The Story of WUSAT

The unique story of the University of Warwick Satellite Engineering team

By Dr Bill Crofts, University of Warwick

In 2006, when I visited Prof Steve Gabriel[1] at the University of Southampton, I had no idea what a remarkable chain of events this would lead to, nor how much this would influence many years of my life to come!

Through some link, long since forgotten, Steve and I had made contact in relation to a forthcoming European Space Agency project called ESMO[2]. ESMO was to be a Moon orbiting satellite, the fourth mission in ESA's Education Satellite Programme. The notion was that ESMO might use grid-ion propulsion as its main thrust mechanism to enable transfer from Earth orbit to Moon orbit. Hence, we would form a joint Propulsion sub-system team for ESMO whereby Southampton would provide the electric propulsion system and Warwick would provide the electrical power supply to provide their electrical power needs.

Dr Bill Crofts (centre) with Prof Steve Gabriel (centre-right) visiting Steve's electric propulsion lab.

As Prof of Aeronautics and Astronautics at Southampton, Steve had plenty of experience in the development of such technologies in Space applications. In contrast, I had no experience or knowledge of satellite engineering at all at that point!

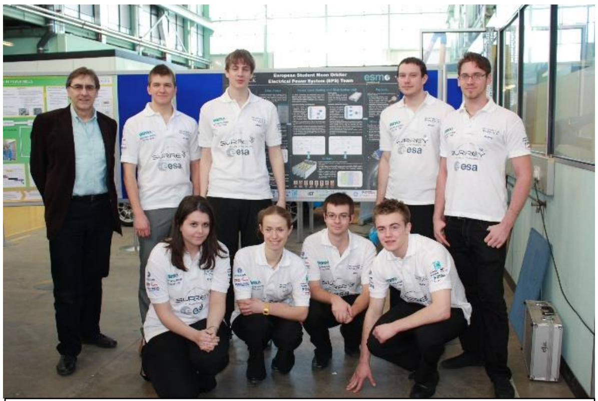
What I did have was many years of engineering experience, including electrical/electronic engineering, and the opportunity to put together a multi-disciplinary team of excellent engineering students from the School of Engineering[3] at Warwick. The – almost unique – organisational structure at Warwick, allows all engineering students to follow their degree discipline in a combined engineering department, but all 4th Year MEng students are then organised into multidisciplinary teams to participate in a major project that emulates how 'real world' engineering is carried out. WUSAT would become one of those teams!

The first of an endless series of remarkable coincidences that continues to shape the story of WUSAT, occurred during that visit to Steve's lab in Southampton. On the same day, Dr Roger Walker[4] (Project Manager for Educational satellite projects at ESA), also happened to be visiting. Whilst I was already feeling that I may be getting into something rather 'over my head', Roger then suggested that, rather than just develop Southampton's Power Supply

[1] https://www.ecs.soton.ac.uk/research/projects/Plasma%20and%20Space%20Science
[2] https://www.esa.int/Education/ESMO_mission
[3] https://warwick.ac.uk/fac/sci/eng/
[4] http://www.esa.int/Education/Young_Engineers_Satellites/Meet_the_team_-_introduction_Roger_Walker

system, Warwick could take on the role of being the Electrical Power Supply sub-system team for the entire ESMO satellite. At this point, also to be repeated many times over the coming years, I gulped, looked confident, and said “Yes, absolutely! Of course we can do that!”

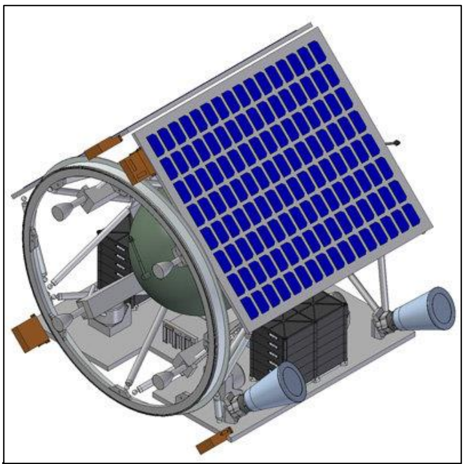
Hence, WUSAT was borne!



