Stellar features in integrated starburst spectra as stellar population diagnostics*

Daniel Schaerer

Laboratoire d’Astrophysique, Observatoire Midi-Pyrénées, 14, Av. E. Belin, F-31400, Toulouse, France (schaerer@ast.obs-mip.fr)

Abstract. We review the main stellar features observed in starburst spectra from the UV to the near-IR and their use as fundamental tools to determine the properties of stellar populations from integrated spectra. The origin and dependence of the features on stellar properties are discussed, and we summarise existing modeling techniques used for quantitative analysis. Recent results from studies based on UV, optical and near-IR observations of starbursts and active galaxies are summarised. Finally, we briefly discuss combined starburst + photoionisation models including also observations from nebular emission lines. The present review is complementary to the recent summary by Schaerer (2000) discussing more extensively nebular analysis of starbursts and related objects.

1 Introduction

The analysis of distinct spectral features in integrated spectra is at the base of numerous investigations on the stellar content of distant galaxies. Indeed, in addition to the overall continuum spectral shape, stellar absorption (and rarely also emission) lines carry crucial information on the presence of stars of various spectral types and luminosity class, and allow thus in principle to “decompose” the integrated galaxy spectrum in its stellar constituents, and to determine their fundamental properties such as ages, IMF, the star formation history etc.

In objects such as active galaxies, where non-stellar emission processes are thought to contribute to the emitted light, the study of possible stellar features allows one to constrain the relative stellar contribution, and thus to determine the efficiency of various emission processes (e.g. stellar versus non-stellar).

These basic properties illustrate the interest of spectroscopic studies of stellar features in starbursts and other galaxies.

The aim of the present review is to discuss the main stellar features observed in starburst spectra over the entire spectral range where such features are detectable, i.e. from the UV over the optical to the near-IR. At longer wavelength dust emission dominates and the stellar continuum and associated lines is not detectable anymore.

An “inventory” of the strongest stellar features is given for each spectral domain and recent results in the respective fields are summarised. In the last Section, we also briefly discuss the use of combined stellar and nebular emission

* Invited review to appear in “Starbursts – near and far”, Eds. L. Tacconi-Garman, D. Lutz, Springer Verlag
line (hereafter EL) analysis for the study of stellar populations in the optical and
IR.

The current review is complementary to a recent review Schaerer (2000) discussing new developments in multi-wavelength modeling tools, the current status of ionising fluxes from massive stars, and their importance for EL analysis of starbursts and related objects.

2 UV features

The UV spectral range (~ 1000 – 3000 Å) of starbursts is rich in stellar lines originating in early type stars (mostly OB, also Wolf-Rayet), it contains few or weak nebular lines, and rather numerous interstellar (IS) absorption lines.

A rough inventory of the strongest stellar lines observed mostly in the ~ 1200 – 1800 Å range follows (cf. the detailed work of de Mello et al. 2000, hereafter DLH00):

- Well known stellar wind lines (P-Cygni or EL) from O and Wolf-Rayet (WR) stars are Si iv 1400, C iv 1550, N v 1240, He ii 1640, and N iv 1720. The following synthesis models include at least partly these lines and discuss their behaviour: Sekiguchi & Anderson (1987), Mas-Hesse & Kunth (1991), Fanelli et al. (e.g. 1987, 1992), Leitherer, Robert et al. (1993-2000).
- Other wind lines blueward of Lyα include O vi + Lyβ + C ii 1010-1060, discussed and modeled by González Delgado et al. (1999), and potentially lines of C, N, P, S, and Ar in the range recently observed with FUSE (see Taresch et al. 1997, Fullerton et al. 2000).
- The strongest photospheric lines from OB stars are Si ii 1265, 1485, Si iii 1295-1300, 1417, C ii 1334, 1335, C iii 1247, 1427, S v 1501 (see de Mello et al. 2000).
- Other stellar features include “depressions” due to numerous Fe lines (at ~ 1400, 1600, 1940), and also Fe ii 2570-2615 and Mg ii 2780-2825 features at longer wavelengths (e.g. Robert et al. 1999, Storchi-Bergmann et al. 1995)

It is important to note that many of these lines can also be formed in the interstellar medium (cf. Heckman & Leitherer 1997, Sahu 1998). A careful separation of the stellar and interstellar component is necessary in many cases (see de Mello et al. 2000). The wavelength range between ~ 1800 and 3000 Å remains still little explored. A similarly detailed understanding of this spectral range is of importance for studies of galaxies in the z ~ 1–2 redshift range (see e.g. Campusano et al. 2000).

