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Investigating UAP Events Using Astronomical Techniques

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ABSTRACT

The most important measurements for the scientific investigation of Unidentified Aerial Phenomena (UAP) using astronomical methods are presented and discussed, where results obtained in the past motivate the proposal for new observations using multiwavelength and multimodal instruments. A special emphasis is given on the techniques of magnetometry, photometry and spectroscopy, and on the importance of studying the variability of the phenomenon in order to try to understand the physical process that governs it, including a possible propulsion mechanism. The most important obtainable physical parameters are discussed in detail, with a particular emphasis on how they might be correlated together. Calculations of the integration times needed for obtaining optimum signal-to-noise-ratios in photometry and spectroscopy are presented. The idea of placing measurement instruments at areas of the world where the phenomenon is recurrent is strongly suggested. Past monitoring campaigns at such locations are briefly described together with the pertinent literature.

1. Introduction

Anomalous phenomena in the Earth's sky have been noted in many forms, ranging from so-called "nocturnal lights" to apparently structured crafts that cannot be identified with known technology, and which often show (especially as with nocturnal lights) kinematic and light emission characteristics that are unusual and apparently not explainable by known physics laws (Knuth *et al.* 2019).

Most of these manifestations can be identified as misinterpretations of known manmade and natural phenomena (Brovetto and Maxia 1995; Condon 1969; Pettigrew 2003), of poorly known natural phenomena (Freund 2003; Monari *et al.* 2013; Pascoli 2021; Smirnov 1994; Straser 2007; Zou 1995) or as hoaxes, especially in this era in which the CGI technology can be used to easily generate fake videos and photos. Independently from this and so far, witnesses are the main "data" that can be evaluated (Hynek 1972; Hendry 1979). Unless we have at our disposal a well-populated database with which acceptable statistics can be built up (Teodorani 2009; Thibault *et al.* 2015), mere human testimony of anomalous phenomena – although sometimes interesting *per se* for human and social sciences

– cannot be used as evidential proof. In principle, this lack can be quite well compensated by the utilization of sensor technology, through which it is possible to obtain an objective and rigorous measurement of the observed phenomenon.

Unfortunately, UAPs are not objects with known coordinates such as stars, and their appearance cannot be predicted in time. This makes any attempt at monitoring extremely difficult and usually unsuccessful, even when an all-sky survey strategy is carried out. We can find the same problem with the SETI Project, which has so far produced no concrete results (Wright 2022). SETI attempts to target specific stars of G and M spectral type, have been unsuccessful as well so far (Lazio *et al.* 2002).

Can we adopt an instrumented "targeted search" strategy for UAP research too? Fortunately yes. Previous research shows that anomalous phenomena tend to occur sometimes in some specific areas of the world with reasonable recurrence. That is where measurement instruments can be used, and this has happened since 1984 in the area of Hessdalen in Norway (Strand 1984). So far, the results of the research carried out there do not show that "Earth is being visited", but rather that prominent anomalies occur in the behavior manifested by the observed phenomena (Teodorani 2004). This partial result shows, at a minimum, that such areas of the world can be used indeed as a laboratory to study the phenomenon systematically using multimodal and multi-wavelength instrumentation. In fact, a new research plan is in preparation for the research in this Norwegian location (Teodorani 2023b). Hessdalen is not the only world location of interest regarding recurring anomalous phenomena (Akers 2001; Rutledge 1982; see Table I).

The main goal of this research is not aimed at searching for the evidence of extraterrestrial intelligence, but rather at trying to understand the physics of the observed phenomena, especially what may be plasma bodies in the atmosphere, which manifest as "nocturnal lights" characterized by strong light and color variability and by unusual kinematic behavior. Sometimes plasma-like objects are overlapped with the transient apparition of apparently solid objects (Project Hessdalen, website; Hessdalen Short Films: 4 December 1999): the reason for this connection is not known yet, but it must be investigated in-depth. Both manifestations may occur together at the same time (as it is shown in the Dec. 1999 film) or alternate over time, being plasma-like ones largely predominant in a number of cases.

LOCATION	STATE	LATITUDE	LONGITUDE	NOTE
Colares	Brazil	00° 56′ 13′′ S	48° 16′ 55′′ W	Aggressive UAP flap in 1977 / Massive military investigation
Boulia	Australia	22° 54′ 35′′ S	139° 54′ 24′′ E	Famous "Min-min" anomalous lights
Marfa	Texas, USA	30° 18′ 42′′ N	104° 01′ 28′′ W	Famous recurrent anomalous lights
Capilla del Monte	Argentina	30° 51′ 31′′ S	64° 31′ 27′′ W	Frequent UAP sightings and anomalous light phenomena
Victoria Entre Rios	Argentina	32° 36′ 39′′ S	60° 10′ 49′′ W	Recurrent anomalous lights
Brown Mountain	North Carolina, USA	35° 54′ 57′′ N	81° 44′ 45′′ W	Recurrent anomalous lights / Monitored by cameras
Taos	New Mexico, USA	36° 24′ 26′′ N	105° 34′ 24′′ W	Most famous recurrent humming sound
Quapaw	Oklahoma, USA	37° 05′ 03′′ N	94° 30′ 47′′ W	Recurrent anomalous lights
Piedmont	Missouri, USA	37° 09′ 14′′ N	90° 41′ 45′′ W	Huge UAP flap in 1973-80, investigated by Dr. Harley Rutledge
Caronia	Italy	38° 01′ 12′′ N	14° 23′ 21′′ E	Recurrent anomalous fires + UAP / Italian Navy investigation
Uintah Basin	Utah, USA	40° 15′ 29′′ N	109° 53′ 18′′ W	Multifaceted anomalies + UAP
Pine Bush	New York, USA	41° 36′ 32′′ N	74° 17′ 55′′ W	Recurrent anomalous lights + UAP
Yakima reservation	Washington, USA	46° 14′ 00′′ N	120° 49′ 19′′ W	Recurrent anomalous lights + UAP
Hoja Baciu forest	Romania	46° 46′ 31′′ N	23° 33′ 43′′ E	Multifaceted anomalies + UAP
Molebka M-Zone	Russia	57° 14′ 17′′ N	57° 55′ 59′′ E	Multifaceted anomalies + UAP
Hessdalen	Norway	62° 47′ 35′′ N	11° 11′ 17′′ E	Recurrent anomalous lights + UAP / Currently monitored

Table 1. A few of the most important locations in the world where recurrent UAP-like phenomena occur. The phenomena are somewhat persistent, since several decades in some cases. In general, photographic, video and witness documentation on most of these crucial locations, has not been considered by mainstream science but it is easily traceable on the web. This documentation has been presented and discussed (Teodorani 2008, 2023a).

