Formazione ed evoluzione delle galassie e strutture cosmiche

Micol Bolzonella
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Galaxy and LSS evolution studies span:

97% of the life of the Universe (from reionization start to now)
10 order of magnitude in mass (from BHs seeds to clusters of galaxies)
8 order of magnitude in temperature (from star forming regions to ICM)
6 order of magnitude in size (from GCP to superclusters)


Planck 2018
Dark Matter
26.6%
Dark Energy
68.5%
Baryons
4.9%
Free H & He
82%
Neutrinos
7%
Heavy elements
1%
Stars
11%
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS


GC
DM
BH
Halo
Ell galaxy
Sp galaxy
SFRD & BH growth
z=9


GC
DM
BH
Halo
Ell galaxy
Sp galaxy
SFRD & BH growth
z=6


GC
DM
BH
Halo
Ell galaxy
Sp galaxy
SFRD & BH growth
z=2


GC
DM
BH
Halo
Ell galaxy
Sp galaxy
SFRD & BH growth
z=1


GC
DM
BH
Halo
Ell galaxy
Sp galaxy
SFRD & BH growth
z=0

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INAF Strategic Vision – Chapter 8

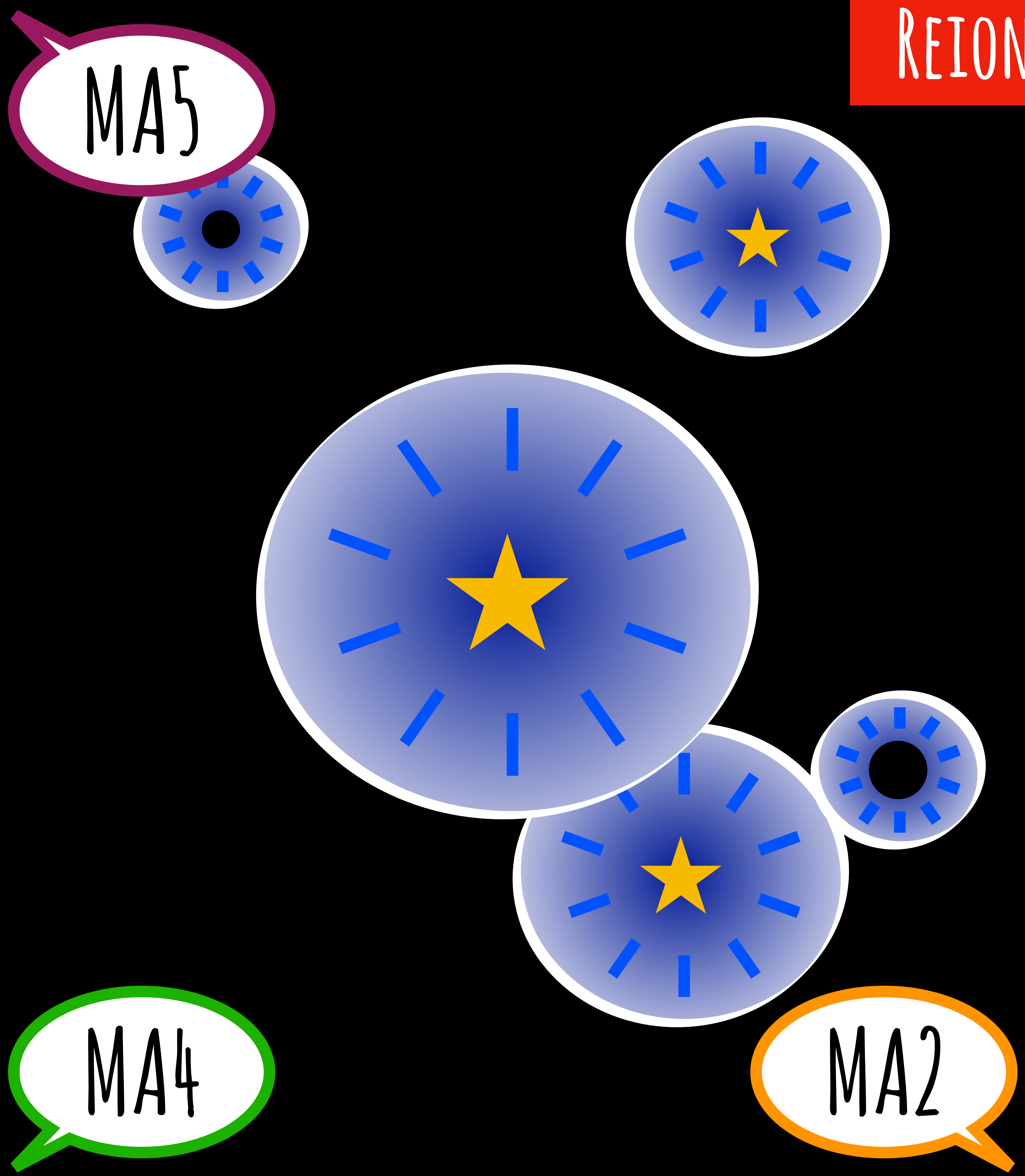
Formation and Evolution of Galaxies and Cosmic Structures

Keywords: Galaxies and AGN, Clusters of Galaxies, IGM and reionization

Key Question: What are the physical processes driving the assembly and the evolution of structures on scales of galaxies up to clusters of galaxies?

1. Properties of first galaxies and black holes. Sources responsible for the **reionization**(s)
2. **Origin and fate of galaxies**, the galaxy stellar mass function and morphological differentiation.
3. **Feedback processes** among the different components of galaxies (stars, gas, dust) and AGN. Role of DM halos.
4. External and internal mechanisms (**environment and relationship with the Cosmic Web**) regulating the efficiency of star formation and the structural parameters of galaxies.
5. Census and **distribution of mass/energy in large-scale structures** (hot baryons, AGN-ICM connection, turbulence, non-thermal phenomena and their relationship with the thermal phenomena mapped in X-ray and with the Sunyaev-Zeldovich effect).

REIONIZATION



When and how did reionization occur?

SKA, LOFAR: 21cm tomography, interaction between the CMB and the diffuse neutral hydrogen

JWST, ELT, SPICA: Lyα emitters at z≥6.

ELT, VLT, SPICA: quasars at z≥6 to put constraints on the amount of neutral hydrogen and, at the same time, detect the imprint of the chemical elements formed by the first objects .

Which sources caused reionization?

JWST, Euclid, WFIRST, ELT, VLT, ALMA, SPICA: NIR and MIR imaging + spectroscopy probe the nature of stellar populations and/or nuclear activity, and the gas and dust content of the first objects; the ionizing radiation and feedback processes, eventually connected to the metal pollution of the intergalactic space; Globular Clusters Precursors to probe the first episodes of star-formation.

How, when and where did the first SMBHs form?

Chandra, XMM, ATHENA, SPICA: deep X-ray observations probe the origin of the BH seeds at z>7, their accretion efficiency and environmental conditions to become SMBH, the nature of the faint AGNs that are still unobserved.

SKA / JWST / ELT / ALMA / ATHENA / EUCLID / WFIRST

Reionization

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Numerical simulations and astroinformatics

Need simulations/models to interpret future data!

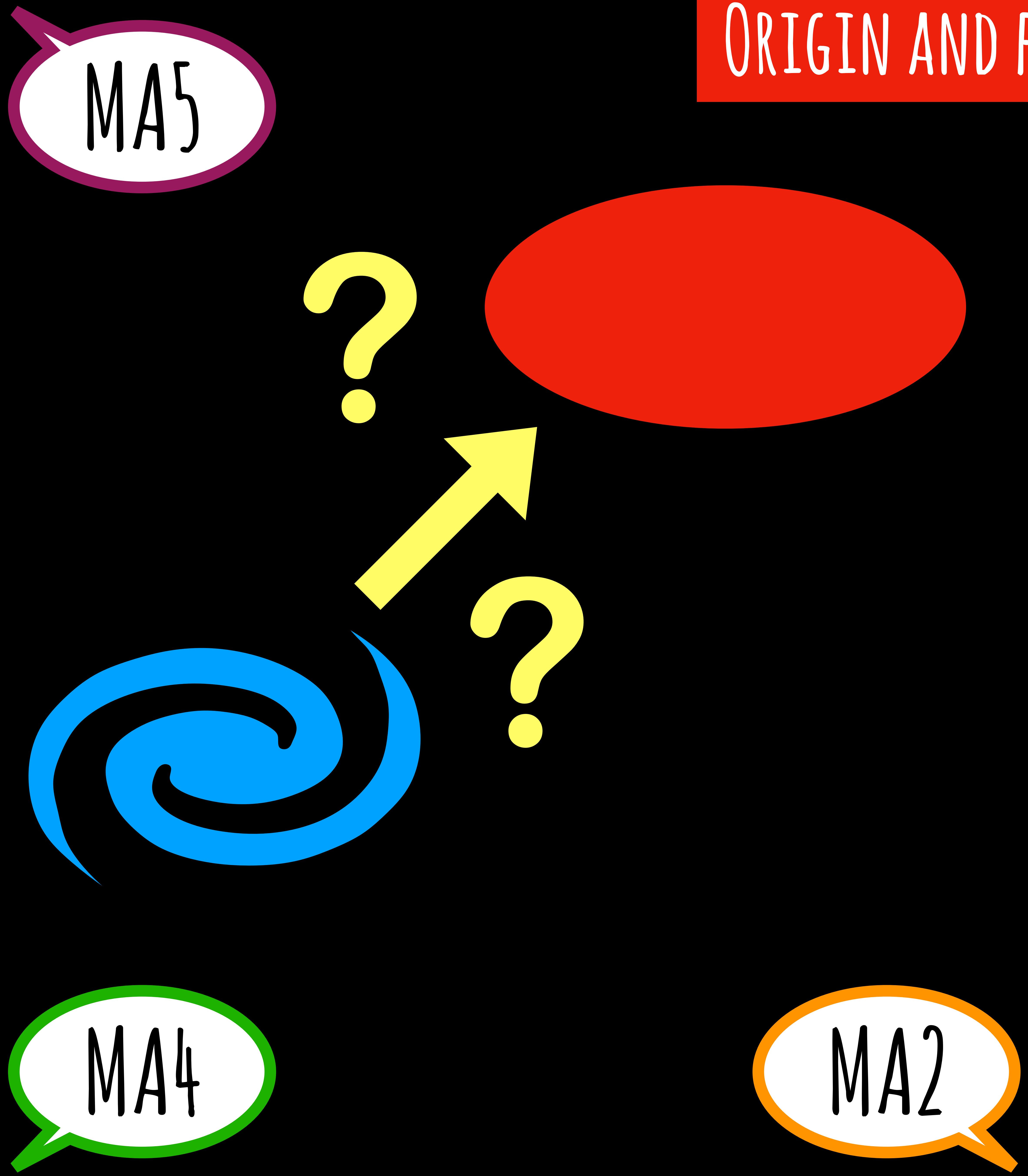
Inclusion of physical processes presently modeled as subgrid or in post processing

- radiative transfer
- star formation
- feedback

What is the pathway of SMBH from primordial BHs seeds?

Is the reionization process uniform or patchy?

