TOBIAS BUCK LEIBNIZ INSTITUT FÜR ASTROPHYSIK, POTSDAM 2.11.2020 tbuck@aip.de

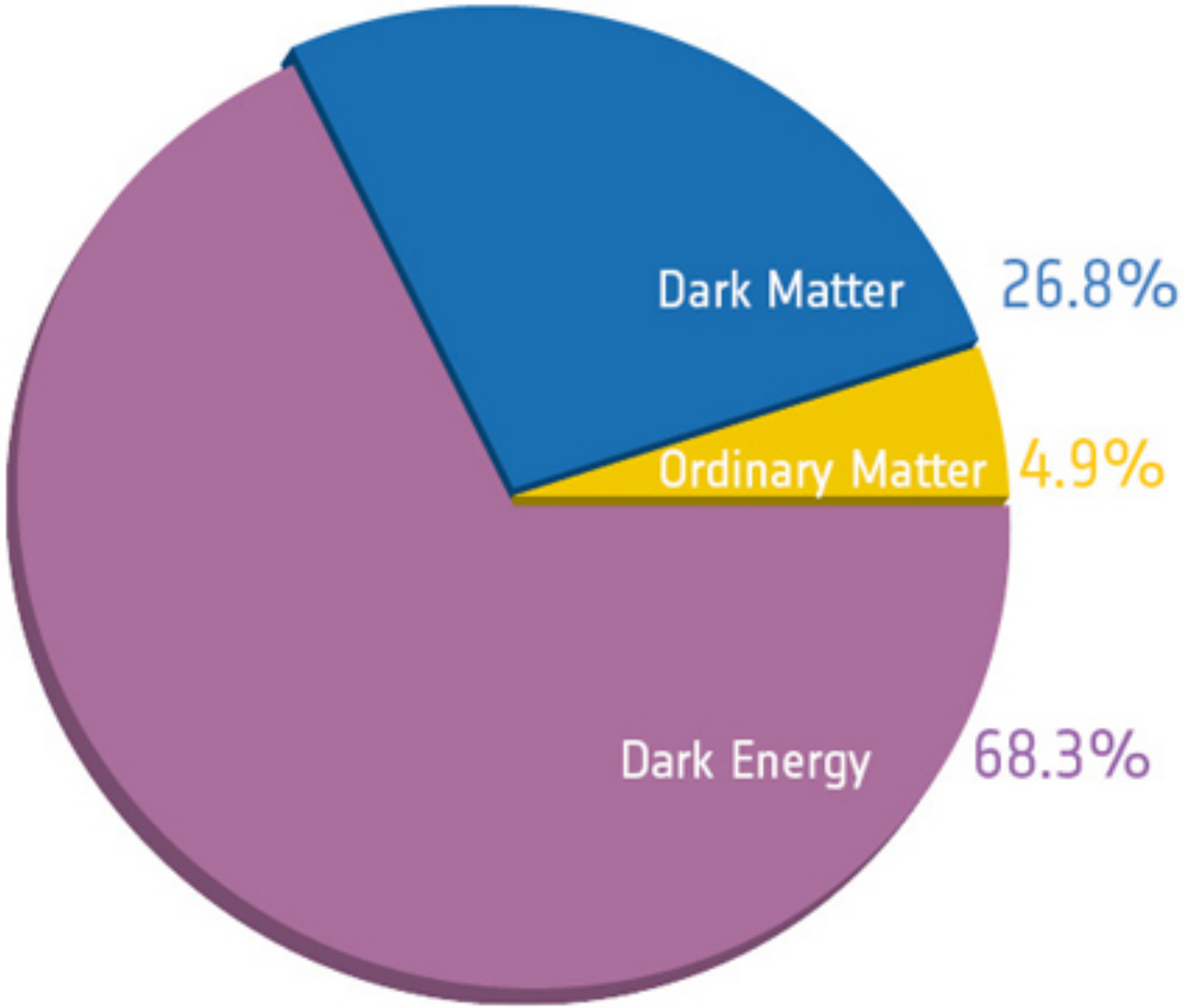
# EXPLORING CAUSAL GENERATIVE MODELS FOR USAGE IN ASTRONOMICAL MODELING

# THE STRUCTURE OF THE NEXT ~30 MINUTES:

- A brief history of the Universe: the cosmological standard model
- Galaxy formation simulations: time evolving models of galaxies
- Observations: the era of large galaxy surveys

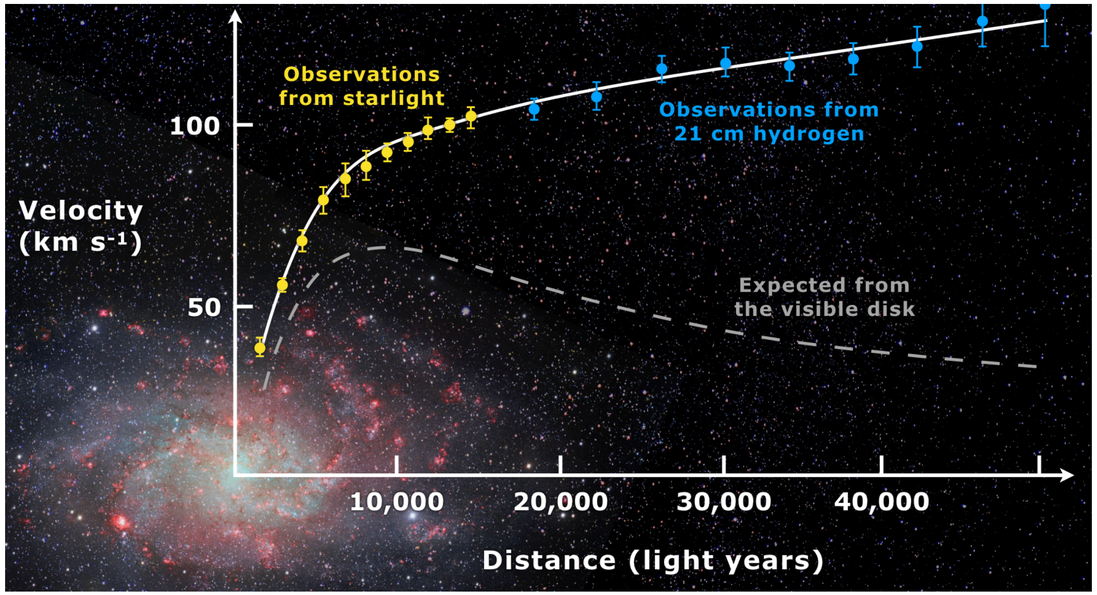
# THE ENERGY CONTENT OF THE UNIVERSE

- Which Cosmology does describe the Universe?
- What is Dark Matter?
- What is Dark Energy?



# THE PROBLEM: NEITHER DARK MATTER NOR DARK ENERGY OBSERVABLE

- Most stringent evidence for DM from galaxy dynamics and structure formation (e.g. Zwicky 1933)




- Evidence for Dark Energy from accelerated expansion of the Universe (Nobelprize 2011, Perlmutter,Schmidt,Riess)

