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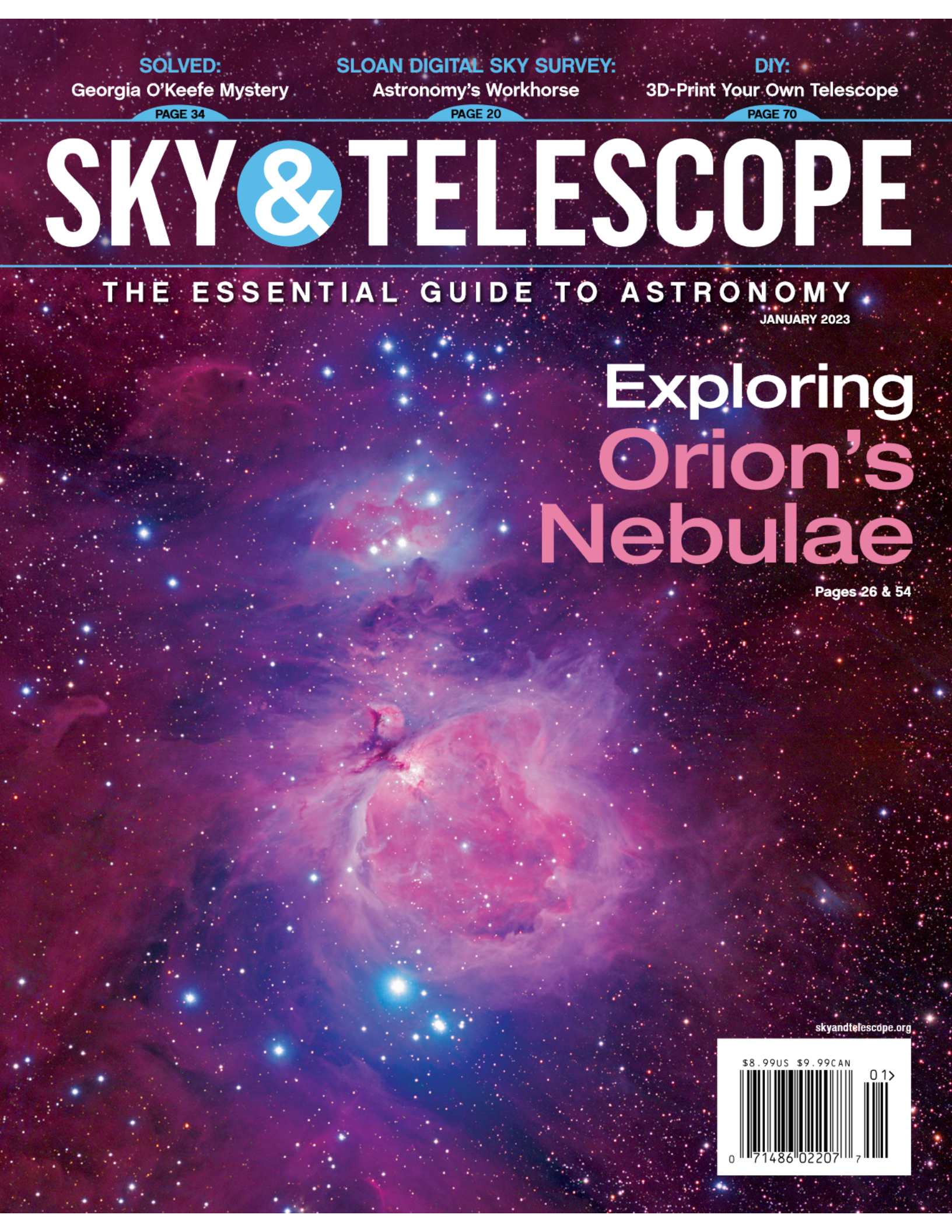
THE ESSENTIAL GUIDE TO ASTRONOMY