Measurements show that unusual phenomena in such recurrence locations do occur, independently from witnesses, and now their behavior is empirically quite well known (Teodorani 2004). What is lacking is the understanding of the physics that produce such events. After all, we shouldn't be so much interested in the possibility of extraterrestrial visitation *per se*, even if the eventuality of interstellar colonization has been theorized quantitatively (Jones 1981), but rather in the physics of the problem. This physics might deal with a natural phenomenon of possible geophysical origin (Freund 2003) as well as with a possible propulsion mechanism that has nothing in common with the one we use with our own aircrafts and rockets (Davis 2004; Holt 1979; Meessen 2012a, 2012b; White 2013). We can investigate all of this using a procedure very similar to that we use in astrophysics and the standard methodology of science.

The key for unveiling the governing physics lies not only on "static characteristics" such as spectra, CCD images or luminosity distribution over extended surfaces but above all on the phenomenon's temporal variability within a wide range of wavelengths. This is especially relevant to understanding nocturnal lights. Multi-wavelength observations of strongly varying phenomena – both kinematically and photometrically – can allow us to understand the physical mechanism on which such phenomena are based. This means acquiring data 24 hours per day and in automatic mode (Watters *et al.* 2023). The interpretation of this dynamics can help us to understand quantitatively what is going on, by subjecting such data to mathematical modelling.

If we hypothesize that Earth is visited by alien intelligence (Loeb 2021), we should expect to see possibly transient anomalies in our atmosphere that have a technological signature and/or a non-random behavior. The difficult task here is to distinguish very carefully which ones of these anomalies are of natural origin, which ones are a product of advanced terrestrial technology, and which ones cannot be identified with the first two categories. Once the third category is possibly identified as an exogenous visitation, the next task consists in trying to understand how this category works in terms of the known laws of physics. This involves both the investigation of possible propulsion systems, which might be identified from the mechanism of radiation emission in a wide range of wavelengths, and the investigation of how such devices are potentially controlled.

2. Astronomical methodology

It is assumed that measurement instruments (Szenher *et al.* 2023; Watters *et al.* 2023) can be deployed at hotspots and used automatically 24 hours per day. Data must be collected using high-resolution and high-sensitivity detectors and analyzed using sophisticated software and artificial intelligence. In a further phase, data must be examined dynamically focusing on the time variability of the observed phenomenon and on possible correlation between physical parameters. A procedure very similar to that is used in the astrophysical field, through which the physical mechanism of celestial objects can be deduced.

Some concrete astrophysical examples (Lang 1991) can illustrate better the concept of how a physical mechanism can be understood from an accurate dynamical analysis of the problem in terms of time variability of physical parameters:

- *Binary Stars* – The light variation of an apparently variable single star is due in reality to the periodic occultation of one component by the other orbiting component of a binary system (Kallrath and Milone 2009).
- *Pulsating Stars* – The pulsation mechanism of Cepheid stars shows evidence of an acoustic wave traveling to the stellar surface and bouncing back to the center in a regular way after a certain time (Catelan and Smith 2015).
- *Pulsars* – The regular very short-period pulsation in some compact radio sources is due to the ultrafast rotation of a neutron star whose rotational axis is misaligned with the magnetic axis along which high-energy particles are accelerated, giving rise to synchrotron radiation (Becker 2009).
- *Supernovas* – The sudden turning on of a light source whose luminosity is exponentially increasing with time inside a galaxy is due to the fast expanding shock wave of a supernova (or hypernova) phenomenon (Branch and Wheeler 2017).
- *Quasars* – The outbursts in the nucleus of galaxies show evidence of material transiently overheating inside an accretion disk located around a giant black hole (D'Onofrio *et al.* 2012).

Astronomical methodologies, when they are devoted to the study of variable and transient phenomena, can be applied to the scientific study of UAP as well, once multi-wavelength and multimodal well-calibrated sensors are used in a simultaneous way. A fuller understanding of the physics of UAP can be obtained from the way in which the measured physical parameters vary both with time and with space, and from the way in which they are correlated together. The accurate measurement of parameter variability of UAP can bring us to the understanding of the physical mechanism, whether natural or caused by some kind of propulsion system. These data will surely generate tremendous insights, but may not be definitive or lead to a complete understanding. After all, astrophysicists have the benefit of studying large populations and making many repeated observations of the same object.

3. Observing UAPs scientifically

As the UAP phenomenon occurs most often inside our atmosphere and is often very luminous (Vallée 1998) we expect to obtain an acceptable signal-to-noise ratio, considering that this research, in order to be carried out using an astrophysical methodology, would deal mostly with the so-called "nocturnal lights" (Hynek 1972).

Scientific data obtained by instrumentation studies at Hessdalen (Strand 1984; Teodorani 2004, 2014) showed characteristics that are not easily interpreted:

1. Optical spectra do not follow a standard behavior but can be both line and (often multi-peaked) continuous spectra.
2. Luminosity is sometimes very high and regularly or irregularly variable, as well as the color.
3. The visibility of UAPs is often correlated with pulsating magnetic disturbances and oscillating radio signals.
4. The UAP shape is often variable as well and it can change from simple light ball to geometric shapes (SCU

2023c).

5. VLF and UHF radio emission can show some anomalies – such as Doppler effects and periodic pulsating signals – which are not explained by manmade or ionospheric causes.
6. Radar signals are often intermittent and sometimes present with nothing in sight.
7. Night vision systems often show something that is not in sight or has disappeared from sight.

Very little of the data obtained so far, although highly anomalous, leads us to think that we are really dealing with a technological phenomenon of exogenous nature, and yet the doubt remains.[1] In fact, we cannot with certainty exclude that the UAP phenomenon represents in reality a multiplicity of manifestations ranging from natural (similar to ball lightning), manmade (such as new kinds of drones) and possibly advanced non-human technology.

