the SERVER LABS

CERN

European Organization for Nuclear Research

# Cloud Science

# or..

# Astrometric Data Processing in Amazon EC2

**CERN, Wednesday October 28th, 2009**

**Paul Parsons,**
CTO, The Server Labs




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# About the Presenter


- Paul Parsons
  - Founder & CTO of The Server Labs
  - Over 20 years experience in many fields of IT


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# Proof of Concept Objectives


- Two main objectives
  - Evaluate the Tecnical Feasibility of using Amazon EC2 to run scientific data processing applications
  - Evaluate the Financial Viability of using pay on demand compute power vs. traditional in-house data processing


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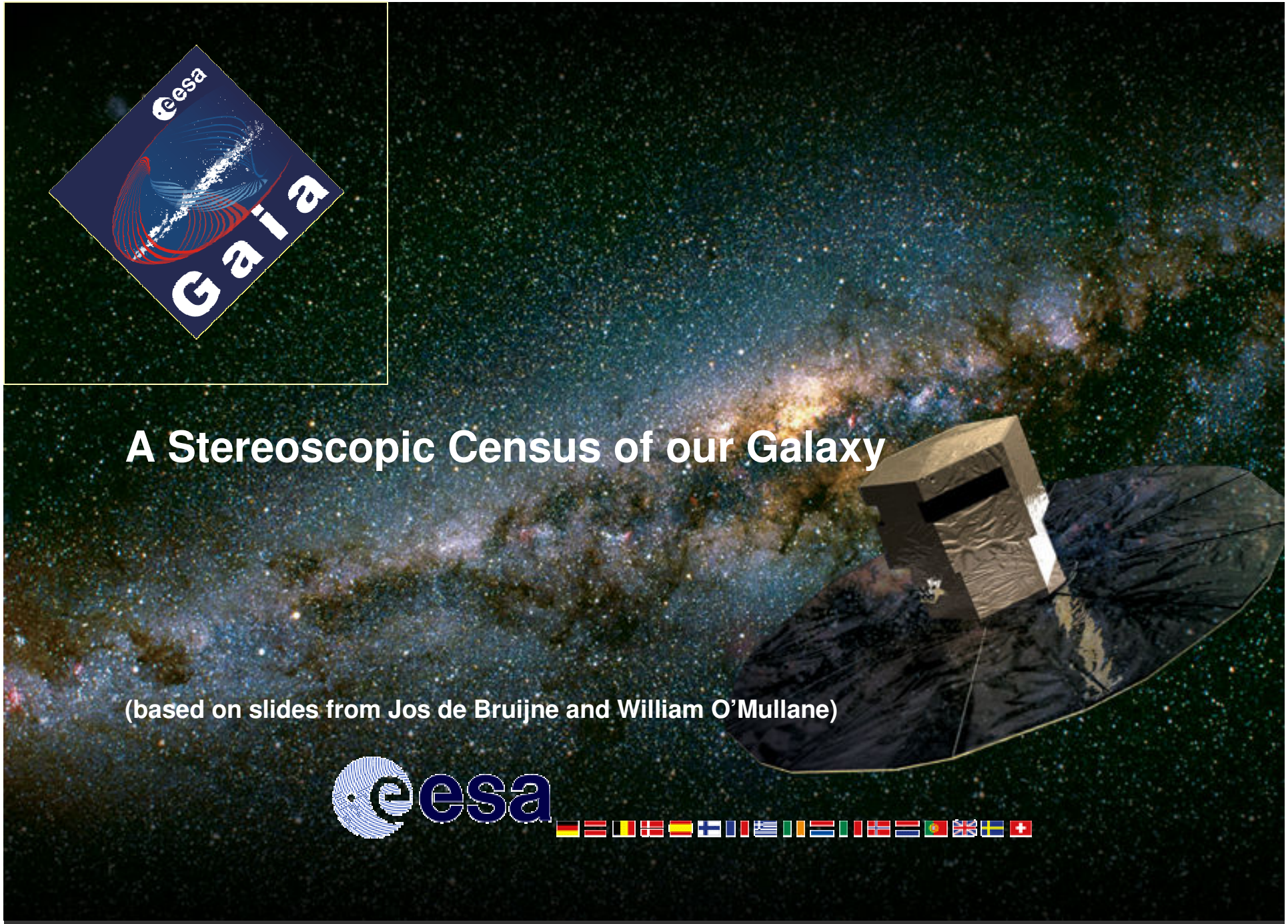


# A Stereoscopic Census of our Galaxy

(based on slides from Jos de Bruijne and William O'Mullane)

esa


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# The Gaia Mission


- Primary goal of the Gaia mission is to create an astrometric catalogue of 1 billion stars (approx 1% of our Galaxy) with micro arc second precision.
- Gaia satellite to be launched in 2011.
- Observations done until 2017.
- Catalogue ready around 2019.


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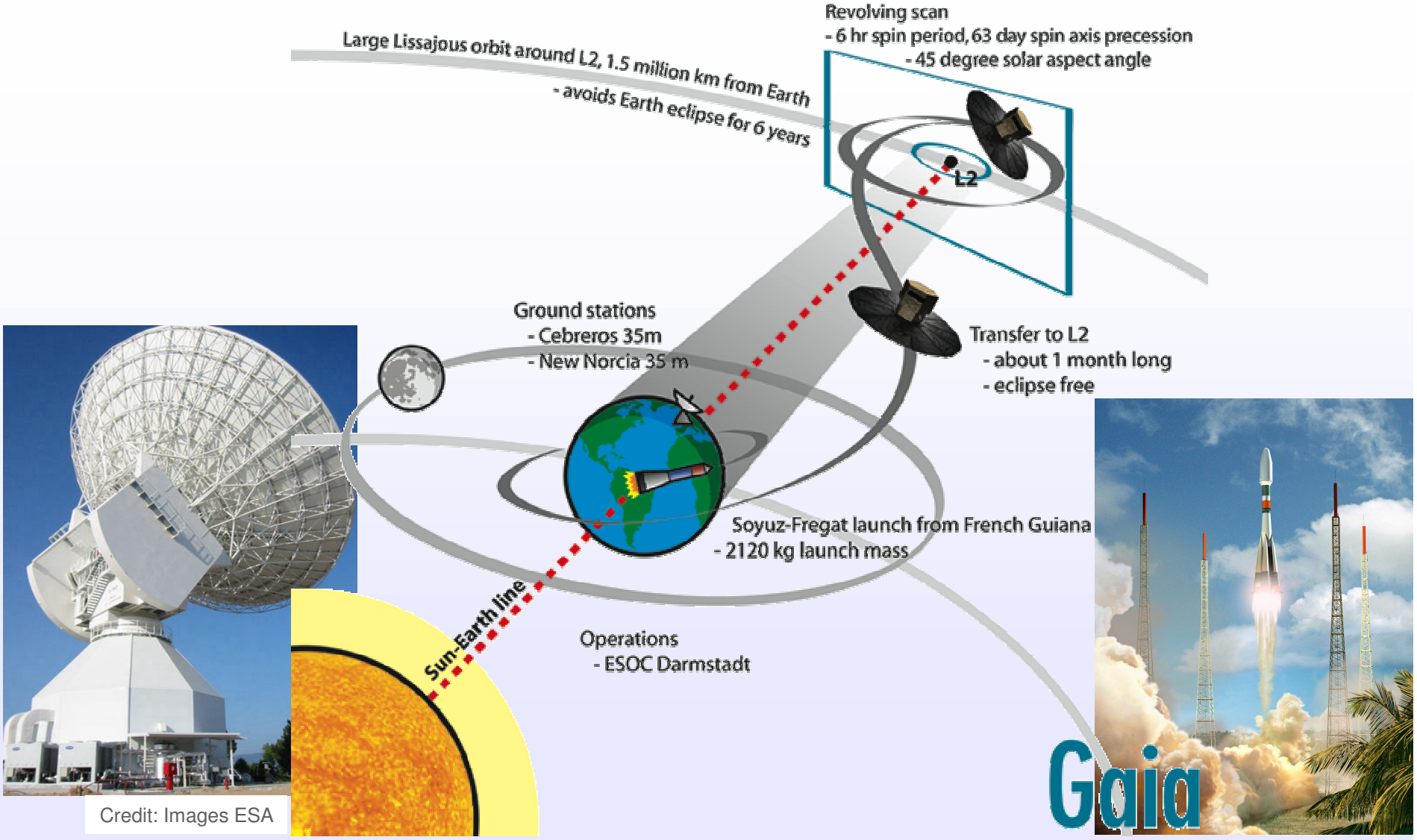


Credit: Images ESA


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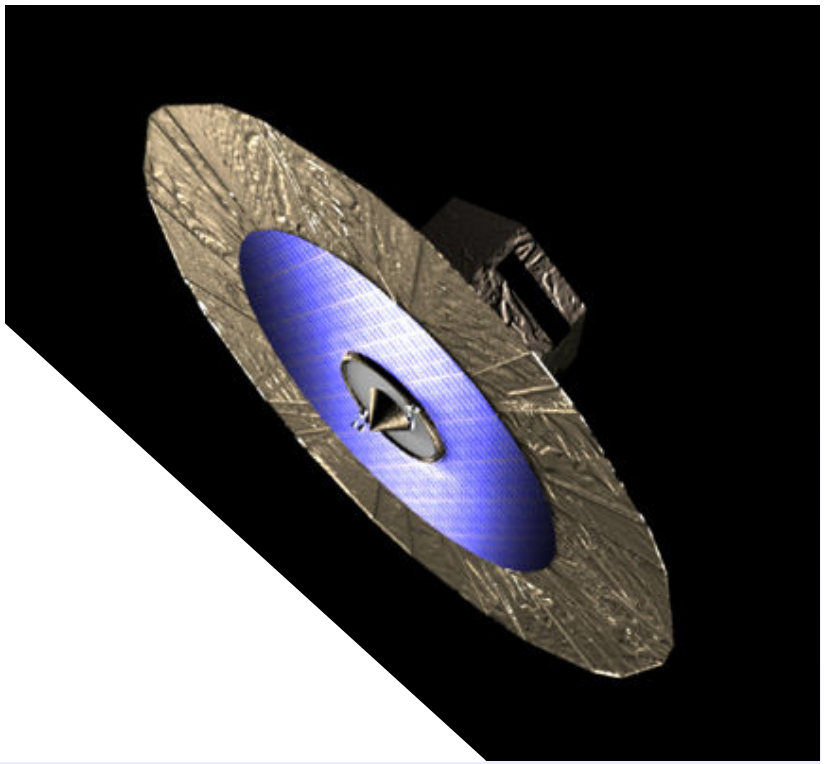
# Satellite – Obligatory Reminder

- Mission:
  - Stereoscopic Census of Galaxy
  - μarcsec Astrometry G<20 (10^9 sources)
  - Radial Velocities G<16
  - Photometry G < 20
  - Discover structure and unravel formation history of Galaxy.



