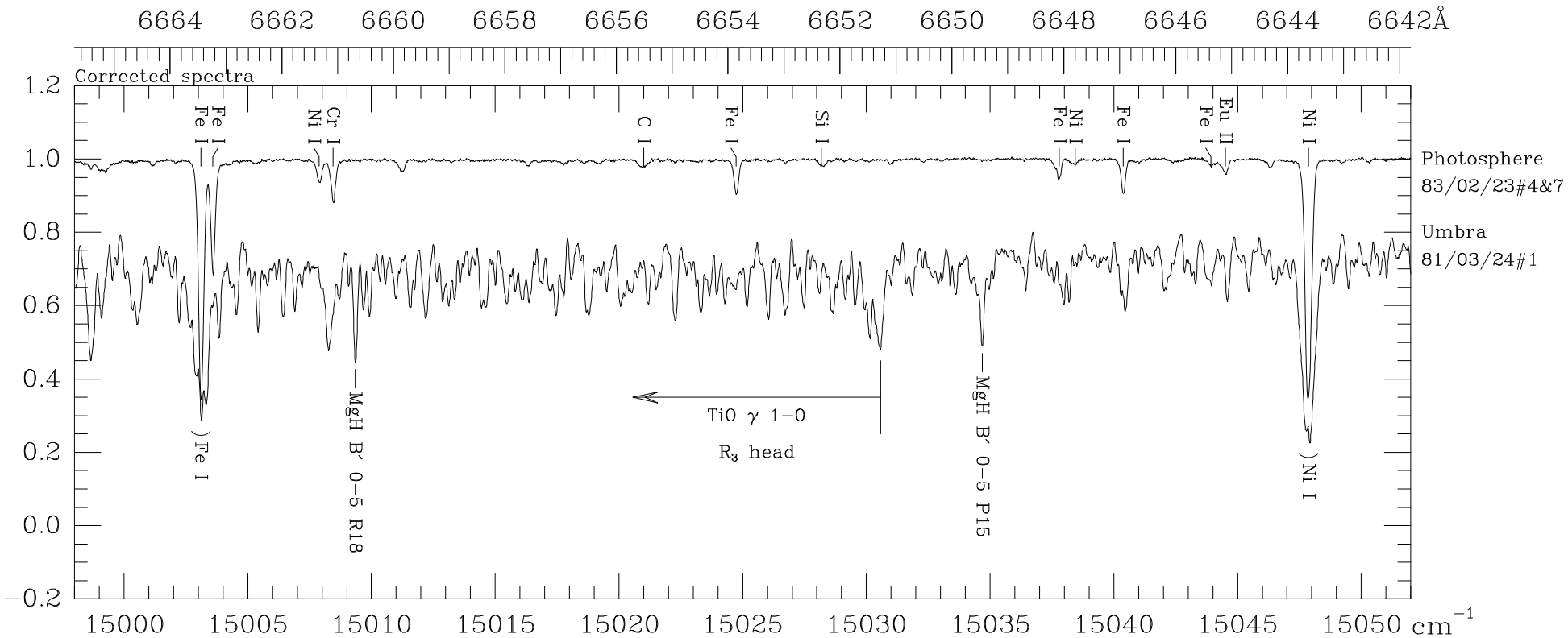
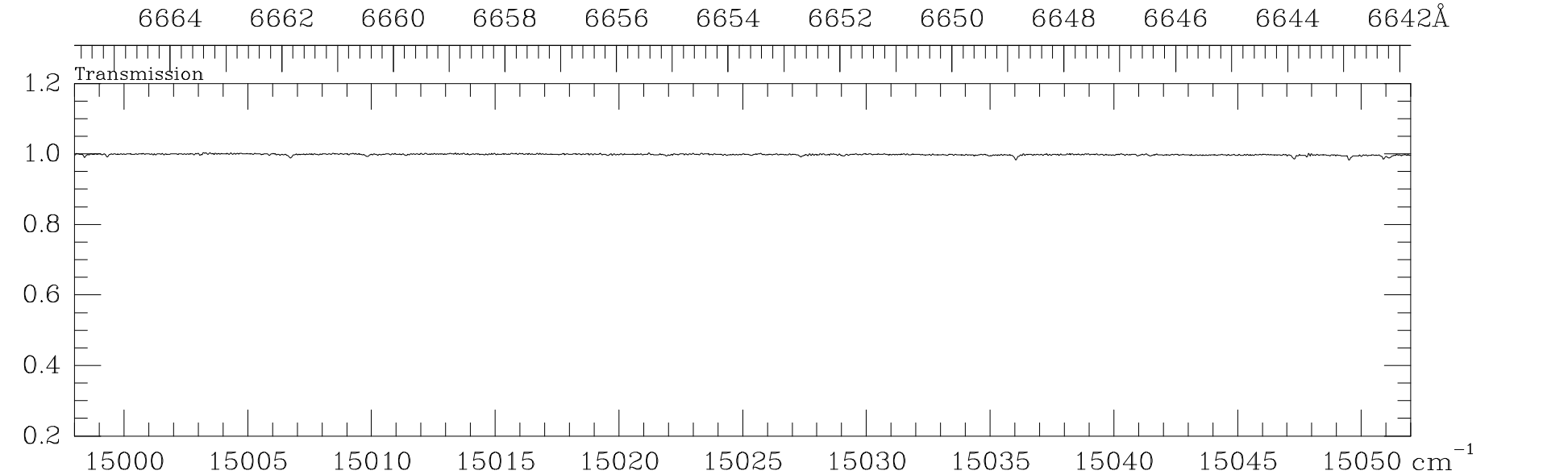
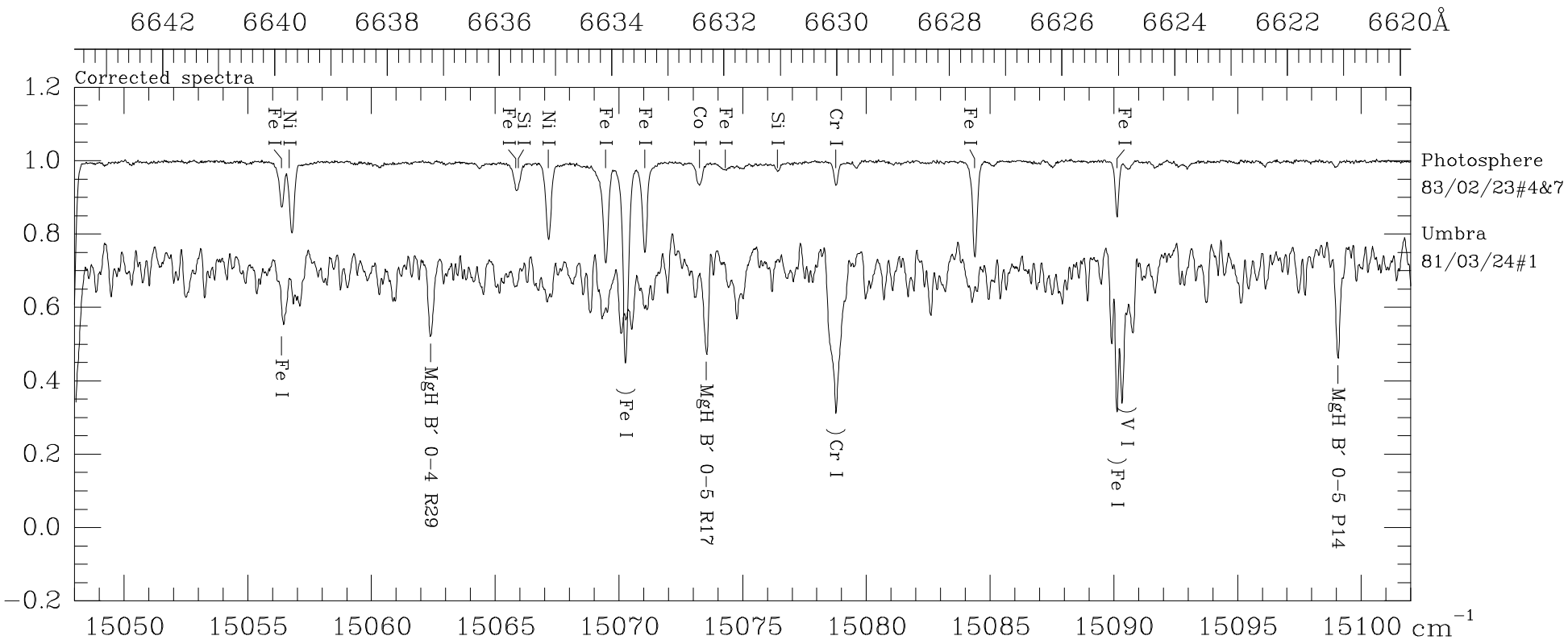


The unlabeled features in the umbral spectrum above are due mostly to lines of the TiO γ and γ' bands.





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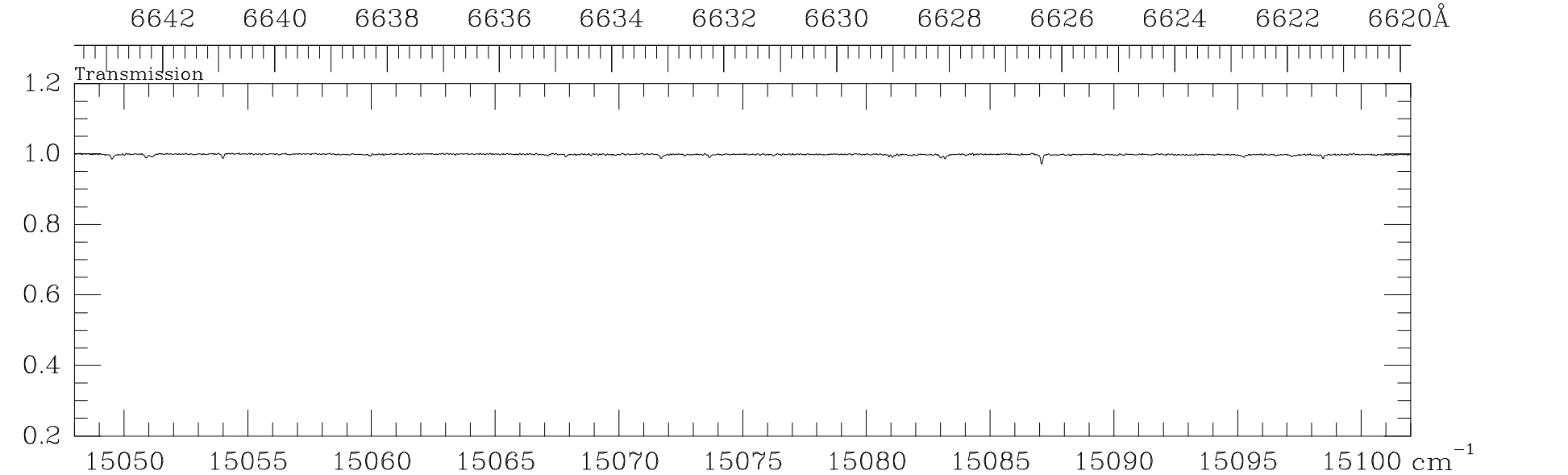

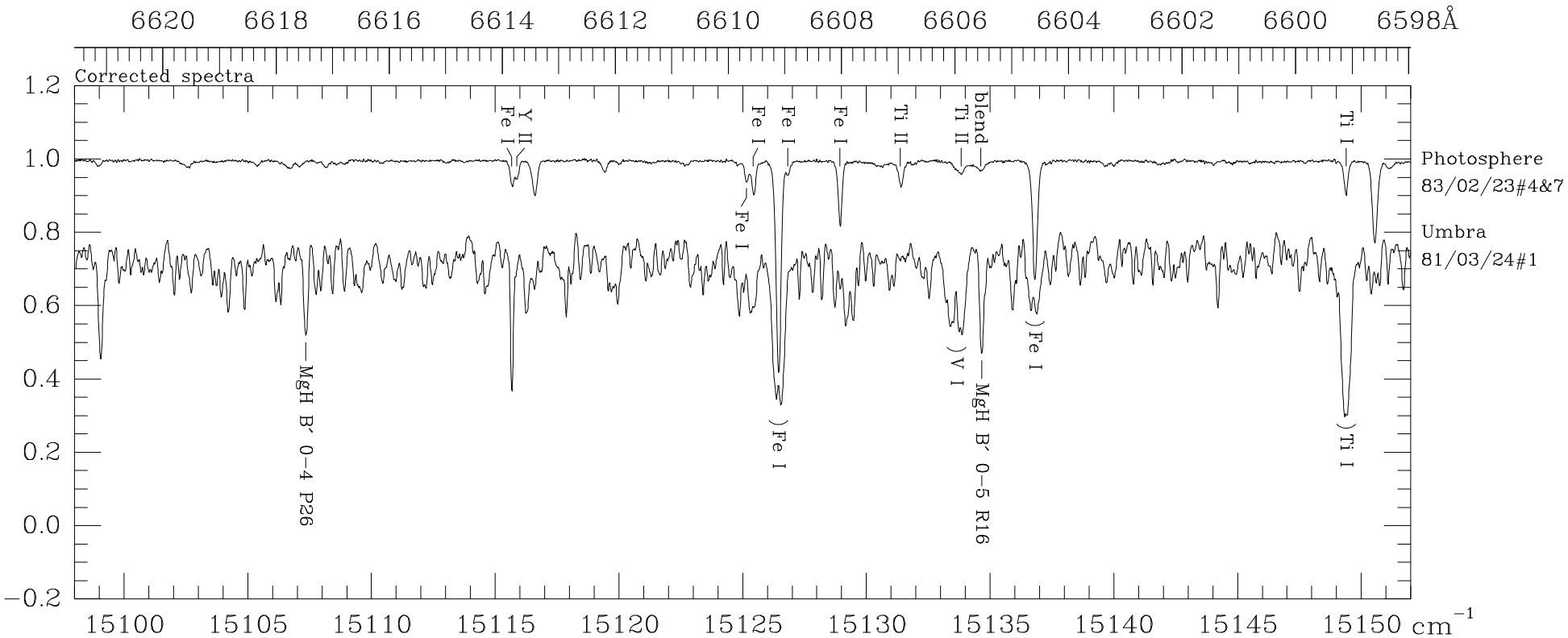

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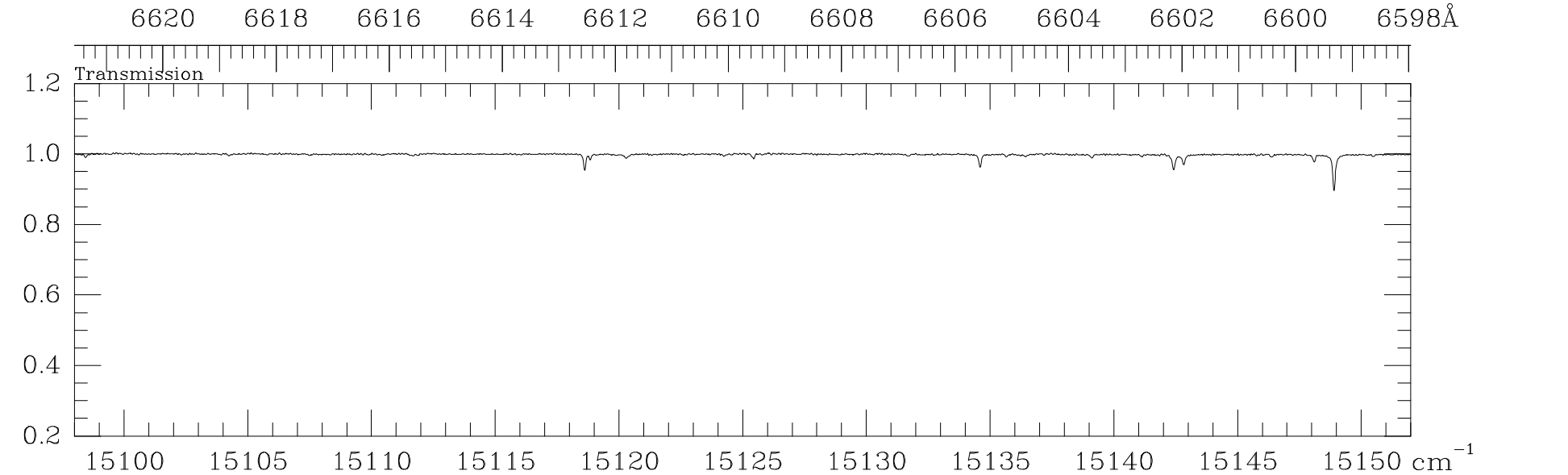

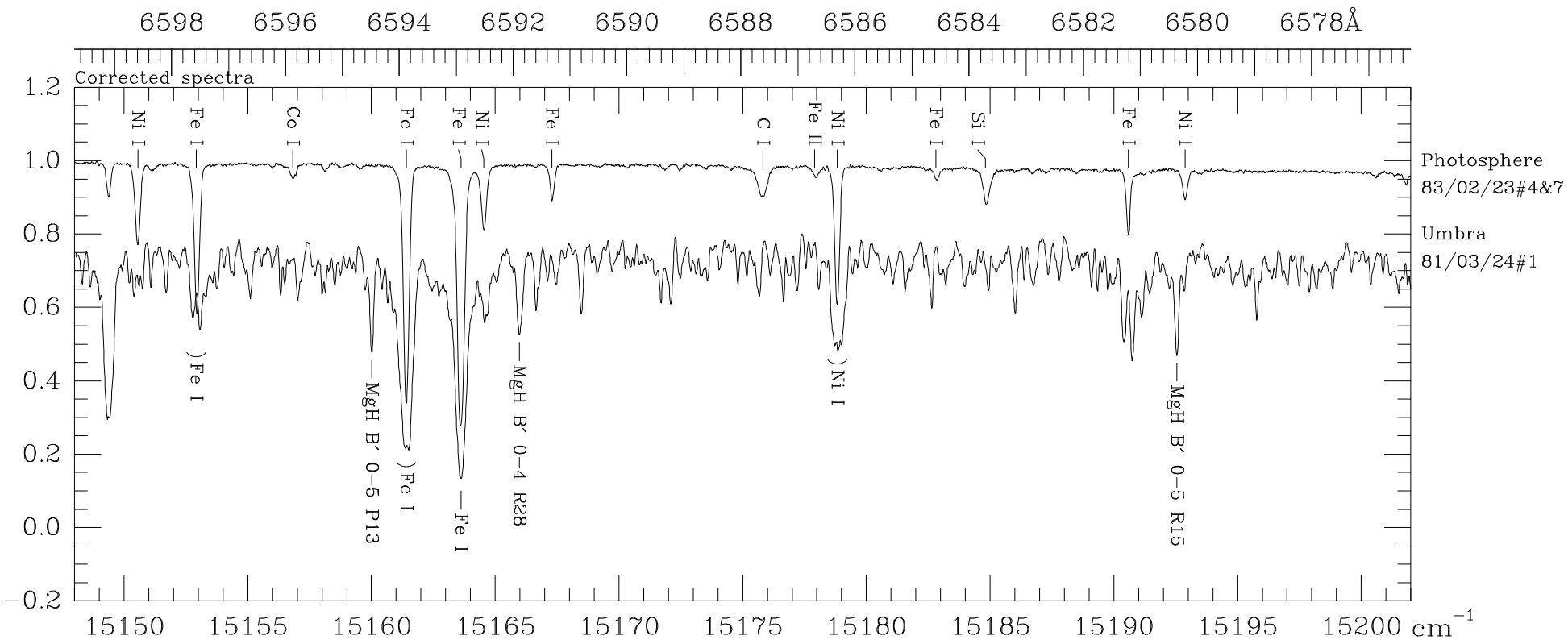

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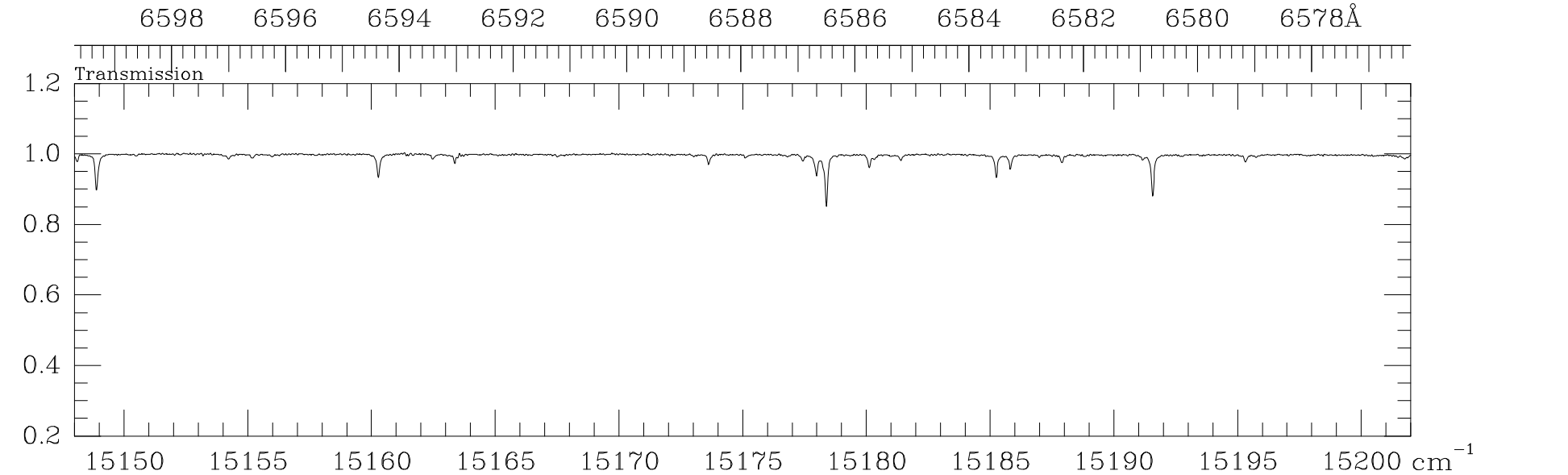

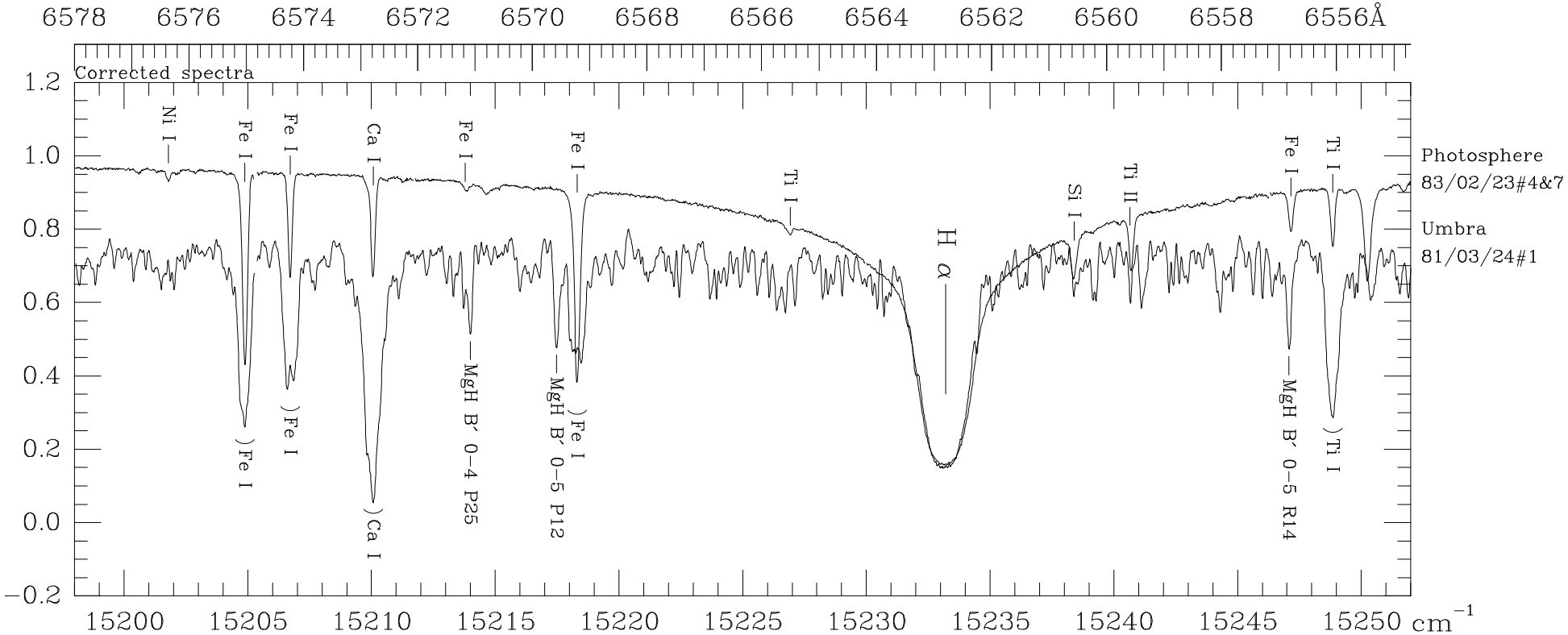

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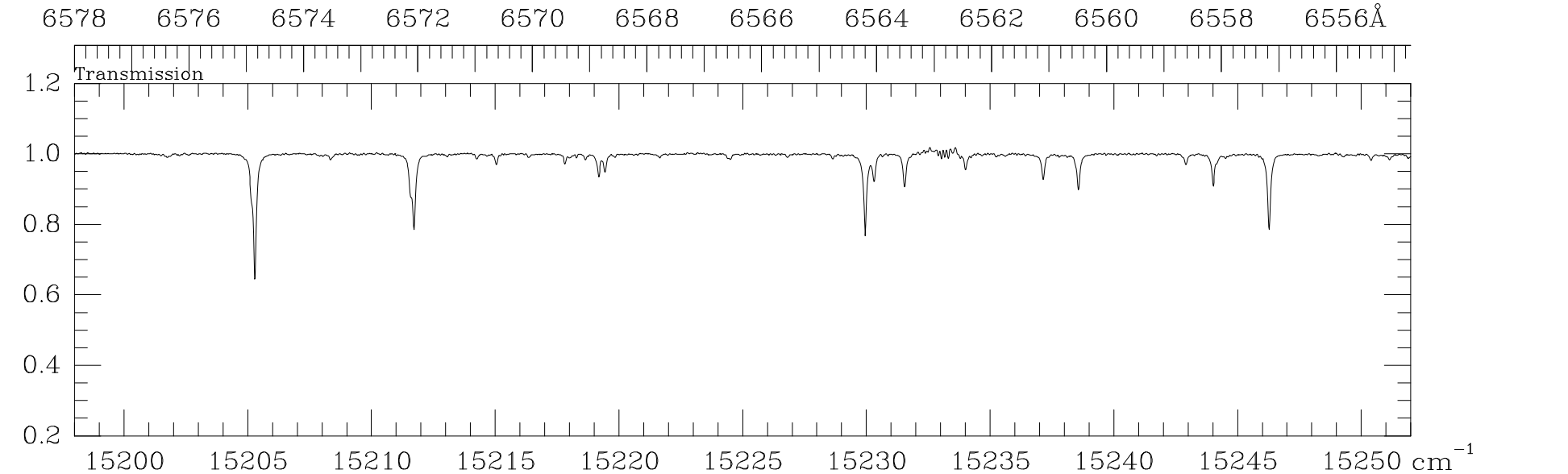

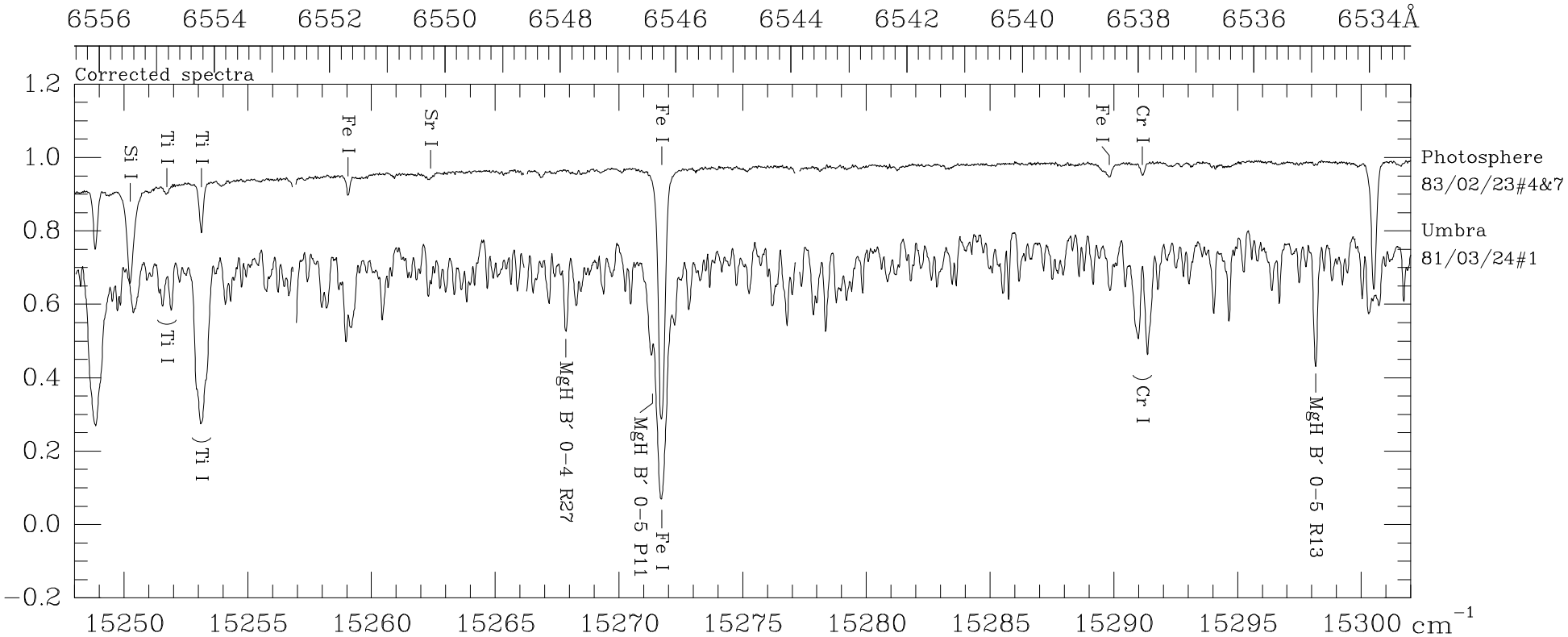

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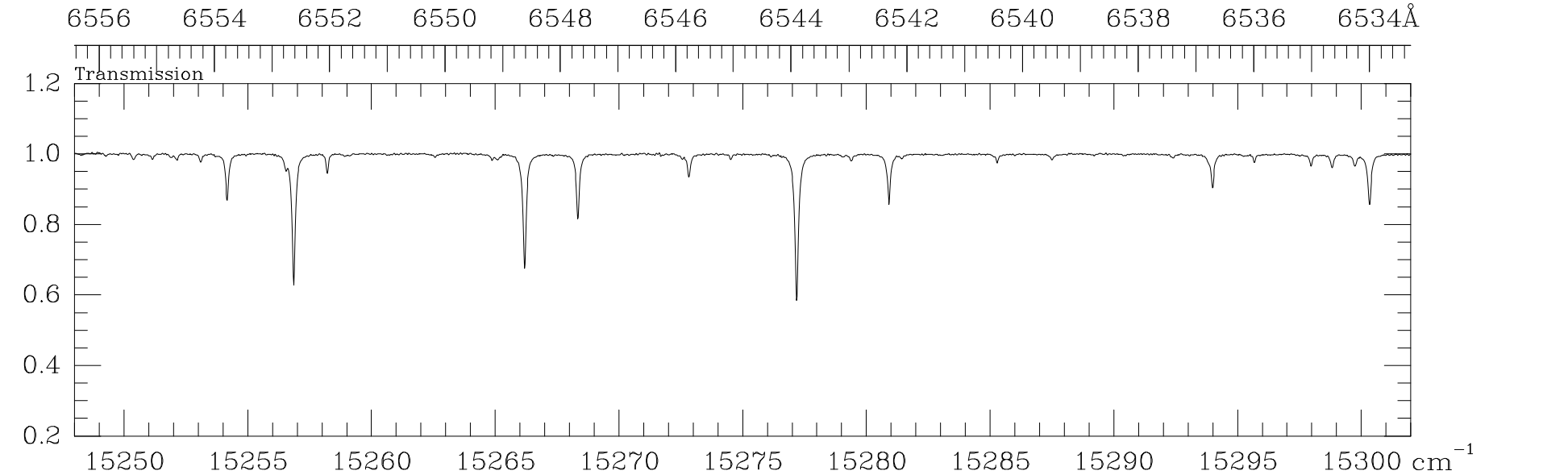

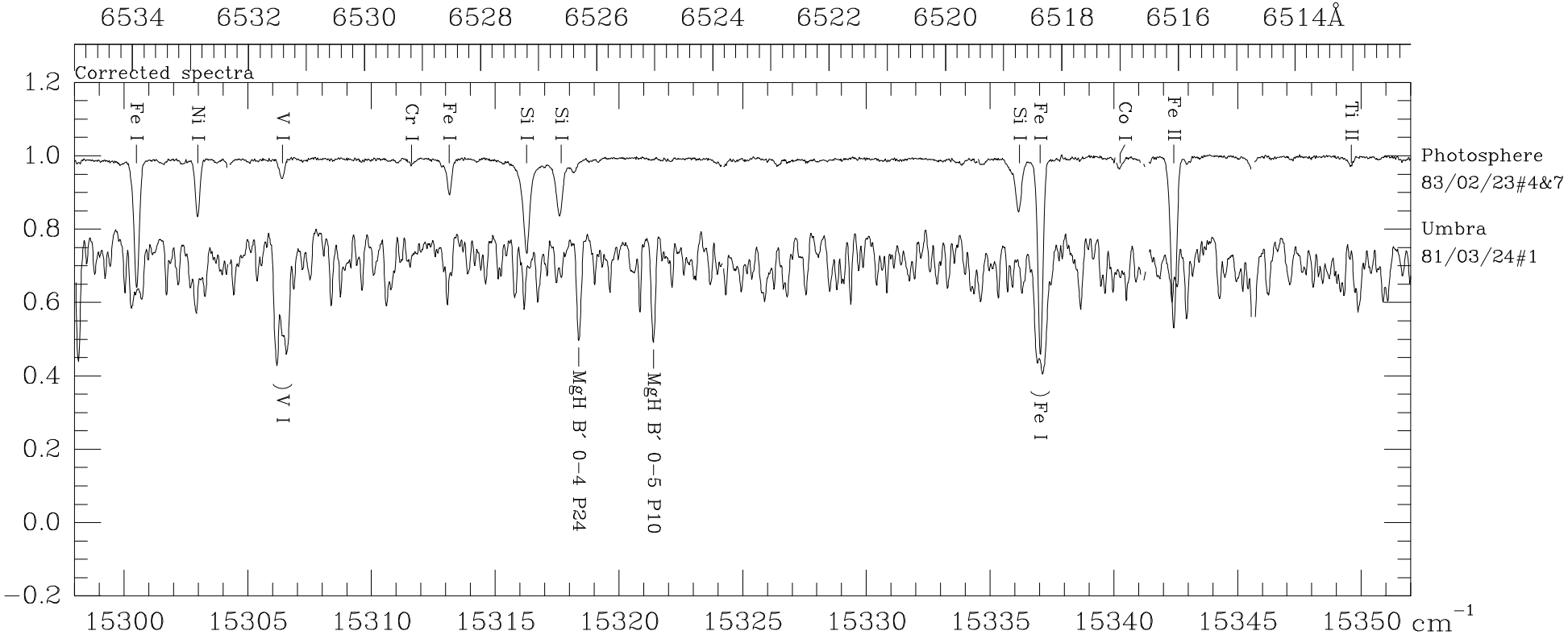

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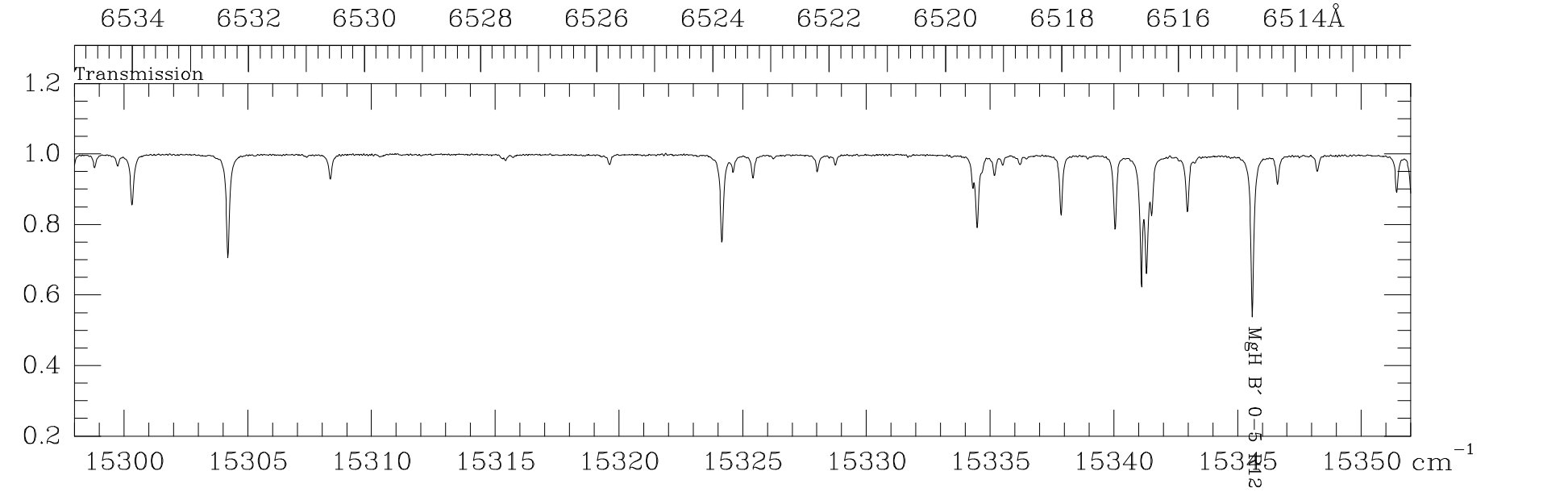

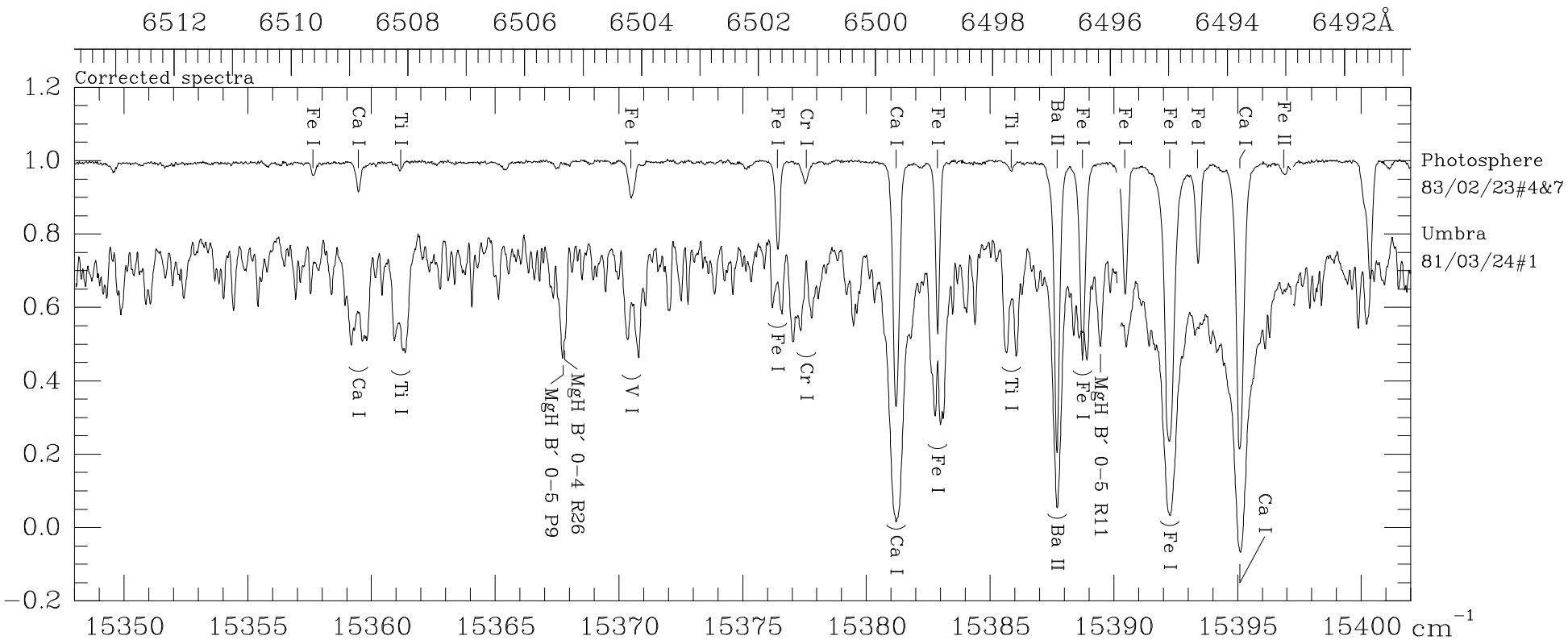

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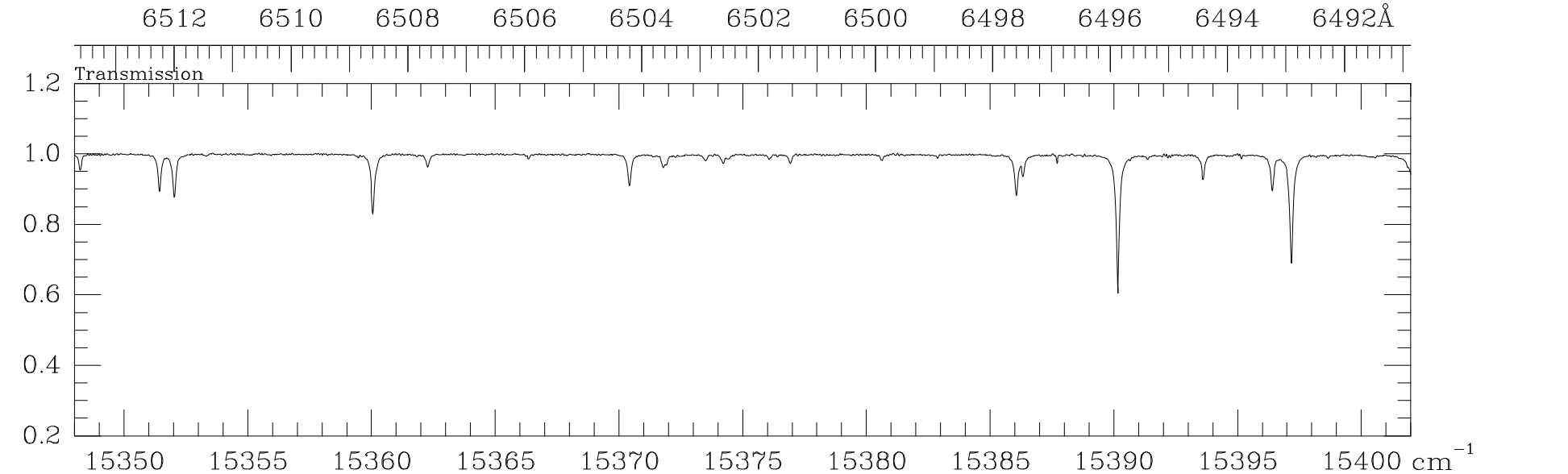

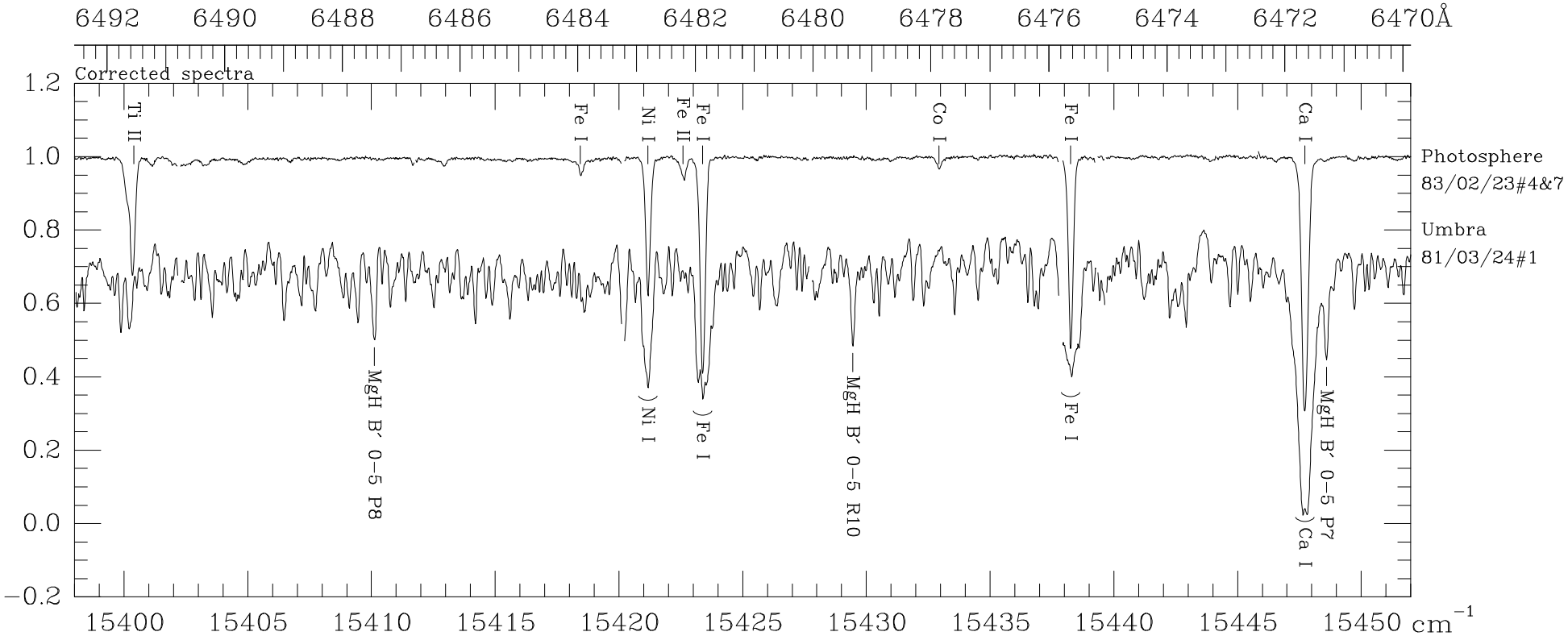

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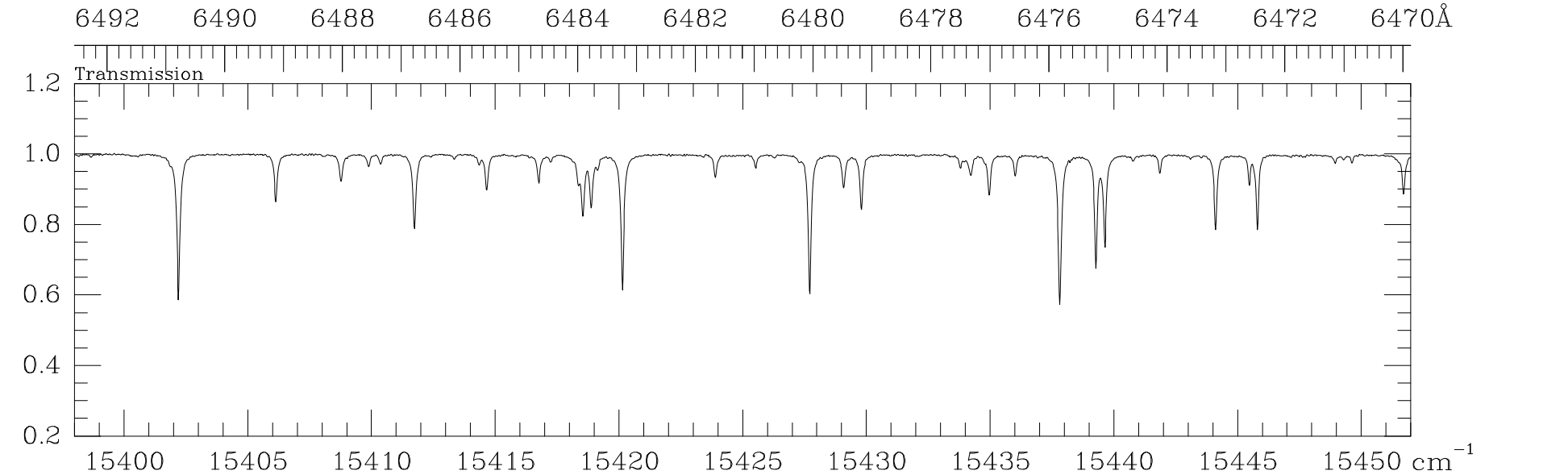

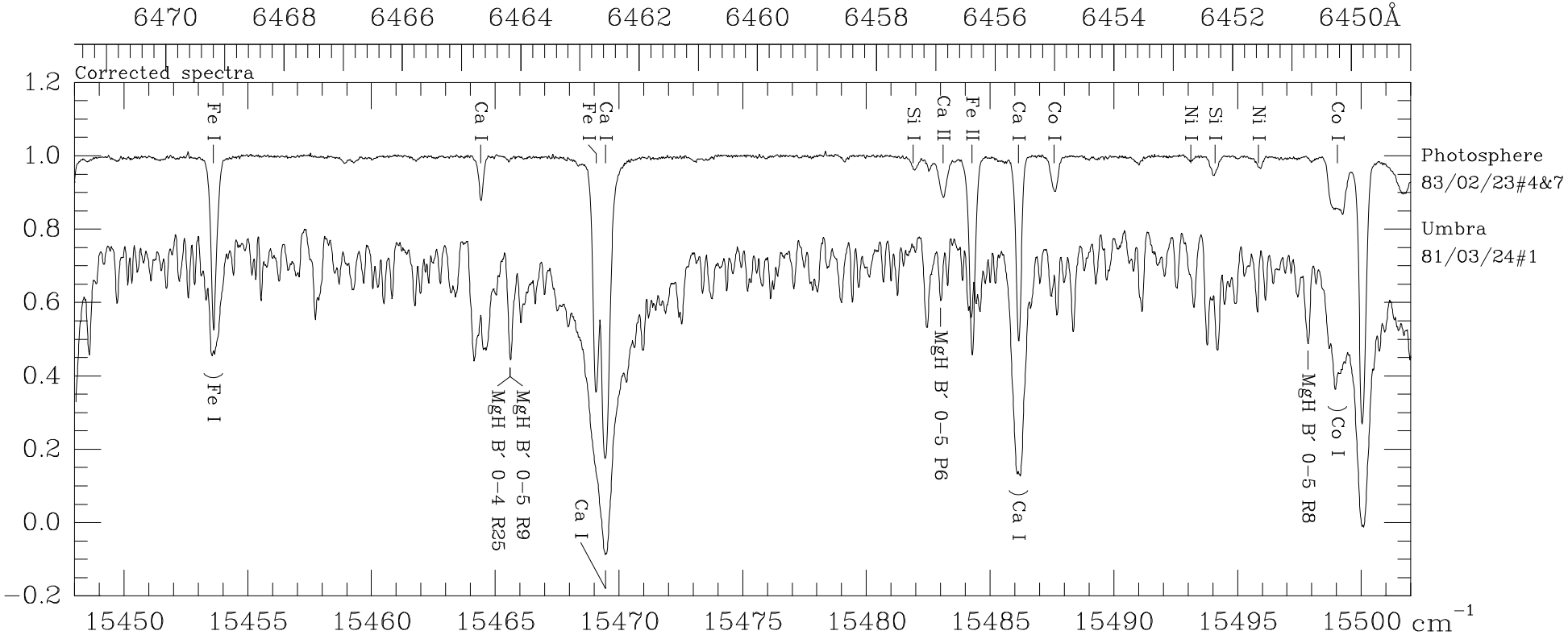

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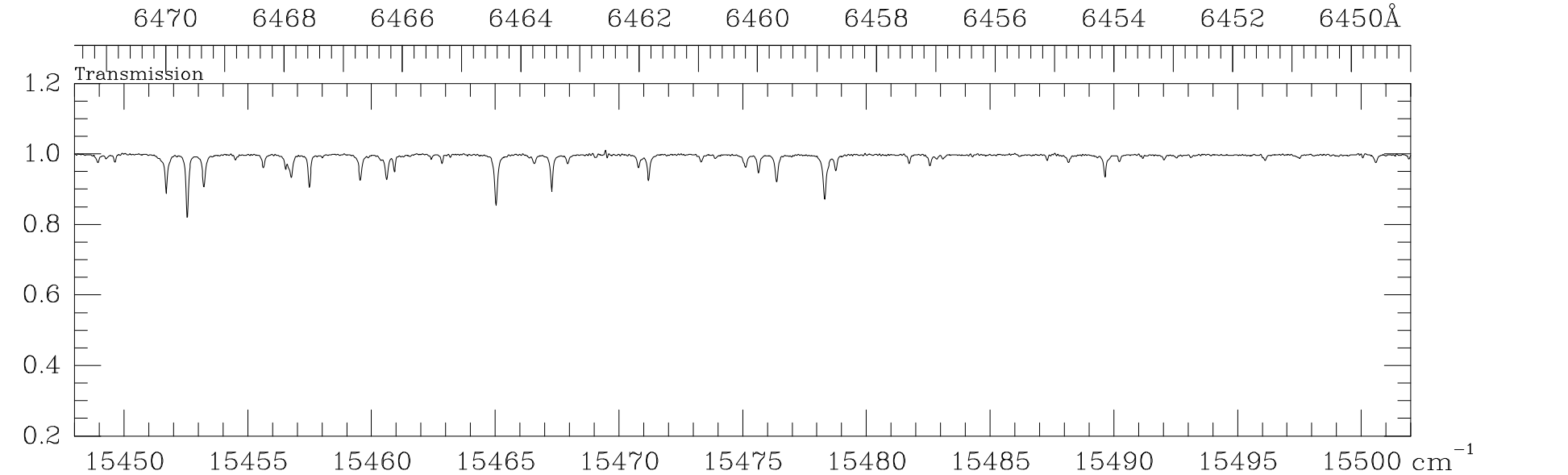

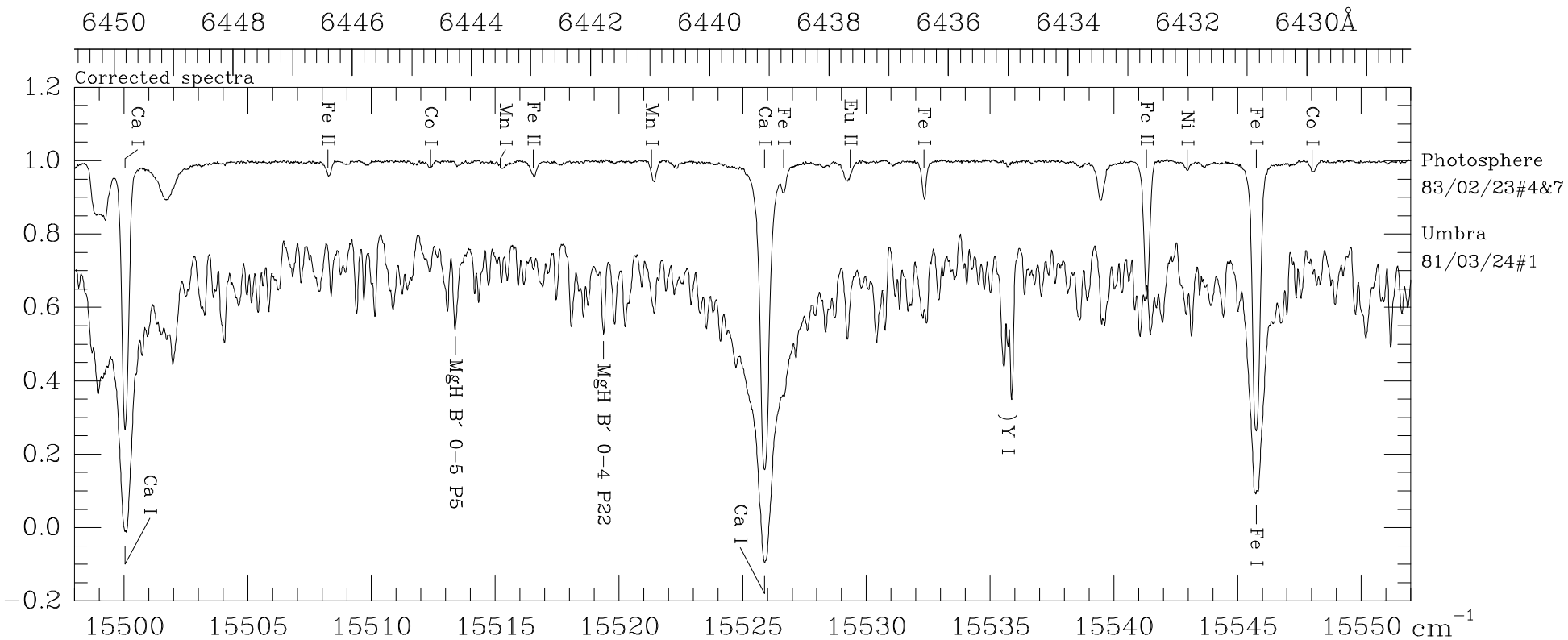

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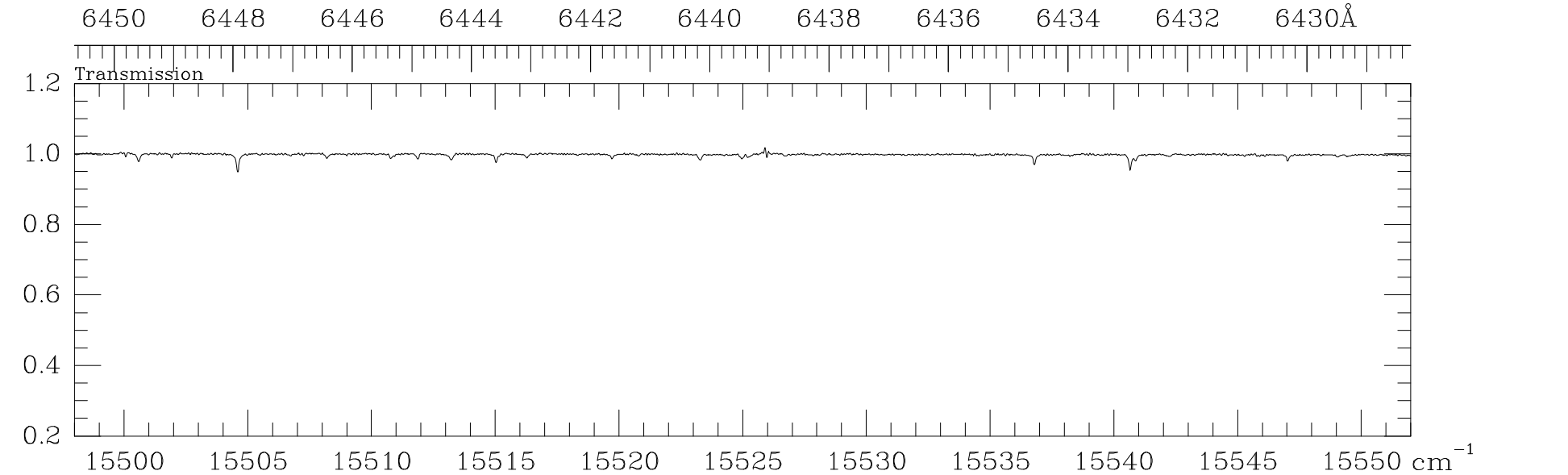

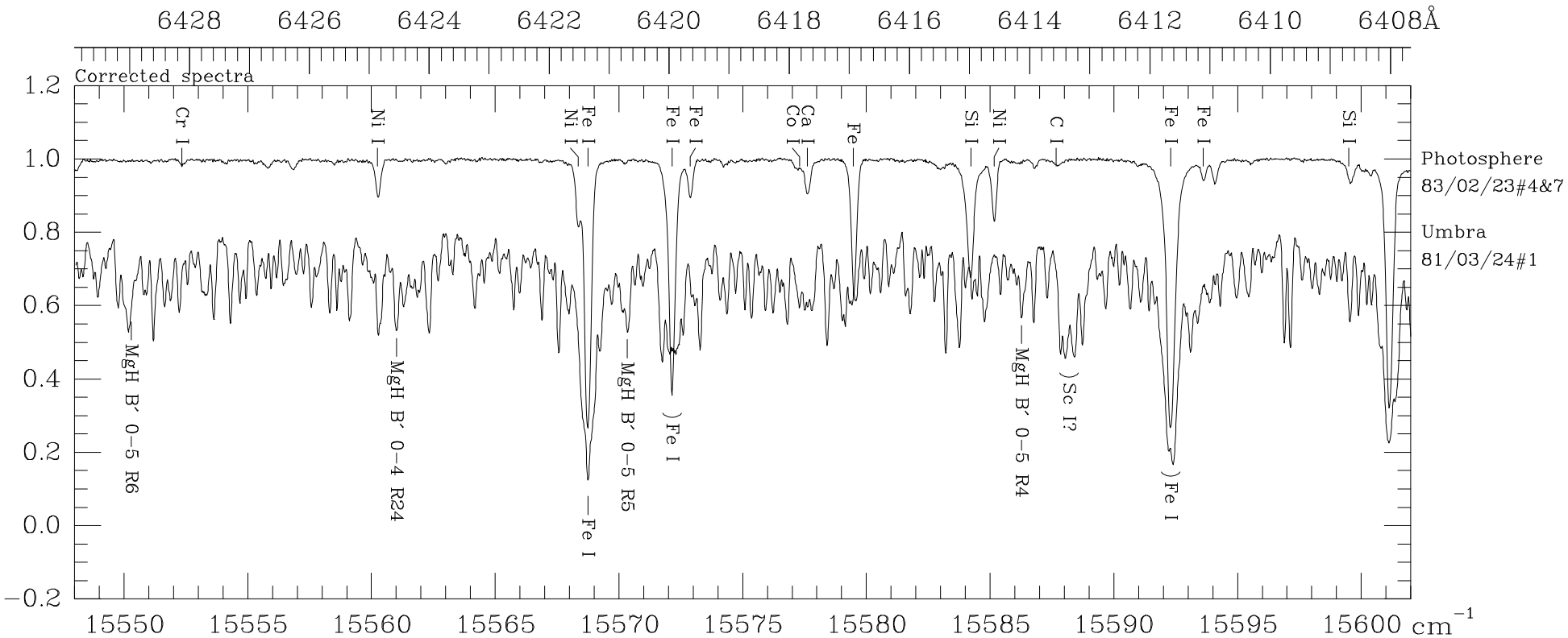

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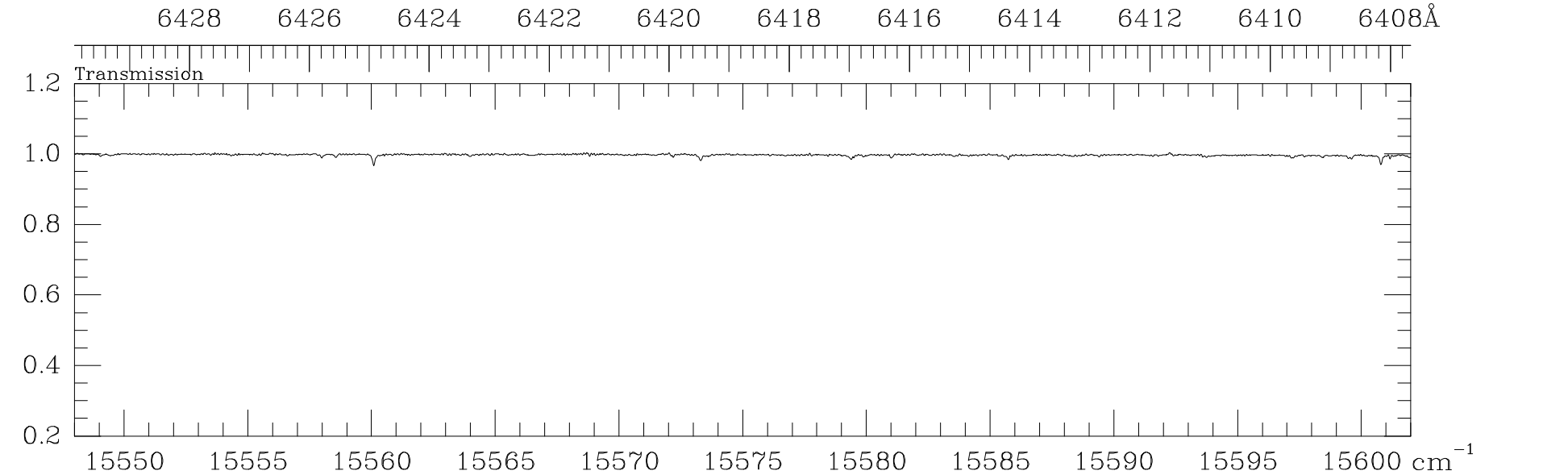

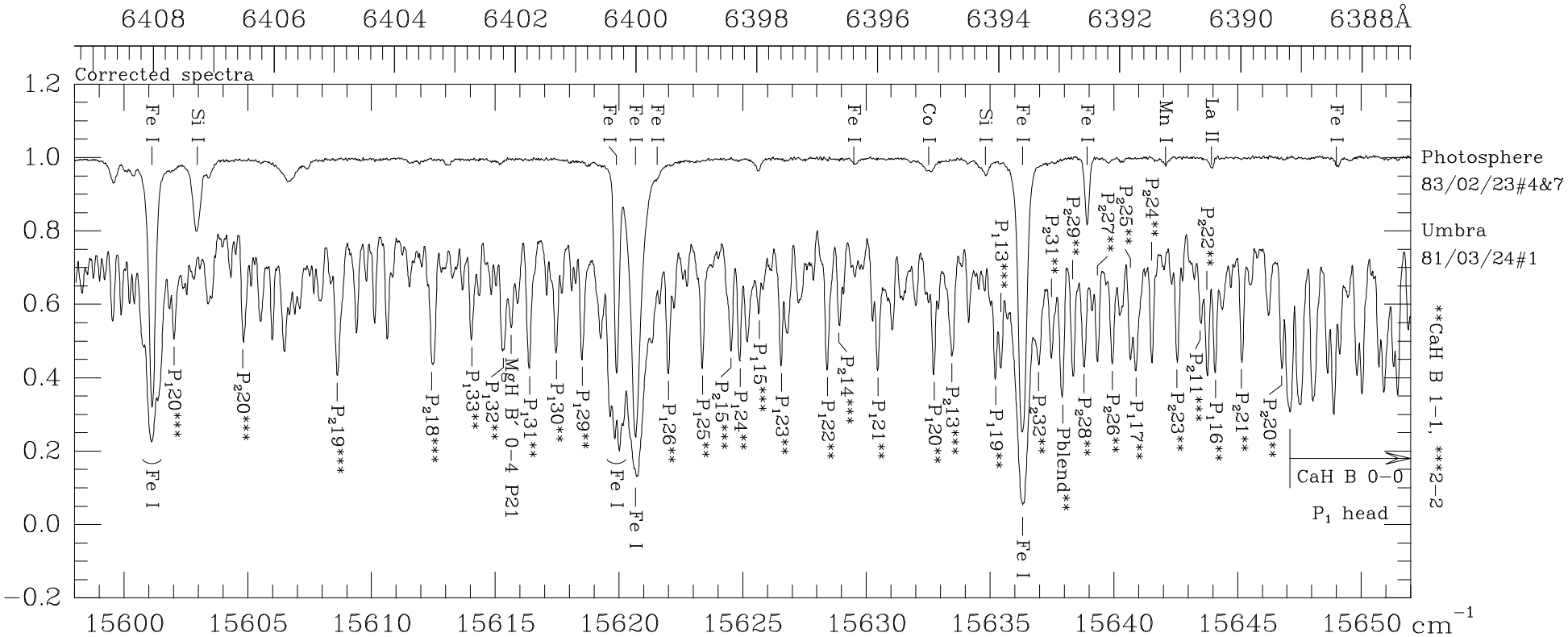

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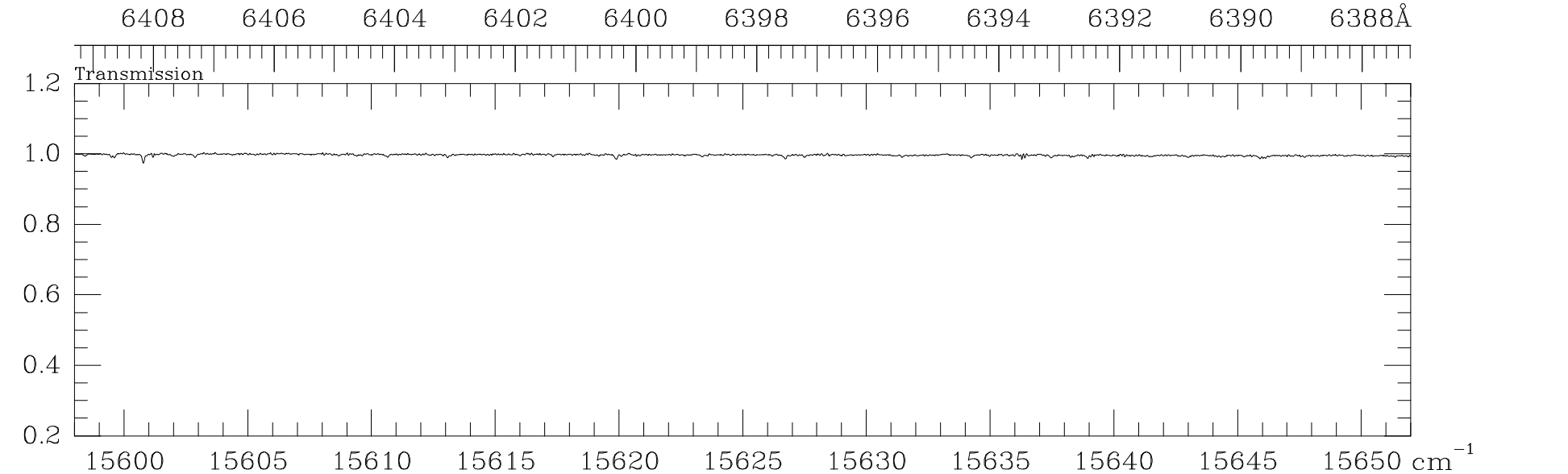

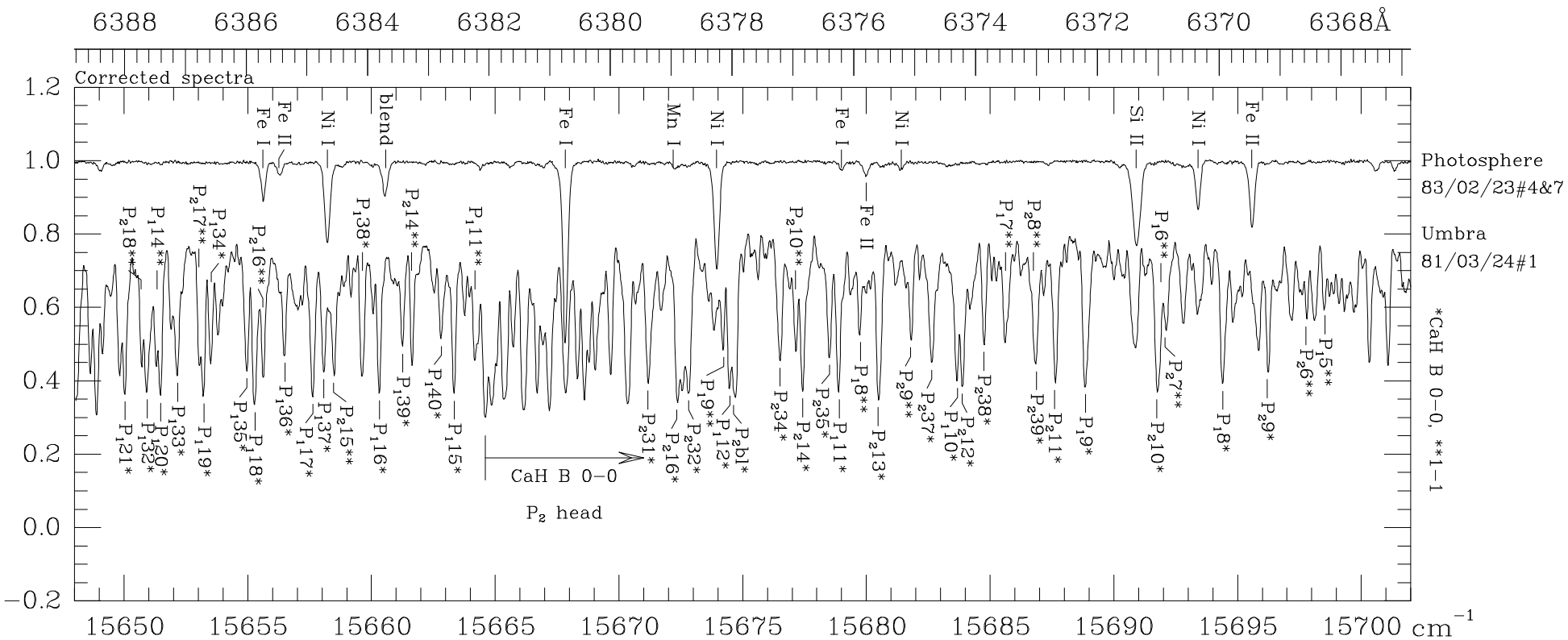

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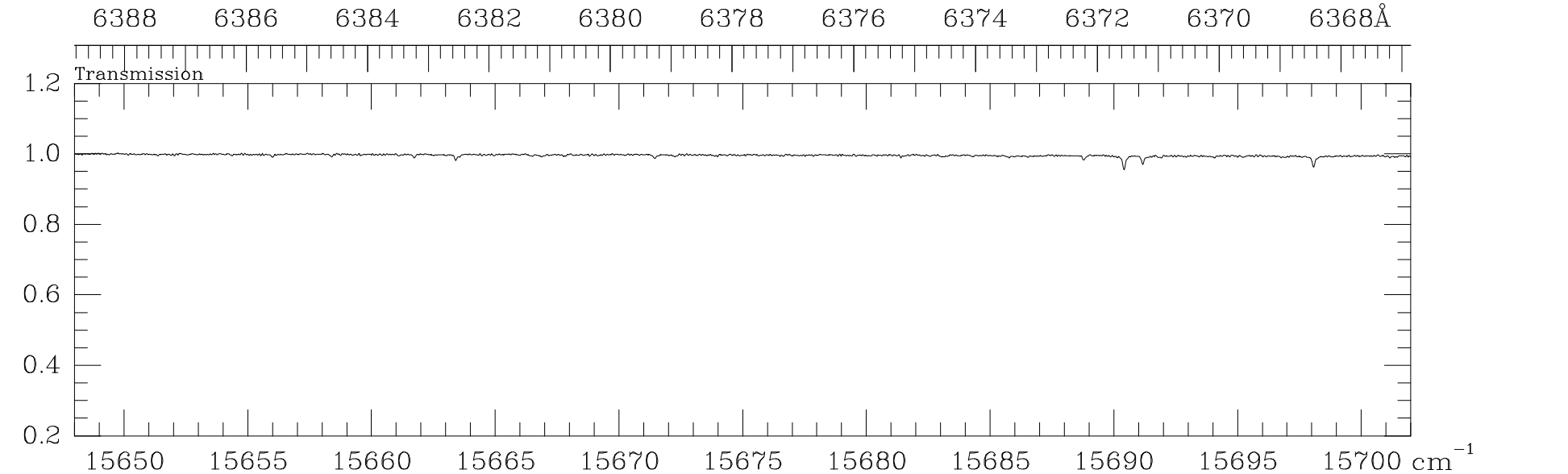

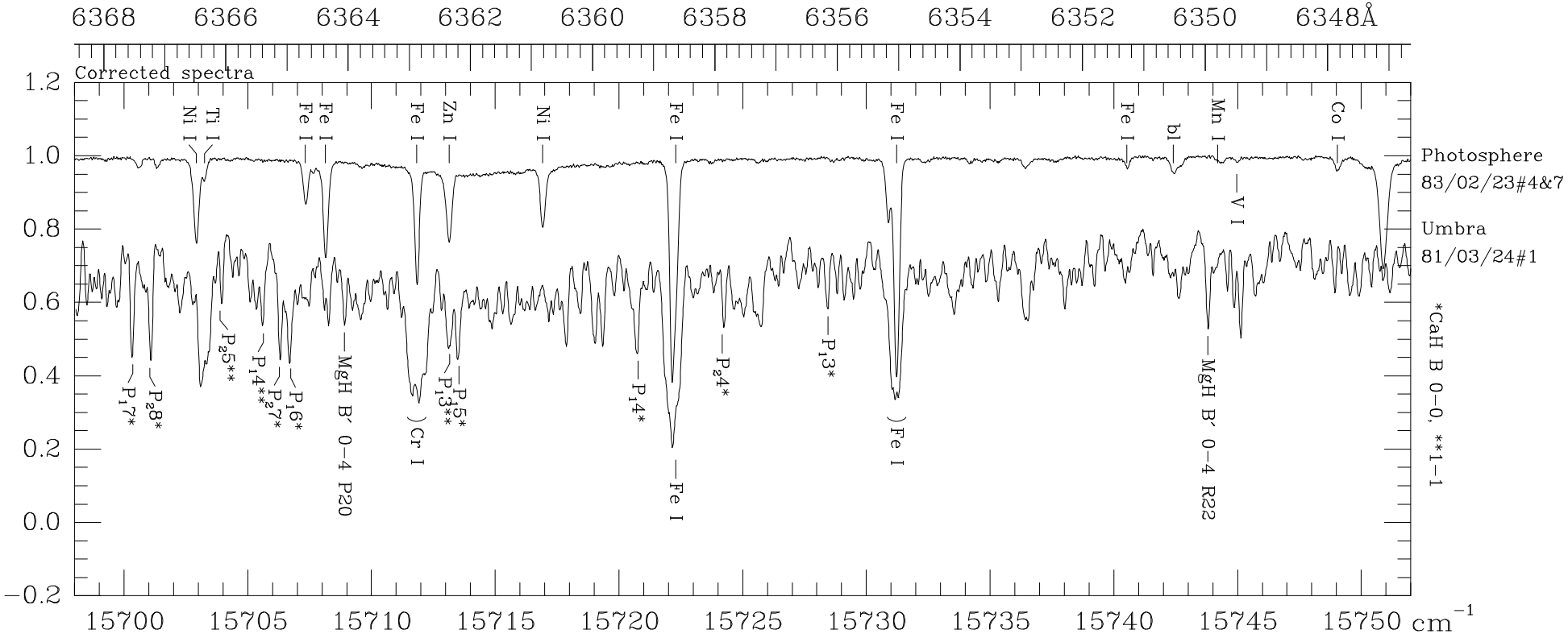

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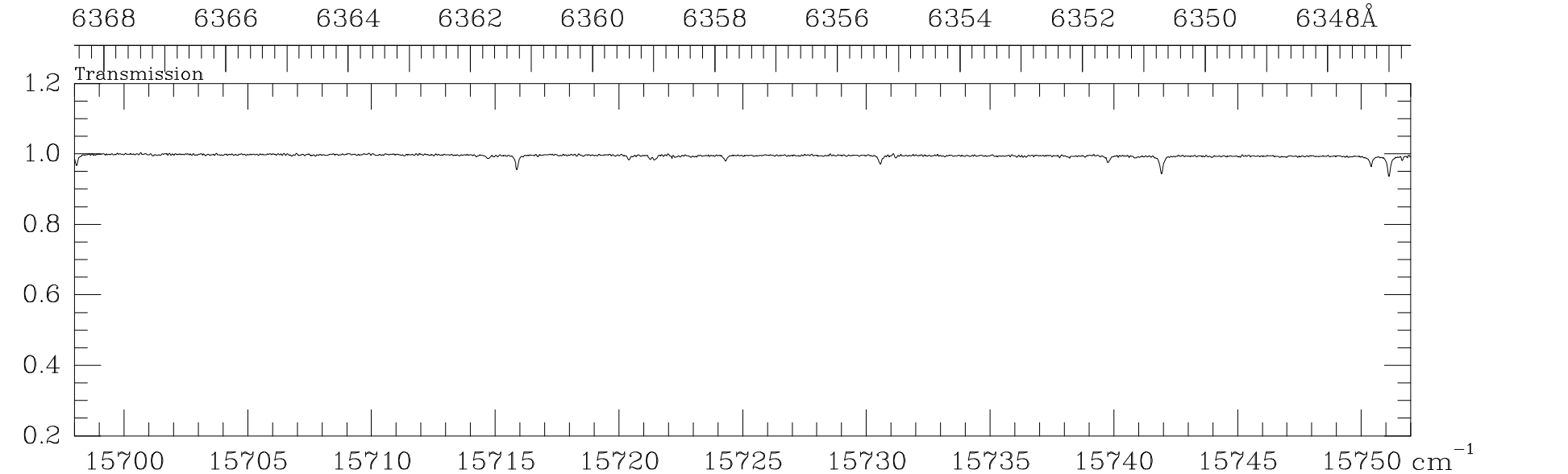

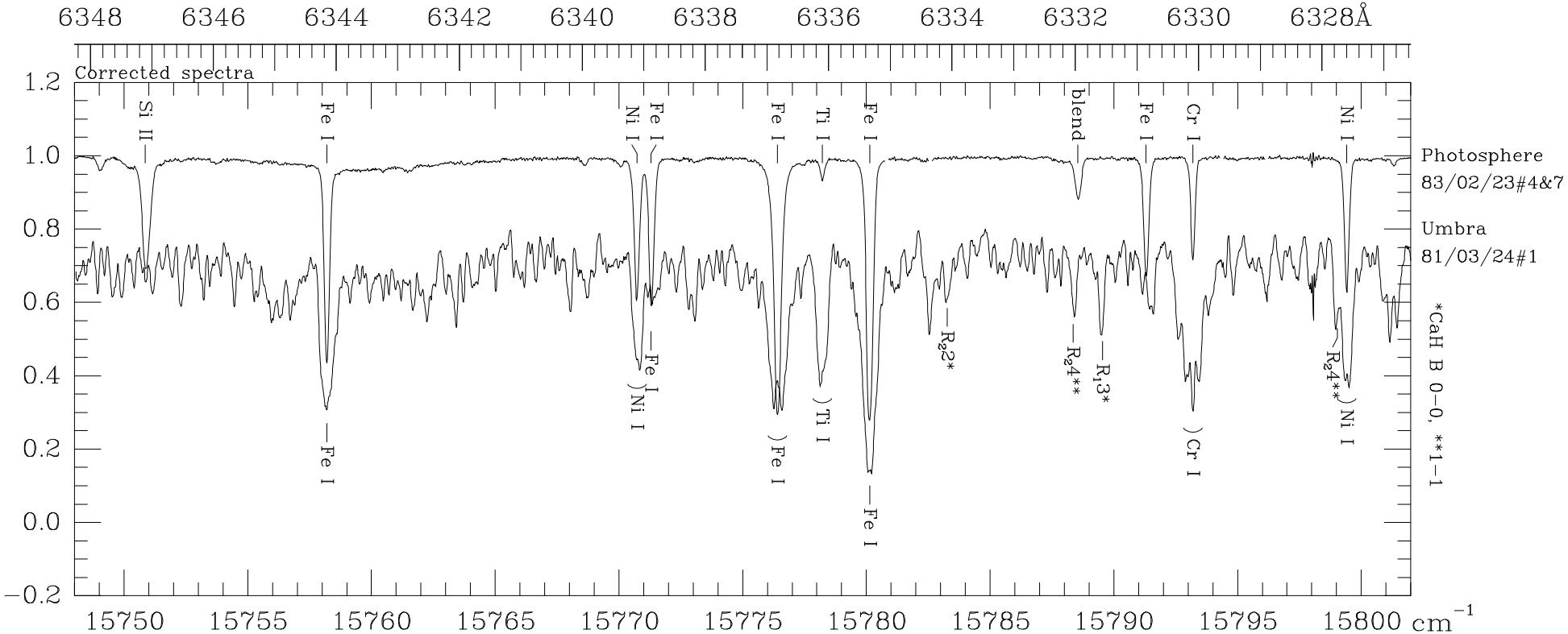

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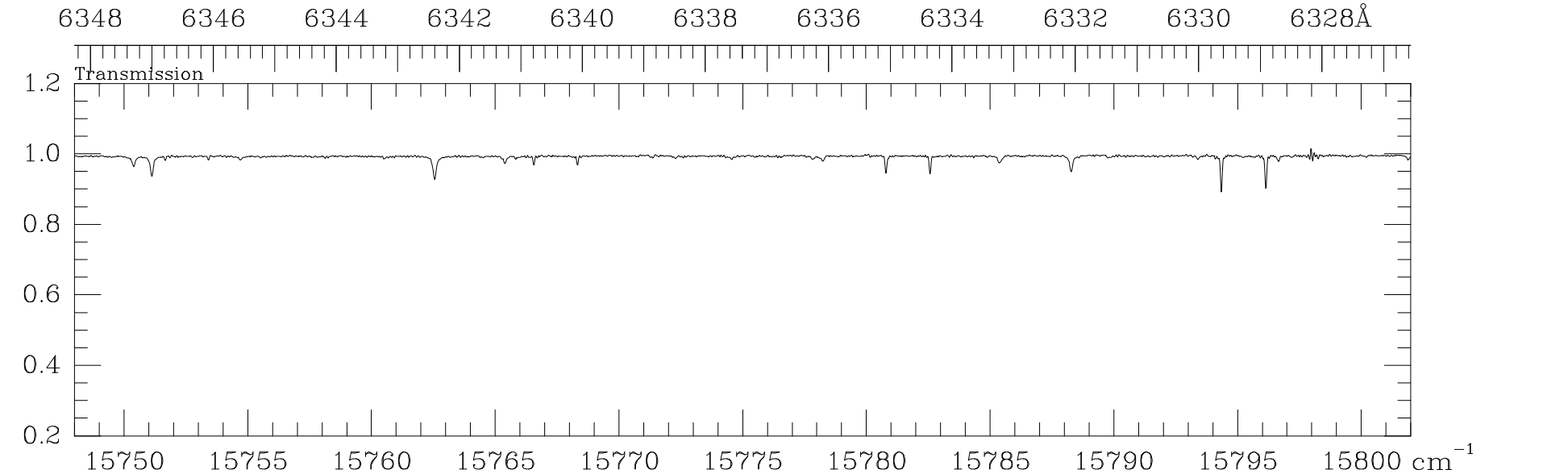

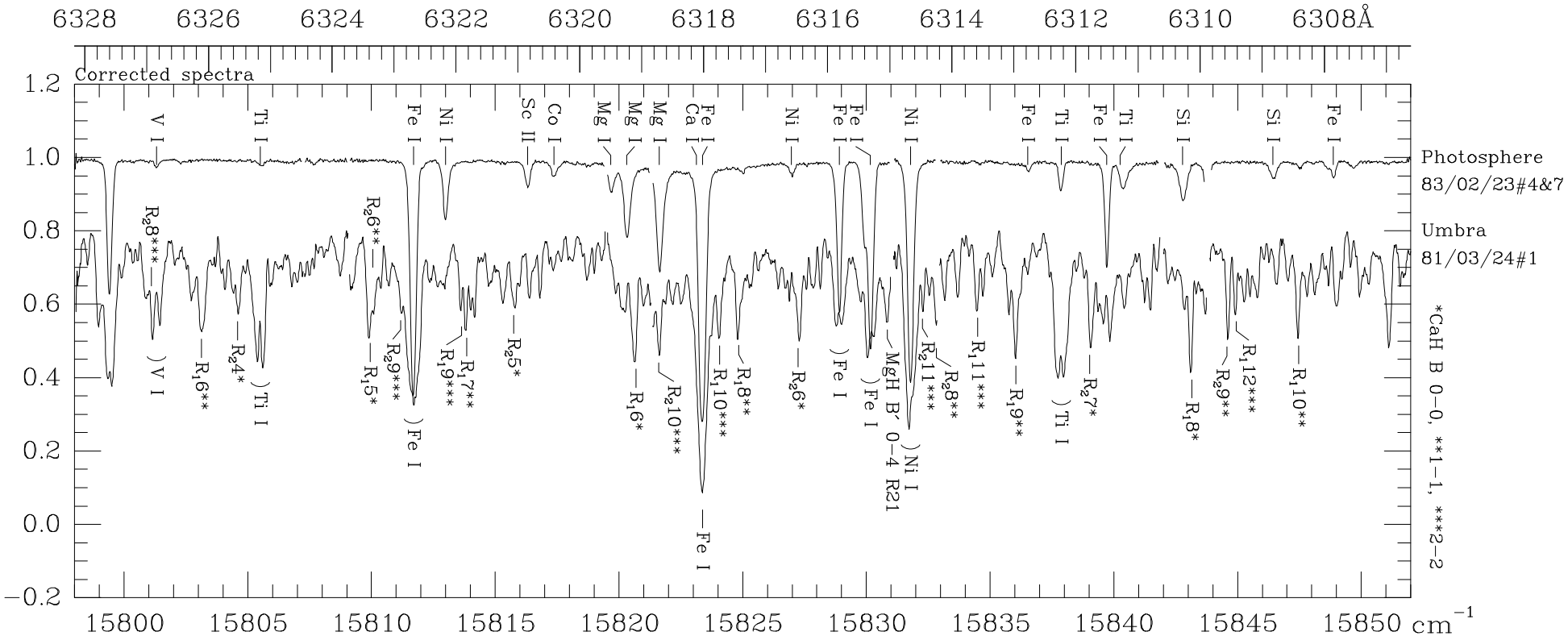

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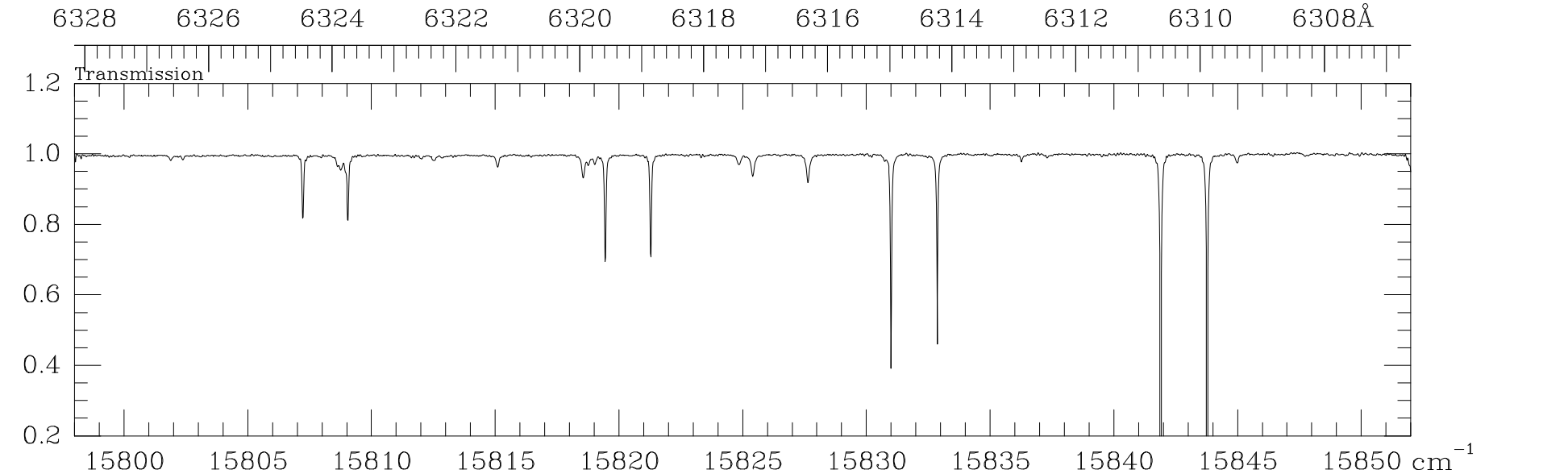

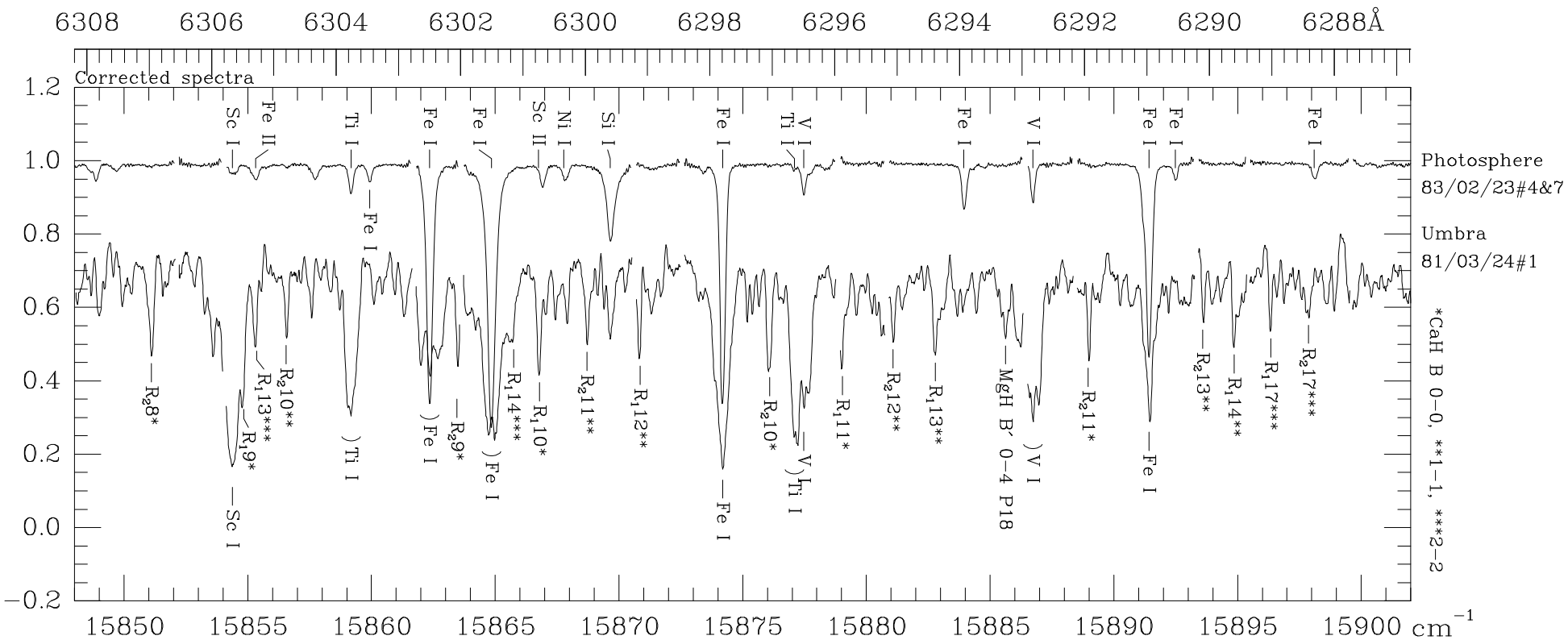

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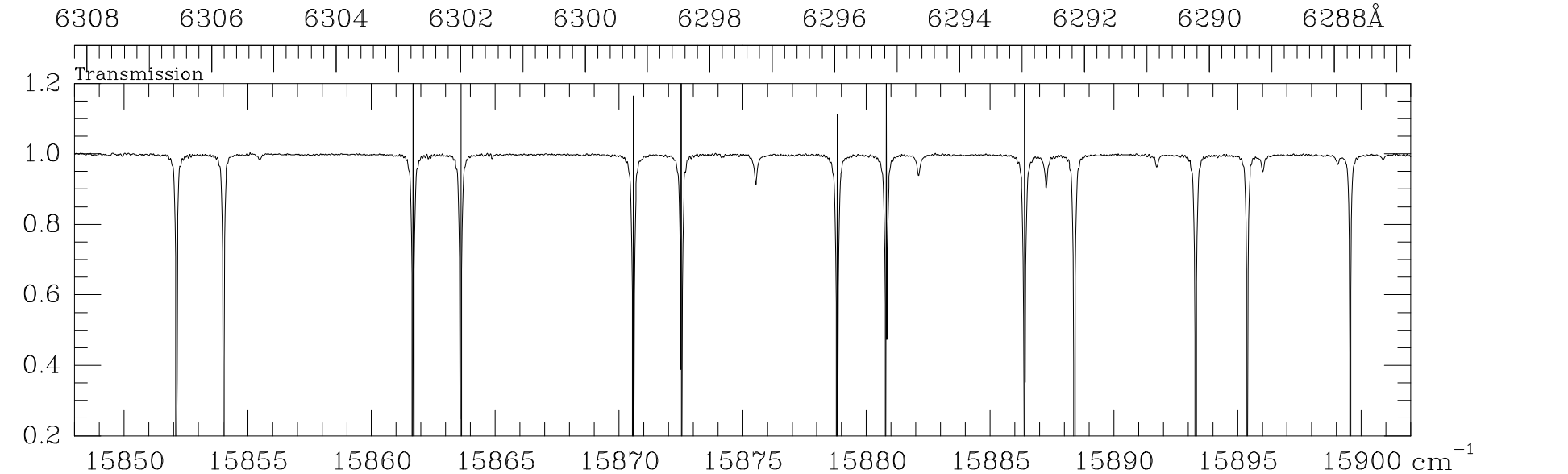
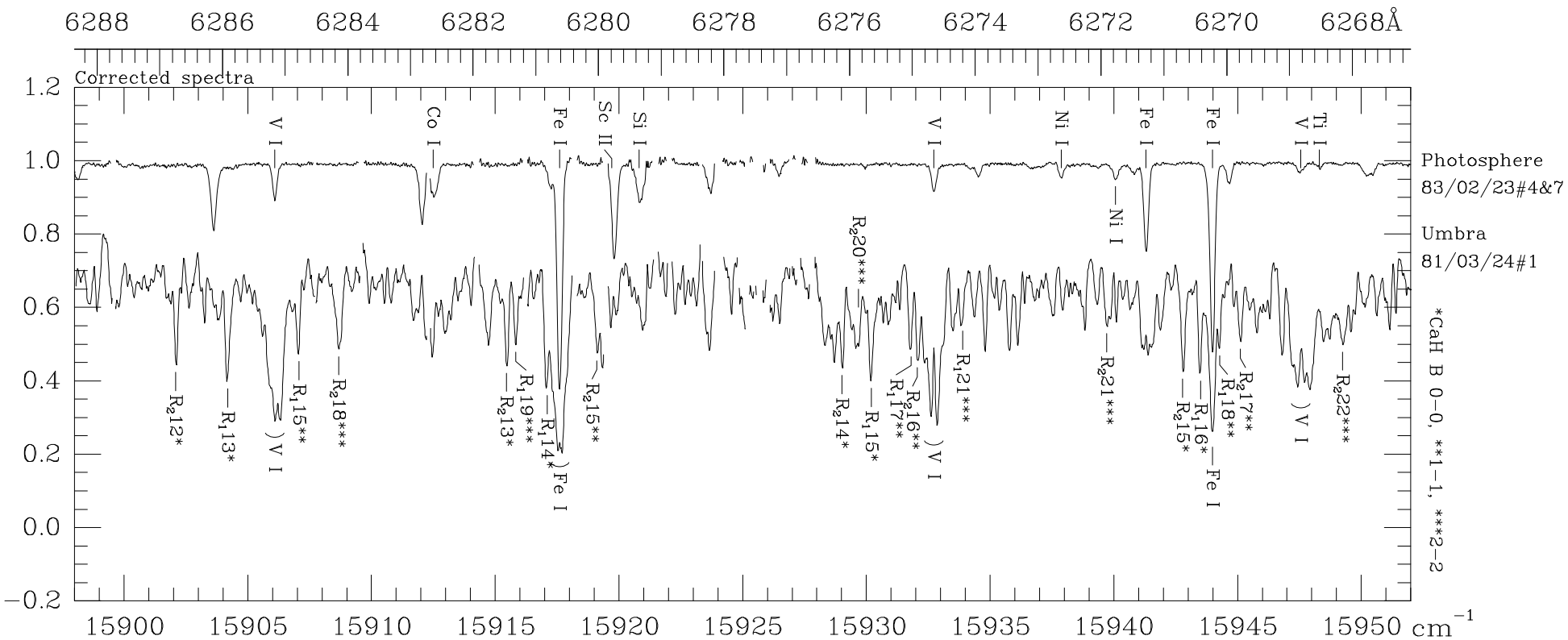
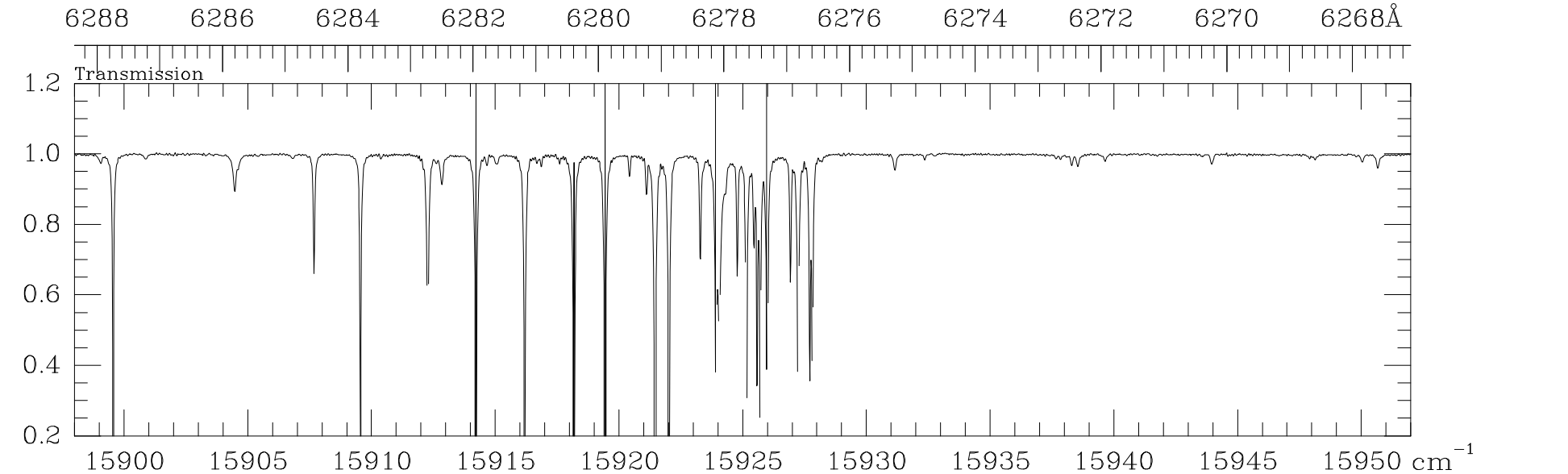
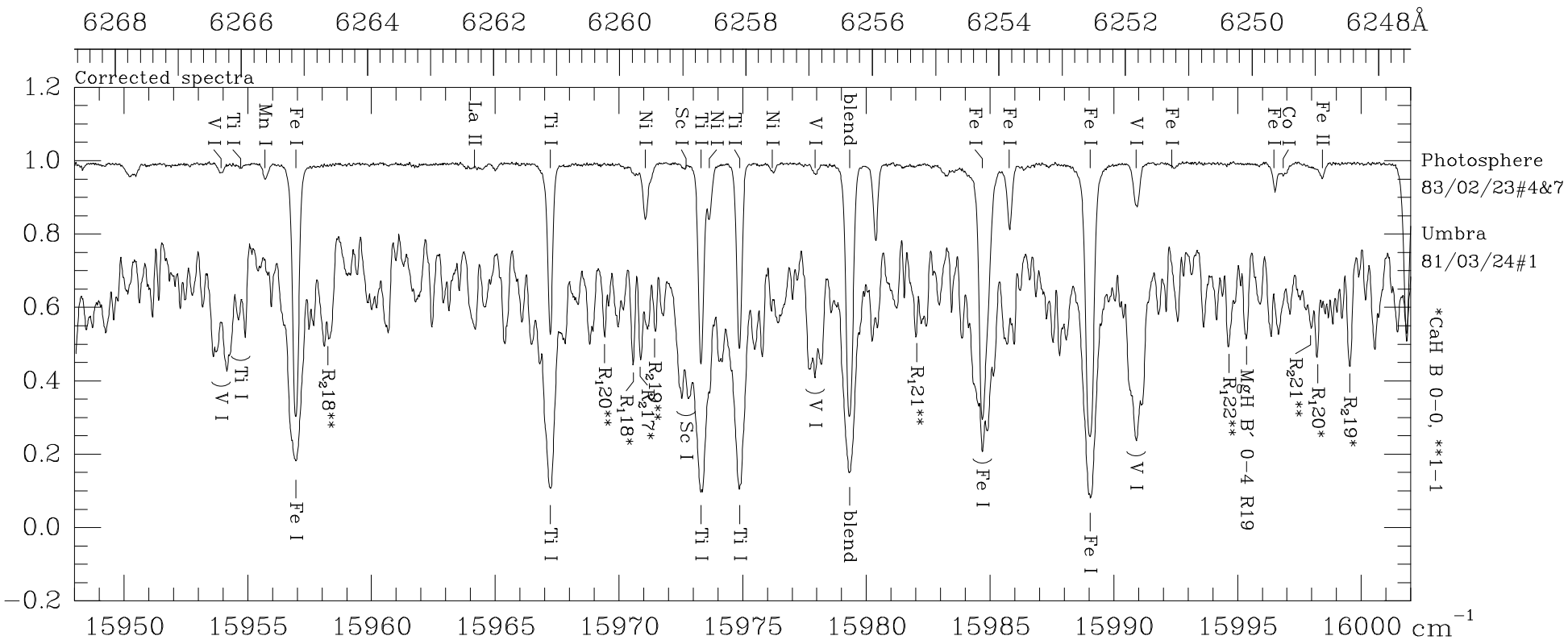




The unlabeled features in the umbral spectrum above are due mostly to lines of the TiO α and γ' bands.





