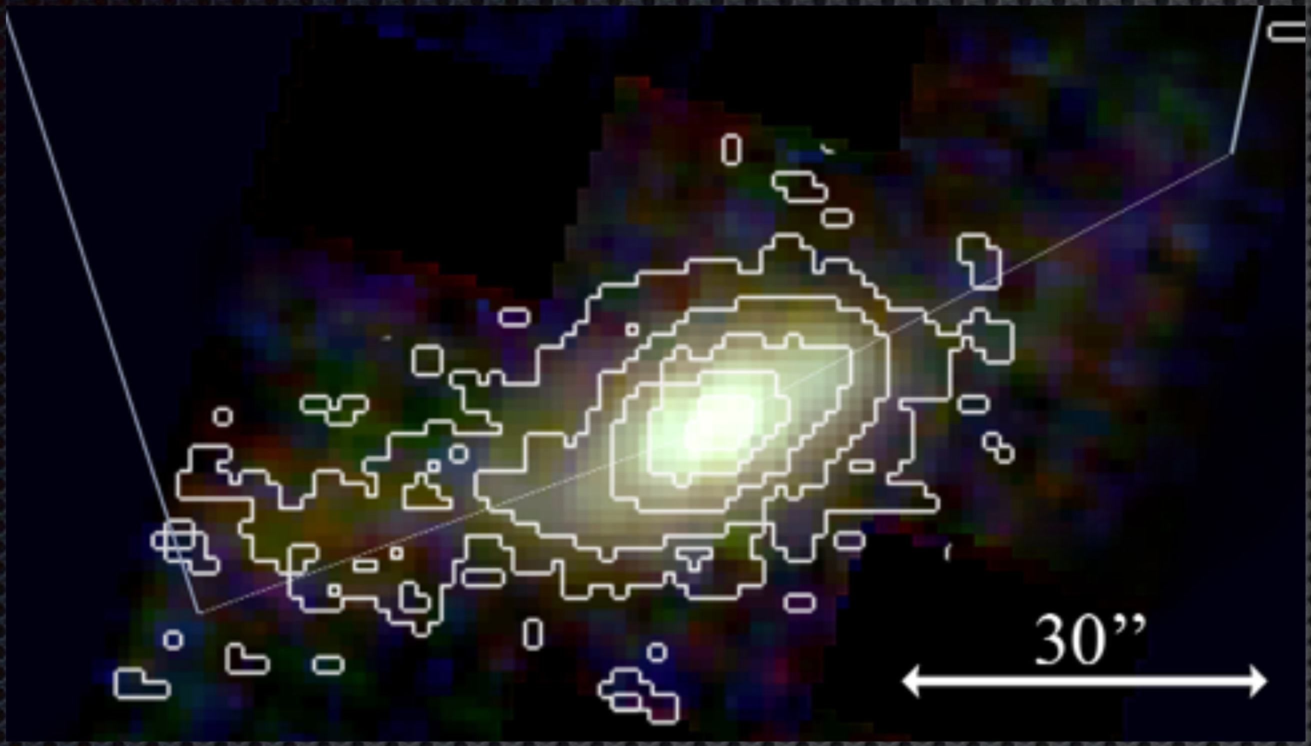
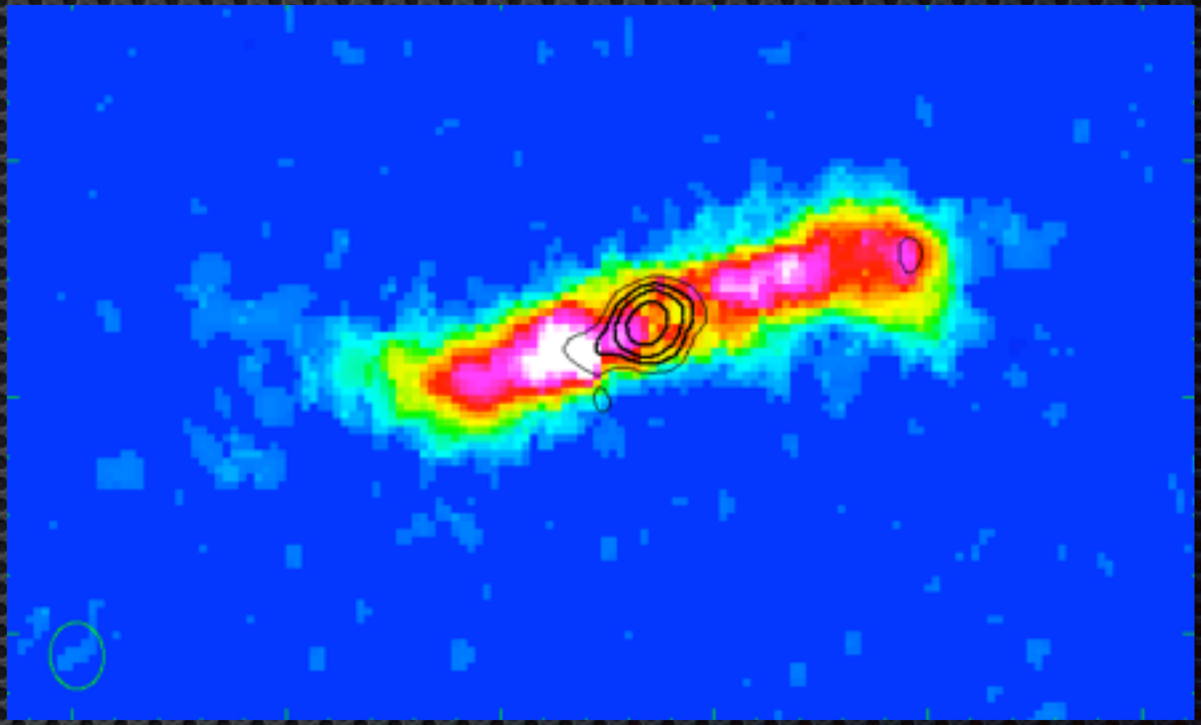
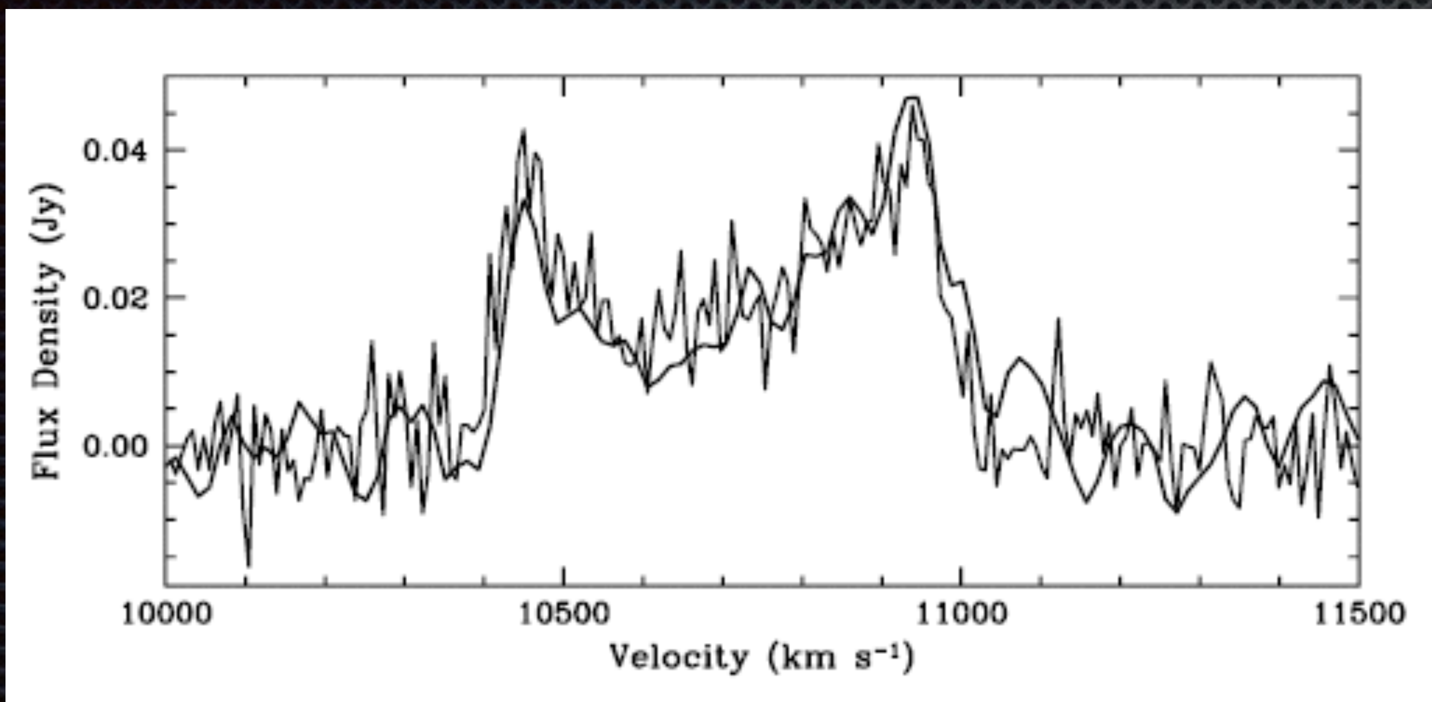
Inside-Out Star Formation in a Giant HI Disk





Michelle Cluver
NRF RCA Fellow
michelle.cluver@gmail.com

HIZOA J086-43:
A rapidly rotating HI Behemoth



$M_{HI} \sim 7.8 \times 10^{10}\ M_{\odot}$

HI diameter ~ 130 kpc

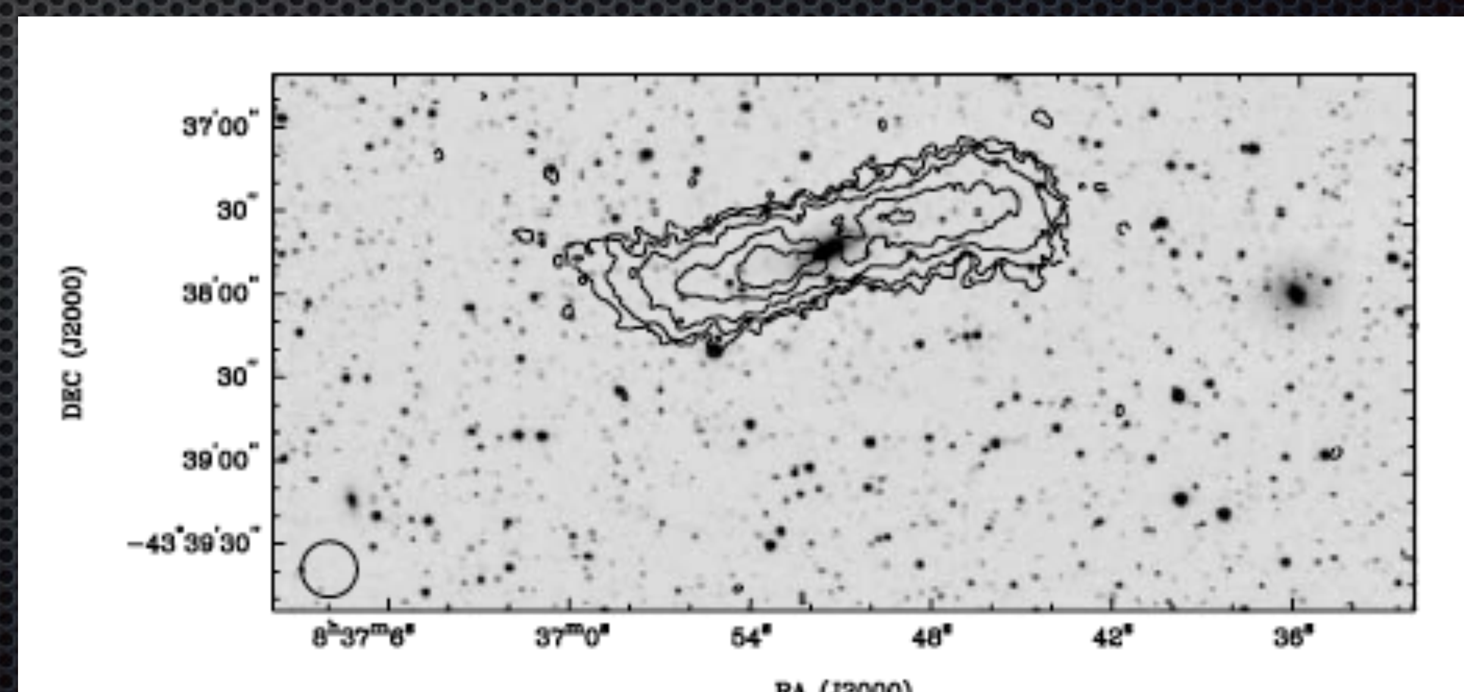
Velocity width ~ 660 km/s

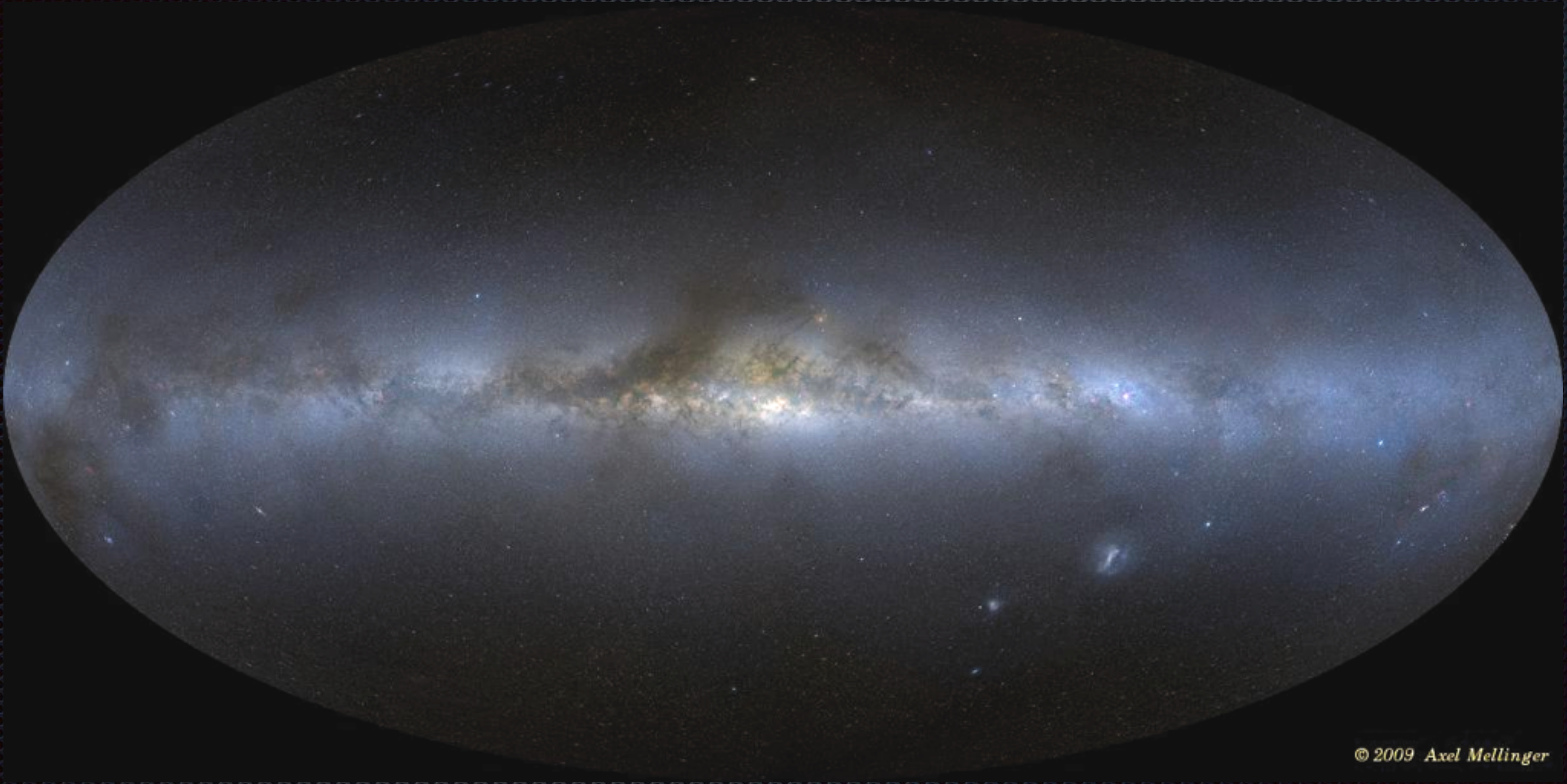
$M_{dyn} \sim 1.6 \times 10^{12}\ M_{\odot}$

