SPECTROSCOPIC IDENTIFICATION OF R-PROCESS NUCLEOSYNTHESIS IN A DOUBLE NEUTRON STAR MERGER

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GW170817/GRB170817A

- GW170817/GRB170817A is the first event of associated detection of a gamma-ray burst (GRB) and a gravitational wave event (GW).
- The source of event is a double neutron star merger (NS-NS).

GW170817/GRB170817A

- GW170817 was detected on Aug 17, 12:41:04 and two seconds later Fermi-GBM and Integral SPI-ACS detected a sGRB.

KILONOVA SSS17A

- Connected to this event is present a transient optical /near infrared source, SSS17a.
- This transient, named kilonova, is powered by radioactive decays of the heavy elements syntetisized via rapid neutron capture.

KILONOVA SSS17A

- The ejecta, associated with kilonova, has speed 0,2c and reaches a radius of 50 UA in 1,5 d.
- In the spectra appeare absorbtion lines associated with atomic species produced by nucleosynthesis.

KILONOVA SSS17A

- Following the grb/gw detection, was reported a new point-like optical source
- Coordinates : RA = 13:09:48,09, DEC -23:22:53,3 at 17arcsec from the center of a S0 galaxy, NGC4993, at 40Mpc from Earth.
- In optical field and near infrared, REM (Rapid Eye Mount) Telescope and ESO-VST detected the new source in the field of NGC4993 12,8 h after GW/GRB.

KILONOVA SSS17A

- Following the detection of this source, it's started an imaging and spectroscopic campaign at optical and NIR wawelenghts.
- For image: REM, ESO-VST and ESO-VLT
- For spectra: VLT/X-shooter (3200-24800 A°), VLT/FORS2 (3500-9000A°), GeminiS/CMOS (5500-9000A°)
- Period: Aug18-Sep 03 2017, 1 at day.

FIRST SPECTRUM

- The first X-shooter spectrum of the transient shows a bright, blue continuum across the entire coverage.
- Maximum: 6000A°, total luminosity: 3,2E41erg/s.

FIRST SPECTRUM ANALYSIS

- It's compatible with a black-body of temperature 5000 pm 200 K and spherical equivalent radius of 8E14 cm.
- Because it is after 1,5 days from GW/GRB trigger, this implies an expansion velocity of ejected material of 0,2c.
- It's colder than 20 hours earlier (8000K)
- In top of this spectra are presents absorbtion features similar to those suggested in merger ejecta simulation.

FIRST SPECTRUM ANALYSIS

- The main important deviation are two absorbition like lines at 8100 and 12300 A°.
- All deviation from a black-body in the first spectrum are below 10% from 3500 to 20000 A°.
- The first spectrum is also similar to that of early, broad line, core collapse Sne.

SECOND SPECTRUM

- In the second epoch, one day later, spectrum only covers the optical range (T = 3300K)
- Longer wavelenghts equal lower temperature.
- Expansion speed of 0,2 c is compatible with the width of the absorbtion line we observe in the second spectrum