Considering that nowadays highly sophisticated instrumentation is available, especially the equipment that the *Galileo Project* is using (Loeb and Laukien 2023; Watters *et al.* 2023), past research experience based both on instrumented field missions and on the quantitative analysis of witness cases makes clear the next observational steps in this research:

1. Obtain a high-resolution image of a UAP, using a little telescope or zoom lens tracked to the target – using a pan-tilt unit – by optical and infrared all-sky systems and using the most advanced CCD or CMOS detectors.
2. Calculate the distance and the linear size of the UAP, using triangulation via multiple radar, optical/IR systems and acoustic detectors.
3. Measure the intrinsic luminosity and its variation with time, once the apparent luminosity is accurately obtained.
4. Obtain high-time resolution images (at least 1000 fps) of a UAP in order to measure both possible fast light/color variations and fast movements in the sky, using 30-300 mm zoom lenses.
5. Measure the velocity, the acceleration and their variation with time, using also medium or high-resolution spectroscopic methods in case of velocities exceeding 10 Km/sec, by detecting blue or redshifts in spectral lines (if present in the spectrum) produced by "nocturnal lights" whose direction of motion is aligned along the line of sight.
6. Measure the intrinsic magnetic field intensity deduced from a possible Zeeman Effect (Lang 1991) recorded in a line spectrum (when lines are present) using a slitless medium-high resolution spectrograph, and its variation with time, compared and simultaneous with the measurement in distance using a magnetometer in order to deduce the action of a moving electric dipole source.
7. Testing a UAP using a Laser beam in its vicinity in order to verify if there is a gravitationally induced deviation and/or (without Laser) if the field stars around the object are displaced by their normal position (Teodorani 2000, 2020).
8. Search for correlations between intrinsic luminosity, radio luminosity, radar signature, infrared luminosity, velocity, audio signals, highly energetic particle emission, magnetic field strength and Laser deflection angle. Do they vary together with time or is there a phase lag?

The most crucial questions are if there is a correlation between: a) luminosities of up to 30,000 MW, velocities up to 3000 m/s or more and accelerations of up to 5,000 g as deduced by physical scientists, engineers and radar operators (Coumbe 2023; Knuth *et al.* 2019; Maccabee 1994, 1999; Vallée 1998), and: b) an hypothesized magnetic field strength of $10 \text{ T} \leq B \leq 1{,}000 \text{ T}$, assuming that in this specific case a magnetically induced Zeeman splitting effect can be detected spectroscopically using a tracking slitless echelle grating with a resolving power of at least $R = 1{,}000$ (see Appendix A). Considering that the predicted magnetic field intensity of ball lightning is expected to be at least a factor 1,000 less than these values (Fedosin and Kim 2001), the main question is: what kind of flying object is able to produce such a high magnetic field strength?

4. The importance of magnetic fields and their measurement

Interesting magnetic measurements were carried out at several locations of the world where anomalous light phenomena occur more often, in particular in Hessdalen, Norway (Strand 1984) and at the Yakama Indian Reservation (Akers 2001). In particular, direct measurements obtained in Hessdalen in February 1984 when the phenomenon was

1 I take 'anomaly' here to mean the any of the following: excessive speed and acceleration; impossible maneuvers (like right-angle turns at high velocity); occasionally extremely high luminosity (greater or much greater than 10 MW); shape changes; object splitting in more parts and vice versa; sudden appearance and disappearance; intermittent radar signals; oscillating magnetic fields and electromagnetic interference.

relatively far away, showed magnetic field strength ranging from 0.5 to more than 10 nT during a few seconds (see Figure. 1), while the amplitude was manifesting an oscillating behavior.

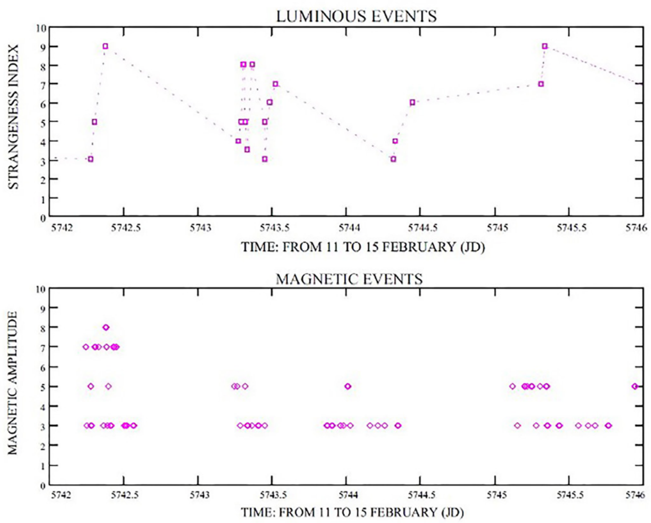

Figure 1. Detailed graph (Teodorani 2004) showing the time-variation of the amplitude of magnetic pulsations (126 data points) occurred in Hessdalen, Norway, in the period 11-15 February 1984 (lower plot, diamonds), compared with the time-variation of the strangeness index of the luminous phenomenon (upper plot; squares). The data were collected continuously. Only unidentified cases are shown (upper plot). The strangeness index is not a quantitative measurement but rather a qualitative one – although determined by an accurate and rational screening process – showing that the level of anomaly grows from 1 (identifiable case) up to 10 (totally unidentified case) (Hynek 1972). Events occurring in the period 25-26 February showed a strictly similar behavior (Strand 1984). As the original plots of the magnetograms could not be digitally recorded or printed out at that time (they were in fact written out as notes about the readings of magnetic strength and their exact timing, which was the only data then available from the Hessdalen researchers), due to the practical ease of viewing values of magnetic amplitude, they have been transformed into the following artificial values: 8 for readings > 10 nT, 7 for readings = 10 nT, 5 for readings = 2 nT, 3 for readings = 0.5 nT (Strand 1984). Due to necessity of time accuracy, the time scale was expressed in Julian Date (JD) after this author's re-plotting of original data (Teodorani 2004).The exact Julian Date in this case must be expressed as JD-2440000 (from 2445742 to 24458746, i.e. four days). What is important to note in these graphs is, above all, the approximate contemporaneity of luminous events and magnetic events.

Let's now consider the striking behavior of the reported UAP phenomenon all over the world (Coumbe 2023; Knuth *et al.* 2019; Maccabee 1994, 1999; Vallée 1998). If we hypothesize that we are dealing with flying machines that are occasionally enveloped within very high electric currents causing strong resistance-driven high temperatures and consequently ionizing effects on the air, there are logical reasons to wonder if the very high values deduced for UAP luminosity may be correlated with a very high intrinsic value of magnetic field intensity, and if velocity and acceleration are strictly related to the magnetic field intensity as well.

According to many reports, very strong magnetic fields related with UAP sightings were responsible for electromagnetic interference with electrical devices (Rodeghier 1981). In particular, in cars, a high magnetic field might saturate the ignition coil and reduce voltage to the spark plugs, and could cause a momentary halt to current flow or increase resistance in some engine component.

