The diagnosing of plasmas using spectroscopy and imaging on Proto-MPEX.

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A. McCleese[6], T.M. Biewer[1], K.A. Baldwin[2], J. Crouse Powers[3], R. Hardin[4], S. Johnson[5], G. Shaw[7], M. Showers[7], C. Skeen[8]

[1]Oak Ridge National Laboratory, Oak Ridge, TN

[2]Windsor Central High School

[3]Laurens Central High School

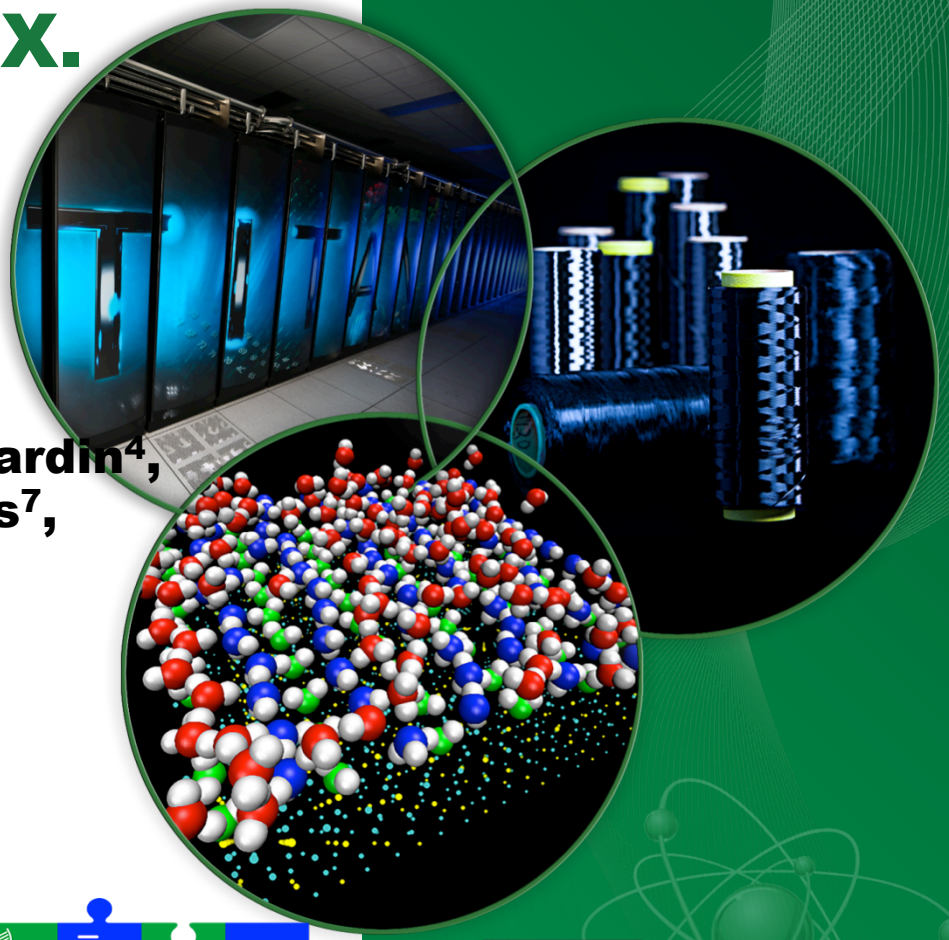
[4]Corinth High School,

[5]Nelsonvile-York High School

[6]Clay High School

[7]University of Tennessee, Knoxville, TN

[8]Oak Ridge High School, Oak Ridge, TN



SCIENCE TECHNOLOGY ENGINEERING MATH ARC/ ORNL SUMMER INSTITUTE 2015

ARC APPALACHIAN REGIONAL COMMISSION

ORAU OAK RIDGE National Laboratory

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Abstract

The Prototype Material Plasma Exposure eXperiment (Proto-MPEX) is a linear plasma device being developed at Oak Ridge National Laboratory (ORNL). This machine plans to study plasma-material interaction (PMI) physics relevant to future fusion reactors. We tested and learned to use tools of spectroscopy and imaging. These tools consist of a spectrometer, a high speed camera, an infrared camera, and a thermocouple. The spectrometer measures the color of the light from the plasma and its intensity. We also used a high speed camera to see how the magnetic field acts on the plasma, and how it is heated to the fourth state of matter. The thermocouples measure the temperature of the objects they are placed against, which in this case are the end plates of the machine. We also used the infrared camera to see the heat pattern of the plasma on the end plates. Data from these instruments will be shown.