- Status:
  - ESA Corner Stone 6
    - ESA provide the hardware and launch
    - Launch: Spring 2012.
  - Satellite In development
    - EADS/Astrium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# Data Downlink


- Using Cebreros, Spain (35M)
  - 3-8Mb/s downlink
    - depends on encoding
    - which depends on weather !
  - ~ 30GB/day -> ~100TB
- Occasionally New Norcia, Australia
  - during Galactic plane scans
  - data accumulated onboard downlinked later
- Data is compressed encoded and requires a lot of processing (~10^21 FLOP)


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*If it took 1 millisecond to process one image,*
*the processing time for just one pass through the data*
*(on a single processor) would take 30 years.*

Obviously the adopted solution is much faster …

…. distributed/parallel processing.


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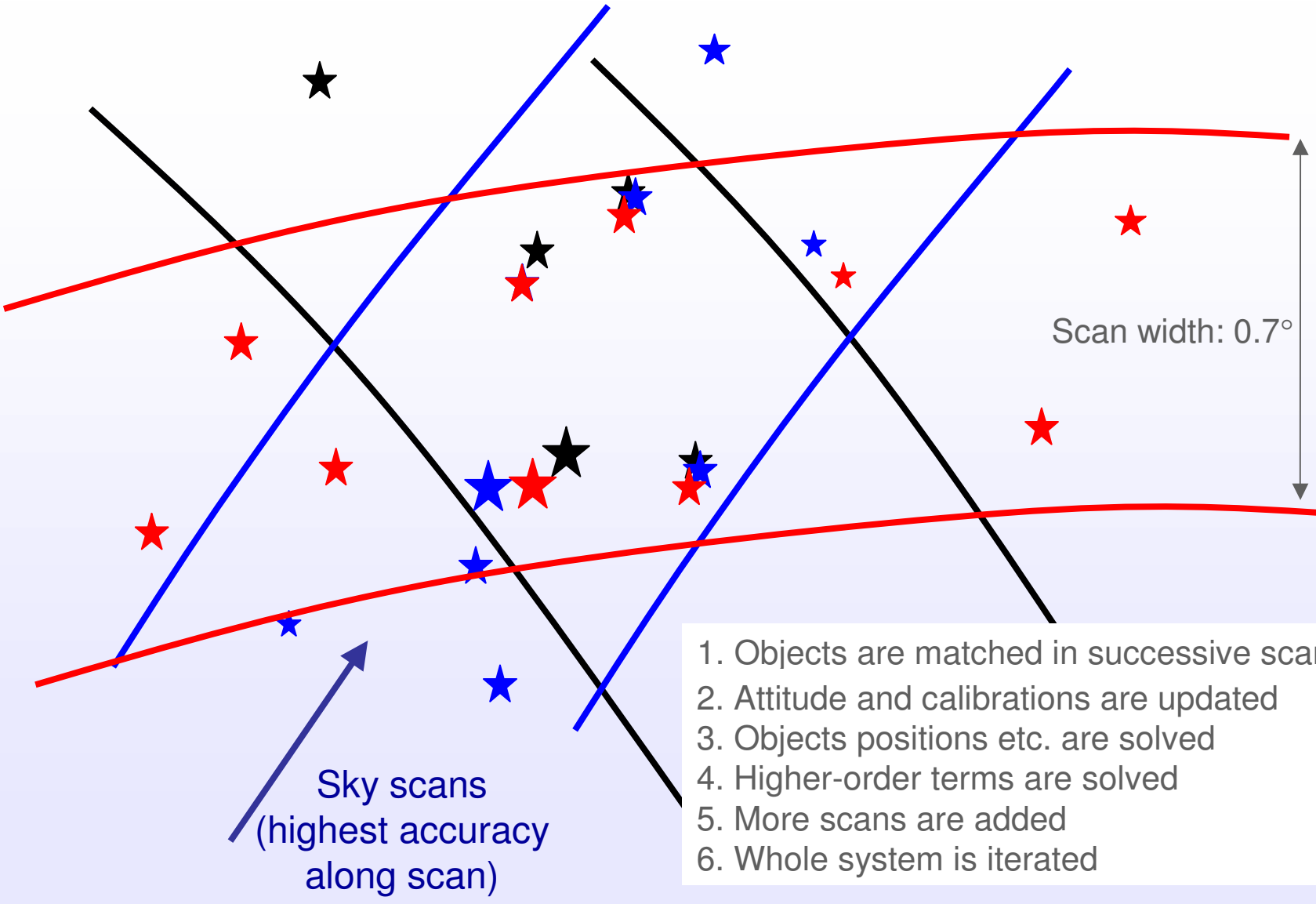
# AGIS: Astrometric Global Iterative Solution




1. Objects are matched in successive scans
2. Attitude and calibrations are updated
3. Objects positions etc. are solved
4. Higher-order terms are solved
5. More scans are added
6. Whole system is iterated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# AGIS – Observation Model

**The centroid of a star image is modelled as**

$$\begin{pmatrix}\text{Observed}\\ \text{location}\end{pmatrix} = \begin{pmatrix}\text{Global}\\ \text{ref. frame}\end{pmatrix} + \begin{pmatrix}\text{Source}\\ \text{position}\end{pmatrix} + \begin{pmatrix}\text{instrument}\\ \text{Attitude}\end{pmatrix} + \begin{pmatrix}\text{CCD/pixel}\\ \text{offset}\end{pmatrix} + \text{noise}$$

e.g. PPN

6 astrometric Parameters $(\alpha_0\ \delta_0\ \pi_0\ \mu_\alpha\ \mu_\delta\ \mu_r)$ fixed

quaternion $\boldsymbol{q}(t)$ represented by cubic spline coefficients

geom. calibration + chromaticity + CTI shift

white Gaussian known σ

Symbolical O = G + S + A + C + n


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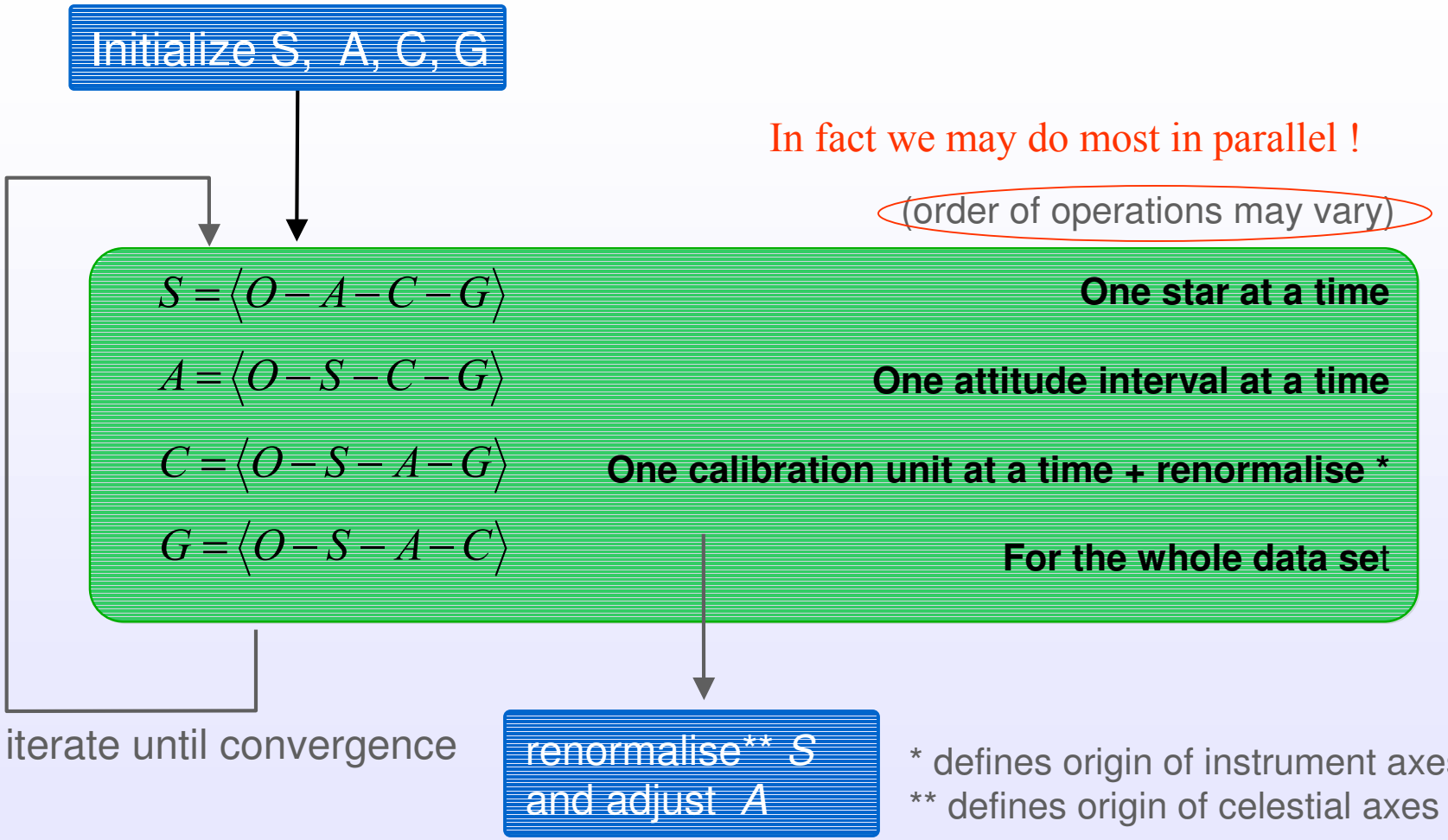
# AGIS – How?

