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UNDERWATER 3D FILMING

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Abstract

After an experimental phase of many years, 3D filming is now effective and successful. Improvements are still possible, but the film industry achieved memorable success on 3D movie's box offices due to the overall quality of its products. Special environments such as space ("Gravity") and the underwater realm look perfect to be reproduced in 3D. "Filming in space" was possible in "Gravity" using special effects and computer graphic. The underwater realm is still difficult to be handled. Underwater filming in 3D was not that easy and effective as filming in 2D, since not long ago. After almost 3 years of research, a French, Austrian and Italian team realized a perfect tool to film underwater, in 3D, without any constrains. This allows filmmakers to bring the audience deep inside an environment where they most probably will never have the chance to be.

Keywords

Underwater 3D filming, 3D movies, underwater realm, underwater photography

1. *Introduction*

It is at least since the '50s that the film industry invests and promotes 3D movies. The results were not homogenous but, in the long run, all efforts were unsuccessful. Since a few years, however, this trend is going to be reversed. Hollywood has made huge investments in 3D movies, and their value has been recognized at the box offices all over the world. Movies as "Avatar" – one of the most profitable investment in the whole cinema history – and "Gravity" are worth being mentioned: only in China Avatar earned 250 Ml Euros. Beside cinema, home televisions and different circuits (IMAX, for instance; or museums and aquariums), are now using 3D contents. Even in a moment when 3d broadcasts are going down, Blue Rays with 3d contents represent a consistent busyness for 3d big screen movie producers. Home video represents today a significant income, aside the "box office" revenues.

The successful development of 3D filming is due to the availability of new technologies. The poor technique that was used so far is the most important reason for the lack of success of 3D film for such a long time. The statement that must be sculpted in marble when filming in 3D is and must be: "*a bad image in 2D will be disliked by the audience; a bad 3D image will hurt the audience's eyes and brains*". Many people complain for headache or sore eyes after a 3D projection. This is simply not acceptable. Many producers wanted to put more emphasis in 3D allowing the stereographer to abuse of "negative parallax" (objects coming out from the screen) or anyway very emphatic 3D effects. The result is a totally unnatural image that eyes can read but that brains cannot work on. 3D must only be a tool to make images much close to reality. And – together with a 3D sound – create an "immersive" experience. Producing fake effects or a funny and unreal world is not the target of a 3D movie.

Lately, digital technology allows a strict control of the stereography, and this calls for the increasing success of 3D. In modern 3D movies, creativity necessarily goes together with mathematical controls and geometrical rules. The artist is free to create, but the basic rules must be obeyed to. The audience will be offered an experience that is invariably perceived as lovely, new, appealing and – most important – relaxing and easy to be enjoyed.

It is in this context that our research took place: the underwater realm is surely one of the most emphatic environments to be reproduced in 3D . When underwater, we naturally live and move in three dimensions.

A diver, just like a fish, is not obliged to move on a surface, as we do on land; this world is almost not submitted to gravity. More, all the space is filled with significant, interesting and appealing elements we can fill up the screen with. Such as fish, plankton, jellyfish, sea mammals. No better challenge for a 3D filmmaker than the underwater realm! On top of all that, the filmmaker will bring most of the audience in a world where they have never been, and where most of them will never be.

Filming underwater, however, means to face several problems. First of all, moving, surviving and acting in a realm that is unsuitable for human survival. Then, the filmmaker has to adapt cameras, lamps, and lenses to the use in such a difficult environment. He needs to protect all equipment inside waterproof and pressure proof housings. Hence, hands cannot directly touch camera commands. Many of these problems have nowadays been solved, yet. Highly sophisticated equipment can be brought underwater; we know how to optimize the use of our lenses for underwater use; we know how to use the unique light of this environment, which is so different from the sunlight we are used to.

The new challenge is now to introduce 3D technology in underwater filming. The target was to have a tool with better chances to involve the audience without suffering from any limitation. We wanted to create a tool making us able to film as we always did during traditional productions, with the benefit of the third dimension.

When we faced the worldwide panorama, some equipment already existed. Some successful 3D movies have already been turned underwater. But, on the over all panorama, there was not a single equipment able to fill up our need without bringing important constrains. Mostly, people have created monster-sized units (Fig. 1).

Fig. 1: Some of these housings have been used for successful movies. But almost all in a controlled environment and with a lot of constrains. The large size and the very wide flat port are evident. Furthermore, the reflection of the camera on the flat port may be also very important: imposing the use of very big shader that hinders underwater movement.

These cameras may be good for controlled conditions in Hollywood stages, but they are too bulky and big to be used under natural conditions. So far, the main unsolved problem was related to optical quality: all existing tools are equipped with flat ports, with very bad impacts on the quality of the final image.

The underwater system we aim to illustrate in this paper is the result of an Italian and Austrian cooperation and fills up all required targets. The well-known French Stereographer Cyril Barbaçon followed the entire project .

Today we can shoot with a relatively small and extremely handy camera, able to be used well below 100 m depth by a single operator. A special monitor allows the cameraman/stereographer to build his own stereography on a mathematical base, so as to avoid mistakes that might cause pain or discomfort to the audience.

Thanks to the innovative use of a special dome port, the quality of the lens is preserved, together with all its optical characteristics, including the angle of view. And this is the true revolution.

2. Basic principles to get 3D images

In the human being the "feeling" of 3D comes from a simple feature. Our two eyes see and capture at the same time two slightly different images from each other. The brain is able to synthetize the two images into one. The difference between the two gives the possibility to see the "dimension" of the object, or the depth of the scene. All this allows human view to estimate distance between objects, size and so on. The brain will integrate all this, using several other perceptions, such as the geometry, perspective, and size of well-known objects. The more the objects are close to the eyes, the more the "dimension" is evident. We can test this concept through simple experiences. Let's observe several objects in front of our eyes, considering a limited space with the first object at one meter, and last at ten or so. We will notice that the effect of seeing the scene in 3D is very strong. Now, let's alternatively open and close one eye. We'll experience the effect of the scene moving from left to right. Let's try now to

UNDEWATER 3D FILMING FOCUS TARGETS

Camera must be cinema standard: able to record in 2K and 4K

The entire system must be light, small, easy to be carried and handled underwater: size must not compromise movements: 3D must be a plus, not a limit

The system must be based on beam splitter technique

All camera functions and commands must be reached underwater

Stereography is a must: the need was to be able to adjust the "IO" at every take. No interest to have a pre set system

