

From nuclei to neutron stars: Combining nuclear physics and multi-messenger observations

Ingo Tews, Los Alamos National Laboratory

04/12/2021, RESANET Scientific Colloquium

LA-UR-21-23345



10/16/2017

The New York Times

LIGO Detects Fierce Collision of Neutron Stars for the First Time

GW170817, Aug 17, 2017

Neutron stars:

- Remnants of core-collapse supernovae
- Typical masses of 1.4 M_{sol}
- Typical radii of only $\mathcal{O}(10)$ km

Neutron star mergers:

- Coalescence of two neutron stars
- Can be detected in gravitational waves and EM spectrum (Multimessenger astrophysics)
- Explore highest densities in the Cosmos!

Credit: ESO/L. Calçada

What are Neutron Stars?

Neutron star physics is extreme:

- Highest densities in the cosmos!
- Extreme magnetic fields, extreme gravity, extreme spin frequencies, ...
- Can not be realized in terrestrial experiments!

Example: iron block, shrink $x \rightarrow 10^{-4} x$ with constant mass.







Gandolfi, Lippuner, Steiner, IT et al., J. Phys. G (2019)



What are Neutron Stars?

Neutron stars are ideal laboratories for fundamental physics:

- Atmosphere: atomic and plasma physics,
- Outer Crust: Solid state physics (lattice of nuclei),
- Inner Crust: Neutron **superfluidity**,
- Core: Strongly interacting matter, may exhibit exotic phases of matter.

Due to their extreme properties, neutron stars provide information complimentary to experiments on Earth.

Data from astrophysical observations is crucial to learn about fundamental physics!



Gandolfi, Lippuner, Steiner, IT et al., J. Phys. G (2019)



- **1932**: Discovery of the neutron by Chadwick.
- **1933/34**: Proposition of the existence of neutron stars by Baade and Zwicky as engines for supernovae.

COSMIC RAYS FROM SUPER-NOVAE

By W. BAADE AND F. ZWICKY

MOUNT WILSON OBSERVATORY, CARNEGIE INSTITUTION OF WASHINGTON AND CALI-FORNIA INSTITUTE OF TECHNOLOGY, PASADENA

Communicated March 19, 1934

In addition, the new problem of developing a more detailed picture of the happenings in a super-nova now confronts us. With all reserve we advance the view that a super-nova represents the transition of an ordinary star into a *neutron star*, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density. As neutrons can be packed much more closely than ordinary nuclei and electrons, the "gravitational packing" energy in a *cold* neutron star may become very large, and, under certain circumstances, may far exceed the ordinary nuclear packing fractions. A neutron star would therefore represent the most stable configuration of matter as such. The consequences of this hypothesis will be developed in another place, where also will be mentioned some observations that tend to support the idea of stellar bodies made up mainly of neutrons.



Walter Baade



Fritz Zwicky

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5/3/21

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- 1939: Tolman, Oppenheimer and Volkoff calculate neutronstar mass limit of 0.7 M_{sol} for cold, degenerate neutron gas.



J. Robert Oppenheimer George Volkoff

Richard Tolman

On Massive Neutron Cores

J. R. OPPENHEIMER AND G. M. VOLKOFF Department of Physics, University of California, Berkeley, California (Received January 3, 1939)

V. Discussion—Application to Stellar Matter

We have seen that for a cold neutron core there are no static solutions, and thus no equilibrium, for core masses greater than $m \sim 0.7 \odot$. The corresponding maximum mass M_0 before collapse is some ten percent greater than this. Since neutron cores can hardly be stable (with respect to formation of electrons and nuclei) for masses less than $\sim 0.1 \odot$, and since, even after thermonuclear sources of energy are exhausted, they will not tend to form by collapse of ordinary matter for masses under $1.5 \odot$ (Landau's limit), it seems unlikely that static neutron cores can play any great part in stellar evolution;¹⁸ and



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- 1967: Bell finds regular pulse repeating every 1.3 s in data taken by radio telescope built with A. Hewish, called it "Little Green Man-1" → Discovery of pulsars (PSR B1919+21).





Jocelyn Bell (1967)

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- **1974**: Discovery of the Hulse-Taylor pulsar PSR B1913+16, first binary neutron-star system. Tests of General Relativity, e.g., gravitational waves lower orbital frequency → observed!
- 2010, 2013, 2019: Discovery of 2 M_{sol} neutron stars.





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- 2010, 2013, 2019: Discovery of 2 M_{sol} neutron stars.
- **2017**: First discovery of gravitational waves from neutron-star merger, GW170817!



Kip S. Thorne (Caltech)

2017 Nobel Prize in Physics

Barry C. Barish (Caltech)



What stabilizes Neutron Stars?

Neutron stars are stabilized against gravity by pressure of strongly interacting matter!

 Neutron star:
 Atomic nucleus, e.g., ²⁰⁸Pb:

 $M \sim 1.4 \,\mathrm{M_{sol}} = 3 \cdot 10^{30} \,\mathrm{kg}$ $M \sim 3 \cdot 10^{-25} \,\mathrm{kg}$
 $R \sim 10 - 13 \,\mathrm{km}$ $R \sim 6 \,\mathrm{fm} = 6 \cdot 10^{-18} \,\mathrm{km}$
 $\rho \sim 10^{14} \,\mathrm{g/cm^3}$ $\rho \sim 10^{14} \,\mathrm{g/cm^3}$

 Nuclear saturation density
 Image: Note that the set of the set

Although the corresponding scales differ by many orders of magnitude, properties of neutron stars and nuclei are strongly connected.

