# Unraveling the complex structure of AGN-driven outflows: GMOS IFU studies of type 1 AGNs with strong gas outflows

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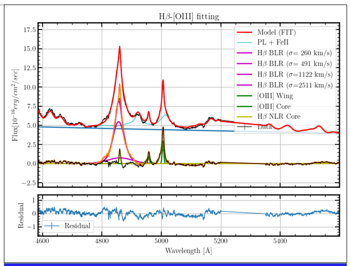
## Abstract

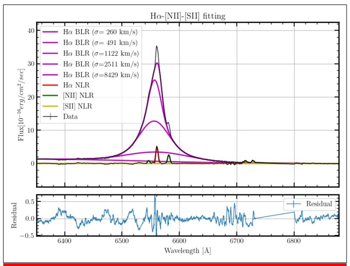
To understand the complex structure of AGN-driven outflows and its impact on host galaxy star formation, measuring their spatial properties and energetics is critical. We present spatially resolved characteristics of ionized gas outflows in 11 type 1 AGNs and 5 type 2 AGNs based on Gemini Multi-Object Spectrograph Integral Field Unit (GMOS/IFU) data. By spectral fitting with multi-components, we analyze ionized gas kinematics and photoionization property in each pixel. Furthermore, we measure the outflow size based on the spatially resolved kinematics and accordingly determine mass outflow rates in order to properly diagnose the impact on host galaxies. Finally, we test the outflow size – [OIII] luminosity correlation by combining with previous measurements of type 2 AGNs and discuss implications for the nature of AGN-driven outflows.

## Observation & Analysis

- We performed GMOS/IFU observations of 11 type 1 AGNs (z<0.3) in 2019 and 5 type 2 AGNs in 2016 (z<0.1), selected by strong [OIII] outflow signature in SDSS spectra.
- We modeled spectra of all spaxels with multiple components by MCMC algorithm. With the results, we analyzed kinematics and BPT classification (Kewley 2006) at each position.
- For **type 1 AGNs**, fitting model includes accretion disk + BLR + NLR components
  - Accretion disk : Power-law continuum
  - BLR : Multiple Gaussians ($H\alpha$, $H\beta$) & FeII template (Boroson & Green 1992)
  - NLR : Multiple Gaussians ($H\alpha$, $H\beta$, [OIII], [NII], [SII]) - Core & Wing (Amp-to-Noise > 3)
- For **type 2 AGNs**, fitting model includes host galaxy stellar emission + NLR components
  - Host galaxy stellar emission : pPXF (Cappellari 17)
  - NLR : Multiple Gaussians ($H\alpha$, $H\beta$, [OIII], [NII], [SII]) - Core & Wing (Amp-to-Noise > 3)