The revolution: I did not want to lose the chance to use a wide angle

Fig. 2: The list of underwater 3D filming targets

concentrate more on the nearest object than on the far away one. We'll notice that the nearest object gives the impression of moving more from left to right in comparison with the far away one. If we repeat the experience with very far away subjects (i.e. some mountains), the apparent left-right movement will be even less pronounced. Hence, the human view can deliver images in 3D up to a certain distance: we can see in 3D within a distance of 150 meters. Then, everything we see turns into 2D. If we push this concept to the limit, we can put an object – a finger, for instance – very close in front of our eye. Opening and closing the eyes, we'll have two very different images for each eye: we are in this case not able to see in 3D. If we want to realize a movie in 3D, basically we just have to reproduce this condition. To do that, we use two cameras. Of course the two cameras must be absolutely the same and equipped with paired lenses. We shoot two "slightly different" images from each other, and we project them in a way that the left eye is fed only with the image captured with the left camera, and the right eye with the image of the right camera. All problems start at this point: to produce good 3D images, a series of technical issues have still to be solved. First of all, during a motion capture cameras must be perfectly synchronised: the start of the two cameras must be on the very same moment. Only under this circumstance the paired frames will capture the same image. This is especially true when either cameras are moving, or when subjects framed are moving. Then, the two cameras must be perfectly aligned. We stated in fact that we need "slightly different" images. But this difference concerns only the horizontal difference: not a vertical misalignment or a rotation between the two frames or other misalignments of this kind is allowed: misalignments of very few pixels of difference between the two cameras are simply not acceptable in a good stereography. When watching a wrong or a just not perfect 3d image, the brain is able to reconstruct a 3D view. But the

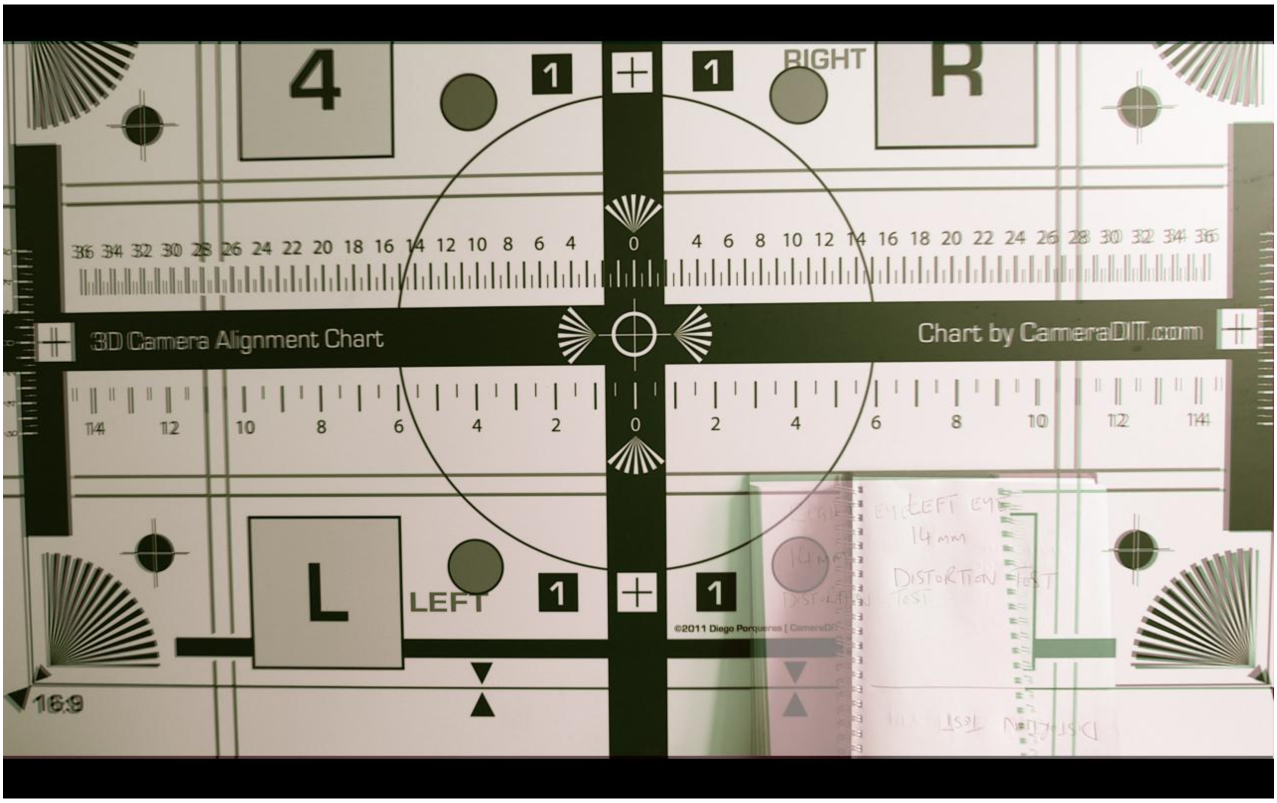

Fig. 3: The image the stereographer sees in the 3d assist monitor: two overlapped frames, taken by the left and the right cameras using a 14mm lens. Geometry is almost perfect and the two pictures overlap almost perfectly. Some issues are evident in both sides of the frame: this depends on the lenses. The two are not exactly paired. And this is more evident when a wide angle is used, since side deformations and distortions can be more evident. Some of this can be fixed in postproduction. The final result must be perfect, not to cause discomfort to audience.

effort may cause discomfort at different levels. Therefore, to build a rig where to set two cameras for a stereographic view means to make sure to produce a perfect mechanical work and provide the camera plates of system able to correct misalignments due to the sensor position in the camera, or differences between two lenses. Before shooting, a good stereographer must make sure that the two views are perfectly overlapped. Some misalignments can be fixed in postproduction, but it is extremely important to capture a perfect image. Special 3D assist screens allow the stereographer to overlap the images coming from the two cameras and fix the mistakes (Fig. 3).

When all is properly set on the rig, the problem of reproducing the eye view using two cameras comes. The most obvious way to cope with this should be to set the two lenses at the same distance existing between the two eyes. But the eyes can converge on the subject and focus on that point, ignoring all other objects around. When the interest shifts to somewhere else, the adjustment will be redone on the new subject. All this comes "natural". When a stereographer is building an image together with a camera operator, he does have to find the way to fill up he whole screen with a "readable" image. Some on the audience, in fact, may focus on the face of the main character; but the mountain in the background may attract someone else. The stereography must be perfect for both levels! More: everything must be perfect from the very first fore ground, to the far background. The stereographer can achieve this result moving the two cameras closer or apart from each other and playing with the convergence. Here we have the two parameters needed to build a correct stereo image. Since now on the inter-axial distance will be called "IO", whereas the angle between the two main camera axes will be called "convergence". IO and convergence must be adjusted for every single scene. This setting is influenced by the position of the objects in the frame. Not only by the distance of the closer object (we said before that the closer we are, the more critical is the

