



Measuring our galaxy and beyond

William O'Mullane, AURA/LSST
DM Project Manager

18th July 2018 Scoil Mhuire, Clontibret, Monaghan, Ireland





Early background



- 1982-87 High School in Fethard Co. Tipperary
- 1984ish started with BASIC on a Commodore (still kept horses)
- 1987-93 MSc BSc Computer Science, University College Cork, Ireland
- 1993 iESA Young Graduate Trainee - ESOC Germany.
- 1994-97 Spacecraft Control Systems (C++), ESA ESOC Germany
- 1997-2001 Hipparcos, Integral, Planck, Gaia, Bepi-Sax (C,Java,Oracle, HTM, HEALPix), ESA ESTEC Netherlands
- 2012 PhD in Physics on Implementing the Gaia Astrometric Solution, Barcelona University

YGT is still running - "about 100 YGT job offers, aimed mainly at engineers and physicists, graduates in Information Technology, Natural or Social Science and Business"

https://www.esa.int/About_Us/Careers_at_ESA/Graduates_Young_Graduate_Trainees



South of Spain



William O'Mullane • Scoil Mhuire Clontibert • 18th June 2018



Outline of the talk



European Space Agency

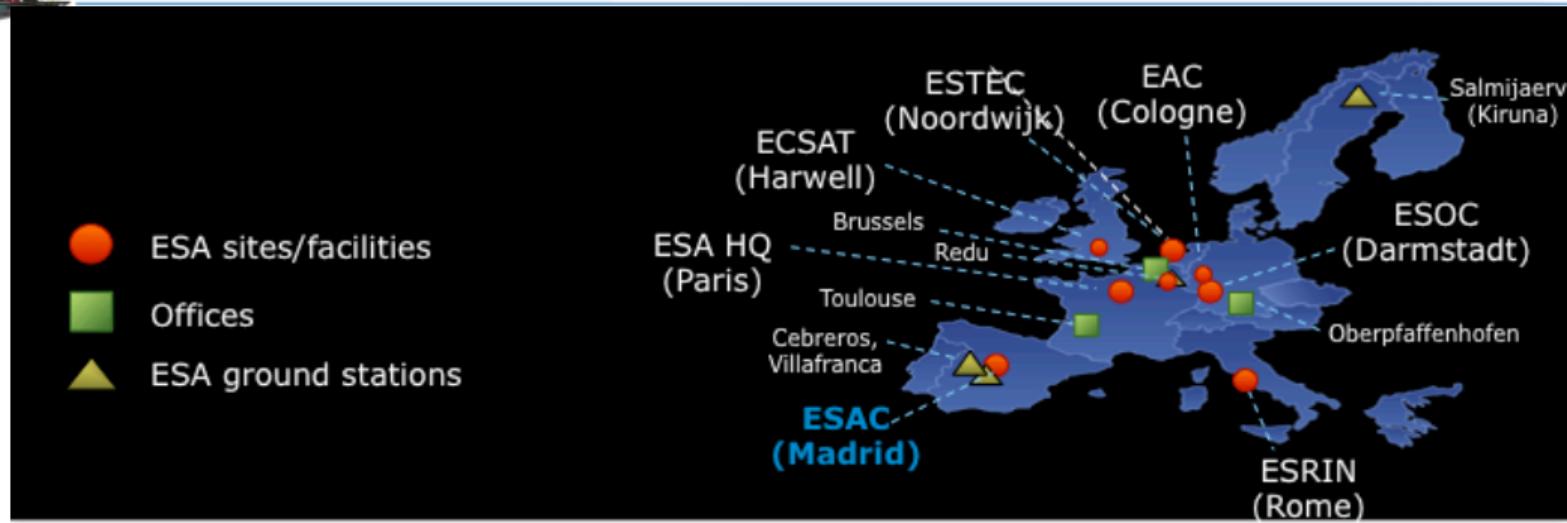
Gaia and LSST

Launch

Astrometry



European Space Agency





Late 1990s SCOSII software contractors



- ESOC - Located in Darmstadt, near Frankfurt, Germany.
- Controls all ESA satellites.
- System design/engineering, requirements management, advanced studies ..
- SCOSII (Satellite Control and Operations System) for ENVISAT



1998 Integral in ESTEC



- ESTEC - Located near Noordwijk, Netherlands.
- Worked on Hipparcos, Integral, Planck and Gaia study phase:
 - First ideas on Global Astrometric Solution (O'Mullane & Lindegren, 1999) and **how to make a consortium**.
 - How to tessellate the celestial sphere : HEALPix and HTM work proved popular (O'Mullane et al., 2001).

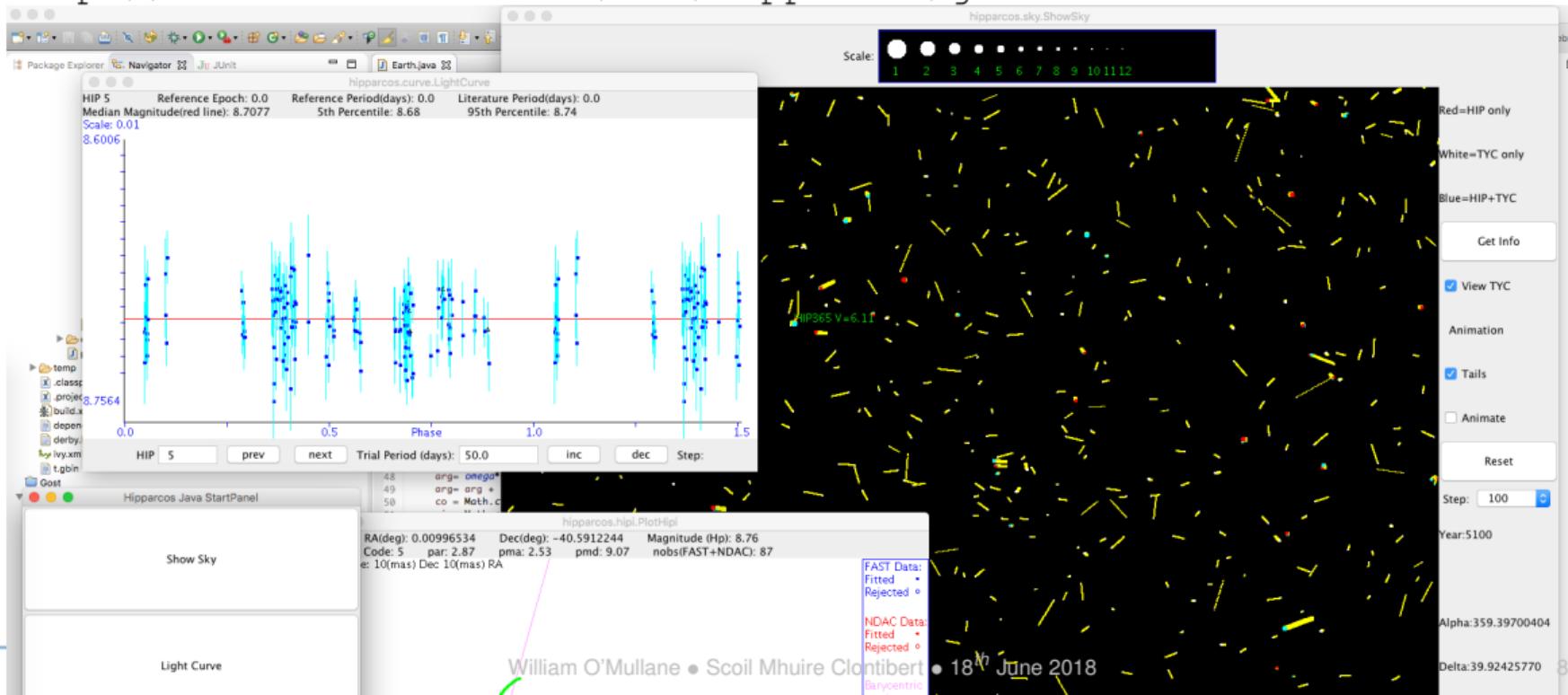


Addition to HIP Catalogue



1997/98 Hipparcos Java Tools - learning Astrometry

<http://www.cosmos.esa.int/web/hipparcos/java-tools>





In the USA early 2000s



Entering the new millennium ..

