Herschel observations of OH and H_2O in compact obscured nuclei

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The hydride toolbox
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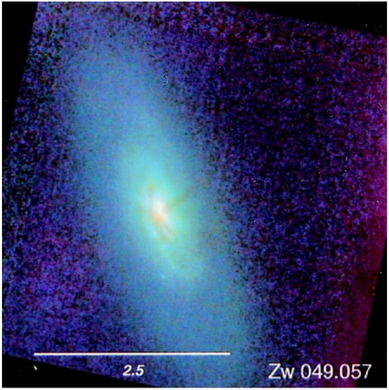
Compact Obscured Nuclei

- What?
  - Subclass of LIRGs
  - Nuclear molecular column densities N(H_2)$> 10^{24}$ cm^{-2}
  - Bright IR emission emerge from within $d < 100$ pc
- Why?
  - Objects in early evolutionary stages
  - AGN statistics
- Examples:
  - NGC 4418
  - Zw 049.057
  - Arp 299A

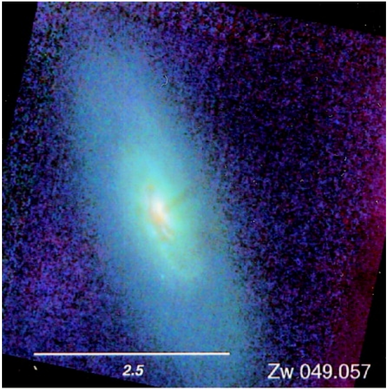


NICMOS near infrared image of Zw 049.057 (Scoville+2000)

Compact Obscured Nuclei

How to study them?

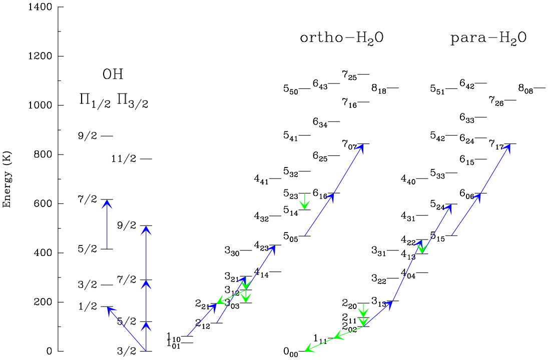
- X-rays: Possibly, but column densities large.
- Mid-IR AGN diagnostics: Complications due to high optical depth.
- **Far-IR/submm molecular observations: Study the obscuring dust!**
- Radio or mm: Probe deeper into the dust (we are doing this too).



NICMOS near infrared image of Zw 049.057 (Scoville+2000)

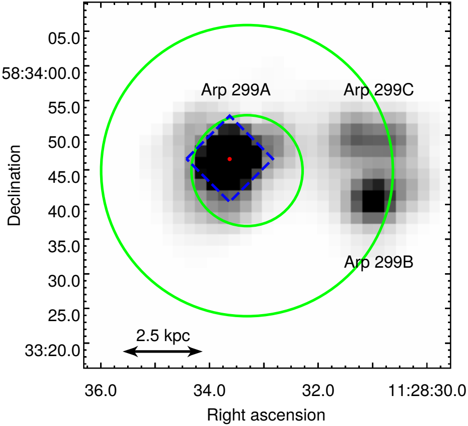
H_2O and OH as probes

- Obscured nuclei are rich in molecular gas.
- H_2O and OH have many rotational transitions in the far-IR and submm.
- ^{18}O isotopologues as evolutionary probes? (e.g. González-Alfonso+2012).



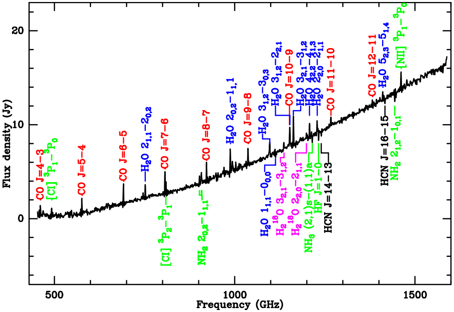
Why does it work?

