

Large Scale Outflows and Dense Outflows in low-z ULIRGs

IRAS 13120–5453 and NGC 6240

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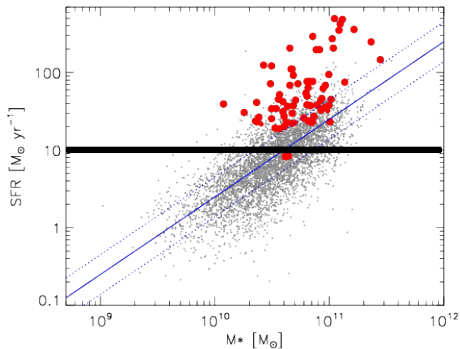
GalPath 2016

02 August 2016



S. Aalto, **E. Treister**, N. Falstad, S. Muller, E. González-Alfonso,
K. Sliwa, F. Costagliola, L. Armus, A. S. Evans, S. Garcia-Burillo,
T. Izumi, K. Sakamoto, P. van der Werf, K. Iwasawa, K. Schawinski,
D. B. Sanders, **N. Z. Scoville**, **V. U**, **F. Muller-Sanchez**, J. Comerford

(U)LIRGs and the Main Sequence

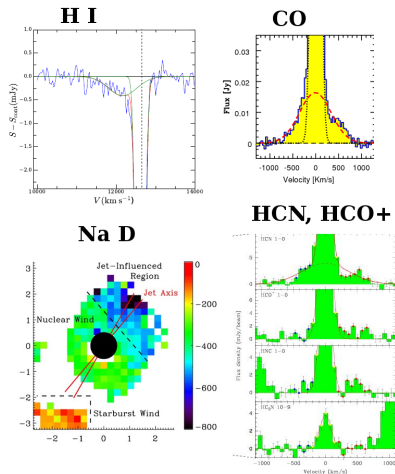


(Elbaz+ 2011; red indicates compact star formation)

(U)LIRGs and Dense Outflows

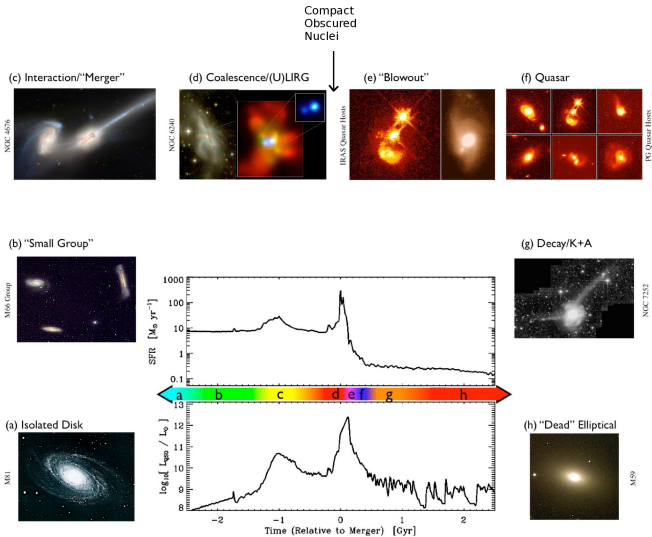
- Outflows seen in neutral, ionized, & molecular gas
- Regulation or quenching?
- AGN or starburst?

Mrk 231 →

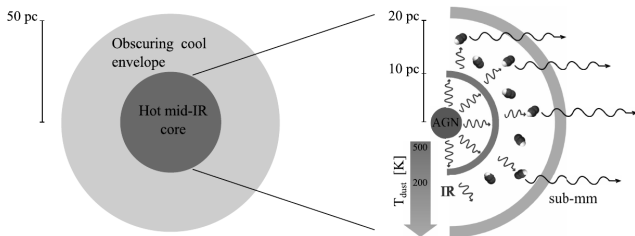


(e.g., Heckman+1987, **Feruglio+2010**, Alatalo+2011, **Rupke & Veilleux 2011**, Westmoquette+2012, Veilleux+2013, **Aalto+2013**, U+2013, Ciccone+2014, García-Burillo+2014, Sakamoto+2014, Alatalo 2015, Martin+2015, Medling+2015, **Morganti+2016**)