Nuclear interactions exert outward pressure that stabilize both nuclei and neutron stars!





Pressure

Why study neutron stars?

Same nuclear interactions among same constituents (nucleons) in the lab and in astrophysics. A measurement or observation has immediate consequences for the other domain.

02

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How does the neutronstar structure depend on nuclear interactions?

• What are the fundamental interactions that govern strongly interacting matter?

What are current observational constraints?

 Constraints from mass measurements, gravitational waves, and NICER. 03

What do observations tell us about nuclear physics and nuclear interactions?

• Multi-messenger astrophysics as test for nuclear physis.



Neutron Stars described by Tolman-Oppenheimer-Volkoff (TOV) equations, equation of state (EOS) only ingredient.

- Neutron stars have typical temperatures of T=10⁷-10⁸ K \rightarrow E_{th} = 8 keV \ll E_F
- Therefore, neutron stars can be considered to be objects at T=0
- Then, EOS relates pressure p and energy density ϵ





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Large number of neutron-star equations of state available in the literature, but which ones are "good"?

- They do **not provide any theoretical uncertainty** estimates.
- They are not constructed based on some fundamental guiding principle; hence, it is **not clear how to improve them** systematically.





Constraints:

Pion condens

star

- At low densities from **nuclear theory** and experiment.
- At very high density from pQCD. see, e.g., Kurkela, Vuorinen et al.
- No robust constraints at intermediate densities from nuclear physics!



Neutron-star structure depends on the EOS, given by $p = p(\epsilon)$

Baryon density: n = A/V
Energy density: \epsilon = E/V = n \cdot E/A
Pressure: p = -\frac{\partial E}{\partial V} = -\frac{\partial E/A}{\partial V/A} = n^2 \frac{\partial E/A}{n}

In neutron star, we have neutrons, protons, and electrons in beta equilibrium. Therefore, we need a function

$$\frac{E}{A}(n,x)$$

where x is the proton fraction, $x = n_p/n$.

- x = 0.5: Symmetric nuclear matter: Connection to **laboratory experiments.**
- x = 0.0: Pure neutron matter: Connection to **astrophysical observations.**
- Difference is called symmetry energy: Connection to heavy-ion collisions, neutron skins, ...



Many different approaches to calculate $\frac{E}{A}(n,x)$ but I will focus on **microscopic calculations**. We need:

A theory for the strong interactions among nucleons

Chiral Effective Field Theory

A computational method to solve the many-body Schrödinger equation.

e.g., many-body perturbation theory, quantum Monte Carlo, coupled cluster, self-consistent Green's function, ...





- Atomic nucleus consists of strongly interacting matter.
- Made up by quarks and gluons (Quantum Chromodynamics).
- Extremely complicated to solve!





- Atomic nucleus consists of strongly interacting matter.
- Made up by quarks and gluons (Quantum Chromodynamics).
- Extremely complicated to solve!
- Probing a nucleus at low energies does not resolve quark substructure of nucleons!
- We can describe the nucleus in terms of neutrons (udd) and protons (uud).







Holt et al., PPNP 73 (2013)

	NN	3N	4N	
LO $O\left(\frac{Q^0}{\Lambda^0}\right)$ (2 LECs)	ΧН		_	
NLO $O\left(\frac{Q^2}{\Lambda^2}\right)$ (7 LECs)	X A A A A A A A A A A A A A		_	
N ² LO $O\left(\frac{Q^3}{\Lambda^3}\right)$ (2 LECs: 3N)	ÞÞ			
N ³ LO $O\left(\frac{Q^4}{\Lambda^4}\right)$ (15 LECs)			↓¥1 +	

Weinberg, van Kolck, Kaplan, Savage, Wise, Epelbaum, Kaiser, Machleidt, Meißner, Hammer ...



Systematic expansion of nuclear forces in momentum Q over breakdown scale Λ_{b} :

- Based on symmetries of QCD
- Pions and nucleons as explicit degrees of freedom
- Power counting scheme results in systematic expansion, enables uncertainty estimates!
- Natural hierarchy of nuclear forces
- **Consistent interactions**: Same couplings for twonucleon and many-body sector
- Fitting: NN forces in NN system (NN phase shifts), 3N forces in 3N/4N system (Binding energies, radii)

	NN	3N	4N
LO $O\left(\frac{Q^0}{\Lambda^0}\right)$ (2 LECs)	ХH	l	l
NLO $O\left(\frac{Q^2}{\Lambda^2}\right)$ (7 LECs)	X X X X	_	_
N ² LO $O\left(\frac{Q^3}{\Lambda^3}\right)$ (2 LECs: 3N)	Þ		_
N ³ LO $O\left(\frac{Q^4}{\Lambda^4}\right)$ (15 LECs)	XMM T		↓ +

Weinberg, van Kolck, Kaplan, Savage, Wise, Epelbaum, Kaiser, Machleidt, Meißner, Hammer ...



Neutron-proton scattering phase shifts



Can work to desired accuracy with error estimates!

Epelbaum et al., PRL (2015) See also Carlsson et al. PRX (2016)



Uncertainty



Present theoretical predictions for nuclear systems are limited by:

- our incomplete understanding of nuclear interactions,
- and our ability to reliably calculate these strongly interacting systems.

