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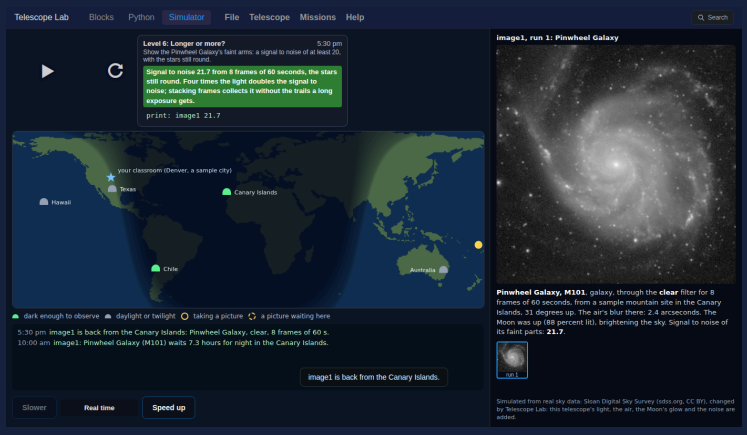
Telescope Lab: Longer or More? Noise and Stacking Frames

Grades 9-12 · 45 minutes

Physical science · Math



Slides, rubric and answer key **Print and go** **No student accounts**

Chromebook friendly

What's included

- A one-page overview: objectives, essential question, vocabulary, standards and assessment
- A 45-minute lesson sequence: warm-up, direct instruction, guided practice, independent practice, closure
- Slides for the board: a PowerPoint file that also opens in Google Slides
- A student worksheet with a QR code and a frames table and a graph grid
- A 3-question exit ticket, two to a page, with an answer key
- A rubric: 3 criteria, 4 levels, scored out of 12
- Differentiation for English learners, students with IEPs or 504 plans, and students who need more support or more challenge
- Cross-curricular extensions, and notes for teaching it in middle school and in physics or astronomy
- Standards: NGSS and Common Core math

Telescope Lab: Longer or More? Noise and Stacking Frames

Grades 9-12 · 45 minutes · Physical science, Math

A faint galaxy's arms come through a telescope's camera as a few counts of light against the sky's glow, and the counts are grainy: the noise grows as the square root of the light. In Level 6 of Telescope Lab students send requests to a school telescope run by a queue, which waits for night in the Canary Islands. One minute on the Pinwheel Galaxy gives a signal to noise of 7.7; the goal is 20. Four frames of a minute give 15.3, twice as much; eight give 21.7. One exposure of 8 minutes gives 22.5, a little more, but the mount holds stars still for only two minutes, so they trail. Students graph signal to noise against the number of frames, compare it with the square root, and explain the choice real observers make.

At a glance

ESSENTIAL QUESTION

Is it better to take one long picture or to add up many short ones?

OBJECTIVES

Students will be able to:

- explain why a picture of faint light is grainy, and why the grain grows as the square root of the light
- predict the signal to noise of N frames from one frame's, and check it
- graph signal to noise against the number of frames and compare it with a square root function
- compare one long exposure with stacked frames, and explain the small difference and the large one
- choose an exposure plan that meets a goal within a limit

VOCABULARY

Signal, Noise, Signal to noise, Exposure, Frame, Stacking

STANDARDS

HSF-IF.C.7b, HS-PS4-5

TIME AND MATERIALS

45 minutes, grades 9-12.

- One computer or Chromebook per student
- A projector
- The worksheet and exit ticket, one copy each per student
- The rubric, one copy per student if you grade the work
- A calculator with a square root key
- Graph paper, or the grid on the worksheet

PREP

Make copies of the worksheet and exit ticket. Before class, open mytekdev.com/try/telescopelab?lesson=longer-or-more-noise-and-stacking&ref=tpt-telescopelab-3 once on a student computer, which checks that your school's filter allows the app, and

ASSESSMENT

- Formative: the questions under What to look for, asked while students work, and the exit ticket (answer key included).
- Summative: the worksheet, scored with the rubric.

TECHNOLOGY AND PRIVACY

Runs in any browser, Chromebooks included, with nothing to install. Students need no account and no email: the link works signed out, and nothing they do is stored on our server unless they choose to save.

follow the short guide yourself: about ten minutes.

