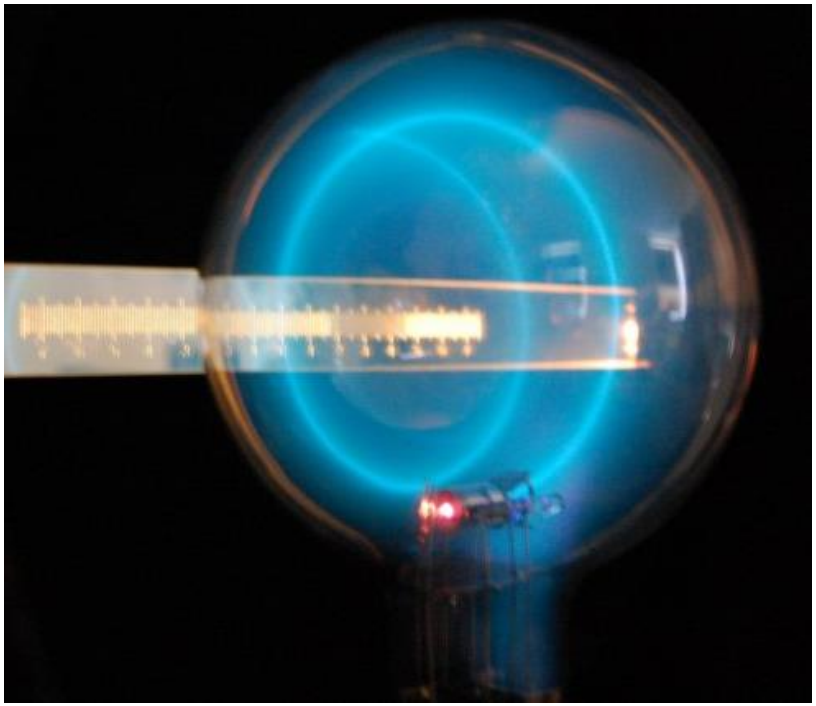
Physics 251: Atomic Physics Lab

[i.e. measurements, uncertainties, waves, light, quanta]



[ixnovi.people.wm.edu]

[wikiwand.com]

Instructors

Prof. Seth Aubin

Office: room 255, Small Hall, tel: 1-3545
Lab: room 069, Small Hall (new wing), tel: 1-3532

e-mail: saaubi@wm.edu
web: http://www.physics.wm.edu/~saubin/index.html

Office hours: Tuesday 12-1 pm & open office hours.

Mariami Bagishvili (TA: Wednesday section)

e-mail: mbagishvili@wm.edu
Office hours: Fridays 2:30-3:30 pm in room 133.

Alexandru Sturzu (TA: Thursday section)

e-mail: amsturzu@wm.edu
Office hours: Fridays 2:30-3:30 pm in room 133.

Course Objectives

- Introduce basic **experimental methods.**
- Use **error analysis** and **data analysis** methods.
- Experiments that probe the **wave** and **quantized** nature of **light & matter.**
- Scientific **communication.**

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- Optical sources (lasers, spectroscopy lamps, etc).
- Optical measurements (photodiodes, spectrometers, etc).
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- Data analysis: plots, fitting data, statistics, etc.
- Error analysis: evaluating uncertainties, error propagation.