Quality tools for GSC2 (Java) →

CasJobs (C#)(O'Mullane et al., 2004)

View Jobs - Mozilla Firefox

File Edit View History Bookmarks Tools Help

SDSS Query / CasJobs

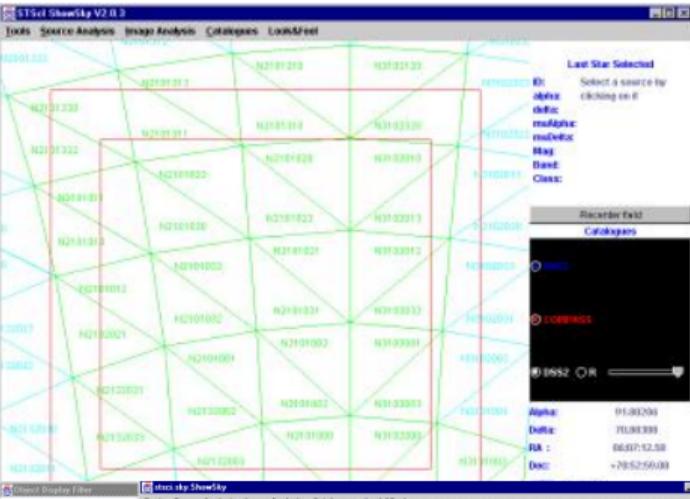
Help Tools Query History MyDB Import Groups Output Profile Admin SkyServer Logout thakar

Refresh this page to get latest info

Status Target Name Like

ANY DR6 Apply

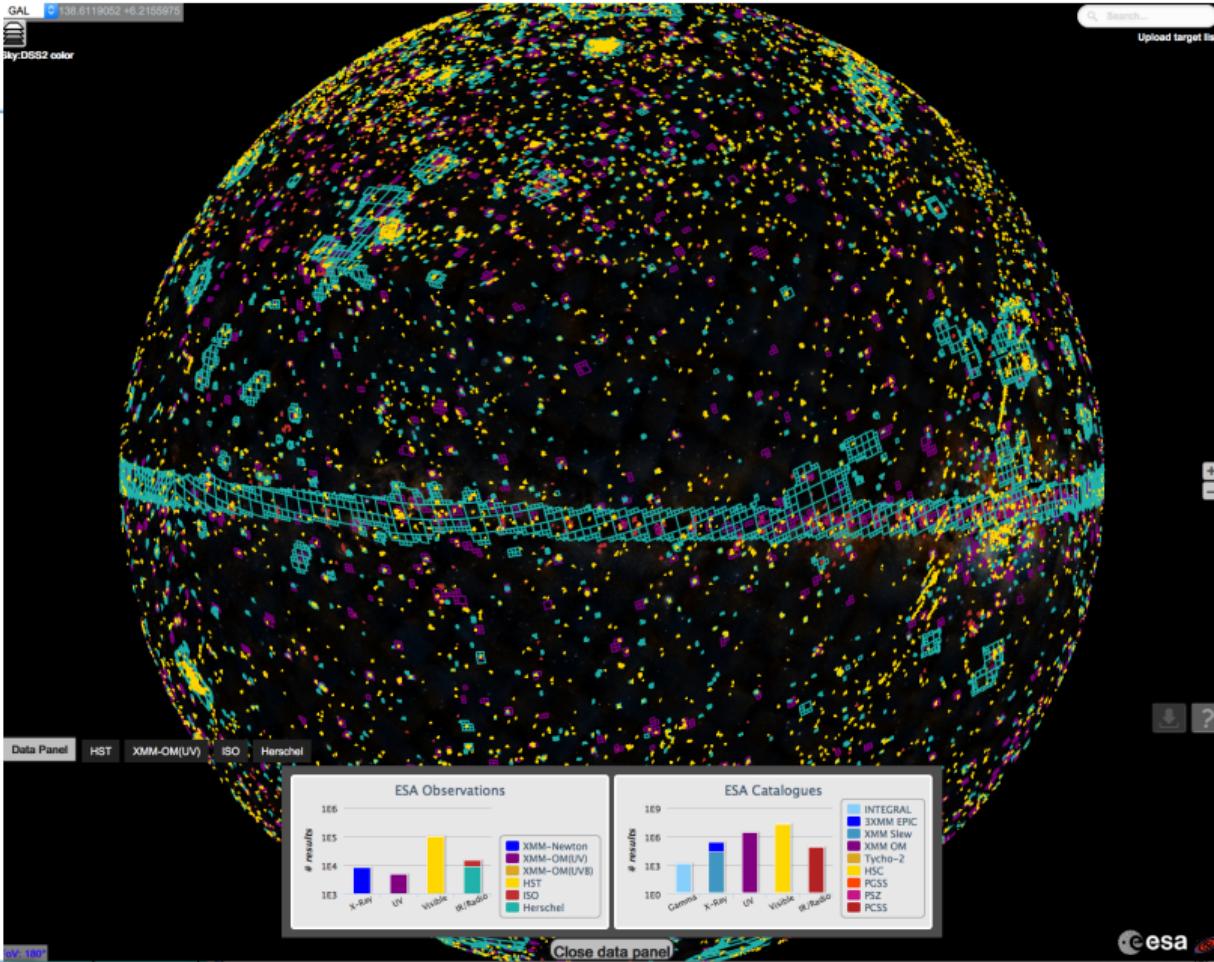
Name	Query	Target	Submitted	Time(h:m:s)	Rows	Status
Info Quasar Search in Imaging	SELECT TOP 1000 run,	DR6/600	7/15/2007 7:56:02 PM	0:0:0	10	Ready
Info Quick Query	-- Galaxies meeting multiple s	DR6/1	7/15/2007 7:55:02 PM	0:0:0	10	Finished
Info Sample Query 1	SELECT top 1000 ObjID, G,u,	DR6/600	7/15/2007 7:54:13 PM	0:0:4	11308	Started
Info My Query	select objid,ra,dec,modelmag_g	DR6/600	7/15/2007 12:17:42 AM	0:0:4	11308	Finished
Info My Query	SELECT count(*) as 'total'	DR6/600	7/8/2007 11:28:37 AM	0:1:1	1	Failed
Info My Query	SELECT TOP 1000 P.ObjID into m	DR6/600	7/8/2007 11:27:47 AM	0:7:53	1000	Finished
Info My Query	SELECT TOP 1000 run,	DR6/600	7/8/2007 11:27:22 AM	0:0:1	1	Failed
Info My Query	SELECT TOP 10000 run,	DR6/600	7/8/2007 11:27:06 AM	0:0:2	10000	Finished
Info My Query	select top 10 * into mydb.MyTa	DR6/1500	6/26/2007 4:30:35 PM	0:0:0	10	Finished
Info My Query	select top 10 * from dr5quasar	DR6/1	6/26/2007 1:08:12 PM	0:0:0	10	Finished
Info My Query	select top 10 * from dr3quasar	DR6/1	6/26/2007 1:08:03 PM	0:0:0	10	Failed





