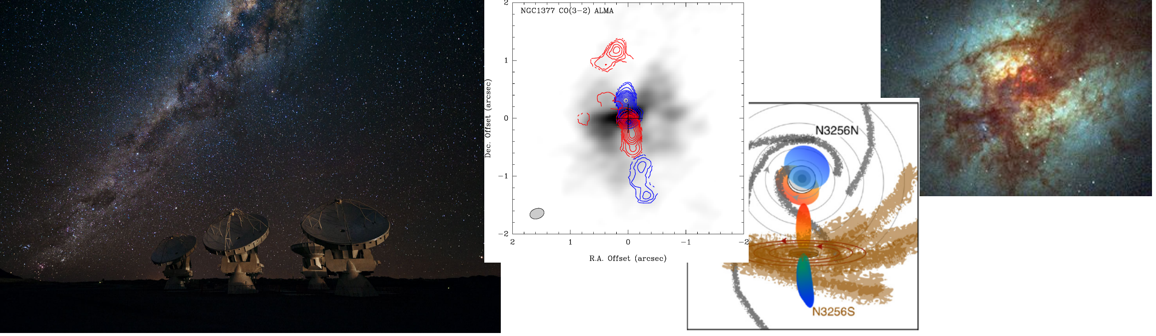

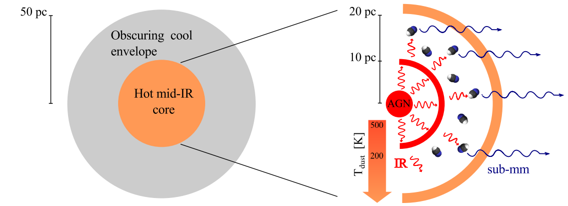

Molecular outflows in dusty AGNs and starbursts

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CHALMERS

N. Falstad, S. König, F. Costagliola, F. Hallqvist,
E. Varenius, R. Aladro, K. Sakamoto, E. Gonzalez-Alfonso,
F. Combes, S. Garcia-Burillo, N. Harada, S. Muller
J. Gallagher, J. Mangum et al

MASTER
MOLECULES AS TOOLS FOR EXTRAGALACTIC RESEARCH

Some questions

- What is the origin of the cold molecular gas in the outflow? Is it entrained disk gas? Is it formed in the outflow from instabilities in the hot gas? Other scenario?
  - Is there a link between the properties of the molecular gas in the inner few 100 pc and that in the molecular outflow?

- What is the fate of the molecular gas? Are there ”fountains” where the gas can return to the disk?

- What are the molecular mass outflow rates?

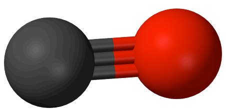
- Can outflows/jets *assist* accretion?(i.e. protostellar analogy)

- What are the timescales for AGN feedback to clear dusty obscuring gas?
  - What is the link between dusty obscuring gas on the scales of tens of pc and sub-pc structures that obscure X-rays?

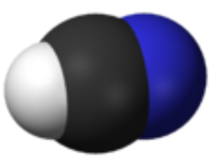
Outline

- Molecules – a crash course
  - Example NGC1068
- Molecular outflows
- Dusty nuclei
  - Compact Obscured Nuclei – CONs
  - Are the most dust-obscured nuclei not driving fast winds?
- Cold winds
  - Collimated flows: NGC1377, NGC3256
  - Dense molecular gas in AGN outflows: Mrk231
  - Dense winds and chemistry
- Conclusions

”Standard” tracers



- CO – low-J transitions
  - Traces molecular gas of low density $n>10^2$ cm^{-3}
  - Overall gas content and dynamics, cloud identification and stability



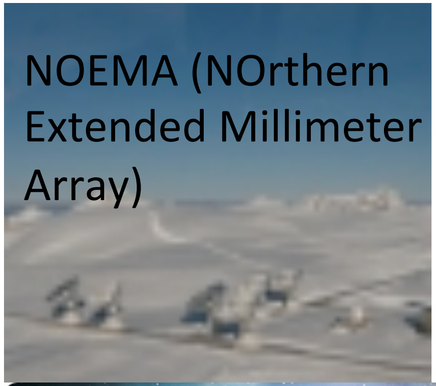
- HCN, HCO^+
  - Traces dense molecular gas $n>10^4$ cm^{-3}
  - Dense gas and star formation, AGN activity.
  - Dynamics of nuclear, dense gas

Cold H_2 ”silent” molecule - must use tracer molecules to probe molecular gas

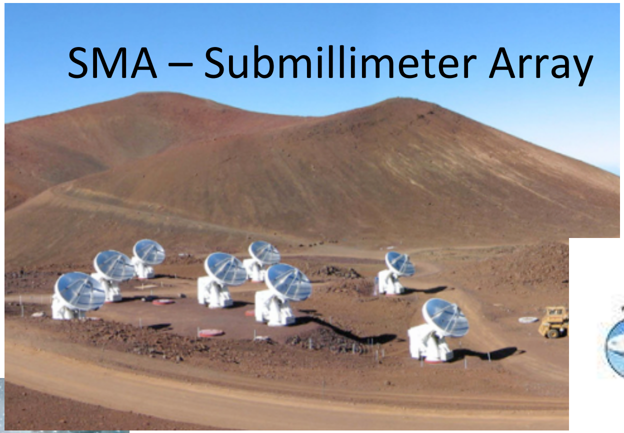
Some useful telescopes

ALMA=The Atacams Large Millimeter/ submillimeter Array

the European Southern Observatory (ESO), the U.S. National Science Foundation (NSF) and the National Institutes of Natural Sciences (NINS) of Japan, together with NRC (Canada), NSC and ASIAA (Taiwan), and KASI (Republic of Korea), in cooperation with the Republic of Chile. ALMA -the largest astronomical project in existence- is a single telescope of revolutionary design, composed of 66 high precision antennas located on the Chajnantor plateau, 5000 meters altitude in northern Chile.



NOEMA (NOrthern Extended Millimeter Array)



SMA – Submillimeter Array

MERLIN

Very Large Array

Chemistry scenarios

- Scenarios:
  - X-ray dominated region (XDR) – large bulk temperatures > 100 K (e.g. Maloney +96; Lepp & Dalgarno 96; Meijerink &Spaans 05)
  - Photon dominated region (PDR) – large surface temperatures 300-1000 K – moderate bulk temperatures 20-50 K (e.g. Hollenbach & Tielens 97)
  - Cosmic ray dominated region (CDR) (e.g. Suchkov +93; Meijerink +11)
  - Dense shielded regions – dusty hot core-like chemistry (IR pumping), 50-300 K (e.g. Van Dishoeck 98, Requena-Torresti+06, Nomura & Millar 04)
  - Mechanically dominated region – shock-chemistry (e.g. Viti +11; Kazandjian +12,15)

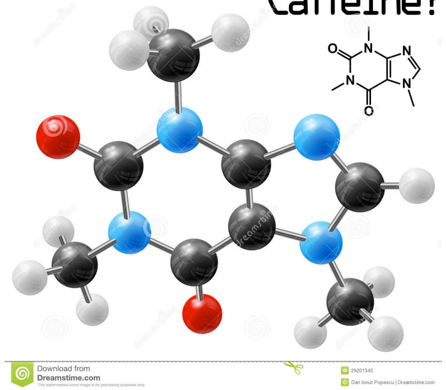
- Popular diagnostic species: CO, HCN, HCO^+, HOC^+, HNC, CN, CS, HC_3N, SiO, HNCO, CH_3OH, CH_3CN, C_2H – just to mention a few + their isotopic variants.
  - Radiation/cosmic rays: e.g. HCO^+/HOC^+, OH^+, H_2O^+, CN
  - IR pumping: e.g. HCN, HNC, HC_3N
  - Shocks: H_2O, H_2S, CH_3OH, HNCO, (HCN?)

Molecular gas conditions:
T=5-500 K
$n>10^2$ cm^{-3}

Extragalactic molecules: >60 detected

2 atoms	3 atoms	4 atoms	5 atoms	6 atoms	7 atoms	8 atoms	>8 atoms
OH	H_2O	H_2CO	c-C_3H_2	CH_3OH	CH_3CCH	HC_6H	c-C_6H_6 *
CO	HCN	NH_3	HC_3N	CH_3CN	CH_3NH_2		C60* (?)
H_2 *	HCO+	HNCO	CH_2NH	HC_4H *	CH_3CHO		
CH	C_2H	C_2H_2 *	NH_2CN	$HC(O)NH_2$	HC_5N		
CS	HNC	H_2CS ?	*l*-C_3H_2				
CH^+ **	N_2H^+	$HOCO^+$	H_2CCN				
CN	OCS	c-C_3H	H_2CCO				
SO	HCO	H_3O^+	C_4H				
SiO	H_2S	*l*-C_3H					
CO^+	SO_2						
NO	HOC^+						
NS	C_2S						
NH	H_2O^+						
OH^+	HCS^+						
HF	H_2Cl^+						
SO^+	NH_2						
ArH^+							
CF^+							

Caffeine?

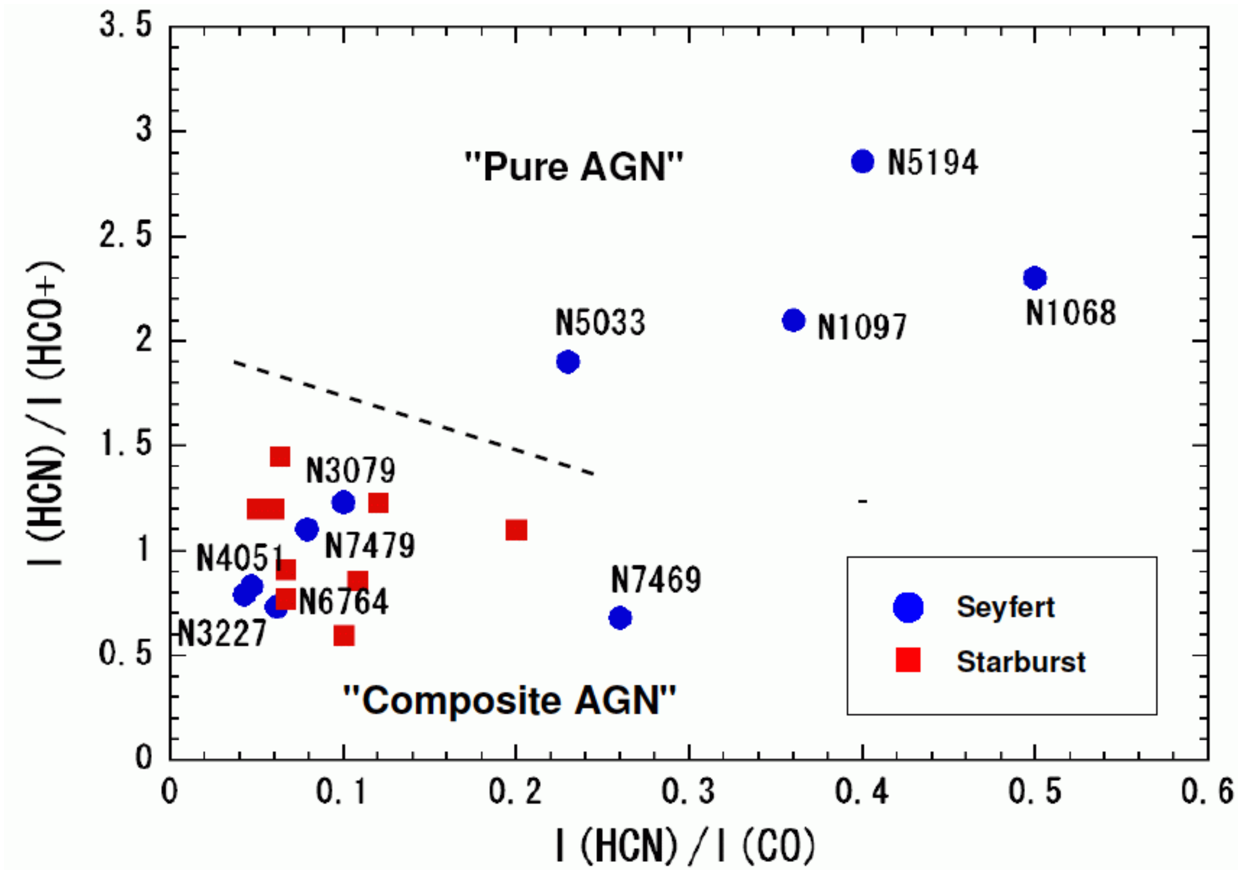


…not yet…

see updates on
http://www.astro.uni-koeln.de/cdms/molecules

* indicates molecules that have been detected by their rotation-vibration spectrum,
** those detected by electronic spectroscopy only.

