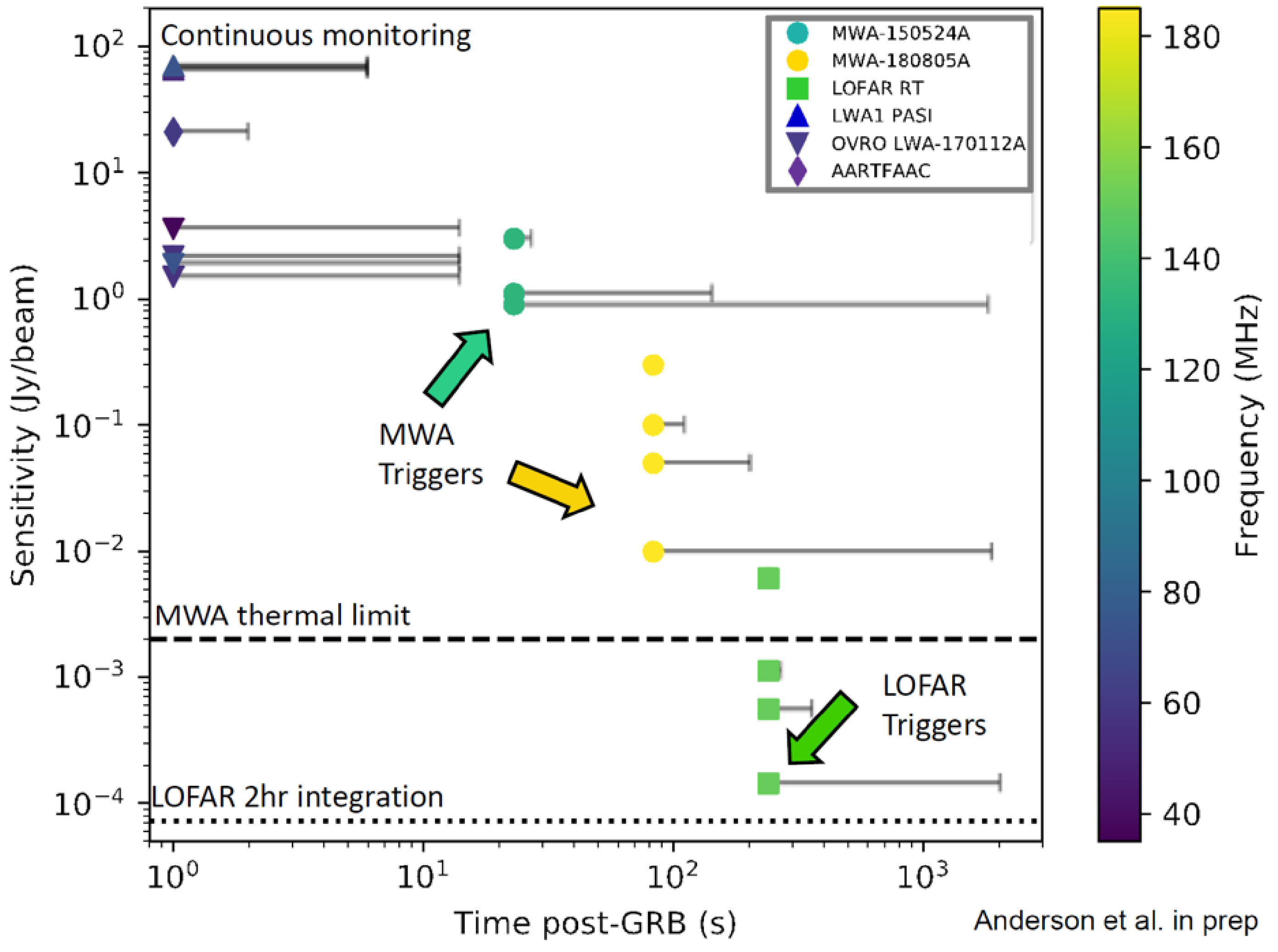
暂现源的射电后随辐射
Radio afterglow of transients

安 涛
上海天文台

为什么在射电波段开展暂现源的观测 ？

- **Benefit:**
  - Quiet transient sky
  - Large FoV, e.g. MWA 1000deg^2, ASAKP 30deg^2
  - Large dispersion delay for SKA-low
- **Limitation:**
  - Faint, off-axis/mis-aligned: Reverse shock flare?
  - Unknown luminosity, timescale, evolution
    - 4 SGRBs are fade within 2 days
  - Only a few radio transients (e.g., 5 sGRB in radio) different case by case
- **Coordination**
  - not easy – interrupt other projects !
  - Out-of-session request



Anderson et al. in prep

- Advantage of low frequency - Dispersion delay
  - 100s arrival delay ; 30s cross 30MHz band
- MWA, LWA, LOFAR -> SKA1-Low

射电波段开展暂现源的观测

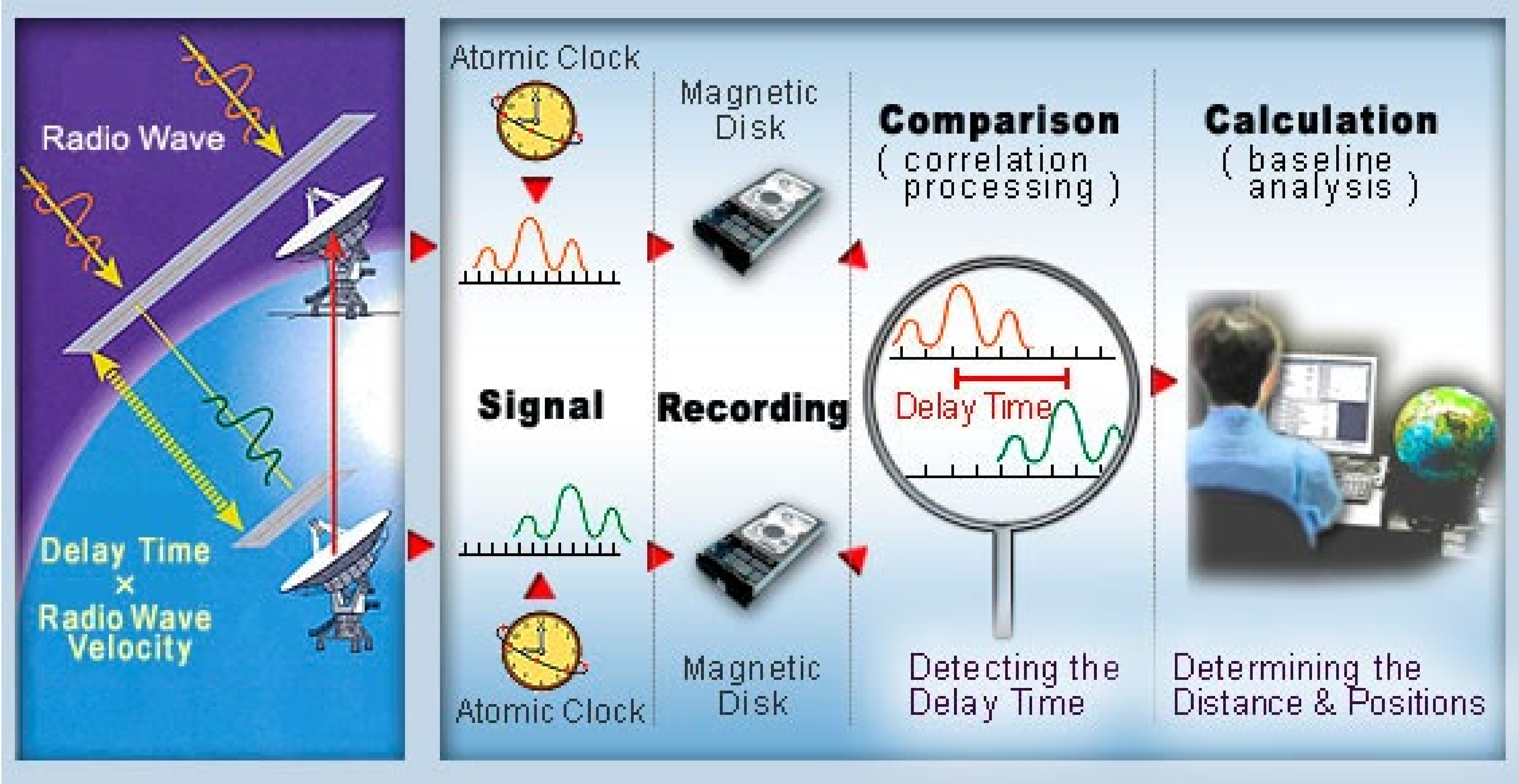
- Radio luminosity and lightcurve
- Temporal evolution of spectral index
- Radio polarization
- Morphology, kinematics, geometry, physical properties of ejecta/jet
- Circumburst ISM
- Constraint on progenitors

暂现源射电后随辐射的高分辨率观测

Most of transient have **radio counterparts** because of their significant **non-thermal** emission - highly interesting targets for the very long baseline interferometry (**VLBI)**

- **Locating** their birthplaces with a sub-mas precision.
- Measuring the **distances** of Galactic transients to constrain their astrophysical parameters.
- Observing the **proper motions** of nearby transients to study relativistic jets or shocks.
- Resolving the **structures** of nearby transients directly to probe their evolution and surrounding medium.
- 1 mas size = 1 pc at z=0.05 1 mas parallax = 1 kpc

Very Long Baseline Interferometry
甚长基线干涉测量 - 最高分辨率天文观测技术



The images are from internet.

Main VLBI networks

European VLBI Network

[VLBI20-30: a scientific roadmap for the next decade - - The future of the European VLBI Network]

https://www.evlbi.org/

East Asian VLBI Network

[Capabilities and prospects of the East Asia Very Long Baseline Interferometry Network]

An, Sohn, Imai 2018, Nat Astron

US VLBA

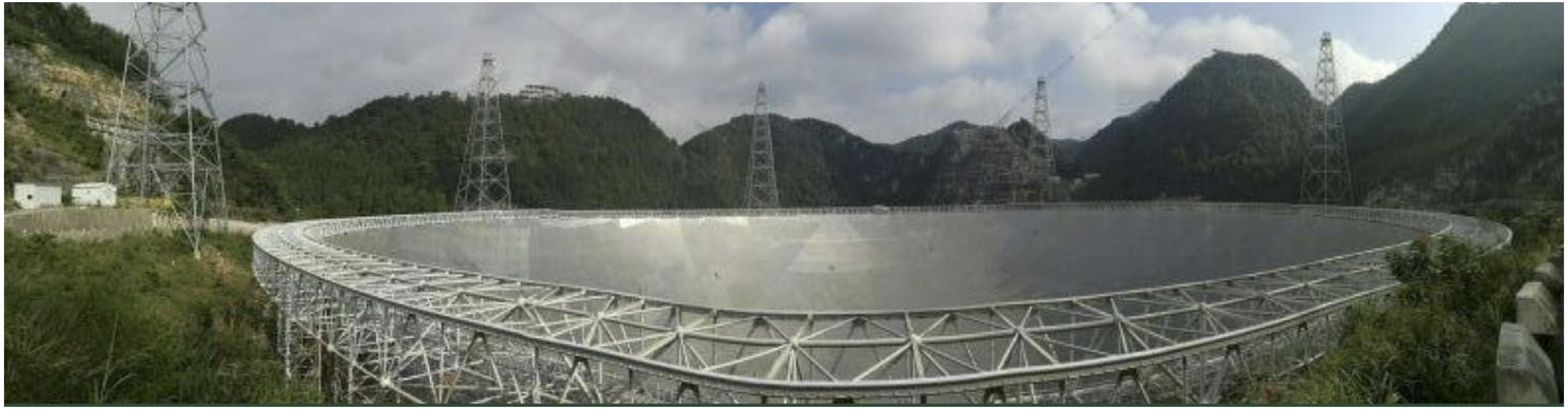
[Mapping the Future of VLBI Science in the U.S.]

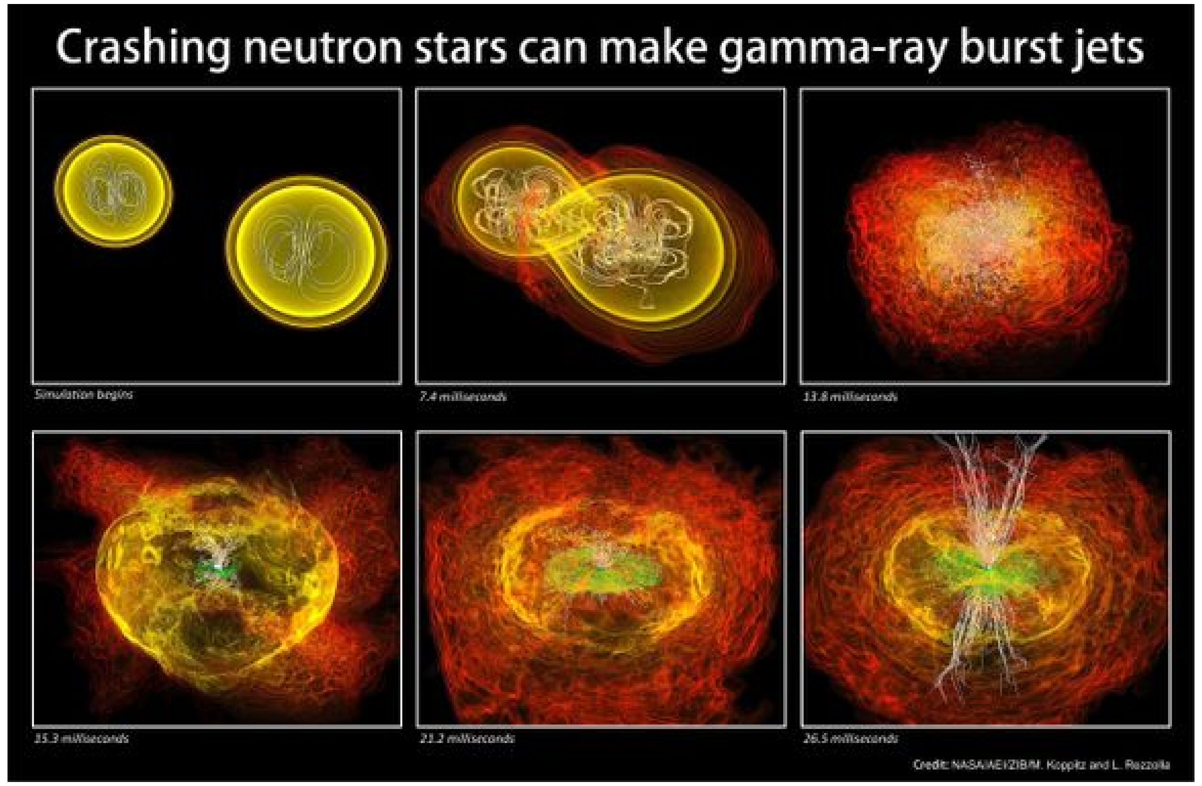
https://science.nrao.edu/facilities/vlba

