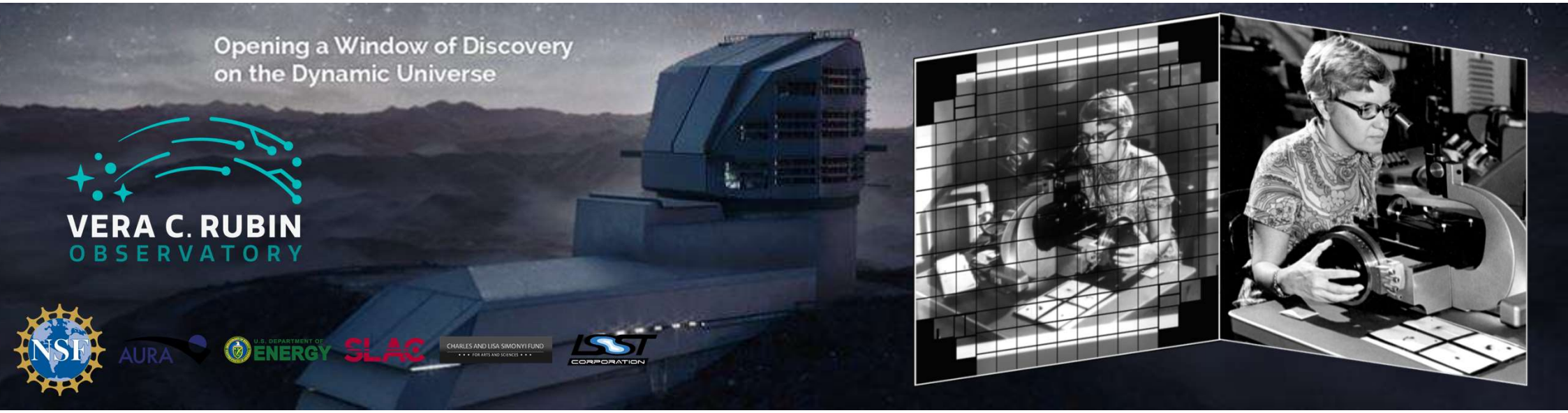


LSST
Legacy Survey of Space and Time

Programma Rubin-LSST @INAF

Scienza e Partecipazione INAF al progetto Rubin-LSST

M. Brescia on behalf of the italian Team

INAF ISTITUTO NAZIONALE DI ASTROFISICA

Legacy Survey of Space & Time: wide, fast, deep

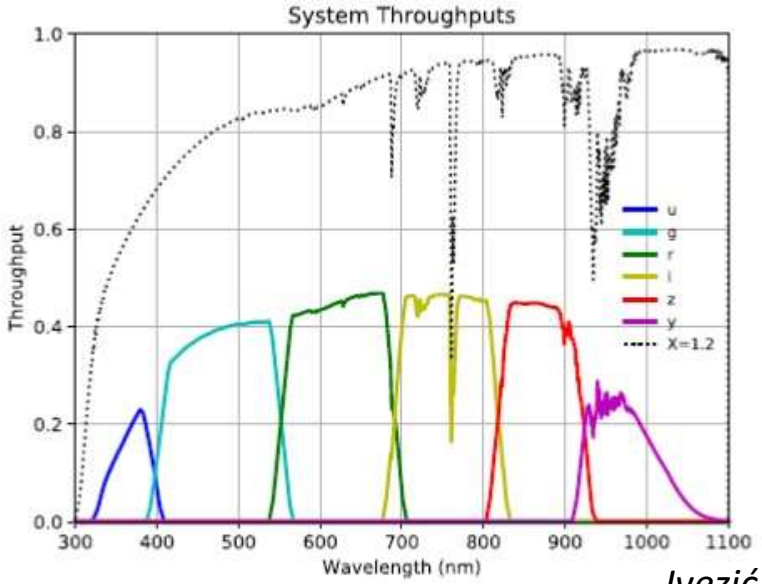
Survey speed (~ Etendue) ≈ 319 $m^2 deg^2$

Optical throughput close to maximum

5σ point source depth:
Single exposure and idealized
for stationary sources after 10 years

u	23.9	26.1
g	25.0	27.4
r	24.7	27.5
i	24.0	26.8
z	23.3	26.1
y	22.1	24.9

Image quality dominated by seeing (median ~0.67")



Ivezić et al. 2019

FoV 9.6 deg^2
0.2"/pixel pitch
3.2 Gpixel camera
8.4m primary mirror
10 year survey of the sky
37 billion stars and galaxies
Site El Penon, Cerro Pachon, Chile
Each image has size of 40 full moons
Up to 10 million alerts, 20 TB of data ... every night!

Legacy Survey of Space & Time: Science

- Wide-Fast-Deep area of 18,000 deg^2
- 825 visits per field over 10 years, and same night & field re-visit “pairs”
- At least four Deep Drilling Fields
- North Ecliptic Spur, Galactic Plane and South Celestial Pole

