Lesson Plan
Making Waves:
France Córdova & Multiwavelength Astronomy

Portrait of Dr. France Córdova, Former NASA Chief Scientist

Image courtesy of Emilio Segrè Visual Archives.

Grade Level(s): 9-12, College	**Subject(s): Contemporary, Physics**

Supplements: Multiwavelength Astronomy

This lesson plan introduces multiwavelength astronomy, briefly covering the advantages of multiwavelength observations and important sources in each wavelength. This teaching guide can be expanded to cover a wider range of astronomical topics including, but not limited to, black holes, the interstellar medium, black body radiation, and pulsars.

In-Class Time: Approximately 50 minutes	**Prep Time: 30-60 minutes**

Materials

- *A/V Equipment*
- *Internet Access*
- *Copies of Supplemental Materials (2 Images, 1 PowerPoint, and 1 Optional Handout)*

Objective

This lesson plan introduces multiwavelength astronomy and engages students with the compelling story of Dr. France Córdova, a Latina astrophysicist who encouraged multiwavelength observations, conducted research in X-ray astronomy, led in education environments, and directed the National Science Foundation (NSF). Students will learn how multiwavelength astronomy offers detailed pictures of astronomical bodies. Furthermore, they will consider their own goals, in the context of encouragement provided by Dr. Córdova's words. This lesson plan is visually rich with several pictures and videos, in addition to lectures and written material.

Introduction

Dr. France Córdova's career was exceptional—both in her scientific research and administrative leadership (at NASA, the National Science Foundation, and several universities). Furthermore, she overcame challenges as a Latina woman in physics.

Although France Córdova was interested in English and journalism during college, she decided to switch career paths and pursue physics, after watching a program on neutron stars and viewing coverage of the Apollo 11 Lunar Landing. After earning her Ph.D. in physics from Caltech, she worked at Los Alamos and NASA, heading teams studying X-ray astronomy. She was the co-principal investigator for the Optical Monitor Digital Processing Unit on ESA's X-ray Multi-Mirror Mission (which is spaceborne on XMM-Newton). She went on to become the first female (as well as youngest ever) NASA chief scientist. After her time at NASA, she became the first Latina Director of the National Science Foundation (NSF). She has also been involved in education, both teaching and administratively leading several universities.

Dr. France Córdova contributed fundamental research to X-ray and gamma-ray observation. She recognized the importance of studying astronomical objects in many different wavelengths and encouraged multiwavelength observations of astronomical events. Accordingly, this lesson plan focuses on multiwavelength astronomy.[1]

[1] All information in this section on France Córdova is from the following two sources:

Gale Biography Resource Center, "Notable Hispanic American Women" <https://web.archive.org/web/20041222020138/http://www.gale.com/free_resources/chh/bio/cordova_f.htm > (Accessed 30 June 2020).

National Science Foundation, "Biography: Dr. France A. Córdova," <https://www.nsf.gov/news/speeches/cordova/cordova_bio.jsp > (Accessed 30 June 2020).

Different ranges of the electromagnetic spectrum contain different astronomical information. Students will learn about significant sources in each range, which are generally summarized in the following table:[2]

Astronomical Features by Wavelength Range

Type of Radiation	Astronomical Source
Microwave/Radio	Cold Interstellar Medium (ISM) Background from the Big Bang
Infrared	Active star-forming regions Warm Dust
Visible	Stars
Ultraviolet	Bright, hot stars
X-ray	Hot gas (linked to black holes and supernovae)
Gamma-ray	Accretion disks around black holes

Depending on the course level, instructors should be prepared to introduce the electromagnetic spectrum (resources for this are provided in this guide), or further related topics such as Wien's Law.

This lesson plan focuses on the topic of multiwavelength astronomy, utilizing several images and videos. The physics content is enhanced by a discussion of France Córdova's life and work in the "Elaborate" section.

Instructions/Activities

Engage: 5 Minutes

Instructors will introduce the lesson using NASA's multiwavelength image of the Milky Way.

What is the teacher doing?	What are the students doing?
Show students NASA's multiwavelength image of the Milky Way (included in the Supplemental Materials section). Ask students what they think the image is. Either by affirming student answers or by offering the information directly, explain that the graphic shows the Milky Way in different wavelengths. Challenge them to compare the images. See the footnote for image source and further information on each component image.[3]	Students examine the graphic of the Milky Way in different wavelengths and respond to the instructor's prompts.