Origin and fate of galaxies



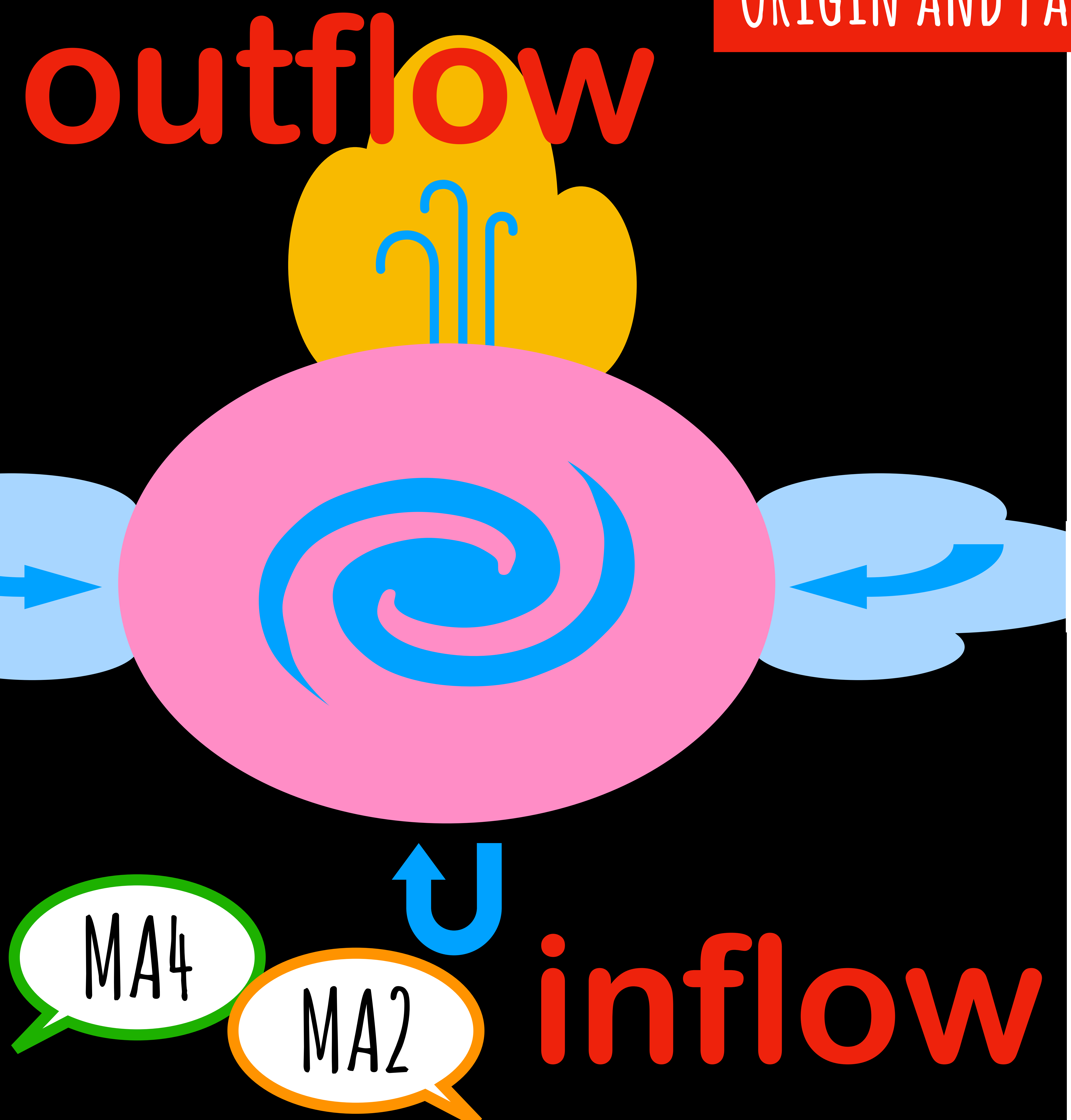
Which physical processes drive the transformation of galaxy properties?

Complex physical processes and evolution of interconnected properties: color, stellar population, stellar mass, SFR, SFH, structural parameters, dynamics, dust and gas content, metallicity, inflow, outflow, AGN/SF feedback, halo mass, environment…

Quenching mechanisms:

- Gas does not accrete
- Gas does not cool
- Cold gas does not form stars
- Cold gas is rapidly consumed
- Gas is removed (outflows)

ORIGIN AND FATE OF GALAXIES



Which physical processes drive the transformation of galaxy properties?

ALMA, NOEMA, JVLA, JWST, ELT, MUSE@VLT, WEAVE@WHT, COS@HST, VLA, SKA&precursors, SPICA: spatially resolved (optical/IR/radio) spectroscopy probe gas kinematics, gas inflows and outflows in star-forming galaxies, connection with the CGM and IGM; baryon cycle and re-cycle, chemical enrichment; calibration of molecular species (e.g. CO and H2) as a function of redshift; HI content of galaxies with 21cm line; next-generation radio surveys will provide a complete census of star formation and AGN processes up to high redshift and irrespective of obscuration.

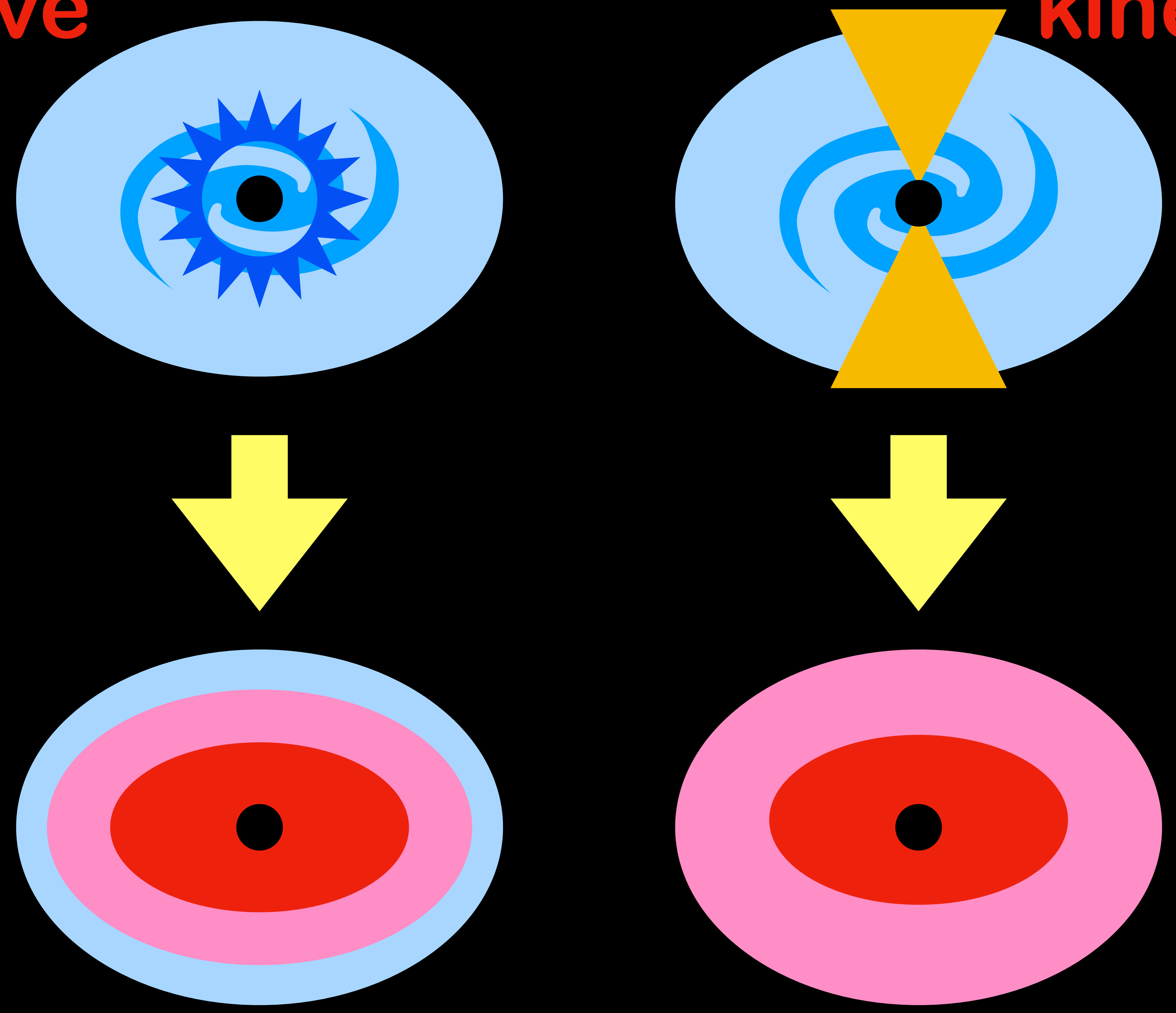
ALMA / JWST / ELT / VLT / WHT / HST / SKA / SPICA

ORIGIN AND FATE OF GALAXIES

AGN feedback

radiative

kinetic



MA4

Which physical processes drive the transformation of galaxy properties?

Radiative/quasar: central BH accretes near Eddington limit, efficiently triggered by major mergers with high gas inflow rates, outflow winds driven by AGN radiation, gas is expelled, stellar mass growth prevented, quick process, act on small scales..

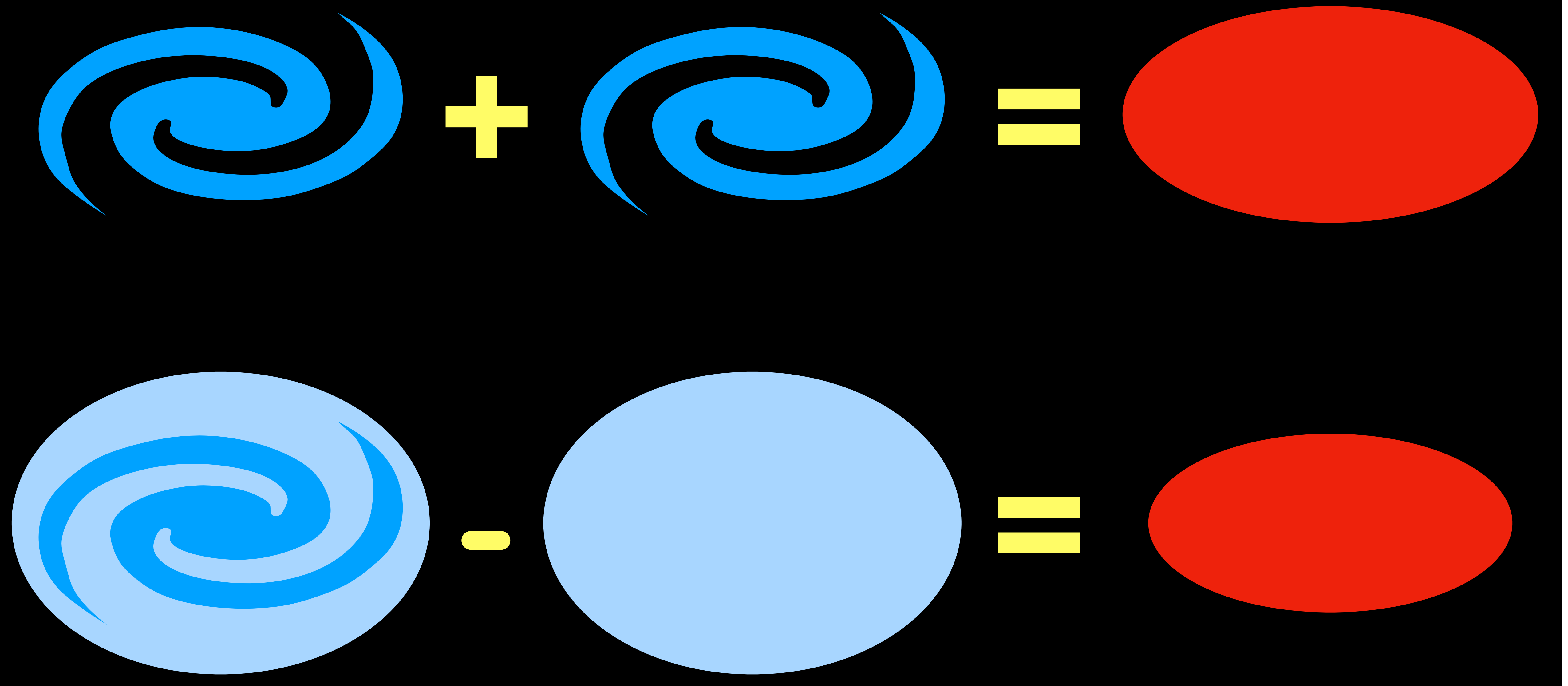
Connected with Star Formation Rate Density

Kinetic/radio: inefficient accretion onto SMBH, radio-emitting jets heat the halo around galaxy, gas does not cool, common on massive galaxies and in clusters of galaxies, long-lived process, act on large scales.

