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The Ultraviolet Photography of Nature: Techniques, Material and (especially) Lacertini results

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Abstract

In this paper we deal on the ultraviolet color (invisible to us): where we can find it, the capability of animals to see it and the advantages that this color perception offers to them. As the simplest way to detect it is the photography, we describe and review how to photograph the UV, as a result of 15 years of amateur experience, searching and testing nearly in complete blindness due to the lack of practical information about "how to do it". We describe the different kinds of photography (chemical and digital); the cameras and objectives suitable (both astronomically expensive ones and cheap options); what are the best characteristics that the objectives should have for this purpose; the films suitable for their use in chemical photography; the different filters (current or discontinued) manufactured along the years; and the subtle combinations among the different materials to obtain pure UV photographs. This kind of scientific photography is mainly used in forensics, forgery detection, art dermatology and less in Natural History, despite the fact that a great part of animals see this color and use it in important questions of their biology as the social behavior, mate choice or the food search.

Resum

Aquest article tracta sobre el color ultraviolat (invisible pels Éssers Humans): on és present i la capacitat dels animals per veure-ho. Com que la manera més senzilla per detectar-lo es mitjançant la fotografia, descric i repasso com fotografiar l'UV, com a fruit de la experiència de 15 anys de proves pràcticament des de zero. Descric els diferents tipus de fotografia (química i digital); les càmeres i objectius utilitzables (tant de preus astronòmics com econòmics) i quines característiques són les desitjables; els films apropiats, els diferents filtres (tant els actualment en el mercat com els històrics), i les subtils combinacions d'uns tipus i altres d'elements amb segons quins filtres per obtenir imatges pures en UV. Aquest tipus de fotografia és utilitzada principalment en investigació forense, detecció de falsificacions, Art i menys en Història Natural, tot i que una bona part d'animals el veuen, i sigui important en qüestions tals com per exemple la conducta social, la elecció de parella o la recerca de l'aliment.

Resumen

El presente artículo trata sobre el color ultravioleta (invisible para los humanos): dónde está presente y qué animales son capaces de verlo. Dado que la manera más sencilla para detectarlo es mediante la fotografía, describo y repaso como fotografiar el ultravioleta, fruto de la experiencia de 15 años empezando prácticamente desde cero. Describo los diferentes tipos de fotografía (química y digital); las cámaras y objetivos utilizables (tanto de precios astronómicos como alternativas económicas) y qué características son las deseables en éstos; las emulsiones apropiadas; los diferentes filtros (tanto actuales como históricos), y las sutiles combinaciones de unos y otros elementos para conseguir imágenes puras en UV. Este tipo de fotografía se utiliza principalmente en investigación forense, detección de falsificaciones, arte, y menos en Historia Natural, a pesar de que una buena parte de animales lo ven y es muy importante en aspectos como por ejemplo su conducta social, la elección de pareja o la búsqueda del alimento.

Key words: Ultraviolet; light, color; UV photography; Amphibians; Reptiles; *Lacertidae*.

Paraules clau: Ultraviolat; llum; color; fotografia en UV; Amfibis; Rèptils; *Lacertidae*.

Palabras clave: Ultravioleta; luz; color; fotografía en UV; Anfíbios; Reptiles; *Lacertidae*.

INTRODUCTION

Sun light contains, among a wide spectrum of radiations, UV-A (Ultraviolet A, or Near Ultraviolet, 320-400 nm), UV-B (320-280 nm) and UV-C (280-200 nm) light. UV-B is absorbed by most materials normally used to manufacture lenses, and digital camera sensors also possess low sensitivities in these ranges. UVB is probably not seen by any living species because its higher energy is too damaging to retinal cells. Humans can experience the deleterious effects of UVB radiation because its high energy causes progressive sun burning of the human skin. Luckily for all living beings, the high energy radiations (UVC, UVD and x-rays) are rapidly absorbed in the environment or by the earth's protective ozone layer. Camera sensors are moderately sensitive to UV-A, as are some retinal cells of most animals. Similarly to x-rays that can penetrate through the human body (humans tissues are largely transparent for them) except our denser bones, UV-radiations can be thought of as similar to a long x-ray, invisible to the human eye but able to penetrate some solid objects much further than visible light, for instance, in water.

Despite we cannot appreciate it, there is a notable variety of animals that are able to perceive the Ultraviolet. Many insects, fish, amphibians, reptiles, birds and some mammals are able to perceive UV. This kind of vision is possible thanks to visual pigments that absorb light with peaks at 360 nm. These UV pigments and violet (or blue) pigments with maximal values of 390–440 nm belong to a short wavelength-sensitive type 1 (SWS1) pigment group (Shi & Yokohama, 2003).

Among invertebrates, insects and crustaceans possess UV vision abilities even though they have compound eyes which are structurally different from those of vertebrates. Insects are the best known group. Ultraviolet patterns of the flowers, invisible to us, are a good example: nectar guides and bull's-eyes (see von Frisch, 1957; Eisner et al., 1973; Arias-Torcal et al., 1995 Knüttel & Fiedler, 2000). Hymenoptera as bees cannot see the red extreme of our visible band, but can appreciate the Near Ultraviolet (UV-A). Butterflies probably have the best color perception of all invertebrates and compete with birds and reptiles for the best color-vision of all the Animal Kingdom, as can perceive all our visible spectrum and the Near Ultraviolet, even using it for orientation in migrations (as Monarch butterflies) (Acorn, 2002). Also among spiders, Australian crab-spiders (*Thomisus spectabilis*) interfere with the ultraviolet signals on flowers to attract honeybees (Heiling et al., 2003). Lampyrids (fireflies) emit by bioluminescence a "cool" yellow-greenish light that is devoid of UV-wavelengths (own data with *Lampyris noctiluca*). Insects compound eyes have four visual cells in each ommatidium that respond best to yellow-green light (544 nm), two other cells that respond maximally to blue light (436 nm) and the remaining two that respond best to ultraviolet light (344 nm).

In vertebrates, it has been suggested that UV vision may be the plesiomorphic condition for the group and has probably been retained in many lineages and extant taxa (Goldsmith, 1990; Robinson, 1994; Ebrey & Koutalos, 2001). The human inability to perceive UV is probably the exception, rather than the rule among vertebrates. Furthermore, recent research has revealed the presence of UV reflectance patterns, invisible to humans, in many other vertebrates, presumably able to see UV. It has been suggested that UV vision and UV reflectance patterns may play a role in navigation, foraging, crypsis, intraspecific signaling, or in mate choice (e.g., Cuthill & Bennet,1993; Bennet & Cuthill, 1994; Tovée, 1995; Church et al., 1998; Cuthill et al., 2000, b; Honkavaara et al., 2002; Siitari et al., 2002).

In fishes, the blue and violet wavelengths of light penetrate deeper in water than other colors wavelengths, before being completely absorbed. Other colors are absorbed much soon. In general visible colors are maximally transmitted only down to 0.6-12 m due to the presence of algae, organic matter etc. Although there are discrepancies among authors, as an orientation, in perfectly clear water, red is the first color that disappears (at less than 10 m), later fades yellow-green (50-100 m) and finally blue (200 m). This maximal radius of transmission is in every direction, not just depth. Thanks to ultraviolet vision, fishes are able to see objects more than 12 m away (perhaps there is sufficient ultraviolet light for vision down to 200 m in clear ocean water) either by reflection or silhouettes. This is important because, as has been suggested also for mammals (see below) UV is advantageous especially in twilight (poor light) conditions (see below).

In fishes UV-detecting pigments appear in species that present themselves brigth colors as the goldfish (*Carassius auratus*), Zebrafish (*Danio rerio*), Malawi cychlids (*Metriaclima zebra*), three-spined sticklebacks (*Gasterosteus aculeatus*) and guppies (*Poecilia reticulata*) but not in the deep sea Coelacanth. It has been noted that many fish have UV vision, but this does not necessarily mean that they use UV vision their entire lives. For instance young brown trout (*Salmo trutta*) has UV vision, but the adults do not use it (young fish live in shallow water and feed on plankton, where UV light is essential, whereas adults live in deeper water and do not receive much UV light (Kodric-Brown & Johnson, 2002; Shi & Yokohama 2003; Boulcott et al. 2005). Teleost fishes are able to detect and behaviorally respond to linearly polarized light (Hawryshyn, 2010).

In amphibians there are few data, and is a field for further study, especially in the vividly colored and diurnal species. A salamander (*Ambystoma tigrinum*) is knonw to see UV, but the clawed frog (*Xenopus laevis*) don't see it.

For terrestrial vertebrates has been demonstrated that some species of birds and reptiles can perceive the Near-Ultraviolet (see for instance Varela et al., 1993; Fleishman et al., 1993; Viitala et al., 1995; Bennet et al., 1996, among others).

UV vision is a general property of diurnal birds, confirmed currently in over 40 species that are sensitive to ultraviolet light. Sensitivity to UV is achieved by means of a special cone-type that is sensitive to UV wavelengths, whereas the two other cone-types are sensitive to "human visible" wavelengths. In other words, they have visual pigments with a sensitivity peak in red, green and blue parts of the spectrum, like humans, plus an additional pigment that is most sensitive in either the violet (400-426 nm) or the ultraviolet (355-380 nm). They have a four-, not three-, dimensional color vision. Most birds are thought to have either a violet-sensitive single cone that has some sensitivity to UV wavelengths (for example, many non-passerine species, VS-type cone) or a single cone that has maximum sensitivity to UV (UVS-type cone, for example, in oscine passerine species). UV sensitivity is also possible because, unlike humans, avian eyes do not absorb UV light before it reaches the retina (Bowmaker et al., 1997).

Possession of a VS cone appears to be typical of non-passerine birds such as ducks, poultry, raptors, the Grey Heron (*Ardea cinerea*), the Little Ringed Plover (*Charadrius dubius*), the Black-winged Stilt (*Himantopus himantopus*), the Great Cormorant (*Phalacrocorax carbo*) and the Eurasian Coot (*Fulica atra*) (Wortel et al., 1987; Hart et al., 1999; Prescott and Wathes, 1999) with the exception of gulls, penguins, parrots and the Rhea (Bowmaker et al., 1997; Jouventin et al, 2005); whereas possession of a UVS cone appears to be typical of songbirds (oscine passerines; Hart et al., 1998; Bowmaker et al., 1997; Hart, 2001) with all exceptions so far being either crows (*Corvus* spp.) or tyrannids. All bird species studied so far have at least four types of cones. The sequence differences between UVS/VS character state is controlled by a single nucleotide difference, so one would expect bird species to rapidly evolve between the two forms. Many birds can identify not only feathers, but also UV-reflected nectar and berries, which appear black to us, but reflect strongly in the UV and become less attractive to frugivores if this UV signal is reduced with wax coats (Altshuler, 2001). Raptors (e.g. Koivula & Viitala, 1999) and shrikes (Probst et al., 2002) use the UV-reflecting scent marks of rodents to detect areas where they are active, and the cuckoo mimics in the UV color of their eggs, the ones of their accepting hosts (Corlett, 1996; Koivula & Viitala, 1999; Altshuler, 2001; Probst et al., 2002; Ödeen & Håstad, 2003; Eaton & Lanyon, 2003; Prum et al., 2003; Hill, 2006; Rajchard, 2009).

Mammals, with a long history of night activity along its evolution, have a poor chromatic discrimination and especially UV-vision (Goldsmith, 1990; and references in Varela et al., 1993). However, mammals possess in their DNA the genes that enable UV vision, but these genes have been inactivated by mutation. These mutations that leaded to the loss of UV-vision (and also to the vision in the red spectrum) occurred during that time period of evolution when mammals existed as underground, night active species. Except great apes and humans, other mammals see only two colors: namely yellow-green and blue (dichromatic vision; colloquially misspelled as "black and white vision", although the comparison is appropiate), and whales and seals missed their eye-cones and are color blind. Ultraviolet vision was discovered in mammals only in few rodents and marsupials (Chávez et al., 2003) and also almost in one nectarivorous bat (Winter et al., 2003). Those bats can see ultraviolet due to the fact that a UV-filter is lacking from their eye lens. Normally, the UV-absorbing lens (as our cornea) protects the mammal eye from UV-radiation and its chirurgical extirpation (as occurred in old cataract surgery) permitted even to humans to see UV (see below). Recently, also Reindeer has been found to be able to perceive short wavelengths, which seem to confer an advantage in the winter environment with periods of extended twilight present in Arctic spring and autumn, due to differential UV-reflections known to occur between snow and food (lichens) or predators (urine and homochromatic-in-visible fur) (Hogg et al. 2011). Rodents leave urine marks in their environment, these marks are visible in UV as well as smellable (as in Degus, Chavez *et al.,* 2003; voles, Koivula *et al.,* 1999; Mice, Desjardins *et al.,* 1973), but these marks are visible to predators, such as diurnal raptors (Viitala *et al.,* 1995). Parts of the mammal body may be reflective to ultraviolet light. In Degus, for example, the belly reflects more UV light than the back, becoming visible when the animal stands up on its hind legs, exposing its belly to other specimens (Chavez *et al.,* 2003). Although ultraviolet light is not available at night, recently has been discovered that there is a significant increase in the ratio of ultraviolet to visible light in the morning and evening twilight hours (Hut *et al.,* 2000). Rats are nocturnal, but they are also active during the twilight hours, starting just before sunset and ending just before sunrise (Robitaille and Bovet, 1976). Ultraviolet vision would be advantageous at these twilight hours of day and it is therefore possible that ultraviolet sensitivity is retained in rats because it is useful during this periods.