**Block-iterative least-squares solution of the over-determined system of equations**

$$O = G + S + A + C + n$$





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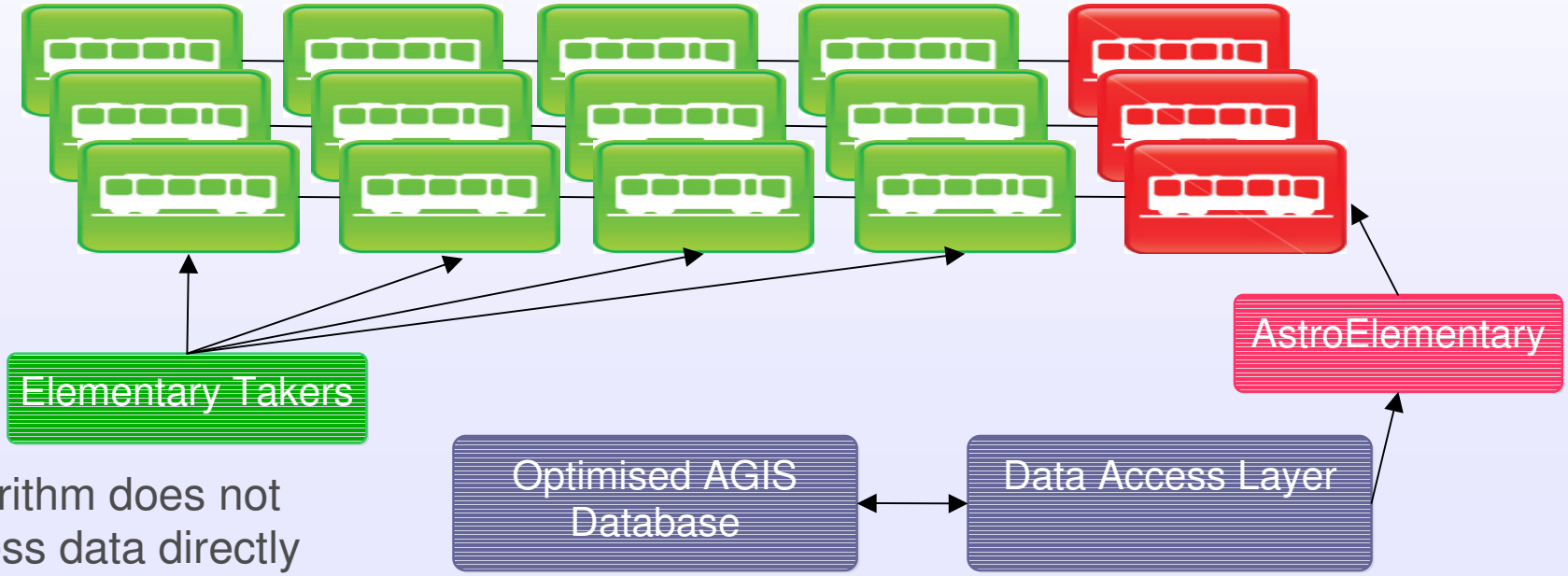
# AGIS Architecture


- Datatrains drive through AGIS Database passing observations to algorithms.
- There can be as many **Datatrains** in parallel as we wish




Algorithm does not access data directly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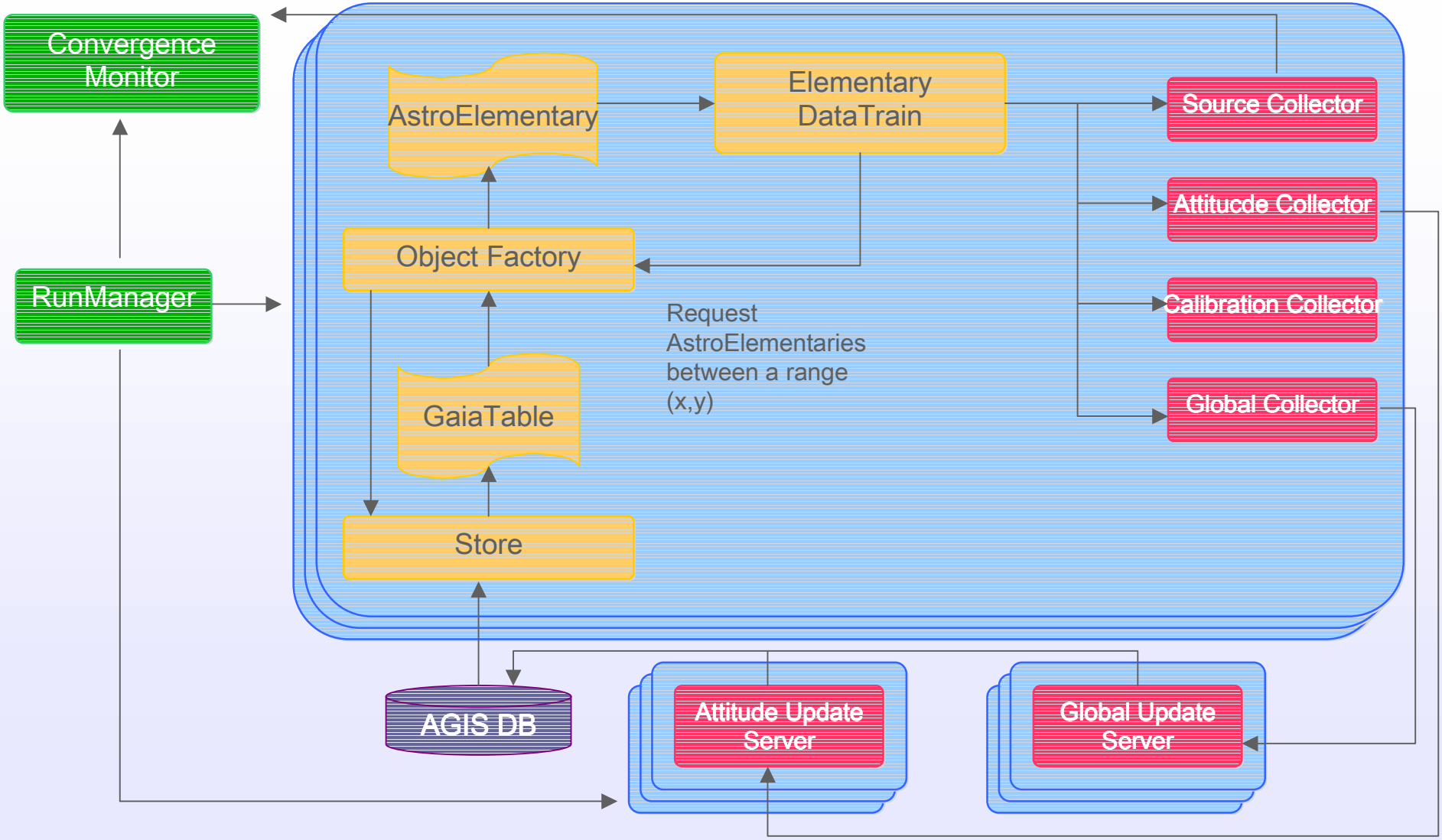
# AGIS Architecture - detailed





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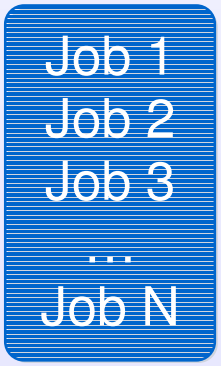
# Scheduling


- Very simple ..
  - Keep all machines busy all the time!
    - Busy = CPU ~90%
  - Post jobs on whiteboard

Trains/Workers Mark Jobs – and do them
Mark finished – repeat until done




Previous attempt had much more general scheduling
It was also ~1000 times slower.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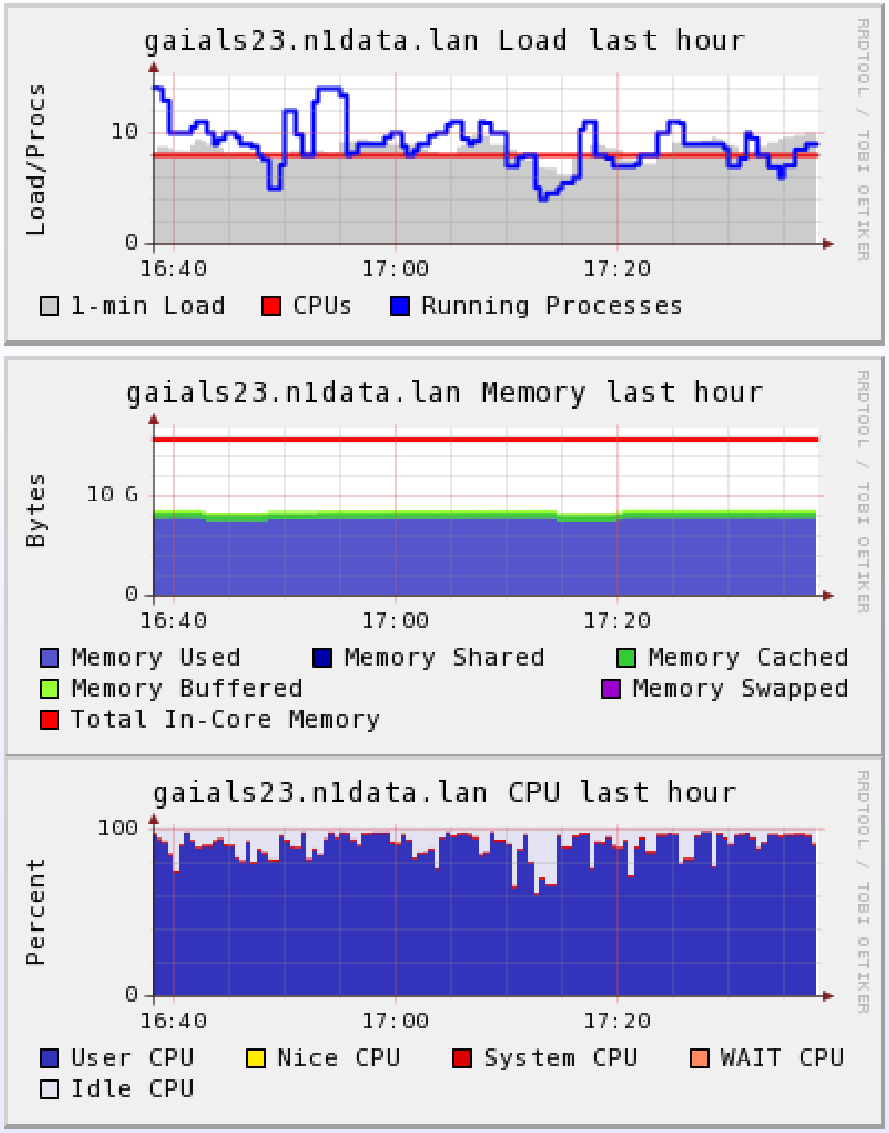
# Data Train load




