# Variable Gamma-Ray Sky: Opportunities and Challenges

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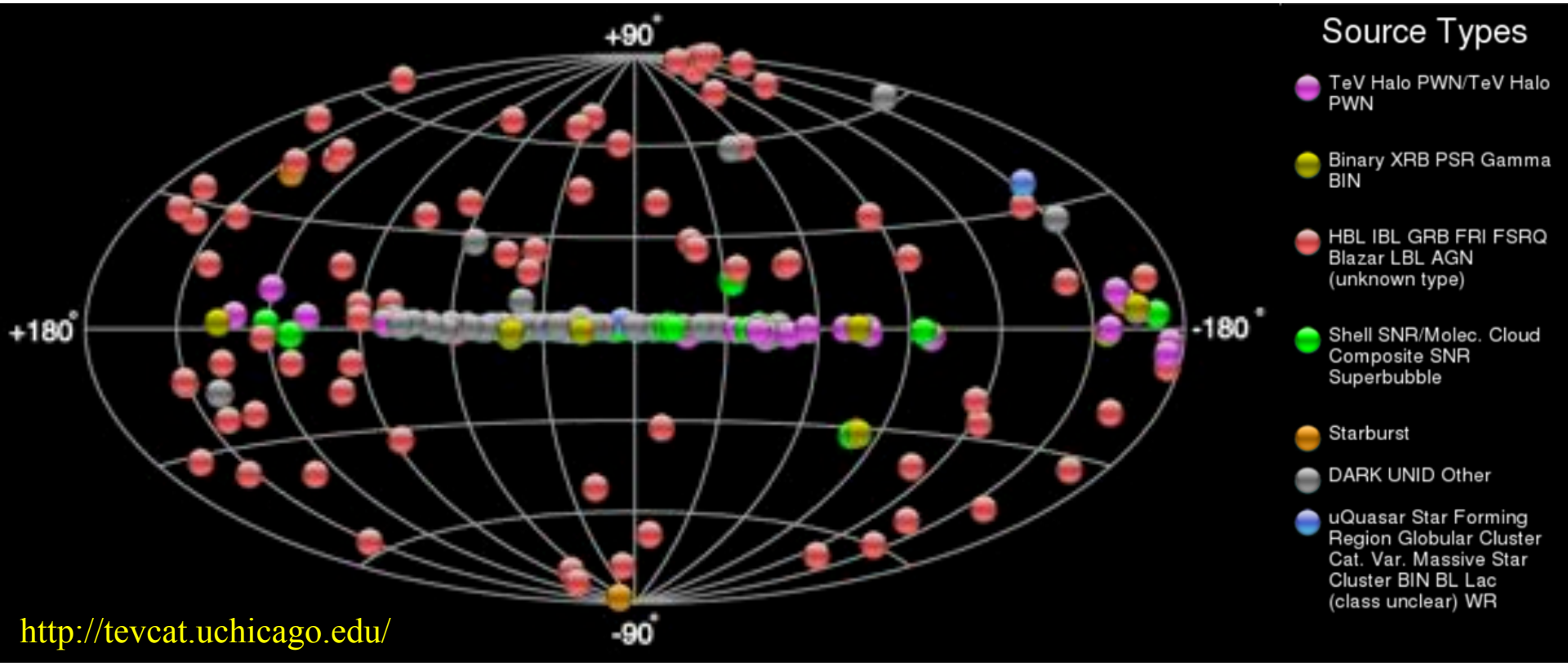
# VHE Gamma-Ray Sky

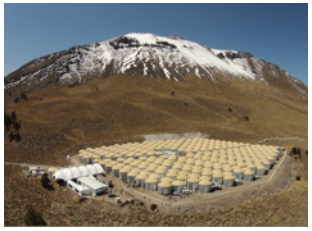


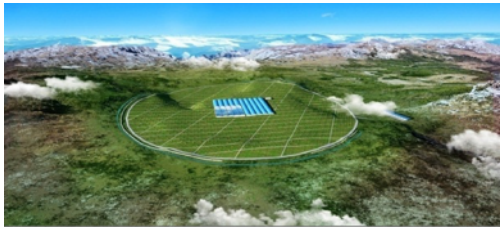
# General Remarks

- The field of VHE gamma-ray astrophysics is now fairly mature, with many classes of sources detected.
- The development of the field needs balance.
  - ⇨ Driven mainly by narrow-field imaging — VERITAS, MAGIC, HESS → CTA
  - ⇨ NEED: sensitive wide-field survey — HAWC → LHAASO
- Prospects for LHAASO
  - ⇨ Transients, variable sources
  - ⇨ Weak steady sources
  - ⇨ Fundamental physics: origin of cosmic rays, nature of dark matter, Lorentz invariance, evaporation of primordial black holes, etc.

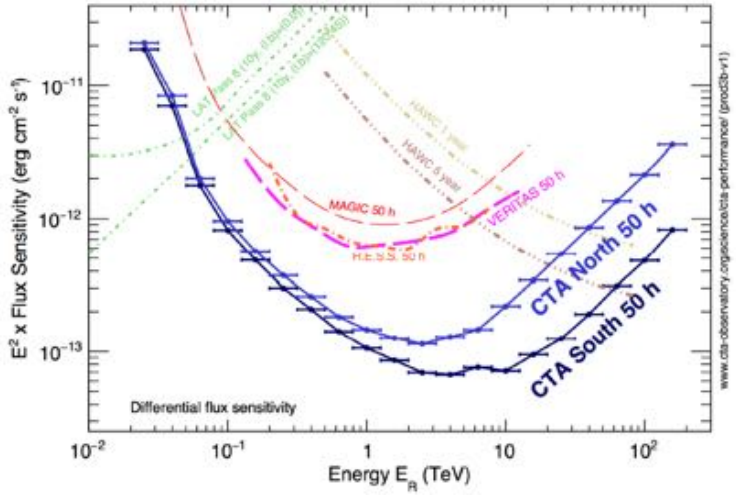
# Complementarity: Technique

- Particle detector
  - Large sky coverage
  - Long duty cycle





- IACTs
  - High sensitivity
  - Low energy threshold
  - Superior energy resolution
  - Better spatial resolution



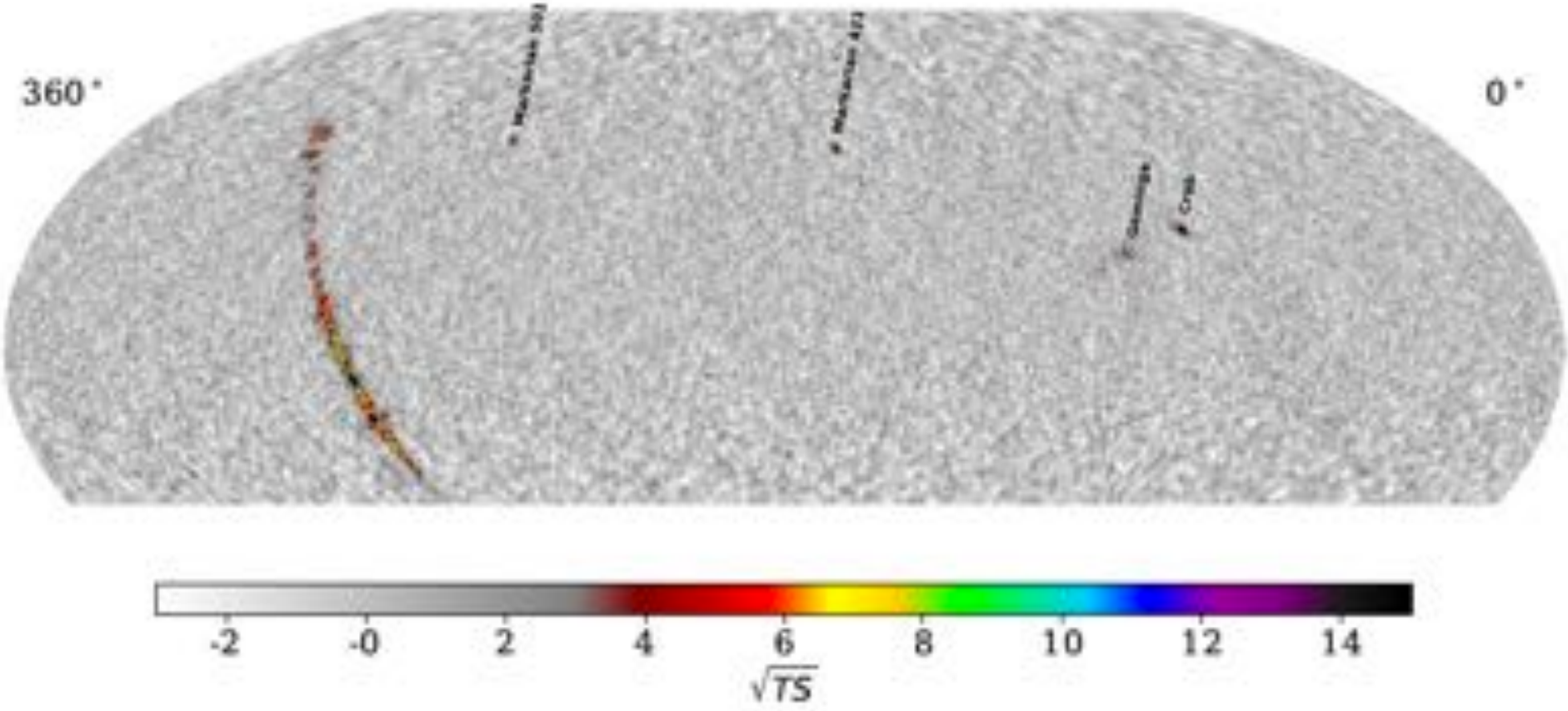
# Complementarity: Science

- Wide-field survey
  - Discovery: transients, flaring sources
  - Monitoring: variability
  - Deep look: fundamental physics