The received magnetic field intensity produced by an electric dipole or electrical engine of some kind typically decreases with the inverse of the cube of the distance, so unless the emitted magnetic field is very high, e.g. 100,000 T, what we would be able to measure with our magnetometer at the distance from the source is expected to be a very low value. The simulation illustrated in Figure 2 shows very clearly that beyond a certain distance – for a magnetometer with a good sensitivity of the order of 30 mV/nT (Grosz *et al.* 2017) – any possibility of measuring the magnetic field ceases already when the distance of a source of magnetic field B = 10 T reaches 2 Km.

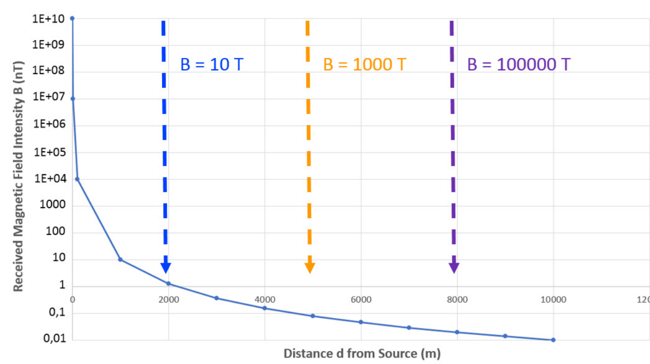

Figure 2. Expected decay of magnetic field intensity with distance from the source if B = 10 T. Comparison with B = 1,000 T and B = 100,000 T is also shown. The vertical dashed arrows show the maximum distance at which a magnetic field can be recorded, according to the magnetic field strength.

If the UAP is some sort of "machine" (manmade or not) very strong values of the magnetic field might be expected (Meessen 2012a, 2012b). Nowadays our technology has reached the capability to build magnets (in the case for plasma confinement in nuclear fusion experiments) where the magnetic field intensity reaches values of up to 1,200 T. If this is the case for the monitored UAP phenomena then – using the same calculation as the one done for the case of B = 10 T (see Figure. 2) – the magnetic field can be still measured at a distance of 5 Km. If B = 100,000 T the magnetic field can be measured at a distance of 8 Km. If the intensity is even a factor 10 higher – which human technology cannot produce yet – then the distance limit might almost reach the maximum range of the general observatory installed by *The Galileo Project*, which is around 12 Km (Watters *et al.* 2023).

Due to their small size and very short duration, it is highly unlikely that a natural phenomenon of the ball lightning kind is able to produce an excessively high magnetic field strength, which according to theory is expected to be typically in the range $0.001 \text{ T} \leq B \leq 0.5 \text{ T}$ (Fedosin and Kim 2001) and for an extended period of time (typically hours, and not seconds as expected from ball lightning phenomena) as observed during previous observations of UAP phenomena (Akers 2001; Strand 1984), as already discussed in the previous section. Other natural phenomena such as fireballs, reentry events (meteors or space debris), Chelyabinsk-like events and powerful conventional lightning are expected to be much more magnetically powerful than ball lightning and with a much shorter duration than in the case of reported UAP events.

In any case, the measurement of a magnetic disturbance alone cannot be considered remarkable if an optical, infrared, radio and/or a radar counterpart ascribed to an UAP is not recorded at the same time. The same can be said for an electromagnetic (VLF, VHF and UHF) disturbance if it is not accompanied by a UAP manifestation in the sky that is visible in the optical and in the infrared.

In conclusion, due to the inverse law of the cube of distance, unless a UAP is just flying very close to the monitoring station (which is highly unlikely, and which would anyway cause the saturation of the magnetic sensor), what would be realistically measured is expected to be in the approximate range of 10-100,000 nT, assuming that the effects due to geomagnetic storms, ferromagnetic rocks, internal instrument noise and manmade machinery can be removed. The intrinsic magnetic field strength of the source can be obtained once the distance is known using radar and/or triangulation. A further and solid confirmation of such a value might come from a possible measurement of the Zeeman Effect (Lang 1991) in optical spectra of the UAP under investigation, if a relatively high resolution is used, if the spectrum shows emission lines and if the intrinsic magnetic field strength is very high.

The measurement of the magnetic field might turn out to be of paramount importance if what we are observing of a UAP is due to the effect of some kind of propulsion mechanism (Griffiths 1984; Meessen 2012a, 2012b), where extremely high electric currents flowing through superconducting devices could be produced. If the surface of the UAP is able to support up to a million or billion volts in order to produce very high magnetic fields without undergoing an appreciable factor of electrical resistance and consequent overheating, and if this effect is able to excite/ionize atmospheric air around, then the object might be highly self-luminous as has been reported very often. Clearly, verifying if there is a time-correlation between magnetic strength and other fundamental physical parameters such as velocity, optical luminosity, color, radio brightness, radar signature, and particle emission would give us fundamental insights regarding the physics of the observed phenomenon, and in particular regarding the propulsion mechanism.

Reasonably high resolution – not more than 1 nT, but preferably 0.1 nT – would also allow us to verify if the detected magnetic field is subject to pulsations, as was recorded in the past during previous research (Strand 1984), and if they are correlated with fast variations of luminosity, color, radio brightness and particle emission. We might be observing a constant or monotonically increasing and/or decreasing pulsation, which can be accurately measured using all of our instruments.

In practice – in the case that we are in fact observing a technological phenomenon of some nature (not necessarily non-human) – our monitoring operations would take the form of "dynamical back-engineering", not by dismantling a machine inside a hangar but rather by meticulous observation of the behavior during flight. Otherwise, if it is not an artificially produced phenomenon, we might have the chance to study in detail a high-energy natural phenomenon that we have never been aware of. In both cases, our knowledge of physics could be greatly enhanced.

5. The importance of optical photometry

The measurement of photons emitted from the surface of a UAP can be of fundamental importance in order to try to understand the physical mechanism that is producing light, especially at night. This is normally done in astronomy when extended sources – such as galaxies and planets – are studied (Henden and Kaitchuck 1982; Kitchin 1984). Leveraging a comprehensive understanding of the physics of light (Lang 1991), once the distance is known using radar or triangulation procedures, the following measurements will be the most helpful for characterizing the intrinsic physical parameters of the source (Teodorani 2000, 2001):

- Superficial intensity – Construction of isophotal contours.
- Luminosity distribution – Measurement of the "slope factor" (or intensity gradient) from the center to the peripheral area of an extended luminous source.
- Total luminosity – Luminosity in a given wavelength interval of the entire surface, once the intrinsic (linear) radius is known after the distance (in some cases the temperature too) has been determined.
- Color index – Ratio of measured fluxes in several contiguous wavelength ranges corresponding to different filters, ranging from the near ultraviolet to the near infrared (analogous to U, B, V, R, I in astronomy).
- Period of luminous variability – Time variation of total luminosity and superficial intensity, of PSF and of color indexes.