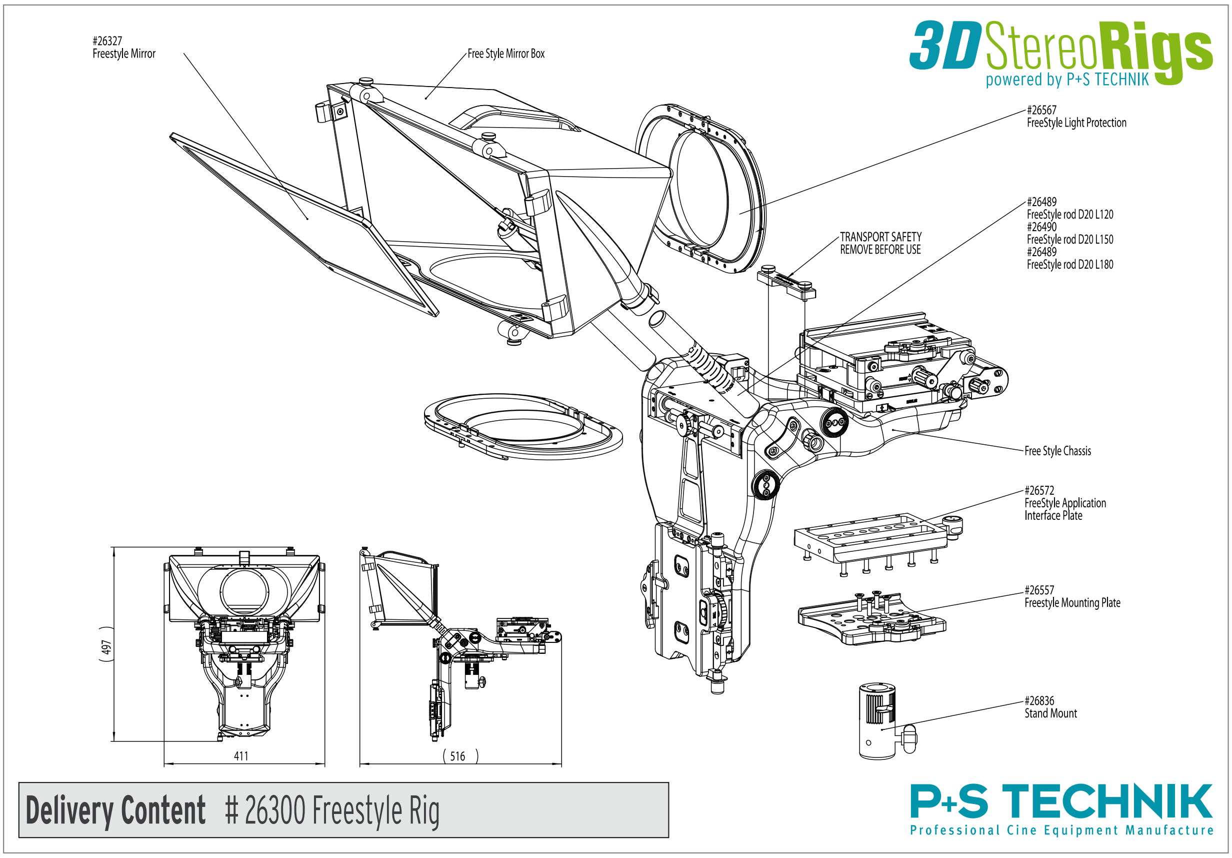

Fig. 4: Scheme of one of the most successful beam splitter rig. Cameras find place in the two plates (lower one vertical, upper one horizontal). On the two mountings plates, the tools to adjust the geometry are evident.

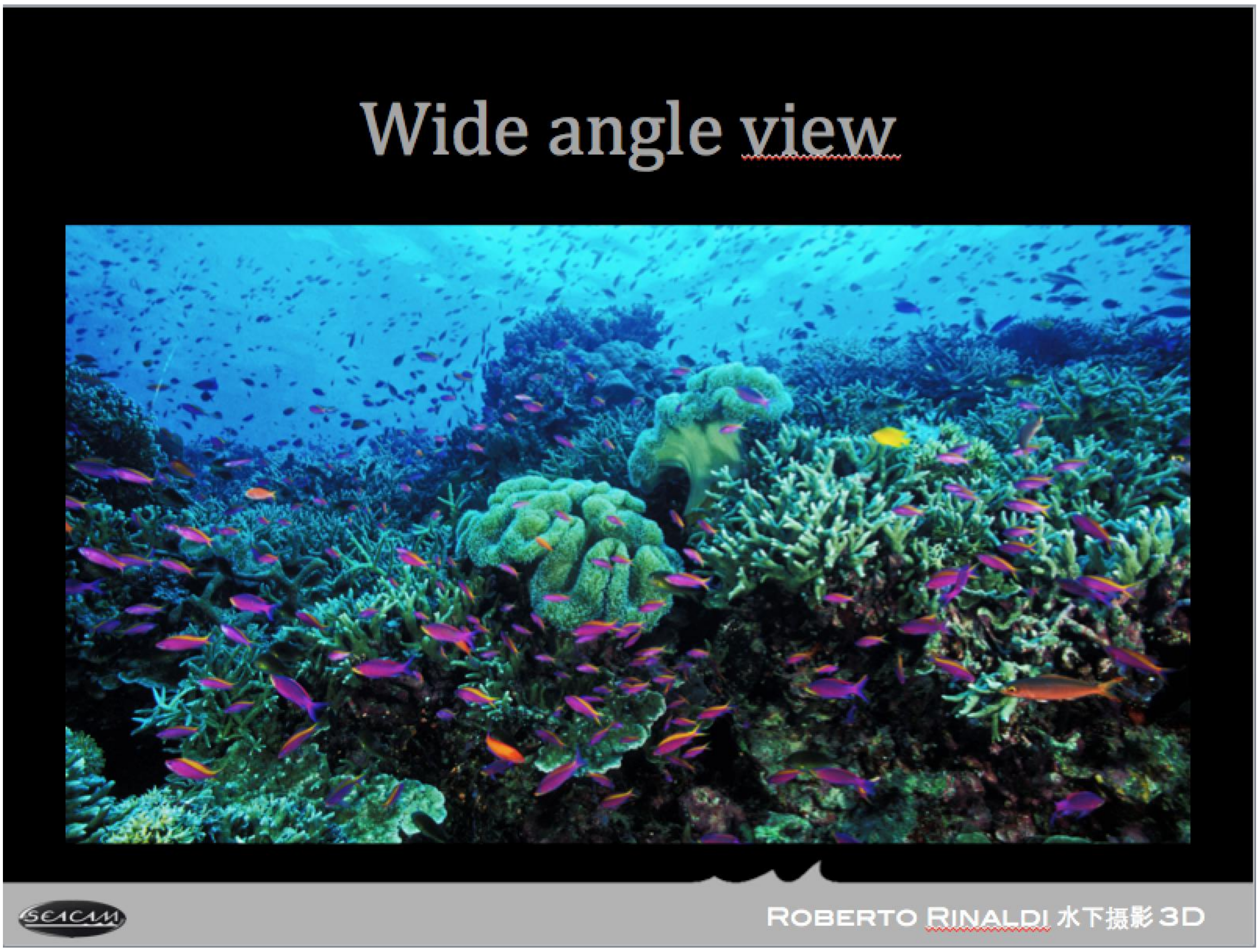

Fig. 5: A picture taken at about 20 m depth: all red fish in the fore ground have been lighted up with two strobes. Otherwise, they would have looked greenish. The wide angle allowed to shoot very close to the subject, still having a wide view of the coral reef.