- Narrow-field imaging
  - Follow-up: transients, flaring sources
  - Detailed studies: morphology, spectral energy distribution, source identification, fundamental physics, …

# Need better sensitivity and lower energy threshold

2HWC sources: 39



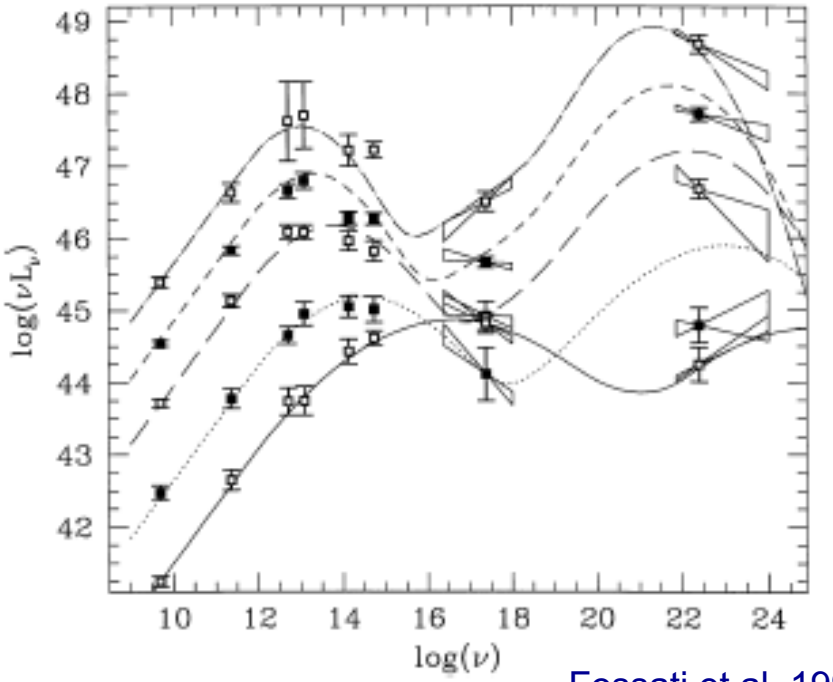
# Opportunities and Challenges

- Golden era for multiwavelength observations
  - Radio: Square Kilometer Array (SKA)
  - Optical: Large Synoptic Survey Telescope (LSST)
  - X-ray: Einstein Probe (EP)
  - Gamma-Ray: Fermi-LAT, LHAASO
- New windows for multi-messenger observations
  - Grav. wave: LIGO, Virgo
  - Neutrino: IceCube, ANTARES
- Challenges
  - Timely alerts
  - Organized campaign

# Example I: Need for simultaneous MW data

***Blazar:* looking down the barrel of the jet**

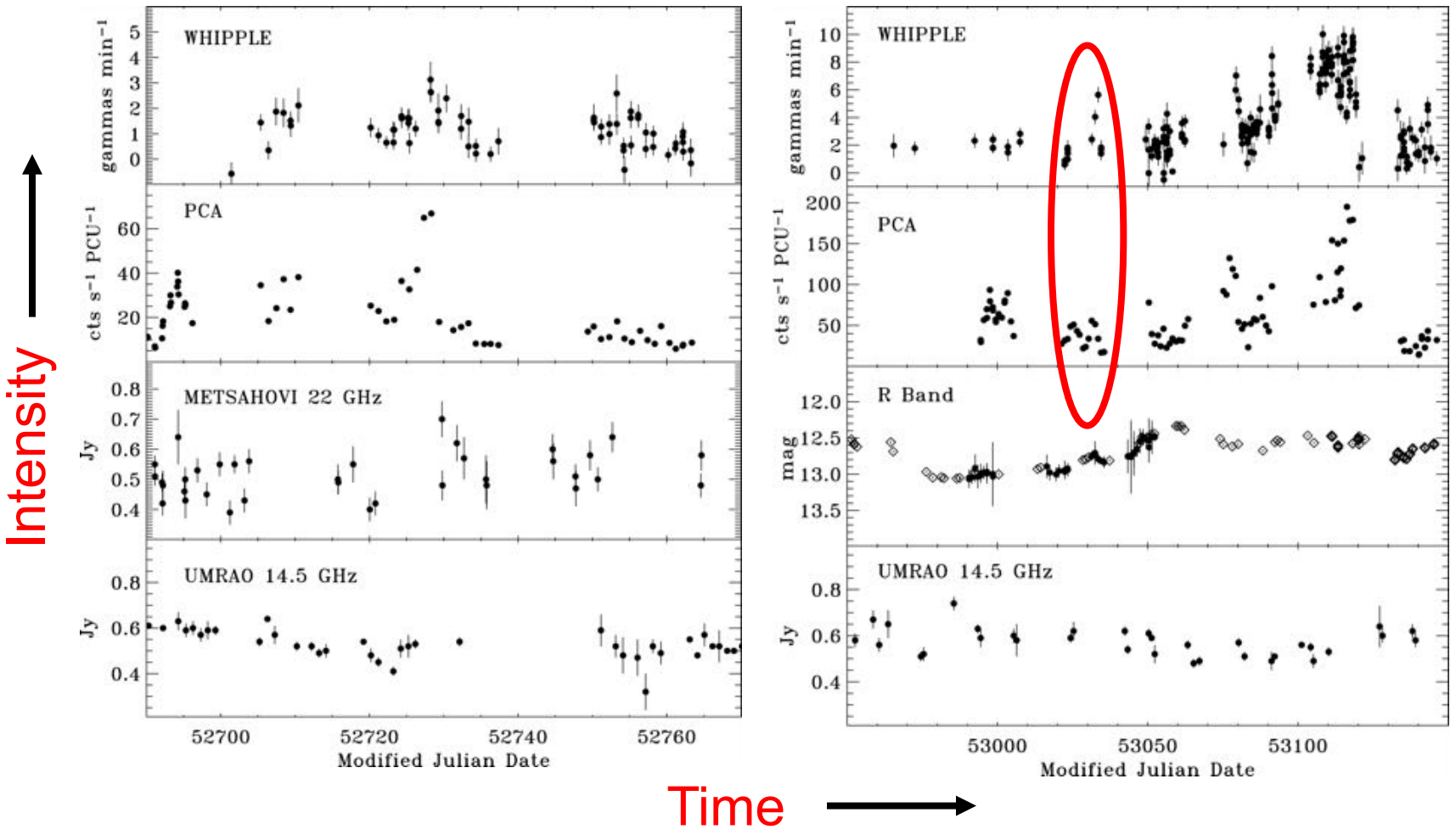
Era of poor data quality at TeV energies!




