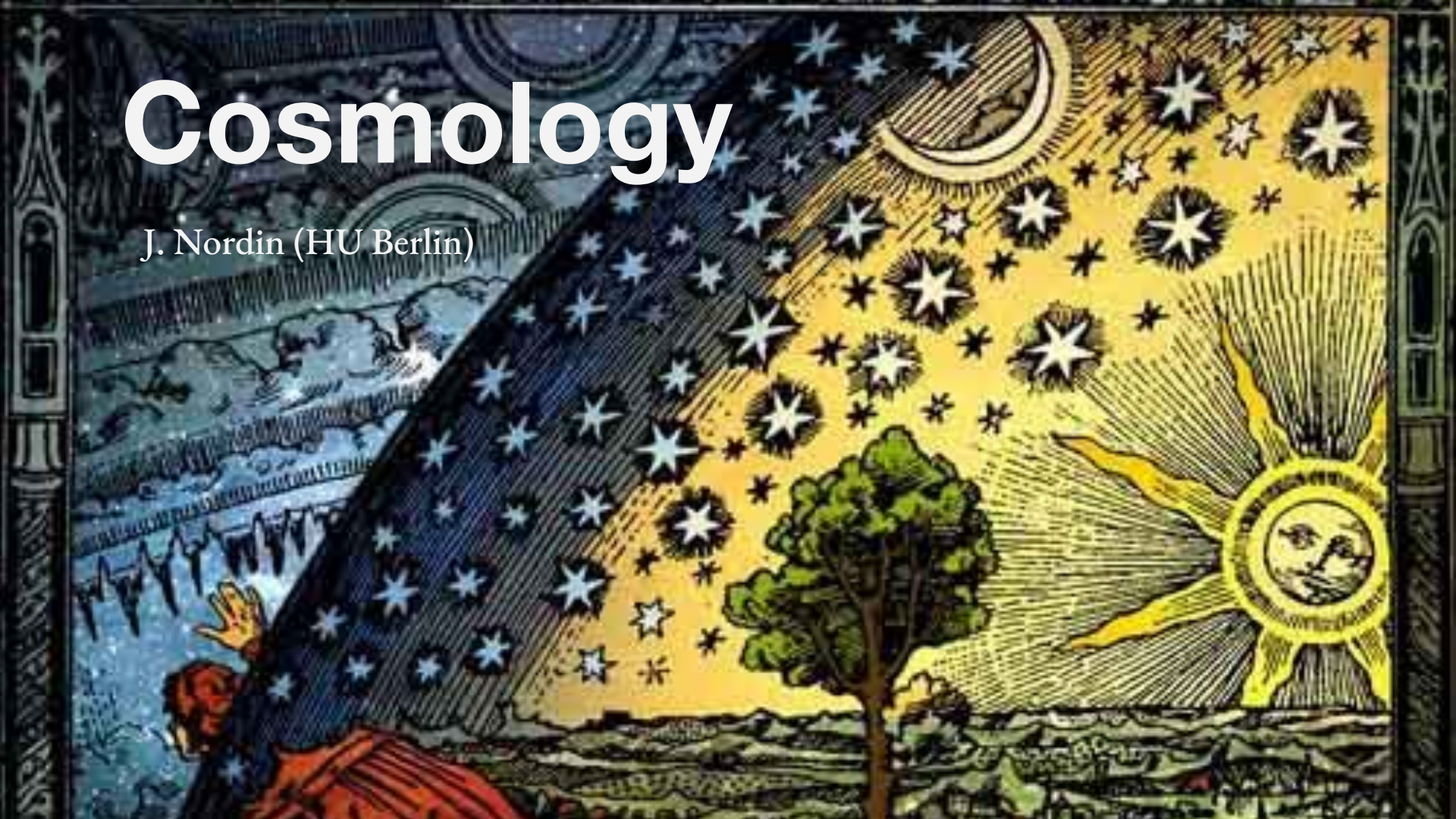
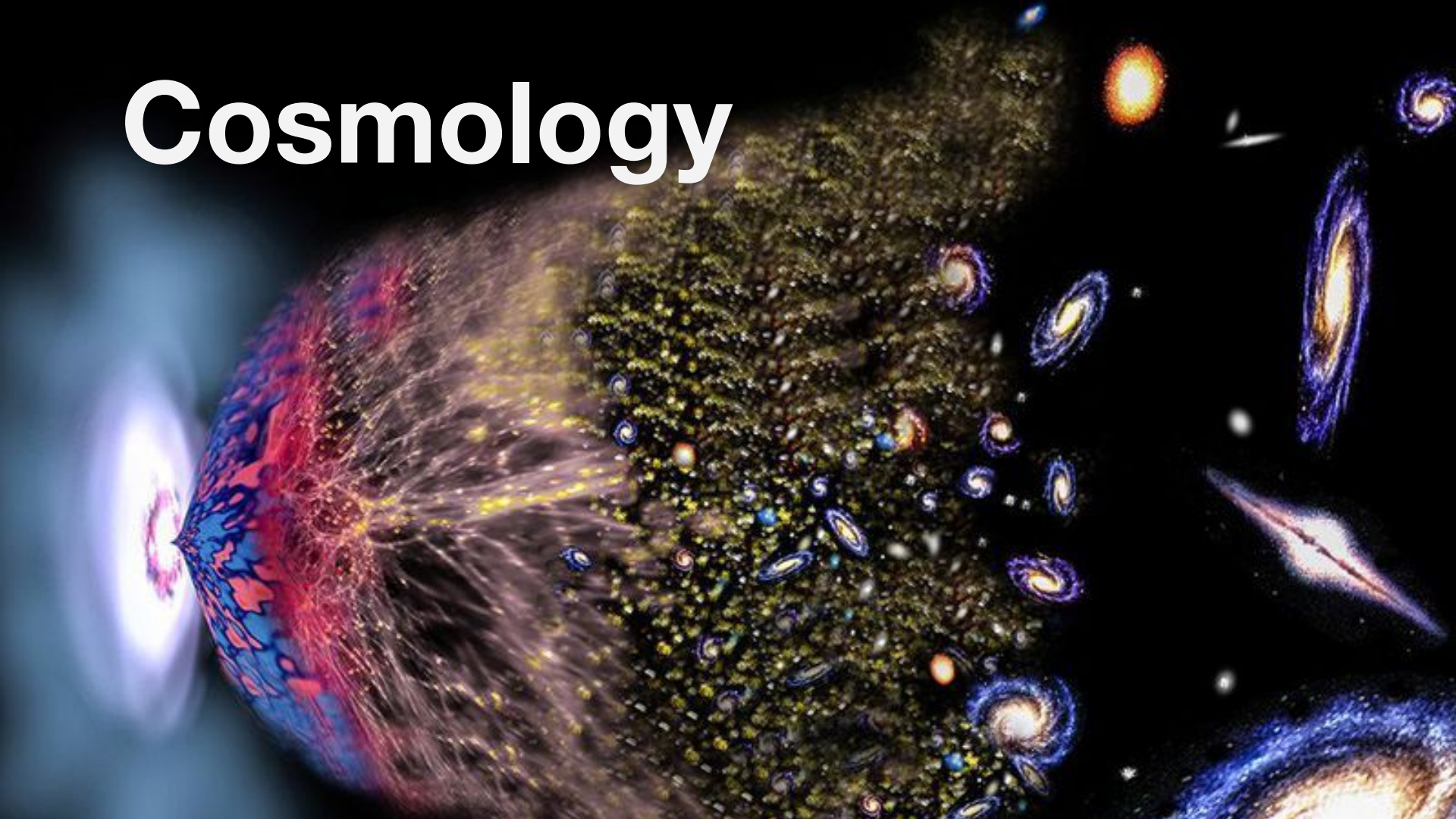