# A BRIEF HISTORY OF THE UNIVERSE

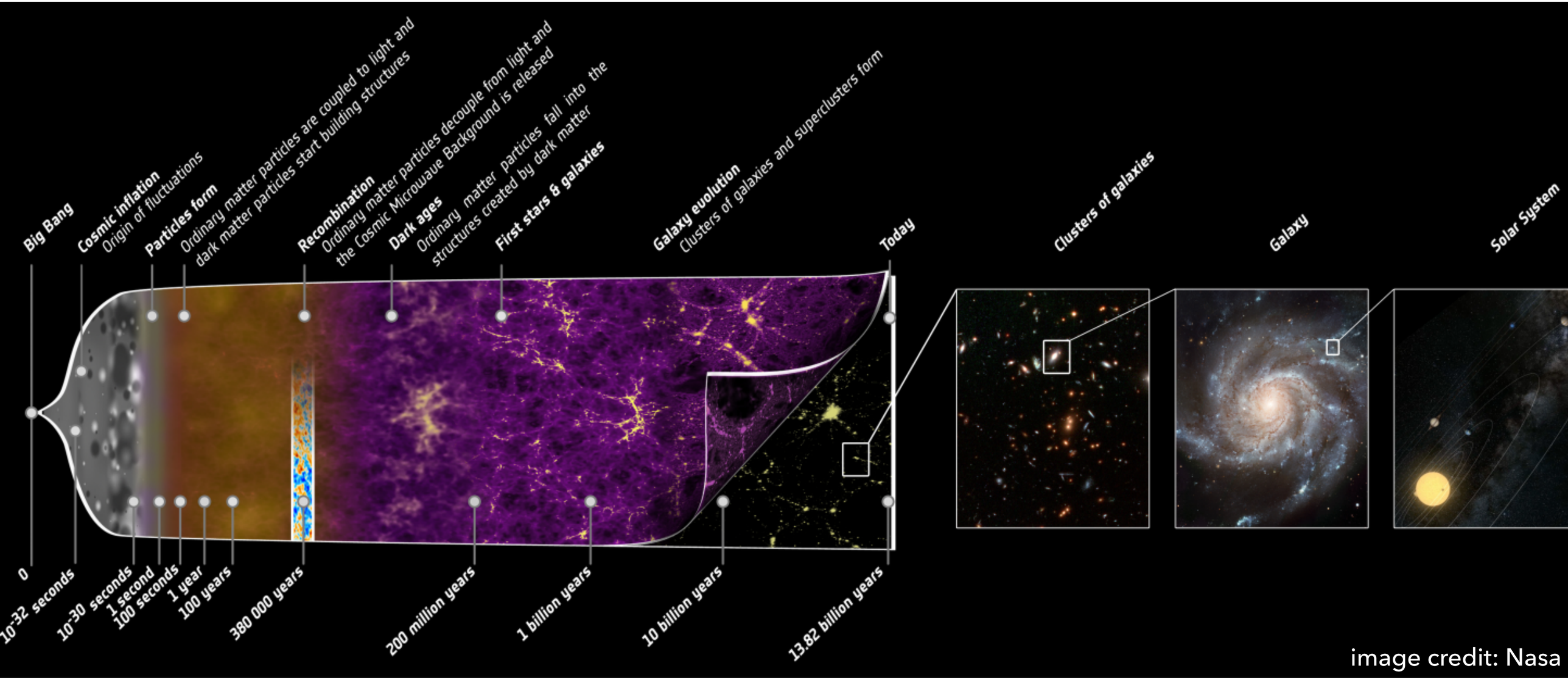
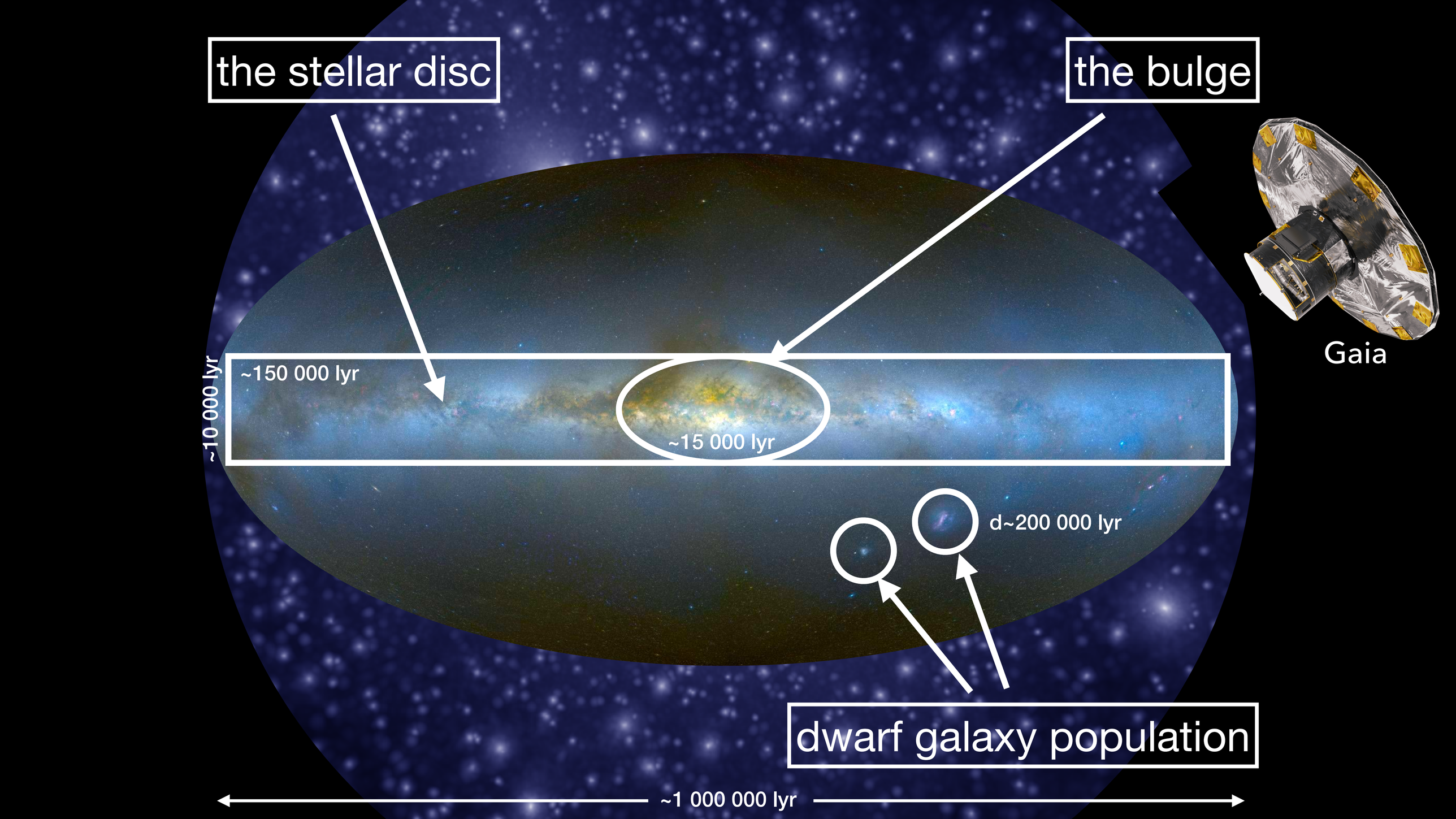



image credit: Nasa

# WHAT IS A GALAXY?

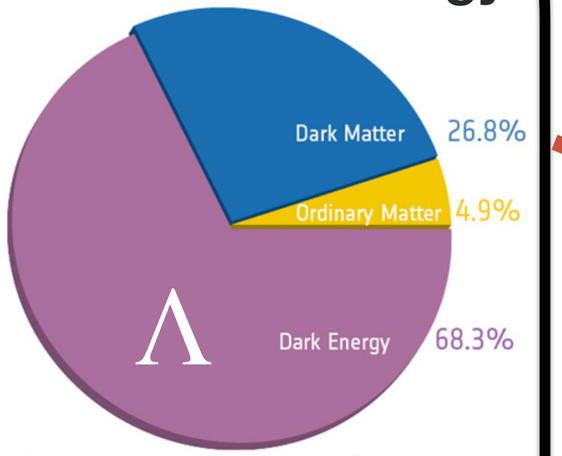

the stellar disc
the bulge
Gaia
~150 000 lyr
~10 000 lyr
~15 000 lyr
d~200 000 lyr
dwarf galaxy population
~1 000 000 lyr

# BUILD A MODEL, DO EXPERIMENTS AND PERFORM THE MEASUREMENTS

# SIMULATIONS

# A GALAXY FORMATION MODEL IN A NUTSHELL

## ΛCDM Cosmology



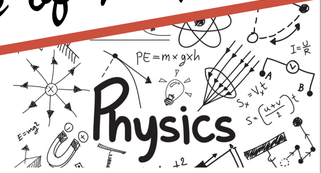

Cold dark matter = GeV mass elementary particle

Ordinary matter = baryons

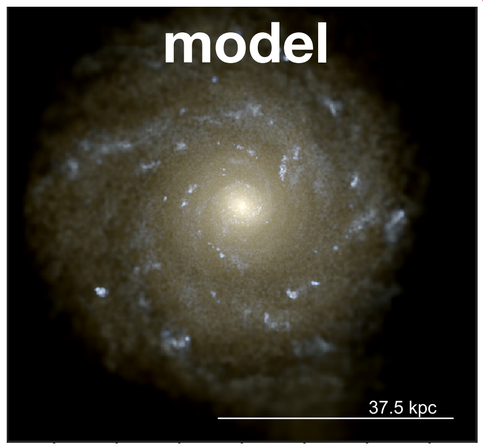
Dark energy, Λ = ???