stereography), but also by the position of all objects in the framed space. This means that the parameters used with the closest object at 50 cm from the lens and the farthest one to the infinite, will be different from the correct ones when the closest object is at 50 cm, but the farthest one is at one meter. A good stereographer must use a "depth budget" to give a 3D dimension to the entire space existing in his frame. The resulting image must be natural and relaxing. Objects must not look as cut off the scene and glued back. Effects like "miniaturizing" must be avoided, but it is also important not to produce a flat image. Besides caring about geometry, IO and convergence parameters, also several rules must be used while framing, compared with a regular 2D framing, even though this involves the camera operator artistic skills, rather than a technical discussion.

Bad 3D images pushed many people away from this experience. Recording a 3D movie must be based on a careful preparation, based on extremely meticulous pre settings: different lenses, misalignments, different chromes between the two cameras, different focus are all elements which will be difficult and expensive to correct in post production. If not properly corrected, these shortcomings will cause discomfort in the audience.

3. *Beam splitter VS side by side*

Both IO and convergence must be adjusted at every take. It rests with the stereographer – together with the camera operator and the director of photography – to decide the amount of 3D needed for any take. It would be a mistake to evaluate the amount of stereography for the scene just on a mathematic basis. This element, in

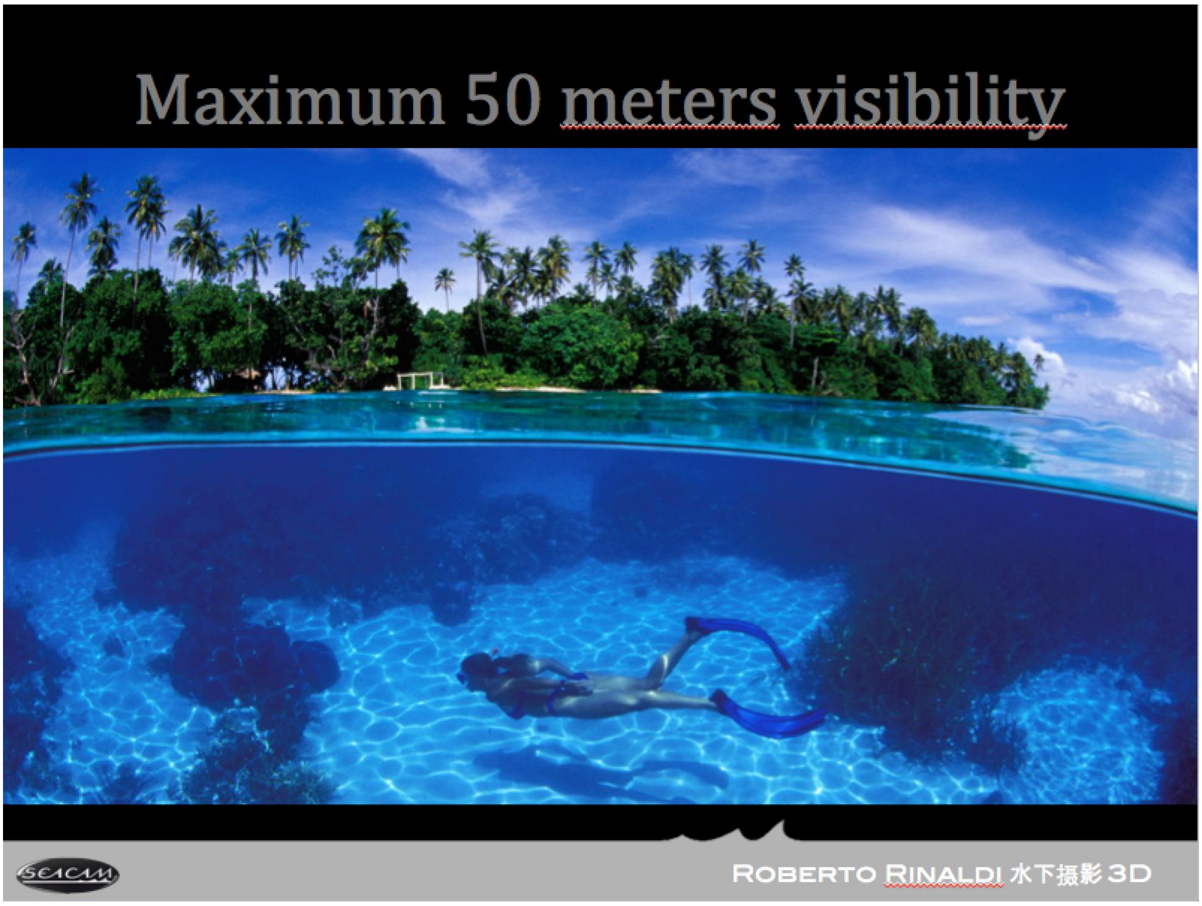

Fig. 6: A picture taken in a wonderful day with crystal clear water: it is evident that corals in the far are not detailed anymore, while palm trees and clouds are perfectly sharp despite to the great distance from the lens.

fact, must fit with the photography (a general view of mountains or any landscape cannot be handled like a portrait...), and must fit in the general project and with the images that, when the movie will be cut, will come before and after. Once again, stereography must be a tool to enhance the dramaturgy, to make the audience feel more immersed in the scene and in the movie in general, and not a tool to simply generate special effects. While shooting an entire movie, the stereographer will use several inter axes ranging from few millimetres to several dozens of centimetres. If a subject is extremely close to the lenses, the inter axe must be drastically reduced. But if we shoot a subject very far (clouds in the sky, a mountain ridge far away, a general view...), we need to increase cameras separation, so as to make the audience feel the dimension. To achieve these goals, we can use several systems. The easiest one is to set the cameras on a base and move them apart, or closer. This system is called side by side. The limit of this system is evident: there is a point where the cameras are touching each other and the inter axe cannot be further reduced. And normally, using professional cameras, sizes and lenses diameter are pretty big. And this does not allow smaller inter axe. If, for instance, a lens of 80 mm diameter is used, it will be impossible to have an inter axe smaller than 8 cm. Which is not enough in many cases. This problem can be coped with by using a rig where the cameras are fixed perpendicular one to the other, with a special glass set at 45° in between. This glass is transparent on one side, and is a mirror on the other side. So, one camera will capture one image going trough the glass, the other one will capture the image reflected on the mirror. With this system the inter axe can be reduced to zero. This is the most common tool used on a cinematographic set, allowing the stereographer to use inter axial values from a few mm to 10 or more cm. Shooting either in one or the other system, the use of a 3D assist monitor is needed: after having set the cameras on the rig, all geometrical issues have to be corrected (vertical, pitch, rotation misalignments), cameras must be perfectly aligned and zoom lenses paired, exposure and white balance must be carefully matched. Then, trough the monitor, the stereographer will be able to give the right dimension to the scene, evaluating all objects in the frame and their position in space. Without a careful use of a 3D assist monitor, good stereography is impossible (Fig. 4).

