D. Rupke

Gas flows in Starburst Mergers

Starbursts in merging galaxies are bookended by gas flows. They are preceded by strong radial inflows that fuel the star formation, and followed by outflows of enriched and entrained gas that act as regulatory feedback. Using both observations and simulations, I will present new results on (1) how we constrain gas inflows by tracking metals in starburst mergers and (2) how we are finally revealing the complex structures of the ubiquitous gas outflows in merging galaxies.

The Ins and Outs of Gas Flows in Major Mergers

David Rupke
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Collaborators: Lisa Kewley, Josh Barnes, Jenny Shih, Dave Sanders (IfA); Lisa Chien (STScI); Sylvain Veilleux, Hannah Krug (UMD); Andrew Baker (Rutgers)

Image credit: Space Telescope Science Institute

Historical Aside ...

14	*l*	22	16	57·19	54	24	39·3	Faible ; très-petite ; ronde ; forte condensation centrale.
15	*l*	22	18	38·39	54	25	34·2	15, 16 et 17 ont à peu près le même aspect que 14 ; 15 est un peu plus faible et plus petite ; 16 est un peu plus brillante et moins petite ; 17 est notablement plus faible et plus petite.
16	*l*	22	18	40·04	54	30	4·0	
17	*l*	22	18	43·19	54	32	21·8	
18	*m*	22	22	28·50	73	51	1·6	Excessivement excessivement faible et petite ; ronde ; légère condensation centrale, avec un très-petit point brillant à peu près central.
19	*n*	22	30	13·70	56	41	46·8	Les quatre nébuleuses 19, 20, 21 et 22 sont excessivement excessivement faibles ; excessivement petites ; très-difficilement observables. La plus belle est 19 ; puis viennent 20, 21, 22. Cependant 22, quoique la plus petite des quatre, est plus brillante.
20	*n*	22	30	19·22	56	40	30·7	
21	*n*	22	30	24·27	56	39	52·4	
22	*n*	22	30	24·92	56	41	35·2	
23	*o*	22	32	56·70	56	34	23·6	Excessivement excessivement faible ; excessivement petite ; ronde ; un peu de condensation centrale enveloppe quelques très-petites étoiles.
24	*p*	22	41	56·69	50	24	56·1	Excessivement excess. faible ; très-petite ; ronde ; légère condensation centrale.
25	*q*	22	52	44·36	54	51	38·6	Excessivement excess. faible ; très-petite ; irrégulièrement arrondie ; condensation centrale mal définie ; plusieurs très-petits points brillants.
26	*r*	22	55	23·47	88	24	12·3	Excessivement excessivement faible, à peine observable ; ronde D = 1′·5 ; condensation centrale à peine sensible.
27	*s*	23	6	32·63	55	47	6·2	Excessivement excess. faible, à peine observable ; irrégulièrement arrondie D = 45″ ; condensation à peine sensible ; quelques points br. soupçonnés.
28	*t*	23	10	18·64	66	10	44·5	Excessivement excessivement faible ; modérément étendue ; irrégulièrement arrondie ; enveloppe plusieurs très-petites étoiles.
29	*u*	23	20	30·76	65	36	4·9	Excessivement excessivement faible et petite ; irrégulièrement arrondie ; une peu de condensation centrale ; enveloppe un très-petite ∗.
30	*v*	23	46	55·11	62	24	19·5	Excessivement faible et petite ; ronde ; condensation centrale.

Le No. 12 est peut-être identique avec 440 Lassell.
14, 15, 16, 17 sont voisines de 474 et 475 Lassell, mais distinctes de celles-ci.

E. Stephan 1877, Astronomische Nachrichten and MNRAS

Gas Flows in Major Mergers

INFLOW

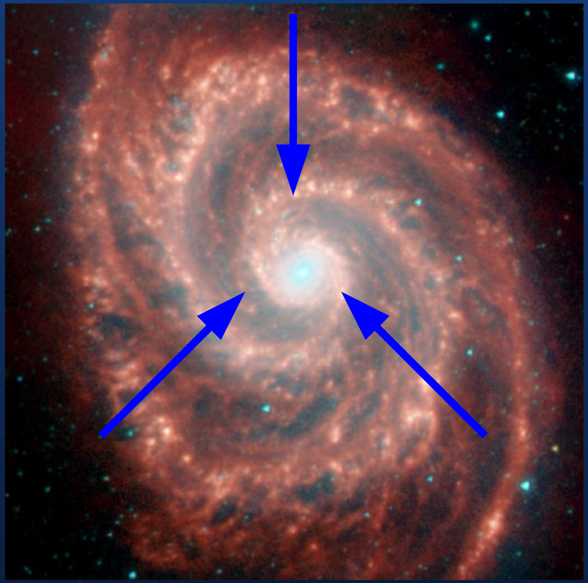
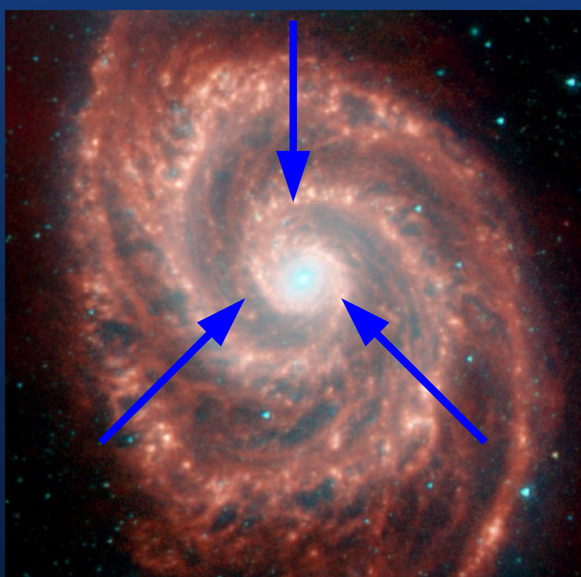


Image credits: Spitzer Science Center / STScI / Engelbracht+06

Gas Flows in Major Mergers

INFLOW

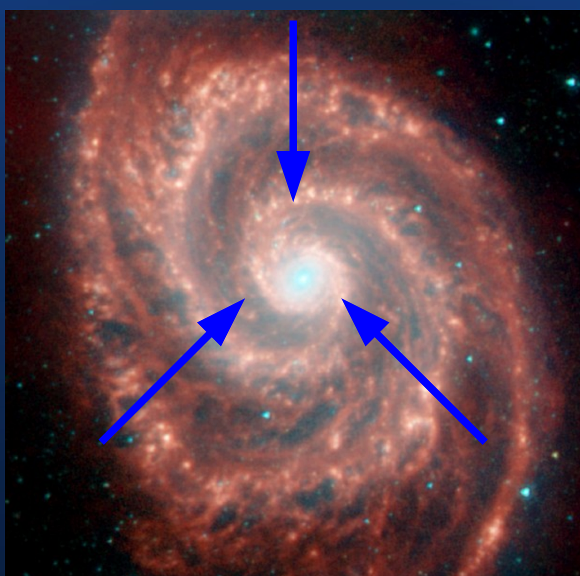


STAR
FORMATION

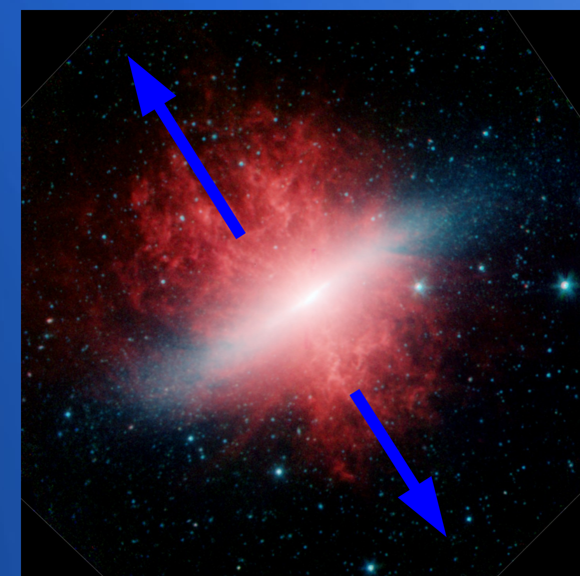
Image credits: Spitzer Science Center / STScI / Engelbracht+06

Gas Flows in Major Mergers

INFLOW



OUTFLOW

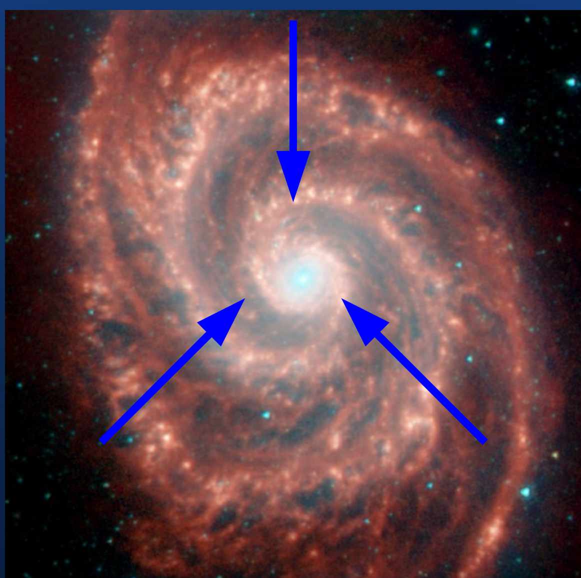


STAR FORMATION

Image credits: Spitzer Science Center / STScI / Engelbracht+06

Gas Flows in Major Mergers

1 INFLOW



STAR FORMATION

OUTFLOW

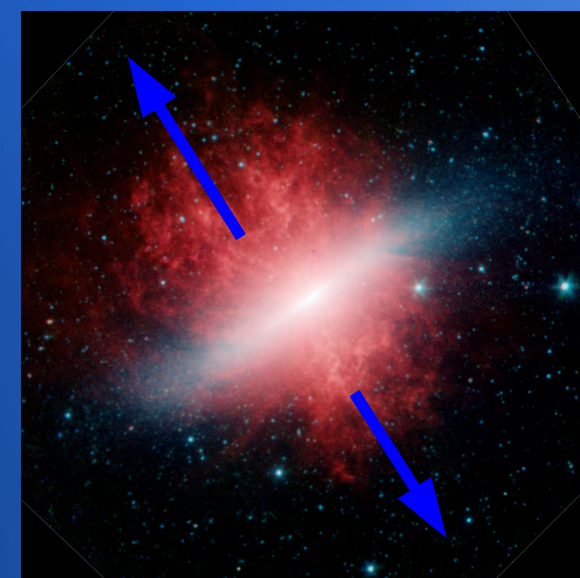
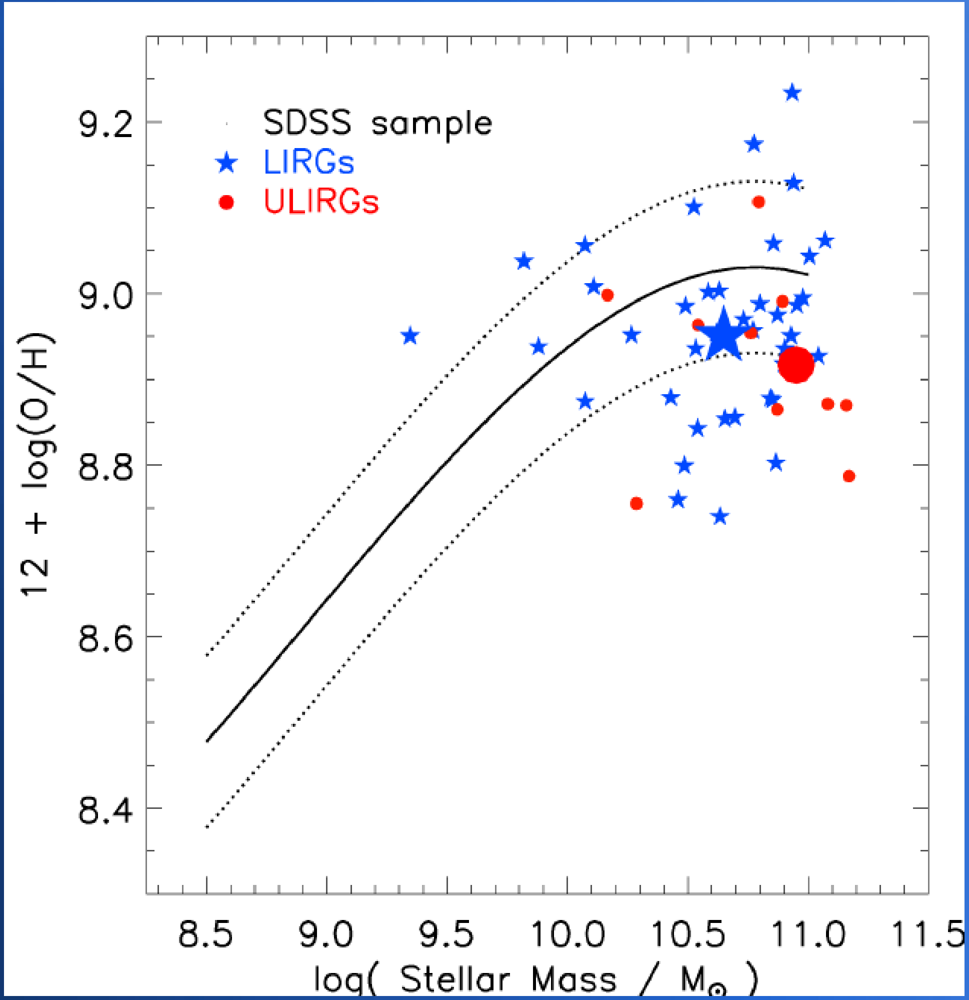


Image credits: Spitzer Science Center / STScI / Engelbracht+06

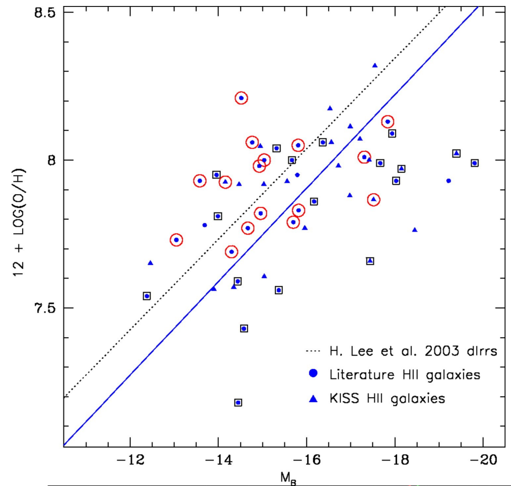
Inflow: Clues from the Mass-Metallicity Relation

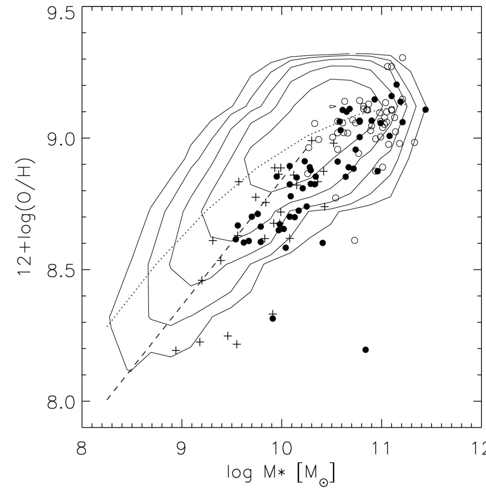
Major mergers fall below the M-Z relation

