FROM DREAM TO REALITY: BUILDING THE HALE TELESCOPE

PRIMARY SOURCE STEAM PROJECT

GRADE LEVELS: 8–12

CREATED BY

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HOW TO USE THIS PROJECT

The 200-inch Hale Telescope (historically known as the "Palomar Telescope") at the Palomar Observatory in California represents an amazing feat of engineering and ingenuity, the result of decades of trial and error. The primary sources in this project describe the last great hurdle in the Hale Telescope's construction: successfully transporting the 40-ton, 200-inch mirror and its packing materials from upstate New York to the top of Palomar Mountain in southern California. Documents include shipping manifests discussing moving the mirror across the country, conversations regarding the movement of the mirror, and photographic documentation of the mirror's journey up Palomar Mountain. These sources can be used for inquiry-based learning exercises, and students are encouraged to annotate in the margins in order to support the development of document analysis and critical thinking skills.

This project is designed for advanced middle school or high school students. It contains a suggested project that puts students in the role of problem-solvers, with students using the actual data points drawn from the 1947 primary sources. Students will learn how to work with a formula, and to manipulate the formula's variables to achieve different outcomes.

HISTORICAL CONTEXT

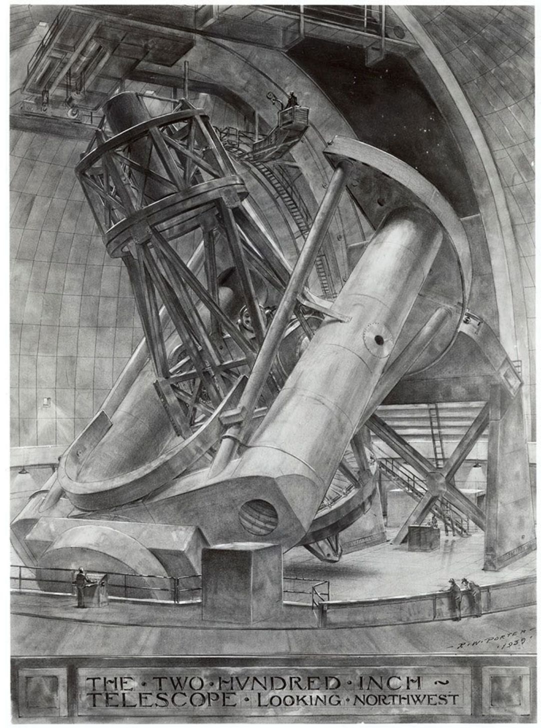

Photo: 1939 drawing of the telescope in Mount Palomar, California. Folder 1091, Box 1, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center.

The story of the giant telescope at the Palomar Observatory on Palomar Mountain, California, begins with the inspiration of astronomer Dr. George Ellery Hale. By the 1920s, Hale had already developed a 40-inch telescope at Wisconsin's Yerkes Observatory, as well as 60-inch and 100-inch telescope reflectors at the Mount Wilson Observatory near Pasadena, California. But Hale wanted to dream even bigger—he wanted to develop a 300-inch telescope. This proposal was later downsized to a 200-inch telescope that today is called the Hale Telescope, one of several telescopes now located at the Palomar Observatory.

The Hale Telescope was the largest telescope in the world from the start of its operations in November 1949 until 1993. In 2020, the world's largest single-mirror reflecting telescope is the Gran Telescopio Canarias in the Canary Islands, while the collecting surface of the Large Binocular Telescope at the Mt. Graham International Observatory earns it the title of the largest telescope in the world.

The desire for a 200-inch telescope stemmed from a need to confirm theories about the ever-expanding nature of the universe, and the prospect of understanding distant galaxies, which, until then, were not well understood. With a larger telescope mirror came the potential for a deeper photographic reach into space.

The realization of a telescope of a large size never-before attempted required a lot of trial and error, as well as significant financial support. The Rockefeller-funded International Education Board (IEB), and later the Rockefeller Foundation, provided the financial backing to execute the vision of Hale and his scientific team. The Hale Telescope remains the largest grant the Rockefeller Foundation has ever awarded to a single project: $6,000,000 in 1928 (over $90,000,000 in 2020 dollars).

Though Hale successfully pitched the telescope project to the IEB in 1928, it was not completed until 1948, a decade after Hale's death in 1938.

Such delays illustrate the difficulties of being a trailblazer, and trying to navigate uncharted territory. For instance, initial plans for the fabrication of the mirror blank needed to be modified and new ones developed.

Hale began the project with ample financial and scientific support for a mirror made of fused quartz, contracting with the General Electric Company. Though the General Electric Company produced a few promising, smaller fused quartz glass mirrors, and though the Rockefeller Foundation provided additional requested funds to support General Electric's new and varied attempts to create the mirror, problem after problem ensued, and it was decided to abandon the prospect of a 200-inch mirror made from fused quartz.

HISTORICAL CONTEXT

This image is of the Crab Nebula in visible light photographed by the Hale observatory optical telescope in 1959. The faint object at the center had been identified as a pulsar and is thought to be the remains of the original star. It had been observed as a pulsar in visible light, radio wave, x-rays, and gamma-rays.

Credit: NASA Image Library

The team then contracted with Corning Glass Works in New York to create the mirror from Pyrex—and this was the largest industrial manufacture in Pyrex to that date. Corning Glass Works completed the 200-inch mirror in 1936, after many delays and many unexpected bumps in fabrication.

Challenges the Hale Telescope team had to face on the road to success, however, extended beyond completion of the 200-inch mirror, and included significant public relations and management concerns. Questions the team had to answer in collaboration with local officials, the federal government, and the public included, for instance: where the telescope should be based, which teams (local or out-of-state) should be responsible for its fabrication and maintenance, how to protect information about the project from rival groups, how to control the flow of information about the project and its purpose to the public, how to transport such a large mirror safely from New York all the way up to the top of Palomar Mountain in California, and how to contend with the financial and personnel disruptions of the Second World War. Indeed, the Hale Telescope's realization, as with all large and complex technological advances, was ultimately a result of both innovative engineering and skilled project management.

By 1948, the Telescope was successfully installed in its current home at Palomar Observatory, and was named in memory of Hale. The Hale Telescope officially captured its first image on January 26, 1949. Some of the notable discoveries using the Hale Telescope include a measure of the expansion rate of the universe and observation of quasars and other galactic bodies, among many others. Since its inception, the Hale Telescope has undergone updates and modernization of its capabilities and mechanics, a testament to the ever-evolving nature of scientific inquiry.

REFERENCES:

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Amazing Space, "Telescopes from the Ground Up," http://history.amazingspace.org/resources/explorations/groundup/. Accessed 7.31.19.

"Astronomy," *The Rockefeller Foundation: A Digital History*, https://rockfound.rockarch.org/astronomy. Accessed 10.18.19.

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NASA Space Place, "How Do Telescopes Work?," June 28, 2019, https://spaceplace.nasa.gov/telescopes/en/. Accessed 7.31.19.