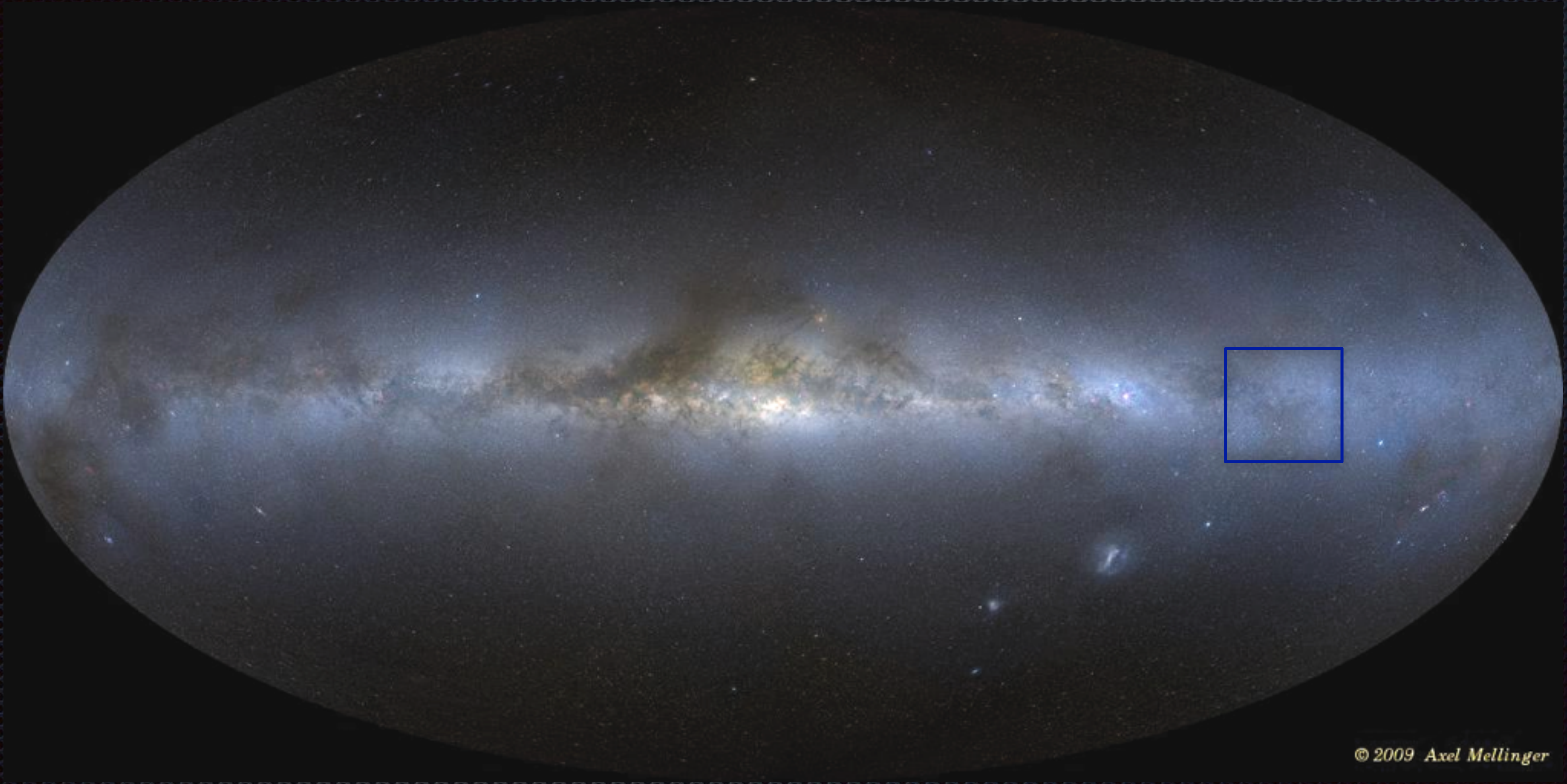
z = 0.036 or

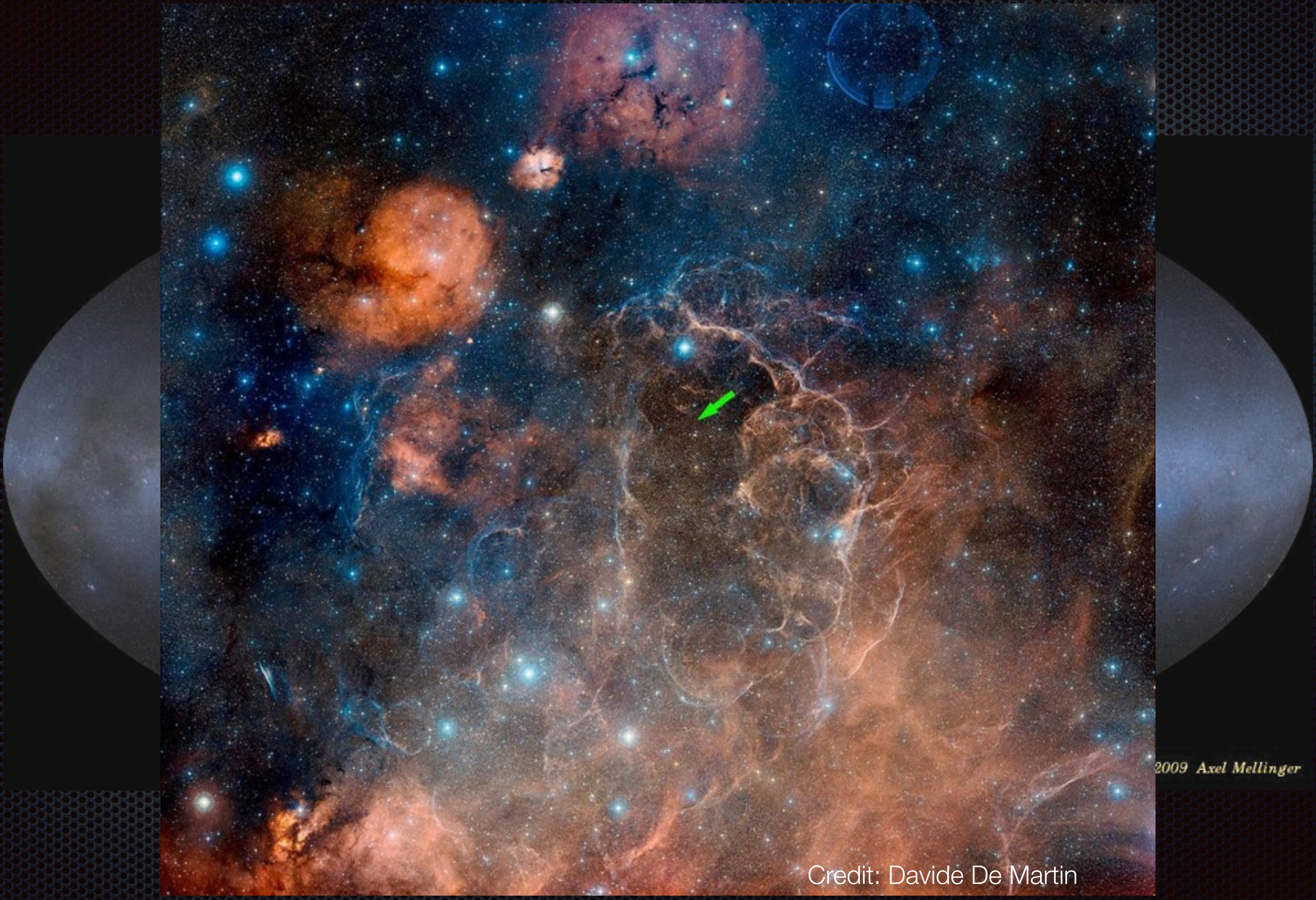
D_L~156 Mpc

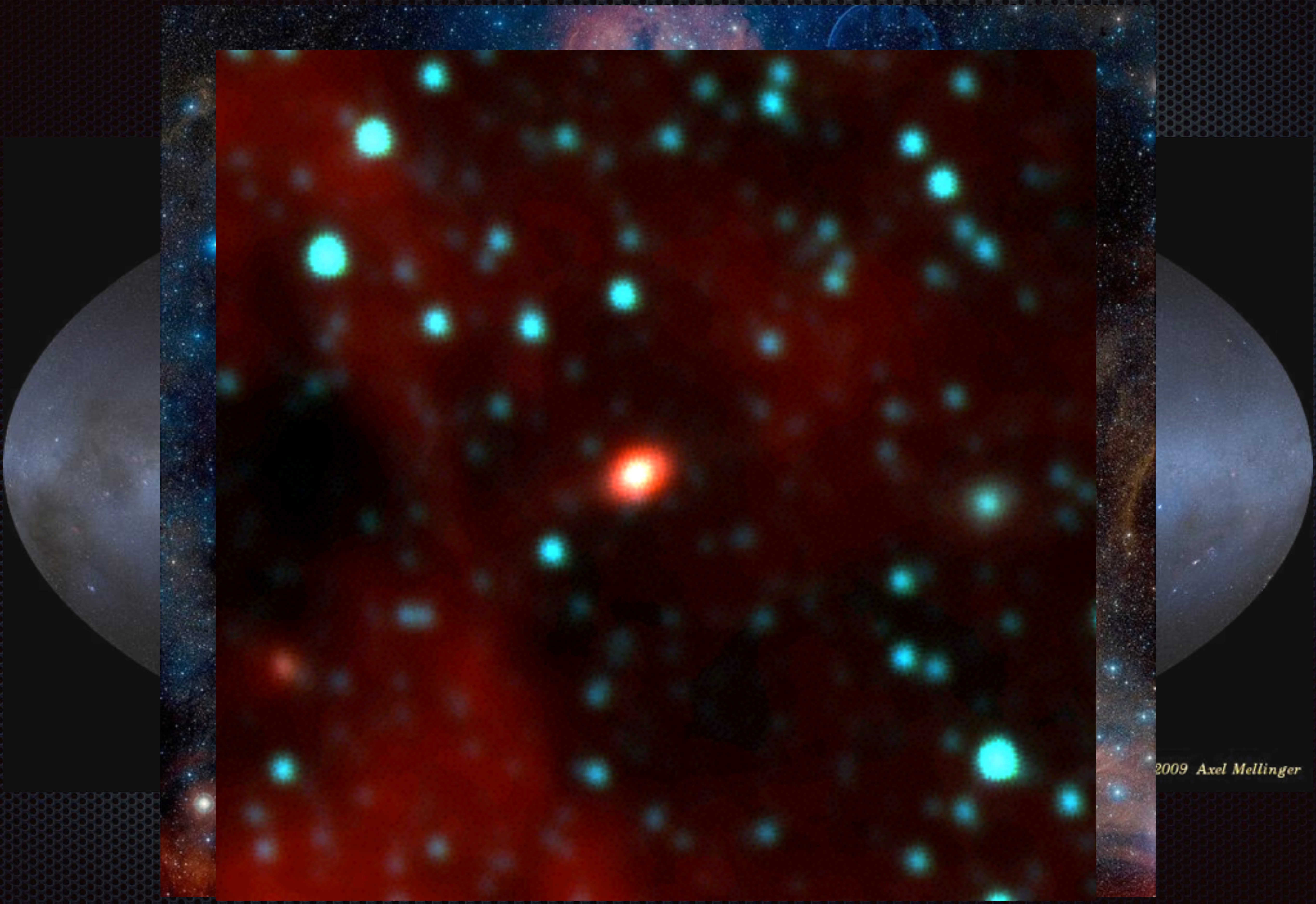
See Donley et al. (2006)




© 2009 Axel Mellinger


© 2009 Axel Mellinger


2009 Axel Mellinger
Credit: Davide De Martin


2009 Axel Mellinger

Collaborators:

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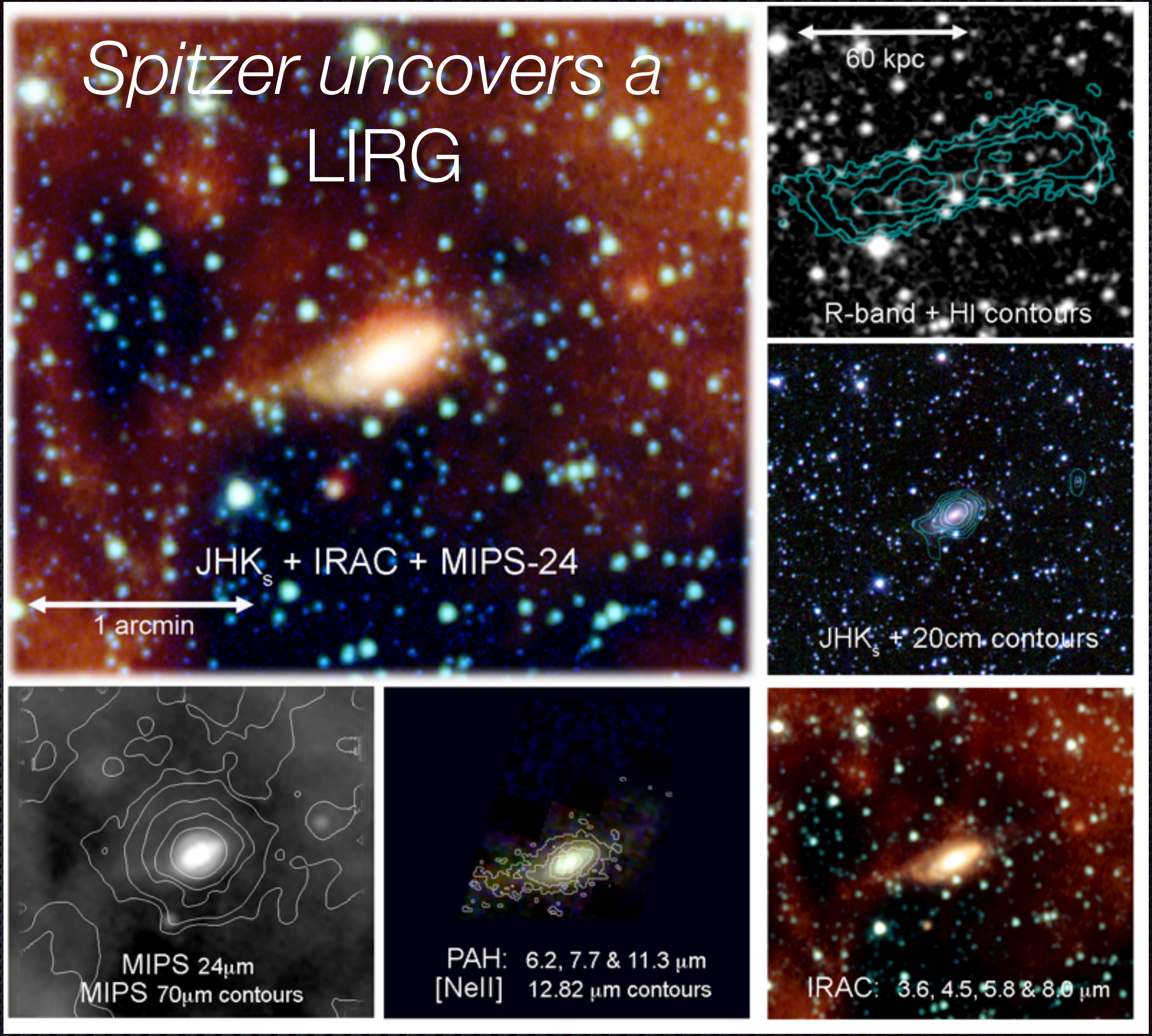
Bjorn Emonts (Centro de Astrobiologia, CSIC-INTA)

Renée Kraan-Korteweg (U Cape Town)

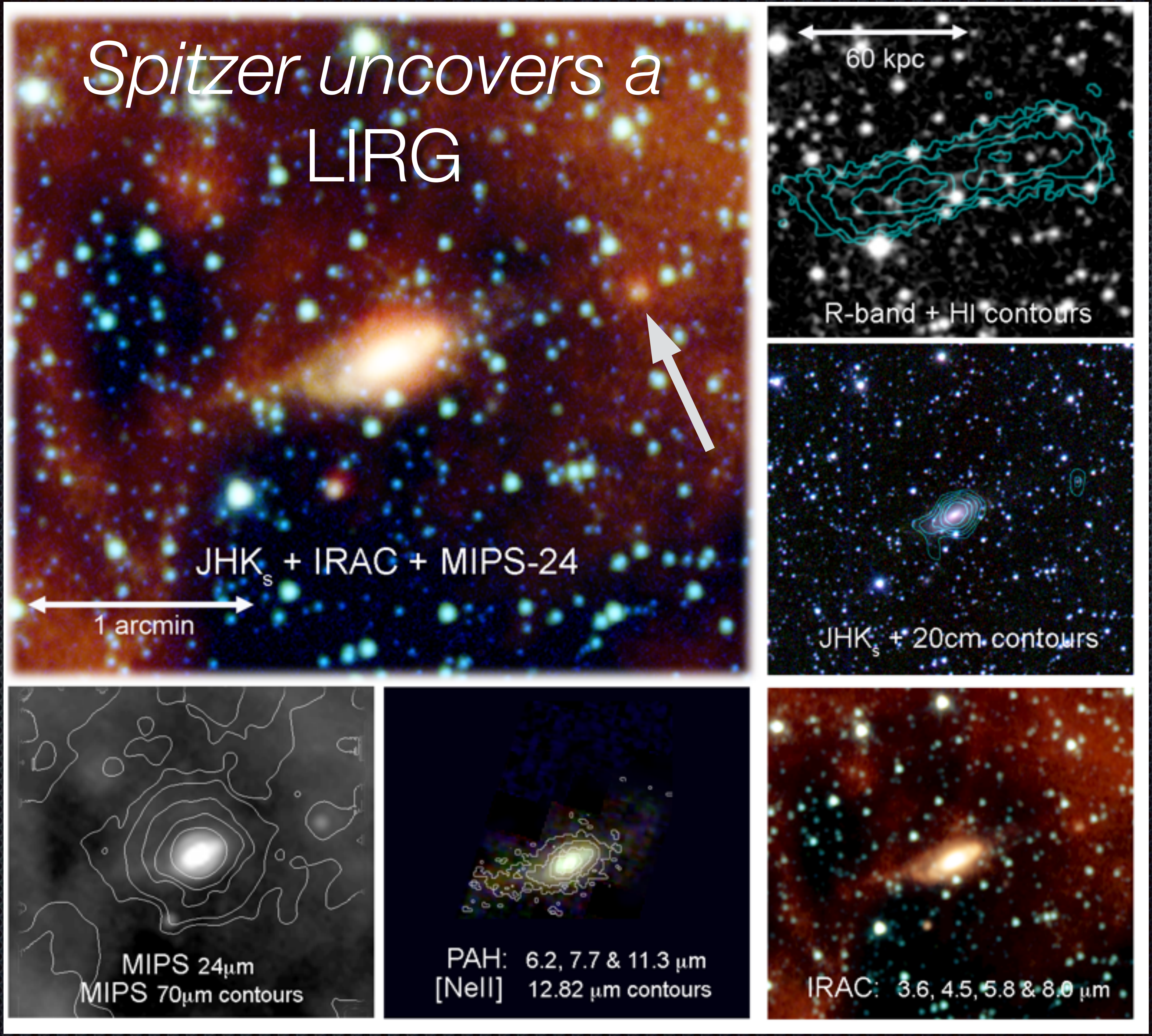
Phil Appleton (NHSC/Caltech)

Ute Lisenfeld (U Granada)