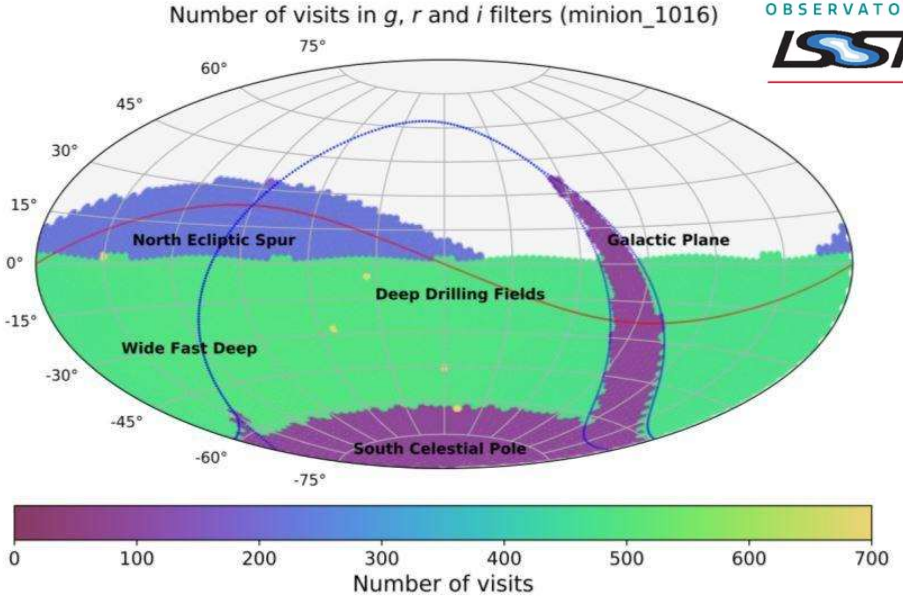
Four main science drivers

Dark energy and cosmology

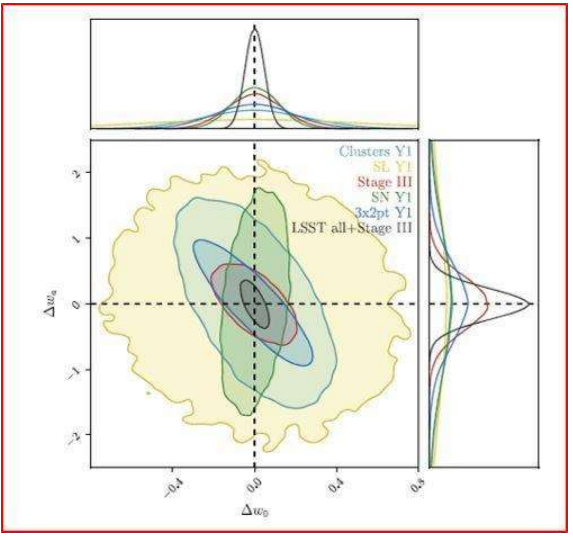
Transient universe

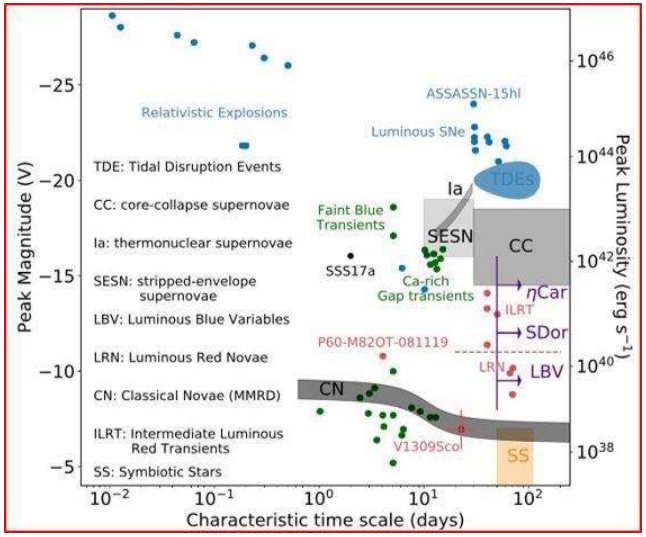
Solar system

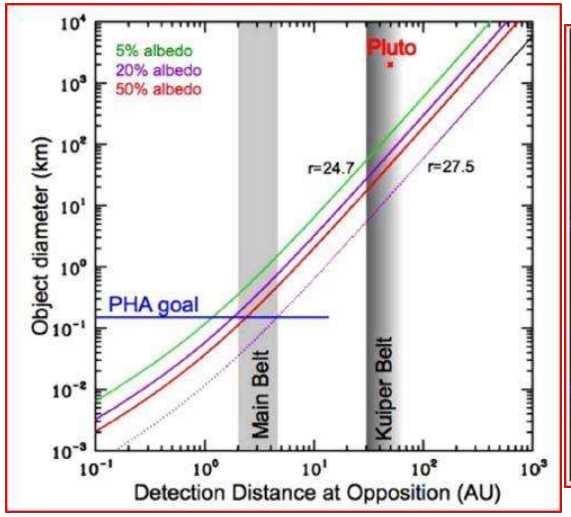
Milky Way and local volume

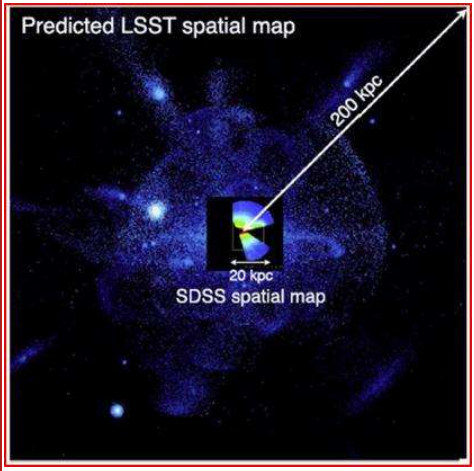


Ivezić et al. 2019



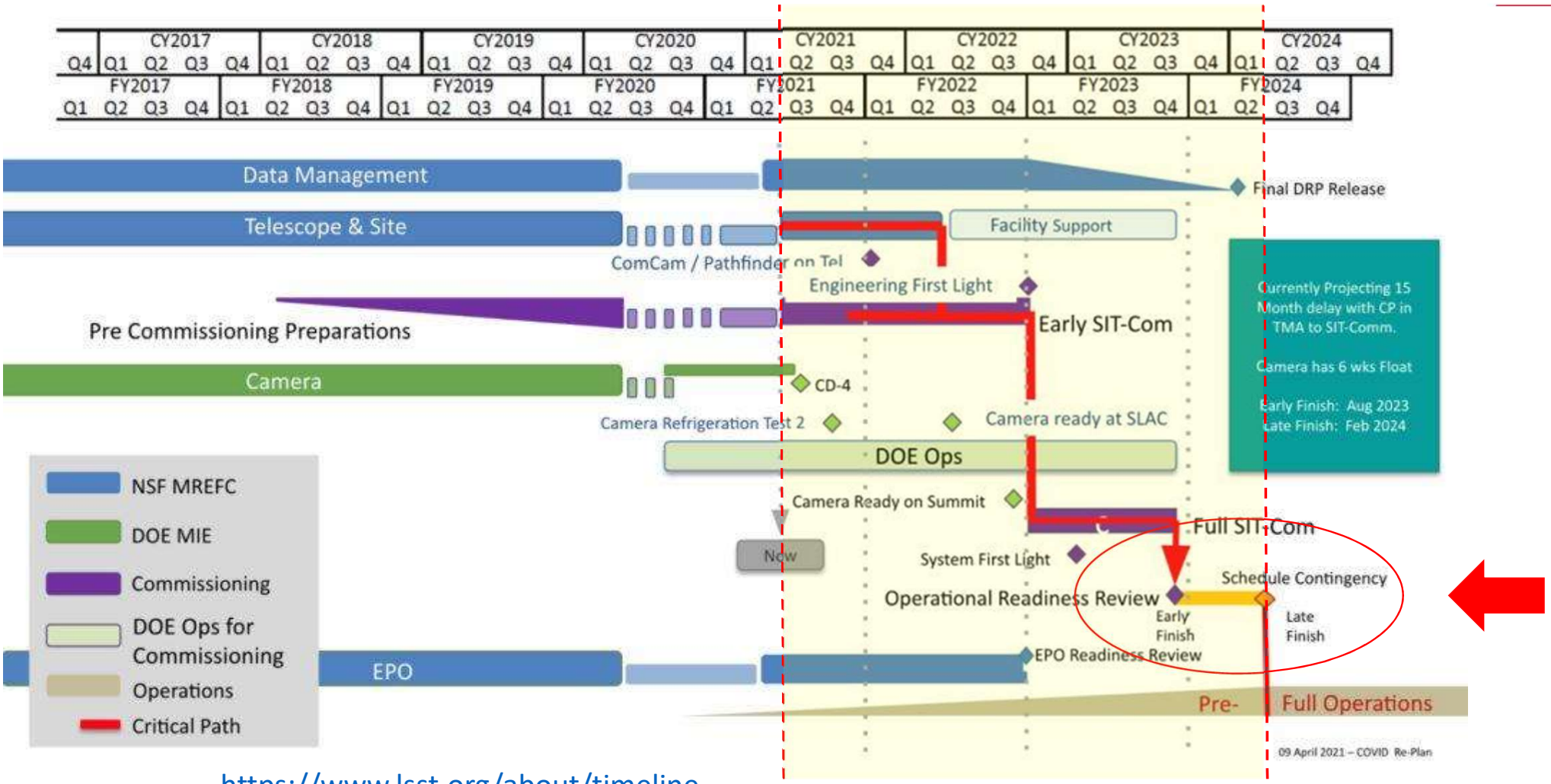






Project Schedule

Very likely 15 months of time shift due to pandemic



https://www.lsst.org/about/timeline

The Rubin-LSST ecosystem & data production

23 World Countries (13 in Europe)
38 Research/Academic Institutes (24 in Europe)

Community Working Groups (CWGs)

- ❑ Data Q&A
- ❑ Statistics Q&A
- ❑ Survey Cadence Strategy
- ❑ Alerts & Brokers
- ❑ Independent Data Access Centers
- ❑ Photometric Redshifts
- ❑ Crowded Fields
- ❑ Milky Way
- ❑ Science Platform
- ❑ Commissioning
- ❑ Simulations

Science Collaborations (SCs)

- ❖ Galaxies
- ❖ Stars, Milky Way & Local Volume
- ❖ Solar System
- ❖ Dark Energy
- ❖ Active Galactic Nuclei
- ❖ Transient/Variable Stars
- ❖ Strong Lensing
- ❖ Informatics & Statistics

Prompt Data Products

Alerts: up to 10 million per night — 60s — via nightly alert streams

Results of Difference Image Analysis (DIA): transient and variable sources

Solar System Objects: ~ 6 million

24h — via Prompt Products Database

Data Release Data Products

Final 10yr Data Release:
- Images: 5.5 million x 3.2 Gpx
- Catalog: 15PB, 37 billion objects

via Data Releases

Italian memberships in all CWGs and SCs. Several coordinating roles played by the italian team within WPs and task forces

Leveraging international interest in Rubin-LSST

In 2017 INAF signed a MoA with LSSTC to acquire 15 data right holders (15 quintuplets) at a cost of 300K$/Y (1 PI = 20K$/Y) for 10 years → estimated total investment 3M$ (excluded other supplementary costs)

