BOWEN FLUORESCENCE

The Symbiotic Novae – RR Telescopii

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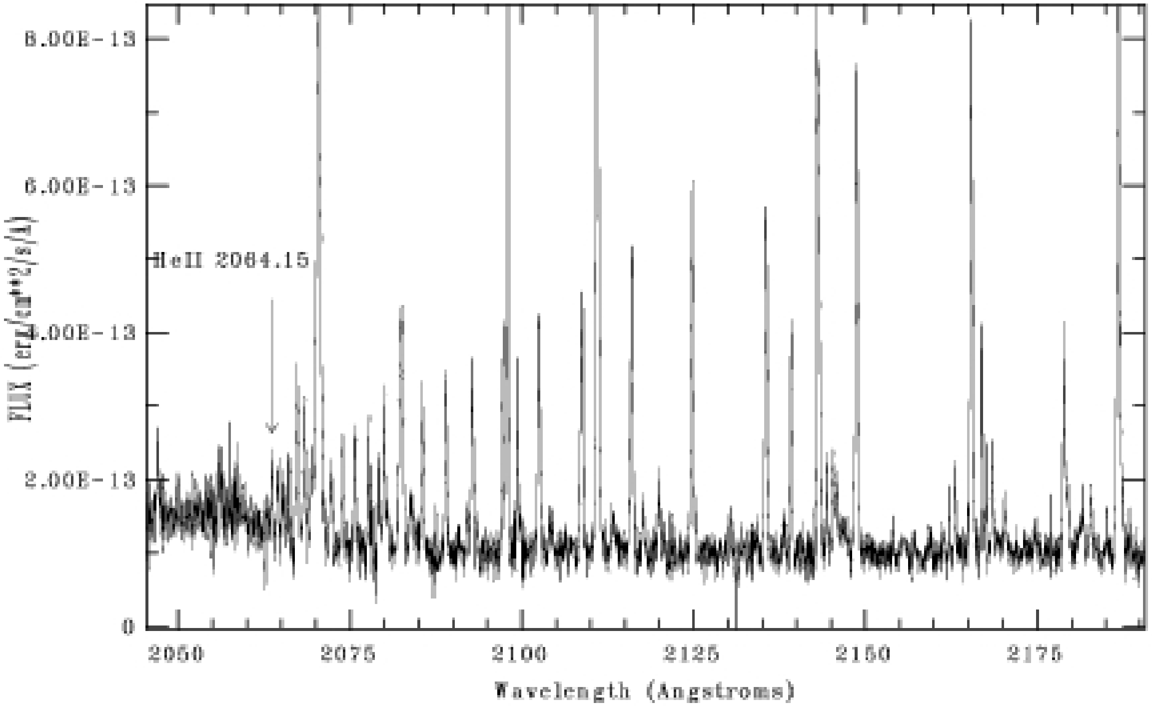
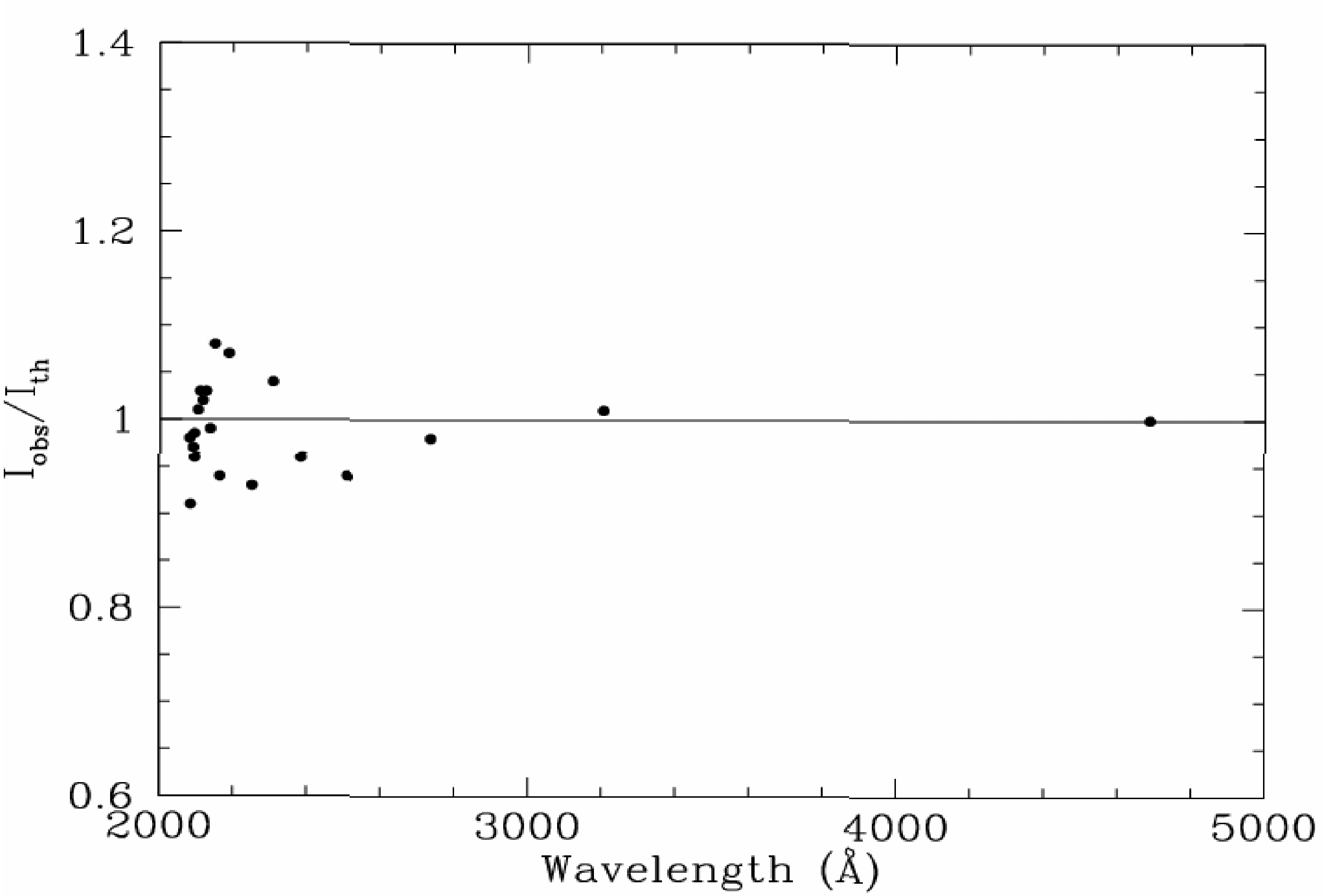
Spectra Used Here.