Palomar Observatory website, http://www.astro.caltech.edu/palomar/about/. Accessed between January – August 2019.

Helen Wright, *Palomar: The World's Largest Telescope* (New York: The Macmillan Company, 1952).

BUILDING THE HALE TELESCOPE: FROM DREAM TO REALITY

Great innovations are riddled with practical considerations, tempering dreams with the logistics necessary to realize them. For the Hale Telescope, such practicalities involved global issues, like the pause necessitated by the expenses of the Second World War, and domestic issues, such as the logistics involved in transporting a giant 200-inch Pyrex mirror all the way across the country and up Palomar Mountain to the observatory site without breaking or damaging it in any way. The mirror's journey from upstate New York to Palomar Mountain needed to be carefully planned and coordinated with packaging and shipping companies, as well as with the railroads and trucking companies.

The journey from the California Institute of Technology (Caltech) optics shop in Pasadena, California up the mountain was particularly difficult, requiring alterations to the cross-country roads to support the mirror's weight, as well as a good-faith agreement reached between Caltech and all national media outlets to keep advance news of the mirror's advance out of the papers, for security purposes. Once the mirror began its journey to its final home on Palomar Mountain, however, bystanders and media couldn't get enough of the spectacle, and documented every step of the mirror's trek.

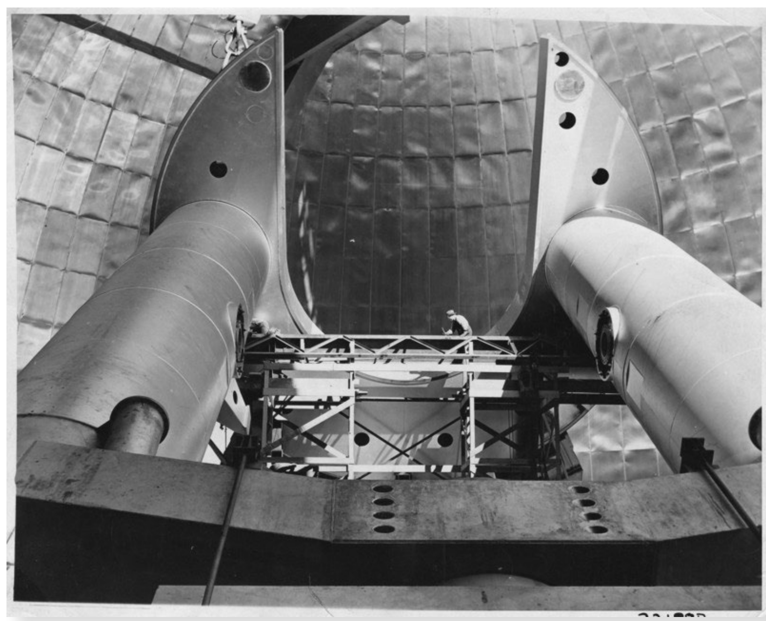

Photo: View from the south end through the telescope, during construction. Folder 1091, Box 45, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center. Copyright Wide World Photos, Inc.

DOCUMENT GUIDE

1. **California Institute of Technology, Press Release,** *November 12, 1947*
Folder 34 | Box 5 | Series 205D
Rockefeller Foundation records, Rockefeller Archive Center

2. **California Institute of Technology, "Confidential—Not for Publication" details about the move of the 200-inch mirror,** *November 12, 1947*
Folder 34 | Box 5 | Series 205D
Rockefeller Foundation records, Rockefeller Archive Center

3. **California Institute of Technology, "Route for Transportation of 200-inch mirror,"** *November 12, 1947*
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4. **Max Mason telephone call,** *November 12, 1947*
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5. **Photograph of Palomar Mountain Observatory Site,** *c. 1945*
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Photograph of General truck caravan moving the mirror, *1947*
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Photograph of mirror going through town, *1947*
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Rockefeller Foundation photographs, Rockefeller Archive Center

9.

Hale Telescope, *c. 1945*
Folder 1091 | Box 45 | Series 205D
Rockefeller Foundation photographs, Rockefeller Archive Center

PRIMARY SOURCE DOCUMENT 1

Office of Public Relations
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena 4, California

November 12, 1947

THE FOLLOWING IS FOR YOUR INFORMATION IN COMPILING DATA FOR YOUR FIRST STORY THAT THE MIRROR IS ON ITS WAY. IT IS REQUESTED THAT THIS NOT BE USED BEFORE THEN SINCE STATE HIGHWAY OFFICIALS AND OTHERS RESPONSIBLE FOR SAFE MOVEMENT OF THE MIRROR HAVE ASKED THAT ALL STORIES ON IT BE WITHHELD FROM NOW ON UNTIL THE MIRROR IS ON THE WAY.

The 200-inch mirror, complete with its mounting mechanism and cell and wooden packing case will weigh approximately 40 tons. It will ride horizontally on a 16-wheel trailer, the combined weight of which will be approximately 20 tons, bringing the total weight of equipment, the mirror and its case, to 60 tons. On mountain grades there will be a truck in both front and rear of the trailer.

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In some instances it has been necessary to shore up culverts along the route to carry this weight and it will also be necessary in some instances to lay additional planking across bridges. In all, there are five culverts and three bridges that required this work.

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The mirror will have a highway patrol escort which will have jurisdiction over the moving and pilot cars will be stationed in front and to the rear of the trucks and trailer.

* * * * * * *

Two I-beams will be welded to the trailer bed and the mirror, in its mounting cell, will rest on these, anchored at three points, two of them stationary and the other moveable. Sponge rubber will be used at certain points within the mounting cell for cushioning purposes and the tires on the trailer will provide all other cushioning deemed necessary.

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(MORE)

California Institute of Technology, Press Release, November 12, 1947
Folder 34, Box 5, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 1 CONTINUED

Office of Public Relations
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena 4, California

November 12, 1947
(Palomar - page 2)

The case which will cover the mirror is built of 2 x 12 timbers and is 20 feet square. The top is insulated with aluminum foil to delay temperature changes within the casing.

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Over main highways it is estimated that the average speed will be between 10 and 15 miles per hour. Through towns and over more narrow highways and streets the average will probably be between 3 and 5 miles an hour. The total distance of the route to be followed is approximately 160 miles.

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At certain points along the route it will be necessary to establish road blocks. This applies particularly to narrow mountain roads and some of the streets and highways over which the mirror will pass.

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The approximate value of the mirror is $600,000.

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California Institute of Technology, Press Release, November 12, 1947
Folder 34, Box 5, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 2

Office of Public Relations, CALIFORNIA INSTITUTE OF TECHNOLOGY, November 12, 1947

CONFIDENTIAL - NOT FOR PUBLICATION

Enclosed are press cards for use during moving of the 200-inch PALOMAR Mirror and also a car card to be placed on the windshield of automobiles to be used in covering this event.

