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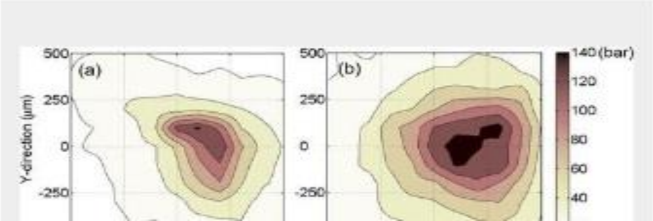

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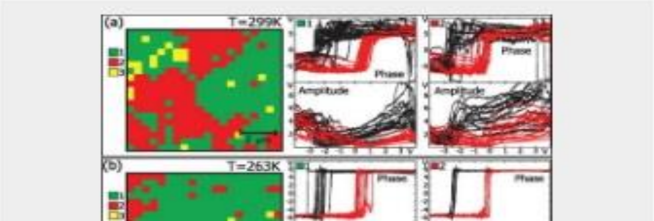

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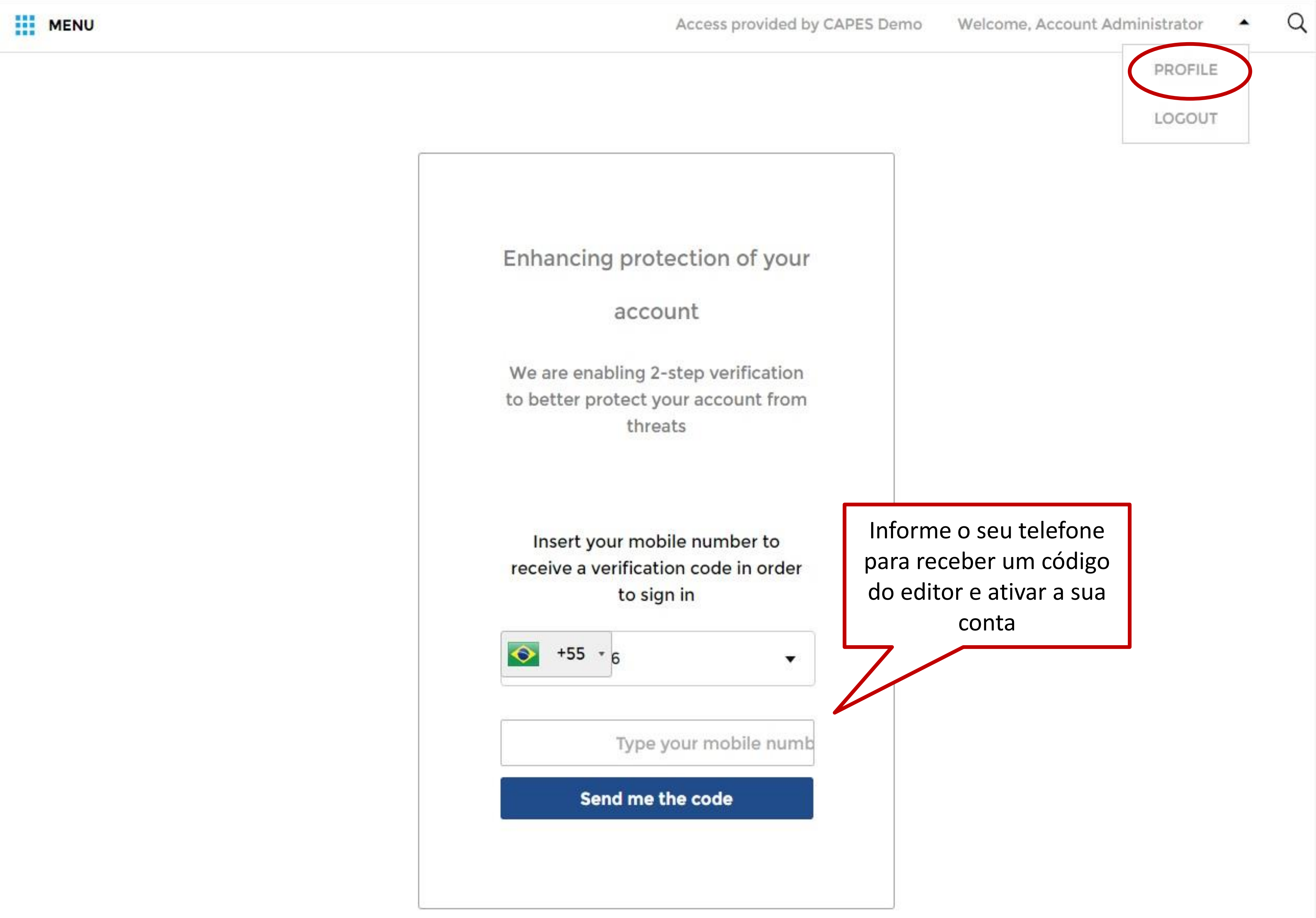
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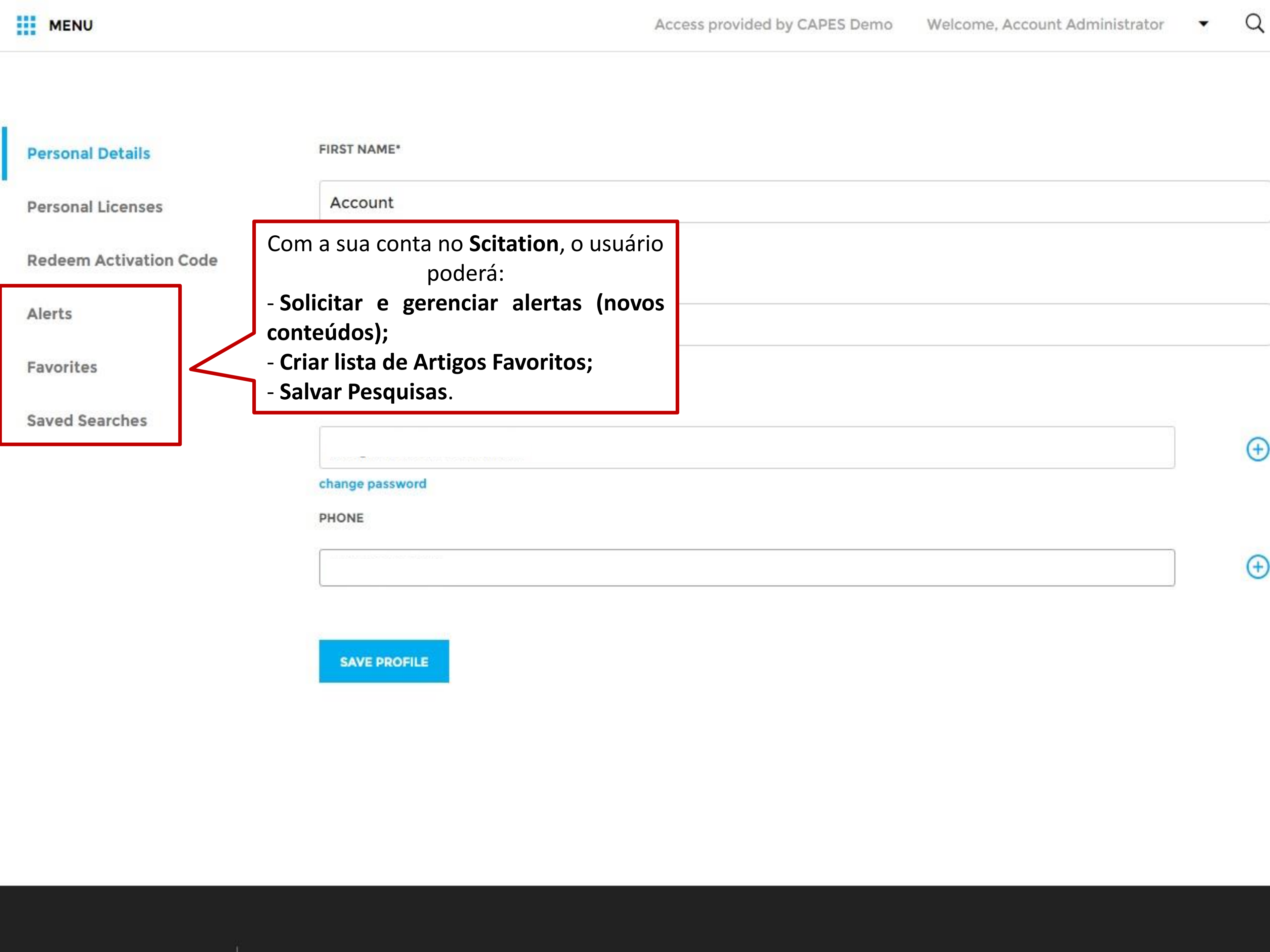

