OUTFLOWS IN LOCAL ULIRGS: [CII] $_{158}$ BROAD COMPONENTS AND OH OUTFLOWS

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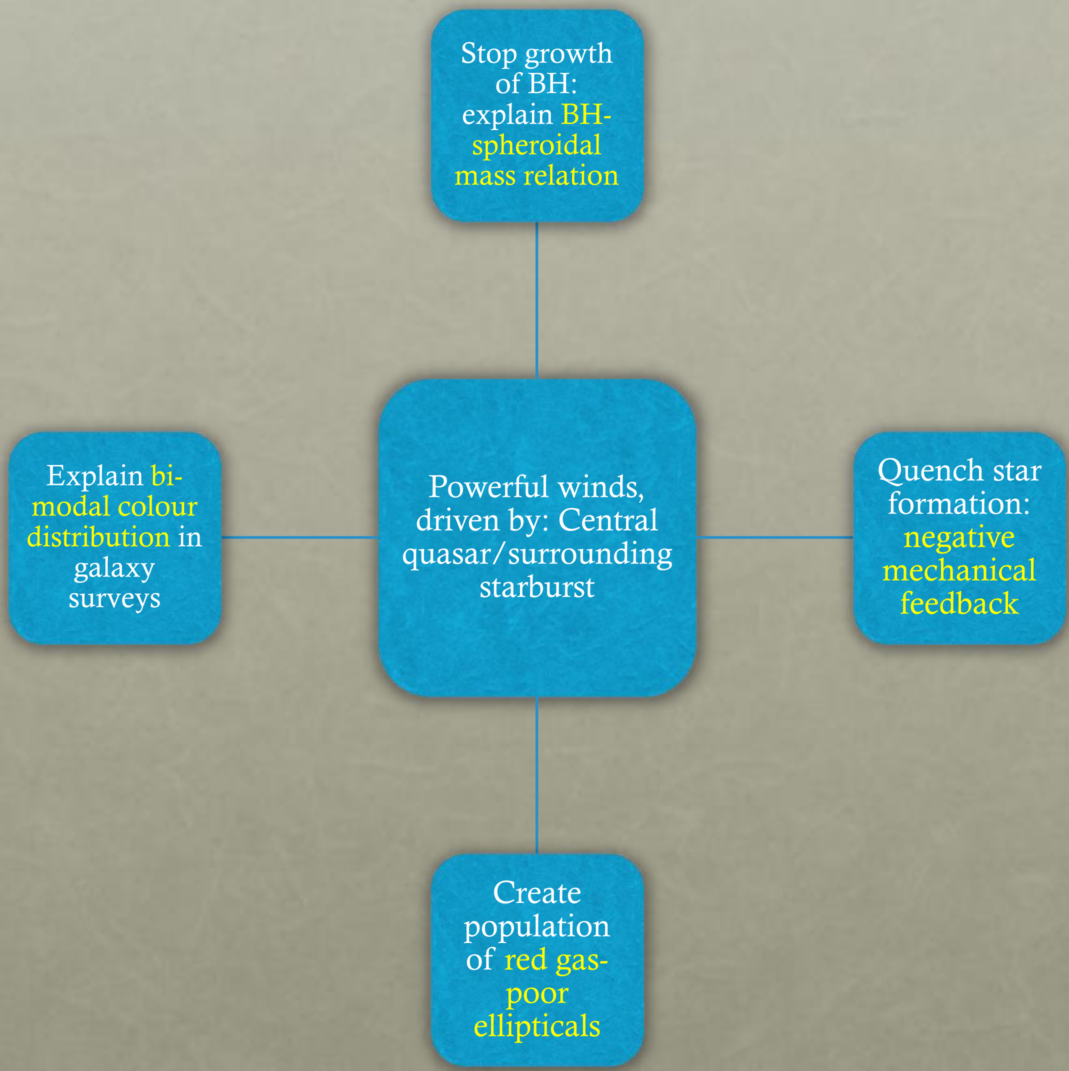
MOTIVATION

