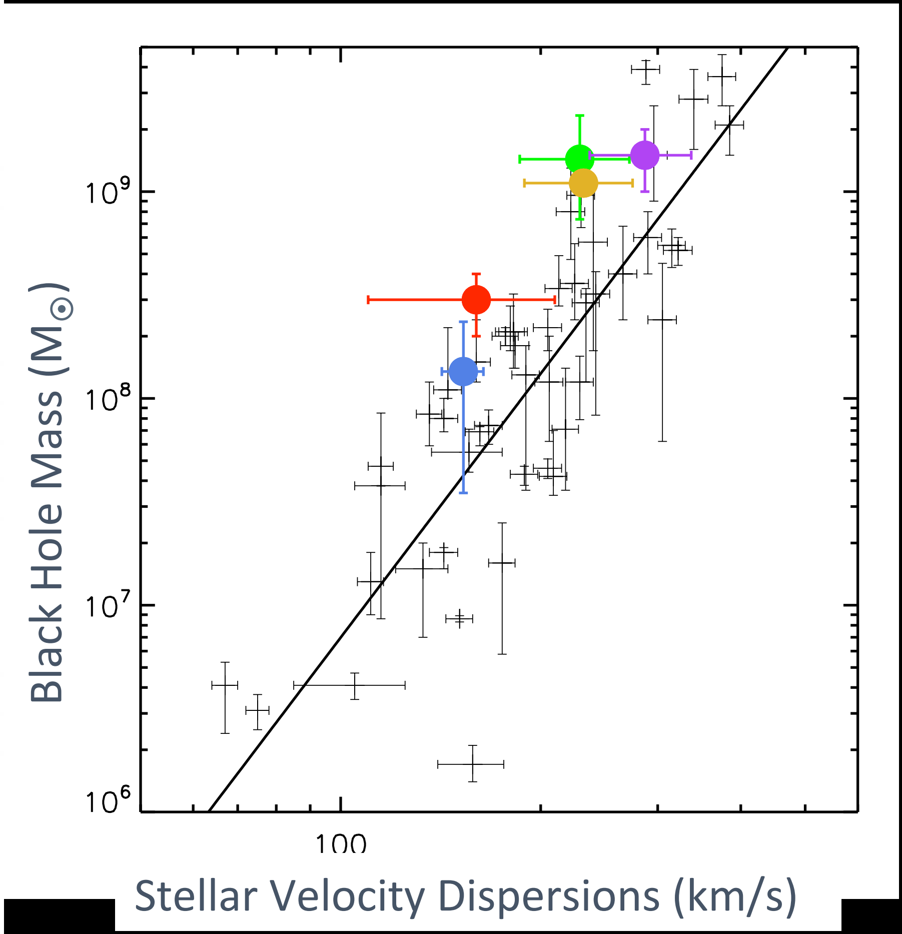
Marconi & Hunt 2003

see AMM+13 in prep

BH-host scaling relations

More points coming!





Marconi & Hunt 2003

see AMM+13 in prep

population studies - individual star clusters - earlier mergers

FUTURE WORK

Future Plans

- Adding to our population studies; increased statistics
- Expanding the population to cover earlier stages of merging
- Comparing nuclear disk properties to a wider variety of simulations
- Stellar population synthesis on individual star clusters

Conclusions

- AO is a powerful tool to locate quiescent black holes in mergers
- Nuclear disks are common features in (U)LIRG mergers
- Gas-rich mergers may lie above BH scaling relations
- Rich dataset for showing outflows and AGN feedback

Image Credit: D. Beales

thank you!

THE END