A far-IR and optical 3D view of the starburst driven superwind in NGC 2146

Kathryn Kreckel

Lee Armus (Caltech), Brent Groves (MPIA), Mariya Lyubenov (Kapteyn), Tanio Diaz-Santos (Caltech)

Galactic Winds and the ISM

M82

Optical (stellar)

Hα (ionized gas)
Galactic Winds and the ISM

M82

- Optical (stellar)
- IR (cold gas & dust)
- X-ray (hot gas)
Galactic Winds and the ISM

Responsible for:

• Metallicity evolution
• Depositing energy
• Multi-phase gas & dust entrainment
• Suppressing star formation
• Morphological transformation

M82

Optical (stellar)
IR (cold gas & dust)
X-ray (hot gas)
NGC 2146

$M_* = 2 \times 10^{10} \, M_{\odot}$

$\text{SFR} = 7.9 \, M_{\odot}/\text{year}$

$L_{\text{IRG}}, \, L_{\text{IR}} = 1.2 \times 10^{11} \, L_{\odot}$

Armus et al. 1995
Inui et al. 2005
Tsai et al. 2009
NGC 2146

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$SFR = 7.9 \, M_{\odot} \, \text{year}^{-1}$

$LIRG, \, L_{IR} = 1.2 \times 10^{11} \, L_{\odot}$

Tsai et al. 2009
KINGFISH
Herschel PACS spectroscopy
• Unextincted view

FISHPPAK
PMAS/PPAK Optical IFS
• Map shock tracers

Wind geometry

Tsai et al. 2009
Wind in far-IR lines

- Herschel PACS Spectroscopy
- 1′ field of view
- 9″-12″ PSF (~1 kpc)
- 100-200 km/s FWHM
- Equivalent to ALMA at z=1-3
Wind in far-IR lines

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Intensity

Velocity

Dispersion
Wind in far-IR lines
Optical IFS data

- PMAS/PPAK instrument at Calar Alto 3.5m
- 331 fibers x 3 dither positions
- 2.7” diameter fibers
- 1’ field of view
- 3700-7000 Å
- 200 km/s FWHM
Mapping the optical shock tracers

Hα line flux

BPT Diagram

Log ([OIII]/Hβ)

Log ([NII]/Hα)

SF

AGN

LINER/shocks
Mapping the optical shock tracers

BPT Diagram

Log ([OIII]/Hβ) vs Log ([NII]/Hα)

AGN
LINER/shocks
SF

~200 km/s shock velocities
A spatial comparison of wind tracers

[Diagram showing various elements such as Stellar disk and [CII] Atomic gas in wind]
A spatial comparison of wind tracers

Stellar disk
[CII] Atomic gas in wind
X-ray hot gas in wind
Molecular outflows
A spatial comparison of wind tracers

- Stellar disk
- [CII] Atomic gas in wind
- X-ray hot gas in wind
- Molecular outflows
- Shock dominated
A spatial comparison of wind tracers

Stellar disk
[CII] Atomic gas in wind
X-ray hot gas in wind
Molecular outflows
Shock dominated

$M_{\text{stars}} \sim 2 \times 10^{10} M_{\text{sun}}$
$M_{\text{CO,disk}} \sim 2 \times 10^{9} M_{\text{sun}}$
$M_{\text{CO, outflow}} \sim 3 \times 10^{8} M_{\text{sun}}$
$M_{\text{atomic, outflow}} \sim 7 \times 10^{8} M_{\text{sun}}$
Connecting optical attenuation ($A_V$) with dust mass

$A_V$ (Balmer) = $A_V$ (Foreground screen) / 3.8

Kreckel et al. 2013
No large scale dust entrainment

Cold dust, as traced by $A_v$ with Hα contours

Warm dust, as traced by SOFIA FORCAST
Decoupled stellar and gas kinematics

Ionized gas kinematics

Stellar kinematics

Stellar continuum fit with pPXF (Cappellari & Emsellem 2004)
Emission lines simultaneously fit with GANDALF (Sarzi et al. 2006)
Impact of wind on final fate

Unimportant

Can form stars for > 2.3 Gyr, double existing stellar mass

High mass outflow rate in central starburst region

Dynamical quenching, shock heating of infalling gas

Very important

Rebuild a disk -> bulge dominated spiral

Exhaust/expel gas -> red and dead elliptical
Summary

• Far-IR lines trace the wind

• Good spatial agreement between atomic wind and shocks, extends farther than the CO outflow & hot X-ray emission

• NGC 2146 is transitioning, wind is crucial in determining the final morphology