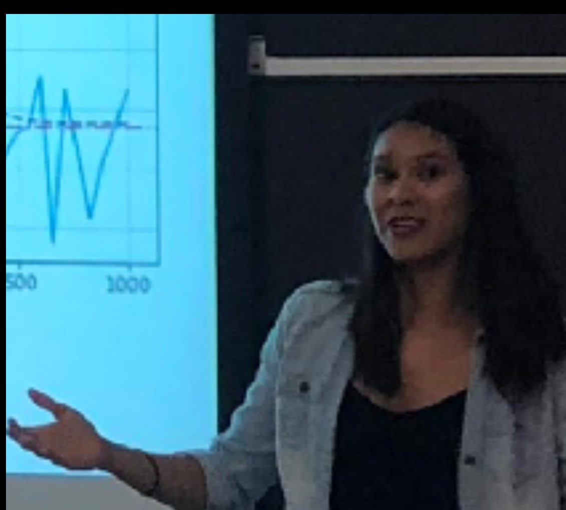
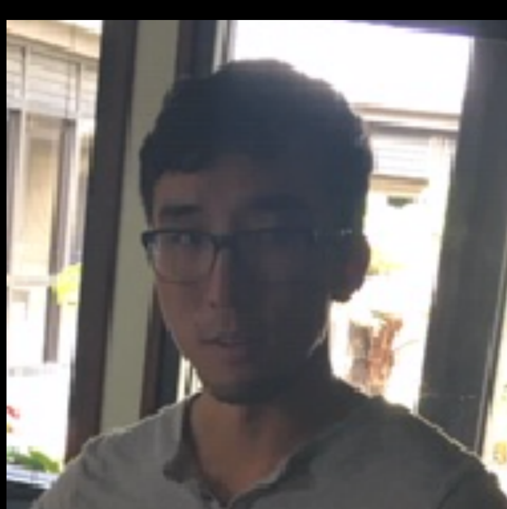
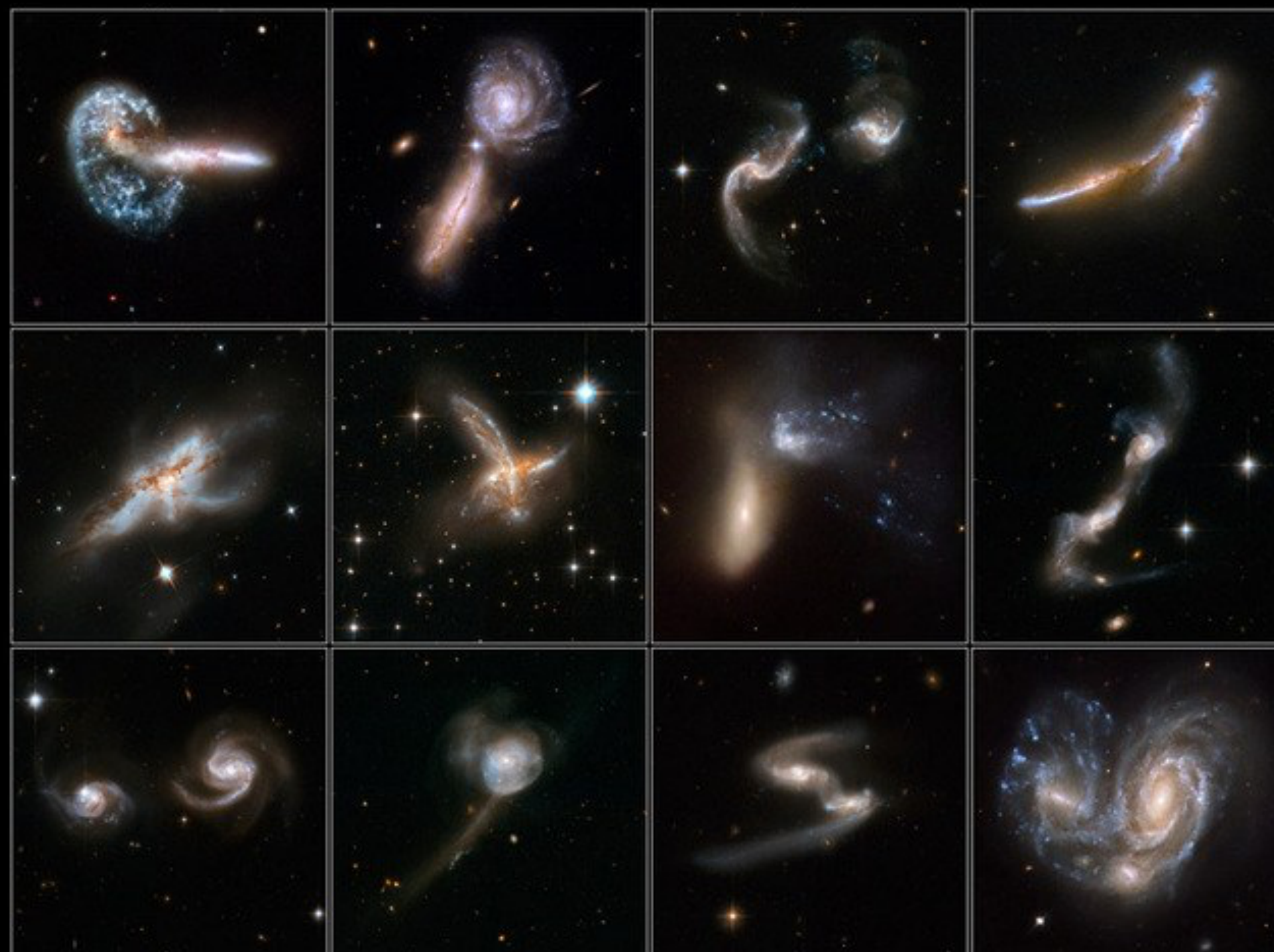
Dancing Galaxies

Andreea Petric - UH Resident Astronomer at CFHT - MSE Deputy Project Scientist

Barbara Mazzilli-Ciraulo (Sorbonne Université, LERMA, Observatoire de Paris)
Simon Prunet, Laurie Rousseau-Nepton, Nicolas Flagey, Kanoa Whittington (CFHT)
Lauren Drissen, Carmelle Robert (Universite de Laval)
Gabriella Sanchez, Nicholas Takamatsu (University of Hawaii)

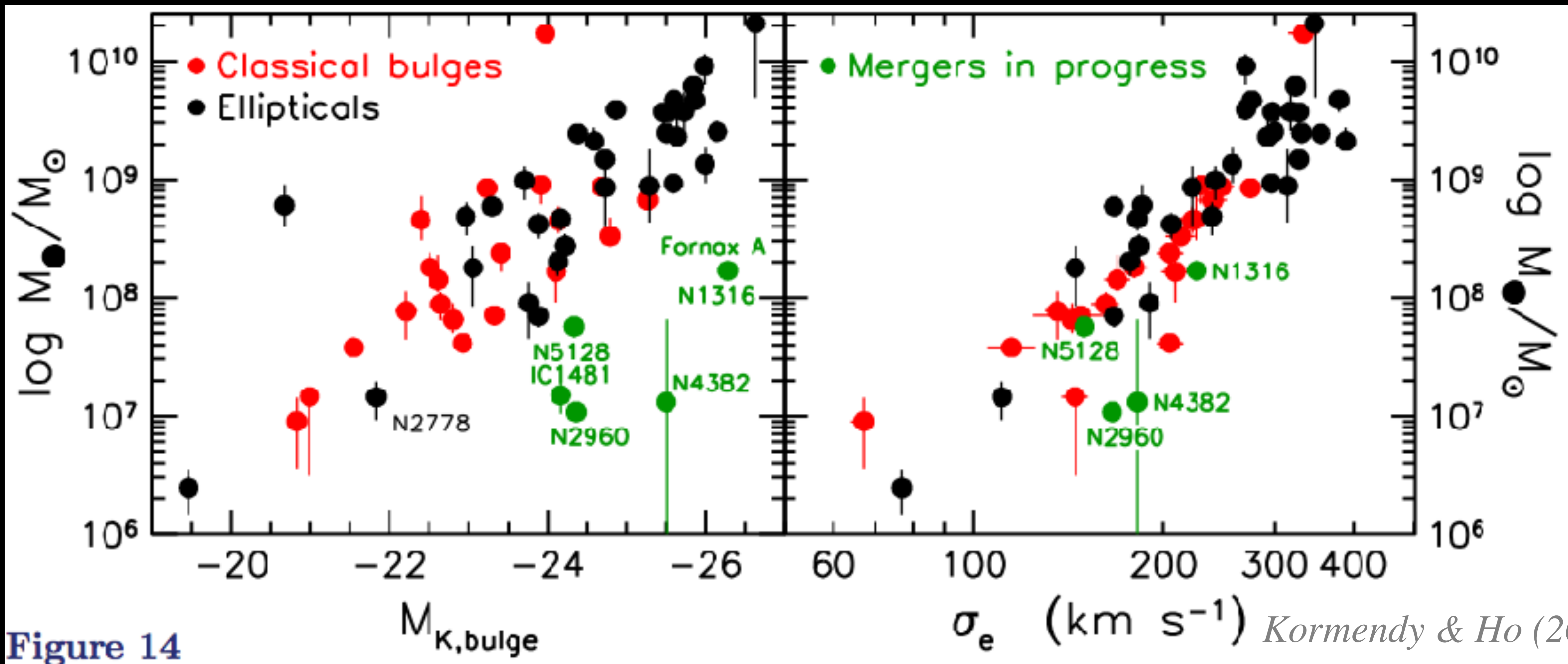






Optical images of Merging Luminous IR Galaxies

Correlations and Co-evolution



Kormendy & Ho (2013)

- A central issue in the study of the formation and evolution of galaxies is the connection between the central supermassive black hole (SMBH) and the surrounding bulge stars.
- Mergers feed central SMBH.
- When and how much do AGN impact the interstellar medium (ISM) of its host galaxy? e.g. through large scale outflows that lower star-formation rates

Dancing Galaxies trigger AGN and AGN affect star-formation

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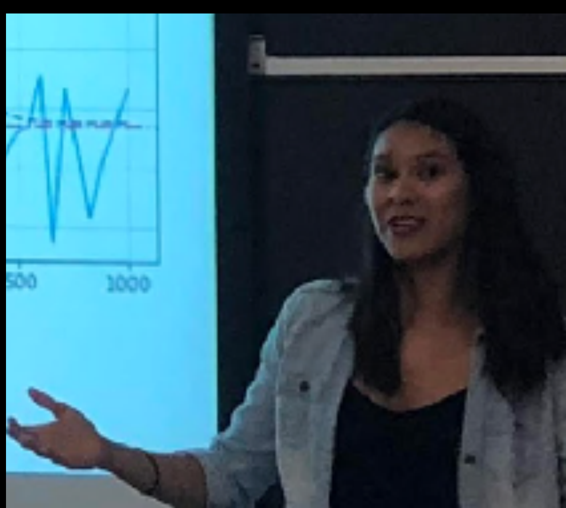
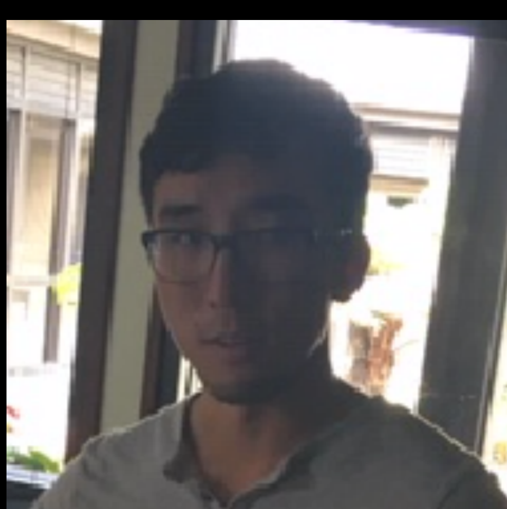
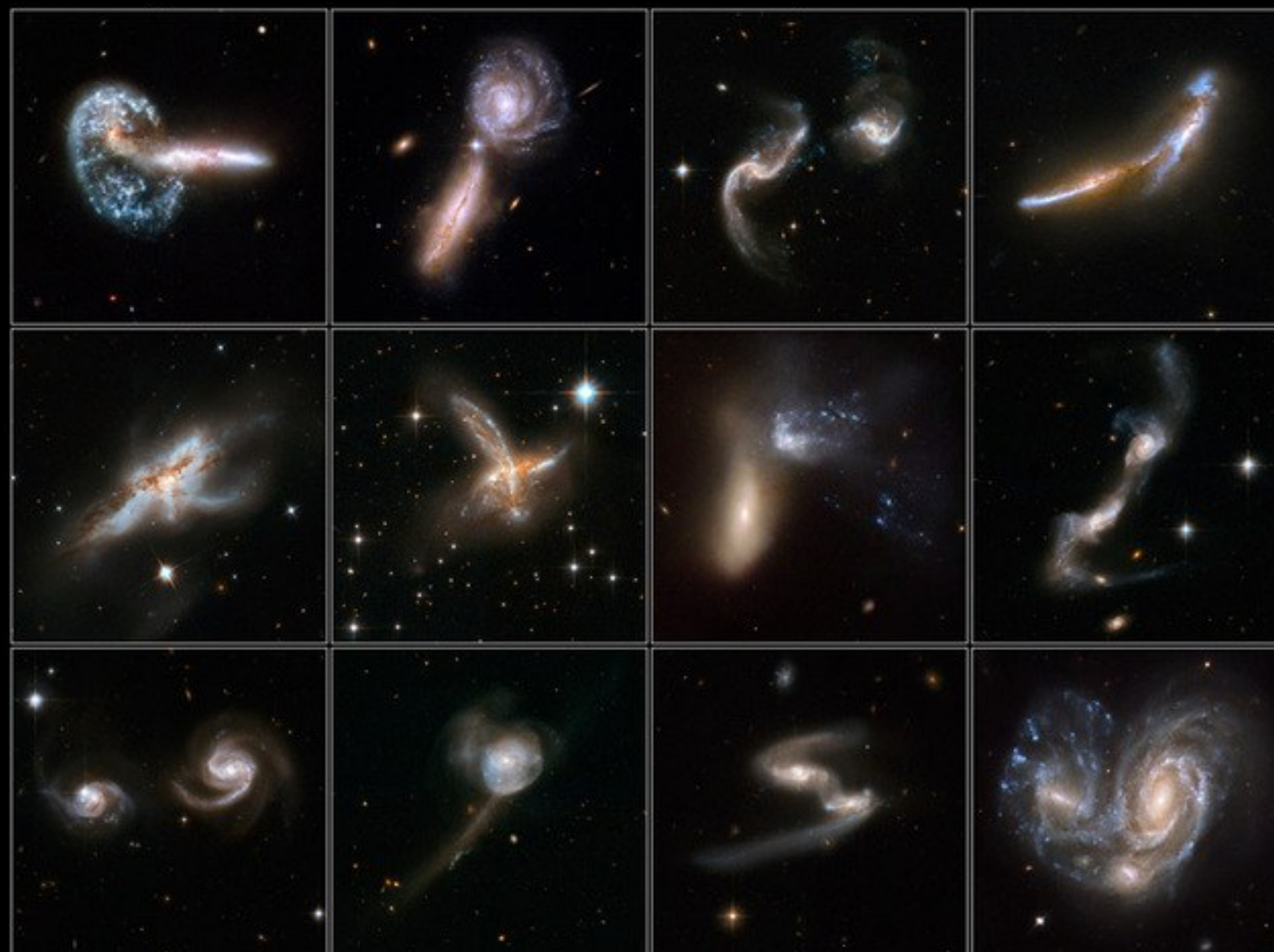






Optical images of Merging Luminous IR Galaxies

But How?


