



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

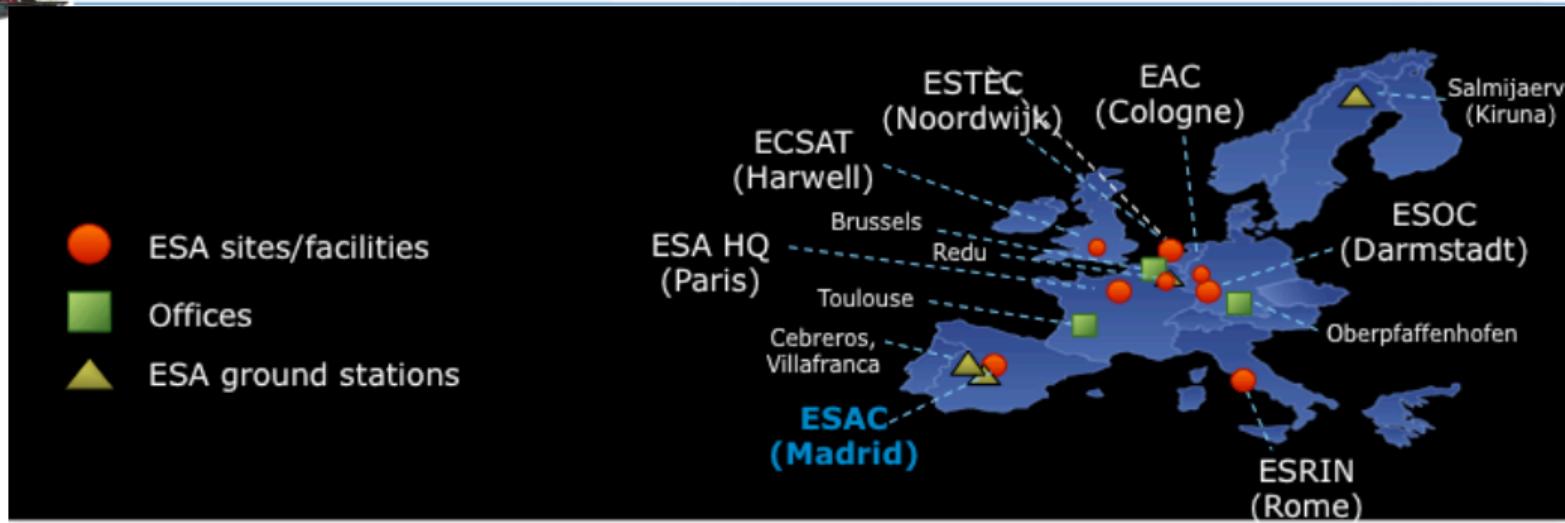
Gaia and LSST

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).