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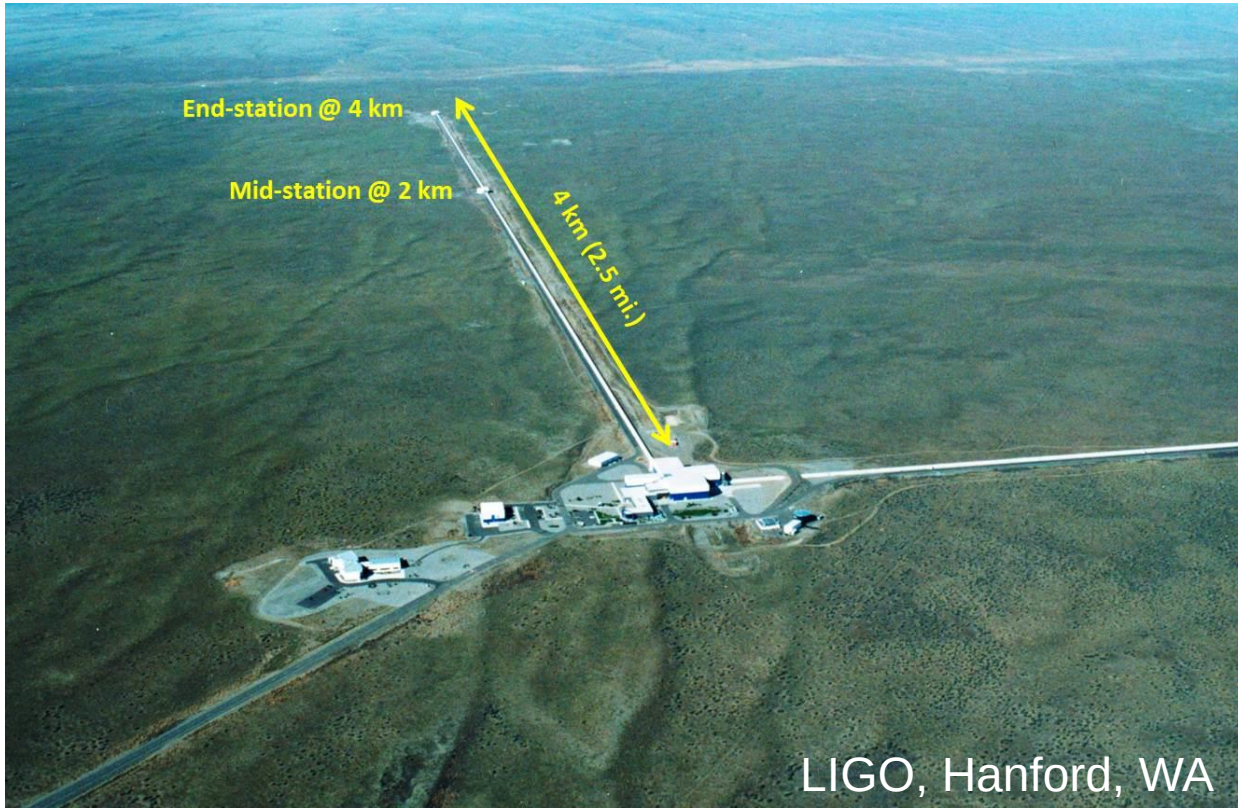
- Scientific communication: writing and presentations.
- Lab book note keeping.

Light as a Wave: Application

LIGO: *Laser Interferometer* Gravitational-wave Observatory

- World's largest laser interferometer
- Most precise measurement of length changes: 10^{-19} m
  → 1/10,000th the radius of proton.



[ligo.caltech.edu, 2022]

Course Work

- **Lab report:** due the week after completion of the lab.
- **Pre-lab exercises** test your knowledge of the upcoming lab experiment.
- **Lab book** is graded on completeness of notes, data, and analysis (and neatness).
- **Special project** is a final experiment with a presentation (replaces exam).
- **Participation** is graded on involvement in lab, teamwork, and attendance.

Weighting:

Lab reports:	50%
Pre-lab exercises:	10%
Lab book:	10%
Participation:	10%
Special project:	20%
Total =	100%

Textbooks

Text: All course materials and lab manuals will be made available on the course website.

https://saaubi.people.wm.edu/TeachingWebPages/Physics251_Fall2023/Physics251_Fall2023.html

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Some useful texts:

Introduction to Error Analysis, by J. R. Taylor (2nd ed.), University Science Books (1997).

Data Reduction and Error Analysis for the Physical Sciences, P. Bevington and D. K. Robinson (3rd ed.), McGraw-Hill (2003).