- Herschel beam large compared to compact far-IR source.
- Nuclear emission and absorption diluted with more extended emission.
- **But:** High far-IR radiation densities required, we exclusively probe the very dense core!

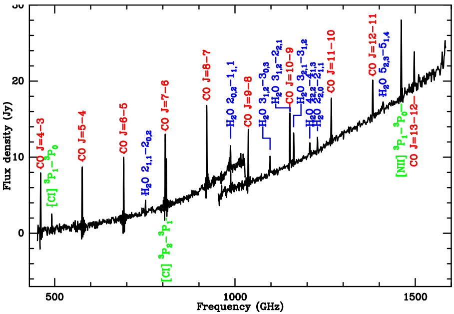


Observations
SPIRE

Zw 049.057



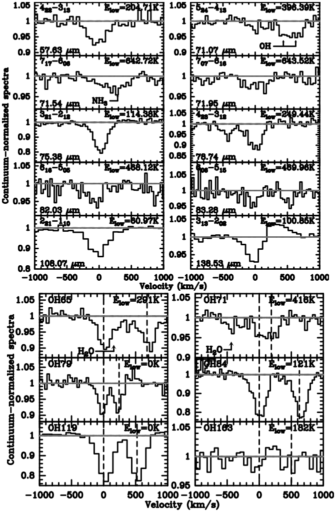
Arp 299A



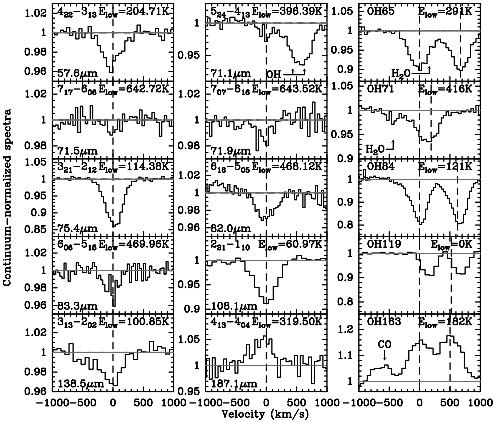
Note: Rich spectra, including strong H_2O emission, in both galaxies. In Zw 049.057 we also detect NH_2, NH_3, HF, and $H_2^{18}O$.

Observations
PACS

Zw 049.057



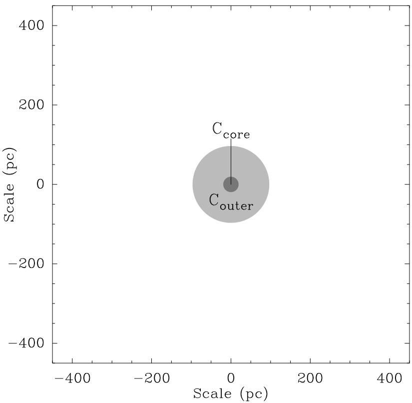
Arp 299A



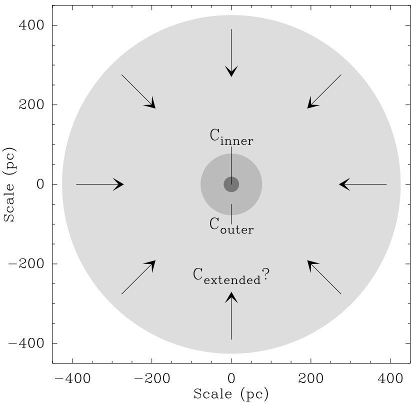
Note: H_2O and OH mostly in absorption in both galaxies