For nucleonic matter and nuclei, we need a consistent approach with:

- a systematic theory for strong interactions
- advanced many-body methods
- controlled theoretical uncertainty estimates.

Microscopic studies of nucleonic matter and nuclei using chiral EFT.



BUT: There are still many open questions and problems!

 What is the breakdown scale? Does it change in the many-body system?





Weinberg, van Kolck, Kaplan, Savage, Wise, Epelbaum, Kaiser, Machleidt, Meißner, Hammer ...

BUT: There are still many open questions and problems!

- What is the breakdown scale? Does it change in the many-body system?
- How do results depend on the regularization scheme (explicit form of the interaction) and scale (cutoff necessary in many-body methods)?
- Does this series converge in the many-body system?
- How to best determine all unknown coefficients?



Weinberg, van Kolck, Kaplan, Savage, Wise, Epelbaum, Kaiser, Machleidt, Meißner, Hammer ...



Results for chiral EFT calculations of nuclei:





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• Selection of a few EOS models that are used in astrophysics.





- Selection of a few EOS models that are used in astrophysics.
- Chiral EFT puts constraints on the EOS of neutron matter.
- Provides systematic and reliable uncertainty estimates!





- Chiral interactions are limited in range of applicability due to breakdown of the theory, rapid increase of theoretical uncertainty.
- Extend results to neutron-star densities using general approach without strong model assumptions (e.g., polytropes, speed-of-sound extension, meta-EOS, nonparametric inference)!



- Extend results to beta equilibrium (small $Y_{e,p}$) and include crust EOS.
- Extend to higher densities using general extension schemes, e.g., in the **speed of sound.**



- Assume some general form for speed of sound above transition density, e.g., linear segments, etc.
- Sample many different curves in allowed region (gray band) and reconstruct EOS.
- Can easily include phase transitions and additional information on c_S.
- Extend systematic uncertainties to higher densities!



IT, Carlson, Gandolfi, Reddy, ApJ (2018)



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- Provides systematic and reliable uncertainty estimates!
- Uncertainty band can be extended to higher densities using general extension schemes.



Neutron-star masses



Heaviest observed neutron-stars provide constraints, because all EOS have to be able to reproduce observation.





Pulsar mass observations

Since 2010, three pulsar-timing observations of heavy pulsars with masses close to 2 $\rm M_{\rm sol:}$

- PSR 1614-2230: 1.908(16) M_{sol}
 Demorest et al., Nature (2010), Arzoumanian et al., ApJS (2018)
- PSR J0348+0432: 2.01(4) M_{sol} Antoniadis et al., Science (2013)
- MSP J0740+6620: 2.08(7) M_{sol}

Cromartie et al., Nat. Astron (2020), Fonseca et al., arXiv:2104.00880





Neutron-star masses



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A two-solar-mass neutron star measured using Shapiro delay

P. B. Demorest¹, T. Pennucci², S. M. Ransom¹, M. S. E. Roberts³ & J. W. T. Hessels^{4,5}

(2010)

A Massive Pulsar in a (2013) Compact Relativistic Binary

John Antoniadis,* Paulo C. C. Freire, Norbert Wex, Thomas M. Tauris, Ryan S. Lynch, Marten H. van Kerkwijk, Michael Kramer, Cees Bassa, Vik S. Dhillon, Thomas Driebe, Jason W. T. Hessels, Victoria M. Kaspi, Vladislav I. Kondratiev, Norbert Langer, Thomas R. Marsh, Maura A. McLaughlin, Timothy T. Pennucci, Scott M. Ransom, Ingrid H. Stairs, Joeri van Leeuwen, Joris P. W. Verbiest, David G. Whelan

Relativistic Shapiro delay measurements of an extremely massive millisecond pulsar (2019)

H. T. Cromartie[®]^{1*}, E. Fonseca[®]², S. M. Ransom[®]³, P. B. Demorest⁴, Z. Arzoumanian⁵, H. Blumer^{6,7}, P. R. Brook^{6,7}, M. E. DeCesar⁸, T. Dolch⁹, J. A. Ellis¹⁰, R. D. Ferdman[®]¹, E. C. Ferrara^{12,13}, N. Garver-Daniels^{6,7}, P. A. Gentill^{6,7}, M. L. Jones^{6,7}, M. T. Lam^{6,7}, D. R. Lorimer^{6,7}, R. S. Lynch¹⁴, M. A. McLaughlin^{6,7}, C. Ng^{15,16}, D. J. Nice⁹, T. T. Pennucci[®]¹⁷, R. Spiewak[®]¹⁸, I. H. Stairs¹⁵, K. Stovall⁴, J. K. Swiggum¹⁹ and W. W. Zhu²⁰





NS (multimessenger) observations

First neutron-star merger observed on Aug 17, 2017 :

The New York Times

NV(

3.5

3.0

2.5 credibility 1.5

1.0

0.5

0.0



Neutron-star mergers

Gravitational waves from neutron-star merger offer possibility to "measure" the neutron-star radius!

LIGO/VIRGO:

- During merger, neutron stars deform under gravitational field of partner.
- This deformation is measured as "tidal deformability" from gravitational waveform during inspiral phase of neutron-star merger, and probes radius.





