Scientific Conclusions / Questions

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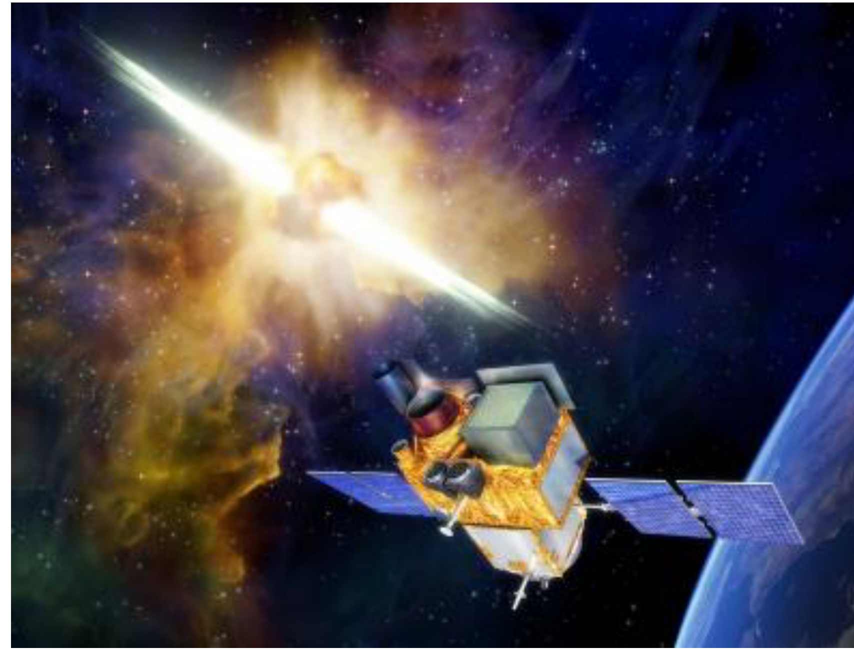
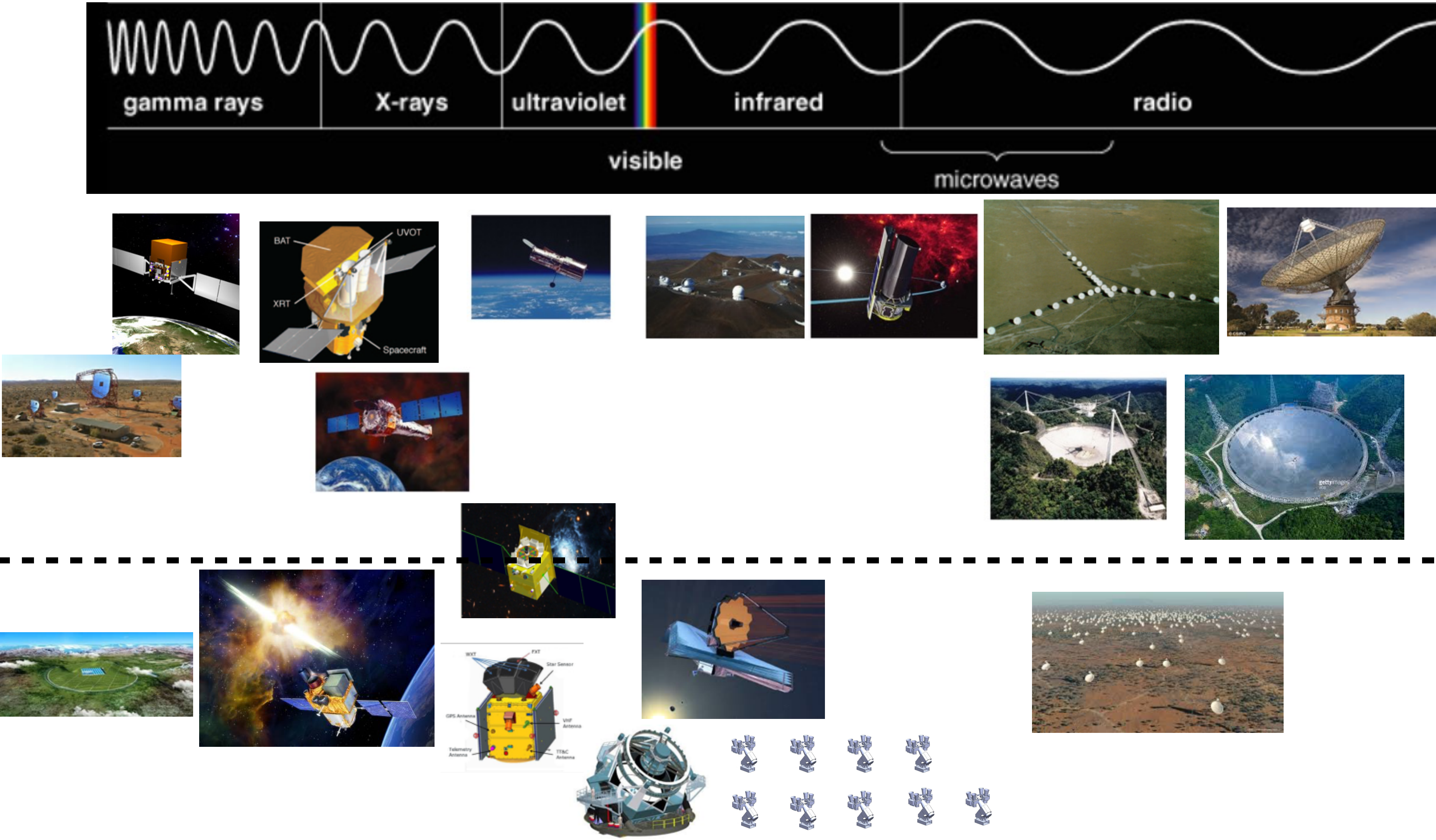


Apr. 28, 2017

Second SVOM Workshop
Qiannan, Guizhou, China, Apr. 2017

A Golden Era of Transient Astrophysics: Multi-wavelength

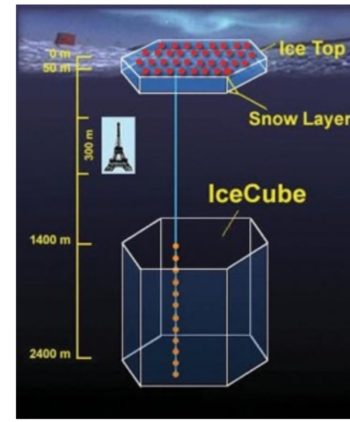


A Golden Era of Transient Astrophysics: Multi-messenger

Cosmic rays

Interacting fermions

Neutrinos



Strong interaction

~1

Weak interaction

$\sim 10^{-13} - 10^{-7}$

Fundamental interactions

Strong & “shallow”

Weak & “deep”

