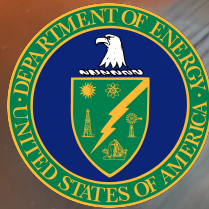


# Novel Signals from Neutron Star Mergers at 511 keV

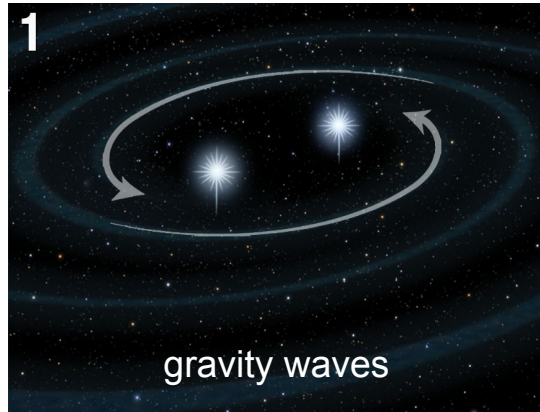
**Volodymyr Takhistov**

University of California, Los Angeles  
(UCLA)



# Neutron star mergers

- NS-NS (+ NS-BH) mergers are fantastic multi-messenger laboratories

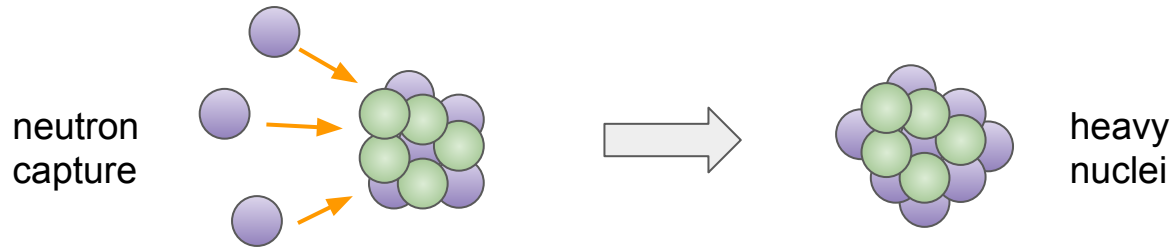


- Definitive confirmation by historic 2017 NS-NS observation by LIGO, Fermi *et.al.*

[Abbott+ (LIGO, Fermi+), 2017]

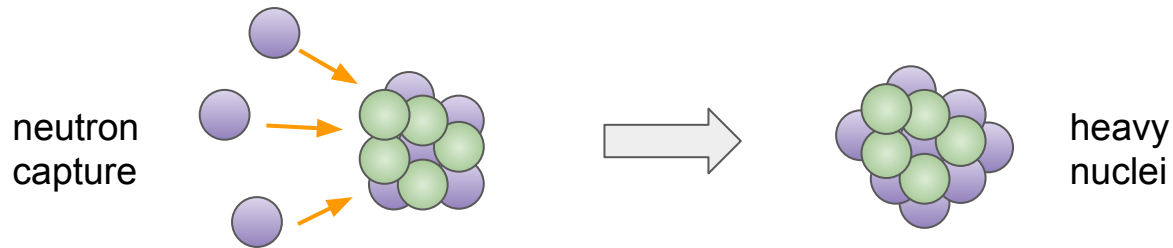
# R-process in ejecta

- Material ejected from NS merger is neutron rich → great site for r-process
- R(apid)-process nucleosynthesis  
→ main furnace of heavy elements (e.g. gold) in astronomy



# R-process in ejecta

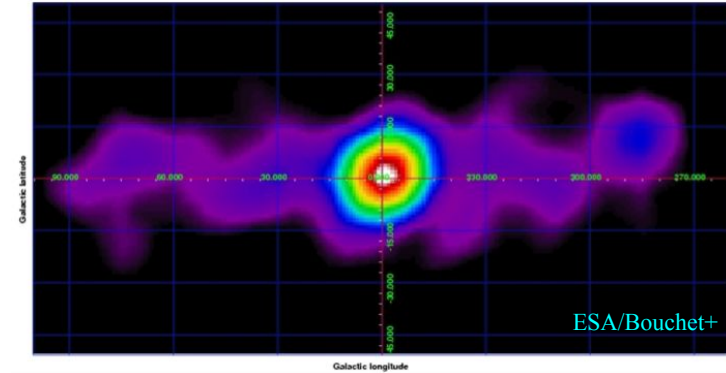
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- Nuclear reactions in expanding ejecta produce heat + afterglow (kilonova)

# 511 keV Galactic Center excess

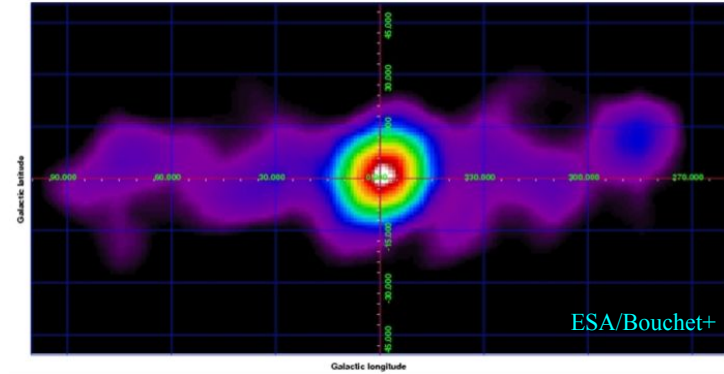
- Extensive observations (SPI/INTEGRAL) show Galactic Center shines in 511 keV  $\gamma$ -rays
  - consistent with  $e^+$  annihilation [Beacom, Yüksel, 2006]
  - source unknown





