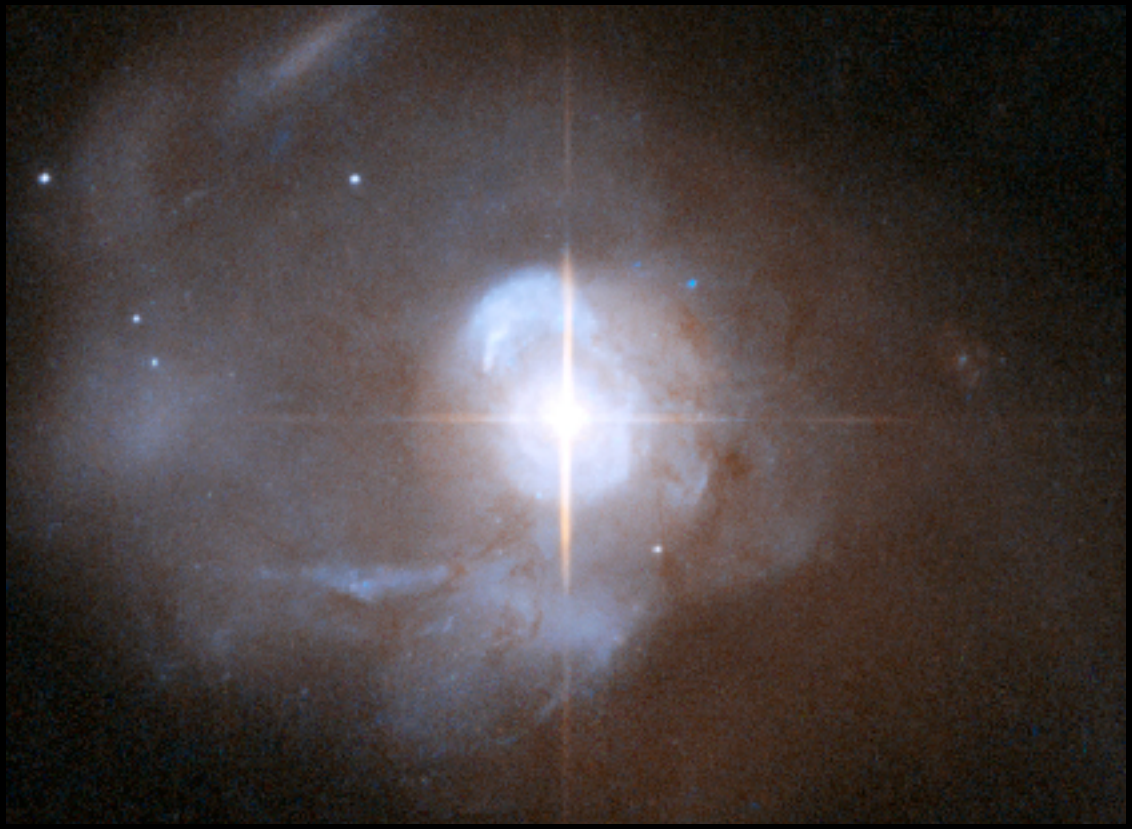
Ubiquitous, Spatially Resolved Quasar-Mode Feedback in Nearby Quasars and Correlations with Black Hole Properties



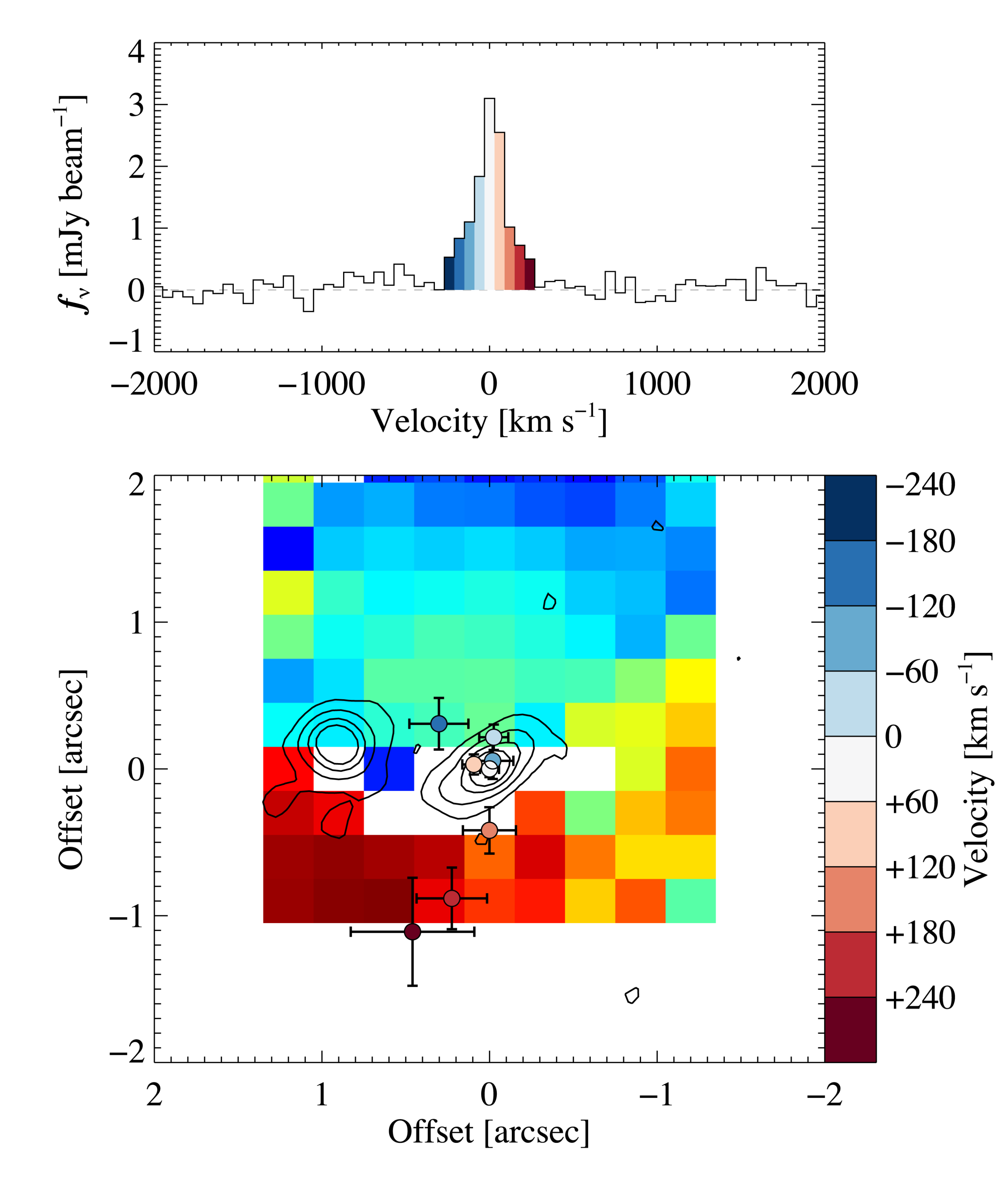
David Rupke

Rhodes College

Based on DR, K. Gültekin, & S. Veilleux 2017, submitted to ApJ

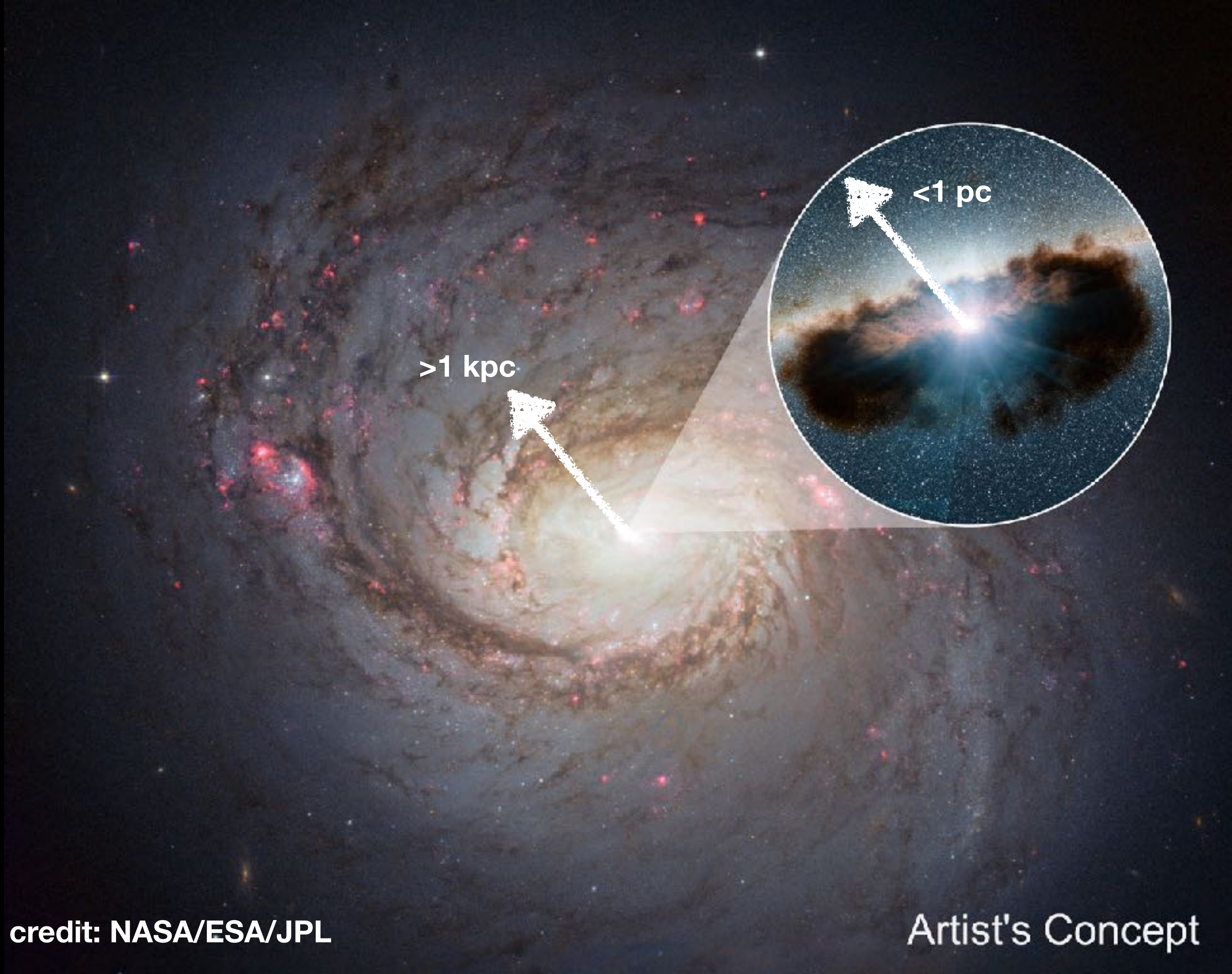
See Jessie Runnoe's poster

molecular gas in a jet-driven outflow (PG1700+518)