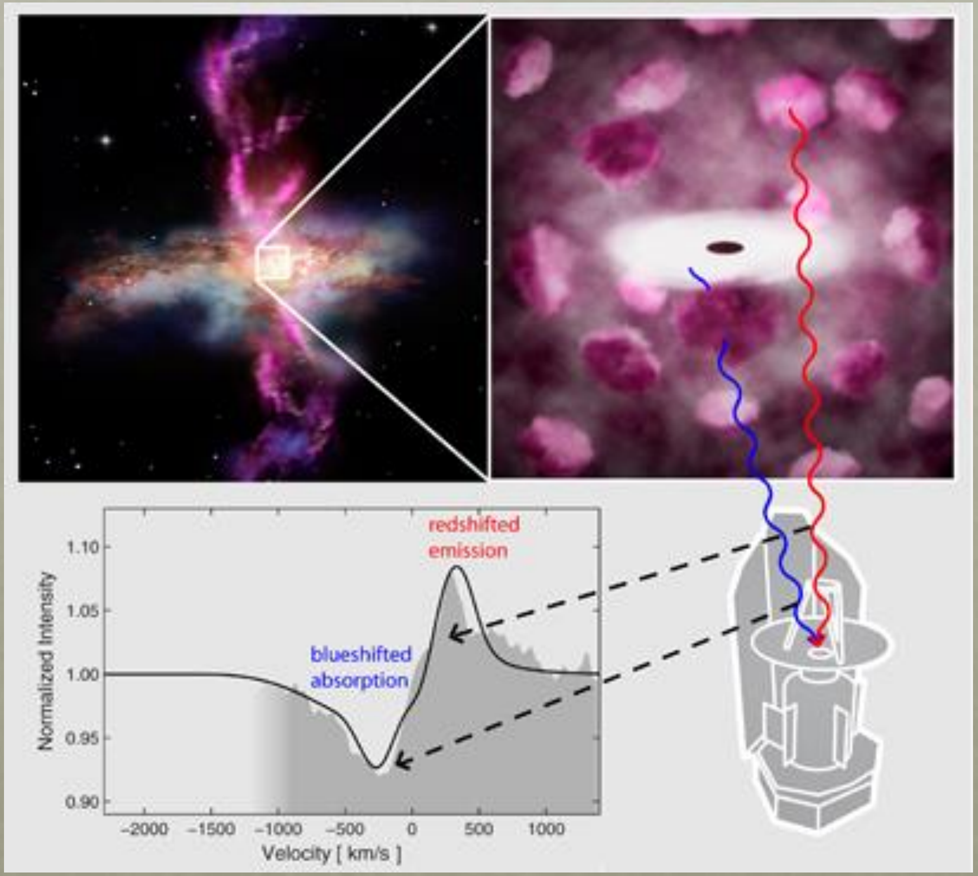


Merger-driven evolution

MOTIVATION

<u>Molecular Outflows</u>

To inhibit star formation in the host galaxy, outflows have to affect the *molecular* gas out of which stars form.



If OH and [CII] originate in similar regions in the host galaxy…

… could $[CII]_{158um}$ be used as a signpost for molecular outflows in high redshift objects?

Image: ESA/AOES Medialab

The Sample

21 local ULIRGS
(z< 0.0876, z_{median}=0.056)

Wide range of starburst & AGN activity

Including:

- Cold, star-burst dominated ULIRGs
- Warm ULIGS (S25/S60>0.15)
- ULIRGS with strong AGN contributions
- Heavily obscured ULIRGs with a powerful AGN

FIR fine structure line $[CII]_{158\mu m}$ observed with Herschel/PACS.

$[CII]_{158\mu m}$ detected in all sources in the sample.