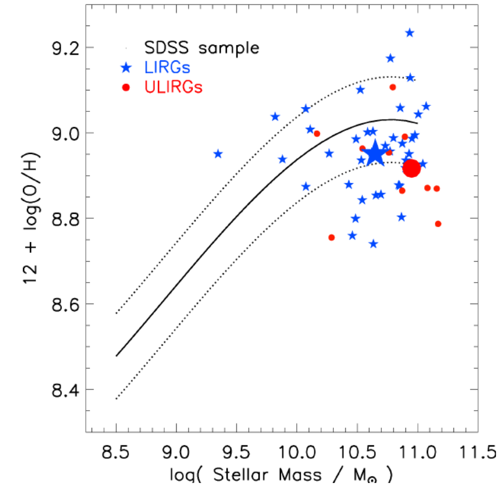


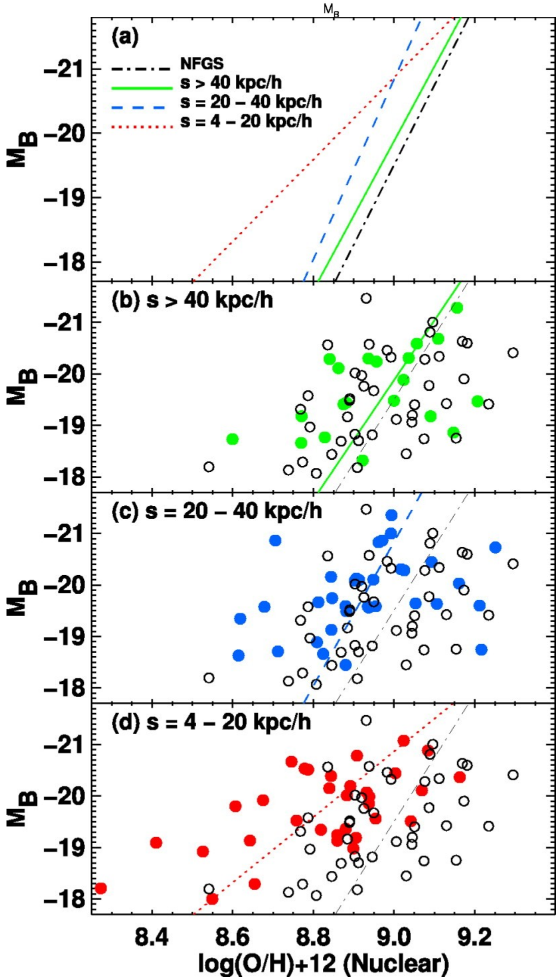
Rupke+08

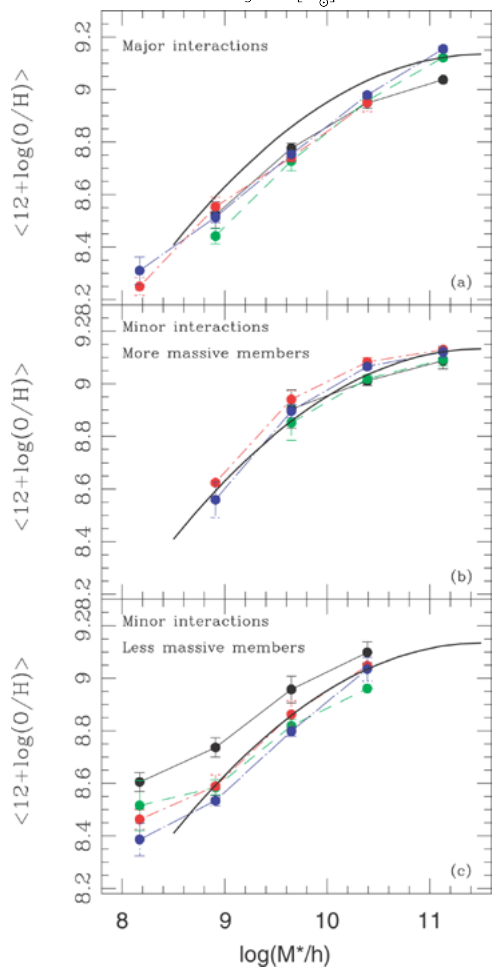
Lee+04, Kewley+06, Hoopes+07, Rupke+08, Ellison+08, Michel-Dansac+08, Peeples+09, Alonso+10

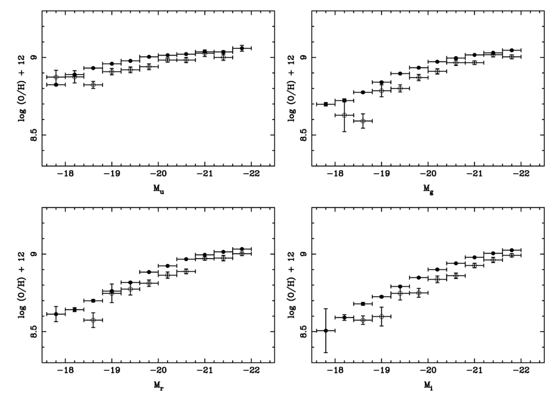


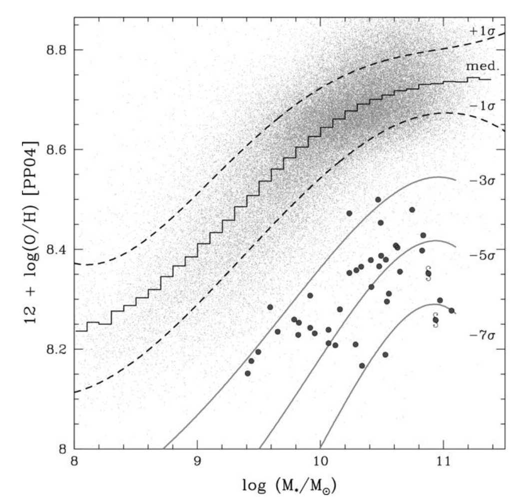




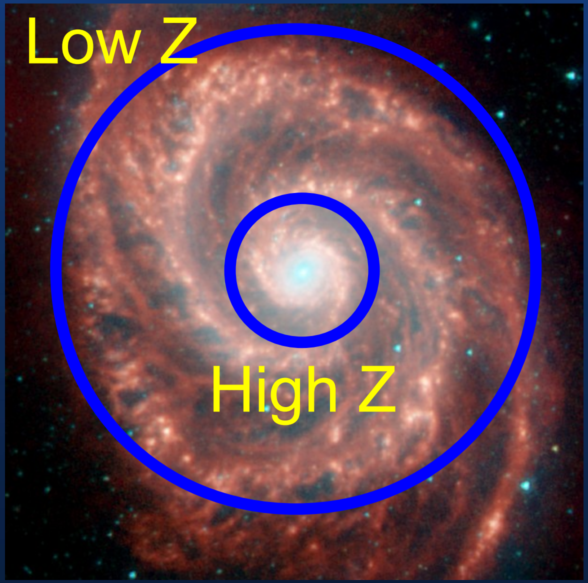








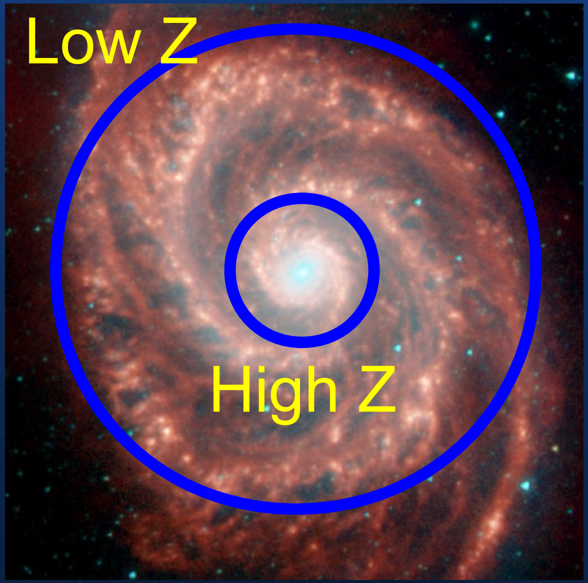
Model: Metal Dilution



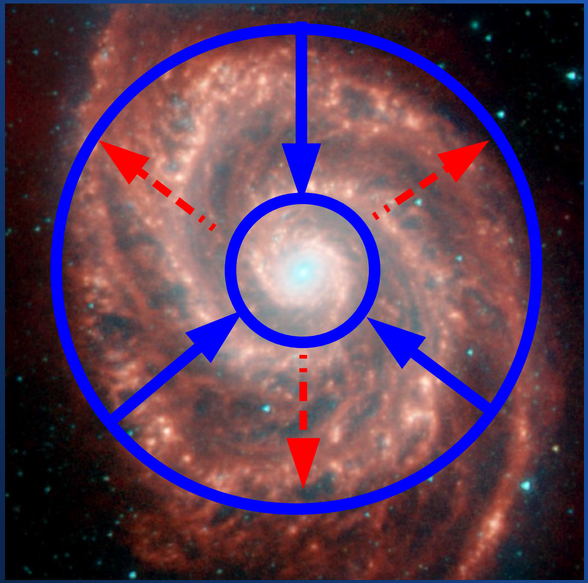
Isolated Galaxy

Kewley+06

Model: Metal Dilution



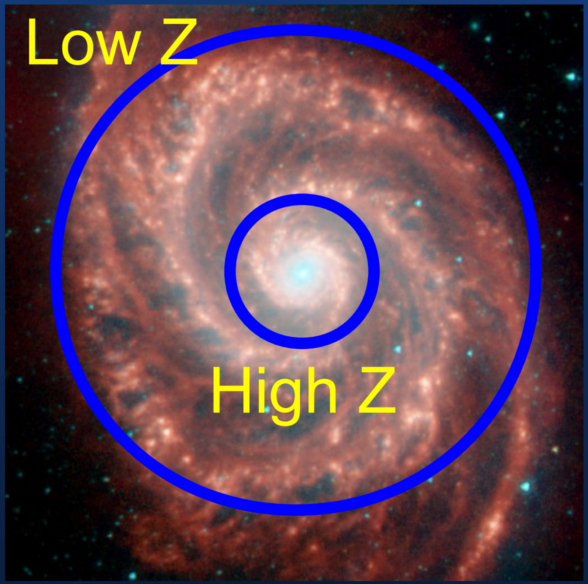
Isolated Galaxy



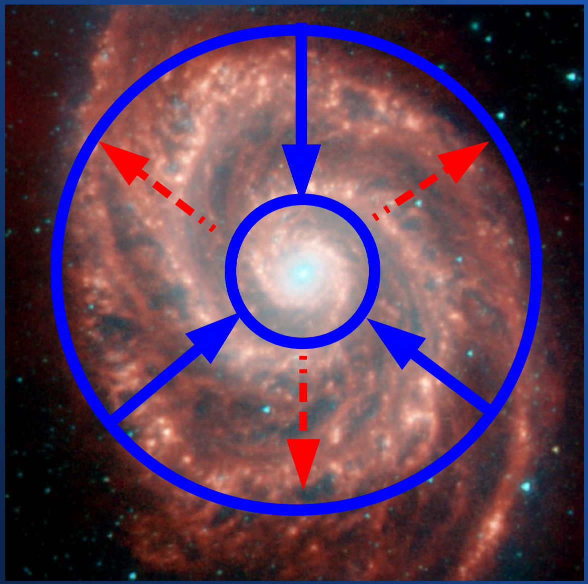
Interaction-Induced Inflow (and Outflow)

Kewley+06

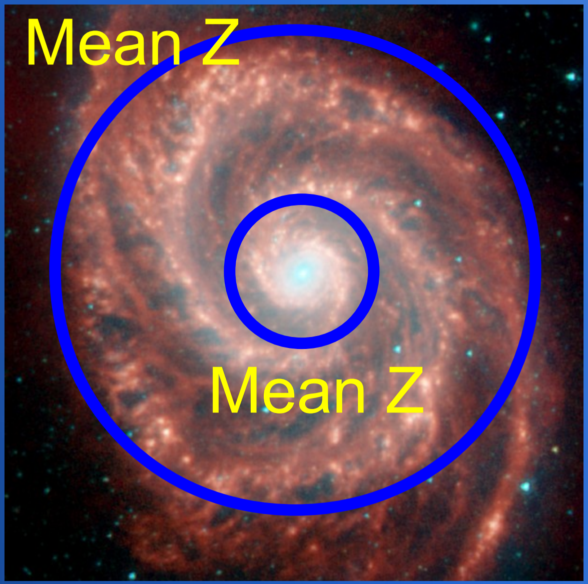
Model: Metal Dilution



Isolated Galaxy



Interaction-Induced Inflow (and Outflow)

