Dust opacity near 24 eV

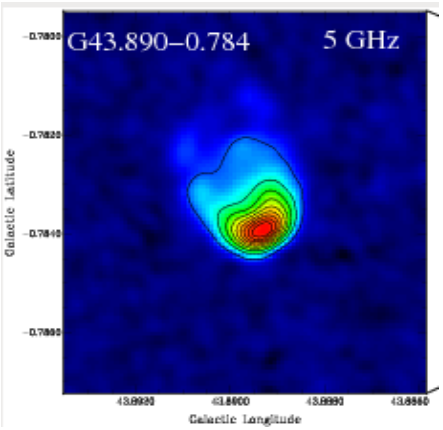
D. Anish Roshi,
NRAO Charlottesville, VA

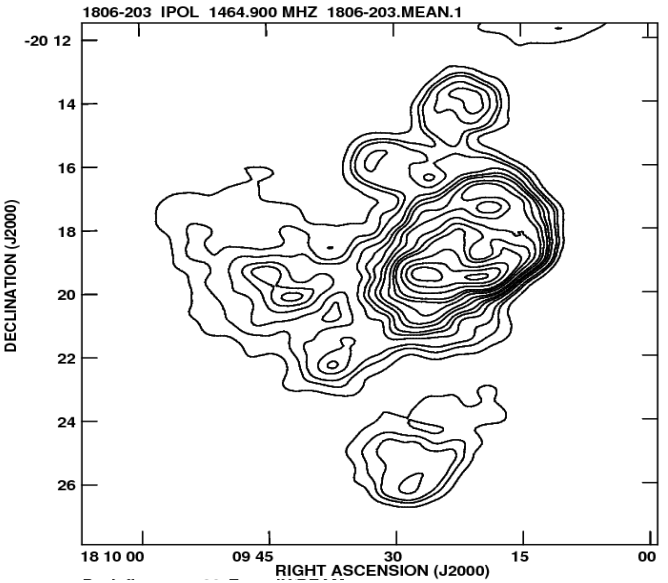
``*Helium Ionization in the Diffuse Ionized Gas surrounding UCHII regions*'',
D. A. Roshi, E. Churchwell, L. D. Anderson, 2017, ApJ, 838, 144

- 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

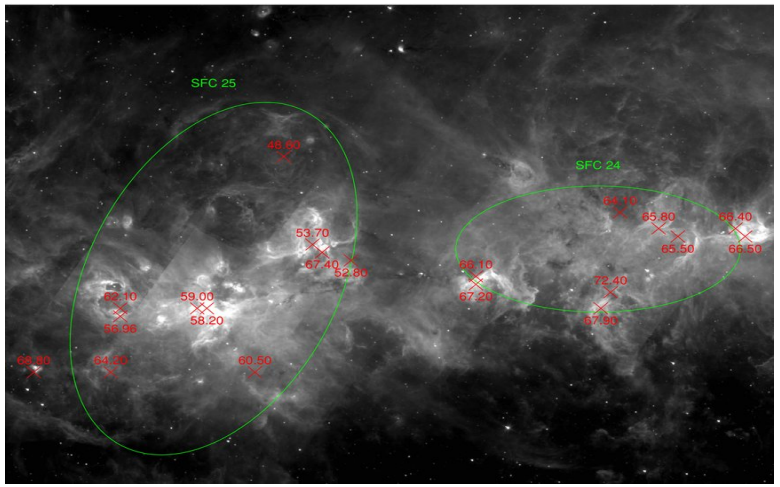
UCHII



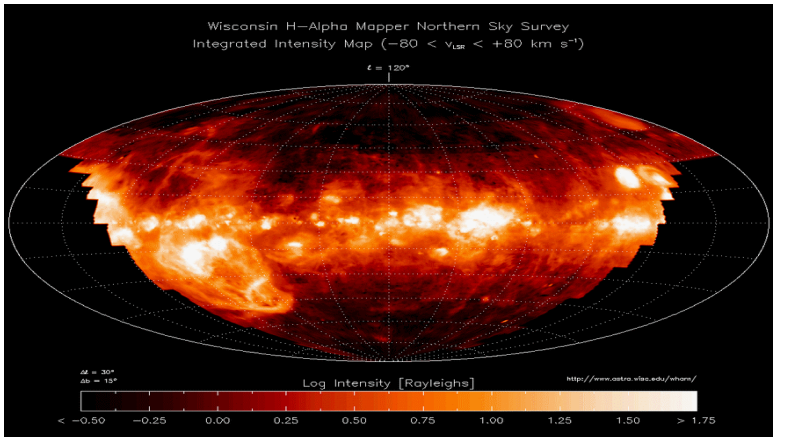


- UCHII envelopes
- Compact HII regions

Diffuse Ionized Gas
(envelopes of starforming complexes)



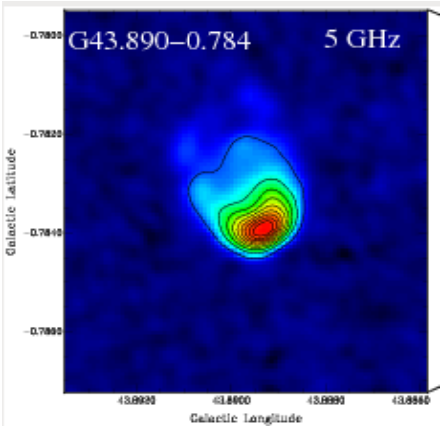
Warm Ionized Medium



- Low freq RRL
- Diffuse thermal Emission (eg. Planck)

