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Credit: SKAO

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Lecture 1011

Federation & scaling approaches for exascale data

Lecturer: **Dr Jeremy Coles (jc574)**

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Lecture 1011

$$(1011)_2 = (1 \times 2^3) + (0 \times 2^2) + (1 \times 2^1) + (1 \times 2^0)$$

Federation & scaling approaches for exascale data

Lecturer: **Jeremy Coles (jc574)**

Credit: SKAO

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Before we start …

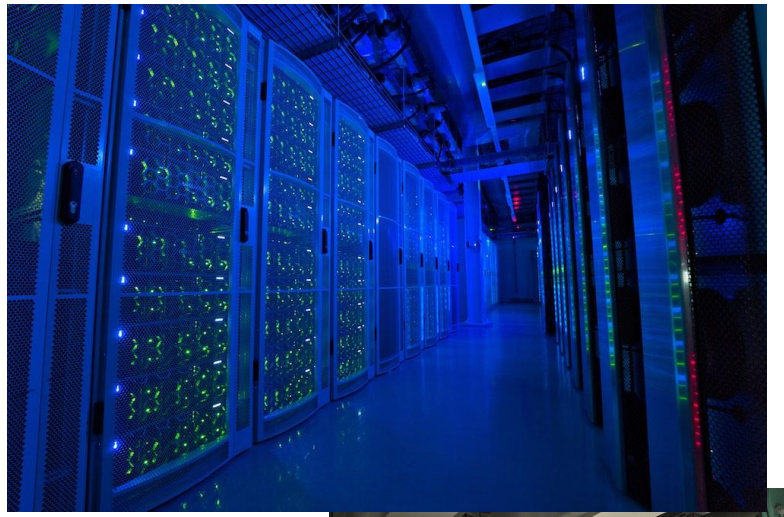
Data Centre tours. 5 signed up for Monday 26th.

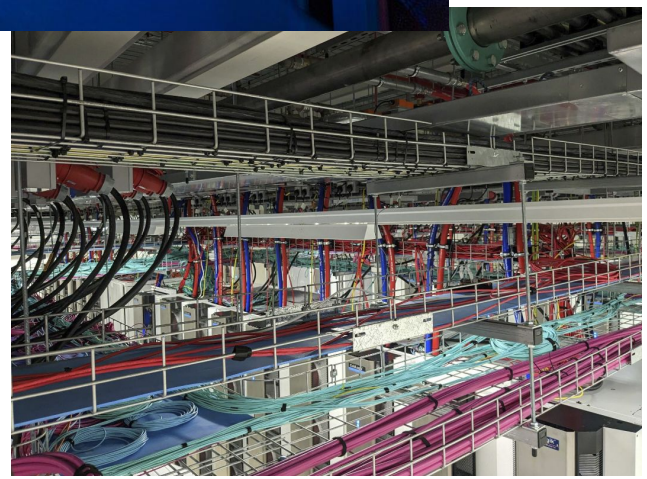
We're also running some visits on Wednesday 28th. But **you must be signed-up in advance** AND **bring your photo ID** on the day.

CSD3 - still in top 500: https://www.top500.org/site/49143/

Dawn - The Cambridge Open Zettascale Lab is hosting Dawn, the UK's fastest artificial intelligence (AI) supercomputer. https://www.hpc.cam.ac.uk/d-w-n

6PB Lustre system …





Credit: Joe Bishop

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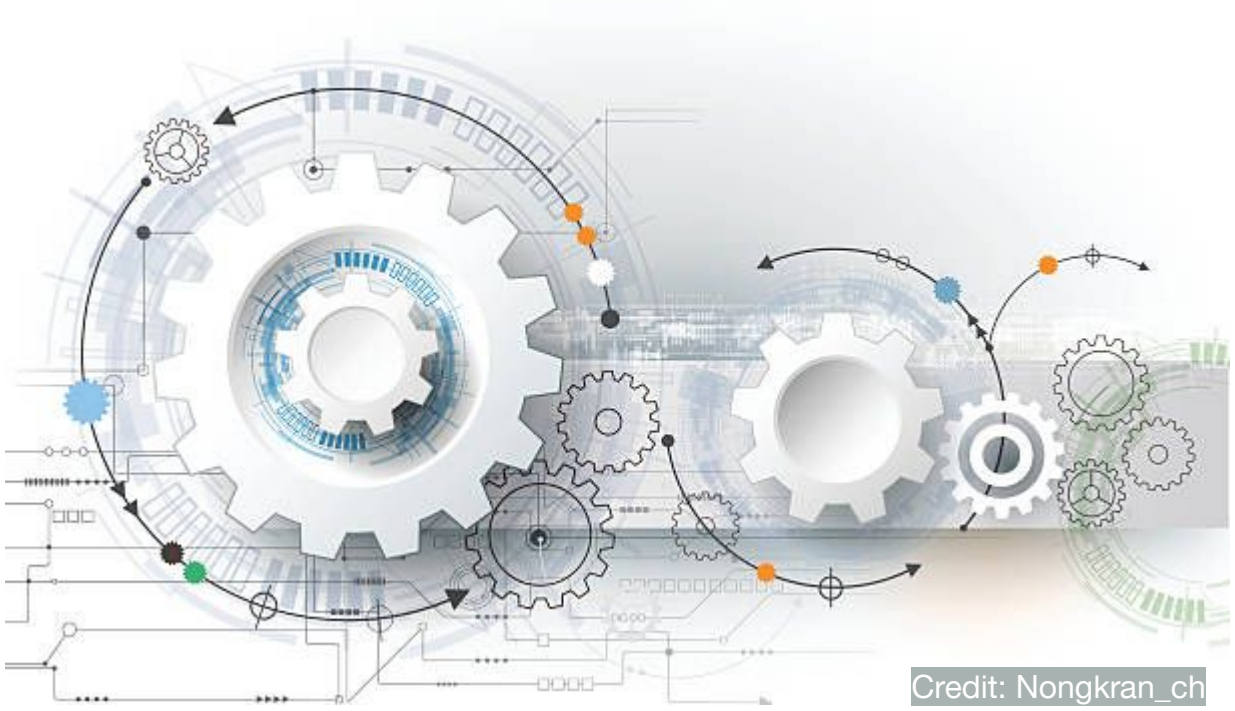
Conclusions

- There are lots of moving parts in large data projects
- This lecture can only cover some aspects
- Existing computing solutions cover specific use-cases. For federating we often evolve them.
- Project constraints and capabilities require constant trade-offs
- High-Performance Computing (HPC), and federated computing, is a research topic in itself!



Credit: Nongkran_ch

Spoiler alert

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Why bother?

http://www.

Credit: Paul Clark

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Be curious!

Infrastructure

Infra- means "below;"

Structure From Middle French *structure*, from Latin *structūra* (“a fitting together…)

The infrastructure is the "underlying structure" … the fixed installations that it needs in order to function.

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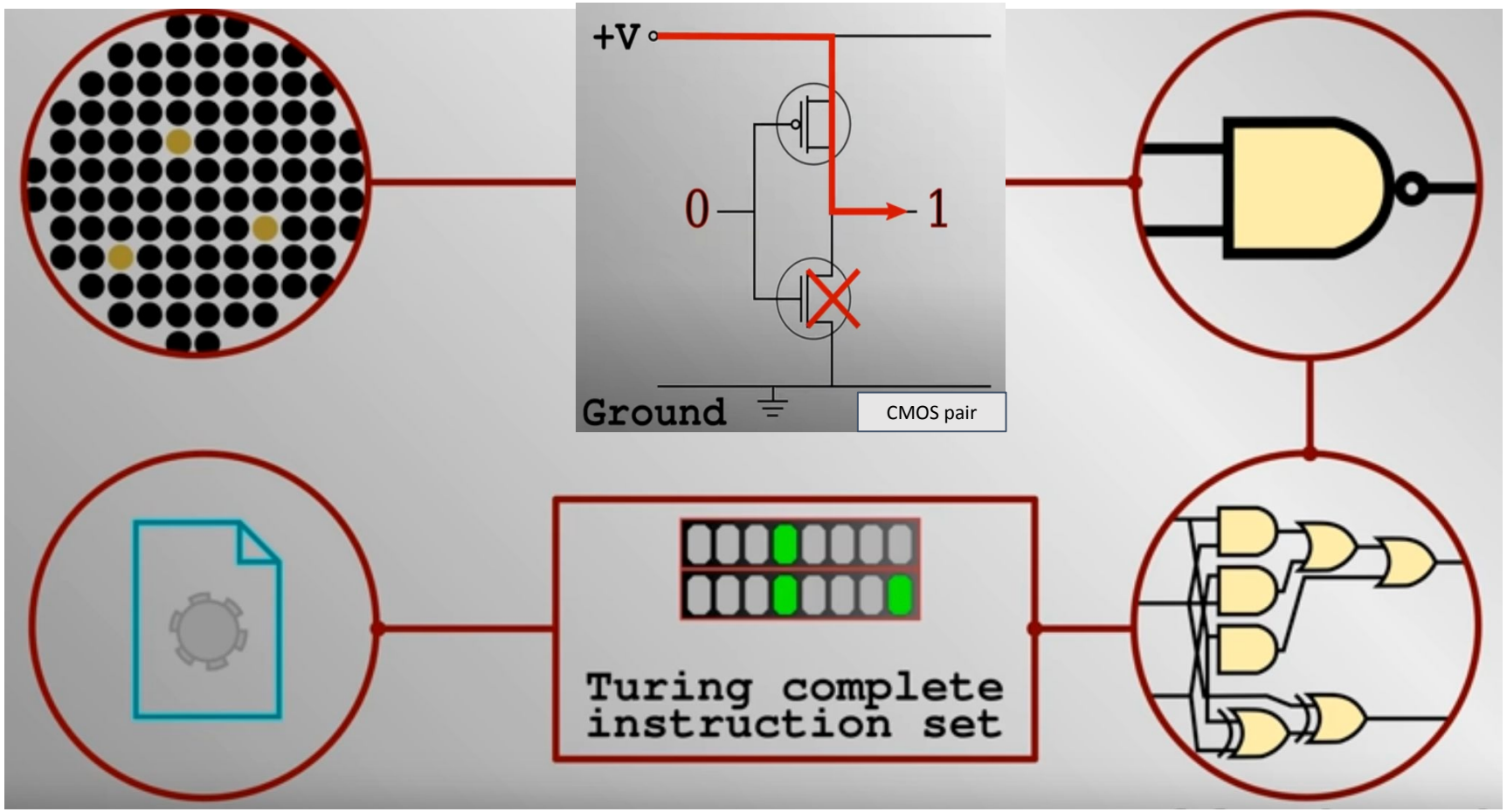
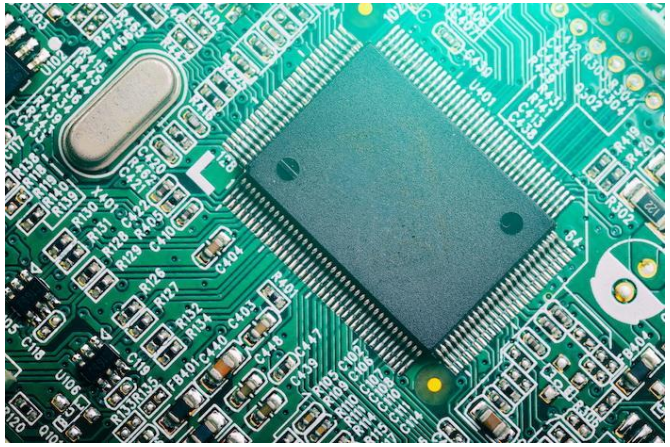
How compute, storage, switch works



Credit: IM



Applying voltages drives switching

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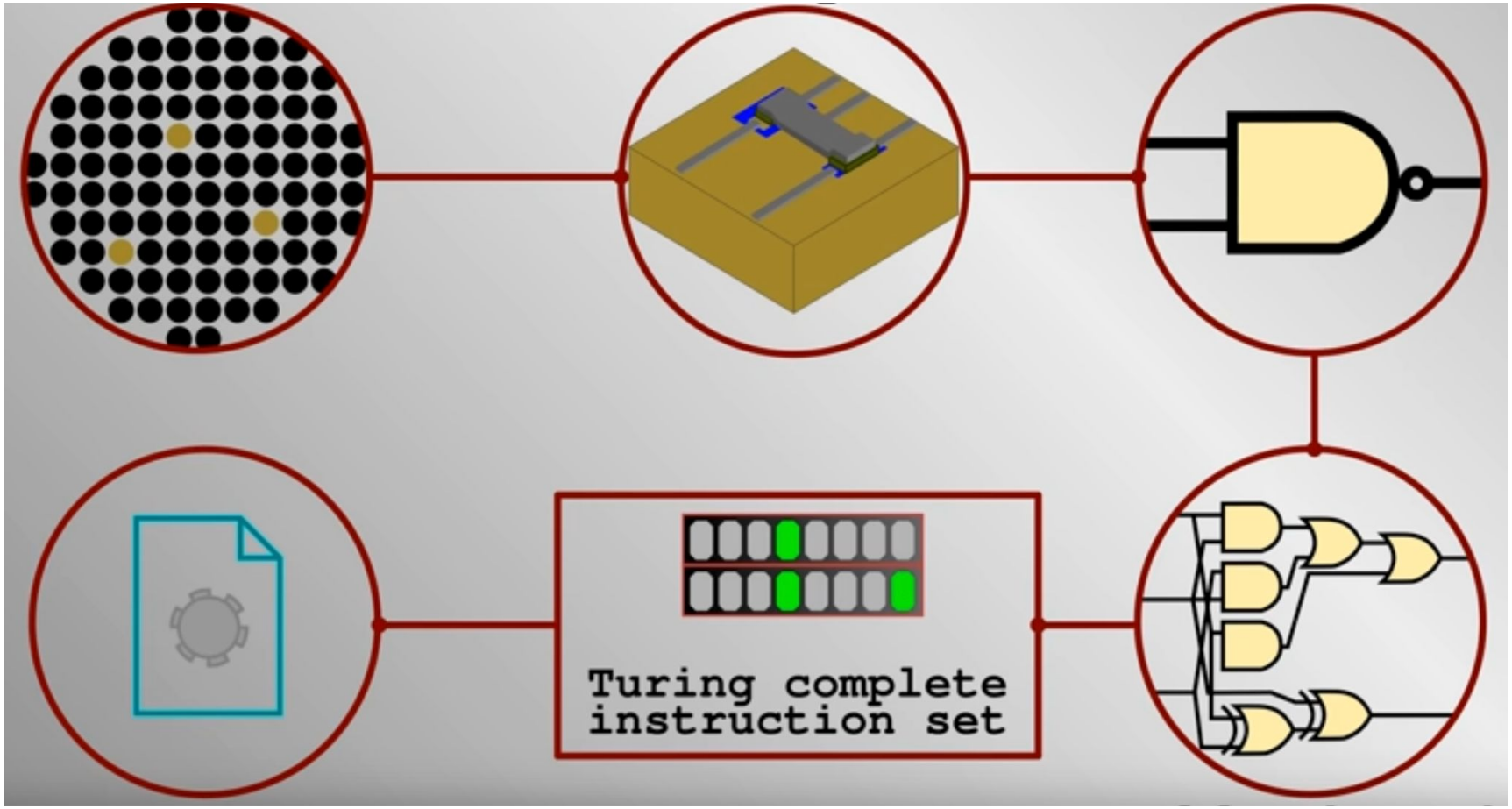
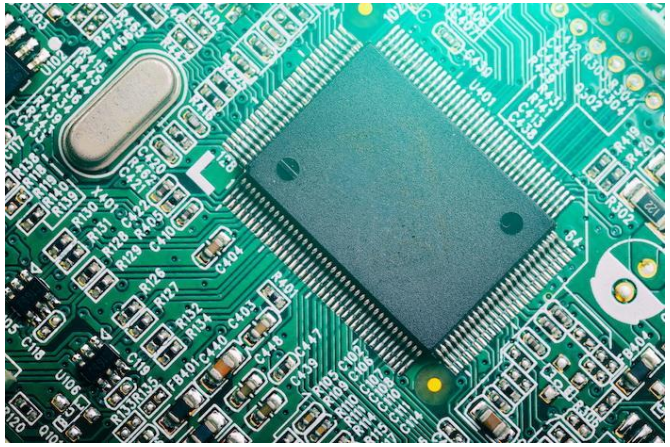
How compute, storage, switch works



