DOWNLOAD PDF OPTICAL INTERFEROMETRY

Chapter 1 : Optical Interferometry -- from Eric Weisstein's World of Physics

Interferometry is a family of techniques in which waves, usually electromagnetic waves, are superimposed causing the phenomenon of interference in order to extract information.

What is Optical Interferometry? Why is it the best measurement method for some materials? Posted by Kristin What is Optical Interferometry? The principle of interferometry is the interaction of reflected light from materials with slightly different Indices of Refraction. The diagram attached explains it quite well. Measurement Diagram Why is Optical Interferometry the best type of thickness measurement for some materials? Optical Interferometry is a reliable form of thickness measurement. It is the best form of thickness measurement for otherwise hard to measure materials. Medical products can pose a challenge to many inspection systems. The medical products that are especially tricky to measure are those products composed of soft material or variable in shape and size. A medical balloon that is not properly inspected can pose a risk- a very costly risk when being used in humans. Think of the vacuum-sealed Chicken you can get at Wegmans. Would you want to eat Chicken that had a defect in the packaging? Would it even be safe to eat? Our technology allows for the accurate real-time measurement of these products to ensure safety in the world around us. Our technology can also be integrated into the manufacturing process to cut costs. Another material that needs to be inspected and can be inspected very well using our technology is a contact lense. These can be measured to ensure the fit and comfort that the customer demands. Without this type of measurement, nobody would really know if these products were otherwise safe or fit for use. What have you found to be a reliable form of thickness measurement for your product? What challenges do you meet when trying to inspect your product for safety and quality?

Chapter 2 : Ground-based optical interferometry - Scholarpedia

In optical astronomy, interferometry is used to combine signals from two or more telescopes to obtain measurements with higher resolution than could be obtained with either telescopes individually.