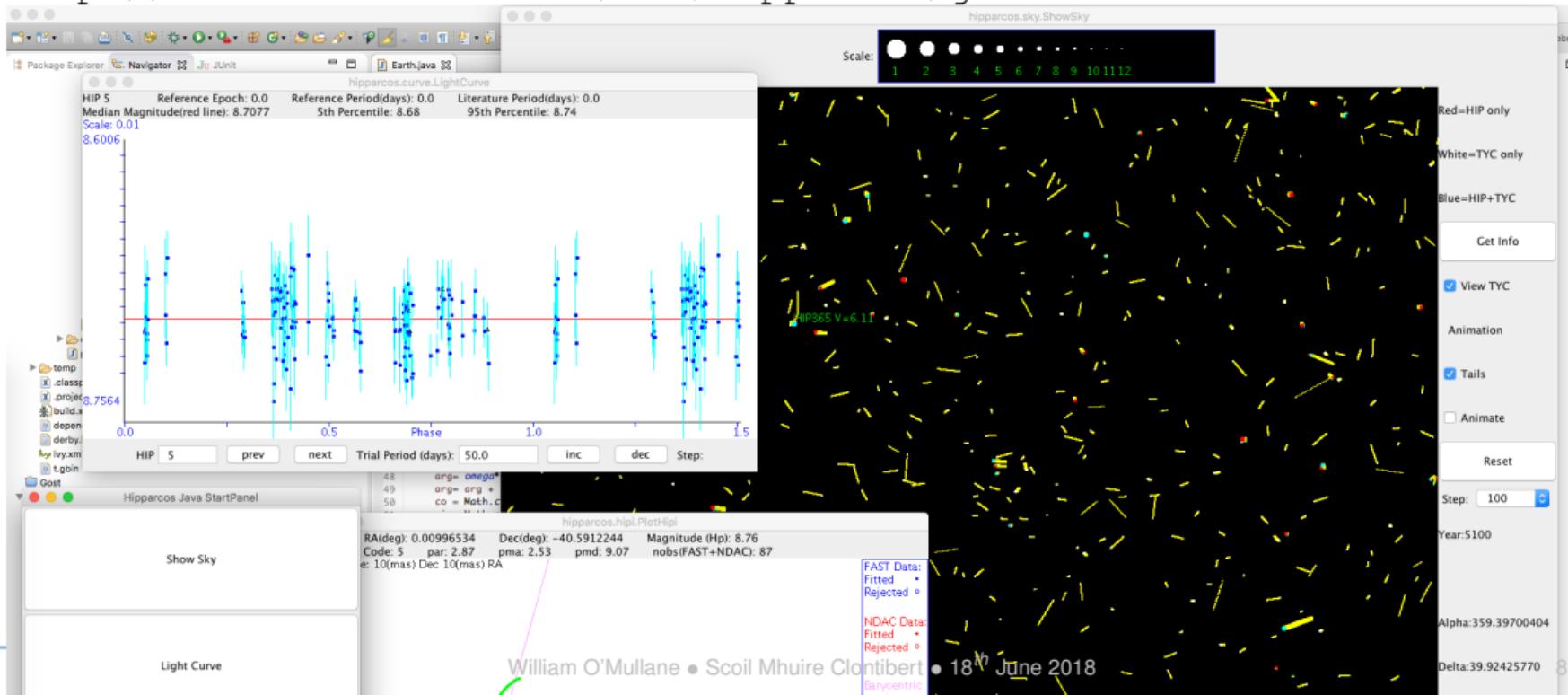


Addition to HIP Catalogue



1997/98 Hipparcos Java Tools - learning Astrometry

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





In the USA early 2000s

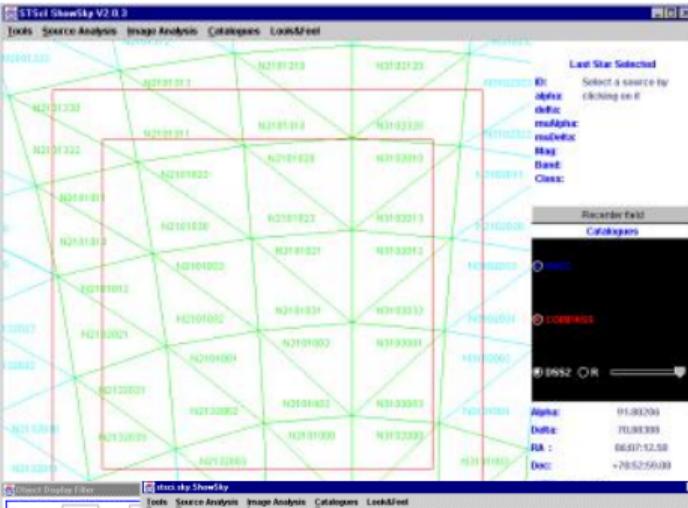


Entering the new millennium ..

Quality tools for GSC2 (Java) →

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

A screenshot of a web browser window showing the SDSS Query / CasJobs interface. The browser title bar says "View Jobs - Mozilla Firefox". The main header has a "File Edit View History Bookmarks Tools Help" menu. The main title is "SDSS Query / CasJobs". Below the title is a horizontal menu with links: Help, Tools, Query, History, MyDB, Import, Groups, Output, Profile, Admin, SkyServer, Logout, and a user name "thakar". A watermark of a spiral galaxy is visible in the background.