- Hα line
- Low freq thermal absorption

Physical properties, Ionization requirement

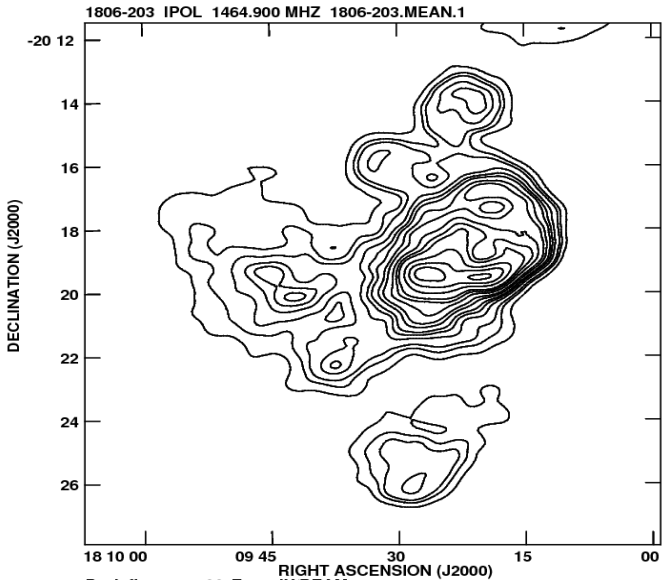


UCHII

Size < 0.1 pc, $n_e \sim 10^4$ cm^{-3}, $T_e \sim 10^4$ K

$t_{dy} \sim 10^4$ yr

Lyc ~ 10^{47} – 10^{49} photons s^{-1} (depends on the embedded star)



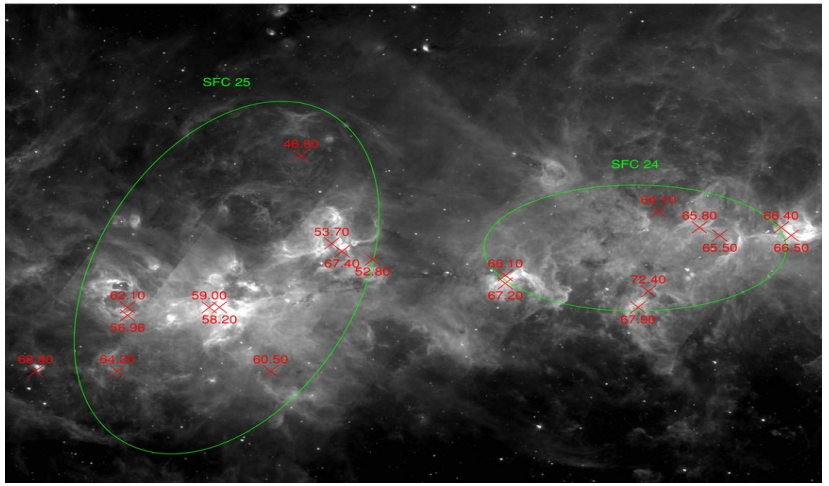
UCHII envelopes (& Compact HII regions)

Size ~ 1 – 10 pc, $n_e \sim 100$ cm^{-3}, $T_e \sim 10^4$ K

$t_{dy} \sim 0.5$ Myr

Lyc ~ 10^{49} – 10^{50} photons s^{-1} (multiple ionizing stars)

Physical properties, Ionization requirement



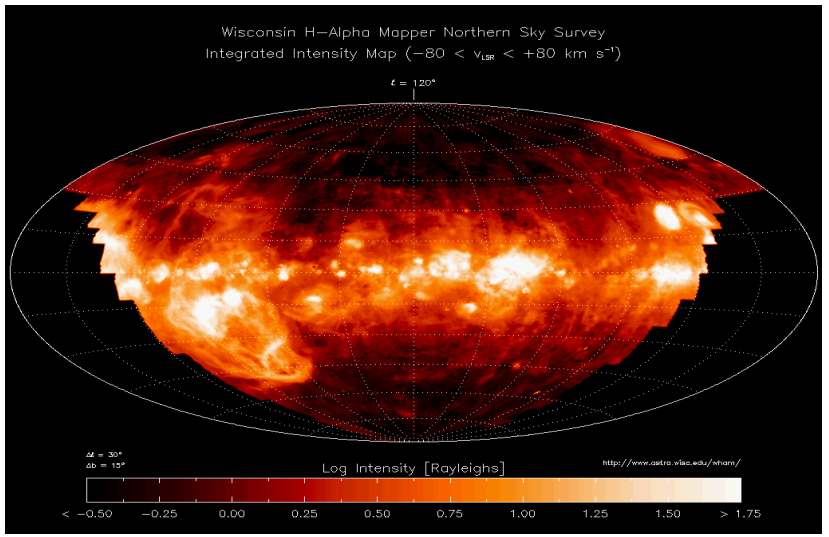
Diffuse Ionized Gas (envelopes of Starforming complexes)