Credit: IM



It all depends on paired transistors

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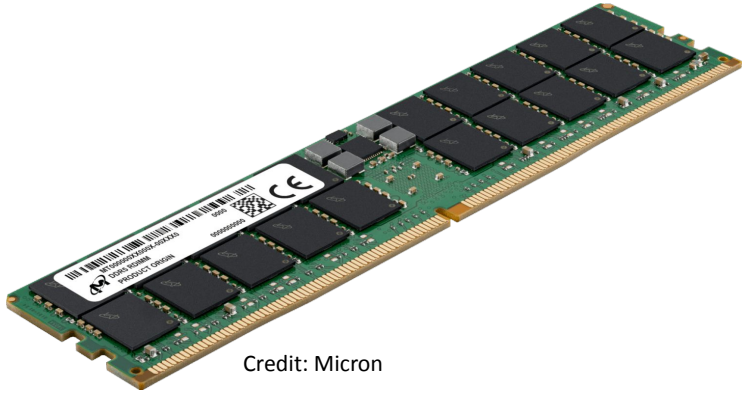
Core components

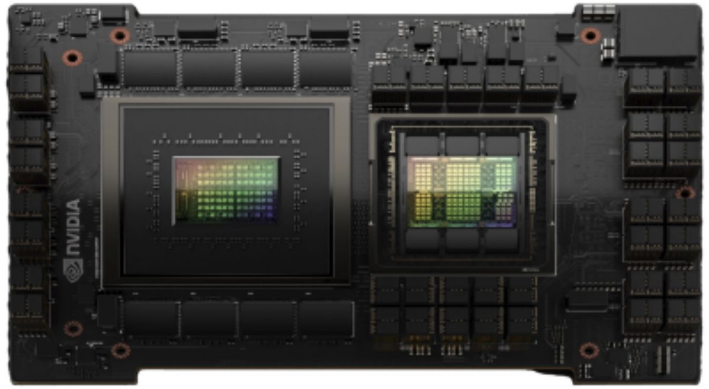


Credit: Micron

Dynamic Random Access Memory (DRAM) - billion capacitor memory cells (17 nanoseconds)

Solid State Drive (SSD) 3D trillion memory cells

Hard disk drive



Credit: nVidia

Memory: Cache | registers | DRAM | SSD | HDD. Speed vs capacity - cost

Processing: CPU vs GPU and combinations!

Each consumes energy to work

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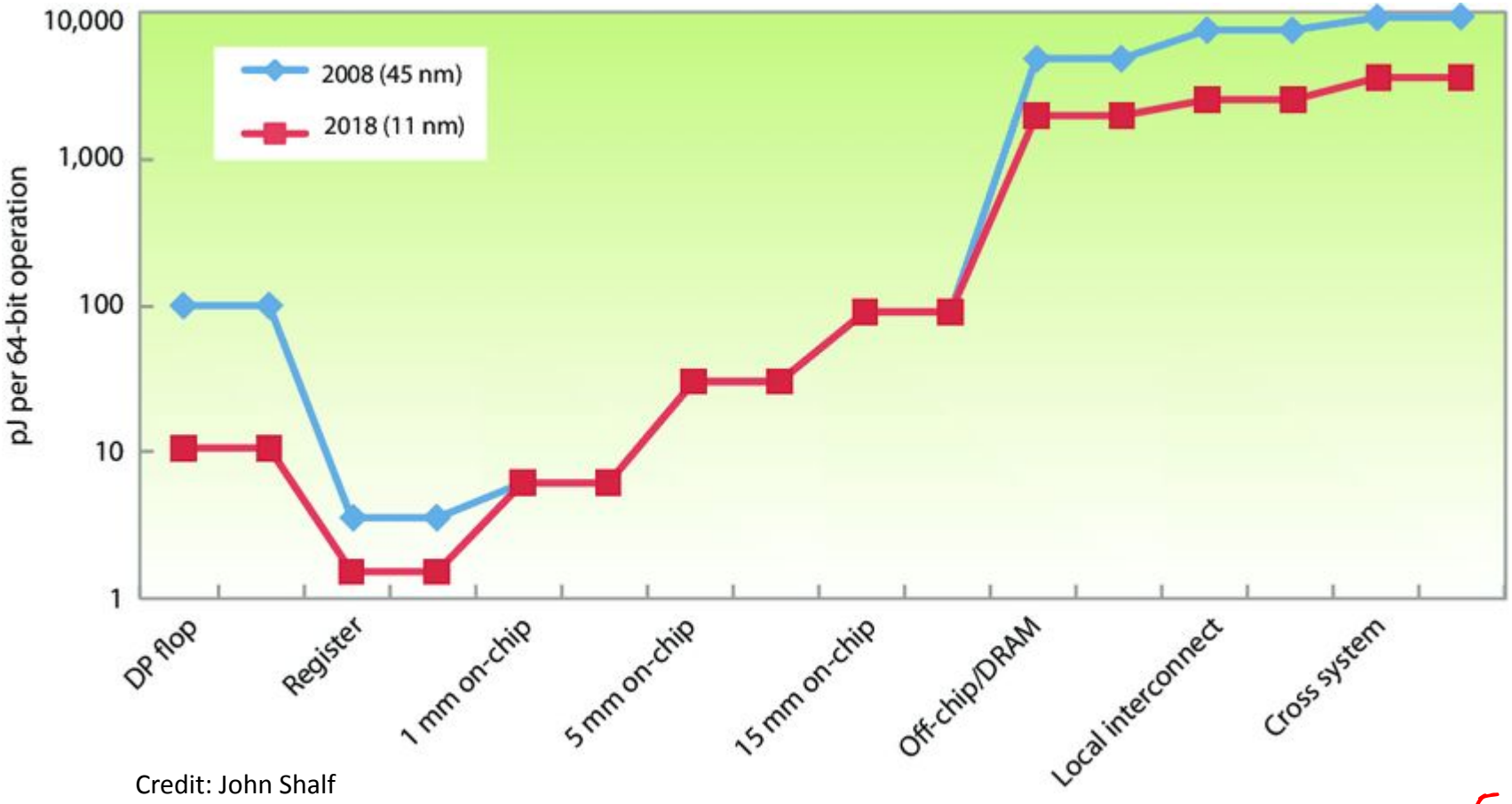
Bits, energy and cost



Credit: John Shalf

Every bit has a cost

1 pJ = One million millionth of a joule
It takes about 1 joule to raise a 100g apple 1m

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How does this impact Data Science activities?

- Maintenance
- Problem solving
- Capabilities
- Performance
- Connectivity
- Optimisation
- Total and hidden costs
- …

Informed tradeoffs are needed

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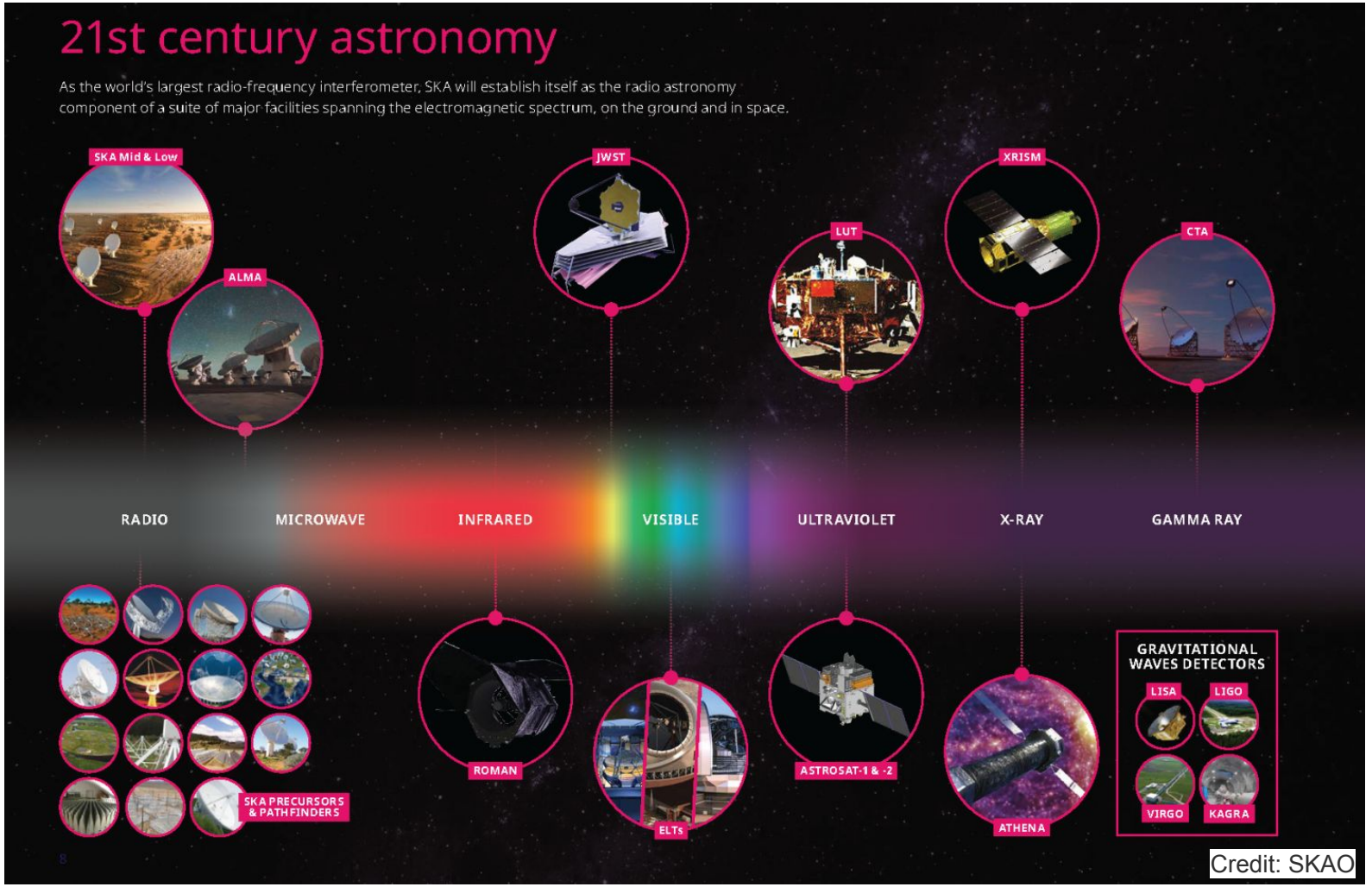
A reminder



Radio and visible wavelengths are less absorbed by the Earth's atmosphere

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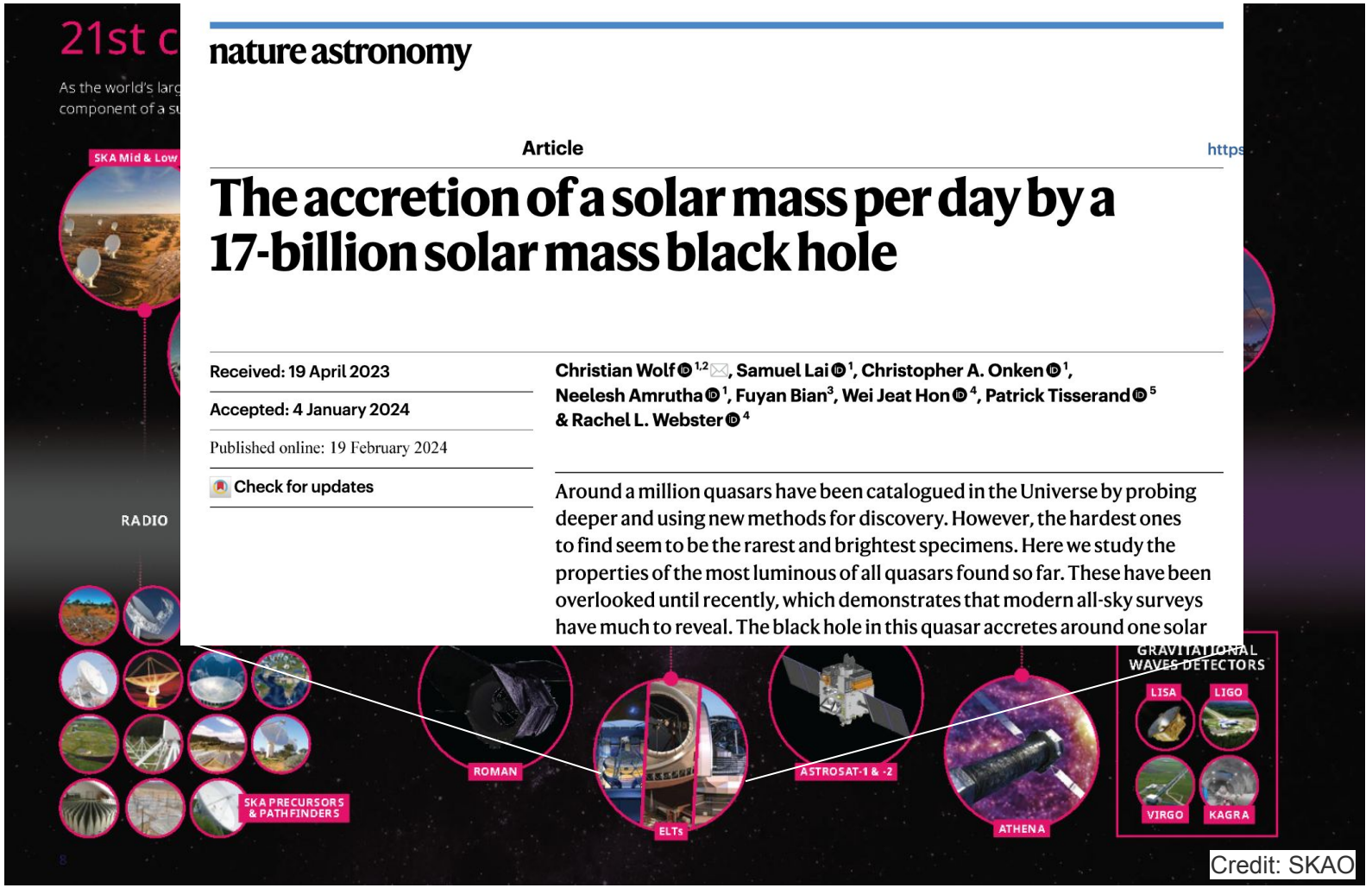
A reminder



nature astronomy

Article

https

The accretion of a solar mass per day by a 17-billion solar mass black hole

Received: 19 April 2023

Accepted: 4 January 2024

Published online: 19 February 2024

Check for updates

Christian Wolf[1,2], Samuel Lai[1], Christopher A. Onken[1], Neelesh Amrutha[1], Fuyan Bian[3], Wei Jeat Hon[4], Patrick Tisserand[5] & Rachel L. Webster[4]

Around a million quasars have been catalogued in the Universe by probing deeper and using new methods for discovery. However, the hardest ones to find seem to be the rarest and brightest specimens. Here we study the properties of the most luminous of all quasars found so far. These have been overlooked until recently, which demonstrates that modern all-sky surveys have much to reveal. The black hole in this quasar accretes around one solar

Lots of exciting discoveries to come!