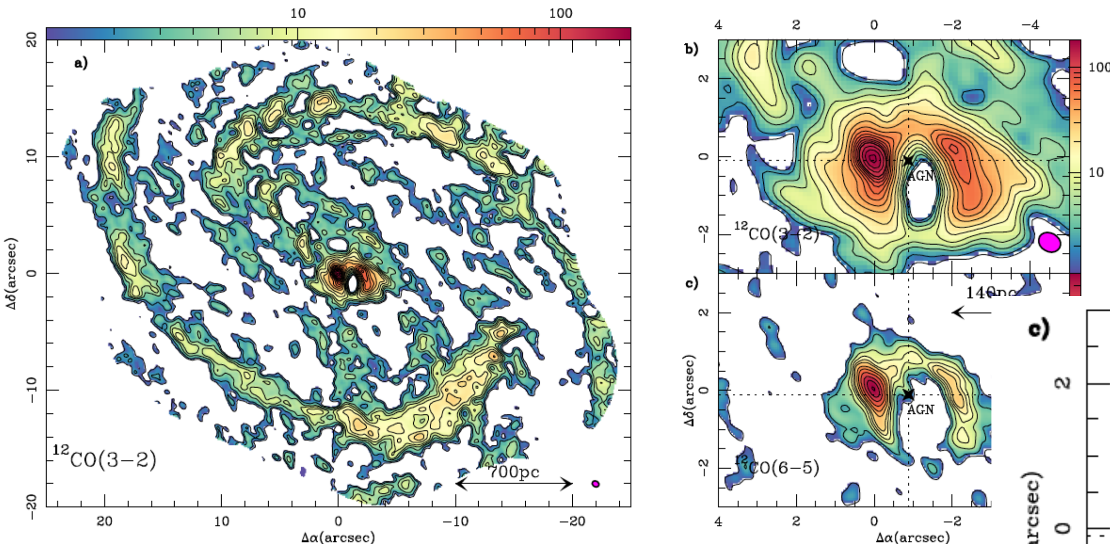
Example: Hunting for the AGN



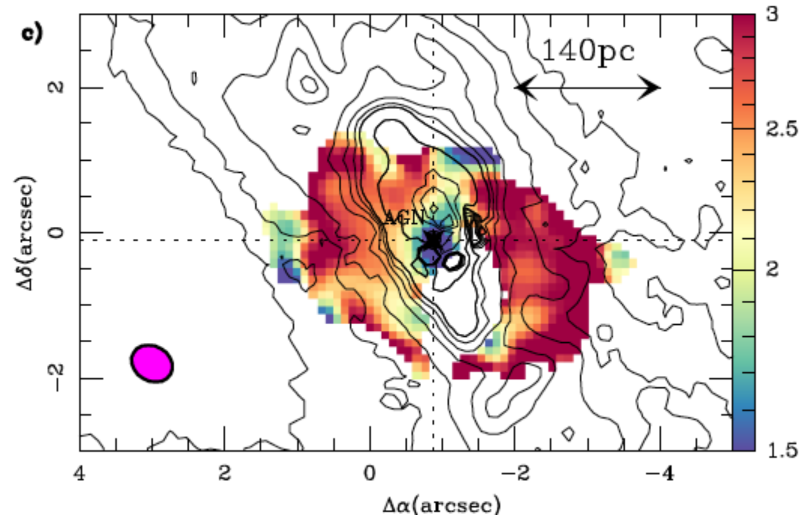
HCN/HCO$^+$ plot of Kohno+11 – is it an AGN tracer?

Many studies underway to explore the diagram and expand it to other molecules

Example: High resolution ALMA observations of the Seyfert galaxy NGC1068



Garcia-Burillo+14, Viti+14



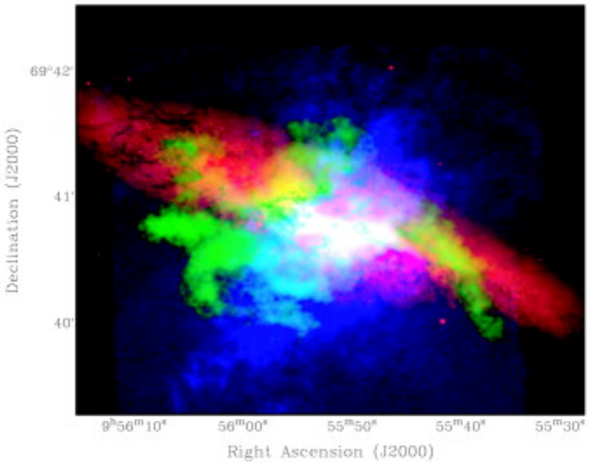
The HCN/HCO$^+$ 4-3 ratio in the CND

HCN/HCO$^+$ ratio high in CND – drops again near the actual AGN

Line ratio changes again closer to the nucleus with HCN/HCO$^+$ >1 (Imanishi+16).

MOLECULAR OUTFLOWS

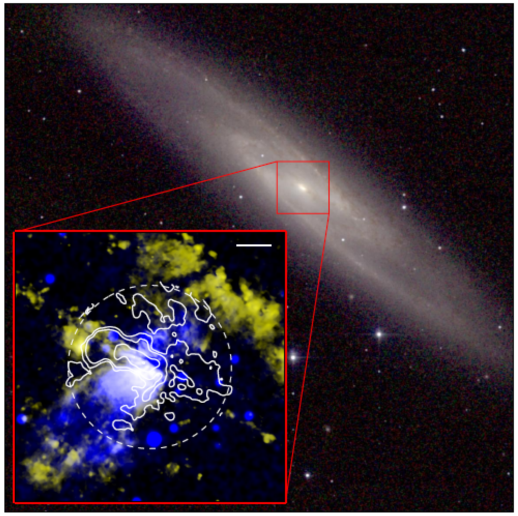
Examples of CO Starburst outflows



M82
e.g. Walter+02
(First detection by Nakai+87?)

Walter+02:
Red: Optical image
Blue: Hα image
Green: OVRO CO 1-0 map

Other examples include:
NGC2146 (e.g. Tsai+09)
NGC1808 (Salak+16)
NGC3628 (Tsai+12)
VII Zw 31 (Leroy+15)
NGC1614 (Garcia-Burillo+15)
Collimated flows:
NGC3256 (Sakamoto+14)
ESO 320-G030 (Pereira-Santaella+16)

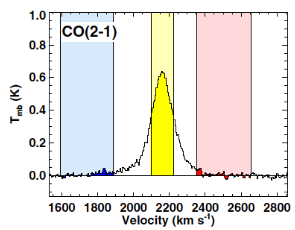


NGC253
Bolatto+13
(Note that OH plume was detected by Turner+87)

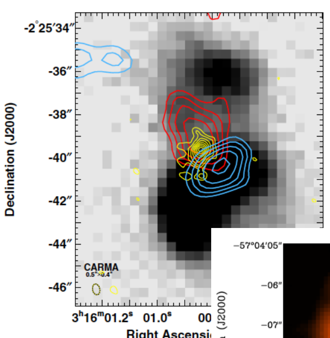
(Bolatto+13)
White contours: CO
Blue: X-ray
Yellow: Halpha
Scale bar is 250 pc

Morphologies: bicones, gas pushed by superbubbles , filaments. Sometimes collimated.
Extent: few x 10^2 – few x 10^3 pc
Radii: few x 10^2
dM/dt – SFR or lower

CO in AGN outflows



Alatalo+11



Morganti+15

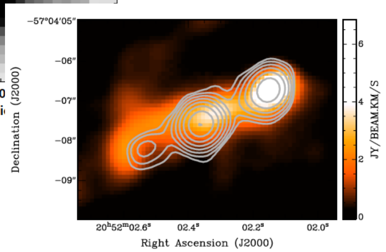
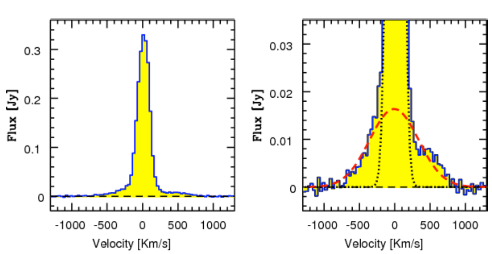


Fig. 2. Contours of the 230 GHz continuum emission super-posed onto the central region of the total intensity of the CO(2−1) illustrating the spatial correlation between the two. Contour levels are 90, 180, 360, 720, 1440, 2880, 5760, and 15 120 μJy beam^{-1}.



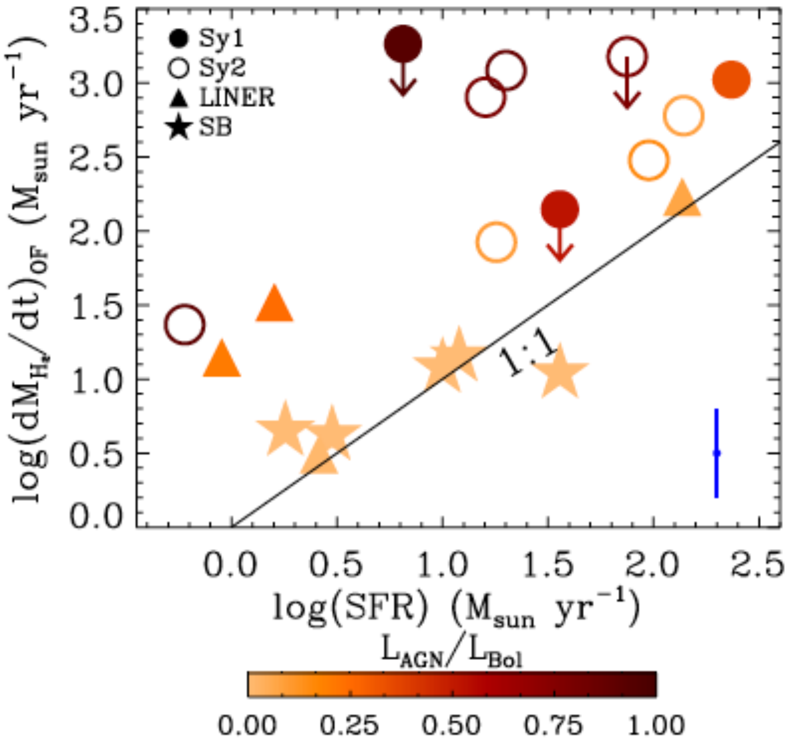
Feruglio+10

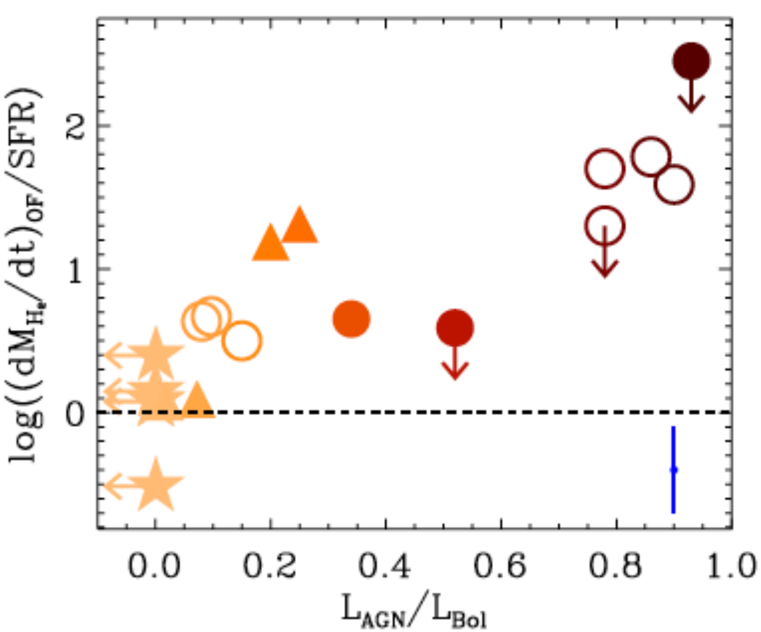
ULIRGs and AGNs: Mrk231 *(e.g. Feruglio+10,15 Aalto +12,15, Cicone+12, Alatalo+15*); M51 (Matsushita +05,15), IRAS13120 (Privon+16), IRAS17208 (Garcia-Burillo+14), NGC7469 (Izumi+15), NGC1433 (Combes +13),NGC1068 (Garcia-Burillo+14). IC5063 (Morganti +15), Circinus (Zschaechner+16, Costagliola+17), Mrk273 (Aladro+17), UGC5101 (Hallqvist+17), , NGC6240 (Feruglio+13)(Combined AGN/starburst driven wind)

Early type galaxies: NGC1266 *(Alatalo+11),* NGC1377 *(Aalto+12,16,17)*

LIRG and ULIRG surveys: *Chung+11* (single dish stacking), Cicone+14

Morphologies: There are several that are highly collimated – jet driven? Wide angle flow in Circinus.
Extent: few x 10^2 – few x 10^3 pc
Radii: Launch radii unclear
dM/dt – SFR or higher





AGNs appear to drive out their molecular gas more effectively than starbursts (e.g. Cicone+14)

How important are timescales and physical scales of outflow launch region?

A hidden AGN population – or extreme starbursts?