Connected with cluster cooling flows

LOFAR / SKA / ALMA / NOEMA / ELT / VLT / ATHENA

ORIGIN AND FATE OF GALAXIES



environment

Which physical processes drive the transformation of galaxy properties?

Euclid, LSST: Statistical studies at different epochs probe the assembly history of different types of galaxies in different environments

Euclid, LSST, VST, VISTA: Structural parameters over large sky areas and in a variety of environments probe the driving mechanisms of galaxy growth and transformation

Euclid, VLT, VISTA: (Proto)clusters at the peak of the cosmic star formation rate (z~2) to study their member galaxies at a critical phase of the cluster assembly, to understand if and how they are connected to the virialized structures observed at lower redshift

MOONS@VLT, WEAVE@WHT, 4MOST@VISTA: MOS follow-ups, strong and weak lensing and X-ray observations to reconstruct the stellar and dark mass assembly of these systems and to study the evolution of the link between the observed baryons and the dark matter halo

EUCLID / LSST / VLT / VST / VISTA / WHT / ATHENA

Origin and fate of galaxies

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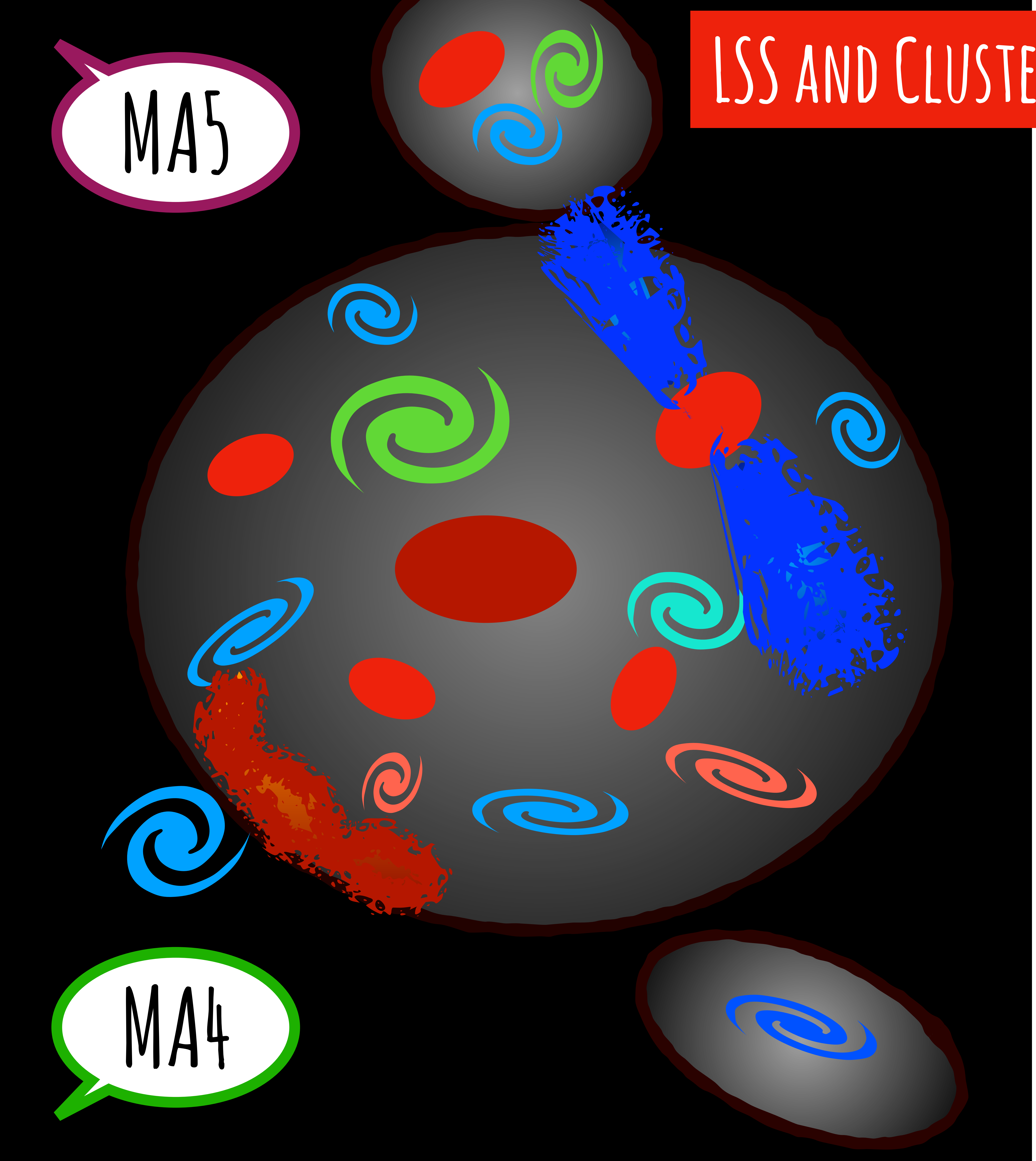
Numerical simulations and astroinformatics

- High resolution hydrodynamical simulations probing physical processes effects on small scales and semi-analytic models probing cosmological volumes, both of them including realistic modelling of metal enrichment, UV photoionization background, stellar and AGN feedback, radiative transfer
- Improving recipes in semi-analytic models to reproduce observations (e.g. quenching at high redshift, galaxy properties as a function of environment, distribution functions)
- Implementation of empirical models for huge galaxy surveys forecasts
- Analysis of large datasets involving data mining techniques
- Advanced machine learning methods
- Efficient archival of observed and simulated data



LSS and Clusters of galaxies

Evolution of baryons in groups and clusters in massive DM haloes - Chemical and thermo-dynamical evolution

Chandra/XMM/ATHENA: X-ray emitting plasma dominates the baryonic content, gas temperature and density, its metal abundance and velocity are provided via observations of the X-ray spectral continuum and emission lines. **Planck, SPT:** intra-cluster medium via SZ effect. **LOFAR, SKA:** thermal and non-thermal components, turbulence and shocks in the ICM caused by merger and accretion events, radio halos and relics, very steep spectrum sources in clusters and groups.

The formation of the first groups

VISTA, Euclid, Chandra, XMM, ATHENA, SKA, SZ facilities: protocluster assembly at z>2.

Interplay between galaxies and SMBHs in galaxy groups and clusters

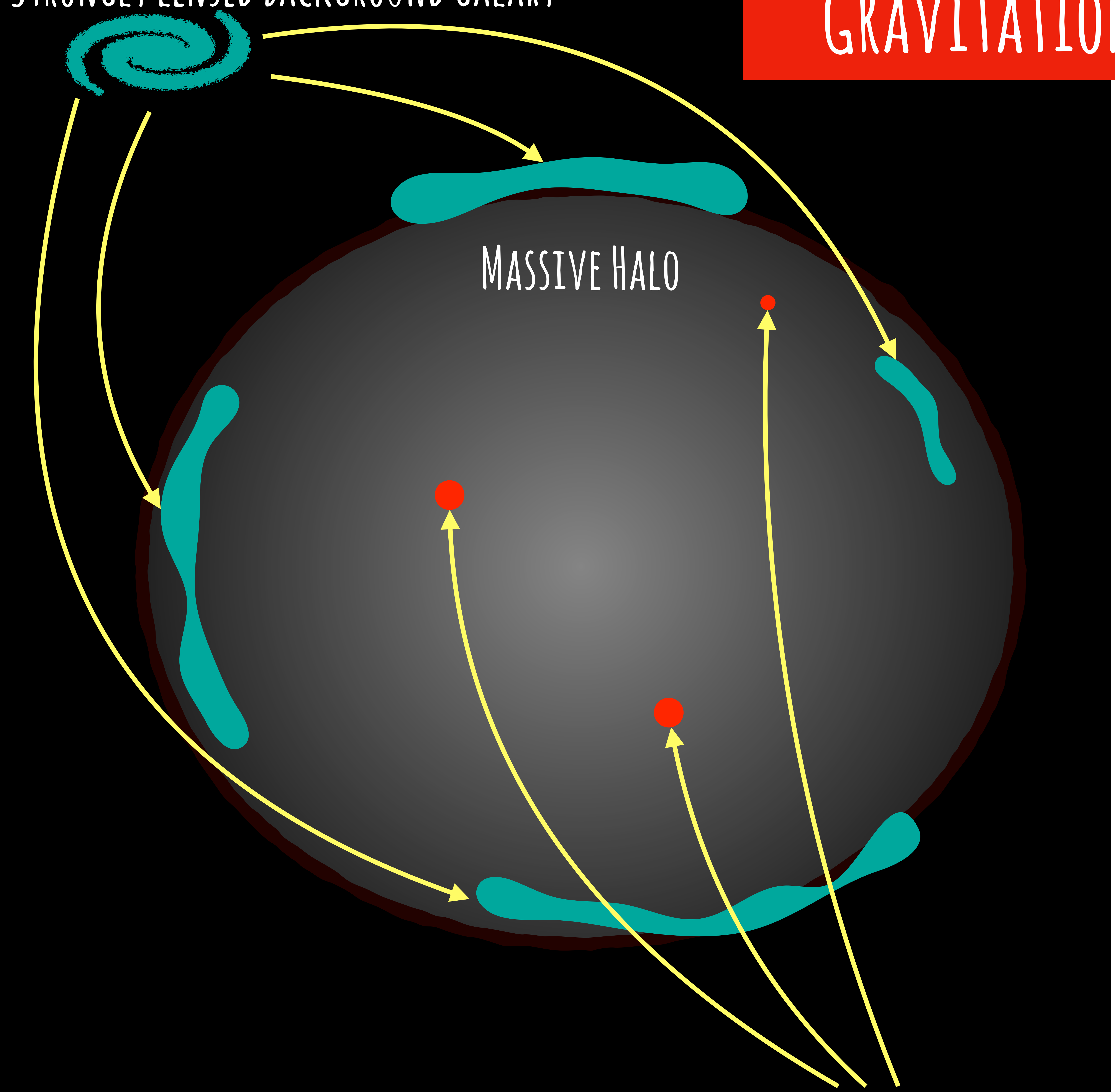
ATHENA, SKA: feedback processes, full baryon cycle in cool cores, X-ray observations with arcsec spatial resolution for energetic balance.

Missing baryons

ATHENA, SKA: Most baryons in the local Universe should reside in filamentary structures in a warm-hot phase connecting groups and clusters. X-ray detect highly ionized metals in WHIM already at redshift ~4; radio emission provides limits to their magnetic field.