2010-11 Warwick Team – a typical mix of Mechanical, Systems, Electrical/Electronic, and Manufacturing Engineers

Despite our humble beginnings, over the next six years (2006 – 2012), WUSAT teams (still generally known as ESMO then) began to earn an excellent reputation with Roger Walker and the ESA team associated with the ESMO mission.

Each year we always provided a first-class multi-disciplinary team who were earning 25% of their 4th Year course credit for working on this project. We brought considerable resources into the ESMO project through an ever-expanding list of top-class companies with whom we made partner arrangements[5]. We were reliable, we adhered to the discipline of the systems engineering approach required for any successful Space project, and our students worked hard to meet the project demands. Given that we started with nothing in terms of knowledge or experience, it was no mean achievement that – after a few years – I was asked by ESA to attend a meeting of other European Space technology universities at ESTEC. I gave a talk on how the Warwick team operated and why our model was the one that ESA would like other European teams to try to emulate.



European Moon Orbiting Satellite Configuration

Surrey Satellite Technology Ltd were appointed as system prime contractor to the project, and after six years of design, analysis, trade-off’s, etc, the satellite concept was at the advanced stage shown.

We successfully completed the Phase A feasibility study, and design activities including completion of the Preliminary Design Review[6].

It was unfortunate that ESA then shelved the project in 2012 for budgetary reasons, but by then we had experience of working with 21 partners in 11 ESA States, and extensive experience of producing ESA documentation, and working with ESA processes, etc. We had also developed a very special way of working as a team that included our partner companies in a successful and unique format!

[5] https://warwick.ac.uk/fac/sci/eng/meng/esmo
[6] http://www.esa.int/Education/ESMO_mission

After six years of working on a relatively large-scale ESA project, we were suddenly on our own and wondering how best to capitalise on our hard-earned heritage. We decided that the only thing we could aspire to, given our modest resources, was CubeSat development. So academic year 2012-13 saw the development and launch of WUSAT-1, our first 1U CubeSat-based prototype.

WUSAT-1 being prepared for launch!

We quickly discovered that what we missed in terms of a large European project (and all of the discipline that went with it) was replaced by a project that we could progress very quickly into prototype/test stages. This was a distinct benefit for us!

WUSAT-1 was never intended to achieve much more than a launch we could track to its landing, and recover some basic data (temperature, etc) from its on-board SD card. It was launched on a high-altitude helium balloon from a CAA approved sight near Welshpool.

Fragments of the Helium balloon after it burst at 33km altitude.

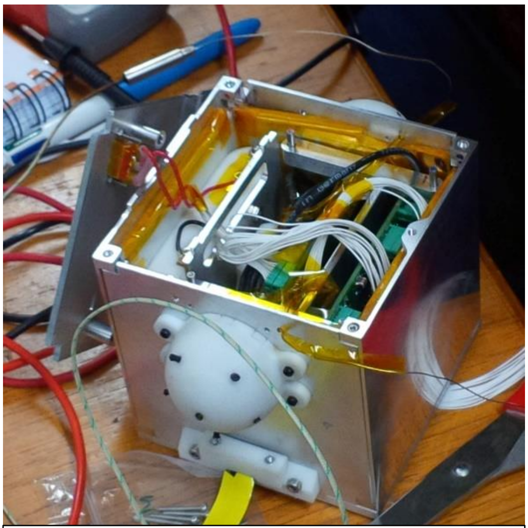
One advantage of a balloon launch is that you can bolt on external cameras, etc, without any worry about normal launch restrictions. As can be seen, this meant that we captured some tremendous images (and video clips). The flight time was quite short, so the CubeSat was encased in polystyrene that included recesses for outdoor activity-type ‘hand-warming’ packs to protect the internal circuitry!!

The team produced a predicted flight path using a proprietary software package and up-to-date meteorological conditions from the Met Office. This proved to be exceptionally accurate, as we eventually recovered WUSAT-1 and its parachute in a field less than 100m from the predicted landing site! A short video of the flight can be seen on YouTube[7].

A WUSAT-1 image looking towards Chester, Liverpool and the River Mersey.

