Deep ALMA imaging of the minor merger NGC 1614 - Is CO tracing a massive inflow of non-starforming gas?

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GALAXY INTERACTIONS

Galaxy merger

- important process in galaxy evolution
- merger = a process in which two or more galaxies collide
- major merger: two disk galaxies, roughly equal mass; quite violent
- minor merger: galaxies with significantly different masses ($\geq$4:1), e.g. collision with a smaller satellite companion
- minor mergers much more common than major mergers

Minor mergers with minor axis dust lanes

- minor mergers: gas brought in by disturbing companion galaxy → generally at large radii in merger remnant (Bournaud et al. 2005)
- gas returning from tidal tails → often forms rings (e.g. polar, appearing as dust lanes when seen edge-on)

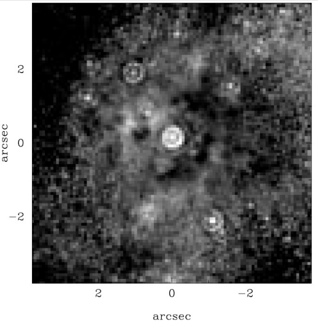
⇒ How are polar rings/dust lanes physically and dynamically coupled to the gas reservoirs at the centers of minor mergers?

FIGURE: Minor axis dust lane minor mergers NGC 1614 (*top*) and NGC 4194 (the Medusa merger, *bottom*).

NGC 1614

- minor axis dust lane
  minor merger
- d = 64 Mpc
- $L_{IR} \sim 3 \times 10^{11}\ L_{\odot}$ (LIRG)
- LINER and starburst activity
- starburst ring detected in different tracers (e.g. Paα, radio continuum, PAHs, $H - K$ imaging)

THE STARBURST RING



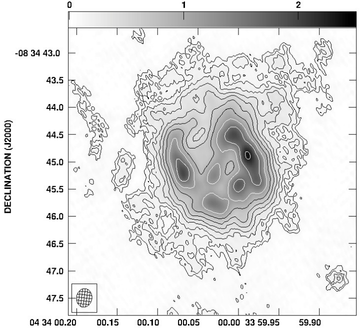
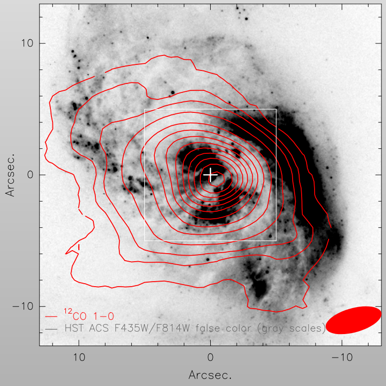
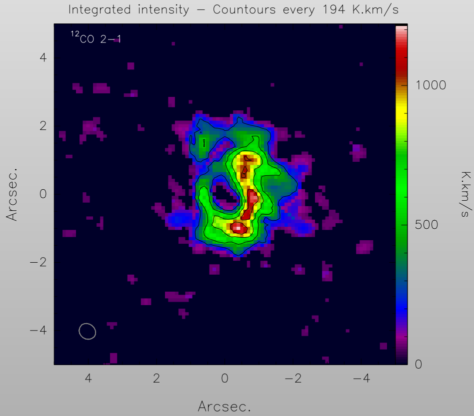


FIGURE: $H-K$ image of the central $8''\times8''$ of NGC 1614 (*left*, Alonso-Herrero et al. 2001), and the 5 GHz radio continuum as seen by the VLA and MERLIN (*right*, Olsson et al. 2010).

⇒ ring in $H-K$ and radio continuum

Molecular gas in NGC 1614



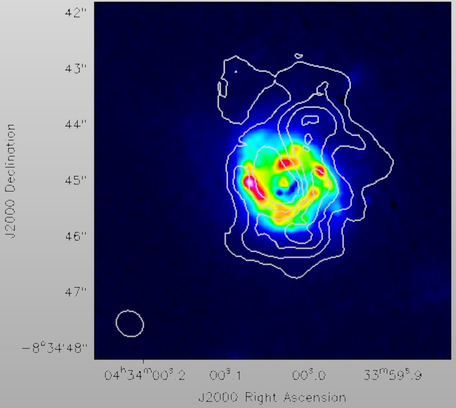


CO 1−0 ⇒ central kpc elongated CO structure associated with foreground dust lane (Olsson+ 2010, König+ 2016)