2009 Axel Mellinger

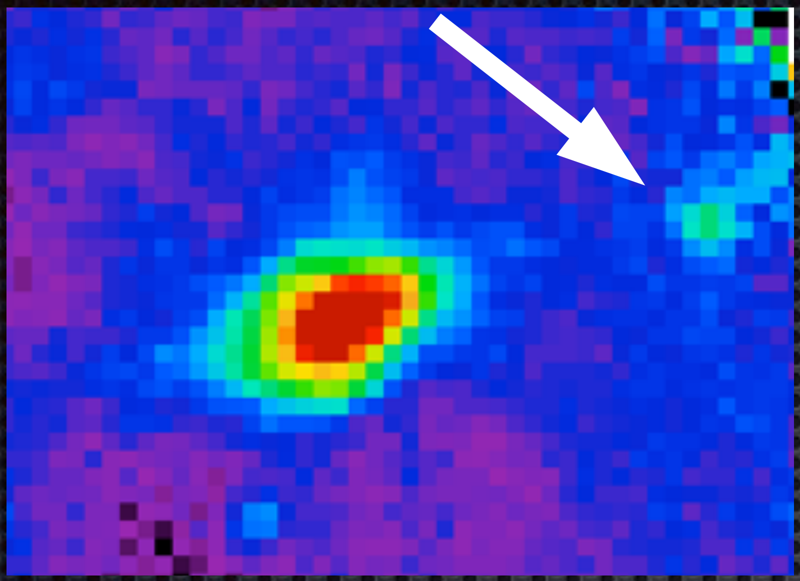


Cluver et al. 2008, 2010



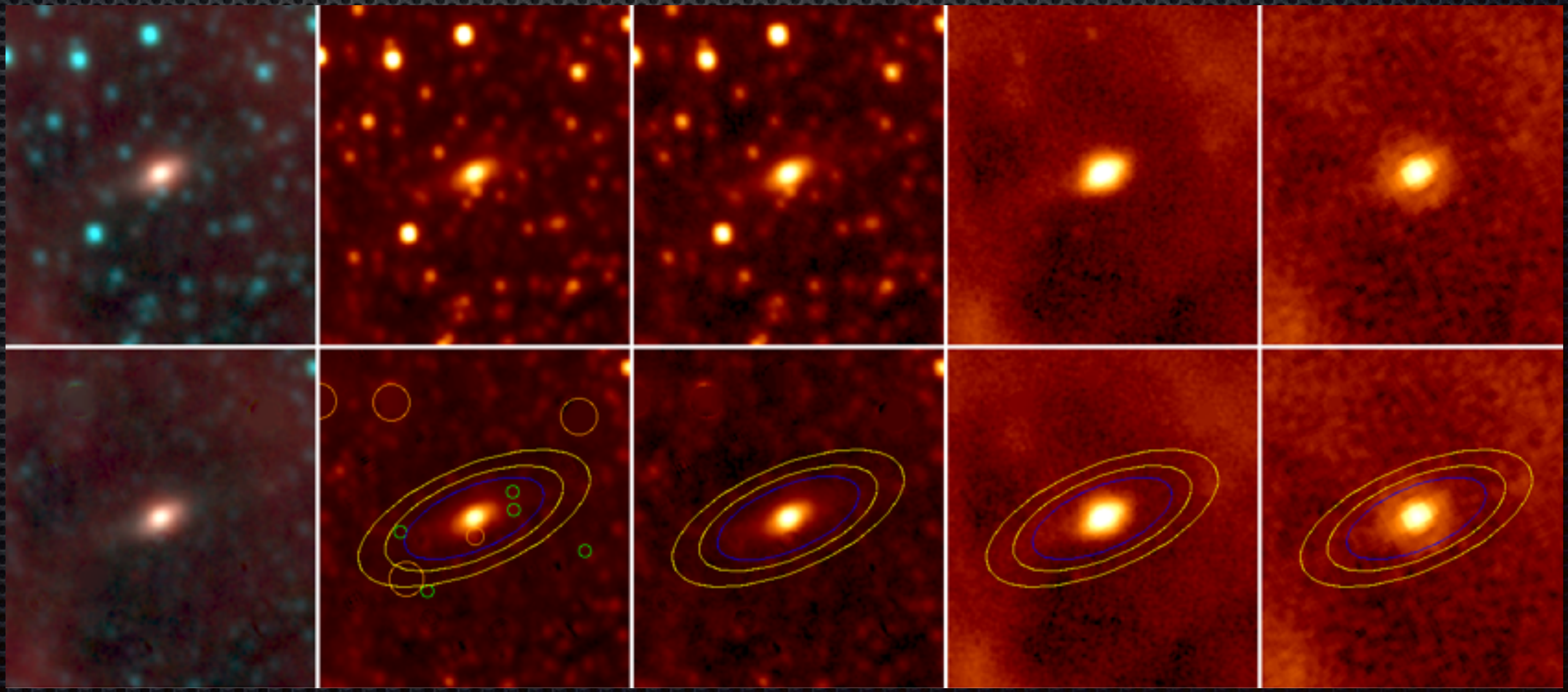
Cluver et al. 2008, 2010

Herschel and WISE Photometry

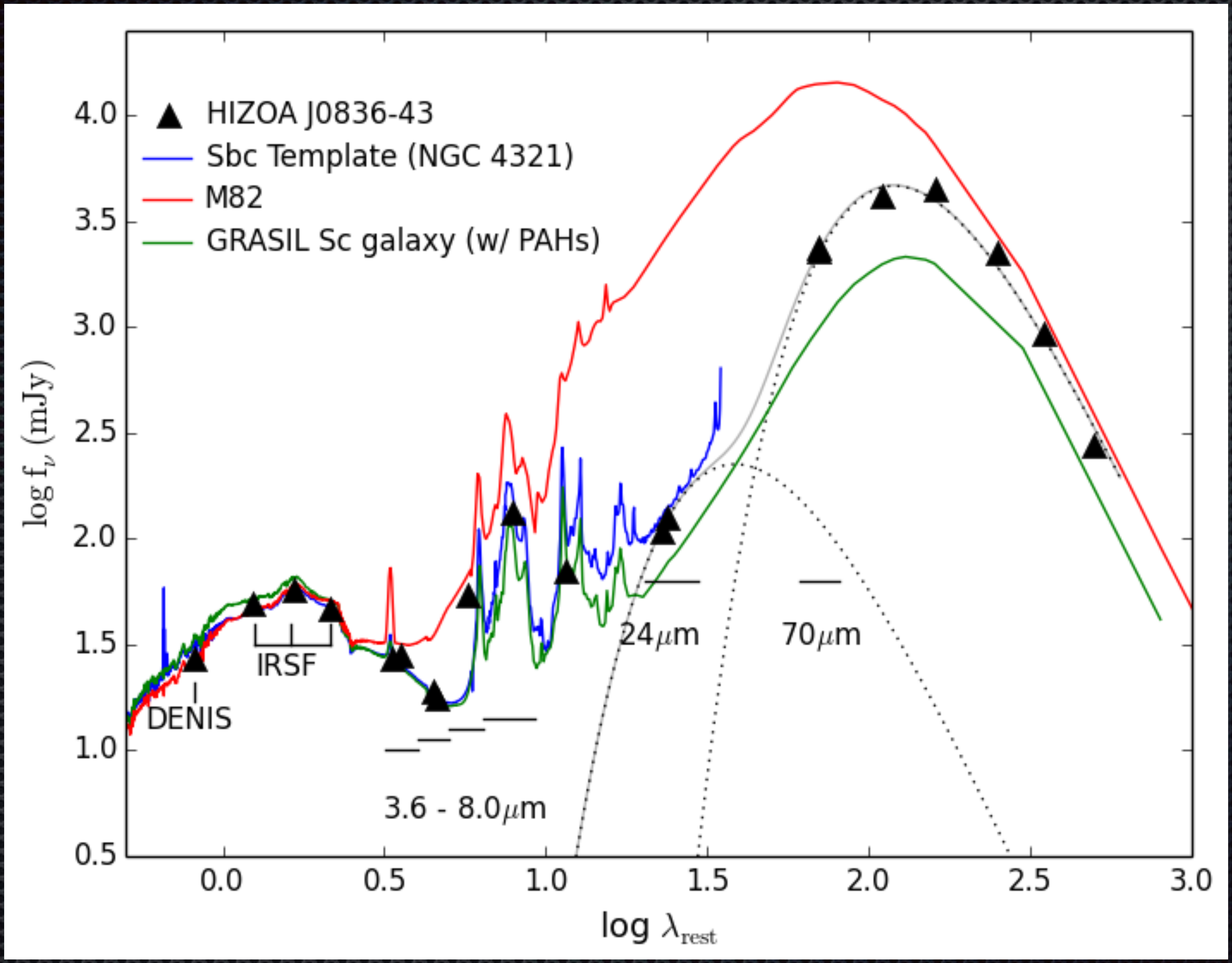


PACS 110μm

WISE



A Living LIRG



$L_{FIR} = 1.4 \times 10^{11}\ L_{\odot}$

SFR ~ 24 $M_{\odot}$ /yr

$M_{stellar} = 1.0 \times 10^{11}\ L_{\odot}$

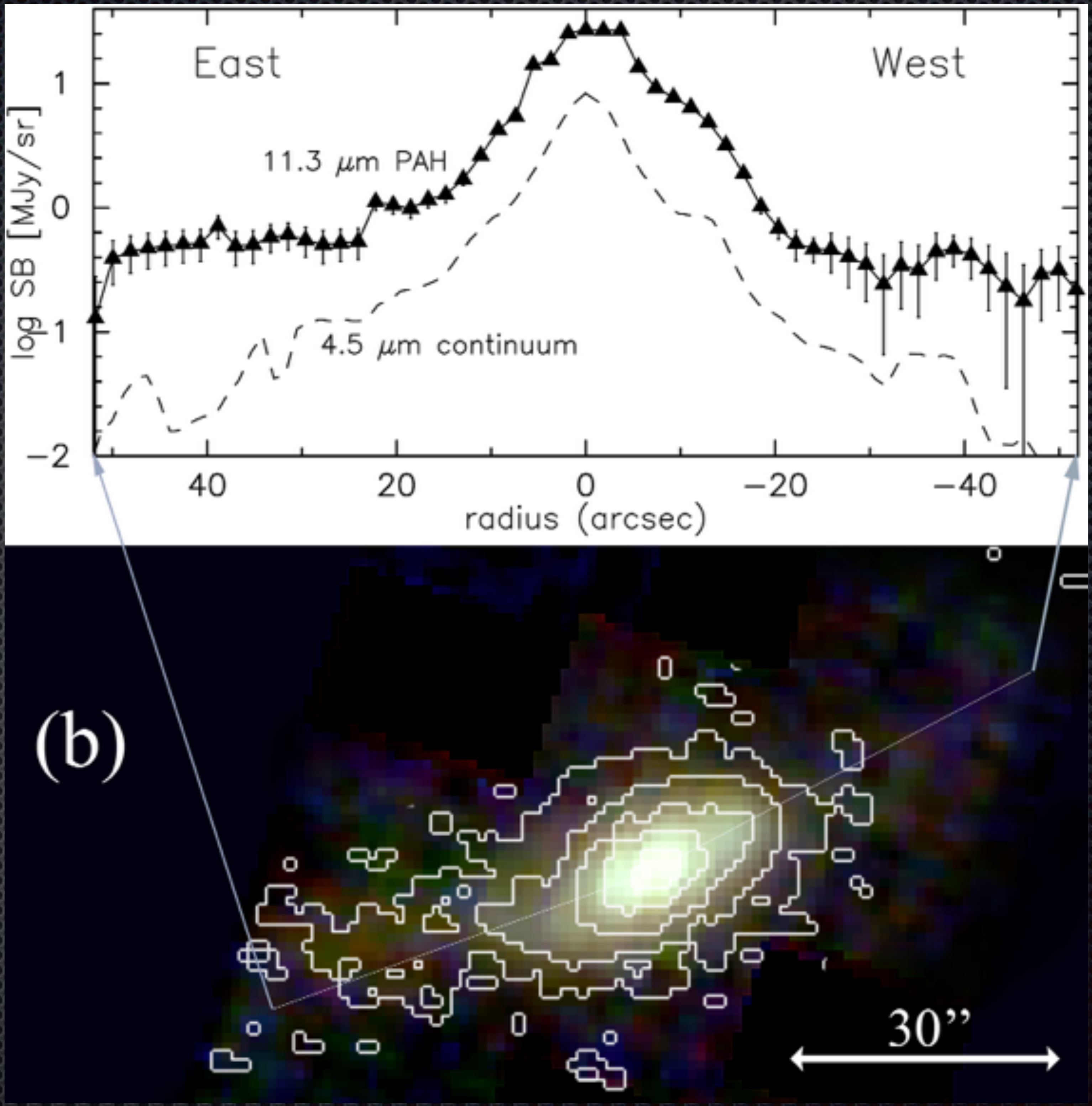
The Science Case

As we probe higher redshifts, populations with large neutral gas reservoirs will begin to dominate

Does this drive the SFR-stellar mass “main sequence” relation?

Models of star formation need a prescription for the chemistry and physics of star formation in extended star forming disks with large HI reservoirs (vs compact starbursts)

Inside-out Disk Building

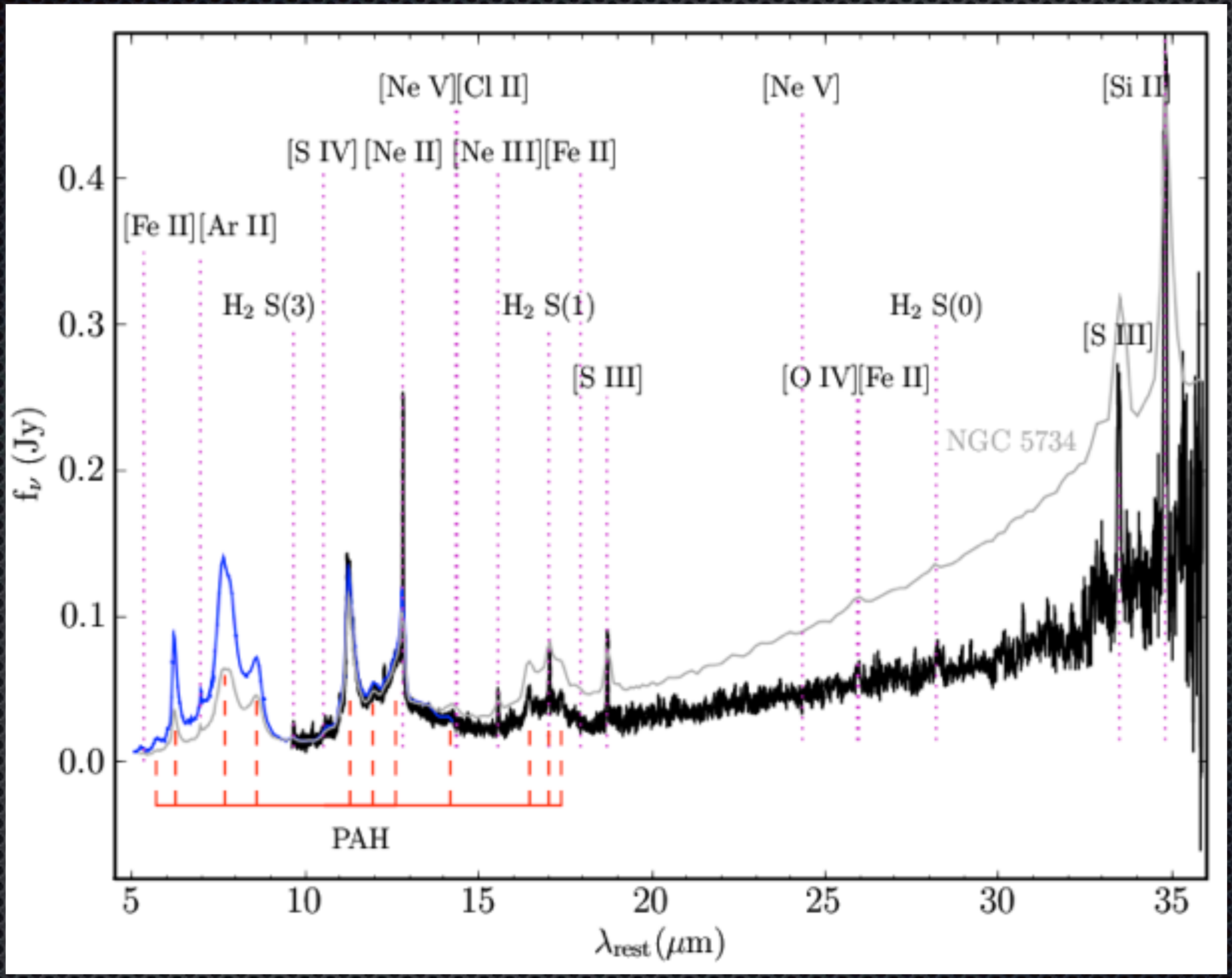


[NeII] contours
6.2+7.7+11.3μm
PAH map

Cluver et al.
ApJL (2008)

(See Perez et al. 2013 — CALIFA)

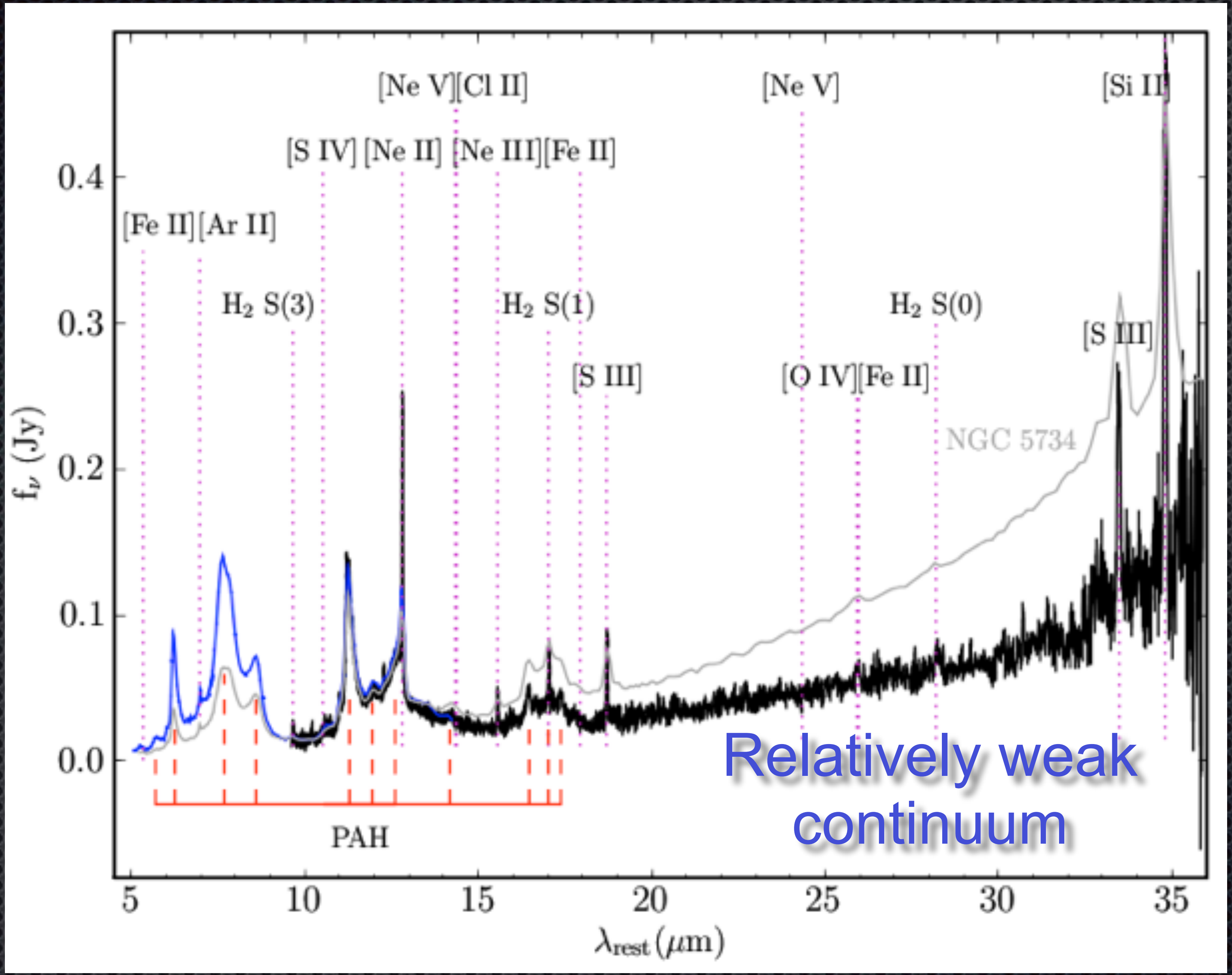
Spitzer Spectroscopy



Cluver et al. 2010

Compared to local LIRGs the PAH emission was anomalously strong and the continuum relatively weak