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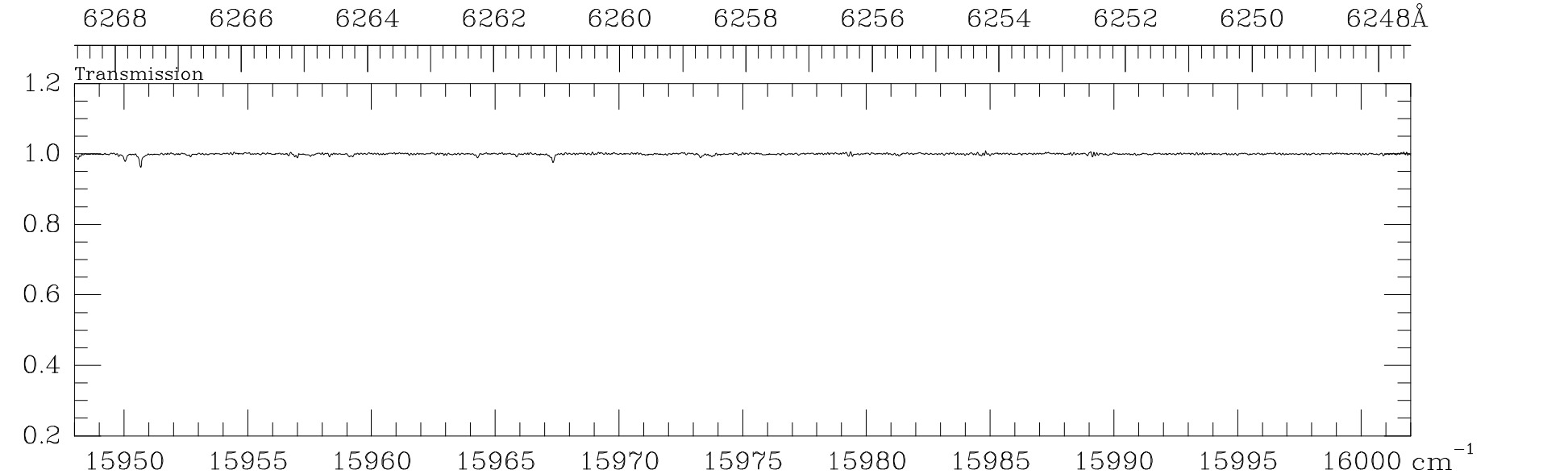

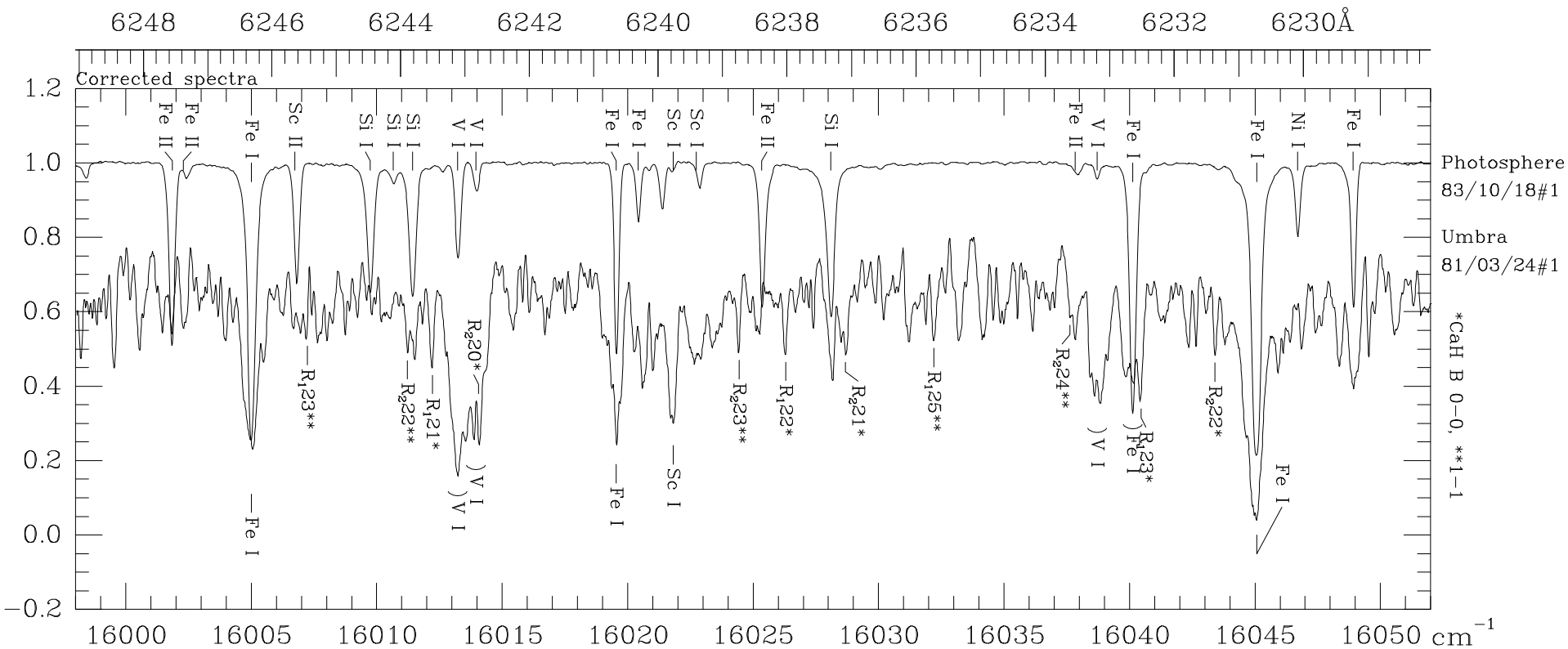

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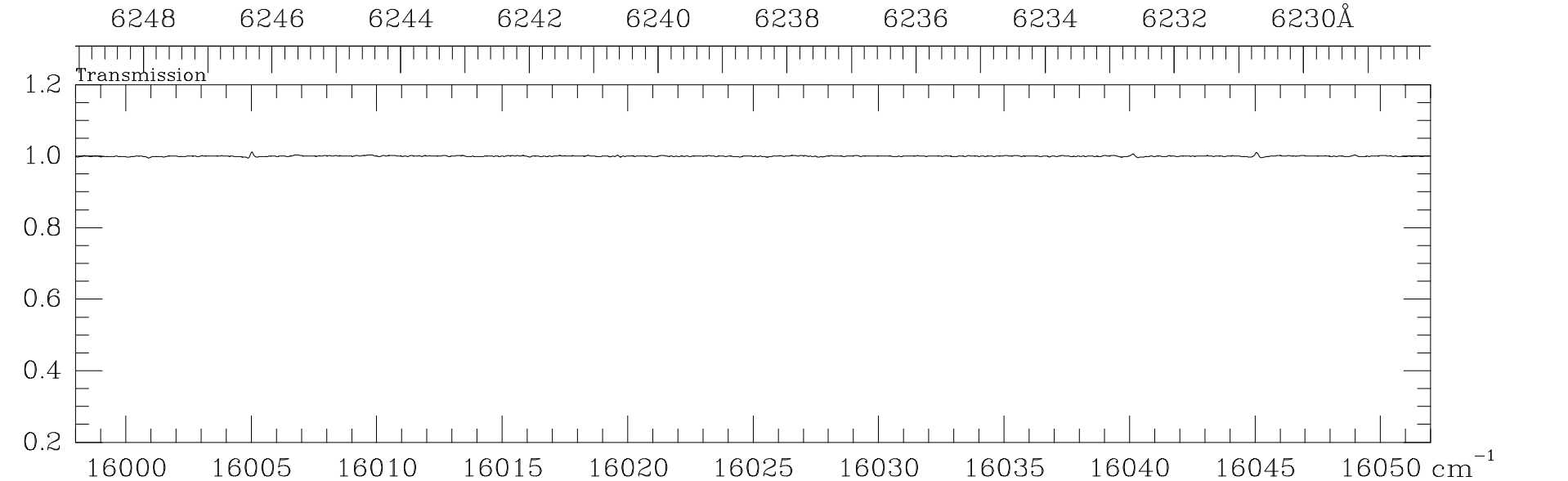

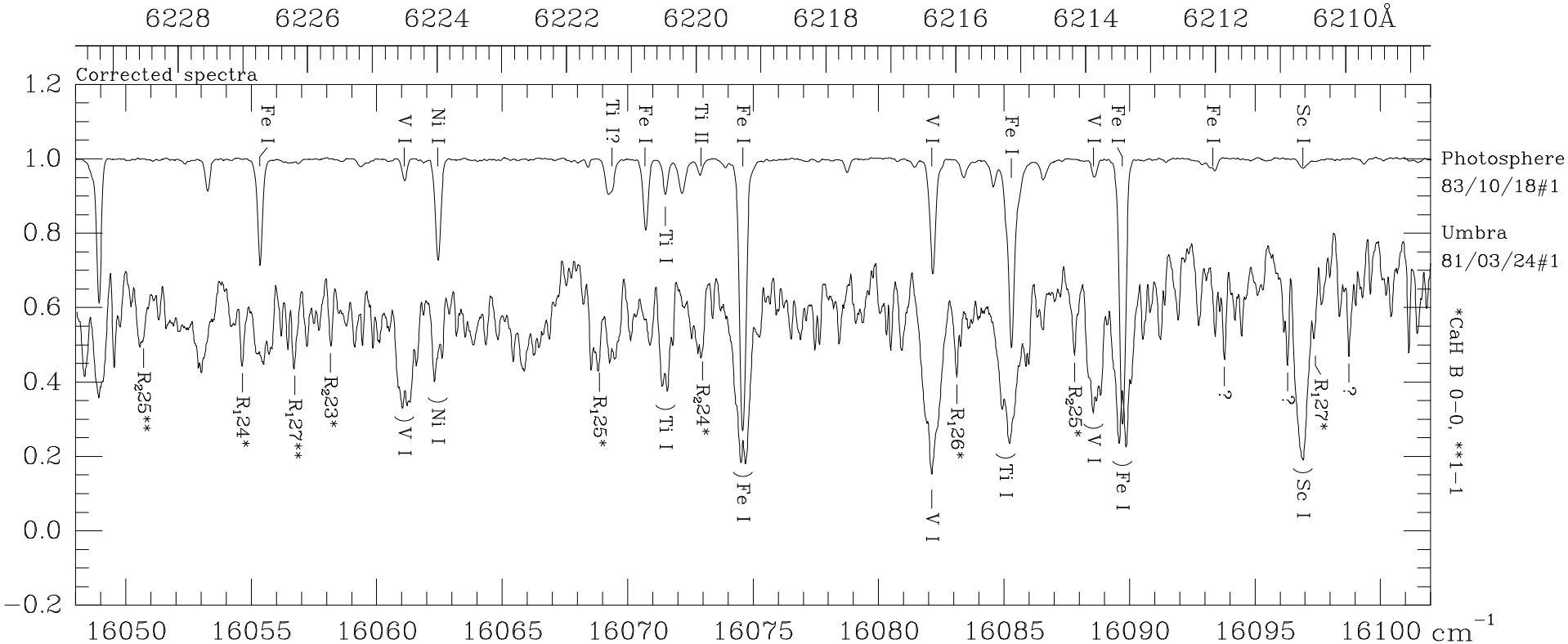

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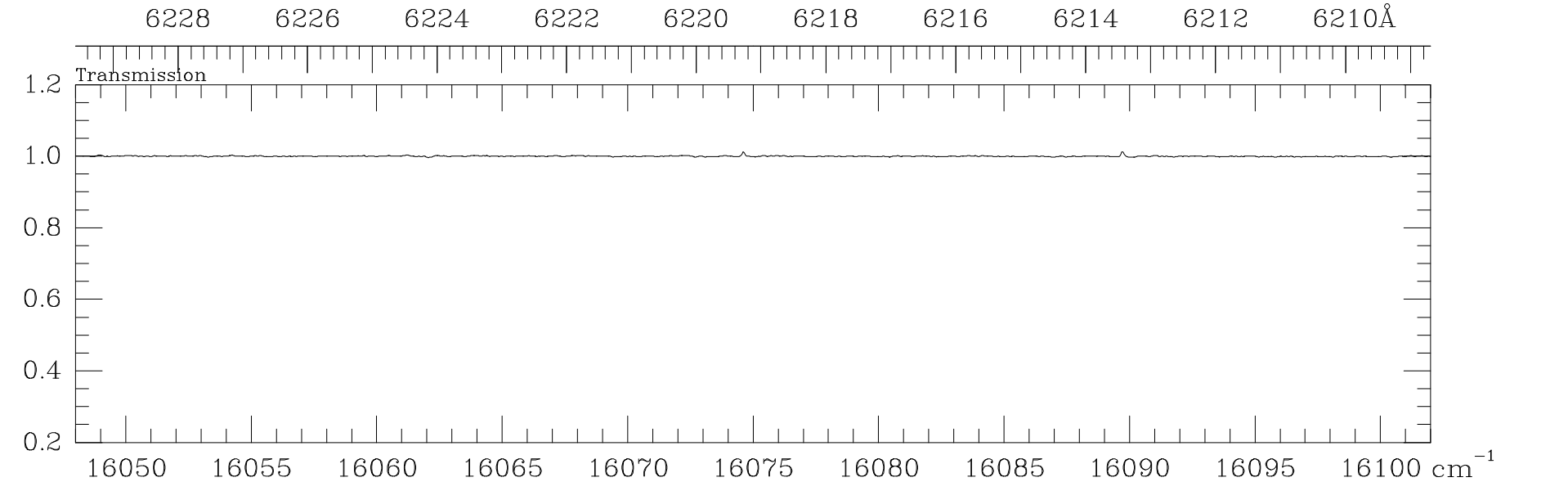

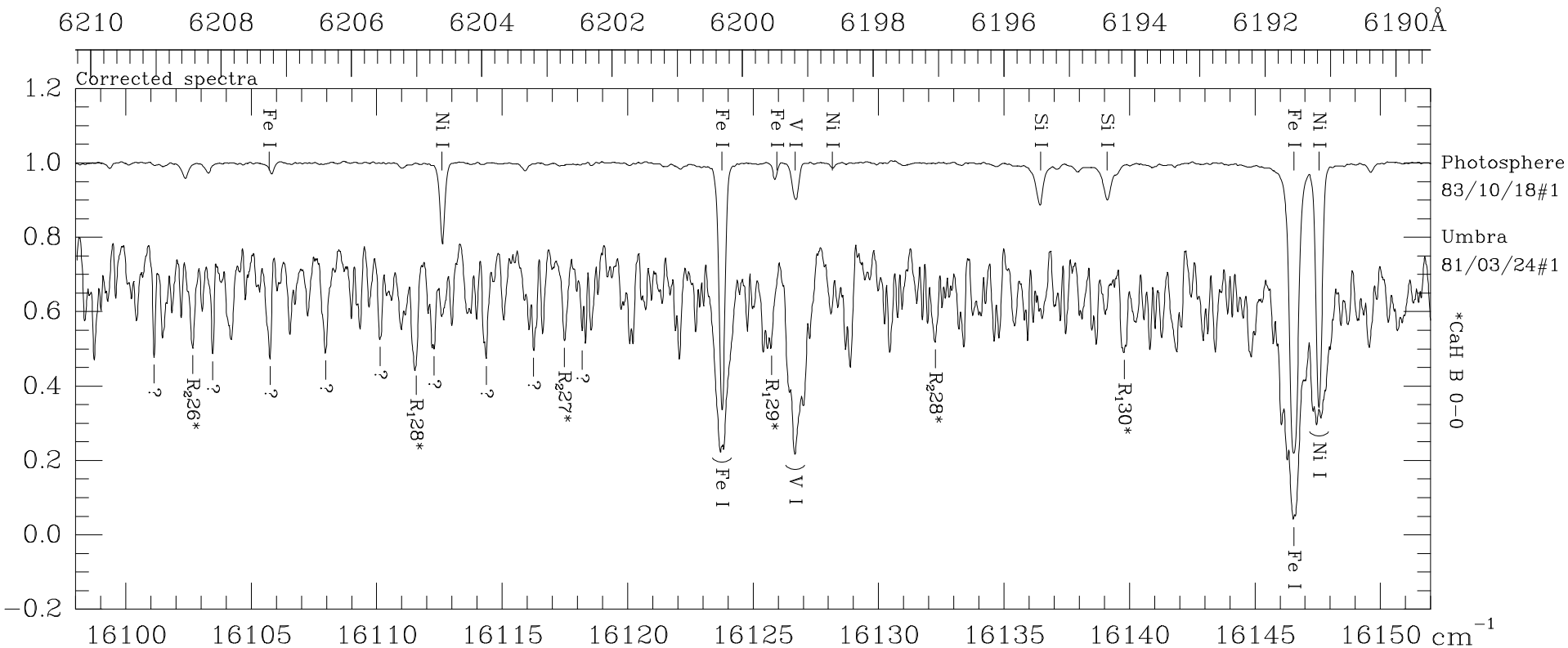

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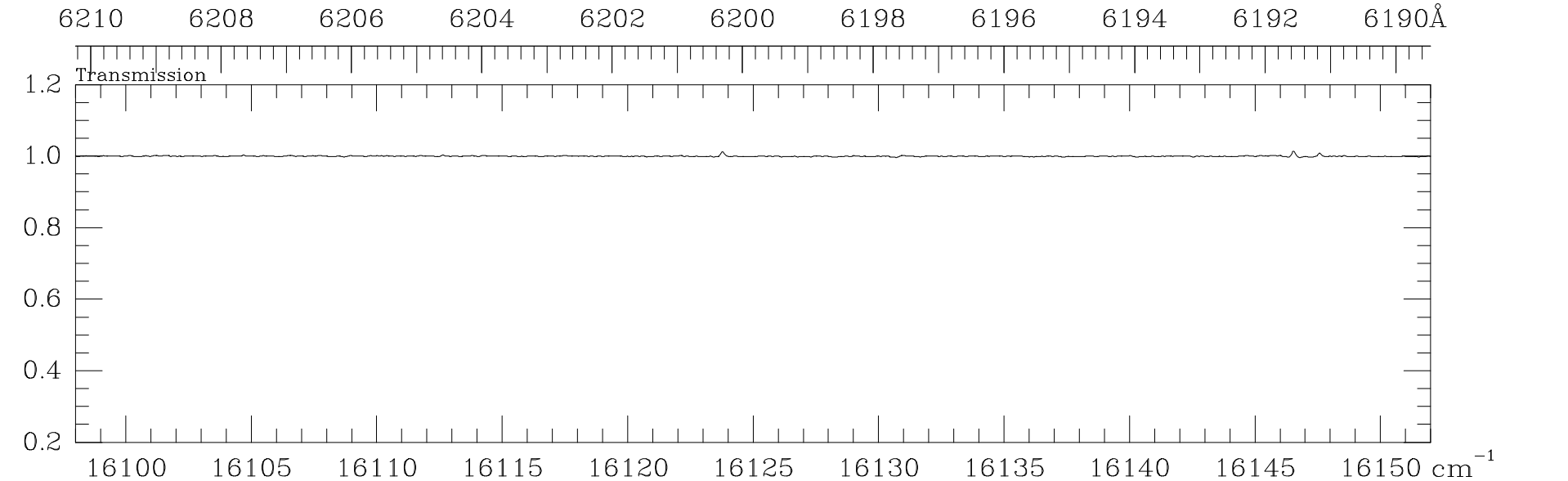

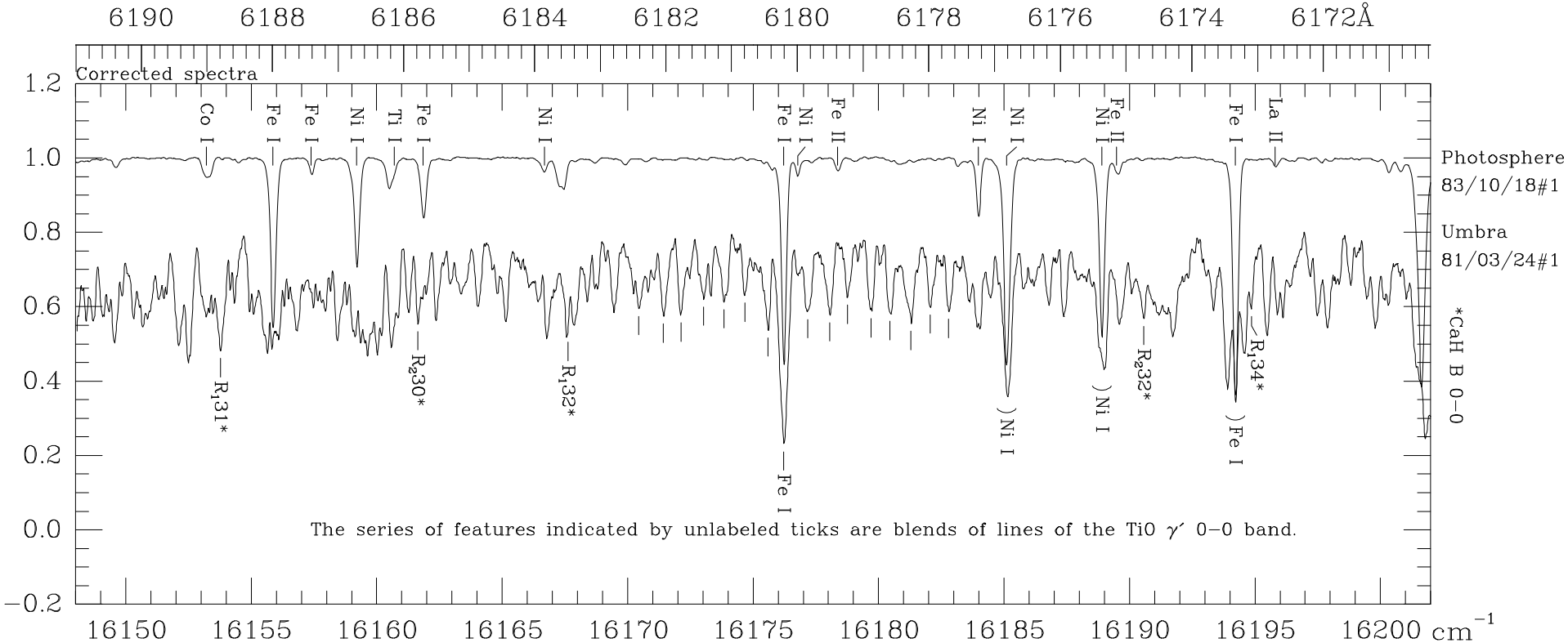

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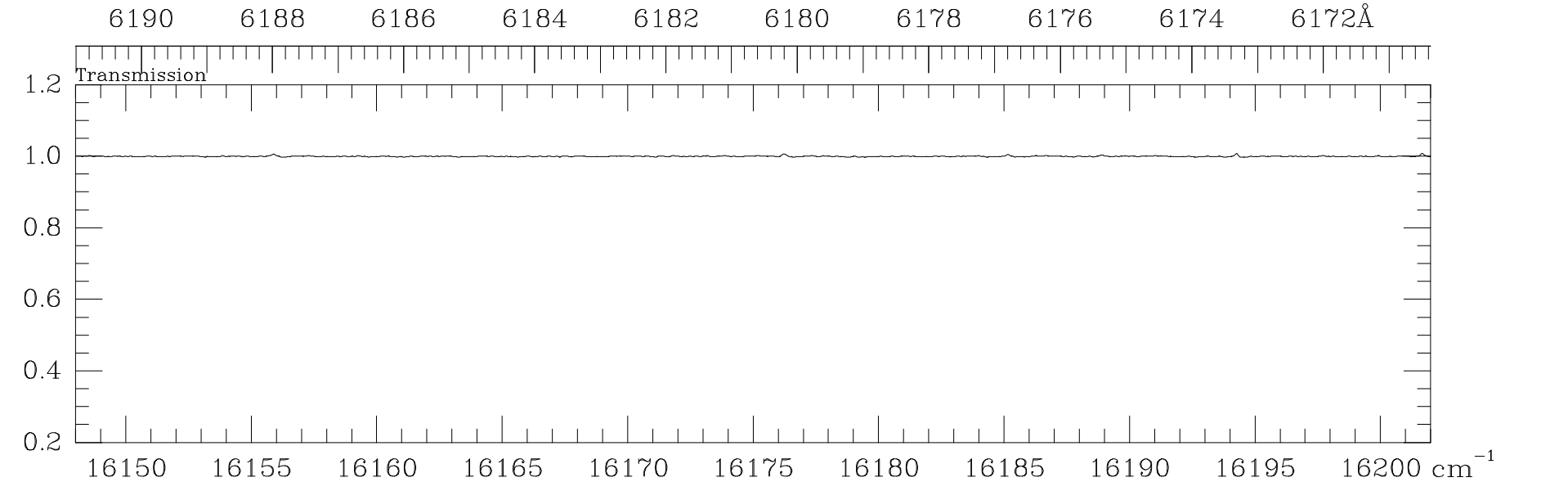

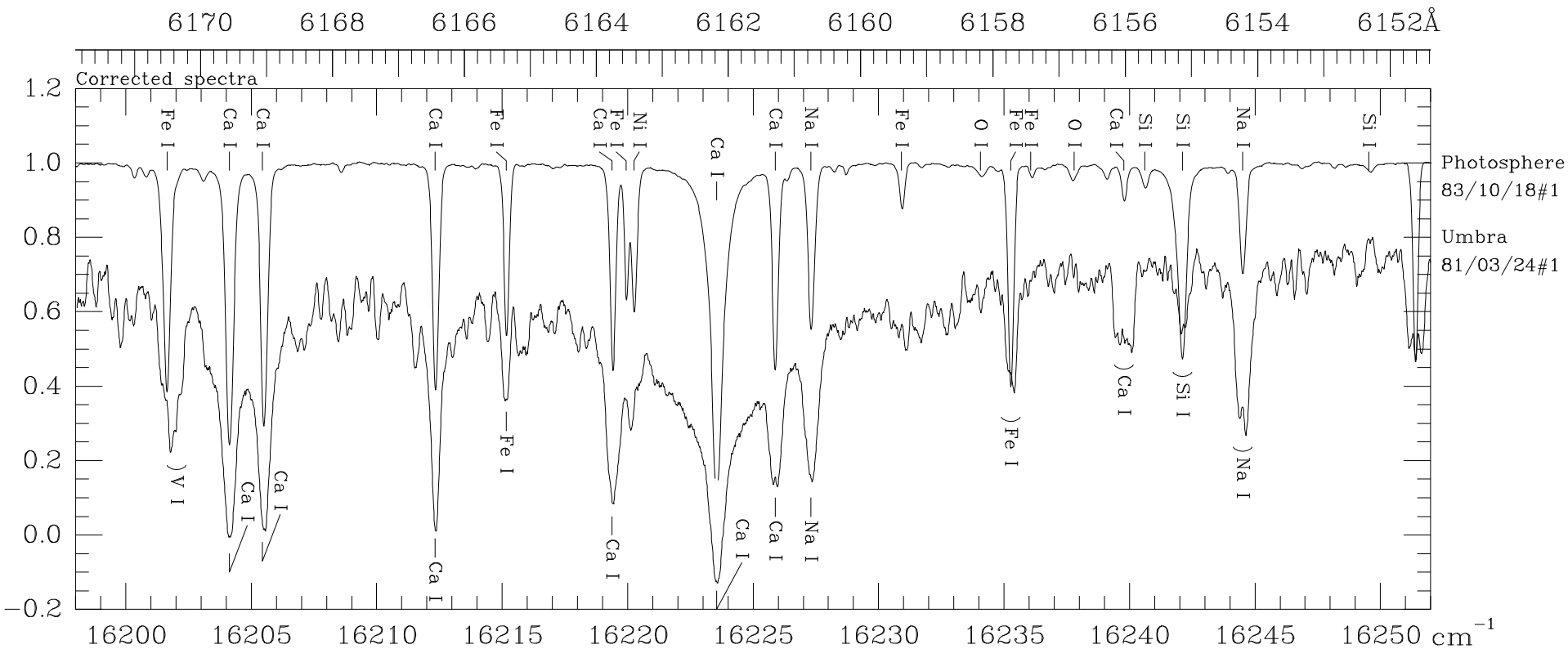

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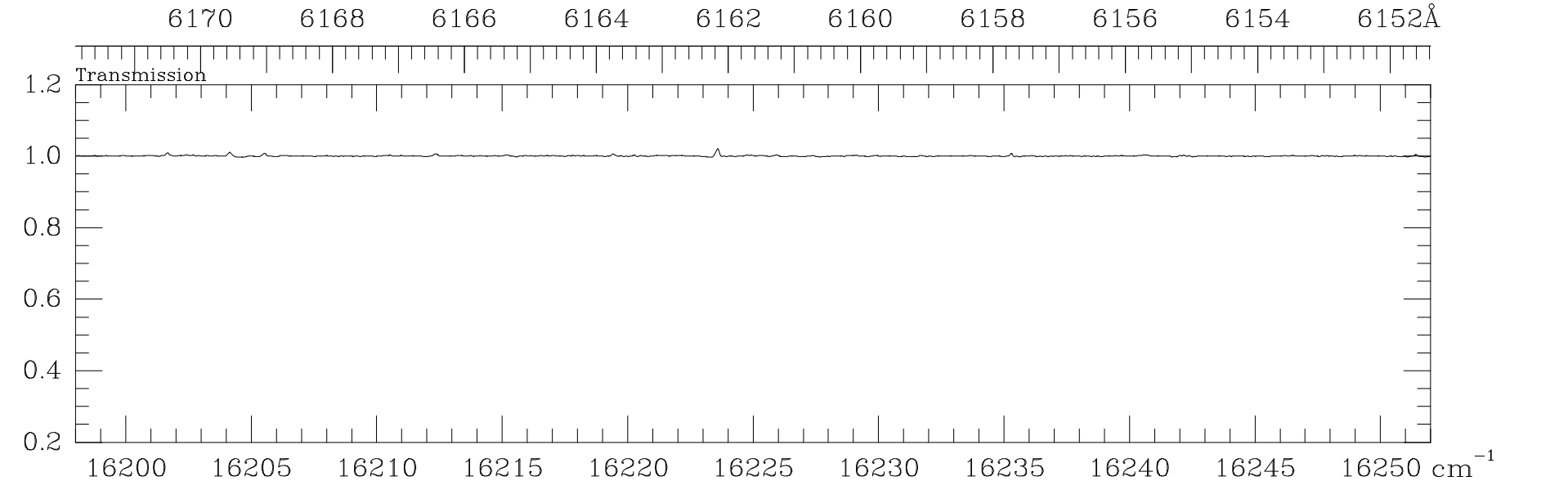
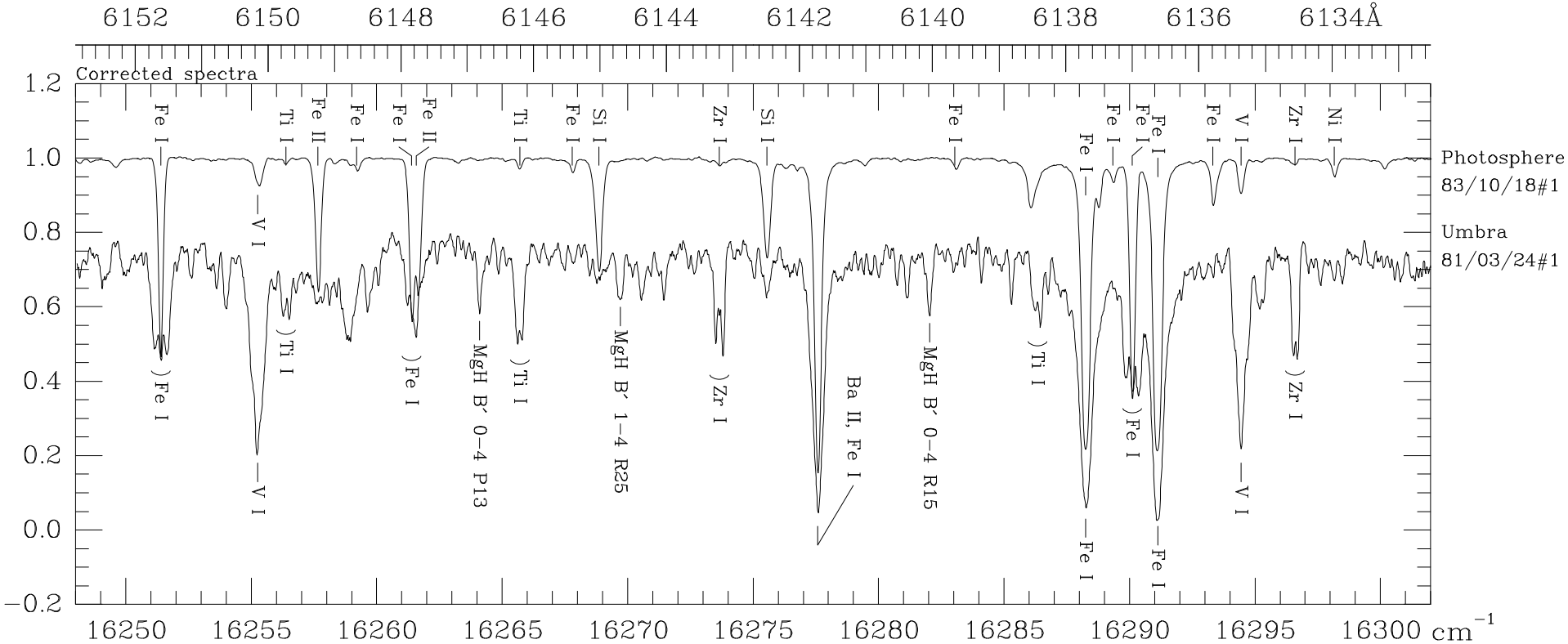
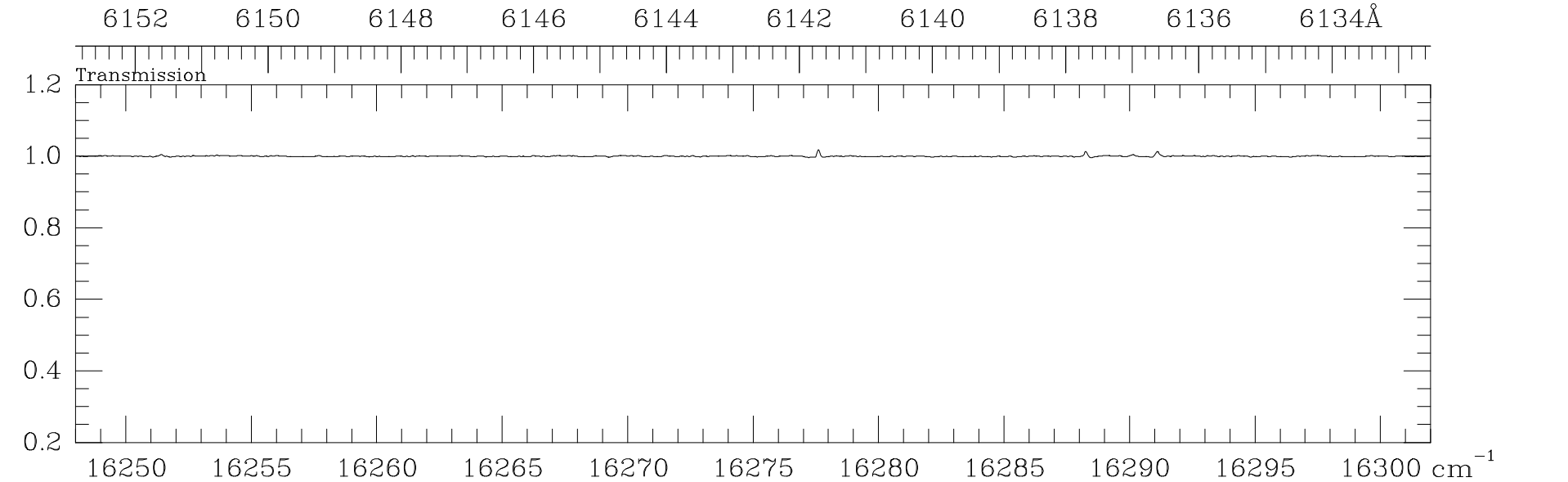
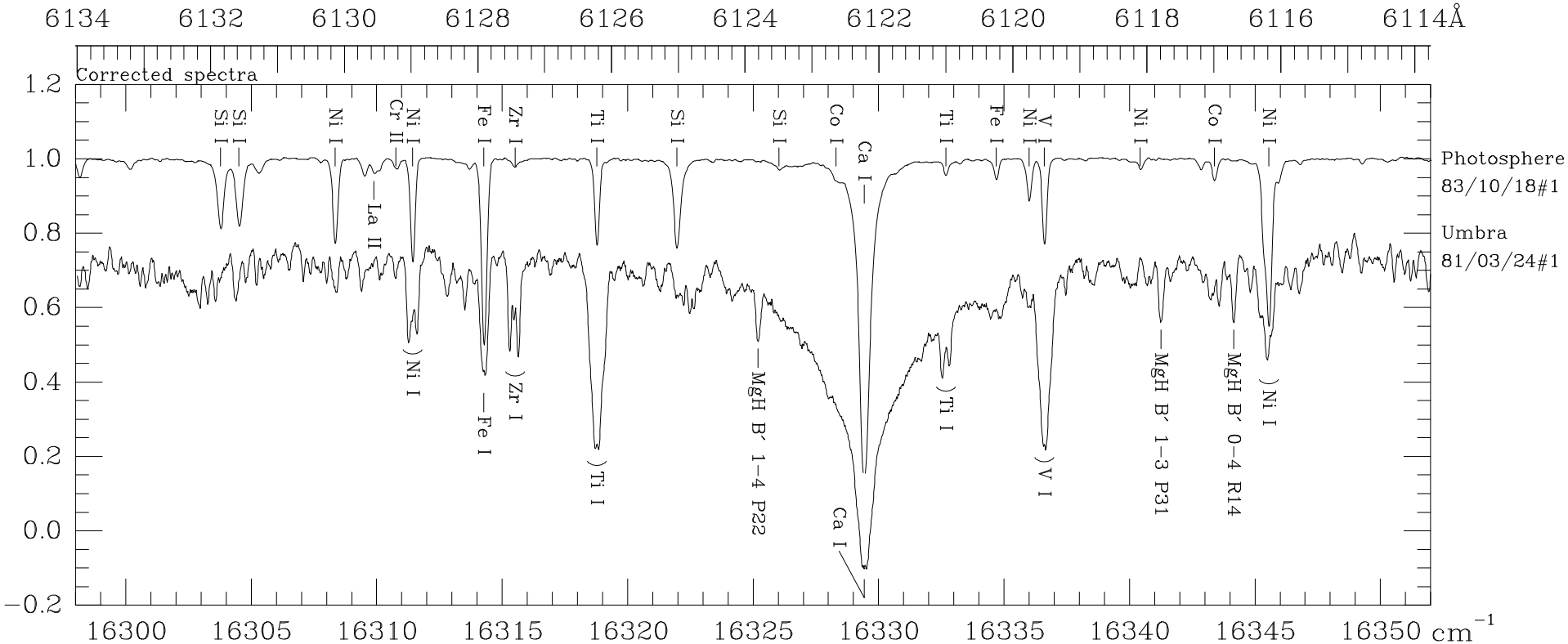


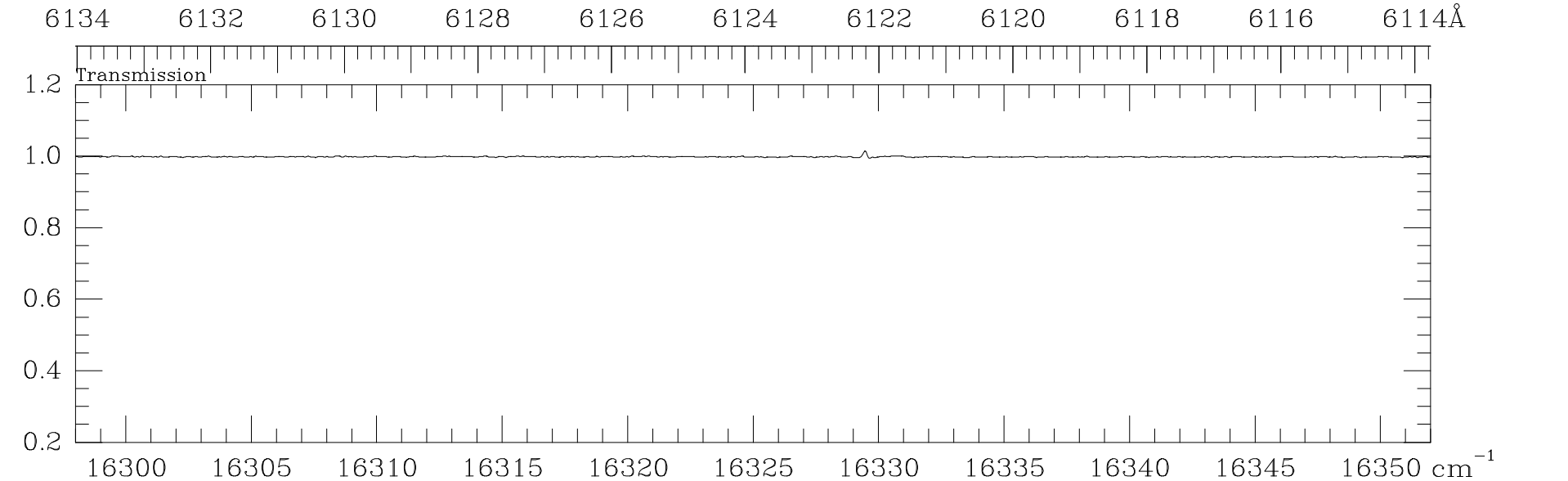


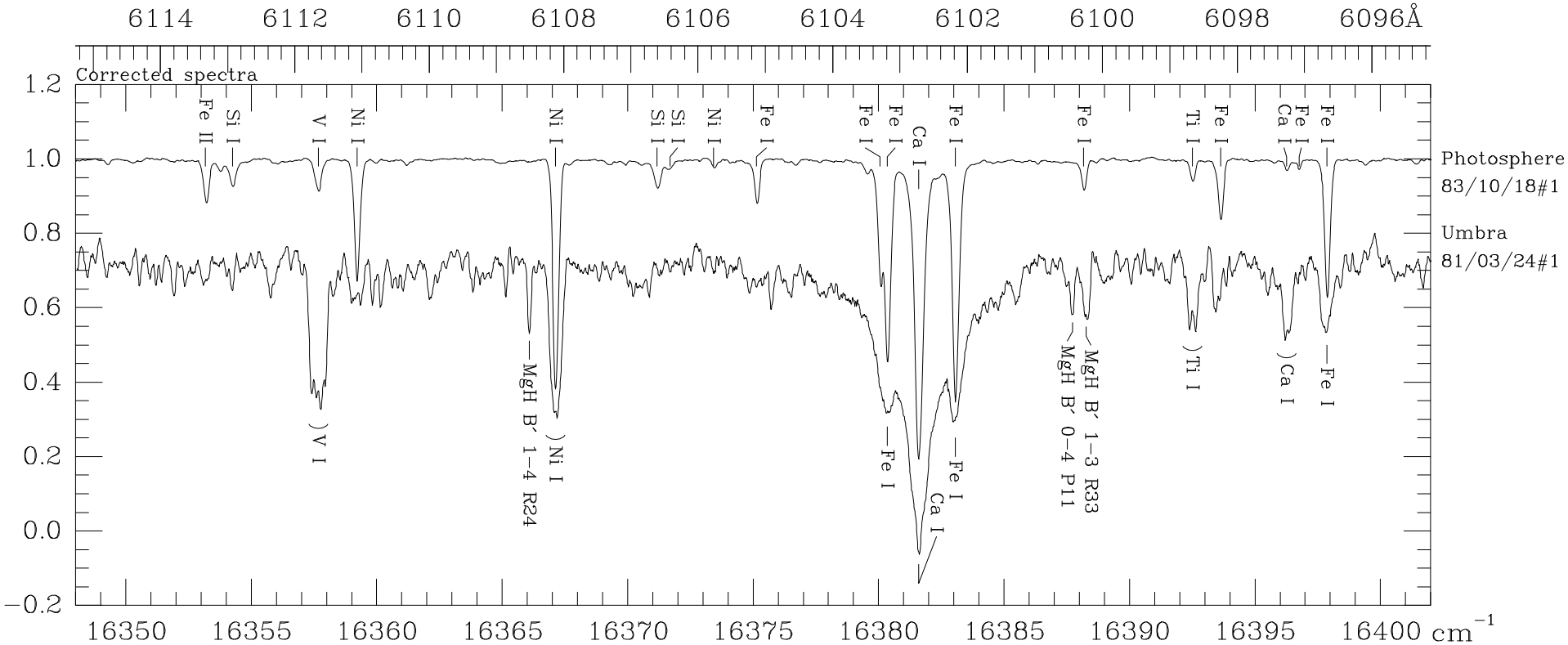
The unlabeled features in the umbral spectrum above are due mostly to lines of the TiO α and γ' bands.





The unlabeled features in the umbral spectrum above are due mostly to lines of the TiO α bands.





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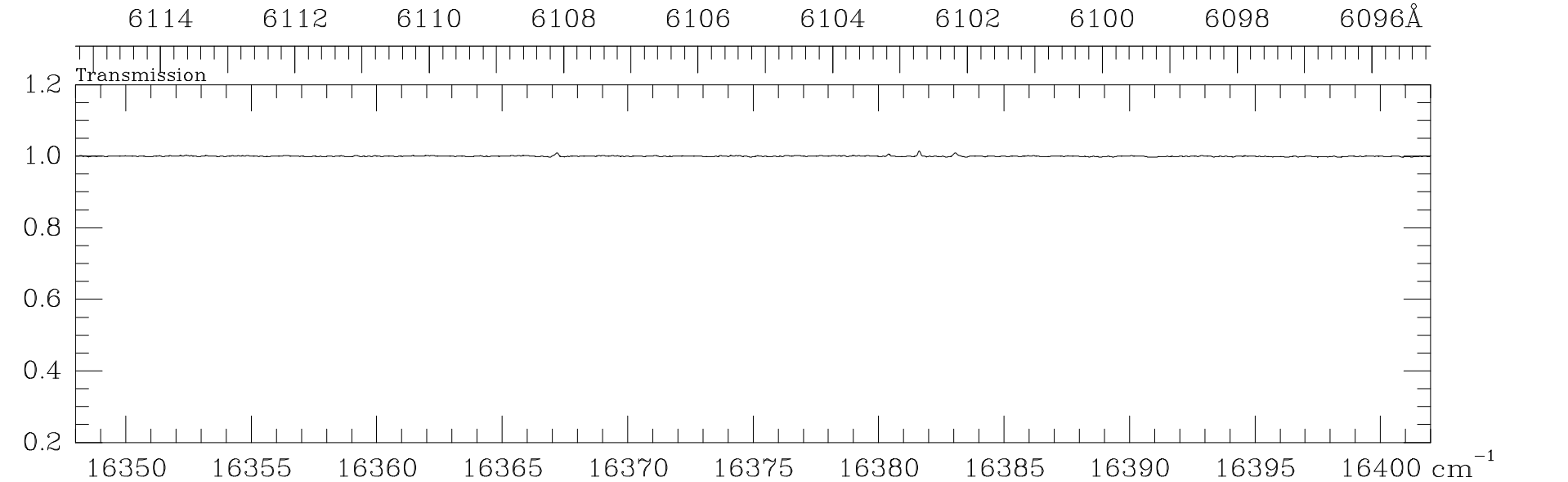

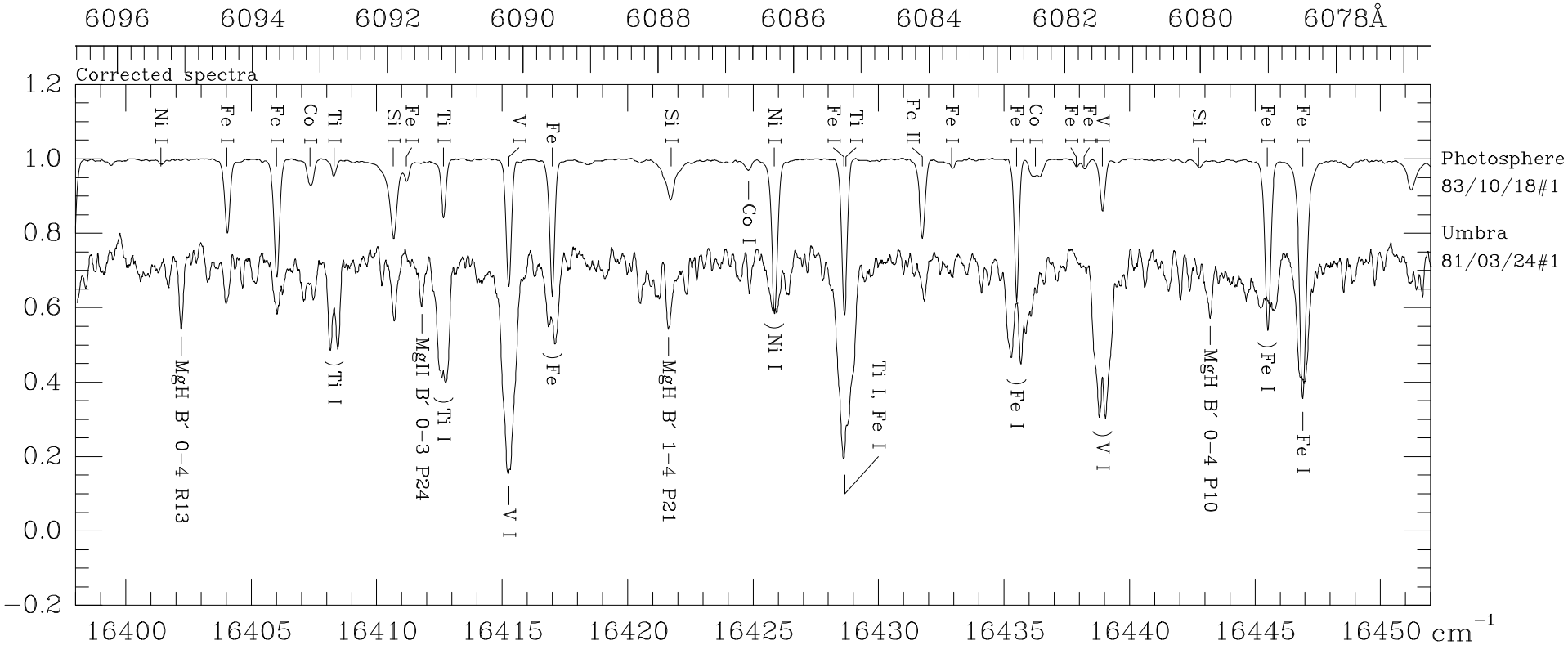

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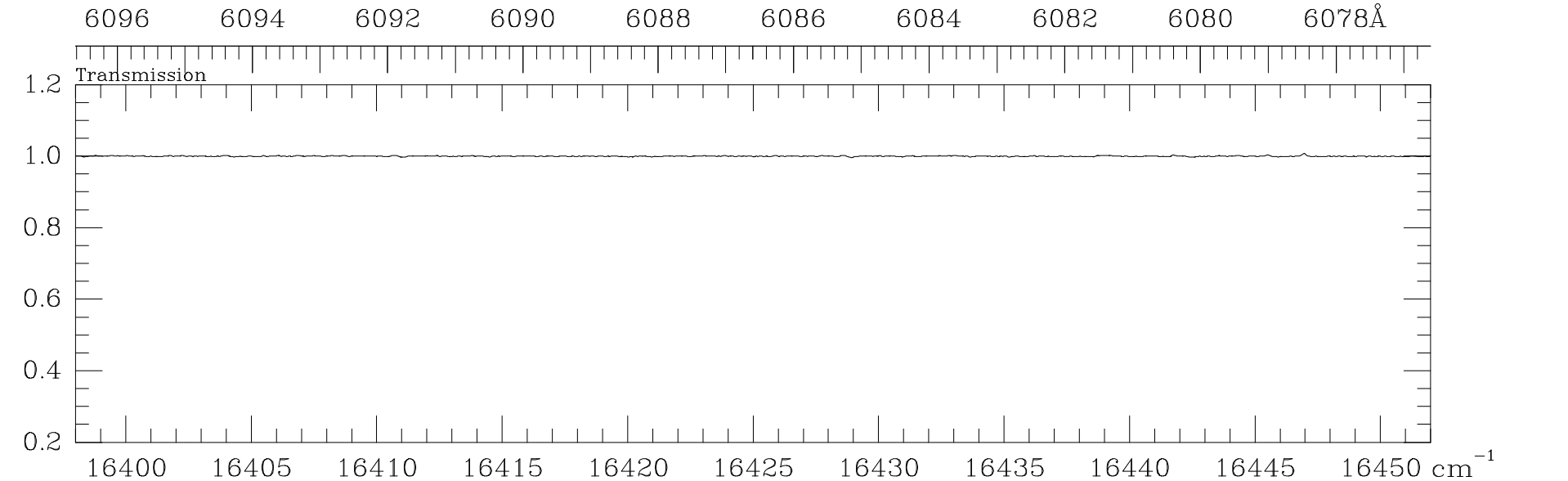

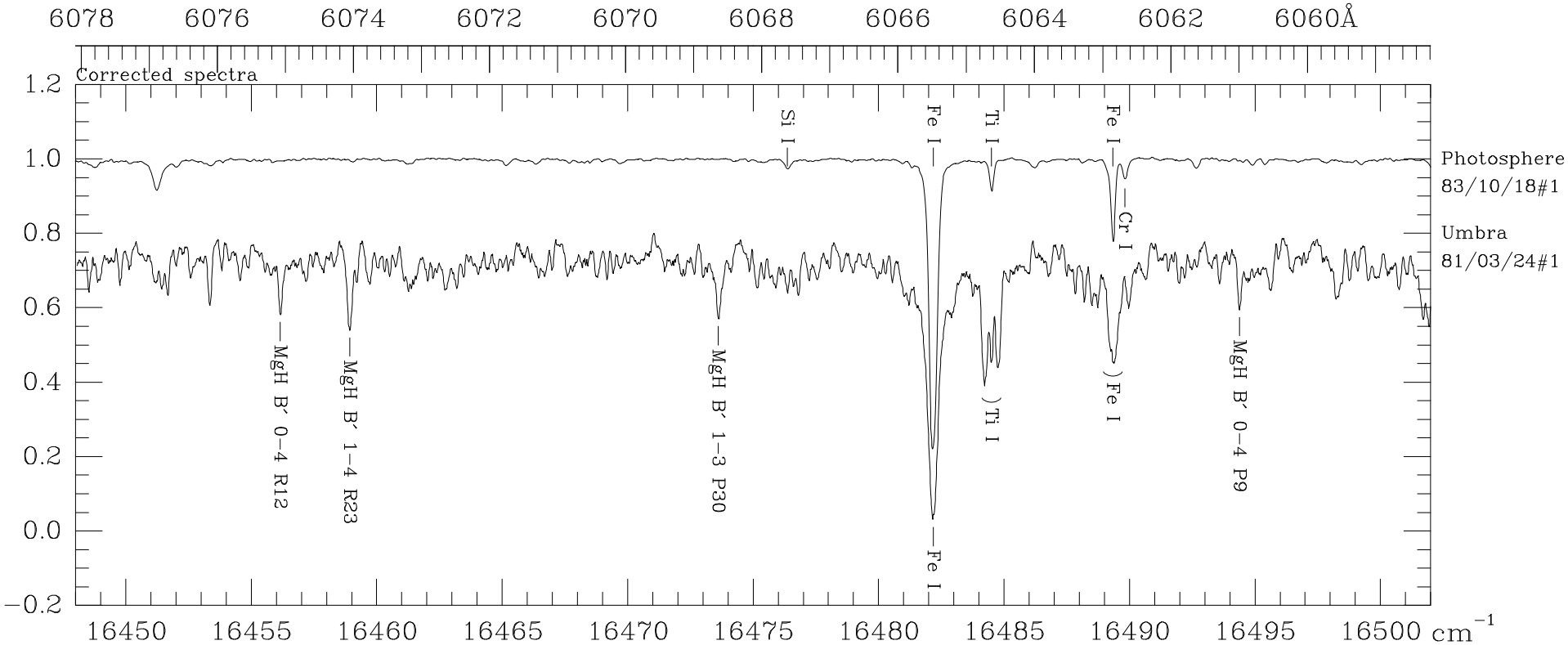

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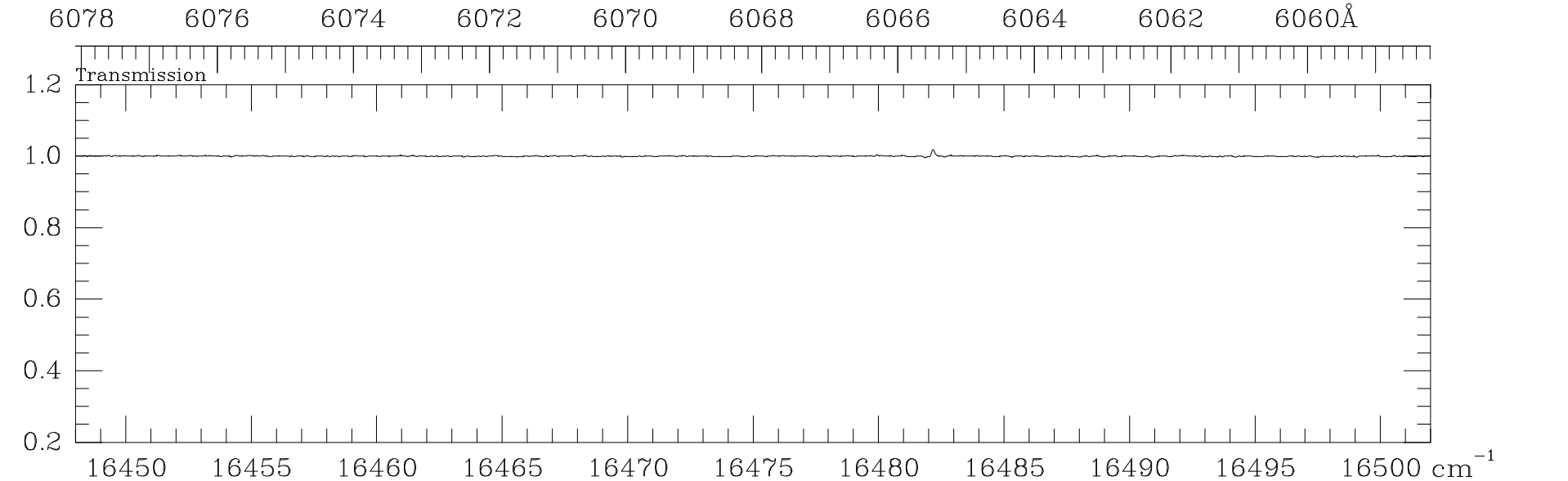
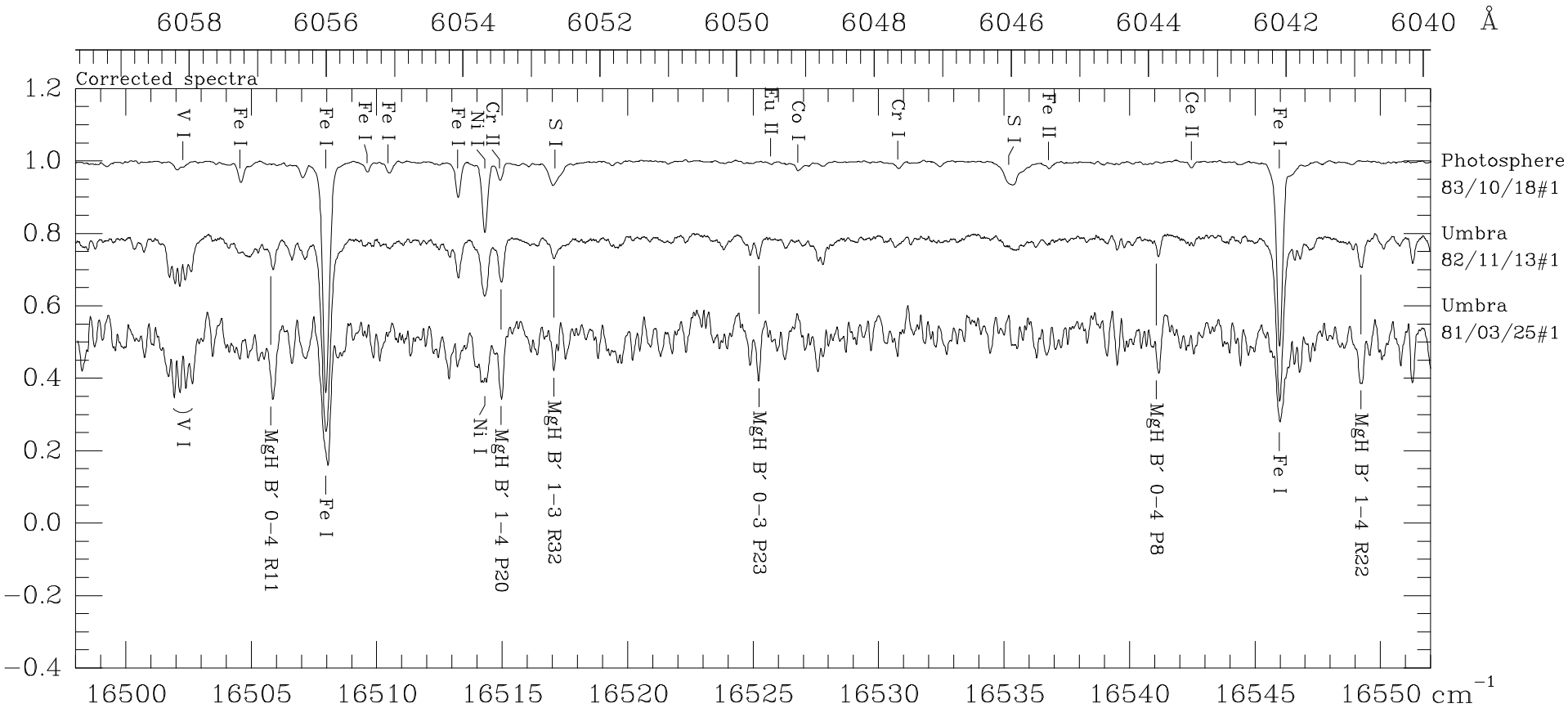
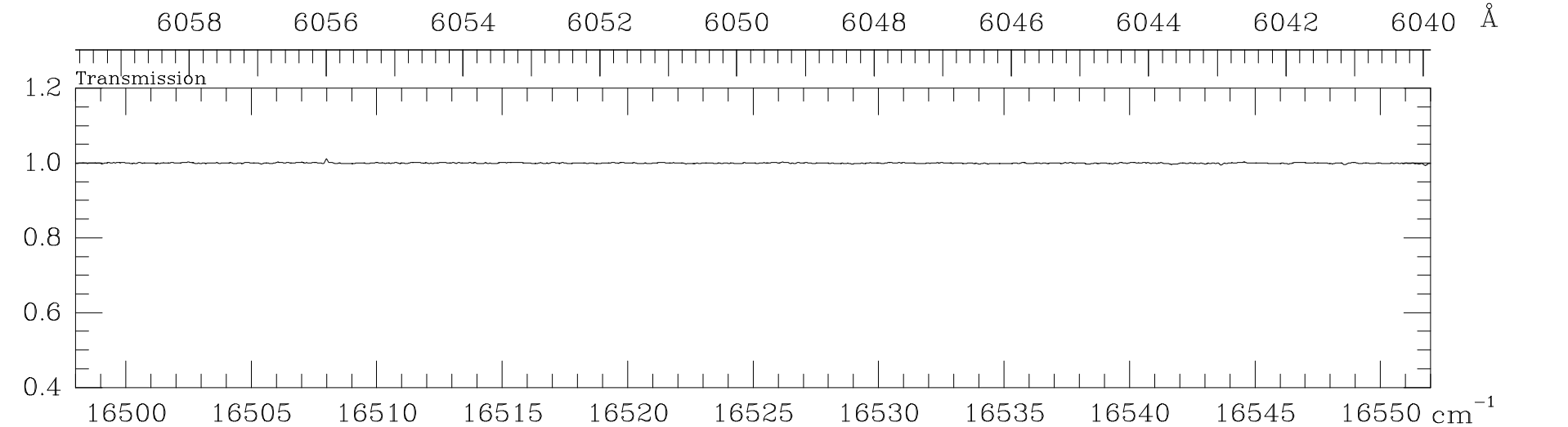
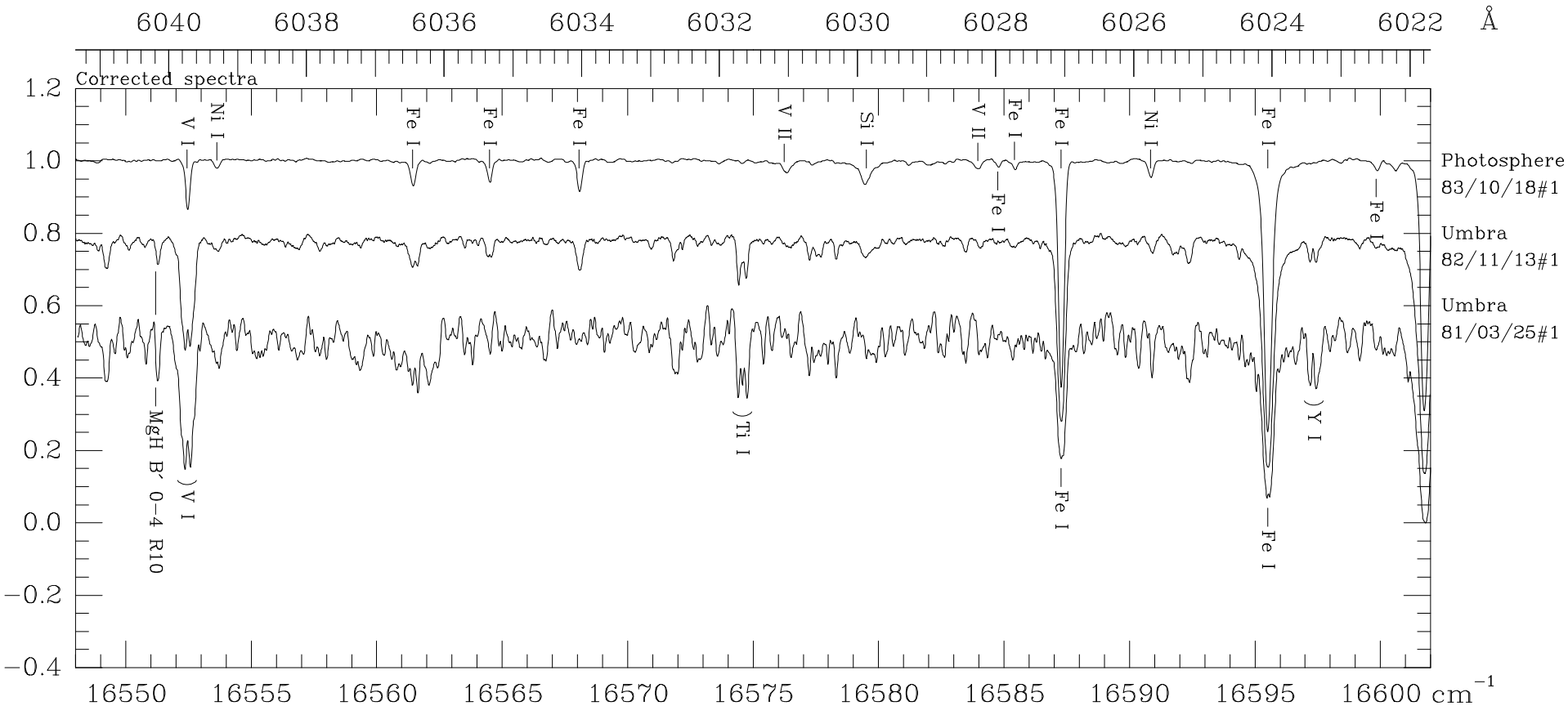


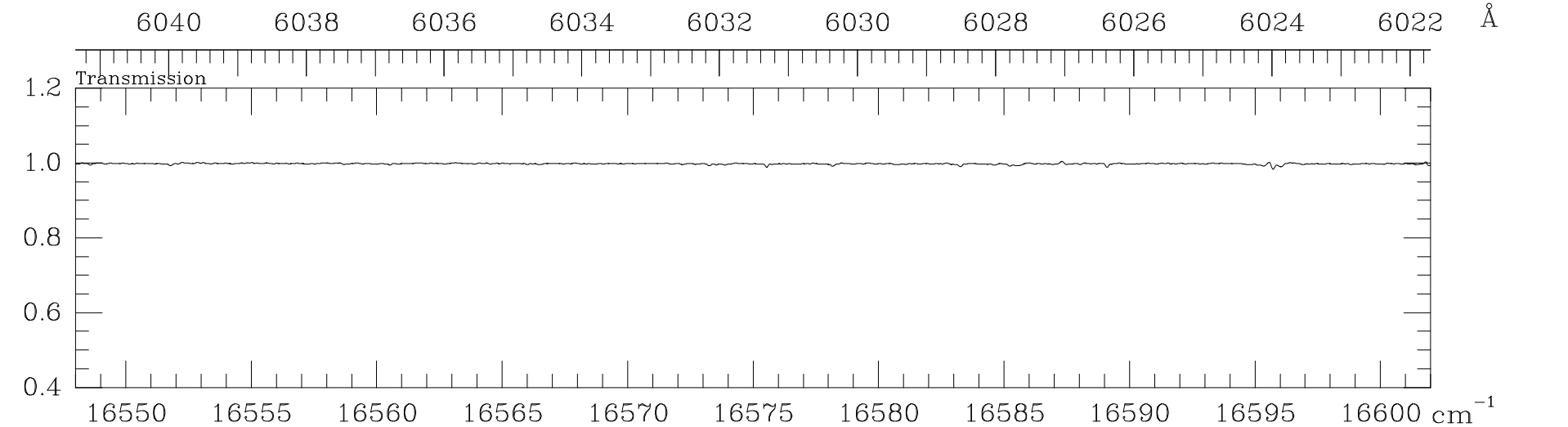


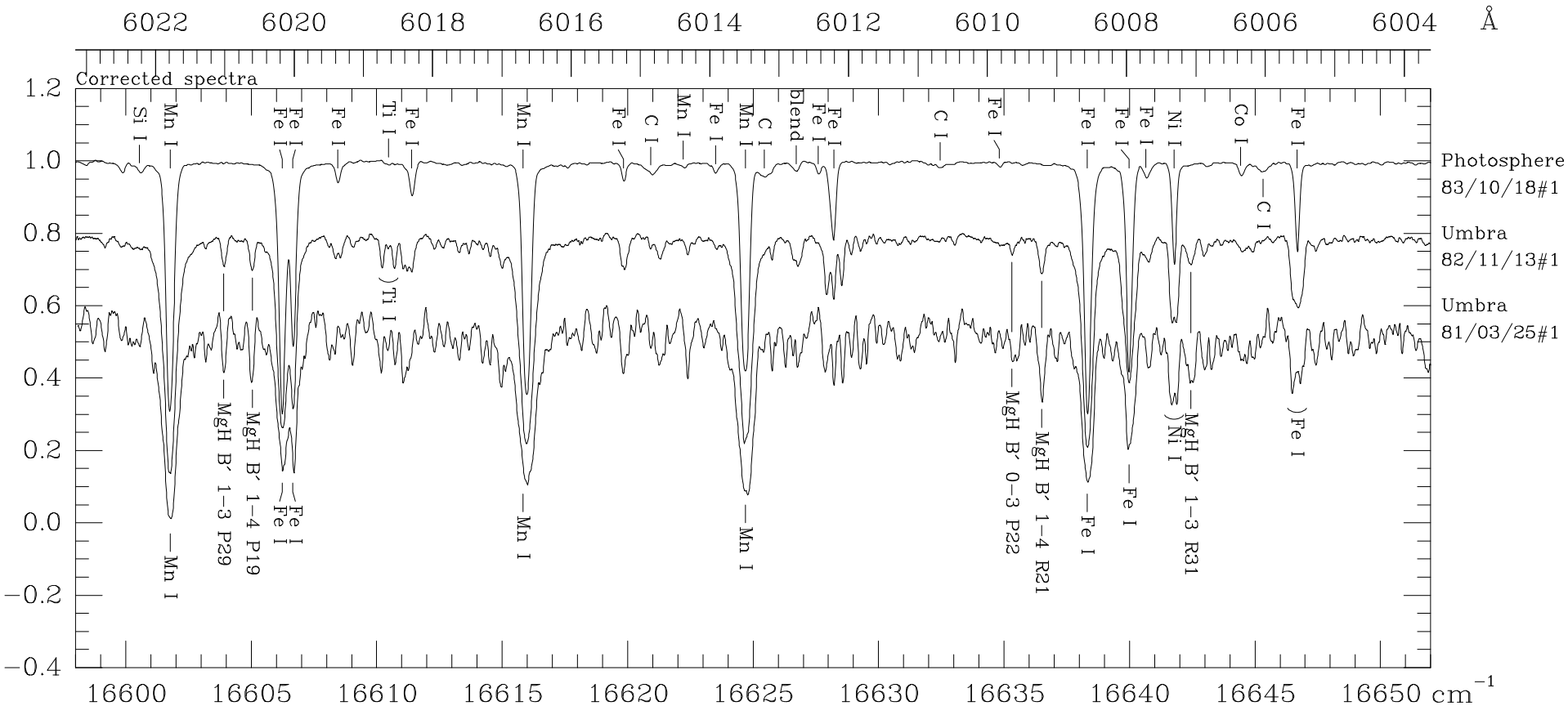
The unlabeled features in the lower umbral spectrum are due mostly to lines of the TiO α bands.





The unlabeled features in the lower umbral spectrum are due mostly to lines of the TiO α and γ' bands.





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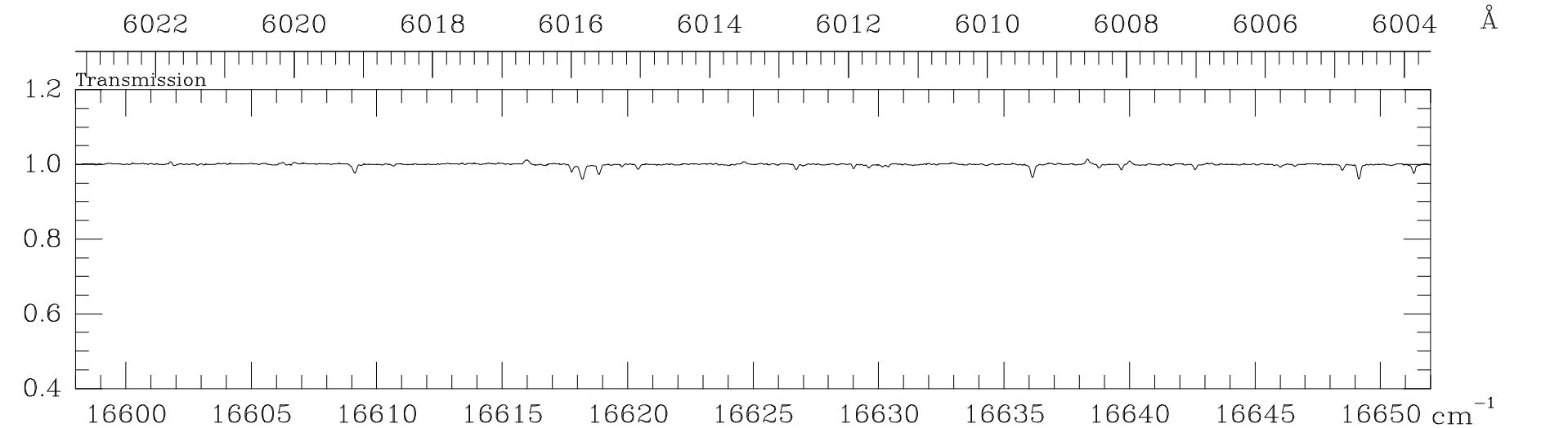

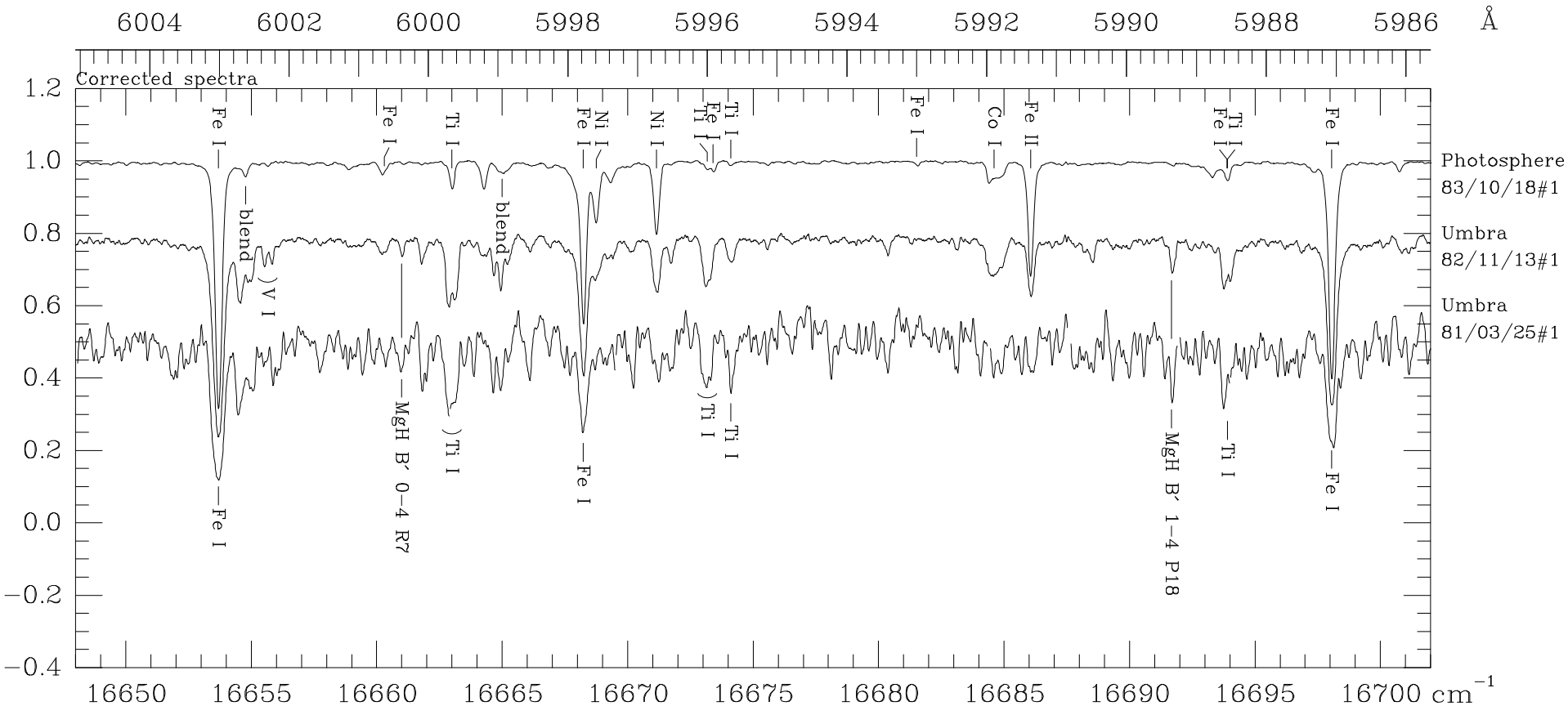

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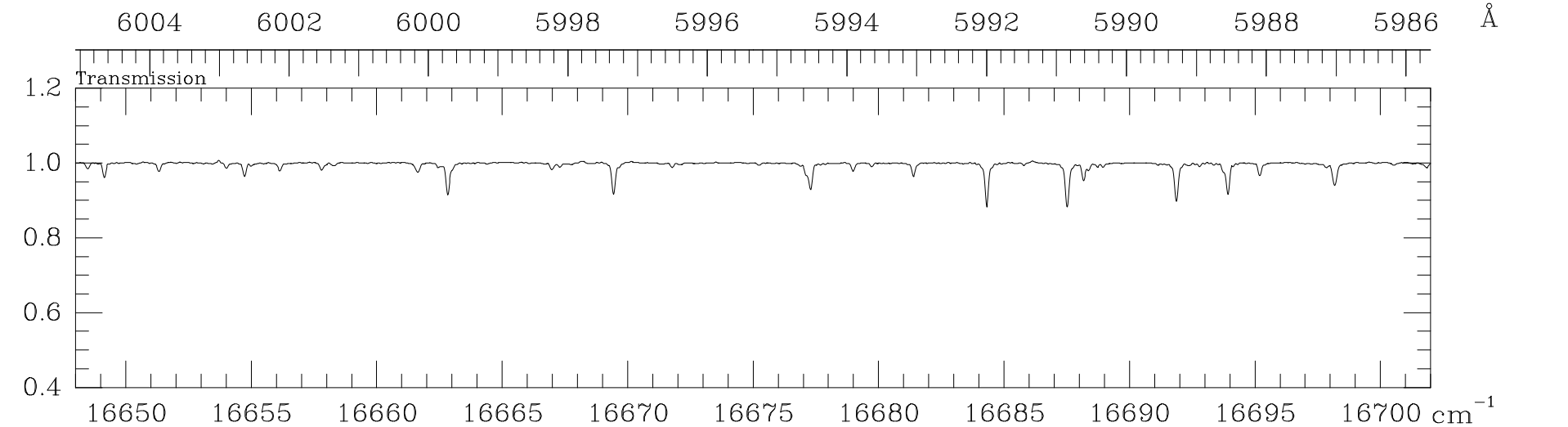

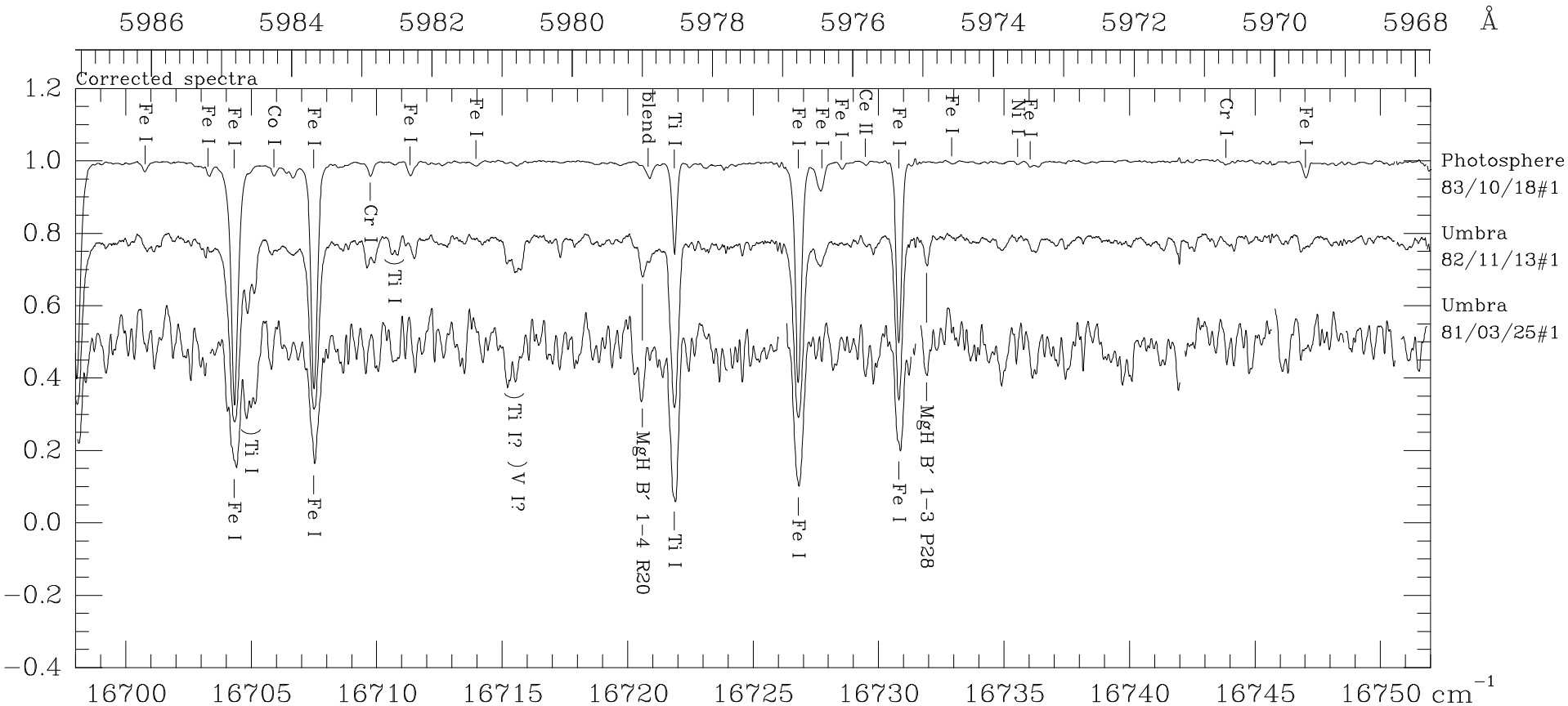

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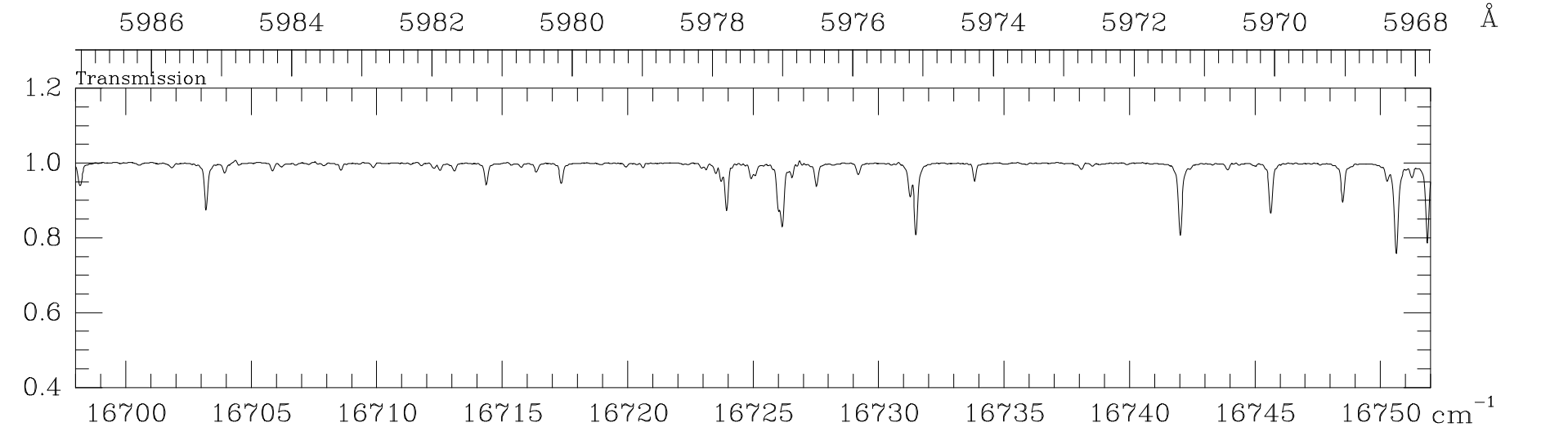

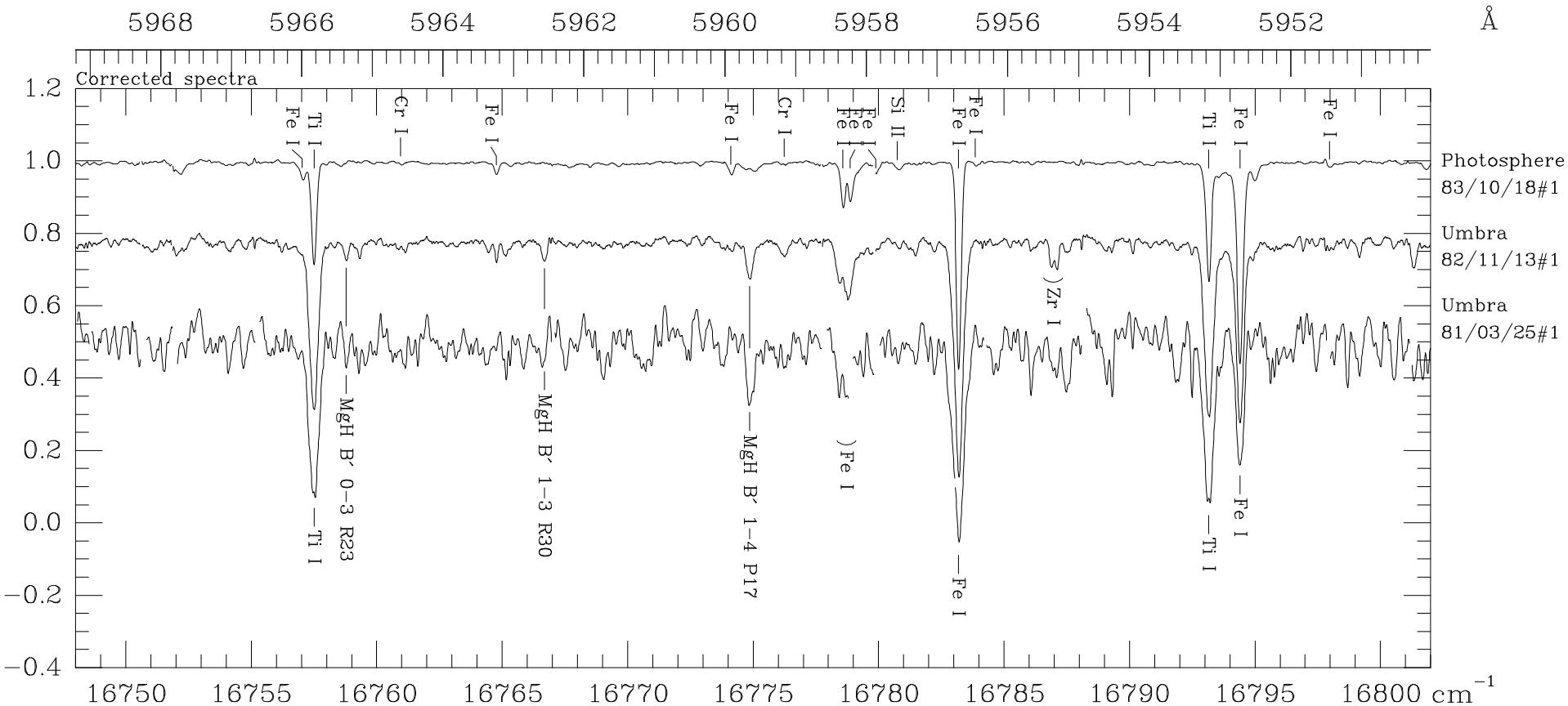

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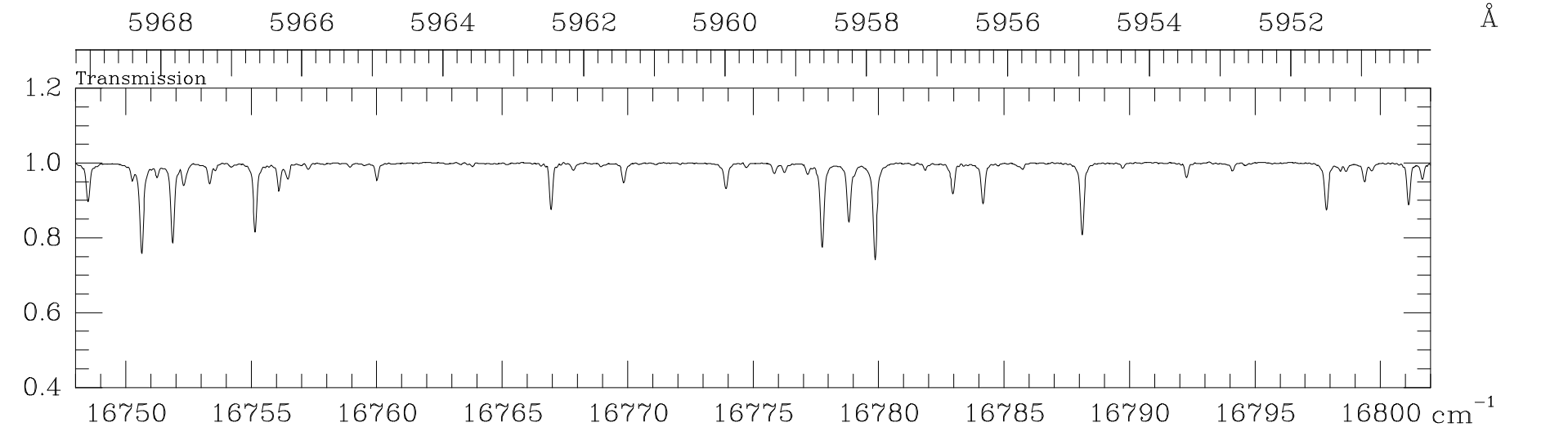

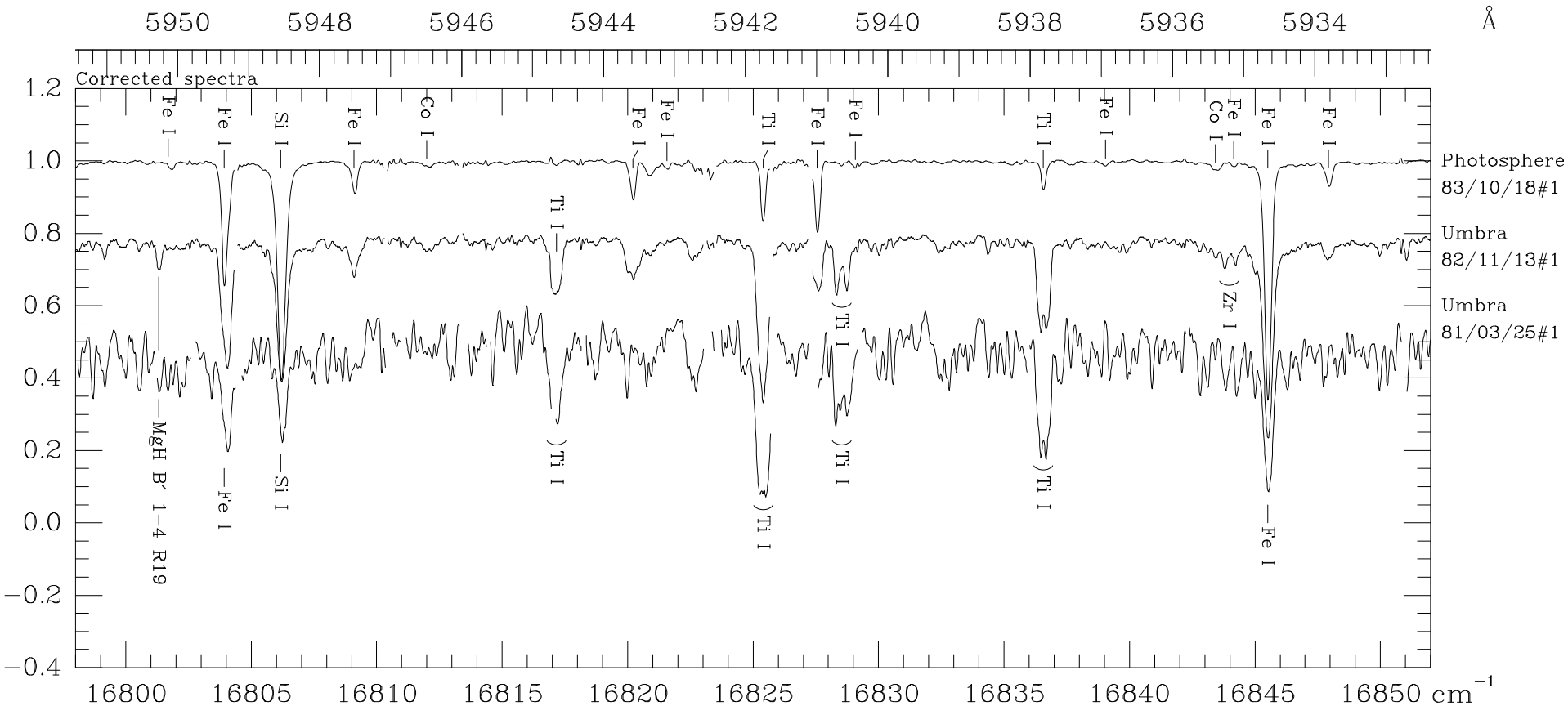

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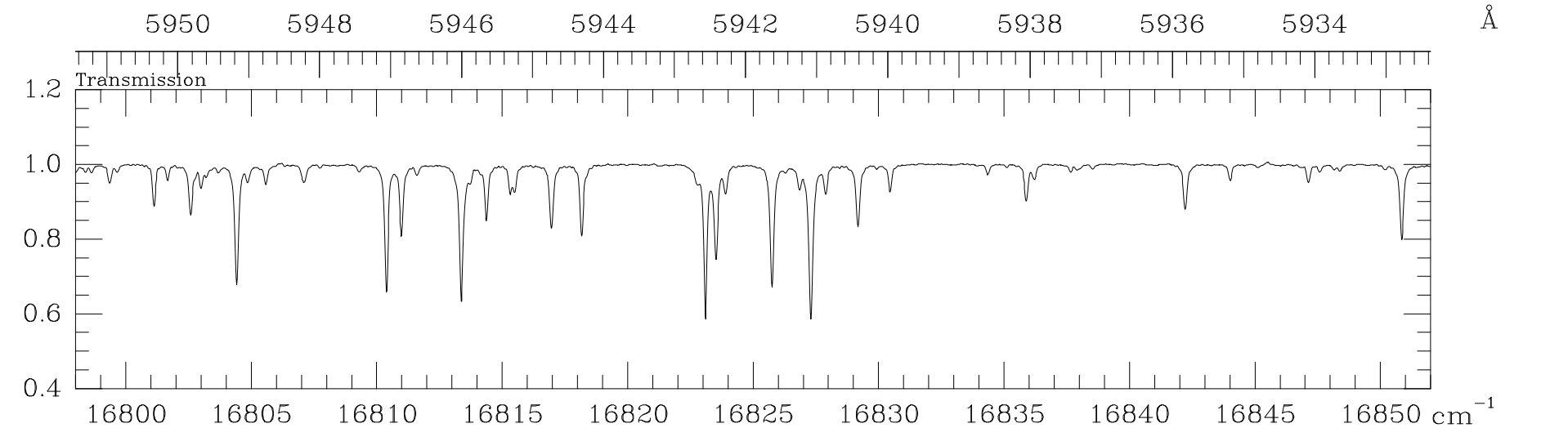

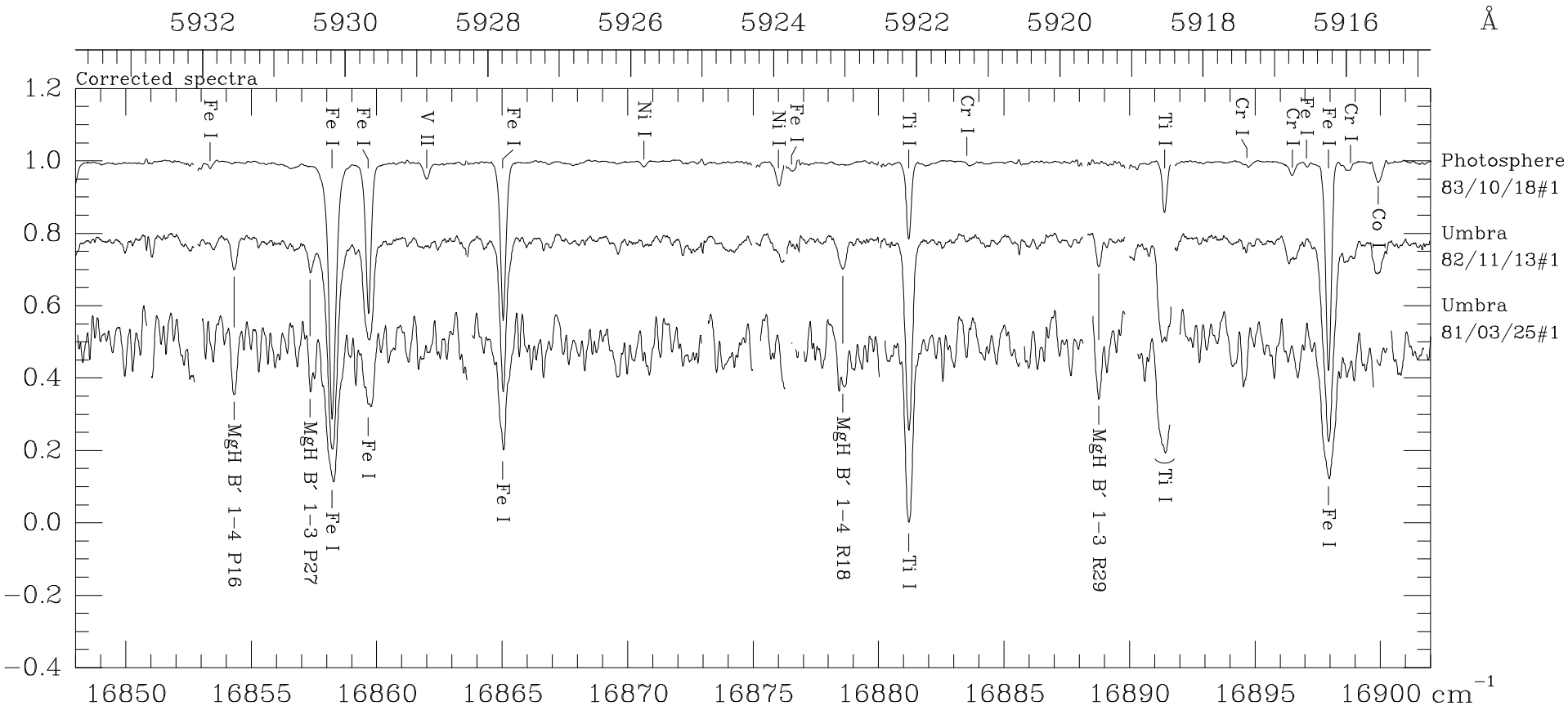

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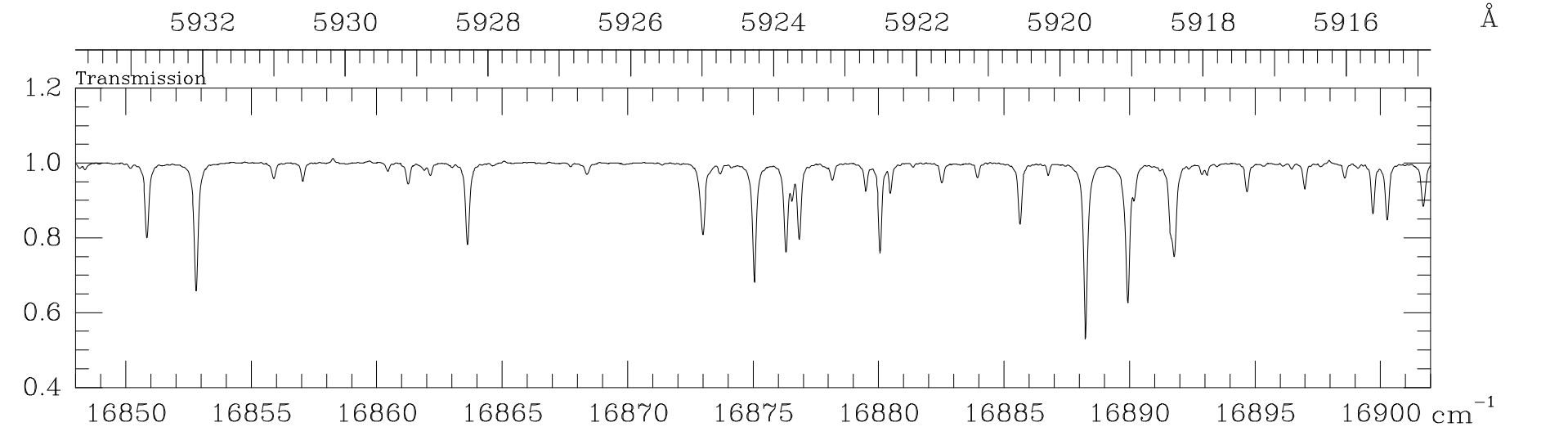

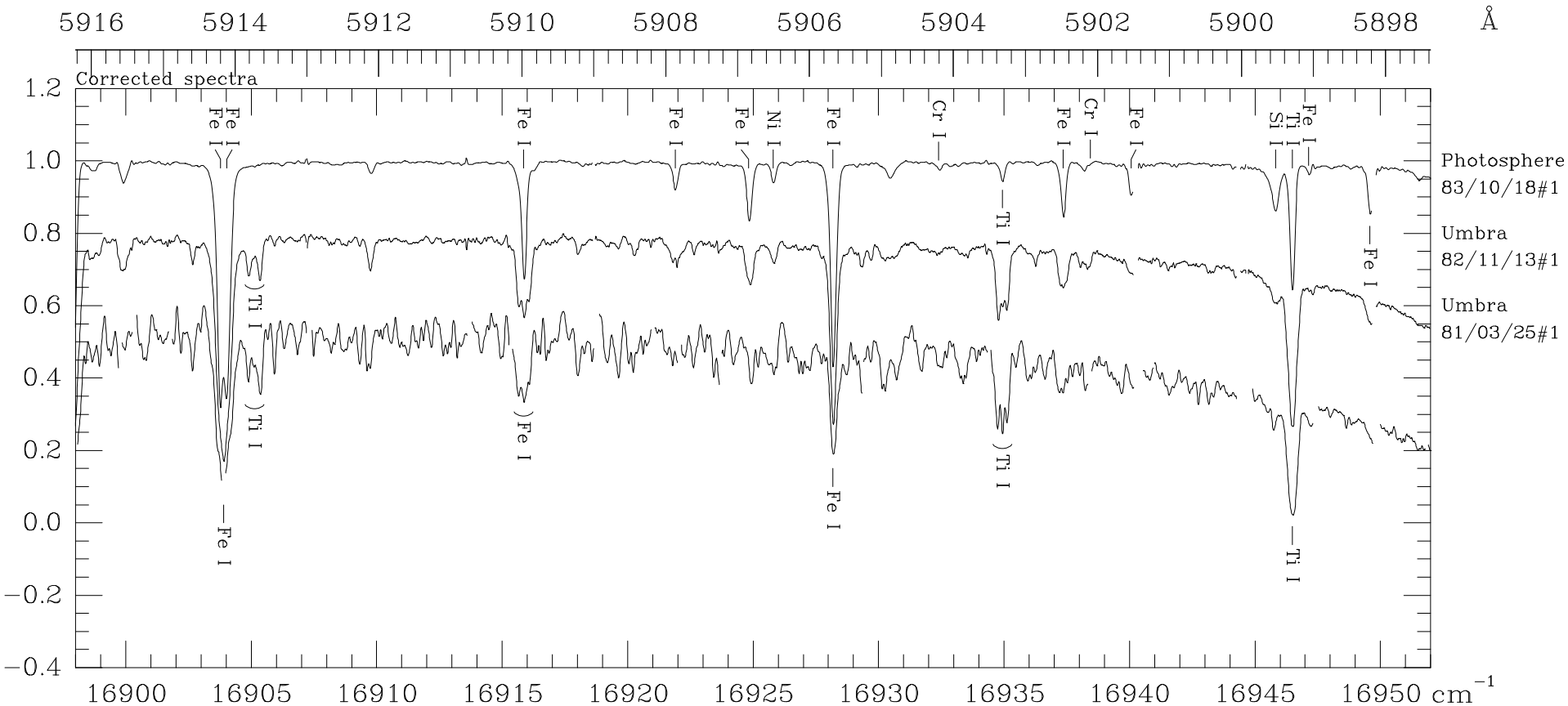

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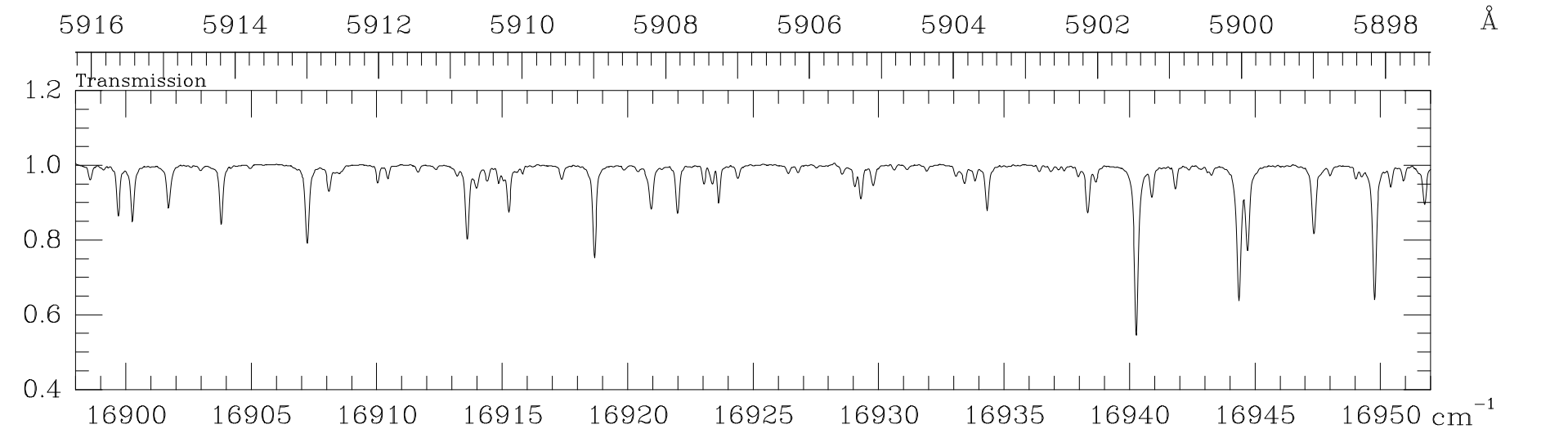