$\sim 10^{-2}$

$\sim 10^{-39}$

EM interaction

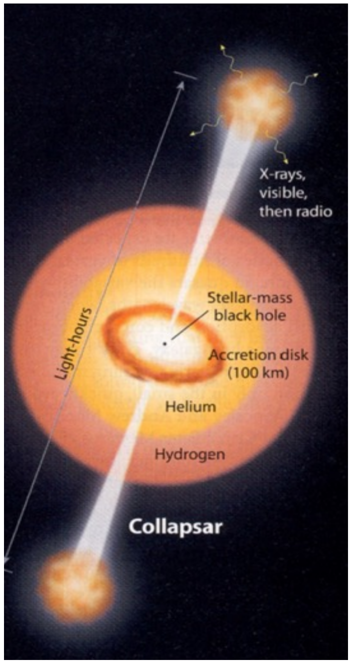
gravitational interaction

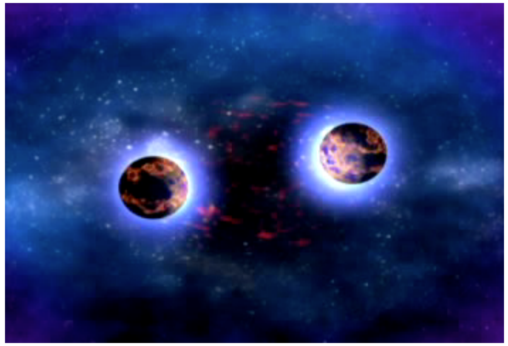
Photons

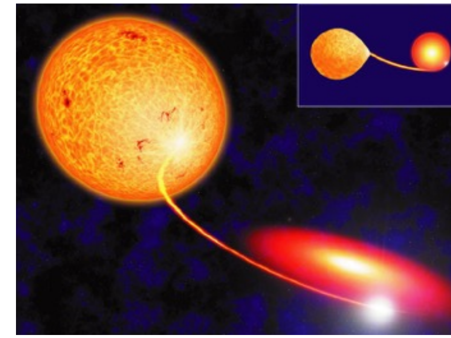
Boson mediators

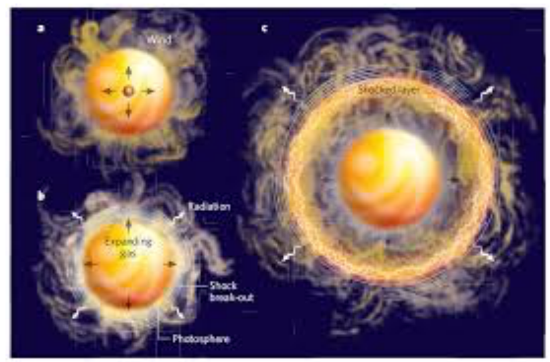
Gravitational waves

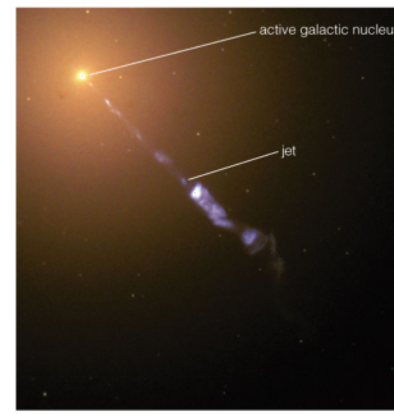
A Violent Universe

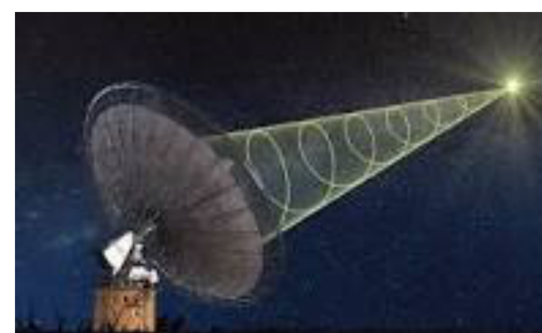




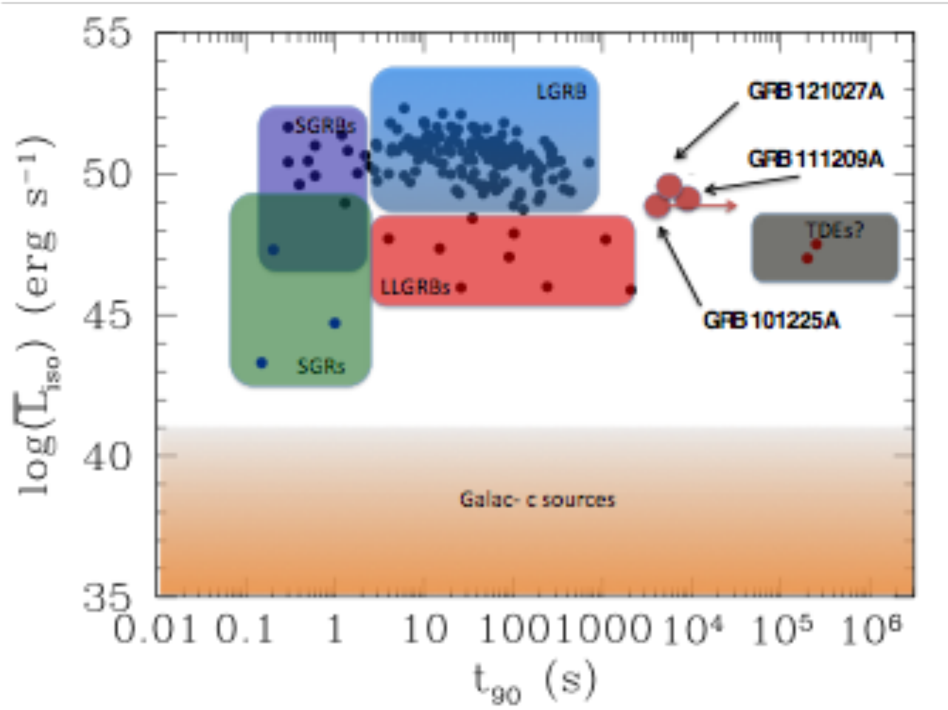


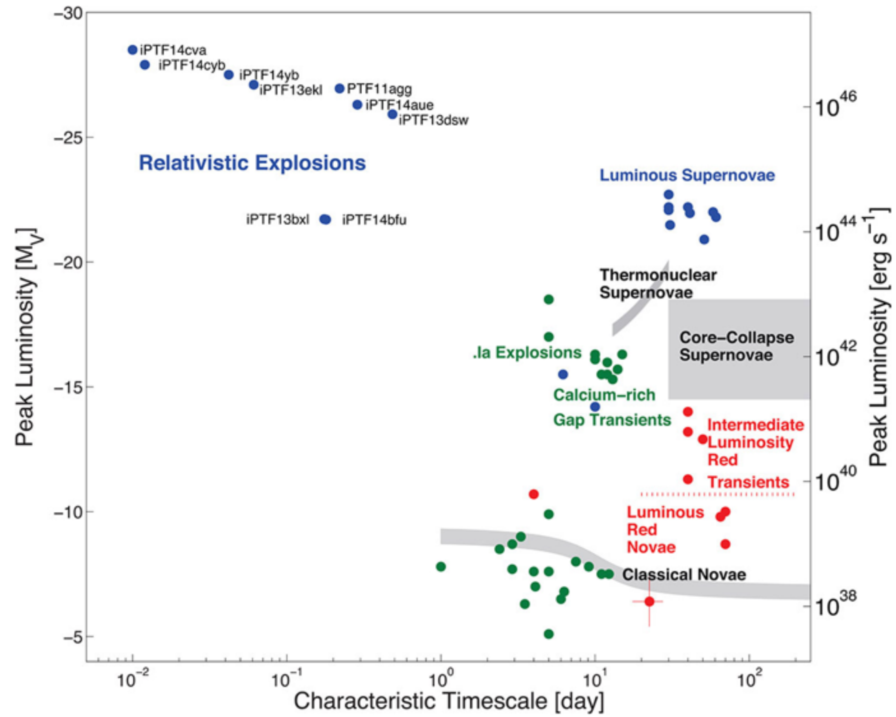






Status of the field





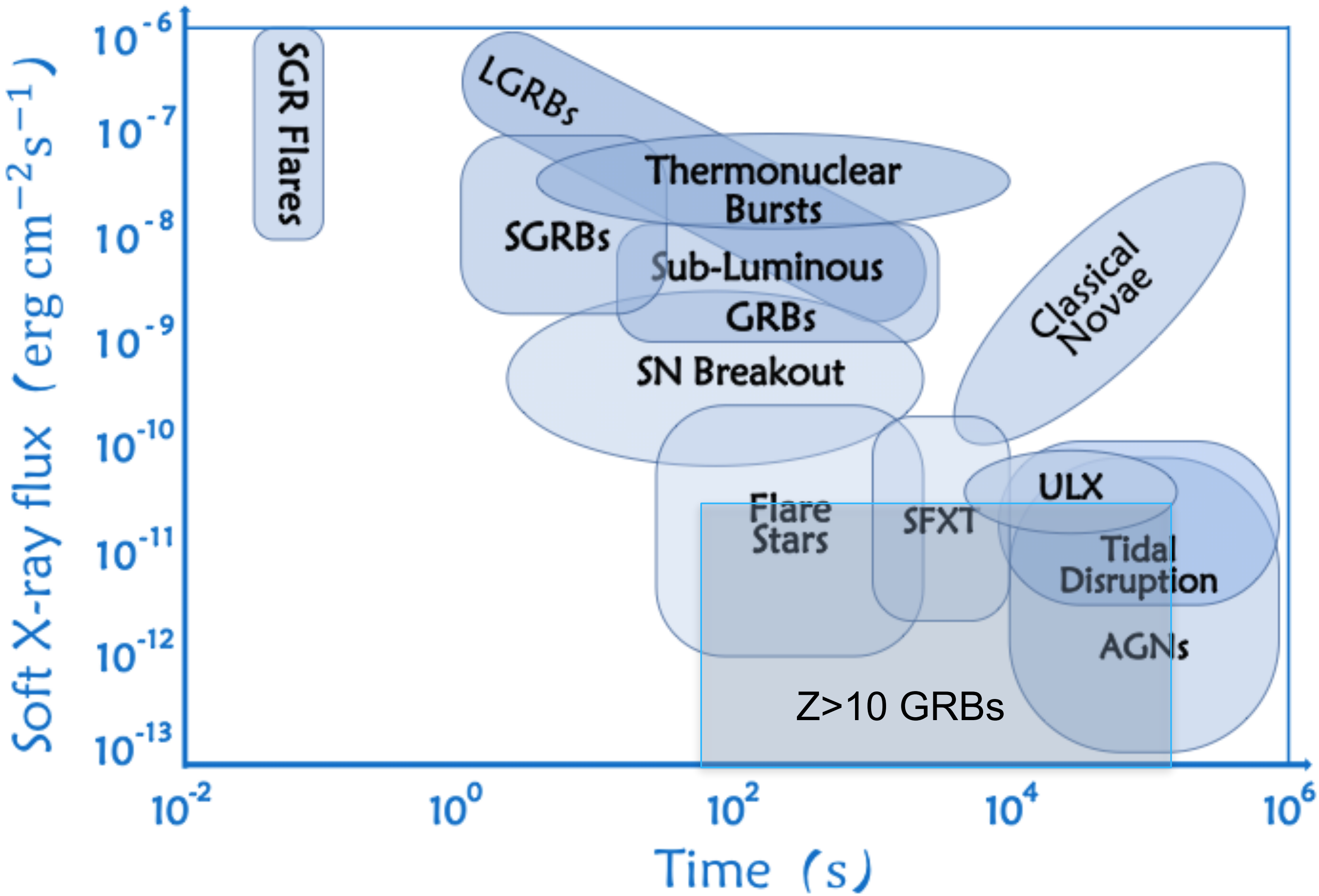
Gamma-rays

Levan et al. (2014)

