A new tool to derive chemical abundances in Type-2 Active Galactic Nuclei

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NARROW LINE REGION (NLR) IN AGNS

- Up to ↑ redshifts
- Bright emission-lines
- Chemical abundances (O/H)
- Physical conditions of the gas

Narrow Line Region (NLR) → Photoionization

Ferland & Netzer (1983); Halpern & Steiner (1983)
**NLR & ABUNDANCES IN TYPE-2 AGNS**

1. Total abundances $\ll$ photoionization models IN AGNS

2. Hydrodynamical effects can affect:
   - O/H
   - [$\text{NII}$]  
   (Pérez-Montero & Contini 2009)

Villarroel et al. (2017)
CHEMICAL ABUNDANCES CODE FOR Type-2 AGNs

Advantages

1. Automatic → Large number of objects
2. Consistent → Same procedures
3. Uncertainties
4. Independent estimation of N/O ratio
5. Consistent with $T_e$ method

Villarroel et al. (2017)
HII-CHI-MISTORY CODE FOR AGNS

Pérez-Montero et al. (2019)

https://www.iaa.csic.es/~epm/HII-CHI-mistry.html

HCM

Characteristics and input data

1. Python (Pérez-Montero 2014)

2. Photoionization models (Cloudy)

3. Reddening-corrected

- [OII] $\lambda 3727$ Å
- [Ne III] $\lambda 3868$ Å
- [O III] $\lambda 4363$ Å
- [O III] $\lambda 5007$ Å
- [N II] $\lambda 6583$ Å
- [SII] $\lambda \lambda 6717+6731$ Å

4. Uncertainties
GRID OF MODELS

- Filling factor: 0.1
- Density: $500 \text{ cm}^{-3}$ (Dors et al. 2014) [2000 cm$^{-3}$]
- SED:
  - Big Blue Bump @ 1 Ryd
  - Power laws:
    - Non thermal X-rays $\rightarrow \alpha_x = -1$
    - Continuum 2 keV - 2500 Å $\rightarrow \alpha_{ox} = -0.8$ [-1.2]
- Chemical abundances scaled to oxygen with ⬤ proportions (except N)
**GRID OF MODELS**

**Cloudy v.17.01** *(Ferland et al. 2017)*

|                | # models | 12 + log(O/H) | N/O | log U |
|----------------|----------|---------------|-----|-------|
| # models       | 5865     | 6.9 → 9.1     | -2.0 → 0.0 | -4.0 → -0.5 |
| 12 + log(O/H)  |          | 6.9 → 9.1     |     |       |
| N/O            |          | -2.0 → 0.0    |     |       |
| log U          |          | -4.0 → -0.5   |     |       |
|                |          |               |     |       |
|                |          | 0.1 dex       |     |       |
|                |          |                | 0.125 dex  |   |
|                |          |                | 0.25 dex   |   |
\[
\log(N/O)_f = \frac{\sum_i \log(N/O)_i/\chi_i^2}{\sum_i 1/\chi_i^2}
\]

\[
\chi_i = \sum_j \frac{(O_j - T_{ji})^2}{O_j}
\]

\[
N2O2 = \log\left(\frac{[\text{NII}]\lambda6583}{[\text{OII}]\lambda3727}\right)
\]

\[
N2S2 = \log\left(\frac{[\text{NII}]\lambda6583}{[\text{SII}]\lambda6717 + 6731}\right)
\]

Observed vs models

No dependence on excitation
**AGN-HCM WORKFLOW**

Constrained by N/O

**Observed vs models**

\[
N2 = \log \left( \frac{[\text{NII}]\lambda 6583}{H\alpha} \right)
\]

\[
R23 = \frac{[\text{OII}]\lambda 3727 + [\text{OIII}]\lambda 4959 + 5007}{H\beta}
\]

\[
RO3 = \frac{[\text{OIII}]\lambda 5007}{[\text{OIII}]\lambda 4363}
\]

\[
O2Ne3 = \frac{[\text{OII}]\lambda 3727 + [\text{NeIII}]\lambda 3868}{H\beta}
\]

\[
12 + \log(O/H) = \frac{\sum_i (12 + \log(O/H))_i / \chi_i^2}{\sum_i 1 / \chi_i^2}
\]

\[
\log(U) = \frac{\sum_i \log(U)_i / \chi_i^2}{\sum_i 1 / \chi_i^2}
\]

\[
\chi_i = \sum_j \frac{(O_j - T_{ji})^2}{O_j}
\]
1. Seyfert 1.9 & 2 galaxies $z \leq 0.1$

2. 44 Cloudy tailored photoionization models from *Dors et al. (2017)* → D17

3. Reddening corrected emission-line fluxes:
   - $\text{[O II]} \lambda 3727 \text{ Å}$
   - $\text{[Ne III]} \lambda 3868 \text{ Å}$
   - $\text{[O III]} \lambda 4363 \text{ Å}$
   - $\text{[O III]} \lambda 5007 \text{ Å}$
   - $\text{[N II]} \lambda 6583 \text{ Å}$
   - $\text{[S II]} \lambda \lambda 6717+6731 \text{ Å}$

