Extragalactic supermassive black holes in the TMT Era

Aaron Barth (UC Irvine)

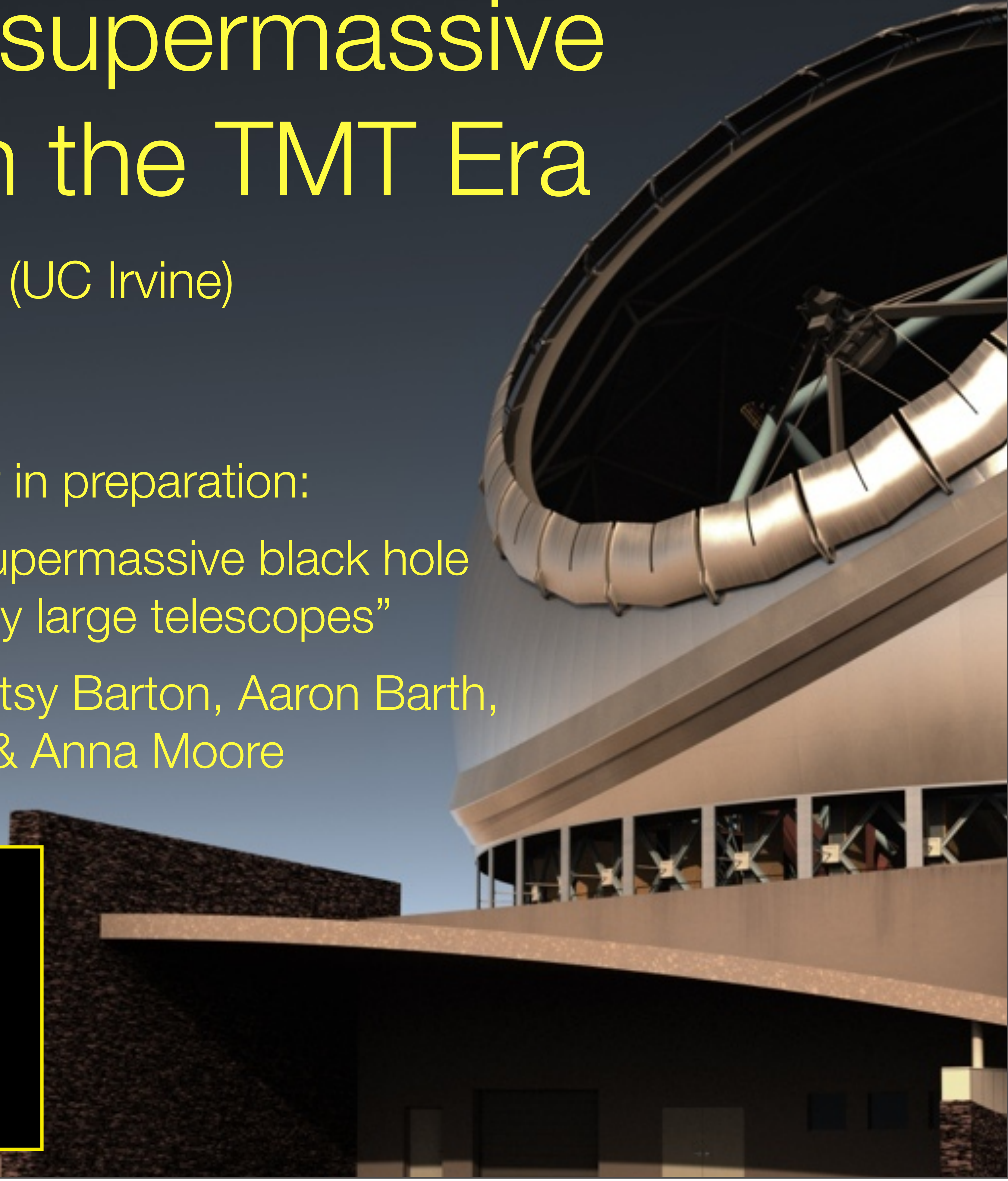
including work from a paper in preparation:

"Prospects for measuring supermassive black hole masses with future extremely large telescopes"

Tuan Do, Shelley Wright, Betsy Barton, Aaron Barth, Luc Simard, James Larkin, & Anna Moore

