# Neural networks estimation of the dense-matter equation of state from neutron-star observables

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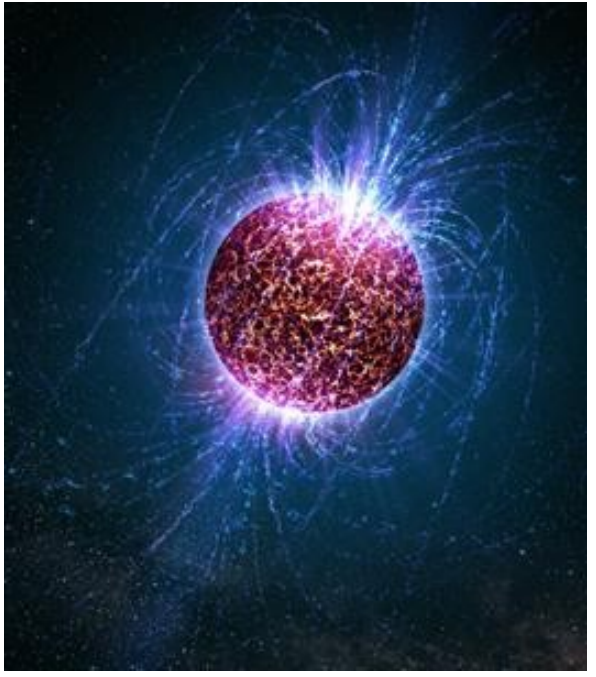
# Neutron stars

- Compact
- Dense
- Laboratory for extreme physics allowing studies of dense matter equation of state (EOS)



# Neutron star EOS

- EOS is defined as the relation between star's density and pressure: $p(\rho)$ which can be translated into relation between between star radii and masses: $M(R)$ and/or mass and tidal deformability: $M(\Lambda)$
- There exist various models of EOS leading to different $M(R)$ relations. The *real* EOS is still unknown

# Tolman-Oppenheimer-Volkoff (TOV)

- Traditionally TOV equations are used on assumed EOS to obtain relation *M(R)* which are further compared with observations
- It is also possible to invert the process and using observations reconstruct EOS
- This approach is not feasible in reality beacuse of measurement uncertainties

# Our project

We wanted to study:

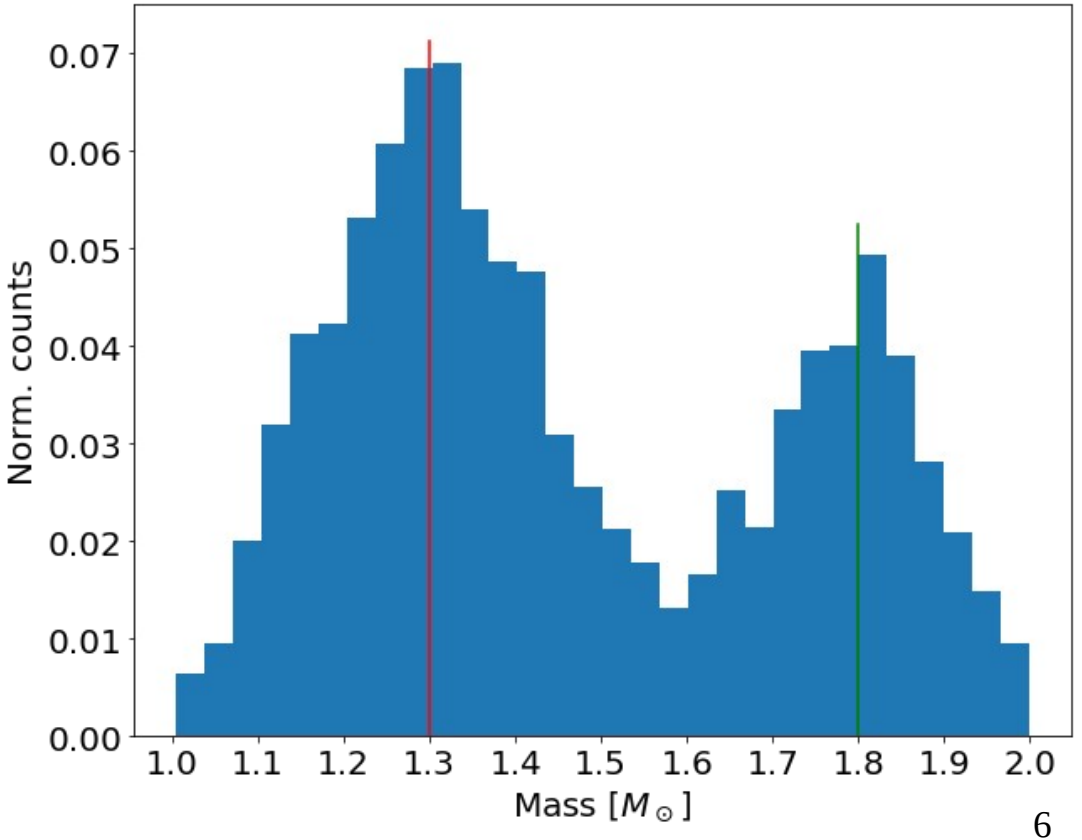
- Influence of neutron star mass distribution (uniform vs double gaussian)
- Influence of observations number
- Influence of measurement uncertainties

On the reconstruction of EOS

# Neutron star mass

Mass range restricted to thea astrophysically-realistic range: [1, 2] M_solar.

It corresponds to the observed NS masses.

