The Rubin LSST Era: opportunities, challenges and simulations for AGN science

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INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

VERA C. RUBIN
OBSERVATORY

Rubin LSST has officially started on June 30 2026

Action! NSF–DOE Vera C. Rubin Observatory Begins Capturing the Greatest Cosmic Movie Ever Made

The 10-year Legacy Survey of Space and Time has officially started, marking the beginning of a new era in astronomy and astrophysics

June 30, 2026

Credit: NSF–DOE Vera C. Rubin Observatory/NOIRLab/SLAC/AURA

Rubin Observatory

Located on **Cerro Pachón**, in the Coquimbo region of Chile

Jointly funded by the **U.S. National Science Foundation** and the **U.S. Department of Energy, Office of Science**

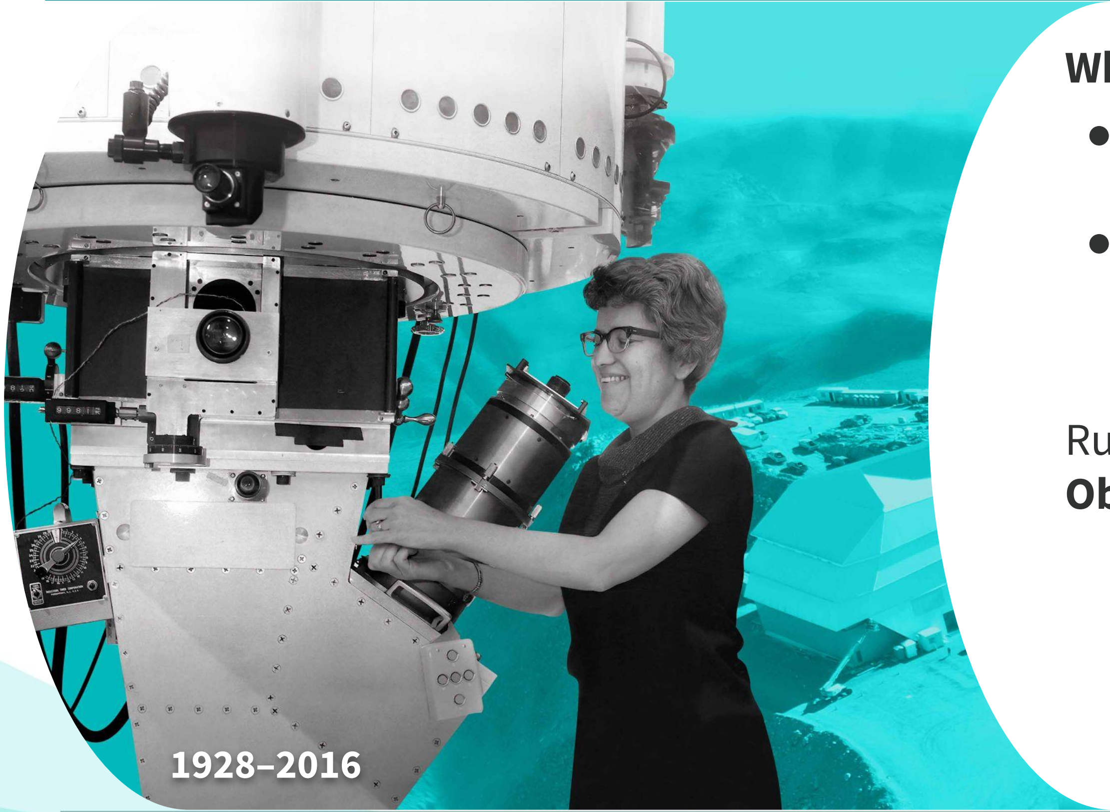
VERA C. RUBIN OBSERVATORY

U.S. National Science Foundation

U.S. DEPARTMENT of ENERGY | Office of Science

NOIRLab AURA SLAC NATIONAL ACCELERATOR LABORATORY

Honoring Vera C. Rubin



Who was she?

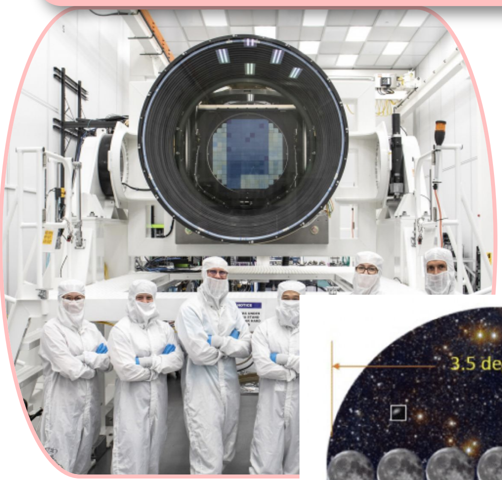
- Provided the first convincing evidence for dark matter
- Advocated for women in astronomy

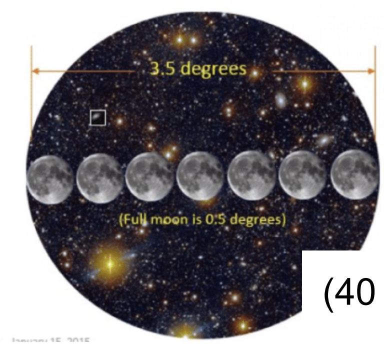
Rubin Observatory is the **first major US Observatory named for a woman**

Mission: Capture the Cosmos

Designed to:
- Take huge and high detail pictures of the entire Southern Hemisphere Sky
- Take those pictures quickly

Wide Field of View
Largest digital camera ever built





(40 full moons)

Speed
Fast moving telescope +
compact design (Novel three-mirror design)

CUTTING EDGE TECHNOLOGY

Rubin’s Legacy Survey of Space and Time (LSST)

The first 10 years of Rubin are dedicated to the **LSST** Survey…**the greatest cosmic movie ever made!**

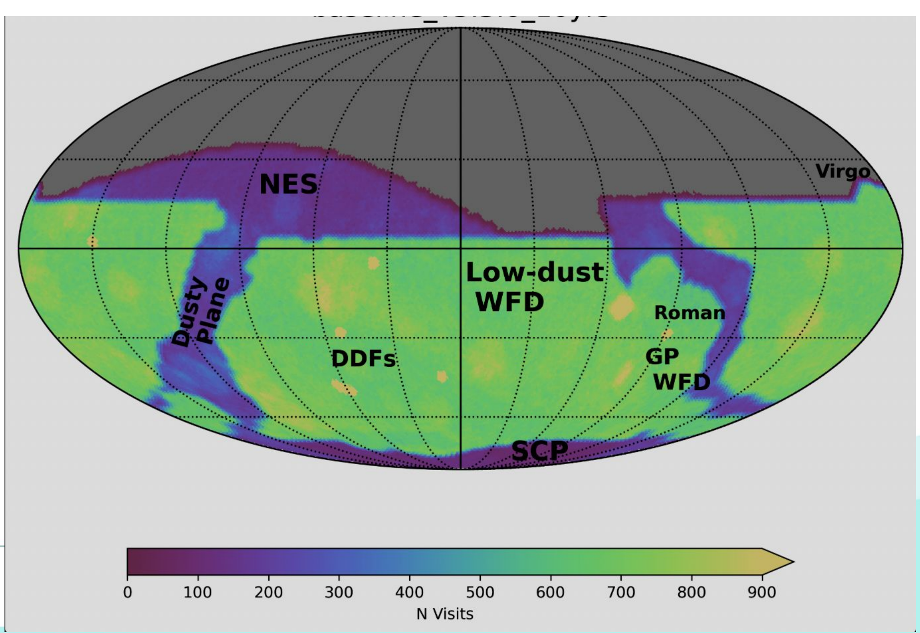
Wide-field survey (19,6k deg2, 80% survey)

5 Deep Drilling Fields (9.6 deg2 each, 7% survey)

!!27 mag in 10 year!!
largest astronomical catalog ever done

20 billions galaxies & 17-20 billions stars

Rubin will repeatedly scan the southern sky every ~3 nights in six UV-to-NIR bands (ugrizy)



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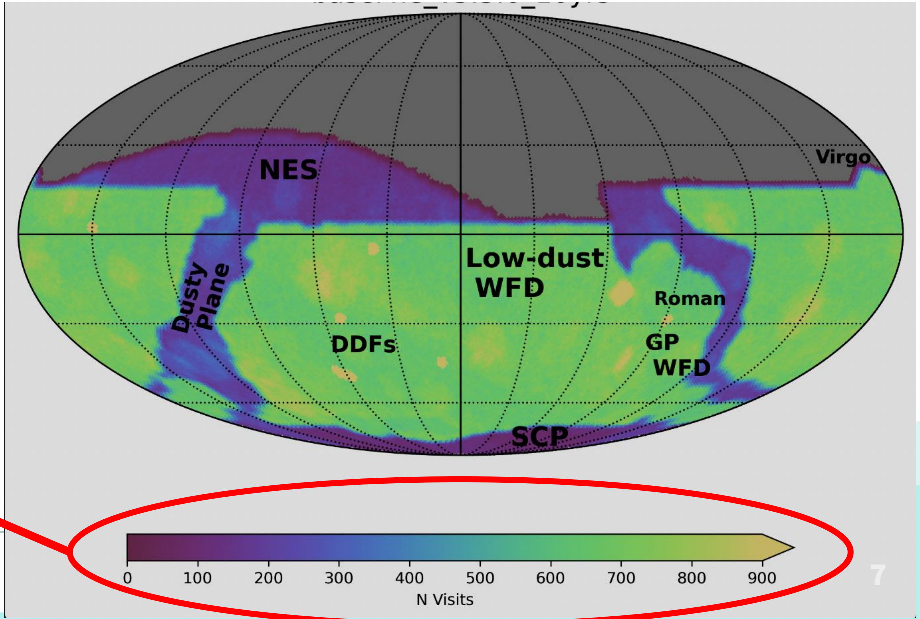


Number of visits

Each pointing observed several times (30 sec visit each)

DEPTH

VARIABILITY

The Wide fast deep survey

DEPTH

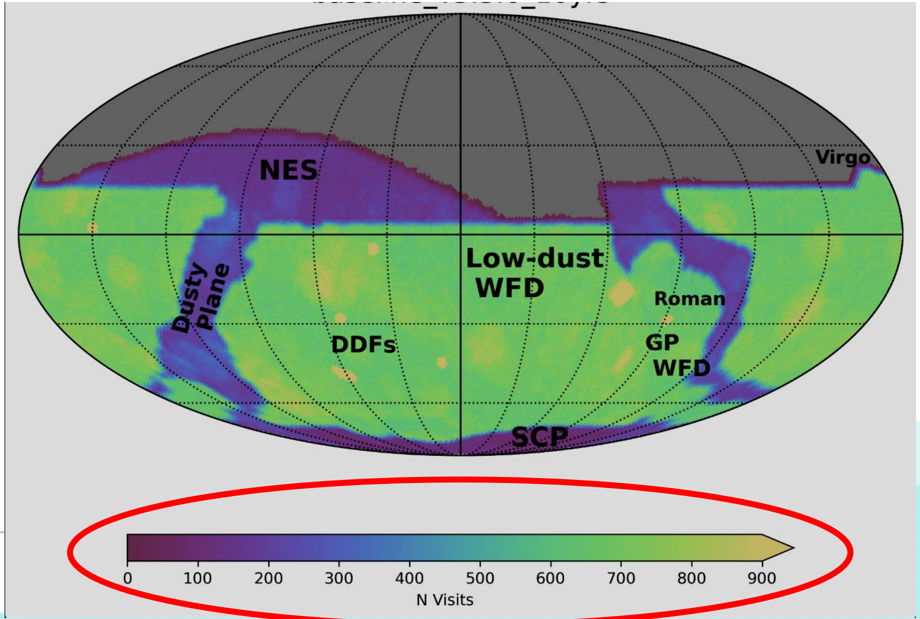
5-sigma point source depths (AB mag) for single exposures and for coadded images

- u: 23.8, 25.6 mag
- g: 24.5, 26.9 mag
- r: 24.0, 26.9 mag
- i: 23.4, 26.4 mag
- z: 22.7, 25.6 mag
- y: 22.0, 24.8 mag

https://rubinobservatory.org/for-scientists/rubin-101/key-numbers

VISITS

- **800 visits** median
- 100 - 250 visits: high dust extinction Galactic Poles



5 Deep Drilling Fields

DEPTH

1.3 mag deeper than the WFD in each band in the coadded depth

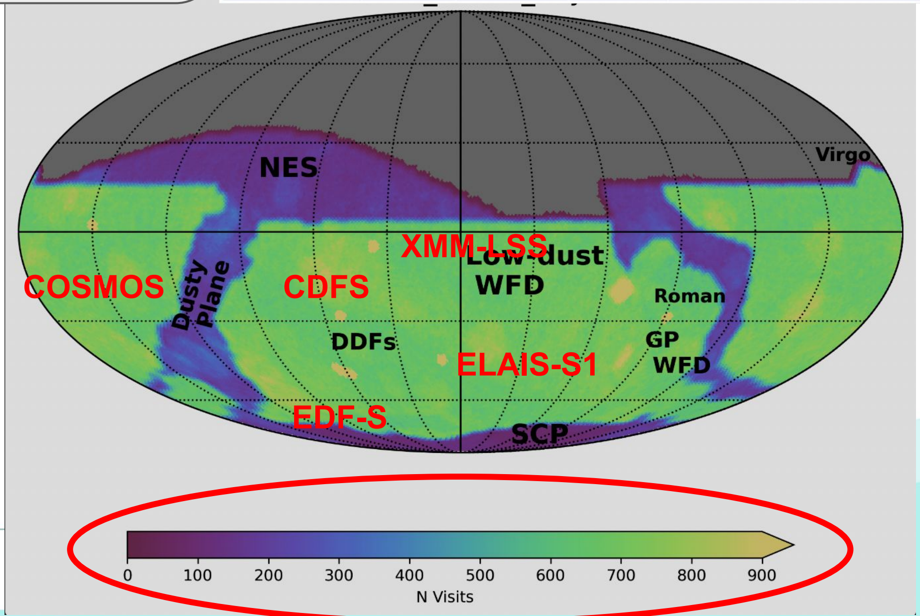
VISITS

20000 visits median

- Euclid DDF: 2 pointings observed at 0.5 visits in 10 years (6600 visits each)
- COSMOS DDF: ~ 40000 visits. 20000 visits will be reached in 3 years

Superb X-ray and multi-wavelength coverage. Critical for early Science studies

	ELAIS-S1	XMM-LSS	Wide Chandra Deep Field-South	Euclid Deep Field-South	COSMOS
RA 2000	00 37 48	02 22 18	03 31 55	04 04 58	10 00 26
DEC 2000	-44 01 30	-04 49 00	-28 07 00	-48 25 12	+02 14 01
Galactic l	311.28	171.10	224.07	256.06	236.78
Galactic b	-72.88	-58.91	-54.60	-47.17	42.13
LSST Solid Angle (deg²)	10	10	10	20	10
Prime Multiwavelength Solid Angle (deg²)	3.2 (XMM-SERVS)	5.3 (XMM-SERVS)	4.6 (XMM-SERVS)	TBD	2 (COSMOS)
Relevant Reference	Ni et al. (2021)	Chen et al. (2018)	Ni et al. (2021)	Laureijs et al. (2019)	Civano et al. (2016)