HST-STIS R = 4870-30000
UVES R = 55000-65000
IUE Low, High Res.
FEROS R = 60000

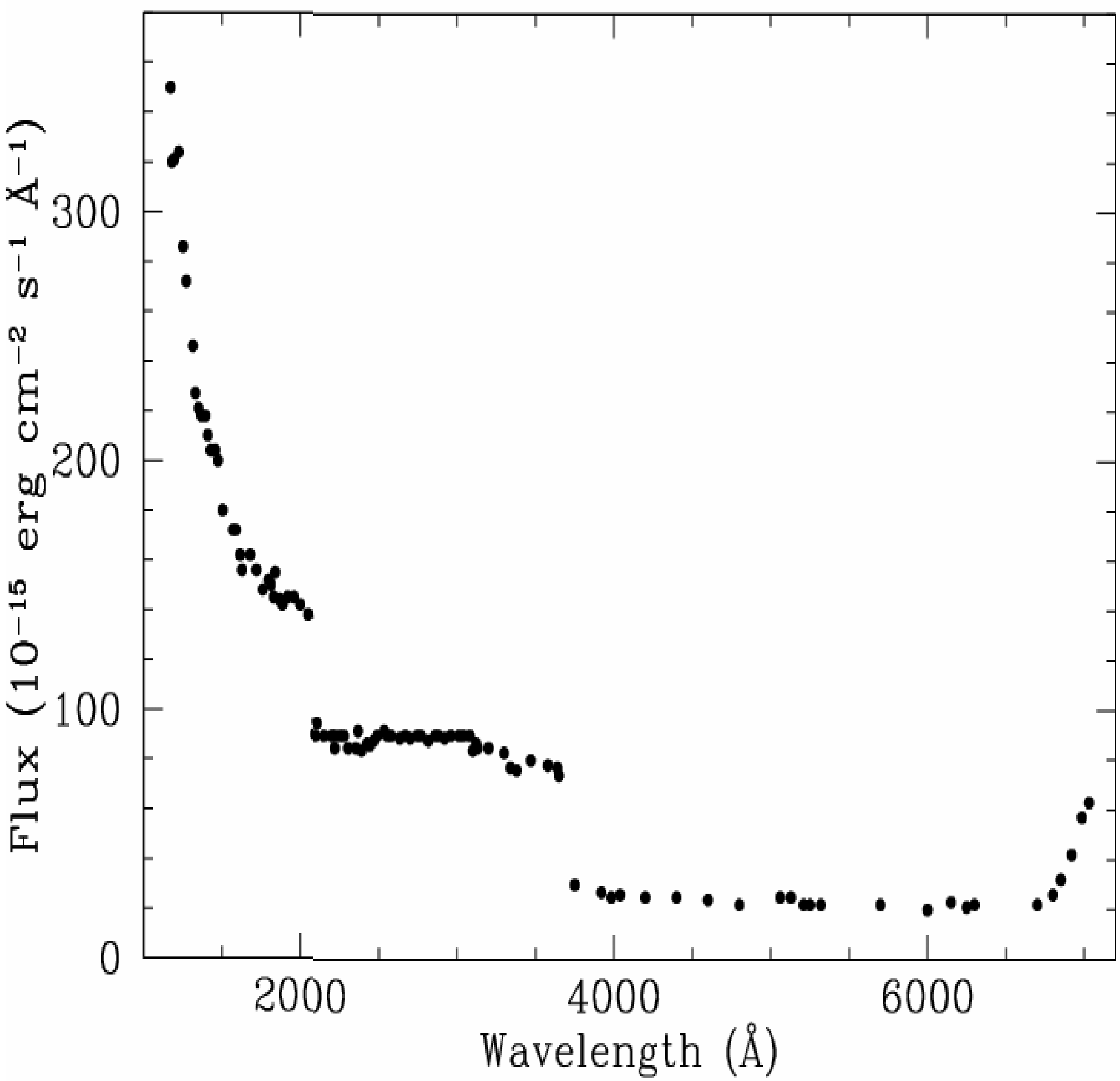


Strong HeII important for fluorescence!

HeII Fowler lines near head of (n-3) series.
Last resolved line is (37-3) 2063.49 A.
Decrement used for reddening.

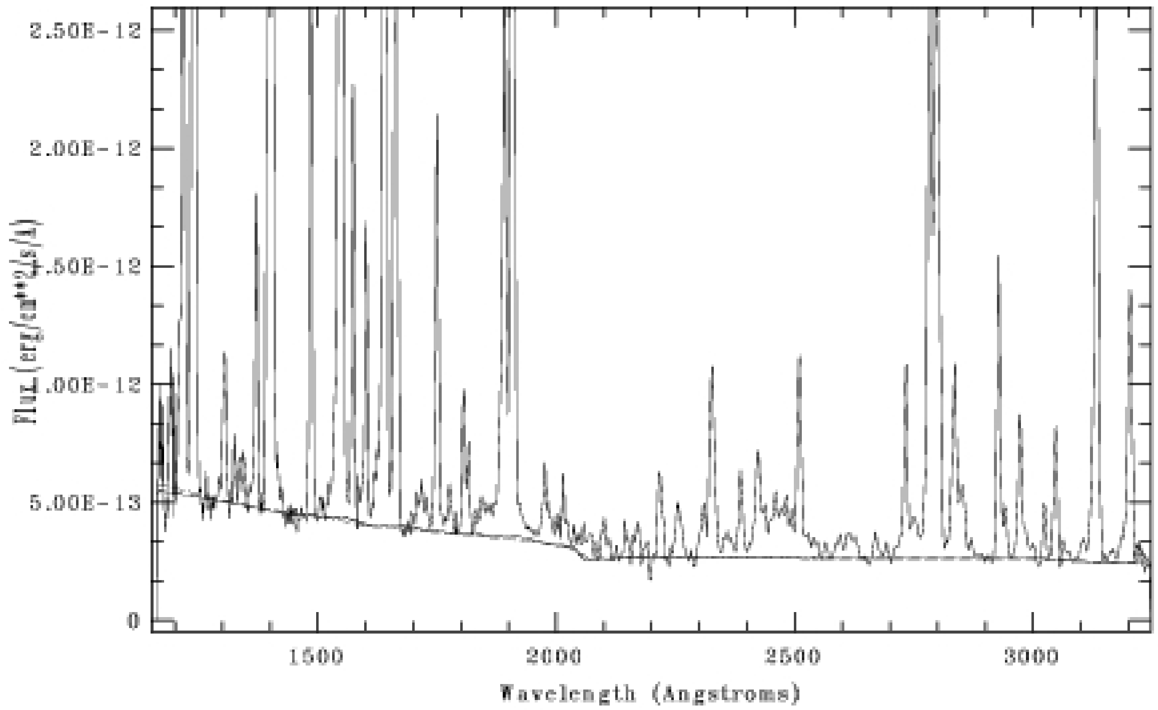


I_{obs}/I_{th} ratio relative to I_{4686} for HeII Fowler lines.
E(B-V) ~ 0.0 . Theoretical from Storey and Hummer (1995).



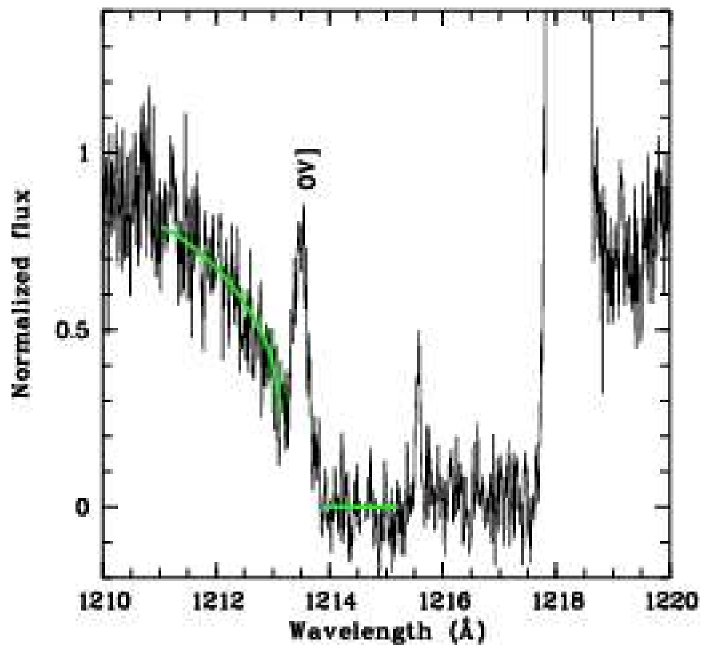
Continuum – nebular + hot star too blue to allow much reddening. Red excess from M giant companion.

Observed continuum of RR Tel (STIS).
b-f discontinuities of Fowler and Balmer (HI) series are evident.



No evidence of claimed IS absorption bump near 2175A giving E(B-V) = 0.1

UV continuum from averaging and merging 39 SWP and 35 LW IUE spectra.