- Typical resolution: 1 mas
- Typical sensitivity (PR): 5-20 microJy/beam
- Soon will be <1microJy/beam (approaching JVLA sensitivity)

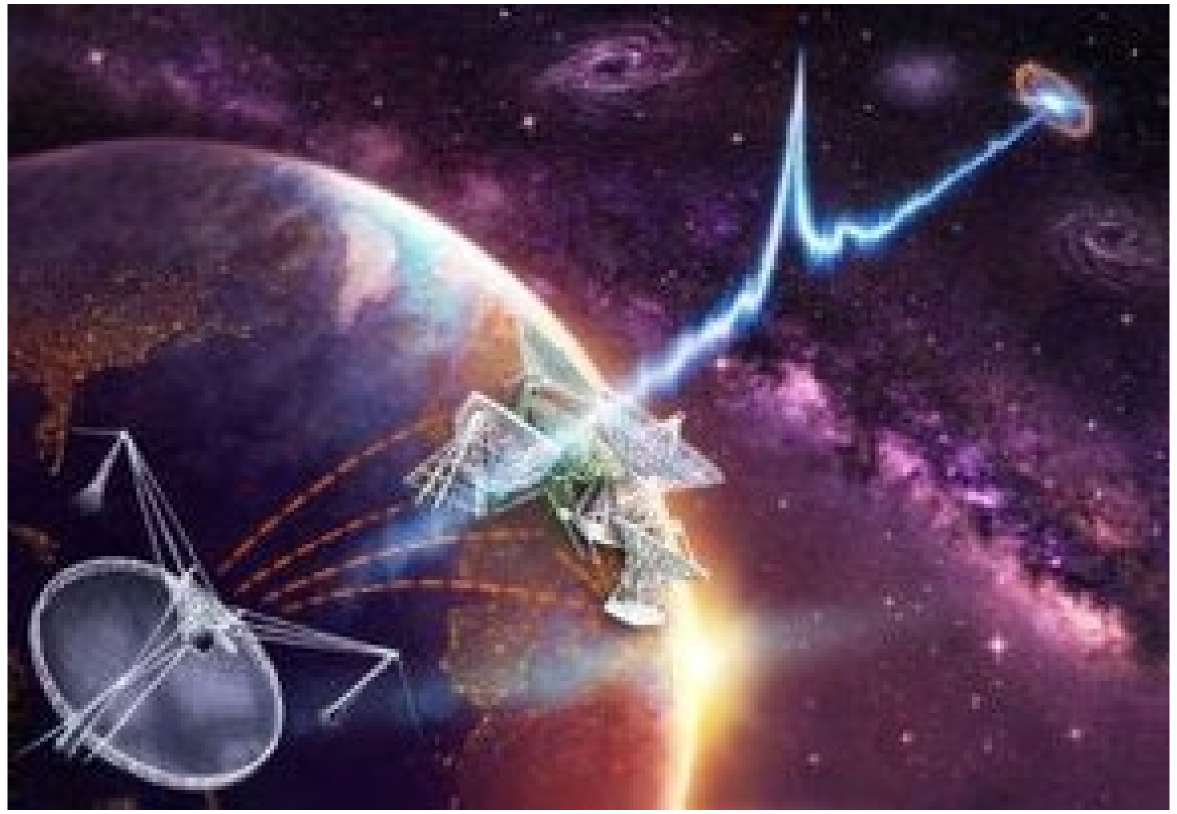
VLBI + FAST, SKA1: Transformational telescope

- VLBI is a standard mode of SKA
- First fringe detected on FAST-TM => regular operation of FAST VLBI
- 16/32Gbps VLBI becomes realistic, increasing current sensitivity by 5x
- **1uJy, 1mas critical for radio transients**
- **Transient is one of the KSPs of SKA-VLBI**

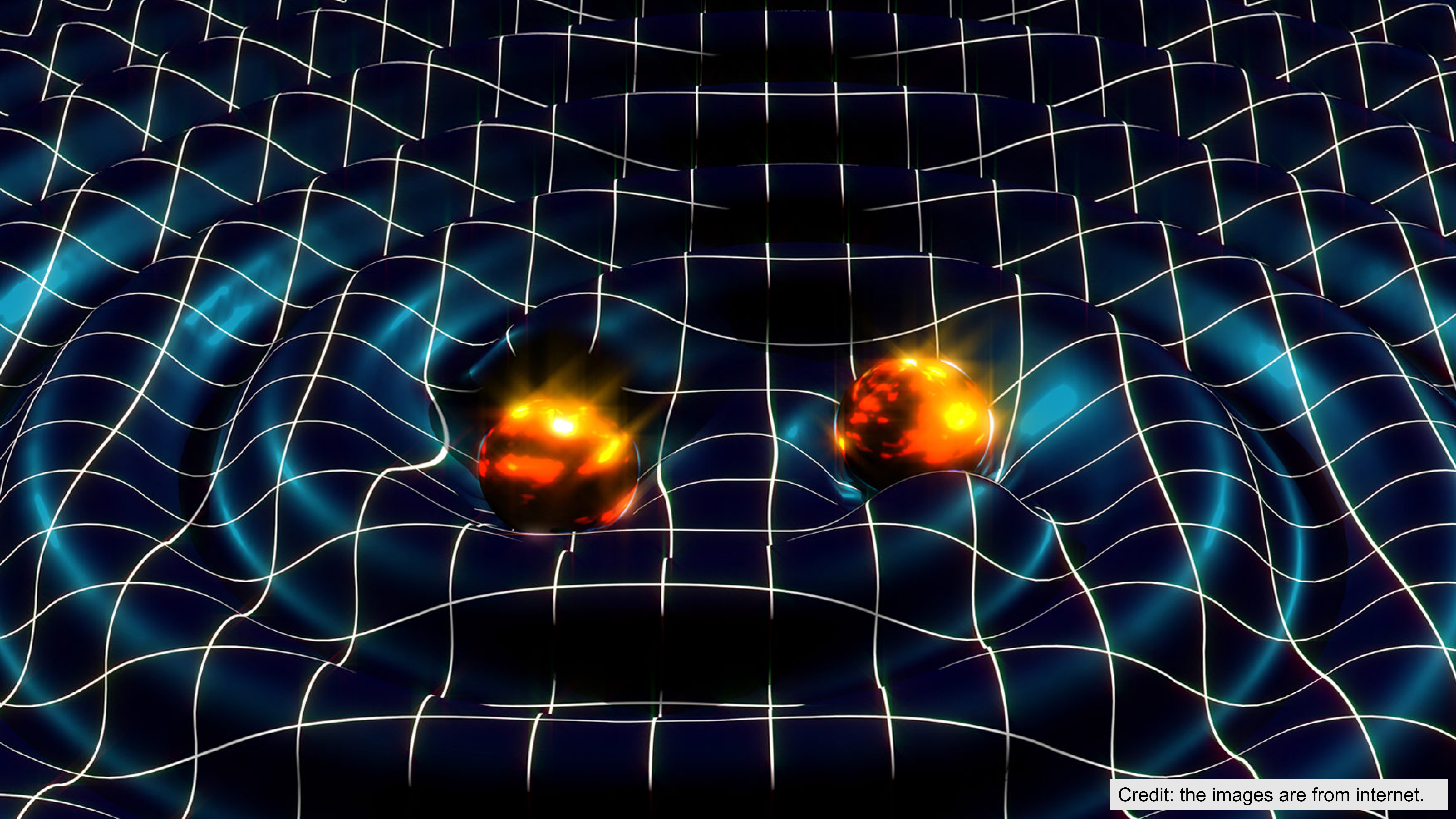




Science Cases: radio observations of transients



Credit: the images are from internet.


Credit: the images are from internet.

Gravitational Wave – LIGO collaboration

Eelectromagnetic counterpart of LIGO source?

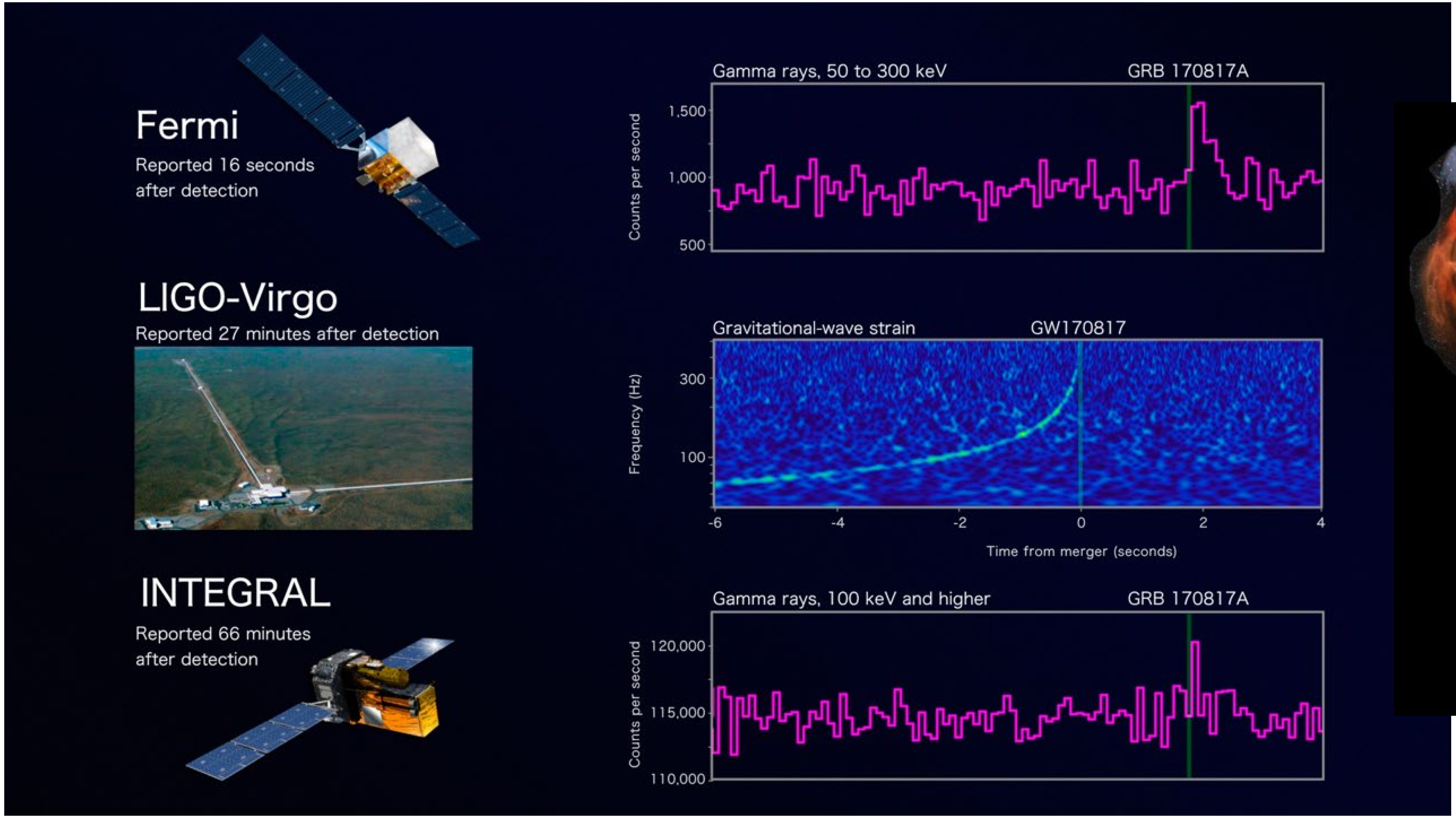
TITLE: GCN CIRCULAR
NUMBER: 20981
SUBJECT: LIGO/Virgo G275404: European VLBI Network (EVN) follow-up of the near-IR transient in the AGL J1914+1043 field
DATE: 17/04/05 14:50:35 GMT
FROM: Zsolt Paragi at Euro VLBI <zparagi@jive.eu>