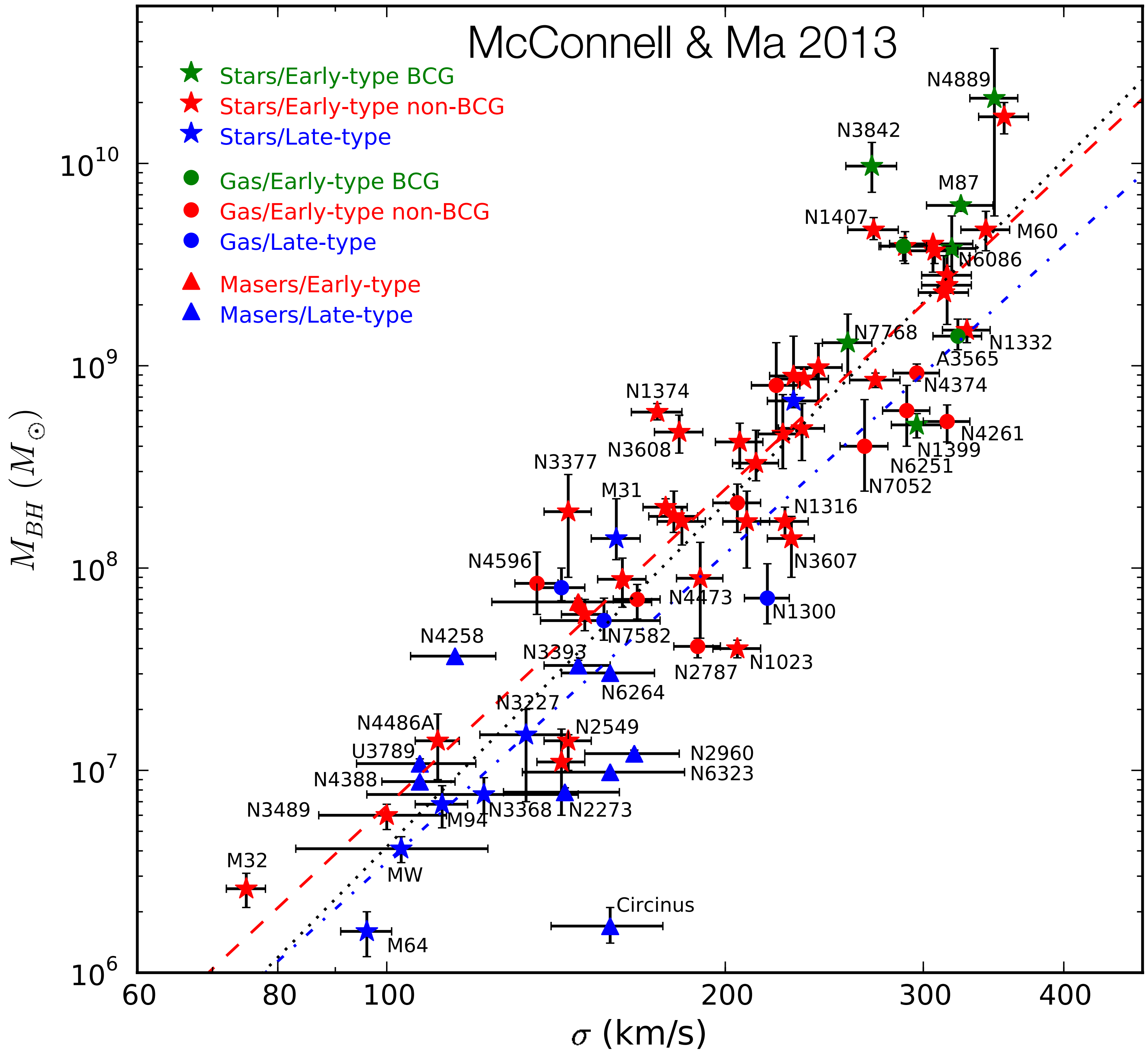
IRiS

InfraRed Imaging Spectrograph



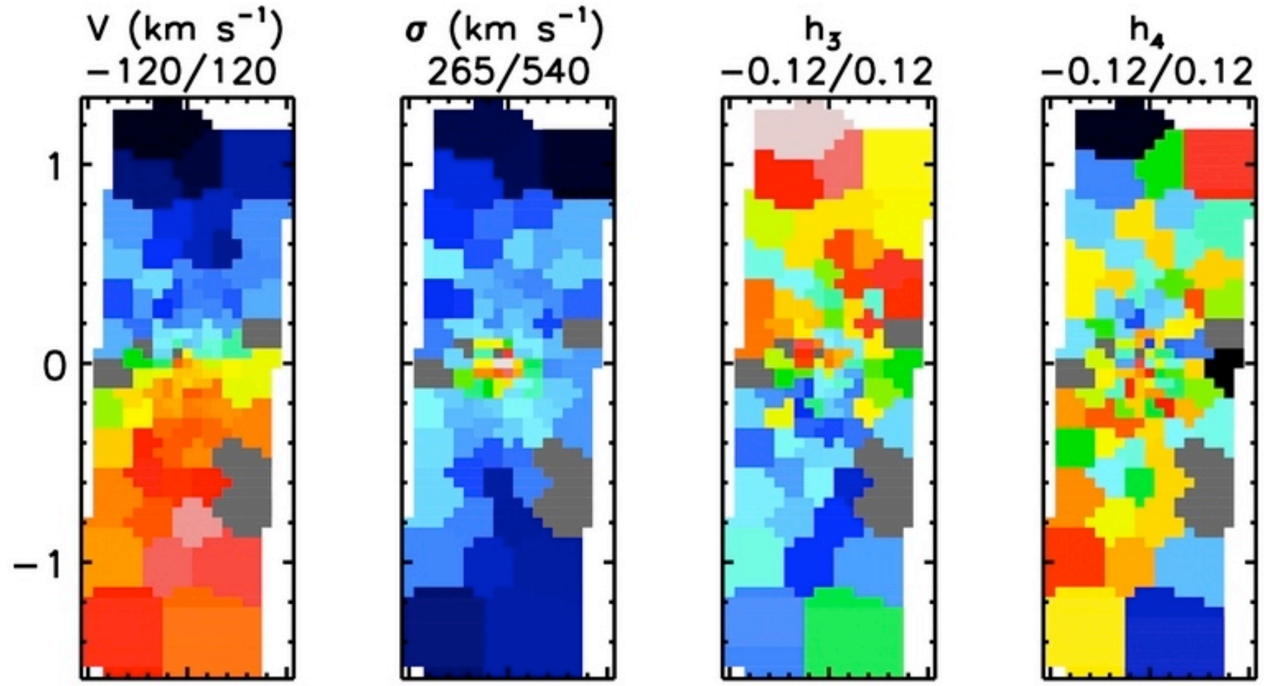
Black hole demographics: current status and open questions

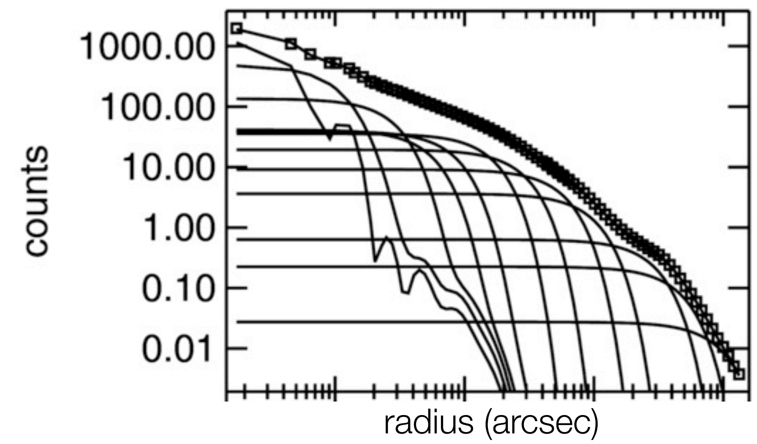
- Below 10^7 M$_\odot$, still very few detections, and large but poorly determined scatter.
- Demographics still very uncertain for the very highest masses, $>10^9$ M$_\odot$.
- Decoupled scaling relations for ellipticals and spirals?
- Recent evidence for extreme outliers, e.g., NGC 1277 (van den Bosch et al 2012)



Example of an AO-based stellar-dynamical BH detection: the S0 galaxy NGC 3998 (J. Walsh et al, 2012)

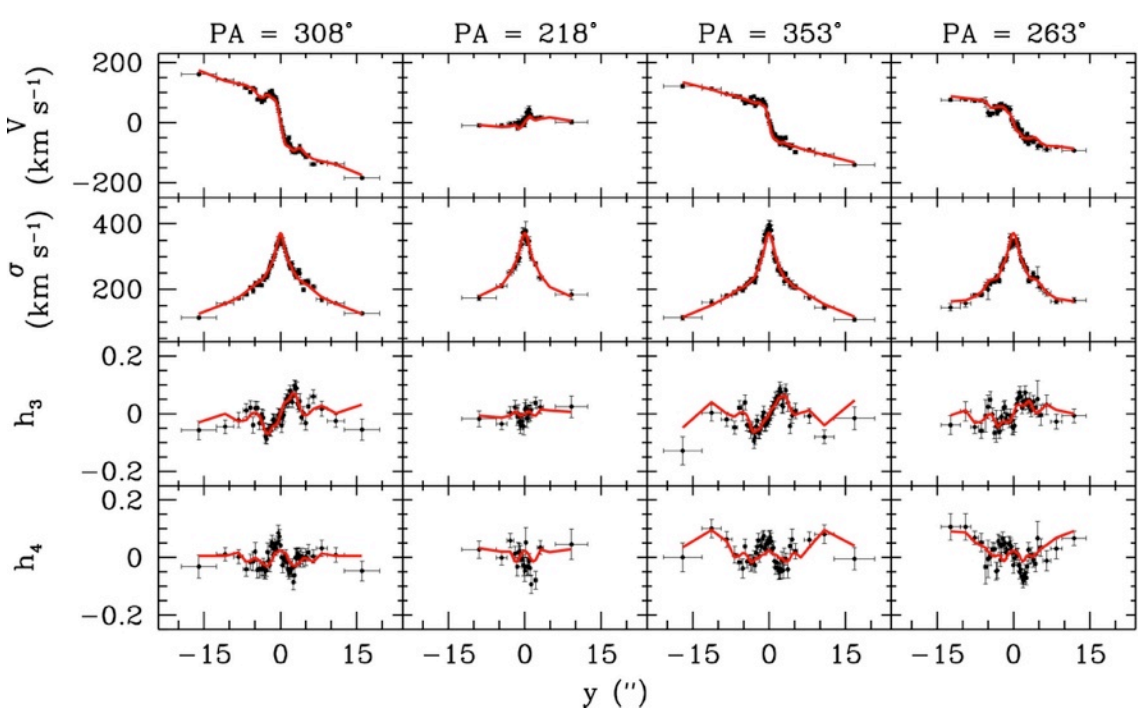
Central kinematics: OSIRIS with 50 mas sampling, measured from K-band CO bandheads