Given the dependence of the various lines on stellar luminosity, age, and also metallicity (cf. below), e.g. well studied for the stellar wind lines (e.g. Walborn et al. 1985, Leitherer & Lamers 1991), the features can be used to constrain the parameters of the integrated population, such as age, SF history, and IMF, by means of evolutionary synthesis techniques (e.g. Mas-Hesse & Kunth 1991, Leitherer et al. 1995). The most up-to-date model suited to such analysis is Starburst99 (Leitherer et al. 1999, de Mello et al. 2000).
These techniques have been extensively applied to the interpretation of UV spectra of nearby starbursts (mostly HST spectra), especially by Leitherer, Heckman, González Delgado and collaborators (some references given below) and by Mas-Hesse & Kunth (1991, 1999). Summarised in one sentence (...) the main result of these studies is that all the objects contain young bursts (≲ 10–20 Myr) characterised by instantaneous burst or continuous star formation, the distinction being often difficult to draw, which are populated with a rather normal Salpeter-like IMF with stars up to $M_{\text{up}} \sim 60 – 100 M_\odot$. In a recent study Tremonti et al. (2000, cf. these proceedings) examine the stellar populations in the field of NGC 5253 and find a possible indication for a steeper IMF, although other explanations (e.g. age effects) are possible.

The similarity of the spectra of many high redshift galaxies (e.g. Lyman break galaxies) with the local starbursts is now well recognised and offers many exciting possibilities. For example, from the beautiful spectrum of the lensed $z \sim 2.7$ Galaxy 1512-cb58 of Pettini et al. (2000) these authors and de Mello et al. (2000) derive a constant star formation, an IMF slope between Salpeter (2.35) and $\sim 2.8$, and find indications for a subsolar metallicity, in agreement with EL measurements from Teplitz et al. (2000).

Obviously it is of great interest to derive/estimate the metallicity ($Z$) from stellar UV lines. Since, for example, the strength of stellar wind lines depend on $Z$ this is in principle possible. This can e.g. be done using the correlation of the equivalent width of Si IV with metallicity found by Heckman et al. (1998). However, a priori, such a correlation should only be valid in a statistical sense, since the line strength also depends on age (cf. Leitherer et al. 1995). This difficulty should be less if the full wind line profile can be analysed. The inclusion of spectral libraries of metal-poor stars in evolutionary synthesis models has just been completed (e.g. Leitherer et al. 2000, see also Heap 2000). Alternative possibilities to derive the chemical composition include the use of IS absorption lines (cf. Pettini et al. 2000), or the use of weak stellar features such as various Fe blends known to vary with $Z$ (cf. Haser et al. 1998).

### 3 Stellar features in the optical

The inventory of the strongest stellar lines in the optical is as follows:

- Broad emission lines from Wolf-Rayet stars of various subtypes (WN, WC) are detected in some young starbursts: He II 4686 bump, C IV 5808, C III 5696, possibly also N III 4512, Si III 4565 (see e.g. Schaerer et al. 1999b, Guseva et al. 2000). Synthesis models treating these lines include Cerviño, & Mas-Hesse (1994) and Schaerer & Vacca (1998).
- H and He absorption lines from OBA stars have been discussed and modeled by Diaz (1988), Olofsson (1995), and González Delgado et al. (1999).
- The Ca II triplet $\sim 8498, 8542, 8662$ has often been studied (e.g. Terlevich et al. 1990ab, Mayya 1997, Garcia-Vargas et al. 1998). Its origin in both late type giants and supergiants complicates a priori the analysis.
• Other metallic features and molecular bands originating in stars with F types and later are Ca\textsubscript{II} H+K 39XX, CH G band 4284-4318, Mg I+MgH 5156-5196, Na I 5880-5914, various TiO bands ≥ 6200. These are found e.g. in the template spectra of Bica & Alloin (1986 and subsequent papers) for clusters and in the starburst spectra of Storchi-Bergmann et al. (1995).