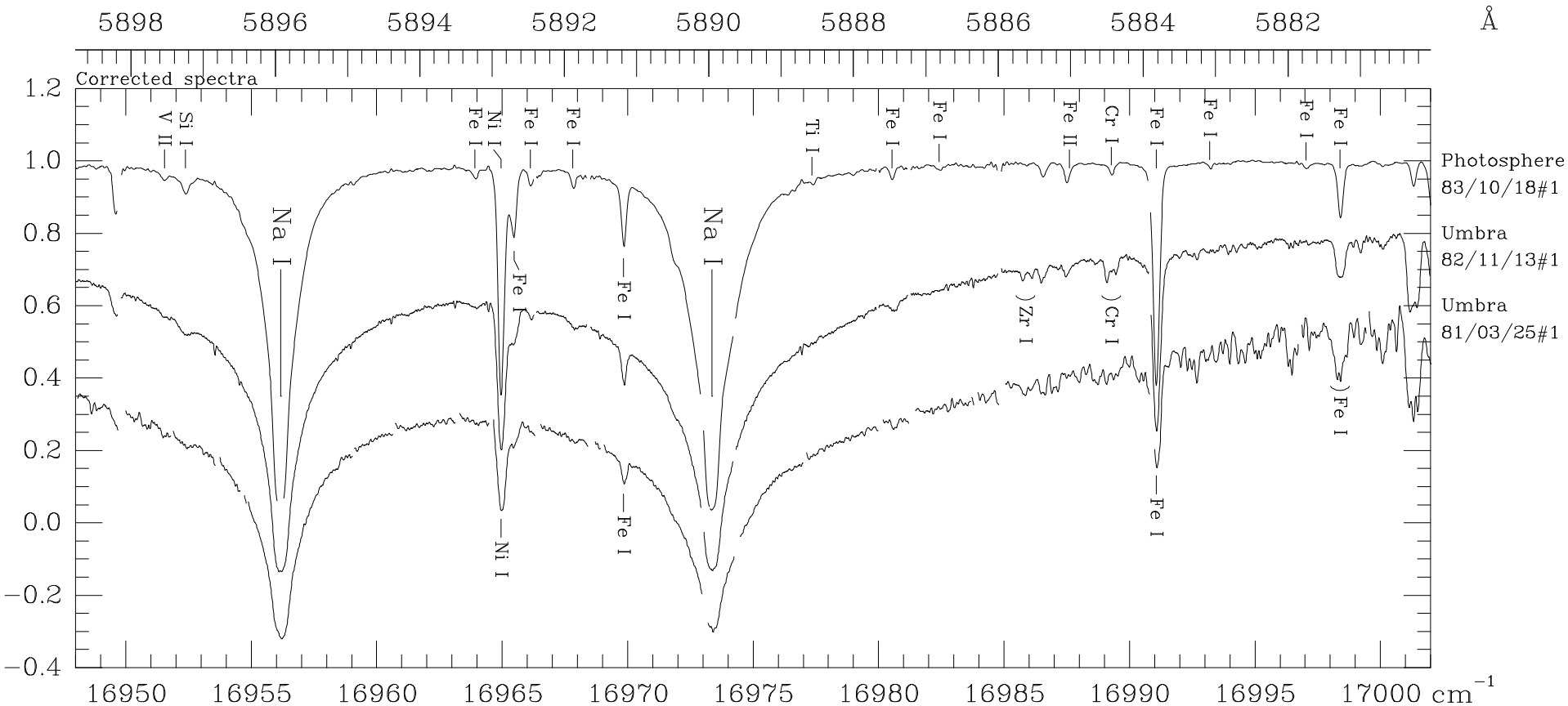

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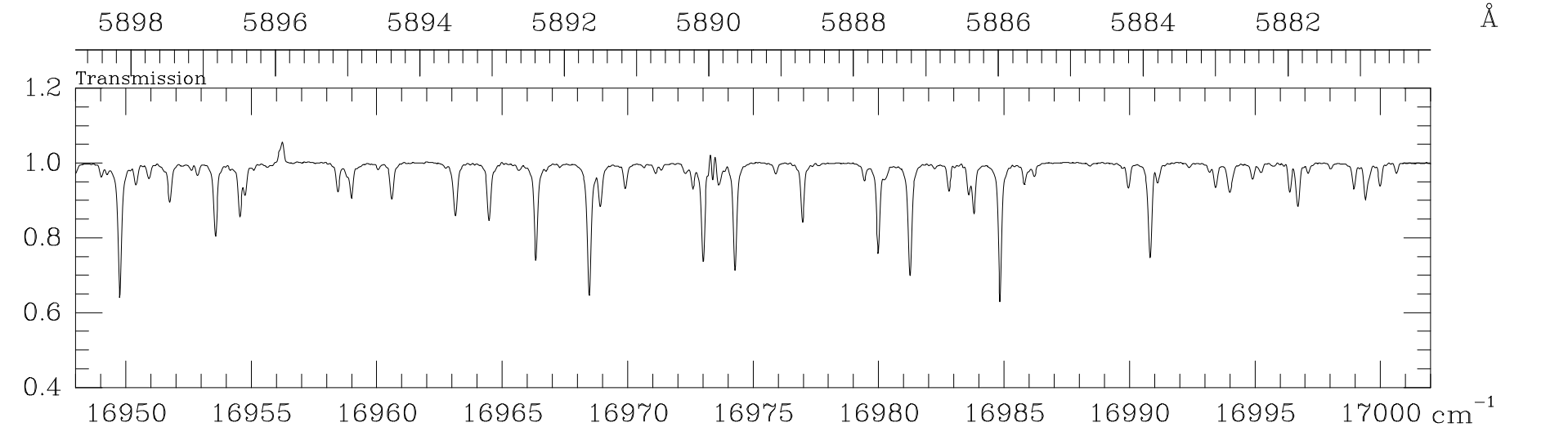

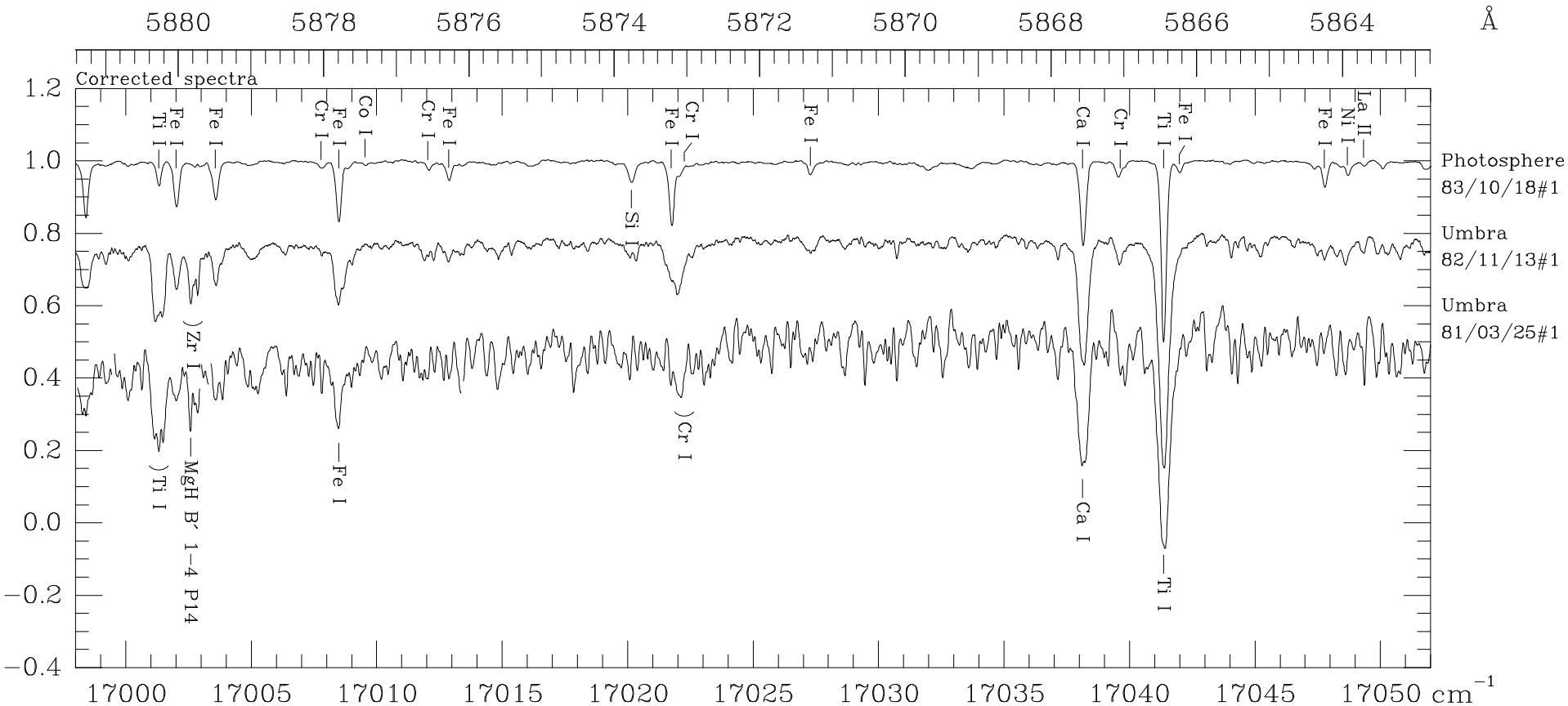

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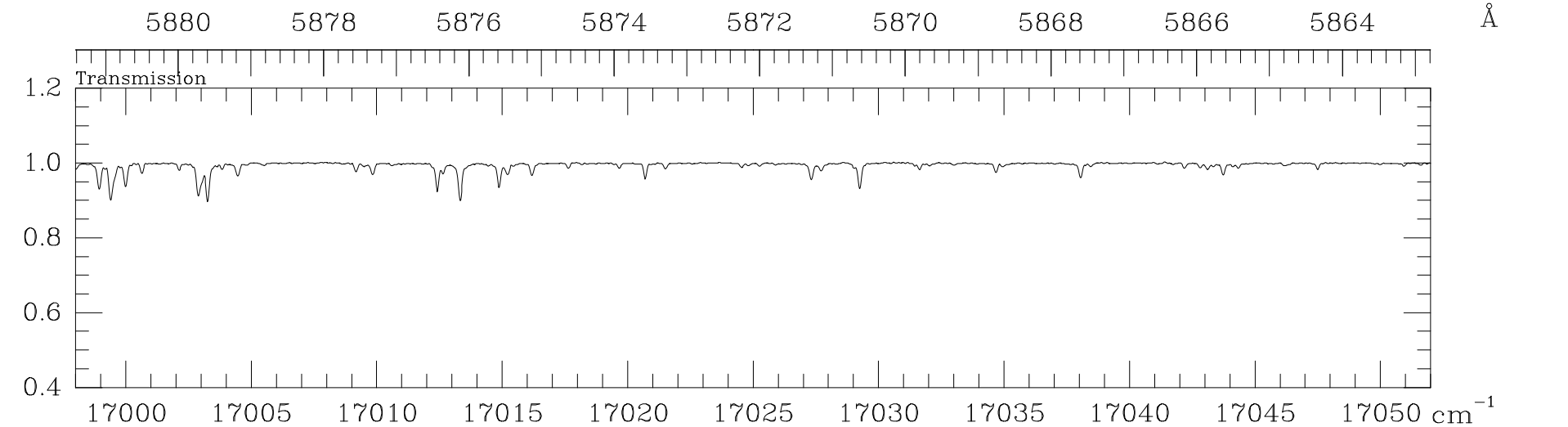

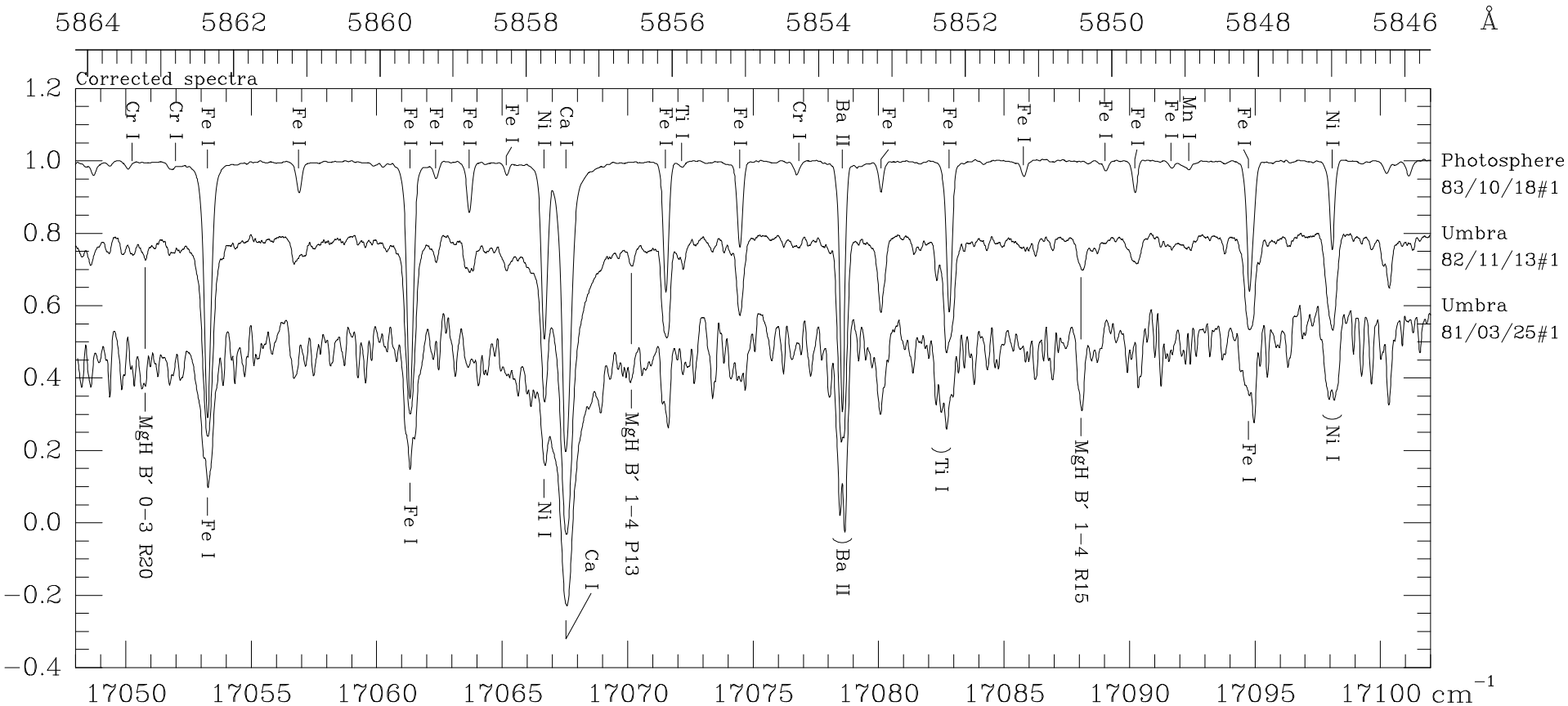

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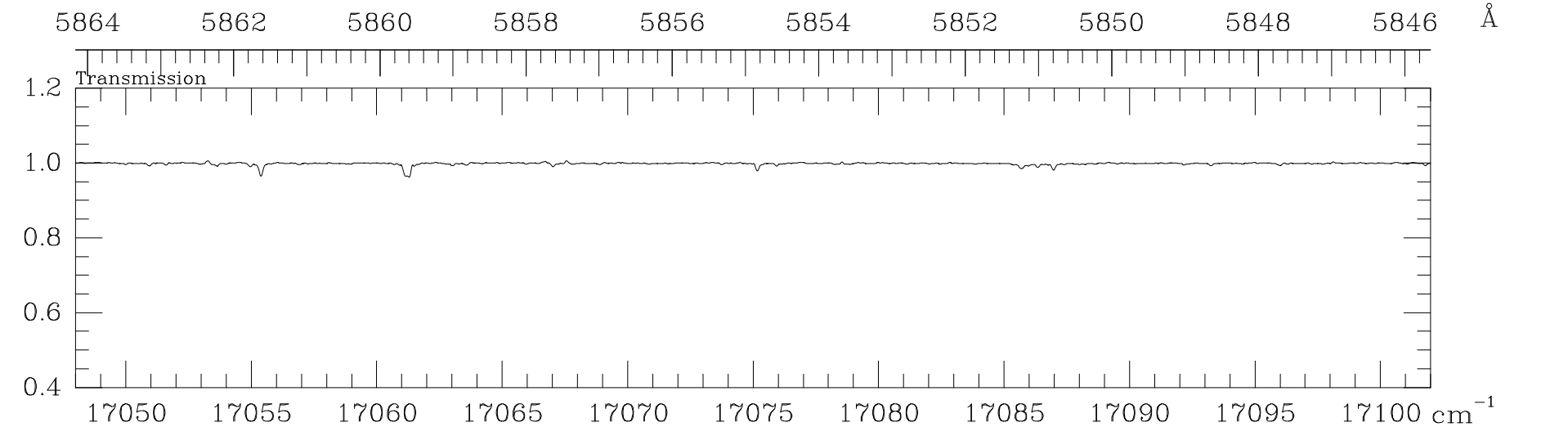

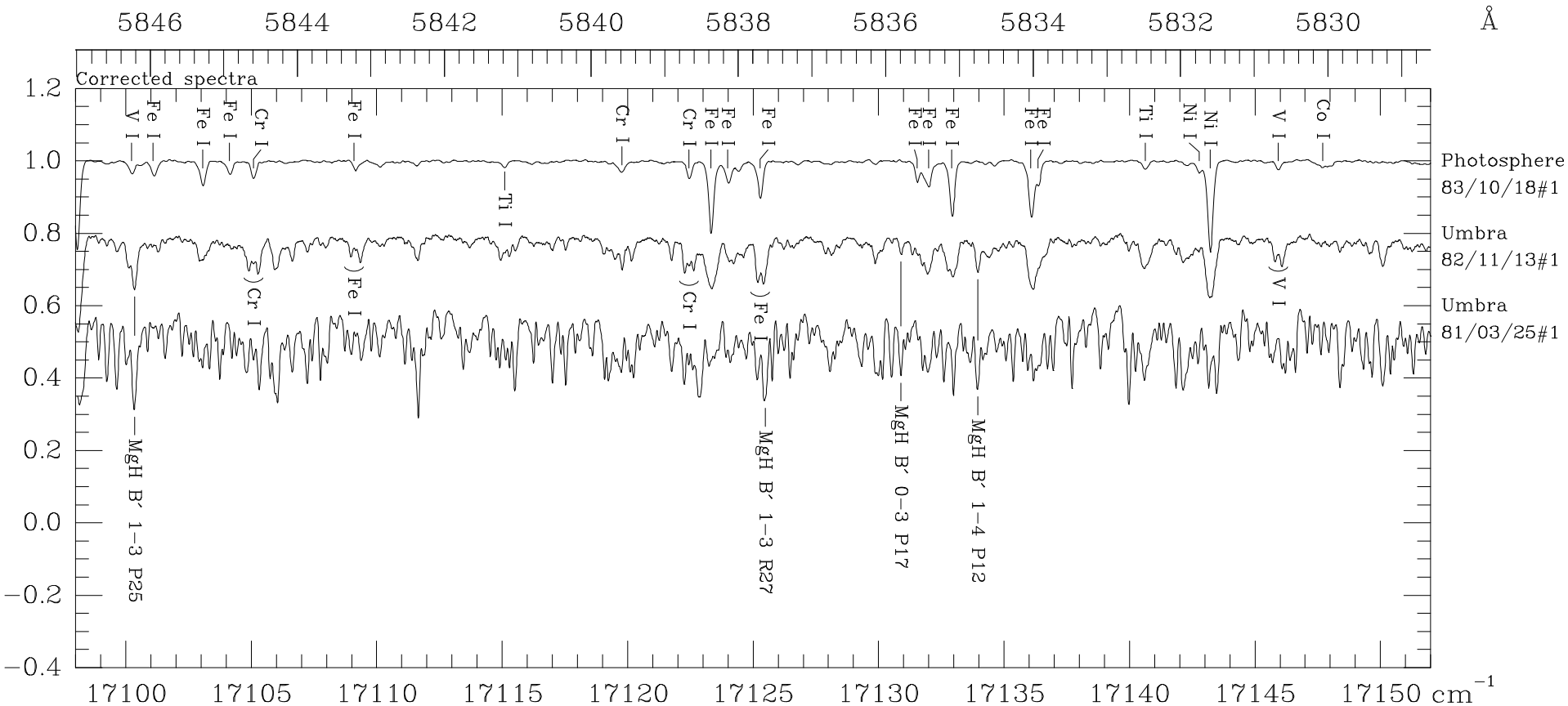

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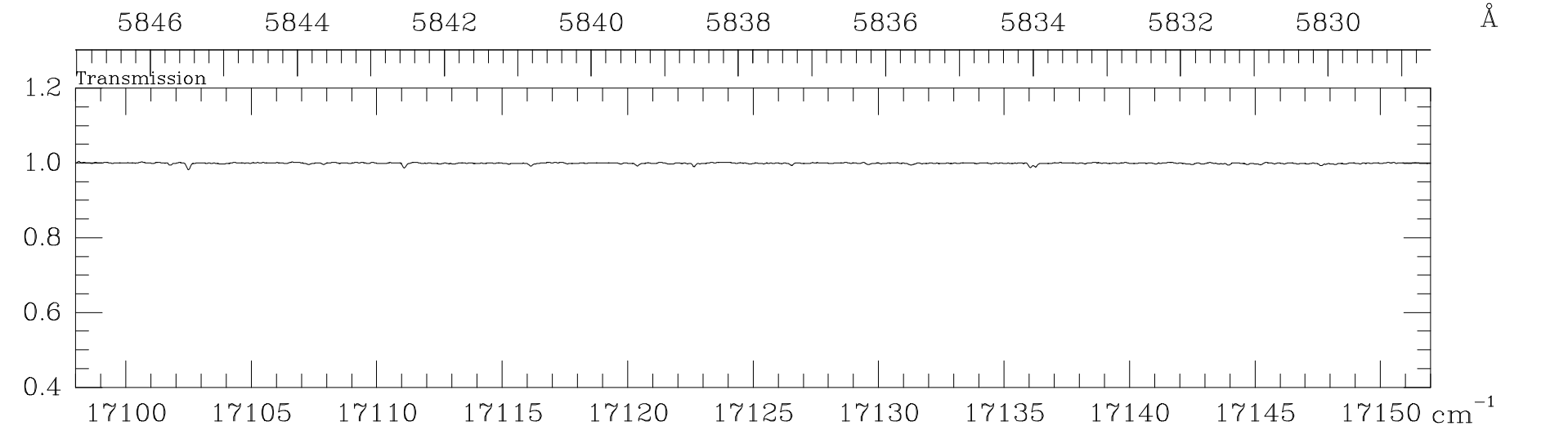

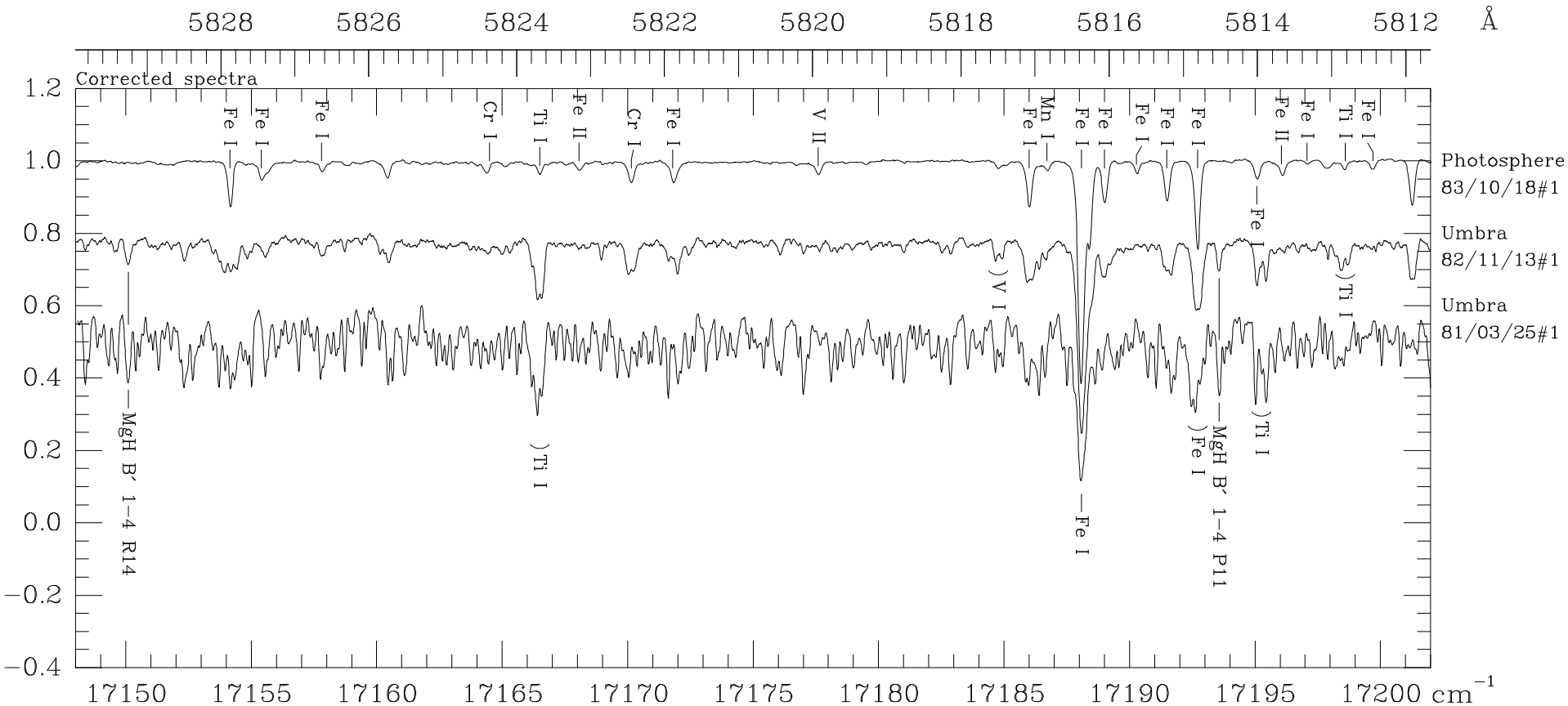

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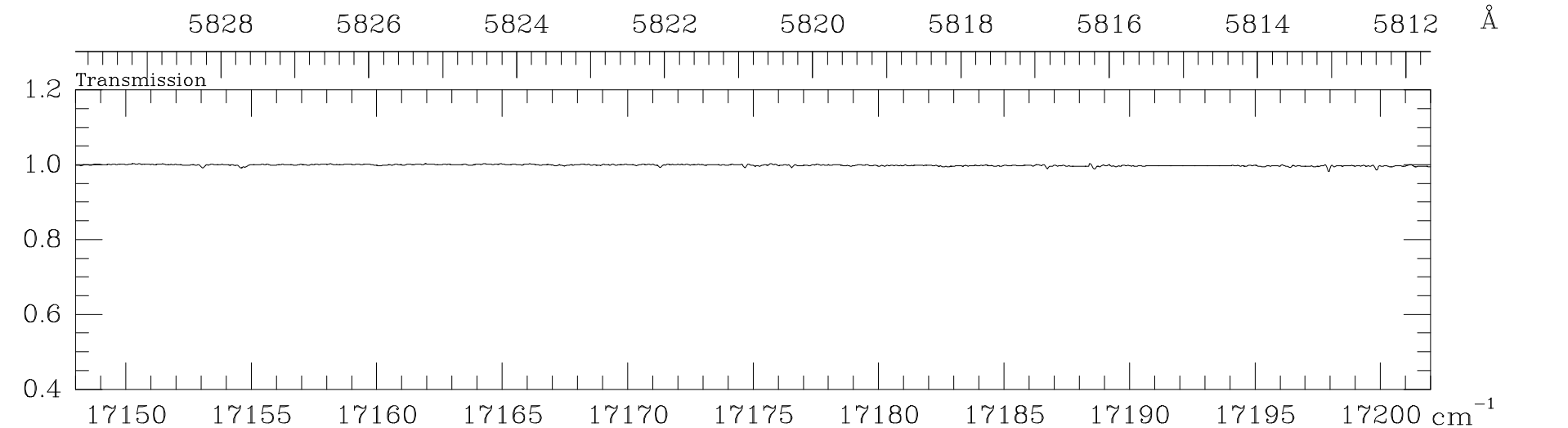

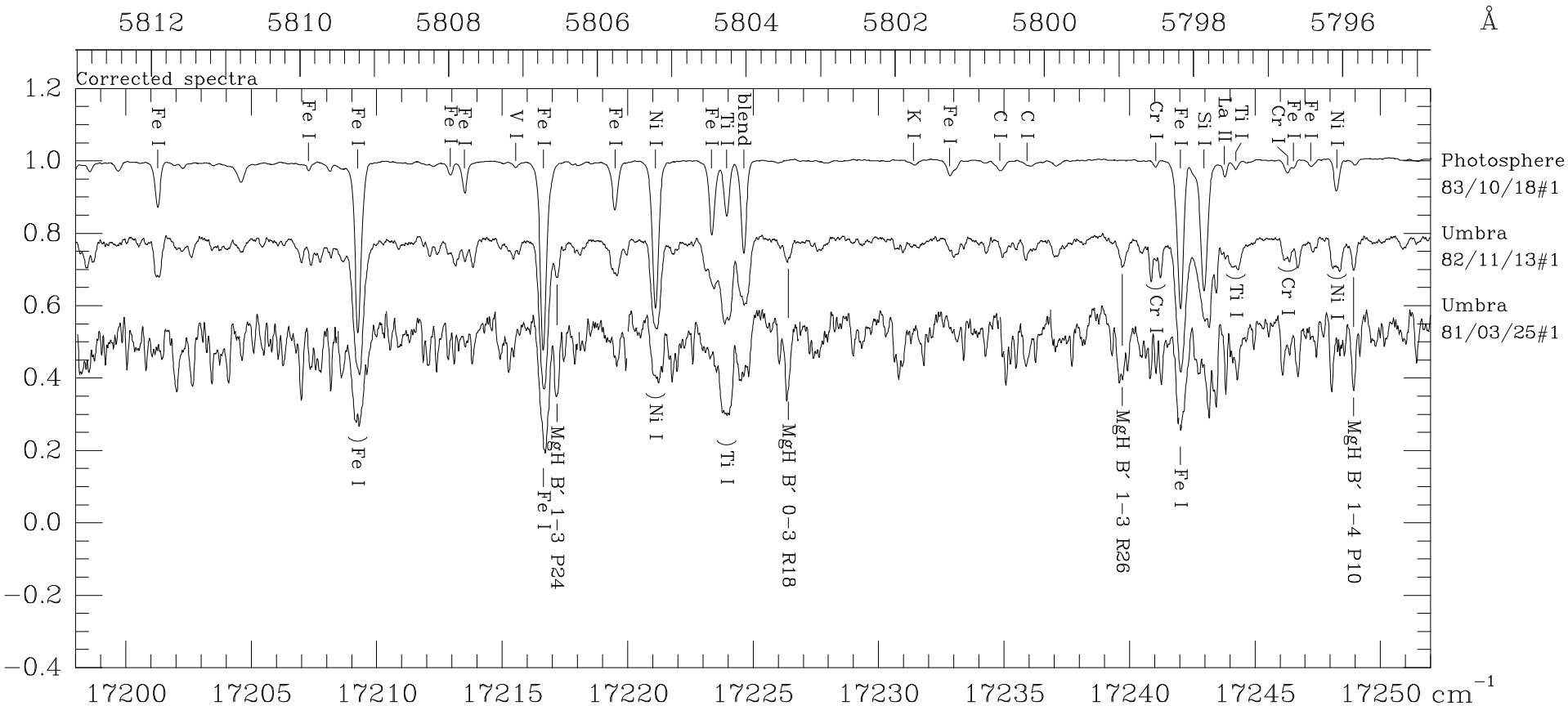

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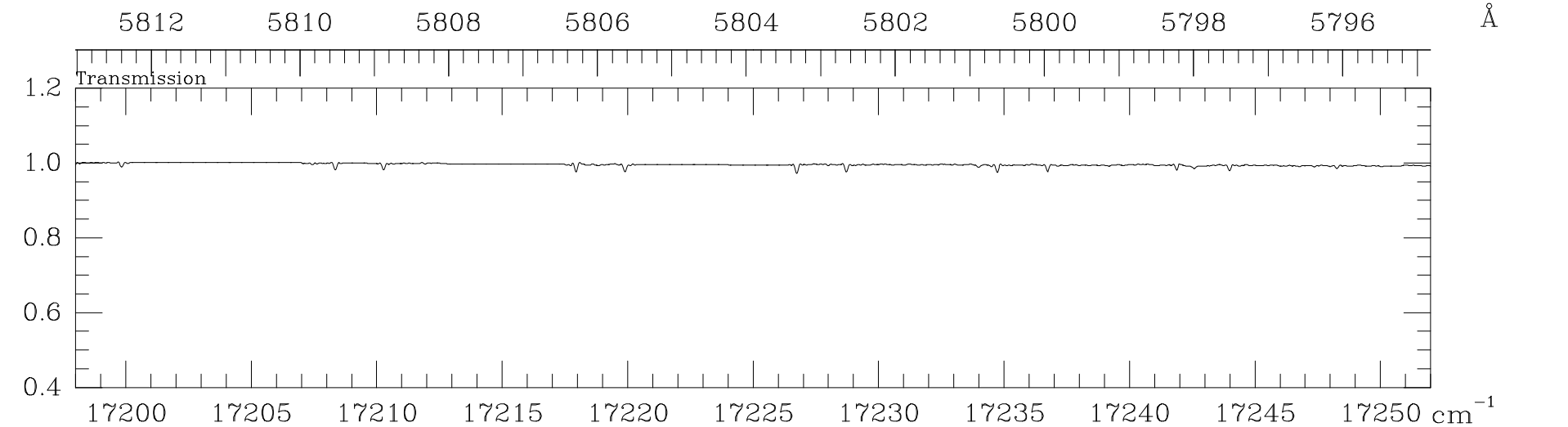

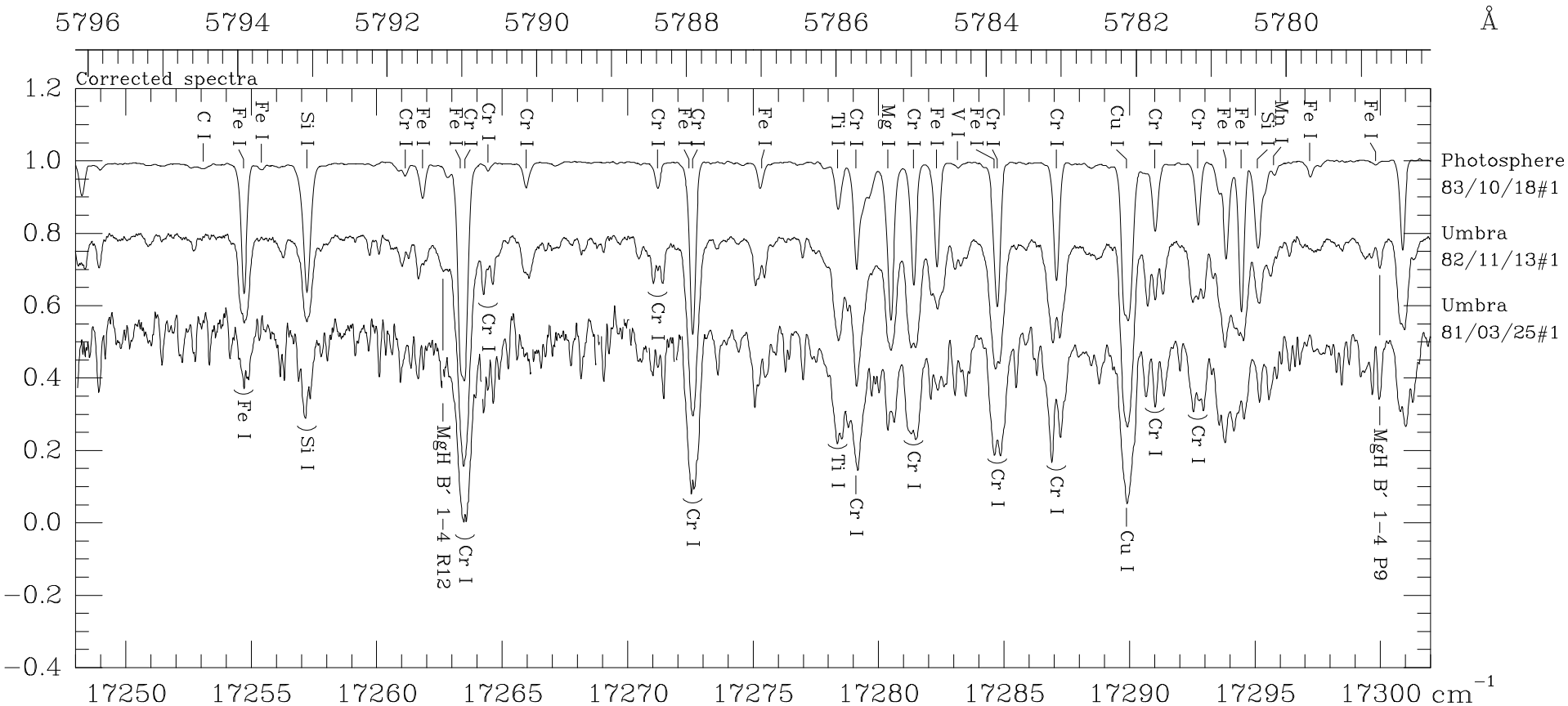

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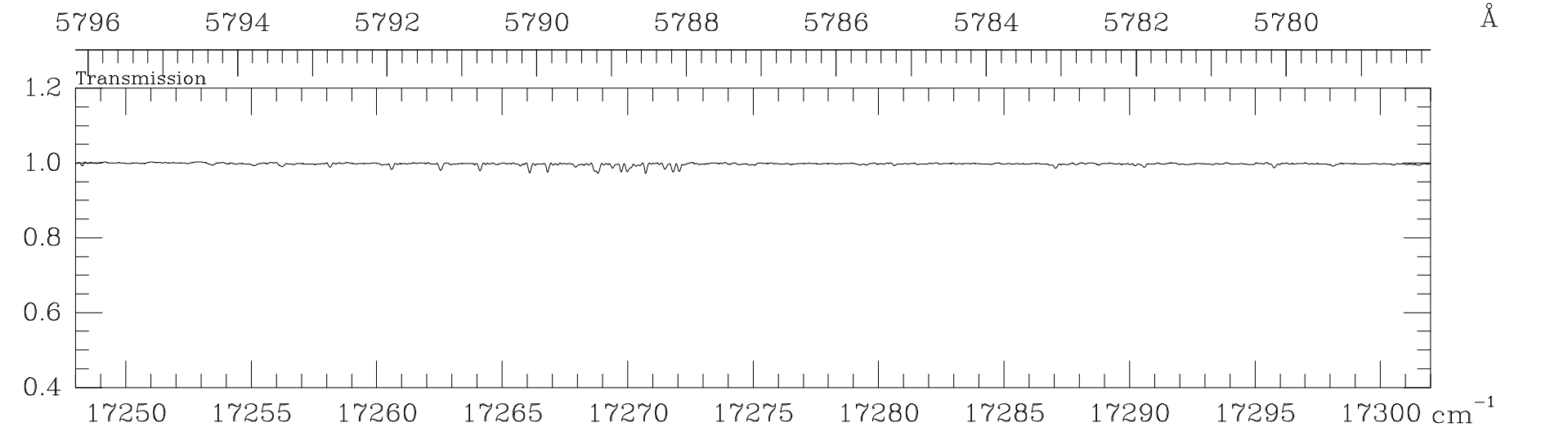

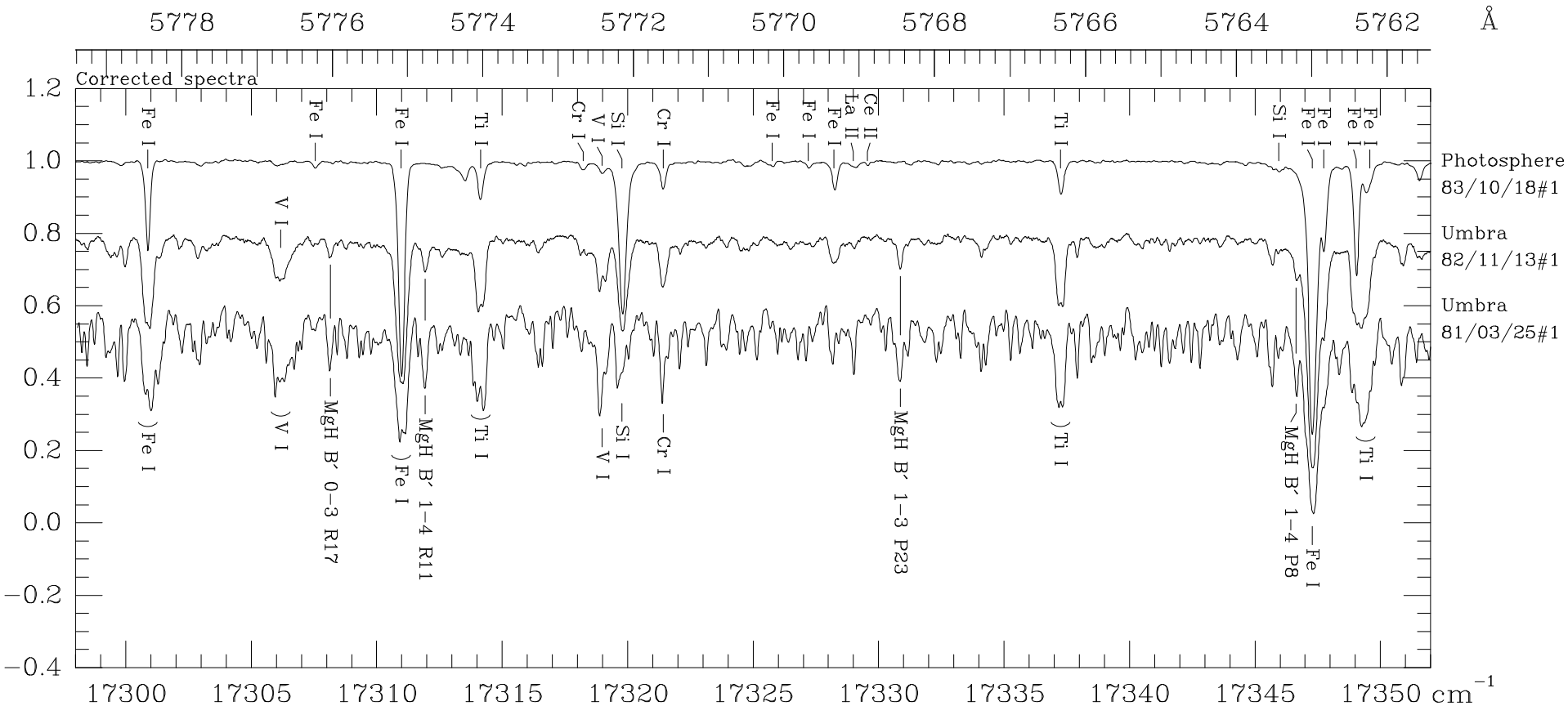

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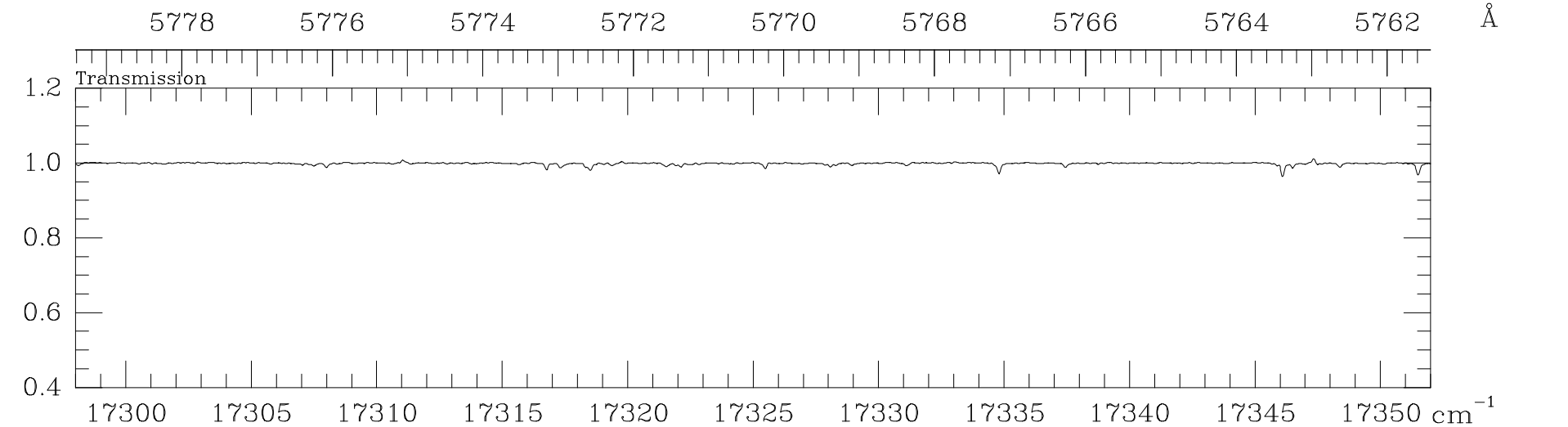

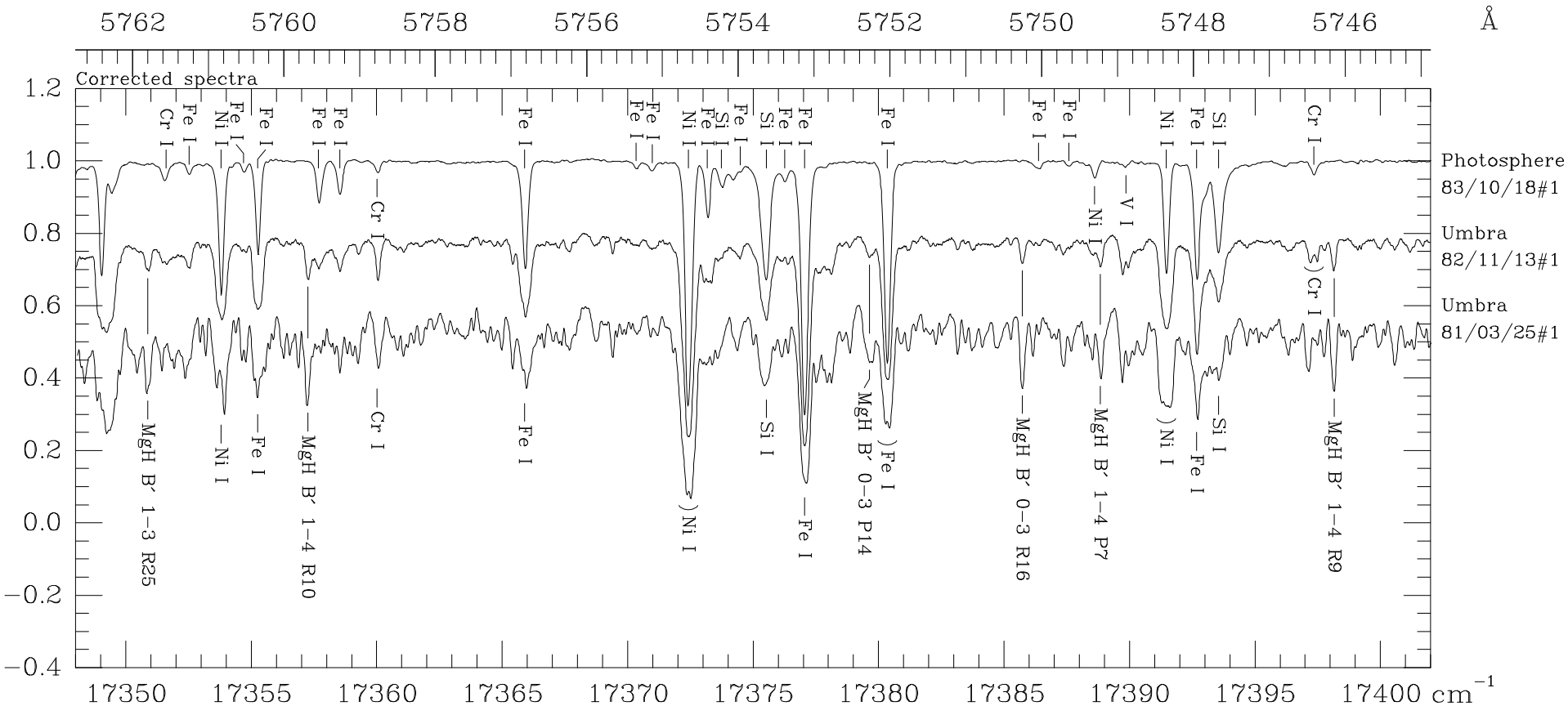

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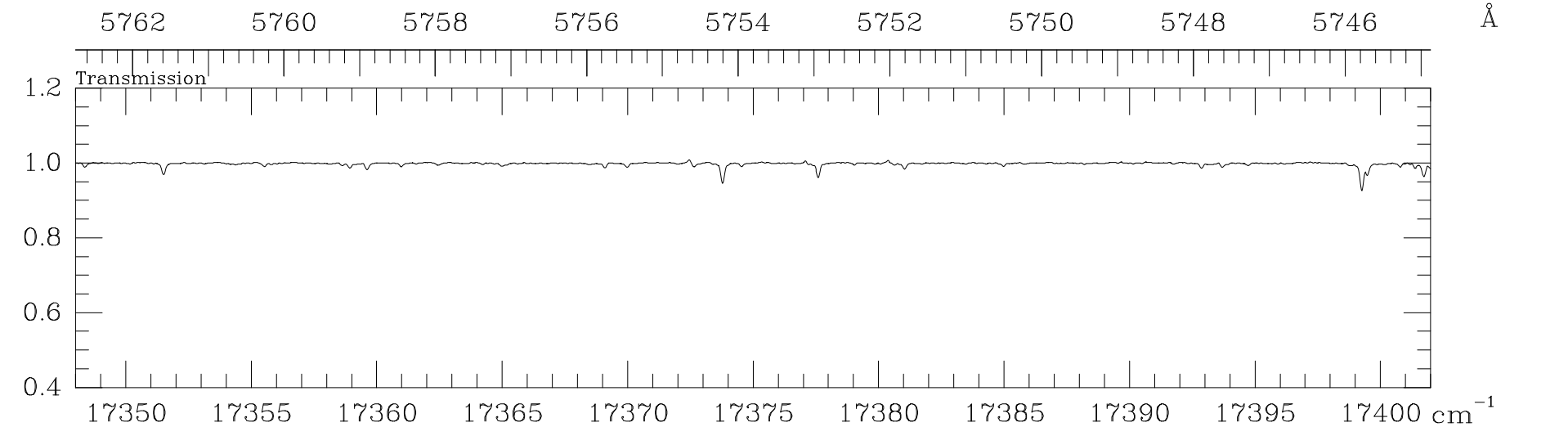
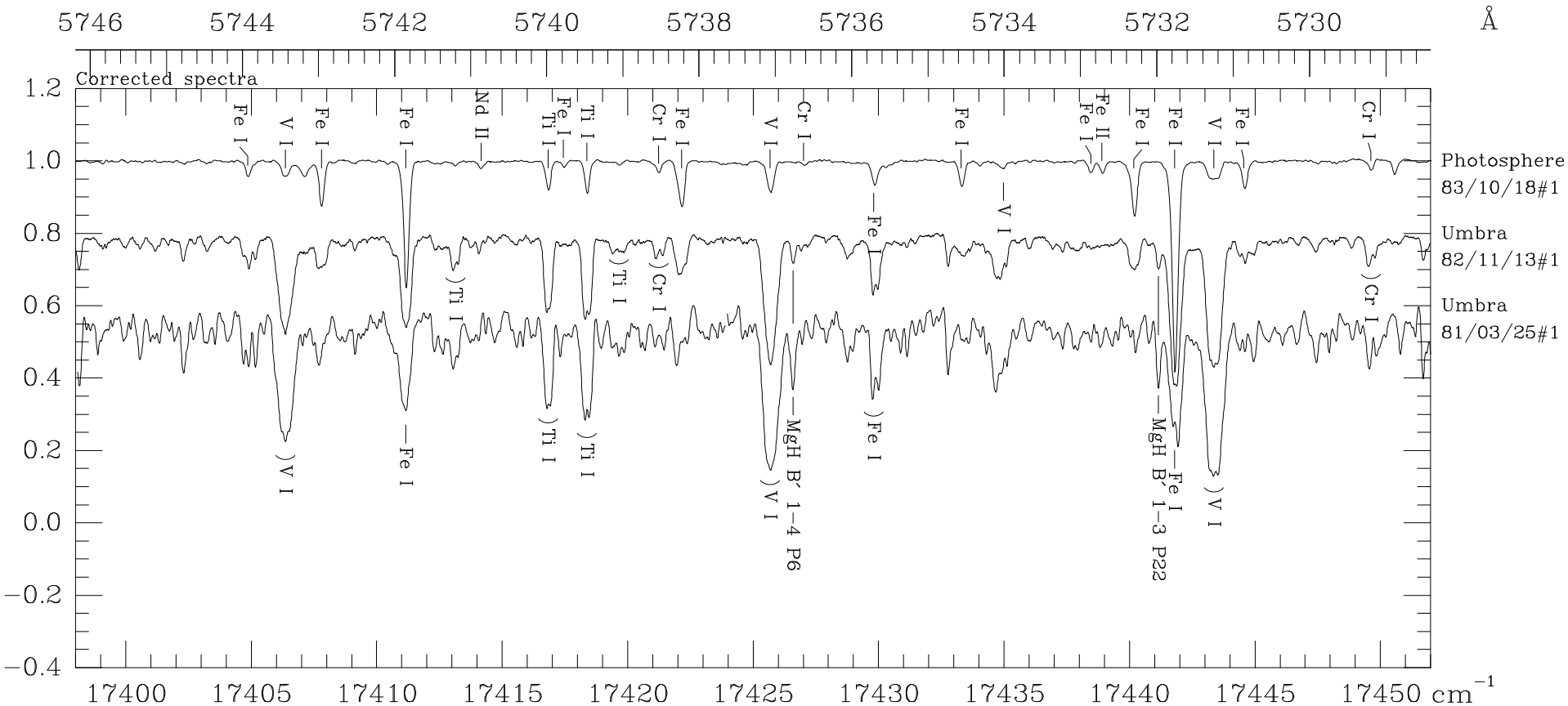
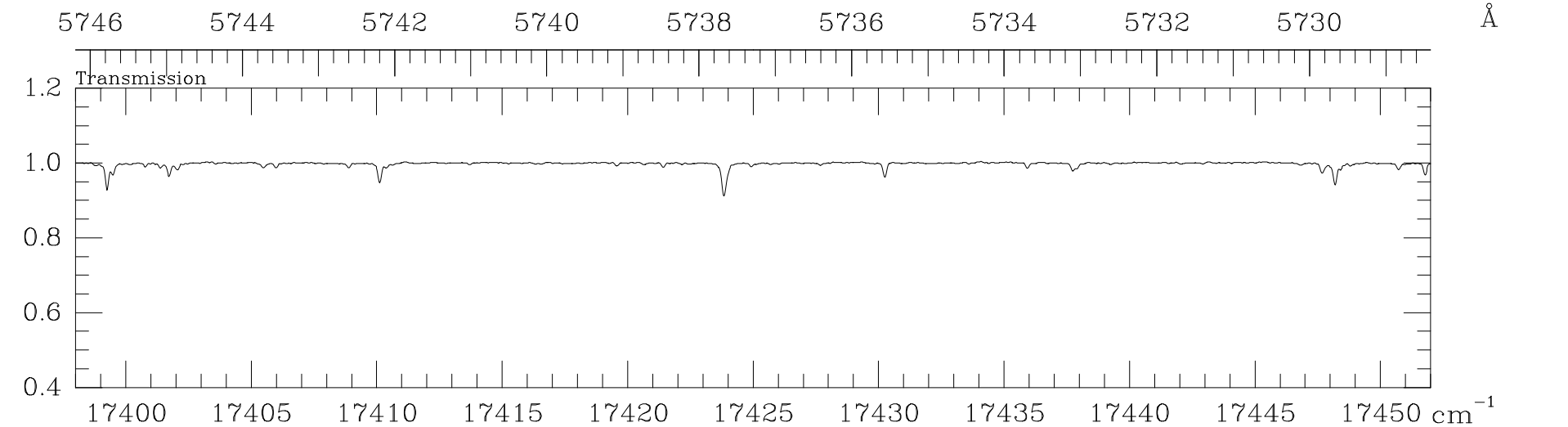
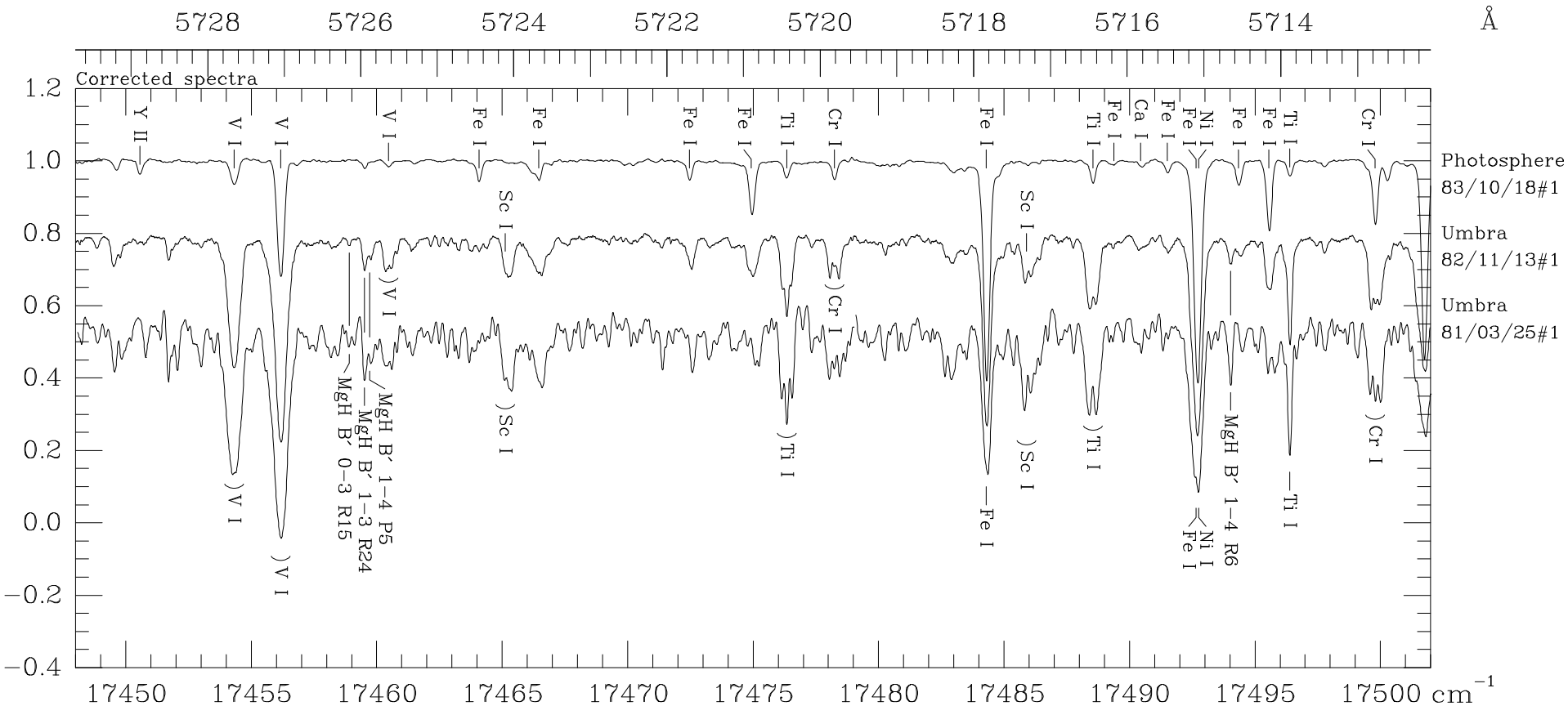




The unlabeled features in the lower umbral spectrum are due mostly to lines of the TiO α and β bands.





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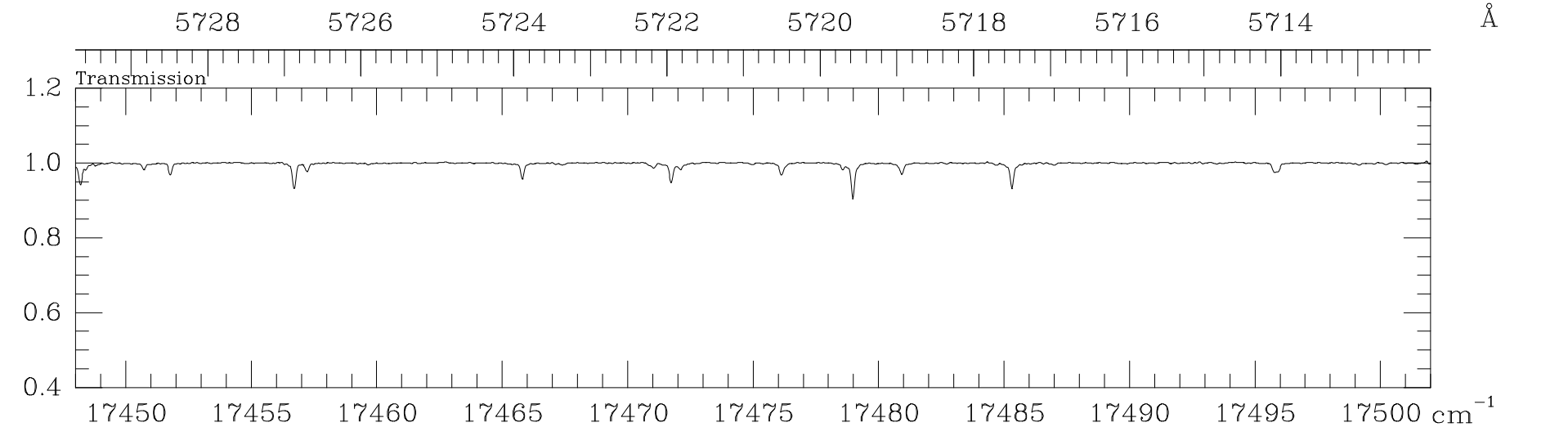

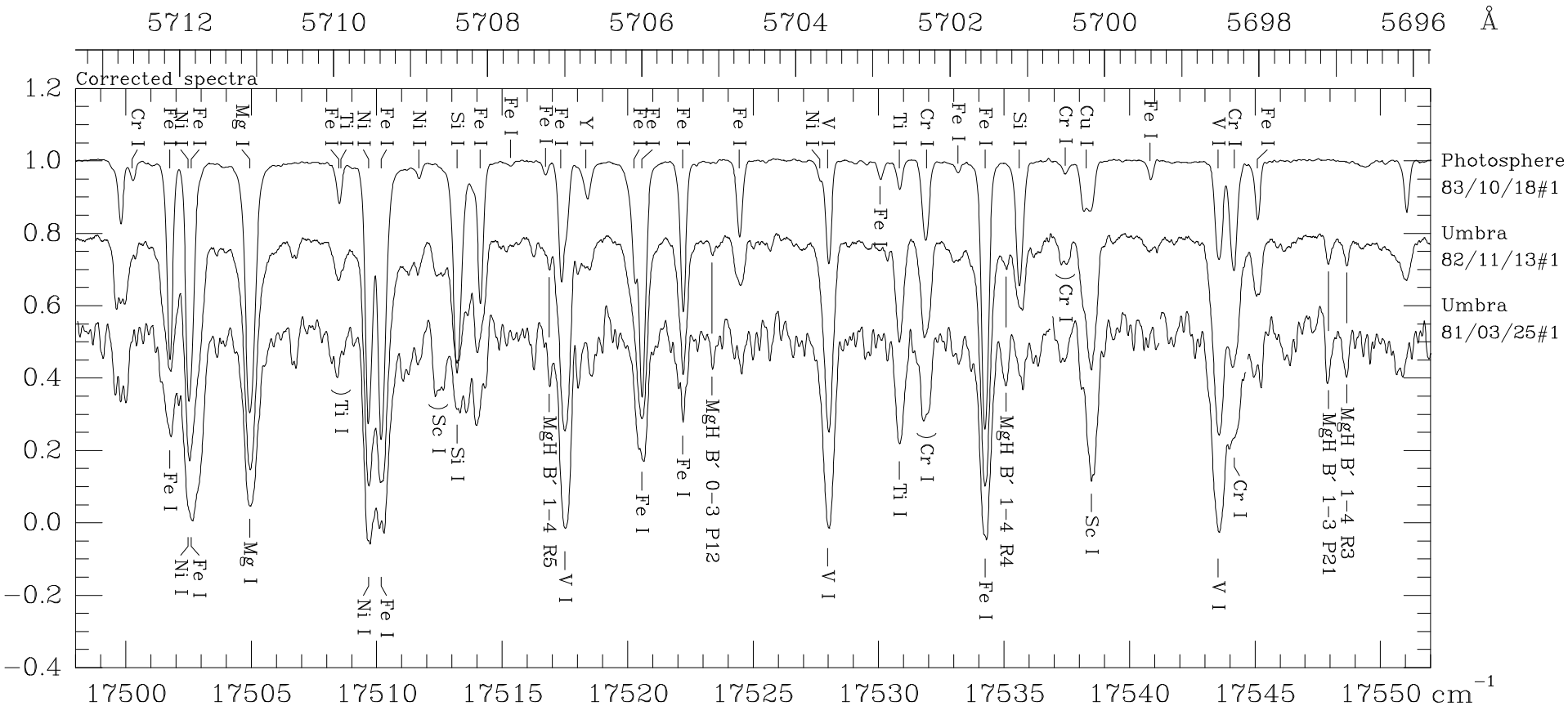

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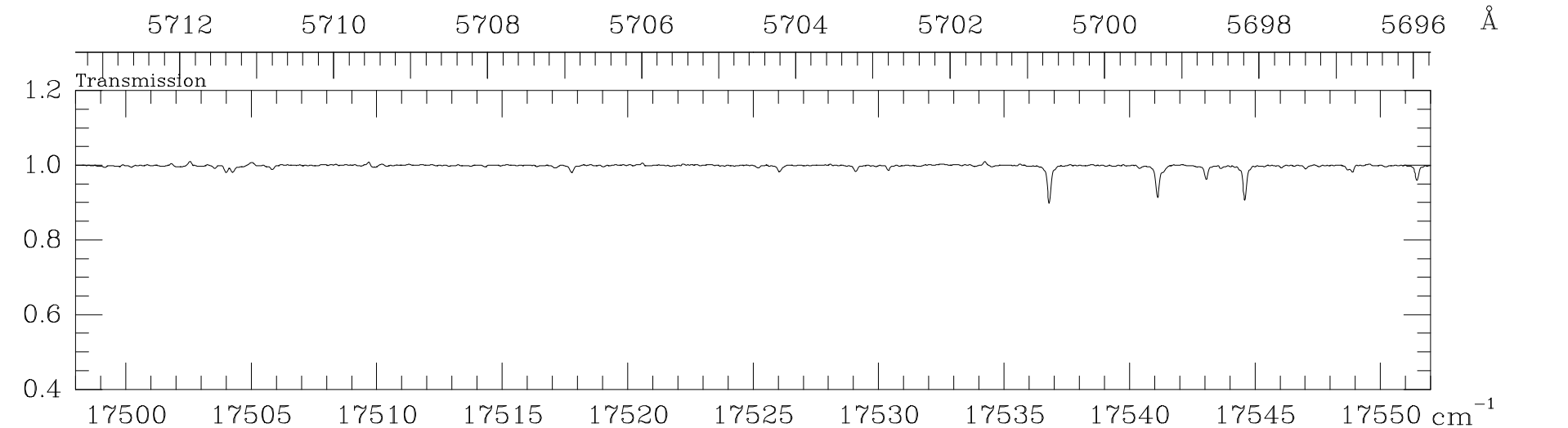

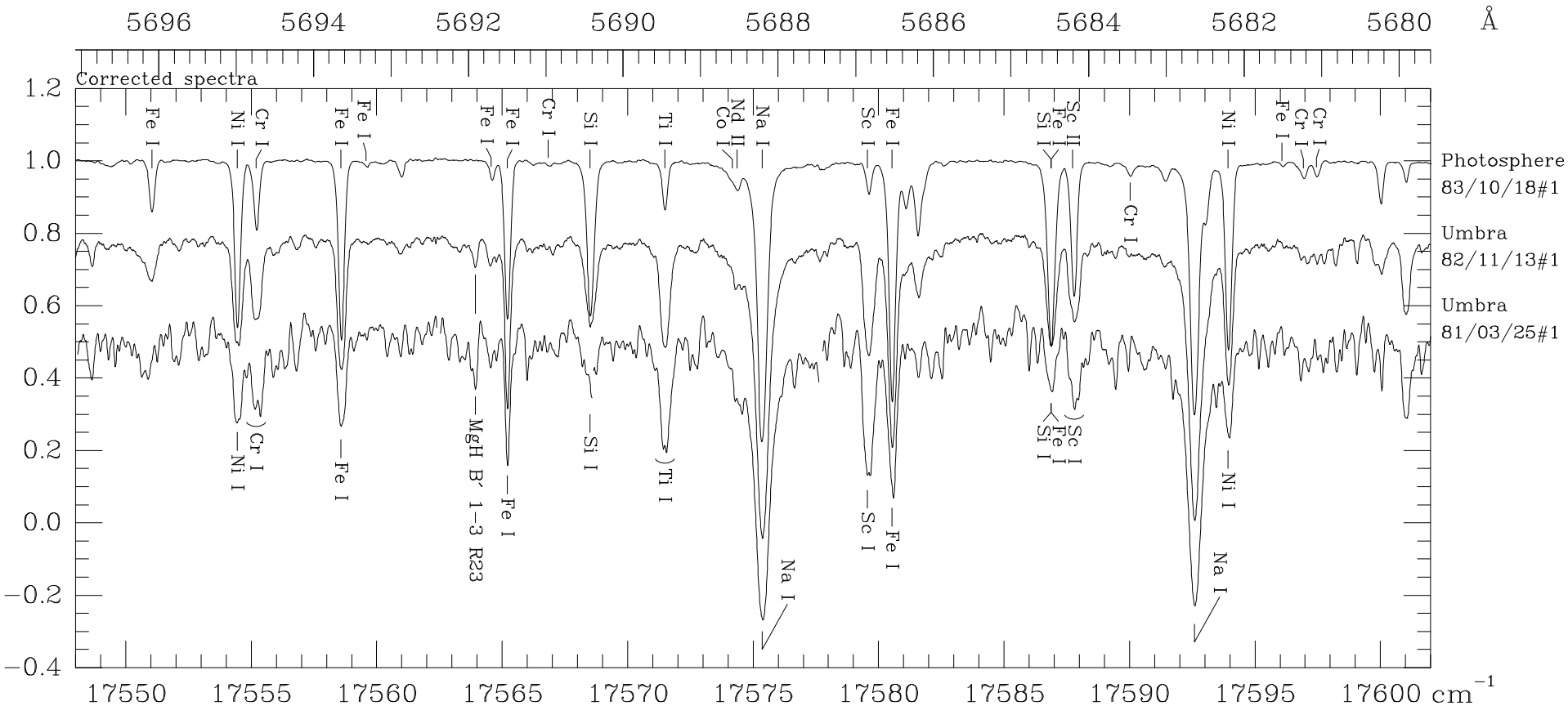

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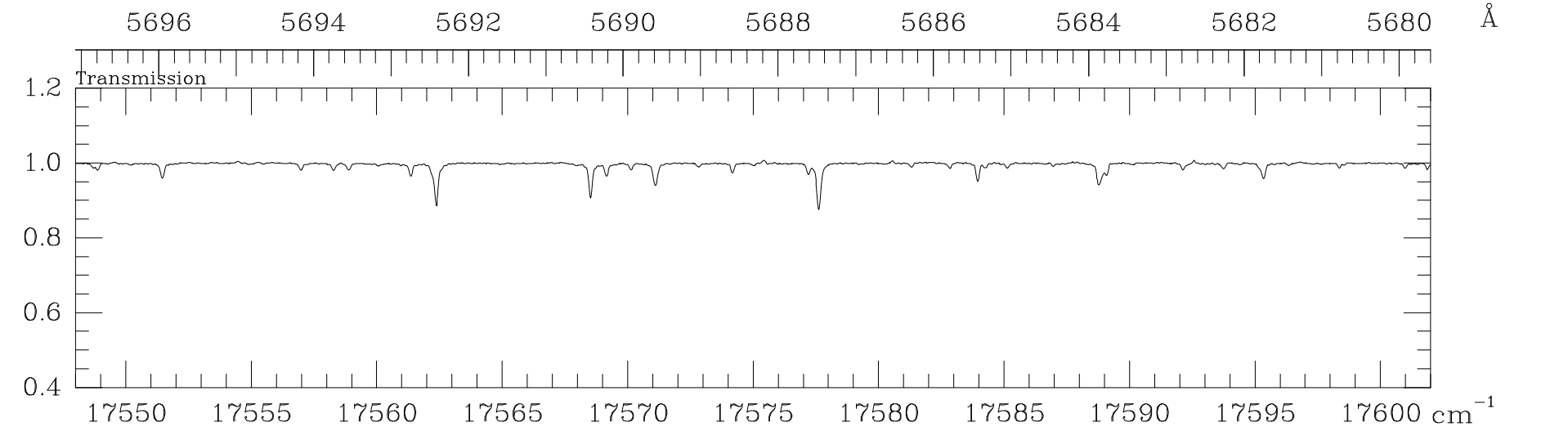

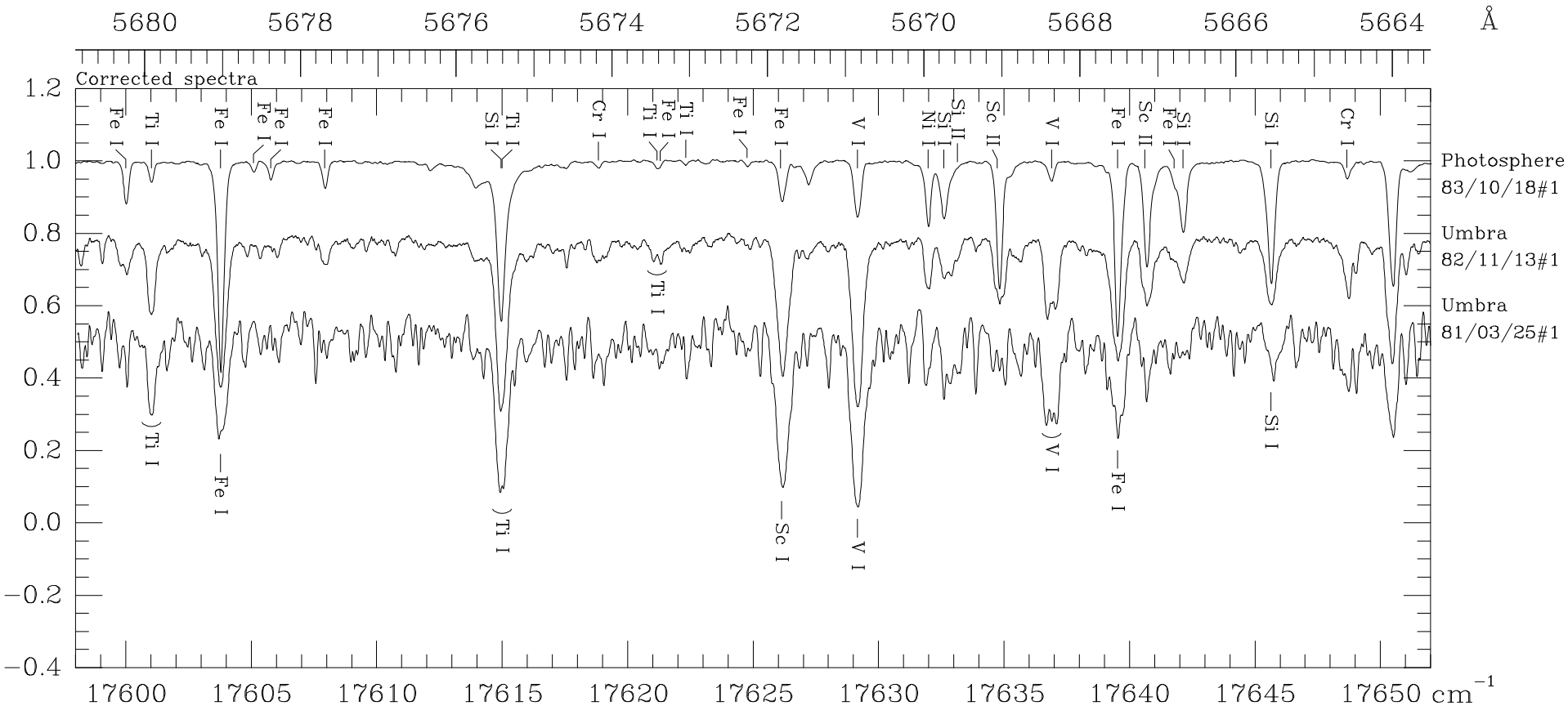

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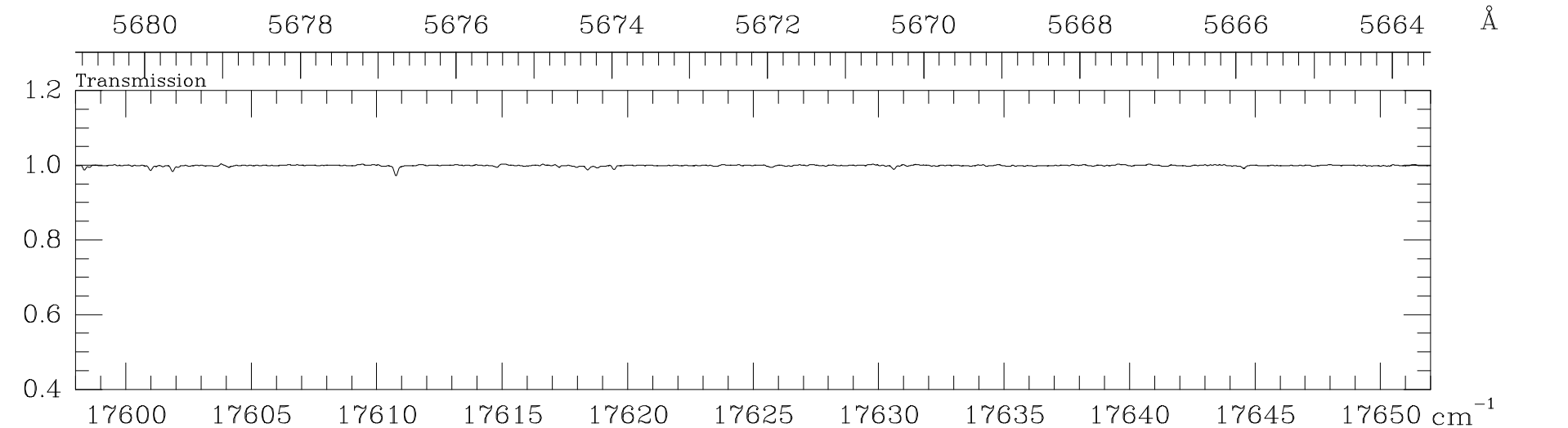

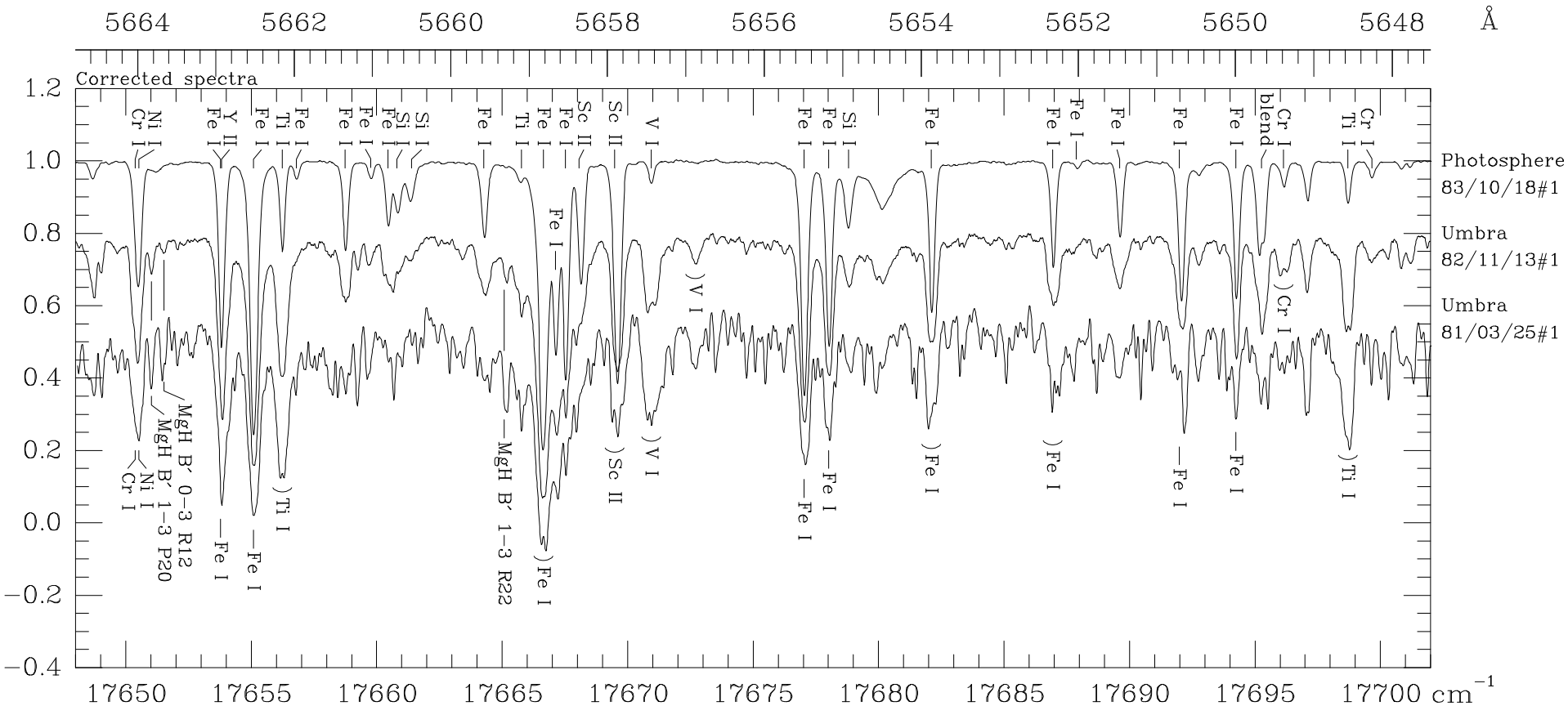

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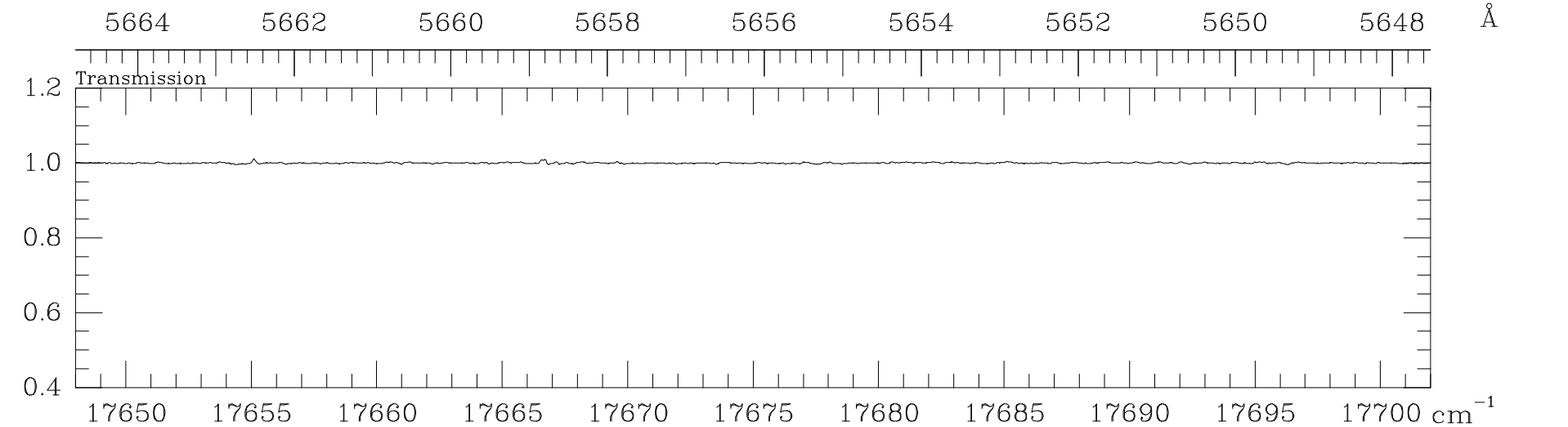

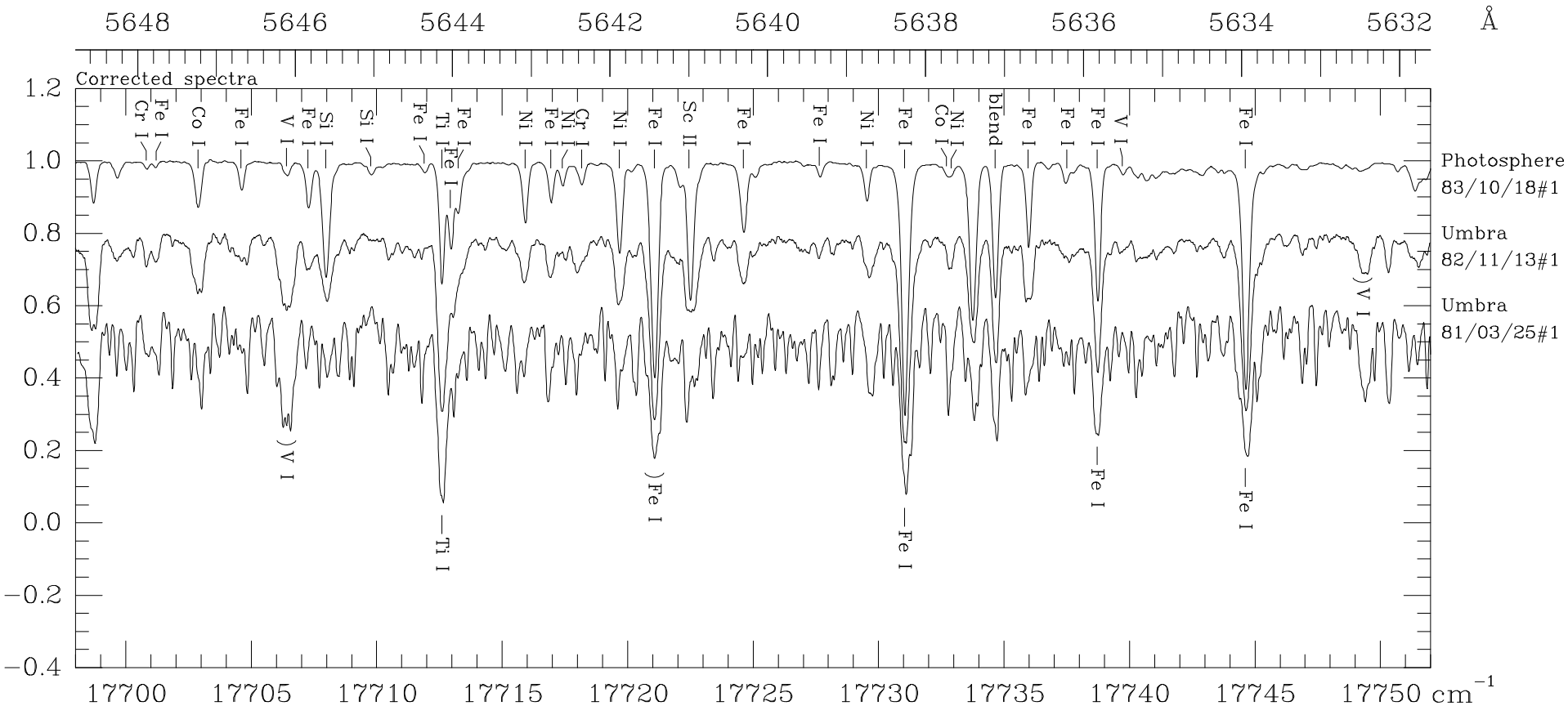

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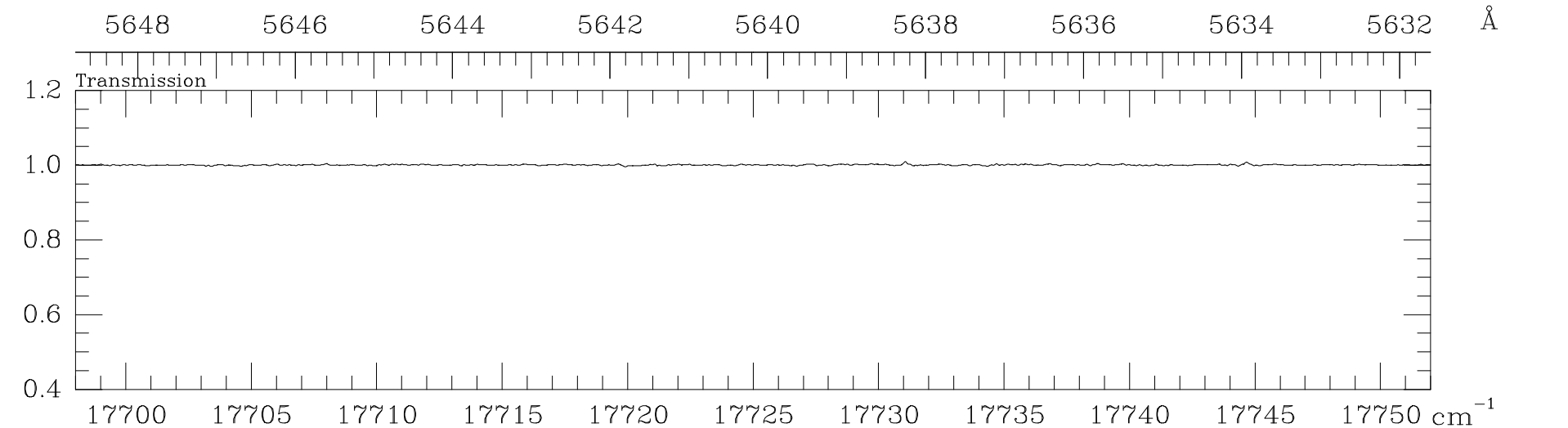

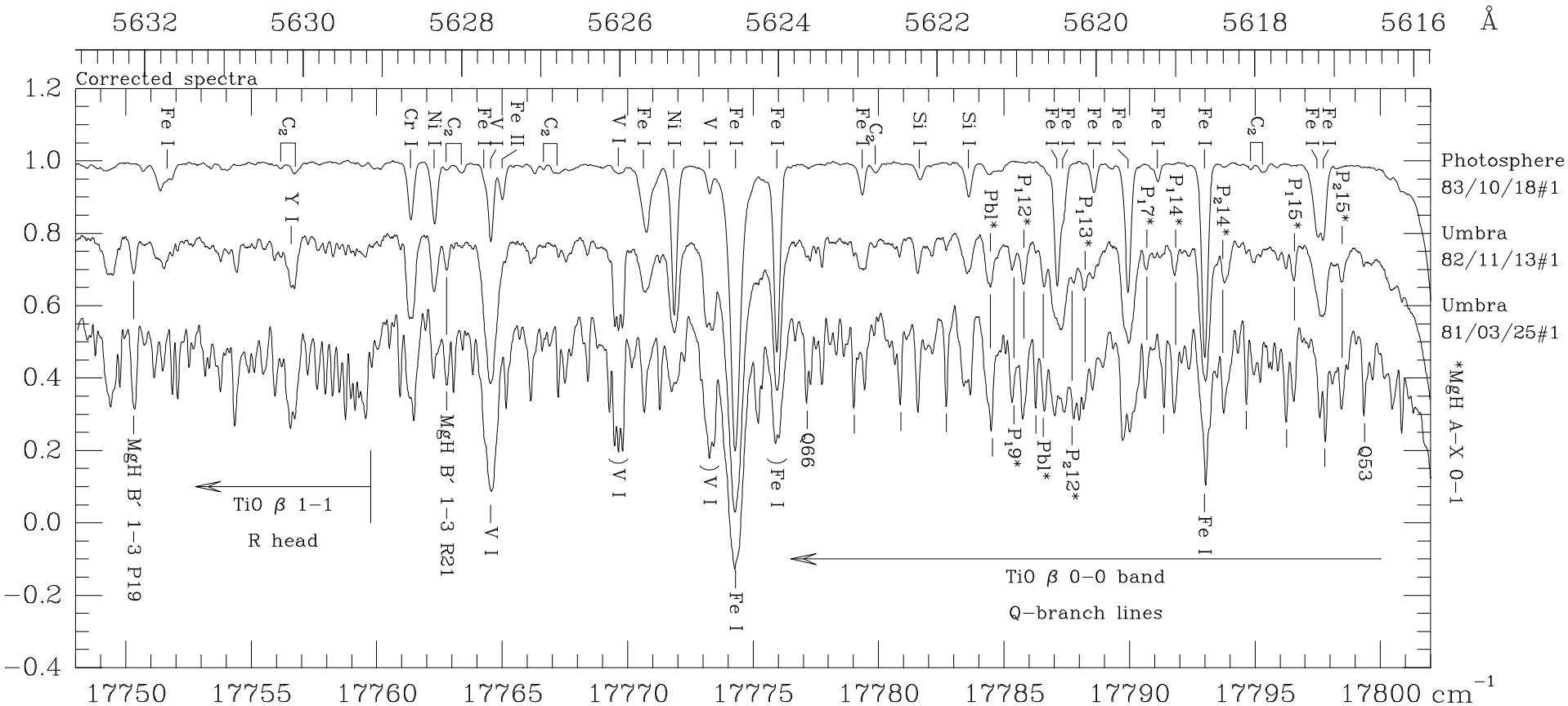

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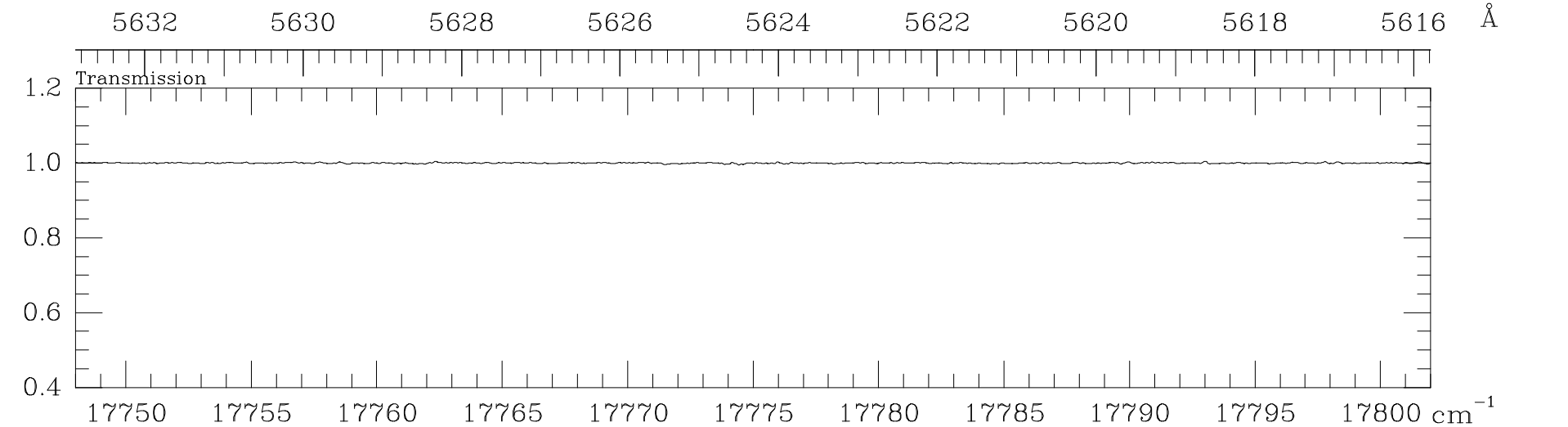

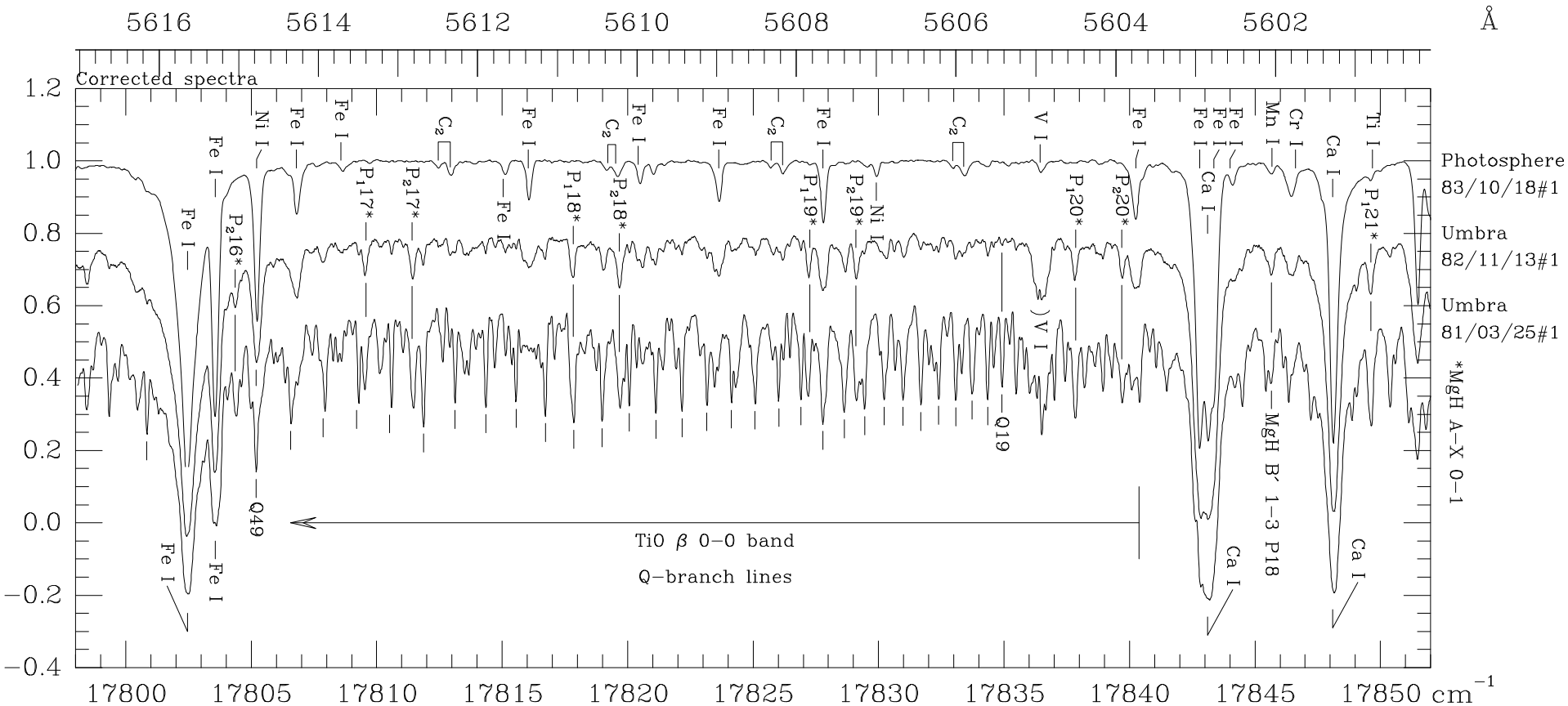

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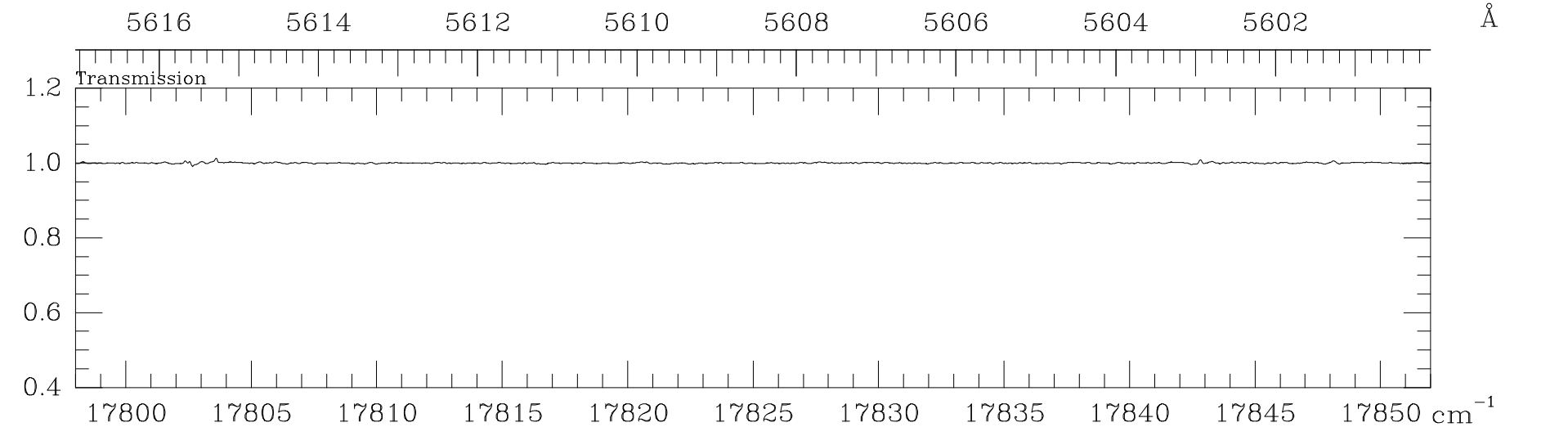

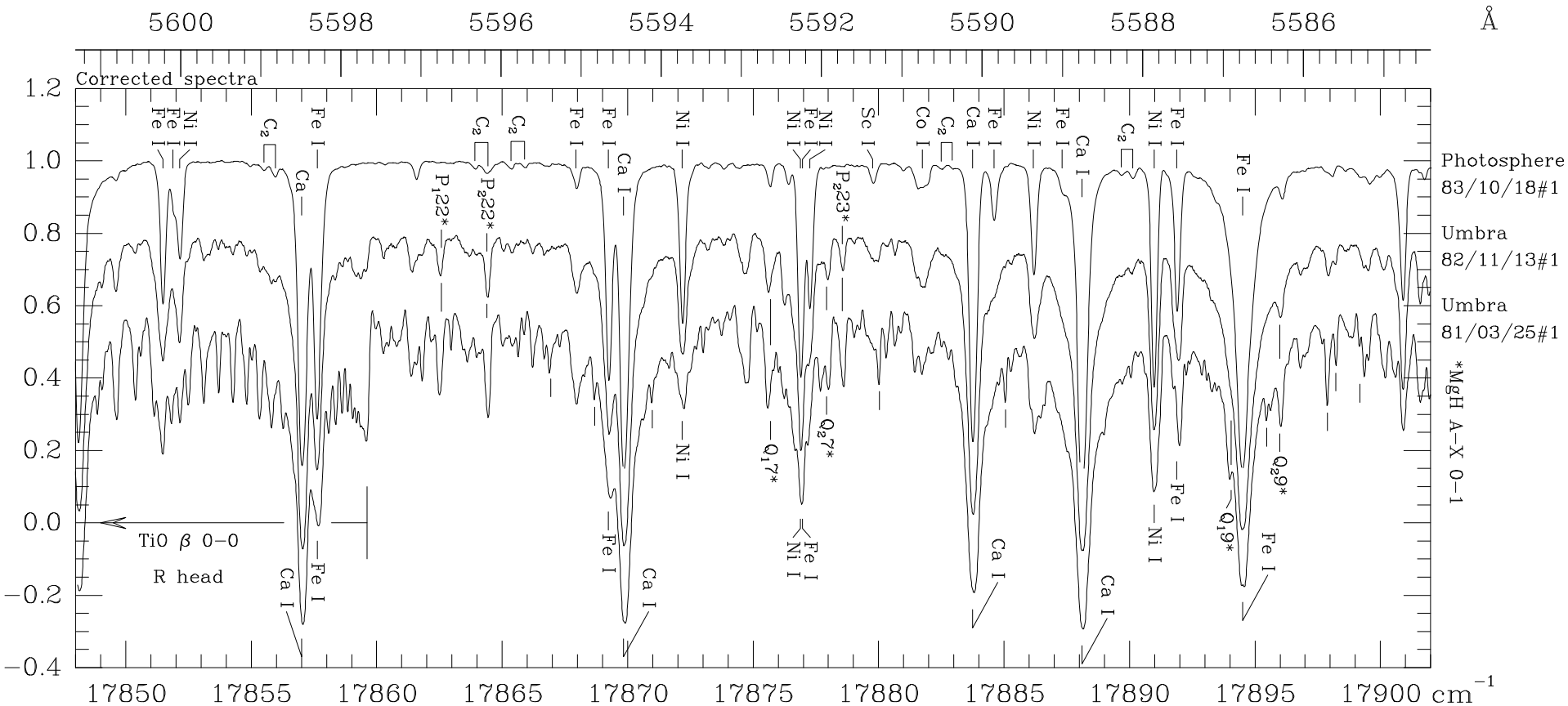

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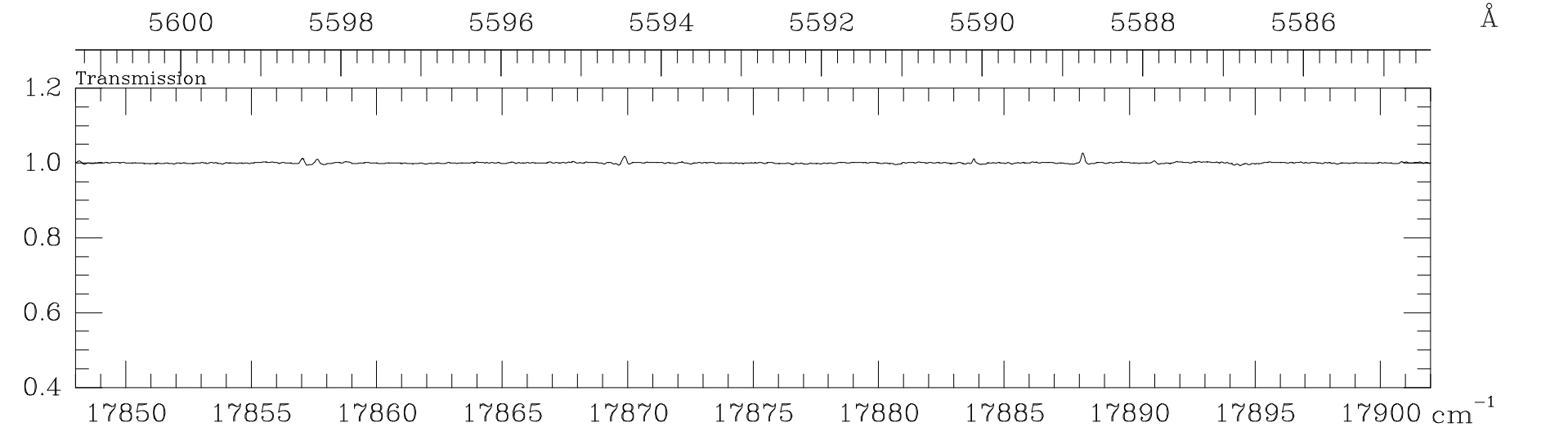