Cosmology

J. Nordin (HU Berlin)

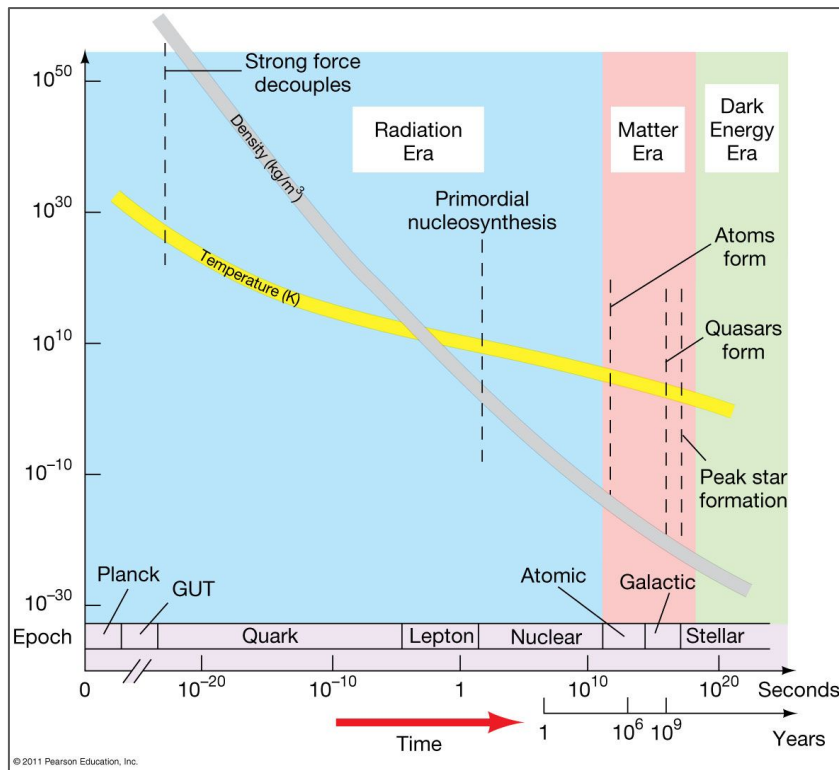


Cosmology



Cosmology

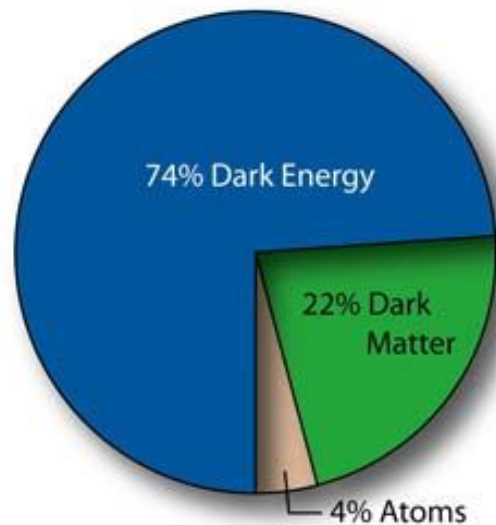
- Origin, development and future of the Universe.
- Fundamental physics through extreme scales.



Λ CDM

- **Standard model of Cosmology.**

- **Big Bang**
- **Dark Matter**
- **Dark Energy**
- **Inflation**
- **+ Photons / Baryons**



Simple
predictions

$$\left(\frac{\dot{a}}{a} \right)^2 + \frac{k}{a^2} = \frac{8\pi G}{3} \rho_{tot},$$

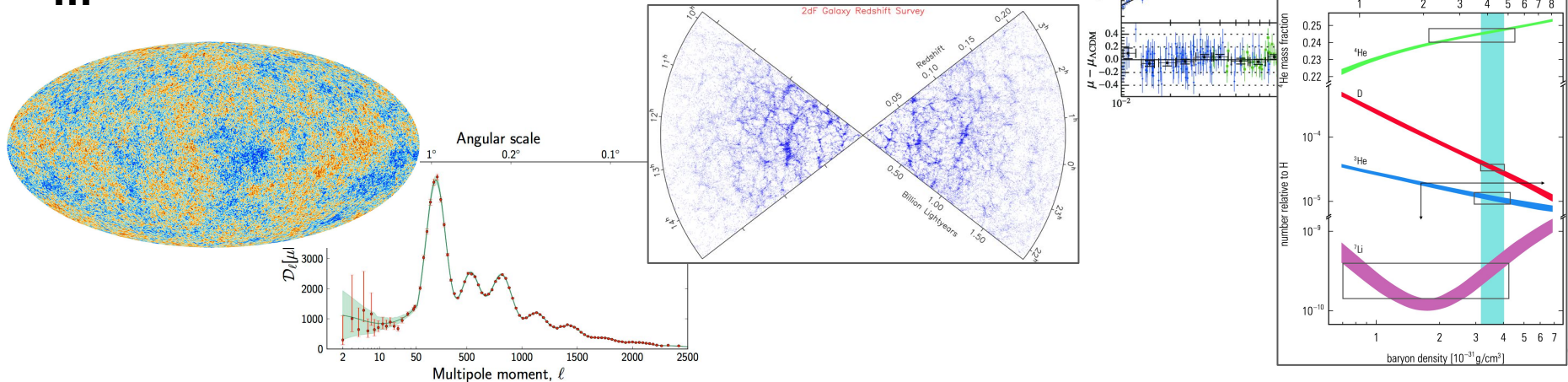
$$H(t) = \frac{\dot{a}(t)}{a(t)}$$

$$d_L(z; H_0, \Omega_M, \Omega_\Lambda) = \frac{c(1+z)}{H_0 \sqrt{|\Omega_K|}} \mathcal{S} \left(\sqrt{|\Omega_K|} \int_0^z \frac{dz'}{H'(z')} \right)$$

Supporting Evidence

- Distribution of elements.
- Rotational velocities.
- Expansion history of the Universe.
- Fluctuations in the CMB.
- Growth of structure & distribution of galaxies.