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			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 G.ObjID, G.u,	DR6/600	7/15/2007 7:54:13 PM			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 11:20:37 AM	0:1:1		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		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		Failed			



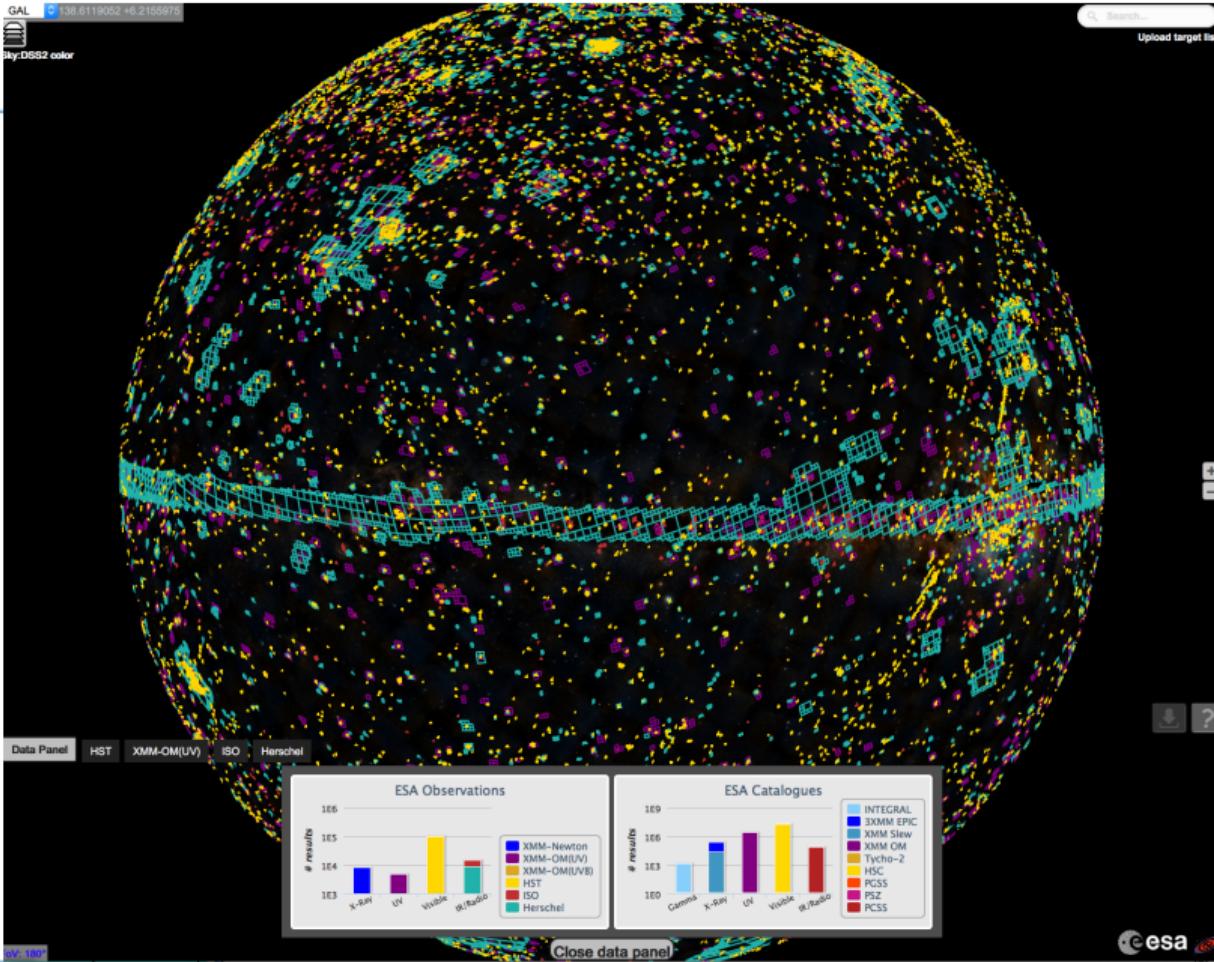
From 2005 to 2017

- 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



Visitors to ESAC 2013







GAL 138.6119052 +6.2155975

Sky:DS2 color

Search...
Upload target list

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

ESA Sky - <http://sky.esa.int/>

Data Panel

HST

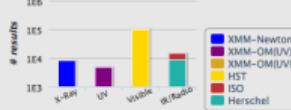
XMM-OM(UV)