Ice cream bicone model for the Seyfert narrow line region

Specialty of the AGN ice cream parlor



<1 pc
>1 kpc
credit: NASA/ESA/JPL
Artist's Concept

Galactic outflows driven by black hole accretion: galaxy—BH coevolution

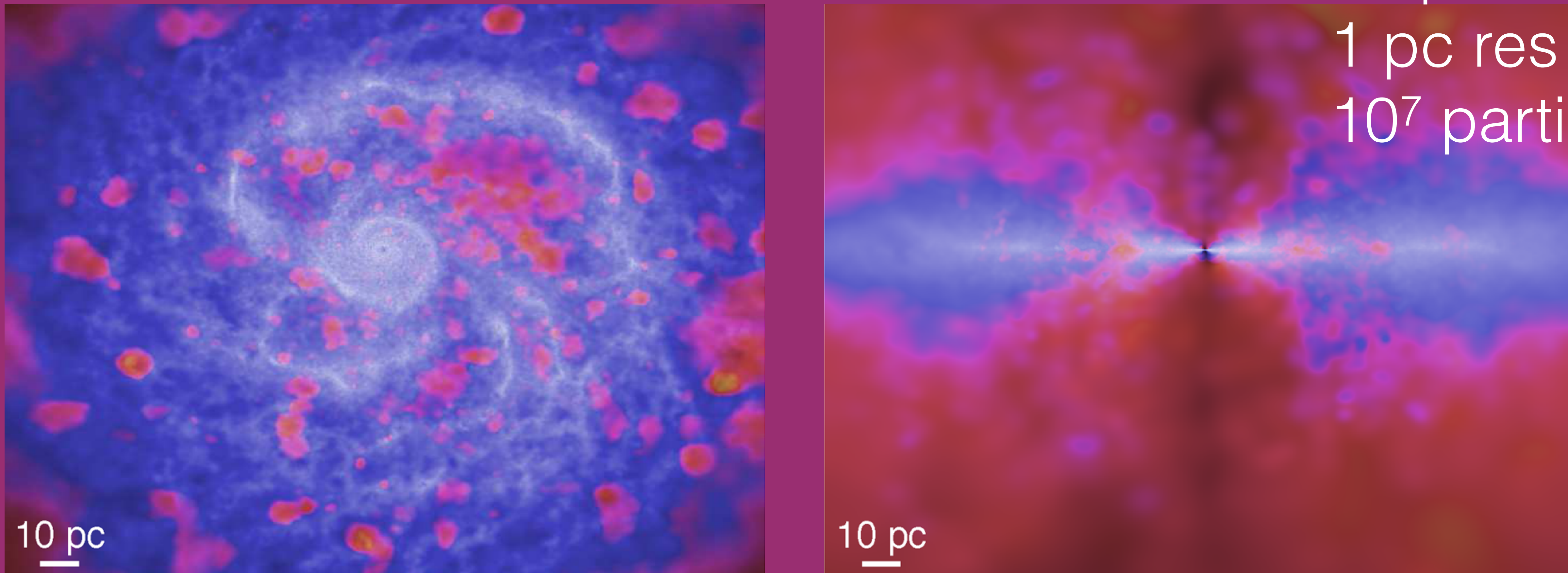
1. The M_BH — sigma relation (King 03)

2. The galaxy stellar mass function (Somerville+08)

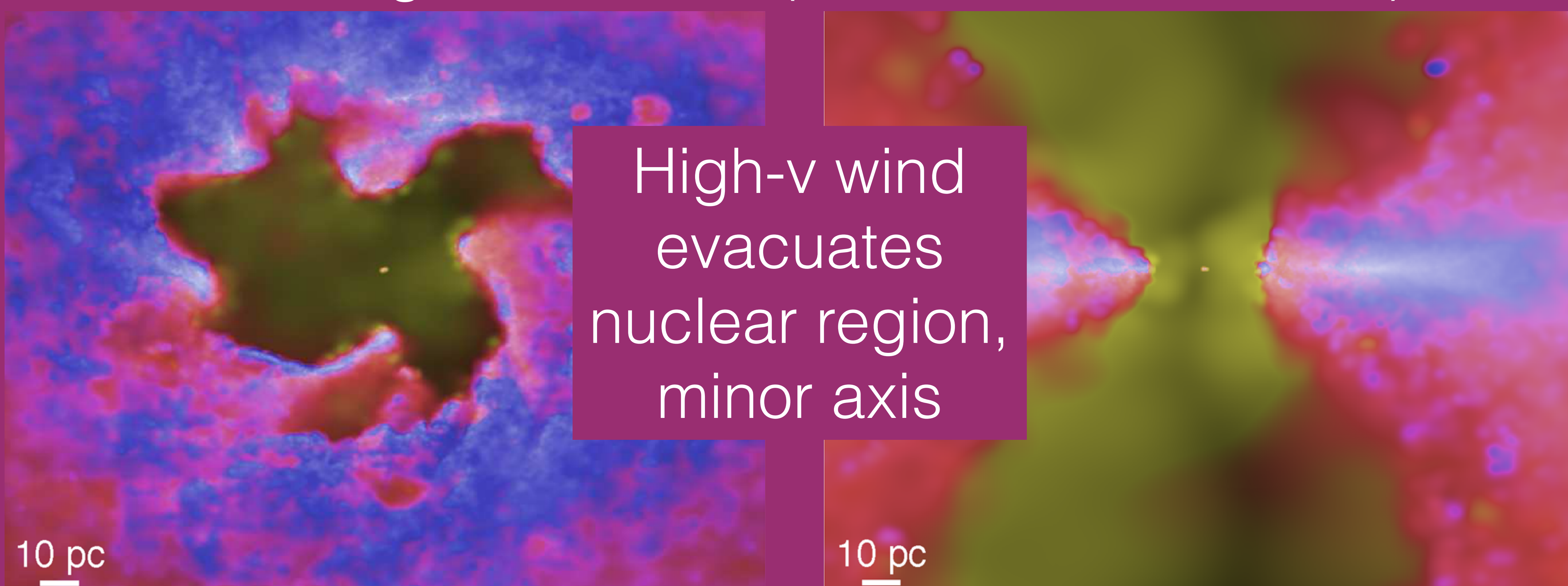
3. The bimodal galaxy color distribution (Di Matteo+05, Springel+05)