[7] https://www.youtube.com/watch?v=m_sMcu_5BMs

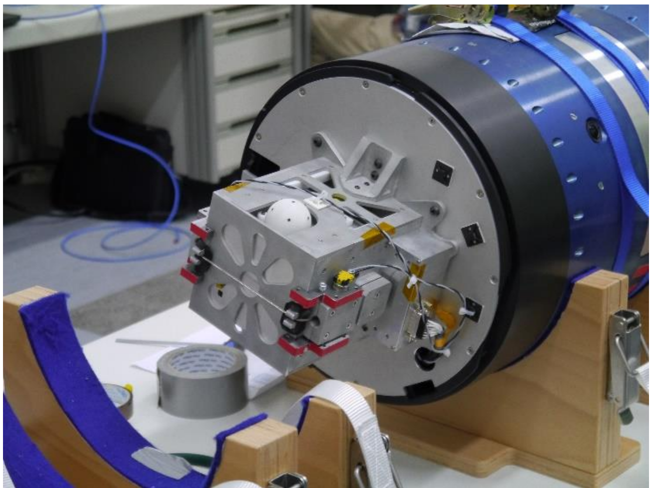
As a result of our success with WUSAT-1, we were encouraged to develop a more sophisticated CubeSat and apply for another ESA-backed project that would provide a launch for WUSAT-2. We applied for a place on the Rexus 17 programme – a collaboration with ESA, the German Aerospace Centre (DLR) and the Swedish National Space Agency (SNSA).



WUSAT-2 in development

In competition with 12 other European teams, we were successful in gaining this place in 2013. Prof Don Pollacco (Warwick, Physics) provided the payload concept for WUSAT-2. Don is an expert in the discovery of exoplanets, and provided the idea of a CubeSat sampling light frequencies as it entered the atmosphere of a planet. The light samples transferred to a light-spectrometer capable of filtering the light frequencies of elements such as Sodium and O^2. This allowed an estimate of the density of each element at different altitudes. From this, exoplanet scientists can deduce a great deal about the history of a planet.

WUSAT-2 was a two-year project, so once again the management of the project and the successful handover between two teams was a key element of the project's success.



WUSAT-2 in its custom-designed ejection module, mounted on the bulkhead of the Rexus 17 service module prior to launch

From an engineering point of view, WUSAT-2 was always going to be difficult. Most experimentation carried on a Rexus launch remains in the rocket's service module. Hence, the rocket's electrical power supply and communications link for downloading their data is available for their use.

However, WUSAT-2 was mounted under the rocket's nose cone that was due to be ejected at 90km altitude. Subsequent to a successful ejection of the nosecone, a signal would be sent to the WUSAT-2 ejection module and this would trigger the ejection of WUSAT-2. After a delay to allow safe clearance from Rexus, WUSAT-2 would boot up its subsystems, including its communications downlink, and begin recording light frequency readings against altitude levels as it descended through the atmosphere. Of course, it was doing this at approximately Mach 2, and through considerable temperature variations, etc. We knew it was highly unlikely we would ever recover the unit as it would bury itself several feet under the arctic tundra north of the Swedish launch site at Esrange. Hence, it was vital that the comms downlink worked under these arduous conditions!

Both WUSAT teams had worked very hard to take the project through each review stage carried out by teams of ESA specialists. Team 2 (2014-15) spent two weeks in Sweden to prepare for the launch.

Preparing WUSAT-2 at Esrange, the Swedish Launch Centre, near Kiruna.

One of the key elements of the WUSAT-2 system was the design of the helical antenna that would receive the downlink signal from WUSAT-2's telemetry antenna. An ESA advisor collaborated on the design of this crucial element.

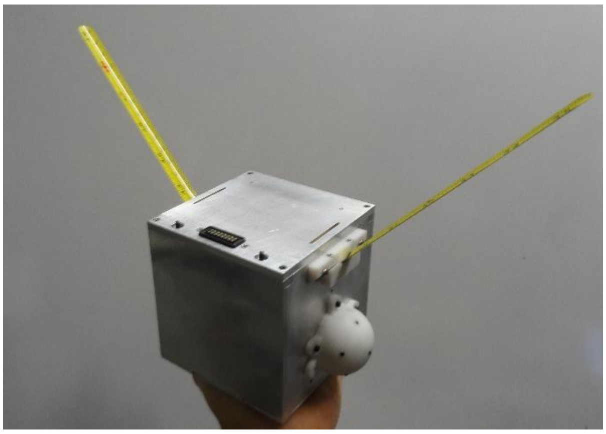
Two of these antenna were mounted on camera tripods as part of our ground segment. The picture shows one of them on Radar Hill approximately two miles from the ESRANGE launch site. We were fortunate to have such a beautiful day for the launch!