Optical

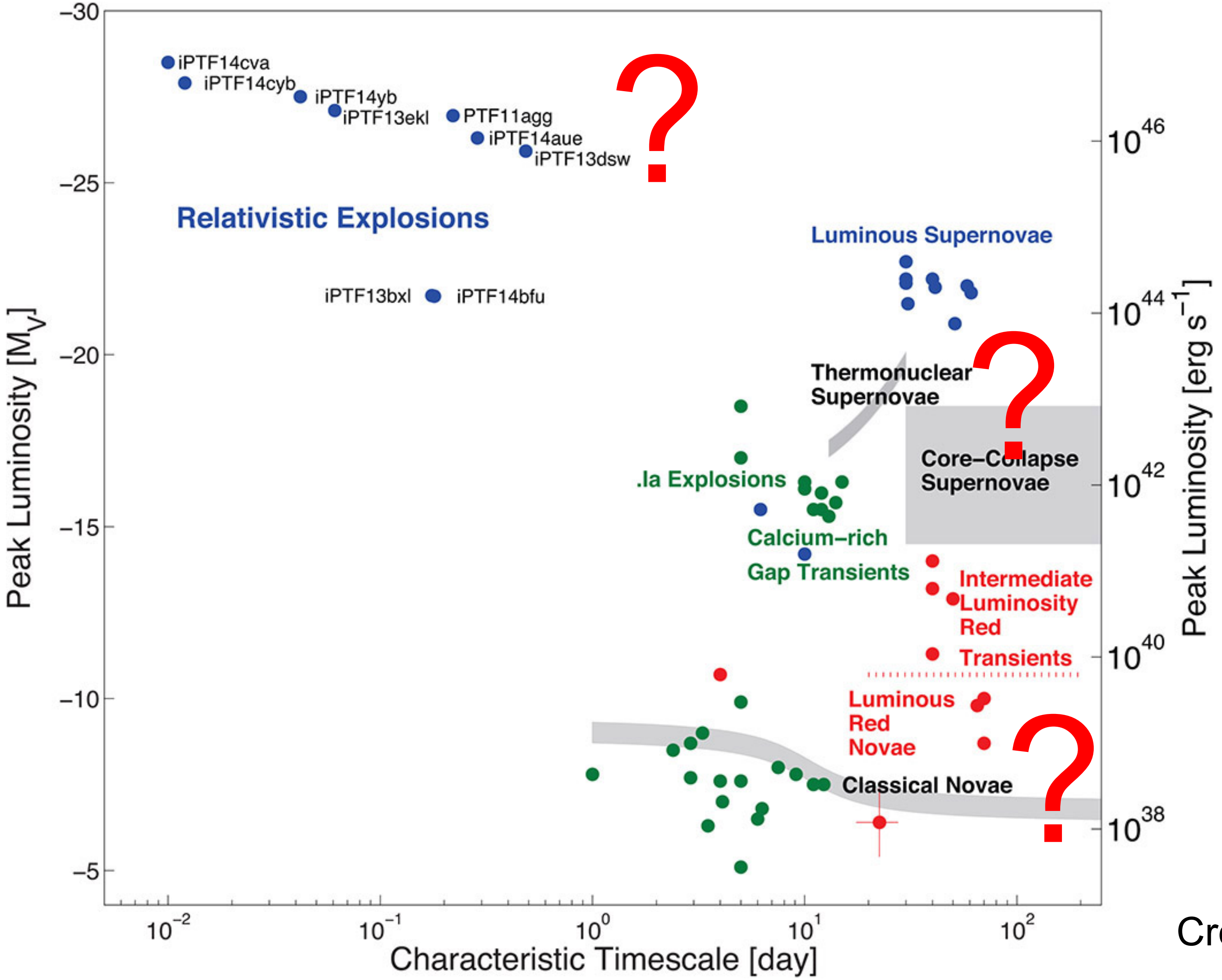
Credit: PTF

Status of the field



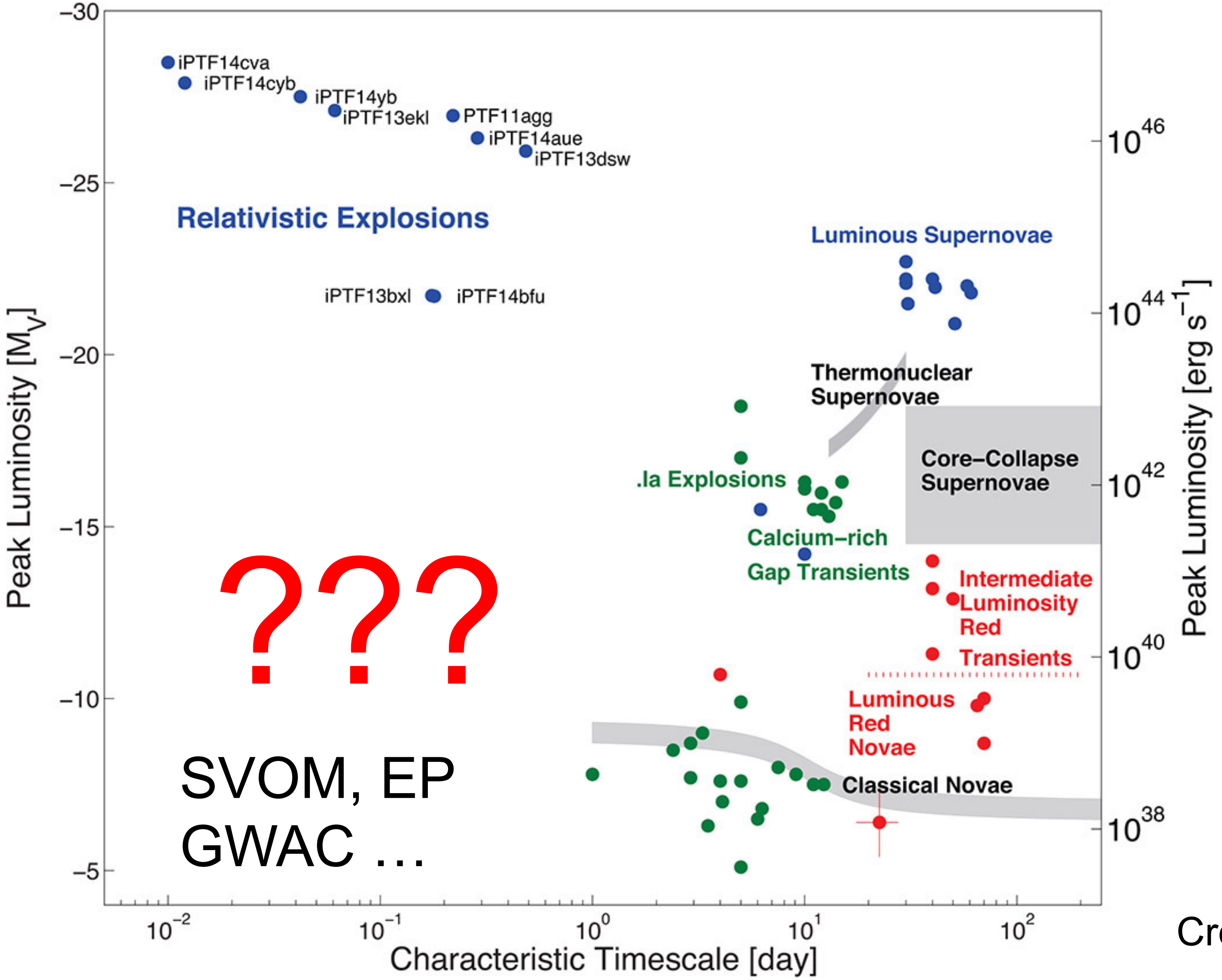
X-ray band (Credit: Weimin Yuan)