4. Underwater photography

Filming in 3D underwater requires awareness on some issues regarding underwater photography. Water is much denser than air, this means that water is less transparent than air, but also that – due to the density – water is able to keep suspended particles that will lower transparency further. All problems in photographing underwater are related to this difference of density. Besides visibility, this affects also light penetration. Sunlight, in fact, cannot reach deep water: the depth light can reach depends obviously on the intensity of the light itself, and by the angle of the sun on water surface: at midday sunlight will arrive deeper than at sunset in the same place with the same water quality. Water transparency, due to the presence of suspended matter, also affects light penetration. Lack of light is another problem that every underwater photographer has to face. The difference in density brings another issue: the water absorbs warm colours. This means that between five and ten meters red is missing. Descending further down, we enter in a world characterized by a green and bluish dominant. This is a bigger problem for the photographer than the lack of light: this, in fact, makes all pictures flat and without details. The use of artificial light becomes a must to achieve nice and coloured images below a certain depth (Fig. 5).

5. Wide angle underwater

To achieve brilliant, sharp and enjoyable underwater scenes, the quantity of water between his lens and the subject must be reduced as much as possible, since water is denser than air and visibility is lower. The more water stays in between lens and subject, the less sharp and detailed the picture will be: a foggy day with 50 meters of visibility is a nightmare for everyone; but the dream for every underwater photographer is a day at sea when visibility underwater is 50 meters (Fig. 6).

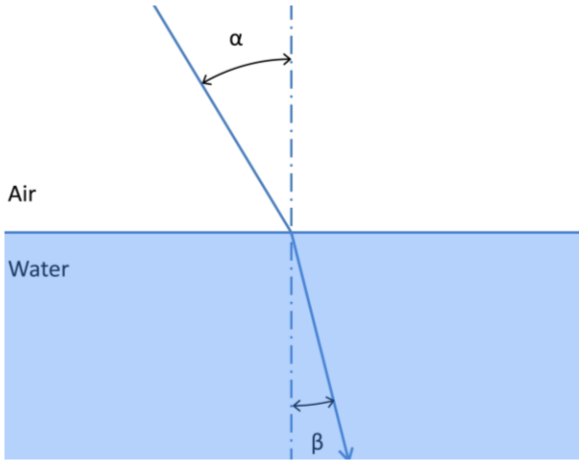

Fig. 7: Refraction bents the light passing from air to water. Lights ray is bent toward the perpendicular to water surface. Wearing a mask, underwater objects will look closer and bigger.

It is for this reason that underwater wide-angle lenses are the most useful lenses: by using a wide angle it is possible to frame a large portion of the underwater realm while being very close to the subject, with the exception of close up pictures: in this case macro lenses are used to capture small details of the reef or of small organisms. To realize this kind of images, the distance from the subject is just few centimetres.

6. Light from air to water

Refraction occurs when light goes trough two elements with different density, such as water and air. The most typical and simple example of that is the spoon in a glass of water: the spoon after the water surface looks bent and bigger, due to refraction. This phenomenon highly affects underwater photography. The system to capture images underwater is basically made of a camera housed inside a waterproof container; a glass is set in front of the lens. If this is a flat glass (so called “flat port” in underwater photography), we experience the same phenomenon mentioned before: images look bigger and deformed. Since passing from one element to another with a bigger “index of refraction”, the light beam is bent, and its direction goes closer to the

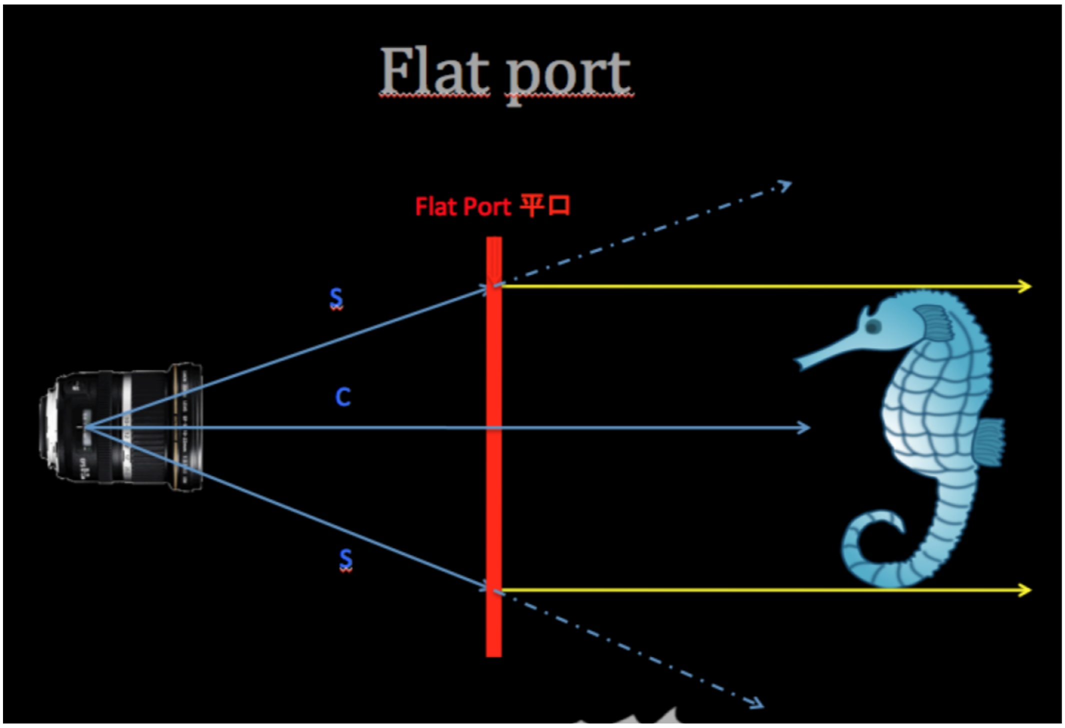

Fig. 8: In this pictures the light getting perpendicularly across the glass is not bent, while the light far away from the centre of the lens is bent after crossing from air to water. The angle of view is reduced, and the object looks bigger and closer.

perpendicular to the glass. A scheme will help to describe this in an easier and faster way.