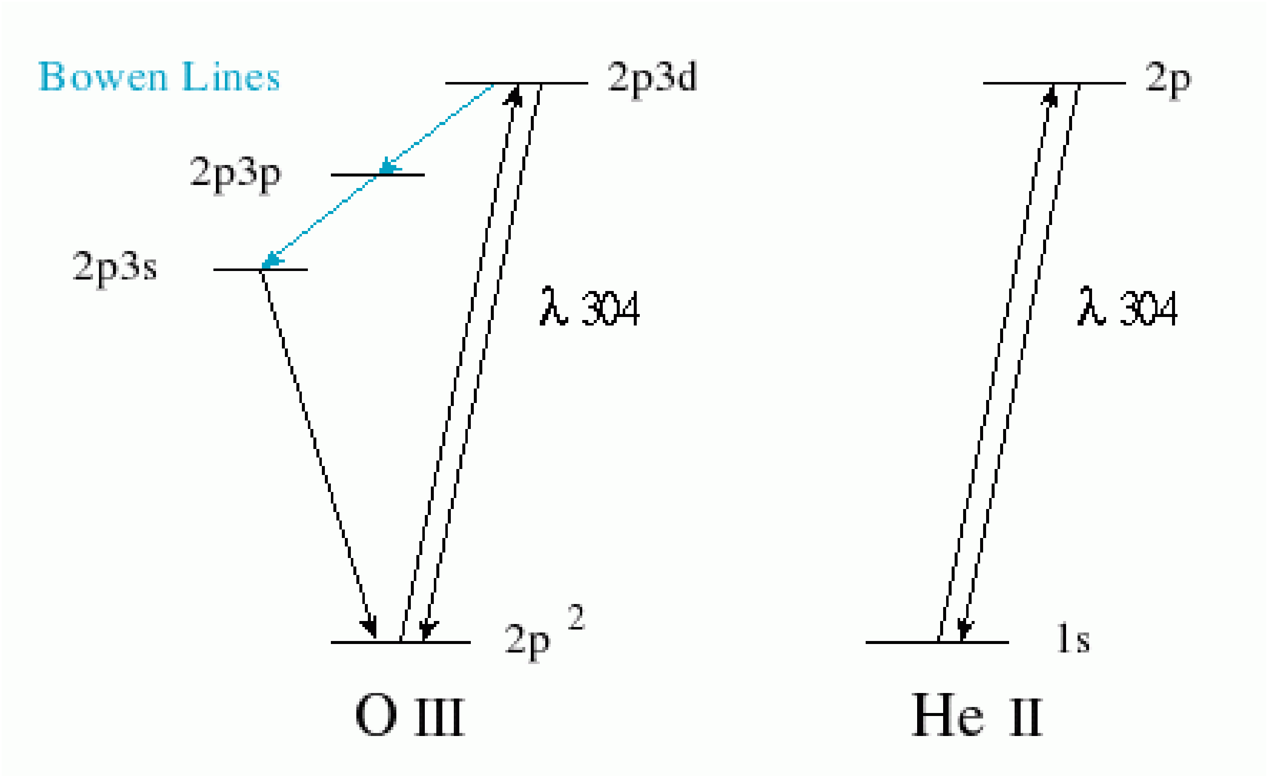


Interstellar Ly alpha line.
Fit gives H column density
N(H)=6.9 x 10^{19} cm^{-2}

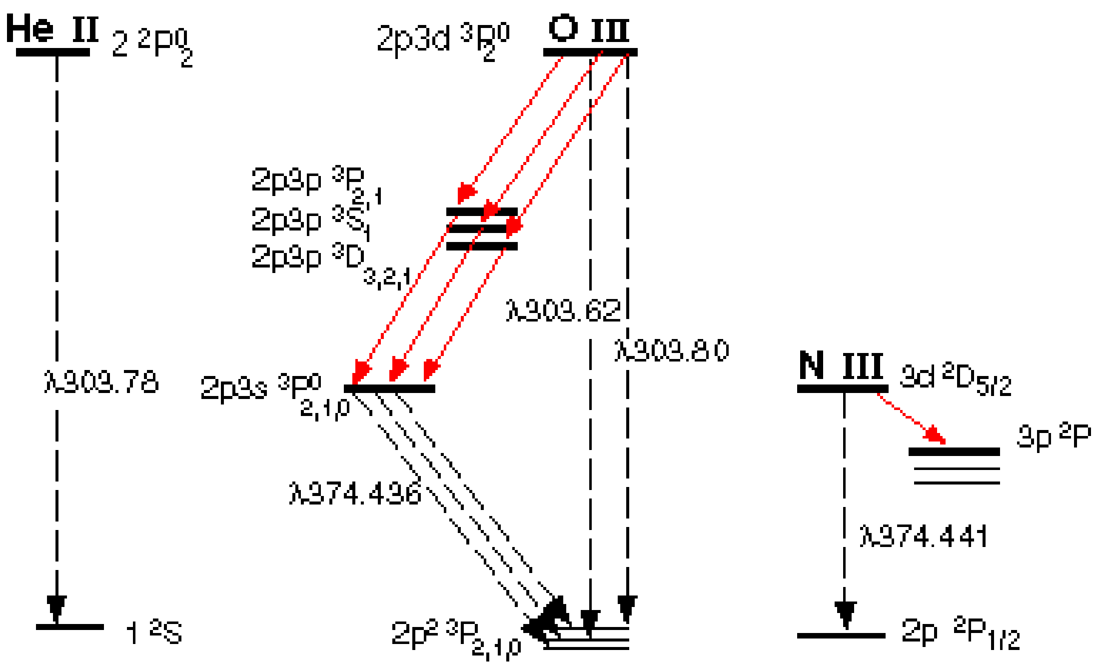
The value of N(H) combined with Diplas & Savage relation between N(H) and E(B-V) gives:
E(B-V) = 0.014

100 micron sky map and HI maps give higher values but spatial resolution is lower.

Derived distance 3.47kpc.
Assume Mv(max)= -6.0 (slow nova)
and mv(max)= 6.7, E(B-V) = 0.0

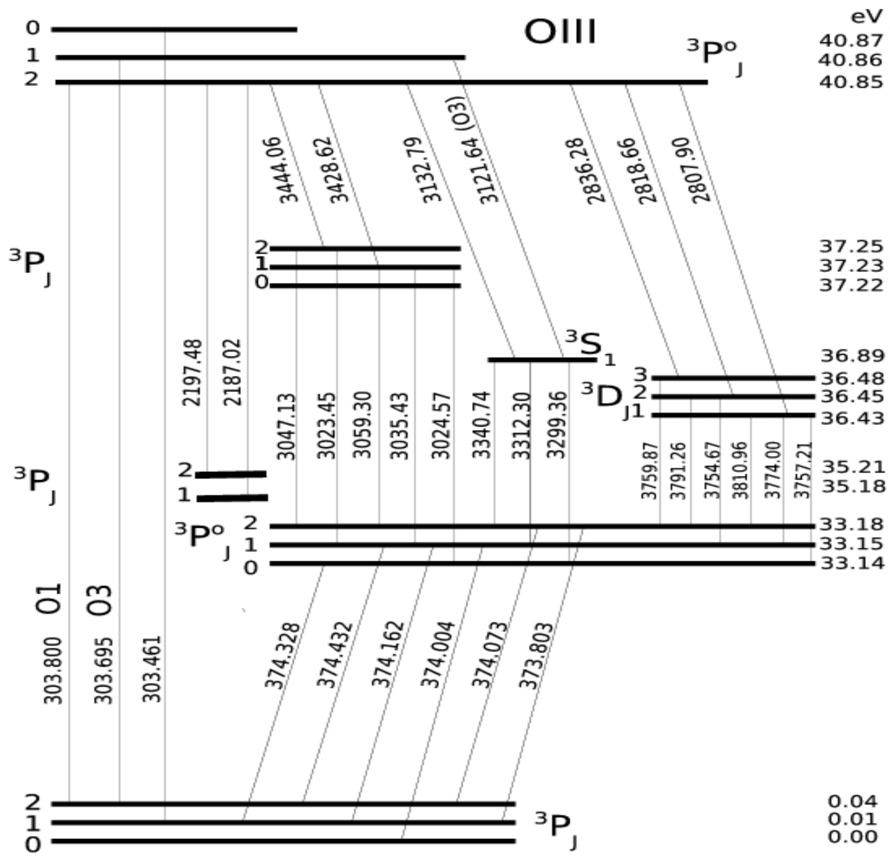


Simple depiction of HeII fluoescence mechanism in OIII.



Simple depiction of fluorescence in NIII caused by OIII resonance lines.

OIII Bowen Lines



Partial Grotrian diagram of OIII including most relevant O1 transitions and 3121.64 line from O3 process.

HeII Lyα 303.782A

J2 – J2 303.80 A (O1) * +18k/s
J1 – J2 303.695A (O3) -86k/s
J2 – J1 303.622A (O2) * -158k/s
* most probable **radiative resonance** scattering. O2 not shown.
Probability 0.98=0.74, 0.24

6 primary decays from J=2 in near UV. Subsequent decays can be common to all 3 processes

High opt. depth of HeII Lyα ensures secondary decays and escape from nebula.