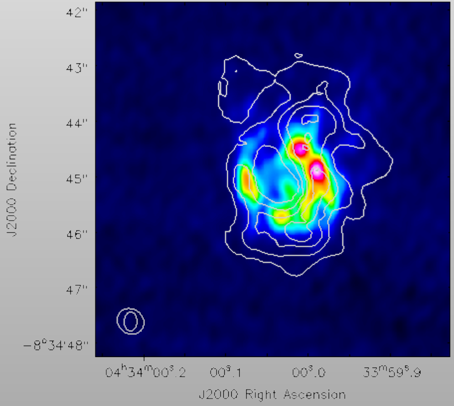
CO 2−1 ⇒ ~230 pc radius, asymmetric ring (~10^9 $M_\odot$, W/E = 2.7:1, König+ 2013)

Tracers of star formation

Paα



8GHz continuum



$\Rightarrow$ Paα & radio continuum inside the molecular gas ring (CO)

ANNULAR PROFILES

- profiles centered with respect to center of Paα ring
- CO 2–1 has no central peak
- radio continuum & Paα aligned quite well, but inside the CO ring
- CO distribution shows strong asymmetry of the ring

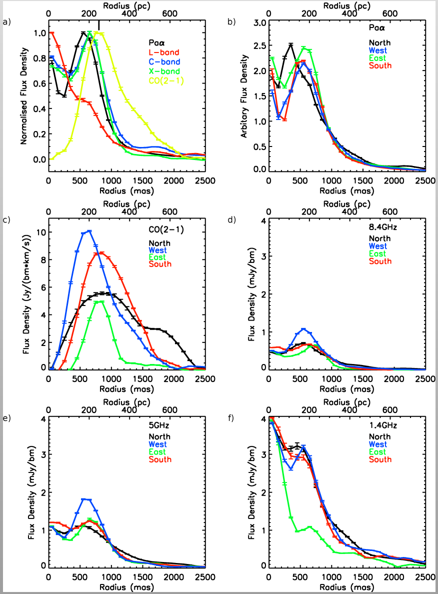


FIGURE: Comparison of the distribution of Paα (b), ^{12}CO 2–1 (c) 8.4 GHz (d, X-band), 5 GHz (e, C-band) and 1.4 GHz emission (f, L-band) in the molecular gas ring of NGC 1614.

“FEEDING” THE RING

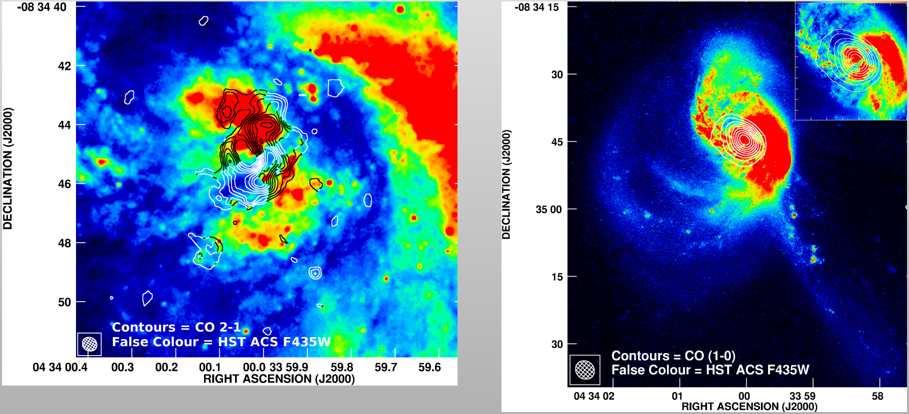
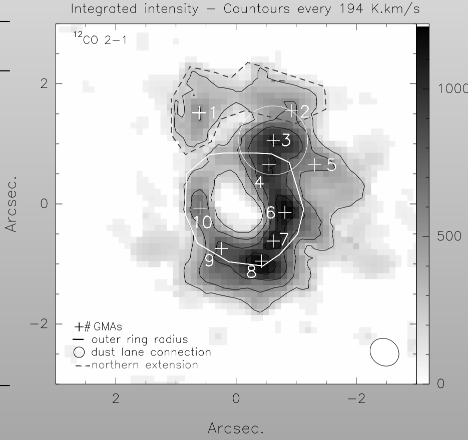


FIGURE: Overlay of CO 2–1 (*left*) and CO 1–0 (*right*) integrated intensity emission on top of HST F435W image on different scales.

