15 Years of Distributed Science Operations with INTEGRAL

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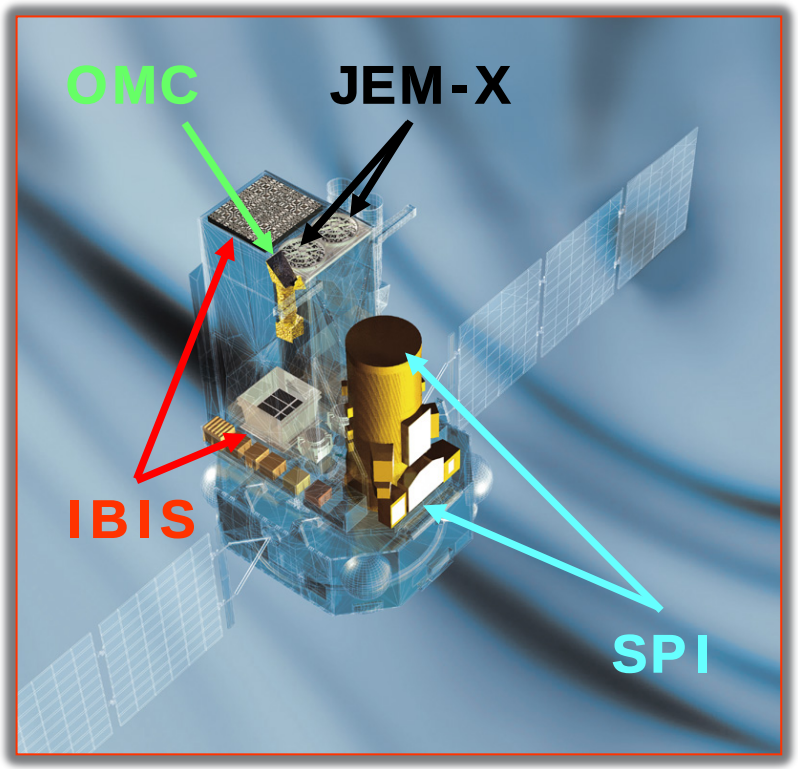
integral

→ SEEKING OUT THE EXTREMES OF THE UNIVERSE

ESA, C. Carreau

A broad-band, wide-field observatory

- **INTE**rnational **G**amma-**R**ay **A**strophysics **L**aboratory
- Medium-sized mission (Horizon 2000), Launched **17 O**
- Highly elliptical orbit (~64 hrs); ~50 hrs of continuous sc e



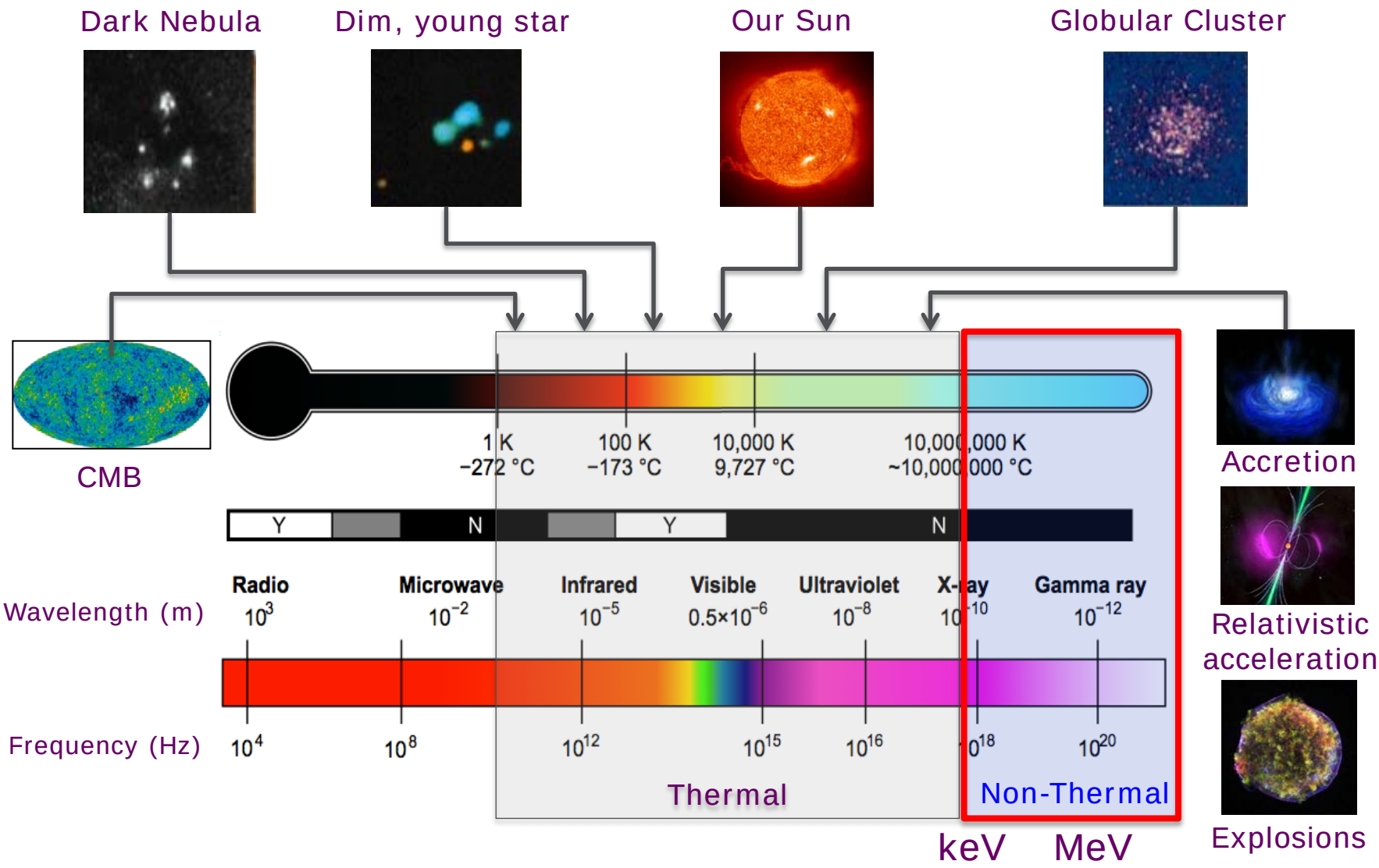
- **4 instruments:**
  - **IBIS:** 15 keV-10MeV imaging [angular resolution: 12']
  - **SPI:** 20 keV-8 MeV spectroscopy [ΔE = 3 keV @ 1.7 MeV]
  - **JEM-X:** 3-35 keV X-ray monitor
  - **OMC:** V-band optical monitor