Humans and other Old World monkeys have trichromatic or three-dimensional color vision due to three interacting cone types. Consequently, all hues can be produced by mixing red, green and blue light (this is how a color television set works; a mixture of three wavelengths that produces several million apparent "colors"). Above this wavelengths occurs the Infrared, and below, the Ultraviolet. Humans see from about 400 nm to 760 nm. The two extremes are certainly in the UV-A and IR range normally considered invisible, but it is only invisible when bright light of more ordinary wavelengths overwhelms the eye's low sensitivity to these wavelengths. Also the retina can see UV-A and some UV-B when there is no lens in the way (aphakia, as resulted from crystalline removal in old cataract surgery) (Lynch, et al., 1995). We have three different opsins on our cones which allow us to discriminate between blues, greens and reds. Phototopic (cones) vision in humans has a peak at 560 nm (yellow-green) and a nominal range from 400 to 760 nm. Scotopic (rod) vision suffers a shift to the blue compared to the cone vision (the so called Purkinje effect) with it best absorption at 500 nm. Overall, human eye has a range of sensibility that extends from 310 to 1050 nm, but strong illumination is necessary to perceive the sensation of any reception at the extremes of the range (Lynch et al., 1995). With age, our sensibility to blue and violet fades when the cristalline lens yellows, as occurs in photography when yellow filters to block the blue are used (Le Grand, 1957).

In contrast with our situation, prosimians, such as lemurs and lorises, have relatively poor color vision, being dichromatic. They can differentiate blues and greens, but not reds. Color vision among New World primate species is surprisingly variable. Some of them are dichromatic and others are trichromatic. Even more curiously, females in some species can distinguish reds (about 40% of the females apparently are also dichromatic, but the other 60% are trichromatic) but no males can distinguish red (only see blue and greens), as occurs with marmosets, tamarins, squirrel and spider monkeys. Both male and female howler monkeys are trichromatic, but on the other hand, the nocturnal owl monkeys are monochromatic (a kind of "B&W" vision). A rare genetic disorder in humans known as achromatopsia causes a similar inability to see colors due to defective cones.

Human eye can be compared with a camera: our retina is sensible to the near UV as the film or digital sensor is, but our crystalline lens is opaque to this as occurs with modern lenses with their coatings. Although the retina can easily detect high intensity ultraviolet light below 400 nm, the lens (crystalline) cannot focus it. Owing to this, the ultraviolet images, as their effect in photographs appear a bit fuzzy. If the crystalline is removed as in a cataract operation, the vision becomes affected (aphakic eye) and ultraviolet sensitivity enhanced until the atmospheric cut-off of 300 nm. In these conditions, in UV the skies appear as very white (luminose), with strong airlight, and the vegetation turns out to be very dark (this is why UV photographs appear to be very dark) and glass appears opaque (below 380 nm). For an aphakic eye (cataract surgery) people look abnormally dark, the sky very bright, and the sun loses importance, being the shadows indistinct. Distant objects fade and fog or mists are enhanced. The interior of cars and buildings become invisible, as the eyes of people-wearing glasses, and at night the city seems abnormally dark. The painter Claude Monet (1840-1926) documented the bluish appearance of UV by painting one of his favorite scenes, water lilies, before and after his cataract surgery in 1923 (Lynch et al., 1995).

Most reptiles can see through ultraviolet light. Reptiles with slit-like pupils are nocturnal and in principle, can only see in "black and white" (monochromatic). Turtles have excellent vision (recent studies have confirmed tetra-chromacy in turtles) but can not see far distances. Snakes have rods and cones in their eyes but they have fewer types of color oil droplets in their cones than birds or mammals, presumably after having lost the other cone types when snakes' ancestors were nocturnal and subterranean. They have a yellow filter that, filling the lens, absorbs ultraviolet light and protects the eye. Color sensibility depends of the species. Lizard (including geckos) and turtle retinas contain multicolored oil droplets in their photoreceptors, and the opsin proteins in their cones detect different wavelengths, so they can perceive color. Saurians see colors in a form very similar to humans, and some of them as blue, green and red pigments seem to have a very important role in both intra and interespecific recognisement and communication (see Darevsky, 1967). It has been show that *Lacerta agilis* recognizes at less eight colors: red, orange, yellow, yellow-green, green, bluish-green, blue and violet (Swiezawska, 1950). The same author finded that maximum discriminative sharpness for this species corresponded to the yellow and green, whereas the lesser to red and violet. She also finded females that discriminate these colors slightly best than males and that they could be divided into three groups: reds + oranges, yellows + greens + clear blues, and blue and violets. They are also able to distinguish light tones among several grey tones (Bellairs, 1969).

Inside the saurians, UV-vision has been confirmed in *Anolis* (Fleishman et al., 1993; Fleishman & Persons, 2001; Macedonia, 1999, 2001; Macedonia et al., 2000; Stoehr & McGraw, 2001; Thorpe, 2002; Thorpe & Stenson, 2003), *Carlia* (Blomberg et al., 2001), *Ctenophorus* (Lebas & Marshall, 2000, 2001) and *Gallotia* (Thorpe & Richard, 2001; Font & Molina-Borja, 2004). In other species this ability is supposed, as they have ocelli or other highly reflective areas that seem to be important in the communication (Arribas, 2002), but studies about the true receptors they have (i.e. the absorbance of retinal oil-droplets in the eye) still lack. Approaches to this study come from UV photography and documented reflectance spectrophotometry. Wavelengths at peak absorption of the UV-sensitive photopigments of lizards, as determined in *Anolis* by microspectrophotometry, lies in the 362-367 nm range (Fleishman et al., 1993, 1997).

The coloration of lizards comes both from pigmentary colors and physical reflectance. Pigments (pigmentary colors) can be carotenoids, pteridines and melanines, whereas physical reflectance (structural colors) comes from, for instance, guanine platelets.

There are three chromatophore types in the uppermost part of the dermis:

-Xanthophores: the most external layer. It contains long wave-length reflective pigments (red, orange and yellow pigments). These pigments disappear in alcohol conserved specimens. They produce the red, orange and yellow colorations, especially in the dorsum and the belly.

-Iridophores (or Guanophores): underneath the xantophores, have reflective guanine platelets that produce structural colors (blue, UV) through light scatter. These are not labile molecules and being physical, don't disappear with the alcohol conservation of the specimens. They are the blue and UV areas. The blue, when combined with superficial yellow pigment gave the green colorations. If the yellow pigment lacks, appear the blue mutants characteristic of a lot of usually green species.

-Melanophores are deep in the dermis and contain melanine that absorbs all the radiations not absorbed or reflected by the precedent layers. By this massive absortion appear as nearly black. They constitute the brown and black patterns in reptiles.

There are no blue or UV pigments in vertebrates (Bagnara et al, 2007), and all these colors are supposed to be structural, not pigmentary.

The aim of this paper is to describe the different techniques and photographic materials that can be used for the UV photography, fruit of 15 years of trials with different objectives and filters, as well as to describe the presence of UV reflective structures in Amphibians and Reptiles, especially in Lacertids. Our approach is only qualitative (presence or absence of UV color in animals) and did not pretends to quantify it nor to extract any conclusion about their significance or the ability of animals to see it.

MATERIAL AND METHODS: HOW TO DO UV-PHOTOGRAPHY

There are two kinds of photography that shall not be mixed up: Fluorescence and UV-reflected photography. The first, fluorescence photography, consists into illuminate the subject with UV ("black") light and the subject returns this radiation with lower wavelength, inside the visible spectrum, being photographed with conventional photography (fluorescence shall not be confounded with phosphorescence in which light disappears after turning-off the illumination source). Fluorescence photography is typically used in mineral identification. It is noteworthy that flowers with UV patterns invisible to us become fluorescent when they are dried for herbarium purposes (Eisner et al., 1973). The second kind (UV-reflected photography) is the type that interests us, and is similar to the natural phenomenon that enables UV-perception in animals; UV-light is reflected by the subject and reaches the eyes or the camera (Kodak, 1968; Silberglied, 1976).

The first thing that must be said is that UV-photographs are not nice. They lack the appeal, *charme* and beauty of the B&W-infrared photographs or the visible spectrum ones, and are fairly more difficult to obtain. They are monochrome, "grainy" and blurry. It shall be remembered that UV-blocking filters are used in conventional photography just to gain sharpness in the images apart from as objective protectors. Due to the very short wavelengths involved (below 400 nm), the UV band carries more than its fair share of atmospheric scatter. Scattered UV light can cloud distant backgrounds and impart an unwelcome bluish cast in film images (this phenomenon is most problematic at very high altitudes over 3000 m and over long stretches of water). UV-photography is used in a wide scope of fields as Art, Forensics, Forgery detection, Medicine (Hansell, 1961; Mustakallio & Korhonen, 1966; Lunnon, 1968; Phillips, 1976; Lunnon, 1979; Kodak, 1968, 1987; Krauss & Warlen, 1985; McEvoy, 1987; Williams, 1988; Redsicker, 1991; Krauss, 1993).

THE CAMERAS

Two types of cameras can be used: digital (for digital photography) and the so-called "analogic" (for chemical-process or classic photography; also called "analog").

Digital photography: Digital sensors are sensitive to a wide and undesirable spectrum of radiations, from near UV to the IR. Camera manufacturers try to avoid these undesirable side-effects that affect the quality and sharpness of the photographs. Usually all cameras have built-in filters of the so-called "Hot Mirror" type that eliminate totally the UV from the photographs. CCD and CMOS image sensors of digital cameras incorporate strong UV and IR filters to achieve good color accuracy with standard visible-light subjects. Normal Digital-SLR cameras are not very sensitive in the UV, but very much to IR ranges.

It is possible to use digital cameras and general-purpose lenses to take pictures in the near UV range, at least for static subjects that allow relatively long exposures. Among Nikon® D-SLRs, the D70, D70s, D1 are reported to be particularly suitable for near-UV photography (UV-A, 320-400 nm). Canon® and other brands are said to be unsuitable, but this is a surprise to be checked with every new improvement or model. The first digital cameras were sensitive to both IR and UV, as the first Nikon® Coolpix (there are tutorials in the web to improve them removing the sensor filters, as for Nikon® Coolpix 950, 990 and 995, or Nikon® D70 body). Also Olympus® C-750 Olympus® C-20x0Z, Konica® Chrome R-100, Orwo® NP15 Fuji® S6500fd and F10 have been used for near UV photography. Perfectioned or not, current digital cameras are sufficiently sensitive to IR to do this kind of photography without problems, but equally are totally insensible to UV. In any case, usually long exposures, image noise, atmospheric scattering and focus shifts are involved.

There are, however, cameras especially designed for UV and IR photography (this is, with an extended spectrum, from UV 380 nm up to IR at 1000 nm) but are very rare, their market is very limited and their price very expensive. Fuji® has a camera special for forensic photography (Fuji® Finepix S3 Pro UVIR; Fuji S5 Pro -model XNiteFujiS5-). And a video camera Sony DSC-F707® can be used as a real-time visor in UV, as well as the SceneScope Advance™®. Other models that can be used are Canfield® Scientific ("ReflecUV-model" instant camera system), SpexForensics ("Scenescope® RUVIS-model"), Faraghan Studios ("UV detect-model"® camera) or Atlanta Camera® and other models that furnish kits based in Fuji® S1 for this mainly dermatologic and dentistry photography.

Finally must be mentioned that other inexpensive and very good testers for UV and IR photography are the mobile-phone cameras. Up till now they have been of sufficiently low quality (yes, low quality!) to be virtually unfiltered and sensitive to all the undesirable radiations, a very interesting side-effect for quick testing of specimens. Phone cameras with the correspondent band pass filter are able to registrate the UV and IR, and the easiest way to check for UV colors in the field. However, if one wants to discriminate if UV or IR is registered in the photo, the correct filter (sensitive to one of the two, but not to both radiations) must be choosen; see filters section).

Chemical photography and films: All photographic films (color negative and slides, black-and-white, infrared) are sensitive to ultraviolet radiation (because silver halide crystals are sensitive to it). There is no significant advantage to using color film for reflected ultraviolet photos because only the blue layer of the tri-color pack will be exposed by the ultraviolet (the integral yellow filter of the film effectively preventing exposure of the red and green layers).

However, not all is happiness with films: As this UV light is undesirable since it adds blurriness to the conventional photographs, coatings are added to the films to prevent this radiation to arrive at the sensitive layers of the film. Artificial-light films (called "tungsten-films" because are used indoors -or for microscopy-) lack these filtering layers, and these films are sensitive, and therefore very suitable for UV-photography. Also tungsten-balanced films are preferable to normal films for UV color work. The reason is that they have an enhanced sensitivity to blue light that also helps to record UV better. Moreover, they have lower sensitivity to yellow and red, and therefore the UV photographs are less likely to be contaminated by the far-red sideband of the main part of band pass filters described below.

Once a band pass filter is added, only UV shall be reflected in the photo, and the result is monochrome. If a B&W film is used, the result is B&W, and if color film is used, the result is blue and white instead of B/W (the same occurs with the "color mode" in digital cameras). A very sensible film can be selected for a quick (less time) exposition, but the image is still more grainy; or a less sensible one, but with best image quality (for the UV standards) and with longer exposition times.

I have used a slide film, which has accurate color rendition but lacks "latitude" (latitude in photography is the ability to produce a good picture from a negative that is slightly underexposed or slightly overexposed). The retouch of photographs, although interesting for amateur, artistic or commercial purposes, in scientific studies is a fraud.

In my case, slide film Fuji® RTP 64 has been used during 15 years. Other films that can be used are Kodak®Fine Grain Positive Release Films TMAX 100, 400 and 3200. Tests revealed that Kodak® tungsten films (EPY, E160T, and E320T) were less suitable for UV color photography than Fuji® RTP. Concerning normal (daylight) films, the UV images obtained with the Kodak Ektachromes® were soft and exhibited muted colors (a reddish tinge frequently overlaid the Kodak images). This color pollution of the UV images was much less evident on Fuji® RTP, which rendered UV scenes with rich colors in blue, white and red (this later when far-red side of the bandpass filter contaminates the scene). Fuji Provia® (RDP-II) is said to give quite useful images, but not as good as with RTP.