Size ~ 10 – 70 pc, n_e ~ 1 – 10 cm^{-3}

T_e ~ 10^4 K

t_{dy} ~ 3 Myr

Lyc ~ 10^{50} – 10^{52} photons s^{-1}

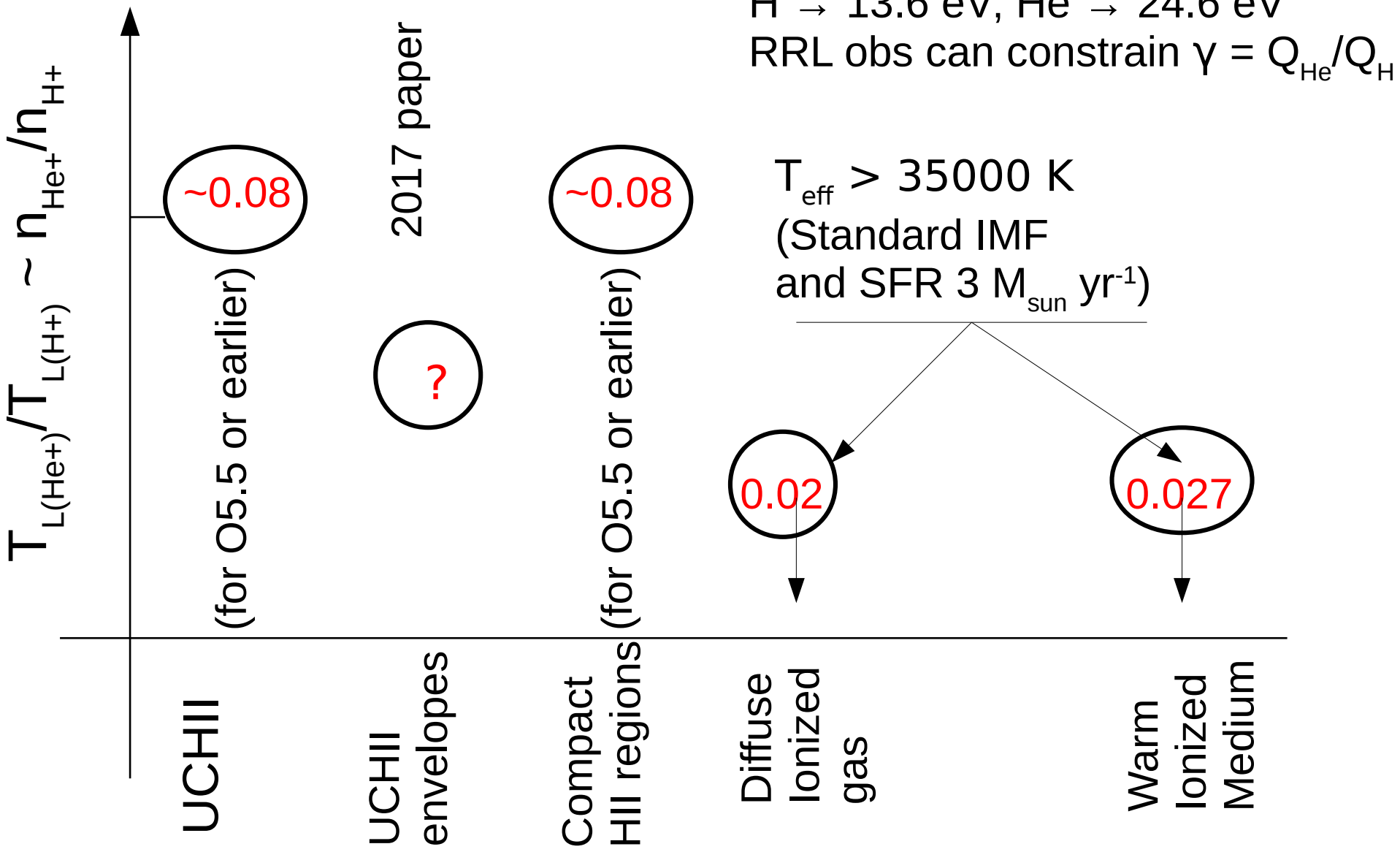


Warm Ionized Medium

Size > 100 pc, n_e < 1 cm^{-3},T_e ~ 10^4 K

Total Lyc ~ 10^{50} photons s^{-1} kpc^{-2}

Ionization Spectrum: He Ionization



GBT observations

Aim: He ionization in UCHII envelopes

•Observed 3 UCHII envelopes :

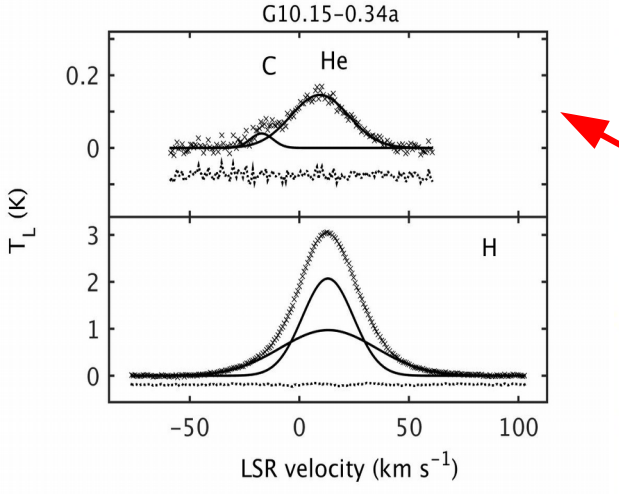
G10.15-0.34, G23.46-0.2, G29.96-0.02 (Kim & Koo 2001)
O5.5 or earlier, 16 positions were observed

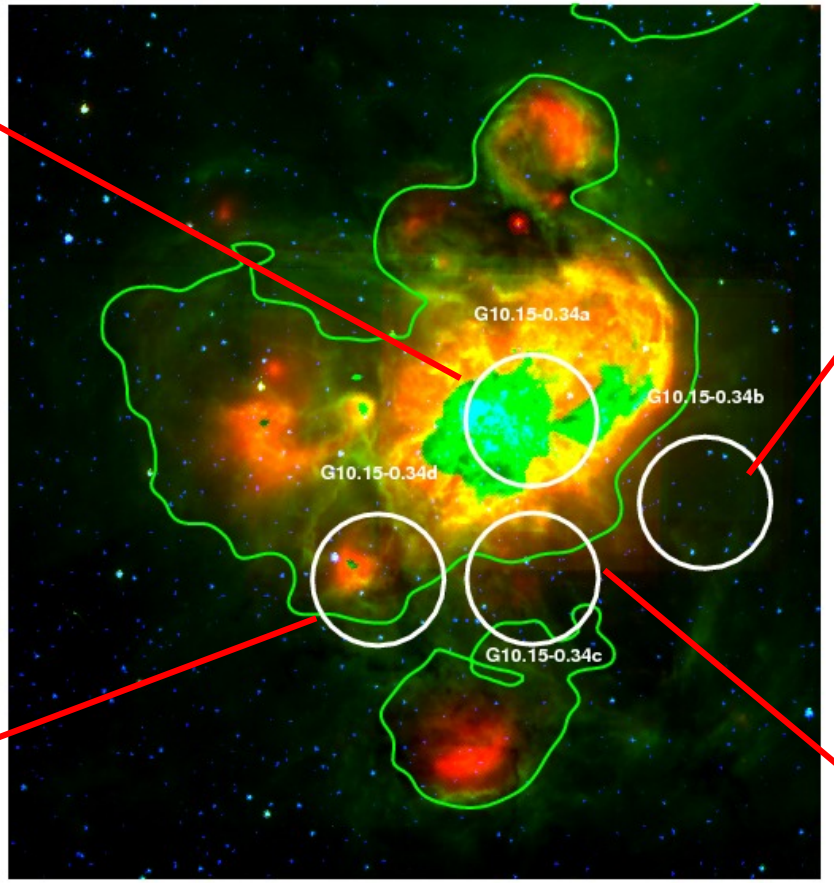
•Observed frequency : 4.8 GHz (beam 2 arcmin)

