

# Emulating Neutron Stars

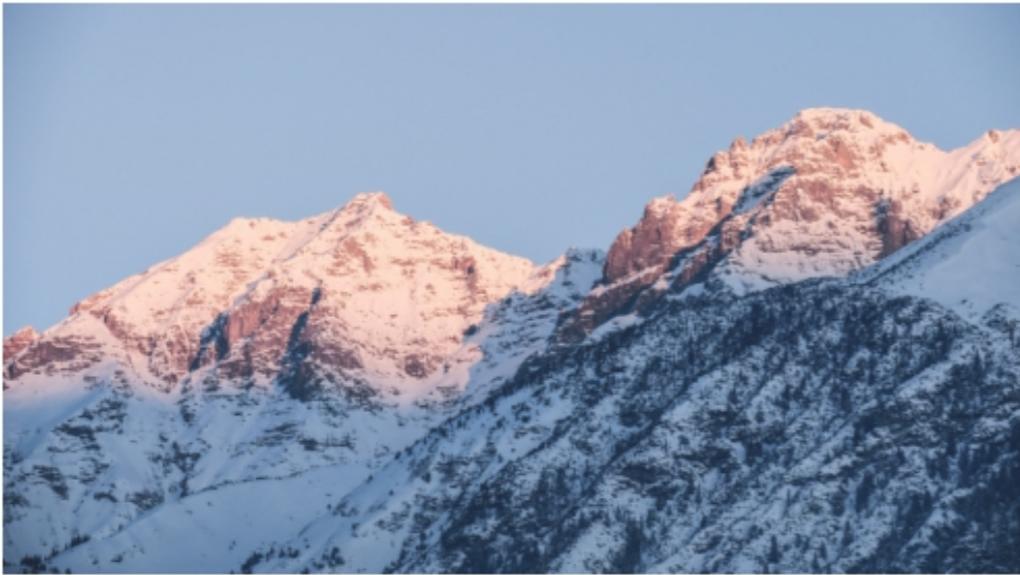
---

**Massimo Mannarelli**  
**INFN-LNGS**  
[massimo@lngs.infn.it](mailto:massimo@lngs.infn.it)

*Phys.Rev.Lett. 131 (2023) 22, 223401*  
*Few Body Syst. 65 (2024) 81*  
*Sterne und Weltraum, Oktober 2024*