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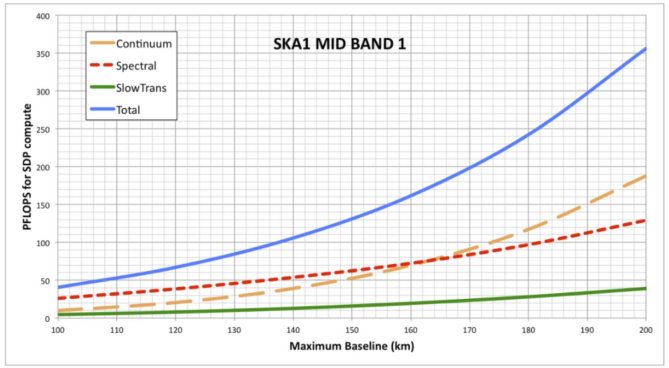
The SKA context

Credit: SKAO



One petaFLOPS is equal to **1,000,000,000,000,000 (one quadrillion) floating-point operations per second!**

A floating-point operation is **an addition or multiplication of two real (or floating-point) numbers represented in some** machine-readable and manipulatable form.

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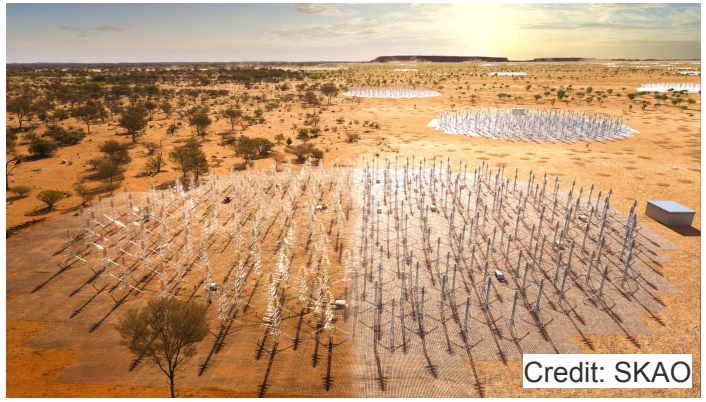
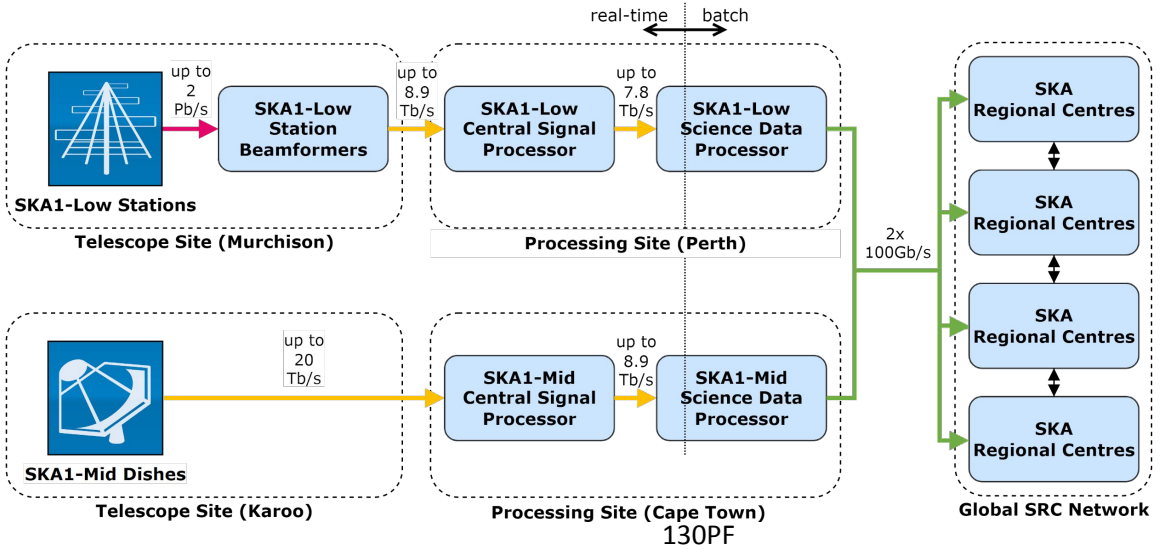
SKA - End-to-End data movement





SKA Project budget: $2.2B - up to Science Data Processor (SDP)

Lower limit for each telescope just for data in year 1:
Commercial cloud storage: $0.021/GB -> $2.73M ($4M to buy)
Data put/retrieve: $0.01/GB -> $1.30M

Cost vs energy vs performance vs science vs ….

Project tradeoffs

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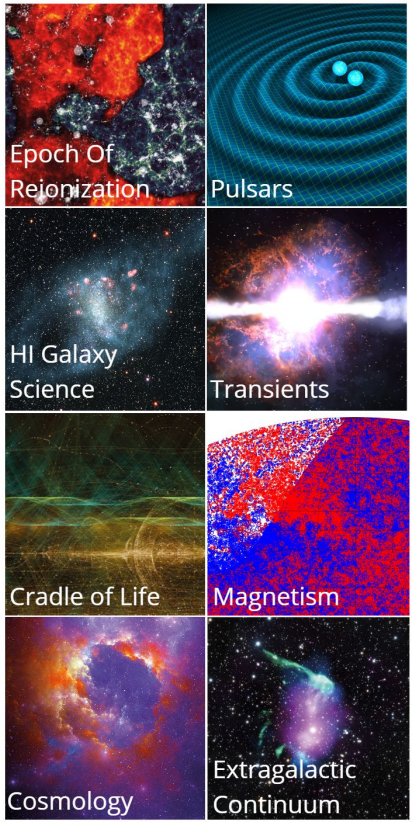
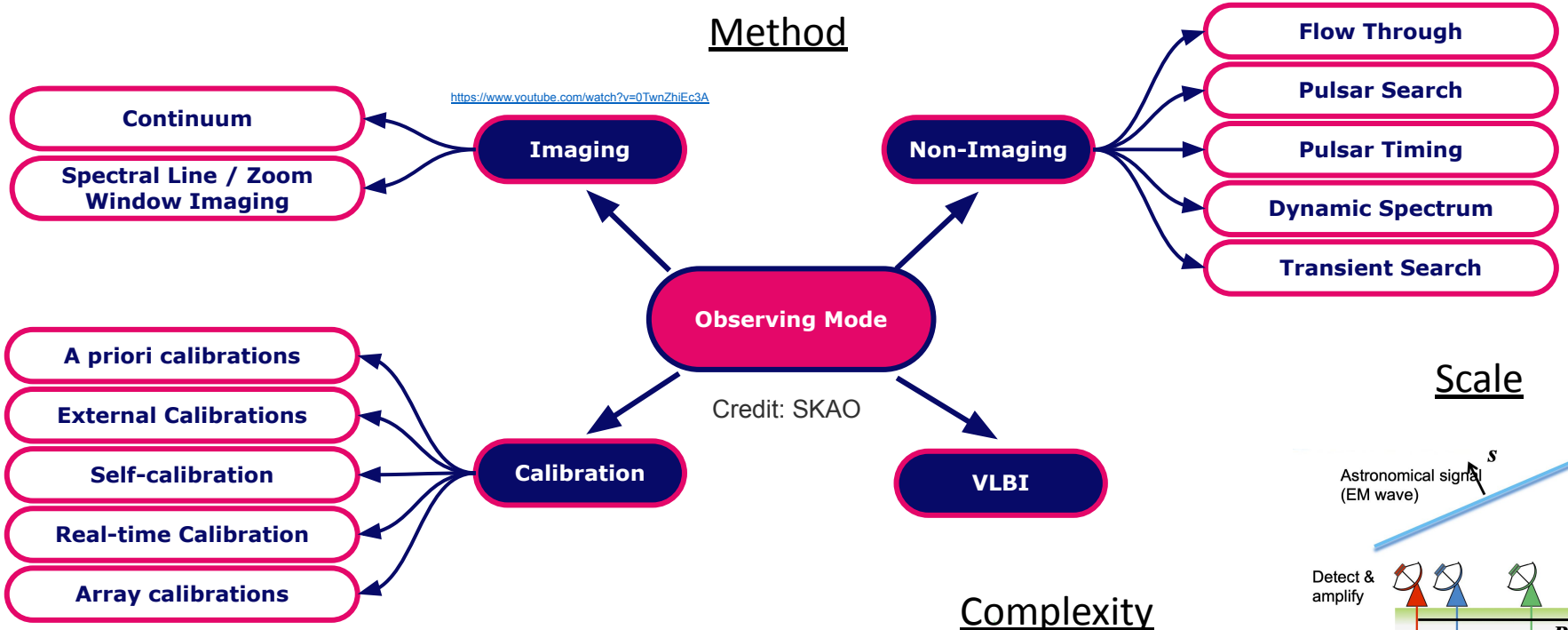
Some of our inputs

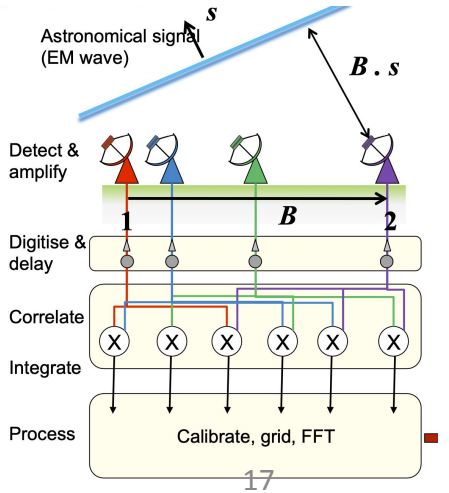
Science



Method



Scale



Complexity

Considerations are complicated!

VLBI = Very-long-baseline interferometry is a type of astronomical interferometry used in radio astronomy. In VLBI a signal from an astronomical radio source, such as a quasar, is collected at multiple radio telescopes on Earth or in space.

Functional vs Non-Functional Requirements

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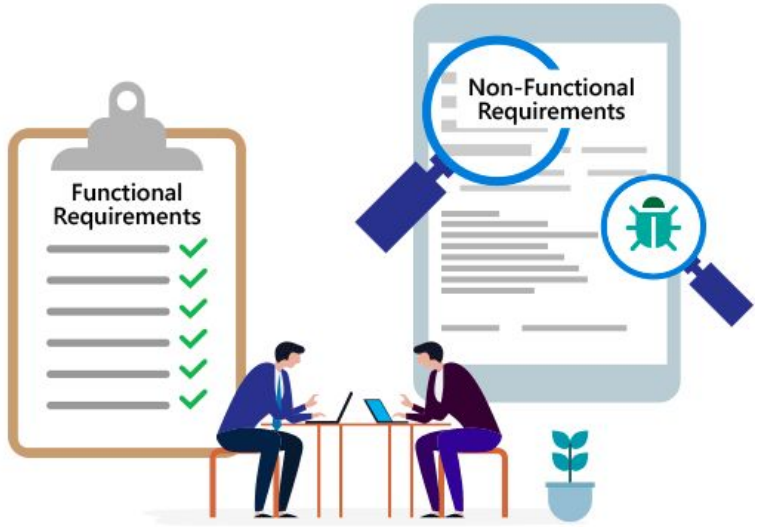
- Functional Requirements direct the system on a functional level.
- Non-Functional Requirements (NFRs) define the **Quality Attributes**.
- Well-defined non-functional requirements:
  - are measurable,
  - can be verified (tested),
  - provide teams with ability to test the outcome of small task, feature, project or process against a defined set of success factors.
- NFRs define what does the success look like before detailed work begins.