To experience this more directly, it is easy to wear a mask and to have a look underwater: objects will look closer and bigger. This happens also to the lens. For this reason we can say that the angle of view of our lens will not be the same underwater: it will be smaller. On land, for example, a 20 mm lens has an angle of more or less 90°. Underwater, the same lens will cover an angle of 65°. The same angle of a 35° lens on land, clearly an undesired effect.

The figure shows that the light on the main axe of the lens is not bent while going trough the glass. It goes straight, as it is perpendicular to the glass. This is not true for all the other rays, which will be increasingly bent as their distance from the centre increases. This will affect the quality of the final image: the focus will not be the same on all the frame, the image will be deformed and colours will be damaged (Fig. 8).

For these reasons, since over 30 years housings equipped with a flat port are not produced anymore. To avoid all these problems it is enough to use a glass commonly called "dome port": a dome made of optical crystal or acrylic.

Figure 9 will help to understand how the system works: the dome is actually a section of a perfect sphere. Building the house, the engineer must take care that the centre of the sphere will coincide with the centre of the lens. In this case, all rays will have the same length. They will coincide with the radius of the sphere, which is the same everywhere. All radiuses hit the surface of the sphere perpendicularly to the tangent. It is for this reason that they all go straight and are not bent. Thanks to that, the lens's properties are not changed: the image is not deformed, the lens's angle is the same as it would be on air, and focus is the same all around the frame.

7. *Dome port on 3D housing*

Hence, using the flat port will cause several problems: loss of image quality, and the objective will not be a wide angle any more. Working with a wide angle, on the contrary, is extremely important. And the importance of this feature increases when producing a 3D movie, when we want to give the audience the feeling and the emotion to be in the underwater world: to achieve this, it is important to feed the audience eyes with panoramic images that will make them

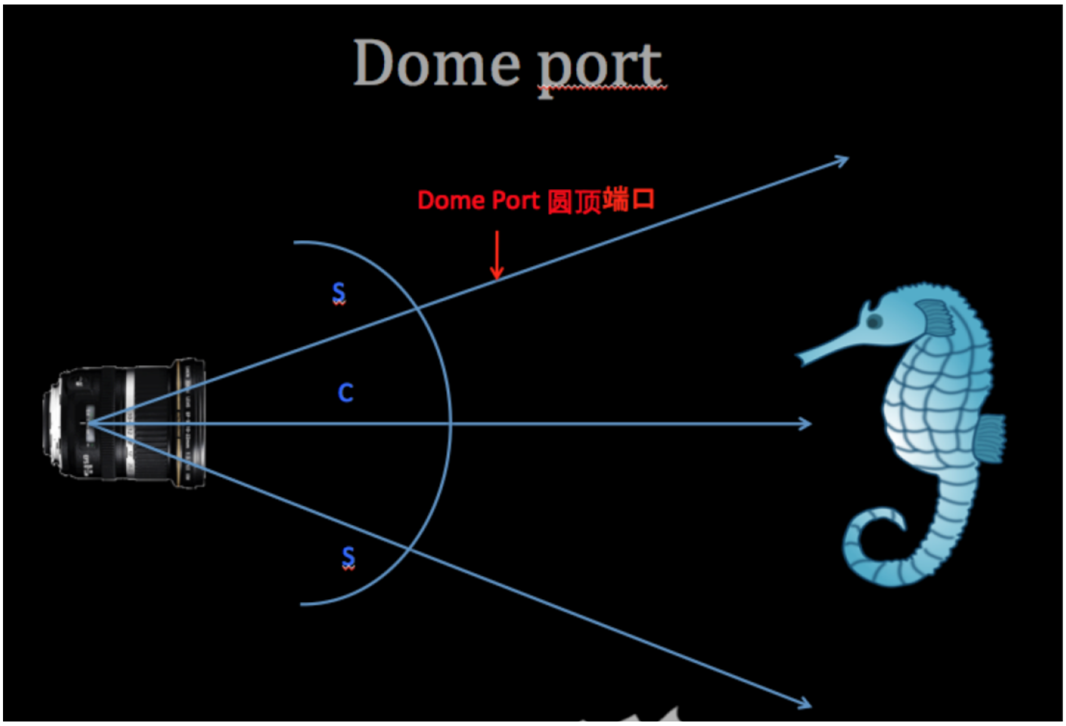

Fig. 9: All rays are perpendicular to the tangent of the sphere. For this reason they are not bent and the lens keeps all its peculiarities.

feel inside the action. Several underwater 3D prototypes adopted the beam splitter system. The

flat port, due to the dimension of the mirror box, is rather far from the two lenses. It happens for this reason that in many cases, the lenses are reflected in the flat port itself and appear in the images. It is exactly what happens when we look at a shop window: if we are far away, we see our image and the outside reflected on the glass, and not the environment inside. To see inside, we are obliged to go closer and closer and – if getting closer in not enough – to shade with our hands around the eyes. This problem affected many productions. Many tried to cover the inside of the port with anti reflex coating, all set a big shader on top of the housing, but the problem was never totally solved. And the big shader is a problem when swimming. On the other hand, we learnt from the theory of the dome port that to have a perfect system the centre of the sphere must coincide with the optical centre of the lens. This was discouraging in the beginning, as it is not possible to set two lenses in the centre of the sphere. We solved the problem by working on the curve, radius and distances. Mr Immanuel Hordosh, an 80-year-old Austrian engineer, practically solved the problem for us. He is the father of Mr Harald Hordosh, the owner of SEACAM, a prestigious underwater housing manufacture. After nine months of work, the prototype was done, and we could finally test it underwater. Tests were incredibly successful and we immediately started to shoot with our housing (Fig. 10).

We created a unique underwater system to film in 3D. It is compact, small, handy. Two Canon C500 4K cameras are set in the beam splitter rig. The stereography can be checked trough a 3D assist monitor. The dome port allows to use all the feature of any wide angle (up to 14mm in HD), and to keep the lens's original quality. This is the only underwater 3D system in the world equipped with a dome port.

All these characteristics made the "system" pretty much successful on the market, and several movies have been shot. The first attempt was done producing a trailer for a movie about dolphins. The project was led by a former BBC team. Filming dolphins underwater may be extremely tricky and difficult, mostly because these animals are incredibly fast and their behaviour is unpredictable. The Academy Award winner team of "Vision 3" (UK) supervised the stereoscopic part. Our equipment was handy, fast, and small enough to successfully follow the dolphins. The director focused a lot on this aspect: he stated that we can film dolphins in the wild, with a perfect and relatively small camera equipment. Such a device was not yet existing in the 3D market.