[2] A. Fraknoi, D. Morrison and S. C. Wolff, Astronomy (OpenStax, Houston, 2016) <https://openstax.org/books/astronomy/pages/5-2-the-electromagnetic-spectrum>; The Imagine Team, "The Electromagnetic Spectrum," <https://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html> (Accessed 30 June 2020); Schneider, Extragalactic Astronomy and Cosmology: An Introduction (Springer, Berlin, 2006).

[3] Astrophysics Science Division/J.D. Myers, "Multiwavelength Milky Wave Images" <https://asd.gsfc.nasa.gov/archive/mwmw/mmw_images.html#about> (Accessed 6 July 2020).

Alternative Engage: 5 Minutes

(If students are unfamiliar with the electromagnetic spectrum) Introduce the electromagnetic spectrum with a video, such as this one.[4] This option is tailored for younger classrooms.	
What is the teacher doing? Instructor shows an introductory video on electromagnetic radiation.	**What are the students doing?** Students are introduced to electromagnetic radiation through a short video.

Explore: 10 Minutes

Students will examine the Antennae Galaxies in different wavelengths and learn what types of astronomical sources are visible in each wavelength.	
What is the teacher doing? Instruct students to visit the National Astronomical Observatory of Japan's Multiwavelength Universe Project.[5] This site has images in different wavelengths of the Antenna Galaxy. Tell students to consider the differences in each of the images and the sources of these variations. If unable to visit the site, distribute the handout on the electromagnetic spectrum in supplemental materials. Instruct students to fill out the table, which will be used in the explain section. Do not provide students with the final page of the handout as it contains the solution.	**What are the students doing?** Students are examining the Antennae Galaxies in different wavelengths and considering what information can be gained from images in different wavelengths. If instructed, read about applications and sources of different electromagnetic wavelength ranges, and fill out the table in the handout.

Explain: 15+ Minutes

Go over typical astronomical sources observable in each wavelength range (if desired, do so using the Andromeda Galaxy). For astronomy classes, this section provides an opportunity to introduce further relevant material to meet content goals. The explain section is broken up into 3 sections.	
What is the teacher doing? (Optional) Part 1: If desired, ask students what astronomical sources are observable in each subset of the electromagnetic spectrum. This step will allow students to offer information they gained during the explore section.	**What are the students doing?** 1. If instructed, students identify observable features in each subset of the electromagnetic spectrum. 2. Students listen to instructor explanation of the reference material.

[4] The Real Physics, "What is Light – Physics (Simple Explanation)," YouTube Video, 4 May 2017 <https://www.youtube.com/watch?v=BUYeQa_-ojk>.
[5] <https://www.nao.ac.jp/study/multiwave/en/>

Part 2: Project a graphic of astronomical sources by wavelength. The recommended visual for this can be found at the National Astronomical Observatory of Japan's Multiwavelength Universe Project website, the same site that was used in the Explore Section. To access it from the main page of the site, select "Wavelength Guide" from the bottom, and then select the middle tab, titled "Wavelengths and Targets." The completed table from the handout can also be used, though the "Wavelength Guide" offers more detail. As students may have not seen the wavelength guide when they were exploring the website, use this time to explain how to read the guide, noting that the astronomical source bars correspond to intervals of the electromagnetic spectrum. It may be useful to point out that frequency and temperature are correlated. (Depending on course level, introduce Wien's and other relevant laws).[6] Part 3:[7] After explaining how to use the selected reference, examine an additional galaxy in many wavelengths. Images of the Andromeda Galaxy, M31, from 5 telescopes are included in the Supplemental Materials section. Ask students to identify astronomical information contained in each image, emphasizing that all of the images combined offer astronomers a more complete view of the galaxy. This analysis can be done in groups or a whole class. The following are talking points for each image that add greater	3. If instructed, students identify astronomical information in 5 images of the Andromeda galaxy. They listen to further explanation.

[6] Wikipedia Contributors, "Wien's displacement law" <https://en.wikipedia.org/wiki/Wien%27s_displacement_law> (Accessed 2 July 2020).

