A Near-Infrared View of Shocks in Nuclear Outflows

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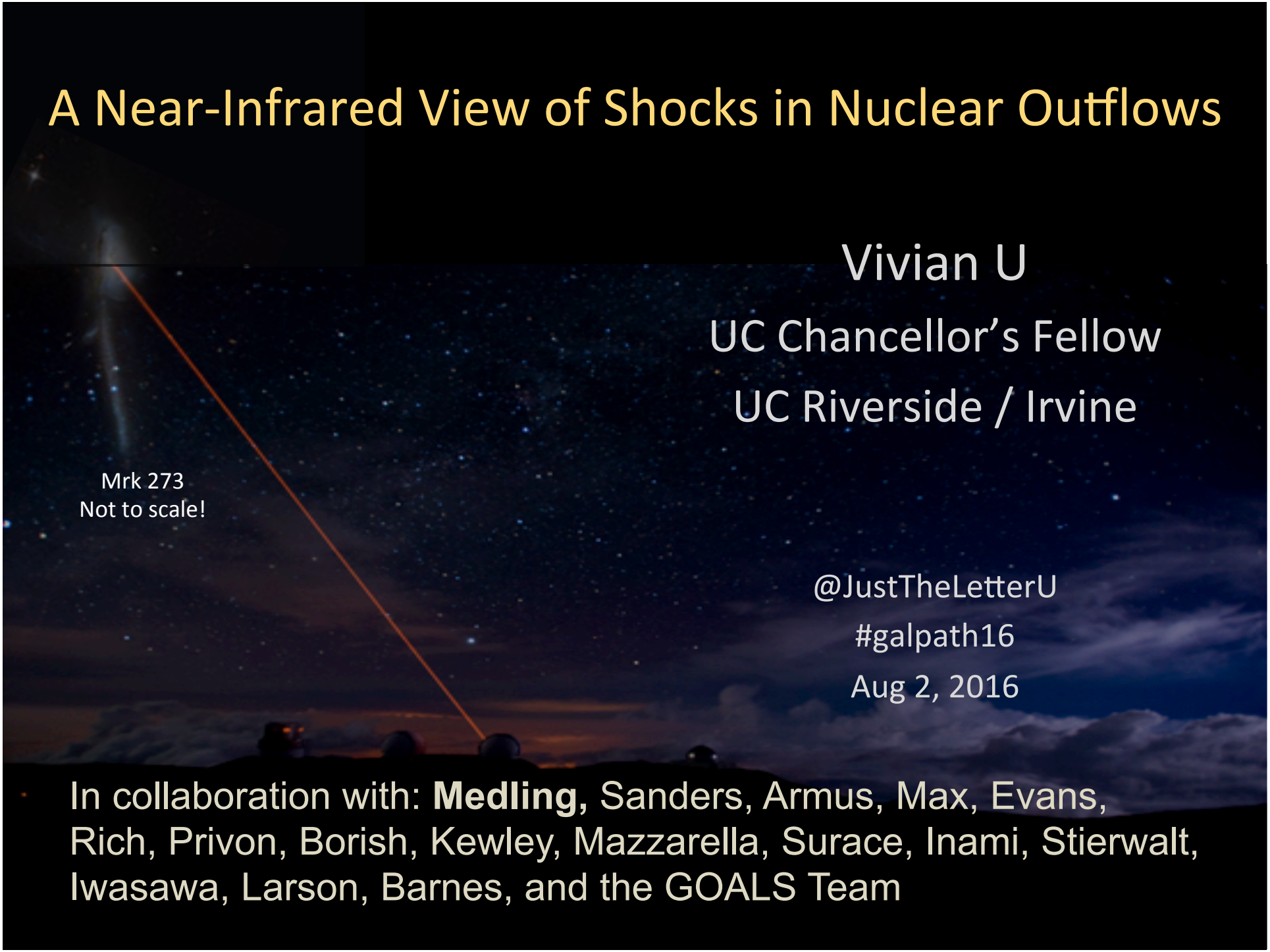


@JustTheLetterU

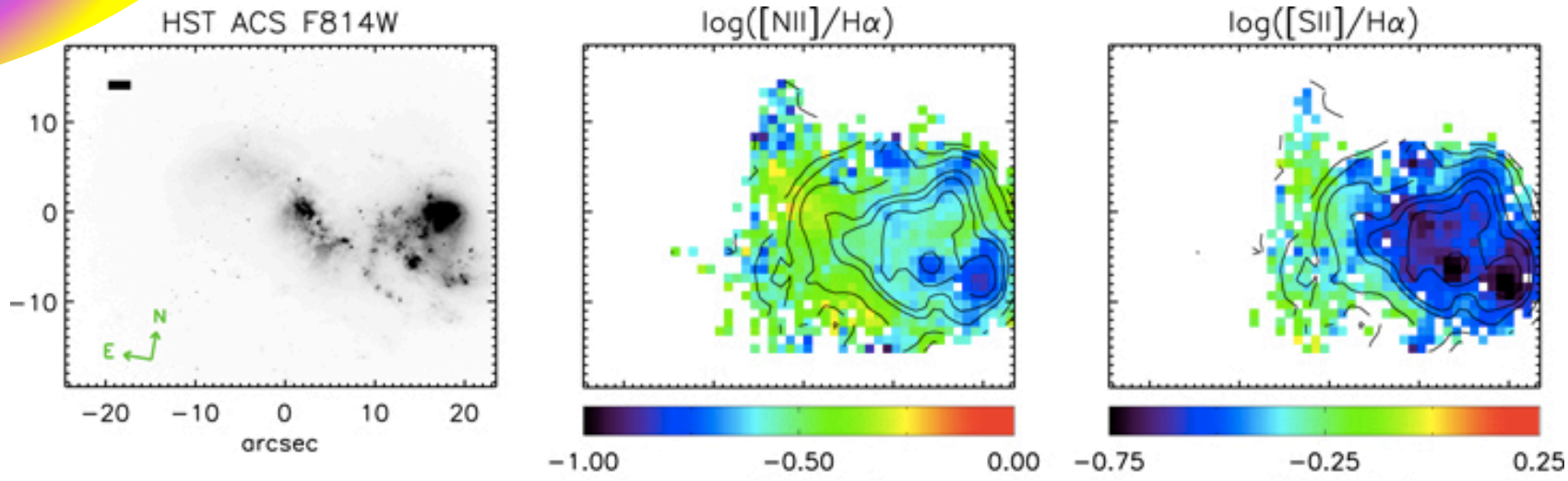
#galpath16

Aug 2, 2016

In collaboration with: **Medling,** Sanders, Armus, Max, Evans, Rich, Privon, Borish, Kewley, Mazzarella, Surace, Inami, Stierwalt, Iwasawa, Larson, Barnes, and the GOALS Team

Shocks in Galaxy Mergers

- Mergers: violent interaction of gas in ISM
- Stellar/AGN feedback: heats up gas / quenches (enhances?) SF
- Galactic-scale shocks induced by outflows (e.g. Rich+11,15; Soto & Martin 12)



(e.g. WiFeS GOALS; Rich+15)

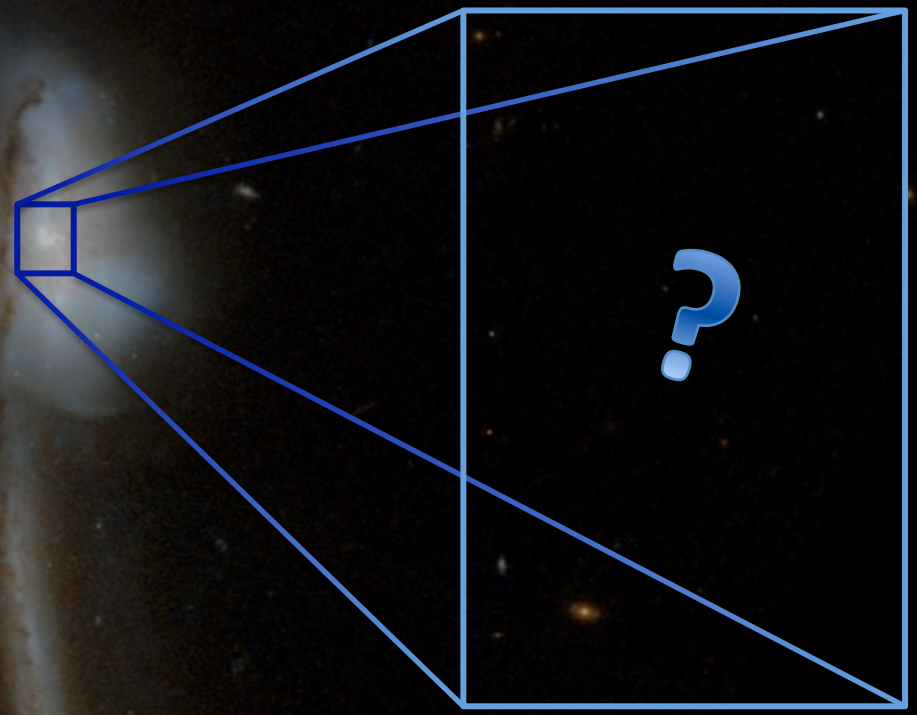
What drives these shocks?

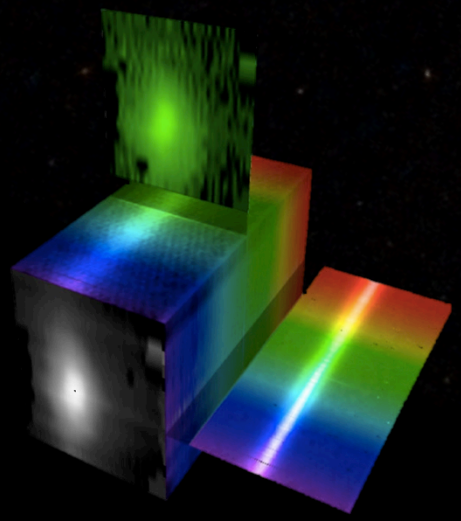
- Cloud cloud collision
- Tidal induced gas stream
- AGN-/SB-driven outflows

What drives these shocks?

- Understand the nuclear gas kinematics
- Identify and characterize nuclear outflows
- Trace the origin of the ionizing source
- Ascertain the conditions at the launch sites

Nuclear Gas Kinematics in Galaxy Mergers





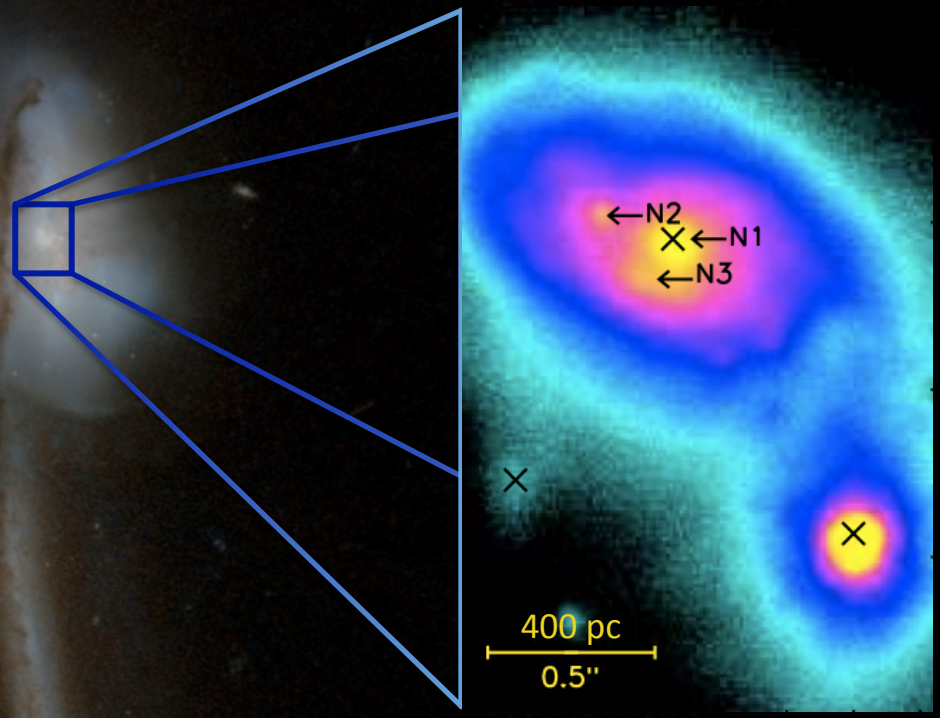
NIR AO IFS observations!