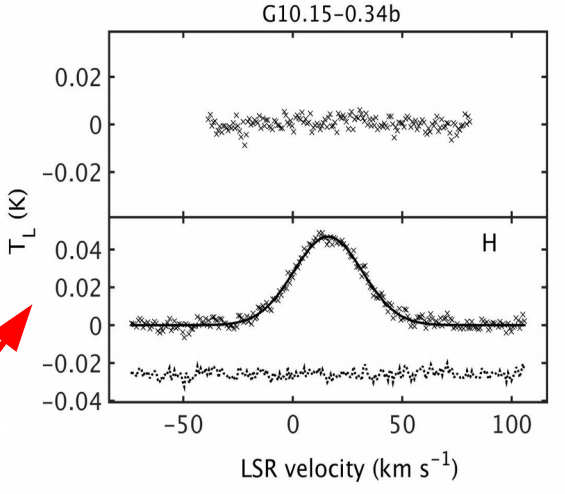
•RRL transitions : 104α, 105α, 106α, 109α, 110α, 111α, 112α, 113α

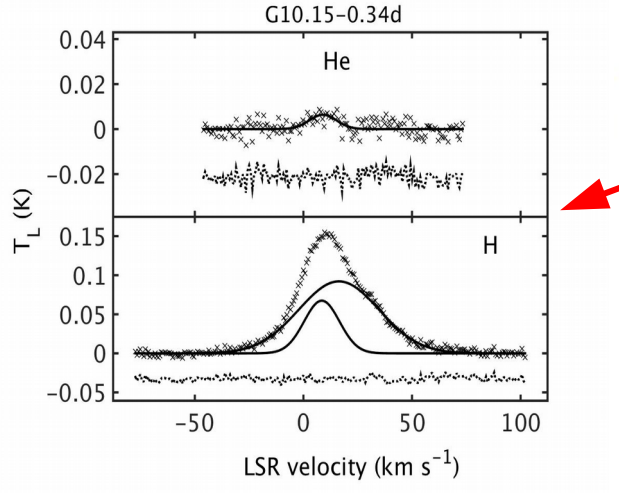
•Int. time per position : ~10 mts (eff int. time ~1.3 hrs)

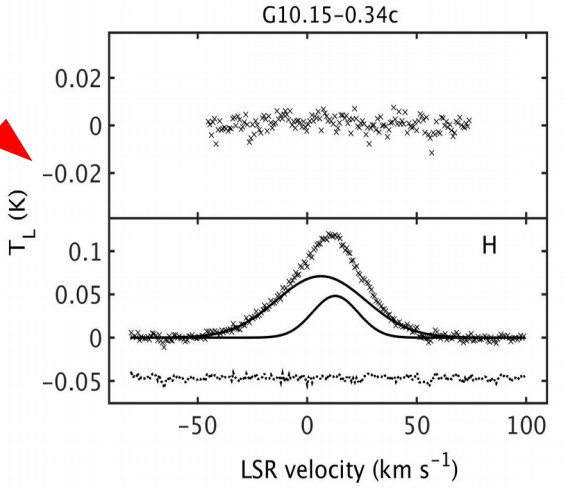
G10.15-0.34


G10.15-0.34a
C
He
H
T_L (K)
LSR velocity (km s^{-1})

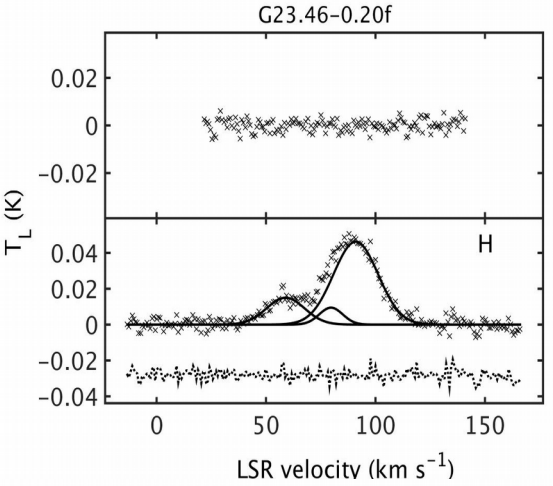

G10.15-0.34a
G10.15-0.34b
G10.15-0.34d
G10.15-0.34c

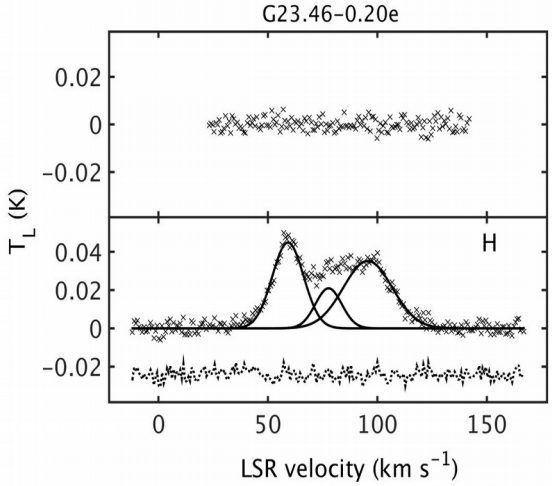

G10.15-0.34b
H
T_L (K)
LSR velocity (km s^{-1})

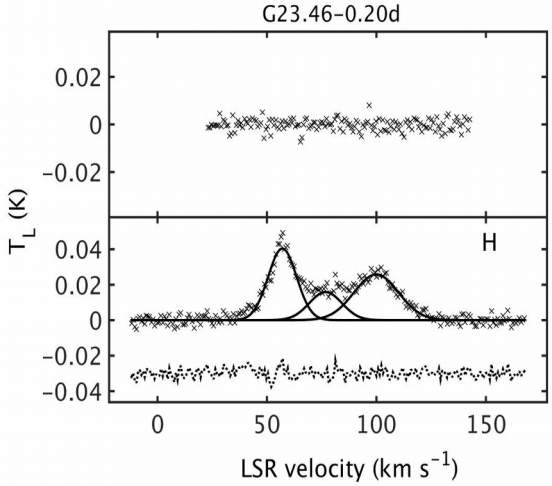

G10.15-0.34d
He
H
T_L (K)
LSR velocity (km s^{-1})