without high-v outflows

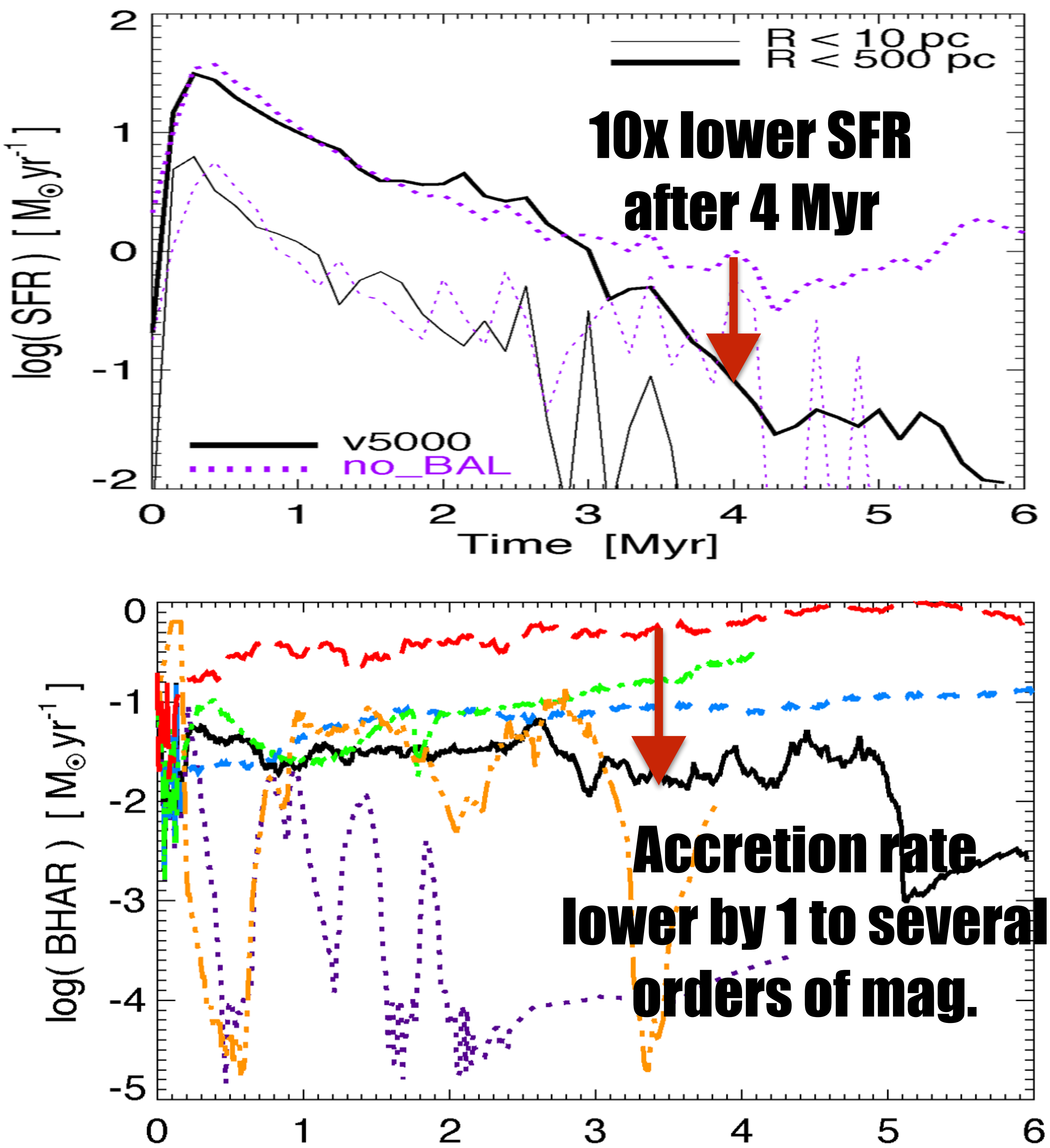
Hopkins+16
1 pc res
10^7 particles



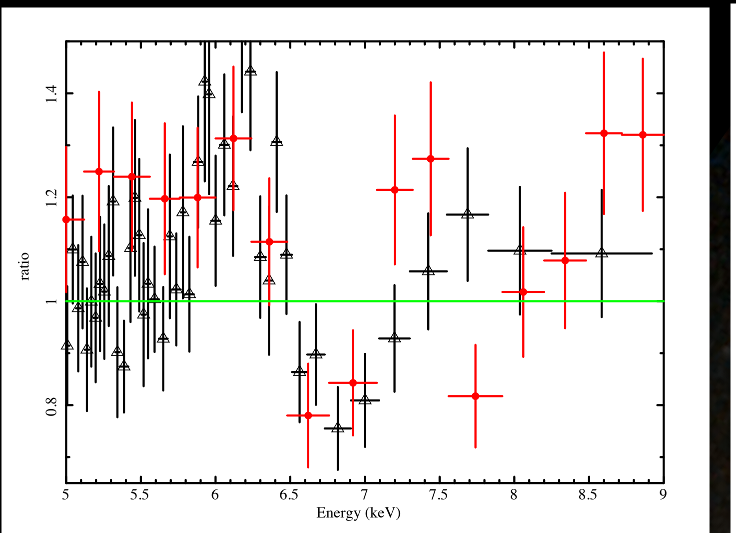
with high-v outflows (5000 km/s, 0.01 L_{AGN})

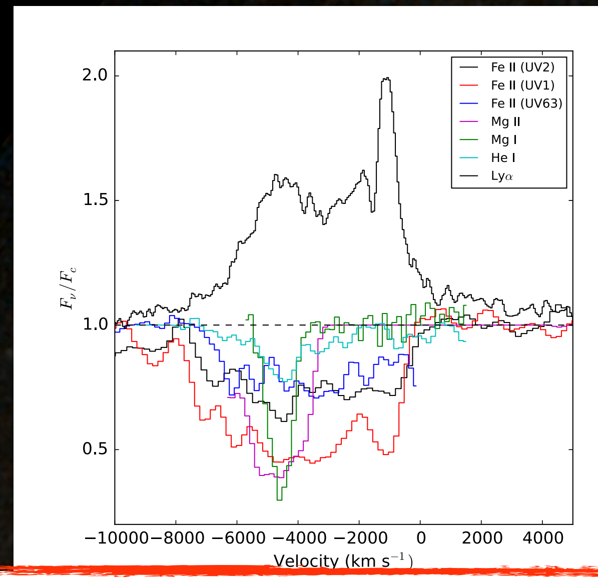


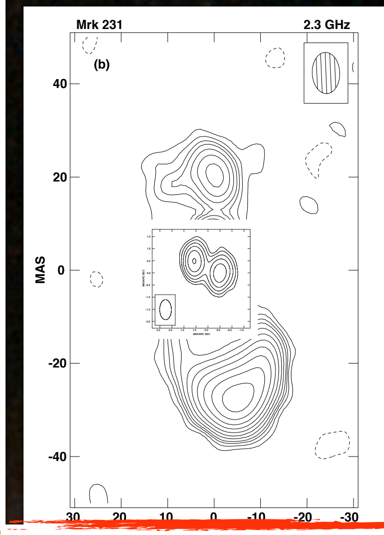
High-v wind evacuates nuclear region, minor axis

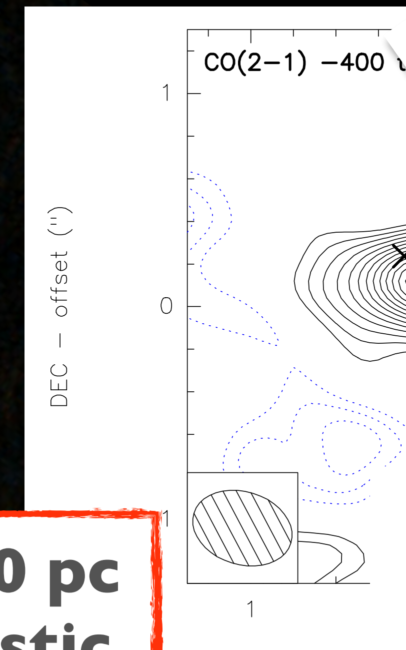


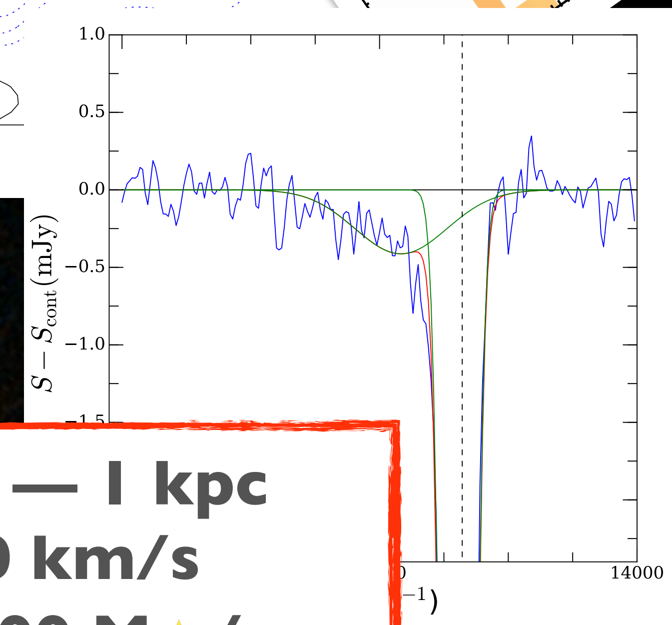
R < 10 pc
R < 500 pc
10x lower SFR
after 4 Myr
v5000
no_BAL
log(SFR) [M⊙yr-1]
Time [Myr]
log(BHAR) [M⊙yr-1]
Accretion rate
lower by 1 to several
orders of mag.











r < 0.01 pc
v ~ 20,000 km/s
dM/dt ~ 1 $M_{\odot}$/yr
Feruglio+15

r < 10 pc
v <10,000 km/s
dM/dt < 100 $M_{\odot}$/yr
Leighly+14,
Veilleux+16

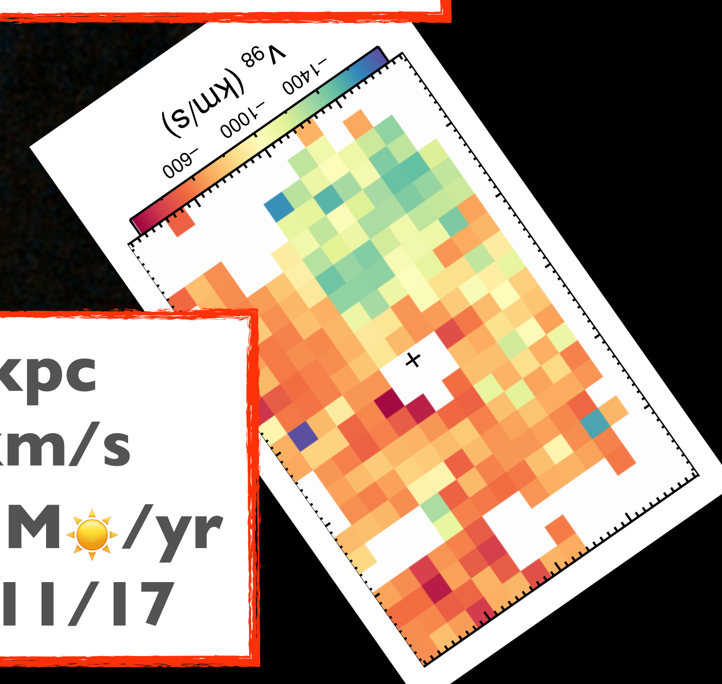
r_{proj} = 1 / 30 pc
v ~ relativistic
dM/dt ~ ?
Ulvestad+99,
Reynolds+09,17

r ~ 100 pc — 1 kpc
v ~ 1000 km/s
dM/dt ~ 1000 $M_{\odot}$/yr
Rupke+11, Feruglio+15,
Morganti+16, Rupke+17

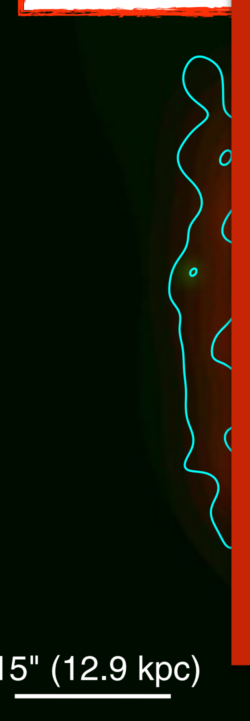
r ~ 1—60 kpc
v ~ ?
dM/dt ~ ?
Veilleux+14