JANUARY 2023



Exploring Orion's Nebulae

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Composite H-alpha and RGB image of the Orion Nebula
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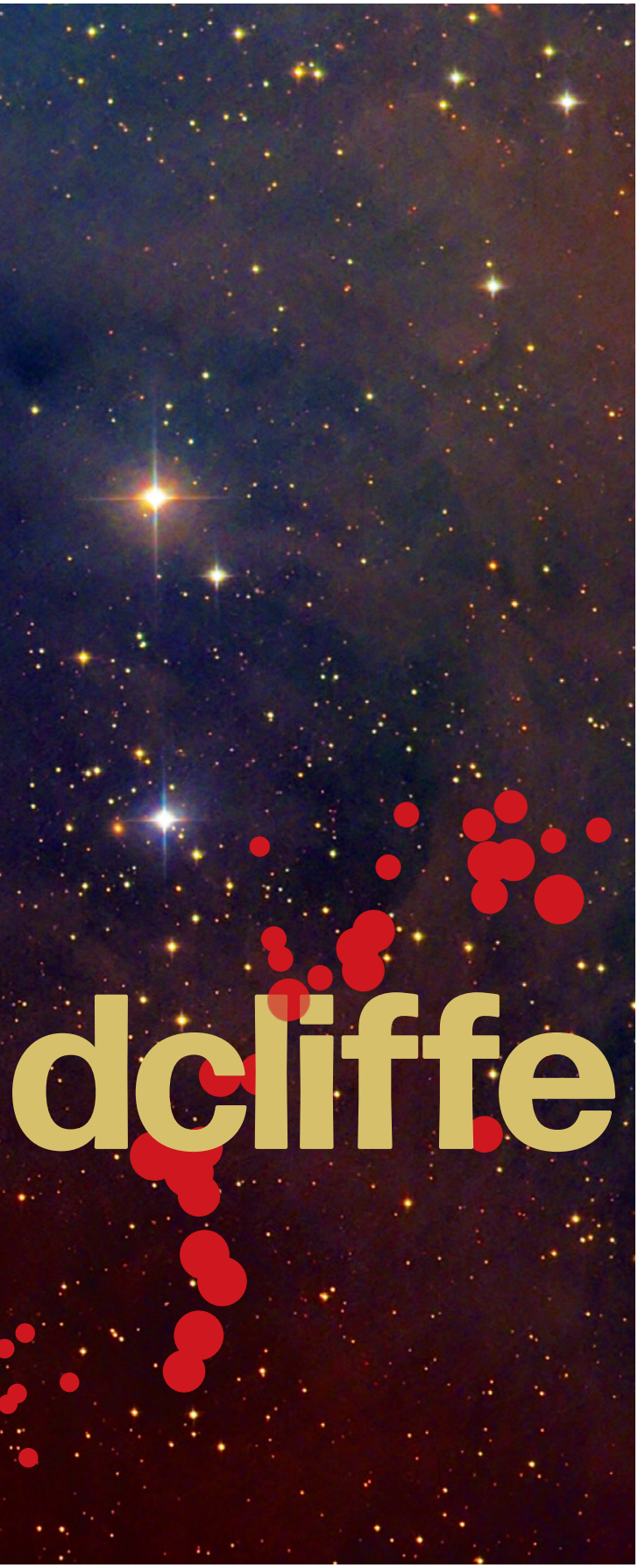
PRIZE IN PERSEUS The stunning reflection nebula NGC 1333 is a sight not to miss. You'll find it close to the southern border of Perseus, the Hero. Infrared observations show 150 new stars have formed in NGC 1333 in the past million years.

Riding the Ra

VOLKER WENDEL / JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY



dcliffe Wave

By observing this selection of targets, you can trace a newly discovered structure in the Milky Way.

The Gould Belt holds a special place in the hearts of deep-sky observers. Distinct from the Milky Way and tilted by 20° to our galaxy's plane, this starry ring spans 3,000 light-years and intersects the galactic equator in the richest regions of Scorpius and Centaurus on one side of the sky and in Orion on the other. The Belt offers stargazers a lavish bounty of blue-white stars, stellar nurseries, and rich open star clusters along its circumference. There's just one problem with the Gould Belt — it doesn't actually exist.