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Margalit and Metzger, ApJ (2017)

- \succ Constraints from the EM signal determined by M_{max}:
 - M_{max} too small: prompt collapse
 - M_{max} too large: remnant deposits too much energy into ejecta



Neutron-star mergers: Mass limits





Consistently combine constraints from low-energy nuclear theory, gravitational-wave observations and electromagnetic observations using Bayesian methods.

(A) Starting point:

EOS samples derived within the chiral EFT framework

(B) Maximum-mass constraints: Add information from pulsar mass measurements and GW170817 remnant classification





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Dietrich, Coughlin, Pang, Bulla, Heinzel, Issa, IT, Antier Science (2020)

NICER: Mass-radius measurement



Recent mass-radius measurement of pulsar PSR J0030+0451 by Neutron star Interior Composition Explorer (NICER) X-ray telescope:

 $R = 12.71^{+1.14}_{-1.19} \text{km}, \ M = 1.34^{+0.15}_{-0.16} M_{\odot} \quad \text{[Riley et al., ApJL (2019)]}$ $R = 13.02^{+1.24}_{-1.06} \text{km}, \ M = 1.44^{+0.15}_{-0.14} M_{\odot} \quad \text{[Miller et al., ApJL (2019)]}$



Still large uncertainties because of unknown number and properties of hot spots, unknown pulsar mass, and statistics -> **new observations expected soon!**

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Dietrich, Coughlin, Pang, Bulla, Heinzel, Issa, IT, Antier Science (2020)

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(C) NICER constraints: Add information from pulsar mass-radius measurement

(D) GW constraints:

Add information from GW170817 (IMRPhenomPv2_NRTidalv2)

(E) Kilonova constraints:

Add information extracted from modeling the observed lightcurves of associated kilonova AT2017gfo



Consistently combine constraints from low-energy nuclear theory, gravitational-wave observations and electromagnetic observations using Bayesian methods.

(E) Kilonova constraints: Add information extracted from modeling the observed lightcurves of associated kilonova AT2017gfo (F) GW constraints: Add information from GW190425 (IMRPhenomPv2_NRTidalv2)





Dietrich, Coughlin, Pang, Bulla, Heinzel, Issa, IT, Antier Science (2020)

Analysis of gravitational-wave and electromagnetic signals constrains radius of NS and orientation and distance to the source, constraining **Hubble constant**

- Stringent constraints on NS radii: $R_{1.4} = 11.75^{+0.86}_{-0.81} \text{ km}$
- Constraints on the Hubble constant:
- $H_0 = 66.2^{+4.4}_{-4.2} \,\mathrm{km} \,\mathrm{Mpc}^{-1} \mathrm{s}^{-1}$

Hubble tension: competing determinations of H₀ from supernovae and from Cosmic Microwave Background (CMB). Our approach in agreement with CMB measurement.



Summary

Multimessenger detections of neutron-star mergers will provide important constraints for nuclear physics:



To tackle these different questions precision studies of neutron-rich systems (matter and nuclei) are very important.



Summary

> Neutron stars represent ideal laboratories for nuclear physics and help to improve our understanding of nuclear interactions!

Uncertainty in neutron-star EOS can be reduced by

- Nuclear-physics constraints at low densities.
- Multimessenger observations of NS and NS mergers.
- > Multimessenger constraints and nuclear theory find $R_{1.4} = 11.8 \pm 0.8 \text{ km} (90\% \text{ confidence}),$ $H_0 = 66 \pm 4 \text{ km} \text{ Mpc}^{-1} \text{ s}^{-1}$
- GW observations favor soft, EM observations (kilonova and NICER) favor stiff EOS, but have large uncertainties, also systematic (depend on information from simulations with limited number of EOS, more EOS need to be explored).
- Even if can obtain EOS, we need to understand it (exotic matter?).



Outlook

GraceDB — Gravitational-Wave Candidate Event Database

HOME PUBLIC ALERTS SEARCH LATEST DOCUMENTATION

Latest — as of 9 September 2019 22:44:52 U
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Test and MDC events and superevents are not included in the search results by default; see the guery help for information on how to search for events and superevents in those categories.