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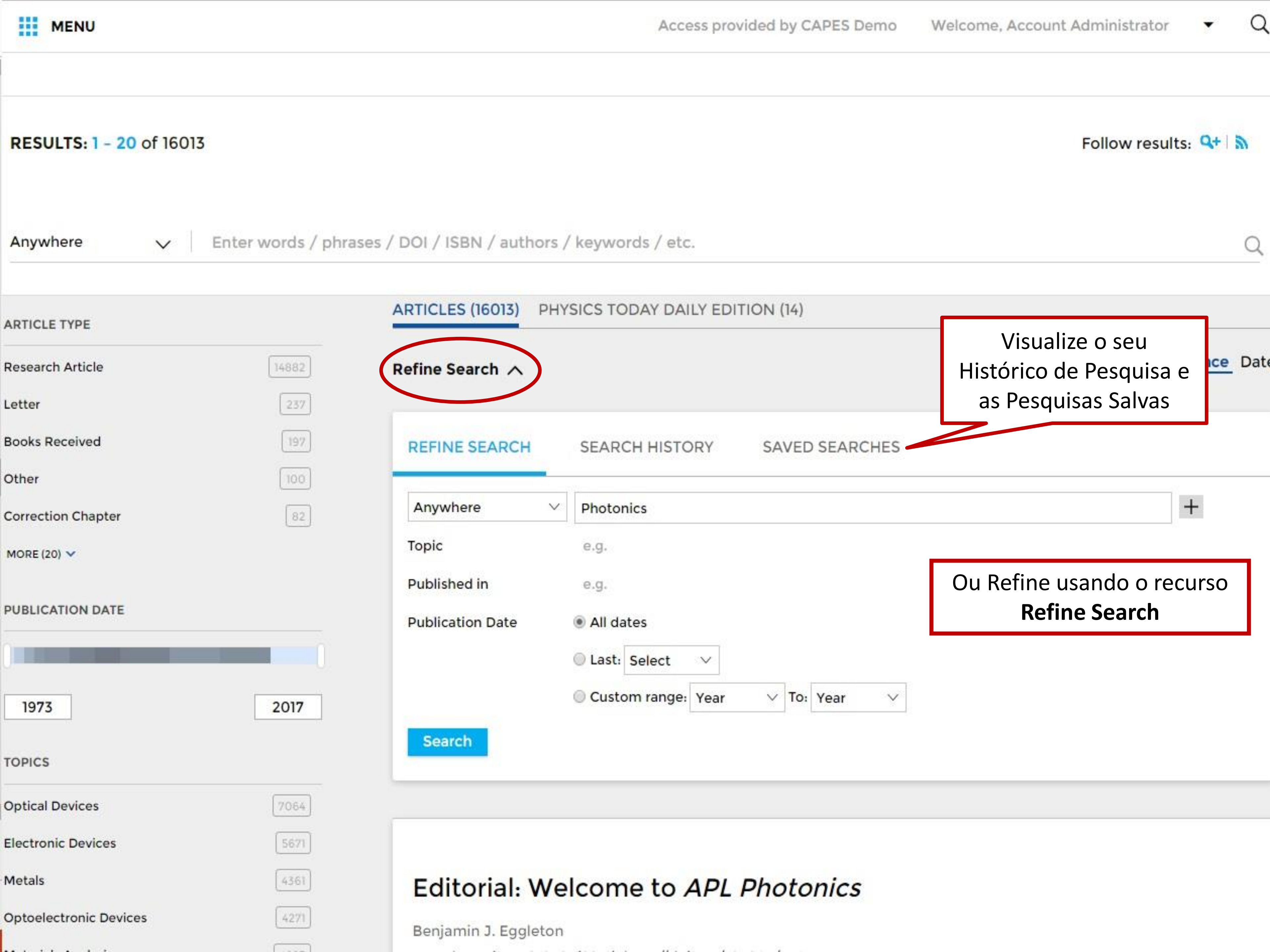
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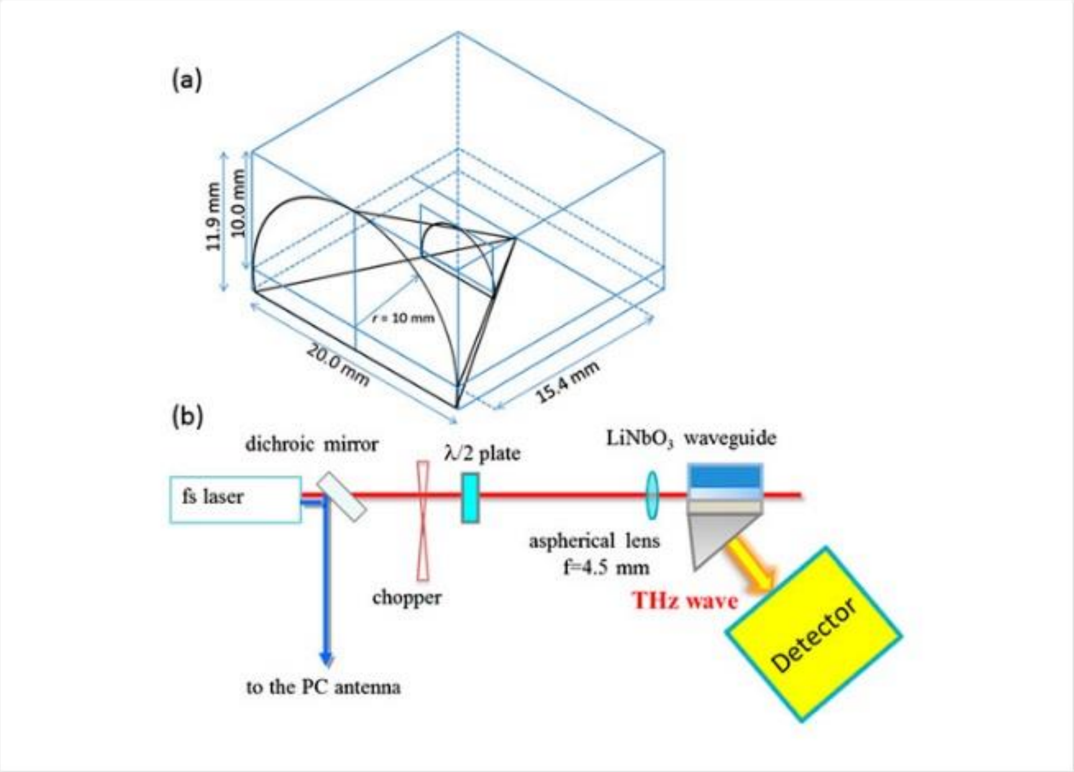