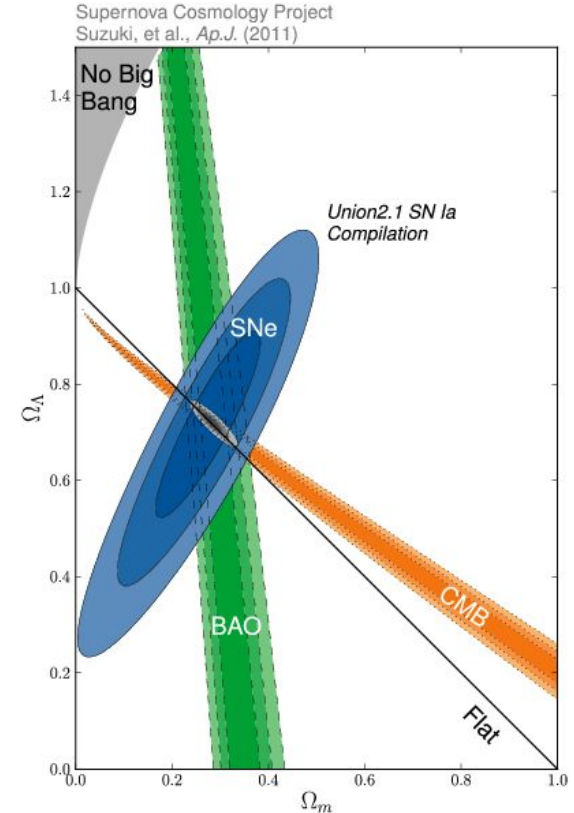
...



Supporting Evidence

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...



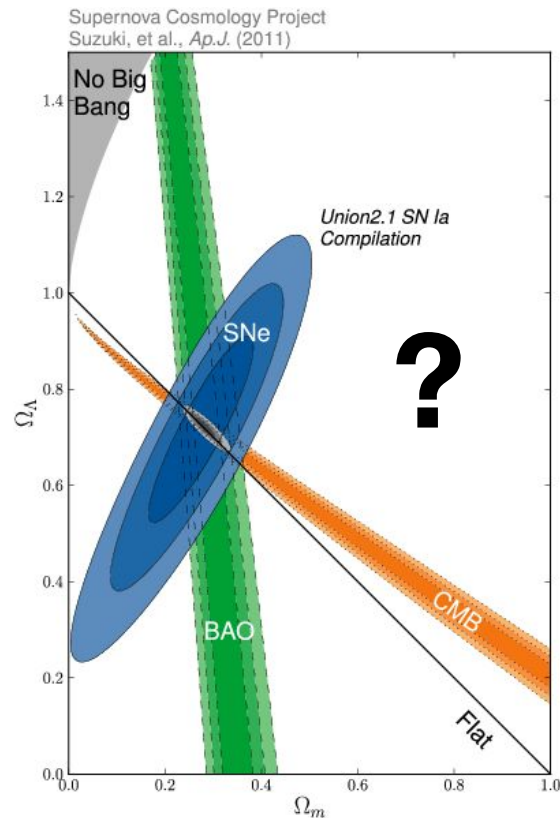
But ...

Annoyances:

- Origin
- Gravity
- Matter / Anti-Matter asymmetry
- What happened to the WIMP?

Tensions:

- Hubble parameter
- Growth of structure



Hubble Tension

$$H(t) = \frac{\dot{a}(t)}{a(t)}$$

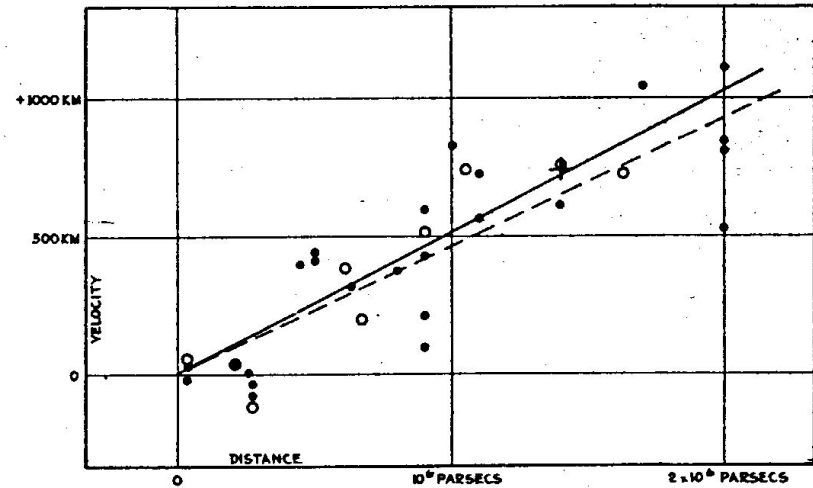
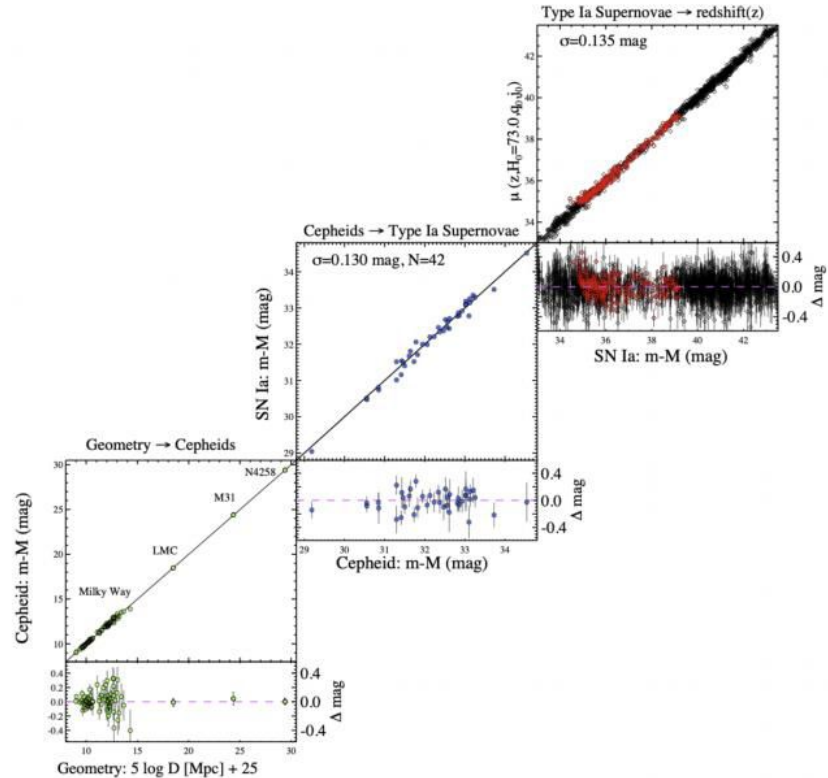