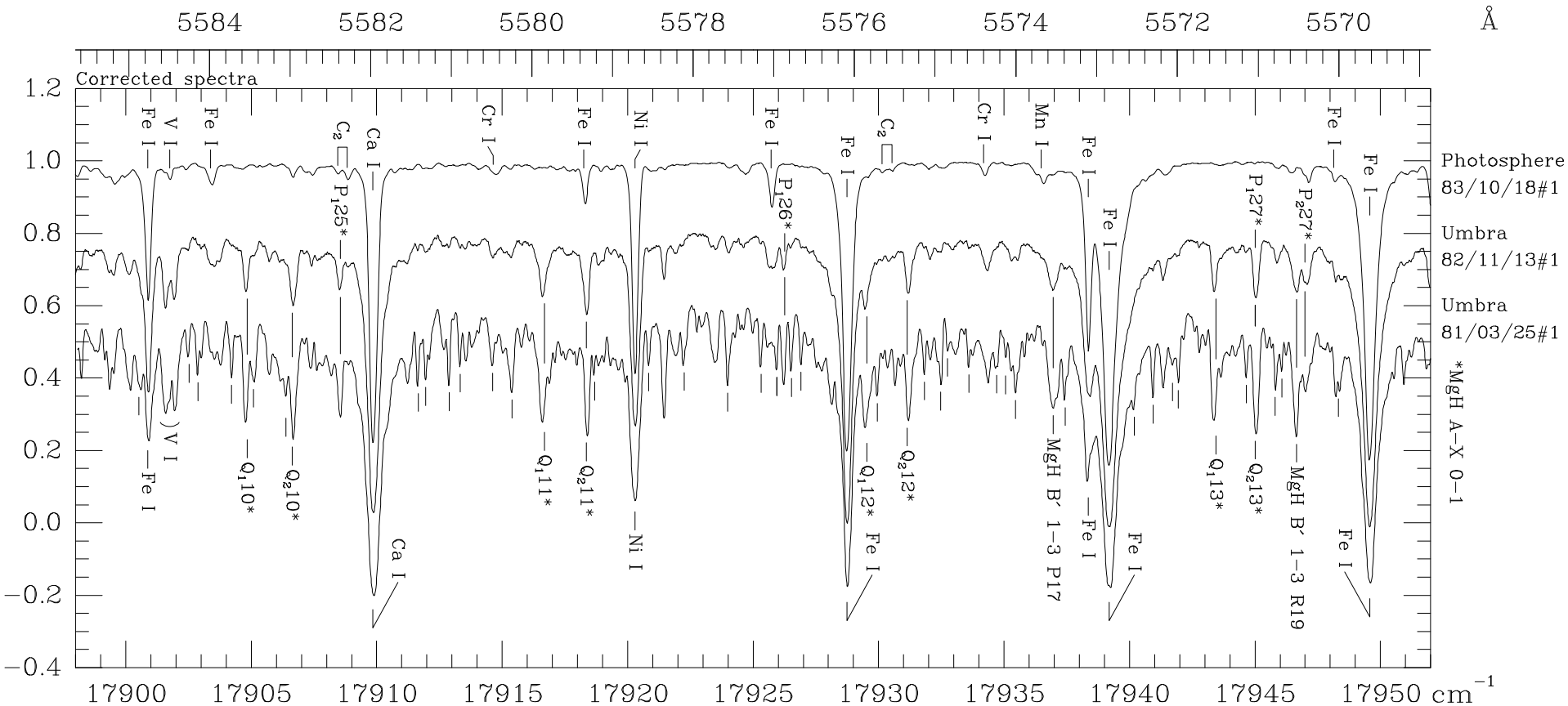

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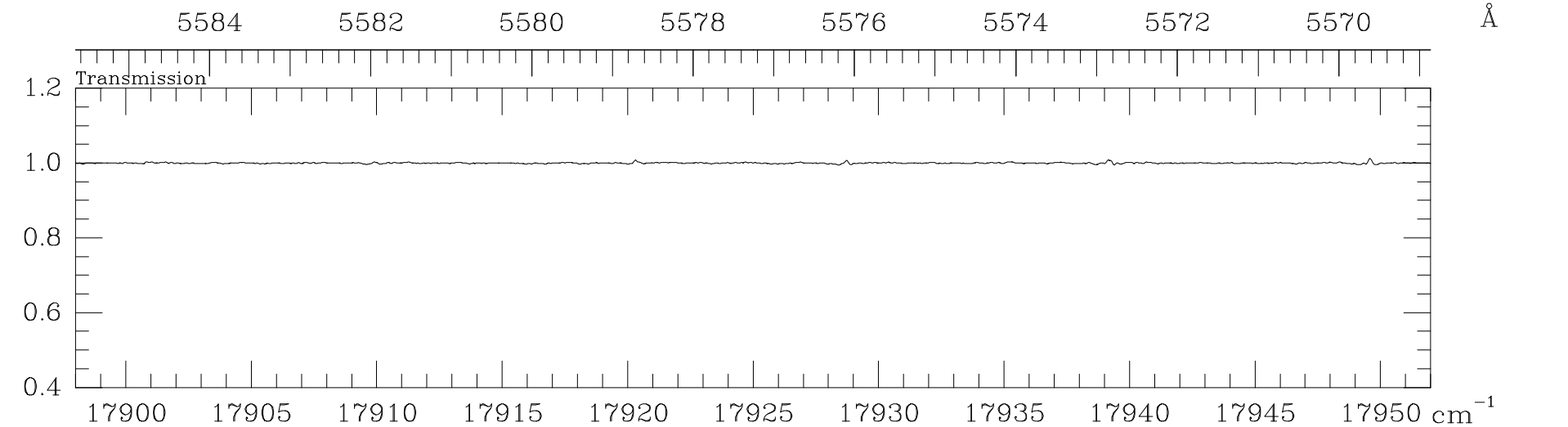

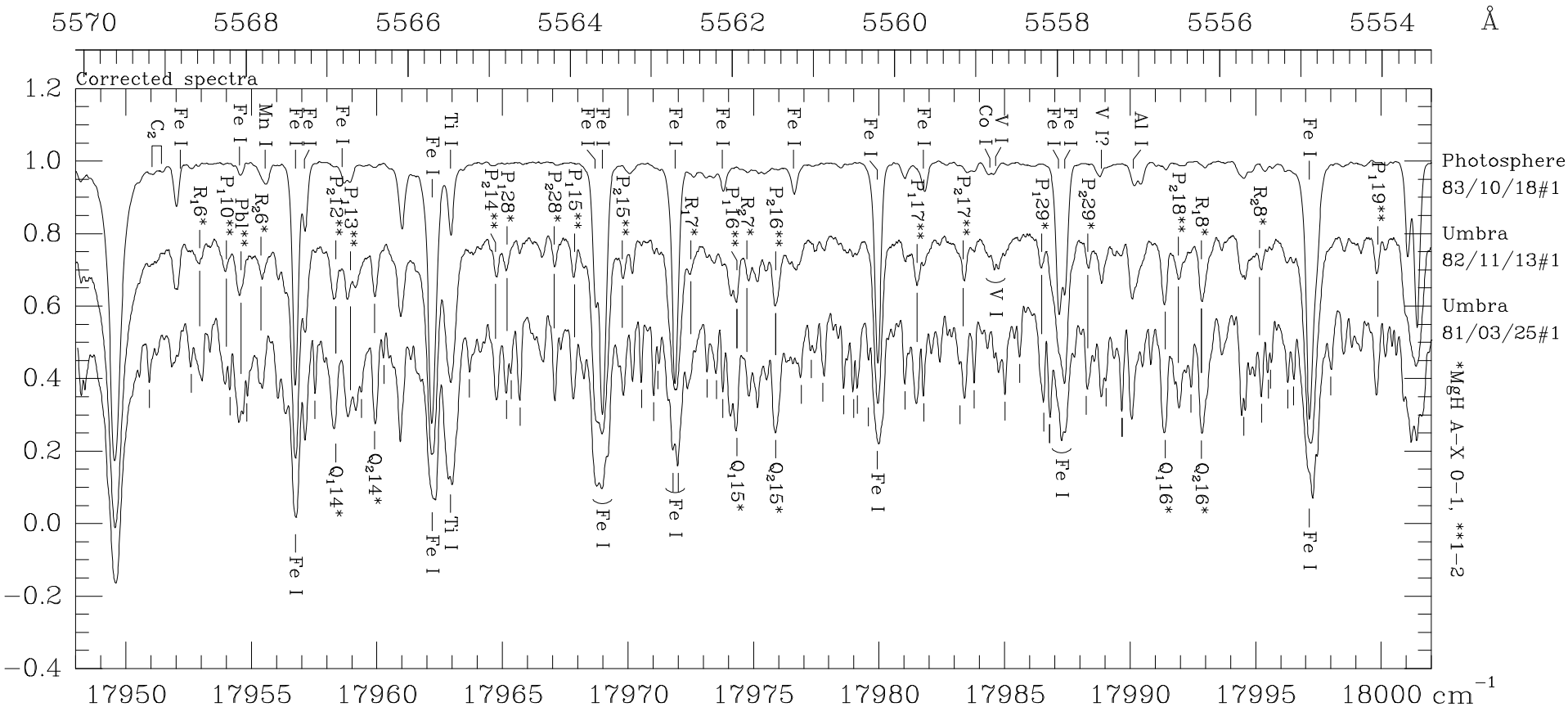

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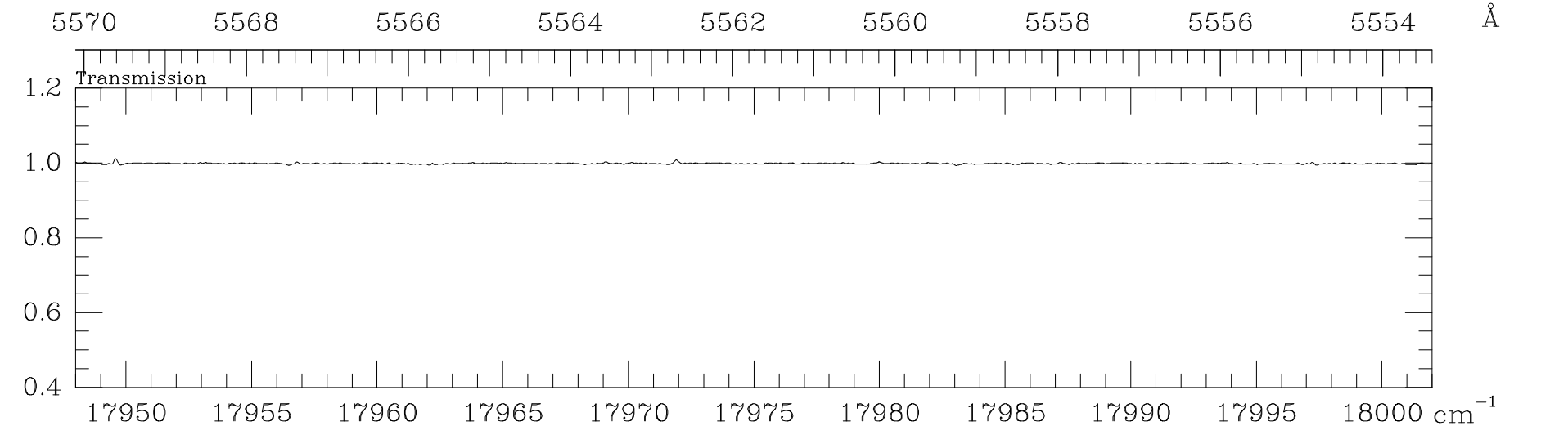

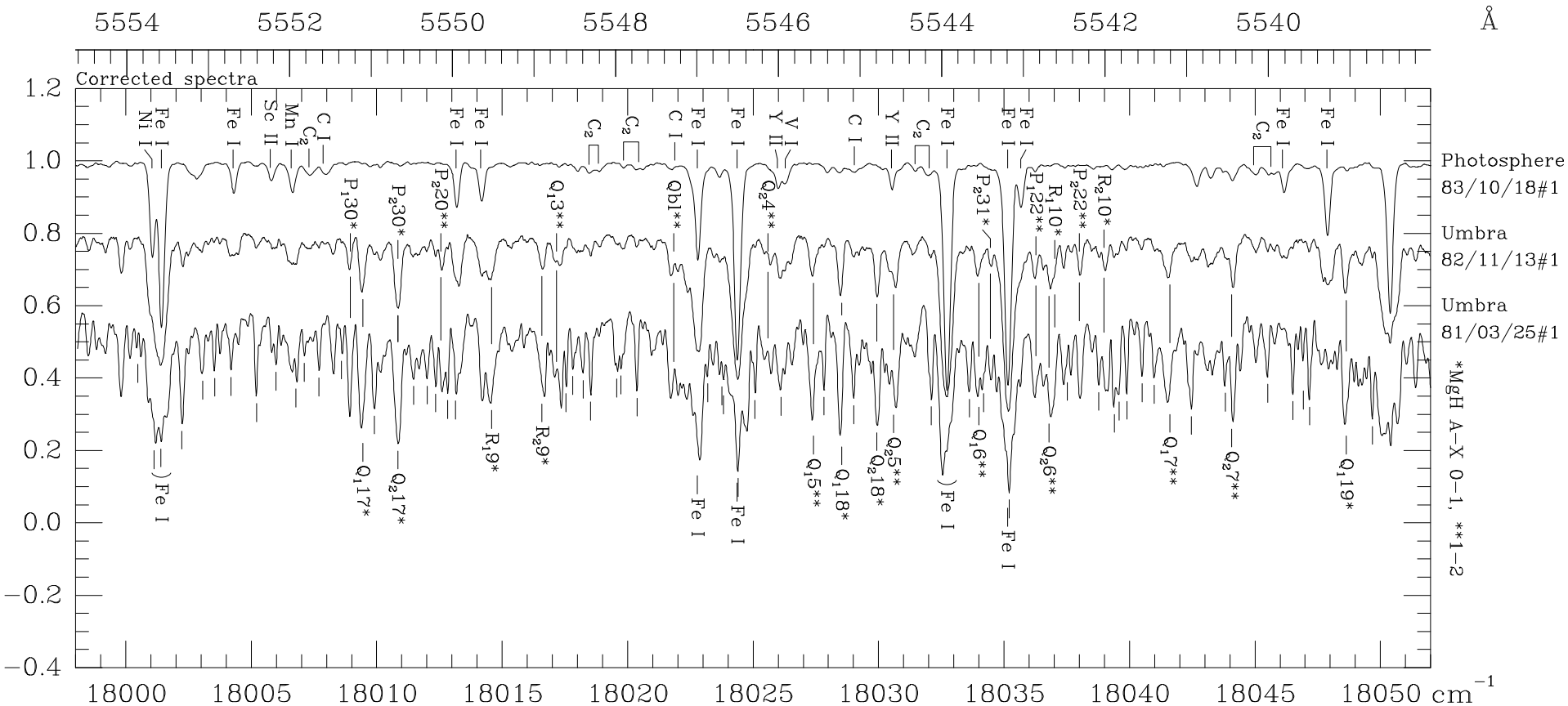

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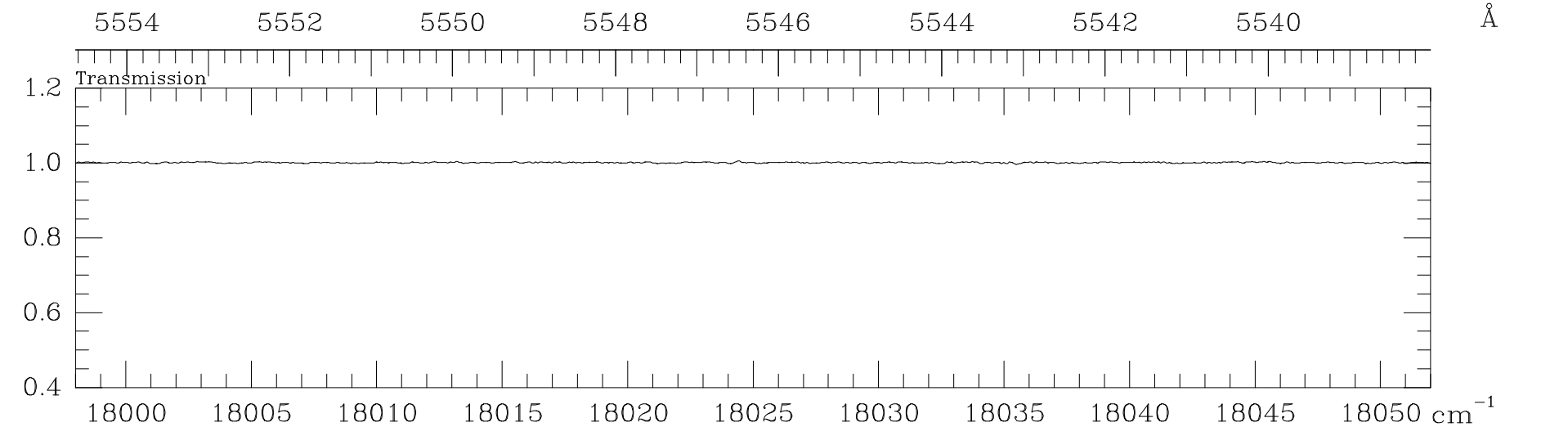

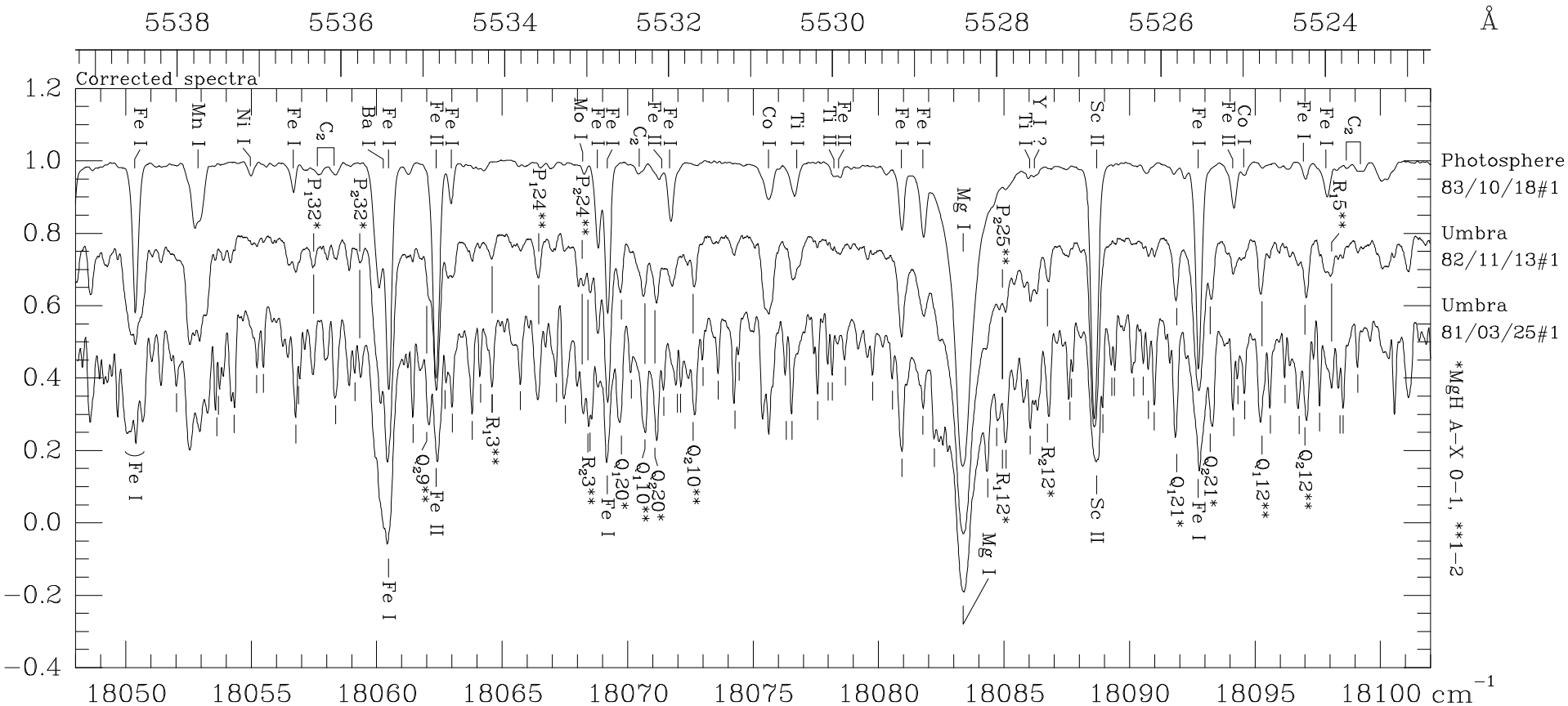

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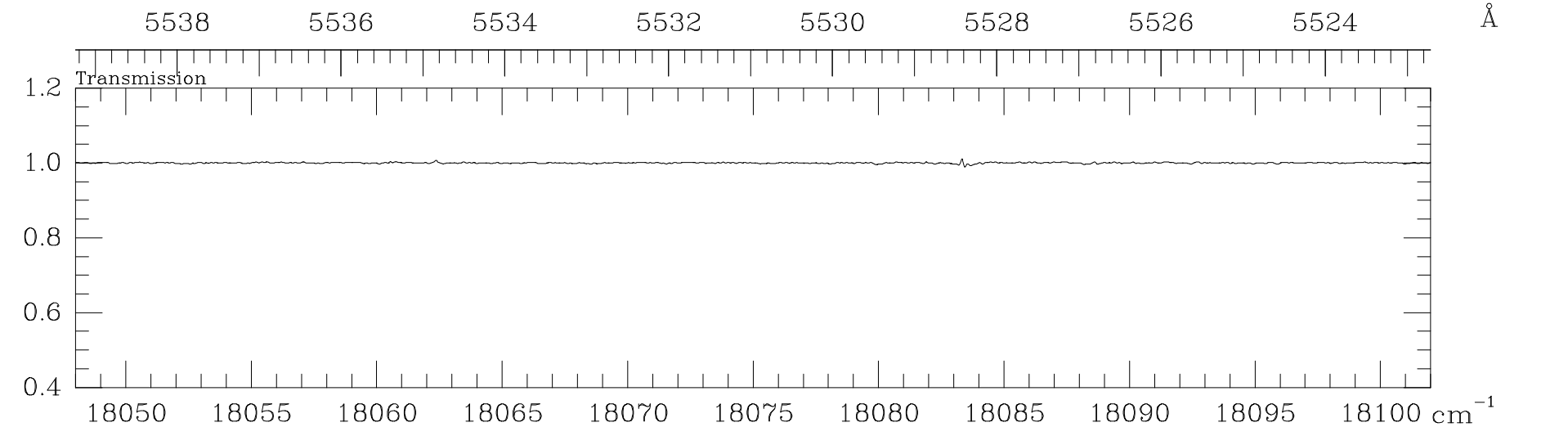

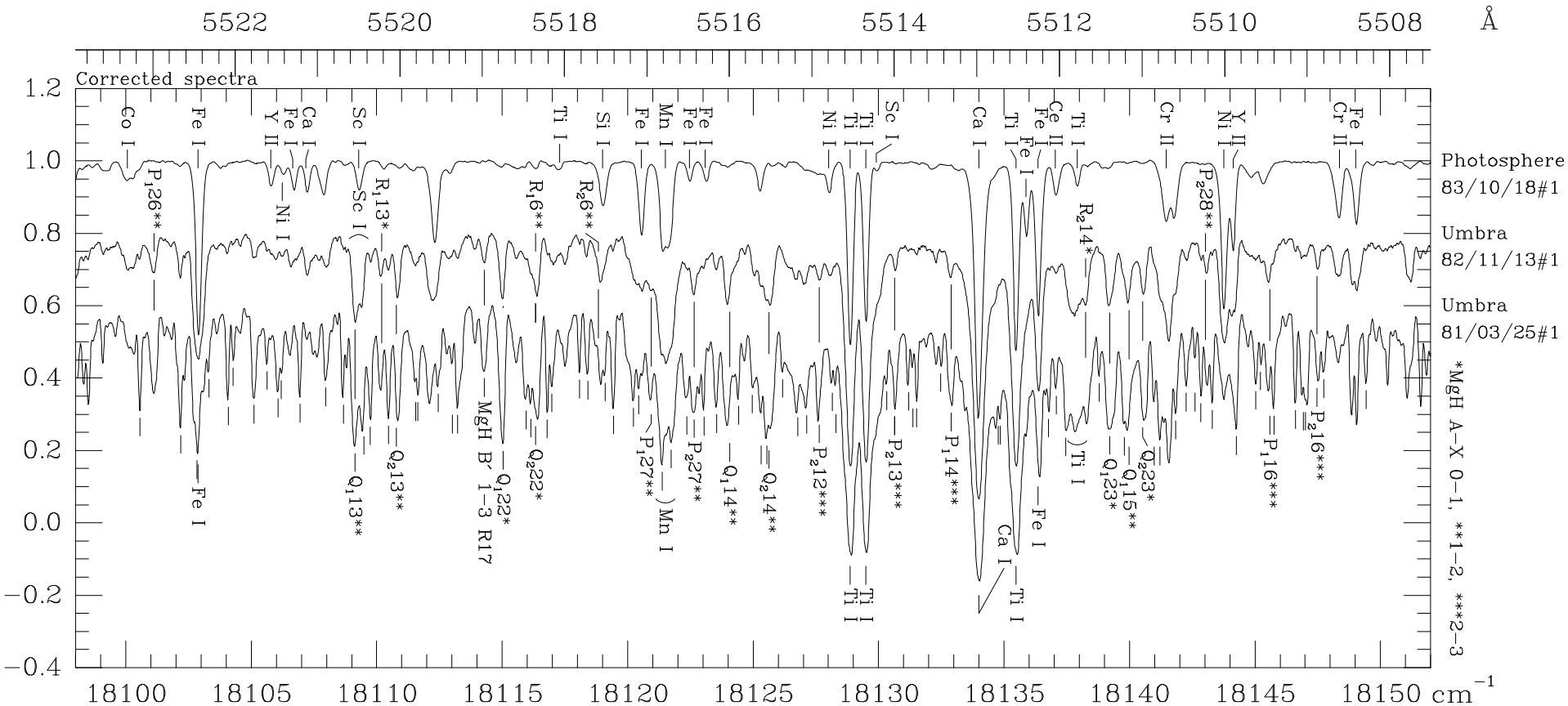

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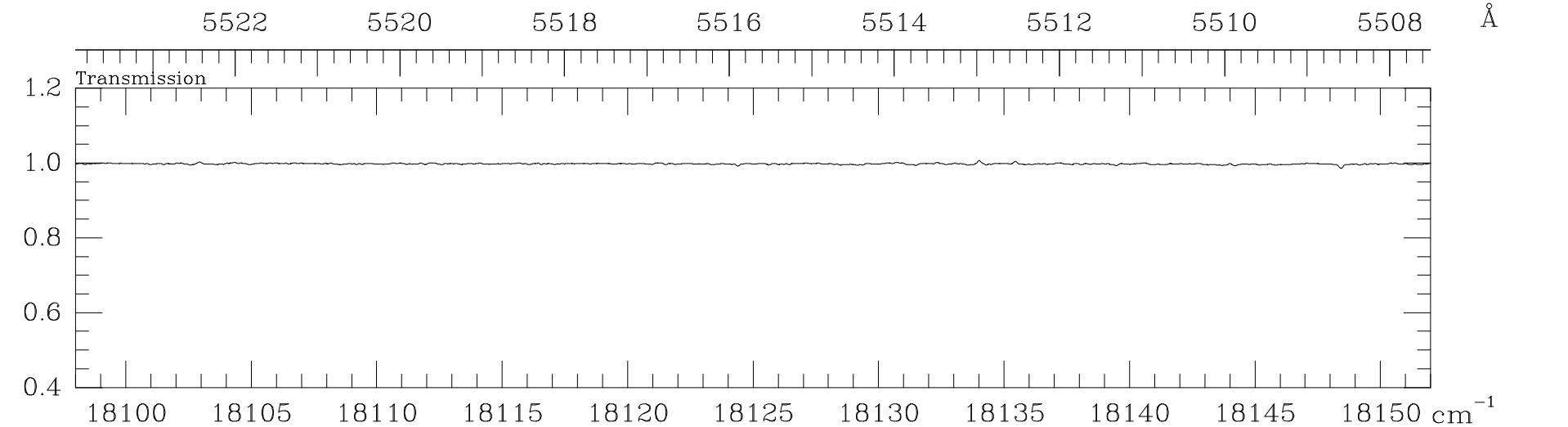

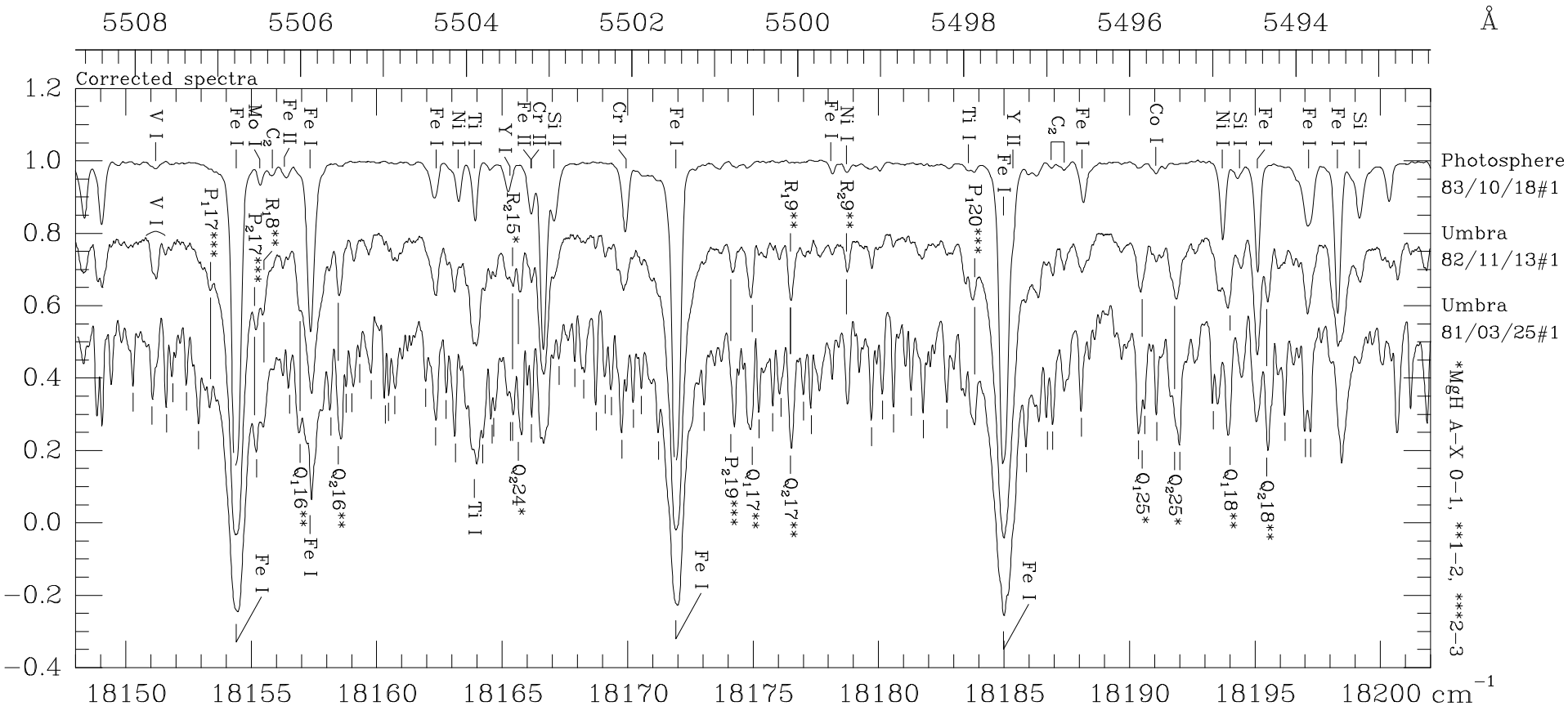

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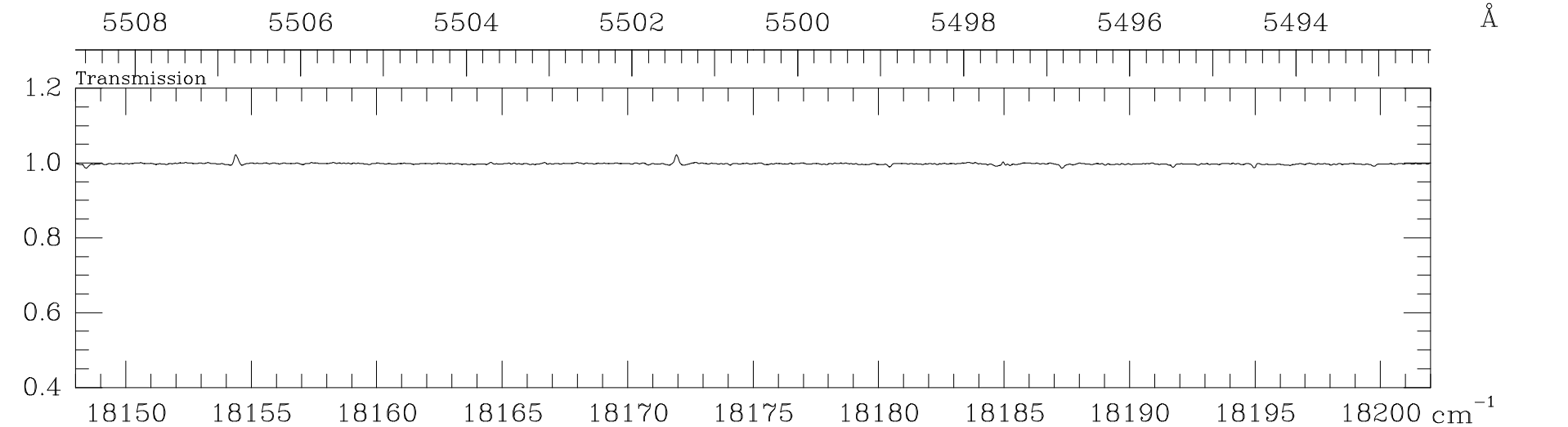

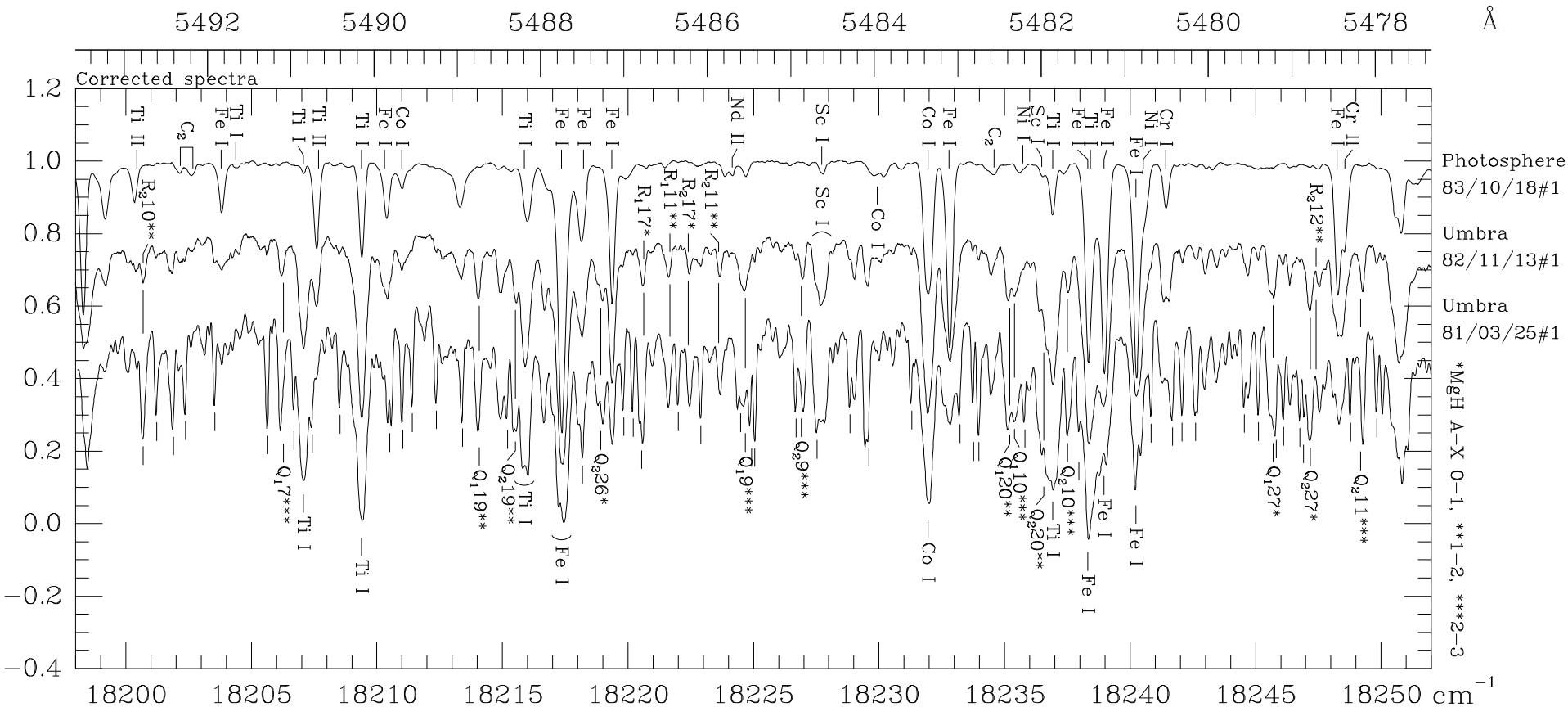

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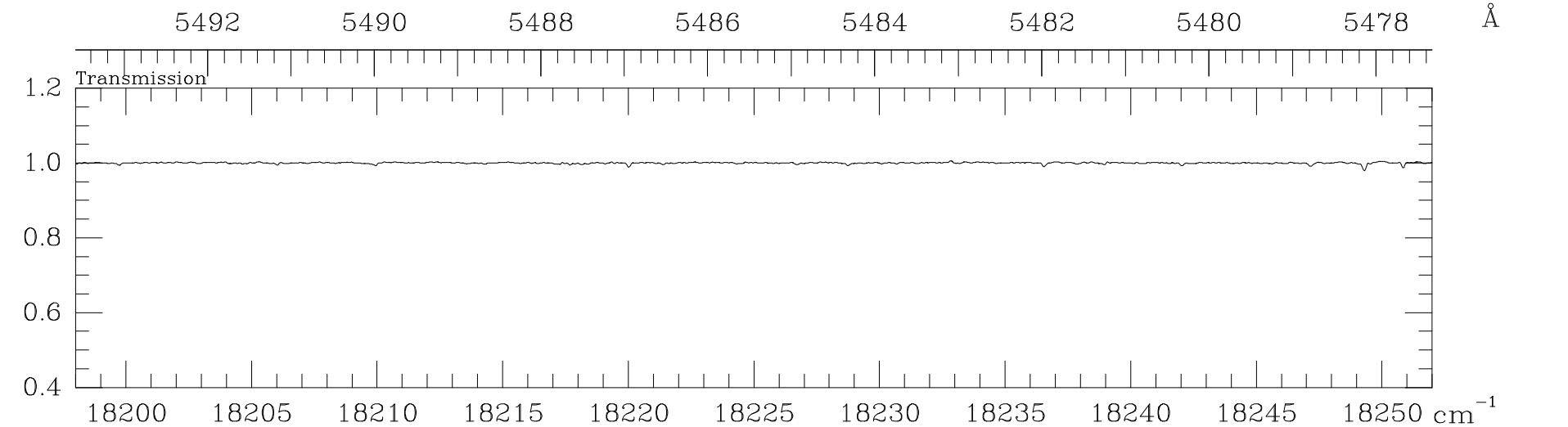

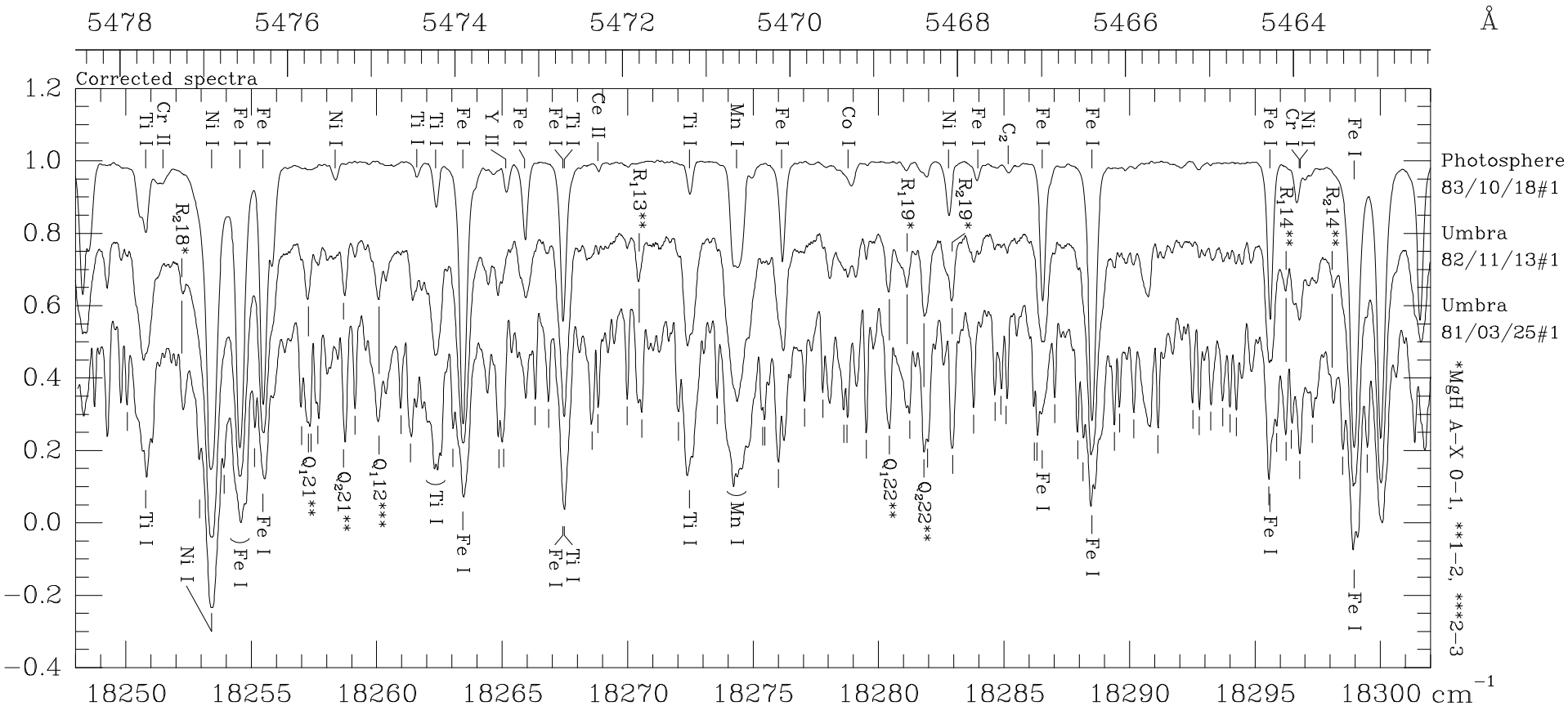

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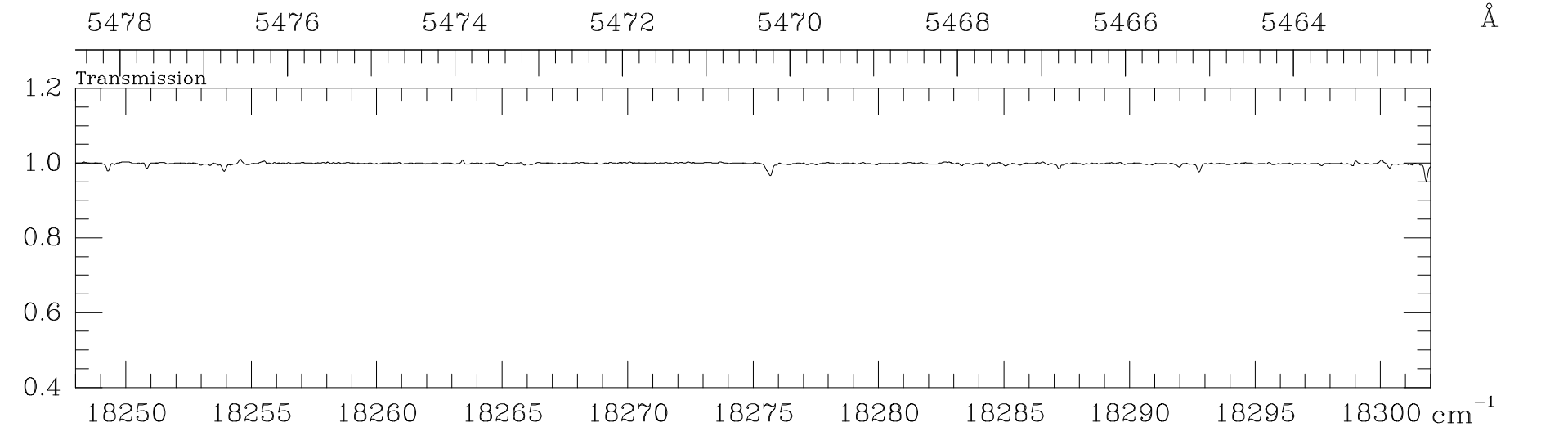

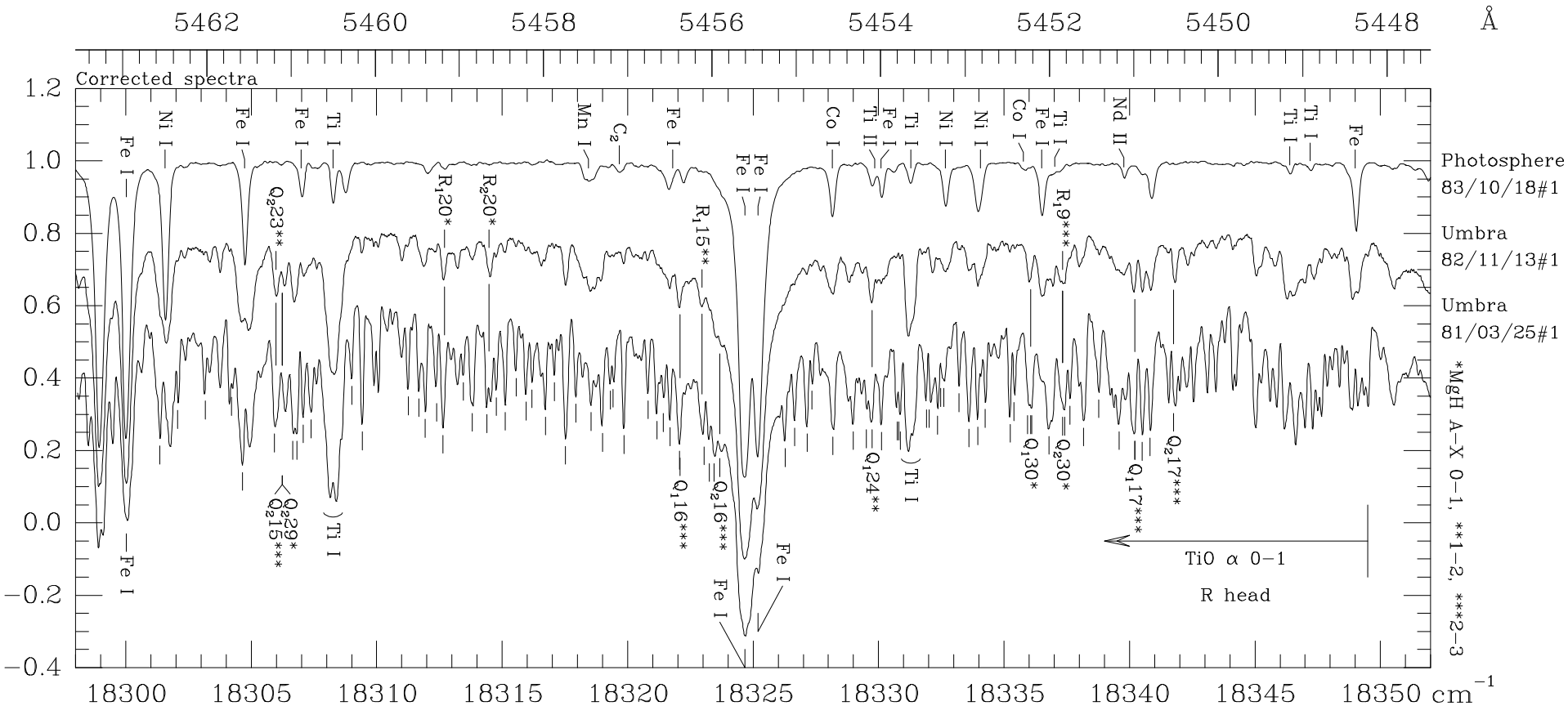

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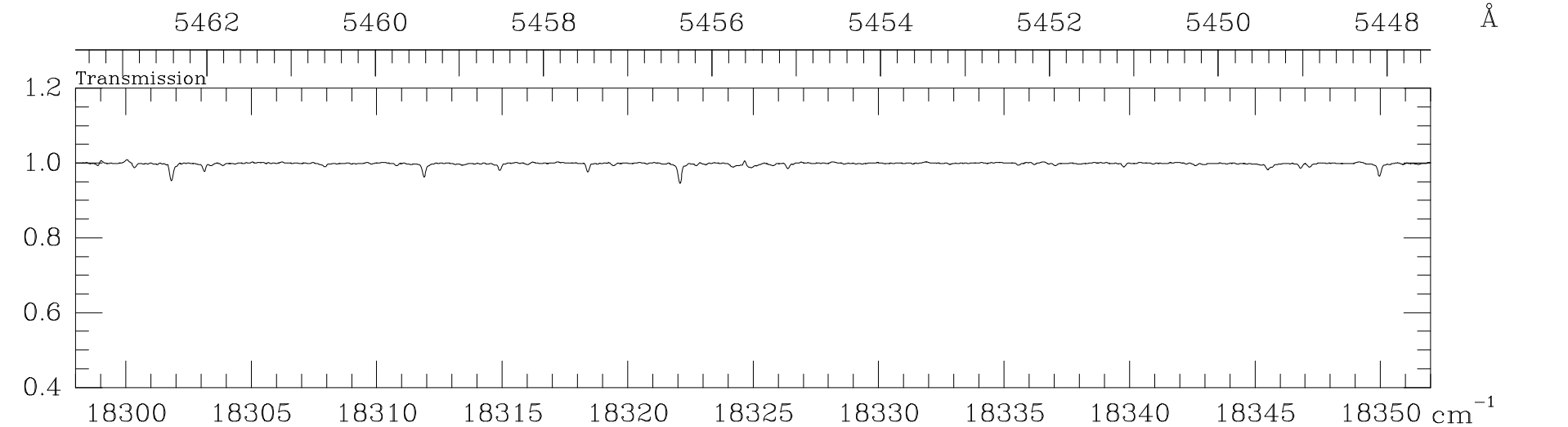
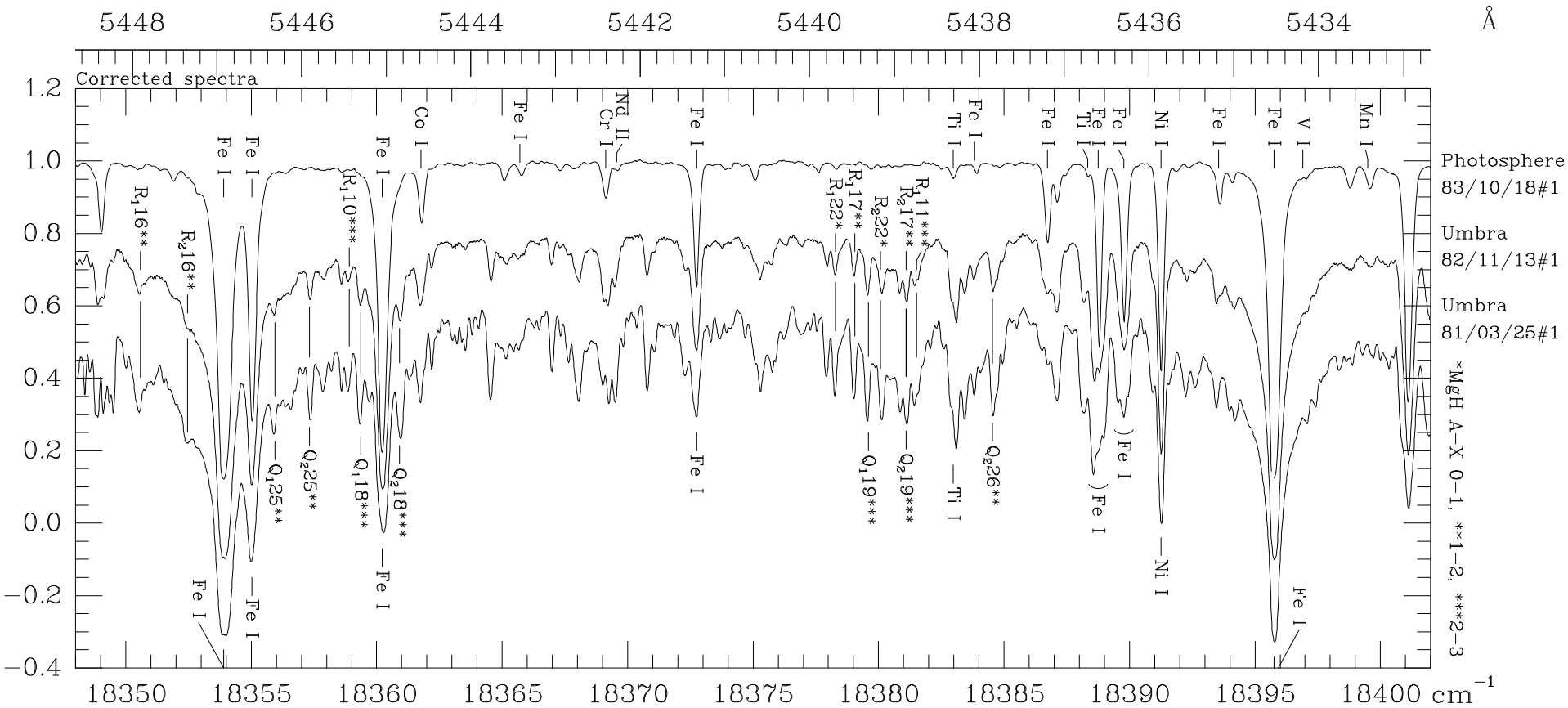
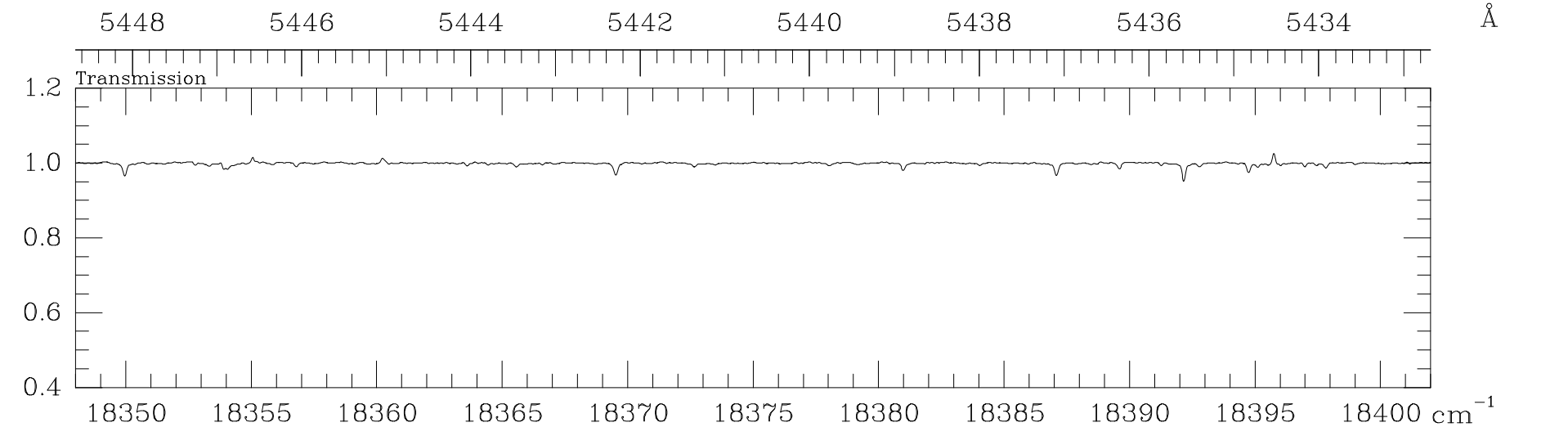
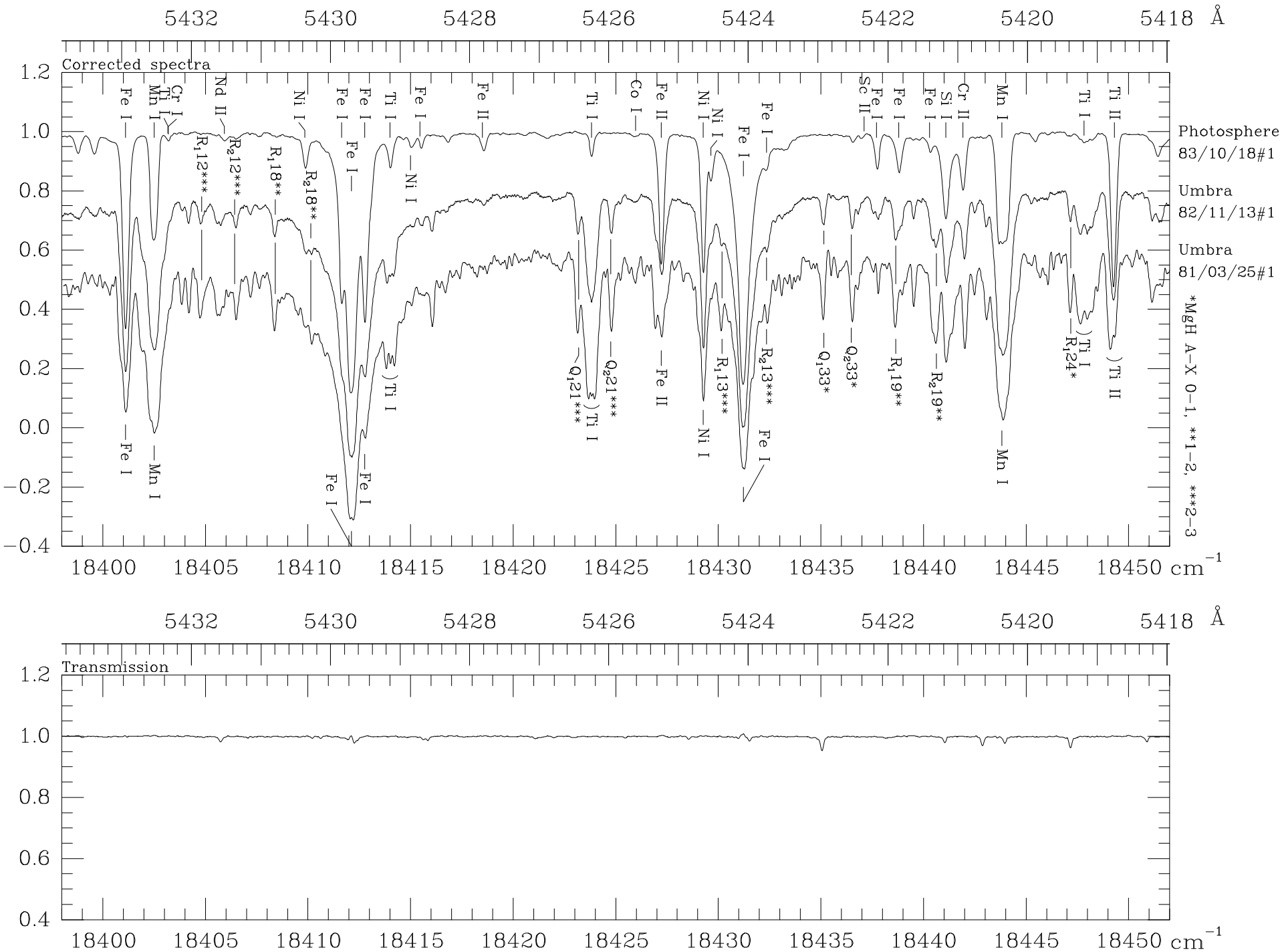
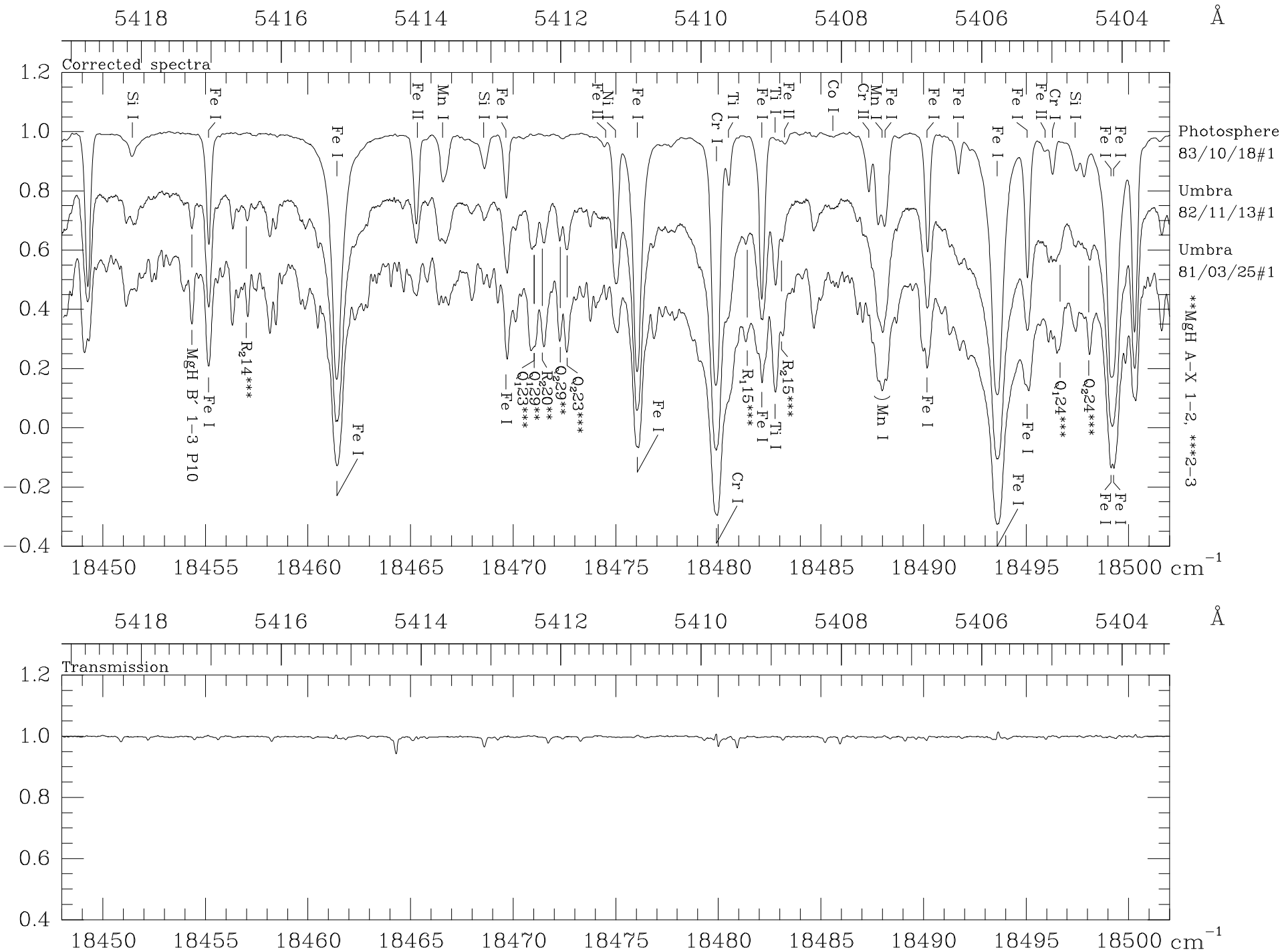


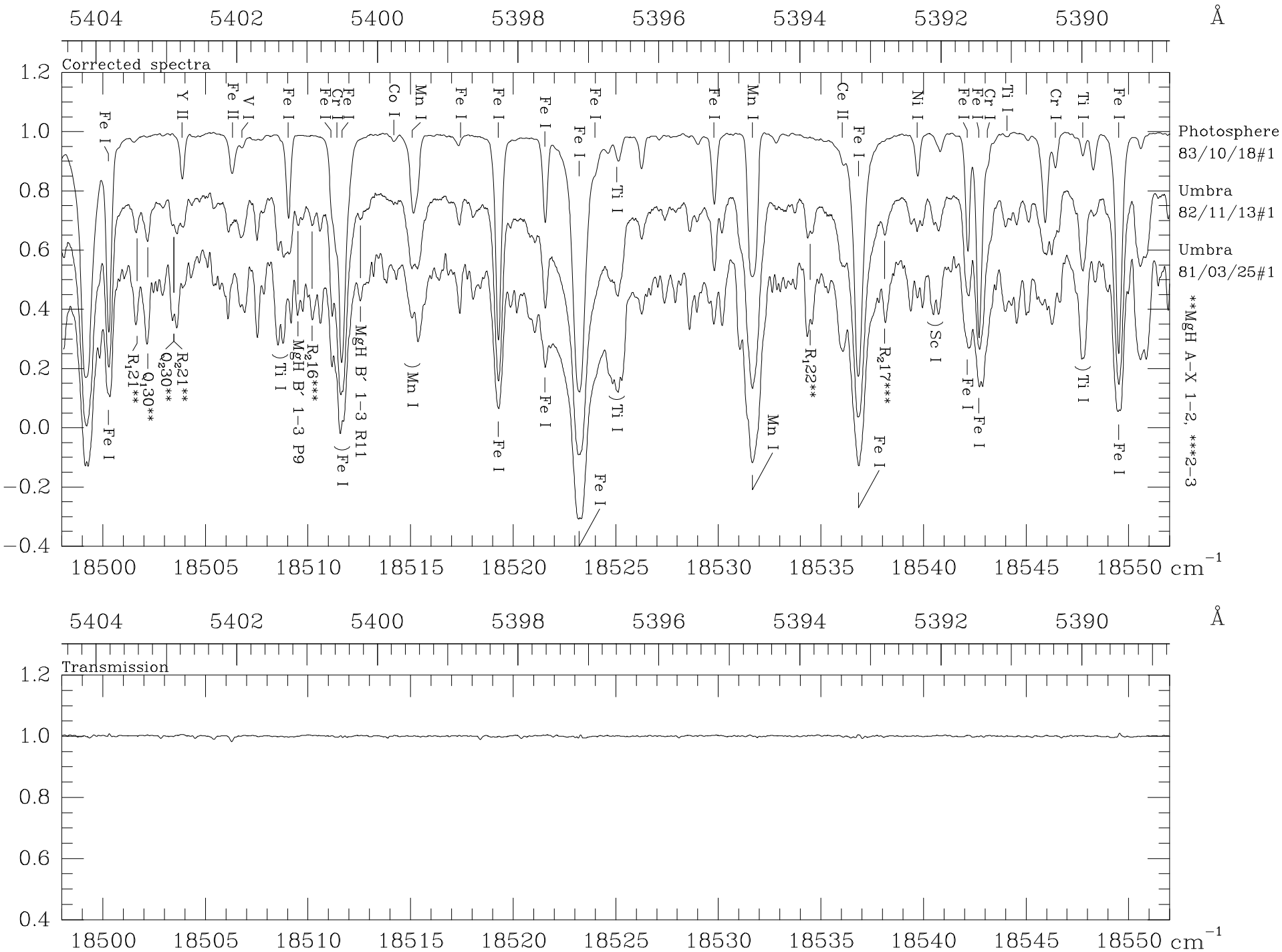


This region is the least conjested with TiO lines.




Corrected spectra
Photosphere 83/10/18#1
Umbra 82/11/13#1
Umbra 81/03/25#1
*MgH A–X 0–1, **1–2, ***2–3
Transmission
Å
cm^{-1}


Corrected spectra
Photosphere
83/10/18#1
Umbra
82/11/13#1
Umbra
81/03/25#1
**MgH A–X 1–2, ***2–3
Transmission
Å
cm^{-1}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Photosphere 83/10/18#1
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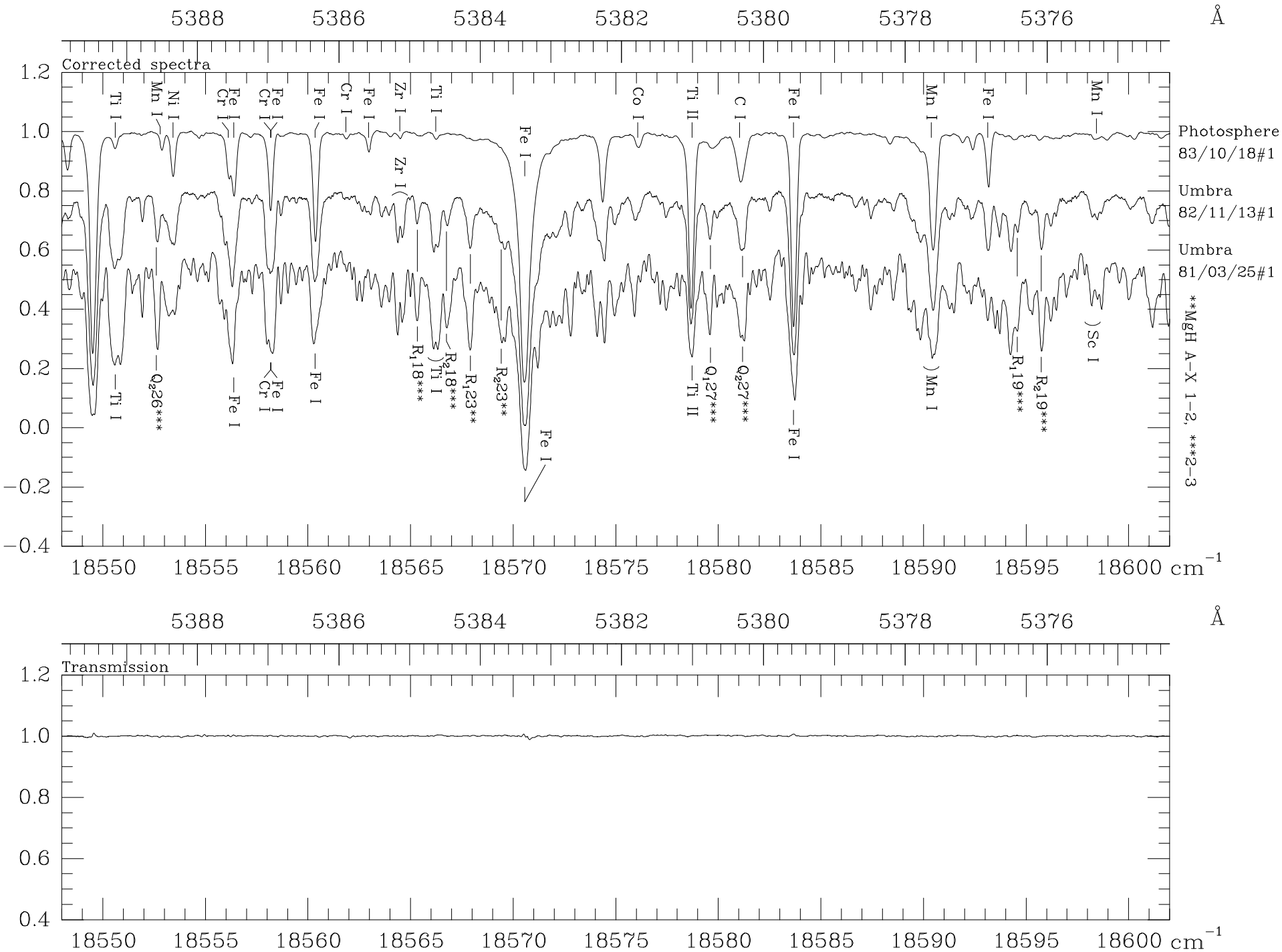
**MgH A–X 1–2, ***2–3
Transmission
Å
cm^{-1}


Corrected spectra
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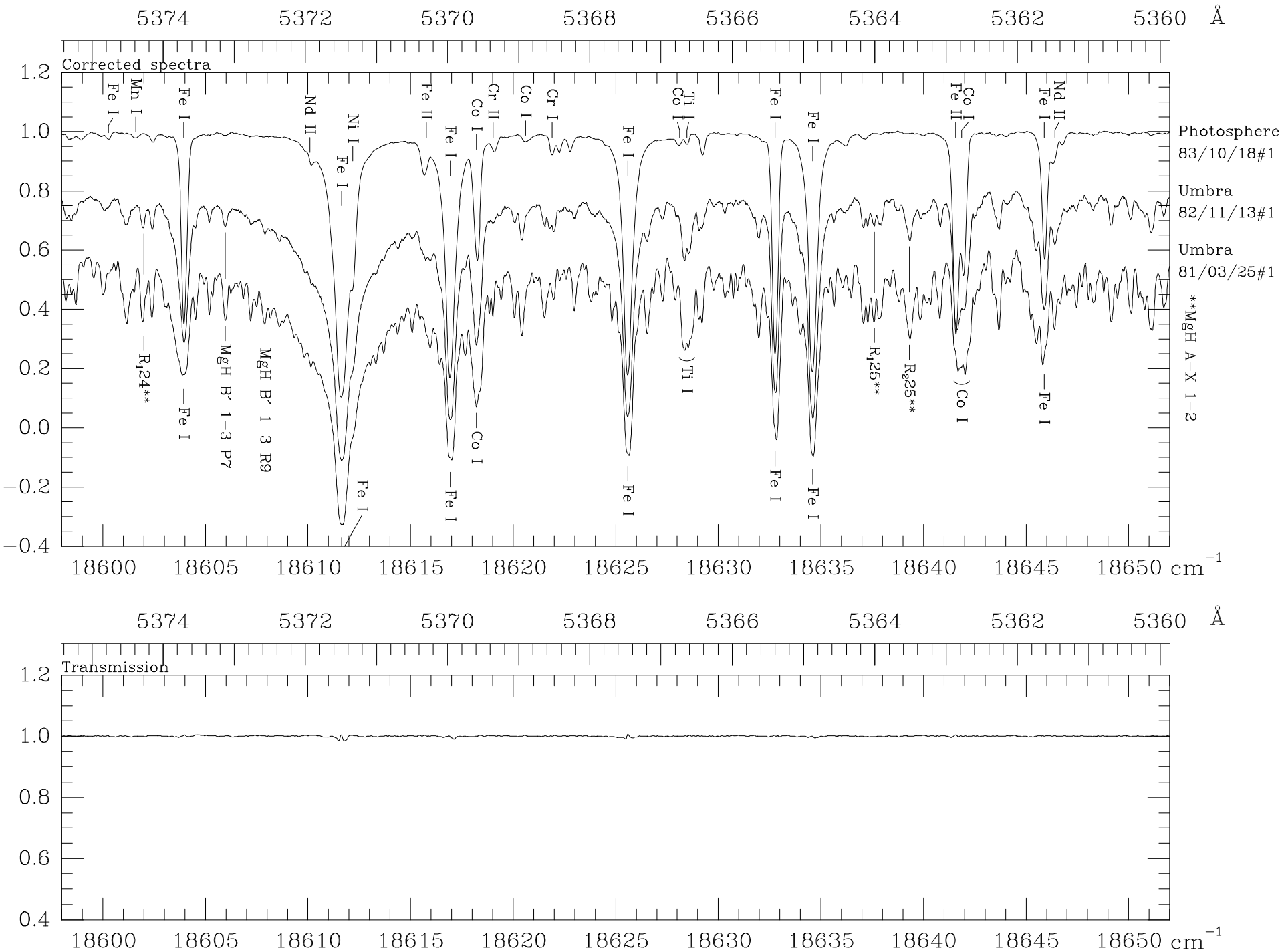
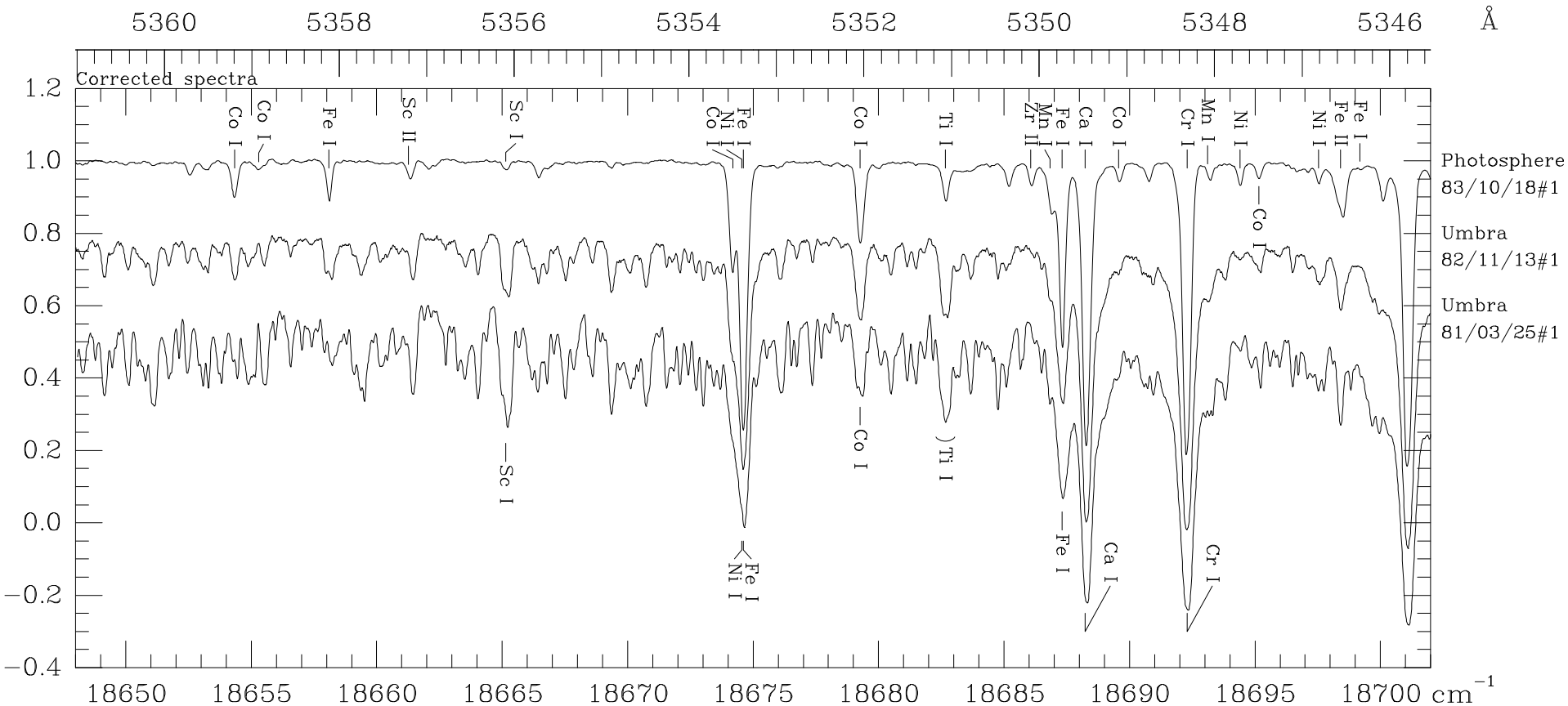
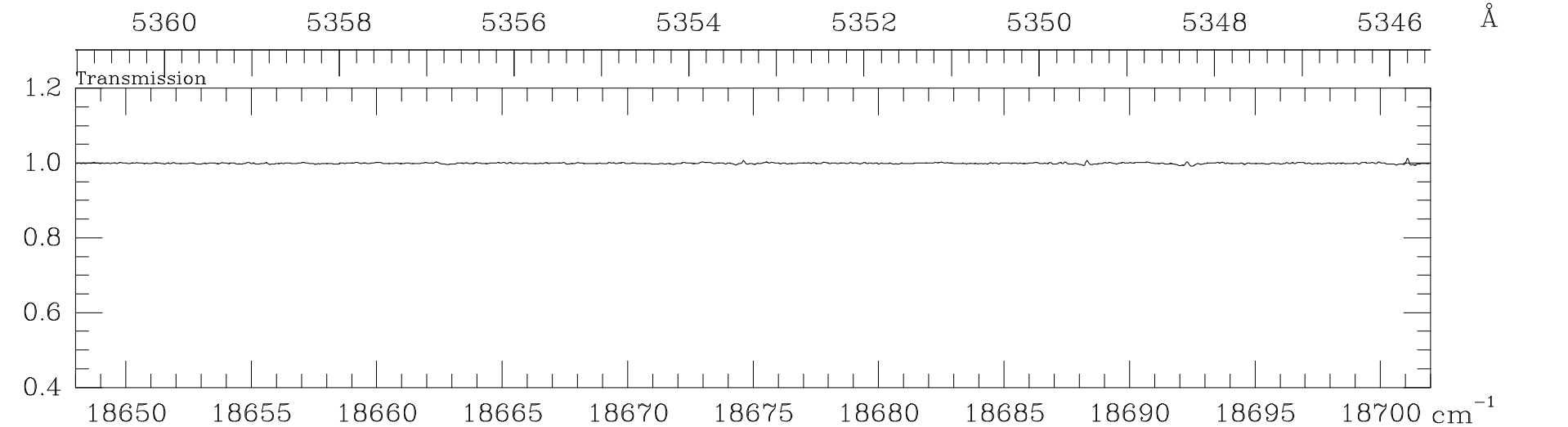
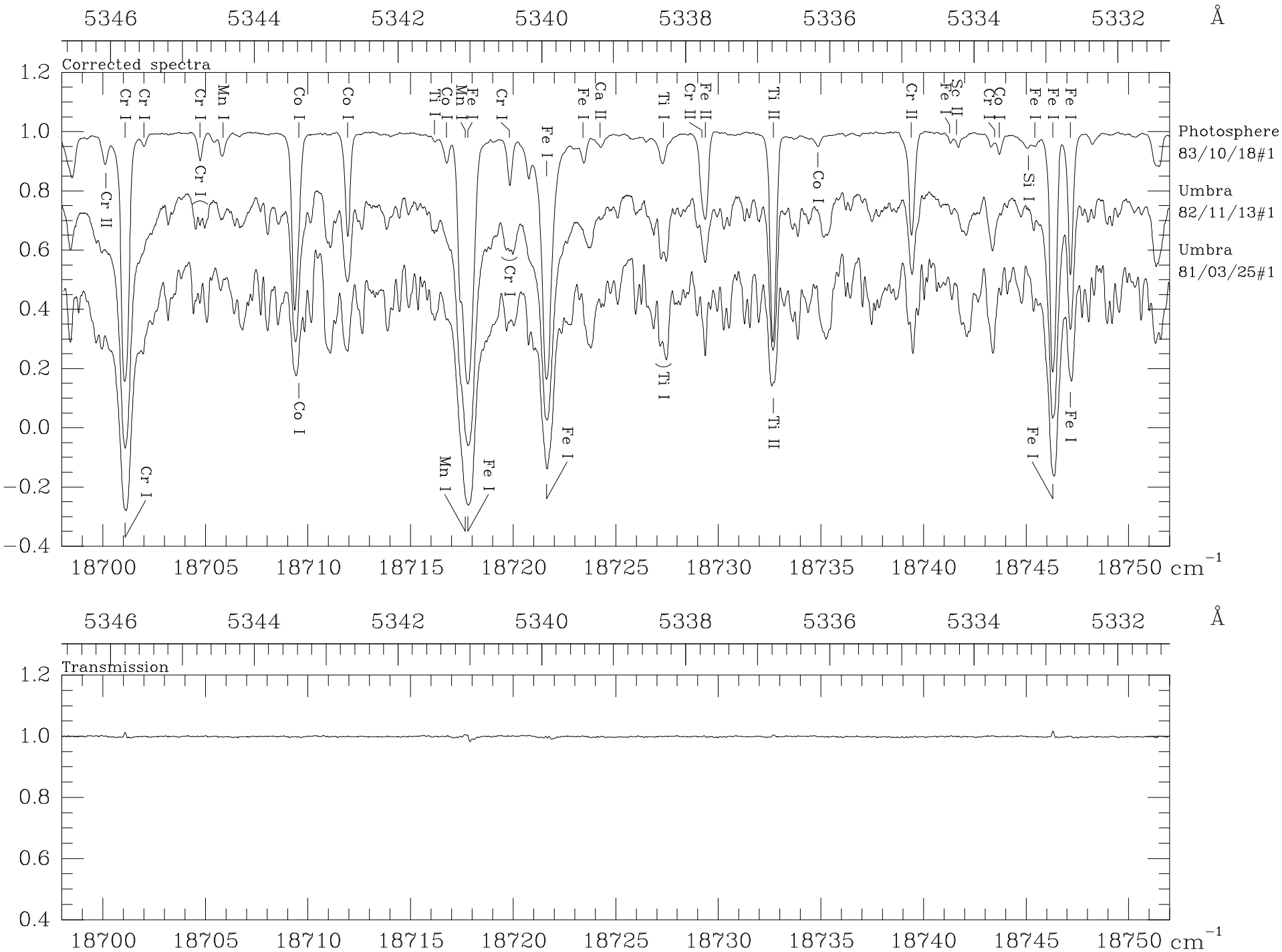
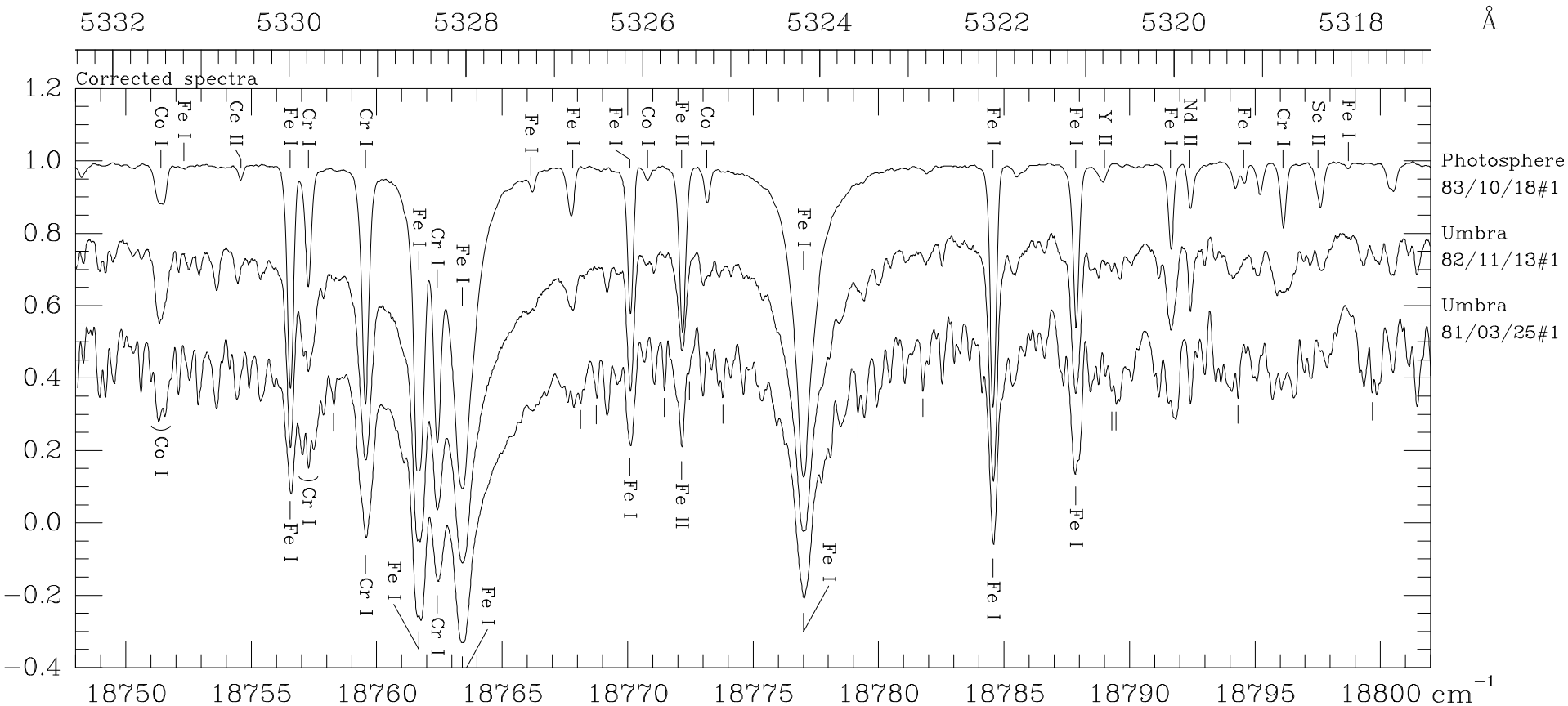
83/10/18#1
Umbra
82/11/13#1
Umbra
81/03/25#1
**MgH A–X 1–2, ***2–3
Transmission
Å
cm^{-1}


Corrected spectra
Photosphere
83/10/18#1
Umbra
82/11/13#1
Umbra
81/03/25#1
**MgH A–X 1–2
Fe I
Mn I
Fe I
Nd II
Ni I
Fe I
Fe II
Fe I
Co I
Cr II
Co I
Cr I
Fe I
Co I
Ti I
Fe I
Fe I
Co I
Fe II
Nd II
Fe I
R1 24**
MgH B′ 1–3 P7
MgH B′ 1–3 R9
R1 25**
R2 25**
Ti I
Co I
Fe I
5374 5372 5370 5368 5366 5364 5362 5360 Å
18600 18605 18610 18615 18620 18625 18630 18635 18640 18645 18650 cm−1
Transmission

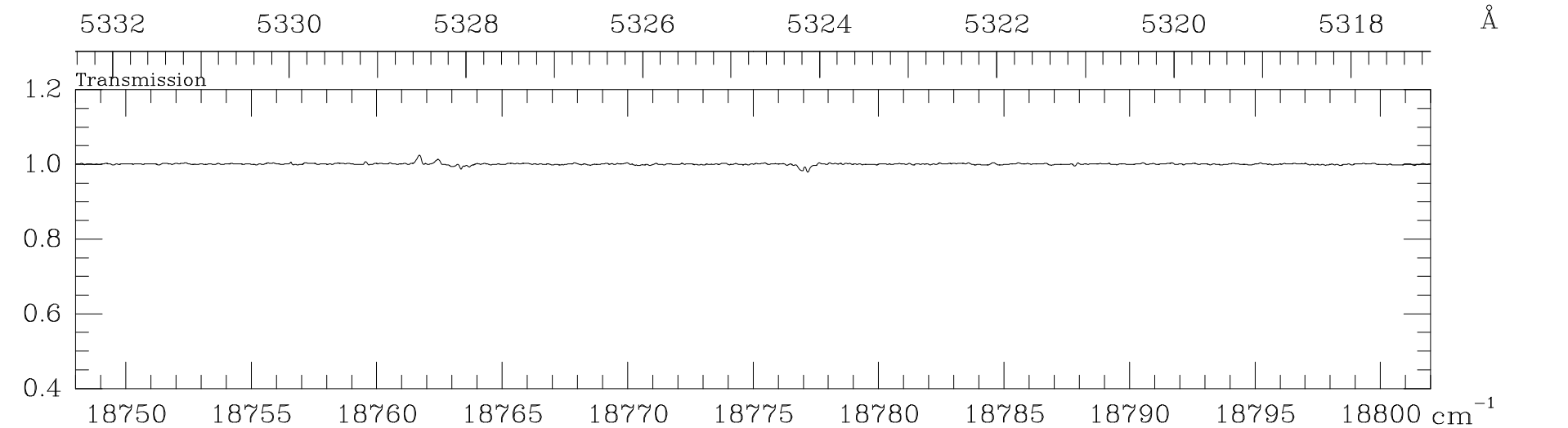

Corrected spectra
Photosphere
83/10/18#1
Umbra
82/11/13#1
Umbra
81/03/25#1
Co I
Co I
Fe I
Sc II
Sc I
Co I
Fe I
Ni I
Co I
Co I
Ti I
Zr II
Mn I
Fe I
Ca I
Co I
Cr I
Mn I
Ni I
Ni I
Fe II
Fe I
Co I
Sc I
Co I
Ti I
Fe I
Ni I
Fe I
Ca I
Cr I
5360
5358
5356
5354
5352
5350
5348
5346
Å
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
18650
18655
18660
18665
18670
18675
18680
18685
18690
18695
18700
cm^{-1}

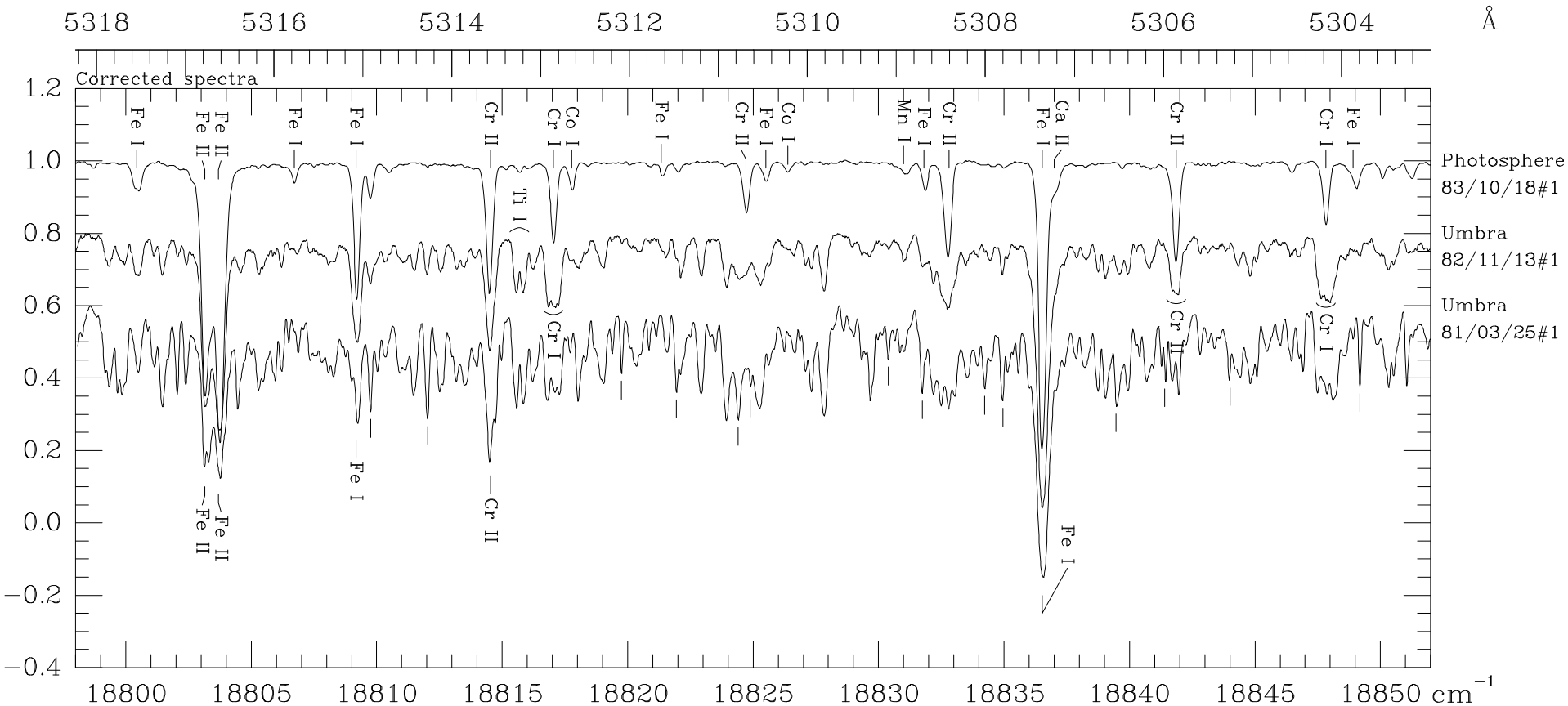

Transmission
5360
5358
5356
5354
5352
5350
5348
5346
Å
1.2
1.0
0.8
0.6
0.4
18650
18655
18660
18665
18670
18675
18680
18685
18690
18695
18700
cm^{-1}


Corrected spectra
Photosphere
83/10/18#1
Umbra
82/11/13#1
Umbra
81/03/25#1
Transmission
Å
cm^{-1}



The features with ticks but no labels in the lower umbral spectrum are due to lines of the TiO α 0–0 band.





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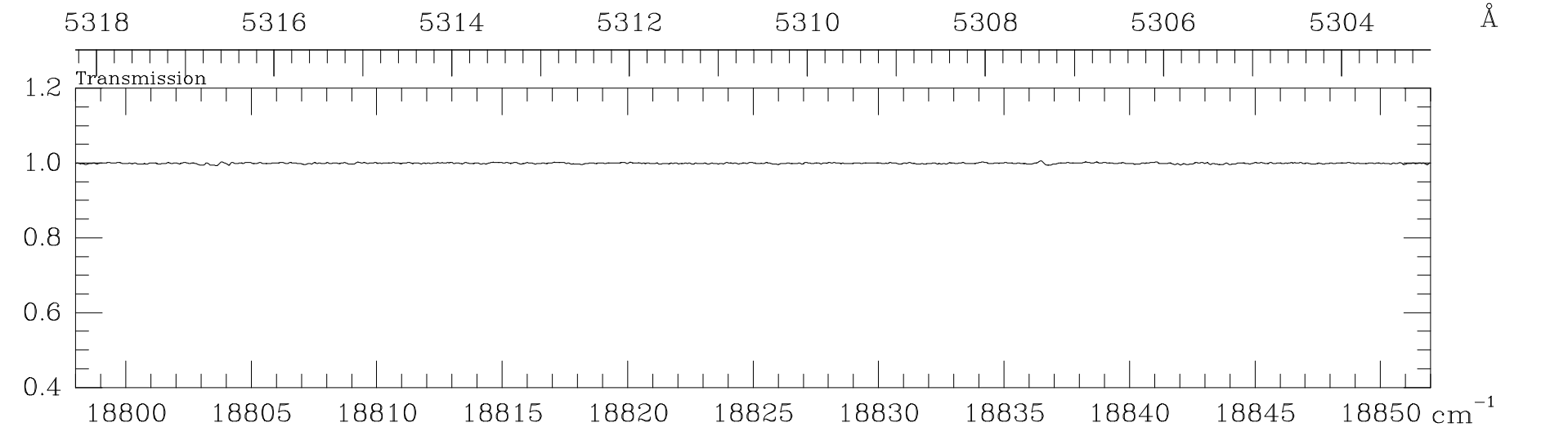

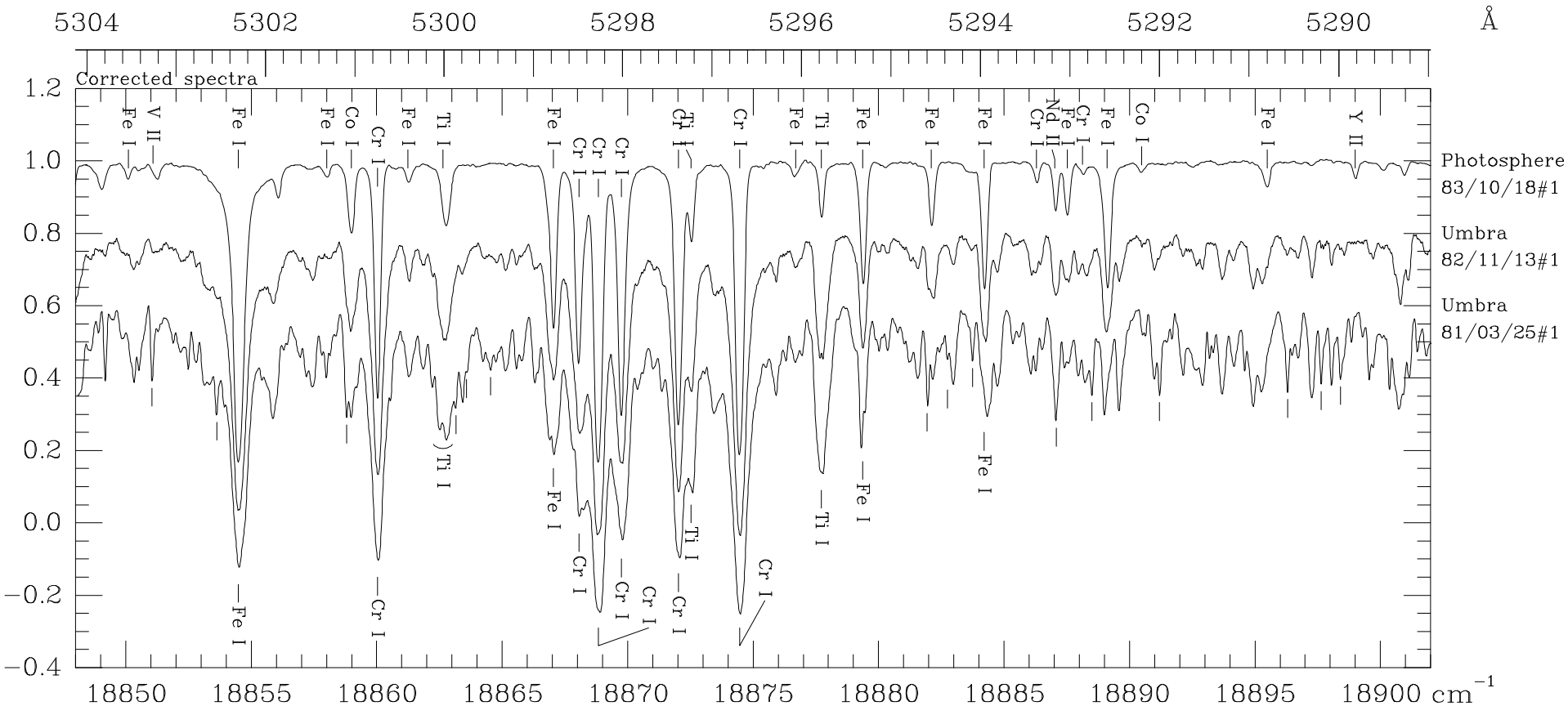

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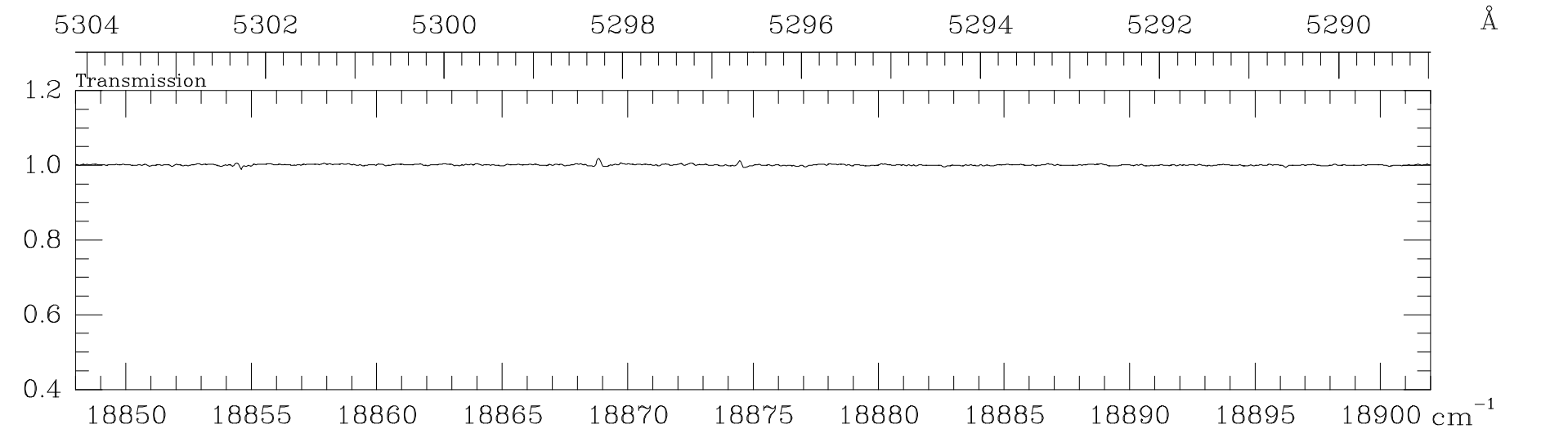
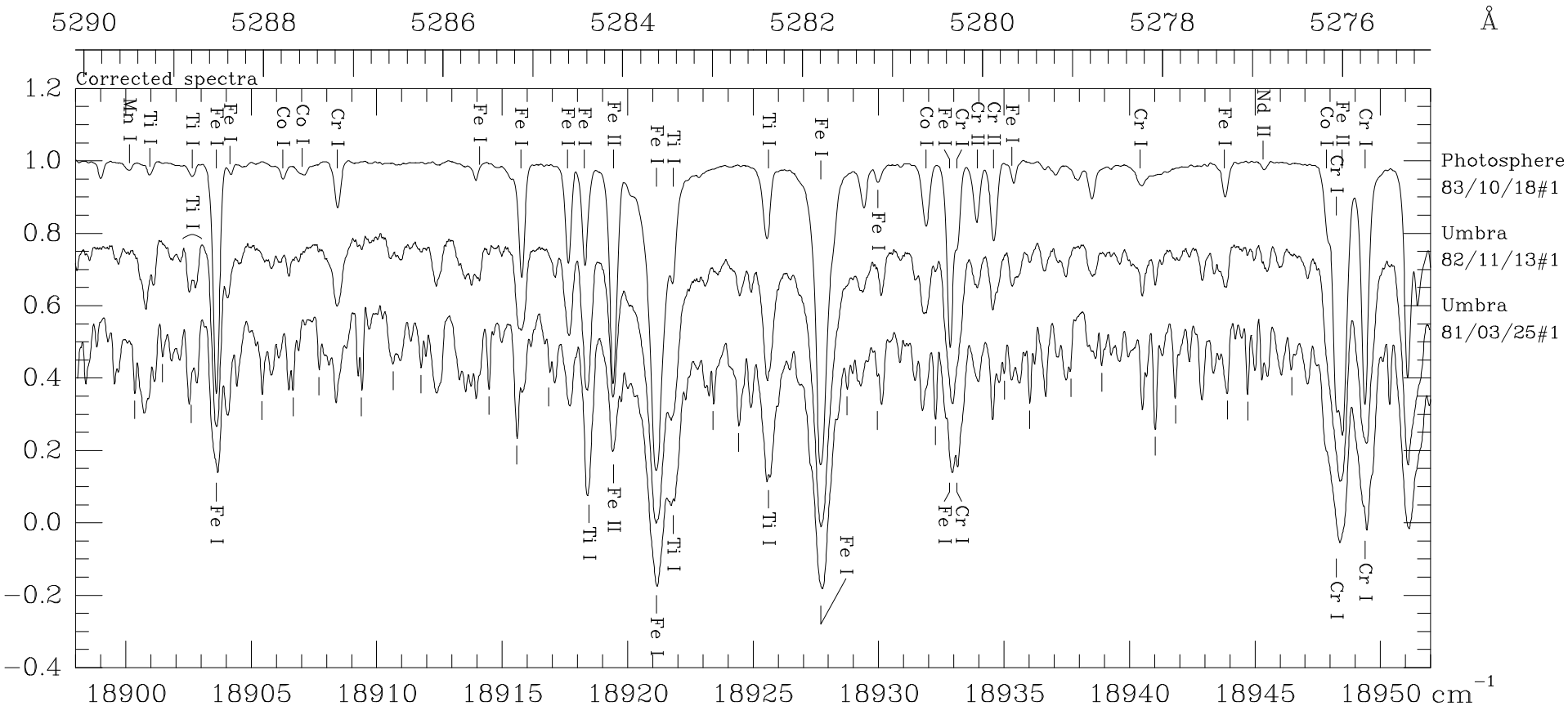
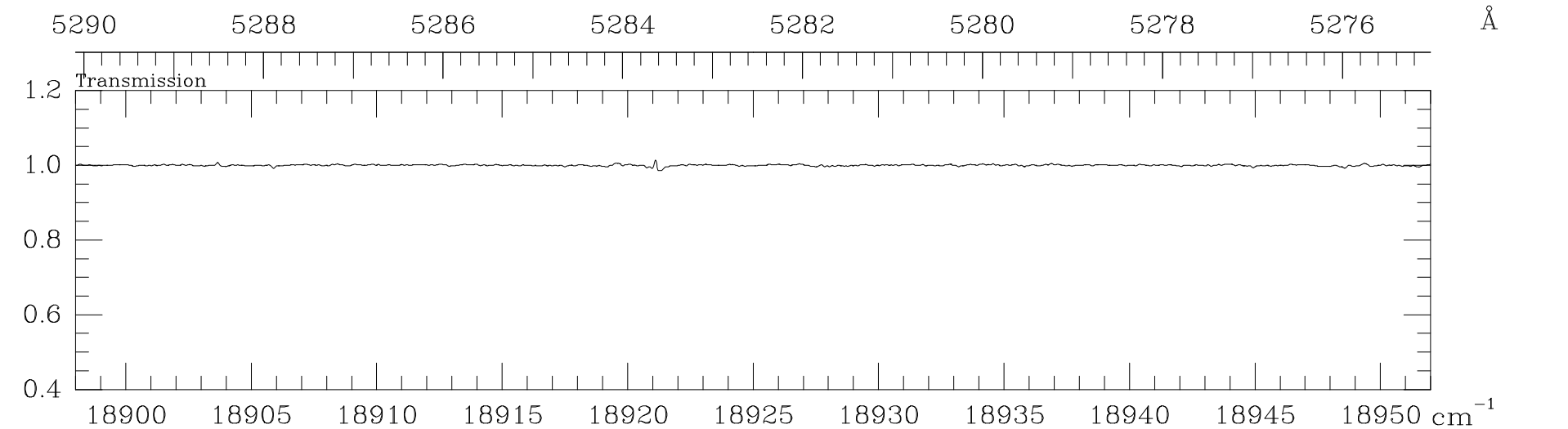
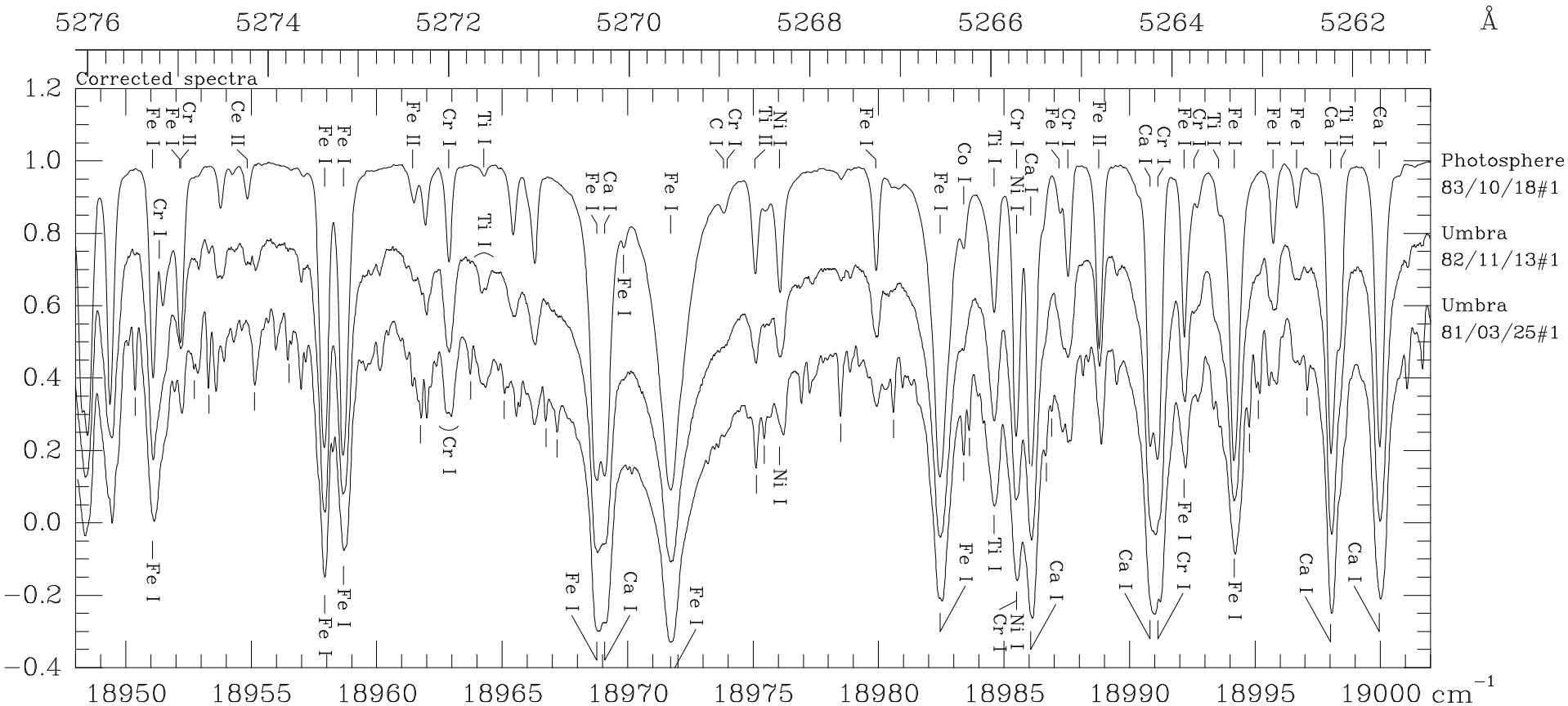




The features with ticks but no labels in the lower umbral spectrum are due to lines of the TiO α 0–0 band.