Theorists' perspectives



Credit: PTF

Observer's perspectives



Credit: PTF

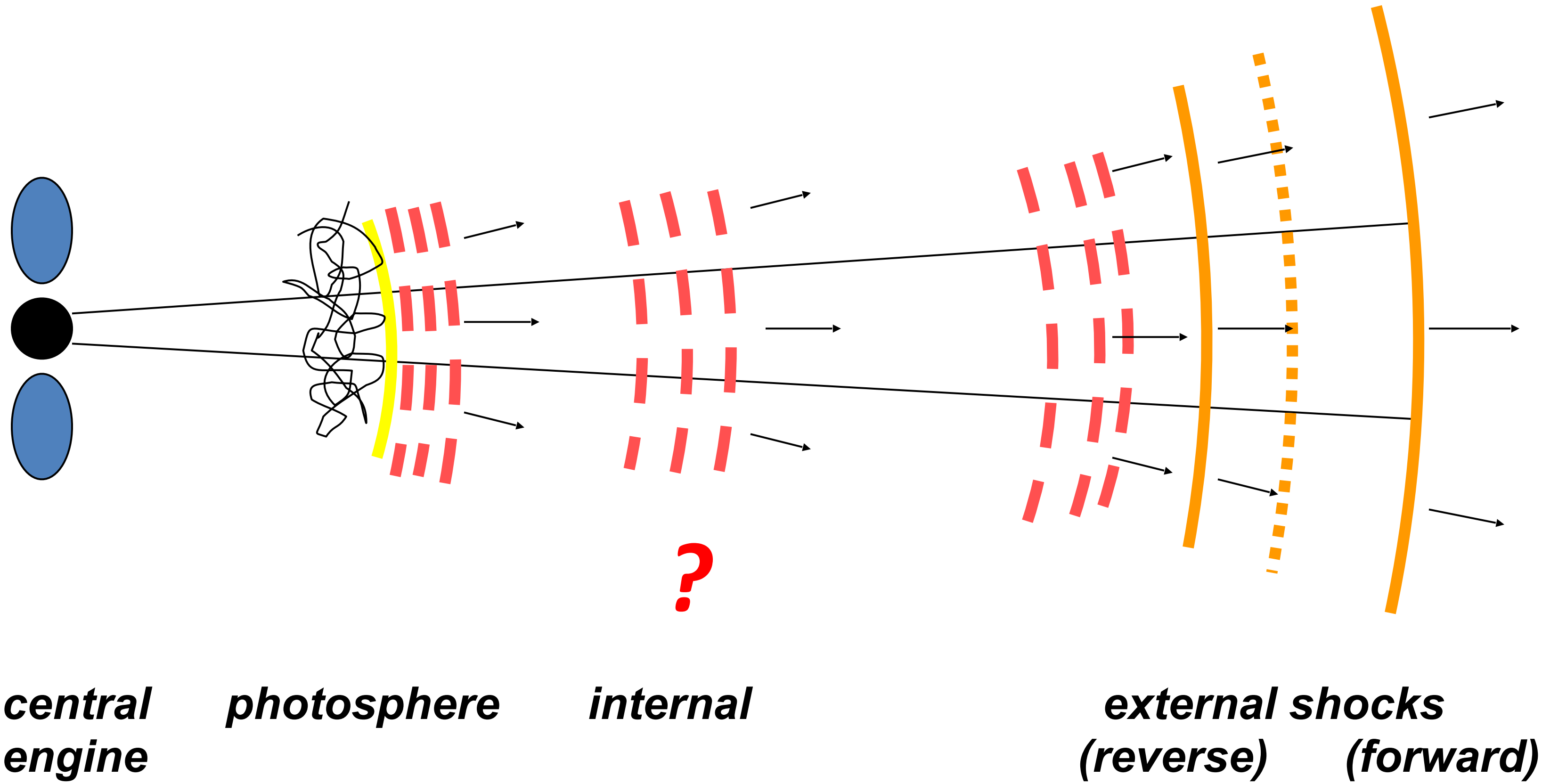
Scientific Conclusions
(on subjects discussed at this meeting)

- Gamma-ray bursts (V. Connaughton):
  - Located in a wide redshift range, good cosmic probes
  - Two broad types of progenitor systems, but explicit progenitors remain elusive
  - Afterglow generally understood, but prompt emission mechanism remains debated
- Gravitational waves (T. Li):
  - Finally detected!
  - The strongest sources are predominantly BH-BH mergers
  - Relatively large BHs
- Neutrinos (J. Vandenbrouke):
  - Astrophysical high-energy neutrinos discovered
  - Origin unknown but likely not from bright GRBs
- Fast radio bursts (E. Petroff):
  - Astrophysical origin
  - One repeating, at cosmological distance

Scientific Questions:
I. Gamma-ray bursts

- Are short GRBs produced by NS-NS mergers or NS-BH mergers (the Gehrels' question) or something else?
- Can both BHs and magnetars make GRBs?
- Can we identify more progenitor systems for long GRBs (e.g. UL-GRBs, LL-GRBs …) (D. Gotz)
- What's the composition of GRB jets (fireball vs. Poynting flux)?
- What's the energy dissipation mechanism (shock vs. magnetic reconnection)?
- What's the radiation mechanism of GRB (synchrotron vs. thermal Comptonization)?

GRB Emission Models



Uncertainties in GRB Prompt Emission:

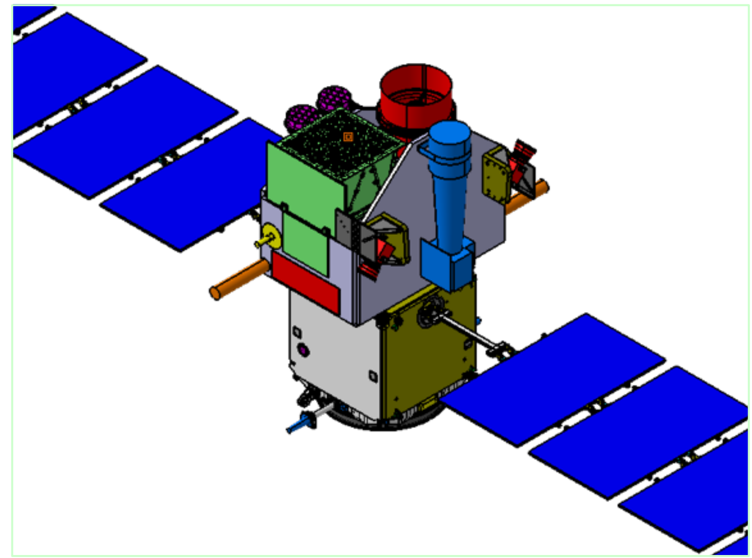
What *is the jet composition (baryonic vs. Poynting flux)?*

Where *is (are) the dissipation radius (radii)? – three possible locations*

How *is the radiation generated (synchrotron, Compton scattering, thermal)?*

SVOM-led GRB observation campaign

- ECLAIRS/GRM: detailed prompt emission physics
- MXT/VT: detailed afterglow physics
- GWAC: prompt and even prior emission from GRBs
- POLAR/HXMT (S. N. Zhang): complementary information
- Multi-wavelength / multi-messenger observational campaign



Talks by Cordier, Wei, Daigne, Bajat, Schanne, Xin, Klotz, Corre, Han, Wang, O'Brien, Goldwurm, Buswitz …

Scientific Questions:
II. Gravitational waves & EM counterparts

- Where are BH-NS and NS-NS mergers?
- Are BH-NS and NS-NS mergers associated with bright EM counterparts (N. Tanvir, J. Osborne, D. Xu)?
- Can BH-BH mergers make detectable EM counterparts (B. Zhang)?
- Can we finally learn the equation of state of nuclear matter (neutron / quark stars) from GW observations?