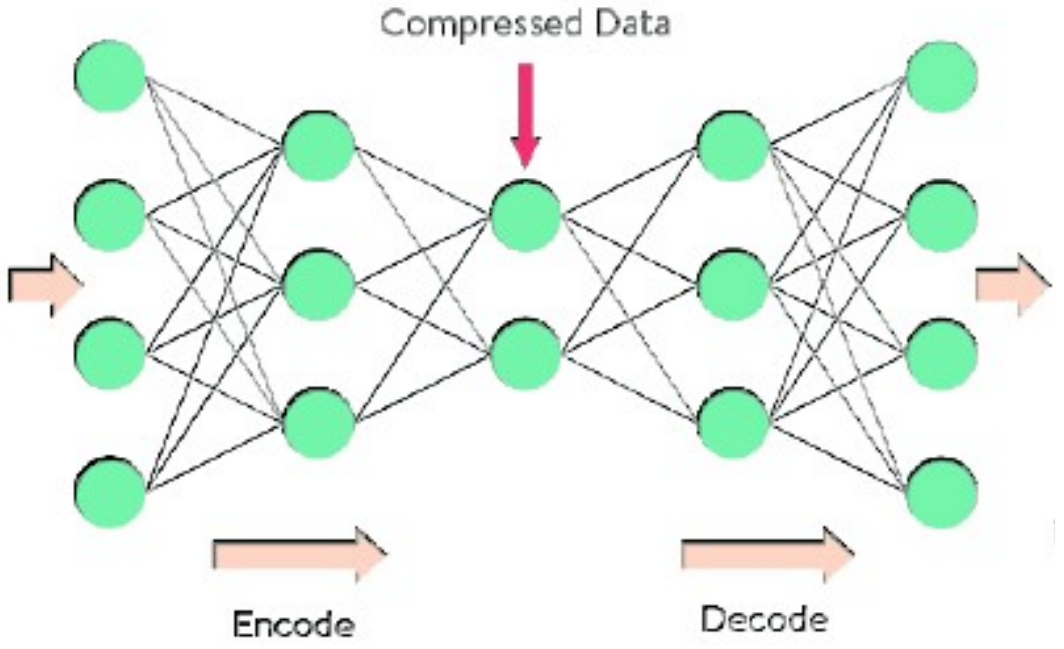


# Autoencoder

*M(R)*

or

*M(Λ)*



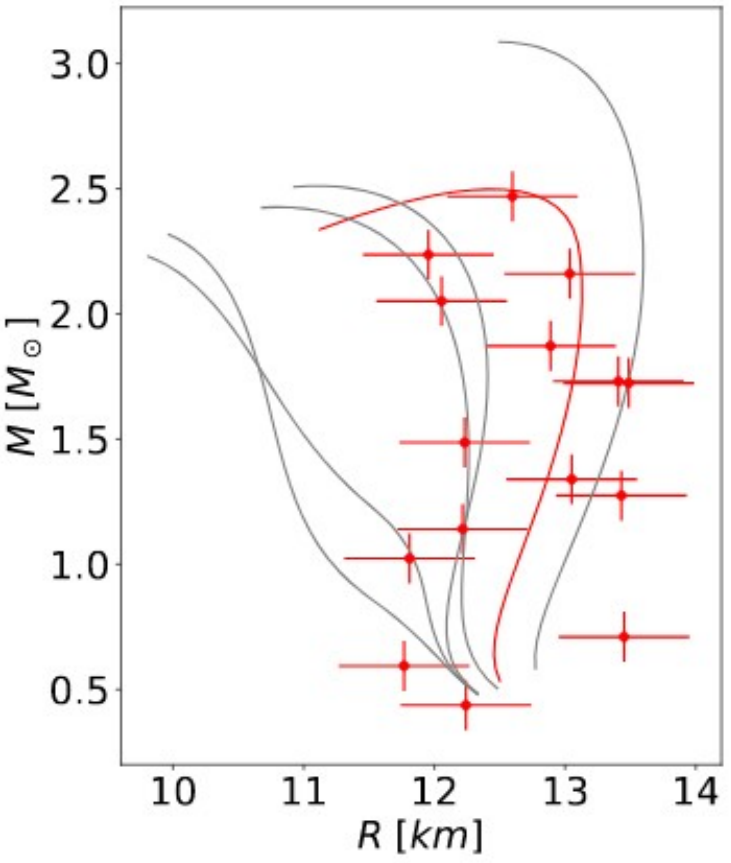

*p(ρ)*

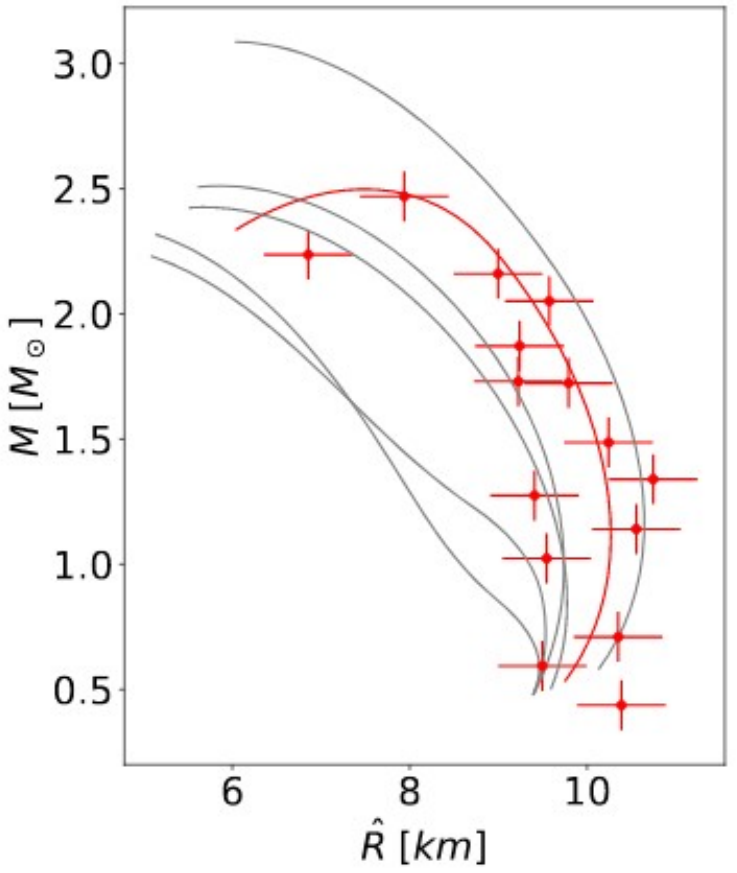
# Data

- Low-density part of EOS is adopted from existing astrophysical model (Sly4) up to particular baryon density $n_0$.
- This part is combined with piecewise relatyvistic polytrope:

$$P(n) = \kappa n^{\gamma} \qquad \rho c^2 = \frac{P(n)}{\gamma - 1} + n m_b c^2$$

