Family edition

Telescope Lab: Longer or More? Noise and Stacking Frames

Ages 14-18 · about 45 minutes, in one sitting

In Telescope Lab your child asks a simulated robotic telescope for pictures of a faint galaxy, and finds out why astronomers add up many short pictures instead of taking one long one.

What you need

- A computer or Chromebook with a current browser.
- The link: mytekdev.com/try/telescopelab?lesson=longer-or-more-noise-and-stacking&ref=fam-telescopelab-3. No account, no email and nothing to install.
- A calculator with a square root key.

Before you start: try it once yourself

Open mytekdev.com/try/telescopelab?lesson=longer-or-more-noise-and-stacking&ref=fam-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 your familyroom (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.

The ideas, in plain words

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.

Do it together

1. Open mytekdev.com/try/telescopelab?lesson=longer-or-more-noise-and-stacking&ref=fam-telescopelab-3, press play, then `Skip to the next picture`. Read the line that starts `print:`.

   > **You'll know it worked when:** About 7.7: the signal to noise of one minute on the Pinwheel Galaxy. The goal is 20.

2. Open `Python` and add a fourth number, the frames: `scope.request('m101', 'clear', 60, 4)`. Go back to `Simulator`, play and Skip.

   > **You'll know it worked when:** About 15.3: four times the light, twice the signal to noise.

3. Predict 8 frames with 7.7 times the square root of 8, then run it.

   > **You'll know it worked when:** About 21.7, and the level is done: over 20 with the stars round.

4. Try one long exposure with the same light: `scope.request('m101', 'clear', 480)`.

   > **You'll know it worked when:** About 22.5, a little more, but the stars trail: past two minutes this mount does not hold them still.

5. Run 2 and 16 frames too, and graph the signal to noise against the number of frames.

> **You'll know it worked when:** 10.8 and 30.6. The points follow 7.66 times the square root of the frames.

Talk about it

Ask these while you work together. A child who has understood it 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 child 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 child who says "it just does" has the result but not the idea.

For younger and older kids

Younger: For a younger child, stay with 1, 4 and 16 frames, where the square roots are 1, 2 and 4.

Older: For an older child, open `Level 5` and make a color picture from red, green and blue filters, then explain why each color frame is noisier than a clear one.

Keep going

- 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.

Bring it into other subjects

- 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.

For your records

Ready to copy into an hour log, a portfolio or a transcript.

LESSON	Telescope Lab: Longer or More? Noise and Stacking Frames
SUBJECTS	Science, Math
TIME	45 minutes
WHAT WE DID	Measured the signal to noise of simulated telescope pictures of a faint galaxy, graphed it against the number of stacked frames as a square root function, and compared stacking with one long exposure.
SKILLS PRACTICED	Square root functions; Graphing data; Signal and noise

Activity sheet (optional)

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?

Quick check

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.

Answers

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.

If your state or umbrella school asks, this lesson covers Common Core Math HSF-IF.C.7b, NGSS HS-PS4-5.

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The app this lesson uses is free and runs in the browser, with nothing to install and no account needed. It is at mytekdev.com.

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