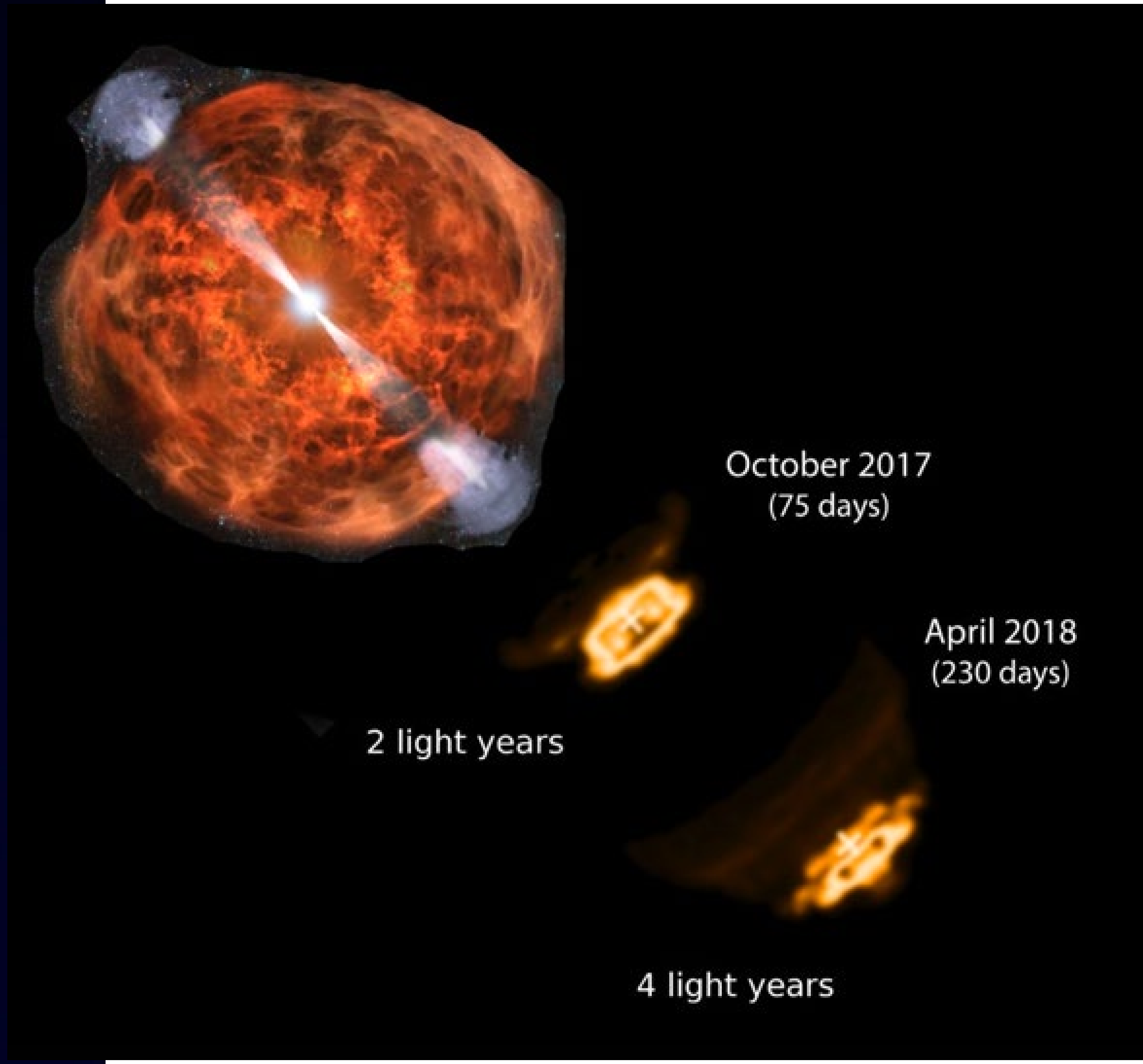
Zsolt Paragi (JIVE)
Tao An (Shanghai Astronomical Observatory)
Philippe Bacon (APC Université Paris Diderot)
Rob Beswick (JBO-Manchester University)
Eric Chassande-Mottin (APC Université Paris Diderot)
Sándor Frey (Konkoly Observatory)
Marcello Giroletti (IRA-INAF)
Peter Jonker (SRON)
Mark Kettenis (JIVE)
Benito Marcote (JIVE)
Arpad Szomoru (JIVE)
Huib van Langevelde (JIVE)
Jun Yang (Onsala Space Observatory)
for the Euro VLBI team

We observed the near-IR transient (Yoshida et al., GCN 20784) within the error circle of AGL J1914+1043 (Tavani et al., GCN 20754) with the e-VLBI technique using the EVN at 4.9 GHz between 2:06—11:48 UT on 24 March 2017.
There is **NO** compact radio emission detected on mas scales within +/-4 arcseconds of the near-IR transient coordinates.

Credit: the images are from internet.

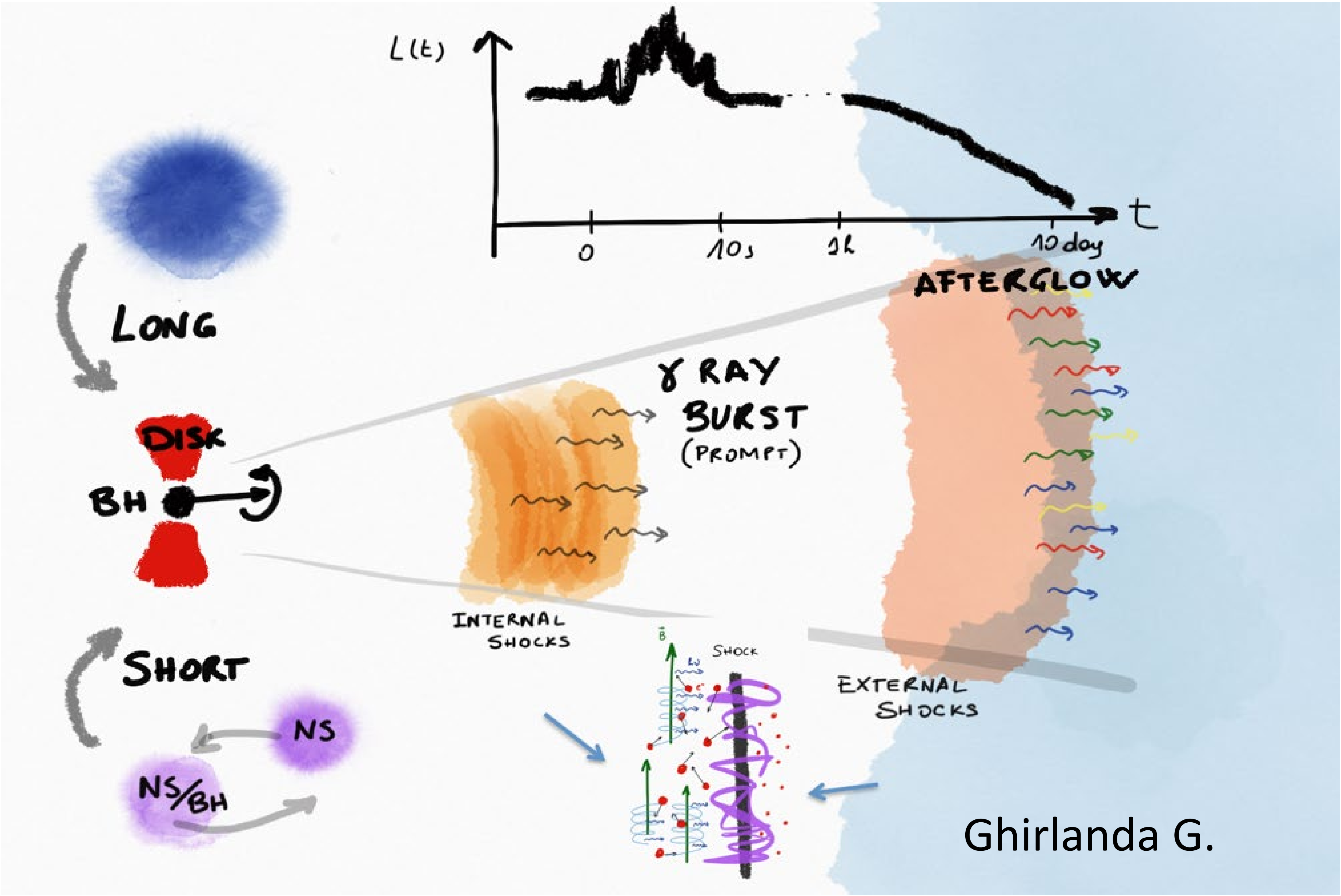
GW170817



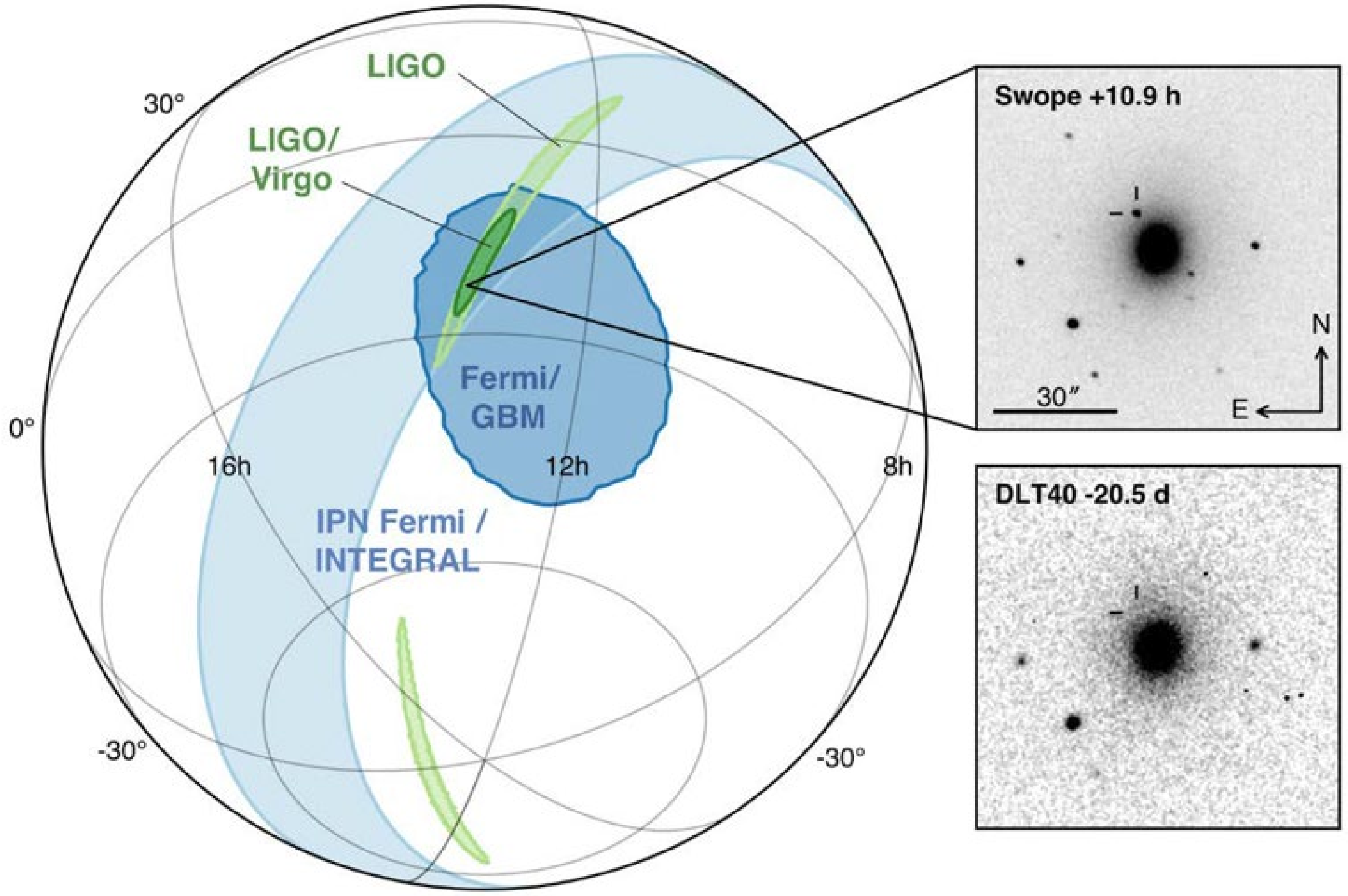


Evans et al. 2017 Sci.
Hallinan et al. 2017 Sci.
Kasliwal et al. 2017 Sci.

GW170817A: sGRB, kiloNova



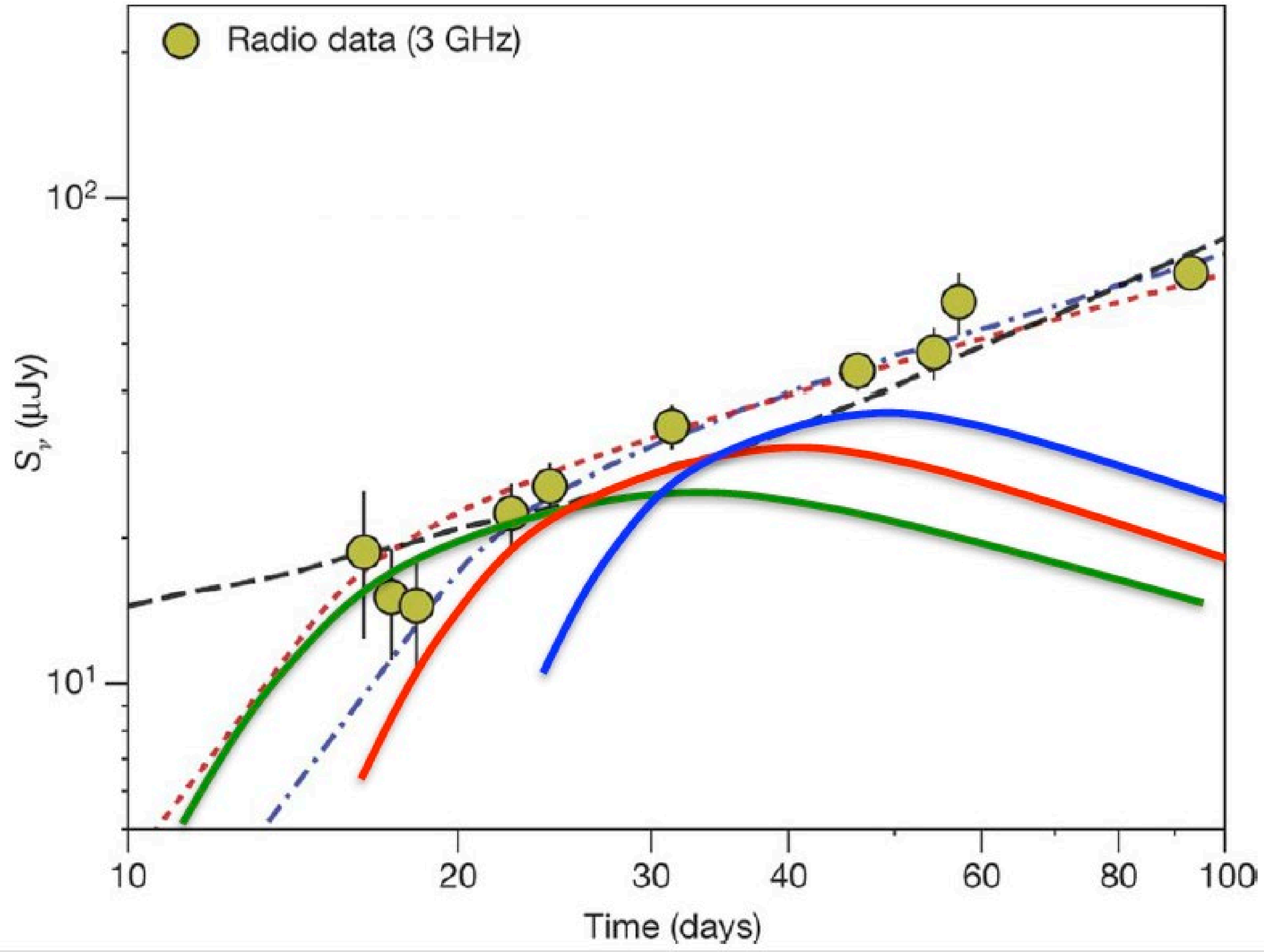
Ghirlanda G.