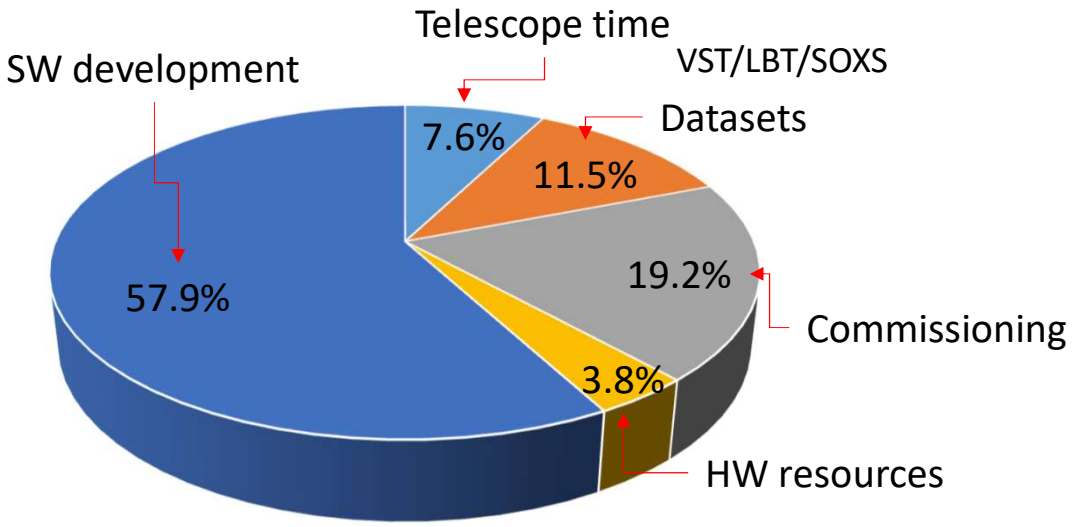
But, from late 2019 the policy changed!

All US and Chilean astronomers have full data rights
International partners may join through "**in-kind contributions**"
Goal: direct science support for US and Chile community

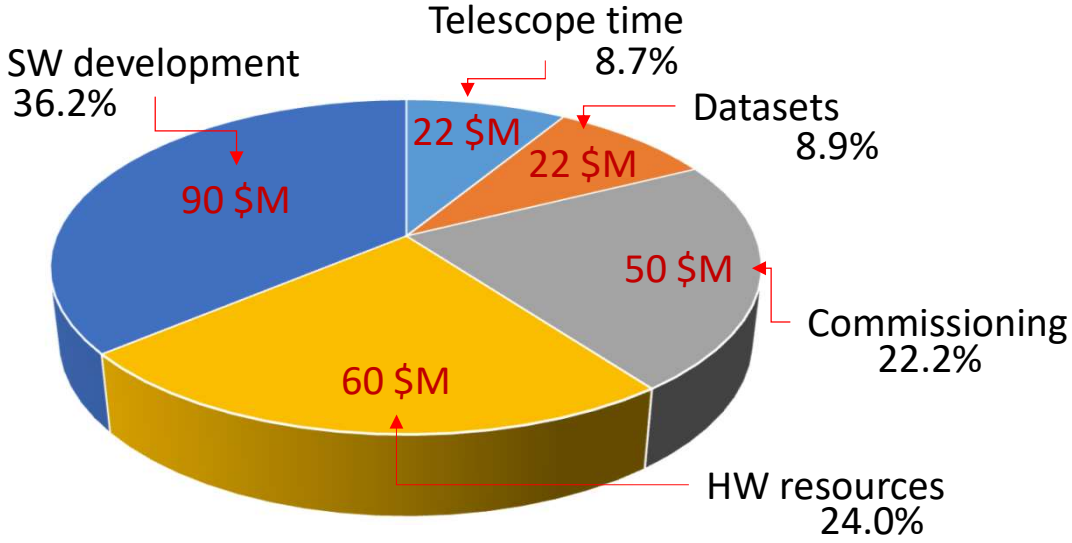
In March 2021 INAF submitted 26 proposals (**under evaluation**).
90% informally accepted, others may be proposed next years.

Estimated return ~100 data right holders

% types of INAF proposed in-kinds [26]



Est. Value of worldwide proposed in-kinds [249 $M]



Critical aspects to maintain in-kind program

Expected return ~100 data right holders

Italian participation to Rubin-LSST project - timeline of planned in-kind activities and AdR postdoc assistant recruitment																				
YCs = AdR contracts per Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**
Agreements with Rubin Corporation			MoA				in-kind prop														
Participation to Science Collaborations	SC roadmap and observing strategies																				
Science, legacy and directable contributions									34 YCs												
HW/SW Infrastructure										1 YCs											
Legacy surveys and observing time at INAF facilities (VST/LBT/SOXS)								2 YCs													
Commissioning contributions							14 YCs														
TOTAL INAF postdoc AdR contracts (YCs)	51																				