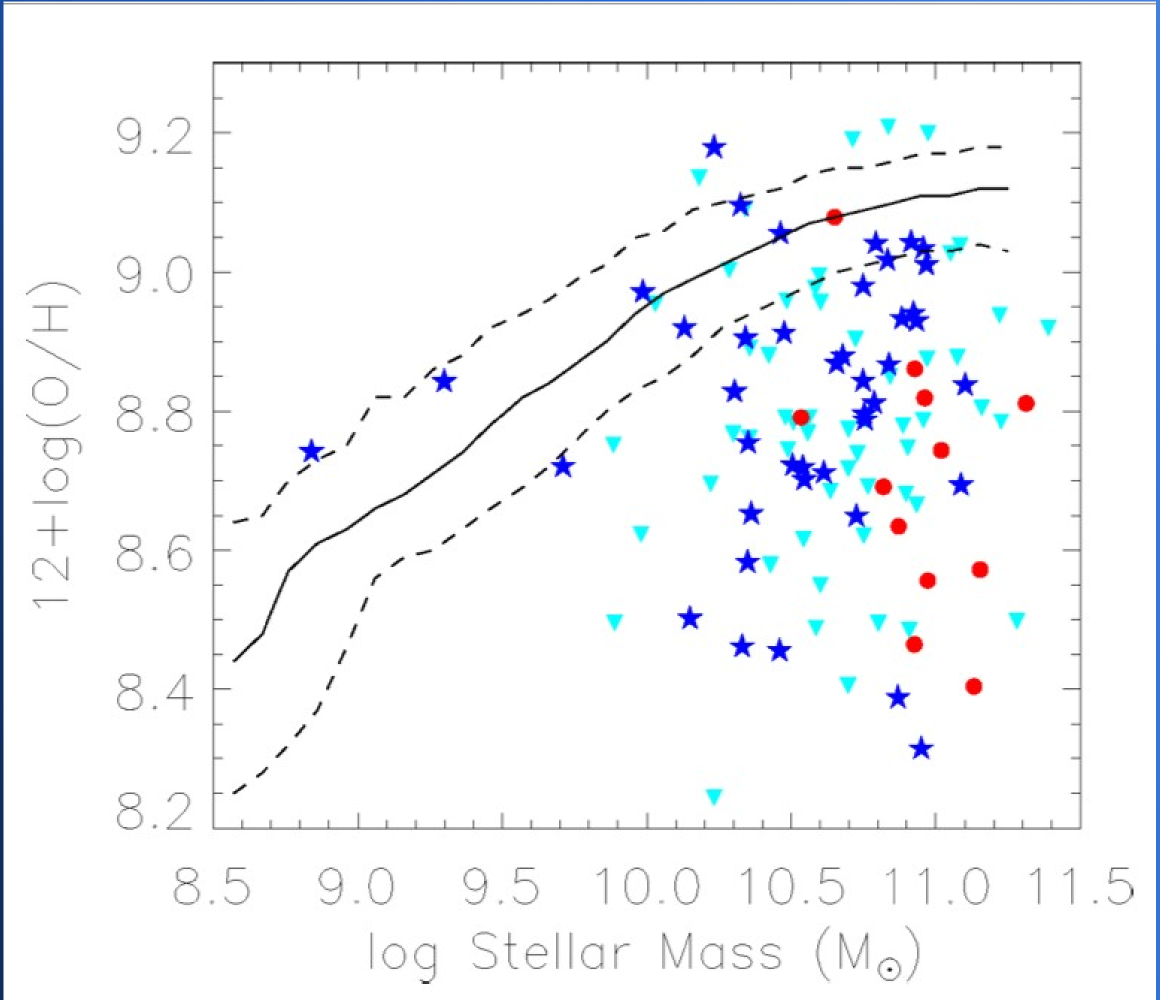


After Inflow

Kewley+06

Simulations of Metal Dilution

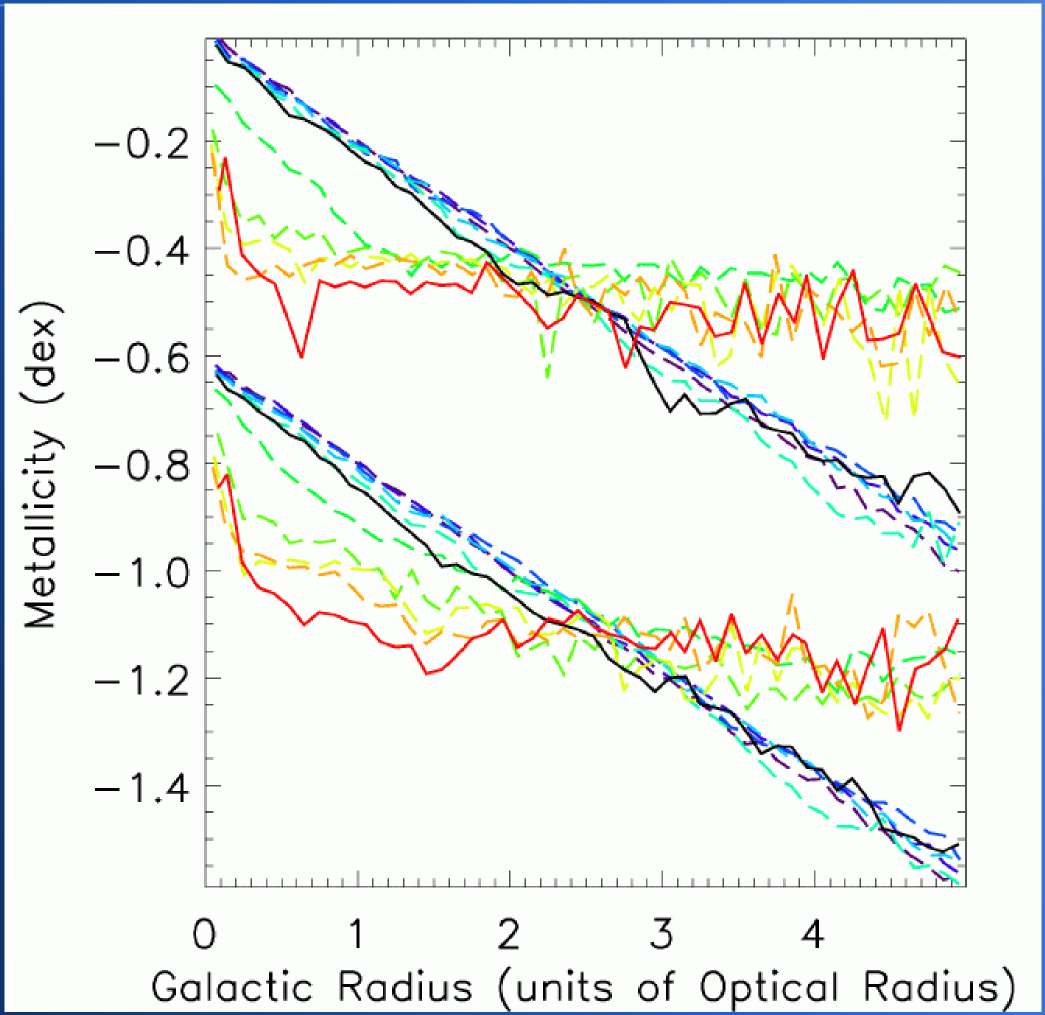
- Reproduce magnitude of observed dilution of nuclear Z *(Rupke+10a, Montuori+10)*



Montuori+10

Simulations of Metal Dilution

- Reproduce magnitude of observed dilution of nuclear Z *(Rupke+10a, Montuori+10)*
- Predict shape of radial gradients in Z *(Rupke+10a)*



Rupke+10a

Test: Gradients in Interacting Galaxies

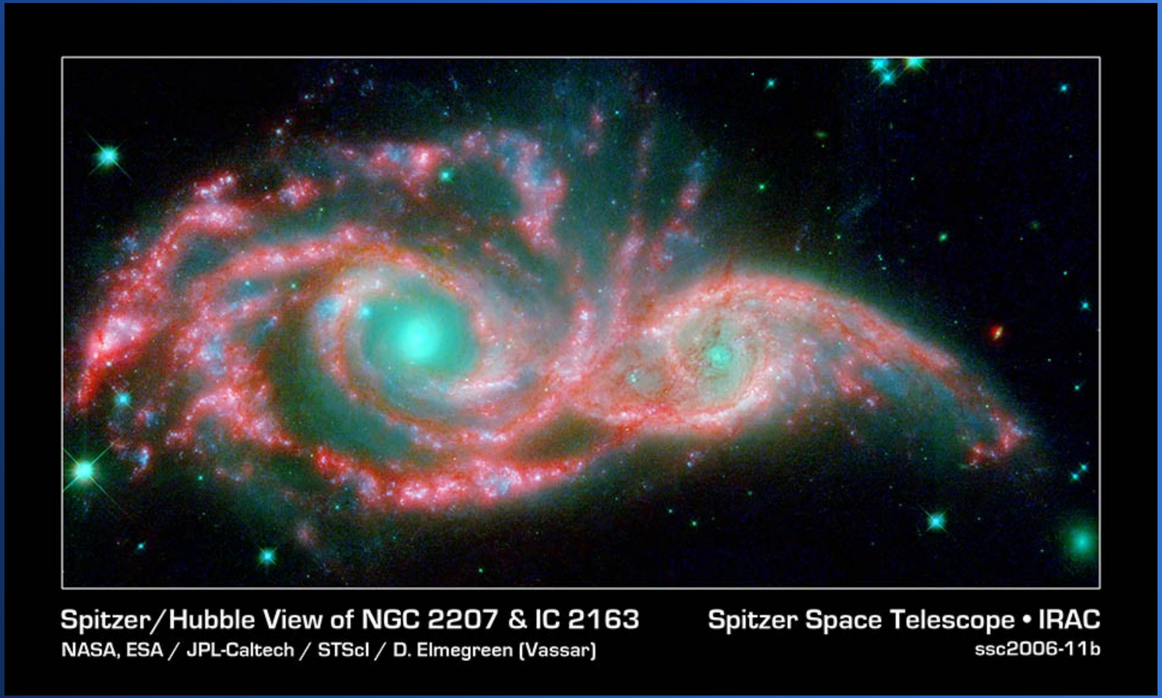
Sample

- 16 gals / 9 systems
- Mass ratios > 1/3
- Sep. ~ 10 – 30 kpc
- 300+ HII regions

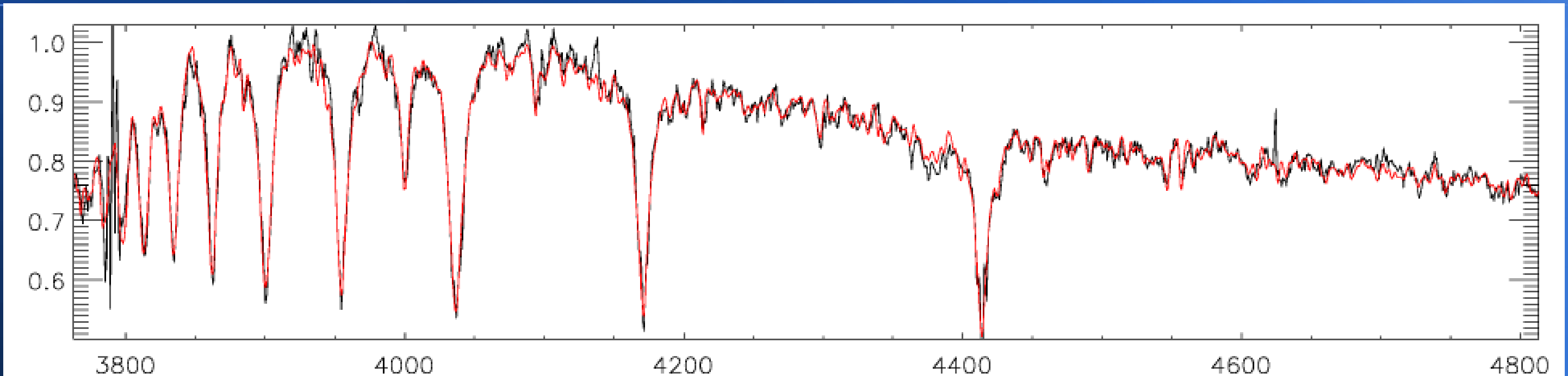
Control

- 12 late spirals

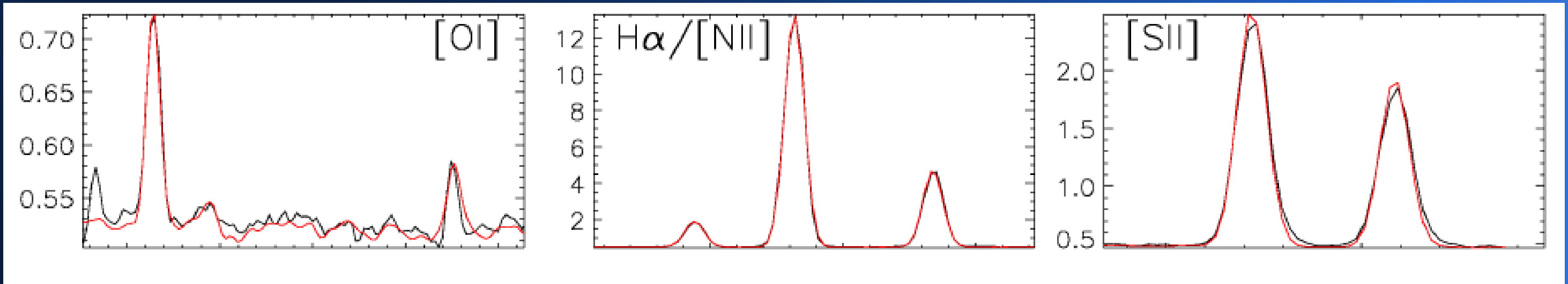
Kewley+10 (ApJL, submitted)
Rupke+10b (ApJ, submitted)