# Collaboration

Innsbruck



Gran Sasso



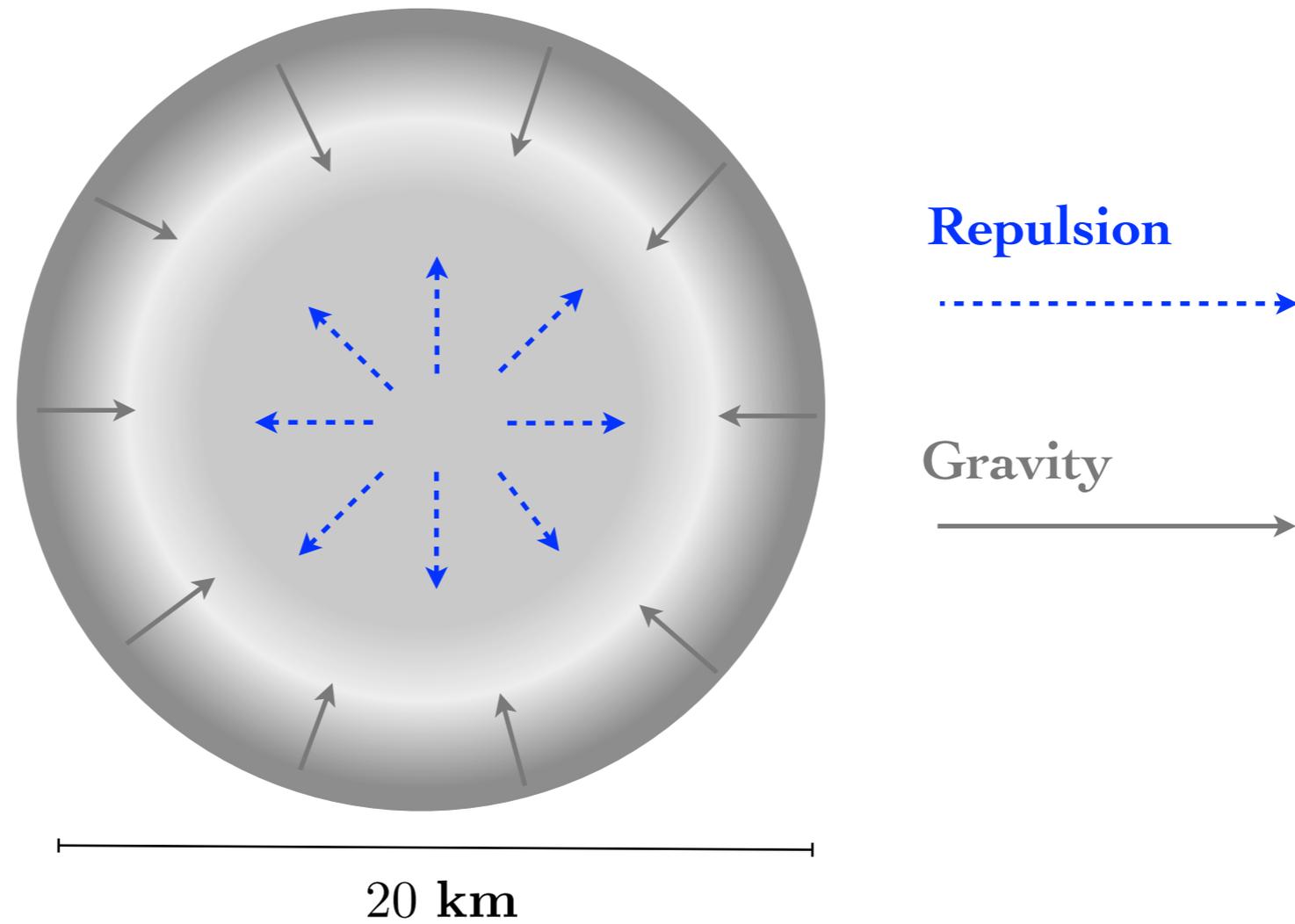
Barcelona



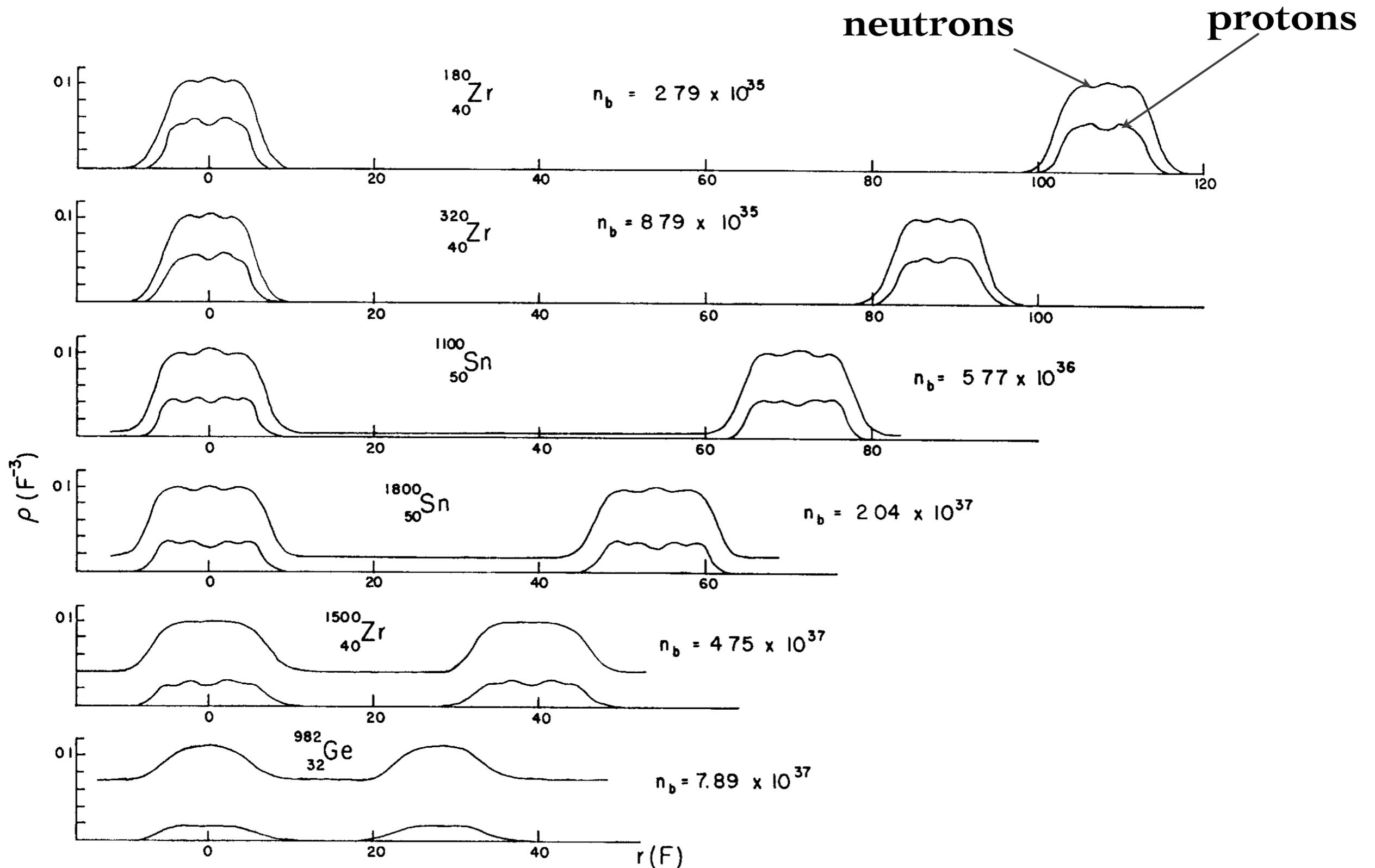
# *Neutron star*

**Mass**  $M \sim 1 - 2M_{\odot}$

**Radius**  $R \simeq 10 \text{ km}$



# Internal structure





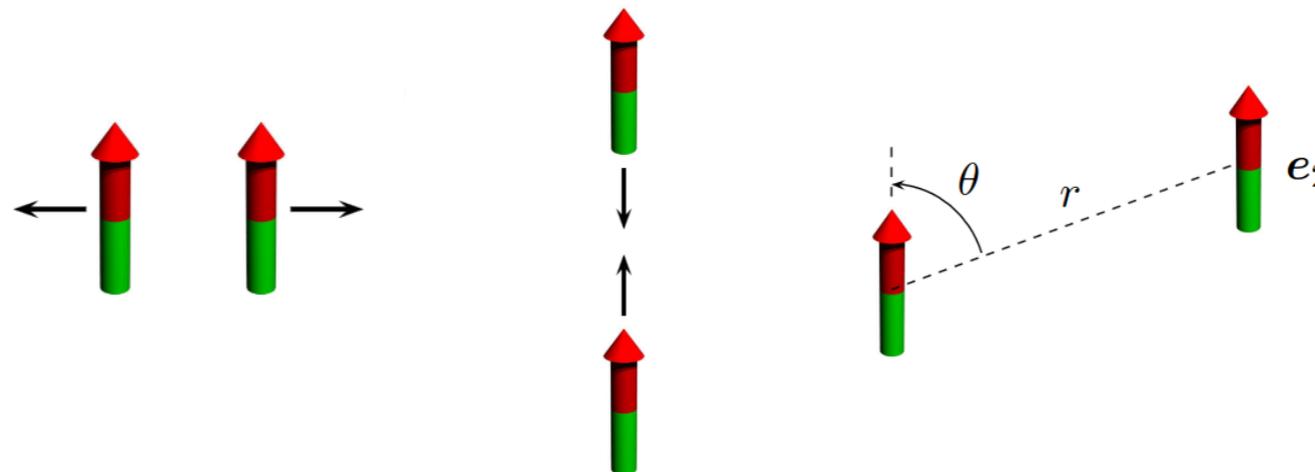
# Ultracold dipolar atoms

	1																	18
1	1 H																	2 He
2	3 Li	4 Be										5 B	6 C	7 N	8 O	9 F	10 Ne	
3	11 Na	12 Mg										13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	* *	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	** **	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
Lanthanides*			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
Actinides**			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

