The FRIPON and Vigie-Ciel networks

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FRIPON (Fireball Recovery and interplanetary Observation Network) is a French fireball network recently founded by ANR (Agence Nationale de la Recherche). His aim is to connect meteoritical science with asteroidal and cometary sciences in order to better understand the solar system formation and evolution. The main idea is to cover all the French territory in order to collect a large number of meteorites (one or two per year) with an accurate orbit computation allowing us to pinpoint the parent bodies of the meteorites. About 100 allsky cameras will be installed in 2015 to create a dense network with an average distance of 100 km between two stations. In order to maximize the accuracy of orbit determination, we will mix our optical data with radar data from the GRAVES beacon received by 25 stations (Rault, 2014). As the network installation and the creation of the research teams for meteorites need many persons, at least much more than our small team of professionals, we will develop in parallel a participative science network for amateurs called Vigie-Ciel. As FRIPON is an open project, anybody will be able to buy a “FRIPON like" camera to be within the network, using our FreeTure detection software (Audureau, 2014; Kwon, 2014). Vigie-Ciel will also be used by observers using other types of cameras and by teams of meteorite researchers. Finally we will use the public affinity with meteors and meteorites to develop scientific activities to popularize science.

1 Scientific goals

The aim of the FRIPON project (Fireball Recovery and interplanetary Observation Network) is to answer questions that arise about the relationship between meteorites and asteroids. It is easy to study a meteorite in a laboratory but we have no idea where it came from because for most of them the orbit is unknown. On the other hand, we have currently more than 700000 orbits of asteroids with little or no physical information. However these parameters are crucial for understanding the origin and evolution of the solar system. In recent years, the planet migration theory has shown that it is possible to find very primitive objects in the main asteroid belt, and that these things may hit the Earth due to the Yarkovsky non-gravitational forces. It is therefore essential to know the orbits of the meteorites found on the ground to connect their dynamic history and composition. This knowledge also works in both directions, namely it will allow us to have an idea about the origin of meteorites, but also about the material that makes up asteroids.

2 The FRIPON and Vigie-Ciel projects

To make the connection between asteroids and meteorites, we need accurate orbit parameters for each recovered meteorite. For this purpose, we plan to install a dense video camera network on the entire French territory. A network with a 100 km spacing between the stations will allow to compute an impact location better than one kilometer (Brown, 2011; Oberts, 2004). We will also install radio receivers using the military radar GRAVES (designed for searching space debris) that will allow us to minimize velocity measurement errors and therefore to obtain better orbital elements, especially for the semi-axis. One of the originalities of our project is that it is linked to a social network called Vigie-Ciel that will form the basis of our organization. We will use public interest in meteorites and asteroids to provide outreach. Our network will be based on regional laboratories which will be responsible for four or five cameras and a radar receiver. The cameras will be installed in all structures disseminating science, such as museums, planetariums, amateur observatories, etc. The data of the cameras will be accessible via the network. The information collected by the Paris Observatory will allow to decide the triggering of a field search mission.

Another originality of the project is that we associate the know-how of two old laboratories of astronomy and celestial mechanics, IMCCE and the National Museum of Natural History. Associating asteroids and meteorites is also the way to connect two laboratories! At the end of the project, we will have very little altered meteorites for the national collection of the museum but also a unique database combining the best available information on these objects. After 10 years, we hope to have about ten to twenty meteorites with statistically rare items. We will also have hundreds of orbits of quality. We will answer the question about the origin of meteorites and may be based on specimens, discover information about the early solar system.

3 FRIPON compared to other networks

France is isolated, especially when compared to networks in Northern, Eastern and Southern Europe (*Figure 1*). Moreover, if we remove the professional observatories dedicated to meteors, then we only have the European Fireball Network, composed of 40 fish eye cameras covering Germany, Belgium, the Czech Republic and Slovakia and the SPanish Meteor Network (SPMN). These networks use mainly analogic video cameras. We will use modern digital cameras offering a better resolution and higher frame rates. We based our reflections on the successful ASGARD All-Sky Camera Network in Canada[1] (Brown, 2011).