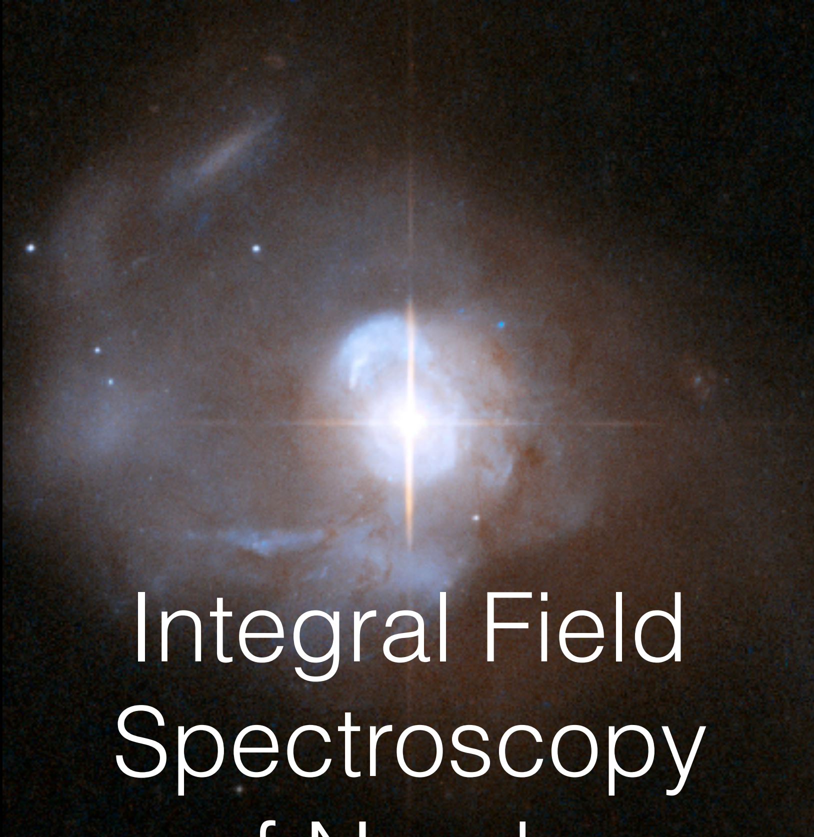
dM/dt_{acc} ~ 2 $M_{\odot}$/yr
dM/dt_{SFR} ~ 200 $M_{\odot}$/yr

Adams+72, Carilli+98, Ulvestad+99, Rupke+02, Rupke+05, Reynolds+09, Fischer+10, Feruglio+10, Rupke+11, Sturm+11, Aalto+12, Cicone+12, Rupke+13, Veilleux+13, Leighly+14, Veilleux+14, Feruglio+15, Aalto+15, Morganti+16, Veilleux+16, Gonzalez-Alfonso+17, Rupke+17, Reynolds+17



r ~ 1—3 kpc
v ~ 1000 km/s
dM/dt ~ 100 $M_{\odot}$/yr
Rupke+05/11/17

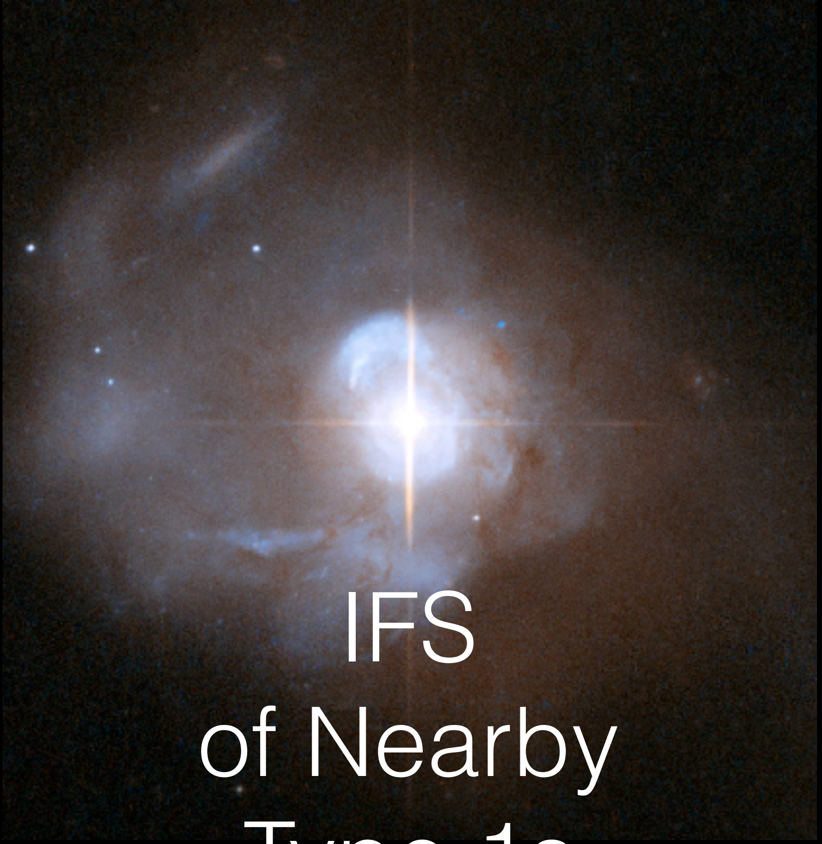




Integral Field Spectroscopy of Nearby Type 1 Quasars

DR, Gültekin, & Veilleux 2017 (submitted to ApJ)

- 10 quasars ($L_{bol} = 3 \times 10^{45} - 5 \times 10^{46}$ erg s^{-1})
  - *some old friends (incl. Mrk 231, I Zw 1)*
  - *4 PGs, 6 IR-selected (<SFR> = 50 $M_\odot$ yr^{-1})*
  - *3 LoBALs (Mrk 231, F07599+6508, PG1700+518)*
- Radio quiet-ish
  - *$P_{1.4\,GHz}$ = 22.7 — 24.8 W Hz^{-1}*
  - *Mrk 231: near face-on jet, <100 pc (Ulvestad+99, Reynolds+09/17)*
  - *PG 1700+518: 1 kpc jet (Yang+12)*
- $\log(M_{BH}/M_\odot)$ = 8.3 — 9.1
  - *reverberation mapping (Bentz & Katz 2015) or HST photometry (Veilleux+09a)*
- L_{bol} / L_{Edd} = 0.003 — 0.3
  - *Spitzer spectroscopy (Veilleux+09b)*



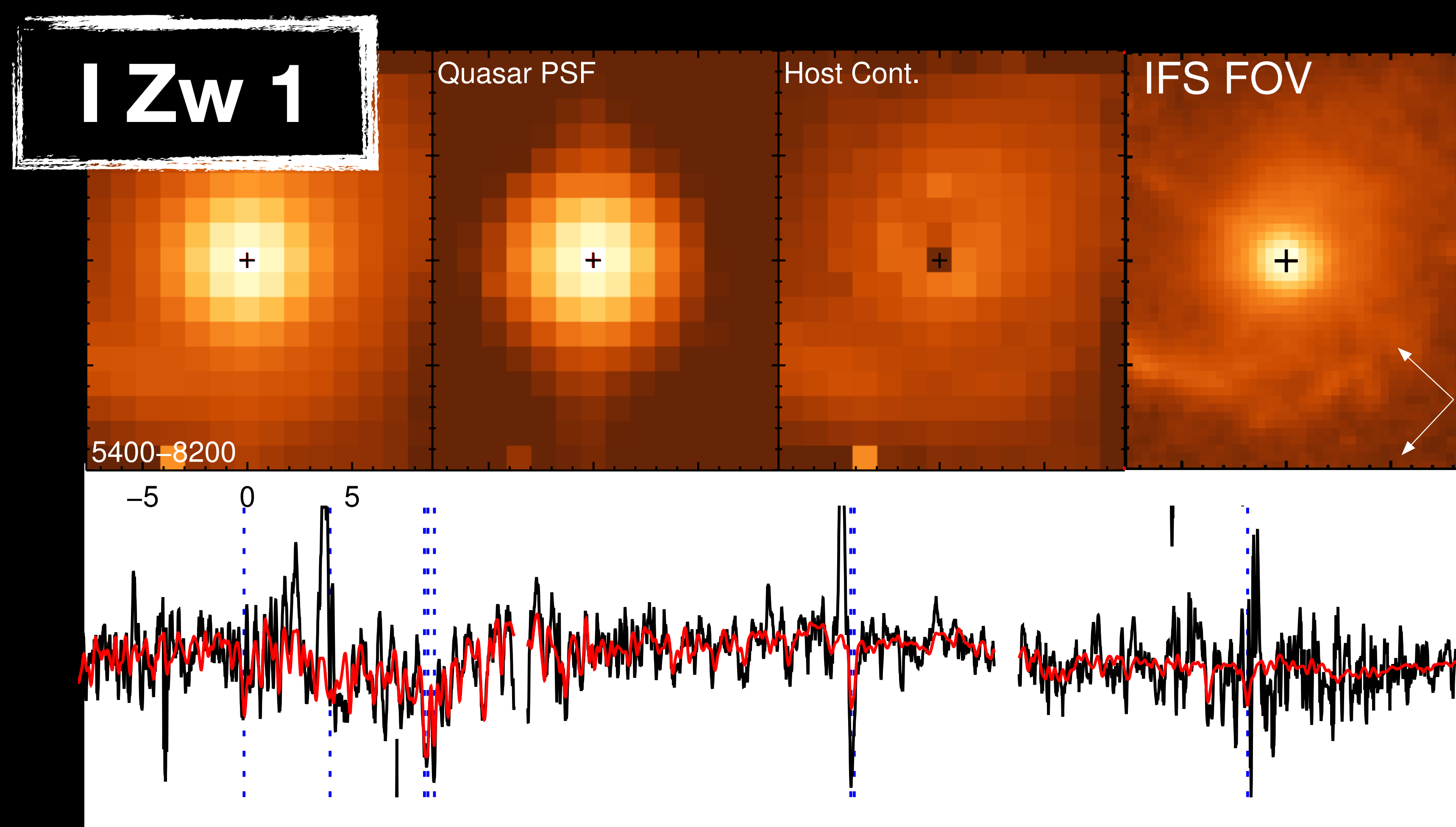
IFS of Nearby Type 1s

- Sample
- Observations
- Analysis
- Gas Disks
- Properties
- Correlations

- Gemini/GMOS IFS
  - *0.2” spatial sampling (PSF removal)*
- 1 — 4 hours integration
  - *detect host at high S/N for stellar and interstellar absorption*
- Ionized gas ($T \sim 10^4$ K) outflow probe
  - *strong optical emission lines*
  - *broad, blueshifted (or redshifted) velocity components that differ from rotation*
- Neutral gas ($T \sim 10^3$ K) outflow probe
  - *NaD interstellar absorption line (Heckman+00, DR+05)*
  - *blue shifted velocity components*
  - *dusty phase of outflow; IP = 5.1 eV and correlates with E(B—V) (Veilleux+95, 99; DR+13, 15)*

IFS of Nearby Type 1s

- Continuum + line fitting
  - *IFSFIT (ASCL, github) + PPXF (Cappellari+)*
- New technique for quasar / host galaxy deblending
  - *spectral PSF fitting*
  - *iterative, multi-step process*