Abbott et al. 2017 ApJ 848, L12

GW170817 – GRB off-axis jet

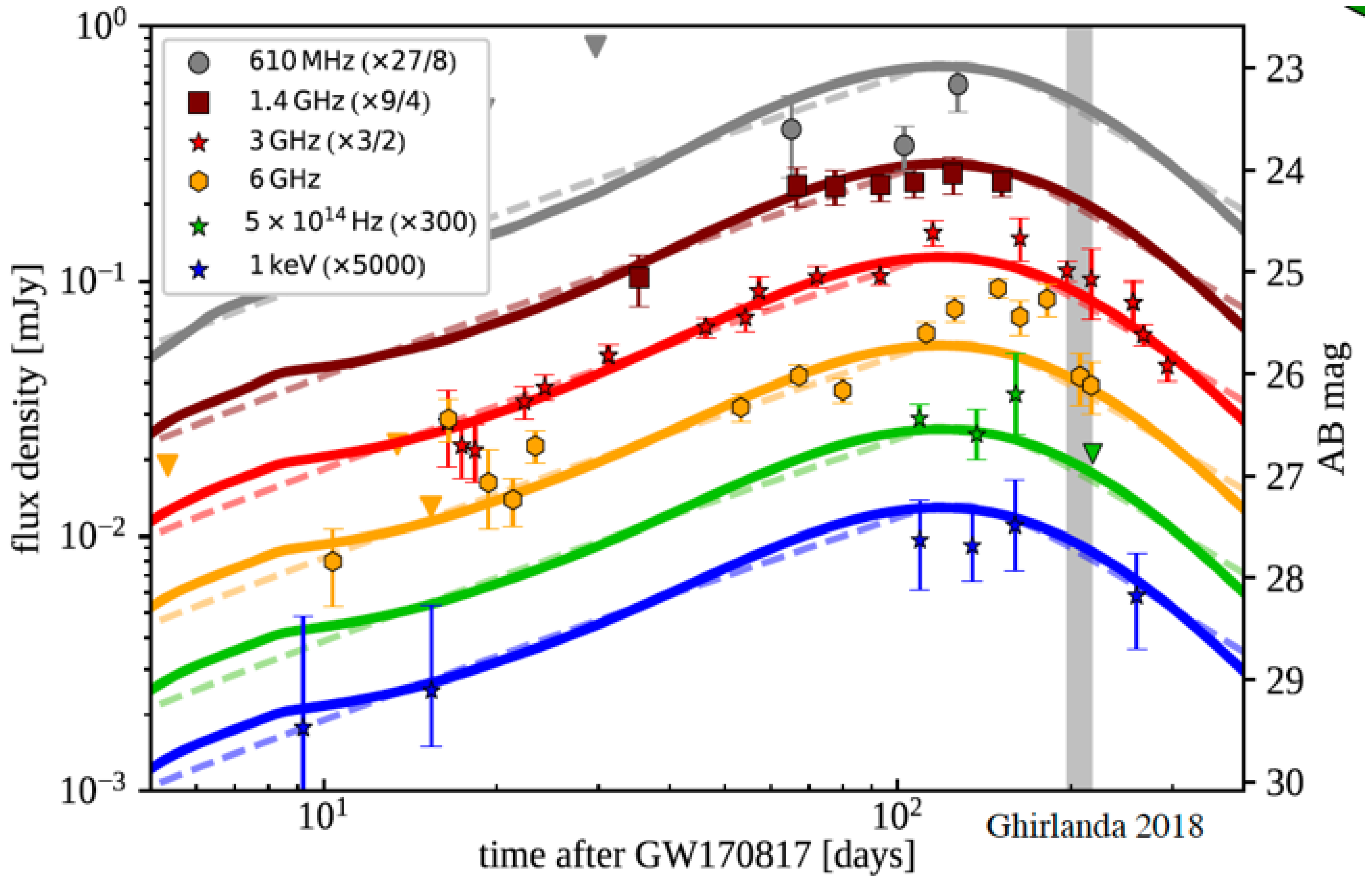
- Clues of unbeamed outflow
  - L ~ 10^{47}erg/s (< sGRB)
  - Afterglow appears late
  - Consistent with GW inclination
- Unexpected outflow
  - GW-EM delay
  - Slow rise and decay
  - non-standard jet seen off-axis
- Structured jet or choked jet ?

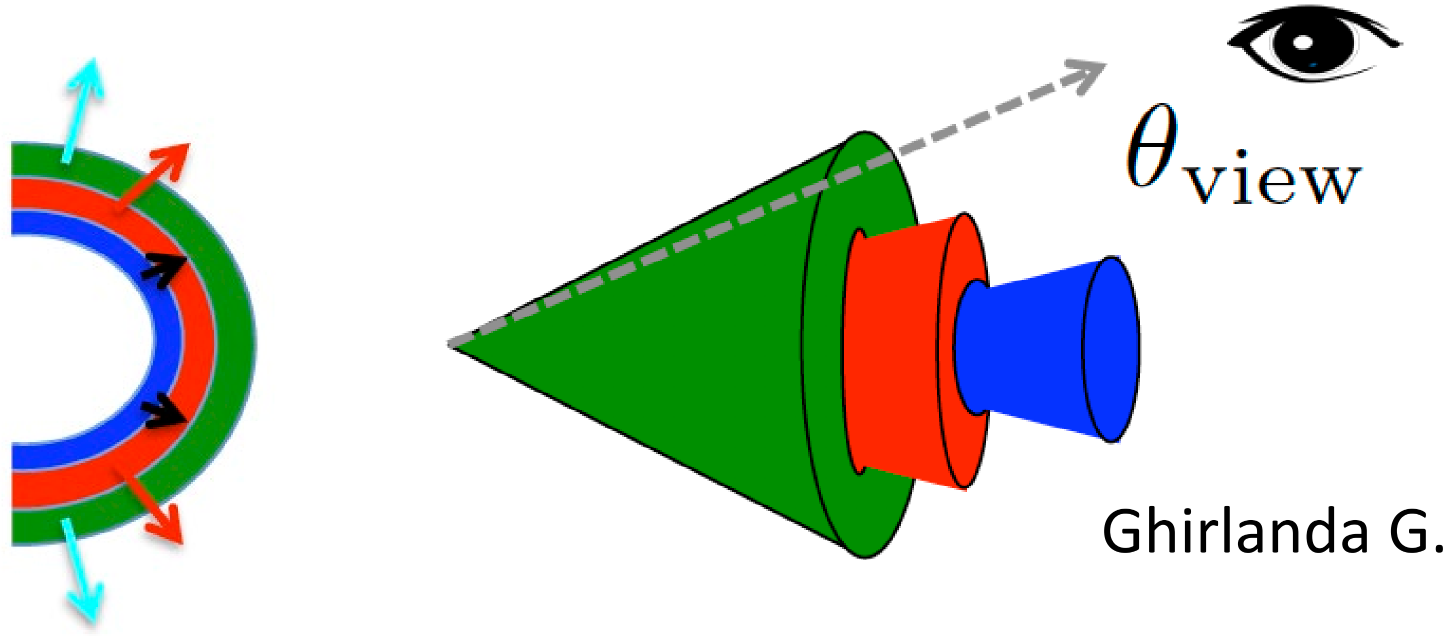


Mooley et al. 2018 Nature

GW170817 jet

- Both structured jet and choked model can explain lightcurve, luminosity, time delay
- VLBI gives unambiguous evidence of successful/structured jet (next slide)





Chocked jet
Or cocoon

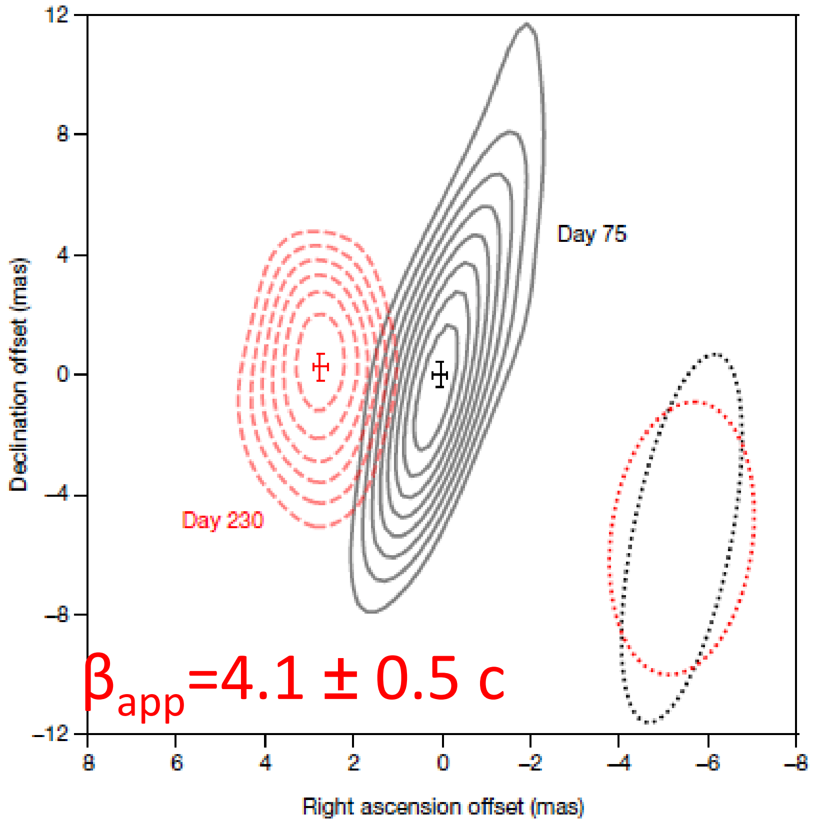
structured jet
Or successful jet

Sari, R., T. Piran, and R. Narayan, 1998, ApJL, 497, 17
Nakar & Piran 2011, Nature, 478, 82-84
Granot, J., A. Panaitescu, P. Kumar, & S. E. Woosley, 2002, ApJL, 570, L61

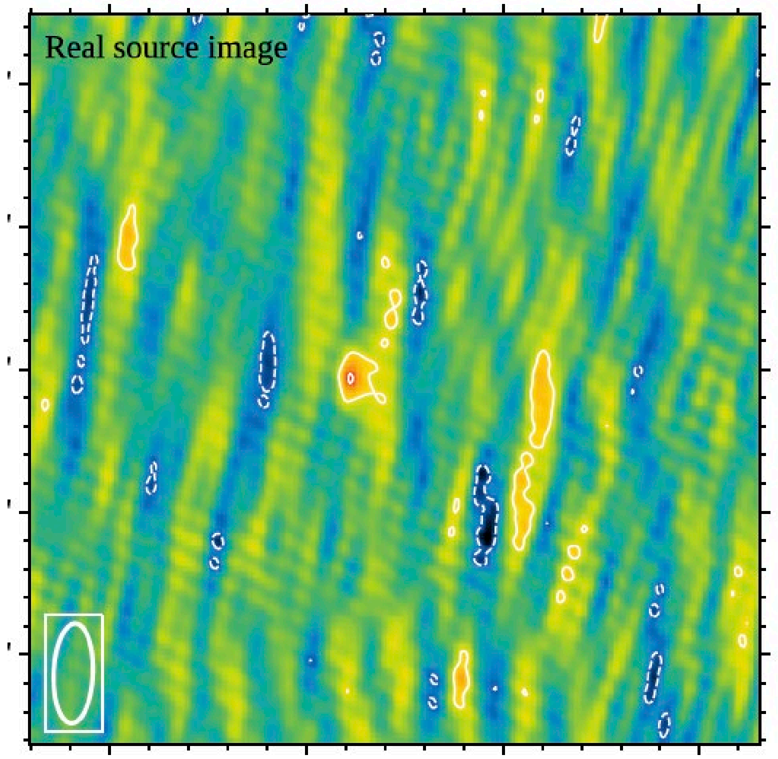
Pescalli et al. 2015, MNRAS, 447, 1911
Ghirlanda et al. 2016, A&A, 594, 84
Mooley et al. 2018, Nature, 561, 355-359
Ghirlanda, Salafia et al. 2019, Science, 363, 968-971

VLBI imaging of structured jet

- **Apparent motion**
- **Source size**
- **Morphology**



Mooley et al. 2018 Nature

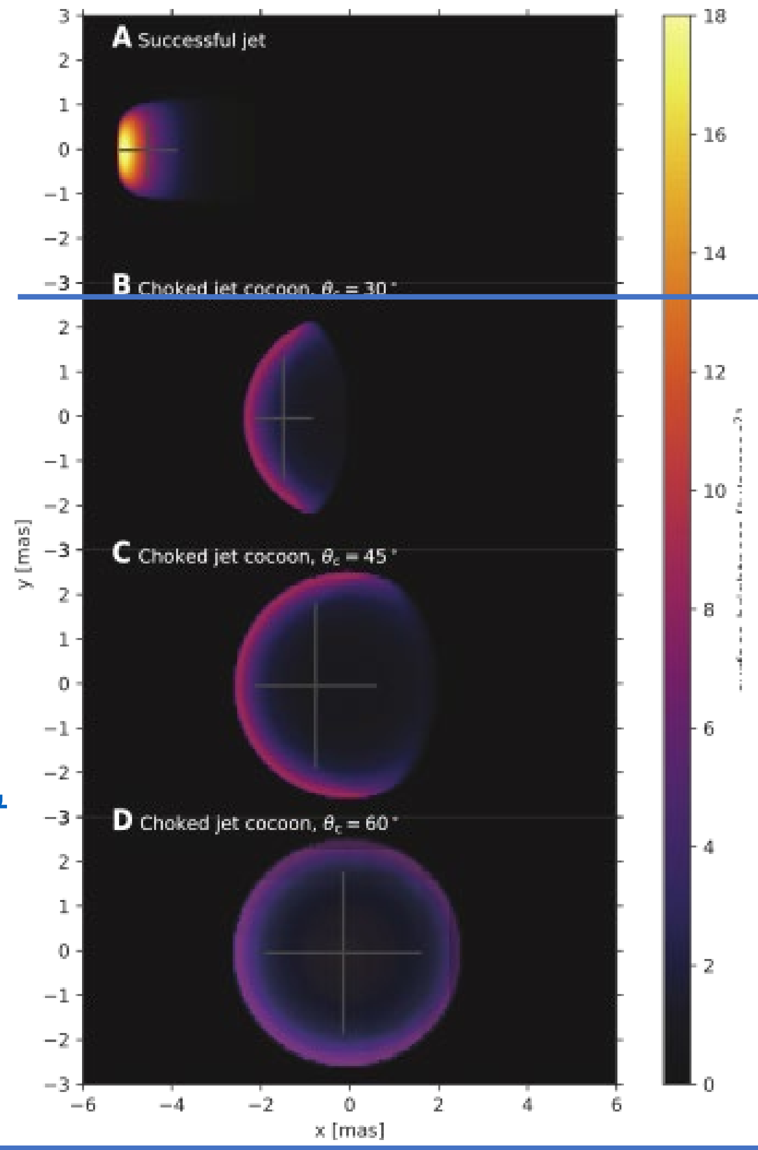


Ghirlanda, Salafia et al. 2019, Science, 363, 968-971

33 telescopes

5 continents

11 Research Institutes



Structured jet
Size < 2 mas
Larger displacement

Choked jet
Size > 3 mas
Smaller displacement

- 射电信号来的晚，但持续时间长，有利于监测；射电余晖甚至能够持续200天，SKA将大有所为！
- SKA-VLBI将在引力波电磁对映体等暂现源的精确定位、多波段认证、射电余晖的结构及其演化方面发挥难以替代的独特优势