- ***All operating simultaneously***
  - IBIS, SPI, JEM-X: coded mask → large FOV [~900 square degrees]

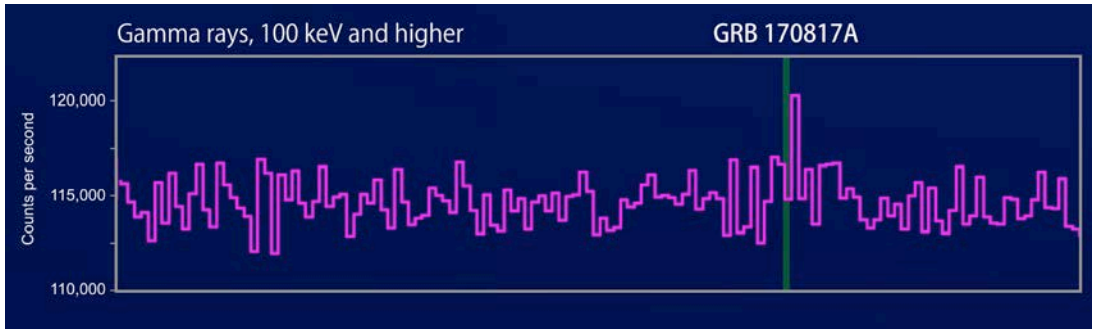
+ Omni-directional view through shields

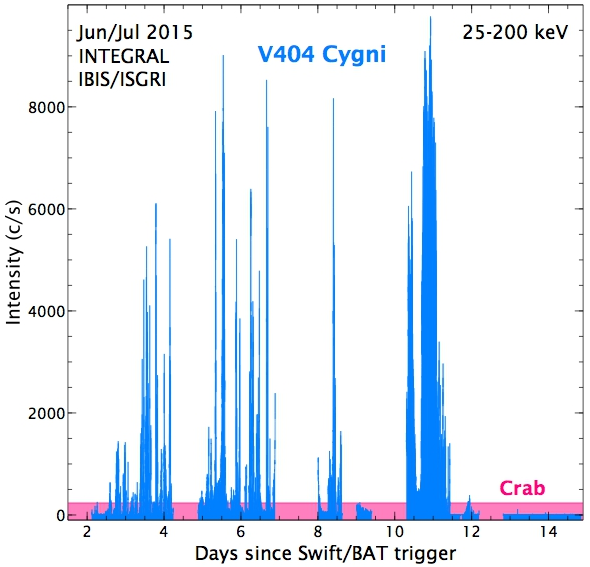
- IBIS, SPI: γ-ray polarimetry

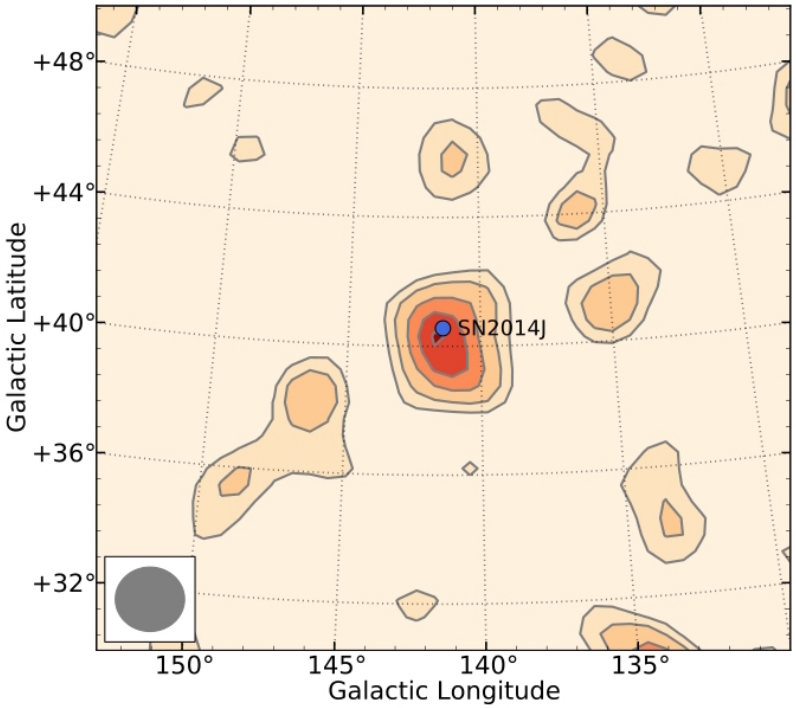
High-energy X/γ-rays probe the extreme, non-thermal Universe