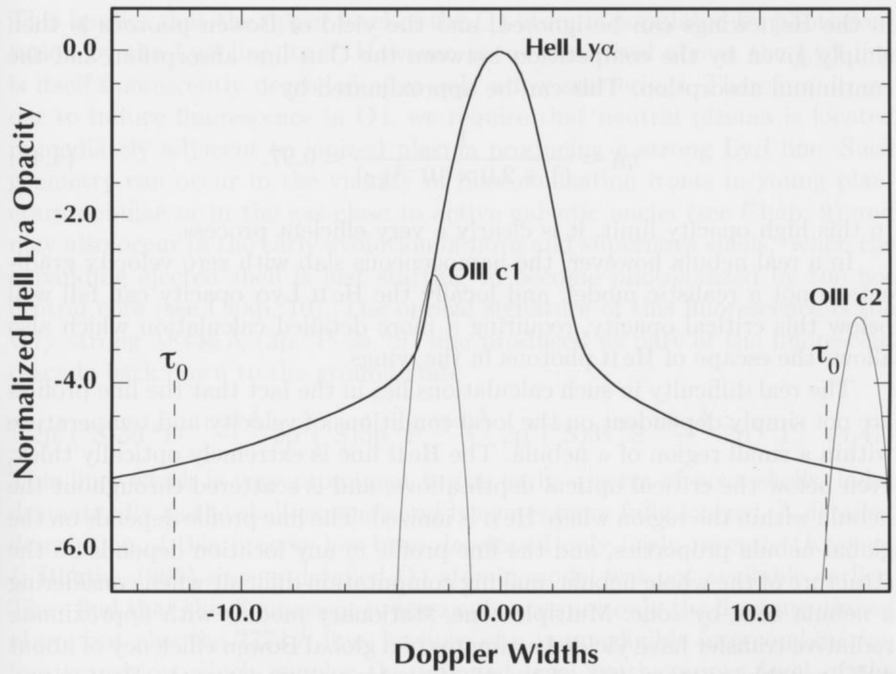
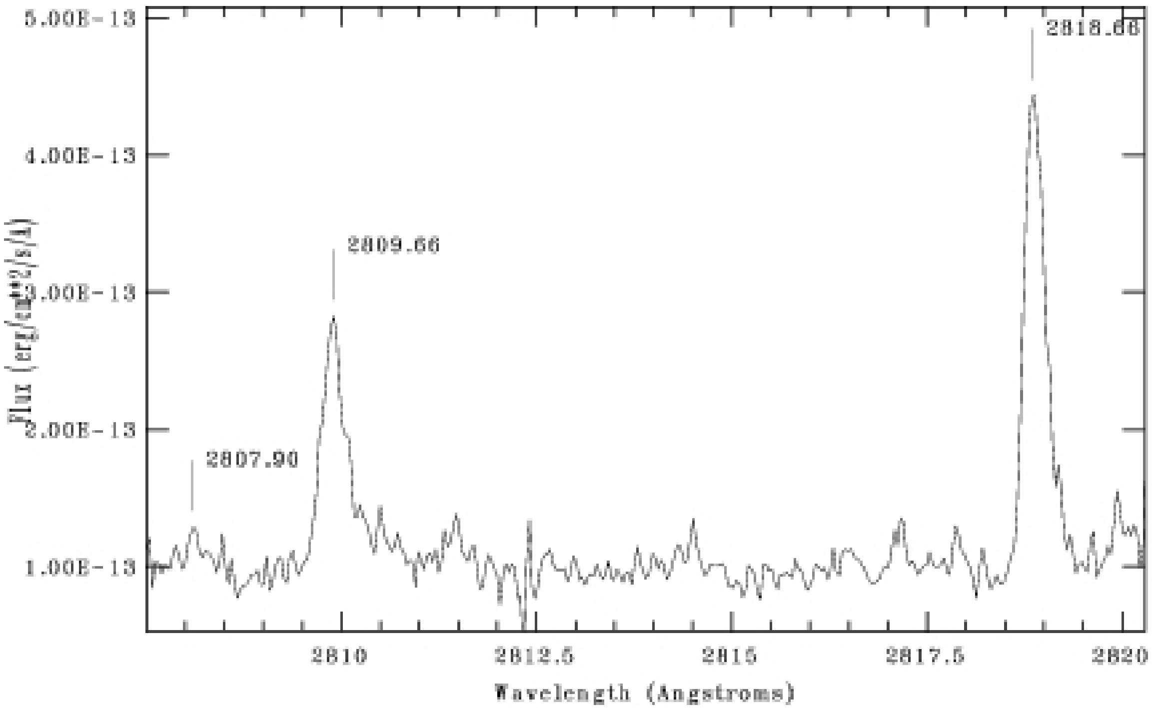


Fig. 4.9. The Bowen fluorescent process: The line opacities for the He II Lyα line in a highly ionized nebula and the line opacities for two of the O III transition components. τ_0 represents the frequency where the optical depth to the photons drops to sufficiently low values to permit direct escape from the nebula. Between the two dashed lines, photons are trapped, scattering off He II ions until they are absorbed by the $c1$ component of the O III ions.

Kallmann & McCray (1982) theoretical line broadening due to resonance scattering.

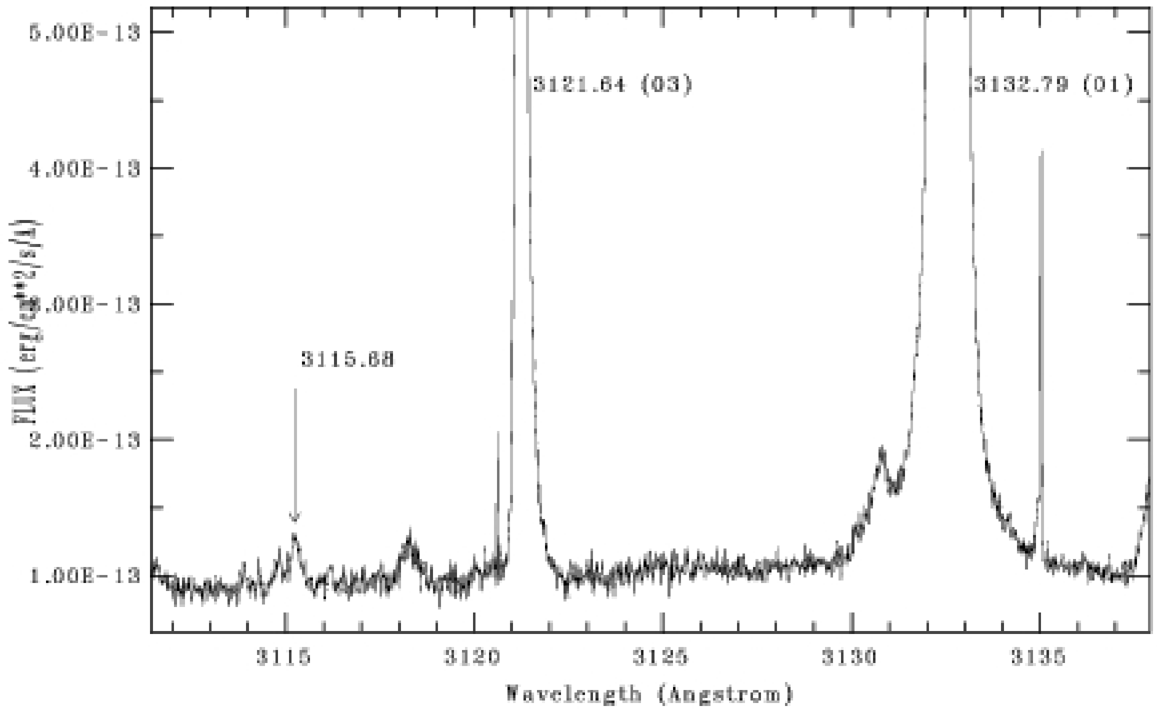


O1 O3 O1

The weak Bowen lines near 2800A in STIS

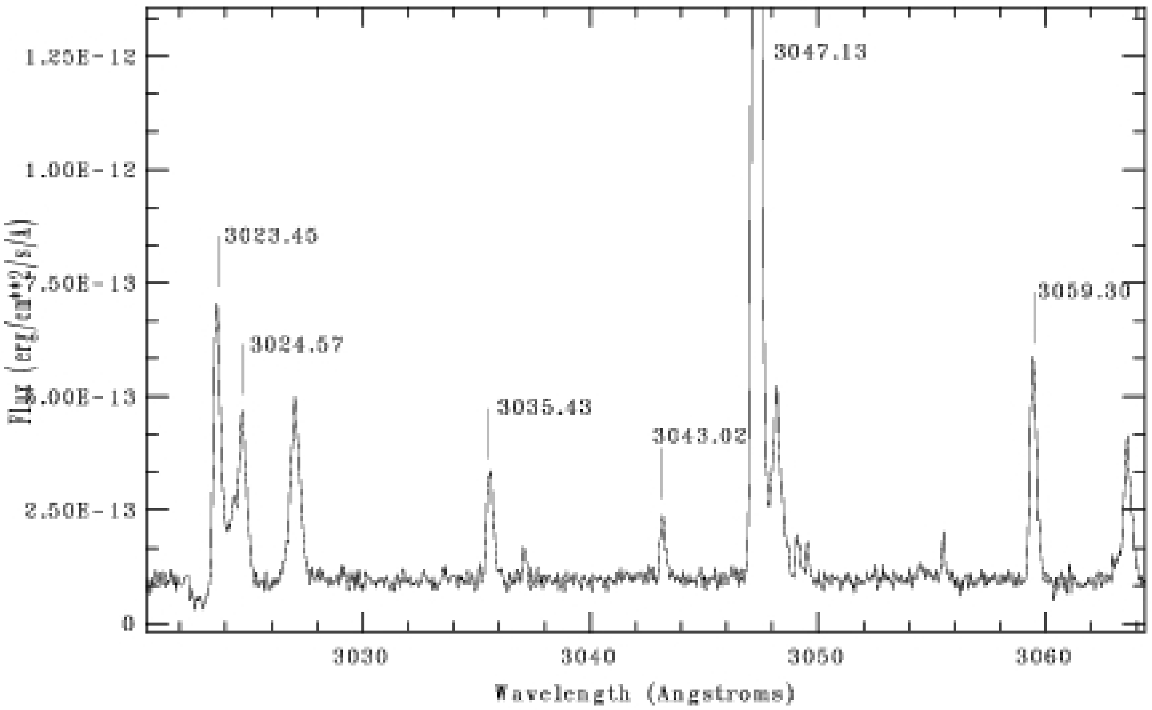
Detected Bowen lines 29
Undetected 2 -strongly blended.
6 pure O1, 7 pure O3.
2 pure from pumping J=0 (wide HeII Lyα).
Most others mixed channels.