COMPACT OBSCURED NUCLEI

CONs – Compact Obscured Nuclei - $N(H_2)>10^{24}$

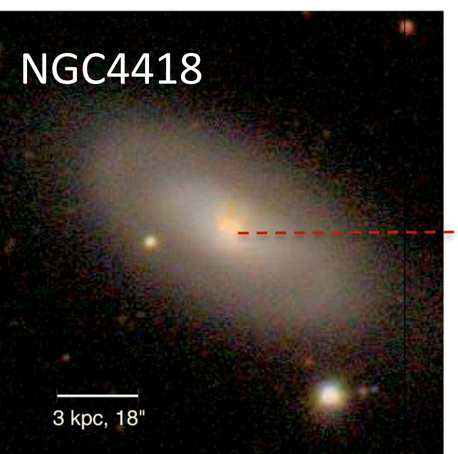
Some (U)LIRGs harbour CONs - Still unknown how common they are

Important to understand obscured phase:

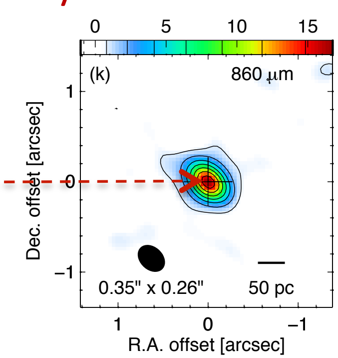
- AGN statistics.
- Growth of nuclear stellar spheroid. Starburst-AGN connection

Example:

NGC4418 (e.g Sakamoto+10,13, Costagliola+13 – see also Varenius+14 for VLBI imaging)



mm/submm continuum



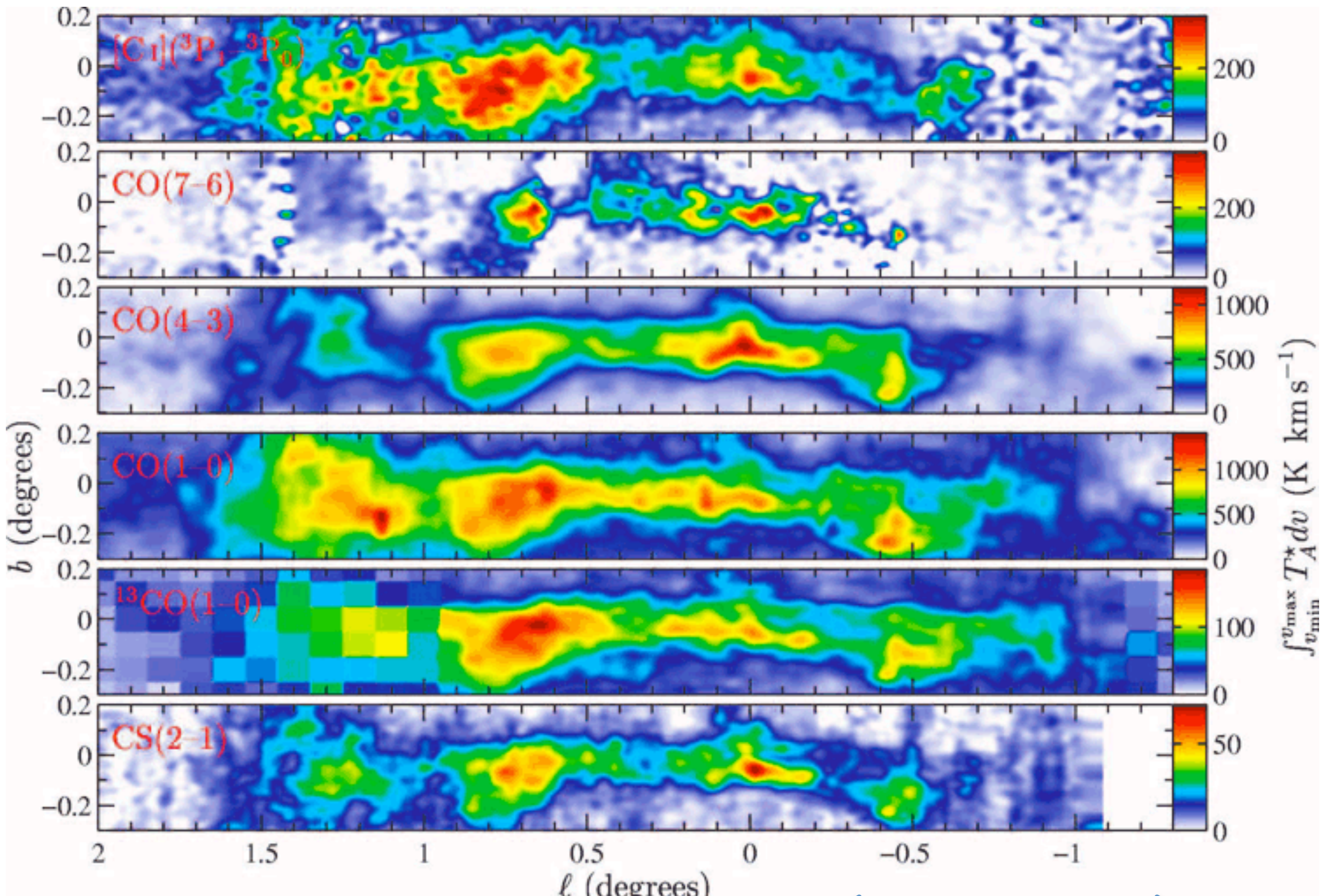
- <0. "1 (<20 pc) nuclear emission
- Core luminosity: $10^{11.0}\ L_\odot$ - bulk of total FIR luminosity of NGC4418.
- $T_B(860\ \mu m)$=120-210 K, $\tau(860\ \mu m) = 1$ (i.e., $N_H>10^{25}\ cm^{-2}$).

Central Molecular Zone (CMZ) of the Milky Way

Size - 450 x 150 pc

M(H_2) - 5×10^7 M_{sun}

(Martin+04, ApJS, 150, 239-262).



100 pc

In comparison: Extreme properties of NGC4418 nucleus.

10^8 M_{sun}

20 pc

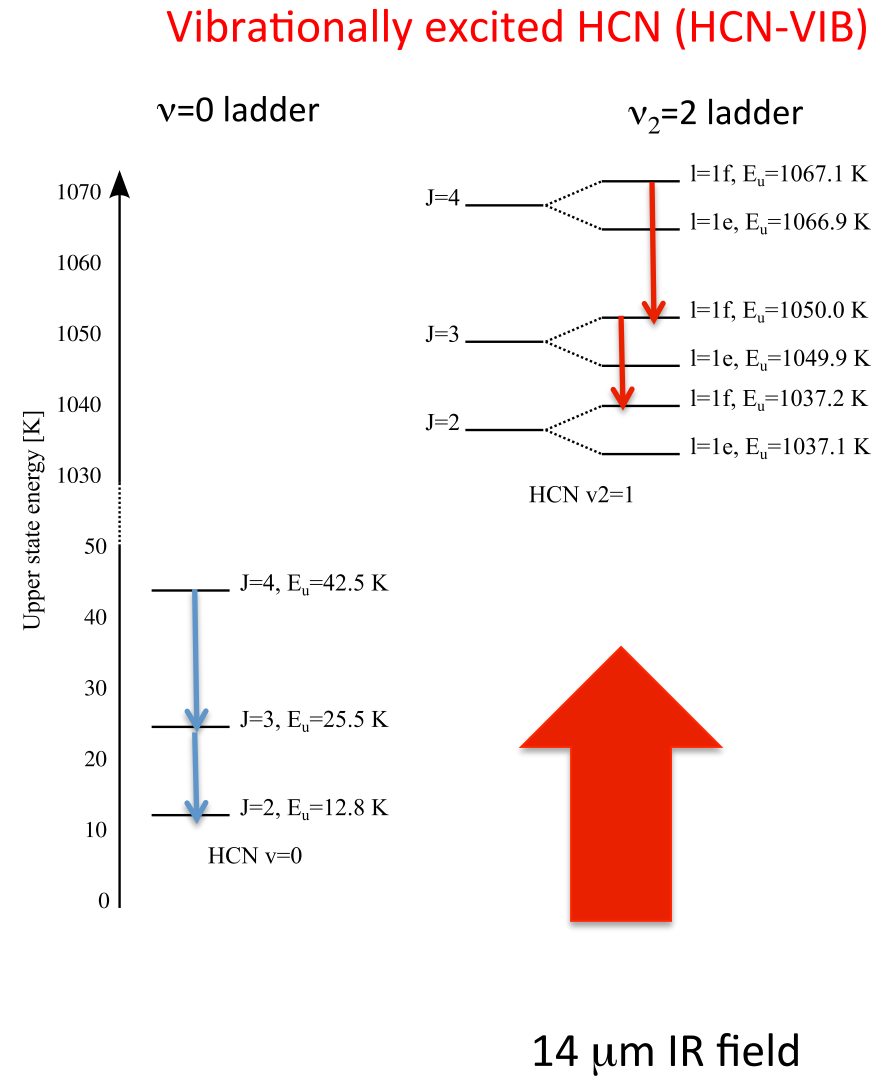
How can we probe behind the veil of dust?

X-rays suffer attenuation when $N(H_2)>10^{24}$ cm^{-2} and mid-IR diagnostics are also compromised by extreme dust obscuration.

Information at long mm/submm wavelengths:

-mm/submm continuum observations: luminosity density, $N(H_2)$ (e.g. Sakamoto+08)

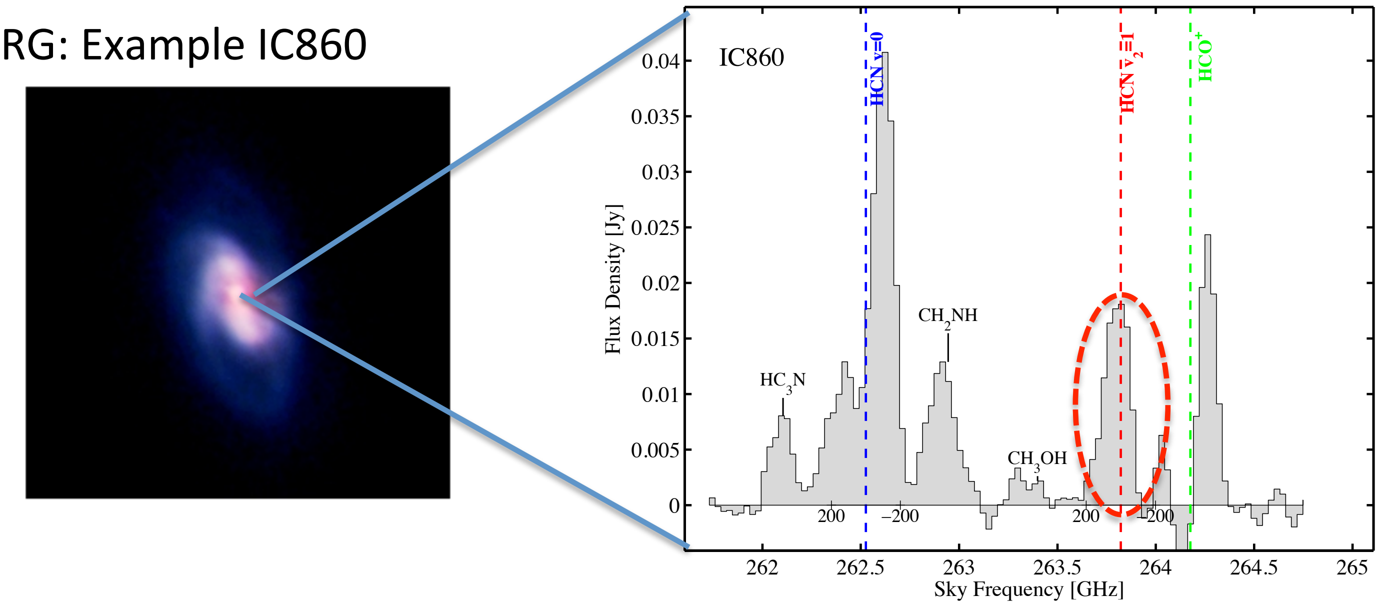
-Vibrationally excited HCN (HCN-VIB) requires T_B(14 μm) > 100 K. Observe rotation transitions in the mm/submm. (e.g. Sakamoto+10, Aalto +15a,b, Imanishi+13, Aalto+15ab, Martin+16, Aalto+16, Imanishi+16). Or in the cm wavelengths (e.g. Salter+08)



Luminous HCN-VIB found in ULIRGs and LIRGs

(Sakamoto+10,+13, Costagliola+13, Aalto+15ab, Imanishi 13,16, Aalto+16, Hallqvist +17)

LIRG: Example IC860



- Ground state lines of HCN and HCO^+ ***self- and continuum absorbed in nuclear region –*** due to large column densities and steep temperature gradient
- **Extremely luminous vibrationally excited HCN line emission** emerging from buried, compact (*r*<15-70 pc) nuclei (Compare to hot cores in the Milky Way – e.g. Rolffs+11))

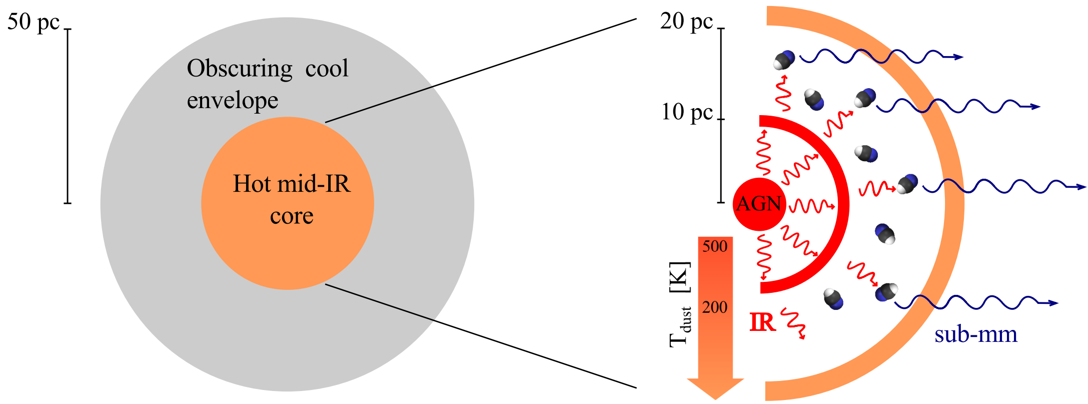
Buried nuclei traced by vibrationally excited HCN

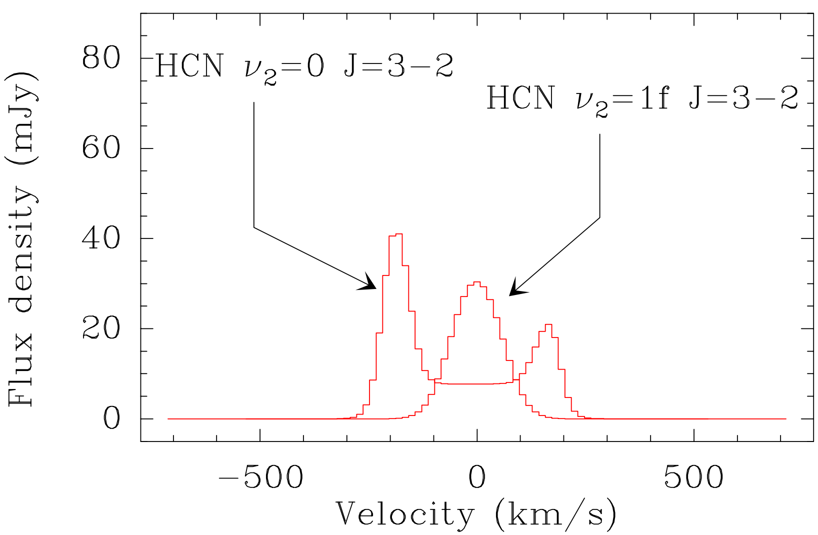
- HCN-VIB emerging from extreme mid-IR cores since ***HCN-VIB requires a mid-IR surface brightness > 5x10^{13} L_{sun}/pc^2 :***
  - ***Extreme compact opaque starburst (Andrews and Thompson 2011)***
  - ***Obscured AGN***

- So far – HCN-VIB only detected in: ULIRGs and LIRG early type spirals

Preliminary statistics: 70% of nearby ULIRGs have HCN-VIB emission

- 30-100% of total IR luminosity of galaxy may emerge from HCN-VIB region.