FIGURE 1

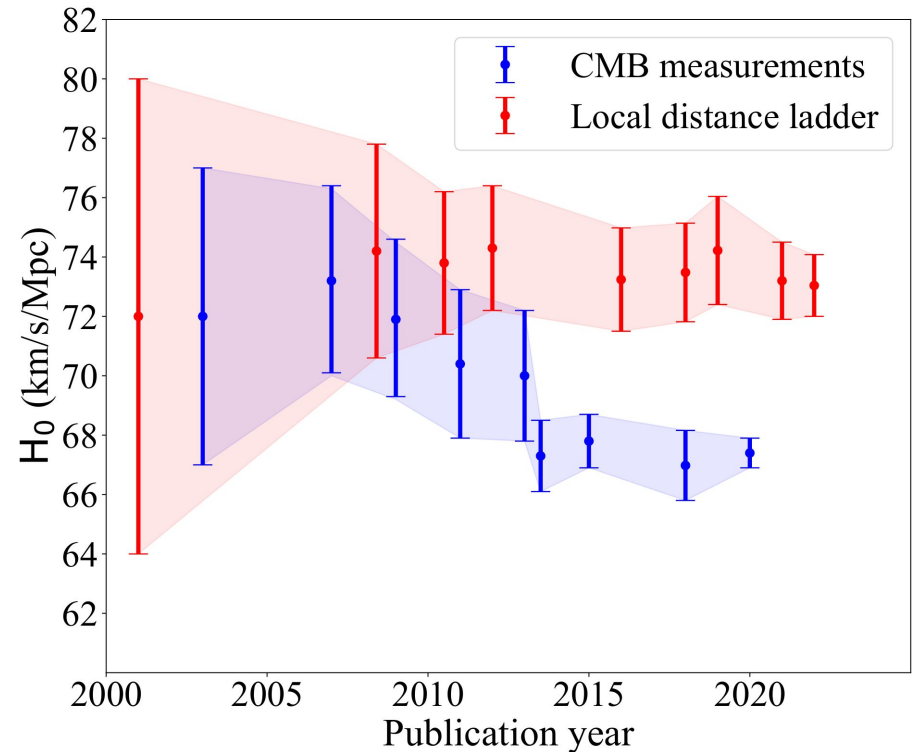
Hubble Tension

$$H(t) = \frac{\dot{a}(t)}{a(t)}$$



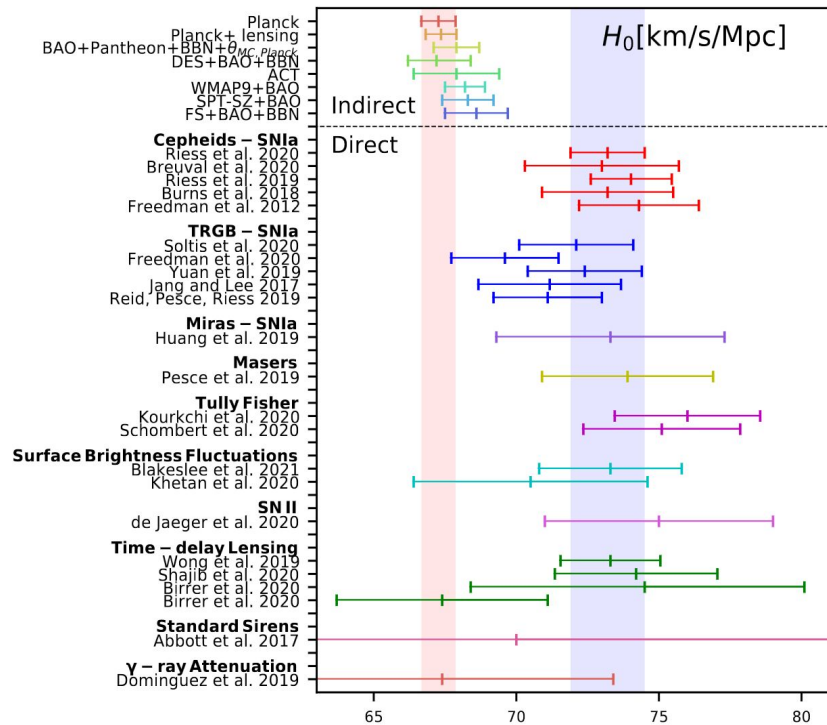
Hubble Tension

Local measurement vs CMB predictions do not agree.



Hubble Tension

Local measurement vs CMB predictions do not agree.