repulsive

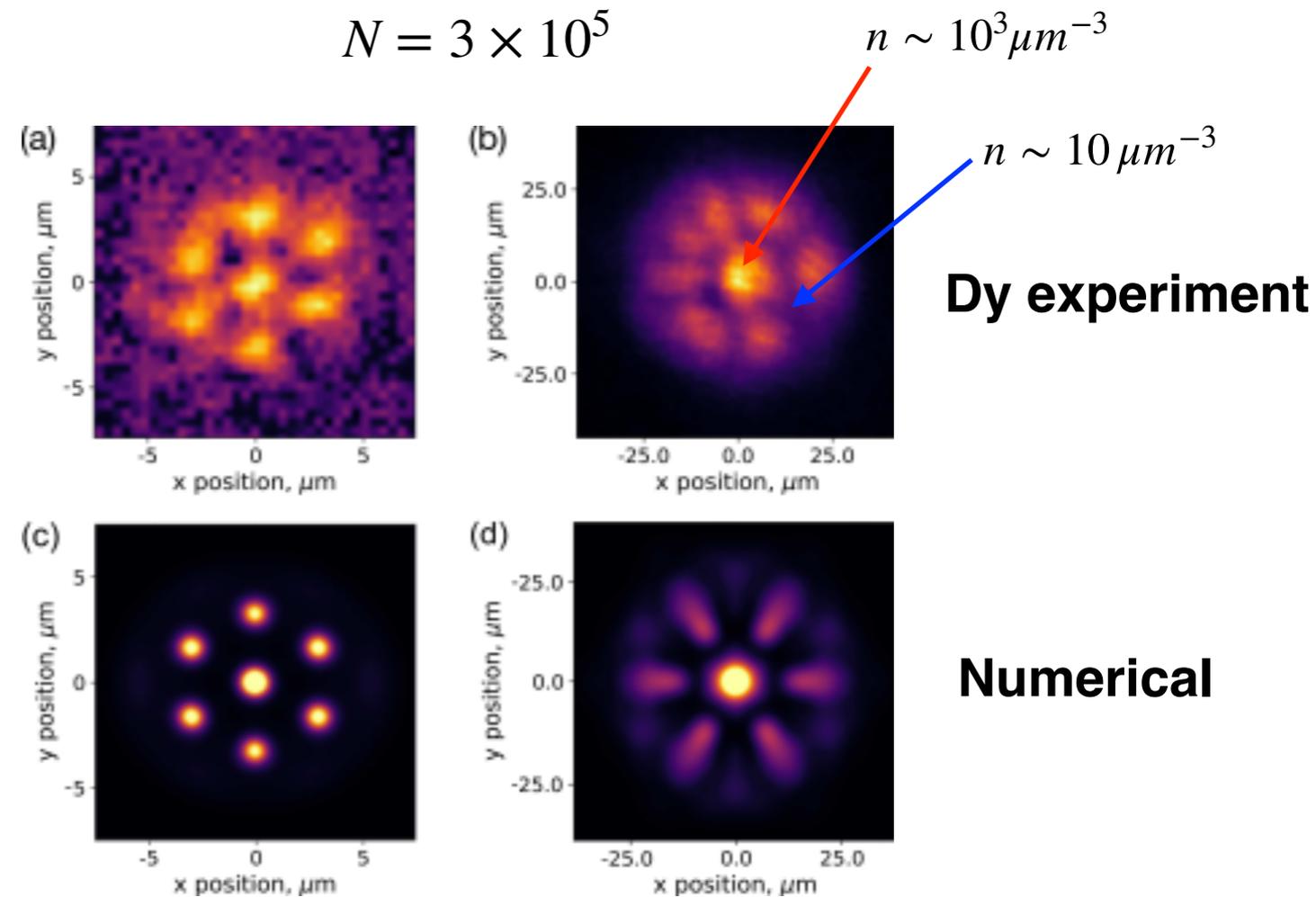
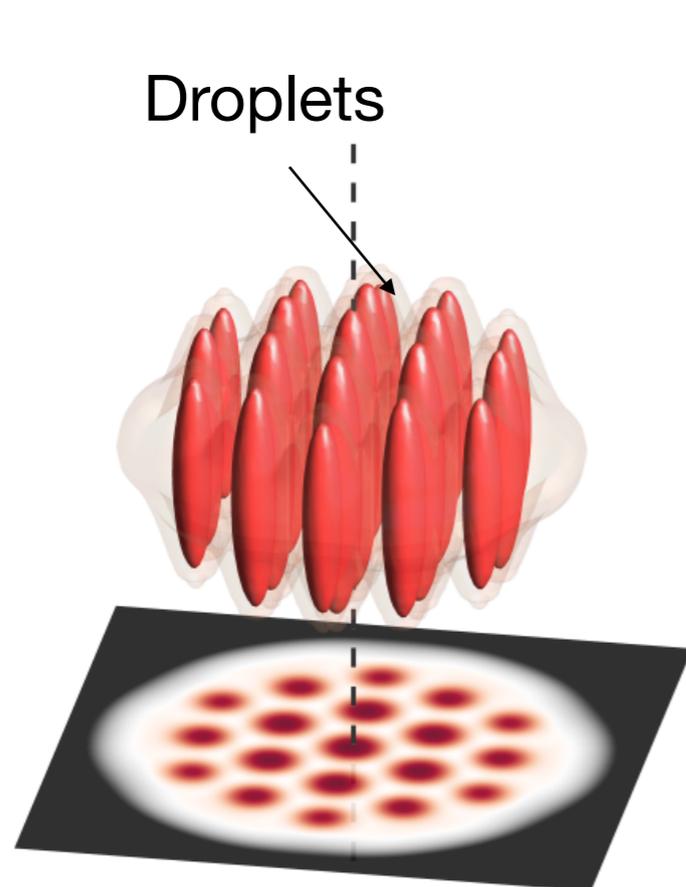
attractive