Lesson sequence

MINUTES	STAGE	WHAT YOU DO	WHAT STUDENTS DO
0 to 5	**Warm-up** Hook	Show the title, essential question and Today I can slides (about 1 minute). Then the warm-up: two rain cups.	Answer the warm-up on the worksheet.
5 to 13	**Direct instruction (I do)** Model it	Project Level 6. The school telescope is a 0.4 meter telescope at five sample sites round the world, run by a queue: it is 10 in the morning in the classroom, so a request waits for night somewhere. Show the picture slide, then the stat slide. Define signal to noise and work the square root rule: 4 frames, square root of 4 is 2, so 2 x 7.7. Students predict 2, 8 and 16 frames on the worksheet. **It's working when:** One frame is 7.66 before rounding. Times the square root of 2, 4, 8 and 16: 10.8, 15.3, 21.7 and 30.6, exactly what the app shows. Students who use 7.7 get 10.9, 15.4, 21.8 and 30.8: close, and a good moment to talk about rounding.	Fill in the vocabulary and predict the frames table.
13 to 22	**Guided practice (We do)** One frame, then four	Students open the link or scan the QR code. A short guide runs the starter (one minute, 7.7), has them add a fourth number for 4 frames (15.3), then 8 frames, which passes. Skip jumps to the picture; the request waits 7.3 hours for night in the Canary Islands. **Watch for:** Students who change 60 to 240 for four times the light. That is a fair test too (15.8), but the stars trail past 120 seconds and the level refuses it. Ask them to compare it with 4 frames later.	Follow the guide. Record each signal to noise in the frames table.
22 to 37	**Independent practice (You do)** Graph it, then go longer	Students run 2 and 16 frames to finish the table, and graph signal to noise against frames, with 7.66 x the square root of frames drawn on the same grid. Then single long exposures: 120, 240 and 480 seconds, recording the signal to noise and whether the stars trailed. Walk the room with the What to look for questions. **If they ask:** "240 seconds in one exposure and 4 frames of 60 collect the same light. Which gives more signal to noise, and by how much?" Equal light **Watch for:** Students who expect 8 frames to give 8 times 7.7. Point at the graph: it bends over, the way a square root does.	Finish both tables and the graph, and answer the questions.
37 to 45	**Closure** Longer or more? And exit ticket	Show the closure slide and take answers. Then the claim: the signal grows with the light and the noise with its square root, so to double the signal to noise you need four times the light. Hand out the exit ticket.	Discuss, then answer the exit ticket.

Before you teach: a ten-minute walkthrough

Open mytekdev.com/try/telescopelab?lesson=longer-or-more-noise-and-stacking&ref=tpt-telescopelab-3. A short guide opens over Level 6, Longer or more?, with the program in the Python tab. The map shows night in dark blue and each of the five sample sites green while it is dark there; the picture panel shows each picture as it comes back, with its source line, and the box at the top says its signal to noise.

1. **The request.** scope.request('m101', 'clear', 60) asks for 60 seconds on the Pinwheel Galaxy through the clear filter; a fourth number is the frames, 1 to 20, and each frame is at most 600 seconds. The program waits until the picture is back and gets its name; scope.snr(name) gives its signal to noise.
2. **The queue.** It is 10 in the morning in the classroom (Denver), so the request waits 7.3 hours for night in the Canary Islands, with the Moon up and 88 percent lit. Skip jumps to the next picture.
3. **The goal.** A signal to noise of at least 20 with round stars. The mount holds stars round for 120 seconds; longer exposures trail and do not count.
4. **Numbers to expect.** Frames of 60 seconds: 1, 7.7; 2, 10.8; 4, 15.3; 8, 21.7 (done); 16, 30.6. One exposure: 120 s, 11.1; 240 s, 15.8, trailed; 480 s, 22.5, trailed. 4 frames of 120 s: 22.1, done. These do not change from run to run, and a program that asks for several in one run gets the same numbers.

> The pictures are simulated from real sky data: each is built from the Sloan Digital Sky Survey's picture of the galaxy (CC BY), then given this telescope's light, the sky's glow with the Moon up, the camera's noise, the site's blur and, past two minutes, trailed stars. They are never real observations. For real ones, school networks such as MicroObservatory and Las Cumbres Observatory take requests from classes.

Background for the teacher

Light arrives in bits, photons, at random, so a camera that counts N of them in a pixel gets a number that varies from picture to picture by about the square root of N. The sky's glow adds counts, and noise, of its own, and the camera adds a little read noise each time a frame is read out. The signal to noise of the faint arms is their counts over the square root of everything counted. Collect four times the light and the signal grows four times, the noise twice: the signal to noise doubles.