Basic principles[edit] Figure 2. Formation of fringes in a Michelson interferometer Figure 3. Colored and monochromatic fringes in a Michelson interferometer: Interference wave propagation Interferometry makes use of the principle of superposition to combine waves in a way that will cause the result of their combination to have some meaningful property that is diagnostic of the original state of the waves. This works because when two waves with the same frequency combine, the resulting intensity pattern is determined by the phase difference between the two wavesâ€"waves that are in phase will undergo constructive interference while waves that are out of phase will undergo destructive interference. Waves which are not completely in phase nor completely out of phase will have an intermediate intensity pattern, which can be used to determine their relative phase difference. Most interferometers use light or some other form of electromagnetic wave. Each of these beams travels a different route, called a path, and they are recombined before arriving at a detector. The path difference, the difference in the distance traveled by each beam, creates a phase difference between them. It is this introduced phase difference that creates the interference pattern between the initially identical waves. This could be a physical change in the path length itself or a change in the refractive index along the path. The characteristics of the interference pattern depend on the nature of the light source and the precise orientation of the mirrors and beam splitter. If, as in Fig. If S is an extended source rather than a point source as illustrated, the fringes of Fig. Interferometers and interferometric techniques may be categorized by a variety of criteria: Homodyne versus heterodyne detection[edit] In homodyne detection , the interference occurs between two beams at the same wavelength or carrier frequency. The phase difference between the two beams results in a change in the intensity of the light on the detector. The resulting intensity of the light after mixing of these two beams is measured, or the pattern of interference fringes is viewed or recorded. The heterodyne technique is used for 1 shifting an input signal into a new frequency range as well as 2 amplifying a weak input signal assuming use of an active mixer. A weak input signal of frequency f1 is mixed with a strong reference frequency f2 from a local oscillator LO. These new frequencies are called heterodynes. Typically only one of the new frequencies is desired, and the other signal is filtered out of the output of the mixer. The output signal will have an intensity proportional to the product of the amplitudes of the input signals. In this circuit, the incoming radio frequency signal from the antenna is mixed with a signal from a local oscillator LO and converted by the heterodyne technique to a lower fixed frequency signal called the intermediate frequency IF. This IF is amplified and filtered, before being applied to a detector which extracts the audio signal, which is sent to the loudspeaker. Double path versus common path[edit] See also: Common path interferometer Figure 4. Four examples of common path interferometers A double path interferometer is one in which the reference beam and sample beam travel along divergent paths. Examples include the Michelson interferometer , the Twyman-Green interferometer , and the Mach-Zehnder interferometer. After being perturbed by interaction with the sample under test, the sample beam is recombined with the reference beam to create an interference pattern which can then be interpreted. Other examples of wavefront splitting interferometer include the Fresnel biprism, the Billet Bi-Lens, and the Rayleigh interferometer. The result is an asymmetrical pattern of fringes. The band of equal path length, nearest the mirror, is dark rather than bright. In , Humphrey Lloyd interpreted this effect as proof that the phase of a front-surface reflected beam is inverted. Other examples of amplitude splitting interferometer include the Michelson , Twymanâ€"Green , Laser Unequal Path, and Linnik interferometer. A precisely figured reference flat is placed on top of the flat being tested, separated by narrow spacers. The reference flat is slightly beveled only a fraction of a degree of beveling is necessary to prevent the rear surface of the flat from producing interference fringes. Separating the test and reference flats allows the two flats to be tilted with respect to each other. By adjusting the tilt, which adds a controlled phase gradient to the fringe pattern, one can control the spacing and direction of the fringes, so that one may obtain an easily interpreted series of nearly parallel fringes rather than a complex swirl of contour lines. Separating the plates, however, necessitates that the illuminating light be collimated. Each of the well separated light paths is traversed only once, and the fringes can be adjusted so that they are localized in any desired plane. If it is decided to produce fringes in white light, then, since white light has a limited coherence length , on the order of micrometers , great care must be taken to equalize the optical paths or no fringes will be visible. As illustrated in Fig. Note also the precise orientation of the beam splitters. The reflecting surfaces of the beam splitters would be oriented so that the test and reference beams pass through an equal amount of glass. In this orientation, the test and reference beams each experience two front-surface reflections, resulting in the same number of phase inversions. The result is that light traveling an equal optical path length in the test and reference beams produces a white light fringe of constructive interference. In a typical system, illumination is provided by a diffuse source set at the focal plane of a collimating lens. A focusing lens produces what would be an inverted image of the source if the paired flats were not present; i. The complete interference pattern takes the appearance of a set of concentric rings. The sharpness of the rings depends on the reflectivity of the flats. If the reflectivity is high, resulting in a high Q factor i. Michelson and Morley [22] and other early experimentalists using interferometric techniques in an attempt to measure the properties of the luminiferous aether , used monochromatic light only for initially setting up their equipment, always switching to white light for the actual measurements. The reason is that measurements were recorded visually. Monochromatic light would result in a uniform fringe pattern. Lacking modern means of environmental temperature control , experimentalists struggled with continual fringe drift even though the interferometer might be set up in a basement. Since the fringes would occasionally disappear due to vibrations by passing horse traffic, distant thunderstorms and the like, it would be easy for an observer to "get lost" when the fringes returned to visibility. The advantages of white light, which produced a distinctive colored fringe pattern, far outweighed the difficulties of aligning the apparatus due to its low coherence length. Applications[edit] Physics and astronomy[edit] In physics, one of the most important experiments of the late 19th century was the famous "failed experiment" of Michelson and Morley which provided evidence for special relativity. Recent repetitions of the Michelsonâ€"Morley experiment perform heterodyne measurements of beat frequencies of crossed cryogenic optical resonators. A frequency comparator measured the beat frequency of the combined outputs of the two resonators. Michelson-Morley experiment with cryogenic optical resonators Figure 8. Fourier transform spectroscopy Figure 9. A picture of the solar corona taken with the LASCO C1 coronagraph Michelson interferometers are used in tunable narrow band optical filters [27] and as the core hardware component of Fourier transform spectrometers. Compared with Lyot filters, which use birefringent elements, Michelson interferometers have a relatively low temperature sensitivity. On the negative side, Michelson interferometers have a relatively restricted wavelength range and require use of prefilters which restrict transmittance. A practical Fourier transform spectrometer would substitute corner cube reflectors for the flat mirrors of the conventional Michelson interferometer, but for simplicity, the illustration does not show this. An interferogram is generated by making measurements of the signal at many discrete positions of the moving mirror. A Fourier transform converts the interferogram into an actual spectrum. The picture is a color-coded image of the doppler shift of the line, which may be associated with the coronal plasma velocity towards or away from the satellite camera. The layer thicknesses were tightly controlled so that at the desired wavelength, reflected photons from each layer interfered constructively. This increases the time a gravitational wave can interact with the light, which results in a better sensitivity at low frequencies. Smaller cavities, usually called mode cleaners, are used for spatial filtering and frequency stabilization of the main laser. The first observation of gravitational waves occurred on September 14, It is frequently used in the fields of aerodynamics, plasma physics and heat transfer to measure pressure, density, and temperature changes in gases. The VLA interferometer An astronomical interferometer achieves high-resolution observations using the technique of aperture synthesis , mixing signals from a cluster of comparatively small telescopes rather than a single very expensive monolithic telescope. A limited number of baselines will result in insufficient coverage. This was alleviated by using the rotation of the Earth to rotate the array relative to the sky. Thus, a single baseline could measure information in multiple orientations by taking repeated measurements, a technique called Earth-rotation synthesis. Baselines thousands of kilometers long were achieved using very long baseline interferometry. The short wavelengths of light necessitate extreme precision and stability of construction. For example, spatial resolution of 1 milliarcsecond requires 0. Optical interferometric measurements require high sensitivity, low noise detectors that did not become available until the late s. Astronomical "seeing" , the turbulence that causes stars to twinkle, introduces rapid, random phase changes in the incoming light, requiring kilohertz data collection rates to be faster than the rate of turbulence. This linked video shows a movie assembled from aperture synthesis images of the Beta Lyrae system , a binary star system approximately light-years parsecs away in the constellation Lyra, as observed by the CHARA array with the MIRC instrument. The brighter component is the primary star, or the mass donor. The fainter component is the thick disk surrounding the secondary star, or the mass gainer. Tidal distortions of the mass donor and the mass gainer are both clearly visible. The first examples of matter interferometers were electron interferometers , later followed by neutron interferometers. Around the first atom interferometers were demonstrated, later followed by interferometers employing molecules. The resolution of conventional electron microscopy is not limited by electron wavelength, but by the large aberrations of electron lenses. There are several examples of interferometers that utilize either absorption or emission features of trace gases. A typical use would be in continual monitoring of the column concentration of trace gases such as ozone and carbon monoxide above the instrument. Optical flat interference fringes How interference fringes are formed by an optical flat resting on a reflective surface. The gap between the surfaces and the wavelength of the light waves are greatly exaggerated. Newton test plate interferometry is frequently used in the optical industry for testing the quality of surfaces as they are being shaped and figured. The reference flats are resting with their bottom surfaces in contact with the test flats, and they are illuminated by a monochromatic light source. The light waves reflected from both surfaces interfere, resulting in a pattern of bright and dark bands. The surface in the left photo is nearly flat, indicated by a pattern of straight parallel interference fringes at equal intervals.