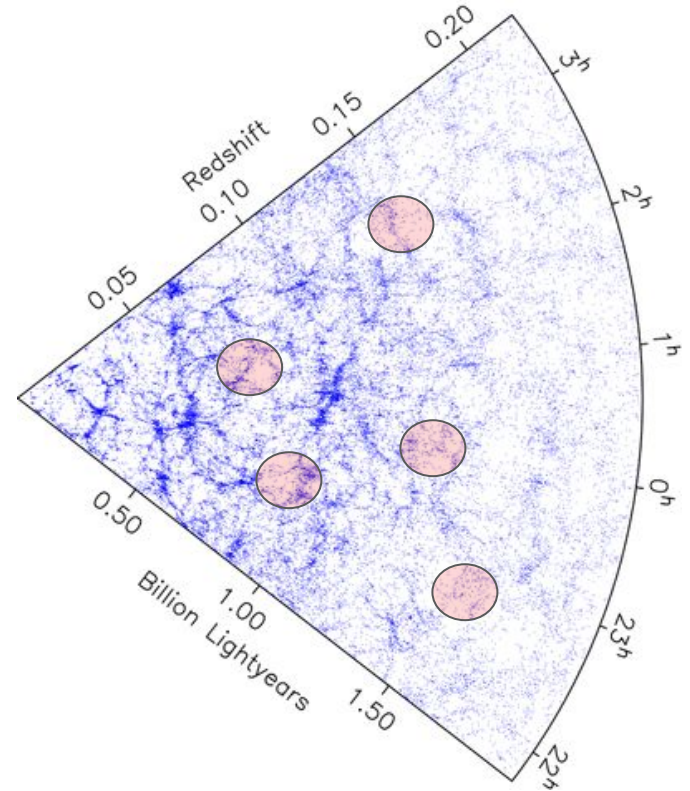
Growth Structure Tension

Initial perturbations grow:

$$\frac{d^2 D_+}{da^2} + \frac{d \ln(a^3 H)}{da} \frac{d D_+}{da} - \frac{3 \Omega_m H_0^2}{2 a^5 H^2} D_+ = 0$$

Reference scale at 8 Mpc:

$$\sigma_8(z) \equiv \sigma_8(z=0) D_+(z)$$



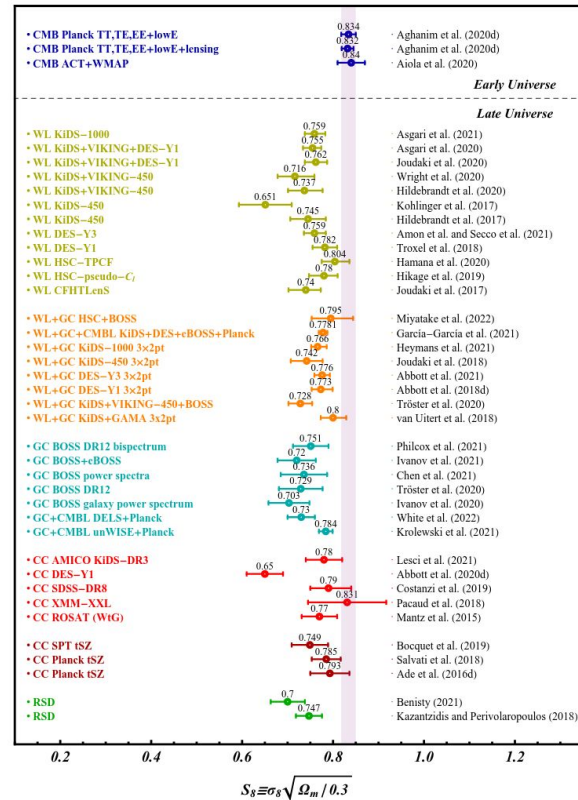
Growth Structure Tension

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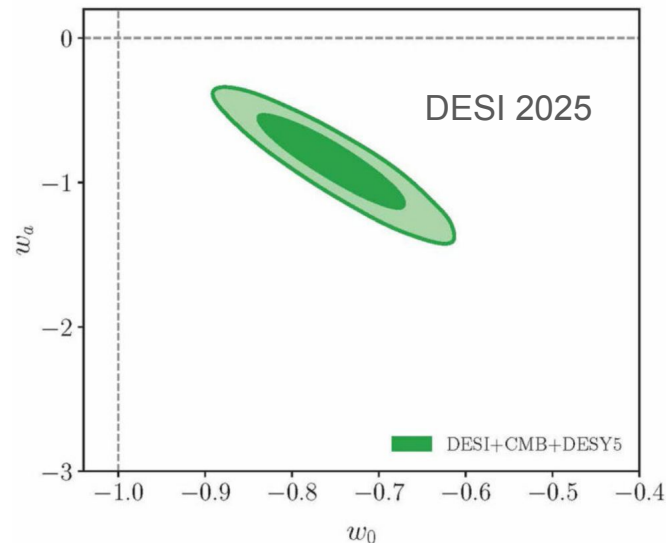
$$\sigma_8(z) \equiv \sigma_8(z=0) D_+(z)$$



Cosmology Today

- Tensions are persistent.
- Individual local measurements uncertain, but they aggregate.
- No comprehensive alternative theory.

Looking for systematics free alternative for confirmation.



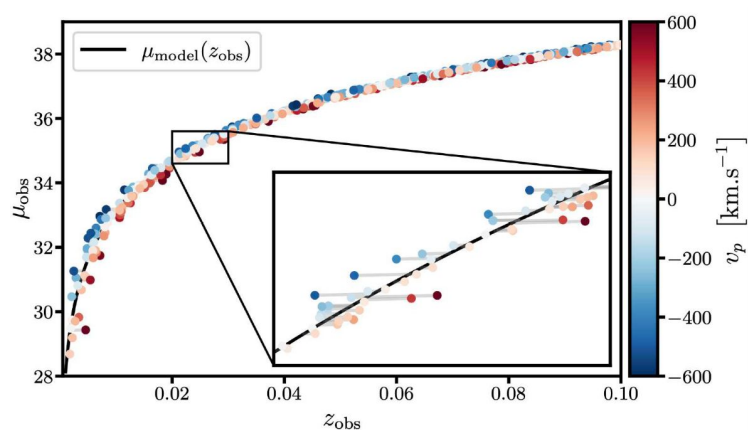
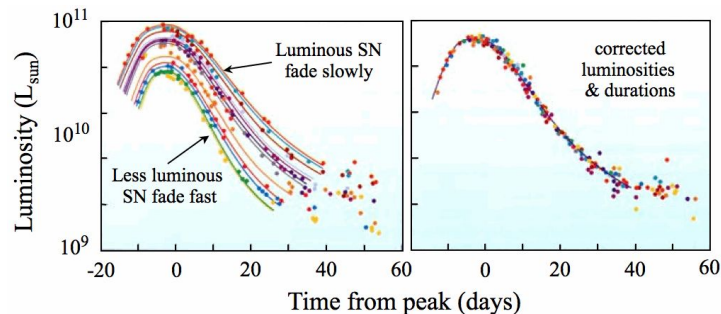
$$\rho \propto a^{-3(1+w)}.$$

$$w(z) = w_0 + w_a(1 - a) = w_0 + w_a z / (1 + z)$$

Cosmology at HU

Standard Candles:

- Type Ia Supernovae
- Kilonovae

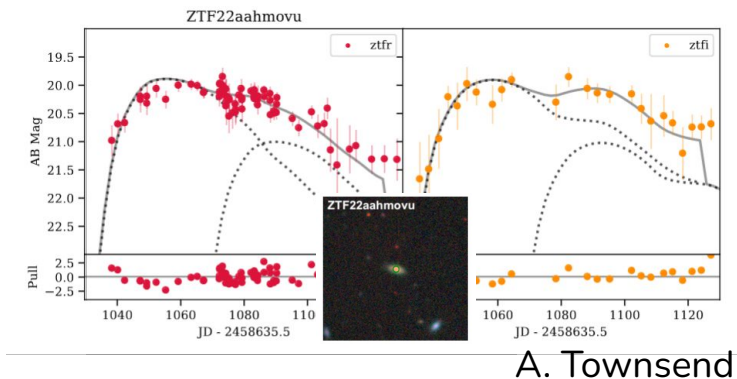
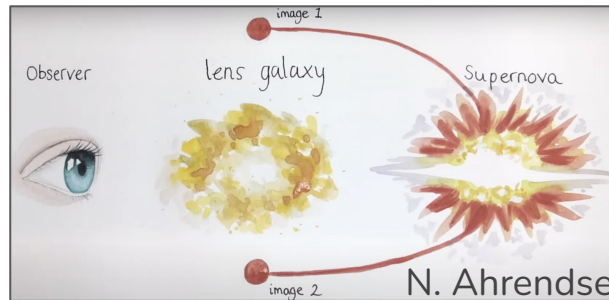


Also trace gravity through peculiar velocities.

Measuring H_0

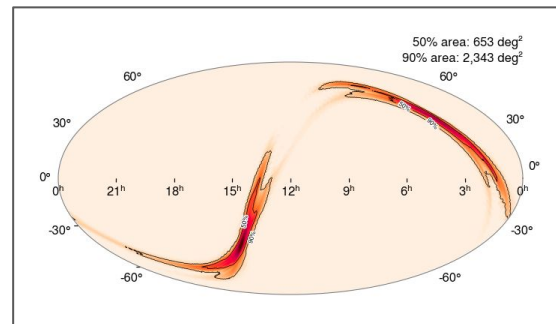
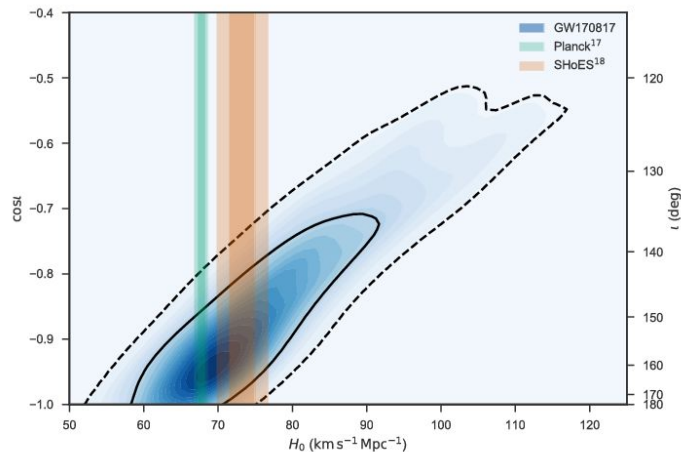
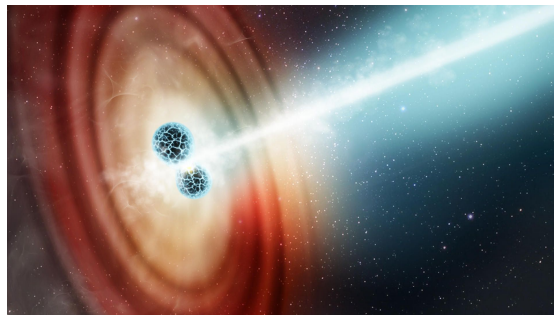
Gravitationally Lensed SNe

First systematic ZTF search:



Measuring H_0

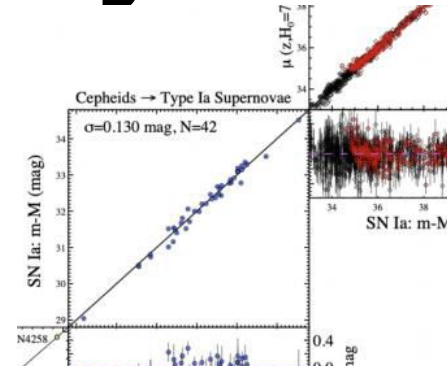
Kilonovae as Gravitational Sirens
Ultrasat!



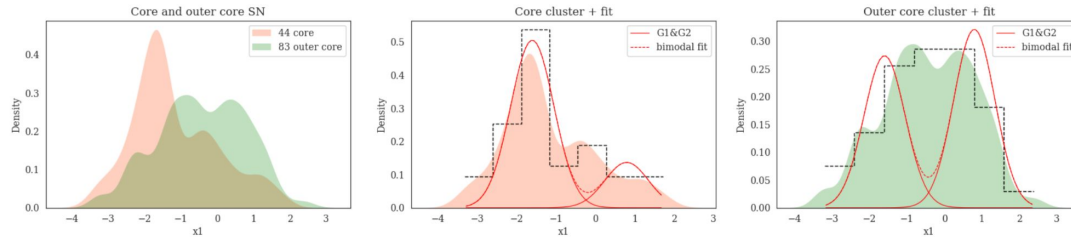
Supernova Physics

Local H_0 limited by (SN) systematics:
SNe Ia are not uniform.

Exploring through large samples
(and UV data).