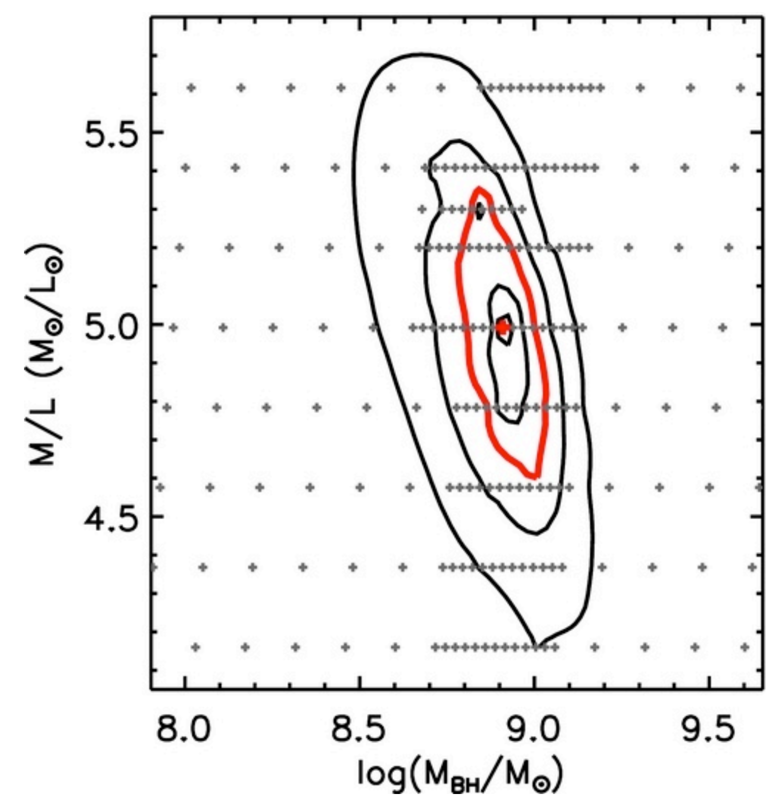




Luminosity profile measured from HST images

Large-scale kinematics measured with LRIS

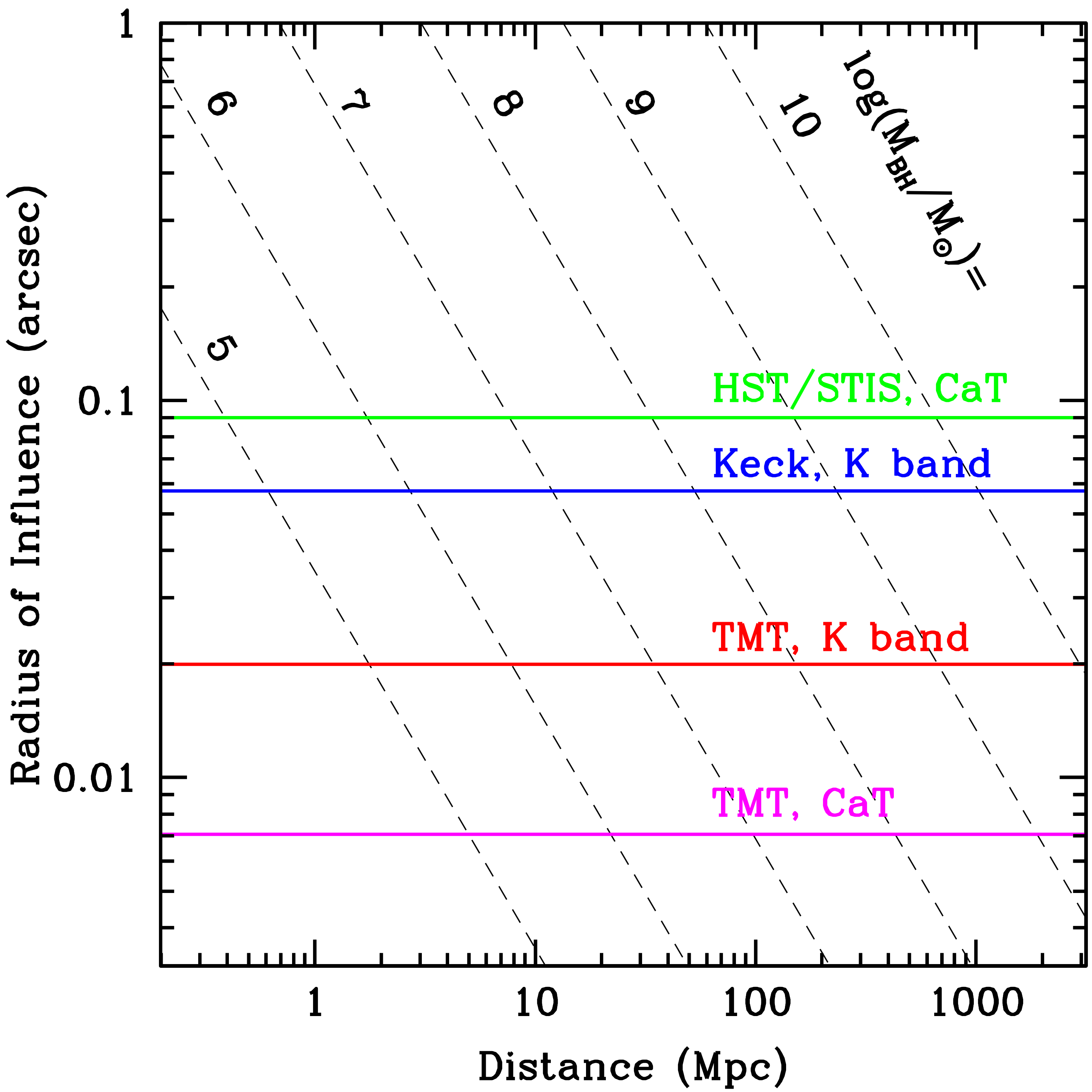




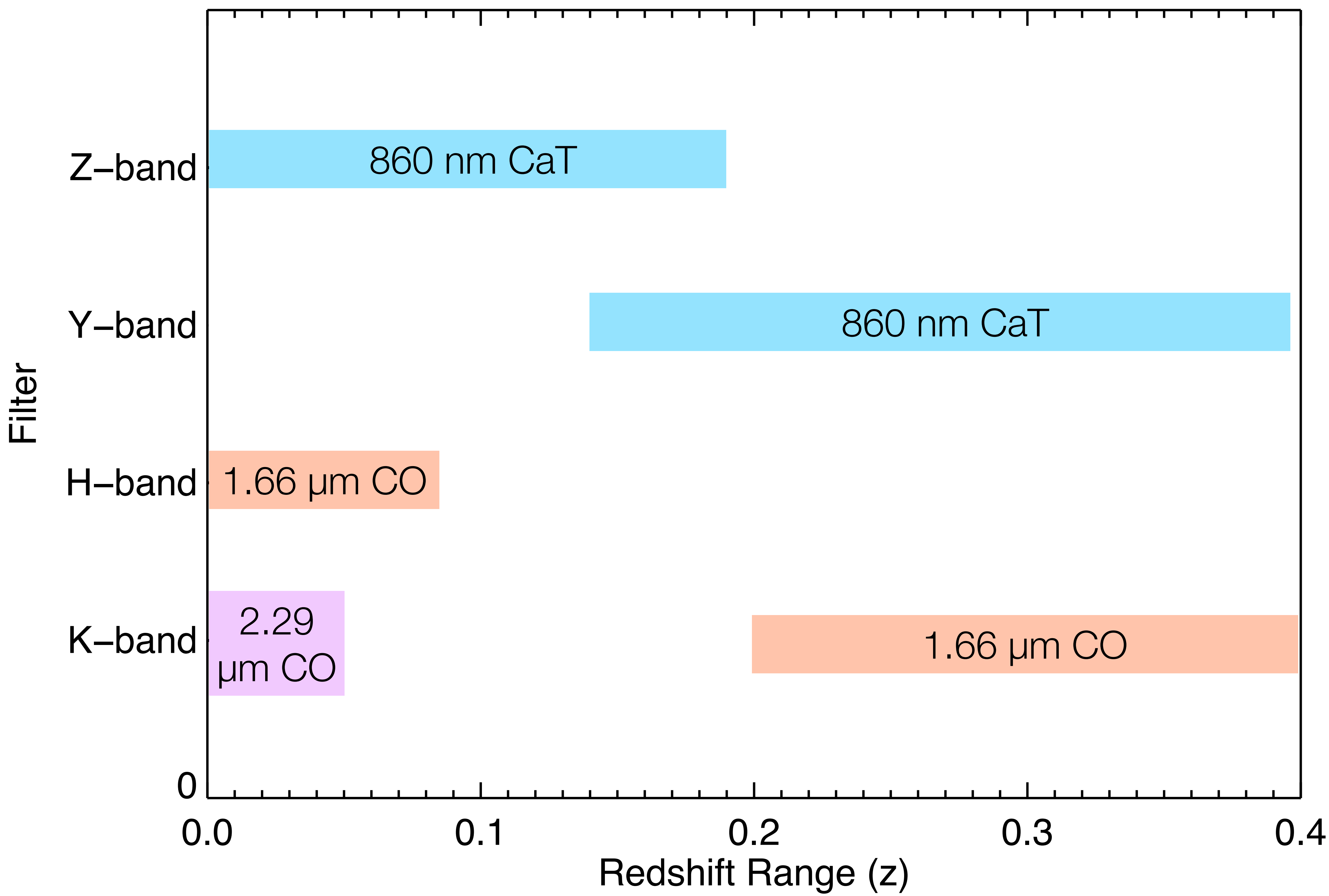
Schwarzschild orbit modeling, fitted to kinematic data to constrain M_{BH}

TMT & IRIS: the next giant leap in angular resolution for SMBH detection

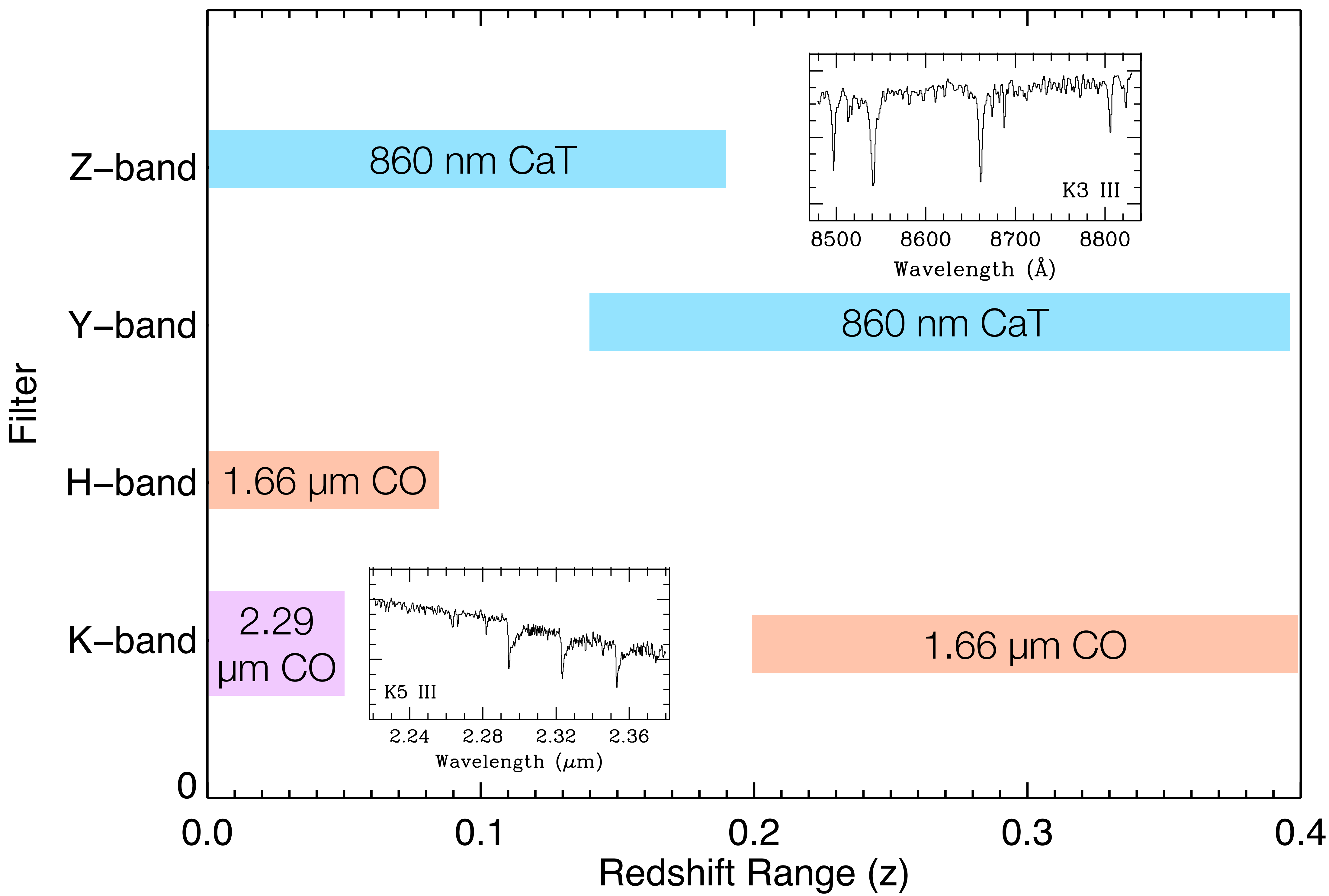
- Dynamical detection requires resolving the gravitational sphere of influence of the BH: $r_g = GM/\sigma^2$
- Assume the scaling relationship from McConnell & Ma (2013): $\log M_{BH} = 8.32 + 5.64 \log(\sigma/200)$
- With K-band observations, TMT can potentially detect MW-equivalent BHs out to 20 Mpc, and the highest-mass BHs to Gpc distances