After that, a series of 52 minute documentaries about "hurricanes" has been produced. And the underwater part was needed to show the effects of the waves underwater, but also to show how a hurricane may affect the local fauna. It was for this reason that I ended up filming under big waves, in murky waters, on reefs destroyed by the energy of the storm. Filming under these conditions is not easy at all, and again the cameras in the housing gave proof to be rugged, easy to use and suited to produce a perfect stereography. In the wild, we filmed several animals as well. Most spectacular were crocodiles in Cuban and Mexican mangroves. Besides the 3 x 52' documentaries, Orange / Paramount produced a movie for the big screen that will be released on next spring.

Also filming in Mediterranean waters was pretty much successful. Many documentaries have been produced about our sea, both from Italian and French productions. In many cases, we have been able to dive very deep and film the environment. And this was a great thing: how many will ever be able to admire the wreck of a 2000-years-old ship that lies on 100 and more metres from the surface? Our 3D movie will bring the audience down there, letting them experience something that it is otherwise impossible.

Some 3D images taken in Mediterranean sea with our system can be downloaded from: https://www.dropbox.com/s/ehoduap3eqib5r9/Trailer%20Rinaldi%20Pechino%2025%20Definitivo-Apple%20Devices%20HD%20%28Best%20Quality%29.m4v?dl=0

On you tube, a short movie of the housing at work in Mediterranean Sea https://www.youtube.com/watch?v=Du_eQ2PWwrE&feature=youtu.be

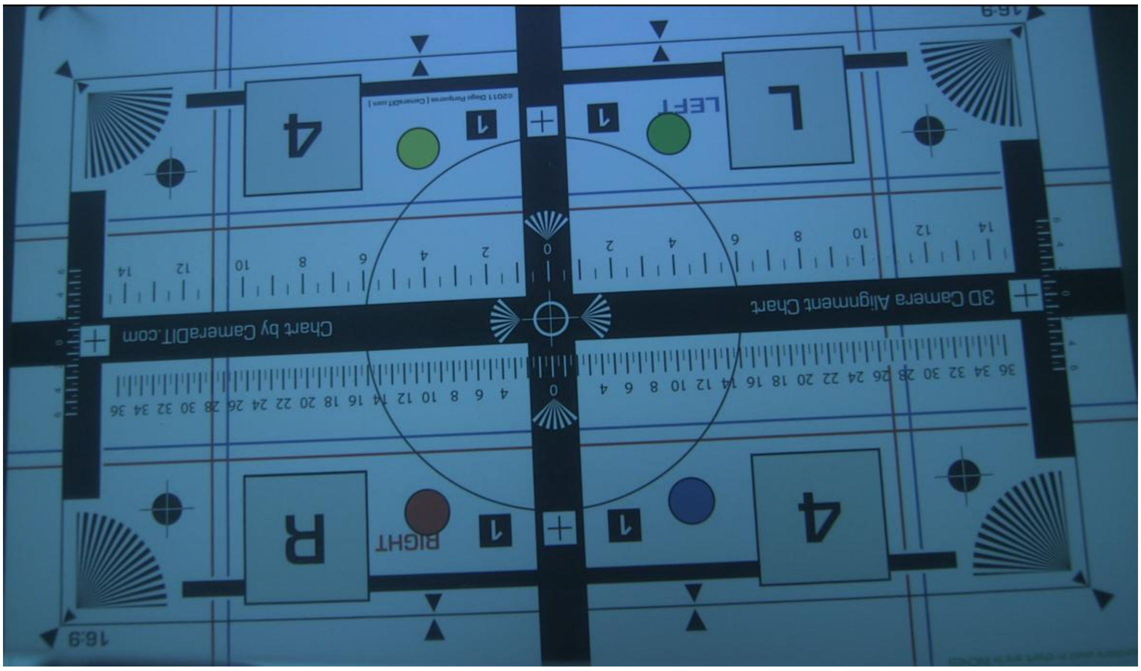

Fig. 10: The first test underwater. Lens was the 14mm Canon. The aperture was set @ f 2.8 in order to minimize the depth of field and to face the most critical condition. As we can see, corners are sharp and lines not deformed at all. The dome port SEACAM was totally successful.

Fig. 11: The housing complete with cameras and monitor as it looks today.

Fig. 12: Filming crocs in 3D

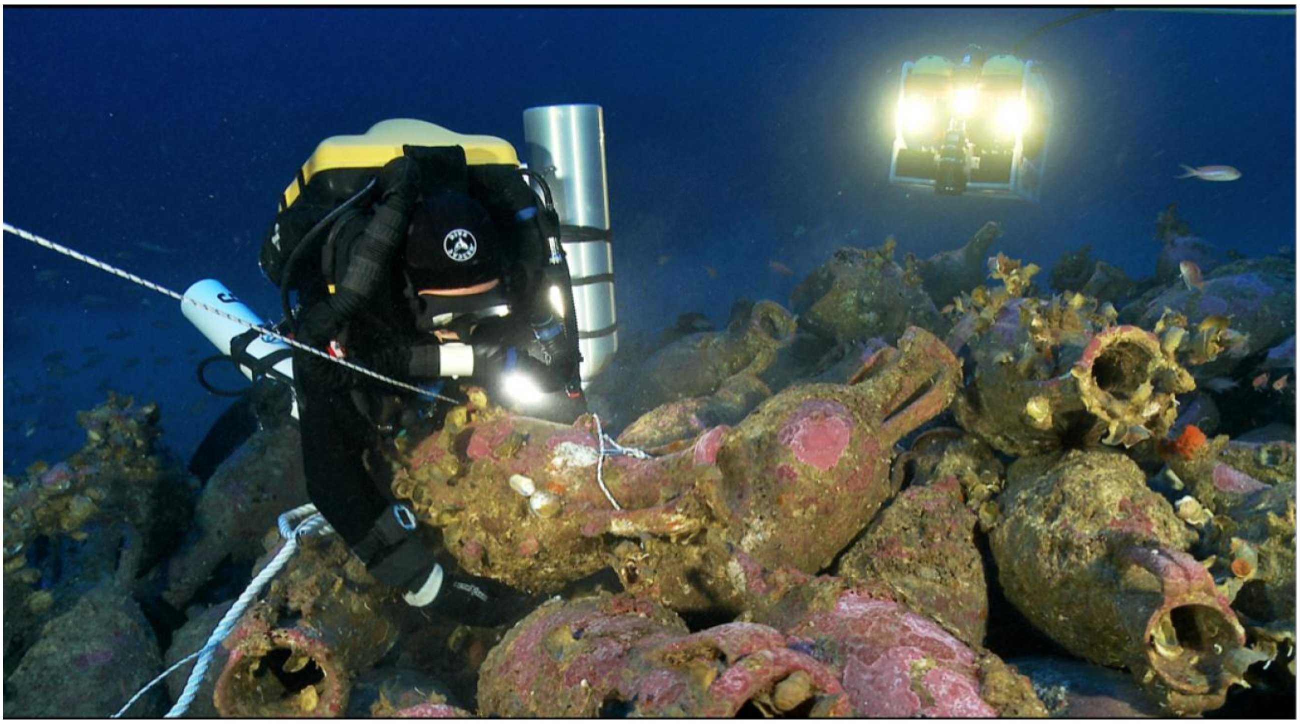

Fig. 13: Filming a diver working on a wreck at 105 metres.

