INCIDENCE, SCALING RELATIONS AND PHYSICAL CONDITIONS OF IONISED GAS OUTFLOWS IN MANGA


(submitted to MNRAS).

*c.r.avery@bath.ac.uk
MaNGA DR15

- Well-defined population of typical galaxies
- Allows removing large-scale velocity field
- Allows identifying low-luminosity AGN

~4,800 datacubes; ⟨z⟩ ~ 0.03; θ ~ 2.5”; 3700Å - 10000Å at R~2000

- Regulator of galaxy growth
- Which galaxies feature winds?
- How does outflow strength scale with galaxy properties?
- Physical conditions of outflowing material?

Law+2016, Wake+2017

c.r.avery@bath.ac.uk

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Stack within elliptical apertures

Remove large-scale velocity field

Continuum subtraction w/ PPXF (Cappellari+2017)

Simultaneous double-Gaussian fitting

Statistically preferred over single-Gaussian?

\[ 300 \text{ galaxies w/ outflows (173 AGN)} \]
SPATIAL EXTENT
CENTRALLY CONCENTRATED

- Stack within elliptical annuli
- Remove large-scale velocity field
- Continuum subtraction w/ PPXF (Cappellari+2013)
- Simultaneous double-Gaussian fitting
- Statistically preferred over single-Gaussian?
- Determine the radius containing 90% of the broad component flux

see also, e.g., Roberts-Borsani+20

c.r.avery@bath.ac.uk
**OUTFLOW INCIDENCE**

- More common at high mass and density
- More common at higher SFR ($\Sigma_{\text{SFR}}$) and/or $L_{\text{AGN}}$
- Weak inclination dependence $\rightarrow$ wide opening angles?

All outflows
SF outflows
AGN outflows

Underlying galaxy population

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c.r.avery@bath.ac.uk

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### Correlations Between Outflow and Host Properties

**Table:**

<table>
<thead>
<tr>
<th></th>
<th>Full outflow sample</th>
<th>Disks</th>
<th>AGN</th>
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<tr>
<td><strong>η</strong></td>
<td>-0.06</td>
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<td>M_{out}</td>
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<tr>
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<tr>
<td>[OIII] BNR</td>
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<td>Hα BNR</td>
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<td>λ_{Edd}</td>
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**Note:**
- η: mass-loading factor
- Μ_{out}: mass outflow rate
- BNR = broad-to-narrow line ratio

**Figure:**

- Spearman's Rank
- Epoch of Galaxy Quenching 2020

**Contact:**
c.r.avery@bath.ac.uk
VARIATIONS ACROSS SFR – $M_*$

Colour-coding based on locally weighted regression (LOESS, Cappellari+2013)

also, e.g., Arribas+14, Cicone+16, Rupke18, Fluetsch+19, Veilleux+20

c.r.avery@bath.ac.uk
Strong dependence on stellar velocity dispersion

$\sigma_\star(<R_e)$

$\sim$ gravitational potential well

$\sim M_{BH}$

see also Rupke+17, Fluetsch+19 & Asa Bluck’s talk (Bluck+20)

c.r.avery@bath.ac.uk

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Galactic winds over 4 dex in \( L_{\text{AGN}} \), down to modest accretion rates

Enhanced incidence at higher \( \lambda_{\text{Edd}} \)
and/or \( L_{\text{AGN}} \)

Also, e.g., Rupke & Veilleux+11, Cicone+14, Fiore+17, Harrison+18, Fluetsch+19, Lutz+20, Wylezalek+20

\[
M_{\text{out}} \propto L_{\text{AGN}}^{0.51}
\]
SF and AGN outflows jointly described by a unified scaling relation

$$\log(\dot{M}_{\text{out}}) = b \log \left( \frac{M_*}{5 \times 10^{10} \, M_\odot} \right) + c \log \left( \frac{\sigma R_e}{100 \, \text{km s}^{-1}} \right) + d \log \left( \frac{\text{SFR}}{3 \, M_\odot \, \text{yr}^{-1}} \right) + e \log \left( \frac{L_{\text{AGN}}}{1 \times 10^{43} \, \text{erg s}^{-1}} \right)^f$$

Fit with emcee (Foreman-Mackey+13)

see also Fluetsch+19
PHYSICAL CONDITIONS

Broad components feature...
Higher excitation $\rightarrow$ shocks

(see also Ho+14).

(see also Perna+19, Villar Martín+14, Rodríguez Del Pino +19)

c.r.avery@bath.ac.uk

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CONCLUSIONS

• Minor fraction of MaNGA galaxies (~ 10% of line-emitting objects) exhibit ionised winds

• Star formation and AGN are both important drivers of galactic winds in galaxies with moderate AGN activity

• A tight scaling relation (0.28 dex scatter) parameterises the mass outflow rate of SF & AGN galaxies as a function of its drivers (SFR, $L_{\text{AGN}}$) and the galaxy’s potential well depth ($M_{\text{star}}$, but most notably $\sigma_1^* \text{Re}$)

• Outflow rates may be enhanced once accounting for additional attenuation to the ionised gas by dust entrained in the wind

• Feedback in typical nearby galaxies comes mostly in the form of galactic fountains → only 25% have $v_{\text{out}} > v_{\text{esc}}$, among them both SF and AGN outflows → fraction of escaping winds increases to lower potential well depth

• Caveat: ionised phase only!