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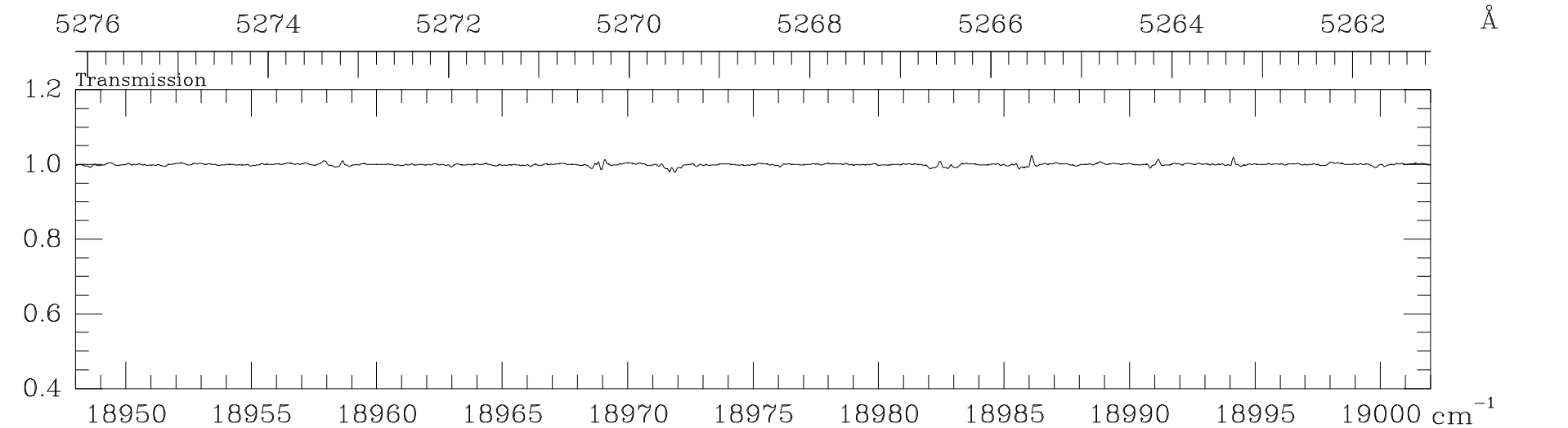

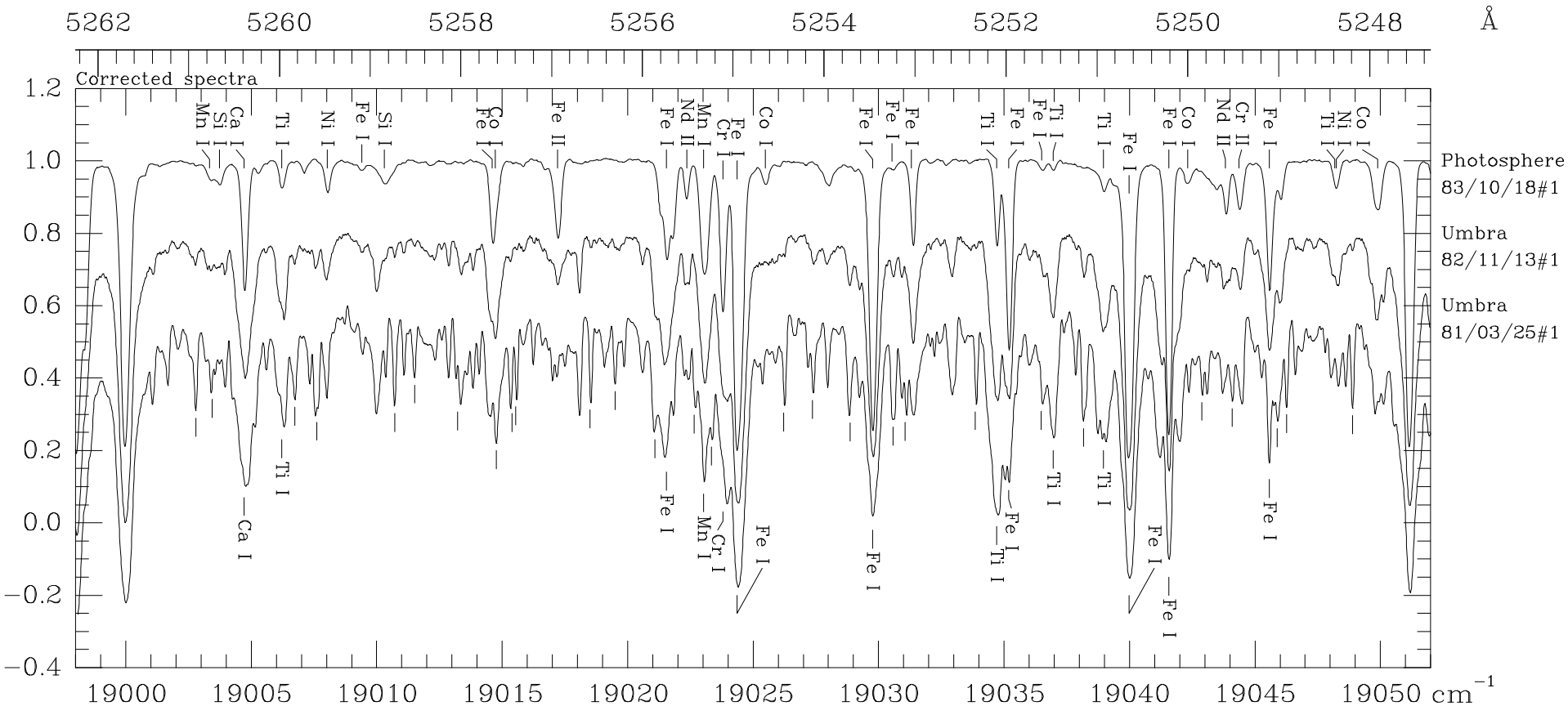

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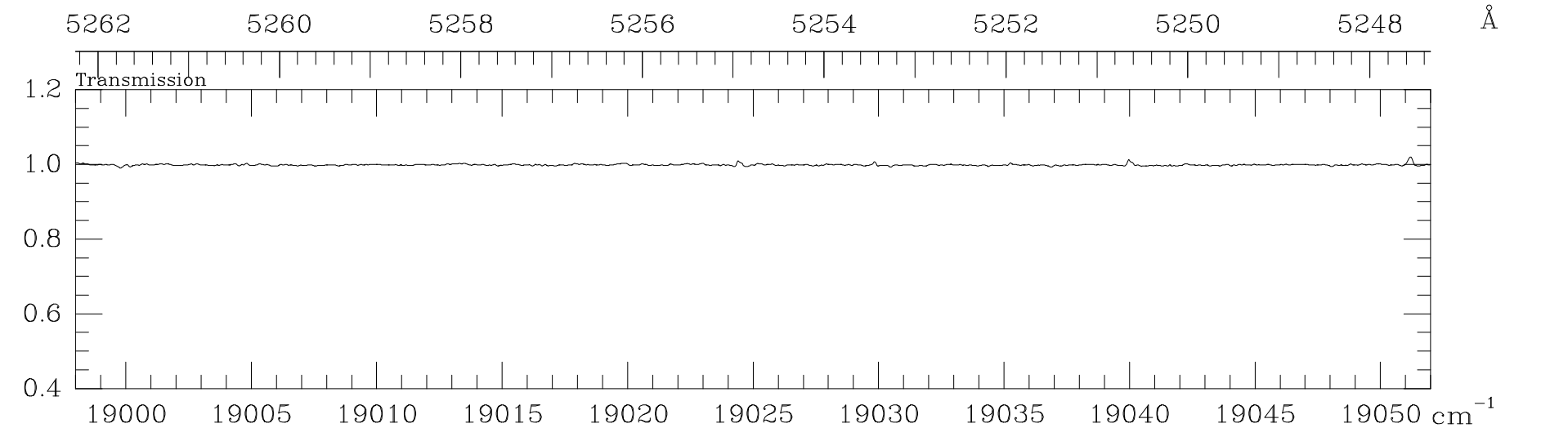

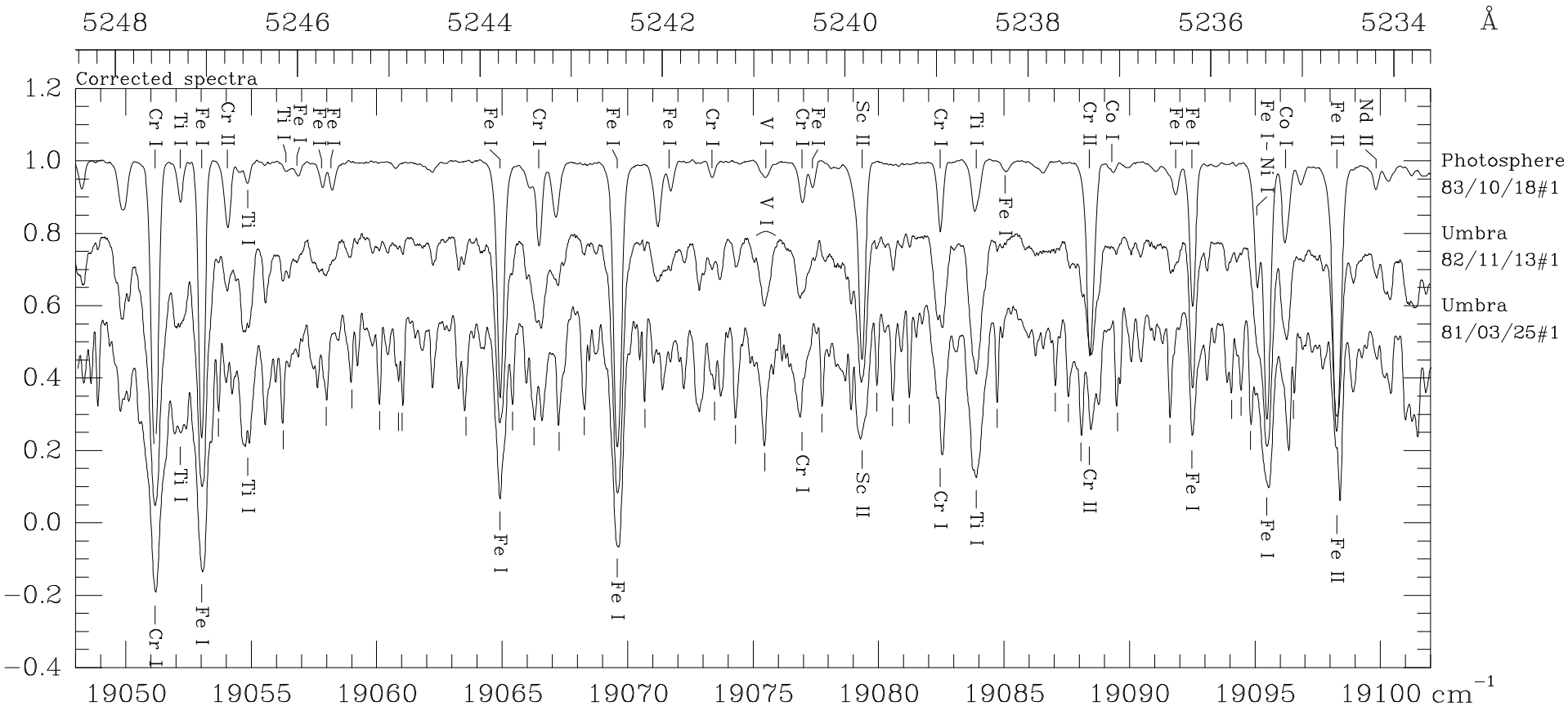

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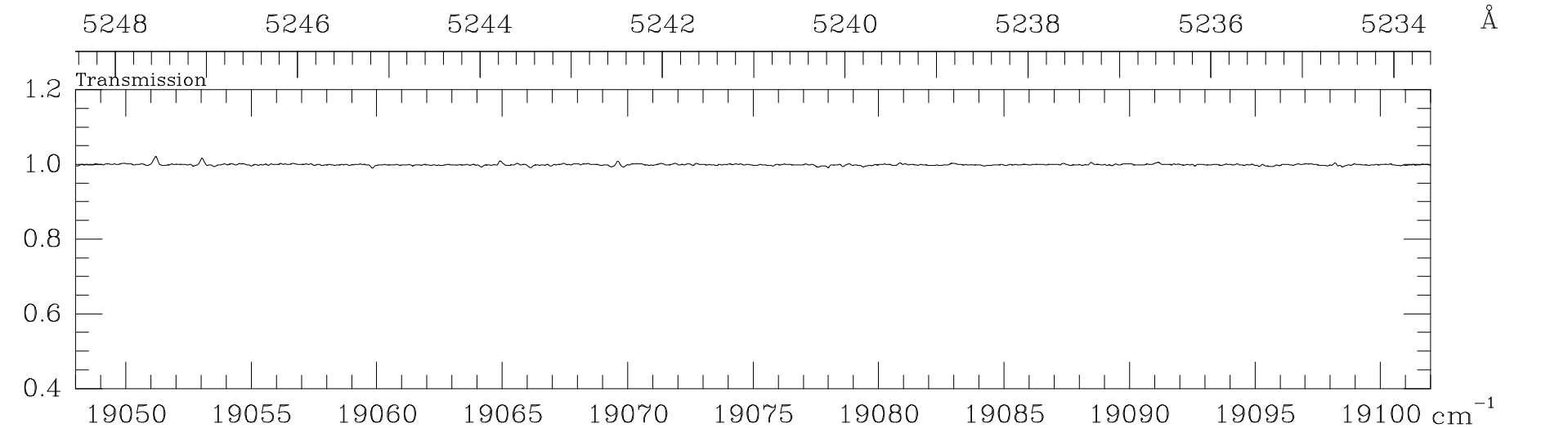

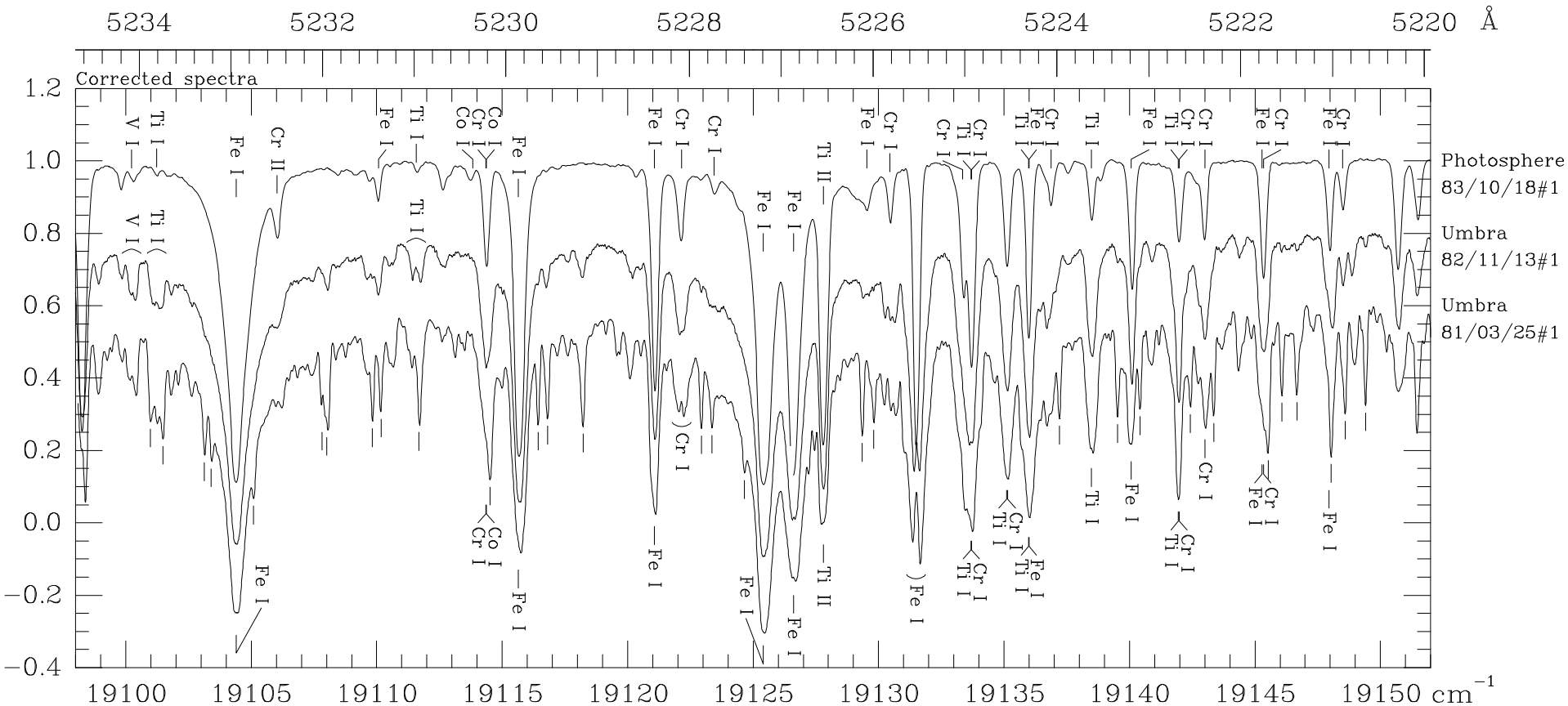

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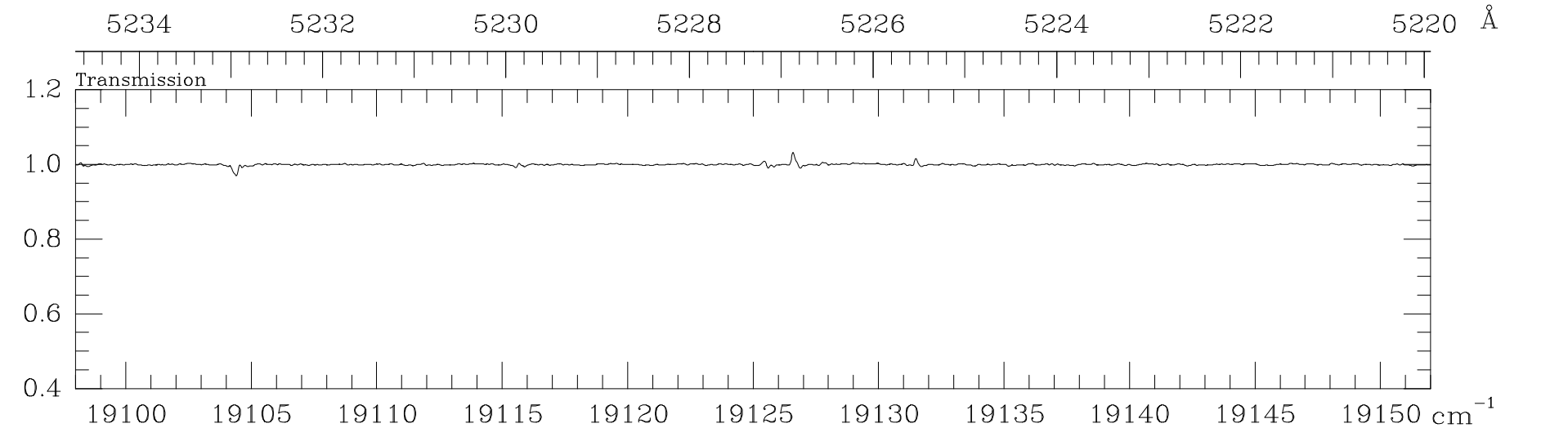
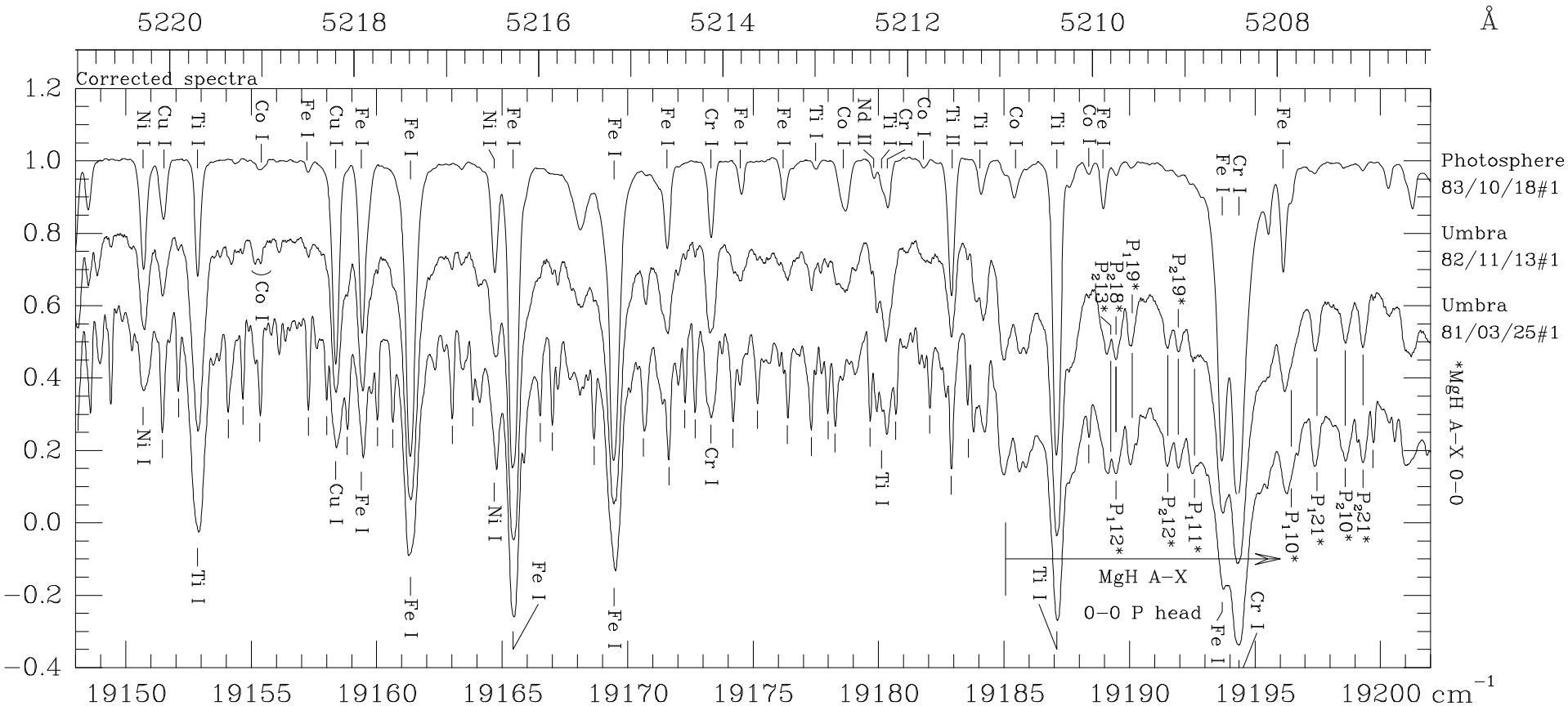
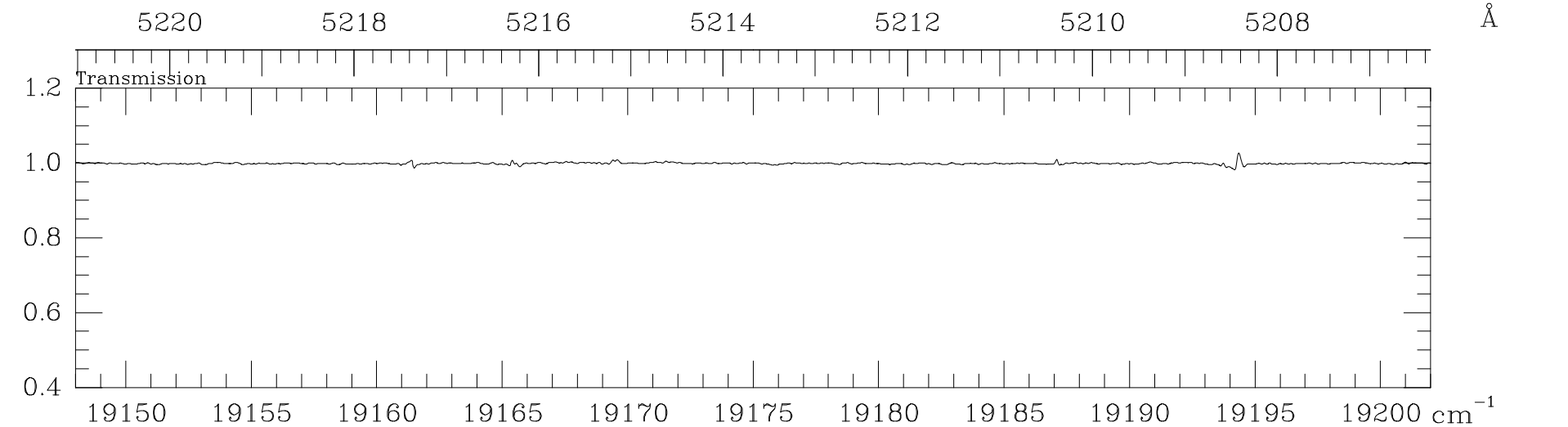
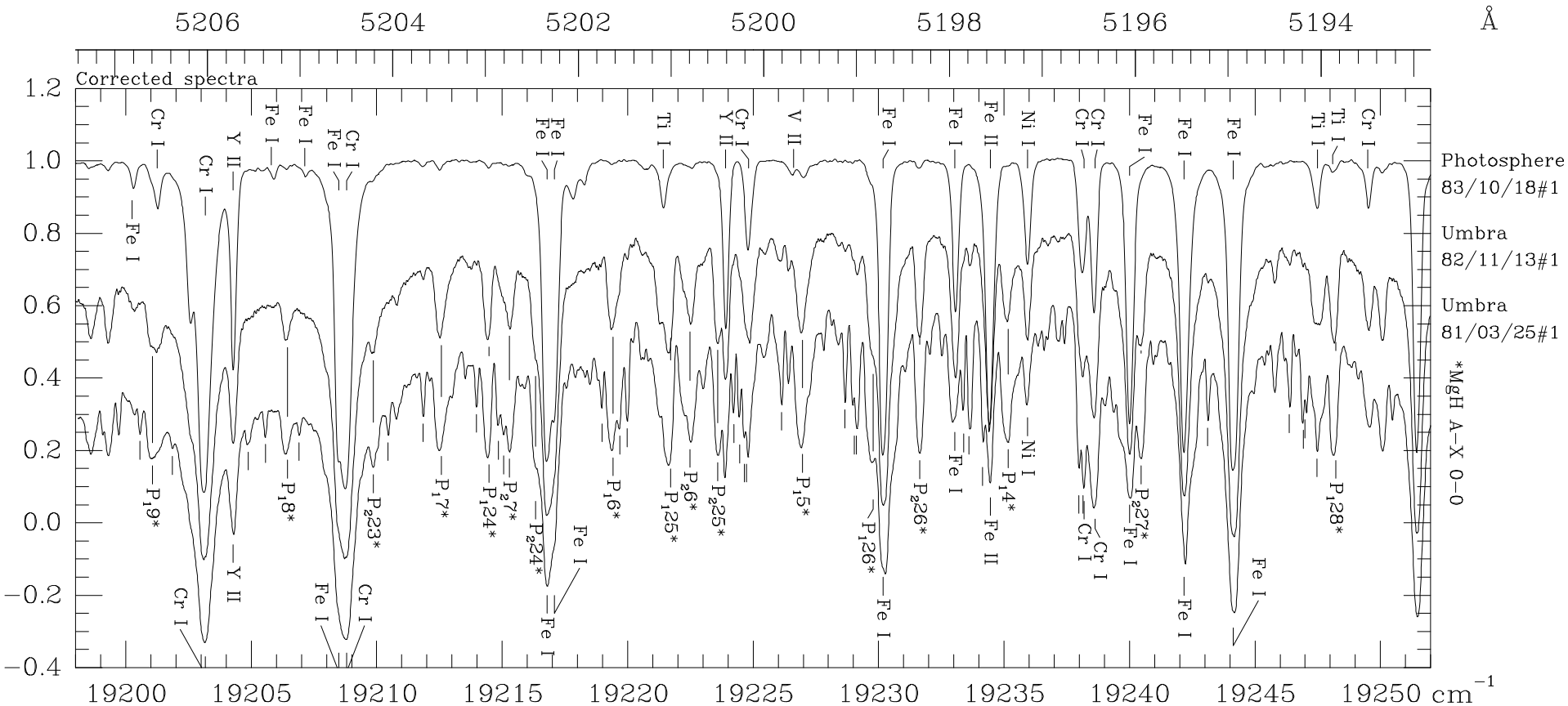




The features with ticks but no labels in the lower umbral spectrum are due to lines of the TiO α 0–0 band.





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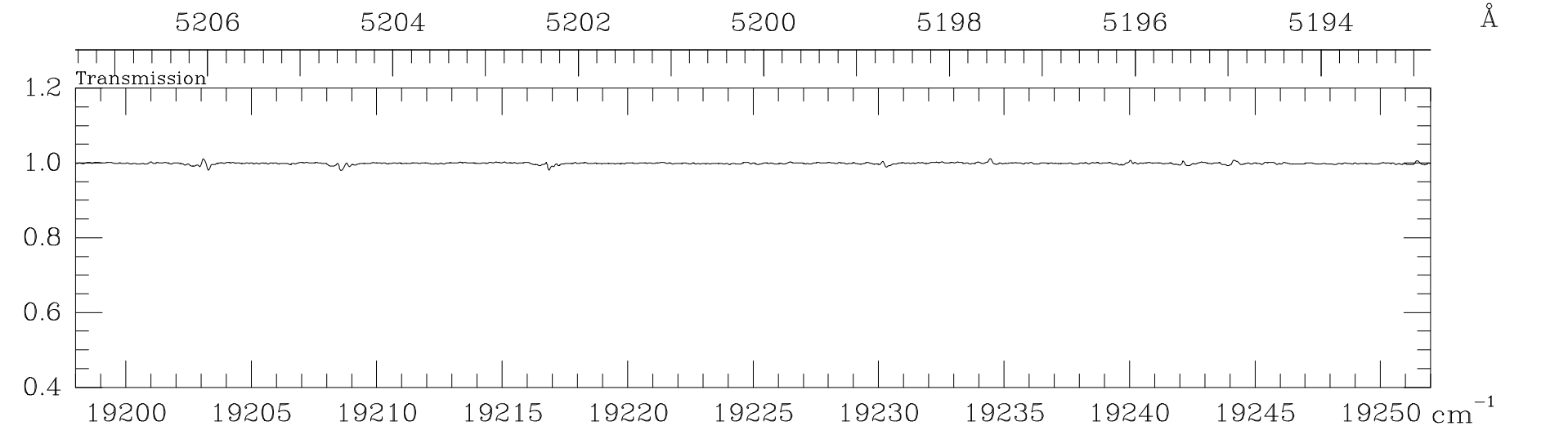

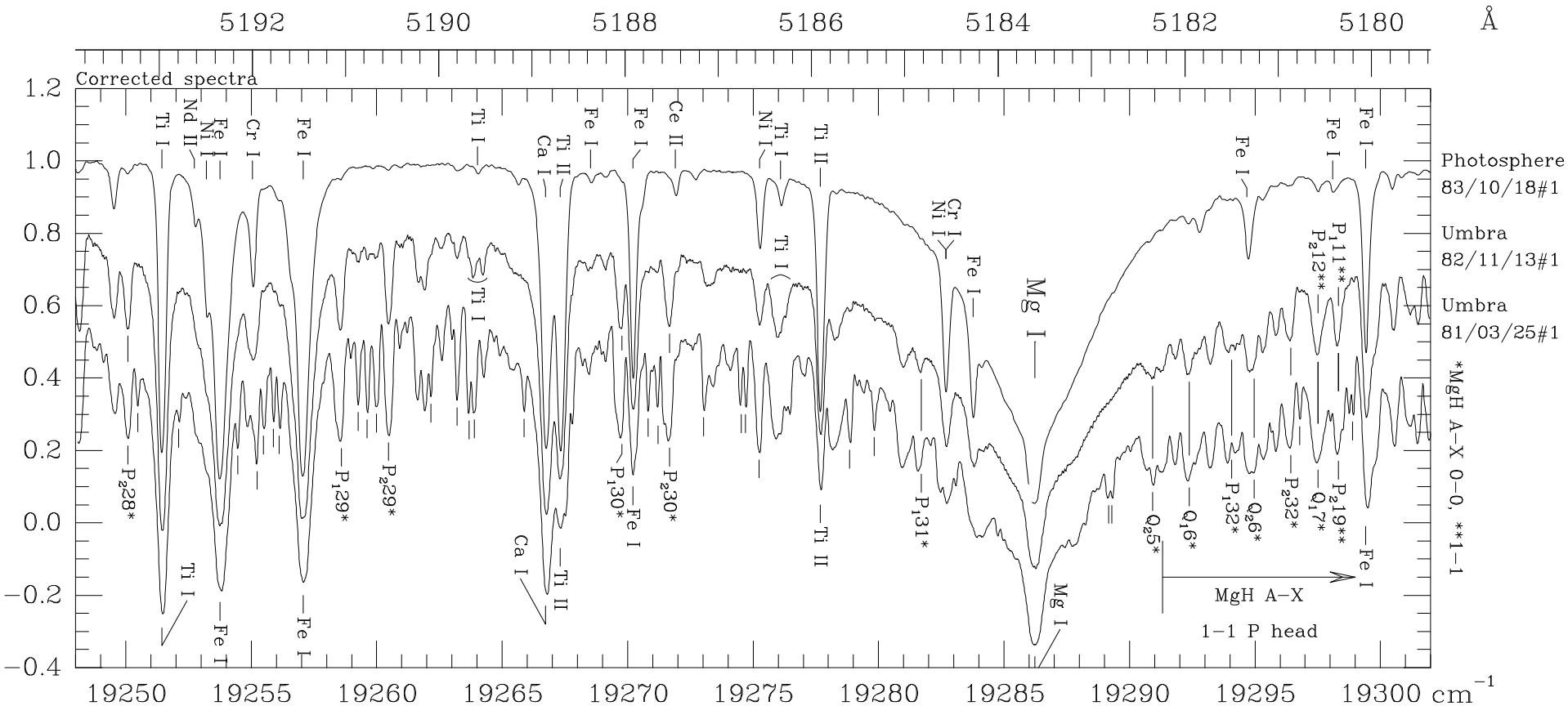

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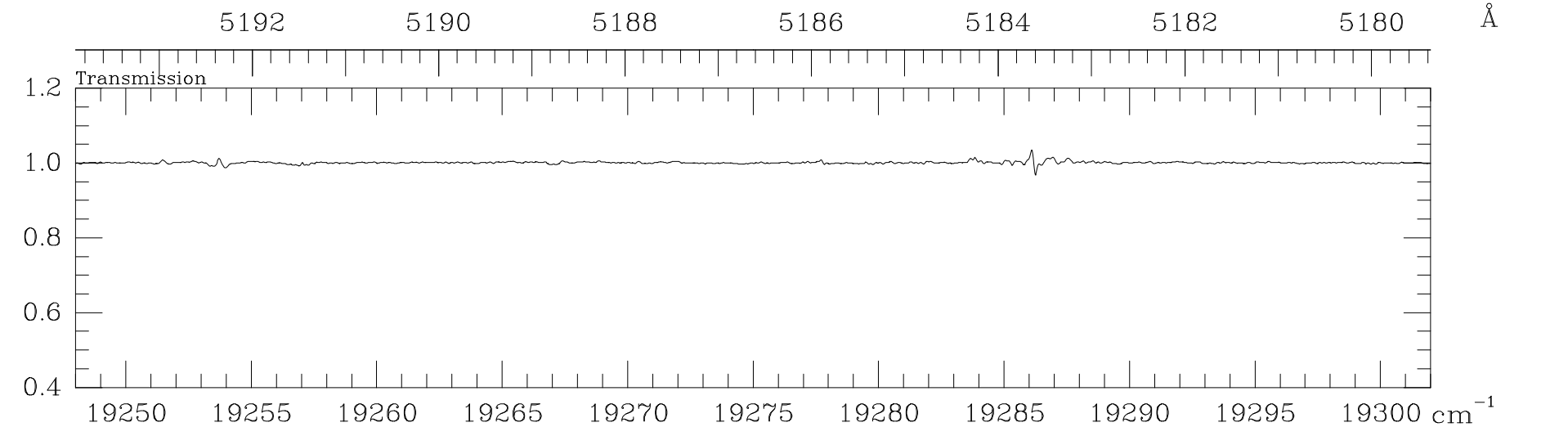

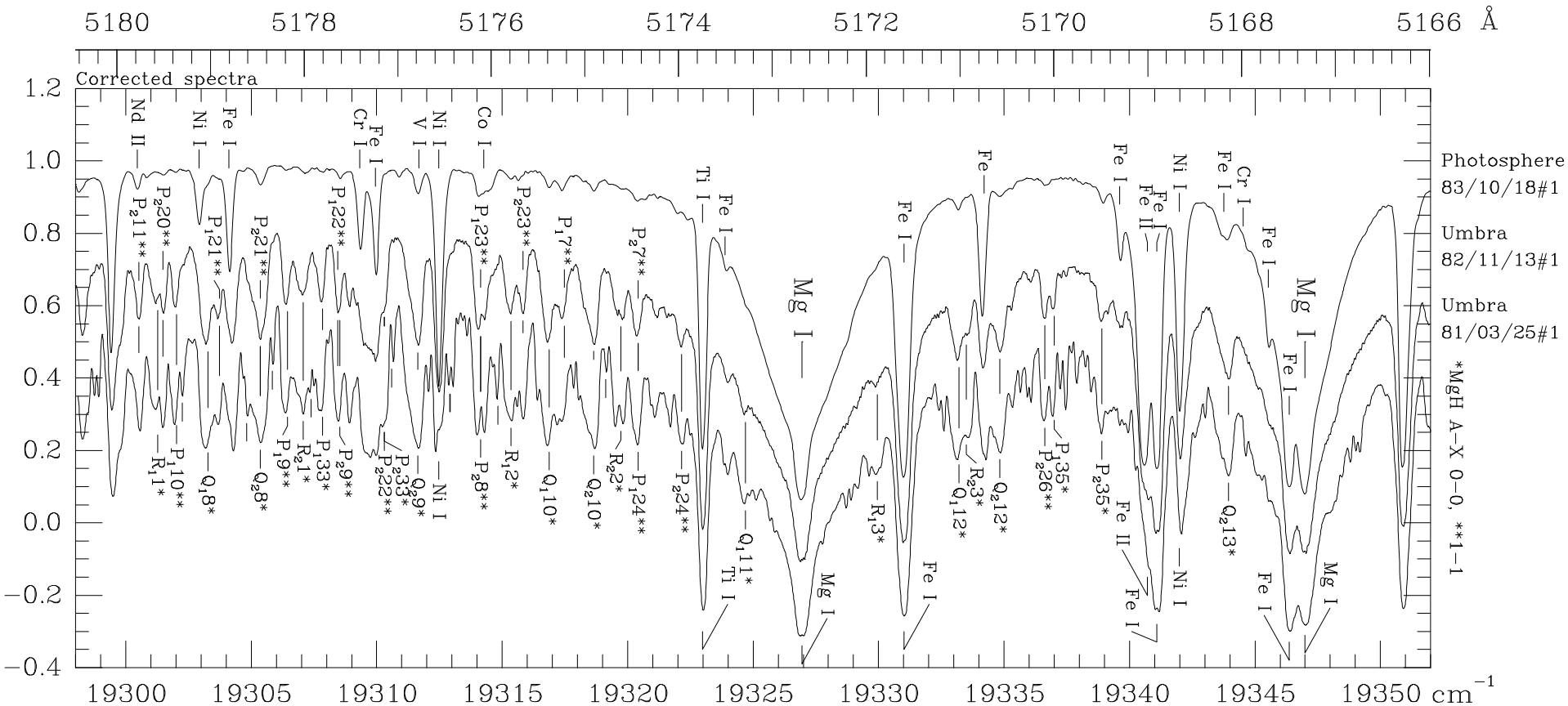

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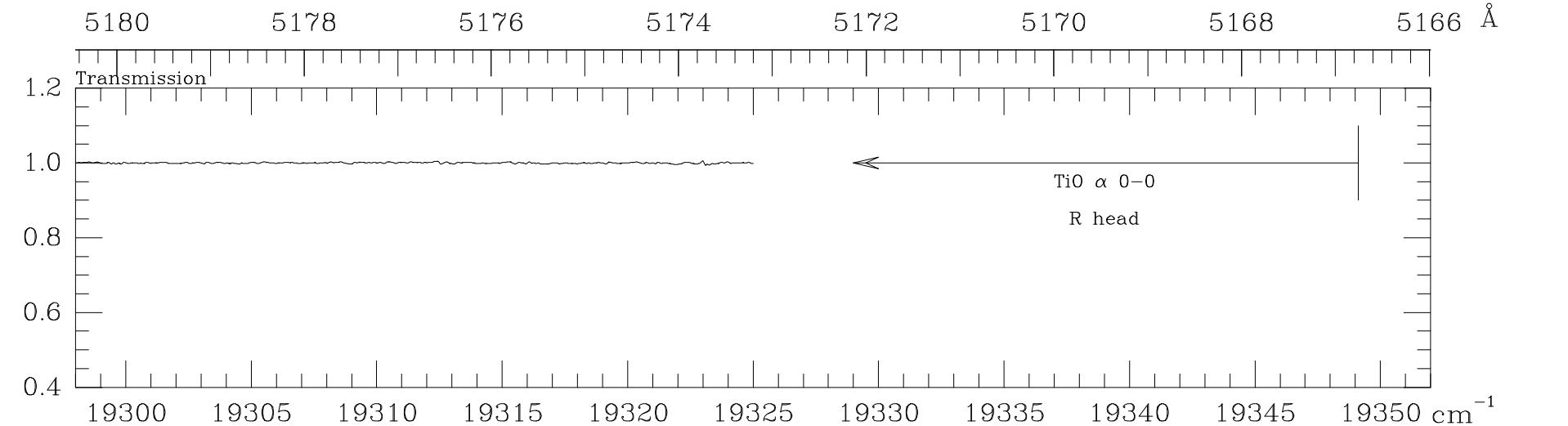

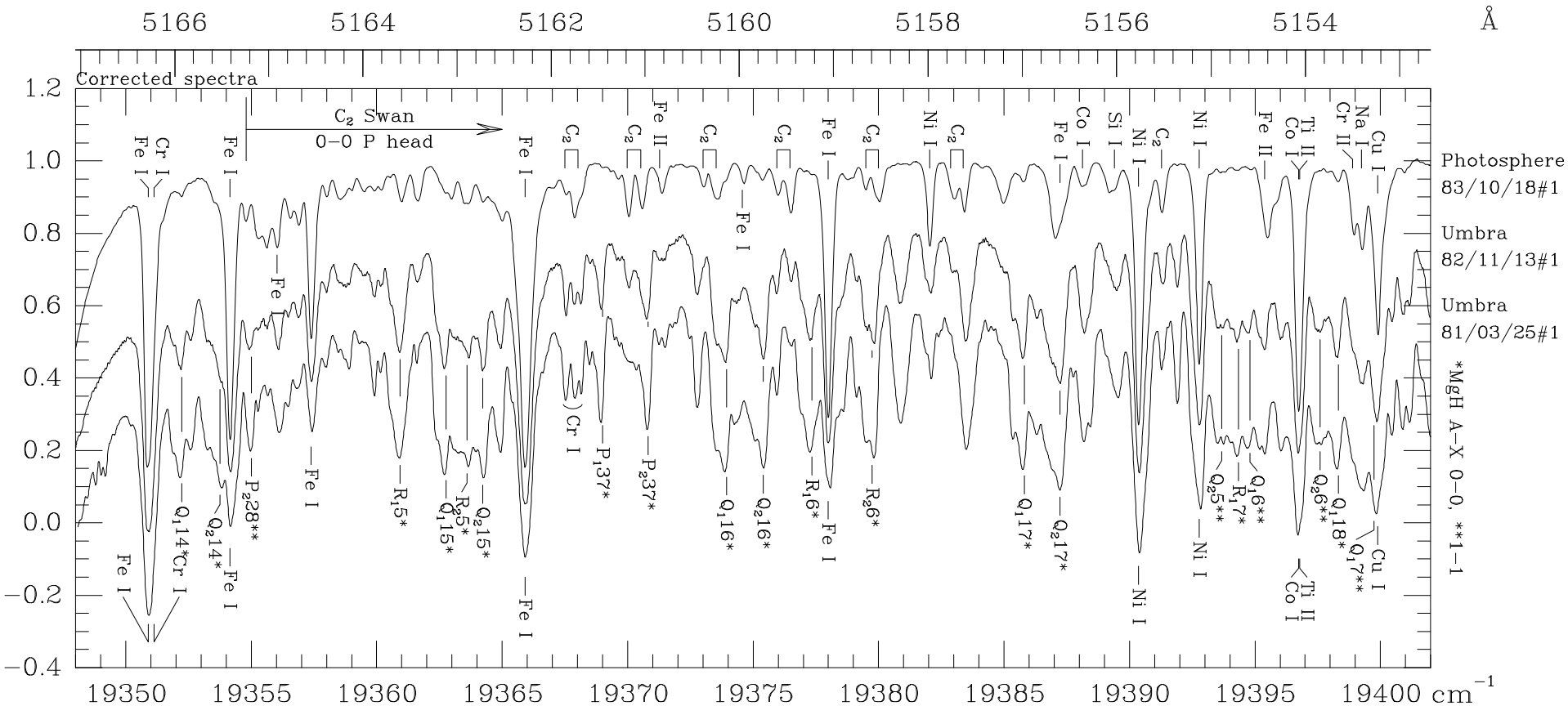
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Å
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5164
5162
5160
5158
5156
5154
C₂ Swan
0–0 P head
Photosphere
83/10/18#1
Umbra
82/11/13#1
Umbra
81/03/25#1
*MgH A–X 0–0, **1–1
Fe I
Cr I
Fe I
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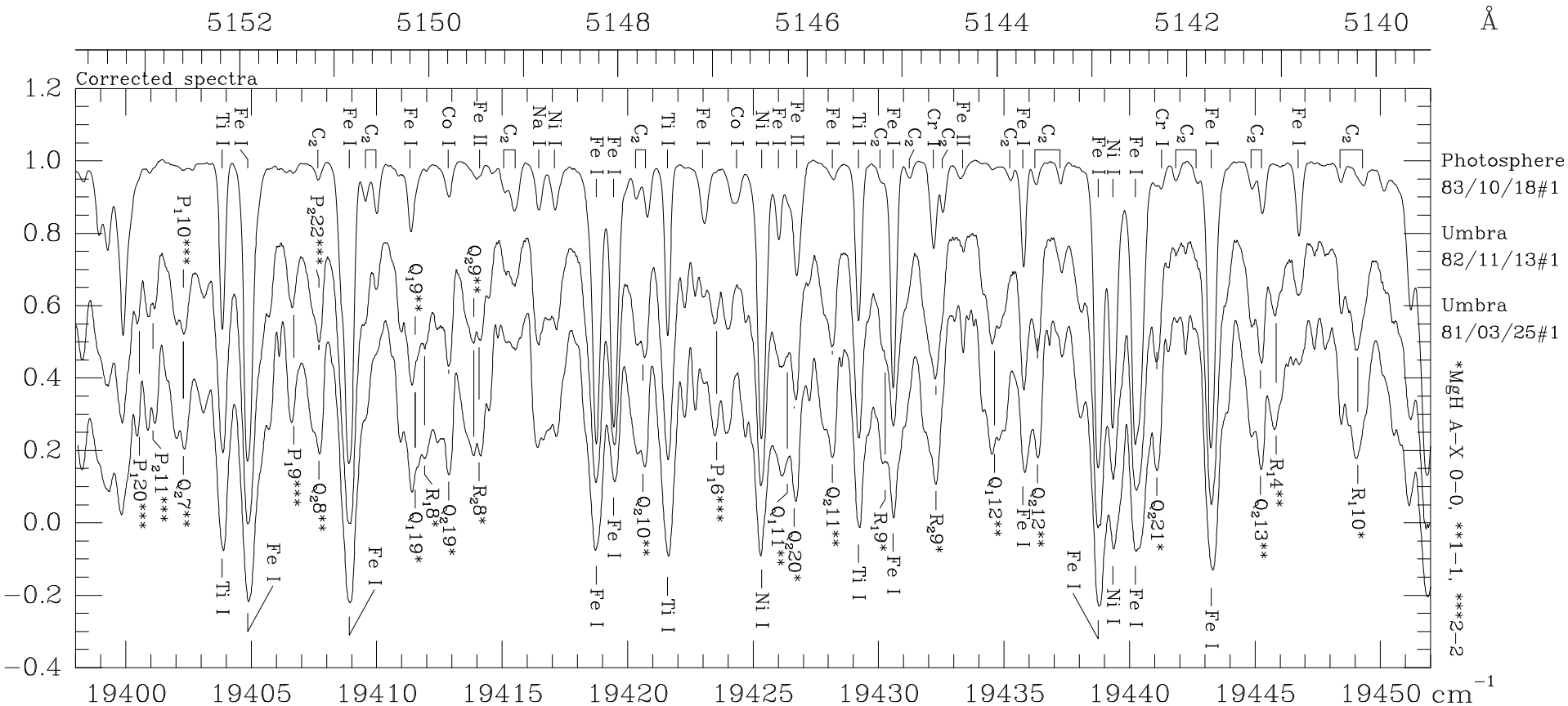
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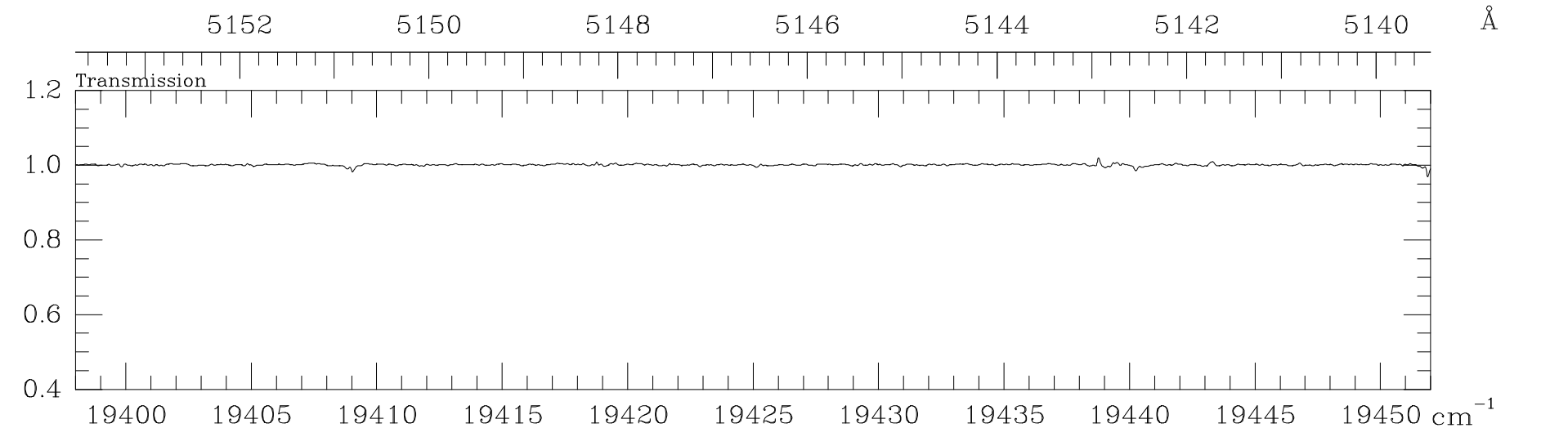
Å
cm^{-1}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Å
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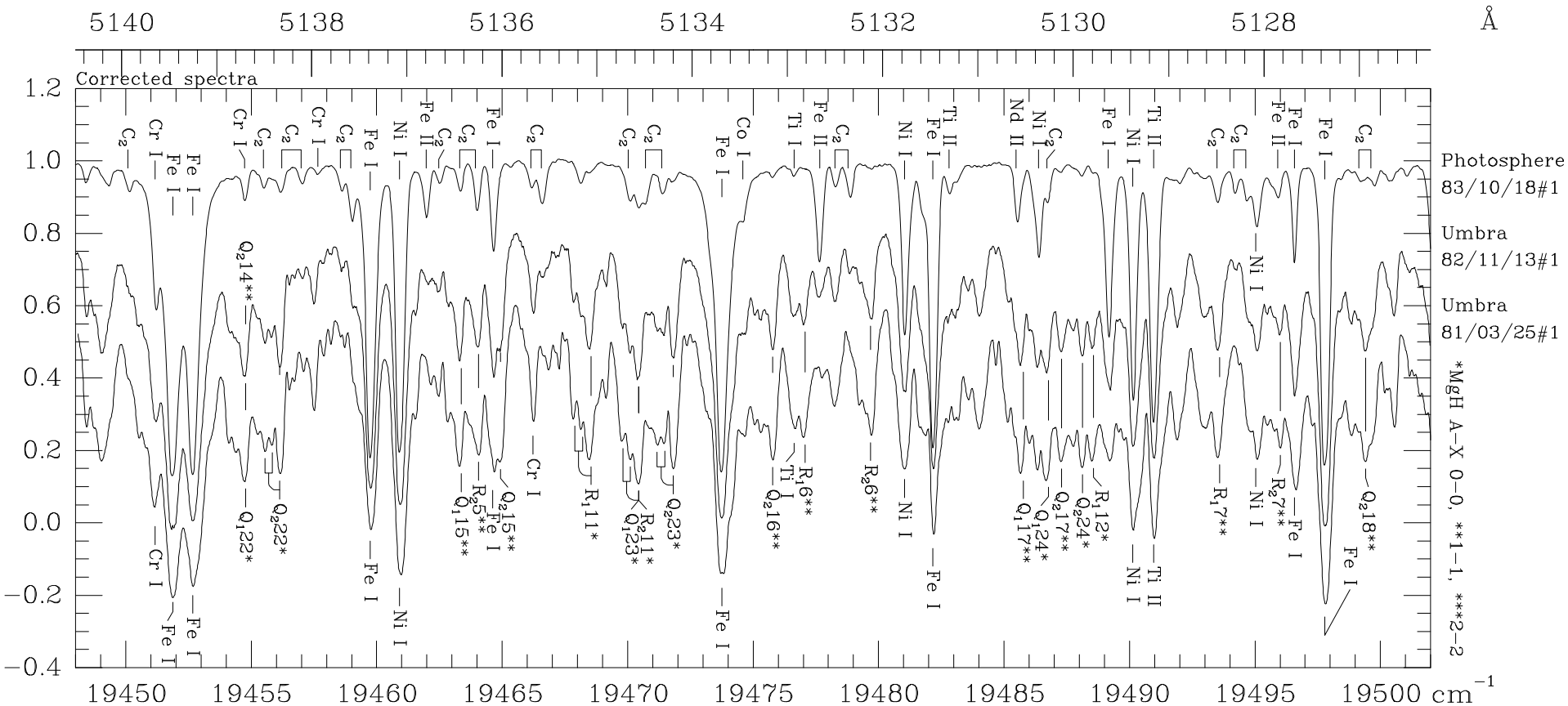
Corrected spectra
Å
Photosphere
83/10/18#1
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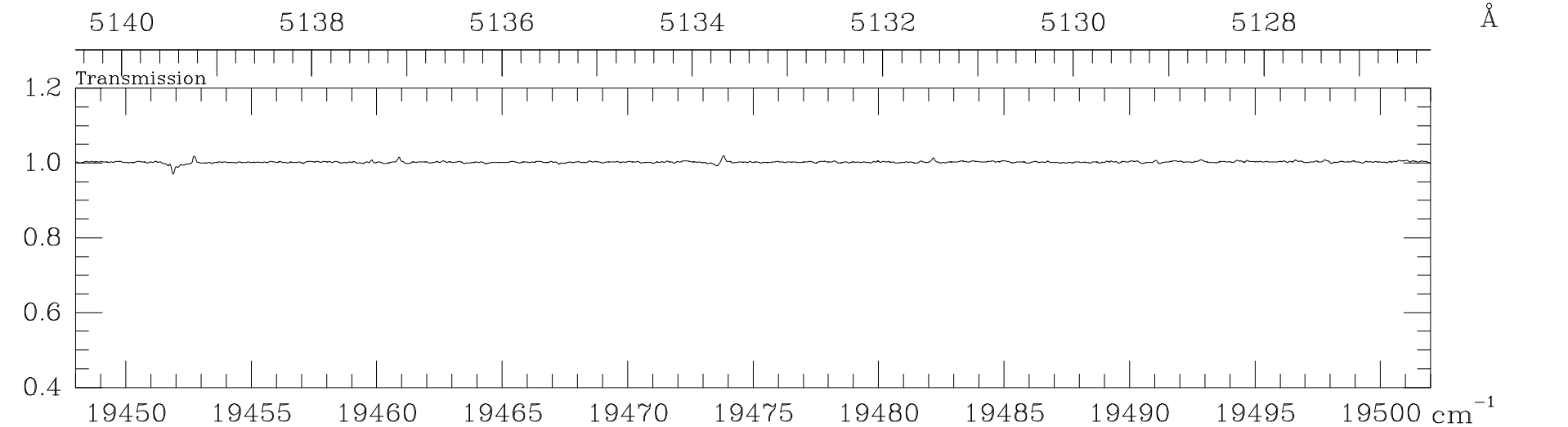
*MgH A–X 0–0, **1–1, ***2–2
cm^{-1}


Transmission
Å
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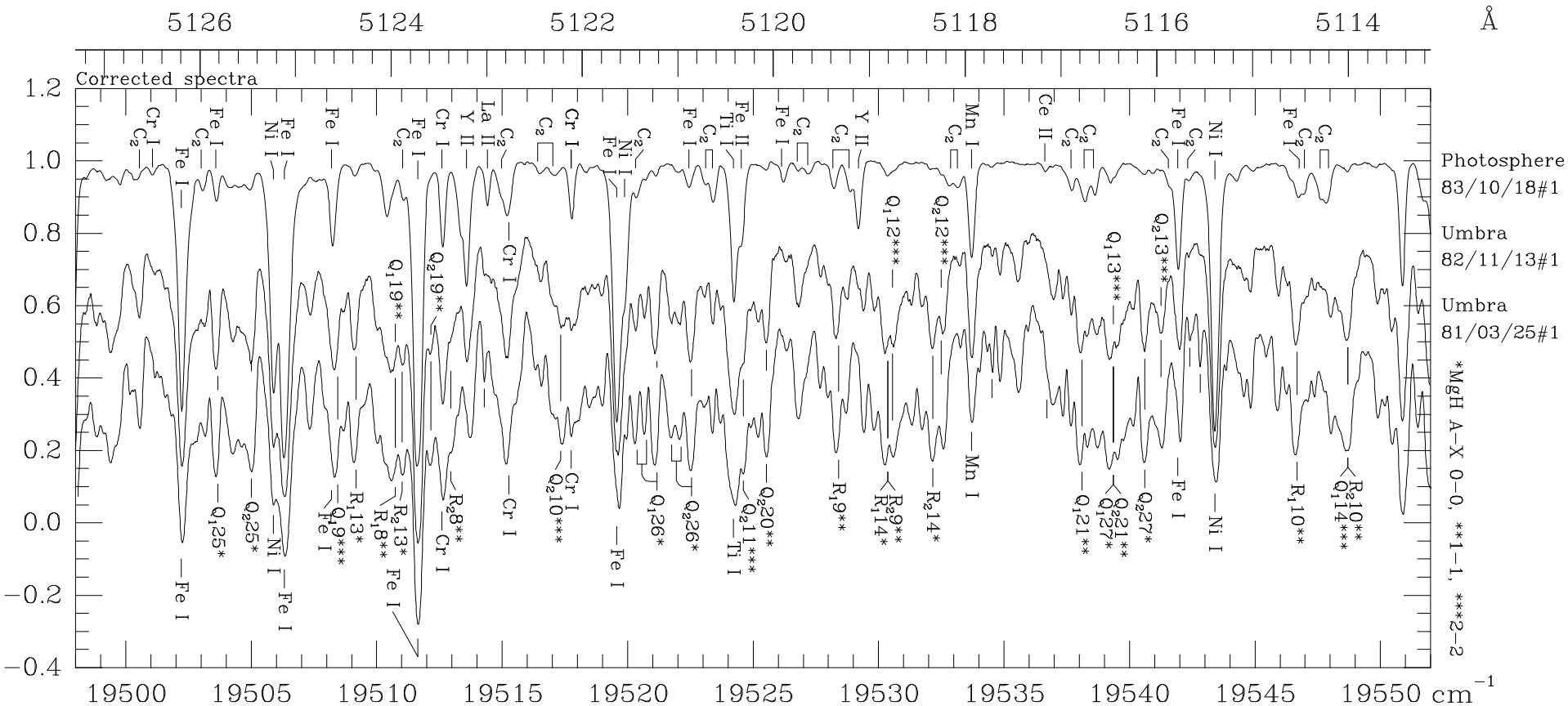
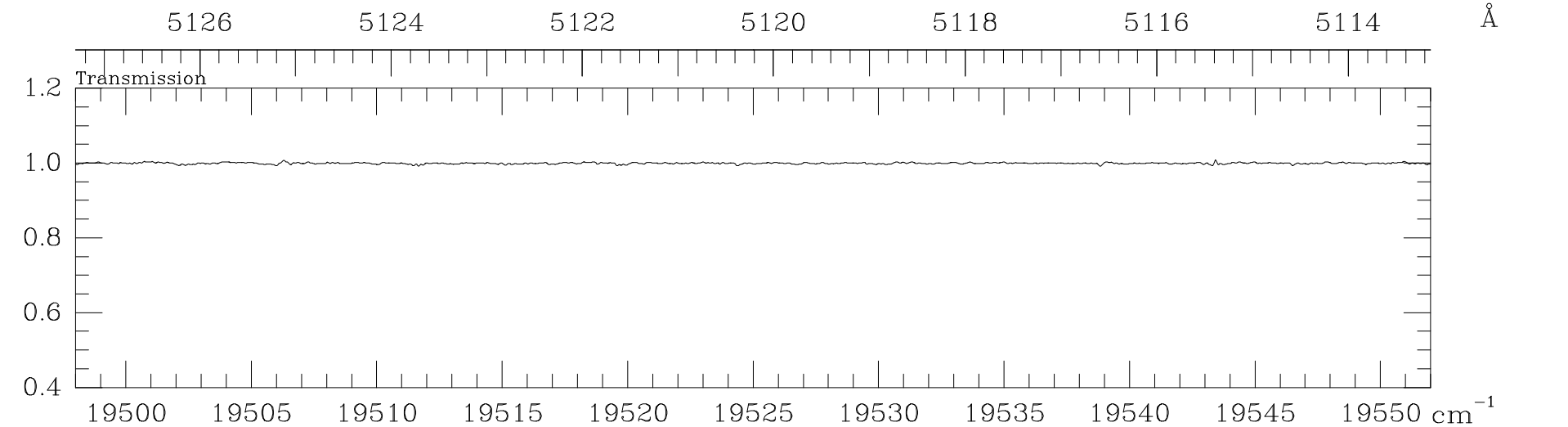
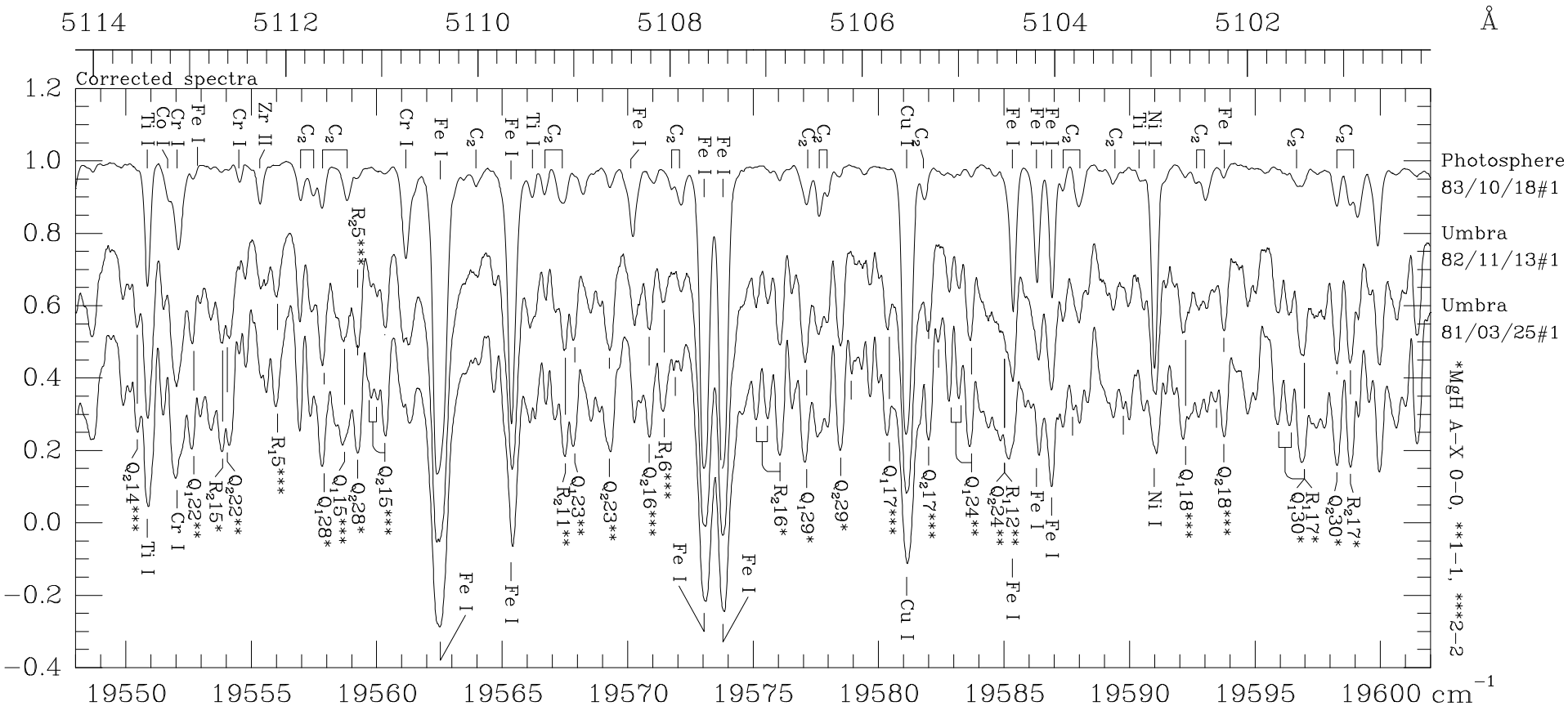


The features with ticks but no labels in the lower umbral spectrum are due to lines of the TiO α 1–0 and 2–1 bands.





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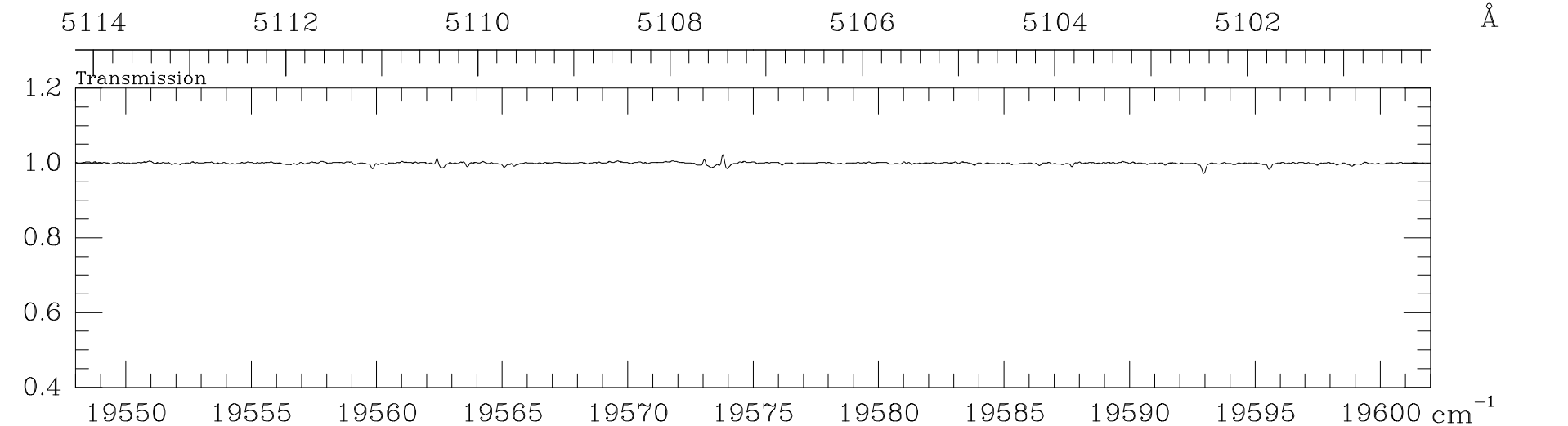

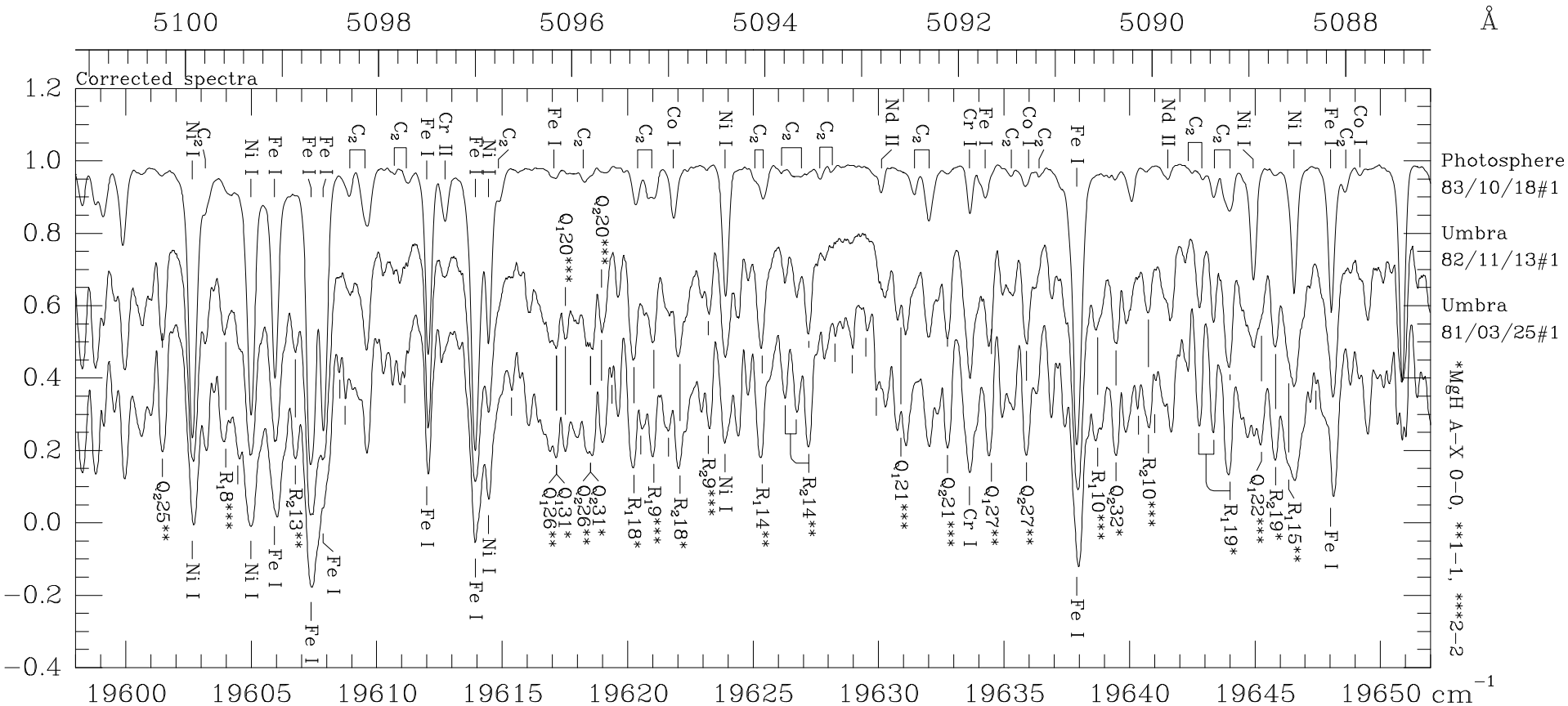

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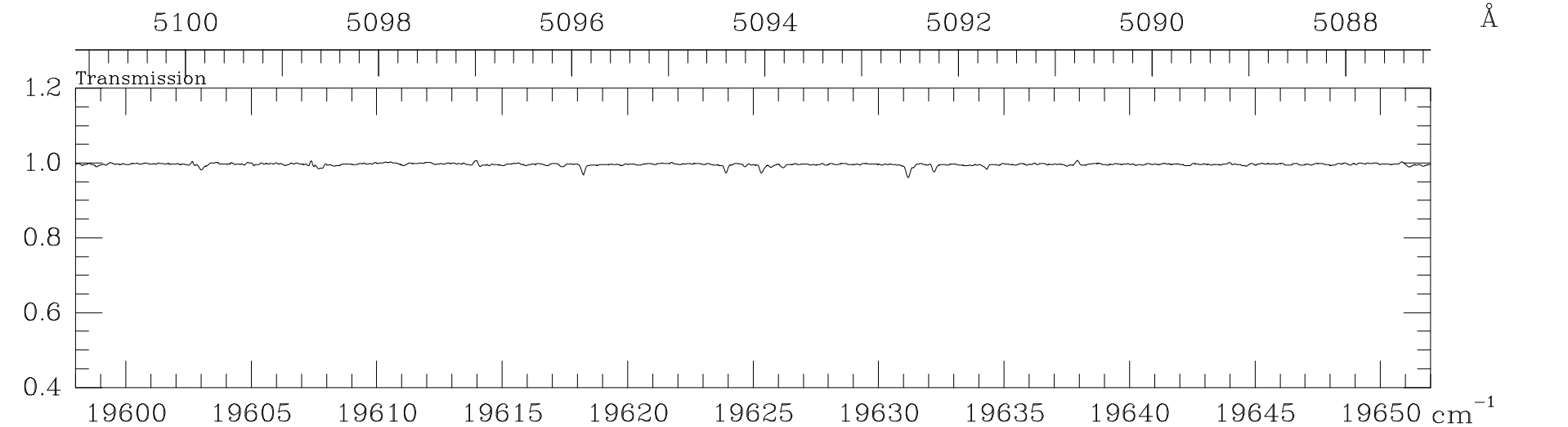

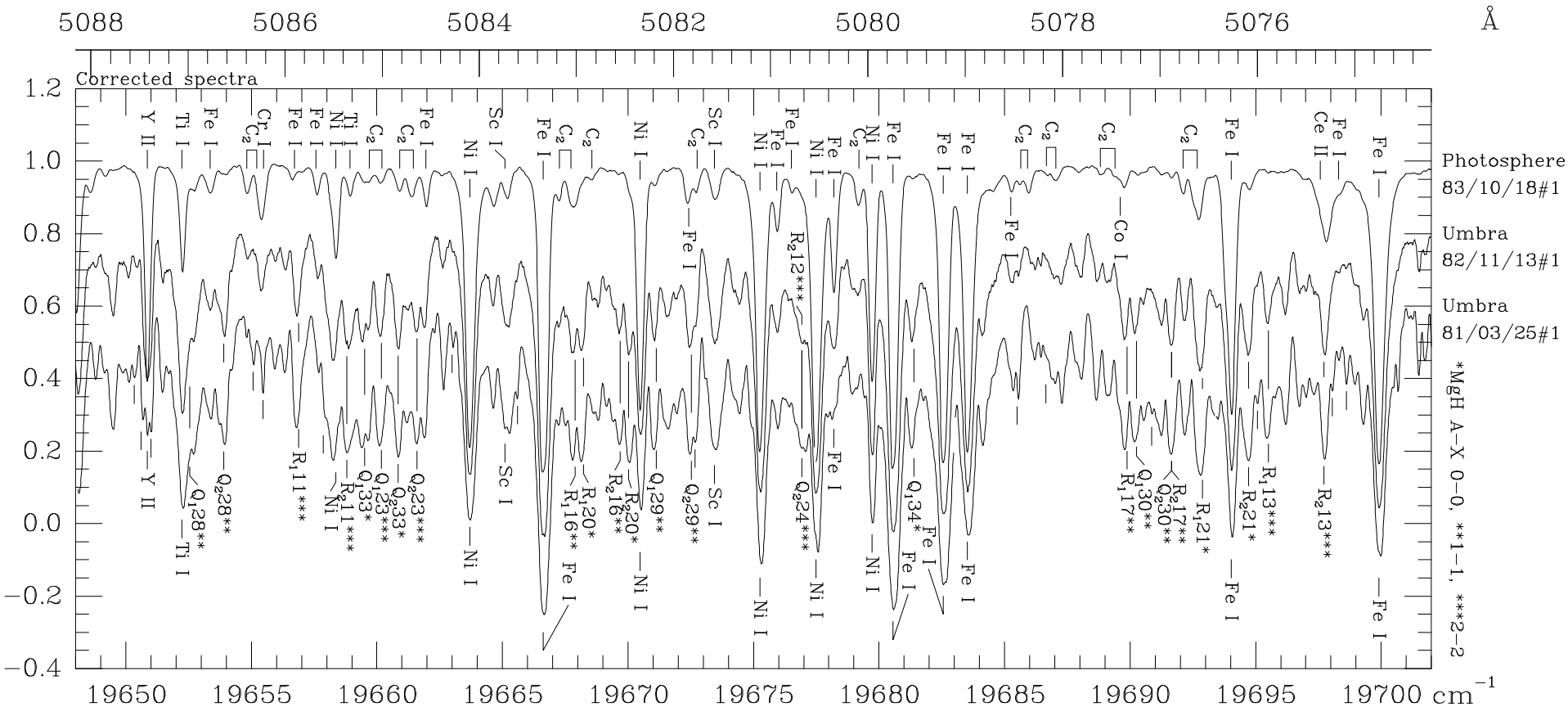

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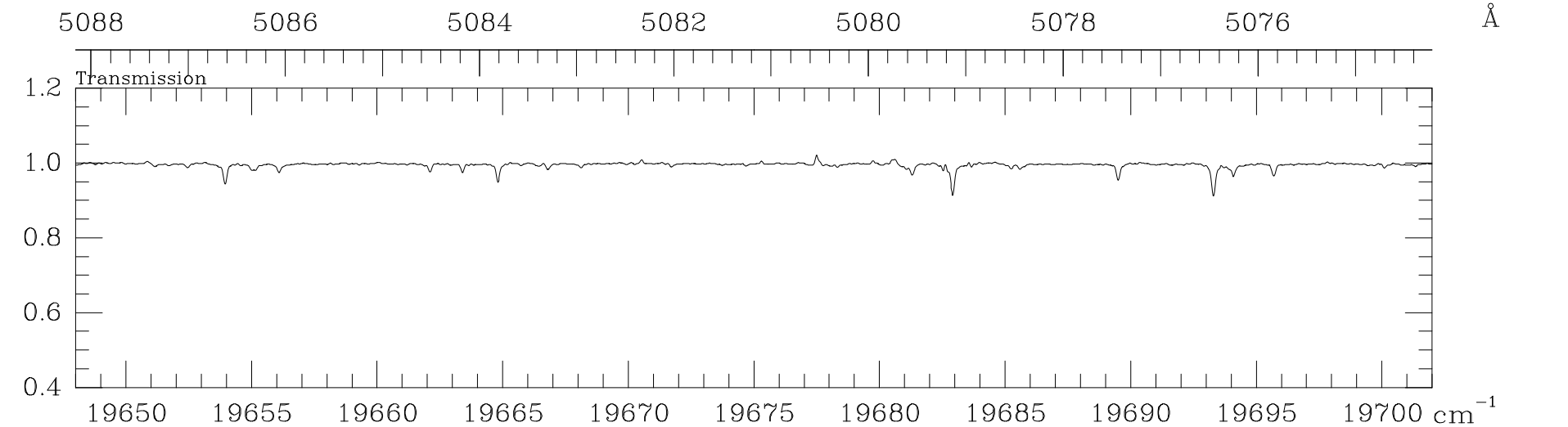

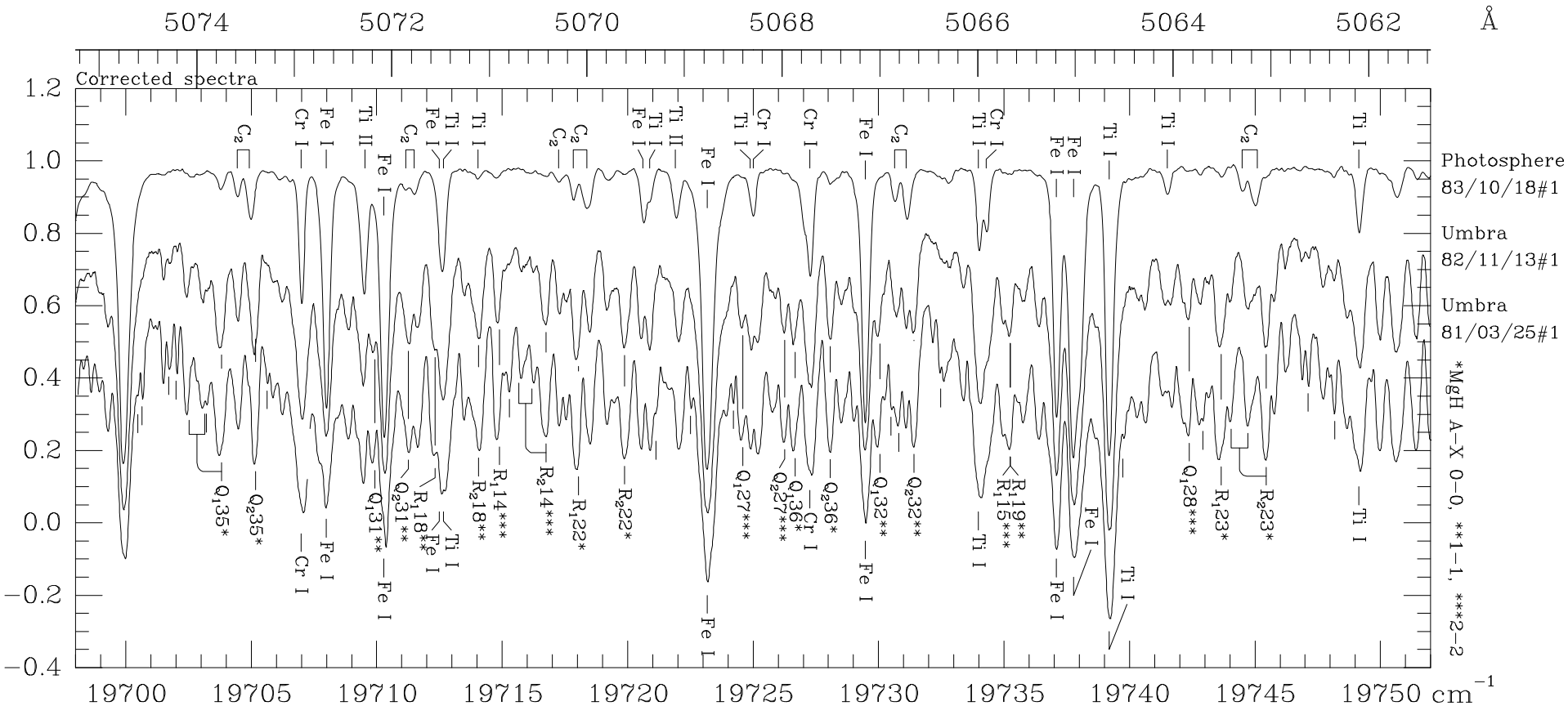

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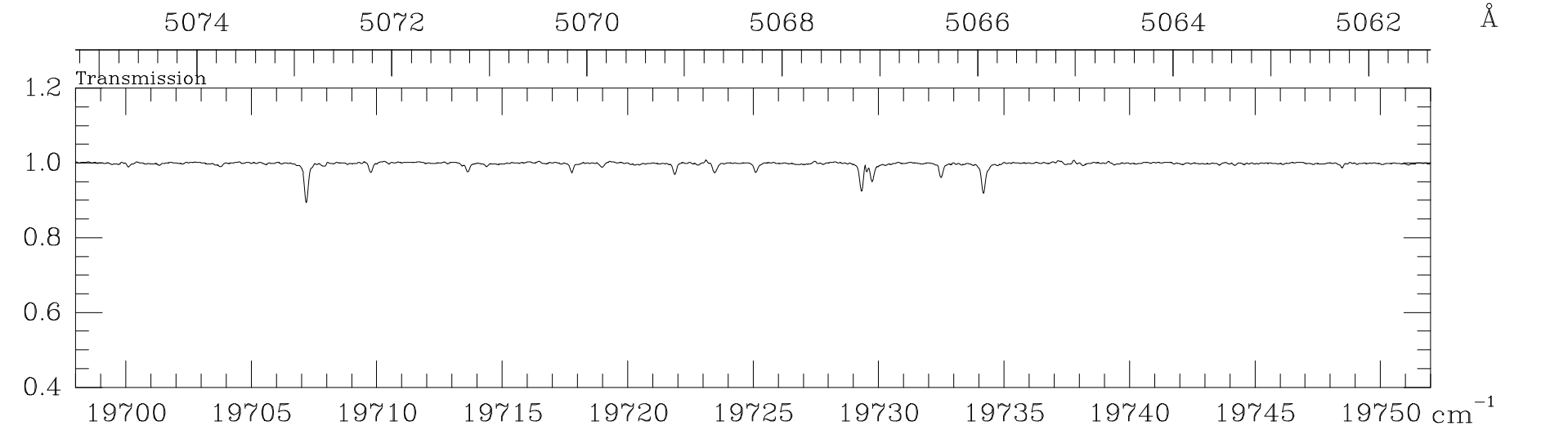

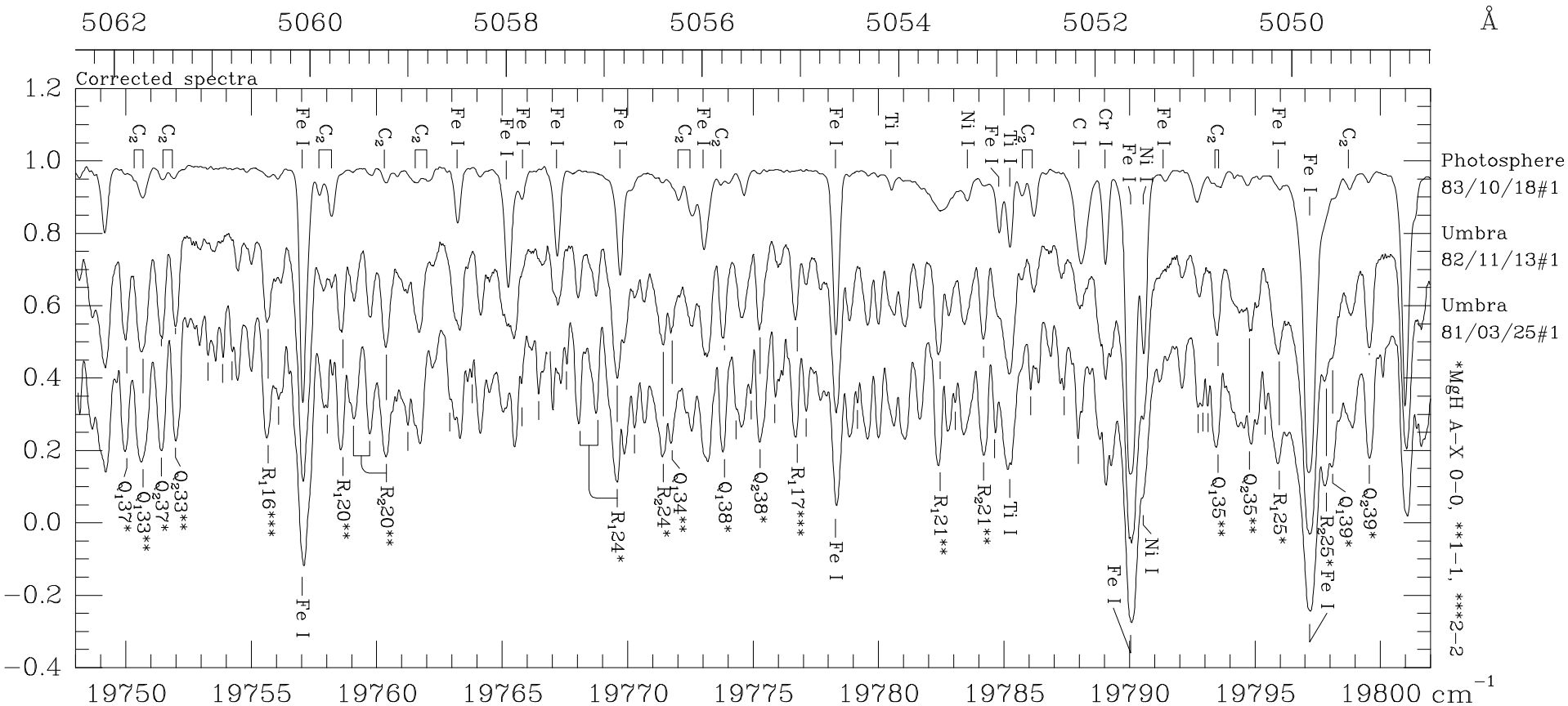

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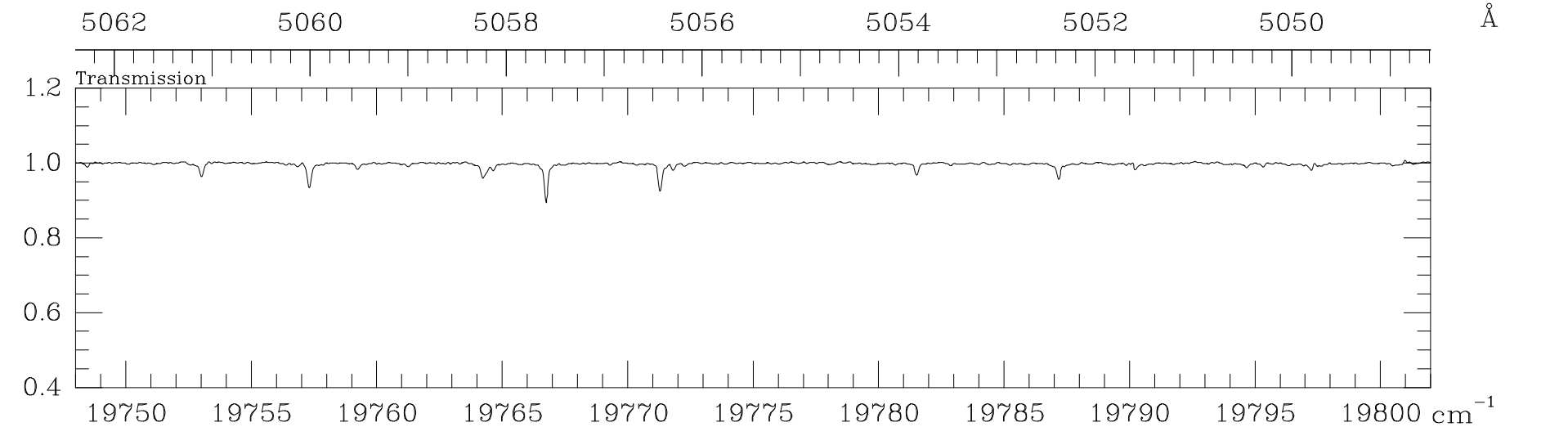

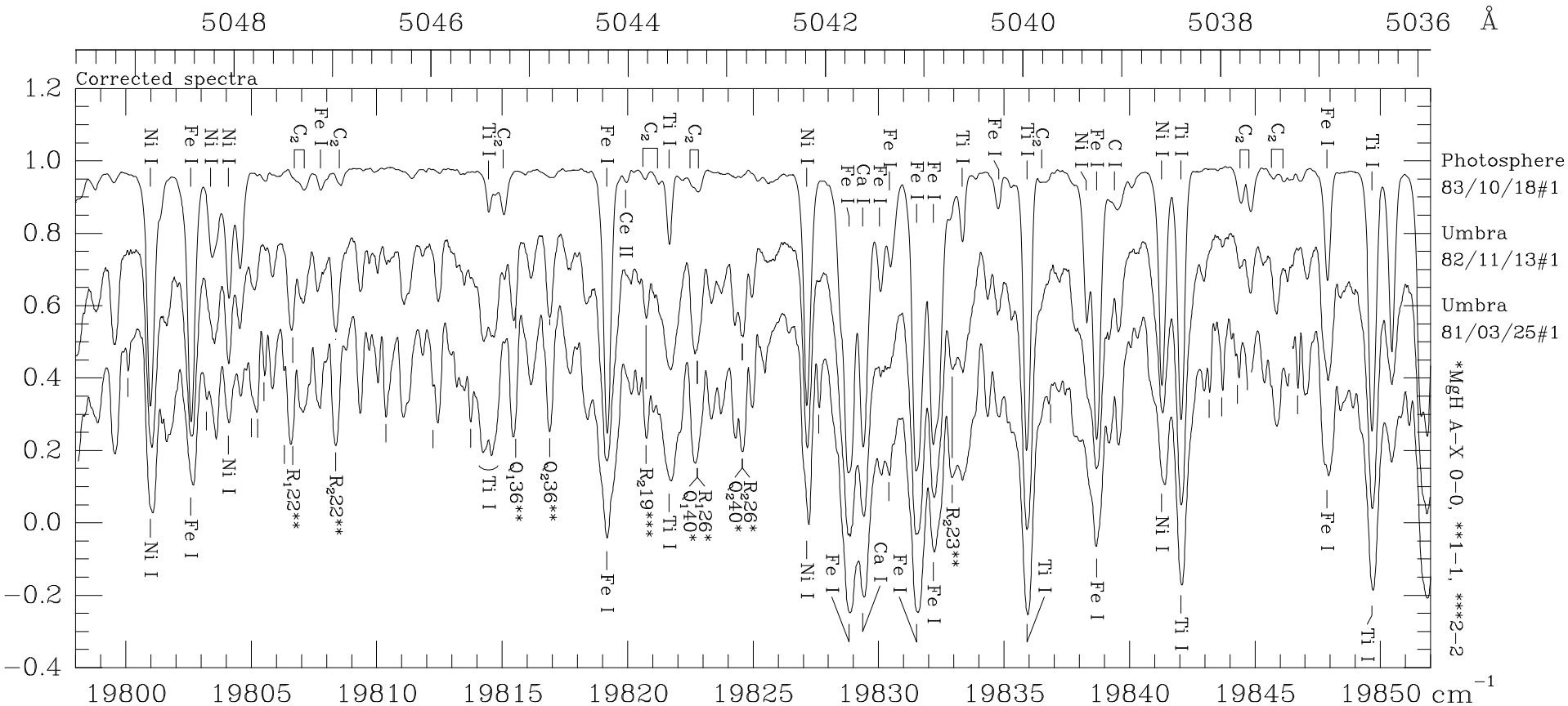

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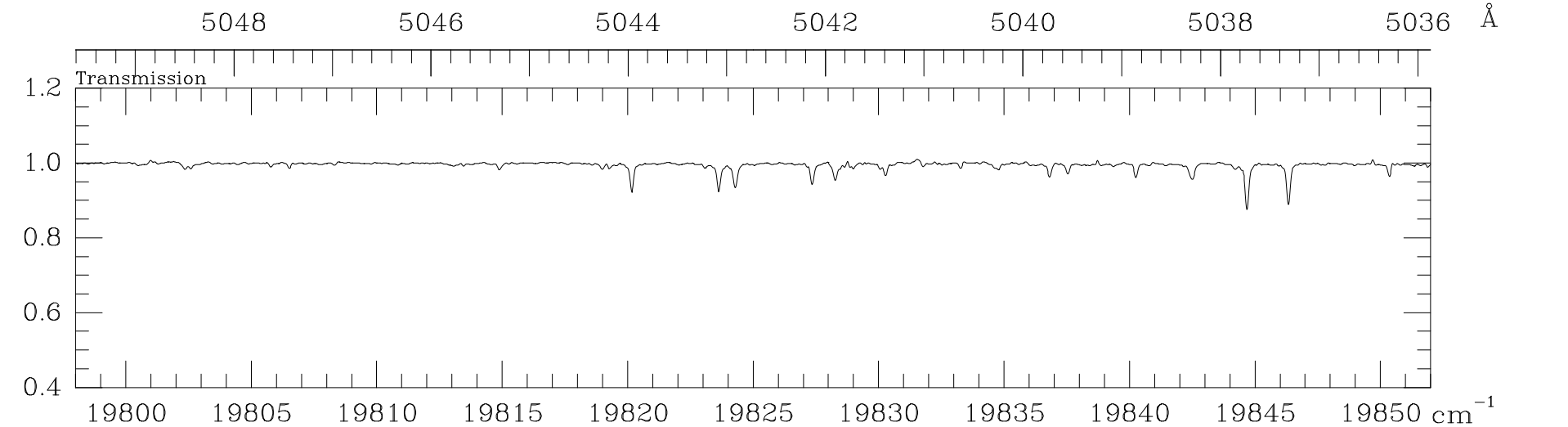

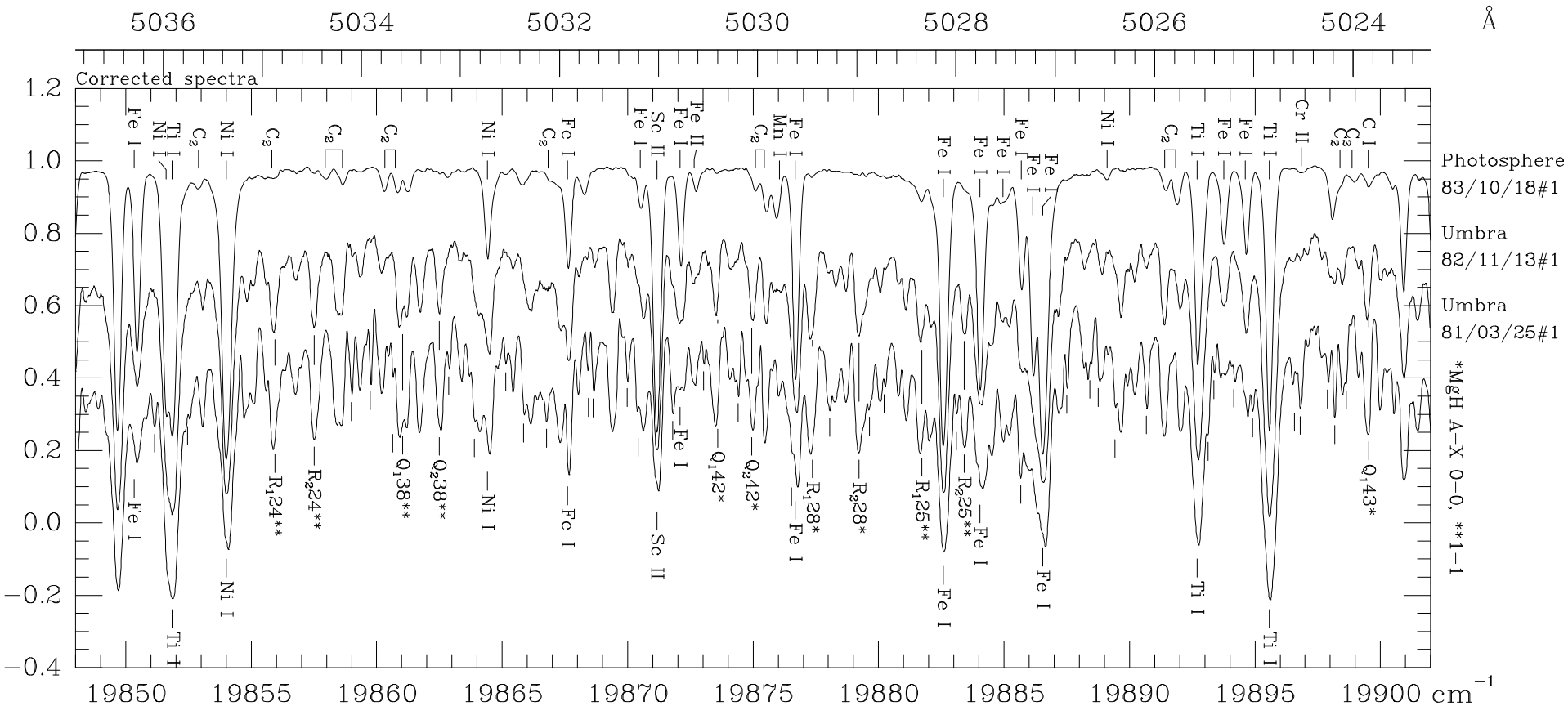

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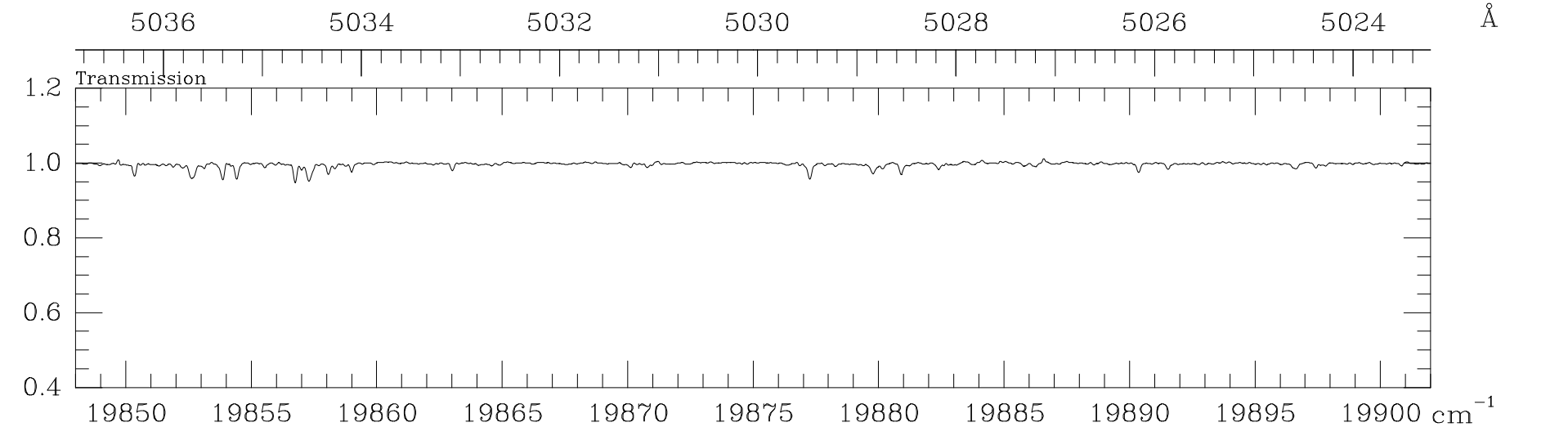

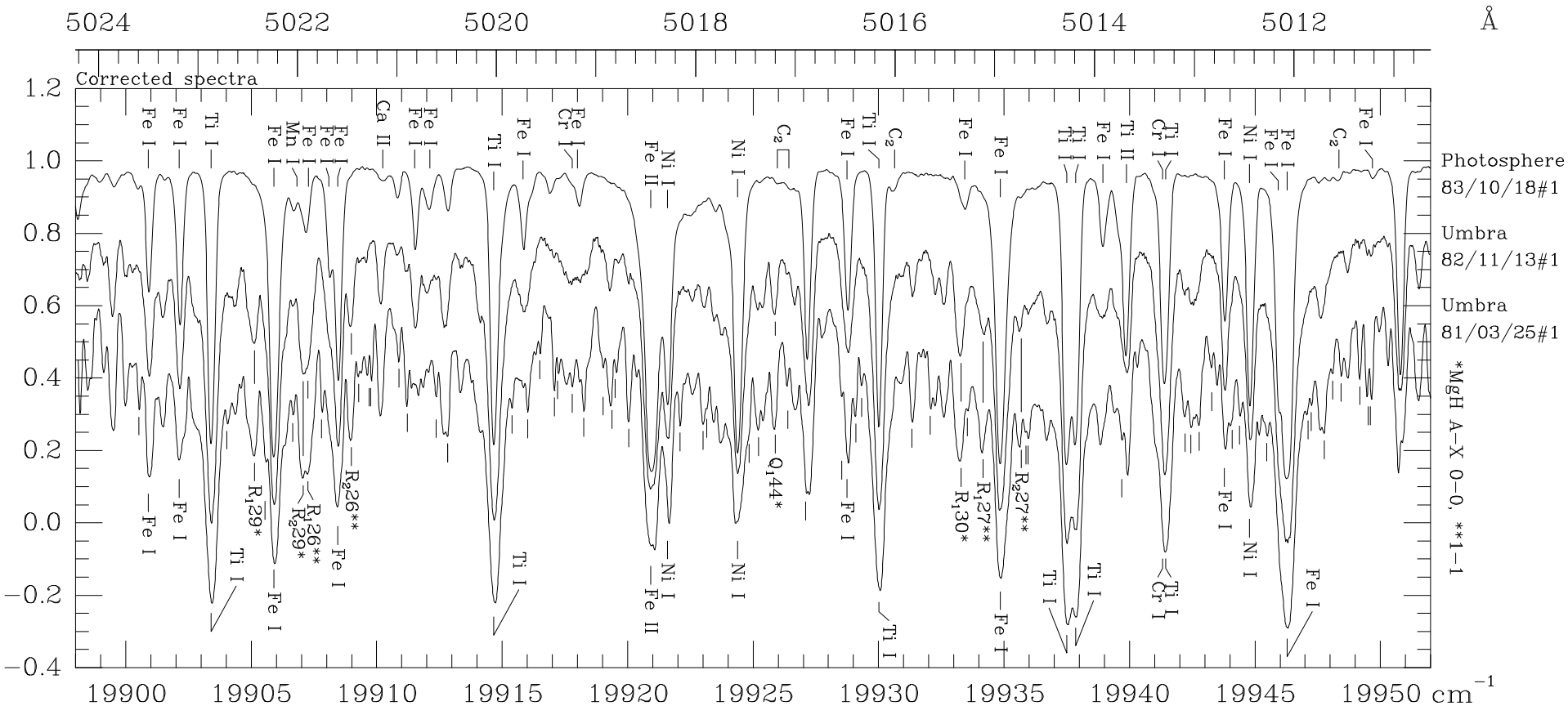

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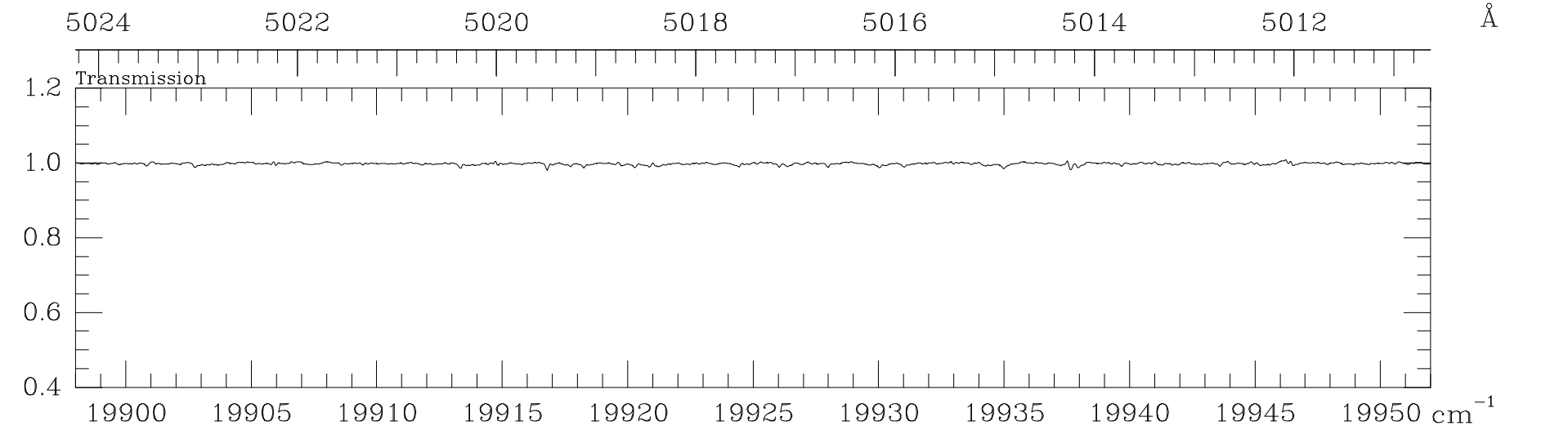