Fossati et al. 1998

# Example I: Orphan Flare?

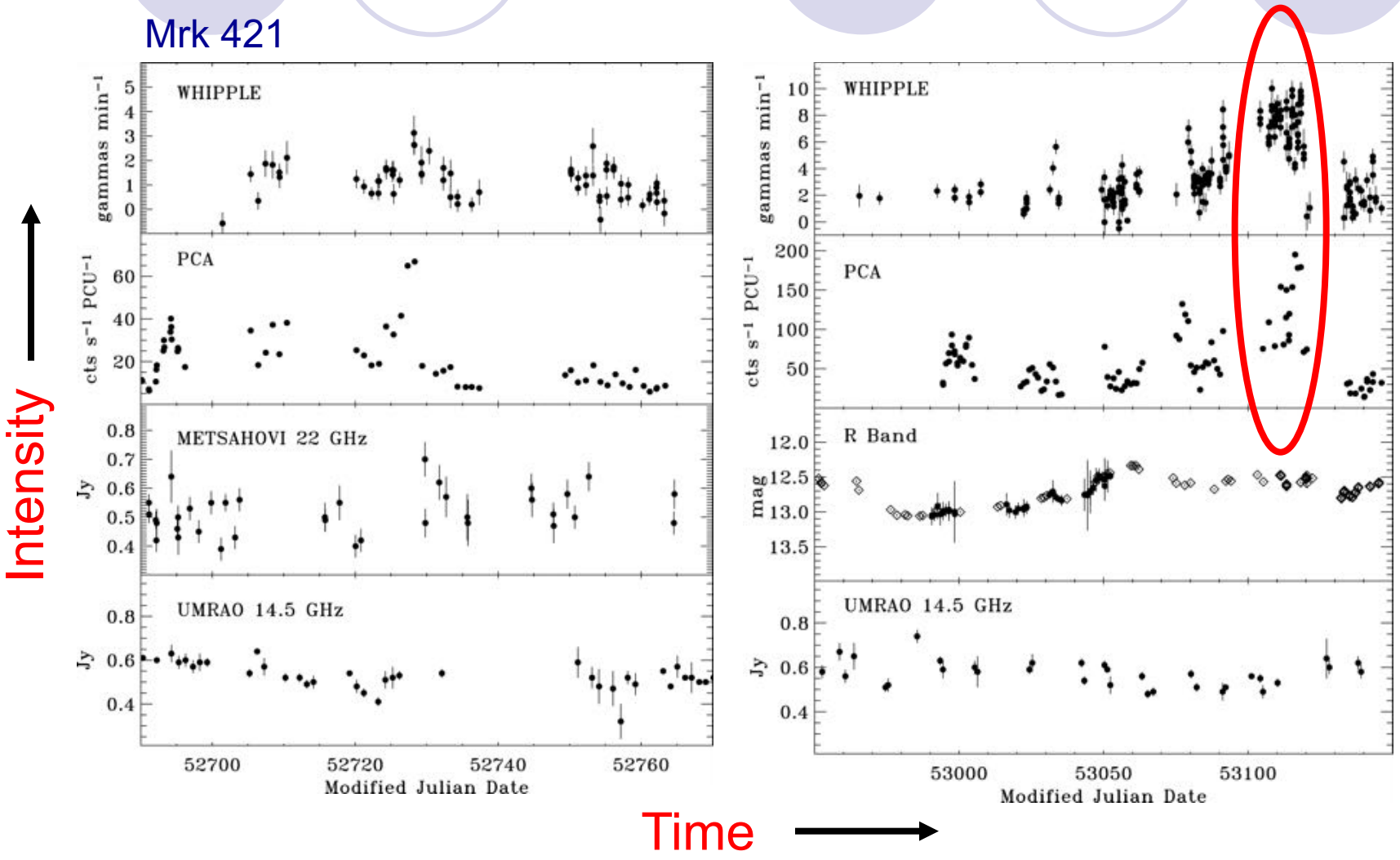
Mrk 421




Blazejowski et al. 2005

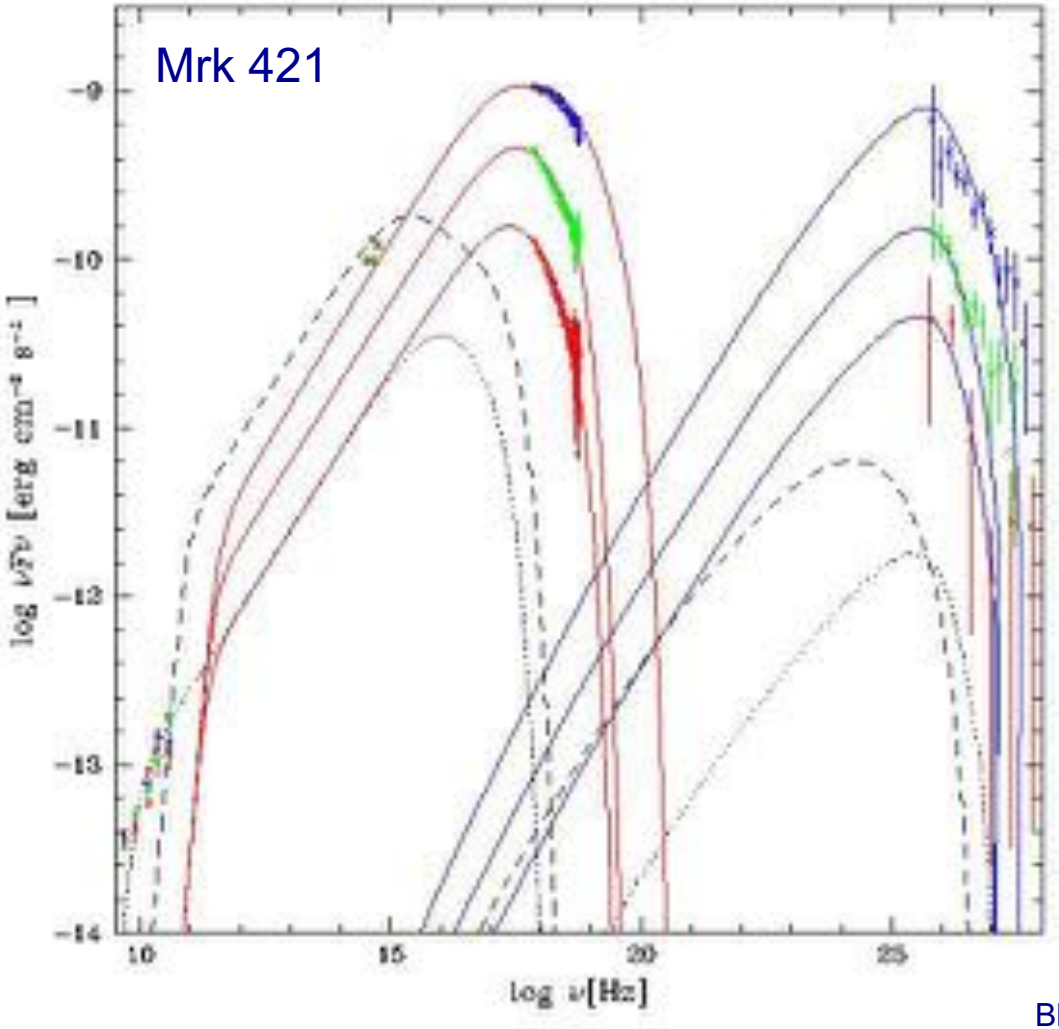
# Example I: Varying Behaviors

Mrk 421



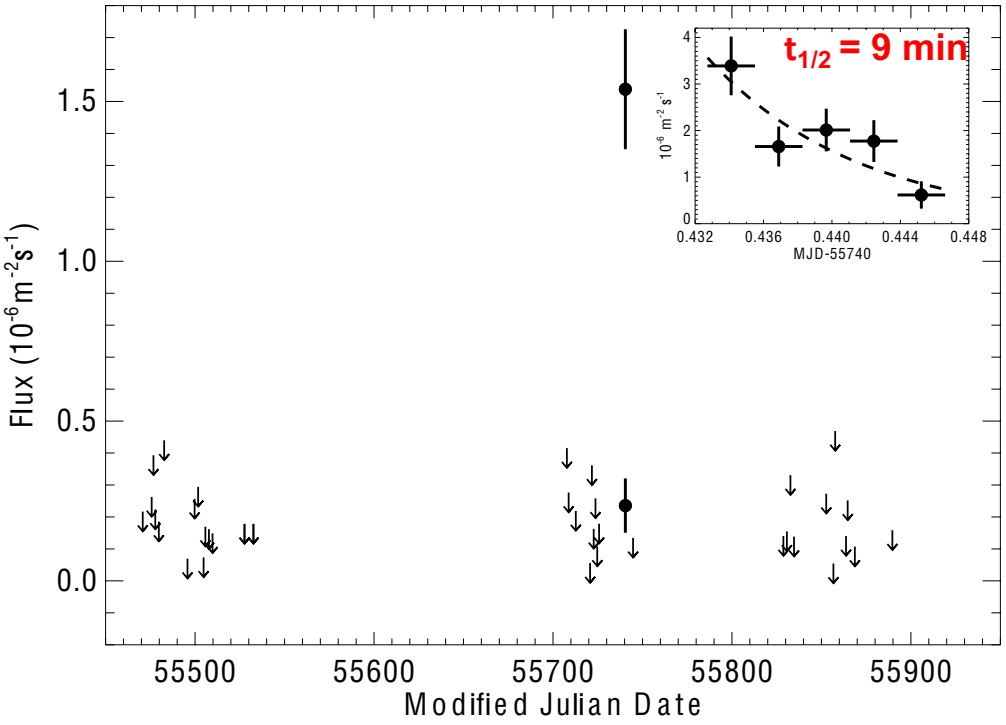

Blazejowski et al. 2005

# Example I: Reliable SED

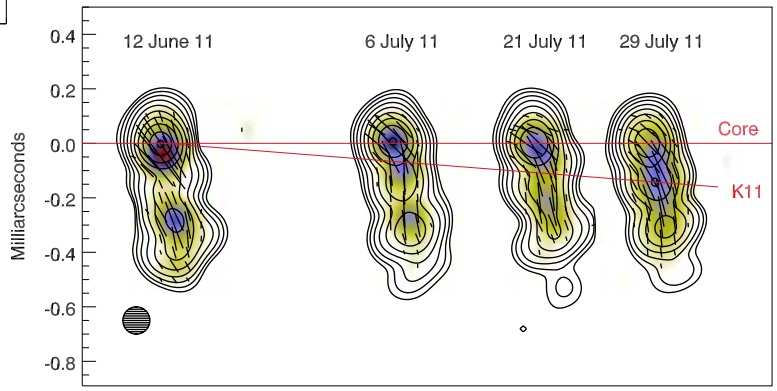



Blazejowski et al. 2005

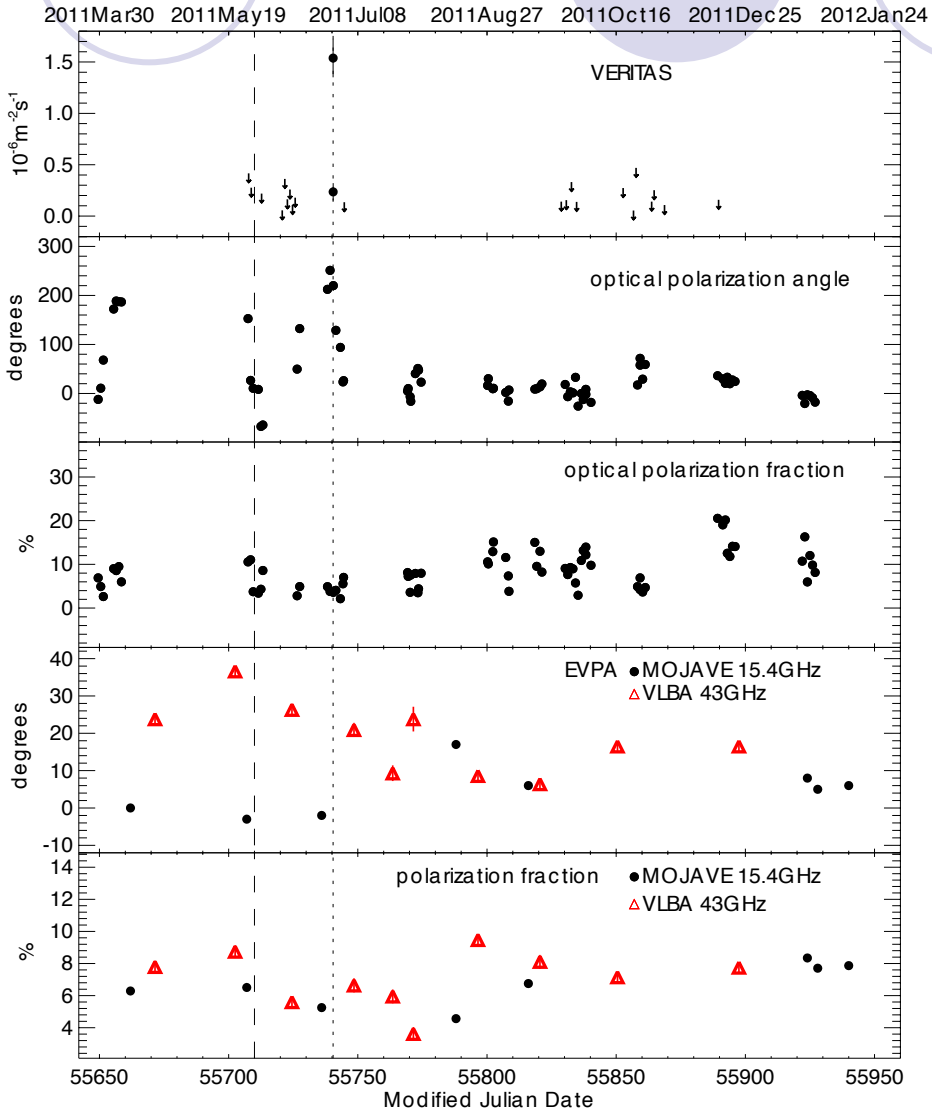
# Example II: Rapid Gamma-Ray Flares



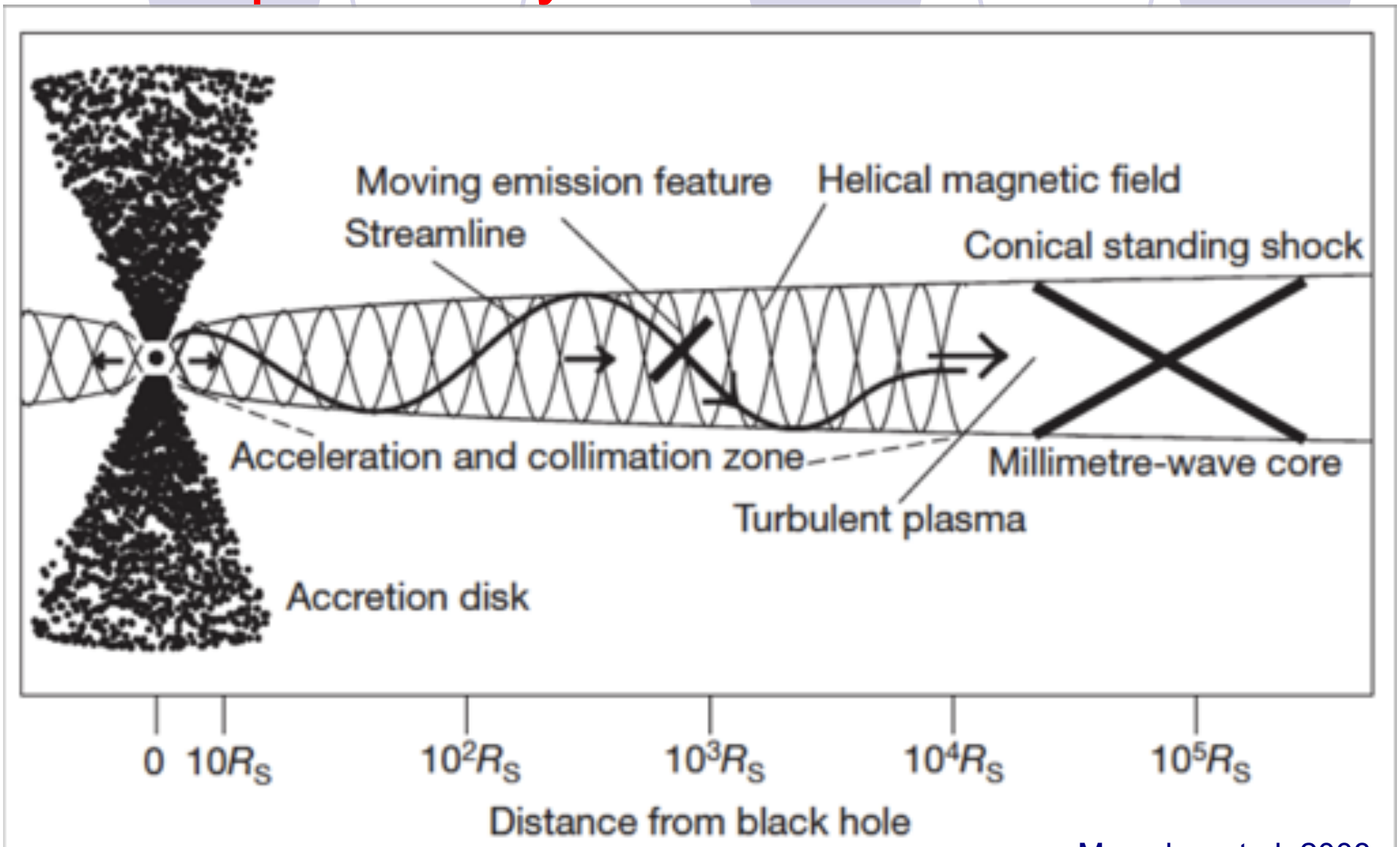