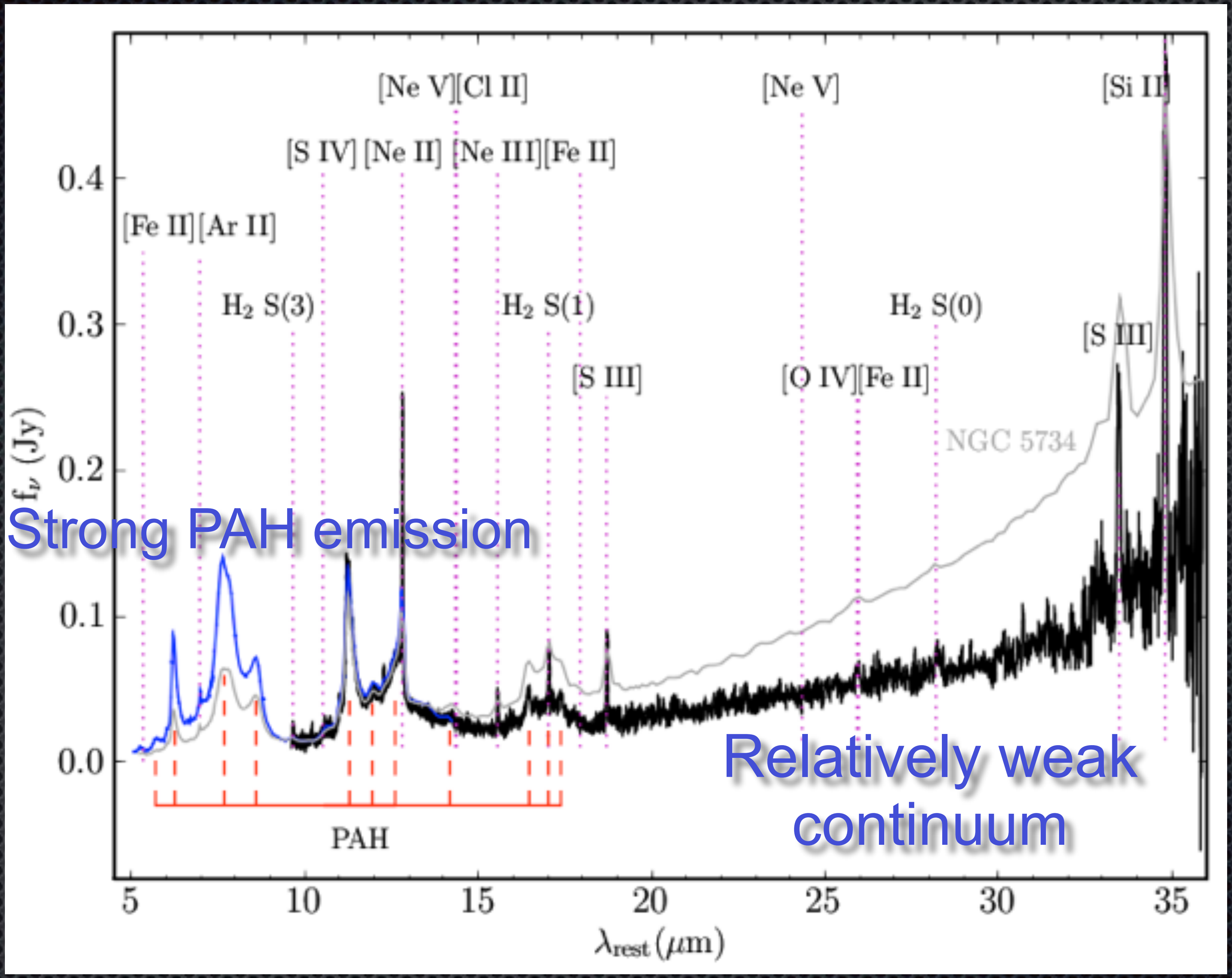
Spitzer Spectroscopy



Cluver et al. 2010

Compared to local LIRGs the PAH emission was anomalously strong and the continuum relatively weak

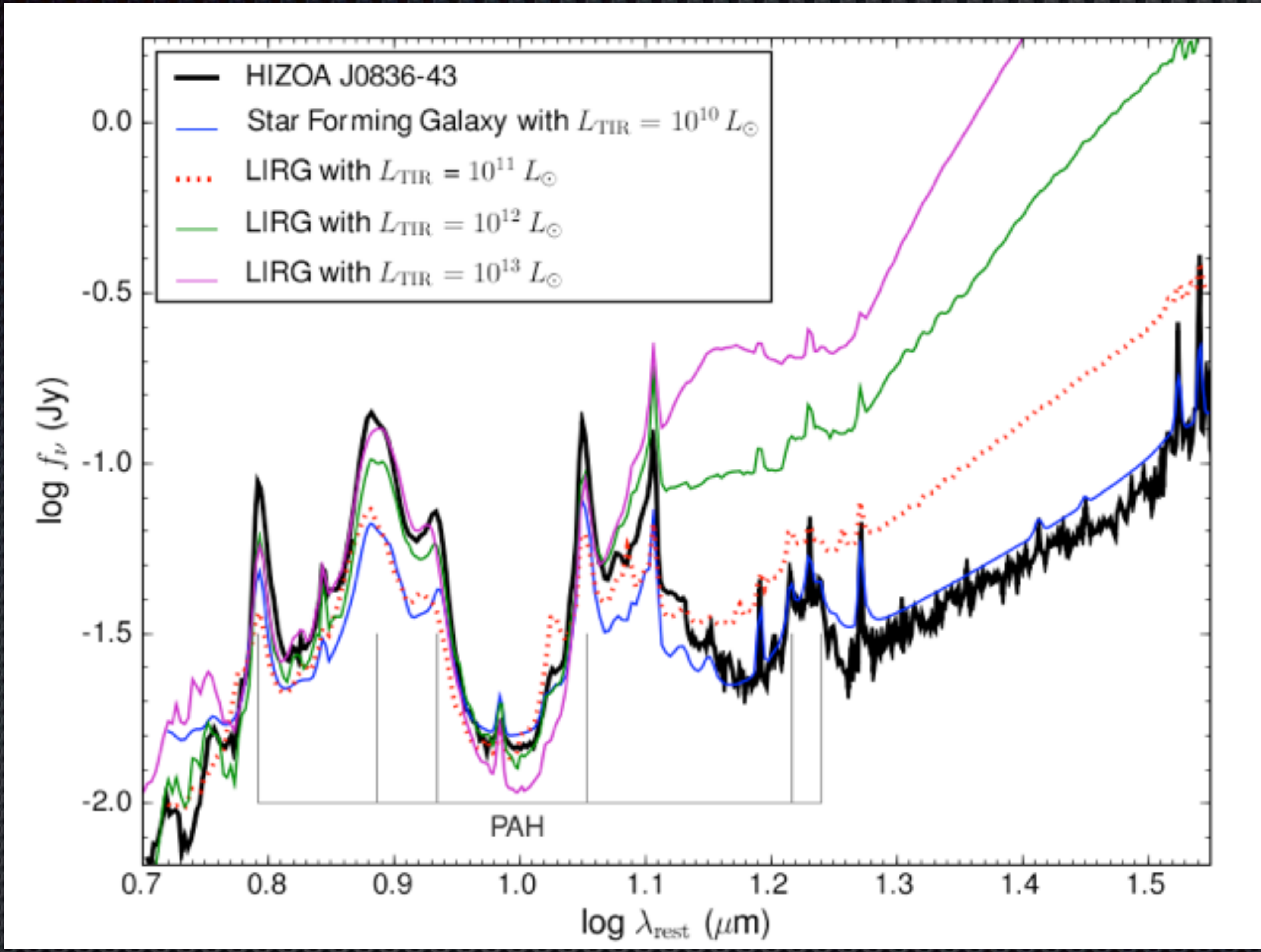
Spitzer Spectroscopy



Cluver et al. 2010

Compared to local LIRGs the PAH emission was anomalously strong and the continuum relatively weak

Local LIRG Models – Rieke et al. (2009)

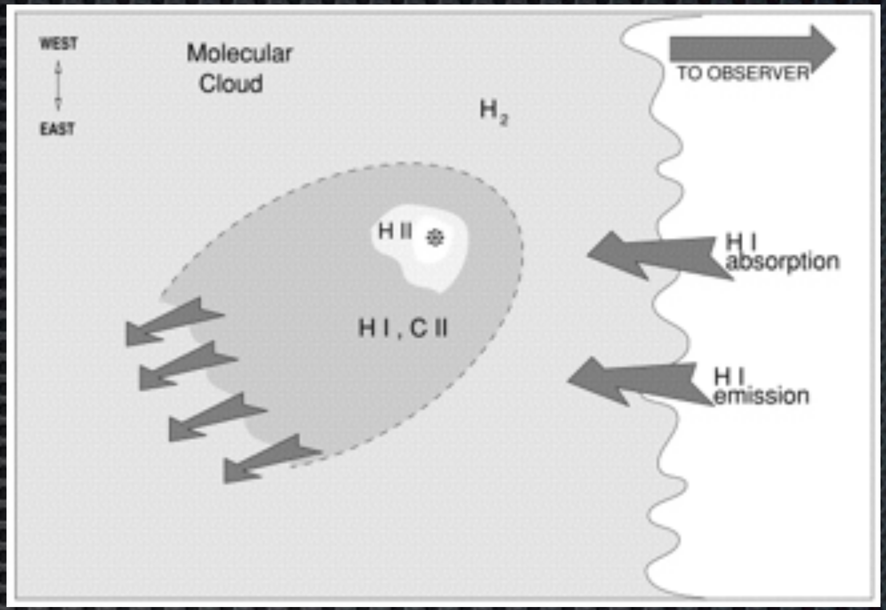


Cluver et al. 2010

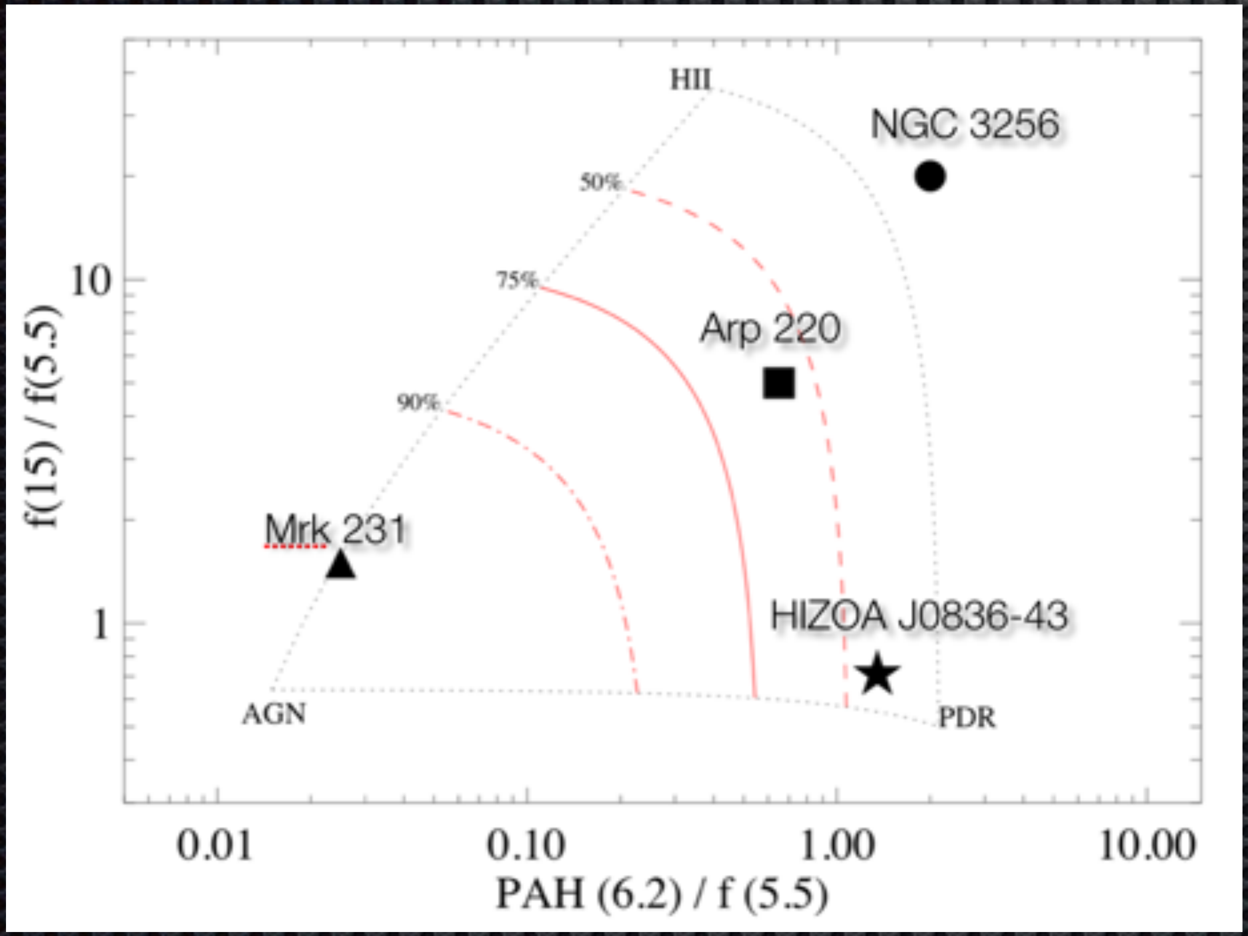
At best it looks like a local star forming galaxy with powerful PAH emission i.e. star formation