Today

A brief stop to talk about some of the ISM components

- **Molecular Medium** (MM): dense molecular clouds, mostly gravitationally bound. On average, this phase contains as much mass as the atomic hydrogen, but occupies only a very small fraction of the ISM.

- **Cold Neutral Medium** (CNM; T 100 K, n 20 cm^{-3}, f 2 - 4%)

- **Warm Neutral Medium** (WNM; T 6000 K, n 0.3 cm^{-3}, f 30%)

- **Warm Ionized Medium** (WIM; T 8000 K, n 0.3 cm^{-3}, f 15%)

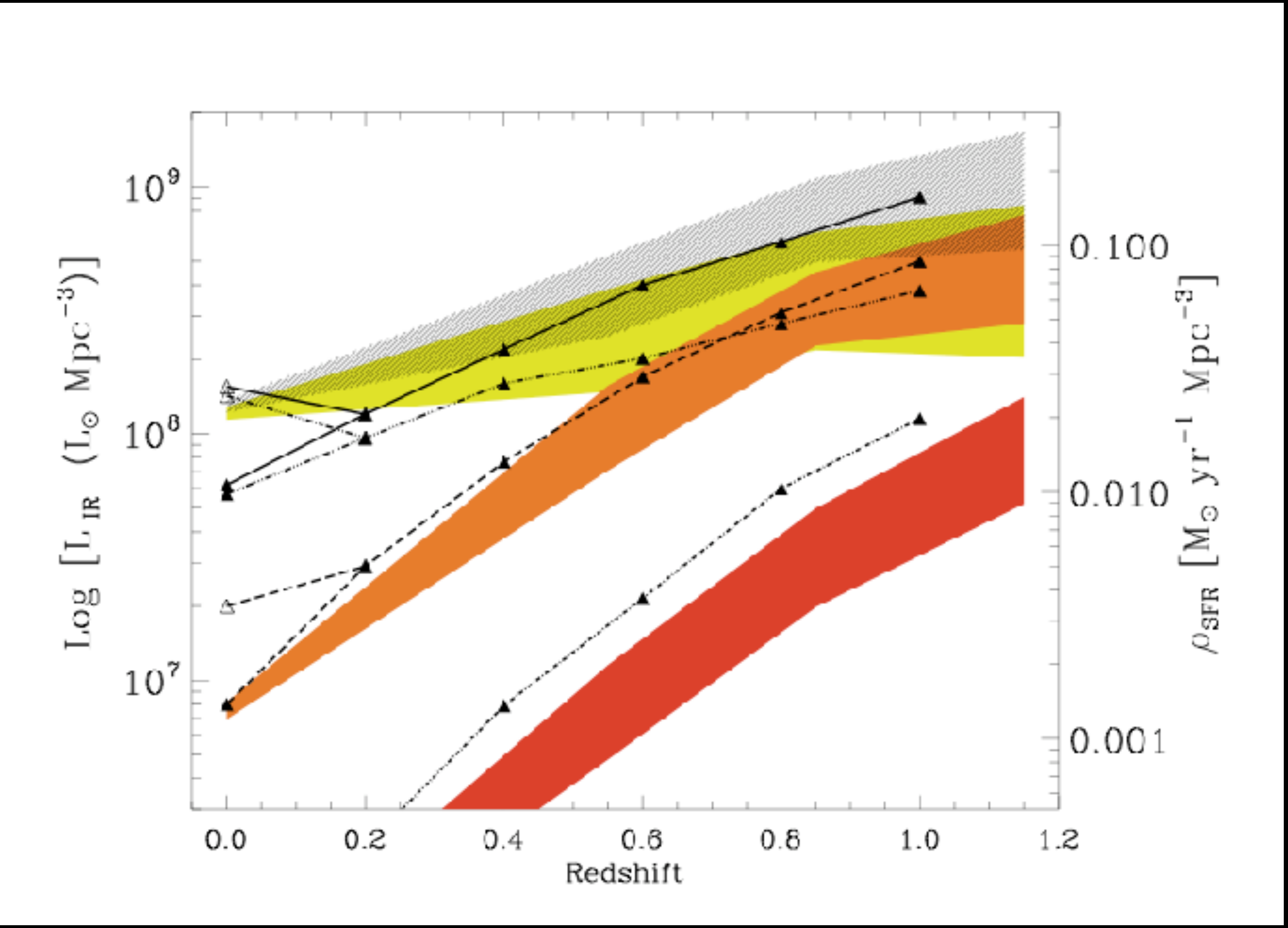
- **Hot Ionized Medium** (HIM; T 10^6 K, n 10^{-3} cm^{-3}, f 50%).

[S III]6717, Ha, [O III]5007
SITELLE @ CFHT
PI: Flagey

Music by Kanoa Withington
using this dataset

A sample of nearby luminous infrared galaxies

Importance of LIRGs – 70 microns number counts



Normal galaxies

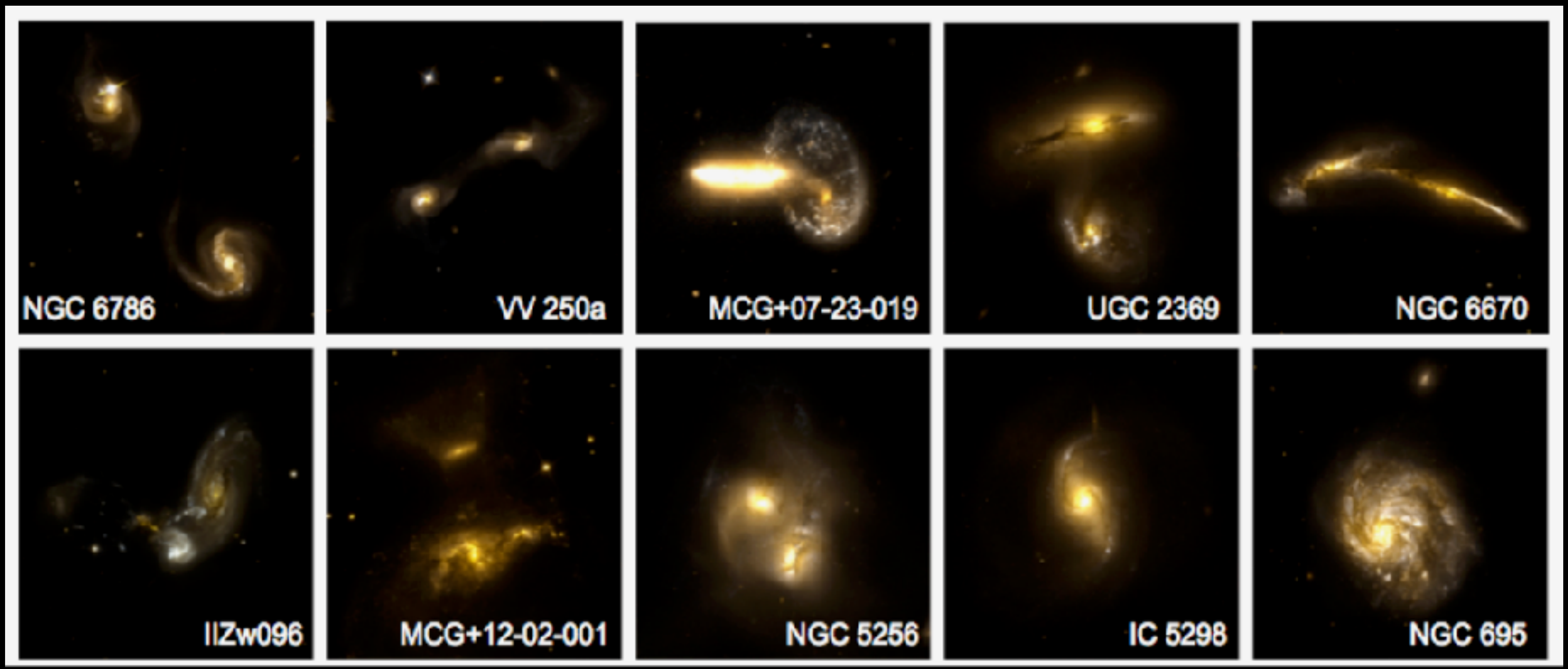
LIRGs $L_{IR} > 10^{11} L_\odot$

ULIRGs $L_{IR} > 10^{12} L_\odot$

Magnelli et al. (2009)

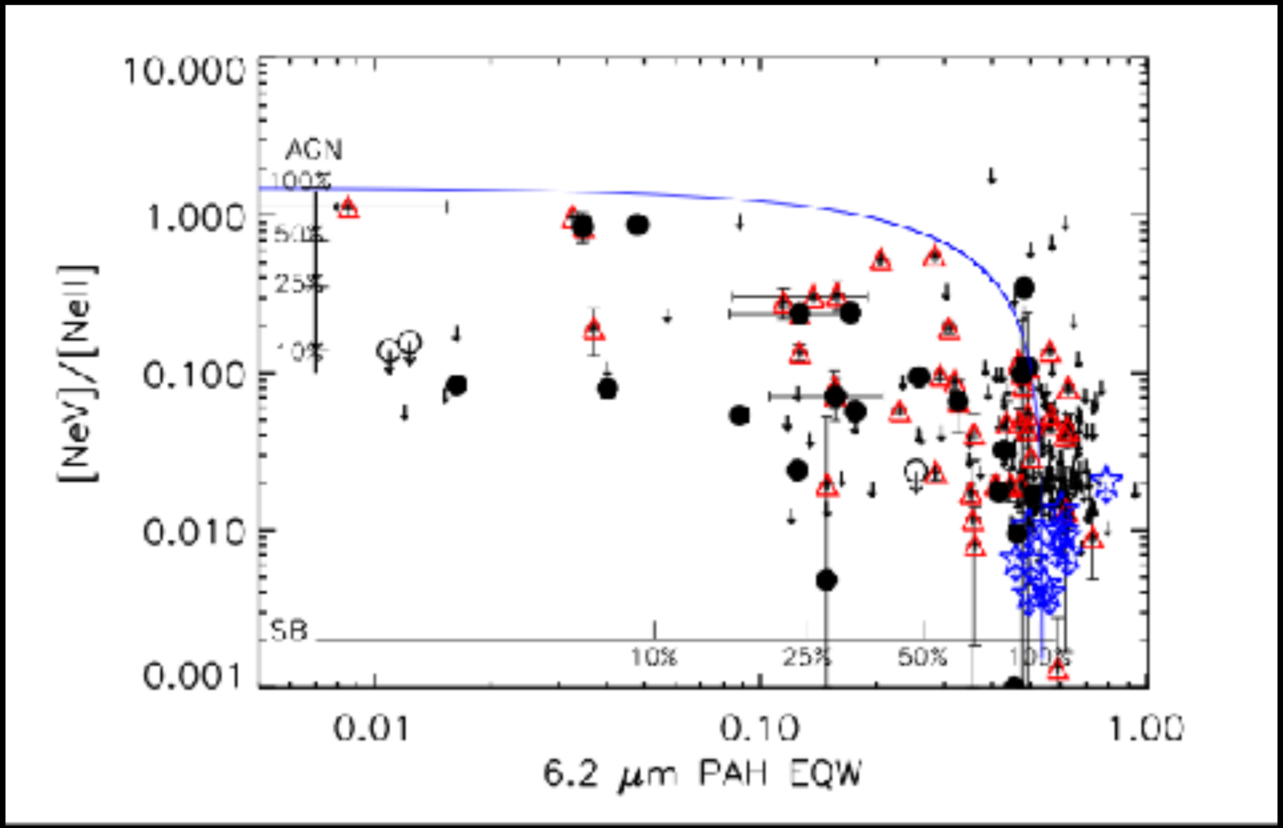
- The co-moving number density of LIRGs has increased by a factor of ~100 between 0<z<1
- By z~1.0 LIRGs produce half of the total co-moving infrared luminosity density.