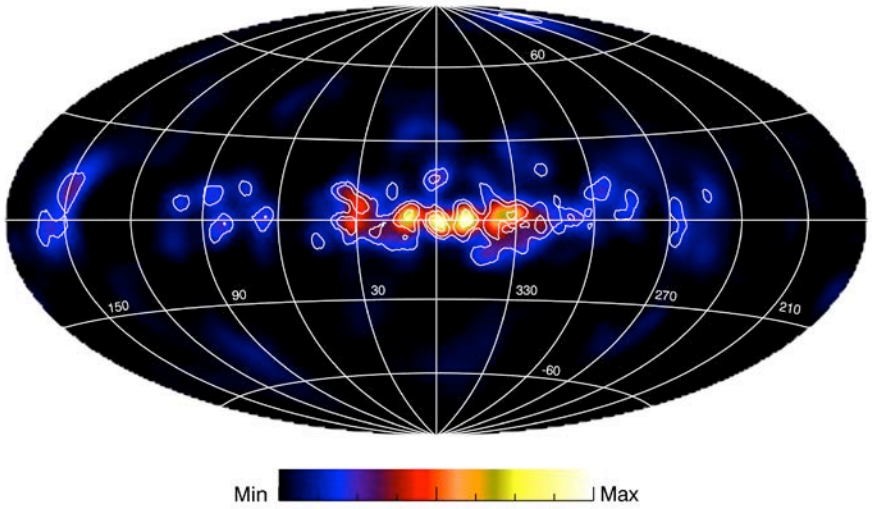


Science on timescales from less than a second to many years

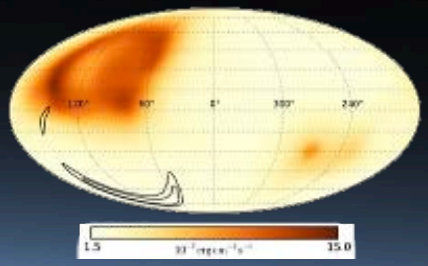


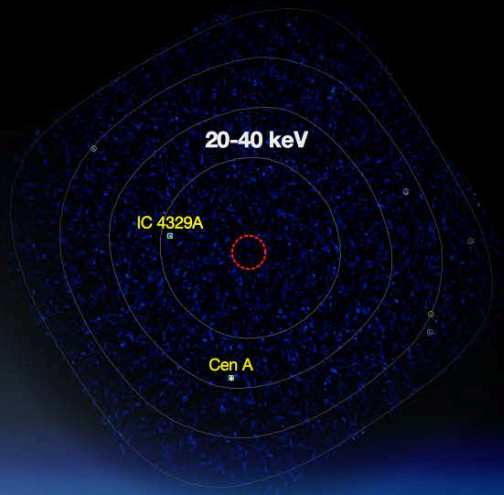


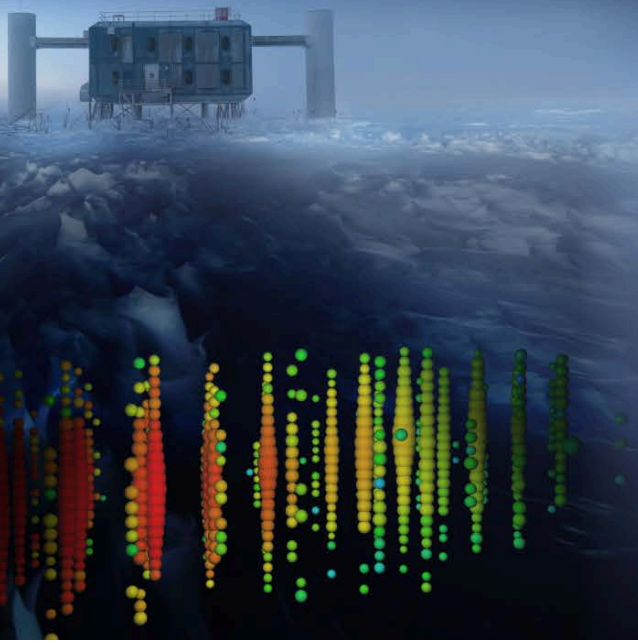




Now also involved in multi-messenger astronomy



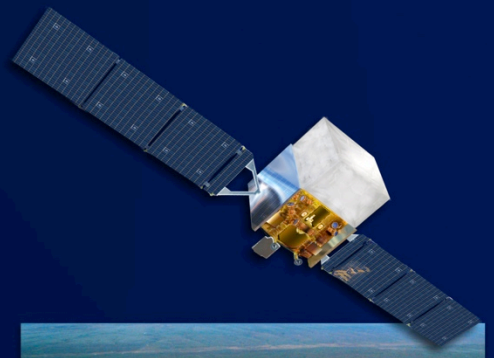




- **Direct omni-directional monitoring**, mainly via the radiation shields
- ToO observations of high-energy neutrino events from IceCube.