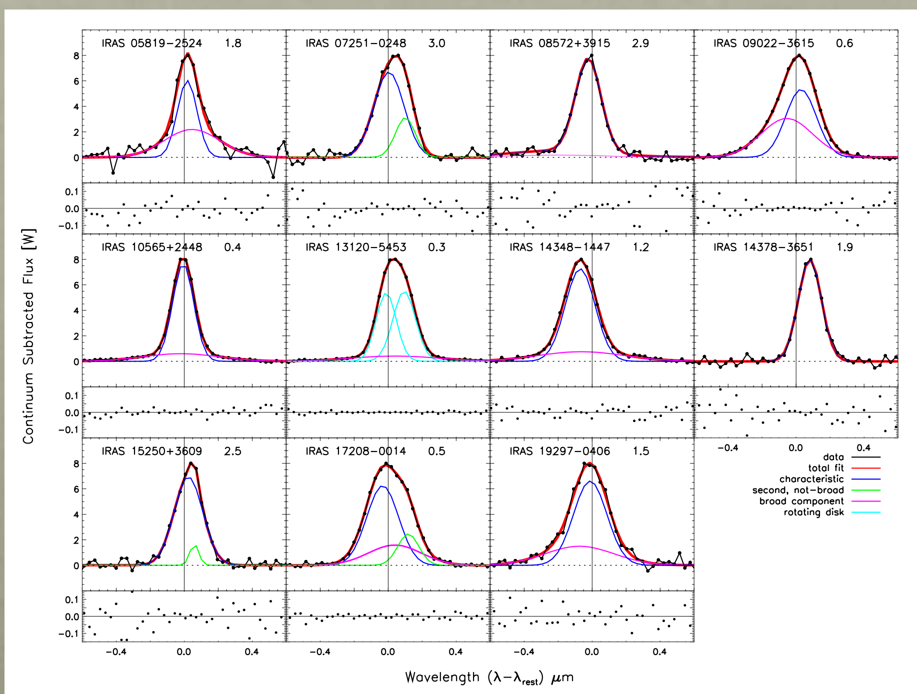
All ULIRGs are unresolved with respect to the PACS beam

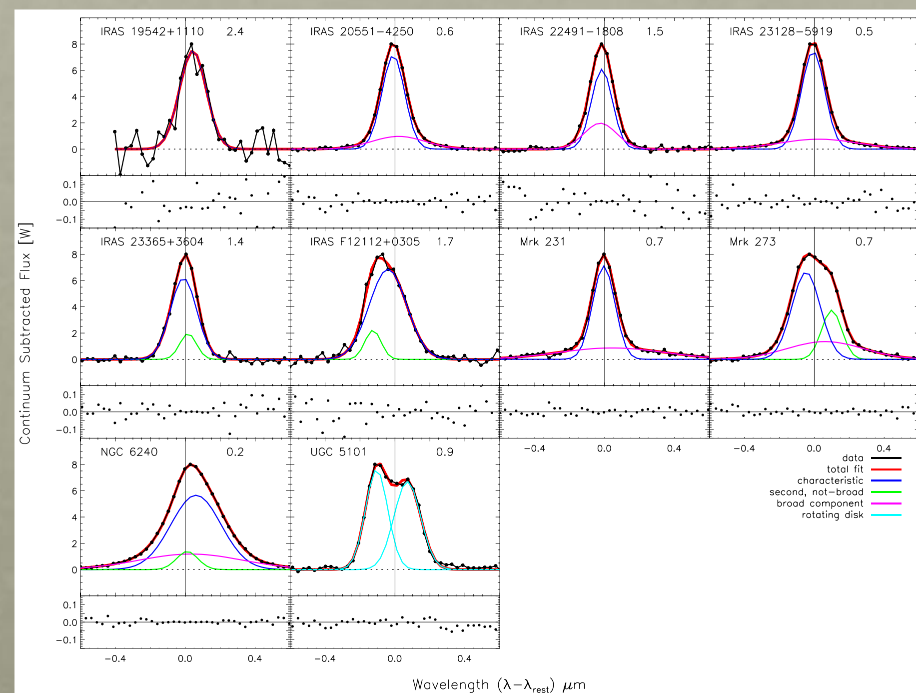
[CII] PROFILES

- Broad components seen in 15/21 (71%) of the sample
- $FWHM_B$: 385 - 1300 km/s

  (mean ~960 km/s)
- Contribution of broad component to total flux:

  up to 51% (IRAS 09022)