In the case that the object contains only one or more luminous spots over the surface, then high spatial resolution would make it possible to resolve the precise location of such spots. A strong dynamic range of the CCD or CMOS cameras will allow distinguishing contiguous areas with weakly luminous and strongly luminous spots. High time resolution will allow ascertaining if the luminous spots are rotating, pulsating or moving across the surface.

Clearly, an optimal quality of measurements will be guaranteed if the object is relatively close to the sensors, so that a better determination of the linear size can be obtained, and/or if it is sufficiently luminous in order to allow short integration times of the optical detector. Both of these situations will greatly help to study the variability of light with time and with radius across the surface.

Photometric observations are intended to be simultaneous with spectroscopic ones, where separate CCD or CMOS detectors are used for imaging and acquisition of spectra.

- CCD/CMOS photometry

Compared to conventional photographic emulsion and plates of the past, present CCD and CMOS cameras allow much improved performance in measuring the light of astronomical objects (Walker 1987), especially when weakly luminous sources are considered. The same technology can be used to study luminous unidentified objects in the sky, whatever they are, and at any time of the day.

- High-speed photometry

Rapidly varying luminosity is not generally detectable during the acquisition of electronic images or video frames of weakly luminous UAPs, for which a long integration time is needed: all possible time variations would be washed out inside the acquired image. According to a scientific evaluation of some witnessed cases (Vallée 1998), UAP's luminosity can occasionally reach very high values (from 500 up to 30,000 MW). In this specific case, due to the very short integration times needed it is possible to verify if what appears as a stable luminosity is in reality the result of a high-speed regular or irregular pulsation that is not ascribable to atmospheric scintillation. We are mostly searching for fast and high-amplitude UAP's light variations in the range 1/1000 – 1/10000 sec, which is typically 10 or 100 times faster than atmospheric scintillation (Osborn *et al.* 2015). This may turn out to be important in order to infer the physics of the phenomenon, natural or otherwise. A regular or semi-regular pulsation or a pulsation with a monotonically increasing period might furnish some insight into a possible propulsion mechanism or a merely physical mechanism of phenomena of natural origin, especially if such pulsation is time-correlated with the color, the speed, the acceleration or even the linear dimension of the UAP. Similarly to the case of high-speed photometry of stars, a light curve of the luminous target with high temporal resolution is obtained. Light curves in astronomy are a crucial measurement that can help to interpret several kinds of phenomena. Exactly the same kind of procedure can be used to investigate unidentified phenomena that are seen in our atmosphere. High-speed luminosity variation (Warner 1988) can be due to the fast rotation of one or more light spots on the surface of the object, to the pulsation of the object's luminosity, to the fast variation of the apparent dimensions of the object itself (due to the possible fast rotation of an elongated or amorphous shape) or to transient light beams that are emitted from the surface of the object. Theoretical modeling of the kind routinely applied in astrophysics may be used to deduce which of many possible mechanisms are responsible for the observed variations.

In order to study fast brightness variations of UAPs, two sensors are of special interest: i) a multi-pixel photon counter (MPPC) and ii) a high-speed camera. In the first case (PANOSETI, website) it is possible to detect transient very short duration luminous events located on an extended surface, using both high time resolution (up to a nanosecond) and high spatial resolution via a many-pixel CCD detector where every pixel works as a photon counting photometer. This procedure is ideal to have a quantitative description of the emitted photons across a luminous surface and their variation in time, in the case of luminous UAP at night, assuming that the detector is attached to a telescope or to a zoom lens. The same technique is currently used in Optical SETI in order to search for Laser events from other stars. In the second case (i-Speed, website) a camera monitoring system is used with a maximum time resolution of up to one millionth of second; as the spatial resolution of every frame decreases with increasing time resolution, using in practice 1,000-5,000 fps is an optimal compromise between time and spatial resolution. This procedure is ideal to study any possible fast variation in the daytime of luminous and non-luminous objects and at nighttime for very luminous objects. Both detectors can be used in wide-angle mode also in order to verify if UAP phenomena are able to move very fast from a point to another in the sky.

6. The importance of optical spectroscopy

In the field of astrophysics, optical spectroscopy is crucial in determining important physical parameters, especially temperature, velocity and chemical composition. The use of spectroscopy in UAP research might turn out to be of paramount importance in understanding the physical characteristics of anomalous "nocturnal lights". Using a diffraction grating (Teodorani 2014, 2021), if we are observing a UAP whose apparent luminosity is very high, we can obtain a spectrum using a very short integration time, such as a few seconds, although with a resolving power of order $\lambda/\Delta\lambda = 10^2$, which is normally considered low resolution. This can be useful if we are able to identify very well separated and intense (presumably emission) lines, and also if we want to measure the continuum once the spectrum has been calibrated in flux and where the responsivity curve has been subtracted. In such a way, we have at our disposal an important tool for spectrochemical identification and for temperature determination.

As has been stressed before, UAPs can be occasionally extremely luminous at night. Witnesses and pilots have reported luminosities that have been estimated approaching 30,000 MW (Vallée 1998). This means that, if the telescope or lens to which the spectrograph is attached has sufficiently large aperture and the detector is sufficiently sensitive, it is possible to obtain a good S/N ratio in a small fraction of a second of integration, a more than sufficiently short time to be able to avoid any possible sudden motion change of the UAP.

In general, using low-resolution spectroscopy is useful for line identification and for the identification of the thermal or non-thermal nature of the UAP from the continuum spectrum that it produces (Lang 1991). Using this option, it is possible to use extremely low integration times. This allows us to obtain a time sequence of many spectra of the same object in order to carry out time variability studies.

