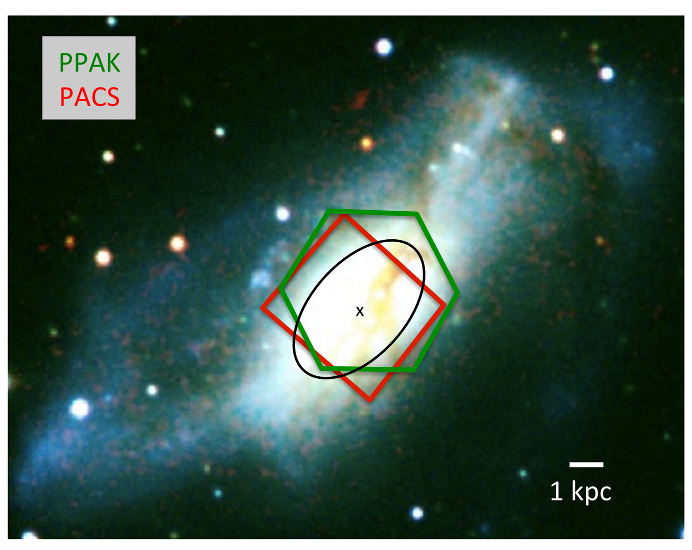
A Far-IR and Optical 3D View of the Starburst Driven Superwind in NGC 2146

Kathryn Kreckel[1], Lee Armus[2], Brent Groves[1], Mariya Lyubenova[1,3], Tanio Diaz-Santos[2], Eva Schinnerer[1], KINGFISH collaboration

[1]MPIA, [2]Caltech, [3]Kapteyn

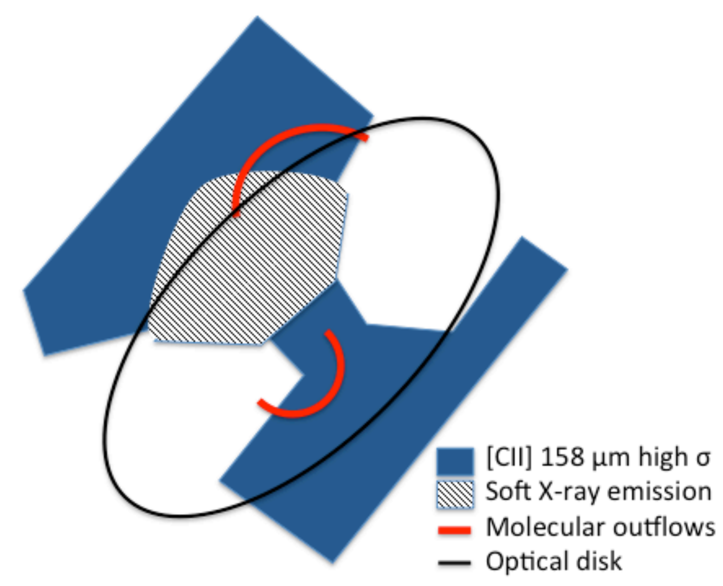
Galaxy outflows are a vital mechanism in the regulation of galaxy evolution through feedback and enrichment. NGC 2146, a nearby infrared luminous galaxy (LIRG, 1.2 x 10^{11} L_{sun}), presents evidence for a starburst driven superwind along the disk minor axis in all gas phases (ionized, neutral atomic and molecular).

We present [1] results from Herschel PACS spectroscopy, observed as part of the Key Insights on Nearby Galaxies: a Far-Infrared Survey with Herschel (KINGFISH) open-time program [2]. They reveal conical outflows in the atomic and ionized gas that can be traced back to the central region of the galaxy disk. We link this to the shocked gas using new optical integral field spectroscopy observed with the PPAK instrument at the Calar Alto 3.5m telescope [3] and trace the ionized shock diagnostics over a broad region both above and below the galaxy disk. We discuss the potential for using [CII] as a tracer of outflows in high redshift systems with ALMA, and speculate on the importance of the superwind for the final fate of this galaxy.