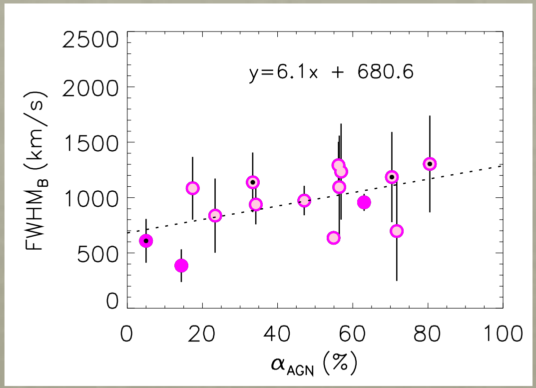


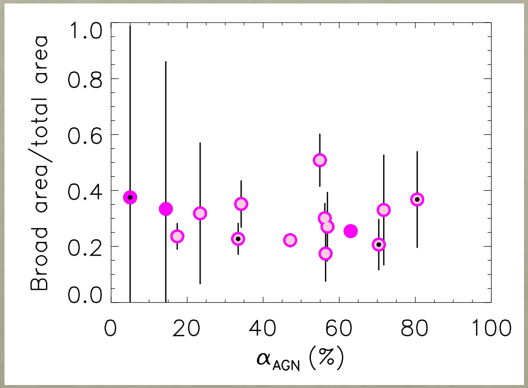
Spectra fit using *Peak Analysis* (PAN; Dimeo (2005)), adapted for astronomical use by Mark Westmoquette (http://ifs.wikidot.com/pan)

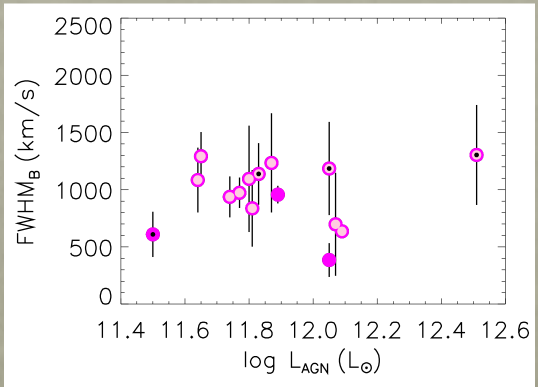
What drives the observed outflows?

FWHM_B= 385-1300km/s

- 800 - 1100 km/s in the range (tending more to the high-end) of the gas velocities found for the mid-IR AGN narrow line region (NLR) tracers 14.32 μm [Ne v] and 25.89μm [OIV] in ULIRGs (Spoon et al. (2013)







- No relation between $FWHM_B$ and L_{IR} or with 9.7μm silicate strength.

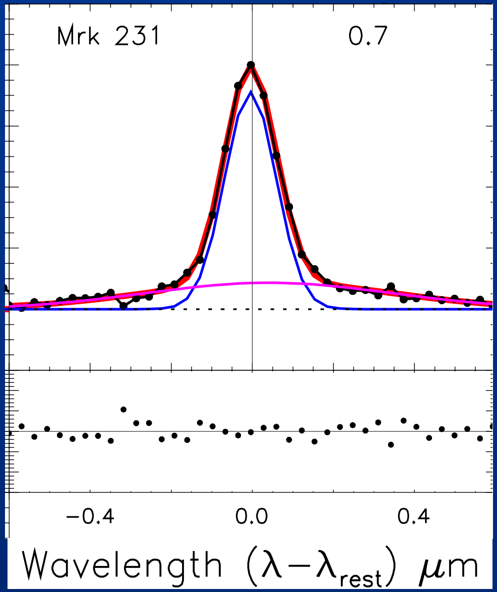
- No connection found between the presence of a broad [CII] component and the merger phase, or ‘interaction class’.

- The ‘relaxed’ or ‘ambient’ ISM, as measured using the ‘characteristic’ FWHM shows no trends with SB or AGN properties.