VLBI观测GW EM的项目仍在继续

- 预计~10%NS-NS会产生喷流，并且能成功地破茧而出；VLBI观测团队已经为下一次观测机遇做准备
- eVLBI和eMERLIN申请已经获得了**120小时**观测时间，这是EVN历史上最“**慷慨**”的一次。
- LIGO-VIRGO的O3已经开放运行，但并没有发现期待中的首例“黑洞-中子星”、“中子星-中子星”并合的电磁对应体。
- **我们等待O4期间的机会！**
- 目前VLBI的灵敏度未能探测到引力波GW170817的瞬时射电辐射，SKA大有机会！
- 未来FAST和SKA1主导下的全球VLBI网有足够高的灵敏度和分辨率，将在引力波电磁对应体的精确定位上发挥独特的关键作用

EUROPEAN VLBI NETWORK

EVN Proposal

RadioNet JIVE Joint Institute for VLBI ERIC

获得120小时的监测时间

Giroletti **E18C012**

The high angular resolution view of the afterglow of GW events during O3

Applicants

Name	Affiliation	Email	Country		Potential observer
Marcello Giroletti	INAF Istituto di Radioastronomia	giroletti@ira.inaf.it	Italy	Pi	
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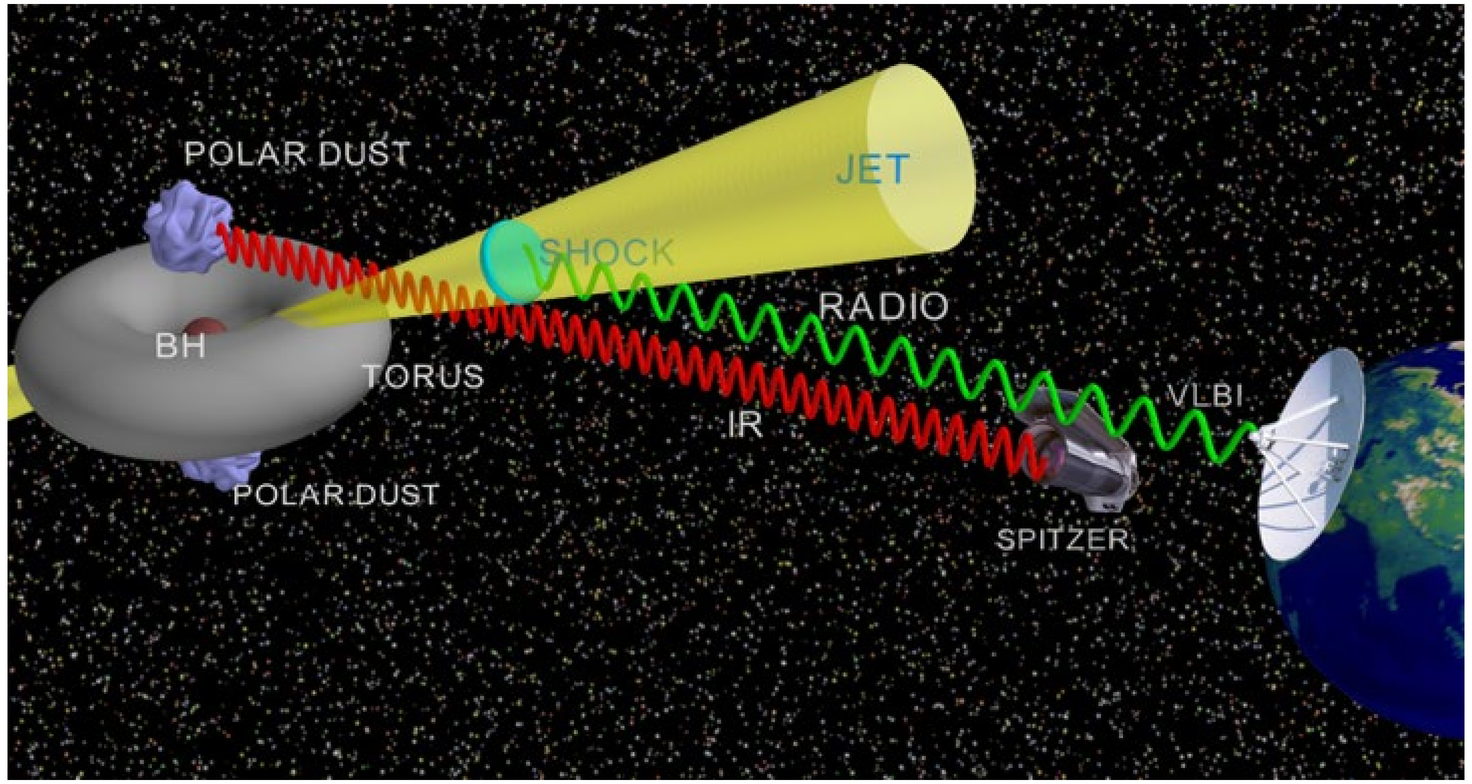
Dr. Zsolt Paragi	JIVE	zparagi@jive.eu	Netherlands		
Miguel Perez-Torres	IAA-CSIC (Radioastronomy)	torres@iaa.es	Spain		
Dr. Benito Marcote	Joint Institute for VLBI ERIC (JIVE)	marcote@jive.eu	The Netherlands		
marica branchesi	Gran Sasso Science Institute	marica.branchesi@gmail.com	Italy		
Dr. Tiziana Venturi	INAF (Istituto di Radioastronomia)	tventuri@ira.inaf.it	Italy		
Dr. Tao An	Shanghai Astronomical Observatory	antao@shao.ac.cn	CHINA		
Eric Chassande?Mottin	APC, Université Paris Diderot	ecm@apc.in2p3.fr	France		
Dr. Ivan Agudo	Instituto de Astrofisica de Andalucia-CSIC (Radioastronomy)	iagudo@iaa.es	Spain		
Dr Sandor Frey	MTA Research Centre for Astronomy and Earth Sciences (Konkoly Observatory)	sandor.frey@gmail.com	Hungary		
Rob Beswick	JBCA/JBO	Robert.Beswick@manchester.ac.uk	UK		

TDE – waken a normal *quiescent* galaxy

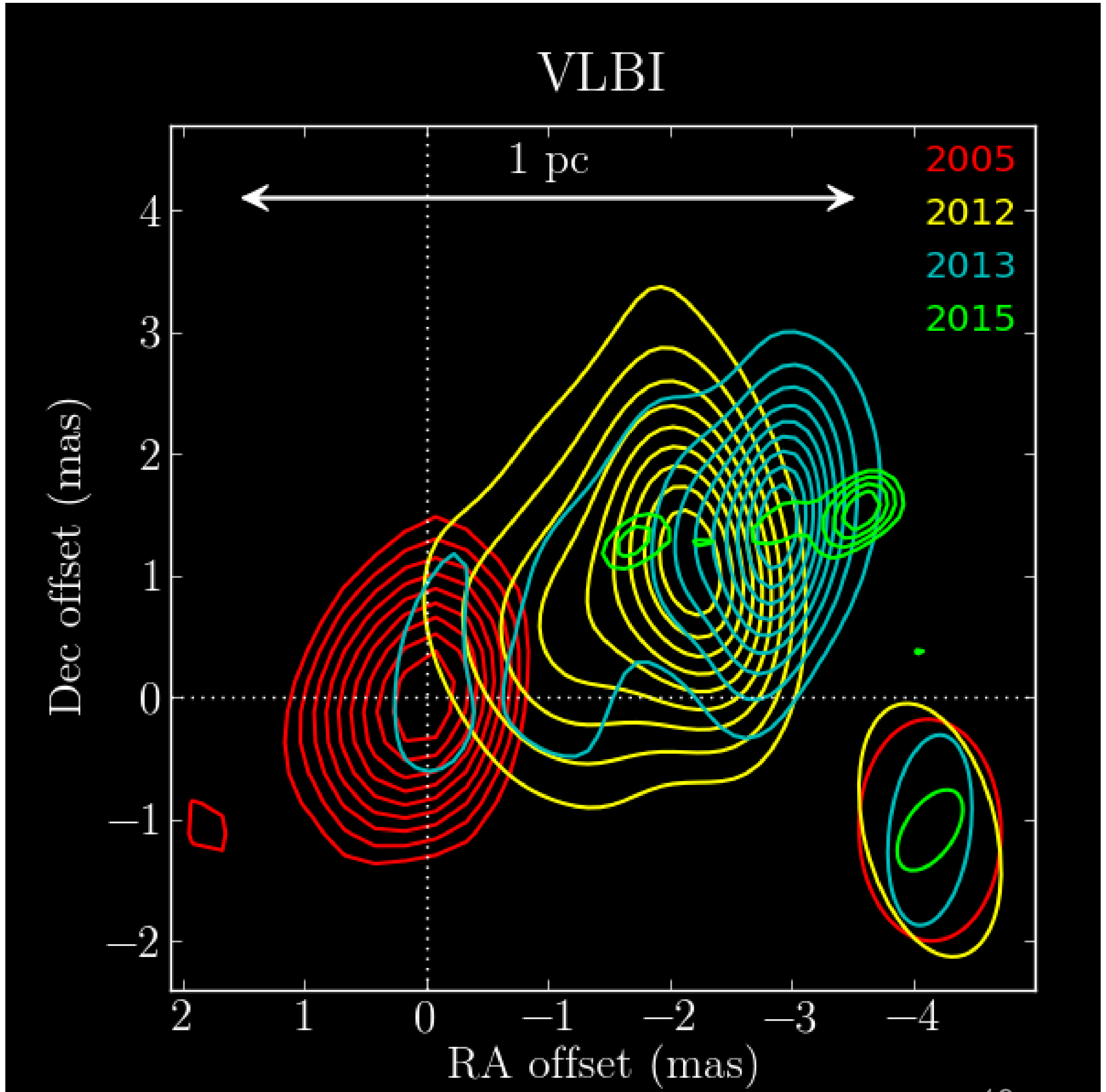
Credit: the images are from internet.

Jetted TDE

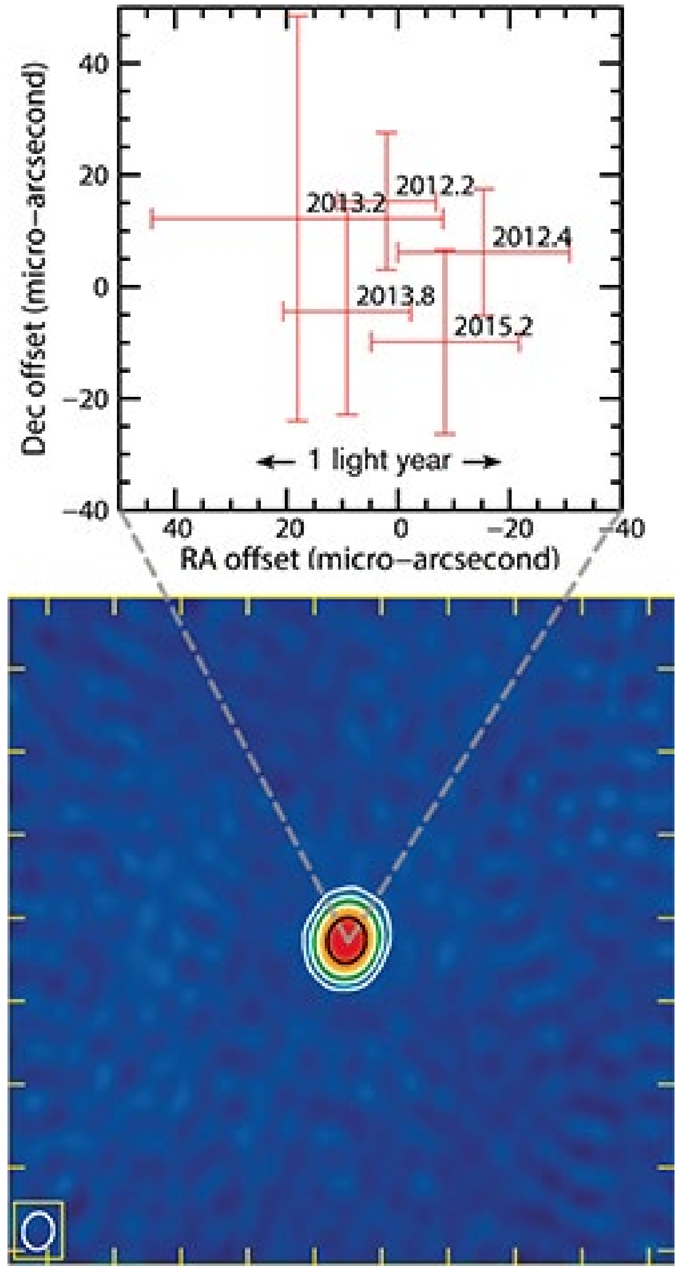
- A small fraction of Tidal Disruption Events (TDE) produce relativistic jets, evidenced by their non-thermal X-ray spectra and transient radio emission
- A new-born jet from the supermassive black hole of Arp 299B-AT1 because of a disruption of a star of 2-7 solar mass.
- Average apparent speed, 0.25± 0.03 c
- The AGN torus is edge-on



(Mattila, Pérez-Torres et al. Sci. 2018, 361, 482-485)



1644+5734 - first jetted TDE



1. **no superluminal motion after 3 years -> jet is decelerated**
2. **Relative astrometry: 13 μas in RA and 11 μas in DEC – best ever achieved with the EVN for a continuum source**

- TDE will be a unique probe
  - of quiescent SMBH at high redshifts, especially in the **low-mass tail**
  - of the SMBH mass function ($L_{TDE} \propto M_{BH}^{-1/2}$)!
- Future surveys in the optical (LSST), X-rays, radio (SKA) have great potential to detect a large number of events

Swift J1644+57 is one of the first tidal disruption events to be studied in detail, and it won't be the last.