VERITAS Collaboration 2013



# Example II: Multiwavelength Coverage



# Example II: Physics

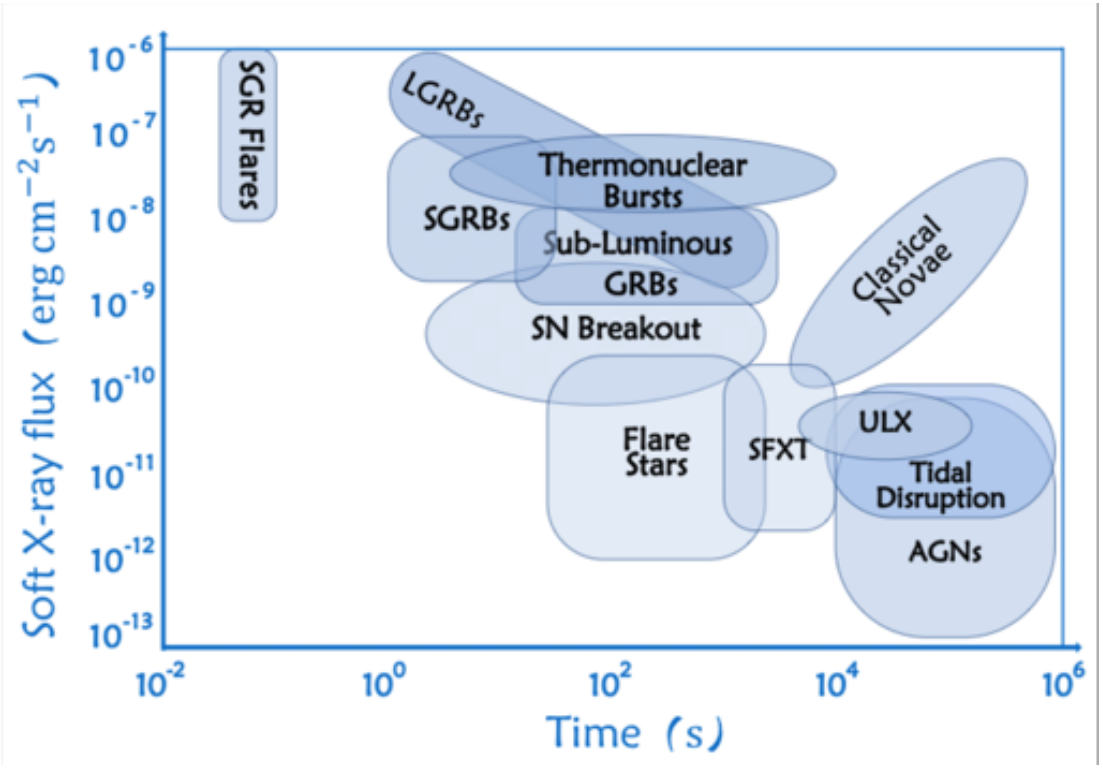



Marscher et al. 2008

# Variable/Transient Phenomena of Interest

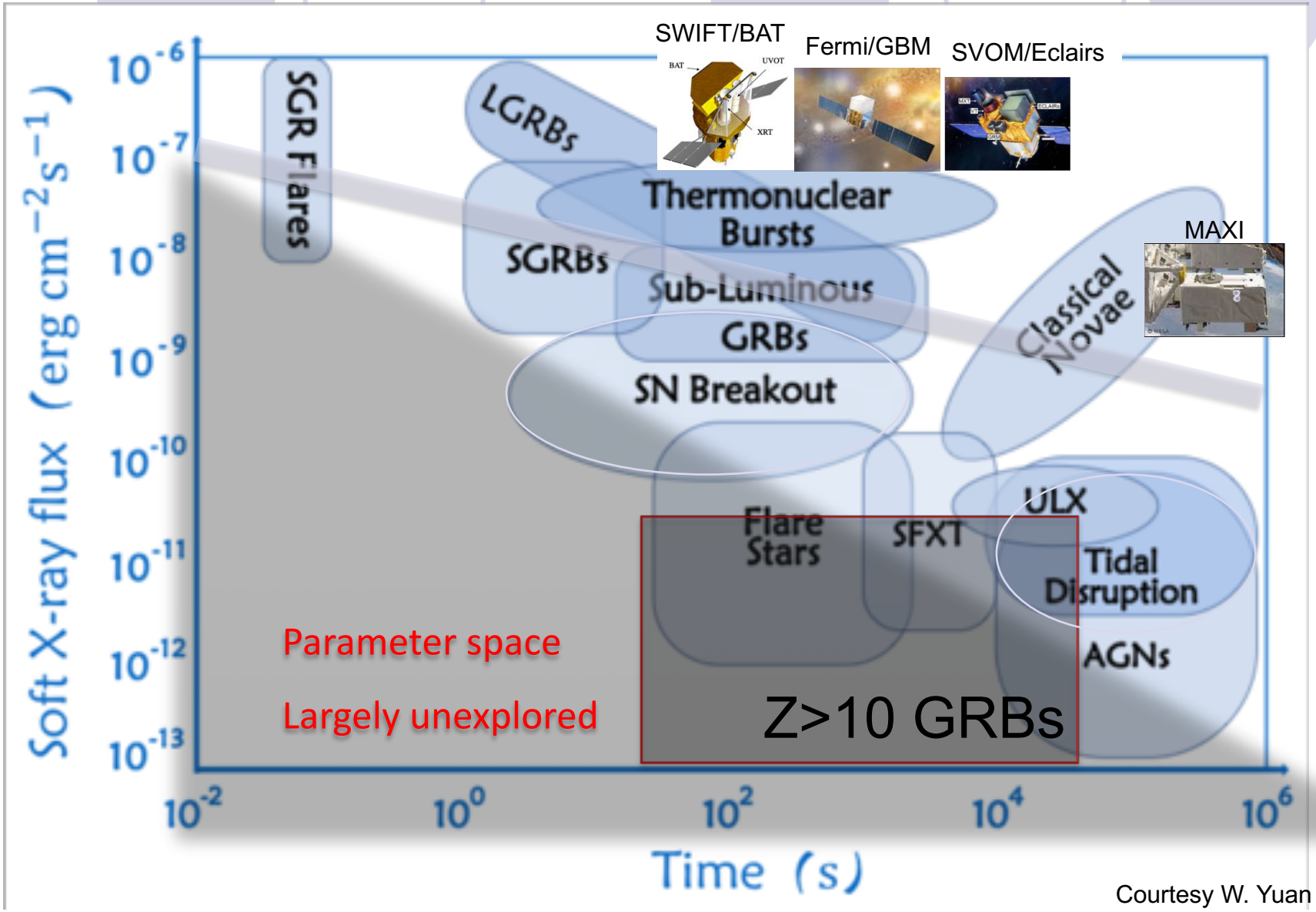
- Blazar flares
- Gravitation wave events
- Fast radio bursts
- gamma-ray bursts
- Tidal disruption events
- Soft gamma-ray repeaters
- X-ray novae
- Supernovae

- Unidentified gamma-ray sources