NFRs define the Quality Attributes

Science Data Processor (SDP) Quality Attributes

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Performance & Scalability

- Compute, I/O & Storage
  - >10 Pflop/s effective
  - ~0.77 TB/s ingest rate
  - ~4 TB/s into processing
  - >40 PB tiered buffer
- Need to scale
  - Trivial (e.g. Ingest) and expensive (e.g. ICAL) workflows co-exist
  - Early Array Assembly workloads will be unrepresentative
  - SKA “>1” will be even harder on SDP

Modifiability & Maintainability

- Long lifespan (>50 yrs)
- Software changes
  - Execution Engines
  - Science Workflows
  - Processing Components
  - Data Models
- Hardware changes
  - Processing
  - Storage
  - Network

Buildability, Affordability

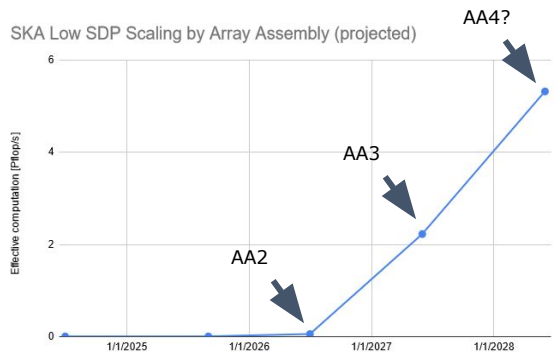
- COTS components
  - Get going quickly
  - Externalise/share maintenance
- Support agile development
  - Small functional increments
  - Parallel work of different teams

Testability

- Continuous Integration
  - Test outside SDP
  - Support different development speeds
- Ensure scientific validity
  - Must trust pipelines with autonomous analysis

Portability

- SKA Low, SKA Mid, SRCs



Key considerations for SDP

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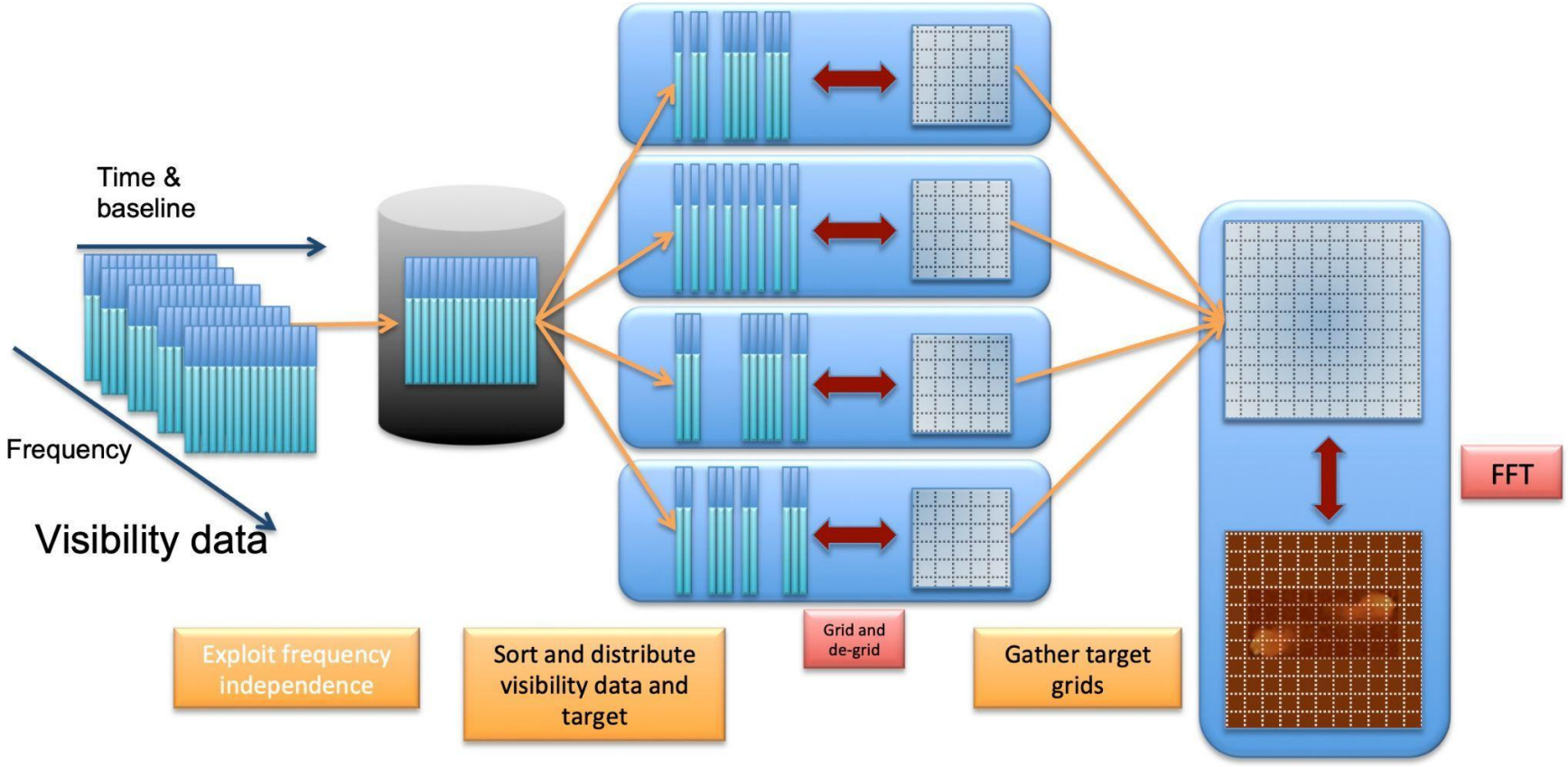
Mapping

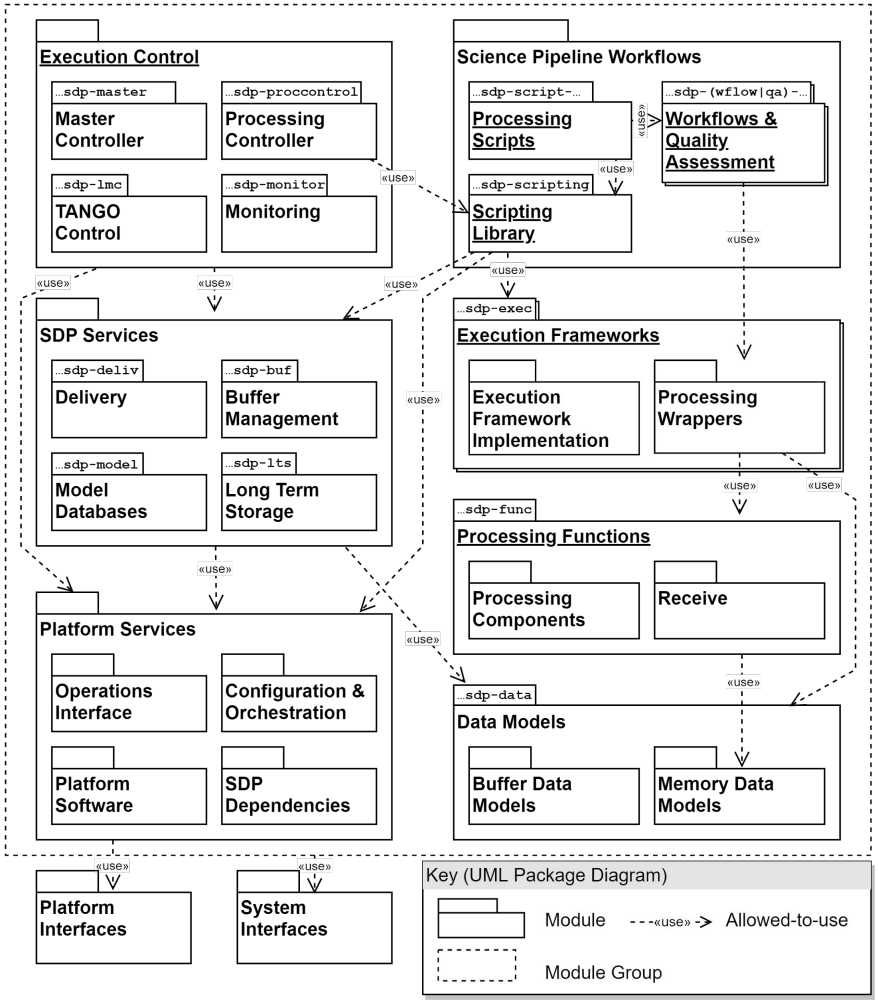


- Parallelize by frequency and time steps
- Can be used for load balancing

FFT = Fast Fourier Transform

Exploit natural parallelism in the data

SDP Module View



Layered processing architecture:

- Workflows
  (Interface of processing for rest of system)
- Execution Frameworks
  (Coordinate data movement and processing)
- Processing Functions
  (Algorithmic kernels)
- Data Models
  (Standards and libraries for data exchange)

Architecture views help us reason about the software

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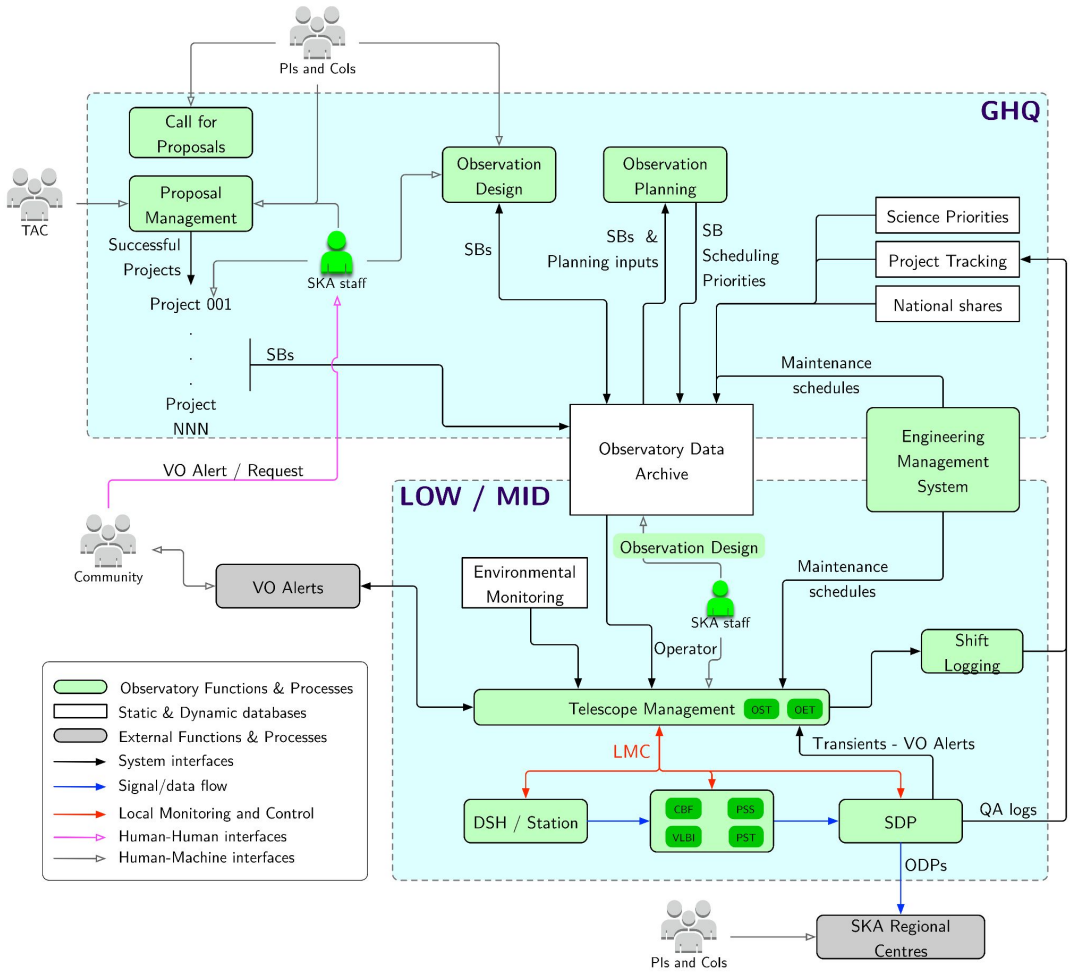
Aside: The broader integration challenge



The SKAO software has various interfaces beyond SDP

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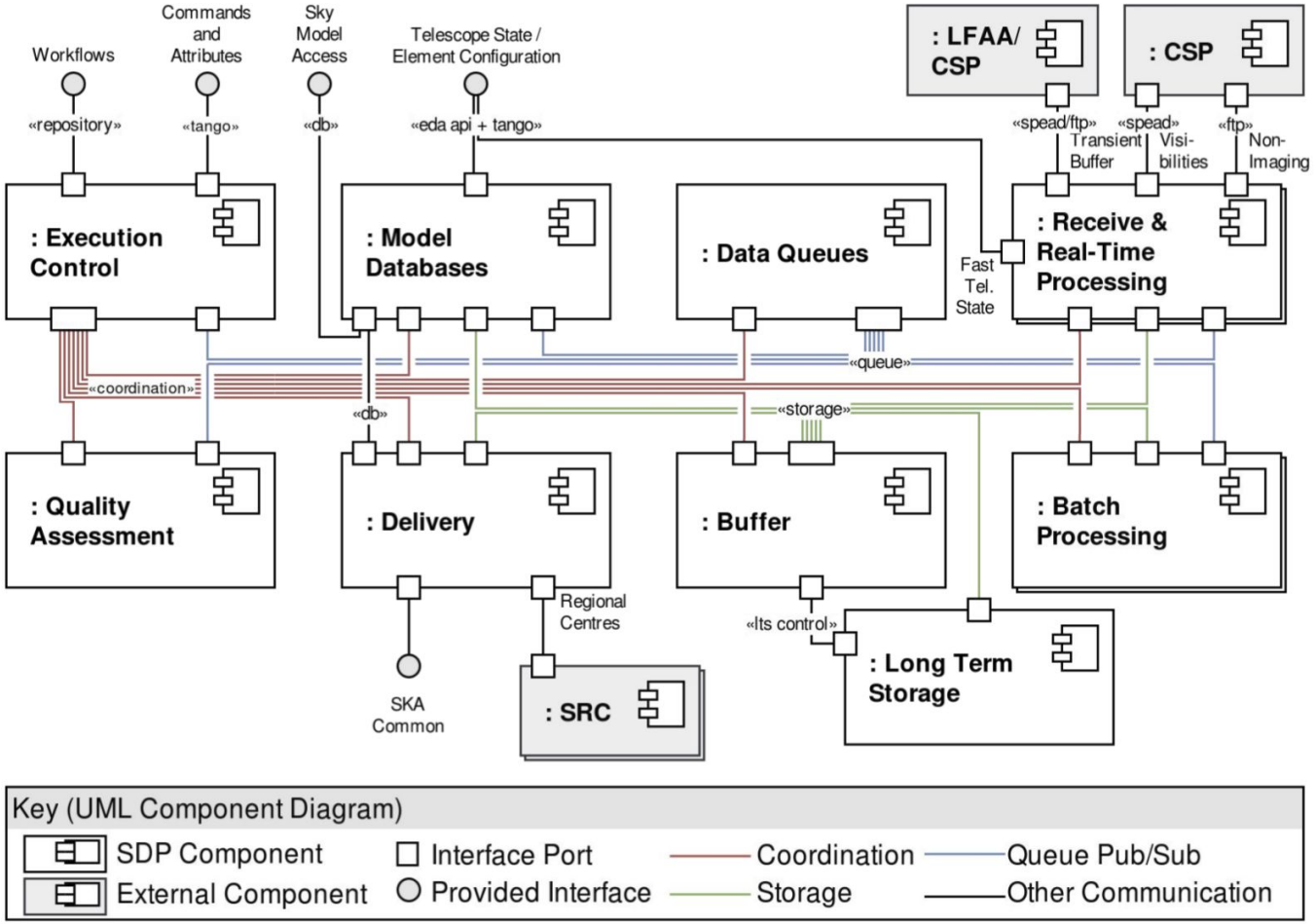
High-level Compontent & Connector view



