
5. An input catalogue, or...

AS GAIA scans the sky, it detects and observes everything brighter than a specified threshold, at about 21 mag. This avoids the use of a pre-defined observing programme, and it ensures that all objects bright enough at the time of their observation – whether regular or irregular variables, transients including supernovae or microlensed events, or moving objects in the solar system – are detected and observed.

This powerful system required some clever techniques to implement. And it circumvented one of the very big challenges that its predecessor, Hipparcos, had to tackle: defining the mission's observing programme.

The principles employed for Gaia were driven by this earlier experience. I will give here an overview of the Hipparcos background, in part as a brief historical record, but equally to demonstrate how hard-won experiences translate into ideas for technological advances.

HIPPARCOS WAS conceived in the late 1960s, and launched in 1989. But a satellite is built around technologies that must be ready and proven when the detailed design is undertaken, some years before that. Hipparcos, accordingly, was designed and built around the technologies to hand in the early 1980s.

CCDs were arriving, but with readout noise and charge overflow properties totally unsuitable for the mission's goals. Instead, the heart of the instrument's measurement system was a (by today's standards) low-efficiency photocathode-based 'image dissector tube'.

Mounted behind a high-precision 'modulating grid', the detector's 30-arcsec diameter sensitive spot was piloted, electronically, to a given physical location. It tracked this moving spot for a few seconds as the telescope scanned the sky, then jumped to another star within the combined field of view. And so the process repeated indefinitely, interlacing the dwell periods on each star, and switching between them as stars entered the field and, 20 seconds later, exited from it.

All of this had important consequences for the satellite observations. First, in terms of the size of the observing programme, only one star could be observed at

a time, and as a consequence of this, the total observing time available had to be carved up between the stars visible in the telescope's combined fields of view at that time. It followed that only a certain subset of all stars could be observed in total.

Second, stars had to be brighter than the instrument's detection threshold (around 11–12 mag), and in view of the available observing time, there could not be too many of these 'faint stars' in any area of the sky.

Finally, the strict demands on the detector piloting, and its sensitive area, meant that each star observed had to have its position known, at the epoch of each observation, to better than about 1 arcsec. To allow an optimum distribution of observing time, magnitudes also had to be known, preferably to better than about 1 mag.

The practical implications were far from straightforward. There would need to be a very careful selection of those stars chosen for measurement by Hipparcos. There would need to be extensive preparations to establish the positions and proper motions of these target stars, and supplemented by new observations if the actual observational knowledge was inadequate. The same was true for the magnitudes of the chosen stars, and all of this was compounded in the case of variable stars, double or multiple stars, selected asteroids, and so on.

To summarise, before the satellite could be set in motion, there was a need for a master catalogue, defining the stars to be observed, and the satellite attitude itself. It would list the star positions at the times of observation, both instructing the satellite's pointing system which part of the sky it was scanning, and informing its detector which stars were next to be observed.

DOWN TO THE faint limit of observability of the Hipparcos telescope, of around twelfth magnitude, there are some million or more stars in the sky. It was not difficult to figure out how much time could be given to each as the telescope scanned, and how many could therefore be observed over its lifetime. Hipparcos would have time enough to observe only around one hundred thousand, so a careful selection had to be made.

DECIDING WHICH out of the million possible were to be observed would itself determine which stars would be in the final catalogue, and therefore which would be handed down to future generations with their accurate distances and proper motions.

But which were the most important? Would it be the few known white dwarfs, or the most nearby stars, or those representative of our Galactic disk or its ancient halo? High proper motion stars were important, so too were a long list of binary stars and variable stars. Stars with unusual chemical abundances had to be included, along with the oldest subdwarfs. And so the list went on.

On top of all, there had to be a fairly uniform distribution of stars across the sky to serve as the celestial reference frame. For each star included, ten would have to be excluded. For each scientist pleased with the wisdom of a certain selection, another might be quite dissatisfied with the myopic choice.