ISO

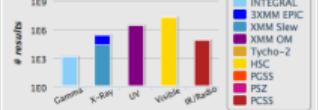
Herschel



ESA Observations



ESA Catalogues



UV: 180P

Close data panel



Outline of the talk



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Milky way analogue

NGC1232

'Our sun' →

Jos de Bruijne

Milky way analogue

NGC1232

‘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



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



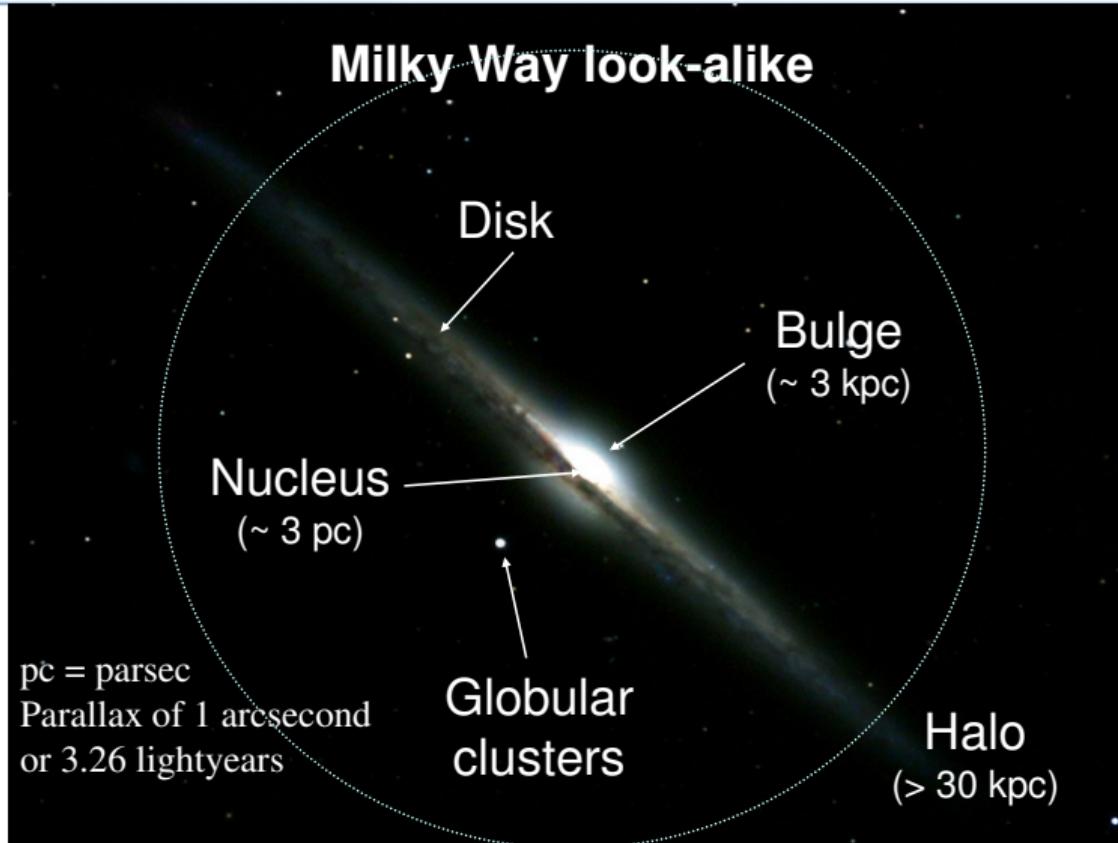
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- Parallax of 1'' known as 1 parsec ~ 3.26 Light years ~ 206165 AU
- 3.26 light years = $3.26 \times 9.461 \times 10^{15} \sim 3.084 \times 10^{16}$ Meters