From 2005 to 2017

- ESAC Located near Madrid, Spain.
- Home of the Science Operations Department of the European Space Agency
- Surprising number of Irish people ..
- This picture from a public stargazing night - ~400 visitors came



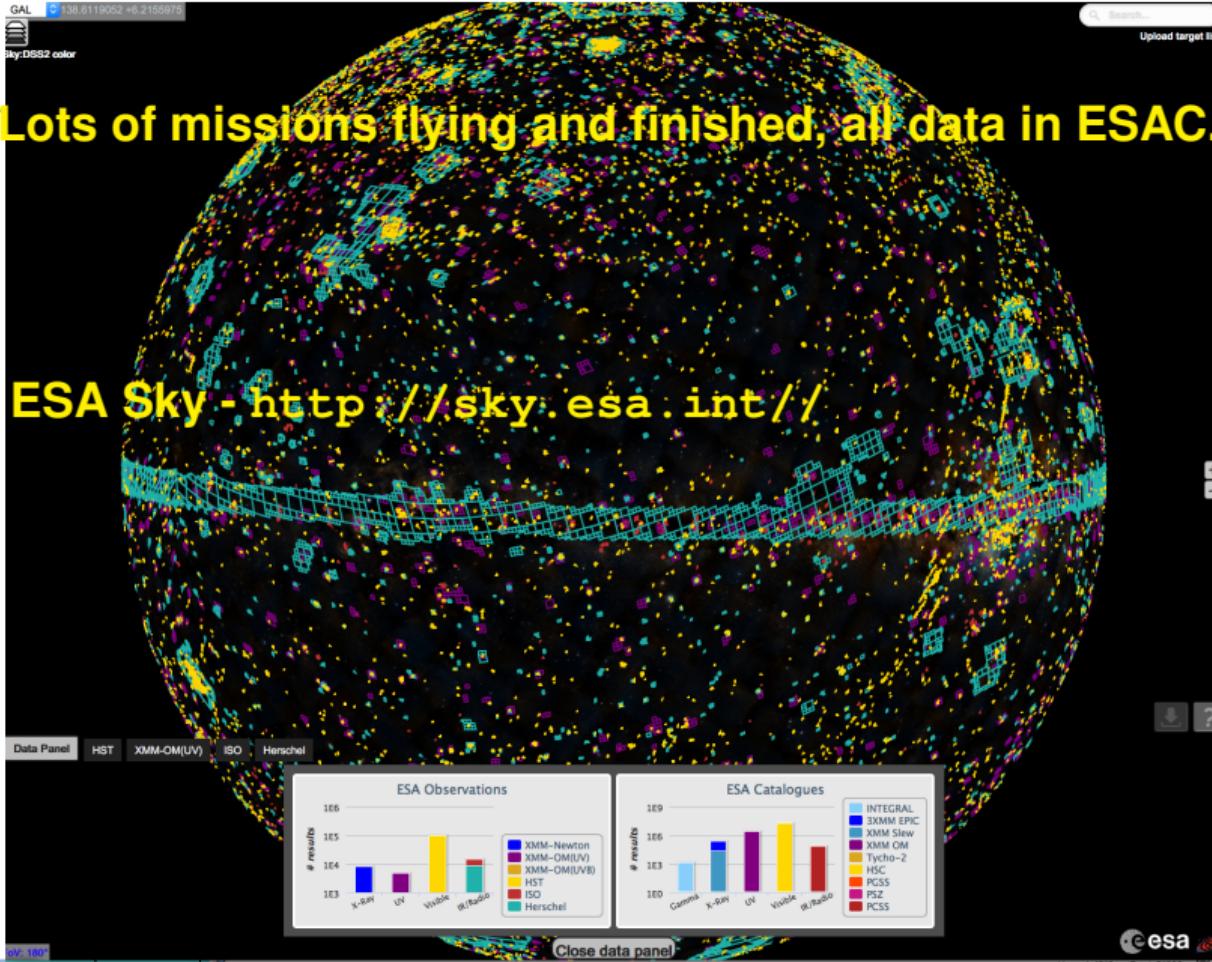


GAL 138.6119052 +6.2155975

Sky:DS2 color

Search...
Upload target list

Lots of missions flying and finished, all data in ESAC.





Outline of the talk



European Space Agency

Gaia and LSST

Launch

Astrometry



Milky way analogue

'Our sun' →

Milky way analogue

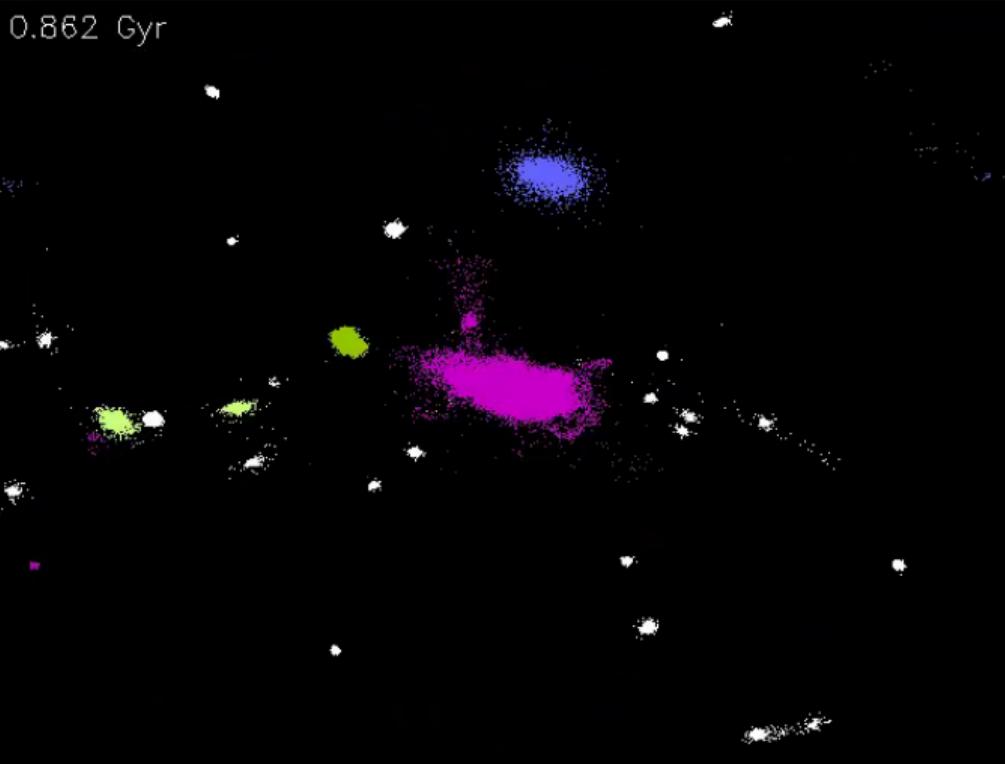
‘Our sun’ →

Our view is severely obstructed by the dust in the disk and relatively little is known about the origin, history, and structure of our own Galaxy