THE OBJECTIVES

There are special objectives (quartz-made) for UV photography (used in forensics, art restauration, forgery detection, etc.) that allow UV imaging down to ~200 nm, but they are very costly, as the Nikon UV Nikkor® f 4.5/105mm (extremely rare and outrageously expensive, more than 3000 Euro a lot of years ago), and only sligthly cheaper versions custom-made by Carl Zeiss Jena (Carl Zeiss Jena® UV Objektiv f 4/ 60mm), Takumar® (Asahi Pentax® Ultra Achromatic Takumar 85 mm), Tomioka® Macro Yashinon f2.8/ 60mm, Steinheil® Quarzobjektiv f1.8/ 50mm, Rodagon® f4/ 60mm, Hypergon® f11/26mm, Lomo Уфар-12 f2.5/41mm, Zeiss UV-Planar f4/60mm, Zeiss® UV-Sonnar f4.3/105 mm, Cerco® UV-VIS-NIR f4.1/94 mm, Rodenstock® UV-Rodagon f5.6/60mm andVoigtländer® Apo-Macro-Lanthar f2.5/ 125mm SL). Despite this “battery” of special lenses, all them are very rare and almost never come to the light in second-hand market. Probably all them were made exclusively to custom order.

For enthusiastic but not rich people, normal objectives (far from perfect, but suitable) for UV photography can be found. First decision is about true-glass versus organic glass objectives. Modern objectives (usually associated to also modern digital cameras) are made of organic glass, light weighed and easy to manufacture. These organic glasses are not more than plastic and are totally unsuitable for UV-photography. True glass (also called optical glass, crown glass or Flint glass) objectives must be used but, as every terrariophyl knows, glass filters the UV radiation. This is in part unavoidable: objectives and filters are made of glass, but this glass must be minimized as much as possible. Not all are sad notices: optical glass lets near-UV (UV-A) up to a limit of around 320 nm (KODAK, 1987).

Prime lenses (a fixed focal, for instance 50mm) are preferable to teleobjectives or other lenses with complex mechanisms inside. Teleobjectives involve a huge number of lens complexes inside that filter the UV. The lesser the number of lenses inside, the more UV reaches the film or the sensor. As said above, optical glass has low transmission in the UV region anyway and the adhesives used in manufacturing some lens groups further attenuate this. Thus, prime lenses, with the lower number possible of isolated lenses, 3 to 5 and not glued is the desirable choice. Manufacturers add coatings to objectives to improve the image and avoid undesirable wavelengths. There is no need to say that these coatings eliminate the UV. Uncoated or monocoated lenses must be used. If a lens is coated, coating layers can be seen in a form of colored shines when closely inspect the front part of the lens. Uncoated ones had no color (but are fairly old, before the 70's). Monocoated ones frequently have yellowish shine (old Nikon® and Zuiko-Olympus®, almost), and finally multicoated ones return several color shines when inspected and must be avoided. Coatings can be removed, but I do not recommend to try it, as the result can leave the lens with still coating-stained areas together others more or less coating free in the same lens, affecting the quality of the photograph and deteriorating the whole objective for other normal uses. Removal can be done rubbing the lens surface with a damp cotton cloth dusted with cerium oxide polishing powder (a very hard substance used for polishing gemstones), but coatings are very hard and a couple of hours rubbing at hand can be necessary. Another problem is that the lens material is softer than the coating, so the lens surface deteriorates on a microscopical scale. Chemical instead of mechanic treatments had been attempted by other photographers, but without apparent success. Old quartz slider-projector or "amplifier" objectives have been used succesfully in UV photography (EL-Nikkors® are approximately as good for this purpose).

Thus, the thumb-rule is "the older and the simplest is the best choice", thus is: prime lenses, with few (3-5 best) optical elements, the thinnest possible and of uncoated true-glass, if possible.

THE BANDPASS FILTERS

The correct choice of a band pass filter is fundamental for the interpretation of the results obtained, and depends on the kind of photography concerned (chemical or digital).

For chemical photography, the main part of band pass filters used are suitable, as its frequently associated near-IR peak does not affect the film (insensible to IR wavelengths). In digital photography, these same filters result not in UV but in IR-photographs (or at best, IR with a few UV mixed). This can lead to important misinterpretations as these filters had usually far more transmittance in this other wavelengths (IR), and images can be mistaken (even in publications) with true UV-photographs (see below about these transmittances and filters).

UV band pass filters are typically "black". This is due to the nickel-oxide glass used (called Wood's glass). For this, the filters are called "Wood's filters", named after Professor Robert Wood, a pioneer of invisible radiation study. These filters have a peak transmittance (near 65 %) towards 360 nm (near UV). As said above, usually have also a small transmittance peak towards the other extreme of the spectrum, in the deep red¿ -Near IR, but this is not a problem since films are not sensitive to this part of the spectrum, except the so called false-color IR slides film (Kodak Ektachrome Infrared). Transmittance curves for each filter (even the discontinued ones) can be found easily in the web (from manufacturers of filters). Five different filters of the nominal eight we know for UV-photography have been tested personally (Fig. 2), but all the known brands are mentioned in the following lines:

-Kodak Wratten® 18A: Is the standard UV-filter in literature (KODAK, 1968, 1987, and many others) to which other filters are frequently compared. It has a peak transmittance (near 65 %) at 350 nm and transmits a 50% at 320 nm and 380 nm. Also, has 14% of IR leakage at 746 nm. It was very expensive and served in square Wood glasses instead in gelatine as other Wratten filters (gelatine do not transmit UV). Wratten 18A filter-factor is said to be 80 (or ~6.5 stops), but frequently there is a reduction in more (6-9 stops) diaphragm steps, depending on the near-IR and UV content of the scene. If combined with a “hot mirror” (a filter that completely blocks IR, absolutely necessary if digital camera is used) to block the IR side lobe, the total light loss is 10-13 stops (Kodak 1968, 1987). Discontinued.

-XNite330 nm filter®: has a peak transmission (85%) at 330 nm, and transmits around the 50% at 270 nm and 375 nm. Also has a slight IR peak at 720 nm. Probably discontinued.

-Nikon FF®: Transmits up to 420 nm and again from 760 nm. Despite the prestigious brand and its use for nice (but few scientifically rigorous) UV (with IR and a bit visible included) digital photographs, results are definitively unusable for scientific photography. It is a thick glass filter which transmits, apart of UV and near IR, slightly in the lower purple range and deep red (both in the visible). It was served together with the Nikon UV Nikkor® f 4.5/105mm. Probably discontinued.

-B+W 403 ® (Schott UG1® glass) has a peak transmittance at 360 nm (UV) and another peak at 750 nm (IR) (approximately 17 % IR leakage at 746nm for B+W 403, but other sources attribute 9% IR leakage at 746nm for Schott UG1 that in fact is the same glass). Its prolongation factor (EV) is 8-20 depending on the film. The easiest UV-filter to obtain.

-Schott® UG5 and UG11 (also commercialized as DUG® 11 & DUG® 11x) are not suitable for scientific use, as have a great part of visible transmittance. Old UV glasses like the Schött UG11 were very transparent to infrared and need to be used with an IR-blocking glass (“hot mirror”). Some modern filters such as Schuler and Baader (based in this UG glasses) have built-in IR coatings and can be used alone. Not difficult to obtain still as square glasses.

-Hoya® U360 is one of the oldest and most known UV filters. It is a quite thick glass filter with a 70 % transmittance at 360 (UV), but also a small peak at 750 nm (IR) and another one in the 4000 nm. As in other classic UV-filters (B+W® 403, Kodak® 18A) an IR-blocking filter ("Hot Mirror") must be used for digital photography (but is not needed for chemical one). Discontinued as a commercial (round threaded) filter, but not difficult to obtain as a square glass.

-Tiffen® 18A: I'm not sure it was made of Kodak® 18A glass as its name suggests, but I suspect to be made in Schott UG1 (as B+W 403®). This filter type transmits 70% of UV in a rather narrow band centred on 360 nm, and 10% of IR (14 % in other measurements) at 740 nm. It transmits smaller amounts of IR in a rather broad range (up to about 850 nm). Discontinued.

-Schuler UV® filter: A small sized filter designed for Astronomy, with a peak at 360 nm. In terms of performance, the Schuler seems to be fairly good as it has a good IR coating, and also a 30% higher UV transmittance. Although Baader U-filter (see below) transmits an higher percentage of UV than the Schuler-filter. Owing to the shorter wavelength peak and narrower band of the former and the decreasing sensitivity of digital cameras toward shorter wavelengths, the recorded UV is overall better with the Schuler, especially if a broadband UV source is used. Is probably the best UV filter for digital photography if one wants to avoid the use of a "hot mirror" filter, as does not leave the IR radiation transmision through it.

-BAADER U-Filter® (also called "Venus Filter", and nicknamed by some "UG11xx" to differentiate it as a second generation UG-11-based Baader Filter) is another UV filter conceived for astronomical photography. It is in fact a UG11 with a "hot-mirror" coating incorporated. This filter transmits light in the 320 to 390 nm. This U-Filter has improved transmission peaking with 85% transmission at 350nm with a 70nm bandwidth, and with a 5 stop reduction in the IR portion of the spectrum (only 0.15% IR leakage at 737nm, 0.3% at 813nm and 0.1% at 872nm). Filters such as Schuler and Baader have built-in IR coatings and can be used alone. Testing made in astronomic webs and also by us, seems to indicate that the Schuler is the best (in the sense of IR-opaque).

Other very rare filters (than can be considered as true collector items) are commercial brands as the Kopp® Glass (before, Corning) 5860, and the Pilkington filters (Chance® OX1, OX5 and OX7), and all they are no longer manufactured.

It must be said that these expensive filters are not for all the life. When exposed to the light (with ultraviolet component) they degrade over time through a process called solarization that reduces the amount of UV light that can pass through the filter. Hoya filters are said to resist fairly well this natural ageing process, whereas in other filters the resistance is not know.

UV SOURCES

To have a UV source is almost as important as the sensitive surface or the filter selected. We can choose among natural (also promising, as is the same source for animals) and artificial sources.

Sunlight is the most available and free UV radiation source. Sunlight has near a 10% of its energy in the ultraviolet region. This source only has the inconvenience of its variation, as the quality and quantity of the radiation depends on atmospheric conditions. Obviously, a bright and dry day is much richer in UV radiation and preferable than a cloudy or rainy day. To minimize atmospheric scattering and maximize exposure, bright clear dry days work best for outdoor UV work. Pre-subject scattering losses in incident sunlight will be least around noon.

Artificial light sources can be very varied. Tungsten lamps (bulbs) are very poor sources of ultraviolet and should be avoided. There are, however “black light” and inexpensive tungsten UV bulbs as the 160 W black light UV-bulb (Philips® MLW 160W; spectral energy distribution 366±20 nm). Common fluorescent tubes are also a very poor source of ultraviolet, but there are special tubes with ultraviolet emitting phosphors - the so-called "black light" tubes, used for fake money detection and decoration-. They are inexpensive and provide sufficient illumination for large subjects. They are, however, quite inefficient when compared with the output of either mercury vapour or xenon flash tubes. Mercury vapour lamps, open arcs, are good emittters but can be fairly dangerous, causing severe burns.

The xenon arc lamps are particularly good continuous sources of ultraviolet and are specifically made for invisible radiation work (Polilight®, Lumilite® and Omniprint® are examples).

For standardized (but artificial, and therefore different to the animal vision conditions), there are rare and expensive flashes. Flash Nikon® SB-140 UV IR (with its clone Nikon® SB-14) with the additional Nikon® SW-5 UV & SW-5IR, the UV enhanced Vivitar® 285/285HV, the Sunpak® 622. If these sophisticated flashes are not available, a “normal” UV bandpass filter can be adapted in an ordinary Flash, perhaps complemented with a ligth regulator (Nikon® SU-2 or SU-3).

HOW TO DETECT IF YOUR CAMERA SENSORS ARE BEING CONTAMINATED WITH IR RADIATION?

As said above, the main part of the UV filters let IR to pass through and the digital cameras LCD sensors are especially sensitive to this radiation, instead to the UV. The simple way to detect IR contamination in your camera+objective+UV band pass filter compound is to take a TV or VCR infrared remote control and point it at your camera (with or without darkening the room). Push a button in the remote control and look on the LCD display for a spot of light. If you see a light, your camera is contaminated with other radiations, and your photos are not pure UV but IR.

THE EXPOSITION

We cannot be confident with the light-intensity measurements of our cameras. Most cadmium sulphide exposure meters have poor sensitivity to ultraviolet radiation. Selenium cells do have a response down to 300 nm but the half-peak sensitivity covers the range from 400 nm to 650 nm. It is therefore necessary to exclude all visible light from the meter's cell by appropriate filtration and then to re-calibrate the meter to ultraviolet.

Overall exposure times of the camera are very long, making it necessary to shoot from a distance and in "pose" or “bulb” position, keeping the camera open for several seconds (the exposure is highly dependent on illumination and the sensitivity of the film, but exposures of more than ten seconds are almost sure, and even of a minute are not uncommon). Although the diaphragm should be as closed as possible to gain some depth of field, is better to shoot with the greatest aperture possible, otherwise the exposure times are excruciatingly long.

Long UV exposures favour both camera shake and image noise. Solid camera support, and therefore the use of a tripod, is an absolute must. The noise can become quite apparent in multisecond exposures.

Most UV-band pass filters suppose an increase of 7 to 9 EV (exposure values). This is due to the fact that UV light is at least 4 stops lower intensity than the near-IR (<3% UV of the incident from the Sun compared to > 40% IR -although these percentages vary with geographical location-). Add to this reduced quantity, the UV attenuation of the lens and filter, and you might lose a total of 8 stops or more, whereas the IR crosses almost unhindered through the same lens.

With an artificial source, typical exposures using the Nikon® SB-140 flash held at the camera back and T-Max rated at 3200 ISO with the 105 UV Nikkor® are as follows: 1:1 (f/32), 1:4 (f/16), 1:8 (f/11), 1:15 (f/8). As ever, trial and error method is needed for all the material to be used by everyone.

FOCUS SHIFTS

For non-quartz lenses, visible and UV focus points are different. It may be convenient (although the difference is almost negligible) to correct focus distance to just at the other side of the infrared point focus that usually appears indicated in quality objectives. As a first approximation, focus normally and then align the setting <u>against</u> the IR mark on the lens (the same range towards the contrary side of the IR mark). Stopping down will ensure adequate depth of field unless we are shooting close-ups (which unfortunately are frequently the case with amphibians and reptiles).