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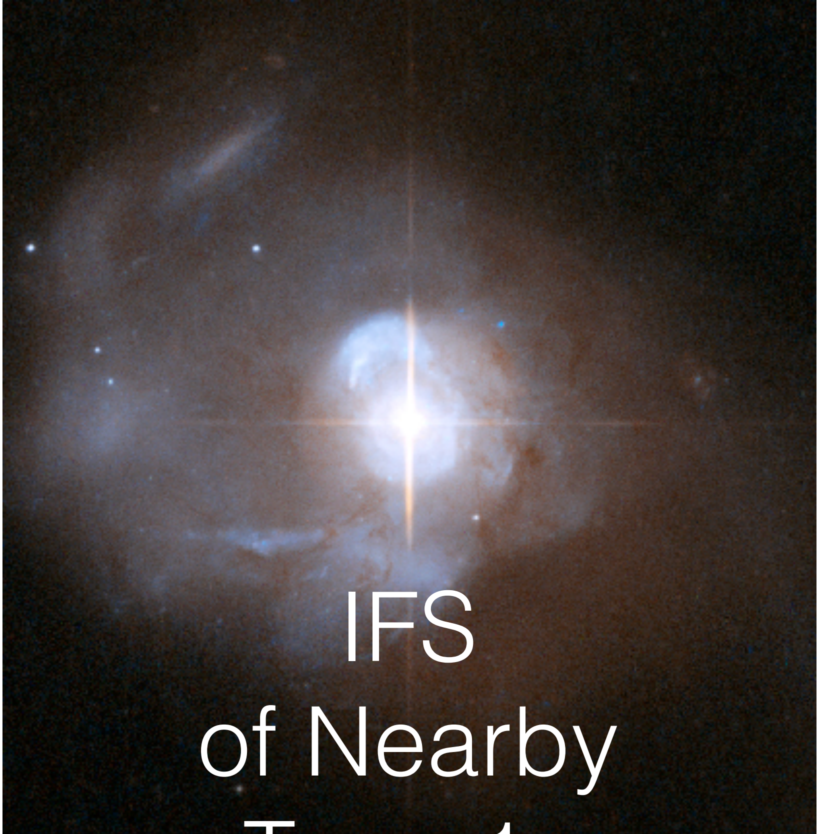

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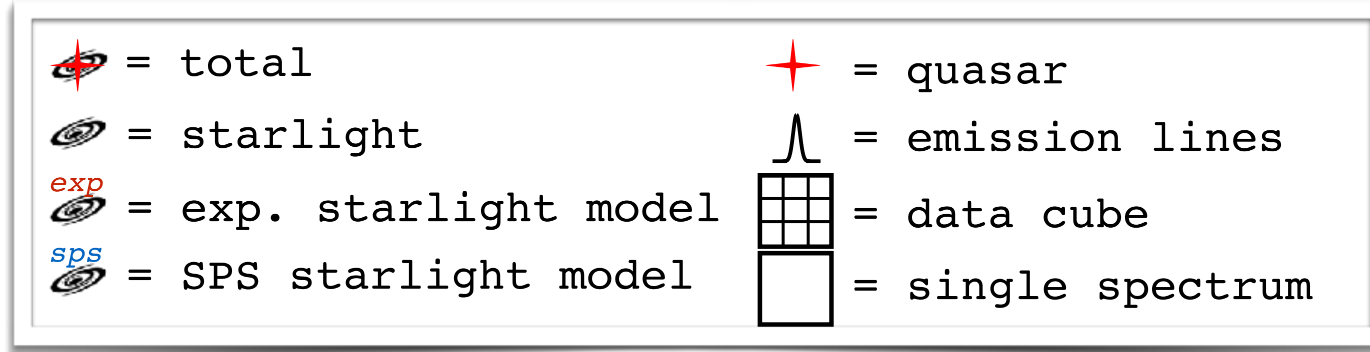
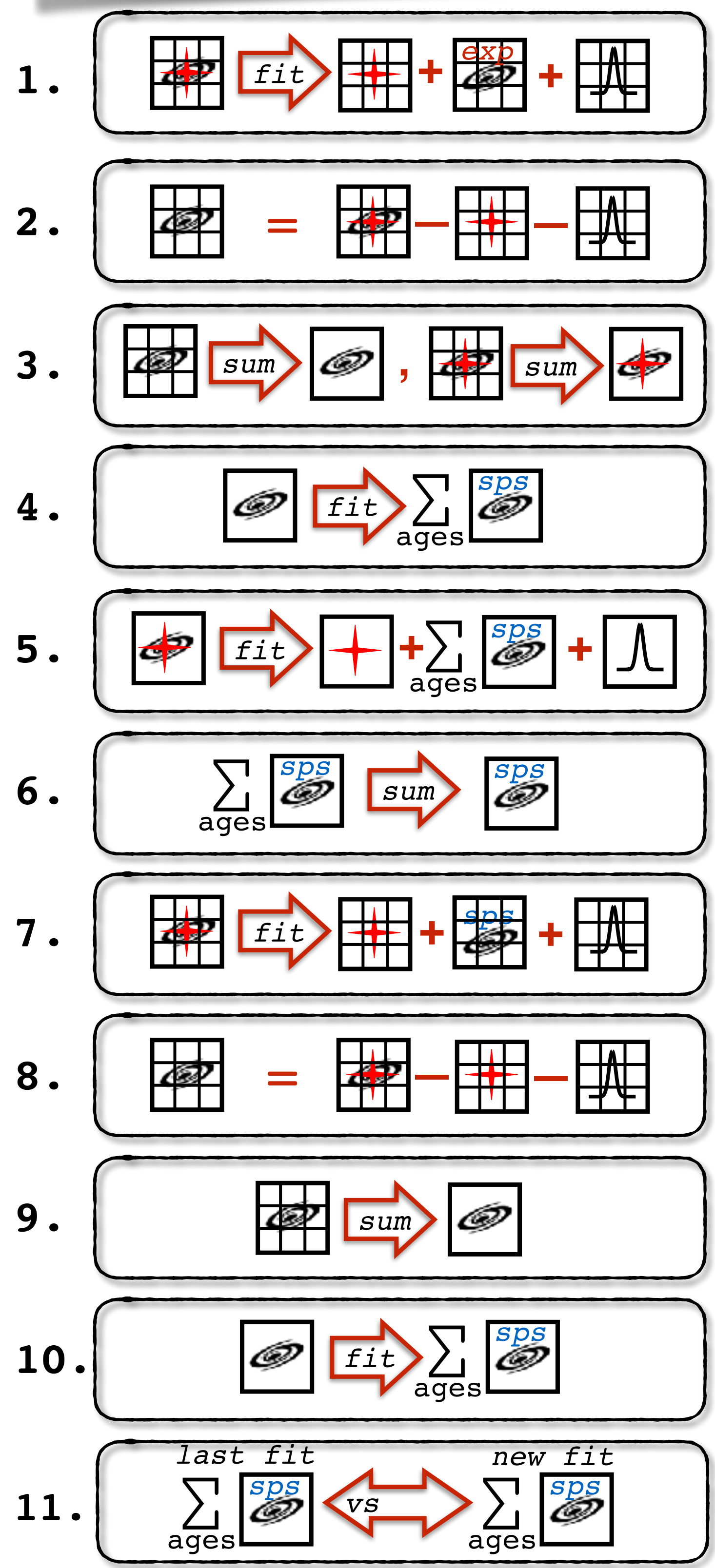
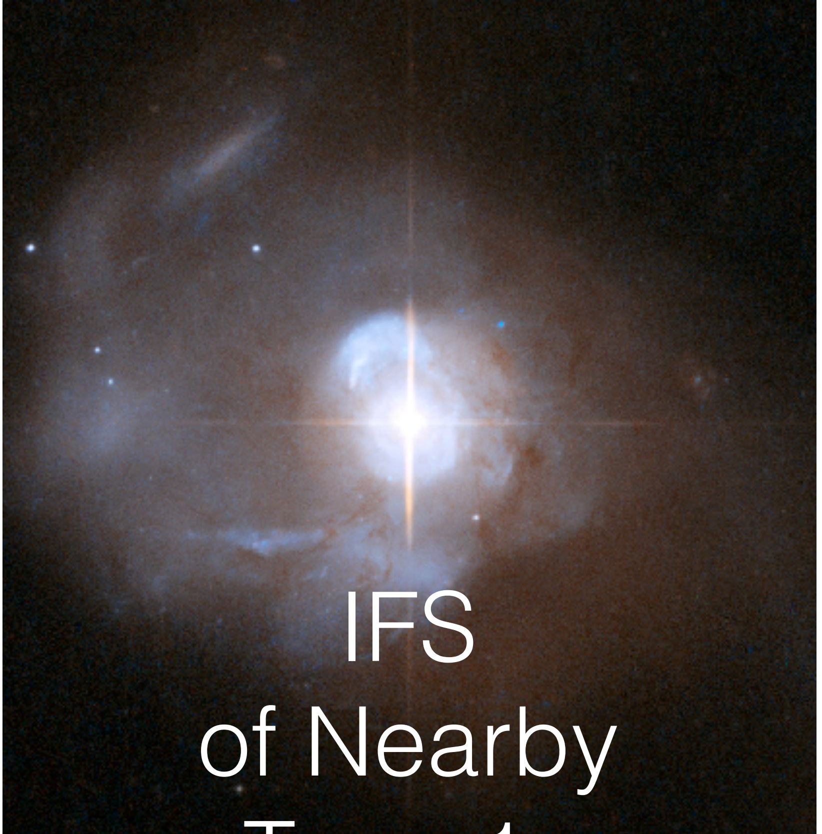
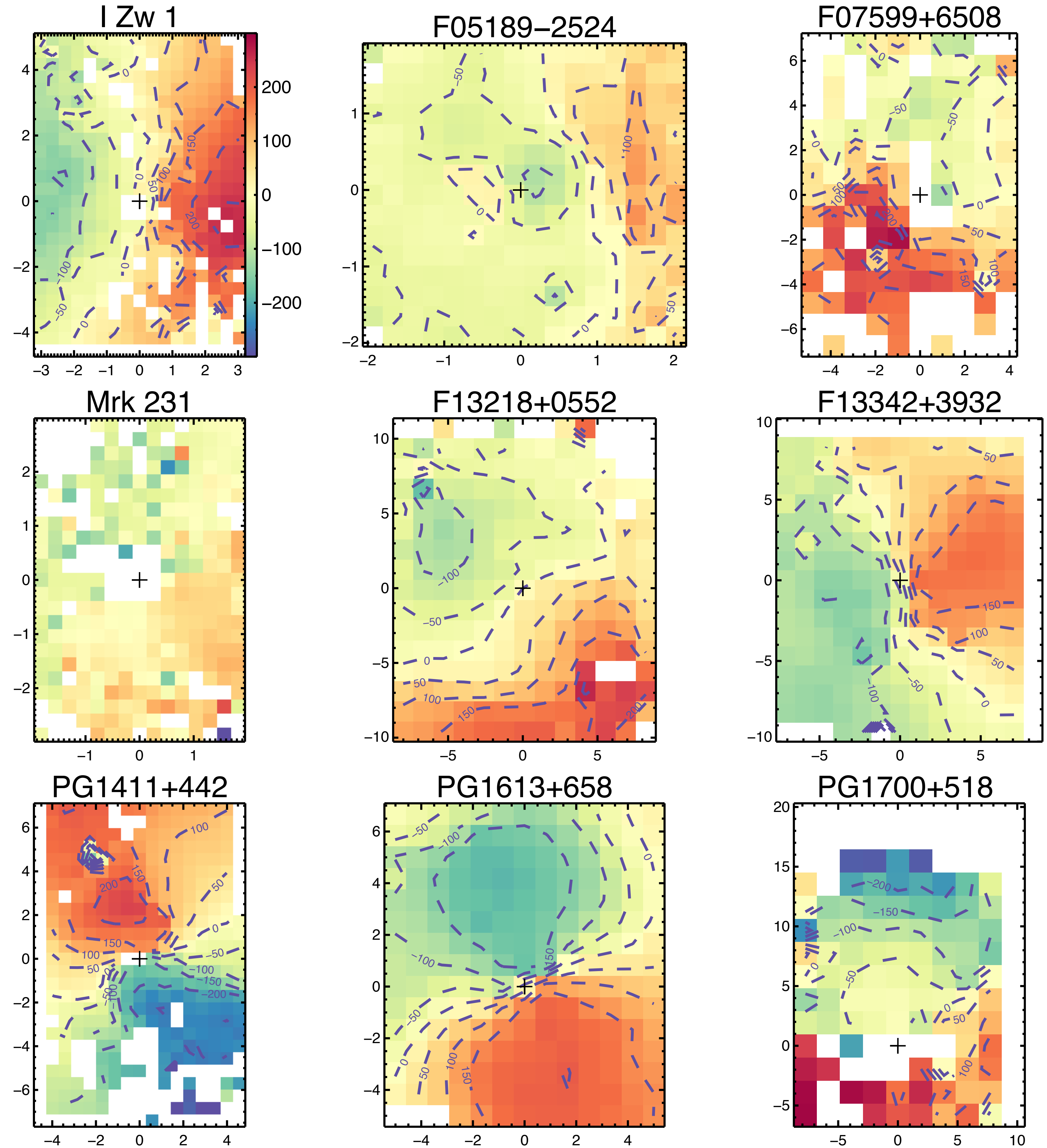