Gaia’s main aim: unravel the formation, composition, and evolution of the Galaxy



Origin of the Milky Way

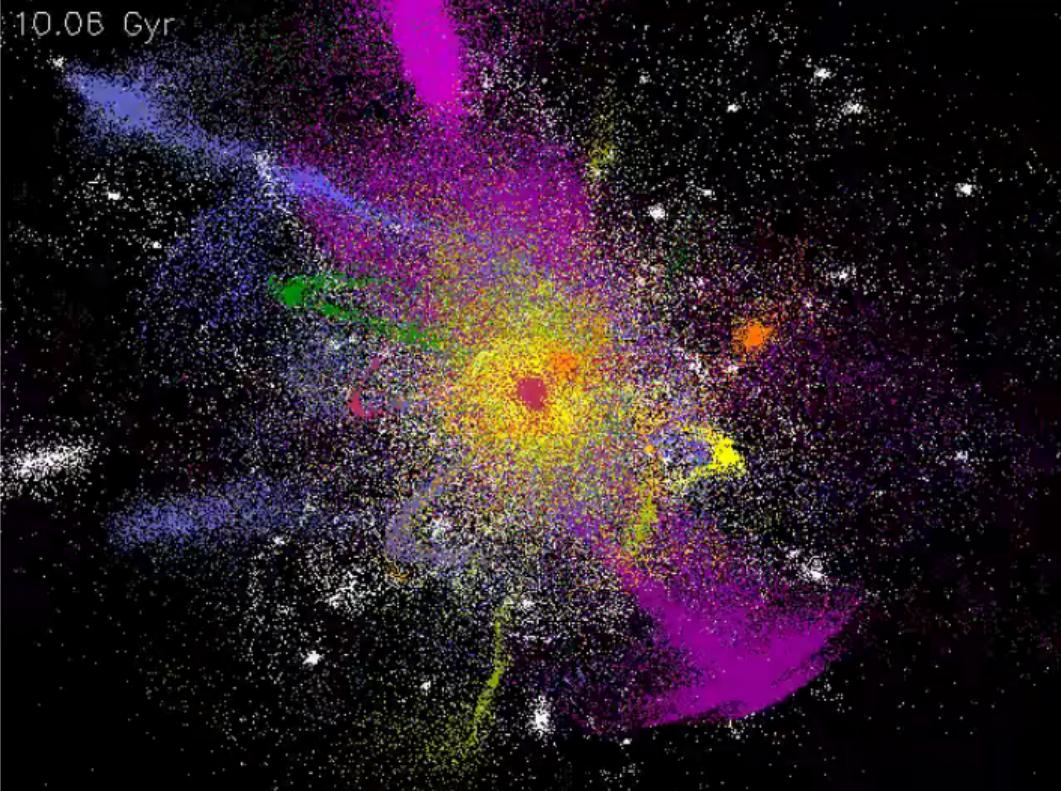


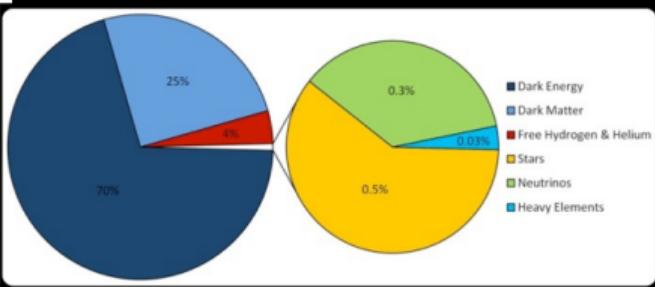
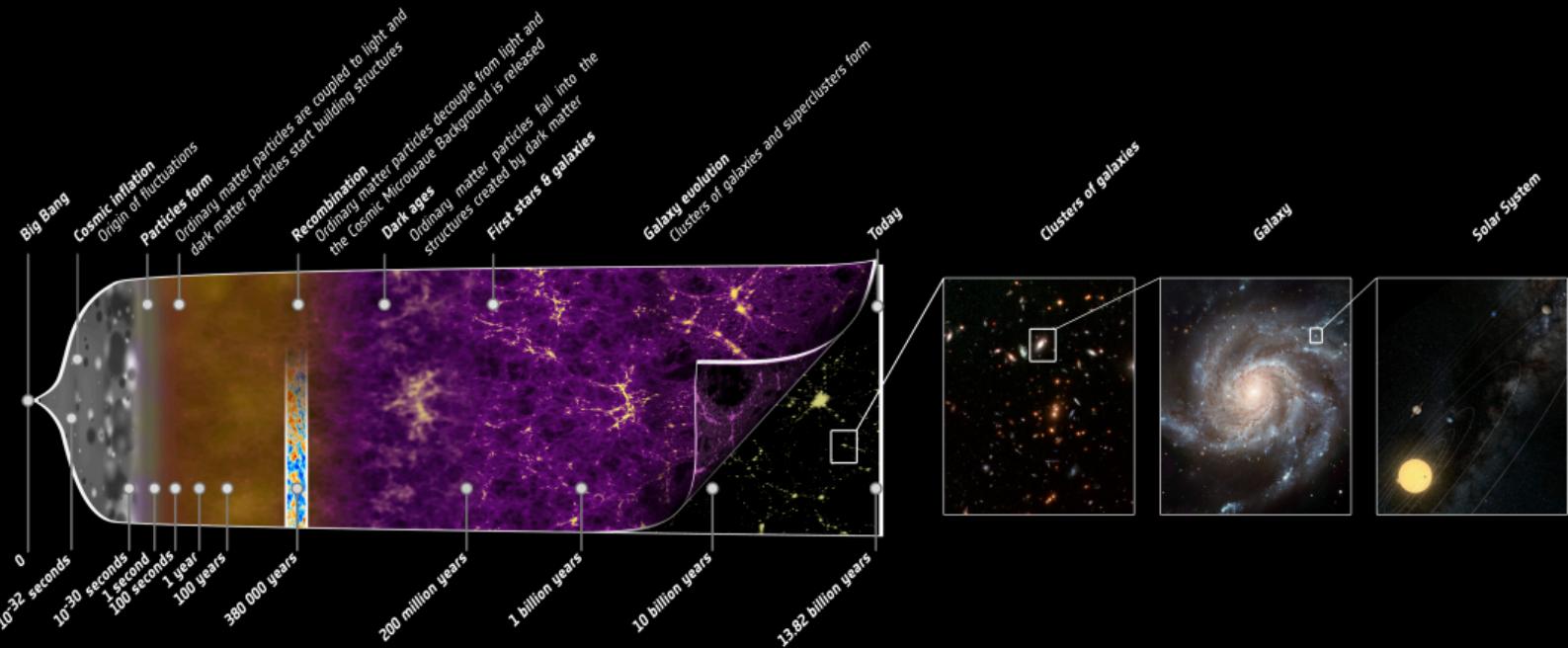
Movie credit: Amina Helmi, University of Groningen