Or at least, it doesn't exist as a coherent physical structure. That's according to a landmark 2020 study in *Nature* in which a team of astronomers mapped the positions to local gas clouds that serve as star-forming regions in the Local Arm of the Milky Way and along the Gould Belt. Using an ingenious approach, the team parsed data from the European Space Agency's Gaia satellite to measure precise distances to hundreds of stars along 380 lines of sight towards dense and dark gas clouds and the more tenuous gas bridges between them. For each cloud, they used photometric measurements to distinguish foreground stars from background stars. The latter appear redder as their bluer light gets preferentially scattered passing through the cloud (the same reason a setting Sun appears red). With this approach, the team bracketed the distance to each cloud to an accuracy of about 5%, far better than any previous survey.

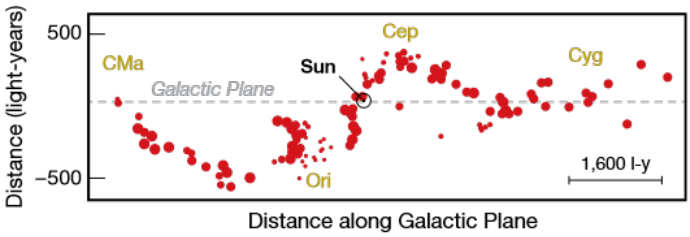
With advanced visualization software (**glueviz.org**), the scientists mapped each cloud across the Local Arm and expected to see the Gould Belt in "high definition." Instead, they discovered something astonishing — a thin, interconnected, wavelike structure about 8,800 light-years long and 400 light-years wide that undulates up to 500 light-years above and below the plane of the galaxy and stretches nearly

halfway across the sky from Cygnus to Canis Major. Our Sun lies as close as 450 light-years from this structure near its middle and some 5,000 light-years away from either end. The team named this structure, which holds the mass of some three million Suns, the "Radcliffe Wave" after Harvard's Radcliffe Institute for Advanced Study.

And the Gould Belt? It simply doesn't fit the data. One section of the Belt intersects with the Radcliffe Wave at Orion, while another passes through gas clouds in Scorpius and Centaurus, a section designated the "split." But a ring can pass through any two points, and the rest of the Belt seems to be a projection of the Wave onto the sky as it rises from Orion through Taurus, Perseus, and Cepheus — a length of sky that's at an angle of about 20° to the plane of the Milky Way. The Gould Belt, according to this study, is finished.

The dark clouds surveyed in the 2020 study don't offer much appeal to amateur astronomers. But can we see blisters of star formation along the Radcliffe Wave to help us trace it across the sky?

That's the question I put to João Alves (University of Vienna, Austria) and Catherine Zucker (now at the Space Telescope Science Institute), lead authors of the study. With their generous help and a trusty star atlas, I assembled a tour of sights along the Wave within reach of visual observers. Most are associated with emission and reflection nebulae emerging from these dark gas clouds. Distances to stars, clusters, and stellar associations that lie along the Wave are less certain, at least until astronomers digest more data from Gaia. This list of sights isn't comprehensive, and in time more deep-sky sights will fall into place along the Radcliffe Wave. Most clouds along its length coalesced 50 million years ago, and its stars and star-forming regions are less than 30 million years old — this helps us weed out objects that are in the line of sight of the Wave but aren't physically associated with it.



▲ **UNDULATION IN THE MILKY WAY** The Radcliffe Wave stretches all the way from Cygnus (at right in the plot above) to Canis Major (at left). Along the way it rises up into Cepheus before plunging down into Orion. All in all the Wave spans nearly 9,000 light-years.

Late autumn and early winter shortly after nightfall offer the best time to trace the entire Radcliffe Wave, with Cygnus low in the northwest at one end and Orion and Canis Major rising in the southeast at the other. So, let's get busy in Cygnus before it sets, then work our way eastward.