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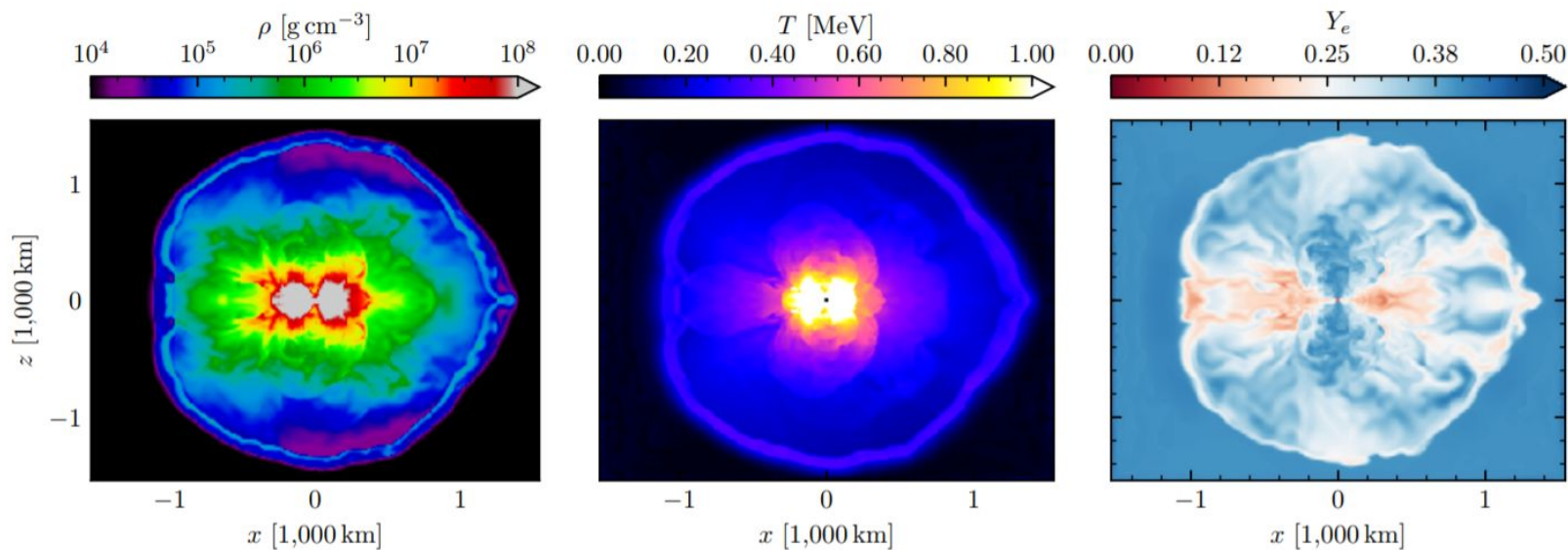


**\*\* could be a hint of new physics, e.g. primordial black holes**

[Fuller, Kusenko, VT, PRL, 2017]

# 511 keV excess naturally explained with neutron star mergers

# Start with NS-NS simulations



$t = 10$  ms

[Fuller, Kusenko, Radice, VT, PRL, 2019]

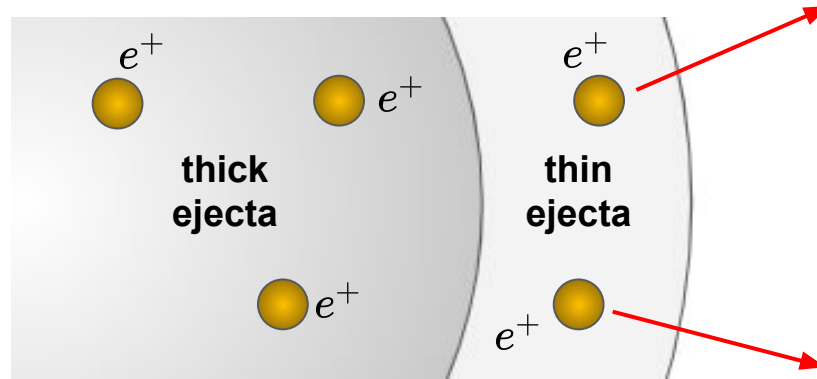


# Positron production

- Expanding ejecta heated to  $\sim \text{MeV}$   $\rightarrow$  lots of thermal positrons produced