An important to bear in mind was that the selection of Hipparcos in the late 1970s and early 1980s was a competitive, protracted and tortuous affair. Coordinating the preparations for its launch throughout the 1980s, I can state that, outside of the traditional astrometric community there were few scientists enthusiastic to see ESA undertake the mission, and indeed some were quite opposed. Amongst the Hipparcos teams at the time, there could be no idea that a follow-on mission would ever be considered, and no idea that the necessary technologies would advance so rapidly.

Hipparcos was seen as the one opportunity to define an observing programme, and reference frame, that would represent the state-of-the-art for a very long time.

CONSTRUCTING THIS starting catalogue – what was called the Hipparcos Input Catalogue – was indeed to prove a mammoth task. It was led by astronomer Catherine Turon of the Paris Observatory in Meudon.

In the late 1970s, Catherine Turon had discovered the intoxicating grandeur of the project through three colleagues: Jean Delhaye, former director of the Paris Observatory, who had conveyed to her his own curiosity about the structure of the Galaxy; Jean-Claude Pecker who, as their paths crossed in the observatory gardens, had asked her to replace him at an early symposium organised by ESRO (the forerunner of ESA) to gauge interest in space astrometry; and Jean Kovalevsky, who had urged her to probe the appeal to French astronomers of large numbers of accurate star parallaxes.

Once committed to the goals, and duly elected to lead the task, she assembled a team of about fifty astronomers ranged across European institutes and observatories to begin the work. Superbly organised, with an encyclopaedic knowledge of the stars, she inspired a large team that would work for more than five years to deliver the starting catalogue.

Always with a smile, always quick to laugh, she had a passion for the task she had undertaken, and a clear view of the final result that she wanted to achieve. People could not wriggle out of commitments they had made, and excuses for anything deviating from perfection, or the pressing schedule, were not well received. ‘*Mais non*, that was *not* what we agreed!’ was heard often, but her reprimands were always issued with a winning smile.

Putting together the satellite’s observing list was a balancing act: figuring out scientific priorities of each star, checking the expected performance of a trial catalogue by detailed simulations, assembling the information already known about each object, and setting up new observations using telescopes on ground to fill in missing data needed for the space operations.

THE PRACTICAL problems that had to be tackled in the 1980s are hard to appreciate today. One was that, in the proposals submitted, the same star could appear under many different names. The bright star Procyon, for example, is HD 61421 in the Henry Draper catalogue, GC 10277 in the General Catalogue, FK5 291 in the Fundamental Katalog, LTT 12053 from a high proper motion survey, and so on. Indeed, much of today’s catalogue cross-indexes grew out of the Hipparcos work.

One might think that the star’s position would resolve this dilemma, but many catalogues at the time did not list accurate positions; indeed, for many stars, accurate positions had often never been measured!

On top of this, all stars have a proper motion, and depending on which reference frame and time standard was used, even the position could differ between catalogues. Reaching the accuracy one second of arc or better by the time of launch, just to point the satellite’s detector, was not too difficult in principle. But, in the early 1980s, it was enormously time consuming.

IT HAD BEEN agreed, during an early phase in the project’s development, that the wider scientific community would be consulted on their opinions as to which stars should be observed—this was considered a once in a lifetime opportunity for science, and the wisest council was, in consequence, sought.

I steered through a policy paper which had to be debated and endorsed by the ESA advisory committees before we could open this to non-European suggestions. The stars observed would form a legacy for decades, and we wanted to make sure that the most important would be observed. This was no time to be parochial, our argument went, and it would be inappropriate to restrict scientific opinion exclusively to European scientists.

There was the counter view, forcefully expressed, that European nations were paying and that, accordingly, it should only be European scientists sowing the ideas and reaping the rewards.

If this should seem small minded, the logic carried force for those who held authority: national funding bodies would expect to see a return on their investment, in the form of scientific publications citing their own astronomers' work, not somebody else gaining the credits. Both arguments had substance, and had to be debated. The more altruistic camp held sway, and a world-wide call for observing programmes was issued early in 1982.

A CLOSING DATE OF OCTOBER 1982 was announced. The delivery format was carefully specified. Suggested star lists, in their hundreds or thousands, came pouring in. Scientists around the world had taken the opportunity as seriously as we had hoped they might.