"Observations with the next generation of radio telescopes will tell us more about what actually happens when a star is eaten by a black hole - and how powerful jets form and evolve right next to black holes", explains Stefanie Komossa, astronomer at the Max Planck Institute for Radio Astronomy in Bonn, Germany.

"In the future, new, giant radio telescopes like FAST (Five hundred meter Aperture Spherical Telescope) and SKA (Square Kilometre Array) will allow us to make even more detailed observations of these extreme and exciting events," concludes Jun Yang.

Yang et al. (incl. An T.) 2016, MNRAS, 462, L66

AT2019dsg: a possible TDE responsible for neutrino

SQUARE KILOMETRE ARRAY
中国 China

NICER X-ray observations of the young tidal disruption flare candidate AT2019dsg

ATel #12825; ***Dheeraj Pasham (MIT), Ronald Remillard (MIT), Michael Loewenstein (NASA/GSFC), Keith Gendreau (NASA/GSFC), Zaven Arzoumanian (NASA/GSFC), Jon M. Miller (U. Michigan), Erin Kara (UMD/MIT), James F. Steiner (SAO) on behalf of NICER team***
on ***31 May 2019; 15:26 UT***
Credential Certification: Dheeraj Pasham (drreddy@mit.edu)

Subjects: X-ray, Transient, Tidal Disruption Event

Referred to by ATel #: 12960

Tweet

Following the detection of X-rays with Swift/XRT (ATel #12777), NICER made several exposures of the tidal disruption flare (TDF) candidate AT2019dsg between 2019 May 21 (MJD 58624) and May 28 (MJD 58630), yielding a total exposure near 11 ks. We investigated the average energy spectrum derived from good time intervals with particularly low background (roughly 9.5 ks of exposure) with a variety of spectral models that included thermal and Comptonization components typically used for accreting black holes.

Unambiguous radio detection of the tidal disruption event AT2019dsg with e-MERLIN

ATel #12960; ***M. Perez-Torres (IAA-CSIC, Spain), J. Moldon (JBCA, Manchester), S. Mattila (Univ. of Turku, Finland), A. Alberdi (IAA-CSIC, Spain), R. Beswick (JBCA, Manchester), S. Ryder (Macquarie Univ., Australia), E. Varenius (JBCA, Manchester), M. Fraser (Univ. College, Dublin), P. Jonker (SRON, Netherlands), E. Kankare (Univ. of Turku, Finland), E. Kool (Stockholm Univ., Sweden).***
on ***26 Jul 2019; 07:45 UT***
Credential Certification: Miguel A. Perez-Torres (torres@iaa.es)

Subjects: Radio, Transient, Tidal Disruption Event

Referred to by ATel #: 13105

Tweet

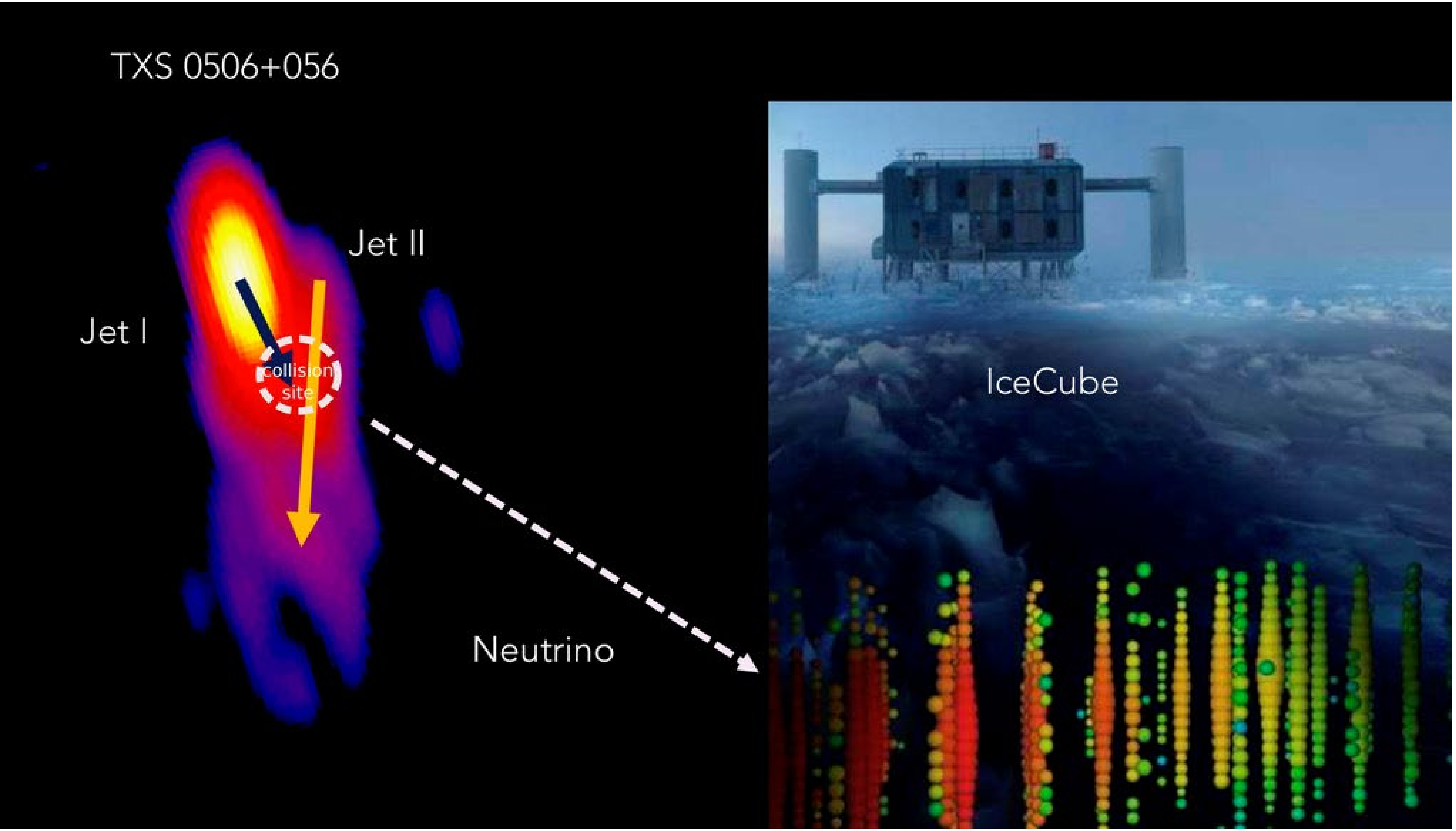
We report the first detection at radio wavelengths of the nuclear transient AT2019dsg, which was discovered by the Zwicky Transient Facility on UT 2019 Apr 9 (TNS Report No. 33340) in the center of the galaxy 2MASX J20570298+1412165 (z=0.0512). AT2019dsg has been classified as a tidal disruption event (TDE), based on the spatial

A high-energy neutrino coincident with a tidal disruption event

Stein, Robert; van Velzen, Sjoert; Kowalski, Marek; Franckowiak, Anna; Gezari, Suvi; Miller-Jones, James C. A.; Frederick, Sara; Sfaradi, Itai; Bietenholz, Michael F.; Horesh, Assaf; Fender, Rob; Garrappa, Simone; Ahumada, Tomás; Andreoni, Igor; Belicki, Justin; Bellm, Eric C.; Böttcher, Markus; Brinnel, Valery; Burruss, Rick; Cenko, S. Bradley; Coughlin, Michael W.; Cunningham, Virginia; Drake, Andrew; Farrar, Glennys R.; Feeney, Michael; Foley, Ryan J.; Gal-Yam, Avishay; Golkhou, V. Zach; Goobar, Ariel; Graham, Matthew J.; Hammerstein, Erica; Helou, George; Hung, Tiara; Kasliwal, Mansi M.; Kilpatrick, Charles D.; Kong, Albert K. H.; Kupfer, Thomas; Laher, Russ R.; Mahabal, Ashish A.; Masci, Frank J.; Necker, Jannis; Nordin, Jakob; Perley, Daniel A.; Rigault, Mickael; Reusch, Simeon; Rodriguez, Hector; Rojas-Bravo, César; Rusholme, Ben; Shupe, David L.; Singer, Leo P. *and 8 more*

Cosmic neutrinos provide a unique window into the otherwise-hidden mechanism of particle acceleration in astrophysical objects. A flux of high-energy neutrinos was discovered in 2013, and the IceCube Collaboration recently associated one high-energy neutrino with a flare from the relativistic jet of an active galaxy pointed towards the Earth. However a combined analysis of many similar active galaxies revealed no excess from the broader population, leaving the vast majority of the cosmic neutrino flux unexplained. Here we present the association of a radio-emitting tidal disruption event (AT2019dsg) with another high-energy neutrino, identified as part of our systematic search for optical counterparts to high-energy neutrinos with the Zwicky Transient Facility (ZTF). The probability of finding any radio-emitting tidal disruption event by chance is 0.5%, while the probability of finding one as bright in bolometric energy flux as AT2019dsg is 0.2%. Our electromagnetic observations can be explained through a multi-zone model, with radio analysis revealing a central engine, embedded in a UV photosphere, that powers an extended synchrotron-emitting outflow. This provides an ideal site for PeV neutrino production. The association suggests that tidal disruption events contribute to the cosmic neutrino flux. Unlike previous work which considered the rare subset of tidal disruption events with relativistic jets, our observations of AT2019dsg suggest an empirical model with a mildly-relativistic outflow.

Neutrino from AGNs



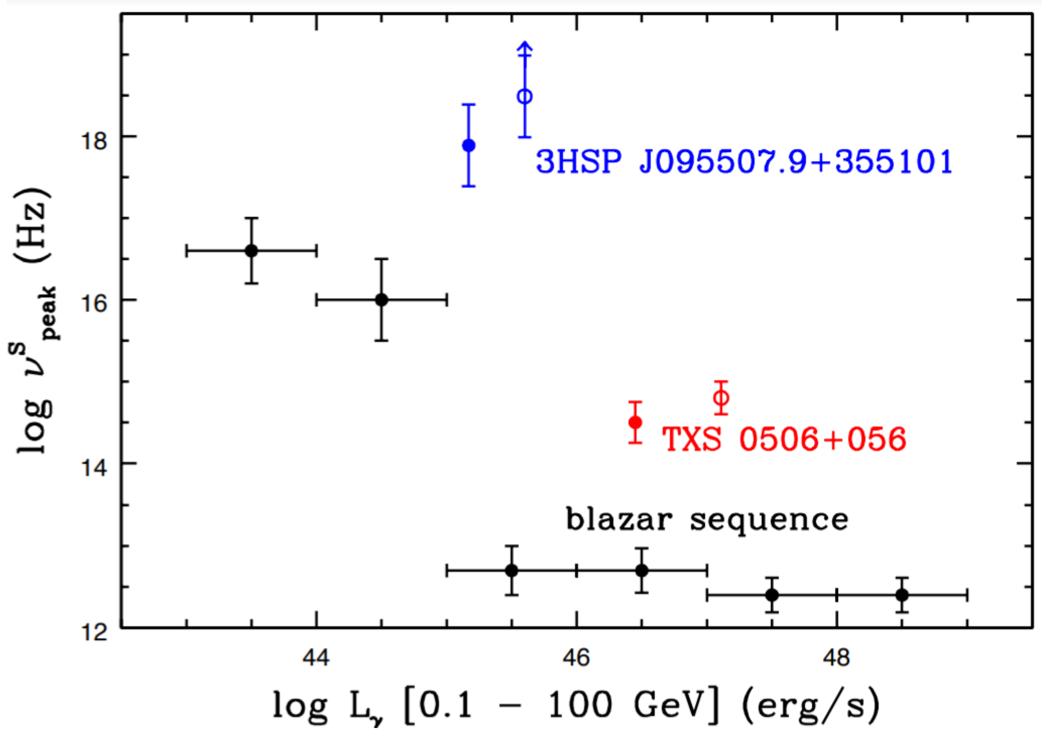
Kun et al. 2019, MNRAS, 483, L42
Britzen et al. 2019, A&A, 630, 103
Ros et al. 2019, A&A, 633, L1
Li, An, Mohan, Giroletti, 2020, ApJ, 896, 63

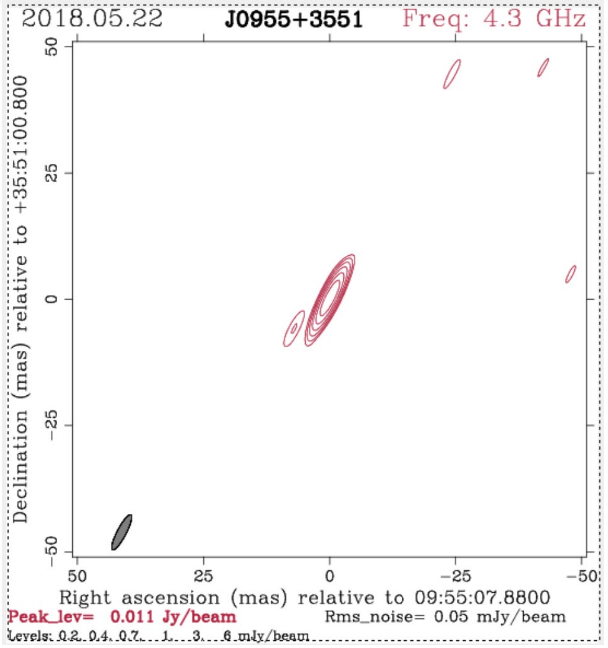
Neutrino AGN

- IceCube-200107A
- 3HSP J095507.9+355101
- Z = 0.557 BL Lac in flaring state
- Again, off blazar sequence
- An HBL
- photo-pion (pπ) interactions
- A different class from 0506+056

- IceCube-190730A
- PKS 1502+106 (4FGL J1504.4+1029)
- Z = 1.833 a FSRQ in flaring state
- VLBA observation approved (Yang Xiaolong etal.)