Computer Software

Lab report writing: LaTex

→ recommend on-line editor/compiler: www.overleaf.com

Data analysis: Python

→ Libraries: Matplotlib, NumPy, SciPy.

→ recommended on-line editor/compiler: Google Colaboratory colab.research.google.com

→ Spreadsheets (e.g. Excel, Google Docs, etc).

→ Alternates: MatLab, C/C++, Java, etc.

Tentative Schedule (I)

Week 1: 8/30-31 **Introduction to Error Analysis**
Basic error estimation, basic error propagation.

Week 2: 9/6-7 **Data Analysis and Scientific Writing**
Plotting data, Python (Matplotlib & NumPy), MatLab, Excel, LaTex.

Week 3: 9/13-14 **Experiment 1: Optical Interferometry I**
Pre-lab exercise & reading, experiment setup, data taking, basic data analysis.

Week 4: 9/20-21 **Experiment 1: Optical Interferometry II**
Data analysis, improved data, write lab report (due following week).

Week 5: 9/27-28 **Experiment 2: Black Body Radiation I**
Pre-lab exercise & reading, experiment setup, data taking, basic data analysis.

Week 6: 10/4-5 **Experiment 2: Black Body Radiation II**
Data analysis, improved data, write lab report (due following week).

Week 7: 10/11-12 **Fall Break – no lab**
Whoo-hoo!

Week 8: 10/18-19 **Experiment 3: Faraday Rotation I**
Pre-lab exercise & reading, experiment setup, data taking, basic data analysis.

Tentative Schedule (II)

Week 9: 10/25-26 **Experiment 3: Faraday Rotation II**
Data analysis, improved data, write lab report (due following week).

Week 10: 11/1-2 **Experiment 4: Single Photon Interference I**
Pre-lab exercise & reading, experiment setup, data taking, basic data analysis.

Week 11: 11/8-9 **Experiment 4: Single Photon Interference II**
Data analysis, improved data, write lab report (due following week).

Week 12: 11/15-16 **Experiment 5: Superconductivity I**
Pre-lab exercise & reading, experiment setup, data taking, data analysis, lab report.

Week 13: 11/22-23 **Thanksgiving Break – no lab**
Note: Superconductivity lab report due Week 14.