Keck OSIRIS AO LIRG Survey

It's not ~~MUSE~~ but…

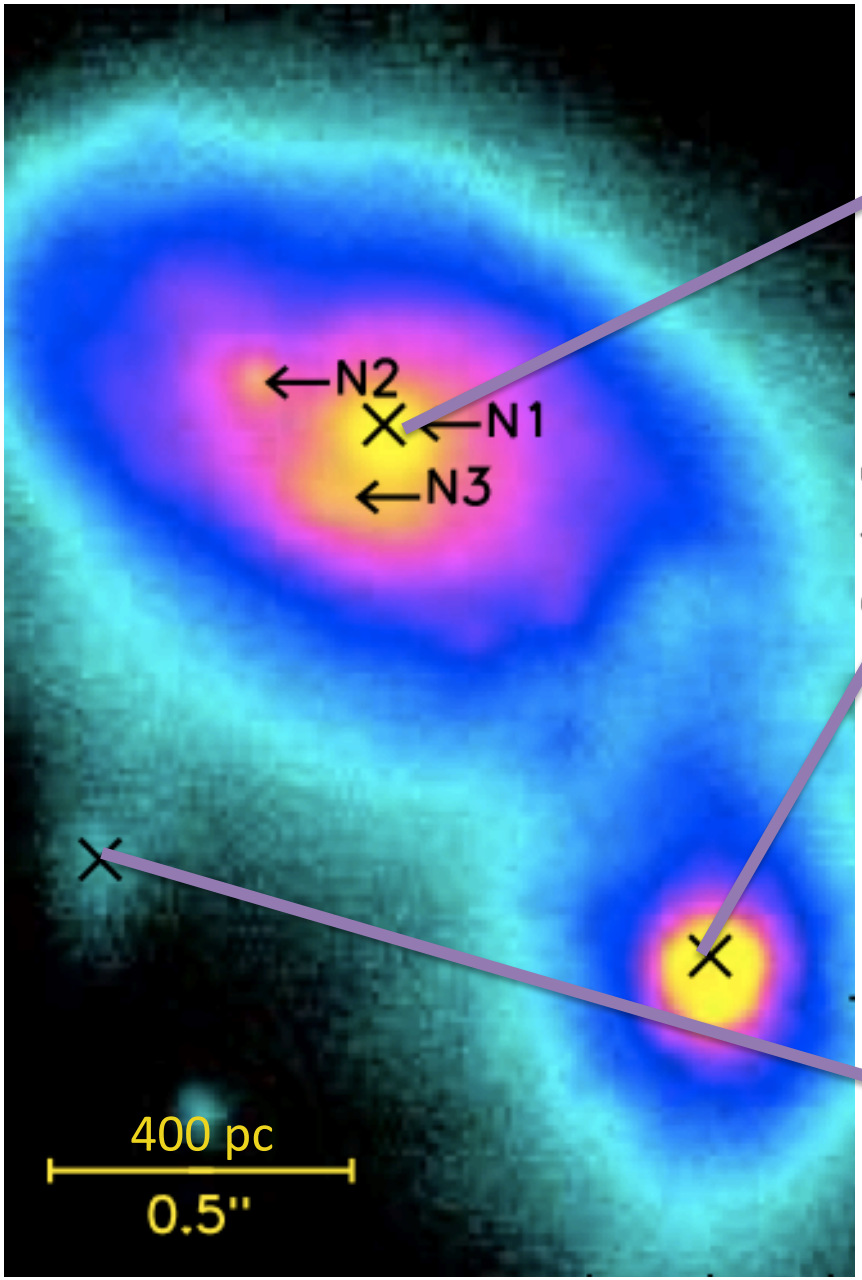
- OSIRIS (+ NIRC2) + AO
  - Nicely complements WiFeS, MUSE, CWI (and all the large IFU surveys)
  - K band, sampling at 0.01" (NIRC2) and 0.035"-0.100"/spaxel (OSIRIS)
  - FWHM ~ 0.05" → 20-50 pc/spaxel at $z < 0.05$

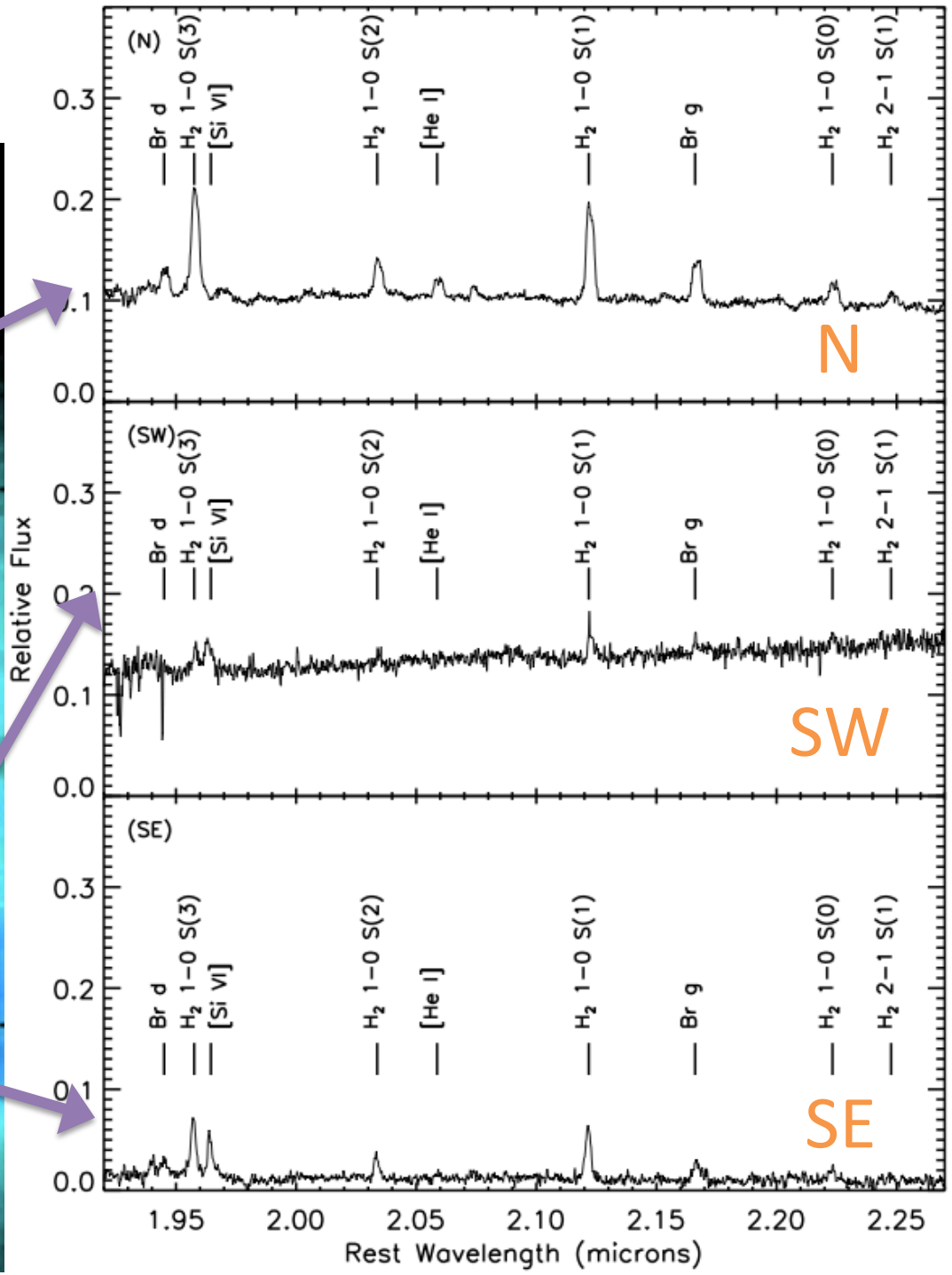
Keck OSIRIS AO LIRG Survey

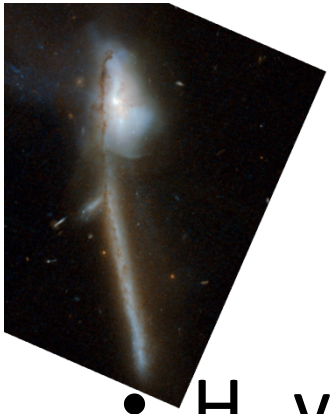


Mrk 273

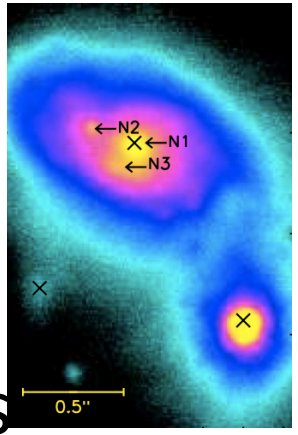
(K band; U+ 2013, ApJ, 775, 115)



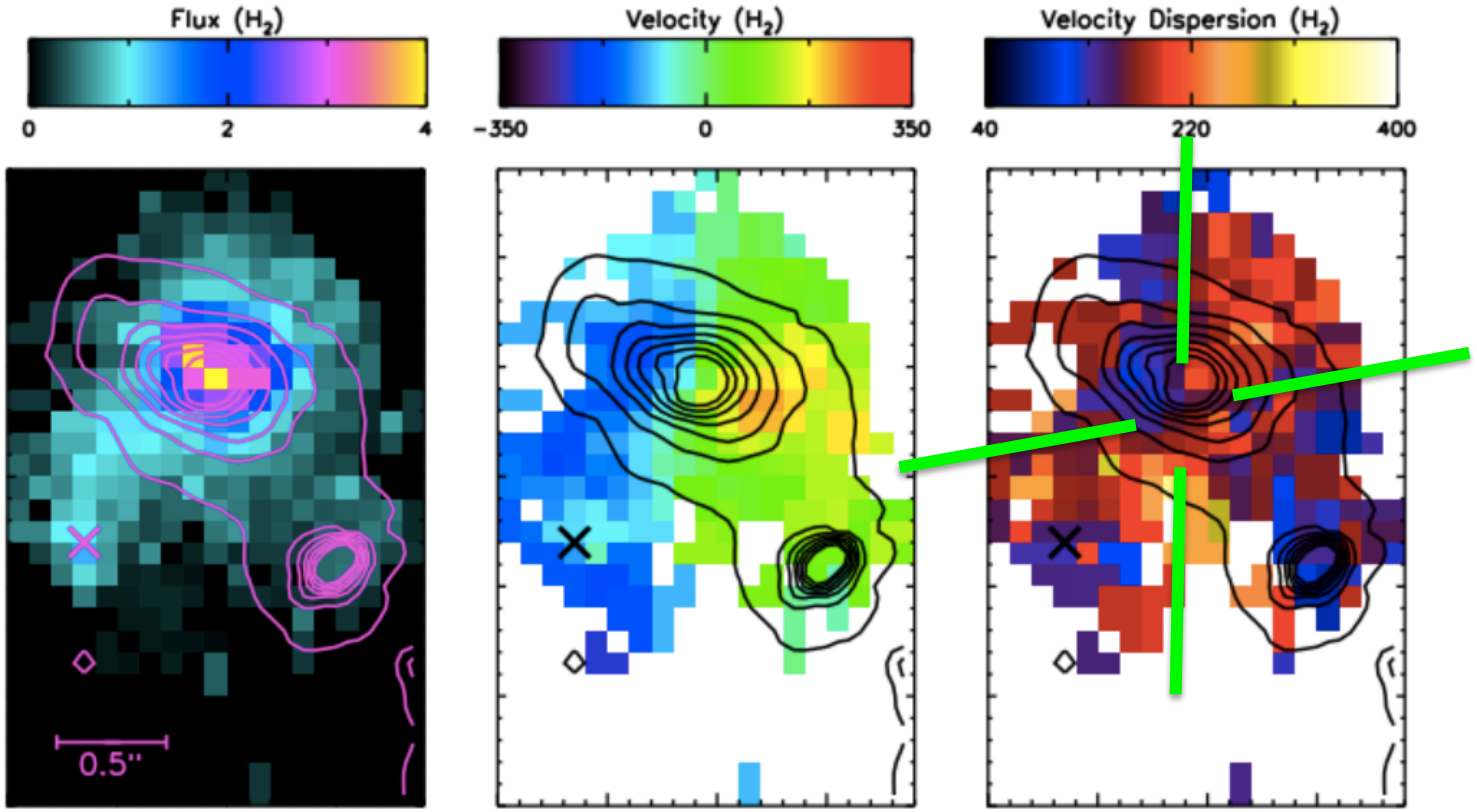




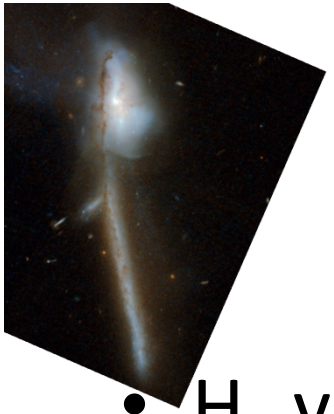
Molecular Outflows: Mrk 273



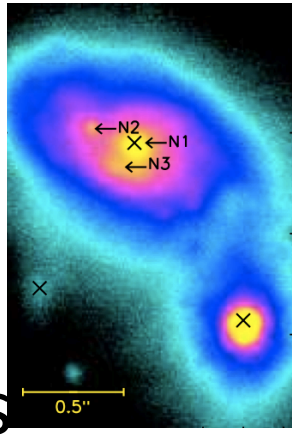
- H_2 velocity dispersion – biconical outflows