So, we made some models

Zw 049.057



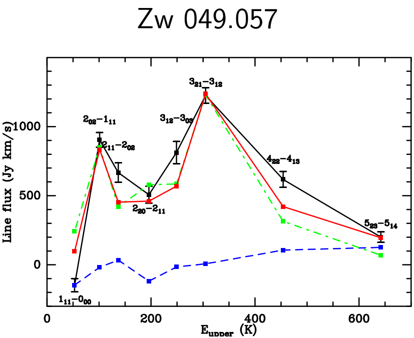
Arp 299A

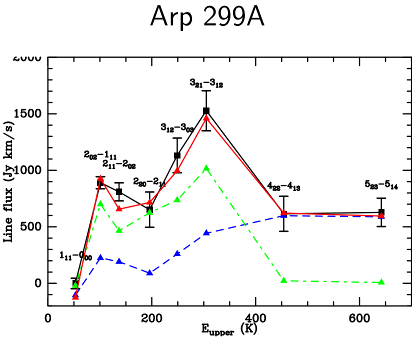


Spherically symmetric radiative transfer code described by González-Alfonso & Cernicharo (1999)

Models

H_2O lines with SPIRE





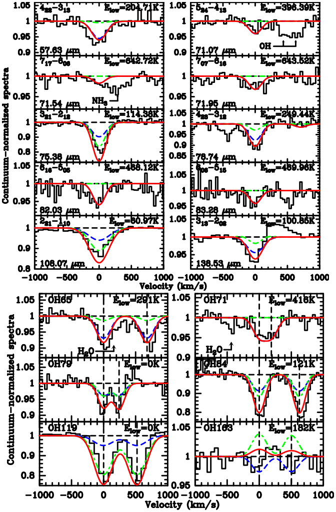
Better method used when modelling Arp 299A

Blue: Inner component **Green:** Outer component **Red:** Total

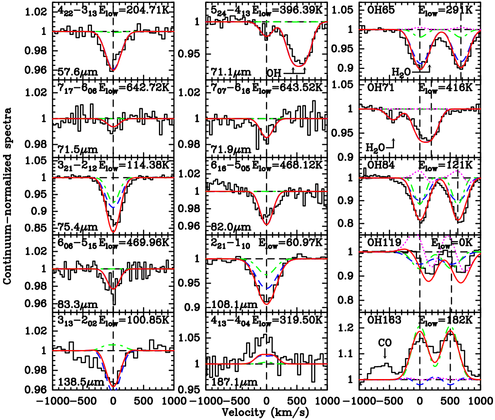
Models

H_2O and OH lines with PACS

Zw 049.057



Arp 299A



Blue: Inner **Green:** Outer
Magenta: Inflowing **Red:** Total

Models

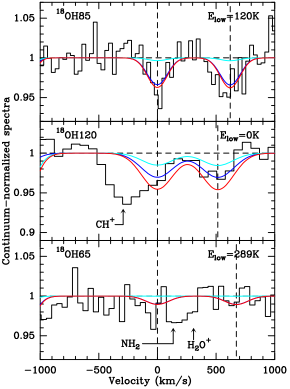
Some numbers (inner components)

	Zw 049.057	Arp 299A	IRAS 13120-5453
R (pc)	$12 - 32$	$20 - 25$	$\ldots$
$T_{\rm dust}$ (K)	$90 - 130$	$90 - 120$	$40 - 60$
$N_{\rm H_2O}$ (cm^{-2})	$\sim 1 \times 10^{18}$	$\sim 1 \times 10^{18}$	3.5×10^{17}
$N_{\rm OH}$ (cm^{-2})	$\sim 5 \times 10^{17}$	$\sim 5 \times 10^{18}$	$\ldots$
$N_{\rm H_2}$ (cm^{-2})	$\sim 5 \times 10^{24}$	$\sim 2 \times 10^{24}$	7×10^{23}
^{16}O/^{18}O	$50 - 100$	> 400	$\ldots$