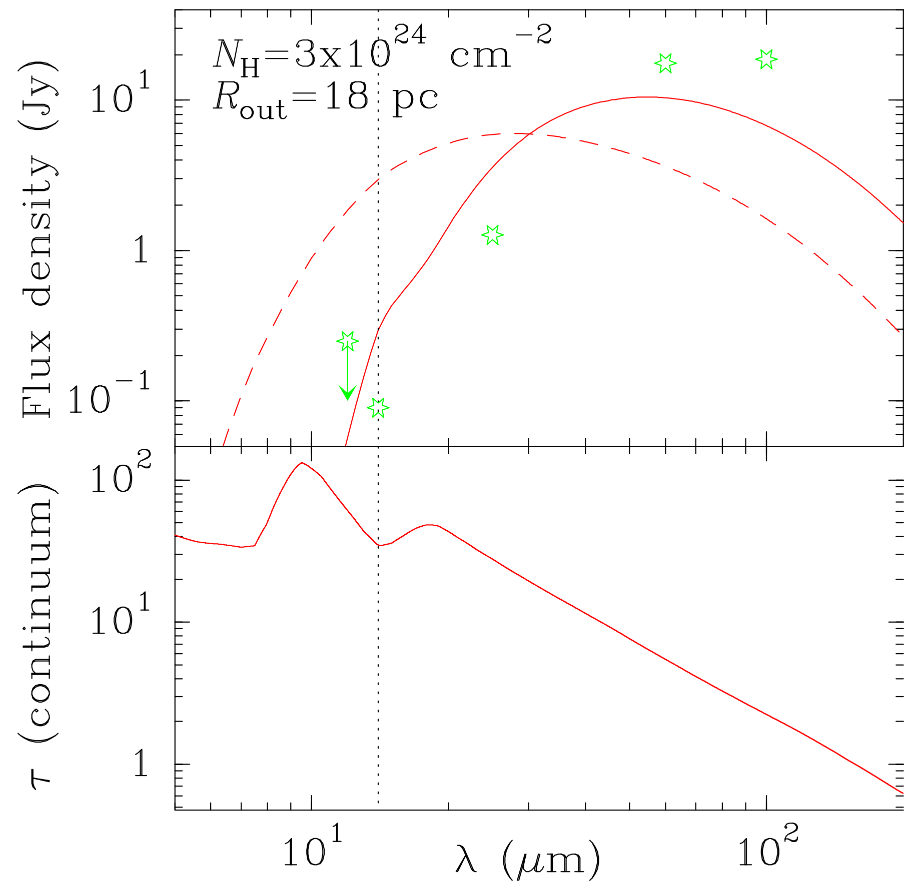




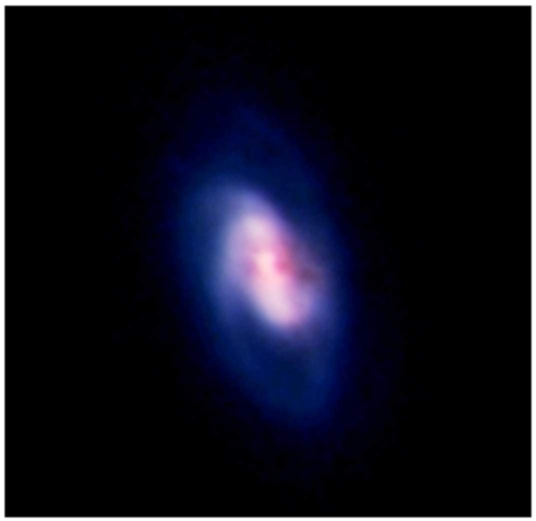
"Too cold" dust SEDs? (see discussion in Aalto+15b)

- Dust Spectral Energy Distribution (SED) may shift due to absorbed nuclear emission.
- high surface brightness mid-IR may be buried (e,g, IRAS17208! No nuclear mid-IR Soifer+01) but very bright mid-IR excited HCN-VIB)
- Trapped radiation from the embedded source may raise the internal temperature ="Greenhouse effect". (See e.g. Rolffs+11)

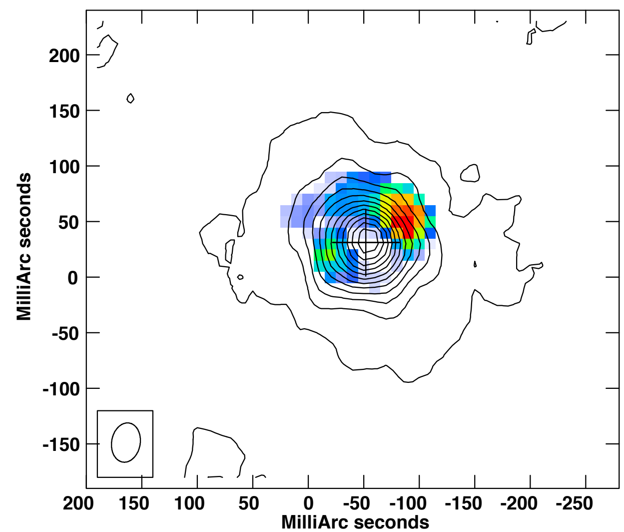
Dust SED can shift to longer wavelengths.



ALMA 345 GHz (850 μm) 30 milli-arsecond observations of IC860 (work in progress)



Contours: 345 GHz dust continuum
Colour: HCN-VIB emission



- Confirm ground state HCN, HCO+, CS lines continuum and self absorbed in Inner 50 pc.

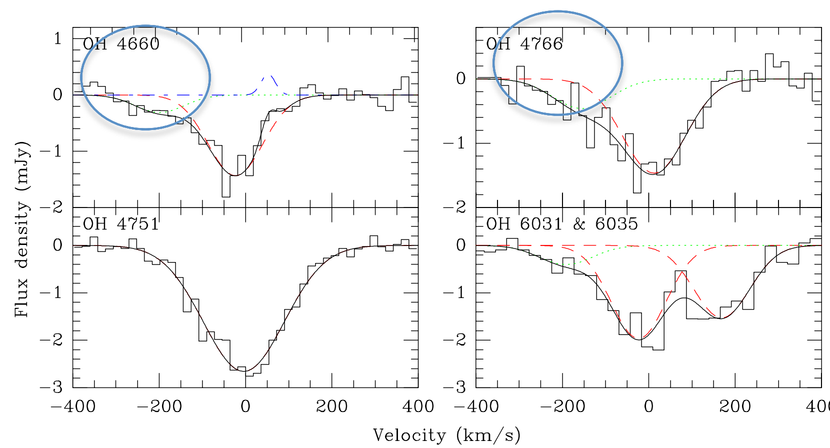
- HCN-VIB tracing emission close to nucleus – but "vanishing" in the inner 0."03 (7 pc) due to excitation and opacity effects in $N(H_2)$ $>10^{25}$ cm^{-2} core. Must go to even longer wavelengths to probe inside inner 7 pc

- Preliminary idea: HCN-VIB line may be probing onset of outflow

Hot and very dusty cores – anticorrelation with outflow speeds?

- Tentative anti-correlation between relative HCN-VIB luminosity and FIR OH 119 μm absorption outflow velocities V_{out} (from Veilleux+13) (see discussion in Aalto +15b, Hallqvist+17)
- Implications
  - No buried AGN activity in the "slow" ULIRGs? IR powered by extremely compact starbursts?
  - Or are they extremely young (restarting?) AGNs where outflows have not yet started?
  - Are OH outflows young, compact and hidden? (e.g. Fast CO/HCN outflow detected in I17208 (Garcia-Burillo+15)

OH outflows may be hidden in the FIR: Buried outflow in LIRG Zw049 revealed by VLA:



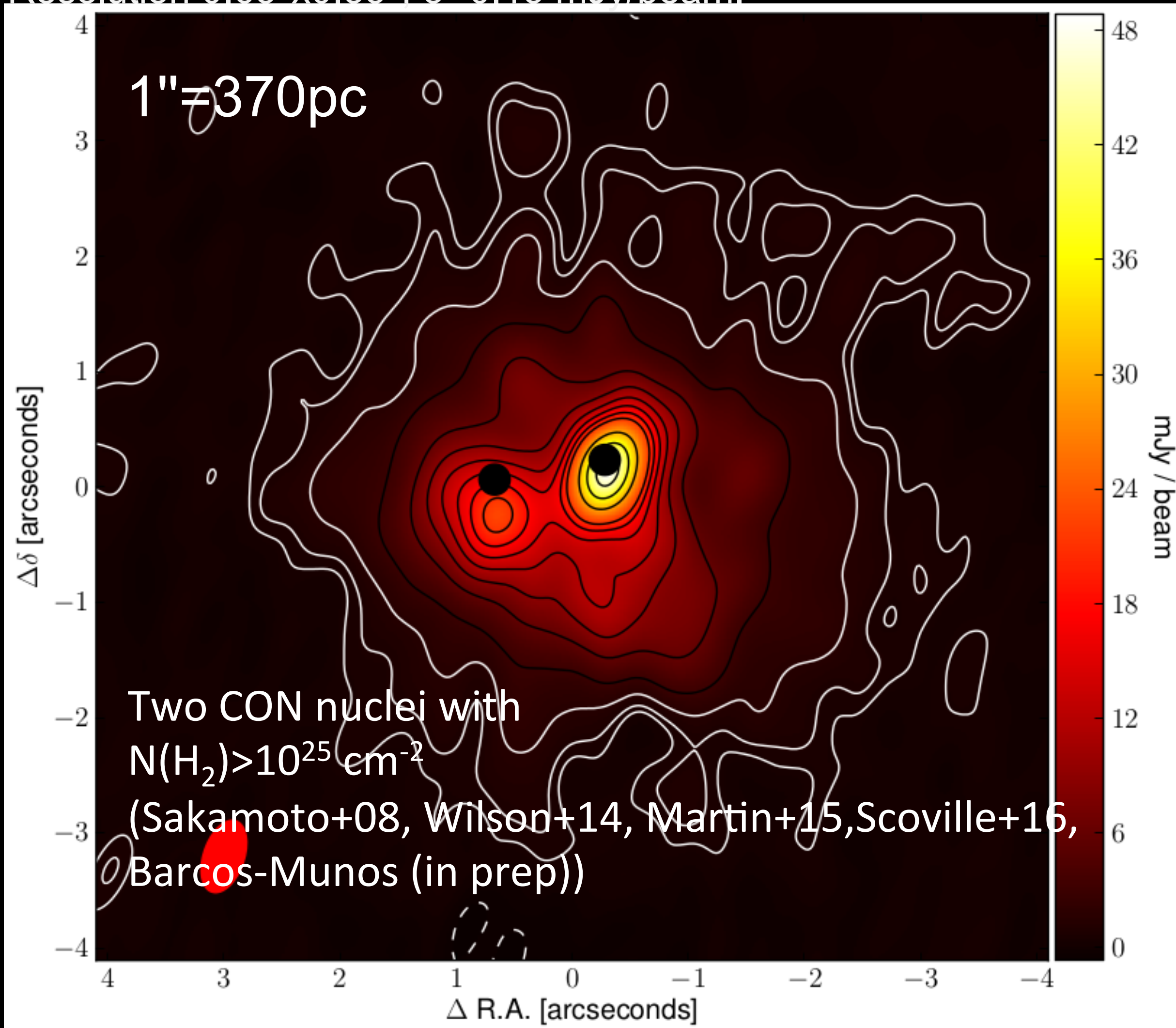
(Falstad+15 and in prep.)

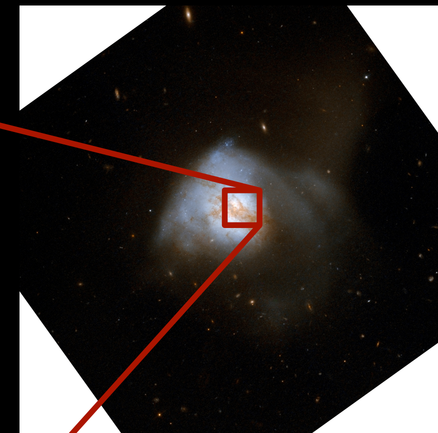
Selection effects: incomplete sampling of ULIRGs. Requires confirmation in larger sample.

First metre-wave image of galaxy Arp 220 with LOFAR

Varenius +16

Resolution 0.65"x0.35", σ=0.15 mJy/beam.