Star Factories in Cygnus

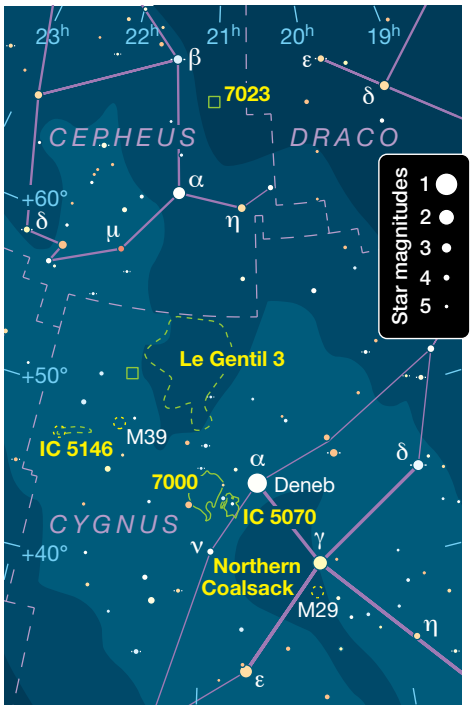
The western terminus of the Radcliffe Wave lies in the Cygnus X star factory, a massive region of stellar associations and

BRIGHT AND DARK CLOUDS OF CYGNUS This wide-field view of the region around Deneb (the bright star near the center of the image) shows the dark clouds of Le Gentil 3 (or, as *S&T* Contributing Editor Alan Whitman dubbed it, the Funnel Cloud) trickling in from top left. The Northern Coalsack lies just right of the colorful North America and Pelican Nebulae.

CHART: GREGG DINDERMAN / S&T; SOURCE: JOÃO ALVES / *NATURE* 578: 237 (2020); CYGNUS CLOUDS: ALAN DYER

molecular clouds at the heart of the Celestial Swan. At a distance of 5,000 light-years, this region harbors hundreds of luminous stellar nurseries. Unfortunately, we can't see them at visual wavelengths because they're hidden behind the dark Cygnus Rift. The first hint of the Wave comes in the form of the Snow Angel Nebula (Sh2-106), about 3,500 light-years away. It's a challenging object for imagers and all but out of reach for visual observers with amateur instruments.

We get our first visual glimpse of the Wave at the famed **North America Nebula** (NGC 7000), just 3° east of Deneb. In a wide-field scope or binoculars it presents a pale sheet of light spanning 120′ × 100′, with dozens of embedded 9th- and 10th-magnitude stars. A 3° or larger field of view frames it nicely. The North America Nebula and the fainter **Pelican Nebula** (IC 5070) next door constitute small sections of an H II region set aglow by a hot young star, which is obscured from sight by intervening dust. Both nebulae lie some 2,600 light-years away. (See page 58 in the September issue for further observing tips.)



In pristine observing conditions, some of the Wave's dark clouds emerge to the unaided eye against the background Milky Way. The **Northern Coalsack**, nestled between Alpha (α) Cygni (Deneb), Gamma (γ) Cygni (Sadr), Nu (ν) Cygni, and Epsilon (ε) Cygni, spans 7° × 5° and lies at the near edge of Cygnus X. Another dark nebula, the sprawling **Le Gentil 3**, is situated about 7.5° north-northeast of Deneb and stands out prominently against a brighter and more uniform stellar background.

The **Cocoon Nebula** (IC 5146) features a photographically reddish emission nebula overlapping with a fainter blue-white reflection nebula, with the clearly etched dark cloud Barnard 168 extending about 2° to the west. The luminous portion of the Cocoon spans around 10′ and has an integrated magnitude of 7.2. An 85-mm refractor and an Ultra High Contrast (UHC) filter at 24× tease out its circular glow under suburban skies, and I can make out two 10th-magnitude stars within. With 12×36 binoculars I can just spot the Barnard dark cloud. This three-in-one gem also harbors Collinder 470, a loose and relatively sparse open star cluster.