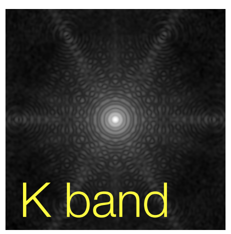
Redshift windows and available spectral features

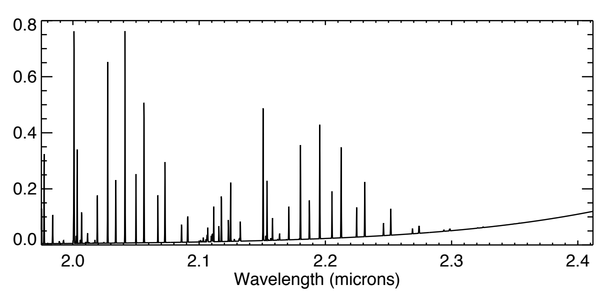


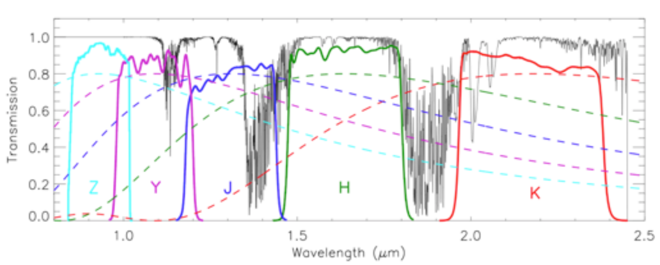
Redshift windows and available spectral features



The IRIS simulator
(Tuan Do, Shelley Wright, & the IRIS science team)







source model

PSF convolution

noise model:
sky background,
telescope, AO system,
detector readnoise and
dark current

options:
imaging/spectroscopy,
slicer/lenslet,
spatial sampling,
grating & filter