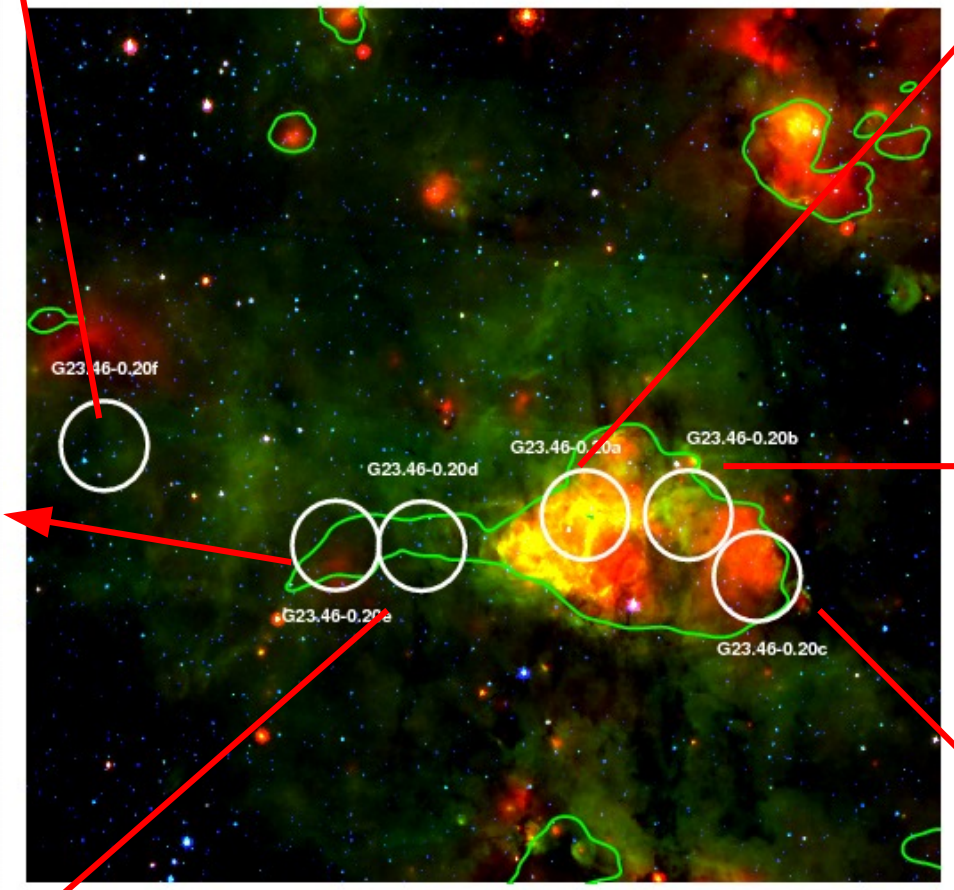

G10.15-0.34c
H
T_L (K)
LSR velocity (km s^{-1})

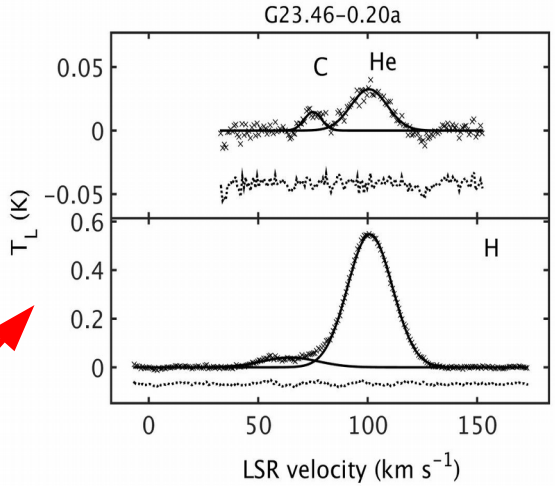
G23.46-0.20

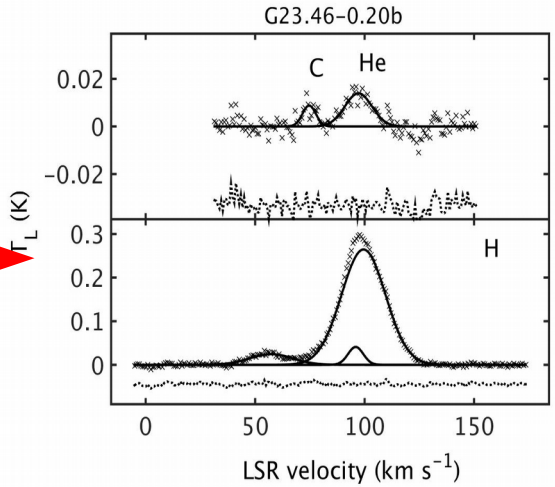

G23.46-0.20f
H
T_L (K)
LSR velocity (km s^{-1})

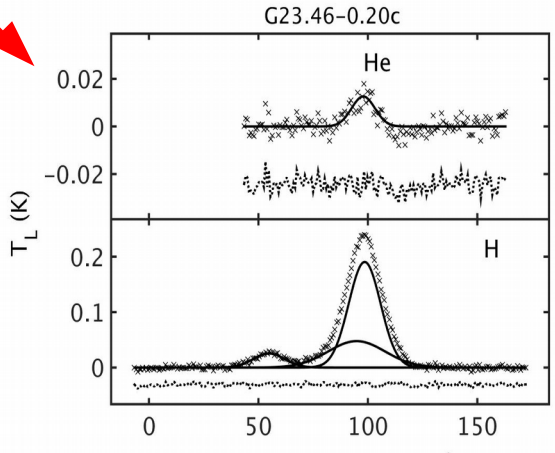

G23.46-0.20e
H
T_L (K)
LSR velocity (km s^{-1})


