BAMS Article

The Secrets of the Best Rainbows on Earth

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ABSTRACT: This paper makes a case for why Hawaii is the rainbow capital of the world. It begins by briefly touching on the cultural and historical significance of rainbows in Hawaii. Next it provides an overview of the science behind the rainbow phenomenon, which provides context for exploring the meteorology that helps explain the prevalence of Hawaiian rainbows. Last, the paper discusses the art and science of chasing rainbows.

KEYWORDS: Tropics; Atmospheric circulation; Dispersion; Orographic effects; Optical phenomena; Machine learning

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Rainbows are some of the most spectacular optical phenomena in the natural world, and Hawaii is blessed with an amazing abundance of them. Rainbows in Hawaii are at once so common and yet so stunning that they appear in Hawaiian chants and legends, on license plates, and in the names of Hawaiian sports teams and local businesses (Fig. 1). Visitors and locals alike frequently leave their cars by the side of the road in order to photograph these brilliant bands of light.

Fig. 1. Collage of Hawaii rainbow references.

The cultural importance of rainbows is reflected in the Hawaiian language, which has many words and phrases to describe the variety of manifestations in Hawaii, a few of which are provided in Table 1. There are words for Earth-clinging rainbows (uakoko), standing rainbow shafts (kāhili), barely visible rainbows (punakea), and moonbows (ānuenue kau pō) (Pukui and Elbert 1986).

In Hawaiian mythology the rainbow is a symbol of transformation and a pathway between dimensions, as it is in many cultures around the world, and those who can freely travel between the upper world and the lower reaches live like gods among humans, enjoying earthly prosperity and abundance. A rainbow is the celestial path that Hawaiian gods use to come down to Earth from their home in the godly realms. Departed souls walk on a rainbow path to pass through Kuaihelani, a mysterious floating island that "supports the heavens" to reach the sacred land of Nuʻumealani, the bright, elevated and fragrant land of "the heavenly one." The rainbow also serves as a footstool for Malanaikuaheahea, the wife of the legendary transpacific voyager and astronomer whose name, Makaliʻi, is also the Hawaiian term for the Pleiades star cluster from which it is believed that the first Hawaiians came to Earth.

Table 1. Words and phrases for rainbow in the Hawaiian language (Pukui 1983; Pukui and Elbert 1986).

1. Ānuenue, ao akua	Rainbow
2. Ānuenue kau pō, pō mākole	Rainbow at night
3. Ānuenue i ka pō mahina	Lunar rainbow
4. Ānuenue pālua	Double rainbow
5. ʻŌnohi, ala muku	Rainbow fragment
6. Haka ʻula a Kāne, mākole	Rainbow with red colors predominating
7. Hakahakaea	Greenish rainbow
8. Kāhili	Standing rainbow shaft
9. Koʻi ʻula	Rainbow-hued rain, mist, cloud
10. Luahoʻāno, (luahoʻāna), luakālai, luakālai lani	Halo around sun (or moon)
11. ʻŌnohi ʻula, ʻōnohi ʻula i ka lani	Red rainbow segment; cloud with red
12. Pūloʻu	Arching rainbow that does not touch Earth
13. Punakea	Barely visible rainbow
14. Piʻo ānuenue	Arcing rainbow
15. Piʻo ānuenue hapa pōʻai	Very large, half-circle rainbows
16. Piʻo-Mōʻī	Primary rainbow; king arc
17. Piʻo-Aliʻi	Secondary rainbow; chief arc
18. Pōʻai ānuenue	Circular rainbow
19. Pōʻai ānuenue piha	Full-circle rainbow
20. Uakoko, lehopulu, pūnohu	Earth-clinging rainbow
21. Uakoko	Rainbow-sparkling rain
22. Waiānuenue	Rainbow water

According to Hawaiian legend, Kahaukani and Kauakuahine, chief and chiefess of Mānoa Valley, had a beautiful daughter, Kahalapuna. When Kahalapuna's parents learned of her death at the hands of a jealous suitor they both transformed to their spirit forms. Kahaukani, resolved into the Mānoa wind, and Kauakuahine became the Mānoa rains. Since then, as the Mānoa winds blow the misty rains down valley, Kahalapuna appears as a rainbow (Fig. 2). The University of Hawaiʻi at Mānoa is frequently blessed with Kahalapuna's presence.

Beyond high school science class: The science behind rainbow phenomena

To understand why the skies over Hawaii have a predilection for rainbows, some understanding of rainbow phenomena is helpful. It is regrettable that the rainbow, like other atmospheric optical effects, is often covered only very briefly at all education levels from primary school to university. This section explores not only how water spheres reflect and refract light to create a special conical geometry for the rainbow, but also more advanced optical effects caused by the wavelike nature of light and size distribution of raindrops on dispersion.

Fig. 2. An uakoko, a low flying rainbow over Mānoa Valley (photo by Dennis Oda). According to Hawaiian legend, Kahalapuna is known as the Rainbow Maiden, born of the divine wind and rain of Mānoa Valley. Since ancient times the valley has been regarded as "the royal palace of rainbows," where the beautiful Rainbow Maiden can be seen playing wherever the light of the sun touches the misty rain.

Many early philosophers (e.g., Aristotle ~350 BC, Alexander of Aphrodisias ~AD 200, Avicenna ~AD 1000, Theodoric of Freiberg ~1300) speculated on the origin of rainbows and knew that they appeared when sunlight fell on raindrops. However, the first person to give a satisfactory explanation of the rainbow phenomenon was René Descartes, in his *Discours de la Méthode* in 1637 (Descartes 1637).