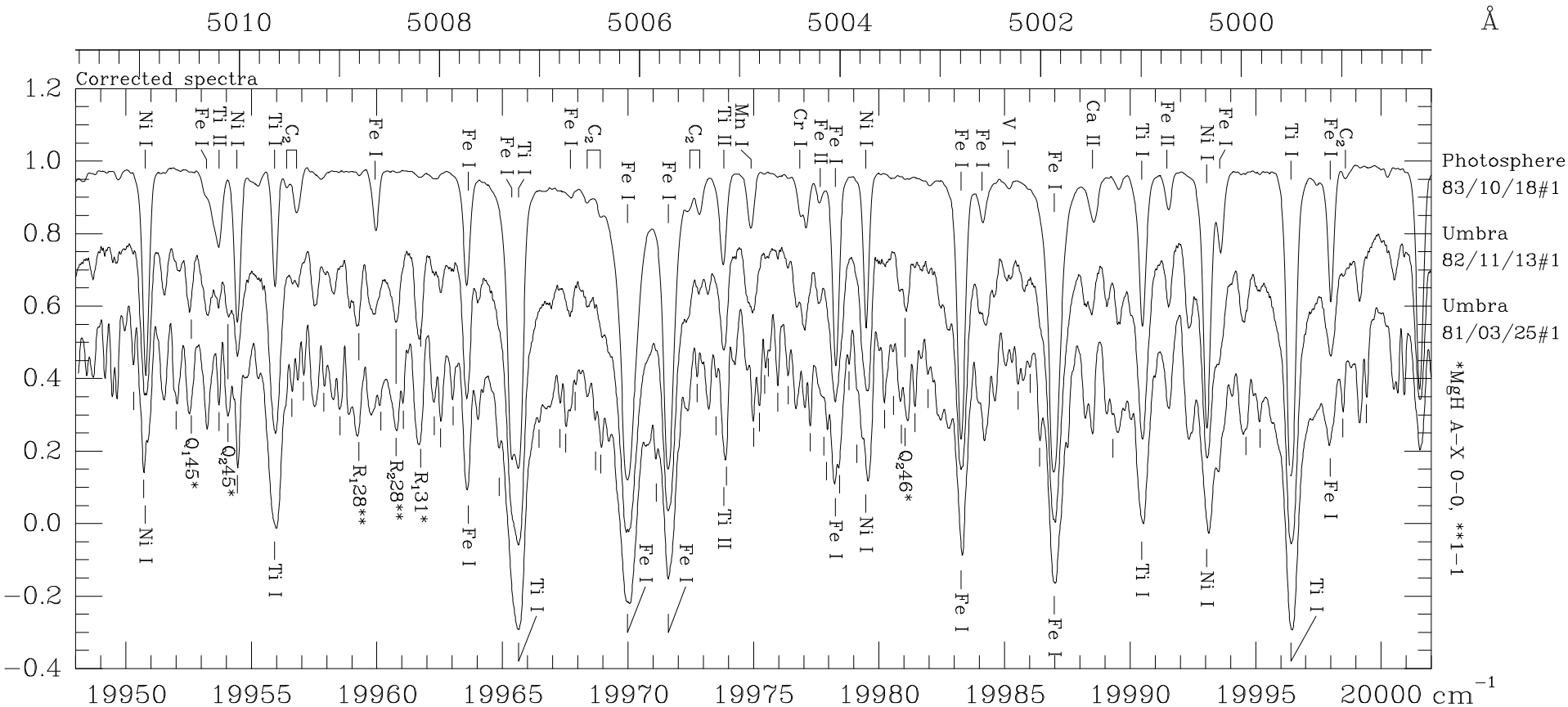

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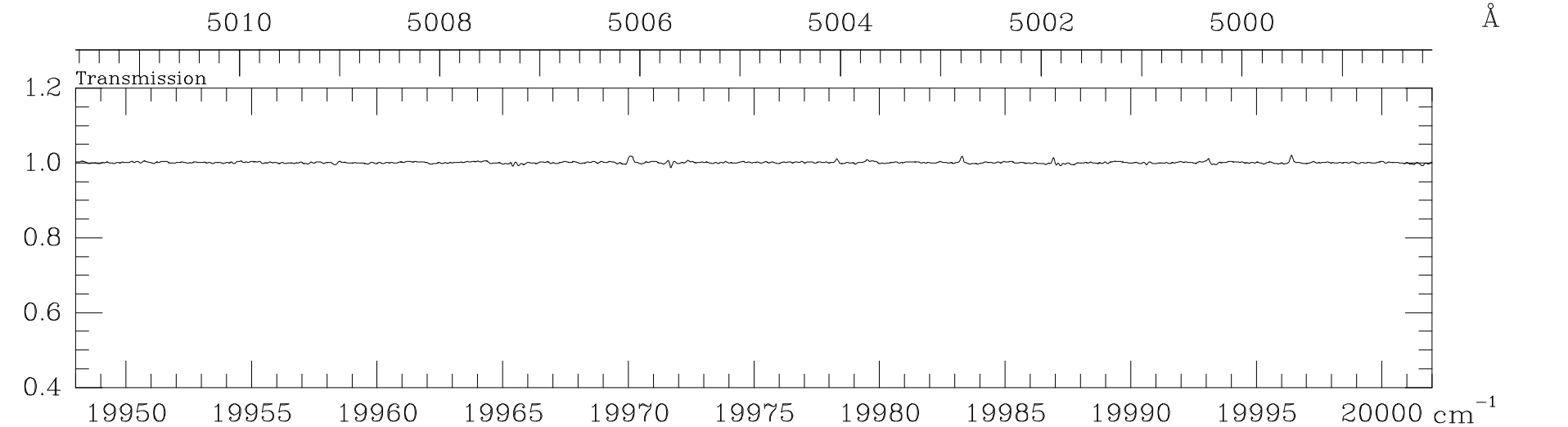

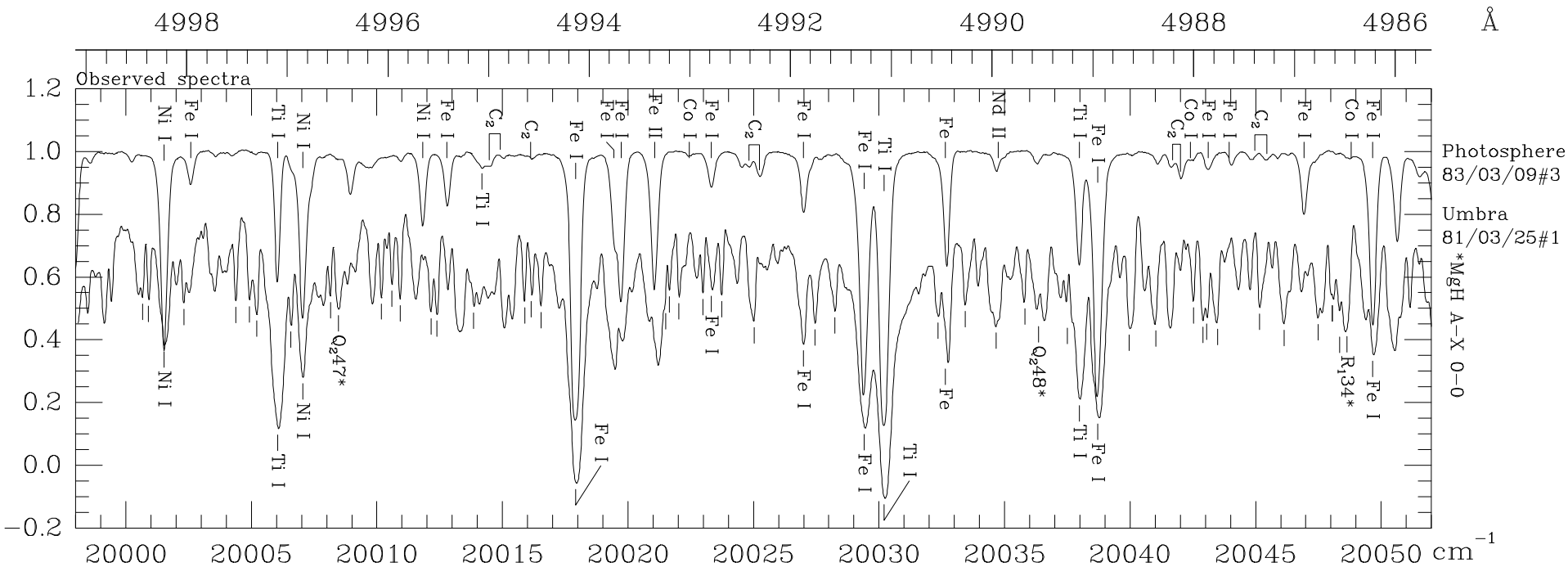

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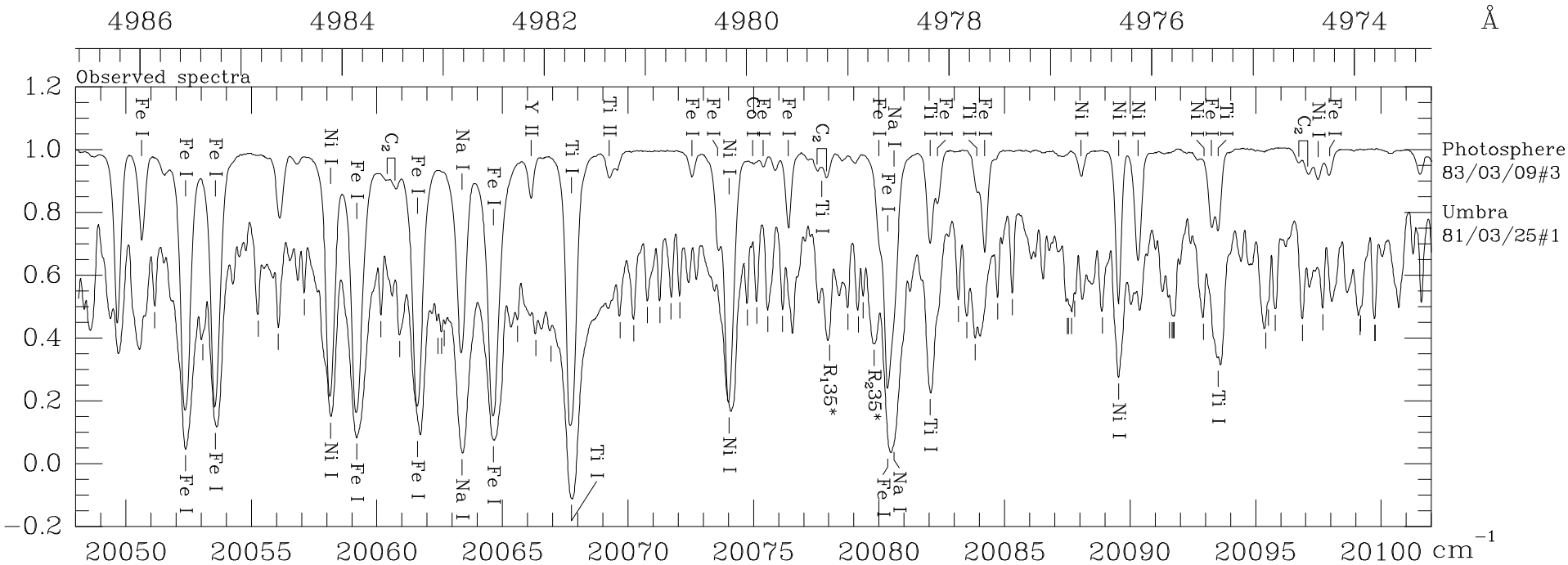

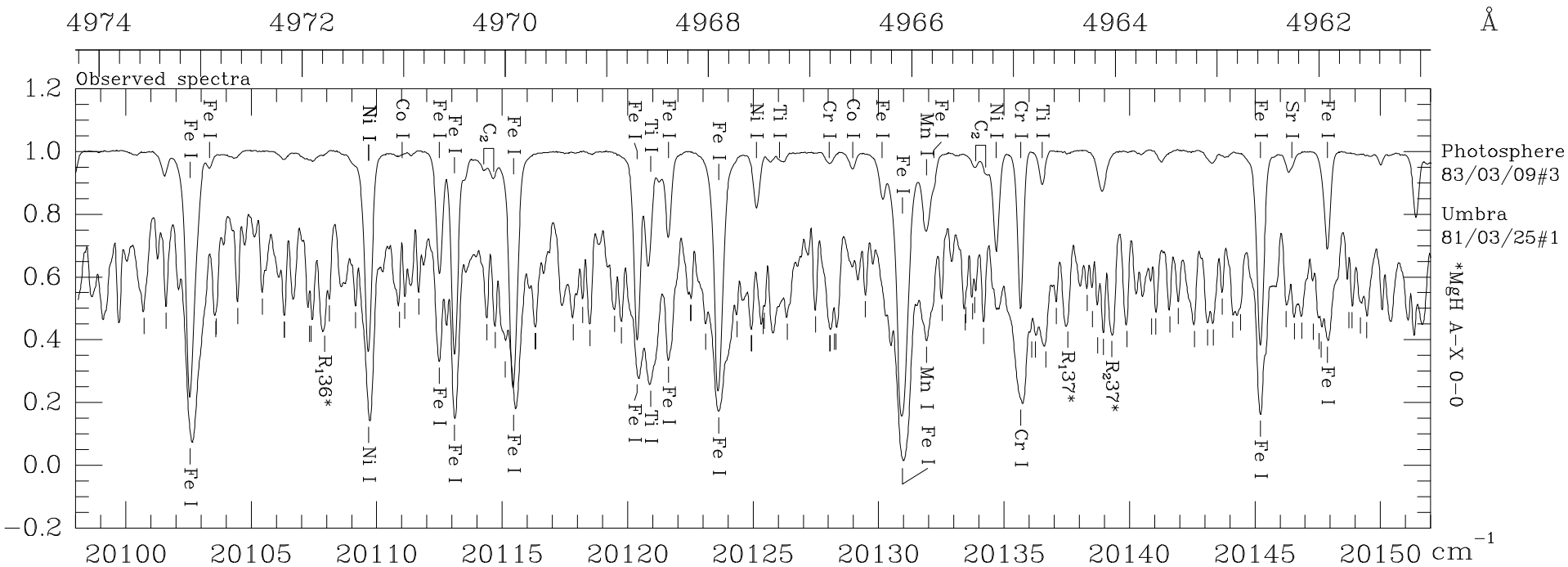

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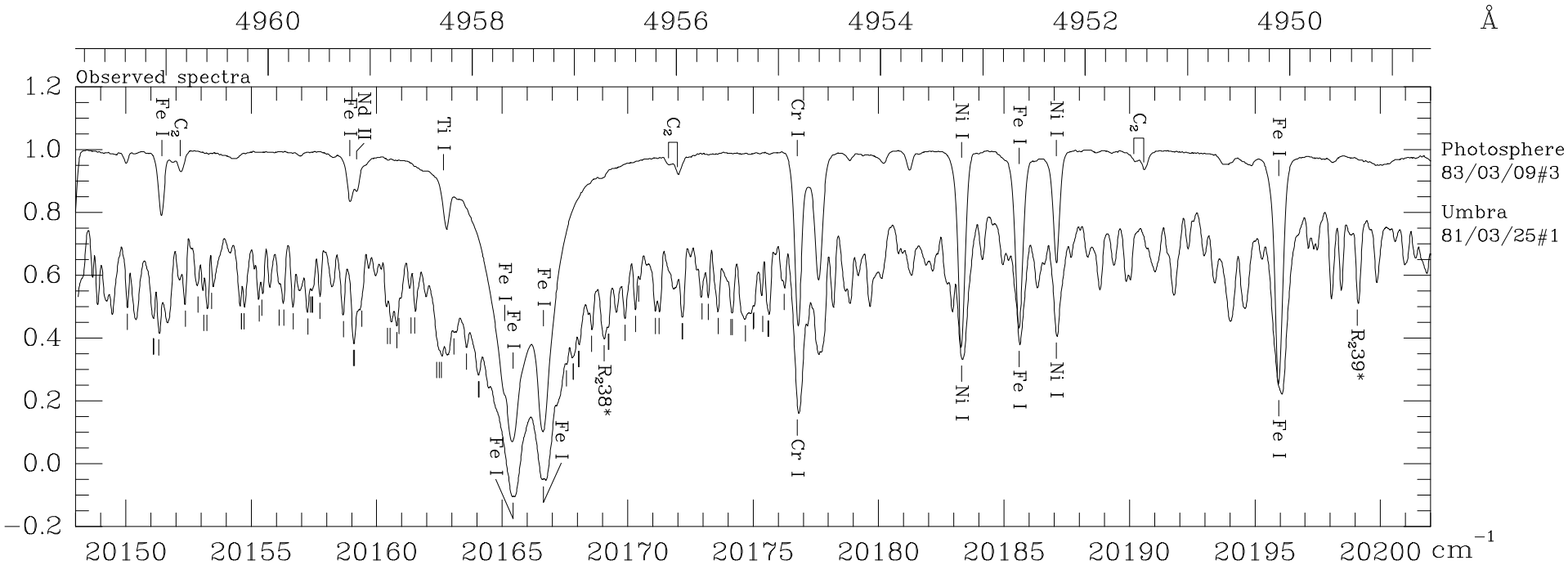
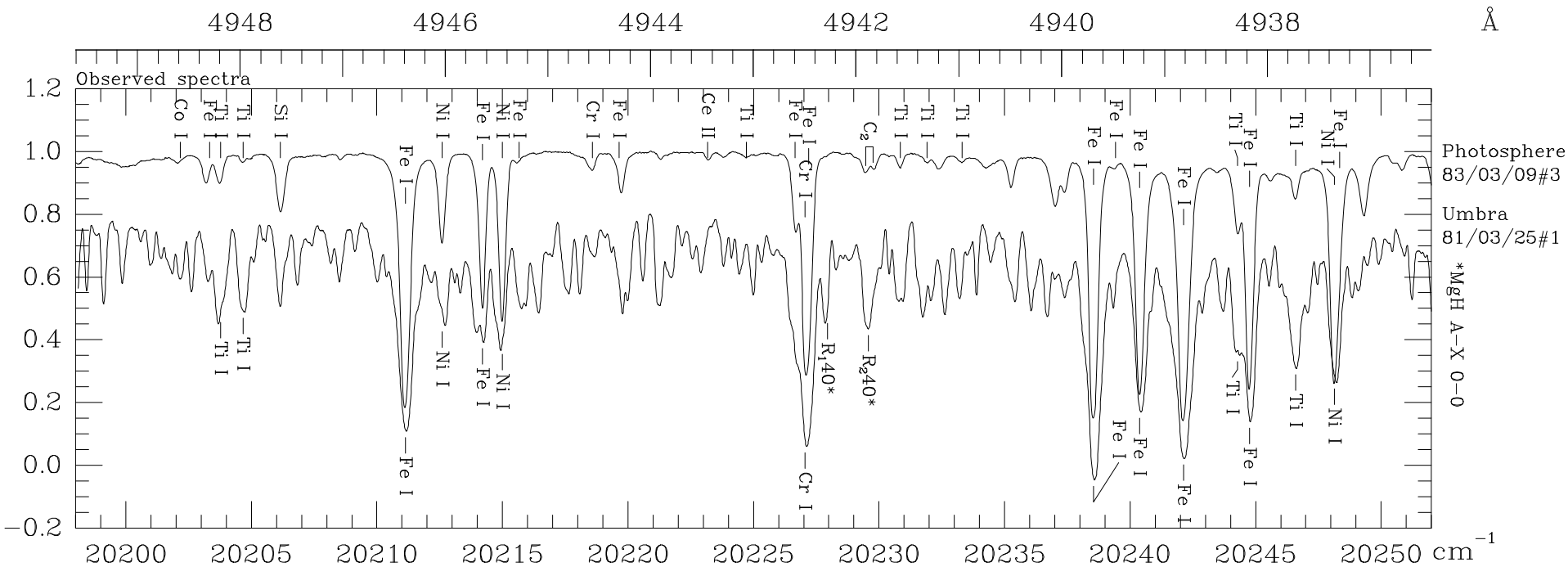
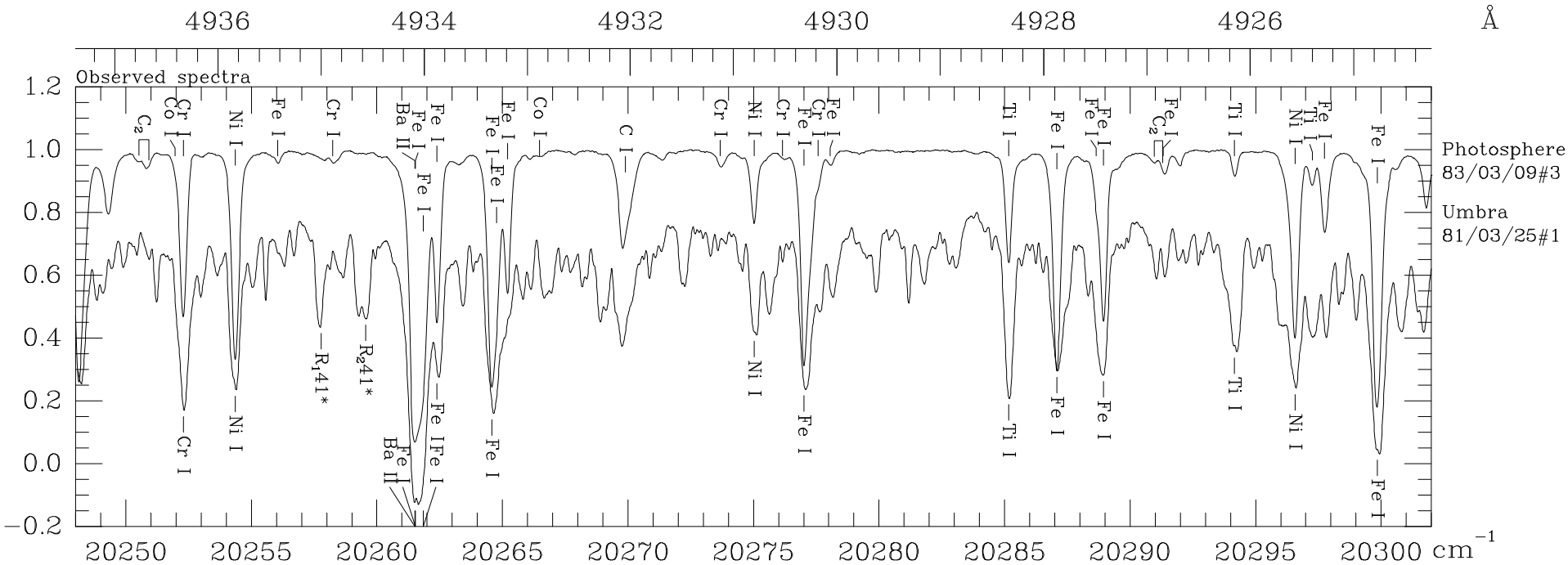
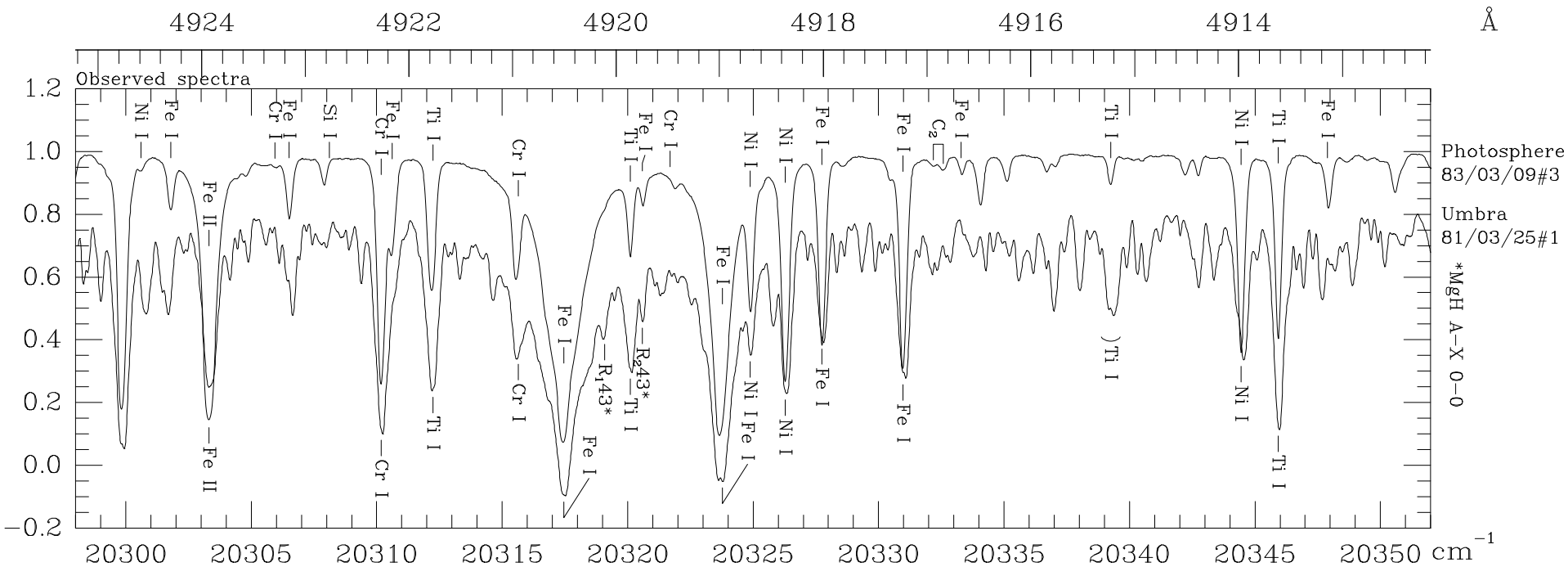


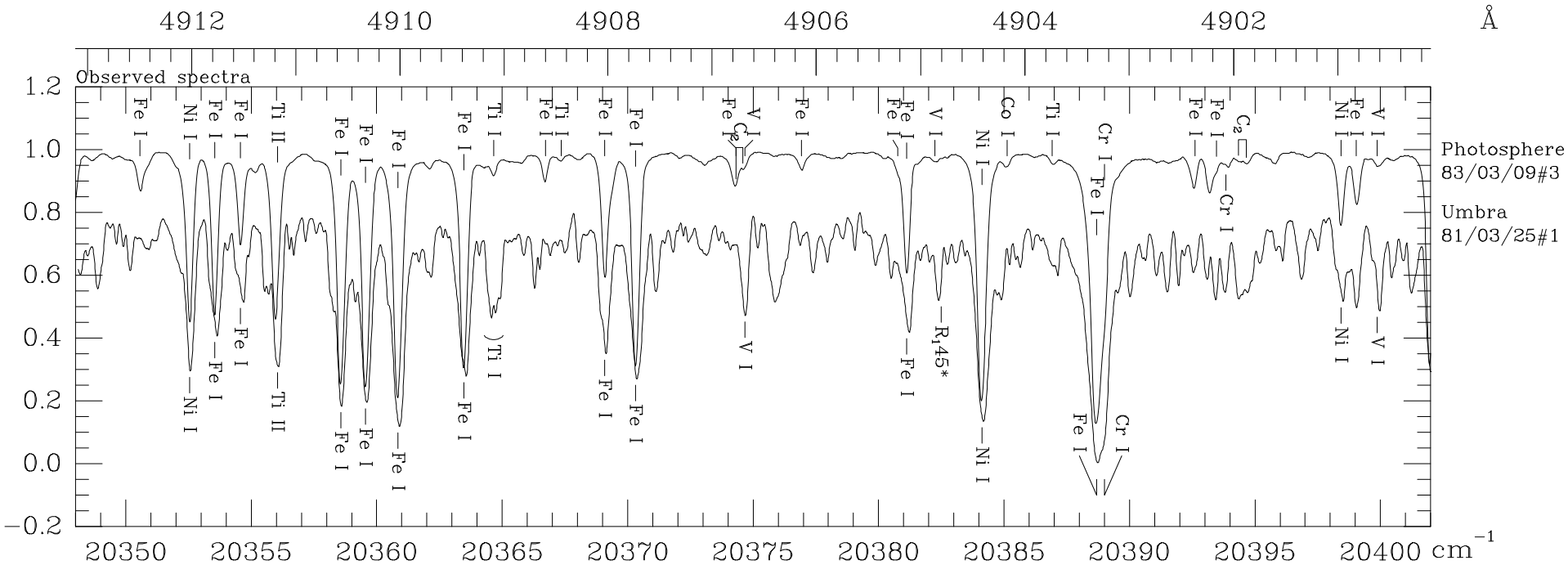


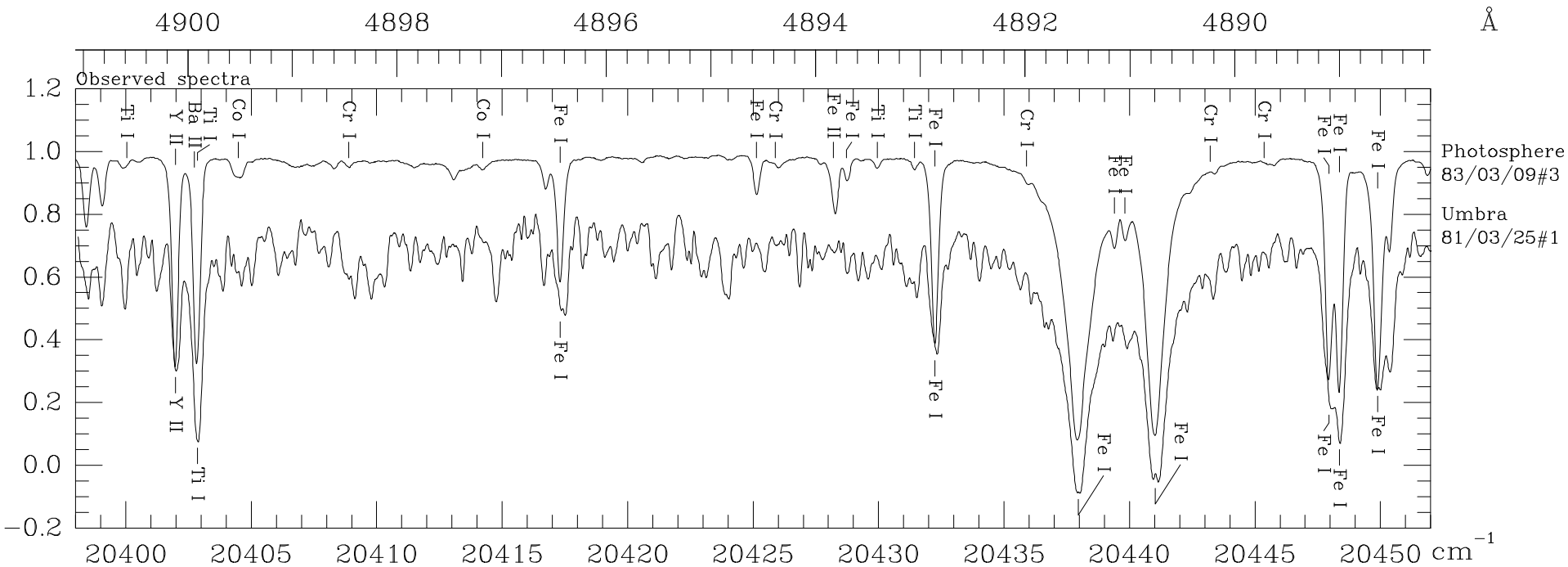
Some of the features in the umbral spectrum here are due to lines of the TiO α $\Delta v=+2$ sequence.



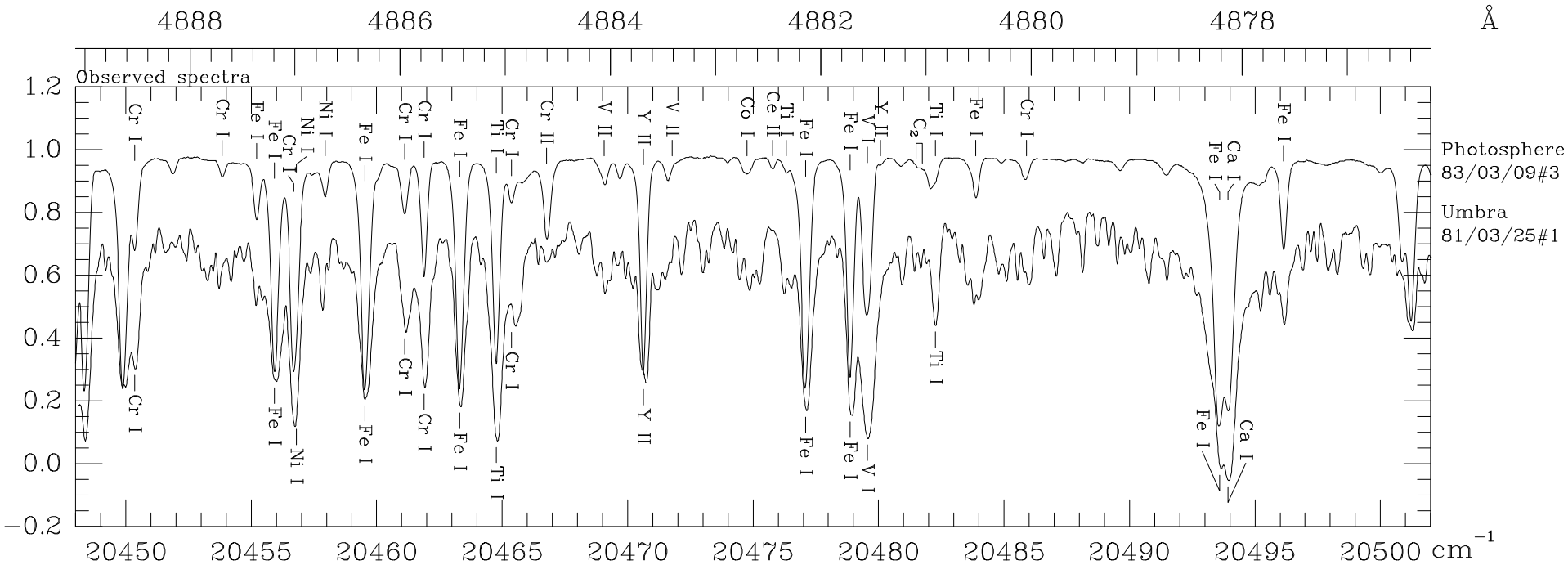


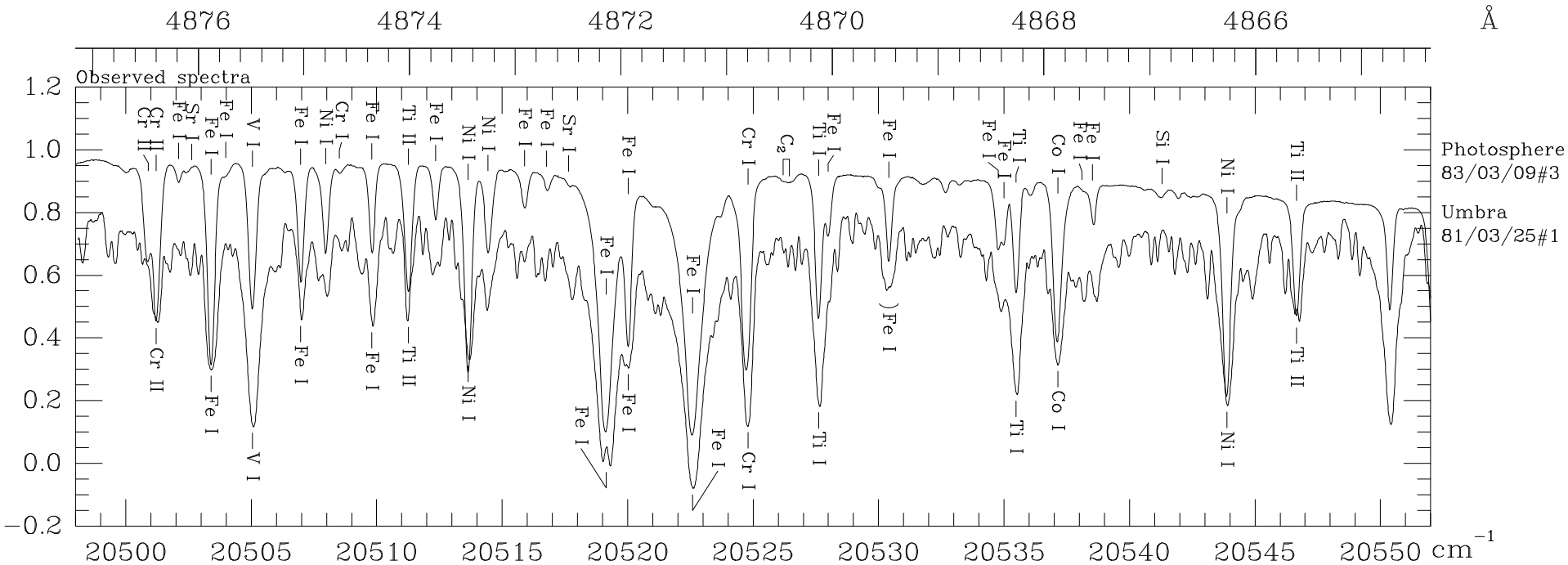
Some of the features in the umbral spectrum here are due to lines of the TiO α Δv=+2 sequence.



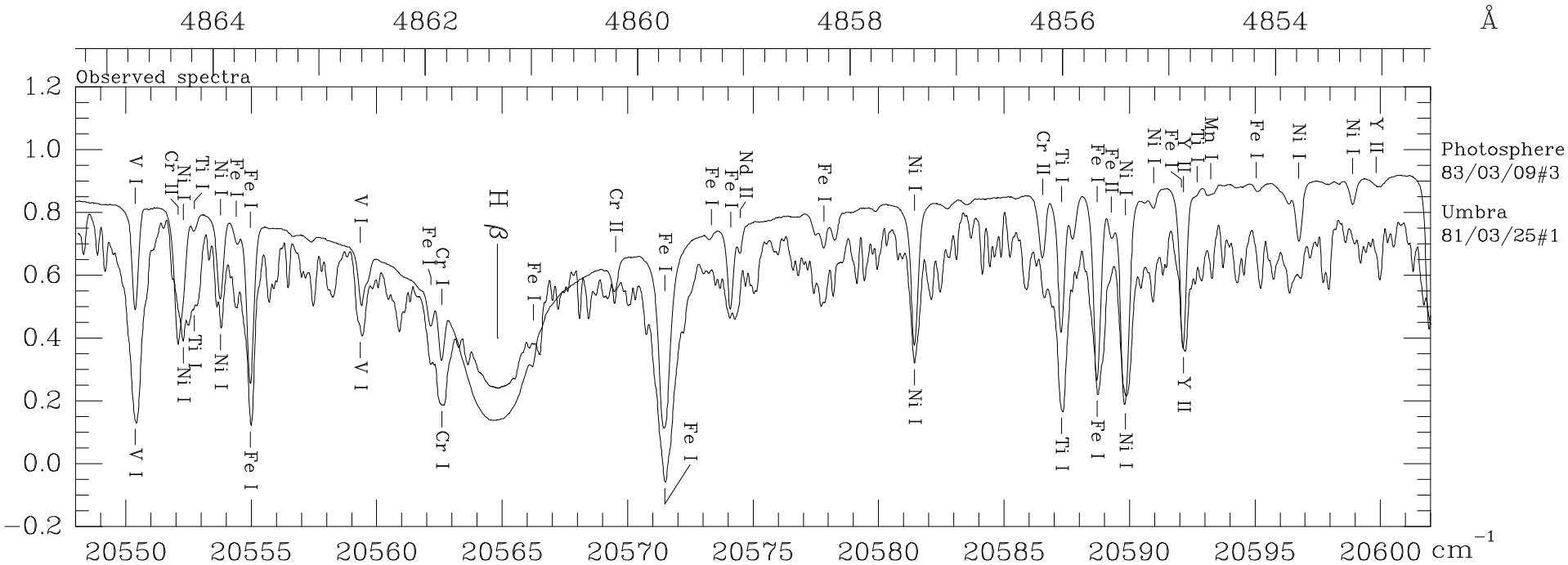


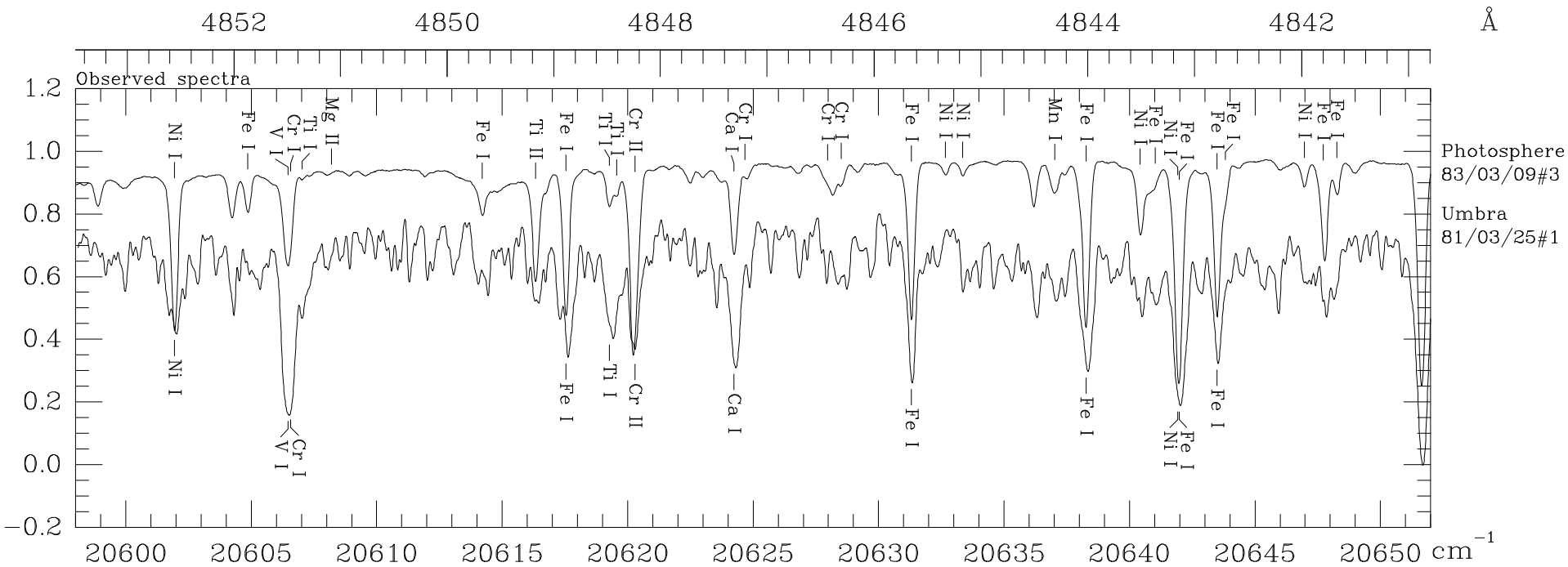
Some of the features in the umbral spectrum here are due to lines of the TiO α $\Delta v=+2$ sequence.



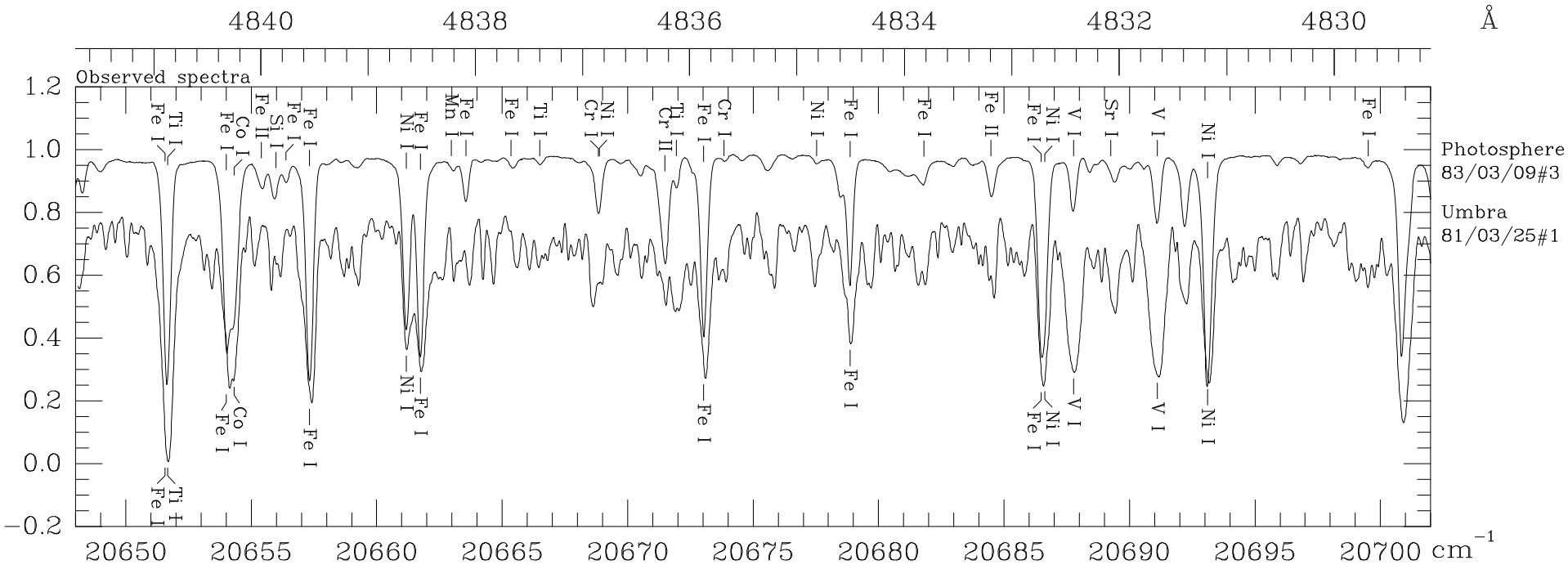


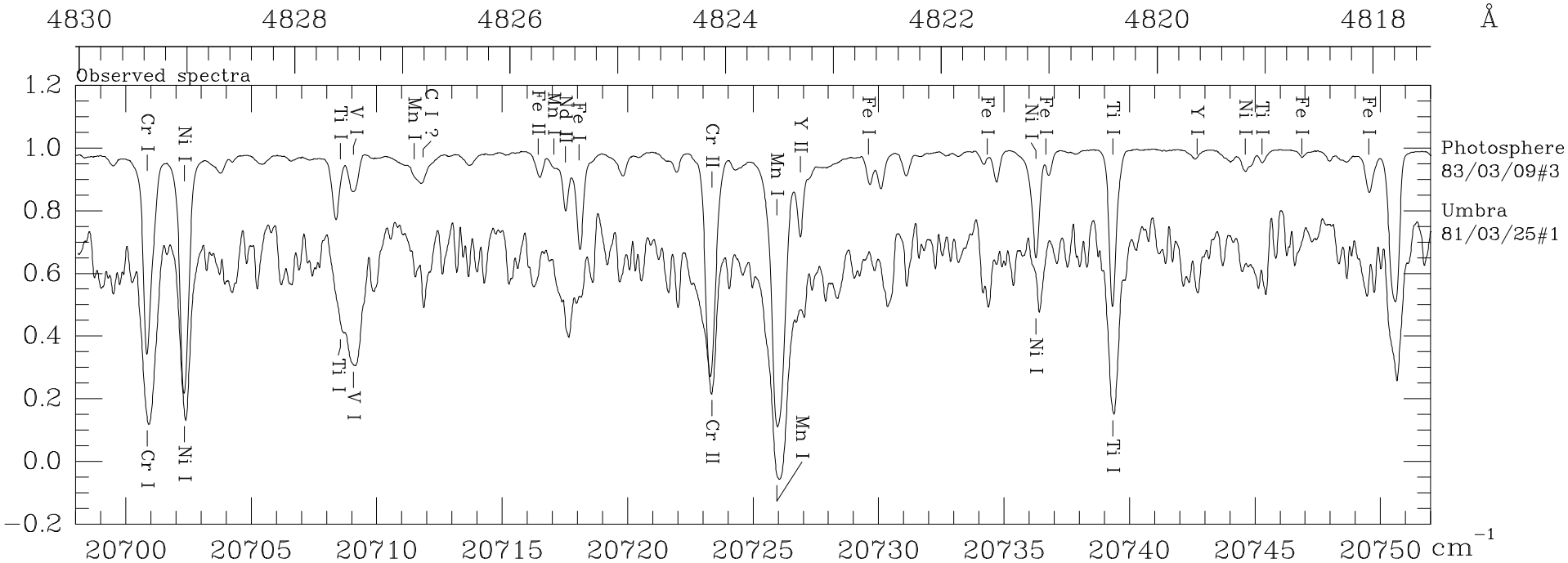
Some of the features in the umbral spectrum here are due to lines of the TiO α $\Delta v=+2$ sequence.



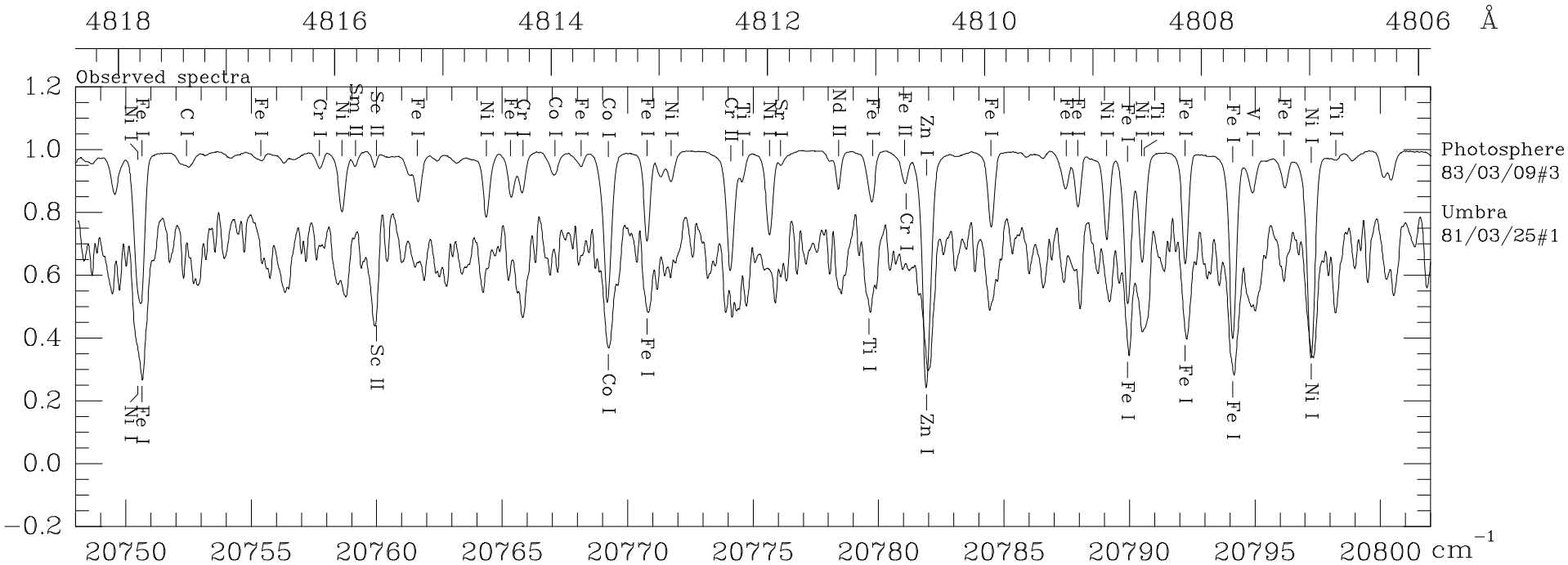


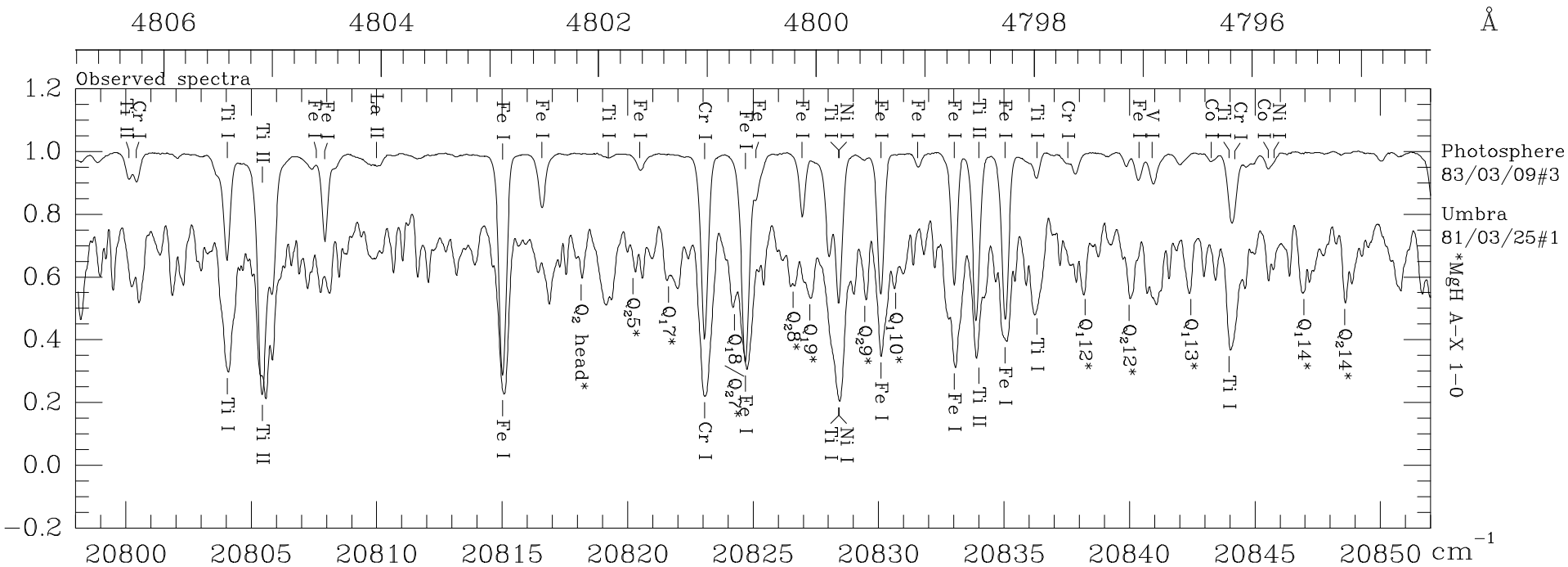
Some of the features in the umbral spectrum here are due to lines of the TiO α $\Delta v=+2$ sequence.



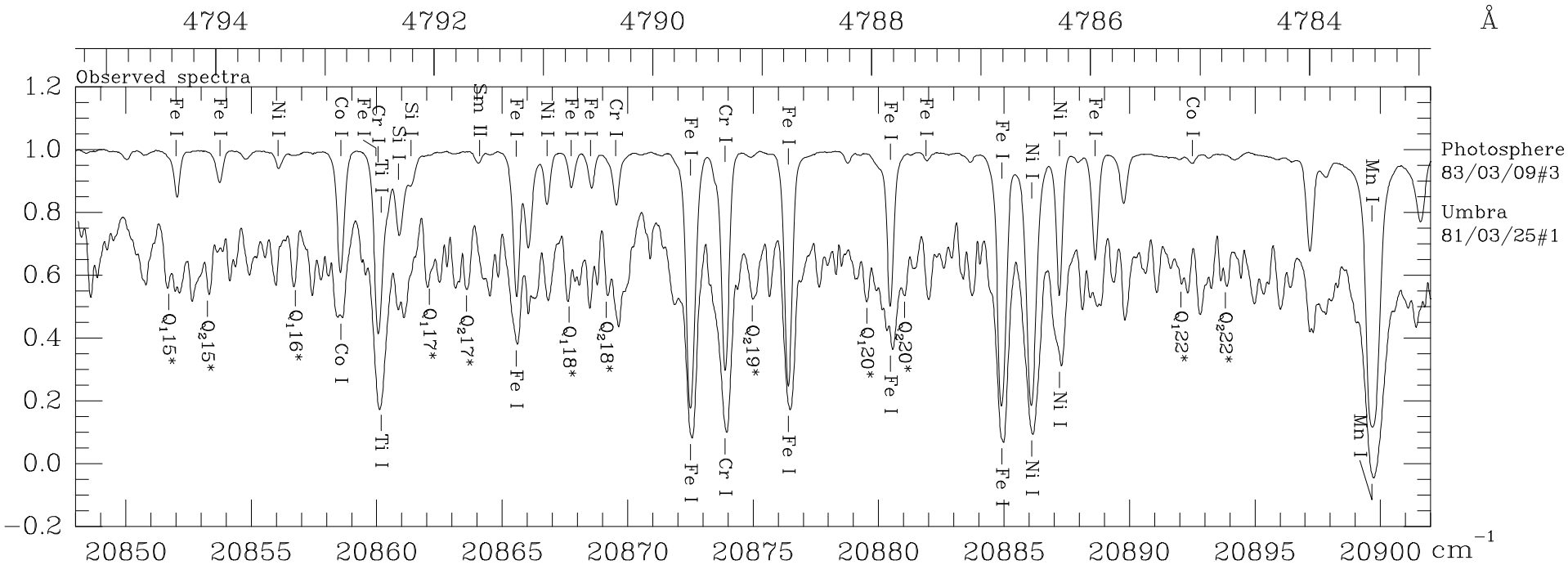


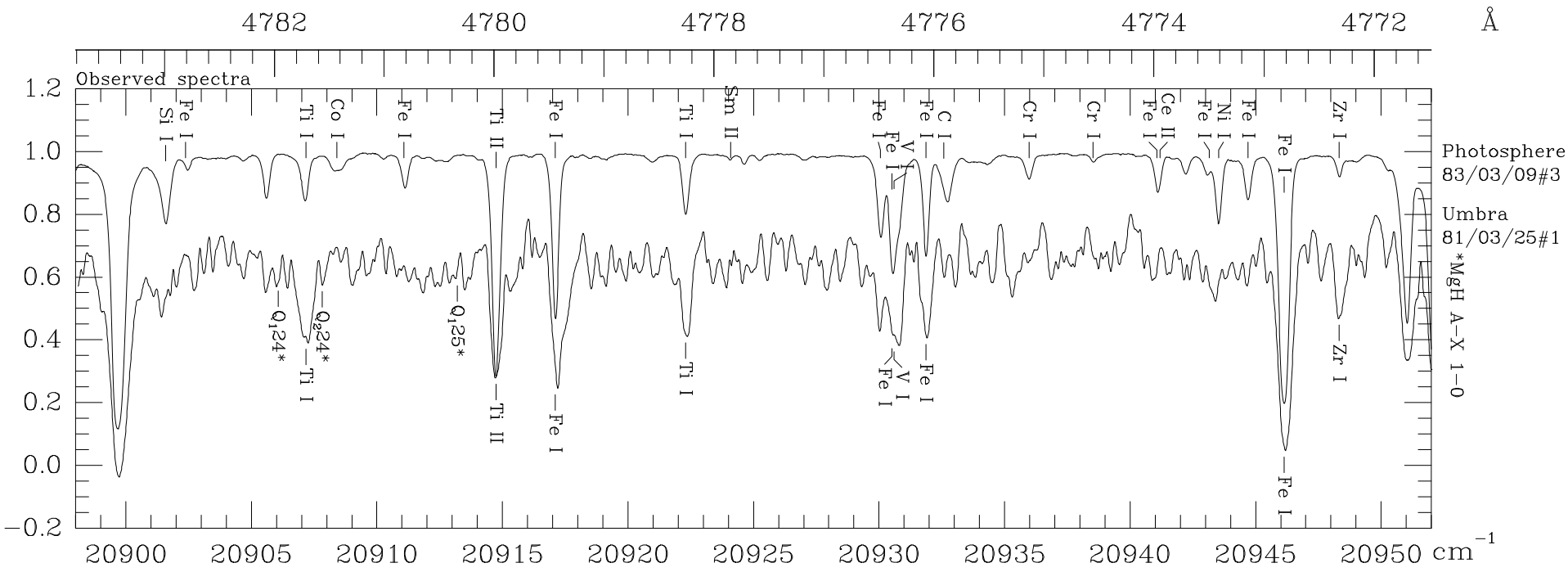
Some of the features in the umbral spectrum here are due to lines of the TiO α $\Delta v=+2$ sequence.

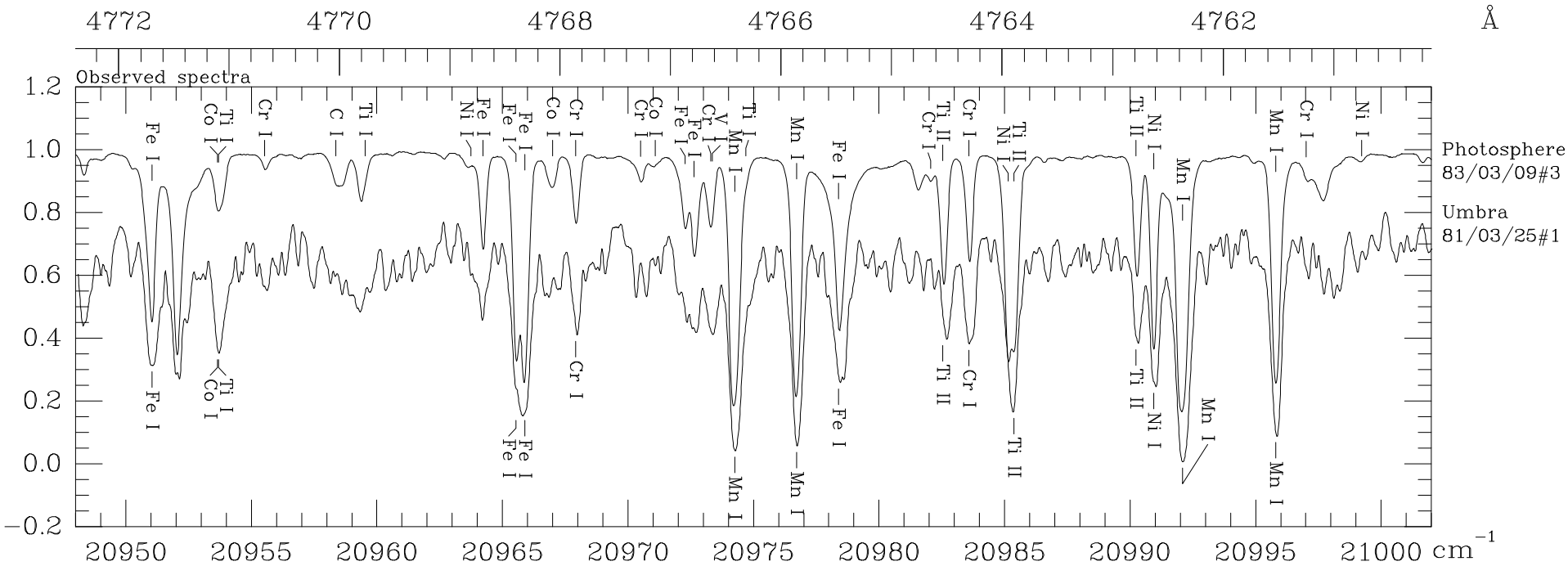


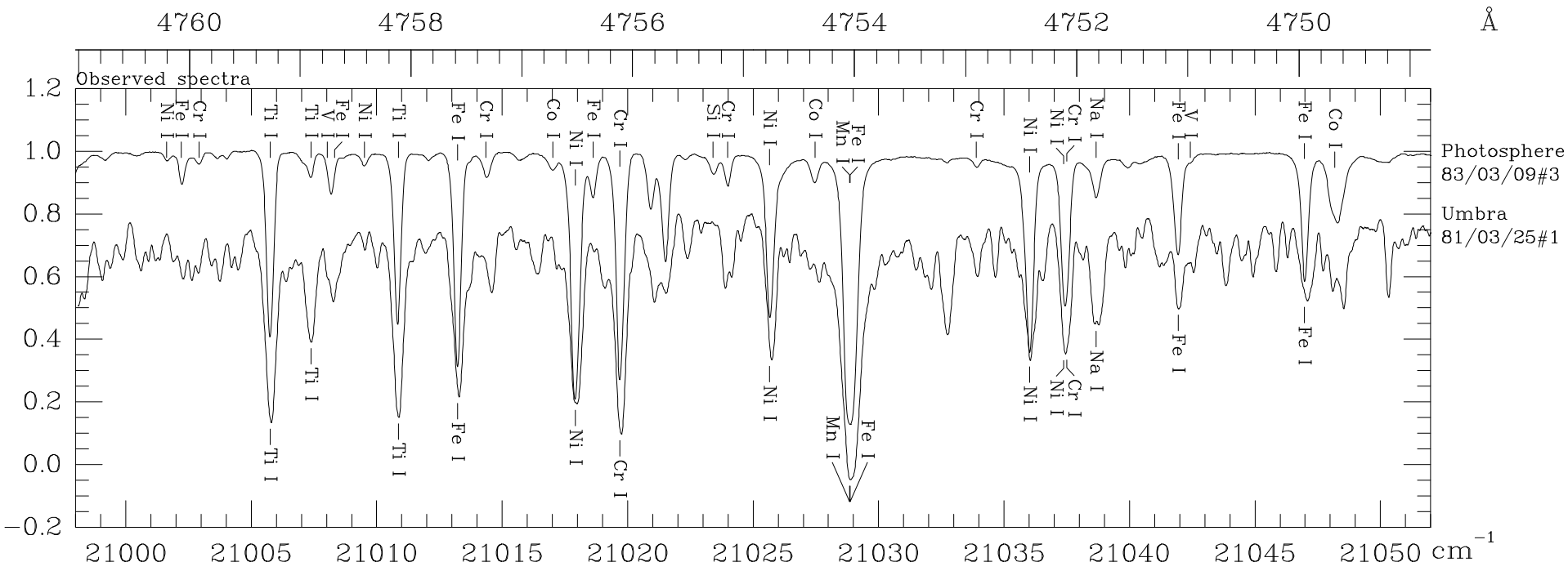


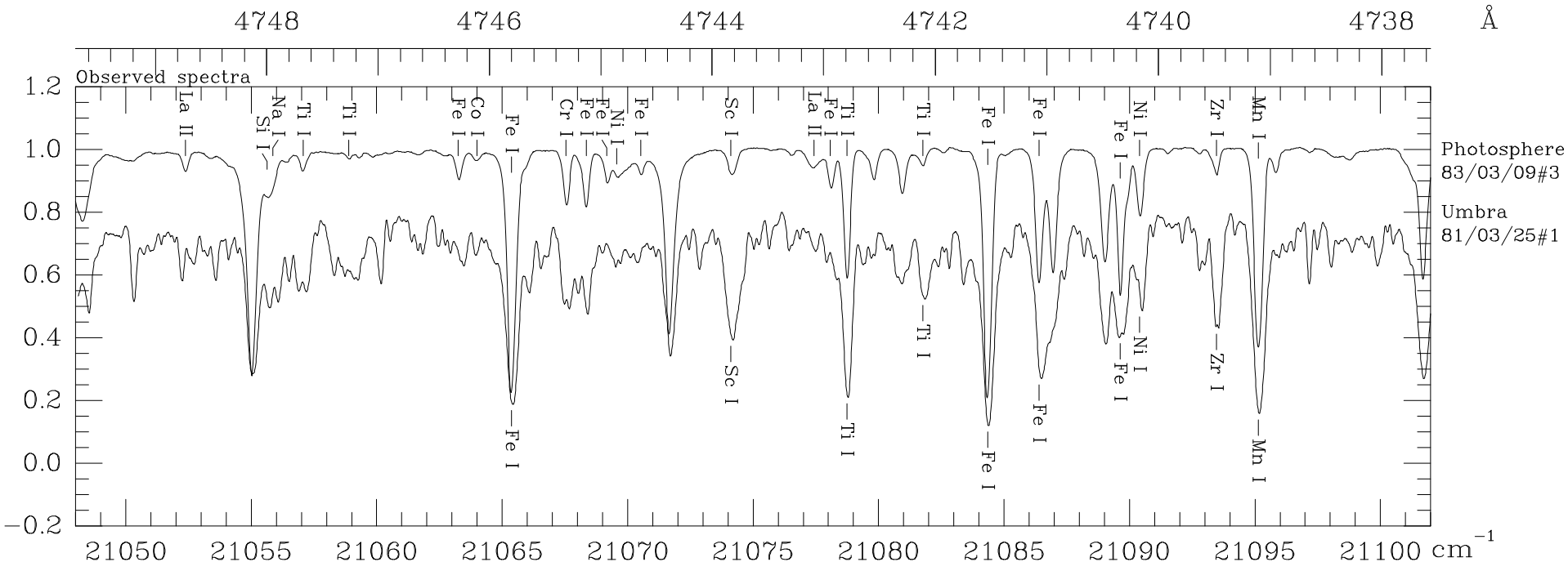
Some of the features in the umbral spectrum here are due to lines of the TiO α Δv=+2 sequence.

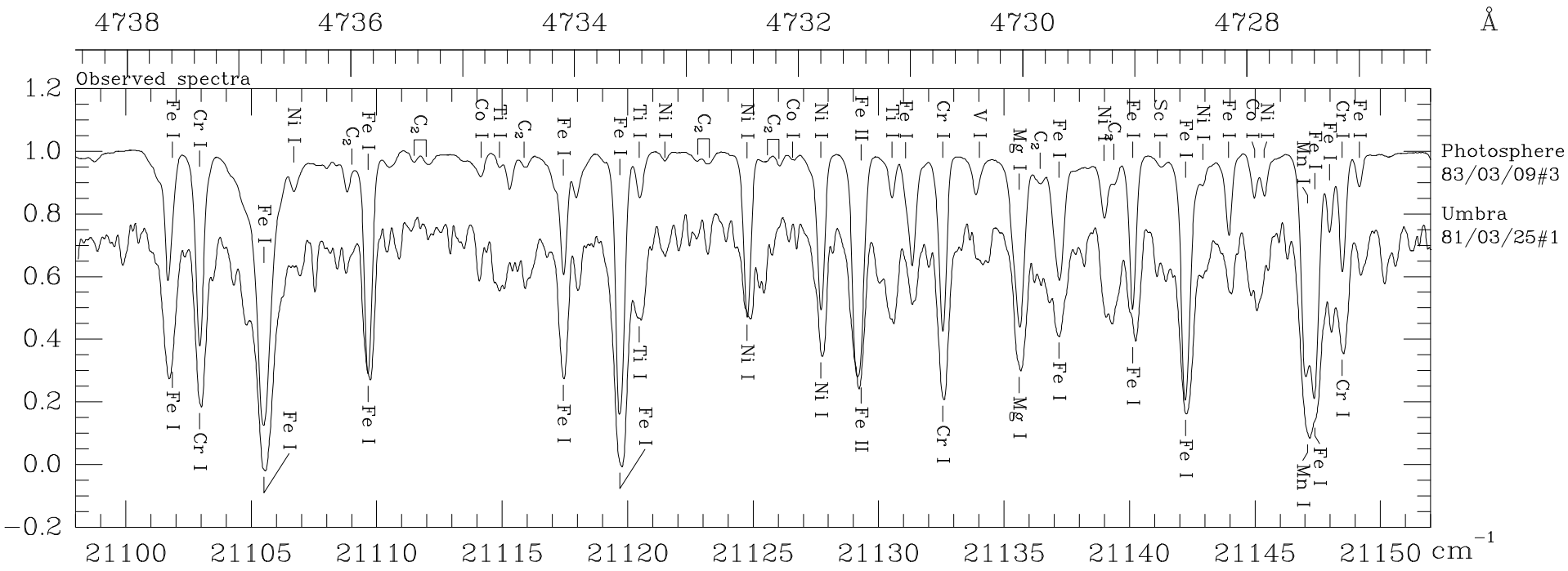


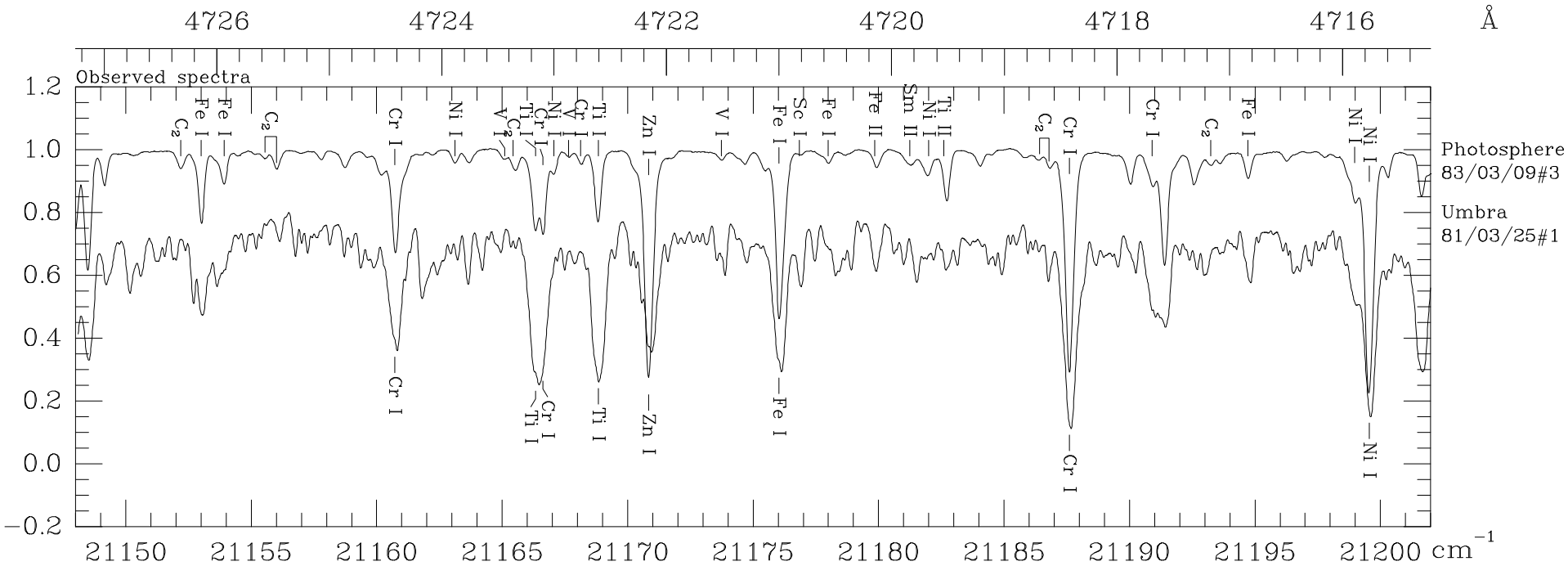

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
*MgH A–X 1–0
Å
cm^{-1}

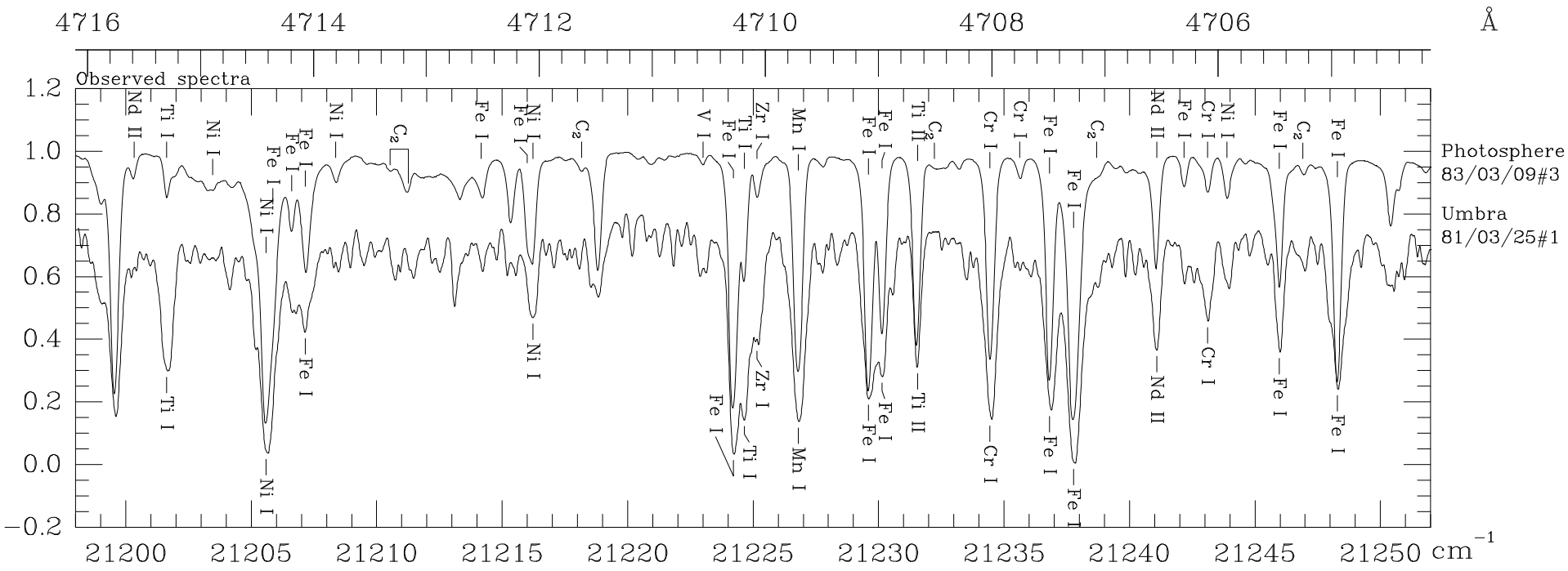

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

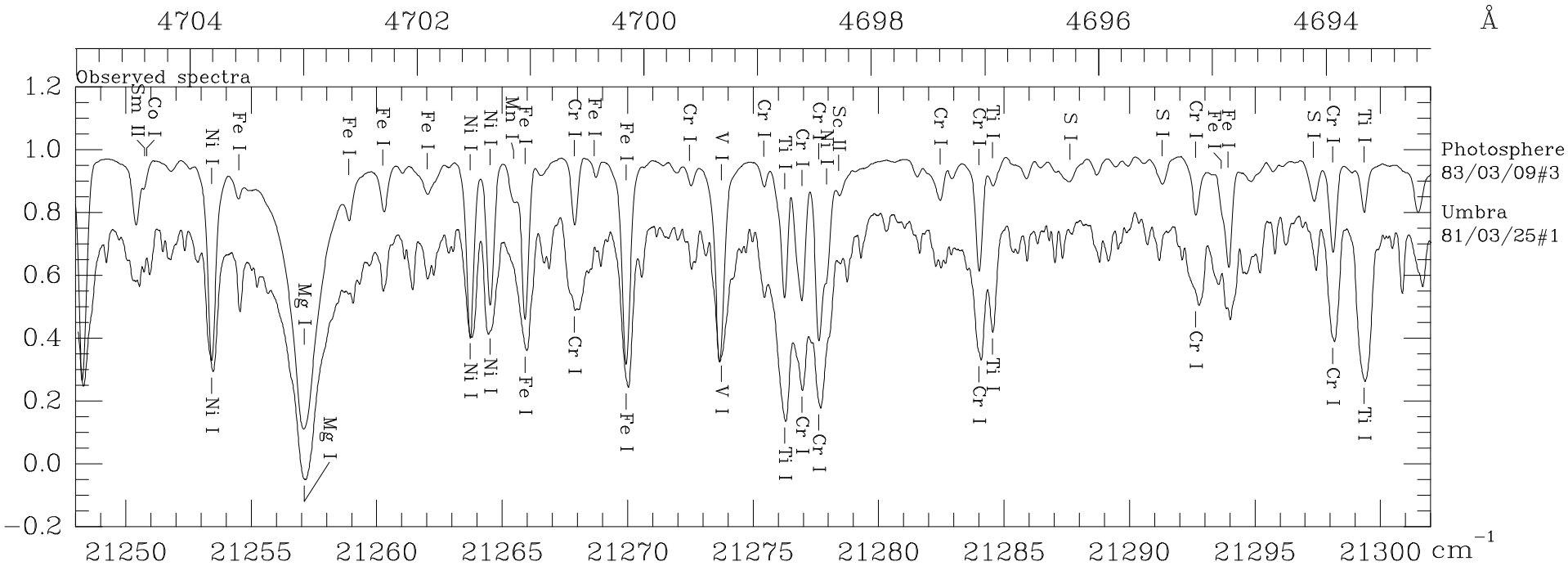

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

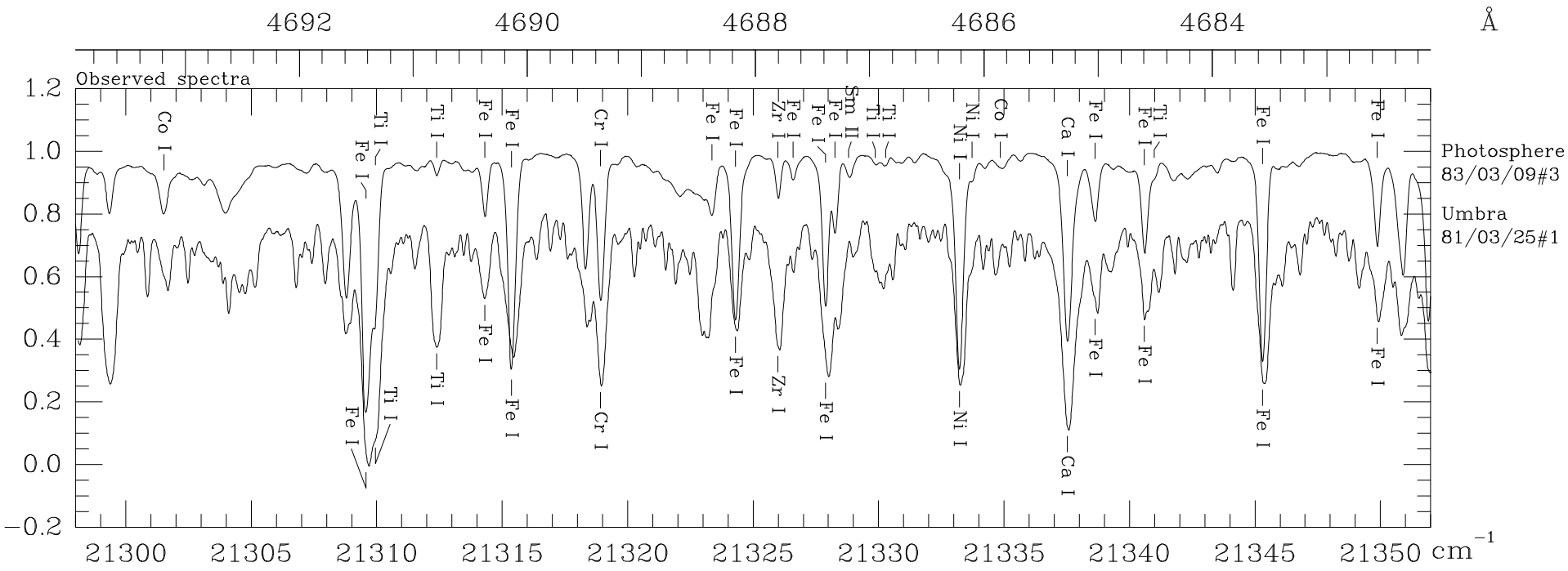

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

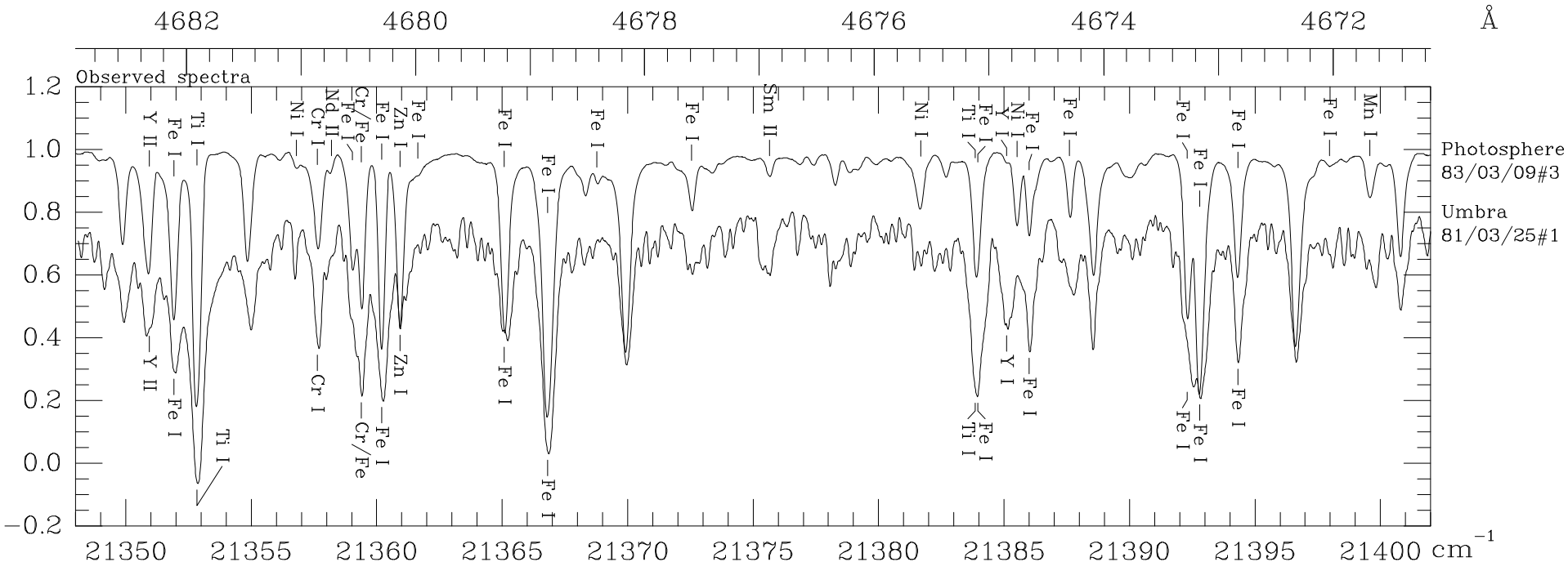

4738
4736
4734
4732
4730
4728
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
21100
21105
21110
21115
21120
21125
21130
21135
21140
21145
21150
cm^{-1}

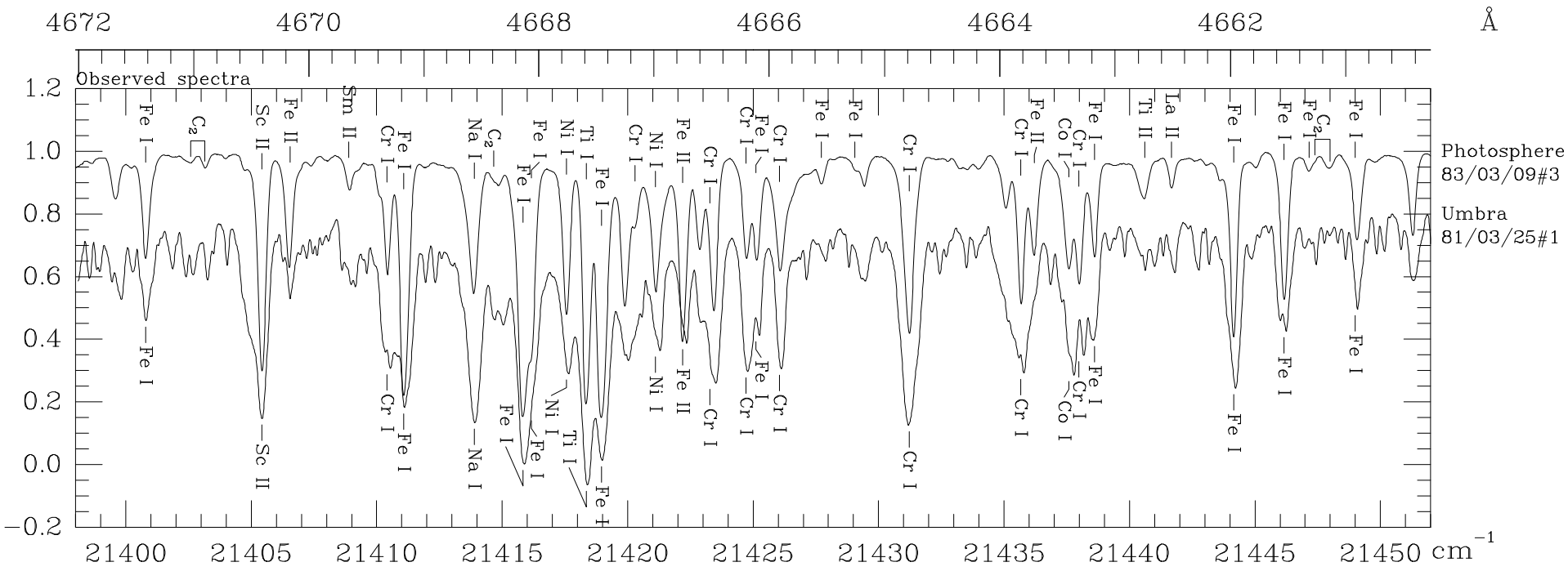

4726
4724
4722
4720
4718
4716
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
21150
21155
21160
21165
21170
21175
21180
21185
21190
21195
21200
cm^{-1}

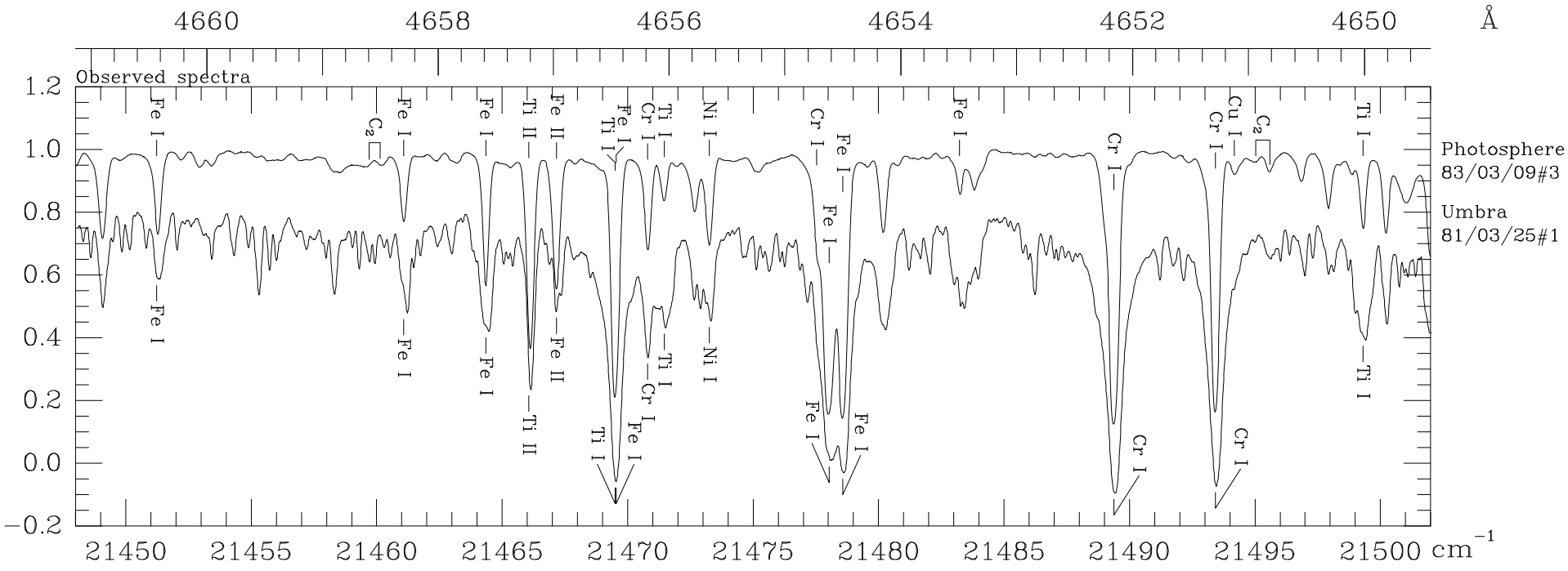

4716
4714
4712
4710
4708
4706
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
21200
21205
21210
21215
21220
21225
21230
21235
21240
21245
21250
cm^{-1}

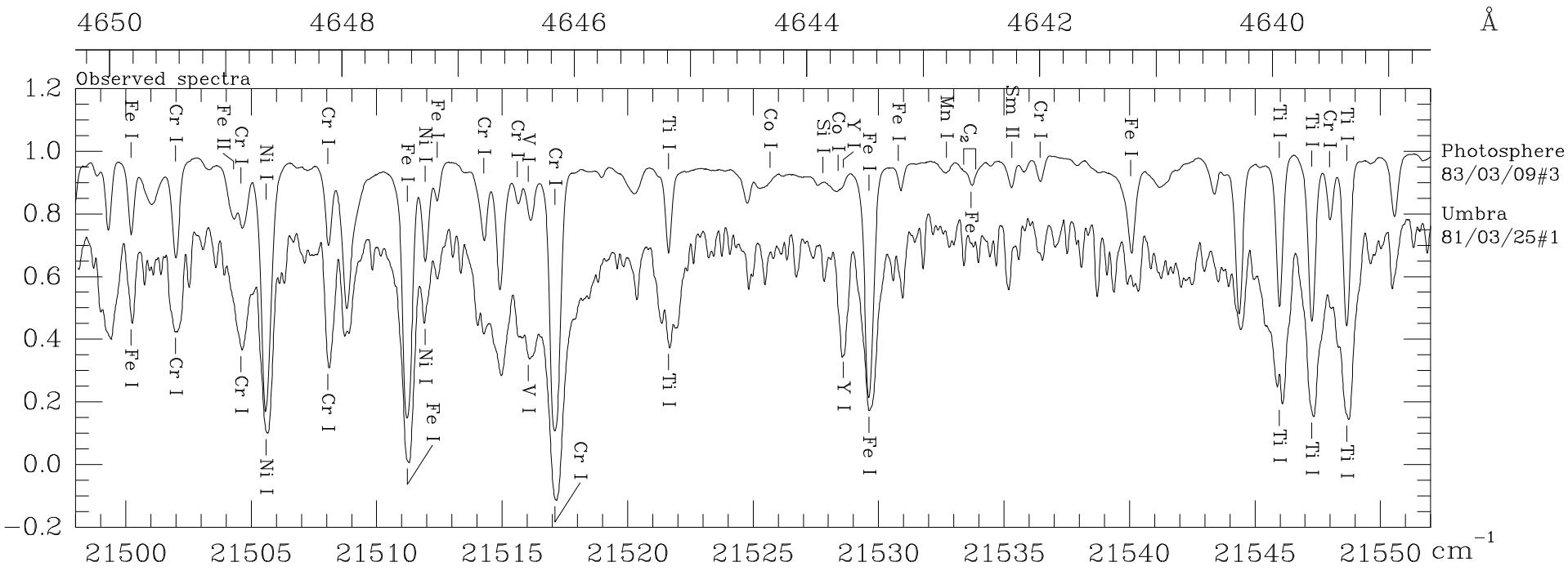

4704
4702
4700
4698
4696
4694
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
21250
21255
21260
21265
21270
21275
21280
21285
21290
21295
21300
cm^{-1}

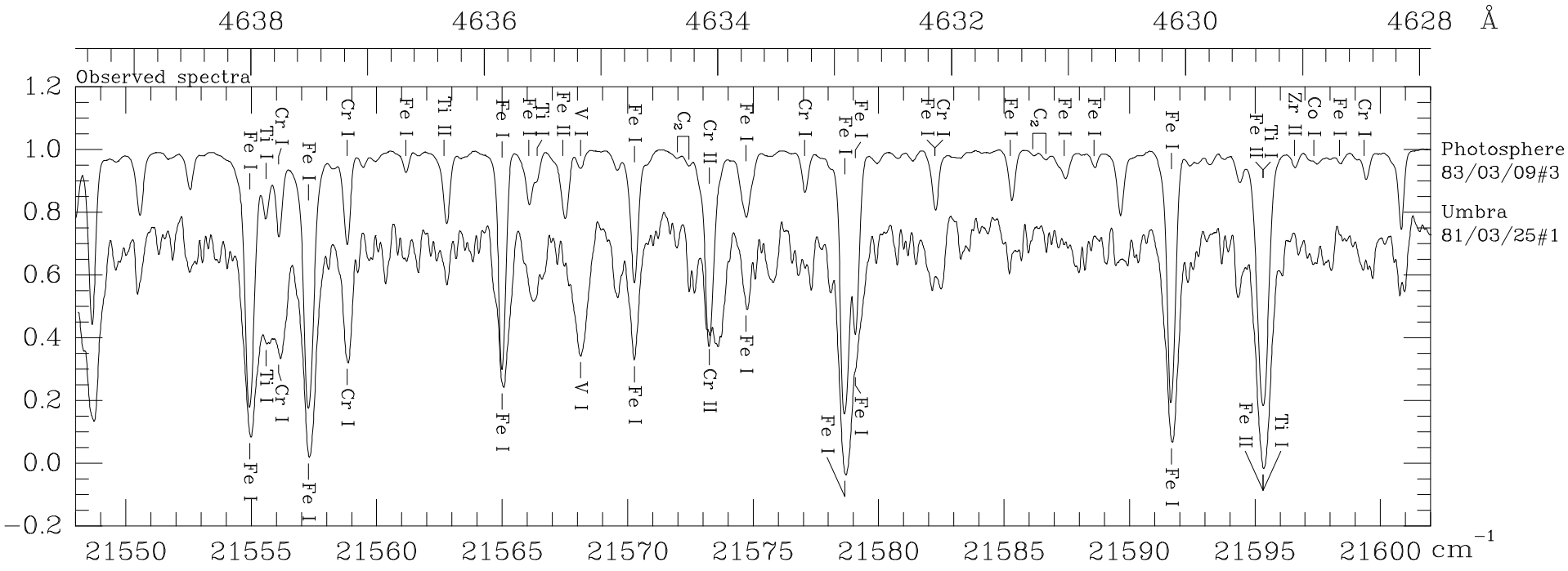

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}
Co I
Ti I
Fe I
Cr I
Zr I
Sm II
Ni I
Ca I

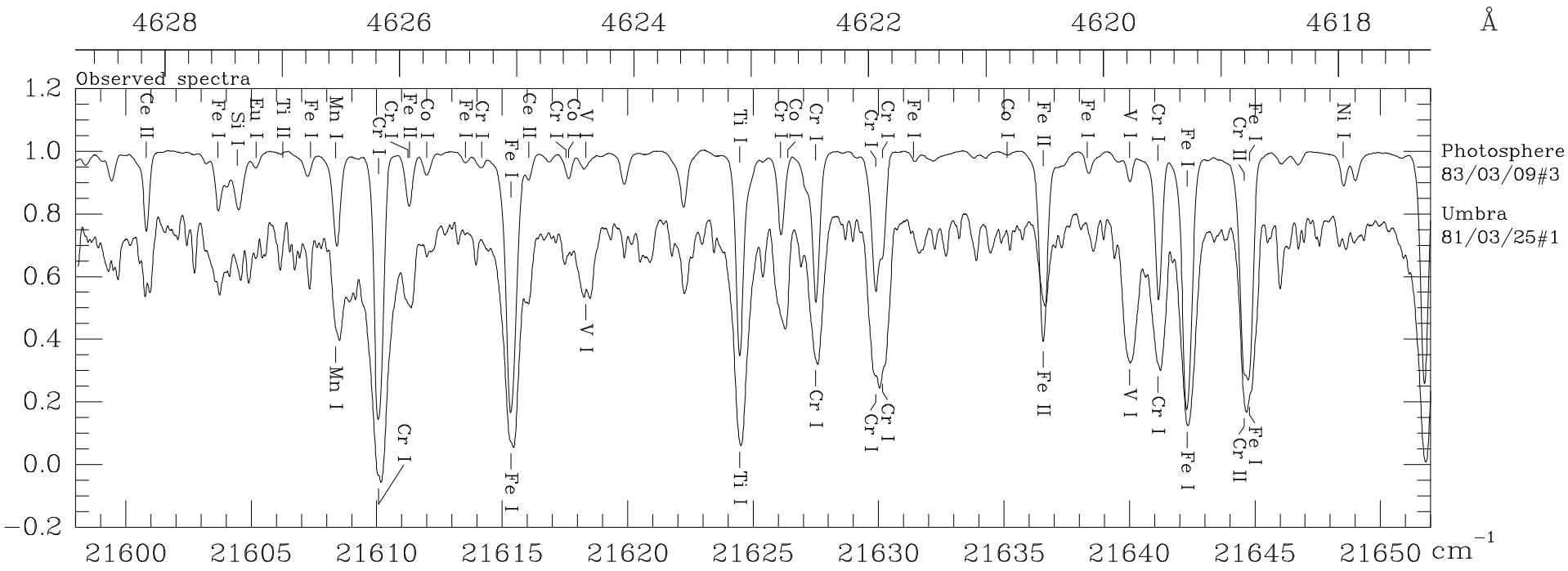

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}
Y II
Fe I
Ti I
Ni I
Cr I
Nd II
Cr/Fe
Zn I
Sm II
Y I
Mn I