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15100220 PE_REAV ANOK SIMMAP_READY PERSIGNT_READY PASTRO_READY DOCK CAL PRELIM_SENT 1251010526,899257 1251010526,891557 1251010526,891557 1251010526,891557 1251010526,891557 1251010526,891557 12500126,799035 47.42 2019-08-26 0:532 0/UTC 15100220 PAGN ANOK SIMMAP_READY PERSIGNT_READY PASTRO_READY DOCK GCN_PRELIM_SENT 125947266,89125 125947261,589020 1259	<u>5190829u</u>	PE_READY ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1251147973.281494	1251147974.283940	1251147975.283940	5.151e-09	2019-08-29 21:06:19 UTC
S100220 PE_READY ADVICK SYMMP_READY PERSIGN_TRADY PASTRO_READY POCK COL_PRELIM_SENT 125100224.379647 125100224.796127 125100224.796127 125100224.796127 125100224.796127 12500225.596777 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905580.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.757780 126905520.75780	S190828I	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1251010526.884921	1251010527.886557	1251010528.913573	4.629e-11	2019-08-28 06:55:26 UTC
S199222 PAVNO SKYMAP, READY EMBRIGHT, READY PASTD, READY DQCK COR, PRELIM, SENT 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.899230 129472615.99928 1294952255.97778 1249852255.07778 1294952255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07778 1249852255.07175 1249852255.07175 1249852255.07175 1249852255.07175 1249852255.07175 1249852255.11012 1249707216.07535 117497571.07865 124945721.07865 124945721.07865 124945721.07865 124945721.07865 124945721.07865 124945721.07865 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945721.078765 124945726.078	<u>5190828j</u>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1251009262.739486	1251009263.756472	1251009264.796332	8.474e-22	2019-08-28 06:34:21 UTC
S1001LW PE_REAV ADVING SYMMP_READY PERMENT, READY PASTRO, READY DQCK GCM, PEELM, SENT 1249993889.757798 1249993889.757798 1249993889.757798 1249993889.757798 1249993889.757798 1249993889.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993989.757798 124993189.7578 124933152 124933152 124933152 124933152 124933152 124933152 124933152 124933152 124933152 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249710.558 1249512.558 1249512.558 1249710.558 1249710.558 1249512.558 1249512.558 1249512.558 1249512.558 1249717.558 1249512.558 1249512.558 1249512.558 1249512.558 1249512.558	S190822c	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1250472616.589125	1250472617.589203	1250472618.589203	6.145e-18	2019-08-22 01:30:23 UTC
51303124 PE, READY ADVICK SIMMAP, READY EMBRIGHT, READY PASTRO, READY POCK COL, PRELIM, SENT 124985228, 201270 124985228, 021271 2.038-33 2019-08-14 211111 UTC 513030288 MOVIN SIMMAP, READY EMBRIGHT, READY PASTRO, READY DOCK COL, PRELIM, SENT 1240331057, 40747 1249331327, 44677 1249331327, 44677 1249331327, 44677 1249331327, 44677 1249331327, 44677 124931329, 74067 5.776-23 0219-07-28 (0-64327, UTC 51302728 PE, READY ADVICK SIMMAP, READY EMBRIGHT, READY PASTRO, READY DOCK GCL, PRELIM, SENT 12442620, 97628 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 98649 124442631, 986494 124442631, 986494 124442631, 986494 124442631, 986494 124442631, 986494 124442631, 986494 124442631, 986494 124442631, 986494 124442631, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494 124446731, 986494	S190816i	PE_READY ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1249995888.757789	1249995889.757789	1249995890.757789	1.436e-08	2019-08-16 13:05:12 UTC
S1000000000000000000000000000000000000	S190814bv	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1249852255.996787	1249852257.012957	1249852258.021731	2.033e-33	2019-08-14 21:11:18 UTC
15107220 PE, READY ADVICK SIMMAP, READY PERBIGIT, READY PASTIO, READY DOCK GCL, PEELLM, SENT 1248331527.4979 1248331528.44979 1248331528.44979 1248331528.44979 1248331527.4978 1248331527.4978 1248331527.4978 1248331527.4978 1248331527.4978 1248331527.4978 124831527.4978 124831527.4978 1248431527.49787 1248431527.49787 1248431527.49787 1248431527.49787 124841553.40014 124716533.40014 124716533.40014 124716533.40014 124716533.40014 124716533.40014 124716533.40014 124716533.40014 124465720.67865 1247495730.67865 1247495730.67865 1247495730.67865 124496721.67814 124657223.48114 145657.578114 12464572.578114 12464572.578114 12464572.578114 12464572.578114 12464572.578114 12464572.578114 12464572.	S190808ae	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1249338098.496141	1249338099.496141	1249338100.496141	3.366e-08	2019-08-08 22:21:45 UTC
S1002200 PE_REAV AVOK SKYMAP_REAV PERBIGHT_REAVY PASTRO_REAVY DQCK GCL_PEELIM_SENT 1248/2403.09288 1248/2403.09287 1248/2423.21411 1248/22723.81810 2.682-12 2019/07.070.033.141/C 51002010 PE_REAV AVOK SKYMAP_REAV PERBIGHT_REAV PASTRO_REAV DQCK GCL_PEELIM_SENT 124692723.181026 124692723.237.8180 5.682-12 2019/07.00.233.411/C 51002010 PE_REAV AVOK SKYMAP_REAV PERBIGHT_REAV PASTRO_REAV DQCK GCL_PEELIM_SENT 124694804.37507 124694804.518441 1.916-08 2019/07.10.233.214 UTC 51002011 PE_REAV AVOK SKYMAP_REAV PERBIGHT_REAV PASTRO_REAV DQCK GCL_PEELIM_SENT 124209864.02518 124209864.02518 124209864.02518 124207874.07869 124207874.07869 124207874.07869 124207874.07869 124207874.07869 124242986.42518 124207874.07869 124207874.07869 124207874.07869<	S190728q	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1248331527.497344	1248331528.546797	1248331529.706055	2.527e-23	2019-07-28 06:45:27 UTC