The national meteorite collection was started over 200 years ago and is one of the largest in the world, holding the main masses (or significant samples) of 520 of witnessed falls, leaving only the collections of the British Museum (Natural History) in London (620) and of the Smithsonian Institution in Washington (530) with a larger number of meteorites. To these 520 "falls", over 1000 "finds" are added - the latter being meteorites found a significant amount of time after their fall, often weathered from being exposed to terrestrial alteration, which makes them scientifically less valuable. Out of the 520 falls within the Museum collection, 59 fell in France. Most of the additional 6 known to have fallen in France date from the 18^{th} century and before and there are no known samples left.

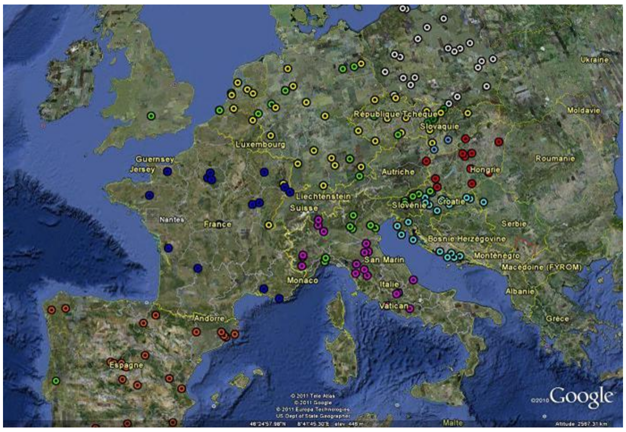

Figure 1 – Observation networks in Europe. The only fish eye observatories are shown by orange (Spain), red (Slovakia) and light blue dots (Czech Republic). All other cameras are small field, not nearly as efficient for the detection of fireballs.

The small number of meteorites known, their scientific interest and financial value (acquired within the last 20 years) makes the national Meteorite Collection unique amongst those preserved at the *Muséum national d'Histoire naturelle* because, despite its patrimonial character, it is being used for outreach and teaching and is, at the same time, the irreplaceable support of the Cosmo-chemistry research of the national and international communities, meaning that a small fraction of samples will be allocated to perform "destructive" analysis or to be included in sample preparations for in situ analysis: over 1300 polished thin and thick sections are thus available for loans. Expending our national collection means to search ourselves newly fallen meteorites in order to bypass the growing private market.

The largest part of the meteorite collections come from unknown falls, so they have undergone significant alteration that prevents comparison with asteroids. Our response time is essential, especially if we find meteorites as fragile as the Orgueil one. Our goal is to start the search for the next day of the fall and to continue for a week. We must also take into account the soil conditions which can quickly get rid of meteorites.

Note that the conservation in the public collections of rare objects is an essential goal. We can compare for example the case of the meteorites Alais (Ales) and Pride, weighing 6 kg and 14 kg respectively, with falls recorded in 1806 and 1864. These meteorites are the only ones to have precisely the same composition as the Sun (except for the most volatile items such as H and He) and are therefore objects of reference for the chemical composition of the solar system. The meteorites of this type have, unfortunately, also the property of being particularly vulnerable. 1864 corresponds to a time when the extraterrestrial origin of meteorites was well established, including the public which had a great interest in science. This led to a great mobilization, many samples reached the Museum. Today, Orgueil is probably the most distributed meteorite of the collection (average 15% of requests for destructive analysis). Despite having the same characteristics, Alais cannot enjoy the same

[1] http://meteor.uwo.ca/research/allsky/overview.html

privileges, only 20 g reached the Museum, mainly due to an unorganized search campaign.

The statistics of *Figure 2* show that in the 19th century about one meteorite was found every two years against one every ten years for the 20th century. Literature (Halliday, 1996) shows that the average fall rate should be about 10 per year for a territory like France. So during the 19th century we found 6% of the meteorites and only 1% for 20th century! So it is possible to perform better especially with our camera network, when we replace farmers by electronic eyes! To conclude, although France is not the best place to search for meteorites (weather, land, etc.); it seems realistic to recover at least one or two meteorites per year.