The extremely high apparent luminosity that UAP can often show are for physicists a favorable opportunity to perform in particular situations medium ($\lambda/\Delta\lambda = 10^3$) or even high-resolution ($\lambda/\Delta\lambda = 10^4$) spectroscopy. Imaging spectrometry would be considered as well. Using medium and high-resolution spectrography in normal astrophysical situations, the light source is centered inside a slit for dispersion. In the case of UAP, this is not possible due to the fast movements and changes that such objects can show, and accurate tracking during the relatively long integration times that are sometimes required for high-resolution spectroscopy can be very difficult (see Appendix A) . However, the problem can be solved using a slitless wide field spectrograph (Masters 2014), using which tracking can be much easier also when anomalous kinematics are present. The wide field and slitless mode allows compensating possible lack of precision of target tracking especially when the UAP moves with sudden accelerations and/or in an erratic way.

Assuming that tracking is viable for medium or high-resolution spectroscopy, extremely luminous UAPs should permit use of relatively short integration times, even short enough to permit acquisition of several spectra of the same target in time sequence in order to study time variability of the spectrum's characteristics, especially at the time in which a change of color and/or of light intensities and speed occurs.

If a spectral resolution as high as $\lambda/\Delta\lambda = 10^4$ yields a S/N ratio greater than 10, we would have at our disposal a very powerful tool to try to understand the physics of the light source in great detail, especially if spectra are obtained simultaneously with measurements obtained using different instruments, such as radio frequency spectrum analyzers, infrared and optical direct imagers and sensors, magnetometers, particle detectors and radar.

The availability of high spectral resolution or at least of medium resolution ($\lambda/\Delta\lambda = 10^3$), would allow us to obtain crucial physical information regarding the following:

1. Ability to resolve blends of spectral lines, as for instance the bands of Oxygen in the red part of the spectrum (Teodorani 2014) and to clearly identify spectral lines of Hydrogen and Nitrogen, assuming that the phenomenon is able to excite the surrounding atmospheric gases.
2. Spectral identification of some chemical elements characterizing materials that are occasionally ejected by the UAP. Evidence of this has been recently analyzed in a lab, where some molten material was dropped on the ground by a hovering UAP (Nolan *et al.* 2022).
3. High accuracy in the measurement of the equivalent width of spectral lines (if present), which would allow determination of the number density of atoms that contribute to the formation of spectral lines and the associated excitation temperature (via Boltzmann equation) able to cause this (Lang 1991).
4. Measurement of the Zeeman Effect in spectral lines, which would allow determination of the magnetic field strength which is responsible for line splitting (Lang 1991). This would be of great importance for drawing inferences about a possible propulsion system (Meessen 2012a; 2012b) hypothetically based on extremely high magnetic fields and superconductors able to sustain very intense electric voltage without appreciable electrical resistance and consequent high temperature. However, a Zeeman Effect (or even Stark Effect, if line splitting is caused by a strong electric field) might also be a sign of an unknown natural event such as a hypothetically enhanced version of the ball lightning phenomenon (Kuersten *et al.* 2021; Fryberger 1997; Rabinowitz 2002; Stenhoff 1999; Turner 2003) whose physics could be investigated in greater depth. Such a measurement might be studied in correlation with measurements obtained using a magnetometer having a resolution of 1 nT and a dynamic range of 100.000 nT; in such a case, simultaneous magnetic detections (where the intensity of magnetic field decreases with the inverse of the cube of distance for a dipole) would confirm the spectroscopic Zeeman detections.
5. High accuracy in studying spectral line broadening at line basewidth (Griem 2013) and its possible variation with time. This could be used to illuminate possible fast plasma vortex-like rotation and/or turbulence, or even more exotic effects such as gravitational broadening. Numerical modeling of these hypotheses can help to decide which effect is more important. Time variability of this effect could be studied if it is possible to obtain many spectra in sequence of very luminous UAPs.
6. High accuracy measurements of blue or red shifts in spectral lines would help to study possible fast plasma ejections and/or collapses at speeds of the order of 1000 Km/sec, in form of a possible P-Cygni-like effect (characterized by a stationary emission line contiguous with a red or blue shifted absorption component) that we often observe in several kinds of unstable stars of early spectral type (Templeton 2009). Such a measurement might be studied in correlation with measurements obtained using a radioactive particle detector and a muon coincidence detector, by hypothesizing that high-energy particles are possibly ejected by the object. Doppler effects in emission lines might be studied also if a luminous UAP is moving faster than 10 Km/sec and if its direction of (approaching or receding) motion is along the line of sight.
7. High accuracy in studying the slope of the continuum, verification of the presence of LED-like bumps caused by quantum dots of natural origin (Teodorani 2004, 229) or simply the manifestation of LED (Light Emitting Diode) lights of human origin. In such a way, spectra could be used to identify mundane sources; Sodium, Mercury, or fluorescent lights, for instance would be other ones, which would help us to exclude these kind of illumination systems from the study.

The advantages of slitless medium-resolution spectroscopy, based on an echelle grating – for which tests have already been done by its designer (Masters 2014) and by this author (Teodorani 2014, 34) – for UAP Research are the following:

- The wide field permits easy tracking of a moving object and therefore also long integration times of sources that are relatively weakly luminous, in order to obtain a good S/N ratio. A calculation shows that it is possible to obtain a value of S/N = 10 using an integration time of about 20 seconds for a UAP whose luminosity is 1 MW and whose distance is 10 Km, assuming that the spectrograph is attached to a lens connected with a CCD or CMOS detector (see Appendix A).
- It permits acquisition of spectra of both point-like and extended luminous sources. A transmission grating allows only the first option and its resolution is a factor 10 less

(see Table 2, Appendix A).

- With a resolution of $R \geq 10^3$ it is possible to resolve Zeeman line splitting if the magnetic field intensity in the source is $1\ T \leq B \leq 10\ T$, for 0.28 Å $\leq \Delta\lambda \leq 2.8$ Å (see Appendix A).
- With a resolution of $R \geq 10^3$ it is possible to resolve blue or redshifts with a precision of 1 Å in spectral lines produced by a luminous source that is moving at a speed of $V \geq 100$ Km/sec along the line of sight, for $\Delta\lambda \approx 2$ Å. Line broadening effects are also well discerned (see Appendix A).
- With a resolution of $R \geq 10^3$ it is possible to make an accurate line spectrochemical identification and measurement of the equivalent width (energy subtracted by the line from the continuum).

All echelle spectral orders, once they are rectified from the typical sloping appearance they show as soon as a spectrum is obtained (Kitchin 1984; Teodorani 2014, 34), can be wavelength calibrated separately, once an appropriate calibration lamp is used, and then merged together in a single spectrum. The use of *RSPEC* software is strongly recommended (RSPEC, website).