The depth of field can be extended by stopping down the aperture and reducing subject magnification, but this is undesirable in most cases.

UV light usually comes to a focus just short of the focal plane suitable for visible light. Visible light rends automatic exposure lectures unreliable. If UV is the only light coming in, auto-focus (AF) should be able to adjust accordingly, provided AF has enough light to do it, but light can get pretty scarce behind a black UV-transmitting filter and possibly a "hot mirror" filter stacked.

Focus shift can be problematic in UV photography, but working on digital, some of it can be buffered within the generous depth of field typical of CCD (digital) cameras.

HOW TO SHOT

The equipment used by the author was a mechanic chemical-process camera Olympus® OM3, with a tripod and a distance shutter to avoid vibrations or shakes during the long exposures (from 5 to 20 seconds). Camera was charged with Fuji RTP® 64 slide film. By far, the most satisfactory objective used was Zuiko® (Olympus) 50 mm f 3.5 macro. This objective has very few and thin glass elements. This equipment can be seen in Fig 1.

For every subject, a normal photograph (in visible spectrum) was shot with a 85B orange filter (for temperature-color correction, as I was using a "tungsten film", developed for artificial bulb photography). After this (as quick as possible, especially if subject were live animals) I put exposure dial in position "B" (bulb) for long exposure, and substitute the 85B filter by the UV-band pass filter (Schott® UG1 glass, B+W®403) as quick as possible in the thread of the objective. Also, I set the aperture at the greatest possible (f 3.5 in our case) and hang lens cap supported in the border of the camera visor to avoid the entry of light. Finally, the shutter can be pushed and exposure time lapsed until release. About ten seconds in summer and direct sun are very acceptable. Deviations of a few seconds (for instance by counting without a chronometer) are unimportant.

INTERPRETATION OF IMAGES AND CHROMATIC ABERRATIONS

As was said above, UV photographs are not nice. Focus shifts (explained above) and distance scattering are in part responsible of the images blurring. Clouds tend to disappear, and if illuminated in artificial light, the interior of buildings and cars appear dark (invisible).

How to interpret a UV-photography?. Being a monochromatic light, illuminated (clear) parts in the photograph are rich in reflected UV and dark ones are poor in it. Pure UV photographs are monochrome (black and white or blue and white, depending of the film or color-mode used). However, nice color photographs can be found in the web, but these are not PURE UV photographs, and have been made using filters very permissive to radiations different to the UV ones (as Schott® UG-11 or Nikon® FF). Bluish overall tones are very frequent in color slides (as Fuji-RTP®). This bluish areas have low UV reflectance, typical for foliage or photosynthethically active parts of plants. The interpretation, from Rorslett (http://www.naturfotograf.com) is as follows: A) Pinkish white: High UV, Blue/Green, Yellow and Red+Near IR. B) Bluish White: High UV and Yellow. C) Low Blue/Green and Red+Near IR. D) White or light Blue: High UV, Low Blue/Green, Yellow and Red+Near IR. E) Dark Grey or Blue: Low in all radiations except Blue/Green. F) Red: Low UV, Blue/Green and high Yellow and Red+IR. G) Purplish Red: All low except Red+Near-IR.

RESULTS AND DISCUSSION

As was said in the introduction, our aim is not to quantify nor extract evolutive conclusions that can be only afforded from individual and accurate casewise studies. Our aim is simply to reflect how to do UV photographs and where we have found this color in Lacertini and some other reptile and amphibian taxa, as a result of our trials with theses techniques.

Animals use their body coloration for mate recognition and intraspecific communication. Both males and females have these same signals, but are more developed in males, especially if strong male competition is involved. In Lacertini, blue ocelli in the shoulders (and occasionally flanks), the outer ventral scales (OVS) frequently (but not ever) blue and throats have demonstrated to be strongly UV reflective. Maximum reflectance seem to be lower 400 nm (Thorpe & Richard, 2001; Font & Molina-Borja, 2004; Perez-Lanuza & Font, 2006; Molina-Borja et al., 2006; Martin & Lopez, 2009), and the (diurnal) lizards visual spectrum lies between 300 and 700 nm (Fleishmann et al, 1993, 1997; Macedonia et al., 2000, among others).

The results on the different groups are in tables 1 (lizards), 2 (snakes) and 3 (amphibians). Commentaries to different taxa included in the three tables, are in the Appendix.

Our qualitative results with lizards (Table 1) show that the specimens reflect some ultraviolet as well as other visible colors. Usually, a very white area in the visible spectrum (reflecting all the visible colors) is suspicious to be UV reflective. The same is true for blue structures. The biggest differences with a photo in B/W would appear as abnormally clear areas (the very reflective ultraviolet ones), which animals that have the ability to see this color see as such (more clear UV reflecting areas) contrasting with other abnormally dark areas (UV absorbent). The combination of reflective and absorptive zones provided, as in the case of many flowers, contrasting bright designs invisible to the naked human eye.

In general, in saurians (Table 1), we found that the integument was only moderately UV-reflective (a modest degree of reflectivity, similar to vegetation and substrate around the lizards), so that contributes to hide them to aerial predators such as kestrels (*Falco tinnunculus*) that detect UV in their hunting (see Viitala et al. 1995). UV-reflecting areas are hidden from aerial predators and concentrated in the sides and visible areas of the throat and belly (animals made them visible by special behaviors), where other conspecific specimens can see them. Rarely the background (BK) color of the animals is weakly reflective, being usually as low reflective as the environment (the study of the different substrates reflectance will be interesting to correlate with the different groups reflectance in UV). Our results show that there are coincident patterns of UV reflectance among most of the Lacertini genus studied.

In animals, the most reflecting areas are:

- Axillar Blue Ocelli (BO in the Table 1): Very strongly reflective. Occasionally in some species, animals bearing yellow ocelli (YO) instead of blue, can be also reflective. This is the case of some *Iberolacerta martinezricai* or of *Podarcis bocagei*. These ocelli increase in number, size and reflectivity along the life of the lizard and some authors speculate about they do not simply reflect the UV, but also the quality of the male as a possible mate choice.

- The clear stripes (CS) and clear dots (CD), which already reflect all colors of the visible spectrum, also in many cases reflect in the UV. However, not all these white areas equally reflect the UV, and UV helps lizards to highlight certain areas such as the axillary ocelli compared to the other white spots of the sides that are not reflective.

- Outer ventral spots (OVS): usually are blue, but in some taxa (i. e. *Podarcis*) the same area of other colors can be also reflective.

-Belly: Blue and pure white bellies (both physical colors) can be reflective. We have proved that if there are pigmentary colors (e.g. yellow), these mask the UV signal of the white (UV reflective) parts and delimit the signal. For instance in *I. aurelioi* the white throat is reflective but the yellow belly is not. The pigment masks and reduces the UV signal.

-Blue throat (BT): In some species (specially in the great *Lacerta*) the blue throat, occasionally extending to all the head surface, is UV reflective and very visible, especially during breeding.

In the *Iberolacerta* studied by us the vividly blue or greenish tail of hatchlings is not UV-reflective. The same is true for *Podarcis* gr. *hispanica* type 1A.

Two remarks are particularly interesting from our study: a) Not all blue and all white (or whitish) are UV reflective. The clear areas instead of BO or OVS can be equally reflective in UV; whereas some blue areas can be not. b) More interesting is that the alcohol-conserved specimens retain reflective properties in the dorsal design and therefore are susceptible to be studied. This is due to the presence of physical structures reflecting UV by dispersion and reflection, instead of being in labile pigments (soluble in alcohol). However, such pigments can be important in masking the underlying UV patterns and allowing to see the especific UV-signals only in some body areas.

The results for Lacertini genera are extracted in Table 1. In snakes (Table 2), apparently there are no reflective areas. Probably their sigth is poor due to the fact they derive from subterranean (and possibly nocturnal) ancestors and have lost part of their color (and UV) sensitivity. In the few amphibians studied (Table 3) the situation is similar. Some spots in urodeles seem to be slightly reflective, perhaps as a mean of camouflage, and in turtles (only *Emys orbicularis* studied) no UV patterns appeared. See appendix 1 for notes and comments to the species included in Tables 1-3.

Available information indicates a significant relationship between UV reflecting areas and structures already striking within the visible spectrum, as the axillary ocelli and lower lateral line of blue spots (OVS), from which appear to be derived. Other colorations as in the gular area (as in *Lacerta* s.str.) seem also to be reflective and used for communication. Although these structures have already more or less conspicuous colors in visible, UV reflectance would give more light and brilliance to these areas. Detailed studies at the intraspecific level reveal intraspecific differences related to the reproductive cycle or the social status of individuals. Other aspects to consider in future are the degree of UV reflectance as protection against excessive radiation (in mountain or offshore islands), potential differences in the development of UV designs between sympatric species, reinforcing the differences that may exist within the visible spectrum, and others.

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APENDIX I (TABLES):

SPECIES	LOCALITY	N.SPEC	HEAD	DORSUM	FLANK	BELLY	TAIL	NOTES	REFERENCES
Apathya cappadocica wolteri	Kirikan (Amanus gebirge); Turkey	1 (F)	(-)	CD(++)	CD(++) BO(++)	¿	(-)	(1)	This paper
Algyroides nigropunctatus	Corfu; Greece	1 (F)	(-) BT(+)	(-)	(-)	(-) OVS(+)	(-)		Arribas (2002); This paper
Algyroides moreoticus	Panakaikon; Greece	1 (M)	CD(+)	CD(+)	CD(+)	¿	(-)		Arribas (2002); This paper
Algyroides marchi	Sierra de Alcaraz (Albacete); Spain	1 (M)	(-)	CS(+)	CD(+)	(+)	(-)		Arribas (2002); This paper
Algyroides fitzingeri	Sardinia; Italy	1 (M)	(-)	(-)	(-)	¿	(-)		Arribas (2002); This paper
Acanthodactylus erythrurus	Huesca, Spain	1 (F)	CS(+)	(-) CS(+)CD(++)	CS(+) CD(+)	OVS(0)	CS(+)	(2)	This paper
Anguis fragilis	Soria, Spain	1 (F)	(-)	(-)	(-)	(-)	(-)	(3)	This paper
Chalcides bedriagai pistaciae	Salamanca, Spain	1	(-)	(-)	(-)	¿	(-)	(4)(Photo 10)	This paper
Dalmatolacerta oxycephala	Dubrovnik; Croatia	-	(-)	(-)	(-)	(++) OVS(++)	(-)		Perez-Lanuza & Font (2010)
Darevskia armeniaca	Ankavan; Armenia	2 (F)	(-)	(-)	BO(++) CD(+)	(+) OVS(+)	(-)		This paper
Darevskia bendimahiensis	Muradiye falls; Turkey	2 (F)	(-)	(-)	BO(++) CD(+)	(+) OVS(+)	(-)		This paper
Darevskia caucasica	Kvarshi;Daghestan & Terek River;Georgia	2 (M&F)	(-)	(-)	BO(++)	(+) OVS(+)	(-)		This paper
Darevskia daghestanica	Khvarshi; Daghestan	2	(-)	(-) BK(+)	BO(++)	(+) OVS(+)	(-)	(5)	This paper
Darevskia dahli	Kodjori; Georgia	2	(-)	(-)	BO(+)	(+) OVS(+)	(-)	(6)	This paper
Darevskia rostombekowi	Papanino; Armenia	2	(-)	(-)	BO(+)	(+) OVS(+)	(-)	(6)	This paper
Darevskia sapphirina	Patnos; Turkey	2	(-)	(-)	BO(++)	(+) OVS(++)	(-)		This paper
Darevskia saxicola	Kislovodsk; Russia	2	(-)	(-)	BO(++)	(+) OVS(++)	(-)		This paper
Darevskia unisexualis	Ankavan; Armenia	2	(-)	(-)	BO(++) CD(++)	(+) OVS(++)	(-)		This paper
Darevskia uzzelli	Horasan; Turkey	2	(-)	(-)	BO(++) CD(+)	(+) OVS(++)	(-)		This paper
Darevskia valentini	Aragatz Mt. (Kutchak);Armenia	1 (M)	(-)	(-)	BO(++)	(+) OVS(++)	(-)		This paper
Darevskia (3n) *valentini X unisexualis*	Aragatz Mt. (Kutchak);Armenia	1 (F)	(-)	(-)	CD(+) BO(+)	(-)	(-)	(7)	This paper
Darevskia unisexualis	Aragatz Mt. (Kutchak);Armenia	1 (F)	(-)	(-)	CD(+) BO(+)	(-)	(-)	(7)	This paper
Dinarolacerta mosorensis	Valobito Jezero; Montenegro	1 (M)	(-)	(-)	(-)	(-)	(-)		This paper
Gallotia galloti		-	(-) BT (++)	(-)	BO (++) OVS(++)				Thorpe & Richard (2001); Font & Molina-Borja (2004)
Iberolacerta aranica	Aran Valley (Lleida); Spain	13	(-)	(-) CS(0)	(-) [OVS(+)]	(0)	(-)	(Photos 11 & 12)	Arribas (2007); This paper
Iberolacerta aurelioi	Andorra	12	(-) WT(++)	(-) CS(0)	(-)	(+)	(-)	(8)(Photos 13-15)	This paper
Iberolacerta bonnali	Lac Bleu (Hautes Pyrenees); France	6	(-)	(-)	(-) [OVS(+)]	(0)	(-)	(Photos 16 17)	This paper
Iberolacerta cyreni	Several localities (Segovia, Avila, Salamanca); Spain	34	(-)	(-)	CD(+)	(0) OVS(++)	(-)	(Photos 18 19)	This paper
Iberolacerta horvathi	Udine, Italy	1 (M)	(-)	(-)	(-)	(-)	(-)	(9)	This paper