LSST vs SDSS data

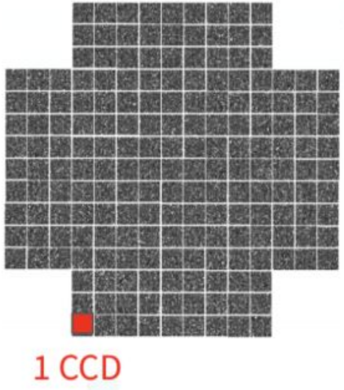
SDSS gri

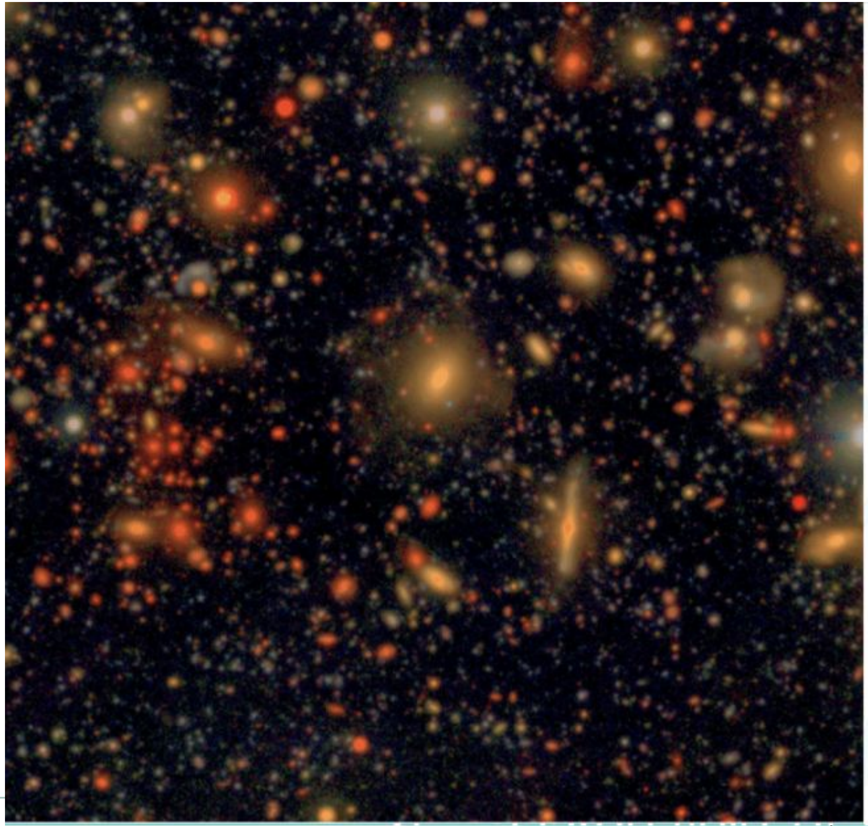
3.5’ x 3.5’
r~22.5

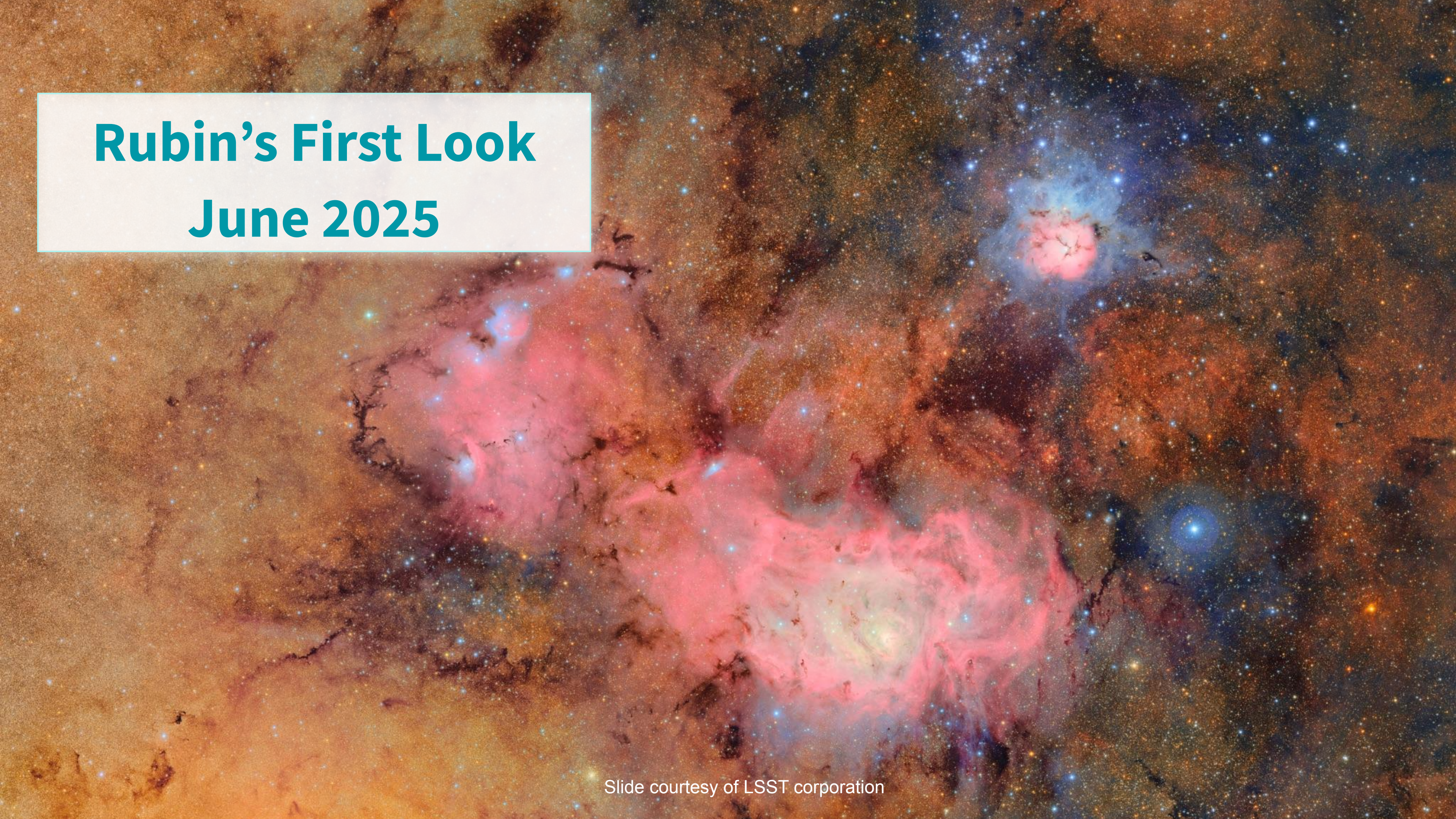
LSST vs SDSS data

HST

about 3000 such images fit into the LSST camera FoV (.i.e.1 /16 of 1 CCD, LSST has 189 CCD)






Rubin's First Look
June 2025
Slide courtesy of LSST corporation

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June 2025

Slide courtesy of LSST corporation

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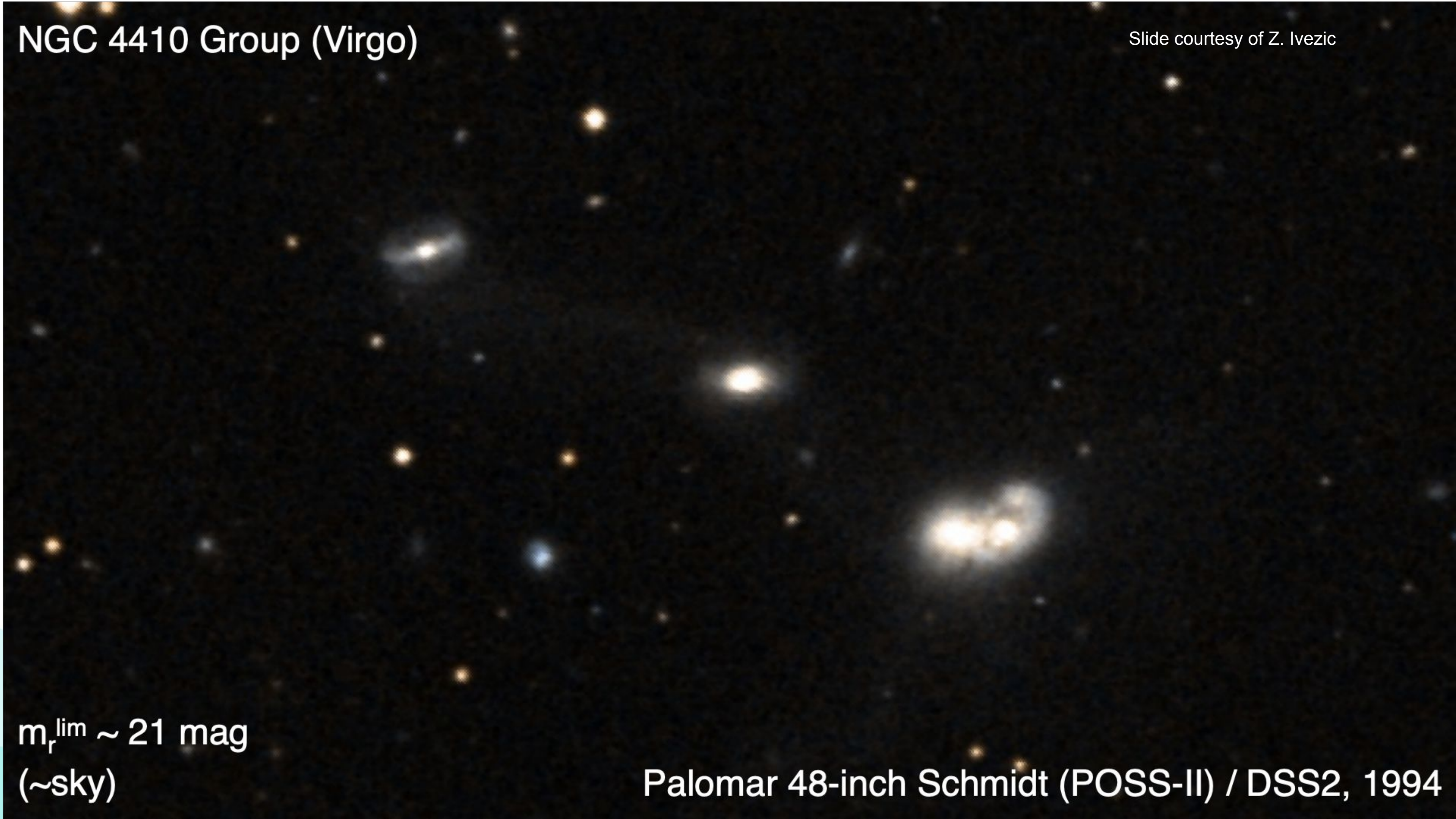
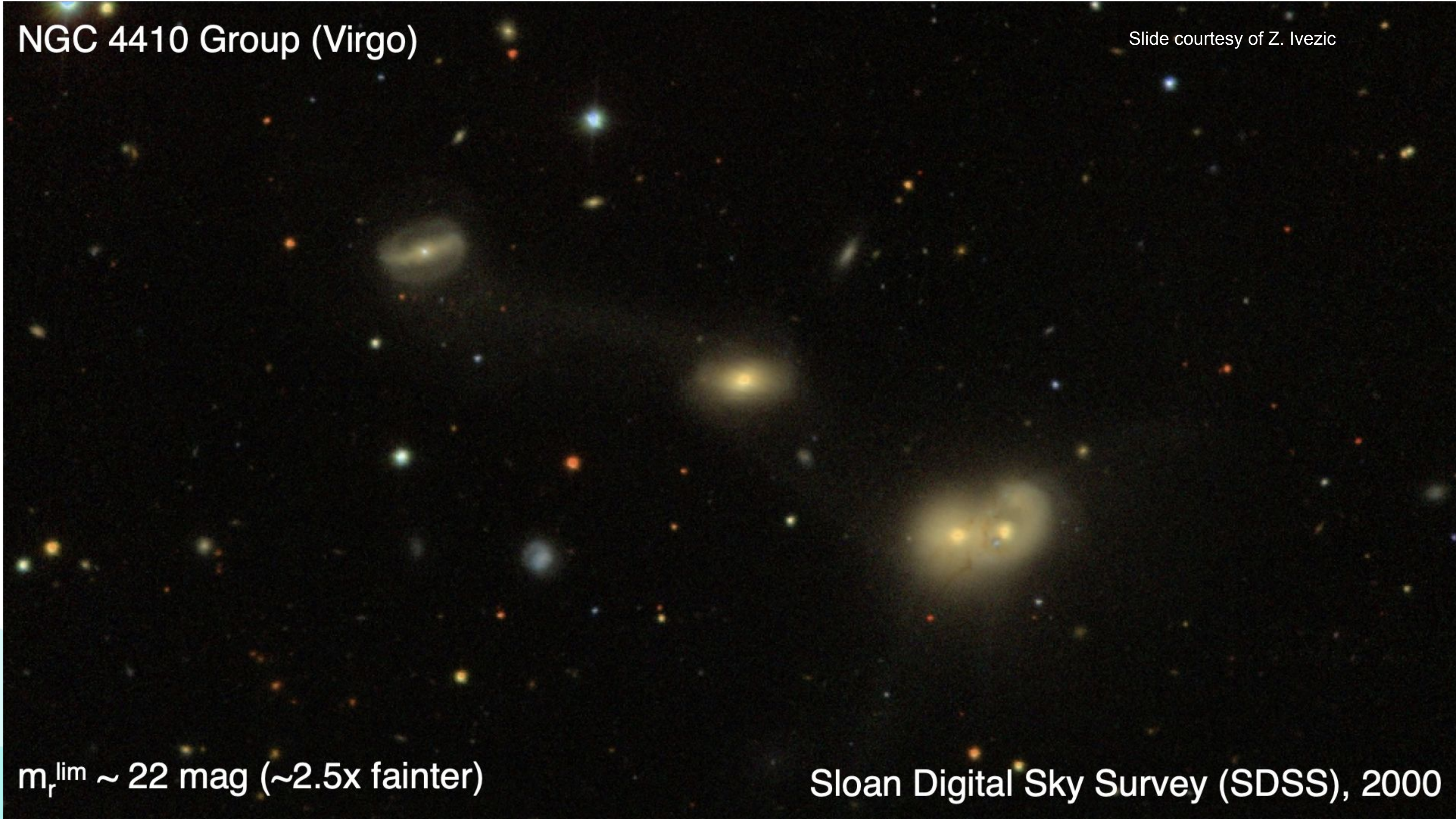
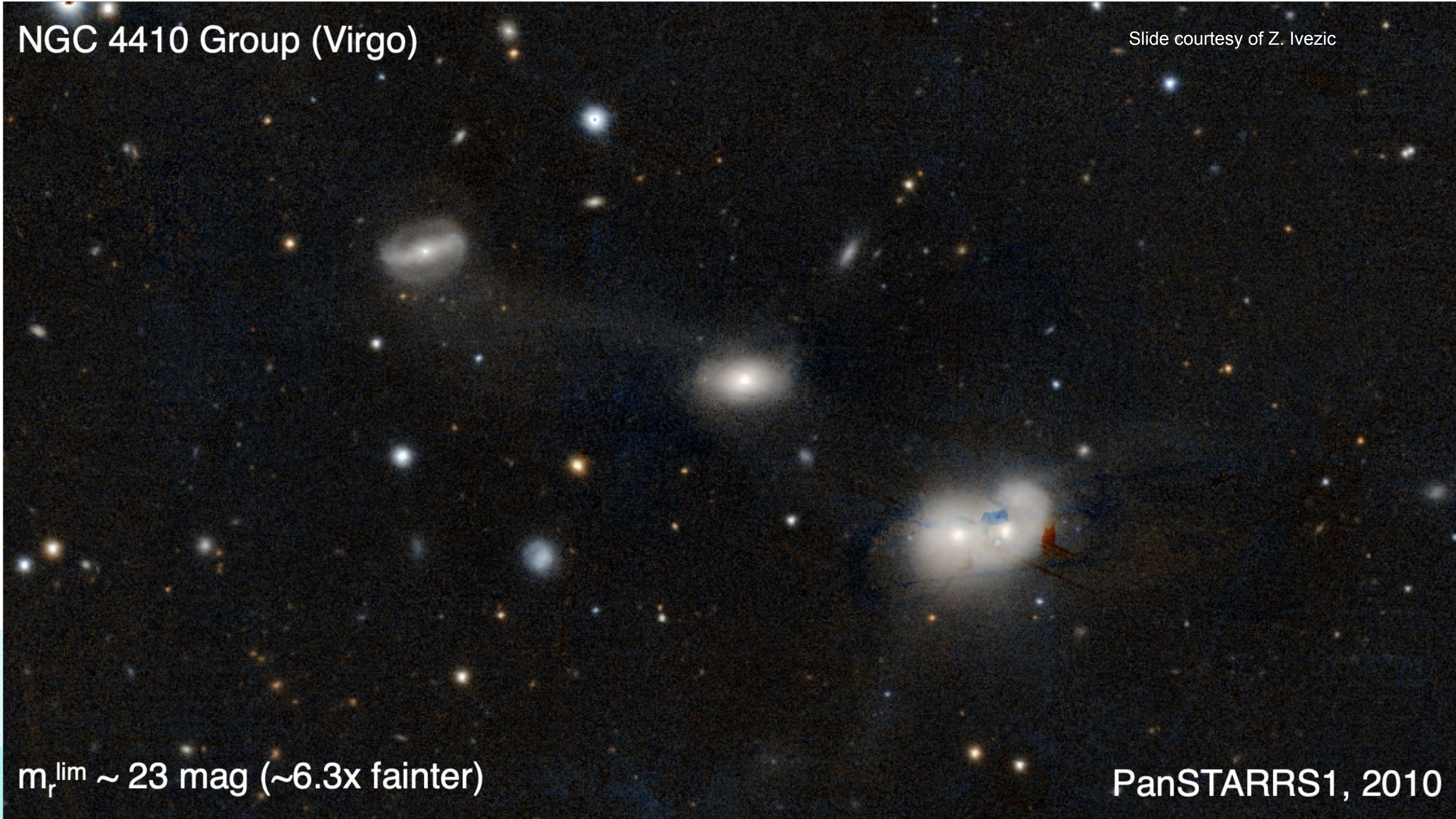
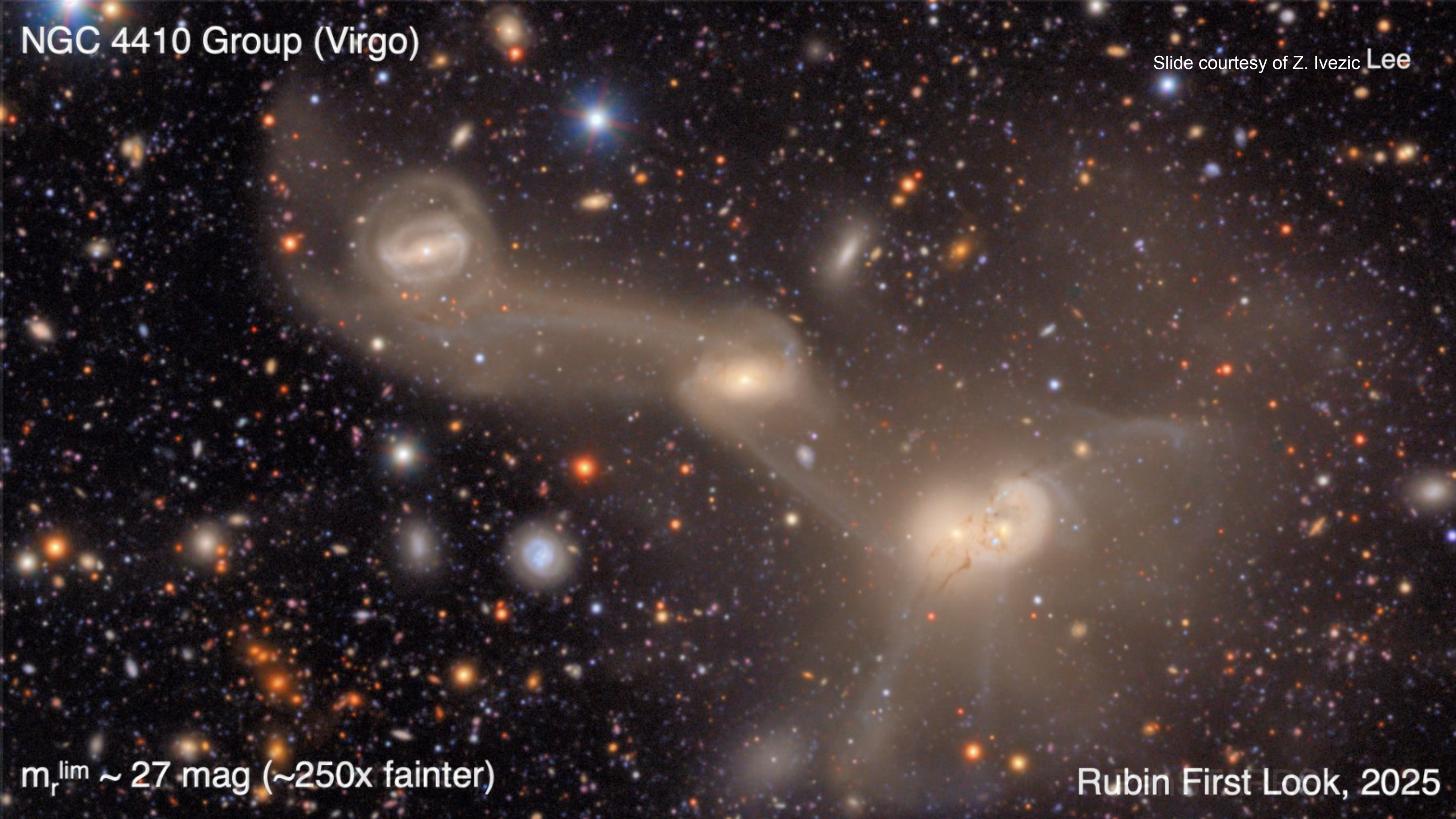
Skyviewer.app