There is no doubt that some of the spectroscopic measurements in particular – such as of the Zeeman and Doppler effects – could shed some light on the propulsion mechanism of a UAP, in the case that it is a flying object, especially if some correlations can be found with measurements obtained by other instruments, such as radio spectrum analyzer, particle detector and magnetometer. The study of the variation of all these physical parameters with time might guide us to the most appropriate theoretical deductions, from which to build up a physical model.

The accuracy of pixel-wavelength calibration (Moore and Burrows 2021) of medium-resolution spectra is of paramount importance in this research, especially when we are searching for Doppler effects produced by objects whose speed is $10 \leq V \leq 100$ Km/sec. The use of He-Ar or Hg calibration lamps allow us to identify a large number of well resolved spectral lines of known wavelength, which permit to minimize the error of calibration after we use high-order polynomial functions (at least third-order fit). The accuracy of flux calibration is important as well, especially when we concentrate our attention on the continuum. Therefore we need to use a "standard candle" of reference, which could be a star of known luminosity such as Vega or a 1 kW reference lamp.

The luminous source is expected to be tracked in such a way that is maintained inside the view field of the slitless (medium resolution) spectrograph while the source is moving in the sky and while an exposure is taken in order to obtain a spectrum with an acceptable S/N ratio (at least ≥ 10). The spectrograph is expected to be attached to a pan tilt zoom CMOS camera (PTZ), using fiber optics (StellarNet, website) in order to avoid possible problems of mechanical inertia caused by the unbalancing effect of the spectroscopic device while tracking. If the light source is moving linearly and slowly in the sky, tracking is expected to be relatively easy. Not the same might happen if the source is moving randomly and/or with sudden inversions of the direction of motion or sudden accelerations. In order to try to solve this problem it is inevitably necessary to carry out preliminary tests flying illuminated drones and recalibrate via software the micrometric movements of the PTZ camera, by expecting that we would use one camera for photometry and one for spectroscopy.

7. Concluding remarks

It is conceivable that some kind of propulsion mechanism is able to provide non-aerodynamic lift to some UAPs. Many physical models, more or less well-founded, have been proposed so far, independently from measurement data that have not been acquired yet. We cite two of them, to provide examples of hypotheses that are testable using the techniques described in the paper.

> "*The conducting fluid will be created by electrodes that cover each of the vehicle's surfaces and ionize the surrounding air into plasma. The force created by passing an electrical current through this plasma pushes around the surrounding air, and that swirling air creates lift and momentum and provides stability against wind gusts.*" (EM Drive) – Subrata Roy, Ph.D. (Roy *et al.* 2011).

> "*The principle is that UFO produce an intense alternating magnetic field with a supraconductive outer shell. They then ionize air around the UFO in specific locations when the intensity of the magnetic field grows or shrinks. This produces a Lorentz force applied on electrons and ionized air in a huge volume. By the principle of reaction, this applies a force on the UFO.*" – Auguste Meessen, Ph. D. (Meessen 2012a, 2012b).

Certainly, our goal is not to plan our measurement experiments on UAPs based on theories that have not been tested experimentally yet. For now our goal is merely to identify what kinds of measurements can lend physical insight, and only later build up a theoretical physics model. For these reasons, data must be of the highest quality and obtained using very well calibrated instruments that are working simultaneously in several wavelength ranges. However, there is no doubt that here the most crucial measurements should involve magnetic fields. In particular, we must investigate if a correlation exists between very high values of luminosity, velocity, acceleration and magnetic field intensity. We have already discussed how the concerted use of different measurement instruments can potentially help to find an answer to this so important problem, assuming that the sky is constantly monitored using optical and infrared all-sky cameras able to direct narrow-field pan-tilt analytic (photometric and spectroscopic) instruments towards the target, while electromagnetic, radar, acoustic and particle detectors are simultaneously monitoring the sky. This procedure is currently employed by the measurement equipment used by the Galileo Project (Watters *et al.* 2023). A similar procedure is being planned for a new phase of Project Hessdalen (Teodorani 2023b).

Theories and hypotheses about the nature of UAPs do not deal only with a possible extraterrestrial visitation and related propulsion mechanisms, but also with something more exotic such as "plasma life forms". In this specific case, measurements of the kinds that have been described here might furnish important hints. Prominent lab experiments and computer modelling have shown that in particular conditions plasma behaves like biological systems (Tsytovich *et al.* 2007). We have to be prepared for any possibility, and be very aware of what data, once analyzed and assembled, are able to show to us (Teodorani 2022). There is no doubt that a possible discovery of the existence of plasma life forms not only would revolutionize our concept of life, but also would allow life to exist in what have been assumed to be the least hospitable environments in the universe. Only the future will be able to give an answer to this, including the possibility that the UAP phenomenon may consist of several classes of phenomena. We have to be very attentive to all possibilities, including natural phenomena of the ball lightning class, about which we have still a lot to learn from a physics point of view.

APPENDIX A – Preliminary numerical simulations for medium resolution spectroscopy

Some calculations have been carried out in order to predict the capability of a slitless medium-resolution spectrograph to measure Zeeman and Doppler effects using acceptably short integration times while a luminous UAP is tracked using a pan tilt unit.

Spectral line H_β 4861 Å (Hydrogen) is used for this test, because it is more or less close to the center (more luminous) of the optical spectrum's range allowed by the used grating and because it is expected that water vapor (H_2O) may be ionized/excited by a heated source, so that H and O emission lines could be seen. O lines are typically blended together and mostly in the red part of the spectrum (its less luminous part), not ideal to see the Zeeman splitting effect. The g-factor is approximated to 2.5 for an "average line". Table 2 shows how **Δλ** varies with the resolution used.

Accuracy of a Spectrograph according to Resolution			
Resolution R = λ/Δλ	**Δλ(Å)**	**VR = ± (Δλ/λ) c (Km/sec)**	**Note**
100	48.6	3000	Transmission grating (low res.)
1000	4.86	300	Medium resolution
2500	1.94	119	Standard Masters' spectrograph
10000	0.486	30	Masters' latest version (high res.)
100000	0.0486	3	Very high resolution

Table 2. Wavelength ranges and radial velocity for different values of spectral resolution.

R = 2500 (giving a precision of the order of Δλ ≈ 2Å) is the spectral resolution that is considered and is exactly the one of the spectrograph that has been tested in the field (Masters 2014; Teodorani 2014). Such a resolution is potentially able to resolve a Zeeman splitting for a magnetic field whose strength is B ≈ 10 Tesla, and to measure a Doppler intrinsic radial velocity if the UAP is traveling at a speed that exceeds 119 Km/sec or if it ejects or it absorbs gases from its surface.