MRK 231

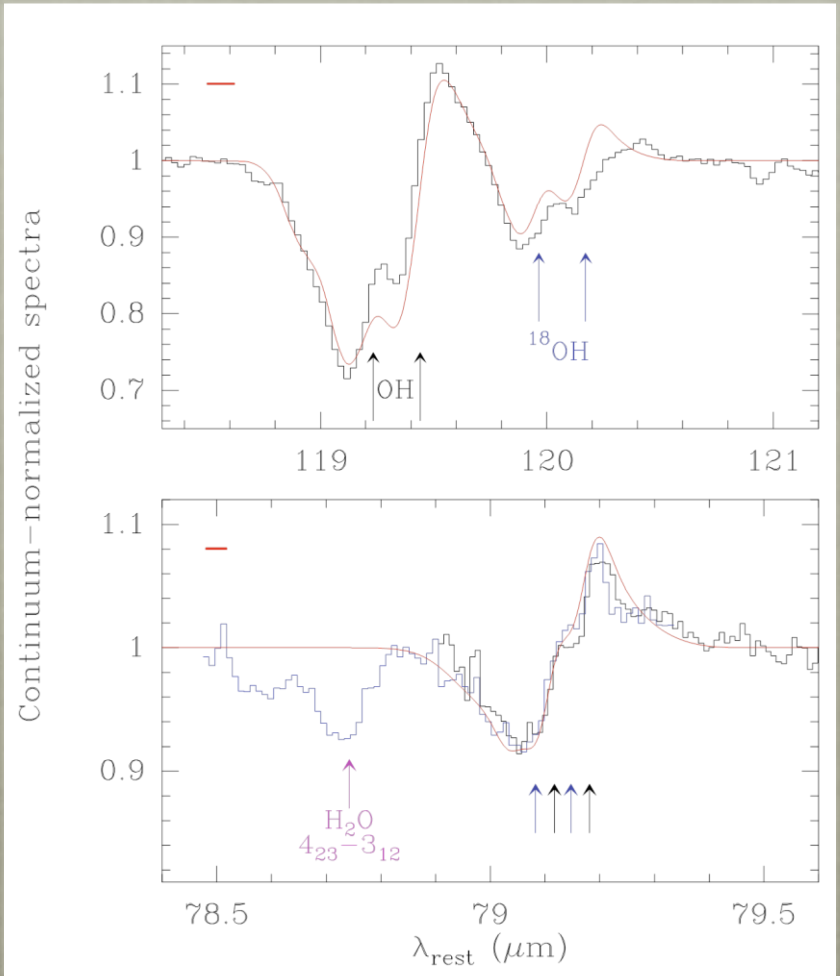
Mass loss rate > 700 $M_{\odot}$/yr ,
several times larger than the IR based SFR

The outflow appears to be a unique signature of the clearing out of the molecular disk that formed with the dissipative collapse during the merger.



$[CII]_{158um}$ $FWHM_B$:
1300 +- 440 km/s
(largest in sample)

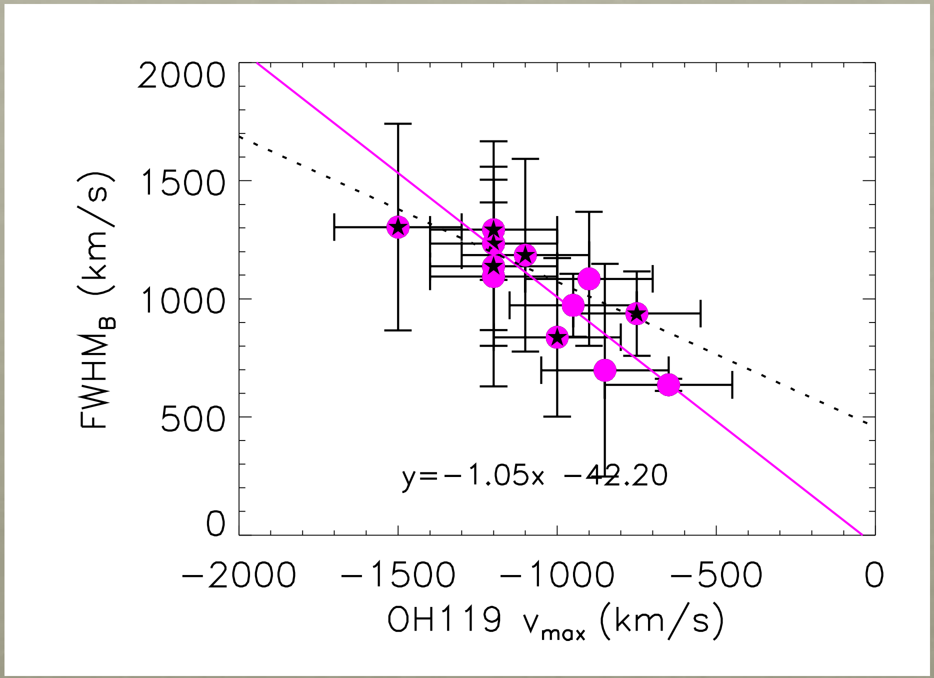
OH_{119um} terminal velocity:
-1500 +- 200 km/s



Fischer et al 2010

Broad [CII] Components Compared to OH Velocities

Define OH as being a wind if OH_{119um} v_{50}(abs) ≤ -50km/s



OH_{119um} v_{max} from Veilleux et al 2013

12/15 (80%) of ULIRGs exhibiting a broad component in [CII] also shows outflow in OH.