NGC 4410 Group (Virgo)
Slide courtesy of Z. Ivezic
m_r^{lim} ~ 21 mag
(~sky)
Palomar 48-inch Schmidt (POSS-II) / DSS2, 1994


NGC 4410 Group (Virgo)
Slide courtesy of Z. Ivezic
m_r^{lim} ~ 22 mag (~2.5x fainter)
Sloan Digital Sky Survey (SDSS), 2000

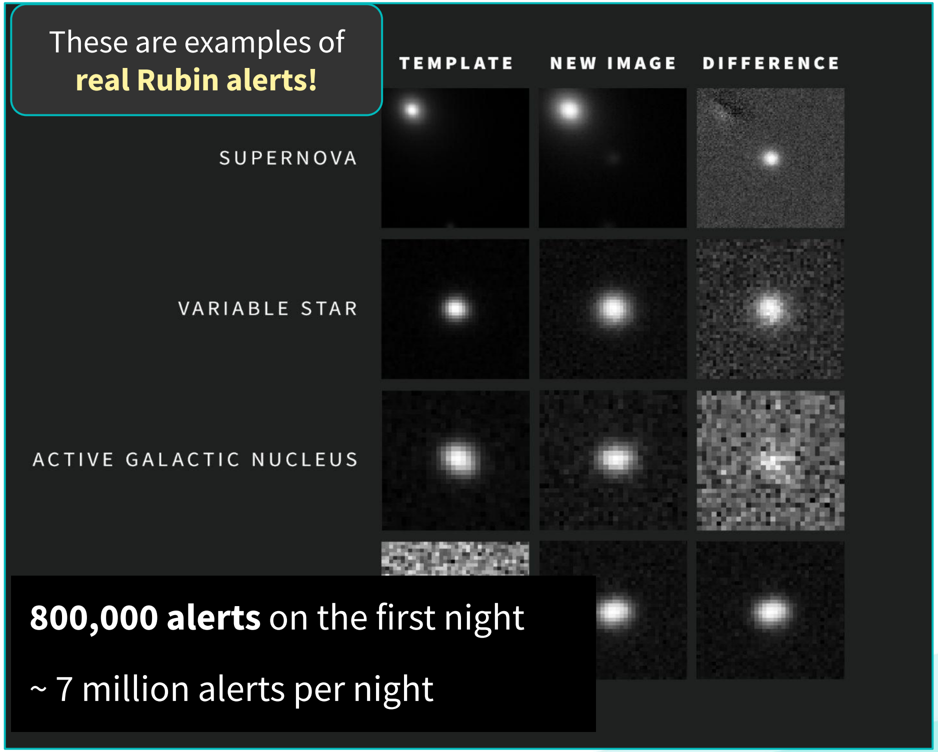

NGC 4410 Group (Virgo)
Slide courtesy of Z. Ivezic
m_r^{lim} ~ 23 mag (~6.3x fainter)
PanSTARRS1, 2010


NGC 4410 Group (Virgo)
Slide courtesy of Z. Ivezic Lee
m_r^{lim} ~ 27 mag (~250x fainter)
Rubin First Look, 2025

Alerts publicly available through Brokers (since Feb 2026)

Alert brokers ingest, process and serve alerts about variable Rubin sources to the Astronomical community

These are examples of
real Rubin alerts!



800,000 alerts on the first night

~ 7 million alerts per night

The Rubin Science Platform

Portal

Discover data in the browser

Learn more about the portal.

Notebooks

Process and analyze LSST data with Jupyter notebooks in the cloud

Learn more about notebooks.

APIs

- Processed Images (single visit and coadded ones)
- Catalogs (photometry and forced photometry)

Data availability (data rights holders/publicly)

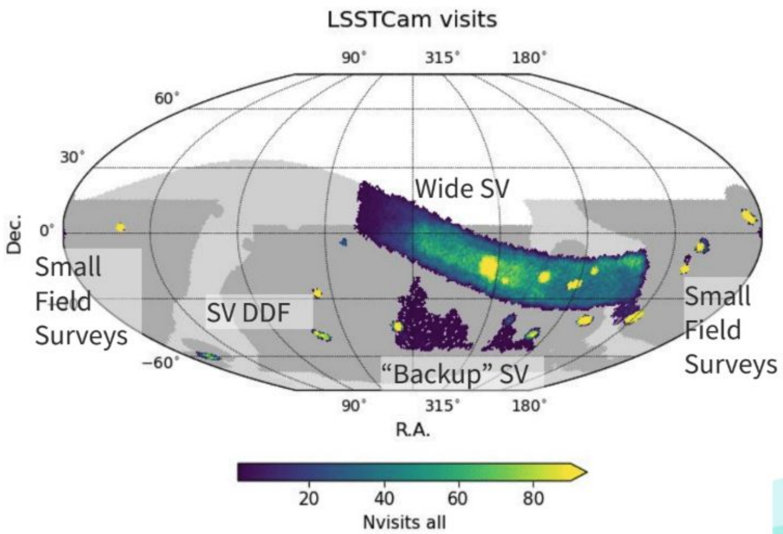
DP1: data take with the ComCam, 1786 visits (June 2025 - data rights)

DP2: first data taken with LSSTCam for Science Validation, 22k visits (July 27th 2026 - data rights)

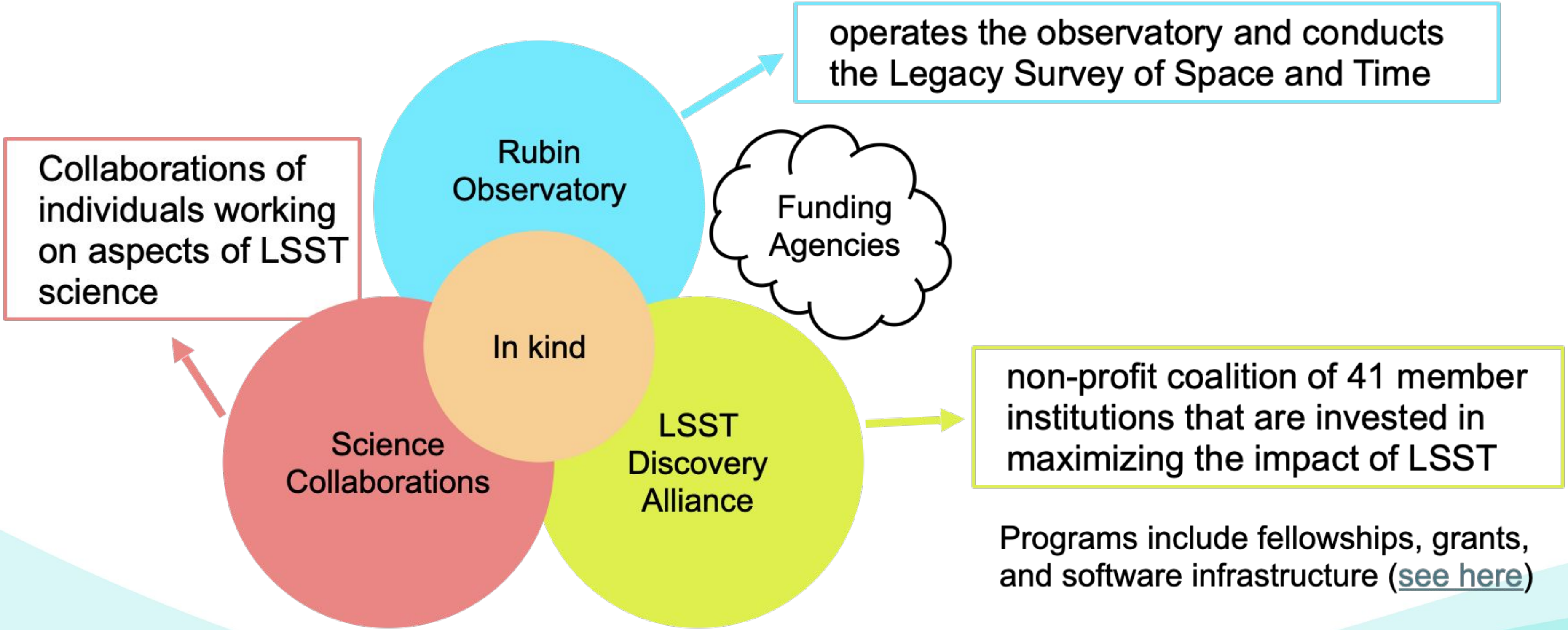
LSST prompt products available to data rights holders after 80h embargo

DR1: 1 year of LSST, available **publicly** in ~2 years

DRx: every year, data will be released **publicly**



The Rubin LSST EcoSystem



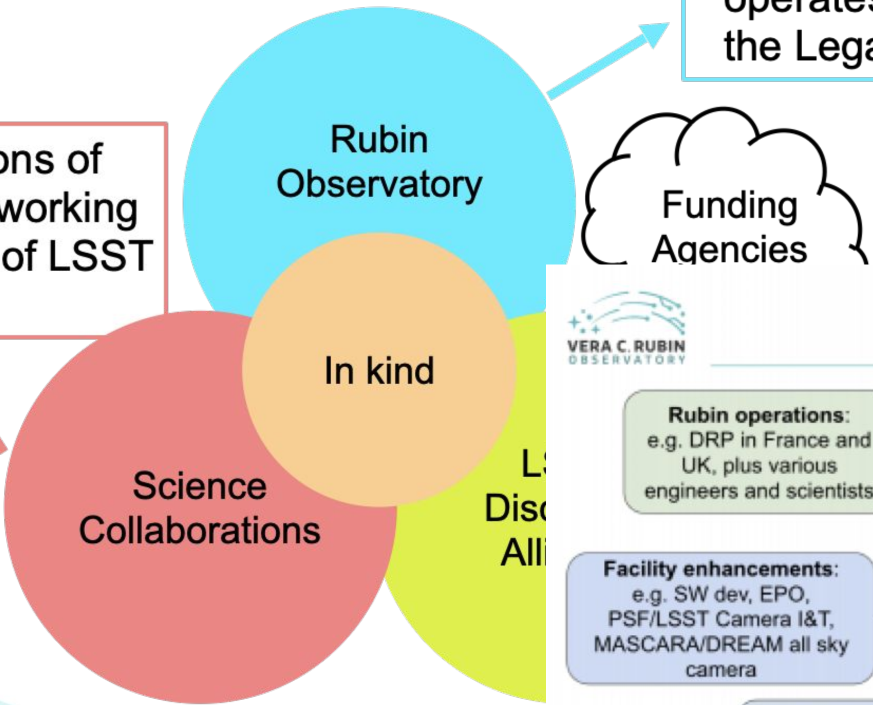
Programs include fellowships, grants, and software infrastructure (see here)

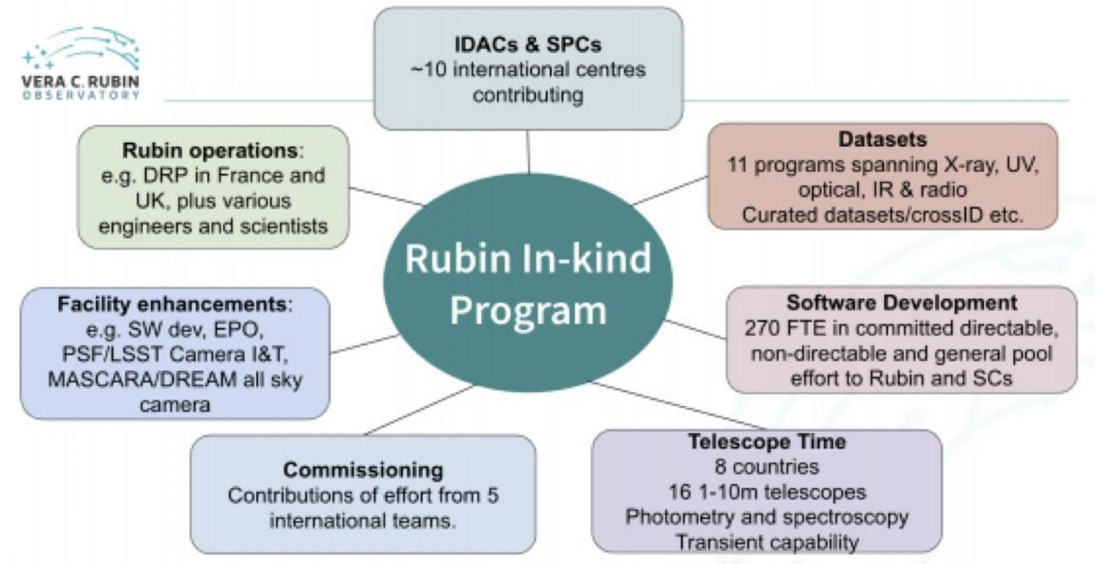
Slide courtesy of T. Jeltema

The Rubin LSST EcoSystem

operates the observatory and conducts the Legacy Survey of Space and Time

Collaborations of individuals working on aspects of LSST science





The LSST Science Collaborations

Transients and Variable Stars
Igor Andreoni, Sara Bonito

Dark Energy
Gautham Narayan, Keith Bechtol

Galaxies
Sugata Kaviraj, Simona Mei

Strong Lensing
Anupreeta More, Crescenzo Tortora

Stars, Milky Way, and Local Volume
Kristen Dage, Peregrine McGehee, Tom Wilson

Solar System
Colin Chandler, Meg Schwamb

Active Galactic Nuclei
Niel Brandt, Matthew Temple

Informatics and Statistics
Melissa DeLucchi, Alex Malz

Slide courtesy of T. Jeltema

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TVS

SMWLV

Stars, Milky Way, and Local Volume
Kristen Dage, Peregrine McGehee, Tom Wilson

Dark Energy
Gautham Narayan, Keith Be

Require LSST data rights for membership

Solar System
andler, Meg Schwamb

Su

You can still participate through external collaborator agreements!