AGIS runs like this

High load, low network, high CPU!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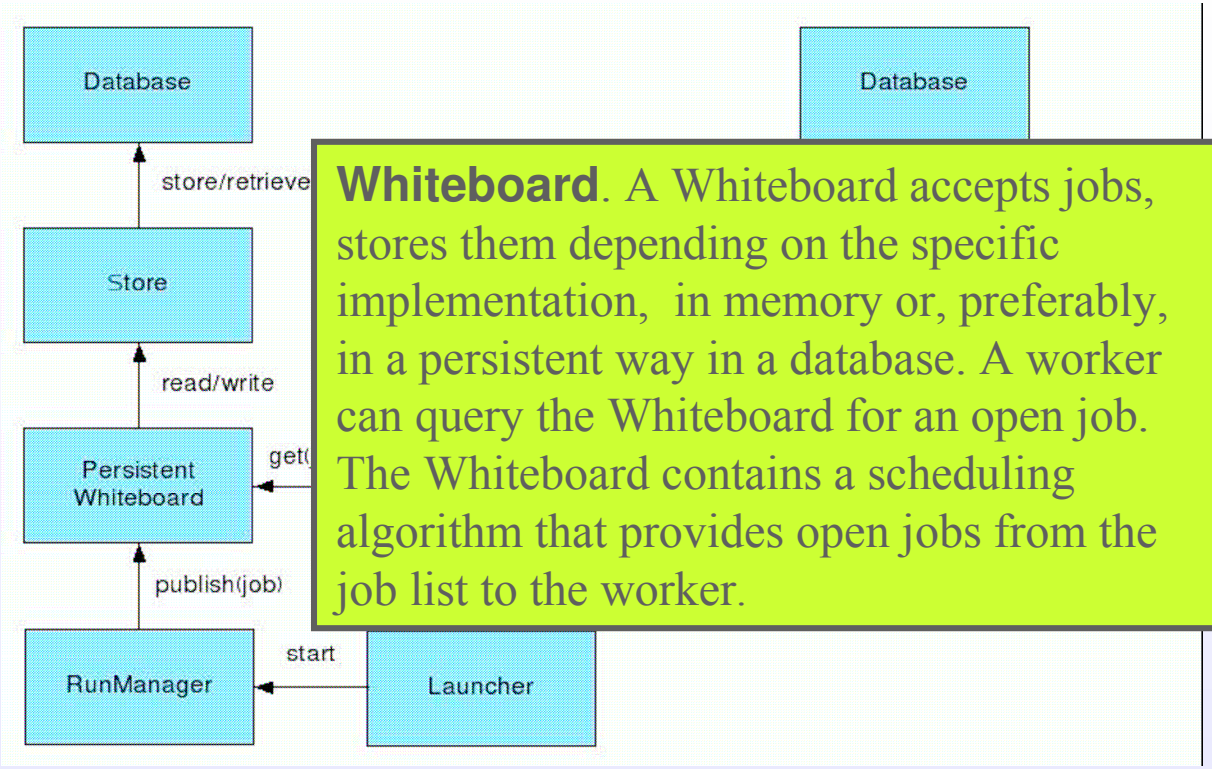
# Whiteboard/Data train concept




**Whiteboard**. A Whiteboard accepts jobs, stores them depending on the specific implementation, in memory or, preferably, in a persistent way in a database. A worker can query the Whiteboard for an open job. The Whiteboard contains a scheduling algorithm that provides open jobs from the job list to the worker.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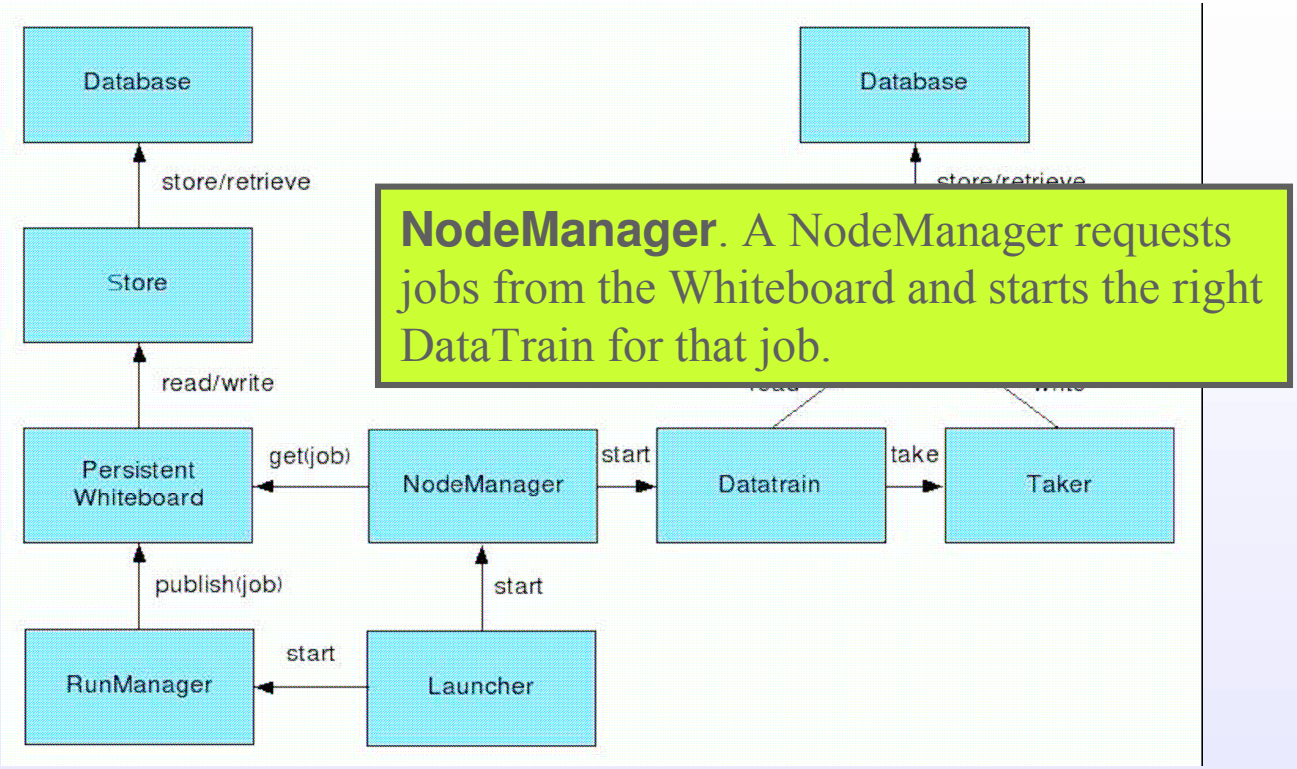
# Whiteboard/Data train concept




**NodeManager**. A NodeManager requests jobs from the Whiteboard and starts the right DataTrain for that job.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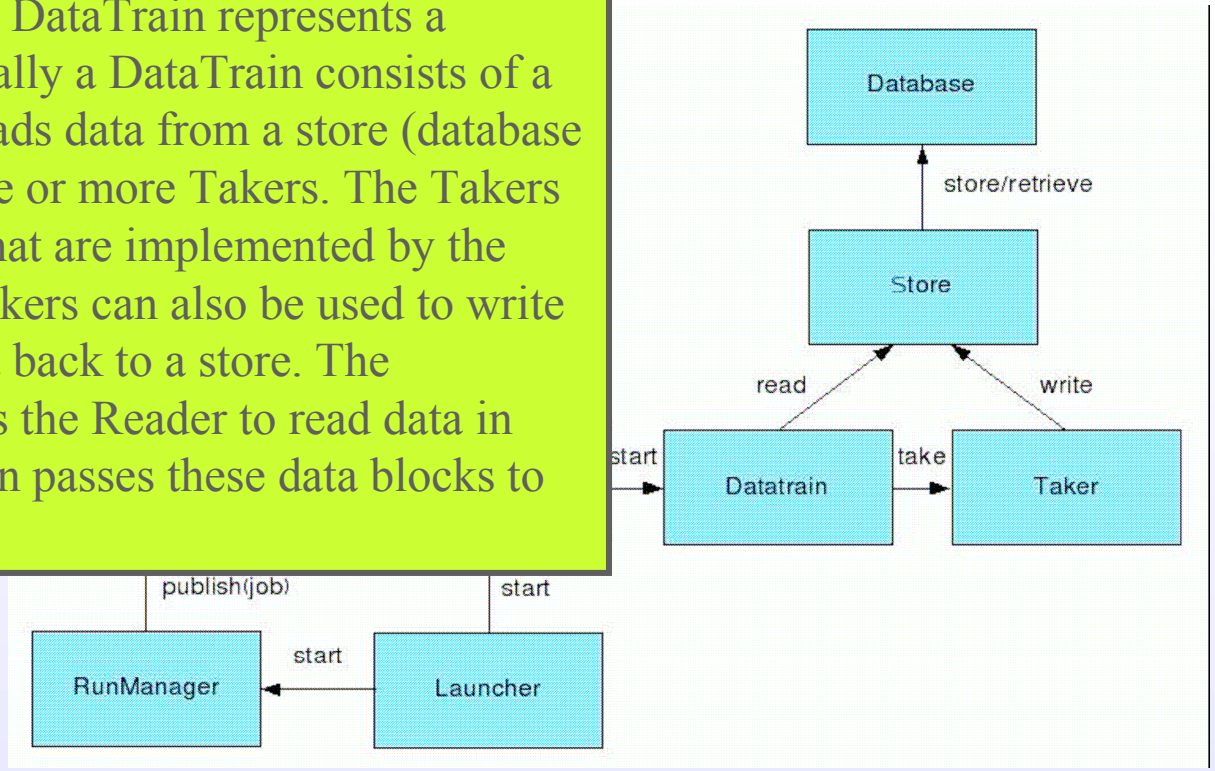
# Whiteboard/Data train concept

**DataTrain**. A DataTrain represents a worker. Normally a DataTrain consists of a Reader that reads data from a store (database or file) and one or more Takers. The Takers are interface that are implemented by the algorithms. Takers can also be used to write computed data back to a store. The DataTrain uses the Reader to read data in blocks and then passes these data blocks to the takers.