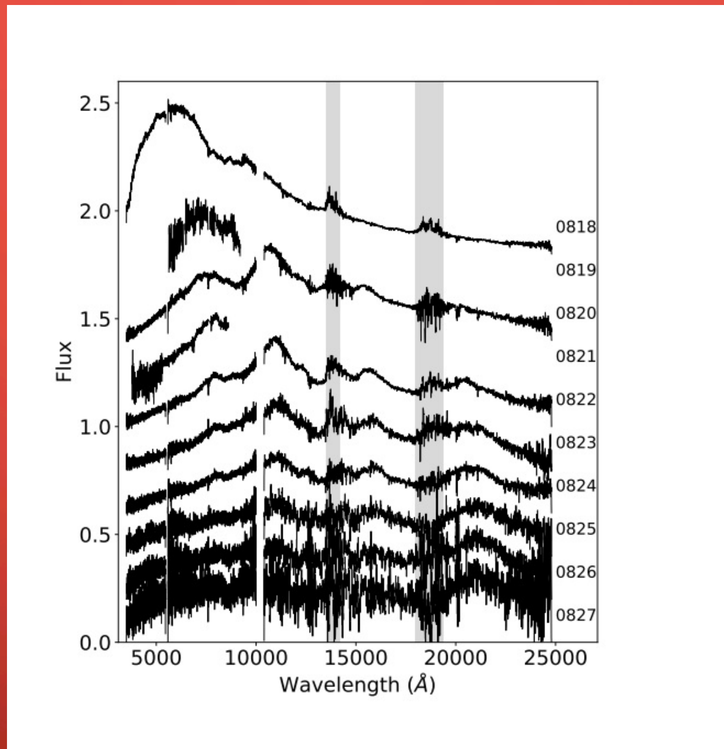
THIRD SPECTRUM AND OTHERS

- In third epoch is present a radiation at NIR and peak is at 10700A° and 16000 A°.
- Overall spectral shape is different:
- Photosphere is receding
- Ejecta are becoming increasily transparent
- More lines become visible
- This variation can be compatible with kilonova and not with supernova

THIRD SPECTRUM AND OTHERS

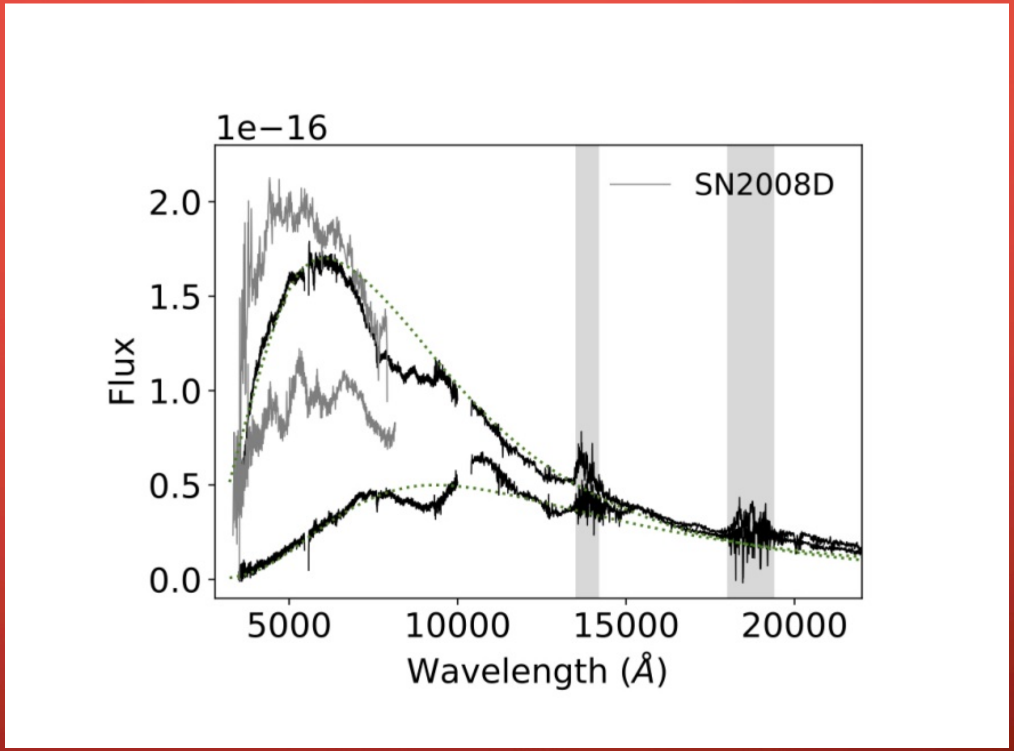
- In the following week the temperature derived from the optical continuum seems to remain roughly constant and the peak at 10700 A° drifts to longer wawelenghts (11200 A° at day 6) and decreases in intensity until at ten days from discovery.
- The dominant feature is a broad emission centered about 21000A°.