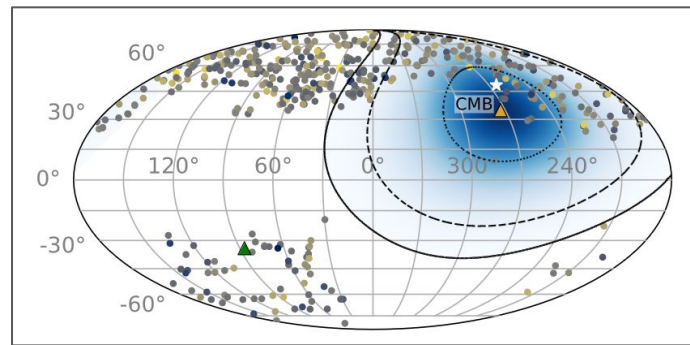
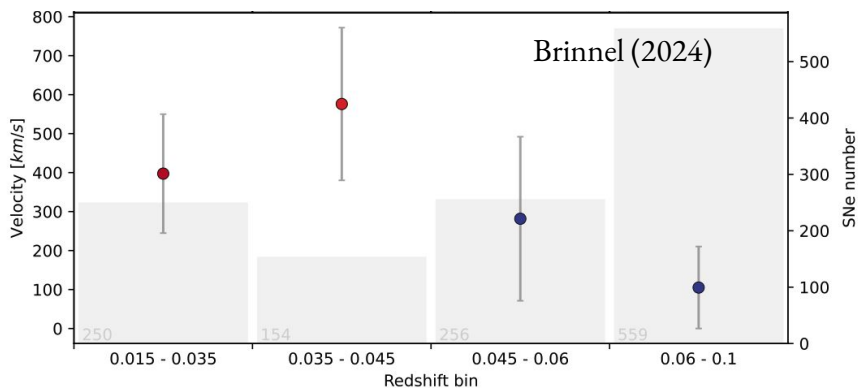
Bimodal fit for x_1 distribution at $\mu_1 = -1.6$ $\mu_2 = 0.8$



A. Eranhalodi

Bulk Flows

Peculiar velocities to first order map our bulk flow.



Significant local flows, decreasing at larger distances - no signs of dark flows.

Demonstrates sample + methodology.

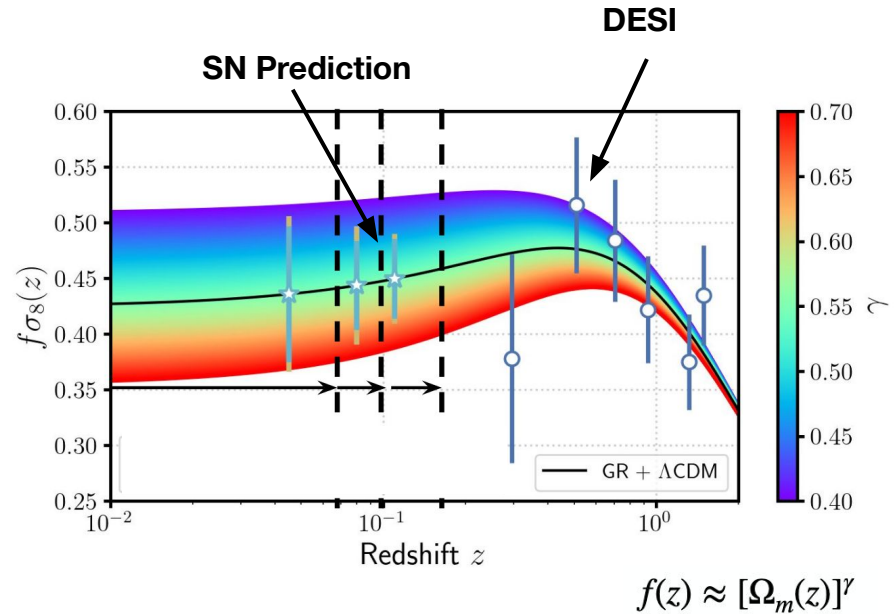
ZTF SN Structure Growth

Goal of next 2-3 years:
Using O(100 000) SNe Ia measure local structure growth to cosmic variance.

- **Most precise distances.**
- **No matter bias or photometric redshifts.**
- **Ideal redshift ($z \approx 0.1$).**

Challenges:

- **Photometric classification.**
- **Host galaxy redshifts.**



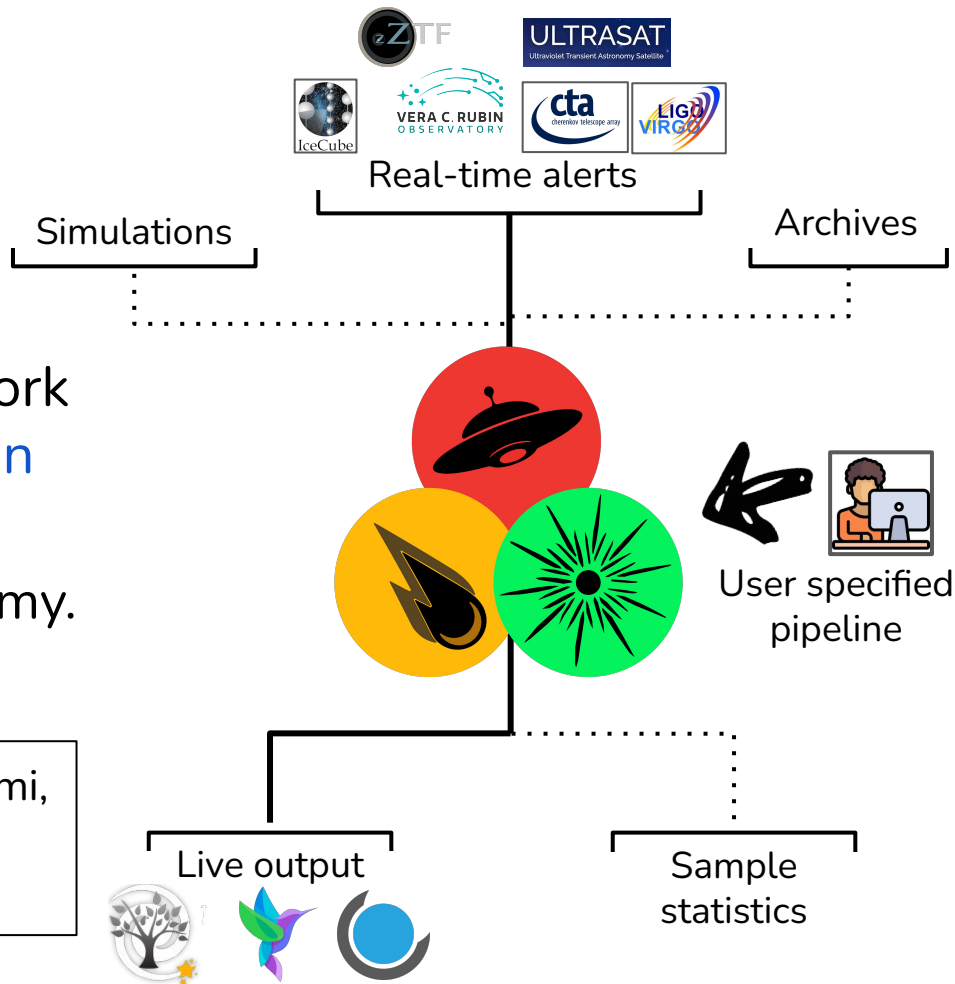
AMPEL

Analysis and workflow framework
for high throughput time-domain
astronomy.

