Topic III: Transients and Variables in Nearby Galaxies with Mephisto

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Mephisto Survey

- The main features of Mephisto can be summarized as follows:

wide-field multi-channel

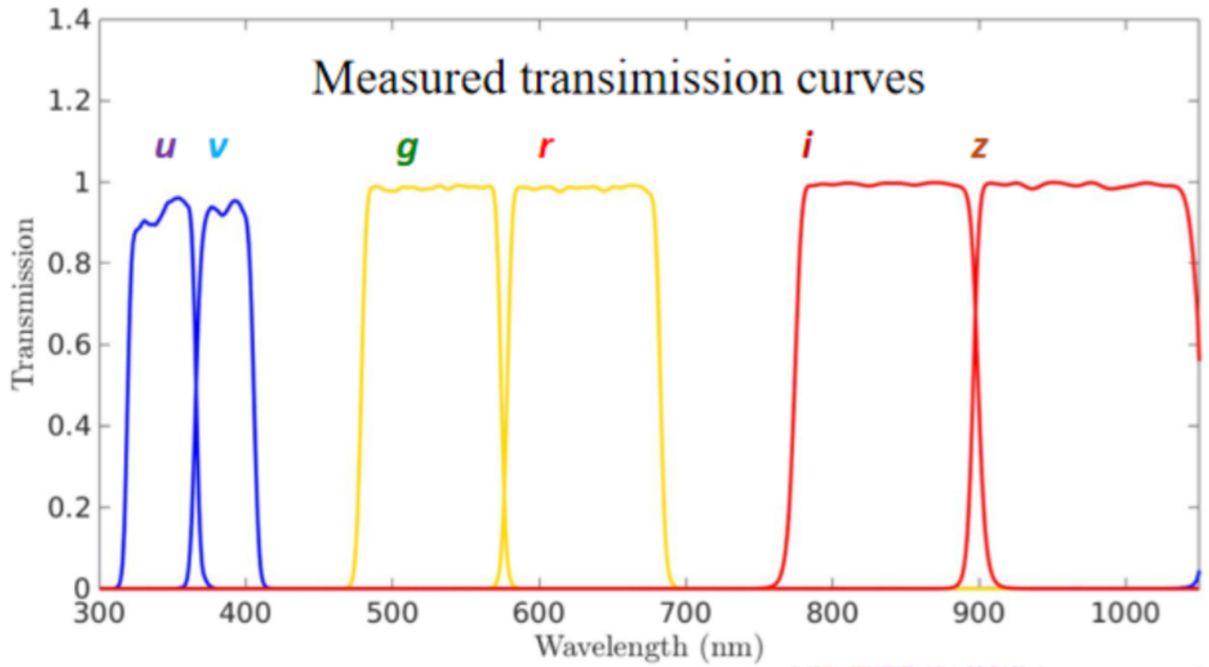
$$\text{Mephisto} = \text{Survey} + \underline{\text{Real}}\ \text{Color}$$

< sub-minute

- Such a characteristic of Mephisto will play an extremely important rule in searching and studying **fast transients with short durations**, because the time for the time of switching filter is about a few minutes for large optical telescopes.

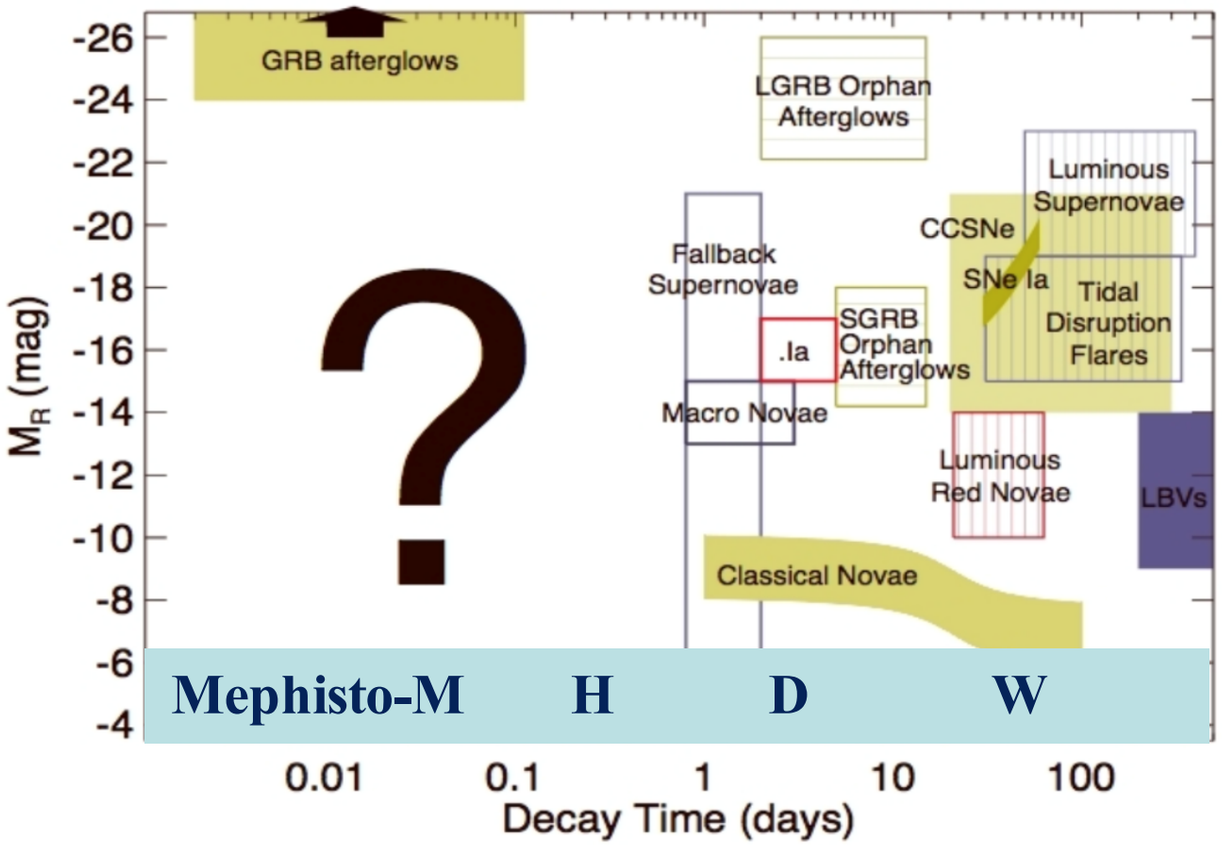
Survey	Area	Cadence
Mephisto-W	27000 deg^2	~ Month
Mephisto-D	N*1800 deg^2	> Day
Mephisto-H	N*180 deg^2	> Hour
Mephisto-M	N*18 deg^2	> Minute