polarized



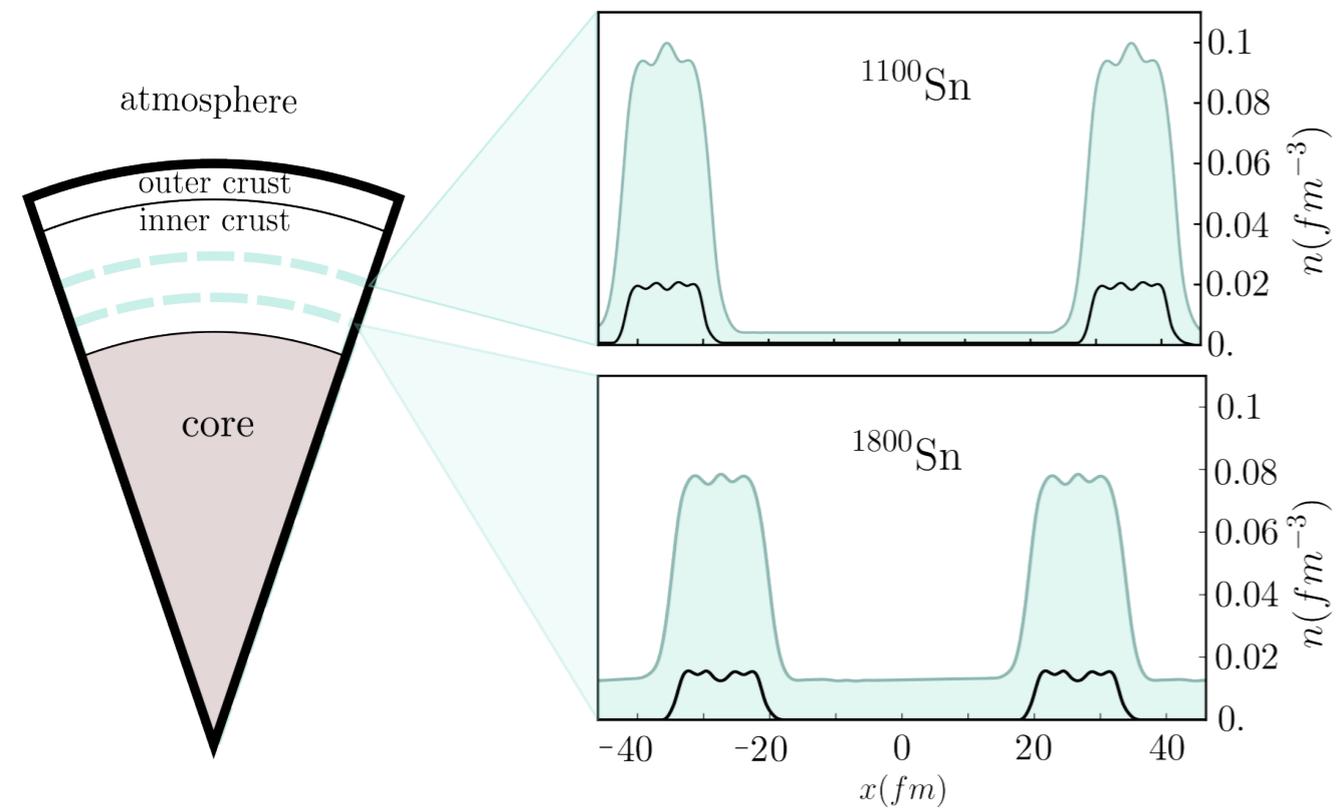
# Supersolid droplets

Observations of supersolids@ MIT, Pisa/LENS, Stuttgart, Innsbruck

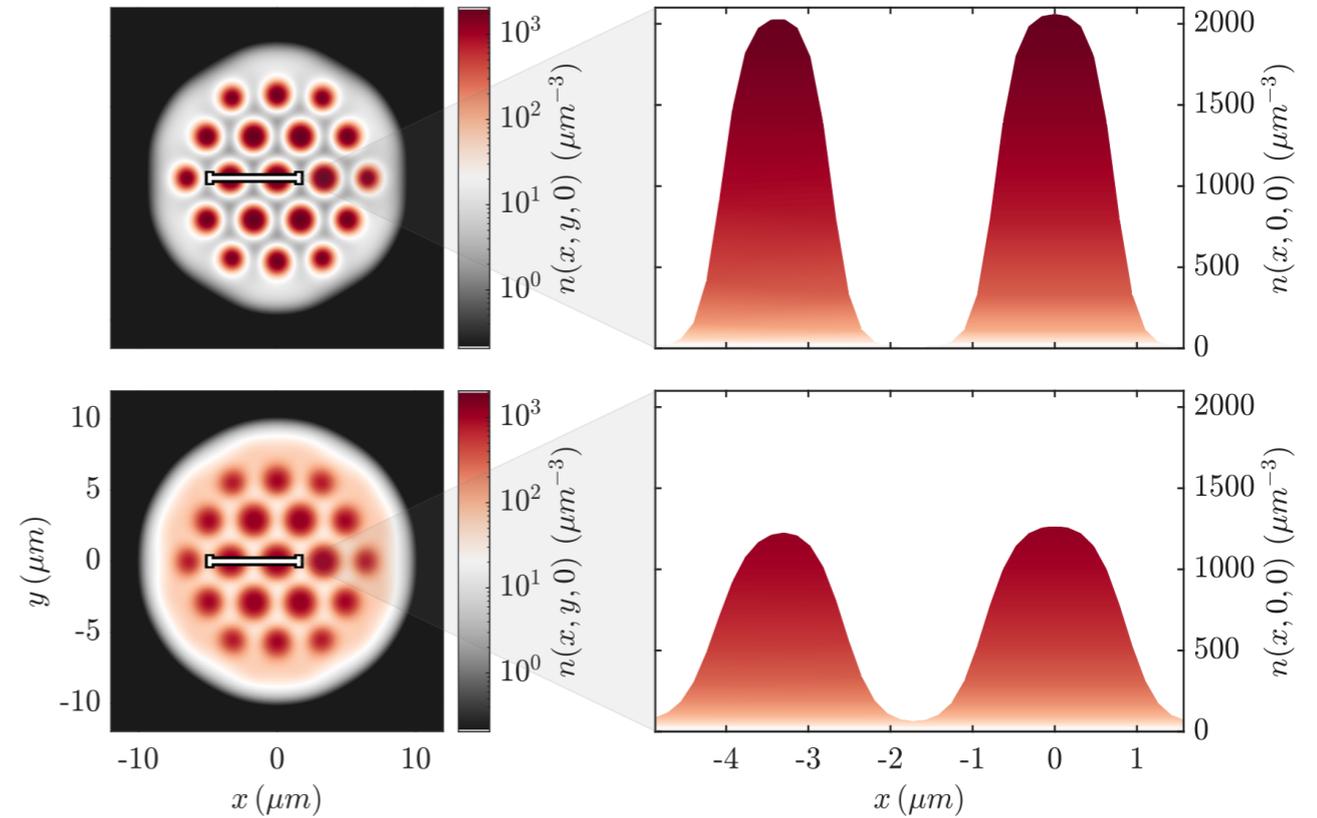


Bland *et al* *PRL* 128, 195302 (2022)