Data Analysis

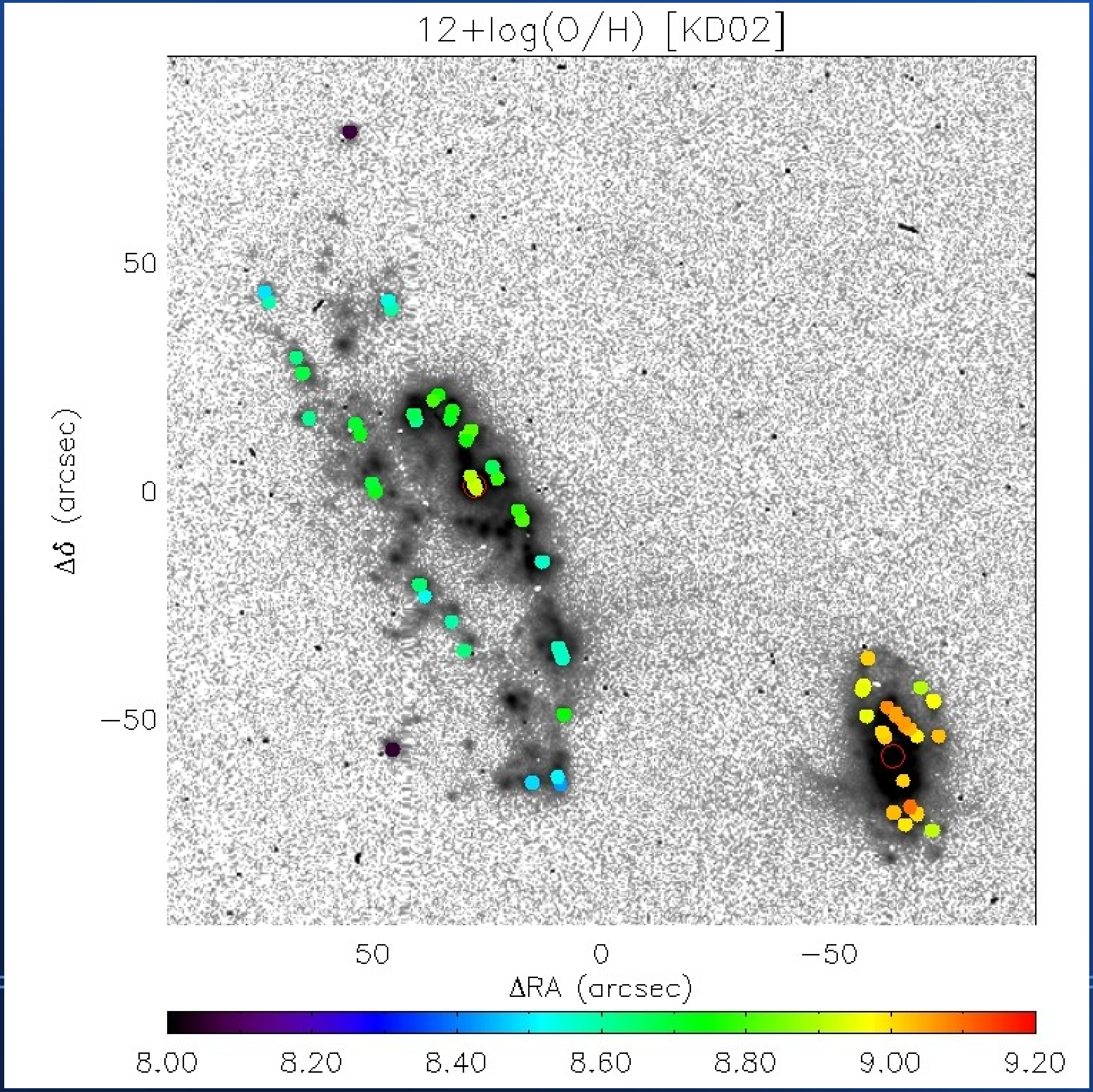


Stellar continuum fits with Gonzalez-Delgado+05 models



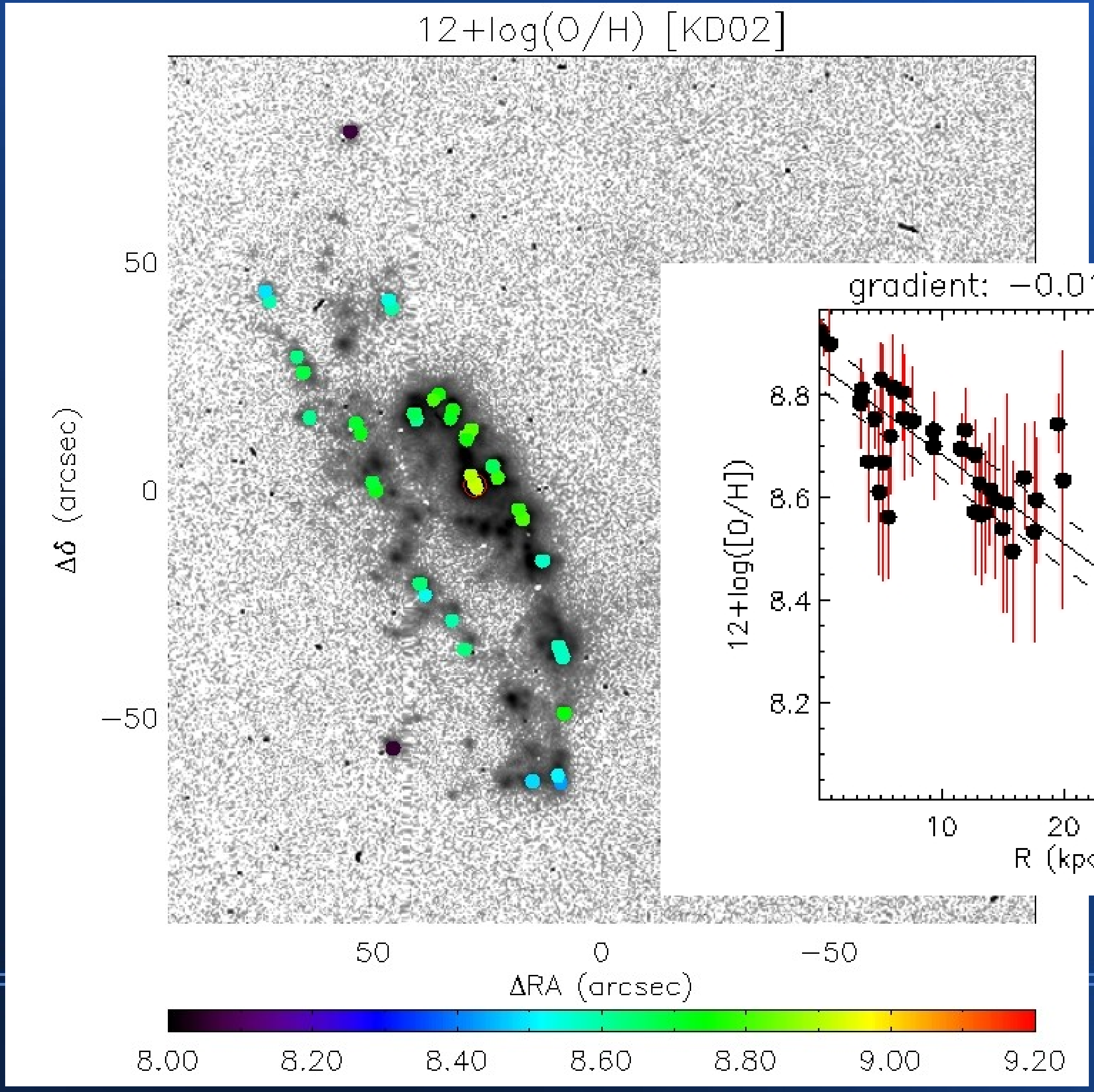
Multi-component emission-line fits with MPFIT *(Markwardt)*

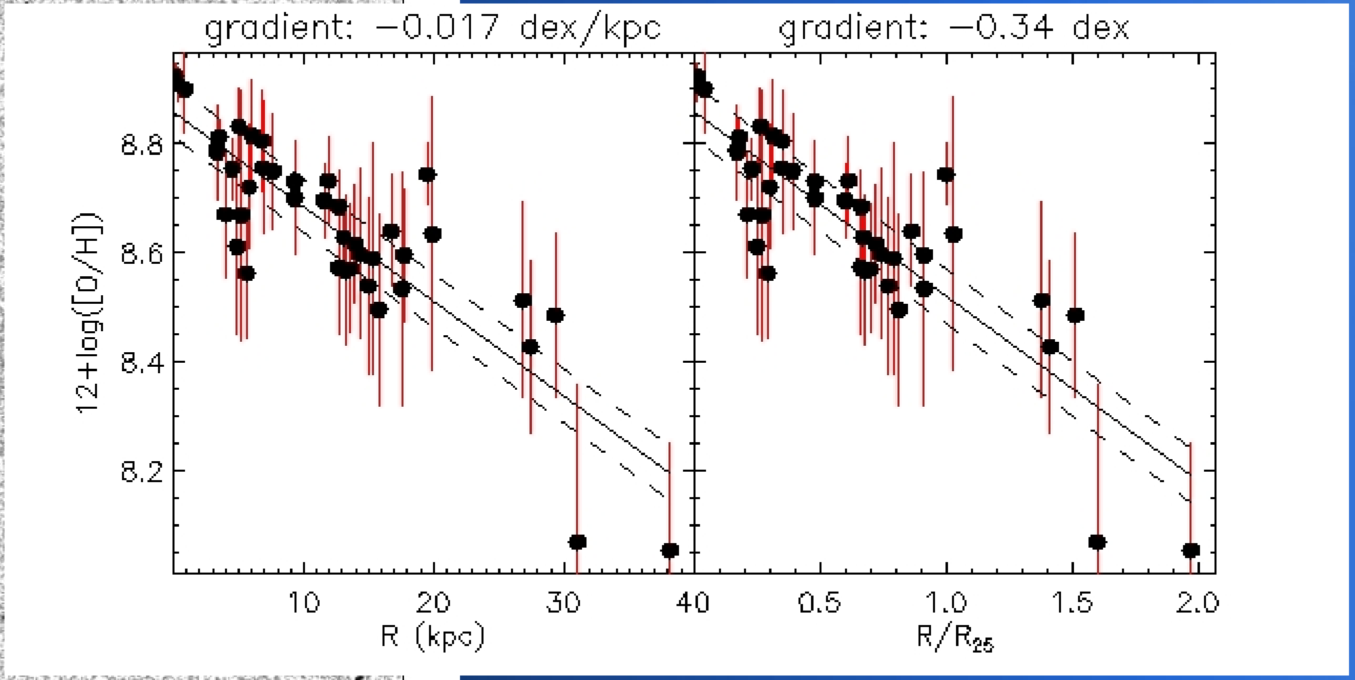
Abundance Maps



- Oxygen abundances from [NII]/[OII] *(Kewley & Dopita 2002)*
- Control sample reprocessed using same abundance diagnostic

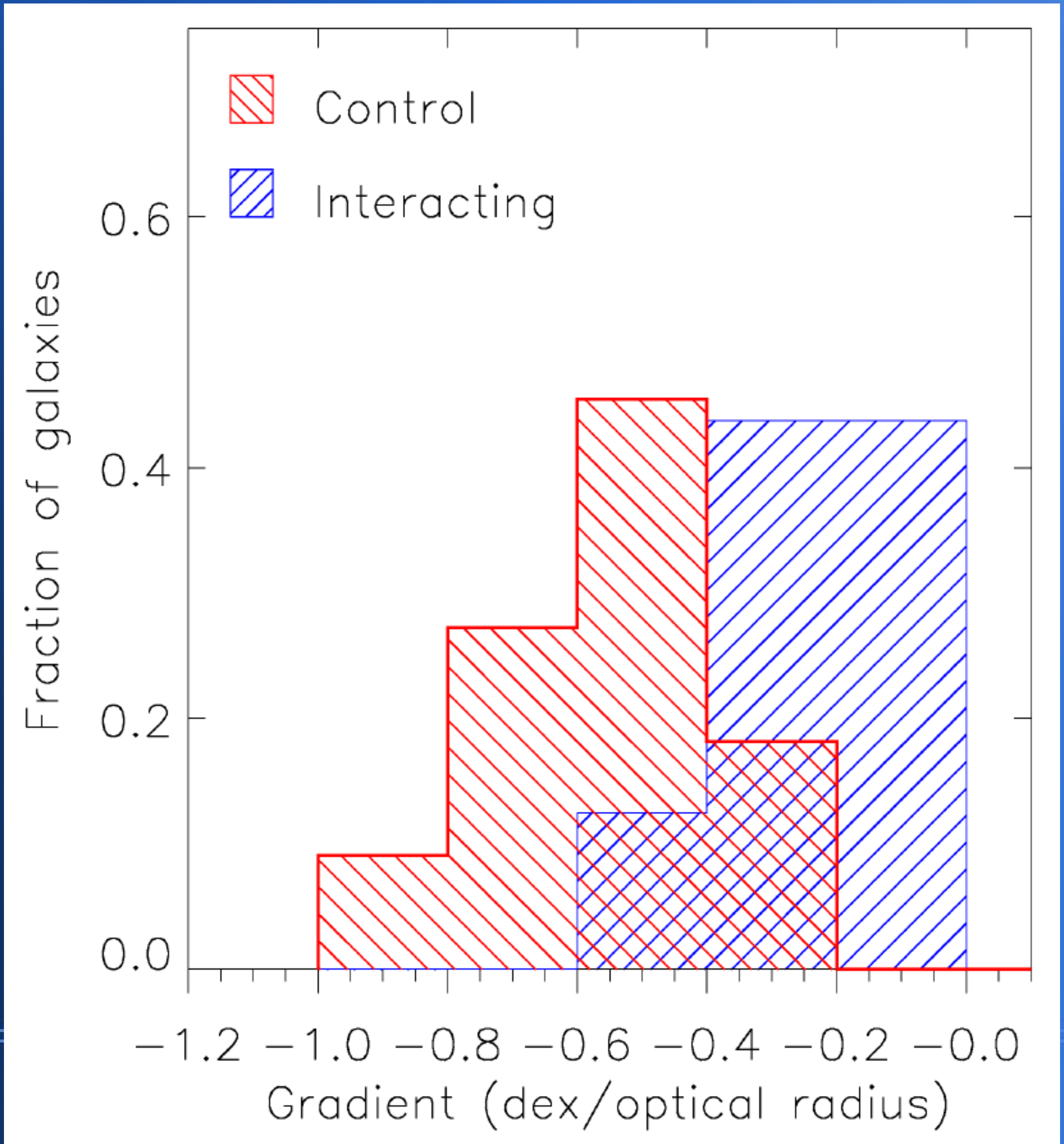
Radial Abundance Gradients





Isolated vs. Interacting Gradients

Interacting gradients lower by factor of >2 on average

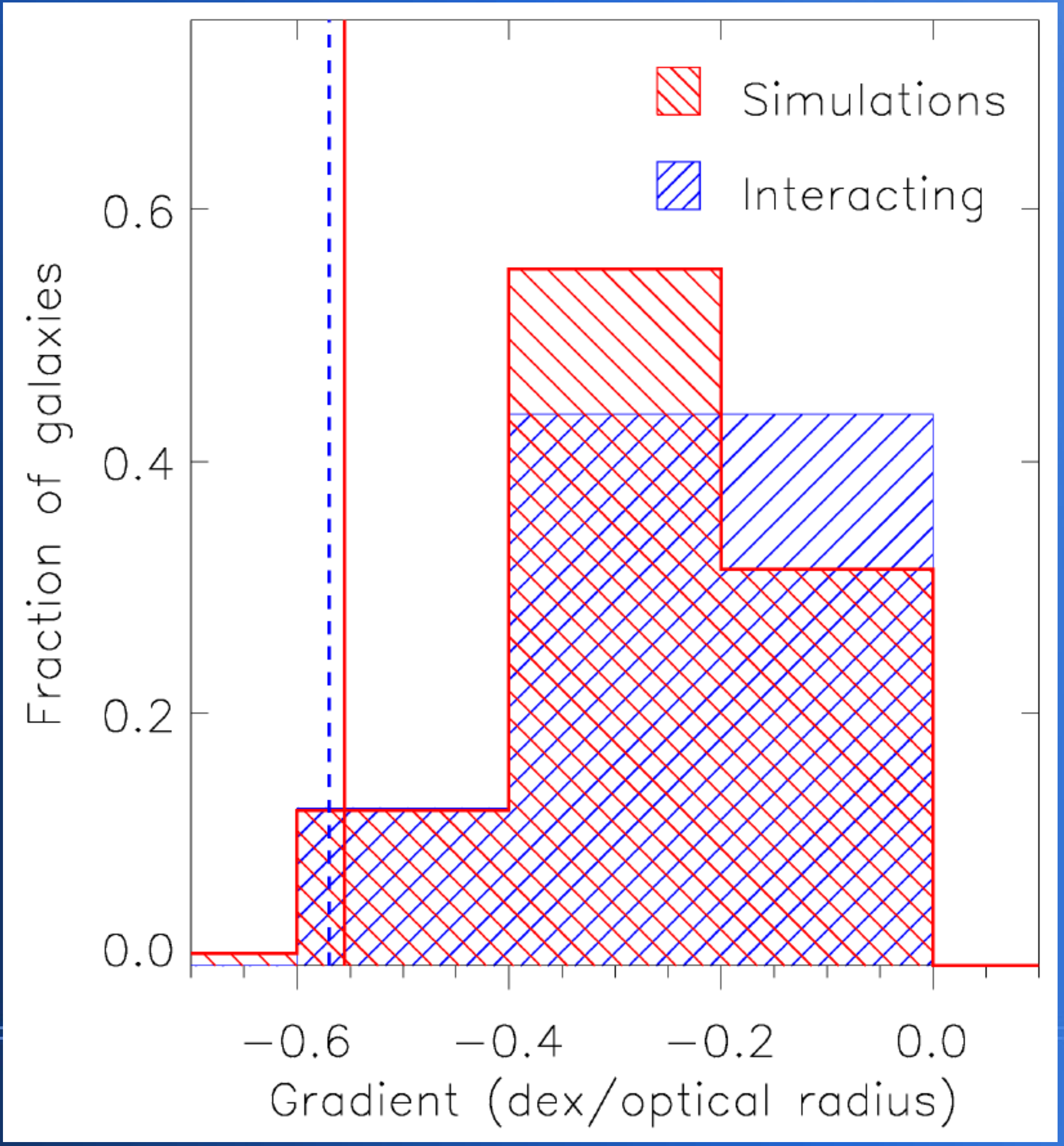


Simulated vs. Observed Gradients

Outstanding agreement!