LOFAR / SKA / ATHENA / EUCLID

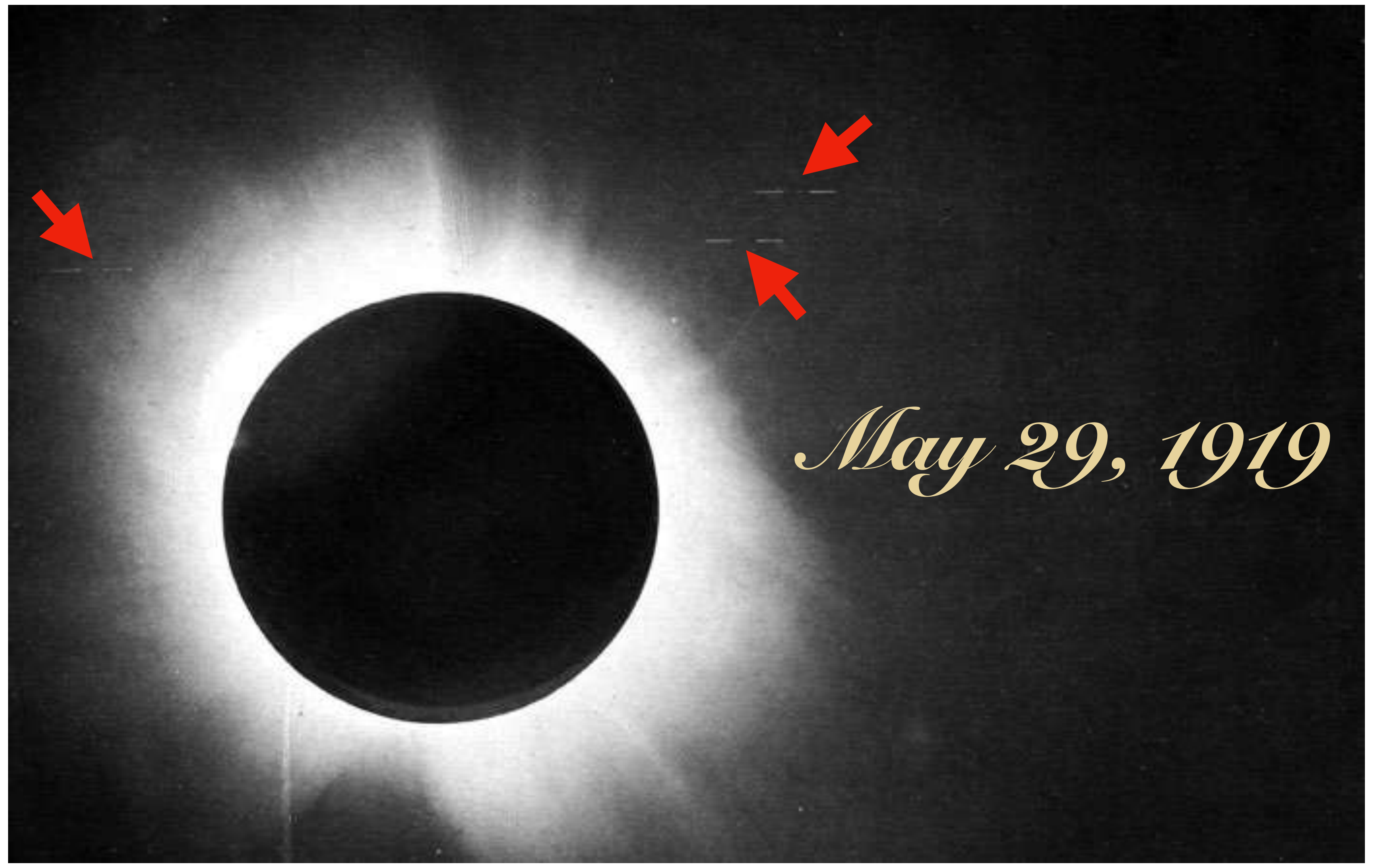
Gravitational Lensing



Cosmic telescopes

JWST, ELT, VLT, HST, ALMA, Euclid: Clusters of galaxies are important not only as places where galaxies are molded, but also as instruments that magnify the signal of background sources. Looking through massive clusters it is possible to detect extremely faint galaxies and spatially resolve them up to very high redshifts, taking advantage of the lens model needed to estimate the mass of the cluster.

100 years since Eddington's eclipse: first detection of light bending according to General Relativity



JWST / ELT / VLT / HST / ALMA / Euclid

LSS and Clusters of galaxies

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Evolution of baryons in groups and clusters in massive DM haloes

Chemical and thermo-dynamical evolution

The formation of the first groups

Interplay between galaxies and SMBHs in galaxy groups and clusters

Missing baryons

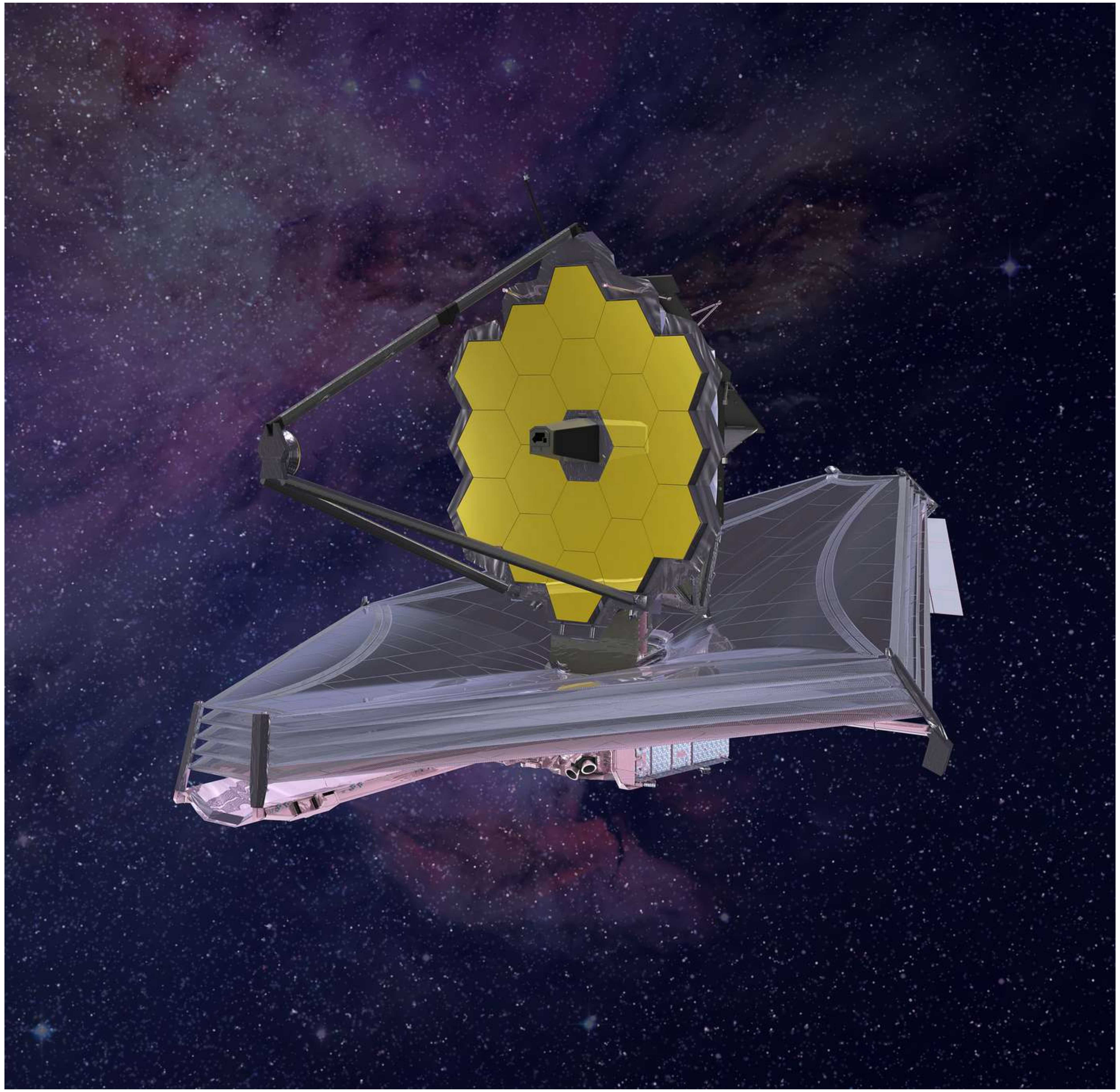
Numerical simulations and astroinformatics

- large cosmological simulations with realistic properties of galaxies in clusters to produce forecast on expected cluster detection
- optimization of cluster detection algorithms
- hydrodynamical simulations of galaxy clusters including turbulence and magnetic fields
- strong lensing simulations
- lens modelling to estimate cluster mass
- inversion of lens models to derive intrinsinc properties of lensed objects


100 m
80 m
60 m
40 m
20 m
Very Large Telescope
Extremely Large Telescope

→ COSMIC OBSERVERS
esa
CONCEPTS
spica
theseus
IN DEVELOPMENT
webb (2021)
ariel (2028)
euclid (2022)
cheops (2019)
plato (2026)
xrism (2021)
einstein probe (2022)
athena (2031)
lisa (2034)
OPERATIONAL
hubble (1990–)
gaia (2013–)
xmm-newton (1999–)
integral (2002–)
microwaves
sub-millimetre
infrared
optical
ultraviolet
x-rays
gamma rays
gravitational waves
LEGACY
planck (2009–2013)
herschel (2009–2013)
iso (1995–1998)
akari (2006–2011)
hipparcos (1989–1993)
corot (2006–2014)
iue (1978–1996)
exosat (1983–1986)
hitomi (2016)
suzaku (2005–2015)
cos-b (1975–1982)
lisa pathfinder (2015–2017)
microscope (2016–2018)
#Space19plus
Space19