Chapter 3 : Optical Profilometry â€“ Covalent Metrology

Optical interferometers are the instruments that rely on interference of two or more superimposed reï¬‚ections of the input laser beam. These are one of the most common optical tools, that are used for precision.

Laser interferometry is a well established method for measuring distances with great accuracy. The measurements may include those of certain characteristics of the waves themselves and the materials that the waves interact with. In addition, interferometry is used to describe the techniques that use light waves for the study of changes in displacement. This displacement measuring interferometry is extensively used for calibration and mechanical stage motion control in precision machining. By using two light beams usually by splitting one beam into two , an interference pattern can be formed when these two beams superpose. Because the wavelength of the visible light is very short, small changes in the differences in the optical paths distance travelled between the two beams can be detected as these differences will produce noticeable changes in the interference pattern. Hence, the optical interferometry has been a valuable measurement technique for more than a hundred years. Its accuracy has later been improved with the invention of lasers. The first demonstration of using light interference principles as a measurement tool was achieved by Albert A. Although the technology and the measurement accuracy has been developed over the years since, the basic underlying principles of the Michelson interferometer still remains at the core of interferometry. A Michelson interferometer consists of a beamsplitter half-silvered mirror and two mirrors. After being reflected back at the mirrors these beams recombine again at the beam splitter before arriving at the detector. The path difference of these two beams causes a phase difference which creates an interference fringe pattern. Interferometry applied In order to generate an interference pattern with high precision distinct fringes , it is very important to have a single highly stable wavelength source, which is achieved using the XL laser. In the XL laser system the two mirrors used in the Michelson interferometer are retroreflectors prisms that reflect the incident light back in the direction parallel to the direction from which it came from. One of these is attached to the beam splitter forming the reference arm. The other retroreflector forms the variable length measurement arm as its distance varies in respect to the beam splitter. The laser beam 1 emerges from the XL laser head and gets split into two beams reflected 2 and transmitted 3 at the polarising beam splitter. These beams get reflected back from the two retroreflectors, recombine at the beam splitter before reaching the detector. The use of retroreflectors ensures that the beams coming from the reference and measurement arms are parallel when they recombine with each other at the beam splitter. The recombined beam reaches the detector where they interfere with each other either constructively or destructively. The optical signal processing in the detector allows the interference of these two beams to be observed. The displacement of the measurement arm causes change in the relative phase of the two beams. This cycle of the destructive and constructive interference causes the intensity of the recombined light to undergo cyclic variation. Therefore the movement is measured by calculating the number of cycles using the following formula: The higher resolution of 1 nm is achieved by phase interpolation within these cycles. No matter how good your laser unit is i. Therefore, the wavelength of the beam needs to be altered compensated to incorporate any changes in these parameters. Environmental compensation Without reliable and accurate wavelength compensation, errors of 20 ppm - 30 ppm would be common in linear measurement readings when variations of temperature, humidity and pressure for nominal values are combined even if the test conditions remain stable. These errors can be reduced by an environmental compensator unit XC ensuring that XL measurements maintain accuracy over a wide range of conditions. The following graph on the right provides an example of the error in an uncompensated interferometry system and the source of these errors. The XC measures the air temperature, pressure and humidity, then calculates the refractive index of air and hence the wavelength of the laser. The laser read-out is then automatically adjusted to compensate for any variations in the lasers wavelength. The advantage of an automatic system is that no user intervention is required and that compensation is updated frequently. Environmental compensation is NOT required for angular or straightness measurements when using a Renishaw laser system. As rotary axis, flatness and squareness measurements are also based on these measurements, they also do not require environmental compensation. By using a remote beam splitter, Renishaw avoids this problem.

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Chapter 4 : Optical interferometry in astronomy - IOPscience

Optical interferometer, instrument for making precise measurements for beams of light of such factors as length, surface irregularities, and index of calendrierdelascience.com divides a beam of light into a number of beams that travel unequal paths and whose intensities, when reunited, add or subtract (interfere with each other).