## Neutron Star inner crust



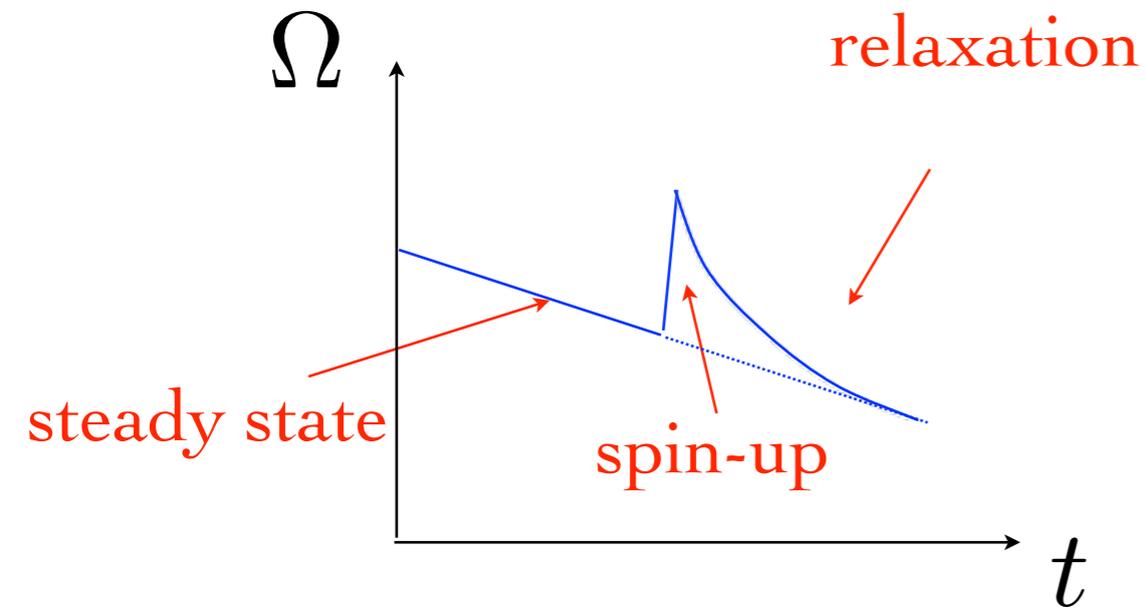
## Dipolar Supersolid



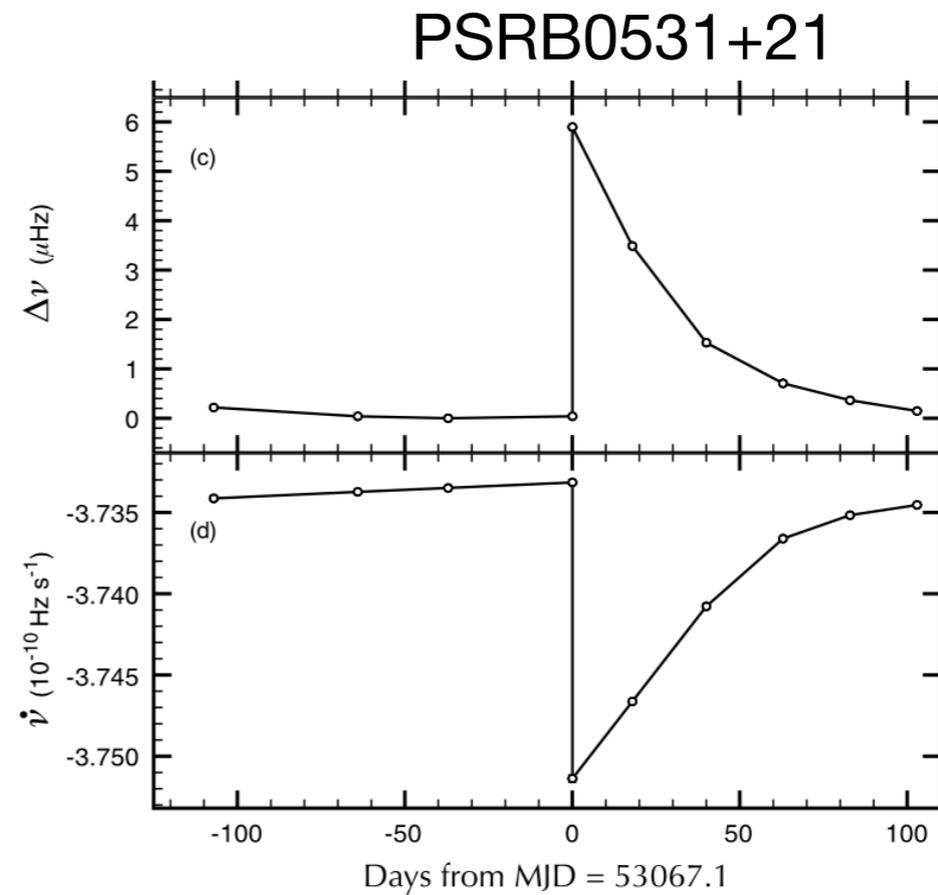
$$\epsilon_{dd} \sim 1$$

Poli, Bland, White, Mark, Ferlaino, Trabucco, MM  
*Phys.Rev.Lett.* 131 (2023) 22, 223401