Mephisto survey for transients and variables

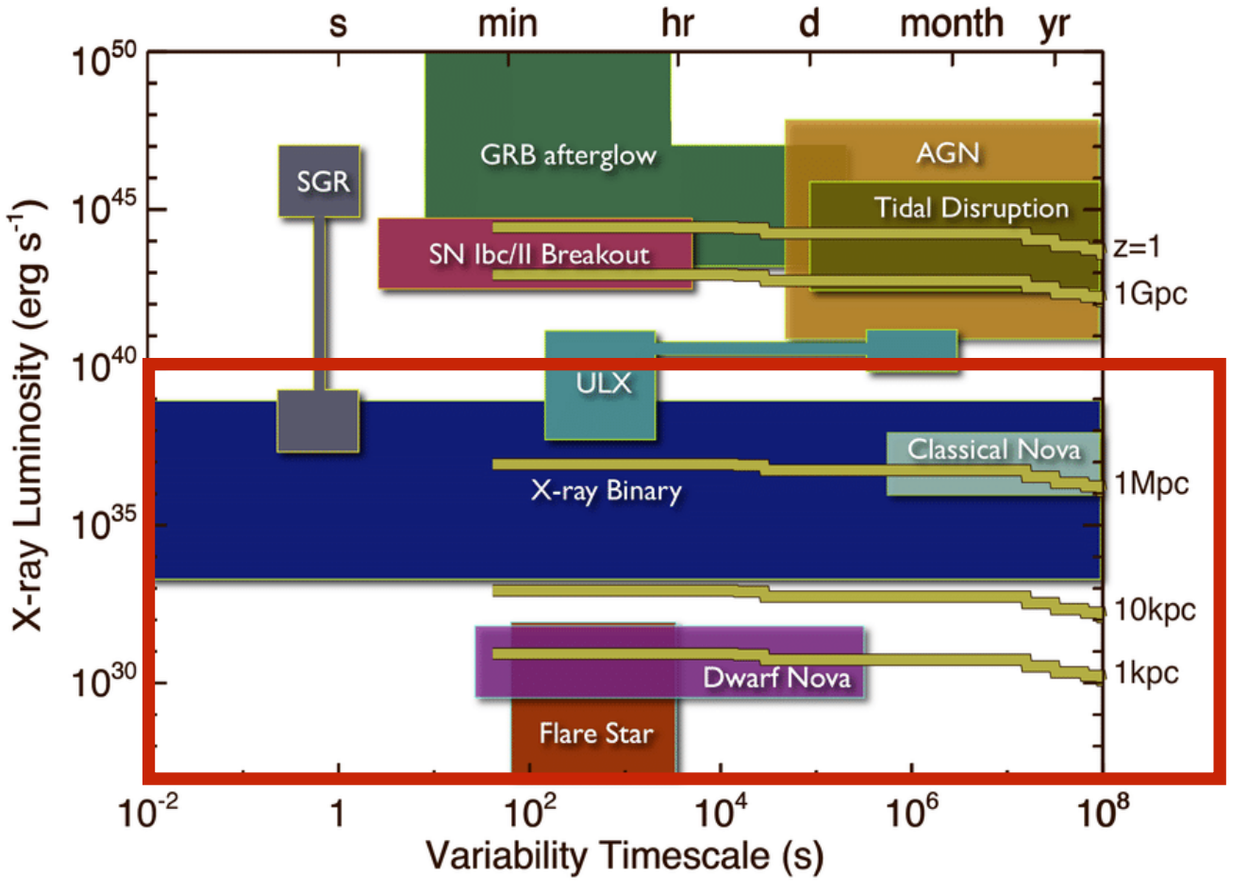


Duration and Luminosity of Transients

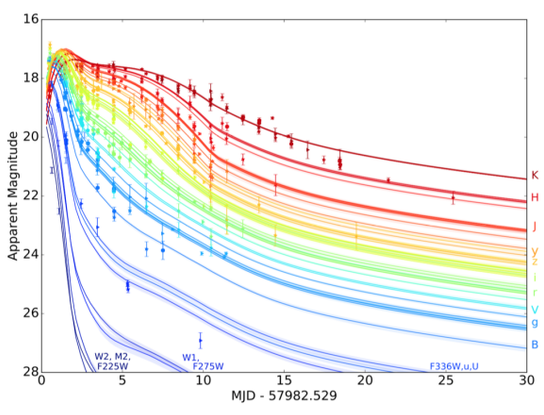
Optical transients



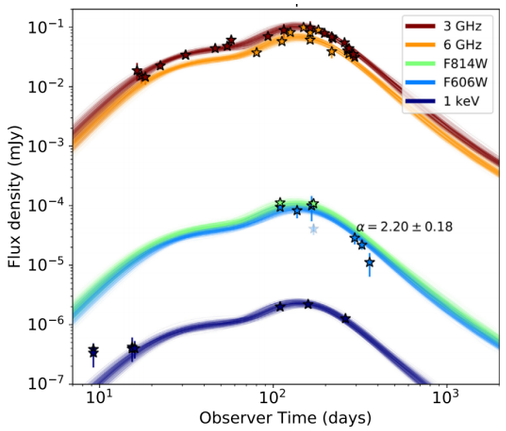
X-ray transients



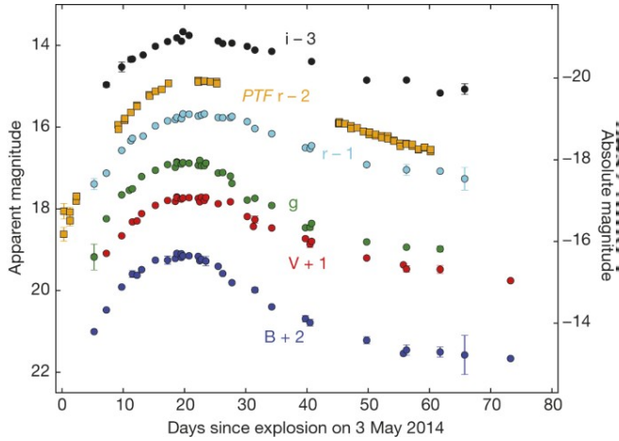
Kilonva



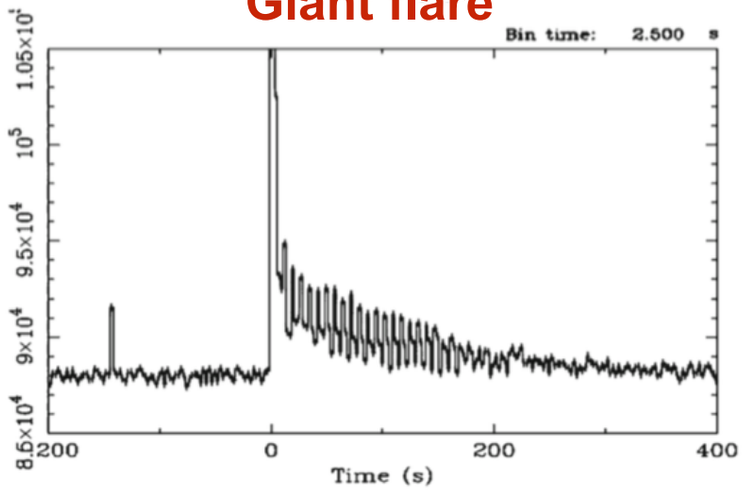
Afterglow



Supernova



Giant flare



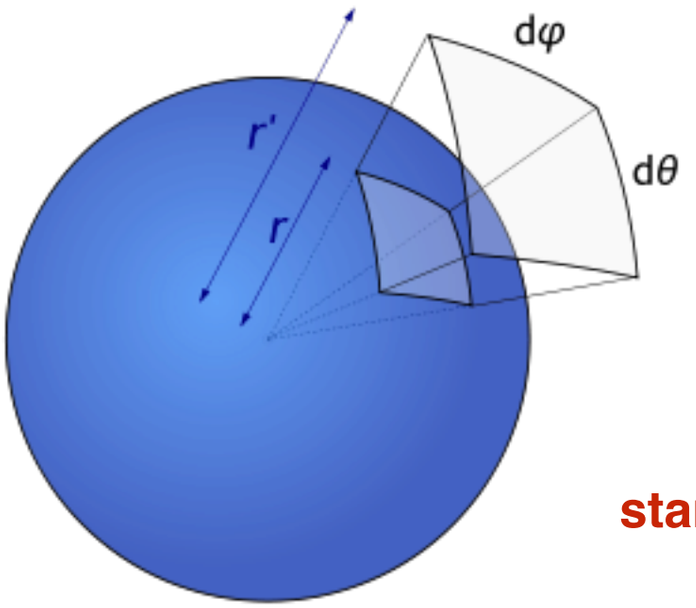
Two Kinds of Cosmic Transients

- **Cosmic Transients from Stellar Population:**

  - Progenitors as **Old Population** associated with **stellar mass**: SNe Ia, compact object mergers, kilonovae, etc.

  - Progenitors as **Young Population** associated with **star formation rate**: CCSNe, GRBs, magnetar flares, etc.

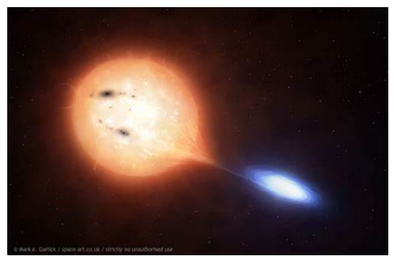
sky coverage distribution

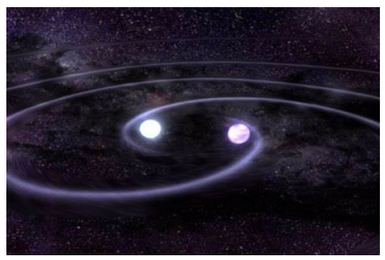


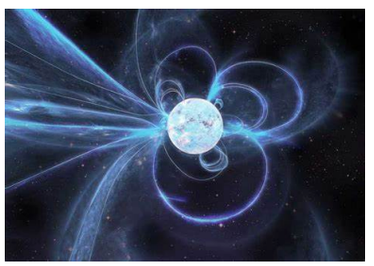
stellar mass

star formation rate

Old Population



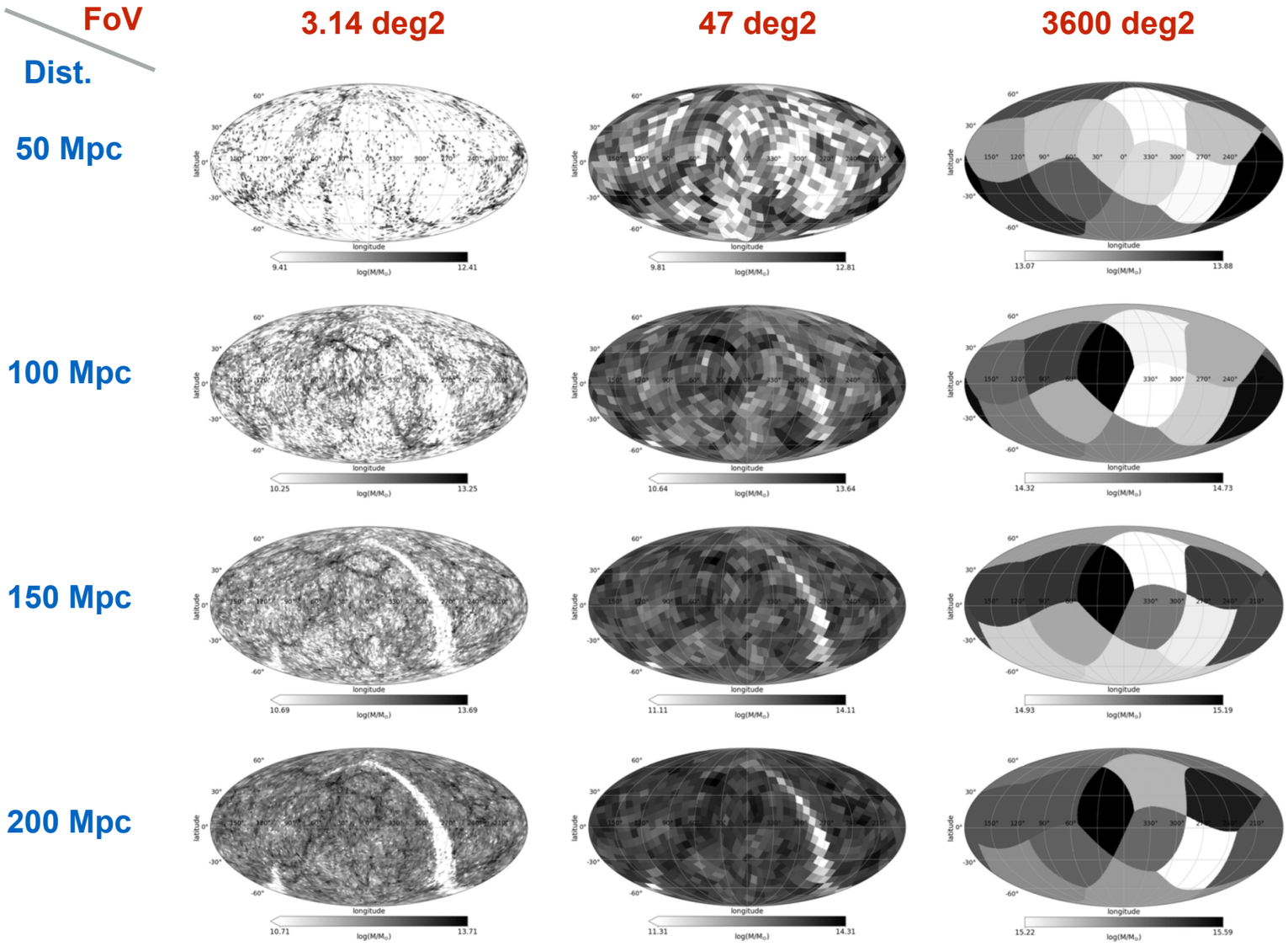


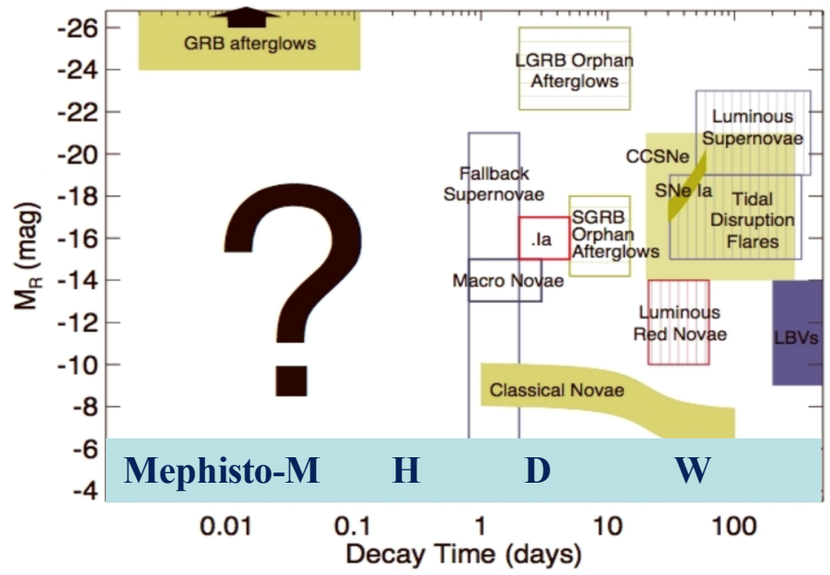


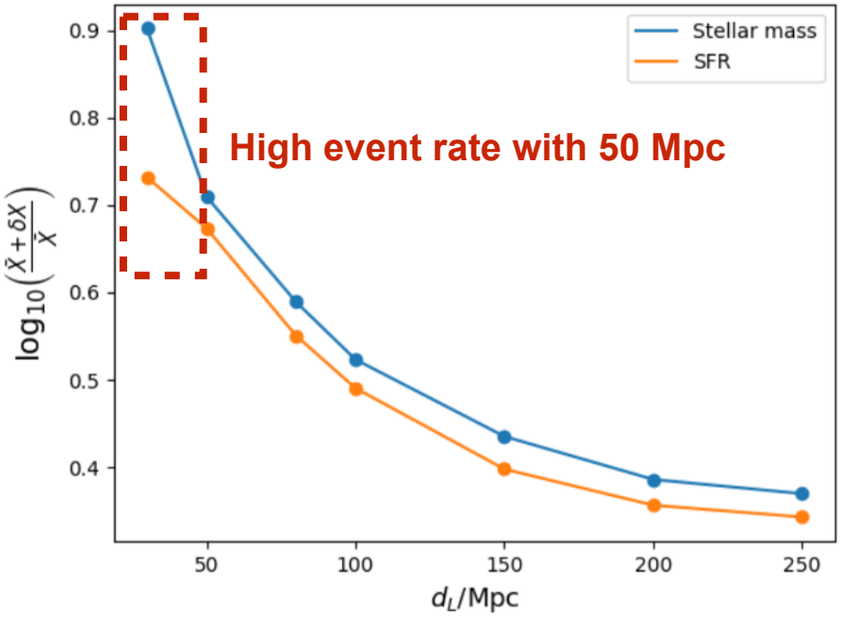
Young Population

Survey Strategy for Cosmic Transients

- A large sample of galaxy catalog was used to calculate **the sky distributions of the stellar mass and star formation rate of galaxies** at different luminosity distances and with different angular resolutions of celestial sphere corresponding to FoV of various telescopes.

