Images of unprecedented sharpness: the first light of NAOS, the adaptive optics of the VLT, is a success

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"The spots are well centered on the wavefront sensor. The turbulence is fairly good, the signal-to-noise sufficient, therefore the image MUST be almost perfect. Let's go. Wouah, exactly as in our dreams....!". This was a few days or rather a few nights ago: for the first time, NAOS, the new adaptive optics system of the Very Large Telescope of ESO had just "closed the loop".

It began its career while offering to the eyes of the team who had installed and tuned it the weeks before, the reward of superb images, 20 times more peaked than those obtained until now with the VLT, in a site considered as one of the best in the world, that of Cerro Paranal which borders the Atacama arid desert in north of Chile.

NAOS was conceived, built and characterized by a consortium including ONERA (in charge of the project), l'Observatoire de Paris (DESPA and DASGAL), the LAOG of Grenoble and with the participation of the technical division of INSU-CNRS. ESO has financed the construction of NAOS and has participated to certain sub-systems. The following photograph shows NAOS (the light-blue cylindrical structure) installed at the Nasmyth focus of Yepun, the most recent of the four VLT 8.2m-telescopes.

NAOS allows to sharpen the view of one of the four giant telescopes by giving it back the capacity - predicted by theoretical wave optics- to distinguish angular details of size inversely proportional to the mirror size, capacity lost due to the atmosphere. It is with a frequency of 600 times a second that commands are sent to a flexible mirror, with the help of 185 micro actuators ; with these commands, NAOS manages to compensate for the deformations (hollows and bumps) affecting the light wave due to the crossing of the atmosphere. Practically restored as it was before its crossing of the atmosphere, this wave can then be focused to form a quasi-perfect image on a camera. NAOS provides its corrected images to CONICA, an infra-red camera built by a consortium of laboratories in Germany.

The pictures below illustrate the remarkable gain brought by adaptive optics while comparing images of the same object, the dense star cluster NGC 3603 in the constellation Carina, obtained with the VLT ISAAC camera (without adaptive optics) and with NAOS/CONICA. The number of stars detected, in particular the weak ones, is much higher on the image obtained with NAOS/CONICA: this allows a detailed study of the distribution in mass of a star cluster, from the smallest to the highest masses, in the star formation process. This region is particularly interesting from this point of view, since it is the locus of one of the most intense star formation activity in our Galaxy.

The Kleinmann-Low region around the Becklin-Neugebauer object in the great Orion nebula. Located near the four stars of the Orion trapeze, the region is extremely active in star formation: it contains in particular a very young stellar cluster, still hidden in the cocoon of gas and dust where it was born. It is only in the infra-red that these baby-stars can be observed. The brighter source is the Becklin-Neugebauer object (BN): it is one of the most studied objects in the class of protostars, which have not yet reached the stage of nuclear reactions as in our Sun. The NAOS image will allow to study the very important matter ejections which characterize the proto-stellar phase, as well as the formation of the very small mass stars which appear as weak sources on this image. Among these sources, "brown dwarfs" are certainly present. This image was obtained using the infrared wavefront sensor produced by the DESPA at Paris Observatory. The BN source serves as the reference for the adaptive optics sensor.

All fields in astrophysics will profit from this remarkable jump in sharpness: from the study of small bodies (satellites and asteroids) of our solar system, to the remote galaxies, for which the formation is not yet well known, when the Universe was much younger. L'Observatoire de Paris, pioneer in the field of adaptive optics, was one of the three partners of this very beautiful success. It was in particular responsible for the development of several critical
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subsystems 2-axes tip-tilt mirrors, infra-red wavefront sensor, simulator of turbulence, and the final assembling phase and characterization. This was led in the integration hall of CNRS-Bellevue, at a few hundred meters from Meudon Observatory where was realized and tested the opto-mechanical systems and electronics.

The team of Paris Observatory, led by researchers, engineers and technicians of DESPA also profited from an active participation of engineers and technicians of DASGAL and the Technical Division of INSU-CNRS. This same institute, in addition, gave a significant financial support in particular for the equipment of the integration hall, supported by the Paris Observatory on its own funds.

Know more

The high angular resolution and adaptative optics. The angular resolution of a telescope characterizes its capacity to distinguish fine details. The larger a telescope is, the higher is its capacity theoretically (the angle under which it sees the smallest detail is given by the ratio between the wavelength of the observation, and the diameter of the telescope). In fact, the turbulent layers of the atmosphere slightly deform the images and the telescopes, even in the best sites, obtain an image quality 20 to 50 times worse than the theoretical limit: the details interesting the astrophysicist are thus lost.

Adaptive optics consists in correcting these effects of the atmosphere, in real time, by operating several hundreds times a second a deformable mirror which compensates for these distortions by producing deformations of opposite sign. Many astrophysical domains profit from this spectacular advance in astronomical instrumentation.