4. No errors in abundances

\[
\begin{array}{|c|c|}
\hline
\text{[O/H]} & 0.4 \leftrightarrow 2 \\
\text{[N/O]} & 0.3 \leftrightarrow 7.5 \\
\hline
\end{array}
\]
0.7 dex ↓ O/H for non-AGN SED

x-axis: AGN SED (power law)
y-axis: HII region SED

both HCM outputs
HCM: ALL LINES

$\text{[O II]} \ \lambda 3727 \text{ Å}$
$\text{[O III]}_a \ \lambda 4363 \text{ Å}$
$\text{[O III]}_n \ \lambda 5007 \text{ Å}$
$\text{[N II]} \ \lambda 6583 \text{ Å}$
$\text{[S II]} \ \lambda\lambda 6717+6731 \text{ Å}$

Mean $\Delta(O/H)$  std $\Delta(O/H)$
-0.01 dex  0.21 dex

$x$-axis: D17 → No errors!
y-axis: HCM
HCM: USING A FEW LINES (1)

Input lines: [OIII]_n, [OIII]_n, [NII], [SII]

Mean $\Delta$(O/H) | std $\Delta$(O/H)
--- | ---
+0.02 dex | 0.21 dex

x-axis: D17 $\rightarrow$ No errors!
y-axis: HCM

[OIII] $\lambda 3727$ Å
[O III]_a $\lambda 4363$ Å
[O III]_n $\lambda 5007$ Å
[N II] $\lambda 6583$ Å
[SII] $\lambda\lambda 6717+6731$ Å
HCM: USING A FEW LINES (2)

- Input lines: [OII], [OIII]_n, [NII], [SII]

- Mean Δ(O/H): -0.08 dex
- STD Δ(O/H): 0.32 dex

- x-axis: D17 → No errors!
- y-axis: HCM
HCM: USING A FEW LINES (3)

Input lines: [OIII]_n, [NII], [SII]

Mean Δ(O/H) | std Δ(O/H)
--- | ---
+0.15 dex | 0.26 dex

x-axis: D17 → No errors!
y-axis: HCM

[OII] \( \lambda 3727 \text{ Å} \)
[O III]_a \( \lambda 4363 \text{ Å} \)
[O III]_n \( \lambda 5007 \text{ Å} \)
[N II] \( \lambda 6583 \text{ Å} \)
[SII] \( \lambda \lambda 6717+6731 \text{ Å} \)
HCM: USING A FEW LINES (4)

$\text{[O III]} \lambda 3727 \text{ Å}$
$\text{[O III]}_{a} \lambda 4363 \text{ Å}$
$\text{[O III]}_{n} \lambda 5007 \text{ Å}$
$\text{[N II]} \lambda 6583 \text{ Å}$
$\text{[S II]} \lambda \lambda 6717+6731 \text{ Å}$

$\text{O/H}$

$x$-axis: D17 → No errors!
$y$-axis: HCM

Mean $\Delta(O/H)$ | std $\Delta(O/H)$
---|---
-0.24 dex | 0.15 dex

Mean $\Delta(O/H)$ | std $\Delta(O/H)$
---|---
-0.25 dex | 0.16 dex
HCM: USING A FEW LINES (5)

\[ [\text{O II}] \lambda 3727 \text{ Å} \]
\[ [\text{O III}]_{\alpha} \lambda 4363 \text{ Å} \]
\[ [\text{O III}]_{\text{n}} \lambda 5007 \text{ Å} \]
\[ [\text{N II}] \lambda 6583 \text{ Å} \]
\[ [\text{S II}] \lambda \lambda 6717 + 6731 \text{ Å} \]

Mean \( \Delta(\text{O/H}) \) | std \( \Delta(\text{O/H}) \)
--- | ---
-0.11 dex | 0.21 dex

**x-axis:** D17 → No errors!

**y-axis:** HCM
**ABUNDANCES: CONSISTENCY WITH THE $T_E$ METHOD**

Difference depends on:

- Total metallicity
- Ionization parameter

**ICF for (O$^+$ + O$^{2+}$)**

Not negligible for NLRS of AGNS!

≠ HII regions

- Total (O/H) → *Dors et al. (2017)*
- Optical Ionic (O$^+$ + O$^{2+}$) → $T_E$ method

- Significant amount of Oxygen in higher ionized species
CONCLUSIONS

https://www.iaa.csic.es/~epm/HII-CHI-mistry.html

AGN-HCM code base on photoionization models

Estimation (and errors!) of:
- Total oxygen abundances
- N/O
- Ionization parameter

Few optical lines needed:
- [O II] λ3727 Å
- [Ne III] λ3868 Å
- [O III] λ4363 Å
- [O III] λ5007 Å
- [N II] λ6583 Å
- [S II] λλ6717+6731 Å

Can be apply to a large number of objects

Consistent with the Te method

Need of ICFs for NLRs if using only optical lines
A new tool to derive chemical abundances in Type-2 Active Galactic Nuclei

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