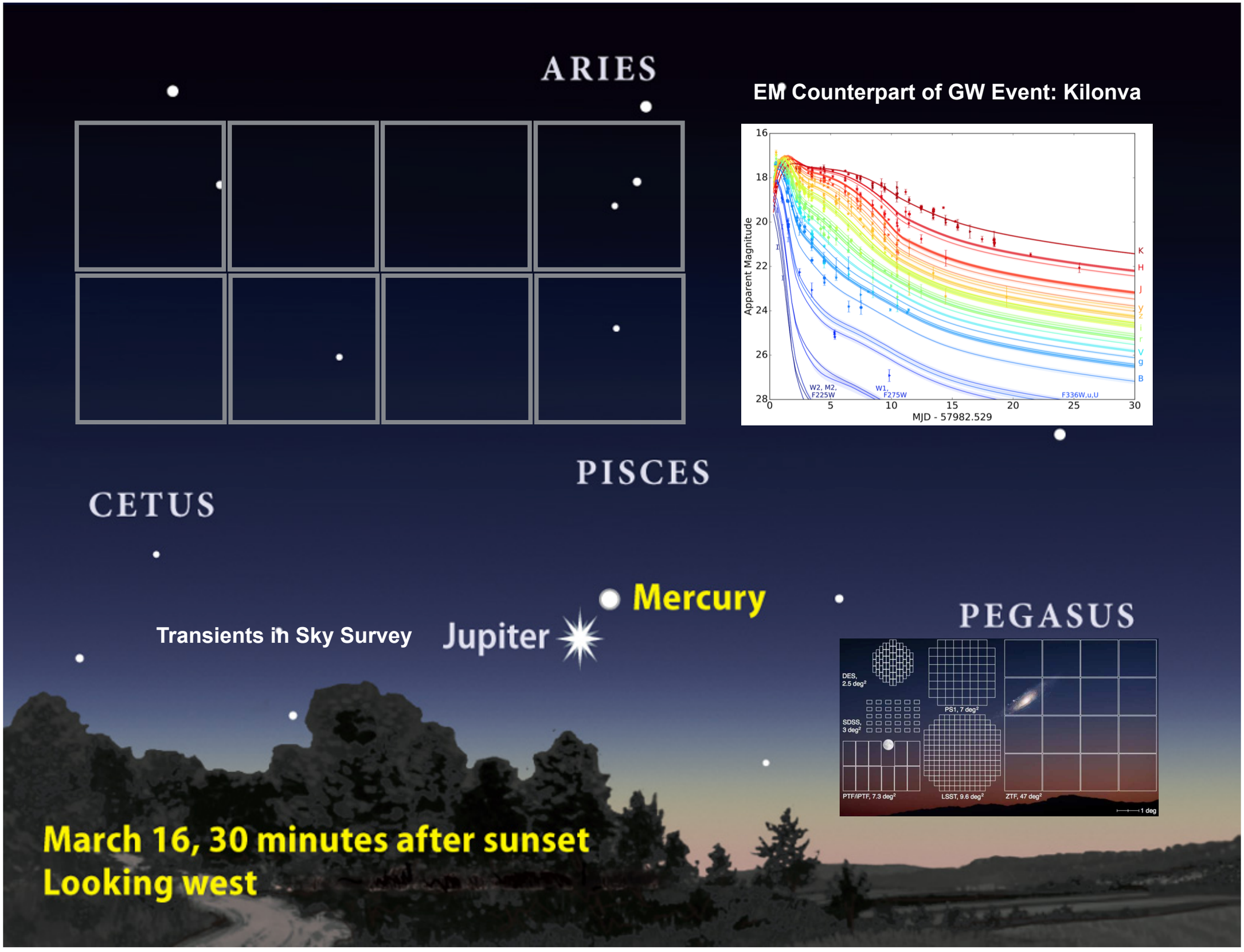




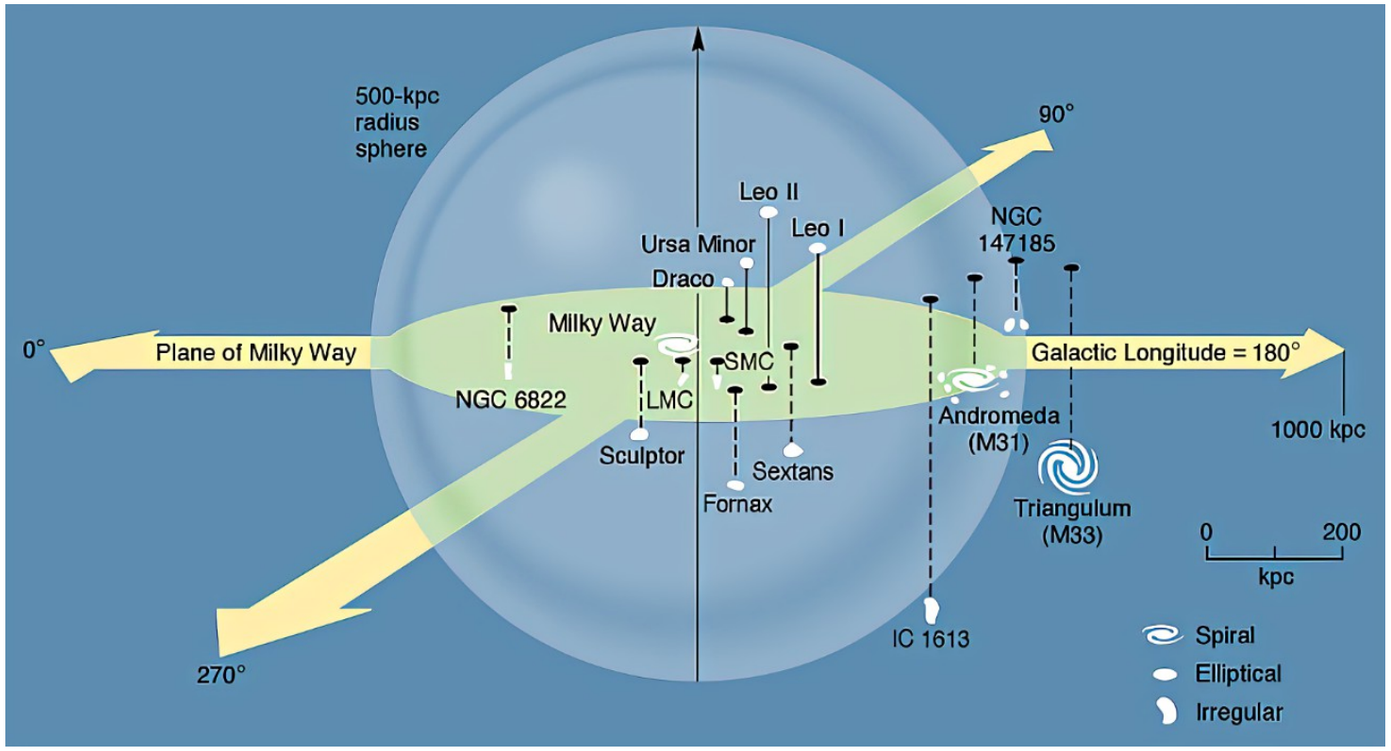


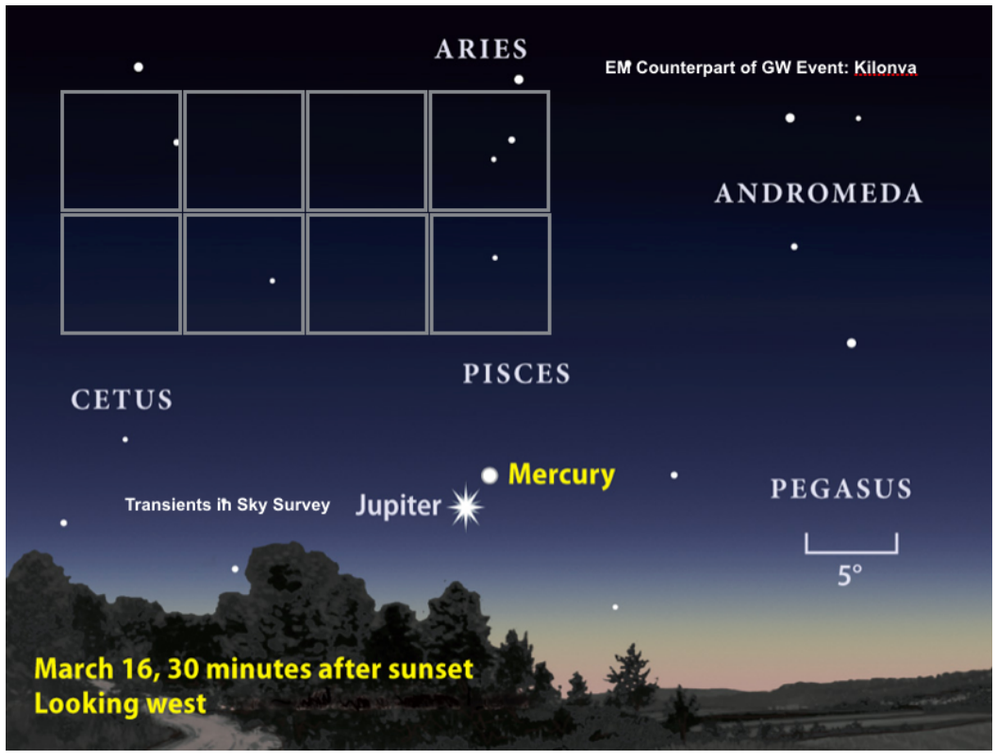
Cheng, Yang et al, 2024, in prep.

Capturing Transients in Sky



Depth or Sky Coverage?