Observational hints of a possible supra-massive / stable NS as the merger product (I)

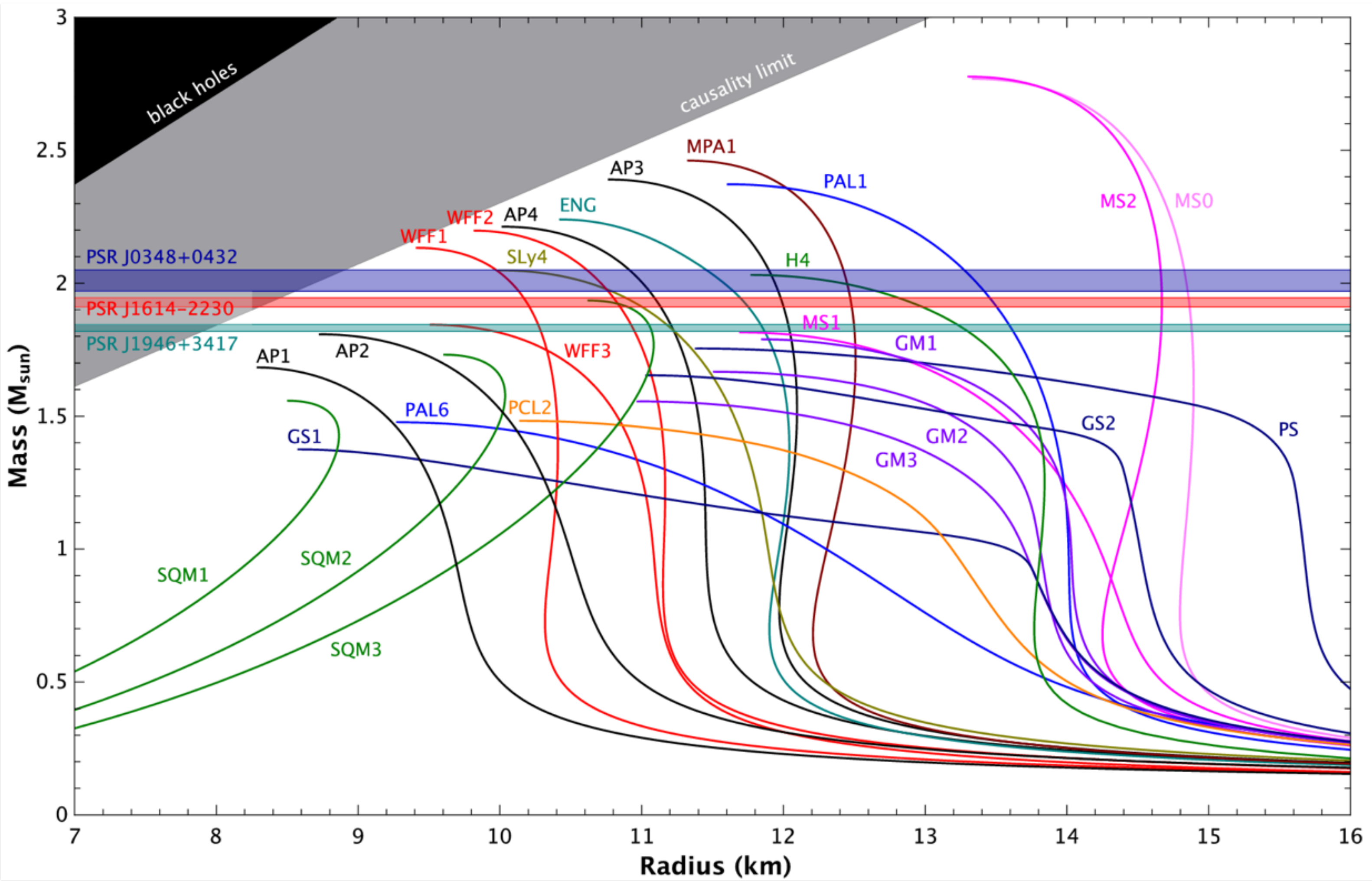
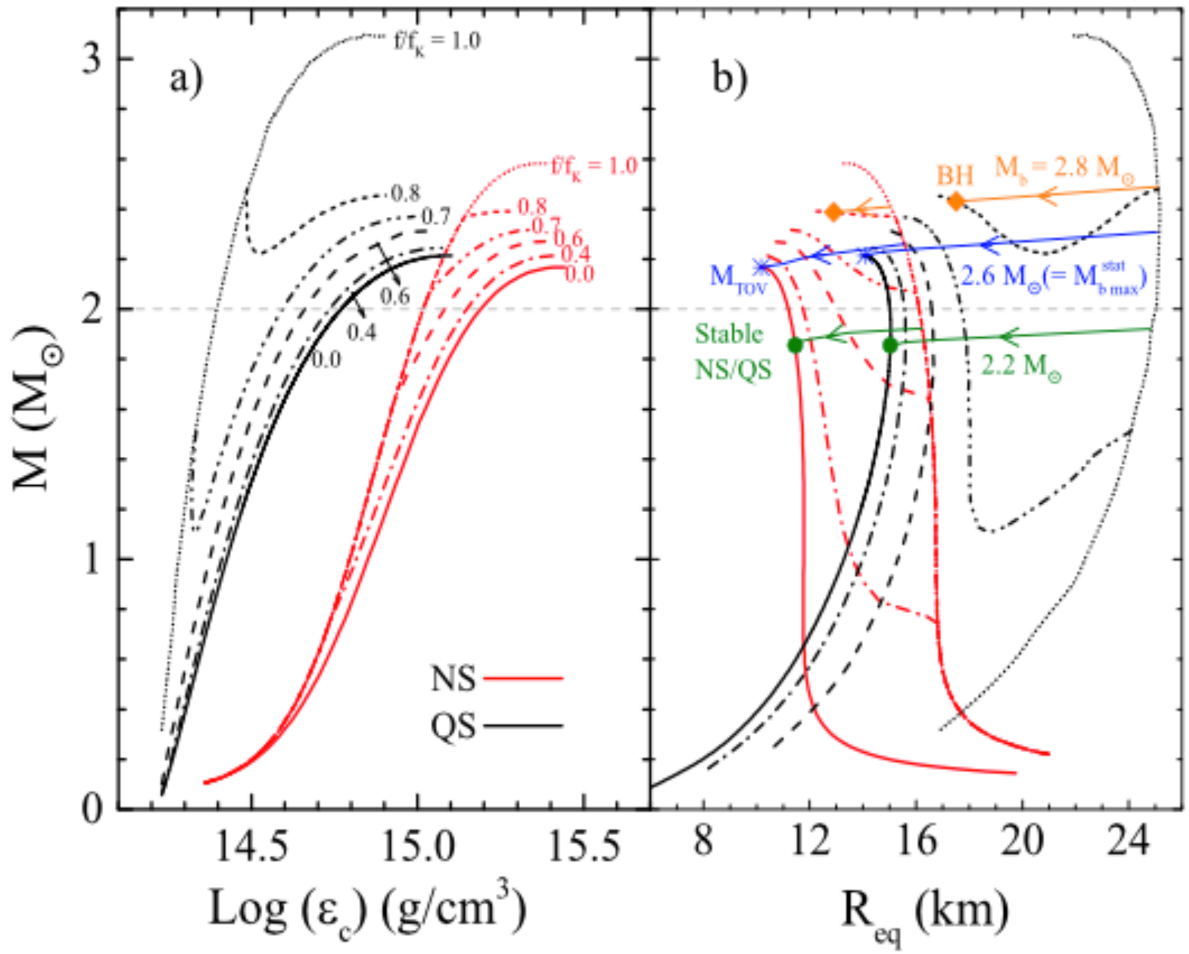


Figure by Norbert Wex. See http://www3.mpifr-bonn.mpg.de/staff/pfreire/NS_masses.html

Supra-massive and stable NSs/QSs



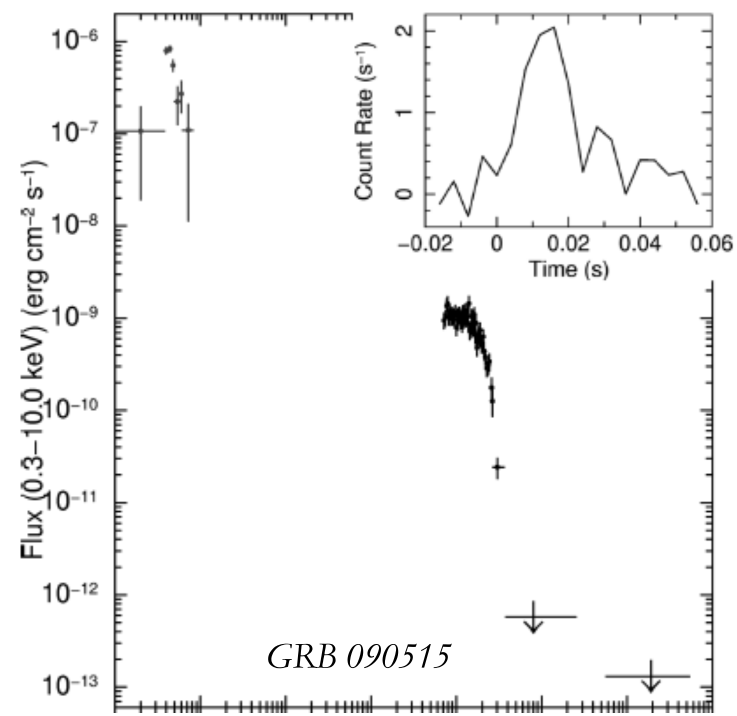
A. Li et al. (2016, PRD, 94, 083010, arXiv:1606.02934)

Example EoSs:

NS: BSK20
QS: CDDM1

A multi-messenger approach to constrain NS/QS equation-of-state

- GW signal: NS-NS system parameters (mass of the merger product); ring-down phase carries info of EoS.
- EM signal: brightness of the X-ray emission, collapse time – infer initial period, magnetic field, ellipticity, etc.; kilo-/merger-nova signal - infer ejected mass
- Putting everything together: constrain NS/QS EoS!