Courtesy W. Yuan

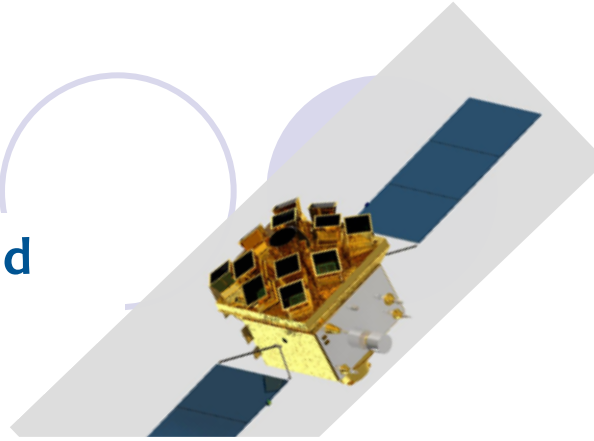
# Einstein Probe (EP)




Courtesy W. Yuan

# About EP

**An X-ray mission for all-sky monitoring to discover and study high-energy transients and variability**



## Status

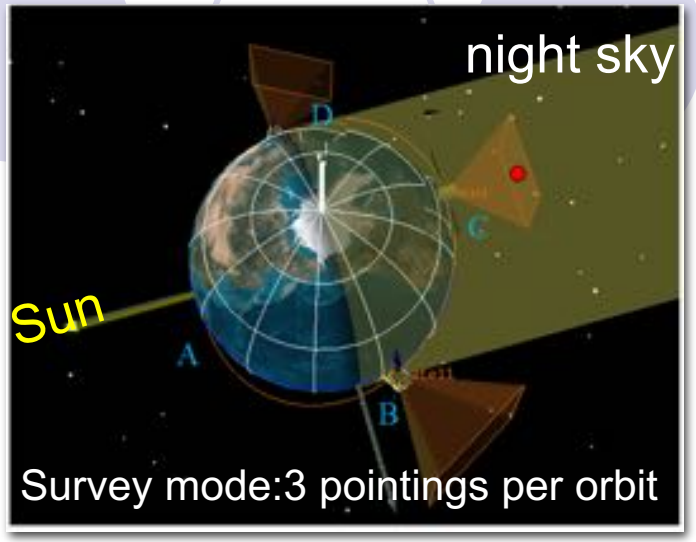
- A mission in the 2nd phase of the Space Science programe of Chinese Academy of Sciences; approved in 2017., fully funded
- Currently in Phase B
- planned launch: 2022/Dec; lifetime 3 years (5 years goal)