A complete overview of all starburst studies exploiting these features is not possible here. I shall instead briefly summarise recent results on starburst (and possibly also AGN) studies using Wolf-Rayet features and metallic lines. The contribution of González Delgado (these proceedings) illustrates the use of H and He absorption lines.

3.1 WR features as a probe of the most massive stars
Since WR are the descendents of the most massive stars, detections of their features provide the best indication of the presence of massive stars ($M_{\text{initial}} \gtrsim 25-60 M_\odot$) and allow to constrain the upper end of the IMF. A catalogue of all known galaxies with WR detections has been compiled by Schaerer et al. (1999b; on the Web at [http://webast.ast.obs-mip.fr/people/schaerer/](http://webast.ast.obs-mip.fr/people/schaerer/)).

**Starburst--AGN connection** The detection of stellar features including the so-called WR-bump, UV lines and the Ca\textsubscript{II} triplet in the Seyfert2 galaxy Mrk 477 by Heckman et al. (1997) has considerably re-vived this subject, before more focused on detections of the Ca\textsubscript{II} triplet (e.g. Terlevich et al. 1990ab). Since then other possible WR detections indicating important massive star populations have been made in Mrk 1210 (Sey2, Storchi-Bergmann et al. 1998), Mrk 463E and Mrk 1 (Sey2, Gonzalez Delgado et al. 2000), TF 1736+1122 (Sey2, Tran et al. 1999), and in three PG QSO (Lipari et al. 2000). Given the strong nebular contamination due to He\textsubscript{II} $\lambda$4686, other unambiguous massive star features are required to fully clearly establish the presence of massive stars in these objects. Such attempts, aiming to detect the WR lines of C\textsubscript{IV} and/or C\textsubscript{III} which are not affected by nebular contamination, have been undertaken by Kunth & Contini (1999) with 2-D spectroscopy in several Sey2.

From the analysis of WR and H+He absorption lines in their sample of 20 Sey2 galaxies, González Delgado et al. (2000; cf. these proceedings) find that the blue and near-UV light of half of their objects is dominated by young and/or intermediate age stars. A similar result was found by Storchi-Bergmann et al. (1998) on a smaller sample.

“Normal” starbursts (so-called WR galaxies) Studies on WR galaxies (mostly BCD, Irr, spirals) are summarised in the reviews of Schaefer (1999ab). Including the detections of spectral signatures from both WN and WC stars in a fair number of objects covering a large metallicity range, the following overall conclusions emerge from the studies of Schaefer et al. (1999a) and Guseva et al. (2000). Except possibly at the lowest metallicities a good agreement is found...
between the observations and the evolutionary synthesis models of Schaerer & Vacca (1998). From this comparison one finds clear indications for short bursts ($\Delta t \leq 2$–4 Myr) in objects with subsolar metallicity, an IMF compatible with Salpeter, and a large upper mass cut-off of the IMF, in agreement with several earlier studies. In addition, the observed WC/WN star ratios provide new constraints for mass loss and mixing scenarios in stellar evolution models (Schaerer et al. 1999a).

We have recently undertaken a first study of metal-rich starbursts (metallicities up to $\sim 2$–3 times solar) with the aim of constraining the upper end of the IMF in such environments. From the strengths of the observed WR features we derive a conservative lower limit of $M_{\text{up}} \sim 30$–40 $M_\odot$ (Schaerer et al. 2000). New observations are being obtained to improve the accuracy of this result. Direct studies of the stellar content are of prime importance, also to verify the reliability of indirect studies based on nebular line analysis (cf. below).

### 3.2 Population synthesis studies using metallic lines

Early starbursts studies using metallic lines have mostly concentrated on the Calcium triplet (see references above). More complete analysis of starbursts and AGN spectra using numerous optical stellar features have recently been presented by two groups. Both approaches are based on “classical” population synthesis using either observed stellar templates (Serote Roos et al. 1998, Boisson et al. 2000) or cluster templates (Raimann et al. 2000ab).