SPECIES	LOCALITY	N.SPEC	HEAD	DORSUM	FLANK	BELLY	TAIL	NOTES	REFERENCES
Iberolacerta monticola	Several localities (Oviedo, Leon, Coruña); Spain	42	(-)	(-)	CD(+) BO(+++)	(0) OVS(++)	(-)	(Photos 20 24)	Arribas (2002); Arribas, Carranza & Odierna (2006); Arribas & Carranza (2007); This paper
Iberolacerta galani	Several localities (Leon, Orense, Zamora); Spain	50	(-)	(-)	CD(+) BO(+++)	(+) OVS(++)	(-)	(10) (Photos 25 29)	Arribas, Carranza & Odierna (2006); Arribas & Carranza (2007); This paper
Iberolacerta martinezricai	Peña de Francia (Salamanca); Spain	18	(-)	(-)	CD(+) BO(+++) YO(++)	(+) OVS(++)	(-)	(Photos 30 32)	Arribas, Carranza & Odierna (2006); Arribas (2007); Arribas & Carranza (2007); This paper
Iranolacerta brandtii	Isfahan; Iran	1 (M)	(-)	(-)	CD(+) BO(+++)	¿	(-)		This paper
Lacerta agilis garzoni	La Molina (Girona); Spain	2 (M&F)	(-)	(0)	CD(+)	(-)	(-)		Arribas (2002); Perez-Lanuza & Font (2007); This paper
Lacerta agilis argus	Oradea; Romania	1 Juv	(-)	(-)	CD(+)	(-)	(-)		This paper
Lacerta agilis exigua	Kharkov; Ukraine	1	(-0)	(0) CS(0)	(0) CD(+)	(-)	(0)		This paper
Lacerta agilis boemica	Buinaksk (Daghestan); Russia	3	(- or 0)	(0) CS(0)	(0) CD(+)	(-)	(0)		This paper
Lacerta bilineata	La Poveda (Soria); Spain	4	(-) BT (++)	(0) CD(0) CS(0)	CD(+)CS(+) OVS(0)	(-)	(-)	(11)	Arribas (2002); This paper
Lacerta schreiberi	Several localities (Soria, Santander,Leon); Spain	7	(-) BT (++)	(0)	CD(+)	(-)	(-)	(12)(Photo 33)	Arribas (2002); Martin & Lopez (2009); This paper
Lacerta strigata	Dyubek (Daghestan); Russia	2	(-)	(0) CS(++)	(0) CD(+)	¿	(-)		Arribas (2002); This paper
Lacerta viridis	Oradea; Romania	1	(-) BT (¿)	(0)	CD(+) CS(+)	(-)	(-)	(13)	This paper
Parvilacerta fraasi	Sannin Mts.,Lebanon	1	(-)	(-)	BO(+++)	(0)? OVS(++)	(-)		This paper
Podarcis bocagei	Several loc. (Zamora, Leon, Coruña); Spain	14	(-)	(-)	CS(+) YO(+)	(0) CS(0) OVS(++)	(-)	(14)(Photos 34-35)	Arribas (2002); This paper
Podarcis carbonelli	Peña de Francia (Salamanca); Spain	5	(-)	(-)	(-)	(-) OVS(++)	(-)	(Photos 36-37)	This paper
Podarcis gr. *hispanica* 1A	La Liebana (Santander); Spain	8	(-)	(-)	(-) CD(0)	(0)? OVS(++)		(15)(Photos 38-40)	Arribas (2002); This paper
Podarcis gr. *hispanica* 1B	P. Francia (Salamanca); Spain	3	(-)	(-) CD (+)	(-)	(0)? OVS(++)	(-)	(16)(Photo 41)	Arribas (2002); This paper
Podarcis lilfordi sargantanae	Balearic Ids.; Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Podarcis lilfordi giglioli	Dragonera Id., Balearic Ids. Spain	-	(-)	(-)	(-)	(-) OVS(++)	(-)		Perez-Lanuza & Font (2010)
Podarcis lilfordi kuligae	Gran de Cabrera Id., Balearic Ids.; Spain	-	(-)	(-)	(-)	(+) OVS(++)	(-)		Perez-Lanuza & Font (2010)
Podarcis liolepis	Soria; Spain	24	(0)	(-)	(-) CS(0)	(0)? WO(+) OVS(++)	(-)	(17)(Photo 42-43)	Arribas (2012); This paper
Podarcis muralis	Several loc. (Asturias, Avila, Teruel); Spain	20	(-)	(-)	CS(+) BO(+)	(+) OVS(++)	(-)	(18)(Photos 44-49)	This paper
Podarcis pityusensis formenterae	Barcelona; Spain	1	(-)	(-) CS(0)	CD(+)	(+) OVS(++)	(-)		This paper
Podarcis pityusensis maluquerorum (melanic)	Pityusic Ids.; Spain	1	(-)	(-)	(-)	(-) OVS(++)	(-)		This paper

SPECIES	LOCALITY	N.SPEC	HEAD	DORSUM	FLANK	BELLY	TAIL	NOTES	REFERENCES
Podarcis pityusensis vedrae	Pityusic Ids.; Spain	1	(-)	(-)	(-)	(-) OVS(++)	(-)		This paper
Podarcis raffonei	Aeolian Id.,; Italy	1	(-)	(-)	(-)	(-)	(-)		This paper
Podarcis sicula campestris	Noja (Santander); Spain	1	(0)	(-) CS(+)	CS(+) BO(+)	(-) OVS(++)	(-)		This paper
Podarcis sicula cetti	Almeria; Spain	1	(0)	(-) CD(+)	CS(+) BO(+)	(-) OVS(++)	(-)		This paper
Podarcis tiliguerta	Corsica; France	2	(-)	(-)	CS(+) BO(+)	(-) OVS(++)	(-)		Arribas (2002); This paper
Podarcis wagleriana	Sicilia; Italy	1	(-)	(-) CS(0)	BO(+) CD(0)	(-) OVS(++)	(-)		This paper
Psammodromus algirus	Soria; Spain	3	(-)	(-)	BO(+++)	(-)	(-)	(Photo 50)	This paper
Scelarcis perspicillata chabanaudi	Jbel Tazzeca Mts.	-	(-) BT(0)	(-)	(-)	(-)	(-)		Perez-Lanuza & Font (2010)
Timon lepidus	Several Loc (Santander, Soria, Teruel); Spain	4	(-)	(-)	BO(+++)	(-)	(-)	(Photo 51)	Font et al. (2009) This paper
Zootoca vivipara louislantzi	Bigorre; France Val d'Aran; Spain	6	(-) WT(0)	(-) CS(0)	(-)	(-)	(-)	(Photos 52-53)	This paper

Table 1: Comparative results of the UV-photographs in diverse taxa of Sauria. Abbreviations of body parts are as follows: BT (blue throat), WT (white throat), BK (dorsum background), CS (clear stripes), CD (clear dots), BO (blue ocelli), OVS (outer ventral scales), YO (yellow or yellowish ocelli). Indications about the presence or absence of UV: (-) No UV; (0) indices or weak reflectance; (+) Reflecting; (++) Very reflecting. Numbers in notes refer to Appendix 1. Previous references or the novelty of the data are indicated. Particle "gr." intercalated in the scientific name (as in *Podarcis* gr. *hispanica*) means "group": A *Podarcis* of the group of *P. hispanica*.

SPECIES	LOCALITY	N.SPEC	HEAD	DORSUM	FLANK	BELLY	TAIL	NOTES	REFERENCES
Coronella austriaca austriaca	La Poveda (Soria); Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Coronella austriaca acutirostris	Peña de Francia (Salamanca); Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Coronella girondica	Herreros (Soria)Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Hemorrhois hippocrepis	St. Llorenç Montgai (Lleida); Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Hierophis viridiflavus	Istria; Croatia Val d'Aran; Spain	2	(-)	(-)	(-)	(-)	(-)		This paper
Natrix natrix astreptophora (melanistic)	Picos Europa (Santander); Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera aspis aspis	Pt. de la Bonaigua, (Lleida); Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera aspis zinnickeri	Val d'Aran; Spain	2	(-)	(-)	(-)	(-)	(-)		This paper
Vipera berus berus	Udine; Italy	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera berus bosniensis	Valobito Jezero, (Durmitor)Montenegr	3	(-)	(-)	(-)	(-)	(-)		This paper
Vipera kaznakovi	Apsheronskii (Krasnodar); Russia	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera latastei	Soria; Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera renardi	Pyatigorsk; Ukraine	2	(-)	(-)	(-)	(-)	(-)		This paper
Vipera seoanei seoanei (bilineata morph)	Picos de Europa,Asturias Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera seoanei seoanei (uniform morph)	Pt. los Tornos, Santander; Spain.	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera seoanei cantabrica	Pto. Las Señales (Leon); Spain	1	(-)	(-)	(-)	(-)	(-)		This paper
Vipera ursinii	Mtgne. de Lure,France	1	(-)	(-)	(-)	(-)	(-)		This paper
Zamenis longissimus	La Liebana(Santander) Osor(Girona) Spain	3	(-)	(-)	(-)	(-)	(-)		This paper

Table 2: As Table 1. Results in the snakes studied. No UV patterns appear in any of the species photographed.

SPECIES	LOCALITY	N.SPEC	HEAD	DORSUM	FLANK	BELLY	TAIL	NOTES	REFERENCES
Bufo bufo	Soria; Spain	1						(Photo 54)	
Calotriton arnoldi	Montseny (Barcelona); Spain	4	(-)	(-) CD(0)	(-) CD(0)	(-)	(-) CD(0)	(19)(Photo 55)	This paper
Calotriton asper	Sª de Guara (Huesca); Spain	2	(-)	(-)	(-)	(-)	(-)		This paper
Hyla (arborea) molleri	Sª Cebollera (Soria); Spain	1	(-)	(-)	(-)	(-)	(-)	(Photo 56)	This paper
Rana pyrenaica	Belagoa (Navarra); Spain	1	(-)	(-)	(-)	(-)	(-)	(Photo 57)	This paper
Salamandra salamandra almanzoris	Guadarrama (Segovia), Gredos (Avila); Spain	3	(-) CD(0)	(-) CD(0)	(-) CD(0)	(-) CD(0)	(-) CD(0)	(20)(Photo 58)	This paper
Salamandra salamandra terrestris	Montseny, (Barcelona); Spain	1	(-)	(-)	(-)	(-)	(-)	(21)	This paper

Table 3: As Table 1. Results in amphibians. Almost no reflective. Only some maculae from urodeles can be weakly reflective and with doubts (see text).

NOTES:

(1) In *Apathya cappadocica* the white ocelli distributed through the body appear fairly bright in UV.

(2) In *A. erythrurus*, the longitudinal white stripes are moderately reflecting, especially brighter ocelli that appear inside these stripes. In the dark stripes, there are yellow (visible) ocelli that are barely visible in UV.

(3) In *A. fragilis*, scares and injures result fairly more reflective in UV than the otherwise cryptic body coloration. It will be interesting to study the UV behavior of the blue ocelli of some males.

(4) Overall tone of *Chalcides bedriagai*, as in *Anguis*, is the lack of reflective elements, very similar to ground or vegetation.

(5) In the males of *D. daghestanica*, the clear background bands of the dorsal tract (at the sides of the dark vertebral band) is moderately reflective in UV, and contrasts with both the vertebral and the temporal bands (unreflective). Females lack these bands, blue ocelli and usually also the OVS UV-reflective dots.

(6) In *D. dahli* and *D. rostombekowi*, the throat is less reflective (without losing it completely) than the UV reflective belly.

(7) In *D. unisexualis* (and in leeser degree in their derived triploid hybrid with *D. valentini*) the bright and round clear dots that form a row in the dorsolateral area are almost as UV reflective as the axillar BO.

(8) In *I. aurelioi* the white parts are UV reflective, but the yellow pigment of the belly masks it and corners the most UV reflecting parts to the foreparts (throat and part of the chest) of the lizards. Is interesting the use of the visible pigment to delimit the UV reflecting area enhancing the contrast. The blue or greenish tails of the juveniles of all these *Iberolacerta* species (if present) are not reflective. In the other two *Pyrenesaura* (*I. aranica* and *I. bonnali*) sometimes males can have blue OVS. If present, these are reflective.

(9) *Iberolacerta horvathi* results oddly dark in UV in comparison with other *Iberolacerta*. It lacks the BO and OVS that result reflective in other congeneric species.

(10) Melanistic *I. galani* had no trace of UV. No BO or OVS in melanistic specimens of both sexes.

(11) *Lacerta bilineata* is fairly cryptic among grass (not reflective). Perhaps the minute clear scales may be a few contributing with a fine spotting to the crypsis. The bluish throats, directed downwards and enhanced during the breeding period are very reflective in UV. This signal is hidden from aerial predators but shown in front of other specimens. Striated females had these stripes moderately reflecting.

(12) *Lacerta schreiberi* males are similar to *L. bilineata* ones (but without the finely clear scales spotting), not or scarcely reflective upwards, but with the throat UV-reflecting area (blue in visible) extending by all the head. Also these throat contrasts against the scarcely or no reflective breast and belly, pigmented of yellow in the visible spectrum (as occurs in *I. aurelioi* -see note 8-). Females are also

moderately reflective in dorsum, similar to juveniles, but the white ocelli of these latter are very strongly reflective.

(13) Our sample of true *L. viridis* is very scarce (only two young specimens). Very probably is very similar to *L. bilineata* (with blue throat reflecting in UV).

(14) In *Podarcis bocagei* (as well probably in other similar species) despite to lack blue OVS (except in some concrete populations), these scales, although yellow or whitish, are also UV reflecting (possibly, the UV signal is present in all the males irrespective of the presence of blue OVS). Also, in the axilar area where in other species there are the blue ocelli, in this species (especially males but also in some females) the yellow area is also UV reflecting. In females the longitudinal clear stripes seem to be faintly reflective, and the black bordered spots of the tight seem to be reflective.

(15) *Podarcis* gr. *hispanica* 1A (populations from Picos de Europa) are fairly inconspicuous from above. Only the OVS (not blue in visible!) are reflective. Also, the black bordered spots of the rear facing part of the thigh seem to be reflective. Finally, is worth to mention that the blue tail of juveniles is unreflective.

(16) Also, as in type 1B, the black bordered spots of the rear facing part of the thigh seem to be reflective.