This formula was used to calculate the Zeeman splitting $\Delta\lambda_Z$:

$$\Delta\lambda_Z = \frac{\pi \cdot e \cdot \lambda^2}{m_e \cdot c} \cdot g \cdot B = 4.67 \cdot 10^{-13} \cdot \lambda^2 \cdot g \cdot B \qquad (1)$$

Where:

B: magnetic field strength = 10 T; λ: wavelength of the spectral line = 4861 Å; e: charge of the electron; m_e: mass of the electron; c: speed of light; g: Landè factor of the spectral line = 2.5.

The calculation shows that a magnetic field in the range 1 T ≤ B ≤ 10 T generates a Zeeman splitting of 0.28 Å ≤ $\Delta\lambda_Z$ ≤ 2.8 Å.

The Integration Time IT needed to integrate photons in a satisfactory way in order to be able to detect $\Delta\lambda_Z$ **=** 2.8 Å, caused by B = 10 T produced by a target whose intrinsic luminosity is L = 1 MW at a distance of 10 Km (realistic), was calculated (see Formula 2). The result is: IT = 28 min if we want an S/N = 100 (ideal, but not at all realistic), and IT ≈ 17 sec if we accept an S/N = 10 (realistic). It is assumed that photons are emitted from an extended source of 10 m in diameter D, using a focal length F_T = 286 mm and an aperture A_T = 200 mm, plus other indicative instrumental factors, such as sky background noise, seeing = 1”, and quantum efficiency of an average CCD of 0.25.

$$IT = \frac{\left(\frac{S}{N}\right)^2 \cdot b \cdot \Delta\lambda \cdot F_T^{\,2} \cdot \beta^2}{\left(\frac{L}{4\pi \cdot d^2} \cdot \Delta\lambda\right)^2 \cdot \pi \cdot D^2 \cdot A_T^{\,2} \cdot \varepsilon} \qquad (2)$$

Where:

UAP diameter D = 10 m; UAP shape approximated to a sphere with diameter D; UAP distance d = 10 km; UAP luminosity assumed to be constantly L = 1 MW; Signal-to-Noise ratio S/N = 10 (dimensionless); Sky background noise b = 2.5 x 10^{-6} $n_{photons}$ sec^{-1} cm^{-1} $arcsec^{-1}$ $Å^{-1}$; Telescope aperture A_T = 20 cm (of a typical portable telescope of the *Celestron* or *Meade* type); Telescope focal length F_T = 286 cm (same as above); Disk-like dimension for a point-like source (the “seeing”) β = 1 arcsec; Photometric CCD detector efficiency factor ε = 0.25.

Here it is easy to see that if luminosity reaches values of up to 30,000 MW (Vallée 1998) the integration time would decrease by several orders of magnitude, with the big advantage of tracking the source during a very short period of time and the opportunity of acquiring several spectra in time sequence.

A graphical example of this kind of calculation is shown in Figure 3, where the integration time IT is calculated for a UAP whose luminosity is L = 1 MW and a diameter D = 10 m, for different values of the spectral resolution (expressed as Δλ) while the UAP distance d varies from 100 m to 10 Km.

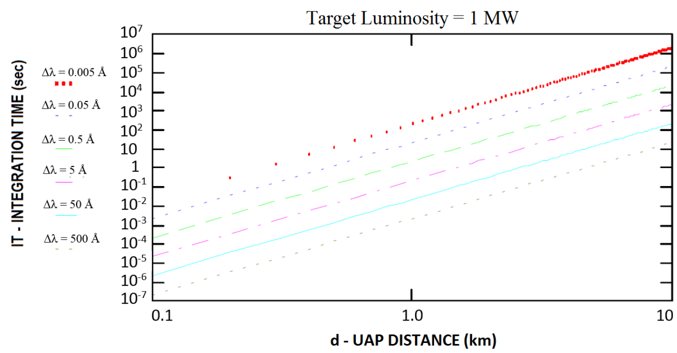

Figure 3. Integration times for a UAP target with luminosity L = 1 MW, given Δλ = 0.005 Å, Δλ = 0.05 Å, Δλ = 0.5 Å, Δλ = 5 Å, Δλ = 50 Å, Δλ = 500 Å. Target diameter is assumed to be D = 10 m. Distance d is varied from 100 m to 10 km. Graph is plotted on a bi-logarithmic scale.

These are the conclusions that can be drawn from these calculations:

1. If we want R = 10,000 or more we would need a very expensive instrument, which – although being potentially connected to the PTZ camera via fiber optics – is not practical at all for our necessities. If we use a cheaper non-echelle instrument, the higher the resolution the shorter the available wavelength range is (StellarNet, website). It is unthinkable to use high-resolution gratings that offer only a wavelength range of 100 Å, even if we can have at our disposal 45 interchangeable gratings (ranging from 3500 to 8000 Å). If we use an echelle instrument (Kitchin 1984) the complete visual range is available simultaneously but the cost is excessively high and the instrument is far too heavy for this kind of utilization. In all cases in which we want to use high resolution, if the UAP is occasionally weakly luminous the integration time while the UAP is tracked would be prohibitive. All this shows that high-resolution is not a viable solution in order to take spectra of UAP

phenomena.

2. The use of a medium resolution slitless echelle spectrograph with R = 2,500 (Masters 2014) is an acceptable compromise. The system – whose wavelength extension is at least 4000 Å – is very light and easily used on a pan-tilt mounting, or even more practically, customized with a fiber optics connection. Due to the absence of a slit, target tracking is relatively easy if the target is moving linearly. Above all, this instrument allows one to use integration times that are at least 10 times shorter than in the case of a high-resolution spectrograph, and consequently being less obliged to track a UAP (which might also suddenly disappear or change its direction of motion) for a too long time.

In general, it is evident that when the value of Δλ increases, the integration time IT decreases (see Formula 2). In fact, when we use low resolution (typical of a diffraction grating) instead of medium resolution spectroscopy the integration time decreases of a factor 10 for a light source with fixed value. When Δλ is around 1000 Å, for which no spectroscopy is possible due to lack of resolution, we enter into the realm of direct imaging (for every U, B, V, R, I filter used), namely (CCD or CMOS) photometry, which obviously permits us to obtain extremely short values of the integration time and which, consequently, allows us to carry out high-speed photometry for very luminous sources.

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