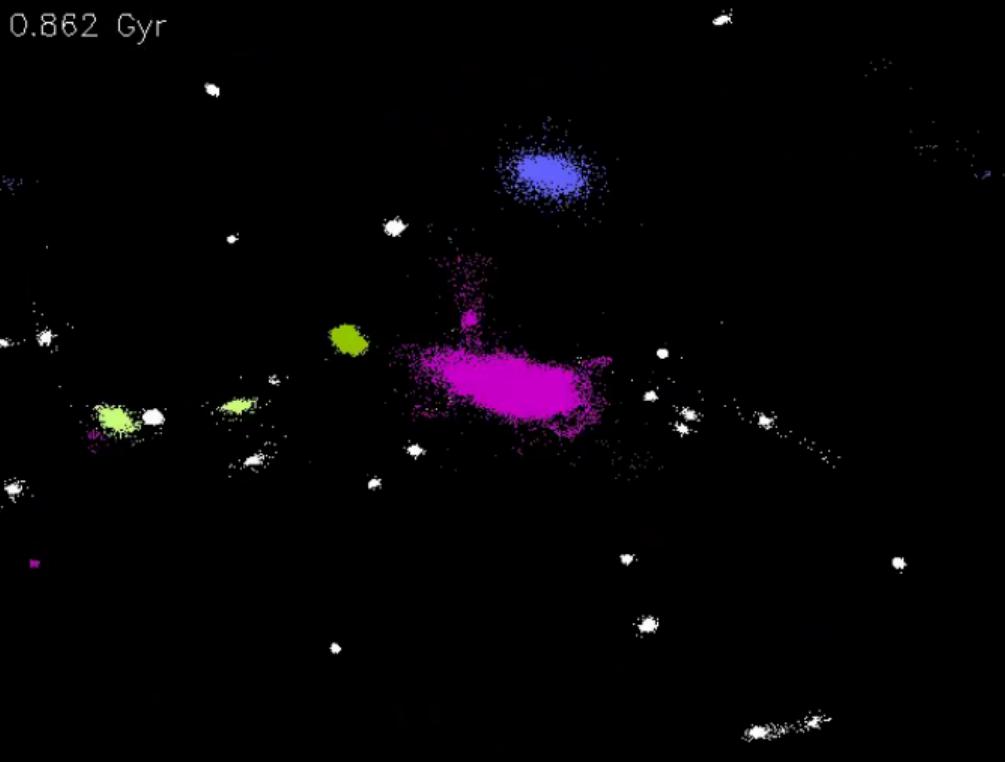


Another Milky way Analogue (NGC4565)





Origin of the Milky Way

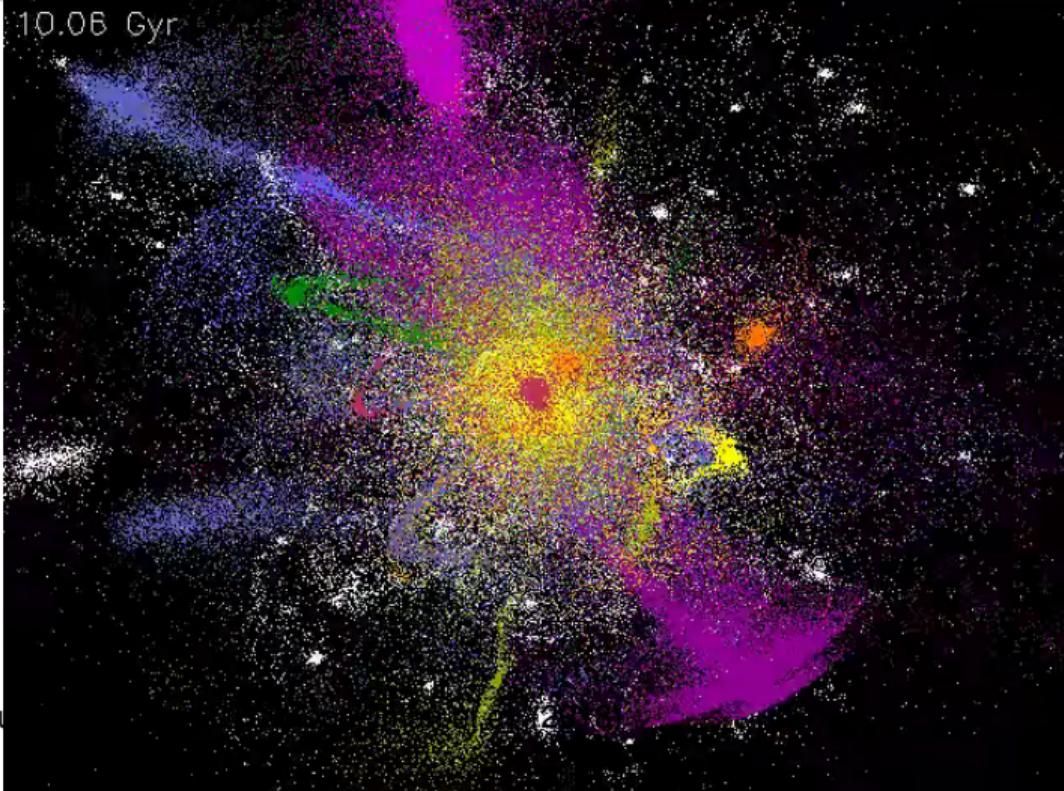


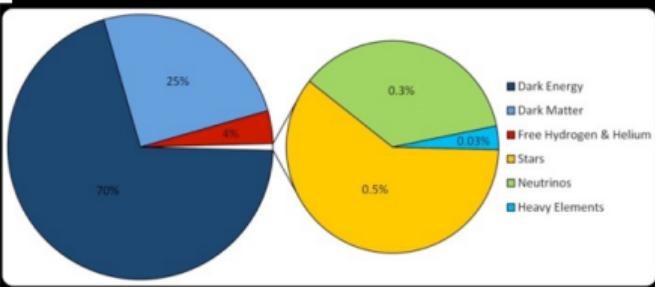
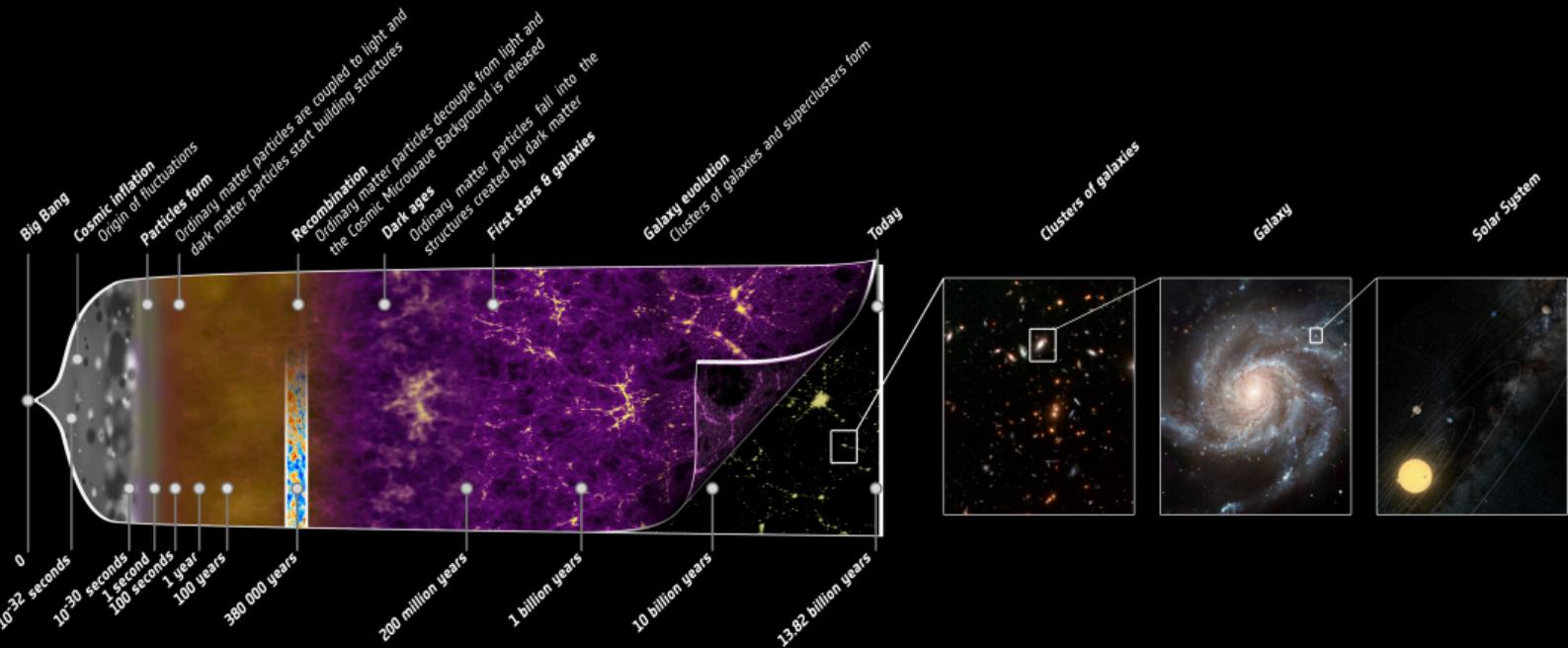
Movie credit: Amina Helmi, University of Groningen