(17) In *Podarcis liolepis*, as in other Iberian Podarcis, the OVS (in this case, blue) and the clear (white or yellowish, only exceptionally bluish) axillar ocelli are reflective. Also white ocelli in the rear part of the thigh seem to be.

(18) In our *Podarcis muralis* studied, the blue axillar ocelli are scarcely reflective in some specimens, but clearly UV-reflective in others. The yellow axillar ocelli from females are not reflective or very few are reflective, also contrary to some *Iberolacerta* (e.g. *I. martinezricai*, in which subadults or females can have conspicuous yellow ocelli instead of the blue ones). The blue OVS are the most reflective part in *P. muralis*.

(19) The clear dots of some *Calotriton arnoldi* can be sligthy reflective, perhaps as a part of the species' camouflage. The belly has not reflective marks.

(20) The UV behavior of yellow marks in *S. s. almanzoris* seen to be different among specimens. In the Gredos ones studied the yellow marks don't seem to be reflective or very few, but in the Guadarrama one represented in the photo, were more reflective and even in the deep-red region (not well represented in the scanned slides). The UG-1 Glass filter used permits a slight "contamination" in the far-red region (just before the Infrared) of the spectrum that we can see but still impresses the film. We have detected this deep-red also in the front of a *Serinus citrinella*. This species has no red in the face, but is a close relative of other fringillids with red faces. In any form, it has also this red-face (deep-red) and is not impossible that birds can see it.

APENDIX II (PHOTOS)

Photo 1 (Equipment)

Photo 2 (Filters)

Photo 3 (*Parnassius apollo*)

Photo 4 (*Merops apiaster*)

Photo 5 (*Helianthemum*)

Photo 6 (*Ranunculus ficaria*)

Photo 7 (*Caltha palustris*)

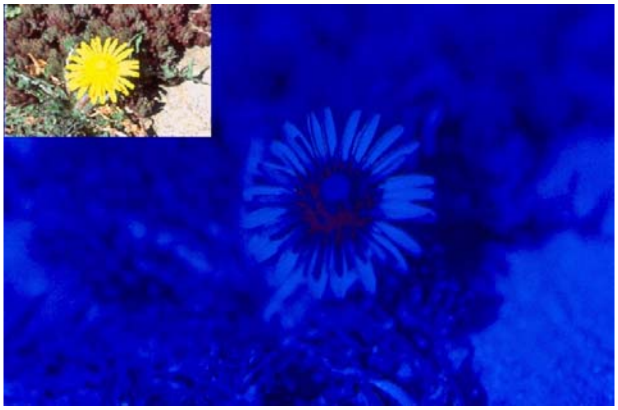

Photo 8 (Dandelion)

Photo 9 (*Silene*)

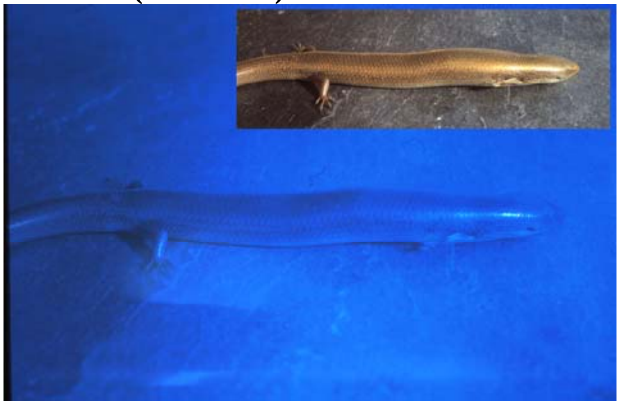

Photo 10 (*Chalcides bedriagai*)

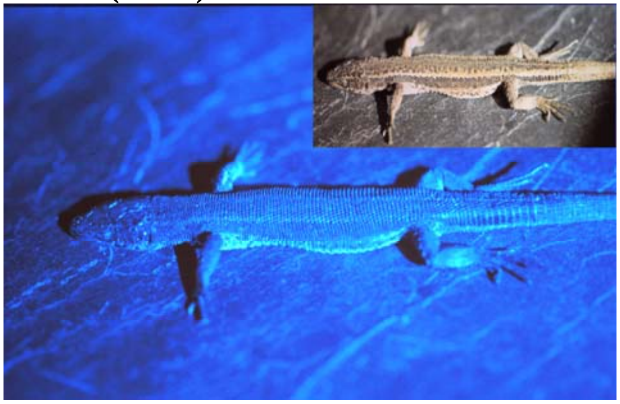

Photo 11 (*Iberolacerta aranica*)

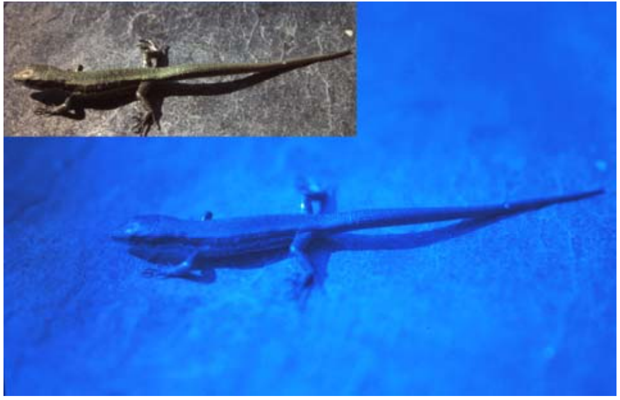

Photo 12 (*Iberolacerta aranica*)

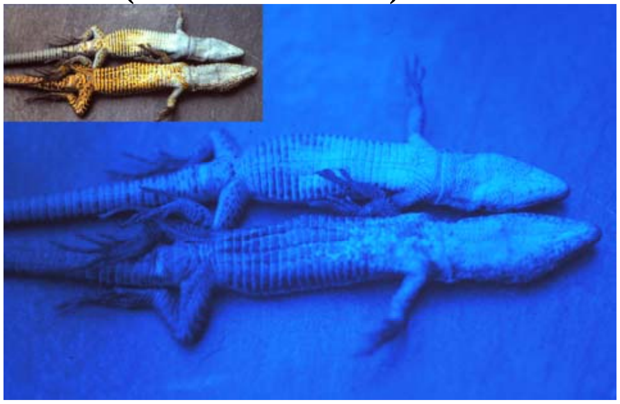

Photo 13 (*Iberolacerta aurelioi*)

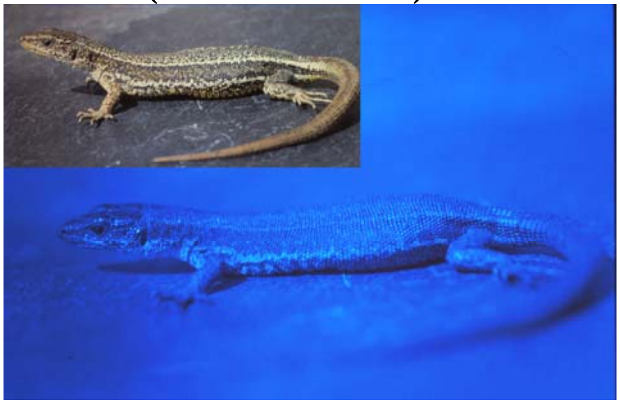

Photo 14 (*Iberolacerta aurelioi*)

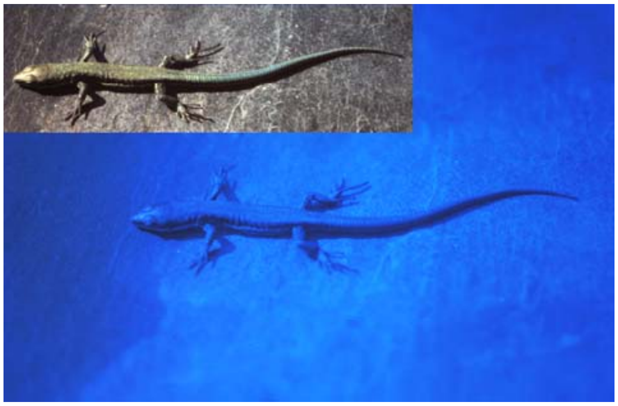

Photo 15 (*Iberolacerta aurelioi*)

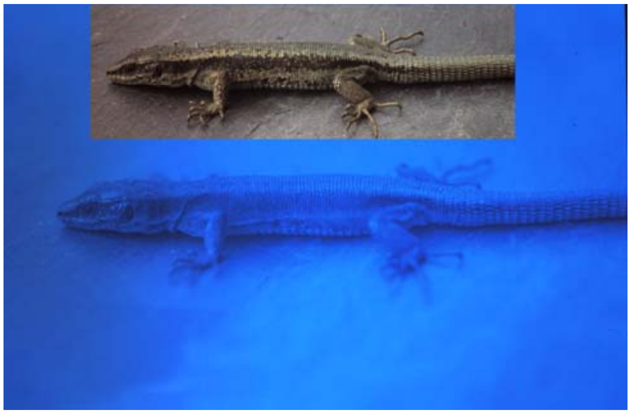

Photo 16 (*Iberolacerta bonnali*)

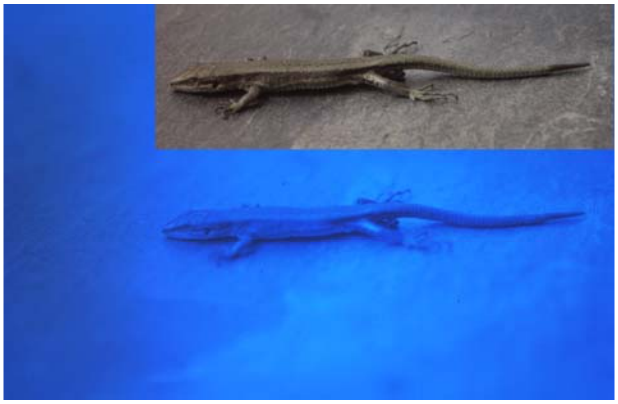

Photo 17 (*Iberolacerta bonnali*)

Photo 18 (*Iberolacerta cyreni*)

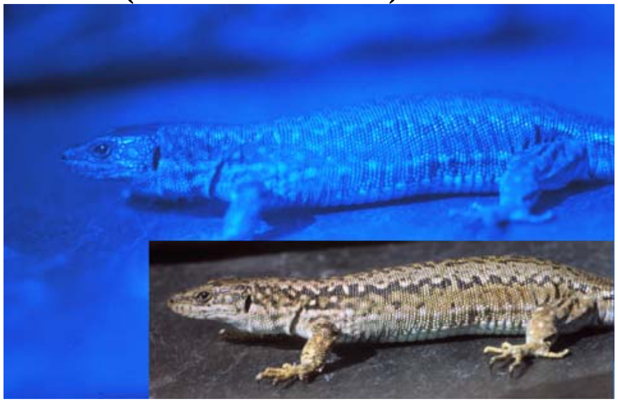

Photo 19 (*Iberolacerta cyreni*)

Photo 20 (*Iberolacerta monticola*)

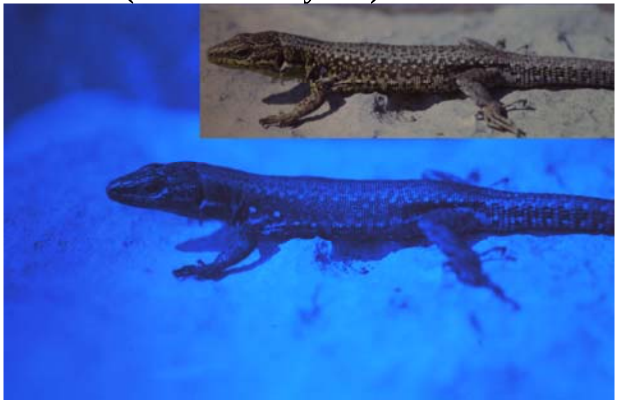

Photo 21 (*Iberolacerta monticola*)

Photo 22 (*Iberolacerta monticola*)

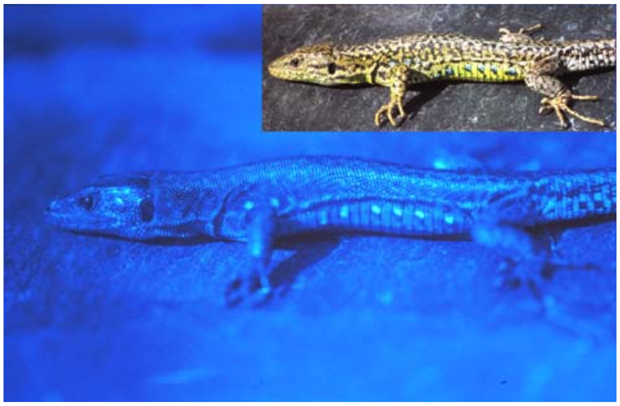

Photo 23 *(Iberolacerta monticola)*

Photo 24 *(Iberolacerta monticola)*

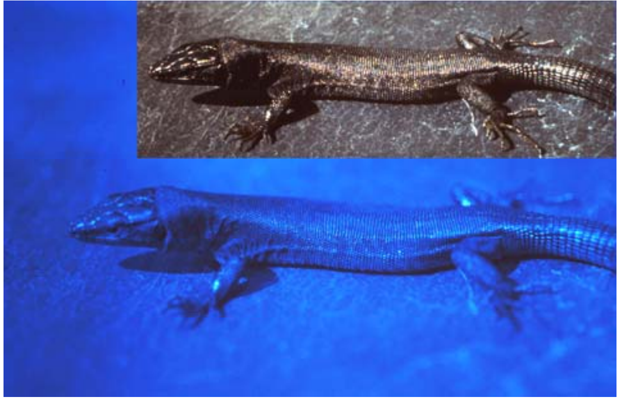

Photo 25 (*Iberolacerta galani*)