If you're looking at a star chart of the region, you'll see that more star clusters abound in northern Cygnus and neighboring Lacerta, but all of them either lie in front of or behind the Radcliffe Wave, or they're simply too old and predate it. Over in Cepheus the sprawling nebula IC 1396 lies slightly behind the Wave. However, 3.5° southwest of Beta (β) Cephei, we find the **Iris Nebula** (NGC 7023), a small reflection nebula embedded in a larger dark cloud about 1,300 light-years away. At magnitude 7.2 and 10′ across, the Iris Nebula looks lovely in a small telescope. I can spot it with my 85-mm refractor at 24×. It takes magnification well: At 67× the nebula displays a complex structure reminiscent of an irregular spiral galaxy. A central 7th-magnitude blue-white star illuminates this small patch of interstellar dust. An inky-black nebulosity, about 0.5° across, surrounds the Iris.

Expansive Dark Nebulae

Invisible bridges of tenuous gas lie eastward on the Radcliffe Wave and thread through Cassiopeia and Camelopardalis. Coming to Perseus, though, we find denser clouds and a pair of visible tracers. Look about 3.3° west-southwest of Omicron (ο) Persei (Atik) to spot **NGC 1333**, a reflection nebula in a much larger dark cloud. German astronomer Eduard Schönfeld discovered it in 1855 with a 3-inch refractor, so it's an easy object in dark sky. This tiny, 5.7-magnitude oval looks like a fuzzy star at low magnification in my 10-inch Dobsonian, but its nebulous form emerges at 92× along with its central 10th-magnitude star.

Just ¼° southeast of Atik sits **IC 348**, another tiny cluster of blue-white stars some 1,000 light-years away just flickering to life. Its designation refers to the cluster itself and to

▲ **TRIPLE DELIGHT** The Cocoon Nebula presents three types of nebulae in one spot in space: emission, reflection, and dark. You'll find it in a fairly empty bit of sky in the far eastern reaches of Cygnus by slewing some 12½° slightly north of due east of Deneb.

MASIL IMAGING TEAM

the dim reflection nebulosity surrounding it. The cluster contains hundreds of stars in an area 10′ in diameter, but only a dozen lie within reach of my 10-inch reflector. The most conspicuous is Struve 439, a wide double star with components of magnitudes 8.8 and 10.3 separated by 23″. The brightest nebulosity surrounds this double. While a challenging visual object, the tiny cluster presents a taste of things to come: In the next several million years, many more clusters will emerge from the dense clouds in this Perseus section of the Radcliffe Wave.

Now on to Taurus to see the major feature of the Radcliffe Wave closest to the Sun: the striking **Taurus Molecular Cloud**. At a distance of just 450 light-years, this inky-dark archipelago presents a worthy challenge for visual observers with ideal conditions. The complex spans about 20°, and its darkest region lies some 10° northeast of the midpoint of a line connecting the Pleiades and Hyades star clusters. In Bortle 2 skies and with the help of a pair of 2.1×42, wide-angle constellation binoculars, I can barely glimpse its darkest fingers adjacent to the Milky Way lacing through Taurus and Auriga. When observing such challenging dark nebulae, success comes when you see the absence of stars against an otherwise rich, stellar background.

Taurus offers only a glimmer of visible light along the Wave. **Hind's Variable Nebula** (NGC 1555, also known as Sh2-238), lies near the Hyades about 4.5° northwest of Aldebaran. With a magnitude ranging from 8.5 to 13.5, this inconspicuous reflection nebula spans just 1′ × 1′ and is illuminated by 10th-magnitude T Tauri just to the east. The nebula presents a serious challenge and requires at least a 12-inch telescope to spot it (see *S&T:* Feb. 2018, p. 22). But astronomers consider T Tauri especially interesting as a prototypical star still sputtering in brightness and yet to settle onto the main sequence.