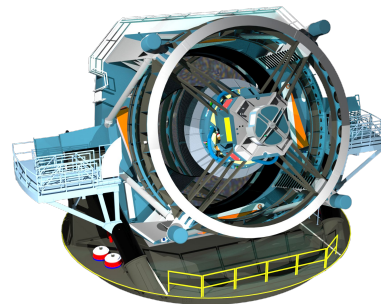
Realizes code-to-data in astronomy.

<https://github.com/AmpelAstro>

Team: JN, **V. Brinnel**, **J. van Santen**, M. Giomi,
S. Reusch, M. Kowalski, R. Stein, A.
Townsend, A. Ernst, S. Velzen,



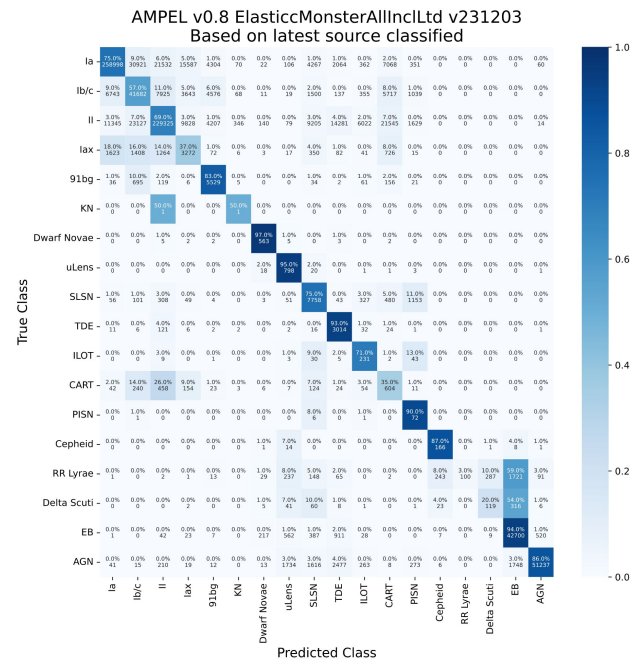
The Vera Rubin Observatory



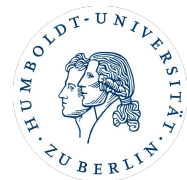
Vera Rubin Observatory:

- **Up to 10 million alerts / night.**
- **AMPEL /DES Y one of six LSST endpoints**
- **Fast response w. ~80% ML classification (ELAsTiCC data challenge)**

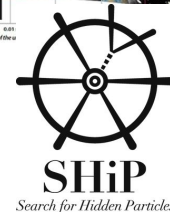
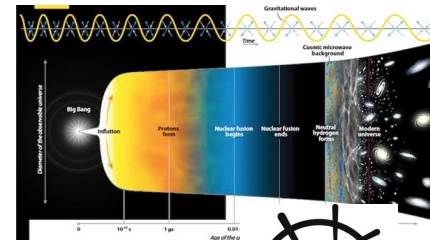
Alerts supposed to start in less than two months. ...



Cosmology



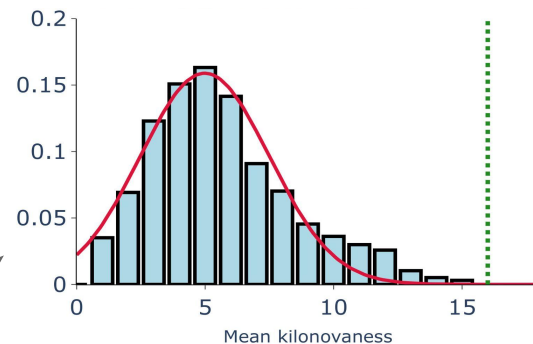
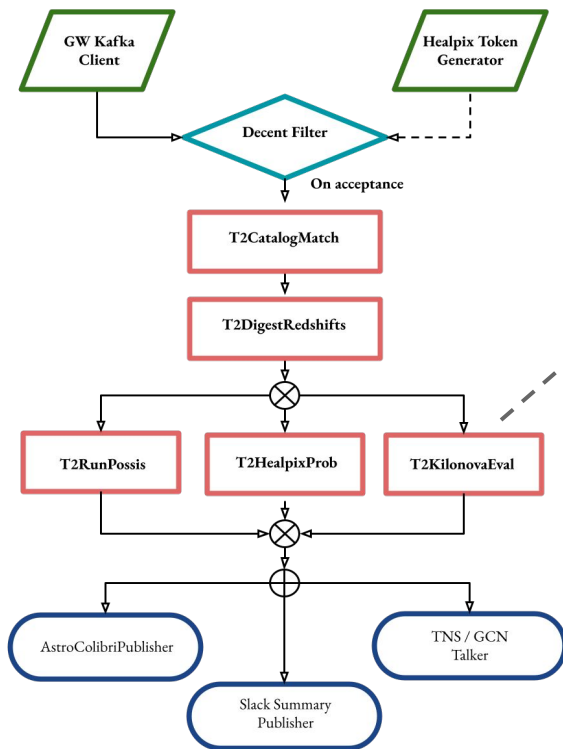
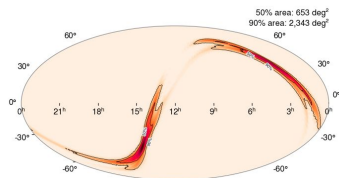
- **Cosmology at an interesting sport:**
 - Tensions will be resolved within the next years
 - Other angles: CMB polarization / SHiP
- **Cosmology @ HU / DESY:**
 - **AMPEL** 🍷🌿
 - Processing and analysis of large transient samples.
 - ML photometric classification.
 - Growth of structure constraints from the ZTF survey.



Workflow design process

1. Design

- Install local environment
- Formalize workflow
- Identify existing units



2. Develop

- Create interface to science specific algorithm(s).
- Test ...

3. Run

- Scale at computer center
- Public live instance @ DESY
- Publish code for others