Rowlinson et al. (2010)

Scientific Questions:
III. Neutrinos

- What source(s) produce astrophysical high-energy neutrinos?
- Do various high-energy transients (GRBs, compact star mergers, AGN flares, even FRBs) produce high-energy neutrinos (J. Vandenbrouke)?
- What is the connection between the neutrino data and the observations of gamma-ray background and ultra-high-energy cosmic rays?
- What physics do we learn from the detection/non-detection of neutrino from astrophysical sources?

Non-detection of neutrinos by Icecube

- IceCube did not detect neutrinos from GRBs yet, upper limit 3 times lower than the most optimistic predictions (Waxman & Bahcall)

LETTER

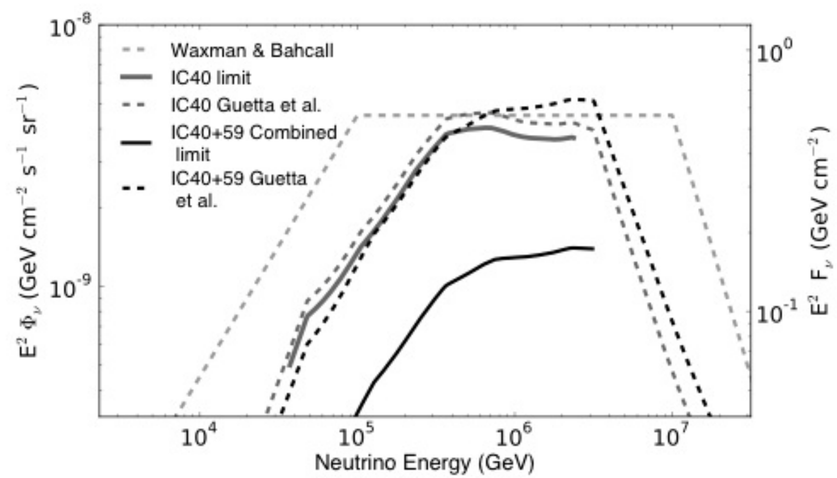
doi:10.1038/nature11068

An absence of neutrinos associated with cosmic-ray acceleration in γ-ray bursts

IceCube Collaboration*

Very energetic astrophysical events are required to accelerate cosmic rays to above 10^{18} electronvolts. GRBs (γ-ray bursts) have been proposed as possible candidate sources[1–3]. In the GRB 'fireball' model, cosmic-ray acceleration should be accompanied by neutrinos produced in the decay of charged pions created in interactions between the high-energy cosmic-ray protons and γ-rays[4]. Previous searches for such neutrinos found none, but the constraints were weak because the sensitivity was at best approximately equal to the predicted flux[5–7]. Here we report an upper limit on the flux of energetic neutrinos associated with GRBs that is at least a factor of 3.7 below the predictions[4,8–10]. This implies either that GRBs are not the only sources of cosmic rays with energies exceeding 10^{18} electronvolts or that the efficiency of neutrino production is much lower than has been predicted.

As in our previous study[7], we conducted two analyses of the IceCube data. In a model-dependent search, we examine data during the period of γ-ray emission reported by any satellite for neutrinos with the energy spectrum predicted from the γ-ray spectra of individual GRBs[6,9]. The model-independent analysis searches more generically for neutrinos on wider timescales, up to the limit of sensitivity to small numbers of events at ±1 day, or with different spectra. Both analyses follow the methods used in our previous work[7], with the exception of slightly changed event selection and the addition of the Southern Hemisphere to the model-independent search. Owing to the large background of downgoing muons from the southern sky, the Southern Hemisphere analysis is sensitive mainly to higher-energy events (Supplementary Fig. 3). Systematic uncertainties from detector effects have been included in the reported limits from both analyses,



IceCube results

Solar neutrino problem

- Early searches for solar neutrinos failed to find the predicted number (about 1/3 of predicted)
- Debate:
  - Astrophysics wrong?
  - Physics wrong?
- It turns out that neutrinos oscillate – physics was wrong

Homestake Solar Neutrino Observatory

Super Kamiokande

A GRB neutrino problem?

- Icecube did not detect high energy neutrinos from GRBs as expected from the theories
- A similar question arises:
  - Astrophysics wrong?
  - Physics wrong?
- This time, very likely astrophysics is wrong!

GRB models invoke a lot more uncertainties than solar models.

LETTER

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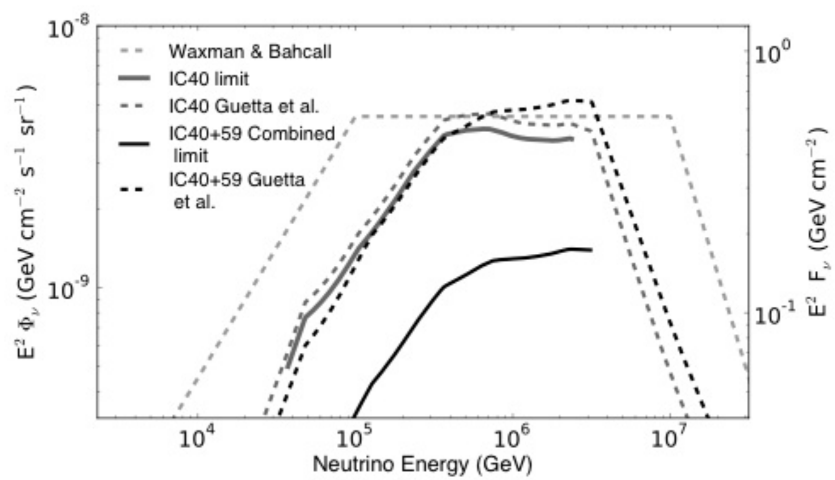
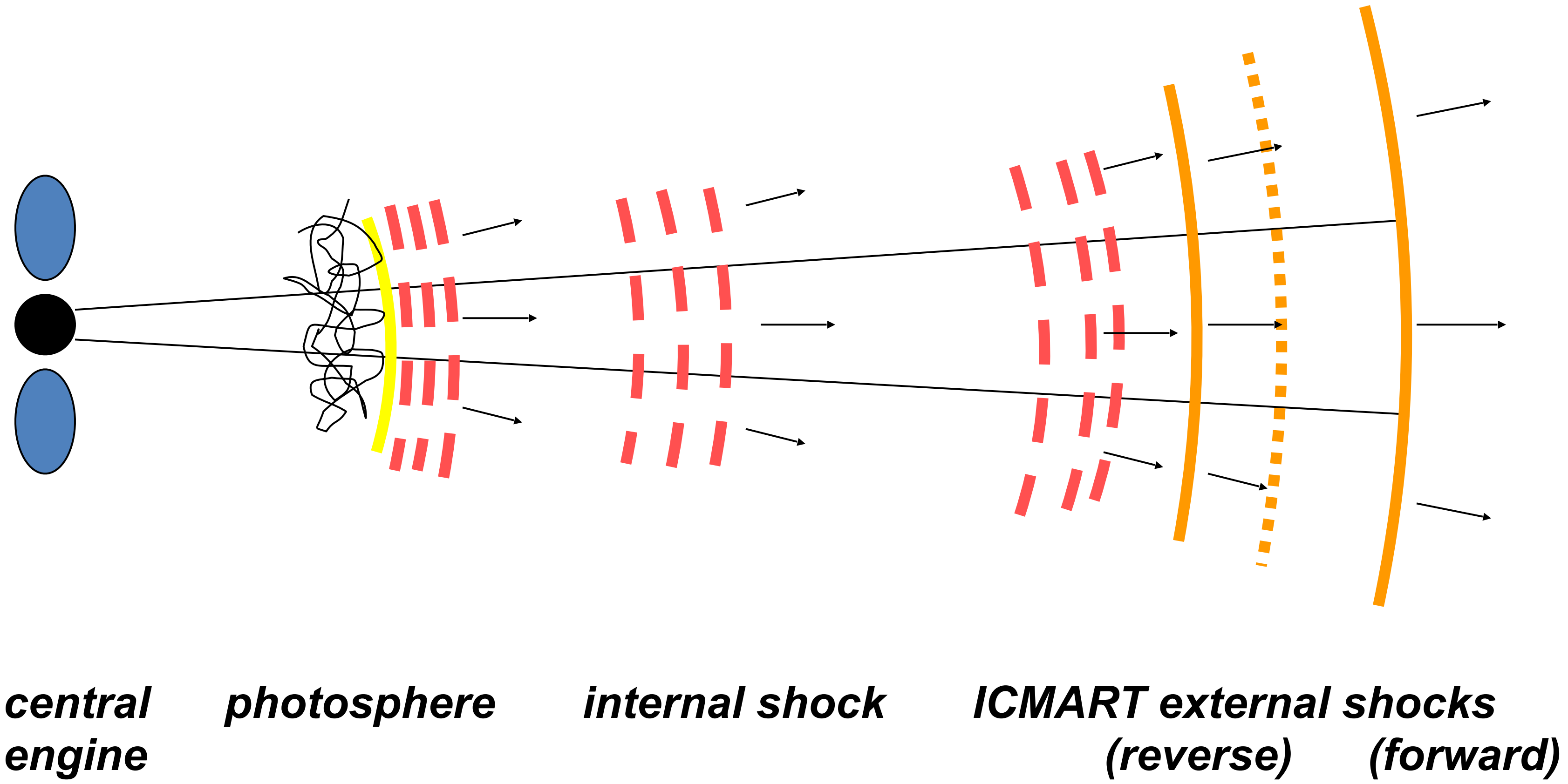
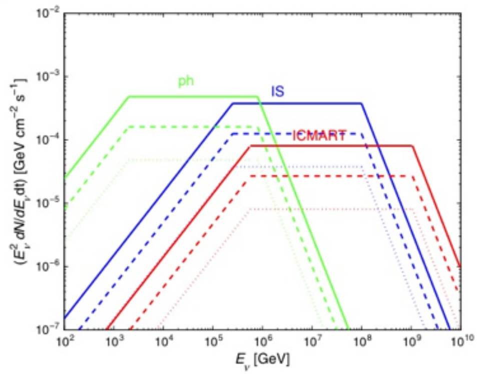