## Computer

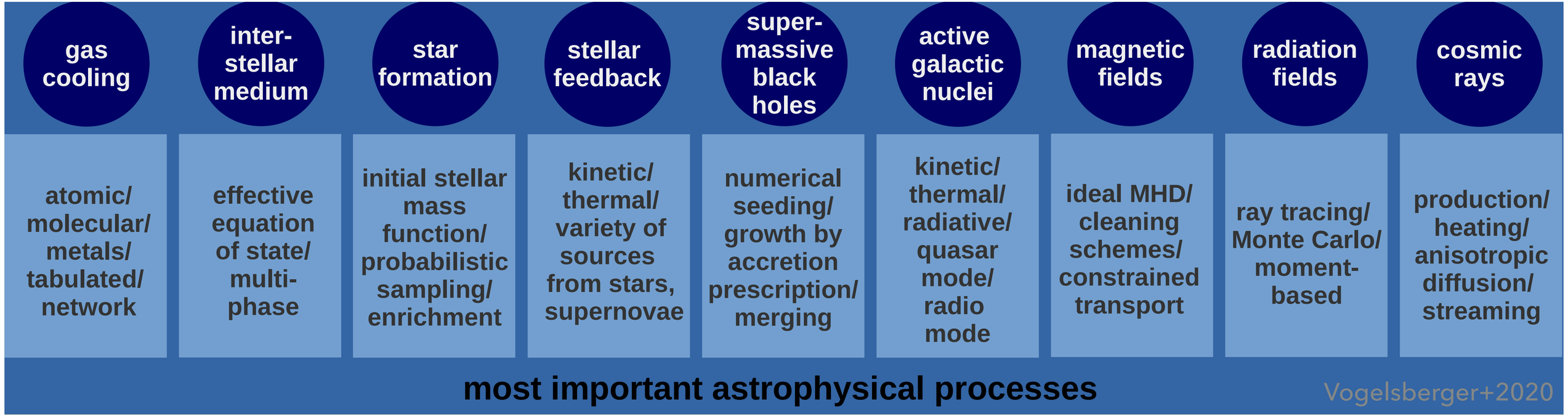
## Laws of Physics




- General Relativity
- Gas Physics
- Stellar Physics
- Radiation Physics



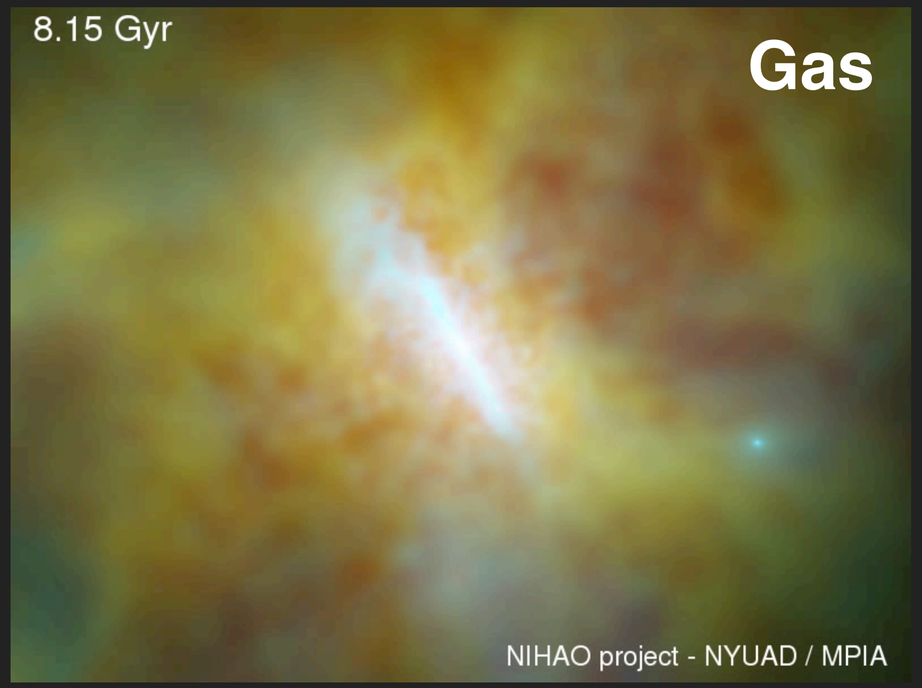

# SIMUALTIONS: THE INPUT PHYSICS

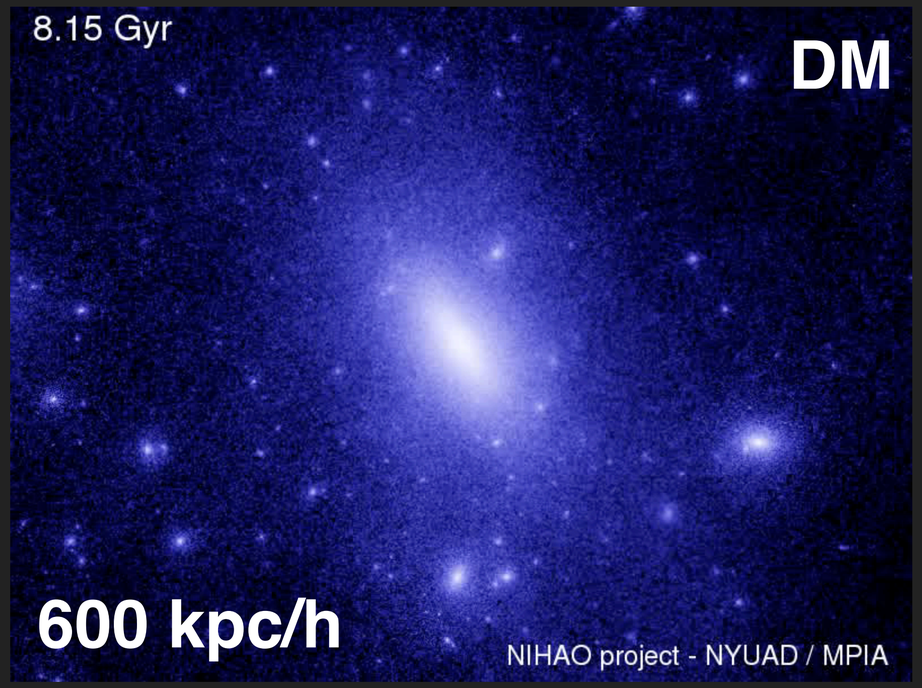


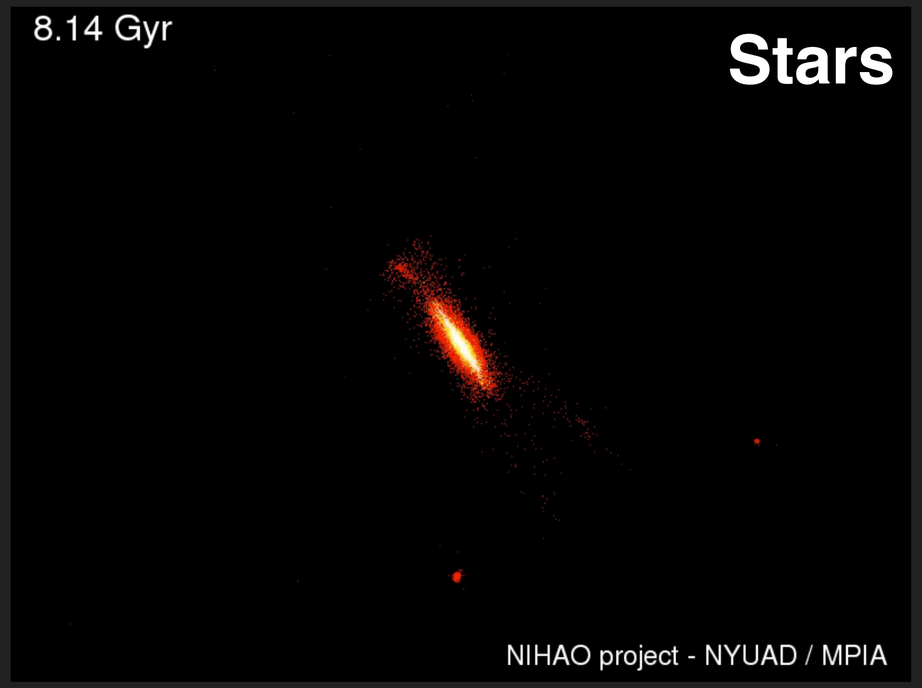

- At the same time: bridging $10^6$ orders of magnitude in spatial scale from sizes of stars to entire galaxies and beyond

MOST MECHANISM PUT IN BY HAND IN A PARAMETRISED WAY.

# cosmological zoom-in hydro simulations of a Milky Way analogue



SIMULATIONS ARE NUMERICAL EXPERIMENTS!

MODEL PARAMETERS FIXED BY HAND

THEY ARE ONLY A LIMITED FORWARD MODEL FOR OBSERVED GALAXIES…

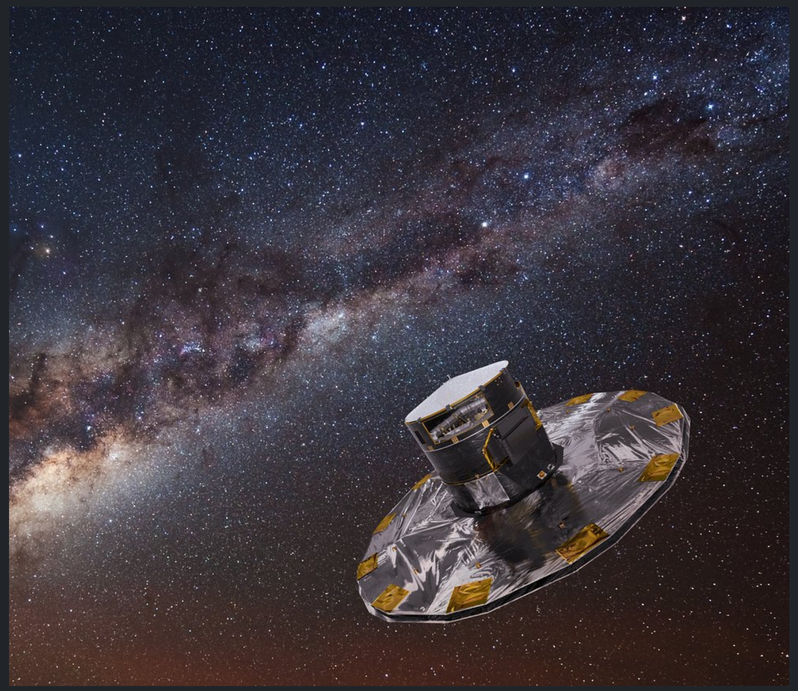
WE WILL NEVER MODEL A CLOSE ANALOGUE TO AN OBSERVED GALAXY.