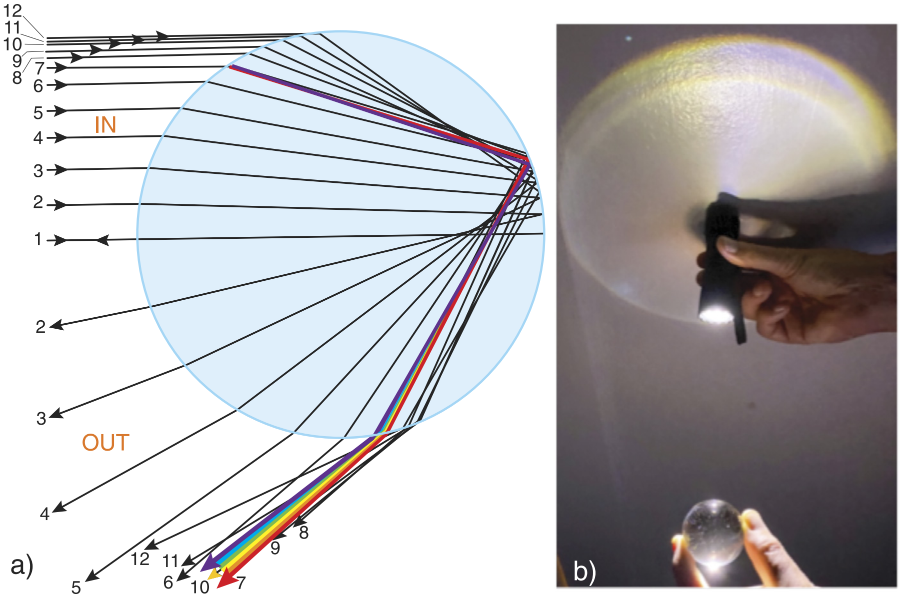

Fig. 3. (a) Path of light rays through a rain droplet. The rainbow colored rays denote the Descartes ray. (b) A cone of colored light projected onto a wall by a polished quartz crystal sphere held by the author, as an analog of what a sunlit raindrop also produces. The refractive index of crystalline quartz for red light in air is 1.520, for water it is 1.333. Thus, a spherical raindrop will result in a larger circle.

Descartes describes experiments with water-filled glass spheres, similar to those done by Theodoric of Freiberg in 1304. However, Descartes also performed quantitative ray tracing for parallel sunlight using the correct law of refraction, which he derived independently of Dutch scientist Willebrord Snell (Fig. 3a). Descartes's analysis correctly predicted high angular concentrations of rays emerging from a spherical drop near the rainbow scattering angle of $\alpha = 42°$, known as Descartes's ray. This concentration of rays helps explain the brightness of the primary bow. Rays entering the drop above the Descartes's ray emerge from the droplet at an angle less than 42°. Descartes showed that each rain droplet projects a cone of light back toward the sun (or light source) with an angle of 42° to an axis parallel to a sun ray that passes through the center of the drop (Figs. 3b and 4a). If a viewer's eye intercepts light along a drop's cone of light, that drop will contribute one sparkle of color to a viewer's rainbow (Fig. 4b). Billions of raindrops distributed along a cone at the correct viewing angles contribute to the phenomenon we perceive as a primary rainbow (Fig. 5).

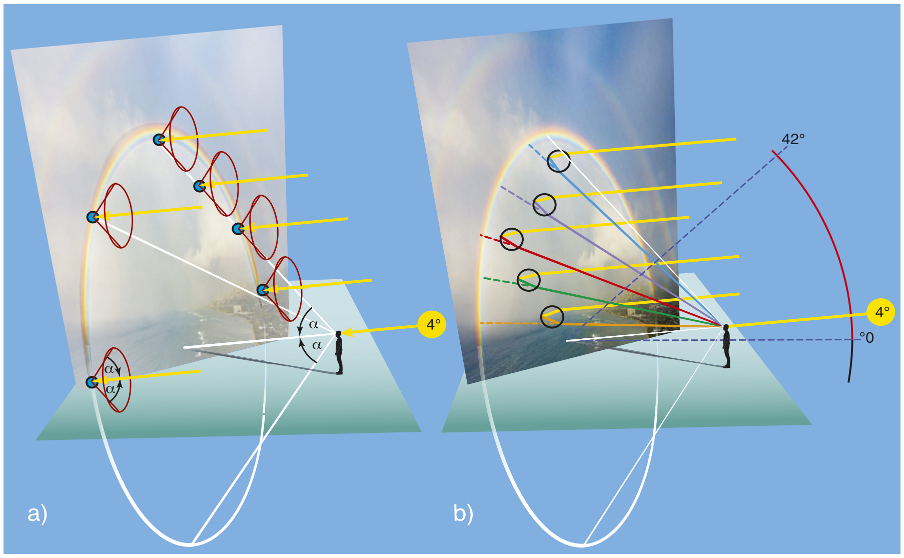

Fig. 4. (a) Each raindrop projects a cone of colored light at an angle of 42° from incoming sunlight (e.g., see Fig. 3b). If a viewer's line of sight aligns with the raindrops cone of colored light, the viewer will see one bright ray of color in that direction, which will be at 42° from the antisolar point. (b) The rays of colored light that make up the primary bow also form a cone, where the tip is at your eye. Its center axis is parallel to the sun's rays and directed to the antisolar point or the head of your shadow. Myriad raindrops along the cone's surface, be they close or far, send rays (one color per drop) of refracted, reflected, and dispersed sunlight to your eyes to create the bow.

Just after sunrise, the sun's angle above the horizon is small (e.g., 2° above the horizon) and rainbows at these times form a tall arch[1] (~40° above the horizon). As the sun rises to higher angles in the sky during the morning, the height of the rainbow diminishes until no rainbow is visible above the horizon (Fig. 5). The pattern is reversed as the sun lowers in the afternoon, with rainbows rising in the east and the tallest rainbows just prior to sunset. In Hawaii, rainbows can be visible in winter throughout most of the day