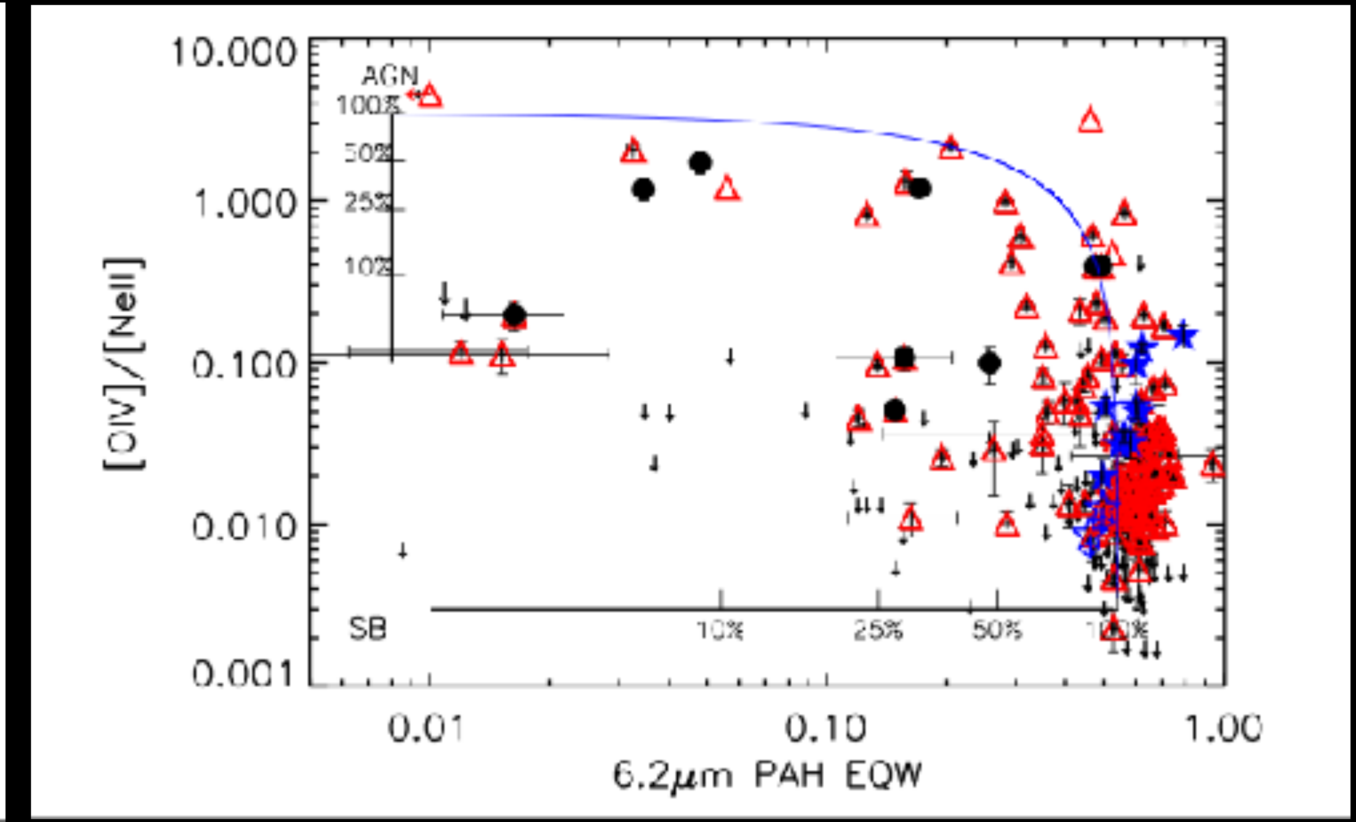
Luminous Infrared Galaxies (LIRGs) as precursors of Quasars?



Do we see a higher incidence of AGN as galaxies merge? *(Petric et al. 2011)*

Contributions of Starburst and AGN to the IR Luminosity





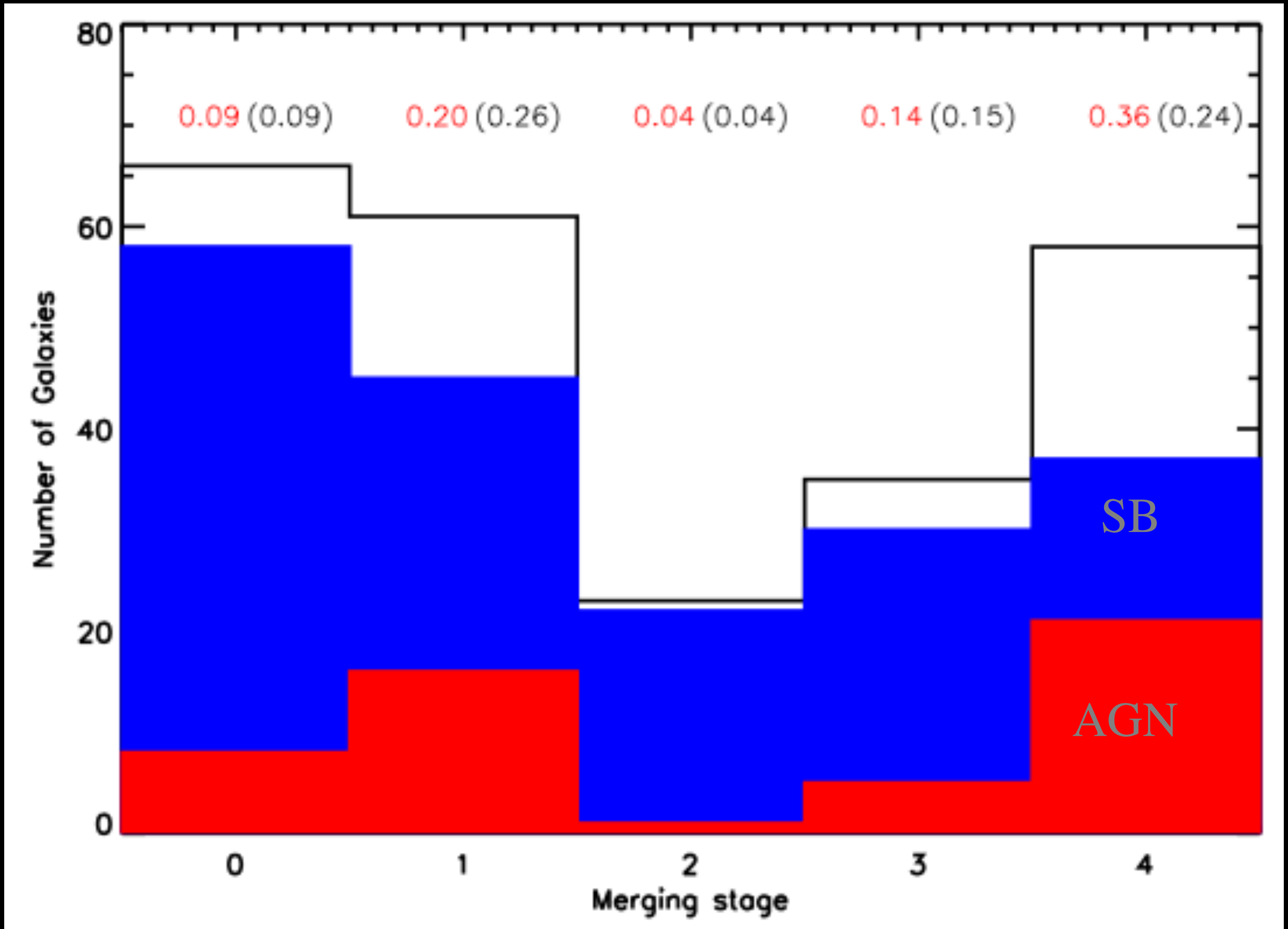
Petric & the GOALS collaboration 2011

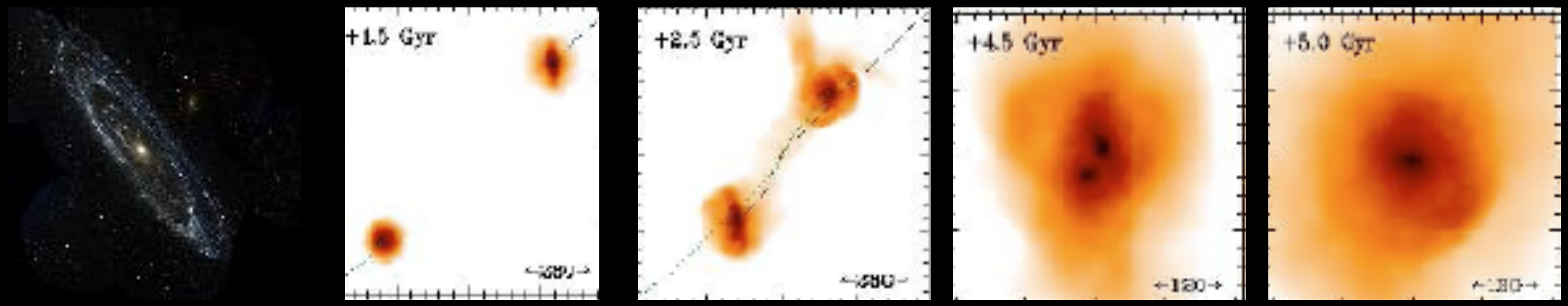
Caveat: Eight PG QSOs used to represent sources in which AGN contributes 100% of the MIR emission because they were not detected by ISO and IRAS in the FIR *(e.g. Netzer et al. 2007; Veilleux et al. 2009)*.

Some of these PG QSOs observed with Herschel turn out to have detectable cold dust. *(Petric et al. 2015)*