5/6 (83%) without broad [CII] exhibit OH outflows

Statistically significant relationship between $FWHM_B$ and OH_{119um} terminal velocity.

NB all SHINING ULIRGs were selected to have IRAS-band 100μm fluxes f100 > 1 Jy to more easily probe OH $_{119μm}$. Therefore our sample did not contain any 'classic' IR-faint QSOs in the critical late merger phases when the quasar has finally gotten rid of its natal cocoon and the effects of feedback are predicted to subside

CONCLUSIONS

- 15/21 of the sample of local ULIRGs exhibit broad components in their [CII] emission.
- FWHMB >1000 km/s in some sources
- The broad component can contribute up to ~50% of the [CII] emission.
- Turbulence in ISM, as traced by [CII] emission line is found to be strongly correlated to the AGN fraction.
    - $FWHM_B$ in two AGN-dominated ULIRGs (Mrk 231 and IRAS 08572+3915) are well above 1000 km/s.
- Broad [CII] components could possibly be a very useful tool in distinguishing AGN-driven outflows from starburst-driven outflows
    - AGN-dominated outflows reach much higher velocities (>1,000km/s)
- [CII] $FWHM_B$ is seen to follow a one-to-one relation with the terminal velocities of molceular outflowas as observed using OH

Outflows in M82

<u>Cold neutral gas outflows</u>

Mass: 2–8 × 107 M⊙

Kinetic energy: and 1–5 × 1054 erg

of are 2–8 × 107 M⊙ and 1–5 × 1054 erg slightly smaller than the corresponding values found for the outflowing molecular gas (~3.3 × 108 M⊙, ~3 × 1055 erg).

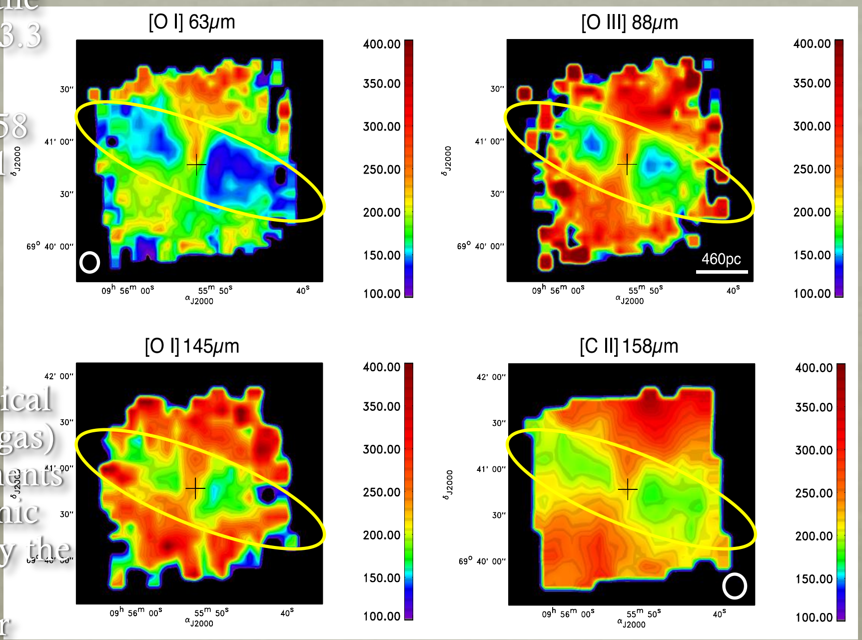
The mass outflow rate of the molecular and atomic gas is ~43–58 M⊙ yr−1 comparable to the SFR of M 82 equal to 25 M⊙ yr−1

, resulting in a mass loading factor M˙/S FR ~ 2. This result, together with the fact that these two components show similar velocities,

suggests that they are dynamically coupled with similar origin.

Since the cold atomic gas is consistent with emission from classical PDRs (i.e. interface regions between the ionized and molecular gas) with small filling factors, the coupling of these two cold components of the ISM is naturally explained if both the molecular and atomic media belong to the same disk clouds entrained in the outflow by the wind where they partially evaporate due to heating driven by thermal conduction from the hot gas, surviving as clouds smaller than their original size.

relation between G_0 and n_H found to be the same regardless if in the starburst, outflow or diffuse disk: confirms that the clouds in the outflow are still organized in PDRs very similar to the clouds in the rest of the galaxy



Contursi et al. 2013