slides from Anthony Brown, Leiden University



Origin of the Milky Way

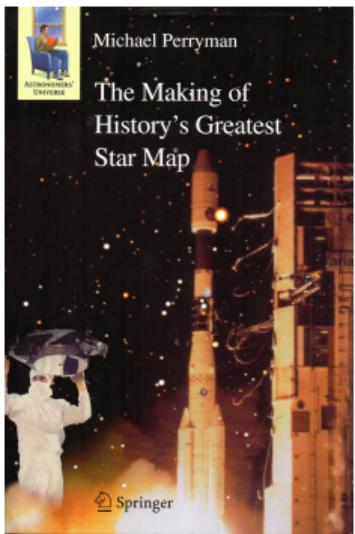
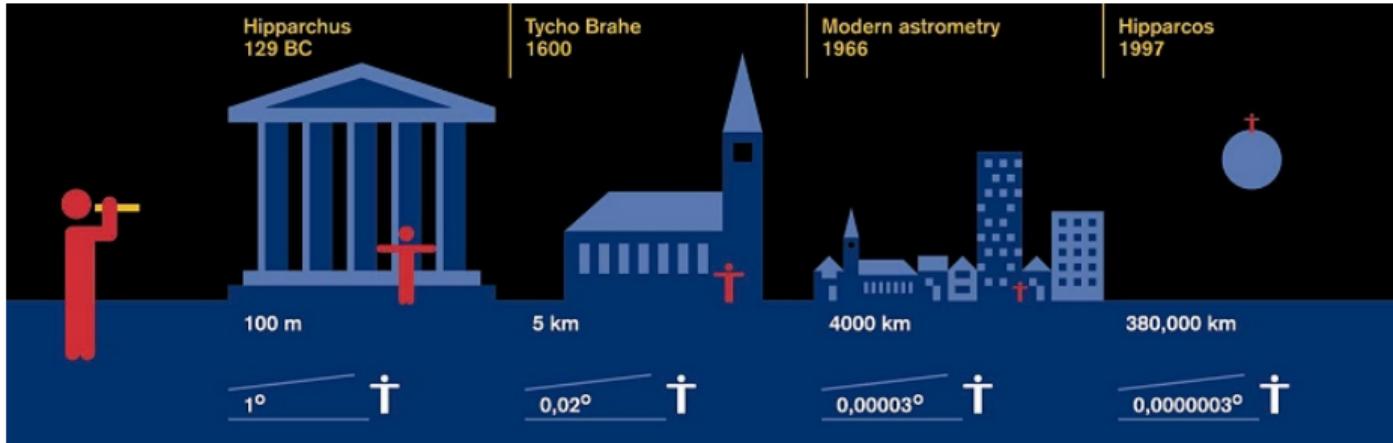




The modern cosmological models can explain all observations, but need to *postulate* dark matter and dark energy (though gravity model could be wrong, too)



Hipparchus to ESA's Hipparcos



Gaia will take us to the next order of magnitude the microarcsecond.
e.g. A euro coin on the moon viewed from earth

Hipparcos measured 10^5 objects : Gaia measures 10^9

← superb account of the Hipparcos mission.



Some numbers and scales



- Kilo = 1000 = 10^3 Mega = 1000000 = 10^6 Giga = 1000000000 = 10^9 Tera = 10^{12}
- But note in computing .. KB = 1024 Bytes .. 2^{10}



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- 1 deg (degree) = 60' (arc minutes), 1' = 60'' (arc second)
- 1 AU (astronomical unit) distance of earth from sun $\sim 1.496 \times 10^{11}$ Meters
- 1 light year $\sim 9.461 \times 10^{15}$ Meters sin63241 AU



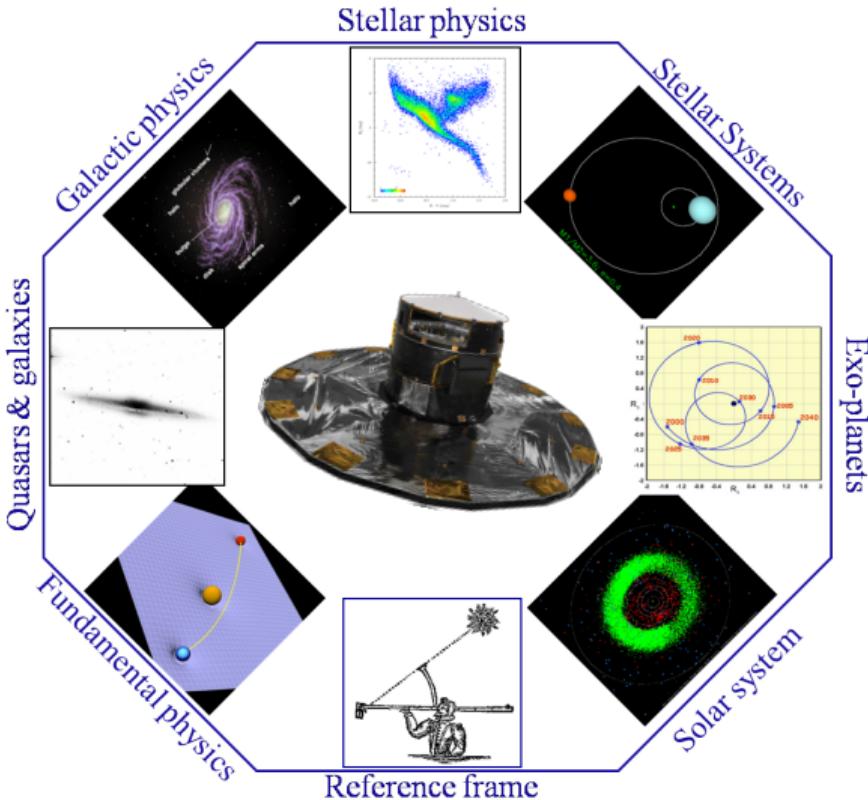
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- Parallax of 1'' known as 1 parsec ~ 3.26 Light years ~ 206165 AU
- 3.26 light years = $3.26 \times 9.461 \times 10^{15} \sim 3.084 \times 10^{16}$ Meters