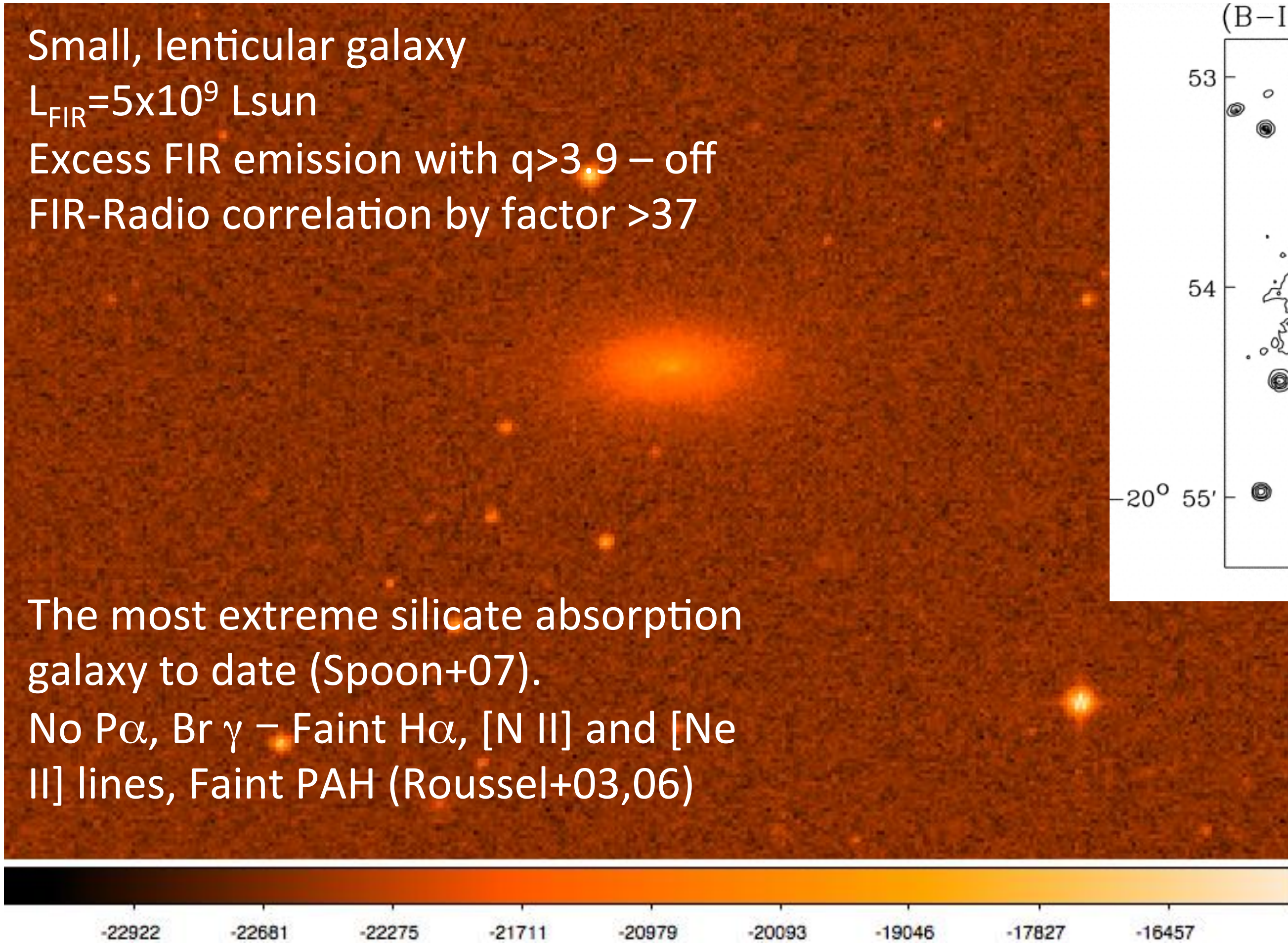


Key results:

- Detection of prev. unknown radio halo
- Map of plasma absorption
- ”Ageing” shocked outflows – signs of recurring episodic outflow?

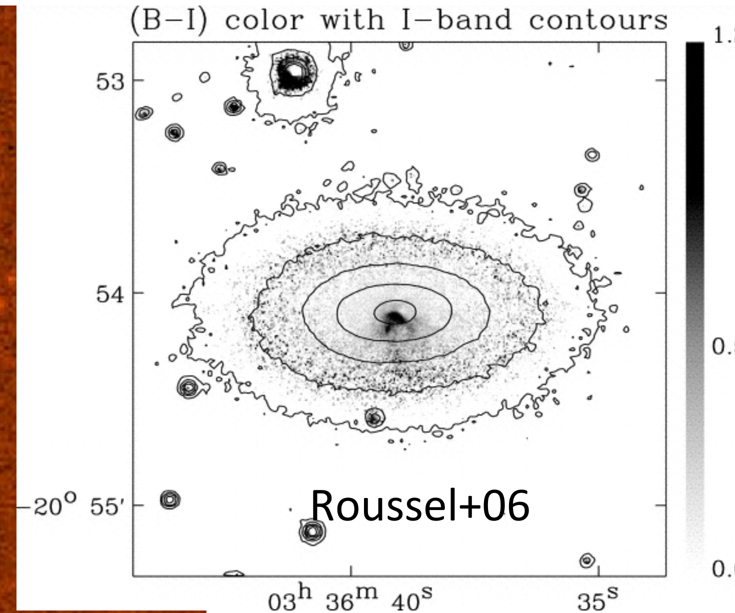
AGN OUTFLOW MORPHOLOGY EXAMPLE: MOLECULAR JET IN DUSTY AGN

A molecular outflow in the most extreme FIR-excess, radio-quiet galaxy NGC1377



Small, lenticular galaxy
L_{FIR}=5x10^9 Lsun
Excess FIR emission with q>3.9 – off FIR-Radio correlation by factor >37

The most extreme silicate absorption galaxy to date (Spoon+07).
No Pα, Br γ – Faint Hα, [N II] and [Ne II] lines, Faint PAH (Roussel+03,06)

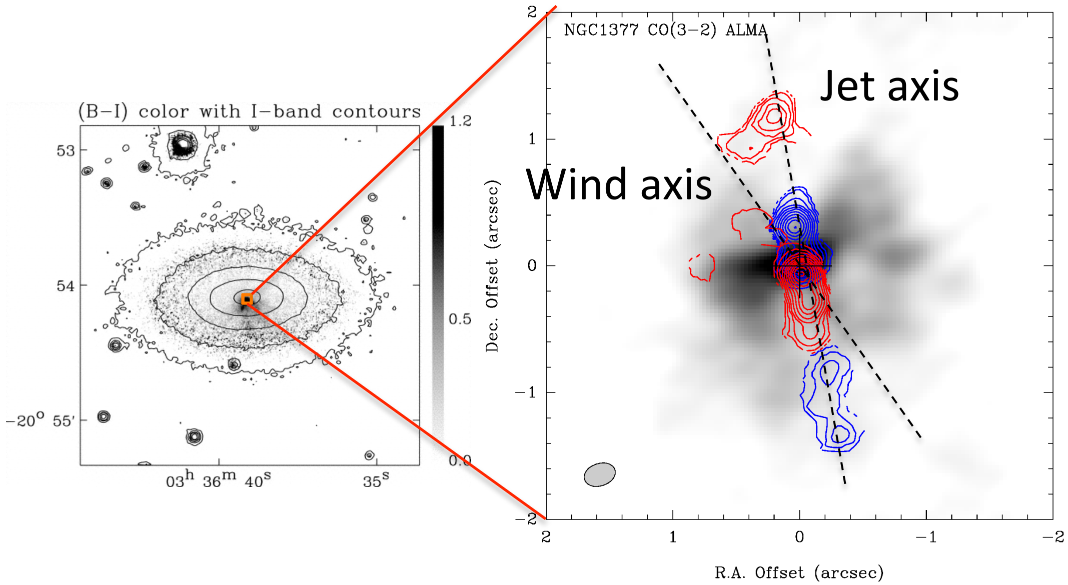


Featureless morphology apart from southern minor axis dust structure

Post starburst/LINER optical characteristics

What is powering the compact IR luminosity - Obscured AGN or nascent starburst?

SMA CO 2-1 imaging: a molecular outflow (Aalto+12b)



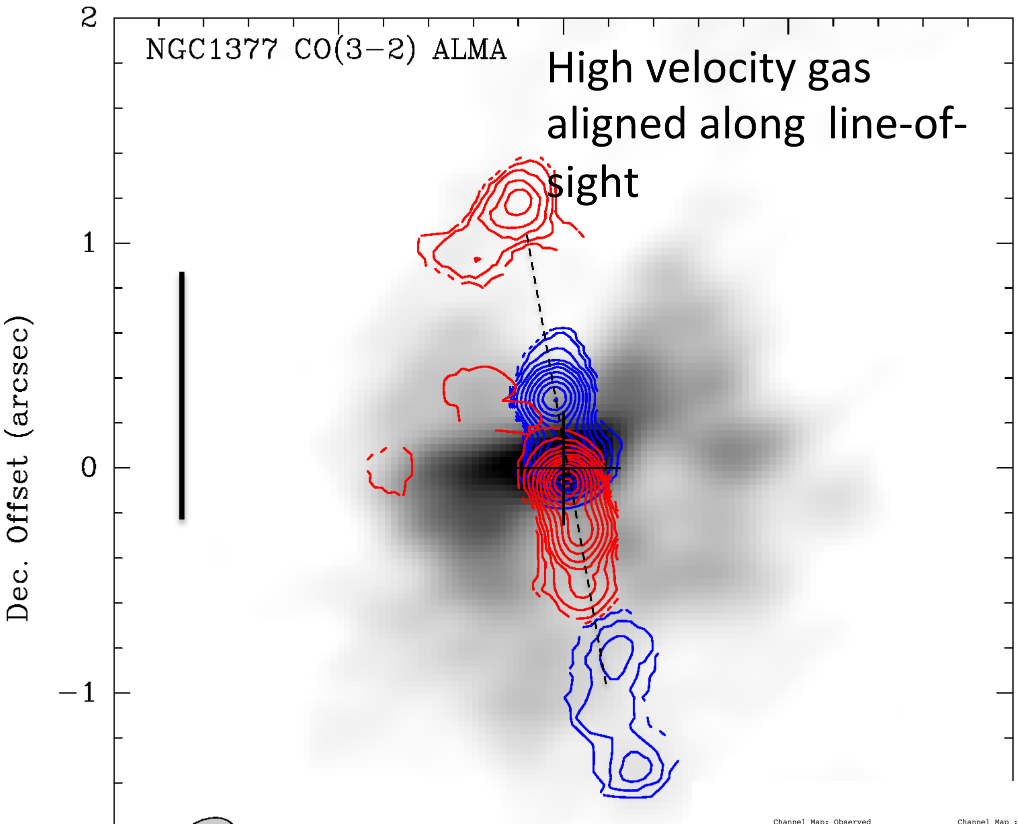
CO 3-2 gray scale: low velocity, red/blue: high velocity

- Molecular mass: jet: 1-6x10^7, "wind": 10^8 $M_\odot$
- Extent: 400 pc
- Opening angle: jet: …, wind: 70°–100°
- Age: jet: 0.5-2 Myr?, wind:?
- Outflow velocity: jet: 200 - 800 kms^{-1}, wind: 30-100 kms^{-1} (v_{esc} approx 250 kms^{-1})
- dM/dt: 8–38 $M_\odot$ yr^{-1}
- dP/dt: jet: 2-7L_{FIR}/c
- Molecular core of N(H_2)>10^{23} cm^{-2}

Low-J CO emission is dominated by minor axis outflow: wind+jet

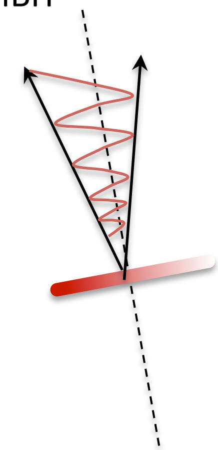
The inner region will be clear of molecular gas within 5-25 Myr?
But – what happens to the molecular gas in the outflow?

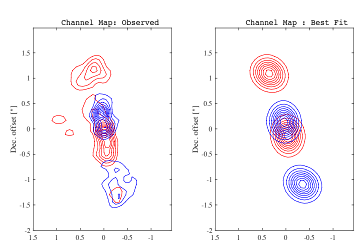
A precessing molecular jet??



High velocity gas aligned along line-of-sight

A molecular ”jet” rotating around an axis perpendicular to the line of sight may reproduce observations. May signal obscured, accreting SMBH





Precessing molecular jet signals accreting SMBH?

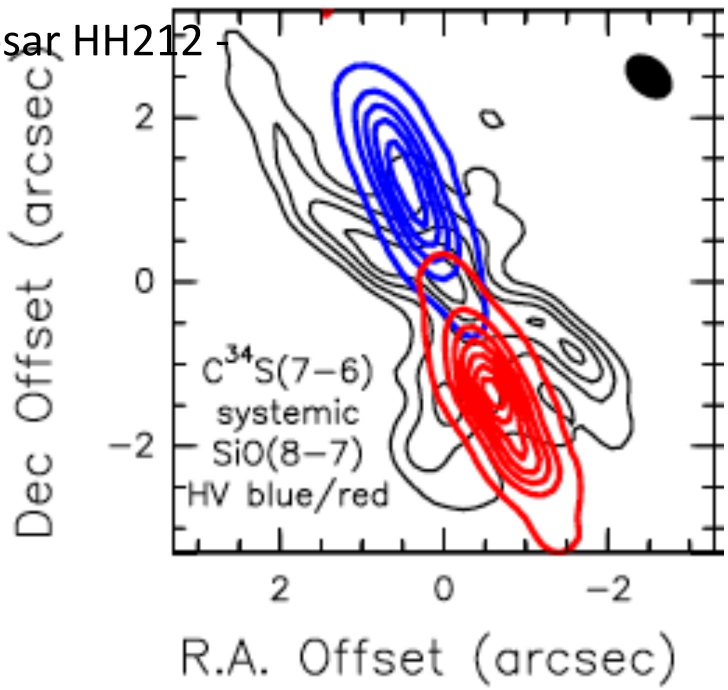
Alternatives: Helical jet? Shocks? Multiple jets?