Except 5592.25A only charge exchange.
Therefore $3D_1$-$3P^o$ lines 3757-3810A influenced by CE.
$O^{3+} + H^0 - O^{2+}$ (2p3p3D)+H^+



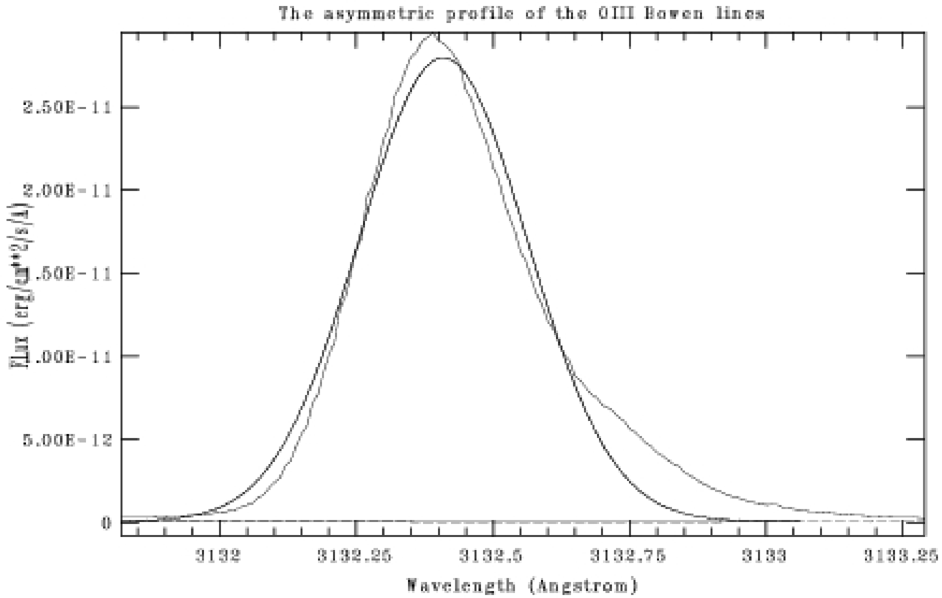
O O3 O1

UVES spectrum showing the strongest line of each of the 3 Bowen excitation channels



O3

Weak OIII Bowen lines near 3030 in STIS



O1

All strong Bowen lines show asymmetry with red excess over Gaussian (FWHM 34.3 k/s.

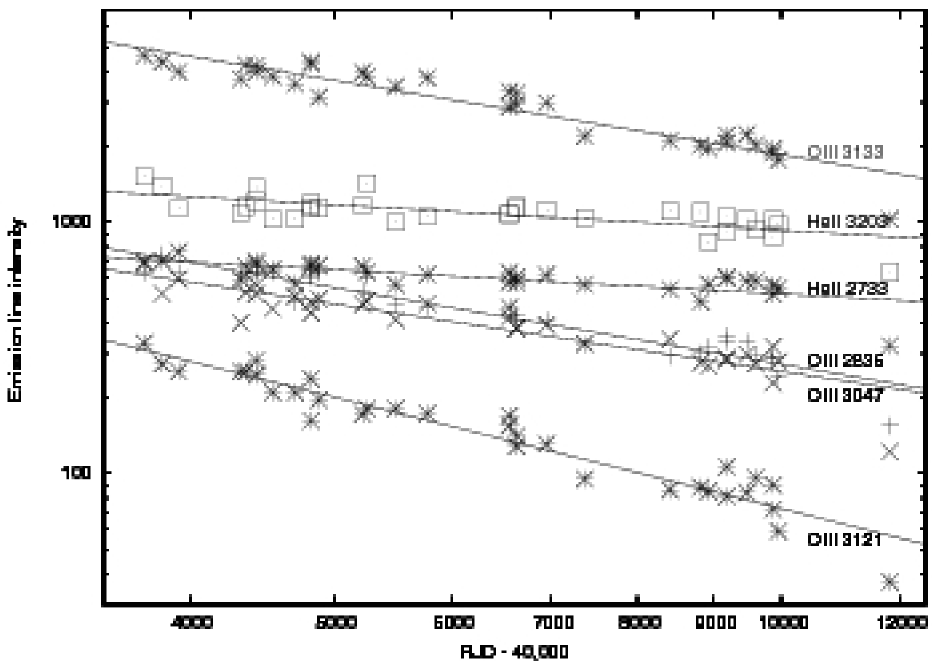
Similar but less pronounced in HeI5875, 6678.

[OIII]5007,4958 have blue excess extending to -150k/s.

All other strong recombination and forbidden lines have pure Gaussian shapes.

Asymmetric profile of OIII 3133 line + Gaussian fit. Also seen in other lines.