Compact Obscured Nuclei

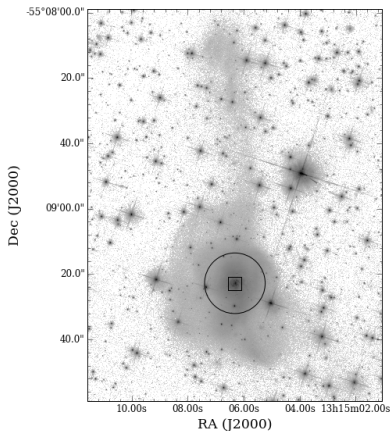


Compact Obscured Nuclei



(e.g., Mrk 231, Arp 220, NGC 4418, Zw049; Aalto+2015a/b)

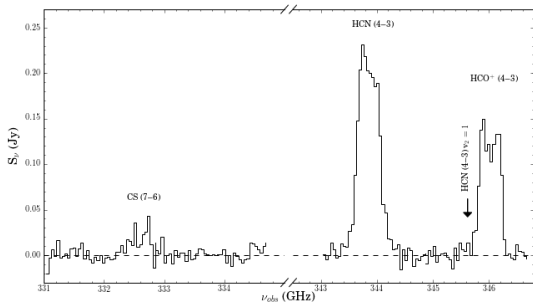
IRAS 13120-5453



- $L_{\text{IR}} = 2.1 \times 10^{12} L_{\odot}$
- Compton-thick AGN $\sim 20\%$ of L_{bol}
- $\text{SFR} \approx 170 M_{\odot} \text{ yr}^{-1}$
- Low $[\text{C II}]/L_{\text{FIR}} \rightarrow$ compact IR source

(Armus+2009, Veilleux+2013, Díaz-Santos+2013, Teng+2015;
HST image: Evans+ *in prep*)

IR13120: ALMA Band 7 Observations



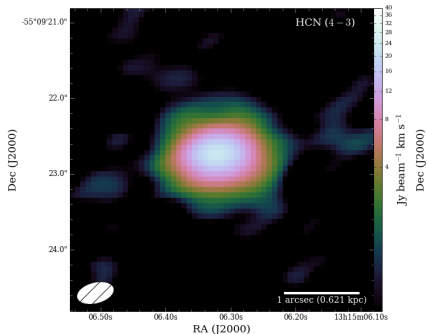
- $0''.5 \times 0''.3$ beam
(325 pc $\times$ 180 pc)
- No IR-pumped line detected

← 3'' circular extraction

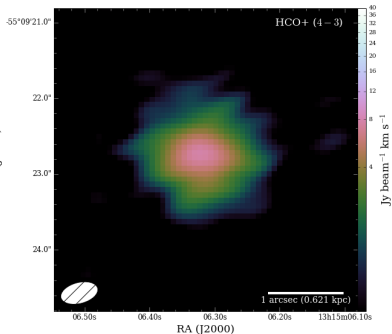
(Privon+ *in prep*)

IR13120: ALMA Band 7 Observations

HCN (4–3)

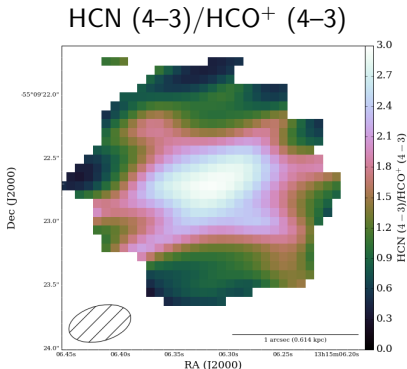


HCO⁺ (4–3)



(Privon+ *in prep*)

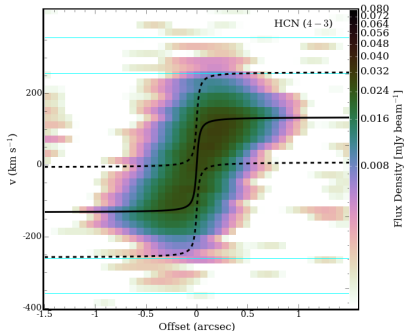
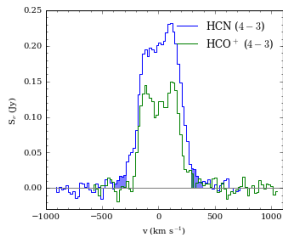
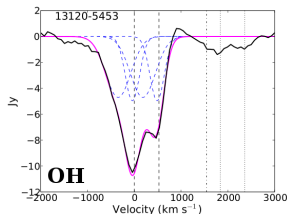
IR13120: ALMA Band 7 Observations