~200 K€ allocated

600 K€

Total estimated cost ~3 M€

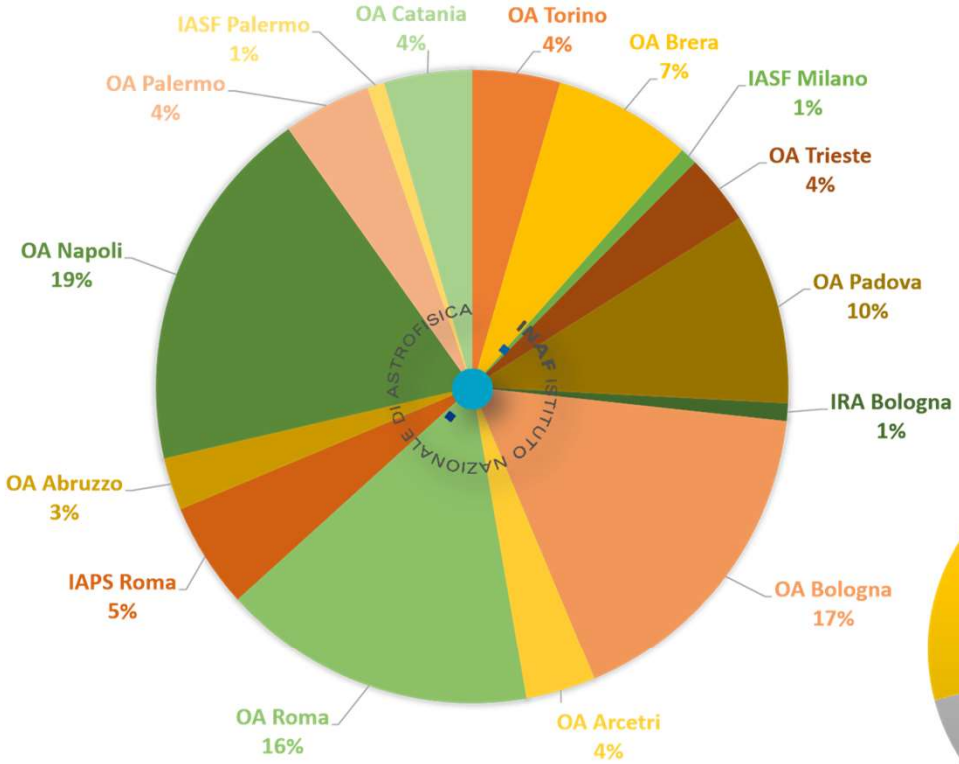
The schedule may be changed, due to the LSST time shift

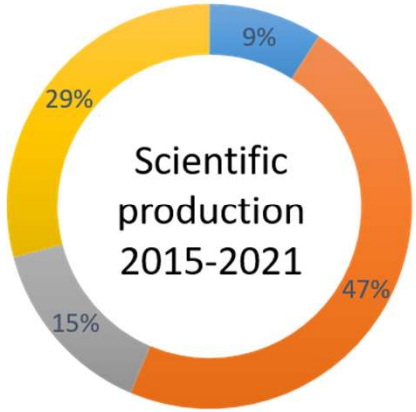
This is a long-term program, articulated in multiple objectives and tasks, strongly dependent on resource availability.
The activities foresee the recruitment of an adequate amount of AdR postdocs, i.e. young researchers,
mostly SW/System Engineers and Astroinformaticians (data scientists with a background on Astrophysics)

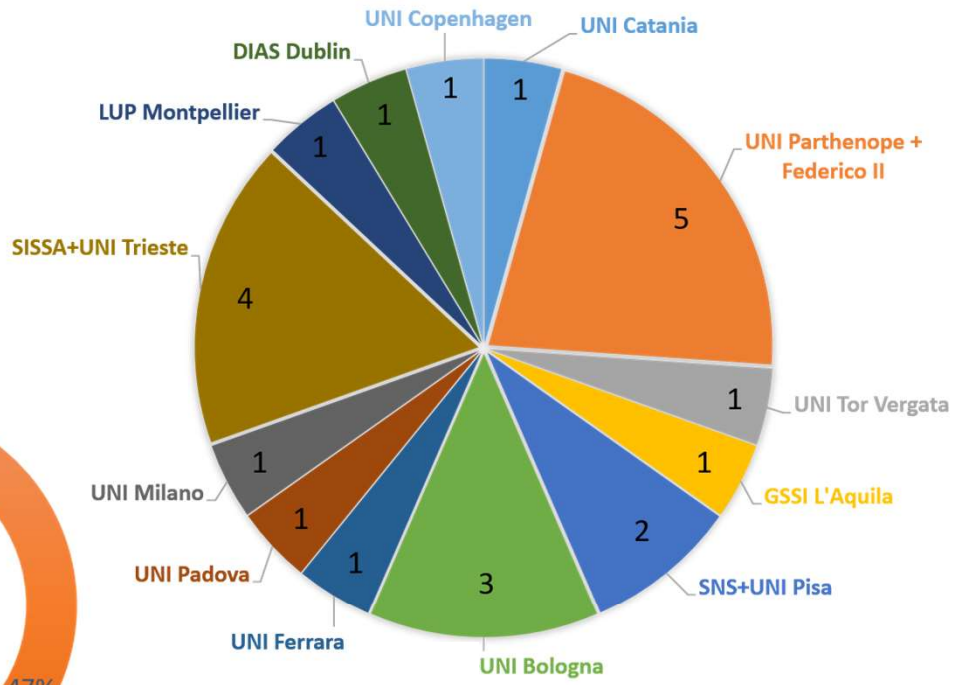
Italian Team distribution

Total **112 INAF members** (+ 23 associates)