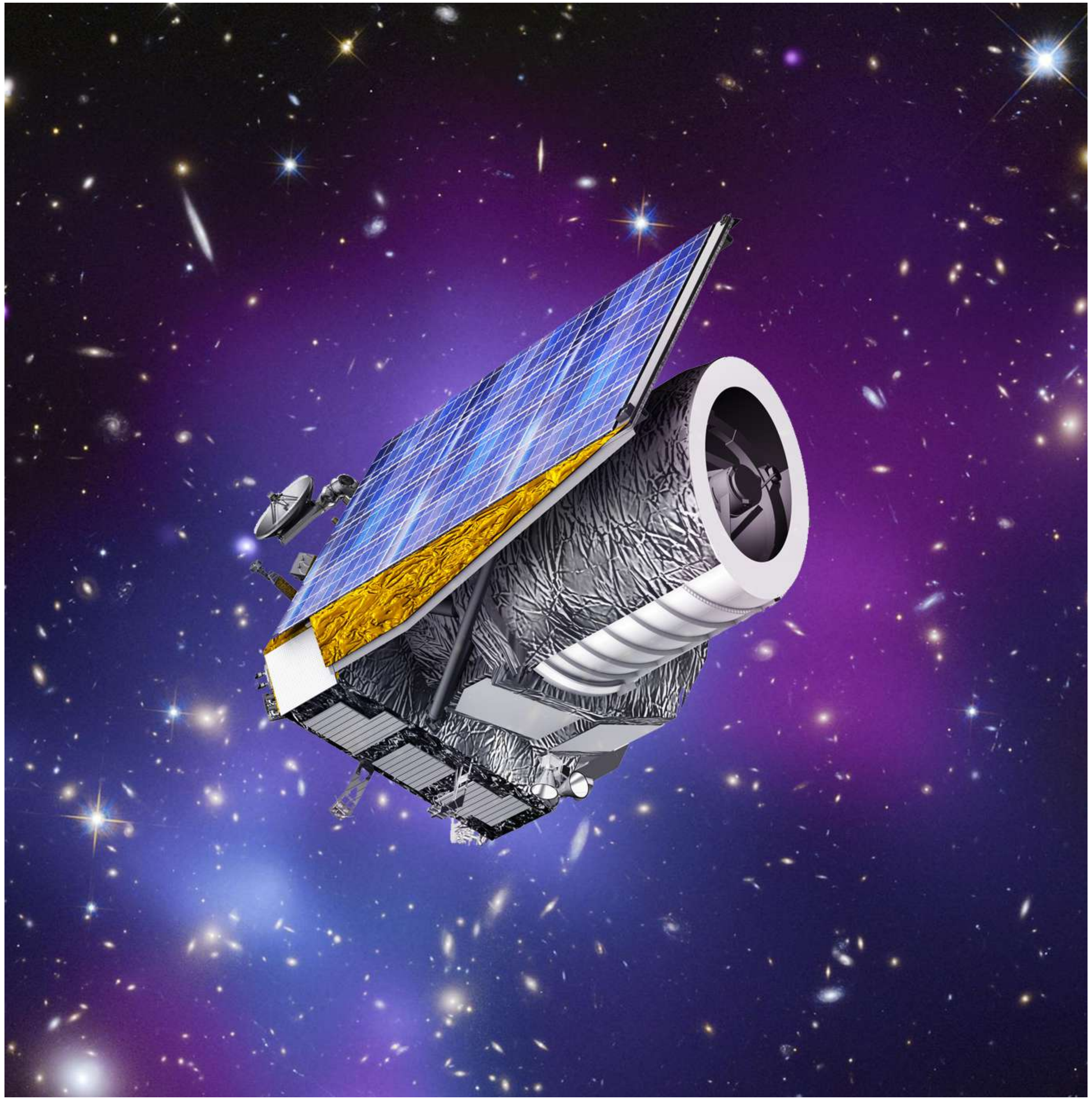
JWST



Launch: March 30, 2021
Collaboration: NASA, ESA, CSA
Wavelength range: 0.6-28.5µm
Observing modes:
- NIRCam: 0.6-5µm
- NIRSpec: 0.6-5µm, R=100,1000,2700
- MIRI: 5-27µm, imaging+spectra

Diameter: 6.5m
FOV: ~10 arcmin^2
Duration: > 5yr

Euclid



Launch: June, 2022
Collaboration: ESA
Wavelength range: 0.55-2μm
Observing modes:
- VIS imager
- NISP imager + slitless spectroscopy

Diameter: 1.2m
FOV: ~ 0.53deg^2
Duration: > 7yr

WFIRST

Launch: 2025?
Collaboration: NASA, JPL, GSFC
Wavelength range: 0.4-2μm
Observing modes:
- imaging
- slitless spectroscopy

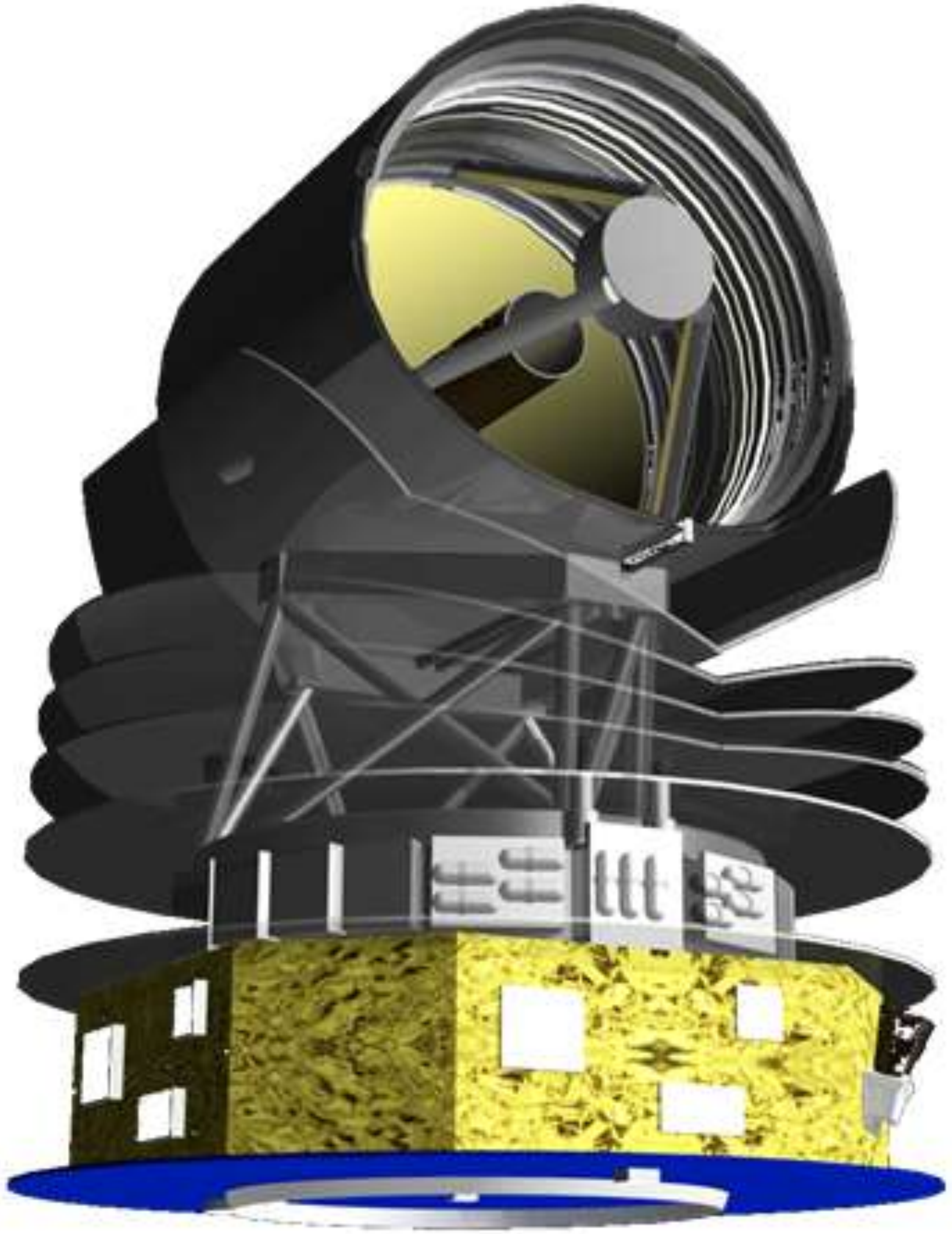
Diameter: 2.4 m
FOV: 0.28 deg^2
Duration: > 5yr

ATHENA

Launch: 2031
Collaboration: ESA+NASA
Energy range: 0.1–15 keV
Observing modes:
- X-IFU [0.2–12 keV; 2.5 eV spectral resolution; 5″arcsec/px; FOV=5′]
- Wide Field Imager [0.1–15 keV; FOV: ~ 40′x40′]

Duration: 5+5yr

SPICA



Cosmic Vision 2015-2015 programme: selected in April 2016 with THESEUS and EnVision; M5 selection planned for 2021

Launch: 2032

Collaboration: ESA, JAXA

Wavelength range: 5-210μm

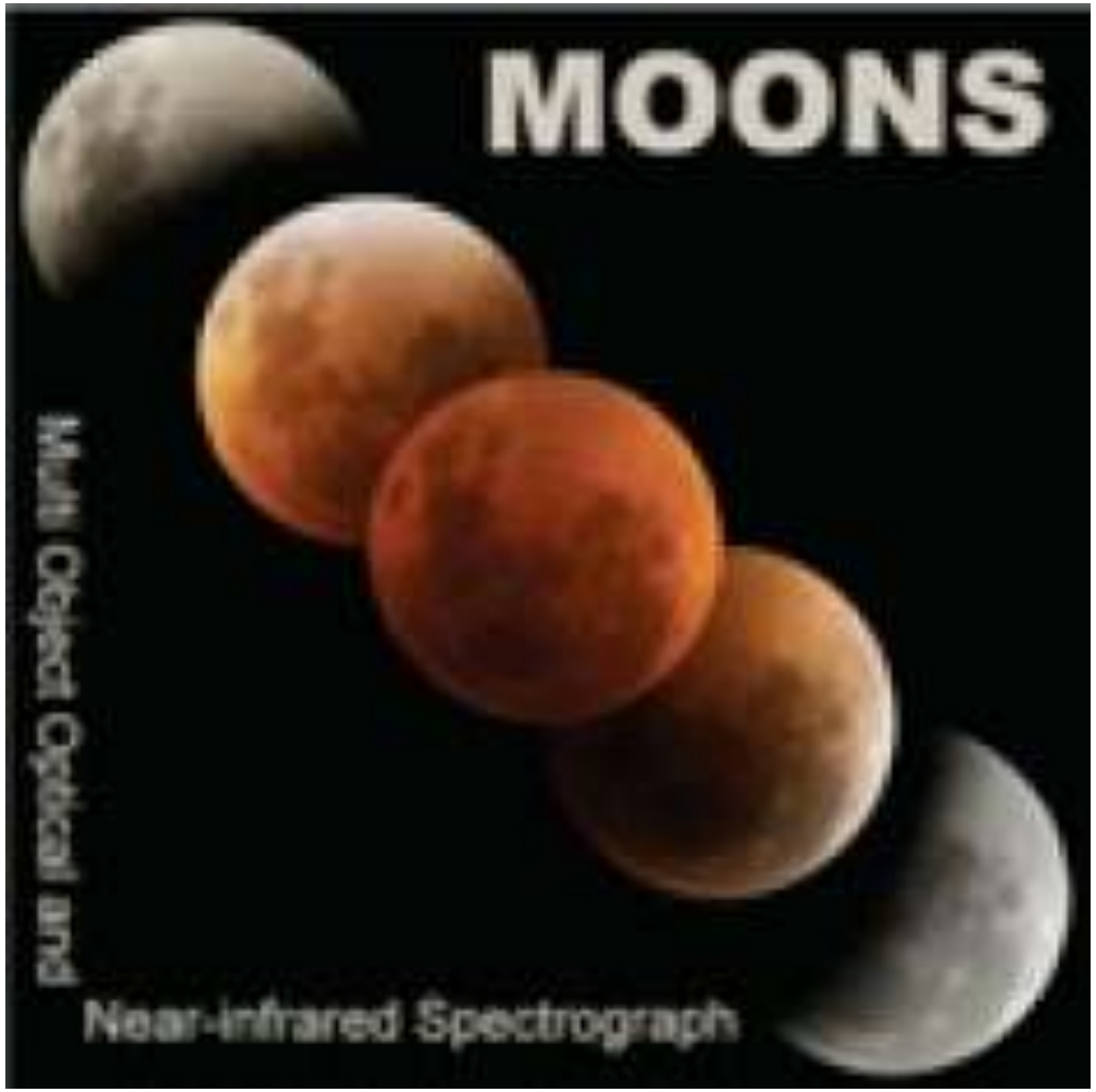
Observing modes: 2 spectrometers

- SAFARI: R~300-11000, high sensitivity, instantaneously covering 35-230 μm
- SMI: R~28000 at 12-18μm and R~150-1500 at 17-35 μm; 10’×12’ wide field imaging
- BiBoP: polarimeter