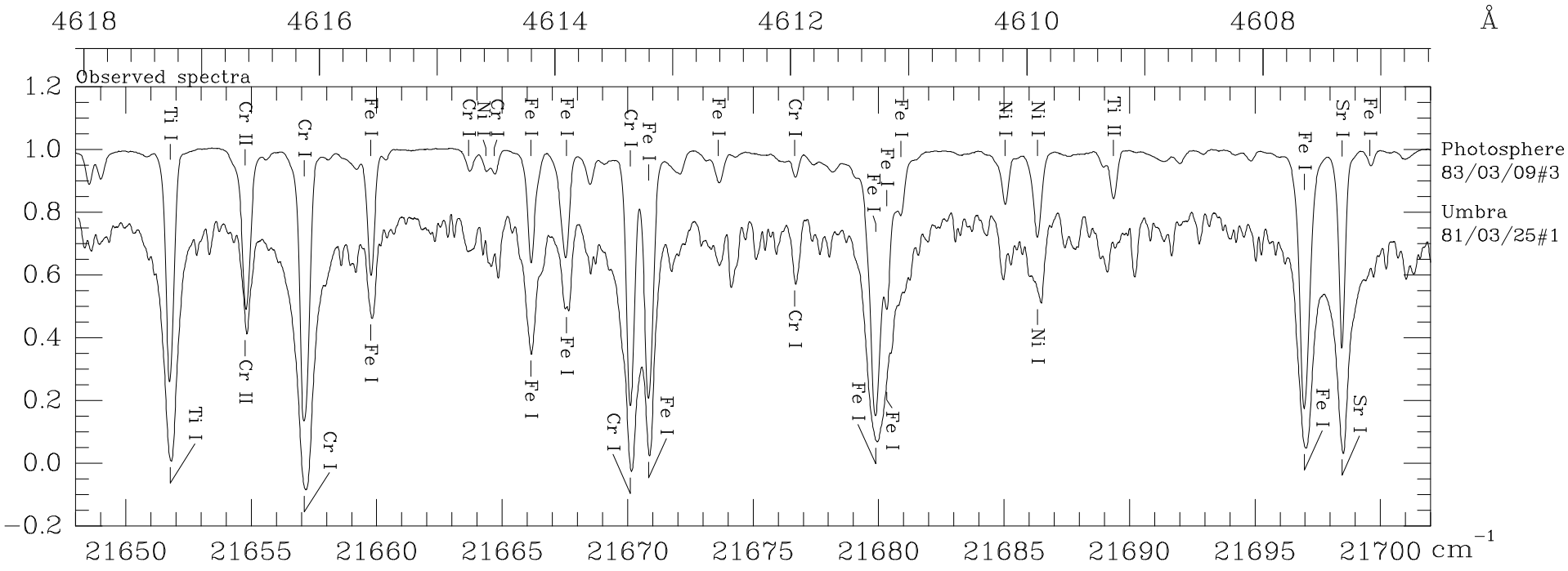

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

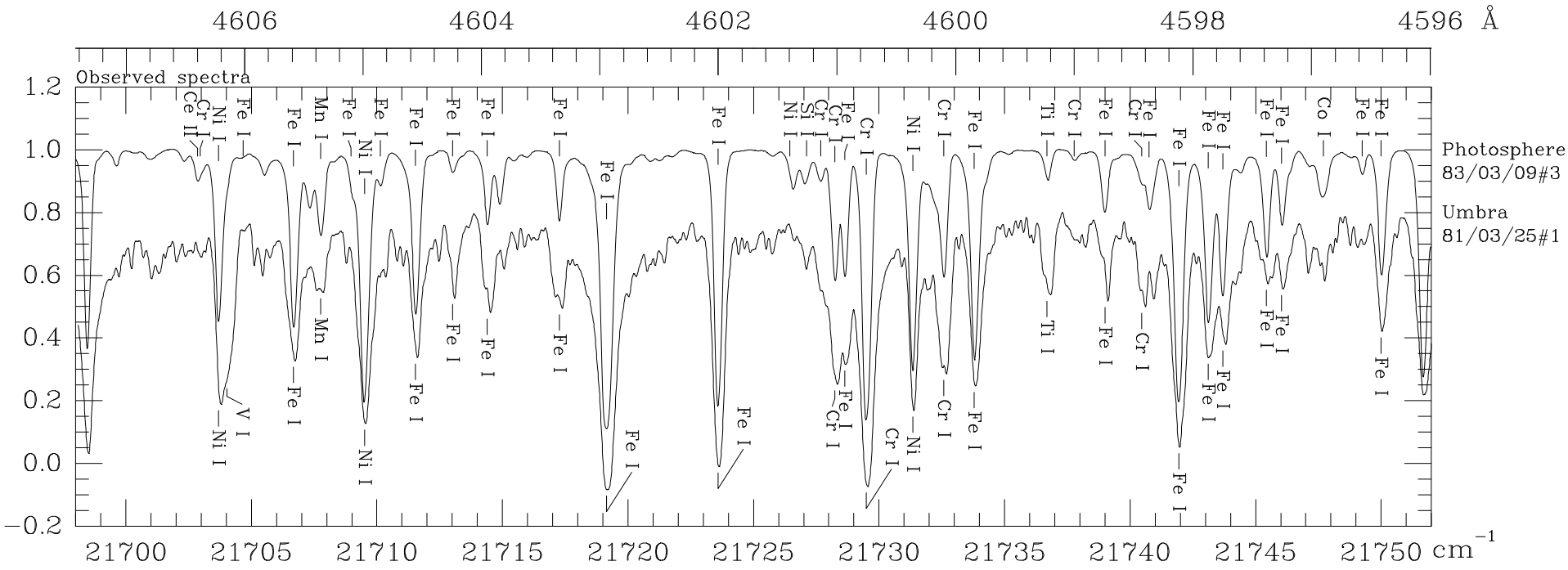

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

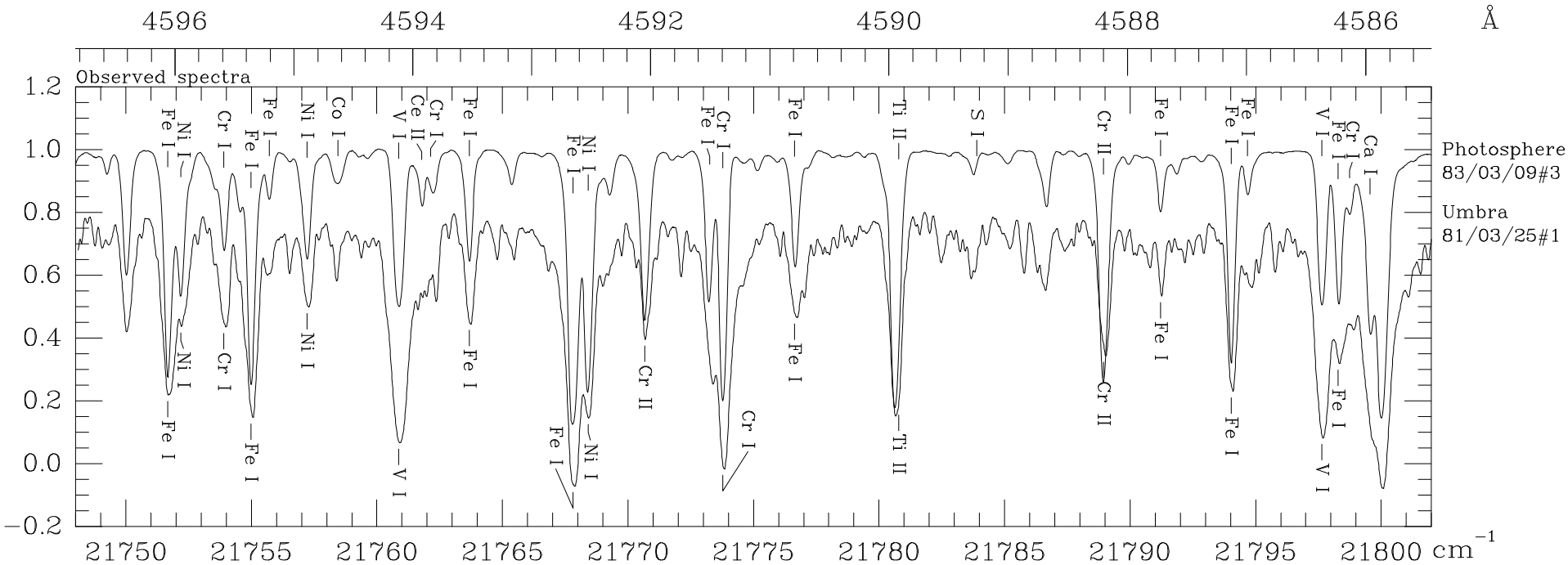

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

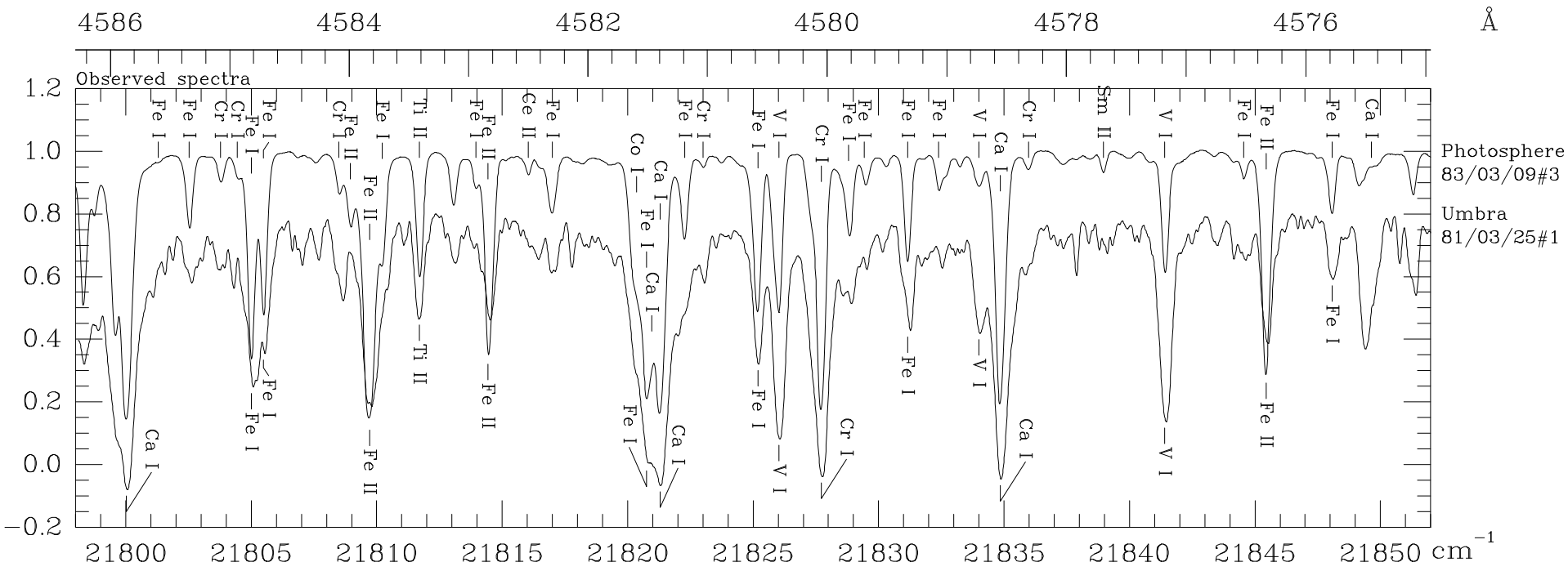

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

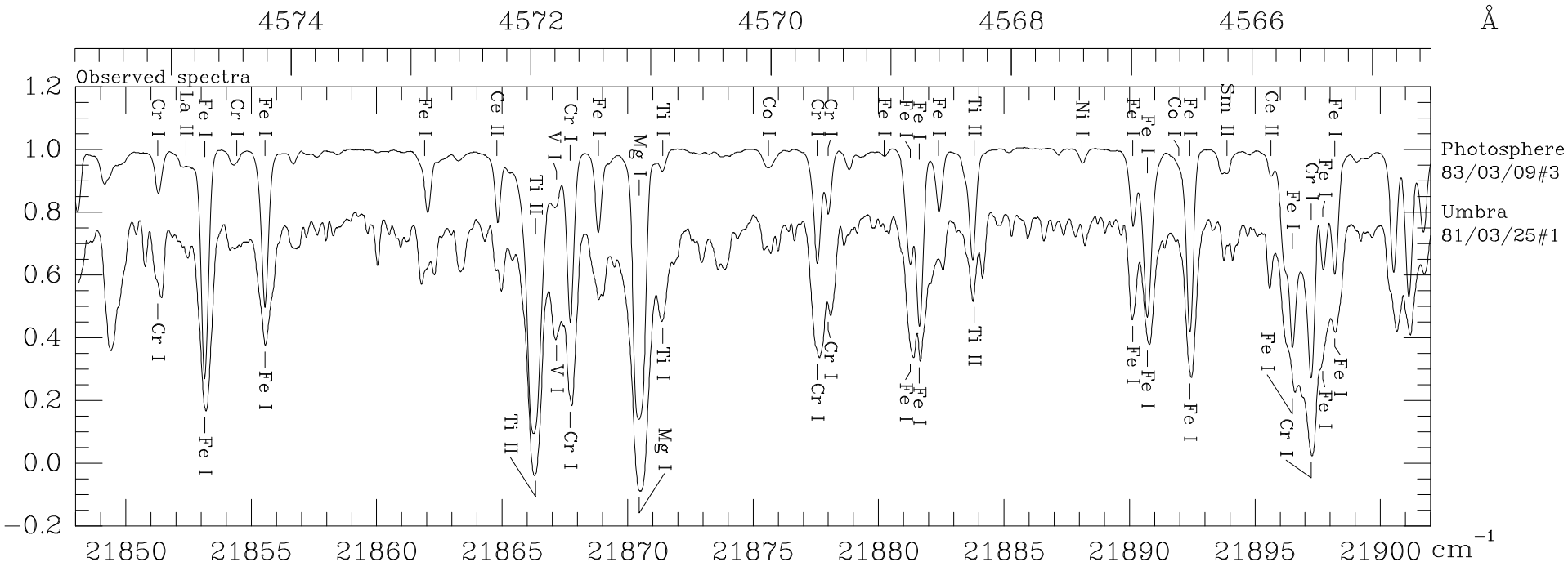

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

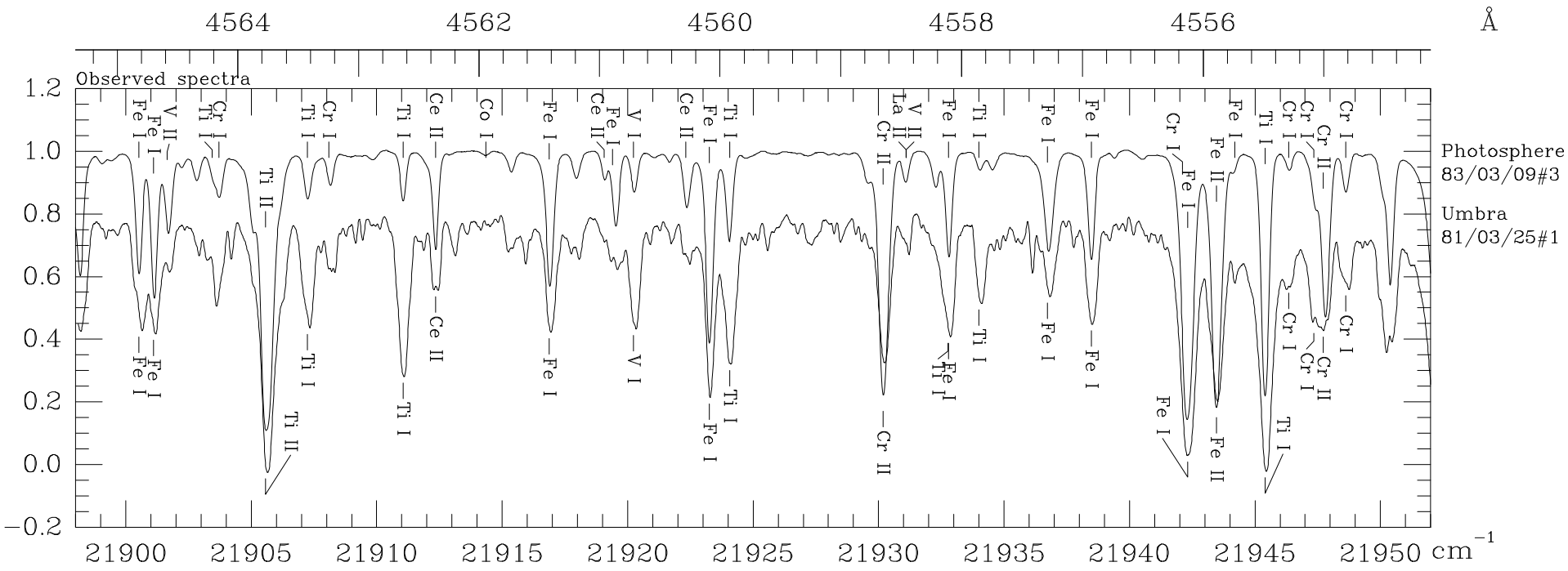

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

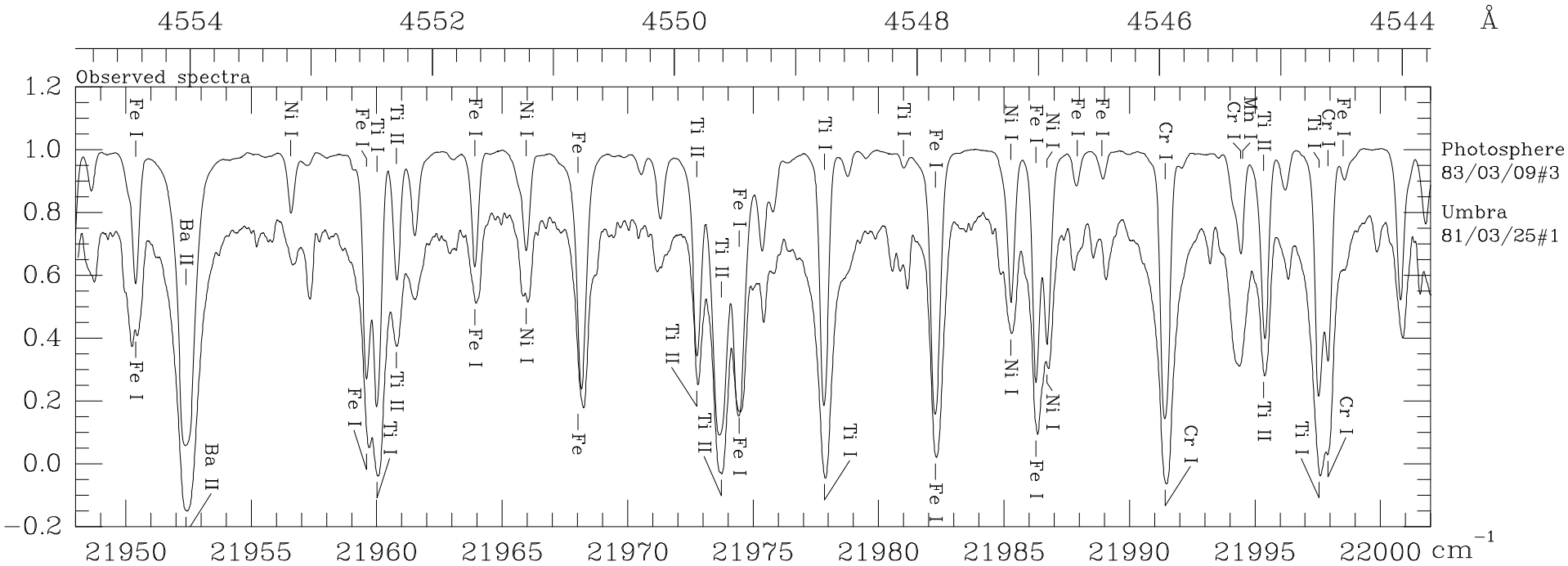

4606
4604
4602
4600
4598
4596 Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
21700
21705
21710
21715
21720
21725
21730
21735
21740
21745
21750 cm^{-1}

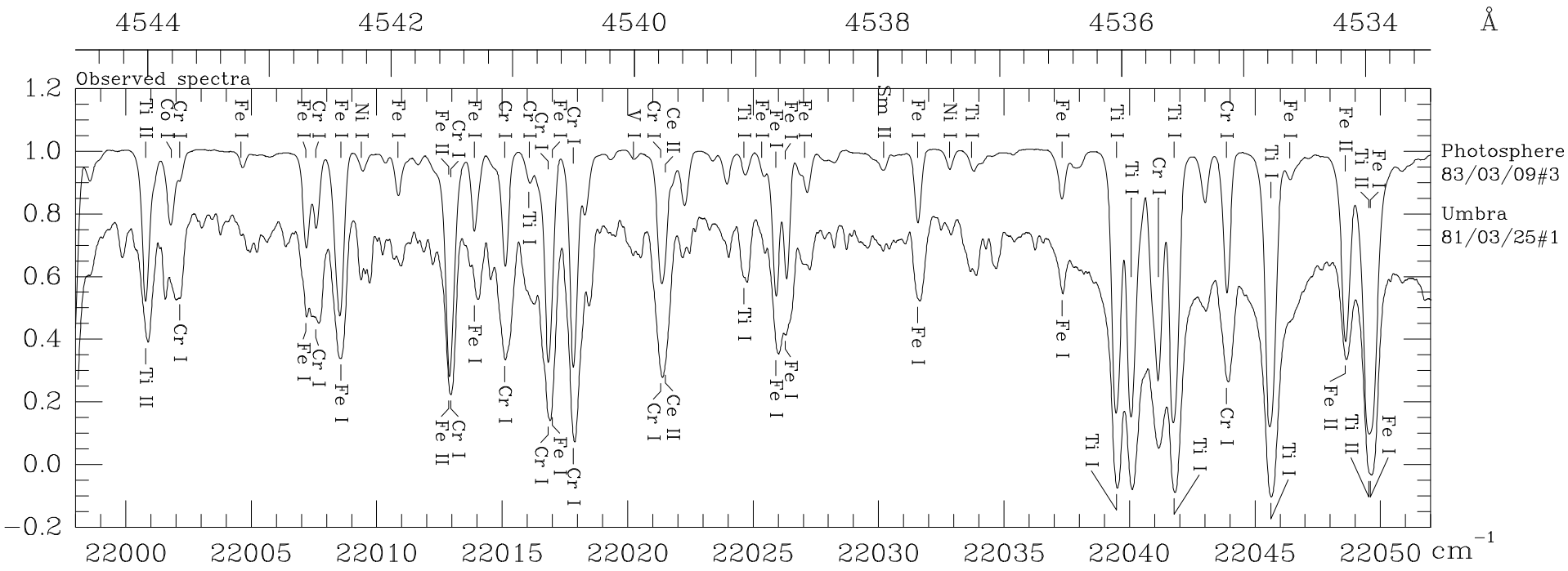

4596
4594
4592
4590
4588
4586 Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
21750
21755
21760
21765
21770
21775
21780
21785
21790
21795
21800 cm^{-1}

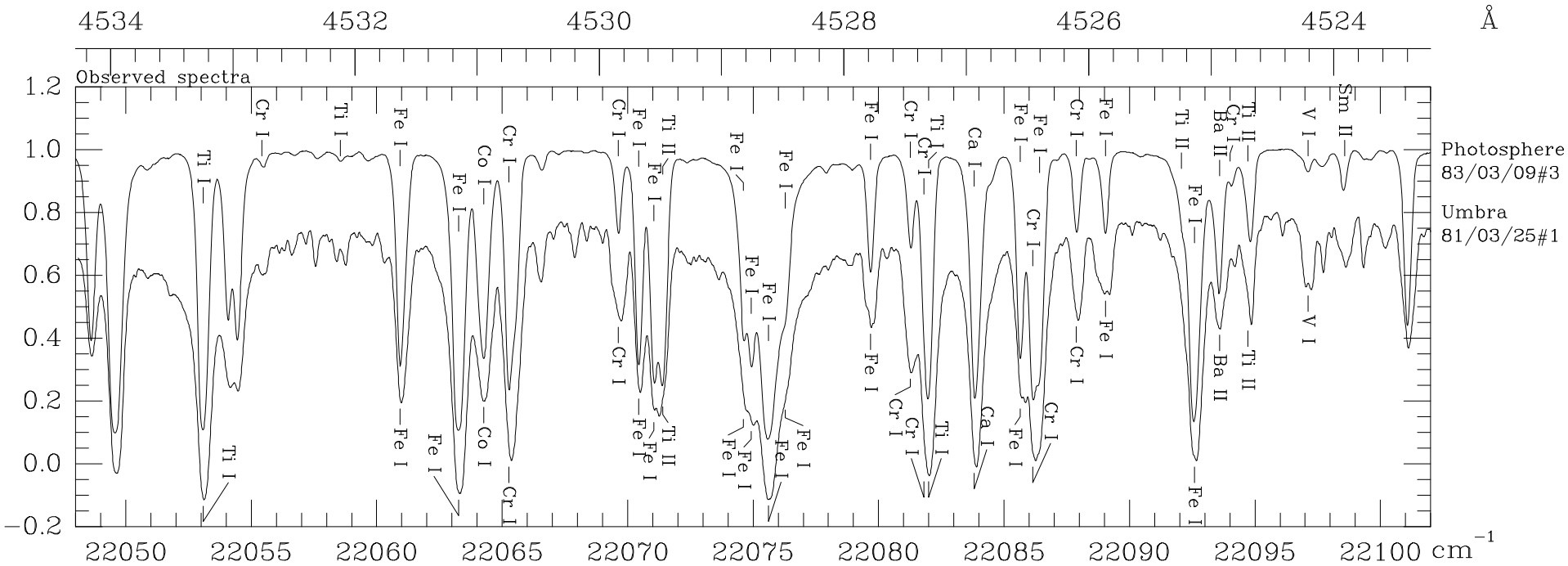

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

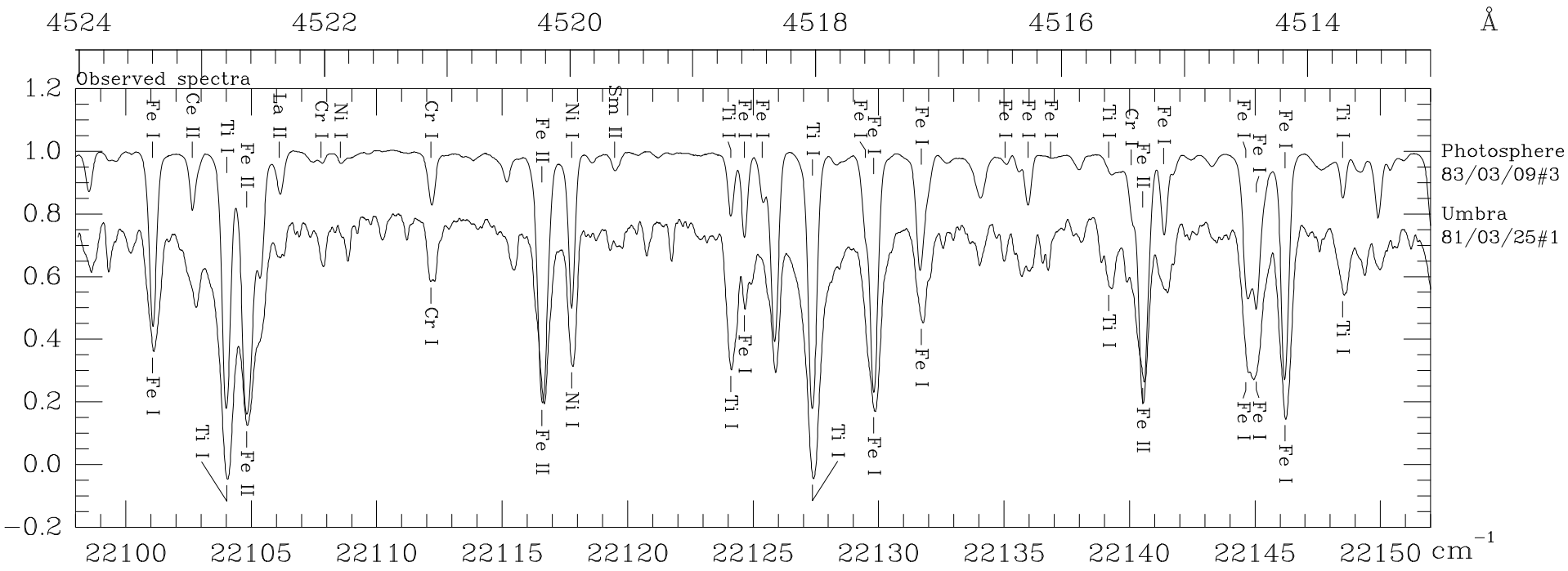

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

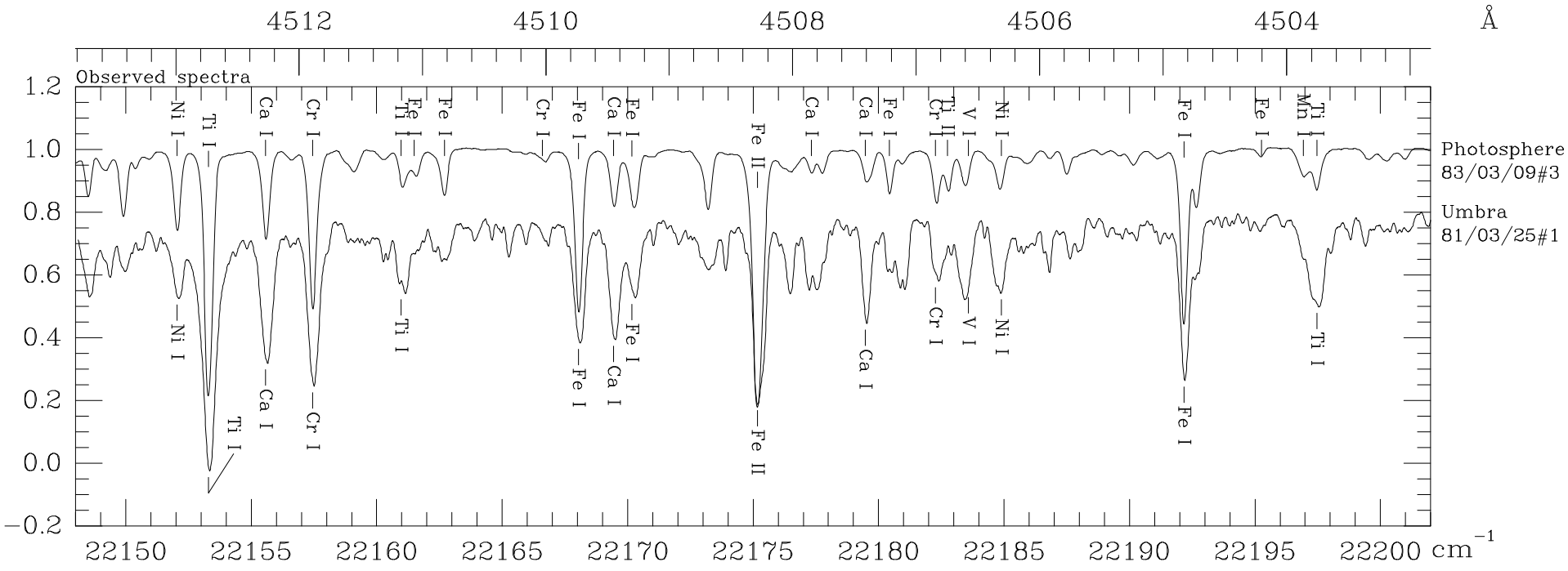

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

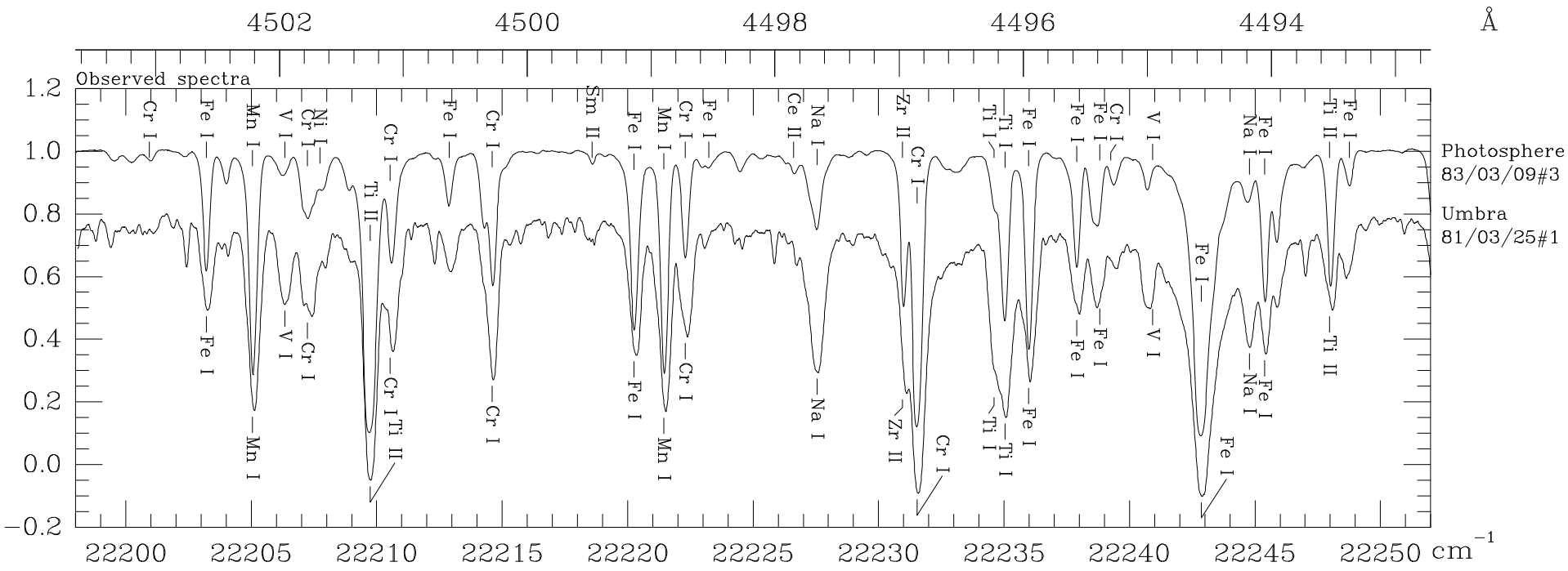

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

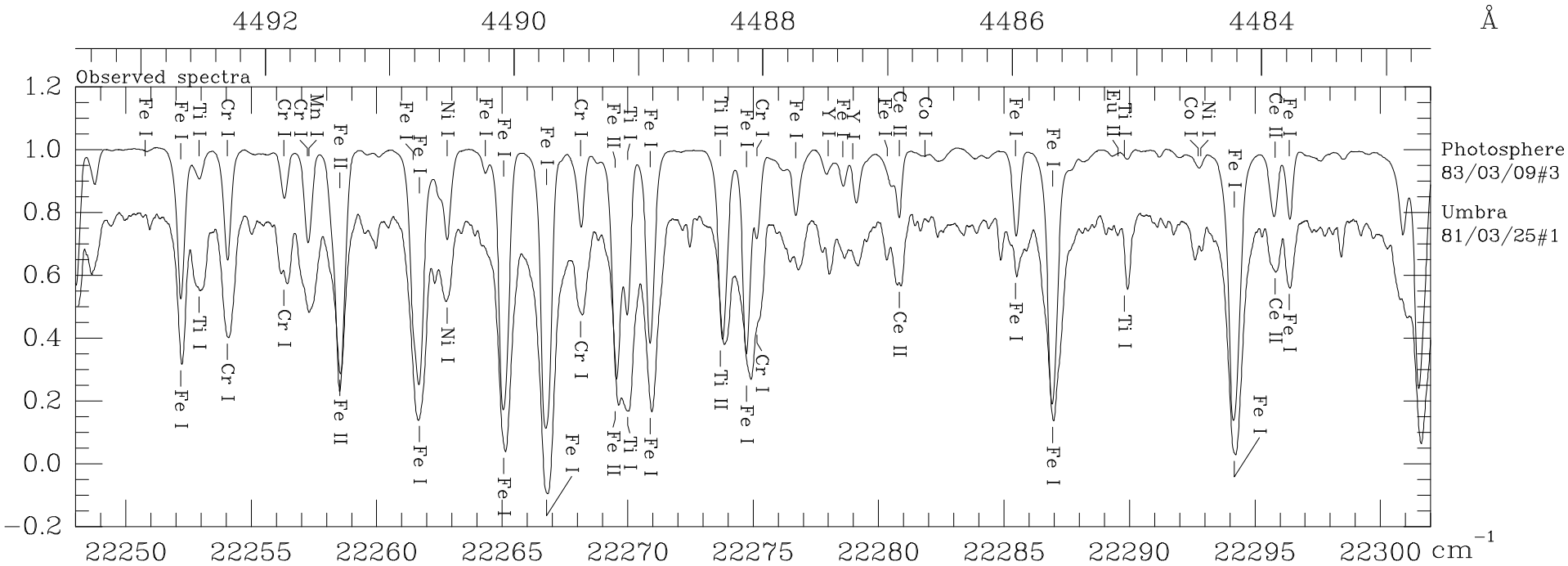

4544
4542
4540
4538
4536
4534
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
22000
22005
22010
22015
22020
22025
22030
22035
22040
22045
22050
cm^{-1}

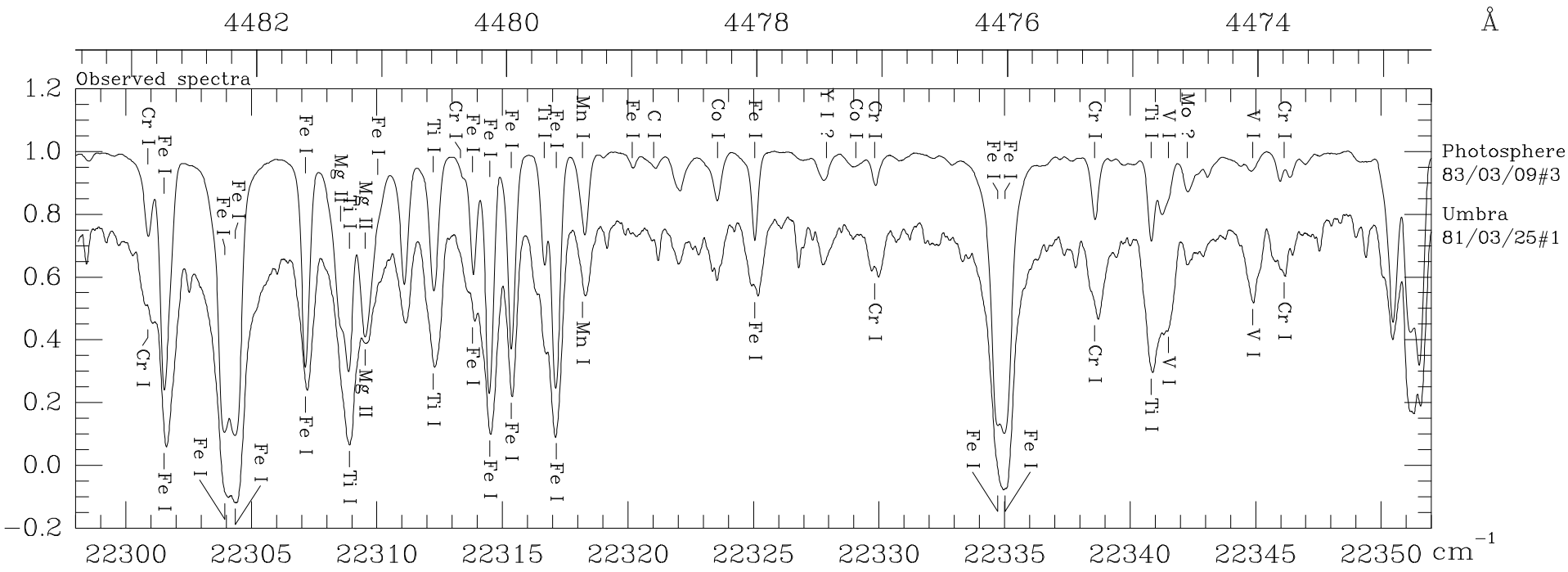

4534
4532
4530
4528
4526
4524
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
22050
22055
22060
22065
22070
22075
22080
22085
22090
22095
22100
cm^{-1}

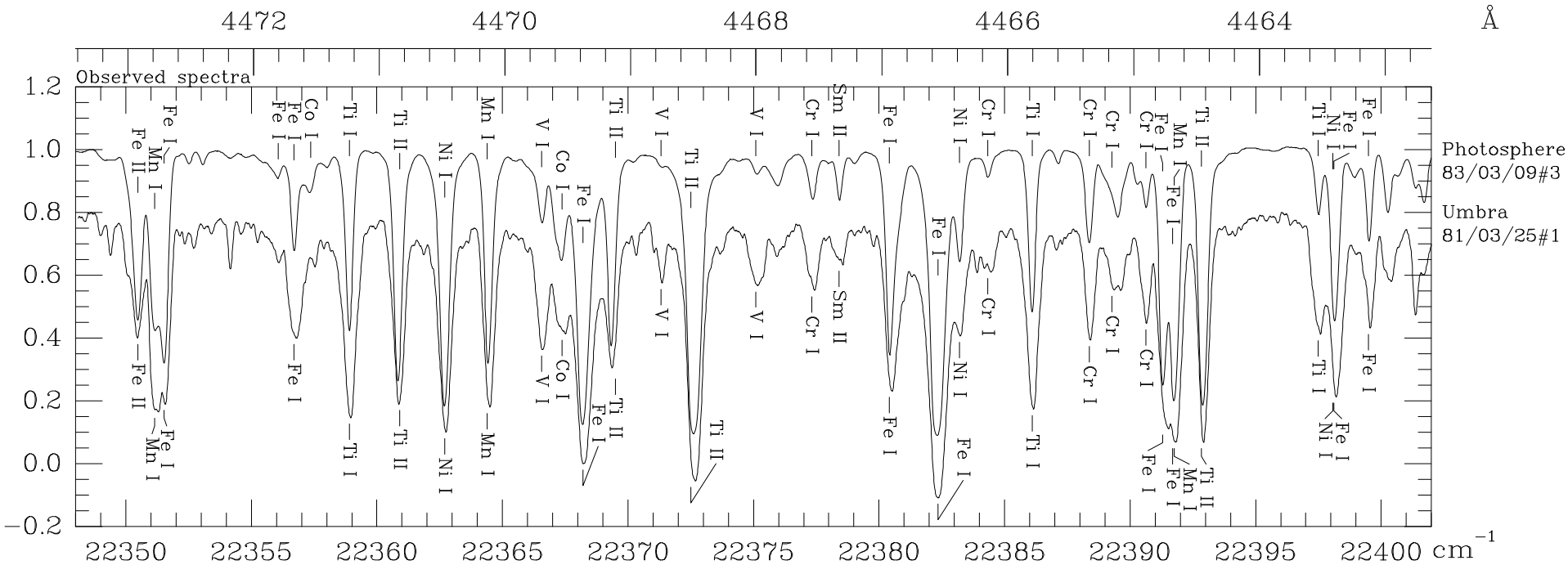

4524
4522
4520
4518
4516
4514
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
22100
22105
22110
22115
22120
22125
22130
22135
22140
22145
22150
cm^{-1}

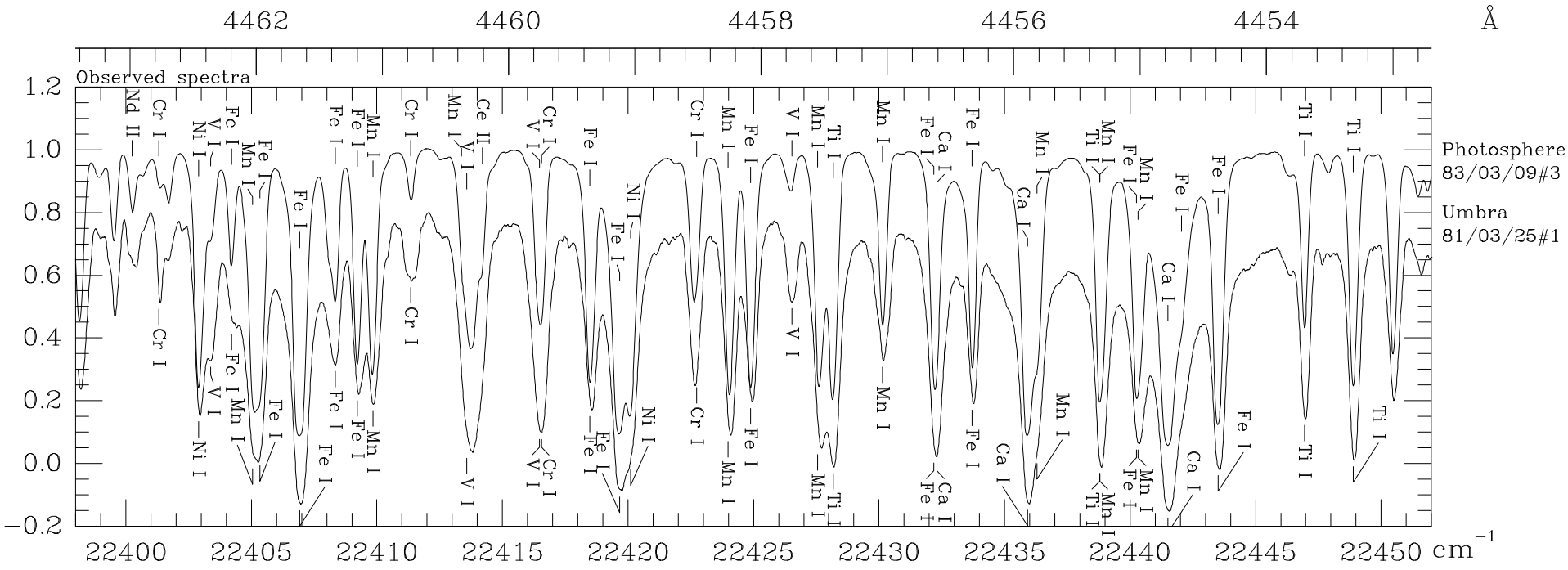

4512
4510
4508
4506
4504
Å
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
22150
22155
22160
22165
22170
22175
22180
22185
22190
22195
22200
cm^{-1}

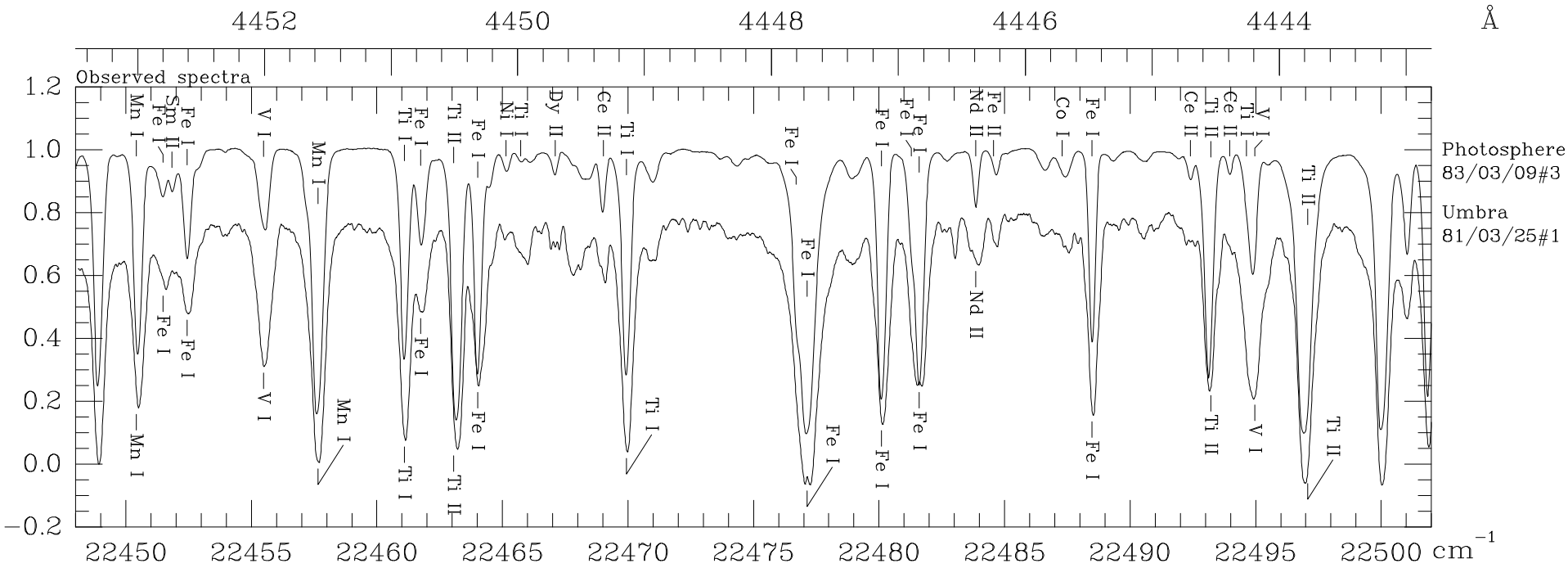

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
4502
4500
4498
4496
4494
Å
22200
22205
22210
22215
22220
22225
22230
22235
22240
22245
22250
cm^{-1}
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2

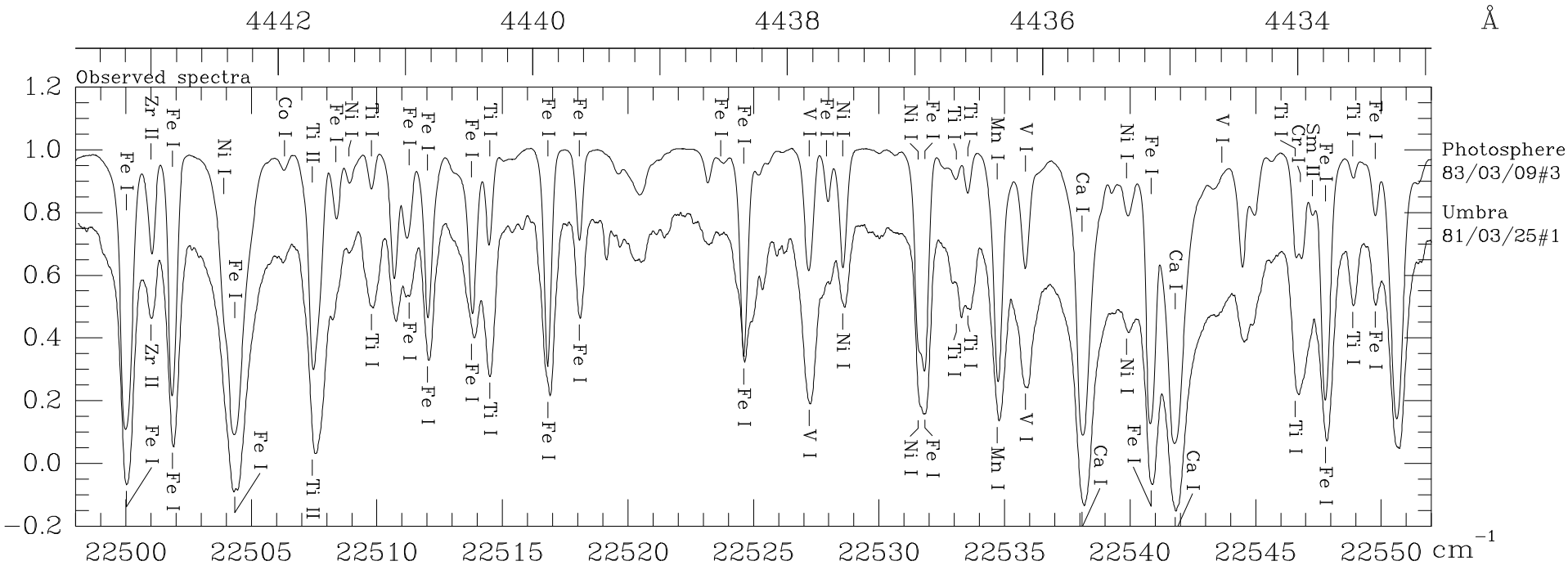

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
4492
4490
4488
4486
4484
Å
22250
22255
22260
22265
22270
22275
22280
22285
22290
22295
22300
cm^{-1}
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2

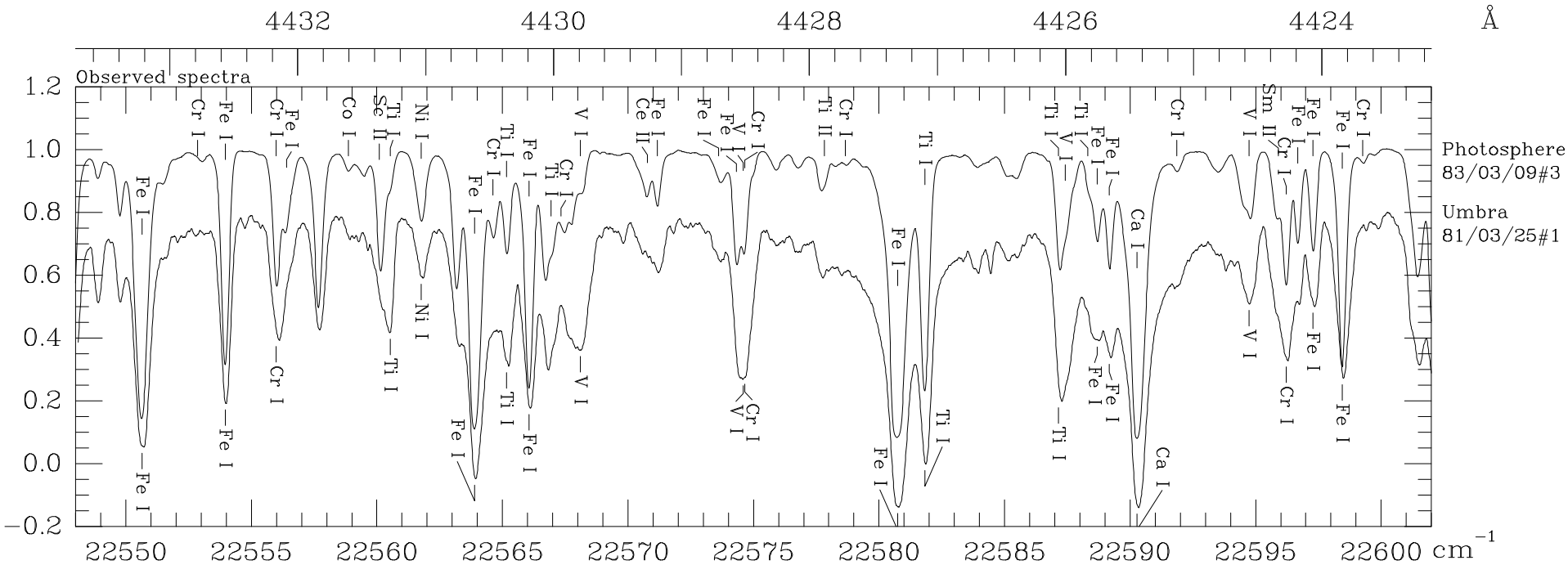

Å
4482
4480
4478
4476
4474
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
22300
22305
22310
22315
22320
22325
22330
22335
22340
22345
22350
cm−1

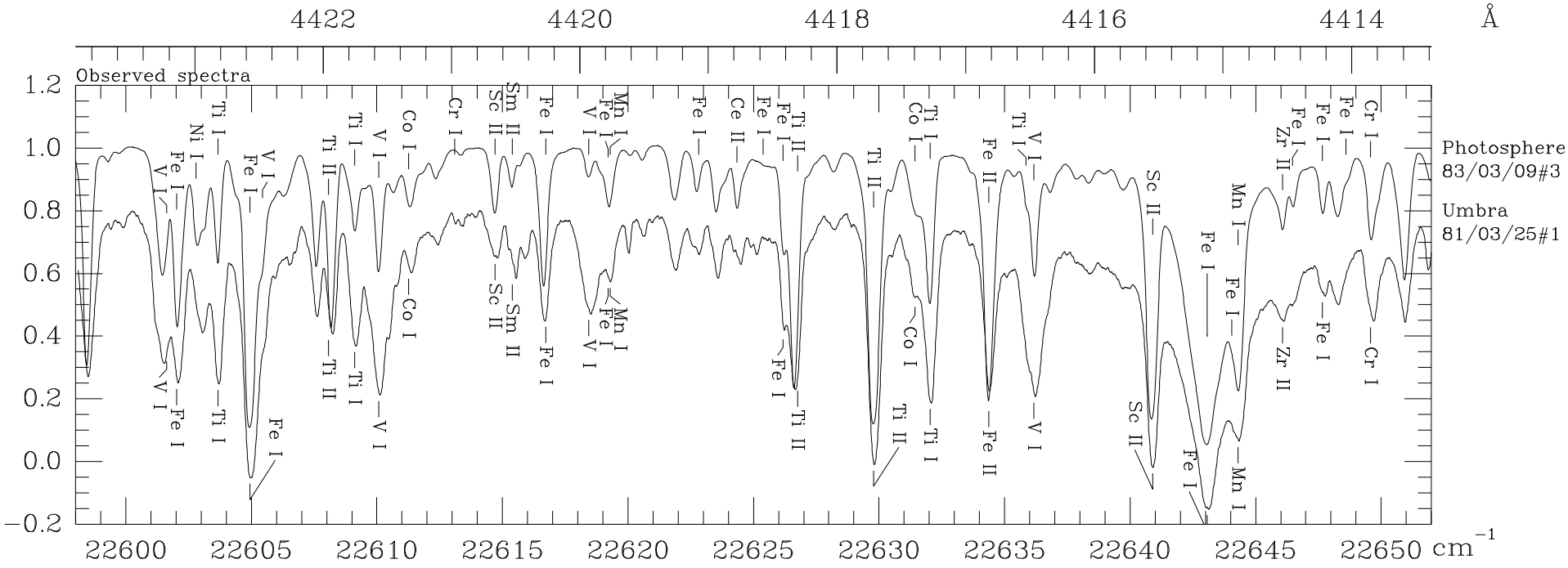

Å
4472
4470
4468
4466
4464
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
22350
22355
22360
22365
22370
22375
22380
22385
22390
22395
22400
cm−1

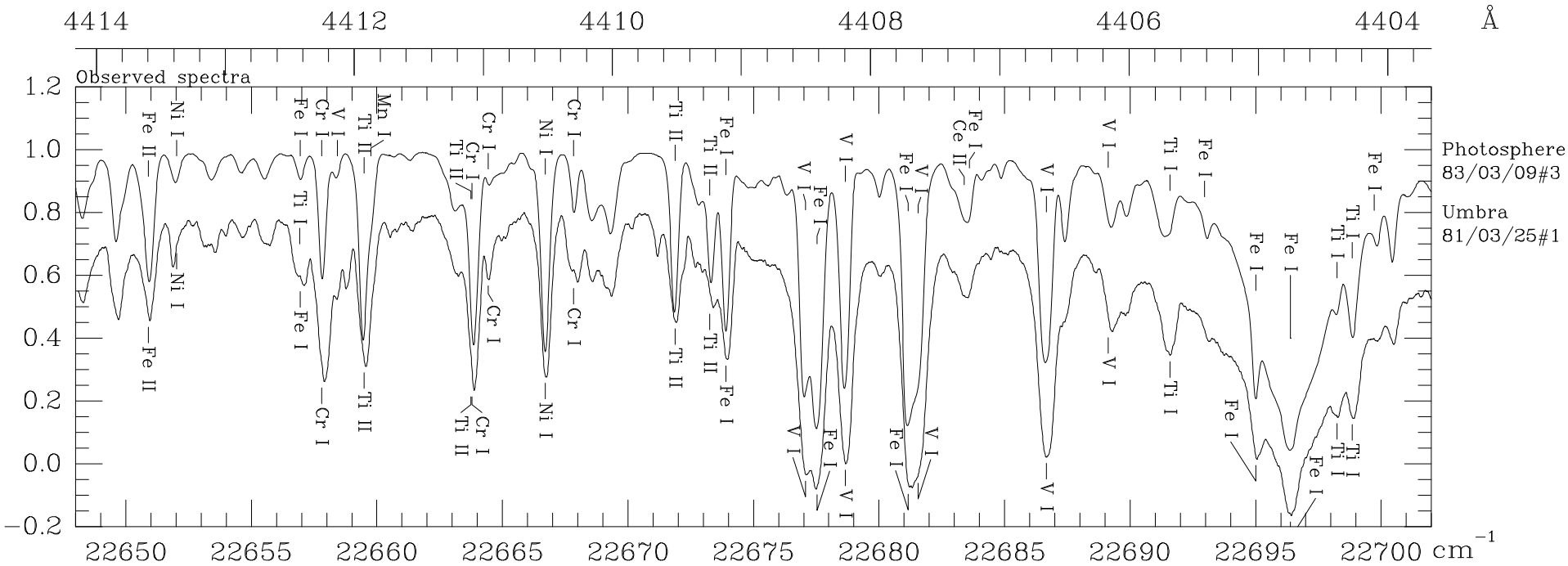

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

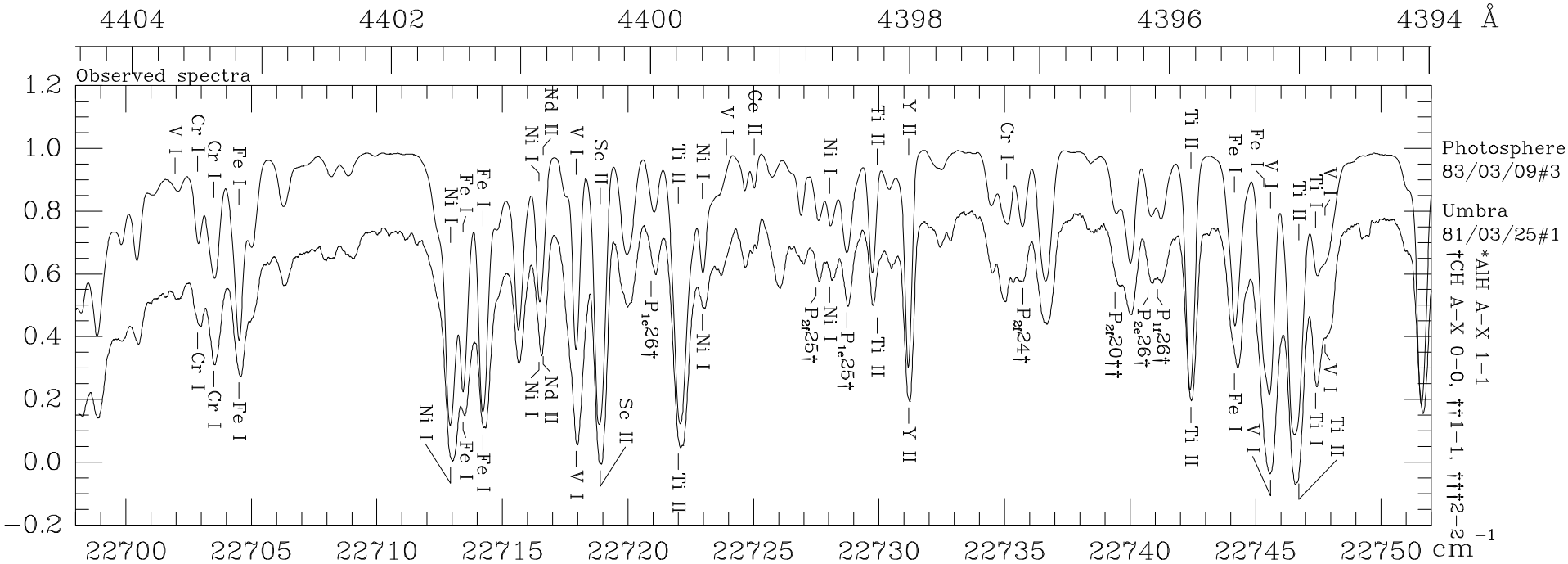

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

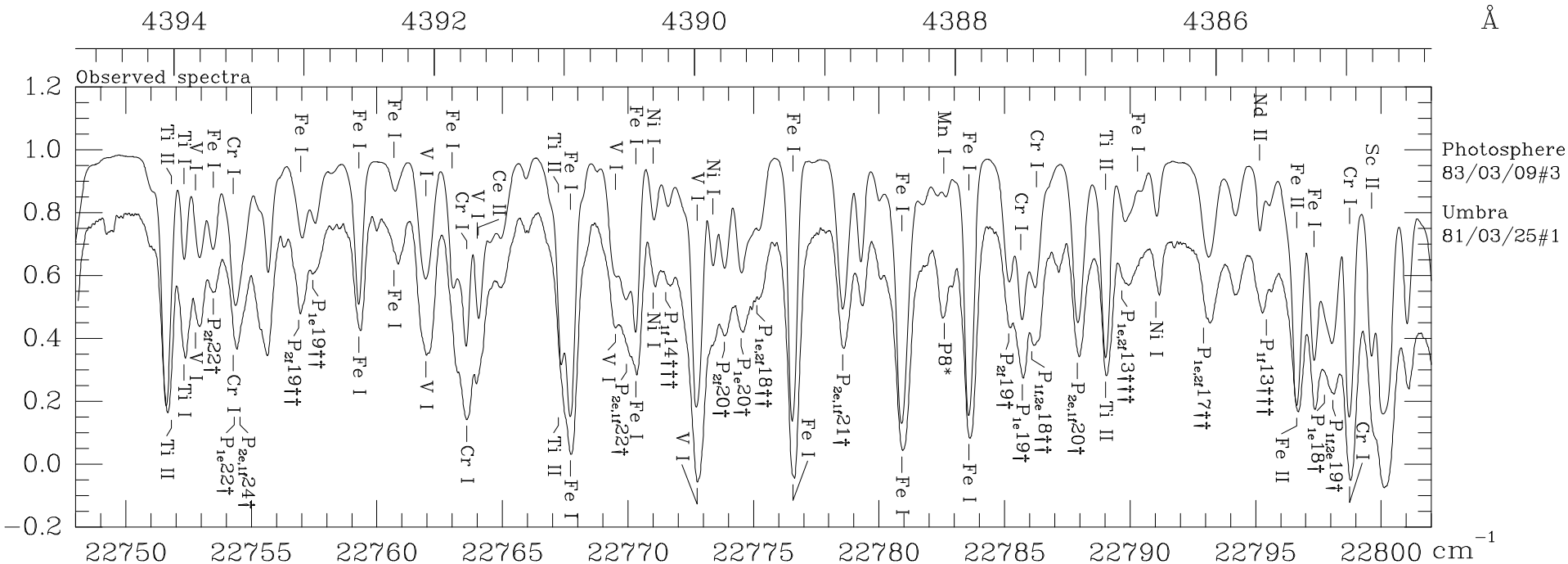

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
4442
4440
4438
4436
4434
Å
22500
22505
22510
22515
22520
22525
22530
22535
22540
22545
22550
cm^{-1}

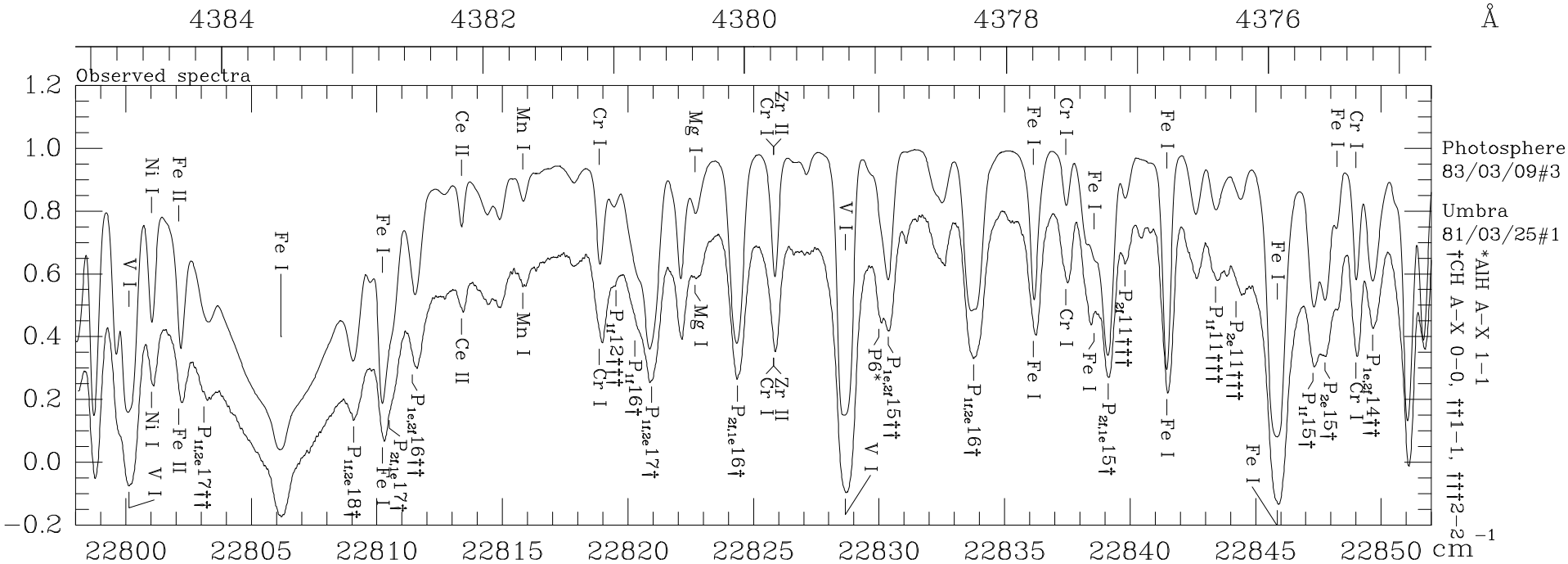

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
4432
4430
4428
4426
4424
Å
22550
22555
22560
22565
22570
22575
22580
22585
22590
22595
22600
cm^{-1}

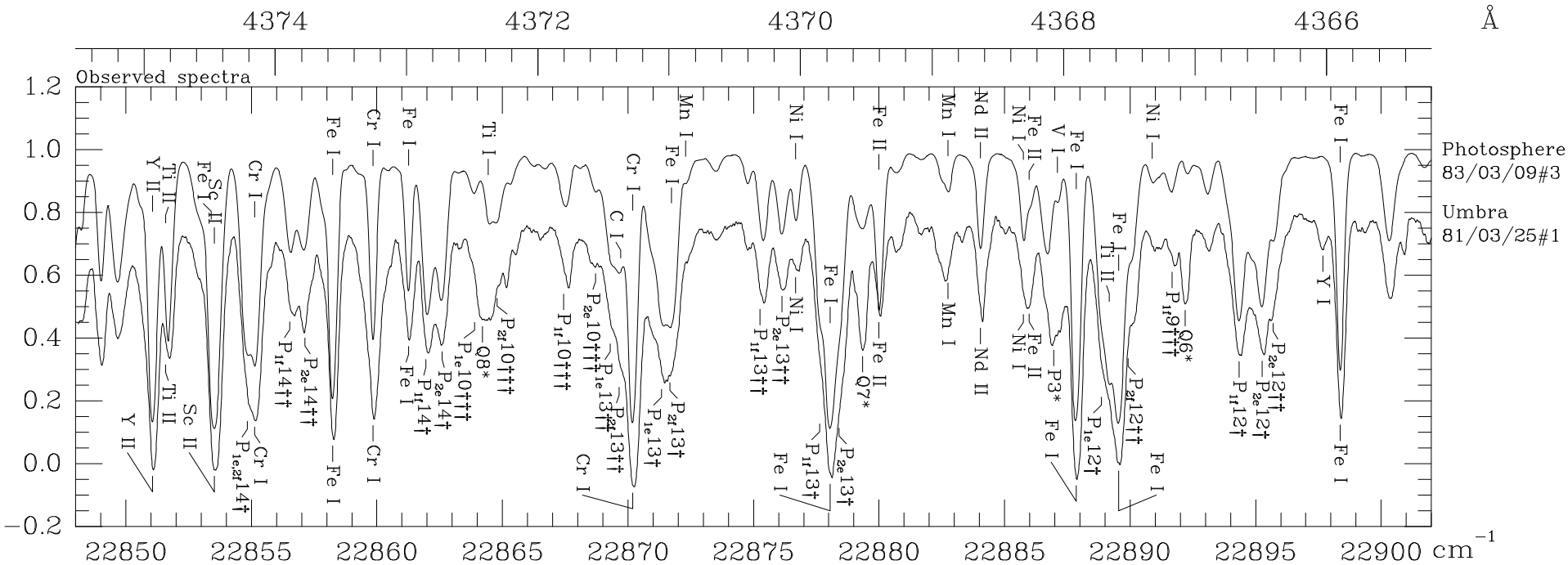

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

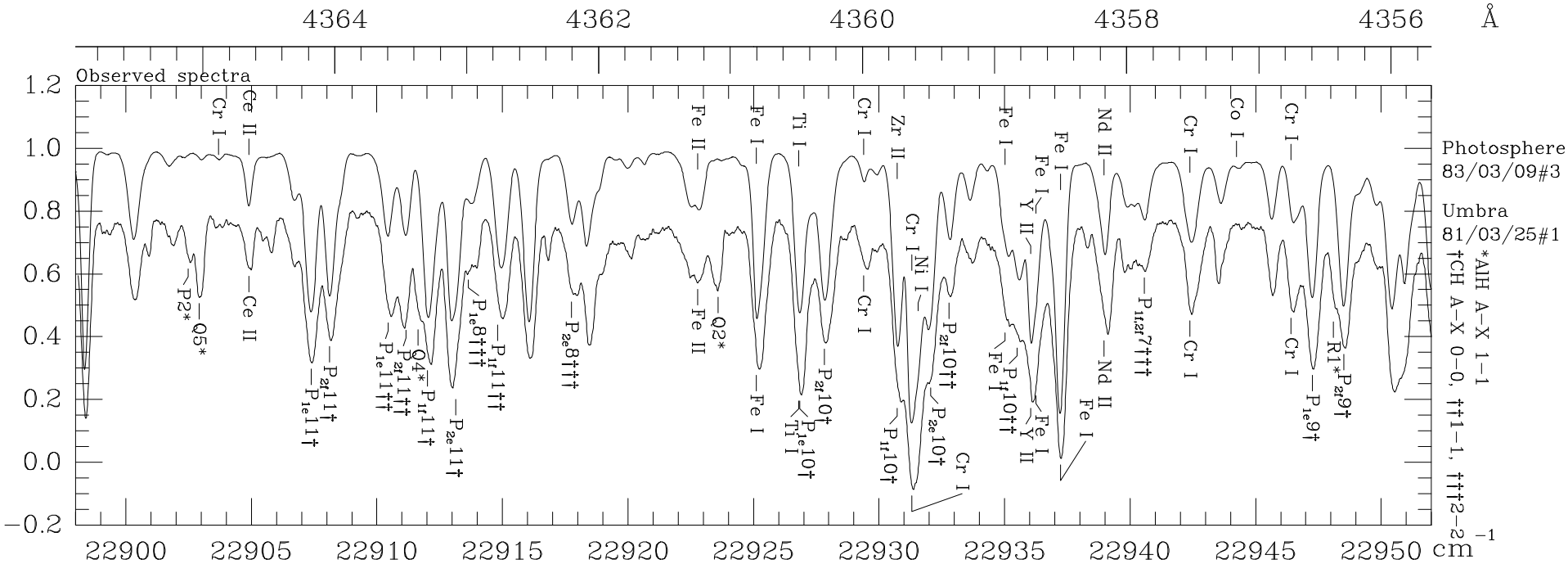

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

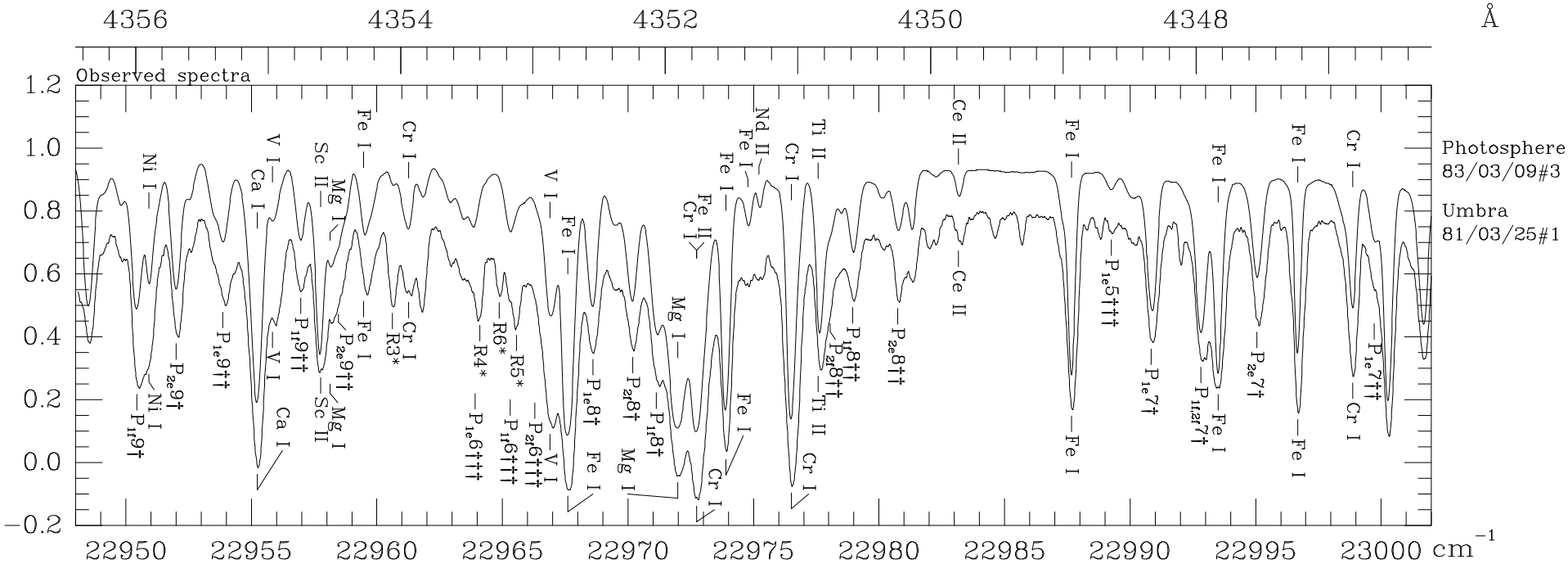

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
*AlH A–X 1–1
†CH A–X 0–0, ††1–1, †††2–2
4404 4402 4400 4398 4396 4394 Å
22700 22705 22710 22715 22720 22725 22730 22735 22740 22745 22750 cm−1
1.2 1.0 0.8 0.6 0.4 0.2 0.0 −0.2

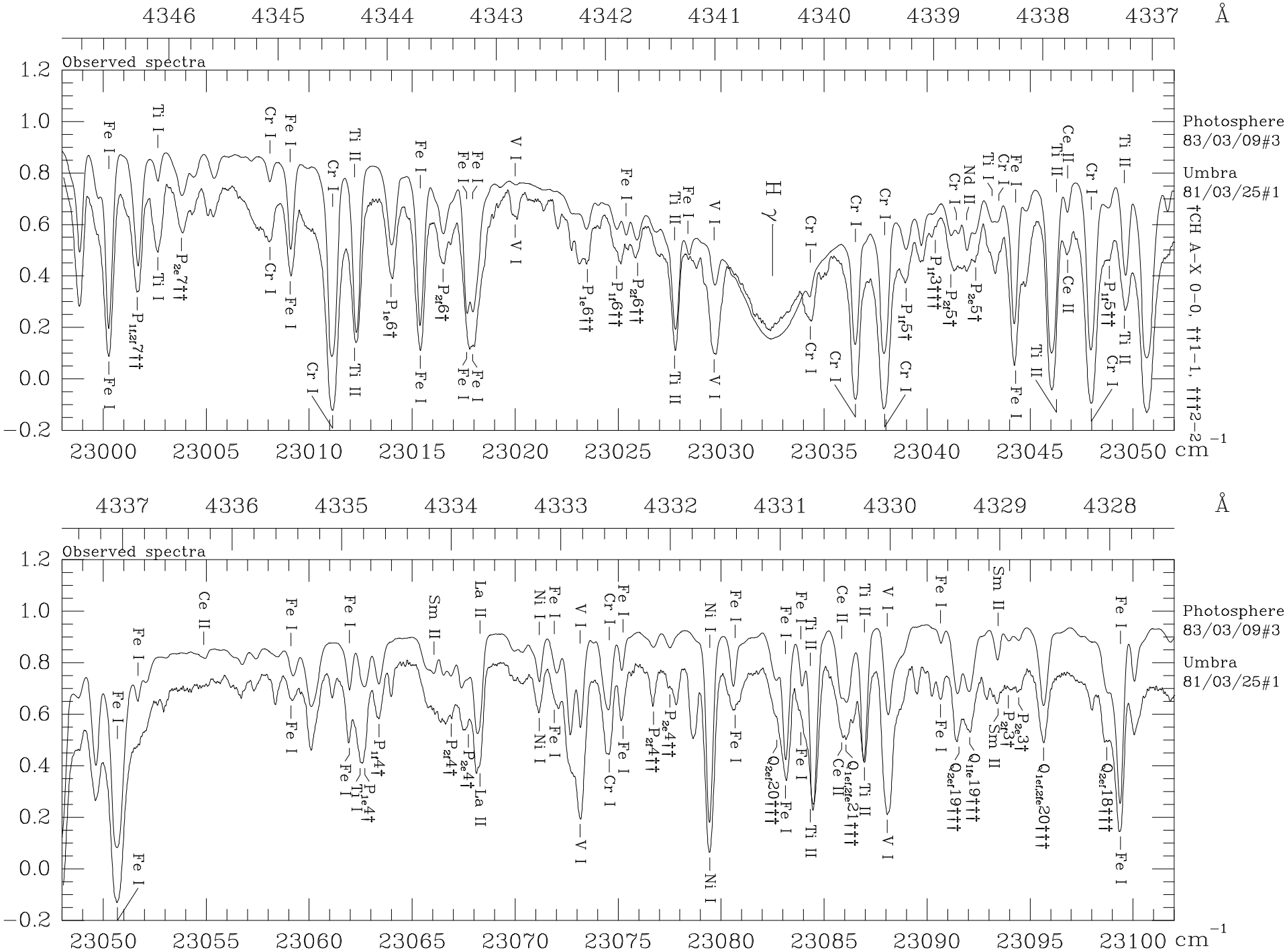

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
4394 4392 4390 4388 4386 Å
22750 22755 22760 22765 22770 22775 22780 22785 22790 22795 22800 cm−1
1.2 1.0 0.8 0.6 0.4 0.2 0.0 −0.2

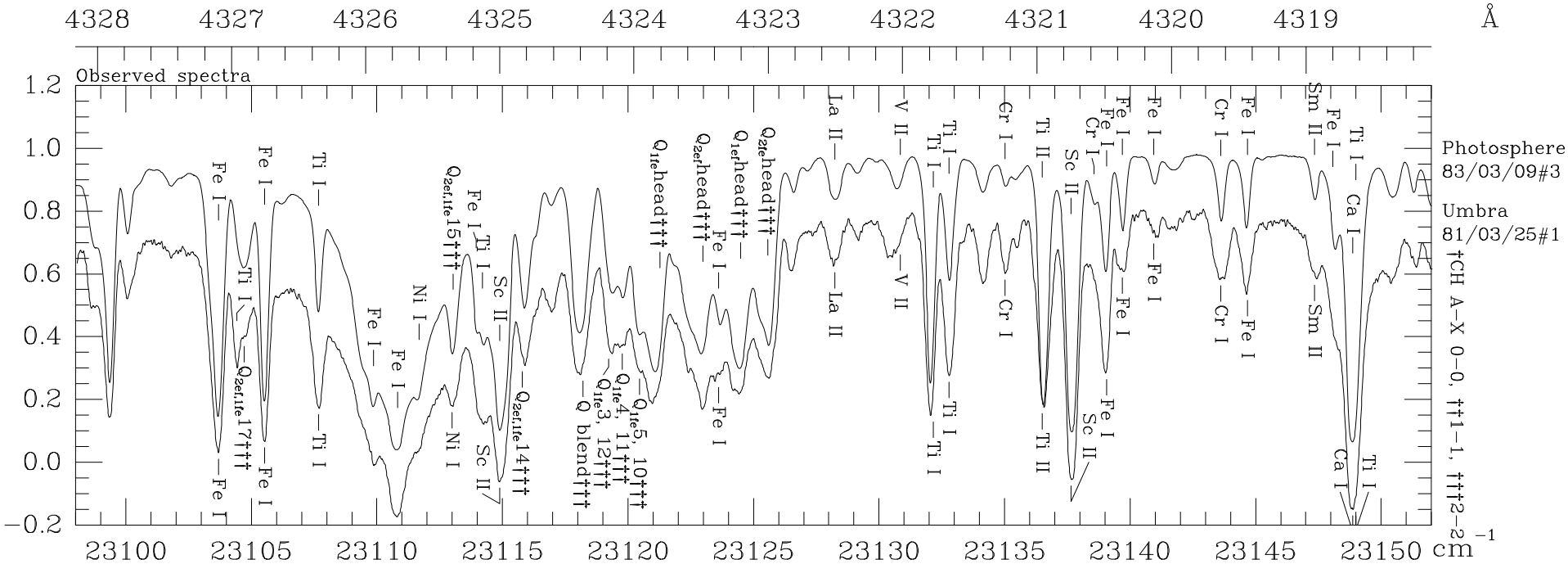

Å
4384
4382
4380
4378
4376
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
*AlH A–X 1–1
†CH A–X 0–0, ††1–1, †††2–2
Fe I
Ni I
Fe II
V I
Ce II
Mn I
Cr I
Mg I
Zr II
Cr I
V I
Fe I
Cr I
Fe I
Fe I
Fe I
Cr I
Fe I
22800
22805
22810
22815
22820
22825
22830
22835
22840
22845
22850
cm^{-1}

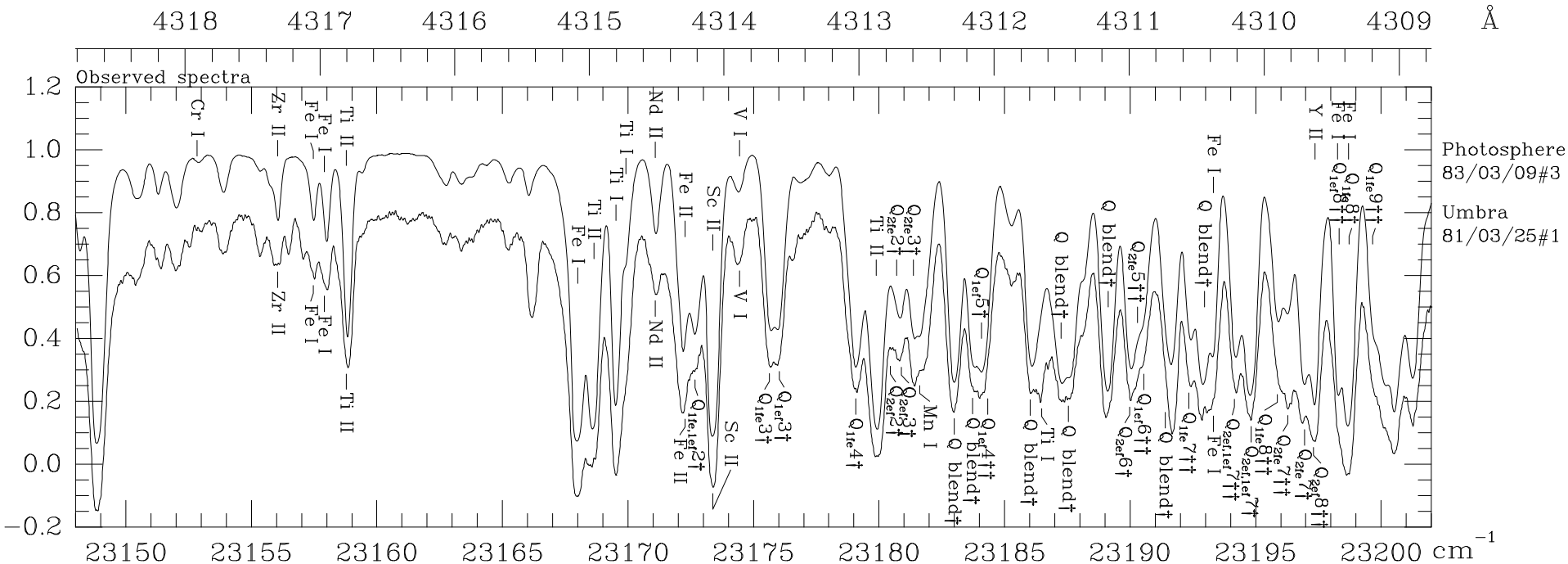

Å
4374
4372
4370
4368
4366
Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Y II
Ti II
Sc II
Fe I
Cr I
Fe I
Cr I
Fe I
Ti I
Mn I
Ni I
Fe II
Mn I
Nd II
Ni I
V I
Fe I
Ti II
Ni I
Fe I
Y I
22850
22855
22860
22865
22870
22875
22880
22885
22890
22895
22900
cm^{-1}

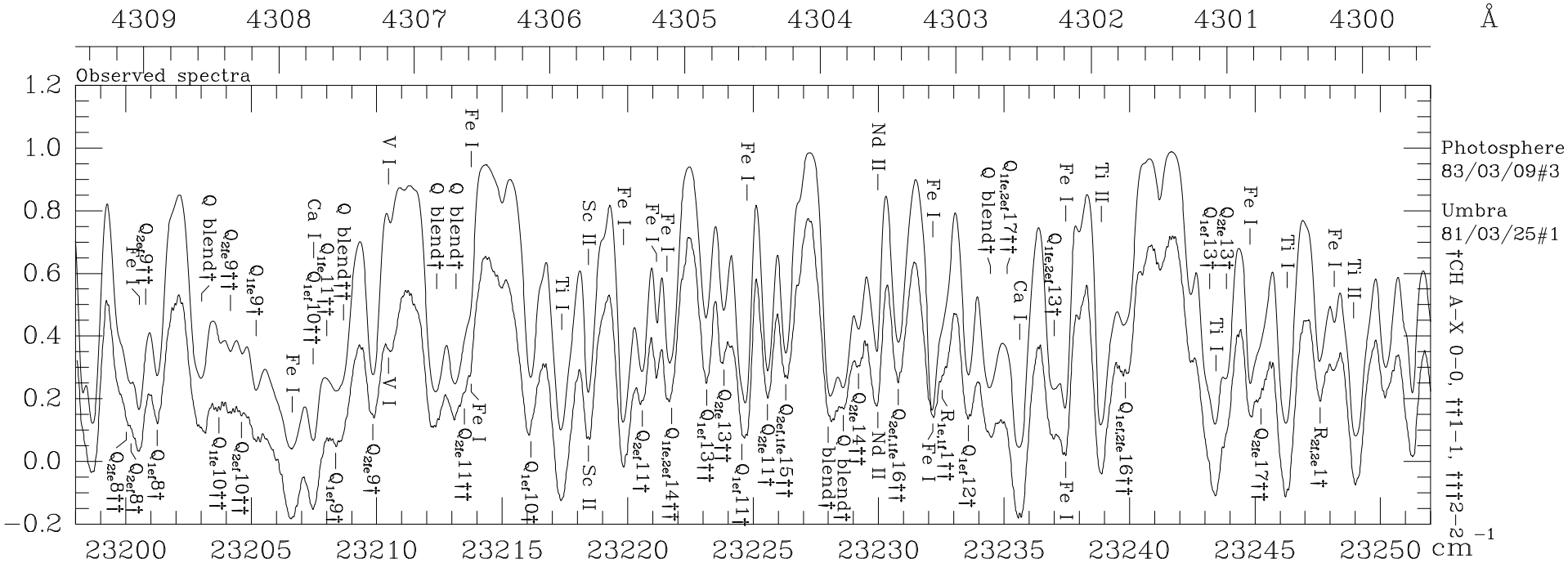

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
*AlH A–X 1–1
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

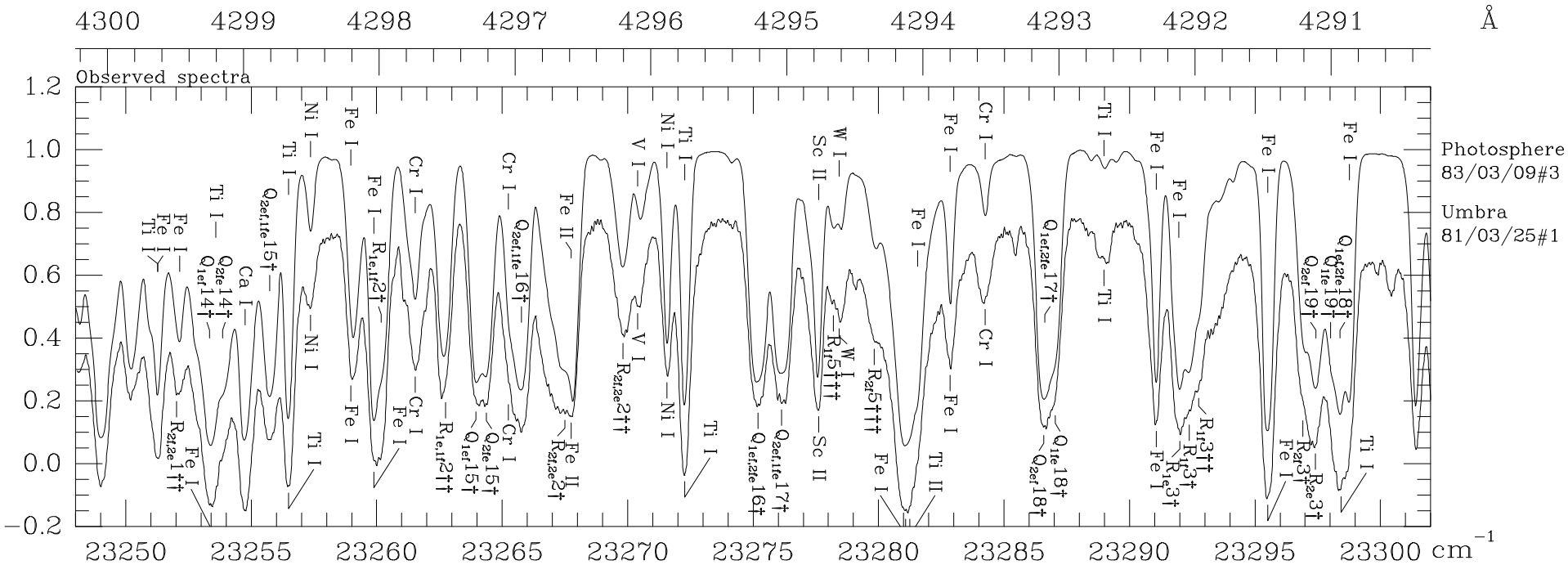

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

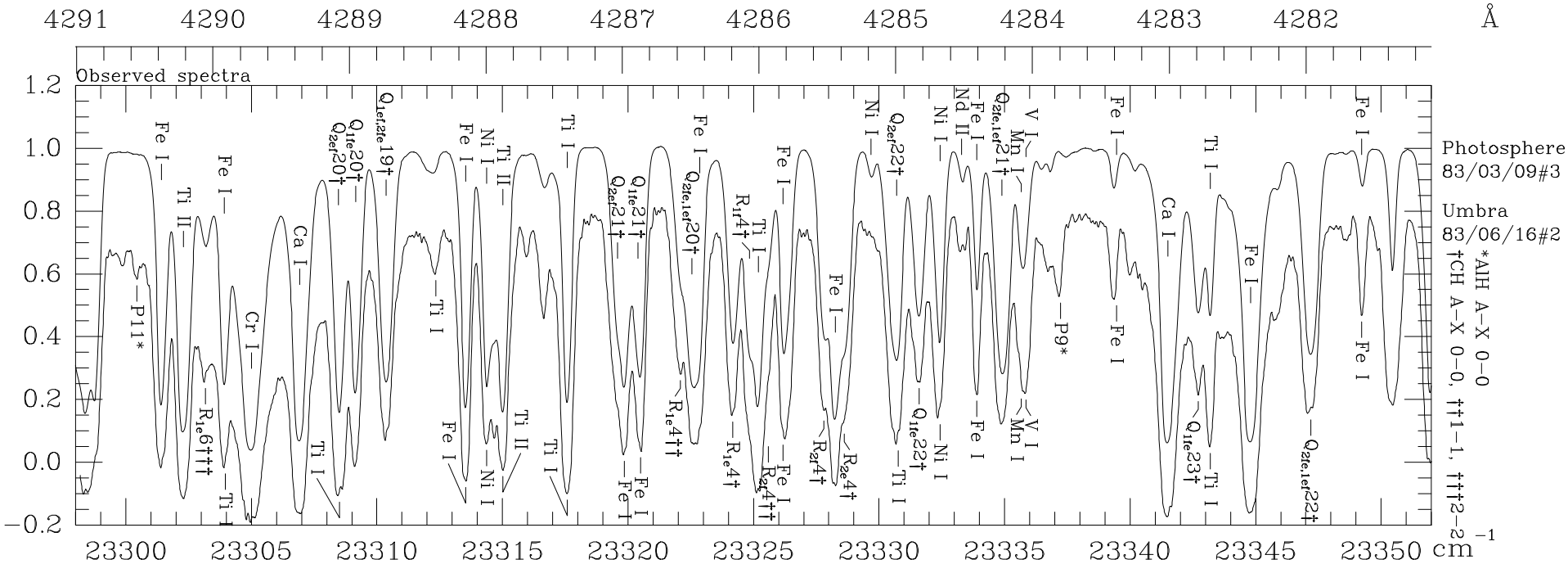

Observed spectra
Photosphere 83/03/09#3
Umbra 81/03/25#1
†CH A–X 0–0, ††1–1, †††2–2
H γ
Å
cm⁻¹

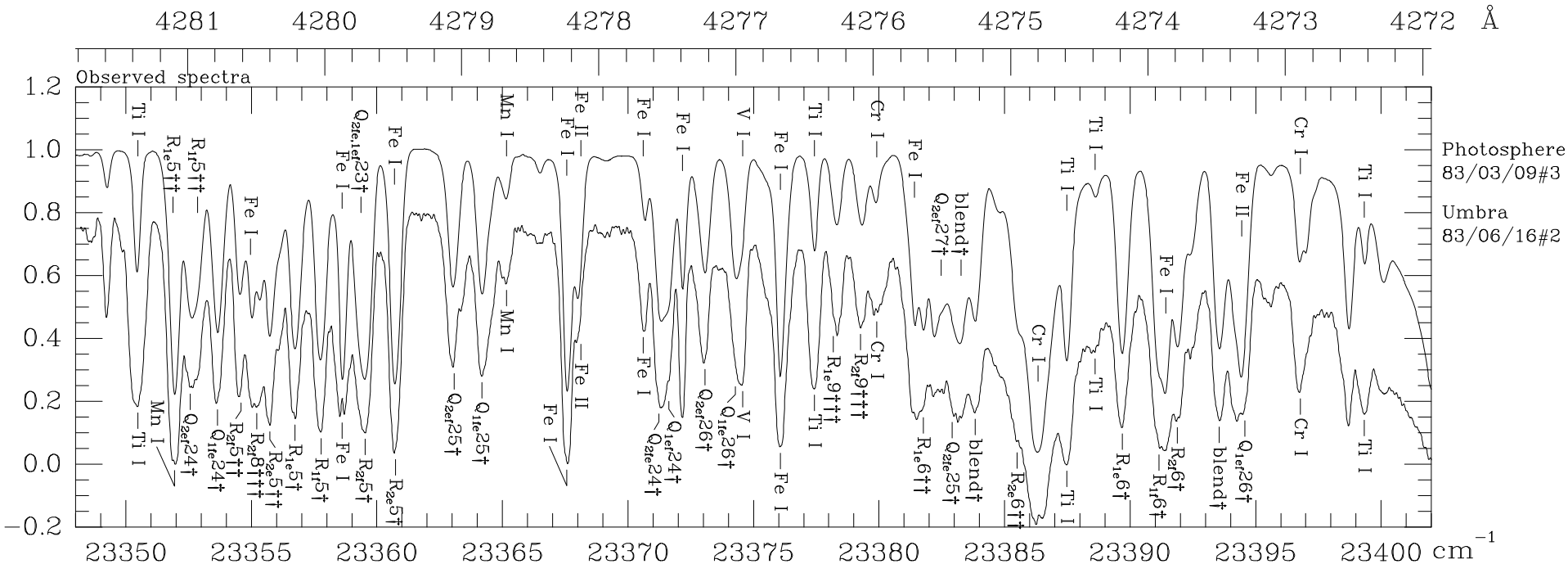

Observed spectra
Photosphere 83/03/09#3
Umbra 81/03/25#1
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

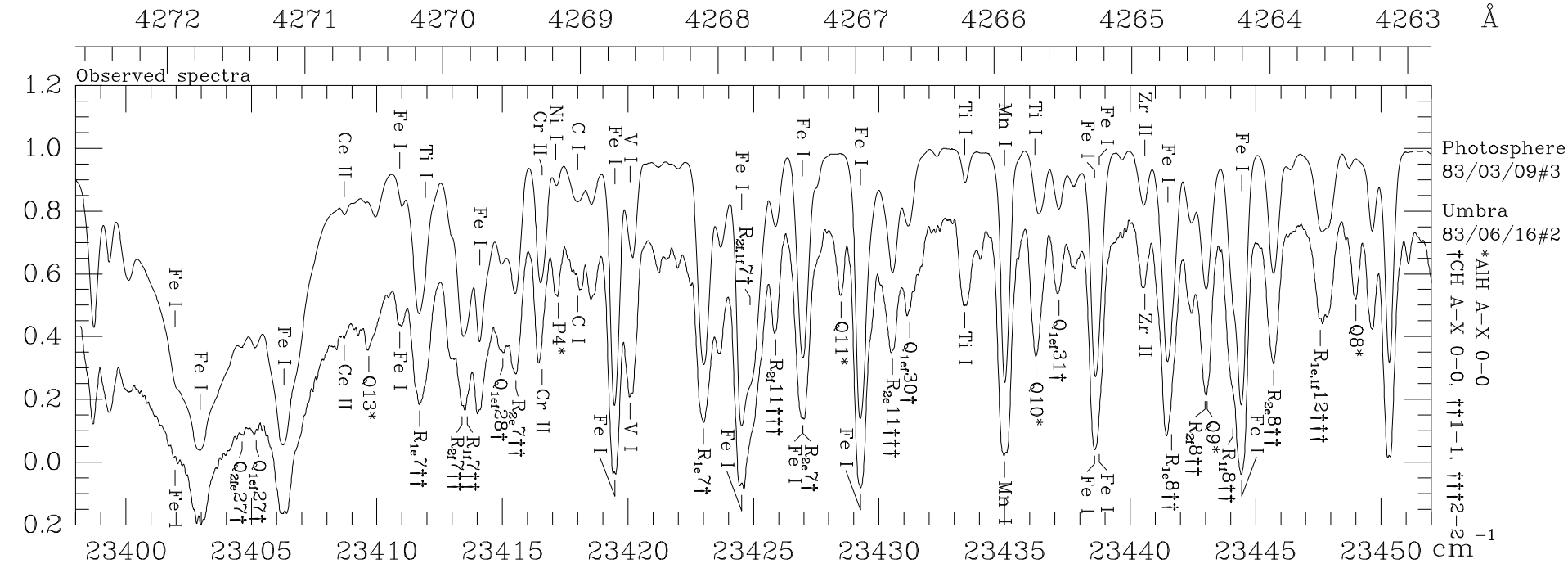

Observed spectra
Photosphere 83/03/09#3
Umbra 81/03/25#1
Å
cm^{-1}

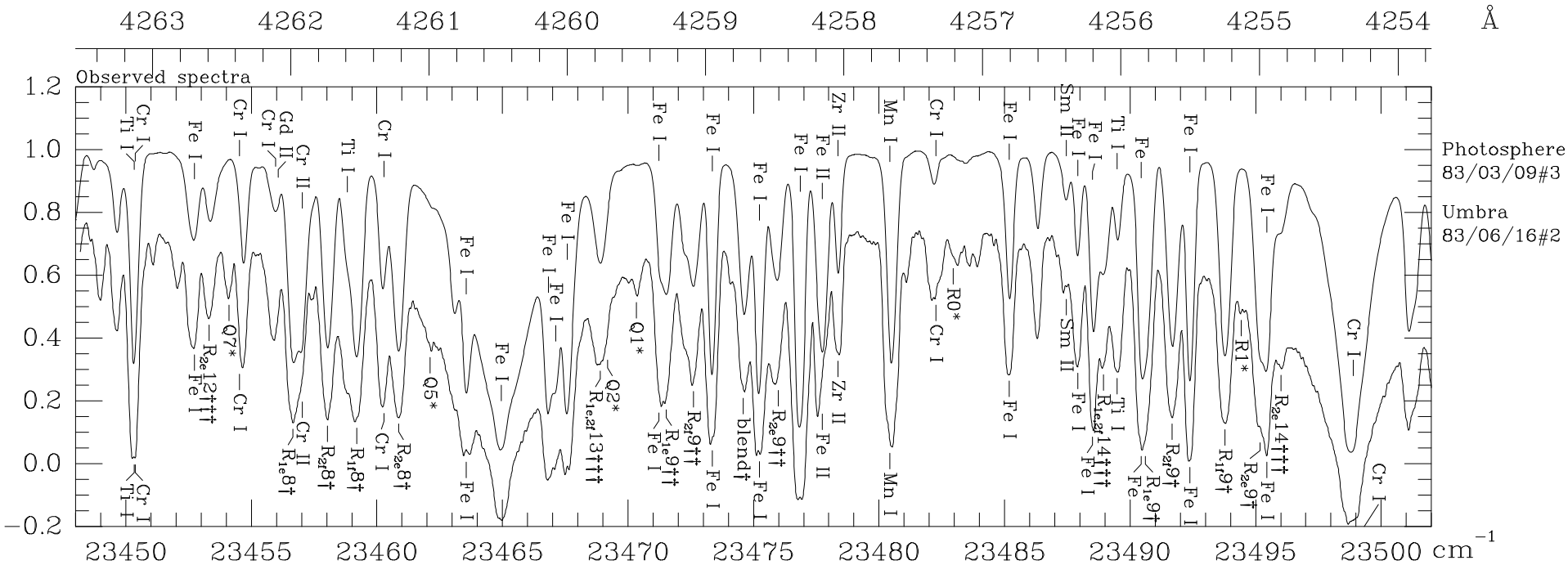

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

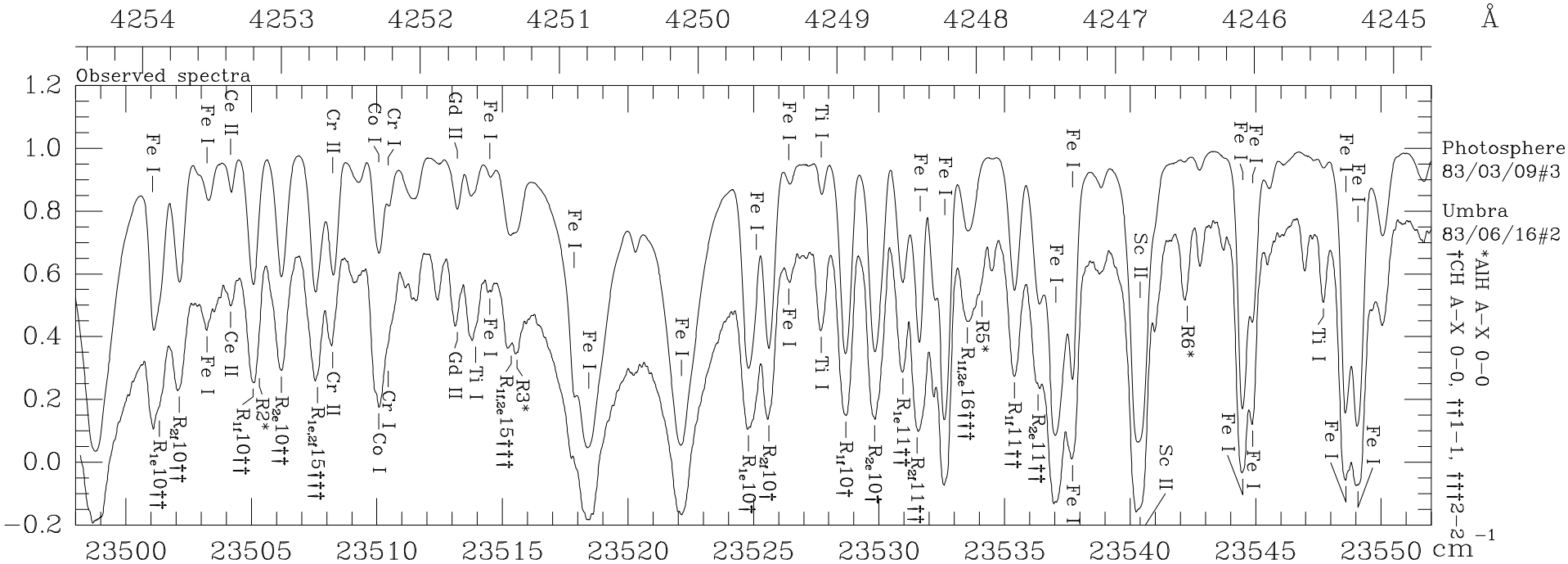

Observed spectra
Photosphere
83/03/09#3
Umbra
81/03/25#1
Å
cm^{-1}

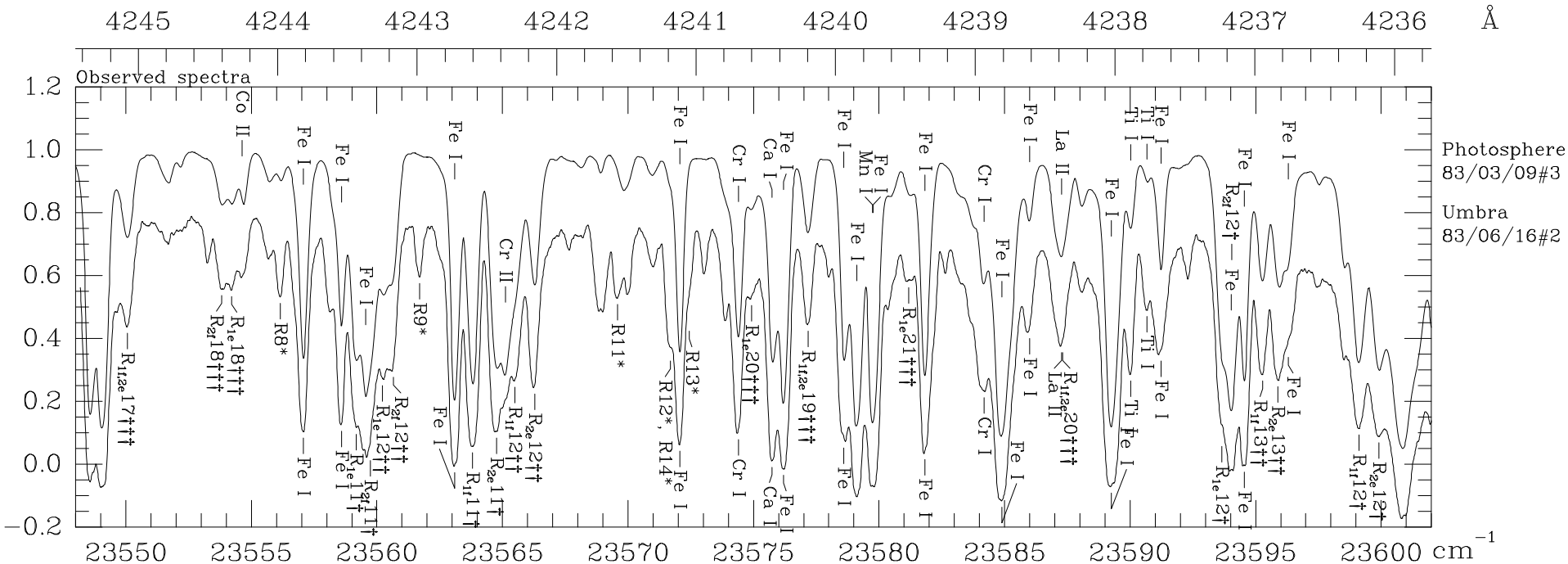

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
*AlH A–X 0–0
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