PDR-dominated emission

Lack of warm dust continuum and strong PAH emission



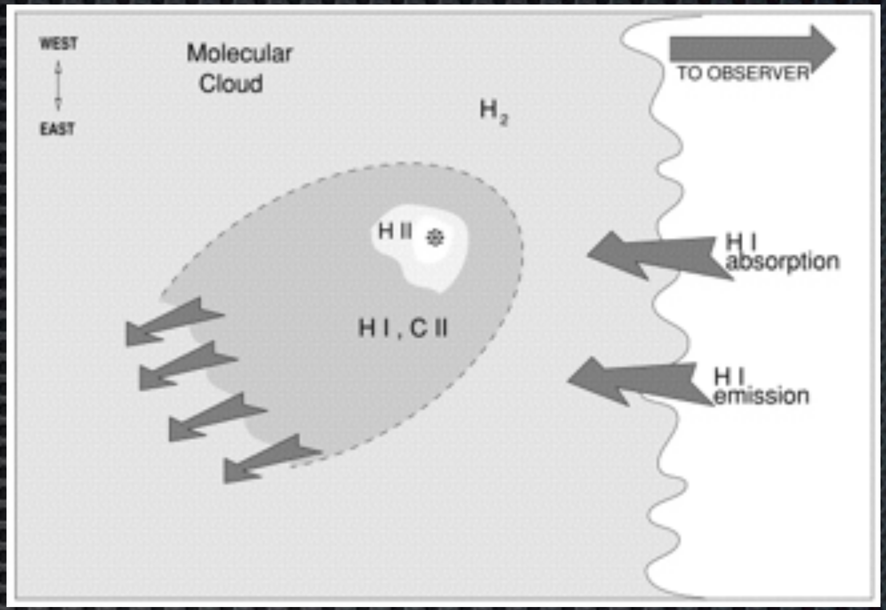
From Gomez et al. 1998



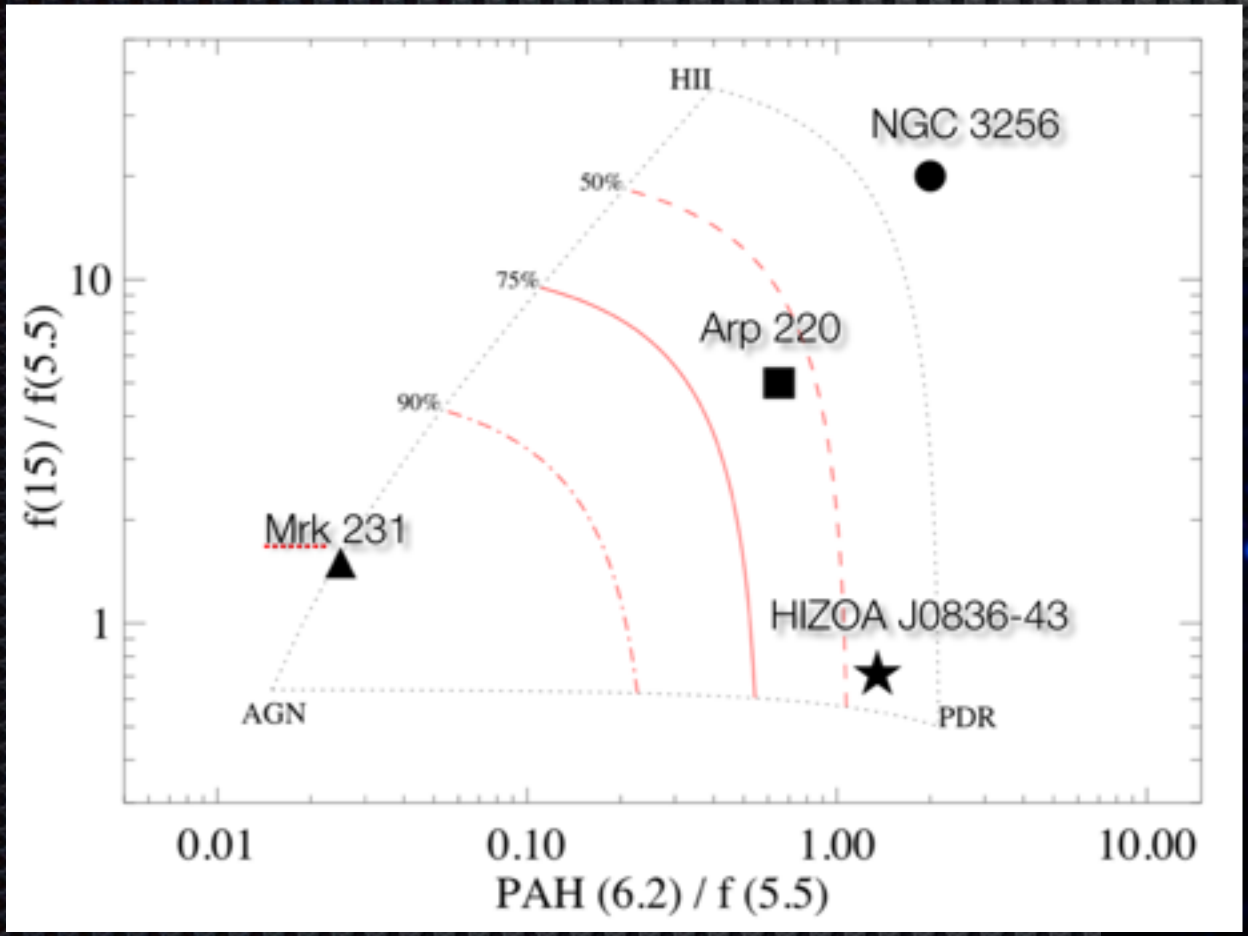
Modified from Armus et al. 2007

PDR-dominated emission

Lack of warm dust continuum and strong PAH emission



From Gomez et al. 1998



Modified from Armus et al. 2007

The prototypical PDR

emission

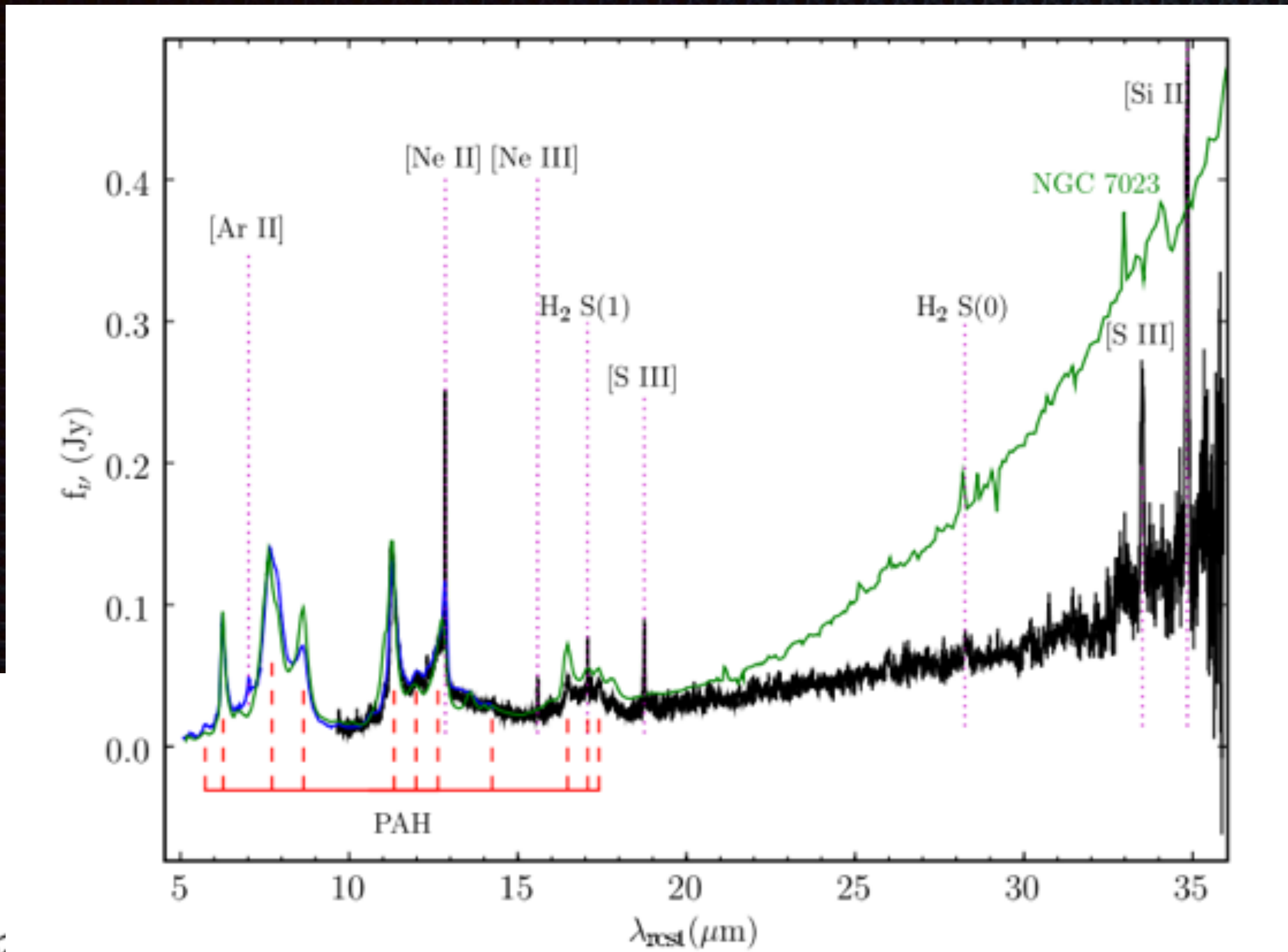
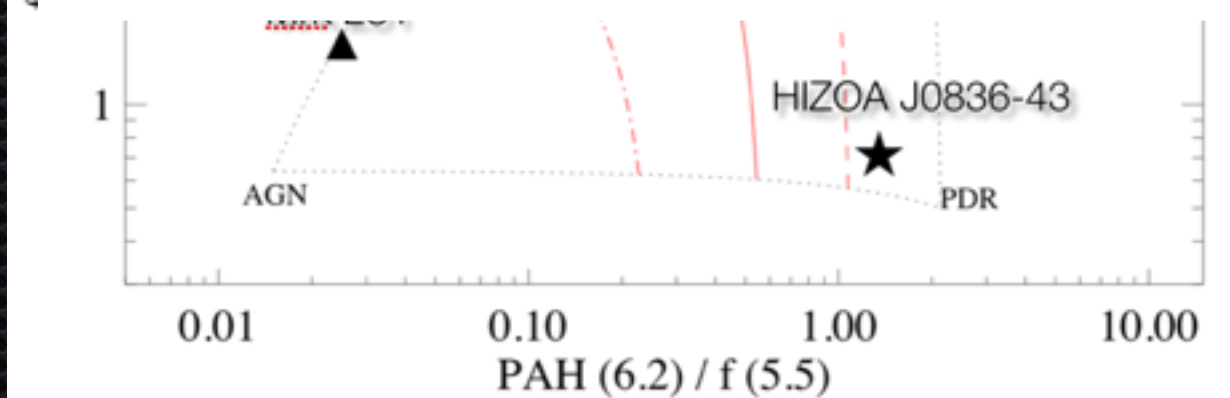
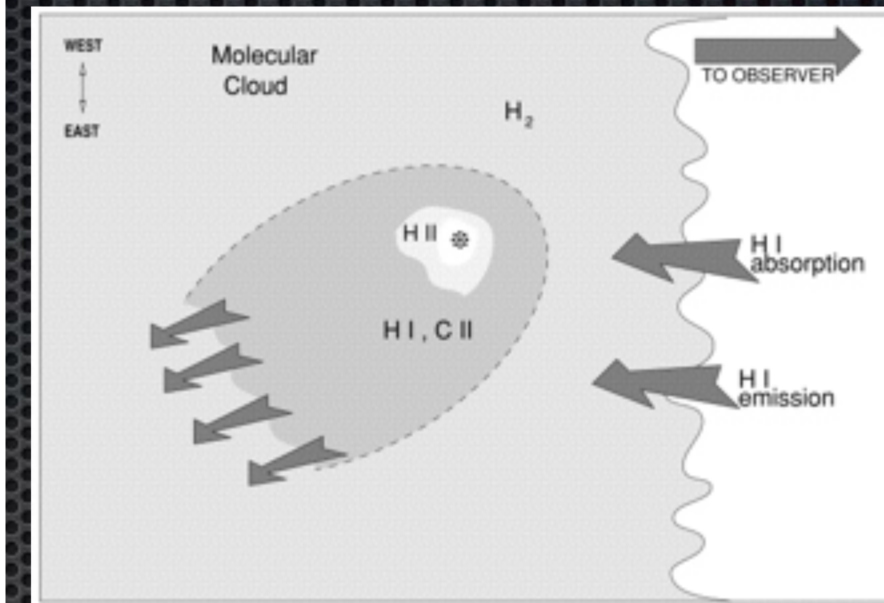


Figure 6. Spectrum of HIZOA J0836-43 in comparison to the Galactic reflection nebula NGC 7023 (green) with the low-resolution *Spitzer* spectrum of NGC 7023 scaled to match HIZOA J0836-43 at 10 μm.



Modified from Armus et al. 2007



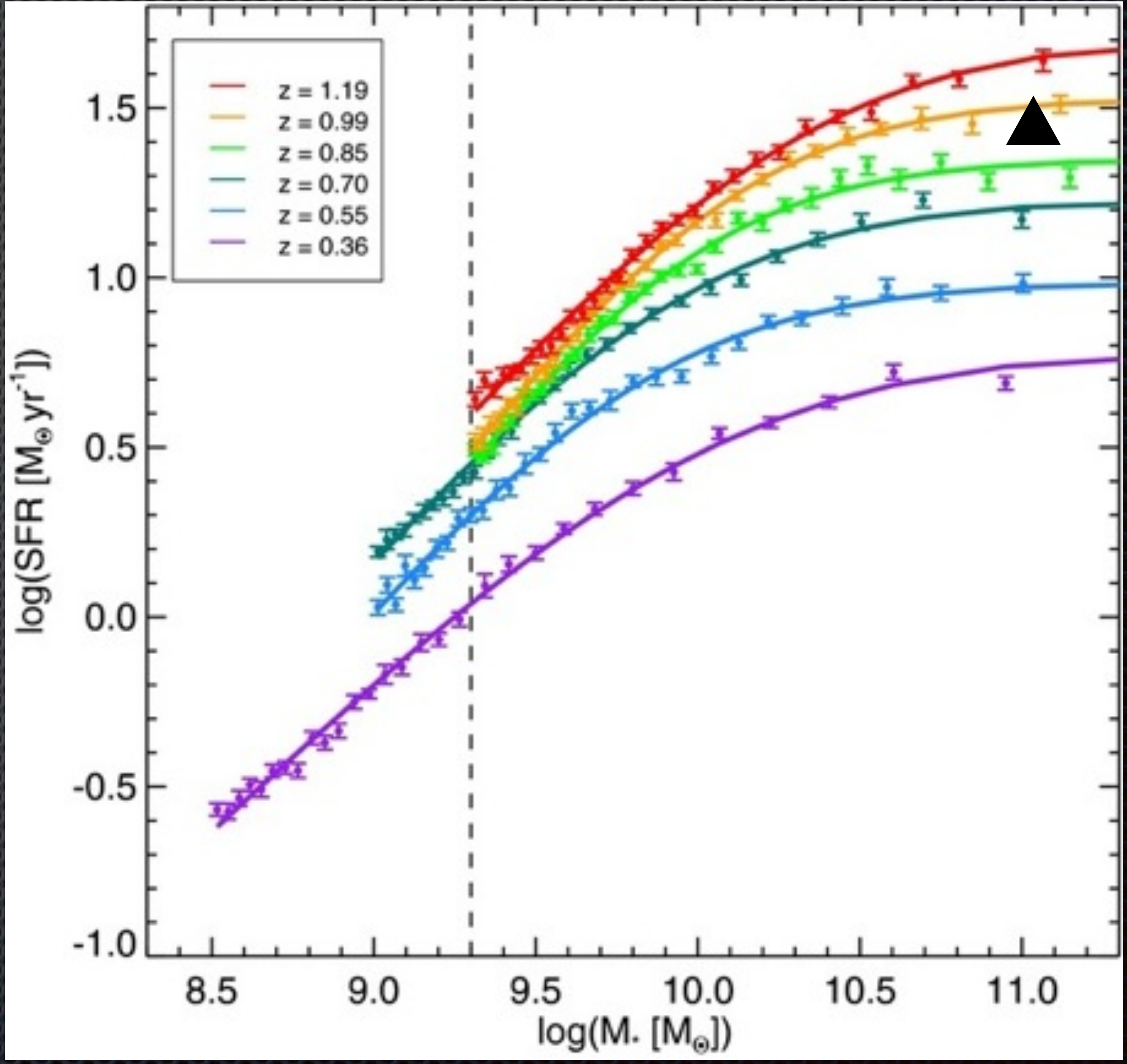
From Gomez et al. 1998

The prototypical PDR

SFR and Stellar Mass are linearly related

Noeske et al. (2007), Daddi et al. (2007), Elbaz et al. (2007)

$M_\star$ - SFR relation scales with cosmic time —> SFR increases with redshift for a given stellar mass



"Main Sequence" galaxies have larger sizes and exponential disk profiles; higher gas to total mass ratios

Lee et al. (2015)

A Local Analogue?

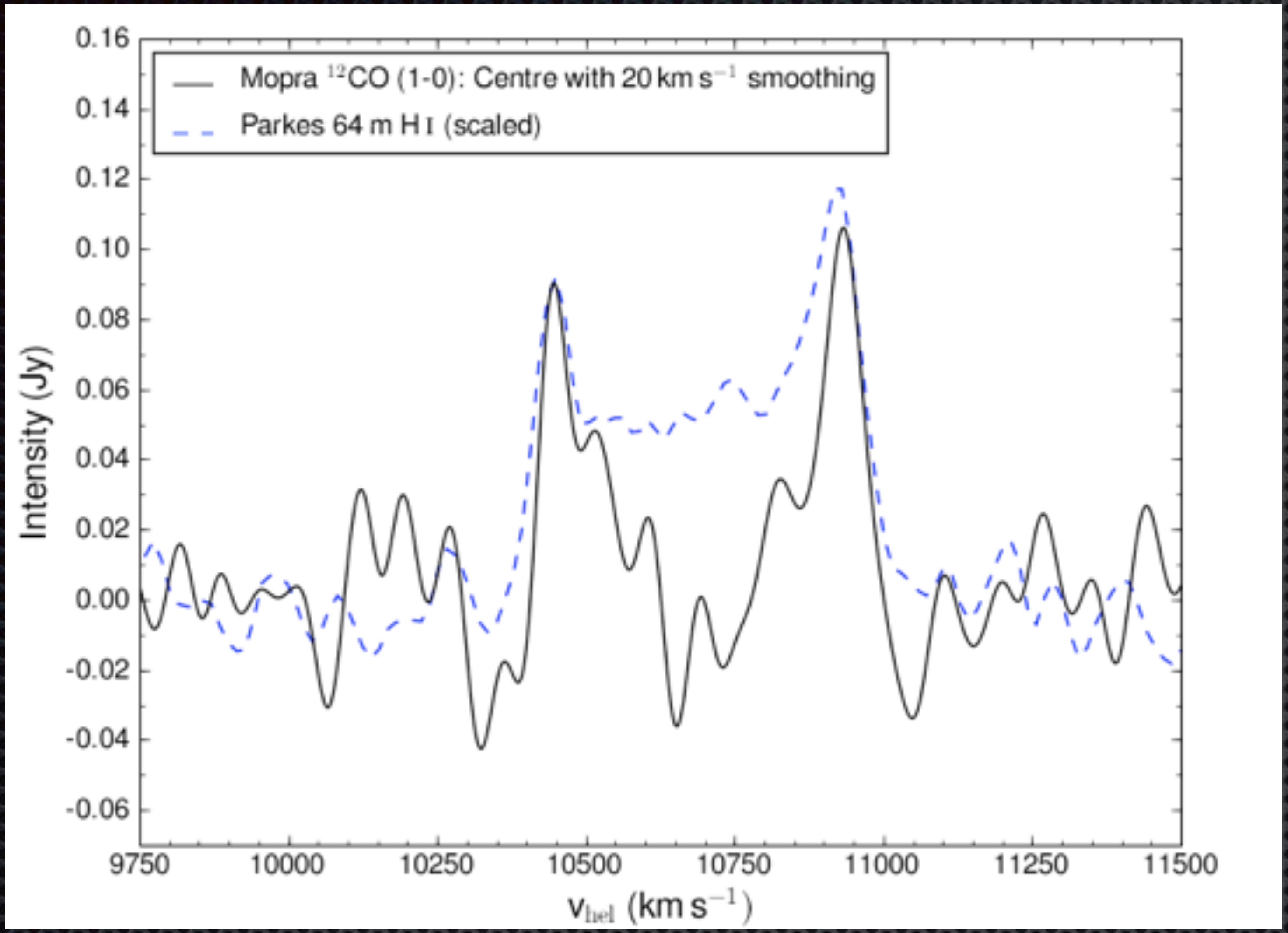
Larger gas fractions at higher redshift permit larger L_{IR} before invoking special events like mergers and will shift correlations with L_{IR} (Nordon et al. 2012)

Main-sequence galaxies at $0.7<z<2.5$ have constant IR8= $L_{IR}/\nu L_{\nu}(8\mu m)$ ~ 3.8 (independent of L_{IR} and redshift)

HIZOA J0836-43 — IR8: $L_{IR}/\nu L_{\nu}(8\mu m)$ ~ 3.4

Lee et al. (2013) — IR8: 4±1.6

What about CO?