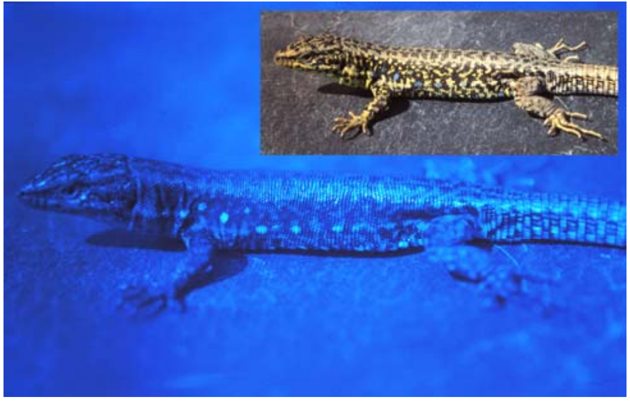

Photo 26 (*Iberolacerta galani*)

Photo 27 (*Iberolacerta galani*)

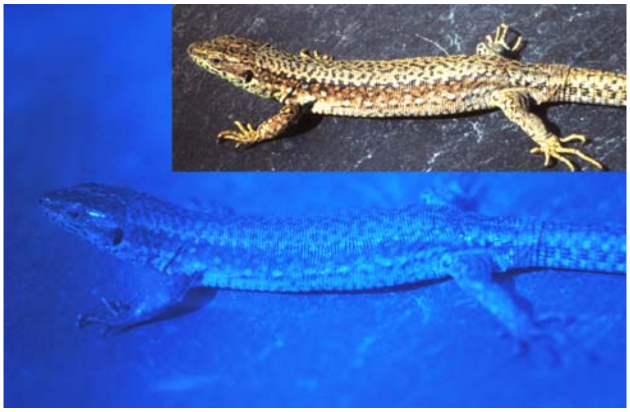

Photo 28 (*Iberolacerta galani*)

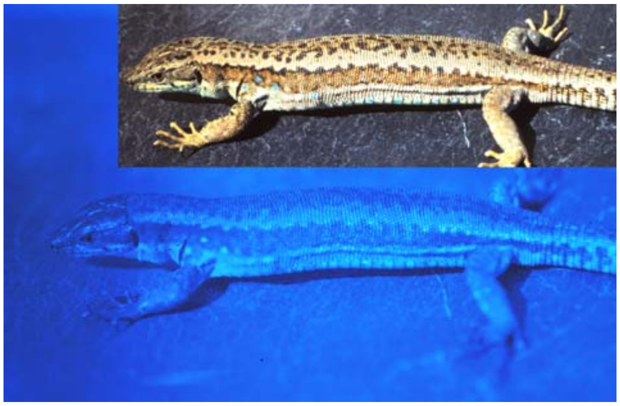

Photo 29 (*Iberolacerta galani*)

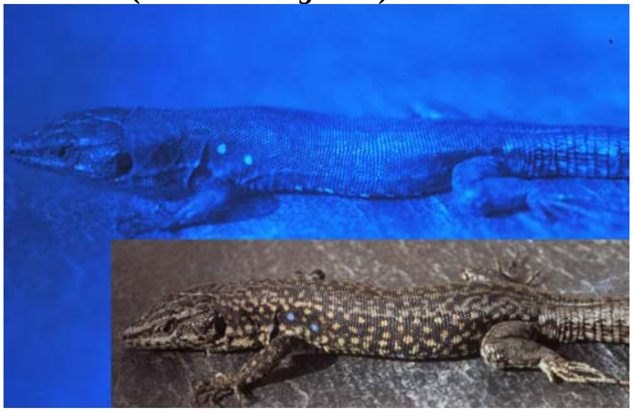

Photo 30 (*Iberolacerta martinezricai*)

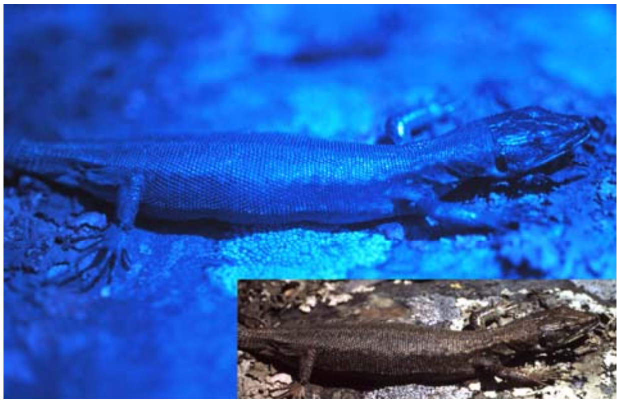

Photo 31 (*Iberolacerta martinezricai*)

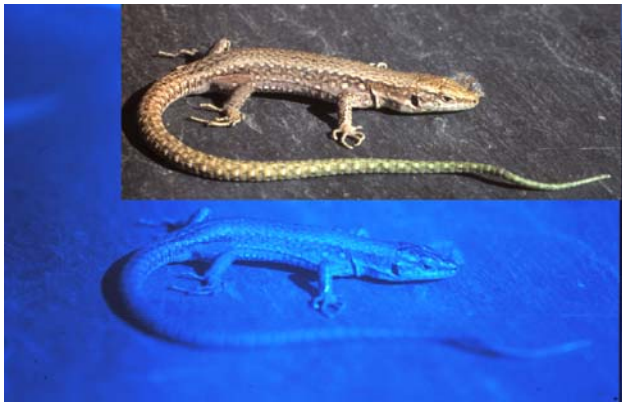

Photo 32 (*Iberolacerta martinezricai*)

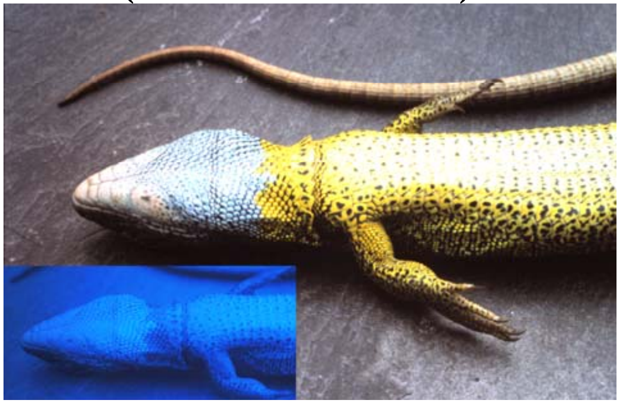

Photo 33 (*Lacerta schreiberi*)

Photo 34 (*Podarcis bocagei*)

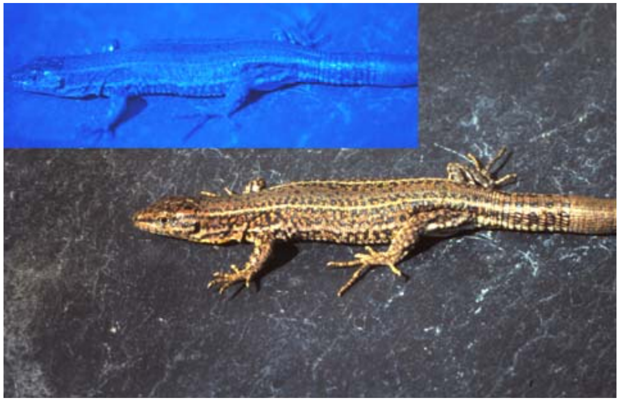

Photo 35 (*Podarcis bocagei*)

Photo 36 (*Podarcis carbonelli*)

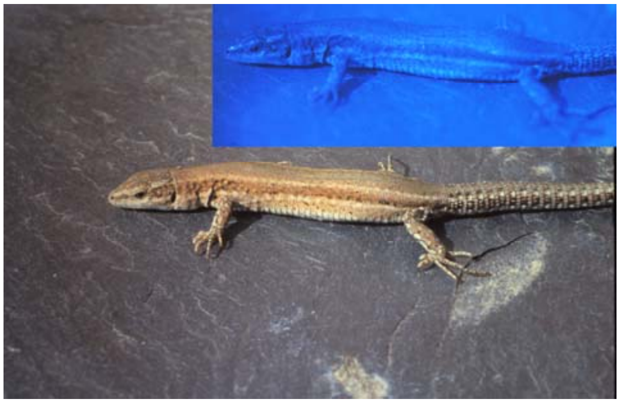

Photo 37 (*Podarcis carbonelli*)

Photo 38 (*Podarcis* gr. *hispanica* 1A)

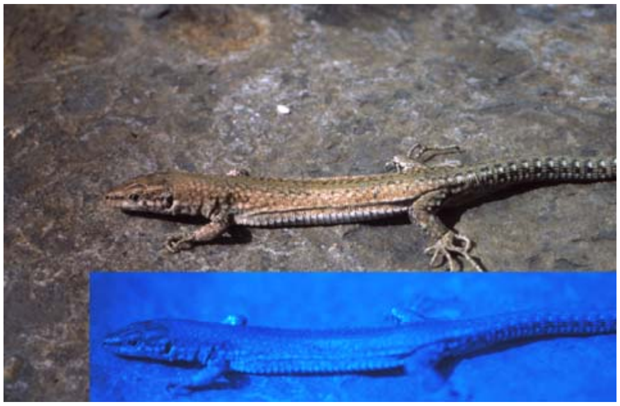

Photo 39 (*Podarcis* gr. *hispanica* 1A)

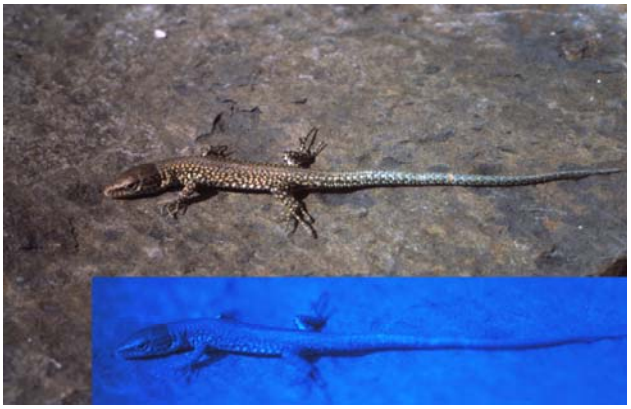

Photo 40 (*Podarcis* gr. *hispanica* 1A)

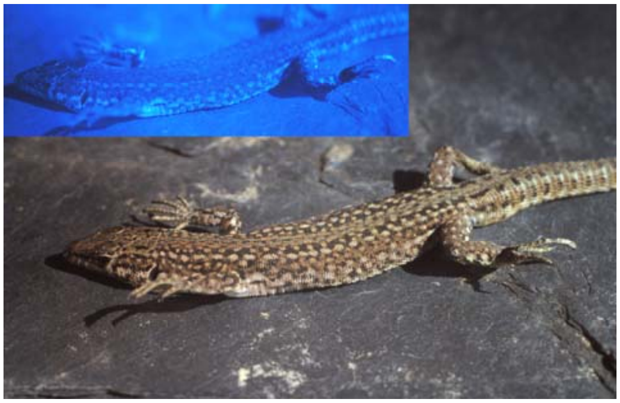

Photo 41 (*Podarcis* gr. *hispanica* 1B)

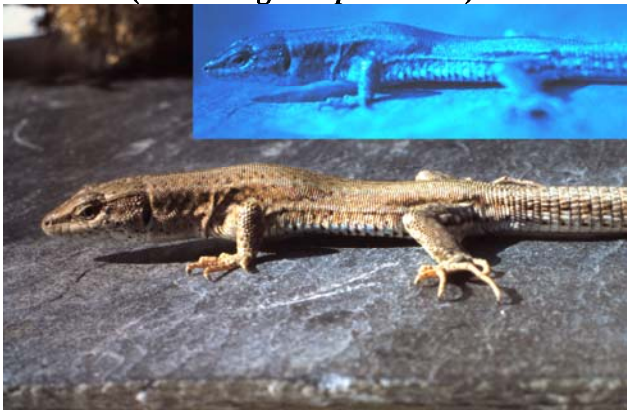

Photo 42 (*Podarcis liolepis*)

Photo 43 (*Podarcis liolepis*)

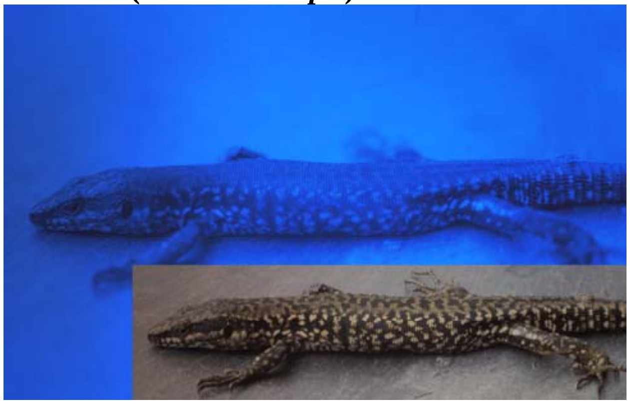

Photo 44 (*Podarcis muralis*)

Photo 45 (*Podarcis muralis*)

Photo 46 (*Podarcis muralis*)

Photo 47 (*Podarcis muralis*)

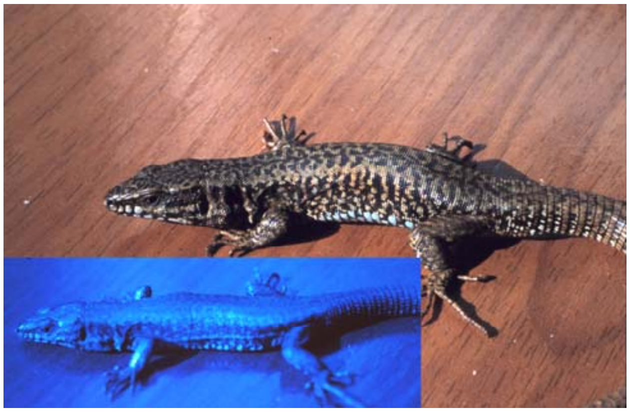

Photo 48 (*Podarcis muralis*)

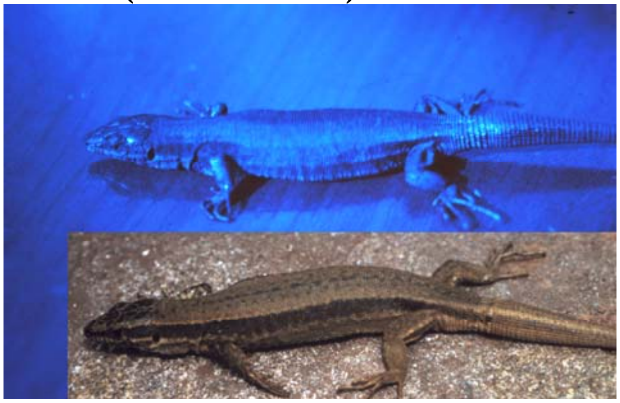

Photo 49 (*Podarcis muralis*)