Strong Lensing
Anupreeta More, Crescenzo Tortora

SLSC

ISSC

Informatics and Statistics
Melissa DeLucchi, Alex Malz

The AGN Science Collaboration

325 members from all over the world

MAIN GOAL:

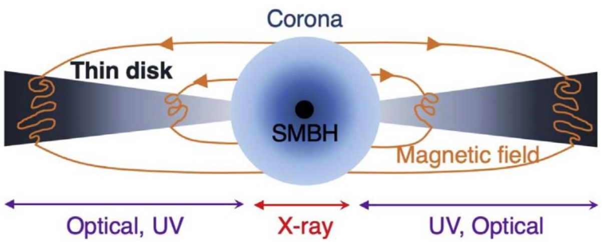
- Maximize the AGN science return of the LSST;
- Give feedback to the Project to ensure excellent AGN science;
- Educate the broader community about LSST AGN science

6 European in-kind contribution

Name	Lead
Italian simulations of high-*z* AGNs and galaxies in the LSST survey	Bongiorno
AGN reverberation-mapping time delays	Czerny
SER-SAG pipeline for periodic variability detection	Kovacevic
TIMEDOMES: VST Monitoring of the LSST DDFs	Paolillo
Canadian contribution to the LSST AGN SC: Data-analysis tools for AGN photometric variability	Ruan
MPE photometric redshifts for LSST-detected AGNs	Salvato

AGN Science with LSST: AGN variability studies

AGN variability is likely driven by a time dependent evolution of the accretion disks. Different models, physical understanding far from being clear.



(Sun et al., 2020)

Millions of AGN lightcurve in 6 bands with high sampling and SNR:

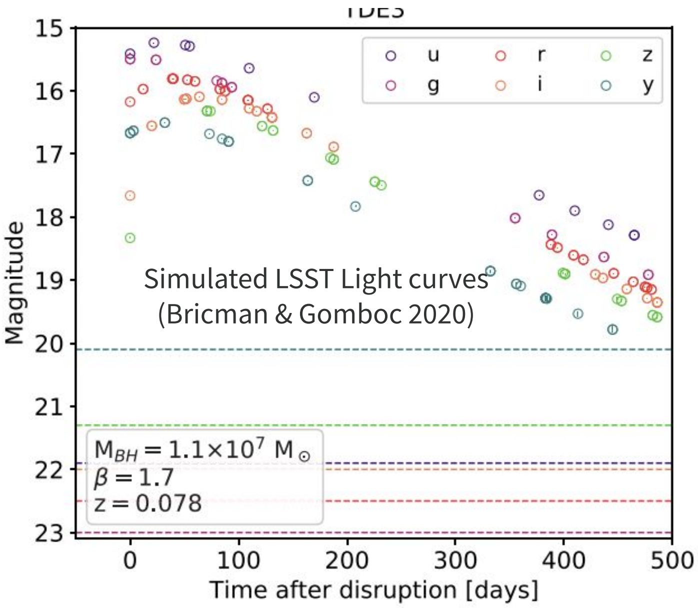
larger statistics on AGN lightcurves → improve statistical models for variability

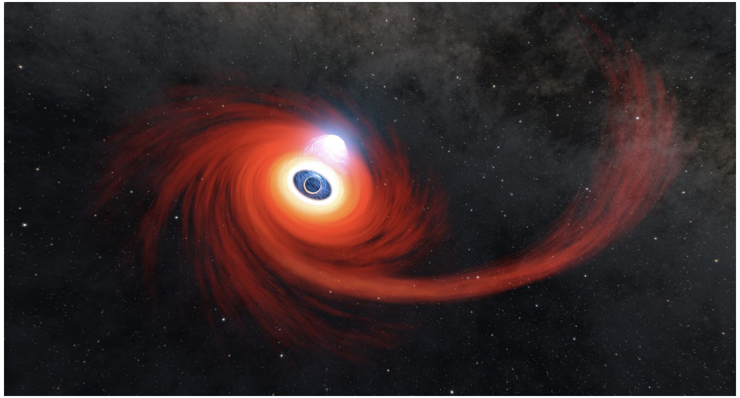
provides infos about the accretion disk and broad line region → Improve physical disk/AGN models

AGN Science with LSST: Tidal Disruption Event

LSST forecast to discover 100s/1000s per year, though will need to avoid SNs confusion

LSST alert → broker classification → TDE candidate → follow-up





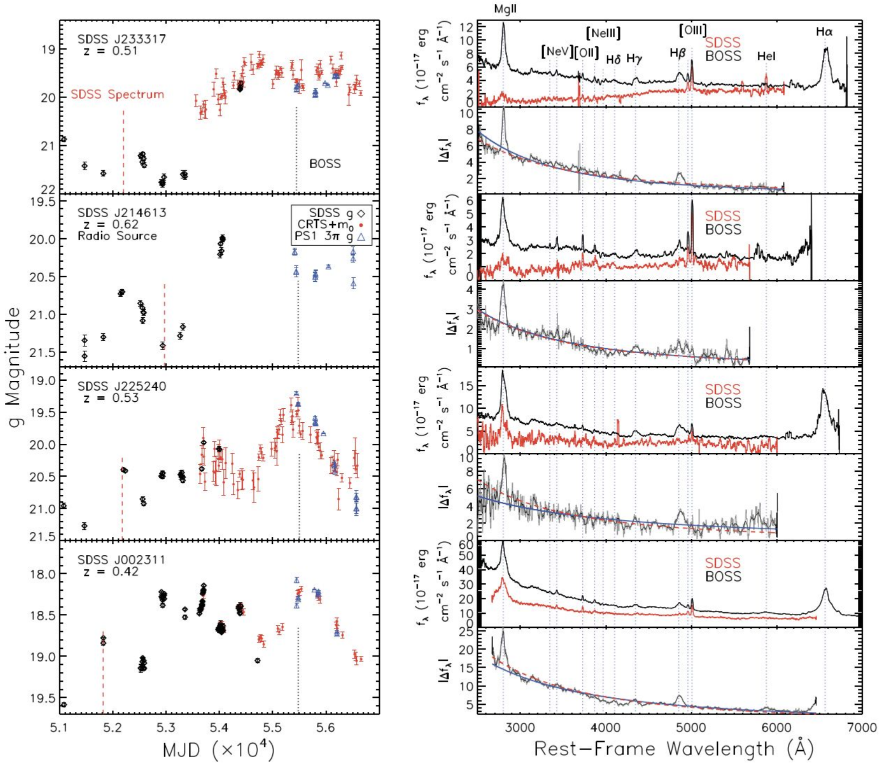
LSST will transform TDE science from the study of individual rare events into statistical population-level astrophysics (study their rate as function of galaxy type and z).

AGN Science with LSST: Changing look AGN

Changing-look AGN: AGN that change their observed properties (obscuration or state) in months to years.

Changing obscuration: gas/dust clouds hide the central engine
Changing state: accretion changes turn broad lines on/off

LSST will find candidates through long-term multi-band variability
→ spectroscopic follow up needed!



(MacLeod et al., 2016)

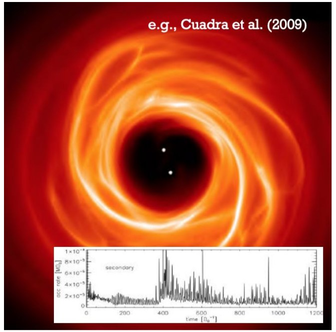
AGN Science with LSST: Binary Black Holes

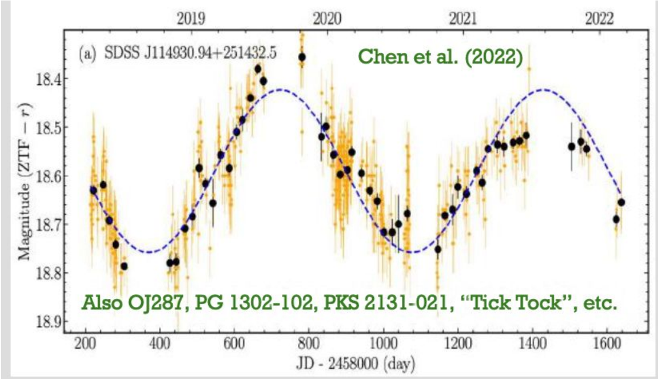
Galaxy mergers creates binary SMBHs

→ periodic variability signatures.

We expect tens to hundreds of sub-parsec massive black hole binary candidates

Main challenge: stochastic AGN variability can mimic periodicity

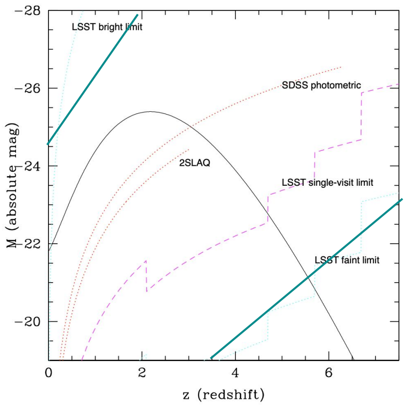


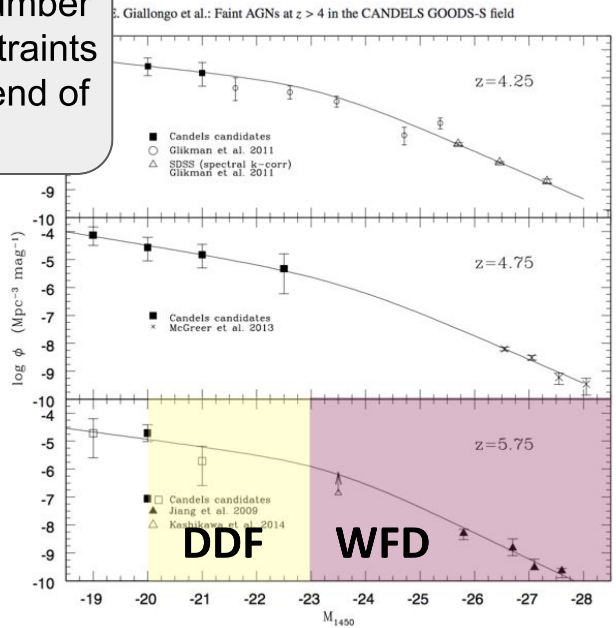


AGN Science with LSST: AGN statistical studies and evolution

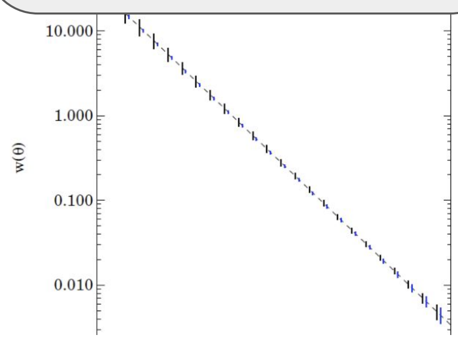
Study the changing demographics and accretion history of supermassive black holes (SMBHs) with cosmic time, and to relate these to the formation and evolution of galaxies.

LSST will significantly increase the number of high-redshift quasars and put constraints on the bright (WFD) and faint (DDF) end of the luminosity function





LSST will improve AGN clustering constraints, with WFD mapping large-scale quasar environments and DDFs probing fainter AGN populations at high redshift.



see [agn.science. lsst.org](agn.science.lsst.org) for more science

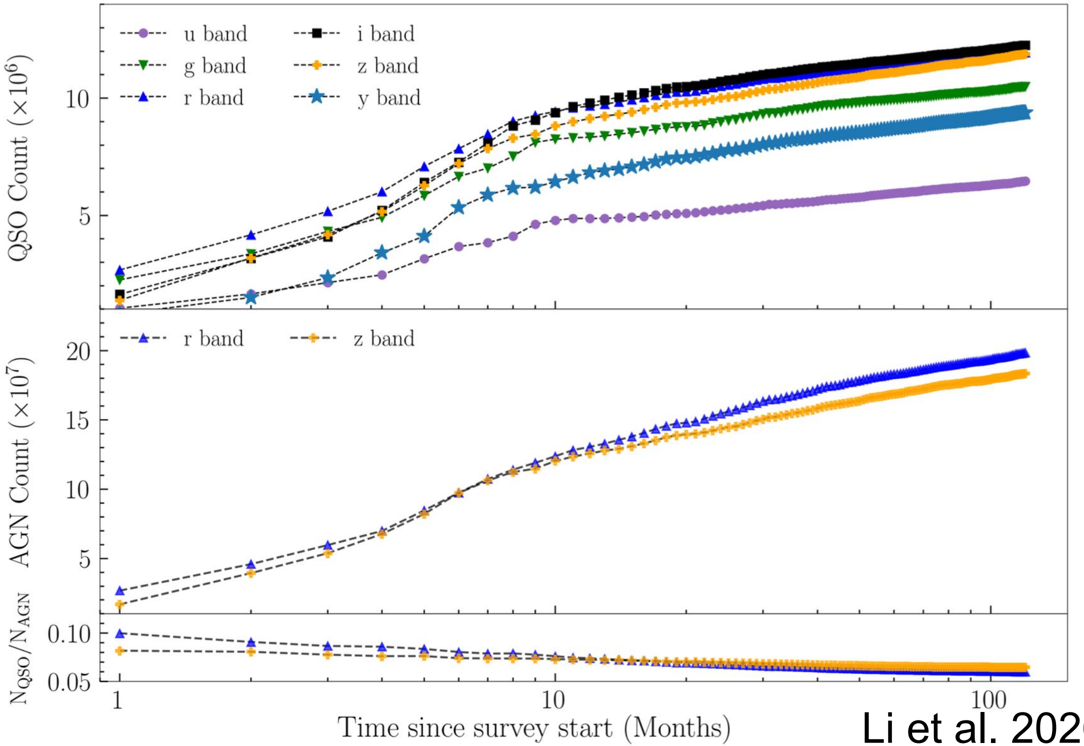
Active Galactic Nuclei in LSST: some numbers

LSST is expected to **detect** in 10 years

~180M AGN out to **z~7**

6% of which are **QSOs (~12M QSOs)**

70% of quasars are expected to be detected within the first year
(LSST will have already reached the break in the LF at most z)



Li et al. 2026

Active Galactic Nuclei in LSST: some numbers

LSST is expected to **detect** in 10 years

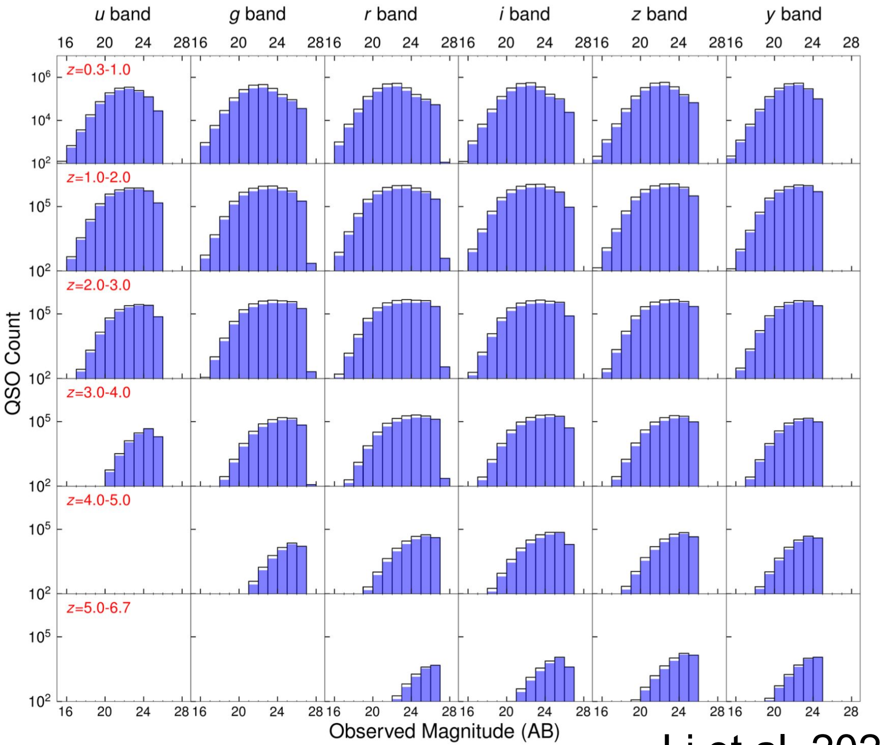
~180M AGN out to **z~7**

6% of which are **QSOs (~12M QSOs)**

8000 QSO@z>6
1000 QSO@z>7

tracer of reionizion

No Quasars at *z* > 3 (z>4) in *u* band (g band) due to IGM absorption.