# Neutron star Glitches

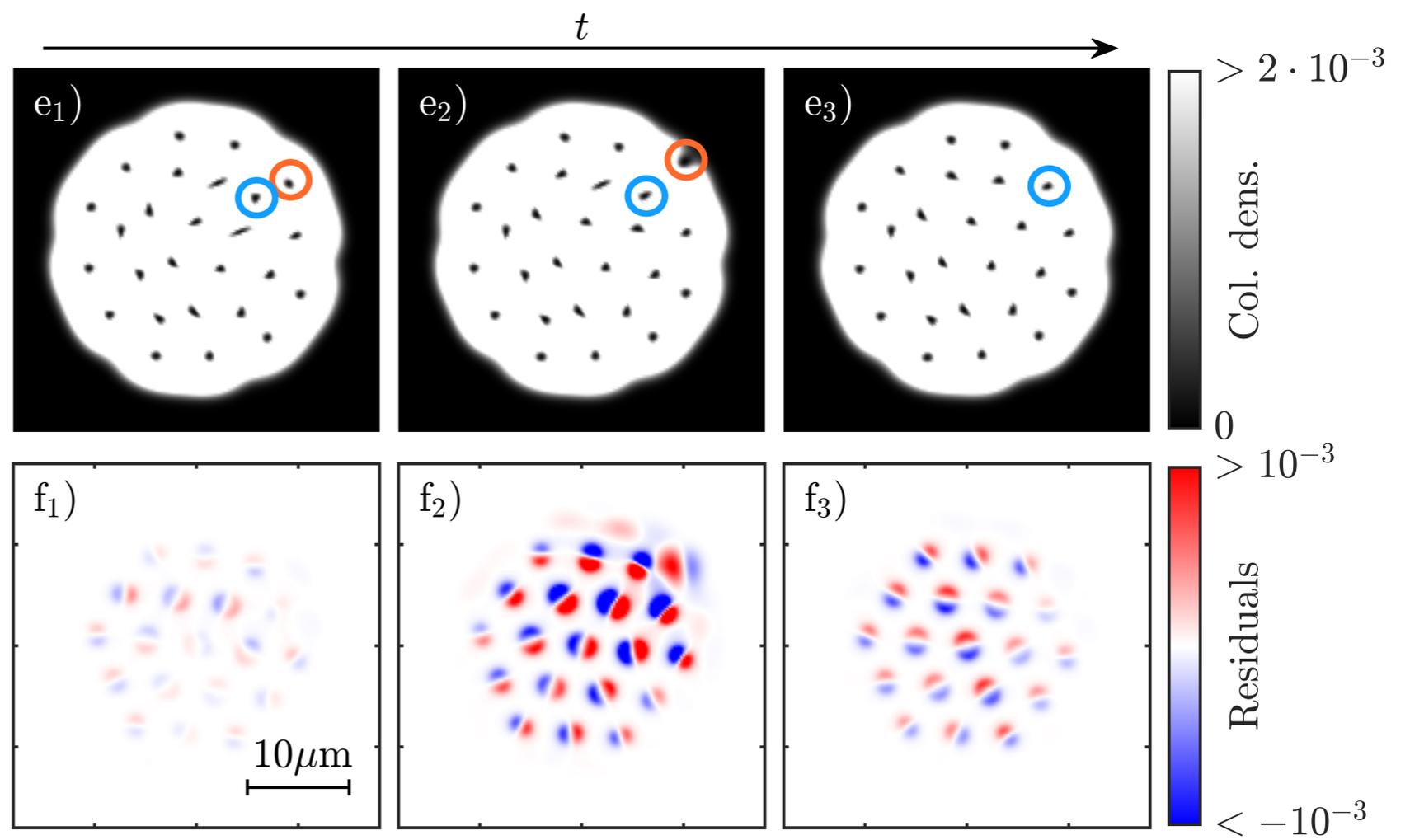
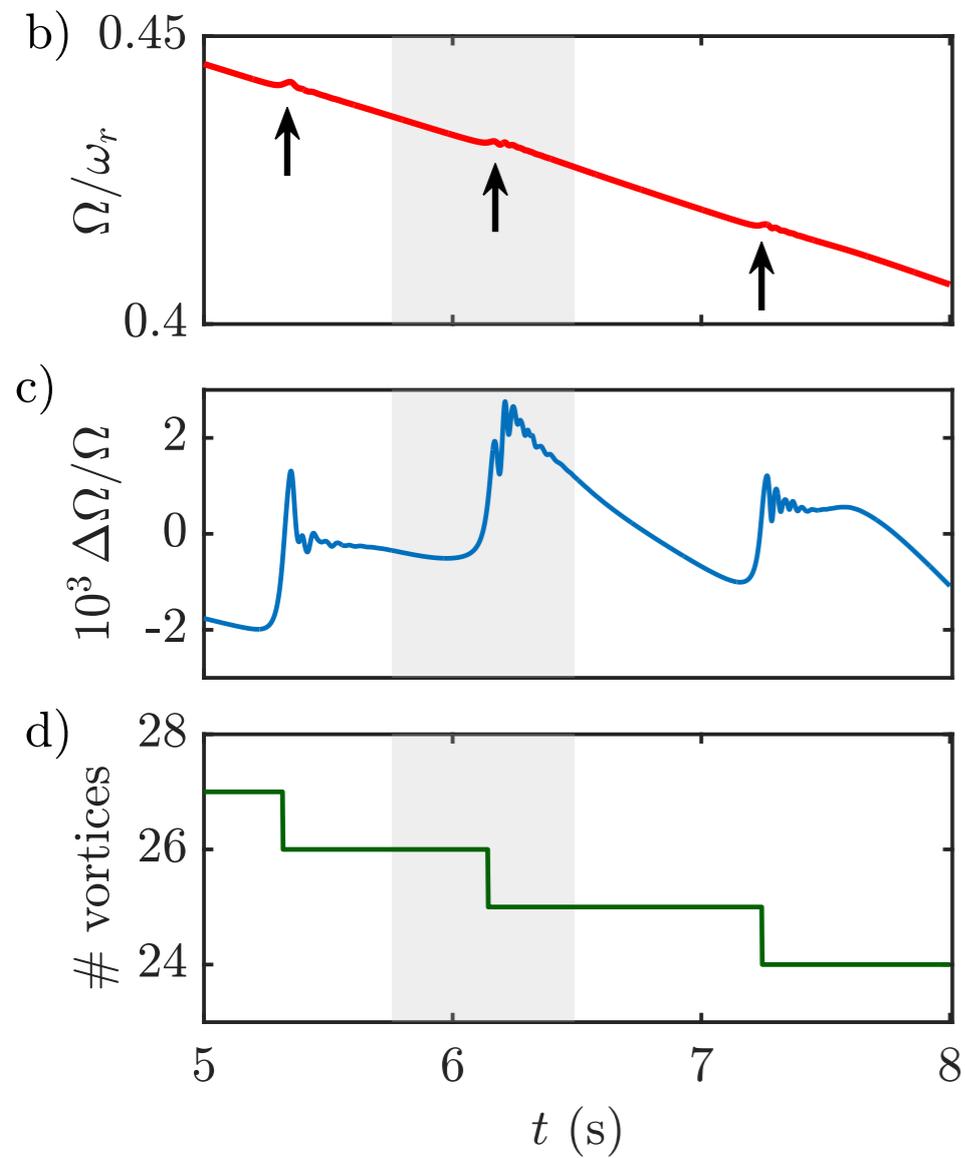