slides from Anthony Brown, Leiden University



Origin of the Milky Way

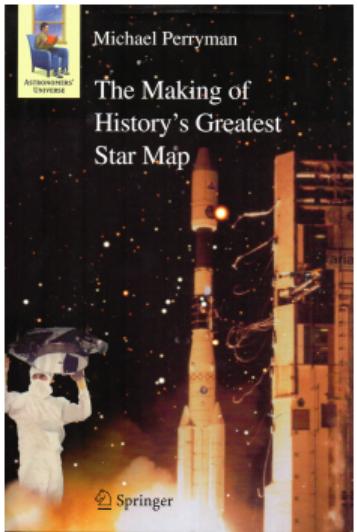
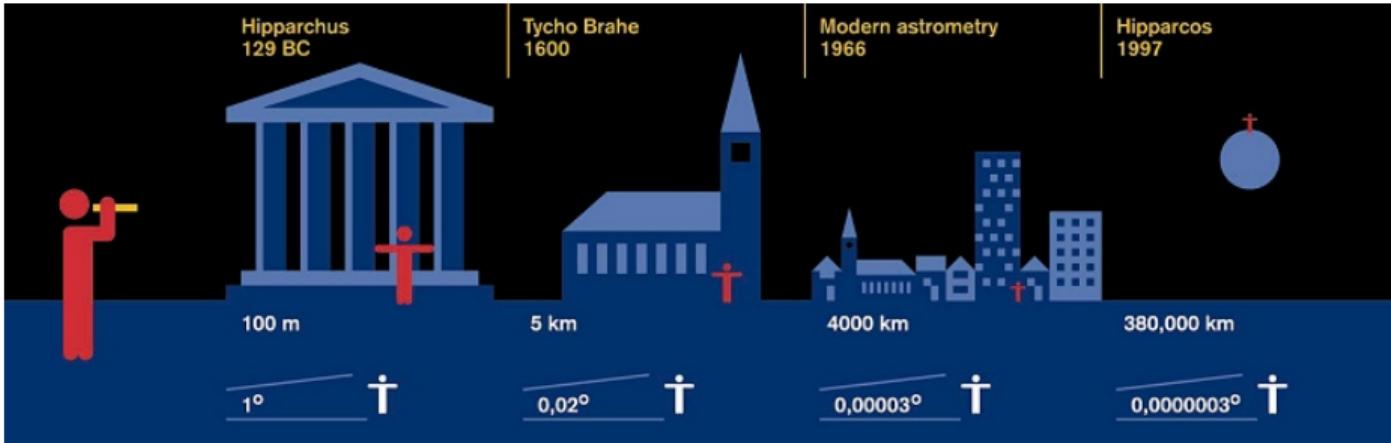




The modern cosmological models can explain all observations, but need to *postulate* dark matter and dark energy (though gravity model could be wrong, too)



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.



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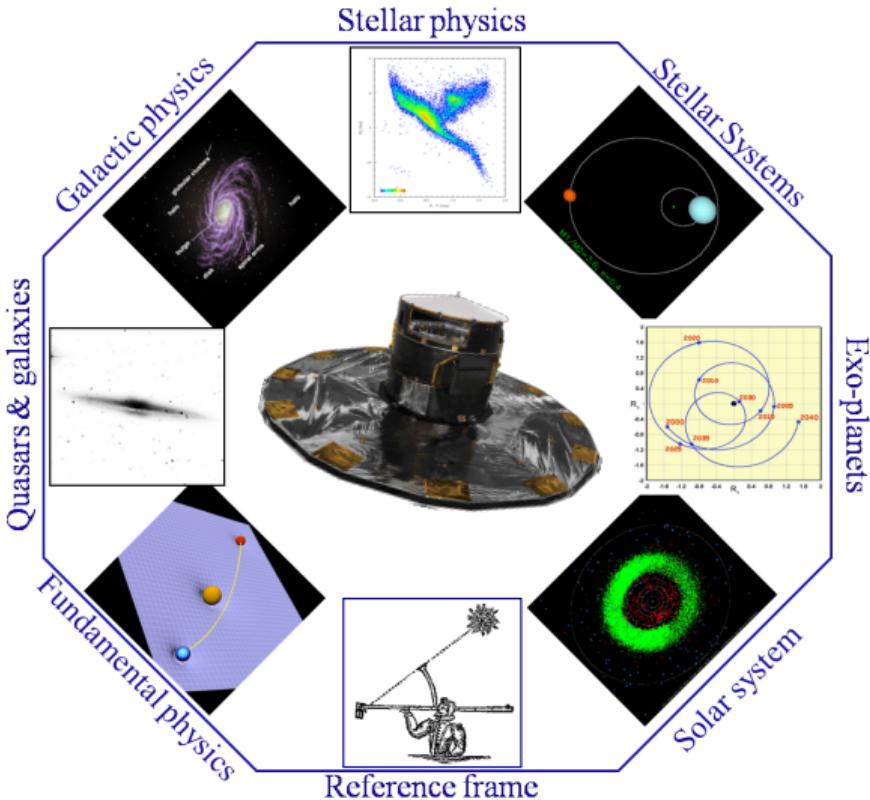
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Science topics