Photo 50 (*Psammodromus algirus*)

Photo 51 (*Timon lepidus*)

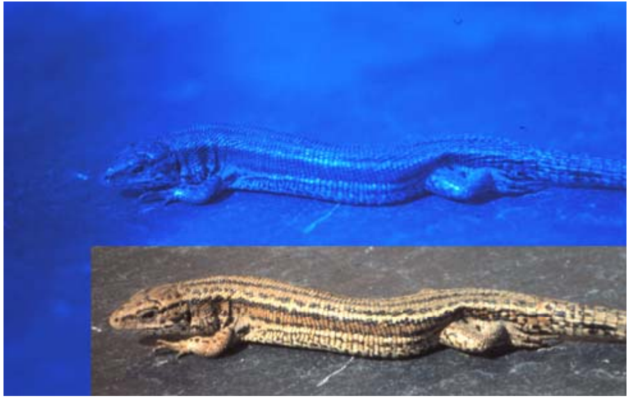

Photo 52 (*Zootoca vivipara*)

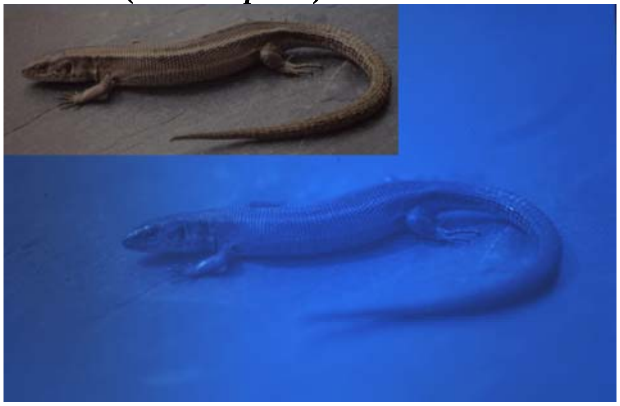

Photo 53 (*Zootoca vivipara*)

Photo 54 (*Bufo bufo*)

Photo 55 (*Calotriton arnoldi*)

Photo 56 (*Hyla (arborea) molleri*)

Photo 57 (*Rana pyrenaica*)

Photo 58 (*Salamandra salamandra almanzoris*)

Photo 1: Basic equipment for the photographs included in this study. A mechanic "chemical-process" camera Olympus OM-3, with a Zuiko 50mm f3.5 Macro mounted. The camera is charged with slide-film Fuji RTP 64 and all mounted in a tripod with a distance shutter. In the front of objective is a 85B orange filter for color correction of "normal photos" when using Tungsten (artificial light film) and in the table lies the B+W 403 UV-band pass filter.

Photo 2: Filters tested by the author during the study. Rigth-top: The small Schüler filter. Probably the best for use with digital cameras. Right-bottom: Hoya U360, an old classic. Very similar to B+W and Tiffen, but fairly denser. Middle (top and bottom): B+W403 (Schott UG1 glass), the easiest to obtain today, perhaps the best for chemical process photography, and the used by the author almost universally in these years. Left-top: Baader U-Filter. Probably also fairly suitable (near as good as Schüler) for digital photography. Left-bottom: The Tiffen 18A, very similar to B+W and Hoya, and only suitable for "chemical photography" of digital if accompanied with a "hot mirror" (reflecting IR radiation). Also UG11 glass (not represented) was tested, but is unsuitable as leaves visible radiation to pass (see text for a comparative of all these filters).

Photo 3: UV patterns in insects. *Parnassius apollo* is a overall white colored butterfly, with black and red white-centered ocelli. The white center of the red ocelli is very UV reflective and very different from the white background color of the animal. These patterns participate in the species and mate recognition and are very widespread in butterflies.

Photo 4: UV in other vertebrates. A DOR Bee-eater (*Merops apiaster*). Note that parts of the plumage are very shiny in UV. Apart of the throat, forehead, the breast, primay feathers and rump appear fair more striking in UV than in visible light.

Photo 5: *Helianthemum* sp. Another common and striking flower with a very different pattern in UV. The dark area in the center (called "bulls eye") is a signal for the insects and absorbs the UV instead of reflecting it. The function of this behavior is to preserve the pollen from the mutagenous effect of the UV radiation.

Photo 6: *Ranunculus ficaria*. One of the earliest flowers in spring. The inner parts of the flower are not UV-reflective, but have a reddish tinge in photos. This is in fact a luminic contamination in the "deep-red" region, just before the invisible Infra-Red.

Photo 7: *Caltha palustris*. A total different pattern, with great part of the petal not reflective, and only the distal parts reflective.

Photo 8: A Dandelion (cf. *Taraxacum*). Dandelions are favorite subjects for UV experimentation and testing of material and filters. They are very common even in urban parks, and are very different in UV and visible.

Photo 9: Bull's-eyes are a common pattern with striking differences between UV and visible light. Here a group of *Silene* and *Helianthemum*.

Photo 10: *Chalcides bedriagai*. Salamanca (Spain). Uniform, without UV patterns. Probably this is part of its camouflage among the ground elements, usually also not reflective.

Photo 11: *Iberolacerta aranica*. Val d'Aran (Spain). Male. Note the bright reflective belly in the body sides, and the lack of bright UV-axillar ocelli.

Photo 12: *Iberolacerta aranica*. Val d'Aran (Spain). Juvenile. Note the lack of UV reflecting structures in the upperparts of body and tail.

Photo 13: *Iberolacerta aurelioi*. Andorra. Two anesthetized specimens (for a photo of long exposition). Note the reflectance of the pure-white areas, whereas the yellow pigment masks the UV in the other areas.

Photo 14: *Iberolacerta aurelioi*. Pallars Sobirà, Lleida (Spain). Gravid female. Note the UV-reflecting white under body and probably also bit in the lower temporal stripe.

Photo 15: *Iberolacerta aurelioi*. Andorra. Juvenile. No reflectance in the upper parts of the body. Also the tail is inconspicuous.

Photo 16: *Iberolacerta bonnali*. Bigorre, Hautes Pyrenees (France). Male. No reflectance in the upperparts, but perhaps a bit in the underside. This specimen has no blue OVS. When present, are UV-reflective.

Photo 17: *Iberolacerta bonnali*. Bigorre, Hautes Pyrenees (France). Juvenile. No reflectance, also in tail.

Photo 18: *Iberolacerta cyreni*. Guadarrama, Madrid (Spain). Male. Note that despite the lack of axillar blue ocelli (BO), the blue points in the outer ventral scales (OVS) are very reflective.

Photo 19: *Iberolacerta cyreni*. Bejar, Salamanca (Spain). Fairly less reflective than males. A bit in the underside parts and if present, in OVS (not in this specimen).

Photo 20: *Iberolacerta monticola*. Montes de Leon, Leon (Spain). Male. A rare few patterned morph. White and blue (BO) ocelli in the sides appear as UV-reflective.

Photo 21: *Iberolacerta monticola*. Picos de Europa, Cantabria (Spain). Male. Note the very UV-brigth BO and OVS.

Photo 22: *Iberolacerta monticola*. Picos de Europa, Cantabria (Spain). Male. Note that despite to have few conspicuous BO in visible, these are very bright in UV.

Photo 23: *Iberolacerta monticola*. Somiedo, Asturias (Spain). Male. Typical pattern, with very bright BO and OVS in UV.

Photo 24: *Iberolacerta monticola*. Somiedo, Oviedo (Spain). Female. No striking patterns in UV. The poor developed BO and OVS in visible are also very poor in UV.

Photo 25: *Iberolacerta galani*. Teleno, Leon (Spain). Female (melanistic). No UV patterns in BO nor in OVS. A melanistic male also lacked UV patterns.

Photo 26: *Iberolacerta galani*. Teleno, Leon (Spain). A typical male with numerous BO and OVS. All they are reflective in UV.

Photo 27: *Iberolacerta galani*. Teleno, Leon (Spain). Another specimen with very bright and contrasting BO and OVS compared to the background color in UV.

Photo 28: *Iberolacerta galani*. Trevinca, Ourense (Spain). Female. Few developed BO and OVS in visible correspond also with poor UV patterns.

Photo 29: *Iberolacerta galani*. Trevinca, Ourense (Spain). Female. As Photo 28, but the more developed BO correspond also with well developed UV-reflective spots

Photo 30: *Iberolacerta martinezricai*. Batuecas, Salamanca (Spain). Male. Very brigth UV axillar BO and OVS.

Photo 31: *Iberolacerta martinezricai*. Batuecas, Salamanca (Spain). A very dark (but not melanistic) Female. Poor BO and OVS, poor UV reflectance in these areas. Again, this is a proof that striking ocelli and points in visible are very frequently also reflective in UV.

Photo 32: *Iberolacerta martinezricai*. Batuecas, Salamanca (Spain). Subadult female. Contrary to the specimen of photo 31, females of this species have usually blue or yellowish axilar ocelli. In this subadult female are yet visible (in yellow) and, as together with OVS, begin to be reflective.

Photo 33: *Lacerta schreiberi*. Bejar, Salamanca (Spain). The blue throat (whitish outside the breeding period) is UV-reflective, whereas the yellow pigmented parts is not. A case very similar to *I. aurelioi* (photo 13).

Photo 34: *Podarcis bocagei*. Trevinca, Ourense (Spain). Male. Despite to lack BO and in general of OVS (although some southern populations have it), this species has UV-reflectance in the yellow (in visible) areas that in other species are blue: the outer ventral areas and the axilar area. The subocular plate of this male seems also particularly brigth in UV.

Photo 35: *Podarcis bocagei*. Trevinca, Ourense (Spain). Female. As in other species, the females are very few reflective, if any.

Photo 36: *Podarcis carbonelli*. Peña de Francia, Salamanca (Spain). Male. The OVS appear very reflective in the animal sides.

Photo 37: *Podarcis carbonelli*. Peña de Francia, Salamanca (Spain). Female. As the male (photo 36) but without the striking OVS.

Photo 38: *Podarcis* gr. *hispanica* 1A. La Liébana, Cantabria (Spain). Male. Only OVS (not visible in the photo) is UV-reflective.

Photo 39: *Podarcis* gr. *hispanica* 1A. La Liébana, Cantabria (Spain). Female. As the male but OVS are scarce or absent.

Photo 40: *Podarcis* gr. *hispanica* 1A. La Liébana, Cantabria (Spain). A juvenile, probably male. The yellow ocelli (axillar) and OVS begin to be clearly reflective.

Photo 41: *Podarcis* gr. *hispanica* 1B. Peña de Francia, Salamanca (Spain). Male. As other *Podarcis* without blue axillar ocelli, only the OVS are reflective.

Photo 42: *Podarcis liolepis*. Soria (Spain). Male. As stated in Arribas (2012) there are males with BO, but, as can be seen, also some whitish axillar ocelli are reflective in UV, unlike other former *P.* gr. *hispanica*. Apart of axillar ocelli, OVS are well reflecting.

Photo 43: *Podarcis liolepis*. Soria (Spain). Female. As in other *Podarcis*, fairly less reflective than males. Only a few OVS, at most, are UV.

Photo 44: *Podarcis muralis*. Val d'Aràn, Lleida (Spain). Male. No BO. Only OVS are very reflecting (not seen in photo). White ocelli can be weakly reflective.

Photo 45: *Podarcis muralis*. Babia, León (Spain). Typical patterned male. The BO are reflective (but never so striking as in *Iberolacerta*), as are the OVS. The BO are not very much contrasted in respect to other white dots or stripes.

Photo 46: *Podarcis muralis*. Guadarrama, Segovia (Spain). Female. The yellow ocelli (YO) and OVS are reflective but not very striking.

Photo 47: *Podarcis muralis*. Puerto de Peña Negra, Avila (Spain). Young female. The yellow ocelli (YO) are not reflective and the OVS very few.

Photo 48: *Podarcis muralis*. Gudar, Teruel (Spain). Male. Almost no BO, but OVS very reflective.

Photo 49: *Podarcis muralis*. Gudar, Teruel (Spain). Female. As the male (Photo 48) but without UV reflectance (at most, some OVS).

Photo 50: *Psammodromus algirus*. Soria (Spain). The tiny blue dots in the sides are very reflective in UV.

Photo 51: *Timon lepidus*. Gudar, Teruel (Spain). Juvenile specimen. Note that the white ocelli of the dorsum are near invisible in UV, but the blue ones in the sides are reflective

Photo 52: *Zootoca vivipara*. Bigorre, Hautes Pyrenees (France). Male. The white throat seems to be a bit reflective in UV, whereas yellow belly is not (a case similar to *I. aurelioi* and *L. schreiberi*).

Photo 53: *Zootoca vivipara*. Val d'Aran, Lleida (Spain). Female. Apparently not reflective.

Photo 54: *Bufo bufo*. Soria (Spain). No reflectance.

Photo 55: *Calotriton arnoldi*. Montseny, Barcelona (Spain). No reflective (perhaps any of the yellow-greenish dots seen in visible can be faintly reflective).

Photo 56: *Hyla (arborea) molleri*. Soria (Spain). No reflectance, as the sorrounding vegetation that constitutes its habitat.

Photo 57: *Rana pyrenaica*. Roncal, Navarra (Spain). No reflectance.

Photo 58: *Salamandra salamandra almanzoris*. Guadarrama, Segovia (Spain). No reflectance. At most, the yellow (clear) dots could be very weakly reflective. Although not well appreciated in the photo, in some specimens (as in this Guadarrama specimen but not in Gredos ones) there is "deep-red" contamination (invisible to us) of the yellow dots. We have observed also this "hidden" deep-red coloration in the face of citril finches (*Serinus citrinella*) that have no visible red, but other related fringillid species have it in visible red.