The mirror will be moved November 18 and 19. We are giving you these dates as promised in our letter of October 31, and again requesting that you do NOT PUBLISH OR BROADCAST ADVANCE STORIES SAYING THAT THE MIRROR WILL BE MOVED ON NOVEMBER 18. These dates are subject to last minute changes should weather or other conditions be unfavorable for starting. If such changes are made we will make every attempt to advise you accordingly. The mirror will probably leave Caltech around 4 a.m. on November 18. This again is not a positive time and is subject to change if necessary. Again, if there are any changes we will attempt to let you know at once. Since two days will be required for the trip, a lay-over will be necessary en route. This will be done the night of November 18 and if all goes well will be inland from Oceanside. We would appreciate no mention on November 18 of the lay-over spot to avoid creating unnecessary traffic hazards on November 19. If the movement goes well, the mirror will arrive at the Observatory before darkness on November 19.

As late a morning publication and broadcast on the 18th as possible will be of great assistance to us and the highway patrol in avoiding unnecessary traffic hazards and we hope that you will see fit to accommodate us in this request.

There will be no opportunity to get pictures inside the observatory upon arrival of the mirror there. It is planned to set a date later when such pictures will be possible. Radio stations wishing to make wire recordings of the arrival at the observatory will have to bring their own power supply since it will not be possible to obtain power otherwise.

We are also enclosing a description by street and highway of the route to be followed, but again request that this NOT BE PUBLISHED. It is given to you only to assist you in covering. Keeping traffic to a minimum is highly essential for safe completion of this undertaking. The matter of routing and escorting the mirror is in the hands of the State Highway Department and Highway Patrol. That they are very much concerned with keeping publicity on this to a minimum as a means of keeping traffic down and free-flowing is putting it mildly, hence our request for holding off on advance announcement or publication of the route.

You will also find enclosed a description of some of the problems involved in moving the mirror for your use as you see fit, but preferably not in advance of the moving date.

Loading of the mirror on the truck inside the optical shop will get underway early the morning of November 17. It will be possible to obtain pictures of this from the observation gallery only and a press card will be necessary to gain admission since the gallery will not be open to the public. A definite time at which this will be accomplished cannot be given at this time, but it is expected that this job will get underway about 9 a.m.

It is suggested that persons assigned to cover moving of the mirror familiarize themselves with the route to be followed in advance, with an eye to spotting themselves where pictures may easily be obtained and also with the thought that there are portions of the route that may be blocked off and make it impossible for them to get back on the main highways without some delay.

If additional press passes or car cards are required, please contact this office by calling RYan 1-7171 (from Los Angeles) or SYcamore 6-7121.

California Institute of Technology, "Confidential—Not for Publication" details about the move of the 200-inch mirror November 12, 1947, Folder 34, Box 5, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 3

Office of Public Relations
CALIFORNIA INSTITUTE OF TECHNOLOGY
Pasadena 4, California

November 12, 1947

ROUTE FOR TRANSPORTATION OF 200-INCH MIRROR

California Street to San Gabriel Boulevard;

San Gabriel Boulevard to Valley Boulevard;

Valley Boulevard to Garfield Avenue;

Garfield Avenue to Olympic Boulevard;

Olympic Boulevard to Greenwood Avenue;

Greenwood Avenue to Washington Boulevard;

Washington Boulevard to Rosemead Boulevard;

Rosemead Boulevard to Bellflower Boulevard;

Bellflower Boulevard to Artesia Avenue;

Artesia Avenue to State Sign Route 35 (Pioneer Boulevard);

State Sign Route 35 to Ocean Boulevard;

Ocean Boulevard to Los Alamitos Boulevard;

Los Alamitos Boulevard to Westminster Avenue;

Westminster Avenue to Tustin Avenue;

Tustin Avenue to U. S. Highway 101;

U. S. Highway 101 to State Sign Route 78 at Carlsbad;

State Sign Route 78 at Carlsbad via Vista to Escondido;

Escondido via Valley Center Road to Rincon;

Rincon to Palomar Junction;

Palomar Junction to Palomar Mountain.

(NOTE: This route is subject to last minute changes. If there are any major changes we will do our best to advise you immediately.)

California Institute of Technology, "Route for Transportation of 200-inch Mirror," November 12, 1947
Folder 34, Box 5, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 4

FB -

205D
CIT
Telescope

Interviews: WW

RBF
TBA
MC
HMM
GRP

JAN 22 1948

AEB

Monday, November 17, 1947

Dr. Max Mason, California Institute of Technology (Telephone call from Pasadena)

The 200" mirror is on the truck ready to go up the mountain. All technical and organizational aspects of the telescope situation are going forward beautifully. But unfortunately the estimate on funds has proved to be grossly in error.

For one thing, many of the items of equipment, such as ordinary gears, which they had expected to be able to buy promptly and at regular production prices, they have been forced to have made by their instrument makers. And for such items the cost compared more or less as would the cost of a Ford, if it had to be made one piece at a time by a mechanic. Secondly they had expected to bring the major construction to a close by September 1, whereas it is now clear that this date is about April 1. Thirdly, a realistic reexamination, at present prices, of the auxiliary equipment, such as measuring devices, etc., including the addition of certain items which they now know they will need although these had not been invented a year or two ago, has increased that part of their budget substantially. The net result is that they will run out of money approximately December 31, and that they need $250,000 additional to meet a carefully trimmed budget.

WW discusses this with RBF, and though we are both dazed and disappointed (much preferring that we had asked for half a million last year), it is agreed that the only thing we can do is to put the matter before the Trustees.