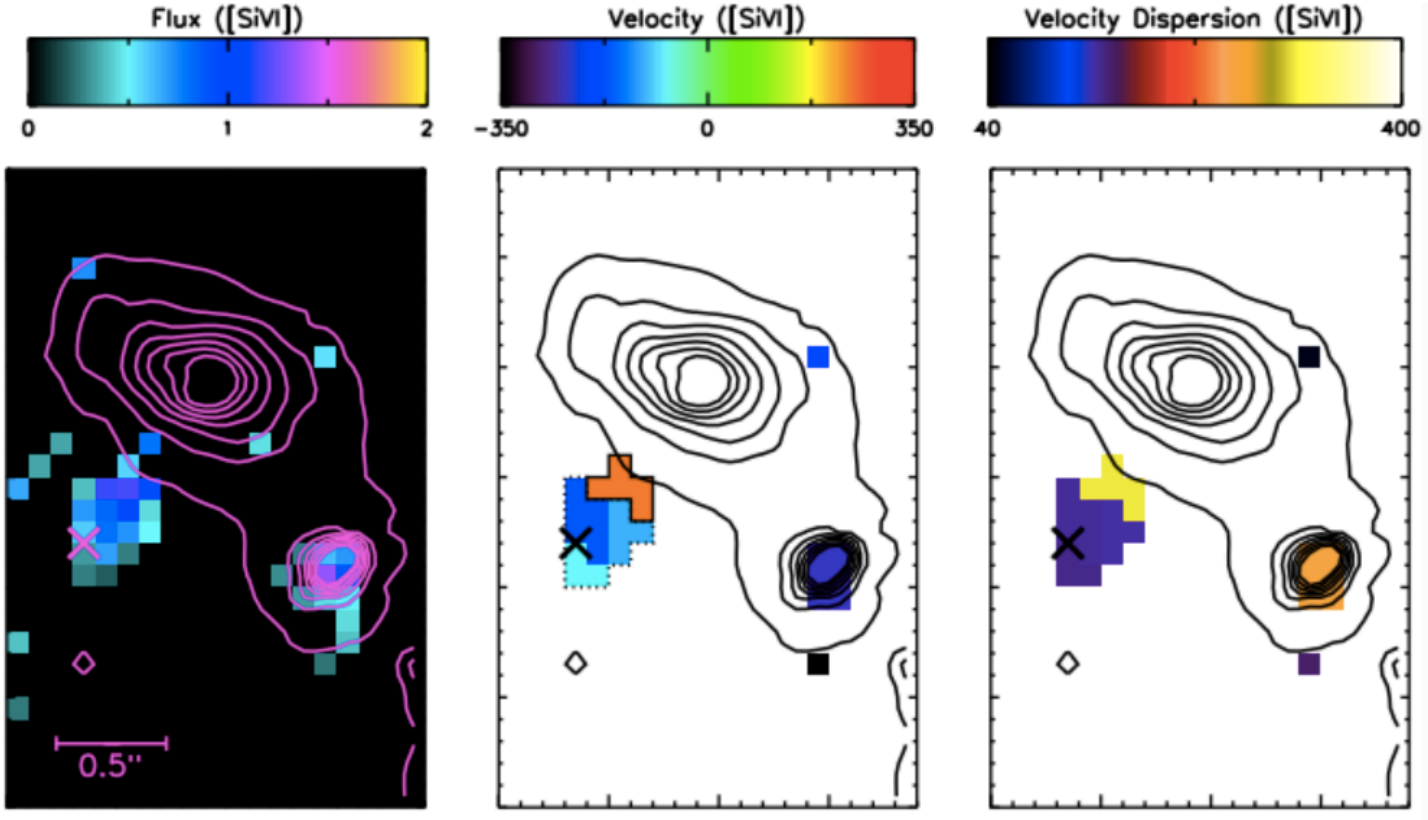
U+2013



Molecular Outflows: Mrk 273

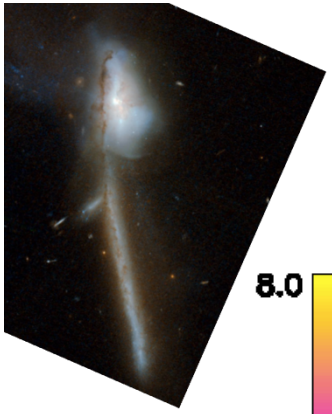


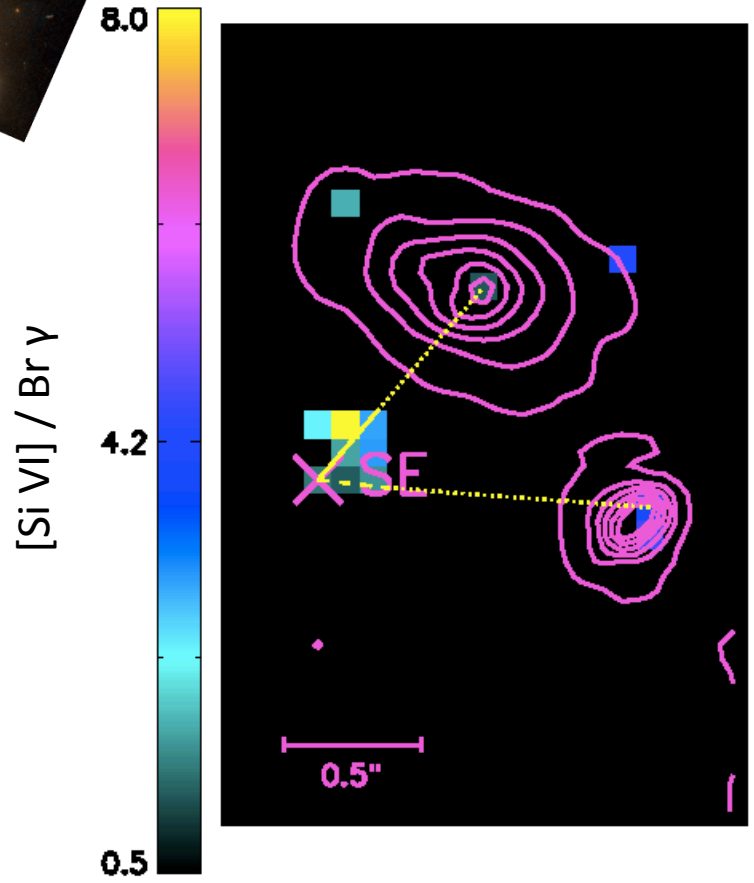
- H_2 velocity dispersion – biconical outflows
- [Si VI] traces extended CLR (Muller-Sanchez+11)

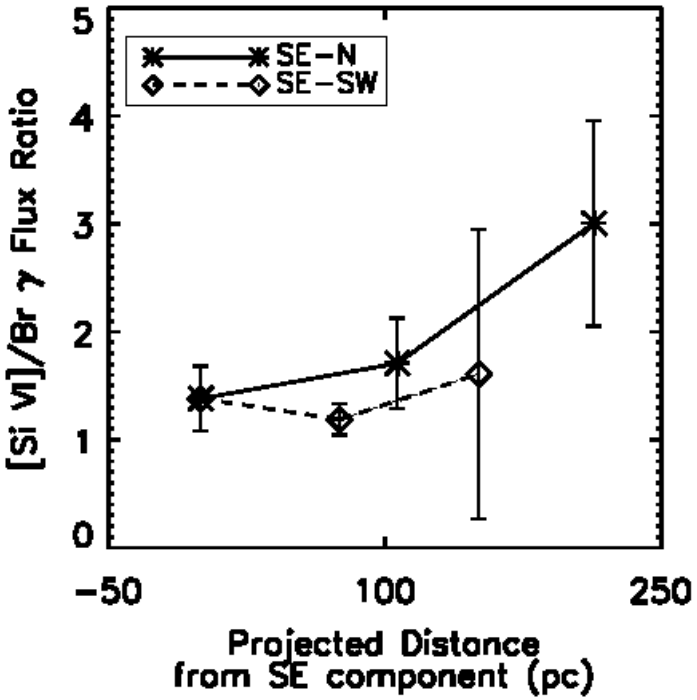


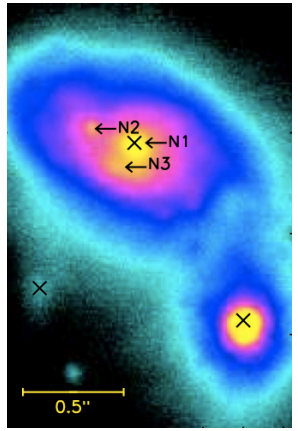
U+2013

Molecular Outflows: Mrk 273









- Shocks + AGN photoionization (at N nucleus)