We received lists of the stars most likely to provide a maximum scientific insight into their inner workings. Other lists identified for us objects likely to give the most knowledge about the rotation or structure of our Galaxy as a whole. Lists detailing nearby stars, high velocity stars, rare but important stars like the pulsating Cepheids and RR Lyrae stars, others mandatory for defining the stellar reference system, important binary systems, bright stars in the Magellanic Clouds, asteroids, and so forth, all flooded in.

Today, such details could be sent comfortably by e-mail. But in the early 1980s, neither e-mail nor the internet existed. Instead, half the proposals came by post on nine-track magnetic tapes, a bulky storage medium the size of a couple of dinner plates, which could hold a hundred megabytes of data, and which were the state-of-the-art in data storage at the time.

The remainder were sent in on the even bulkier punched cards! These had dominated data entry and computer programming for almost half a century, and although their popularity was waning, they were still in use. Each card, of size $7\frac{3}{8} \times 3\frac{1}{4}$ inches, encoded up to 80 characters over its 80 columns, each represented by rectangular holes in each of 12 punch locations.

At ESA's technology and research centre in Noordwijk, I found an office for the temporary storage of these tapes and cards, before their onward despatch to the Observatory of Paris in Meudon, which would be the command centre for the next phases. By the time of the proposal deadline, the office was piled high with tapes of different sizes, and punched cards of varying colours. It was an Aladdin's Cave representing humanity's collective knowledge of the stars at that time. I regret not having a photograph to recall the one-time existence of this weighty collection, and of this seemingly primitive way that data was stored such a very short time ago.

TO PASS FROM disparate lists of suggested stars, to a true master list which could be used to operate a satellite, required a huge amount of work. Redundancies had to be eliminated, and obvious omissions recti-

fied. Sky regions too much in demand had to be whittled down. Holes had to be plugged in areas where too few stars had been submitted. Positions had to be checked, and proper motions too. But it was the scientific priorities that would cause the biggest headache.

Adriaan Blaauw, elder statesman in the astronomical world, Director General of the European Southern Observatory between 1970–75 and one-time president of the International Astronomical Union, provided a guiding hand in defining the observing programme.

Following a suggestion by Henk Olthof, the secretary of ESA's Astronomy Working Group at the time, Blaauw was approached, and invited to set up and chair an independent committee to assist. It would be tasked to scrutinise the scientific suggestions, and to assign priorities to the goals laid out. Its brief was to ensure that the starting catalogue observed by the satellite was put together as carefully as possible.

In the early 1980s, Olthof took charge of nurturing all new projects entering, or wishing to enter, the privileged ranks of ESA's science programme, and he moved calmly and confidently through the various communities encouraging and facilitating. He felt that his compatriot's authority and contacts would rise to the challenge.

Mindful of this unique opportunity to get the list of stars to be observed chosen optimally Blaauw, who was nearing 70 at that time, assembled his own team of fifteen prominent figures in

the astronomy world, from institutes around Europe, to contribute their impartial advice. Over the next few years, their task would be to debate the state of knowledge—of nearby stars, stars for the reference frame, stars of specific astrophysical interest, and so on—and adjust the observing programme to reflect the results most demanded from the satellite.

Three meetings of the committee over a period of three years were to guide the priorities. Each resulted in a progressive adjustment in the catalogue's contents, all changes to be made in careful dialogue with the leader of the scientific effort, Catherine Turon and her own international team.

OVER SEVERAL YEARS, the team constructing this 'input catalogue' met up for many progress meetings, traveling to one or other of the leading institutes. Astronomers managed to occupy some splendid real estate centuries ago, high points outside major cities, and



Selection committee, Paris (April 1987)

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many have retained these superb sites down the years. The observatories of Paris and Nice, Rome and Torino, Heidelberg and Edinburgh are just a few that have cornered some of these great locations.

The goal of these meetings was to report on progress, reassess priorities, and debate plans and problems. But they served the additional purpose of bringing team members from different countries into close contact. This fostered a spirit of great collaboration and mutual trust, so essential to the big task building up around us.