We need to map the data interfaces

https://arxiv.org/abs/2304.13797

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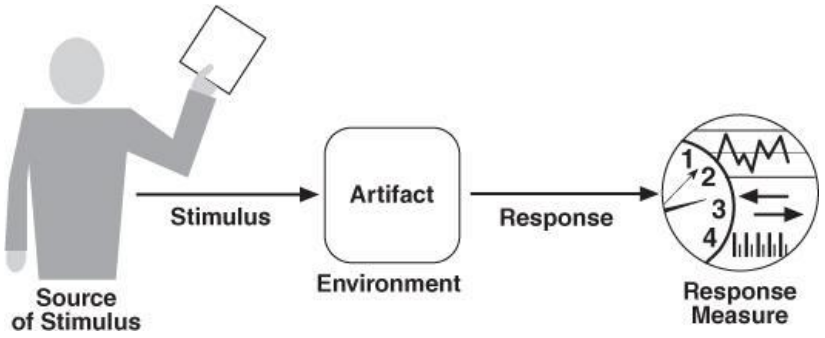
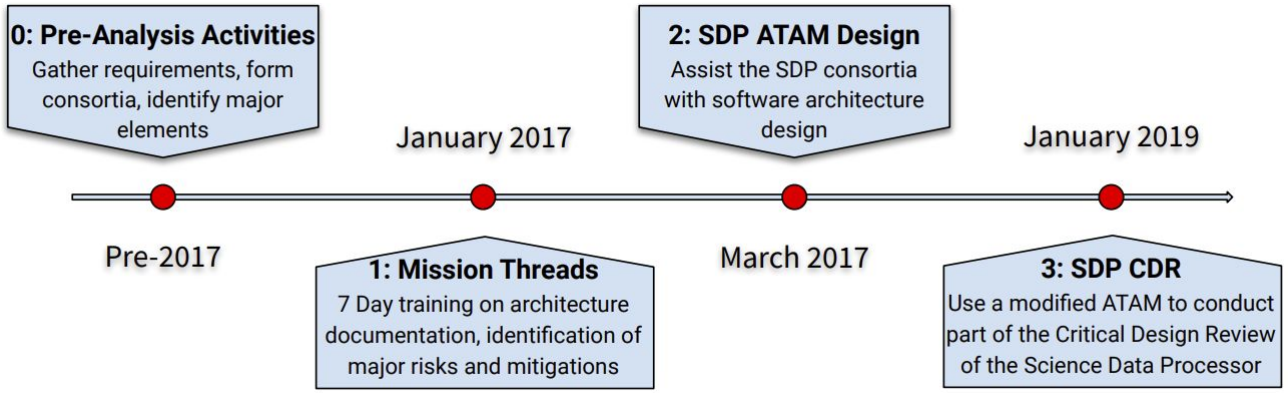
A way to approach trade-offs

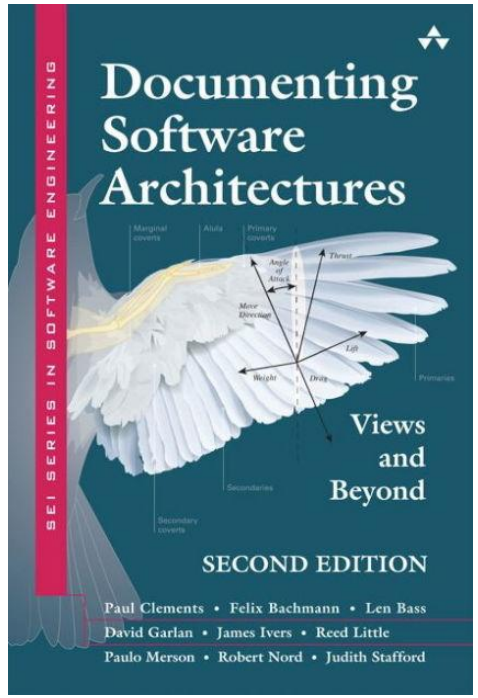


A scenario stresses a **quality** of the system … the Non-functional Requirements



"Software Architecture refers to the high-level structures of a software system and the discipline of creating such structures and systems. Each structure comprises software elements, relations among them, and properties of both elements and relations."

Modules, Components and **Allocations**



There are methods to help us validate the architecture

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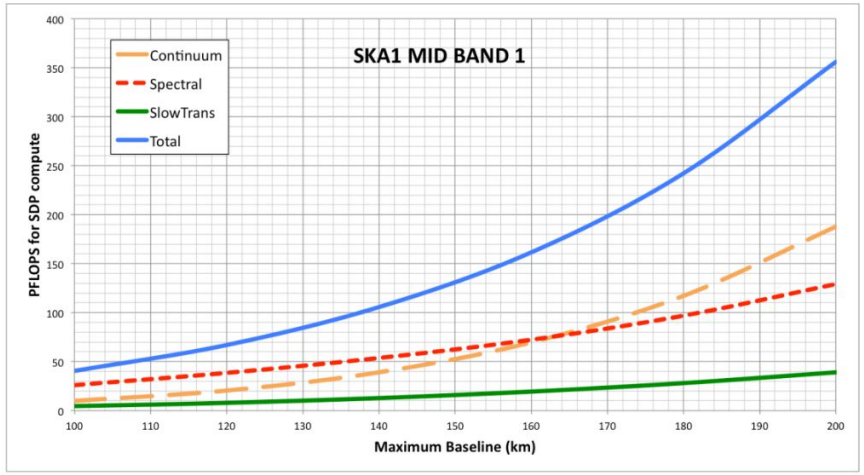
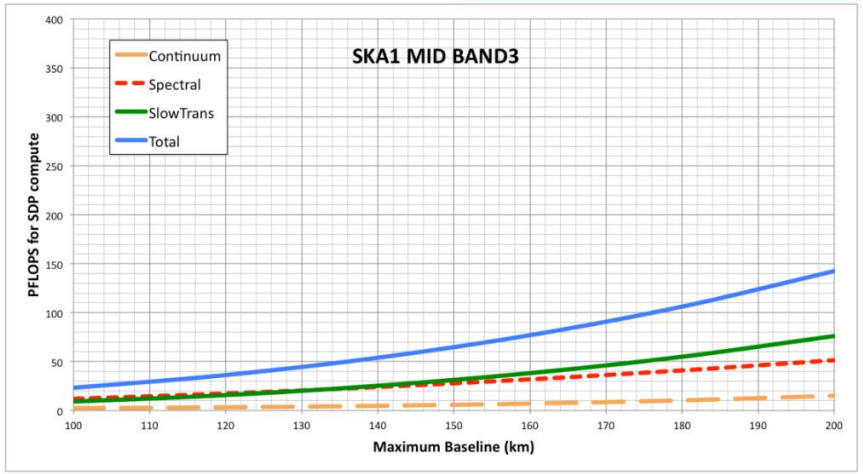
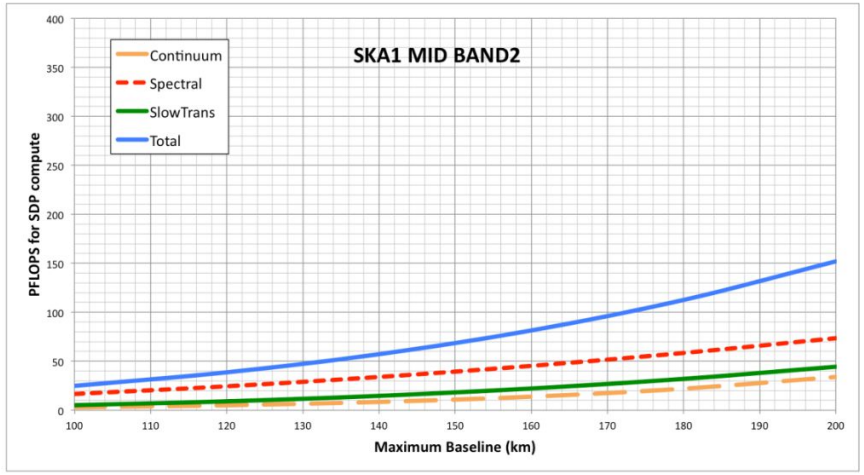
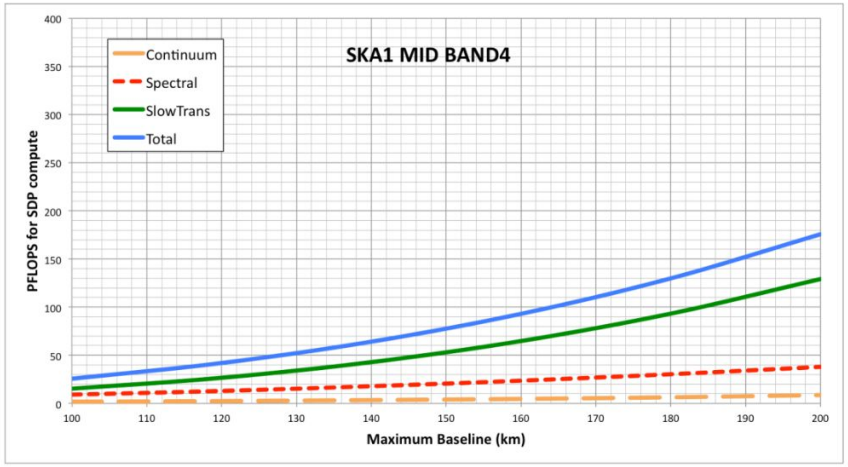
Energy budgets (4-10MW)









We are limited by funding not science opportunities

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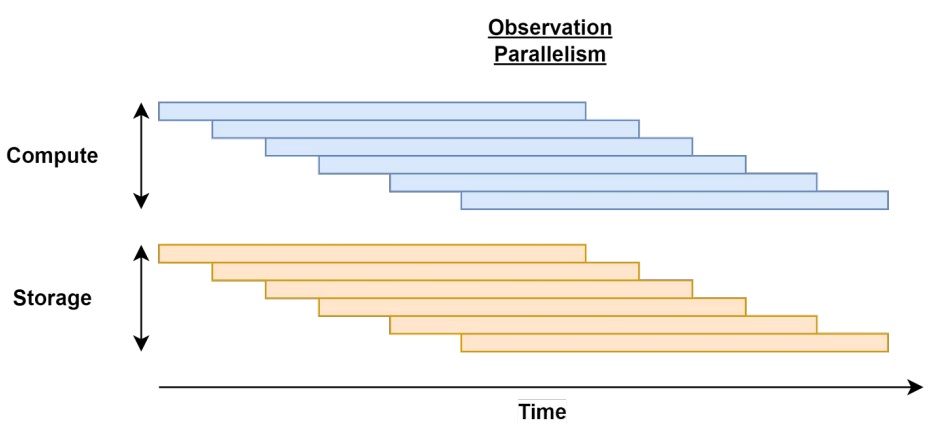
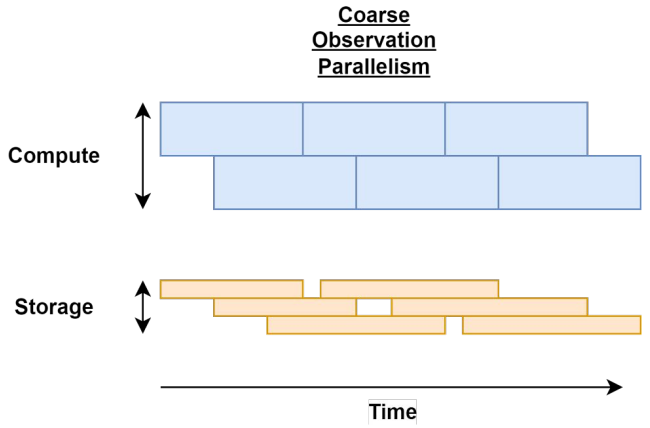
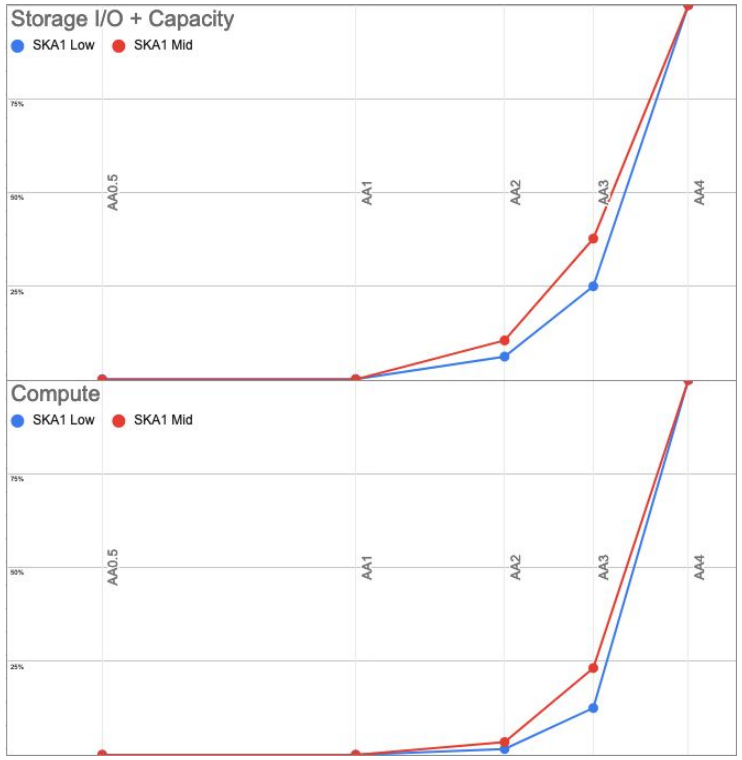
The challenge of data volumes







Storage needs/costs grow rapidly

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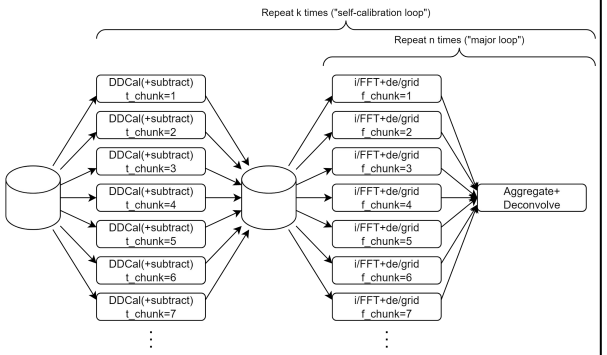
Improvements for key pipeline(s)

Scaling

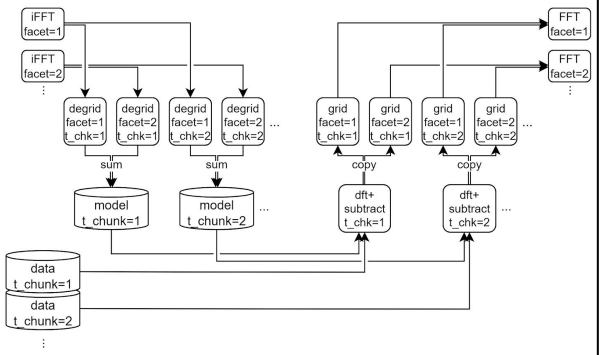


Scale to additional nodes

- Frequency parallelism
  (main focus for AA2)
- Snapshot parallelism
- Facet parallelism
  (main focus for AA*)

Potential: ~x10 improvement?
(3 nodes → 30 nodes for AA2? More later…)

I/O efficiency

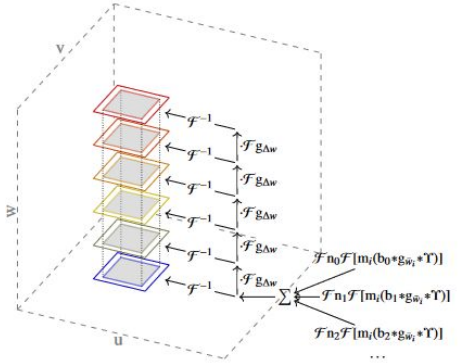


Minimise I/O overheads

- Minimise inter-node I/O
  (main focus for AA2 - current bottleneck preventing scaling)
- Work entirely in-memory
  (i.e. not even write model visibilities)

Potential: ~x5 improvement?
(assuming 10 facets, half of time spent on I/O?)

