The Reversed Field Pinch (RFP) is a magnetic configuration for the confinement of plasmas of thermonuclear interest [1]. The appeal of the RFP for fusion purposes is that the configuration owes its persistence in time to magnetic self-organization processes, which are responsible for the spontaneous production of a significant fraction of the confining magnetic field. This strongly reduces the need for complicated, and expensive, external coil systems and makes the plasma less prone to disruptive phenomena in comparison with tokamaks since much less free energy is available.

In the last years a significant effort of the RFP community has been dedicated to the study of helical RFP states. This is based on the theoretical prediction that the RFP plasma can spontaneously access, through a self-organization process, the Single Helicity (SH) regime [2]. In this condition the dynamo needed to sustain the RFP configuration is driven by an individual $m=1$ saturated resistive kink and has a laminar character. Closed magnetic flux surfaces are preserved in the SH regime. The SH state is naturally resilient to the magnetic chaos and this is therefore beneficial for plasma confinement. Given the potential benefit of a self-organized, non-chaotic RFP configuration, we have started an experimental and theoretical project, which involves several RFP devices and numerical codes. This initiative is devoted to collect and organize all the QSH evidence in a unique database to study QSH in a variety of different conditions and to control and optimize this helical regime. In this paper we report the results of a QSH study performed in the

![Fig. 1](a) Multiple and (b) Quasi Single Helicity ($m=1,n$) magnetic spectra from the standard discharge # 13216 (see Fig. 2).
EXTRAP-T2R [3] is a medium-sized RFP \((R/a = 1.24 \text{ m} / 0.18 \text{ m})\) characterized by a shell penetration time to vertical magnetic fields of approximately 6.3 ms. EXTRAP-T2R is operated at plasma currents between 50 and 120 kA, with a resistive toroidal loop voltage of 25 V and a pulse duration up to 20 ms. The electron density is in the range \(0.5-2.0 \times 10^{19} \text{ m}^{-3}\) without the use of a gas refuelling system. The relevance of these results for the QSH multi-machine database is strengthened by the fact that they have been obtained in a large aspect ratio device \((A=R/a = 6.8)\) equipped with a thin resistive shell. A large \(A\) is certainly preferable in a fusion perspective in terms of machine accessibility and technological simplicity. The drawback is that the RFP equilibrium is such that a large aspect ratio configuration has a richer spectrum of \(m = 1\) and \(m = 0\) dynamo modes [4], which in principle makes harder the task of controlling their amplitude and reaching a monochromatic spectrum. The thin resistive shell is also important in fusion perspective, since it allows direct active control of MHD instabilities, but it is also source of resistive wall modes (RWM), which might contribute to pollute the \(m=1\) modes spectrum. RWM are not up to now a very severe issue for T2R, and do not prevent plasma duration up to three times the shell penetration time [5].

Our results show that QSH spectra can be obtained in EXTRAP-T2R: large aspect ratio and resistive wall do not seem a severe problem for the onset of QSH and, hopefully, for the path towards pure SH.

A comparison between a Multiple Helicity (MH) and QSH spectrum measured in T2R is shown in Fig. 1. First of all we note that in MH condition the spectrum is rather broad, as expected for a large aspect ratio device. In QSH the \((1,-13)\) mode dominates the spectrum. The QSH phase can last for a period longer...
than several confinement times, as shown in Fig. 2, where the waveforms of various relevant quantities are shown for the discharge # 13216. Fig. 2-a shows the plasma current, while Fig. 2-b the reversal and Fig. 2-c the pinch parameters. The $m=1$ modes amplitudes, are reported in frame 2-d. We observe that at $t=5\text{ms}$ the plasma self-organizes in a QSH state, which lasts up to $t=11\text{ms}$. This kind of events are more evident when the magnetic equilibrium is such that the reversal parameter $F$ is in the range (-0.6,-0.4). These $F$ values correspond to a reversal of the toroidal field, which is deeper than in standard operation in EXTRAP-T2R, where $F=-0.2$. This result is consistent with measurements taken in the Japanese TPE-RX RFP device [6], where in low plasma current plasmas a basin of higher QSH probability is found when the magnetic field reversal is deeper than in standard cases.

The dominant mode, as also other core resonant $m=1$ modes, rotate during the QSH period, as it can be seen from Fig. 2-e where the rotation frequencies of the $m=1$ modes are reported for $n=-11/-14$. The QSH phase reported in Fig. 2 is associated with a rather quiescent phase in the plasma. Fig. 2-f shows that the amplitude of $m=0$ modes remains low and not bursty during the QSH phase. In the same period the soft x-ray emission increases over the whole plasma core, as displayed in Fig. 3. Fig. 3 reports the SXR brightness spatial profile along a plasma diameter. The SXR emission has been measured by a multichord SXR photocamera, which has been custom developed for EXTRAP-T2R [7]. The growth of the dominant mode is therefore associated with a stronger SXR emission, which is suggestive of a core plasma heating. It is interesting to note that if the reversal parameter $F$ is made very negative, i.e. if we increase the toroidal field reversal even more, we do not observe any more quiescent QSH phases. Strong relaxation events (sawteeth) are observed, very likely driven by the very peaked current density profile present in the plasma core in these conditions. In this situation there is excessive free energy and the plasma cannot steadily survive in a quiet QSH condition. As a final point it is worth reporting that QSH spectra are obtained also as a results of Pulsed Poloidal Current Drive (PPCD) experiments. PPCD experiments have been successfully performed in T2R [8]. When running strong-reversal PPCD discharges, one internally resonant tearing mode is sometimes observed to dominate the $m=1$

![Fig. 3](contour_plot_of_the_SXR_brightness_profile_as_a_function_of_impact_parameter_p_and_time_t.png)
mode spectrum, while the other internally resonant modes decrease, or remain with the same amplitudes. In this case $F$ reaches values up to $-1.5$, but in a very transient fashion. During PPCD, a single mode, $n = -14$, dominates over the others. At the SXR crash its amplitude is reduced to a level comparable to the other modes. However, later on in the discharge, an $n = -13$ QSH spectra is produced (note, as previously discussed, the strong sawtooth in the SXR signal). The transient nature of the PPCD is certainly influencing the QSH dynamics in this case, and work is ongoing to analyze this situation.

In conclusion, the EXTRAP-T2R results are promising, since QSH spectra have been observed also in the largest aspect ratio RFP devices and with a thin resistive shell. T2R results complete the worldwide database on QSH and prove that this kind of spectrum is found in all existing RFP devices, characterized by very different magnetic boundary conditions and operating regimes. Our results are also encouraging in view of the coming operation in the renewed RFX device, which has a shell thinner than in the previous device and is equipped with a set of $48$ (toroidal) x $4$ (poloidal) active coils for the control of MHD modes.

---