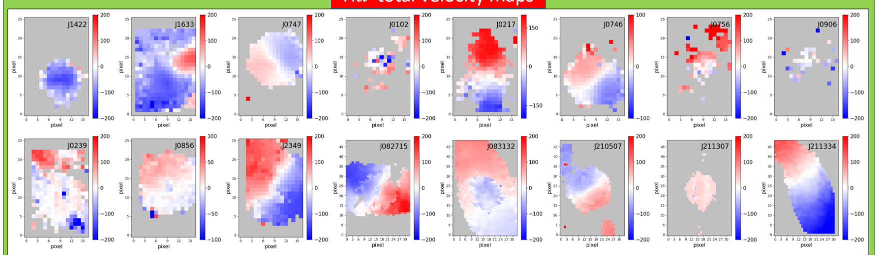

$H\beta$ & [OIII] (core, wing) fitting example



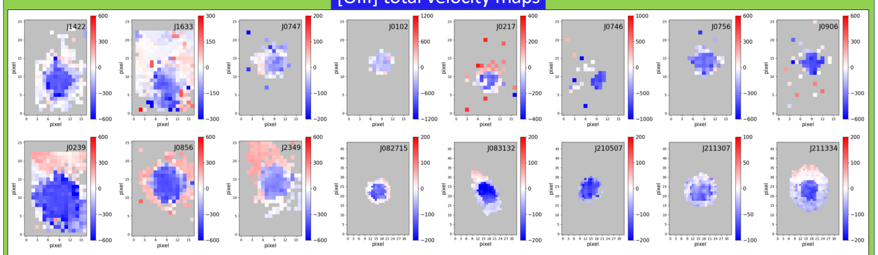

$H\alpha$ & [NII] & [SII] fitting example

## Ionized Gas Kinematics

$H\alpha$ total velocity maps

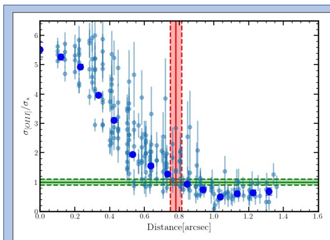



[OIII] total velocity maps



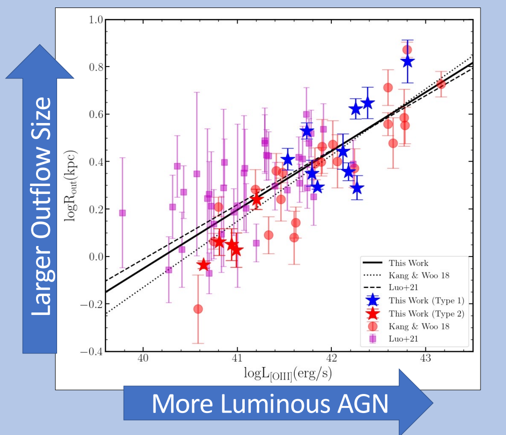

- **$H\alpha$ velocity maps show clear blue- & redshifted regions, which indicate rotation by gravity**
  - J1422, J1633, J083132 have blueshifted region at the center -> Outflows also shown in $H\alpha$
- **[OIII] velocity maps are blueshifted, which indicate blueshifted cone of biconical outflows.**
  - Post-starburst galaxy (J1422) has three Gaussians, and one of them shows $\sigma_{[OIII]}$>1,000km/s!
  - Many Narrow-line Seyfert 1 (J0102, J0746, J0906 etc.) galaxies show extreme [OIII] velocities, but detected regions are small.
  - We determined outflow sizes ($R_{out}$) of total 16 AGNs kinematically as where velocity dispersion ratio between [OIII] total profile and star becomes 1. (See the right hand side)

## Outflow size – [OIII] Luminosity Relation




$$\sigma^2_{[OIII]} = \frac{\int \lambda^2 f_\lambda d\lambda}{\int f_\lambda d\lambda} - \lambda_0^2$$

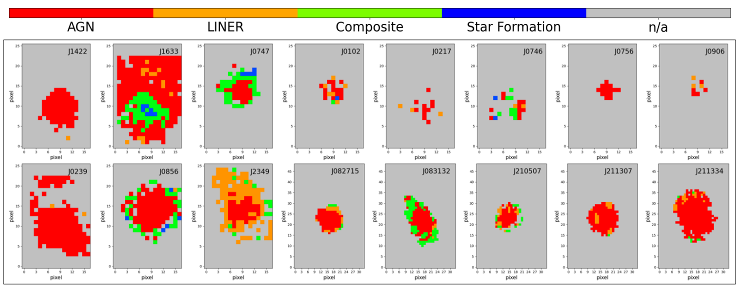
Define $R_{out}$ : where $\sigma_{[OIII]}/\sigma_* = 1$




**More luminous AGN has a larger outflow!**

$$\log R_{out} = 0.247 \log\left(\frac{L_{[OIII]}}{10^{42} ergs^{-1}}\right) + 0.443$$

## Photoionization Classification




- **Most targets are photoionized by AGN radiation at the center** (red) except J1633.
- J0747, J0856, J2349, J083132 : surrounded by composite or LINER region
  - Ring-like structure: consistent with Karouzos+16, Kang & Woo 18
- J1633 shows opposite trend! (SF at the center -> composite -> AGN at the edge)
  - Nuclear starburst dominates AGN radiation?
  - Interacting galaxy & Narrow-line Seyfert 1 class -> recently triggered SF & AGN?

## Discussions

- Our new **type 1 AGNs are consistent with outflow size – [OIII] luminosity relation obtained by previous type 2 sample**. Updated outflow size – [OIII] luminosity relation is located between Kang & Woo 18 and Luo+21 relations.
- Mass outflow rates ($\dot{M}_{out} = \frac{dM_{out}}{dt} = \frac{3M_{out}v_{out}}{R_{out}}$) of our sample are 0.05 – 3 $M_\odot yr^{-1}$, which are comparable with BH mass accretion rates. However, $\dot{M}_{out}$ estimation is affected by many factors, such as assumed electron density (here we adopted $500cm^{-3}$), definition of outflow mass, size and velocity so needed to be cautious.
- We measured global star formation rates of our sample based on dust IR luminosity from SED modeling and found that our sample is located on or above main-sequence SFGs. Thus, even strong outflows exist, its instantaneous impact on global star formation is not significant, though there may be some local impacts.
- Further studies on Narrow-line Seyfert 1 & post-starburst galaxies seem necessary.

**References**

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