Li et al. 2026

Active Galactic Nuclei in LSST

LSST is expected to **detect** in 10 years

~180M AGN out to **z~7**

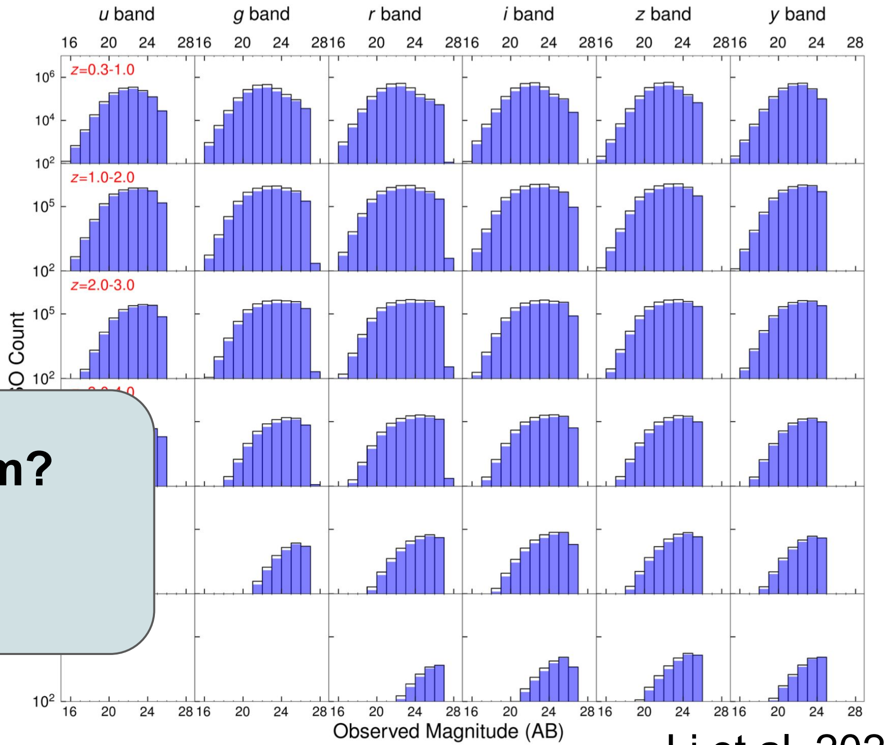
6% of which are **QSOs (~12M QSOs)**

5000 QSO@z>6
1000 QSO@z>7

No Quasars at z > 3
due to IGM absorption.

Are we able to find them?

How?



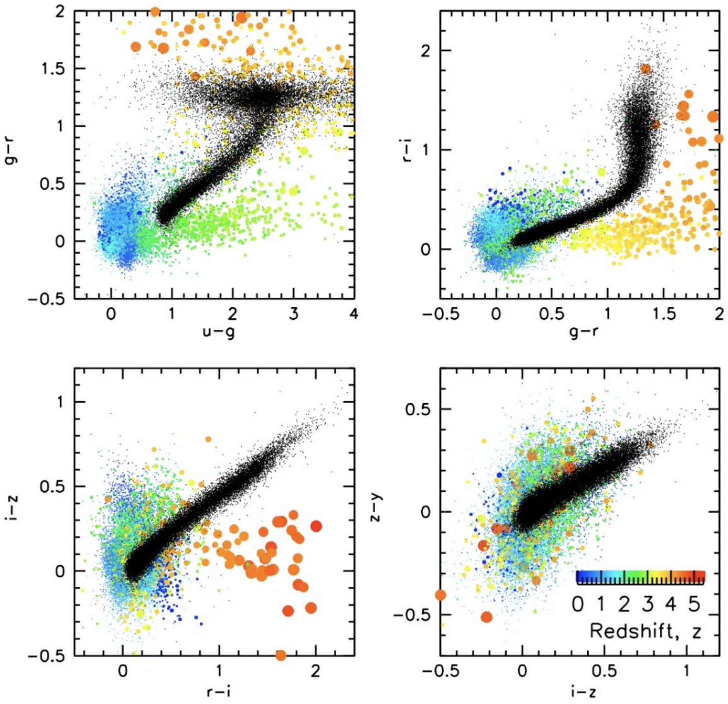
Li et al. 2026

Challenge: discover AGN

- **ugrizy multicolor selection**
  → work best when Lagn>Lhost

- **Variability**
  → helps when Lagn~Lhost

- **Lack of proper motion and differential chromatic refraction**
  → minimizes confusion with stars



(Richards et al, 2002)

Challenge: discover AGN

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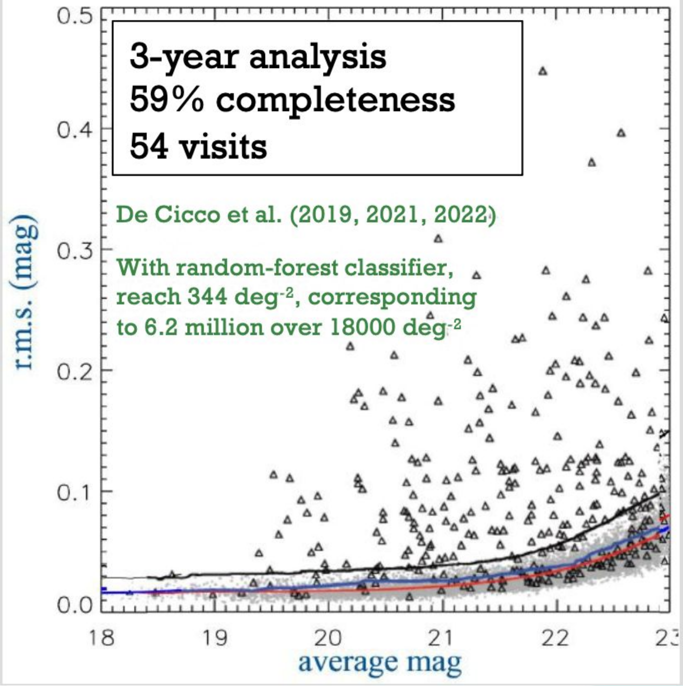


These Selections are incomplete and not pure

Challenge: discover AGN

- **ugrizy multicolor selection**

  → work best when Lagn>Lhost

- **Variability**

  → helps when Lagn~Lhost

- **Lack of proper motion and differential chromatic refraction**

  → minimizes confusion with stars

These Selections are incomplete and not pure

How do we improve?

Option I: add telescope time
Increase multi-wavelength coverage, ideally X-rays over full area and depth or optical/NIR spectroscopy

Option II: add CPU time
Use simulations to test the most efficient way to select the interesting sources and to compute the selection function (completeness and purity)

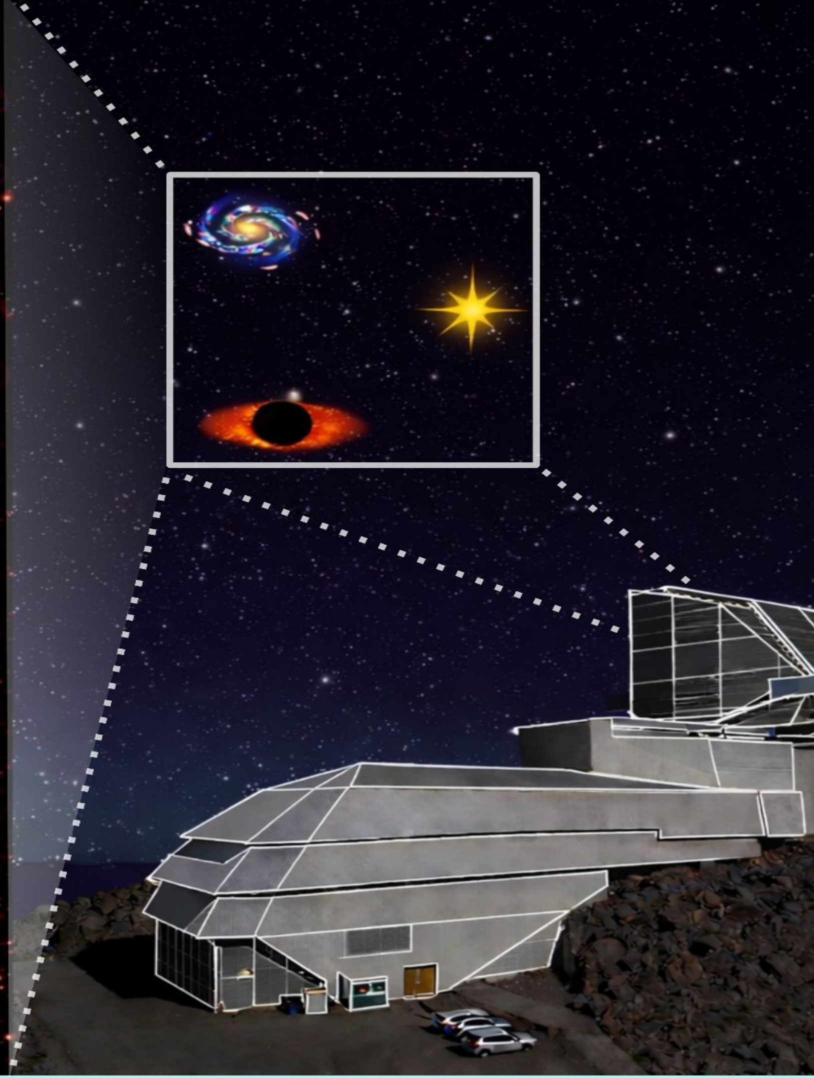
AGILE: AGN in the LSST Era

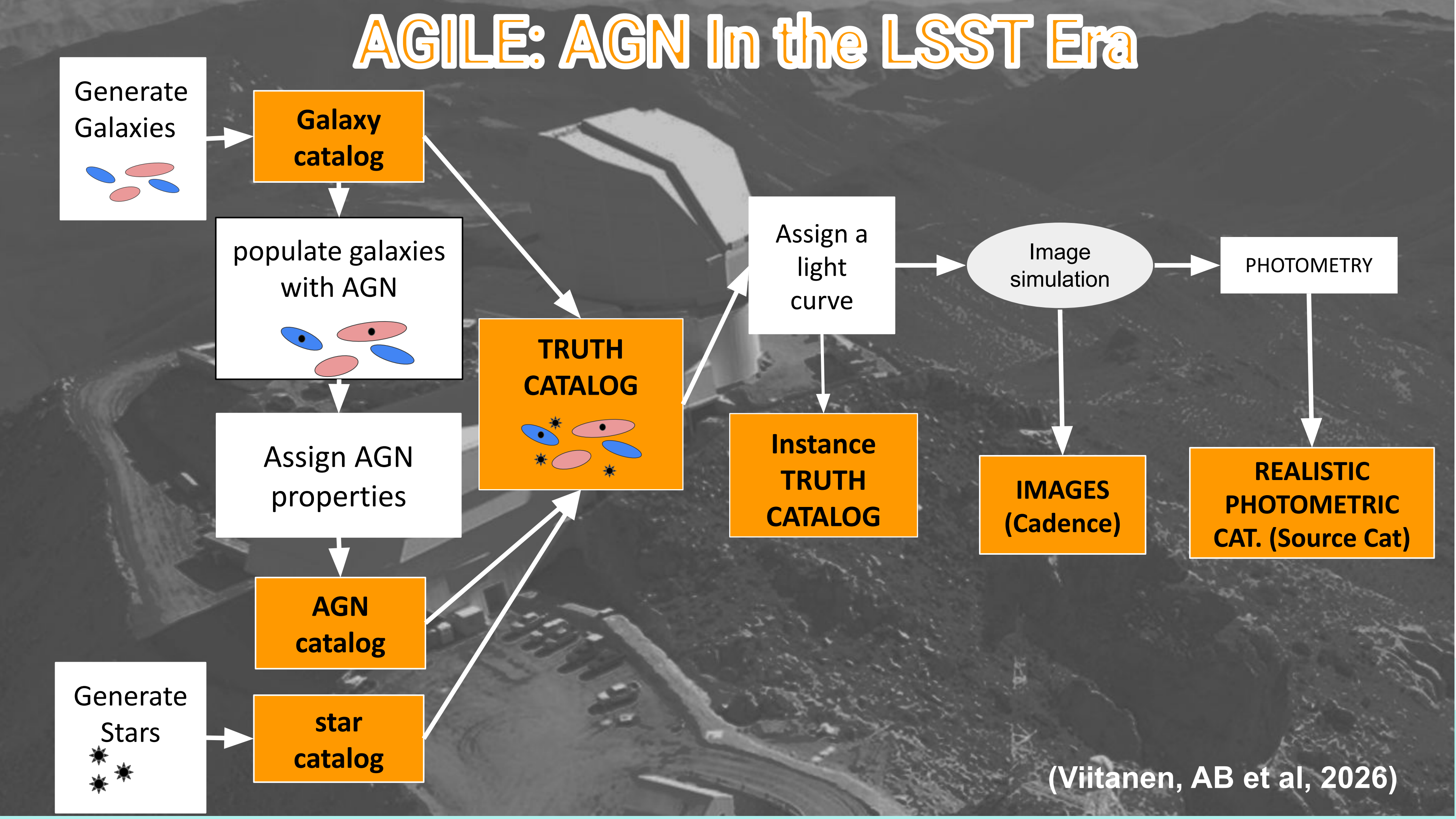
INAF in-kind contribution (PI: Bongiorno)

AGILE

End-to-end simulation Software
to create LSST data
and
anticipate how LSST will
observe galaxies, AGN and stars

(Viitanen, AB, et al., 2026, A&A 710, A56)




AGILE: AGN In the LSST Era
Generate Galaxies
Galaxy catalog
populate galaxies with AGN
Assign AGN properties
AGN catalog
Generate Stars
star catalog
TRUTH CATALOG
Assign a light curve
Instance TRUTH CATALOG
Image simulation
IMAGES (Cadence)
PHOTOMETRY
REALISTIC PHOTOMETRIC CAT. (Source Cat)
(Viitanen, AB et al, 2026)