One of two helical receiving antenna, mounted at the optimum angle to detect the download signal from the descending satellite.

WUSAT-2 Ground Support team (including me!) who spent many cold hours on Radar Hill (north of the Arctic Circle)!

In the event, we had a perfect day! The launch went exactly to time. Everything worked as planned, and, after a short wait, we had the most exciting experience of receiving the signals on our ground station laptops.

This caused enormous exhilaration, not only for our team, but also for the ESA guys who were there and told us that we were the first ejectable unit to work and return data in 17 REXUS launches! An exceptional achievement for a small university team!!

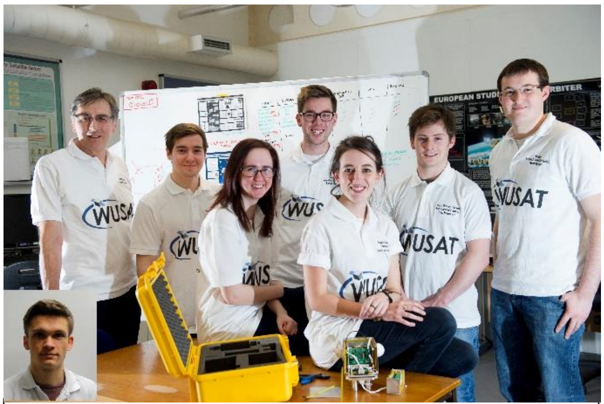


This image of WUSAT-2 shows one of the two 3D printed light sensing domes, the downlink antenna (made from pieces of retractable steel rule!), and the electrical connection for a link cable that detached at the point of ejection from the rocket.

An excellent video of the launch campaign can be seen on YouTube[8]. Well worth watching!

Following on from the success of WUSAT-2 was not going to be easy. We had spent eight of our nine years working on ESA supported projects. A significant achievement in itself for such a small, almost unfunded, university engineering team. However, what was to follow in the concept of the WUSAT-3 mission and the remarkable addition to the management of the WUSAT team is an amazing story in itself!

As the 2014-15 team prepared to graduate, I knew that we now needed to progress to a far more ambitious orbital launch. Despite our success and our good reputation with ESA, I also knew that to gain a place on a launch programme you needed to show that (a) you could produce the quality of engineering, and (b) you had an interesting payload/mission that would enhance the profile of such an ESA-supported project.



2014-15 WUSAT Team Press Photo

In my view, we already had a proven record for (a), so the task now was to find an exciting payload concept that would make WUSAT-3 look very special, and win us a place on the ESA launch programme that we wanted!

I already had in mind that, in order to do something really useful with a CubeSat in orbit, we probably ought to go for a 3-Unit CubeSat – essentially,

- 1U for electrical power control, central processing, etc,
- 1U for the payload
- 1U for battery, orbit control actuators, etc

though not necessarily segregated as strictly as that!

[8] https://www.youtube.com/watch?v=0E7G5_oZ00g

I also thought that ESA's 'Fly Your Satellite'[9] programme would be the most logical target to enable us to launch WUSAT-3 to Low Earth Orbit (LEO). The possibility of this FYS launch being via the International Space Station (ISS) was also a hugely exciting and highly ambitious prospect!

Secondly, in order to find a payload concept with 'real world' potential, I thought it would be better to approach one of our industrial partners for ideas of a concept that would be of interest to them. Once again, in typical WUSAT style, we really fell on our feet with this!

During the period of WUSAT-1 (2012-13) we had formed a partnership with Roke Manor Research[10], who are based near Romsey in Hampshire. Roke are a world-class electronics engineering consultancy with a very impressive range of technological developments, so we thought it would be well worth sounding them out for interesting WUSAT-3 payload ideas.

What they initially came up with was fascinating in itself! They proposed a direction-finding payload that would be capable of detecting a radio signal from a tagging device and then determining its location on the surface of the Earth. Apparently, this was a concept that they had been considering previously as a solution to an earth-bound requirement, but the possibility of trialling it from Low-Earth Orbit was of significant interest to them.

However, the whole WUSAT-3 payload/mission concept then took another enormous leap forward when Roke Engineer, Jonathan Pearson, had a stroke of genius in linking this idea to that of the ICARUS[11] programme.