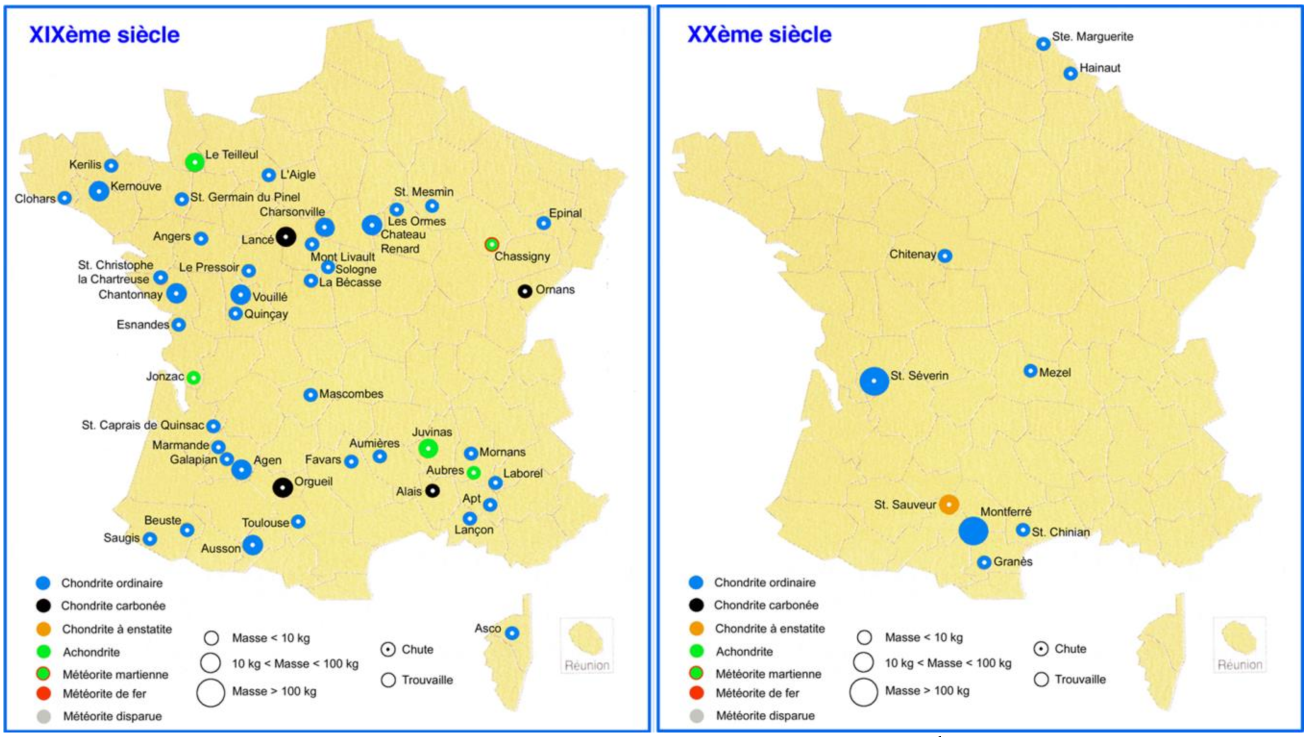

Figure 2 – Comparison of the discoveries in France. There were 64 falls in France during the 19th century, compared to 18 for the UK, 31 for Italy, 32 for Germany and 23 for Spain. Note also that 70% of the French meteorites have been found during the 19th century. This is probably due to the fact that France is (with England) the country where the origin of meteorites was early recognized as extraterrestrial. In the 19th century, the French population was mainly rural but was also aware of science. Our goal is at least to reach the same efficiency!