Grey scale: Systemic velocities

Red and blue: High velocity gas

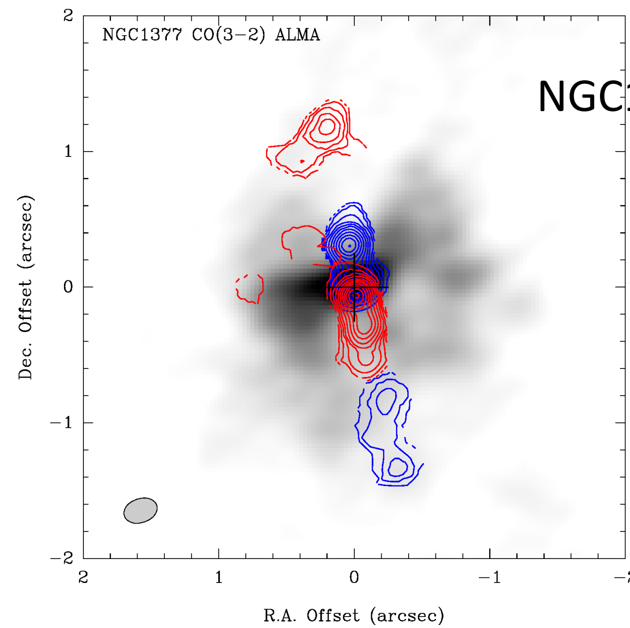
Analogy: protostellar jet??

Protosar HH212 -



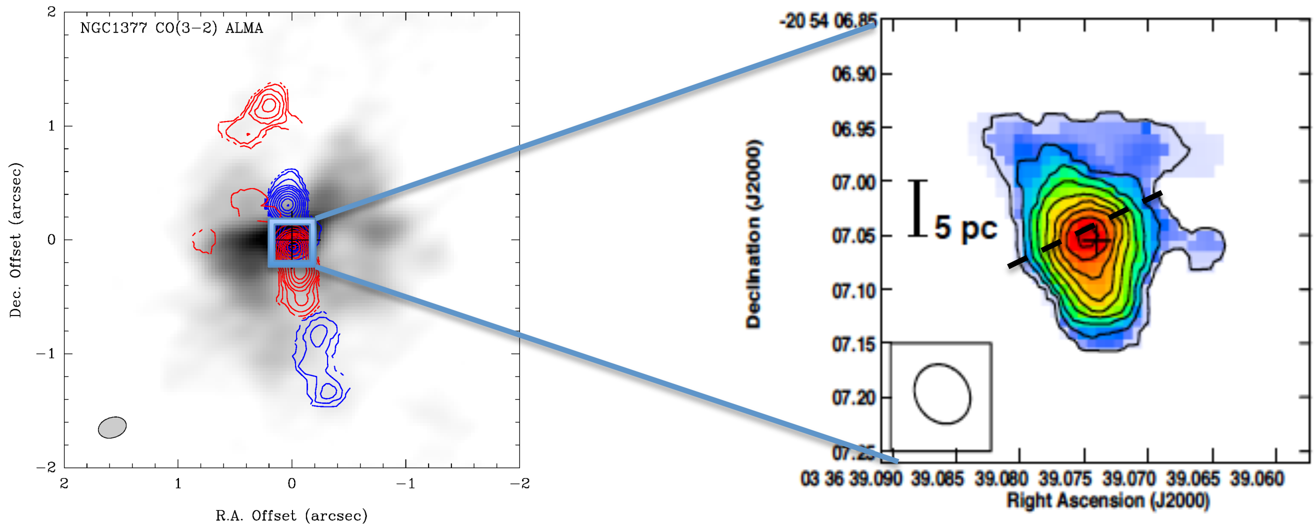
Codella+14: High velocity SiO jet surrounded by systemic emission outlining the cavity and a wide angle flow. Here – no evidence for jet precession

NGC1377



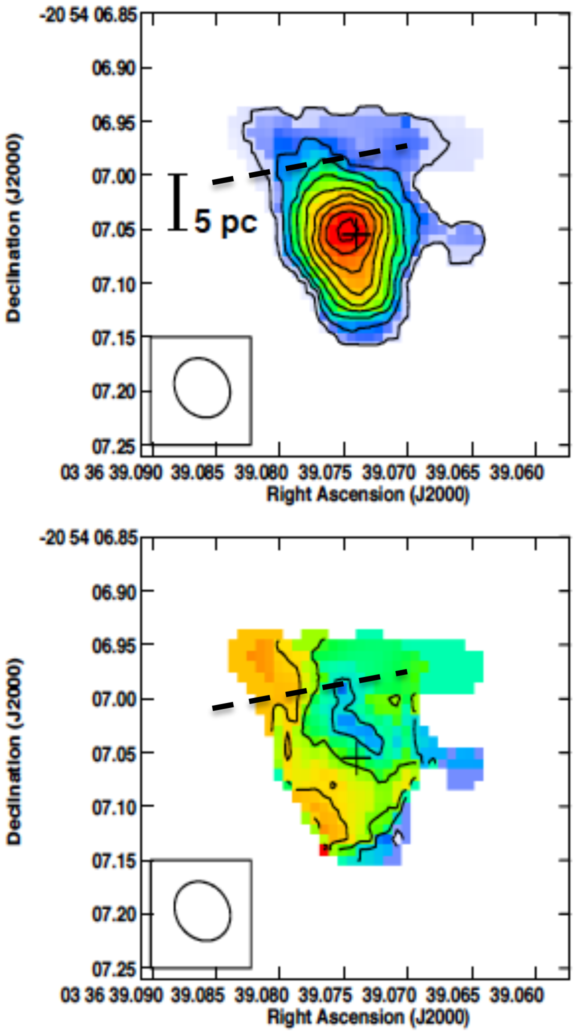
Accretion state of SMBH of NGC1377 Is however unclear. Extremely faint radio emission finally detected (Costagliola+16) – but its origin is unclear.

New ALMA Band 9 CO 6-5 observations with 50 mas (5 pc) beam.



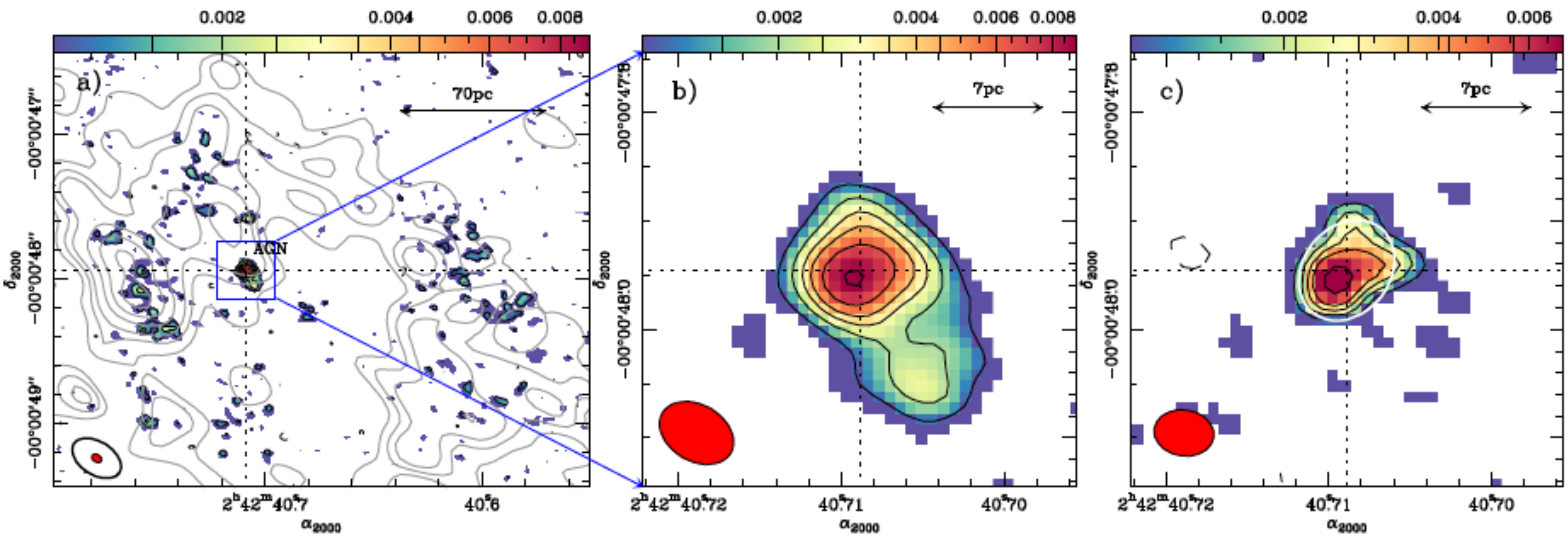
- Dense ($n>10^4$ cm-3), warm molecular gas (>100 K) in the nucleus on scales of 10 pc.
- Rotating nuclear disk with r=2.5 pc. Enclosing 10^6 M_{sun} SMBH.
- Complex dynamics in the inner 5-10 pc
  - High velocity gas in nuclear rotation – not in jet
  - Near-systemic jet-like features on 5-10 pc scales.
  - Evidence of warping from stellar disk to inner r=2.5 pc disk.
- No 690 GHz continuum detected. Very faint 345 GHz continuum – where is the dust obscuration?

Outflow rotation? Expansion?



- ALMA allow for studies of structures of AGN outflows with 5 pc resolution.
  - Study onset of feedback.
- CO 6-5 is likely shock excited
- Velocity shift across outflow
  - Jet/outflow rotation?
  - Multiple dynamical components?
- Note however – incomplete dynamical picture.

ALMA observes NGC1068 at high resolution

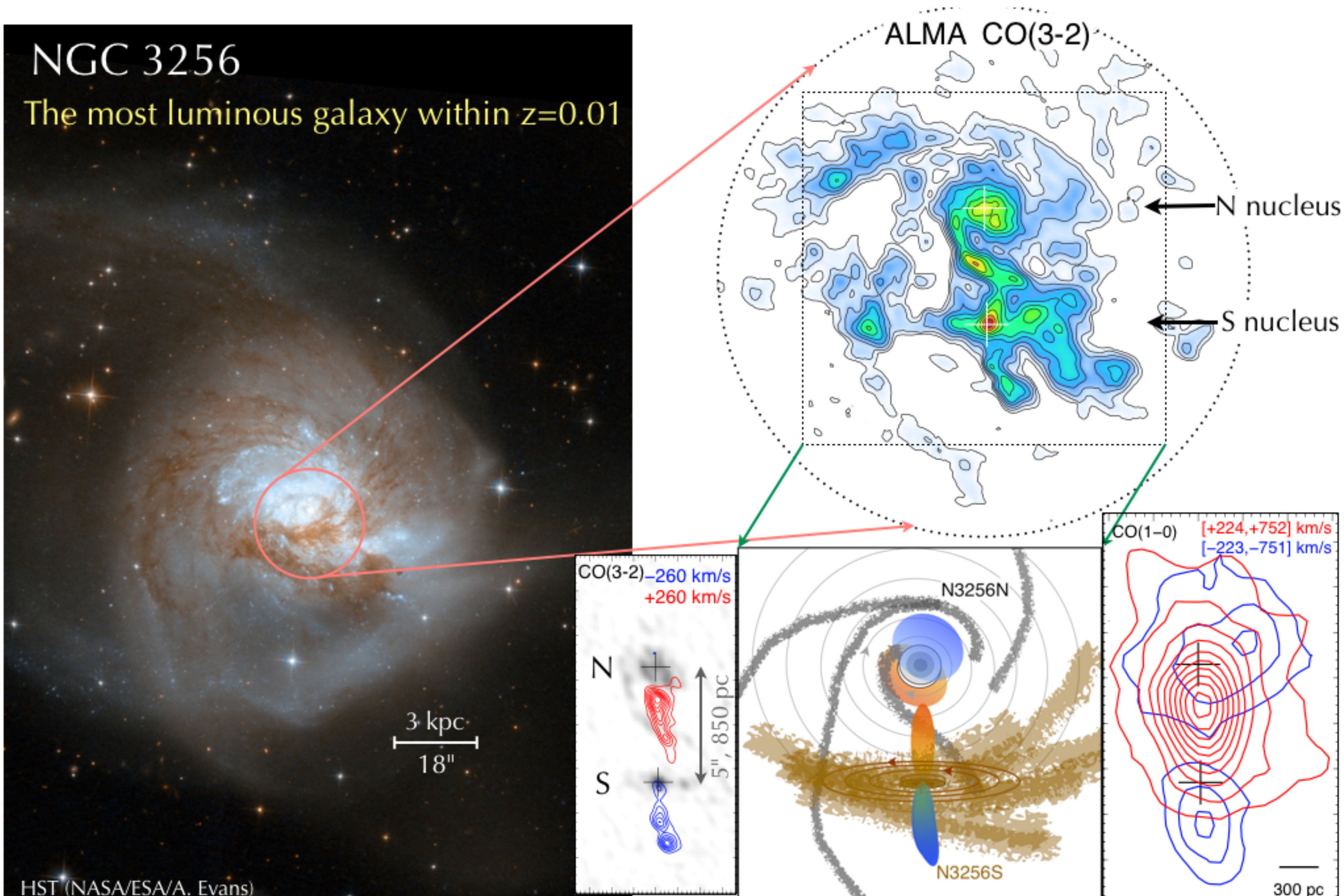


- Very high resolution (0."06) ALMA observations:
  - *r*=3.5 pc dusty turbulent torus with M_{gas}=1x10^5 M_{sun} (Garcia-Burillo+16 – see also Gallimore+16).

