Dust opacity near 24 eV

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``Helium Ionization in the Diffuse Ionized Gas surrounding UCHII regions'',
• Helium Ionization issue; our observations

• Selective dust absorption of Lyman photons

• Inferred dust opacity near 24 eV and comparison with dust opacity model

• Summary and future work
Star formation and Ionized gas

- UCHII envelopes
- Compact HII regions

Diffuse Ionized Gas (envelopes of starforming complexes)

Warm Ionized Medium

- Low freq RRL
- Diffuse thermal Emission (eg. Planck)
- Hα line
- Low freq thermal absorption
Physical properties, Ionization requirement

UCHII
Size $< 0.1$ pc, $n_e \sim 10^4$ cm$^{-3}$, $T_e \sim 10^4$ K
$t_{dy} \sim 10^4$ yr
$Lyc \sim 10^{47} - 10^{49}$ photons s$^{-1}$ (depends on the embedded star)

UCHII envelopes (& Compact HII regions)
Size $\sim 1 - 10$ pc, $n_e \sim 100$ cm$^{-3}$, $T_e \sim 10^4$ K
$t_{dy} \sim 0.5$ Myr
$Lyc \sim 10^{49} - 10^{50}$ photons s$^{-1}$ (multiple ionizing stars)
Physical properties, Ionization requirement

Diffuse Ionized Gas (envelopes of Starforming complexes)

Size $\sim 10 - 70$ pc, $n_e \sim 1 - 10$ cm$^{-3}$
$T_e \sim 10^4$ K
$t_{dy} \sim 3$ Myr
$\text{Lyc} \sim 10^{50} - 10^{52}$ photons s$^{-1}$

Warm Ionized Medium

Size $> 100$ pc, $n_e < 1$ cm$^{-3}$, $T_e \sim 10^4$ K
Total $\text{Lyc} \sim 10^{50}$ photons s$^{-1}$ kpc$^{-2}$
Ionization Spectrum: He Ionization

H → 13.6 eV; He → 24.6 eV
RRL obs can constrain $\gamma = \frac{Q_{\text{He}}}{Q_{\text{H}}}$

$T_{\text{eff}} > 35000$ K
(Standard IMF and SFR 3 $M_{\odot}$ yr$^{-1}$)

- UCHII
- UCHII envelopes
- Compact HII regions (for O5.5 or earlier)
- Diffuse ionized gas
- Warm ionized Medium

$T_{L(\text{He}^+)} / T_{L(H^+)} \sim n_{\text{He}^+} / n_{\text{H}^+}$

(for O5.5 or earlier)

~0.08

2017 paper

~0.08

? 0.02

0.027

The Cosmic Cycle of Dust and Gas in the Galaxy, Vietnam, 13 June, 2018
GBT observations

Aim: He ionization in UCHII envelopes

• Observed 3 UCHII envelopes:
  
  G10.15-0.34, G23.46-0.2, G29.96-0.02 (Kim & Koo 2001)
  O5.5 or earlier, 16 positions were observed

• Observed frequency: 4.8 GHz (beam 2 arcmin)

• RRL transitions: $^{104}\alpha$, $^{105}\alpha$, $^{106}\alpha$, $^{109}\alpha$, $^{110}\alpha$, $^{111}\alpha$, $^{112}\alpha$, $^{113}\alpha$

• Int. time per position: \(~10\) mts (eff int. time \(~1.3\) hrs)
G10.15-0.34
G23.46-0.20

mic Cycle of Dust and Gas in the Galaxy, Vietnam, 13 June,
G29.96-0.02

Mic Cycle of Dust and Gas in the Galaxy, Vietnam, 13 June,
Results from the observations

- \( \frac{n_{\text{He}^+}}{n_{\text{H}^+}} \sim 0.06 \) (0.02) toward UCHII regions
  (As expected for ionization due to O5.5 or earlier star)

- \( \frac{n_{\text{He}^+}}{n_{\text{H}^+}} < 0.033 \) toward the diffuse gas

- \( \text{He}^{++} \) lines not detected in the diffuse gas
  (Helium is neutral; Spectrum of ionizing radiation is changing)
Selective absorption by dust?

(Mezger, Smith & Churchwell 1974)

Dust free HII region

- Size of He\(^+\) to H\(^+\) zones determined by 
  \[ \gamma = \frac{Q_{\text{He}}}{Q_{\text{H}}} \]
  of the star or cluster
  (ratio of the number of photons available for
  He and H ionization.)

- For \( \gamma > 0.2 \) He\(^+\) and H\(^+\) zones overlap.

- Lyc \( \sim 5 \times 10^{49} \) s\(^{-1}\) (for the observed clusters)

- \( M_{\text{cluster}} \sim 800 \) M\(_{\odot}\) (standard IMF) and \( \gamma > 0.2 \)
Selective absorption by dust?

Dusty HII region

- $\text{Ly}_H$ attenuated by dust $\propto \sigma_H$
  (dust absorption cross-section for $\text{Ly}_H$)

- $\text{Ly}_{He}$ attenuated by dust $\propto \sigma_{He}$
  (dust absorption cross-section for $\text{Ly}_{He}$)

$\gamma = Q_{He}/Q_H$ changes as the Lyc photons propagate through the HII region
  → changes the $\text{He}^+$ and $\text{H}^+$ region size

- Size change is determined by $a_0 = \sigma_{He}/\sigma_H$
  → can be constrained from observed $n_{\text{He}^+}/n_{\text{H}^+}$ upperlimit.

The Cosmic Cycle of Dust and Gas in the Galaxy, Vietnam, 13 June, 2018
Absorption cross-section @ 24 eV

Range of values at 24.6 eV required to explain the observed $n_{\text{He}^+}/n_{\text{H}^+}$ upperlimit.

- $n_{\text{He}^+}/n_{\text{H}^+} < 0.033$
- $a_0 = \sigma_{\text{He}}/\sigma_{\text{H}}$
- in the range 2 to 4 (depends on filling factor and value of $\sigma_{\text{H}}$)
- Not consistent with dust model

(Weingartner & Draine 2001)
Summary

- Helium is under ionized in diffuse ionized gas near UCHII regions with O5.5 or earlier stars ($n_{\text{He}^+}/n_{\text{H}^+} < 0.03$).

- $a_0 = \sigma_{\text{He}}/\sigma_{\text{H}} \rightarrow 2$ to 4 if selective absorption by dust is causing the low He ionization. (Not consistent with dust opacity model)
Future work

• Rule out other possibilities causing low He ionization. (e.g. statistical uncertainty at the high end of the mass function.)

• Understand why $n_{\text{He}^+}/n_{\text{H}^+} \sim 0.08$ (i.e. not 0.1) in HII regions with embedded O5.5 or earlier star type.

• Develop a self-consistent dust extinction model for dust in HII regions with embedded O5.5 or earlier star type.

Thank you