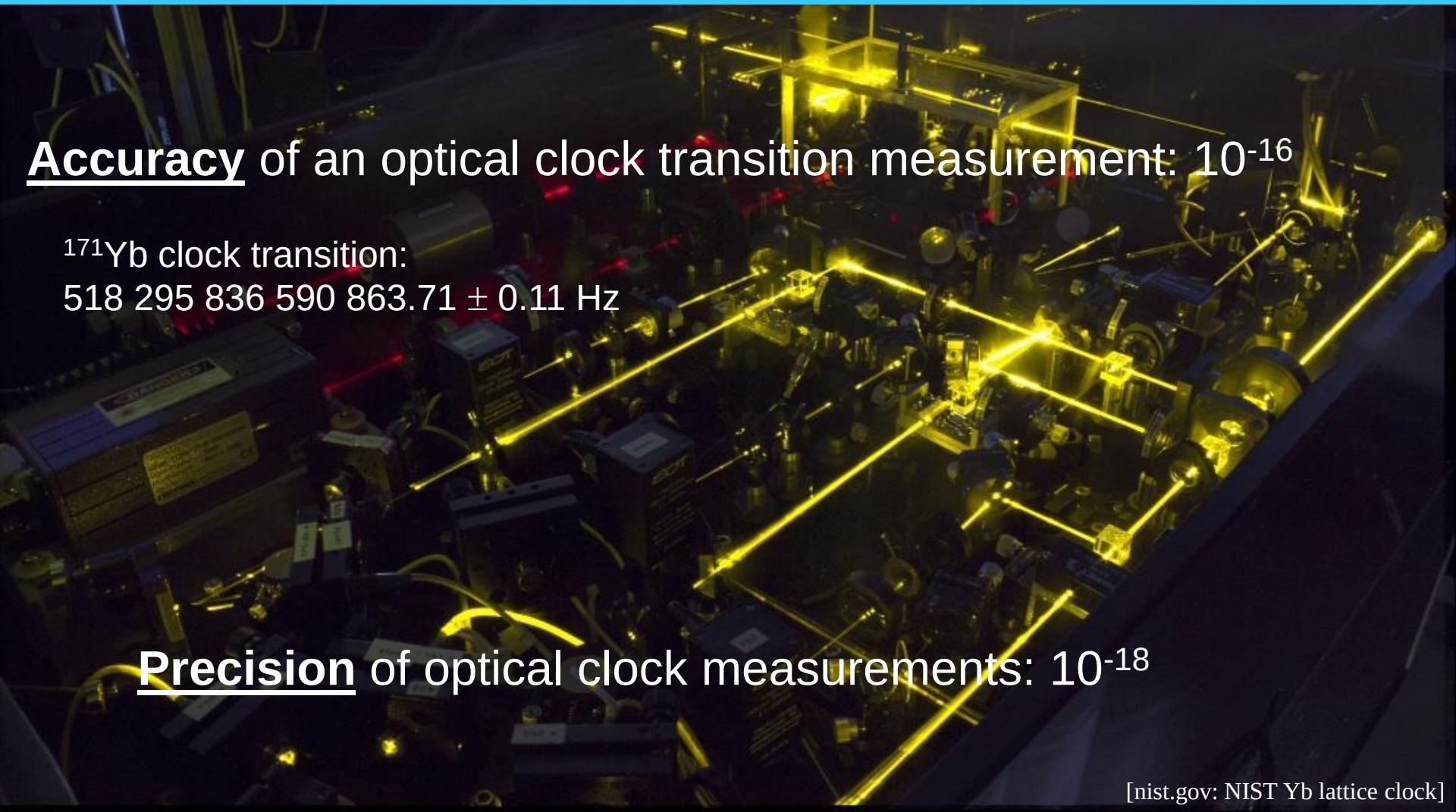
Week 14: 11/29-30 **Special Project I**
Pre-lab preparation, experiment setup, data taking, basic data analysis.

Week 15: 12/6-7 **Special Project II**
Data analysis, improved data, presentation preparation.

Dec. 14, 2023, 5 pm **Special Project Due (Thursday section)**
Dec. 15, 2023, 5 pm **Special Project Due (Wednesday section)**

Precision & Accuracy

Optical Atomic Clocks



Accuracy of an optical clock transition measurement: 10^{-16}

^{171}Yb clock transition:
518 295 836 590 863.71 ± 0.11 Hz

Precision of optical clock measurements: 10^{-18}

[nist.gov: NIST Yb lattice clock]

Accuracy = Confidence/Proof

Electron's g-factor (relates spin to magnetic moment)

Classical EM / Schrodinger: $g_e = 1.0$

Relativistic electrodynamics + spin-1/2: $g_e = 2.0$

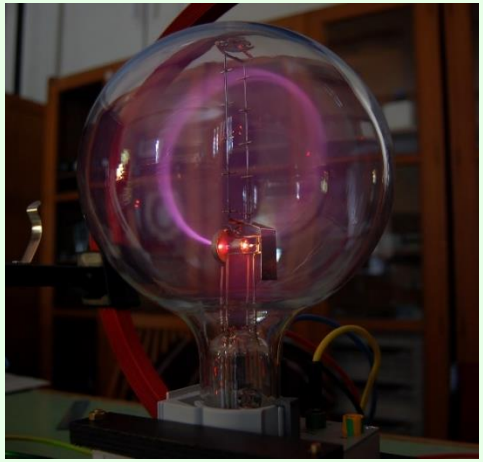
Dirac: $g_e = 2.0$

12-digits

Quantum Electrodynamics (QED): $g_e = 2.002\ 319\ 304\ 362(1)$

Theory and experiment agree to 9 digits.

→ High confidence in QED/Standard Model.



[Wikipedia, 2009]