- Check of LIGO/Virgo events (MoU for direct contact) and follow-up, when possible.

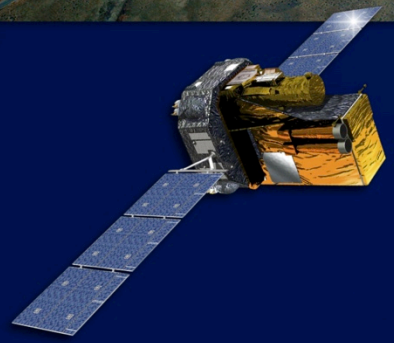
First electromagnetic counterpart to Gravitational Wave event found!

Hot news 16 Oct 2017!



Fermi

LIGO Hanford



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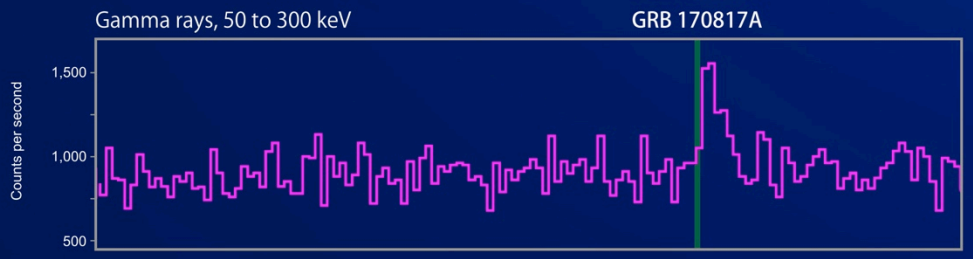
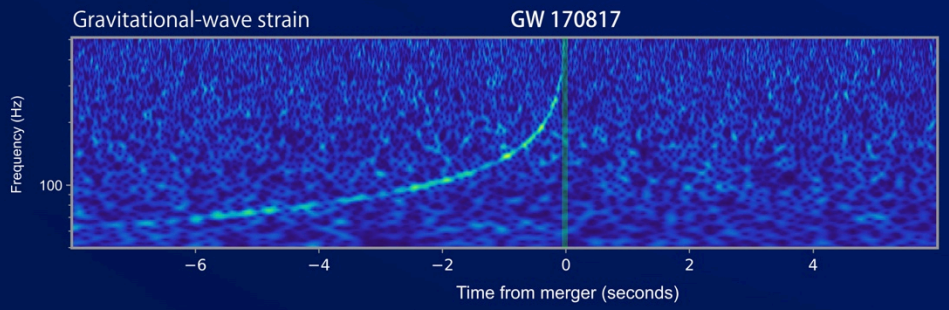
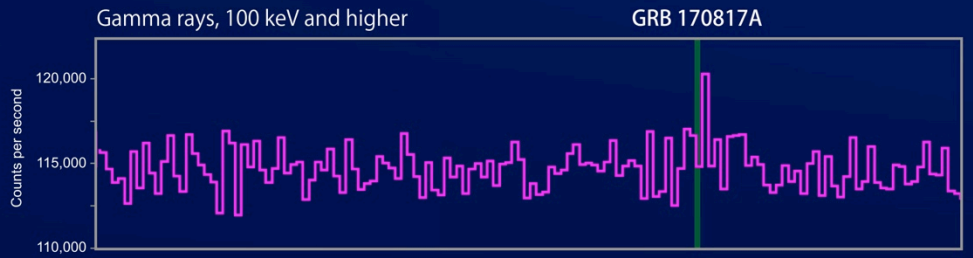
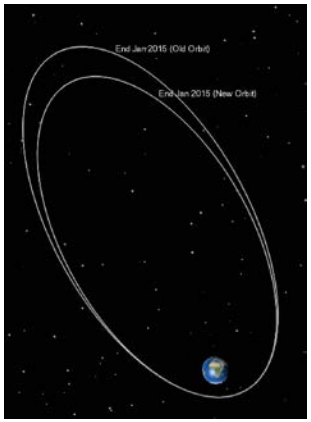