The NAOS

For two years, the European astronomers have had access to the 8.2 meters telescopes of the ESO-VLT (Very Large Telescope). The finest details that can be distinguished (the angular resolution) with an instrument of such a size is 25 millisecond of arc at a wavelength of 1 µm. This is, for example, sufficient to distinguish the number on the tee-shirt of an OM-footballer in Marseille, observed from the Great Stadium in Paris. To reach actually this resolution, or at least to approach it significantly, was the objective of Europeans with the VLT project, when deciding to equip it with the system of adaptive optics NAOS. This objective represents both a major qualitative and quantitative jump for many programs in astrophysics, from the physics of planets and satellites of our solar system, to those very remote headlights of the Universe which are the quasars, not forgetting the gas discs around stars, progenitors of the extrasolar planets discovered at high frequency these recent years.

NAOS (Nasmyth Adaptive Optics System) is an integrated system (see animation at right) (click on the image to see the animation, 3 Mo). It is autonomous, using its own optics, electronics, mechanics and computers. It provides to the camera CONICA (COUDE Near Infrared CAmera) a beam corrected from the effects of atmospheric turbulence. NAOS analyzes in real time the disturbances of the wave surface induced by turbulence. This analysis is made, according to the objects observed, either in the visible, or in the near infra-red (0.9-2.5µm) up to 600 times a second. The measurements are based on the light from a star present in some part of the sky observed, or, in a near future, from an artificial star created in the upper atmosphere by a laser.

The corrections to be applied to the surface of the deformable flexible mirror and to the orientation of the image stabilization mirror (tip-tilt) are calculated at the same rate by a dedicated computer in real time. A nearly perfect image is provided in permanence to CONICA. The deformable mirror (115 mm diameter) of the CILAS company is...
controlled in 185 points (a point every 7 mm) by piezoelectric actuators which lower or raise its surface on 5 µm range. 5 computers cooperate to control NAOS, its mechanics, its wavefront sensor, its deformable optics. The system is self-configured in an optimal way according to the conditions of observations, the objects observed, or the configuration defined by the astronomer to the camera CONICA.

The Paris Observatory, pioneer in Adaptive Optics

The department DESPA of Paris Observatory, with its industrial and institutional partners, has been for more than twelve years one of the astronomical institutes leaders at the international level, in Adaptive Optics applied to Astronomy. It largely contributed to the development and to the scientific exploitation of the first instrument proving the power of this technique, the prototype COMEON, in collaboration with ESO, ONERA and Parisian industrials (Cilas). Paris Observatory has also participated to the realization of a second instrument available to the community: PUEO, the Adaptive Optics system of the Canada-France-Hawaii telescope. The prototype system COMEON obtained its first astronomical results in October 89 on the 1m50 telescope at OHP (Haute Provence), then some time after at the focus of the 3m60 telescope of ESO (La Silla, Chile). Many completely original astrophysical results were obtained. New versions of this experiment, COMEON+ then ADONIS, allowed very significant progress, in particular with a deformable mirror of 52 actuators (instead of 19 for the first version), with new wavefront sensors and with the original concepts of modal command and artificial intelligence developed in Paris Observatory. In the PUEO system of CFHT, the Paris Observatory was in charge of several subsystems and especially of the integration and characterization of the instrument. The latter, in operation for six years, has offered the best performances at international level, both for weak sources imaging (extragalactic sources) and for high quality correction thanks to the excellent site of Hawaii.

Adaptive optics and research in medical ophthalmology

The eye vitreous humor constitutes a sufficiently inhomogenous medium so that the focusing a light beam (laser, for example) cannot be made in a perfect way. It would however be of prime importance to be able to carry out such a concentration of the light, either for therapeutic goals in surgery or for research as well (concentration of stimuli on a single sensitive cell, cone or rod). Adaptive Optics is a means to solve the problem; just born, this research is extremely promising. Under the initiative of P. Léna and the Academy of Sciences, a working group has been created in France, to which several researchers from Paris Observatory participate. An adaptive optics test bench is presently in operation on the Meudon campus and has begun to provide the first retinian images in-vivo.

Research and Developments

Several original developments were undertaken at Paris Observatory:

• a) The development of an entirely new concept of analysis of a wavefront in the infrared. This innovative idea allows to reach in certain cases performances higher than those with the analyzer in the visible: many stars in our Galaxy are cold or obscured by interstellar dust and emit especially in the infra-red; besides, the infra-red matrix sensors have possibilities to address pixels at a much higher rate than those in the visible CCD. A prototype, RASOIR, was developed at DESPA then tested twice successfully on the 3m60 telescope of ESO (Chile). NAOS benefitted directly from this realization.
• b) The development of powerful two-axes correction mirrors: these mirrors which use a very effective feedback control system thanks to engines of strong power, specially designed, and sensors of high degree of accuracy,
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- became components sought for in the whole world: they equip the adaptive optics systems of two 4m telescopes, and not less than 5 telescopes of 8 m will be equipped soon (VLT and Gemini).
- c) the DASGAL of Paris Observatory is now a specialist in the design and realization by photo-lithogravure of micro-structured optical systems: phase mask to simulate atmospheric turbulence (for NAOS in particular), matrices of micro-lenses used in the analyzers of wave fronts.