& scientific production





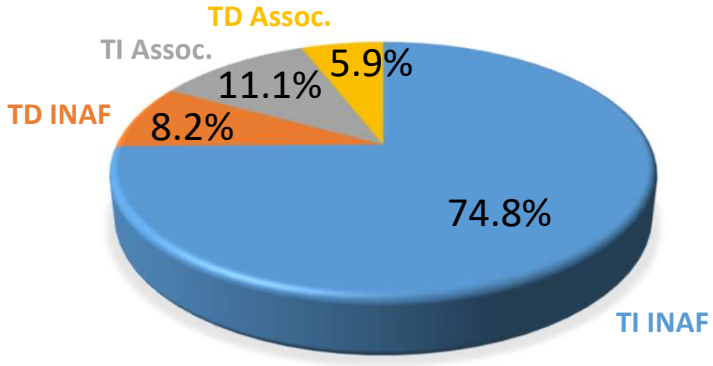


5 meetings | 26 articles | 8 white books | 16 research notes

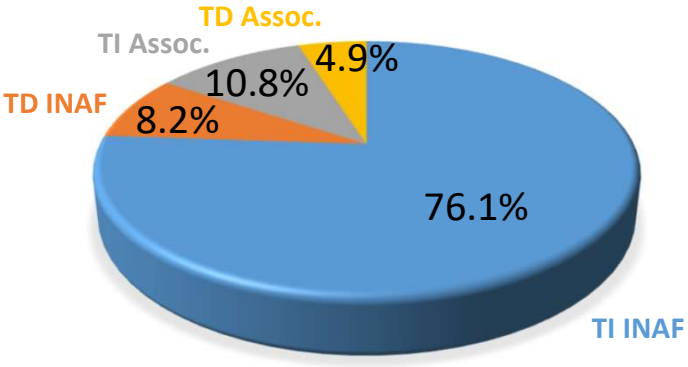
Scheda INAF – Scienza e partecipazione INAF al progetto Rubin-LSST – M. Brescia

Distributions of FTEs among researchers

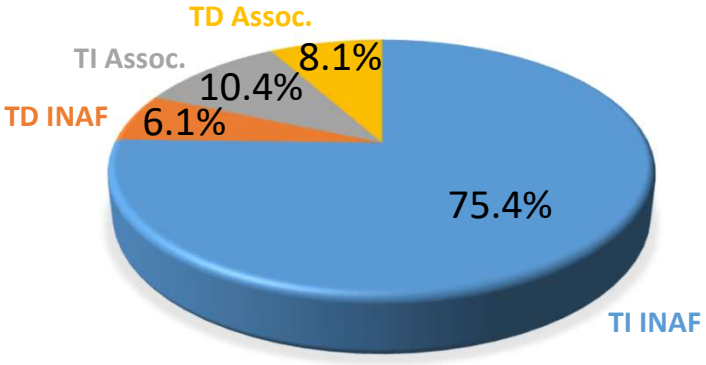
% PEOPLE [135]



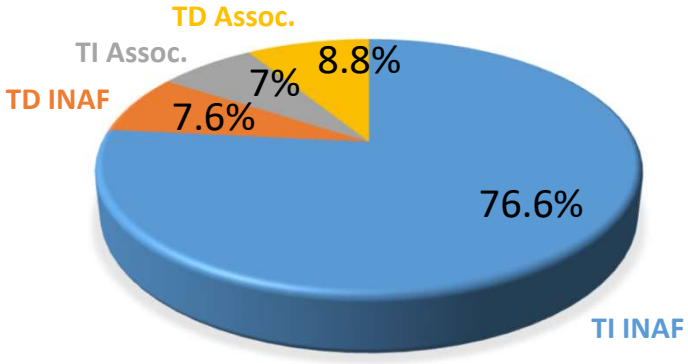
% FTE ANTE 2021 [27]



% VERIFIED FTE 2021-23 [34]



% POTENTIAL FTE 2021-23 [18]



Returns for INAF from Rubin-LSST & in-kind program

Expected ~100 data right holders

In perspective, an excellent investment for the formation of new generation of scientists

Internal re-use of all detection/classification/characterization methods and pipelines, developed as in-kind contributions, in all fields (from solar system to cosmology)

Opportunities for in-house science transfer (Rubin Science Platform, synergies with other survey projects and legacy data, combined exploitation of proprietary infrastructures)

Opportunities for in-house technology transfer (big data warehouse, data mining)

Caveat

The considerable interest and involvement of the national community has so far not been sufficiently balanced by adequate financial support and by consolidated perspectives.

The pursuit of the program objectives is linked to the negotiation process with Rubin-LSST for the acquisition of data access rights. **However, this process is in turn highly dependent on the level of support that INAF is able to provide**.

Interest @INAF in Rubin-LSST

26 INAF proposed in-kind contributions, increasing interest involving more than 100 researchers

↓ as an obvious consequence generated a bunch of programs/projects connected with Rubin-LSST

RSN 1

Rubin-LSST-**04**, **SBF** (**M. Cantiello**), *Surface Brightness Fluctuations: measurements and models beyond 2021*
Rubin-LSST-**12**, **LENS-ML** (**C. Tortora**), *LENses and Structural parameters with Machine Learning*
Rubin-LSST-**13**, **BlaRub** (**C. Raiteri**), *Blazars with Rubin-LSST*

RSN 2

Rubin-LSST-**01**, **Rubin-LSST-YSO** (**R. Bonito**), *Rubin LSST: from young stars to the use of the Rubin Science Platform*
Rubin-LSST-**02**, **SNdem** (**M.T. Botticella**), *The demographics of core collapse and thermonuclear supernovae: rates and progenitors*
Rubin-LSST-**05**, **GaLS** (**G. Clementini**), *Gaia-LSST Sinergy*
Rubin-LSST-**07**, **MOVIE@LSST** (**I. Musella**), *Modeling and Observations of Variable stars as distance Indicators and stellar Evolution*
Rubin-LSST-**08**, **popstar-LSST** (**L. Girardi**), *Population models of the LSST stellar content*
Rubin-LSST-**09**, **CRAM** (**I. Busà**), *Cosmic rays accelerators: in loco measurements*
Rubin-LSST-**11**, **SVARIO** (**M. Dall'Ora**), *Stellar VAriability On LSST crowded fields*
Rubin-LSST-**14**, **TimeDome** (**M. Paolillo**), *Time domain precursor studies for AGN science*, Rubin-LSST-14

RSN 3

Rubin-LSST-**06**, **CI-LSST** (**L. Inno**), *Vera Rubin LSST for Comet Interceptor*