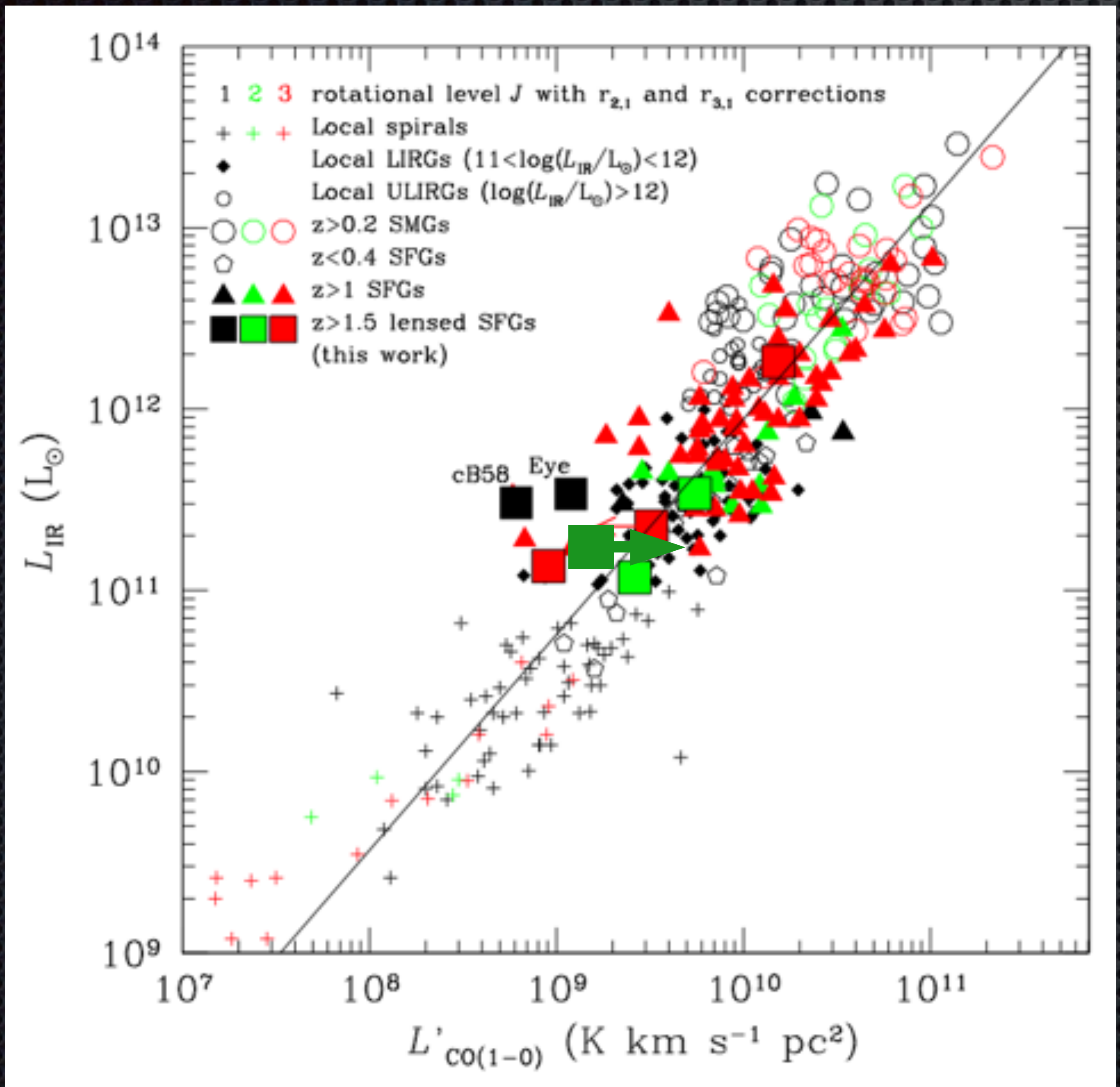


Lower Limit: M_{H2+He} = $3.7 \times 10^9\ M_\odot$

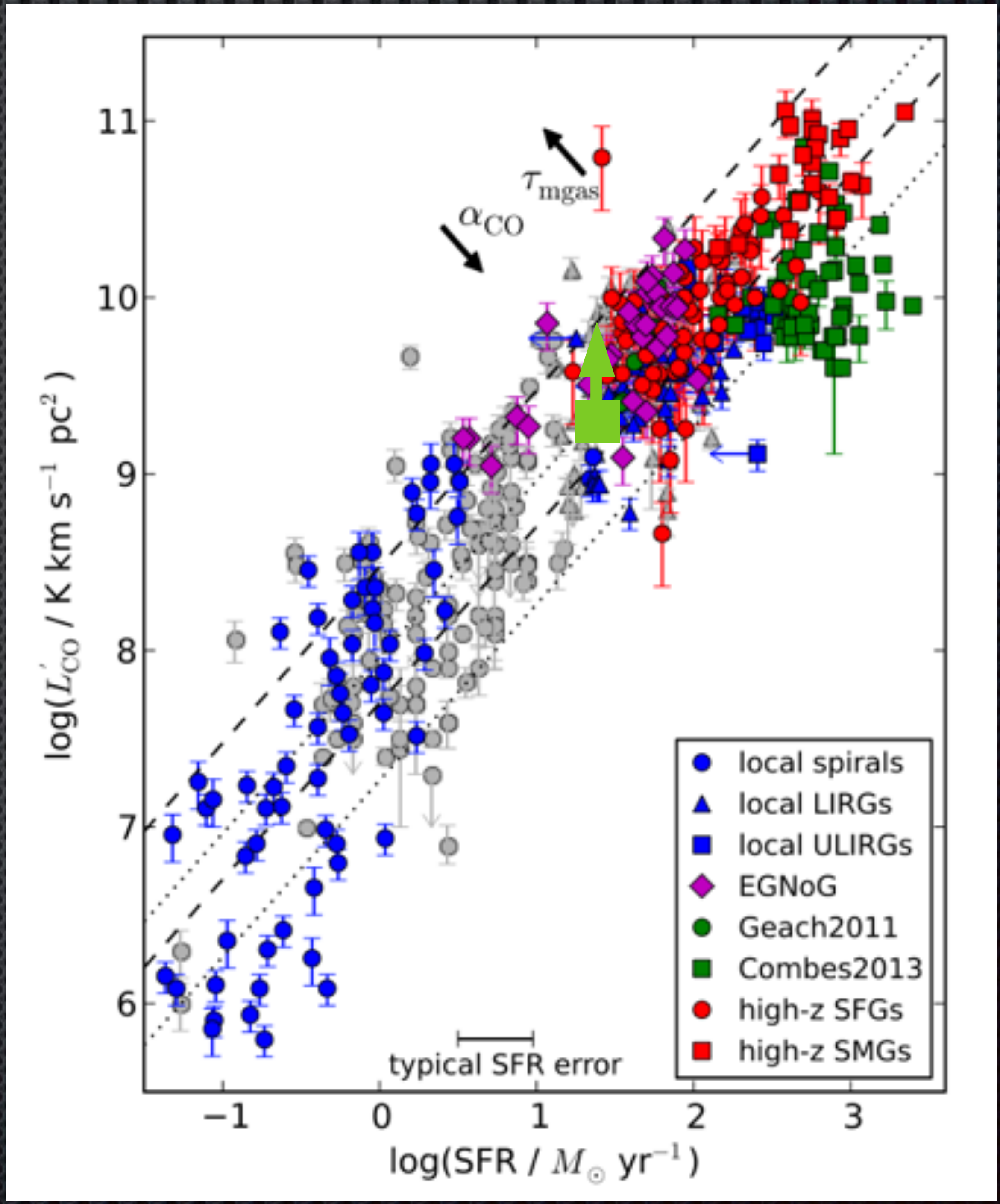
Gas Fraction > 0.64 & Mol. Gas Fraction > 0.08

$L'_{CO} \sim 9.14 \times 10^8$ K.km.s^{-1}.pc^2

Trying to fit in….



Dessauges-Zavadsky et al. (2014)



Bauermeister et al. (2013)

The Main Sequence

z~ 0.6

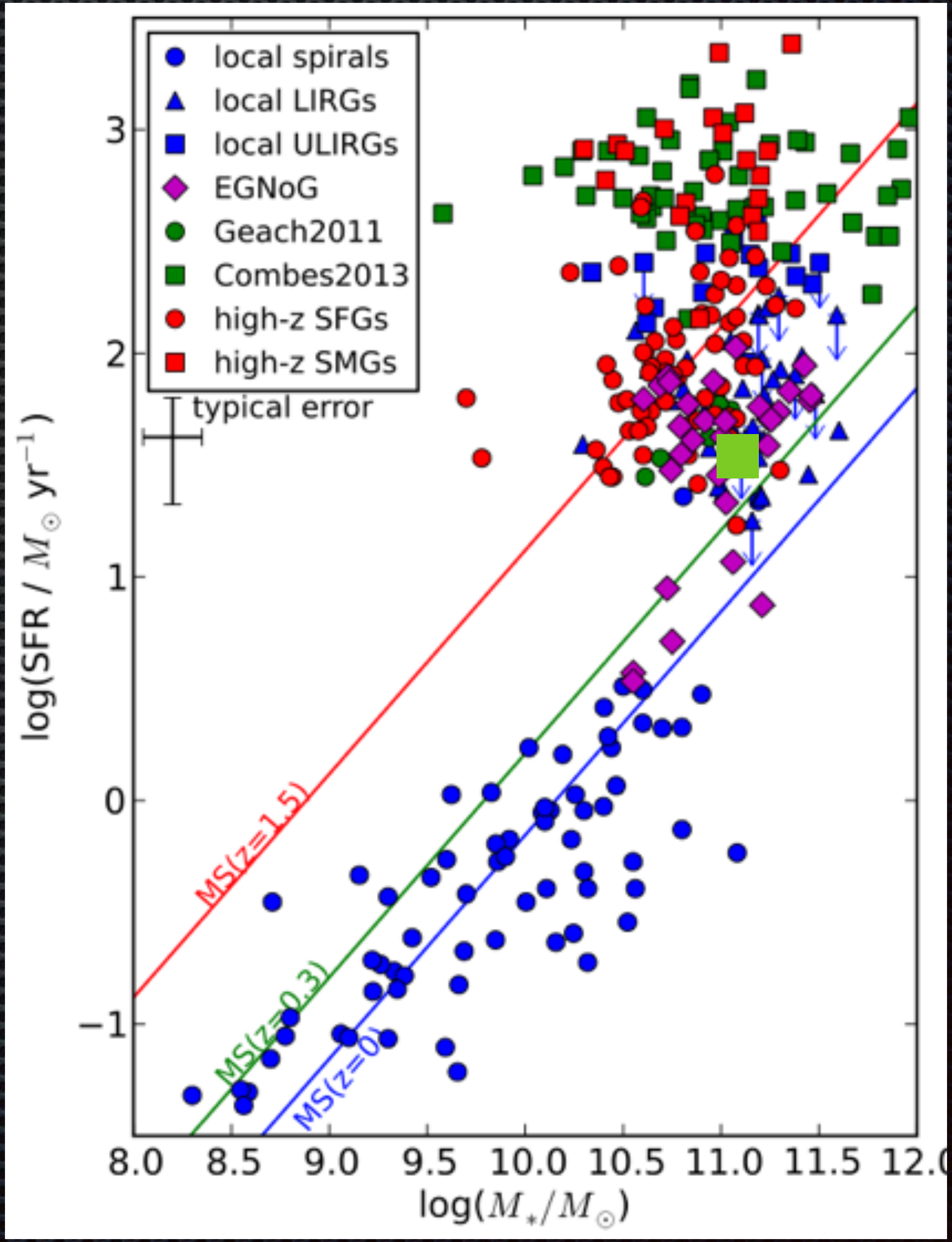
$$\dot{M}_\star = 150\, M_{\star,11}^{p}\, (1+z)_{3.2}^{q}\, M_\odot\ \mathrm{yr}^{-1}\,, \qquad (1)$$

where $M_{\star,11} \equiv M_\star/10^{11}\, M_\odot$, $(1+z)_{3.2} \equiv (1+z)/3.2$, $p \simeq 0.8$, and $q \simeq 2.7$ in the redshift range $z = 0$–2.[6] Reproducing the

Bouché et al. (2010)

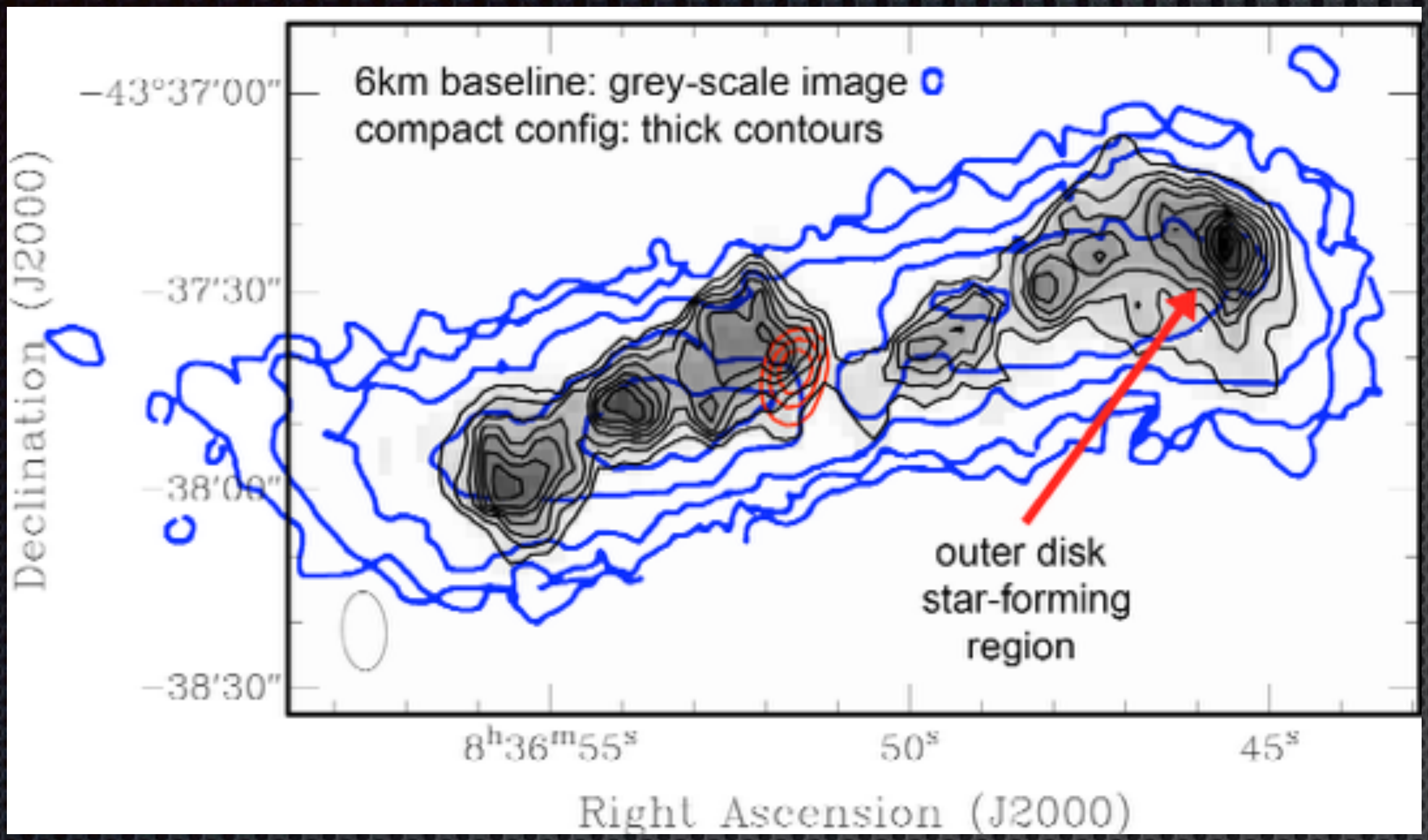
z~ 0.5

$$\mathrm{sSFR_{MS}}(\mathrm{Gyr}^{-1}) = 0.07(1+z)^{3.2} \left(\frac{M_*}{10^{11}\ M_\odot}\right)^{-0.2}$$



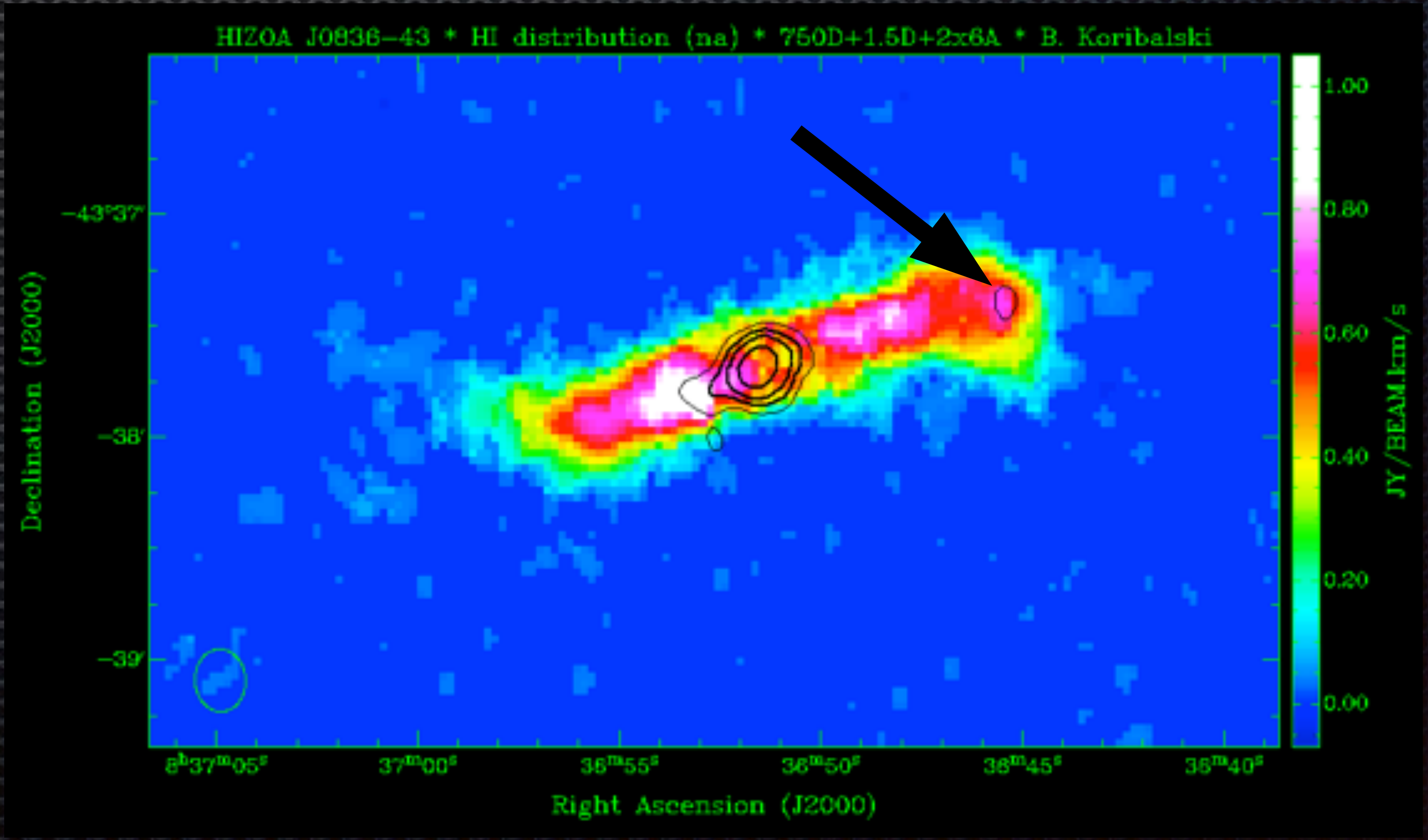
Bauermeister et al. (2013)