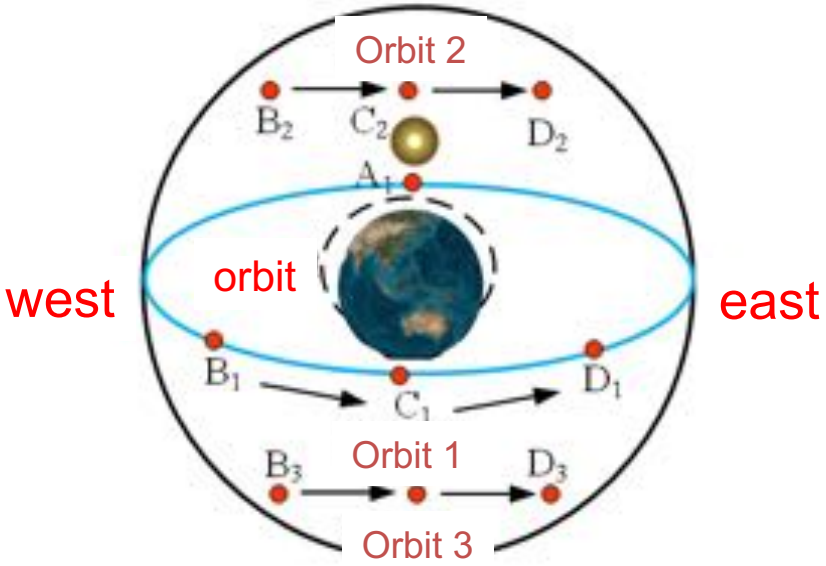
## Requirements

- Large Field of View 3600 sq. deg.
- Monitoring: soft X-ray band: 0.5-4 keV
- Sensitivity: > 1 order of magnitude higher than those in orbit
- Good angular resolution (~5' fwhm) and positioning accuracy (<1')
- Autonomous follow-up (<10 arcsec localisation; 0.3-10keV)
- Fast alert data downlink and (possible) fast uplink (ToO)

# Mission profile

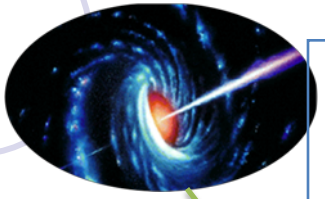
- Orbit: 550km (~97m), i < 30deg
- Weight: ~1040kg, power ~900W
- Observation modes
  - **Survey**: 3 pointings per orbit to the night-sky, each ~20 min exposure
  - cover whole night sky in 3 orbits
  - **Autonomous follow-up**: FXT
  - **ToO** (fast ToO)
- On-board data reduction & transient search
- Nominal lifetime: 3 +2 years



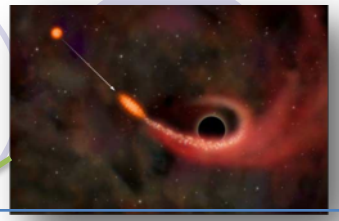



# EP Science

X-ray flash
& LL GRB
GRB physics



Active galactic nuclei
Extreme gravity, BH
accretion/jets/growth



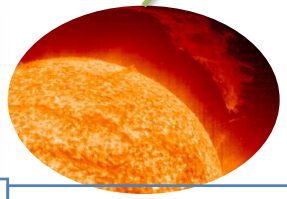
BH Tidal disruption
Quiescent MBH finder
BH accretion/jets
30-300/yr

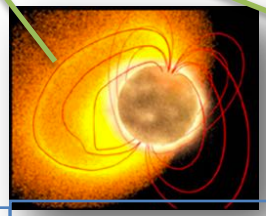
High-redshift GRB
Trace first stars/BH
Early universe

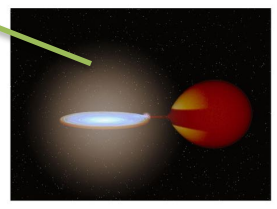
4-5 detection in 3yr

Intermediate-mass BH
BH physics/accretion

SN shock breakout
SN physics
Size of progenitors







BH X-ray binary
Extreme gravity
BH physics/accretion

Comets
charge exchange
emission

Star X-ray flares
Magnetic fields
Corona activity

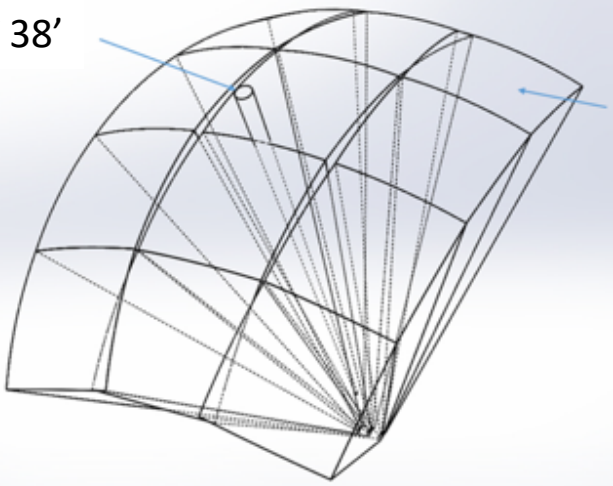
SGR/magnetar
extreme
magnetic Field

Thermal nuclear burst
Neutron stars physics

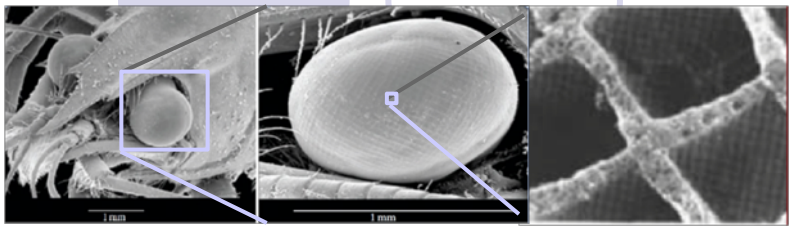
# EP Instruments

- **Wide-field X-ray Telescope (WXT)**
  - Wide-field Monitor
  - X-ray optics: lobster-eye MPO
  - 12 modules; total FoV~ 3600 square degrees
- **Follow-up X-ray Telescope (FXT)**