RSN 4

Rubin-LSST-**10**, **GRAWITA** (**S. Piranomonte**), *GRAvitational Wave Inaf TeAm*

RSN 5

Rubin-LSST-**15**, **IQ4VRO** (**G. Fiorentino**), *Image quality for VRO commissioning*
Rubin-LSST-**03**, **Astroinformatics** (**M. Brescia**), *Data driven Science in Astrophysics*

Interest @INAF in Rubin-LSST

RSN 1

Rubin-LSST-**04**, **SBF** (**M. Cantiello**), *Surface Brightness Fluctuations: measurements and models beyond 2021*

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Rubin-LSST-**13**, **BlaRub** (**C. Raiteri**), *Blazars with Rubin-LSST*

The "SBF with LSST" project intends to use precursor data of LSST **to develop new Surface Brightness Fluctuations measurements** to enhance the accuracy of the galaxy distance estimation within 150 Mpc, propaedeutic to numerous fields (cosmological parameters, estimation of masses of black holes, time estimation dynamics scale, age, etc.)

Interest @INAF in Rubin-LSST

Rubin-LSST-**04**, **SBF** (**M. Cantiello**), *Surface Brightness Fluctuations: measurements and models beyond 2021*

RSN 1

Rubin-LSST-**12**, **LENS-ML** (**C. Tortora**), *LENses and Structural parameters with Machine Learning*

Rubin-LSST-**13**, **BlaRub** (**C. Raiteri**), *Blazars with Rubin-LSST*

Using machine learning, this proposal aims at complementing the ongoing effort of the Data Management division of the Rubin Observatory to derive **single Sérsic fitting of galaxies and expand this to multi-band and multi-component analyses** in a fast and efficient way, **contributing to the process of deblending sources and star/galaxy separation**. The production of galaxy-subtracted images will be implemented within the LSST strong lensing pipeline.

Scheda INAF – Scienza e partecipazione INAF al progetto Rubin-LSST – M. Brescia

Interest @INAF in Rubin-LSST

RSN 1

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Rubin-LSST-**12**, **LENS-ML** (**C. Tortora**), *LENses and Structural parameters with Machine Learning*

Rubin-LSST-**13**, **BlaRub** (**C. Raiteri**), *Blazars with Rubin-LSST*

Main purpose of our team is the **study of the variability, census and environment of blazars**, integrated within the work of Rubin-LSST Science Collaborations, concerning the observation strategy, modality of data dissemination and the exploiting of the survey data through the science platform and brokers.

Scheda INAF – Scienza e partecipazione INAF al progetto Rubin-LSST – M. Brescia

Interest @INAF in Rubin-LSST

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Rubin-LSST-**11**, **SVARIO** (**M. Dall'Ora**), *Stellar VAriability On LSST crowded fields*

Rubin-LSST-**14**, **TimeDome** (**M. Paolillo**), *Time domain precursor studies for AGN science*, Rubin-LSST-14

Focusing on young stellar objects (YSOs), the project will improve the expertise on the Rubin Science Platform (Chair of TVS TF: Bonito), develop tools for the **classification of YSOs variability** (Bonito et al. in-kind contribution), collaborate with the Project **to optimize the observing strategy** (Chair of TVS TF 2018: Bonito). Furthermore, the team will support the **organization of next Rubin LSST@Europe workshop** (Bonito is the PI of a LSST Corp. granted proposal) and will work to ensure a more inclusive environment in the context of the TVS Justice, Equity, Diversity, and Inclusion group (Chair: Bonito).

Interest @INAF in Rubin-LSST

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Main goal is **to identify the progenitors of different types of SNe through the statistical study of SN events as a function of the properties of the relative stellar population**. We will carry out the measurement of SN rates from LSST data that will allow us to sample a wide age range of galaxies and increase the SNe sample tenfold. The combined use of VST and SOXS could be suitable to validate the classification.

Interest @INAF in Rubin-LSST

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Rubin-LSST will obtain astrometry and multiband time series data of southern hemisphere sources up to 5 magnitudes weaker than the Gaia limit (G ~ 20.7). The aim of GaLS is **to extend the study of pulsating stars as standard candles and stellar population tracers and the reconstruction of the history of star formation** at the magnitude limits of the LSST survey.

Interest @INAF in Rubin-LSST

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This project is part of a more general program, where multi-band time series data collected by Rubin-LSST, combined with its very accurate parallaxes measurements and adopting pulsational models (PULCINELLA), will provide a fundamental benchmark, extending Gaia's capabilities by five magnitudes, thus allowing us **to observe and characterize variable stars not only in the Milky Way, but also in Local Group galaxies.**

Interest @INAF in Rubin-LSST

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Our group intends to produce **extensive simulations (19 billion stars) of the stellar content of the LSST survey**, including the Milky Way and Magellanic Clouds, with interacting binaries and different types and rates of variables, capable of contributing to the optimization of the WFD LSST survey.

Interest @INAF in Rubin-LSST

RSN 2

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The team is collaborating with Science Collaborations (we have applied for 2021 LSST Corporation Enabling Science Call for Proposals for funding a student) to apply machine learning classification for the identification of galactic diffuse nebulae. The goal is **the discovery of new GCRs nearby sources, by observing their effects through diffuse clouds within the Milky Way**, that can contribute significantly to the total cosmic-ray luminosity at Earth. The newly collected information will certainly contribute to uncovering the still debated origin of galactic cosmic rays.