THIRD SPECTRUM AND OTHERS



Time evolution of spectra

THIRD SPECTRUM AND OTHERS



Black-body fit to SSS2017a spectra

NUCLEAR REACTIONS

- Idenfification of kilonova atomic species is not secure.
- Neutron-rich environment of the progenitors suggests r process nucleosynthesis as the mechanism responsable for the elemental composition of the ejecta.
- Various nuclear reaction networks are considered and included in modles of radiative transfer of kilonova spectrum fondation

NUCLEAR REACTIONS

- Part of this atoms are radioactive: when they decade, they radiate thermally.
- All atomics species in the ejecta are excitated and ionizated and they absorb the contnuum and form the lines.

NUCLEAR REACTIONS

- In kilonova nucleosynthesis takes place in different regions with different neutron excess and ejecta velocities.

A MODEL OF KILONOVA

- We compare the spectra with a scenario where these three components
- Lantanide-rich dynamical ejecta region with a proton fraction in the range Ye = 0,1-0,4, v=0,2c
- Ye = 0,25 and mixed (lanthanide rich and free) composition (green)
- Ye = 0,30 and lanthanide-free
- All spectra falls luminisity in factor 2.

A MODEL OF KILONOVA

- With a rescale of this model (⚠) is possible estimated ejected mass (0,03 – 0,05 Ms)

AFTERGLOW

- Nine days after GW/GRB, an X-ray source was discovered by Chandra at a position consistent with the kilonova.
- This source could be delayed X-ray afterglow emission from GRB, produced by a off-beam jet.
- The optical afterglow predict is much fainter than the kilonova.

THE DUST EXTINCTION

- We extimated the intervening dust extinction toward the source using the Na ID doublet line at 5896A°.
- E (B-V) = 0,06 mag.

Spectrum of sodium

POSITION IN THE HOST GALAXY

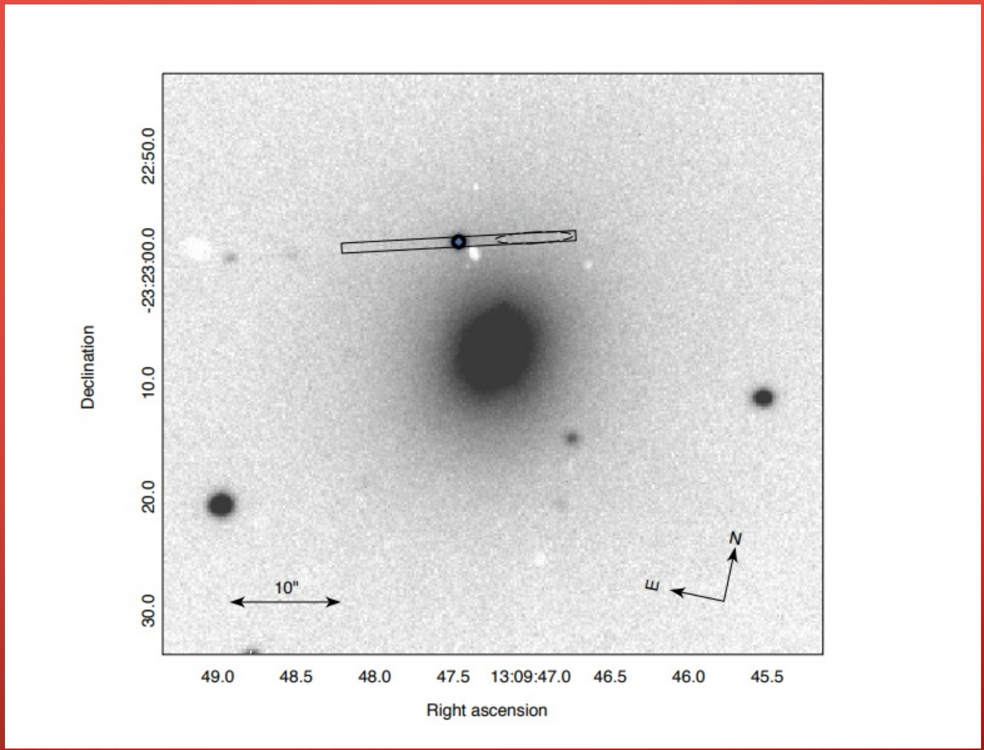


Image of NGC 4993 galaxy with OT (blue circle)

THE TANAKA'S MODEL

- The X*shooter spectra was compared with kilonova models from Tanaka et al.
- The models use calculation for Se (34), Ru(44), Te (52), Ba (56), Nd (60) and Er (68) to construct the atomic data for a wide range of r process elements.