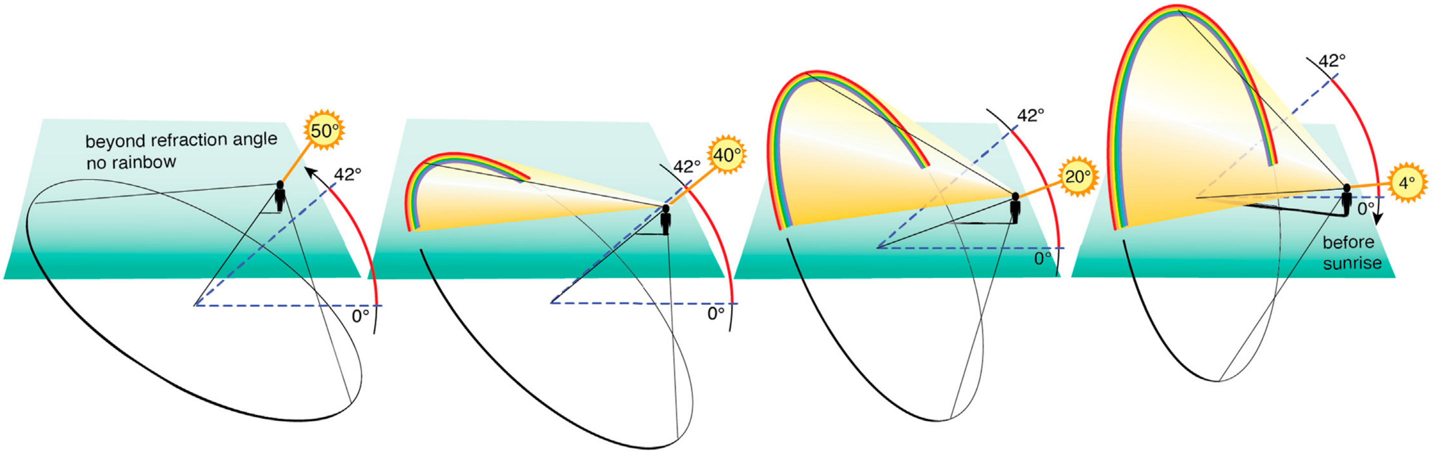

Fig. 5. (far right) The tallest rainbow occurs just after sunrise, followed by diminishing rainbow height as the sun rises higher in the sky during the morning, until (far left) the rainbow sets below the horizon when the sun's angle exceeds 42°. The red portion of the curve on the right side of each figure indicates the sun angles that can produce a visible rainbow above the horizon when the observer is standing on flat ground. The numbers inside the yellow suns give the sun's angle above the horizon. The shading illustrates that the rainbow is not a two-dimensional object in the sky, but rather follows a conical surface.

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[1] See Fig. 5 at https://rainbowchase.com/about-rainbows/ for an animation of the rainbow height as the sun rises and sets.

(~8.5 h, ~78% of daylight hours at winter solstice), and in summer, rainbows can grace our morning and afternoon hours (~6.5 h, ~58% of daylight hours at summer solstice).

When sun rays experience two internal reflections in spherical drops, the result is a concentration of rays emerging from the drops at a scattering angle of $\alpha = 51°$, which results in a secondary rainbow that appears outside of the primary rainbow (Fig. 6). Because of the added reflection, the order of the colors in the secondary rainbow is reversed from those of the primary, with red on the inside and violet on the outside of the bow.

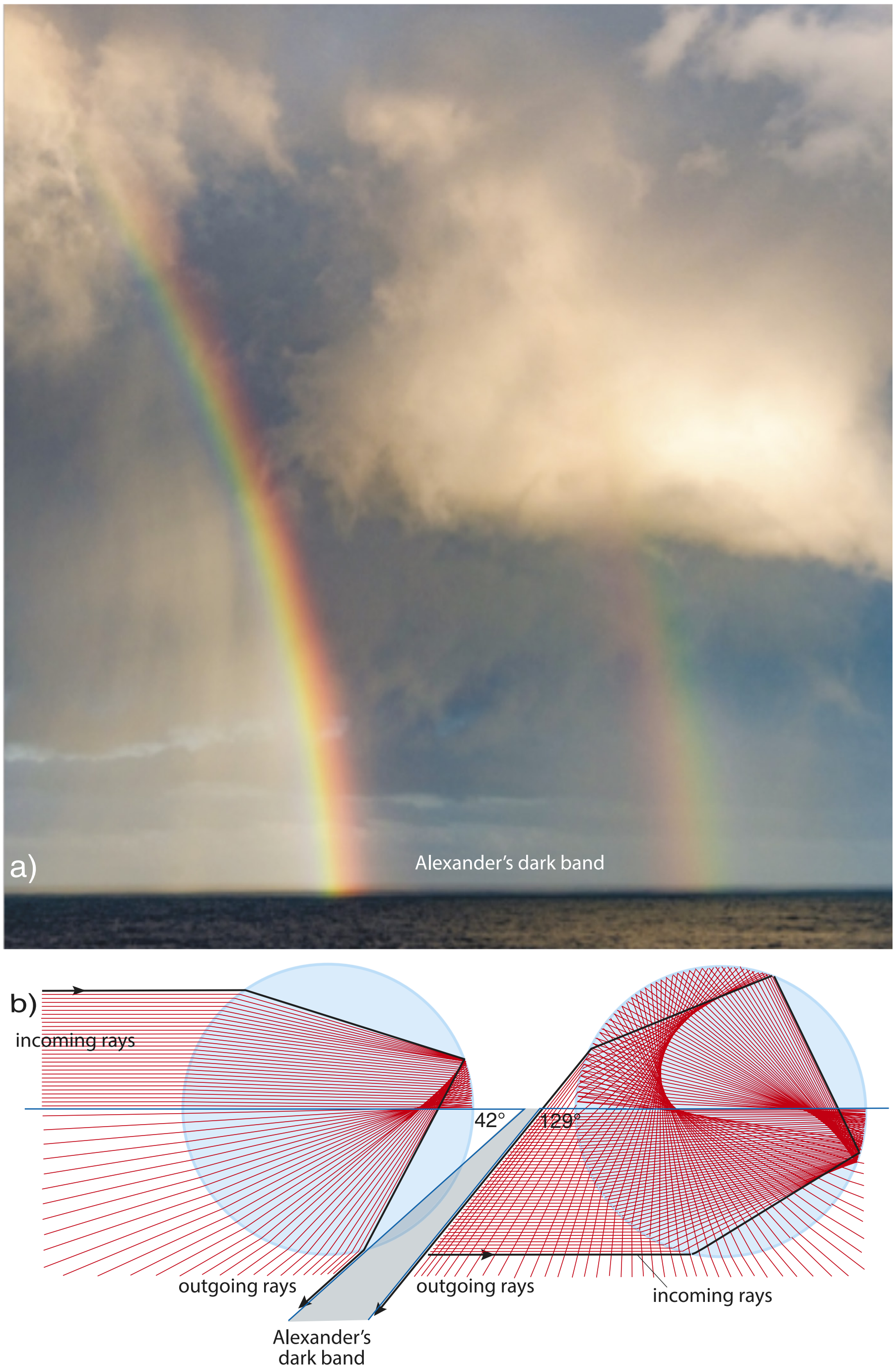

Fig. 6. (a) Example of Alexander's dark band. Note the enhanced light scattering by rain inside the primary bow and increased cloud brightness outside the secondary bow. (b) Schematic of scattering from spherical raindrops illustrating the reason for Alexander's dark band. The black arrows denote the Descartes's rays for the primary and secondary rainbows.

Descartes's analysis also confirmed that no ray can be deflected more than ~42° along a ray path involving exactly one internal reflection, and no ray can be deflected more than ~51° along a ray path involving exactly two internal reflections. Thus, there is a region between the primary and secondary rainbows that appears dark, which is known as Alexander's dark band after Alexander of Aphrodisias who first described it (Fig. 6). Alexander's dark band is not completely dark, because of an "extrinsic" background of light from the sky and clouds, or diffuse multiple scattering from other raindrops as common in natural rainbow displays. Light also enters this region as a result of dispersion because of the wave nature of light, which was not fully understood by scientists of Descartes time, as will be discussed below.