(Privon+ *in prep*)

- SFR $170 \text{ M}_{\odot} \text{ yr}^{-1} \rightarrow 1.2 \text{ SNe yr}^{-1}$
- SB size $\sim 0.5 \text{ kpc}$
- consistent with enhanced nuclear HCN abundance from mechanical heating (e.g., Kazandjian+2012)
- $\Sigma_{IR} \approx 4.7 \times 10^{12} \text{ L}_{\odot} \text{ kpc}^{-2}$

IR13120: Dense Component of Molecular Outflow?



(OH from Veilleux+ 2013; Right: colorscale, HCN (4-3), Black, rotation curve (solid) and virial range (dotted))

IR13120: Summary

- HCN/HCO⁺ ratio consistent with HCN abundance enhancement from mech heating
- Suggestion of dense molecular gas entrained in outflow, dense mass uncertain but $< 100 M_{\odot} \text{ yr}^{-1}$
(Pending ALMA proposal for HCN/HCO⁺ SLED)
- Nuclear starburst near radiation-pressure limit
- Witnessing feedback in post-CON phase?

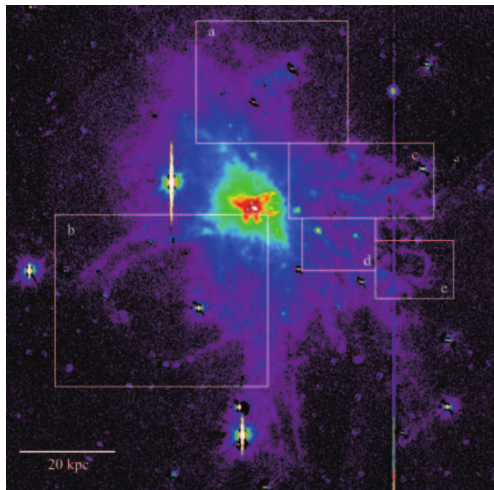
NGC 6240: Dual AGN, Starburst, Trainwreck



- $L_{\text{IR}} = 8.5 \times 10^{11} L_{\odot}$
- $\text{SFR} \lesssim 150 M_{\odot} \text{ yr}^{-1}$
- Dual AGN, southern SMBH
 $M_{\bullet} \approx 10^9 M_{\odot}$
- Superwind and CO Outflow

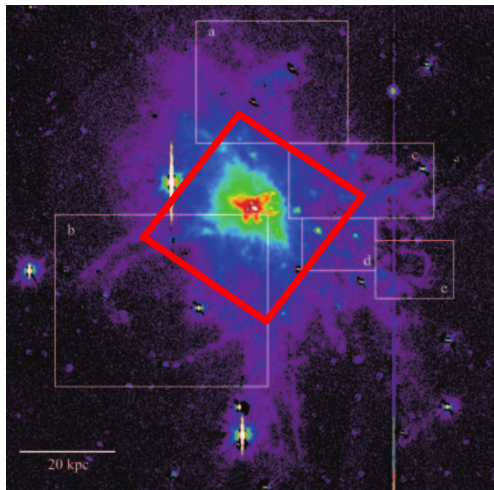
(Heckman+1987, Komossa+2003, Armus+2009, Medling+2011, Feruglio+2013ab)

NGC 6240: H α Nebula



(Heckman+ 1987, Yoshida+ 2016)

NGC 6240: H α Nebula

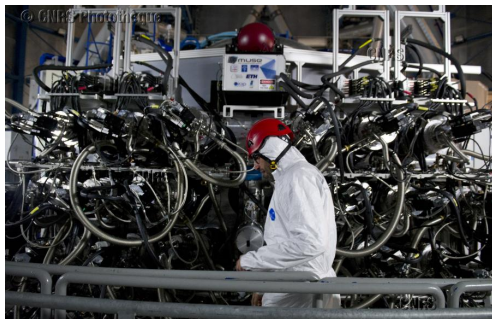


(Heckman+ 1987, Yoshida+ 2016)