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High School Summer Science Program

- 2014 High School Summer Math-Science-Technology Institute
  - July 11-24, 2015 at Oak Ridge National Lab.
  - http://www.orau.org/arc-ornl/2015/index.html
- Applications will be accepted for 2016 beginning in December through the state program managers of the Appalachian Regional Commission
  - http://www.arc.gov/program_areas/ARCOakRidge2015SummerPrograms.asp

OAK RIDGE National Laboratory

ARC/ORNL 2015 Team

Introduction

- Throughout the course of the 8 days spent at Oak Ridge National Laboratory, our group studied the diagnostics and creation of plasma and nuclear fusion. Among the questions, which the group attempted to answer in this experiment, were the following:
  - What is plasma & how is it generated?
  - What is nuclear fusion?
  - What makes nuclear fusion a more effective means of producing electrical power?
  - With what devices are diagnostics composed on plasma machines, and what is the importance of such devices?

What is plasma and how is it generated?

- Motivation: The first question, “What is plasma?” is extremely relevant in this experiment, because understanding the makeup of plasma will allow for researchers and scientists to understand how it is made in the laboratory setting using the MPEX system, which generates plasma from gasses such as Helium and Deuterium.

- Plasma is the 4th state of matter, and is a collection of un-bound electrons and ions, created by super-heating a gas.

What is nuclear fusion?

- Motivation: "What is nuclear fusion?" provided the group with the understanding of not only what occurs among the stars, but also what can occur when plasma is heated.

- Fusion occurs when two plasma ions collide and join together. This releases energy stored in the mass of the ions.

What makes nuclear fusion a more effective means of producing electrical power?”

- Motivation: The question of “What makes nuclear fusion a more effective means of producing electrical power?” provided an answer for the question which has existed in society since the dawn of the industrial revolution, and that is the question of which is the most effective, in terms of both human and environmental safety and economics.

- Fusion is the direct conversion of mass into energy, as described in Einstein’s equation: $E=mc^2$.

With what devices compose diagnostics on plasma machines, and what is the importance of such devices ?

- Motivation: “Which devices compose diagnostics on plasma machines and what is the importance of such diagnostics?” allowed our group to understand how information is gathered from plasmas.

- High-speed cameras, spectrometers, infrared cameras, thermocouples, and high-powered green laser were the devices as diagnostics in this experiment.

High Speed Camera

- The purpose of using the high-speed camera was so that observers could see the generation of plasma in slow-motion, as the reaction occurs in the short time span of about half a second.

- The high-speed camera used in this experiment obtains images at 18,000 frames per second, which allowed for observers to see the reaction at a much slower pace of 30 seconds so that they were able to process the information.

Laser

- The laser, a high-powered green laser, is positioned so that its light can travel through the cylindrical beam of plasma.
- The wavelength of the green light was able to be analyzed by the spectrometer in order to determine the effects on the wavelengths of light as it passes through the beam of plasma.

Spectrometer

- The spectrometer is also very important in this experiment, as it acted as an electronic eye able to see the effects of the plasma on interfering light which would have been unobservable otherwise.
- Spectrometers are able to detect wavelengths in the ultraviolet, visible color, and infrared spectrum

Thermocouple

- Temperature-measuring device consisting of two dissimilar conductors that contact each other at one spot. The temperature induces a voltage difference that is measured by the device.

Following are the steps and methods used to operate each diagnostic:

High Speed Camera set-up and use

- Select the lens that is best fit for the job, there is a wide angle lens (also known as fish eye lens) and a regular lens.
- Turn on and point the camera toward the person or objects that you want to record and adjust the focus by turning the lens.
- To change the frame rate on the camera, go to the settings on the computer and type how many frames per second and adjust the shutter speed.
- Afterwards, change the brightness/sensitivity(ISO) and recording duration.
- This device is used to watch the plasma in the linear plasma machine in slow motion, since the plasma lasts for such a short amount of time(about half a second).

Spectrometer set-up and use

- Point the light source directly at the opening in the end of the fiber optic.
- Adjust the exposure time.