One of Descartes's great insights is that each observer sees their own rainbow made up of light rays from a unique set of raindrops that happen to be located in an arc at a 42° angle away from the shadow of that observer's head (Fig. 4b). A friend sharing the experience nearby will actually be enjoying a different rainbow. Moreover, if a reflection of a rainbow is seen in water, the reflected bow receives its light from a different set of raindrops than the rainbow it seems to be reflecting (Fig. 7). Therefore, the reflected rainbow in the water is actually not a true reflection of the rainbow above. To make matters even more complex, if the sunlight is reflected on a surface of a lake or bay just behind the viewer, the result is two sets of rainbows: one produced by rays from the sun above the horizon; and a second set produced by rays that are reflected from the surface of the still lake or bay (Fig. 8a). In this case there are two antisolar points, one below the horizon and the second above the horizon associated with the reflected sun (Figs. 8b,c).

Fig. 7. Rainbow over Honolulu Harbor with what appears to be its reflection (photo by Minghue Chen). However, the reflected bow is not what it appears to be. See the text for explanation.

In Hawaii rainbows are commonly seen in the spray blown up by the apparent wind associated with large, fast-moving wave crests that break near shore. The refractive index is slightly larger for saltwater than for freshwater; therefore, the radius of a rainbow in saltwater is less than that for freshwater (Fig. 9).

Descartes did not have an explanation for the colors of the rainbow. That insight was provided by Sir Isaac Newton, who showed that white light can be separated into a “spectrum” of colors, a term he coined. From careful experiments with prisms, he deduced that light was a particle and that the separation of colors was the result of a slight variation of the refractive

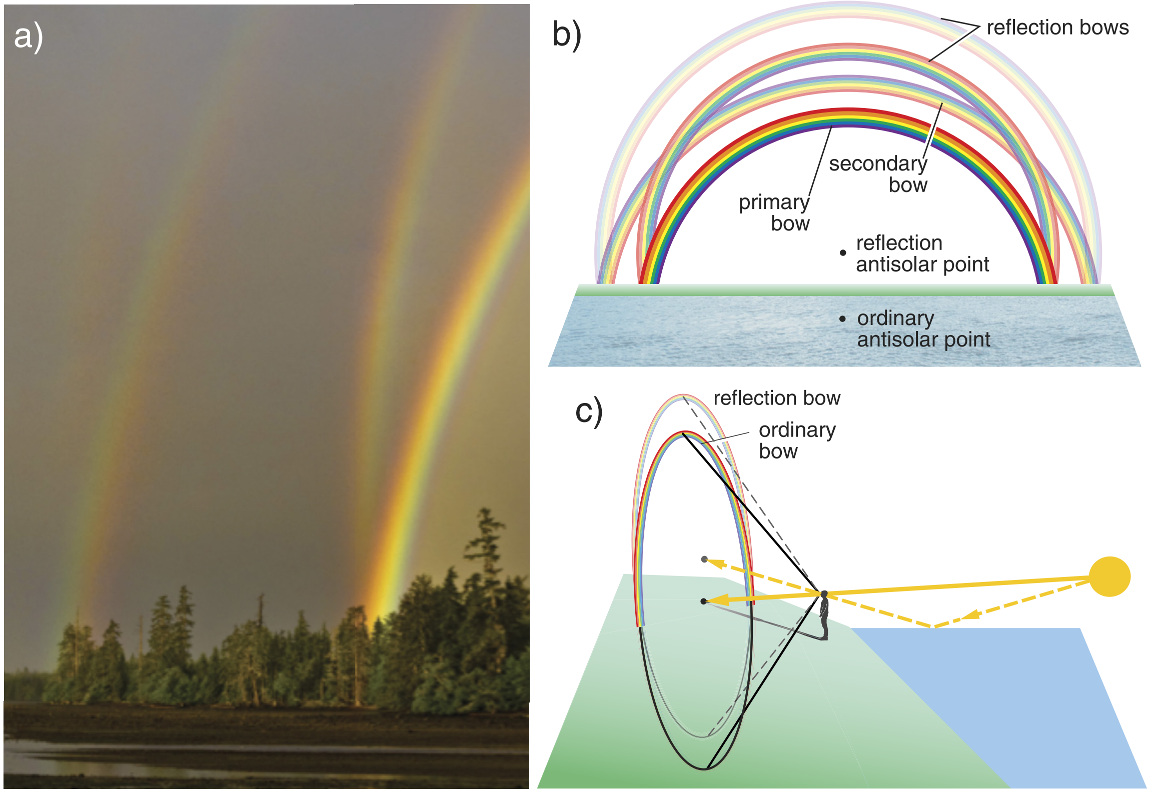

Fig. 8. (a) Photograph by Jason Drury taken in British Columbia, showing two sets of primary and secondary rainbows. (b) Schematic of four bows and two antisolar points. (c) Schematic illustrating how the second set of rainbows is produced by sunlight reflected by a still surface of water.

index for different colors of light. Newton chose to divide the visible spectrum into seven colors[2] informed by the beliefs of ancient Greek sophists, who thought there was a connection between the colors, musical notes, known objects in the solar system, and the days of the week. This somewhat arbitrary choice, because the human eye can discern many more than seven colors, is still reflected in how we describe the colors of a rainbow today.

Fig. 9. Rainbow in saltwater wave spray with freshwater rainbow behind (photo by Nick Stokes).

In Newton's time there was controversy among scientists regarding whether light is a particle or a wave. Neither Descartes nor Newton had an explanation of the faint colored bows sometimes visible within the primary bow and, more rarely, visible outside of the secondary bow. These faint bows are called supernumerary bows (Fig. 10a) and are the result of diffraction of sunlight (Airy 1838; Fraser 1983). Supernumerary arcs caused great consternation because they were not