Contributions of Starburst and AGN to the IR Luminosity

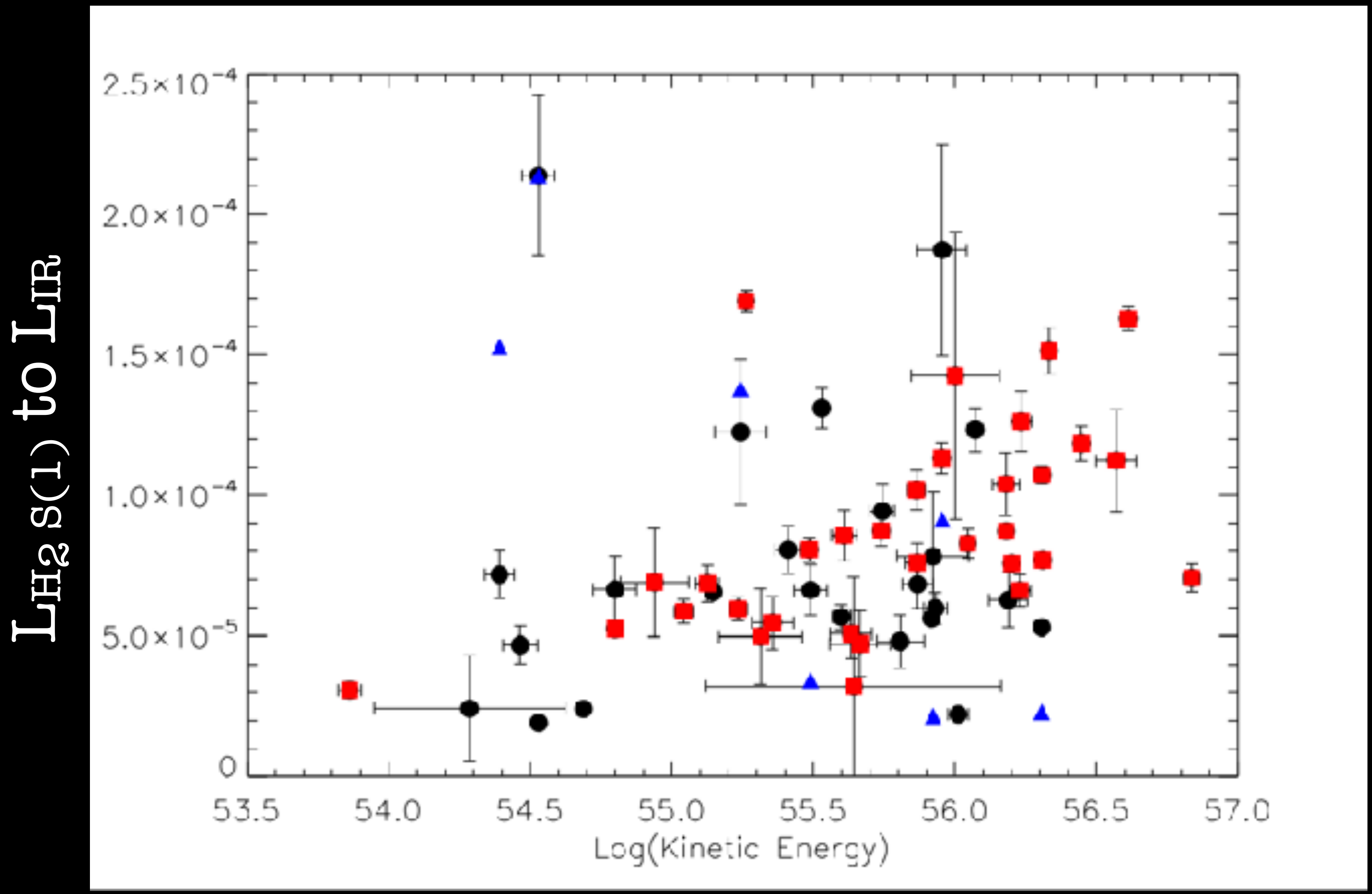
AGN fraction is higher in mergers





Petric & the GOALS collaboration 2011c

Warmer Molecular Gas in LIRGs with AGN

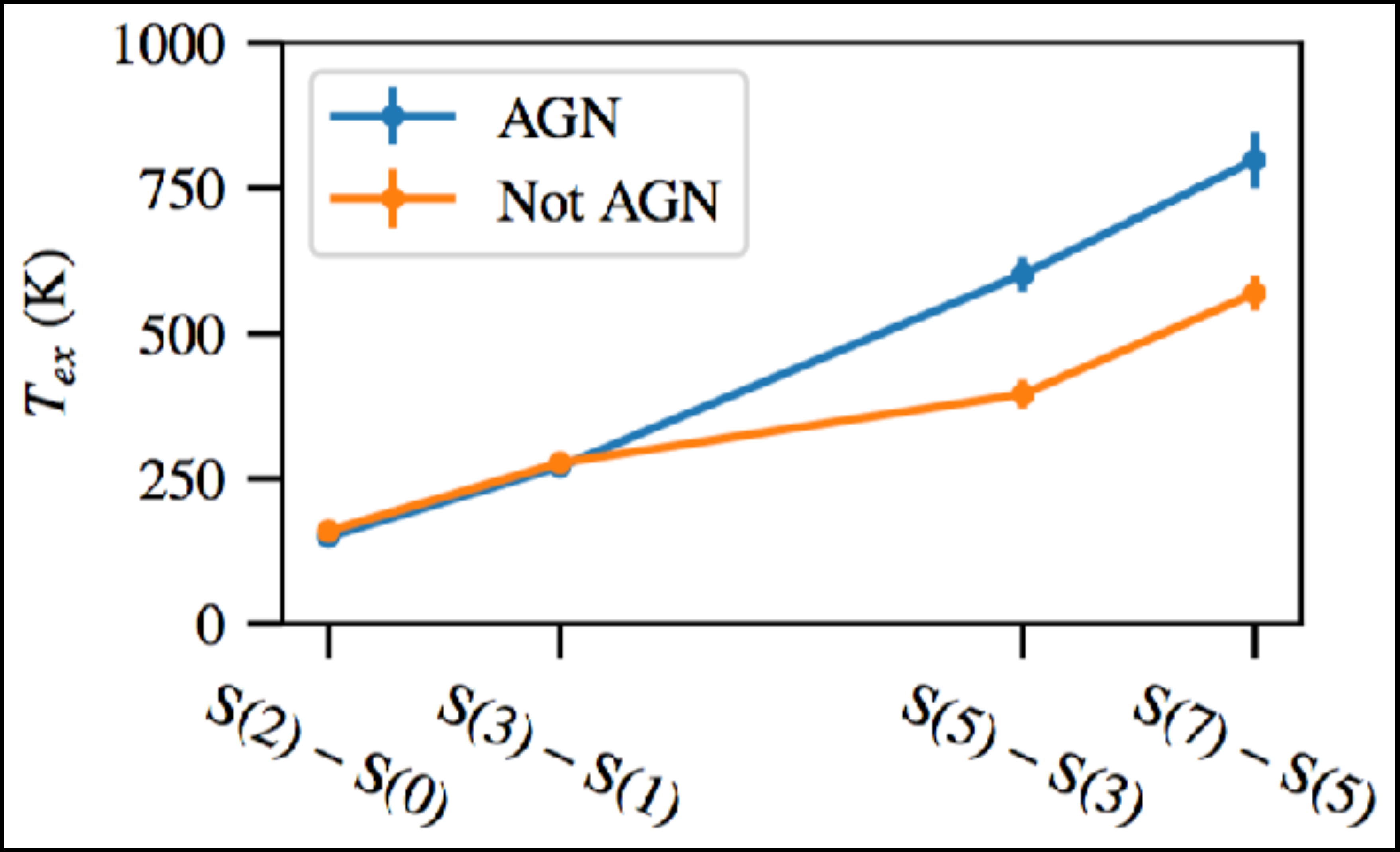


Black: non-mergers
Blue: early mergers
Red: advanced mergers

(Petric et al. 2018)

20% of LIRGs have more H2 than we would expect from PDRs
(Stierwalt,+, AP+ 2018)
Estimated kinetic energies comparable to what is needed for the gas to escape the system.

Warmer Molecular Gas in AGN hosts



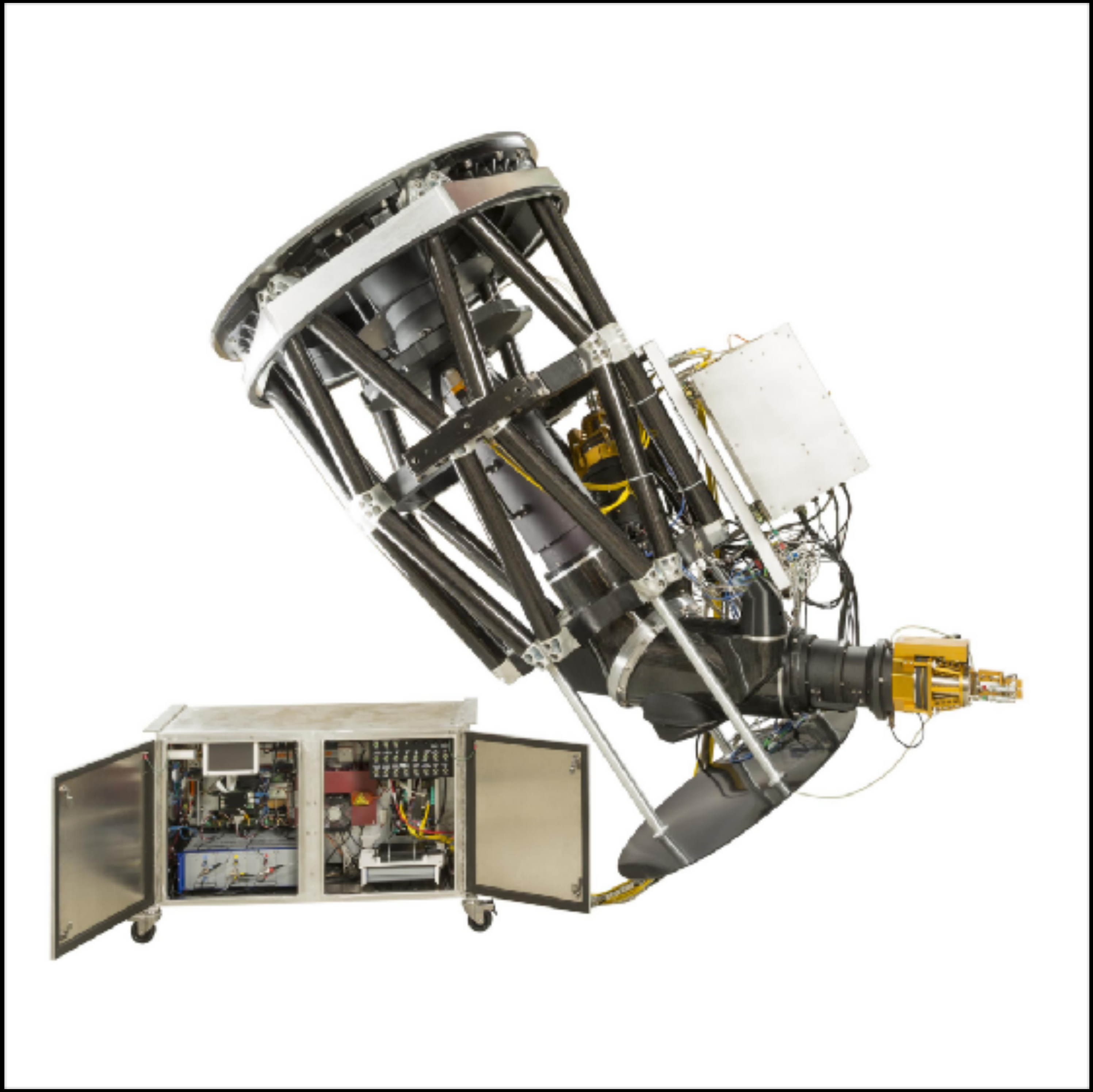
Erini Lambrides
John Hopkins University
Gemini/CFHT visitor

Class	T_{warm} (Median, K)	T_{warmer} (Median, K)	$\frac{M_{warmer}}{M_{warm} + M_{warmer}}$
AGN-Dominated	198.3 ± 31.2	522.1 ± 169.4	0.13 ± 0.06
SF-Dominated	192.9 ± 34.9	519.6 ± 276.0	0.11 ± 0.08

(Lambrides, Petric, +. 2019 MNRAS in press)

AGN hosts have warmer warm H_2 .

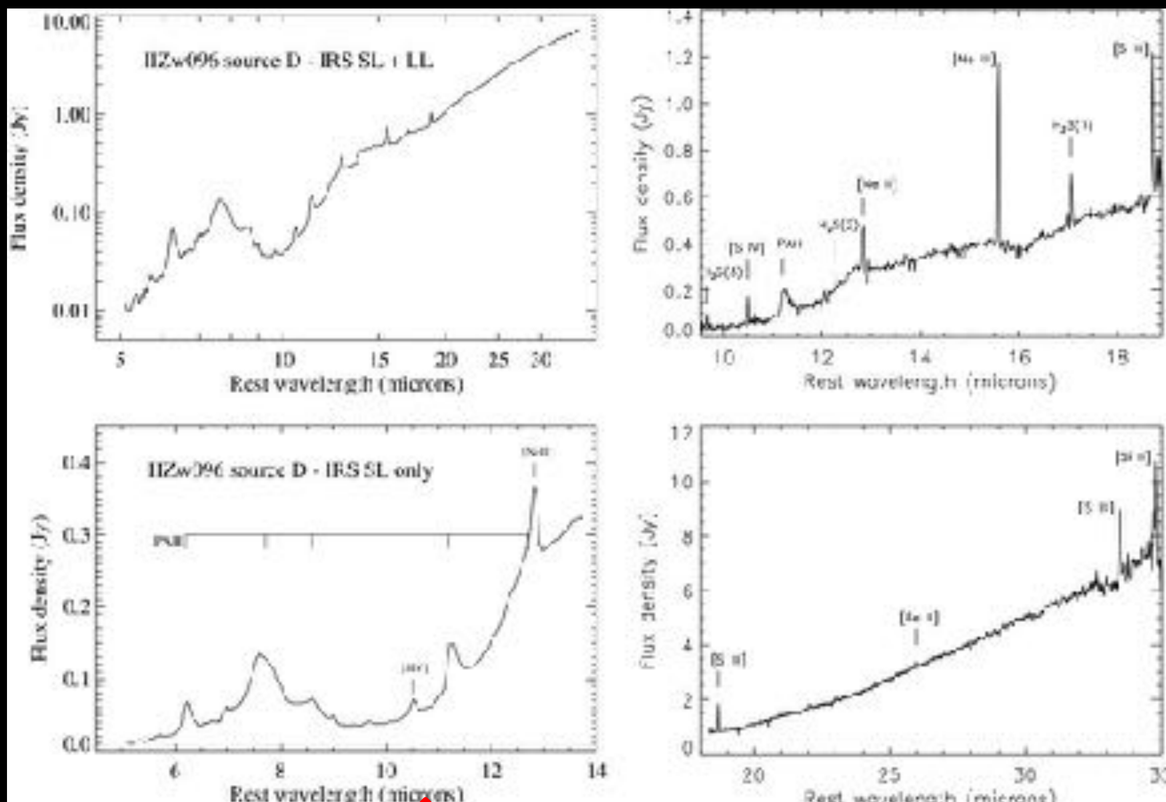
But How?



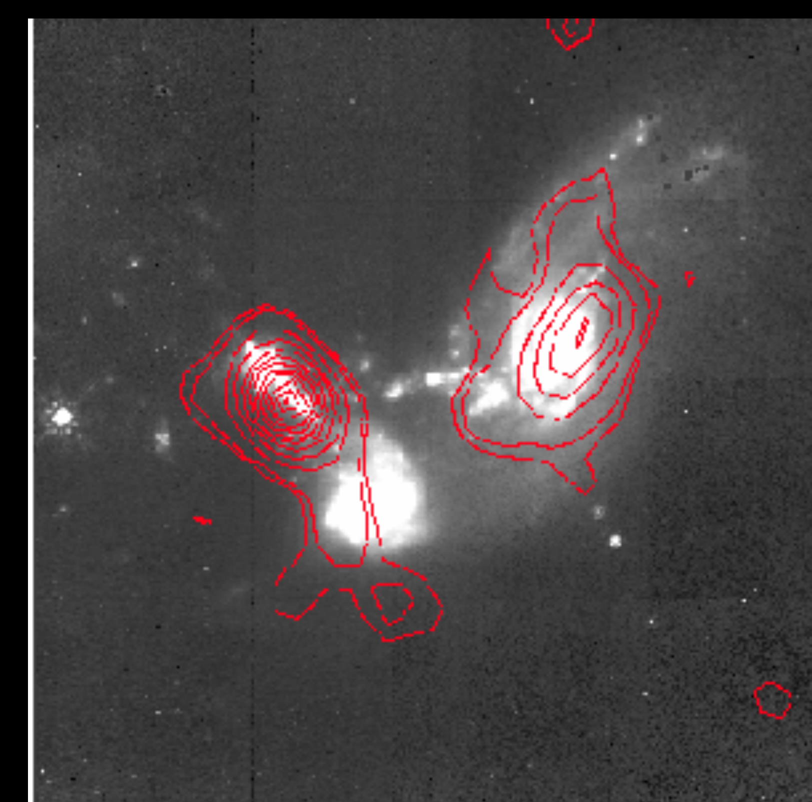
➔ SITELLE can simultaneously estimate ionization properties of the gas, and widths of the lines, from which we can derive outflow masses and energetics, and see how they change for AGN dominated vs SFR mergers