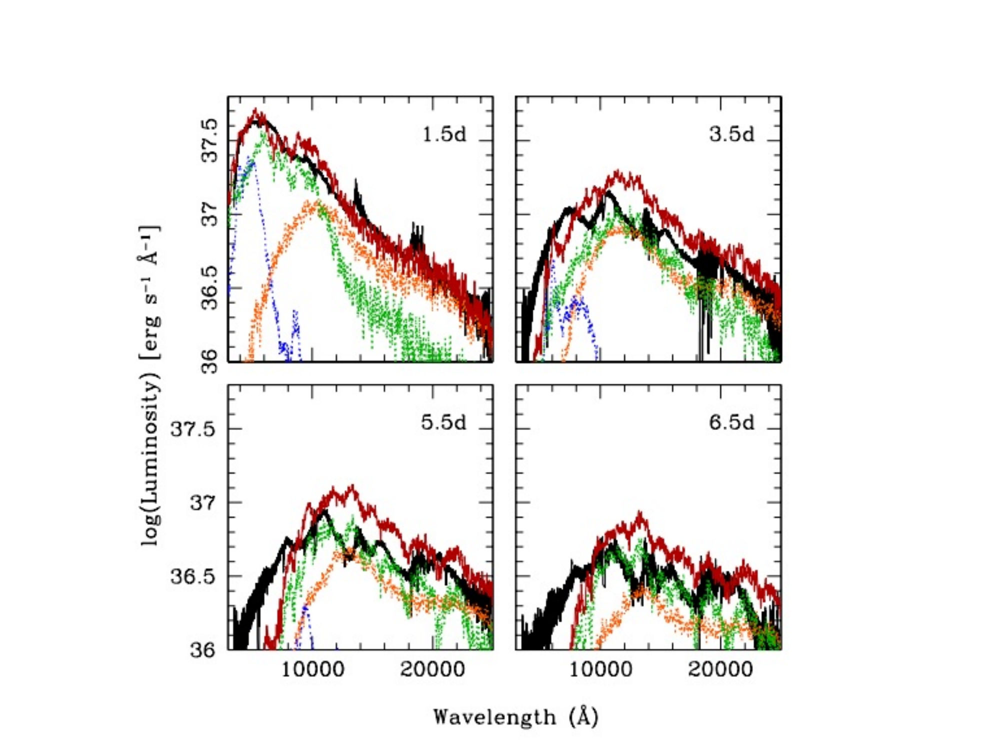
THE TANAKA'S MODEL

- Thise elements are selected because Lanthanides has high opacity in ejecta and:
- 1. Ba is an open s shell element
- 2. Se and Te are open p-shell elements
- 3. Ru is an open d-shell element
- 4. Nd and Er are open f-shell elements (Lanthanides).
- Are considerated only neutral atoms and singly and doubly ionized ions.

COMPARIZATION WITH MODEL

- Atomic structure calculations returned uncertanties in the opacity by a factor of up to 2.
- We apply the multiwavelenght radiative transfer to predict a possible variety of kilonova emmission
- In this model, Ye is homogeneous in the ejecta (in reality high Ye in polar region and low Ye in equatorial region).
- Energy released is proportional to t^-1/3 (related to radioactive decays of various nuclei).

COMPARISON WITH MODEL



Comparing the spectrum with dynamical ejecta (Ye = 0,1-0,4, orange)
Wind polar region Ye = 0,3, blue
Wind polar region, Ye = 0,25 green
Sum of this, red

COMPARISON WITH MODEL

- We have not attempted a real fit of this model to our X*shooter spectra but have rather locked into an interpretation that was in reasonable agreement.
- The match is satisfactory only for the first spectrum and not completly satisfactory for the following three.
- For this reason is not present a light curve model.

THANK FOR YOUR ATTENTION