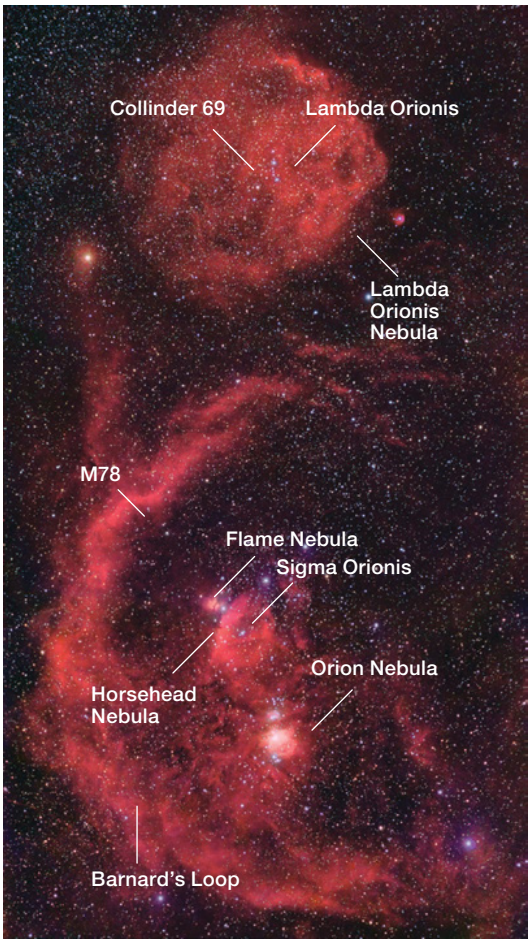
The Brightest Section of the Radcliffe Wave

We arrive at the richest part of the Radcliffe Wave, which is found in the Orion Molecular Cloud. Here the Wave plunges some 500 light-years below the plane of the Milky Way to rise back toward the galactic plane in Canis Major. The Orion Molecular Cloud holds some of the brightest and best-known groups of newborn stars and star-forming regions.

Even naked-eye observers can see the fruits of the Radcliffe Wave in the bright, blue-white stars of the **Orion OB 1 association**. This encompasses the region just north and west of Orion's Belt (OB 1a), the Belt itself (OB 1b), and the Sword of Orion (OB 1c), which includes the **Orion Nebula** (M42 and

▼ BRIMMING WITH TARGETS *Below right:* Orion, the Hunter, presents a wealth of observing opportunities. Enjoy the fruits of this constellation during the long winter nights.

MASIL IMAGING TEAM



▲ **MAGNIFICENCE IN ORION** As you sweep from top left to bottom right in this image you'll encounter the hint of a swirl of Barnard's Loop, the Horsehead and the Flame Nebulae, and the clouds that form the spectacular Orion Nebula.

▲ **INTRICATE SIGHT** Western Cepheus holds the marvelous Iris Nebula, a reflection nebula illuminated by the 7.4-magnitude star HD 200775, the whole surrounded by a dark cloud. The best of it is you only need a small telescope to snag it.

▲ **DON'T BE FOOLED** The photogenic California Nebula (NGC 1499) just 5° northeast of Atik is a lovely object, but precise measurements show it's unconnected to the rest of the Wave. The pretty but tiny cluster IC 348 (at bottom right) *is* part of the Radcliffe Wave, though.

IRIS NEBULA: NASA / ESA / DIGITIZED SKY SURVEY 2; IC 348: STEFAN BINNEWIES / RAINER SPARENBERG / CAPELLA OBSERVATORY; ORION: FRANK SACKENHEIM

▲ **WITCH HEAD** IC 2118 is a delightful — but challenging — target that you'll find in Eridanus just across the border from Orion's blue supergiant Rigel. The nebula's dust grains reflecting the star's light make it appear grayish blue (scattering also contributes to this effect).

▲ **SEAGULL IN SPACE** IC 2177 is one of those objects that truly seems to represent its nickname. If you look closely, you'll note that multiple open clusters, smaller bright nebulae, and dark patches all contribute to shaping the Seagull.