1. Fit total spectra with quasar + exponential starlight model + emission lines.
2. Calculate starlight-only spectra.
3. Spatially integrate spectra.
4. Fit spatially-integrated starlight spectrum.
5. Fit spatially-integrated total spectrum.
6. Choose best-fit SPS model and sum over ages.
7. Fit total spectra with quasar + SPS starlight model + emission lines.
8. Calculate starlight-only spectra.
9. Spatially integrate spectra.
10. Fit spatially-integrated starlight spectrum.
11. Compare SPS fits to starlight-only spectrum. Iterate from step 6 if different. Finish if same.



IFS of Nearby Type 1s



- Sample
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IFS of Nearby Type 1s

- Sample
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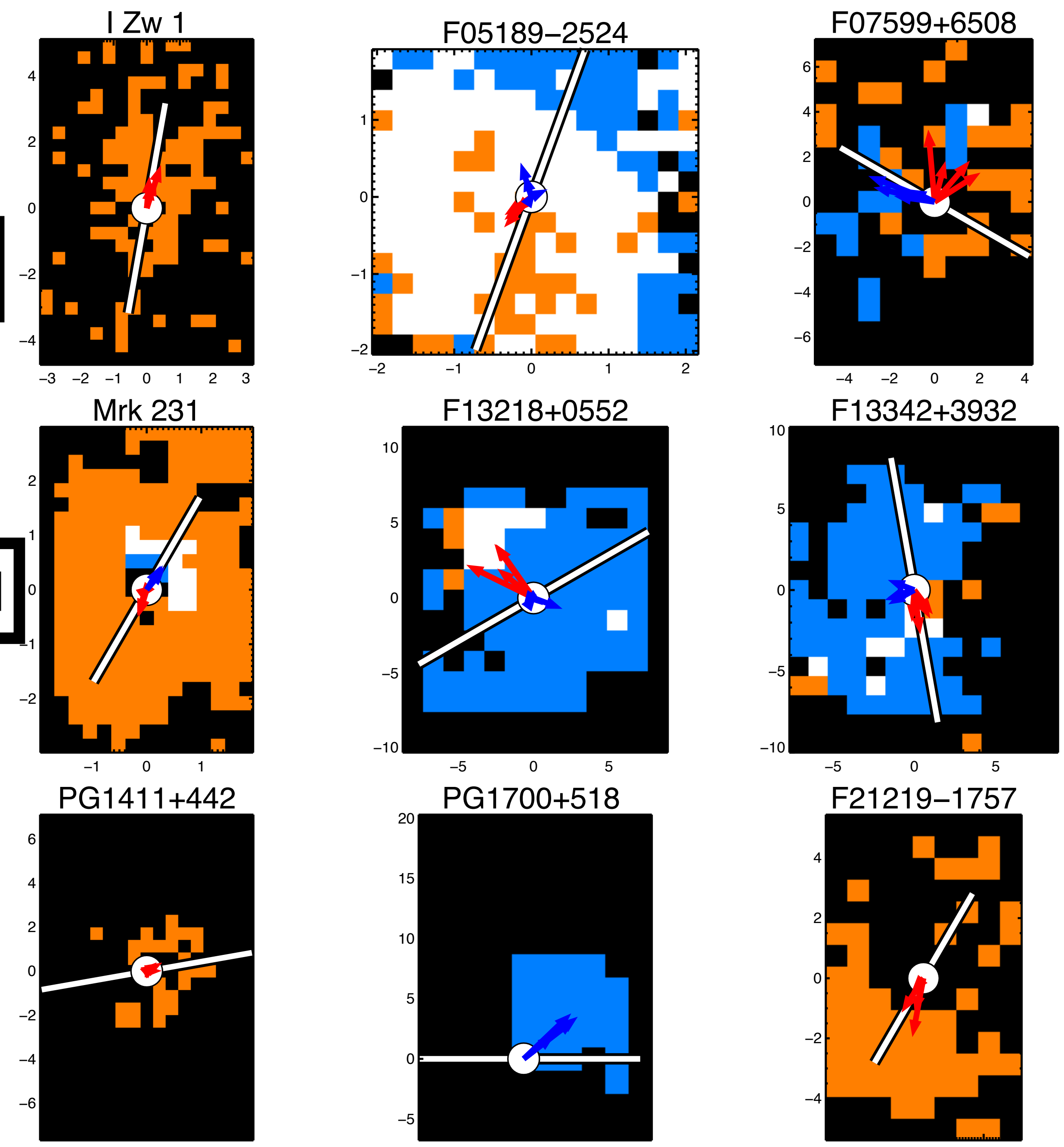
- Detection rate 90—100%
  - ≫ *15% (Husemann+14)*
- Minor-axis outflows
  - $R_{max} \geq 3-10$ *kpc (FOV limited)*

Warm, Ionized Wind

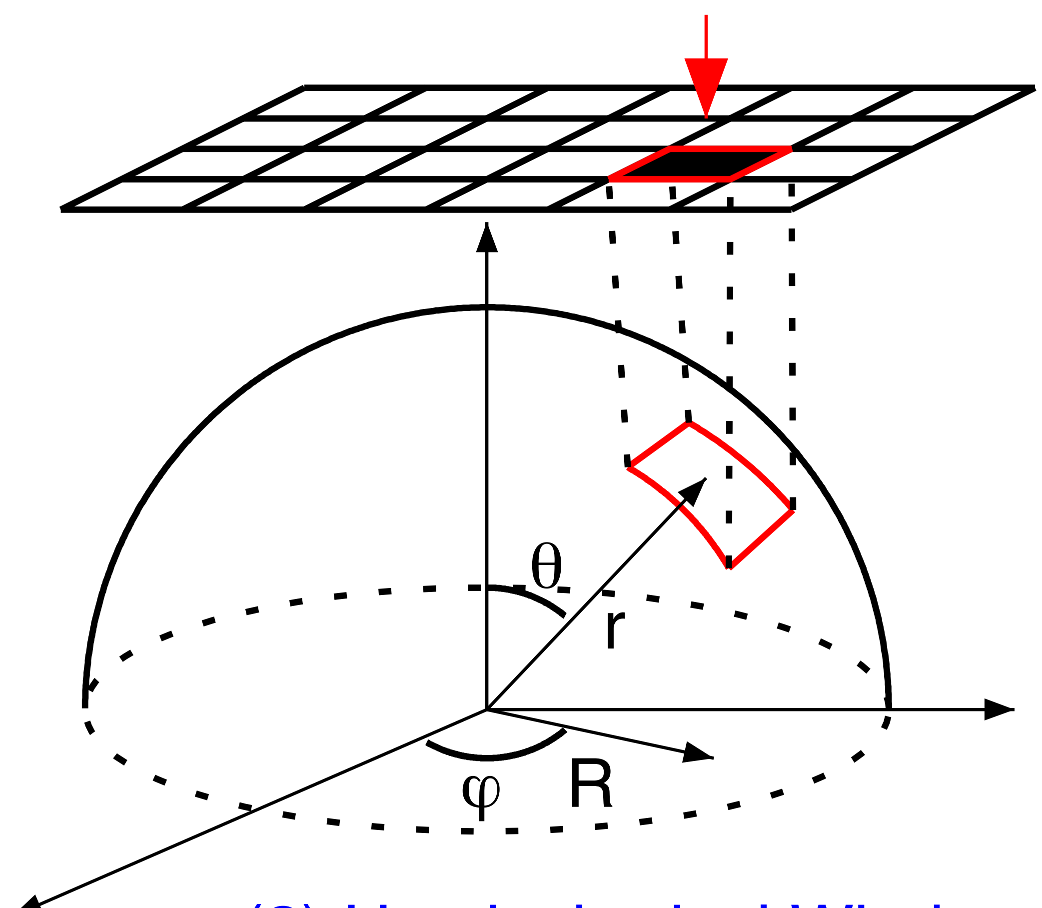
Cool, Neutral Wind

Ionized+Neutral Wind



- Outflow model: single radius free wind *(DR+05, Shih+DR 2010, DR+13)*
  - ❑ *thin spherical shell with single radius r*
  - ❑ *mass-conserving*