See Article History Optical interferometer, instrument for making precise measurements for beams of light of such factors as length, surface irregularities, and index of refraction. It divides a beam of light into a number of beams that travel unequal paths and whose intensities, when reunited, add or subtract interfere with each other. This interference appears as a pattern of light and dark bands called interference fringes. Information derived from fringe measurements is used for precise wavelength determinations, measurement of very small distances and thicknesses, the study of spectrum lines, and determination of refractive indices of transparent materials. In astronomy, interferometers are used to measure the distances between stars and the diameters of stars. In the American physicist A. Michelson constructed the interferometer used in the Michelson-Morley experiment. The Michelson interferometer and its modifications are used in the optical industry for testing lenses and prisms, for measuring index of refraction, and for examining minute details of surfaces microtopographies. The instrument consists of a half-silvered mirror that divides a light beam into two equal parts, one of which is transmitted to a fixed mirror and the other of which is reflected to a movable mirror. By counting the fringes created as the mirror is moved, the amount of movement can be precisely determined. Michelson also developed the stellar interferometer, capable of measuring the diameters of stars in terms of the angle, as small as 0. In the British physicist Lord Rayleigh described the Rayleigh interference refractometer, still widely used for determining the refractive indices of gases and liquids. It is a split-beam instrument, like the Michelson interferometer. One beam serves as a reference, while the other is passed first through a material of known index of refraction and then through the unknown. The index of refraction of the unknown can be determined by the displacement of its interference fringes from those of the known material. It consists of two highly reflective and strictly parallel plates called an etalon. Because of the high reflectivity of the plates of the etalon, the successive multiple reflections of light waves diminish very slowly in intensity and form very narrow, sharp fringes. These may be used to reveal hyperfine structures in line spectra, to evaluate the widths of narrow spectral lines, and to redetermine the length of the standard metre. The Fizeau-Laurent surface interferometer see Figure reveals departures of polished surfaces from a plane. The system was described by the French physicist A. Fizeau in and adapted in into the instruments now widely used in the optical industry. In the Fizeau-Laurent system, monochromatic light light of a single colour is passed through a pinhole and illuminates a reference plane and a workpiece directly below it. The light beam is perpendicular to the workpiece. By maintaining a slight angle between the surface of the workpiece and the surface of the plane of reference, fringes of equal thickness can be seen through a reflector placed above them. The fringes constitute a contour map of the surface of the workpiece, enabling an optical polisher to see and to remove defects and departures from flatness. The Twyman-Green interferometer, an adaptation of the Michelson instrument introduced in by the English electrical engineer Frank Twyman and the English chemist Arthur Green, is used for testing lenses and prisms. It uses a point source of monochromatic light at the focus of a quality lens. When the light is directed toward a perfect prism, it returns to a viewing point exactly as it was from the source, and a uniform field of illumination is seen. Local imperfections in the prism glass distort the wave front. When the light is directed toward a lens backed by a convex mirror, it passes through the lens, strikes the mirror, and retraces its path through the lens to a viewing point. Imperfections in the lens result in fringe distortions. Learn More in these related Britannica articles:

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The aim of this chapter is to review briefly the major developments that have revolutionized interferometry, such as the wave theory of light, the Michelson-Morley experiment, optical testing, stellar interferometry, quantum effects, etc.