G23.46-0.20d
H
T_L (K)
LSR velocity (km s^{-1})

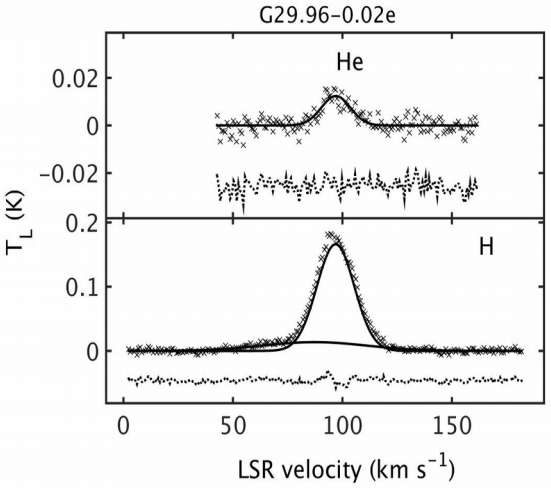

G23.46-0.20f
G23.46-0.20d
G23.46-0.20e
G23.46-0.20a
G23.46-0.20b
G23.46-0.20c

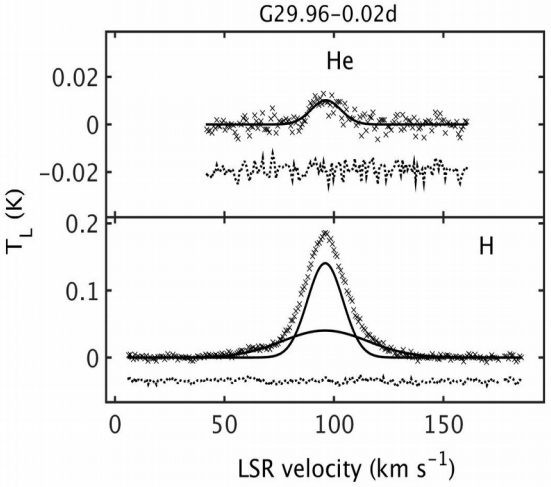

G23.46-0.20a
C
He
H
T_L (K)
LSR velocity (km s^{-1})

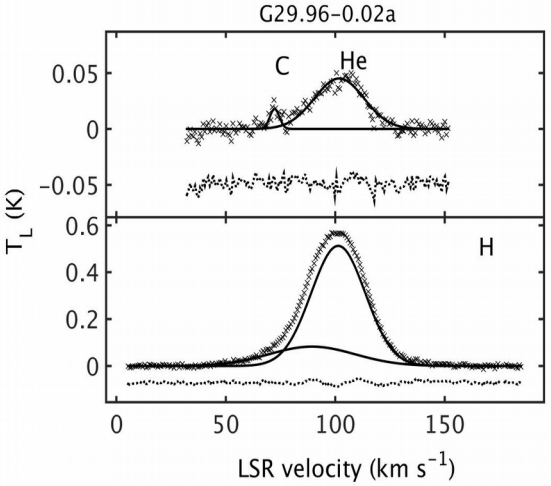

G23.46-0.20b
C
He
H
T_L (K)
LSR velocity (km s^{-1})

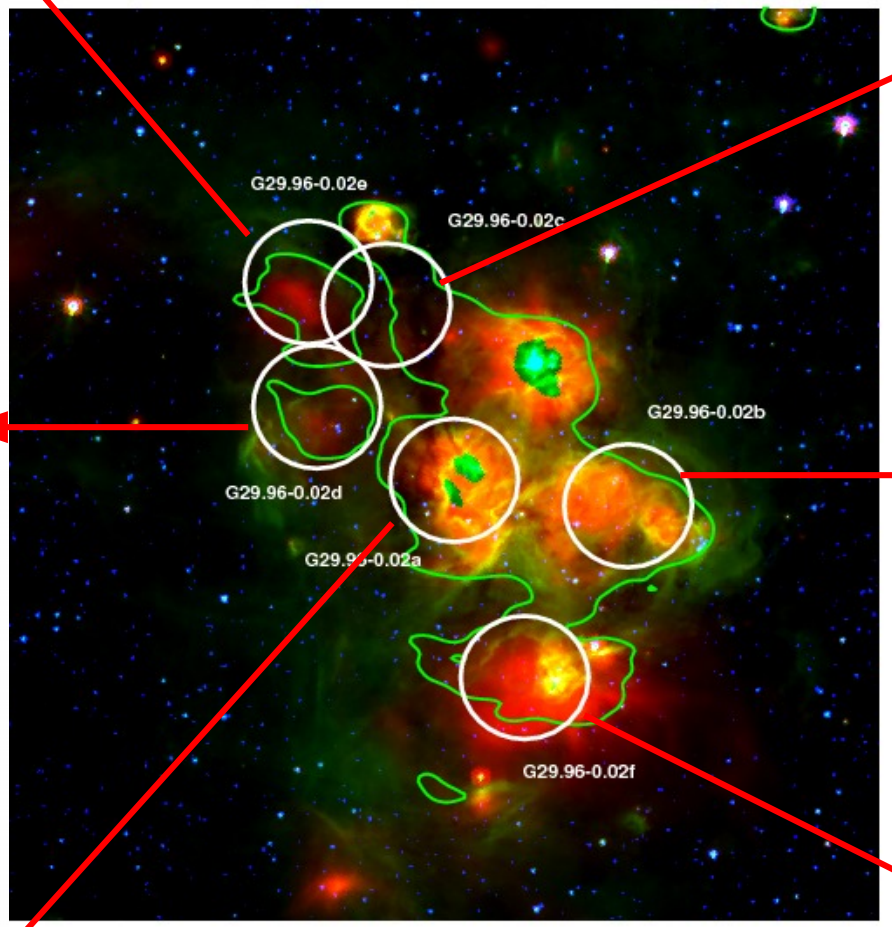

G23.46-0.20c
He
H
T_L (K)
LSR velocity (km s^{-1})