Interest @INAF in Rubin-LSST

RSN 2

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The goal is **to reconstruct the structure of the Bulge** (and other critically crowded environments related to the Galaxy), using appropriate population/age/distance tracers. For this, it is necessary to develop adequate data reduction/analysis techniques, not extensively envisaged by the Rubin-LSST pipeline. A pilot experiment has already been underway for three years, formalized in the activities of the TVS - Crowded Field Task Force.

Interest @INAF in Rubin-LSST

RSN 2

Rubin-LSST-**01**, **Rubin-LSST-YSO** (**R. Bonito**), *Rubin LSST: from young stars to the use of the Rubin Science Platform*

Rubin-LSST-**02**, **SNdem** (**M.T. Botticella**), *The demographics of core collapse and thermonuclear supernovae: rates and progenitors*

Rubin-LSST-**05**, **GaLS** (**G. Clementini**), *Gaia-LSST Sinergy*

Rubin-LSST-**07**, **MOVIE@LSST** (**I. Musella**), *Modeling and Observations of Variable stars as distance Indicators and stellar Evolution*

Rubin-LSST-**08**, **popstar-LSST** (**L. Girardi**), *Population models of the LSST stellar content*

Rubin-LSST-**09**, **CRAM** (**I. Busà**), *Cosmic rays accelerators: in loco measurements*

Rubin-LSST-**11**, **SVARIO** (**M. Dall'Ora**), *Stellar VAriability On LSST crowded fields*

Rubin-LSST-**14**, **TimeDome** (**M. Paolillo**), *Time domain precursor studies for AGN science*, Rubin-LSST-14

The ongoing and future activities **exploit the expertise acquired with VST surveys on AGN and time-domain science** end its application to LSST. The project also proposes to perform additional VST surveys in support to LSST science (before and during LSST operations) to be offered as an in-kind contribution from the italian community.

Interest @INAF in Rubin-LSST

RSN 3 Rubin-LSST-**06**, **CI-LSST** (**L. Inno**), *Vera Rubin LSST for Comet Interceptor*

The goal is to use LSST images **to dynamically identify and characterize interstellar comets on their journey to the inner Solar System**. This program is crucial for the success of the next ESA Comet Interceptor space mission (of which our team is co-I), the target of which will be one of these objects. In fact, the statistical study, so far elusive, of this population of minor bodies of the Solar System will allow us, not only to obtain a catalogue of potential targets for spacecraft, but also to determine the physical parameters of the dust environment in which it will come, thus ensuring their safety during the flyby

Scheda INAF – Scienza e partecipazione INAF al progetto Rubin-LSST – M. Brescia

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RSN 4 Rubin-LSST-**10**, **GRAWITA** (**S. Piranomonte**), *GRAvitational Wave Inaf TeAm*

The astrophysical sources of gravitational waves and multi-messenger studies with Rubin-LSST inside the GRAWITA collaboration - GuRu (GRAWITA using Rubin)

Rubin-LSST will play a key role in the newborn multi-messenger astronomy field allowing us **to study and identify the likely faint and rapidly fading electromagnetic counterparts of the hundreds of gravitational wave (GW) events** expected by the 2nd generation GW detector network at full sensitivity. This program requires Rubin-LSST to operate in synergy with other multi-wavelength facilities, available for our team GRAWITA expressly dedicated to this project.

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RSN 5

Rubin-LSST-**15**, **IQ4VRO** (**G. Fiorentino**), *Image quality for VRO commissioning*

Rubin-LSST-**03**, **Astroinformatics** (**M. Brescia**), *Data driven Science in Astrophysics*

Our Image Quality team will support the Rubin-LSST commissioning mainly in remote. We will follow two main activities and some sub-activities. We will perform an **Active Optics sanity check** through the study of the quality of science images. We will **describe geometric distortion of the ComCam and LSSTCam** using mainly Gaia DR3 as an astrometric distortion-free reference frame. We will also study **how to recover magnitudes for saturated stars** and we may contribute in the validation of both photometric and astrometric LSST output catalogues.

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Interest @INAF in Rubin-LSST

RSN 5

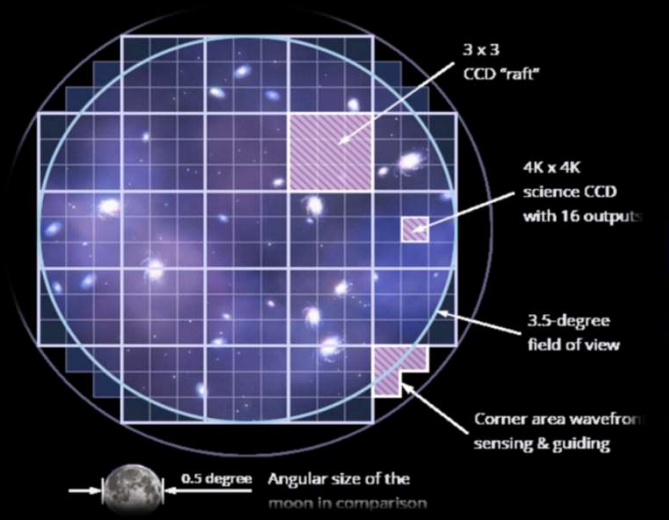
Rubin-LSST-**15**, **IQ4VRO** (**G. Fiorentino**), *Image quality for VRO commissioning*

Rubin-LSST-**03**, **Astroinformatics** (**M. Brescia**), *Data driven Science in Astrophysics*

Main goal for LSST is **to automate commissioning and scientific data analysis**, by exploiting the so-called “data driven science” and the machine learning paradigms, thus permitting an efficient and proper exploration of its huge amount of multi-wavelength information and multi-dimensional parameter space.

Vera C. Rubin Observatory & LSST Science: a promise!

The telescope will produce the deepest, widest, image of the Universe



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