Killer asteroids: the impact probability is not 0! LSST



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

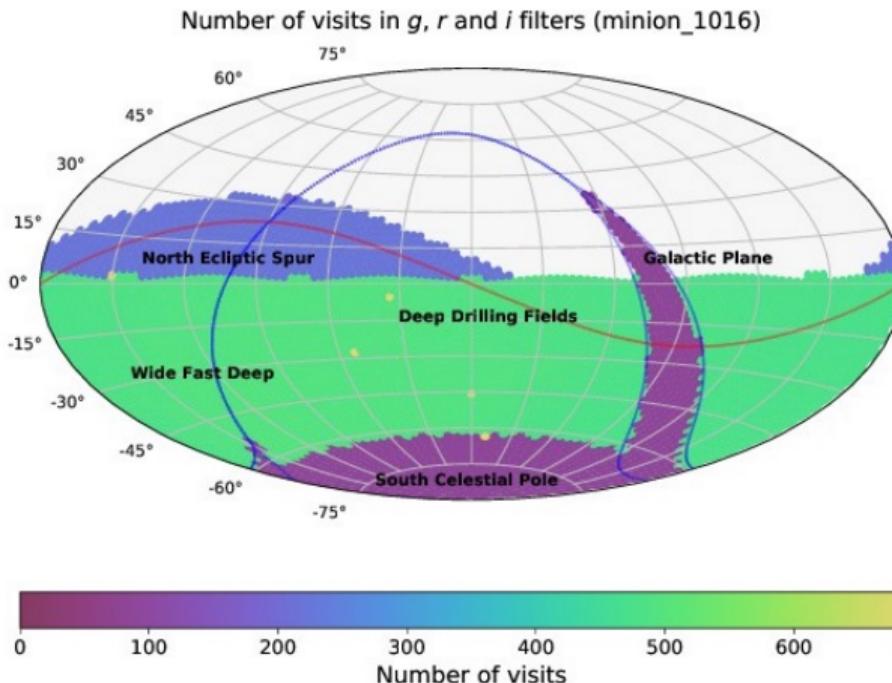


LSST:uniform sky survey



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!**

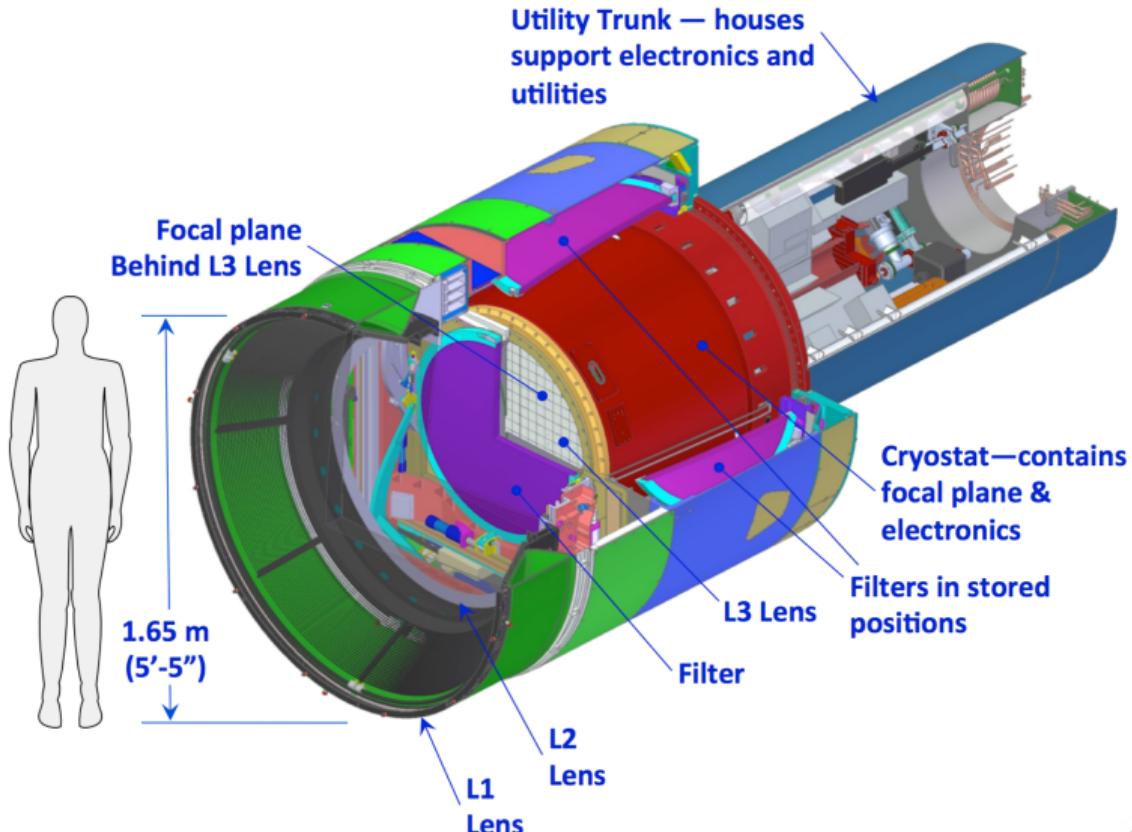


see also <http://www.lsst.org> and Ivezić et al. (2008)-arXiv:0805.2366

**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/>

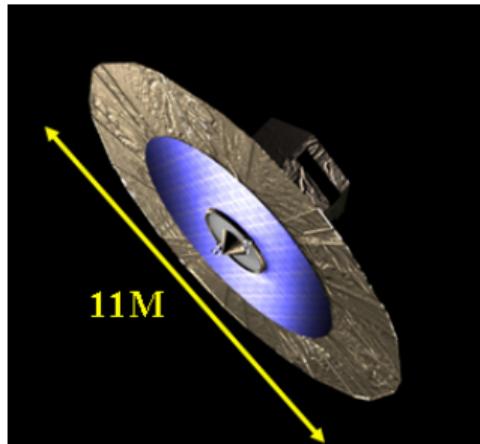
Image HSC collaboration, Robert Lupton



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 $G < 20$

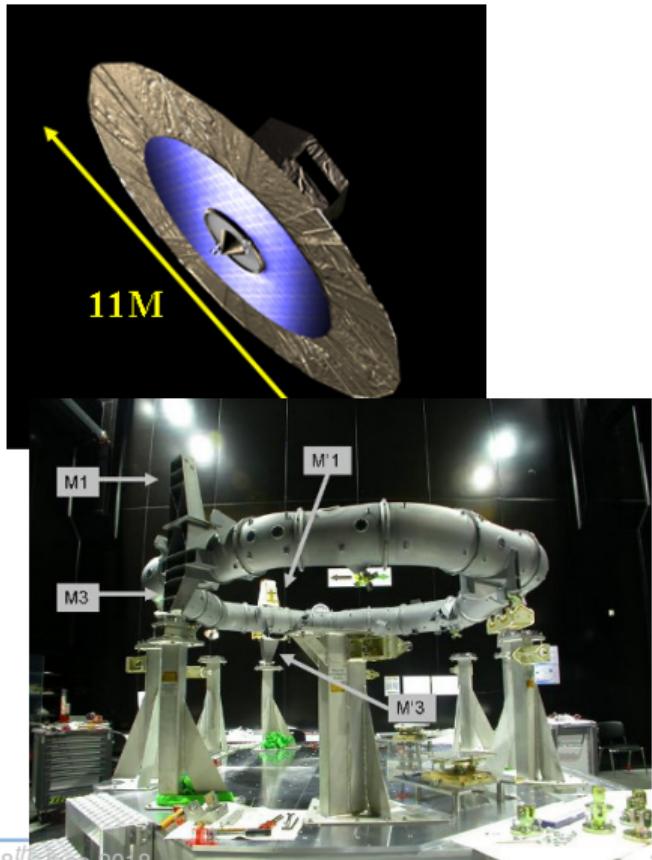




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- Final catalogue \approx 2022