Cosmic volume during one non-repeating observation:

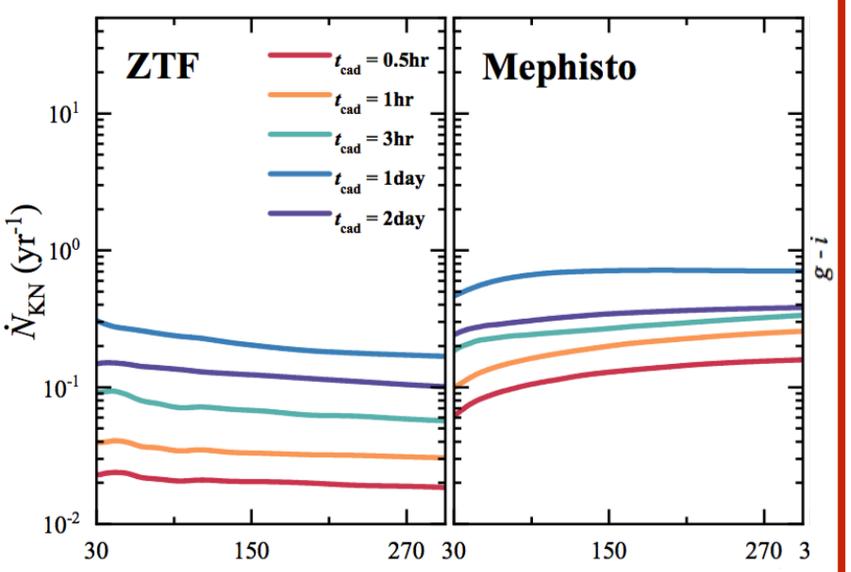
$$V(t_{\rm exp}) = N_{\rm pat}(t_{\rm obs})\frac{\Omega_{\rm FoV}}{3}D_{\rm th}^3(t_{\rm exp}) \propto \boxed{\frac{t_{\rm exp}^{3\alpha/2}}{t_{\rm exp}+t_{\rm oth}}} \quad N_{\rm pat}(t_{\rm exp}) = \frac{T_{\rm NR}}{t_{\rm vis}} = \frac{T_{\rm NR}}{n(t_{\rm exp}+t_{\rm oth})} \leqslant \frac{\Omega_{\rm cov}}{\Omega_{\rm FoV}}$$

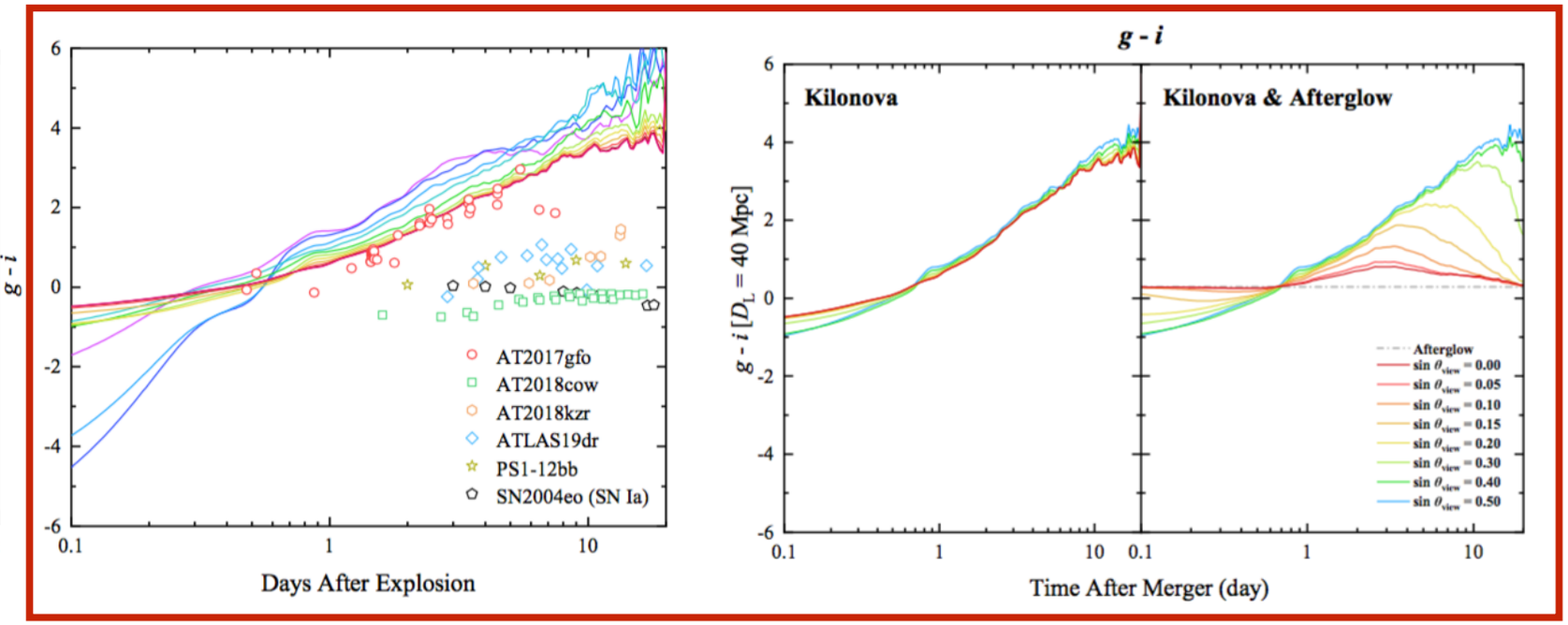
Maximizing survey volume

Optimal exposure time in one case: $t_{\rm exp} = \dfrac{3\alpha}{2-3\alpha}t_{\rm oth} \simeq \underline{(3.9-24)t_{\rm oth}}$ for $\alpha \simeq 0.53-0.64$

Yang, 2024, in prep.