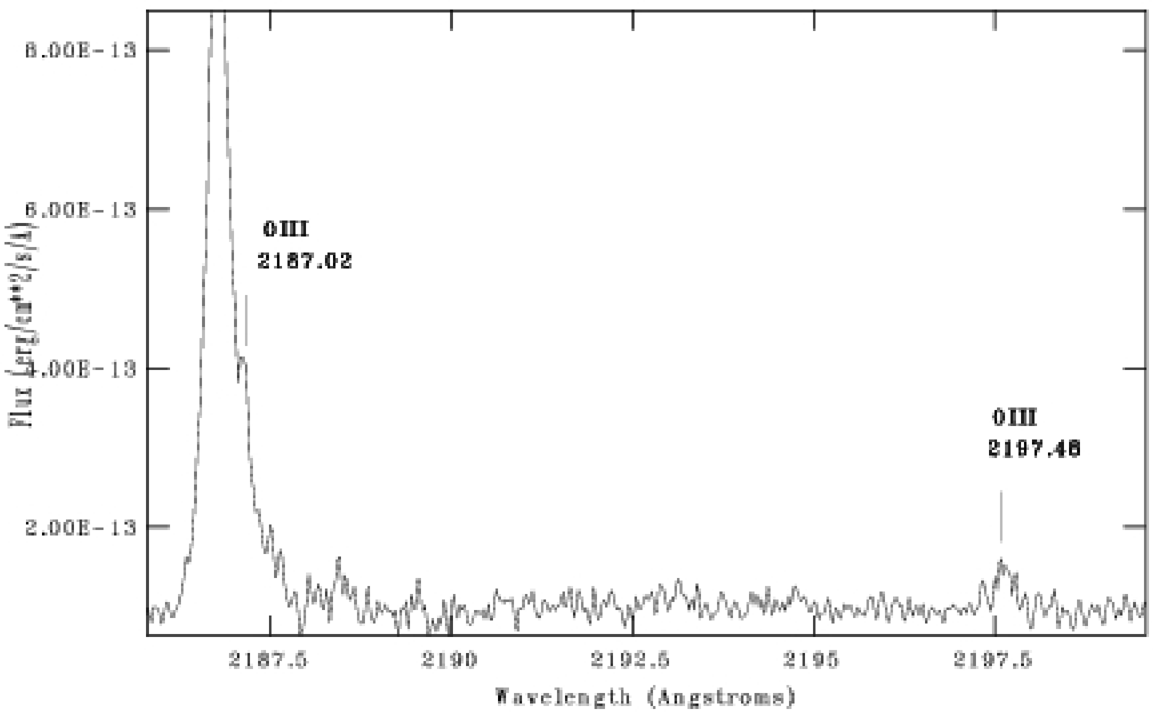
TEMPORAL VARIATIONS

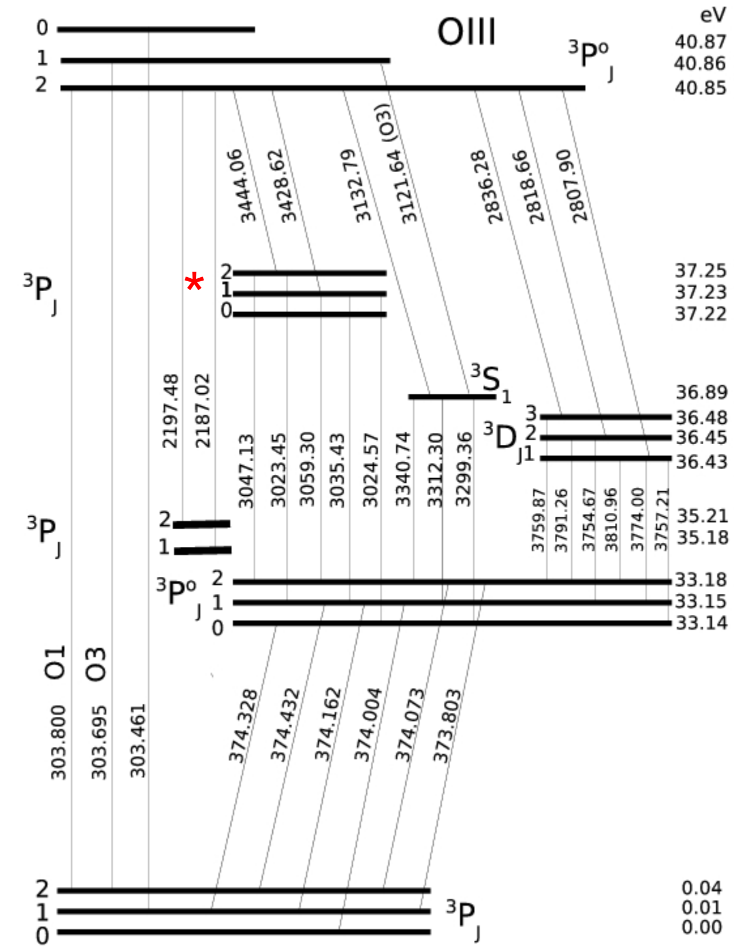


Steady decrease of all with time. In17 years He lines decrease x 1.5; O1 lines by > x3; O3 lines by >x 5.

The O3 line shift is -86k/s relative the HeII Lyα so decrease in may be due to larger width in past due to turbulence or optical depth. HeII decrease due to decrease of luminosity of central source. Stronger decline in Bowen efficiency caused by decrease in optical depth of OIII resonance lines as nebula thins

Log-log plot of decrease with time of intensities of HeIIand OIII lines 1978 – 1995 (IUE spectra). Power law fits give indices: -0.33 for HeII 2733,3203; -0.97 for OIII (O1) 2836,3047,3132; -1.48 for OIII(O3) 3122 line.





Two new Bowen lines from primary decay (O1) never seen before. See *

Strong line is Fowler HeII 2186.60

In total there are 8 BF lines (all weak) clearly identified for the first time as unblended.

DETAILS of OIII FLUORESCENCE

1. 8 primary decays from 2p3d $^3P^0_2$ level. Observed relative photon numbers in agreement with relative A_{ij}.

2. 2p3p $^3P_{2,1}$ levels populated by 3444.06 and 3428.62 from (1) above. This level depopulated by 5 observed lines and 5 EUV lines near 554.5A + some weaker decays. Using A_{ij} values for all these transitions, we find the sum of 5 observed line strengths are ~12% deficient for the observed strength of the 2 primary decays.

3. The 2p3p $^3S_1$ level fed by primary (O1) 3132.79 and primary (O3) 3121.64 (very small). Observed decays from this level via observed 3 lines 3340.74, 3312.30 3299.36 show strong inbalance by factor 3. Other transitions pass through $2s2p^3$ $^3P^0_j$ (not shown) giving 3 lines near 644.44A (mult. UV 16.20). These account for imbalance. Obviously important for study of Bowen fluorescence.(Studied in Sun by Bhatia et al. 1982).

4. The 3 2p3p $^3D_{1,2,3}$ levels are fed from the O1 upper level. These 3 levels depopulated by 6 observable lines of which only one at 3759.87 from D_3 is a “pure” secondary O1 line but strongly blended with a strong [FeVII] line.

Details of OIII Fluorescence - continued

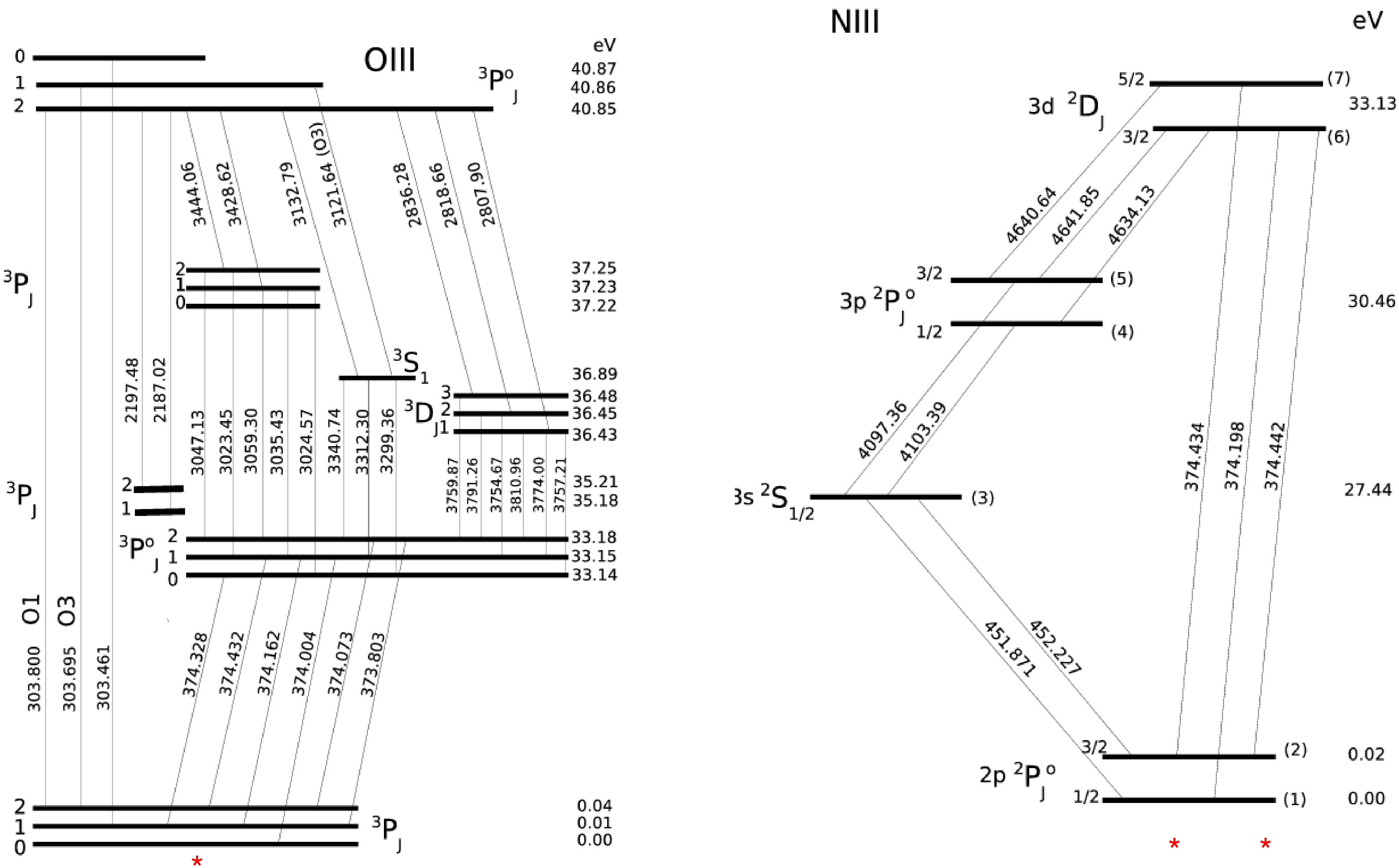
4. (cont).From D_2 level lines at 3754.67, 3791.26 have a combined strength similar to the parent line at 2818.66A. But other EUV transitions of similar strength from D_2 at 574 and 659 A suggest that this D_2 level may be populated by charge exchange. The strength of 3 lines from the D_1 level, 3757.21, 3774.40, 3810.96 (blended) is too great to be consistent with the weak parent line at 2807.90. Therefore the D_1 level population must be dominated by charge exchange as directly evidenced by the detection of the "pure" CE line at <u>5592.25</u>A.