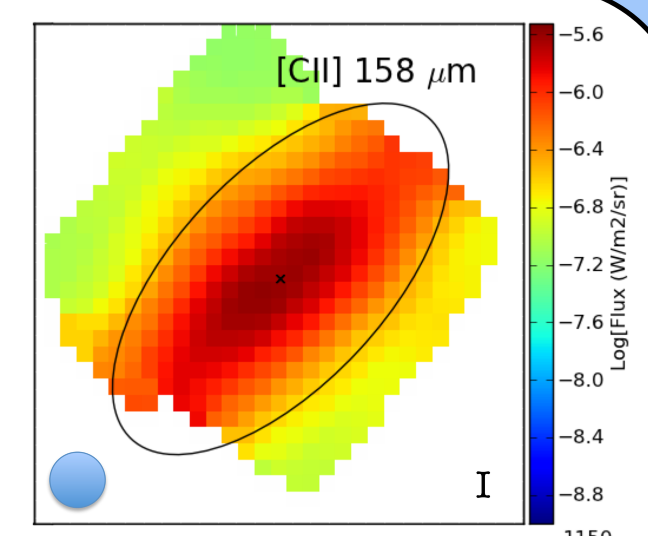
NGC 2146 displays a disturbed optical morphology due to a past merger, with a bright central bulge, extended irregular spiral arms, and deep dust lanes. The location of our PACS (red) and PPAK (green) footprints are indicated. The (black) ellipse serves as a reference for the extent of the disk.

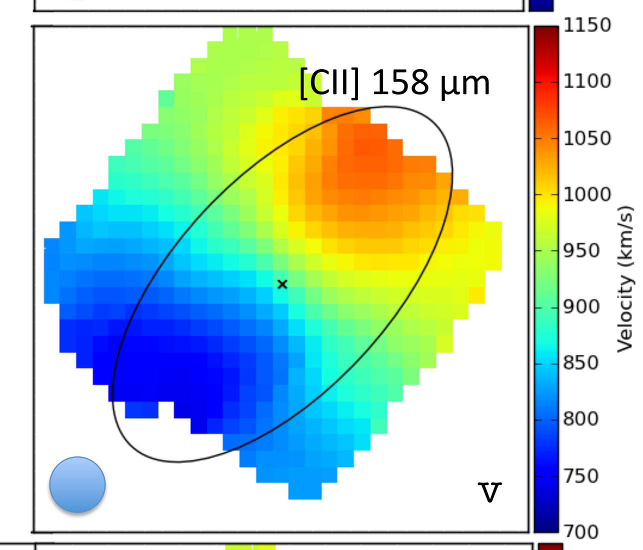
The Far-IR View



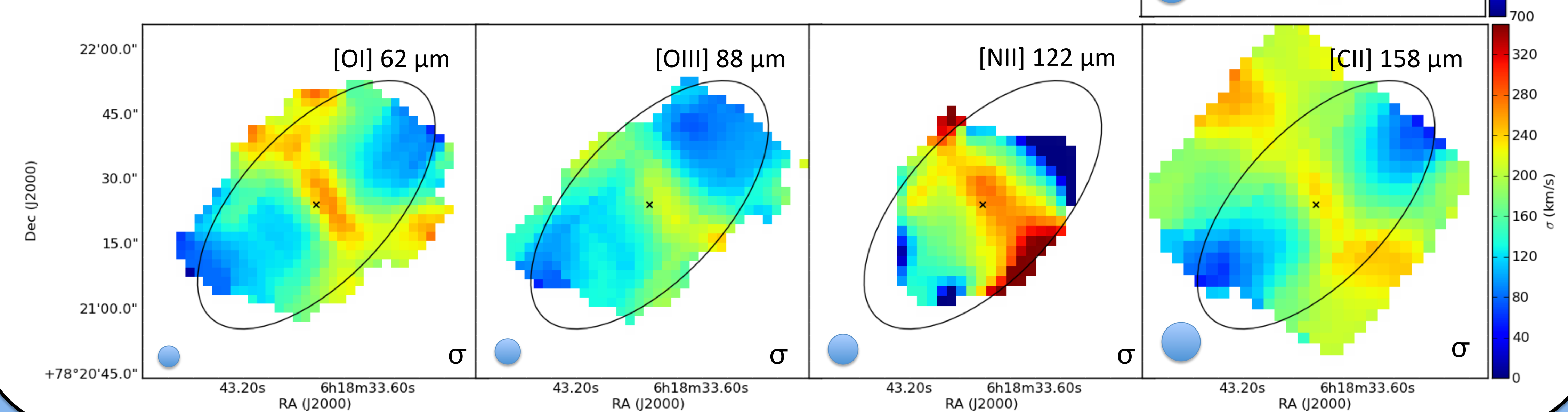
Abundant emission from fine-structure cooling lines ([OI] 62 µm, [OIII] 88 µm, [NII] 122 µm, [CII] 158 µm) is detected across the disk. We find high velocity dispersions (σ) in all lines, with deconvolved linewidths of ~250 km/s that extend along the minor axis through the disk center and open into conical regions above and below the galaxy disk.