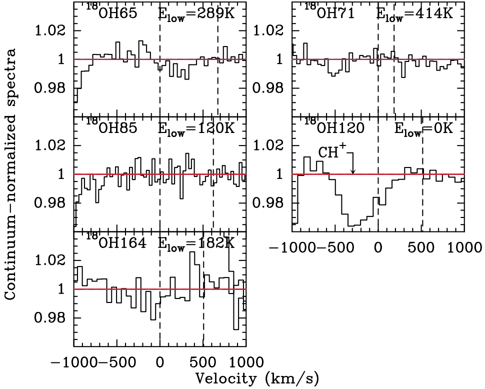
- Warm and compact dust components
- High water abundances
  - Cannot distinguish between formation scenarios
- OH/H_2O ratio much higher in Arp 299A
- Very different ^{16}O/^{18}O ratios

^{18}OH lines with PACS

Zw 049.057:
$^{16}\text{O}/^{18}\text{O} \sim 50 - 100$



Arp 299A:
$^{16}\text{O}/^{18}\text{O} > 400$

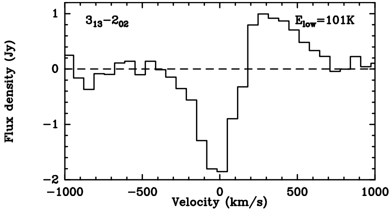


For reference:

- Solar system: $^{16}\text{O}/^{18}\text{O} \sim 500$
- Galactic centre: $^{16}\text{O}/^{18}\text{O} \sim 250$

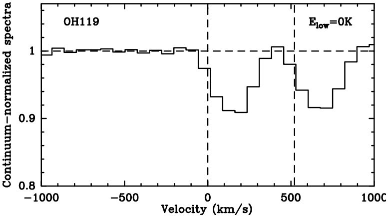
Signatures of in- and outflows

Zw 049.057



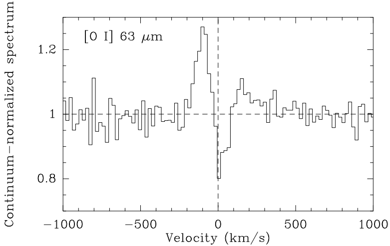
Outflowing gas?

Arp 299A

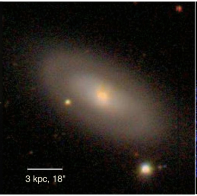
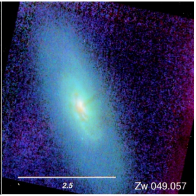
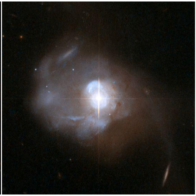


Inflowing gas

Also [O I]63μm inflow signature



Evolutionary scheme (tentative)

OH inflow No outflow? $\frac{^{16}\mathrm{O}}{^{18}\mathrm{O}} \gtrsim 400$	[O I]63 inflow Dusty outflow $\frac{^{16}\mathrm{O}}{^{18}\mathrm{O}} \gtrsim 250$	[O I]63 inflow H_2O outflow $\frac{^{16}\mathrm{O}}{^{18}\mathrm{O}} \sim 50 - 150$	No inflow? HCO^+ outflow $\frac{^{16}\mathrm{O}}{^{18}\mathrm{O}} \sim 70 - 130$	No inflow? OH outflow $\frac{^{16}\mathrm{O}}{^{18}\mathrm{O}} \sim 30 - 40$
				
Arp 299A	NGC 4418	Zw 049.057	Arp 220	Mrk 231
(Falstad+16)	(González-Alfonso+12)	(Falstad+15)	(Sakamoto+09, González-Alfonso+12)	(Fischer+10)

Caveats: Small number of sources, model uncertainties.

Summary

Conclusions:

- Compact obscured nuclei are rich in molecular gas
- OH and H_2O can be used to probe central dust concentrations.
- High molecular column densities ($N(\mathrm{H_2}) > 10^{24}$ cm^{-2}) towards the warm ($T > 100$ K), compact ($R < 50$ pc) cores.
- Evolutionary effects?
  - Out- and inflows?
  - ^{16}O/^{18}O ratios: $50 - 100$ in Zw 049.057 and > 400 in Arp 299A.

The future:

- High resolution observations: Map the hot core and disk.
- Isotopic ratios from other tracers.