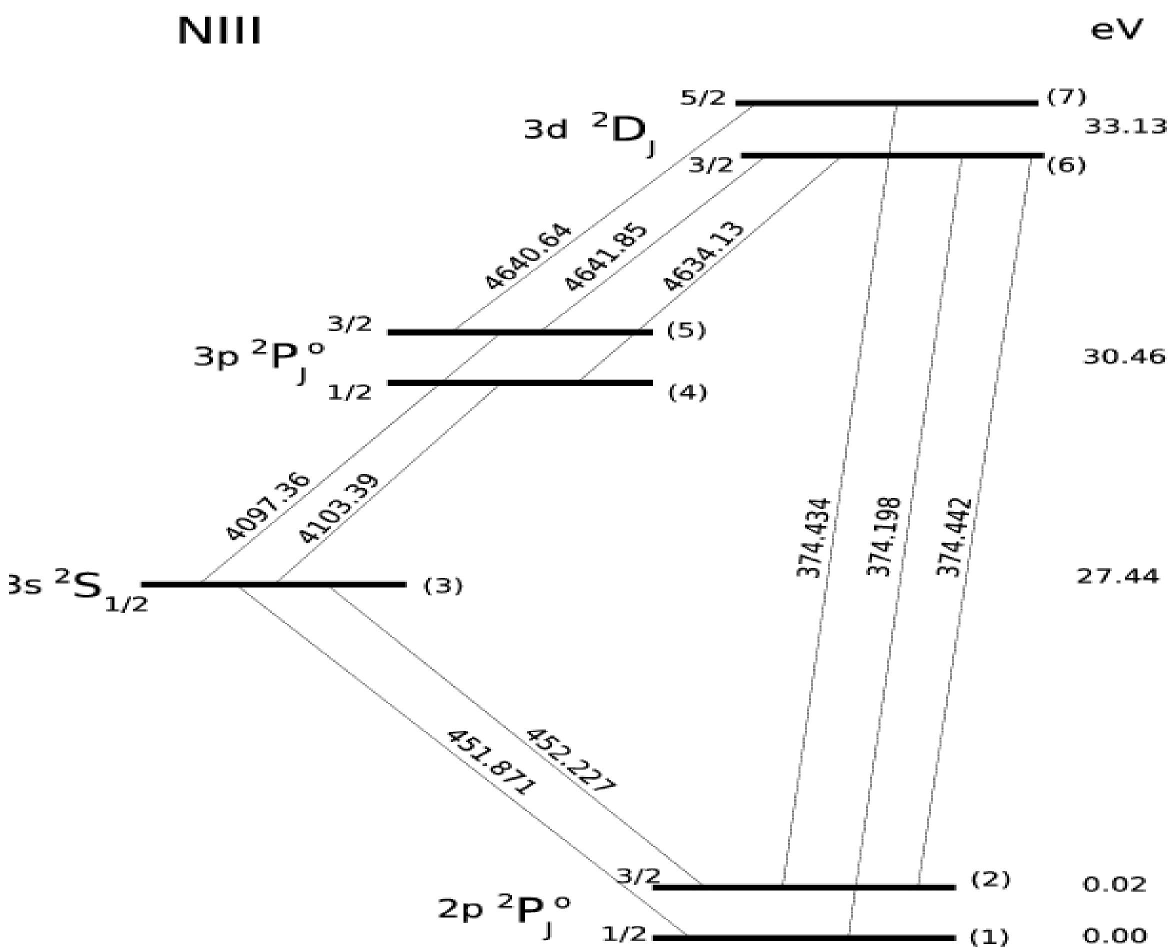
5. Most of the difference between the number of decays populating the three 2p3s $^3P^0_{0,1,2}$ levels and those primary decays from 2p3d $^3P_2$ (O1) can be ascribed to the 644A lines (see (3) above).

6. The photons from the decay of the 2p3s $^3P^0$ levels to the ground state are the only means of depopulating these levels and are effective through resonance scattering in fluorescence excitation of NIII levels.

NIII FLUORESCENCE

Line coincidences in OIII and NIII





Now note the 5 lines in the decay from $^2D_{5/2,3/2}$ levels.

All 5 in the 4000-4700A region have been detected. Seen in PNe, Xray binaries, symbiotic stars, novae.

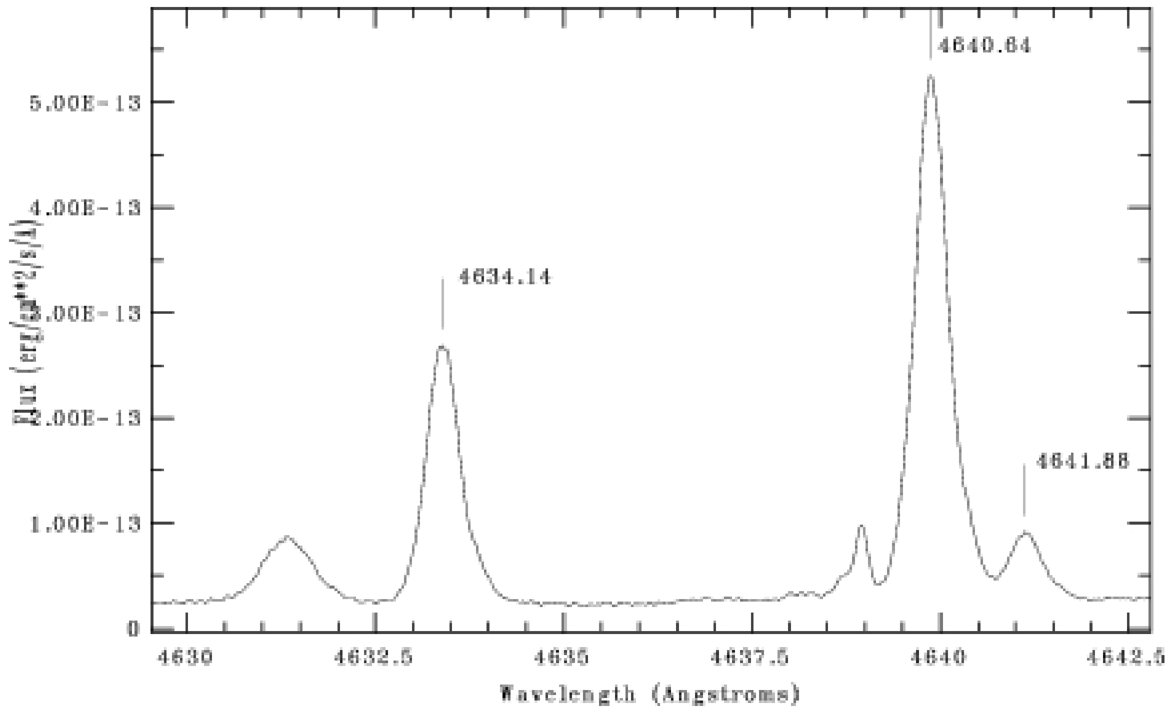
Partial Grotrian diagram for NIII.
Number index used for identification.

Various mechanisms discussed for explaining the NIII lines and their relative strengths, some challenging secondary Bowen fluorescence:

Eriksson et al. (2005) suggest radiative recombination after examining BF.

Difficulty with CF: Absence of decay lines from excitation of levels by other EUV resonance lines.
Difficulty with recombination: No decays that would feed upper levels for NIII lines (parents) are detected.

Therefore a selective process seems necessary.
We note that OIII Bowen lines are generally associated with the NIII4640 lines in all well studied objects.