The former authors analyse 5000 – 8000 Å spectra of 12 starburst, Seyfert and LINERs, and use a synthesis technique yielding a mathematically unique solution to determine the relative contributions of different stellar populations. Regarding e.g. the importance of super metal-rich stars their results differ from other work (e.g. Cid Fernandes et al. 1998, González Delgado et al. 2000). Raimann et al. have analysed average spectra of H II galaxies, starbursts and Sey2 taken from the Terlevich et al. (1991) catalogue. Their main result regarding H II galaxies is the finding of significant old ($\leq 500$ Myr) underlying populations, which also modifies emission line diagnostics based on equivalent widths. Their conclusions are supported by the study of selected BCD’s by Mas-Hesse & Kunth (1999) and by comparisons of predicted and observed EL trends in several large samples of H II galaxies (Stasińska et al. 2000).

### 4 Stellar features in the near–IR

This spectral range is in most cases dominated by features from late type stars (G, K, M) corresponding to red supergiants (RSG), asymptotic giant branch stars (AGB), or red giants. Typical ages for the appearance of these stars are $\gtrsim 10^7$, $10^8$, and $10^9$ yr respectively. The strongest features in the K and K band are

- atomic transitions of Si i 1.59 µm, Na i 2.21, Fe i 2.23, 2.24, Ca i 2.26, Mg i 2.28
molecular features, such as CO (6,3) 1.6, CO (2,0) 2.29 and many OH lines (all wavelengths given in $\mu$m here).

The following papers (incomplete selection) describe their dependence on stellar type and luminosity class and/or provide spectral libraries: Kleinmann & Hall (1986), Lancon & Rocca-Volmerange (1992), Origlia et al. (1993), Ali et al. (1995), Förster-Schreiber (1998). Recently, some authors (e.g. Gilbert & Graham, these proceedings) have begun to use also theoretical spectra of cool stars for population studies.

Rather than providing a detailed review of the many studies undertaken in this area, I will briefly recall some difficulties affecting near-IR studies of stellar populations. While obviously the traditional method of population synthesis, decomposing the integrated spectrum in various template constituents, can be equally applied to any wavelength range, the near-IR properties predicted by evolutionary synthesis models are unfavourably affected by uncertainties in post main-sequence stellar evolution and the modeling of cool stars.

Indeed, it is found that all current non-rotating stellar evolution models predict an incorrect variation of the relative red/blue supergiant lifetimes with metallicity $Z$ (Langer & Maeder 1995). In addition the predicted $T_{\text{eff}}$ of RSG may be too high (Origlia et al. 1999). This implies, e.g. that the CO features predicted by evolutionary synthesis models based on these tracks are weaker than observed at subsolar $Z$ (Origlia et al. 1999). Also, the predicted strong metallicity dependence of colors like V-K (see Cerviño & Mas-Hesse 1994) is therefore incorrect. Improvements are expected from new stellar models allowing for more realistic mixing scenarios including rotation (cf. Maeder & Meynet 2000) and better understanding of mass loss in these phases.

Uncertain mass loss scenarios render the prediction of AGB stars, whose influence at long wavelength is non negligible for populations with ages $\sim 1$ Gyr (e.g. Bruzual & Charlot 1993), rather difficult, as best illustrated by Girardi & Bertelli (1998). For regions with small masses stochastical effects (Lancon & Mouhcine 2000) and fluctuations of the IMF from the finite number of stars (Cerviño et al. 2000) also lead to an expected dispersion. While these effects are obviously of general nature, they are of particular importance for predictions involving the dominant contribution from stars with very short lived phases (e.g. AGB, WR).

5 Combined stellar and nebular analysis of starbursts

In various situations (e.g. starbursts with strong optical EL; IR observations – $\lambda \gtrsim 4$–10 $\mu$m where the continuum emission is dominated by dust and stellar features are thus completely absent) analysis of nebular emission lines are of interest to constrain the stellar population.