IceCube results

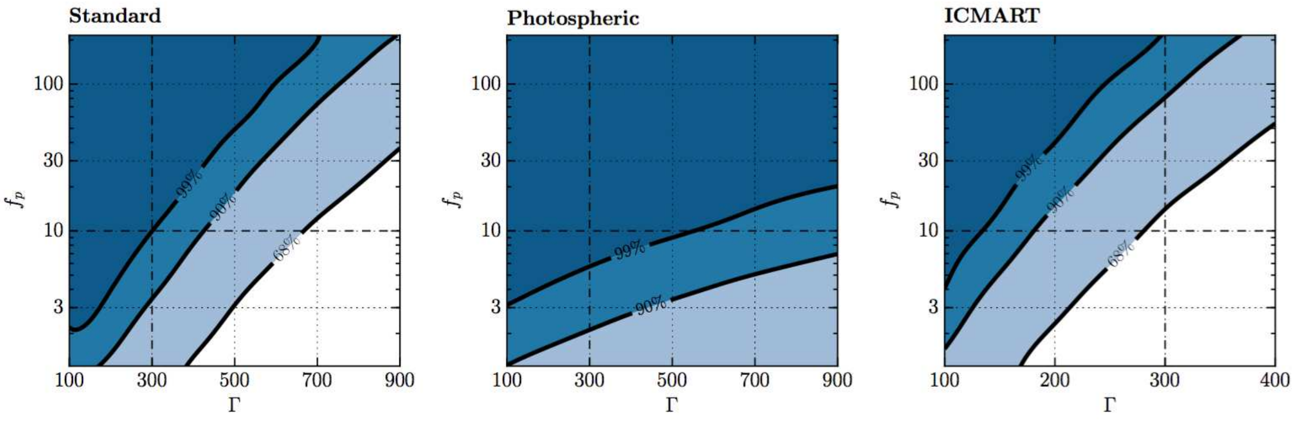
GRB Emission Models



Non-detection of neutrinos constrains GRB prompt emission models



Zhang & Kumar (2013)



IceCube collaboration (2016)

Scientific Questions:
IV. Fast radio bursts

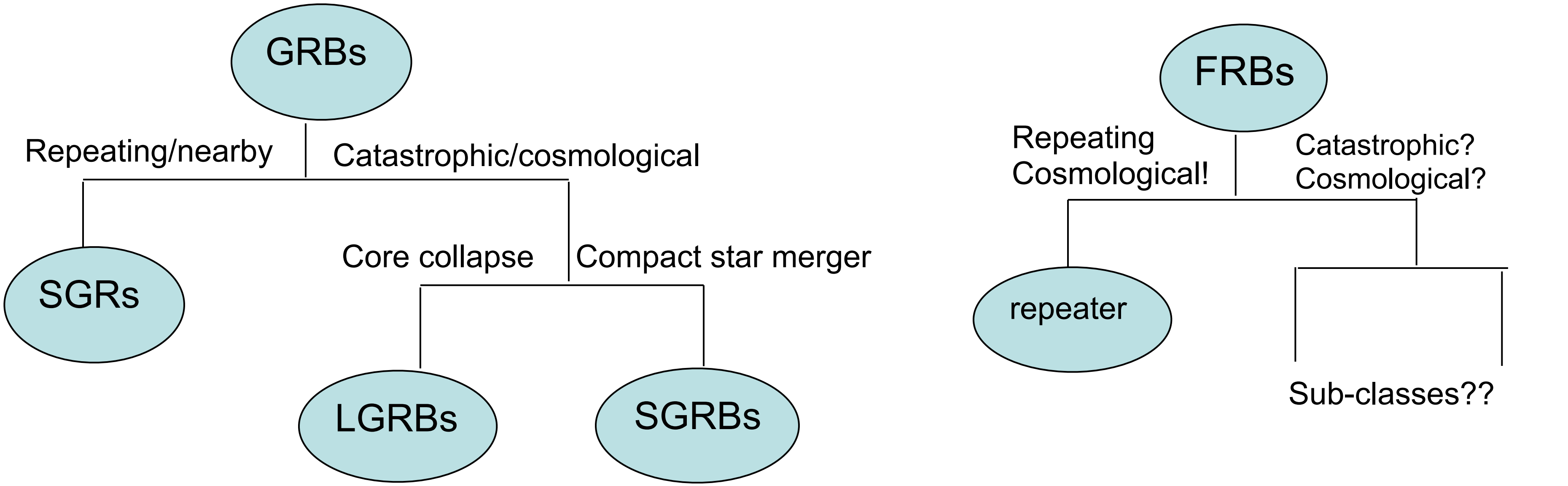
- Do all FRBs repeat (E. Petroff)?
- Are there bright counterparts associated with FRBs (D. Turpin, C. Gouiffe)?
- Are there more than one mechanism to produce FRBs? What are the progenitor systems of FRBs (Z. G. Dai, Y.-W. Yu)?
- Can FRBs serve as unique cosmic probes (S. Xu, Y.-P. Yang)?

FRBs vs. GRBs

	GRBs	FRBs
Step one: Are they astrophysical?	1967 – 1973	2007 – 2015
Step two: Where are they (distance)?	1973 – 1997 – 2004 (Afterglow counterpart, host galaxy)	2016 (Persistent radio source, host galaxy)
Step three: What make them?	1998 – ??? (SN Ic, GW?)	??? (AGN? GRB? magnetar-powered nebula?)

Observationally driven
Healthy dialog between observers and theorists

Multiple progenitor systems?