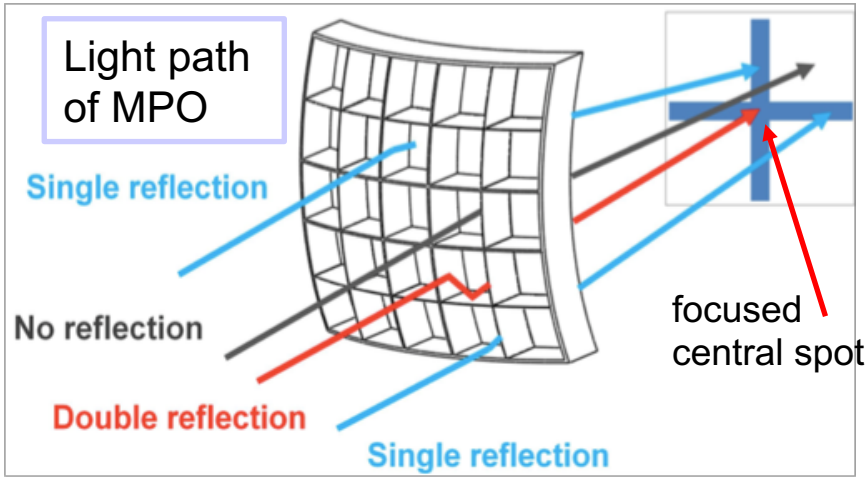
**fields of view**

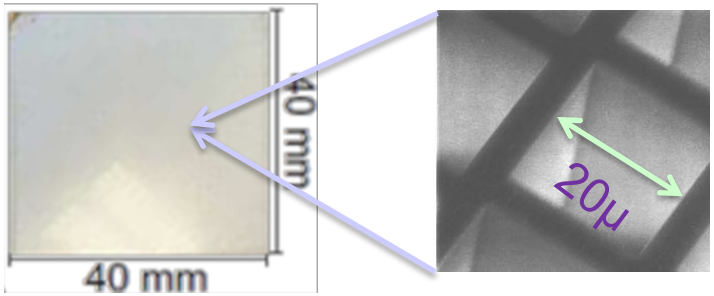


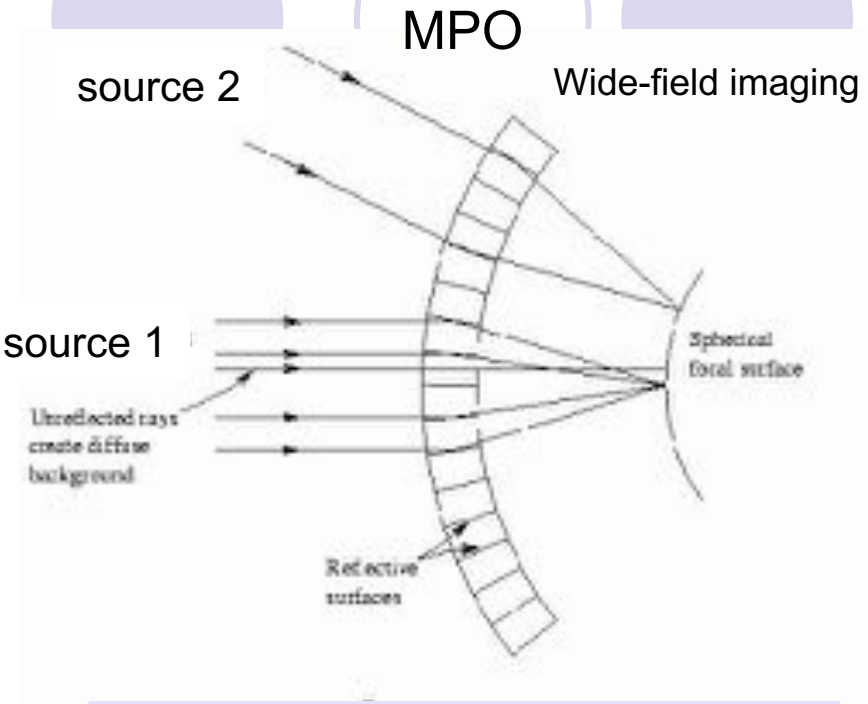

# EP WXT: Lobster-Eye Optics



Light is collected & focused in lobster eyes by two reflections off adjacent walls



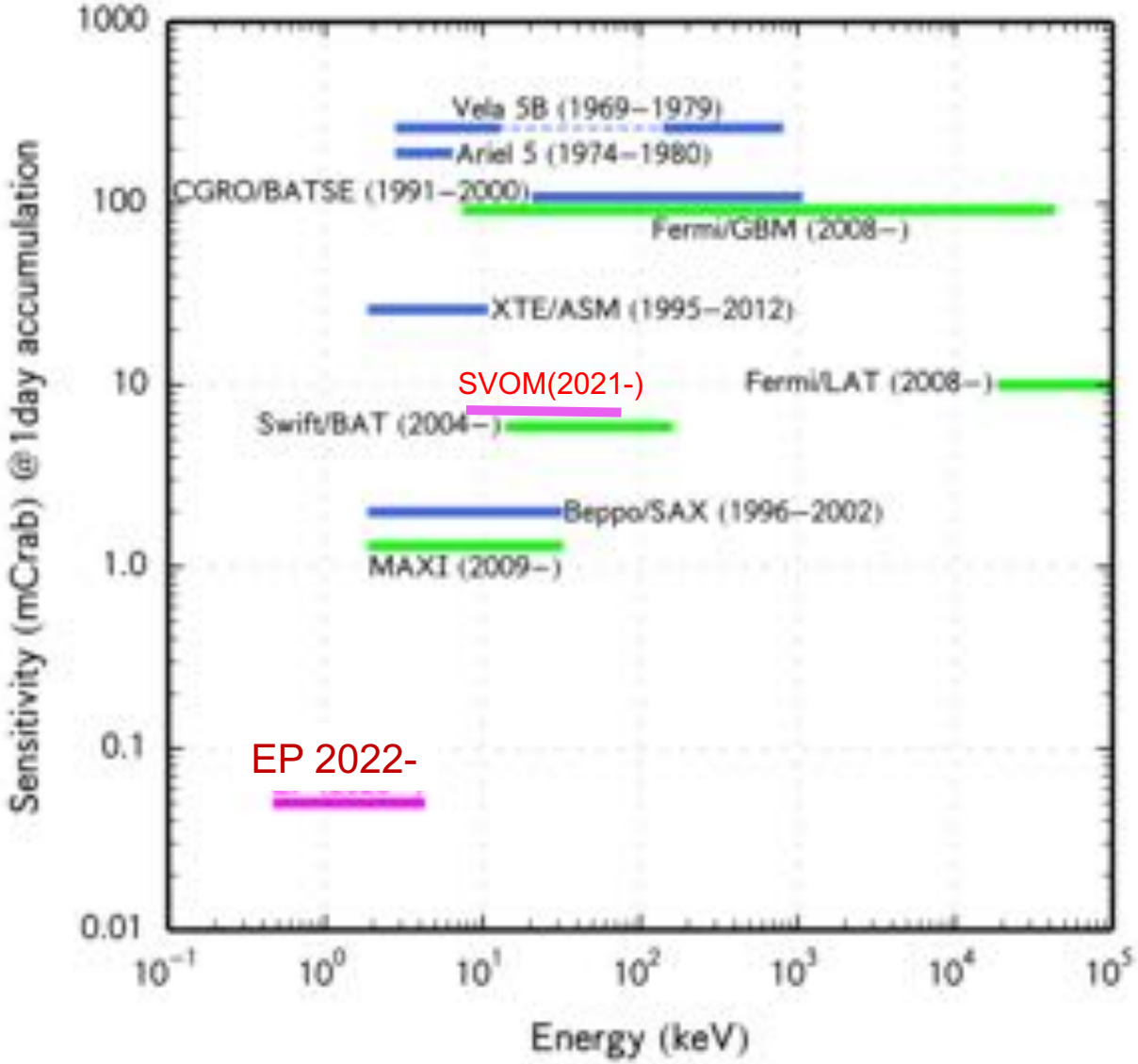



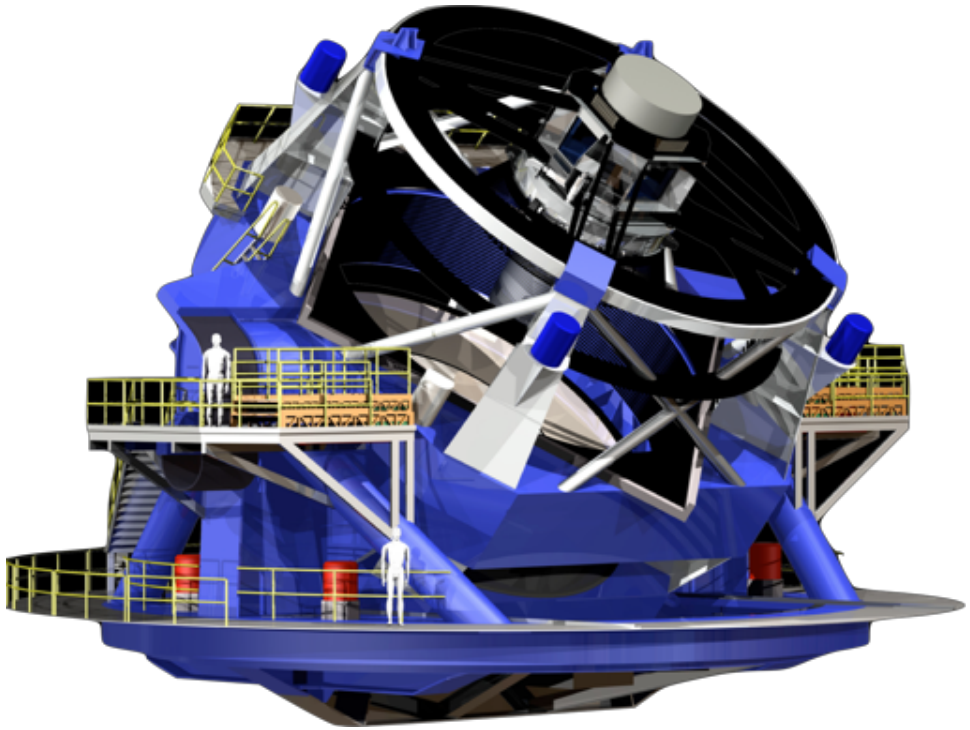

Ideal for X-ray All-sky monitor

- True imaging by focusing X-rays
- Wide FoV (un-vignetted)
- Good resolution: a few arcmin
- High sensitivity
- Low weight