In the app's model one minute collects 270 counts from the arms against 874 from the sky (the Moon, up and 88 percent lit, makes the sky's glow 3.6 times what it is without it), with a read noise of 10 counts. Stacking N frames multiplies one frame's 7.66 by exactly the square root of N. One exposure as long as all the frames does a little better, because the read noise comes once, but past two minutes this mount's small tracking errors trail the stars. Real observatories stack for the same reasons, and because a frame spoiled by a satellite or a cloud can be dropped.

Astronomers, telescope operators (the job this app is closest to), engineers who build cameras and adaptive optics, and data scientists who sort survey pictures all work with telescopes like these. Anyone can help with real data through citizen science projects such as Zooniverse and the AAVSO.

What to look for

Ask these while students work. A student who has understood the lesson can answer them without help:

- What is the noise in a picture, and where does it come from?
- Four frames gave about twice one frame's signal to noise. Why not four times?
- How many frames would it take to reach 40?
- Why did 480 seconds in one exposure give a little more than 8 frames of 60?
- Why does the level refuse the 480 second picture?

> The second question is the one that matters. A student who says "the signal went up four times but the noise went up by the square root of four, two, so the ratio doubled" understands the square root rule. A student who says "it just does" has the result but not the idea.

Cross-curricular extensions

- Statistics: flip a coin 10 times and 40 times, several runs each, and compare how much the count of heads varies. Does it grow as the square root?
- Photography: phones take night photos by stacking many short frames. Find what a phone's night mode does.
- Computer science: write the frames table as a for loop in the app, and print it.
- Careers: look up what an observatory's data scientists do with thousands of frames a night.

Vocabulary

Signal	The light from the thing you want, counted by the camera.
Noise	The random grain in a picture: the light arrives in bits, and the camera adds a little of its own.
Signal to noise	The signal divided by the noise. The bigger it is, the more clearly a faint thing stands out.
Exposure	How long the camera collects light for one picture.
Frame	One exposure. Several frames of the same thing can be added up.
Stacking	Adding up frames so their signal builds up faster than their noise.

Differentiation

ENGLISH LEARNERS

- Keep the vocabulary slide up, and point at the telescope, the eyepiece view or the box at the top as you say each word: the picture carries the meaning.
- Give a sentence frame on a card: With ____ frames the signal to noise was ____, which is ____ times

STUDENTS WITH IEPS OR 504 PLANS

- Pair students, one at the keyboard and one recording results.
- Give the square roots of 2, 4, 8 and 16 on the worksheet (1.41, 2, 2.83, 4).

one frame's.

- Show the two Pinwheel pictures side by side and name what changed: grain, arms, stars.

- Where the IEP allows a modified assignment, score the first two rubric rows only.

STUDENTS WHO NEED MORE SUPPORT

- Do the 4 frame prediction together on the board.
- Graph only 1, 4 and 16 frames, where the square roots are whole numbers.
- The box at the top says after each picture whether it is enough, and whether the stars trailed.

STUDENTS READY FOR MORE

- Run 1, 2, 4, 8 and 16 frames from one program with a for loop: for n in [1, 2, 4, 8, 16], request, then print n and scope.snr(picture). The numbers match one request per run.
- Open Level 5, Three filters make color. Each color filter passes about a third of the light: predict a red frame's signal to noise from the clear one, then check.
- Write the model: with signal S, sky B and read noise R for one frame, the signal to noise of N frames is N S / the square root of N (S + B + R squared). Show that it is the square root of N times one frame's.

Adapting for other grades

Younger students: In middle school, stay with 1, 4 and 16 frames, where the square roots are 1, 2 and 4, and focus on the pattern: four times the light, twice the signal to noise. Score the first two rubric rows, total 8, and 6 meets the objectives.

Older students: In physics or astronomy, derive it: photon counts follow Poisson statistics, so the noise in N counts is the square root of N. Add the sky and the read noise, and show why the long exposure wins by a little and why it still loses to trailing.

Student worksheet

Name: _____ Date: _____

Open the app: scan the QR code, or go to mytekdev.com/try/telescopelab?lesson=longer-or-more-noise-and-stacking

Essential question: Is it better to take one long picture or to add up many short ones?

Warm-up: A 1 minute rain cup and a 4 minute rain cup: which is more reliable, and how much more?

_____

1. **Vocabulary.** Signal, noise, signal to noise, exposure, frame, stacking: write each in your own words.

2. **Frames table.** Frames of 60 s. Predicted (7.7 x the square root of frames) and measured. 1: _____ _____ 2: _____ _____ 4: _____ _____ 8: _____ _____ 16: _____ _____

3. **Graph.** Plot measured signal to noise (up) against frames (across, 0 to 16). Draw 7.66 x the square root of frames on the same grid.