Implication:

- Gradients not sensitive to ongoing SF (distributed and/or shock-induced SF? *Barnes 02)*
- Ongoing SF consumes small % of gas prior to second pericenter

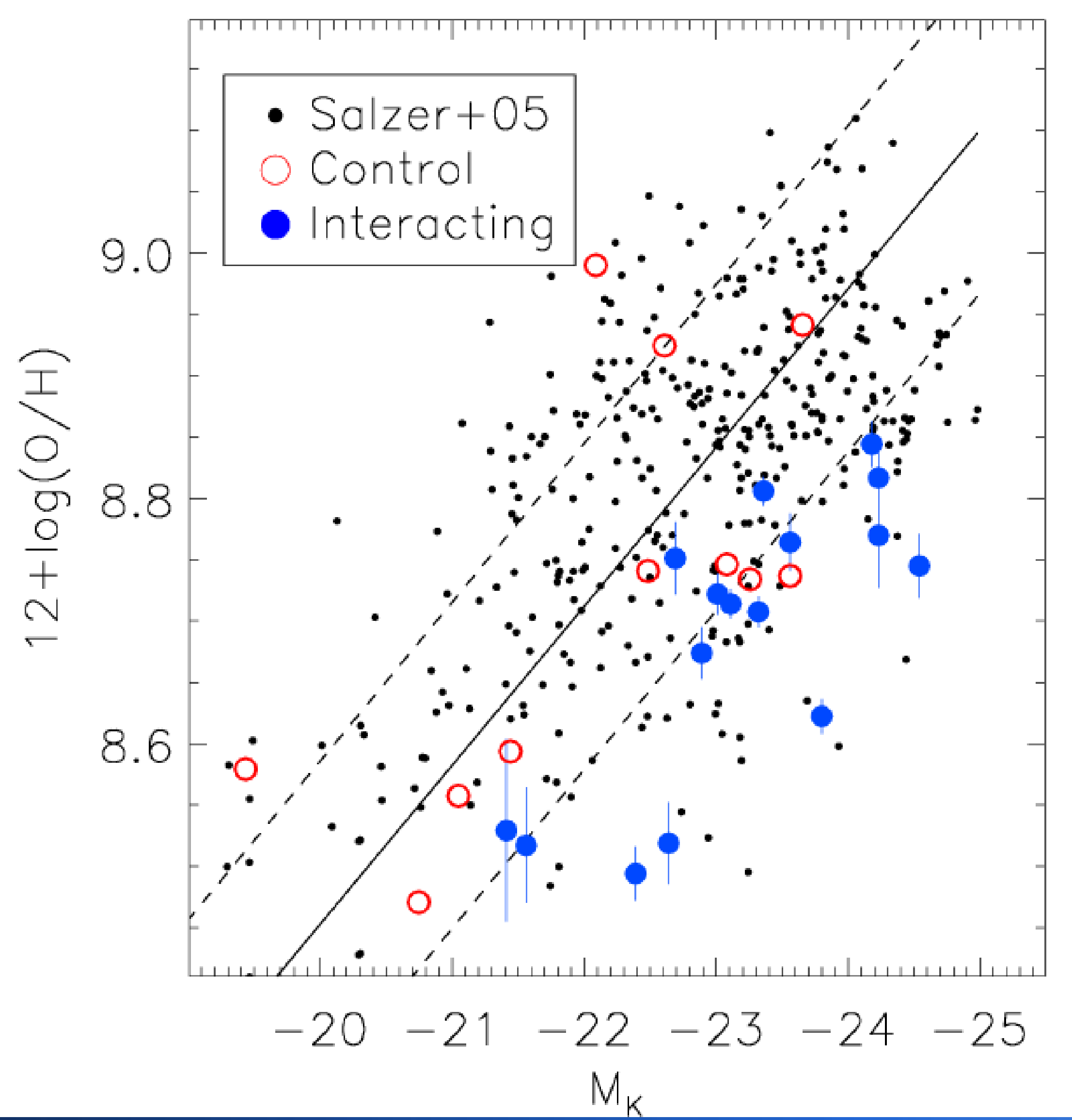


Comparison to L-Z relation

- Near-IR L-Z relation
  (Salzer+05)

- Nuclear Z (control)
  >
  Nuclear Z (interacting)

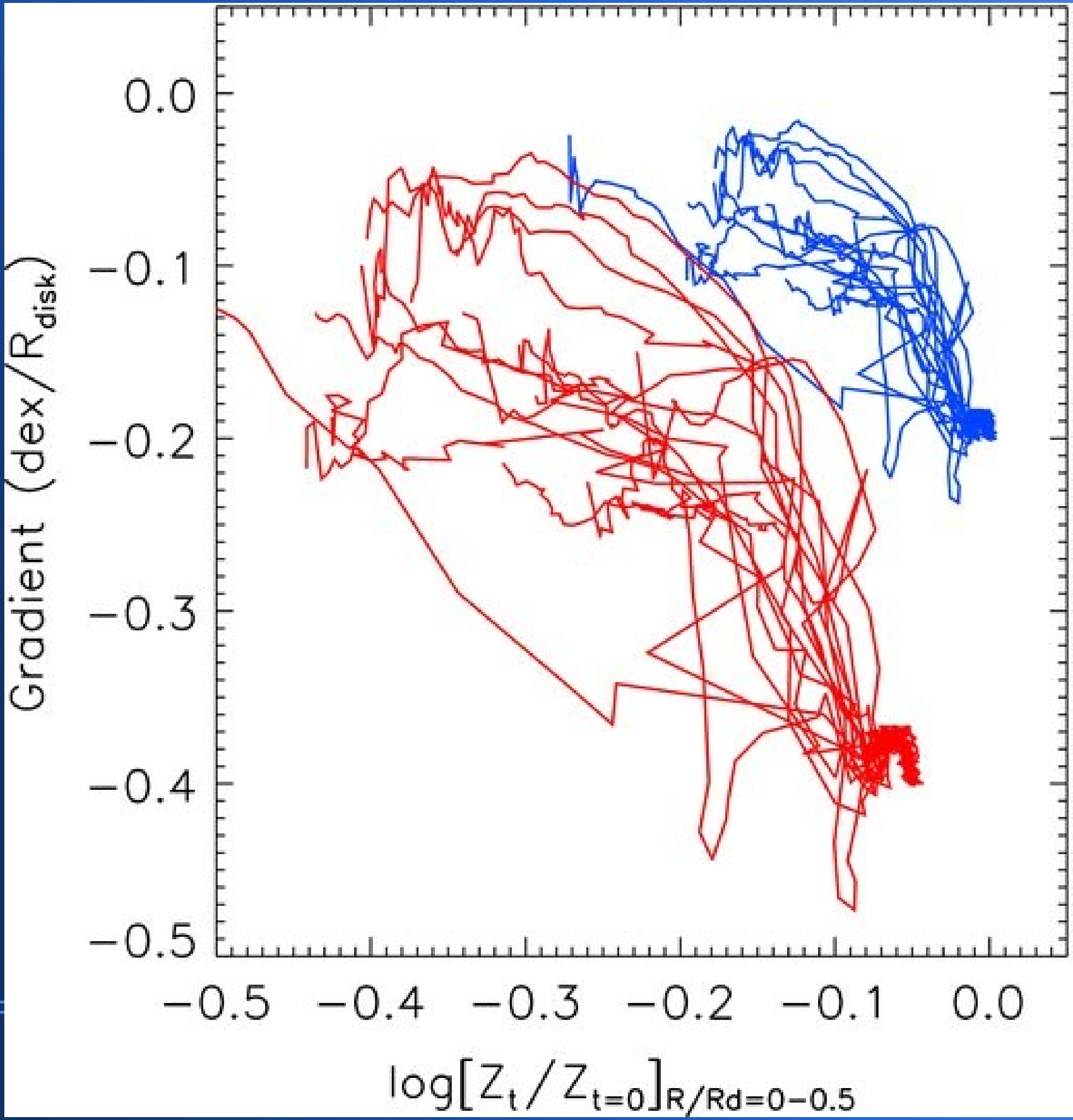
  at a given M_K



Gradients vs. L-Z offset

Simulations predict:
(Rupke+10)

- Gradient changes first
- Nuclear Z changes more slowly

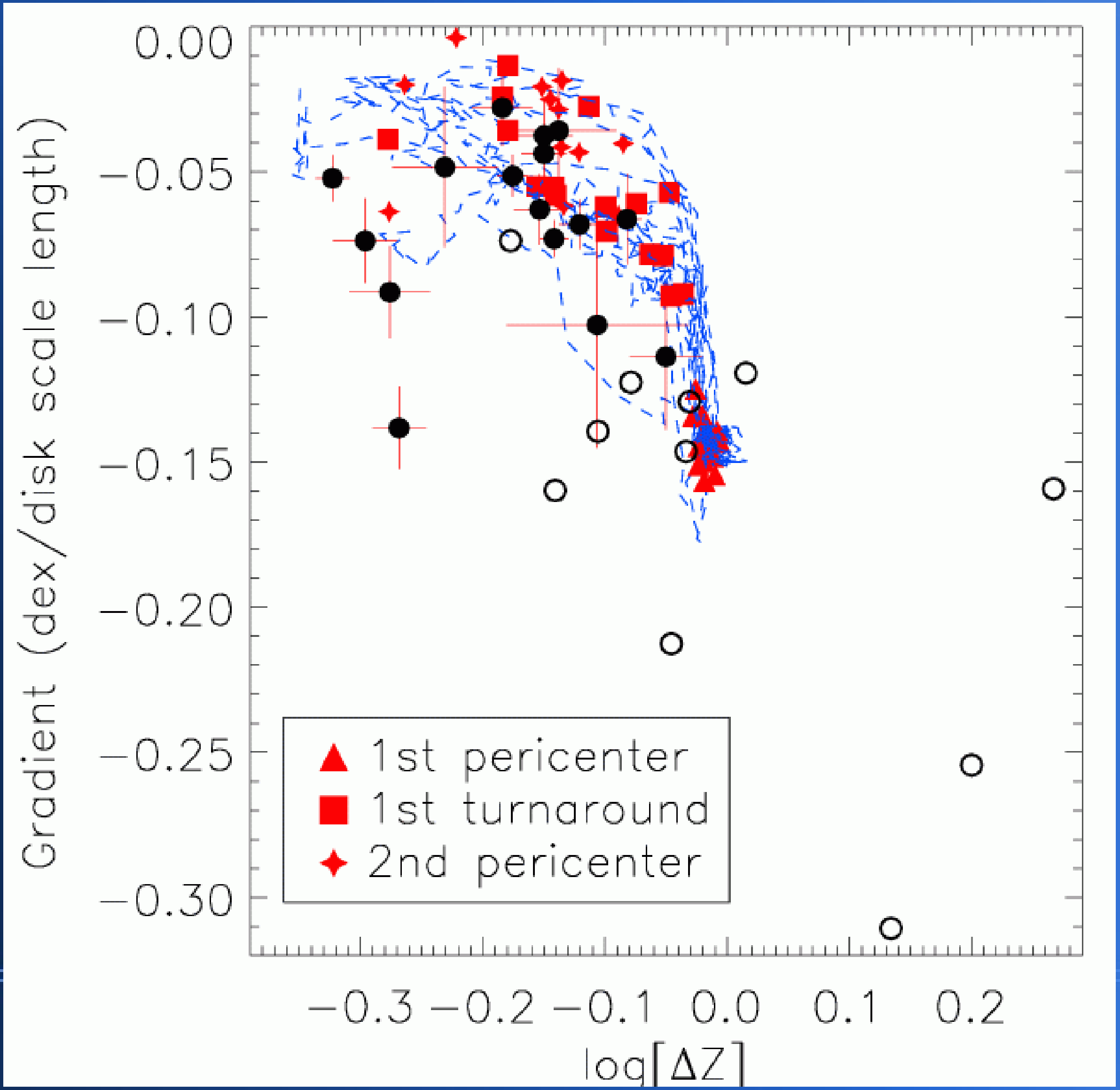


Gradients vs. L-Z offset

Simulations predict:
(Rupke+10)

- Gradient changes first
- Nuclear Z changes more slowly

Data agrees!



Gradients vs. L-Z offset

Simulations predict:
(Rupke+10)