U+2013

Mrk 273
Outflow Properties

V ~ 200 km/s

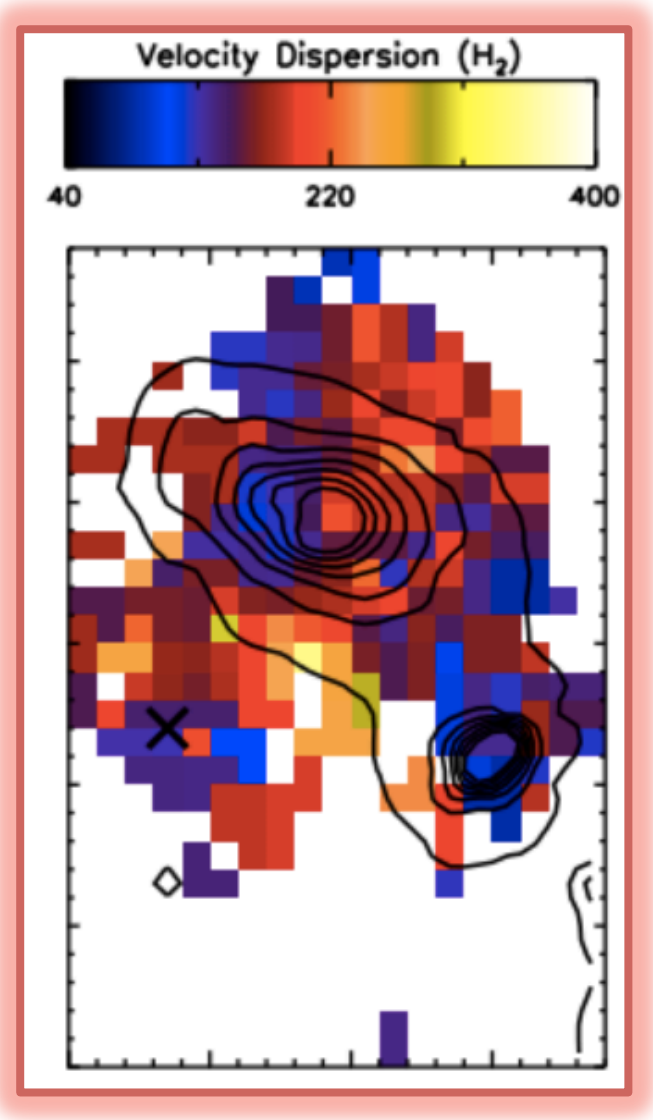
Distance from nucleus = 640 pc

$M_{H2} = 7.7 \times 10^3 \ M_\odot$

Age of outflow ~ 3.3 Myr

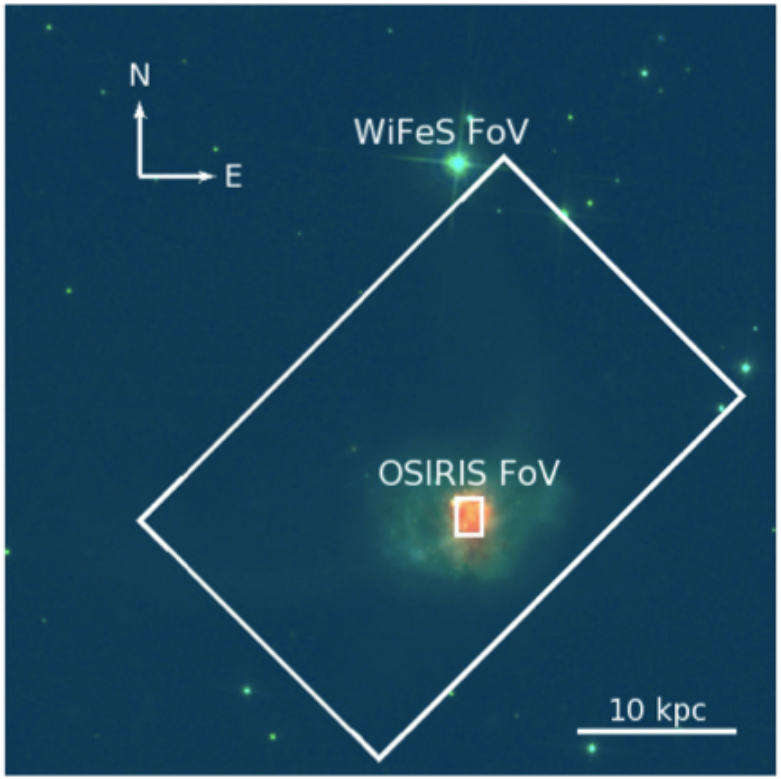
$E \sim 1.3 \times 10^{43}$ erg/s

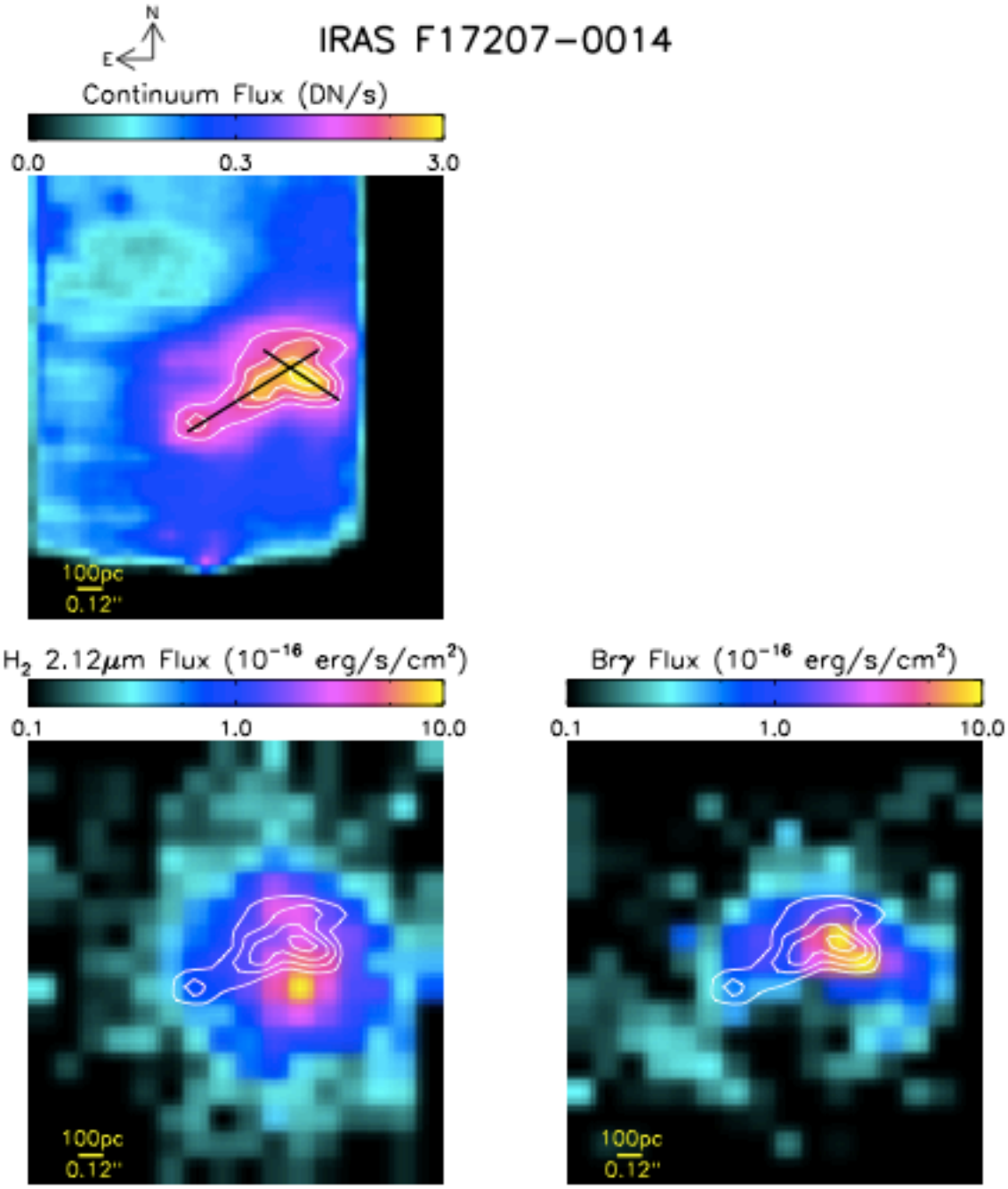
→ AGN-driven winds



U+ 2013, ApJ, 775, 115

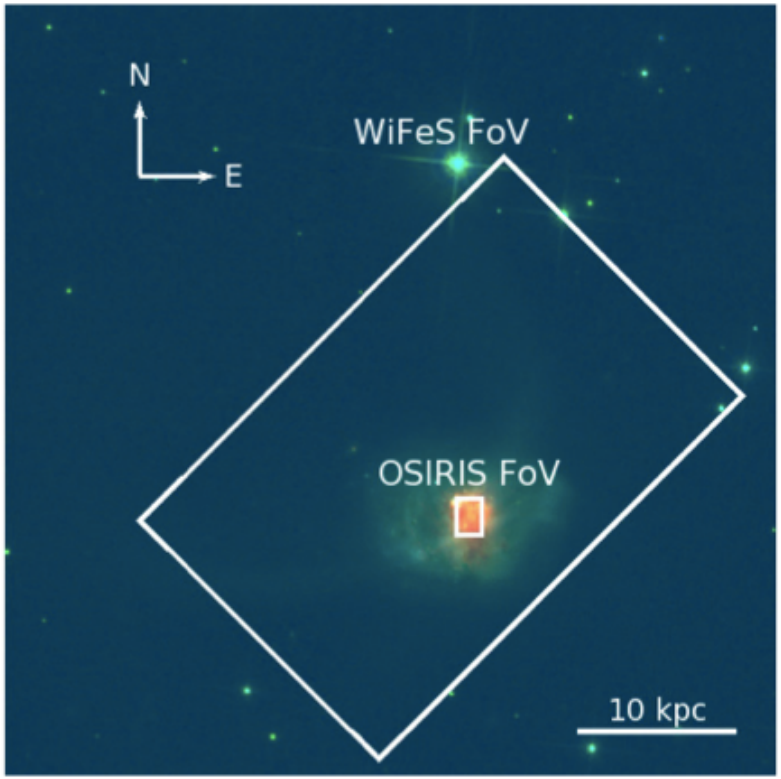
IR 17207

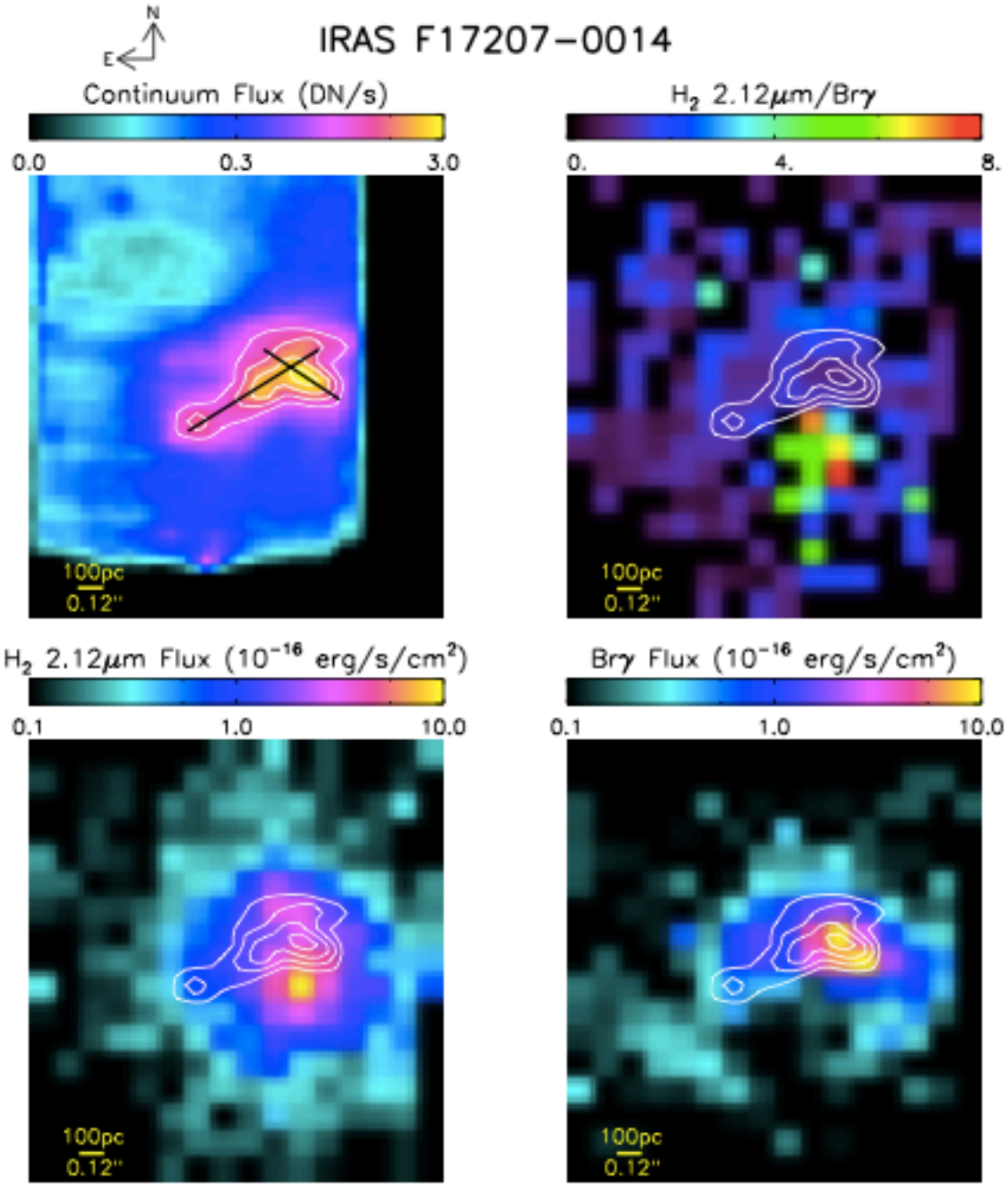




Medling, VU+ 2015a, MNRAS, 448, 2301

IR 17207





Medling, VU+ 2015a, MNRAS, 448, 2301

IR17207
Shocked ISM

v ~ 200 km/s

Mass = $4M_{\odot}$ (Soto+ 12)