Diameter: 3.2m

Duration: 5yr

MOONS@VLT



Start of scientific operations: end 2020
Collaboration: ESO
Wavelength range: 0.6-1.8μm
Observing mode: ~1000 fibres (1.2″ diameter) over 500arcmin^2; R~4000, 9000, 20000
Diameter: 8m
FOV: ~ 25 arcmin diameter

WEAVE@WHT & 4MOST@VISTA

Start: end 2019; Surveys 2020
Collaboration: A lot of institutes + INAF
Wavelength range: 3700-9600 Å
Observing mode:
- MOS ~1000 fibres 1.3″ Ø, R=5000,20000;
- IFU: 20 mIFU 9″x 9″ hex 1.3"+ 1 IFU 1.5′x1.5′

FOV: ~ 3.14 deg^2 (Ø = 2 degrees)
Diameter: 4.2m (WHT)

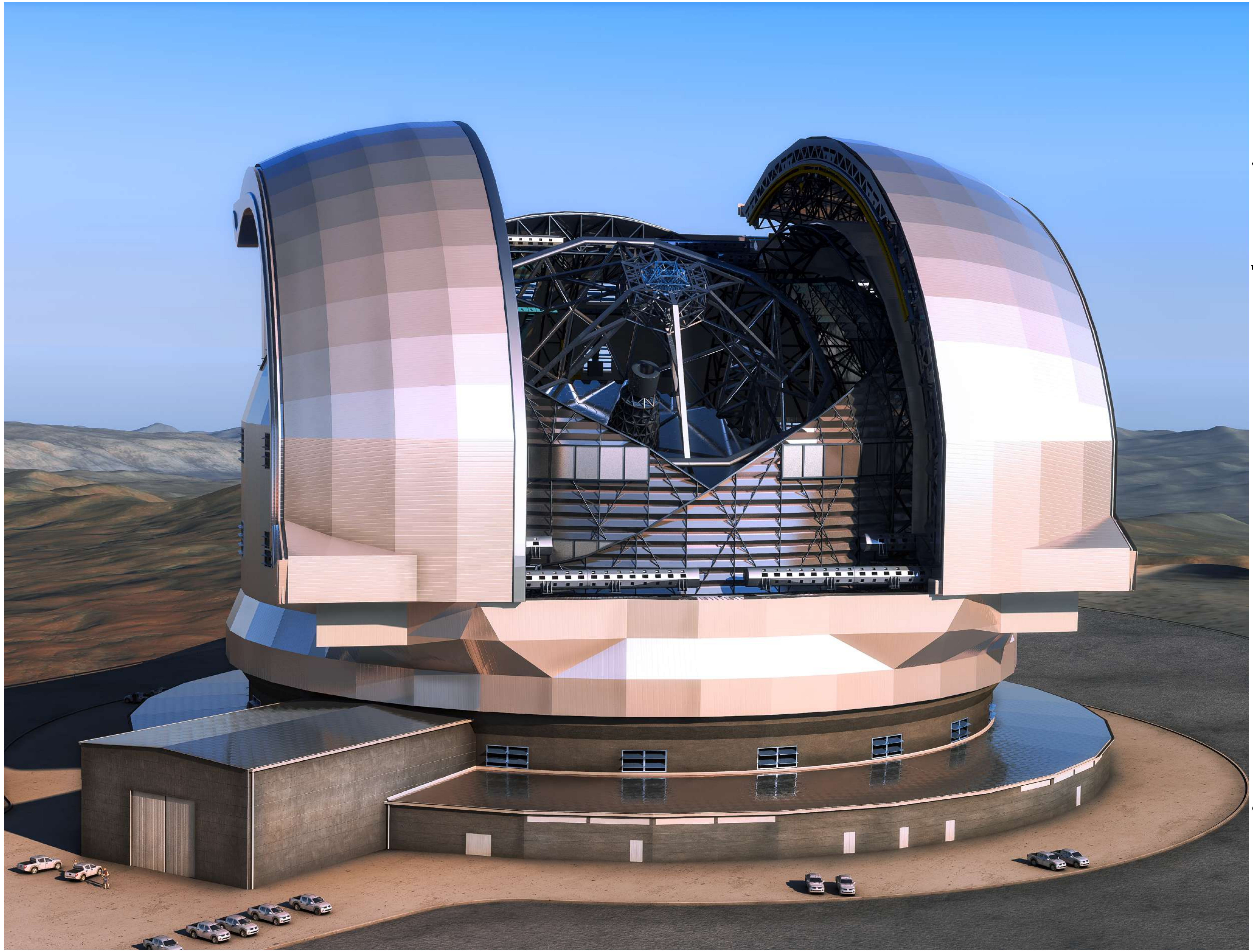
Start: Commissioning Nov. 2022; 5yr surveys 2023
Collaboration: ESO
Wavelength range: 3700-9500 Å
Observing mode: ~2400 fibres 1.45″ Ø, R=6500,20000;
FOV: ~ 4.2 deg^2 (Ø = 2.6 degrees)
Diameter: 4m (VISTA)

LSST

Large Synoptic Survey Telescope

Start: full science operation 2023
Collaboration: NSF (+UK, Chile, France)
Italy: INAF contribution for 15 co-Is (+ non-staff)
Wavelength range: 3200-10600 Å
Observing mode: imaging, 6 filters ugrizy
FOV: 9.6 deg^2
Diameter: 8.4 m (6.5 effective)
Survey duration: 10yr

ELT



Start: 2025
Collaboration: ESO
Wavelength range: UV to IR
Diameter: 39.3m
1st light instruments:

- MICADO [multi -AO imaging 0.8-2.4μm and slit spec 1.45-2.46μm + 0.84-1.48μm at R~20000]
- HARMONI [IFU 0.47 μm-2.45 μm]
- METIS [MIR imager and spectro]

+ MAORY [multi-conjugate adaptive optics]

ALMA & NOEMA

Start: 2013
Collaboration: ESO + NRAO
Wavelength range: 9.6-0.3mm (31-1000GHz)
Observing modes: imaging & spectro
Receiver: 66 telescopes (15 of them 12-meter antennas)

ALMA
ATACAMA LARGE MILLIMETER ARRAY

Start: 2016
Collaboration: IRAM (F,G,S)
Receiver: 12 15-meter antennas

SKA

Start: 2024 (full operation 2027)
Collaboration: Australia, Canada, China, India,Italy, New Zealand, South Africa, Spain, Sweden, The Netherlands, UK
Energy range: 50 MHz-14 GHz (SKA1+2)
Receiver: dishes and antennas
Tot. collecting area: 1 km^2

SKA pathfinder
Start: 2012
Collaboration: The Netherlands
Energy range: 10-240 MHz
Receiver: >20 000 antennas
Tot. collecting area: 300 000 m^2

ASKAP (SKA precursor)
Start: 2012
Collaboration: Australia
Receiver: 36 12m dishes
Tot. collecting area: 4000 m^2

MeerKAT (SKA precursor)
Start: 2024
Collaboration: South Africa
Receiver: 64 13.5m dishes
Tot. collecting area: 9000 m^2

BIG DATA

Good Italian involvement
Italy not involved
Italy not involved but ready
To be decided
X-RAY
RADIO
XMM
Chandra
eROSITA
ATHENA
HST
WEAVE@WHT
4MOST@VISTA
LSST
MSE
VLT
ELT
MOONS@VLT
We are here
Euclid
WFIRST
JWST
SPICA
ALMA
OST
LOFAR (+MeerKAT + ASKAP)
SKA
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030

MSE

Mauna Kea Spectroscopic Explorer is a proposed 11.25m telescope designed to replace the CFHT 3.6m telescope.

Partners at 2018: Canada, France, Hawaii, Australia, China and India.

Dedicated survey telescope, 1.5 deg^2 field and several thousand fibres [http://mse.cfht.hawaii.edu]

Table 1: Summary of major science capabilities of MSE.

Accessible sky	30000 square degrees (airmass<1.55)						
Aperture (M1 in m)	11.25m						
Field of view (square degrees)	1.5						
Etendue = FoV x π (M1 / 2)^2	149						
Modes	Low		Moderate	High			IFU
Wavelength range	0.36 - 1.8 μm		0.36 - 0.95 μm	0.36 - 0.95 μm ♯			IFU capable; anticipated second generation capability
	0.36 - 0.95 μm	J, H bands		0.36 - 0.45 μm	0.45 - 0.60 μm	0.60 - 0.95 μm	
Spectral resolutions	2500 *(3000)*	3000 *(5000)*	6000	40000	40000	20000	
Multiplexing	>3200		>3200	>1000			
Spectral windows	Full		≈Half	λ_c/30	λ_c/30	λ_c/15	
Sensitivity	m=24 *		m=23.5 *	m=20.0 ♮			
Velocity precision	20 km/s ♪		9 km/s ♪	< 100 m/s ★			
Spectrophotometic accuracy	< 3 % relative		< 3 % relative	N/A			

♯ Dichroic positions are approximate

* SNR/resolution element = 2   ♪ SNR/resolution element = 5

♮ SNR/resolution element = 10   ★ SNR/resolution element = 30

The future of MOS - ESO

The Future of Multi-Object Spectroscopy: a ESO Working Group Report
Ellis et al. (2017) https://arxiv.org/abs/1701.01976

What is the most important capability for your research in 2020-2030? [ESO Messenger 161, 2015]

→ *wide field spectroscopic surveys*

→ high multiplex gain with high spectral resolution

→ optical (0.4-1 microns) and NIR (1-2.4 microns)

A 10-12m class optical spectroscopic survey telescope with a field of view comparable to that of LSST could enable transformational progress in several broad areas of astrophysics […]

5 square degree field of view and an additional focus that could host a next-generation panoramic IFU.