Unlike in optical studies, which are limited by the high extinction at the galaxy center, we are able to observe the superwind launching region, which extends ~1 kpc along the center of the galaxy.

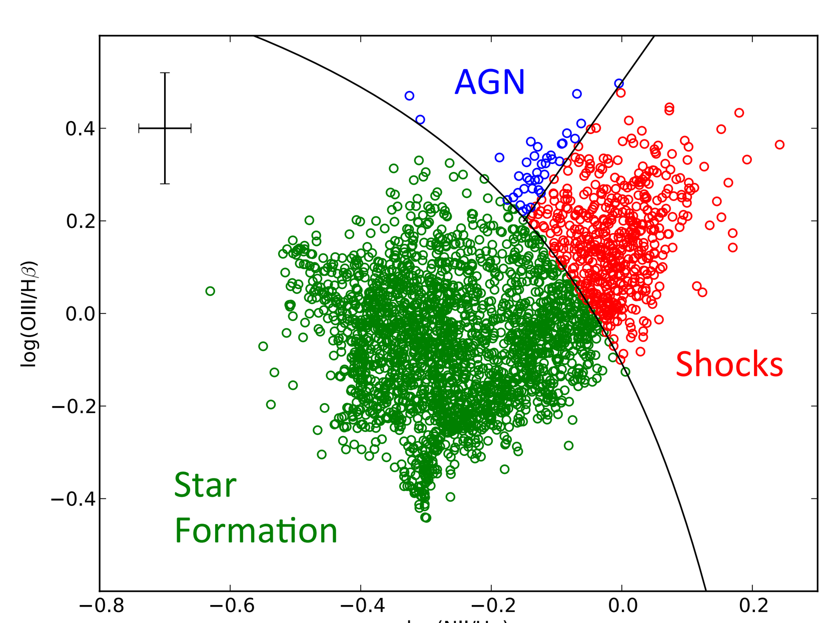


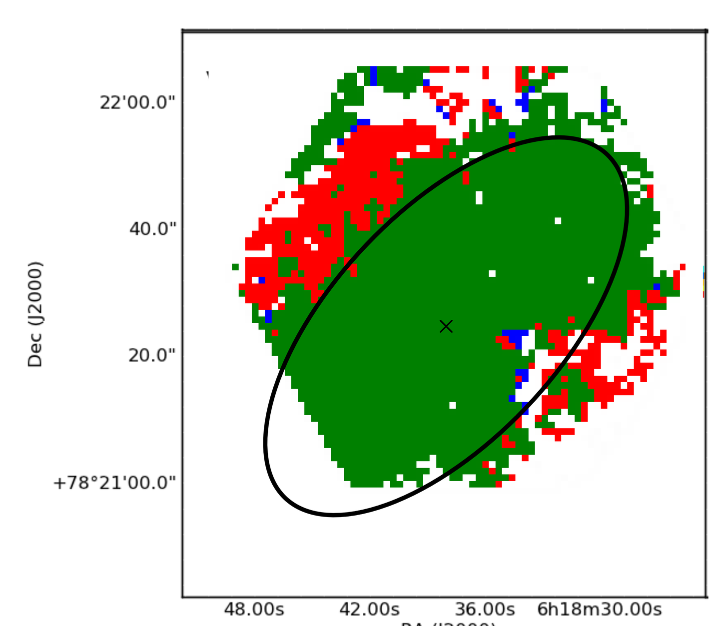


Previously reported soft X-ray emission [4] and molecular outflow bubbles [5] are located within the full extent of the outflow cone we identify in Far-IR lines. This suggests the material outflow traced by the X-ray and molecular gas is constrained to be closer to the disk, and is swept up in the cone.