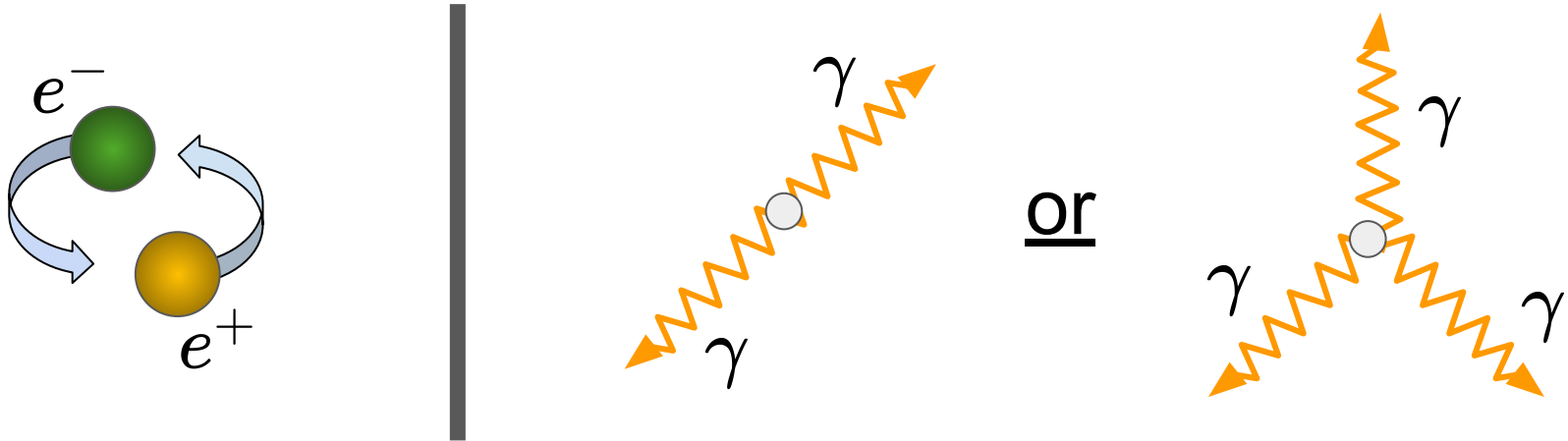
# Positron production

- Expanding ejecta heated to  $\sim\text{MeV}$   $\rightarrow$  lots of thermal positrons produced
- Magnetic confinement in ejecta not perfect  
 $\rightarrow$  some positrons escape from “optically thin” outer layers



# 511 keV radiation

- Escaping  $\sim$ MeV positrons annihilate via positronium bound state formation (as desired for GC excess)  $\rightarrow$  **511 keV radiation** ✓



# Galactic Center emission

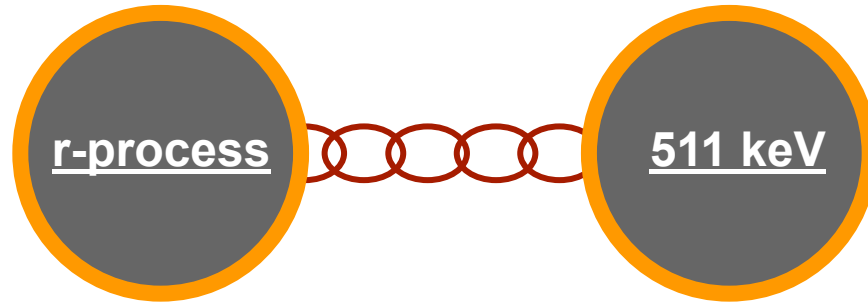
- Take LIGO merger rates  $\rightarrow$  511 keV emission consistent with GC excess ✓

# Galactic Center emission

- Take LIGO merger rates → 511 keV emission consistent with GC excess ✓
- NS binary kicks → expect some signal in Galactic disk, not only bulge ✓
  - consistent with GC excess, difficulty for other proposals

# Smoking gun signal !

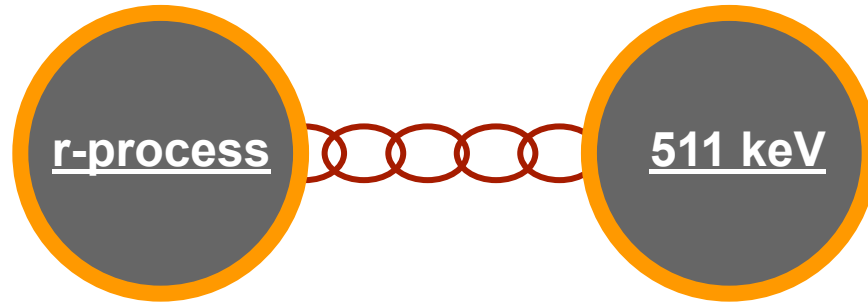
- Proposal directly links r-process and 511 keV





# Smoking gun signal !

- Proposal directly links r-process and 511 keV



- Observations of Reticulum II dwarf spheroidal show heavy elements + 511 keV  
→ smoking gun signal of merger emission !

[Ji, Frebel+, *Nature*, 2016; Siebert+ 2016]

# Summary

- Neutron star mergers are great multi-messenger laboratories
- Positrons and 511 keV radiation expected as generic new merger signals
- Merger emission consistent with Galactic Center excess (without new physics)
- **Reticulum II signal is smoking gun of r-process/511-keV link from mergers**