In this category, but unfunded at present, is the Mauna Kea Spectroscopic Explorer (MSE) […] Only MSE represents a dedicated survey telescope […]

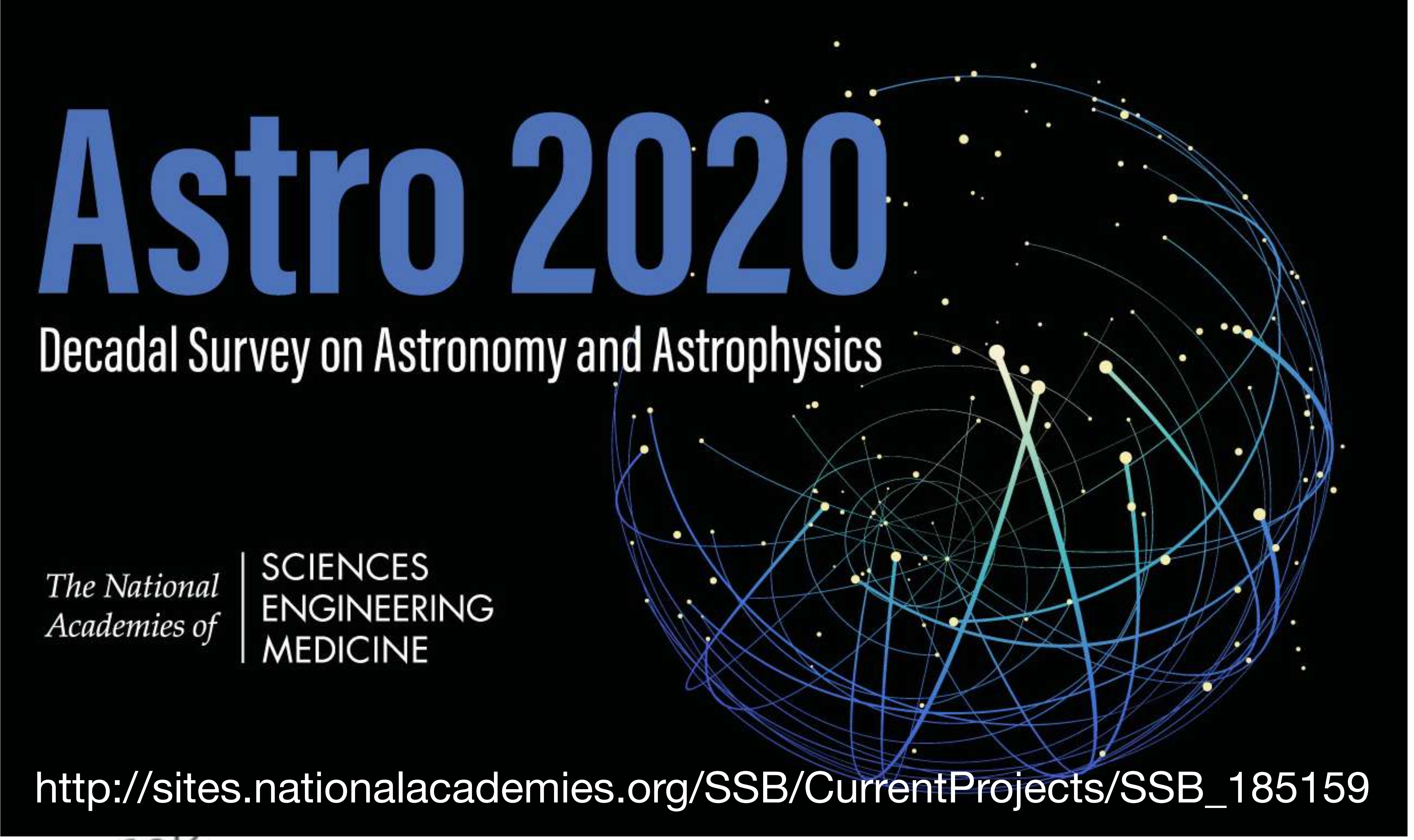
A facility of this scope could be considered an optical parallel to ALMA or the SKA.

Science Requirements (ESO WG)

- **Diameter > 10 m**
- **FOV = 5 deg²** (~25 X VLT, or ~25 X full Moon)
- **N_{obj} = >5000 LR, ~5000 HR**
- R = 1000-3000 LR, 20-40000 HR
- Δλ = 360-1000 nm LR, 3(TBD) regions for HR
- IFU: FOV>3x3 arcmin, R~5000, Δλ =325 - 1000 Nm
- Non-science requirements (project)
  - Use same LR spectrograph for IFU and fibres
  - Use E-ELT components, located in ESO site
  - Ambitious: Enhancing by > 10 existing/planned facilities

From Luca Pasquini's talk at ***Science with multi-object spectrographs: perspectives and opportunities for the Italian community*** meeting in Milano, Dec. 18, 2018
https://indico.ict.inaf.it/event/729/

SINERGIES WITH LSST, EUCLID, ELT!!!



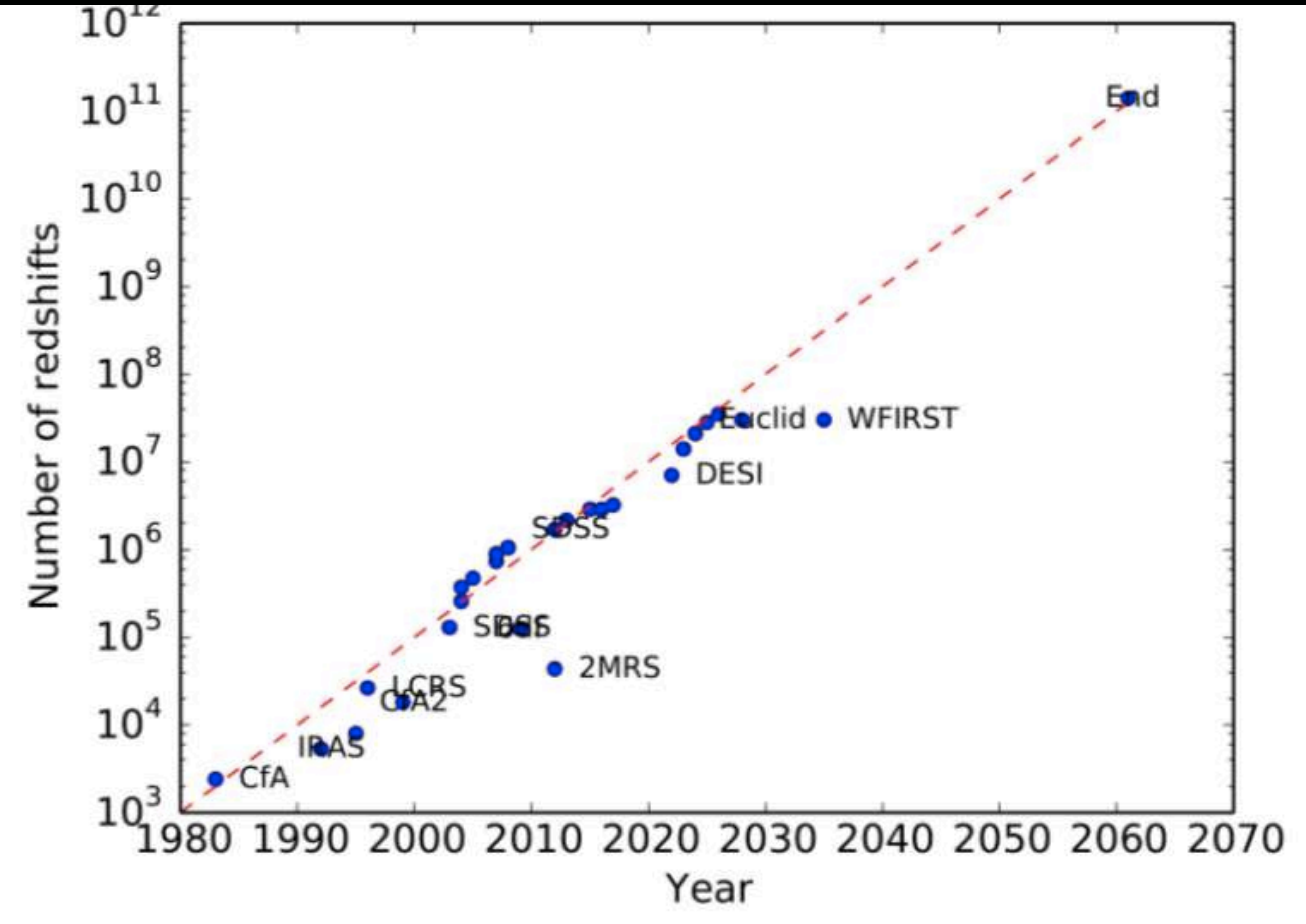


Figure 1: Spectroscopic redshifts as a function of year. The number goes up be a factor of 10 every decade.

~600 Science White Papers submitted

Most frequent topics: reionizations, first BHs, CGM and IGM, cosmic web at high redshift; extremely large telescopes (TMT, GMT, ELT), massive multiplex spectroscopy, sub-mm facilities with large FOV, astroinformatics, astrostatistics and machine learning, …

Some highlights

Dickinson: advances in understanding galaxy evolution would be enabled by very large spectroscopic surveys at high redshifts

Behroozi: Empirical techniques in the next decade will link halo assembly histories with galaxies' circumgalactic media, supermassive black holes, morphologies, kinematics, sizes, colors, metallicities, and transient rates

Rhodes: a path to **end the era of galaxy surveys** by making the definitive measurements of the galaxy population in the optical/NIR (see figure)

Carilli:

THE ERA OF PRECISION GALAXY FORMATION STUDIES

Futur(istic) projects: **ATLAS** (Astrophysics Telescope for Large Area Spectroscop) launch ~2030?; **LUVOIR** (The Large UV Optical Infrared Surveyor); **AtLAST** (Atacama Large Submillimeter Telescope)