# Sample data



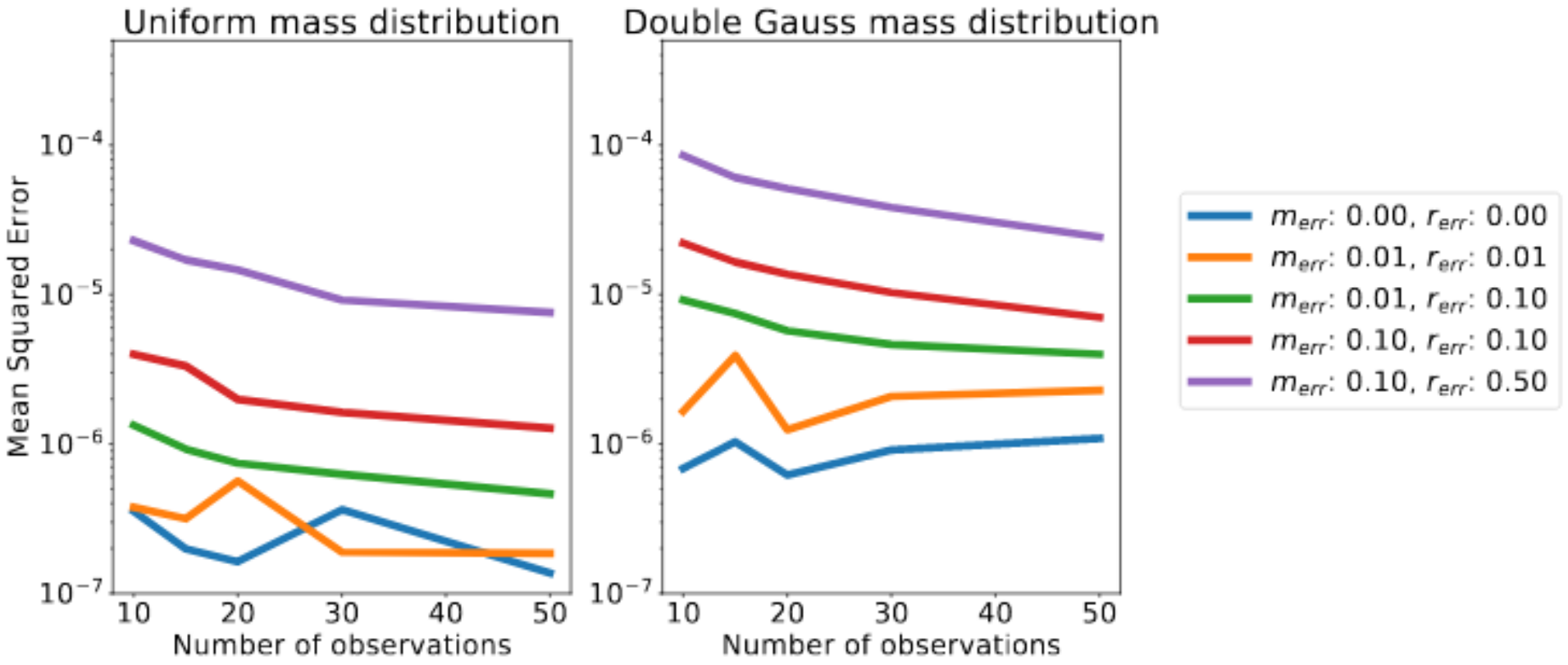

$$\hat{R} = 2\left(M\,\Lambda^{1/5}\right)$$

# Reconstruction errors

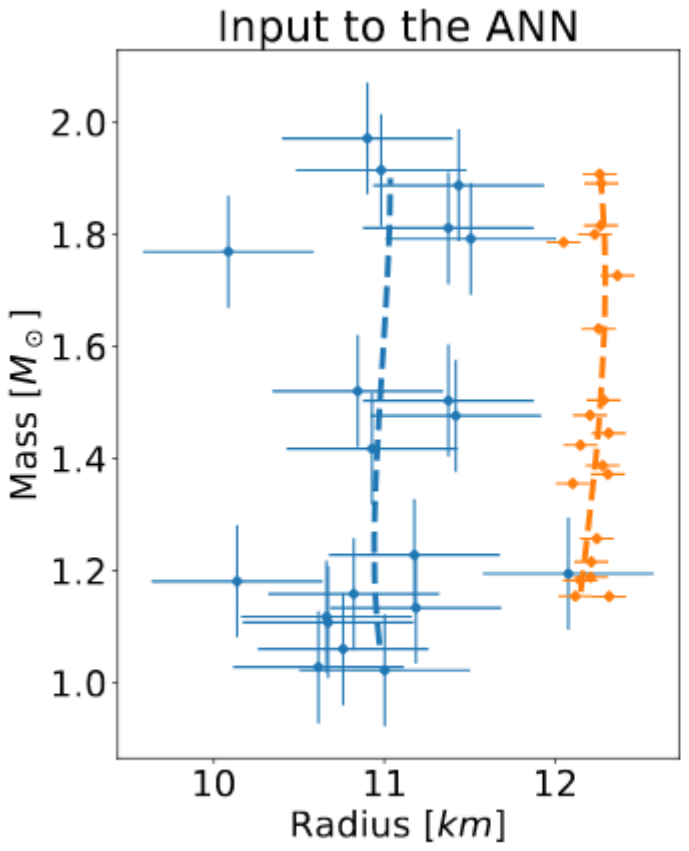
- We did not use loss function (Mean squared error)
- Instead for each polytrope we generated 30 different instances of data and computed reconstruction errors on EOS – the mean value for whole dataset is present on results

