

# BURSTING STAR FORMATION AND THE OVERABUNDANCE OF WOLF-RAYET STARS

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## Abstract

The ratio of the number of WR-stars to their OB progenitors appears to be significantly higher in some extragalactic systems than in our Galaxy. This overabundance of WR-stars can be explained as a consequence of a recent burst of star formation. It is suggested that this burst is the manifestation of a long period nonlinear oscillation in the star formation process, produced by positive feedback effects between young stars and the interstellar medium. Star burst galaxies with large numbers of WR-stars must generate  $\gamma$ -fluxes but due to the distance, all of them are beyond the reach of present-day ray detectors, except probably 30 Dor.

1. Introduction. Supersonic stellar winds from luminous early-type stars create shocks in the interstellar medium that could be agents of cosmic ray acceleration. The Wolf-Rayet phase in the evolution of massive stars is especially important because of the extremely high mass loss rates and wind terminal velocities. O-stars are the exciting sources for the ionized gas in which the particles are trapped.  $\gamma$  rays are generated by the interaction of the relativistic particles with the interstellar medium. It is generally accepted that the ratio of WR-stars to blue supergiants in the solar neighborhood is close to 0.1. Assuming a Conti formation scenario, described in section 2, for all single stars of more than  $20 M_{\odot}$ , this ratio corresponds with a continuous star formation rate. However, higher ratios are found in some external galaxies, especially in giant HII regions and blue compact galaxies.

It is argued in this paper, that a local overabundance of WR-stars can be explained by a recent burst of star formation in that location. The interaction of the local CR fluxes provoked by WR stars in these bursting galaxies with molecular clouds surrounding the star-formation region could then be a source of  $\gamma$  rays.

2. The Wolf-Rayet production scenario. WR-stars can originate from massive stars through mass loss during the main sequence phase (Conti, 1975) or during the red supergiant phase (Maeder, 1981, 1982) or through Roche lobe overflow in close binary systems (de Loore, 1980). According

to the Conti scenario single O-stars evolve into Of-stars, that are further transformed into WN7-stars, normal WN-stars and possibly into WC-stars. The lifetime of the WR stage is short. According to the evolutionary computations for massive stars ( $M > 50 M_{\odot}$ ) that include mass loss, extended mixing and a detailed nucleosynthesis network (de Loore et al. 1985, Prantzos et al. 1985) the duration of the WR stage including all subtypes, is approximately  $4 \cdot 10^5$  years, i.e. about 10 % (for a  $100 M_{\odot}$  star) to 8 % (for a  $60 M_{\odot}$  star) of the total stellar lifetime.

The minimum initial mass of a WR-progenitor is difficult to estimate but should be approximately between 20 and  $40 M_{\odot}$  (Schild and Maeder, 1984; Conti et al. 1983) in our Galaxy. However, in low-metallicity regions, such as the Magellanic Clouds and blue compact galaxies, the production efficiency of single WR-stars through radiation driven mass loss may be considerably lower, leading to a much higher minimum initial mass within these systems (Pylyser et al. 1984).

### 3. Nonlinearities in the star formation process system.

Assuming a production scenario, the number of WR-stars in a region depends on the star formation rate and the initial mass function. Large variations in the star formation rate could lead then, with a time delay of the order of the main O-star lifetime, to considerable deviations in the WR/O ratio. Rapid changes in the star formation rate can occur as a consequence of positive feedback effects operating in the process system of a star formation region.

Triggered star formation by the emissions of previously formed young stars (e.g. Elmegreen and Lada, 1977) is a kind of autocatalysis that destabilizes the star formation process system. Another positive feedback may operate as a consequence of molecular cooling and shielding from UV radiation in molecular clouds, leading to low cloud temperatures. Hence, collapse of these clouds can occur, so that more molecules are produced through the increased density in the cloud.

Bodifee and de Loore (1985) have shown by model calculations of a star formation region, that nonlinear oscillations may occur under certain circumstances. Under the influence of the different timescales of the processes involved, various behavioral regimes of the star formation system may occur. Within certain ranges of the relevant parameter values the stationary state is unstable and develops limit cycle oscillations. For large values of the efficiency coefficient of triggered star formation, limit cycles are produced, exhibiting long quiescent periods, interrupted by short and violent bursts of star formation.

Star formation events that are observed in some low-metallicity dwarf galaxies, and in the nuclei of some emission-line galaxies may be manifestations of this bursting mode.

#### 4. Star formation bursts and abnormal WR abundances.

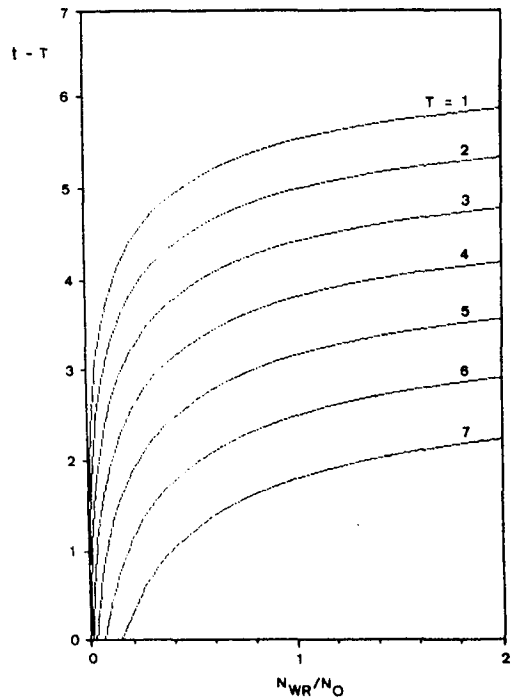
The sudden variations in the star formation rate that are inherent to a burst can lead to abnormal WR/O ratios. Shortly after the start of the burst, when massive O-stars are formed, but not yet enough time has elapsed to let them evolve into WR-stars, abnormal low values may be expected. On the other hand, after the burst, the O-star number decreases but the production of WR-stars still goes on for some time, so that high values may be attained. The figure shows the WR/O ratio for a time  $t-T$  after a burst of duration  $T$ , based on calculations that assume only the Conti-scenario as a way for WR production.