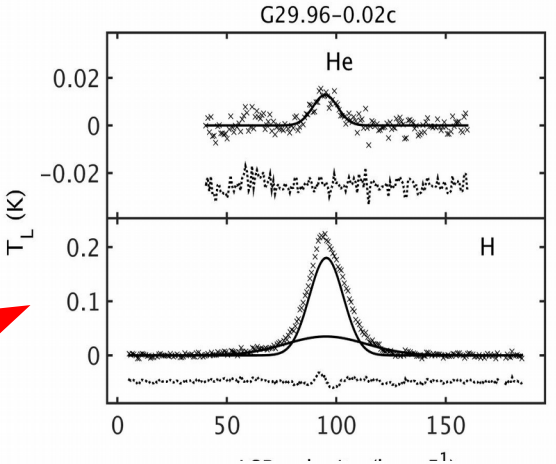
G29.96-0.02

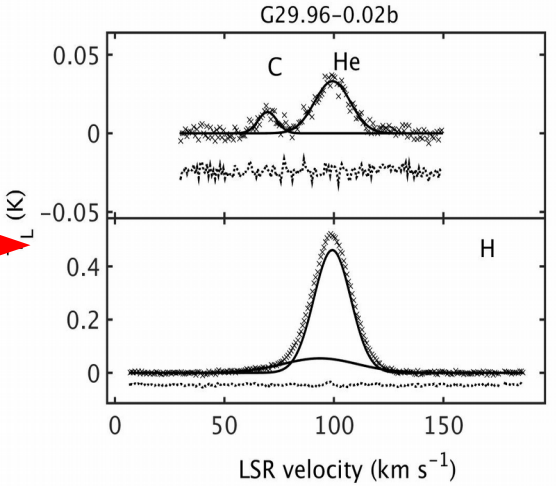

G29.96-0.02e
He
H
T_L (K)
LSR velocity (km s^{-1})

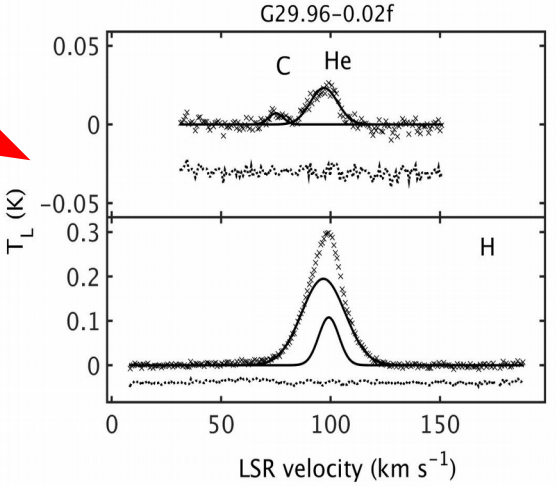

G29.96-0.02d
He
H
T_L (K)
LSR velocity (km s^{-1})


G29.96-0.02a
C
He
H
T_L (K)
LSR velocity (km s^{-1})


G29.96-0.02e
G29.96-0.02c
G29.96-0.02b
G29.96-0.02d
G29.96-0.02a
G29.96-0.02f


G29.96-0.02c
He
H
T_L (K)


G29.96-0.02b
C
He
H
T_L (K)
LSR velocity (km s^{-1})


G29.96-0.02f
C
He
H
T_L (K)
LSR velocity (km s^{-1})

Results from the observations

- n_{He+}/n_{H+} ~ 0.06 (0.02) toward UCHII regions

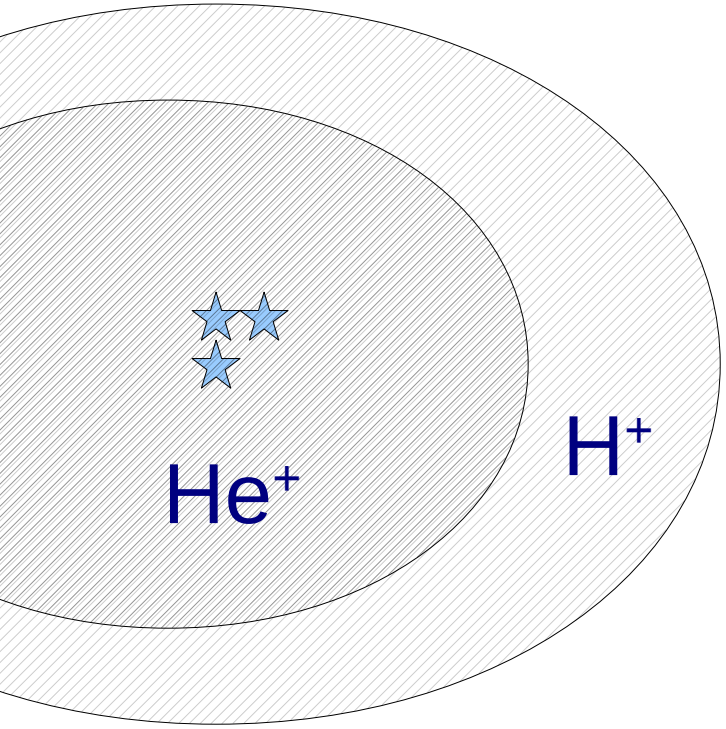
  (As expected for ionization due to O5.5 or earlier star)

- n_{He+}/n_{H+} < 0.033 toward the diffuse gas

- He^{++} lines not detected in the diffuse gas

  (Helium is neutral; Spectrum of ionizing radiation is changing)

Selective absorption by dust ?