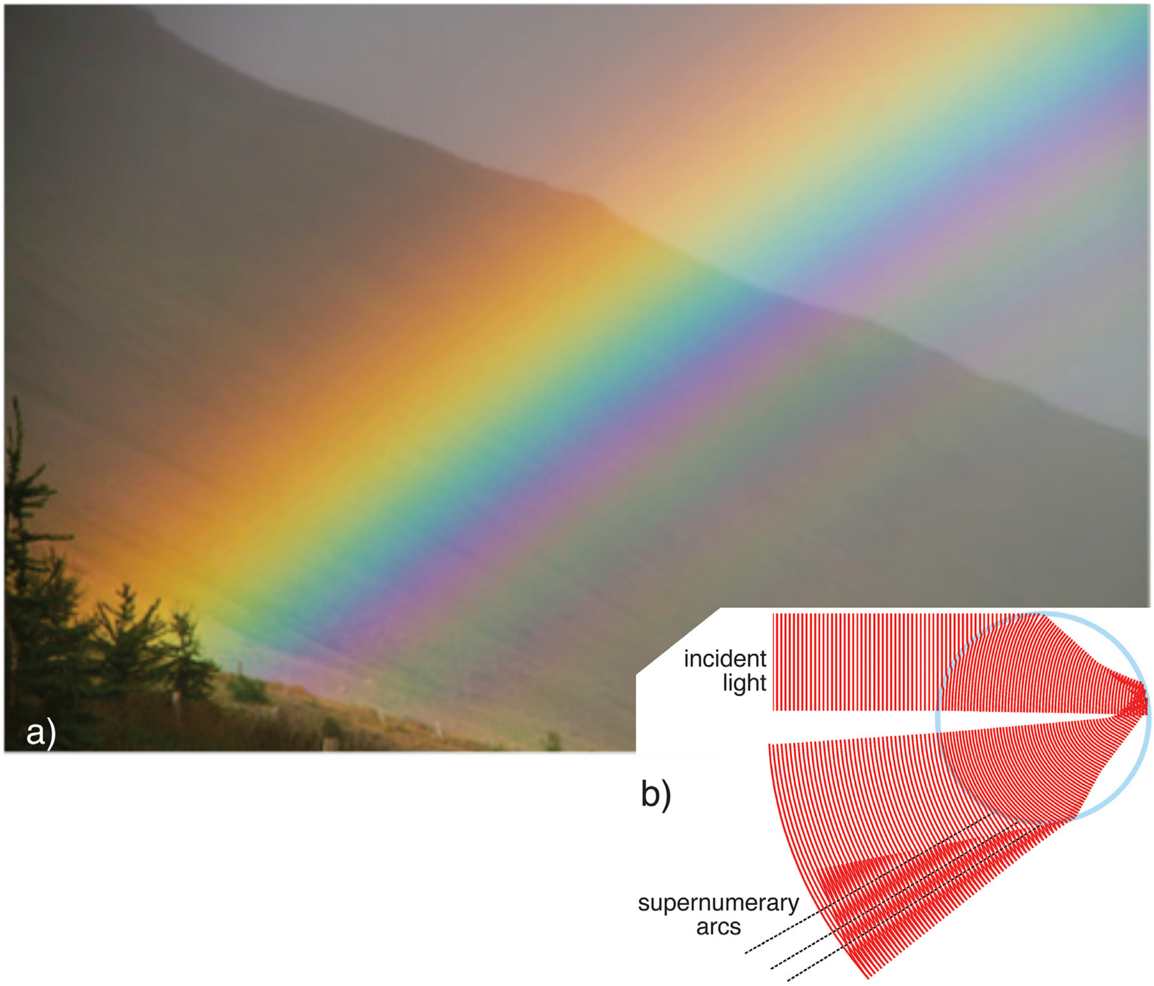

Fig. 10. (a) An example of supernumerary bows beneath the primary bow (photo by Matt Champlin). (b) Schematic of a moiré pattern that mimics the constructive and destructive interference pattern of sun rays emerging from a raindrop.

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[2] Red, orange, yellow, green, blue, indigo, and violet.

predicted by geometric optics. It was not until the 1830s that scientists such as Thomas Young and George B. Airy showed that supernumerary bows were a consequence of the wave nature of light. Light scattering from small raindrops produces an interference pattern consisting of a series of maxima and minima as a function of the scattering angle (Fig. 10b) (Bohren and Clothiaux 2006). Small spherical rain droplets that are uniform in size produce the most coherent diffraction pattern. That is why supernumerary bows are more commonly visible just beneath the top of the rainbow because raindrops grow as they fall and become less spherical in shape and less uniform in size as they approach the surface.

There have been a number of increasingly sophisticated mathematical treatments of rainbows since Descartes's attempt in the mid-seventeenth century. The Lorenz–Mie theory is by far the most accurate approach as it takes into account optical effects such as dispersion, polarization, interference, and diffraction (Lorenz 1898; Mie 1908; Debye 1908). During the last 20 years, many new and intriguing effects have been photographed or documented for the first time, such as higher-order (tertiary, quaternary, etc.) and twinned rainbows, and rainbows generated by nearby artificial light sources. These observations have been spurred by the increasing numbers and capabilities of digital cameras.[3] To provide a more complete explanation of the myriad observations, the inclusion of natural nonspherical (i.e., oblate) raindrop shapes as well as natural nonuniform raindrop distributions into the classical rainbow theory is needed. Providing examples of all these effects is beyond the scope of this paper; however, Haußmann (2016) provides a comprehensive review of these observations and more recent theories and applications of physically based computer models for simulating rainbows that accommodate nonspherical raindrops (Sadeghi et al. 2012).

Why is Hawaii the rainbow capital of the world?

To answer this question involves understanding processes that range from the planetary-scale Hadley circulation to microscale raindrop formation, in addition to prevailing orographic impacts. In this section these processes are discussed in the context of the circumstances needed for rainbow sightings, including bright sunshine (ka lā) that is able to illuminate rain (ka ua).

Hawaii is located at ~20°N latitude in a region of the subtropics that is dominated by the Hadley cell. The Hadley cell results in subsidence and generally clear skies over Hawaii and produces our prevailing northeast trade winds. Northeast trade wind conditions occur over Hawaii 9 days out of 10 during the summer and 6 out of 10 during winter (Schroeder 1993). The airflow around the North Pacific high (Fig. 11) takes air from just off the West Coast and transports it over Hawaii in just over a week's time. During this traverse, the marine boundary layer gradually deepens as a result of entrainment or mixing at the top and warming from below (Krueger et al. 1995; Bretherton and Wyant 1997). Low marine stratus common along the West Coast gradually changes to closed cell convection and eventually transforms to open cell convection, as the air passes from California to Hawaii (Kodama and Businger 1998; Albrecht et al. 2019) (Fig. 11). Therefore, Hawaii's trade wind weather is characterized by convective showers with clear skies between the showers. As can be discerned from Fig. 11, the spacing between the showers is sufficient (~30–50 km) to allow sunlight to reach the rain beneath the showers, producing optimal conditions for rainbow sightings. At night a warm sea surface heats convection from below, while radiation cools cloud tops, resulting in deeper rain showers in the morning that produce rainbows in time for breakfast.

A critical factor in producing frequent rainbows is the mountainous character of the Hawaiian Islands. Without mountains, Hawaii would be a desert with a scant ~430 mm (17 in.) annual rainfall as estimated from TRMM data over the proximate ocean. The impact of the Koolau

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[3] The reader can view photos of rainbows and other atmospheric optical phenomena at the following site: www.atoptics.co.uk.