Optimisations



Optimise processing functions (intra-node)

- Continue following algorithmical advances
- Use of vectorisation and accelerators

Potential: ~x2 improvement?
(typical GPU lead per-cost, algorithmic advances harder to predict)

We are exploring ways to improve the compute performance

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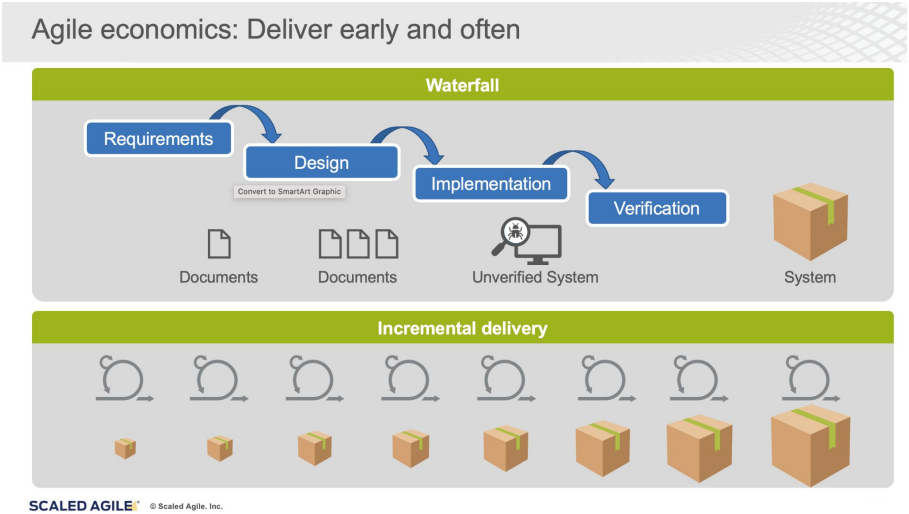
Aside: How do we develop the software and systems?



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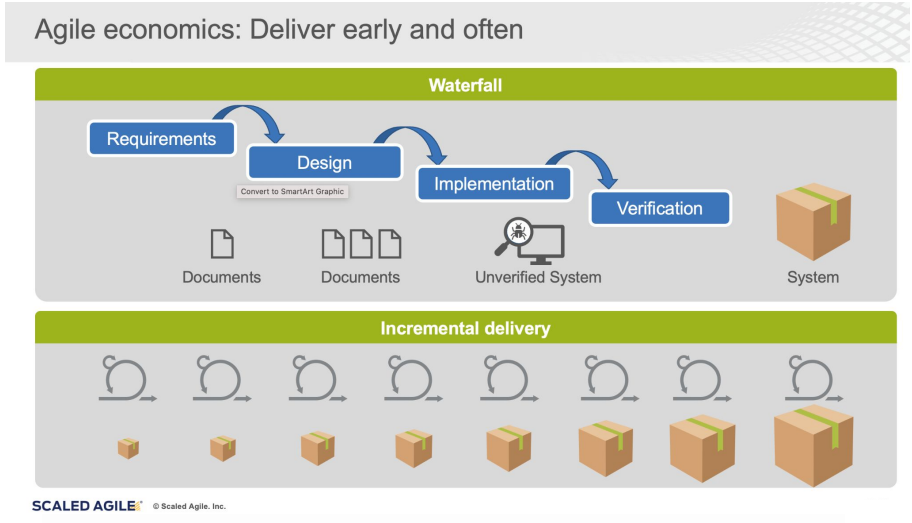

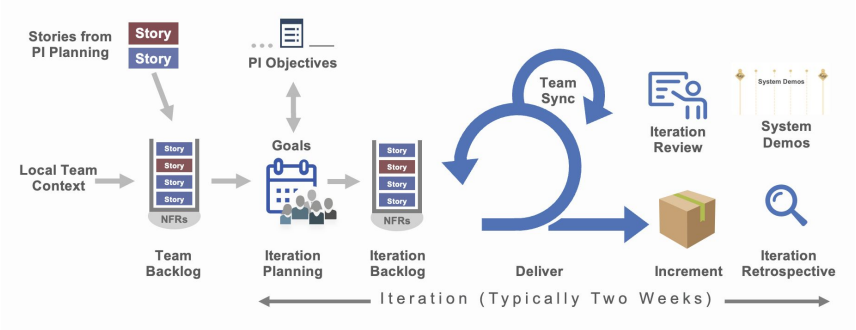

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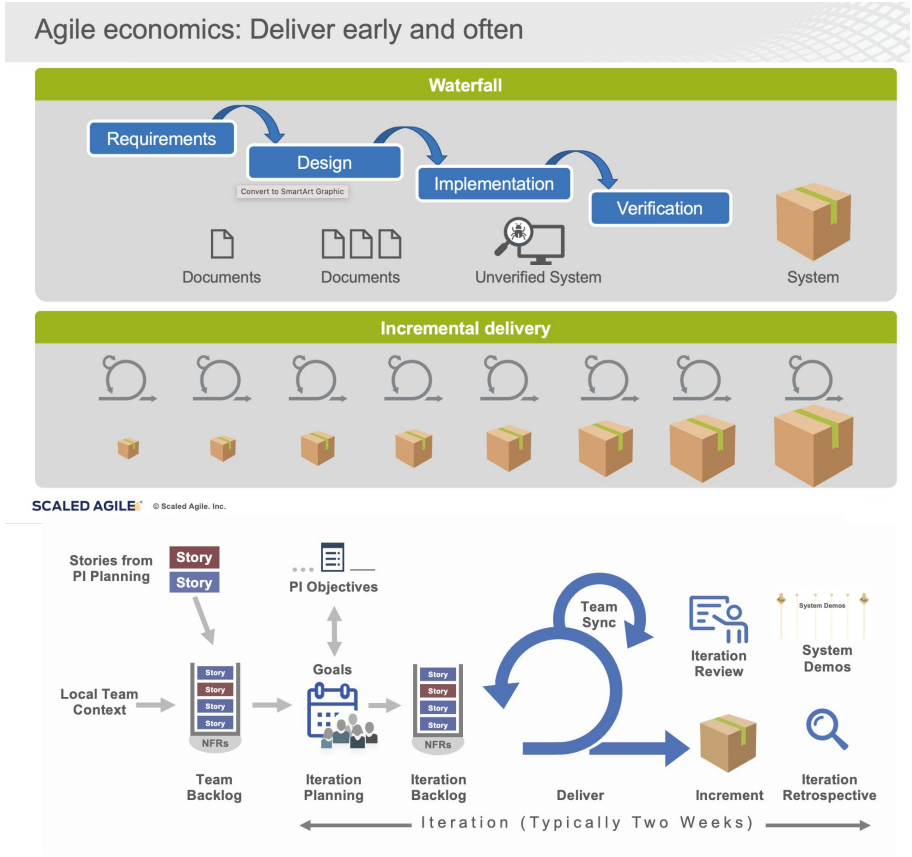
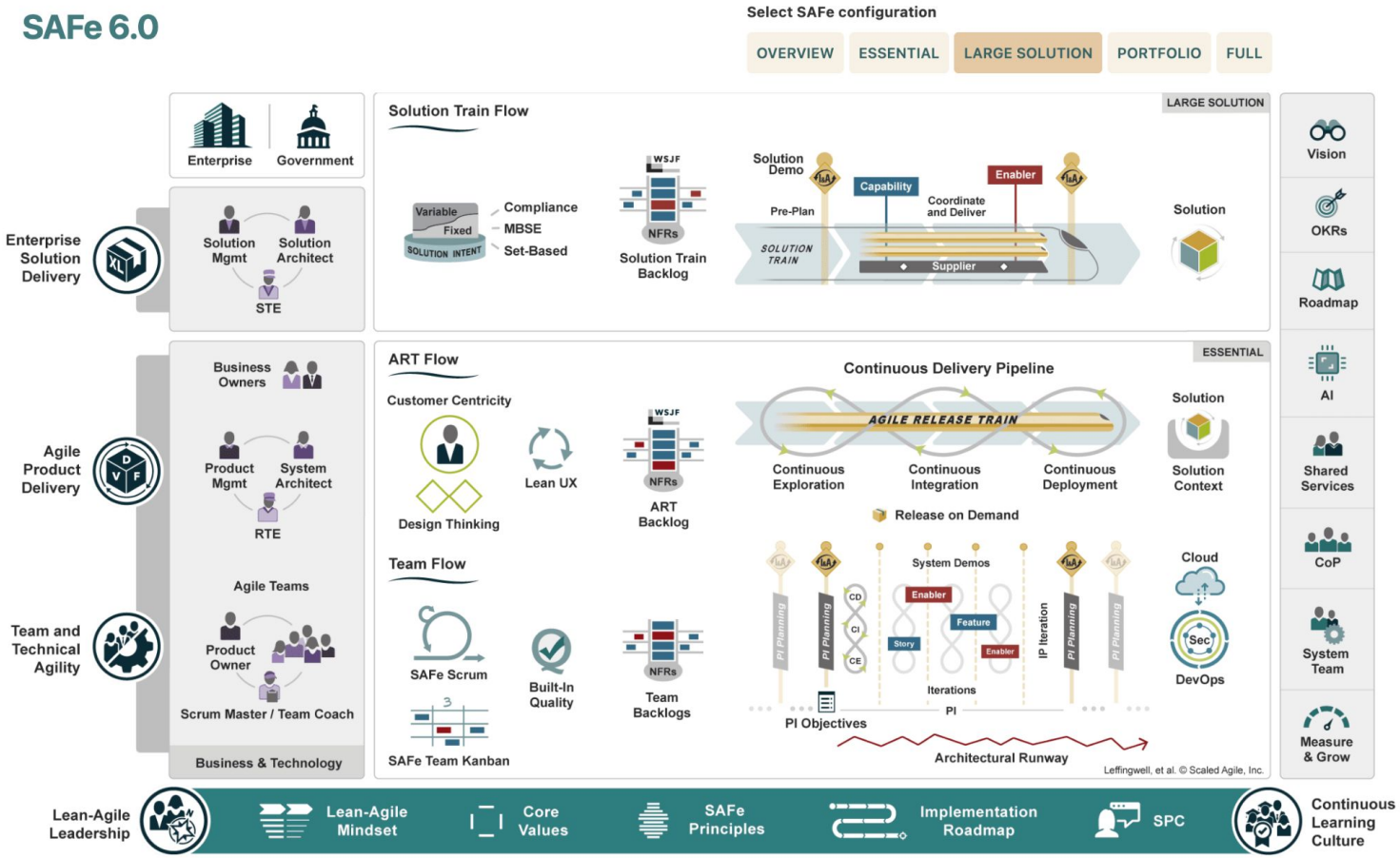
Aside: How do we develop the software and systems?

https://scaledagileframework.com/#largesolution





Agile techniques are being used

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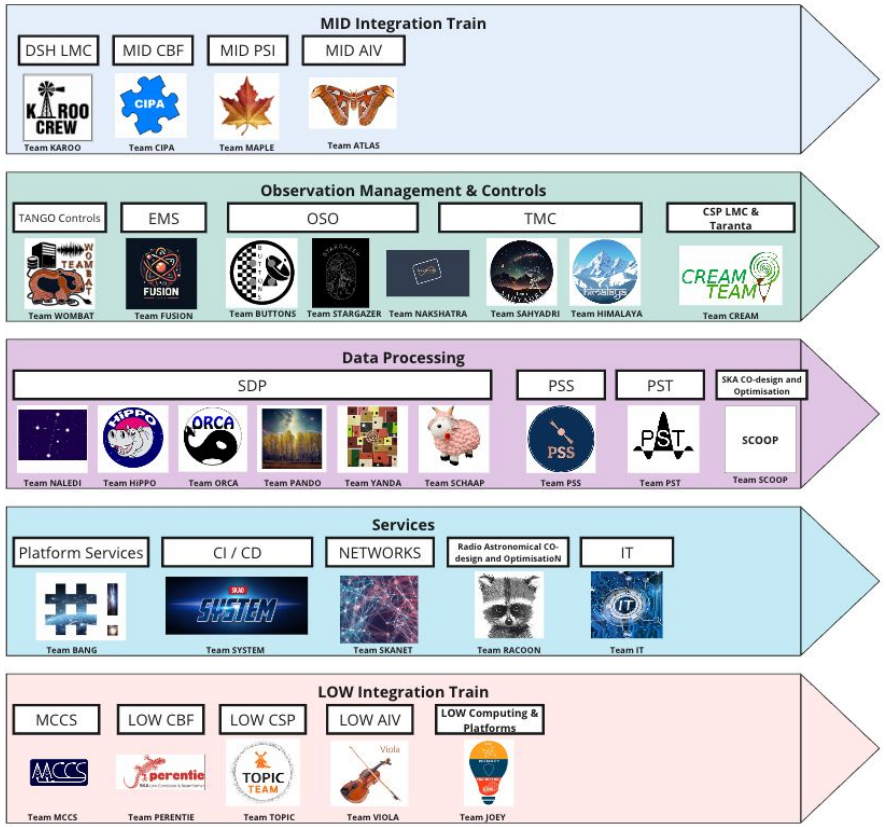
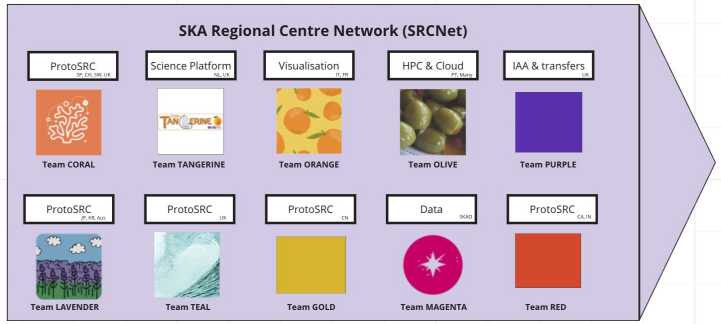
The team of teams