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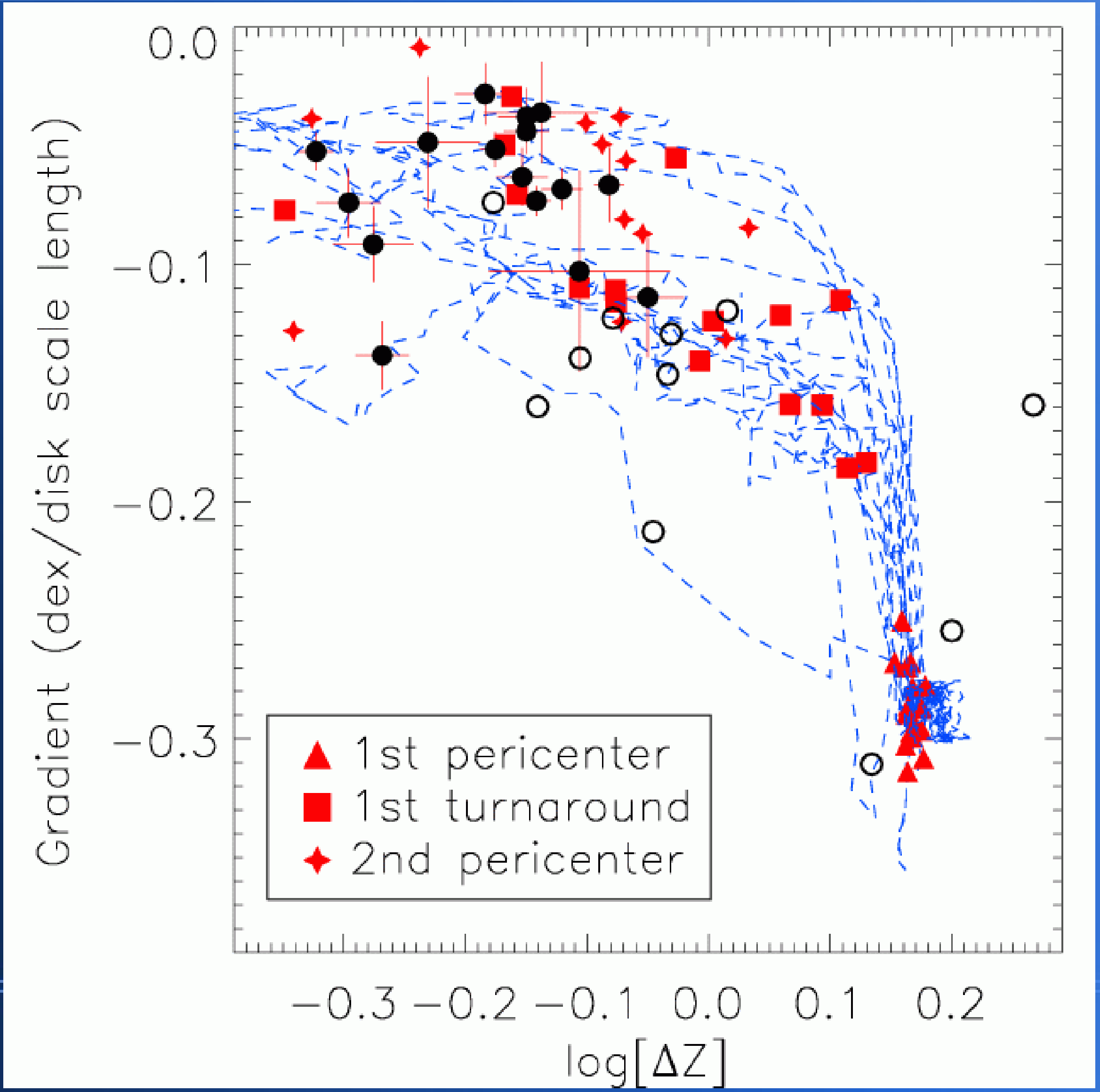
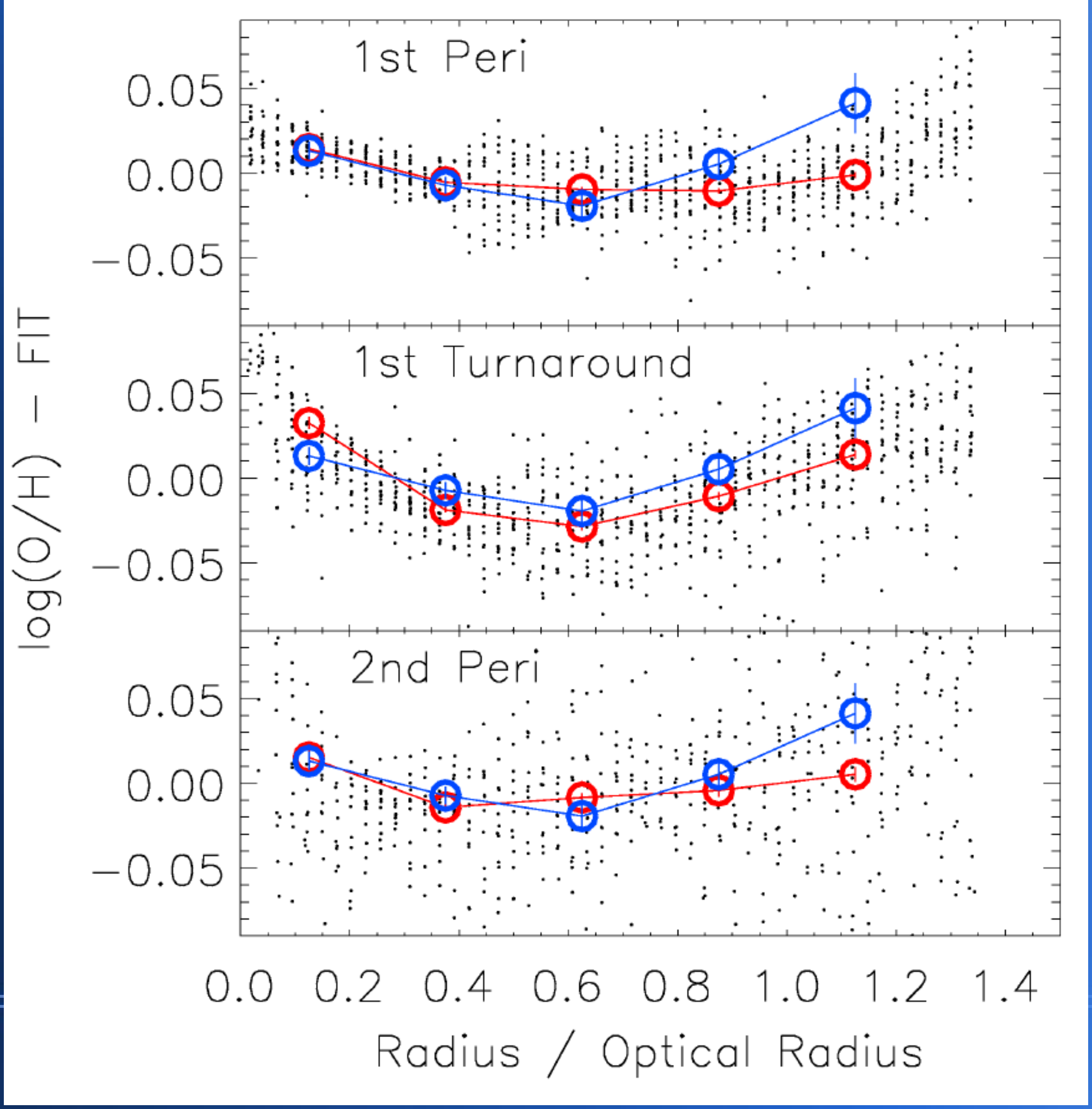


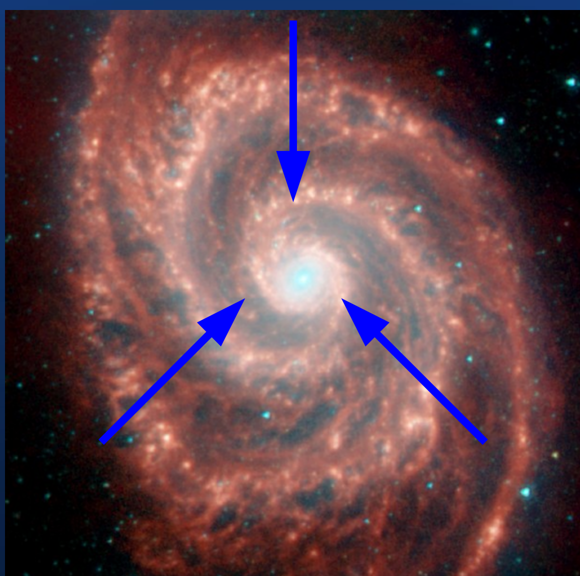
Simulated vs. Observed Gradients

Data matches shape of simulated profiles near first turnaround



Gas Flows in Major Mergers

1 INFLOW



STAR FORMATION

2 OUTFLOW

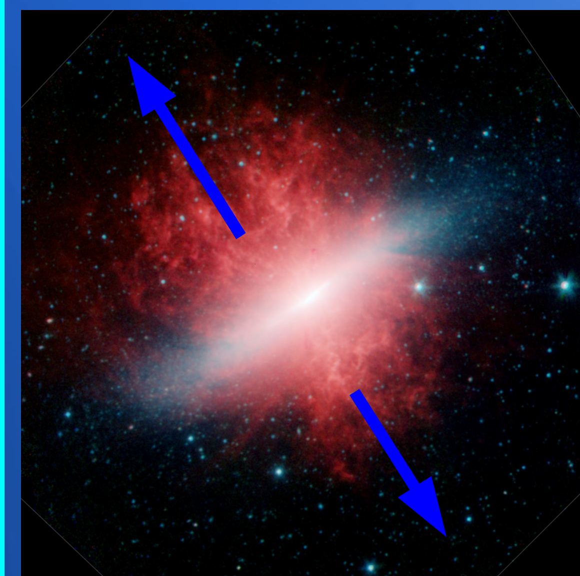
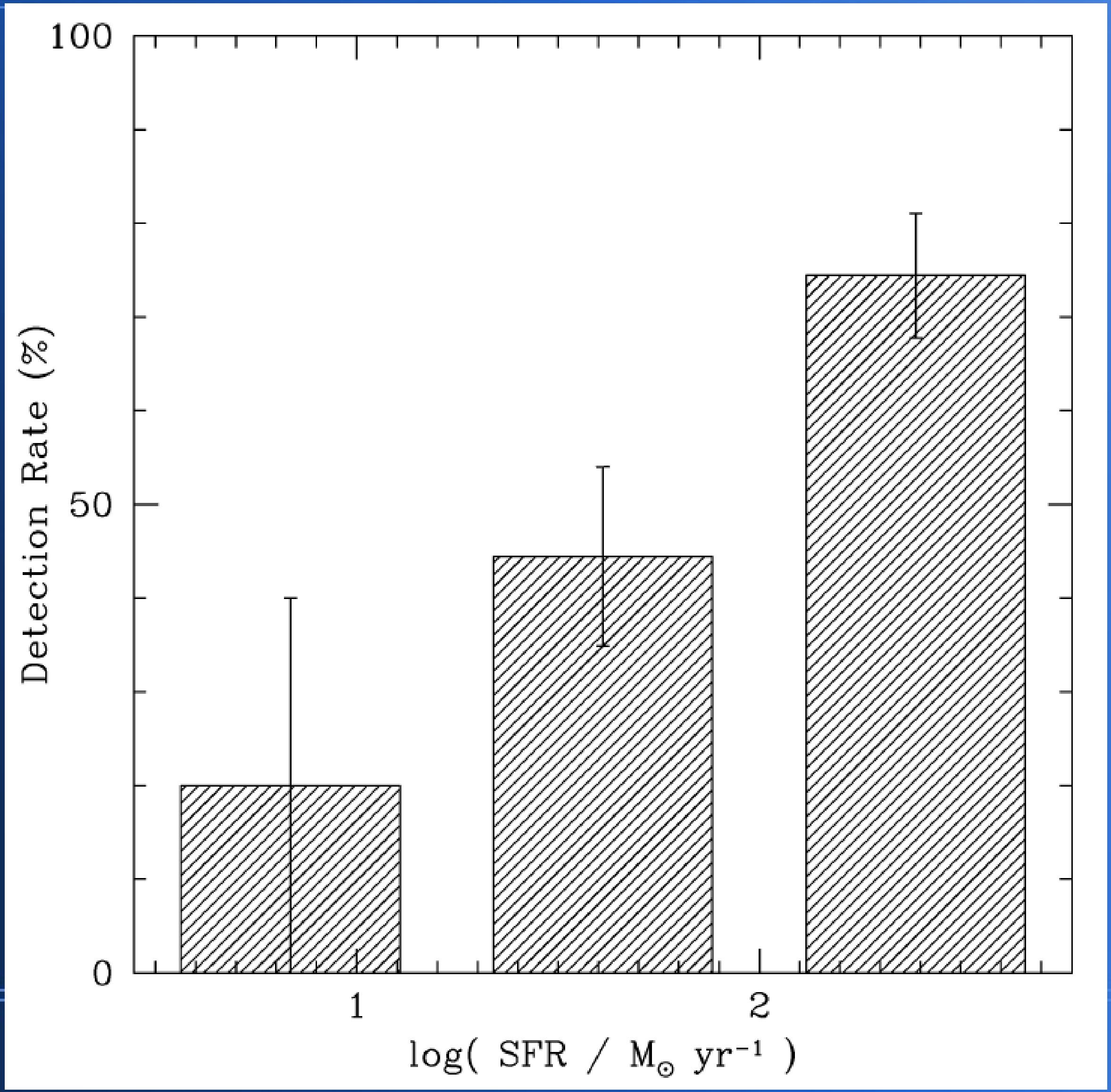


Image credits: Spitzer Science Center / STScI / Engelbracht+06

Outflow Frequency and Morphology

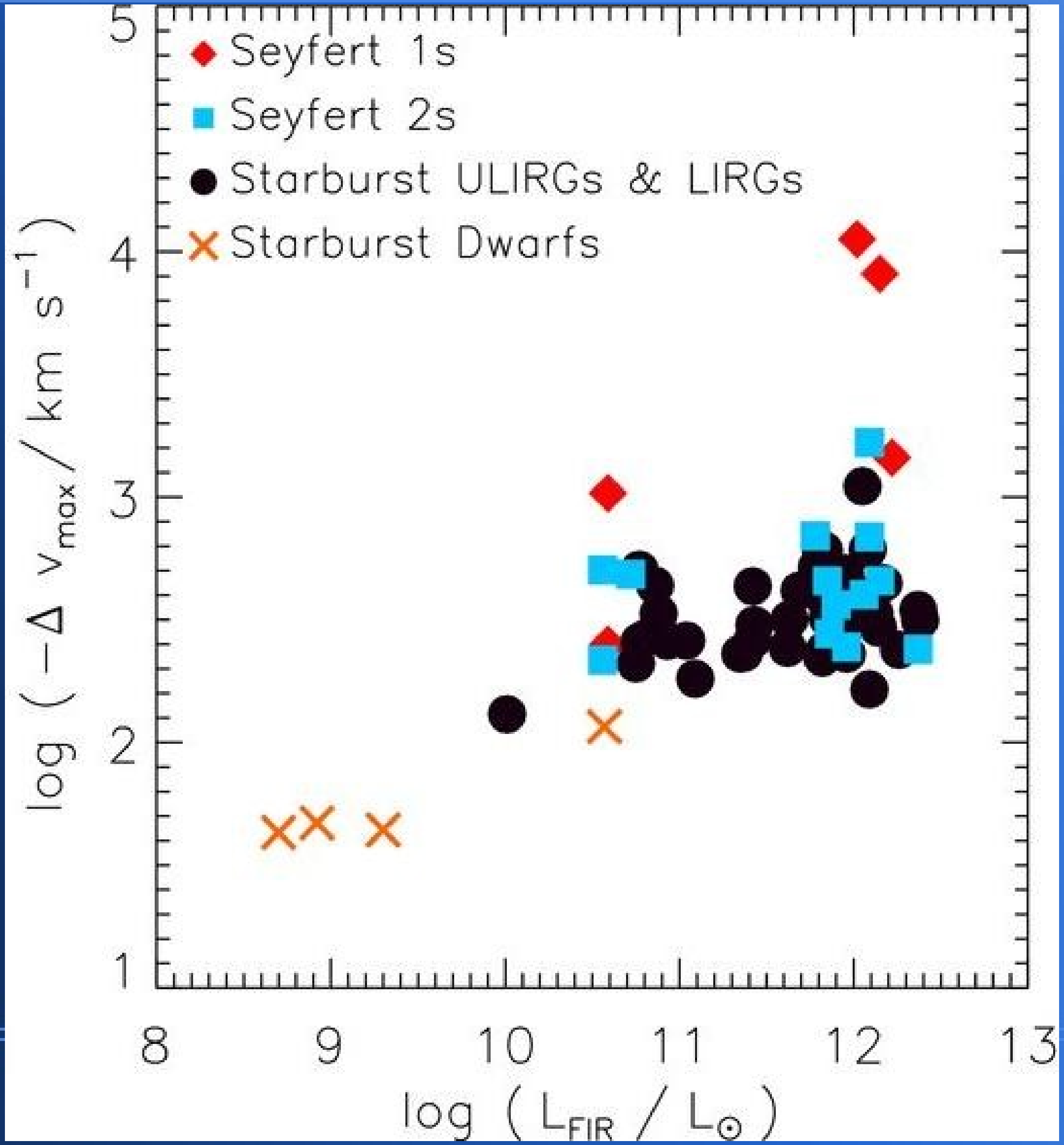
- Winds are found in *all* starburst mergers
- Differences in detection rate with SFR related to morphology



Rupke+05b (also Martin 05)