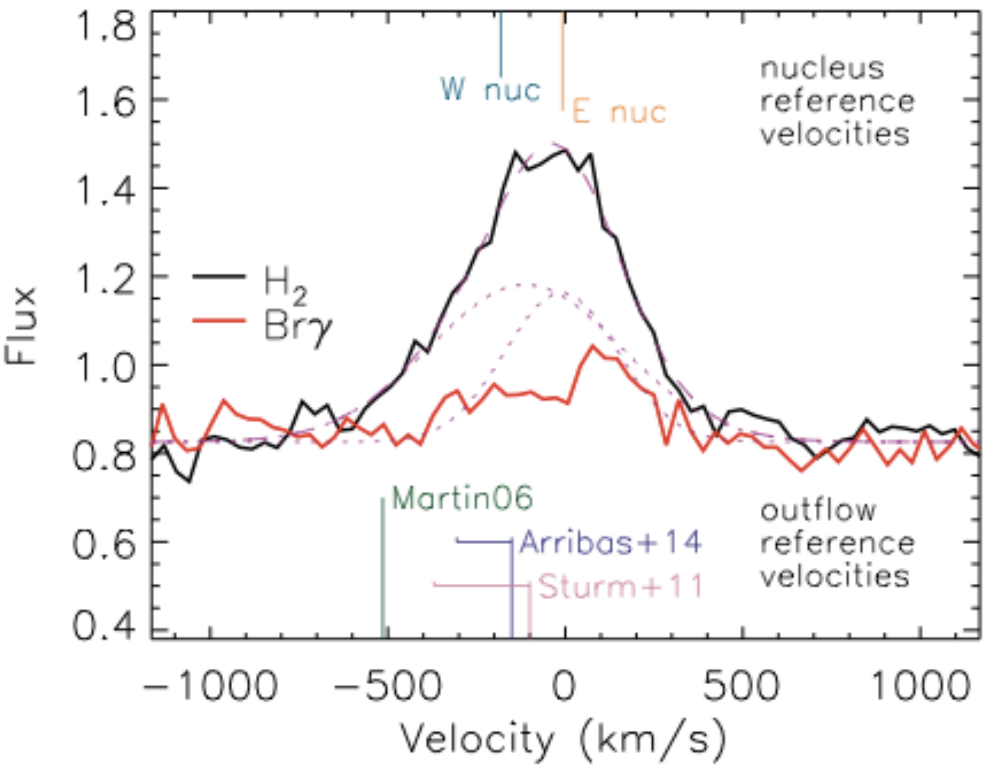
Distance from nucleus = 340 pc

E = 5.1 x 10^{40} erg/s

Reasons for shocks:

→ SB-driven winds

→ cloud-cloud collisions



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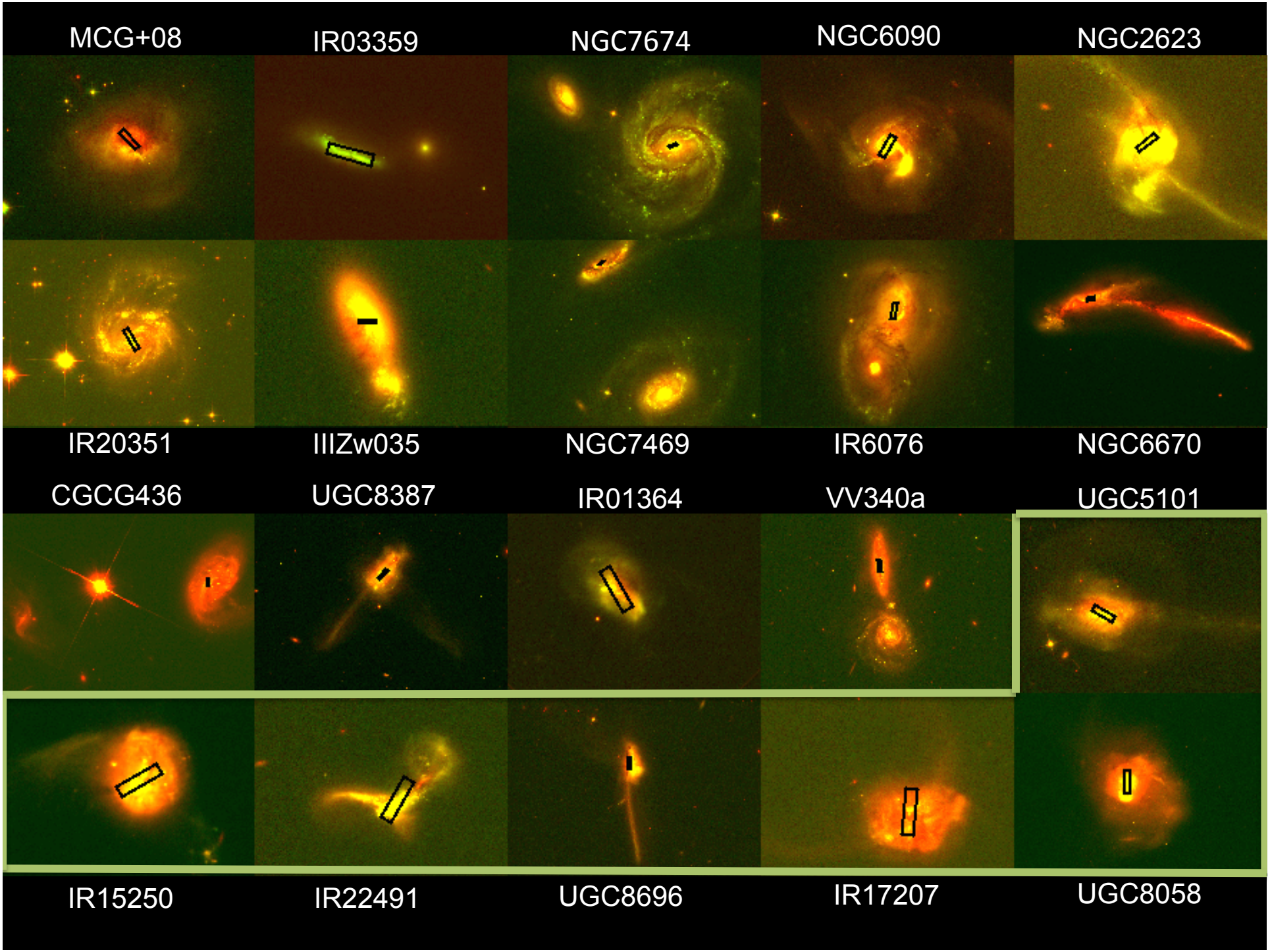
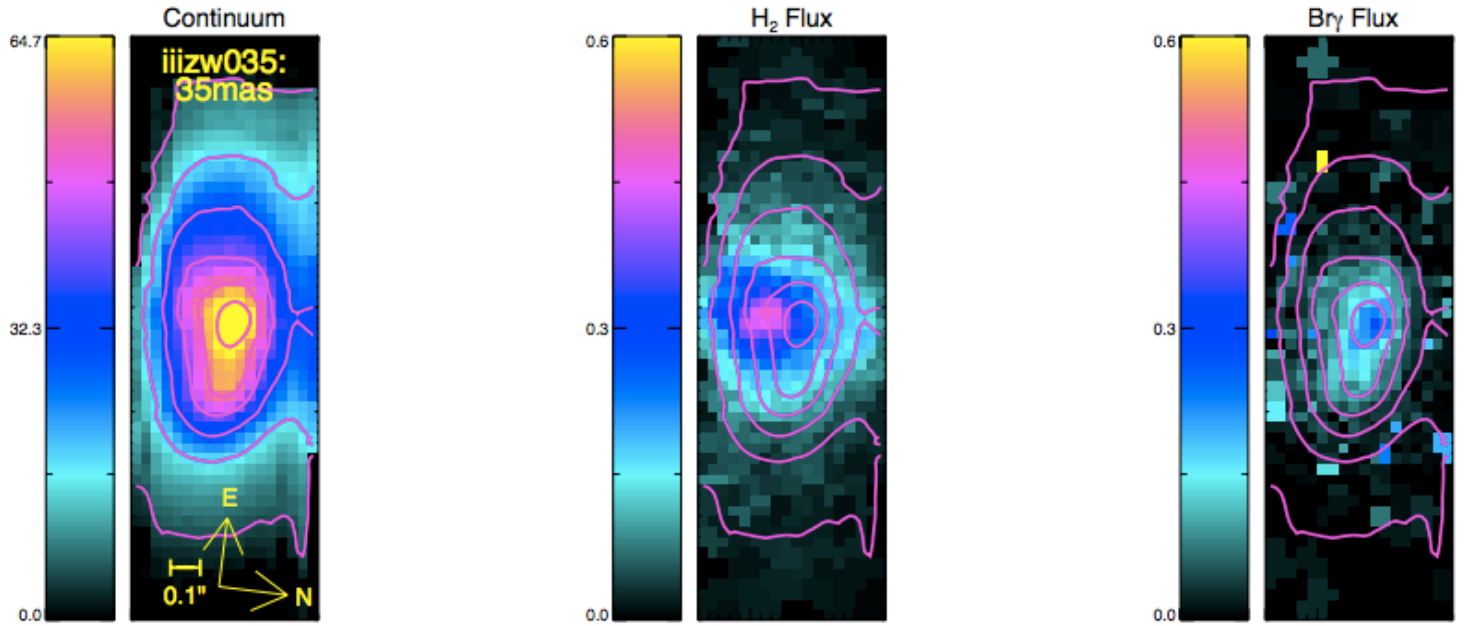

MCG+08
IR03359
NGC7674
NGC6090
NGC2623
IR20351
IIIZw035
NGC7469
IR6076
NGC6670
CGCG436
UGC8387
IR01364
VV340a
UGC5101
IR15250
IR22491
UGC8696
IR17207
UGC8058

Even more shocked molecular gas… III Zw 035



U+16 in prep.