- NGC1068
- Sources of steady neutrino flares
- Aartsen, M. G., and 361 colleagues, Time-Integrated Neutrino Source Searches with 10 Years of IceCube Data, Physical Review Letters, 2020, 124, 051103.





IceCube-190730A an astrophysical neutrino candidate in spatial coincidence with FSRQ PKS 1502+106

ATel #12967; *Ignacio Taboada (Georgia Institute of Technology), Robert Stein (DESY Zeuthen)*
on *30 Jul 2019; 23:58 UT*
Credential Certification: Ignacio Taboada (itaboada@gatech.edu)

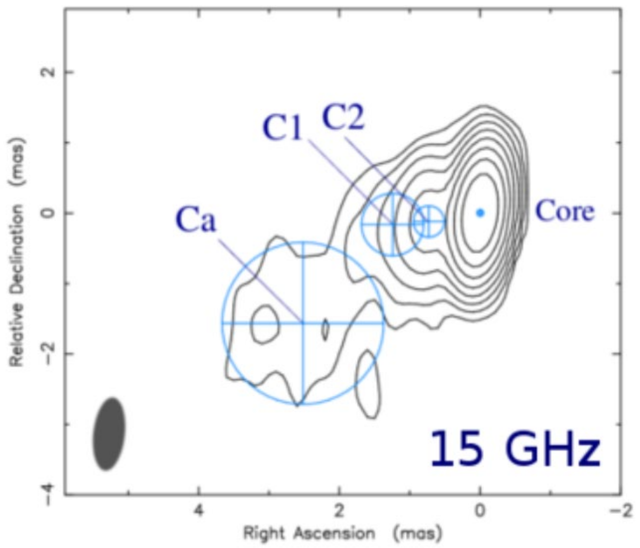
Subjects: Neutrinos, AGN

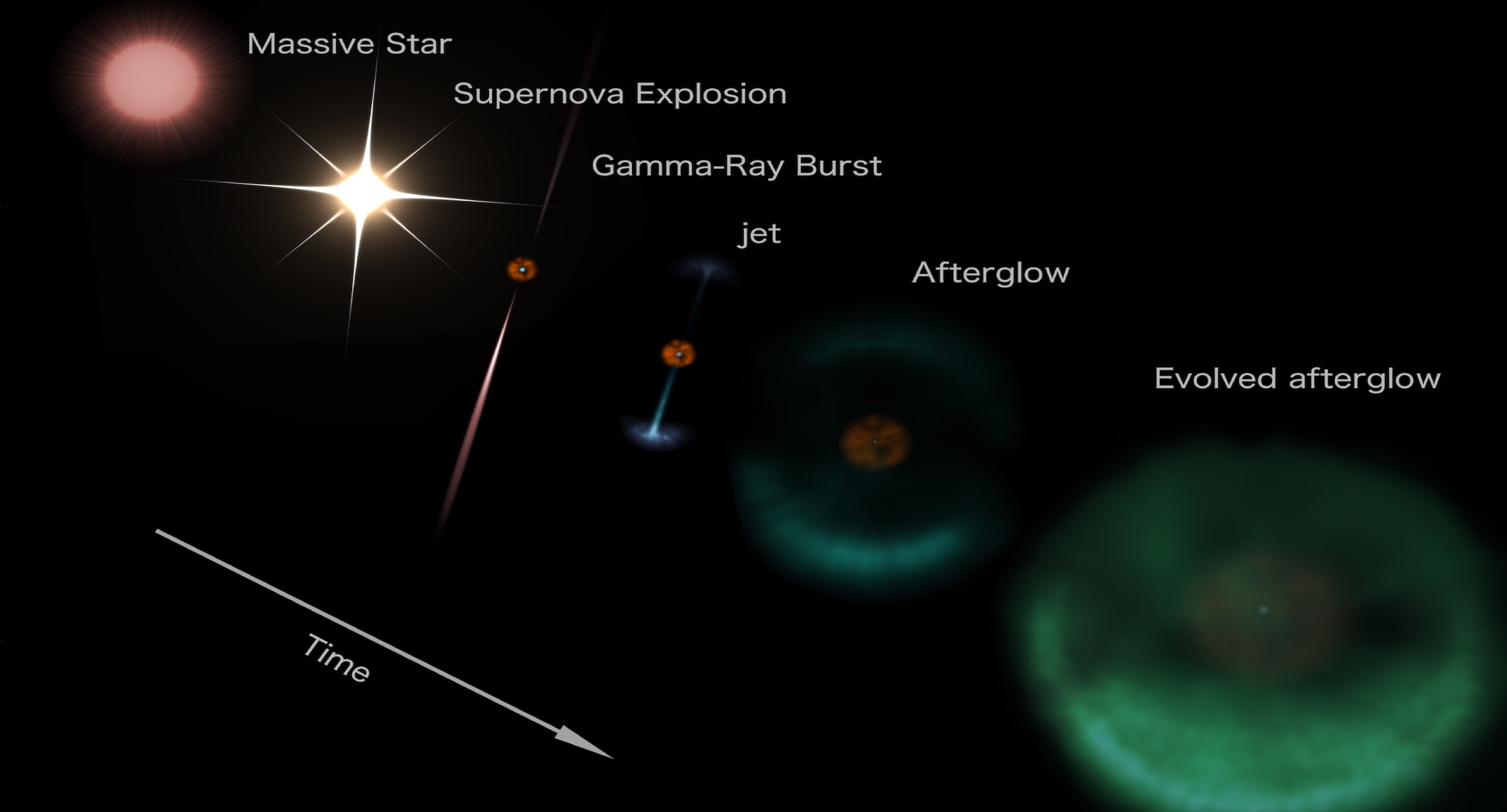
Referred to by ATel #: 12971, 12981, 12983, 12985, 12996

Tweet

The IceCube Collaboration (http://icecube.wisc.edu/) reports:

On 2019/07/30.86853 UT IceCube detected a high-energy astrophysical neutrino candidate (Stein, R. et al., GCN Circ. 25225). The neutrino was selected by the ICECUBE_Astrotrack_Gold alert stream. The threshold astrophysical neutrino purity for Gold alerts is 50%. This alert has an estimated false alarm rate of 0.68 events per year due to atmospheric backgrounds. The IceCube detector was in a normal operating state at the time of detection. The best fit information for this event is:





Credit: the images are from internet.

VHE GRB 190114C

- GRB 190114C is the first GRB observed in the TeV band. The highest photon energy is more than 10 times that of previous cases. It is the most dazzling flash in the universe.
- After the VHE GRB was detected, telescopes in multiple bands immediately carried out joint measurement of the afterglow radiation. It is one of the few gamma bursts that can be detected in all electromagnetic wavebands. It is used to study the origin and origin of high-energy photon radiation.
- An international team led by researcher An Tao from Shanghai Astronomical Observatory coordinated the observations of the East Asia VLBI network at the fastest speed, and was able to complete three observations on the 6, 15 and 32 days after the outbreak.
- In the three observations, the source was not detected. From this the author concludes that the radio flux density of GRB190114C has dropped rapidly. This observation gives the upper limit of the radio brightness of GRB 190114C at three time points, which is used as a reference to limit the parameter space of the theoretical model.
- The paper is published online in Science Bulletin, which is the only radio data of the GRB during the decline period.

ELSEVIER
Science Bulletin
Available online 20 November 2019
In Press, Corrected Proof

Short Communication

East Asia VLBI Network observations of the TeV Gamma-Ray Burst 190114C

Tao An [a, h], Om Sharan Salafia [c], Yingkang Zhang [a, b], Giancarlo Ghirlanda [c], Gabriele Giovannini [d, e], Marcello Giroletti [d], Kazuhiro Hada [f], Giulia Migliori [d, e], Monica Orienti [d], Bong Won Sohn [g]
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https://doi.org/10.1016/j.scib.2019.11.012
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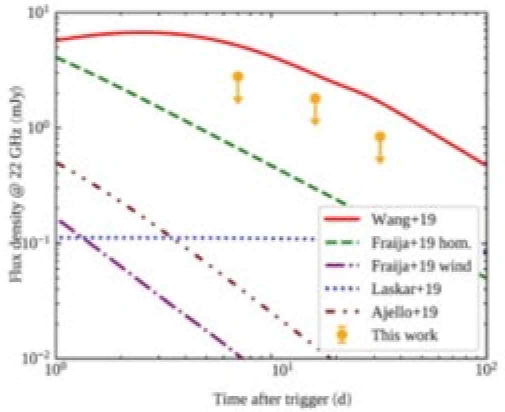
Graphical abstract

This paper reports the VLBI observations of radio afterglow from Gamma ray burst (GRB) 190114C, the first ever detected TeV GRB by the MAGIC Cherenkov telescope. The observations were made with the East Asia VLBI Network (EAVN) at 22 GHz on three epochs. No significant source brighter than 5σ confidence was detected, as yields useful constraints on the parameter space for the afterglow emission. These limits are found to be consistent with most afterglow models proposed so far in the literature. This is the first effort for the EAVN to search for a radio transient in the Target of Opportunity mode.



VHE GRB 190829A and 201015A

GRB190829A: Detection of VHE gamma-ray emission with H.E.S.S.

ATel #13052; *M. de Naurois (H. E. S. S. Collaboration)*
on 30 Aug 2019; 07:12 UT
Credential Certification: Fabian SchÃ ¼ssler (fabian.schussler@cea.fr)

Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Tweet

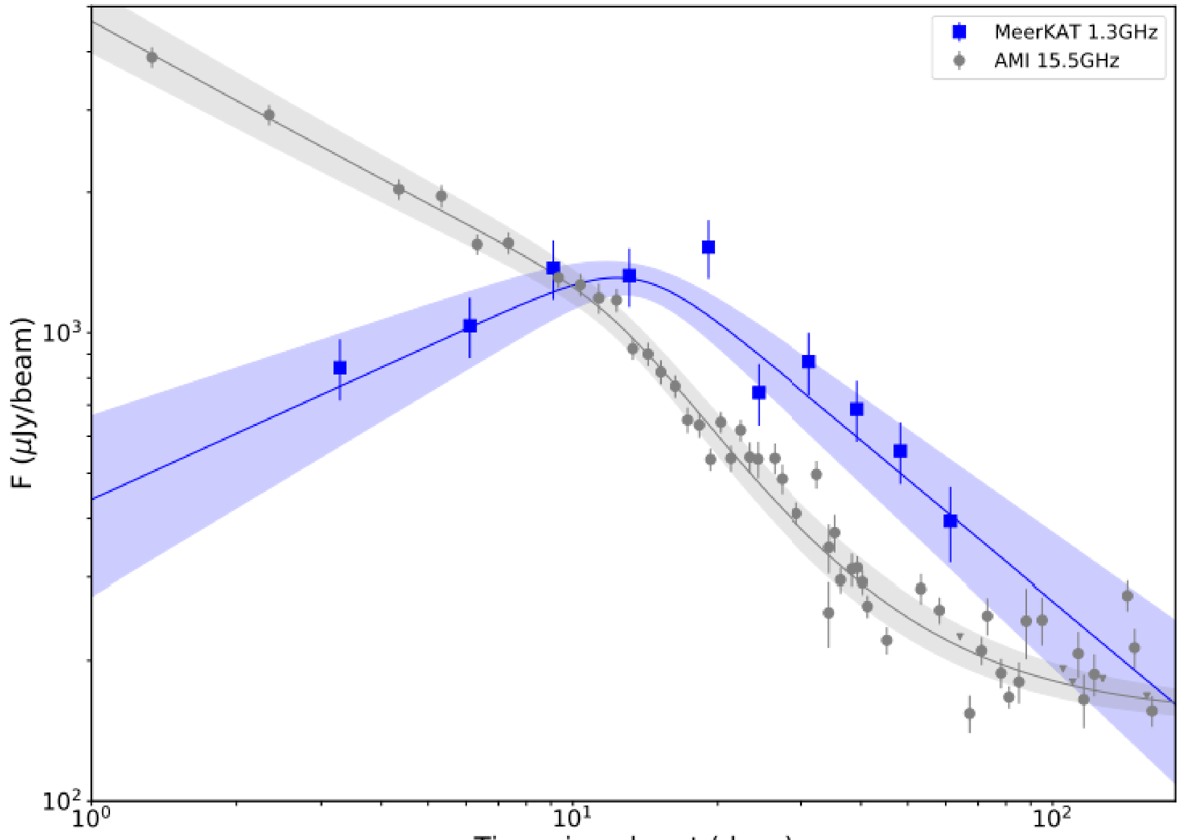
The H.E.S.S. array of imaging atmospheric Cherenkov telescopes was used to carry out follow-up observations of the afterglow of GRB 190829A (Dichiara et al., GCN 25552). At a redshift of z = 0.0785 +/- 0.005 (A.F. Valeev et al., GCN 25565) this is one of the nearest GRBs detected to date. H.E.S.S. Observations started July 30 at 00:16 UTC (i.e. T0 + 4h20), lasted until 3h50 UTC and were taken under good conditions. A preliminary onsite analysis of the obtained data shows a >5sigma gamma-ray excess compatible with the direction of GRB190829A. Further analyses of the data are on-going and further H.E.S.S. observations are planned. We strongly encourage follow-up at all wavelengths. H.E.S.S. is an array of five imaging atmospheric Cherenkov telescopes for the detection of very-high-energy gamma-ray sources and is located in the Khomas Highlands in Namibia. It was constructed and is operated by researchers from Armenia, Australia, Austria, France, Germany, Ireland, Japan, the Netherlands, Poland, South Africa, Sweden, UK, and the host country, Namibia. For more details see https://www.mpi-hd.mpg.de/hfm/HESS/

TITLE: GCN CIRCULAR
NUMBER: 28659
SUBJECT: MAGIC observations of GRB 201015A: hint of very high energy gamma-ray signal
DATE: 20/10/16 16:48:37 GMT
FROM: Oscar Blanch at MAGIC Collaboration <blanch@ifae.es>

O.Blanch (IFAE-BIST Barcelona), M. Gaug (UAB Barcelona), K. Noda (ICRR University of Tokyo), A. Berti (INFN Torino), E. Moretti (IFAE-BIST Barcelona), D. Miceli (University of Udine and INFN Trieste), P. Gliwny (University of Lodz) S. Ubach (UAB Barcelona), B. Schleicher (University of Wuerzburg), M. Cerruti (University of Barcelona) and A. Stamerra (INAF Rome) on behalf of the MAGIC collaboration report:

On October 15, 2020, the MAGIC telescopes observed GRB 201015A following the Swift-BAT trigger (Dâ€™Elia et al., GCN 28632).
MAGIC started observations under good conditions about 40 seconds after the initial Swift trigger, revealing a hint of signal
with significance >3 sigma in the very high energy band. Refined off-line analyses of the data are ongoing.