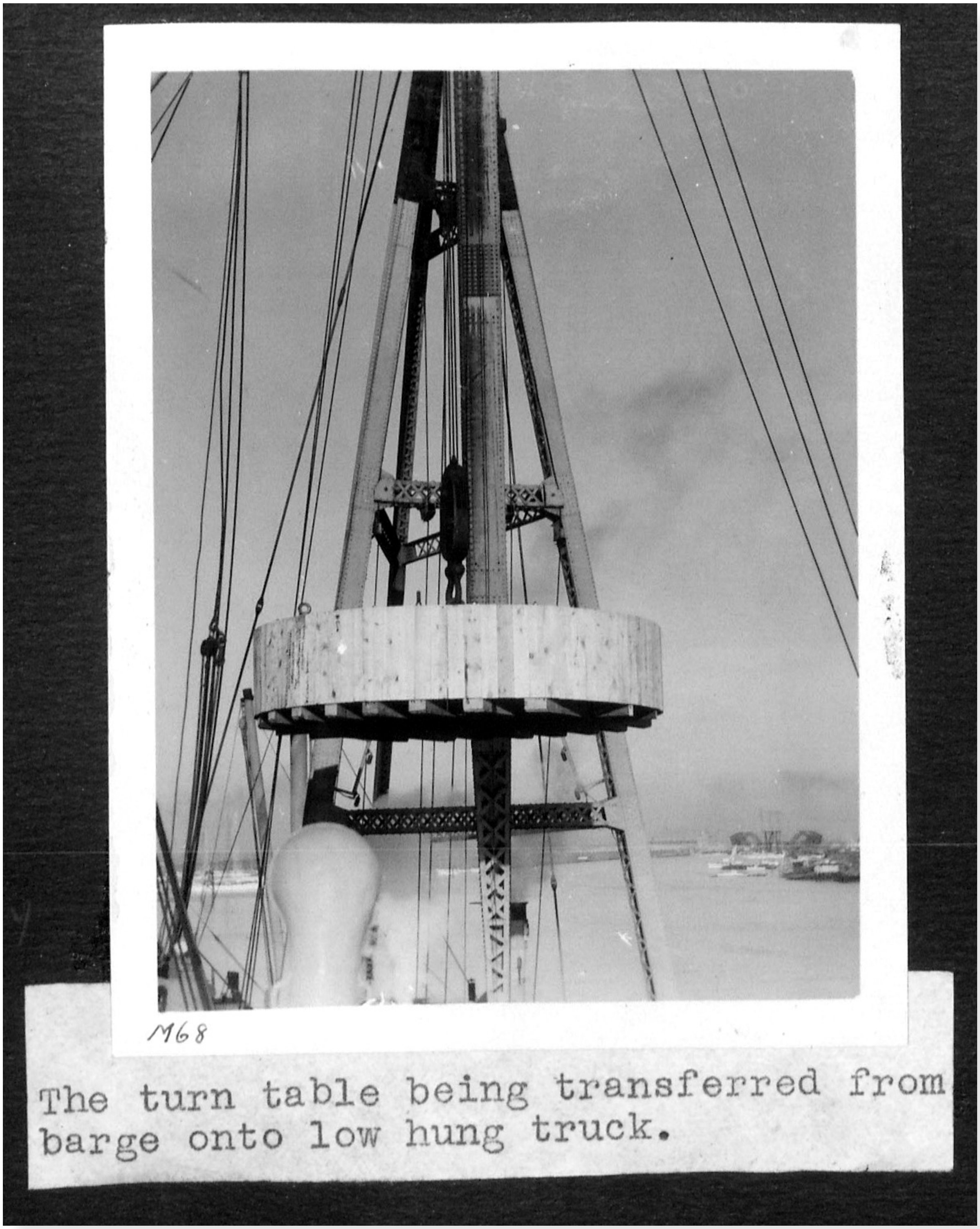
WW calls MM and asks that a written statement be sent to him at once. EB

Max Mason telephone call, November 12, 1947
Folder 34, Box 5, Series 205D, Rockefeller Foundation records, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 5

Photograph of Palomar Mountain Observatory Site, c. 1945
Folder B1, Box 5, Series 205D, Rockefeller Foundation photographs, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 6



Photograph album pages that document the move of the 200-inch mirror, 1947
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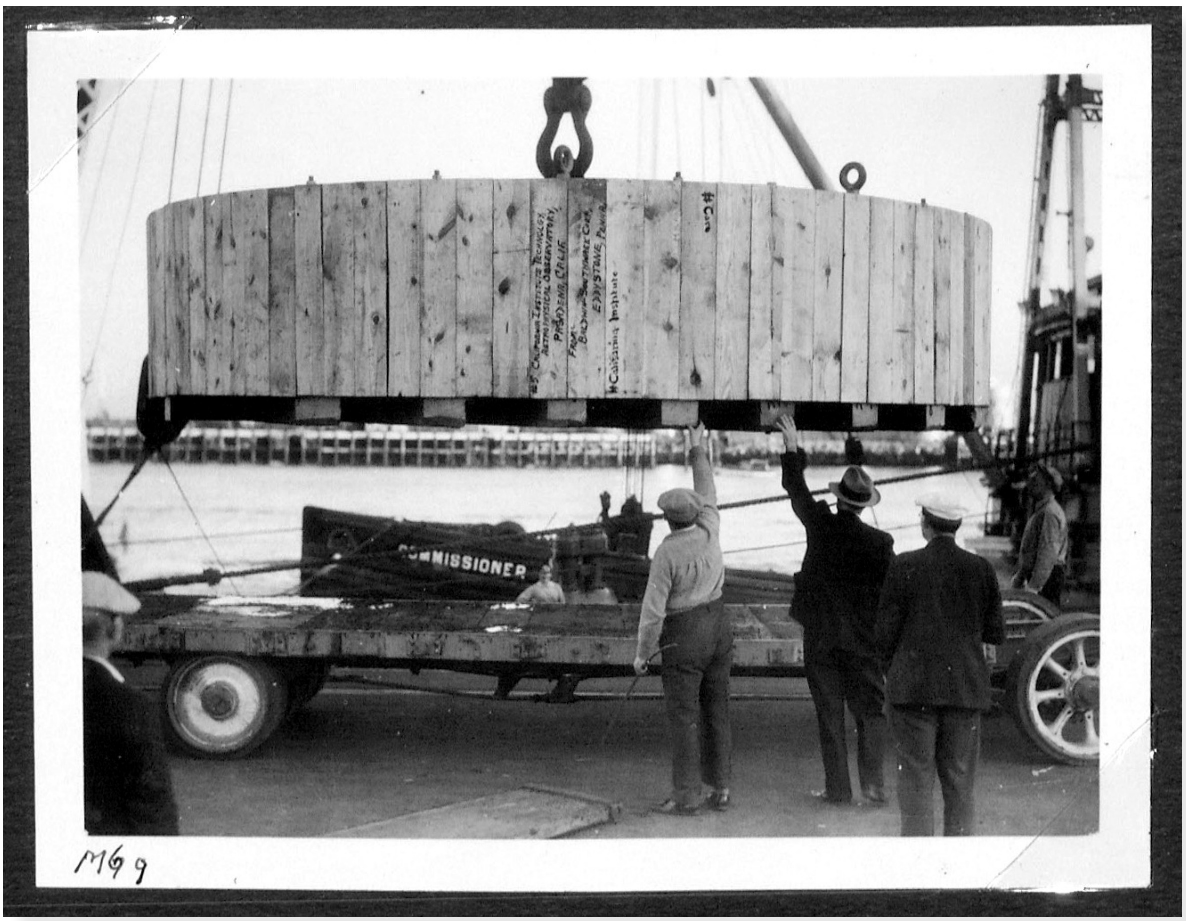
PRIMARY SOURCE DOCUMENT 6 CONTINUED