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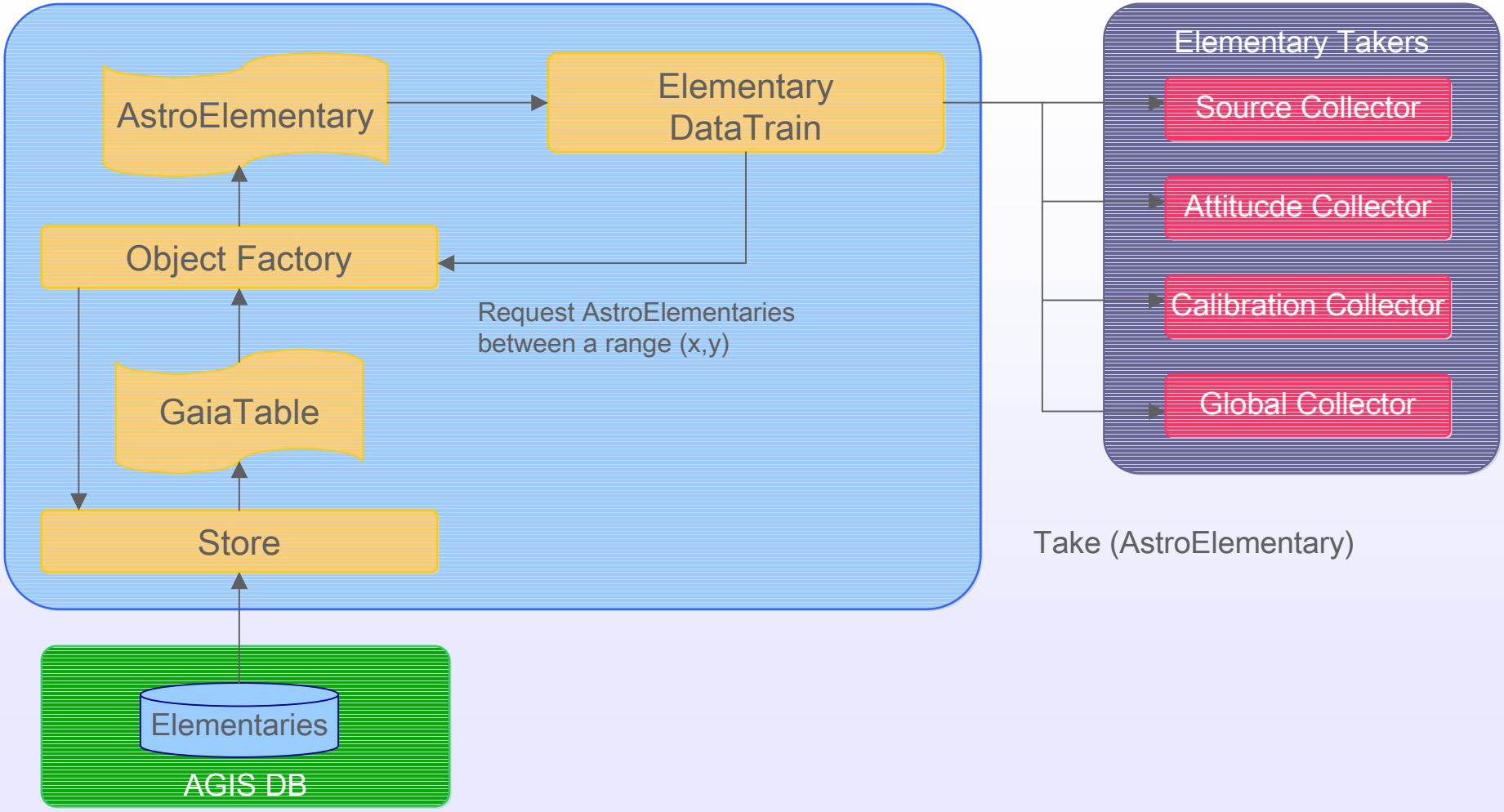
# Taker Architecture





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# The problem

- Data centre cost

AGIS run times decrease as more processors are added. Note that the data volume increased from 2005 to 2006 from 18 months to 5 years, the processor power also increased but the run time went up. This was dramatically improved in 2007. The normalised column shows throughput per processor in the system (total observations/processors/hours) e.g. an indication of the real performance.

| Date | Dataset | Procs | Time | Normalised |
|---|---|---|---|---|
| 2005 | 18mnt $10^6$ src | 12 | 3h | $0.9 * 10^6$ obs/hour |
| 2006 | 60mnt $10^6$ src | 36 | 5h | $0.5 * 10^6$obs/hour |
| 2007 | 60mnt $10^6$ src | 24 | 3h | $1.3 * 10^6$ obs/hour |
| 2008 | 60mnt $10^6$ src | 31 | 1.5h | $2.1 * 10^6$ obs/hour |
| Feb 2008 | 60mnt $10^6$ src | 31 | 1h | $3.2 * 10^6$ obs/hour |

- on


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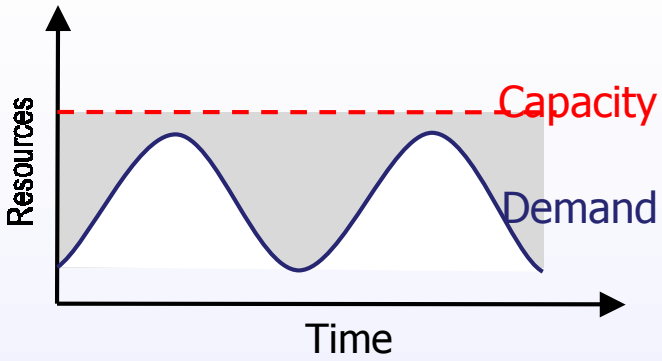
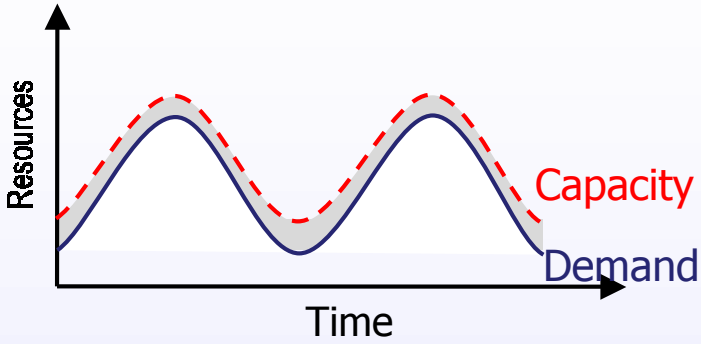
# Economics of Cloud Computing




Static data center




Data center in the cloud

Unused resources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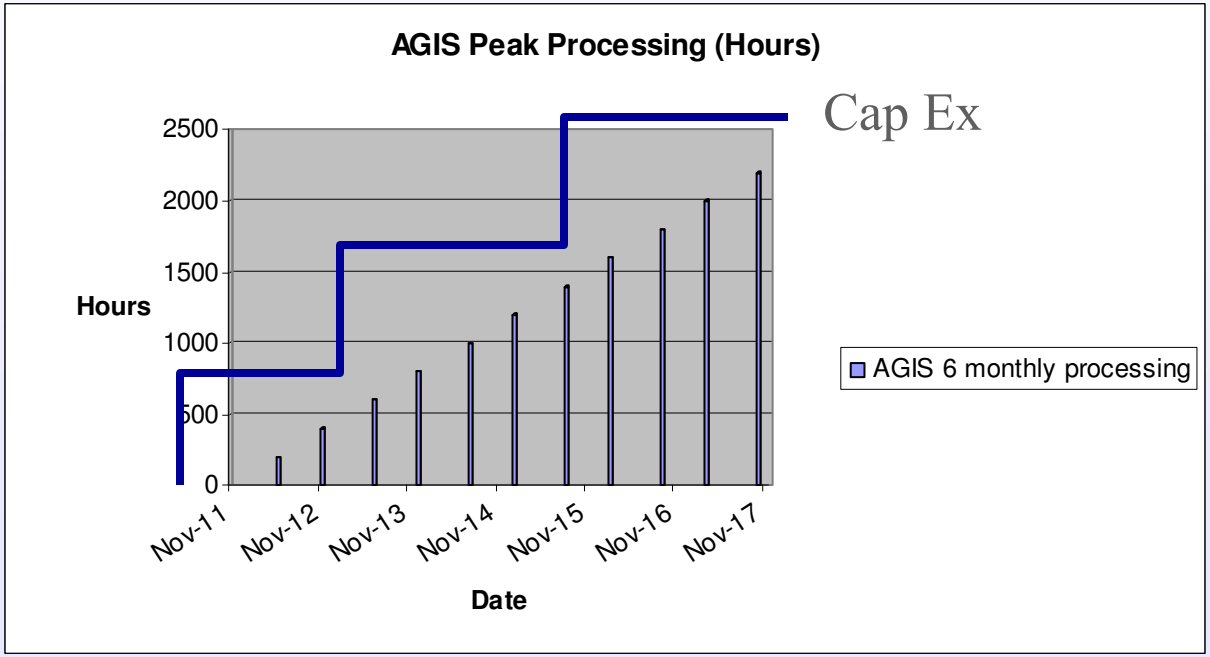
# AGIS Peaks

- Iterative processing – 6 month Data Reduction Cycles
- At current estimates AGIS will run 2 weeks every 6 months
- Amount of data increases over the 5 year mission





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# The Study: Running AGIS in Amazon EC2


- Technical Feasibility:
  - Can AGIS run in the cloud?
  - What are the restrictions?
  - What modifications do we have to make?
- Financial Viability
  - What would be the cost of using EC2 for AGIS?
  - Can we do a hybrid solution using a local data centre followed by a mix of local/EC2?