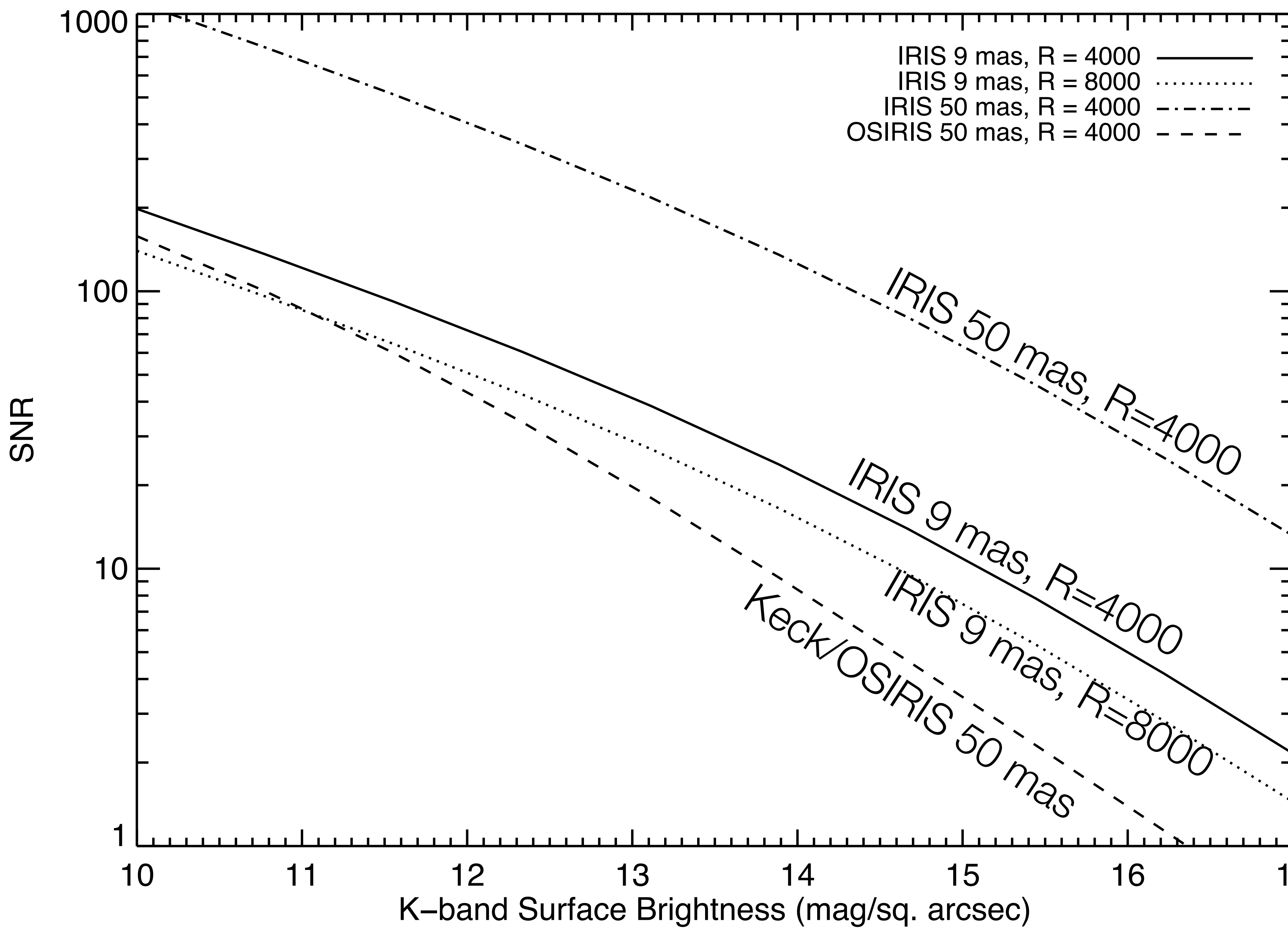
→

S/N maps

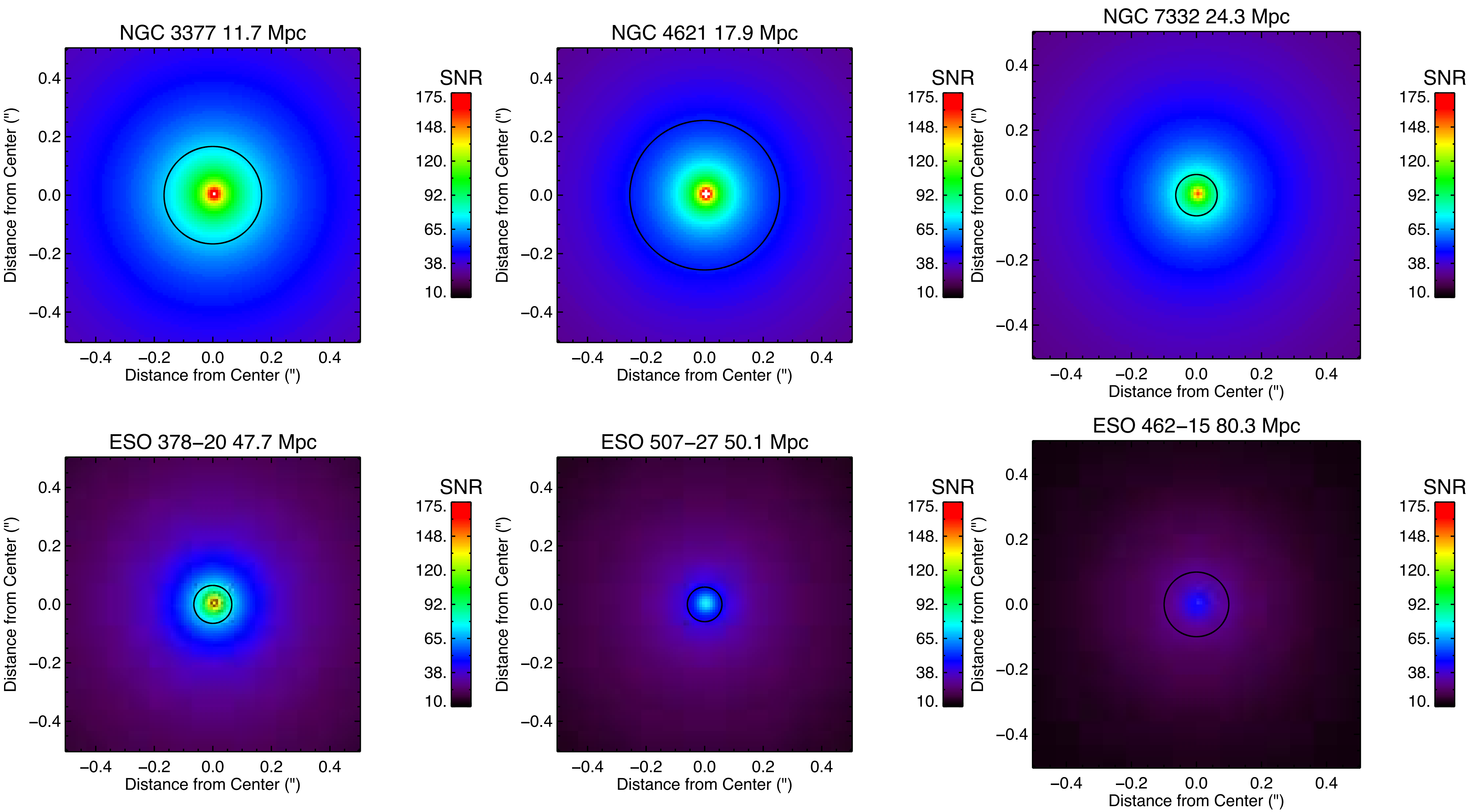
simulated images and IFU spectra

S/N predictions for IFU observations of extended sources

- S/N estimates shown here for total integration time of 5 hours in the K band
- IRIS sensitivity in the 9 mas scale will be better than Keck/OSIRIS in the 50 mas scale

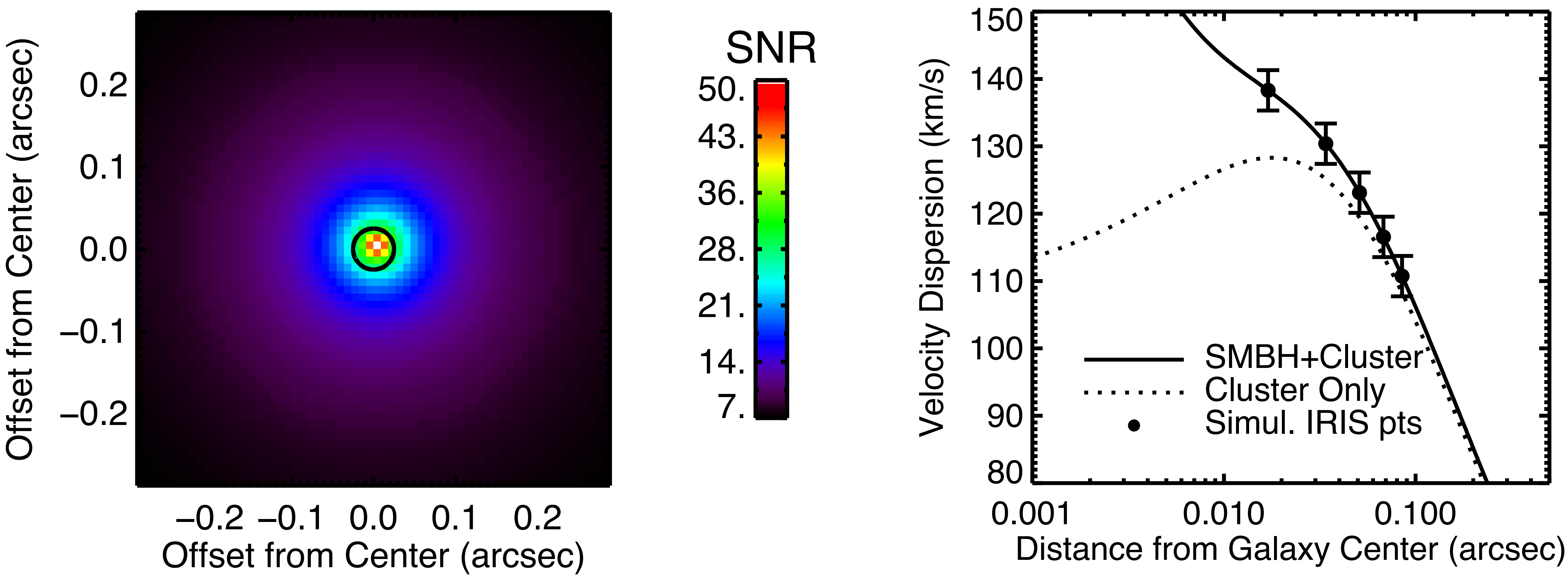


Simulations for nearby early-type galaxies



- Simulation parameters: K band, 9 mas scale, R=4000, 1 hour exposures

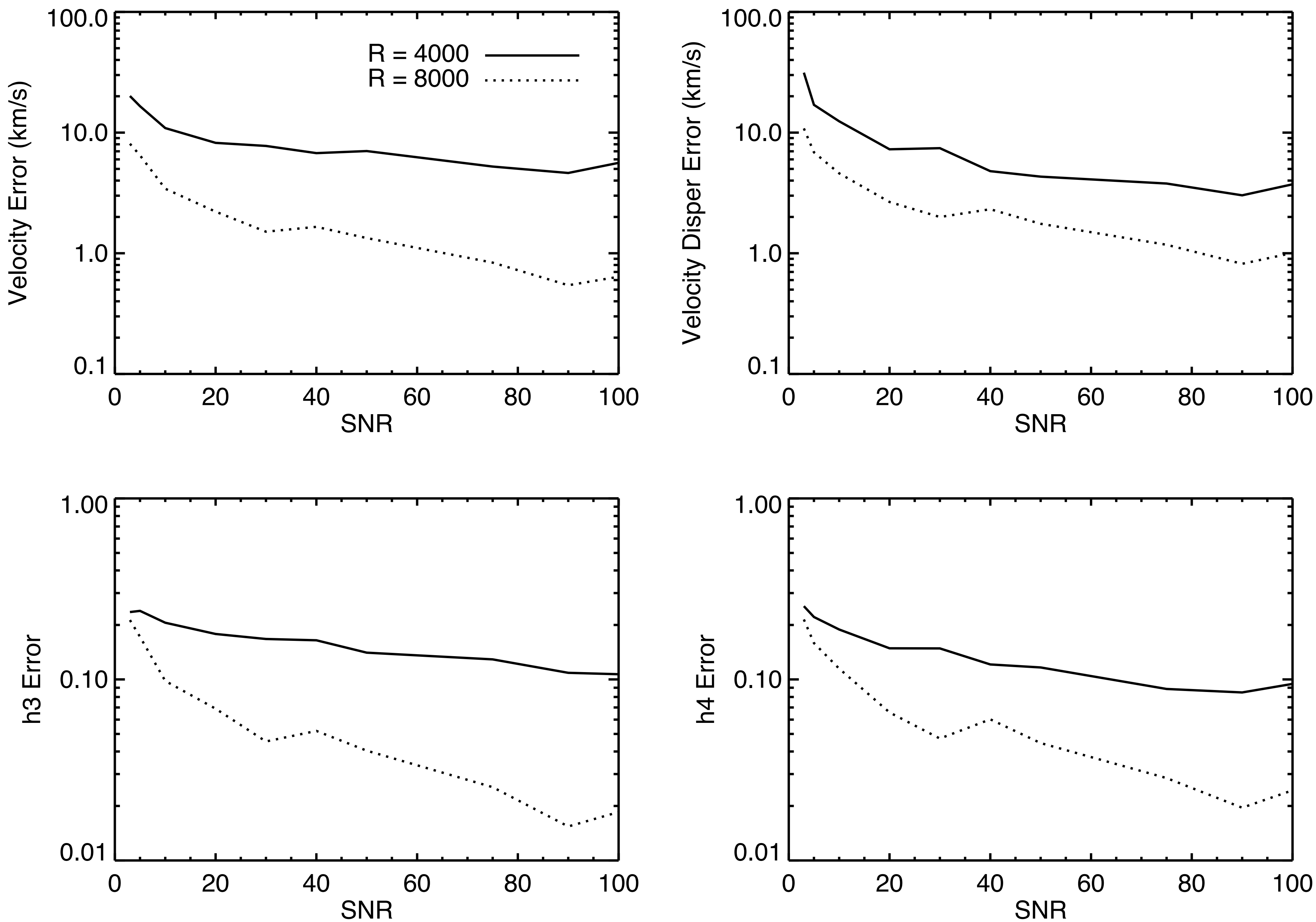
Simulating an observation of the MW core at the distance of the Virgo Cluster (16 Mpc)