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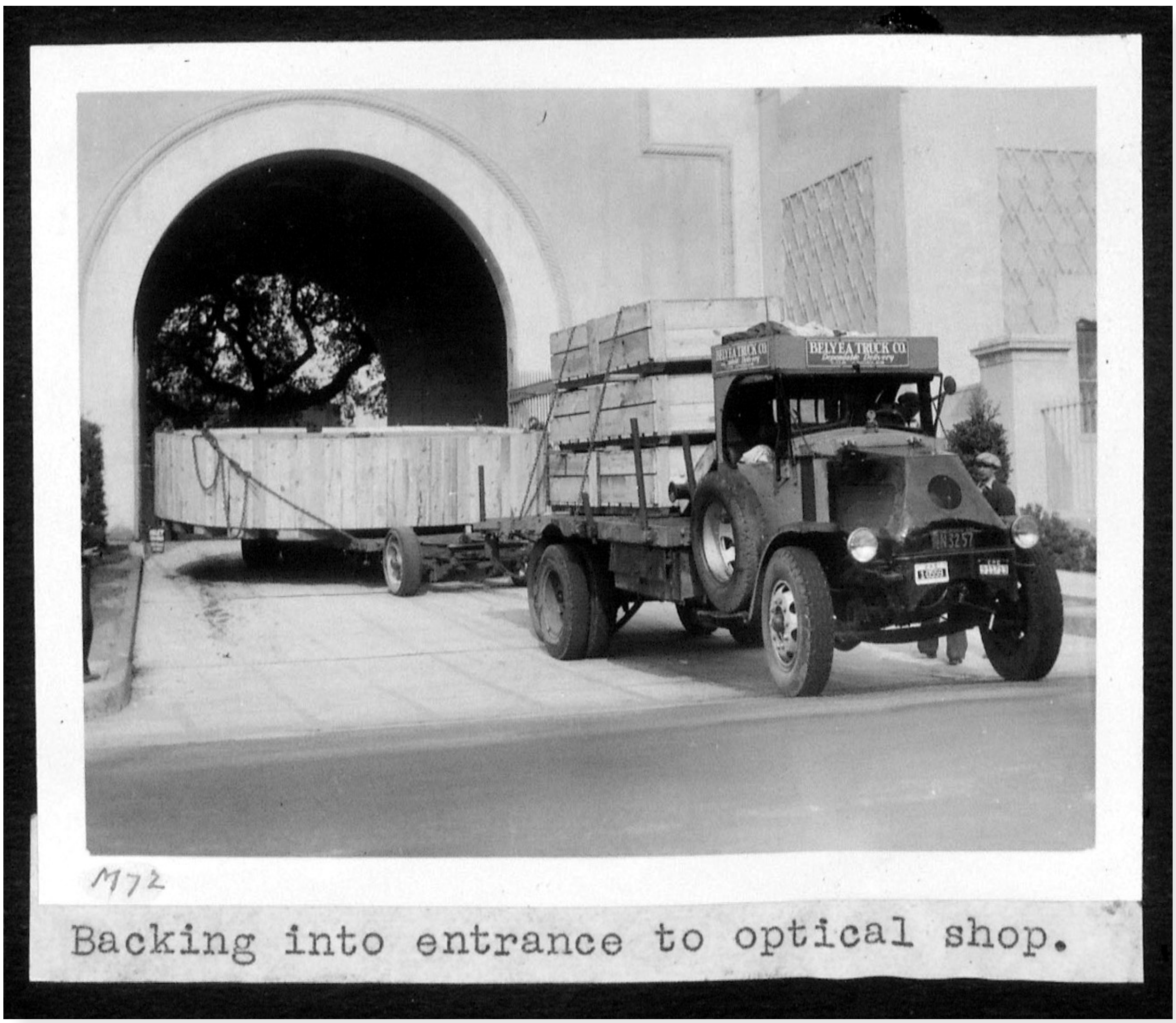

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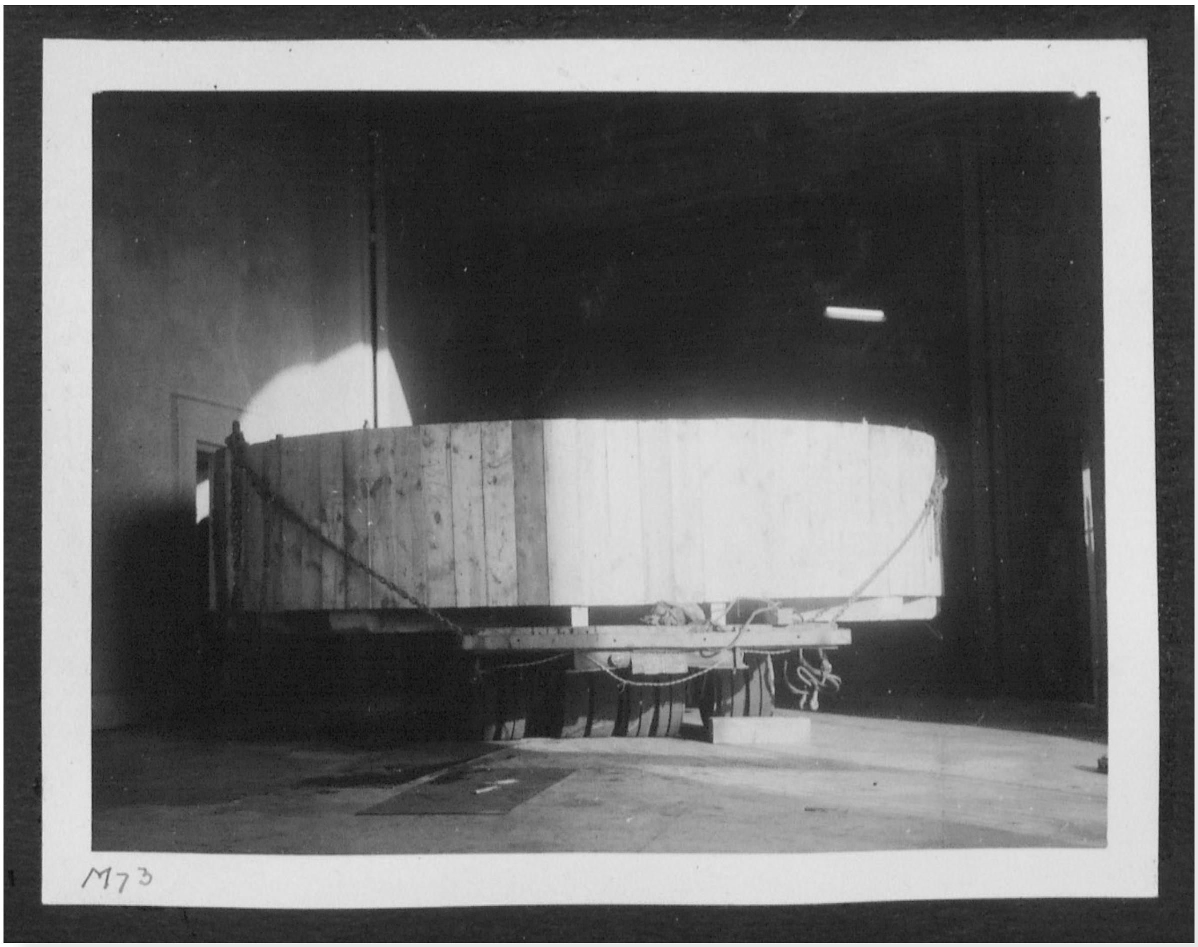