Buck+2020

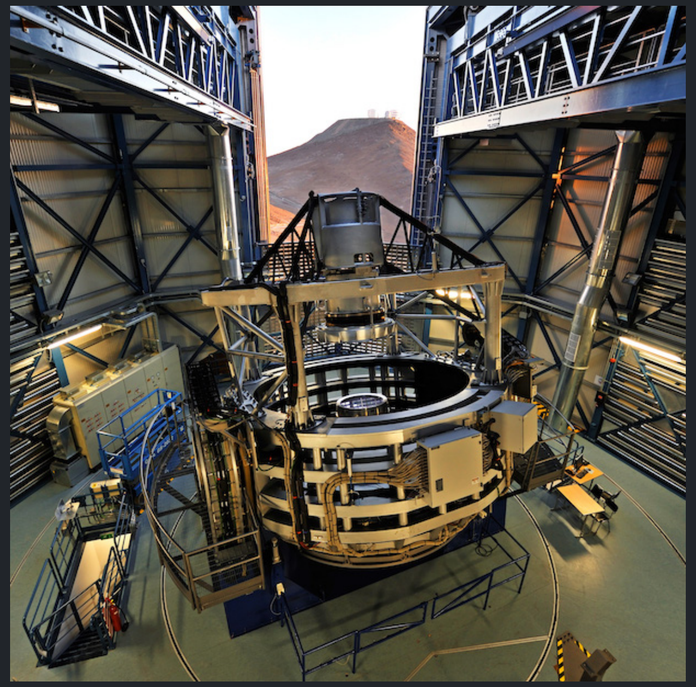
# OBSERVATIONS

## THE ERA OF LARGE GALAXY SURVEYS

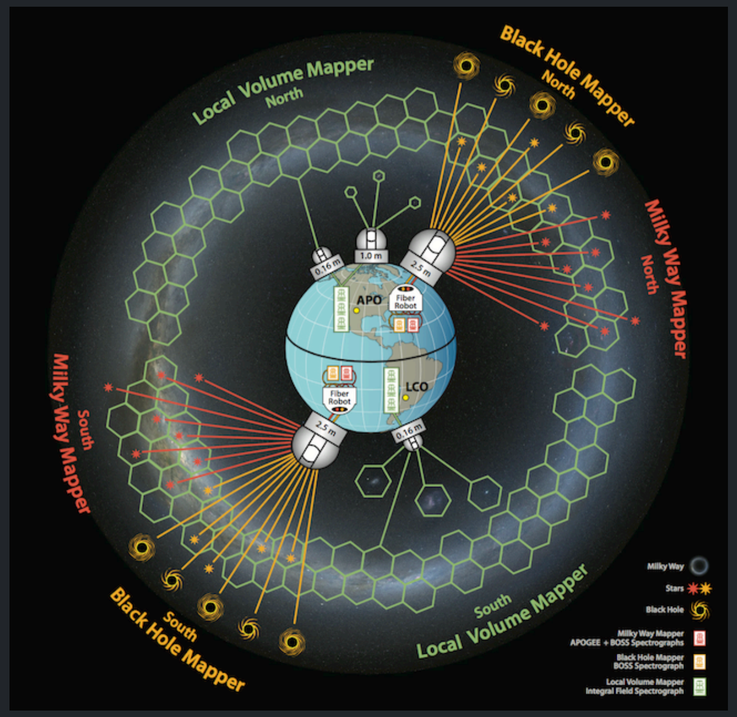
# MILKY WAY SURVEYS



Gaia



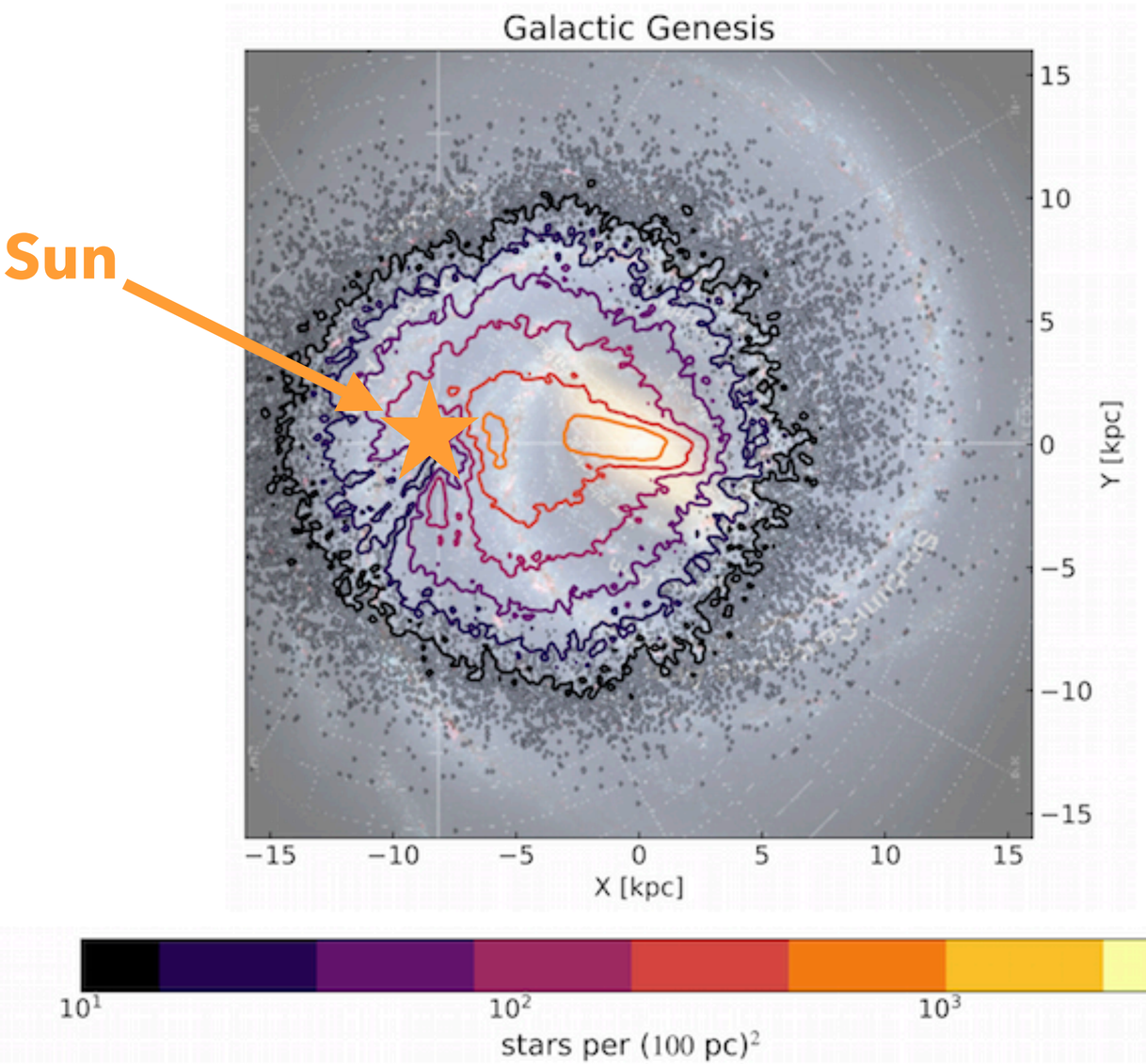
4MOST




SDSS-V

**MAIN DATA PRODUCT: ~$10^7$ STELLAR SPECTRA**

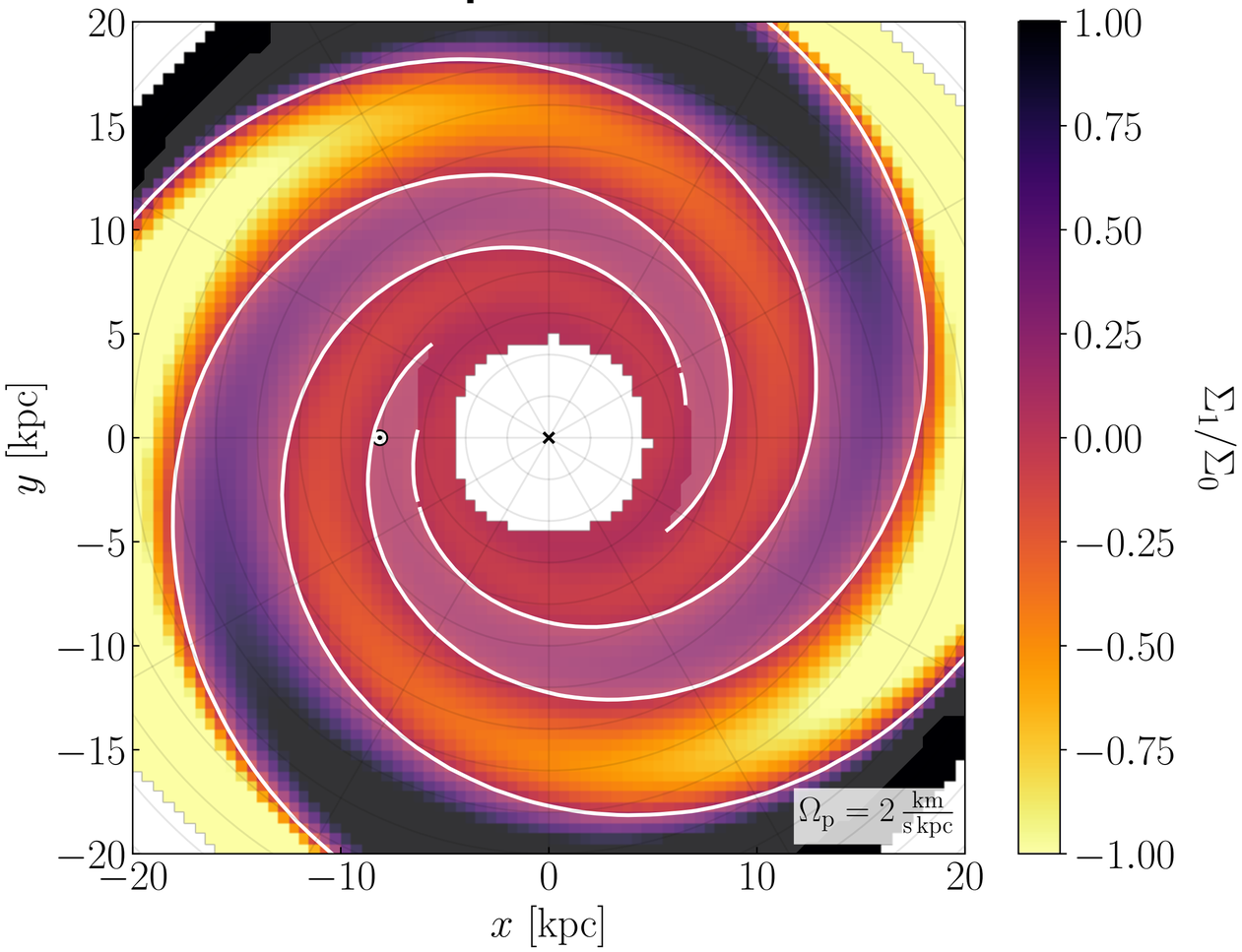
# MILKY WAY AS A RESOLVED MODEL GALAXY:



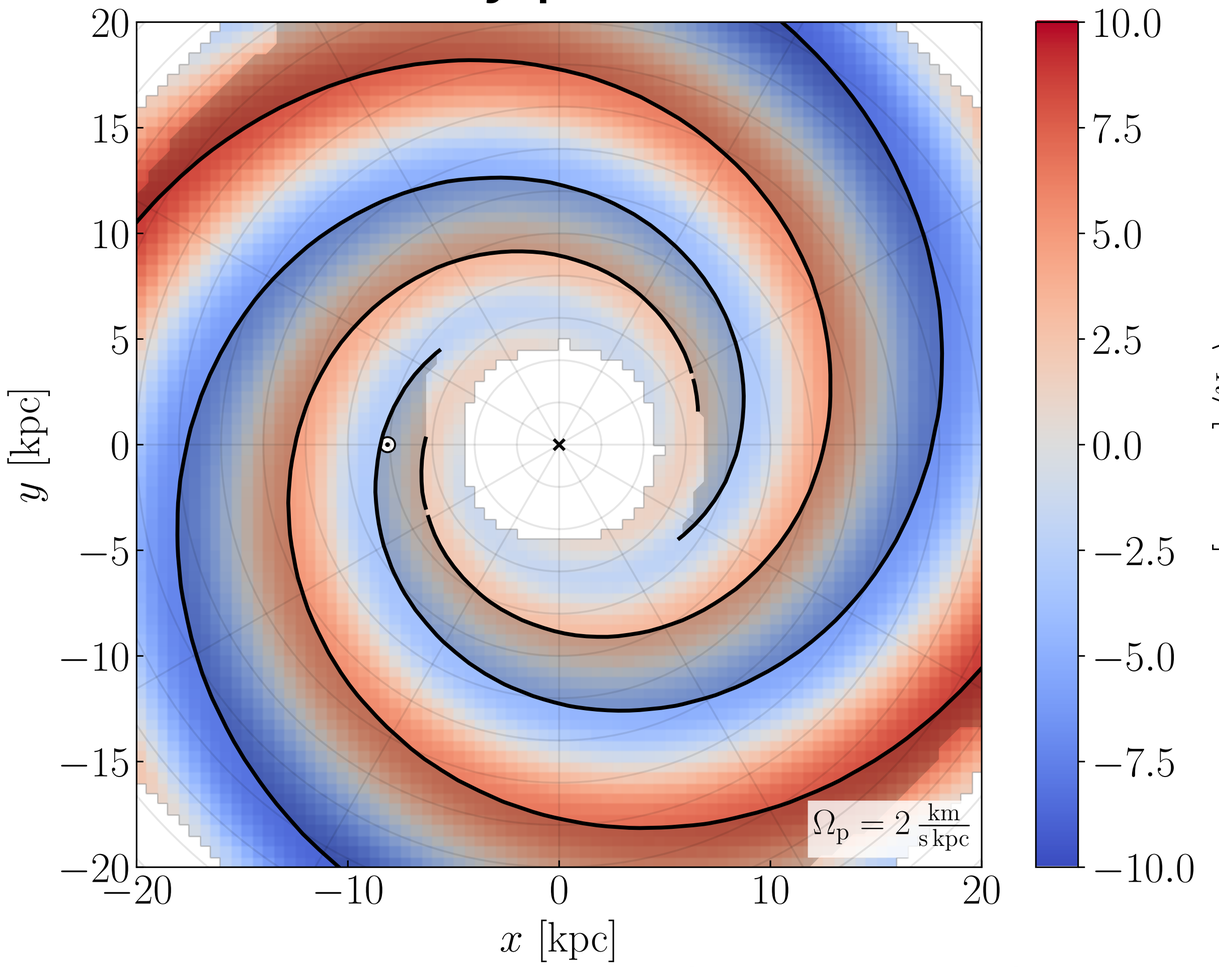

- Milky Way's formation history is encoded in its structure
- Stellar properties like age and chemical composition correlate with stellar orbits
- Stellar orbits in turn are set by global properties like gravitational potential (dark matter, gas and stars), size and shape
- –> Need to understand Milky Way in context