Back to ATCA



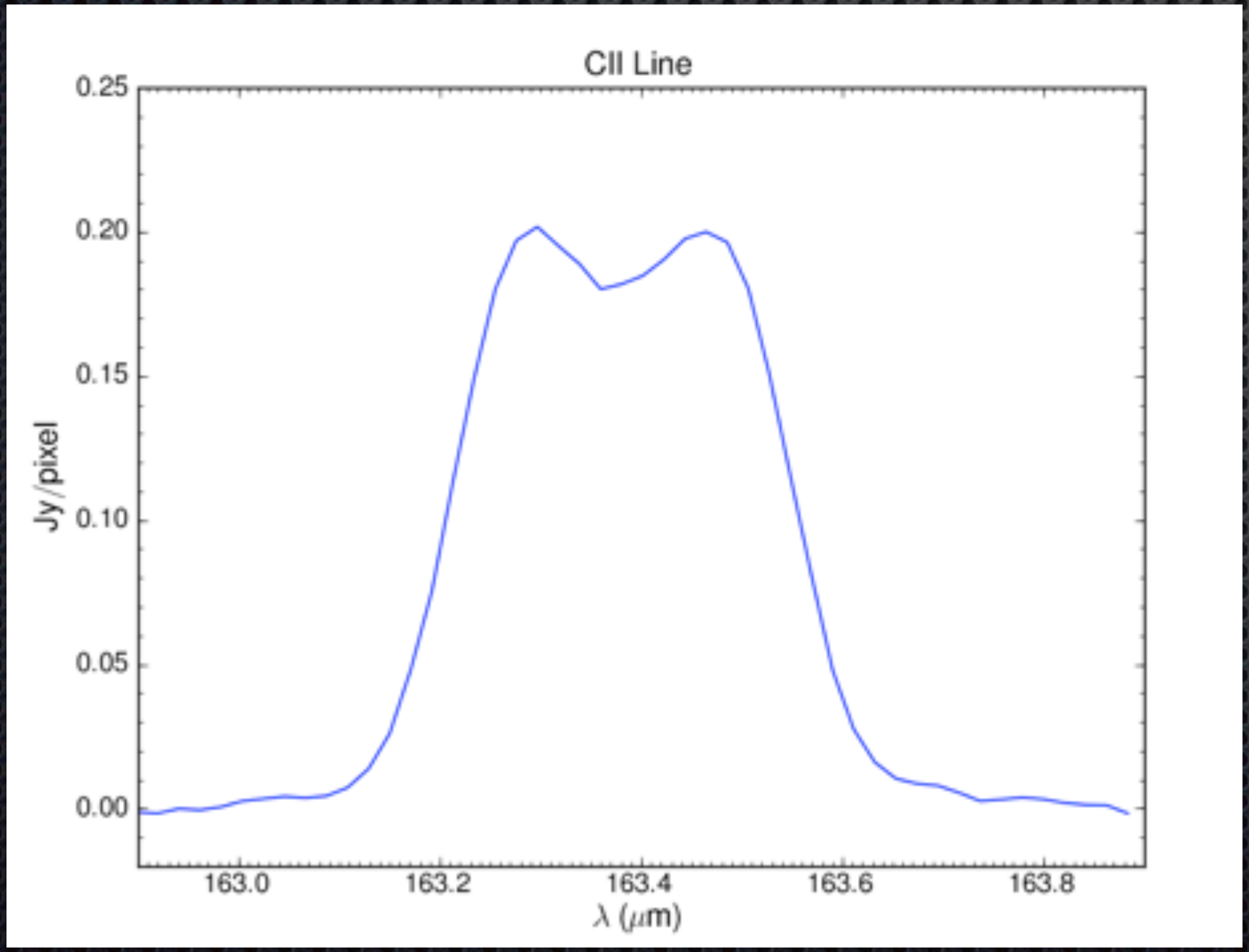
ATCA 6km baselines + CABB added February 2011

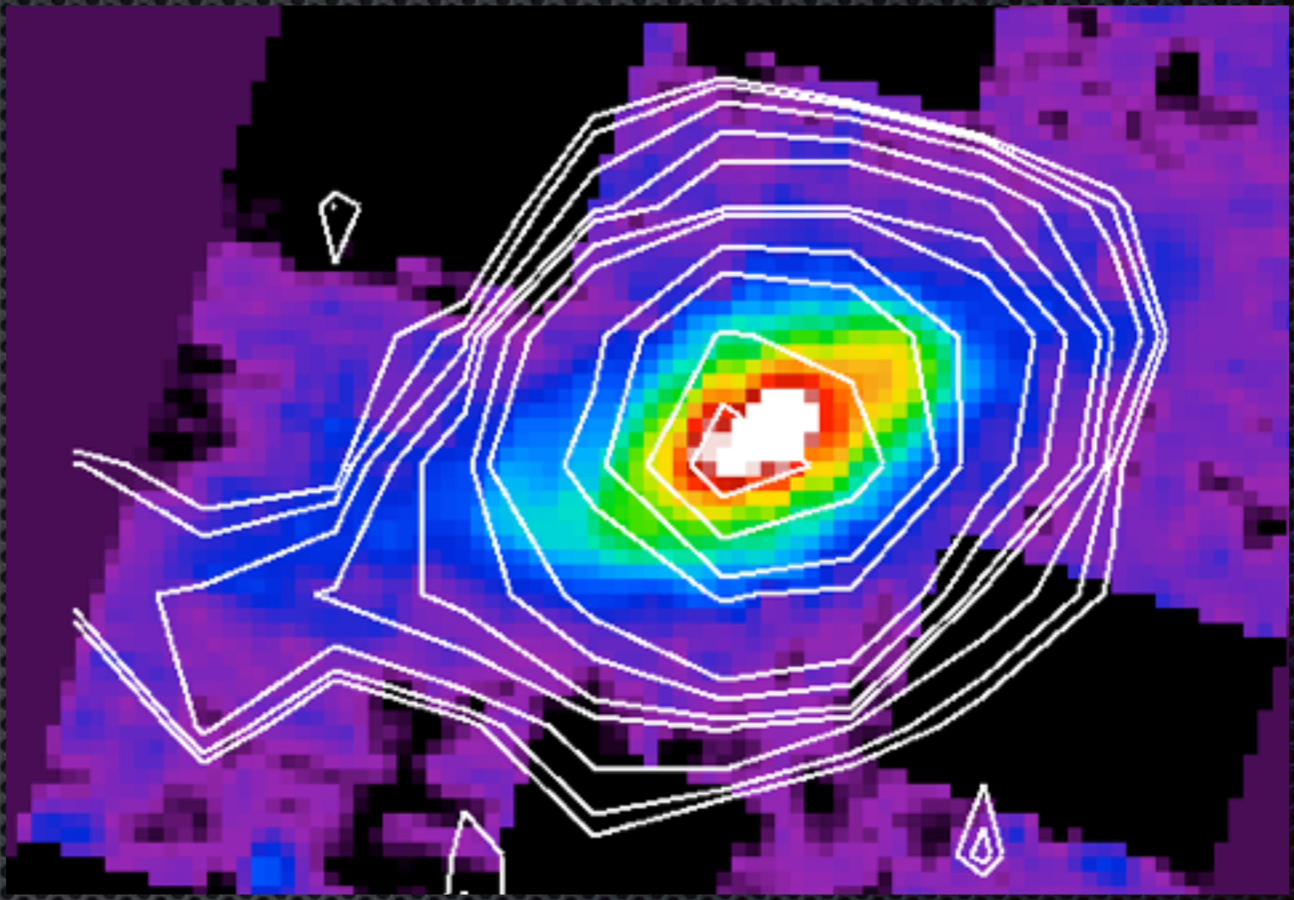
HI data combined by B. Koribalski



Herschel PACS Spectroscopy

[CII] tracers PDR cooling and also dominant ionisation in neutral gas



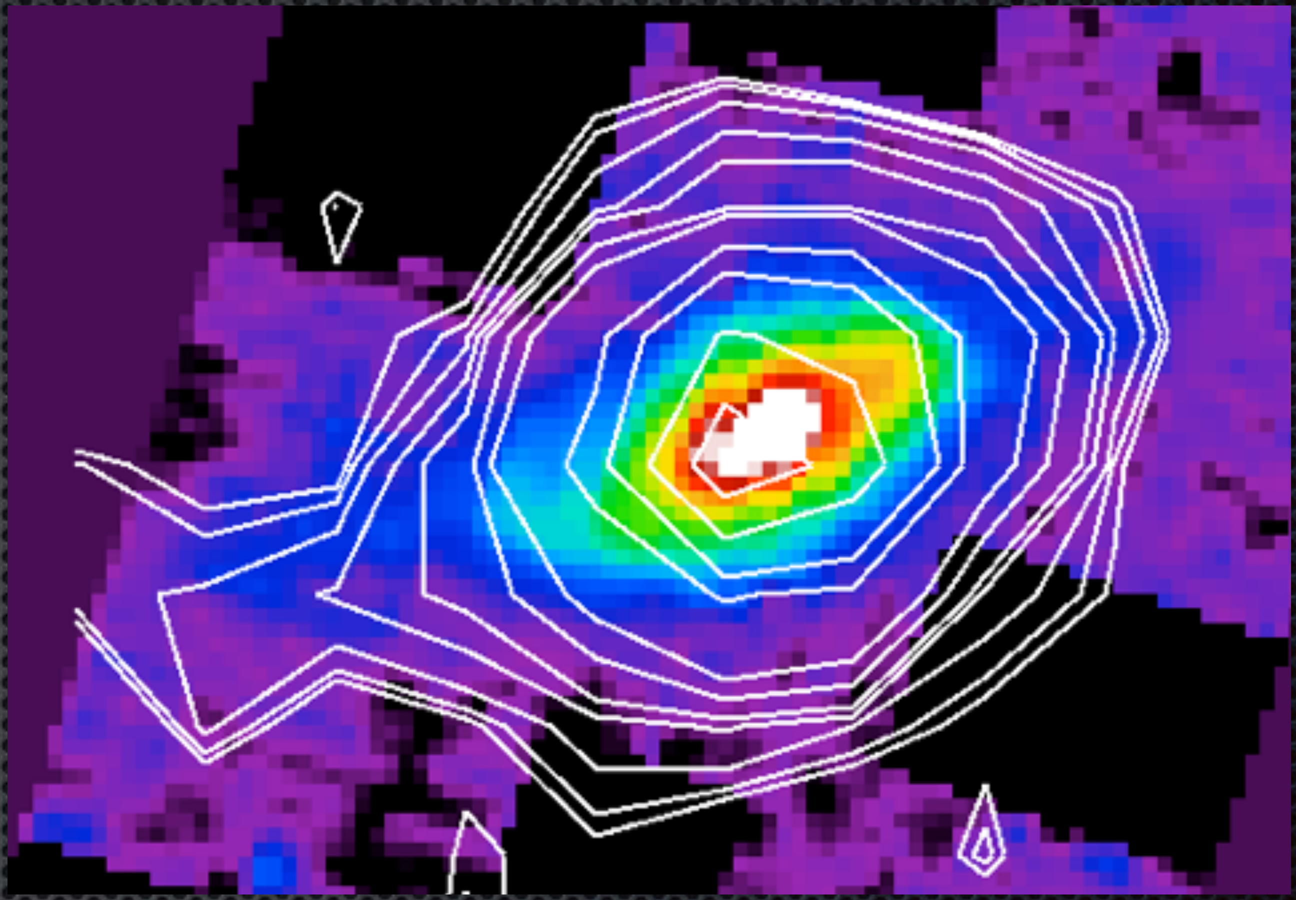


[CII] on 8μm PAH map

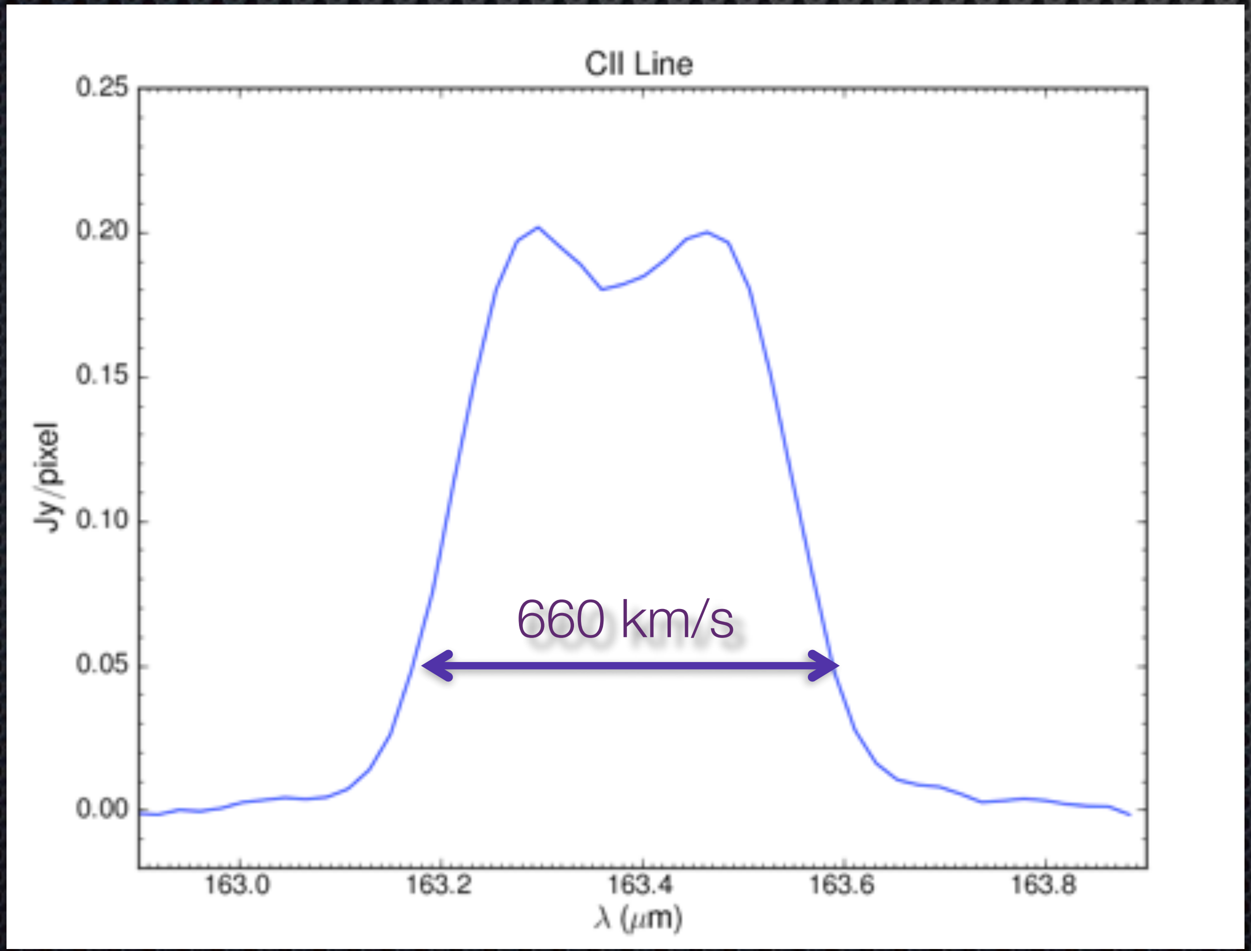
Cluver et al. (in prep.)