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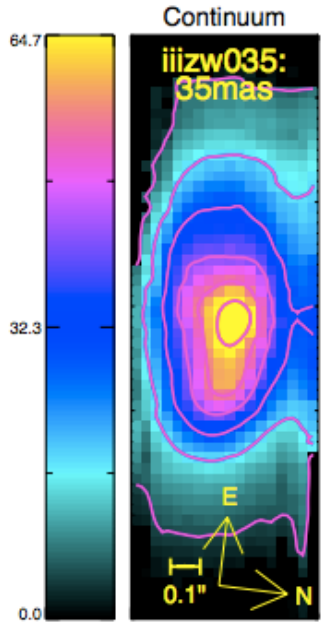

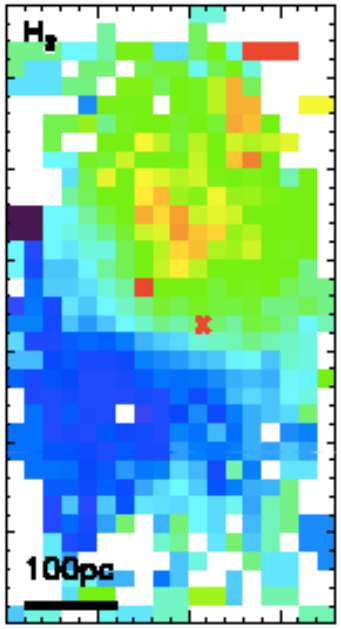

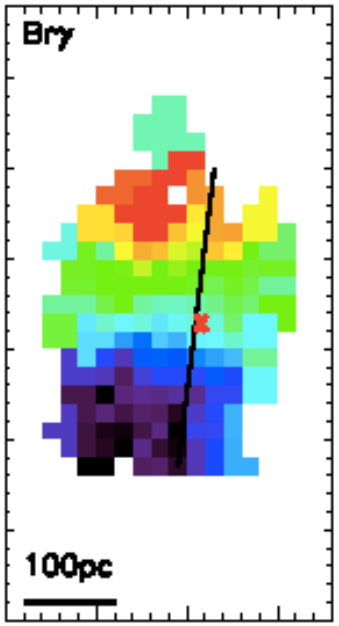

Medling, VU+ 2014

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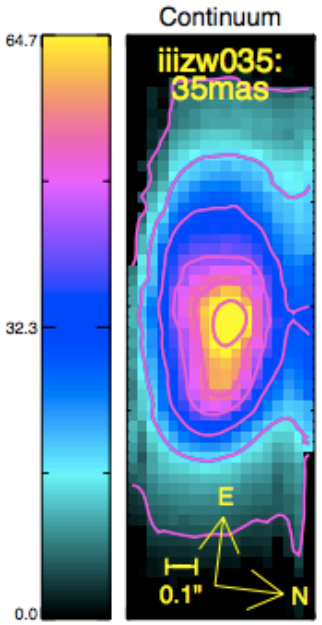
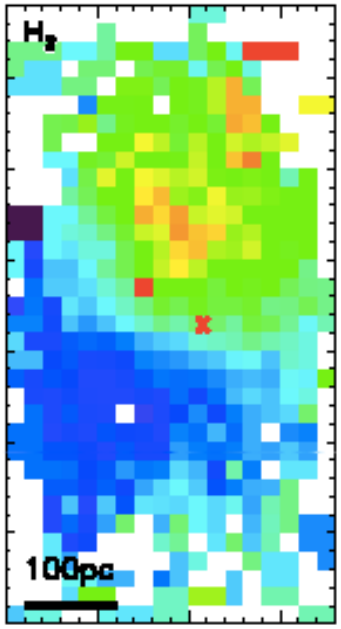
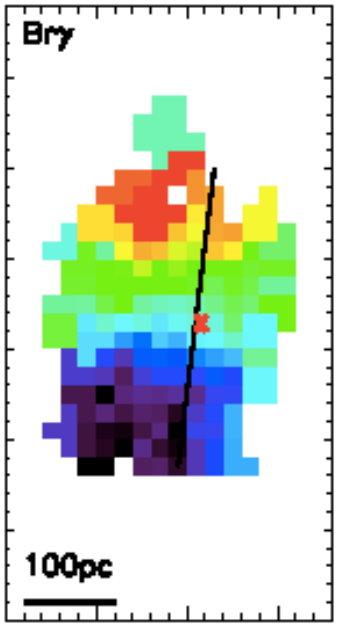
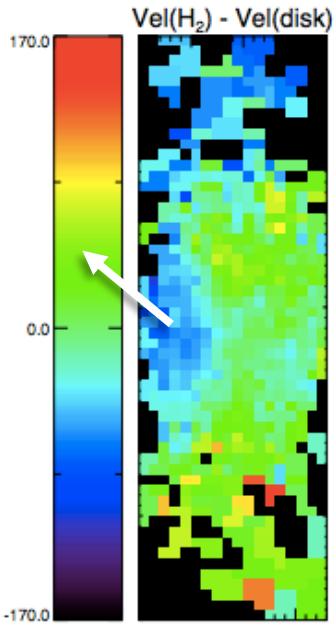




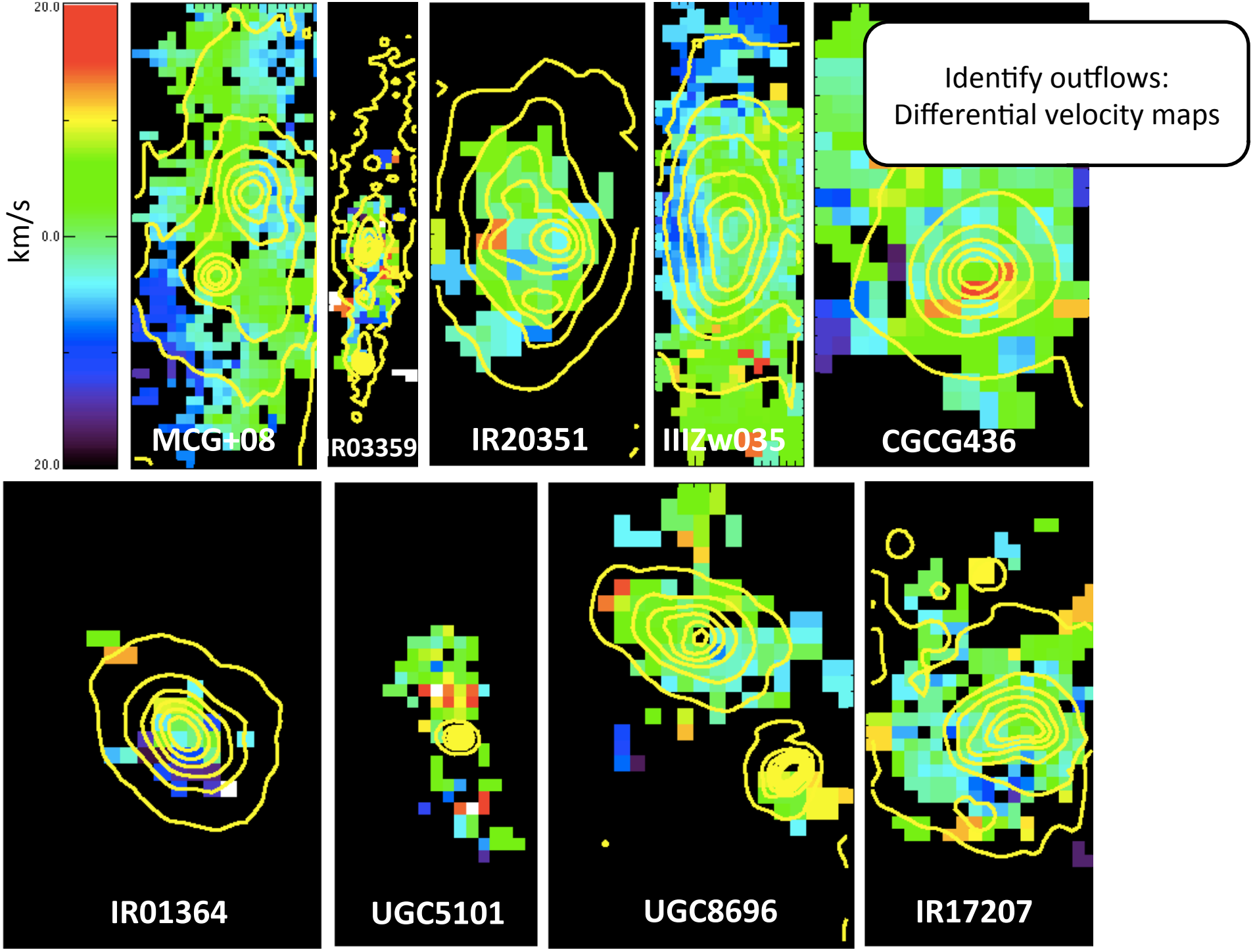


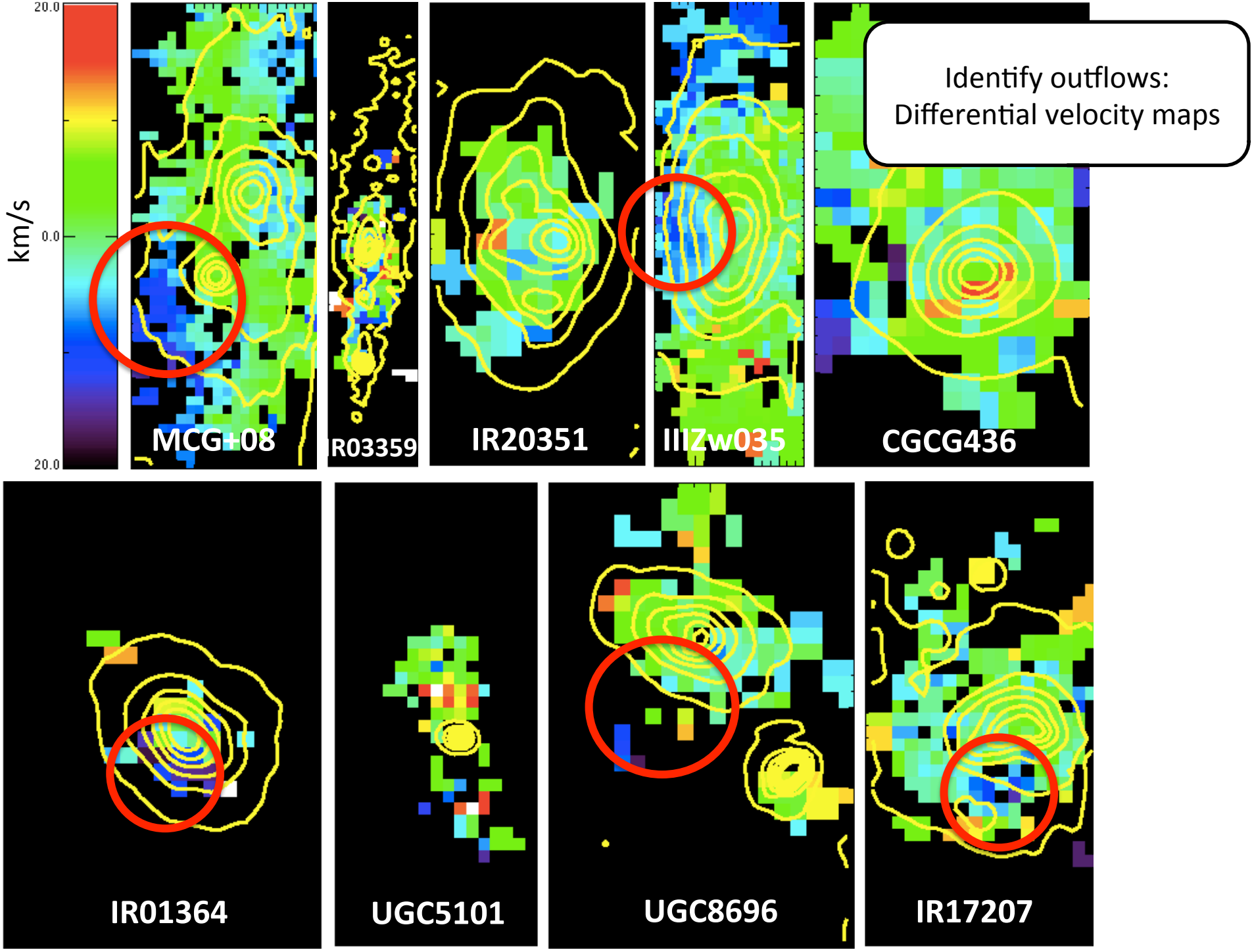


Medling, VU+ 2014

Look for non-Keplerian kinematics with differential velocity maps: vel(gas) – vel(disk)

U+16 in prep.