The strangest LIRG

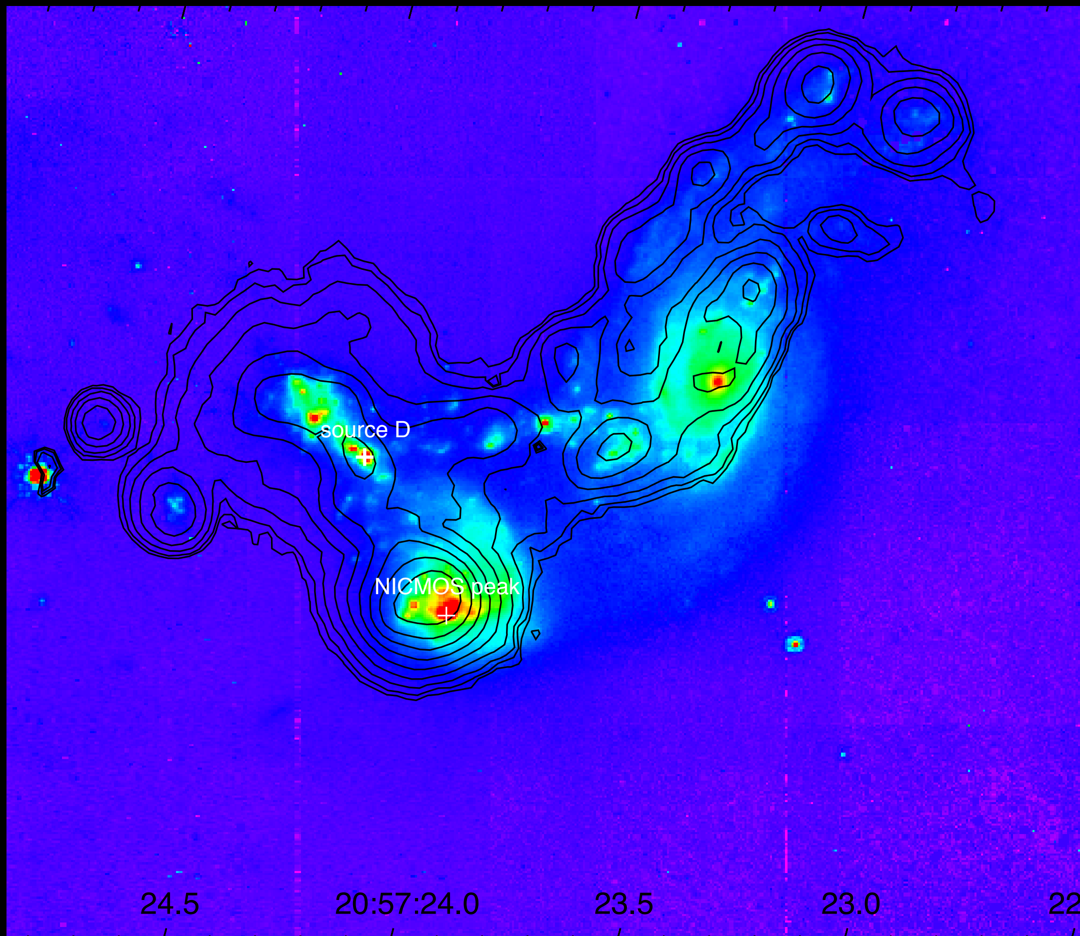
II Zw 96 – a Test Case for SITELLE

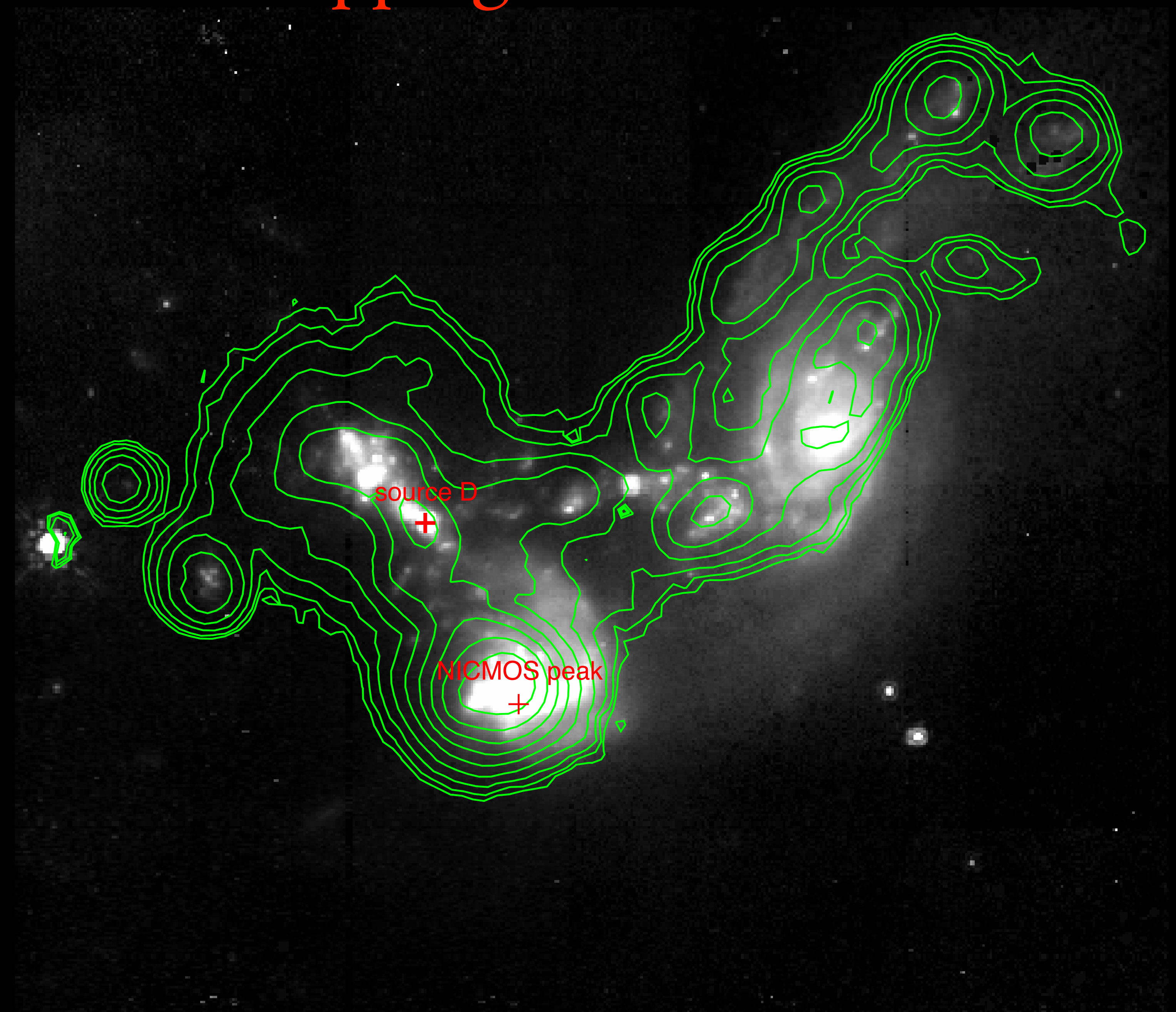


- Extinction and star-formation rates from Balmer decrement across the entire LIRG
- Spitzer 120M ⊙ /yr , AKARI 40 M ⊙ /yr
- Connecting kinematics with SFR to assess impact of feedback from stars vs AGN feedback

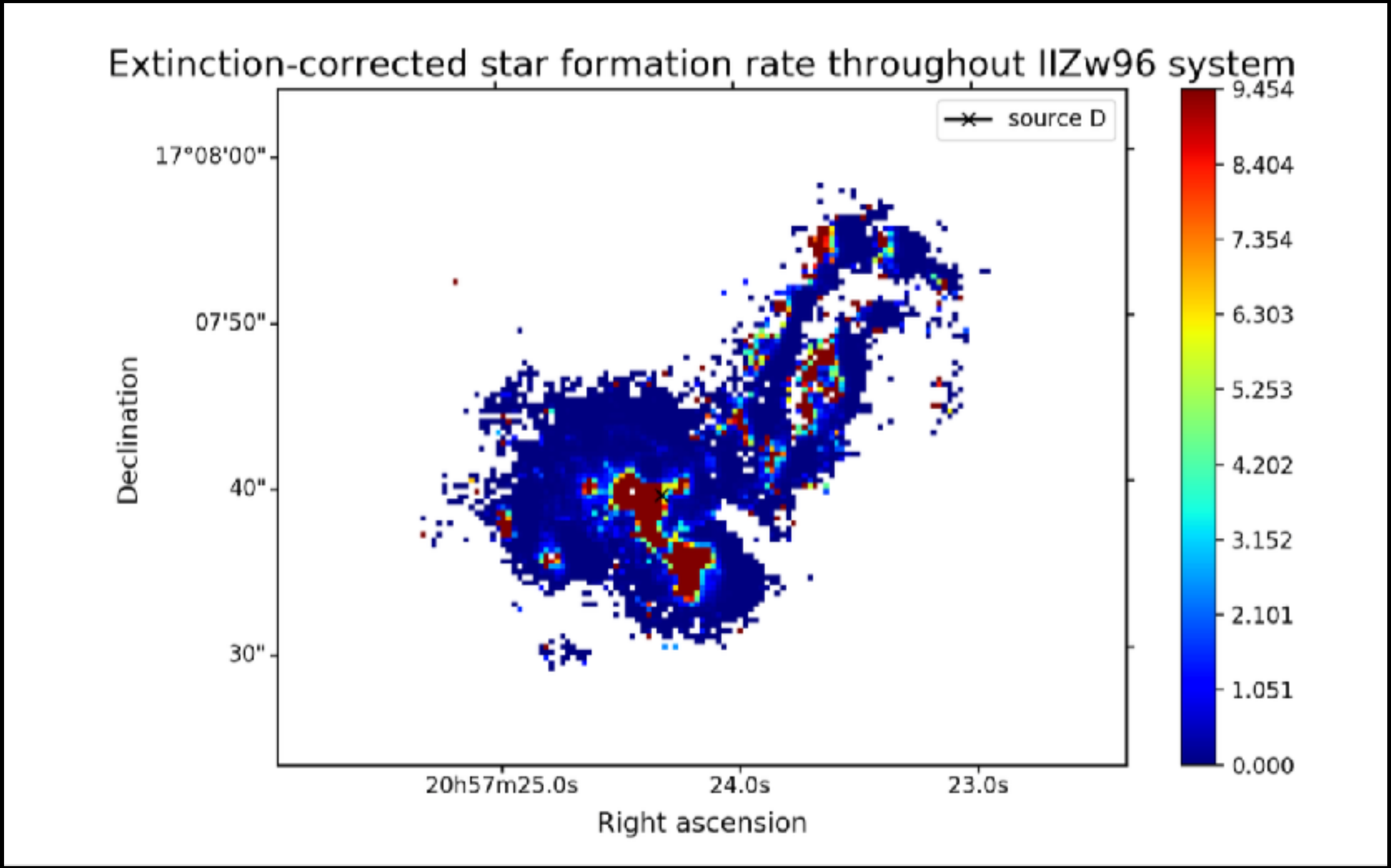


Hydrogen Recombination Lines Mapping with SITELLE





- Hα sensitivity 5 x 10^{-18} erg s^{-1} cm^{-2}
- Velocity resolution @R = 2500 ~ 120km/sec



Extinction corrected SFR (190 M$\odot$ / yr^{-1})

similar to those derived from IR emission which.

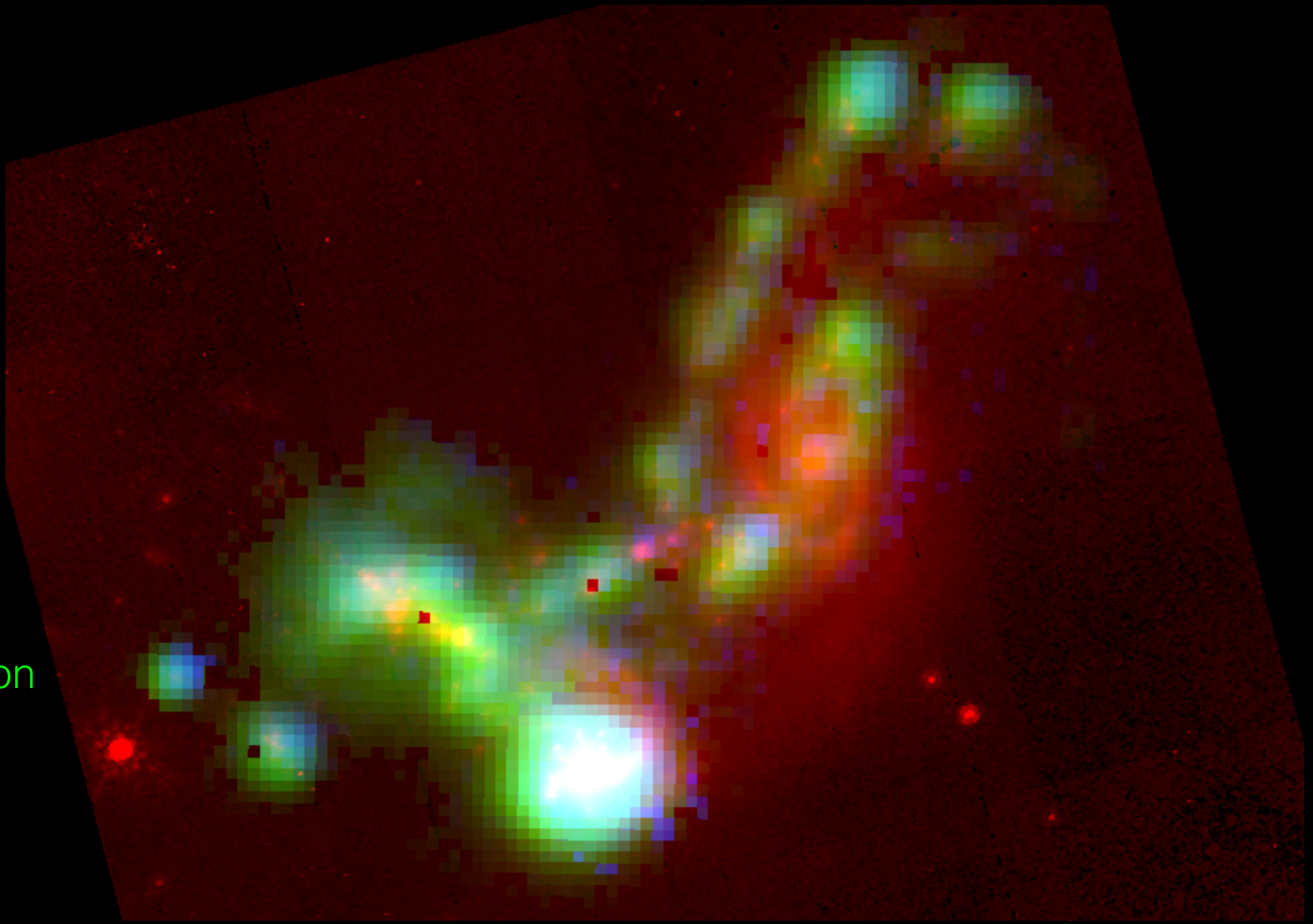
What do we mean by ionized emission in a source like II Zw 96 ?

Is this a three or a two galaxy merger?