1 Depending on the adopted set, the predicted RSG/BSG may well be correct for a certain metallicity (e.g. Geneva models ok for solar metallicity). The predicted metallicity variation does, however, not follow the observed trends.
However, given the very nature of nebular physics, the EL are not only sensitive to the ionising spectrum carrying information of the stellar populations, but depend also strongly on the nebular geometry and chemical composition. The dependence on these additional parameters (essentially the so-called “ionisation parameter” $U$ and composition) render EL studies of stellar populations more complex and require thus the use of sufficient observational constraints.

Recent developments and the current state-of-the-art of stellar ionising fluxes forming the input to photoionisation models have been reviewed by Schaerer (2000) and shall not be repeated here. In the following we briefly summarise the main recent studies undertaken in the optical and IR (cf. Schaerer 2000 for more details.)

5.1 Optical studies

Recent tailored starburst and photoionisation models are presented in the studies of Gracía-Vargas et al. (1997: NGC 7714), Luridiana et al. (1999: NGC 2363, 2000: NGC 5461), Stasińska & Schaerer (1999: I Zw 18), and González Delgado & Pérez (2000: NGC 604). Although somewhat different in each study, the general approach is summarised in Gracía-Vargas et al. (1997).

Overall one finds that both the stellar and nebular lines give consistent results regarding the main properties of the stellar population, such as age, IMF etc. At a more detailed level, however, several of these studies encounter significant difficulties (e.g. the temperature sensitive ratio $[\text{O III}]$ $\lambda$4363/$\lambda$5007 is underpredicted), which indicates that some physical are missing in the photoionisation models (Stasińska & Schaerer 1999, Luridiana et al. 1999, also Stasińska et al. 2000). In short, although most observables can be reproduced by the combined starburst and photoionisation models — and the tool can thus be used to derive SB properties from the EL — one has to conclude that for accurate studies relying on nebular lines from H II regions (and presumably also more complex objects) some additional physical process(es) (possibly shocks, conductive heating at X-ray interfaces etc.) must be taken into account (cf. Schaerer 2000).

5.2 Starburst + photoionisation models in the IR domain

Analysis of IR observations (mostly from SWS and LWS on ISO) of starbursts based on combined SB + photoionisation models are just beginning to appear in the literature. In this context it is useful to keep some intrinsic difficulties in mind are. Given the nature of objects and the large apertures involved, the integrated spectrum generally includes a large variety of regions. This fact, together with the complex geometries involved, render a priori the construction of photoionisation models difficult.

Simple models were constructed for case studies of Arp 299 and M82 by Satyapal et al. (1998) and Colbert et al. (1999) to interpret their LWS (40-200 $\mu$m) spectra. Colbert et al. (1999) find that the observed EL spectrum of M82 is compatible with an instantaneous burst at ages $\sim$ 3–5 Myr, a Salpeter IMF, and a high upper mass cut-off. Surprisingly, inspection of models with similar
ingredients (cf. Stasińska & Leitherer 1996), show that the shorter wavelength data (see Genzel et al. 1998) is clearly incompatible with the Colbert et al. model predicting too hard a spectrum. In view of the few line ratios originating from the \( \text{H} \text{\,II} \) gas and the large number of free parameters the photoionisation model is underconstrained. A larger wavelength coverage or other constraints are required.

Fürster-Schreiber (1998) has described the geometry of clusters and gas clouds in M82 by a single “effective” ionisation parameter. This value has been adopted as typical for a sample of 27 starbursts in the SB + photoionisation models of Thornley et al. (2000). Instead of modeling a simple stellar population their models are based on an ensemble of \( \text{H} \text{\,II} \) regions following an observed luminosity function, which overall leads to a reduction, albeit small, of the hardness of the ionising spectrum. From the ISO/SWS \([\text{Ne} \text{\,III}] / [\text{Ne} \text{\,II}]\) line ratios they conclude that the observations are compatible with a high upper mass cut-off \((M_{\text{up}} \sim 50–100 \, M_\odot)\). To reproduce the relatively low average \([\text{Ne} \text{\,III}] / [\text{Ne} \text{\,II}]\) ratio, short timescales of SF are required. More detailed studies including additional observational constraints would be very useful to confirm this result.