More diversified scenarios can alter the numbers somewhat, but the conclusion remains quantitatively the same: shortly after a burst there is an overabundance of WR stars with respect to the WR/O ratio in our Galaxy. Although the results of the figure should not be overinterpreted in a quantitative sense, it is interesting to relate them to the high HeII emission lines that are observed in some blue compact galaxies and giant extragalactic HII regions. Kunth and Sargent (1981) observed a large  $I(4686)/I(H\beta)$  in Tololo 3. If the strong HeII emission feature in this galaxy is ascribed to a population of WN4-5 stars, the number of WR-stars can be estimated at 150.

Assuming that only O-stars ionize the gas, they derive the presence of 375 O9-4 stars from the  $H\beta$  flux. The number ratio of about 1/2 could indicate the end of a short burst, 5-6 million years ago. High  $I(4686)/H\beta$  values are observed in some other star burst regions, such as IZw36 (Viallefond and Thuan, 1983), IZw18 (Bergeron, 1979; Kinman and Davidson, 1981), He2-10 (Allen et al. 1976; Hutsemekers and Surdej, 1984), IIZw70 (Lequeux et al. 1979), NGC604 (D'Odorico and Rosa, 1981; D'Odorico et al. 1983) and in some HII regions of NGC300 (D'Odorico et al. 1983).

#### 5. Star burst regions as $\gamma$ -sources.

In the galactic Carina OB association (distance 2.5 kpc), three  $5$  WR-stars are present, and the HII mass is determined at  $10^5 M_{\odot}$  (Dorland et al. 1985). COS-B observed a flux of  $1.3 \cdot 10^{-6}$  photons  $\text{cm}^{-2} \text{s}^{-1}$  from this region (Bignami and Hermsen, 1983). The flux of a region can be put proportional to the number of WR-stars, and to the HII mass within the region (from Montmerle



and Cesarsky, 1981), where the HII mass is a function of the age of the cluster. The  $\gamma$  intensities of the galaxies mentioned in the previous paragraph can then be roughly estimated. It turns out that all these sources are far too weak to have been observed as individual sources by COS-B (In fact, only one extragalactic object has been observed, the 3C273 quasar).

6. Conclusion. A star formation region may undergo repetitive bursts as a consequence of the intrinsic nonlinear dynamics of the star formation process system. The interaction of the energetic outflows of massive young stars with the interstellar medium make a star formation region a site of CR acceleration and  $\gamma$  sources. The high energy phenomena will happen especially during a short time after a burst, when the region is unusually rich in WR-stars. Only 30Dor, however, is within the reach of  $\gamma$  satellites to be launched in the near future.

#### References

- Allen, D.A., Wright, A.E. Goss, W.M., 1975, Month.Not.R. Astron.Soc., 77,91
- Bergeron, J., 1977, Astroph.J. 211,62
- Bignami, G.F., Hermsen, W., 1983, Ann.Rev.Astron.Astroph.21,67
- Bodifee, G., de Loore, C., 1985, Astron.Astroph.,142,297
- Conti, P.S., 1975, Mem.Soc.Roy.Sci.Liege, IX,193
- de Loore, C.,1980, in "Effects of Mass Loss on Stellar Evolution, IAU Coll. 59, C. Chiosi and R.Stalio eds.,p 405
- de Loore, C., 1985, Prantzos, N., Arnould, M., Doom, C., 1985 5th Noriond Astroph.Meeting, J.Audouze, J. Tran Thanh Van,eds.
- D'Odorico, S., Rosa, M., 1981 Astroph.J., 248,1015
- D'Odorico, S., Rosa, M., Wampler, E.J., 1983, Astron.Astroph. Suppl. 53, 97.
- Dorland, H., Montmerle, T. Doom, C., 1985, Astron. Astroph. in press.
- Elmegreen, B.G., Lada, C.J., 1977, Astroph. J., 214,725
- Hutsemekers, D., Surdej, J., 1984 Astron.Astroph., 133,209
- Kinman, T.D., Davidson, K., 1981, Astroph.J., 243,127
- Kunth, D., Sargent, W.L.W., 1981, Astron.Astroph., 101,L5
- Lequeux, J., Peimbert, M., Rayo, J.F., Serrano, A., Torres-Peimbert, S., 1977, Astron. Astroph.,80,155
- Maeder, A., 1981, Astron.Astroph., 99,97
- Maeder, A., 1982, Astron.Astroph., 105,149
- Montmerle, T., Cesarsky, C.J., 1981, Proc.Int. School and Workshop and Plasma Astroph., Varenna, ESA SP-161,319
- Prantzos, N., de Loore, C., Doom, C., Arnould, M., 1985, in 5th Noriond Astroph. meeting, J.Audouze, J.Tran Thanh Van,eds
- Pyllyser, E., de Loore, C., Doom, C., 1984, Proceedings of the Coll. Birth and Evolution of massive stars and stellar systems, W. Boland, H. Van Woerden, eds.
- Schild, H., Maeder,A., 1984, Astron.Astroph., 136,237
- Viallefond, F., Thuan, T.X., 1983, Astroph.J. 269, 444
- Walborn, N.R., 1983, Proc. of the IAU Symposium 108, Reidel, Dordrecht