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# EC2 Instance Types


| | Small | Large | Extra Large | High CPU Medium | High CPU Large |
|---|---|---|---|---|---|
| Bits | 32 | 64 | 64 | 32 | 64 |
| RAM | 1.7 GB | 7.5 GB | 15 GB | 1.7 GB | 7 GB |
| Disk | 160 GB | 850 GB | 1690 GB | 350 GB | 1690 GB |
| EC2 Compute Units | 1 | 4 | 8 | 5 | 20 |
| I/O Performance | Medium | High | High | High | High |
| Firewall | Yes | Yes | Yes | Yes | Yes |


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# EC2 Images


- 64 bit images
  - Large, Extra Large and High CPU Large
- Oracle ASM Image based on Oracle Database 11g Release 1 Enterprise Edition - 64 Bit (Large instance) - ami-7ecb2f17
- AGIS Self configuring Image based on Ubuntu 8.04 LTS Hardy Server 64-Bit (Large, Extra Large and High CPU Large Instances) - ami-e257b08b


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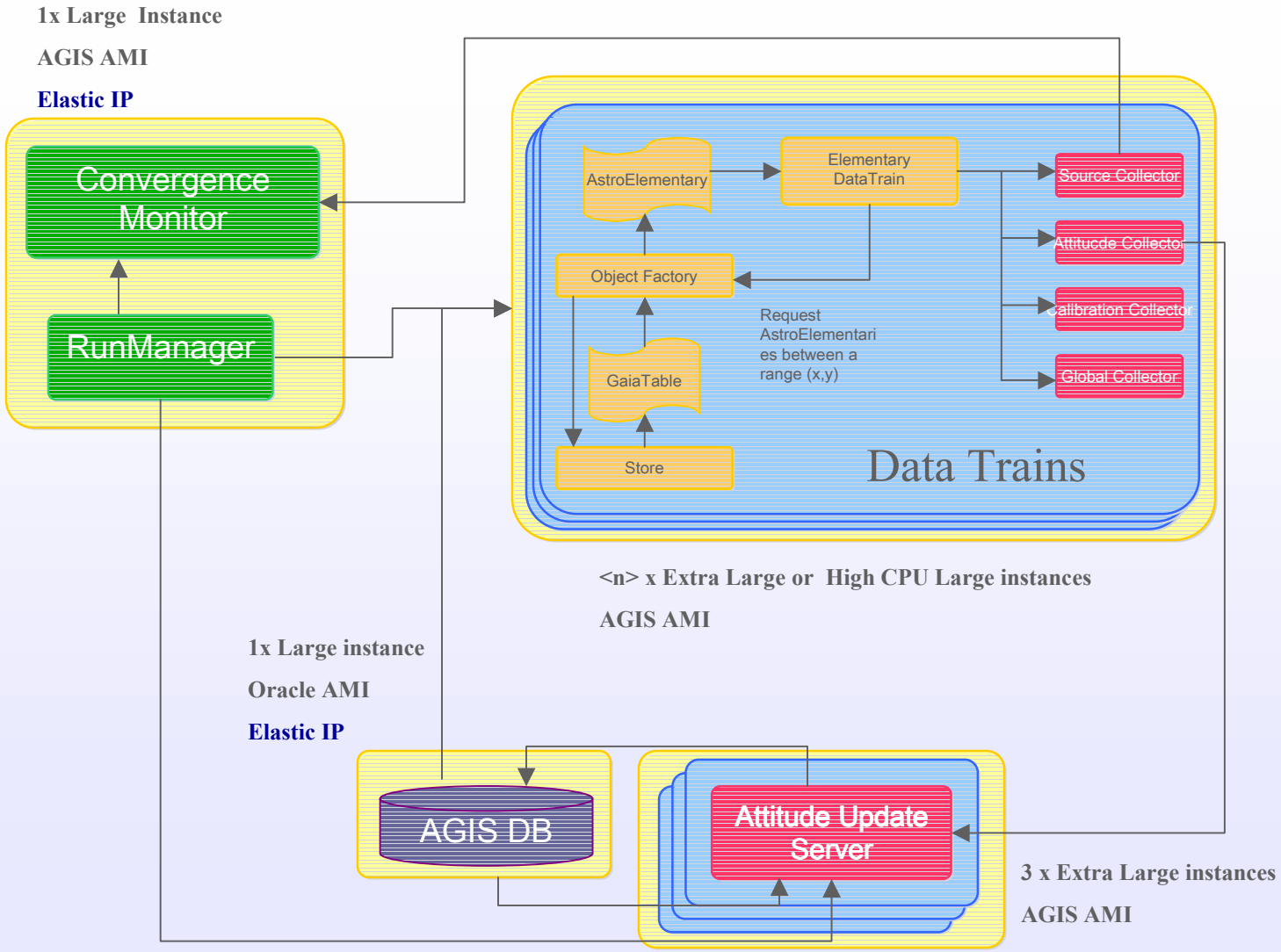
# Architecture in the Cloud





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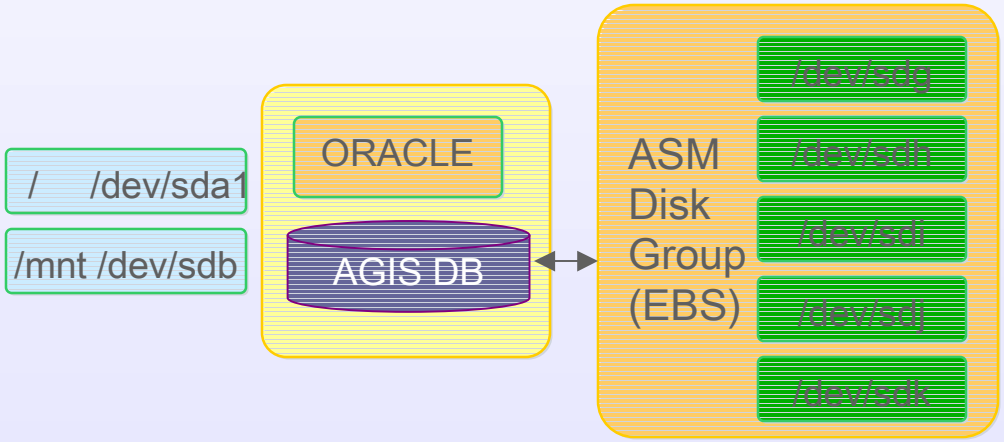
# Oracle Image

- EC2 Large instance (m1.large)
- Oracle Enterprise Edition 11g 64 bit (11.0.6)
- Oracle ASM
- Elastic Block Storage
  - 5 x 100GB disks /dev/sdg - /dev/sdk





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# Configuring Oracle


- Launch an m1.large instance of ami-7ecb2f17
- Attach the /mnt partition properly so it has enough space
- Create 5 EBS vols of 100GB each and attach them to the instance
- Set up Oracle ASMLib
  - Install drivers
  - Run oracleasm_debug_link
  - Run oracleasm configure, createdisk
- Copy a pre-recorded Oracle response file up to create an ASM instance
- Run Oracle installer to create the ASM instance
- Copy a pre-recorded Oracle response file up to create the AGIS DB instance
- Run Oracle installer to create the AGIS DB instance


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# Configuring Oracle cont.


- Create an Elastic IP and associate it with the instance
- Change the hostname to be the new public DNS name
  - hostname ec2-174-129-223-59.compute-1.amazonaws.com
- Run localconfig remove followed by localconfig add
- This will run for ever unless you edit /etc/inittab and change the following line

  h1:35:respawn:/etc/init.d/init.cssd run >/dev/null 2>&1 </dev/null

  to

  h1:345:respawn:/etc/init.d/init.cssd run >/dev/null 2>&1 </dev/null

- Start the ASM instance
- Start the AGIS DB instance

Don’t forget to make a new image!!!


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# AGIS Image


- Instances (m1.large and c1.xlarge).
- Java version 1.6.0_13
  - Java(TM) SE Runtime Environment (build 1.6.0_13-b03)
  - Java HotSpot(TM) 64-Bit Server VM (build 11.3-b02, mixed mode)
- Apache Tomcat 6.0.14
- AGIS software.
- Creation of agis user acoount
- rc.local script modified to run the AGIS process
  - Self configuring using user-data


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# Configuring AGIS Image


- Launch an m1.large instance of  ami-e257b08b
- Checkout the source code from the svn server.
- Create an agis user to run the process.
- Set up /etc/rc.local to execute the runAgis.sh
- Create a generic runAgis.sh script that reads data passed to the ami during boot time (using the AWS).
  - Data contains JVM parameters and especific application parameters (Depending on the  DataTrain that will be executed at that node).


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# Launching AGIS Images


- Launch the RunManager
  - User data is passed to the AMI at boot time.
    - Process type (RunManager, DataTrain, Server)
    - JVM args
    - User Data args

```
export RUNMANAGER_DATA="\"RunManager|-Xmx6g\${IFS}-
    XX:MaxPermSize=512M\${IFS}-Xnoclassgc\${IFS}-
    Dgaia.cu3.agis.algo.gis.attitude.AttitudeUpdateServer.numServers=${NODES}\${IFS}
    -D\${HOSTNAME}=gaia.cu3.agis.progs.run.RunManager\""
export NODES=1
ec2-run-instances ami-9ea442f7 -n 1 -k gaia-keypair -g default -z us-east-1c -t m1.large -d
    ${RUNMANAGER_DATA} > instance_id.txt 2>&1
...
ec2-associate-address $IP -i $INSTANCE_ID
```


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# AGIS Image at boot time

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the IT architects

- Script executed at boot time
  - Get the data from an Amazon WebService
  - Run the Launcher with the JVM args

```
export USER_DATA=`GET http://169.254.169.254/2007-03-01/user-data`
export NODE_TYPE=`echo ${USER_DATA} | awk -F\| '{print($1)}'`
export VMARGS=`echo ${USER_DATA} | awk -F\| '{print($2)}'`

nohup java ${VMARGS} -cp $AGIS_HOME/conf:$AGIS_HOME/dist/GaiaAGIS.jar  -
    Dgaia.cu1.tools.hostid=1 -Dgaia.cu3.agis.mgr.CycleDesc=$1
    gaia.cu3.agis.progs.run.Launcher >> ${LOG_FILE} 2>&1 &
```


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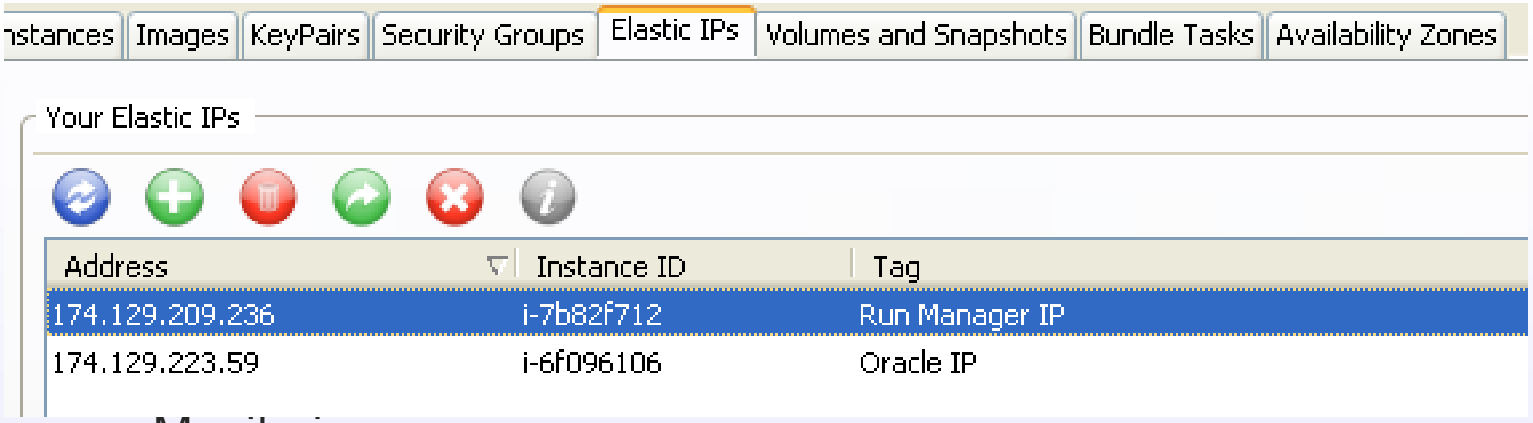
# Other considerations

- Elastic Ips for Oracle and the Whiteboard




- Monitoring
  - Plan to use Hyperic or Nagios
  - Amazon CloudWatch now available
- Security
  - Be very careful with keys and passwords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# Lessons Learned


- Creating new images takes a long time so make sure you get it right ☺
- Oracle is very fussy about it's IP address, hence the Elastic IP
  - Oracle instance hostname changed to be the public DNS name
- Some work still needed on the startup script to make sure the ASM boots first time
  - Fixed with new Oracle AMIs
- The Attitude Servers took a long time to start up (20 mins)
  - This was due to a race condition caused by spin locks in the type of java Thread Pool we were using.