# QUANTIFYING MILKY WAY'S SPIRAL STRUCTURE FROM STELLAR SPECTRA

Mass perturbation



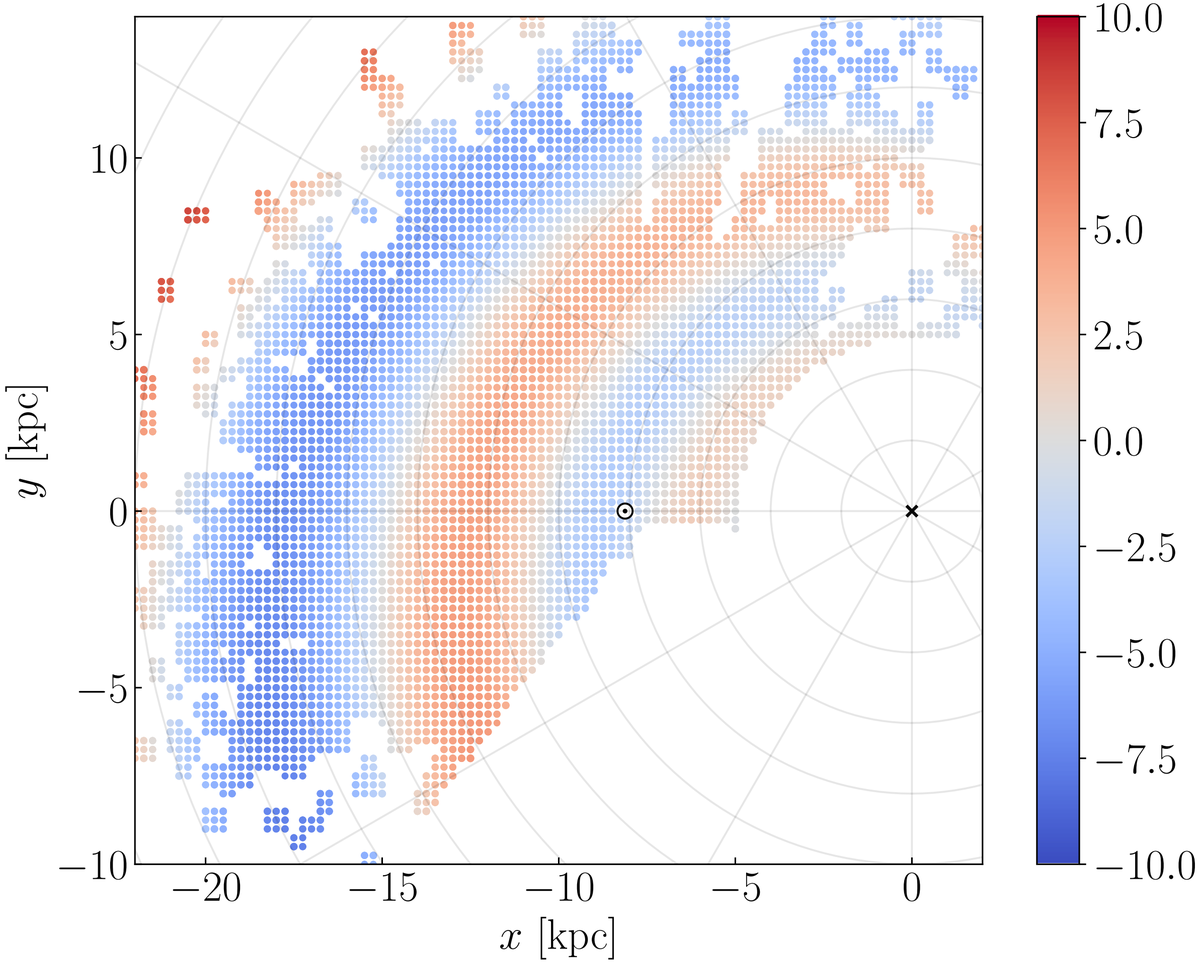

Velocity perturbation



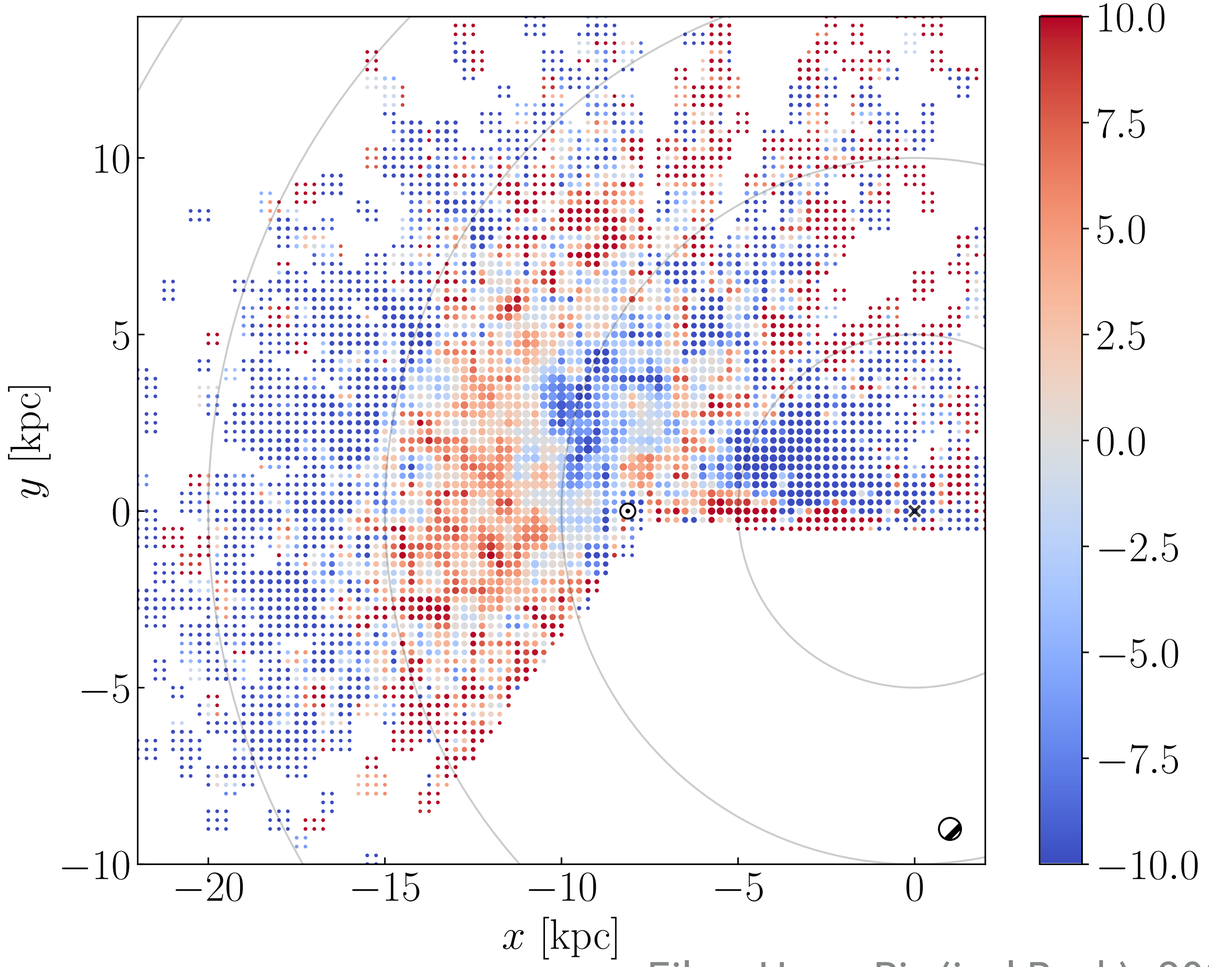

Eilers,Hogg,Rix,(incl.Buck)+2020

# QUANTIFYING MILKY WAY'S SPIRAL STRUCTURE FROM STELLAR SPECTRA

Model

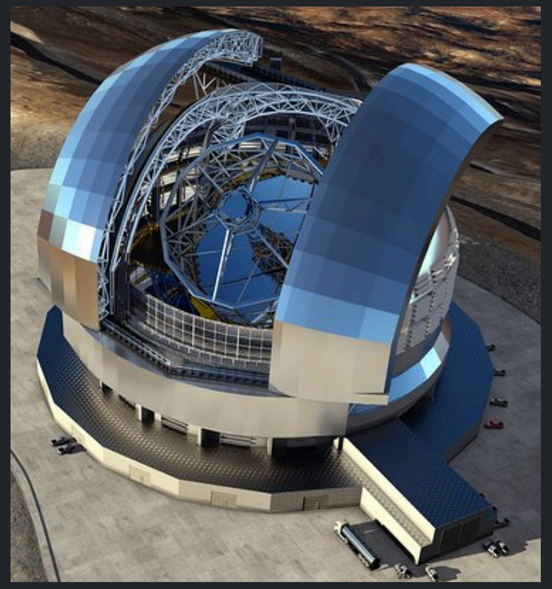



Data

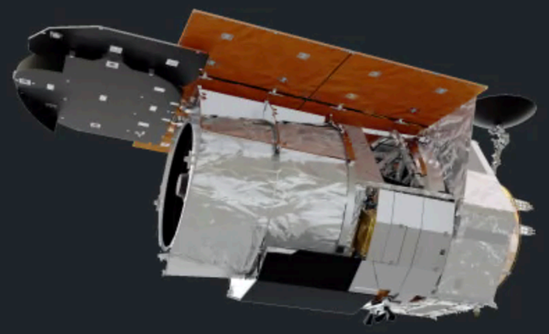



Eilers,Hogg,Rix,(incl.Buck)+2020

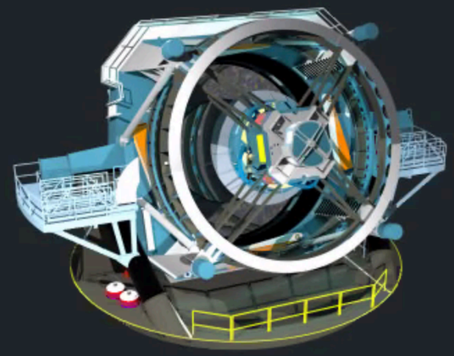
# EXTRAGALACTIC SURVEYS



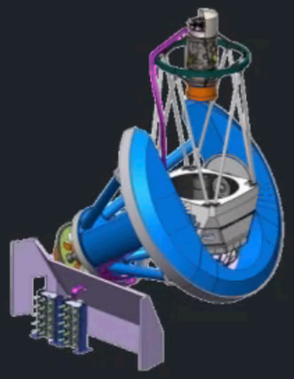
European Extremely Large Telescope



Nancy Roman Space Telescope



Vera Rubin Observatory



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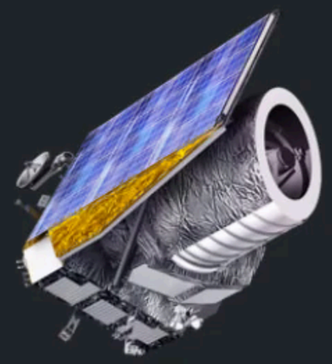


Euclid

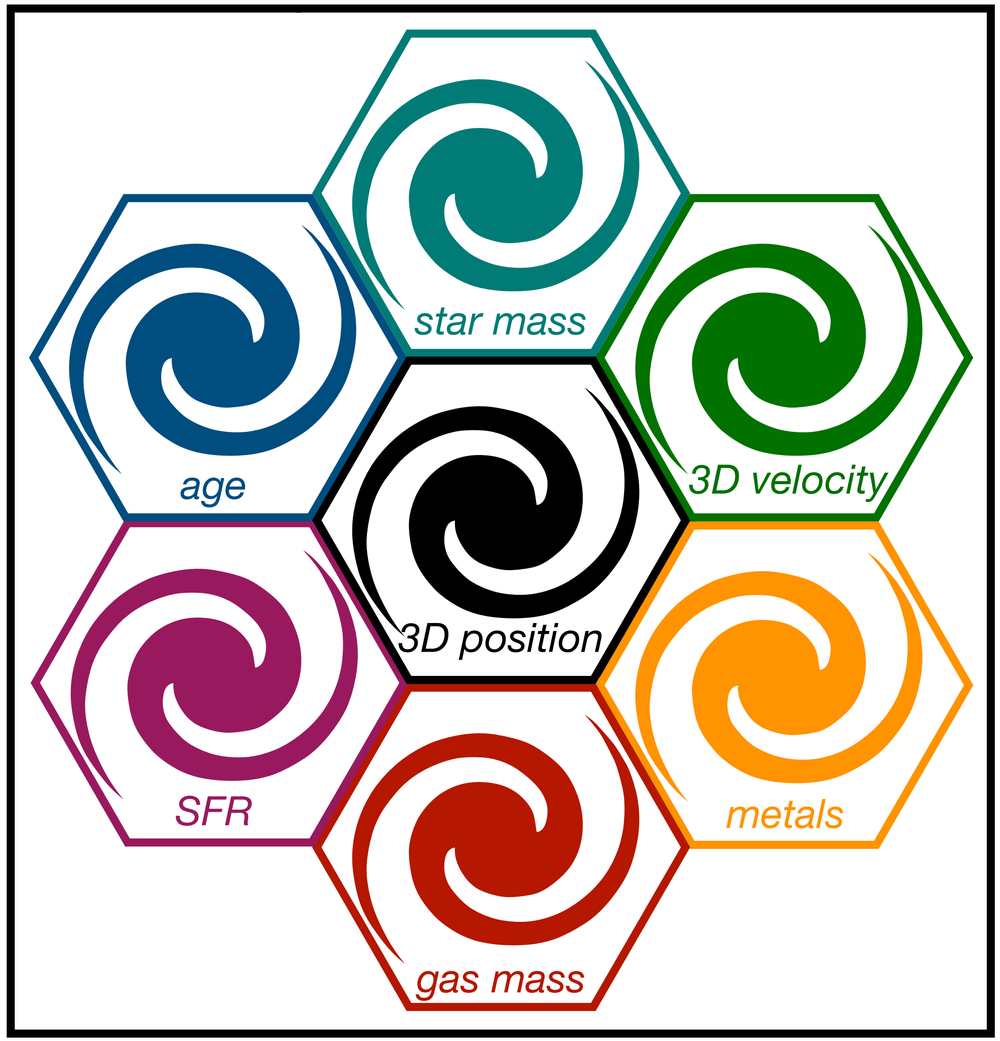
**MAIN DATA PRODUCT: ~$10^6$ GALAXY IMAGES**