M43) and a spray of young star clusters. All lie around 1,350 light-years away. Point an 80-mm or larger telescope just northeast of Zeta (ζ) Orionis (Alnitak) to catch a view of the **Flame Nebula** (NGC 2024), a 30′-wide glow bifurcated by a dark dust lane. About 1° southwest of the center of the Flame lies the fine multiple star **Sigma (σ) Orionis**, a gravitationally bound system of five stars, four of which split nicely in my 85-mm refractor at 133×. About 2.5° northeast of Alnitak, you'll find the reflection nebulae **M78** and **NGC 2071**, challenging targets in a small scope even in good conditions.

Orion offers fainter sights for sharp-eyed observers. About 4° northeast of Alnitak, look for NGC 2112, a foreground cluster that points the way to the immense **Barnard's Loop**. Visual observers can spot the brightest portions of this emission nebula with binoculars under ideal conditions. Its 14°-long arc is an easy target for wide-field imagers. About 1° south of Zeta Orionis you'll come to the **Horsehead Nebula**, which consists of the emission nebula IC 434 and the dark cloud Barnard 33 (the Horsehead itself). Only larger instruments equipped with a hydrogen-beta filter and ideal skies will reveal this notoriously difficult object. At Orion's head, binoculars show the star cluster **Collinder 69** and the fine double star **Lambda (λ) Orionis**. With components of magnitudes 3.5 and 5.4 separated by 4.3″, Lambda Orionis splits easily in my 85-mm refractor at 133×. The **Lambda Orionis Nebula**, about 5° across, envelops the cluster and appears in wide-field images of the area, but it's too faint to spot visually.

For wide-field optics, the Radcliffe Wave includes the faint, smoky **Witch Head Nebula** (IC 2118), a reflection nebula that you'll find about 3° west of Rigel in neighboring Eridanus. It extends northeast-southwest and spans 3° × 1°. This nebula makes Barnard's Loop seem easy. I've barely glimpsed it — after considerable effort — on a crystal-clear (but freezing cold) winter night with my 85-mm refractor and a 35-mm Panoptic eyepiece with a 4° field of view. I saw no structure, just an ethereal smudge at its brightest section about 1.2° south-southwest of Beta Eridani.

Monoceros and Canis Major present an oblique glance towards the eastern end of the Radcliffe Wave. About 2,900 light-years away, the giant Monoceros R2 molecular cloud emerges into view at **NGC 2170**, a small reflection nebula some 1.5° west of Gamma (γ) Monocerotis. Just 2′ across, this featureless glow is within reach of a 6-inch reflector.

And so we come to our last stop on the Radcliffe Wave, the **Seagull Nebula** (IC 2177). It's a large and faint emission nebula that lies 4,050 light-years away embedded in the Canis Major OB 1 cloud and is a favorite of imagers. Visual observers can spot it with a telescope that captures its 20′ × 20′ size. I've only been able to glimpse it in my 10-inch Dobsonian at 35× with a UHC filter in black skies.

As you've seen on this tour, there's still plenty to see along the Radcliffe Wave's 8,800-light-year length. Perhaps most remarkable is the physical connection among the many deep-sky sights along the Wave. The North America Nebula, the Taurus Molecular Cloud, and the bright nebulae of Orion and

IC 2118: RAINER SPARENBERG / STEFAN BINNEWIES / CAPELLA OBSERVATORY;
IC 2177: STEFAN BINNEWIES / RAINER SPARENBERG / CAPELLA OBSERVATORY