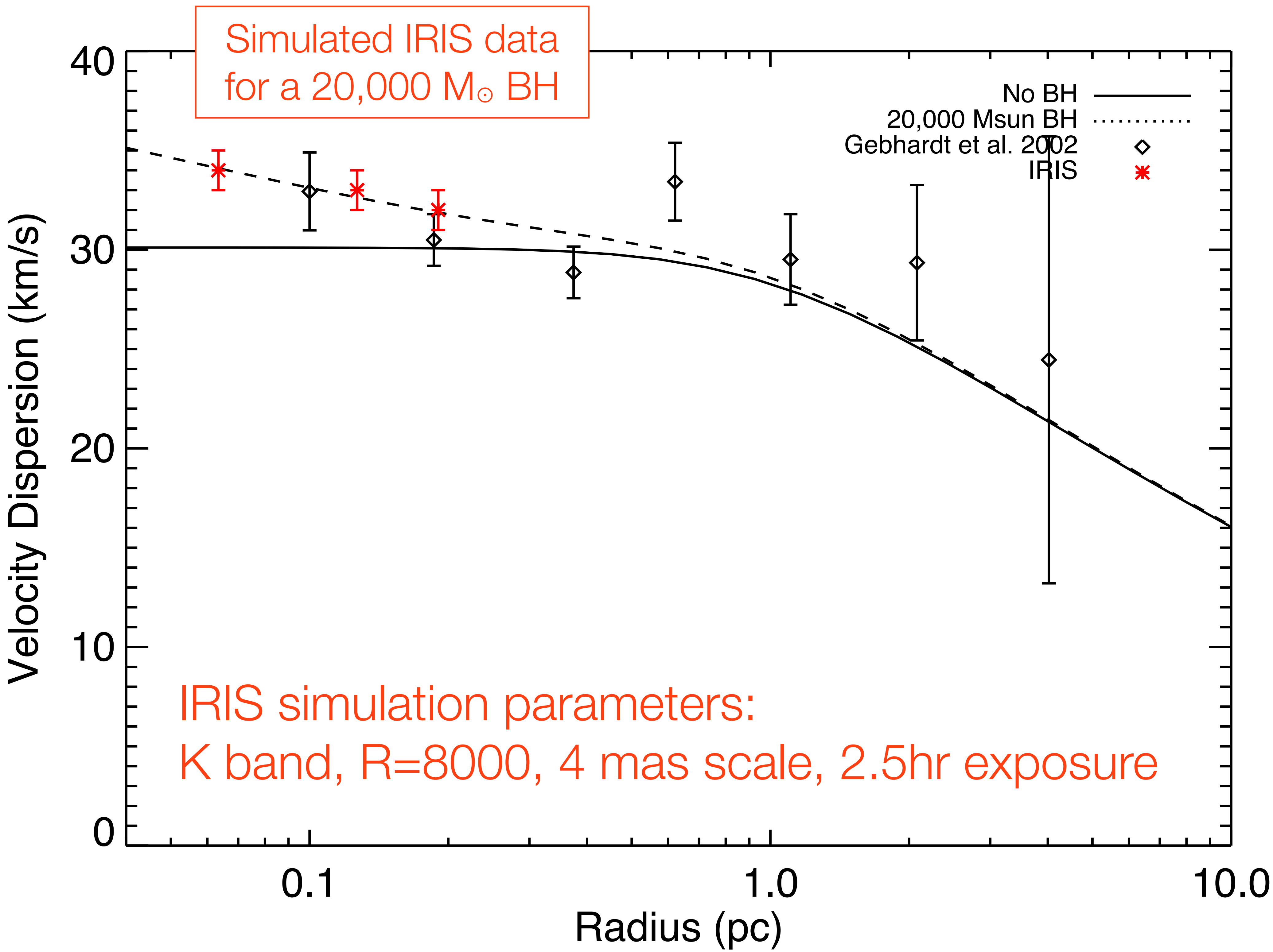
- Parameters: K band, 9 mas scale, R=4000, 10×900 sec exposure

A unique IRIS feature: R=8000 for observing kinematics of low-mass galaxies and clusters

Predicted errors in V, σ, h_3, and h_4, for an object with actual velocity dispersion 30 km/sec, as observed at R=4000 or R=8000