Photograph album pages that document the move of the 200-inch mirror, 1947
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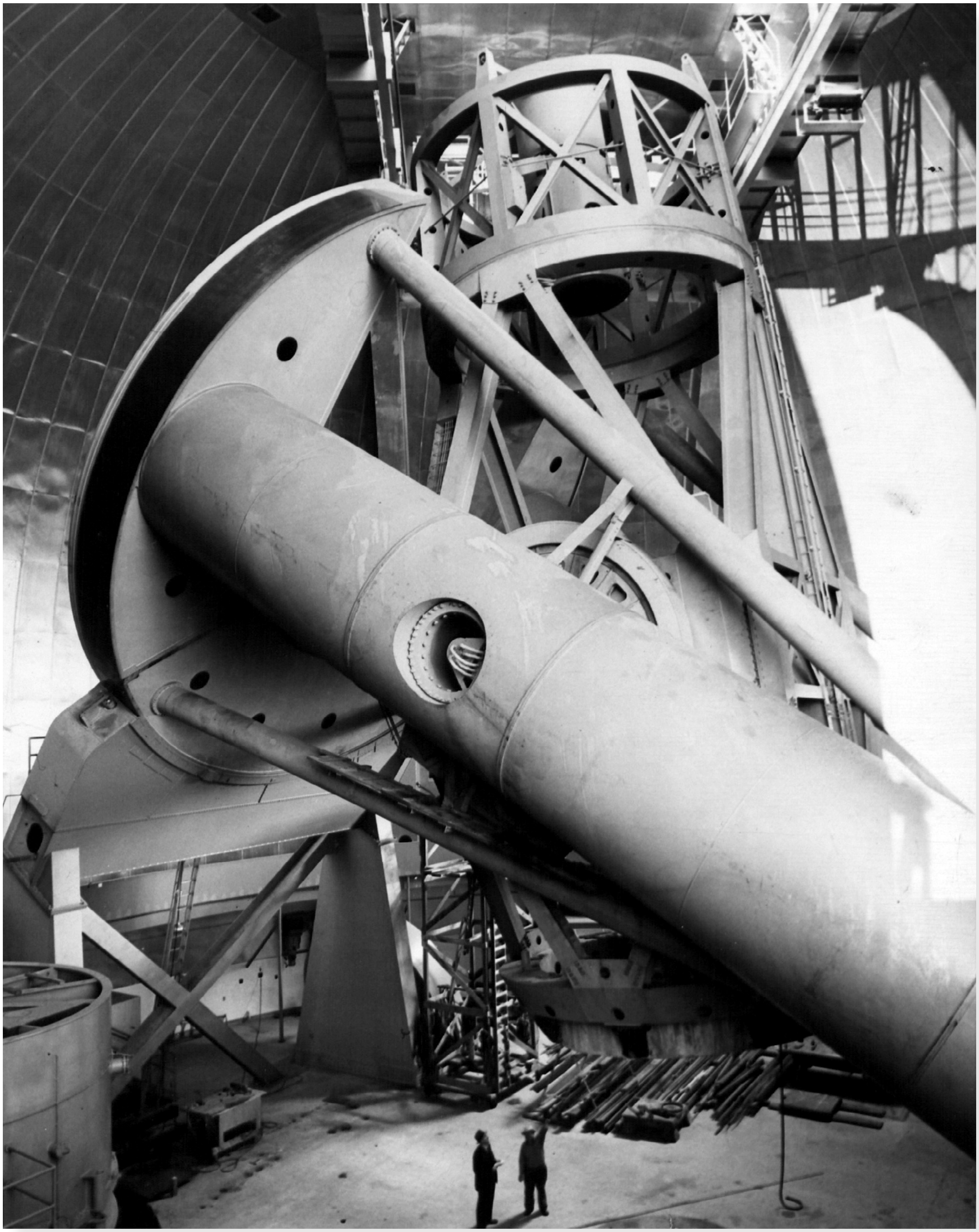
PRIMARY SOURCE DOCUMENT 7

Photograph of General truck caravan moving the mirror, 1947
Folder 1091, Box 45, Series 205D, Rockefeller Foundation photographs, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 8

Photograph of mirror moving through town, 1947
Folder 1091, Box 45, Series 205D, Rockefeller Foundation photographs, Rockefeller Archive Center.

PRIMARY SOURCE DOCUMENT 9



Hale Telescope, c. 1945
Folder 1091, Box 45, Series 205D, Rockefeller Foundation photographs, Rockefeller Archive Center.

FOLLOW-UP QUESTIONS

- What were the concerns of Hale and his team in moving the mirror up to Palomar Mountain?
- Which stage of the journey did Hale and his team seem most concerned about, and why?
- What do you think the bystanders thought of the mirror as it moved through town?
- What do you think would be the biggest risk to the telescope mirror's safety?
- Why do you think the California Institute of Technology asked that the press not make the telescope mirror's travel route public? What were they concerned about?

SUGGESTED RELATED ACTIVITY

TOO STRESSFUL? HOW FORMULAS WORK

Put all together, the mirror and its supports weighed over 60,000 pounds. In order to get the mirror and its supports up to the top of Palomar Mountain, a truck would have to carry the load across roads, bridges, and mountains. How could a mirror this heavy make such a trip without either breaking, or destroying the roads?

The California Department of Public Works told the trucking company not to worry—most of the roads would be able to handle the load. There was only one, more rickety bridge to worry about: the Galivan Overhead, a wooden bridge, made of redwood planks, that crossed over a pair of railroad tracks (today, the bridge no longer exists). The engineers at the Department of Public Works told the trucking company they would be allowed to cross the bridge, but the risk was their own. "You and the California Institute of Technology must decide for yourselves whether to risk the safety of the cargo against the stress," they wrote.

Stress is generated when force is applied to a region. The amount of stress caused depends both on the force and the area of the region in which it is applied.

In this activity students will use the Stress Formula to understand how formulas work. This activity compares the stress caused by different objects as they move across a bridge to gives students practice manipulating a formula using different variables. The activity concludes with a real-world application of the formula derivation, with students calculating the stress imposed by the Hale Telescope mirror on the Galivan Overhead, a bridge on the path to the observatory, and discussing ways to reduce stress on the journey.

LEARNING OBJECTIVES

- To understand how a formula works, and how it can be applied using different variables.
- To understand what stress is and how it is calculated using a formula.
- To use the Stress Formula to understand how stress increases/decreases depending on the force, or weight, of an object, and the area, or size of the force's impact.
- Using the example of the Hale Telescope mirror and its journey from Pasadena, CA up to the observatory on Palomar Mountain, to apply students' explorations of formula derivations to understand how engineers can manage the stress a heavy load places on the roads and bridges it travels on.