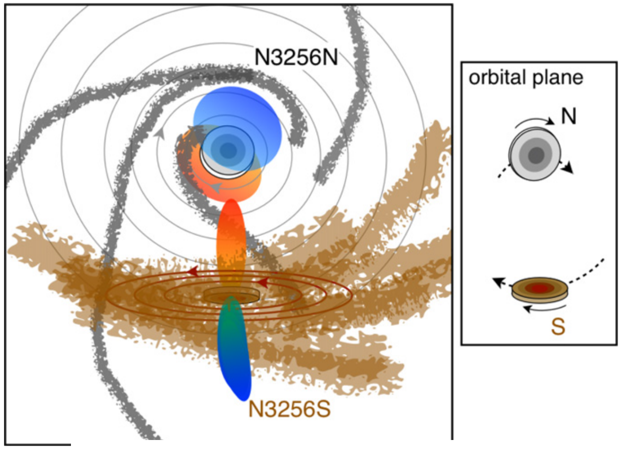
THE DUAL MOLECULAR ”JETS” OF THE LIRG MERGER NGC3256

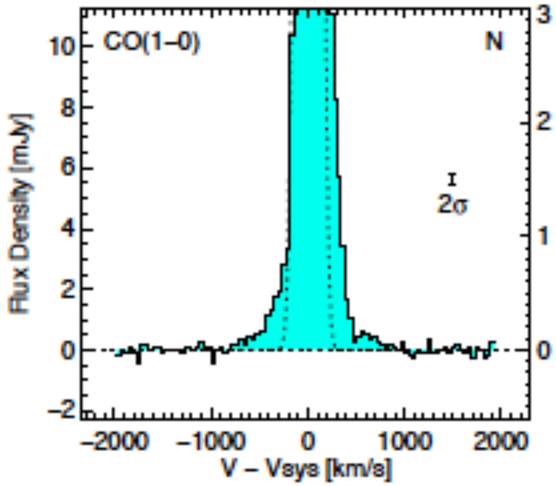
A LUMINOUS INFRARED MERGER WITH TWO BIPOLAR MOLECULAR OUTFLOWS: ALMA AND SMA OBSERVATIONS OF NGC 3256

Kazushi Sakamoto[1], Susanne Aalto[2], Francoise Combes[3], Aaron Evans[4,5], and Alison Peck[4]



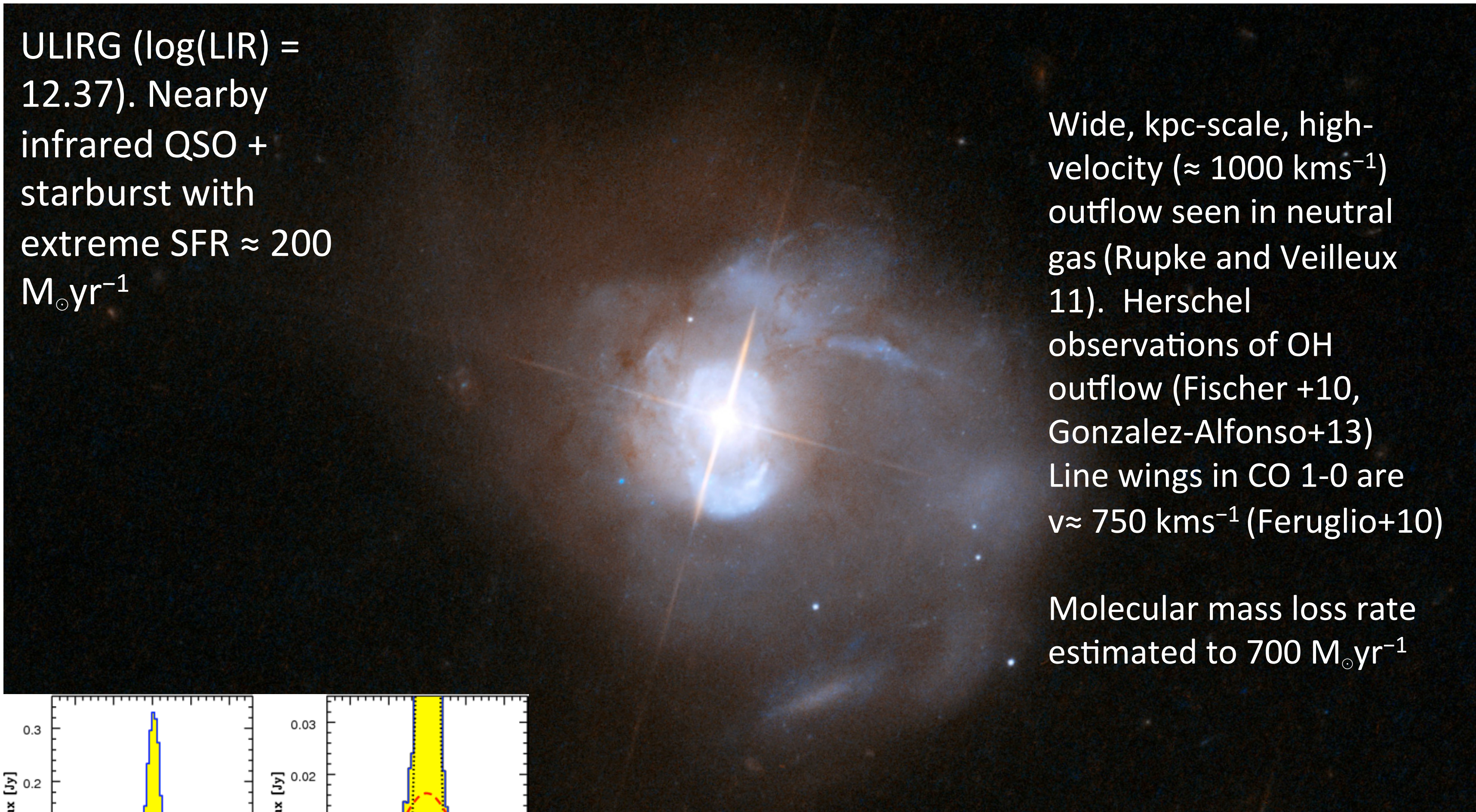
- Extremely high velocities – 1000 – 2000 km/s
- Accelerating outflow??
- dM/dt > 50 M_{sun} yr^{-1}
- Twin molecular jets?
  - Compare with NGC1377
  - Also radio quiet?
- Driving mechanism?
  - "dead" or dormant AGN?
  - Starburst?





DENSE MOLECULAR GAS IN OUTFLOWS

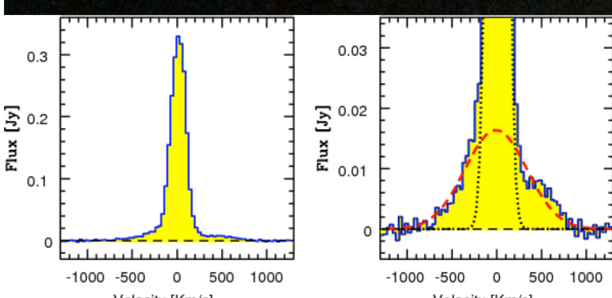
Mrk231- high velocity gas in the QSO outflow



ULIRG (log(LIR) = 12.37). Nearby infrared QSO + starburst with extreme SFR ≈ 200 $M_{\odot} yr^{-1}$

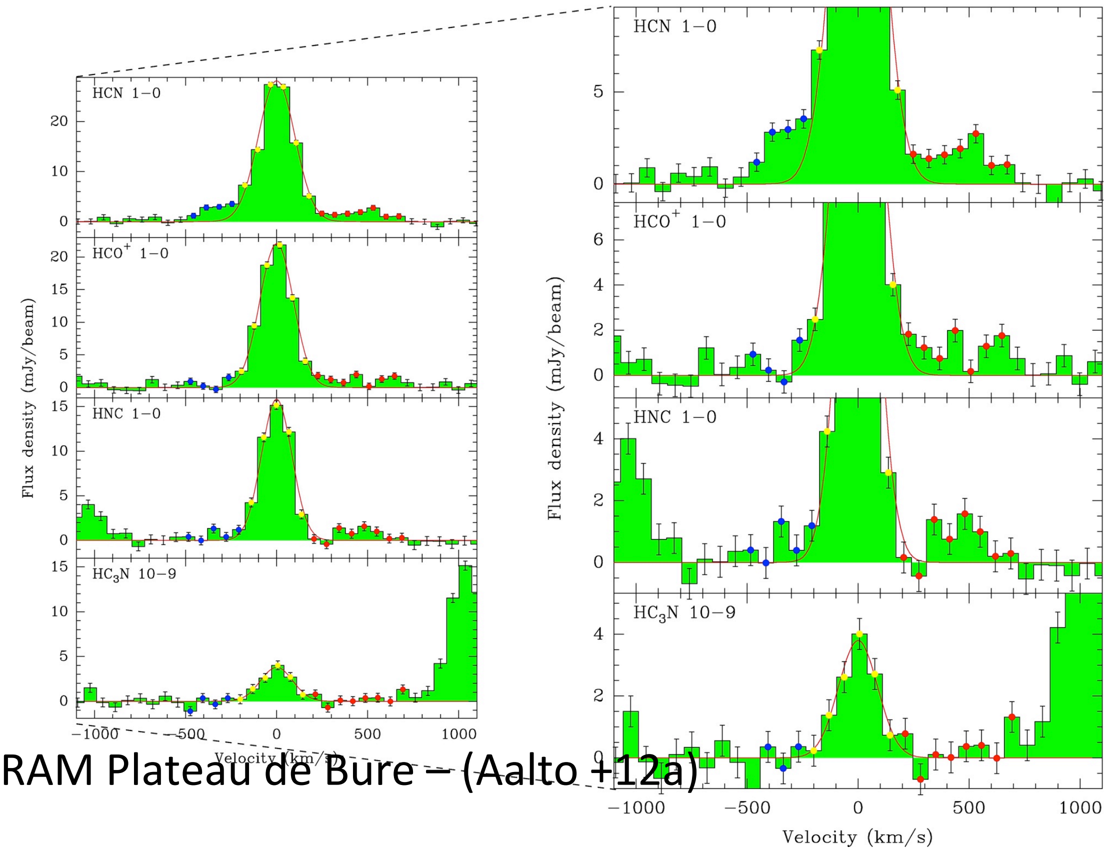
Wide, kpc-scale, high-velocity (≈ 1000 kms^{-1}) outflow seen in neutral gas (Rupke and Veilleux 11). Herschel observations of OH outflow (Fischer +10, Gonzalez-Alfonso+13) Line wings in CO 1-0 are v≈ 750 kms^{-1} (Feruglio+10)

Molecular mass loss rate estimated to 700 $M_{\odot} yr^{-1}$



Other molecules: HCN, HCO^+, HNC 1-0 in an AGN wind. Dense ($n>10^5$ cm^{-3}) gas

I(HCN)>I(HCO+)>I(HNC)



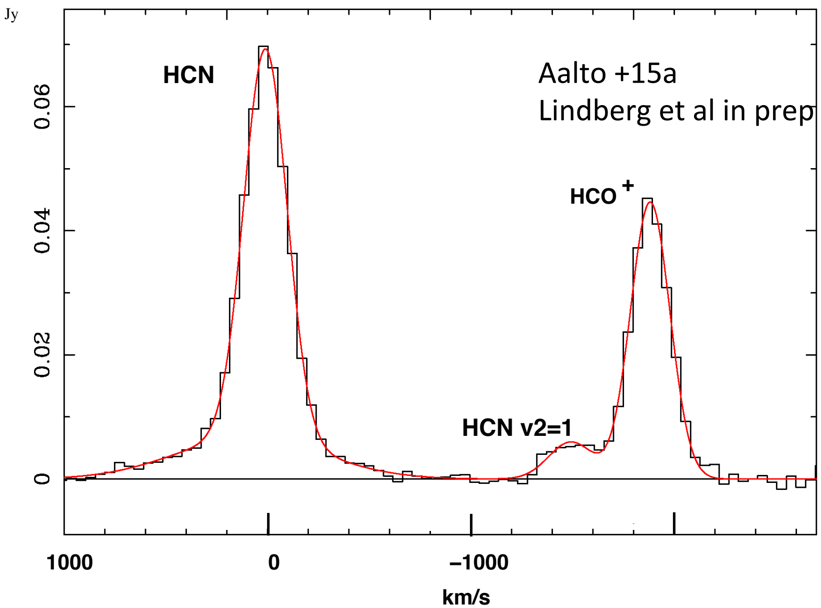
IRAM Plateau de Bure – (Aalto +12a)

HCN 1-0 wings appear spatially extended on scales of 700 pc

Outflow also detected in OH and H_2O absorption by Herschel (Fischer +10, Gonzalez-Alfonso+10)

Is the outflow in Mrk231 clumpy?

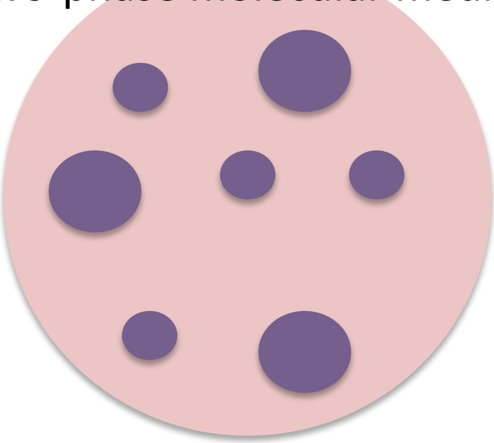
HCN 2-1, 3-2 detected in the outflow – extent 400 pc



Evolution of gas properties in the outflow? r(HCN 3-2)<r(HCN 1-0)<r(CO 2-1)r<(CO 1-0) (Cicone+12; Feruglio+15, Aalto+15)

HCN/HCO^+/HNC velocity differentiated in outflow - "pile-ups" and clumpiness in velocity space. Shocks? (Lindberg+15)

A two-phase molecular medium?