Release trains provide alignment

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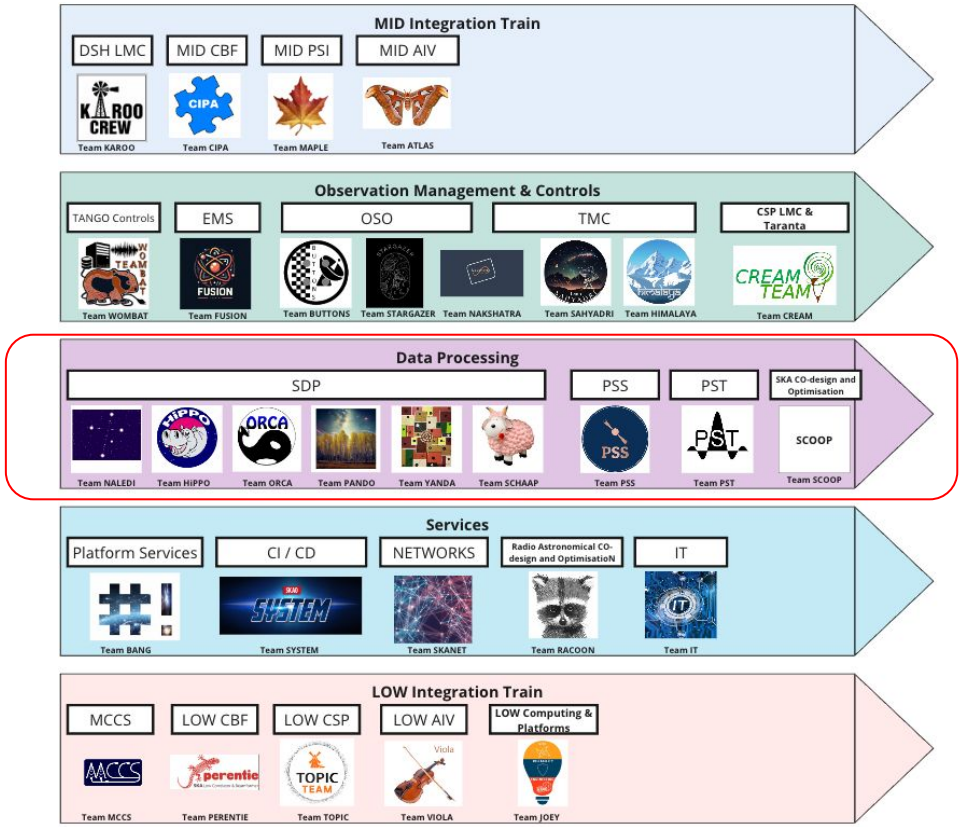
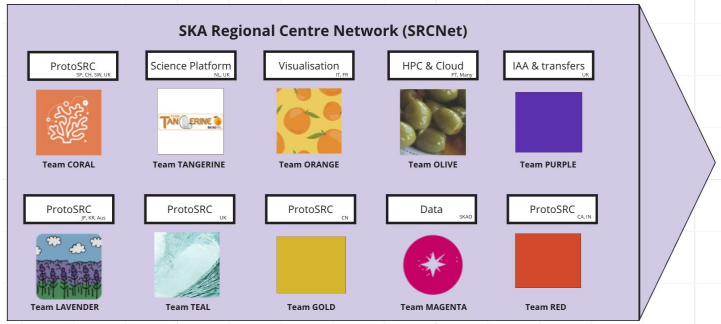
The team of teams





Next come the federating considerations

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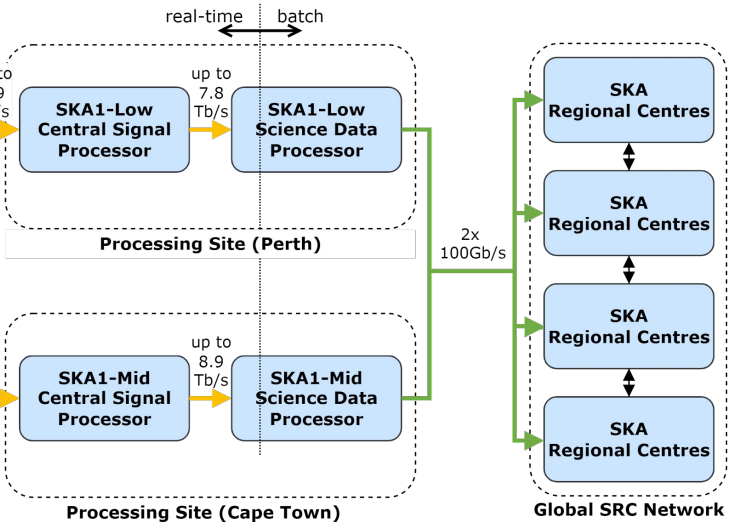
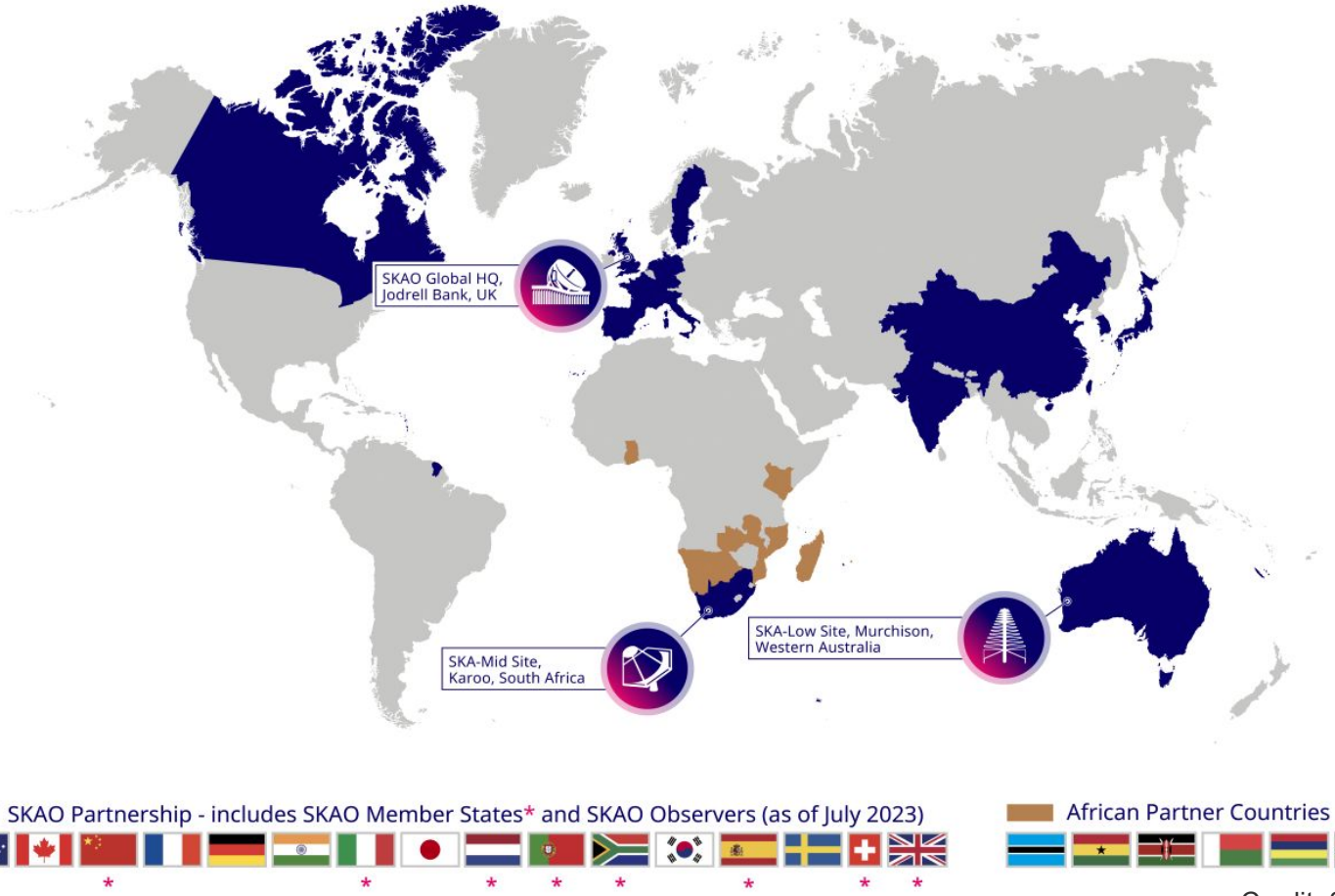
Where does the data analysis happen?





Credit: SKAO

Data is to be distributed and further processed globally

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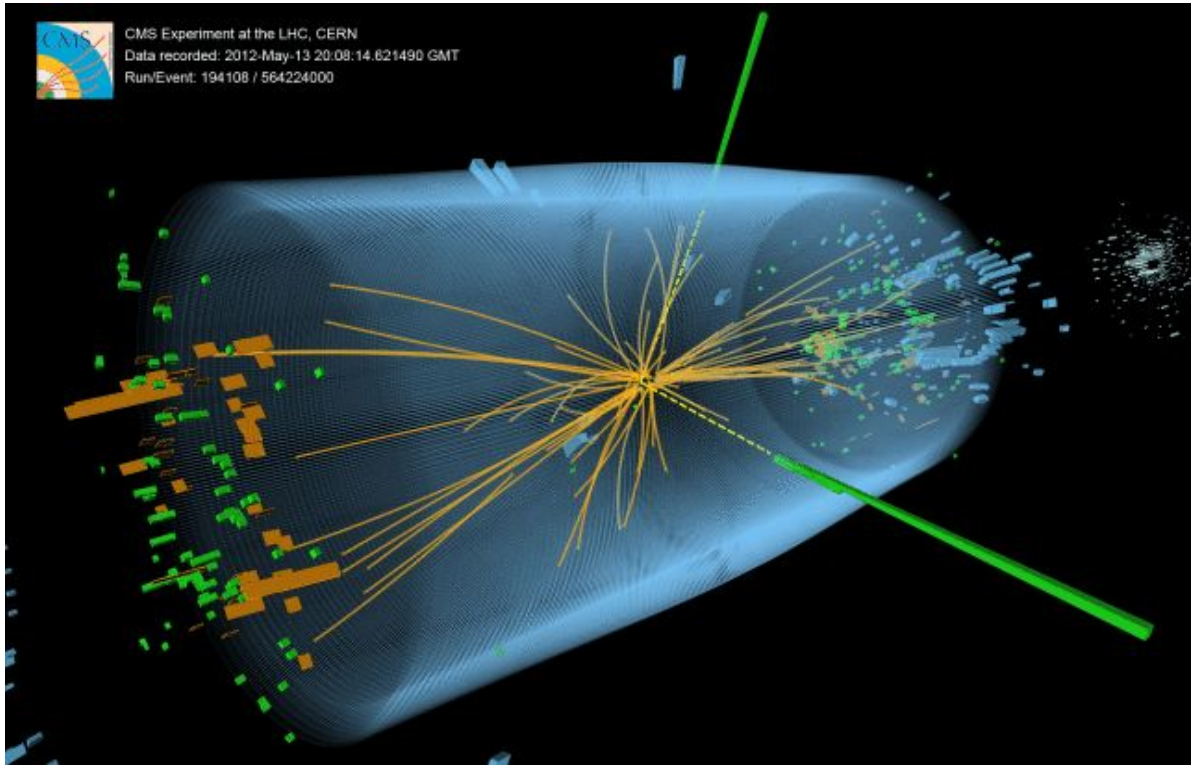
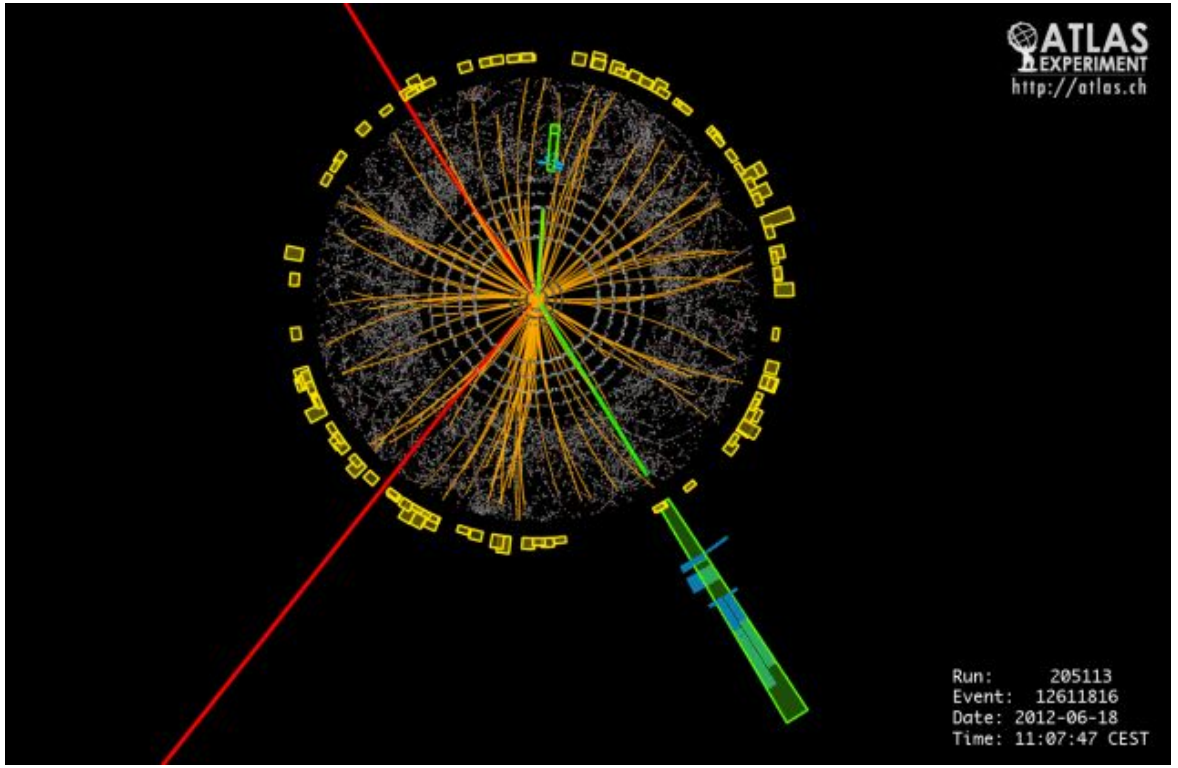
We've been in a similar situation

Credit: CMS, CERN



Event recorded with the CMS detector in 2012 at a proton-proton centre of mass energy of 8 TeV. The event shows characteristics expected from the decay of the SM Higgs boson to a pair of photons (dashed yellow lines and green towers). (Image: CERN)

Credit: ATLAS, CERN



Event display of a H -> 2e2mu candidate event with m(4l) = 122.6 (123.9) GeV without (with) Z mass constraint. The masses of the lepton pairs are 87.9 GeV and 19.6 GeV. The event was recorded by ATLAS on 18-Jun-2012, 11:07:47 CEST. (Image: CERN)