SUGGESTED RELATED ACTIVITY

GLOSSARY OF MEASUREMENTS

The units of measurement used in this project are taken directly from the historical documents. Consult this glossary for an explanation of equivalent measurement, should you wish to use metric as opposed to Imperial units.

Imperial Units of Measurement: a system of measurement predominantly used in Great Britain from the nineteenth century until the mid-twentieth century; it remains in use today.

Metric System of Measurement: a system of measurement which today forms the basis for the International System of Units (SI) and is commonly used.

REFERENCES:

State of California to Belyea Truck Company, "Transportation Permit," October 27, 1947; S.V. Cortelyou to Belyea Truck Company, August 11, 1947; George H. Hall to Milton Harker, October 29, 1947; Bruce H. Rule to Jack Belyea, November 3, 1947; Dr. John A. Anderson and Bruce H. Rule, "200-inch Transportation Arrangements," November 3, 1947; "Final 200-inch Transportation Schedule," November 18, 1947; File 4, Box 9, Bruce H. Rule Papers, Archives, California Institute of Technology.

With many thanks to Loma Karklins, Archivist for Reader Services at the Caltech Archives & Special Collections for finding and sending us the Bruce H. Rule papers, and to Peter Sachs Collopy, University Archivist and Head of Caltech Archives & Special Collections for his help identifying and securing Hale Telescope resources.

UNITS OF MEASUREMENT USED IN THIS PROJECT AND METRIC EQUIVALENTS

Imperial Unit of Measurement	Metric System Unit of Measurement	Equivalents	Purpose
ton (t) *(referred to as "short tons" or "net ton")*	metric ton (t) or tonne (t)	1 t = 0.907 t	weight measure *(1 [short] ton = 2000 lbs)* *(1 tonne = 1000 kg)*
pound (lb)	kilogram (kg)	1 lb = 0.454 kg	weight measure
square inch (sq in)	square centimeter (sq cm)	1 sq in = 6.542 sq cm	area measure
pounds per square inch (psi)	pascal (Pa)	1 psi = 6894.76 Pa	pressure measure *(how much weight per how much surface area)*
pounds per square inch (psi)	kilopascal (kPa)	1 psi = 6.89476 kPa	pressure measure *(how much weight per how much surface area)*

SUGGESTED RELATED ACTIVITY

DIRECTIONS

1. Discuss what a formula is, if students are not yet familiar with the concept. Explain that a formula is a mathematical principle described using numbers or symbols, typically one that manipulates several variables within a set of criteria.
2. Explain that a formula is a guide that allows you to understand the relationships among different objects and concepts.
3. Display the Stress Formula to calculate stress for students "**Stress = Force ÷ Area**"
4. Ask a question: "A material—like ice, wood, or cement—is more likely to strain and break when the stress is high. According to the formula, does adding wheels to a truck impact how much damage it causes to a road?"

   Answer: *Yes, adding wheels reduces the stress imposed by any individual wheel by spreading out the weight of the load over a great contact area.*

5. Show students a photograph of a standing elephant on a floor and use this example to test out the Stress = Force ÷ Area formula.

   Weight (Force of Elephant): 6000 lb
   Area of Elephant's Foot: 180 square inches
   Stress = 6000 lb ÷ 720 sq in = 8.33 lb/sq in

6. Ask Students:

   a. Why is the weight divided by 720 square inches? Isn't the area of the elephant's foot just 180 square inches?

      Answer: *180 Square inches per wheel x 4 wheels = 720 square inches*

   b. While walking, elephants are supported by just two feet at a time. What is the stress a moving elephant places on the surface it walks on?

      Answer: *6000 lb ÷ 360 sq in = 16.67 psi*

   c. How do you think this compares to the stress a typical human puts on a surface he or she stands on? More or less?

SUGGESTED RELATED ACTIVITY

7. Use the weight (force) of an average adult male to compare the stress of an elephant standing on the ground to that of a human being.

    a. According to the Centers for Disease Control and Prevention (CDC), the average adult male weighs about 200 lbs., and other studies estimates that a human foot touches the floor at an area of about 15 square inches in each foot. Complete the stress calculation for a human and compare it to the stress created by a standing elephant.

    Answer: *200 lbs ÷ 30 sq in = 6.67 psi*

8. Explore other variables that impact the stress caused by a human being.

    a. A snowshoe expands the contact area between a person and the floor. Some snowshoes are 25 inches long, and about 9 inches wide. Calculate the stress a 200 lb person creates while walking.

    Answer: *While walking, all the weight is on one foot. Area is about 25 x 9 or 225 sq in.*
    200 lb ÷ 225 sq in = 0.89 psi

    b. A stiletto is a high heel that is famously damaging to floors. Some stilettos have heels that are about a 1/4 in. on each side. Suppose a person weighs 100 lbs and puts all of their weight one of the stiletto heels. Calculate the stress they put on the floor.

    Answer: *Area is roughly 1/4 in x 1/4 in = 1/16 sq in*
    100 lb ÷ 1/16 sq in = 1600 psi

SUGGESTED RELATED ACTIVITY

9. Apply the lessons learned using the **Stress Formula** of **Stress = Force ÷ Area** to calculate the maximum stress the roads could handle when transporting the Hale Telescope mirror.

   a. The truck carrying the load up to Palomar Mountain was a 16-wheeler. Truck tires are often adjusted to accommodate up to 110 pounds per square inch (psi), and the tires have a "contact area" of about 75 square inches. Using the Stress Formula, Stress = Force ÷ Area, what was the maximum weight such a truck might be able to carry?

   Answer: *110 psi x 75 sq in per wheel x 16 wheels = 132,000 lb*

   b. The Weight (Force) of Hale Telescope Mirror and Truck was 60 tons, or 120,000 lbs. When the 16-wheeler and the telescope mirror crossed the Galivan Overhead, what is the stress each tire would impose on the bridge?

   Answer: *120,000 lb ÷ (75 sq in per wheel x 16 wheels) = 100 psi, close to the pressure of the tires and far more than an elephant or a person imposes while walking.*

   c. The engineers were worried that this might damage the bridge. In the end, they added several other trailers so the weight would be spread out over 42 tires. If each of these tires could handle 110 psi, what is the maximum weight it could carry?

   Answer: *110 psi x 42 wheels x 75 sq in per wheel = 346,500 lb. Much safer!*

SUGGESTED RELATED ACTIVITY

CONCLUDING DISCUSSION

- How did you use the Stress Formula in this exercise? How many different problems did you solve using the same formula?
- How can a formula help you understand the relationship between the two variables discussed, force and area?
- Moving beyond the Stress Formula, what else do you think the engineers could have done to help make the Galivan Overhead safer for the truck carrying the telescope mirror to cross?

  Answer: *Possible responses include reinforcing the bridge to reduce strain on the planks. Students might also mention using larger tires, using several trucks (if possible).*

- How would you devise a test to determine how much stress the planks in a bridge could take? (This is called a "stress test.")