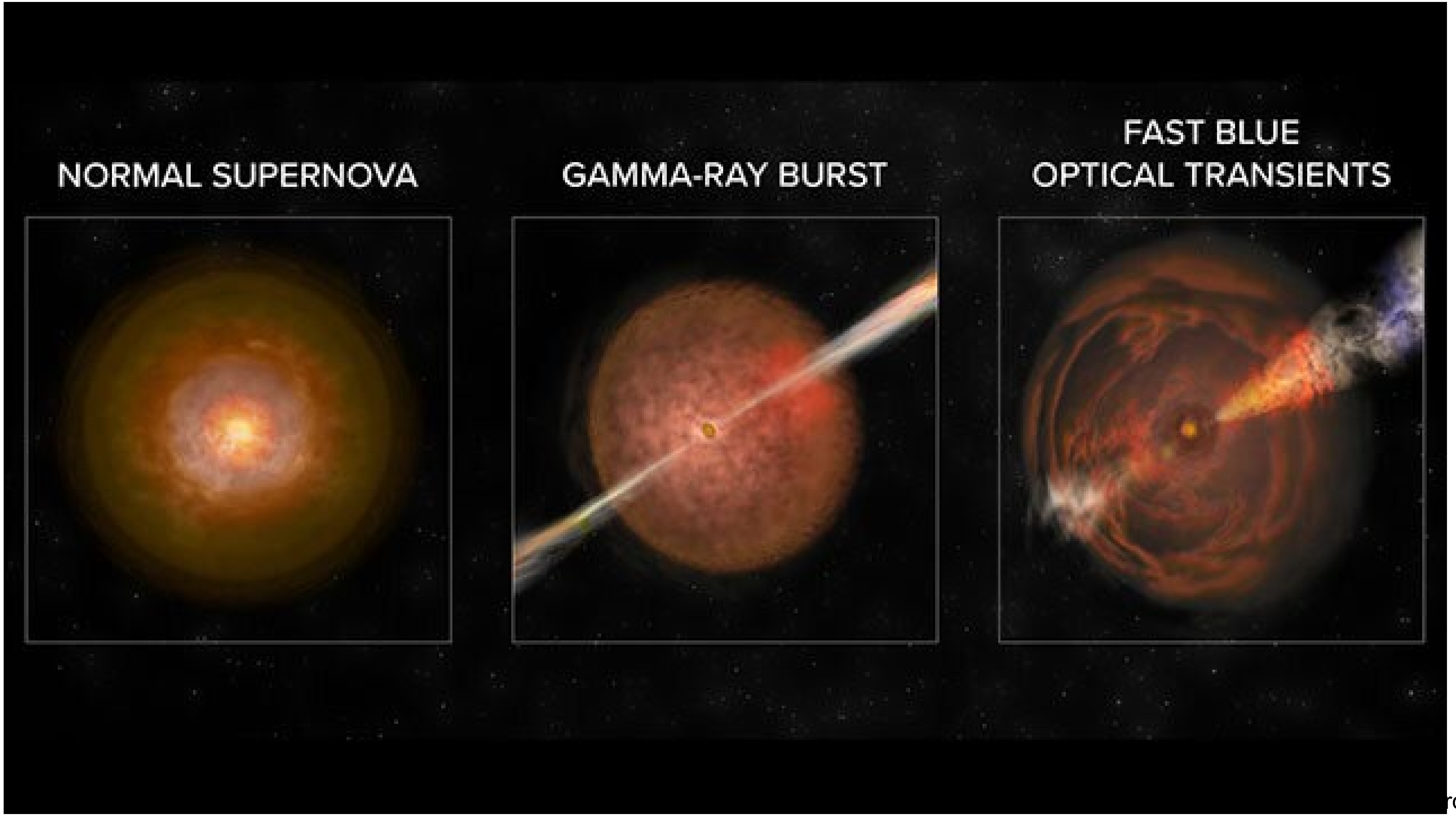
Further MAGIC observations on GRB 201015A are planned in the coming night. We strongly encourage follow-up observations by other instruments at all wavelengths.



Frequency	Array	epoch
15GHz	VLBA	20190907
5GHz	VLBA	20190911
5GHz	EVN	20190917
15GHz	VLBA	20191003
5GHz	EVN	20191015
5GHz	VLBA	20191016
5GHz	EVN	20191112
5GHz	VLBA	20191117
5GHz	VLBA	20191224

- Data analysis is complete
- Modelling is almost finalized
- Start paper drafting

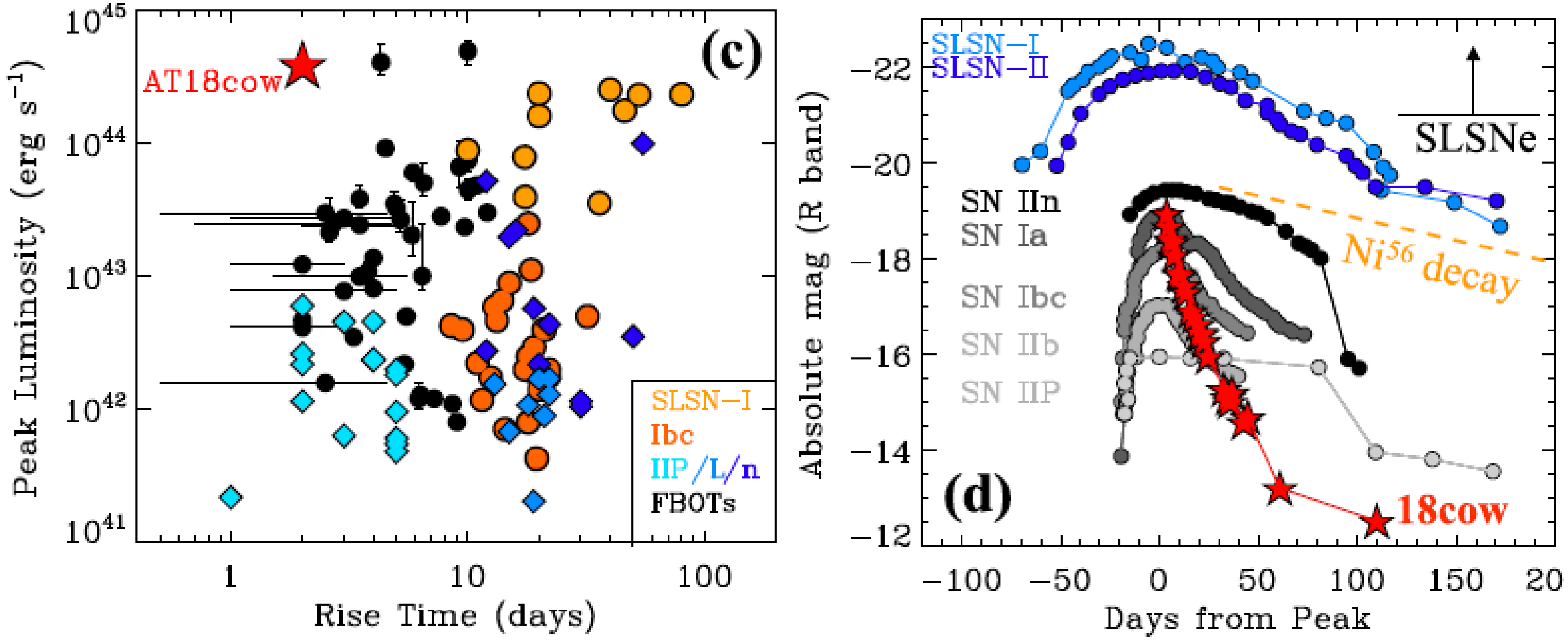
Fast Blue Optical Transients

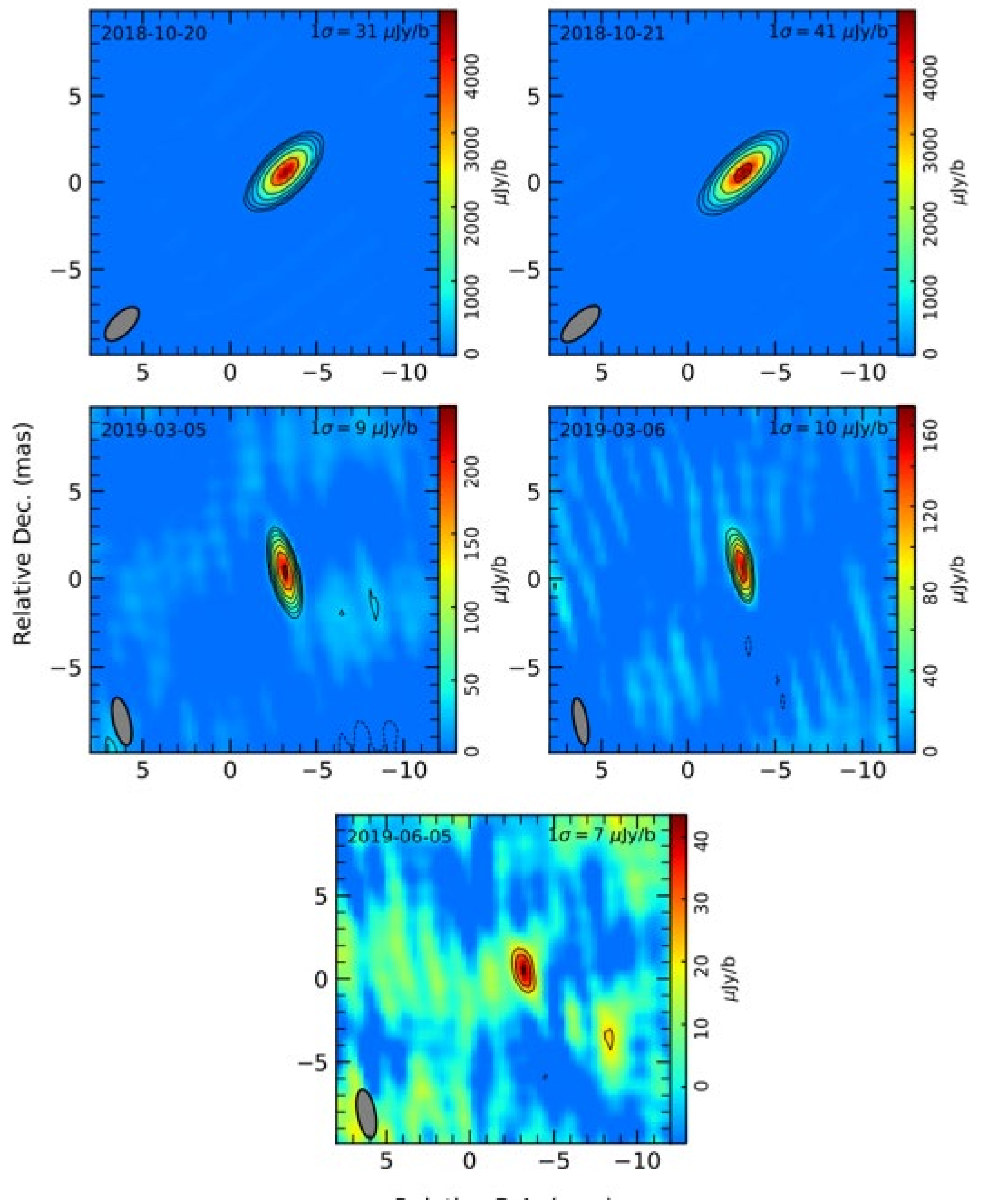


rom internet.

AT2018cow: FBOT

Superluminous SN could be FRB? Could be magnetar?





- A central engine
  - E.g. Margutti et al.(2019)
- A luminous Millimeter Transient
  - E.g. Ho et al. (2019)
- Other interpretations

AT2018cow represents a peculiar class of super luminous transients: closest, brightest. And possible connection with magnetar. Will be targets of future multi-wavelength campaigns

Mohan, P.; An, T.; Yang, J.. The nearby luminous transient AT2018cow: a magnetar formed in a sub-relativistically expanding non-jetted explosion, ApJL, 2020, 888, 2

Ongoing our radio transient projects

- GW EM counterpart – radio afterglow monitoring (Ghirlanda, Salafia, et al. 2019, Sci.)
- FRB&SGR – timing, localization, ISM
  - SGR 1935+2154 (An et al. ATel#13816)
- TDE – jetted or non-jetted
  - AT2019dsg – a TDE with neutrino emission (Mohan, An, Yang, Zhang in prep.)
- Neutrino emitting AGN
  - 0506+056 – 1st discovered neutrino emitting blazars (Li, An, Mohan, Giroletti, 2020, ApJ)
  - NGC1068 – nuclear region of non-blazar neutrino AGN
  - IC200109A – are gamma-ray blazars neutrino sources? (VLBI observations done)
- GRB – long and short
  - GRB190114C – upper limit of radio flux densities (An et al. 2020, SciBull)
  - GRB190829A – VHE long GRB (in prep.)
- SN – Superluminous SN in radio's view
  - AT2018cow (Mohan, An, Yang, 2020, ApJL)

Welcome to your comments and collaborations

Summary

- Transients are a box of surprises and serendipities for the extreme astrophysics
- Radio observations offer complementary info for constraining transient nature
- SKA allows to trigger radio transients, enabling statistical study
    - SKA Pathfinders already demonstrate its power as an FRB discovery machine
- VLBI is unique to infer precise localization of transients and structure change
    - VLBI capacity keeps increasing, enabling to detect most transients
    - an image sensitivity of ~1 uJy/beam at C band comparable to JVLA
    - New large telescopes (FAST, QTT) enhances the global VLBI capability
- **Transient is an important science use case of the MM MW astronomy**