I assume the question is about an optical interferometer combining light from several telescopes. If two telescopes observe the same star and the light beams are superimposed, a phenomenon called interference occurs. If the arrival times are the same, the crest of one wave will add up to the crest of the other wave producing a new wave with twice the amplitude and four times the energy of a single wave. Yet as the earth rotates, one telescope becomes closer to the star than the other. When it is closer by half of a wavelength, a crest in one beam will correspond to a trough in the other beam, and the two light waves will exactly cancel each other, making the star disappear. In other words, the star looks as if it were moving behind a dark picket fence. The wider apart the telescopes are, the smaller the fringe spacing the tighter the picket fence. Two telescopes only a few meters apart produce fringes as close as the diameter of a giant star like Betelgeuse. In this case, the star is larger than the size of a picket. It can no longer hide behind it, that is, it no longer disappears. Michelson and Francis Pease detected and measured the apparent diameter of Betelgeuse in This was the first direct measurement of a stellar diameter. Instead of using two telescopes, they used two apertures on the same Mount Wilson telescope, which was easier to implement. Betelgeuse is the largest star in the sky. Most other stars require much larger separations and therefore separate telescopes, which is much more difficult to implement because of the very stringent mechanical tolerances. As a result, the star seems to move randomly behind the picket fence, making measurements more difficult. They are now commonly used at millimetric wavelengths. An indirect radio technique called intensity interferometry was first used in the visible spectrum in by Hanbury-Brown and Twiss but was limited to very bright stars. In Antoine Labeyrie was the first to observe fringes directly with two independent optical telescopes. Although several optical interferometers have now been built around the world, the technique is still under development. It is best used for astrometric purposesthat is, for accurate measurements of distances between stars and of stellar diameters. Yet, by using a sufficient number of telescopes or by moving the telescopes in a sufficient number of directions and distances, one can reconstruct images of the source with an extremely high angular resolution. Progress in instrumentation such as adaptive optics and infrared detector arrays now make interferometry a very promising technique for use with optical telescopes operating in the infrared. Michelson in about It is an optical instrument that has been redesigned in numerous forms and has many applications in optics where precision measurements are required. Michelson originally designed the interferometer for ether-drift experiments to prove the existence of the medium, which was thought to explain the propagation of light. He also used the interferometer to define the International Standard Meter in terms of the red wavelength of cadmium light, to study the fine structure in spectral lines, to determine the degree of rigidity and elasticity of the earth, and to measure the angular diameters of the satellites of Jupiter and the diameters of several of the largest stars. In recognition of his development of precision measurement techniques using the interferometer, Michelson was awarded the Nobel Prize in Interferometers are now widely used for spectroscopy, the study of thin films, the testing of precision optics, measurements of refractive indices, and both radio and optical astronomy. The fringes are a striking example of the wave nature of light: If the pathlength in one arm of the interferometer is changed by even a fraction of a wavelength, the fringes will appear to move. This extreme sensitivity to minute path variations has made interferometry a powerful tool with a wide range of applications. An astronomical long-baseline interferometer is composed of an array of several separate telescopes, which redirect starlight to a central location where interference fringes are formed. The available angular resolution depends only on the telescope separations, which may in principle be arbitrarily large. Most observations with optical interferometers have used telescope separations of less than meters, although instruments exist that will eventually use separations several times larger. In marked contrast to this, conventional telescopes have a resolution restricted by their aperture diameter, which is unlikely ever to be much larger than 10 meters. Interferometry is therefore clearly the future of high-angular resolution astronomy. An optical interferometer does not produce direct images of stars and typically has only a rudimentary ability to make images. The observations consist of measurements of the fringe contrast or position. An infinitesimally small source will produce interference fringes that have a high contrast. If, as viewed with a given telescope separation, the source has any appreciable size, the fringe contrast is reduced. The loss in contrast is usually calibrated with observations of stars that are known to be unresolved. In this way, by fitting mathematical models to the data, it is straightforward to determine stellar diameters and the parameters of binary star orbits. It is also possible to determine stellar radii, surface fluxes and effective temperatures. More difficult still is the modeling of limb-darkening, stellar rotation and the detection of surface features on stars. These are more challenging because accurate measurements must be made of low-contrast fringes, and many of the most interesting stars are notoriously variable. It is hoped that interferometric measurements will be able to maintain the catalogue established by the Hipparcos satellite. Most interestingly, narrow-angle astrometry is being developed for the detection of extrasolar planets. Stellar Optical Interferometry in the s, by J. Mozurkewich in Physics Today, Vol. Measuring the Stars, by J. Davis in Sky and Telescope, Vol. The Quest for High Resolution, by J. This is a more comprehensive review of technical aspects of interferometry, with an emphasis on astrometry. He offers the following reply: Hence, the great excitement about inventions mirror mosaics, thin mirrors, spin-cast mirrors , which can produce telescope apertures of eight to 10 meters. For example, the meter Keck I telescope has recently resolved stars separated by only 0. Yet for many purposes, this resolution is still not sufficient. A resolution times better is required, for example, to resolve spots on a typical solar-type star. An array of telescopes can be operated synchronously as an interferometric array so as to achieve the resolving power of a single telescope having a diameter equal to the largest spacing between the individual telescopes. We feel that we can intuitively understand the formation of an image by a lens or mirror because we are accustomed to handling themin binoculars, magnifiers and so on. Also, on closer look, the rays of light for example, in a science hall museum exhibit of a telescope or a textbook ray trace are seen to propagate in a simple fashion from the source to the image. Still, the simplicity of geometric optics hides the complexity of electromagnetic-wave propagation. Examined in detail, image formation is a subtle process involving the interference of light waves that propagate by different paths through space and through the telescope s. Understanding this process, we can carry out image formation by a combination of light collection multiple telescopes , interferometry bringing the signals together and analysis from multiple measurements, reconstructing by computer the image that would have been formed with a single ultralarge telescope. This is not so difficult in the radio wavelengths tolerances of one millimeter to one centimeter or so , and arrays of radio telescopes have been providing high-quality radio images for decades. Through most of the history of astronomy, this has not been possible at visible wavelengths. The technique lay dormant until it was reinvented by the French astronomer Antoine Labeyrie in the s. More than a dozen optical arrays have been built. Most were prototypes that served their purpose and were phased out. Major new projects with five or more telescopes each are under construction on Mount Wilson and in Chile, and a major array is planned for Mauna Kea in Hawaii. Astronomers hope these facilities will generate the technical demonstrations and scientific momentum required to bring interferometric arrays into the mainstream of astronomical research. Dramatic advances in stellar astrophysics should rapidly follow as we obtain the first detailed views of stars other than the sun. Faint sources still require large telescopes, and complex sources require an array with many telescopes, so the success of optical interferometry with a few small telescopes will naturally lead to the planning of an array of many large telescopes--a facility consisting of 20 to 30 telescopes, each of three- to four-meter aperture, has been suggested as a likely concept for the early 21st century. NASA is intensively planning a Space Interferometry Mission SIM , which will directly measure the distances to stars on the other side of our galaxy and the orbits of stars in nearby galaxies. The scientific return in understanding of galaxies and their evolution will be immeasurable. SIM could fly within five years. The Terrestrial Planet Finder, employing array interferometry, could detect terrestrial planets and scrutinize their atmospheres spectroscopically for trace gases indicative of life. The TPF could launch within 10 years. And enthusiasm for these opportunities is worldwide: There are two essential attributes of an astronomical telescope: The first allows a telescope to detect but not necessarily to resolve the faintest possible objects in the sky and, therefore to look back the furthest in time. This characteristic is proportional to the collecting area of the telescope or to the square of its diameter. It is usually measured by the limiting magnitude of an object that can be clearly detected above the background; it is currently hovering around the 28th or 29th visual magnitude for the most powerful existing telescopes. Thus, the bigger the diameter, the better, because the telescope will be able to collect more photons from the source. This is analogous to the water-collecting power of a reservoir: It is measured by astronomers in seconds of arc, or arcseconds for short. A resolution of one arcsecond corresponds roughly to the ability to distinguish from the earth a person standing on the moon. This characteristic is, of course, of great importance in a very wide range of applications, from the determination of diameters of stars, the direct detection of extrasolar planets and the unraveling of the structure of the nucleus of an active galaxy. Like sensitivity, resolution depends in principle on the diameter of the telescope. So again, the bigger the better! And this is where interferometry comes in. Sensitivity does require such behemoths. We can achieve the same effect by placing two or more small telescopes at large distances from each other and appropriately combining their output beams together in one common spot. What counts in this particular application is the distance between separate collecting elements, and these do not have to be physically connected. This is, in essence, what interferometry is all about, and it is called optical interferometry if the light being combined is in the visible range of the electromagnetic spectrum. This has to be done to an accuracy of a few tenths of the wavelength, which in the case of visible light is of order one thousandth of a millimeter. For visible light, telescopes separated by several hundred meters must have precisions maintained to within several parts in a billion! But enormous progress has been made recently so in a few years this technique should be routine.