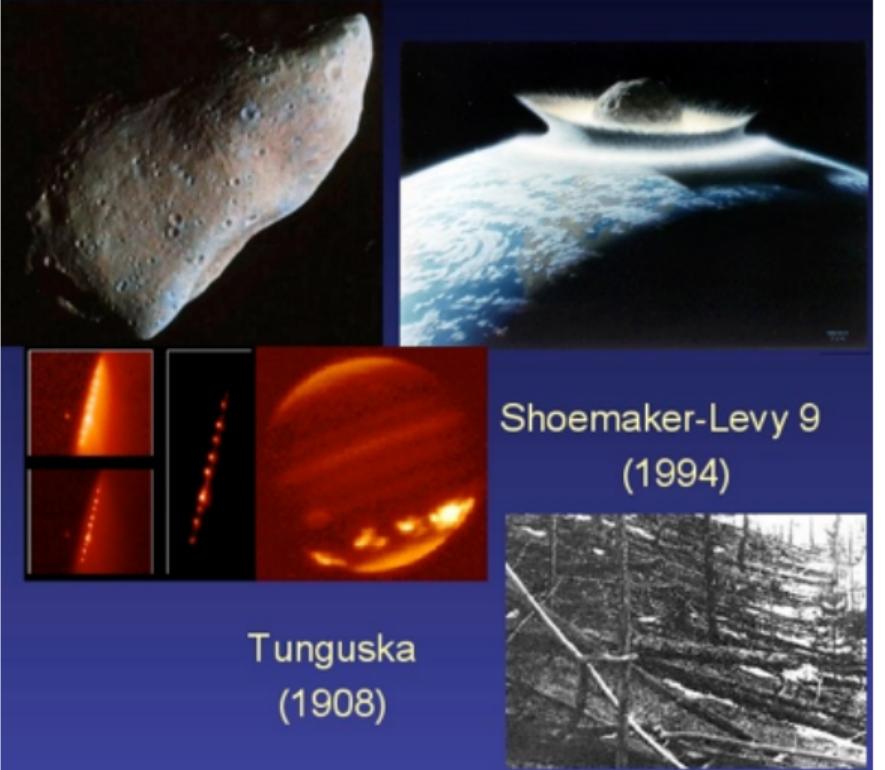


Science topics





Killer asteroids: the impact probability is not 0! LSST



Tunguska
(1908)

Shoemaker-Levy 9
(1994)

LSST is the only survey capable of delivering completeness specified in the 2005 USA Congressional NEO mandate to NASA (to find 90% NEOs larger than 140m)



The Barringer Crater, Arizona: a 40m object 50,000 yr. ago

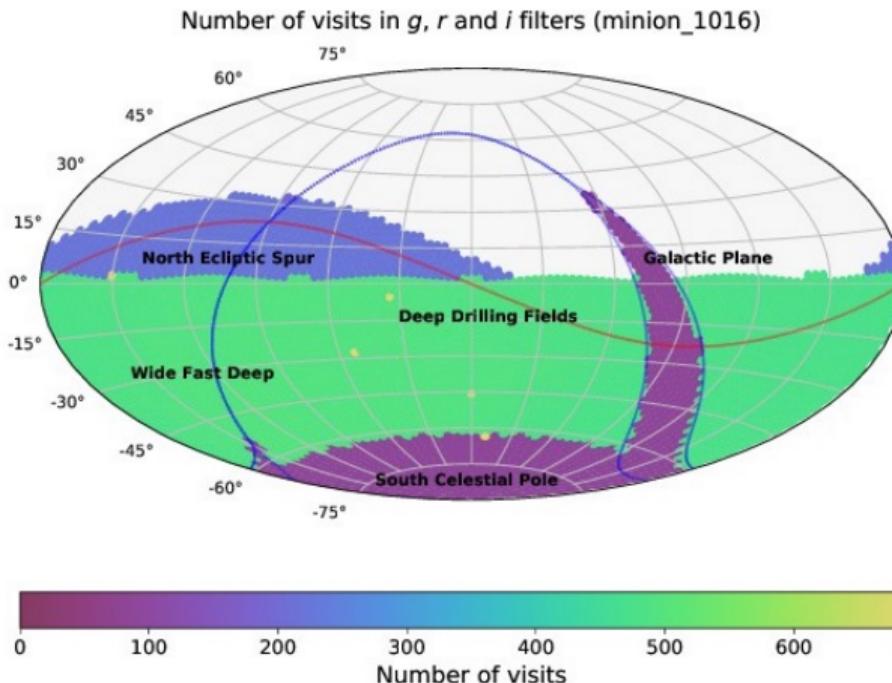


LSST:uniform sky survey



An optical/near-IR survey of half the sky in ugrizy bands to r 27.5 (36 nJy) based on 825 visits over a 10-year period: *deep wide fast*.

- 90% of time spent on uniform survey: every 3-4 nights, the whole observable sky scanned twice per night
- 100 PB of data: about a billion 16 Mpix images, enabling measurements for **40 billion objects!**

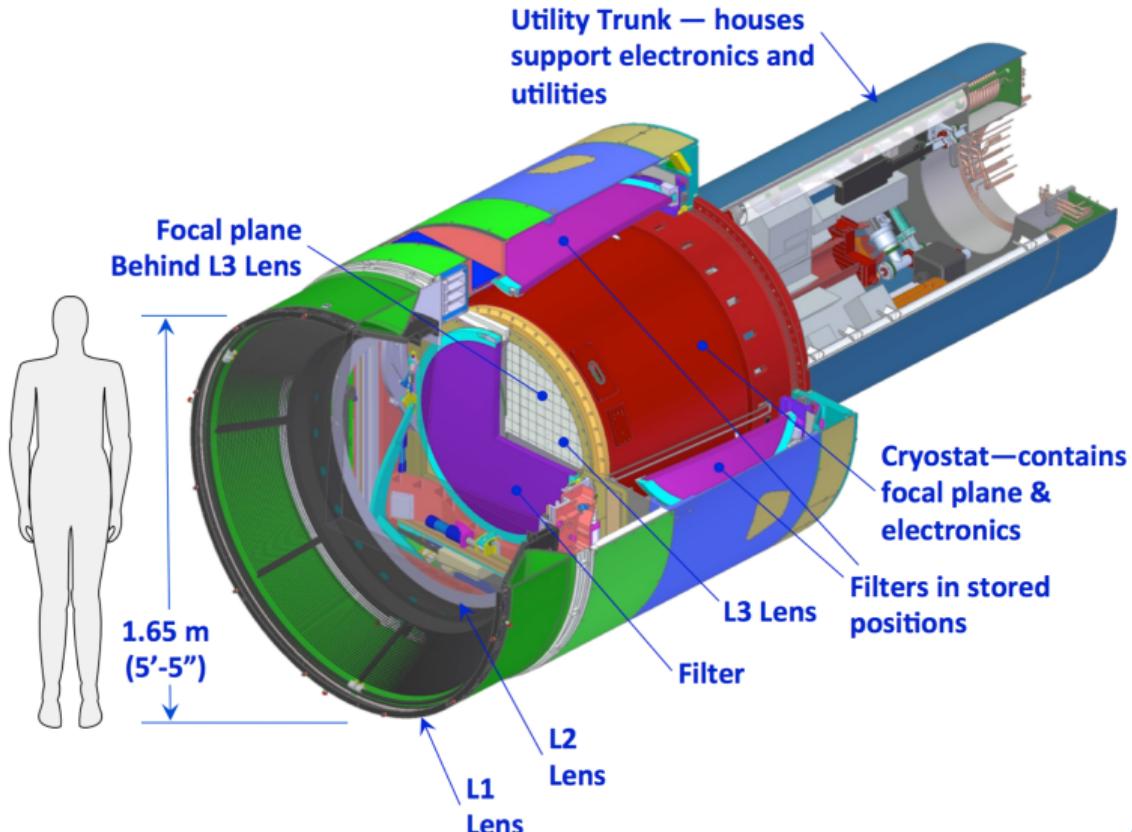


see also <http://www.lsst.org> and Ivezic et al. (2008)-arXiv:0805.2366

**10-year simulation of LSST survey:
number of visits in u,g,r band (Aitoff
projection of eq. coordinates)**



LSST Camera



The largest astronomical camera:

- 2800 kg
- 3.2 Gpix



Site shaping up





Data management



DM Mission :
Stand up operable, maintainable, quality services to deliver high-quality LSST data products for science, all on time and within reasonable cost.