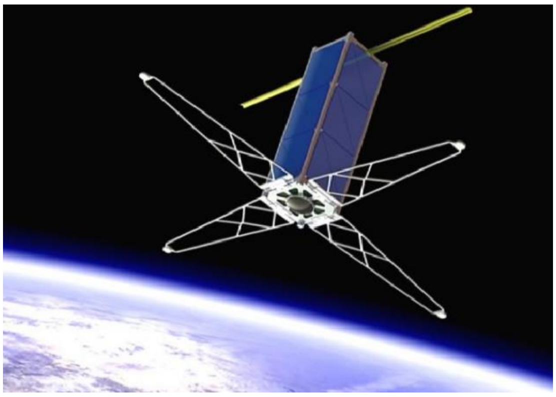
ICARUS (International Cooperation for Animal Research Using Space) is a large-scale wildlife monitoring project being developed by the Max Planck Institute for Ornithology. They plan to develop miniature tags that can be fitted to various forms of wildlife with the purpose of collecting GPS (movement tracking) and other forms of biological data. Their system has been launched to the International Space Station where it will be fitted and evaluated with a view to eventually producing their own satellite systems for future research use.

The ICARUS system for determining the location of a wildlife tag once detected, is to upload the GPS data stored in the tag when the ISS is within 'uplink' range. All other biological data

[9] http://www.esa.int/Education/CubeSats_-_Fly_Your_Satellite/Fly_Your_Satellite!_programme
[10] https://www.roke.co.uk/
[11] https://www.icarus.mpg.de/en

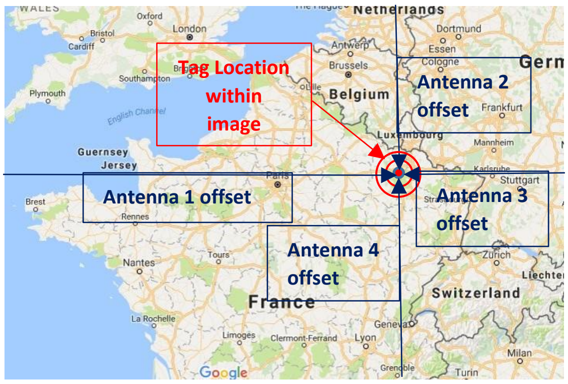
would also be transferred via the tag signal during the same uplink communication. The required functionality of the tag, could prove to be a barrier to how much its size & weight could be reduced.

We initially thought that WUSAT-3's direction finding payload could be used to detect the ICARUS tags. However, we soon realised that that could cause too much reliance on shared, confidential data from them, and decided that production of our own tag technology was far preferable. Nevertheless, we established communication with Prof Martin Wikelski (Max Planck), and we hoped to compare how our more modest system for tracking location data only will compare with ICARUS results.



WUSAT-3 would now incorporate, as part of its payload, a four-arm deployable antenna system. (See rendered image of an early WUSAT-3 concept). The orientation of this antenna system – pointing towards the Earth – would be maintained by an on-board Alignment Determination Control System (ADCS).

Receipt of a tag signal by the payload antenna would trigger a camera, installed in the centre of the antenna system, to take an image of the Earth's surface containing the location of the signal source – i.e. the wildlife tag. Post-processing could later use signal-shift differences between the four payload antenna chips in order to fix the location of the tag signal source within the image taken. Further processing of the image and source location could map the image location to Earth coordinates to give an actual map reference location of the tag at that time.



This diagram shows the concept of the image/antenna location process.

The WUSAT-3 tag-signal location process would not expect to provide location information anything like as accurate as the ICARUS system using GPS data. However, we do not require our tag to collect GPS data, nor biological data, and therefore, in principle, the functionality of the tag would be much simpler, and potentially the tag could be smaller and lighter. The tag would only need to transmit a relatively simple signal that WUSAT-3 would identify and recognise as a viable tag ID.

Users of wildlife tracking technology have a considerable range of requirements, and hence a tag capable of being fitted to, e.g. a smaller bird species previously incapable of carrying a tag, would increase the range of wildlife capable of being monitored for research/conservation purposes. In such cases, a location accuracy in the range of 100 to 200km would often be more than adequate. Hence, we had an extremely exciting mission concept with an output that could provide a real 'market' need within the wildlife tagging community!