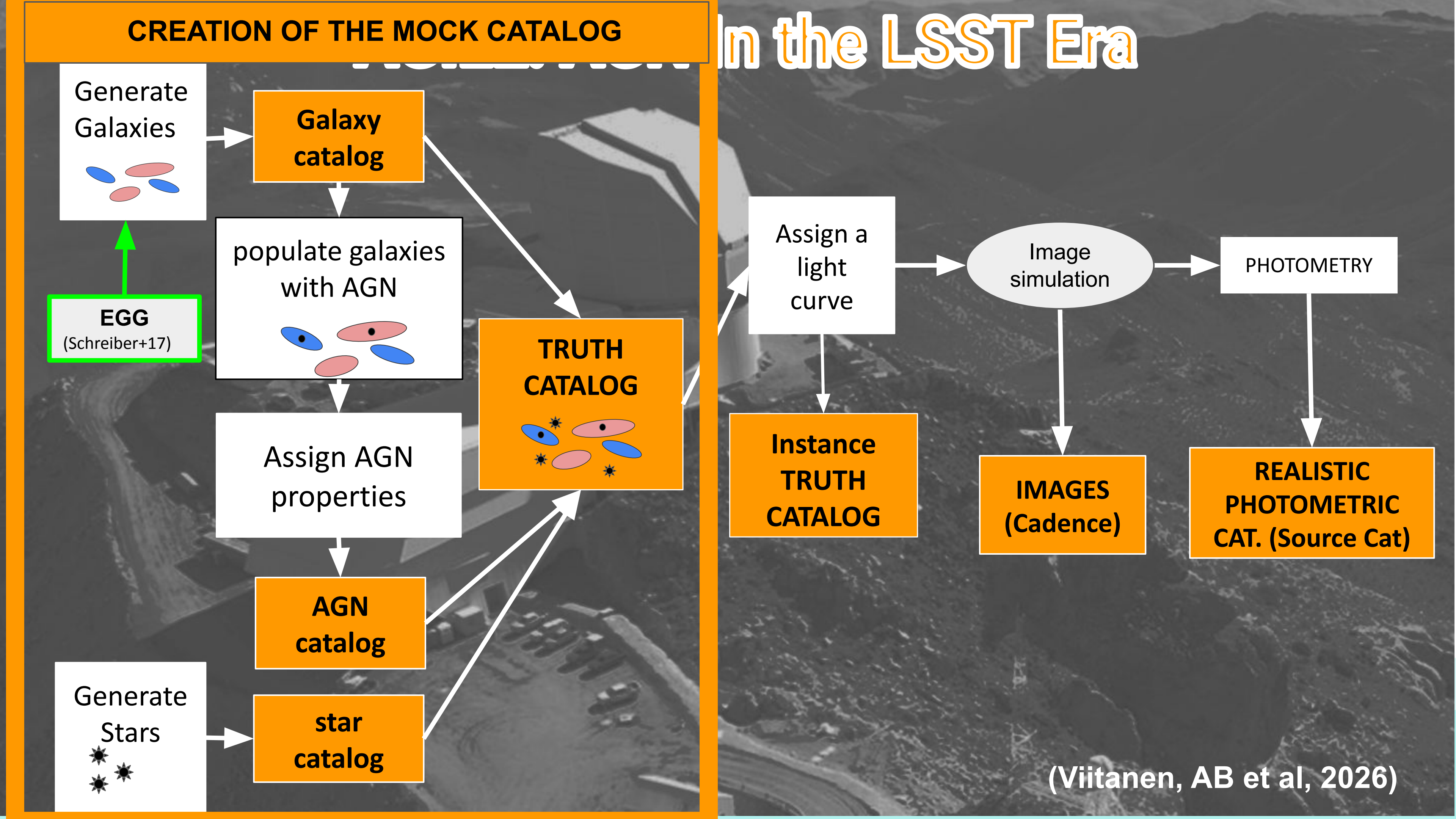

CREATION OF THE MOCK CATALOG
In the LSST Era
Generate Galaxies
Galaxy catalog
EGG
(Schreiber+17)
populate galaxies with AGN
Assign AGN properties
AGN catalog
Generate Stars
star catalog
TRUTH CATALOG
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Image simulation
PHOTOMETRY
Instance TRUTH CATALOG
IMAGES (Cadence)
REALISTIC PHOTOMETRIC CAT. (Source Cat)
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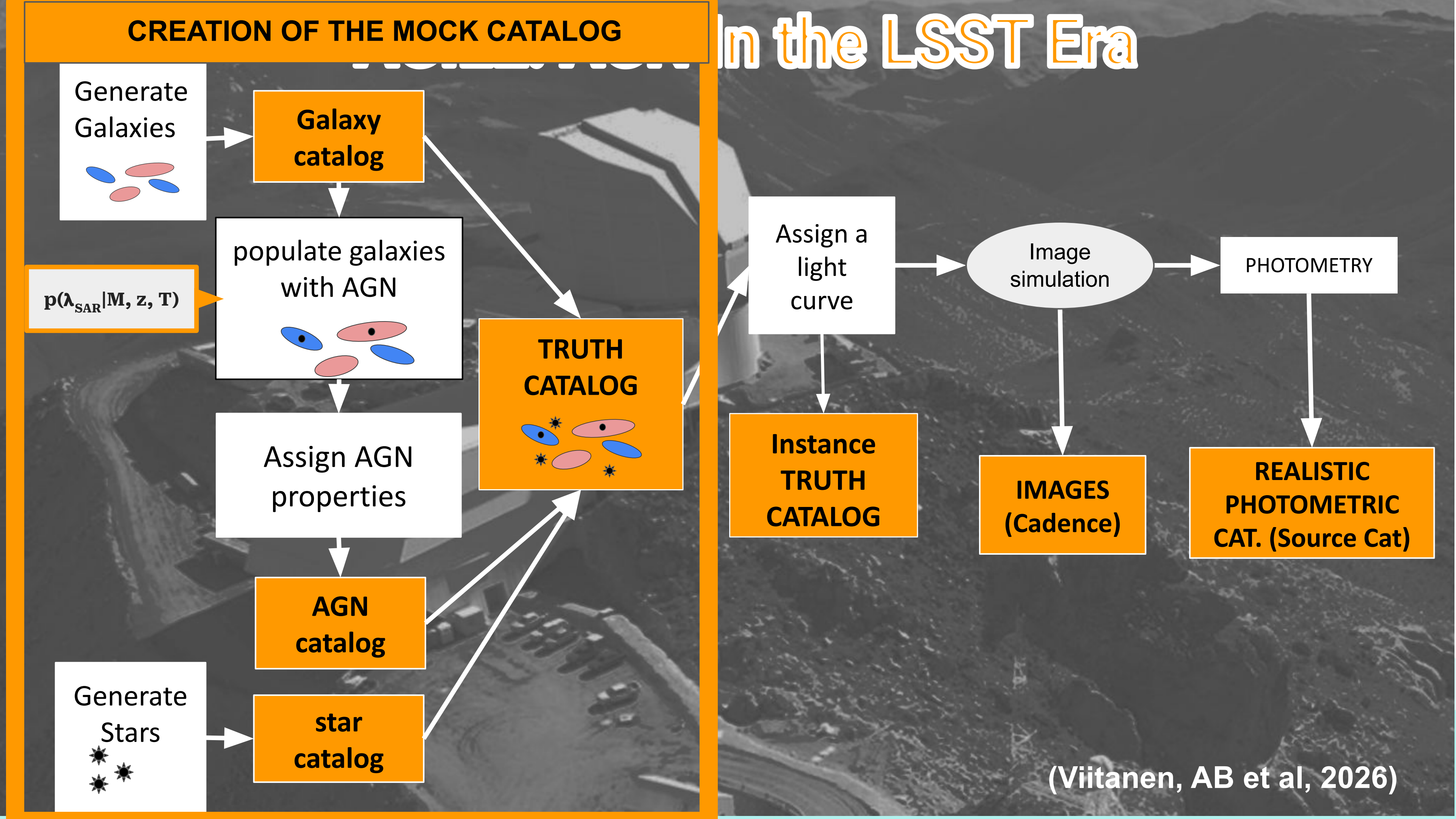
CREATION OF THE MOCK CATALOG
In the LSST Era
Generate Galaxies
Galaxy catalog
populate galaxies with AGN
$p(\lambda_{SAR}|M, z, T)$
Assign AGN properties
AGN catalog
Generate Stars
star catalog
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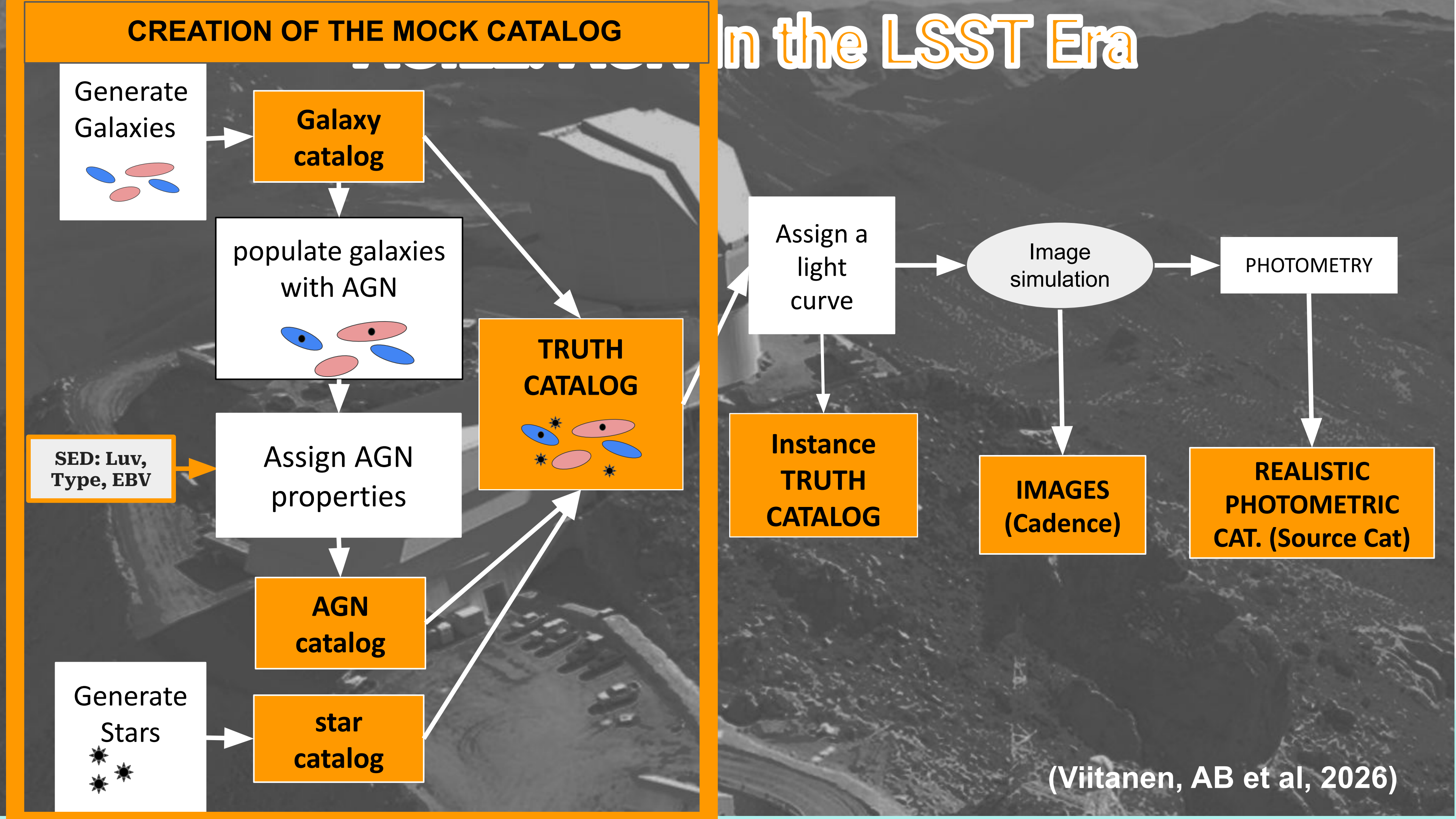
In the LSST Era
CREATION OF THE MOCK CATALOG
Generate Galaxies
Galaxy catalog
populate galaxies with AGN
SED: Luv, Type, EBV
Assign AGN properties
AGN catalog
Generate Stars
star catalog
TRUTH CATALOG
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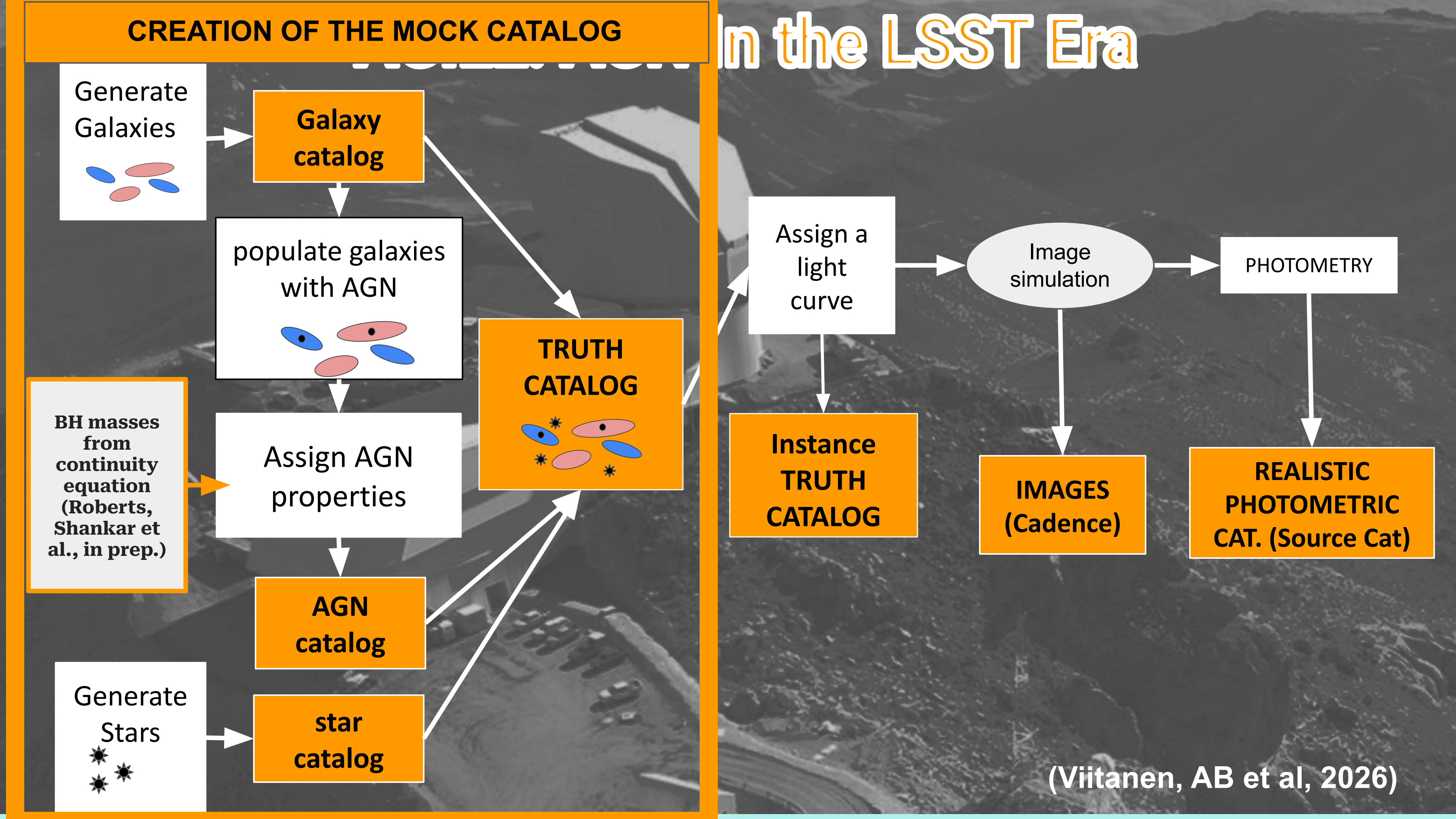
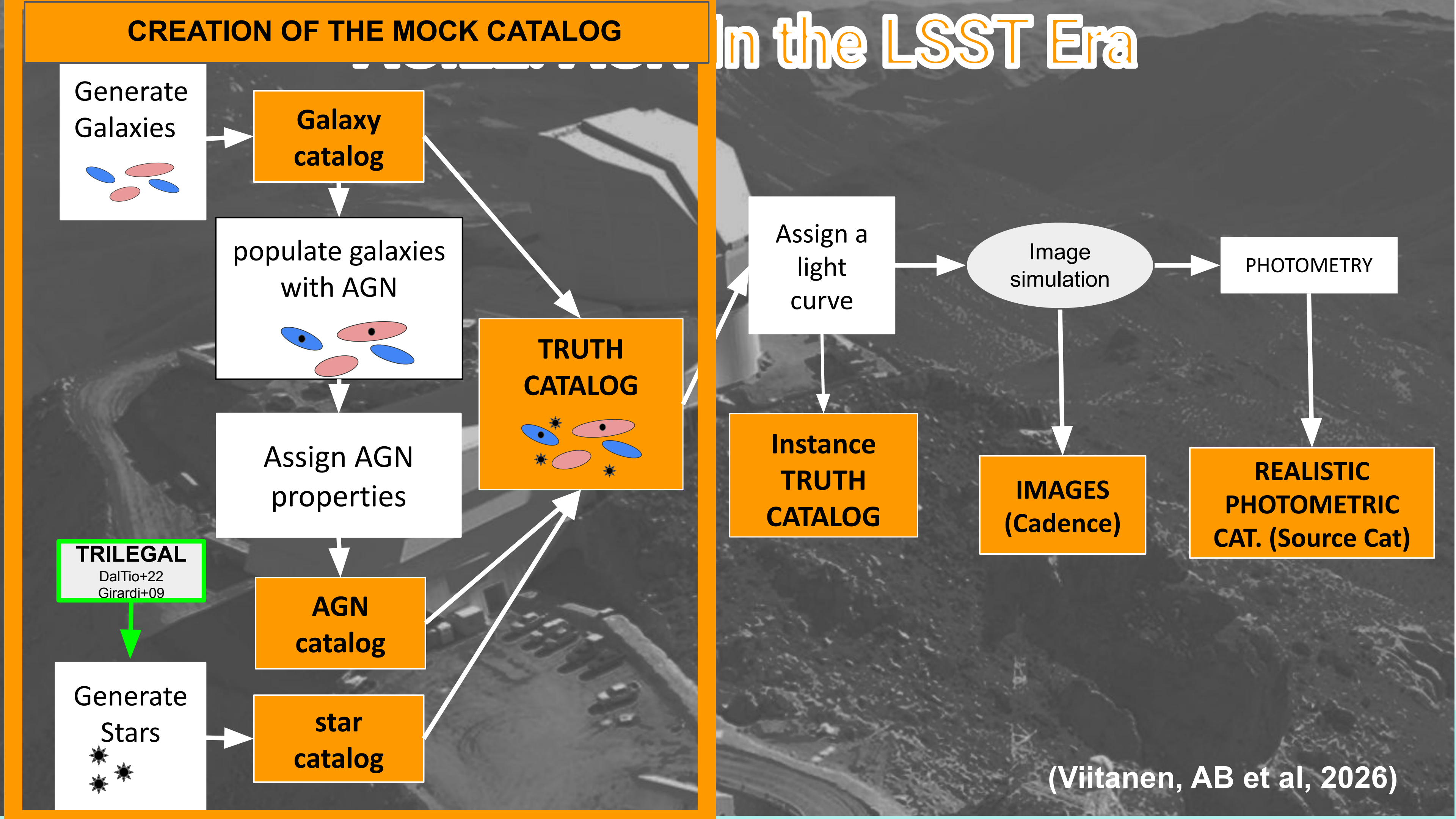
REALISTIC PHOTOMETRIC CAT. (Source Cat)
(Viitanen, AB et al, 2026)



CREATION OF THE MOCK CATALOG
the LSST Era
Generate Galaxies
Galaxy catalog
populate galaxies with AGN
BH masses from continuity equation (Roberts, Shankar et al., in prep.)
Assign AGN properties
AGN catalog
Generate Stars
star catalog
TRUTH CATALOG
Assign a light curve
Image simulation
PHOTOMETRY
Instance TRUTH CATALOG
IMAGES (Cadence)
REALISTIC PHOTOMETRIC CAT. (Source Cat)
(Viitanen, AB et al, 2026)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TRILEGAL
DalTio+22
Girardi+09
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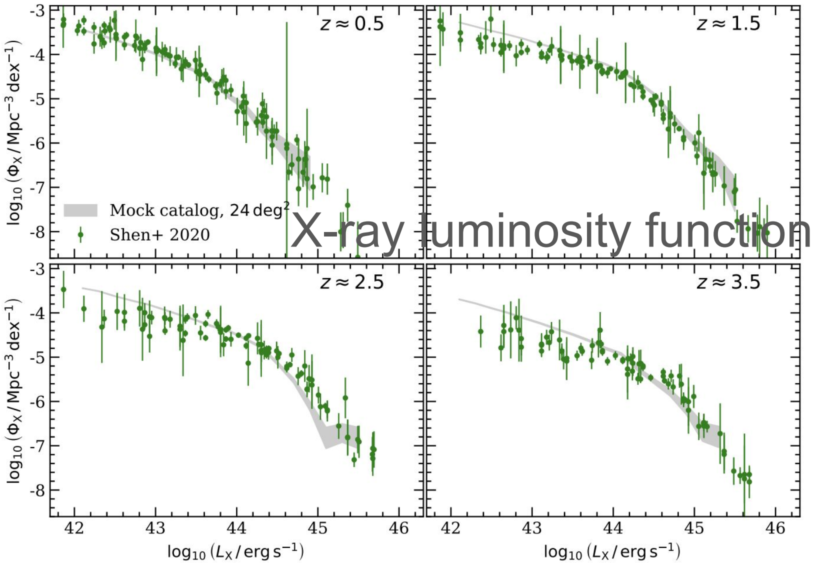
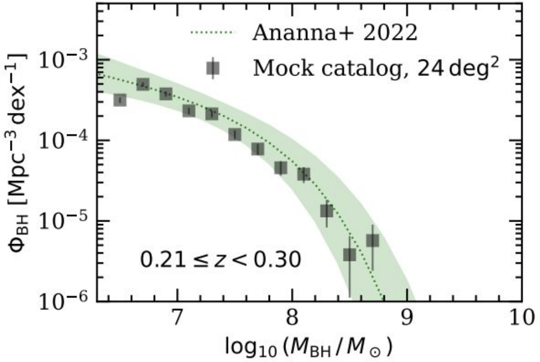
Validating the mock/truth catalog