51922220 PE_READY ADVICK SYMMP_READY PERSIGNT_READY PASTRO_READY POCK CK_PERLIM_SENT 1247616533.70127 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 1247616533.70120 124761533.70120 12477616	S190727h	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1248242630.976288	1248242631.985887	1248242633.180176	1.378e-10	2019-07-27 06:03:51 UTC
S1902/LIV AVX/K SKYMAP, REAV YMBRIGHT, REAV PARTO, READY DQCK CON, PRELIM, SENT 124499730.06786 124499730.06786 124499731.06786 142499731.06786 142499731.06786 142499731.06786 142499731.06786 142499731.06786 142499731.06786 124949731.06786 124949731.06786 124949731.06786 124949731.06786 124949732.118398 12012 12492723.11839 12012 12492732.11839 12012 12492732.11839 12012 12492732.11839 12012 12492732.11839 12012 12492732.11839 12012 12492732.11839 12012 12492732.11839 12112 12494973.06786 12494978.07886 12494978.07886 12494978.0788 12494988.04200 1249498.0430 1249498.0430 1249498.0430 1249498.0430 1249498.0430 12494988.04200 12494988.04200 12	S190720a	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1247616533.703127	1247616534.704102	1247616535.860840	3.801e-09	2019-07-20 00:08:53 UTC
51902/201 PE_REAV AVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK GCM_PERLIM_SENT 124627223.181998 1246272224.181226 124627223.28180 5.269-12 2019-07-07 09.33144 UTC 51902/201 /r PE_REAV AVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK GCM_PERLIM_SENT 124662723.318199 124662723.2724.181226 124662723.2528.8938 10.10 2019-07-07 09.33144 UTC 51902/201 /r PE_REAV AVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK GCM_PERLIM_SENT 124663734.57537 124604405.516491 1.016-08 2019-07-01 20:332.4 UTC 51902/201 /r PE_READY AVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK GCM_PERLIM_SENT 124505354.081506 124505554.041106 4104-0502.173:531 UTC 51902/201 /r PE_READY AVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK GCM_PERLIM_SENT 12424097.467690 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124242986.40200 1.661-10 10.01-02 10.91-02 11.73:51 UTC 51905210 PE_READY AVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK GCM_PERLIM_SENT 124242986.457486 124242987.647391 124242987.647391 124242987.647391 124242987.647391 124242987.647391 124242987.647391 124242987.647391 124242498.64591 1.016.91 <	S190718y	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1247495729.067865	1247495730.067865	1247495731.067865	3.648e-08	2019-07-18 14:35:34 UTC
S19020200 PE, READY ADVICK SIXMAP, READY PERBIGIT, READY PASTRO, READY DOCK COL, PEELLH, SENT 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 124448728.321541 1244587384.31155 1244587384.31155 1244587384.31155 1245953544.11518 1.345 123155321 0111111111111111111111111111111111111	S190707q	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1246527223.118398	1246527224.181226	1246527225.284180	5.265e-12	2019-07-07 09:33:44 UTC
S1902/2014 PE, READY ADVICK SKYMAP, READY PERINGHT, READY PASTRO, READY DOCK GCK, PERLIM, SENT 124064404.57920 124064404.57920 124064404.57920 124064404.57920 124064404.57920 124064404.57920 124064404.57920 124064405.814941 1.910-6-08 2019-07-10 20:3324 UTC S10902000 PE, READY ADVICK SVMAP, READY BRIGHT, READY PASTRO, READY DOCK GCM, PRELIM, SENT 124055304.15720 124055304.15720 12405504.15120 6.971-09 2019-05-21 759:51 UTC S1090200 PE, READY ADVICK SVMAP, READY BRIGHT, READY DOCK GCM, PRELIM, SENT 124242984.63740 124270874.678690 124270874.678690 124270874.63800 6.971-09 2019-05-21 759:51 UTC S1090510 PE, READY ADVICK SVMAP, READY BRIGHT, READY DOCK GCM, PRELIM, SENT 124242986.457416 124242987.667931 124242986.45208 1301-09 2019-05-21 03:224 UTC S10905100 PE, READY ADVICK SVMAP, READY BRIGHT, READY PASTRO, READY DOCK GCM, PRELIM, SENT 124242986.457416 124242987.667931 124242986.457400 124242987.657937 124242988.657418 1301-09 2019-05-11 03:0124 UTC S10905100 PE, READY ADVICK SKYMAP, READY BRIGHT, READY PASTRO, READY DOCK GCM, PRELIM, SENT 124242986.457410 1242107480.9141 1242142986.457418 124217	S190706ai	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1246487218.321541	1246487219.344727	1246487220.585938	1.901e-09	2019-07-06 22:26:57 UTC
51050200 PE_REAV AVOK SKYMAP_REAV PERBIGIT_REAV PASTRO_REAV POCK GCL/PEELLM_SENT 124955994.179250 124955994.18350 124955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14955994.18310 14956994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951994.13310 14951951 14941996.10691414 149419961.106914 <	S190701ah	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1246048403.576563	1246048404.577637	1246048405.814941	1.916e-08	2019-07-01 20:33:24 UTC