  Answer: *Possible response could be using a single plank and imposing stress on it until it strains. No need to test the strain under trucking in particular.*

- Looking at the November 12, 1947 press release issued by the California Institute of Technology (primary source #1), can you identify other choices the engineers made to help safely bring the telescope mirror up to the top of Palomar Mountain?
- How many trucks did the engineers require to bring the mirror up Palomar Mountain? Why do you think the engineers made this choice?

ADDITIONAL RESOURCES

Maynard, Mark, "'Singing Wheels'—the story of Fruehauf Trailers," *The Baltimore Sun*, May 14, 2015, http://www.baltimoresun.com/sdut-Fruehauf-Trailers-2015may14-htmlstory.html. Accessed 2.27.20.

"Palomar Construction, Palomar Archives 2 and Palomar Archives 3," film footage from the construction of the Hale Telescope's 200" mirror and transportation from Pasadena, CA, up to the top of Palomar Mountain, January 1, 1935 – December 31, 1948, Palomar Observatory Motion Pictures Collection, Archives, California Institute of Technology, https://archive.org/details/capsca_00001/capsca_00001_r1_access.HD.mp4. Accessed 2.27.20.

ABOUT US

Elizabeth Berkowitz was the 2018–2020 Mellon/ACLS Public Fellow at the Rockefeller Archive Center, where she worked as the Outreach Program Manager for the Research and Education division. An art historian, Elizabeth has taught extensively in museums and universities, and has published both popular and academic articles. She holds a BA in Art History and English, an MA in Modern Art, a Graduate Certificate in Museum Studies, and a PhD in Art History.

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Michael Pershan is a middle and high school math teacher and writer at Saint Ann's School in New York City. He has published pieces in *Tablet*, *Deans for Impact*, *The American Bystander*, and *The Learning Scientists*. He is the author of an upcoming book on teaching with worked examples for John Catt. He received National Board Certification and is a past recipient of a Heinemann Fellowship.

ABOUT US

The Rockefeller Archive Center (RAC) is a major repository and research center dedicated to the study of organized philanthropy and the Third Sector. It holds the records of over forty major foundations, cultural organizations, and research institutions, as well as the papers of over one hundred individuals associated with these organizations.

The Research and Education (R&E) Program at the RAC brings together historians, educators, and archivists to explore topics in the history of philanthropy for public, scholarly, and professional audiences and to cultivate new audiences for archival research. The team's activities include digital publishing, conferences and workshops, educational outreach, practitioner engagement, and a competitive research stipend award program.

R&E develops and makes available archive-based interdisciplinary projects and curricula for levels ranging from upper elementary grades to graduate study. These materials support the development of information literacy and research skills, as well as deeper engagement with primary sources and the practice of history. R&E also works to strengthen the bridge between education and archives by hosting workshops and discussions for a growing professional network through its Archival Educators Roundtable.

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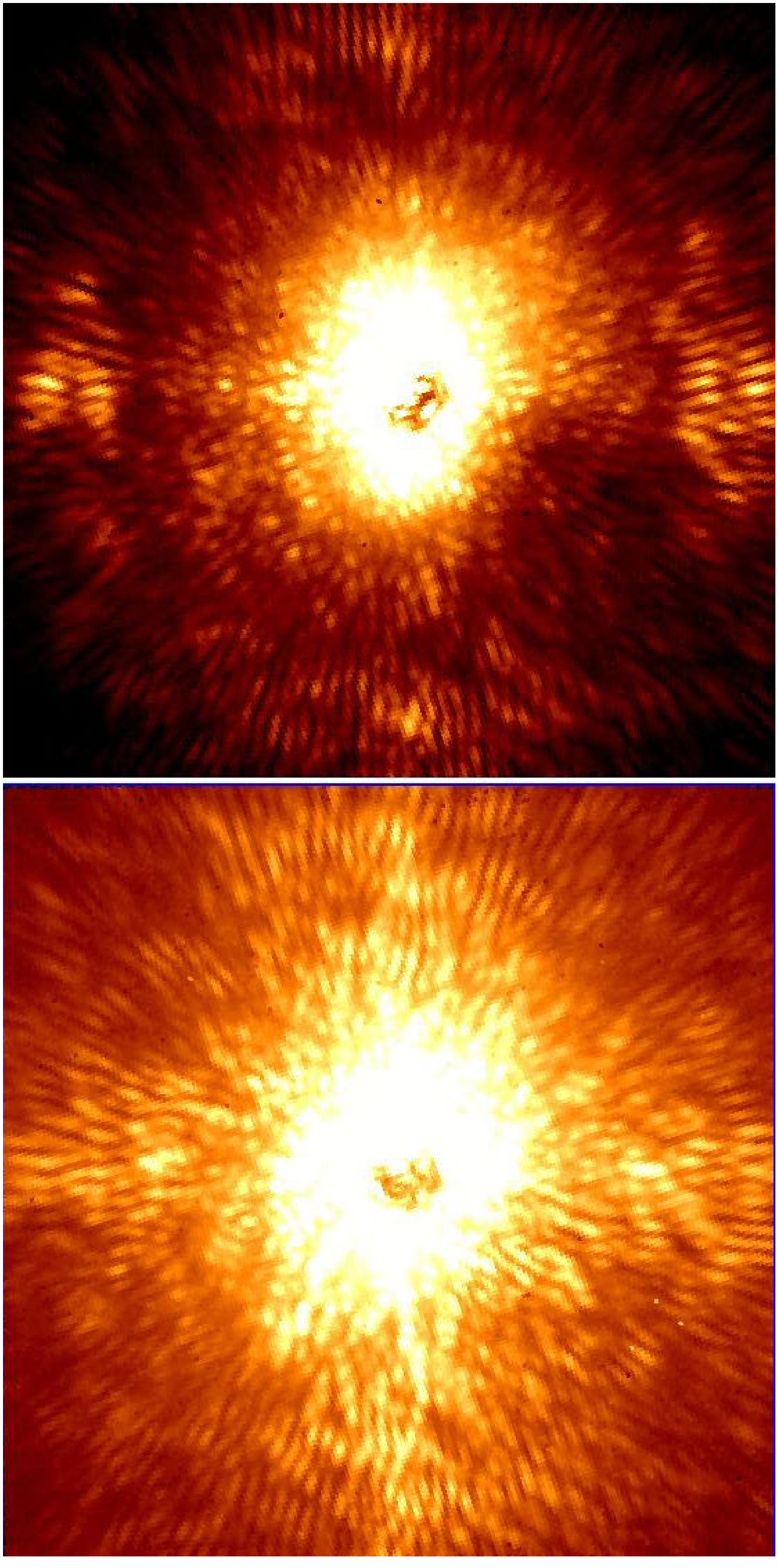

These two images show HD 157728,
a nearby star 1.5 times larger than the sun.
Project 1640 uses new technology on the
Palomar Observatory 200-inch Hale telescope
near San Diego, California, to spot planets.

Credit: NASA Image Library