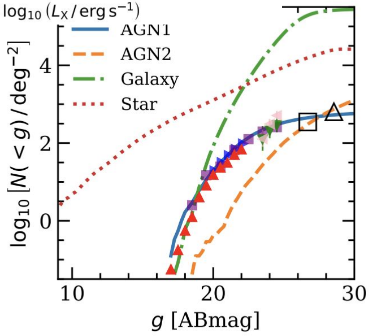


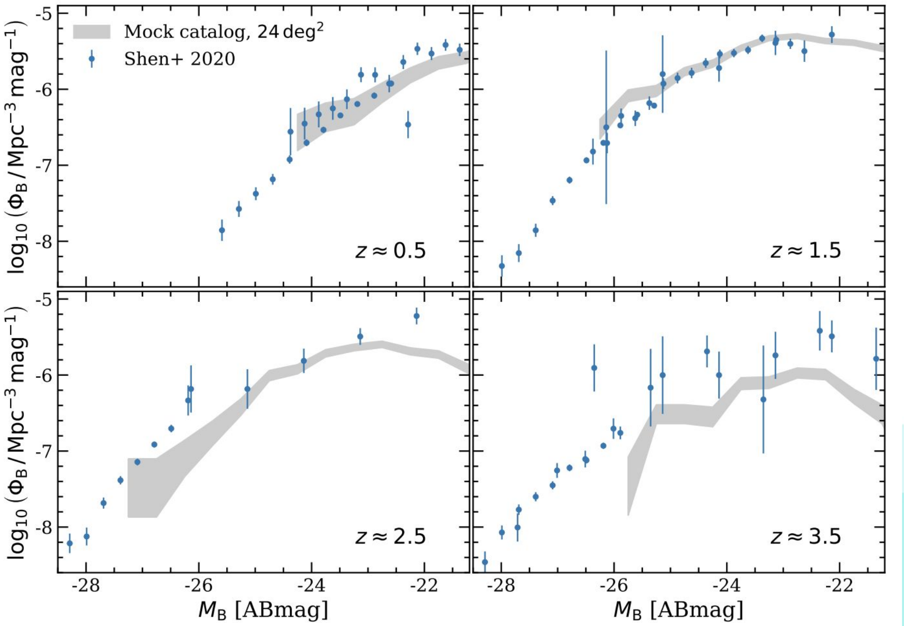
X-ray luminosity function

Local BH mass function

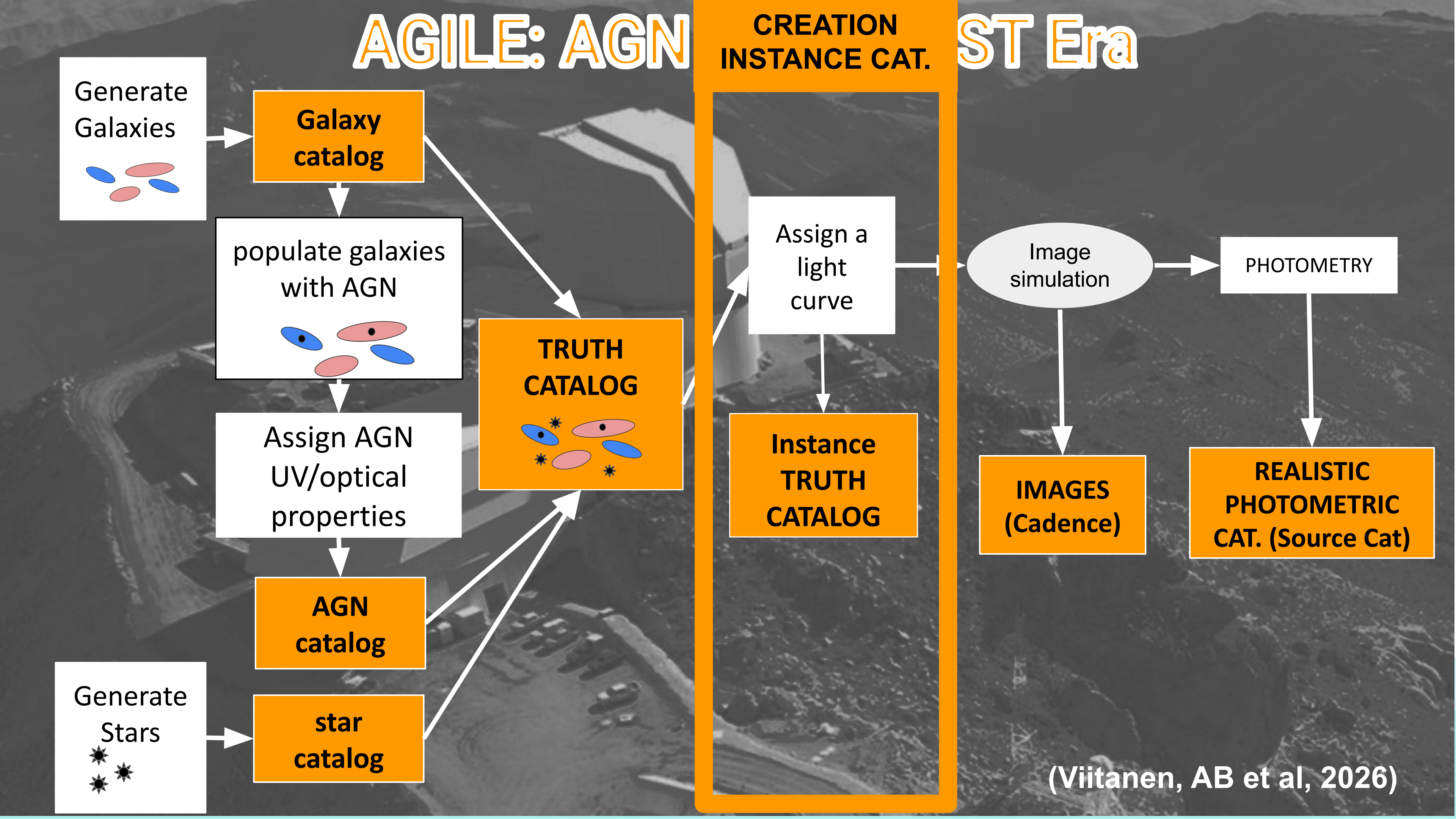


Optical Number counts and luminosity function





AGILE: AGN ST Era



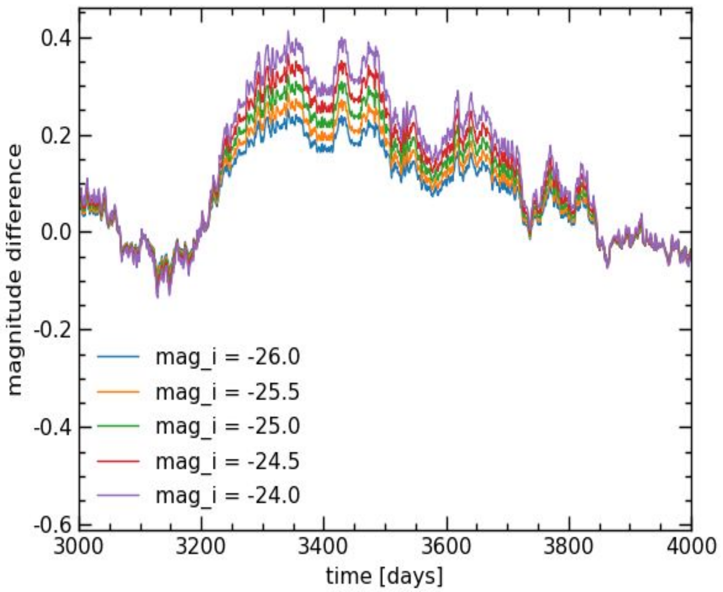
Variability recipe

AGN Model: Damped Random Walk (DRW; Kelly+09) with code from Kovacevic+21

Input: damping timescale τ and variability amplitude σ

Scaling relations: *f* is either τ or σ (Suberlak+21)

$$\log_{10} f = A + B\log_{10}(\lambda_{RF}/4000\mathring{A}) + C(M_i + 23) + D\log_{10}(M_{BH}/10^9 M_\odot)$$



(Suberlak+ 21, de Cicco+ 22)

Variability recipe

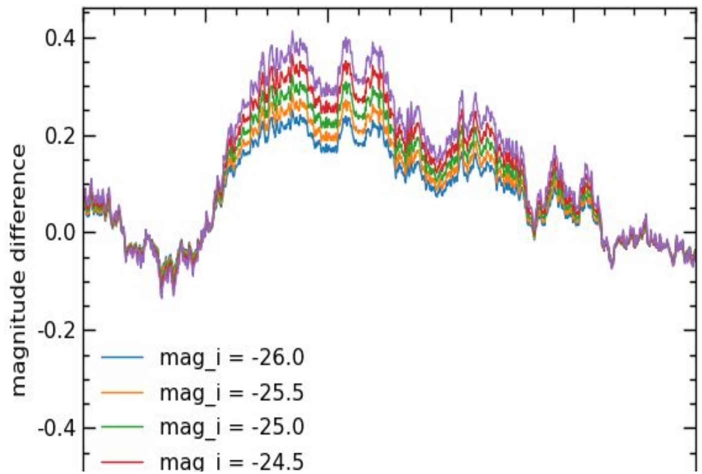
AGN Model: Damped Random Walk (DRW; Kelly+09) with code from Kovacevic+21

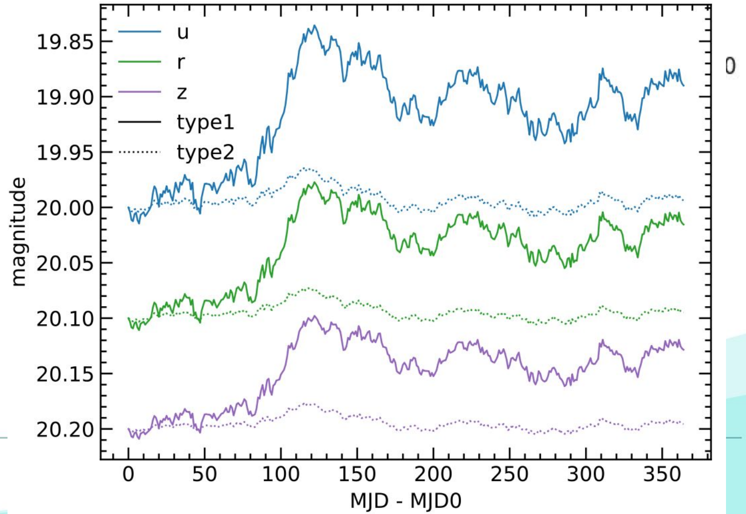
Input: damping timescale **τ** and variability amplitude **σ**

Scaling relations: *f* is either **τ** or **σ** (Suberlak+21)

$$\log_{10} f = A + B\log_{10}(\lambda_{RF}/4000\text{Å}) + C(M_i + 23) + D\log_{10}(M_{BH}/10^9 M_\odot)$$

type2:
general shape is the same, amplitude significantly lower (Suberlak+ 20, **de Cicco+ 22**)





Variability recipe

AGN Model: Damped Random Walk (DRW; Kelly+09) with code from Kovacevic+21

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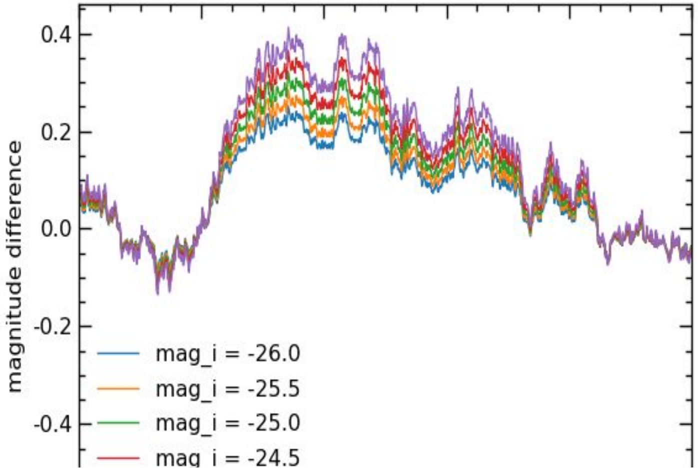
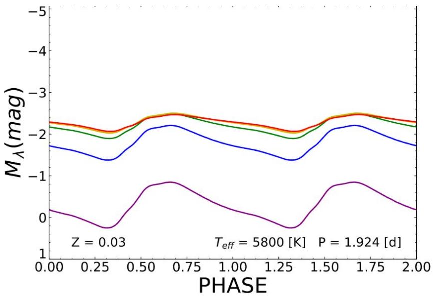
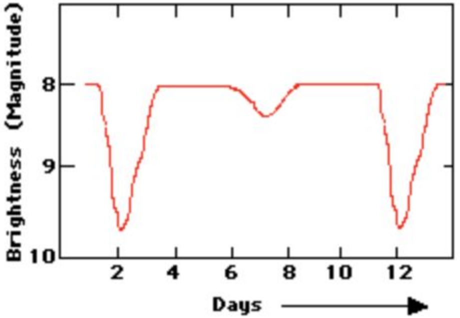


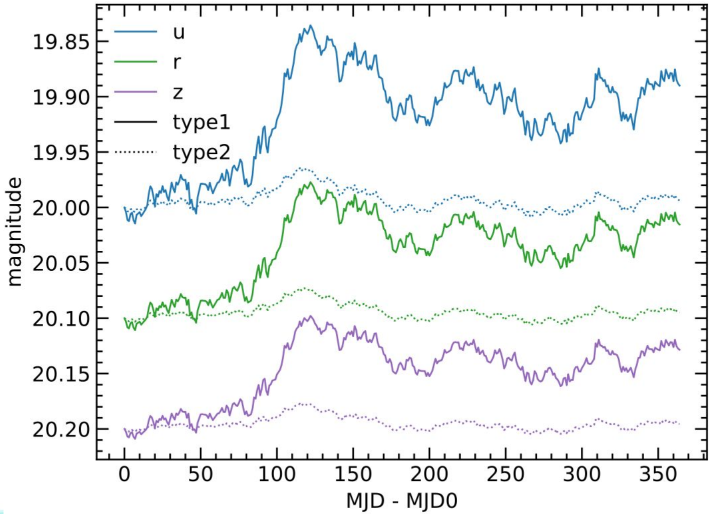
Stars:



Cepheid/Long Period Variable



Eclipsing binaries



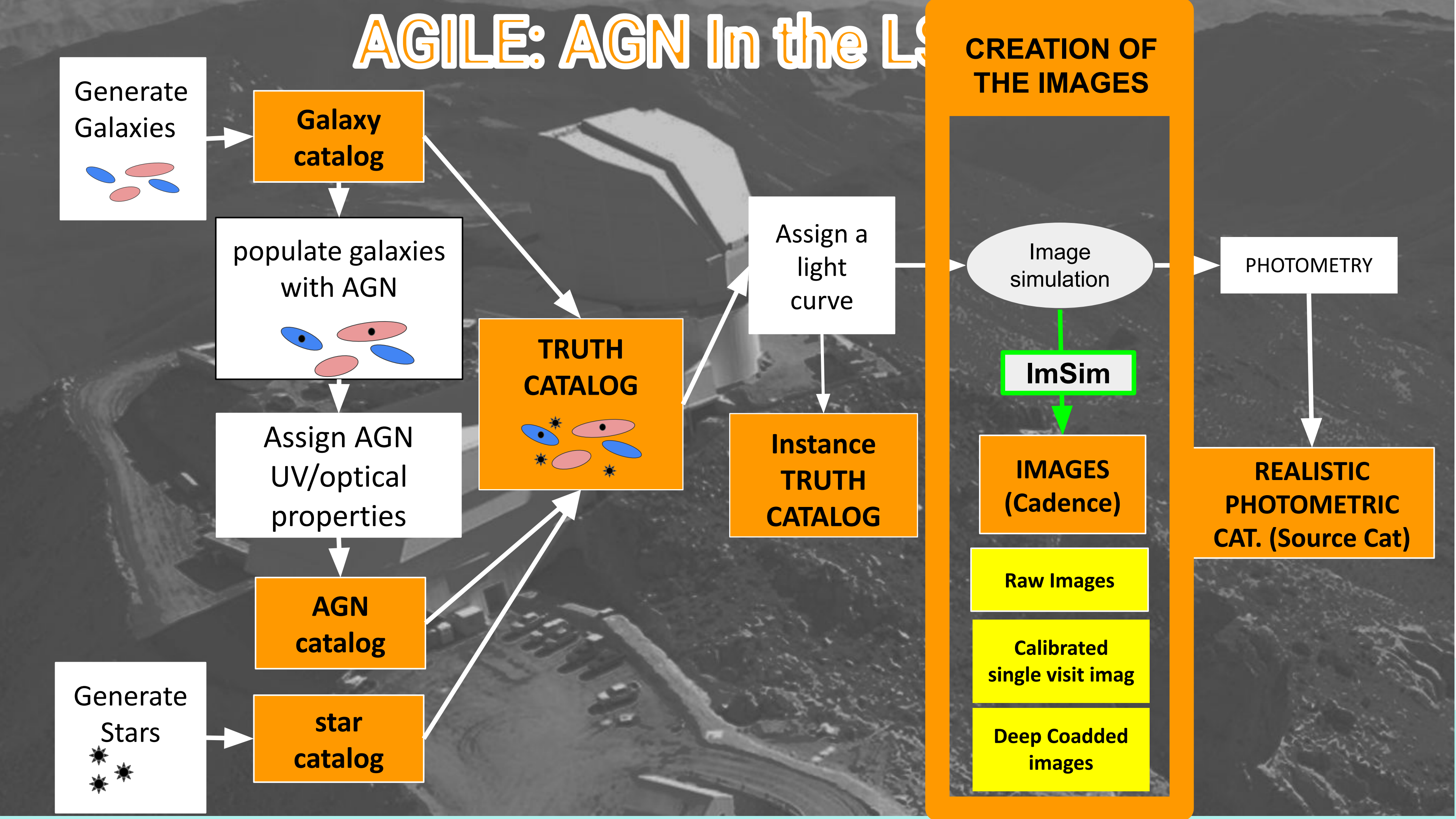

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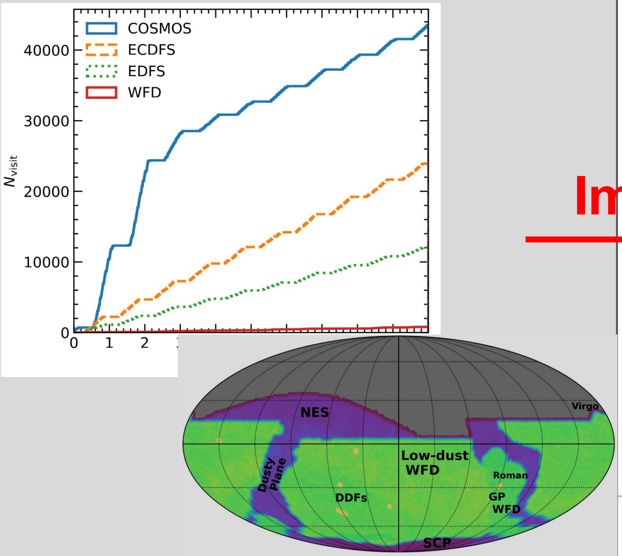
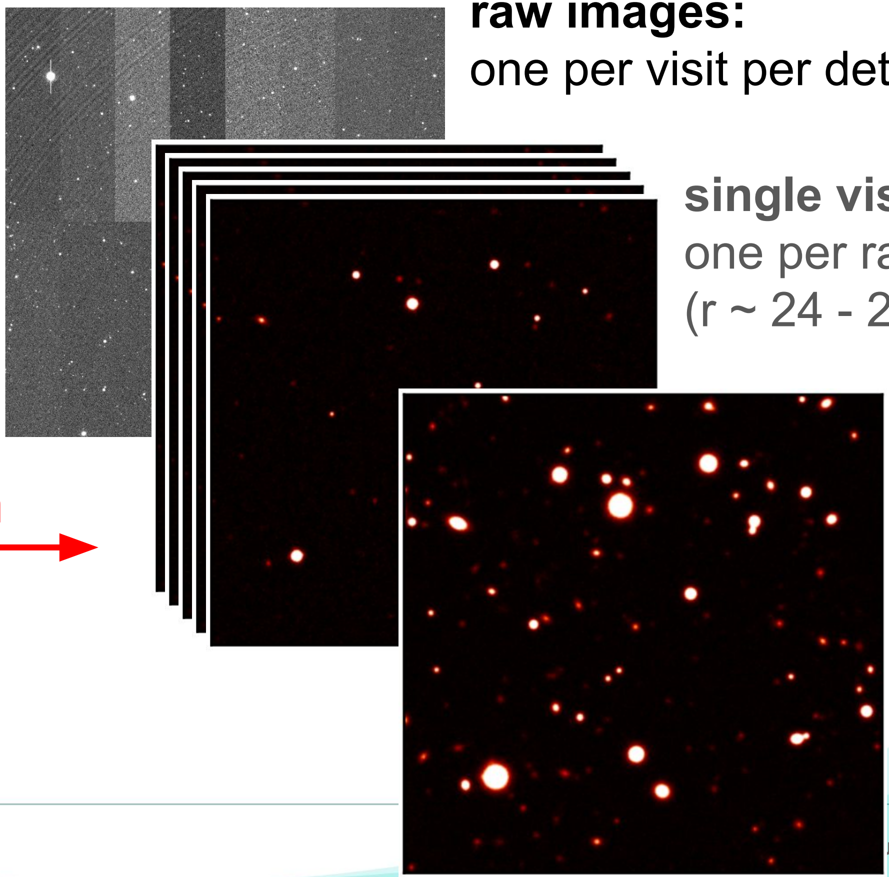
Image simulation
ImSim
IMAGES (Cadence)
Raw Images
Calibrated single visit imag
Deep Coadded images
PHOTOMETRY
REALISTIC PHOTOMETRIC CAT. (Source Cat)

AGILE images

INSTANCE TRUTH CATALOG
+
SURVEY STRATEGY



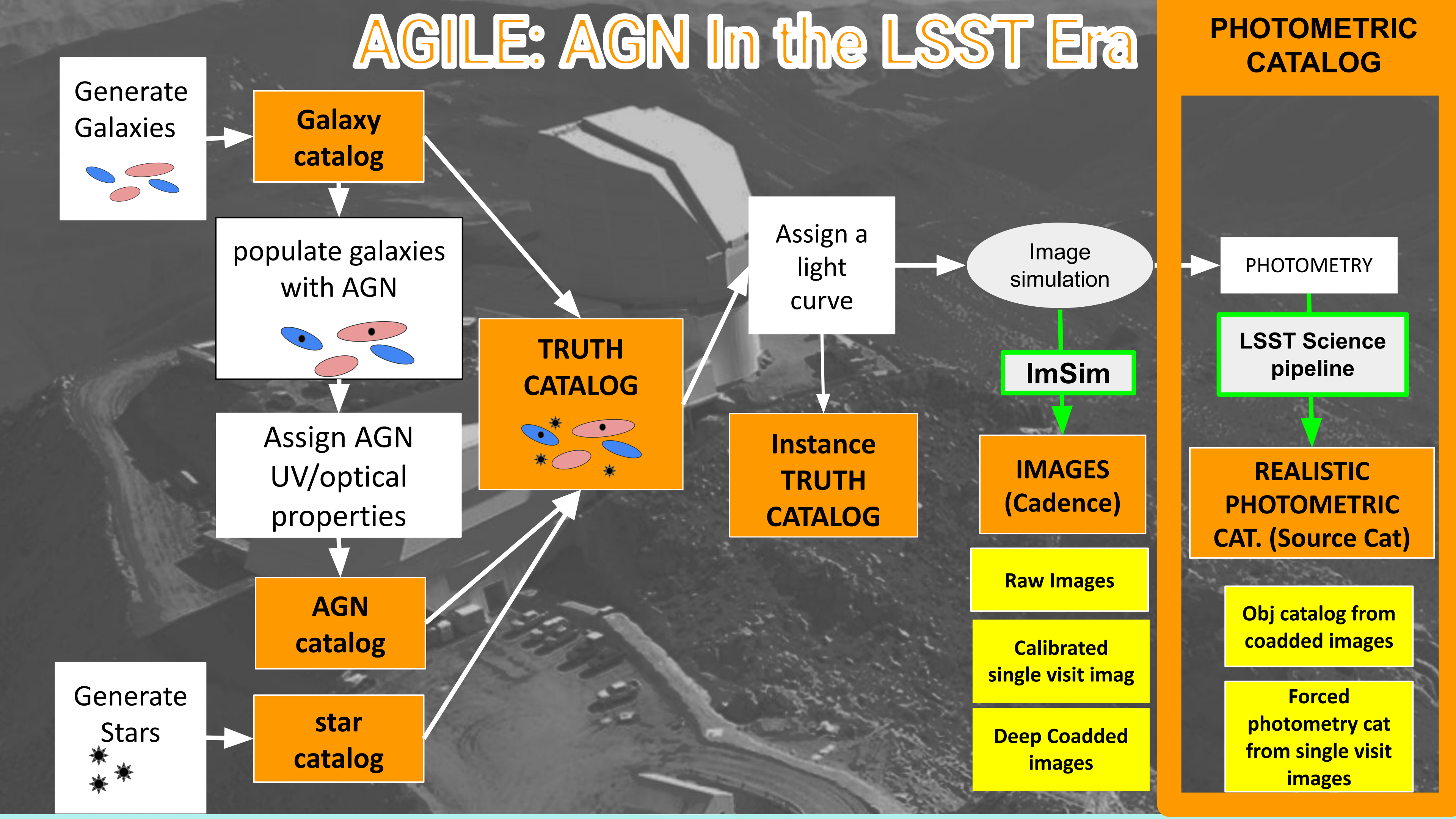
ImSim



raw images:
one per visit per detector

single visits:
one per raw images
(r ~ 24 - 24.5)

coadded images:
one per *patch* (~ detector)
(r ~ 26)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PHOTOMETRY
LSST Science pipeline
REALISTIC PHOTOMETRIC CAT. (Source Cat)
Obj catalog from coadded images
Forced photometry cat from single visit images

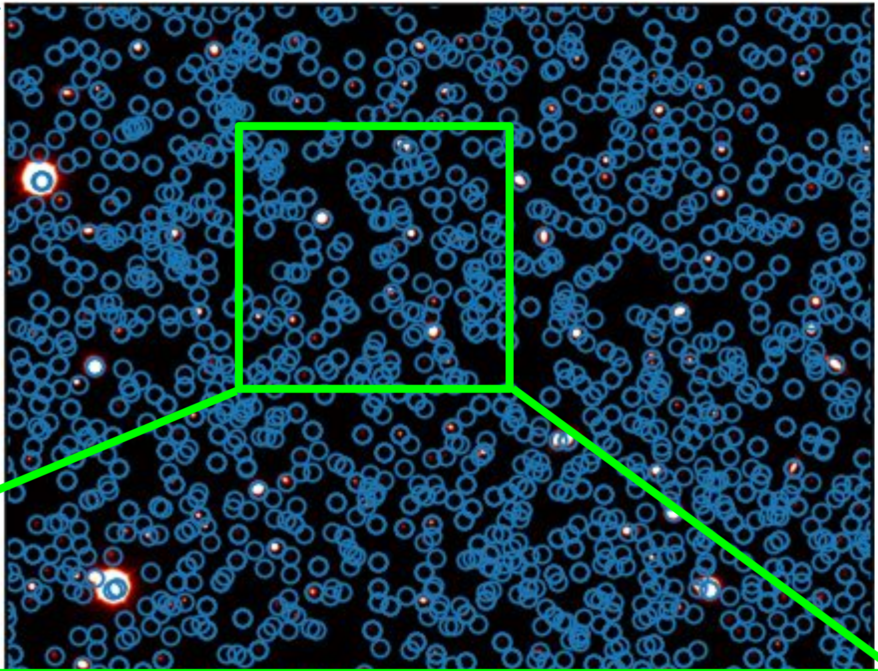
AGILE Photometric catalog

photometric catalogs

Object catalogs from coadded images

Forced photometry catalogs from single-visit images

LSST official Science pipeline



coord_ra	coord_dec	g_psfFlux	i_psfFlux	r_psfFlux	u_psfFlux	y_psfFlux	z_psfFlux
150.35769	2.11536	1116.61678	2343.69851	1552.84465	913.51278	2665.95582	2377.11034
150.33324	2.11601	267.50682	584.88535	475.10733	30.80897	710.36956	666.9564
150.29835	2.11603	1154.81855	16132.4848	4207.43841	61.90247	40263.57372	29976.01269
150.29638	2.11586	109.75589	178.71824	139.02539	123.8991	580.42405	250.30176
150.28728	2.11523	142.79915	255.48712	164.64102	92.48297	686.64076	318.44489
150.28467	2.11568	17493.68004	20477.58885	19657.52973	14644.40447	25253.53635	24549.83432
150.27621	2.11658	301.09698	2306.51761	796.61598	222.91218	4796.62832	3776.72296

AGILE Data Release 1 (DR1)

- 24 deg2 truth catalog of AGN, galaxies and stars

- 1deg2 simulated images according to baseline v4.0 for the first **3yrs in COSMOS – 1,441 visits**

LSST Science Pipelines products:

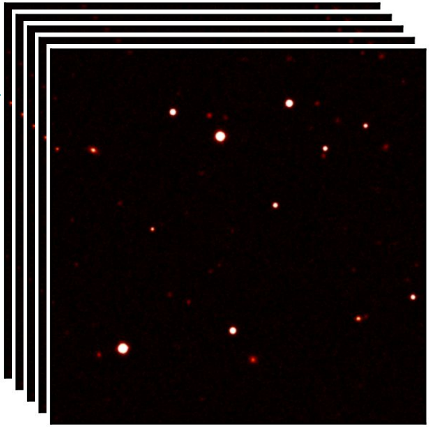
- Calibrated single-visit images (30K)
- Single-visit source catalogs (30K)
- Deep coadded images
- Coadded object catalogs
- Forced photometry catalogs

See: <u>www.oa-roma.inaf.it/lsst-agn/</u>

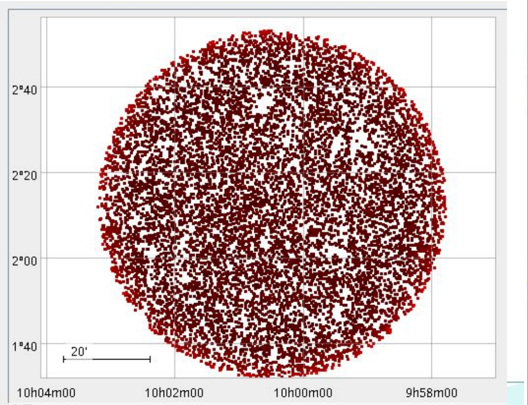
Truth catalog

ID	Name	Description
0	ID	unique ID
1	RA	Right ascenscion
2	DEC	Declination
3	Z	Cosmological redshift
4	D	Luminosity distance OR distance modulus for stars
5	M	log10 of stellar mass
6	SFR	Star-formation rate
7	PASSIVE	Is passive (non-star-forming)
8	CLUSTERED	Is clustered
9	DISK_ANGLE	Galaxy disk rotation angle
10	DISK_RADIUS	Galaxy disk half-light radius
11	DISK_RATIO	Galaxy disk ratio of minor to major axis
12	BULGE_ANGLE	Galaxy bulge rotation angle
13	BULGE_RADIUS	Galaxy bulge half-light radius
14	BULGE_RATIO	Galaxy bulge ratio of minor to major axis
15	AVLINES_BULGE	Emission line extinction in the bulge
16	AVLINES_DISK	Emission line extinction in the disk
17 – 40	band_disk	Galaxy disk band flux
41 – 64	band_bulge	Galaxy bulge band flux
65 – 88	magabs_band	Galaxy band absolute magnitude
89	log_lambda_SAR	log10 of specific accretion rate
90	is_agn_ctn	is Compton-thin AGN
91	is_agn_ctk	is Compton-thick AGN
92	is_agn	is Compton-thin or Compton-thick AGN

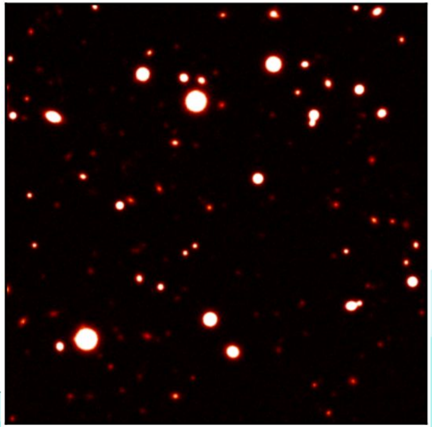
Single-visit images



Photometric catalogs



Coadded images



We are entering the LSST Era

Very exciting science is ahead of us

Join the collaboration or come talk to us if you are interested

Thank you

angela.bongiorno@inaf.it