SITELLE / [OIII]
— highly ionized gas

SITELLE / Hα
— recombination emission

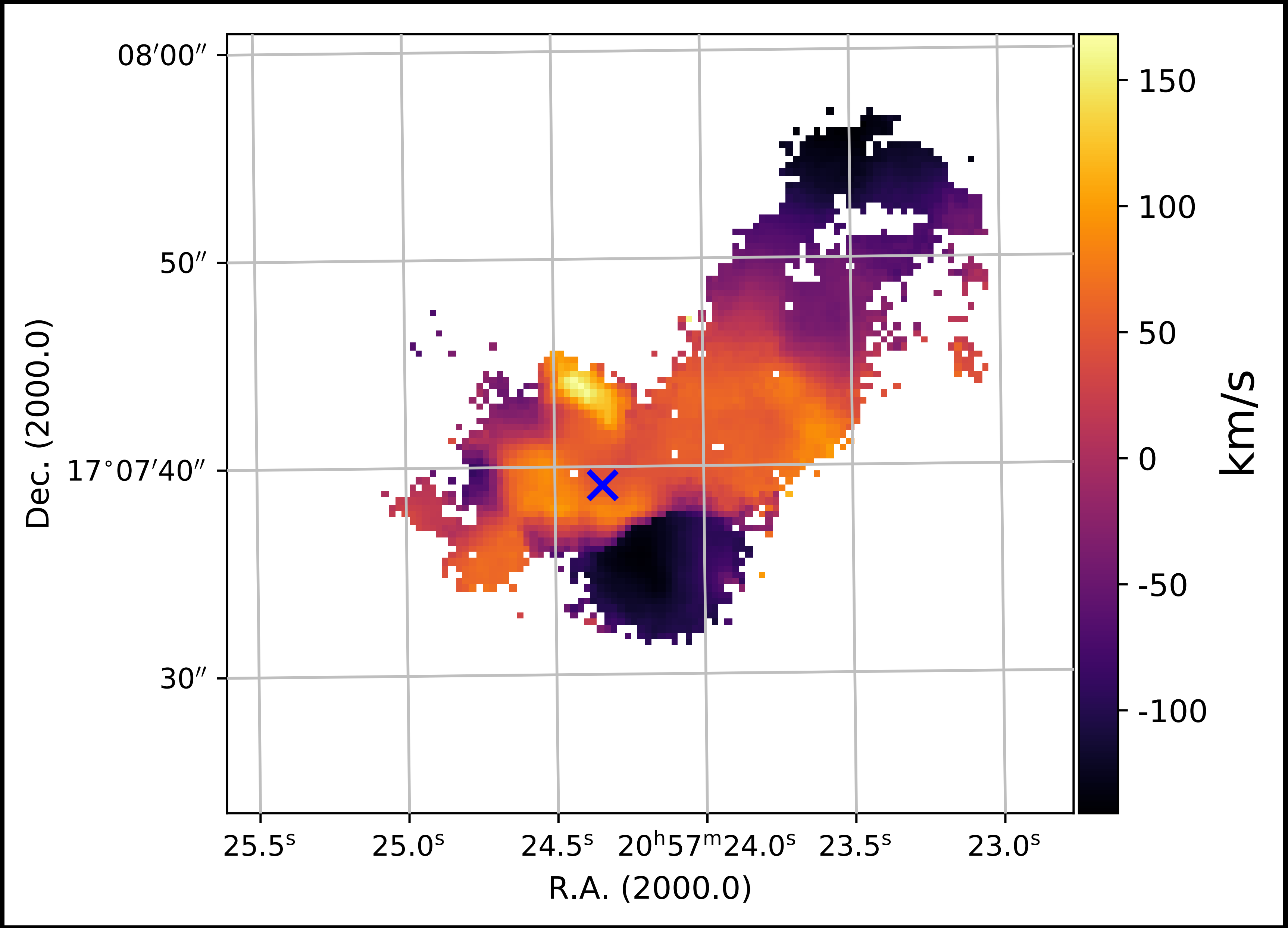
NICMOS / H-band
— hot dust/old stars



Hα does not correlate with some of the diffuse NICMOS emission

Why ?

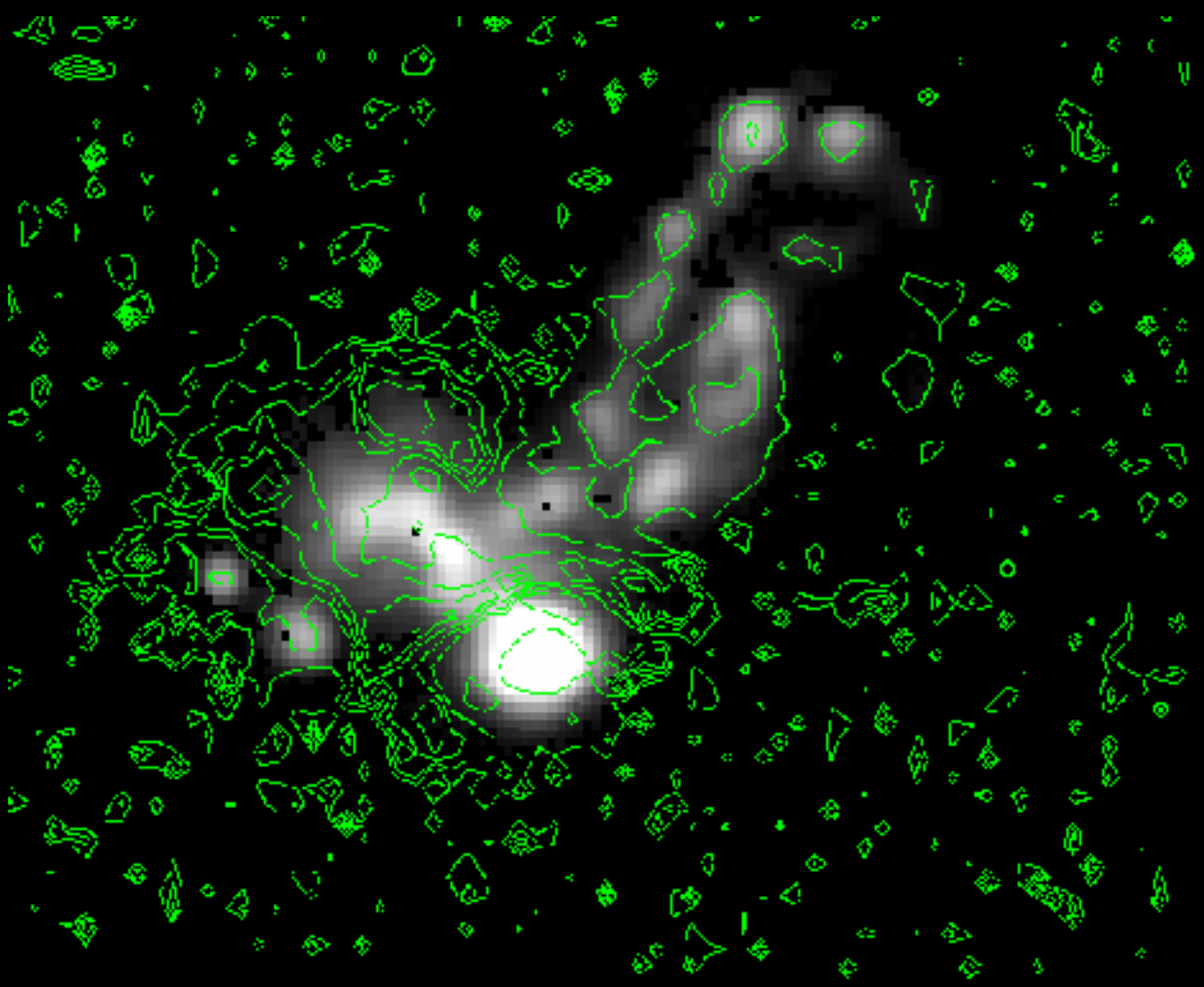
II Zw 96 – Velocities of ionized gas



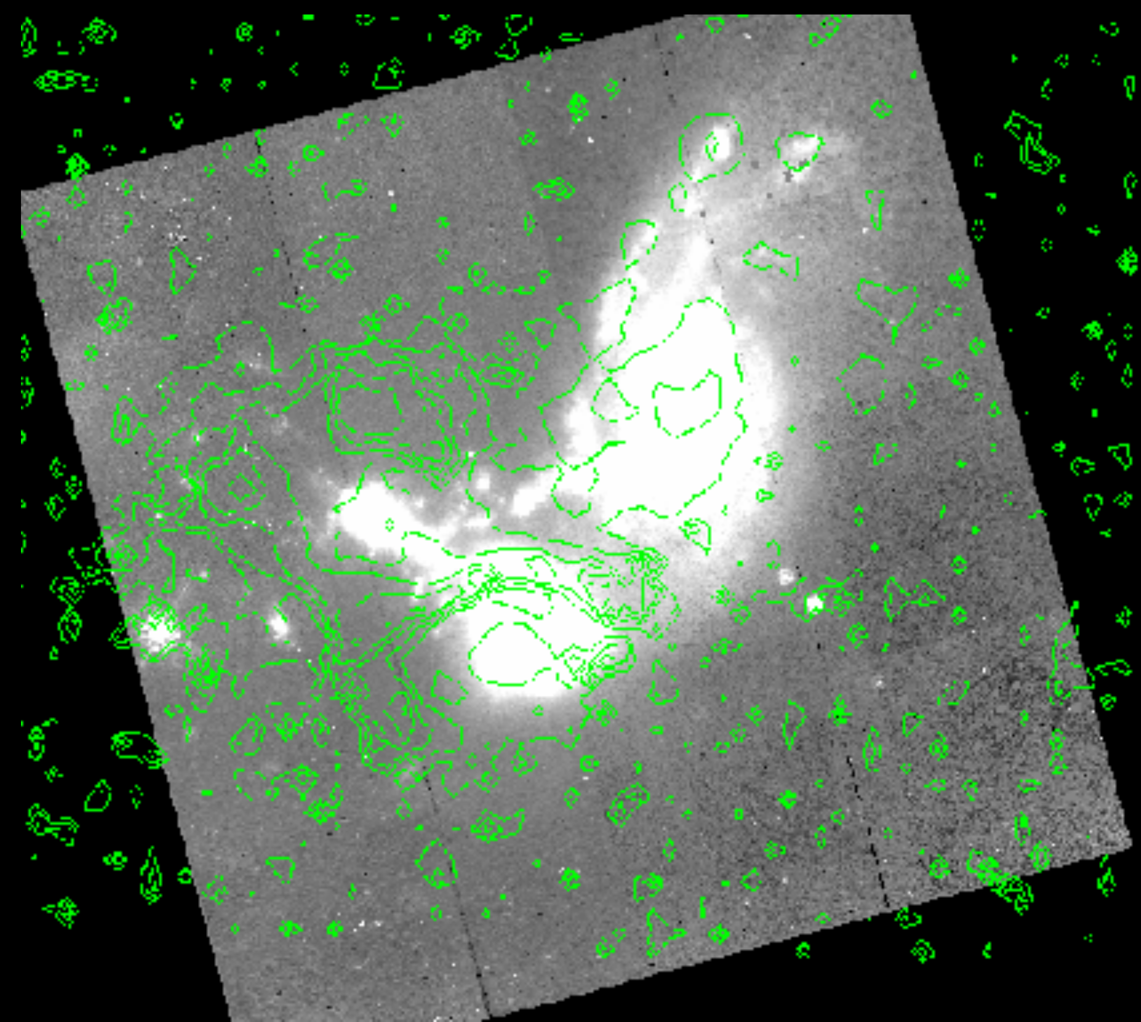
- Velocity gradient suggests bulk motions of ionized gas. The highest widths correlate with highest velocity gas, suggesting shocked gas.

- The high star-formation may be triggered by infall of cold gas from the merger.