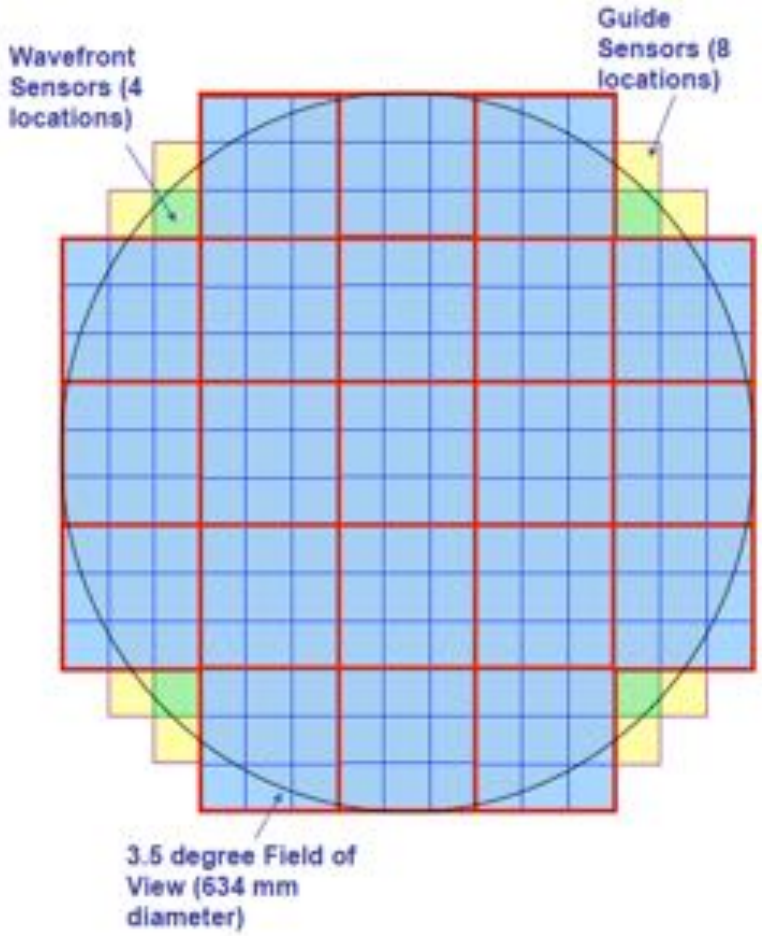
# EP WXT: sensitivity



# Large Synoptic Survey Telescope



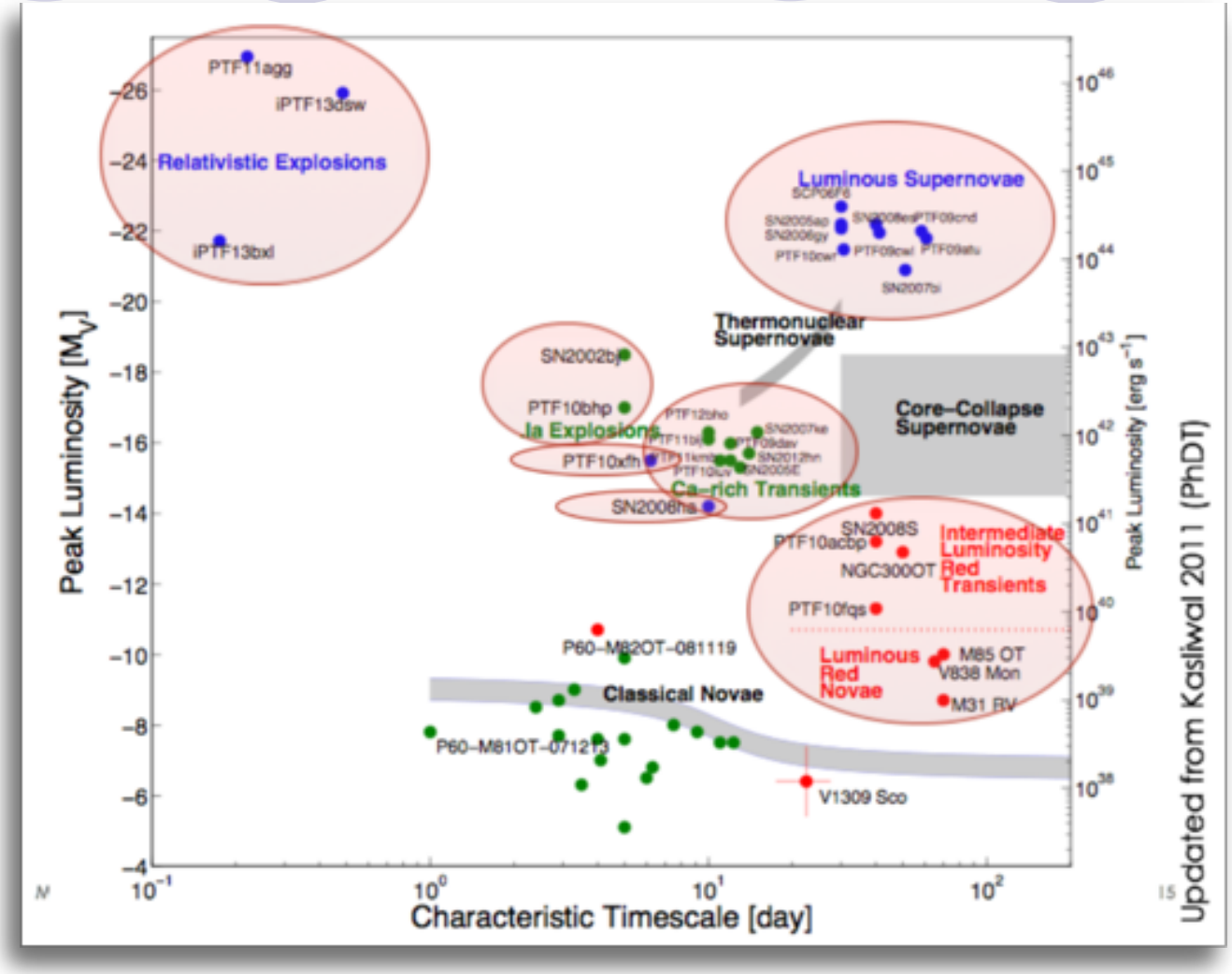
# LSST: Large FOV




| Survey Property | Performance |
|---|---|
| Main Survey Area | 18000 sq. deg. |
| Total visits per sky patch | 825 |
| Filter set | 6 filters (ugrizy) from 320 to 1050nm |
| Single visit | 2 x 15 second exposures |
| Single Visit Limiting Magnitude | u = 23.5; g = 24.8; r = 24.4; I = 23.9; z = 23.3; y = 22.1 |
| Photometric calibration | 2% absolute, 0.5% repeatability & colors |
| Median delivered image quality | ~ 0.7 arcsec. FWHM |
| Transient processing latency | 60 sec after last visit exposure |
| Data release | Full reprocessing of survey data annually |

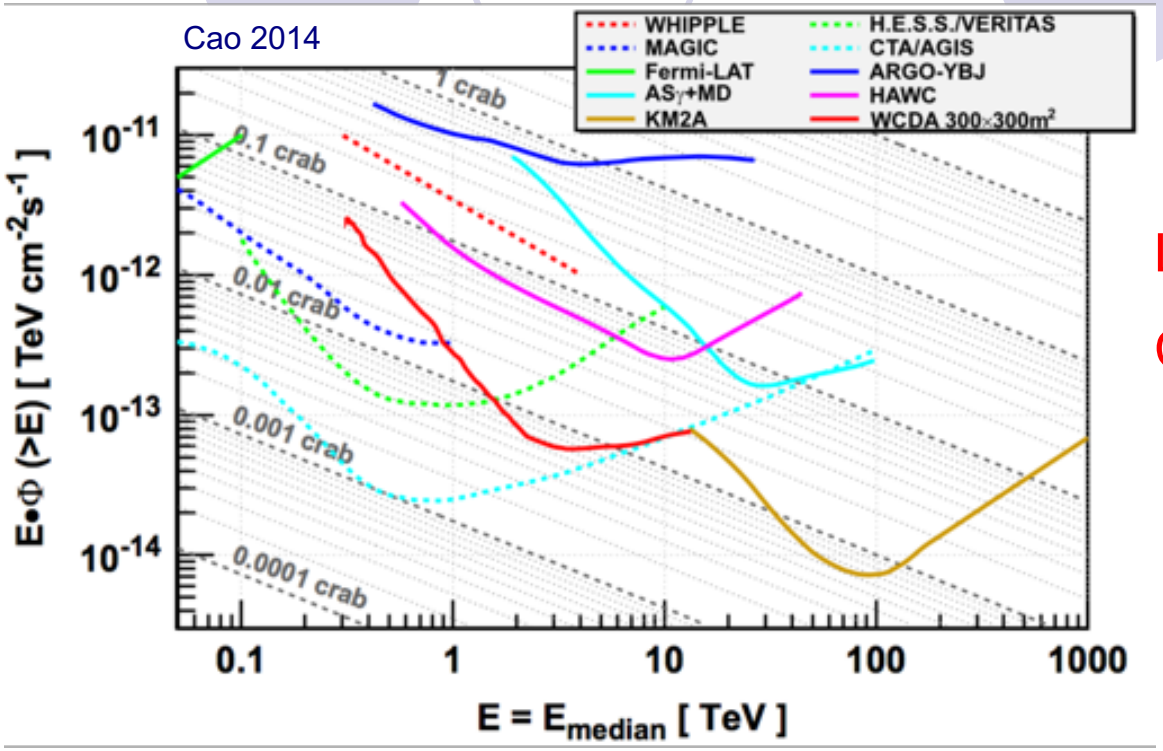
Estimated millions of transient/variable events per night!

# LSST Transients




Taken from F. Bianco (LSST web site)

# Future Outlook: Time-Domain Astronomy




LHAASO: discover transients

CTA: follow up on the alerts