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# Timescales


- Took a team of 2 less than 20 man days to get running (Parsons,Olias).


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# What did we have to change in AGIS?

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- To avoid the Spin Locks in the Thread Pool we had to change these lines of code:

```
this.stack = new ConcurrentStack<Runnable>();

this.threadPoolExecutor = new ThreadPoolExecutor(
                          numberOfWorkingThreads,
                          numberOfWorkingThreads,
                          100,
                          TimeUnit.SECONDS,
                          this.stack);

this.threadPoolExecutor.prestartAllCoreThreads();
```

← Non blocking stack - CAS

- **To this**

```
this.threadPoolExecutor = (ThreadPoolExecutor)Executors.
            newFixedThreadPool(numberOfWorkingThreads);
```


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# EC2 Instances

Instances | Images | KeyPairs | Security Groups | Elastic IPs | Volumes and Snapshots | Bundle Tasks | Availability Zones

**Your Instances**

| Owner | State | Public DNS | Private DNS | Idx | Type | Local Launch Time | Tag |
|---|---|---|---|---|---|---|---|
| | running | ec2-174-129-223-59.compute-1.amazon... | domU-12-31-39-03-69-71.compute-1.internal | 0 | m1.large | 2009-04-21 10:56:20 | Oracle |
| | running | ec2-174-129-209-236.compute-1.amazo... | domU-12-31-39-00-29-51.compute-1.internal | 0 | m1.large | 2009-05-07 14:27:58 | RunManager |
| | running | ec2-75-101-208-129.compute-1.amazon... | domU-12-31-39-00-F0-B1.compute-1.internal | 0 | c1.xlarge | 2009-05-07 14:35:56 | |
| | running | ec2-174-129-187-101.compute-1.amazo... | domU-12-31-39-01-85-B1.compute-1.internal | 1 | c1.xlarge | 2009-05-07 14:35:56 | |
| | running | ec2-75-101-248-164.compute-1.amazon... | domU-12-31-39-00-90-A1.compute-1.internal | 2 | c1.xlarge | 2009-05-07 14:35:56 | |
| | running | ec2-174-129-175-175.compute-1.amazo... | domU-12-31-39-00-F4-81.compute-1.internal | 0 | c1.xlarge | 2009-05-07 14:40:38 | |
| | running | ec2-67-202-33-107.compute-1.amazona... | domU-12-31-39-00-F5-D1.compute-1.internal | 1 | c1.xlarge | 2009-05-07 14:40:38 | |
| | running | ec2-67-202-42-56.compute-1.amazonaw... | domU-12-31-39-01-70-E1.compute-1.internal | 2 | c1.xlarge | 2009-05-07 14:40:38 | |
| | running | ec2-174-129-184-8.compute-1.amazona... | domU-12-31-39-01-70-A1.compute-1.internal | 3 | c1.xlarge | 2009-05-07 14:40:38 | |
| | running | ec2-67-202-11-61.compute-1.amazonaw... | domU-12-31-39-00-BD-B1.compute-1.internal | 4 | c1.xlarge | 2009-05-07 14:40:38 | |
| | running | ec2-75-101-206-68.compute-1.amazona... | domU-12-31-39-01-B9-01.compute-1.internal | 5 | c1.xlarge | 2009-05-07 14:40:38 | |
| | running | ec2-75-101-204-217.compute-1.amazon... | domU-12-31-39-00-D4-71.compute-1.internal | 6 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-67-202-2-184.compute-1.amazonaw... | domU-12-31-39-00-B8-01.compute-1.internal | 7 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-75-101-176-225.compute-1.amazon... | domU-12-31-39-00-F9-61.compute-1.internal | 8 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-174-129-142-128.compute-1.amazo... | domU-12-31-39-00-8C-B1.compute-1.internal | 9 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-174-129-98-165.compute-1.amazon... | domU-12-31-39-00-98-61.compute-1.internal | 10 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-67-202-10-82.compute-1.amazonaw... | domU-12-31-39-00-60-11.compute-1.internal | 11 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-72-44-60-224.compute-1.amazonaw... | domU-12-31-39-00-71-21.compute-1.internal | 12 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-174-129-184-53.compute-1.amazon... | domU-12-31-39-01-91-91.compute-1.internal | 13 | c1.xlarge | 2009-05-07 14:40:39 | |
| | running | ec2-174-129-188-181.compute-1.amazo... | domU-12-31-39-01-88-01.compute-1.internal | 14 | c1.xlarge | 2009-05-07 14:40:39 | |


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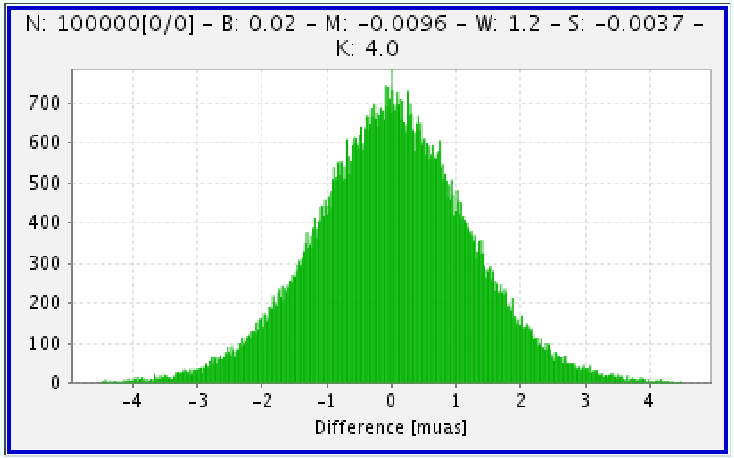
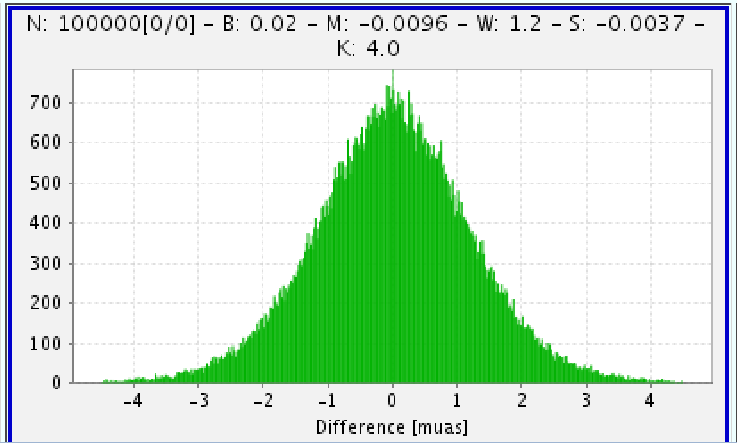
# AGIS Works!

Astrometric Global Iterative Solution Monitoring Site

Current Plots | Diagnostic Monitor | Retrieve Plots | All Cycles | All Runs | Cycle | WhiteBoard Monitor | Node Summary | Schema Description | Properties | Java Docs

Source | Attitude

X | Y | Z

| Iteration | Iteration 1 (N), Run 2883993437692100674 | Iteration 2 (N), Run 2883993437692100675 |
|---|---|---|
| Update |   | No image available yet |
| Absolute error |   | No image available yet |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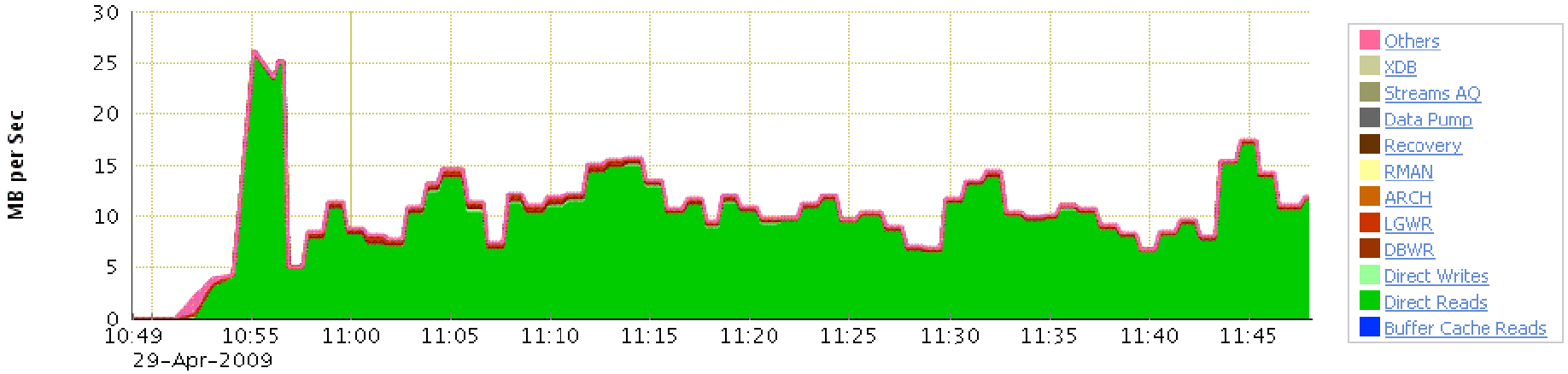
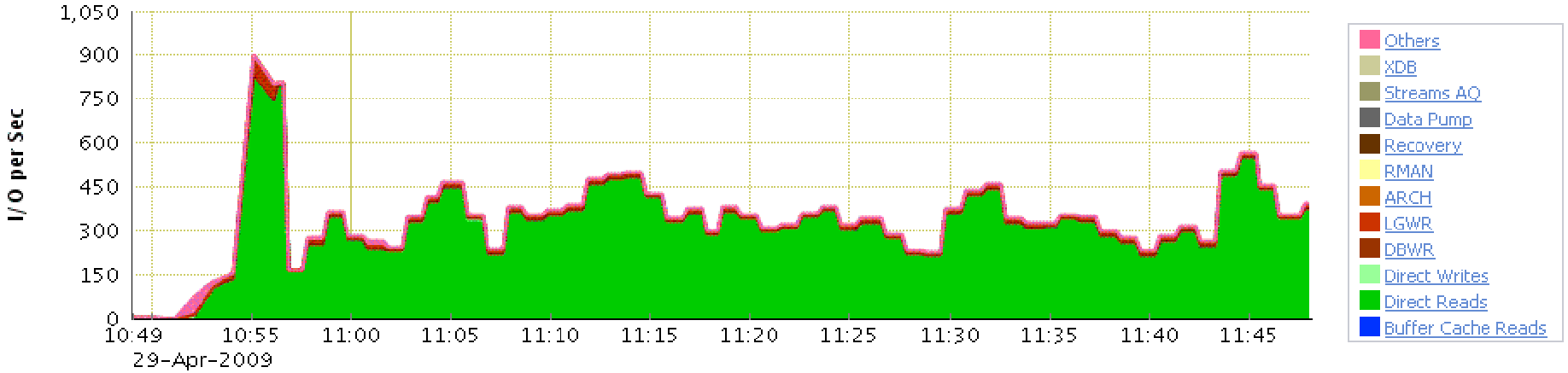
# Oracle Performance in the Cloud