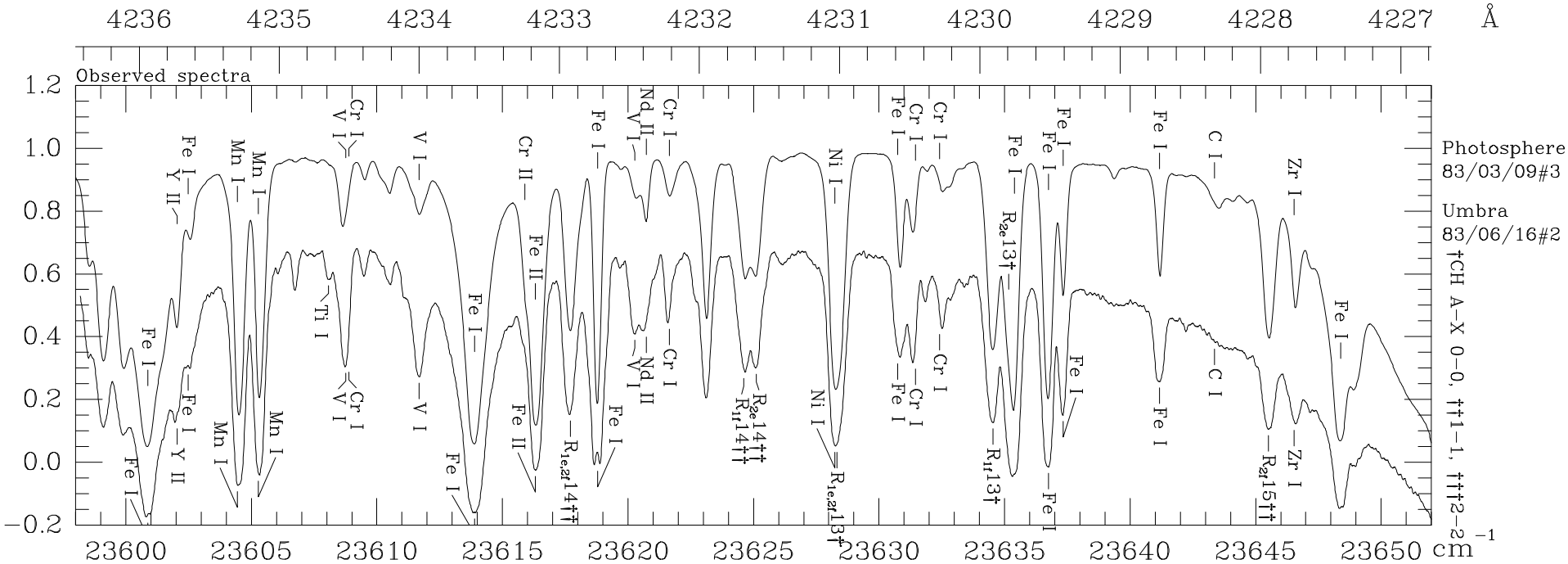

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

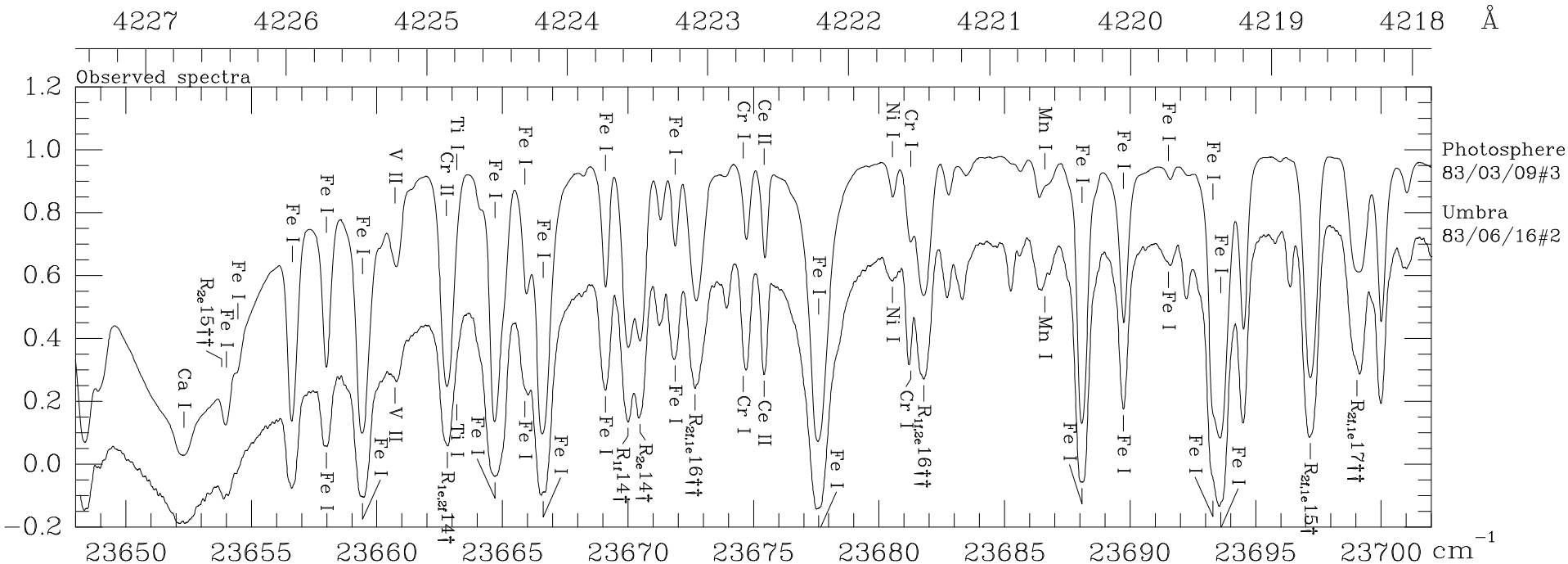

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
*AlH A–X 0–0
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

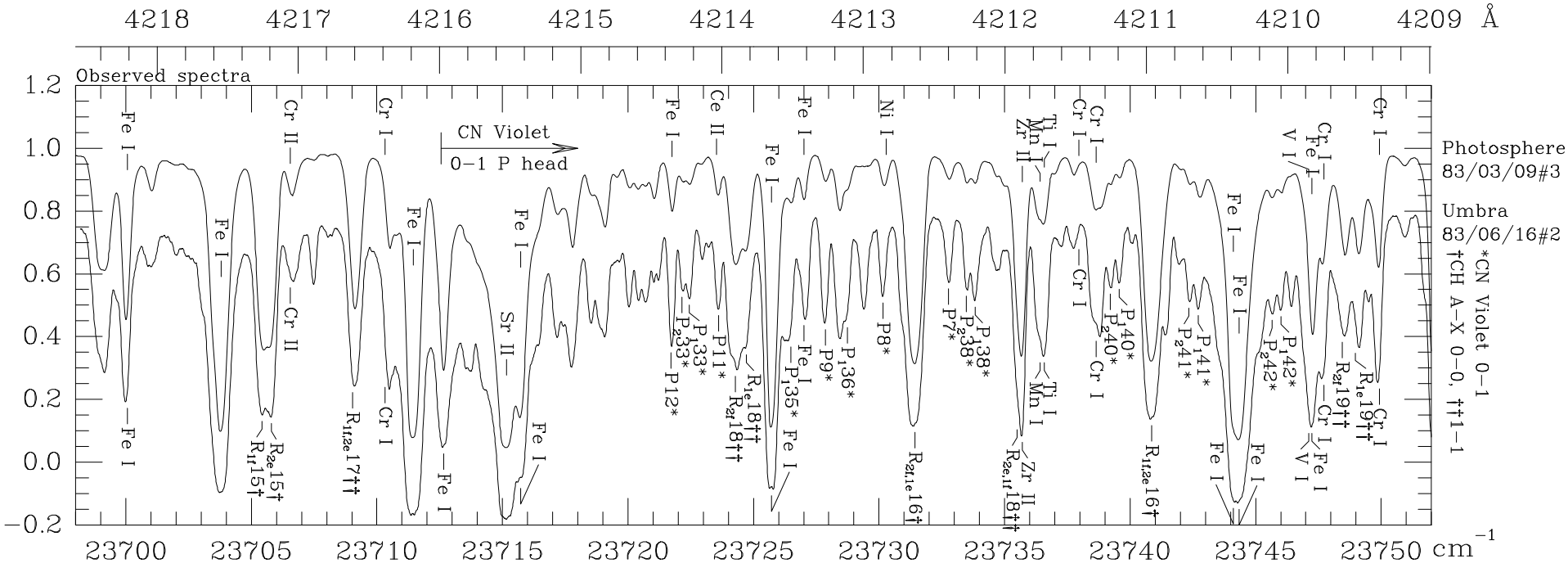

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

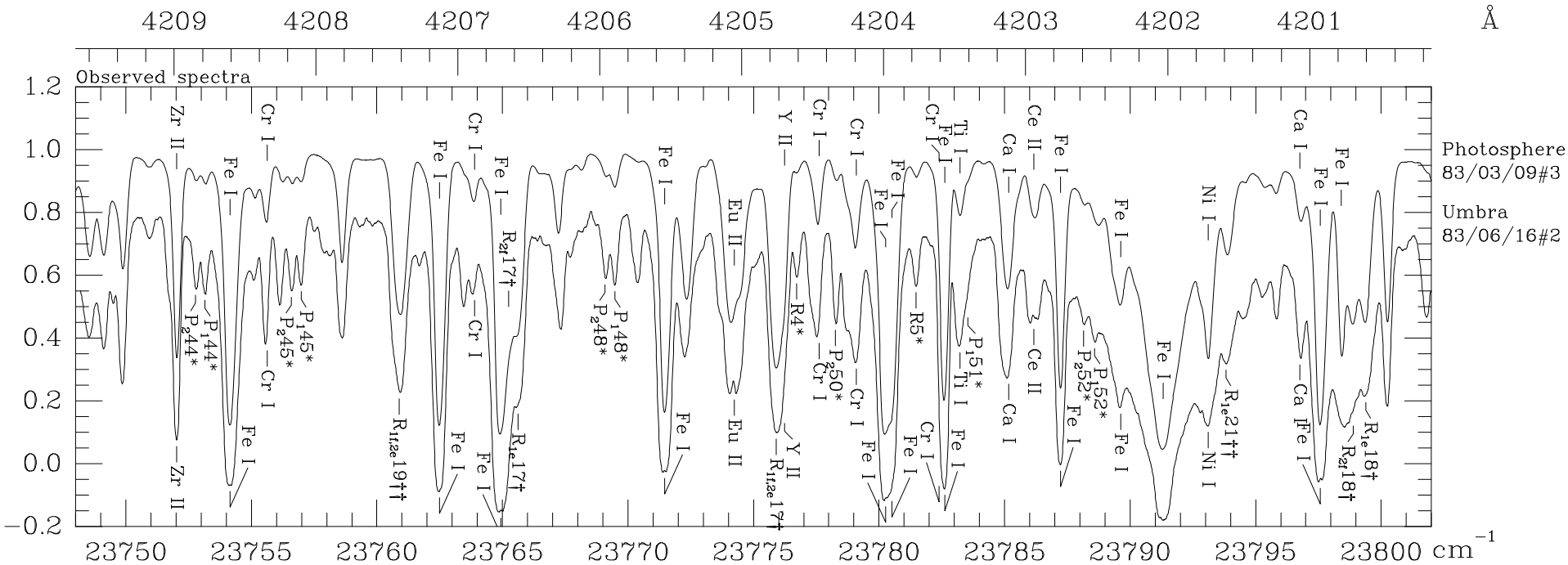

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
*AlH A–X 0–0
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

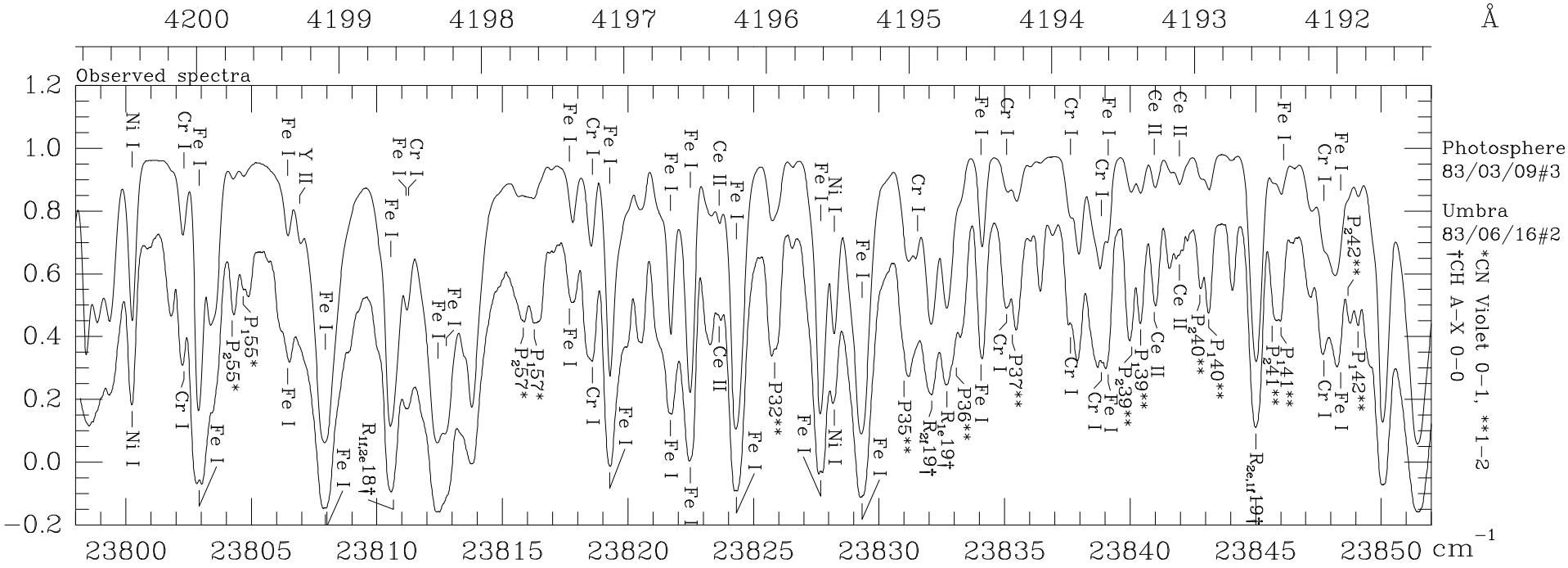

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

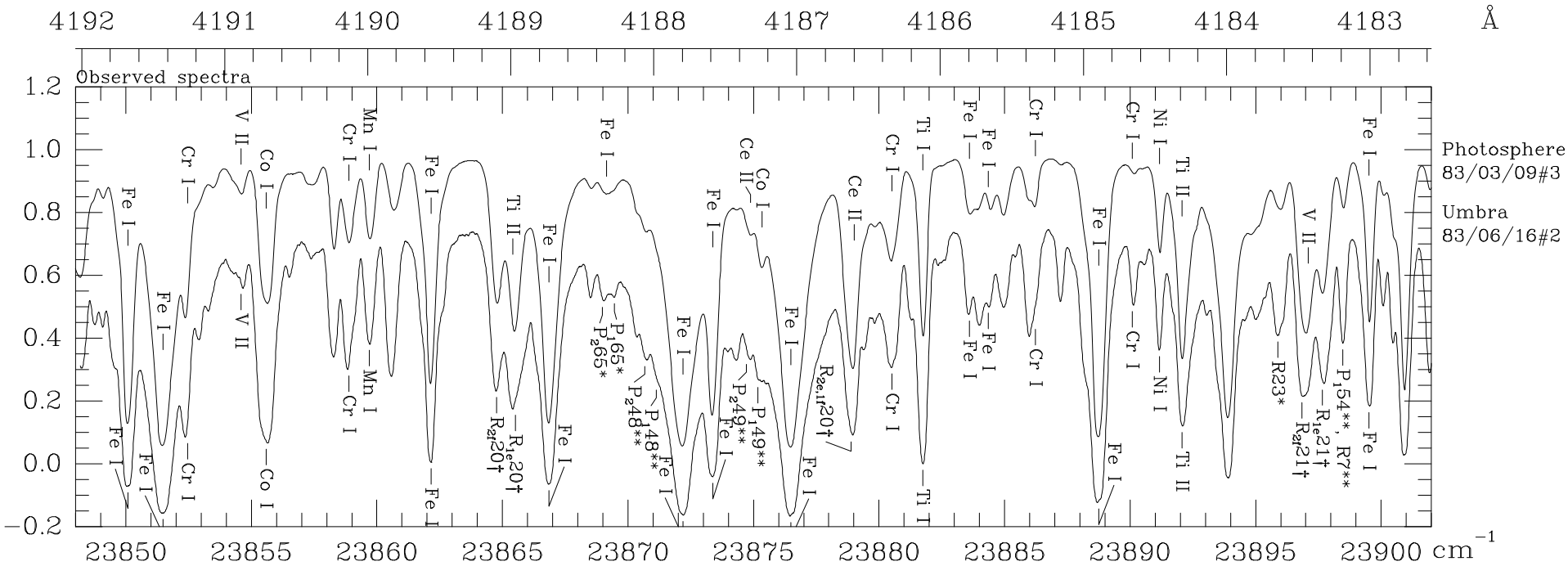

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH A–X 0–0, ††1–1, †††2–2
Å
cm^{-1}

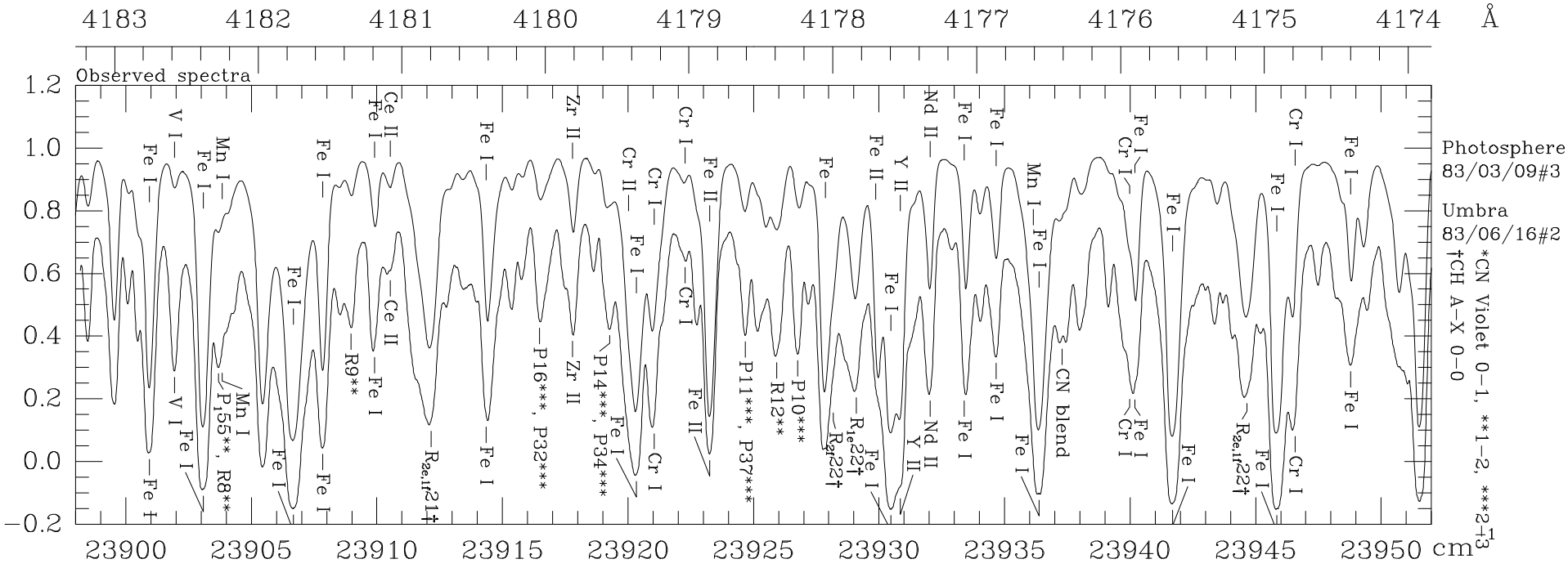

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}

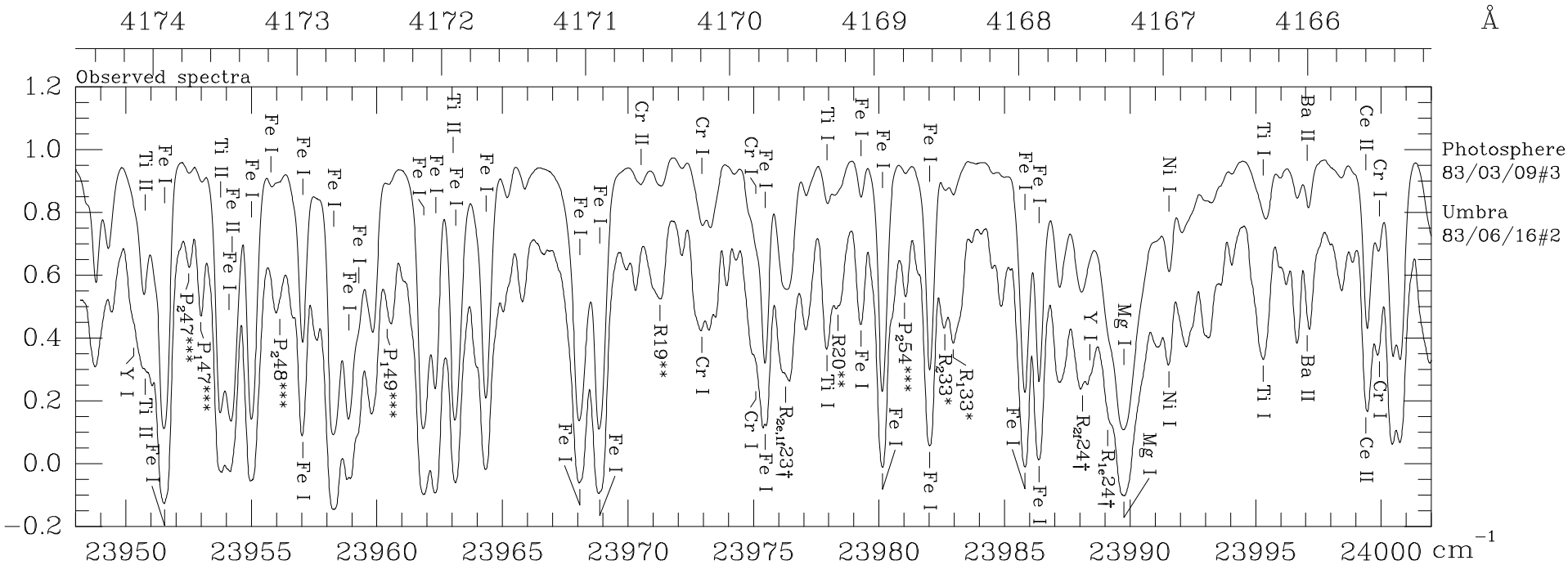

Observed spectra
CN Violet
0–1 P head
Photosphere
83/03/09#3
Umbra
83/06/16#2
*CN Violet 0–1
†CH A–X 0–0, ††1–1
Å
cm^{-1}

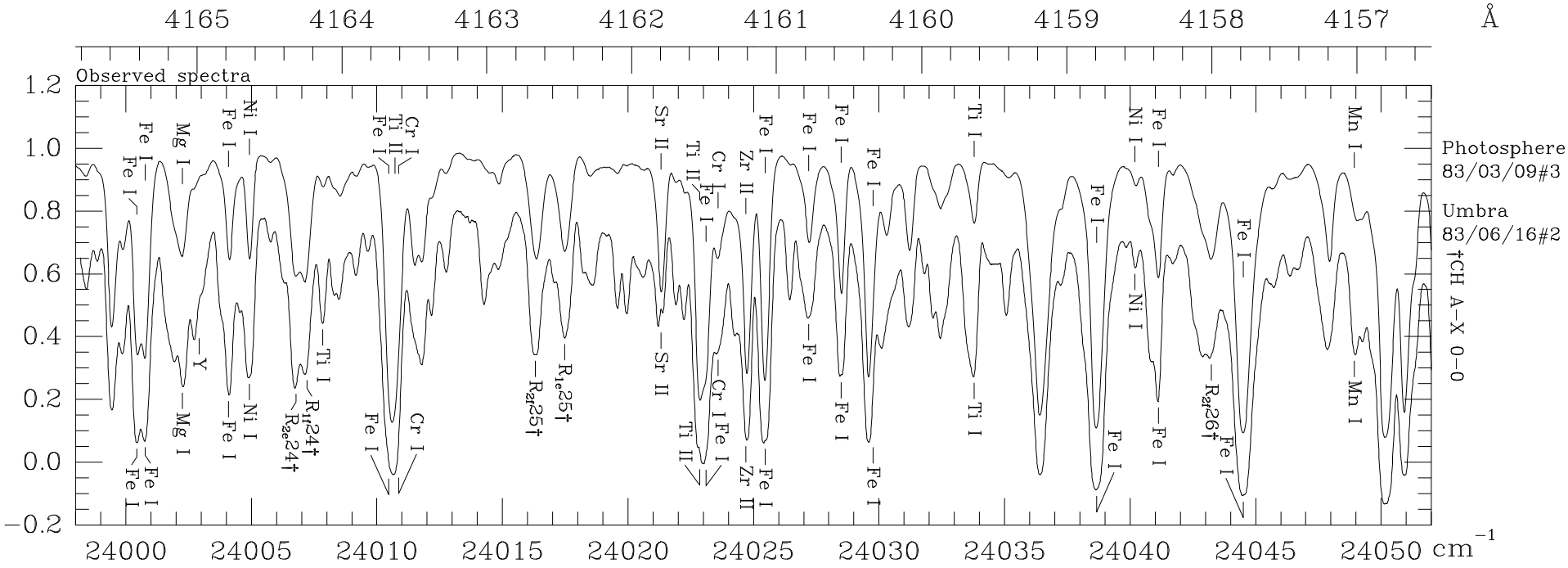

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}

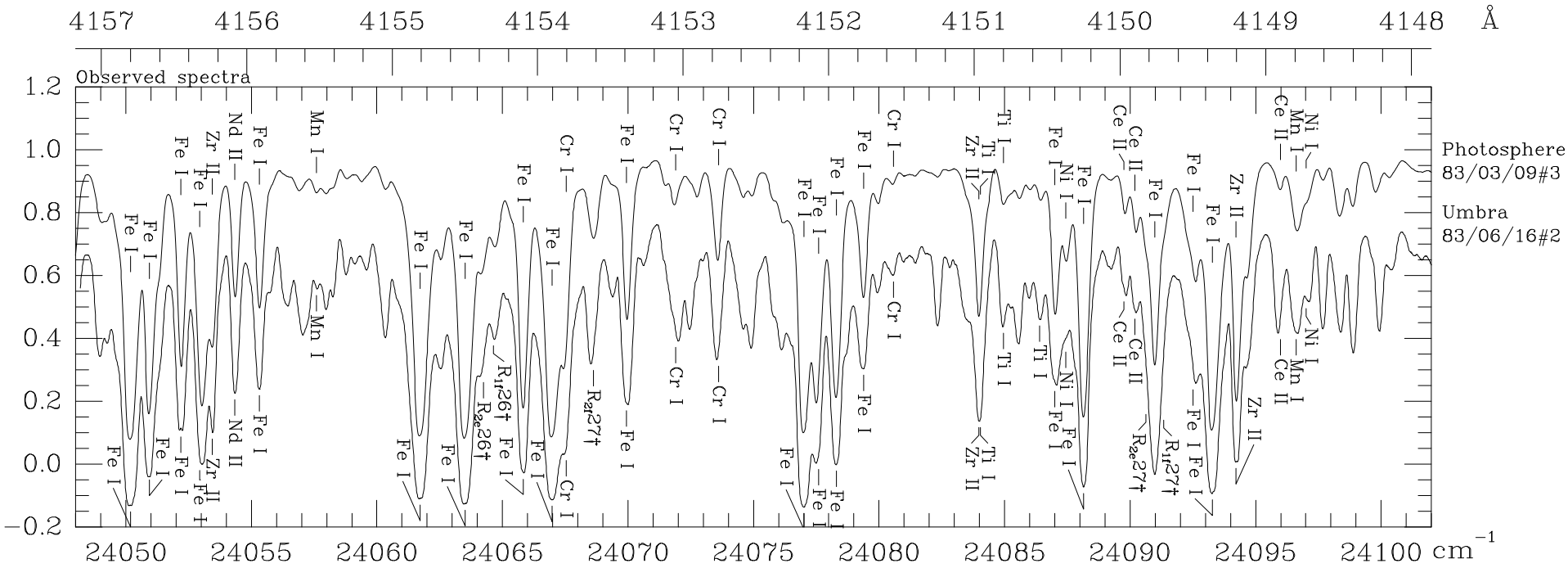

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
*CN Violet 0–1, **1–2
†CH A–X 0–0
Å
cm^{-1}

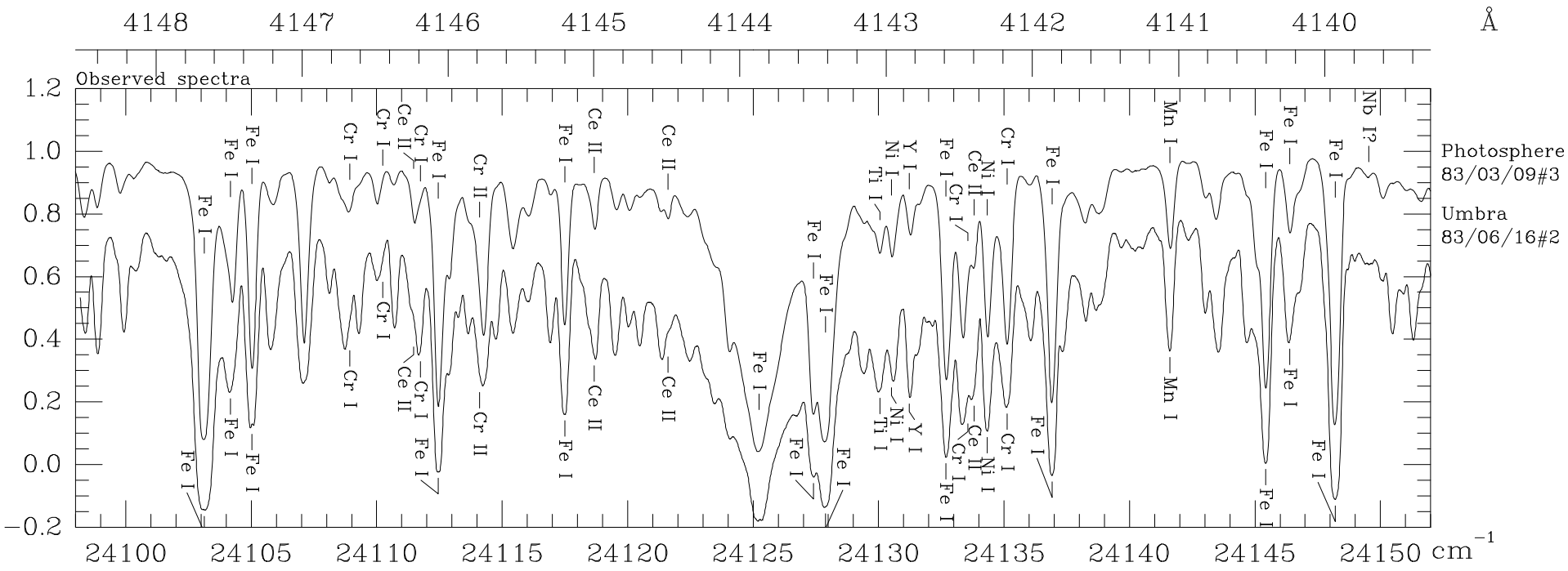

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

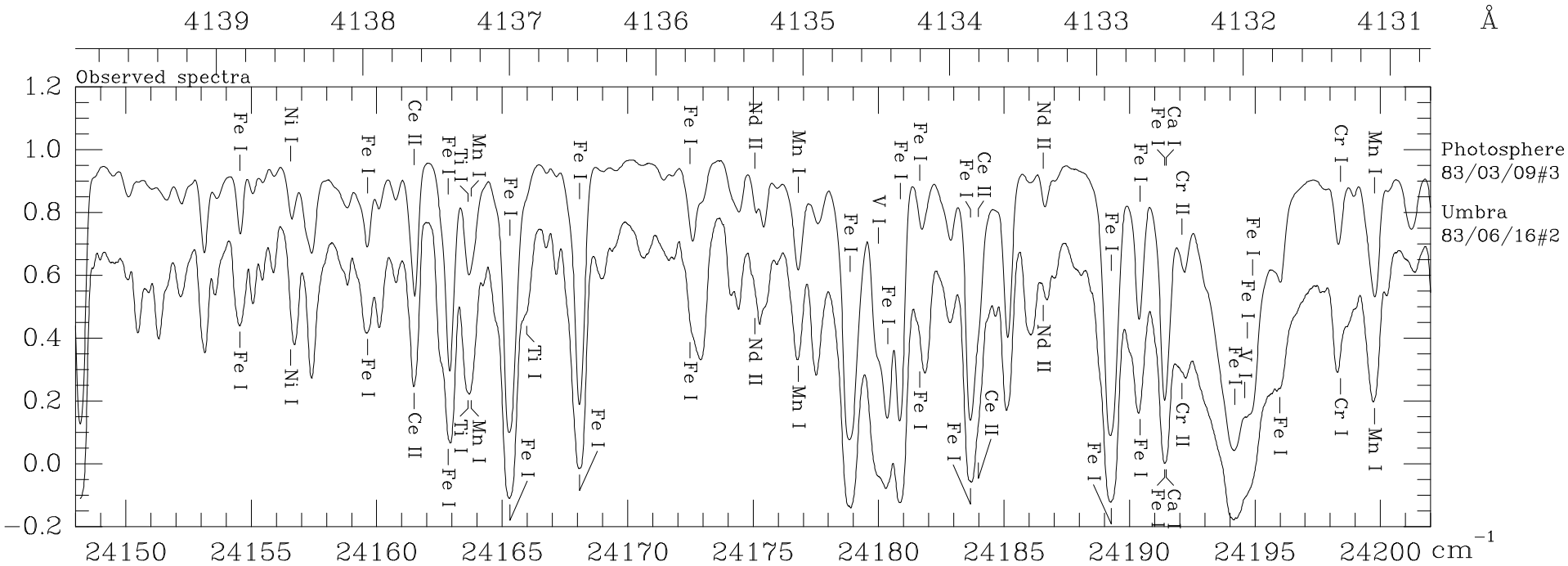

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
*CN Violet 0−1, **1−2, ***2−3
†CH A−X 0−0
Å
cm^{-1}

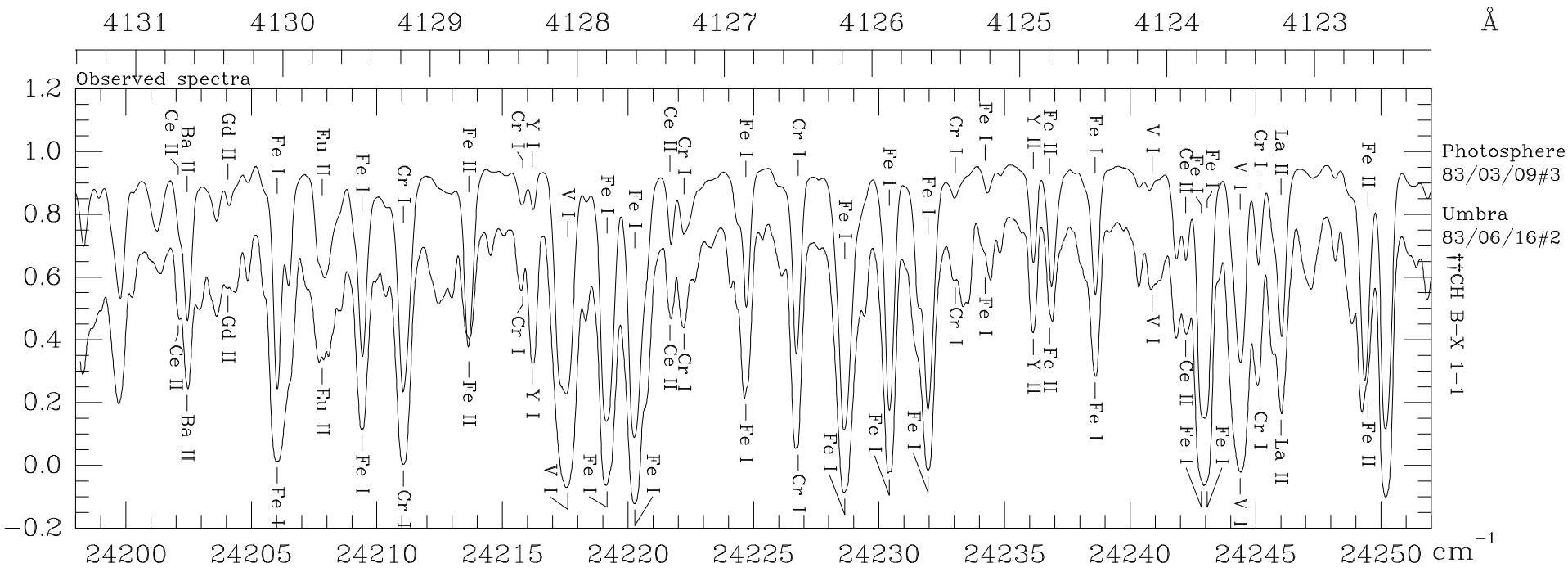

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

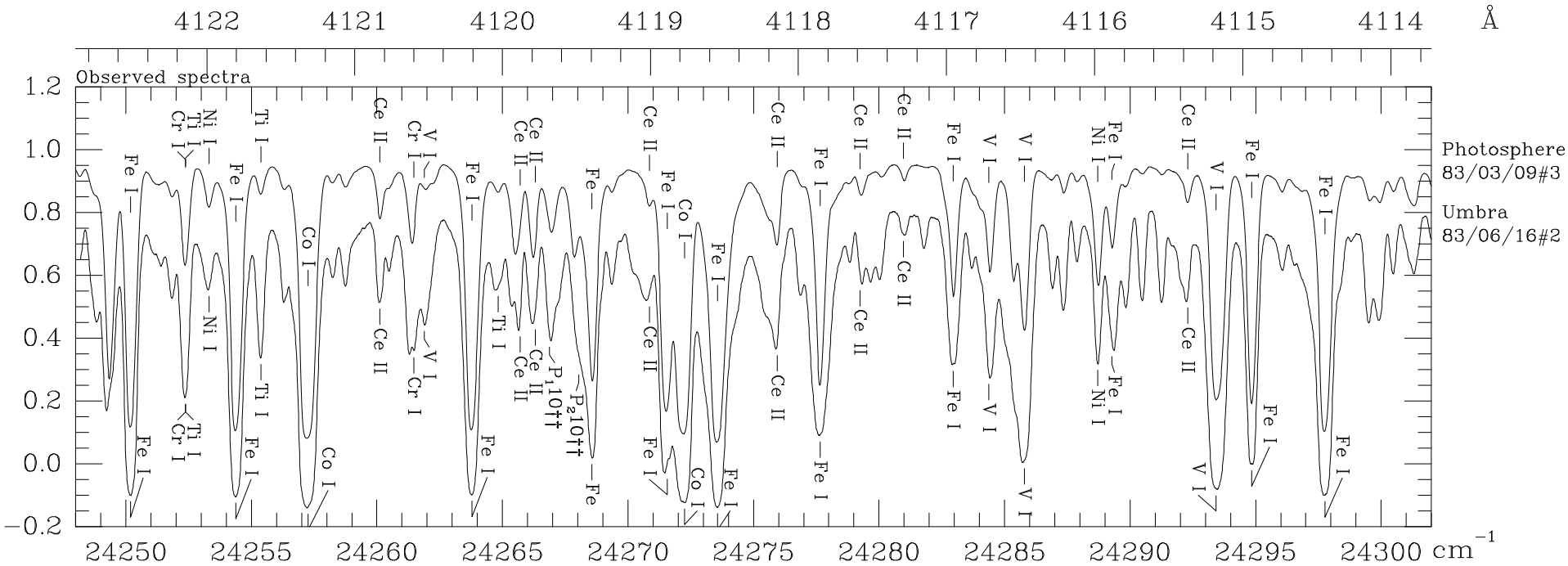

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH A–X 0–0
Å
cm^{-1}

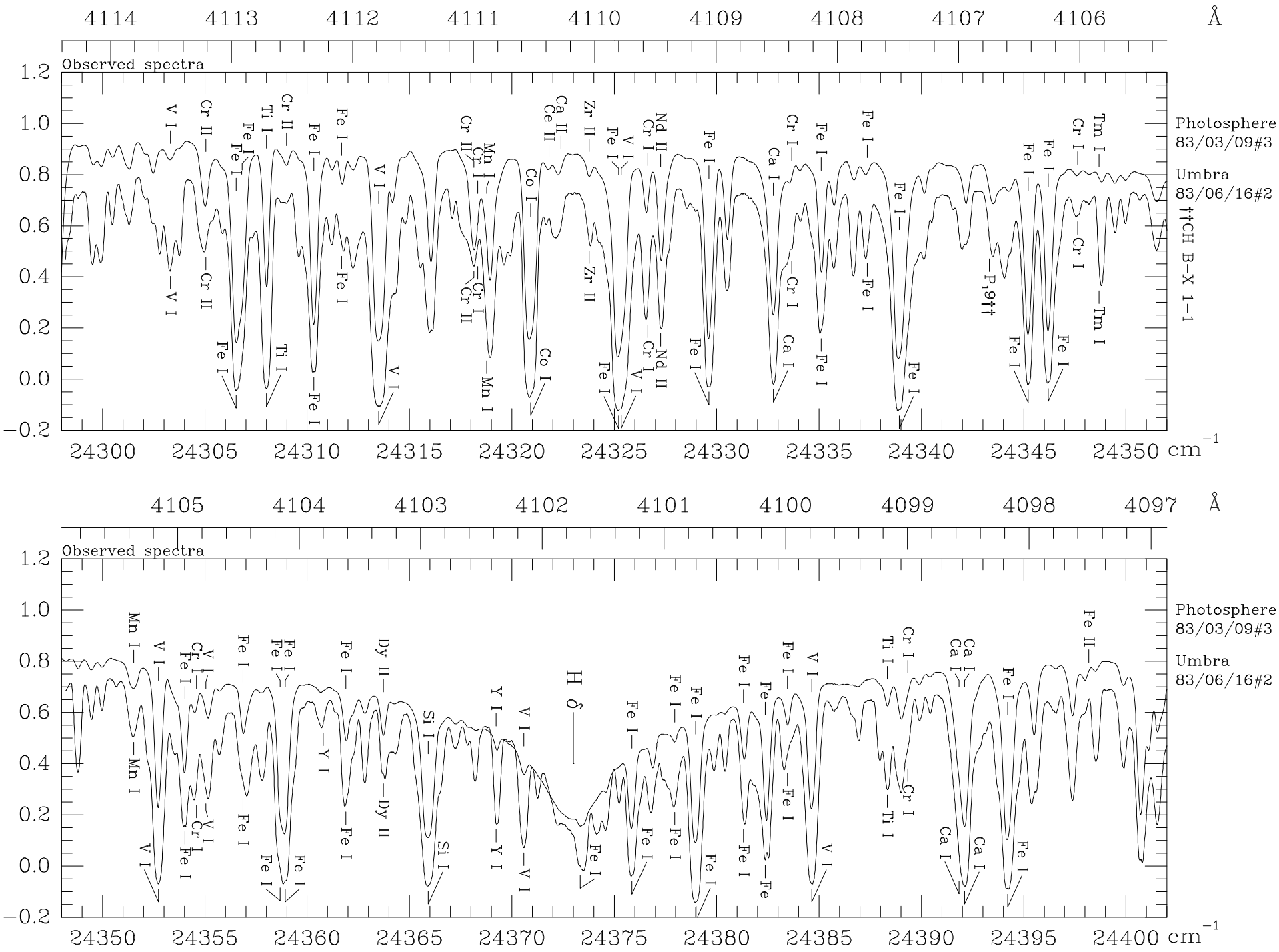

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}

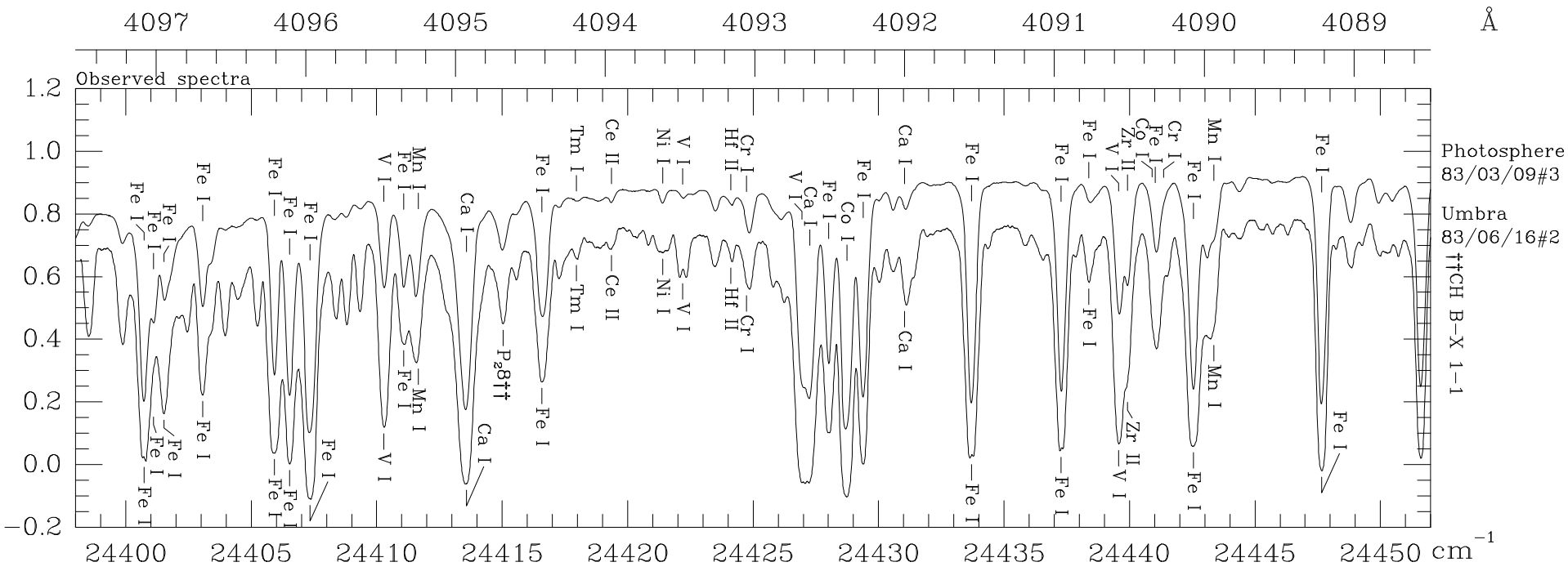

Observed spectra
Å
cm^{-1}
Photosphere
83/03/09#3
Umbra
83/06/16#2

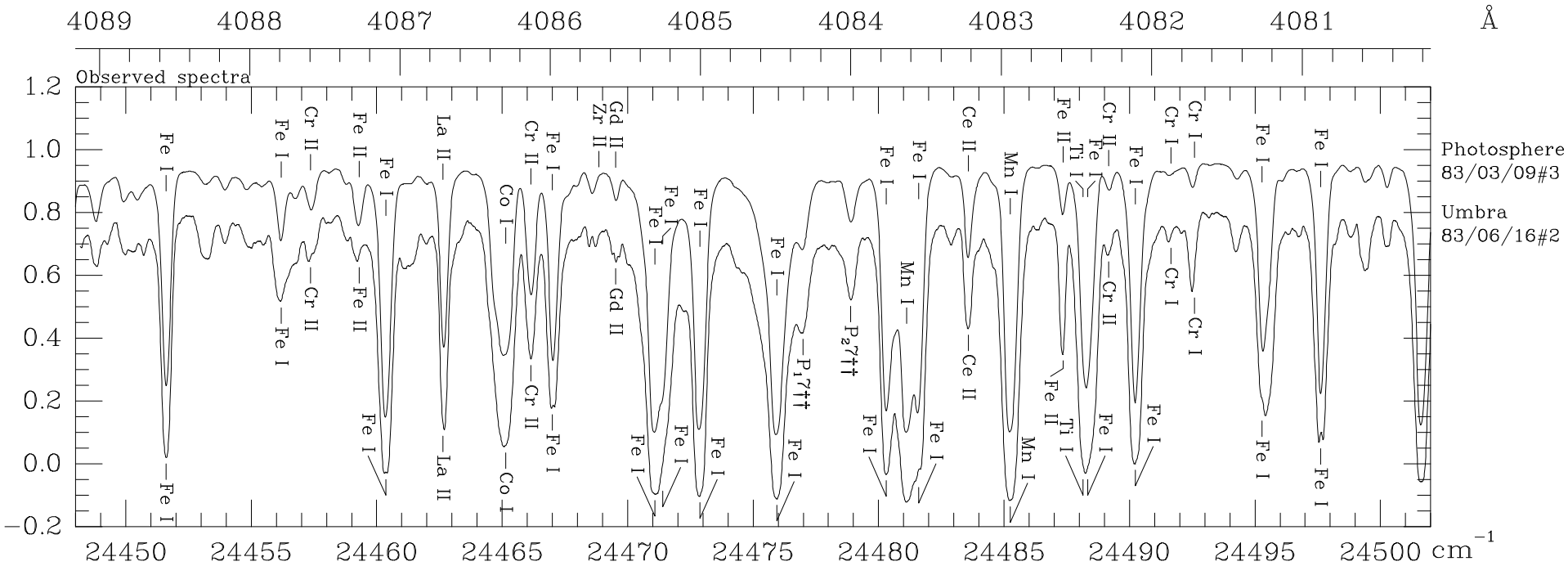

Observed spectra
Å
cm^{-1}
Photosphere
83/03/09#3
Umbra
83/06/16#2

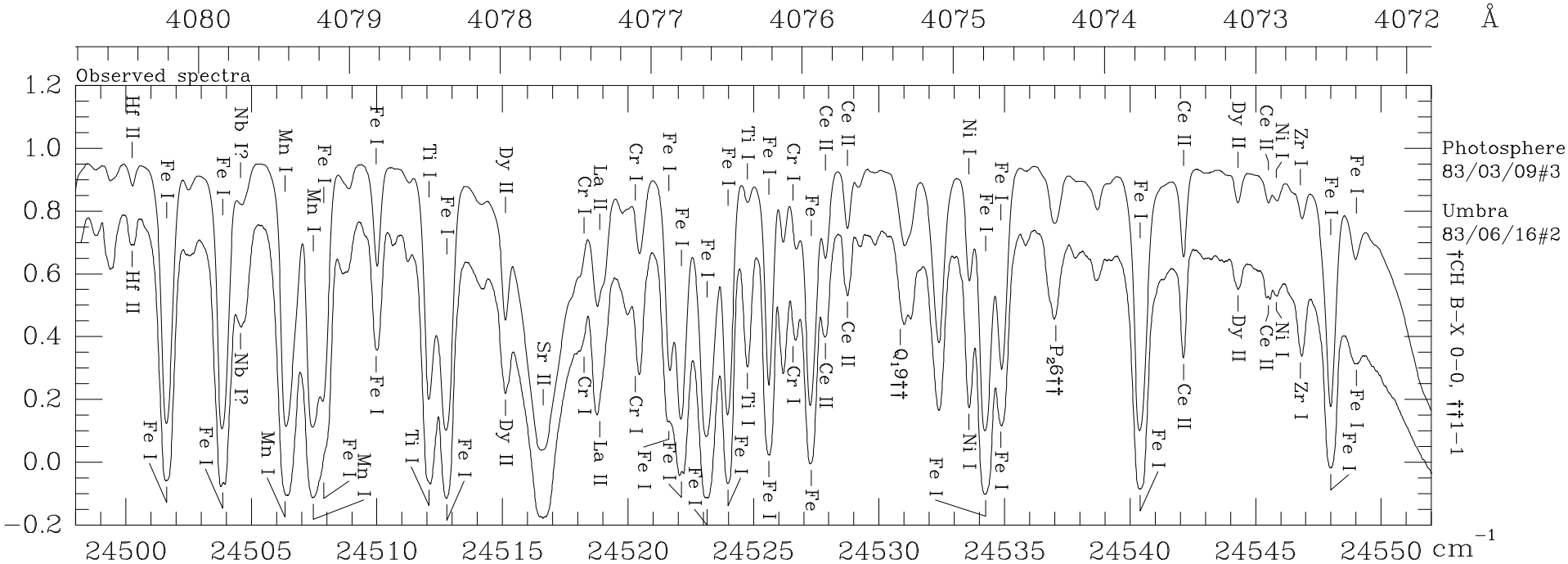

Observed spectra
Å
cm^{-1}
Photosphere
83/03/09#3
Umbra
83/06/16#2
††CH B–X 1–1

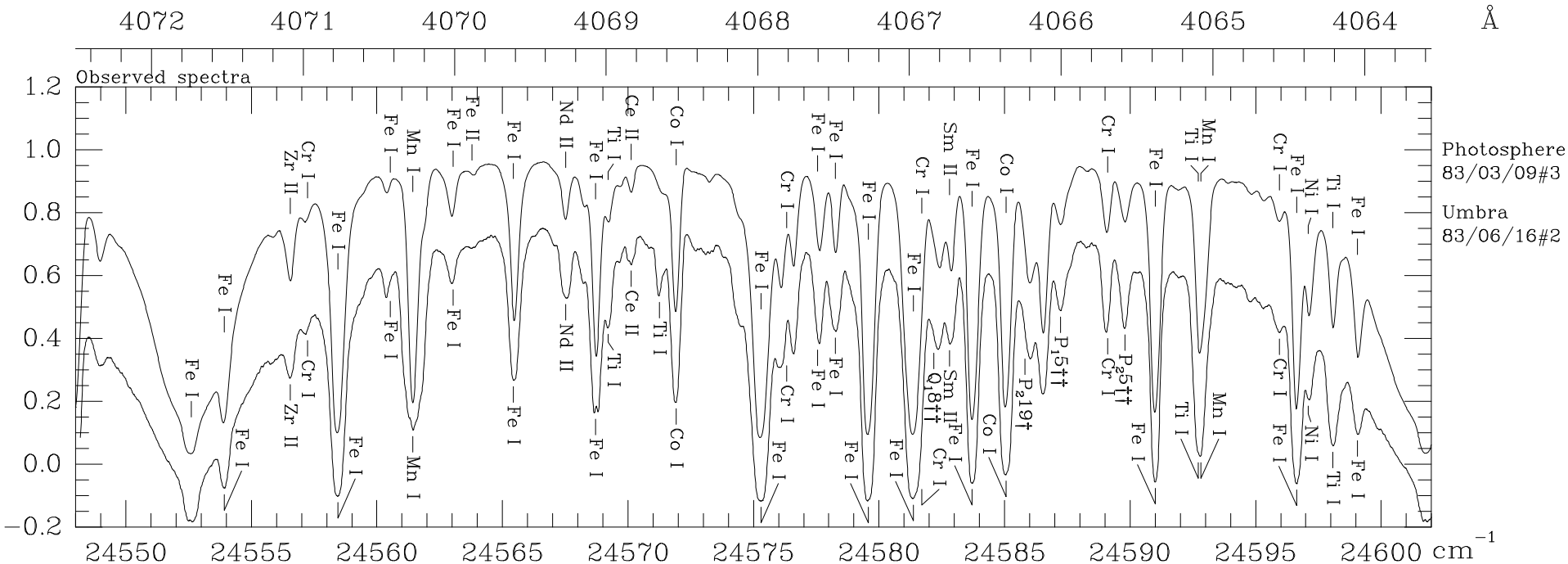

Observed spectra
Å
cm^{-1}
Photosphere
83/03/09#3
Umbra
83/06/16#2

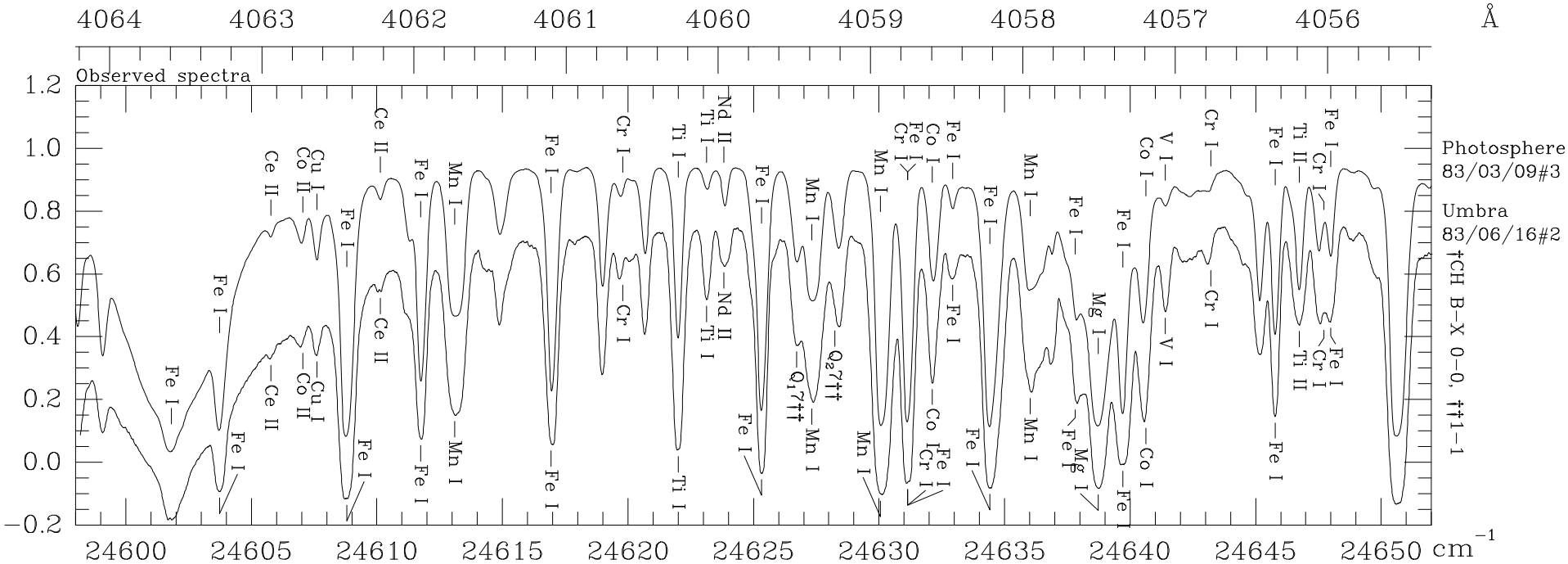

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
††CH B−X 1−1
Å
cm^{-1}
H δ

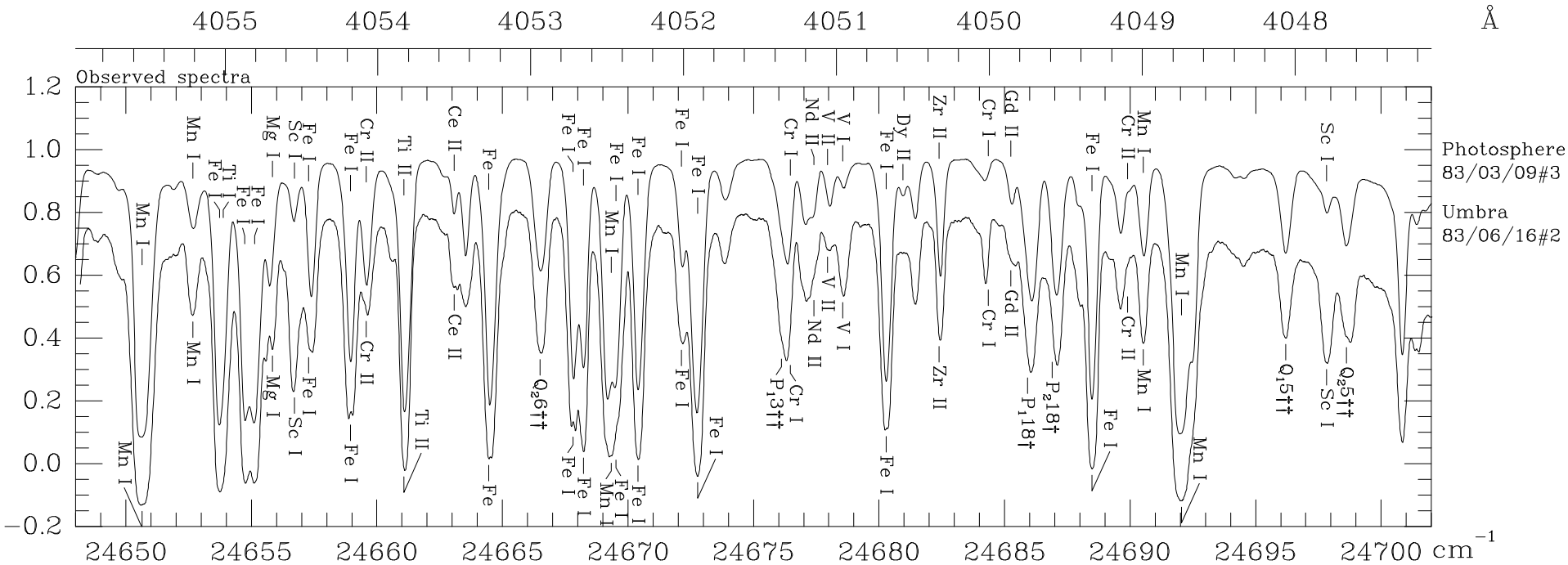

Å
4097
4096
4095
4094
4093
4092
4091
4090
4089
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
††CH B−X 1−1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
24400
24405
24410
24415
24420
24425
24430
24435
24440
24445
24450
cm−1

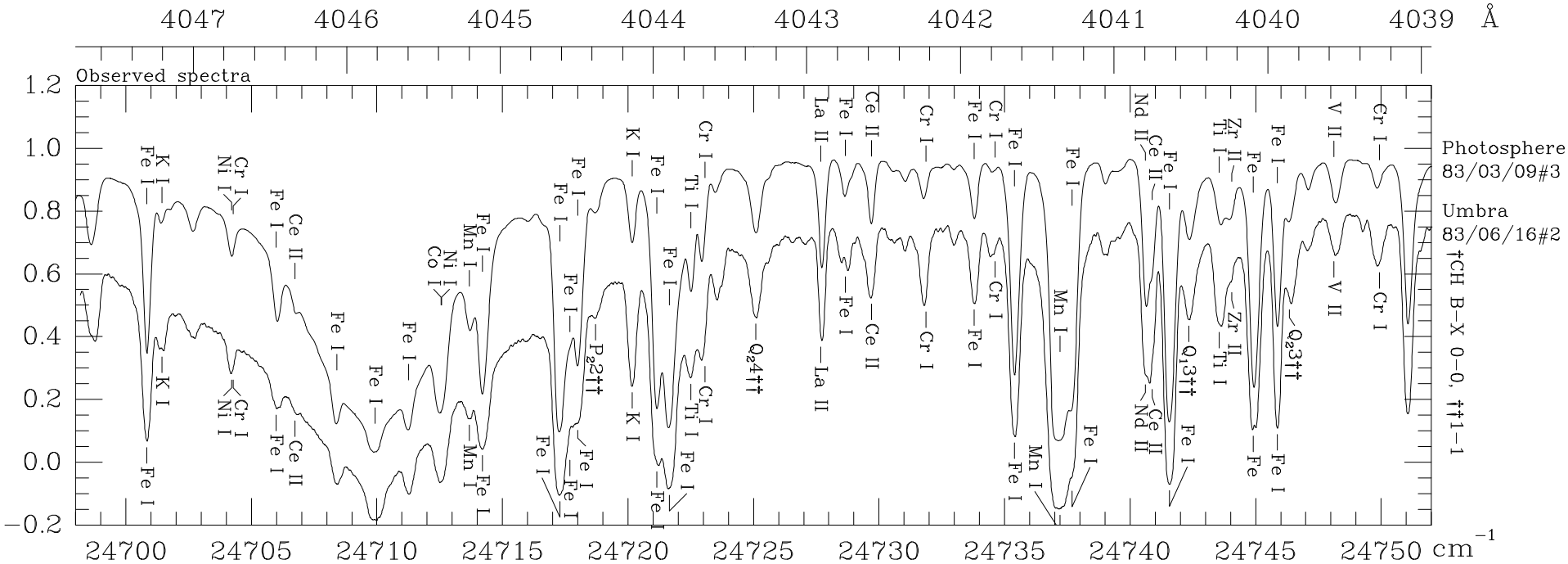

Å
4089
4088
4087
4086
4085
4084
4083
4082
4081
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
24450
24455
24460
24465
24470
24475
24480
24485
24490
24495
24500
cm−1

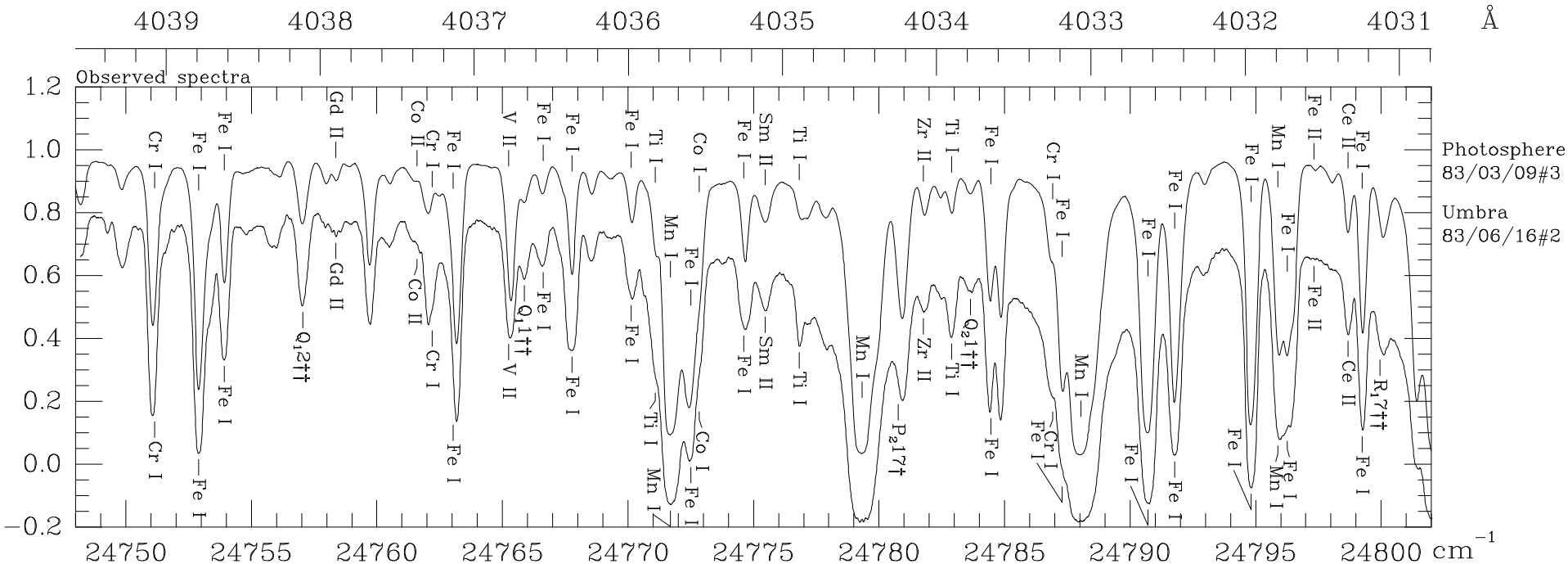

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B–X 0–0, ††1–1
Å
cm^{-1}

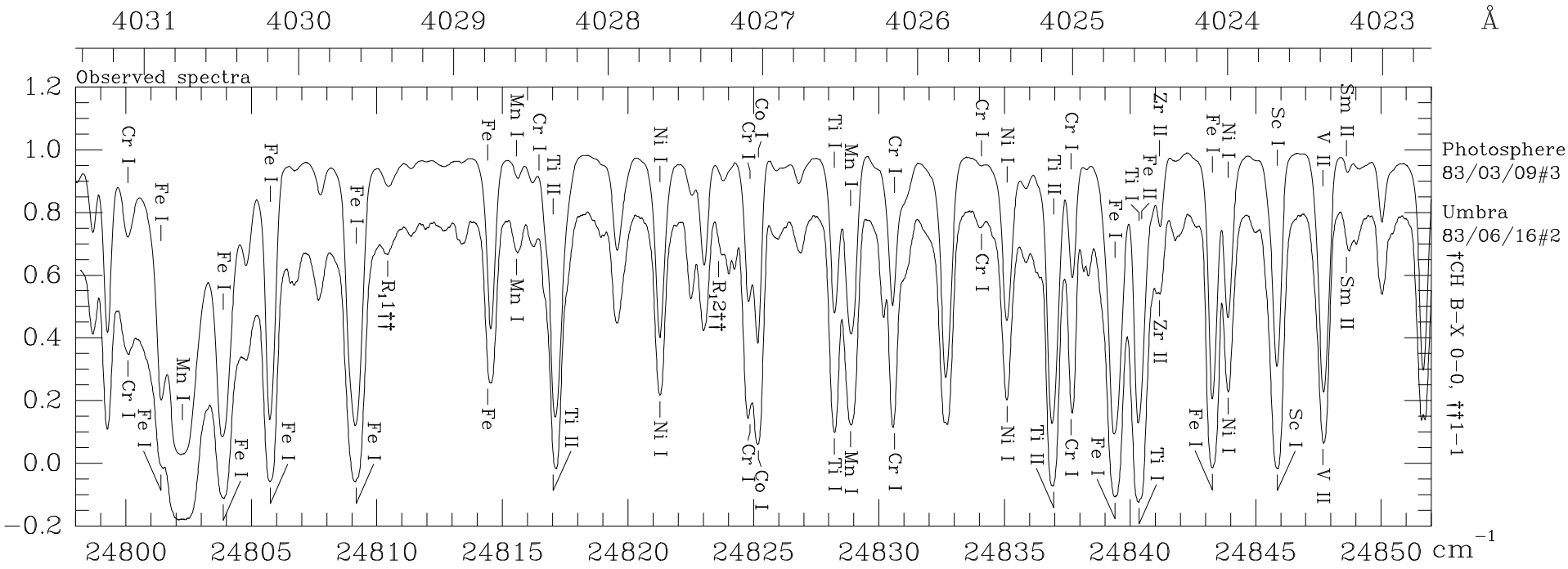

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}

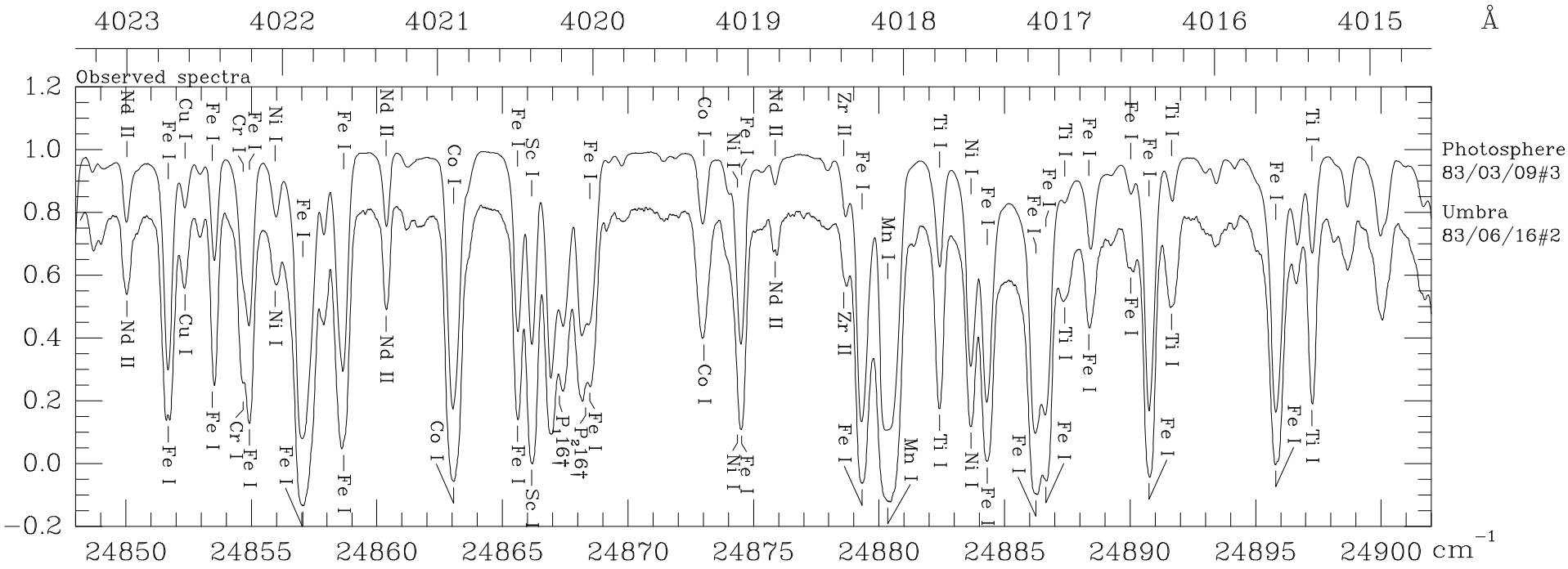

Å
4064
4063
4062
4061
4060
4059
4058
4057
4056
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B−X 0−0, ††1−1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
24600
24605
24610
24615
24620
24625
24630
24635
24640
24645
24650
cm−1

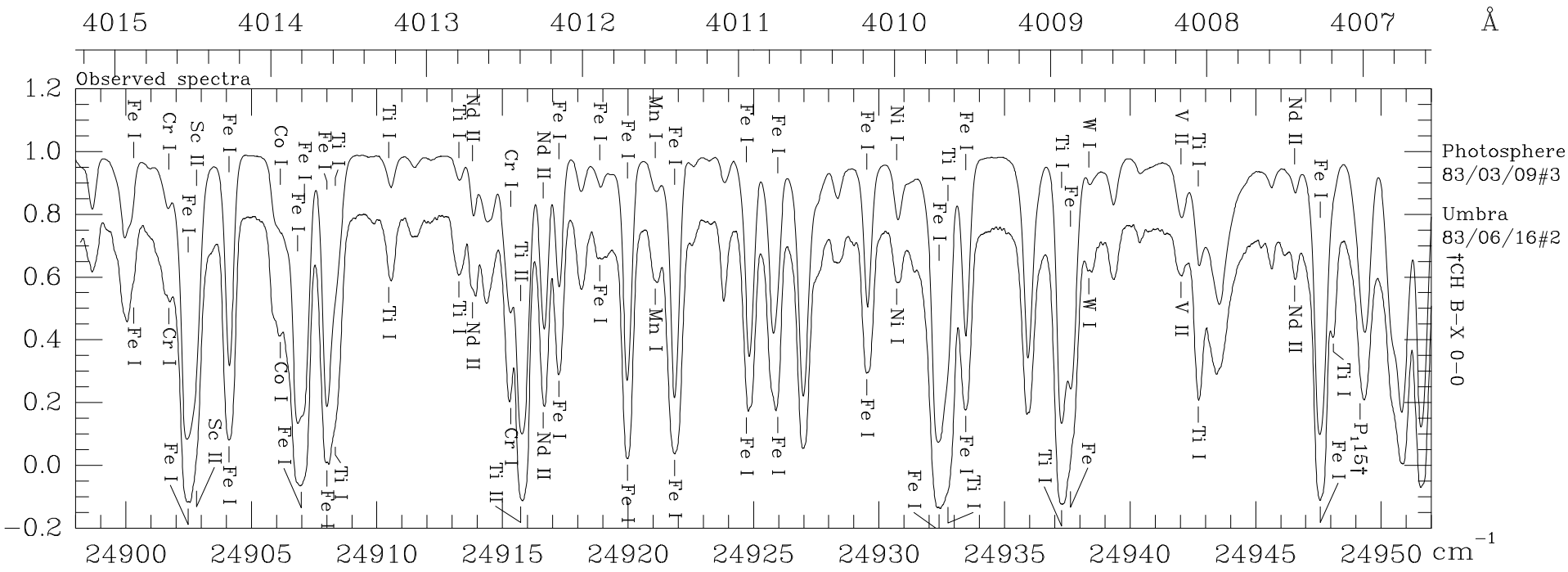

Å
4055
4054
4053
4052
4051
4050
4049
4048
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
24650
24655
24660
24665
24670
24675
24680
24685
24690
24695
24700
cm−1

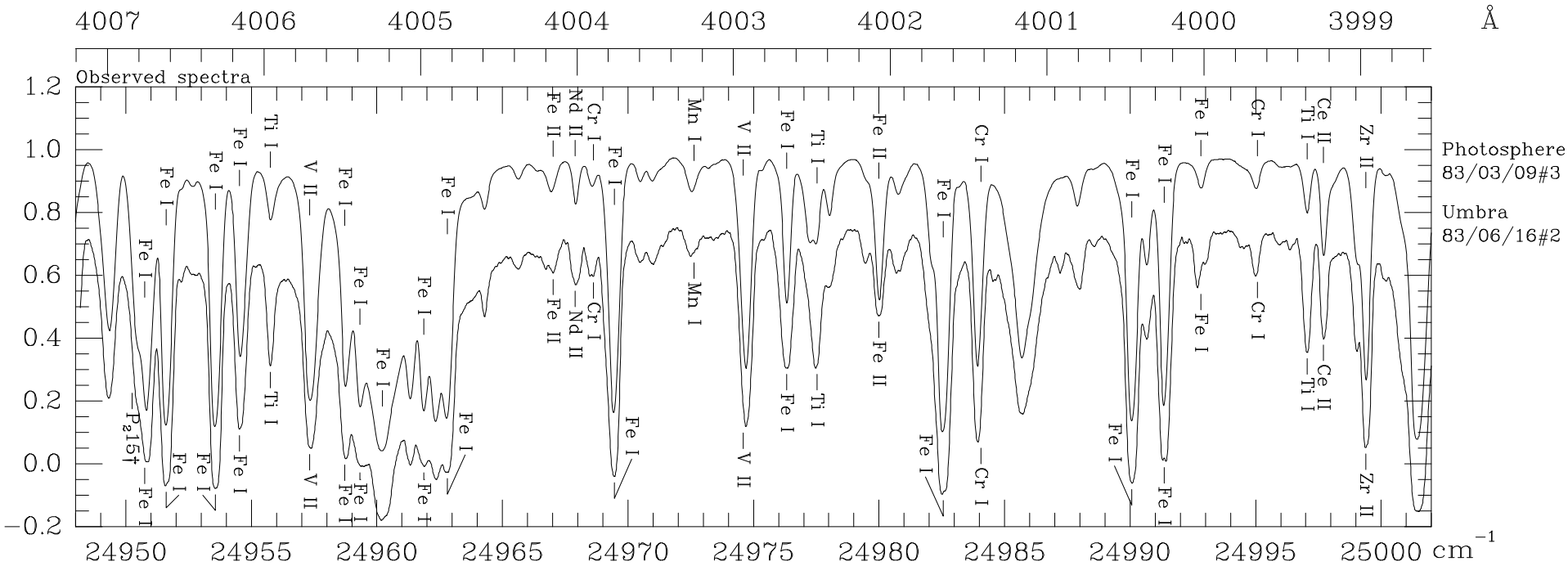

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
†CH B−X 0−0, ††1−1
Å
cm^{-1}

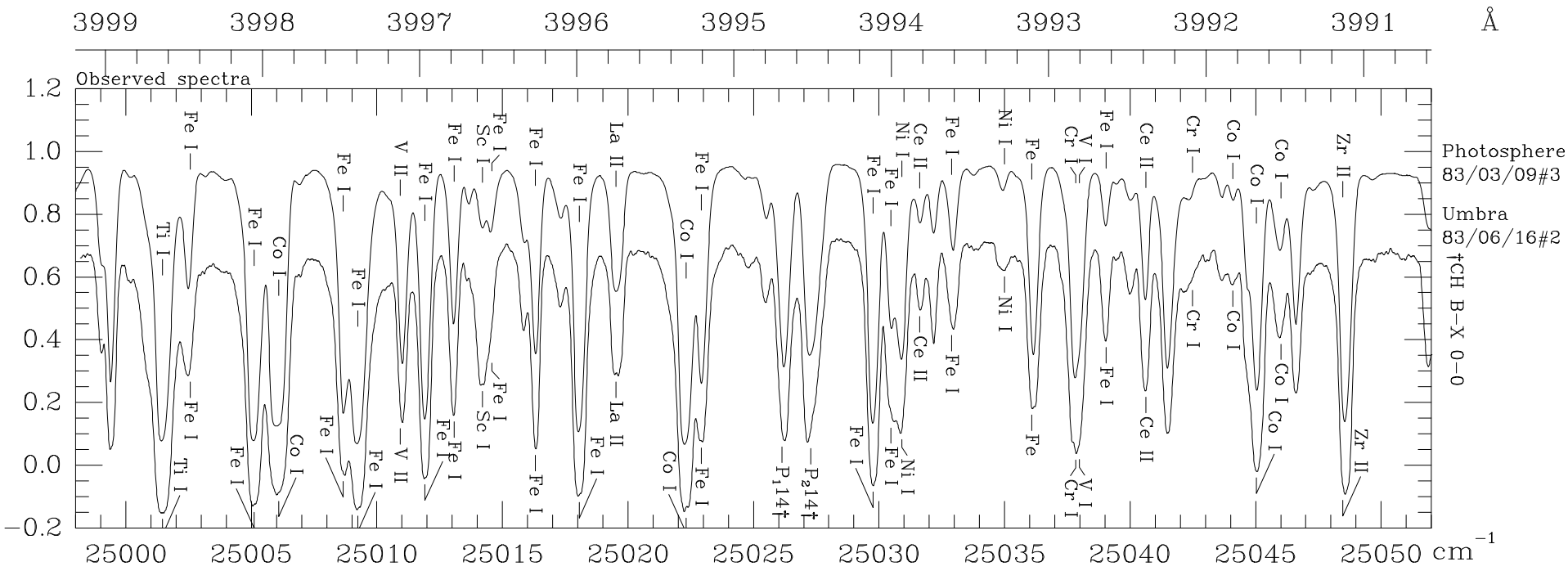

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

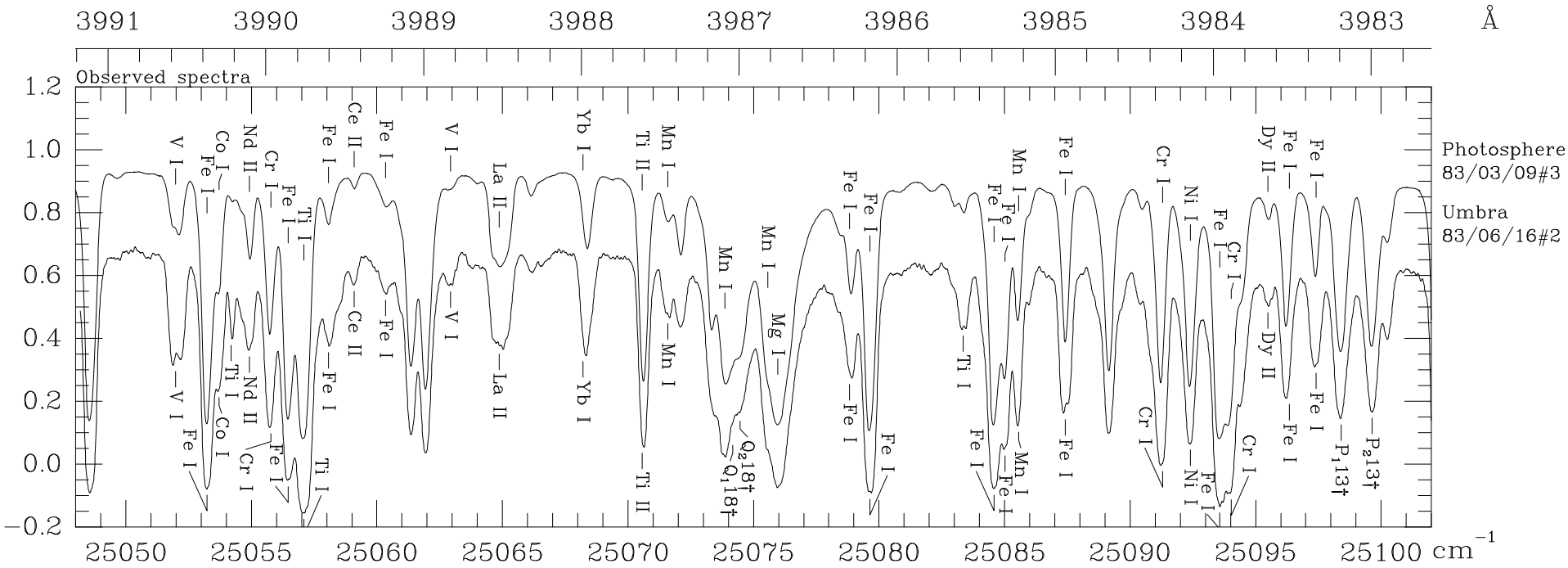

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
†CH B−X 0−0, ††1−1
Å
cm^{-1}

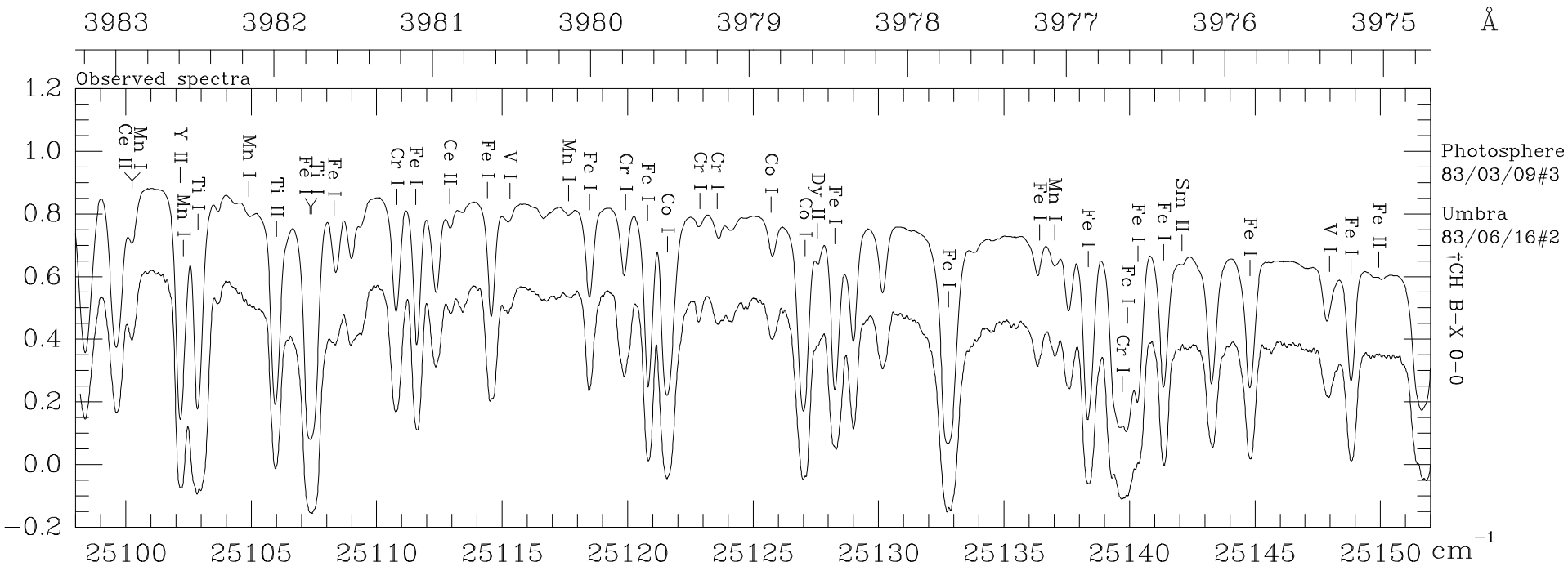

Observed spectra
Photosphere 83/03/09#3
Umbra 83/06/16#2
Å
cm^{-1}

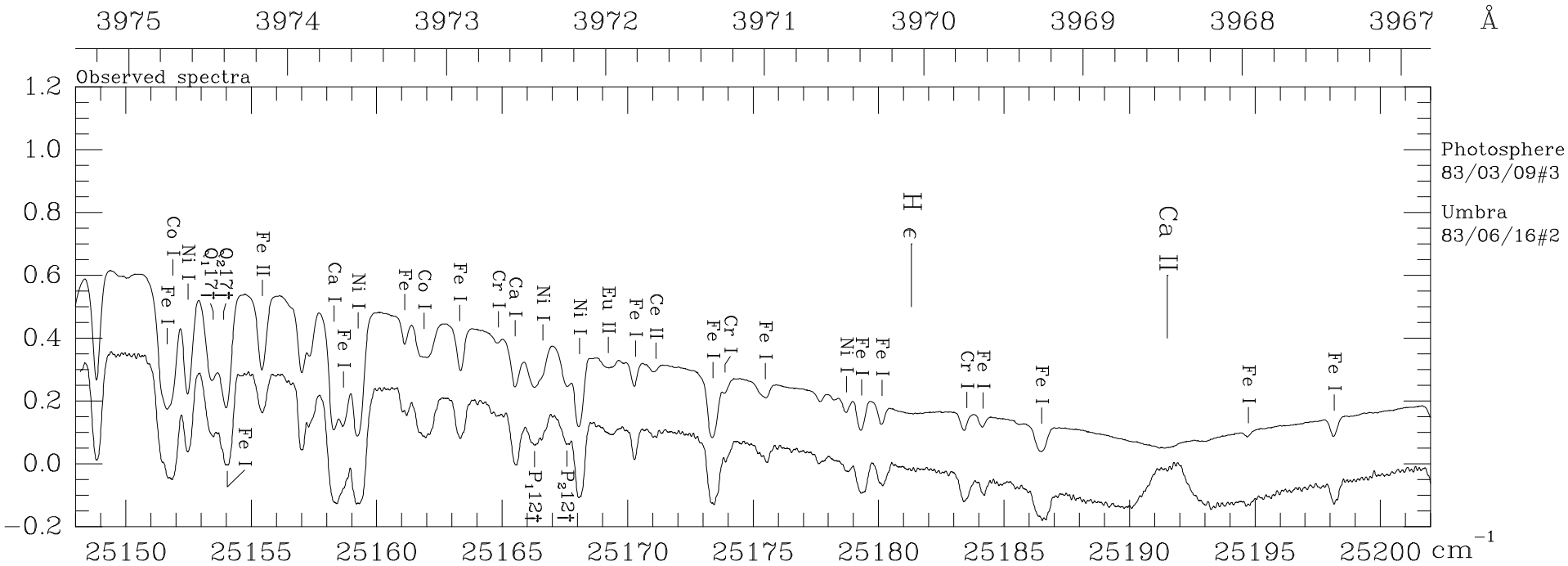

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B−X 0−0
Å
cm^{-1}

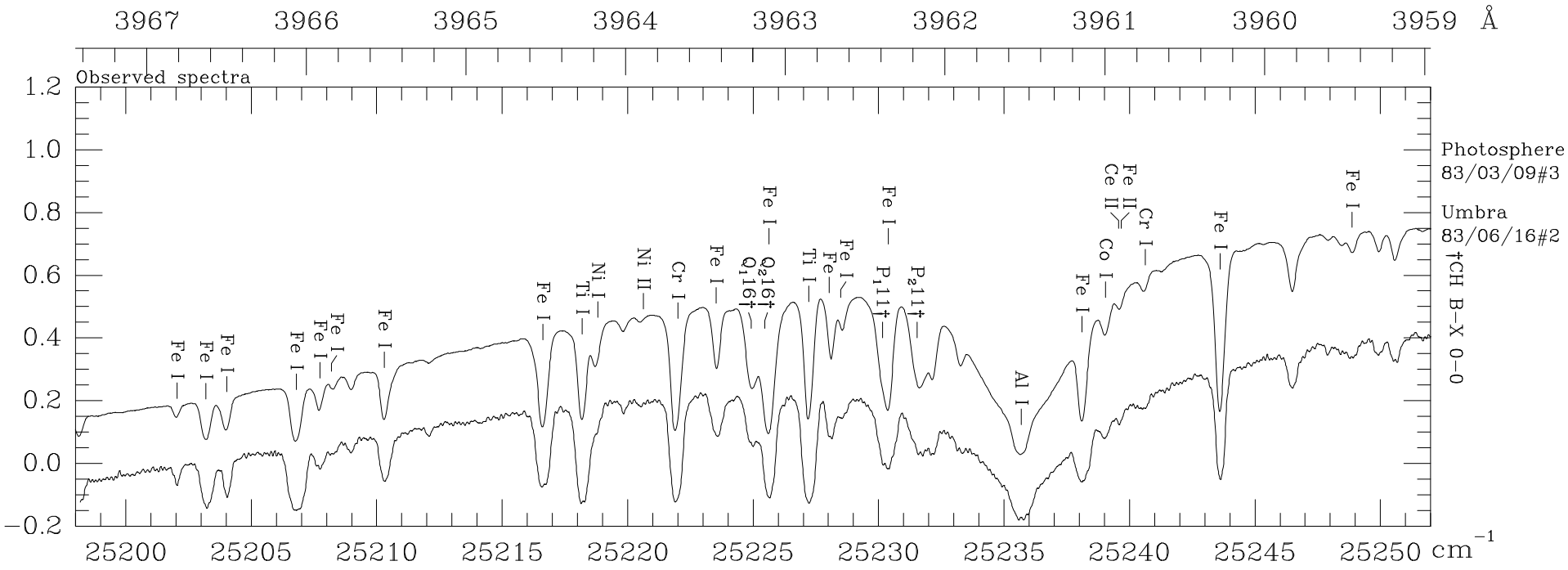

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}

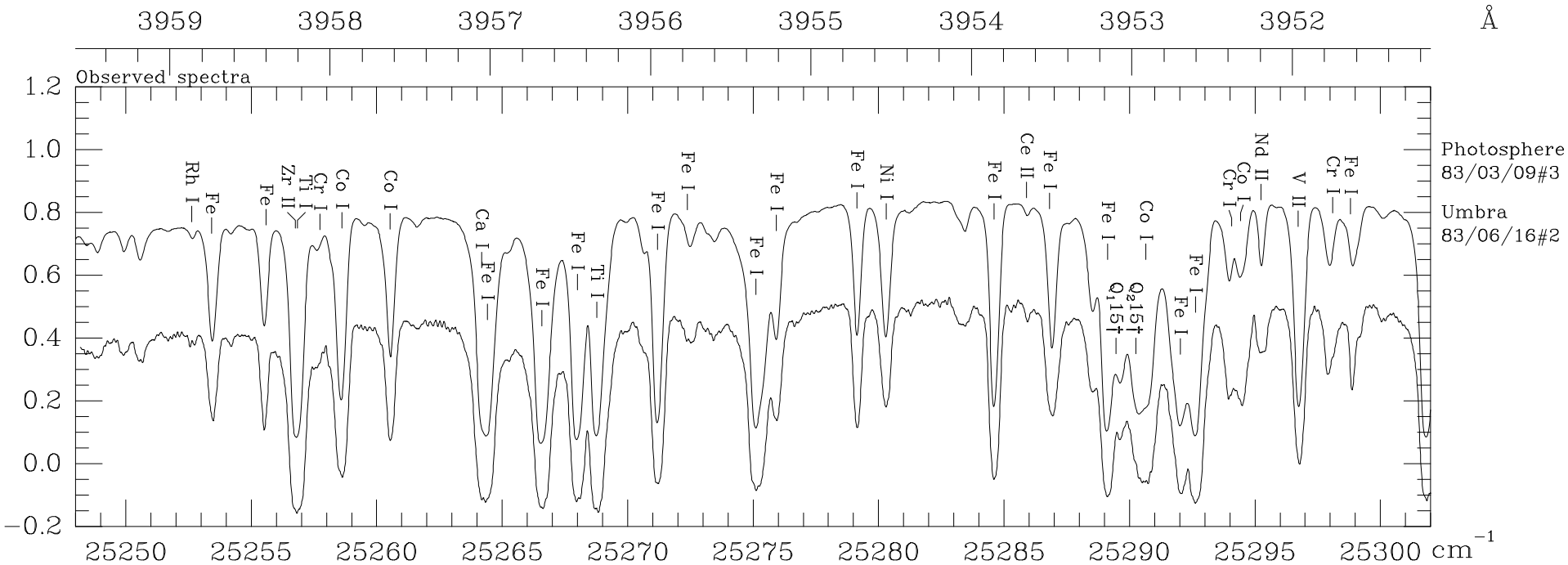

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B–X 0–0
Å
cm^{-1}

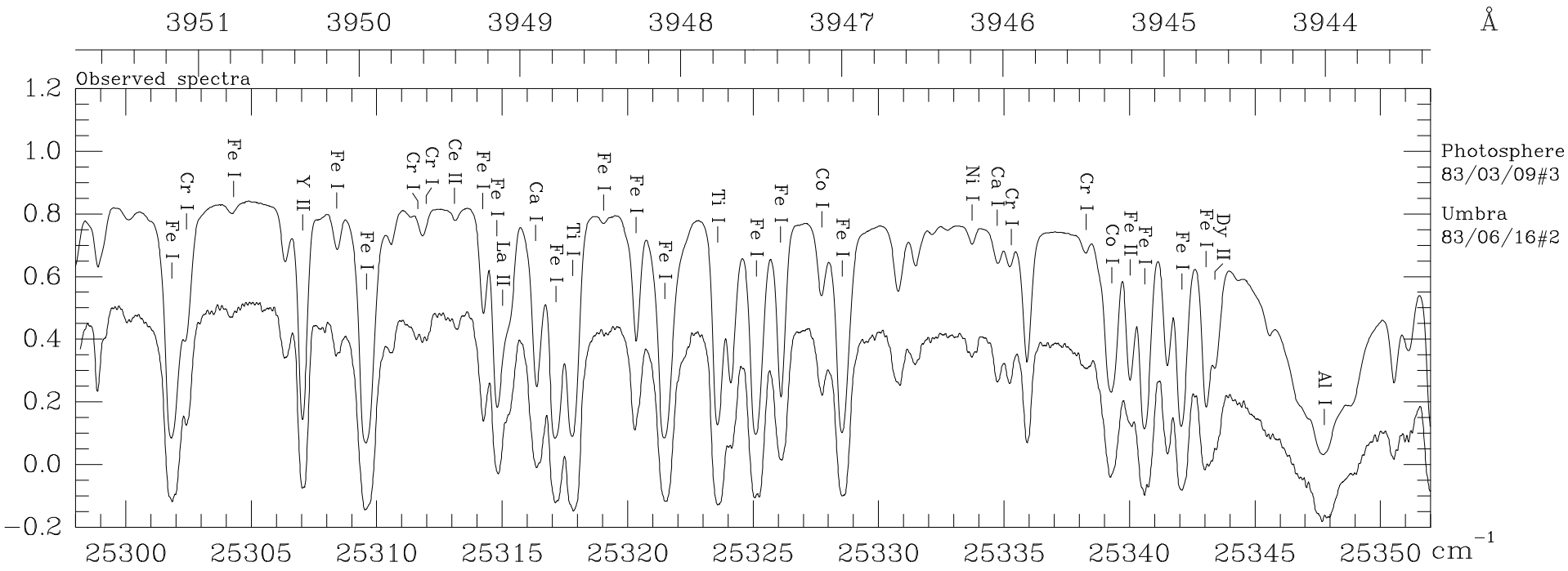

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}

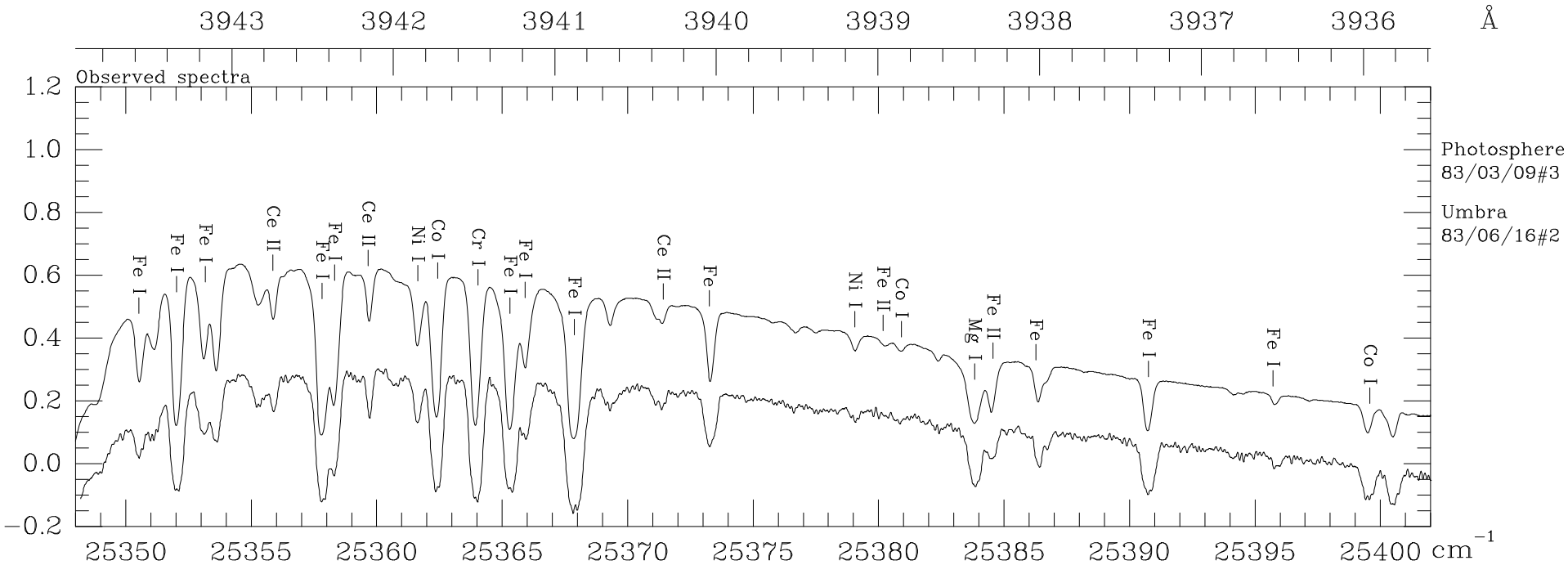

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B−X 0−0
Å
cm^{-1}

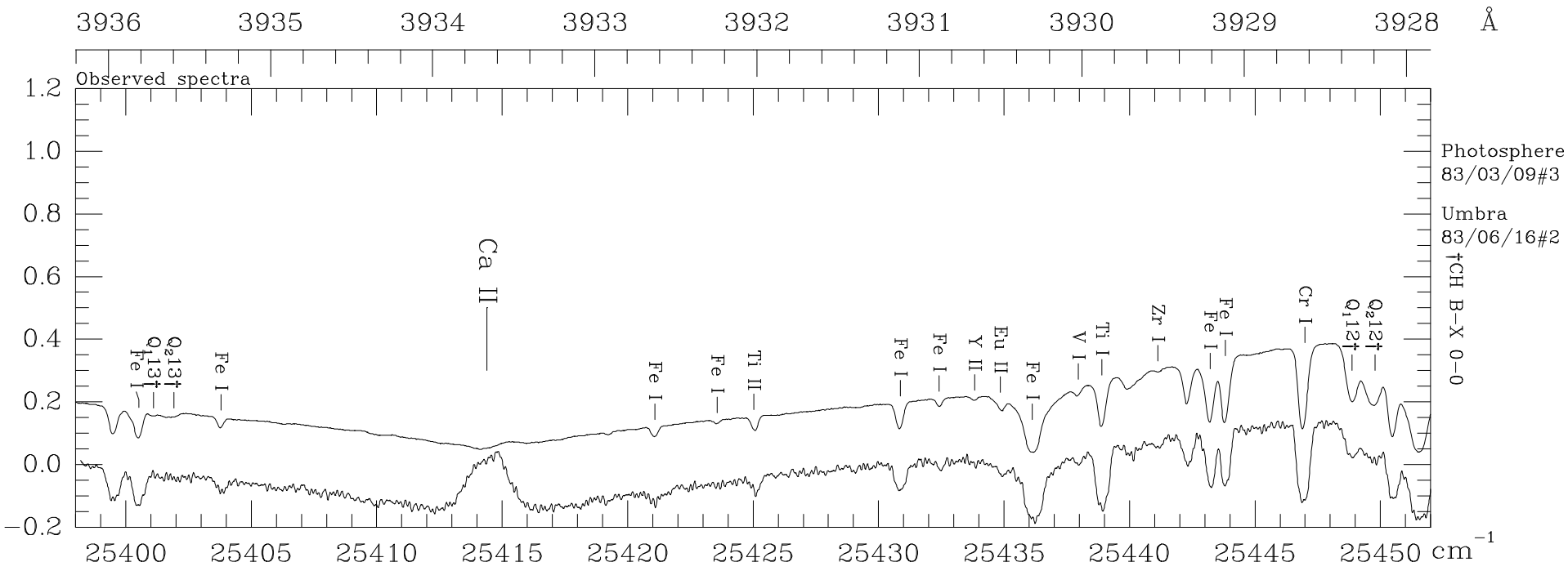

Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
H ε
Ca II
Å
cm^{-1}

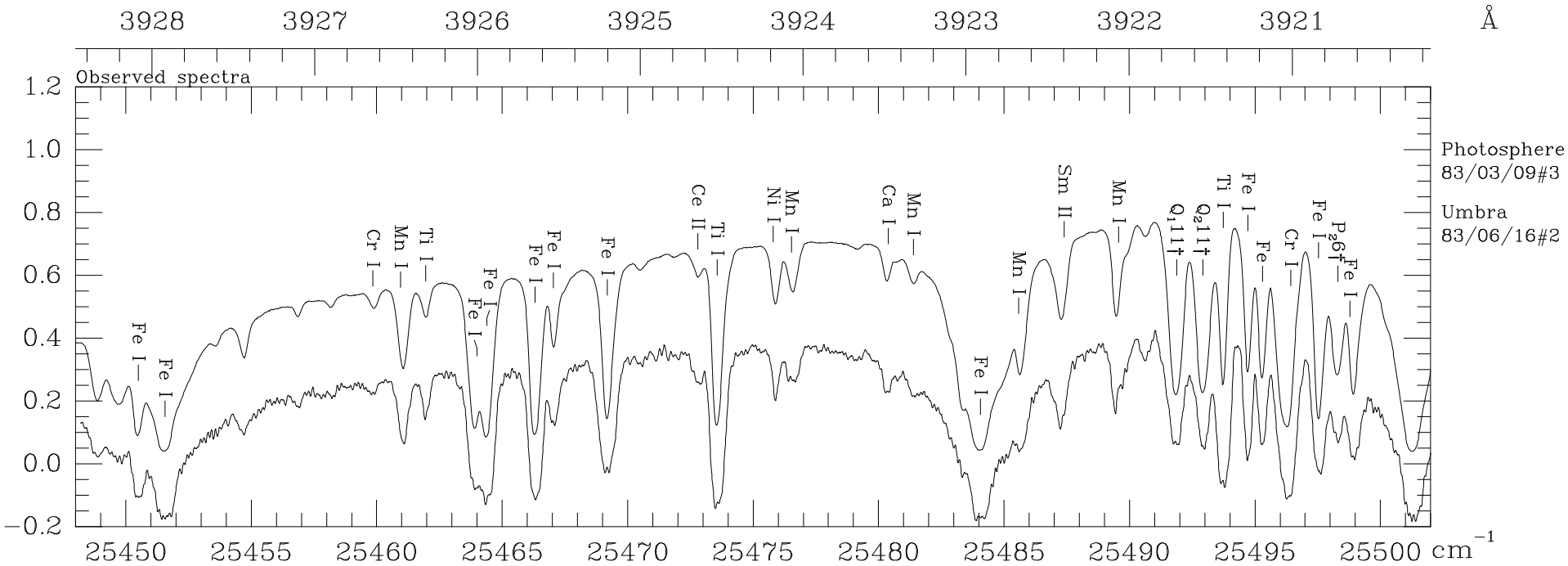

3967 3966 3965 3964 3963 3962 3961 3960 3959 Å
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B–X 0–0
Fe I
Ni I
Ti I
Ni II
Cr I
Al I
Ti I
Fe
Ce II
Fe II
Co I
25200 25205 25210 25215 25220 25225 25230 25235 25240 25245 25250 cm^{-1}


3959 3958 3957 3956 3955 3954 3953 3952 Å
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Rh I
Fe
Zr II
Cr I
Ti I
Co I
Ca I
Ti I
Ni I
Ce II
Nd II
V II
25250 25255 25260 25265 25270 25275 25280 25285 25290 25295 25300 cm^{-1}


3951 3950 3949 3948 3947 3946 3945 3944 Å
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Cr I
Fe I
Fe I
Y II
Fe I
Fe I
Cr I
Cr I
Ce II
Fe I
Fe I
La II
Ca I
Fe I
Ti I
Fe I
Fe I
Fe I
Ti I
Fe I
Fe I
Fe I
Co I
Fe I
Ni I
Ca I
Cr I
Cr I
Co I
Fe II
Fe I
Fe I
Fe I
Dy II
Fe I
Al I
25300 25305 25310 25315 25320 25325 25330 25335 25340 25345 25350 cm^{-1}


3943 3942 3941 3940 3939 3938 3937 3936 Å
Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Fe I
Fe I
Fe I
Ce II
Fe I
Fe I
Ce II
Ni I
Co I
Cr I
Fe I
Fe I
Fe I
Ce II
Fe
Ni I
Fe II
Co I
Mg I
Fe II
Fe
Fe I
Fe I
Co I
25350 25355 25360 25365 25370 25375 25380 25385 25390 25395 25400 cm^{-1}


Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
†CH B−X 0−0
Å
cm^{-1}
Fe I
Q$_1$13†
Q$_2$13†
Fe I
Ca II
Fe I
Fe I
Ti II
Fe I
Fe I
Y II
Eu II
Fe I
V I
Ti I
Zr I
Fe I
Fe I
Cr I
Q$_1$12†
Q$_2$12†


Observed spectra
Photosphere
83/03/09#3
Umbra
83/06/16#2
Å
cm^{-1}
Fe I
Fe I
Cr I
Mn I
Ti I
Fe I
Fe I
Fe I
Fe I
Fe I
Ce II
Ti I
Ni I
Mn I
Ca I
Mn I
Fe I
Mn I
Sm II
Mn I
Q$_1$11†
Q$_2$11†
Ti I
Fe I
Fe
Cr I
Fe I
P$_2$6†
Fe I