Nebular emission from AGN in the ultraviolet/optical: diagnostics of the ionizing source and gas properties

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Spectral models
linking theory and observations

- diagnostics of the **nature ionizing source**: star formation vs AGN vs shocks
  (e.g. Villar-Martin+97; Allen+98, Groves+04a,b; Kewley+01,06,13a,b; Feltre+16 and many others)

- study the **physical properties of the ionized gas**: e.g. metallicity, density

- implemented in a **SED fitting tools** to retrieve the physical parameters of the ionized gas (e.g. Pacifici+12, Chevallard+16)

- combined with **cosmological simulations**
Spectral models

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  (e.g. Villar-Martin+97; Allen+98, Groves+04a,b; Kewley+01,06,13a,b; Feltre+16 and many others)
  ➞ UV emission-line ratios as diagnostics (stellar vs nuclear) for high z

- study the **physical properties of the ionized gas**: e.g. metallicity, density
  ➞ rest UV spectra of ~90 obscured AGN

- implemented in a **SED fitting tools** to retrieve the physical parameters of the ionized gas
  (e.g. Pacifici+12, Chevallard+16)
  ➞ Bayesian fitting code BEAGLE *(Chevallard+16)*

- combined with **cosmological simulations**
  ➞ understand feedback processes and interpret selection criteria of local and high redshift galaxies *(Hirschmann, Charlot, Feltre +16, in prep.)*
Optical/UV nebular emission

Standard optical diagnostic diagrams: nuclear vs stellar activity (e.g. Baldwin, Phillips & Terlevich 81 BPT; Veilleux & Osterbrock 87)

Availability of some emission-lines in the JWST NIR range vs redshift

Current (e.g. VLT-KMOS/MUSE, Keck-MOSFIRE) and future (e.g. JWST, E-ELT) NIR spectroscopy —> UV rest spectra of primeval galaxies $z \geq 7$

Photoionization models to interpret the rest-frame optical/UV spectra of both active and inactive galaxy at all cosmic epochs
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—> UV rest spectra of primeval galaxies $z \approx 7$
Spectral modeling

\[ F_\nu \propto \nu^\alpha \]
(UV spectral index in the range 10-2500 Å)

**AGN NLR**
Feltre+16

**SF regions**
Gutkin+16 sub

**CB16 (GALAXEV)** new stellar evolutionary tracks and atmospheres, also for massive stars

<table>
<thead>
<tr>
<th>ionizing spectrum</th>
<th>AGN NLR</th>
<th>SF galaxies</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha = -1.2, -1.4, -1.7, -2.0 )</td>
<td>constant SFR, age 10</td>
<td></td>
</tr>
<tr>
<td>-1.0 ÷ -4.5</td>
<td>-1.0 ÷ -4.5</td>
<td></td>
</tr>
<tr>
<td>2.0, 3.0, 4.0</td>
<td>2.0, 3.0, 4.0</td>
<td></td>
</tr>
<tr>
<td>0.0001 ÷ 0.07</td>
<td>0.0001 ÷ 0.03</td>
<td></td>
</tr>
<tr>
<td>0.1, 0.3, 0.5</td>
<td>0.1, 0.3, 0.5</td>
<td></td>
</tr>
</tbody>
</table>
Standard optical diagnostics

models can describe simultaneously various standard optical emission-line ratios

SDSS sources

$0.04 < z < 0.2$

$\xi_d = 0.3$

$n_{H(AGN)} = 10^3 \text{ cm}^{-3}$

$n_{H(SF)} = 10^2 \text{ cm}^{-3}$
Synthetic nebular spectra

- photoionization models from SF galaxies, AGN and evolved stellar populations
- set of 20 cosmological zoom-in simulations of massive galaxies

main questions:
- which galaxies are selected using standard optical diagnostics at $z = 0$?
- is there a redshift evolution of optical emission line ratios?
- local Universe optical diagnostics are still suitable for high $z$? how can we improve?
- feedback constraints in spatially resolved BPT?