- This machine shows where the light source is on the color spectrum of light and its intensity.
- This machine is used to see how plasma affects rays of light such as light from lasers and the light that the plasma emits.

Infrared Camera set-up and use

- Point camera at an object and focus by turning the lens.

- The infrared camera shows how hot objects are using the infrared spectrum.
- This is used to determine the temperature of materials that the plasma touches, such as the end plates of the machine.

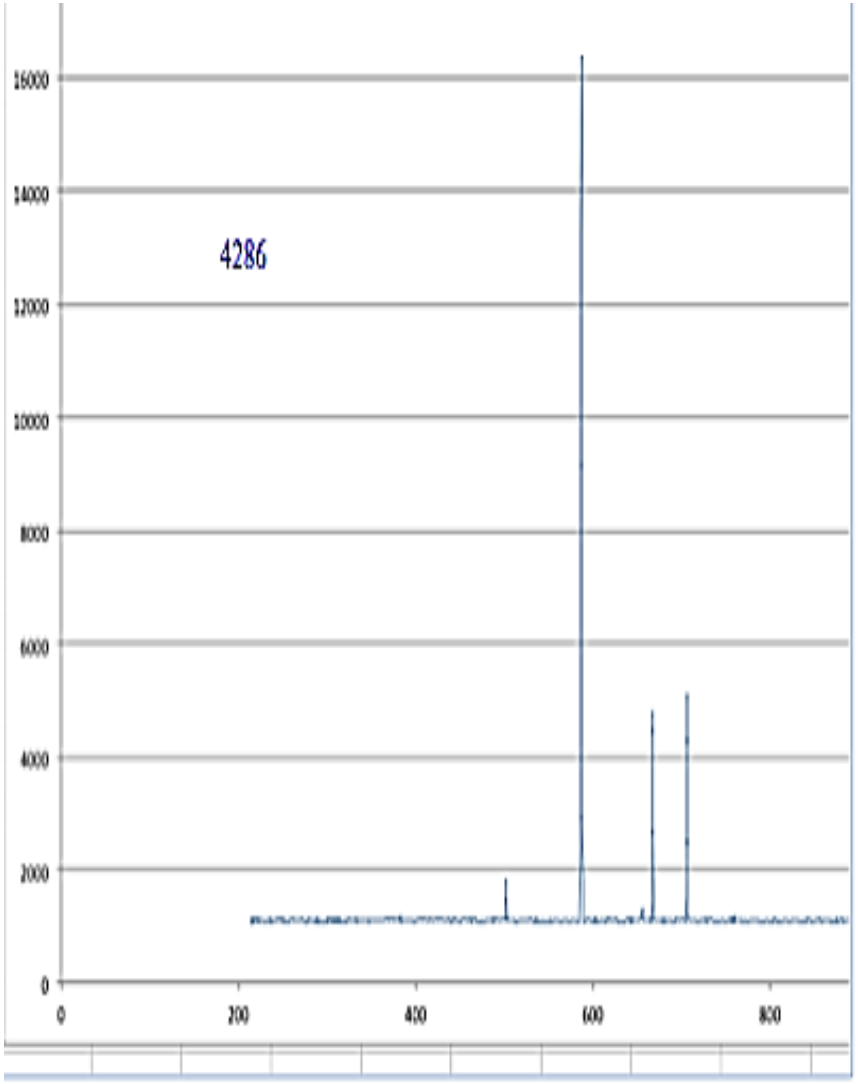
Thermocouples

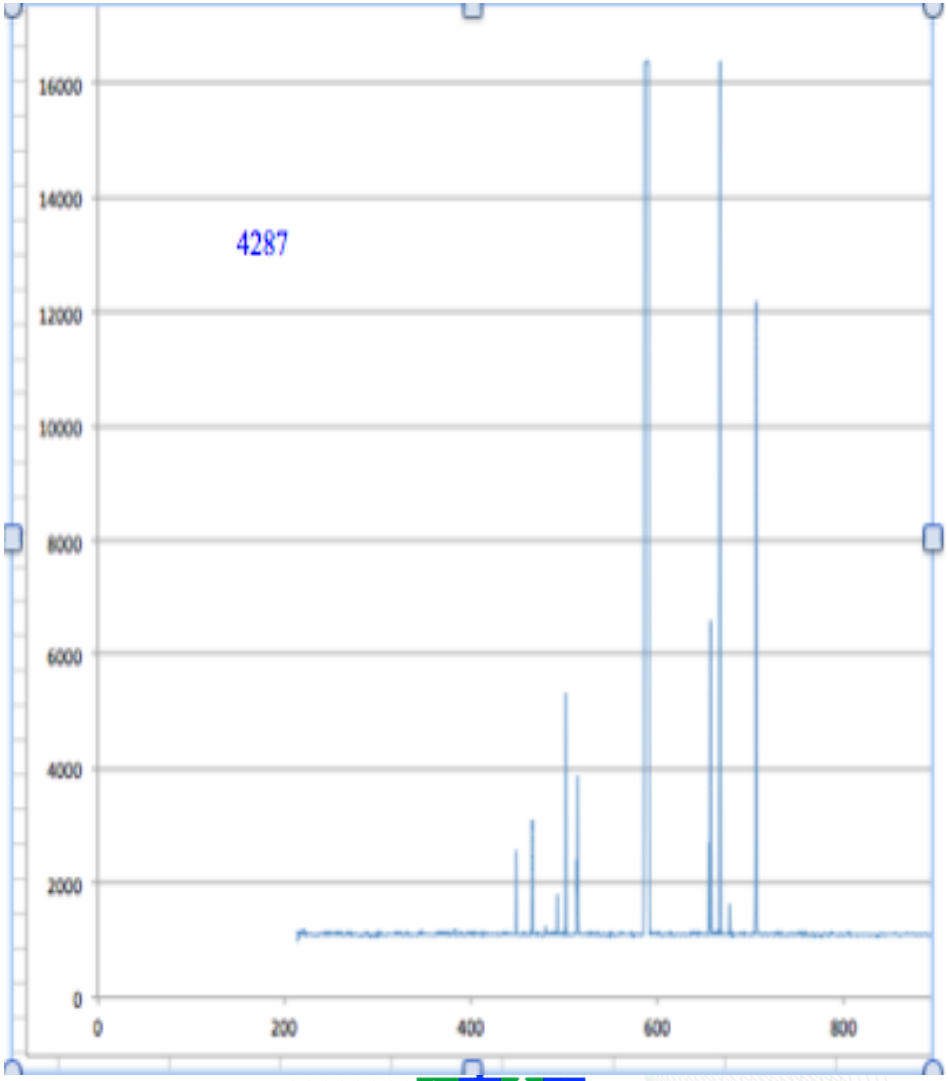
- Touch the end of the cable to any object that the temperature of what needs to be found.
- The thermocouple is used to not only take the temperature of an object (e.g. the plates), but also to test the accuracy of the infrared camera by testing to see if the same reading has been obtained for certain objects.

Overall Purpose

- The overall purpose of this experiment was to provide the group with a higher understanding of the production of plasma, diagnostics, and nuclear fusion.
- Learning about plasma physics, the use and importance of the Proto-MPEX machine and diagnostic tools has helped in obtaining a greater understanding of how plasma is made, why it is studied, and the significance thereof in powering the future.

Results





Conclusions

The first ocean optics spectrometer chart shows exactly the expected spectrum from helium plasma. The picture under it however, shows light from the helium plasma and light from additional plasma. This is most likely metal plasma (impurities) from the end plates, which are stainless steel. The thermocouples measure the excepted temperature of the dump and target plates in the machine. Both charts for the holospec spectrometer are identical leading to the deduction that the plasmas are similar to each other. The filter scopes picked up light for one specific wavelength (656nm) at many places in the machine, and the data showed the time response of the plasma as expected. This data also shows that the plasma is brightest at the helicon (the main heating system).

Future Work in the field of Plasma

- Though the ITER project, which will occur in southern France, and will be the first plasma fusion reactor expected to achieve “break even”, is still a few years away, the understanding of the above topics will allow for the group to also comprehend the events which will occur throughout, and after the ITER project has expired.

A little bit about Plasma

- Break even is when the machine produces as much energy from fusion as it takes to create the plasma. Plasma fusion is, therefore, a scientific frontier, which remains both a mystery in some aspects, but a known scientific breakthrough in others. The study of plasma and nuclear fusion has allowed for several understandings to have occurred, and will continue to lead the scientific community into a new era of discovery.

Significance of ITER

- ITER will be the first plasma fusion reactor through which net energy will be produced.