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Chapter 6 : Laser Interferometers

In recent years, the importance of optical interferometry methods for research has dramatically increased, and applications range from precise surface testing to finding extrasolar planets.

These differ only in the way that the signal is transmitted. Aperture synthesis can be used to computationally simulate a large telescope aperture from either type of interferometer. At the beginning of the 21st Century, the VLTI and Keck Interferometer large-telescope arrays came into operation, and the first interferometric measurements of the brightest few extra-galactic targets were performed. A simple two-element optical interferometer. Light from two small telescopes shown as lenses is combined using beam splitters at detectors 1, 2, 3 and 4. A single large telescope with an aperture mask over it labelled Mask , only allowing light through two small holes. The optical paths to detectors 1, 2, 3 and 4 are the same as in the left-hand figure, so this setup will give identical results. By moving the holes in the aperture mask and taking repeated measurements, images can be created using aperture synthesis, which would have the same quality as would have been given by the right-hand telescope without the aperture mask. In an analogous way, the same image quality can be achieved by moving the small telescopes around in the left-hand figure â€" this is the basis of aperture synthesis, using widely separated small telescopes to simulate a giant telescope. This method was extended to measurements using separated telescopes by Johnson, Betz and Towns in the infrared and by Labeyrie in the visible. The red giant star Betelgeuse was among the first to have its diameter determined in this way. In the late s improvements in computer processing allowed for the first "fringe-tracking" interferometer, which operates fast enough to follow the blurring effects of astronomical seeing, leading to the Mk I, II and III series of interferometers. Similar techniques have now been applied at other astronomical telescope arrays, such as the Keck Interferometer and the Palomar Testbed Interferometer. Techniques from Very Long Baseline Interferometry VLBI , in which a large aperture is synthesized computationally, were implemented at optical and infrared wavelengths in the s by the Cavendish Astrophysics Group. The use of this technique provided the first very high resolution images of nearby stars. In this technique was demonstrated on an array of separate optical telescopes as a Michelson Interferometer for the first time, allowing a further improvement in resolution, and allowing even higher resolution imaging of stellar surfaces. Projects are now beginning that will use interferometers to search for extrasolar planets , either by astrometric measurements of the reciprocal motion of the star as used by the Palomar Testbed Interferometer and the VLT I or through the use of nulling as will be used by the Keck Interferometer and Darwin. A detailed description of the development of astronomical optical interferometry can be found here. Additional results included direct measurements of the sizes of and distances to Cepheid variable stars, and young stellar objects. Interferometers are seen by most astronomers as very specialized instruments, as they are capable of a very limited range of observations. It is often said that an interferometer achieves the effect of a telescope the size of the distance between the apertures; this is only true in the limited sense of angular resolution. The combined effects of limited aperture area and atmospheric turbulence generally limit interferometers to observations of comparatively bright stars and active galactic nuclei. However, they have proven useful for making very high precision measurements of simple stellar parameters such as size and position astrometry and for imaging the nearest giant stars. For details of individual instruments, see the list of astronomical interferometers at visible and infrared wavelengths. Astronomical heterodyne interferometry[edit] Radio wavelengths are much longer than optical wavelengths, and the observing stations in radio astronomical interferometers are correspondingly further apart. The very large distances do not always allow any usable transmission of radio waves received at the telescopes to some central interferometry point. For this reason many telescopes instead record the radio waves onto a storage medium. The recordings are then transferred to a central correlator station where the waves are interfered. Historically the recordings were analog and were made on magnetic tapes. This was quickly superseded by the current method of digitizing the radio waves, and then either storing the data onto computer hard disks for later shipping, or streaming the digital data directly over a telecommunications network e. Radio arrays with a very broad bandwidth, and also some older arrays, transmit the data in analogue form either electrically or through fibre-optics. A similar approach is also used at some submillimetre and infrared interferometers, such as the Infrared Spatial Interferometer. Some early radio interferometers operated as intensity interferometers , transmitting measurements of the signal intensity over electrical cables to a central correlator. A similar approach was used at optical wavelengths by the Narrabri Stellar Intensity Interferometer to make the first large-scale survey of stellar diameters in the s. At the correlator station, the actual interferometer is synthesized by processing the digital signals using correlator hardware or software. Common correlator types are the FX and XF correlators. The current trend is towards software correlators running on consumer PCs or similar enterprise hardware. As most radio astronomy interferometers are digital they do have some shortcomings due to the sampling and quantization effects as well as the need for much more computing power when compared to analog correlation. The output of both a digital and analog correlator can be used to computationally synthesize the interferometer aperture in the same way as with direct detection interferometers see above.