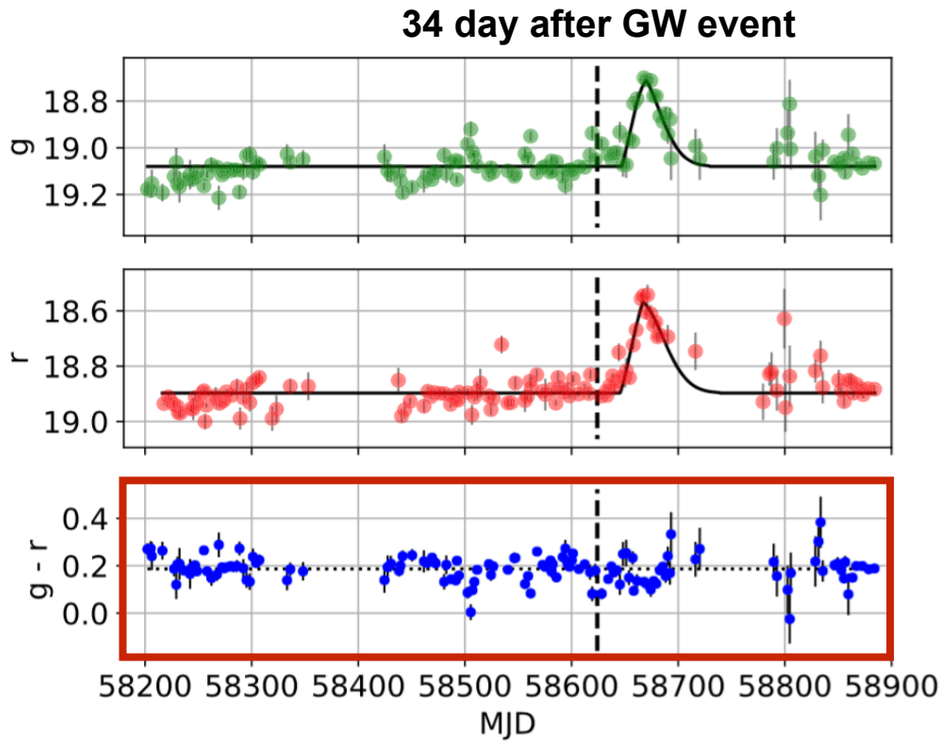
Identify Transients via Color Evolution

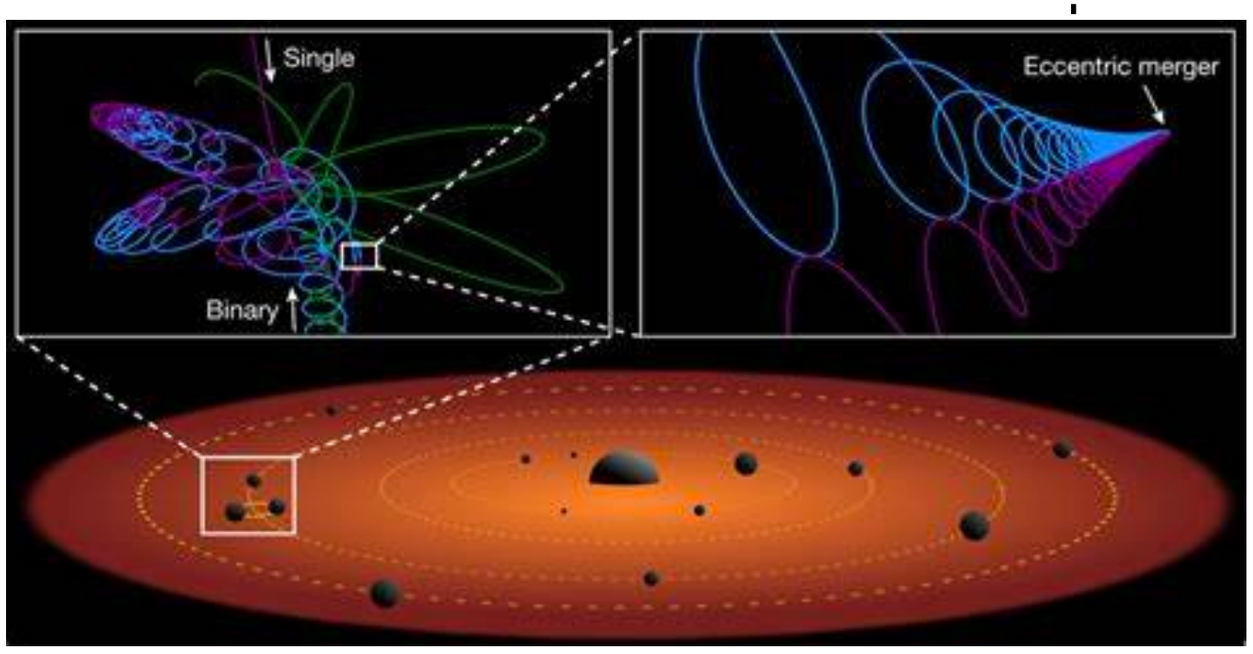




Color Evolution of GW Optical Counterpart: Zhu, Yang et al, 2022, 2023, ApJ

see Dezi's report

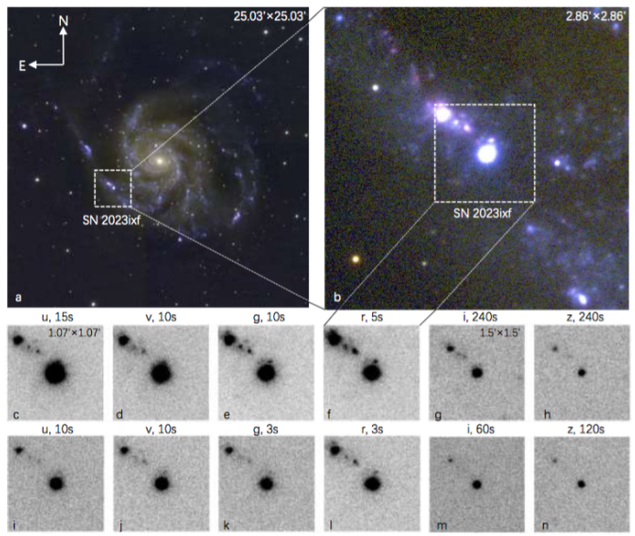


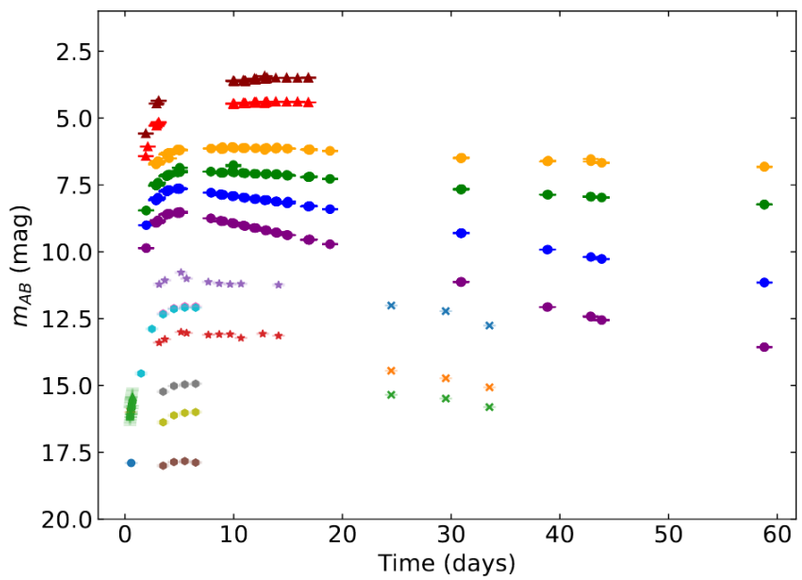


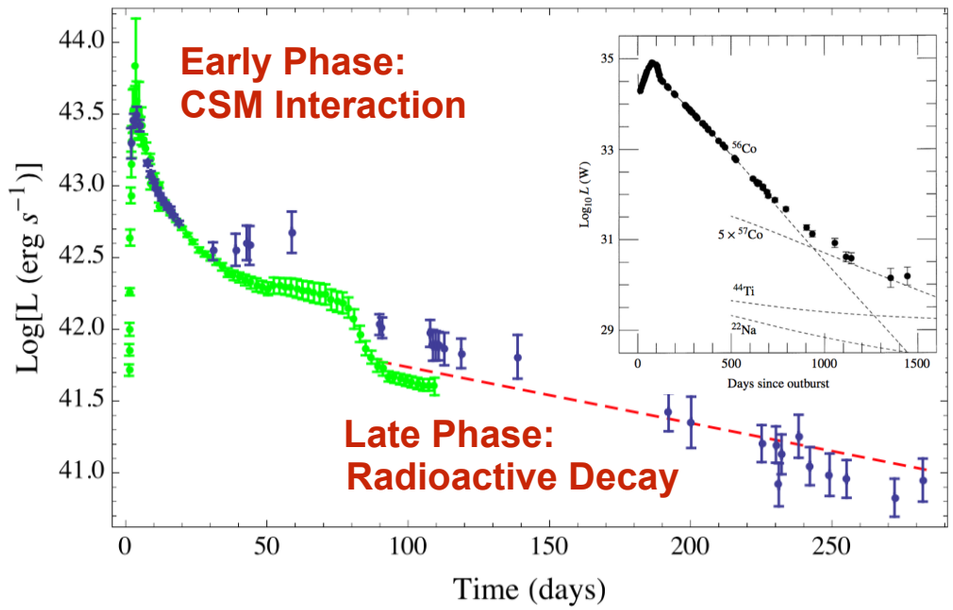
Optical Counterpart of GW 190521: Graham et al., 2021, PRL

Black hole merger in AGN disk

1. SNe and SBs in Nearby Galaxies

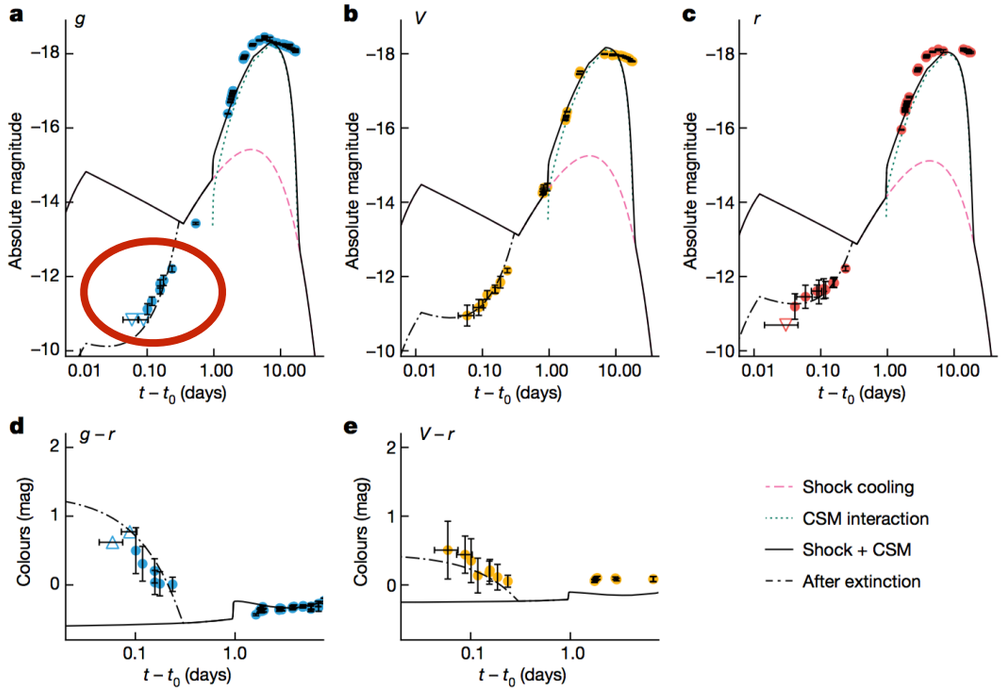


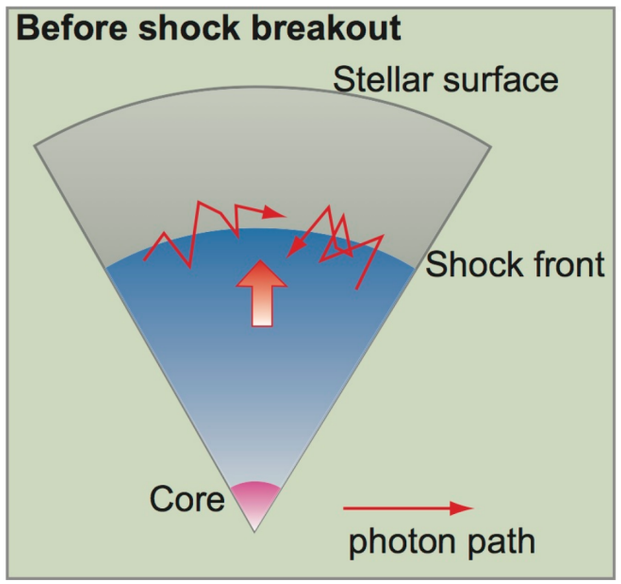


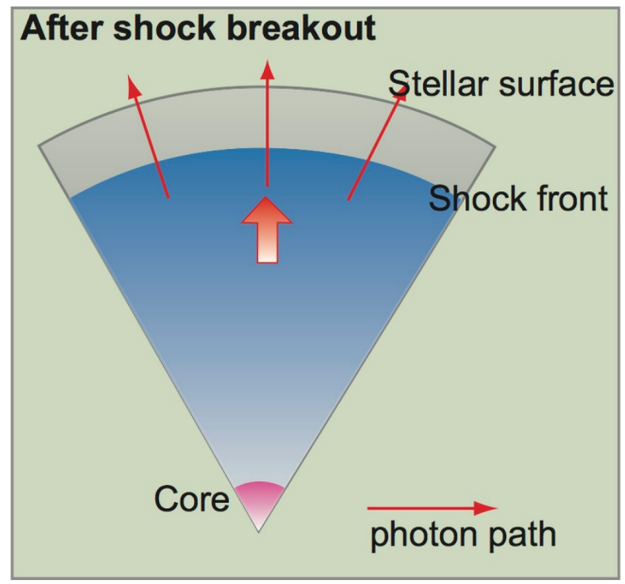


Multi-band Observation of SN 2023ixf (Yang et al, 2024, ApJ)

see Brajesh's reports





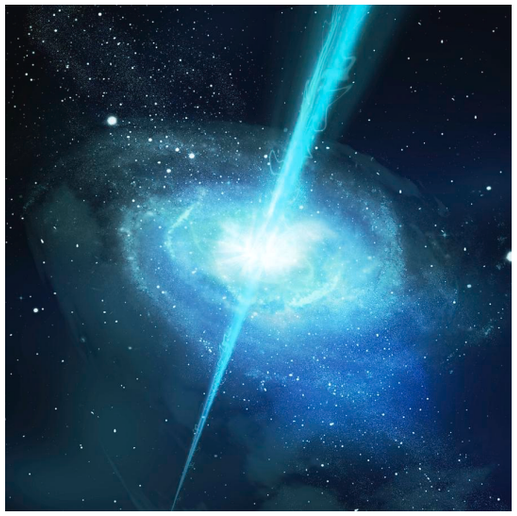


Shock breakout of SN 2023ixf (Li, et al, 2024, Nature)

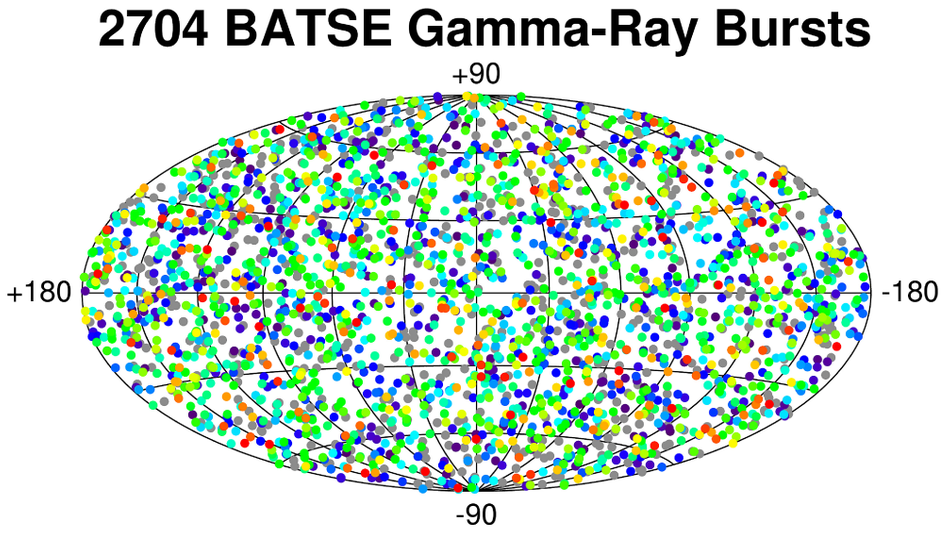
Physical Interpretation of Shock Breakout of Supernova