The Higgs discovery depended on distributed computing

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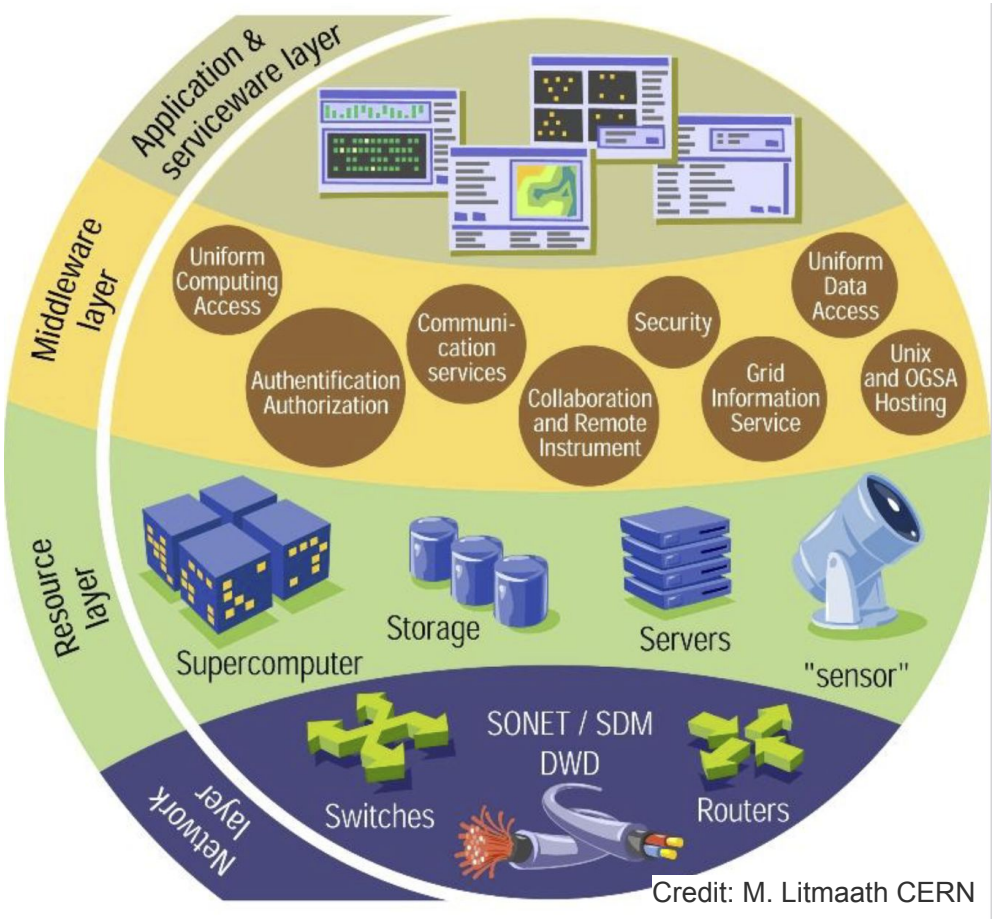
Worldwide LHC Computing Grid

- What is a computing grid: facilitates collaboration between members of a distributed community.

- Middleware: multiple data centres appear as a single system:
- Monitoring & accounting
- Job management
- Data management
- Information system
- Security
- Operations

Challenges include:

- Local policies & priorities
- Systems
- User communities …



Credit: M. Litmaath CERN

Grids came before clouds

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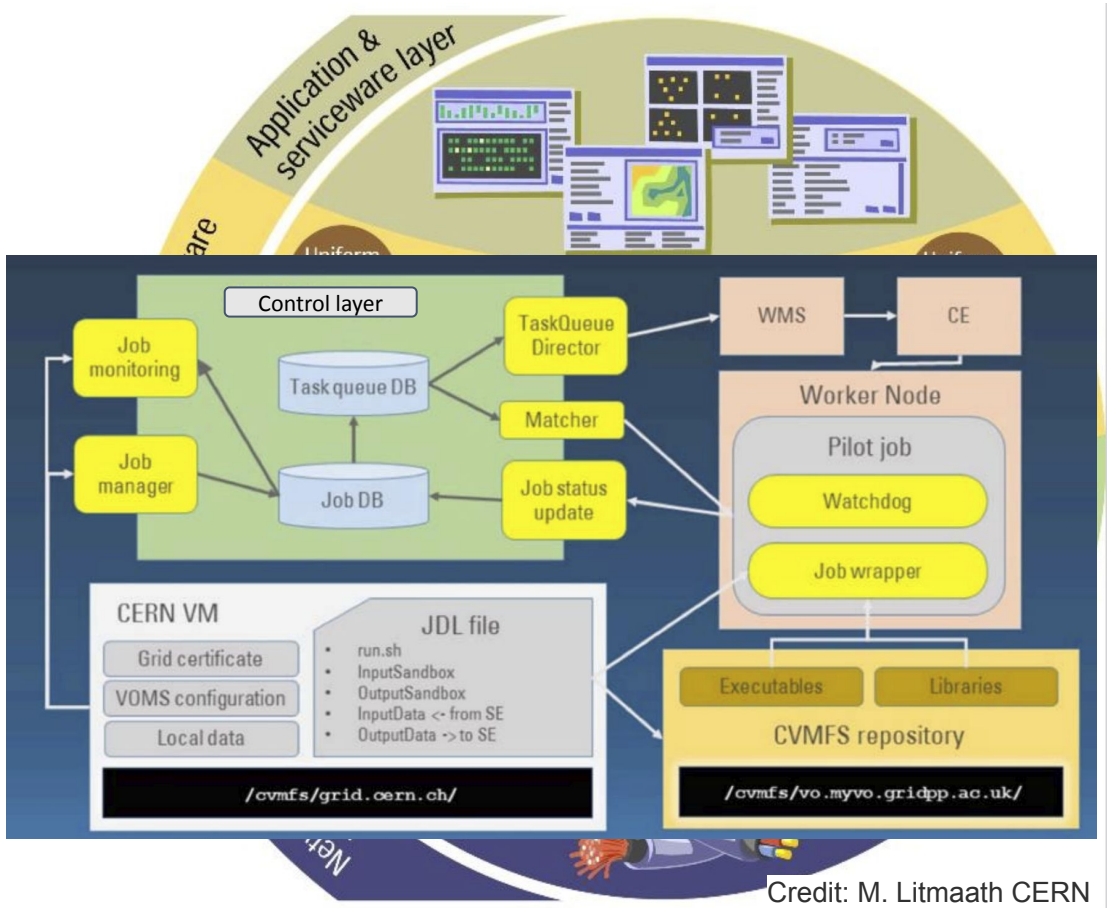

Credit: M. Litmaath CERN

Centralised job scheduling depended on various middleware developments

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Job flows in WLCG

WLCG provides global computing resources for the storage, distribution and analysis of the data generated by the LHC.

WLCG combines about **1.4 million computer cores and 1.5 exabytes of storage** from over 170 sites in 42 countries. This massive distributed computing infrastructure provides more than 12 000 physicists around the world with near real-time access to LHC data, and the power to process it.

It runs over 2 million tasks per day and, at the end of the LHC's LS2, global transfer rates exceeded 260 GB/s.

Credit: CERN

Future directions: https://link.springer.com/article/10.1007/s41781-018-0018-8

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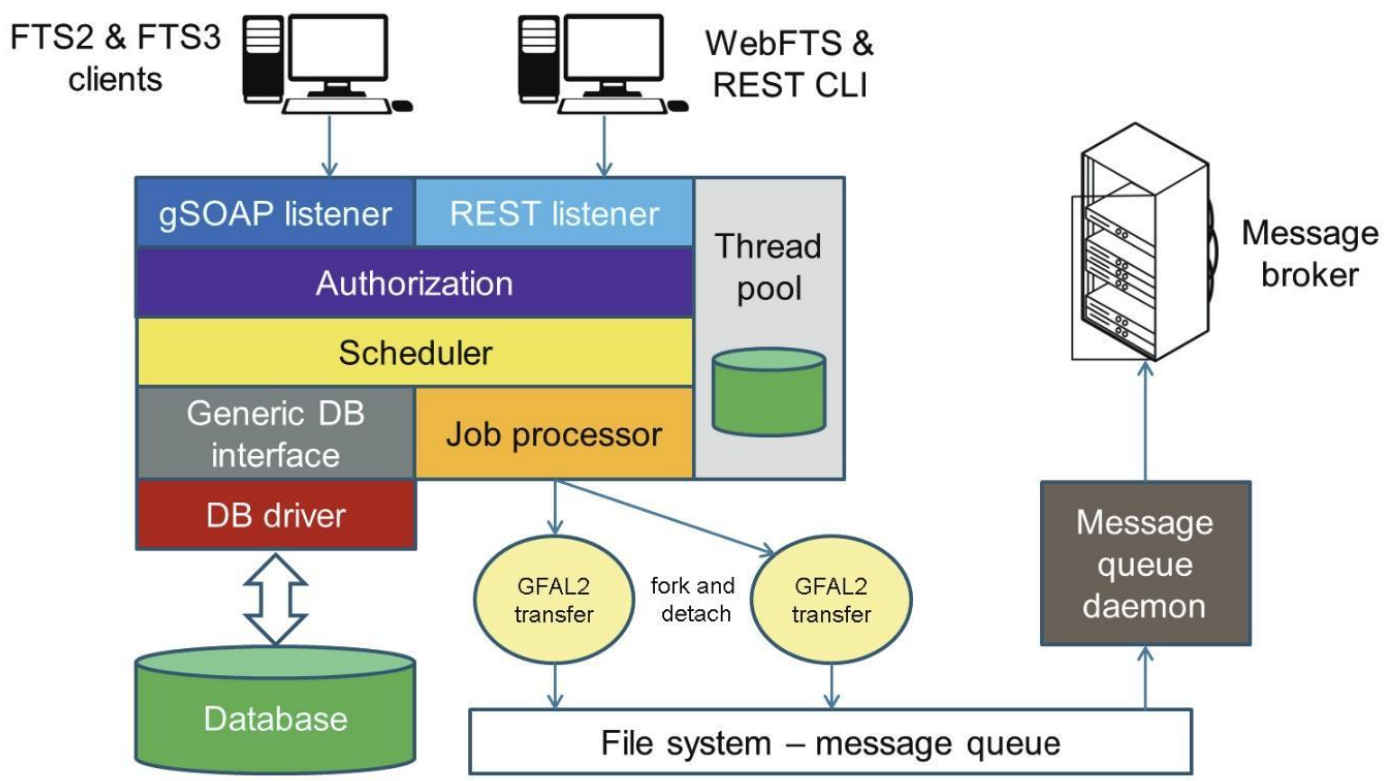
File Transfer Service

One of the most important tasks is reliable file replication. It is a complex problem, suffering from transfer failures, disconnections, transfer duplication, server and network overload, differences in storage systems, etc.

Example capabilities:

transfer auto-tuning / adaptive optimization;

- endpoint-centric VO configuration;
- transfer multi-hop;
- VO activity shares;
- multiple replica support;
- REST-style interface for transfer submission and status retrieval;
- retry failed transfers mechanism;
- staging files from archive;
- bulk deletions;
- support for Oracle and MySQL database back-ends



Reliable 'at scale' data transfer is essential

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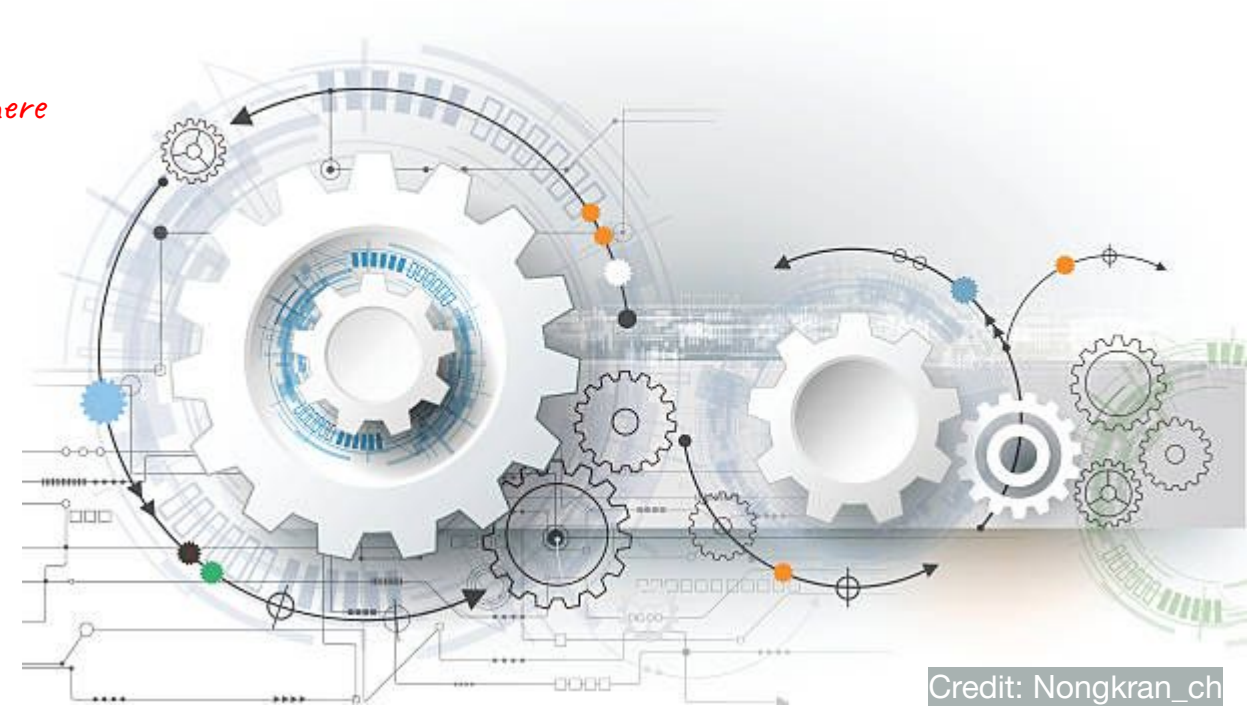
The story so far …

It all depends on paired transistors
Each consumes energy to work
Every bit has a cost
Informed tradeoffs are needed
Radio and visible wavelengths are less absorbed by the Earth's atmosphere
Considerations are complicated!
NFRs define the Quality Attributes
Exploit natural parallelism in the data
Architecture views help us reason about the software
Software has various interfaces
There are methods to help us validate the architecture
We are limited by funding not science opportunities
We are exploring ways to improve the compute performance
Agile techniques are being used
Release trains provide alignment
SKA data is to be distributed and further processed globally
The Higgs discovery depended on distributed computing
Centralised job scheduling depended on various middleware developments
Reliable 'at scale' data transfer is essential



Credit: Nongkran_ch