A different approach has been taken by Schaerer & Stasińska (1999), who modeled two well studied objects (NGC 5253, II Zw 40) with a fairly well known massive star population and existing UV-optical-IR observations. While their model successfully reproduces the stellar features and the observed ionisation structure of H, He, and O (as revealed from the optical and IR lines), the predicted IR fine structure line ratios of \([\text{Ne} \text{\,III}] / [\text{Ne} \text{\,II}]\), \([\text{Ar} \text{\,III}] / [\text{Ar} \text{\,II}]\), and \([\text{S} \text{\,IV}] / [\text{S} \text{\,III}]\) show too high an excitation. The origin of this discrepancy (atomic data? separate emission components ? other?) is still unknown. In any case this attempt to describe two relatively “simple” objects illustrates the current limitations and shows that further progress is needed for a proper understanding and use of the IR fine structure lines as reliable diagnostics. Improvement is expected from multi-wavelength analysis of simpler objects (e.g. Galactic and LMC \( \text{H} \text{\,II} \) regions, PN) and other ongoing work. Such studies should be crucial to reliably extend the diagnostic tools to the IR to fully exploit the enormous observational capabilities provided by recent and upcoming facilities in probing the properties of massive star formation from the local Universe to high redshift.

Acknowledgements I thank the organisers for this very interesting and stimulating workshop and for financial support. Part of this work is also supported by the INTAS grant 97-0033.