2. Lost Generation in Universe

New-Born | **Young** | **Old**

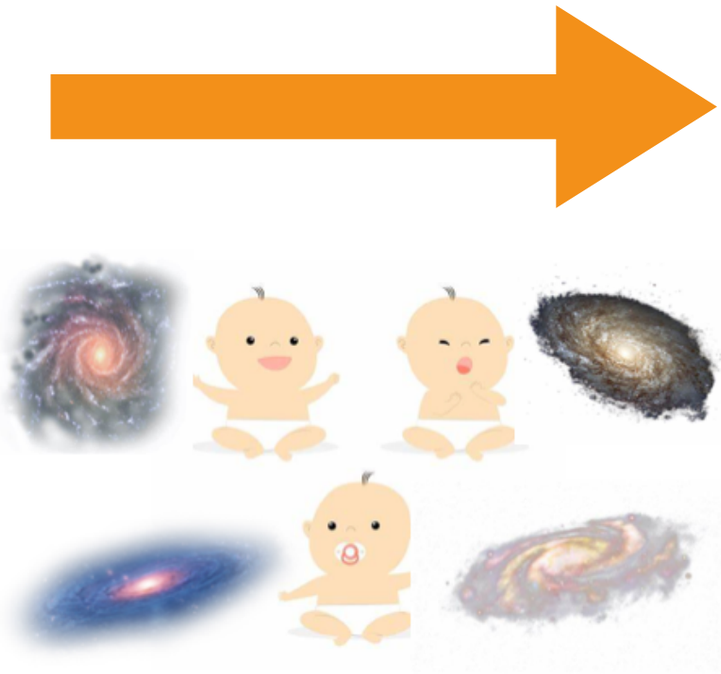


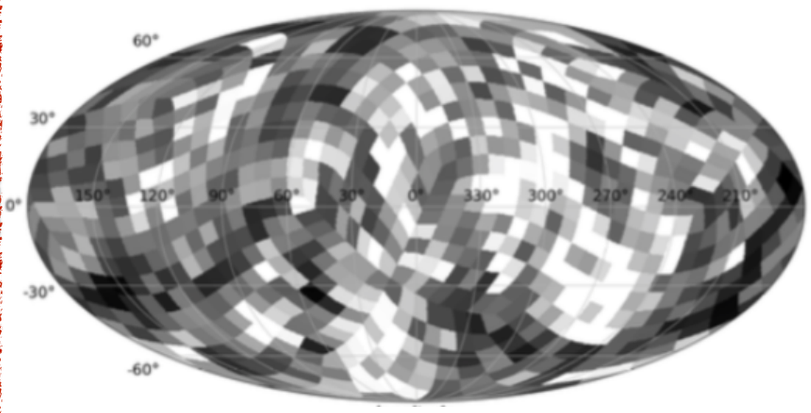
Supernovae | **GRBs**



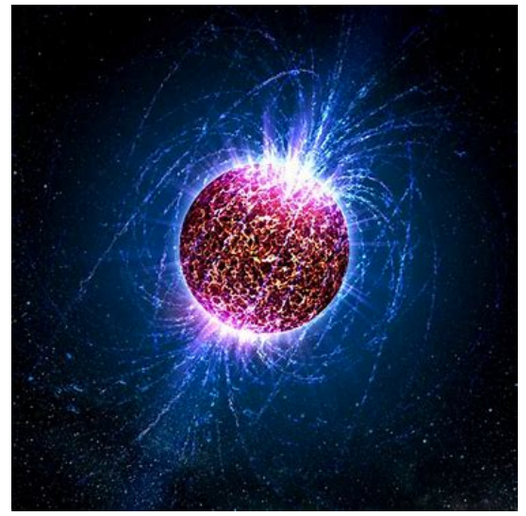
Cosmological Origin

Young active NSs

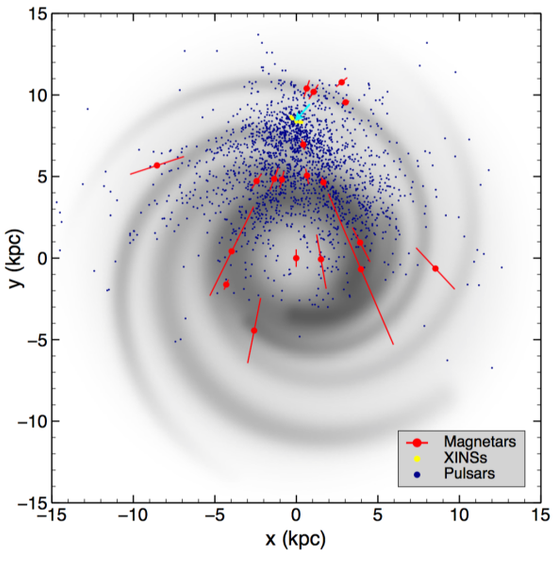




Nearby-galaxies Origin



Olausen & Kaspi, 2014, ApJ

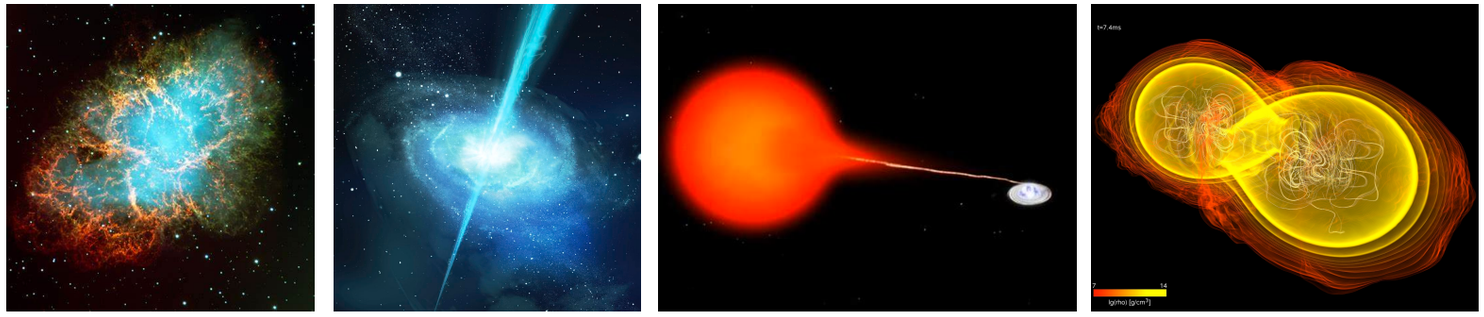


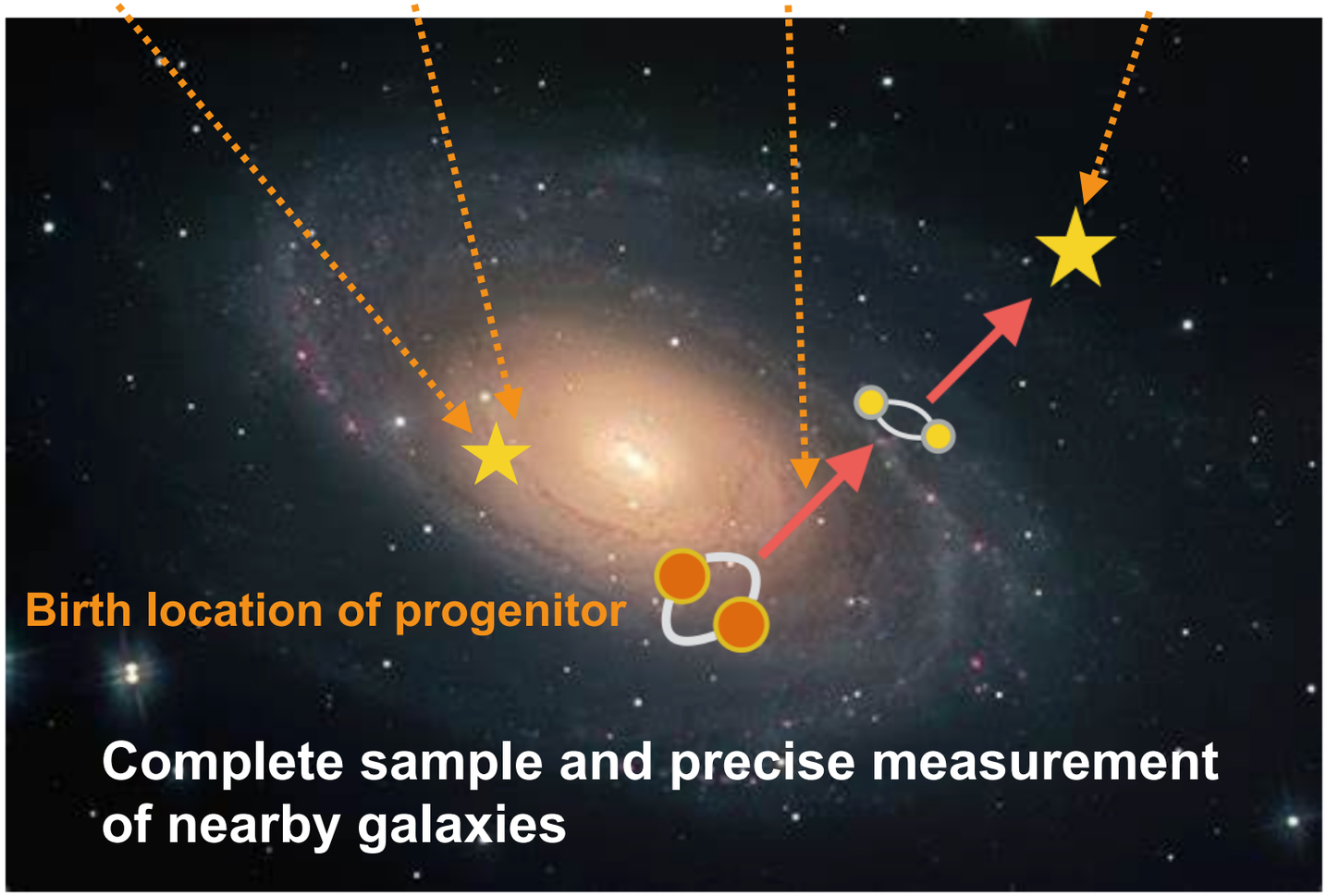
Galactic Origin

Pulsars / Magnetar

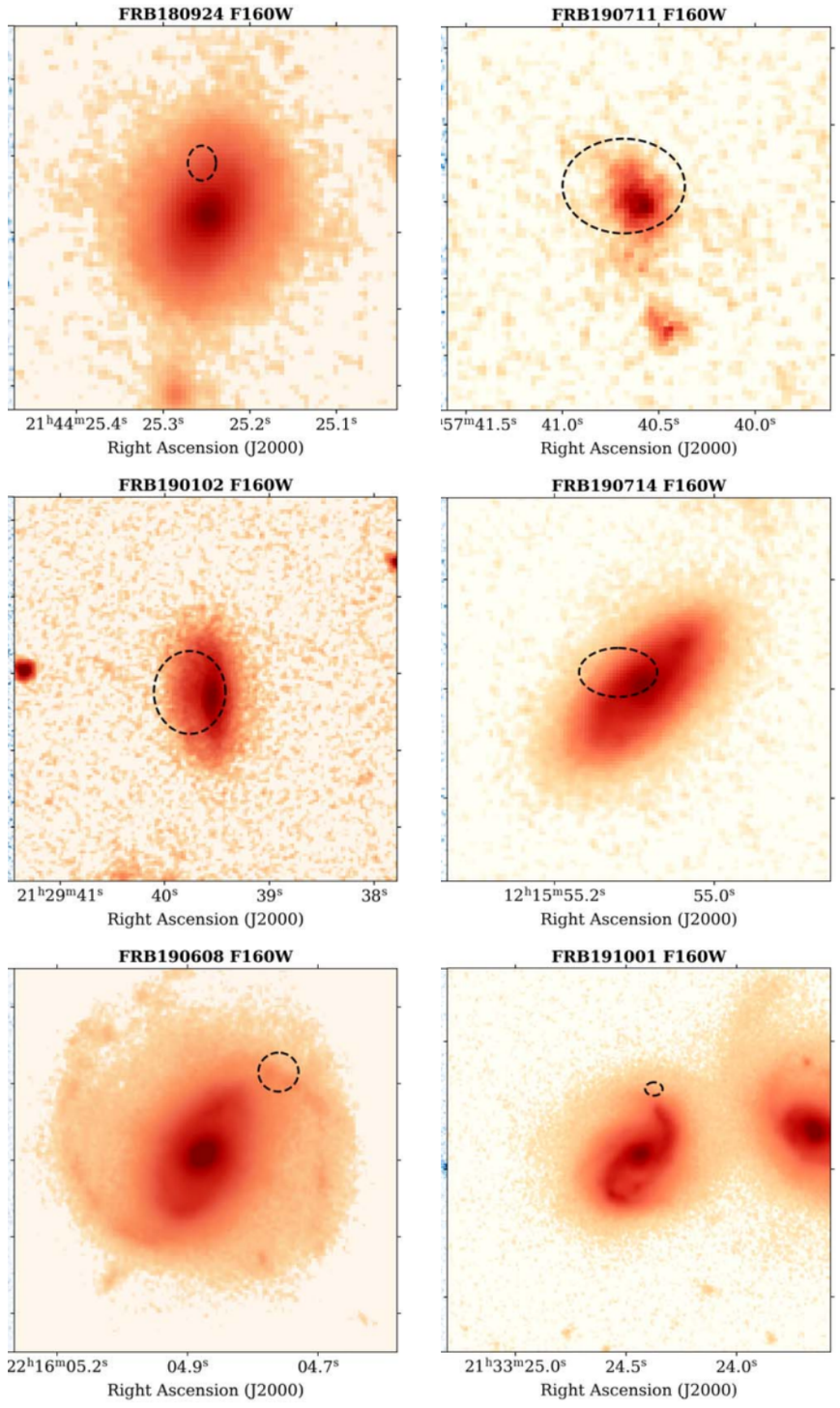
3. Transients and Their Host Galaxies