- Plasma fusion energy is a cleaner and more efficient energy source than coal, natural gas, and even nuclear fission energy, as nuclear fusion produces about 1000 times the amount of energy as nuclear fission.

Reprints

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  - http://sprott.physics.wisc.edu/biewer/APS2015ARCposter.pdf
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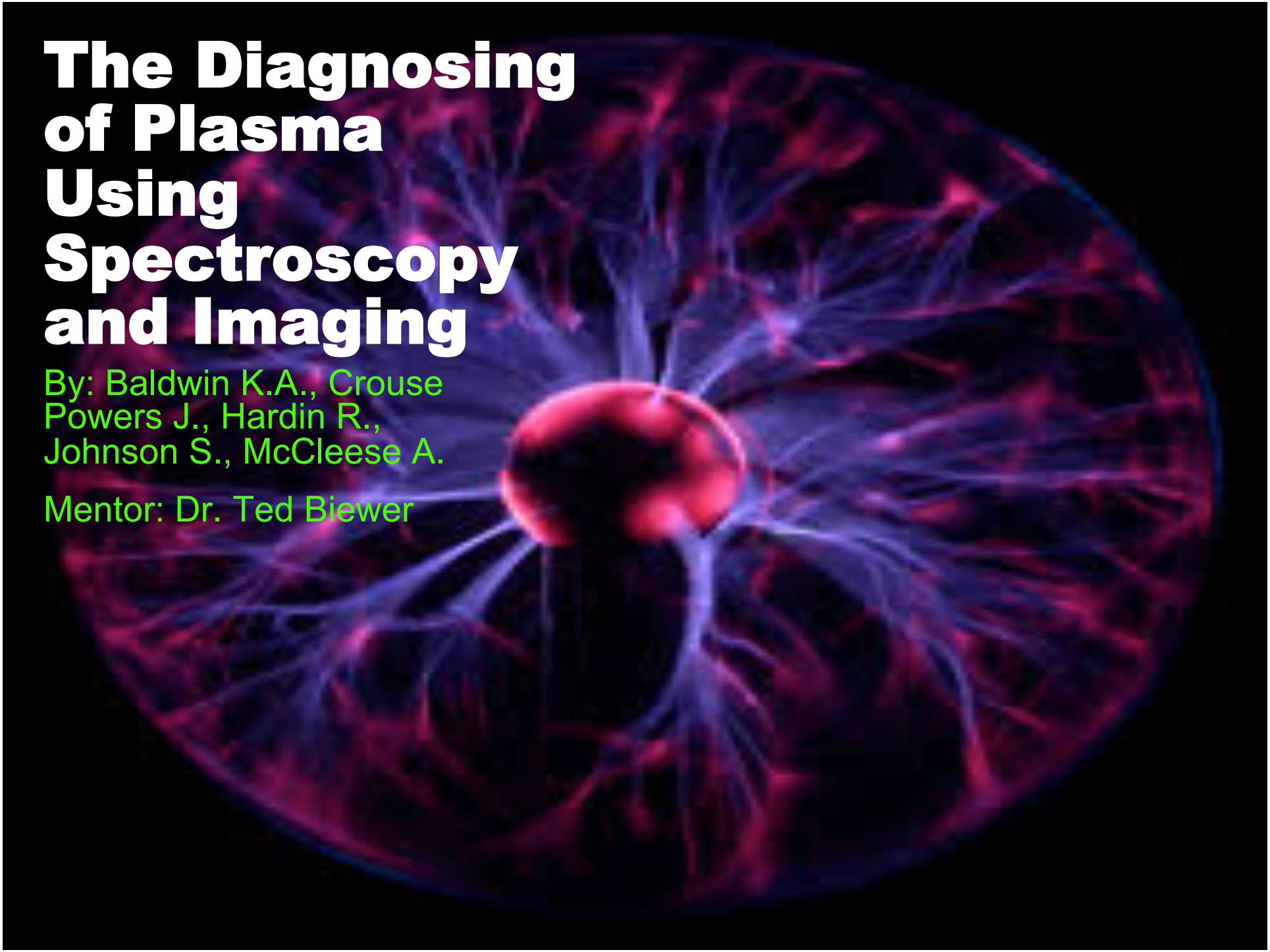
The Diagnosing of Plasma Using Spectroscopy and Imaging

By: Baldwin K.A., Crouse Powers J., Hardin R., Johnson S., McCleese A.