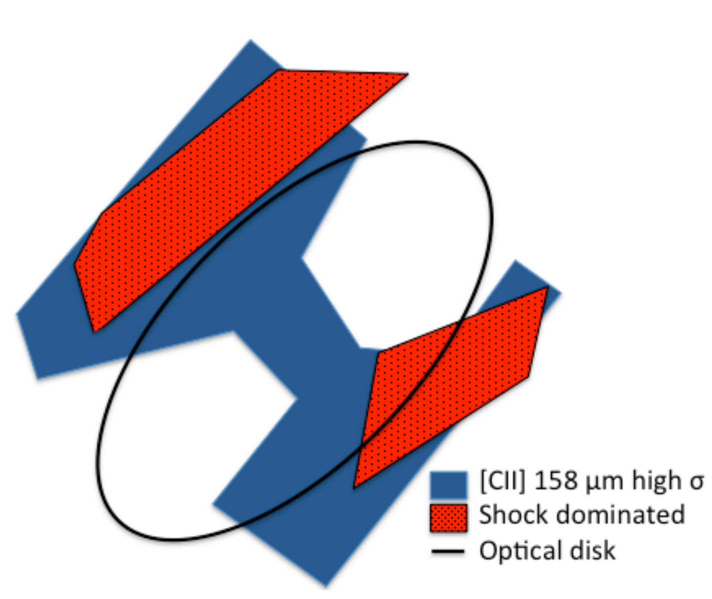
Mapping the Shocks





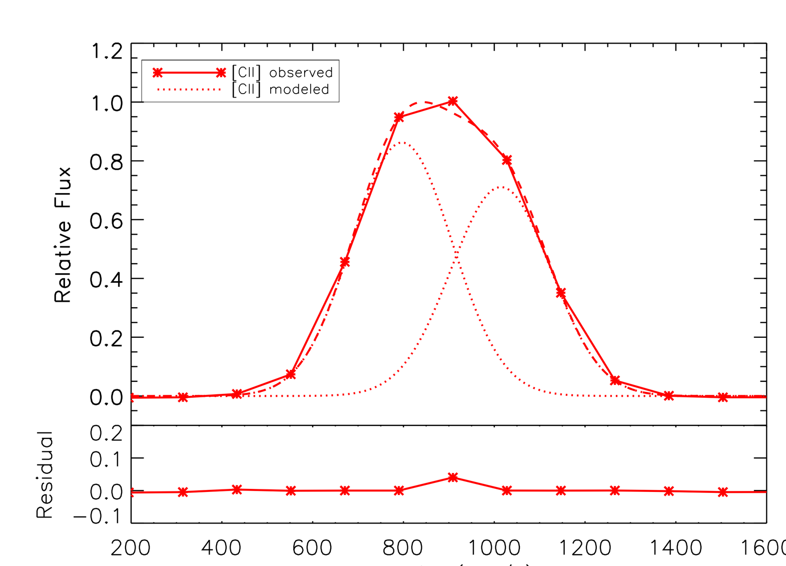
Optical line ratios can be used to establish the ionization and excitation state of gas in galaxies. In NGC 2146 these show evidence for shocks outside the plane of the galaxy, while the disk is dominated by stellar photoionization. There is no clean separation of the regions excited by star formation from these shocked regions, so it is likely we see a combination of stellar photoionization in projection with the shocked region above the disk. Comparison with shock models are consistent with a low shock velocity of about 200 km/s.

These shocked regions are well aligned with the regions of increased velocity dispersion seen in the PACS line maps, fully consistent with a conical outflow both above and below the disk. In [CII] and the shock tracers we map the superwind out to the edge of our field of view, about 2.5 kpc above the disk



A Prototype for High-z Systems

NGC 2146 is undergoing a substantial starburst which drives the superwind, however this SFR is typical for high redshift z=1-3 galaxies. X-ray emission and ionized gas kinematics trace outflows in galaxies in the local universe, however their use at high redshift is limited. The [CII] line provides a complimentary picture. While for some systems an outflow may be identified from high velocity dispersion wings in the global spectrum [6,7], for galaxies similar to NGC 2146 spatially resolving the wind is essential to identifying the outflow using [CII] line emission.

