Fe II emission in AGN

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A major characteristic of type 1 AGN: the emission of Fe II from UV to near IR.

This Fe II emission is highly variable from object to object.

\[ 0 < \frac{\text{Fe II } \lambda 4570}{\text{H}\beta} < 10 \]

Broad range of total strength: from null to several tens of H\(\beta\)
In a few cases FeII is the strongest contributor to the line spectrum.

See the example of the ULIG IRAS 07598+6508 (Boroson & Meyers, 1992; Schmidt & Hines, 1999; Lipari, 1994; Ogle et al., 1999; Véron-Cetty et al., 2006).
Where are the emission regions?

From line widths and correlations with other species: Fe II is emitted somewhere in the BLR (cf. e.g. Sulentic et al. 2000) but also in the NLR (cf. e.g. Véron-Cetty et al. 2004).
Véron-Cetty et al. (2004, 2006):
- identified all the emission lines in I Zw1 and IRAS 07598+6508
- measured the line ratios referred to Hβ
The emission regions

Optical Fe II is emitted in regions as different as:

- The NLR of I Zw1, a low-excitation region:
  \( \text{H I, Ni II, Ti II, Si II, Cr II, [NII], [SII], [CaII], [OI], [FeII]}; \)
  no [OII] or [OIII]
  \( \frac{\text{Fe II } \lambda 4570}{\text{H}\beta_{\text{narrow}}} = 3.1 \quad L_{\lambda 4570} = 7.10^{41} \text{ ergs s}^{-1} \)

- The BLR of I Zw1:
  \( \text{H I, He I, Na I D, Ti II, Si II}; \text{ no HeII} \)
  \( \frac{\text{Fe II } \lambda 4570}{\text{H}\beta_{\text{broad}}} = 1.9 \quad L_{\lambda 4570} = 5.10^{42} \text{ ergs s}^{-1} \)

- The nucleus of IRAS 07598+6508:
  \( \text{HI, CaII H and K, NaI D}; \text{ no HeI, HeII, no NLR} \)
  \( \frac{\text{Fe II } \lambda 4570}{\text{H}\beta} = 8.0 \quad L_{\lambda 4570} = 10^{43} \text{ ergs s}^{-1} \)
Physical Conditions in the NLR of I Zw1

\([\text{NII}] \rightarrow \text{Ne} > 10^5 \text{ cm}^{-3} \quad \text{if } T \sim 8000 \text{ K}\)

\([\text{SII}] \rightarrow 10 < \text{Ne} < 10^5 \text{ cm}^{-3}\)

\([\text{OI}] \rightarrow \text{Ne} \sim 10^7 \text{ cm}^{-3} \quad \text{if } T \sim 8000 \text{ K}\)

no \([\text{OII}], [\text{OIII}] \rightarrow \text{very low ionization parameter, Ne} \sim 10^8 \text{ cm}^{-3}\)

Standard photoionization model using CLOUDY (Ferland 2002)

\[\text{with } U = 4.10^{-5} \quad \text{and } N_H = 5.10^{17} \text{ cm}^2\]

\(\text{FeII} \lambda 4570/\text{H}\beta \text{ cal} = 0.30 \quad \text{FeII}\lambda 4570/\text{H}\beta \text{ obs} = 3.\)
Physical Conditions in the BLR of AGN

From variability and reverberation mapping we have a guess of the size of the BLR (cf. e.g. Kaspi et al. 2005):

few tens of light days

Using standard parameters for a BLR, i.e.:

\[ n = 10^{12} \text{ cm}^{-3}, \quad U = 10^{-2}, \quad N_H = 10^{23} \text{ cm}^{-2} \]

CLOUDY photoionization models

\[ \text{FeII } \lambda 4570/\text{H}\beta = 0.9 \]

1.9 for I Zw1
8.0 for IRAS 07598+6508

Some lines are much too strong in models:
HeII \( \lambda 4686 \), HeI \( \lambda 5876 \), Ly\( \alpha \), MgII, Balmer Continuum
Problems

Standard photoionization models are not able to explain the Fe II emission.

Generally current models do not account:
● for the total Fe II luminosity
● for the line intensity ratios with other species
● for the intensity ratios between Fe II multiplets (e.g. \( \text{FeII}_{\text{opt}} / \text{FeII}_{\text{UV}} \))

Optical and UV multiplets are not emitted in the same region (cf. e.g. Baldwin et al. 2004, Tsuzuki et al. 2006)

A controversy: the dominant excitation process
What are the Excitation Mechanisms?

- continuum and line fluorescence
- collisional excitation (most efficient)
both produced by radiative processes in standard models as the Locally Optimally emitting Clouds model (LOC, Baldwin et al., 1995).

LOC models account for the Low Ionization Lines (LIL, Collin, 1986): H I, He I, Mg II, Ti II, Na I, Ca II, Balmer Continuum including a small contribution of Fe II and [Fe II].

To get large Fe II emission something else is needed. Pure radiative heating is not sufficient.
The goal is to weaken the HII region and to strengthen the HI*
Need for an efficient heating like Mechanical Heating.
Models

Radiative + Mechanical Heating:

\[ n = 10^{12} \text{ cm}^{-3} \quad R = 1 \text{ to } 10 \text{ pc} \]
mechanical heating: \( 6 \times 10^{45} \text{ ergs s}^{-1} \)

\[ \text{FeII}\lambda4570/\text{H}\beta = 8. \]
\( \text{L}\alpha, \text{MgII, FeIIUV, CaII, NaID much too strong} \)

\[ n = 10^{14} \text{ cm}^{-3} \quad \text{mechanical heating: } 2 \times 10^{46} \text{ ergs s}^{-1} \]

better for MgII and FeIIUV but still too strong
worse for CaII, NaID

Need of a region producing only FeII?
Purely Collisional Models

Emission region shielded from the central source of radiation

Excitation and ionization only due to mechanical heating

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<th>I Zw1</th>
<th>IRAS 07598+6508</th>
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<tbody>
<tr>
<td>$L_{\lambda 4570}$</td>
<td>$5 \times 10^{42}$</td>
<td>$10^{43}$ ergs s$^{-1}$</td>
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<tr>
<td>n</td>
<td>$10^{14}$</td>
<td>$10^{15}$ cm$^3$</td>
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<tr>
<td>$N_H$</td>
<td>$10^{24}$</td>
<td>$10^{25}$ cm$^2$</td>
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<tr>
<td>Heating</td>
<td>$2 \times 10^{44}$</td>
<td>$6 \times 10^{44}$ ergs s$^{-1}$</td>
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<td>f</td>
<td>5 %</td>
<td>5 %</td>
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CONCLUSION

The FeII emission is highly variable from object to object. It is emitted in BLR and NLR of AGN. In strong FeII emitters the emission region has probably a high density and column density, is shielded from the central source of radiation and mechanically heated.

In order to make progress, we need both:
- better theoretical models and atomic data,
- high resolution, high S/N spectra in order to identify individual lines.