Herschel PACS Spectroscopy

[CII] tracers PDR cooling and also dominant ionisation in neutral gas



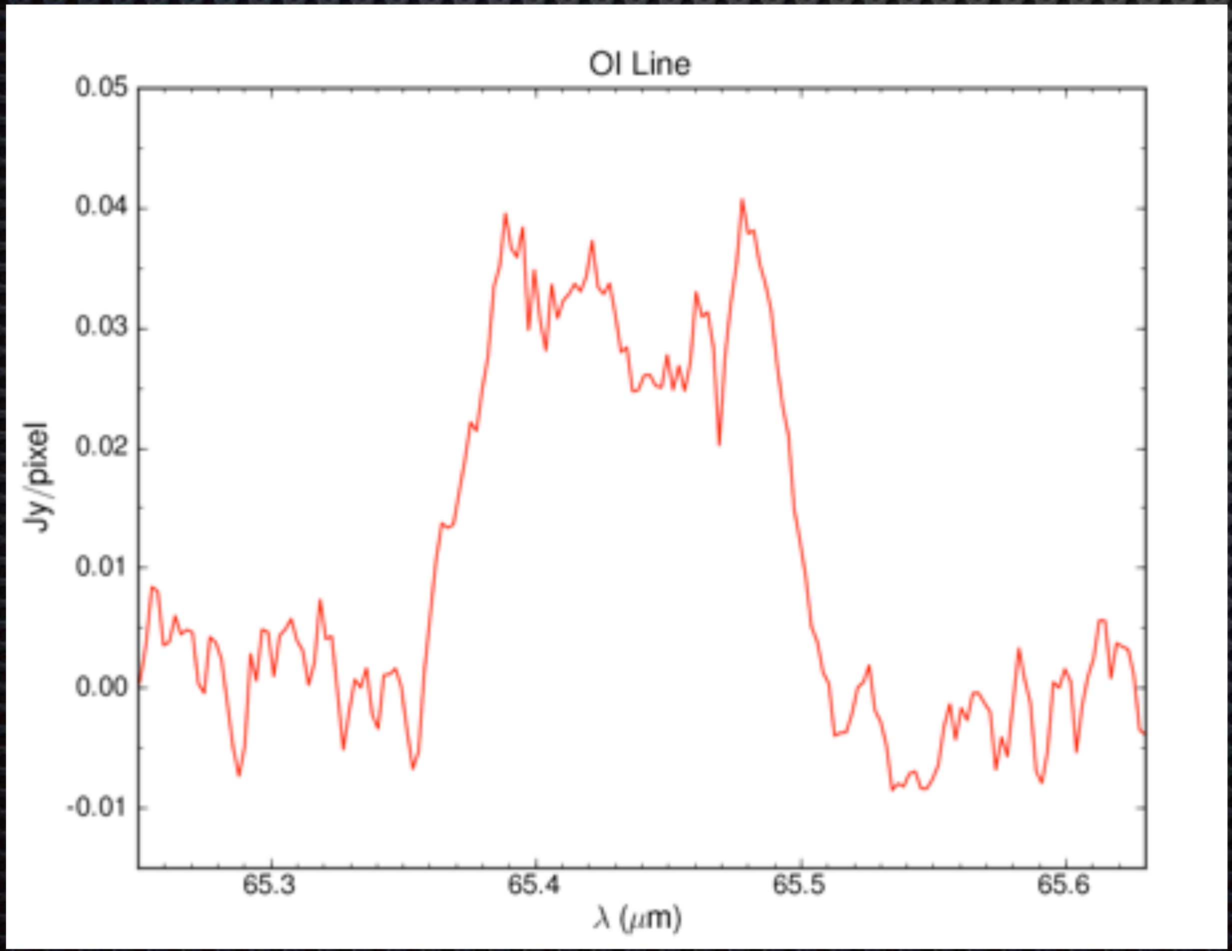
[CII] on 8μm PAH map

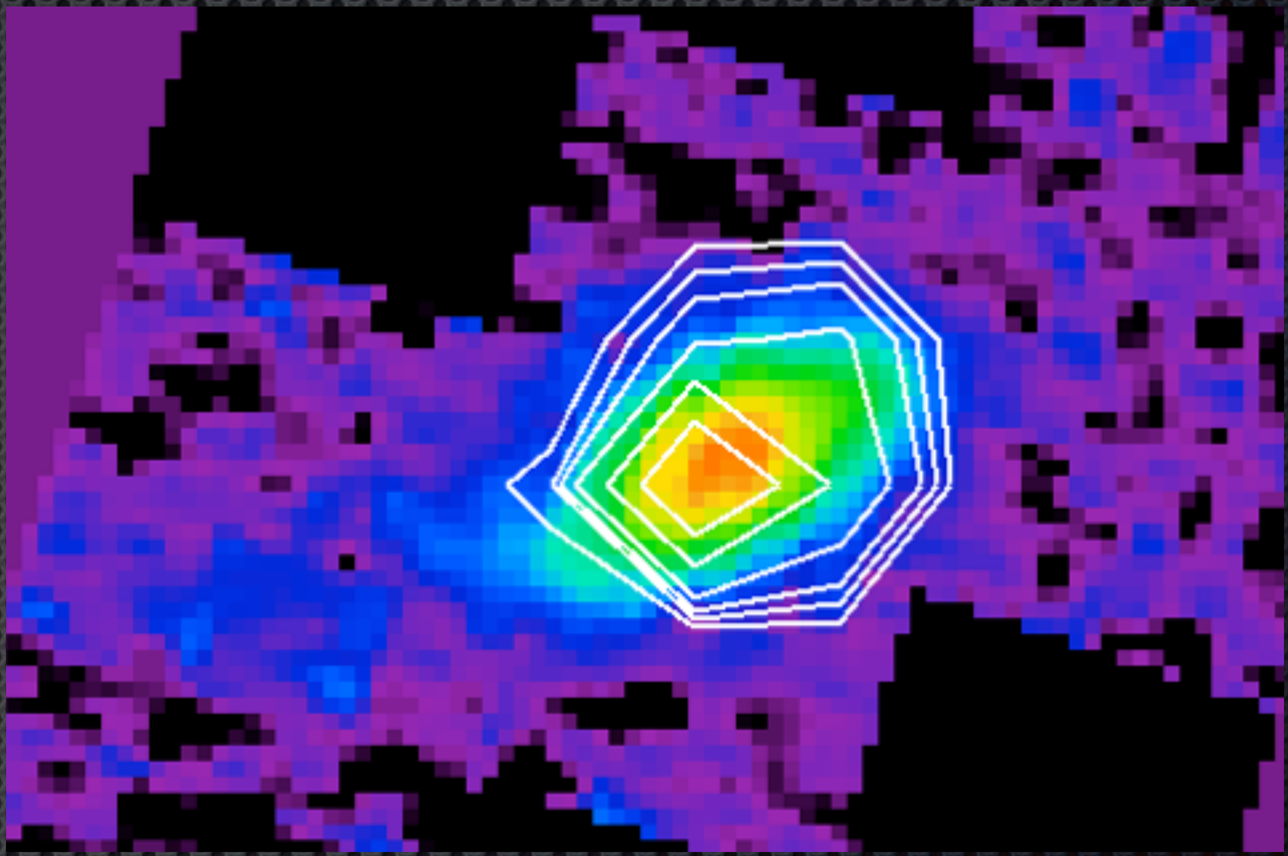


Cluver et al. (in prep.)

Herschel PACS Spectroscopy

[OI] tracers dense PDR cooling e.g. compact starburst

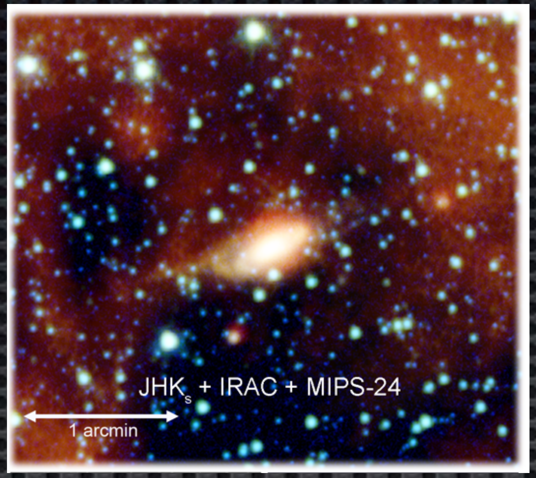


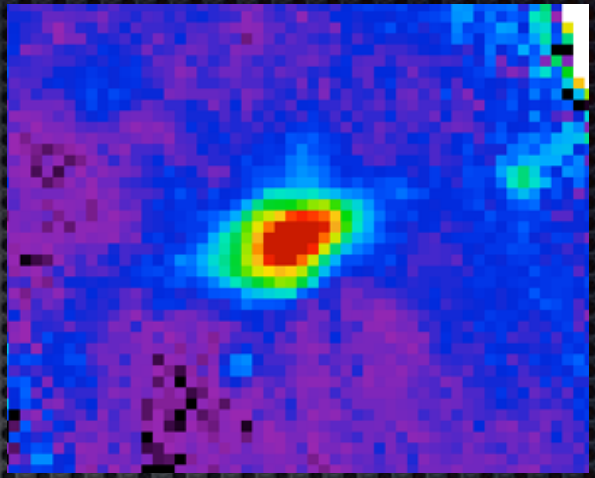


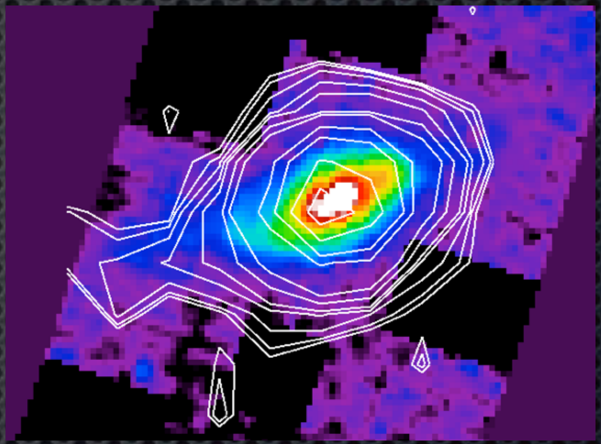
[OI] on 8μm PAH map

Cluver et al. (in prep.)

Summary

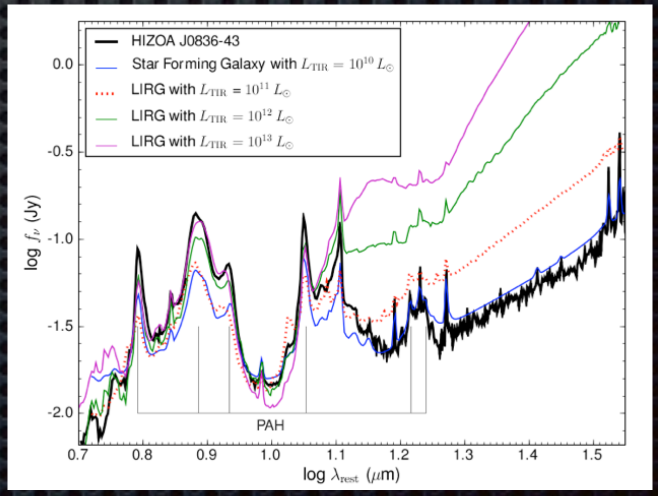






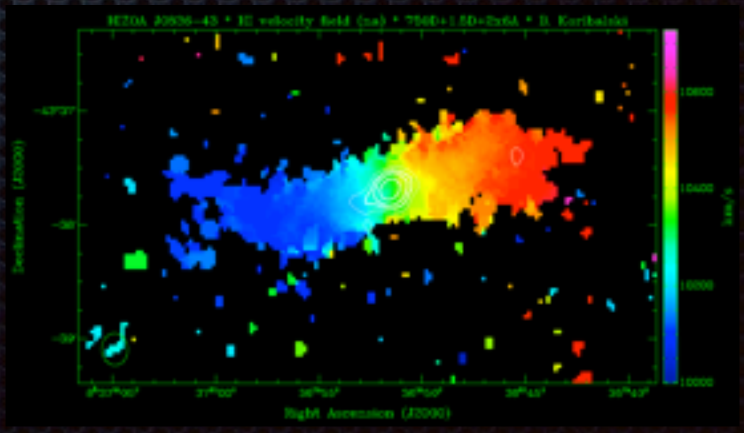
The coolest galaxy you've never heard of

Gas-rich LIRG—> PDR-dominated star formation



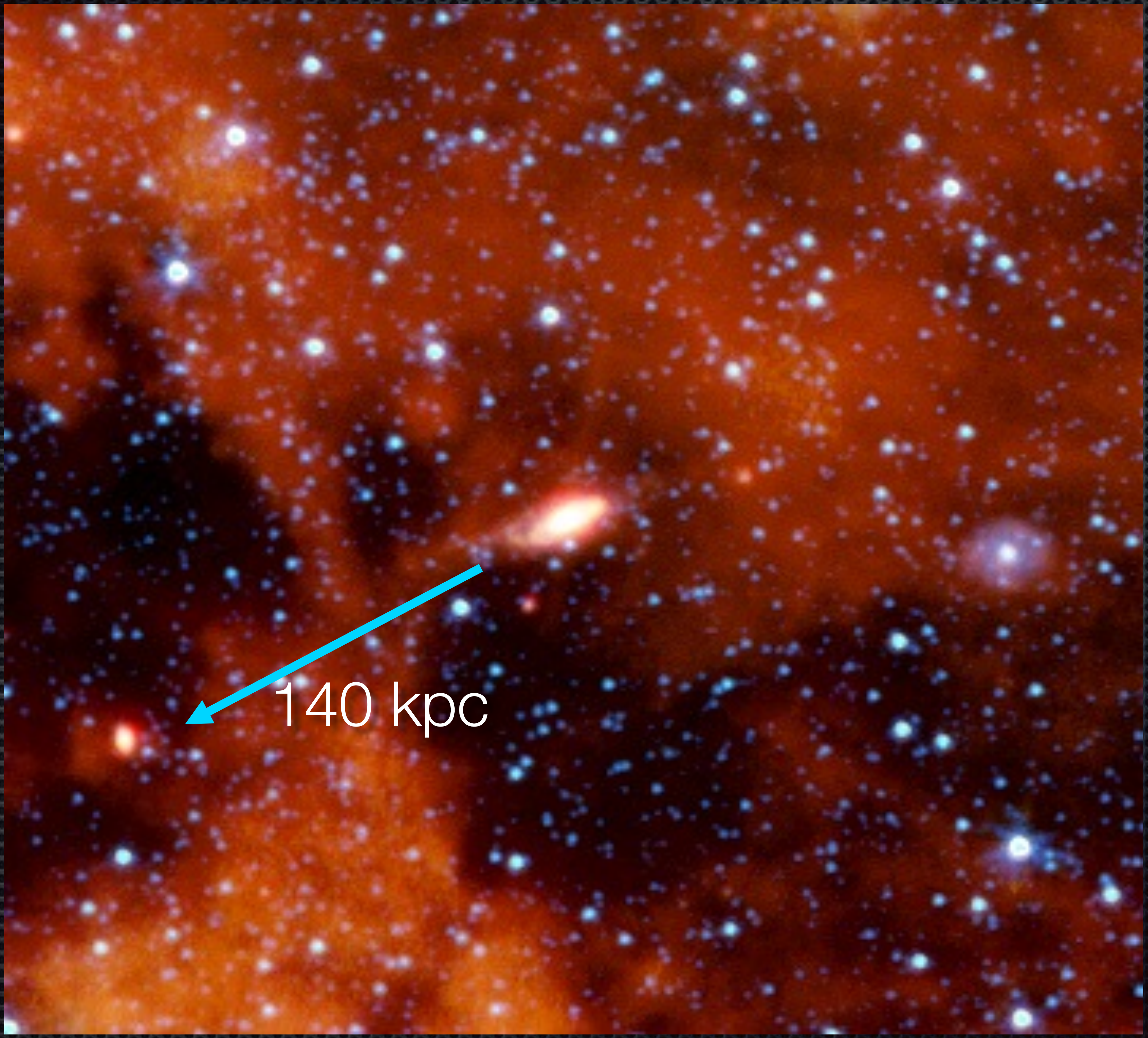
A local analogue to z~1 star formation?

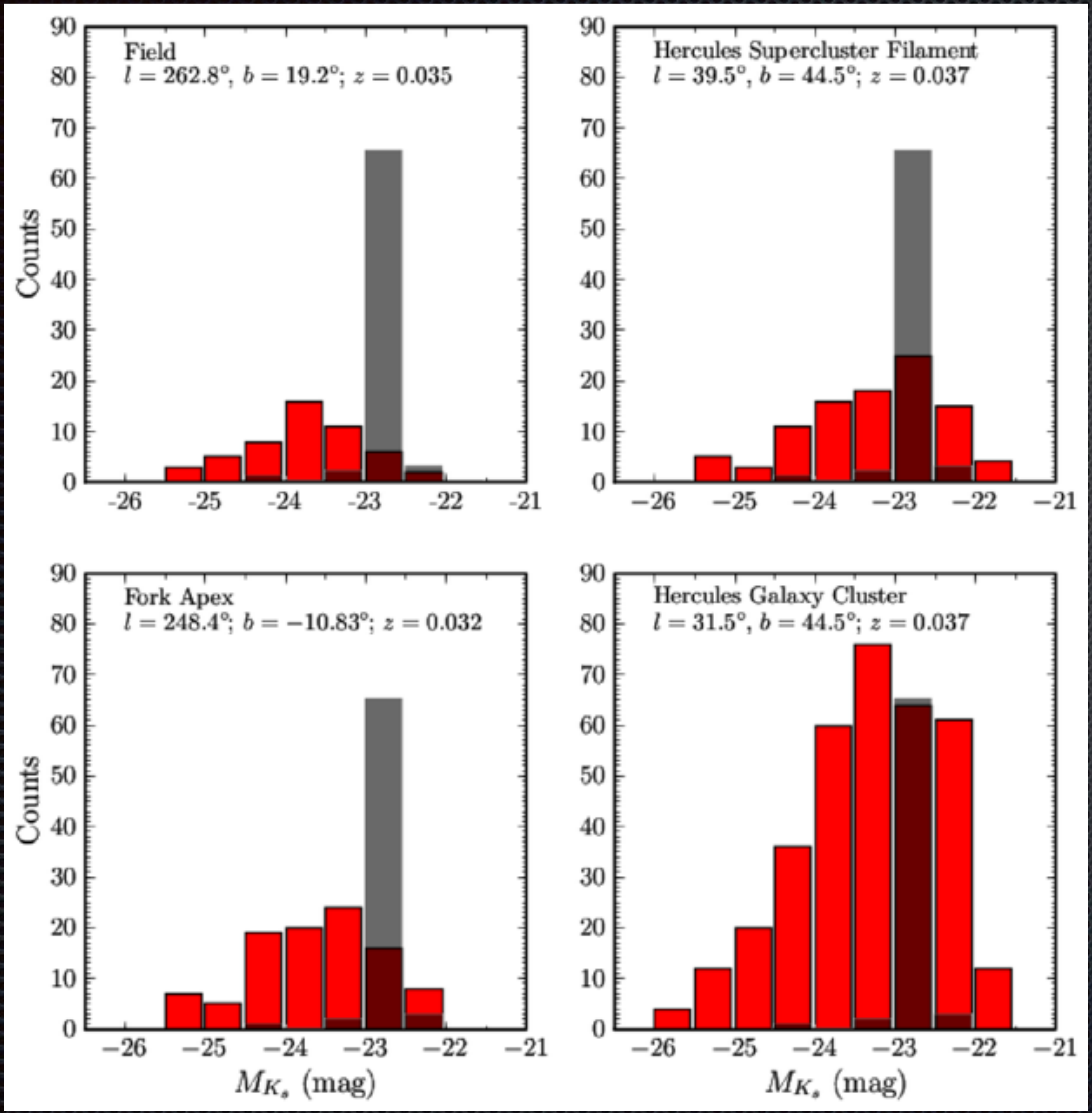
Next steps: Reprocess *Herschel*



Chemistry from ALMA

The ‘Hood





Grey = galaxies within 10 Mpc HIZOA J0836-43

Compared to four regions at similar redshift

Low mass galaxies dominate!!