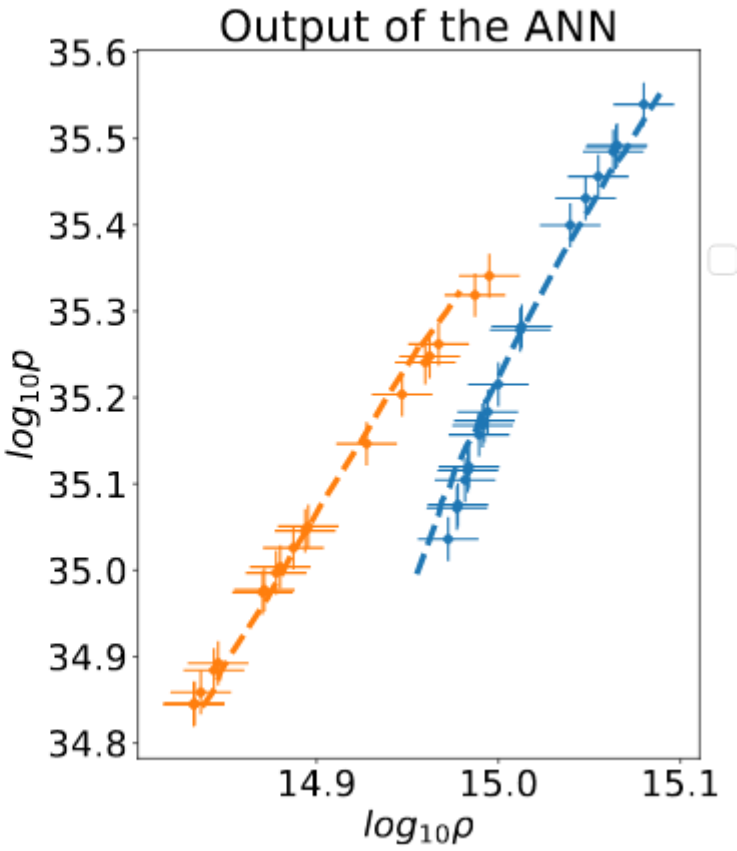
# M(R) to EOS

# M(R) to EOS - loss



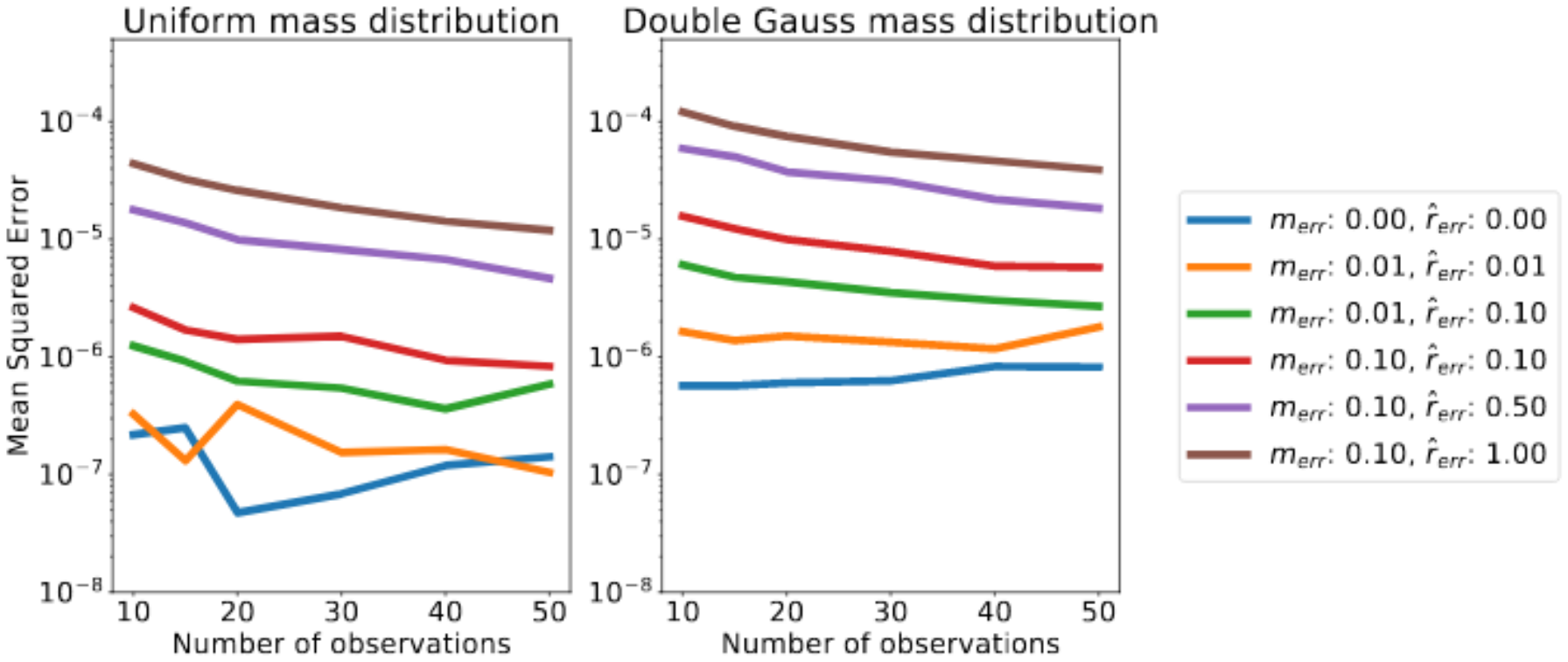
# M(R) to EOS - reconstruction



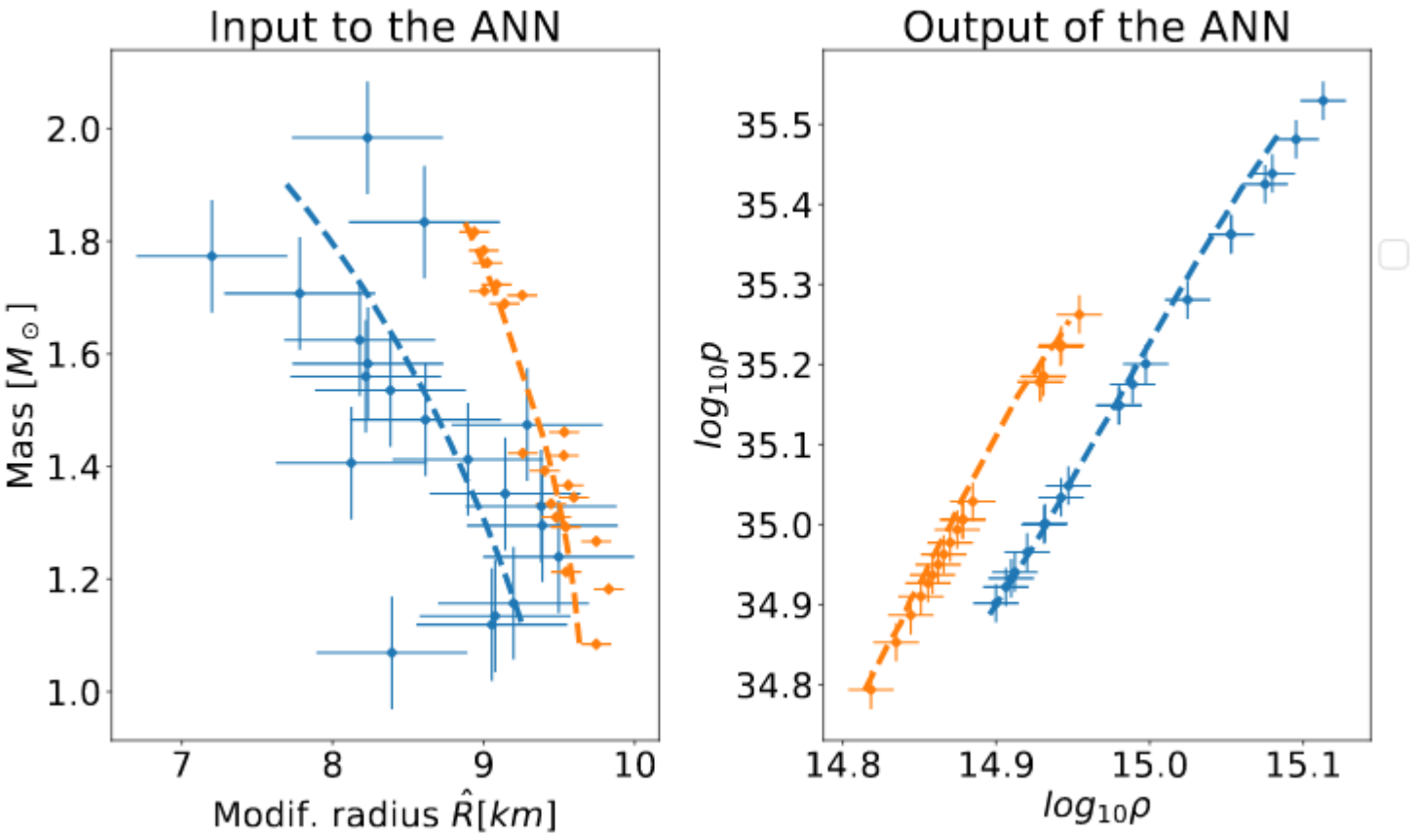



# M(R̂) to EOS

# M(R̂) to EOS - loss

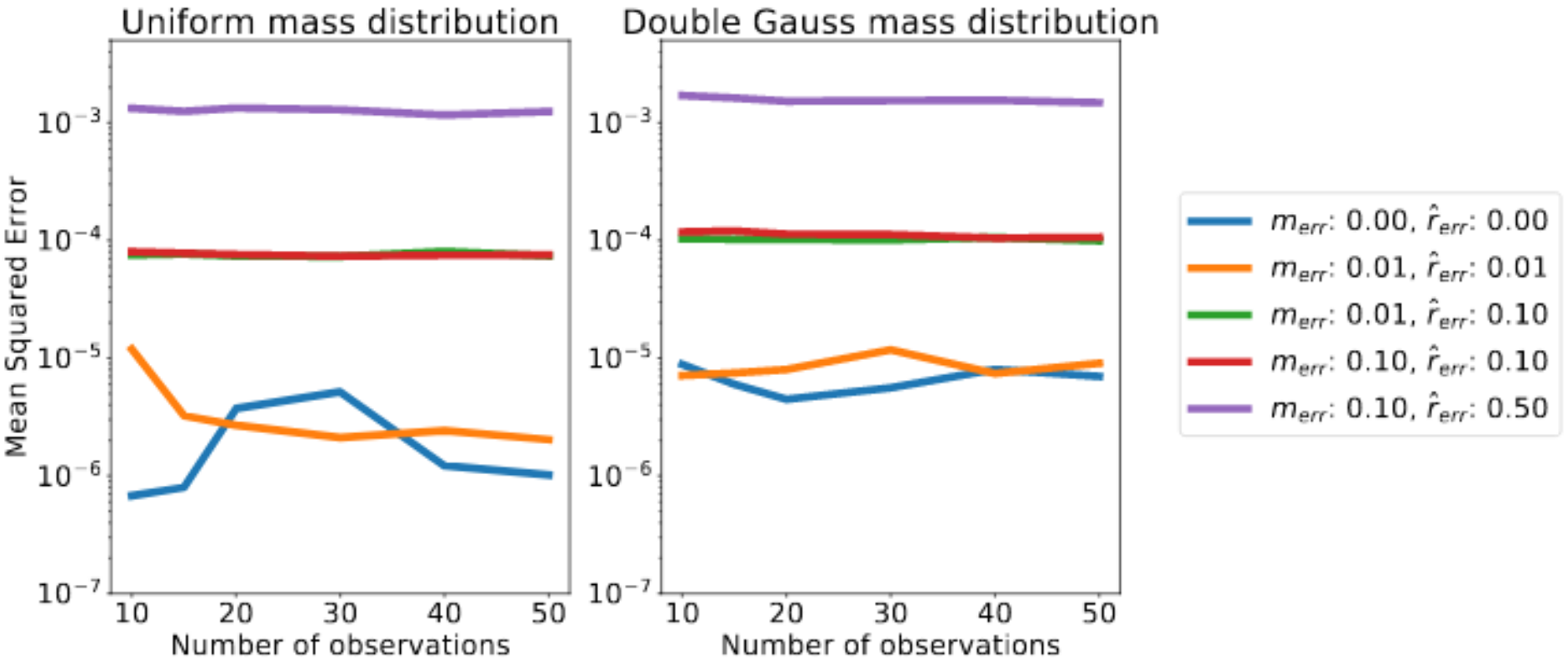