LSST DM development is distributed across the Americas.
Plus we have partners like IN2P3



SDSS image



Nice colours Lupton et al. (2004)
 $\approx 3.5'$

Image Robert Lupton



Hyper Suprime Cam (HSC) on Subaru



HSC image (COSMOS) from g,r(1.5 hrs) ,i(3 hrs) PSF matched co-add (≈ 27.5)

Processed with *LSST Stack*

<https://pipelines.lsst.io/>

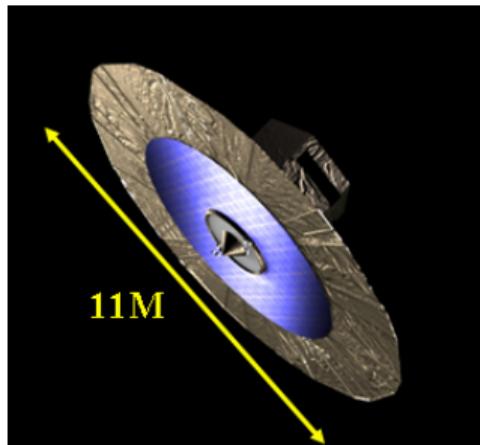
Image HSC collaboration, Robert Lupton



Satellite overview



- Mission:
 - ESA Corner Stone 6
 - ESA provided the hardware and launch
 - Mass: 2120 kg (payload 743 kg)
 - Power: 1631 W (payload 815 W)
 - Launched December 19th 2013
 - Stereoscopic Census of Galaxy over 5 years
 - Possible extension of 1 year - have fuel for at least that
 - μarcsec Astrometry $G < 20$ (10^9 sources)
 - Radial Velocities $G < 16$
 - Photometry millimag $G < 20$

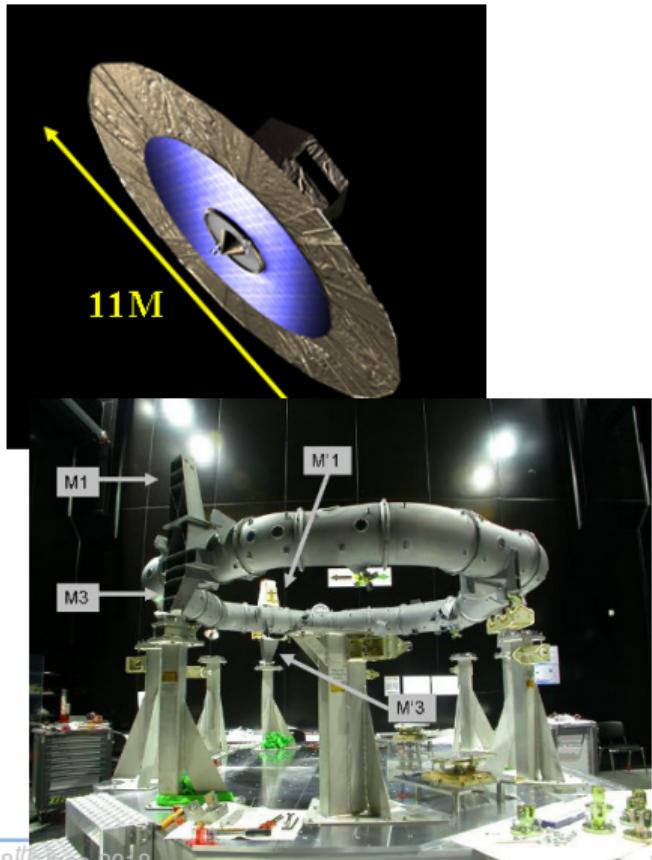




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- Final catalogue \approx 2022





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To Kourou



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Lots of interesting signs ..





Up close



Dec 18th saw (touched) our Fregat.
Meanwhile a full dress rehearsal ongoing.
Later road closed for Ariane movement





Countdown..



Dec 18th 17:12 (20:12 UTC) the count down started. In Jupiter control room





Flawless lift off 19/12 06:12am

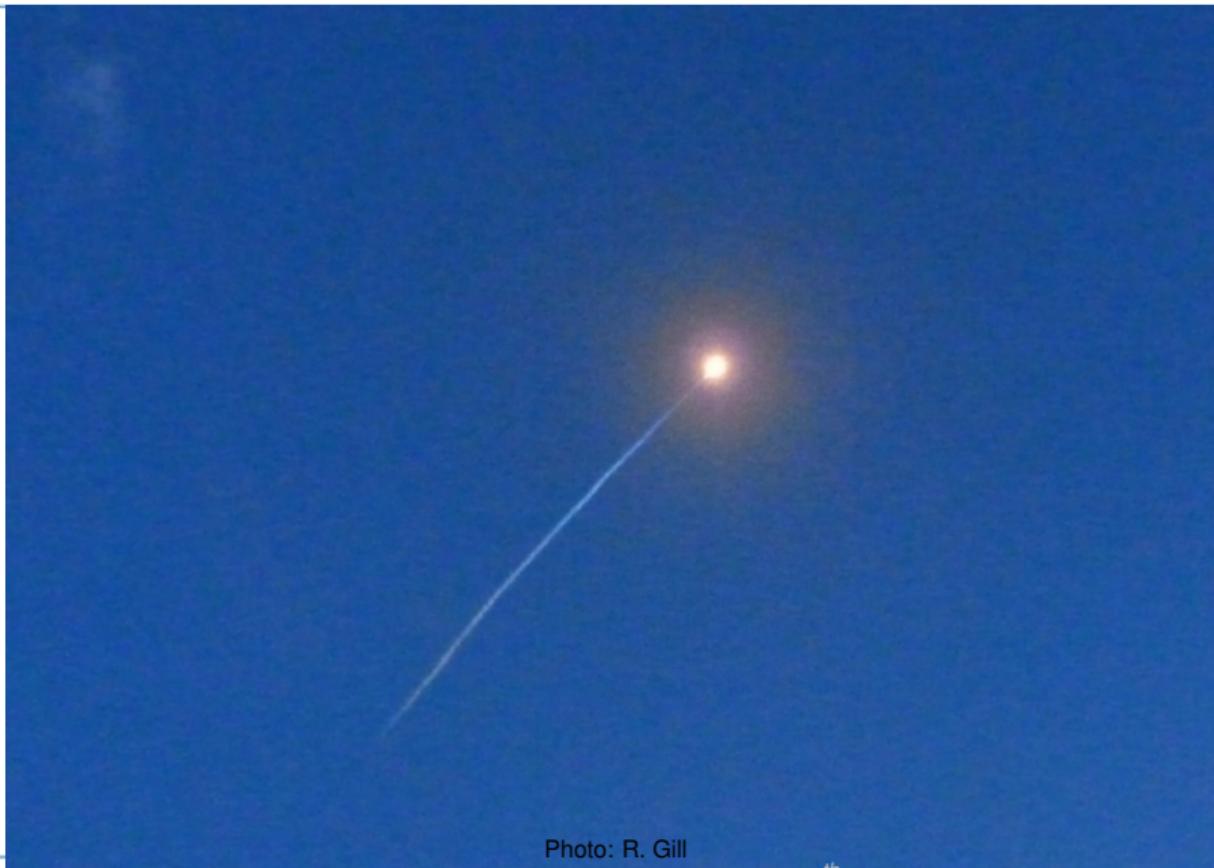


Photo: R. Gill

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Clontibert rocket flight - Quidnunc rocket - 22.5 (motorised) 11.6



Video clips



- Gaia Launch <https://youtu.be/xDmQvJVJg8Y?t=87>
- Gaia Data Release 2 <https://youtu.be/KULtrwVSq6g?t=10>
- Cerro Pachon LSST

<https://gallery.lsst.org/bp/#/folder/2689925/64565141>



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Just one part of the Gaia processing !