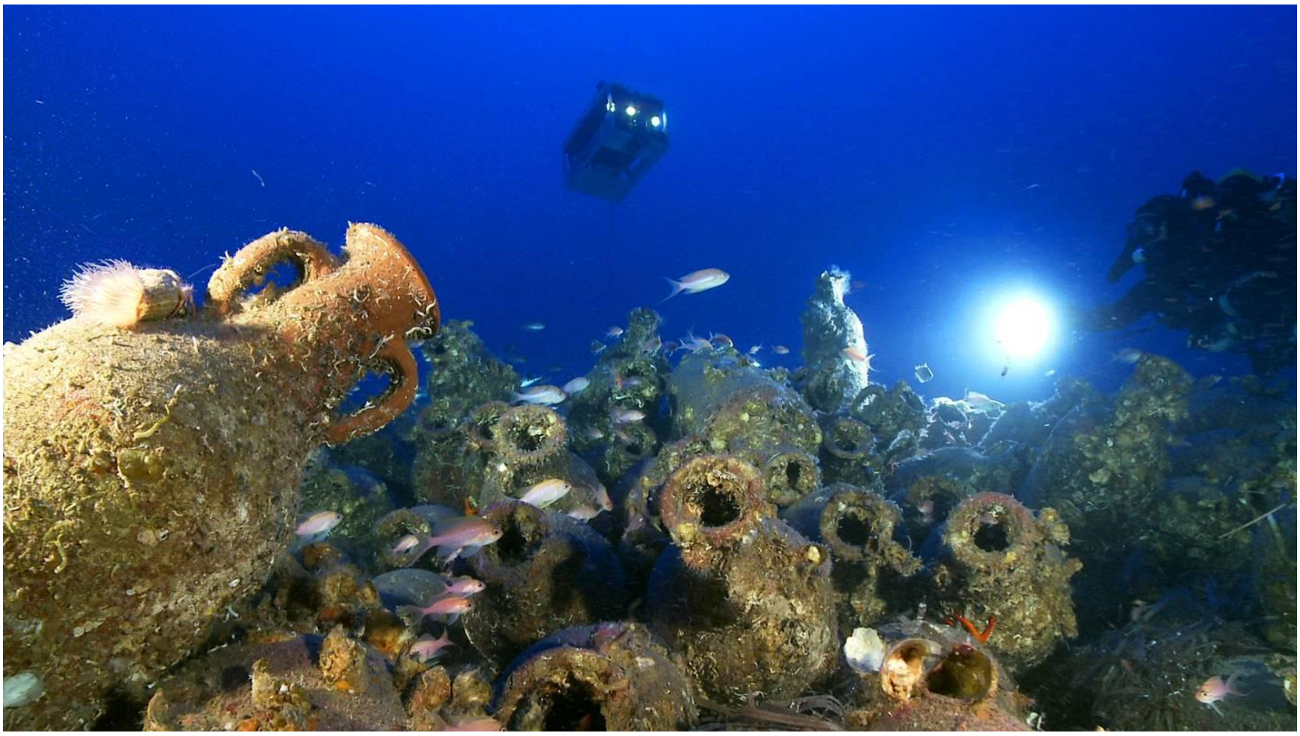

Fig. 14: Filming a Remotely Operated Vehicle (ROV) and a diver working on a wreck at 105 metres.

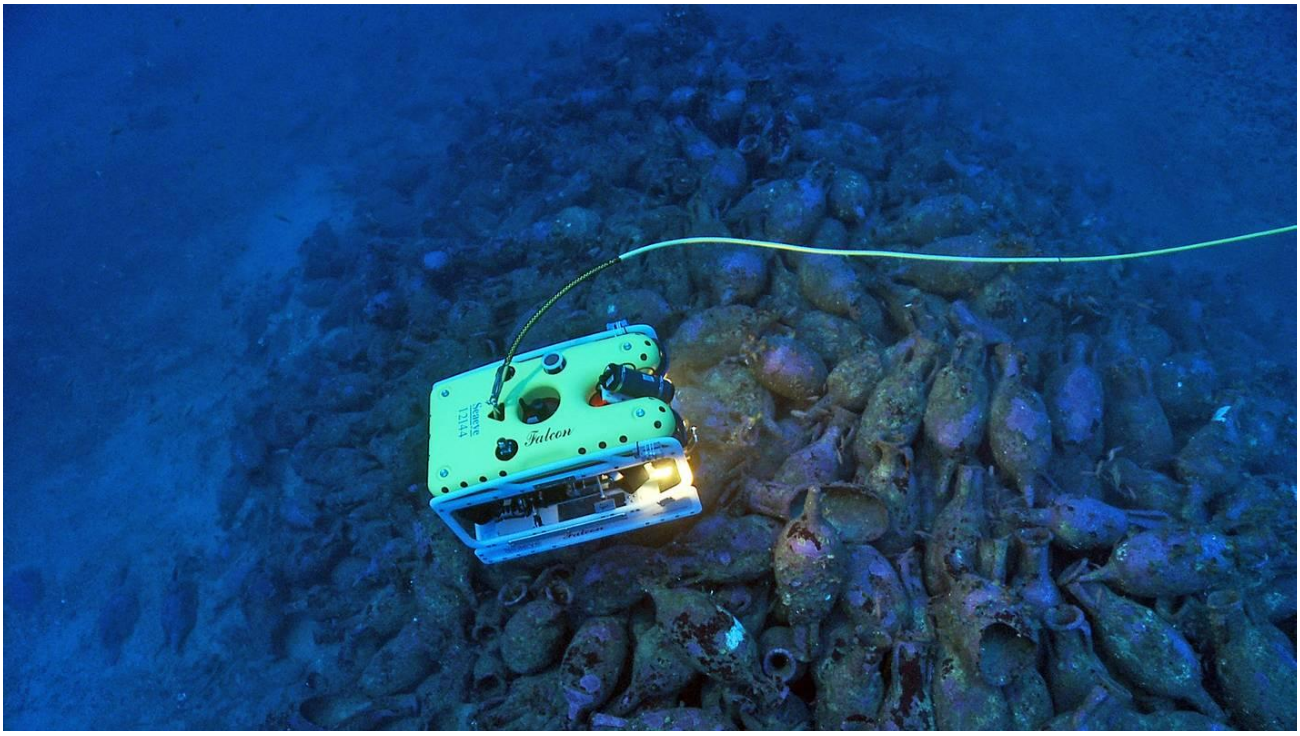

Fig. 15: Filming a Remotely Operated Vehicle (ROV) operating on a wreck at 105 metres.

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