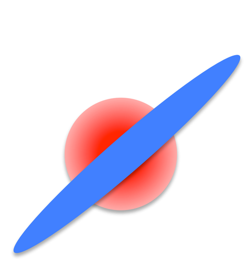


In the spatially integrated far-IR line profile of NGC 2146 we find that the [CII] line is well fit by two Gaussians, decomposing the galaxy into two components that represent the motion of the disk and have widths consistent with the instrumental resolution. We recover no broad residual component that could be attributed to an outflow.

ALMA will be well suited for identifying superwinds through the [CII] line kinematics in high redshift systems, for which NGC 2146 provides a key local analog. The ALMA Band-9 and Band-10 receivers provide 0.1-0.2 arcsecond resolution for the [CII] line at z=1-3, with a resulting 1-2 kpc spatial resolution that is equivalent to what we observe in NGC 2146.

The Role of the Superwind in the Evolution of NGC 2146

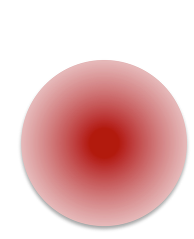
Based on the optical spectra, fits to the stellar kinematics show no ordered motions, in stark contrast to the gas kinematics that are consistent with a disk with a velocity gradient of 500 km/s. This galaxy has undergone a major merger but has not yet settled into a stable configuration, raising the question of what the final morphology of this galaxy will be. We consider two possibilities:



The substantial gas reservoir could serve to stabilize and rebuild the disk, resulting in a **bulge dominated spiral galaxy**

Total M_{H2} = 1.2×10^{10} M_{sun}
Total M_{HI} = 6.2 × 10^9 M_{sun}
SFR (during starburst) = 7.9 M_{sun}/year

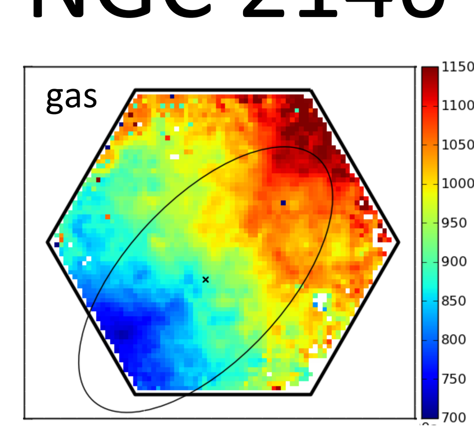
=> NGC 2146 could form stars for > 2.3 Gyr and double the existing stellar mass

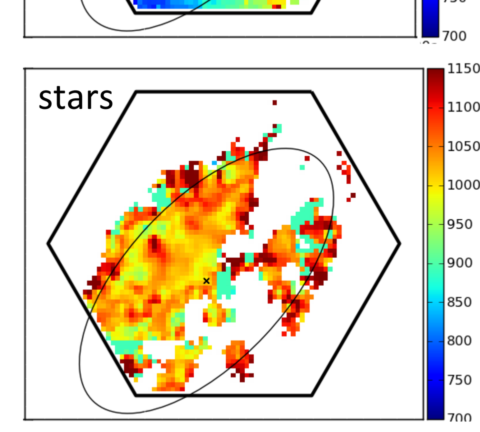


The starburst and wind could stop star formation and fully convert the system to a **red and dead elliptical**

Central M_{H2} = 2 × 10^9 M_{sun}
Central M_{HI} = 1.6 × 10^9 M_{sun}
Outflow M_{atomic} = 7.4 × 10^8 M_{sun}
SFR = 7.9 M_{sun}/year
Mass outflow rate = 9 M_{sun}/year

=> NGC 2146 could form stars for 200 Myr, exhausting or expelling all gas





The starburst driven wind will be crucial to the ultimate fate of this galaxy.

PhD position available : “The cold ISM on sub-100pc scales” please contact K. Kreckel or E. Schinnerer

References

[1] Kreckel et al. 2014, ApJ accepted, arXiv:1403.2381
[2] Kennicutt et al. 2011, PASP, 123, 1347
[3] Kreckel et al. 2013, ApJ, 771, 62
[4] Inui et al. 2005, PASJ, 57, 135
[5] Tsai et al. 2009, PASJ, 61, 237
[6] Maiolino et al. 2012, MNRAS, 425, L66
[7] Carilli et al. 2013, ApJ, 763, 120

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