20.0
0.0
20.0
km/s
MCG+08
R03359
IR20351
IIIZw035
CGCG436
Identify outflows:
Differential velocity maps
IR01364
UGC5101
UGC8696
IR17207


20.0
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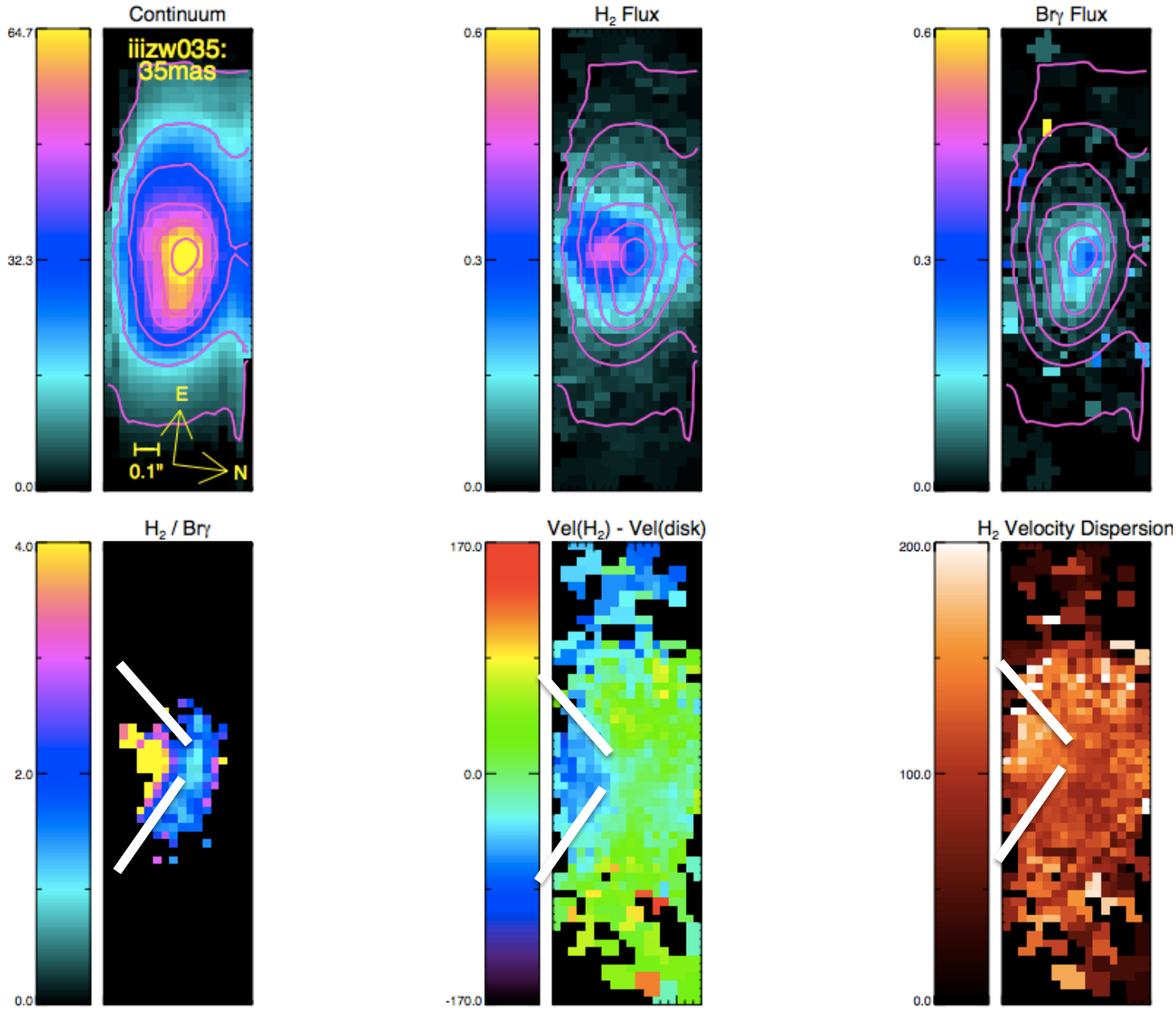
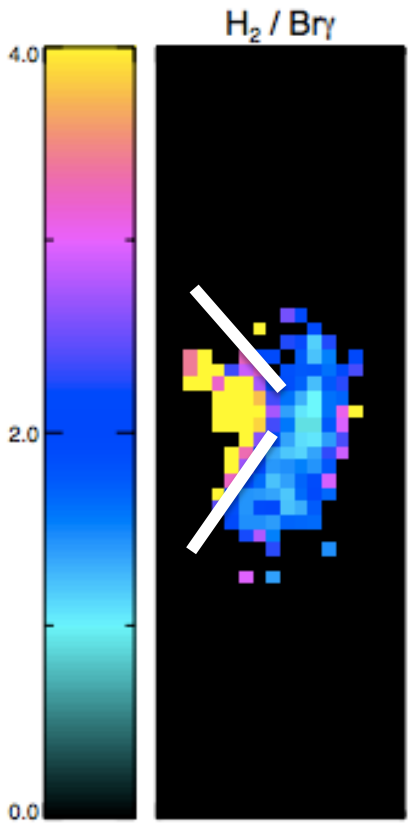
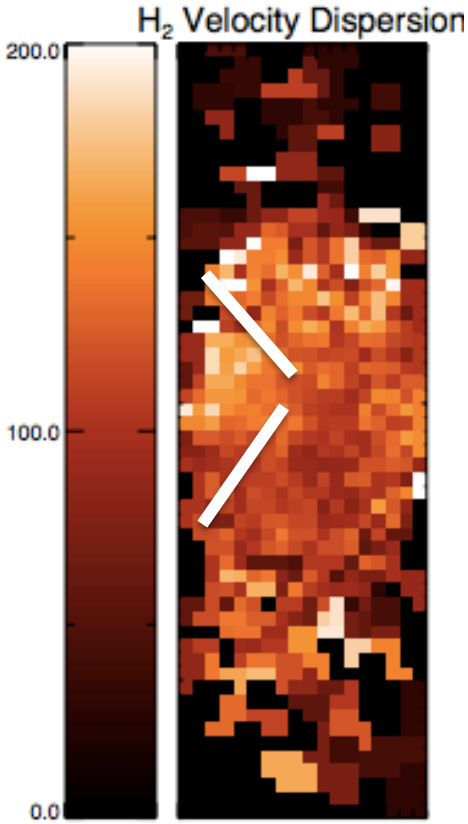


U+16 in prep.