FIG. 1.

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Department of Electrical Engineering, Nagoya University, Nagoya 464-8603, Japan

(Received 16 September 2016; accepted 7 November 2016; published online 28 November 2016)

When combined with a nonlinear waveguide crystal, Cherenkov phase matching allows for highly effective generation of high power and broadband terahertz (THz) waves. Using a ridged Lithium Niobate ($LiNbO_3$) waveguide coupled with a specially designed silicon lens, we successfully generated THz waves with intensity of approximately three orders of magnitude stronger than those from conventional photoconductive antenna. The broadband spectrum was from 0.1 THz to 7 THz with a maximum dynamic range of 80 dB. The temporal shape of time domain pulse is a regular single cycle which could be used for high depth resolution time of flight tomography. The generated THz wave can also be easily monitored by compact room-temperature THz camera, enabling us to determine the spatial characteristics of the THz propagation. [http://dx.doi.org/10.1063/1.4968043]

I. INTRODUCTION

Remarkable advances in terahertz (THz) technologies have been made over recent decades. THz waves, which lie between microwave and infrared (IR) waves in the electromagnetic spectrum, have unique features. Novel THz technologies are eagerly anticipated in many fields. These include security, medicine, communication, and spectroscopy.[1,2] To further develop THz applications, we must improve sources of THz radiation so that we can obtain waves with a higher power and bandwidth. Many methods have been used to generate THz waves, for example, using plasma,[3] optical rectification using a tilted optical pulse front,[4–6] and photoconductive antenna (PCA).[7,8]

A typical application of THz waves is THz time domain spectroscopy (THz-TDS),[9] which is a spectroscopic method that employs femtosecond laser pulse excitations. Two methods based on femtosecond pulse laser pumps are widely used to generate THz waves. One is the PCA,[7,8] and the other is based on non-linear optical (NLO) crystals, which allows for the optical rectification of femtosecond laser pulses.[10–16] Although PCAs are well known to emit THz waves, there are problems with using this type of source, as this type of source has a low laser induced damage threshold. This makes it difficult to generate high power THz waves. In contrast, NLO crystal-based sources have a higher damage threshold, so we expect them to be better at generating high power THz waves. The power of THz waves generated by NLO crystals is proportional to the square of the pump laser power. Therefore, NLO crystals are suitable for high power THz generation. In this study, we used ridged lithium niobate ($LiNbO_3$) waveguide excited by high power fs laser for the emission of high power, single-cycle THz pulse.

When we use a femtosecond pulse laser with an appropriate wavelength and a crystal that has an appropriate thickness, as determined by the coherence length, we are able to generate coherent

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