Various Catastrophic Events





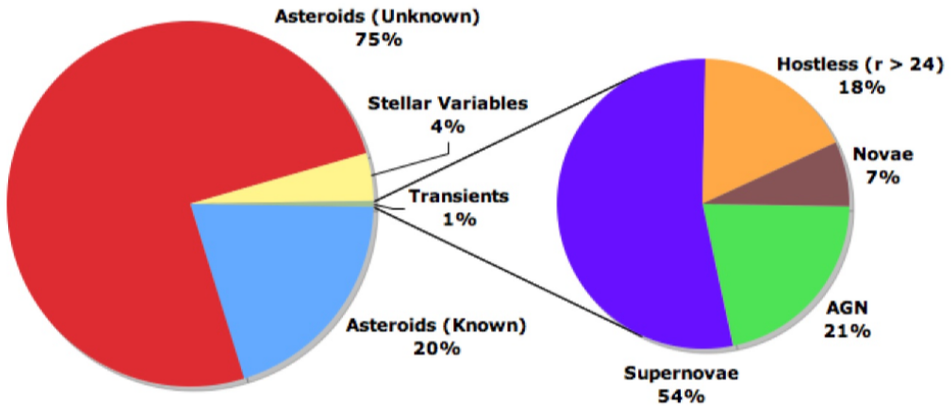
Various Host Galaxies

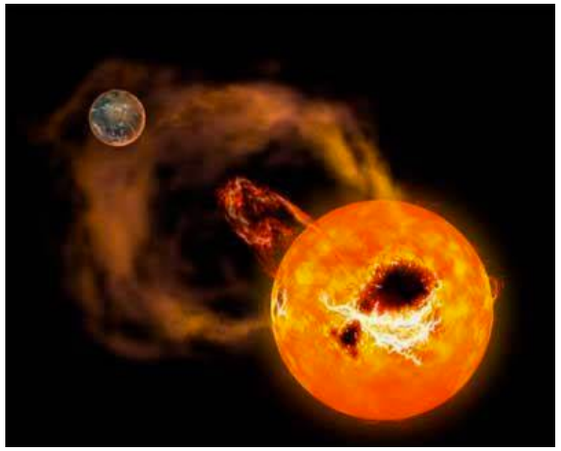


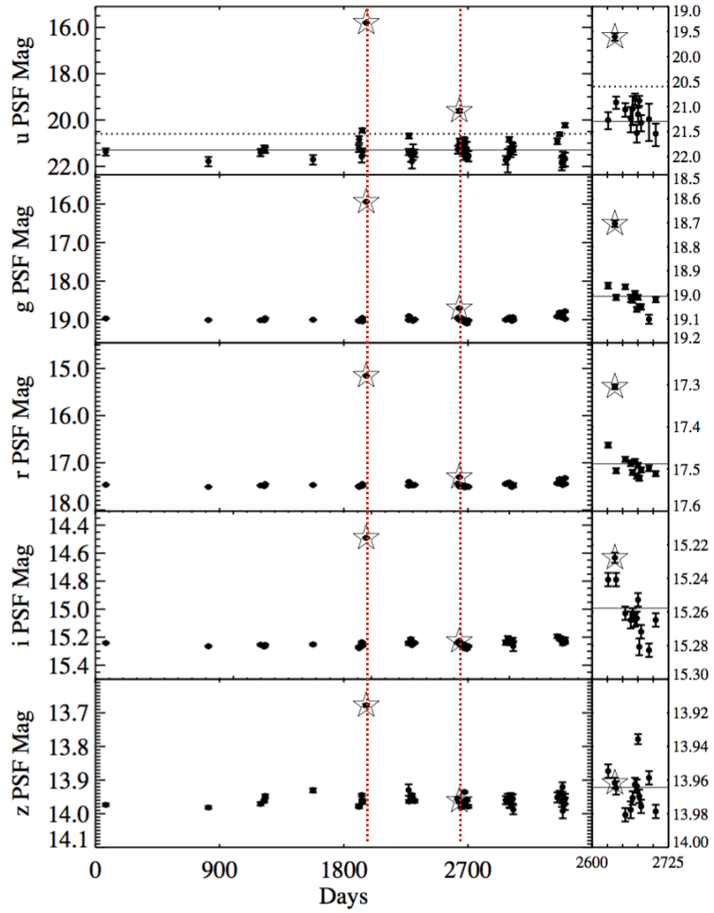
Mannings, 2021, ApJ

Combining with Topic II (nearby galaxies)

4. Real-Color Properties of Stellar Flares



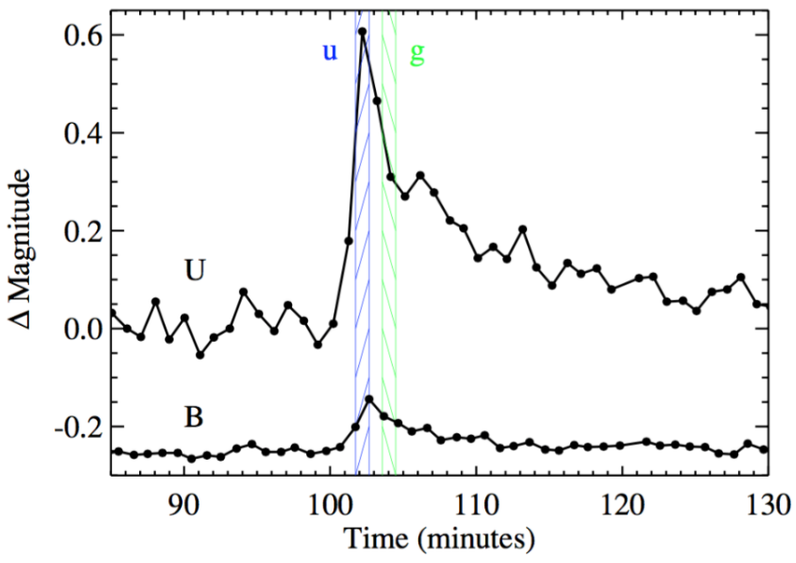


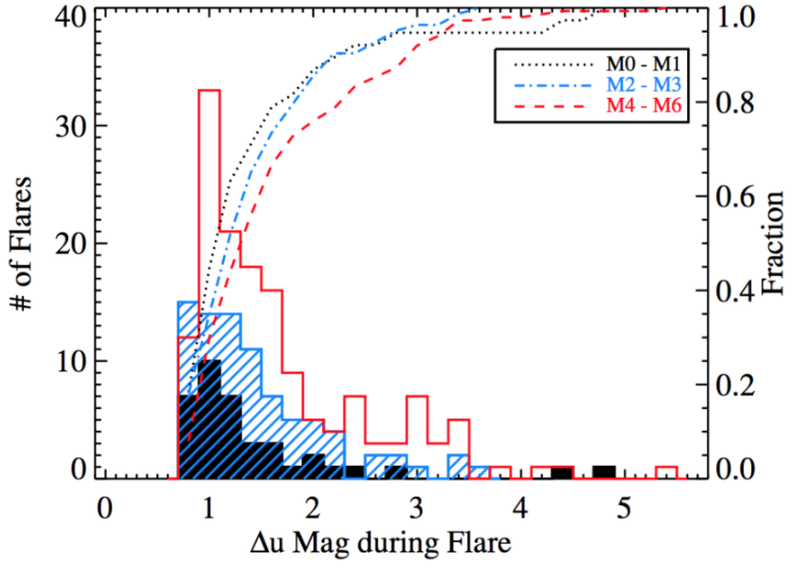


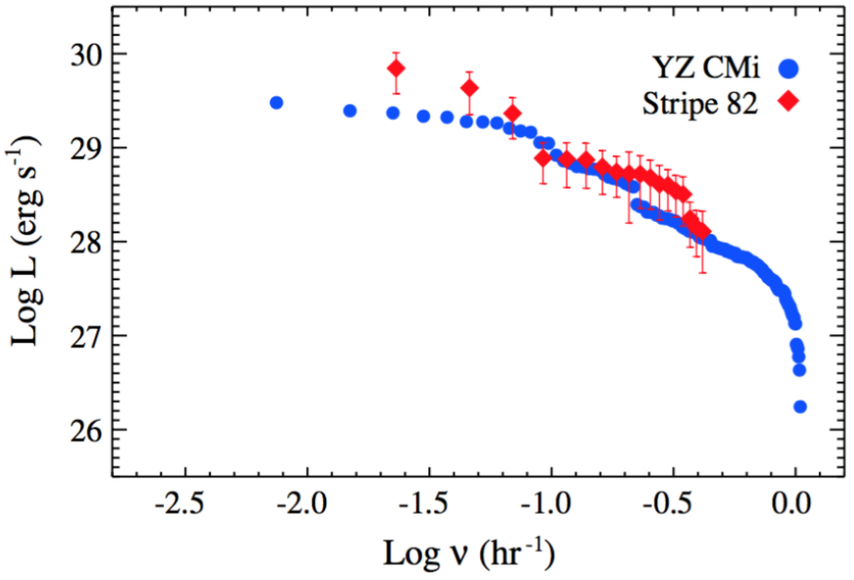
Flare rate density with m_u=21.3 mag (one-min exposures)

$$\Sigma = 10^{\frac{3(m_u - m_{S82})}{5}} \Sigma_{S82} \sim 0.5 \text{ flares hr}^{-1} \text{ deg}^{-2}$$