- successful in reproducing the observed SDSS results
- synthetic spatially resolved spectral diagnostics for IFU surveys

Choi+16, in prep; Hirschmann, Naab + 16, in prep

Hirschmann, Charlot, Feltre + 16 in prep
Synthetic nebular spectra

successful in reproducing the observed SDSS results

Hirschmann, Charlot, Feltre + 16 in prep
Synthetic nebular spectra

Hirschmann, Charlot, Feltre + 16 in prep

successful in reproducing the observed SDSS results at high redshift: new diagnostics, e.g. UV emission line ratios
AGN and SF populate different regions of the diagrams. Models predictions agree with data.
and many others such as CIII]1909/HeII1640 or CIV1240/HeII vs NV1240/HeII, NV1240/CIV1549, NV1240/NIII]1750, OIII]1661,1666/HeII, NIII]1750/HeII, [NeV]3426-[NeIV]2424 based
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z-COSMOS DeepType 2 AGN

zCOSMOS Deep (PI: S. Lilly)
BzK selection + U dropout colour
selected galaxies with $z>1.4$
8k sample ($K<23.5$ & $B<25.5$)
192 CIV-selected AGN
with $1.5 < z < 3.0$
VIMOS/VLT

- search for Type 2 (obscured AGN) at high $z$
- study the excitation properties of the AGN NLR ionised gas

Mignoli+ in prep

COMPOSITE SPECTRUM
90 Type 2 AGN

Ly\(\alpha\)
NV
SiIV+OIV]
CIV
HeII
OIII]
CIII]
CII]
NeIV]
NV/HeII often stronger than model predictions
—> N over abundance and super-solar metallicities
(e.g. Hamann & Ferland 92, 93)

—> UV emission line ratios are *not* reproduced with the same model parameters

Mignoli+ in prep
Feltre+ in prep
Diagnostics - CIV selected AGN2

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Mignoli+ in prep
Feltre+ in prep

3-10 x smaller inner radius (30 - 90 pc)
Diagnostics - CIV selected AGN2

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Diagnostics - CIV selected AGN2

+ internal microturbulence (e.g. Bortoff & Ferland 2000, Kraeme_07) 
  \( \text{v}=100-200 \text{ km/s} \)

\[ \text{NV/HeII often stronger than model predictions} \]

\[ \rightarrow \text{N over abundance and super-solar metallicities} \] 
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A_v=1
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Mignoli+ in prep
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CIV selected AGN2 - M* vs O/H

- no need of models with very high metallicity to reproduce the observed ratios
- flat relation O/H vs stellar mass
- metallicity evolution with redshift?
  future plan: simultaneous fit of photometry + spectral lines to with a Bayesian fitting code (e.g. BEAGLE, Chevallard+16)

Mignoli+ in prep

PRELIMINARY

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\[ Z_\odot \text{ Gutkin+16} \]
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BayEsian Analysis of Galaxies

sEds - BEAGLE

MAIN FEATURES

- combines in a coherent way emission from different components (stars, gas, dust, AGN)
- adopts Bayesian approach to obtain posterior PDF of every model parameter
- includes predictions from galaxy formation models

APPLICATIONS

- fit spectro-photometric data at UV to IR wavelengths
- create synthetic catalogues of galaxy SEDs
- study retrievability of galaxy physical parameters for different type of observations

- broad-band photometry
- and/or spectral features (e.g. emission line intensities or EWs)
- full spectra fit
Summary

- UV emission-line ratios are good **diagnostics of the ionizing source** (nuclear vs stellar activity)

- Interpretation of spectroscopic observations to study **physical properties of the ionized gas** (e.g. metallicity, density) of both active (Mignoli+ in prep.) and inactive galaxies (Stark+14,15a,b,16)

- Can be easily implemented in **SED fitting tools**, e.g. **BEAGLE** (Chevallard+16)

- Combined with **cosmological simulations** to better understand feedback processes and black hole growth (Hirschmann + in prep)

- Interpret current spectroscopic observations (VLT-KMOS/MUSE and Keck-MOSFIRE) of high redshift sources

- **Groundwork for future facilities**, such as NIRspec on-board JWST and the ELTs which will push studies up to the **epoch of reionization** (z>7)