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Chapter 7 : Interferometry explained

Optical interferometry in astronomy (power per unit area per unit bandwidth) from an astronomical source, where the bright star Vega (Î± Lyrae) is deï¬•ned as 0 mag (corresponding to a K blackbody); the magnitude.

By comparison, modern space missions utilizing drift-scanning techniques are capable of far higher accuracy. As space techniques are very costly, ground-based optical interferometers play an important role. With operational lifetimes measured in decades, they have the potential to maintain the accuracy of these catalogs by improved measurements of the proper motions of these and additional stars. This field of view is limited by atmospheric turbulence and thus this technique has been limited to close double stars. Optical interferometry basics Figure 1: Schematic of a single-baseline optical interferometer. Powerful inversion algorithms Pearson have been developed to transform visibility measurements to the object irradiance Sec. Binary stars - Current status. Binary stars - Observations and analysis , etc. Conversely, for most astrometric applications Sec. Narrow-angle astrometry measurements of the fringe phase are of primary interest. Figure 1 shows a schematic of a simple two-element interferometer. Light is collected by the apertures and is routed to a combining beamsplitter. Variable optical delay lines Figure 2 in the arms of the interferometer match the path delays from the incident wavefront to the beam combiner. If these pathlengths are matched to within a few wavelengths, an interference fringe is detected. The complex fringe visibility is the phase and amplitude of the interference pattern. The delay is the measured difference of the delay-line positions at which the fringe is detected. Wide-angle astrometry Figure 3: Siderostat at the Navy Optical Interferometer [Armstrong et al. The goal of wide-angle astrometry is to determine accurate positions of stars over the entire sky. The problem of astrometry via interferometry is to recover the two coordinates for each star from the observed delays. In the absence of atmospheric effects, the geometrical delay can be defined as Armstrong et al. In principle, sufficient delay measurements would allow the determination of the interferometer baseline vectors and delay constants, along with the positions of the stars. The design of, and the analysis of the data from, any ground-based optical interferometer must overcome all of these effects. Atmospheric corrections The correction of the delay variations caused by the atmosphere relies on the fact that, in the optical, atmospheric dispersion varies in a significantly nonlinear manner with wavelength Edlen The first term gives a constant offset in phase. The second term produces a phase term that is indistinguishable from an error in the position of the star by the Fourier transform shift theorem, Bracewell Since rapid path length variations are typically present, an internal metrology system must be used to continuously monitor the optical paths through the instrument. A single-color laser metrology system can be employed to measure the relative changes in the paths, in combination with occasional fringe tracking observations of an internal white-light source, with the siderostats in autocollimation, to measure the absolute differential path length. Alternatively, a two-color absolute metrology system could be employed Peters et al. As noted above, the baselines are not stable to that degree, due to instability of the siderostat mounts. However, since it can be shown Hines et al. Such measurements can then be used to correct for the temporal variations in the baseline in the astrometric solutions eq. Current status Figure 4: Right Ascension precisions of stars observed with the NOI. The use of vacuum delay lines renders the interferometer insensitive to atmospheric refraction and allows simultaneous fringe tracking in spectral channels over a wide bandpass nm. The delay on each baseline is modulated over a 2 ms period by a small number of wavelengths while, for each spectral channel and baseline, synchronously measuring the photon count rates with the phase of the delay modulation. This allows the coherent addition of the data to provide sufficient signal-to-noise to determine the variation of the fringe phase with wavenumber and thus determine the dispersion correction. The NOI utilizes single-color laser metrology, as described in Sec. Several interferometers measure the positions of a retroreflector near the intersection of the rotation axes of each siderostat relative to the table. With the application of baseline metrology and other data analysis improvements, accuracies of this order are expected for these and many more stars. Radio star observations are being used to orient the preliminary catalog with respect to the fundamental reference defined by extragalactic radio sources. The longer-term goal of wide-angle astrometric observations with the NOI is to produce a catalog of positions for several thousands of the brighter Hipparcos stars with an internal accuracy of a few mas. Narrow-angle astrometry While atmospheric turbulence significantly limits the accuracy of wide-angle astrometric measurements, the limitations are far less severe for narrow-angle measurements. Measurements made in this regime are useful for a number of investigations, including the search for extrasolar planets. Astrometry measures the reflex motion of the parent star in the plane of the sky for evidence of an unseen companion and is complementary to radial velocity spectroscopic and other astrometric measurements. Atmospheric effects Figure 6: Traditional and interferometric narrow-angle astrometry. In conventional narrow-angle astrometry using single-aperture telescopes, the position of a target star is measured relative to a number of reference stars within the detector field of view. In conventional astrometry with long-focus telescopes, the size of the telescope D is much smaller than the separation of the beams high in the atmosphere Figure 6 , left , and the accuracy is independent of the diameter of the telescope. However, with a long-baseline interferometer, it is possible to construct baselines that are larger than the typical beam separation Figure 6 , right. In this regime, there is a