Starburst vs. AGN Winds

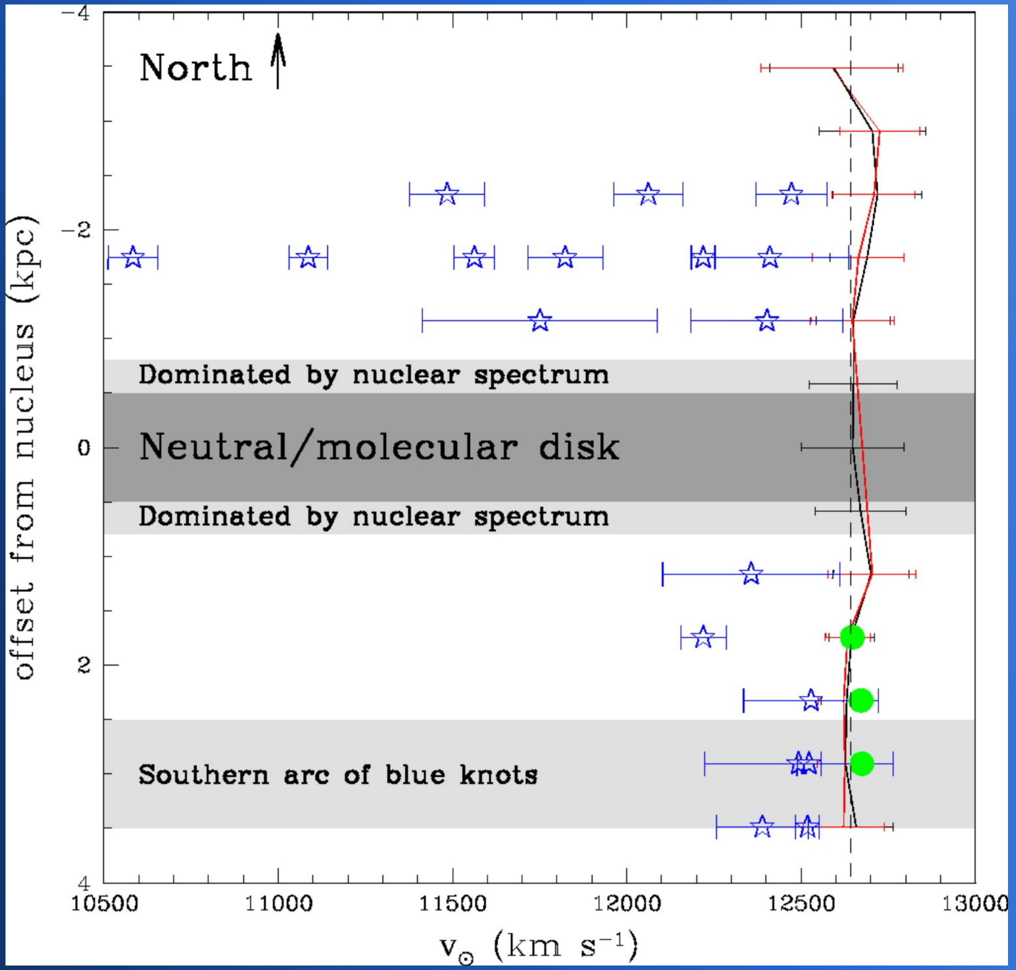
- Large scale winds have similar properties in SB and AGN (U)LIRGs
- Seyfert 1s have high velocity winds, probably at small scales



Rupke+05c, Krug+10 (also Martin+05)

Starburst vs. AGN Winds

- Large scale winds have similar properties in SB and AGN (U)LIRGs
- Seyfert 1s have high velocity winds, probably at small scales
- Exception: Mrk 231 (see also Fischer talk!)



Rupke+05c

3D Observations of ULIRG Winds

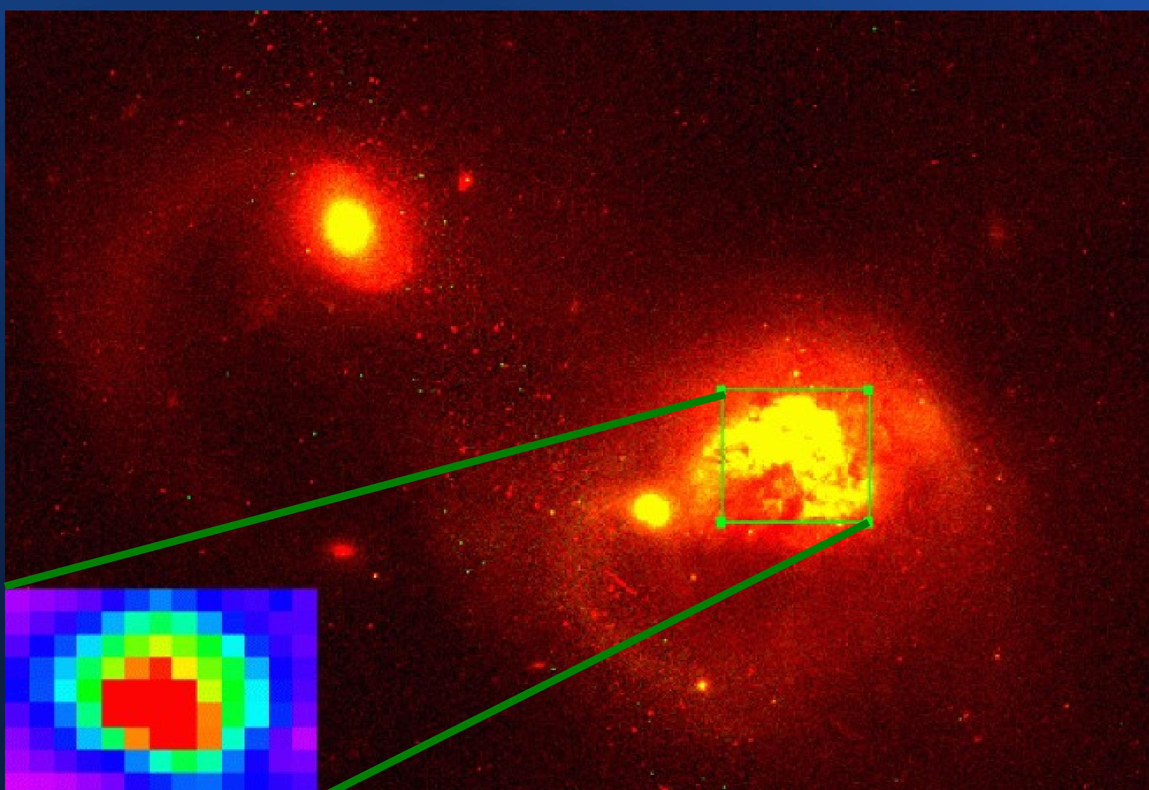
Goals

- Understand change in structure with SFR
- Search for differences btwn. SB and AGN winds

Methods

- Deep obs. of ULIRGs with known winds
- Neutral gas absorption + ionized gas emission