(1) Observer Meaures R, v(R), N(R)

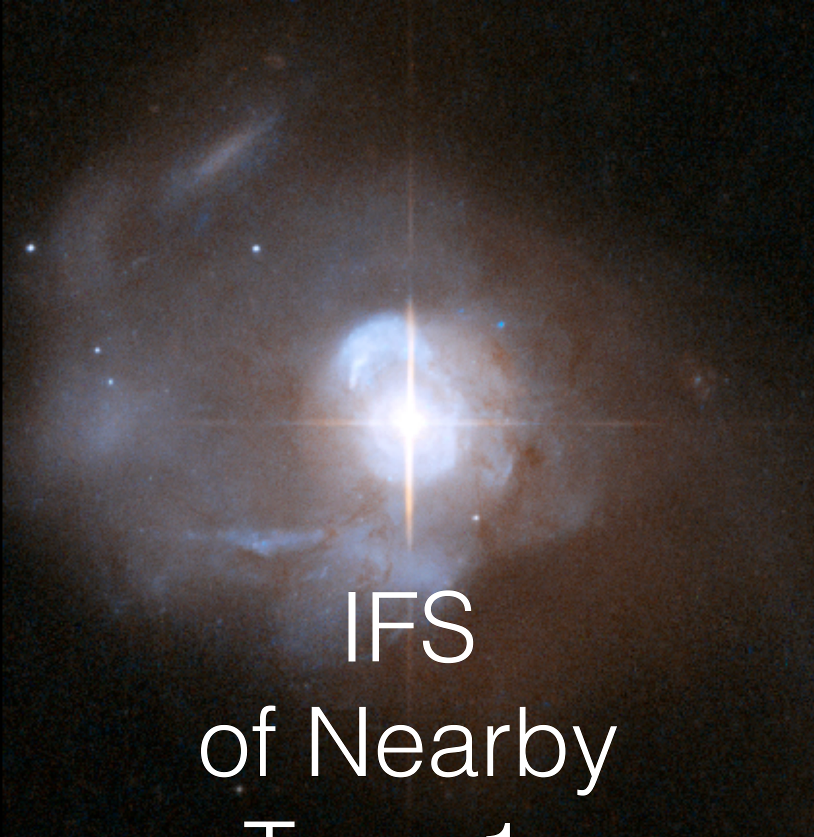


(2) Hemispherical Wind
De–Projection: Given r, turn R to θ,φ

(3) Wind Properties from
Measured Properties:

$$\frac{dM}{dt}(\text{neutral}) = \mu m_p r \times \sum_i^{\text{spaxels}} N_i(\theta,\phi) v_{r,i}(\theta,\phi) \sin\theta \; \Delta\theta\Delta\phi$$

$$\frac{dM}{dt}(\text{ionized}) = \frac{\mu m_p}{n_e j r} \times \sum_i^{\text{spaxels}} L_i(\theta,\phi) v_{r,i}(\theta,\phi)$$



IFS of Nearby Type 1s

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Velocities

- ionized gas: $\langle v \rangle = -300$ km/s, $\langle v_{max} \rangle = -800$ km/s
- neutral gas: $\langle v \rangle = -175$ km/s, $\langle v_{max} \rangle = -420$ km/s

Masses

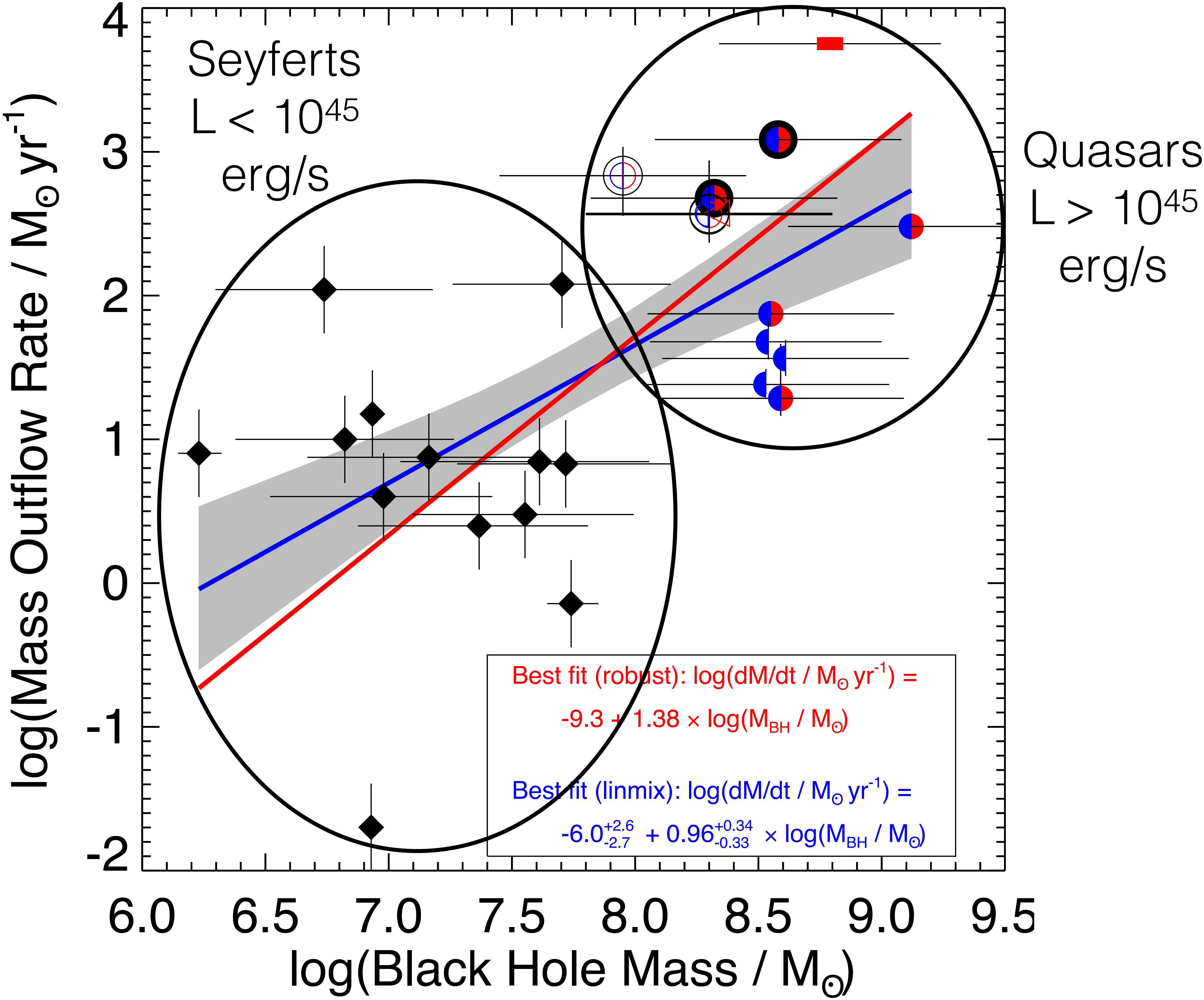
- ionized $\langle dM/dt \rangle = 90\ M_{\odot}\ yr^{-1}$
- neutral $\langle dM/dt \rangle = 30\ M_{\odot}\ yr^{-1}$