a large sample with real-color information



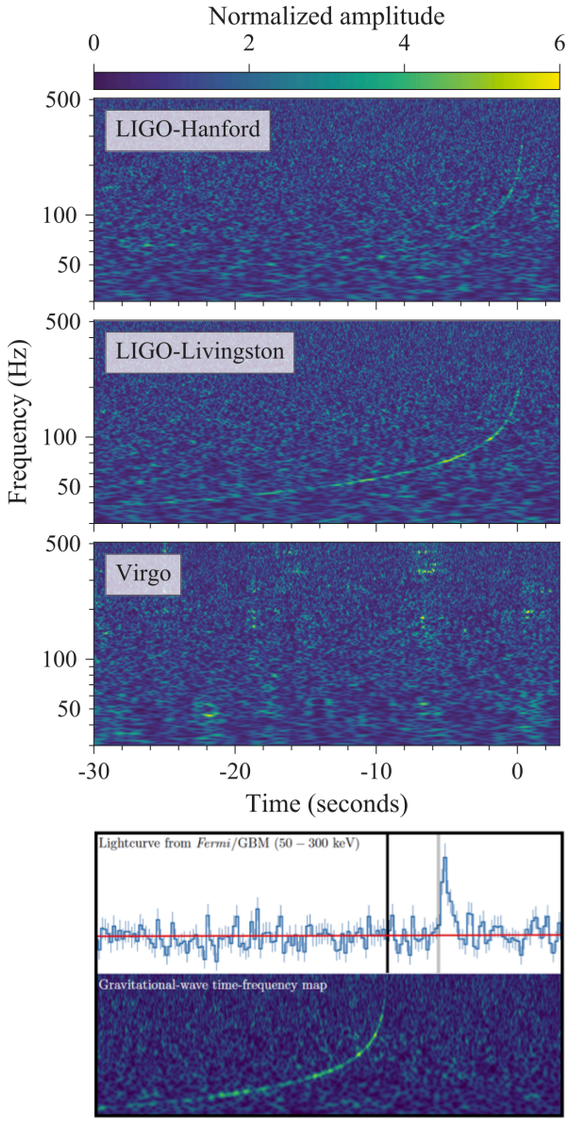


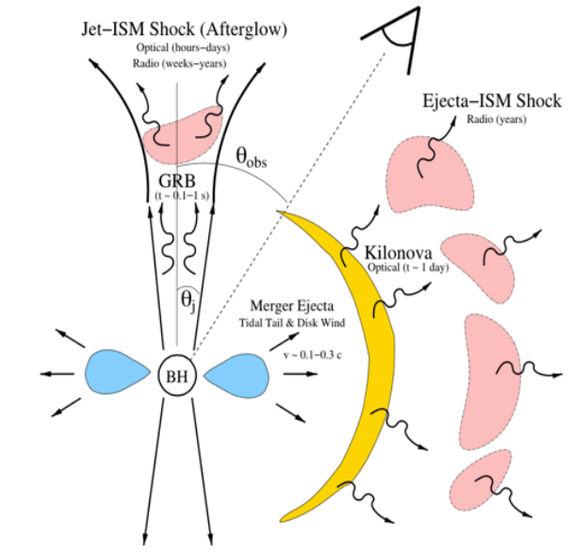


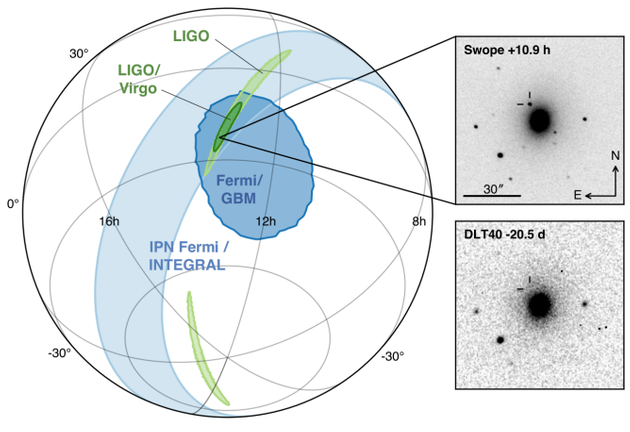
Kowalski et al., 2009

5. Limited by Multi-wavelength or Multi-messenger Observation

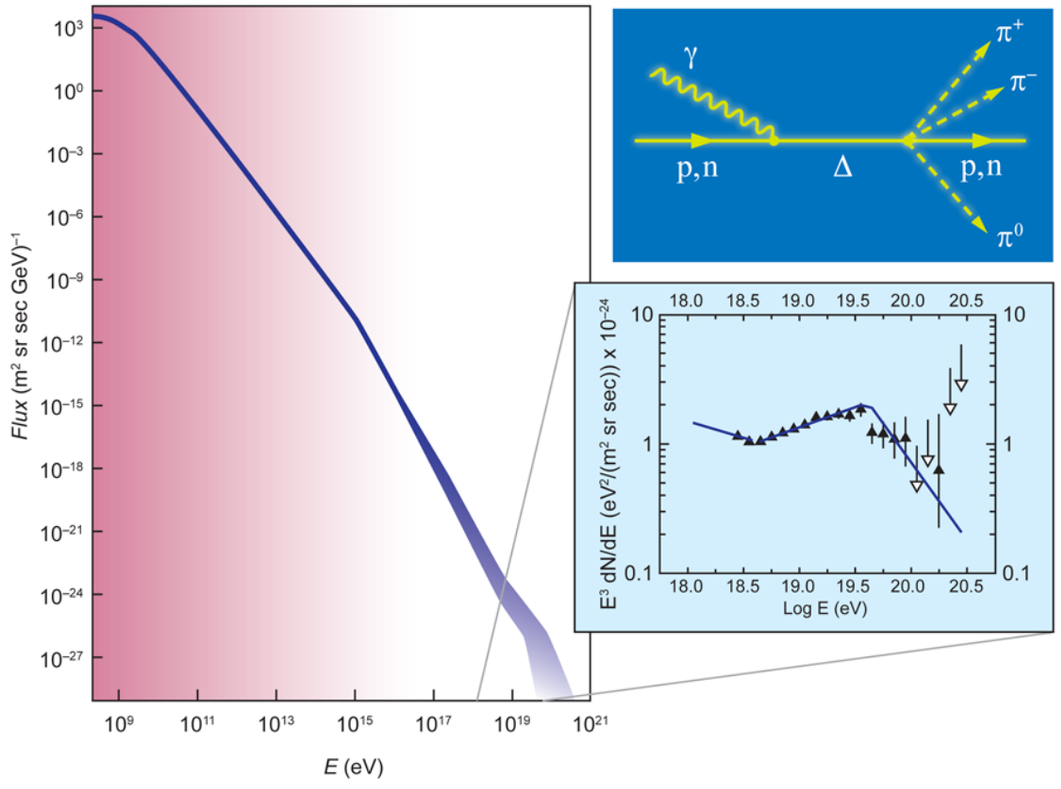
Limited by sensitivity and spatial resolution (GW, neutrino, gamma-ray)







Limited by propagation effects (GZK, EBL, etc.)



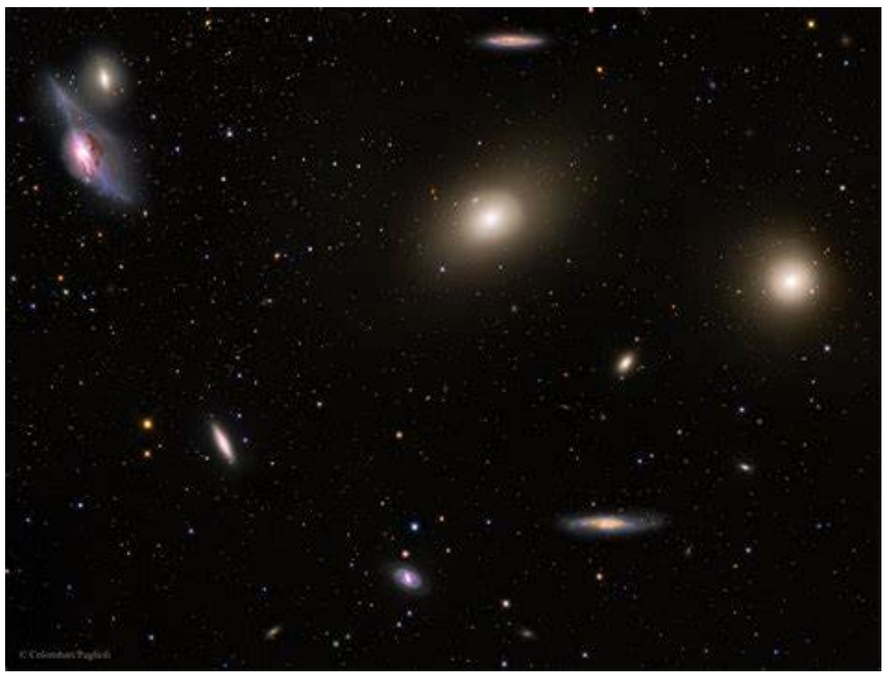
Mean free path of GZK photopion energy-loss

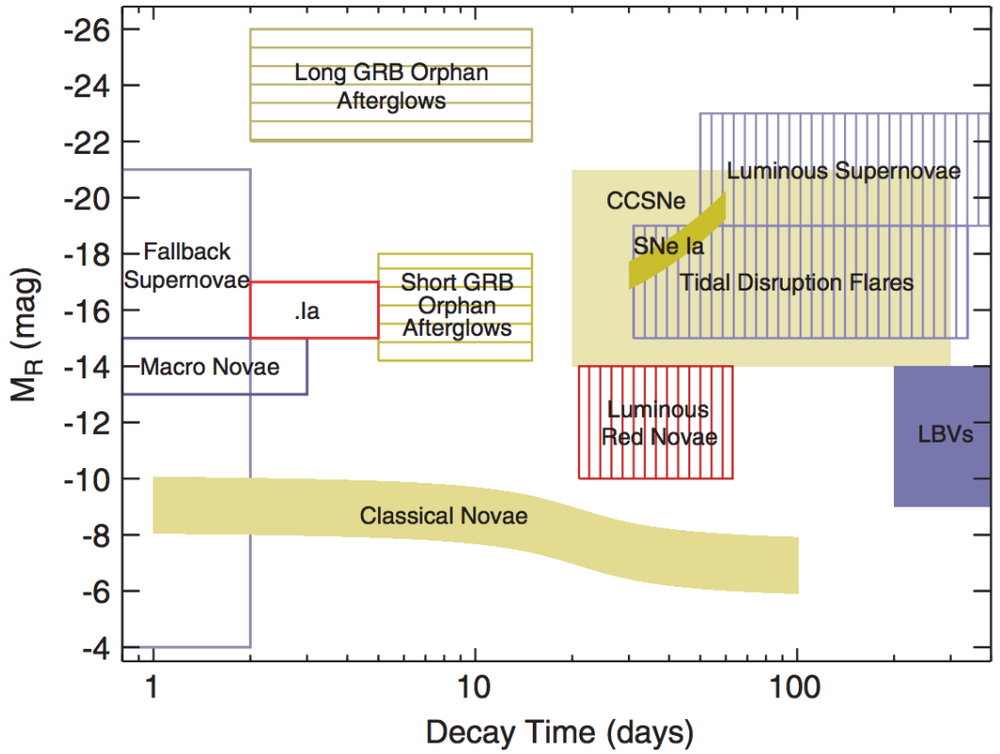
$$r_{\phi\pi}(E_{20}) \cong \frac{13.7\exp(4.0/E_{20})}{(1+4.0/E_{20})}\ \mathrm{Mpc}.$$

Combining with Topic IV (multi-wavelength observation)

Topic III: Summary

- **Scientific goals for Mephisto nearby-galaxies survey:**
  - **Extremely-early-phase and Extremely-late-phase** properties of various transients
  - Astrophysical phenomena from **young population**.
    - **Middle-brightness** transients, e.g., classical nova, luminous red nova, or **missing transients**, etc.
  - Precise information of **host galaxies** with complete sample
  - Real-time survey could reveal the properties of **stellar flares**
  - Constrained by **Multi-wavelength or multi-messenger** observation, e.g., gravitational wave, cosmic rays, etc.





MEPHISTO

Thank You!