I/O Breakdown (•) I/O Function ( ) I/O Type ( ) Consumer Group

I/O Megabytes per Second by I/O Function




I/O Requests per Second by I/O Function





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# Demo


- Let's see it in action!


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# Test run 1


- AGIS Primary star update
  - 2 million stars 5 years observations
- 1x Oracle Instance (m1.large)
- 1x AGIS RunManager/Monitor Instance (m1.large)
- 3x AGIS AttitudeServer Instances (m1.large)
- 15x AGIS DataTrain Instances (c1.xlarge)

- Results
  - Iteration time 100 mins
  - Performance slightly slower than in-house cluster


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# Test run 2


- AGIS Primary star update
  - 2 million stars 5 years observations
- 1x Oracle Instance (m1.large)
- 1x AGIS RunManager/Monitor Instance (m1.large)
- 4x AGIS AttitudeServer Instances (c1.xlarge)
- 45x AGIS DataTrain Instances (c1.xlarge)

- Results
  - Iteration time 50 mins
  - Performance comparable to in-house cluster


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# Test run 3


- AGIS Secondary star update
  - 20 million stars 5 years observations
- 1x Oracle Instance (m1.large)
- 1x AGIS RunManager/Monitor Instance (m1.large)
- 30x AGIS DataTrain Instances (c1.xlarge)

- Results
  - Run Time 43 minutes


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# Test run 4


- AGIS Secondary star update
  - 20 million stars 5 years observations
- 1x Oracle Instance (m1.large)
- 1x AGIS RunManager/Monitor Instance (m1.large)
- 48x AGIS DataTrain Instances (c1.xlarge)

- Results
  - Run Time 48 minutes (Slightly Slower)
  - Oracle Row lock contention problems


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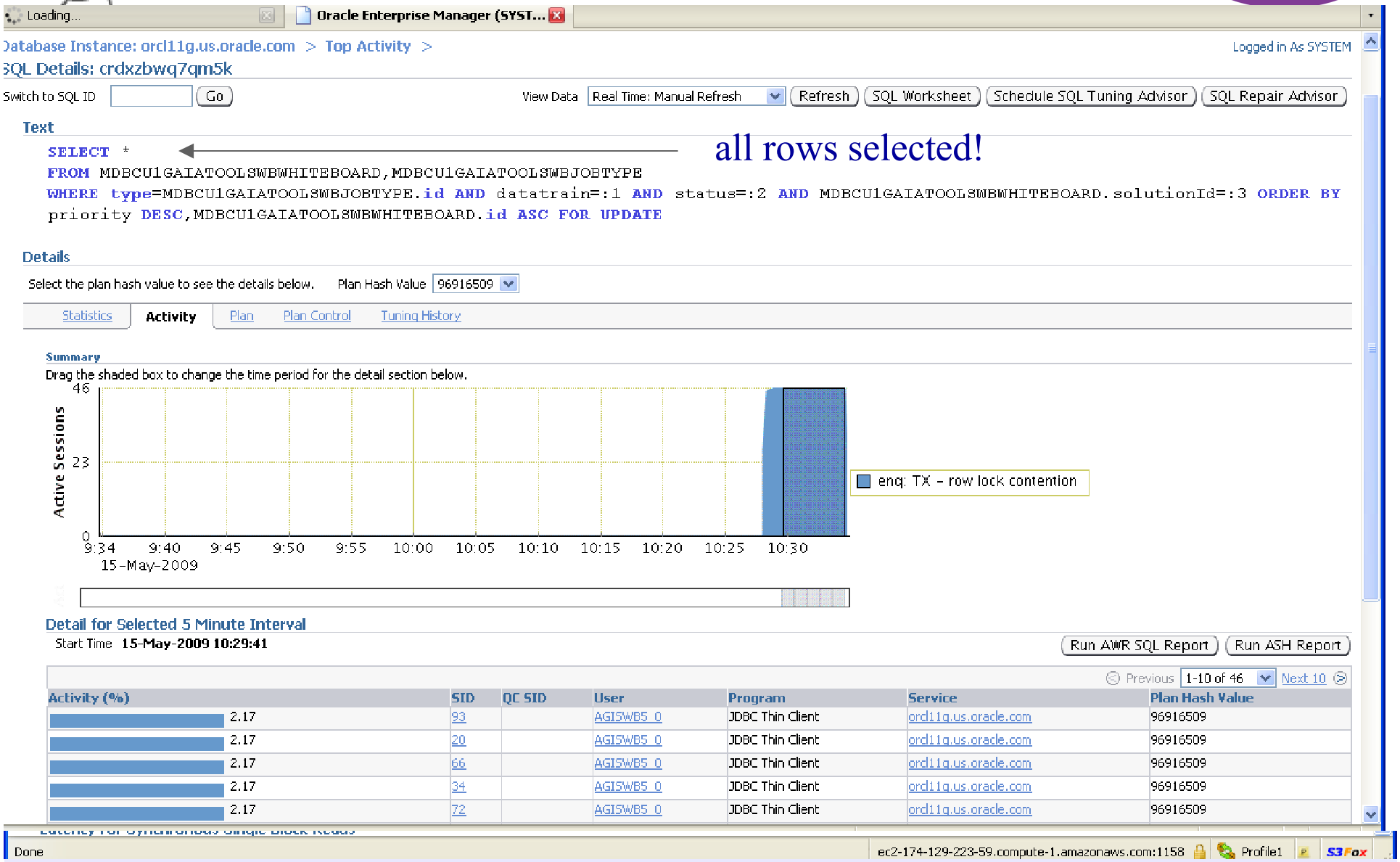
# Test run 4 continued!





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# Financial Analysis


- 2 million stars 5 years data
  - 24 iterations of 100 minutes = 40 hrs x 20 EC2 instances
  - Secondary update 30mins * 10 = 5hrs x 20 EC2 instances
- For the Full 1 billion data set we will have 100 million primary stars plus 6 years of data
  - 40 x 50 x 6/5 = 2,400 hrs x 20 EC2 inst.
  - Sec = 300 hrs x 20 EC2 inst.
- Average over the whole mission will be
  - 2,700 x 12 / 2 = 16,200 hrs x 20 EC2 inst.


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# Financial analysis cont.


- For the 2 million star run the cost will be
  - 45 x 15 x 0.8$ (c1.xlarge) = 540$
  - 45 x 5 x 0.4$ (m1.large) = 90$
  - Data transfer in 50GB x .1$ = 5$
  - EBS 471GB Storage x .1$ = 47$
  - EBS I/O = 9$
  - Elastic IP = 2.29$
  - S3 Storage = 5.91$
- Total 699.2$ = 525 EUR (at current exchange rates)


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# Financial analysis cont.


- Extrapolating to 1 billion stars 6 year mission
  - 2700 x 6 x 15 x 0.8$ (c1.xlarge) = 194,400$
  - 2700 x 6 x 5 x 0.4$ (m1.large) = 32,400$
  - Data transfer in 500 x 50GB x .1$ = 2,500$
  - EBS 500 x 250GB Storage x 6 x .1$ = 75,000$
  - EBS I/O = 500 x 9$ = 4500$
  - Elastic IP = 48180 x 0.01$ = 481$
  - S3 Storage = 5.91$
- Total 309,286.$ = 229,066 EUR
- Allowing for mistakes (wrong configs etc.)
- Estimated Total 343,599 EUR at current exchange rates


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# Cost effectiveness of E2C.


- AGIS runs intermittently with growing Data volume.
- Estimate 2015 ~1.1MEuro (machine) + 1Meuro (energy bill less ?) = ~2Meuro
  - In fact staggered spending for machines
  - buy machines as data volume increase
- Estimate on Amazon at today prices with 10 intermittent runs ~400Keuro
  - Possibility to use more nodes and finish faster !
- Reckon you still need in house machine to avoid wasting time testing on E2C
- Old nut, Vendor lock-in ? Need standards


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# Conclusions


- AGIS can be run in the cloud!
- Running with 48 Data train nodes gave us new scalability problems we hadn't seen before!
- The Economics work out:
  - To do the same amount of processing in the same time, EC2 works out cheaper for AGIS!
  - With the knowledge that EC2 is an option we can delay buying more machines until the middle of the mission (2014) and decide then.


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# Next Steps


- Currently running a second feasibility study
  - New data set, 60 million primary stars (1/3 final primaries). Approx 1.5 TB
  - Idea is to see how scalable the Gaia DataTrain grid is. Try and scale to 1000 8CPU EC2 instances
  - Compare S3 performance with Oracle
  - Using Rightscale technology
  -


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# Thank you for listening

Thank you for listening

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