Outline of the talk



European Space Agency

Gaia and LSST

Launch

Astrometry



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

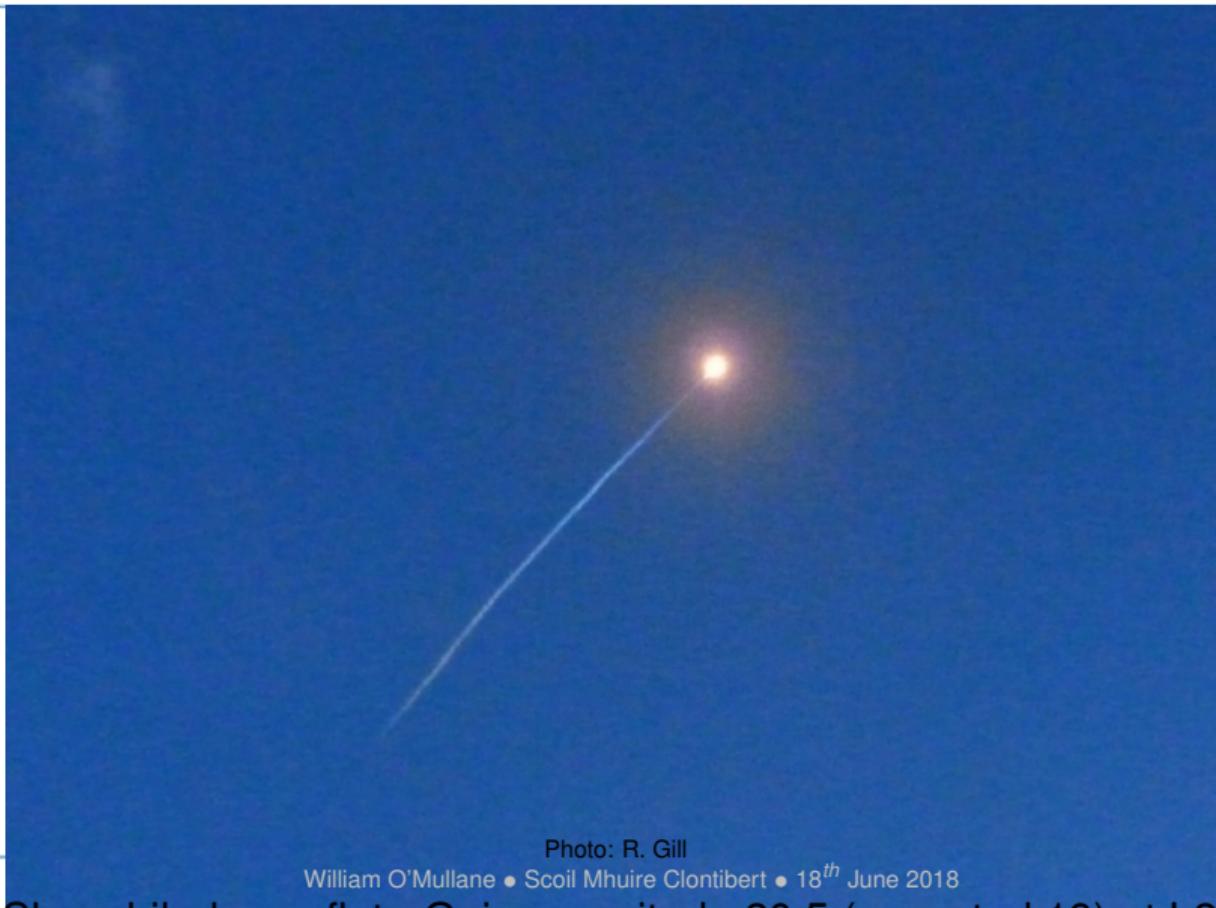


Photo: R. Gill

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Clontibert - flat to Gairloch - site 1 - S2.5 (part 1 of 10) - H.S.



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 modeling (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

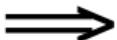


Put more simply the data reduction must:

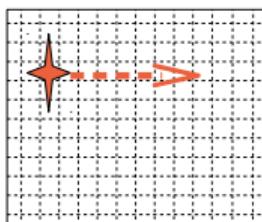
find the astrometric parameters (catalogue) best predicting the (10^{12}) focal plane observations of the sources. (O'Mullane et al., 2011)

Catalogue Data

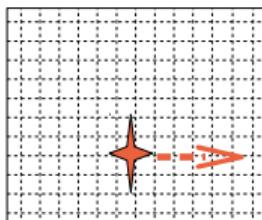
ID	α	δ	ϖ	μ_α	μ_δ	μ_r
0000101	1.4	3.1	0.1	0.02	0.02	-
1001000	27	1.2	0.2	0.05	0.01	0.01



Gaia Focal Plane



$t_{\text{obs}} 1$



$t_{\text{obs}} n$

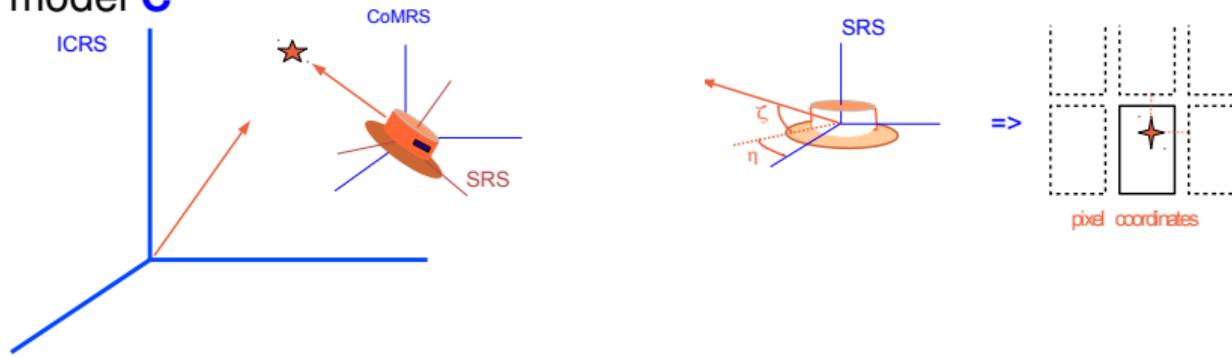


Look at one block: Source modeling



The mapping or modeling of the observables **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...
```



Its all team work on big projects





The END



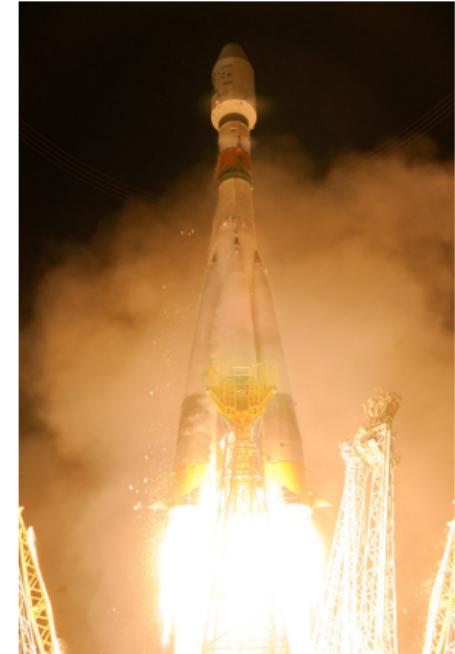
Blast 20 Cerro Pachón April 2011.

<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
AU	deprecated acronym for astronomical unit, use au instead
AURA	Association of Universities for Research in Astronomy
C	Specific programming language (also called ANSI-C)
CU	Coordination Unit (in DPAC)
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)
GB	GigaByte
HEALPix	Hierarchical Equal-Area iso-Latitude Pixelisation
HSC	Hyper Suprime-Cam
HTM	Hierarchical Triangular Mesh
K	Kelvin; SI unit of temperature
L2	Level 2 (ambiguous could mean milestone or processing)
LSST	Large Synoptic Survey Telescope
M	Mega; SI units prefix for 1E6
NASA	National Aeronautics and Space Administration (USA)
NEO	Near-Earth Object
NGC	North Galactic Cap
PB	PetaByte



Acronyms II



PSF	Point Spread Function
PhD	Doctorate in Philosophy
S	Strip (CCD chip along-scan coordinate identifier in focal plane)
SDSS	Sloan Digital Sky Survey
USA	United States of America
UTC	Coordinated Universal Time
W	Watt; SI unit of power
arcmin	arcminute, minute of arc (unit of angle)
arcsec	arcsecond, second of arc (unit of angle)
deg	degree; unit of angle
k	kilo; SI units prefix for 1E3
kg	kilogram; SI unit of mass
mu	micro; SI units prefix for 1E-6
n	nano; SI units prefix for 1E-9



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