ONE PARTICULARLY memorable meeting was of the entire consortium, some fifty people, held in the mountain village of Aussois on the edge of the Vanoise National Park in France, in early spring 1985. Catherine Turon, supported by her executive team and her international steering committee, drew up plans for a one week conference to get a complete picture of the current state of play of the starting catalogue.

Bernard Nicolet, hailing from Switzerland, had brought his impressively dimensioned Alpine horn along with him, and he roused us at sunrise each morning with a haunting reveille performed on the slopes outside. At the close of business each day, we could walk up from the Paul Langevin conference centre at the edge of the village into the still snow-covered alpine pastures from which marmots were starting to emerge.

Later we might be entertained by evening concerts from the more musically accomplished. To talk science for a week in such a location was an inspiration.

THE MEETING coincided with the 79th birthday of Pierre Lacroute, the satellite's originator, who was there. There was a great cake, and even some dancing.



Input Catalogue Consortium, Aussois, 1985

On such occasions I could meet with some of the senior figures who had dominated astrometry from the ground over the previous decades, including the influential Heidelberg as-

tronomers Wilhelm Gliese (1915–1993), whose name still eponymises our knowledge of nearby stars, and Walter Fricke (1915–1988), who led the construction of the state-of-the-art catalogue of ground-based positions and proper motions of stars, the FK5.

The FK5 was a small but very select catalogue of just 1535 stars published in 1988, constructed meticulously following an enormous observing effort over decades. It was the authoritative word on the stellar reference frame before Hipparcos started on its own revolution.

Fricke, small in stature, large and jovial in character, had devoted his professional life to ground-based astrometry, but became an enthusiastic convert to its future from space. Despite our forty-year age difference, I found him charming, and encouraging, and he slipped me some valued advice along the way.

Two decades later, we would be looking at thousands of scientific papers making use of the final catalogue. We would be grateful that its unique content had been assembled with such attention and passion. Even before launch, Adriaan Blaauw proclaimed that Hipparcos had served as astronomy's great 'vacuum cleaner', its preparations already providing good positions for many stars hitherto unmeasured, cleaning up the confusing plethora of star names, and consistently identifying and labeling the components of binary star systems.

In a Foreword to the pre-launch mission description in 1989 Blaauw reflected: *All those who have contributed... are to be congratulated for their achievements – achievements that we will remember vividly when the Hipparcos satellite leaves us behind on earth to assume its heavenly high-precision task.*

Thirty years on, I would go further: it was the scientific content of the final catalogue which underpinned a wider appreciation of the importance of space astrometry, and played its part in ensuring the approval of Gaia.

FIVE YEARS AFTER THE WORK on the starting catalogue began, the Hipparcos Input Catalogue was completed. The list of stars to be observed was formally delivered to ESA at a ceremony presided over by its Director General, Reimar Lüst, on 11 April 1988 at Noordwijk.

Roger–Maurice Bonnet as Director of Science participated, and Pierre Lacroute, now 82, was guest of honour. Catherine Turon handed over a magnetic tape to Reimar Lüst in a symbolic gesture of a major milestone: the list of stars that had cost so much effort to prepare.

After the ceremony, Hamid Hassan (ESA's project manager) and I led Reimar Lüst and Roger–Maurice Bonnet, with Pierre Lacroute and Catherine Turon, Erik Høg and Jean Kovalevsky, along the warren of corridors, through the security barriers, and into the integration vault where, coated and masked, we could see Hipparcos being assembled under 'clean room' conditions.

Wires hung everywhere. Motors hummed, and lights flashed as tests and checks progressed. For the last time, we could gaze upon this remarkable construction of glass and metal, and reflect on the complex combination of circumstances which had led to its creation.

SUCH WAS THE monumental task that confronted the construction of the 120 000 star Hipparcos Input Catalogue in the 1980s.

It really was not at all difficult to see that a different approach would be needed for Gaia's 20–21 mag, billion star catalogue. Easy to comprehend, but it would prove to be a great technical challenge too.