[7] This activity was motivated and informed by the following sources:
IPAC/JPL-Caltech/NASA, "Multiwavelength Messier 31," <http://coolcosmos.ipac.caltech.edu/cosmic_classroom/multiwavelength_astronomy/multiwavelength_museum/m31.html> (Accessed 2 July 2020); Multiwavelength Andromeda Galaxy, <https://spaceplace.nasa.gov/review/posters/spitzer_posters/spitzer_andromeda_8x11_all.pdf> (Accessed 23 July 2020). With thanks to Dr. G. Zasowski at the University of Utah.

explanation (these can be reached either by students or provided by the instructor): • Visible: The main structure of the galaxy can be seen in visible light. Some starlight is obscured by dust lanes. Two dwarf galaxies are clearly visible. • Radio: The ring, made up in part by cold gas, is clear. Note: the strong point sources are mostly external to Andromeda, tracing objects like radio-loud quasars. • Infrared: Infrared traces star formation, which is concentrated in the spiral arms and disk. • UV: UV points are commonly hot stars. The brightest stars are short-lived bluer stars, and because of their short lifespan, they are located nearly exclusively in the same star formation regions shown in the infrared range. • X-ray: The X-ray image shows hot dust, centralized around the galaxy center where a supermassive black hole is located. Note: the small point sources are X-ray binaries.	

Elaborate: 15 Minutes

This section will introduce students to Dr. France Córdova, who encouraged multiwavelength astronomy. This elaborate section provides context for the approach to the study of galaxies investigated in this lesson plan.	
What is the teacher doing? Transition to a brief overview of the biography of Dr. France Córdova, noting her encouragement of multiwavelength observations and work on X-ray astronomy. To aid in presenting Dr. France Córdova's biography, use the PowerPoint slides which can be found in Supplemental Materials. Alternatively, the slides and presentation are also available as a narrated video on the AIP History YouTube channel.[8]	**What are the students doing?** Students learn about Dr. France Córdova. They engage with the reflection question if instructed.

[8] AIP History, "Making Waves: France Córdova & Multiwavelength Astronomy," YouTube, 5 August 2020 <https://www.youtube.com/watch?v=pHACLpcWVh0>.

An optional reflection question is found on the final slide. Students can write a response to it, or they can simply reflect on it on their own time.	

Evaluate:

There are several options for evaluation.

1. The optional handout can be assigned as pre-lecture reading to introduce students to multiwavelength astronomy. The table can be graded for completion or accuracy. Additionally, instructors can make a short quiz to check reading comprehension.
2. Students can write a short response to the reflection question. It may be useful to also have students consider takeaways from Dr. Córdova's life and work. This assignment should only be graded for completion (you may wish not read their responses, and tell students that you will not, and will only grade for completion; this may encourage them to take advantage of the reflection activity).
3. Student comprehension of multiwavelength astronomy, or other included topics, can be assessed through homework problems, quizzes or exams.

Required/Recommended Reading and Resources

Required Resources:

- National Astronomical Observatory of Japan's Multiwavelength Universe Project. This site includes explanations for astronomical sources, observable in different wavelengths. Furthermore, it offers visually-rich images of the Antenna Galaxy across the electromagnetic spectrum that students can engage with. This website will enrich both the "Explore" and "Explain" sections of the lesson plan. < https://www.nao.ac.jp/study/multiwave/en/>
- If applicable, younger groups unfamiliar with the electromagnetic spectrum can be introduced to the topic with a video, such as this one from The Real Physics, accessible on YouTube. <https://www.youtube.com/watch?v=BUYeQa_-ojk>.
- All other required resources, including 2 images, 1 Pdf of PowerPoint slides, and 1 optional handout, are located in the "Supplemental Materials" section of the lesson plan website.
    - The PowerPoint includes links to two videos, from Nautilus and Inspirefest.
    - The PowerPoint is also available as a narrated video on the AIP History YouTube Channel: <https://www.youtube.com/watch?v=pHACLpcWVh0>

Recommended Resources for Physics/Astronomy Content:

- IPAC/JPL-Caltech/NASA's "Multiwavelength Messier 31" site is an educational resource that provides further information on the Andromeda Galaxy, as observed in different wavelengths.
- NASA's Archival Site, "Multiwavelength Milky Way Images" provides further information on the images used in the Engage Activity.

Discussion Questions

One open-ended discussion question is included at the end of the Dr. France Córdova PowerPoint:

- Dr. France Córdova was interviewed by *The Hispanic Outlook in Higher Education*. In this interview, she offered advice to Hispanic American youth, saying, "At all steps of my career

there was someone saying, you're too old, too young, too inexperienced. There are naysayers. Ask yourself: What is important to me? What is my vision?"

What is your vision (either/both short term or long term)? What steps can you take now towards it?