Decadal 2001 → JWST

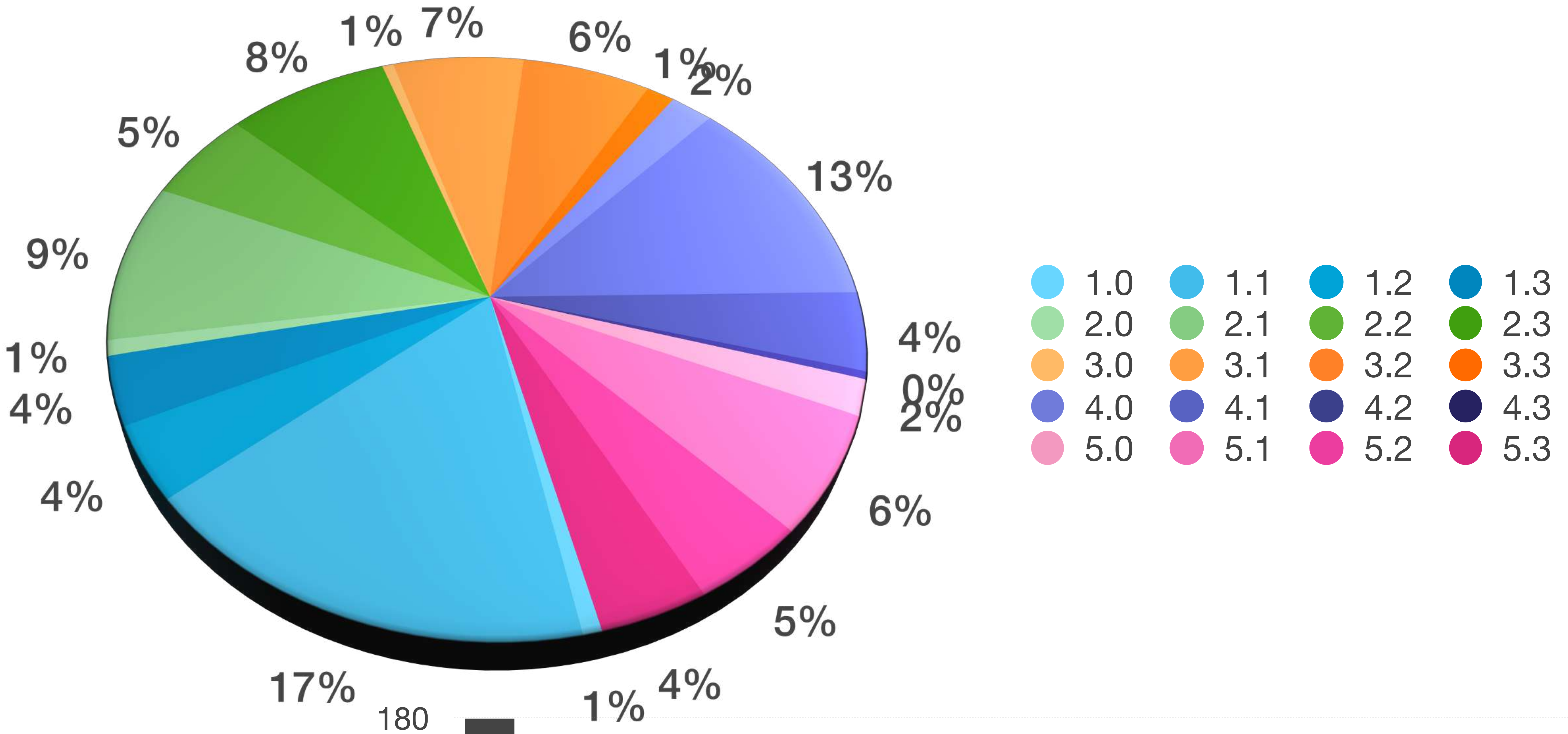
Decadal 2010 → WFIRST

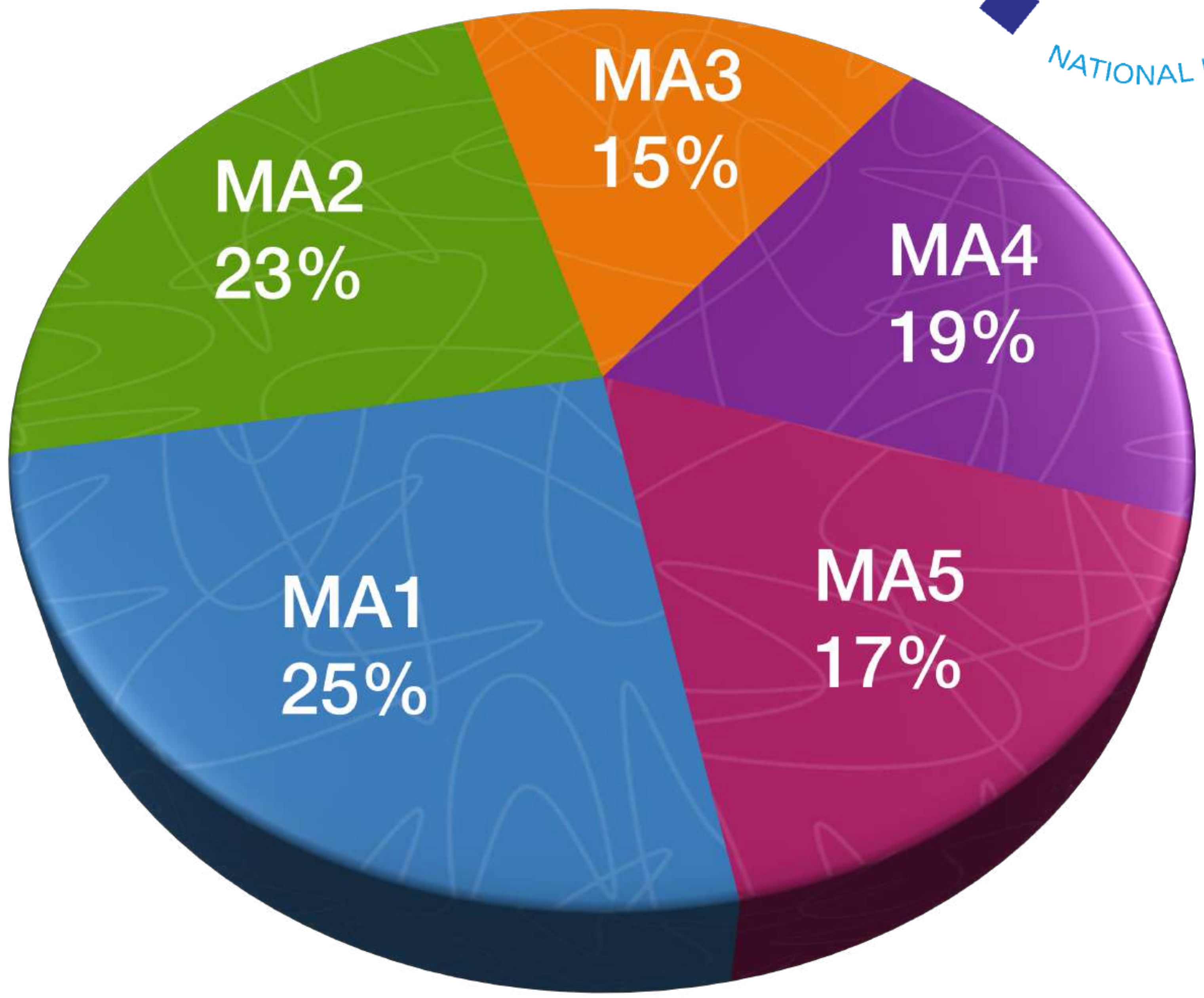
Conclusions (I)

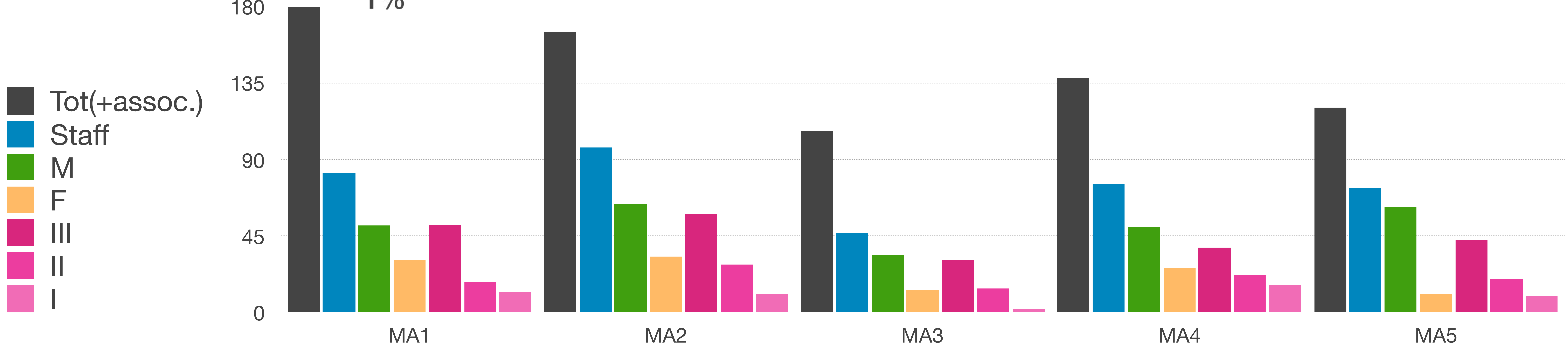
1. The big questions are interconnected (also with other MAs): a big effort have to be done to reconstruct the picture emerging from different observations (variables are not separable)
2. The huge amount of data (observed and simulated) will pose problems on how to handle them: need a big effort for astroinformatics and astrostatistics
3. New instruments/projects cannot be "local": we should evaluate (new?) partnerships
4. Marginal use of Italian facilities (TNG, LBT, SRT)

Tematic Areas balance

from http://www.ced.inaf.it/anagrafica/ at the date of 17/03/2019

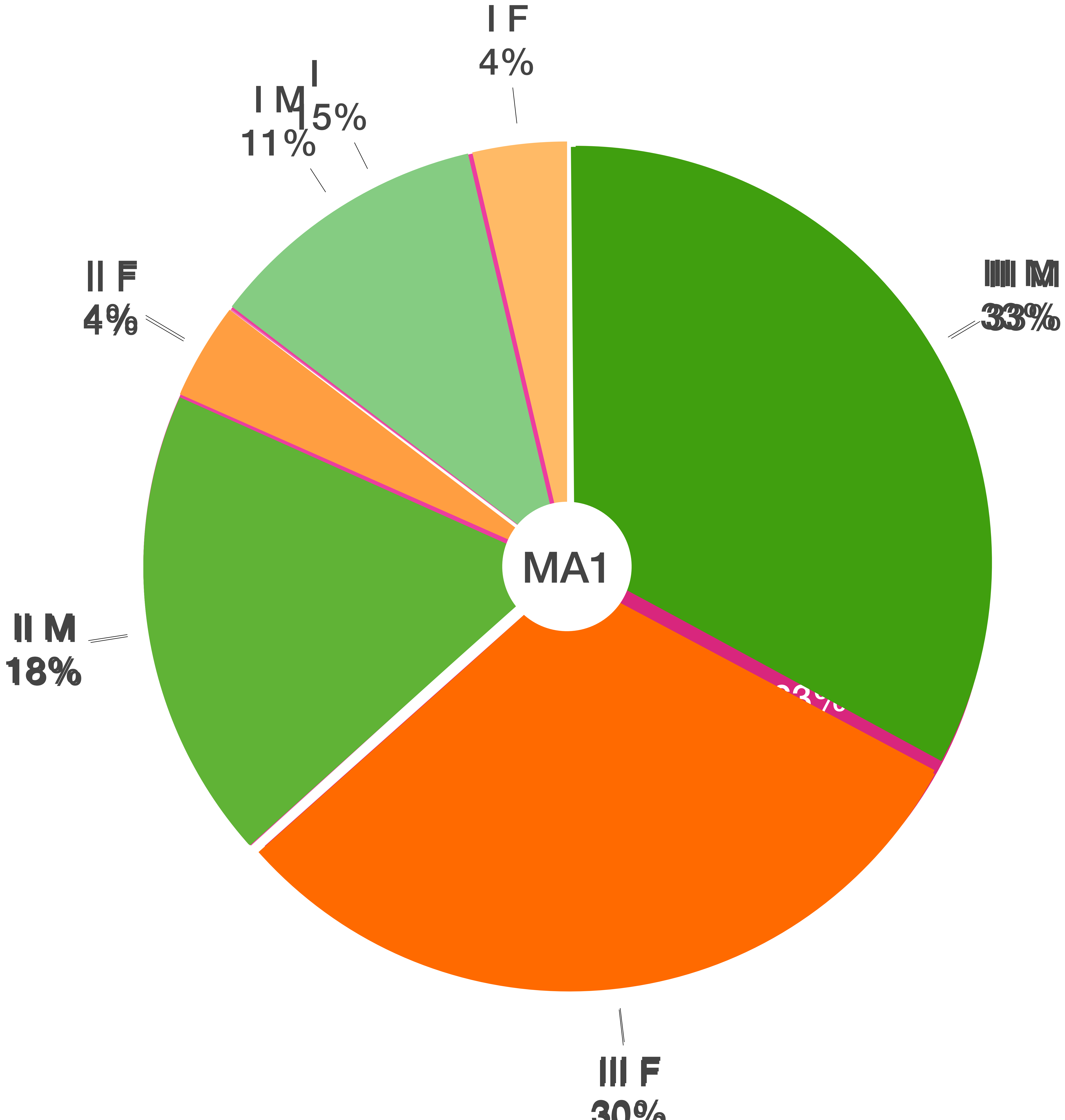






Gender balance

from http://www.ced.inaf.it/anagrafica/ at the date of 17/03/2019



Gender and role balance in MA1

from http://www.ced.inaf.it/anagrafica/ at the date of 17/03/2019

Conclusions (II)

1. MA1 is the most "populated" counting INAF staff <u>and</u> associates.
2. MA1.1 is the most populated subtopic
3. MA1.3 (Cosmology) still dominated by associates (i.e. staff from Universities), but some improvement is ongoing with the last recruitments
4. MA1 shows a good gender balance BUT **<u>only at the lowest level!!!</u>** Scissor in gender gap needs to be filled in career opportunities…
5. Lowest level overcrowded by many researchers burdened with high responsibilities in international projects (also tutoring master/PhD students) without acknowledgement
6. International collaborations and partnerships can be successfully sustained only if the staff is qualified and recognized also at career level

⇒ Need clear career paths

open and periodic possibilities <u>at all levels</u>