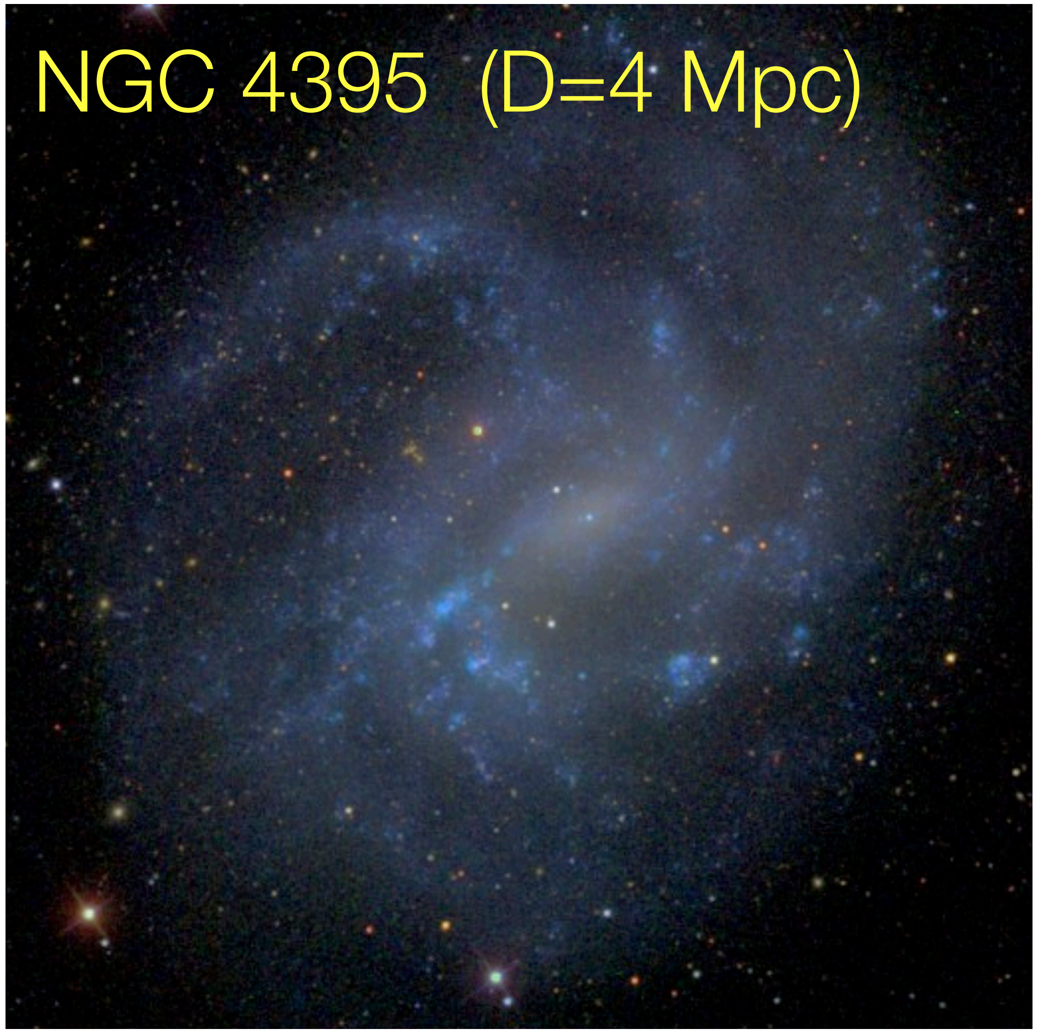


IRIS's ability to detect an IMBH in the M31 globular cluster G1



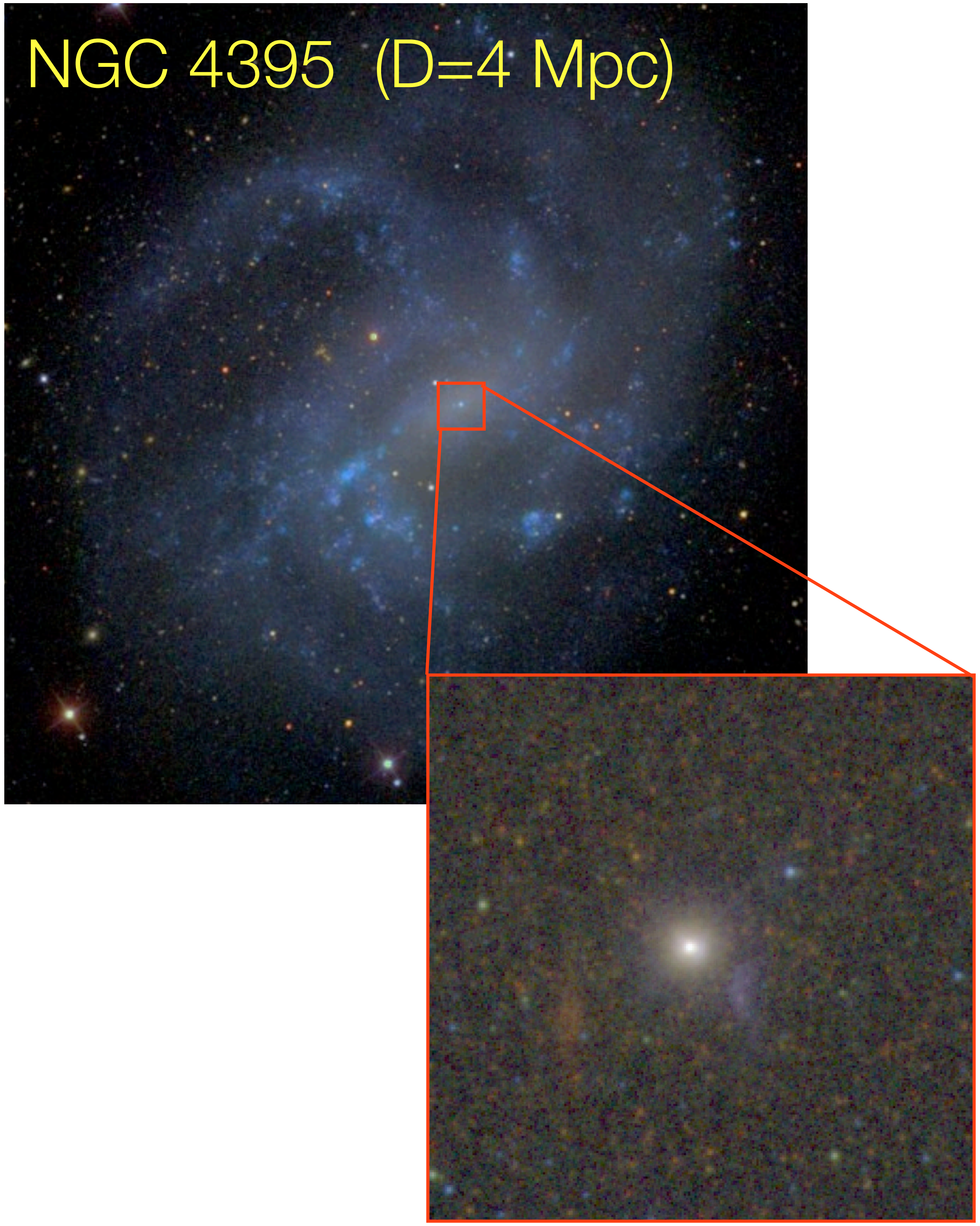
Nuclear clusters in low-mass galaxies: do they contain IMBH?

- NGC 4395: a bulgeless Sd galaxy with a Seyfert 1 nucleus inside a nuclear cluster
- BH mass from reverberation mapping: 3.6×10^5 $M_\odot$ (Peterson et al 2005), or 4.9×10^4 $M_\odot$ (Edri et al 2012)
- The nuclear cluster has r_{eff} = 0.15 arcsec (3 pc). In the R=8000 mode, IRIS can resolve the spatial and kinematic structure of the cluster for the first time.

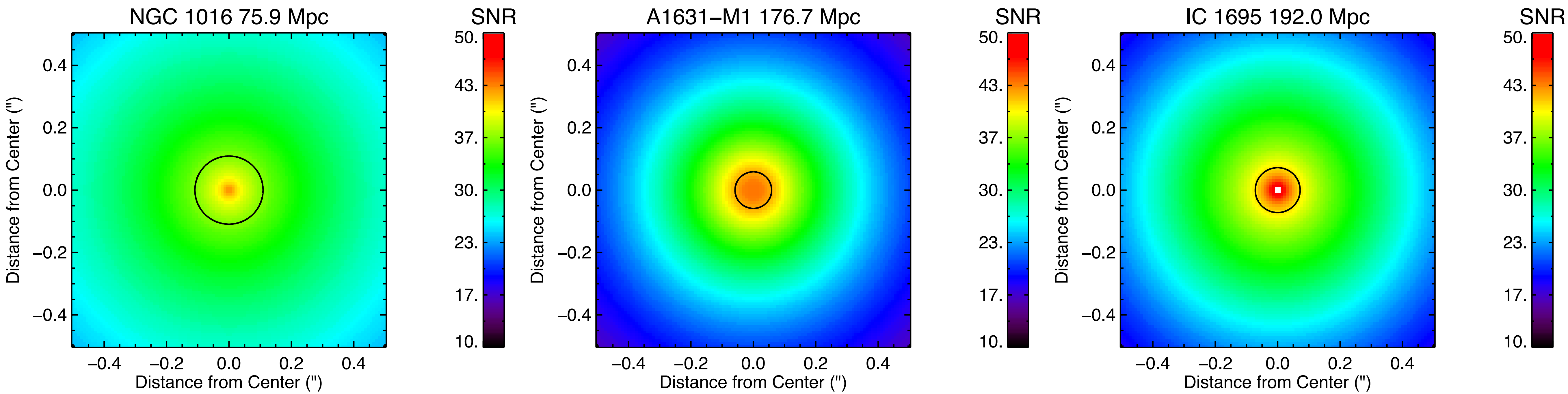


Nuclear clusters in low-mass galaxies: do they contain IMBH?

- NGC 4395: a bulgeless Sd galaxy with a Seyfert 1 nucleus inside a nuclear cluster
- BH mass from reverberation mapping: $3.6\times10^5\ M_\odot$ (Peterson et al 2005), or $4.9\times10^4\ M_\odot$ (Edri et al 2012)
- The nuclear cluster has r_{eff} = 0.15 arcsec (3 pc). In the R=8000 mode, IRIS can resolve the spatial and kinematic structure of the cluster for the first time.



