IR Emission from Ionized Gas in Disks around Low Mass Stars

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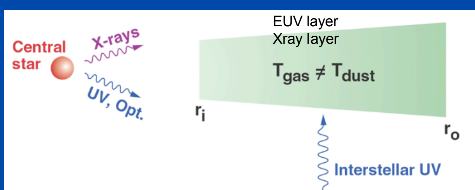
Abstract

We present results from our disk models of the IR fine structure emission generated by EUV and X-ray fluxes from the central star. We focus on lines which require hν>13.6 eV photons to generate, such as [NeII] 12.8 um, [NeIII] 15.5 um, [ArII] 7 um, and [SIII] 18.7 and 33 um. Young solar mass stars produce relatively high luminosities in EUV (extreme ultraviolet-13.6 eV < hν < 100 eV) and X-ray (hν > 100 eV) photons. These photons heat and ionize the surface of the disk. The EUV photons heat and completely ionize the very top 10^4 K surface layer. The X-rays, typically dominated by roughly 1 keV photons, penetrate deeper and heat a partially ionized layer to temperatures greater than about 1000 K, sufficient to excite these lines. We provide a parameter study of the infrared line luminosities produced by ionized species in disks as a function of the EUV and X-ray luminosities, and the EUV spectral shape. Strong lines include [NeII] 12.8 um, [NeIII] 15.6 um, and [ArII] 7.0 um, although we also include estimates of the fine structure lines of [SIII]. Some of the observed [NeII] lines cannot be produced by the observed Xrays, and may originate from the EUV layer. Because the line strengths scale with the EUV luminosity, the lines can be used to measure the EUV luminosity of the star, which is not directly observable. Comparisons are made with *Spitzer* data.

Disk Illuminated by EUV and X-Rays



Disk Model Features:

- Two-layer Dust Radiative Transfer.
- Gas and Dust Temperatures computed separately.
- Chemistry with ~ 90 species, ~600 reactions
- Ionization/Heating by X-rays, UV and cosmic rays
- Dust grain size distribution
- Dust and gas surface density $\Sigma \propto r^{a}$ a~1-1.5
- Vertical gas density structure consistent with gas T.

Stellar Parameters

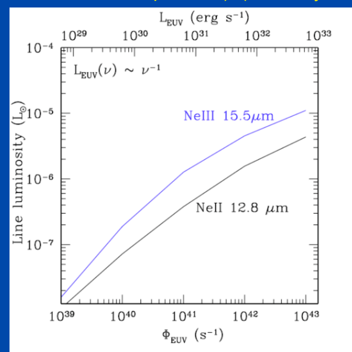
Star	Young Sun
Mass	1.0 $M_\odot$
Stellar Temperature	4300 K
Stellar Radius	2 $R_\odot$
FUV Luminosity	0.01 $L_\odot$, 6-13.6 eV
X-ray Luminosity	variable, 0.1-10 keV
EUV Luminosity	variable, 13.6 - 100 eV

(Φ_{EUV} is the EUV photon luminosity -- photons/s)

Disk Parameters

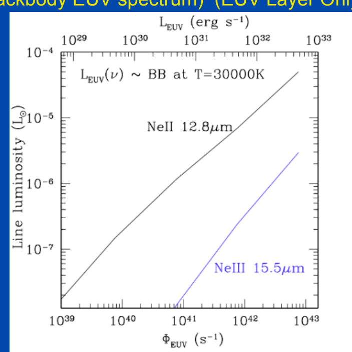
Surface density	1000 $(r/1AU)^{-1}$ gm cm^{-2}
Gas/dust ratio	100
Dust size (min.)	50 A
Dust size (max.)	20 µm (less τ than ISM dust)
Outer radius, r_o	200 AU (irrelevant if > 20 AU)
Inner radius, r_i	0.5 AU, variable

Luminosity of [NeII] and [NeIII] vs EUV Luminosity (Power Law EUV spectrum) (EUV Layer only)