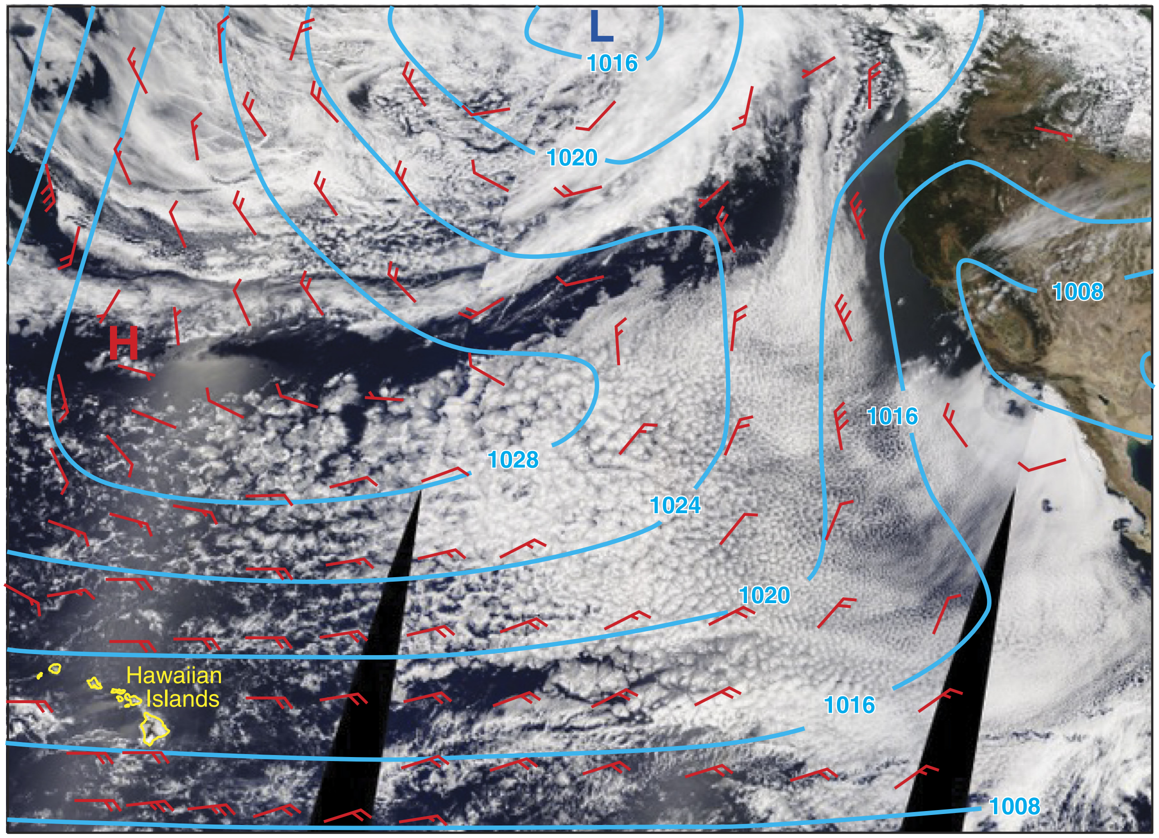

Fig. 11. GOES true color satellite image overlaid with sea level pressure analysis (hPa) valid at 2100 UTC 14 Jun 2013. Hawaii is visible at the lower left.

Mountains of Oahu on the trade wind flow is apparent in the sharp gradients of cloud fraction and rainfall over the island (Fig. 12). Although each Hawaiian island has unique topography and attendant orographic affects, in every case the mountains produce sharp gradients in clouds and rainfall (Giambelluca et al. 2013), which are key to abundant rainbow sightings. Hawaii's mountains generally enhance shower activity, but they also induce rain in moist flows (Robinson and Businger 2019; Houze 2014, chapter 12).

During the cool season (November–March), the mountains will lift stable, moist air in the wake of weak cold fronts or shear lines to create a rainband over the crest with increasingly clear skies in the lee. Sun passing beneath the orographic rain clouds provides a perfect configuration for rainbows, which have been observed to last for hours on end (Robinson

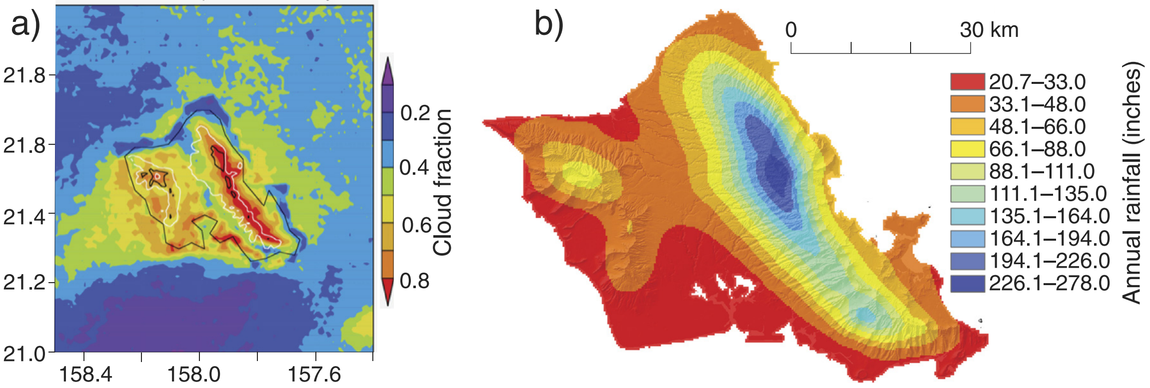

Fig. 12. (a) Mean cloud fraction over Oahu for the months of June, July, and August 2004, calculated at 1-km resolution, using *GOES-15* visible satellite data. Terrain contours given at 500-m intervals. (b) Mean annual rainfall over the island of Oahu (mm) (Giambelluca et al. 2013).

and Businger 2019) (Figs. 2 and 13a). Surface fluxes of sensible and latent heat into the air over the ocean are generally greater on the cold side of the front than on the warm side, because the air–sea temperature difference is larger on the cold side (Businger and Reed 1989). As a result, fronts tend to dissipate and become shallower as they approach Hawaii, which commonly leads to a decrease in stratiform clouds that block the sun, resulting in the rope-cloud appearance of the front (Fig. 13b). A cool season weather pattern that results in enhanced showers, especially over the lee slopes of the Hawaiian Islands, is the *kona low* (Morrison and Businger 2001). Kona lows are associated with cold troughs aloft and the resulting thunderstorms can sometimes become severe (Businger et al. 1998) (Fig. 13c).