Long-lived, but not forever in space …



Phase A start
1991

Mission selected
1993

AO for instruments & ISDC
1994

Selection of instruments & ISDC
1995

ISOC & ISDC start development
1995

GSRR + FAR
2002

Launch
2002

ISOC moves to ESAC
2005

Orbit change for Disposal
2015

15th Anniversary
2017

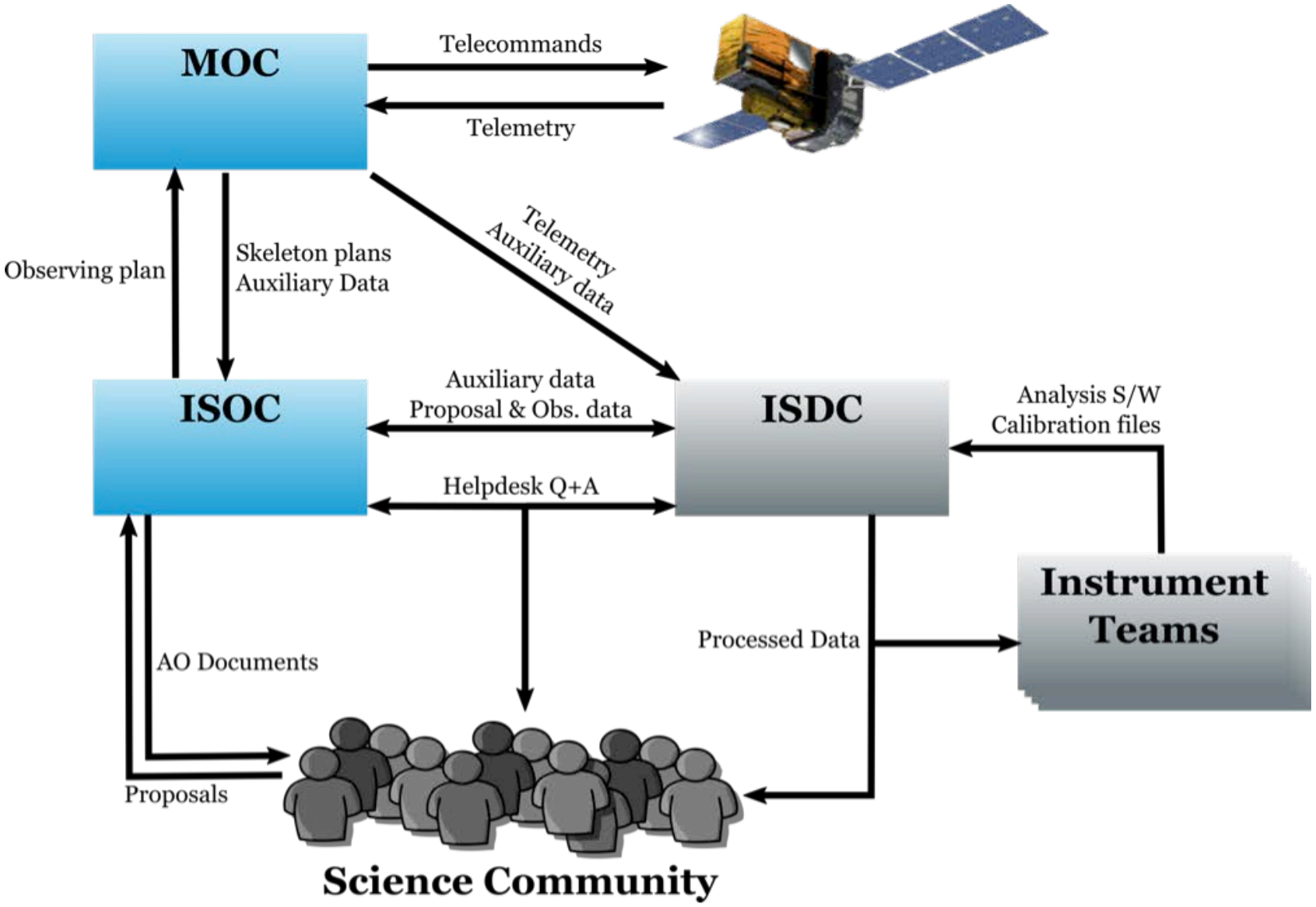
Re-entry
2029

1990 2000 2010 2020 2030

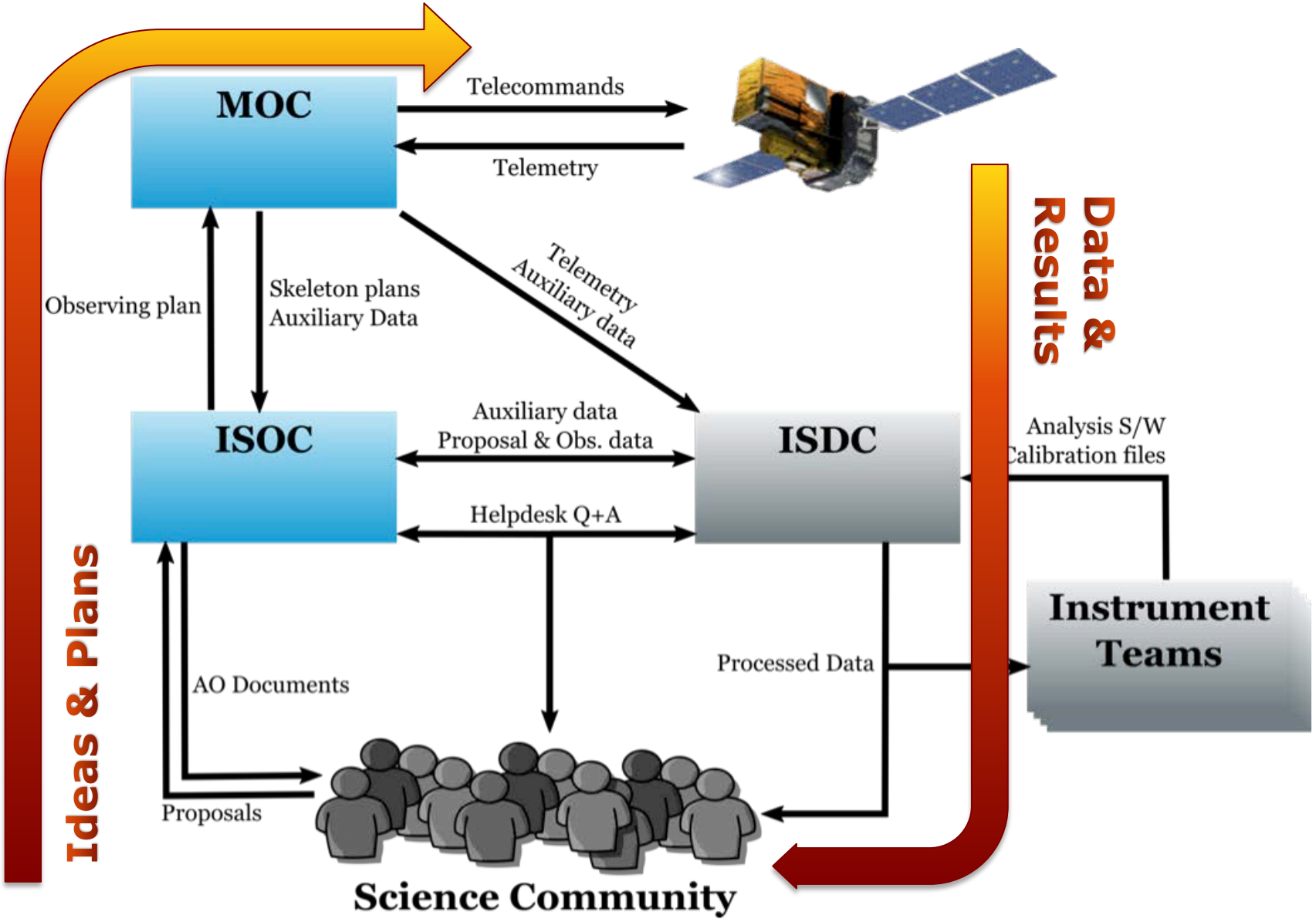
Operational duties distributed over Europe