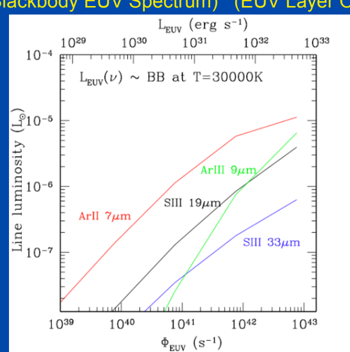
See panel on right for definition of EUV layer and Xray layer

Luminosity of [NeII] and [NeIII] vs EUV Luminosity (Blackbody EUV spectrum) (EUV Layer Only)

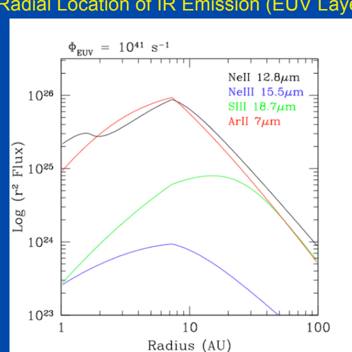


Because observations give [NeIII]/[NeII] < 0.1, the power law spectrum is ruled out and we assume 30000 K blackbody spectrum for EUV henceforth.

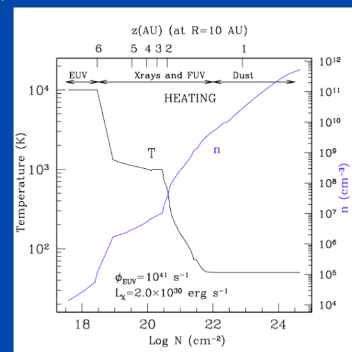
Other Strong Lines as a Function of EUV Luminosity (Blackbody EUV Spectrum) (EUV Layer Only)



Radial Location of IR Emission (EUV Layer)

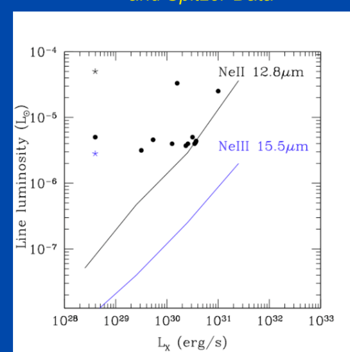


Vertical Structure at 10 AU for Φ_{EUV} = 10^{41} s^{-1} (10 AU = Radial Source of Most IR Emission)



Surface of disk is to left, midplane to right. EUV layer extends down to an H column N of about 10^{19} cm^{-2}. Xray layer is just below it, and the warm part extends to about $3x10^{20}$ cm^{-2}

Luminosity of [NeII] and [NeIII] vs X-Ray Luminosity and *Spitzer* Data



The star (*) data is the [NeII] and [NeIII] from the one source with detections of both lines (Sz102, Lahuis et al 2007)

Conclusions

1. [NeII], [NeIII], [ArII], and [SIII] lines may originate in either the EUV surface layer or the Xray layer just underneath it. An alternate possibility, not explored here, is from internal shocks in the outflow, such as excite Herbig Haro objects.
2. The lines generally scale with the Xray luminosity and the EUV luminosity. Measurements of [NeII] thereby constrain the EUV luminosity, which cannot be directly observed.
3. If the [NeII] and [NeIII] lines originate from the EUV layer, the EUV spectrum must be relatively soft (e.g., a 30000 K blackbody). A power law F(ν) ~ ν^{-1} is ruled out.
4. We predict almost equal [ArII] and [NeII] luminosity from the EUV layer.
5. Although not shown here, the luminosities from the ionized lines in the EUV layer are only weakly sensitive to the inner radius. Therefore, large inner holes, such as is sometimes observed, do not change our conclusions
6. Erg for erg, Xrays produce about 2-3 times as much [NeII] luminosity as do soft EUV photons.
7. A number of sources apparently have too little Xray luminosity to explain the [NeII] luminosity. In order for EUV photons to generate the observed [NeII], the soft EUV luminosity must be much higher than the Xray luminosity. We speculate it might arise from disk accretion onto the star (but see Alexander et al 2005). If it arises from internal shocks in the outflow, the wind mass loss rate must be at least 10^{-8} $M_\odot$ yr^{-1}.