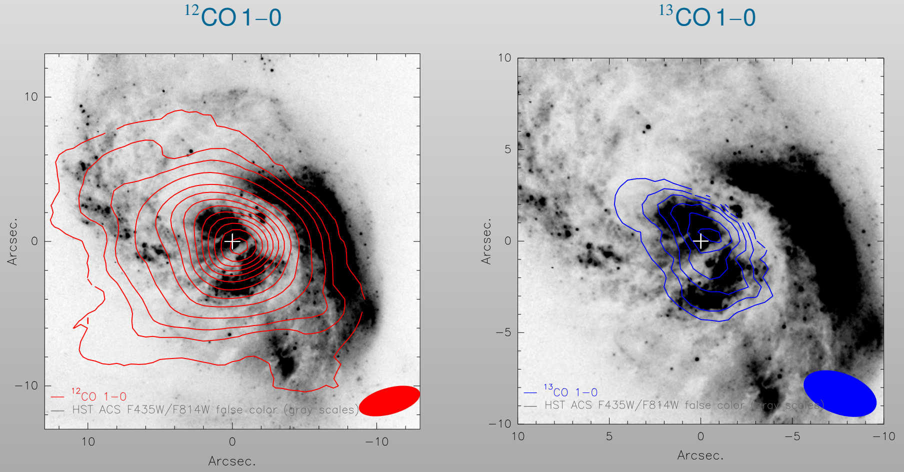
CO gas distributions well correlated with dust lanes ⇒ feeding of the ring via the dust lanes?

GIANT MOLECULAR ASSOCIATIONS (GMAs)

GMA	diameter [″]	dispersion [km s^{-1}]	mass [$M_\odot$]
GMAs on the ring:			
GMA 4	0.6 × 1.0	61 ± 6	5.70×10^7
GMA 6	0.6 × 0.9	64 ± 4	9.74×10^7
GMA 7	0.8 × 1.1	38 ± 4	5.97×10^7
GMA 8	1.3 × 0.8	73 ± 5	9.36×10^7
GMA 9	0.6 × 1.2	54 ± 5	5.98×10^7
GMA 10	0.5 × 0.7	40 ± 5	4.96×10^7
average	*259 ± 24 pc*	*55 ± 5*	*6.95×10^7*
GMAs off the ring:			
GMA 1	0.6 × 1.1	57 ± 7	8.29×10^7
GMA 2	1.1 × 0.5	31 ± 4	1.64×10^7
GMA 3	0.8 × 1.1	53 ± 3	6.23×10^7
GMA 5	1.8 × 0.6	48 ± 5	3.70×10^7
average	*273 ± 20 pc*	*47 ± 5*	*4.97×10^7*

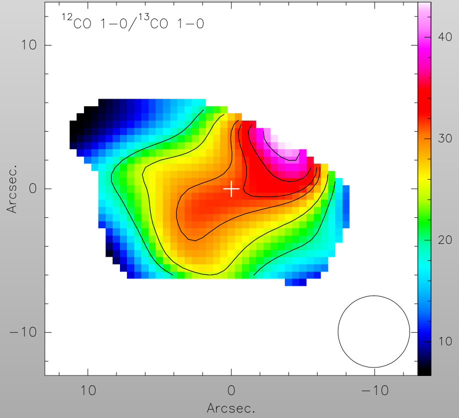


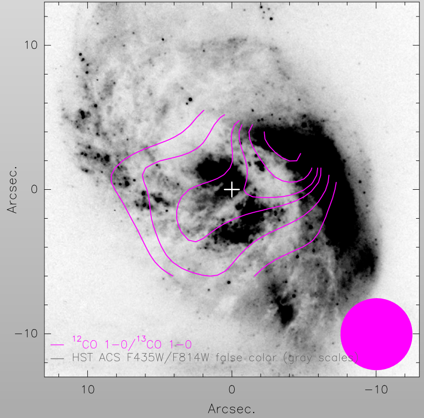
New ALMA observations (König+ 2016)



⇒ ^{12}CO covers dust lane, ^{13}CO not

LINE RATIOS





⇒ ratio gradient caused by diffuse, unbound molecular gas in the dust lane?