- SOC at ESAC (up to 2005 at ESTEC).
- MOC at ESOC.
- Project Scientist at ESTEC.
- Science Data Centre near Geneva (CH).
- Main PI teams in France, Italy, Germany, Denmark and Spain.

Data & information flow



Data & information flow



Responsibilities in Science Operations

- **SOC**
  - AO handling, incl. technical evaluation, TAC support.
  - Observation planning – long- and short-term.
  - Community support (Helpdesk & News).
  - Legacy Archive (in post-operations).
- **ISDC**
  - Data processing from telemetry to standard data products (L0 – L3), data distribution to observers and operational Archive.
    Near-real time data available few hours after data taking on-board.
  - Quick-look analysis & status monitoring, incl. trend analysis.
  - Analysis s/w development (general & infrastructure), distribution, and documentation.
  - User support (shared with SOC within one environment).
- **Instrument Teams**
  - Calibration, responses, etc.
  - Development of instrument-specific analysis s/w (ISSW).

Building up Science Operations

- ISDC and Instrument Teams had little experience in systematic software development for an open observatory. Major effort to achieve coherence and usage of standard formats and libraries by software developers across sites.
- ESA contributed to build-up of ISDC. First with training, then support for QA and for testing. Closer to launch also with direct support for operations.
- At launch >20% of ISDC personnel were under ESA contract. Some support remains until today.

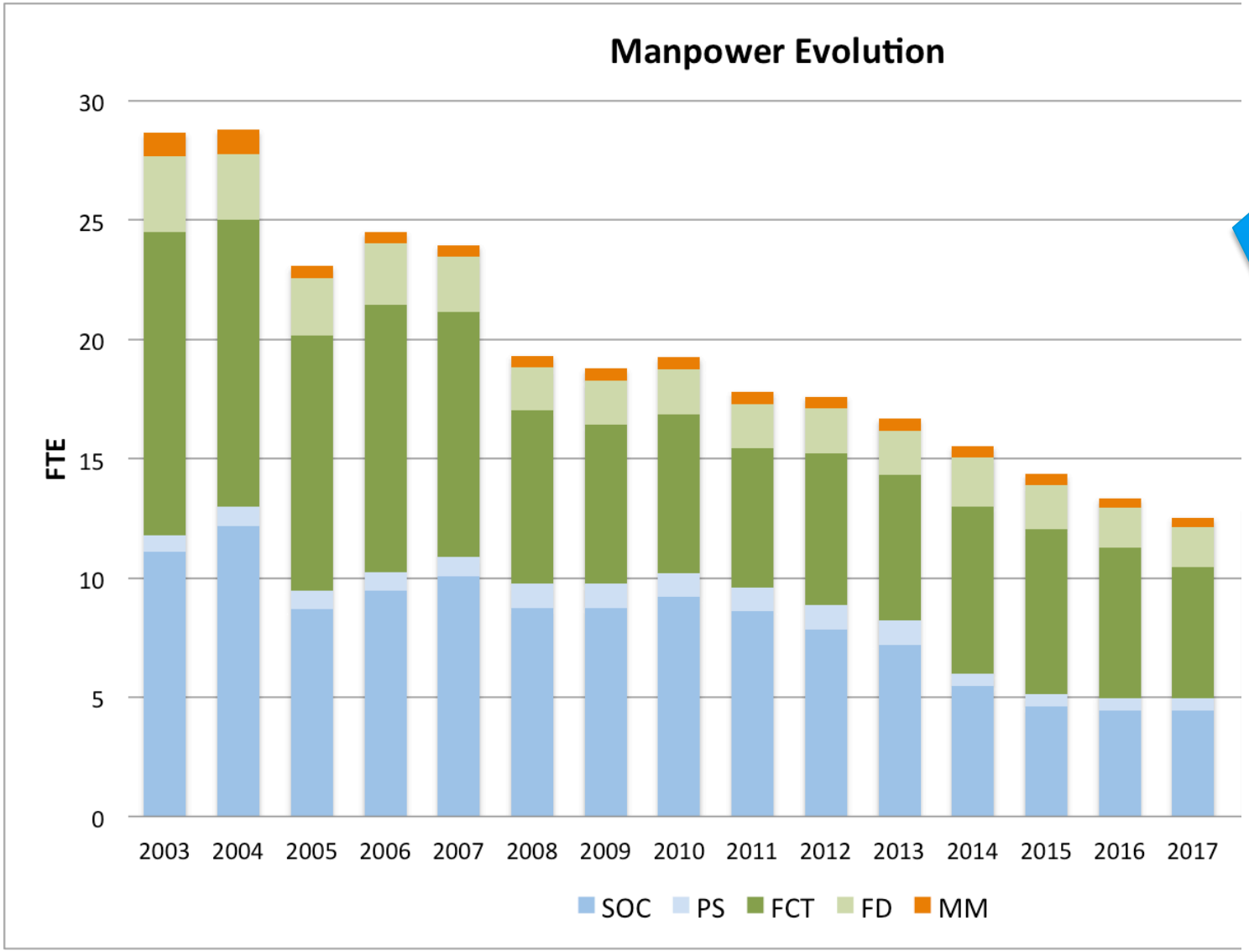
➥ Very useful experience for Univ. Geneva in future large projects!