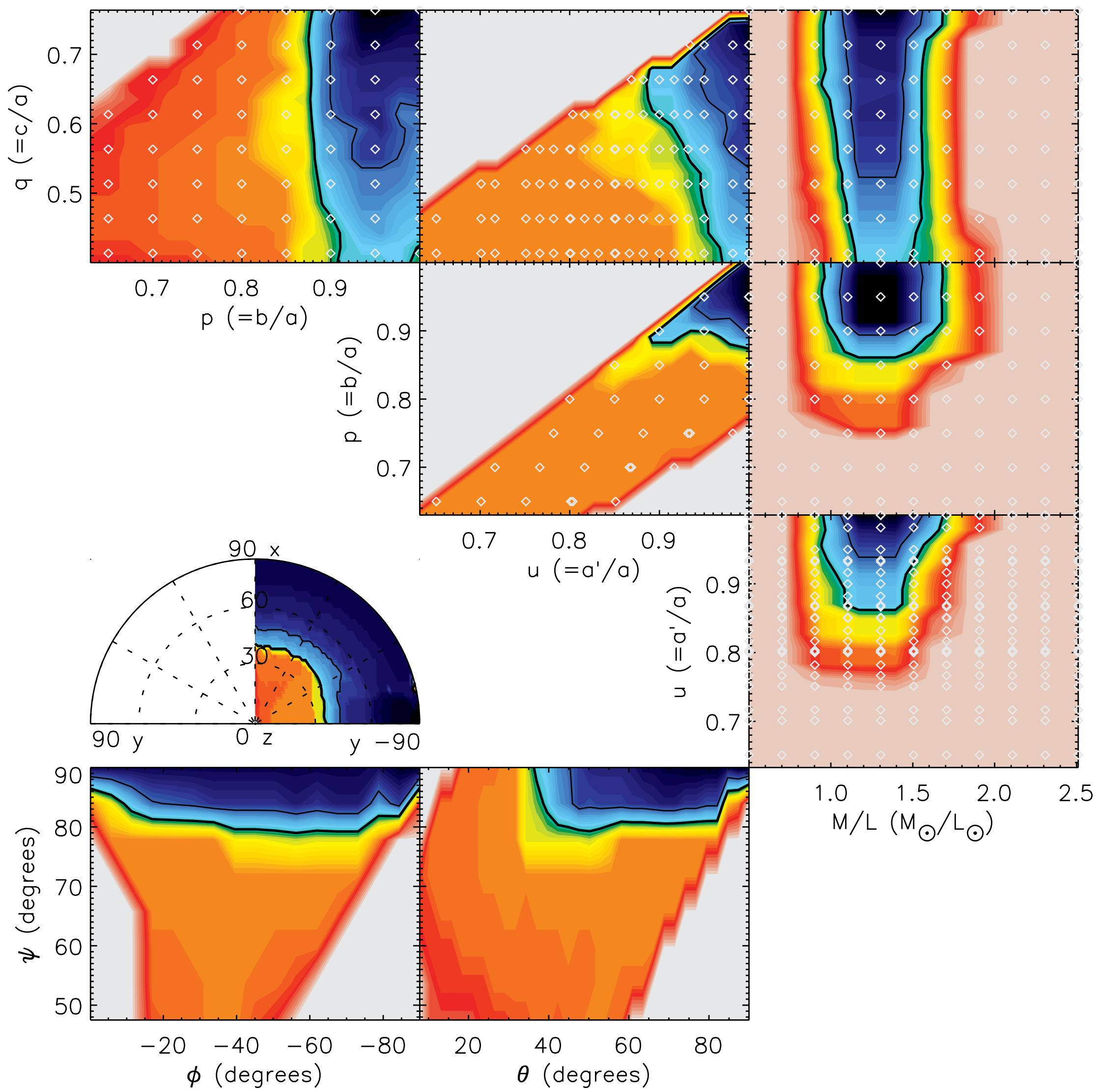
Pushing the limits: very high mass BHs

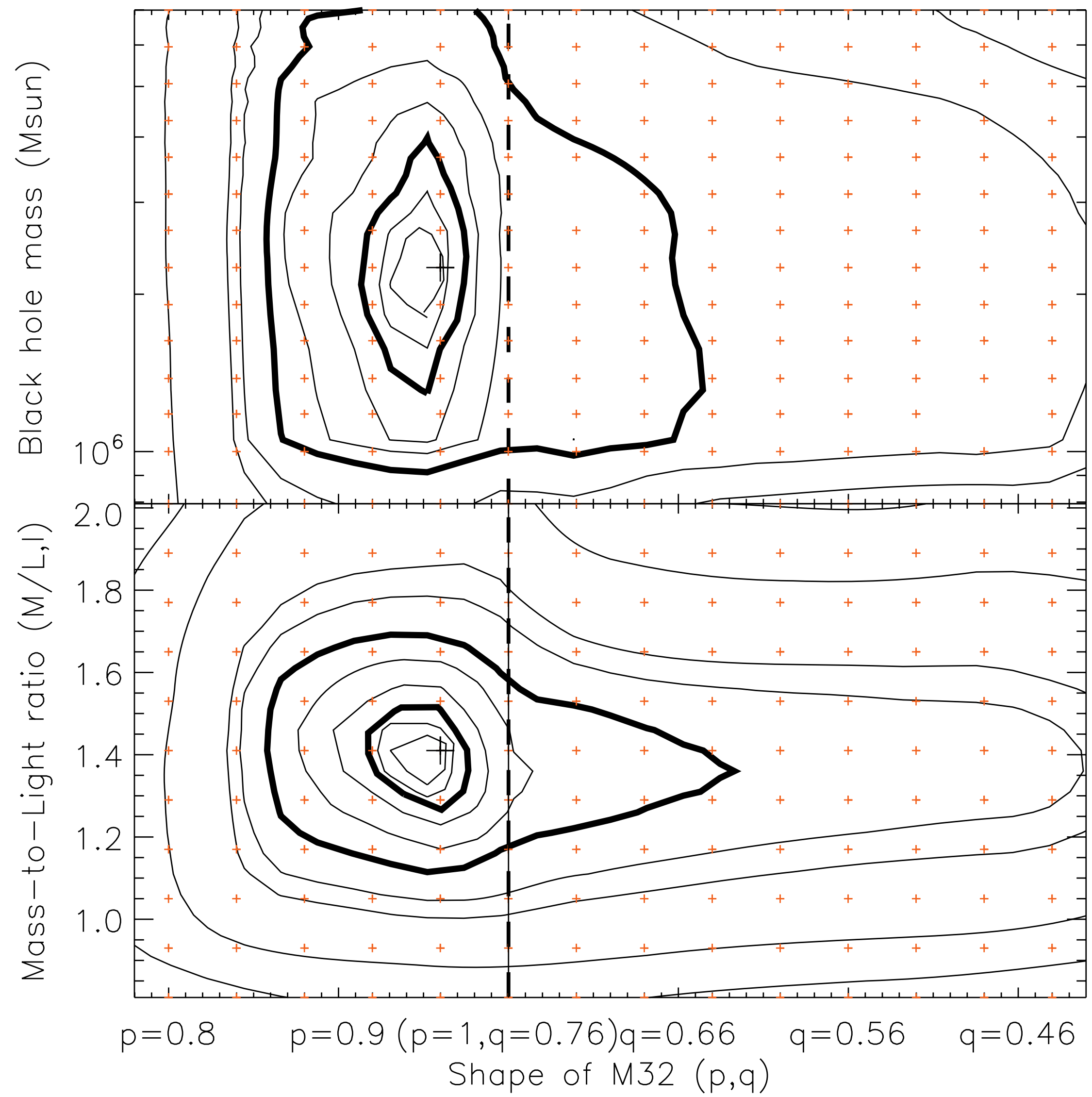


- Galaxies with estimated $M_{BH} > 10^9\ M_\odot$
- Parameters: K band, 9 mas scale, R=4000, 5 hour exposures

Going from data to discovery

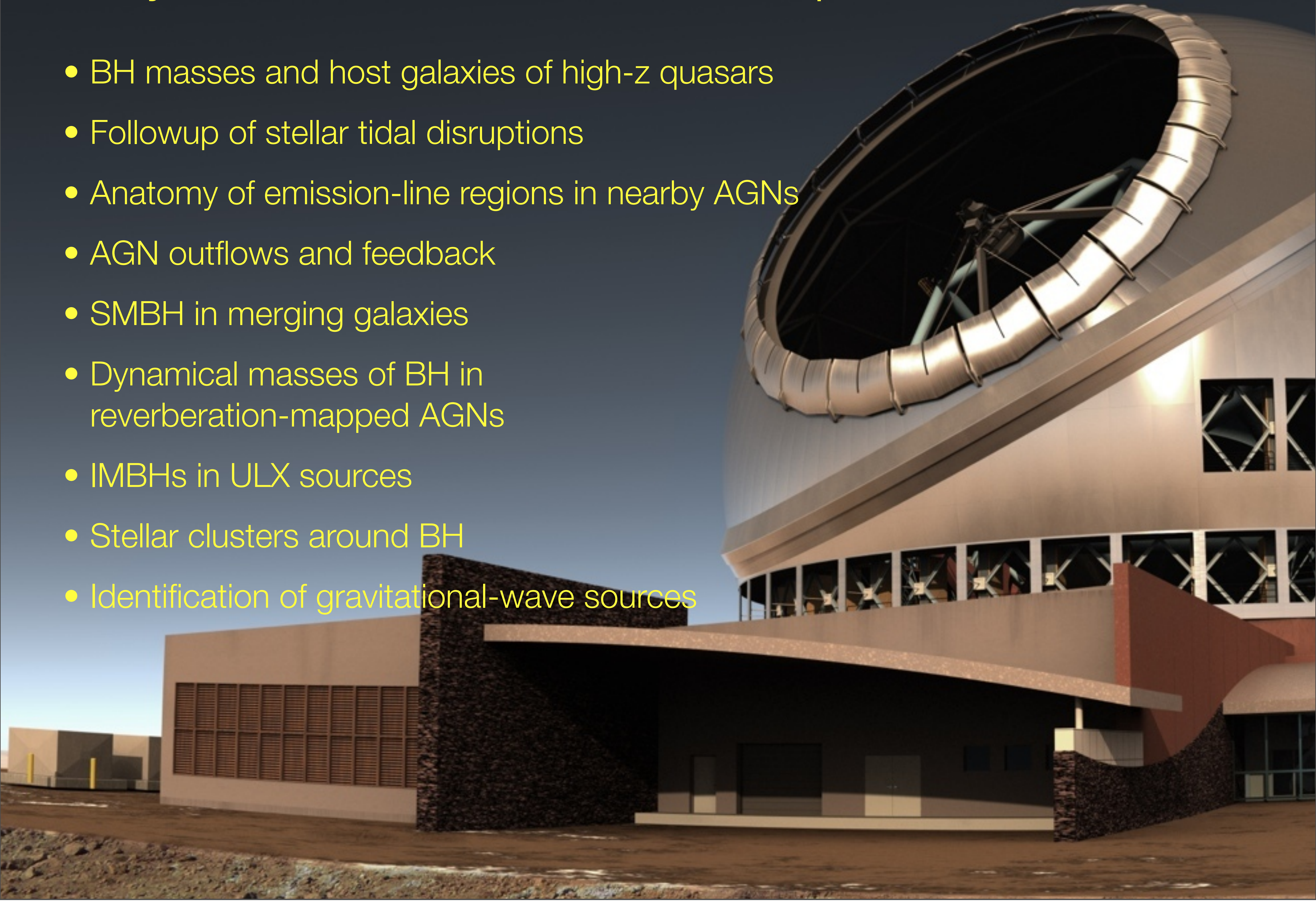
For TMT to be the world's greatest BH discovery engine, stellar-dynamical modeling expertise is critically important.





M32: Constraints on triaxial shape parameters, M_{BH}, and stellar M/L
(van den Bosch & de Zeeuw 2010)

Many other BH science cases to pursue:



- BH masses and host galaxies of high-z quasars
- Followup of stellar tidal disruptions
- Anatomy of emission-line regions in nearby AGNs
- AGN outflows and feedback
- SMBH in merging galaxies
- Dynamical masses of BH in reverberation-mapped AGNs
- IMBHs in ULX sources
- Stellar clusters around BH
- Identification of gravitational-wave sources