Mentor: Dr. Ted Biewer



Plasma is loosely described as an electrically neutral medium of unbound positive and negative particles.

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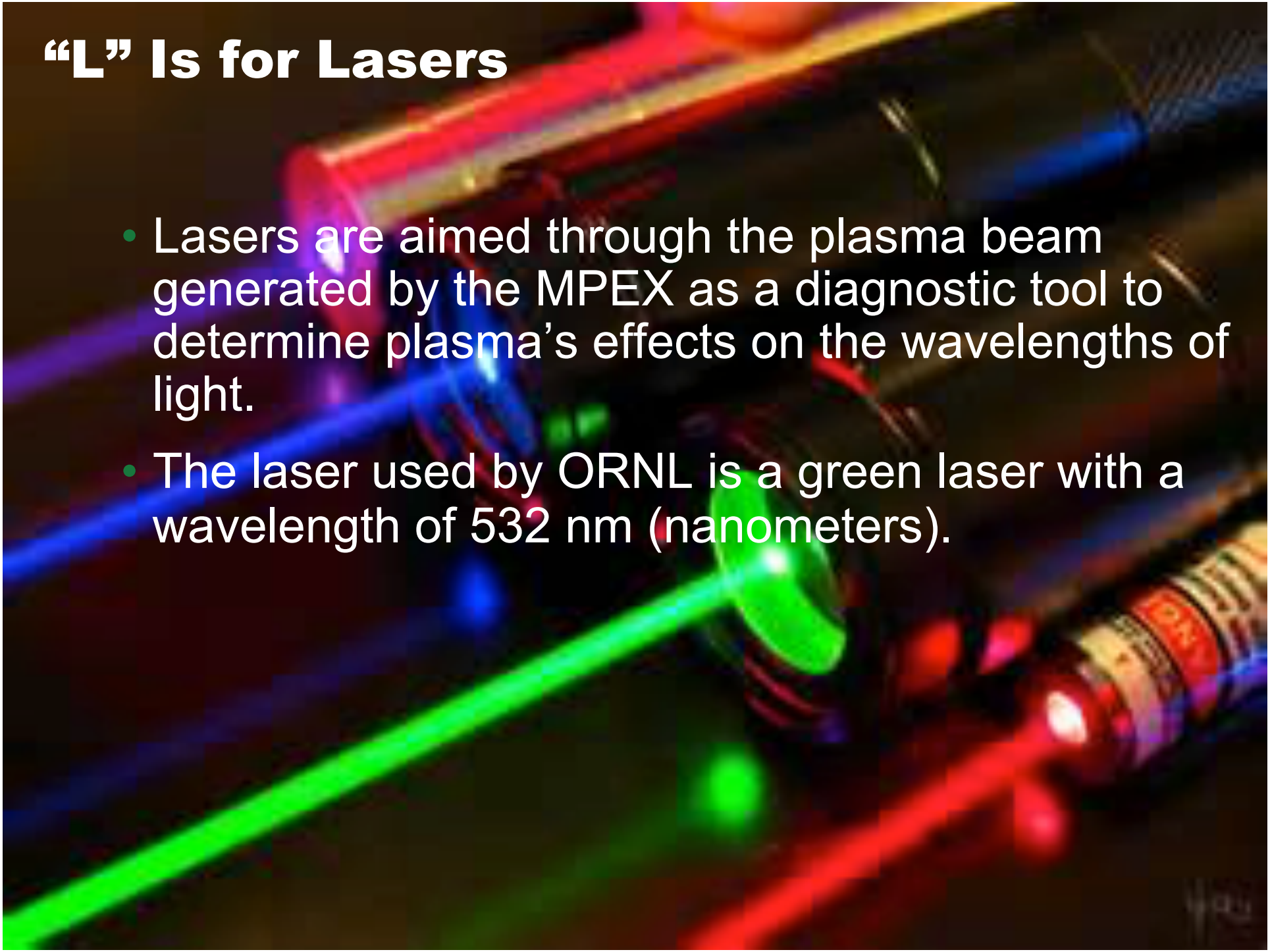
“P” Is for Photons

- Light can be described as either a particle or a wave.
- Photons are the fundamental quanta of light. Representing light in the terms of particles.
- The spectrometer operates by collecting photons.
- The more energy a photon has, the more it shifts toward the blue end of the spectrum.