# M(R̂) to EOS - reconstruction

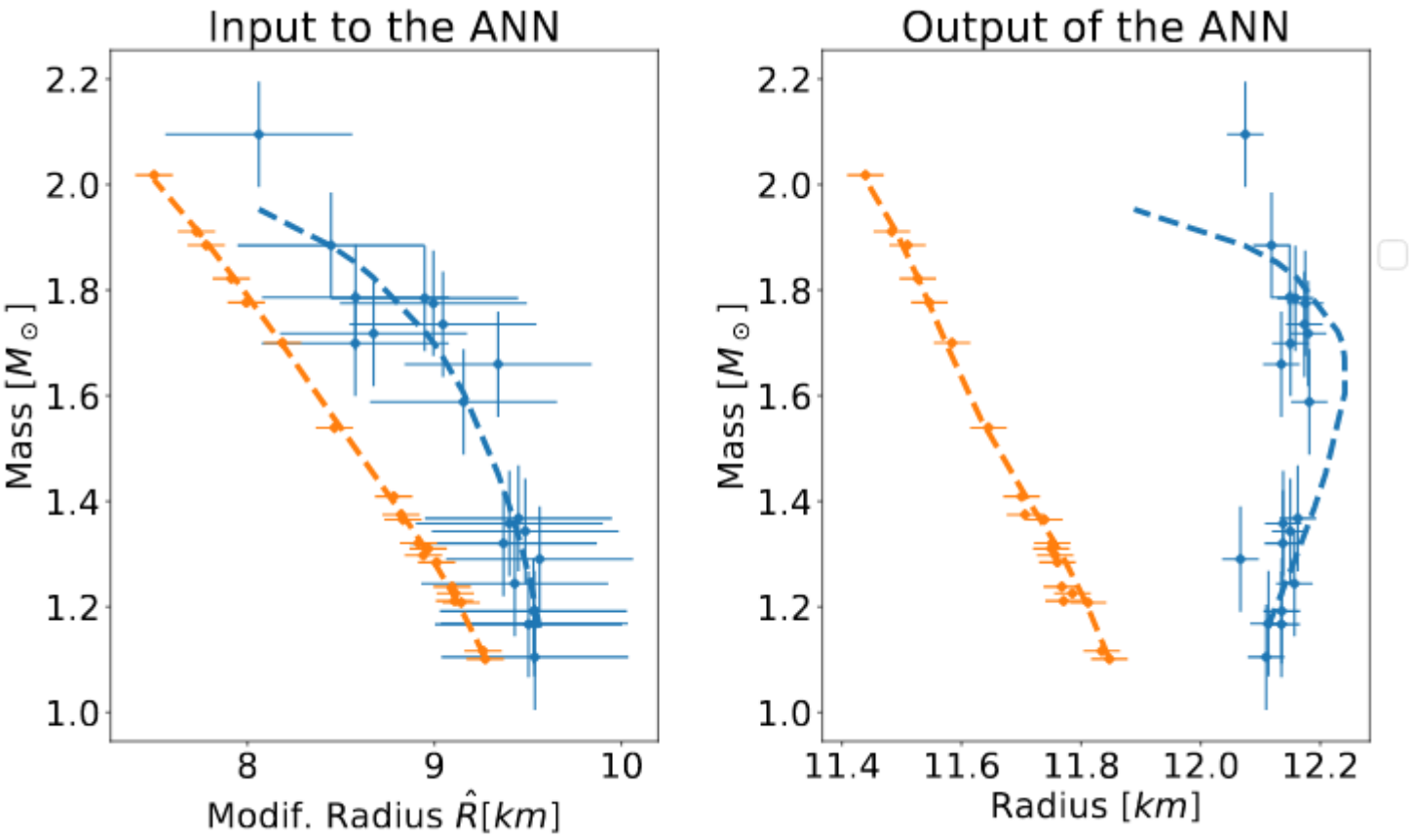


# M(R̂) to R

# M(R̂) to R - loss

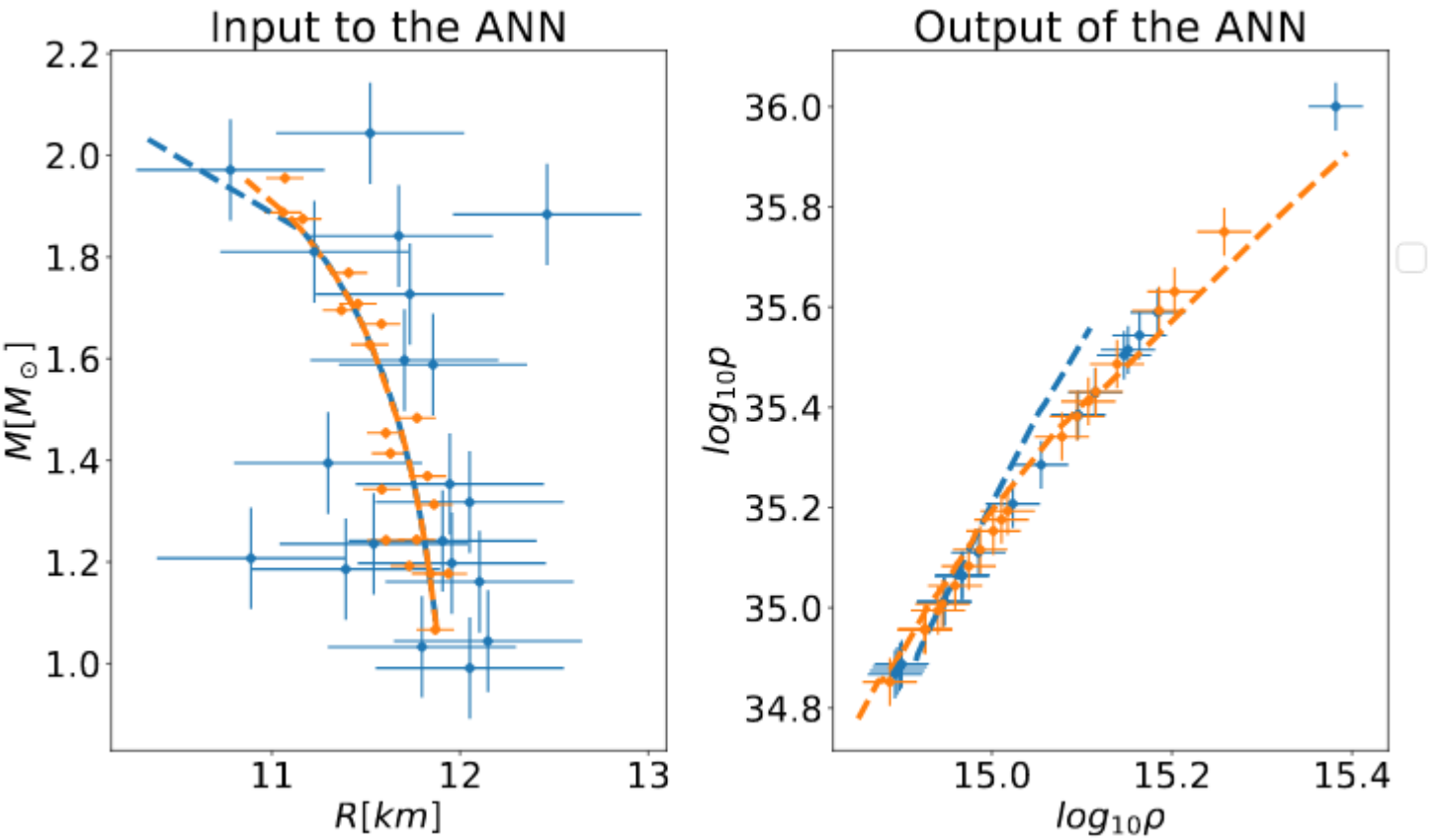

Uniform mass distribution
Double Gauss mass distribution