4. **Long exposures.** One exposure of 120 s: _____ trailed? ____ 240 s: _____ trailed? ____ 480 s: _____ trailed? ____

1. Why does four times the light only double the signal to noise?

2. Longer or more: which would you choose here, and why?

Exit ticket

Name: _____

1. One frame gives a signal to noise of 5. Nine frames stacked give about: (A) 15 (B) 45 (C) 9

2. To double a picture's signal to noise you need: (A) twice the light (B) four times the light (C) half the noise from the sky

3. A friend says one 10 minute exposure is always better than ten 1 minute frames. Use what you learned today to answer.

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Exit ticket

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3. A friend says one 10 minute exposure is always better than ten 1 minute frames. Use what you learned today to answer.

Answer key: exit ticket

QUESTION	ANSWER	WHY
1	A	The square root of 9 is 3, and 3 x 5 = 15.
2	B	The signal grows with the light and the noise with its square root; the square root of 4 is 2.
3	Open answer	The long one is a little better (the camera's read noise comes once), but past two minutes this mount trails the stars, and one ruined frame of ten can be thrown away. 480 s gave 22.5 trailed; 8 frames of 60 gave 21.7 with round stars.

Worksheet: what students should find

BLANK	WHAT THE APP SHOWS
Warm-up	The 4 minute cup, about twice as reliable: random counts vary as the square root of the count.
Frames table	Predicted with 7.7: 7.7, 10.9, 15.4, 21.8, 30.8. Measured: 7.7, 10.8, 15.3, 21.7, 30.6.
Graph	The points lie on 7.66 x the square root of frames: rising fast, then bending over.
Long exposures	120 s: 11.1, round. 240 s: 15.8, trailed. 480 s: 22.5, trailed.
Question 2	8 frames of 60 s (21.7), or 4 of 120 s (22.1): enough signal to noise with round stars. One long exposure trails.

> These numbers are the same on every run and every computer. The predictions with 7.7 run a tenth or two high because the app works from 7.66 before rounding.

Rubric

Score each row from 1 to 4.

Name: _____

CRITERIA	4 EXCEEDS	3 MEETS	2 APPROACHING	1 BEGINNING
Predicting and measuring	Predicts 2, 4, 8 and 16 frames from one frame with the square root rule, measures all four, and explains any difference.	Predicts and measures all four.	Measures without predicting, or predicts without measuring.	Neither.
Graphing	Graphs signal to noise against frames with the square root curve on the same grid, labeled, and describes the fit.	Graphs the points and the curve.	Graphs the points only.	No graph.
Longer or more	Compares long exposures with frames at equal light, with numbers, and explains both the small difference and the trailing.	Compares them and names the trailing.	Runs a long exposure without comparing.	Does not try.

Total: ____ / 12. A score of 9 or more meets the objectives.

Standards

The lesson is built for HSF-IF.C.7b: students graph signal to noise against the number of frames and compare it with a square root function. Explaining how the telescope's camera captures faint light, and why exposure and stacking change what it can show, is HS-PS4-5.

FRAMEWORK	CODE	GRADES	STANDARD	HOW THE LESSON MEETS IT
Common Core Math	**HSF-IF.C.7b**	9-12	Graph square root, cube root, and piecewise-defined functions, including step functions and absolute value functions.	Students graph measured signal to noise against frames (1 to 16) with 7.66 times the square root of the frames on the same grid.
NGSS	**HS-PS4-5**	9-12	Communicate technical information about how some technological devices use the principles of wave behavior and wave interactions with matter to transmit and capture information and energy.	Students explain how a telescope camera captures faint light as counts, why the counts' noise grows as the square root of the light, and how exposure length and stacking change what the picture shows.

Checked November 2026 against: Common Core State Standards for Mathematics: High School Functions, Interpreting Functions, NGSS HS-PS4-5, Waves and their Applications in Technologies for Information Transfer.

Optional: save student work in a free class

The whole lesson runs at the link on the worksheet, with no accounts and no sign-up.

To keep students' work, and see it all in one place, make a free class. It takes about ten minutes, once, and covers every lesson in this series: mytekdev.com/tools/class-setup

Students in a class open mytekdev.com/tools/telescope-lab/lessons/longer-or-more-noise-and-stacking/start instead of the worksheet link. Each one gets their own copy of the starter, and the same link reopens it next time.

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