From the Hipparcos catalogue (ESA, 1997, Volume 3 Chapter 23).

Minimisation problem for astrometry

$$\min_{\mathbf{a}, \mathbf{n}} \|\mathbf{g}^{\text{obs}} - \mathbf{g}^{\text{calc}}(\mathbf{a}, \mathbf{n})\|_M \quad (1)$$

- \mathbf{a} is the vector of unknowns describing a star's barycentric motion represented by the measurement vector $\mathbf{g}_k = (G_k, H_k)'$ and associated statistics.
- \mathbf{g}^{obs} represents the vector of all measurements
- \mathbf{g}^{calc} represents the vector of detector coordinates calculated from the astrometric parameters.
- \mathbf{n} is a vector of nuisance parameters - required for realistic modelling (e.g. attitude, instrument calibration)
- M metric defined by the statistics of the data, (error weighting)

The complete new formulation for Gaia is in (Lindegren et al., 2012).



Basic Gaia Problem

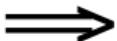


Put more simply the data reduction must:

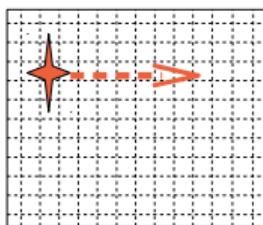
find the astrometric parameters (catalogue) best predicting the (10^{12}) focal plane observations of the sources. (O'Mullane et al., 2011)

Catalogue Data

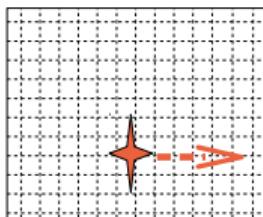
ID	α	δ	ϖ	μ_α	μ_δ	μ_r
0000101	1.4	3.1	0.1	0.02	0.02	-
1001000	27	1.2	0.2	0.05	0.01	0.01



Gaia Focal Plane



$t_{\text{obs}} 1$



$t_{\text{obs}} n$

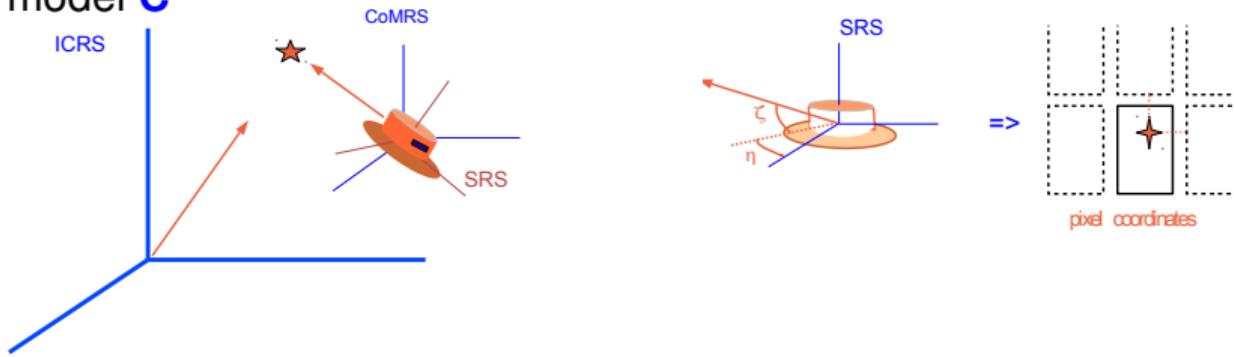


Look at one block: Source modelling



The mapping or modelling of the observables \mathbf{g} is done by three successive transformations:

1. from astrometric parameters to the celestial directions of a star at the instant of observation, using an astrometric model **S**
2. from celestial to instrument frame directions using an attitude model **A**
3. and finally from instrument directions to detector coordinates using an instrument model **C**





Source Update



We fit the model to the observations:

Least squares for source update

$$\mathbf{Ax} \sim \mathbf{b} \pm \sigma \quad (2)$$

$$\text{where } \mathbf{b}_i = \mathbf{y}_i - f_i(\mathbf{a}, \mathbf{q}) \quad (3)$$

Here \mathbf{y}_i are the observed field angles f_i is a function to calculates field angles from the current model.



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In java (SourceUpdateCalculatorWrapper):

```
// get calculated angles + derivatives ...
ExtendedFieldAngles ecfA = angleCalc.getCalculatedEtaZeta(ae, origSrc, UpdateBlock.Source.getId());

// ... from those, get just calculated angles
double[][] calcEtaZeta = ecfA.getEtaZeta();

// ... and the observed ones from the angle calculator
double[][] obsEtaZeta = angleCalc.getObservedEtaZeta(ae);

// compute residuals [rad] and attach these to the Elementary...
```



The END



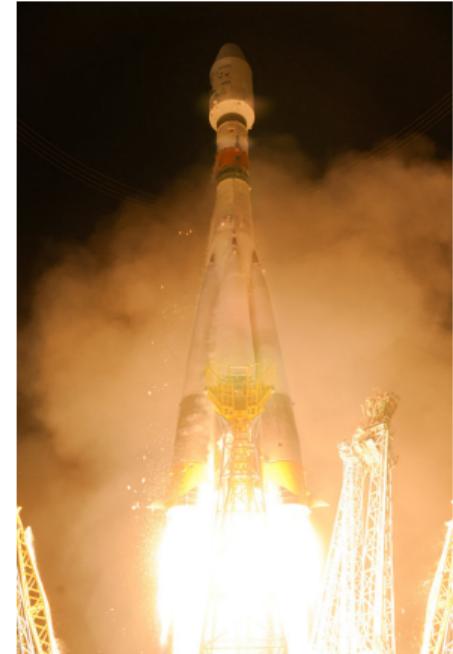
Blast 20 Cerro Pachón April 2011.

<http://www.lsst.org>

<http://community.lsst.org>

Gaia blast off on Soyuz December 2013

<http://www.cosmos.esa.int/web/gaia>





Acronyms I



Acronym	Description
AURA	Association of Universities for Research in Astronomy
C	Specific programming language (also called ANSI-C)
DM	Data Management
ESA	European Space Agency
ESAC	European Space Astronomy Centre (ViSpa)
ESOC	European Space Operations Centre (ESA)
ESTEC	European Space research and TEchnology Centre (ESA)
HEALPix	Hierarchical Equal-Area iso-Latitude Pixelisation
HTM	Hierarchical Triangular Mesh
LSST	Large Synoptic Survey Telescope
PhD	Doctorate in Philosophy
SDSS	Sloan Digital Sky Survey
TEC	Thermo-Electric Cooler
USA	United States of America
arcmin	arcminute, minute of arc (unit of angle)
arcsec	arcsecond, second of arc (unit of angle)



References



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