Ride the Radcliffe Wave

Object	Name	Type	Mag(v)	Size/Sep	Dist. (l-y)	RA	Dec.
NGC 7000	North America Nebula	Emission nebula	—	120′ × 100′	2,600	$20^h\ 59.3^m$	+44° 31′
IC 5070	Pelican Nebula	Emission nebula	—	60′ × 50′	2,600	$20^h\ 51.0^m$	+44° 24′
	Northern Coalsack	Dark nebula	—	7° × 5°	1,800	$20^h\ 20.2^m$	+36° 24′
	Le Gentil 3	Dark nebula	—	7° × 5°	1,800	$21^h\ 05.0^m$	+52° 30′
IC 5146	Cocoon Nebula	Emission/Reflection/ Dark	7.2	10′ × 10′	2,470	$21^h\ 53.4^m$	+47° 16′
NGC 7023	Iris Nebula	Reflection nebula	7.2	10′ × 8′	1,300	$21^h\ 01.6^m$	+68° 10′
NGC 1333		Reflection nebula	5.7	6′ × 3′	950	$03^h\ 29.3^m$	+31° 25′
IC 348		Open cluster/ reflection nebula	7.3	10′	1,000	$03^h\ 44.6^m$	+32° 10′
	Taurus Molecular Cloud	—	—	14° × 9.5°	450	$04^h\ 41.0^m$	+25° 52′
NGC 1555	Hind's Variable Nebula	Reflection nebula	8.5–13.5	1′ × 1′	650	$04^h\ 21.8^m$	+19° 32′
	Orion OB 1 association	—	—	14°	1,040–1,600	$05^h\ 36.0^m$	–01° 12′
M42/M43	Orion Nebula	Emission nebula	4.0	40′ × 35′	1,350	$05^h\ 35.3^m$	–05° 23′
NGC 2024	Flame Nebula	Emission nebula	—	30′ × 30′	1,350	$05^h\ 41.9^m$	–01° 51′
Sigma Orionis		Multiple star	4.1, 5.3	0.3″	1,070	$05^h\ 38.7^m$	–02° 36′
M78		Reflection nebula	8.3	8′ × 6′	1,350	$05^h\ 46.7^m$	+00° 05′
NGC 2071		Reflection nebula	—	7′ × 5′	1,300	$05^h\ 47.2^m$	+00° 18′
	Barnard's Loop	Emission nebula	—	14° × 1°	1,400	$05^h\ 35.0^m$	–03° 00′
IC 434		Emission nebula	—	60′ × 10′	1,380	$05^h\ 41.0^m$	–02° 24′
B33	Horsehead Nebula	Dark nebula	—	6′ × 4′	1,380	$05^h\ 40.9^m$	–02° 28′
Collinder 69		Cluster	2.8	70′	1,100	$05^h\ 35.0^m$	+09° 56′
Lambda Orionis		Double star	3.5, 5.4	4.3″	1,100	$05^h\ 35.1^m$	+09° 56′
Sh2-264	Lambda Orionis Nebula	Emission nebula	—	270′ × 240′	1,340	$05^h\ 35.0^m$	+10° 00′
IC 2118	Witch Head Nebula	Reflection nebula	—	180′ × 60′	950	$05^h\ 06.9^m$	–07° 13′
NGC 2170		Reflection nebula	—	2′ × 2′	2,900	$06^h\ 07.5^m$	–06° 24′
IC 2177	Seagull Nebula	Emission nebula	—	20′ × 20′	4,050	$07^h\ 05.3^m$	–10° 38′

Angular sizes and separations are from recent catalogs. The data for Sigma Orionis include only the A and B components. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

Canis Major all owe their formation to this vast conglomeration of gas and dust.

But what caused the Radcliffe Wave to form? How do its constituent parts move with respect to one another and the Milky Way? And are there similar structures in the Milky Way and other galaxies? Astronomers have plenty of work ahead to answer these questions. And as data from Gaia and other surveys continue to arrive, we look forward to more surprising discoveries about the structure and dynamics of our little corner of the galaxy.

■ Contributing Editor **BRIAN VENTRUDO** is a writer, scientist, and longtime amateur astronomer. He tries to make sense of nearby structures in the Milky Way under the relatively dry and clear skies of Calgary, Canada. Brian writes about astronomy and stargazing at his website **CosmicPursuits.com**.