By the completion of academic year 2015-16, the first WUSAT-3 team and I – working with Roke Manor Research – had determined the basic mission for WUSAT-3:-

- A 3-Unit CubeSat
- Carrying a signal direction-finding payload
- Potentially enabling the development of a satellite-tracked wildlife tag smaller in size and weight than any previously available for Space monitoring.

The next major development of this mission – and of the WUSAT story in general – was something I could never have envisaged! I had now been working on my own with WUSAT teams for 10 years. Although this had often proved difficult, I had never wanted to share it with anyone as I had developed a culture, a method of working with partner companies, ESA, and the teams themselves, that was very much my own. And it worked!

Of course, by 'anyone' I really meant another Warwick academic. Not that I didn't have good relationships with everyone in the School of Engineering at Warwick, but I was concerned that the approach of most academics would not be conducive to the whole 'spirit' of WUSAT and the way we operated.

In October 2016 this was to change, but in a way that I never could have envisaged, and in a manner that seemed so natural and seamless that I never once questioned it.

At that time, I was still acting as a volunteer beekeeper at the Natural Trust's Hidcote Manor Gardens near Stratford-on-Avon. During my usual Wednesday visit, I was pushing my wheelbarrow full of beekeeping kit back up through the gardens, having just inspected the bees. One of the staff gardeners pointed out to me that a new volunteer gardener called Julia had just started. Looking behind him, I saw a head of red curly hair and a woman kneeling in one of the borders doing some weeding. I said hello, we exchanged a few words about beekeeping, and I carried on without further thought.

Later that day, as I pushed a large trolley of my kit back up to the car park, I saw Julia making her way back to her car. I said cheerio, and when she came over, I fully expected to have the usual conversation with most people there, based on 'How are the bees doing?". To my amazement she said "Do you have something to do with satellites?". I was even more amazed when, having told her about my role with WUSAT, she reeled off all of her incredible experience as a Space Systems Engineer with British Aerospace, EUMETSAT, etc.

Here we are meeting in Hidcote's Gardener's mess room, looking as remote from Space engineers as you could possible get!

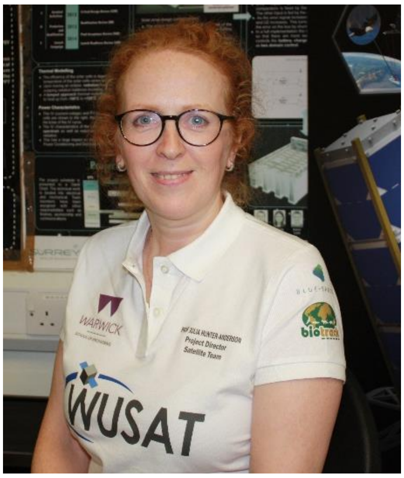
Julia came into a WUSAT Team Meeting at Warwick. We met the Head of Engineering who offered to make her a Visiting Industrial Professor for WUSAT (Professor Julia!!), and since then we have gone from strength-to-strength extending the WUSAT programme into a number of areas that I would never have found the time to pursue when running WUSAT alone. Fate taking matters in hand once again!

This image shows Julia and I with the 2018-19 WUSAT team. A typical team discipline mix of Mechanical, Manufacturing, Systems, and Electronics engineers. As with all of our teams, they are bright, very capable, and a delight to work with. We do our best to make every opportunity and experience available to them. The fact that every one of this particular team were able to attend ESA training programmes during their year with us, is testament not only to the great experience they receive, but also to the excellent reputation we have with ESA.

At the time of writing, we are looking forward to the final stages of WUSAT-3, seeing a launch to the International Space Station, and hopefully concluding a successful evaluation of its wildlife-tracking mission. We are part of a new Midlands Space Group and aim to be instrumental in helping to develop Space technology resources in the Midlands area. We also intend to pursue research into how satellite-based wildlife tracking can best meet the needs of researchers and conservation groups who will have a wide range of requirements.

We continue to pursue new partnerships, which during this year has included Airbus, BAE and AMSAT-UK. We work hard with limited resources, but despite how far we have come in the last 14 years, WUSAT mainly continues to thrive on a series of happy coincidences, intuition, personality and being the sort of people that other people want to work with!

Who knows what the future will bring!



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