4 Technical specifications

Camera

We made extended searches and tests to find the best technical solution for the all sky optical cameras. Our requests were to use at least 30 fps devices in order to get many points to measure the fireball. Of course it is better to use the biggest and the fastest camera possible, but for economic reasons, we choose one megapixel cameras presenting an affordable price. The GigE Vision protocol was chosen, as it allows cables as long as 100 m, and because it can deliver power to the camera via the "Power over Ethernet" (PoE) protocol. We focused our efforts on cameras based on the Sony chip ICX445 (1348×976 pixels, 5 x 4 mm). Finally, we choose the DMK 23G445 from the company Imaging Source. This camera can provide exposures as long as 30s, allowing astrometrical calibration frames and it is also able to use a 10µs exposure time for daytime observations. It uses a CS mount.

Lens

As we used a 1/3 inch sensor, we have to use a 1 to 1,5mm focal length. The question was between a long focal length to be more sensitive and to reduce the pixel size on the sky, or a shorter one to get the full sky. The problem was to find a lens covering the whole CCD spectrum, as many "old" design lenses were not computed to use the near infrared spectrum of the CCD. The quality of the lens is important to observe very bright objects: on saturated images, a bad lens can corrupt large CCD areas. Finally we choose the Focusave 1.25mm F/2.0 (*Figure 3*). The fwhm at zenith is 1.5 pixel and 1.8 at the horizon (*Figure 4*). We have the full sky with this lens; we did not find longer focal lengths with this quality. We choose that lens for its optical quality. The whole set with the camera will be less sensitive, but this is not so important as the goal of the operation is to observe very bright events.

Camera housing

Camera housing is important to protect the camera against weather conditions, to cool it and to avoid mist on the dome (*Figure 5*). Power over Ethernet was choose mainly because it allows using the same cable for data and for power supply, it simplifies the mechanical design but on the other hand, the camera produces as much as 10 watt of heat that must be evacuated. If not the camera will heat too much and will deliver high dark frames incompatible for our use.

Figure 3 – CS mount 1.25mm F/2.0 lens for the FRIPON.

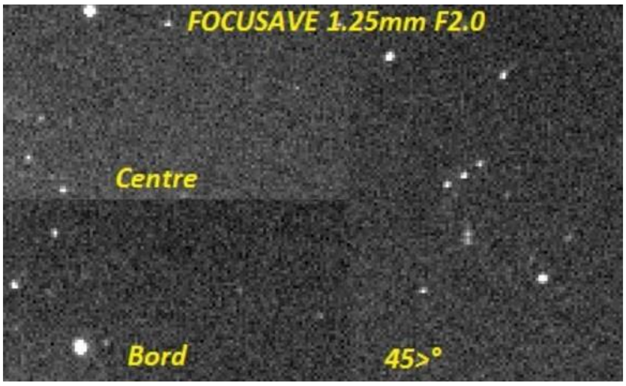

Figure 4 – Test on night sky at zenith (Centre) and horizon (Bord).

So we paid attention to design a passive-cooling system. We performed thermal tests from –20°C to +50°C, we measured a ΔT of 8°C between the temperature outside and inside the camera.

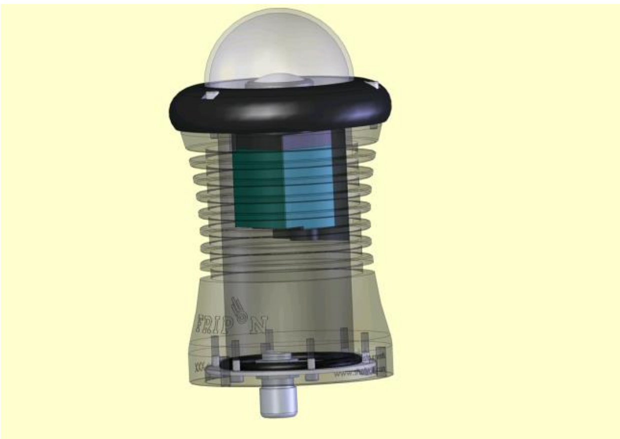

Figure 5 – FRIPON housing with passive-cooling. The main body is semi-transparent to show the camera. The overall dimensions are 150 x 70 mm and the weight is less than 1kg.