Excitation vs. abundance

- change in gas temperature vs. change in gas density as cause for change in line ratio → diffuse gas in dust lane → infalling gas via dust lane + density wave in addition
- [^{12}CO]/[^{13}CO] ~90 → typical value further out in Galactic disk ⇒ infall of chemically less processed gas
- [^{12}C^{16}O]/[^{12}C^{18}O] ~900 → mixing between infalling & prevailing gas very inefficient
- large [^{12}C^{16}O]/[^{12}C^{18}O] also in NGC 4418 & Arp 299A (Gonzalez-Alfonso+ 2012, Falstad+ in prep.)

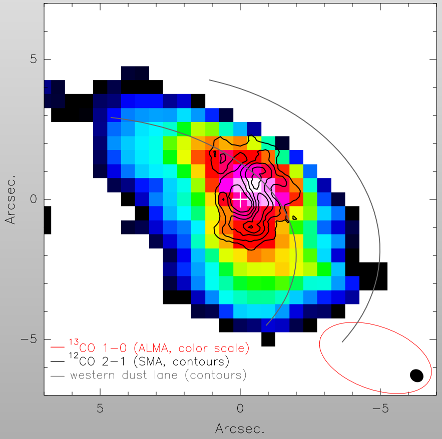


FIGURE: ^{12}CO 2–1 (contours) on top of ^{13}CO 1–0 (color).

NGC 1614 - A MODEL

- ^{12}CO 1−0 in the dust lane (diffuse, non-selfgravitating gas) + density wave → ^{13}CO 1−0 (selfgravitating gas)

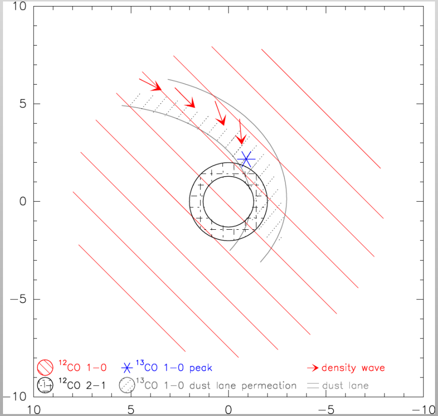


FIGURE: Cartoon representation of the molecular gas structures in NGC 1614.

NGC 1614 - A MODEL

- ^{12}CO 1–0 in the dust lane (diffuse, non-selfgravitating gas) + density wave → ^{13}CO 1–0 (selfgravitating gas)
- smaller GMCs “trapped” at connection dust lane - ring (merger potential) → coaggulation to GMAs → transport onto starburst ring ⇒ feeding of molecular gas to starburst ring via dust lanes

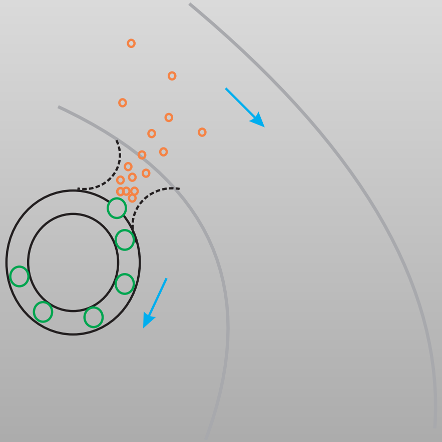
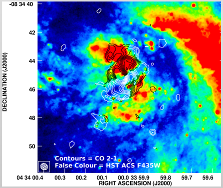
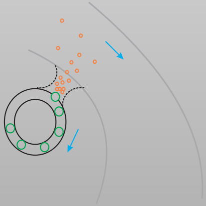


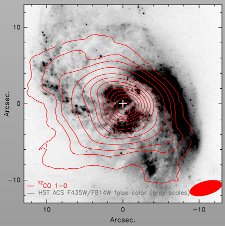
FIGURE: Toy model for the formation of the molecular gas ring and the GMAs in the ring in NGC 1614..

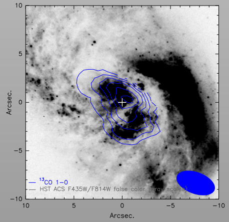
Summary

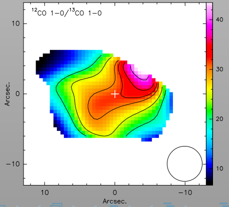
- molecular gas reservoir associated with the dust lanes
- bulk of the gas not associated with star formation
- circumnuclear molecular gas ring
- ^{13}CO 1–0-to-^{12}CO 1–0 ratio peaks in the dust lane
- feeding of the ring via the dust lanes











THANK YOU!