Ha Kinematics in II Zw 96



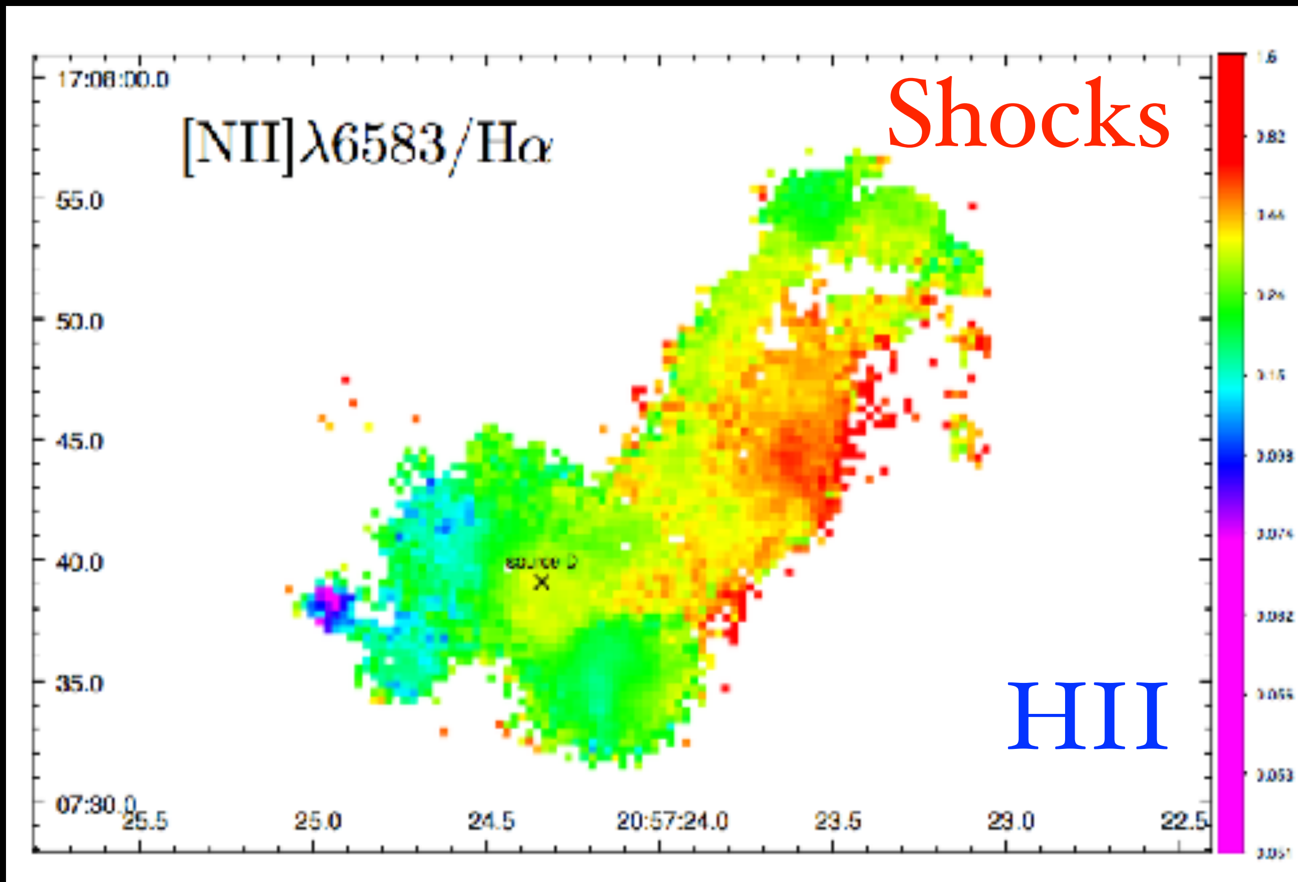
Ha width

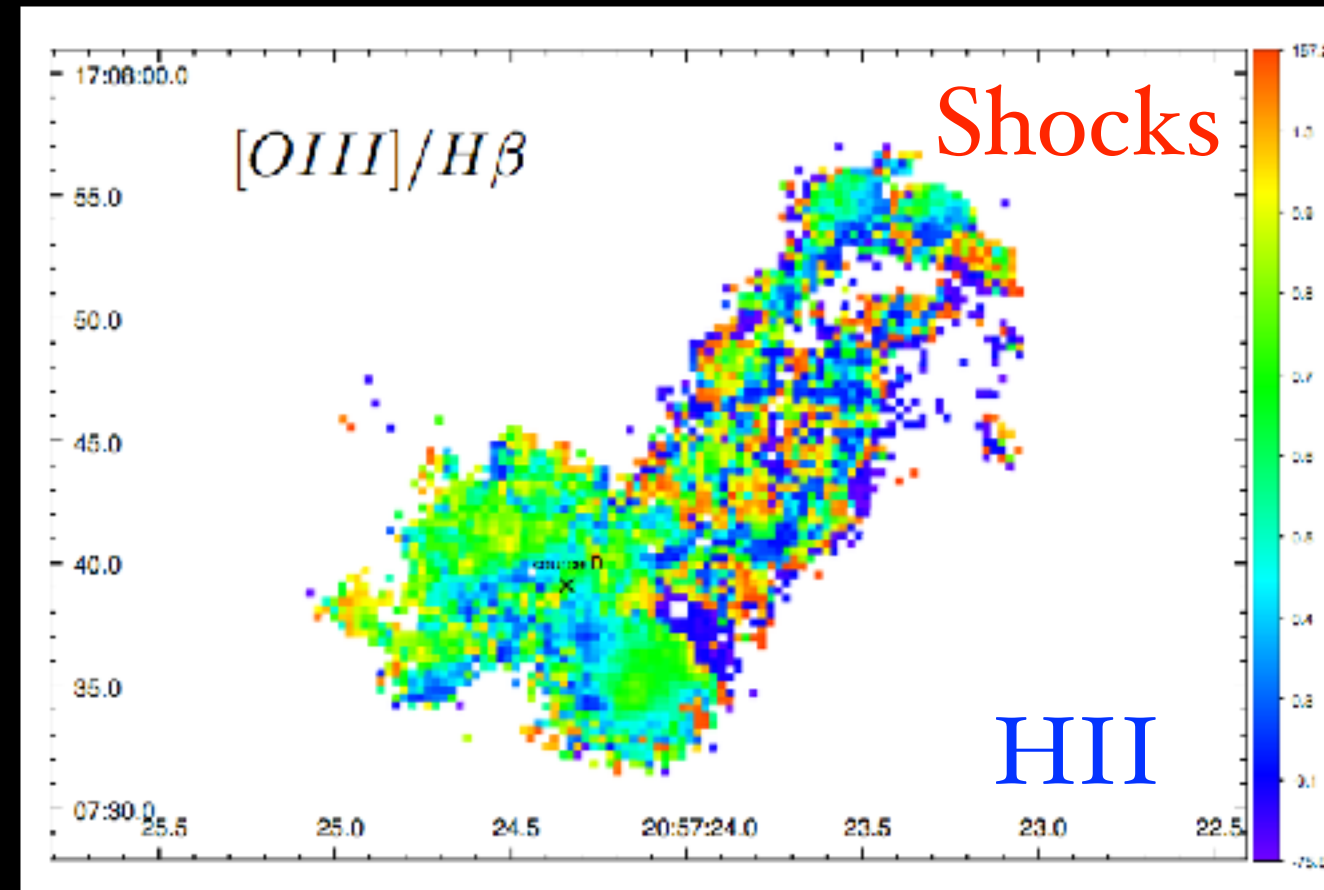


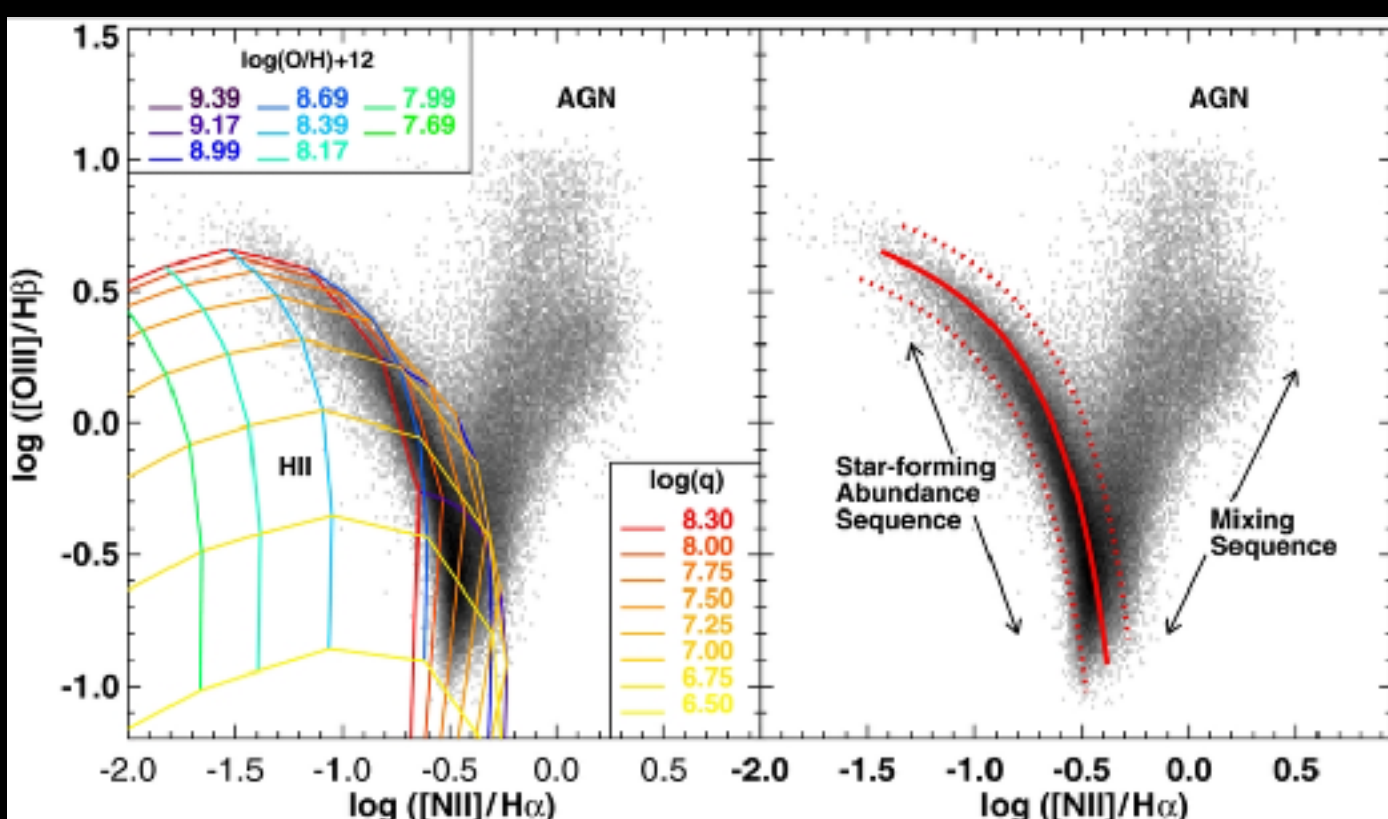
Ha width on NICMOS

- Large scale (kpc) structures, of faint (but SNR >2) gas, have the largest resolved widths (60-140 km/sec).
- The widths are likely a combination of beam smearing, associated with rapidly moving gas in our 0.5kpc region probed by those observations.

Emission Line Ratios in II Zw 96



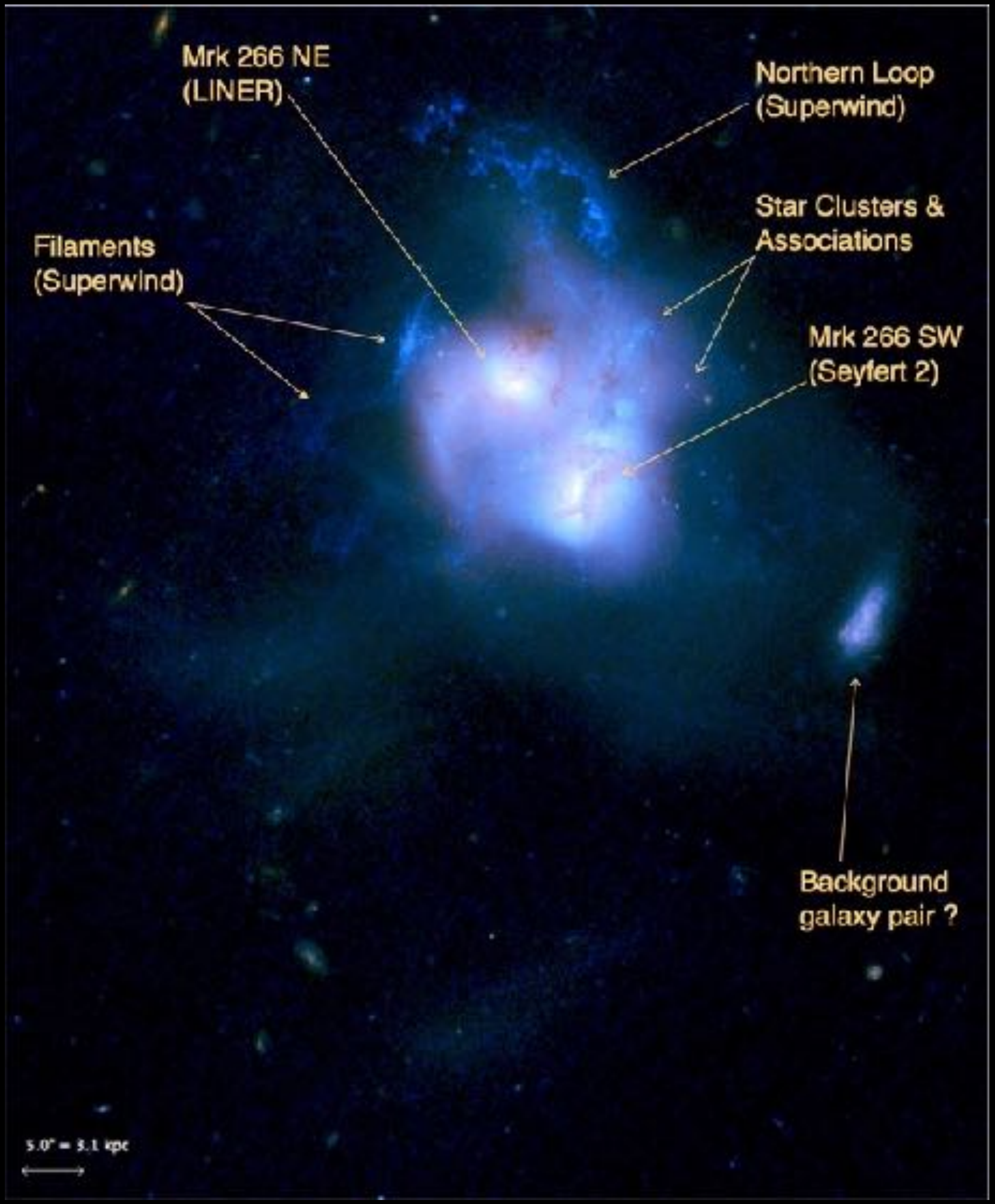


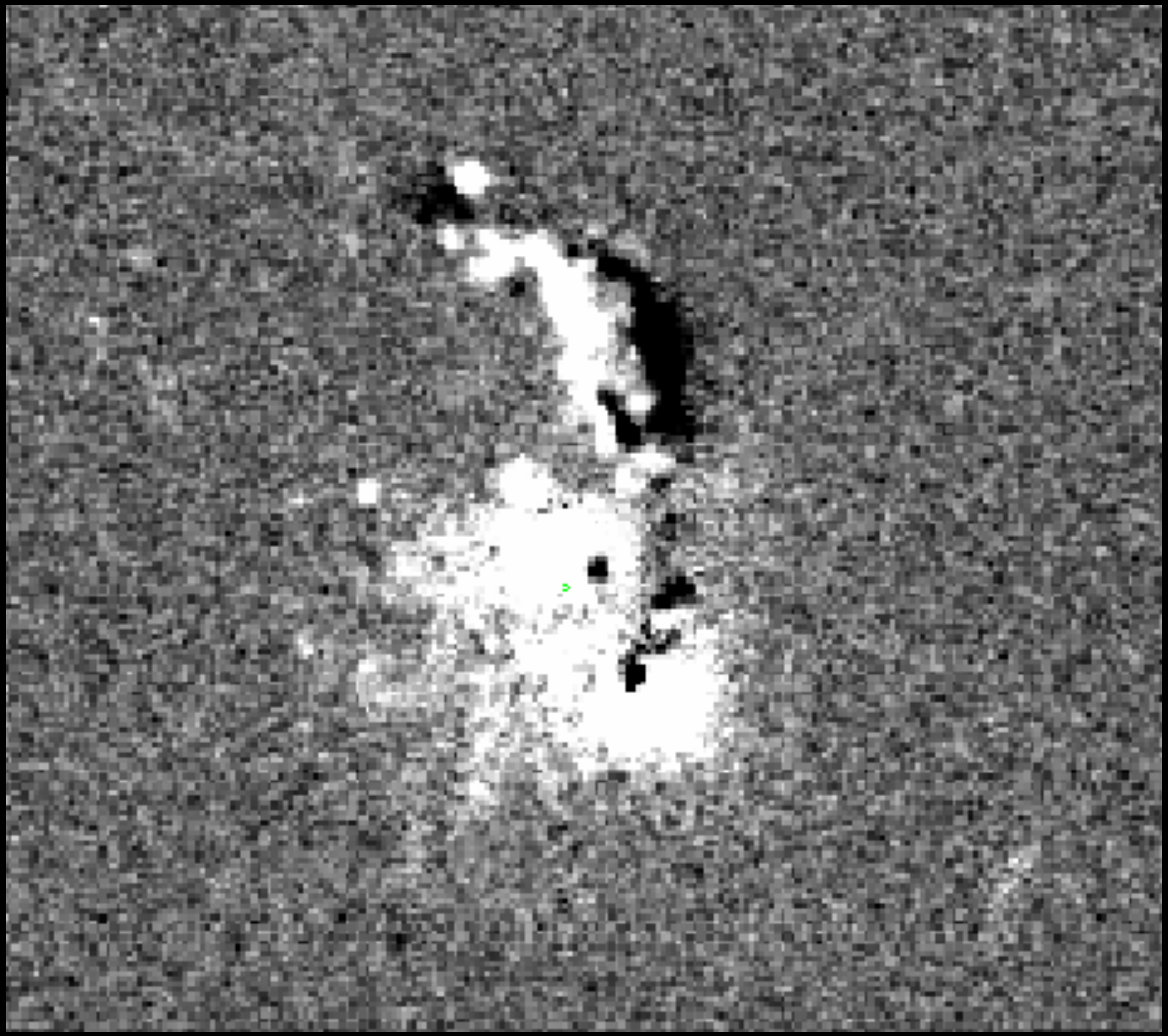


- For II Zw 96, emission line ratios are consistent with composite emission from shocks and HII
- Some of the high dispersions may point to multiple kinematic components.
- Caveat - no stellar absorption corrections

Kewley et al. 2013, Rich et al. 2011, Rich et al. 2015, Mortazavi & Lotz 2017, Garcia-Lorenzo et al. 2015

Next: Mrk 266, host of two AGN





Use SITELLE to study double AGN in mergers.
IfA REU student Maya Merhi will start the analysis over the summer.