$$\Delta\Omega/\Omega \sim 10^{-12} - 10^{-3}$$



Espinoza et al., Mon. Not. R. Astron. Soc. 414, 1679–1704 (2011)

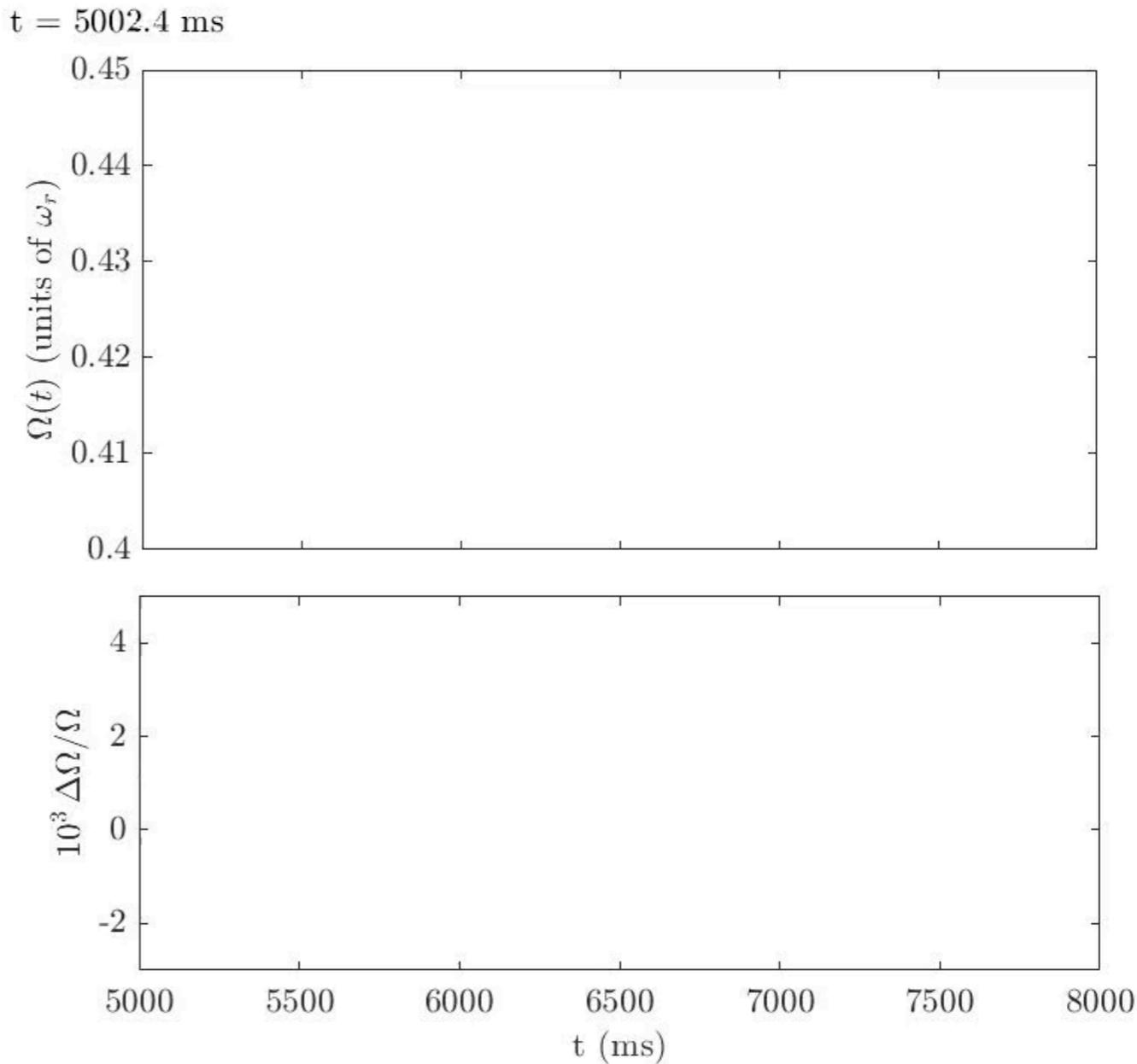
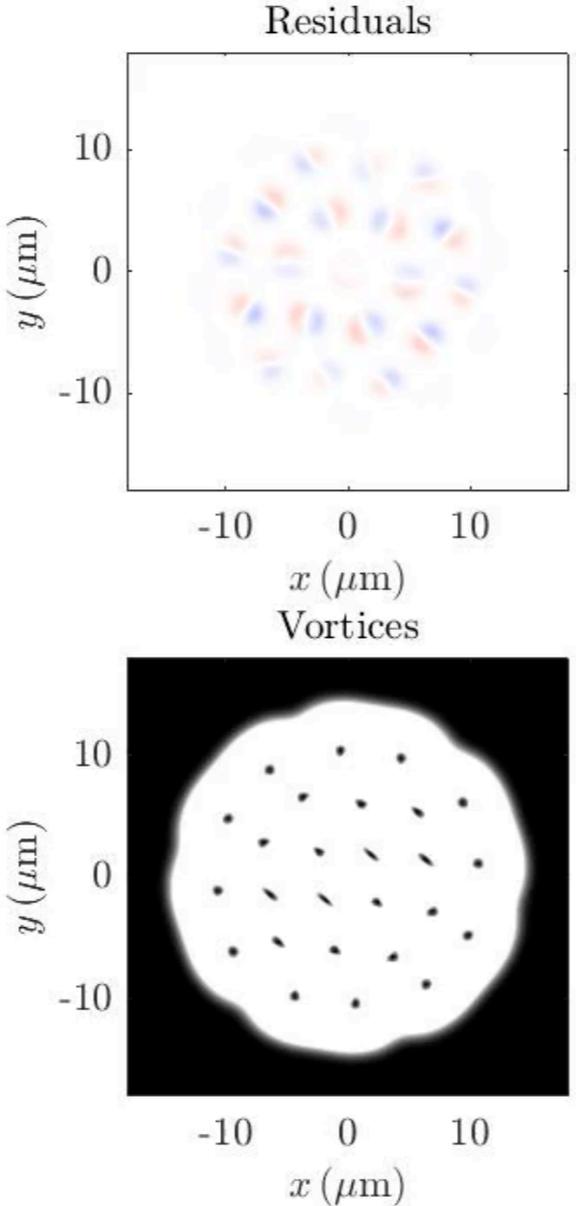
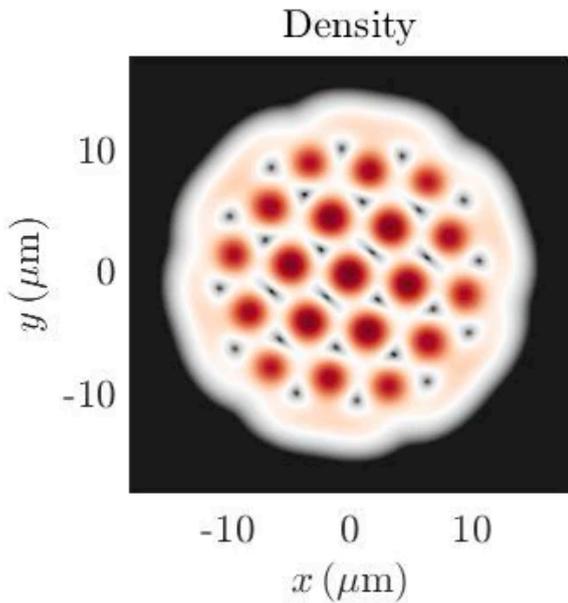
# Supersolid glitches