“L” Is for Lasers



- Lasers are aimed through the plasma beam generated by the MPEX as a diagnostic tool to determine plasma’s effects on the wavelengths of light.
- The laser used by ORNL is a green laser with a wavelength of 532 nm (nanometers).

“A” is for Atoms

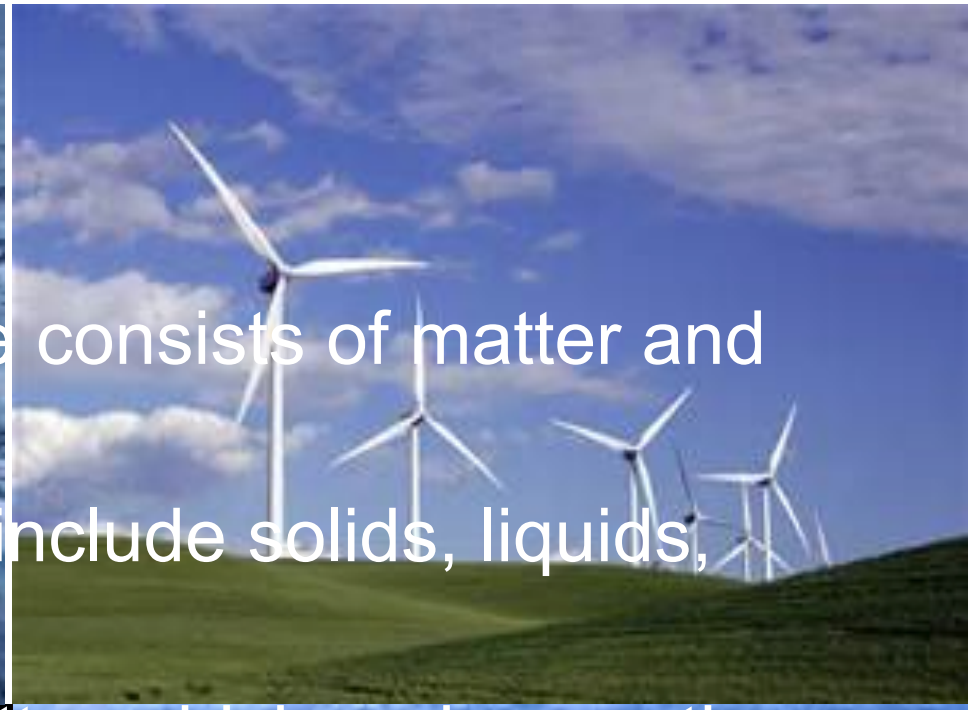
- In plasma, the fourth state of matter, the extreme heat causes an alteration in the atomic structure.
- When the atoms reach the heat level required to make plasma, the electrons become separated from the nuclei.