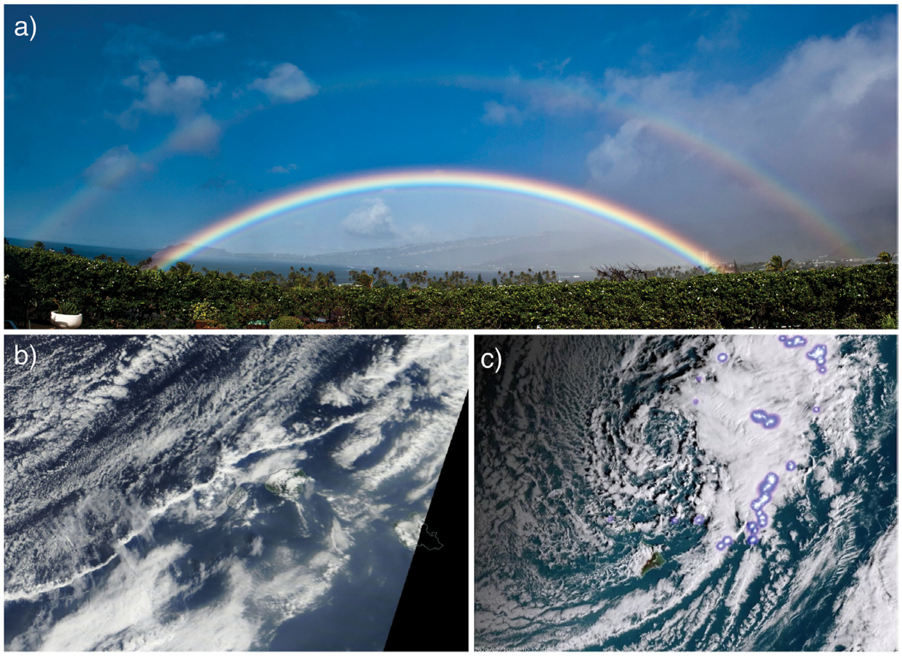

Fig. 13. (a) Double rainbow in the lee of the Koolau Mountains. (b) MODIS true color image valid for 1900 UTC 18 Feb 2017. (c) *GOES-17* true-color image with LIS lightning data overlaid, valid at 0000 UTC 12 Feb 2020.

A third factor conducive to rainbow sightings is diurnal heating, which drives island-scale circulations. The volcanoes of Maui and the island of Hawaii are tall enough to block the prevailing trade winds. Therefore, these islands experience the most consistent sea breezes and mountain–valley circulations (Chen and Nash 1994). During periods of light winds, all the Hawaiian Islands experience island-scale circulations driven by diurnal heating (Fig. 14). Under these conditions showers form over the ridge crests over Oahu and Kauai in the afternoon, resulting in prolific rainbows as the sun sets (Fig. 14).

The fourth factor that contributes to the numerous bright rainbows in Hawaii is the role of aerosols in cloud and precipitation physics. Hawaii is known as one of the most remote island chains on Earth. Hawaii's remoteness means that the air is exceptionally clean and free of air pollution, continental dust, and pollen. As a consequence, there is less scattering of sunlight by aerosol, and the sunlight contains the full spectrum of colors even at low angles when the sun is close to setting. Moreover, with fewer cloud condensation nuclei vying for water vapor in a cloud, there are fewer but larger cloud droplets in the warm clouds around the Hawaiian Islands (Twomey 1974), which are more conducive to generating rain through coalescence.

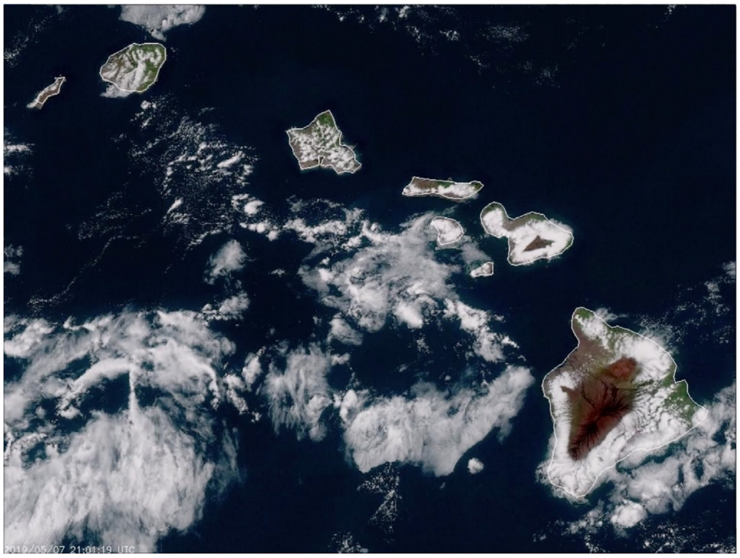

Fig. 14. *GOES-17* true-color image valid at 2100 UTC 7 May 2019.

A primary source of aerosols in the vicinity of Hawaii is the sea surface where air–sea interaction and breaking waves loft salt aerosols into the marine boundary layer (Fig. 9) (Porter and Clarke 1997). Small sulfate aerosols also occur over the ocean as a result of natural gas to particle conversion. Salt and sulfate aerosols are hygroscopic and soluble in water, making them conducive to generating a spectrum of cloud drop sizes (Houze 2014, chapter 3). In addition, recent aircraft measurements in shallow cumulus made with a phase Doppler interferometer suggest that entrainment, especially near cloud top, is important in initiating collision coalescence and warm rainfall (Small and Chuang 2008). As a consequence, in Hawaii even small cumulus clouds can and do generate rain (Fig. 15). A characteristic of these small rain clouds is that on the lee side of the mountains the cloud itself dissipates as a result of orographically induced sinking motion and adiabatic warming. Meanwhile the rain continues to fall to the ground, leaving rain and rainbows under mostly blue skies (Figs. 2, 7, and 13a).

Fig. 15. Warm rain falling from a small cumulus cloud over the lee slope of Koolau Mountains.