MUSE: Multi-Unit Spectroscopic Explorer

- Image slicer with 24 identical IFUs
- seeing-limited mode: arcmin sq. FOV, 0.2 arcsec sampling
- 480 – 930 nm, $R \sim 1770 - 3500$

(Bacon+2010)



(CNRS)

MUSE: **M**ake if**US** gr**E**at again

- Image slicer with 24 identical IFUs
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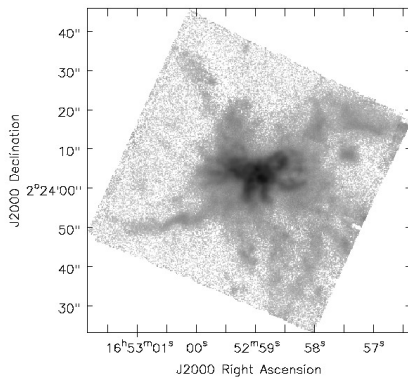
(Bacon+2010)



(CNRS)

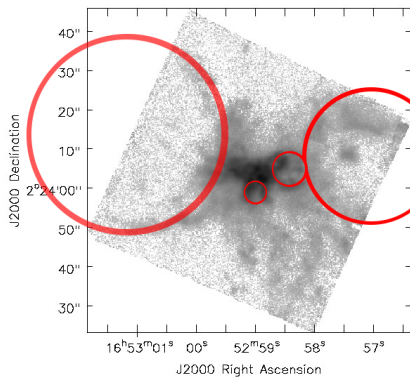


NGC 6240: kpc-scale Ionized Bubbles



(Grayscale: single H α channel, $\Delta v = 55 \text{ km s}^{-1}$; Privon+ *in prep*)

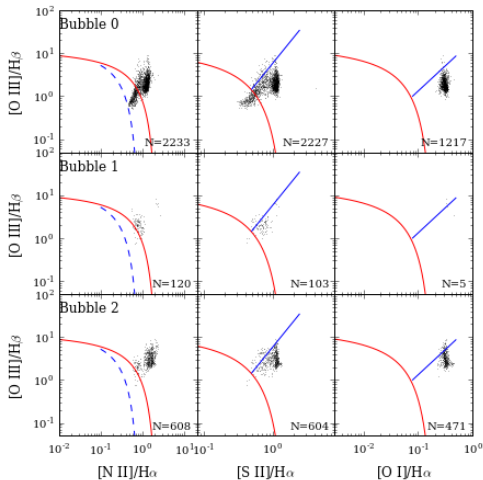
NGC 6240: kpc-scale Ionized Bubbles



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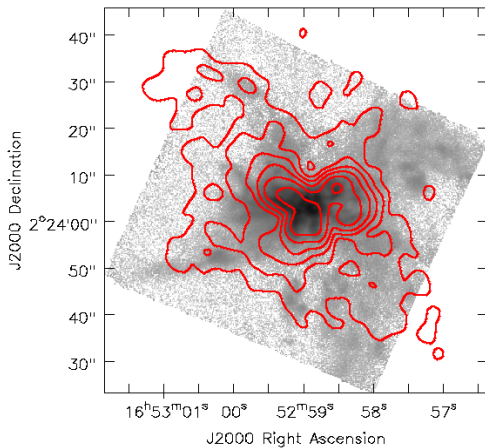
NGC 6240: Bubble Properties

- 5 – 100 Myr old
- Multiple orientations:
AGN direction changes?
Varying breakout of SB
wind?
- Inner bubbles most
likely associated with S
nucleus
- (atomic) gas excitation
consistent with shocks



(Privon+ *in prep*)

NGC 6240: Bubbles & X-rays



(X-rays from Iwasawa+ *in prep*; Privon+ *in prep*)

Dense and Wide Outflows in Local (U)LIRGs

IRAS 13120–5453

- HCN luminosity enhancement consistent with HCN abundance enhancement by mechanical heating
- Possible dense gas outflow associated with the OH molecular outflow
- Less dense, cooler dust temps than CONs: post-CON feedback in action?

NGC 6240

- 4 bubbles evident in MUSE observations (additional, larger bubble from Yoshida+2016 not covered by MUSE FOV)
- 5 – 100 Myr old, youngest bubble associated with S nucleus
- Shocked (BPT diagram, co-spatial X-ray emission)