Conclusions

- Extinction - corrected SFR match those from FIR estimates (modulo corrections from tidal shock emission, stellar absorption, and possible AGN activity).

- In II Zw 96 the high star-formation may be triggered by infall of cold gas from the merger.

(Mazzilli-Ciraulo, AP+, in prep)

- MSE's synergy with X-ray, IR, and imaging wide field, large surveys will revolutionize our understanding of AGN triggering (see my MSE poster).

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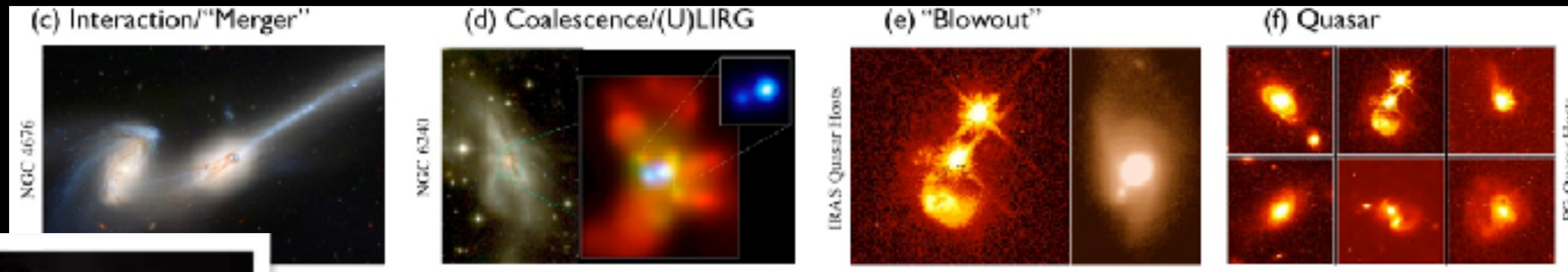
UH Resident Astronomer at CFHT

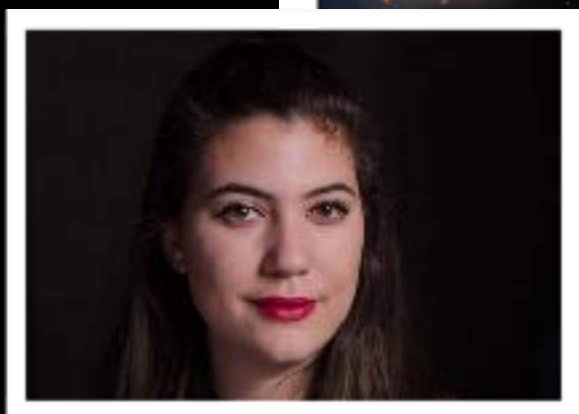
Student Collaborators



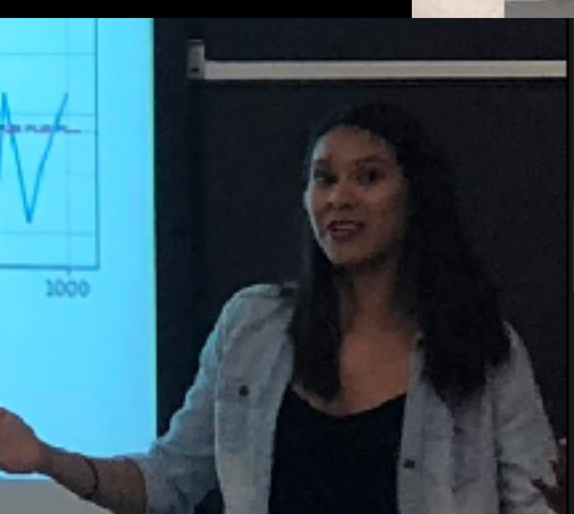
Eduardo Vitral
Ecole Polytechnique

Jordan Raffard
Observatoire de Paris

Barbara Mazzilli
Universite de Starsbourg



Erini Lambrides
John Hopkins & Gemini

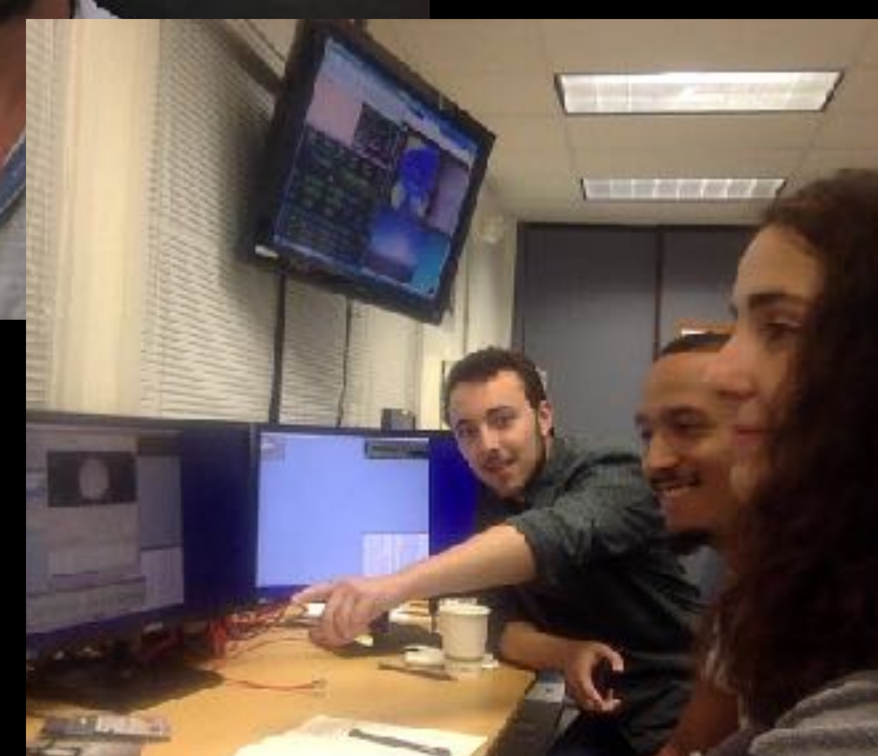


Gabriella Sanchez
University of Hawaii, Manoa

Jameeka Marshall
University of Hawaii, Hilo

Stefan Kimura
Willamette College

Simon Petrus
Universite Grenoble



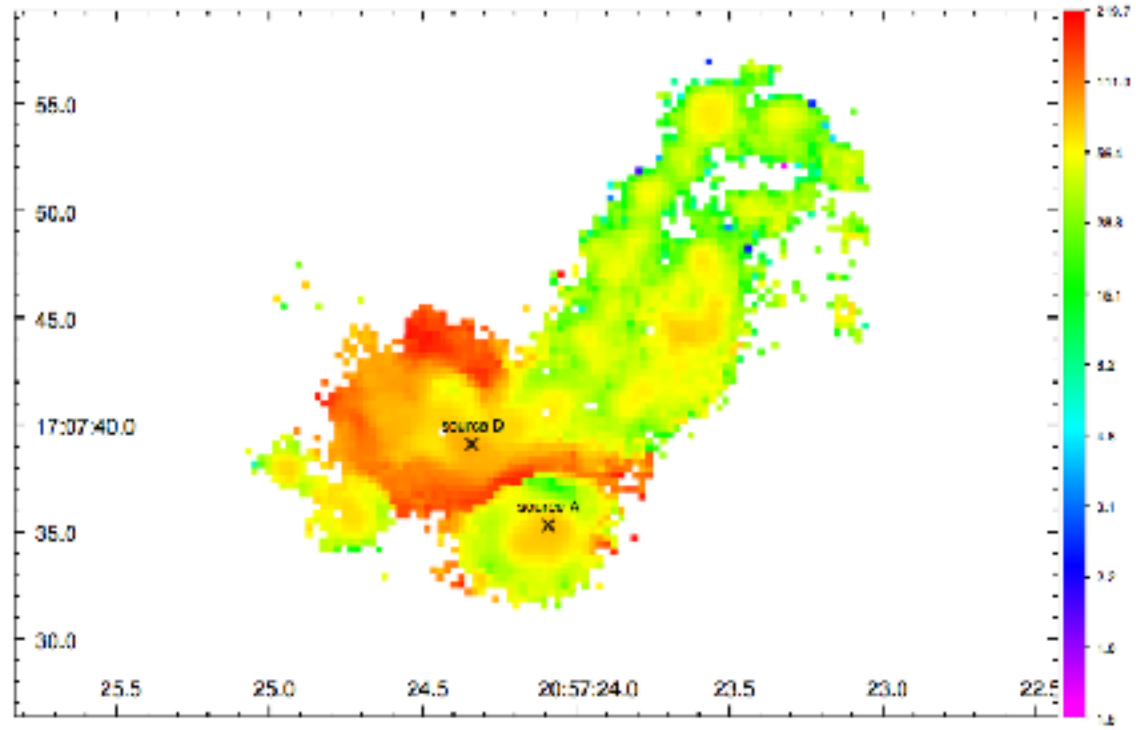
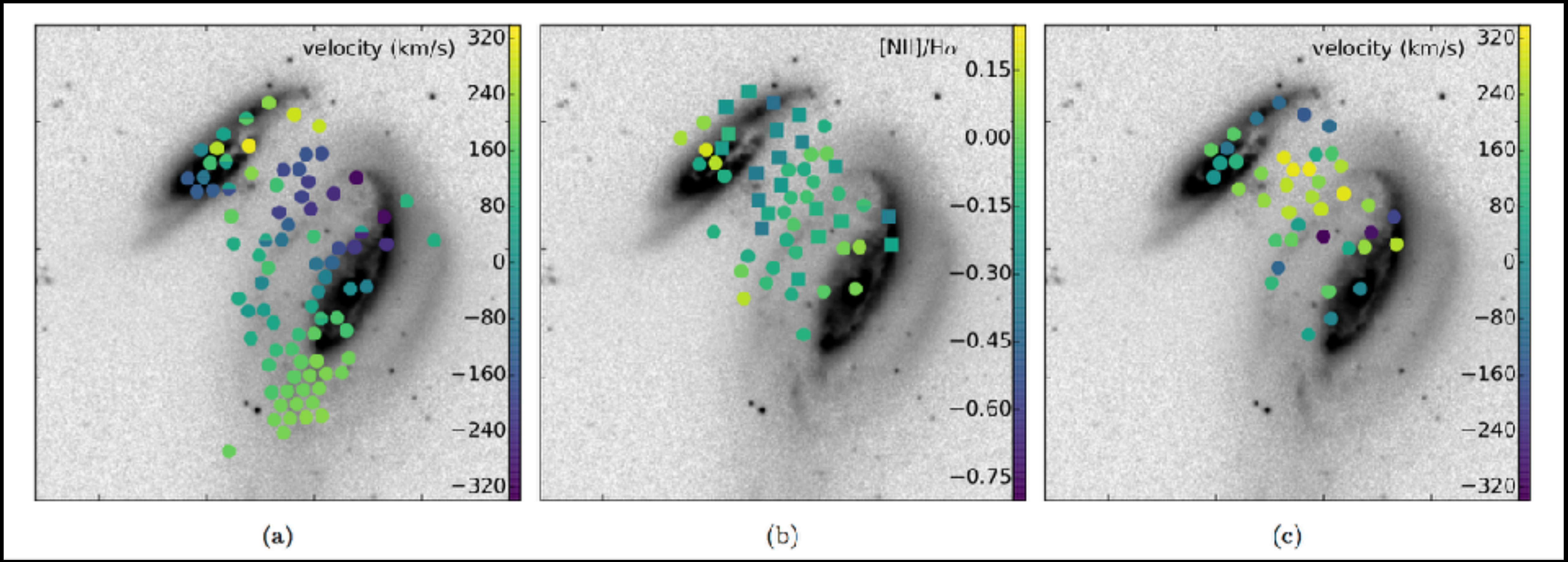


Figure (4.6) Line (here, Hα and [NII]λ6583) broadening map, with sources A and D displayed as black crosses

II Zw 96 and The Taffy Galaxy



Mortazavi & Lotz 2018

Dynamical modeling by Vollmer et al. (2012) suggests that "the gas was already displaced from the bulk of old stars before forming new stars, the star-forming Hα velocity would not match the velocity of stars".

X-ray compact source => AGN (Appleton et al. 2015)