3D Observations of ULIRG Winds

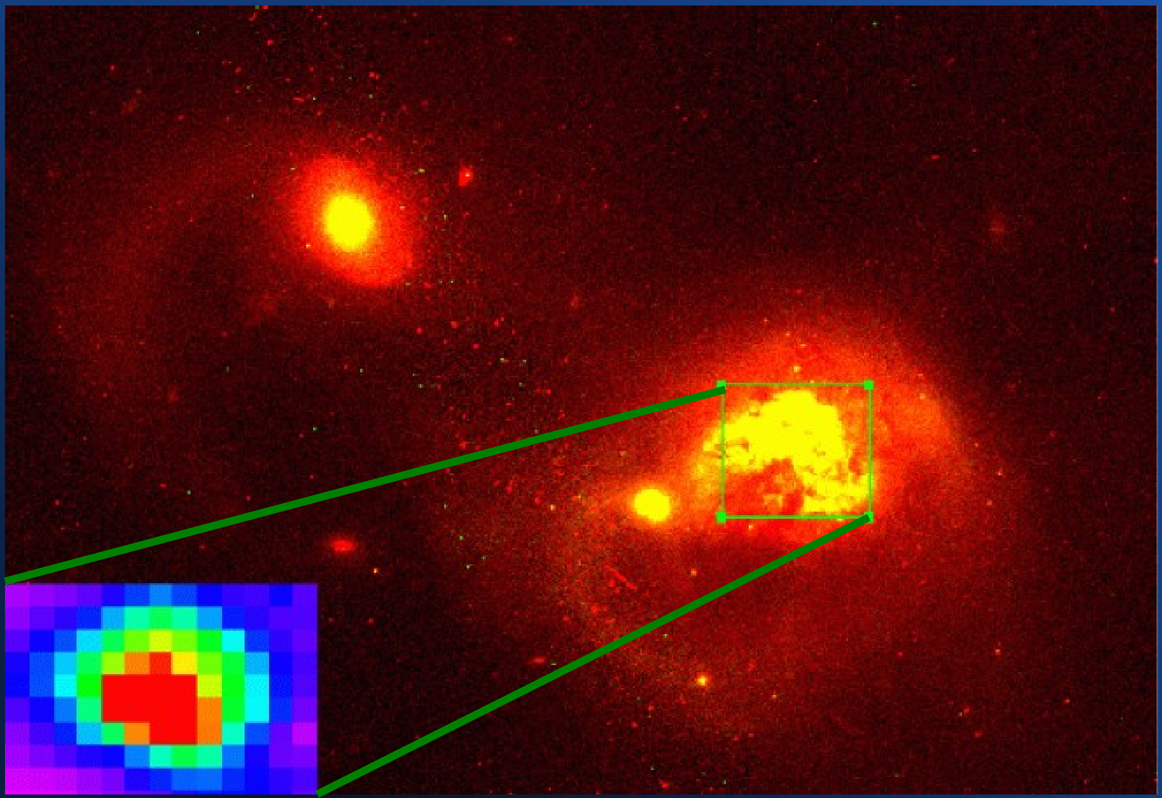


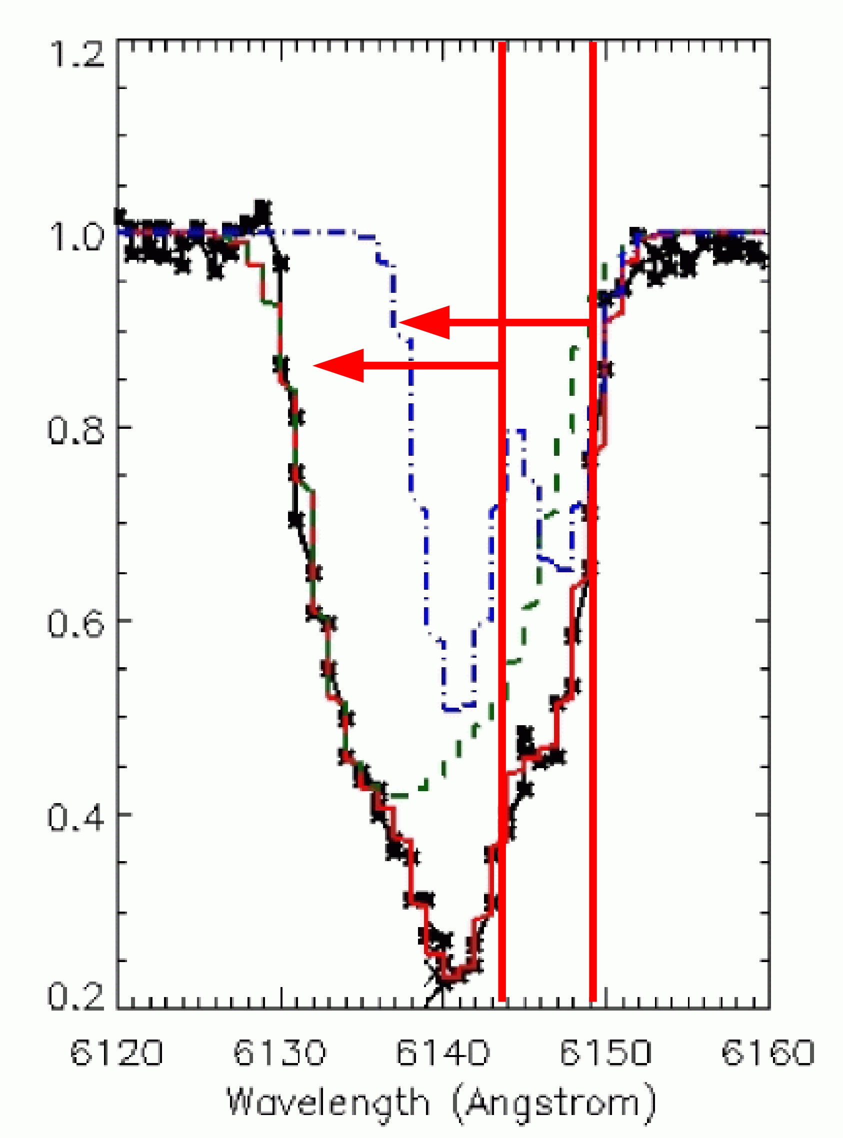
F10565+2448

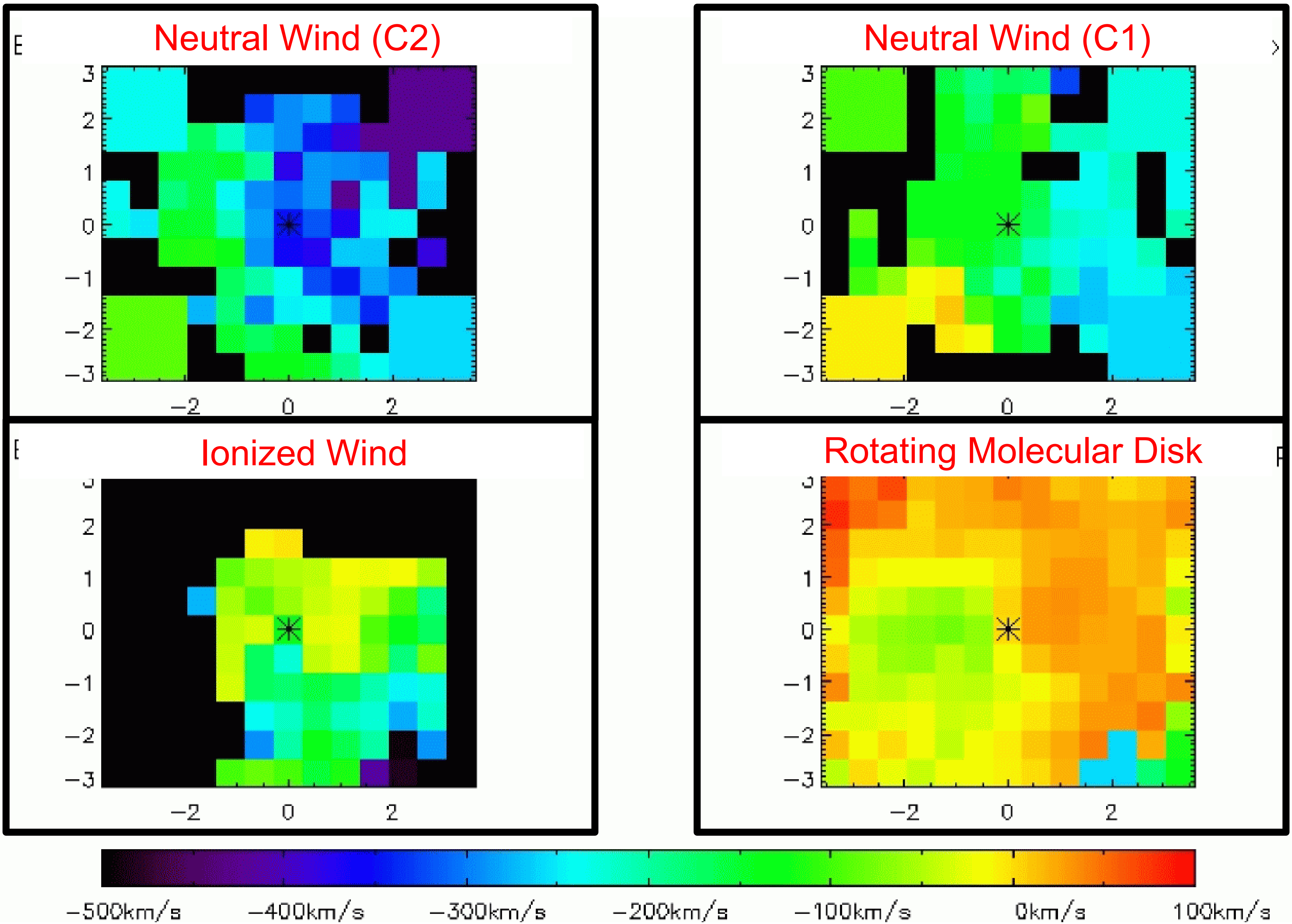
- z = 0.043
- GMOS IFU

Shih & Rupke 2010, submitted

3D Observations of ULIRG Winds



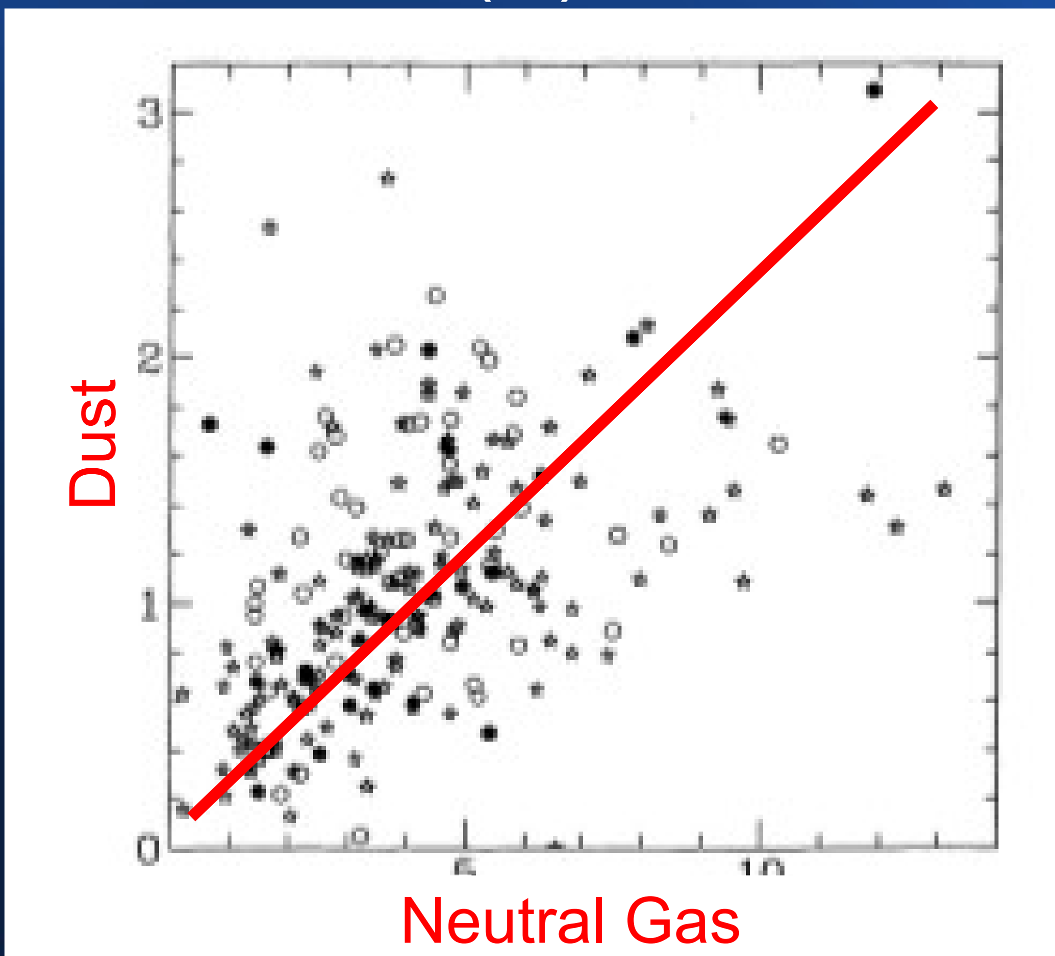




Neutral Wind (C2)
Neutral Wind (C1)
Ionized Wind
Rotating Molecular Disk
−500km/s
−400km/s
−300km/s
−200km/s
−100km/s
0km/s
100km/s

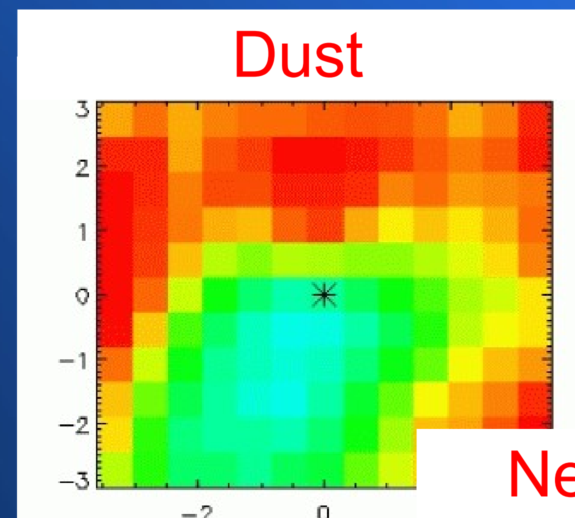
The Multiphase Wind

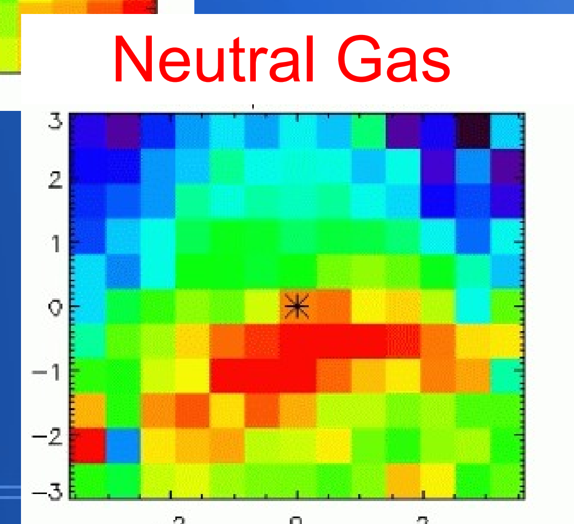
Unresolved (U)LIRG Nuclei



Veilleux+95

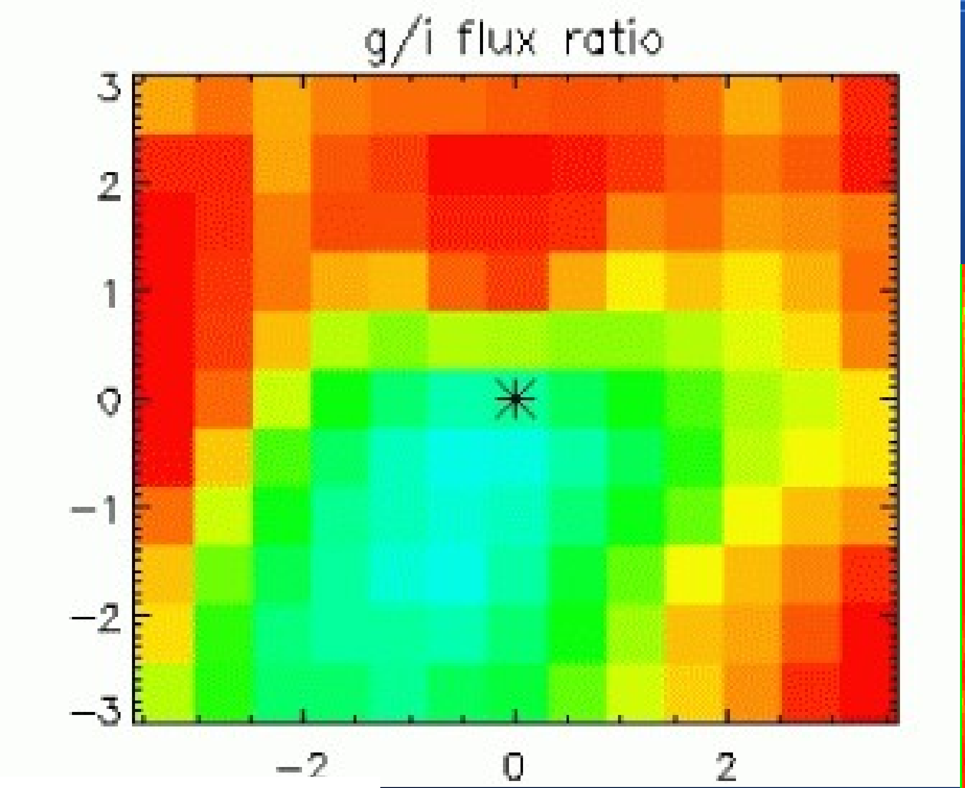
Resolved ULIRG Nucleus





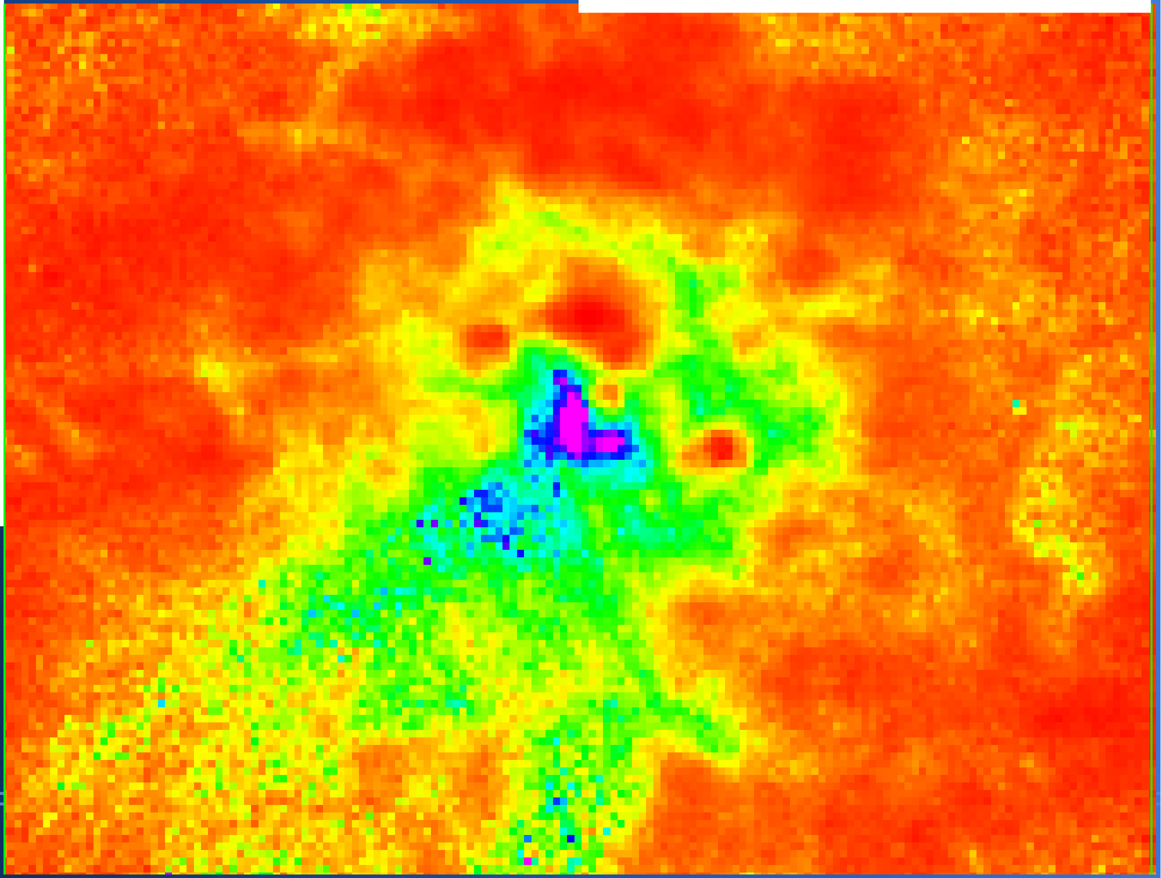
Shih & Rupke 2010

Blowing Out the Dust Screen? SF Feedback

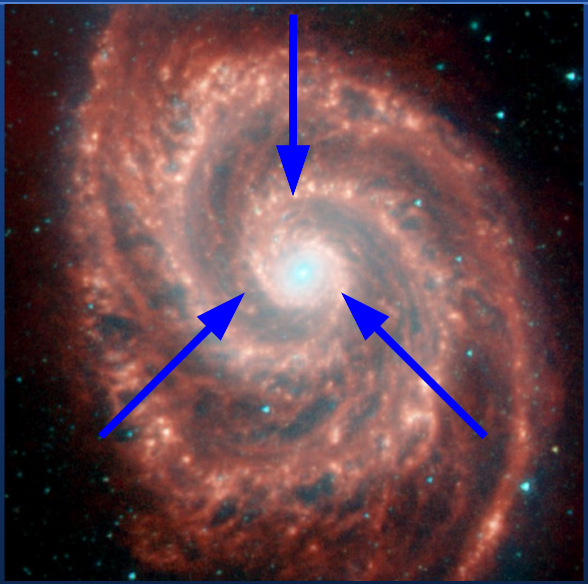


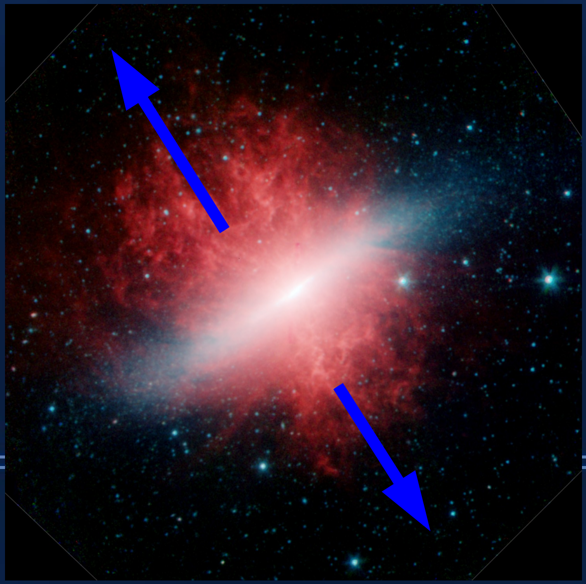
SDSS g - i

HST 435W-814W



New Constraints on Inflows and Outflows in Major Mergers





Inflows

- Flatten gradients
- Gradients flatten quickly, Z offset comes later

Outflows

- Change with SFR
- AGN contribution?
- Blow out dust screen? SF feedback?