FEROS spectrum of 3 NIII lines near 4640A

NIII Fluorescence Mechanisms

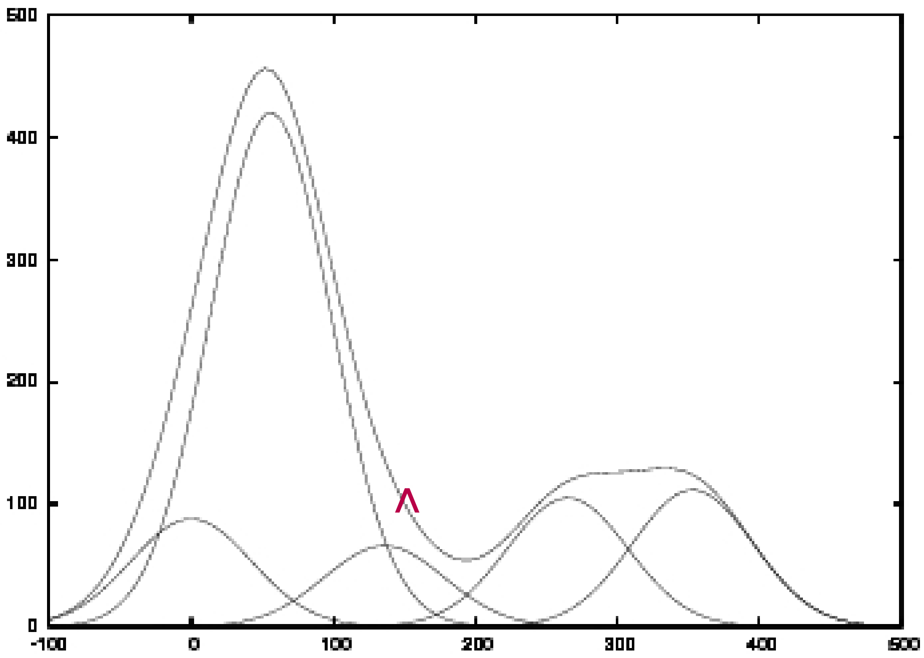
Resonance line of OIII 374.432 pumps both levels of 3d $^2D_{5/2,3/2}$ whose resonance photons are at 374.434 and 374.442A.
Subsequent decay through emission of 3 lines near 4640A followed by the 2 lines near 4100 and then 2 UV lines near 450A.
Fluorescence decay suggests 4634/4640 ratio ~1/9. Statistical value should ~ 0.67. Our observed value of this ratio is 0.49

Eriksson et al. (2005) consider extra pumping of $^2D_{3/2}$ upper level from the $^2P^0{}_{1/2}$ lower level (corresponding to a wavelength of 374.198A) with the OIII374.162 line. They calculated the above ratio to be 0.245
Hence a negative conclusion!

Essential differences between Eriksson et al. and Selvelli et al.

1. Their line widths were based on Gaussian widths of intercombination lines NIII]1750 and OIII]1660. STIS and FEROS spectra show subordinate lines have widths 5km/s greater. Since the difference in wavelength of the 2 lines is 30km/s this extra width increases the overlap
significantly.

2. More importantly Eriksson et al. assumed all lines were optically thin. But all 6 OIII lines and the 3 NIII lines at 374A are optically thick.



The 5 OIII resonance lines close to 374A together with sumof 5 components.
X-axis gives line separation in km/s with 0 at 374.0: 374.004, 374.073, 374.162, 374.328, 374.432

With FWHM 100km/s this shows how pumping efficiency, particularly by weak lines can be enhanced by overlap of intrinsically stronger lines.
^ marks position of NIII374.198 line.

Therefore the upper level of 374.198 NIII line is pumped not only by OIII 374.162 and 374.442 but also by overlapping OIII 374.073. This demonstrates the role of resonance broadening, and in this case the role of a more distant but stronger line.

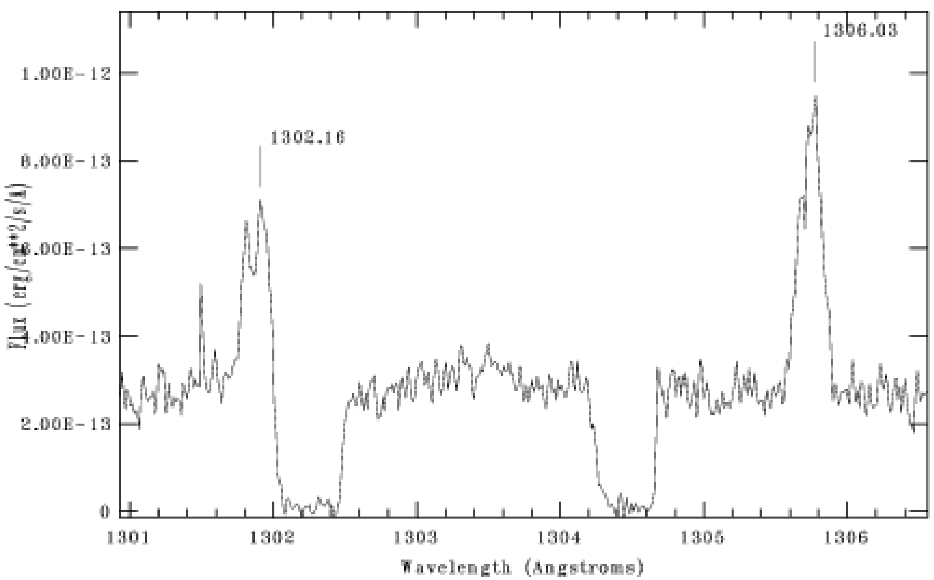
Some extra comments.

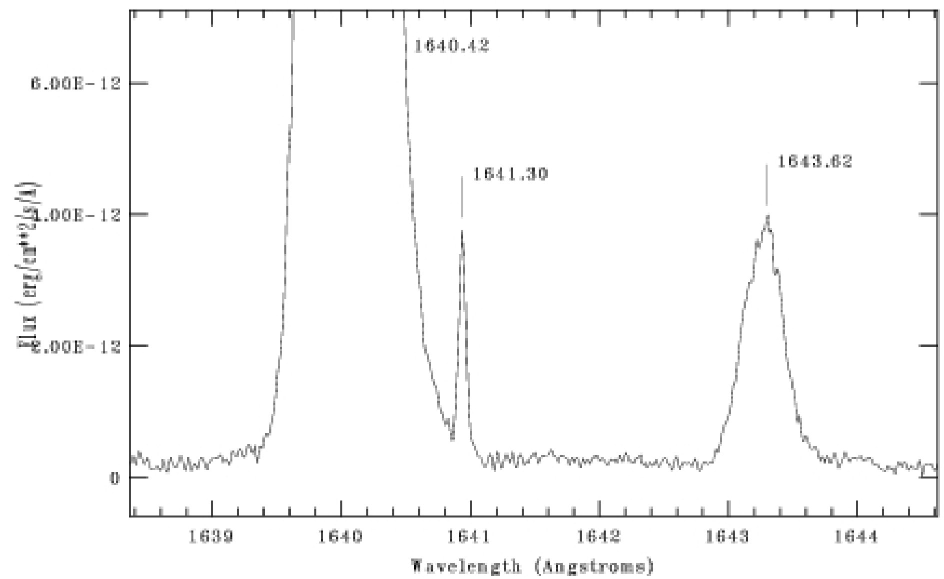
1. The great strength of OIII and NIII Bowen fluorescence lines is probably helped by the overabundance of these 2 elements and the high excitation and ionization state of RRTel.

2. Support for effective pumping with line separations of ~ 100km/s comes from the presence of the O3 channel lines where a separation of pumping and pumped line is 88.2 km/s. The OIII 3115.68, 3408.12 lines produced by the “other” channel where a separation of 250km/s exists. This requires very broad resonance wings. (see Kallmann & McCray 1982).

3. High T of central source guarantees a lot of He^{2+} a condition also obtaining in X-ray binaries where NIII 4640 lines appear.

The Effects of Large Optical Depths Demonstrated by the OI Spectrum





Resonance OI lines near 1302.17, 1304.86 and 1306.03. 1^{st} partly, 2^{nd} wholly aborbed by IS lines of OI and SiII.

Intercombination line OI 1641.30 has same upper level as 3 UV resonance lines, viz.2p 3s $^3S^0_1$

With zero optical depth the ratio of 1306.03/1641.30 ~ 3.5×10^4, the ratio of A_{ij}s. Instead it is 0.55. Whatever the mechanism for populat -ing the upper level (Ly-β fluorescence, since OI 8446 is present) the UV resonance lines must be trapped. Using method of Bhatia et al. (1995) an optical depth of log τ ~6.0 is indicated.

CONCLUSIONS

1. New low reddening determination.

2. Most complete set of Bowen fluorescence lines detected and quantitatively assessed. a. 6 pure O1 lines. b. 7 pure O3 lines c. 2 weak lines at 3115.68 and 3408.12 pumped with 303.46, a “new” channel. d. 2 weak lines near 2180A from primary decay in the O1 channel.

3. Comparison with theory gives good agreement with Froese-Fischer (1994) transition strengths.

4. Efficiencies in O1 and O3 channels decrease with time.

5. We conclude that NIII 4640 lines must be produced by line fluorescence involving 3 (or even 4) resonance lines of OIII.

THE END