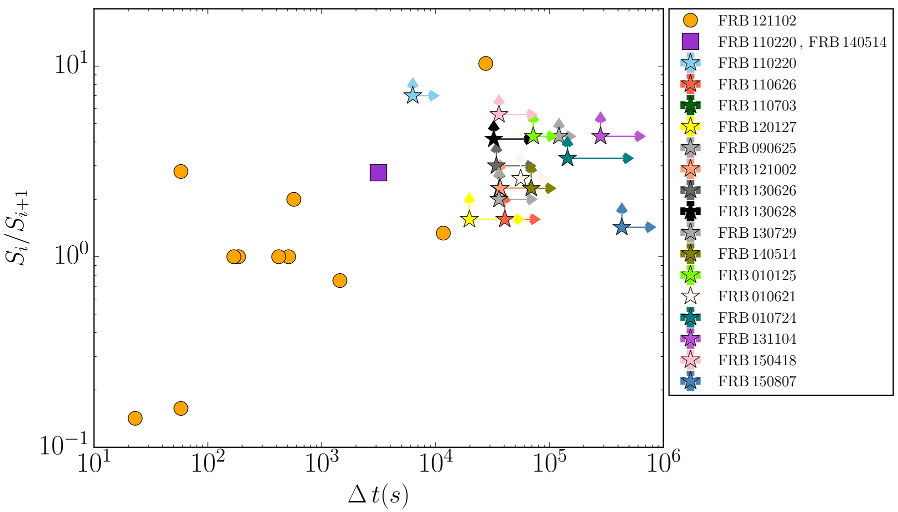


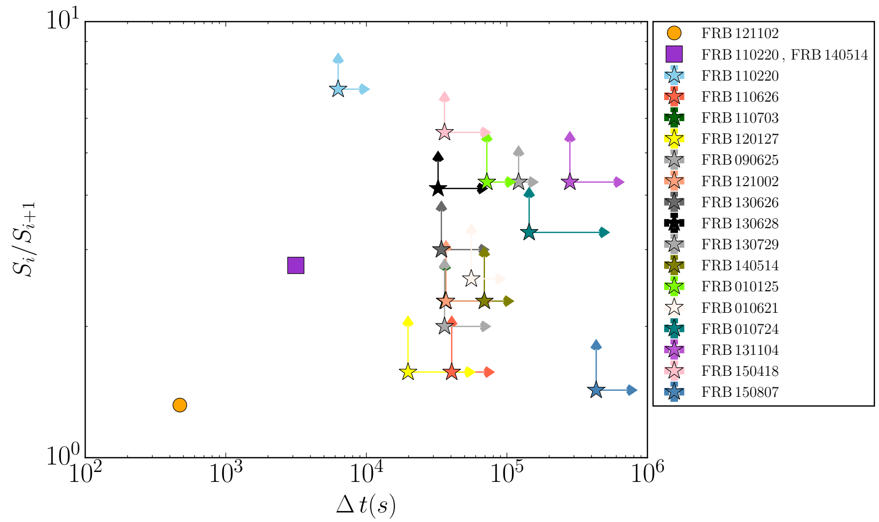
Known observationally-defined transients have multiple progenitors (SNe & GRBs)

Following discussion not limited to repeating models

Is FRB121102 representative?

Palaniswamy & Zhang (2017)





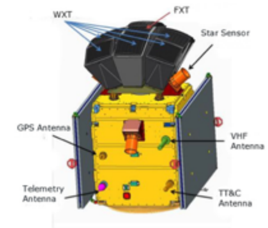
More data are needed!

Multi-wavelength / multi-messenger Observations of FRBs

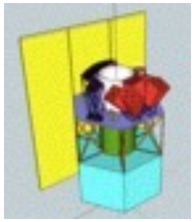
- Follow-up observations
- Temporal coincidence observations with wide field detectors (gamma-ray, X-ray, optical, GW, neutrino detectors)
- Archival searches on prior emission of any kind

Transient Astrophysics in the SVOM era

LIGO/Virgo

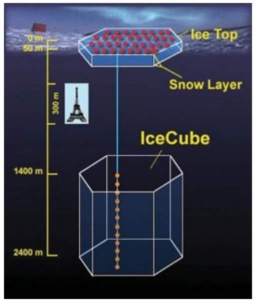


EP

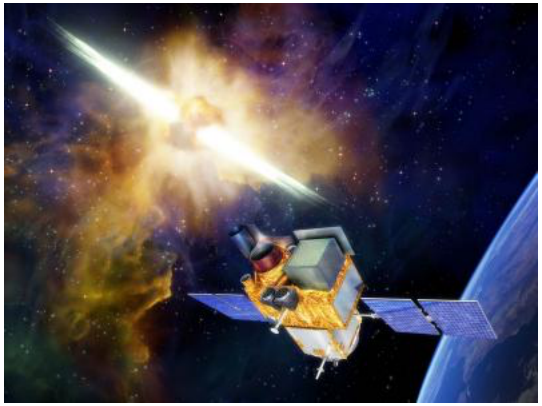


THESEUS

SKA



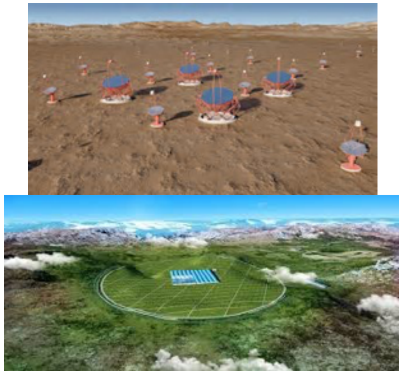
IceCube/ANTARES



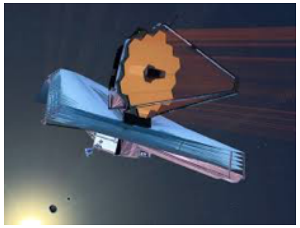
SVOM

FAST

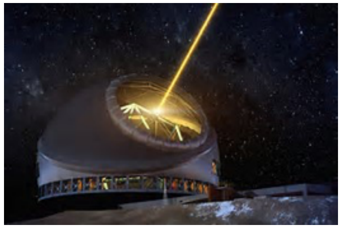
CHIME



CTA/LHASSO



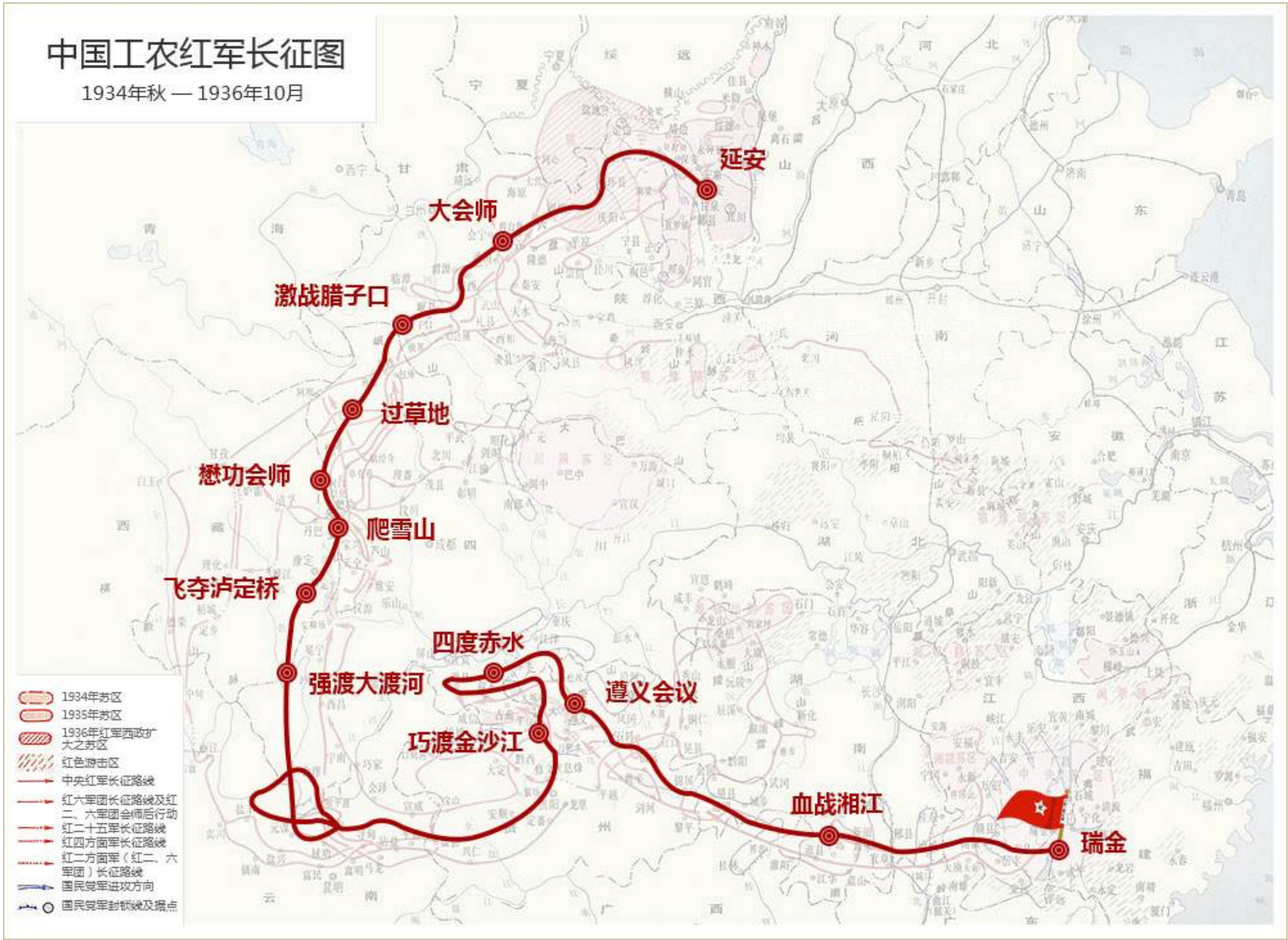
JWST



TMT/GMT

LSST

Historical “Red Army” Long March in Guizhou



SVOM’s happy “Long March” towards 2021