**~30 TERABYTES PER NIGHT**

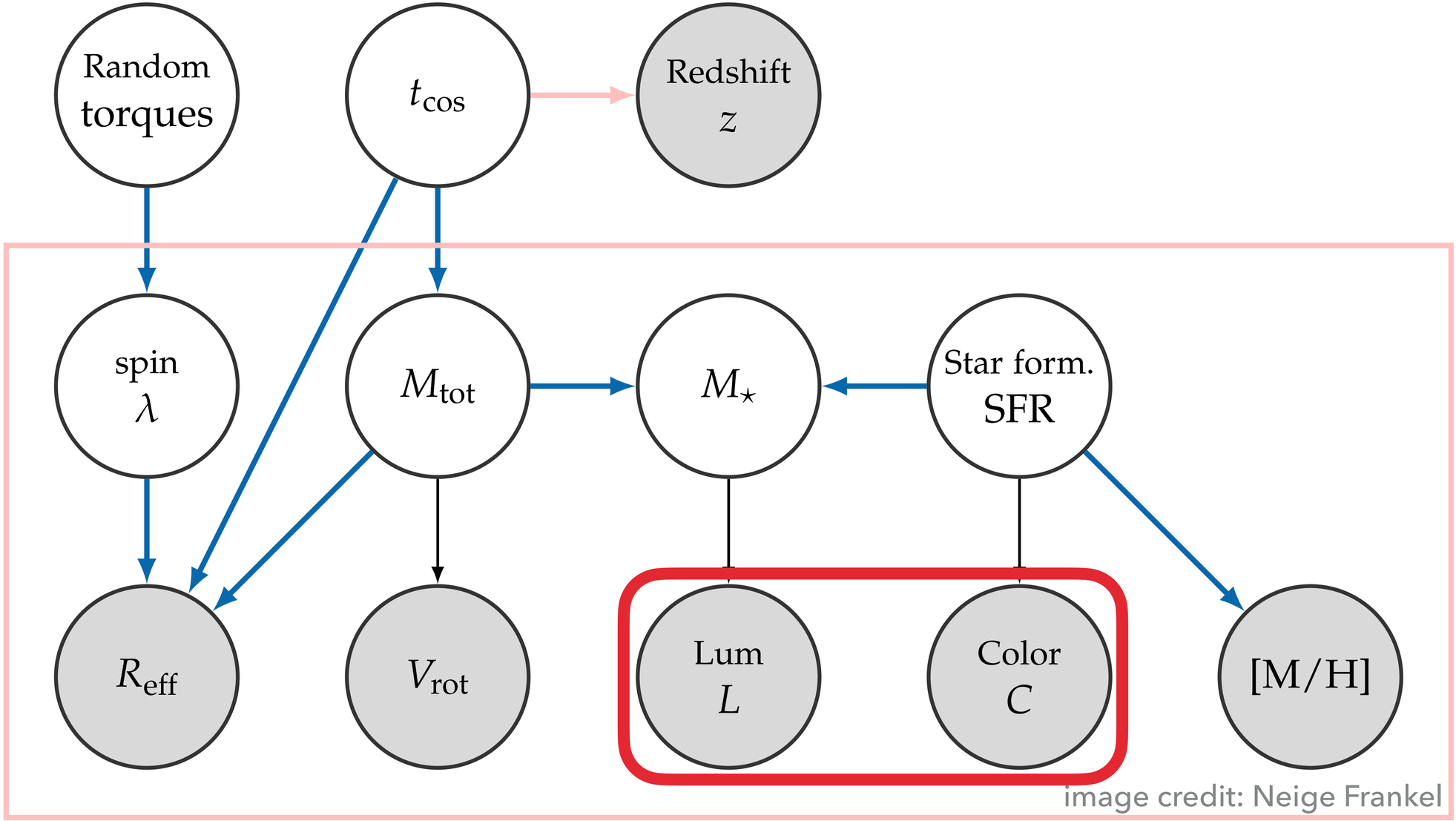
# EXTRACTING GALAXY PROPERTIES FROM THOSE IMAGES?

- Can we reconstruct intrinsic galaxy properties from their images?
- Can we build a (3D) galaxy model from multi-band images?