- Dense clumps/filaments of 10^4–10^5 cm^{-3} traced by HCN, CS, HCO^+,HNC etc
- Low density diffuse molecular gas traced by e.g. low-J CO , [C I], [C II|

What is the mass of dense molecular gas in the Mrk231 outflow? (Aalto +15a)

Self-gravitating clouds

- RADEX model of HCN 3-2, 2-1,1-0. Assume cloud ensemble of self gravitating clouds.
- M_{dense} typically 4×10^8 (+-x2) M_{sun}. Gives same value as from the L(HCN) to M_{dense} conversion factor.
- $X(HCN)=10^{-8} - 10^{-6}$

Non self-gravitating clouds

- Take ensemble of self-gravitating clouds and increase ΔV/cloud with factor of 10.
- Resulting $M_{dense} = 7 \times 10^7$ M_{sun}
- $X(HCN)>10^{-6}$

$$\boxed{1\text{-}2\ L_{AGN}/c < dP_{dense}/dt < 10\text{-}15\ L_{AGN}/c}$$

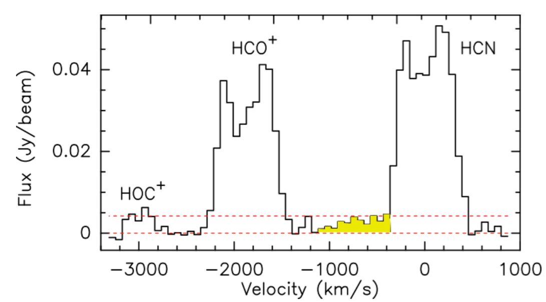
Dense gas in outflows: CO/HCN ratios

CO/HCN 1-0 ratio:

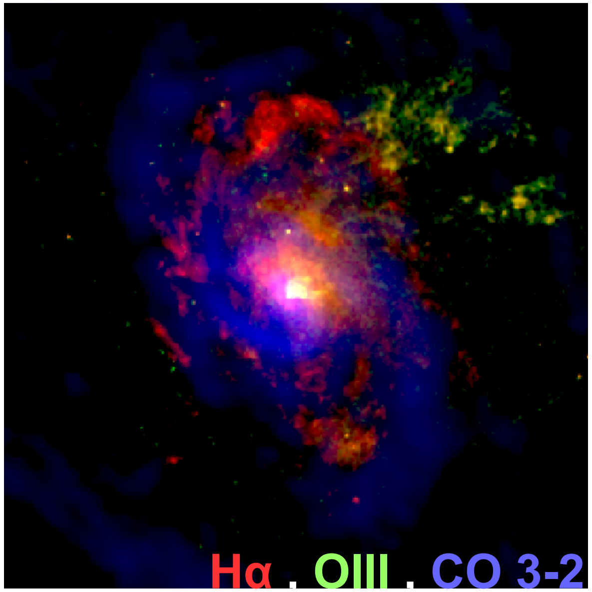
- ULIRGs: 1-3 (Mrk231, Mrk273, UGC5101, I17208)
- Nearby AGNs:
  - NGC1068: 2-5 (Garcia-Burillo +14). Outflow boosted by jet acceleration?
  - Circinus: 10 (Costagliola in prep). Wide angle wind?
- Starburst galaxies:
  - NGC3256: 10-12 (Harada in prep)
  - NGC253: 10 (Walter+17)
  - M82:15-30 (Salak+16)

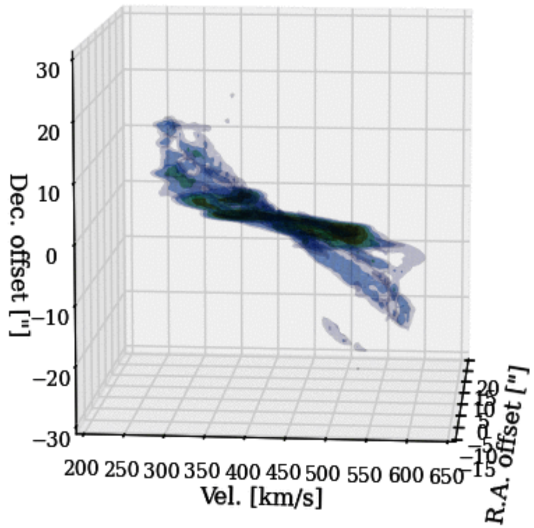
More wild, tentative speculations based on poor statistics:

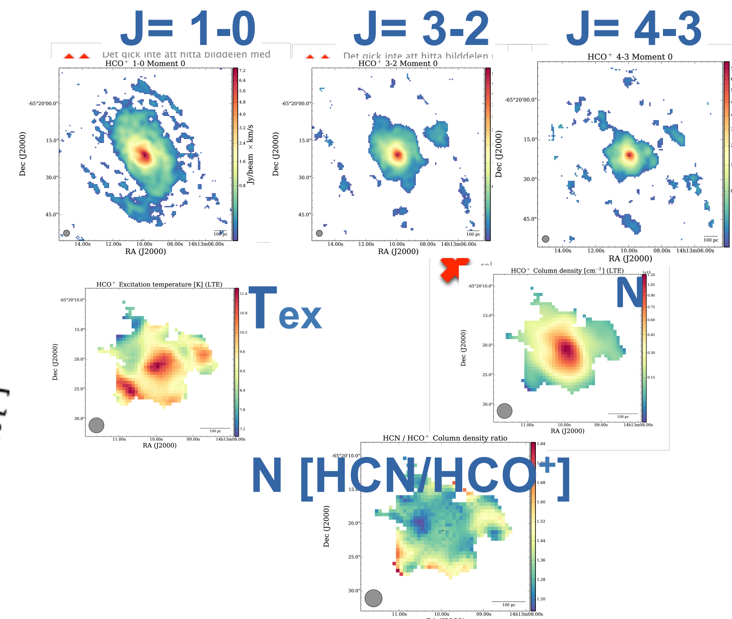
- It appears that the outflow gas ”know”s about the properties in the centre of the galaxy
- HCN (relative to CO) x 1-2 of those in the line core – relative to CO



Beam-matched multi-band ALMA observations in the Circinus Galaxy (Costagliola in prep)

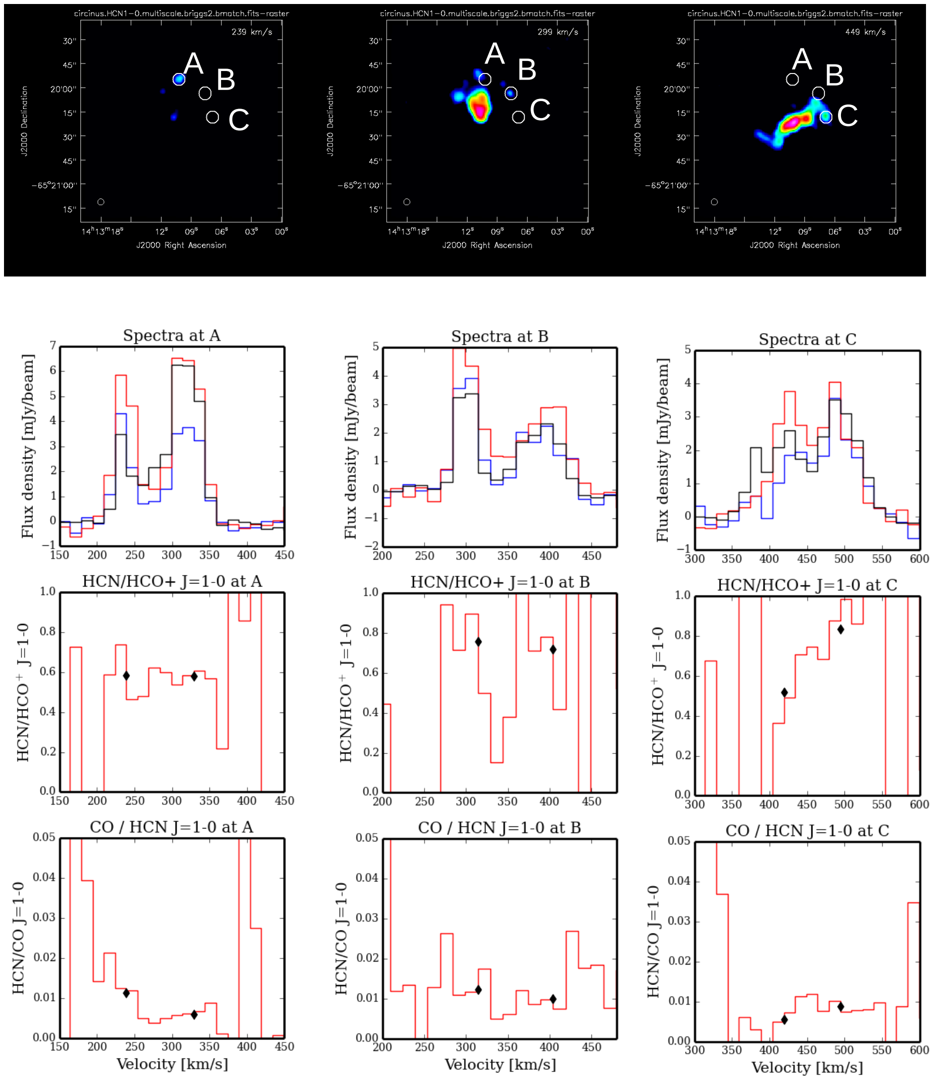






- Band 3, 6, 7 Beam-matched observations at 2.5=35 pc resolution
  - Detected HCN (1-0,3-2,4-3), HCO+ (1-0,3-2,4-3), CS, HC_3N, C_2H, CO 3-2
- Pixel-by-pixel modeling of HCO+ and HCN emission, including IR pumping:
  - Is the HCN abundance enhanced in AGN?
- Hunting for the molecular outflow: CO dynamical modeling + chemical tracers
- High-resolution, spatially-resolved physics and chemistry around an AGN
- Spatially resolved star formation laws : CO, IR, mm, Hα

Clumpy dense gas in the Circinus outflow (Costagliola in prep)

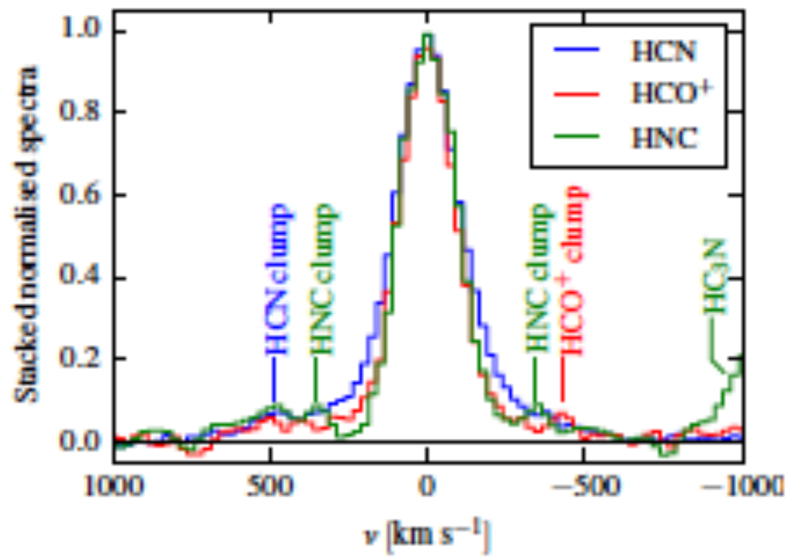


AGN driven outflow

Molecular dense gas content and chemistry appear similar to that of the starburst driven outflow of NGC253 (Walter+17)

Physical conditions/chemistry in outflows

- OH excellent tracer of LIRG/ULIRG outflows (Fischer+10,Sturm+11,Veilleux+13, Gonzalez-Alfonso+13, 14)
- HCN enhancement in outflow also in: NGC1068 (Garcia-Burillo+14), M51 (Matsushita+14), NGC7469 (Izumi+15.), NGC1266 (Alatalo et al in prep).
  - HCN/HCO+ in Mrk231: Signatures of "pile-ups" and clumpiness in velocity space. HCN and HCO^+ velocity – differentiated . (Lindberg et al in prep)
- HCO^+ and HNC in Mrk231 outflow (Aalto+12a, Lindberg+16) but suppressed w.r.t. HCN. See also Salas+15 on M82.
- HCN/HCO+/CS in starburst outflows M82, NGC253. NGC3256
- CN detected in NGC3256 outflow (Sakamoto+14) and in Mrk231 (Cicone in prep.)
- SiO in Arp220 bipolar outflow (Tunnard+15) and also in M82 (Garcia-Burillo+01)
- CO 2-1/1-0 ratio in Mrk231 outflow (Cicone+12, Feruglio+15), 3-2/1-0 ratio in N3256 outflow (Michiyama+15),



HCN/HCO^+/HNC velocity differentiated in quasar outflow (Lindberg+16). HCO+ tracing high velocity pre-shock gas. HCN tracing recently ejected gas that Is interacting with surrounding gas. HNC is tracing braked post-shock gas.

Conclusions

- ALMA very powerful tool for probing obscured nuclei and molecular outflows at high resolution and sensitivity. We need help from low frequency observations: VLA, Merlin, LOFAR
- Compact Obscured Nuclei – CONS (N(H2)>10^{25} cm^{-2}) are found in some U/LIRGs.
  - The most extremely dust-obscured do not seem to have fast winds – are they compact and dense, inside dust cocoon?? Orientation?
  - There are some evidence that they may have recurrent nuclear activity. AGN flickering?
- AGN molecular outflows are found in a variety of morphologies: wide angle, jet driven, wind+jet. Protostellar analogy jets?
- ULIRG AGNs have extreme CO/HCN ratios (close to unity) in their outflows – and in their nuclei. Very high dense gas fractions.
- We are now starting to do chemistry in AGN outflows.