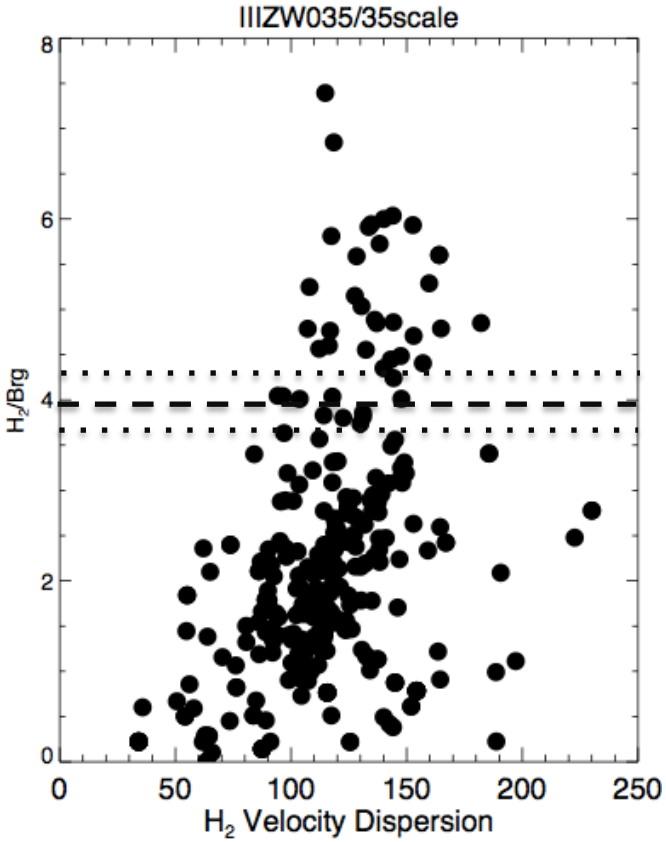
H_2/Brγ + enhanced vdisp = shocks



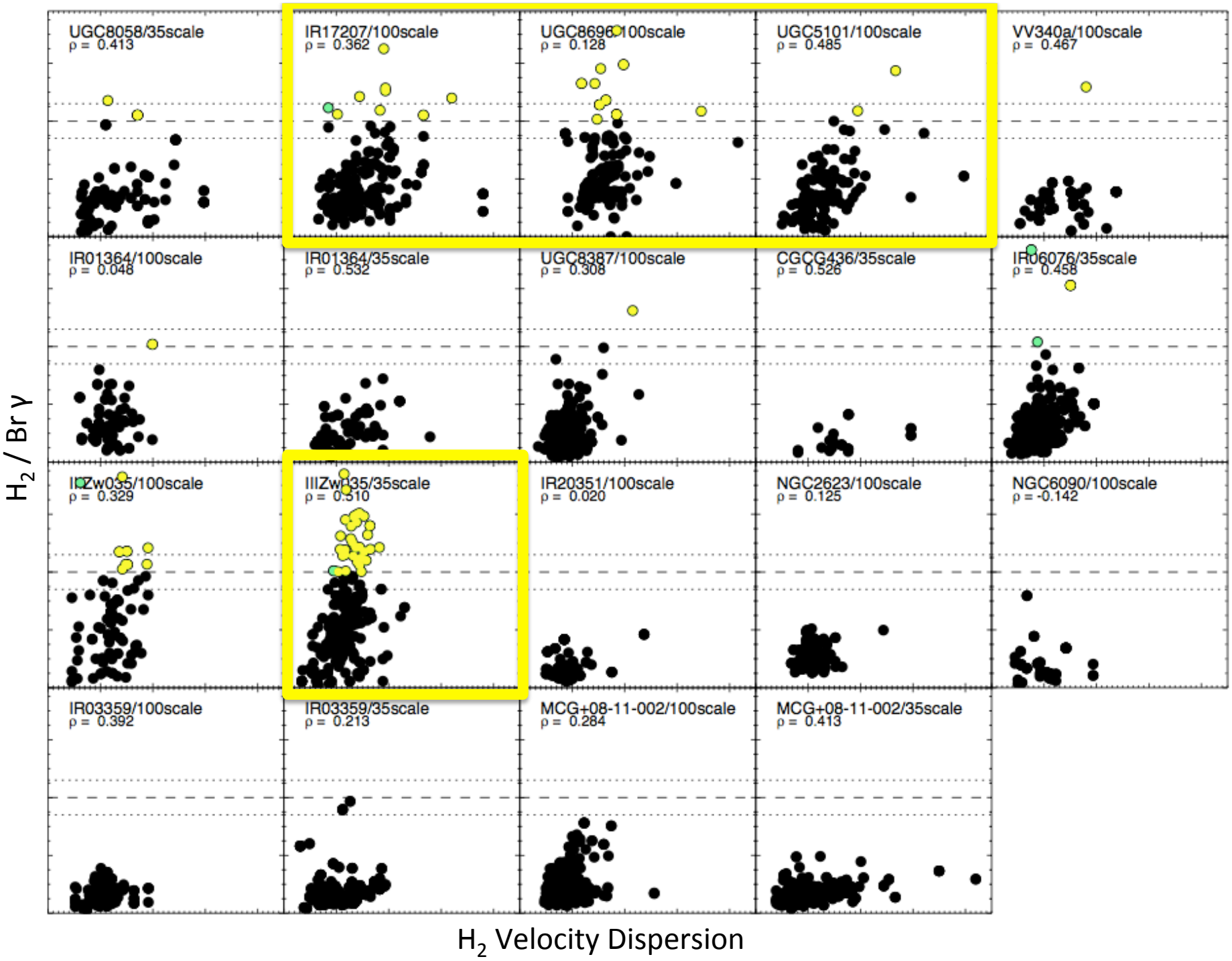
H_2/Brγ map



H_2 velocity dispersion



pixel to pixel plot


UGC8058/35scale
ρ = 0.413
IR17207/100scale
ρ = 0.362
UGC8696/100scale
ρ = 0.128
UGC5101/100scale
ρ = 0.485
VV340a/100scale
ρ = 0.467
IR01364/100scale
ρ = 0.048
IR01364/35scale
ρ = 0.532
UGC8387/100scale
ρ = 0.308
CGCG436/35scale
ρ = 0.526
IR06076/35scale
ρ = 0.458
IIZw035/100scale
ρ = 0.329
IIIZw035/35scale
ρ = 0.510
IR20351/100scale
ρ = 0.020
NGC2623/100scale
ρ = 0.125
NGC6090/100scale
ρ = -0.142
IR03359/100scale
ρ = 0.392
IR03359/35scale
ρ = 0.213
MCG+08-11-002/100scale
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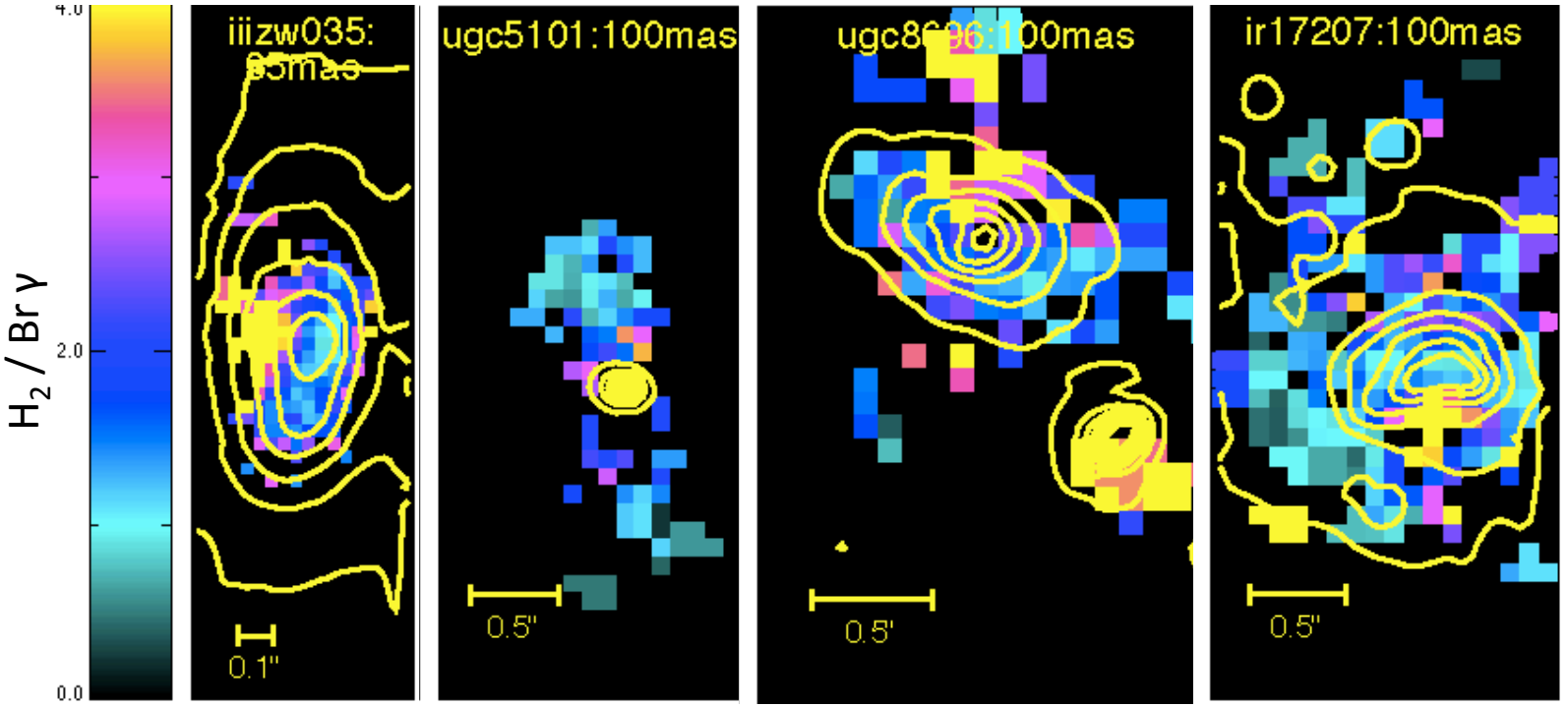
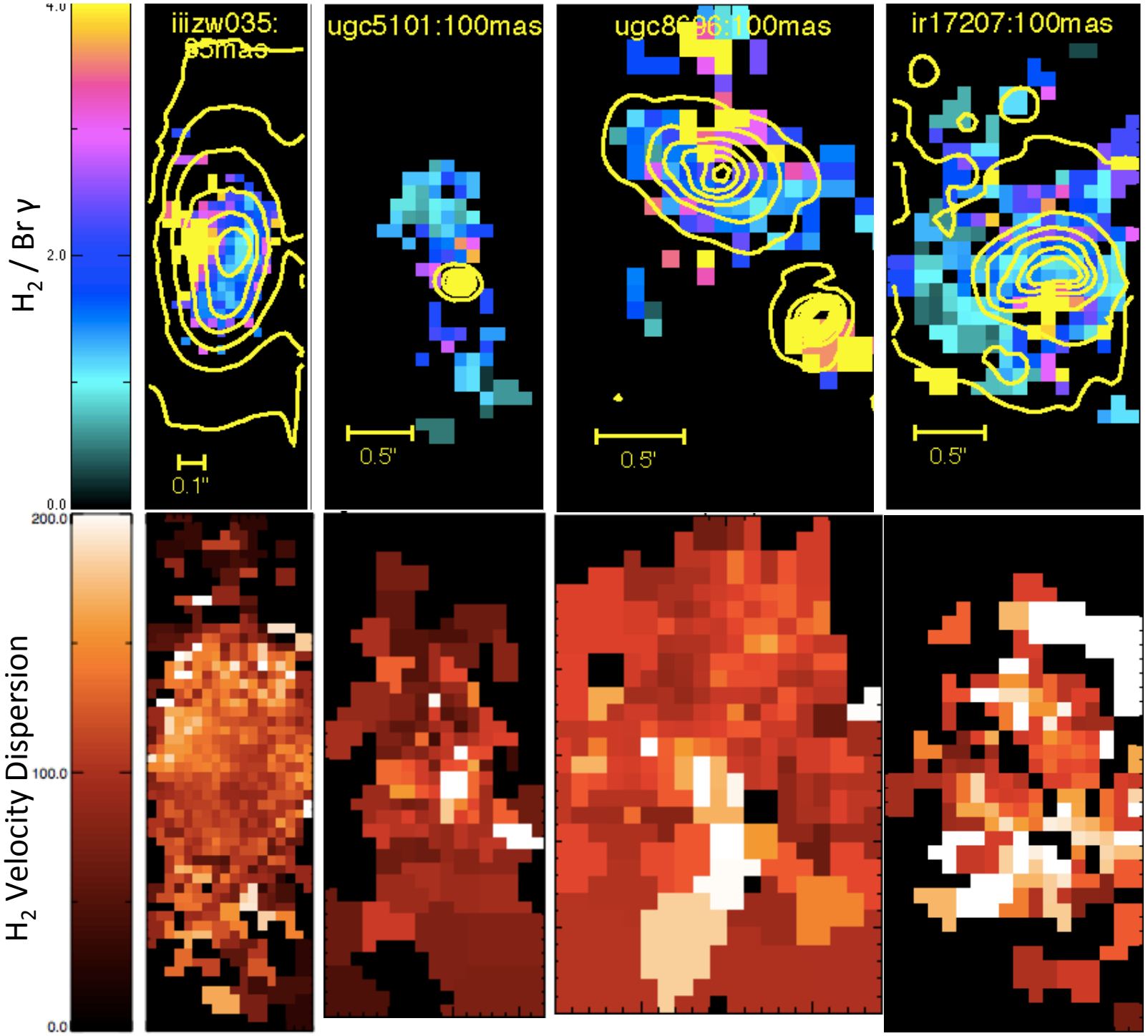
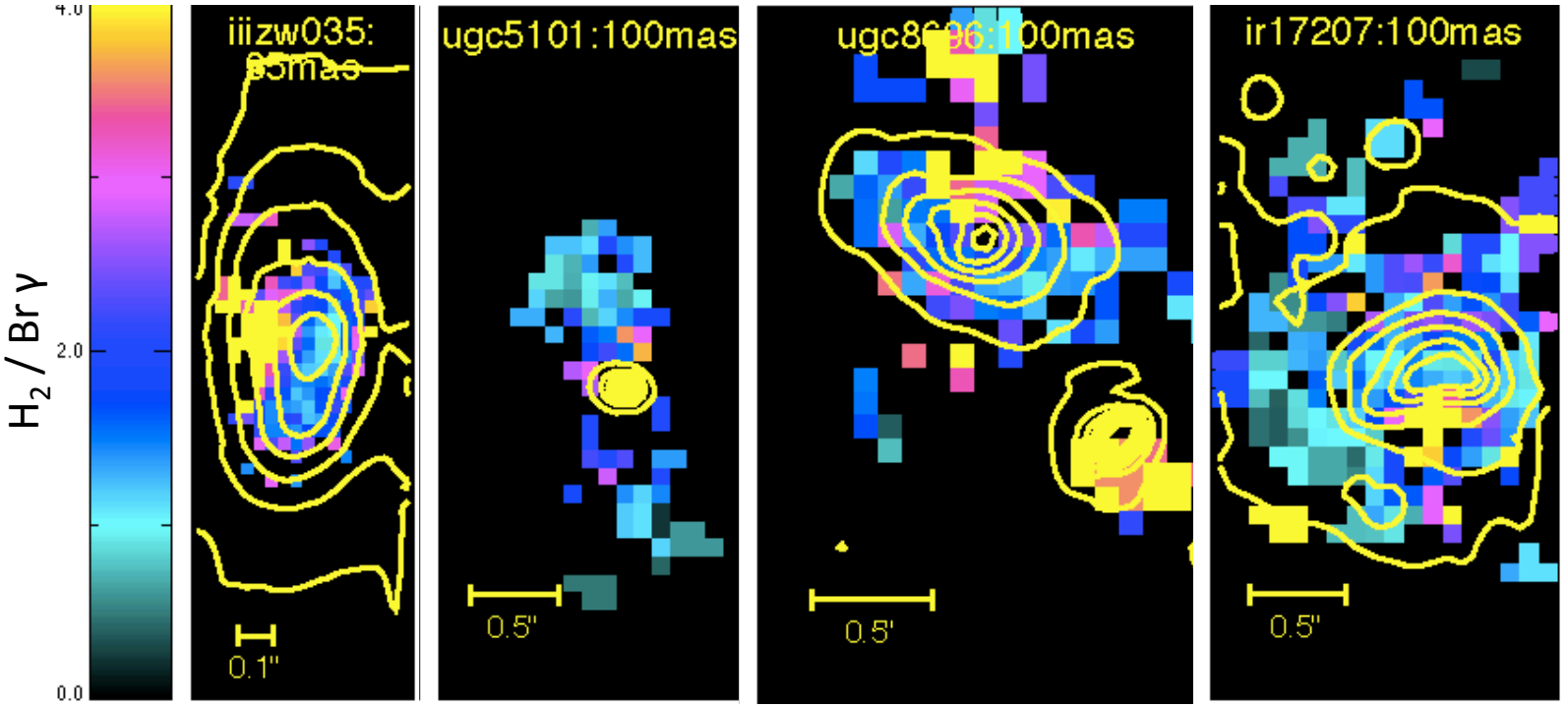
MCG+08-11-002/35scale
ρ = 0.413
H2 / Br γ
H2 Velocity Dispersion



- Elevated H_2/Brγ values are necessary (but not sufficient?) to confirm coherent shocked, potentially outflowing gas


H2 / Br γ
4.0
2.0
0.0
iiizw035:
100mas
0.1"
ugc5101:100mas
0.5"
ugc8696:100mas
0.5"
ir17207:100mas
0.5"
H2 Velocity Dispersion
200.0
100.0
0.0



- Elevated H_2/Brγ values are necessary (but not sufficient?) to confirm coherent shocked, potentially outflowing gas
- Look for cases with H_2/Brγ > 4 and good correlation with velocity dispersion!

Take-home Messages

- Nuclear gas kinematics – important for probing the launch sites of potential outflows and identifying shocks
- NIR AO IFS observations provide high spatial resolution (e.g. 20-50pc/ spaxel FWHM) view of the inner kpc region in local galaxy mergers
- Detected AGN- / SB-driven outflows as traced primarily by H_2 in a few systems using differential velocity maps
- Identify shocks with H_2/Brγ and H_2 velocity dispersion correlations and verify with 2D distributions
- Expected to occur more frequently in ULIRGs / advanced merger stage systems, but also seen in lower luminosity / early merger stage objects
- Need more statistics to pinpoint when and how they might be triggered; NIR diagnostics may come in handy in the JWST / 30-m class scope era!