S1990200 PE, READY ADVICK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK CK_PERLIM_SENT 124333384.08126 1244333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124333384.08125 124345885.45209 3.168-10 2019-06-22 17:9511 UTC 51952512 PE, READY ADVICK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK CK_PRELIM_SENT 12445986.45318 12442596.66534 124442966.68818 3.061-09 2019-05-21 07:44:22 UTC 51951529 PE, READY ADVICK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOCK CK_PRELIM_SENT 12443296.474609 124242597.674609 124242385.07627 7.270-20 2019-05-11 03:12	S190630ag	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1245955942.175325	1245955943.179550	1245955944.183184	1.435e-13	2019-06-30 18:52:28 UTC
S1903220 PAXNO SYMMP_READY EMBRIGHT_READY PASTIO_READY DOCK COM_PRELIM_SENT 1242708743.07869 124270874.07869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 124270874.67869 12424987.60931 12424987.60931 12424987.60931 12424987.60931 12424987.60931 12424987.60931 12424987.60931 12424987.678031 12424987.678031 12424987.678031 12424987.678031 12424987.678031 12424987.678031 12424987.678031 12424987.678031 12421978.678101 12410788.61811	S190602aq	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1243533584.081266	1243533585.089355	1243533586.346191	1.901e-09	2019-06-02 17:59:51 UTC
S1905210 PE, READY ADVICK SKYMAP, READY EMBRIGHT, READY PASTRO, READY DQCK GCL, PELLM, SENT 122439884.5318 120439887.40279 122439884.63209 0.16e-10 2019-05-10 0.74212 UTC S1905210 PE, READY ADVICK SKYMAP, READY EMBRIGHT, READY PASTRO, READY DQCK GCL, PELLM, SENT 122439864.43218 1224439864.43264 1224439864.43264 1224439864.43264 122431536.67627 5.702+09 2019-05-19 15.3664 UTC S1905100 PE, READY ADVICK SKYMAP, READY EMBRIGHT, READY PASTRO, READY DQCK GCL, PELLM, SENT 124242376.44609 124242320.42664 4726 124242376.460914 124242308.025255 1.004-08 2019-05-19 15.3664 UTC S1905120 PE, READY ADVICK SKYMAP, READY EMBRIGHT, READY PASTRO, READY DQCK GCL, PELLM, SENT 1242107878.199121 124210780.09114 124210780.09114 124210780.09114 1241810087.60914 .734-19 2019-05-19 15.19.19.19.19.19.19.11 S1905120 PE, READY ADVICK SKYMAP, READY EMBRIGHT, READY PASTRO, READY DQCK GCH, PELLM, SENT 124107078.09151 1241170653.181066 1014-08 2019-05-12 18.07.12.10.07.01.01.01.01.01.01.01.01.01.01.01.01.01.	S190524q	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242708743.678669	1242708744.678669	1242708746.133301	6.971e-09	2019-05-24 04:52:30 UTC
S1002120 PE_READY ADVICK SIMMAP_READY PERBIGIT_READY PASTRO_READY DQCK GCM_PERLIM_SENT 124442986.70893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124424987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.60893 124242987.61893 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618913 124212978.618914 124116085.76106 124116985.741068 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 124116985.74108 1241116985.741018 1241116985.74108 <t< td=""><td>S190521r</td><td>PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT</td><td>1242459856.453418</td><td>1242459857.460739</td><td>1242459858.642090</td><td>3.168e-10</td><td>2019-05-21 07:44:22 UTC</td></t<>	S190521r	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242459856.453418	1242459857.460739	1242459858.642090	3.168e-10	2019-05-21 07:44:22 UTC
S19051200 PE_REAV ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 124231358.137877 124231358.25576 124231358.3376720 57.02-00 2019-05-19 15:30:04 UTC S19051200 ADVIK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 124231358.137877 124231358.25576 12424239.022555 1.004-00 2019-05-18 19:19:39 UTC S19051200 PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 124107479.819911 1241017048.094111 1241017048.094111 12	S190521g	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242442966.447266	1242442967.606934	1242442968.888184	3.801e-09	2019-05-21 03:02:49 UTC
S1005120 PERADY ADVIC SYMMAP_READY MERIGIT_READY PASTRO_READY DQCK CON_PRELIM_SENT 12424237.44960 124214350.49165 124121455.4111 124121455.4111 124121455.41111	S190519bj	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242315361.378873	1242315362.655762	1242315363.676270	5.702e-09	2019-05-19 15:36:04 UTC
S1005120 PE, READY ADVICK SYMMP, READY PERBIGHT, READY PASTRO, READY POCK CAC, PERLIM, SENT 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 124210749.09141 12410749.091411 12410749.091411 12410749.091411	S190518bb	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242242376.474609	1242242377.474609	1242242380.922655	1.004e-08	2019-05-18 19:19:39 UTC
S10031200 PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQCK GCM_PRELIM_SENT 1241810087.30010 1241810087.80014 3.7.4+12 2019-05-13 20:5444 UTC S10031201 PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQCK GCM_PRELIM_SENT 1241810087.30016 1241810087.80014 3.7.4+12 2019-05-13 20:5444 UTC S10031201 PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQCK GCM_PRELIM_SENT 124192302.31056 1241492307.20156 1241492307.20156 1241492307.20156 1241492307.20156 1241492307.20156 1241492307.20156 124192307.20156	S190517h	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242107478.819517	1242107479.994141	1242107480.994141	2.373e-09	2019-05-17 05:51:23 UTC