derive maps of physical parameters

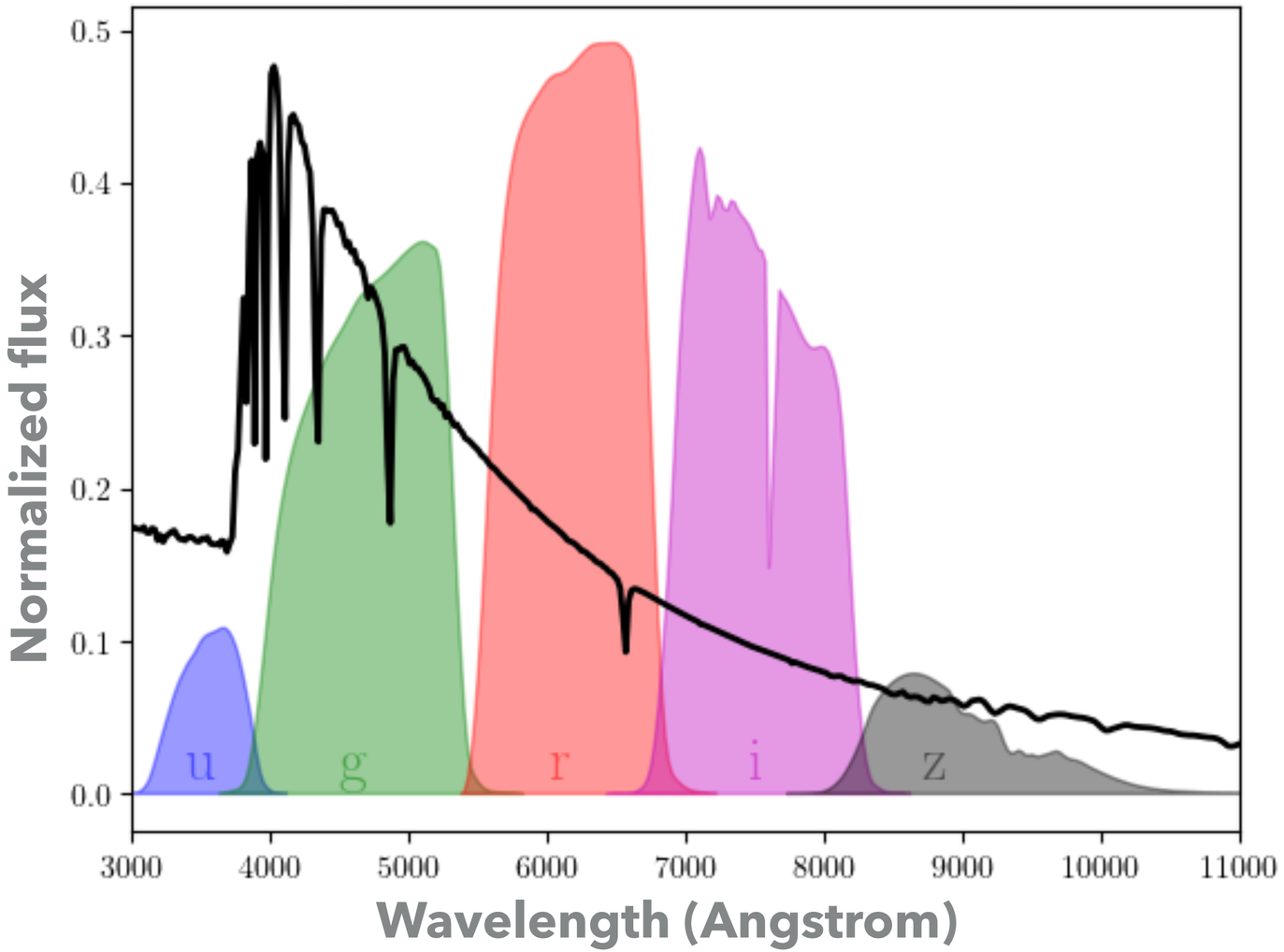


# ESTABLISHED CORRELATIONS BETWEEN OBSERVABLES AND PHYSICAL PROPERTIES

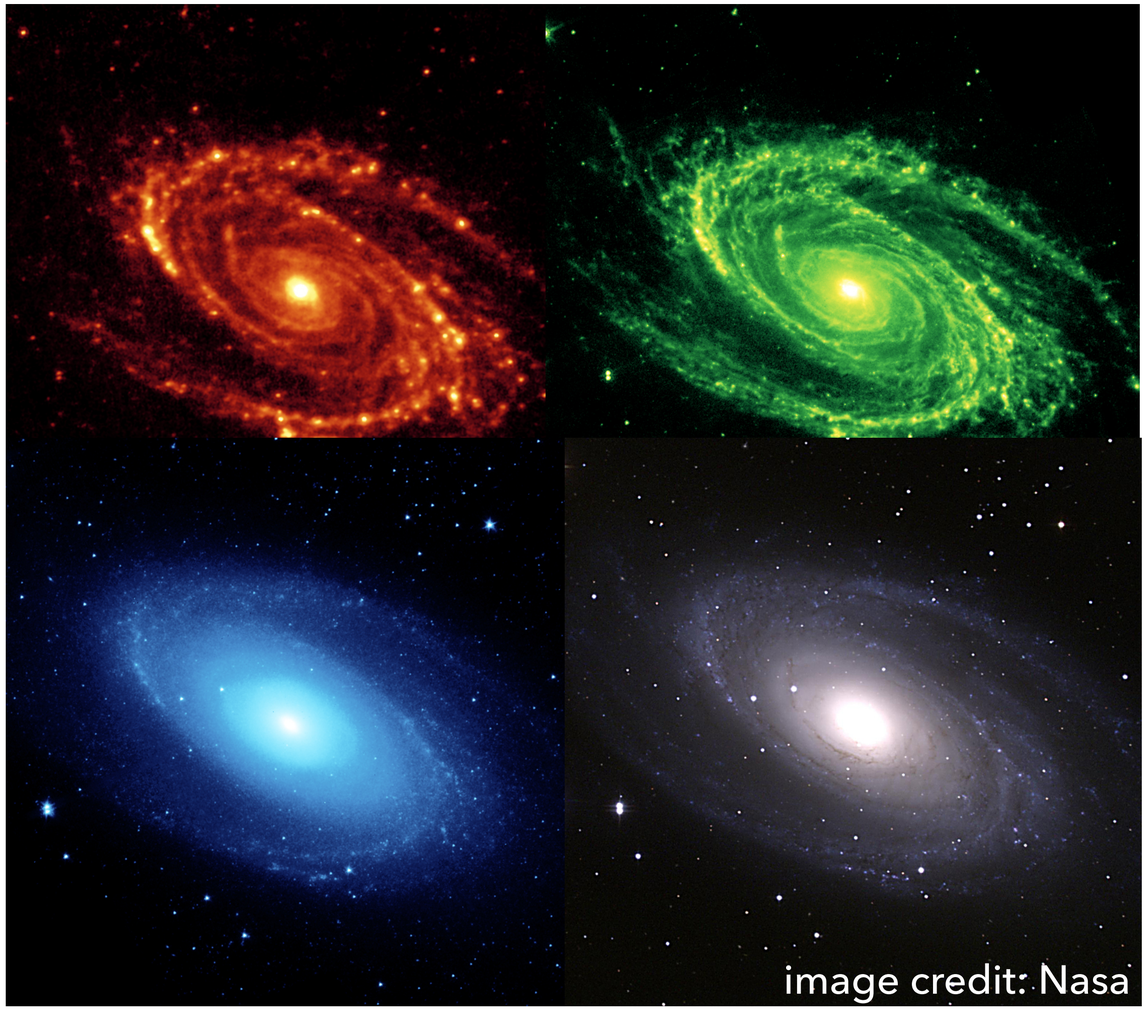


# OBSERVATIONS: SPECTROSCOPY VS. PHOTOMETRY

Spectroscopy




Photometry



# MoFA: Model-based Deep Convolutional Face Autoencoder for Unsupervised Monocular Reconstruction

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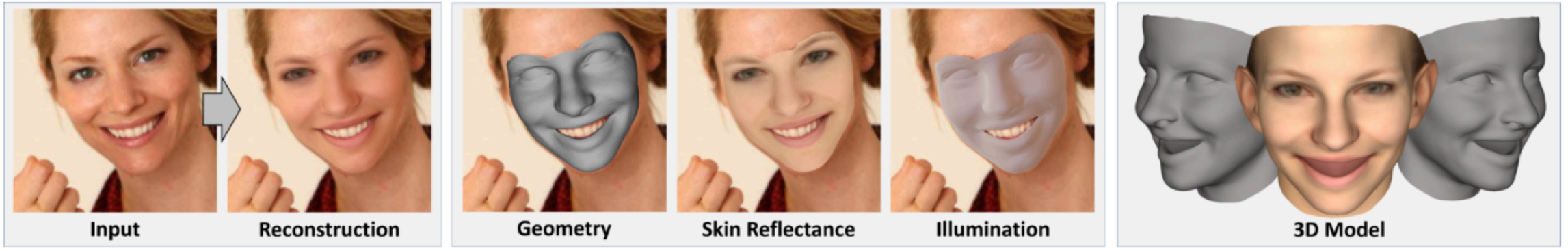
Florian Bernard[1,2] Patrick Pérez[3] Christian Theobalt[1]
[1]Max-Planck-Institute for Informatics [2] LCSB, University of Luxembourg [3]Technicolor



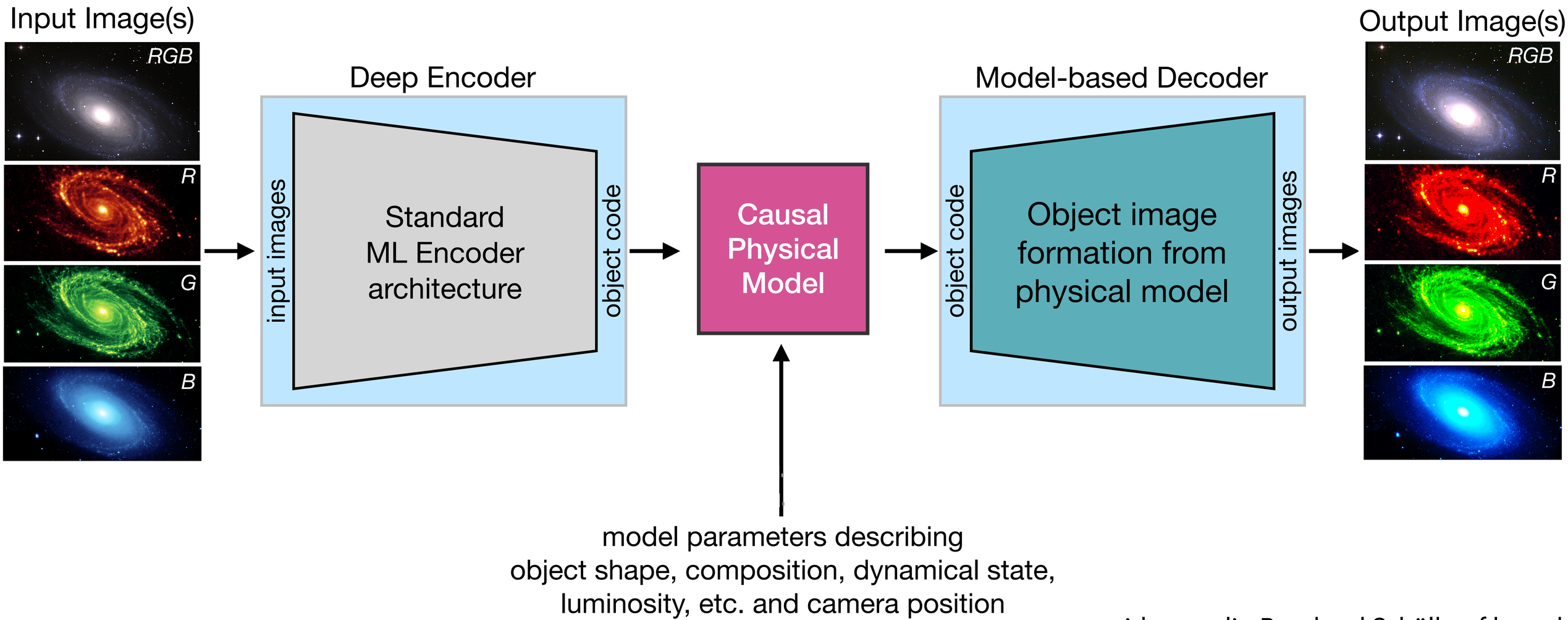

Our model-based deep convolutional face autoencoder enables unsupervised learning of semantic pose, shape, expression, reflectance and lighting parameters. The trained encoder predicts these parameters from a single monocular image, all at once.

## Abstract

*In this work we propose a novel model-based deep convo-*

tailed three-dimensional face reconstruction from a single arbitrary in-the-wild image, e.g., downloaded from the Internet, is still an open research problem due to the high degree

# THE IDEA: RECONSTRUCTING GALAXY MODELS FROM IMAGES




idea credit: Bernhard Schölkopf based on face reconstruction by Tewari+2017

# SUMMARY AND CONCLUSION

- simulations: great success in modelling the formation of galaxies
  - can describe statistical properties of galaxies well
  - but limited in describing individual objects
- observations: exquisite data for Milky Way and external galaxies
  - big data challenge in astronomy
  - Need to think about smart methods to process the data

ASTRONOMY CAN GREATLY BENEFIT FROM EXPLORING CAUSAL MODELS!