Spectroscopic observations

In order to combine all the science from asteroid/comet with meteorites, spectroscopic observations can be made from Earth at possible parent bodies with a telescope and for meteors with dedicated instruments. In fact it will be a kind of Grail to get one meteorite with the best data gathered by the best laboratory on Earth with spectroscopic and dynamical data obtained in space. More than the study of one single object, it will help for all other objects with partial knowledge. As obtaining spectra with a fish eye lens is quite impossible, we have to use small field spectroscopes in just a few locations. Fireballs brighter than magnitude -11 are easily visible from a few hundred kilometers by using a high altitude observatory. As these events occur far from the observatory, they are low on the horizon, so it is possible to use small field spectroscopes only at a low elevation to limit their number. It is typically possible to use only 8 low cost spectroscopes each with one video camera and one prism. In France, it could be possible to use Pic du Midi for the South of France and the North of Spain, Puy de Dôme for almost all France and Aiguille du Midi near Mont Blanc for the East of France and Central Europe.

5 Vigie-Ciel the collaborative network

FRIPON extended network

The FRIPON network (100 cameras over France) is founded by the ANR (Agence Nationale pour la Recherche), but since the entire project is based on open source software and hardware, it will be possible for any person or institution to copy our set-up and to install their own cameras. If the hardware is identical (GigE Vision interface for the camera and a Linux dedicated control computer) it will be possible to integrate FRIPON VPN and to be a real FRIPON partner. In fact, our 100 km spacing is mandatory for astrometric measurements, however weather conditions can be different at locations separated by only a dozens of kilometers, so more observing locations are really valuable.

Vigie Ciel "Camera"

If a person doesn't want to use the FRIPON software (Audureau, 2014), it is possible to participate in the collaborative project Vigie-Ciel. A web service will be proposed for storing any data coming from the public, even small field cameras. Detection can be manual or by using another software like UFOCapture.

Vigie Ciel "Meteorite search"

One of the goals of FRIPON is to be able to go on the strewn field within 24 hours with a large team in order to get the freshest matter. In other words we have to form a team of 50 experienced persons in one day! As this is impossible, we will train persons before the fall and maintain the motivation by organizing meetings and repetitions on the terrain.

Figure 6 – Simulation of a search at "La Ferme des Etoiles" (August 2014).

6 Schedule

FRIPON started in January 2014 for a duration of 3.5 year (ANR grant). The first half of the year was dedicated to the definition of the hardware and to consult literature for the software. The second half of the year was used to prepare contracts with companies chosen to define and to build the hardware. Meanwhile we are testing the reduction pipe line with a few cameras located in the Paris area. 2015 will be used to install the whole optical network and to finalize the software pipe line (acquisition, detection, astrometry, computing orbits and strewn field) (Kwon, 2014). The optical network will be fully operational before the end of 2015. During the same year, we will start to install the radio network. 2016 will be used to mix optical and radar data as well as to process the meteor radar observations, the seismic and the infra-sound data.

7 Conclusion

FRIPON is not really innovative as most of the techniques are known for a long time, but many things are specific:

- Size of the network (640 000Km^2);
- Number of cameras (100);
- Density;
- Daytime operation;
- Mega pixel digital cameras;
- Systematic combination with radar data;
- Systematic spectroscopic observations;
- Systematic measurement of Cosmic Rays;
- Exposition time (CRE);
- Systematic measurement of isotopic elements;
- Formation of a collaborative science network;
- Open project.

This last point is perhaps one of the most important as no detection software at that time is free of charge. Moreover, all the code will be also released for personal modifications. This is important to allow installing new cameras types in the future. We also try to keep the budget reasonable to permit everybody to copy the tools for personal use. To popularize our extended network, it will be possible to use the FreeTure software in a sharing mode (Audureau, 2014). In this mode, 5 to 10% of the time could be used to make long time exposure and therefore nice deep images usable to monitor dark sky, the remaining time could be used for FRIPON with a high acquisition rate.

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