51005124 PE, READY ADVICK SIXMAP, READY PERBIGIT, READY PASTRO, READY POCK COL, PRELIM, SENT 124171655.14141 124171655.241626 124171655.31806 1001-09 2019-05-12 18:07/42 UTC 51005104 AOVICK SIXMAP, READY PERBIGIT, READY PASTRO, READY POCK COL, PRELIM, SENT 124102926.37105.05 124102926.37105.05 124102926.37105.05 12410292.05 124004480.32285 1.569-09 2019-05-12 18:07/42 UTC 51005104 AOVICK SIXMAP, READY EMBRIGIT, READY PASTRO, READY DOCK COL, PRELIM, SENT 124094480.12885 124094480.32285 1.26094480.32285 1.569-09 2019-05-01 18:5426 UTC 51005124 PE, READY ADVICK SIXMAP, READY EMBRIGIT, READY PASTRO, READY DOCK COL, PRELIM, SENT 1240021530.118491	S190513bm	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241816085.736106	1241816086.869141	1241816087.869141	3.734e-13	2019-05-13 20:54:48 UTC
S1005000 AVOVE SKYMAP_READY MEMBRIGHT_READY PASTRO, READY DQXE GCN_PRELIM_SENT 1214/02298.20165 1214/02298.20165 1214/02298.20165 8.84-e9 2019-05-10 0.300.01 UTC S10050000 PE_READY ADVXE SKYMAP_READY MEMBRIGHT_READY PASTRO, READY DQXE GCM_PRELIM_SENT 1240921862.11269 123091262.11269 123091262.11269 123091262.11269 123091262.11269 123091262.11269 123091262.126912 123091262.126912 1230912	S190512at	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241719651.411441	1241719652.416286	1241719653.518066	1.901e-09	2019-05-12 18:07:42 UTC
S1000200 PE_READY ADVOK SKYMAP_READY ENBRIGHT_READY PASTRO_READY DQCK GCM_PRELIM_SENT 124094486.12887 124094486.12898 124094486.32282 1.63e-09 2019-05-31 IB-51/2 0TC S1000200 PE_READY ADVOK SKYMAP_READY ENBRIGHT_READY PASTRO_READY DQCK GCM_PRELIM_SENT 124094486.12897 124094486.34288 124094486.34288 124094486.34288 124094486.34288 124094486.34288 124094486.34288 1240934333451 1940-56 124021353 124021353 1649 124021553 1519 124021553 1519 124021553 1519 124021553 1519 124021554 1519 124021554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 12401554 1519 124015554 1519 124015554 1519 124015554 12519 12519 12401554 12519 12519 12519 12519 12519 12519 12519 12519 12519 12519	S190510g	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241492396.291636	1241492397.291636	1241492398.293185	8.834e-09	2019-05-10 03:00:03 UTC
S1004226 PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 124023733.31868 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124023733.31865 124021550.011596 125021202 12502120 12502120 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 124021550.201159 125015955.20070	S190503bf	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1240944861.288574	1240944862.412598	1240944863.422852	1.636e-09	2019-05-03 18:54:26 UTC
S1993220 ADVICK SKYMAP, READY EMBRIGHT, READY PASTRO, READY DOCK 124021550.01194 12401194 12401194	S190426c	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1240327332.331668	1240327333.348145	1240327334.353516	1.947e-08	2019-04-26 15:22:15 UTC
S109421ar PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 1239917953.25097 1239917954.409180 1239917955.409180 1.499-08 2019-04-21 21:31:16 UTC S109421ar PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 1239012051.40171 1239012052.222168 1239012053.232949 1.683-27 2019-04-21 20:31:03 UTC S109408ar PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 1238702699.268295 123970270.287958 12397270.359863 2.811-18 2019-04-18 118:27 UTC S109408ar PM_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT 123875307.863564 123875370.863564 1248515370.863564	S190425z	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK	1240215502.011549	1240215503.011549	1240215504.018242	4.538e-13	2019-04-25 08:18:26 UTC
S100412m PE_READY ADVOK SKYNAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCM_PRELIM_SENT 123002261.146717 123002262.22216 122902263.22949 1.683-e72 2019-04-12 05:31:03 UTC S100408m PE_READY ADVOK SKYNAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCM_PRELIM_SENT 123872209.36936 123872270.387963 123872270.159963 2.811-18 2019-04-12 05:31:03 UTC S100405m PE_READY ADVOK SKYNAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCM_PRELIM_SENT 123872200.387963 123872270.387963 2.811-18 2019-04-18 15:15:27 UTC S109050m ADVOK SKYNAP_READY EMBRIGHT_READY PASTRO_READY DQOK 123851307.683546 123851307.693546 1248151308.695646 2.811-14 2019-04-03 16:15:27 UTC	S190421ar	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1239917953.250977	1239917954.409180	1239917955.409180	1.489e-08	2019-04-21 21:39:16 UTC
S100408an PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOOK GCN_PRELIM_SENT 1238782699.268296 123878270.287958 123878270.359863 2.811e-18 2019-04-08 18:18:27 UTC S100405ar ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DOOK 123878270.287958 123878270.359863 2.811e-18 2019-04-08 18:18:27 UTC	<u>5190412m</u>	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1239082261.146717	1239082262.222168	1239082263.229492	1.683e-27	2019-04-12 05:31:03 UTC
5190405ar ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK 1238515307.863646 1238515309.863646 2.141e-04 2019-04-05 16:01:56 UTC	S190408an	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1238782699.268296	1238782700.287958	1238782701.359863	2.811e-18	2019-04-08 18:18:27 UTC
	S190405ar	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK	1238515307.863646	1238515308.863646	1238515309.863646	2.141e-04	2019-04-05 16:01:56 UTC

Observing run O3 complete: 50-60 events!





LIGO



LOGIN

O4 scheduled in 2022 after LIGO upgrades.

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Thank you for your attention!