# Supersolid glitches



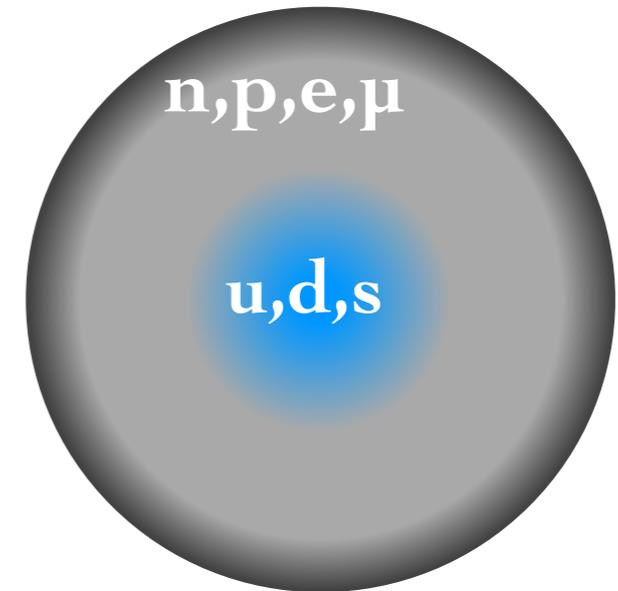
# *Taxonomy of compact stars*

Neutron star



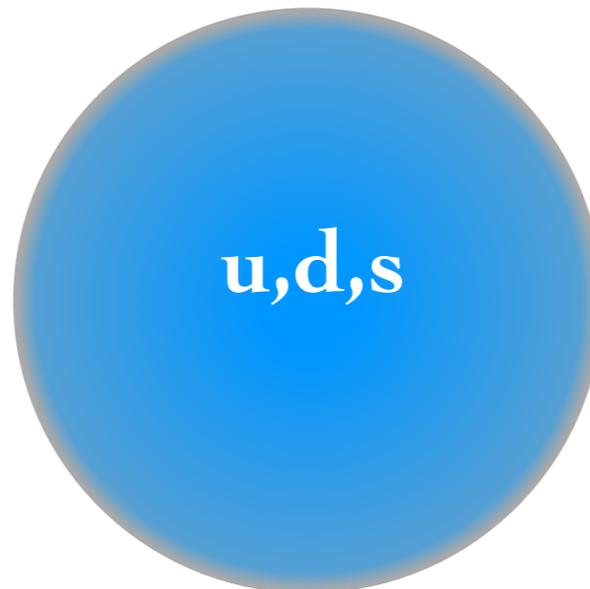
$$R \sim 10 \text{ km} \quad M = 1 - 2 M_{\odot}$$

Hybrid star



$$R \sim 10 \text{ km} \quad M = 1 - 2 M_{\odot}$$

Strange star



$$R \sim 0 - 10 \text{ km} \quad M < 3 M_{\odot}$$