Momenta

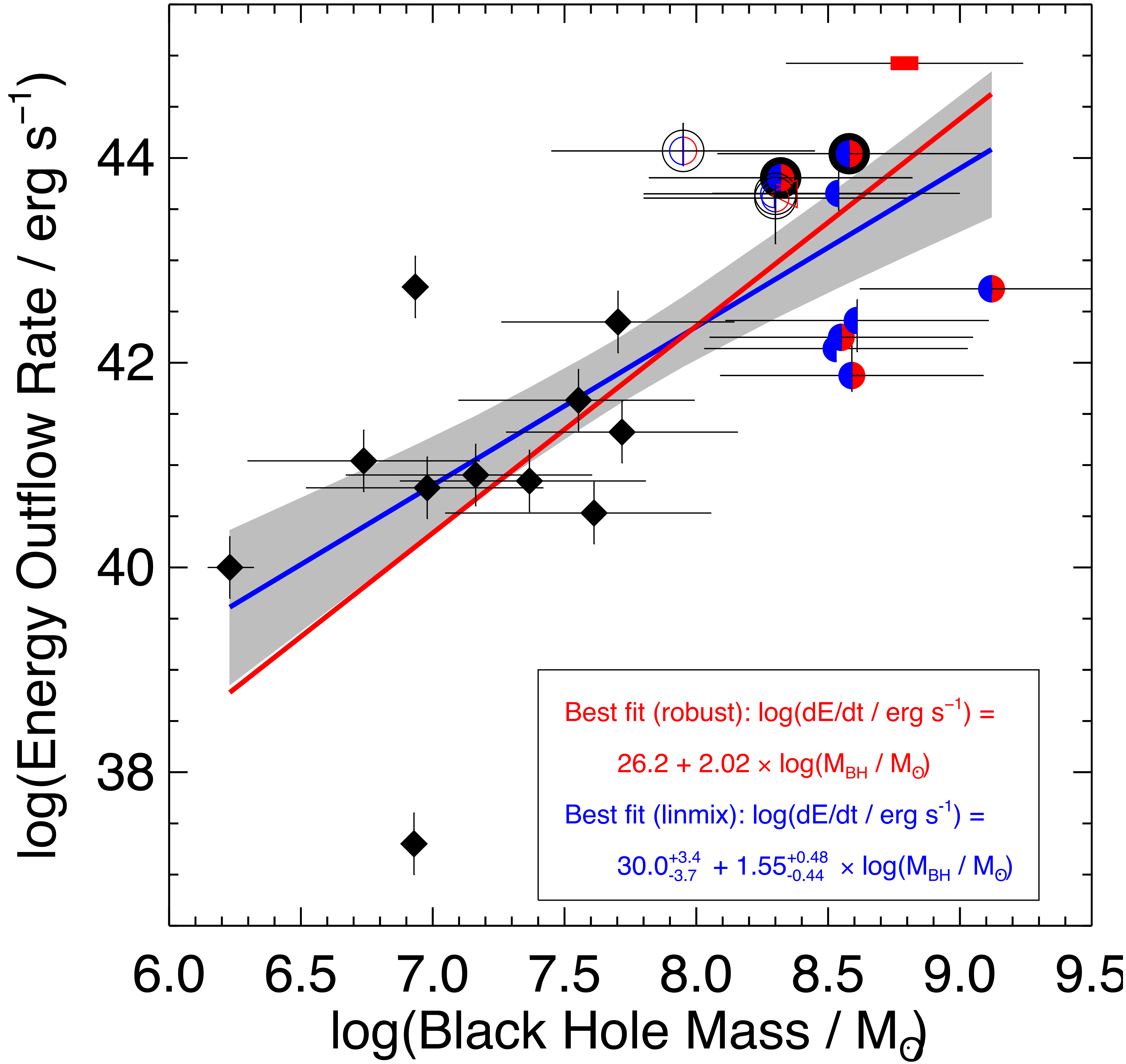
- $\langle dp/dt\ /\ (3.5\ L_{SB}/c) \rangle = 6$ (range 0.7 — inf)
- $\langle dp/dt\ /\ (L_{AGN}/c) \rangle = 2$ (range 0.1 — 20)

Energies

- $\langle dE/dt\ /\ dE/dt_{starburst} \rangle = 0.5$ (range 0.02 — inf)
- $\langle dE/dt\ /\ L_{AGN} \rangle \sim 0.1\%$ (range 0.01% — 2%)



Seyferts
L < 10^45
erg/s
Quasars
L > 10^45
erg/s
Best fit (robust): log(dM/dt / M⊙ yr^-1) =
-9.3 + 1.38 × log(M_BH / M⊙)
Best fit (linmix): log(dM/dt / M⊙ yr^-1) =
-6.0 +2.6 -2.7 + 0.96 +0.34 -0.33 × log(M_BH / M⊙)
log(Mass Outflow Rate / M⊙ yr^-1)
log(Black Hole Mass / M⊙)
4
3
2
1
0
-1
-2
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5

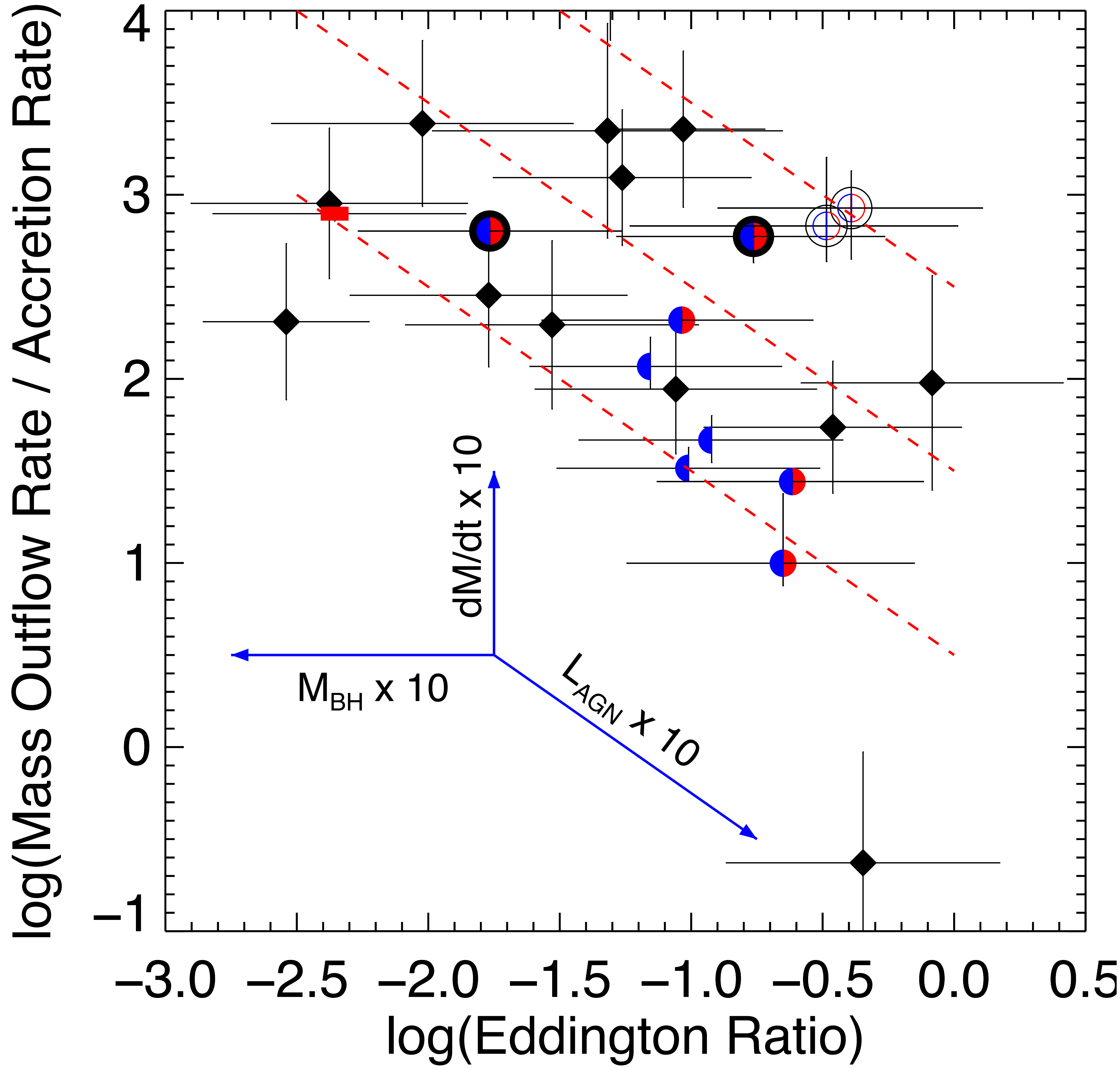


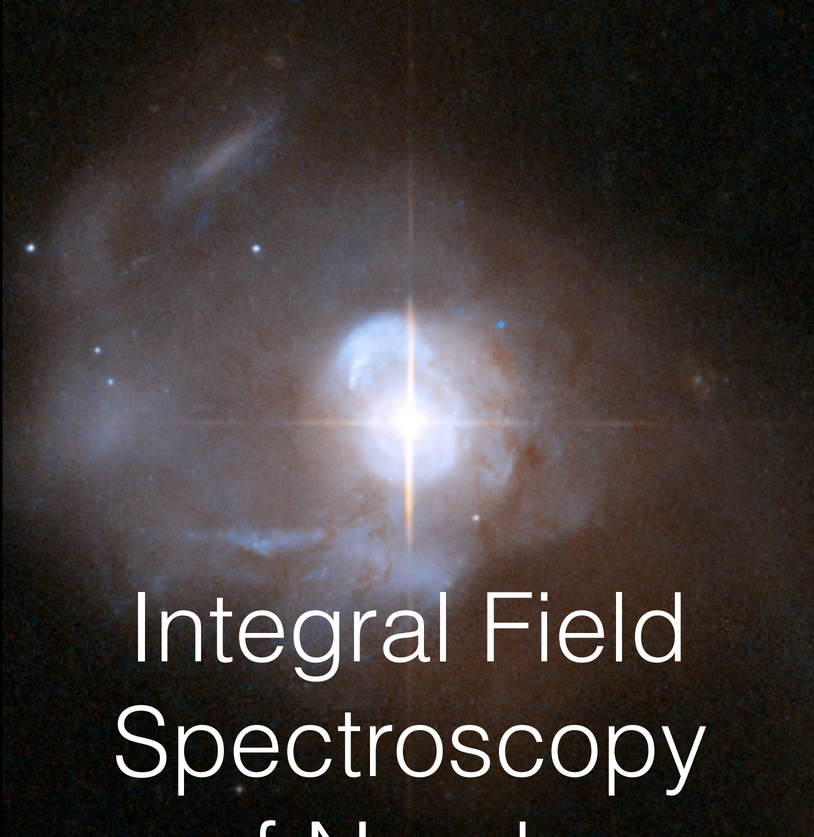
log(Energy Outflow Rate / erg s^{-1})
44
42
40
38
6.0
6.5
7.0
7.5
8.0
8.5
9.0
9.5
log(Black Hole Mass / M$_\odot$)
Best fit (robust): log(dE/dt / erg s^{-1}) =
26.2 + 2.02 × log(M$_{BH}$ / M$_\odot$)
Best fit (linmix): log(dE/dt / erg s^{-1}) =
30.0$^{+3.4}_{-3.7}$ + 1.55$^{+0.48}_{-0.44}$ × log(M$_{BH}$ / M$_\odot$)

Recall:

$$\left(\frac{dM}{dt}\right)_{acc} \sim L_{\mathrm{AGN}}$$

$$\text{Edd. rat.} \sim \frac{L_{\mathrm{AGN}}}{M_{\mathrm{BH}}}$$





Integral Field Spectroscopy of Nearby Type 1 Quasars

DR, Gültekin, & Veilleux 2017 (submitted to ApJ)

- Most/all nearby quasars host large-scale (R_{max} ~ 5—10 kpc) outflows in warm ionized / dusty neutral gas
- Most/all large-scale outflows are powered by the quasar
- Outflow masses / energies scale may with M_{BH} (but small sample sizes, possible selection effects)