Mean Squared Error
$10^{-3}$
$10^{-4}$
$10^{-5}$
$10^{-6}$
$10^{-7}$
10
20
30
40
50
Number of observations
$m_{err}$: 0.00, $\hat{r}_{err}$: 0.00
$m_{err}$: 0.01, $\hat{r}_{err}$: 0.01
$m_{err}$: 0.01, $\hat{r}_{err}$: 0.10
$m_{err}$: 0.10, $\hat{r}_{err}$: 0.10
$m_{err}$: 0.10, $\hat{r}_{err}$: 0.50

# M(R̂) to R - reconstruction

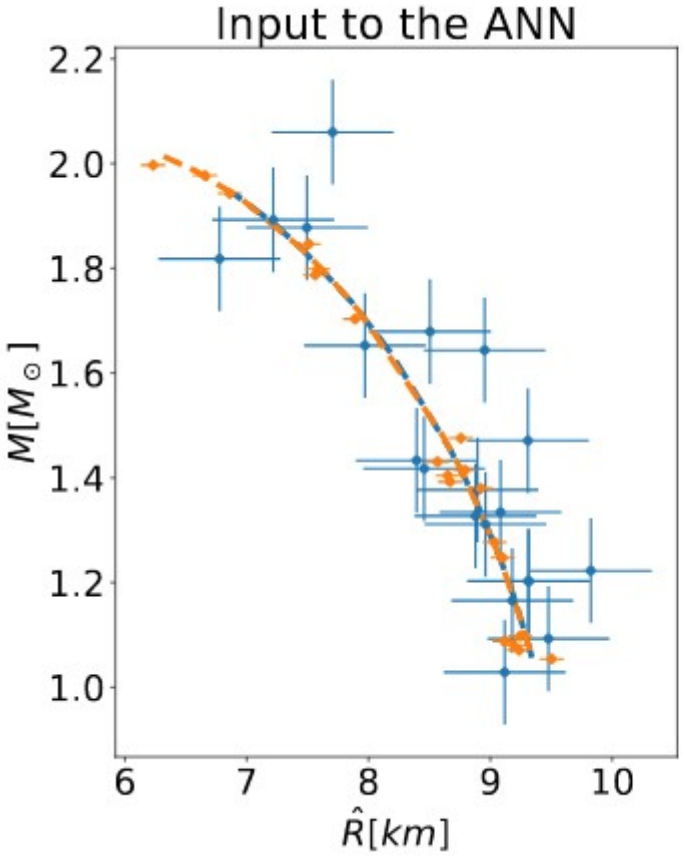


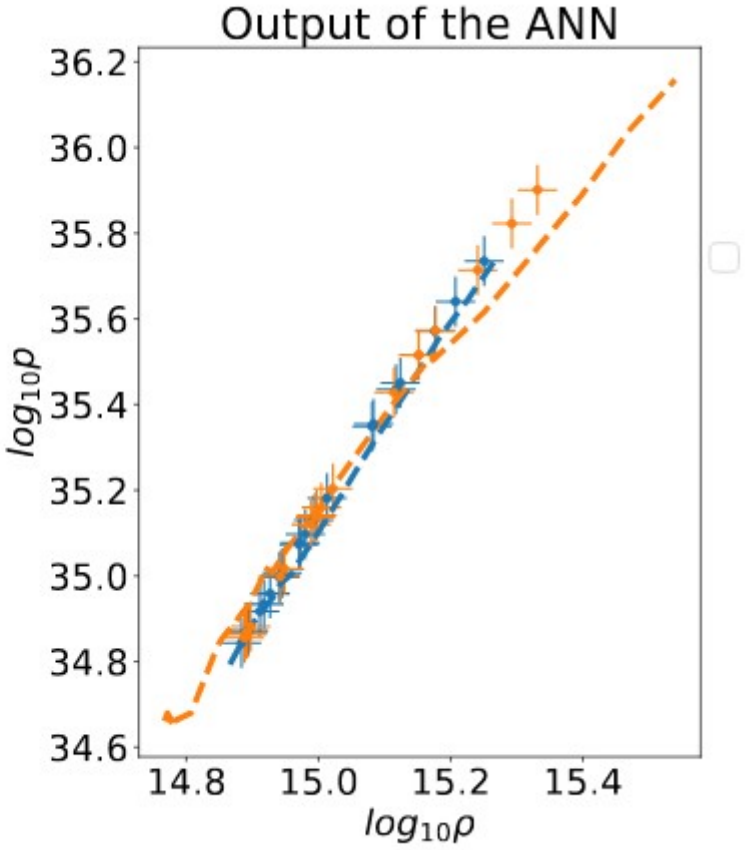
# Real model - SLy4

# Tests on Sly4 - M(R)



# Tests on Sly4 - M(R̂)



# Summary

- Our method allows to reconstruct EOS using both electromagnetic and gravitational observables in all considered cases
- Reconstruction of realistic EOS – Sly4 needs further work
- Will using both M(R) and M(R̂) allow to achieve better reconstruction?