References
1. Ali, B., et al., 1995, AJ, 110, 2415
2. Bica, E., Alloin, D., 1986, A&A, 162, 21
3. Boisson, C., et al., 2000, A&A, 357, 850
4. Bruzual, G.A., Charlot, S., 1993, ApJ, 405, 538
5. Campusano, L., et al., A&A, submitted
6. Cerviño, M., Mas-Hesse, J.M., 1994, A&A, 284, 749
7. Cerviño, M., et al., 2000, A&A, 360, L5
8. Cid Fernandes, R.Jr., et al., 1998, MNRAS, 297, 579
9. Colbert, J.W., et al., 1999, ApJ, 511, 521
10. de Mello, D.F., Leitherer, C., Heckman, T.M., 2000, ApJ, 530, 251 (DLH00)
11. Díaz, A.I., 1988, MNRAS, 231, 57
12. Fanelli, M.N., O’Connell, R.W., Thuan, T.X., 1987, ApJ, 321, 768
13. Fanelli, M.N., et al., 1992, ApJS, 82, 197
14. Förster-Schreiber, N., 1998, PhD thesis, Ludwig-Maximilian Universität, München
15. Fullerton, A., et al., 2000, ApJ, 538, L43
16. García-Vargas, et al., 1998, A&AS, 130, 513
17. García-Vargas, M.L., et al., 1997, ApJ, 478, 112
18. Genzel, R., et al., 1998, ApJ, 498, 579
19. Giradi, L., Bertelli, G., 1998, MNRAS, 300, 533
20. González Delgado, R.M., 1997, ApJ, 489, 601
21. González Delgado, R.M., 1999, ApJS, 125, 489
22. González Delgado, R.M., et al., 2000, ApJ, in press (astro-ph/0008417)
23. González Delgado, R.M., Pérez, E., 2000, MNRAS, in press (astro-ph/0003067)
24. Guseva, N., Izotov, Y.I., Thuan, T.X., 2000, ApJ, 531, 776
25. Haser, S.M., et al., 1998, A&A, 330, 285
26. Heap, S.R., 2000, in “Evolution of Galaxies. I. Observational clues”, Eds. J.M. Vilchez, G. Stasinska, Astrophysics and Space Science, in press.
27. Heckman, T.M., Leitherer, C., 1997, AJ, 114, 69
28. Heckman, T.M., et al., 1997, ApJ, 482, 114
29. Heckman, T.M., et al., 1998, ApJ, 503, 646
30. Kleinmann, S.G., Hall, D.N.B., 1986, ApJS, 62, 501
31. Kunkel, D., Contini, T., 1999, IAU Symp. 193, 725
32. Lancon, A., Rocca-Volmerange, B., 1992, A&AS, 96, 593
33. Lancon, A., Mouhcine, M., 2000, in “Massive Stellar Clusters”, Eds. A. Lancon, C.M. Boily, ASP Conf. Series, 211, 34
34. Langer, N., Maeder, A., 1995, A&A, 295, 685
35. Leitherer, C., Lamers, H., 1991, ApJ, 373, 89
36. Leitherer, C., et al., 1995, ApJS, 99, 173
37. Leitherer, C., et al., 1999, ApJS, 123, 3 (Starburst99)
38. Leitherer, C., et al., 2000, ApJ, in press (astro-ph/0012358)
39. Luridiana, V., et al., 1999, ApJ, 527, 110
40. Luridiana, V., et al., 2000, ApJ, submitted
41. Lipari, S., et al., 2000, ApJ, in press (astro-ph/0007316)
42. Maeder, A., Meynet, G., 2000b, ARAA, 38, 143
43. Mas-Hesse, J.M., Kunkel, D., 1991, A&A, 349, 399
44. Mas-Hesse, J.M., Kunkel, D., 1999, A&A, 349, 765
45. Mayya, Y.D., 1998, ApJ, 482, L149
46. Olofsson, K., 1995, A&AS, 111, 57
47. Origlia, L., et al., 1993, A&A, 280, 536
48. Origlia, L., et al., 1999, ApJ, 514, 96
49. Pettini, M., et al., 2000, ApJ, 528, 96
50. Raimann, D., et al., 2000a, MNRAS, 314, 295
51. Raimann, D., et al., 2000b, MNRAS, 316, 559
52. Robert, C., et al., 1999, in preparation
53. Salu, M.S., 1998, AJ, 116, 1205
54. Satyapal, S., et al., 1998, in preparation
55. Schaerer, D., 1999a, IAU Symp. 193, 539
56. Schaerer, D., 1999b, in “Spectrophotometric Dating of Stars and Galaxies”, I. Hubeny, S.R. Heap, R.H. Cornett (eds.), ASP Conf. Series 192, p. 49 (astro-ph/9907164)
57. Schaerer, D., 2000, in “Stars, Gas and Dust in Galaxies: Exploring the Links”, Eds. D. Alloin, G. Galaz, K. Olsen, ASP Conf. Series, in press (astro-ph/0007307)
58. Schaerer, D., Contini, T., Kunth D., 1999a, A&A, 341, 399
59. Schaerer, D., Contini, T., Pindao M., 1999b, A&AS, 136, 35
60. Schaerer, D., Guseva, N., Izotov, Y.I., Thuan, T.X., 2000, A&A, 362, 53
61. Schaerer, D., Stasińska, G., 1999, A&A, 345, L17
62. Schaerer, D., Vacca, W. D. 1998, ApJ, 497, 618
63. Sekiguchi, K., Anderson, K.S., 1987, AJ, 94, 644
64. Serote Roos, M., et al., 1998, MNRAS, 301, 1
65. Stasińska, G., Leitherer, C., 1996, ApJS 107, 661
66. Stasińska, G., Schaerer, D., 1999, A&A, 351, 72
67. Stasińska, G., et al., 2000, A&A, submitted
68. Storchi-Bergmann, T., et al., 1995, ApJS, 98, 103
69. Storchi-Bergmann, T., et al., 1998, ApJ, 501, 94
70. Taesch, G., et al., 1998, A&A, 320, 500
71. Teplitz, H.I., 2000, ApJ, 542, 1
72. Terlevich, E., et al. 1990a, MNRAS, 242, 48
73. Terlevich, E., et al. 1990b, MNRAS, 242, 271
74. Terlevich, R., et al. 1991, A&AS, 91, 285
75. Thornley, M.D., et al., 2000, ApJ, 539, 641
76. Tran, H.D., et al., 1999, ApJ, 516, 85
77. Tremonti, C., et al., 2000, ApJ, submitted
78. Walborn, N.R, et al., 1985, IAU Atlas of O type spectra from 1200 to 1900 Å, NASA Ref. Publ. 1155