qualitative change in the behavior of the atmospheric errors, resulting in strong dependencies on both baseline length and star separation. Implementing a narrow-angle measurement Figure 7: Reproduced by permission of the AAS. Exploiting the tens-of-microarcsecond astrometric accuracy possible with a ground-based narrow-angle astrometric measurement requires the ability to utilize nearby reference stars. One approach to this problem uses a long-baseline interferometer with dual beam trains Figure 7 , Colavita et al. The light at each aperture forms an image of the field containing the target and reference stars. The light from each star is then fed to its own interferometric beam combiner. These beam combiners are referenced with laser metrology to a common fiducial at each collector. These common fiducials tie together the two interferometers allowing fringe-tracking errors on the primary star to be fed forward to the secondary star beam combiner. The secondary interferometer, cophased by the primary interferometer, makes the actual astrometric measurement by switching between the secondary star and the primary star; the change in delay between the two stars is the astrometric observable. Current Status Figure 8: Declination motion of the day subsystem in the triple star HR At these closer separations, it is possible to operate in a simpler mode, without the dual-star feed, since both binary components are within the field of view of a single interferometric beam combiner Lane and Muterspaugh In this mode, a portion of the incoming starlight is directed to a second fringe-tracking beam combiner that measures the phase difference between the fringe packets of the two stars by modulating the instrumental delay. Observations of 51 multiple star systems made in this mode, yielded results that included precision binary orbits and component masses, studies of the orbits and physical properties of stars in triple Figure 8 , Muterspaugh et al. Other astrometric applications include the determination of parallaxes and measuring the dynamics of objects near the galactic center. With the high angular resolution available, optical interferometers can resolve many spectroscopic binaries, and provide observations that complement speckle interferometry and single telescope, direct imaging results for binary systems with significantly eccentric orbits. Long baseline interferometry can independently determine all the parameters describing a binary star orbit, as well as the angular diameters of the stars and their brightness ratio. In conjunction with spectroscopic and photometric measurements, the fundamental physical parameters of the system, including masses, luminosities, colors, and distance, can be determined. For binaries where the components can be resolved, linear radii and effective temperatures can also be determined. Observations and analysis As noted in Sec. For a binary star, even a single-baseline interferometer can produce very useful results. As the projected interferometer baseline varies with Earth rotation, the fringe amplitude fluctuates for narrow bandpasses as shown in Figure 9 left, Armstrong et al. Observations over many nights may thus be fitted to an orbit for the binary system Figure 9 , right. Fluctuations in the squared fringe amplitude for a binary star over one night left and the resulting orbit fit from many nights data right. Current status Most modern optical interferometers include three or more apertures and thus can obtain simultaneous measurements of complex fringe visibility Sec. Optical interferometry basics on each of several baselines. However, measured phases in ground-based interferometry are severely disturbed by propagation effects in the turbulent atmosphere. Fortunately, because the phase noise is additive at each telescope and the measured phases are phase differences between telescopes, the phase noise cancels when the measured phases are added up along a closed loop of three or more telescopes. Many modern optical interferometers exploit closure phase measurements to produce images Figure 10 , left; Zavala et al. These images can provide initial estimates of the separation and relative orientation of the stars subsequently used in simultaneous fits to all the complex fringe visibility data to derive accurate orbit solutions Figure 10 , right. Image of the triple star Algol left, dot shows motion of inner pair , and orbits of the outer component and the inner pair right. Summary Ground-based wide-angle optical interferometric astrometry is beginning to update the best currently available catalogs of bright star positions. With an expected operational lifetime measured in decades, an optical interferometer such as the NOI can significantly improve the measure proper motions of these and additional stars. Position measurement repeated at regular intervals will also allow unambiguous separation of binary motion from proper motion, an accomplishment that might be difficult to achieve from future space-based observations of limited duration. In the area of narrow-angle observations, ground-based optical interferometry has already contributed to the determination of dozens of binary and multiple star orbits and stellar masses, and is beginning to contribute to the study of exoplanets. Future developments in this technology promise even higher accuracies: The successes of ground-based interferometry have also pointed the way toward future applications of long-baseline interferometry in space-based astrometric missions. Astronomical Journal, , Astrophysical Journal, , Astronomical Journal, in preparation. The Fourier Transform and Its Applications. New Astronomy Reviews, 52, Astronomical Journal, 97, Proceedings SPIE, , Journal of the Optical Society of America A, 12, Interferometry and Synthesis in Radio Astronomy. Astrophysical Journal Letters, , L

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"An optical interferometer is a device in which two or more light waves are combined together to produce interference. I assume the question is about an optical interferometer combining light from.

Chapter 9 : Astronomical optical interferometry - Wikipedia

3 5 Optical vs. Radio Interferometry Radio interferometry functions in a fundamentally different way from optical interferometry. Radio Telescope arrays areheterodyne, meaning incoming radiation is.