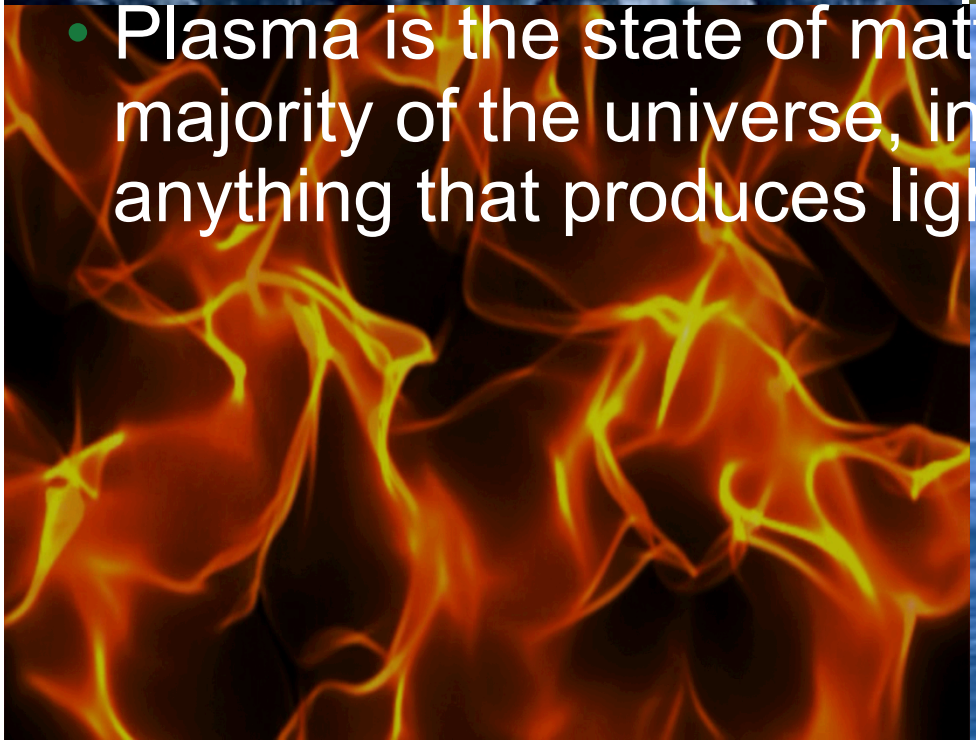
“S” Is for Spectroscopy

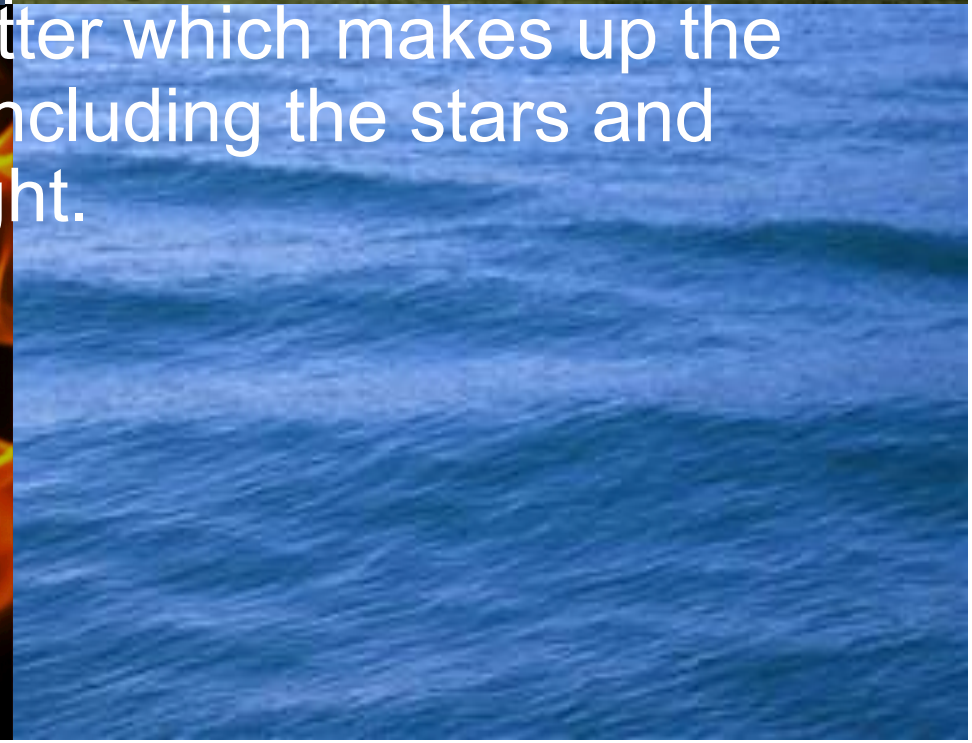
- Spectroscopy is the study of the wavelengths of light produced by the plasma.
- The wavelengths of the light span the entire spectrum-Ultraviolet, visible colors, and Infrared
- The wavelengths (colors) of light produced by plasma are dependent upon the gasses used to generate the plasma.

“M” Is for Matter

- Everything in the universe consists of matter and energy.
- The four states of matter include solids, liquids, gasses, and plasma.
- Plasma is the state of matter which makes up the majority of the universe, including the stars and anything that produces light.







“A” Is for Air

- Gas, the second least dense state of matter to plasma, is easiest to convert to plasma as it is the state of matter which requires the least amount of energy and heat in comparison to solids and liquids.
- Gasses are converted to plasma in the Proto-Mpex machine
- Among the most frequently used for conversion are the tritium, helium, and deuterium gasses.

OVERVIEW

- Plasma: What is it?
  - Fusion
- ITER and Proto-MPEX
- Diagnostic Systems: Why, What, and How?
  - Ocean Optics Spectrometer
  - Fast Camera Imaging
  - Infra-red Imaging
- Summary
- Acknowledgements