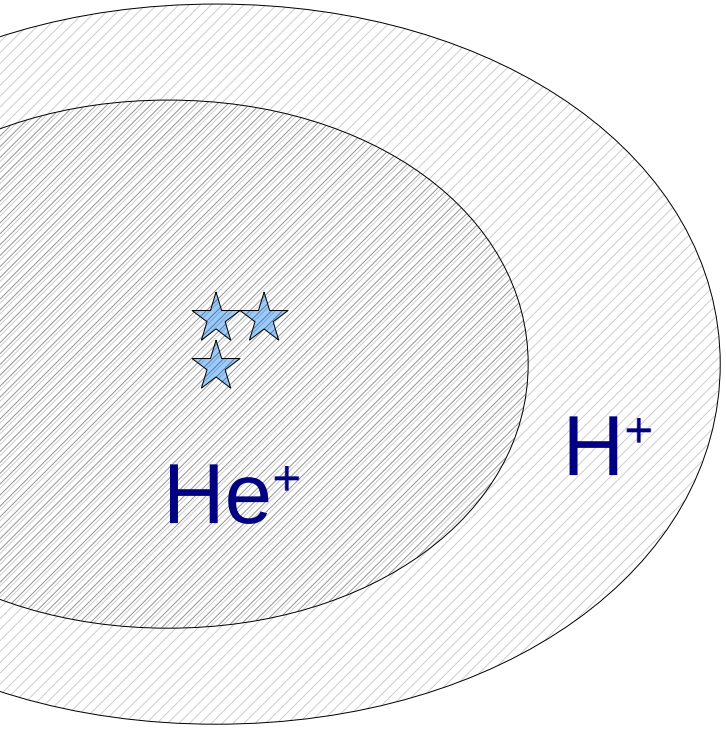


(Mezger, Smith & Churchwell 1974)

Dust free HII region

- Size of He^+ to H^+ zones determined by $\gamma = Q_{He}/Q_H$ 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 ~ 5×10^{49} s^{-1} (for the observed clusters)
- $M_{cluster}$ ~ 800 M_{sun} (standard IMF) and $\gamma > 0.2$

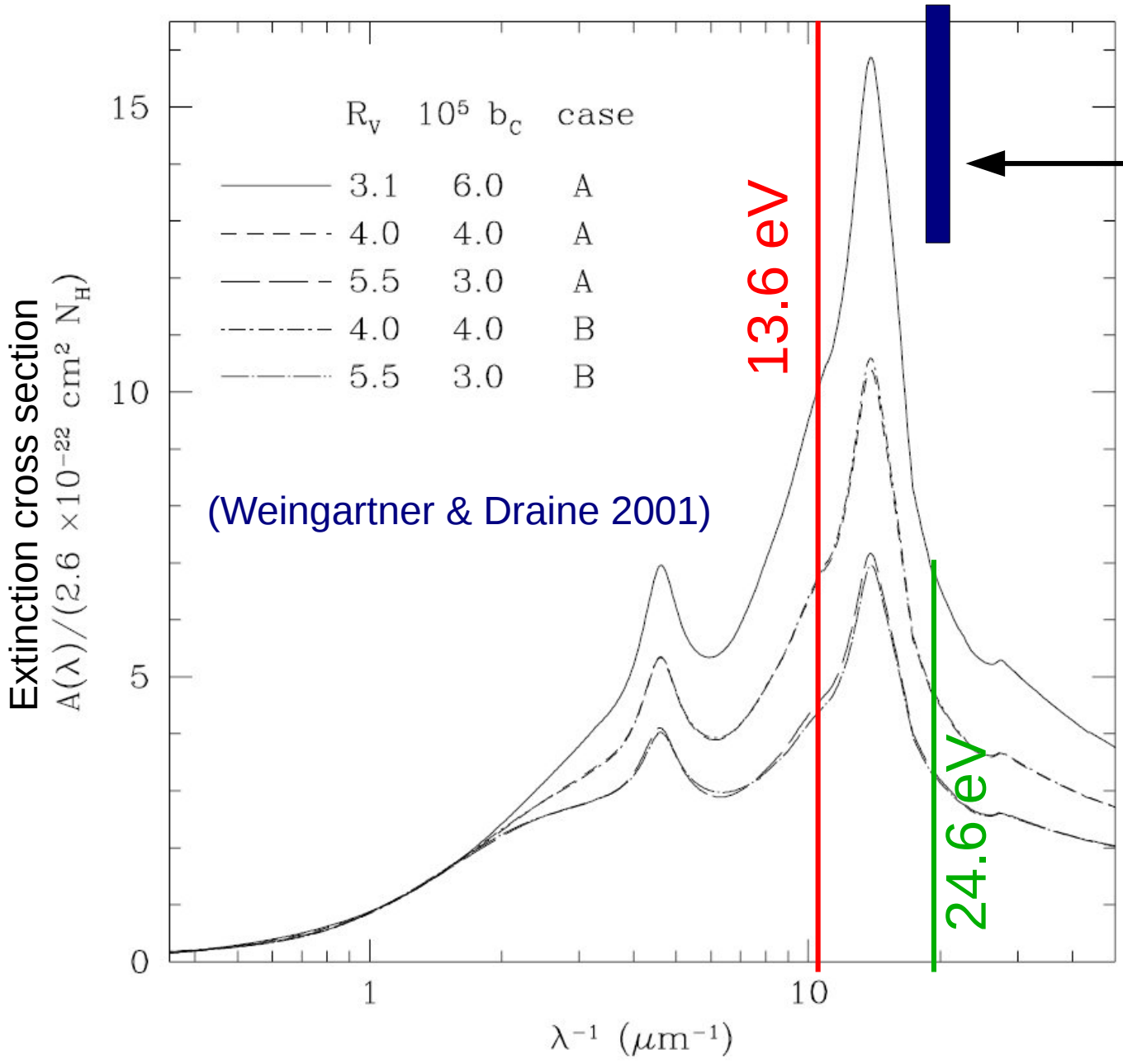
Selective absorption by dust ?



Dusty HII region

- Ly_H attenuated by dust $\propto \sigma_H$
  (Ly_H dust absorption cross-section)
- Ly_{He} attenuated by dust $\propto \sigma_{He}$
  (Ly_{He} dust absorption cross-section)
- $\gamma = Q_{He}/Q_H$ changes as the Lyc photons propagate through the HII region
  → changes the He^+ and H^+ region size
- Size change is determined by $a_0 = \sigma_{He}/\sigma_H$
  → can be constrained from observed n_{He+}/n_{H+} upperlimit.

Absorption cross-section @ 24 eV



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

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

Summary

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

- $a_0 = \sigma_{He}/\sigma_H \rightarrow$ 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_{He+}/n_{H+} ~ 0.08 (i.e. not 0.1) in HII reigions 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