An additional exercise can be found at the end of the Electromagnetic Spectrum Handout, which would require students to fill out a table. A completed table with the solutions is included at the end of the handout.

Further Reading and Additional Resources

Physics/Astronomy Content

- A chapter on the electromagnetic spectrum, specific to astronomy, can be found from the following Open Access textbook:
  A. Fraknoi, D. Morrison and S. C. Wolff, Astronomy (OpenStax, Houston, 2016) <https://openstax.org/books/astronomy/pages/5-2-the-electromagnetic-spectrum>.

Dr. France Córdova

- There are many short biographies available on Dr. France Córdova. Most of the information in these biographies are included in the PowerPoint presentation, however, instructors may find them useful to consult. Linked are bios from the NSF and Gale Biography Resource Center. Citations to these resources are available at the end of the PowerPoint slides.
- Further videos on France Córdova can be found on Maker's YouTube channel.

Extensions

Astronomical Extension Topics:

- There are many topical connections to the physics/astronomy portions of the lesson plan, based on the content goals of a given course. Additional topics may include black holes, ISM, black body radiation, pulsars, AGN, etc.
- Upper-division college courses may choose to examine one of her papers, such as her 2018 paper on X-ray transients (PDF).[9]

Extension Project:

- Teachers may have students complete a report on a female astronomer/astrophysicist of their choice (other than Dr. France Córdova), focusing on her life and contributions to the field. Names of contemporary women in astronomy can be found via She Is An Astronomer.[10]

Related AIP Teacher's Guides:

- "Curiosity, Creativity, Compassion: Albert V. Baez," accessible here.[11] This lesson plan covers Albert Baez's contributions to the X-ray microscope. Later in his life, he worked on early X-ray

[9] Sergey Trudolyubov, William Priedhorsky, and France Cordova, "Bright X-Ray Transients in M31: 2004 July *XMM-NEWTON* Observations," ArXiv.org (Draft version 24 November 2018) <https://arxiv.org/pdf/astro-ph/0512260.pdf>.
[10] <https://www.sheisanastronomer.org/>.
[11] <https://www.aip.org/history-programs/physics-history/teaching-guides/curiosity-creativity-compassion>

telescopes. Additional teaching guides on Latinx people in the history of the physical sciences can be found on AIP's website.

- "When Computers Wore Skirts," accessible here.[12] Like "Making Waves," "When Computers Wore Skirts" highlights the contributions of women in physics and astronomy. Additional teaching guides on women in the history of astronomy can be found on AIP's website.

Common Core Standards

For more information on Common Core Standards, visit http://www.corestandards.org/.

Speaking & Listening	
CCSS.ELA-LITERACY.SL.9-10.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9-10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
CCSS.ELA-LITERACY.SL.11-12.1	Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 11-12 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.
History/Social Studies	
CCSS.ELA-LITERACY.RH.9-10.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary of how key events or ideas develop over the course of the text.
CCSS.ELA-LITERACY.RH.9-10.5	Analyze how a text uses structure to emphasize key points or advance an explanation or analysis.
CCSS.ELA-LITERACY.RH.11-12.2	Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas.
Subject Writing (applicable for the Extension Activity)	
CCSS.ELA-LITERACY.WHST.9-10.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
CCSS.ELA-LITERACY.WHST.9-10.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
CCSS.ELA-LITERACY.WHST.9-10.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
CCSS.ELA-LITERACY.WHST.9-10.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate;

[12] <https://www.aip.org/history-programs/physics-history/teaching-guides/when-computers-wore-skirts-katherine-johnson>

	synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
CCSS.ELA-LITERACY.WHST.9-10.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
CCSS.ELA-LITERACY.WHST.9-10.9	Draw evidence from informational texts to support analysis, reflection, and research.
CCSS.ELA-LITERACY.WHST.11-12.1	Write arguments focused on *discipline-specific content*.
CCSS.ELA-LITERACY.WHST.11-12.2	Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.
CCSS.ELA-LITERACY.WHST.11-12.4	Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
CCSS.ELA-LITERACY.WHST.11-12.5	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.
CCSS.ELA-LITERACY.WHST.11-12.7	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
CCSS.ELA-LITERACY.WHST.11-12.8	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.
CCSS.ELA-LITERACY.WHST.11-12.9	Draw evidence from informational texts to support analysis, reflection, and research.

Next Generation Science Standards

For more information on the Next Generation Science Standards, visit http://www.nextgenscience.org/.
N/A