- SOC system built up new by internal team (staff & contractors).
- MOC system based on SCOS 2000.

15 years of successful operations

- Ground Segment worked from day of launch, essentially without interruptions.
- Longest breaks due to major solar flares or similar issues outside ground control.
- Typical performance >99% of planned!
- Adapted in many ways over years:
  - fix problems, improve performance, add functionality;
  - accommodate changes in instrument operations, data policies, observing modes, …;
  - streamline routine operations, simplify work for humans.

Work remains, available people diminish …



Similar picture for ISDC & Instrument Teams

Science Operations with fewer people

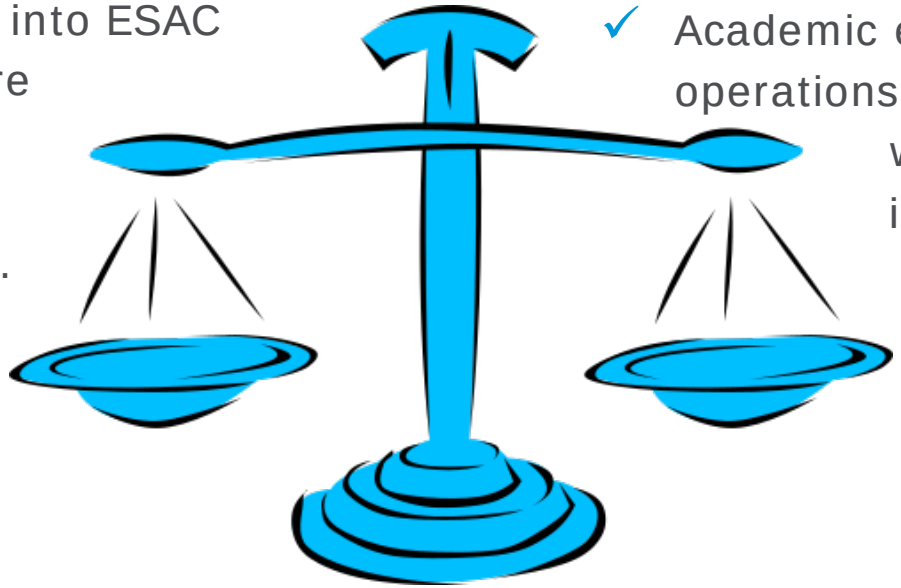
- General strive to simplify operations, streamlining routine tasks.
- Increased use of automatic processes, interfaces and checks, wherever possible.
- Less meetings in person, less formal structures, *more* formal and informal electronic exchange. *Increase* in networked meetings or video-conferences, some regular, some ad-hoc.
- Reduced reporting, more direct access (Web) to relevant data.

➥ SOC + MOC + ISDC work more like one, distributed team.

- Less capacity to due special, non-standard observations.
- Slower updates of calibration data and of analysis software.
- Anomaly recovery slower and specialists less reliably in touch.

In the balance

- More complex interfaces within Science Ground Segment than “one SOC does all” solution. Strong dependency on ISDC.
- National support for data centre activities less stable.
- Significant effort to build up operational skills in community.
- PostOps will require special effort to integrate Archive into ESAC system and assure long-term maintenance of analysis software.



- ✓ A well-working system, developed and maintained with limited funding.
- ✓ Build-up of operational knowledge for different projects in community.
- ✓ Sense of community reinforced by common effort.
- ✓ Strong data centre helped achieve coherence across very varied instruments.
- ✓ Academic environment ensures operations driven by scientists with personal interest in results ➟ special motivation for e.g., quick-look analysis, transient follow-up, GW counterparts, etc.