A recent effort aimed to map out the rainbow potential within the northern American continent (B. Brettschneider 2019, personal communication) shows the greatest rainbow potential in southwest Alaska with high potential extending along the British Columbia coast to include Washington and Oregon west of the Cascade crest. To create the map, Brettschneider noted when hourly weather station observations reported the presence of liquid precipitation and then calculated sun angle to see if a rainbow could appear above the horizon (e.g., Fig. 5). Hawaii is not included in his analysis. The limitation of Brettschneider's approach is the lack of reference to cloud cover data. Rain in these coastal areas, especially during the cool half year when the sun angle may be favorable, can be frequent. However, the rain is most often associated with frontal systems, which cast vast stratiform cloud decks that obscure the winter sun. During the summer months, when the chance of sunshine is greatest, the frequency of precipitation reaches a minimum in Washington and Oregon because the Pacific high pressure ridge causes subsidence over the Pacific Northwest. Moreover, cool upwelling ocean water along the West Coast keeps dewpoint temperatures very low, which inhibits moist convection. One of the most frequent precipitation types during summer is drizzle from marine stratus associated with marine pushes (Mass 1982), a weather pattern that is not conducive to rainbows sightings.

If you chose Honolulu Airport, a relatively dry leeward location on Oahu, to do Brettschneider's analysis, the sharp gradient in clouds and precipitation associated with Hawaii's steep mountains is not captured (Fig. 12). It is left to future research to quantify these mesoscale effects, perhaps with reference to a high-resolution regional numerical model, satellite, and radar data. Rainbow photos posted on social media could be collected and curated to eliminate photos of rainbow trout, etc. In addition, you would need a way to control for the number of outdoor users of digital cameras in a given location.

Chasing rainbows

Just as you can chase tornados in the U.S. Midwest, you can chase rainbows in Hawaii. In both locations, the greatest hazard in the chase is the potential for a motor vehicle accident. With a combination of weather satellite and radar loops, a rainbow hunter can discern likely places for rainbow sightings. Great care must be taken while driving not to be too distracted by the sky. Besides sun and rain, a good viewing location is key. Local knowledge of places with an excellent view of the sky is helpful. In Hawaii scenic overlooks, beach parks, and local hikes up cinder cones, like Diamond Head, give especially good vantage points from which to see rainbows. To see a rainbow on flat ground the sun must be within ~38° of the horizon (Fig. 5). This value is a little less than the angle of 42° for the height of the rainbow above the antisolar point. However, a search of rainbow photographs on social media that reference local time and, thus, solar angle, show that very few rainbows are photographed when the sun is higher than 38° above the horizon (Mora et al. 2021, manuscript submitted to *Proc. Natl. Acad. Sci. USA*). When the sun is very near the horizon, obstacles (trees, hills, clouds, etc.) are more likely to block the sun's rays.

An exception to the above limitation for the sun angle occurs when the rainbow chaser is on the summit of a mountain ridge or peak so that the rain continues to fall below the observer. Perhaps the best platform of all for chasing rainbows is a small plane or a helicopter, ideally one equipped with access to weather radar. Typical summer trade wind conditions prevailed on 31 August 2019, and a friend chartered a helicopter and invited the author along for the purpose of photographing rainbows from the air. The helicopter's radar showed a small echo in a region of converging air in the lee of Molokai Island. Sunshine and rain when seen from the air provide a special opportunity to capture a full circle rainbow (Fig. 16a). The next stop was the sea cliffs on the north side of Molokai, where more rain was in evidence. However, the clouds were too widespread to let in the requisite sunshine. So we headed back westward toward Oahu and encountered a lenticular cloud over the west end of Molokai. The short residence time of air passing through a quasi-stationary lenticular cloud results in very uniform small cloud droplets (Rangno 1986). As a result, conditions were ideal for the formation of a glory with an attendant cloud bow and supernumerary bow (Fig. 16b). Both the glory and the supernumerary bow are the result of scattering (reflection and diffraction) of sunlight by uniform cloud droplets. Regarding the cloud bow, the spectral colors of the white light have a much larger range of Mie scattering angles from small uniform cloud droplets and, as a result, colors overlap and the cloud bow appears white (Mie 1908; Bohren and Clothiaux 2006).

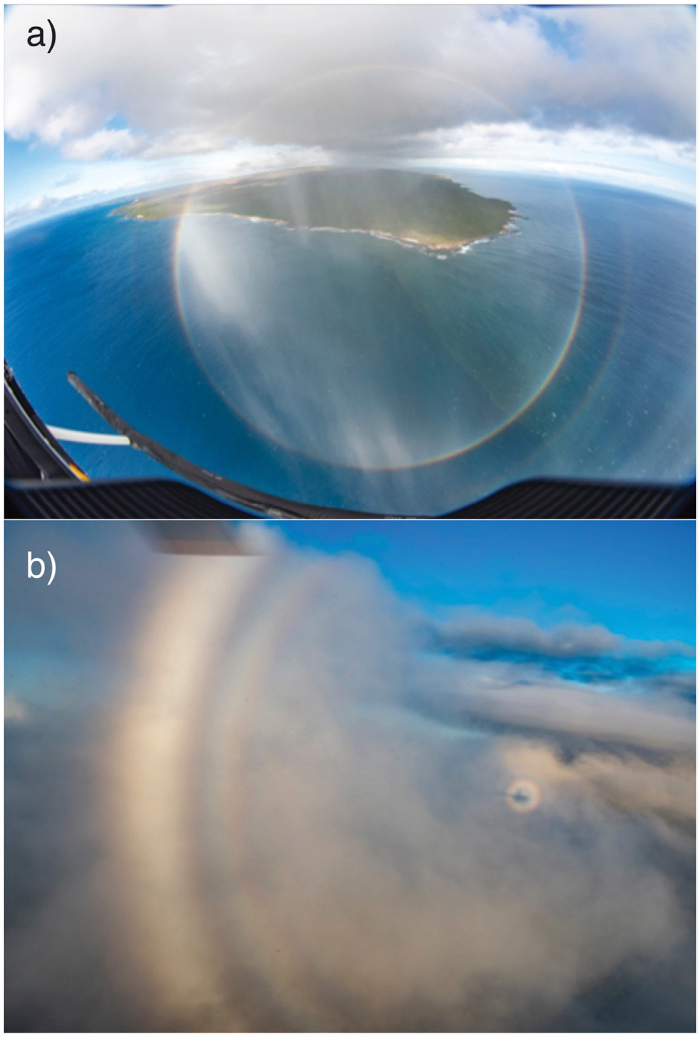

Fig. 16. (a) Circle rainbow with Molokai Island in the background. (b) Cloud bow with supernumerary bow and glory surrounding shadow of helicopter.

One can imagine that a smartphone app with access to Doppler radar data and geostationary high-resolution satellite data could be designed to alert users when nearby conditions become conducive for rainbow sightings, with directions to the nearest location for optimal viewing. Users could then share photos with other users and machine learning could be applied to improve user experience. Such an app, called RainbowChase, is now in the design phase.

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