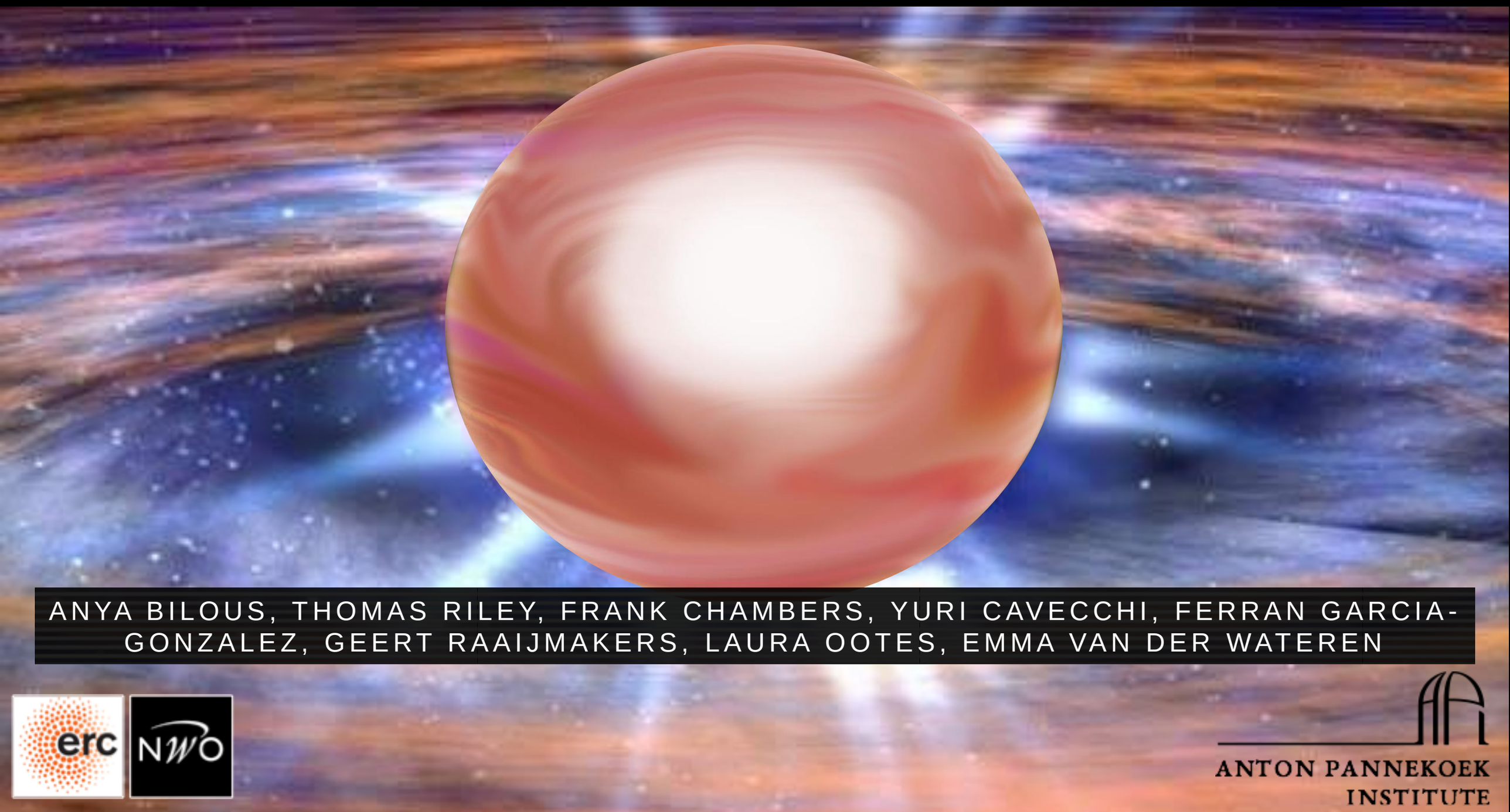
DENSE MATTER WITH EXTP
BURST OSCILLATIONS

DR. ANNA WATTS,UNIVERSITY OF AMSTERDAM



ANYA BILOUS, THOMAS RILEY, FRANK CHAMBERS, YURI CAVECCHI, FERRAN GARCIA-GONZALEZ, GEERT RAAIJMAKERS, LAURA OOTES, EMMA VAN DER WATEREN

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ANTON PANNEKOEK INSTITUTE

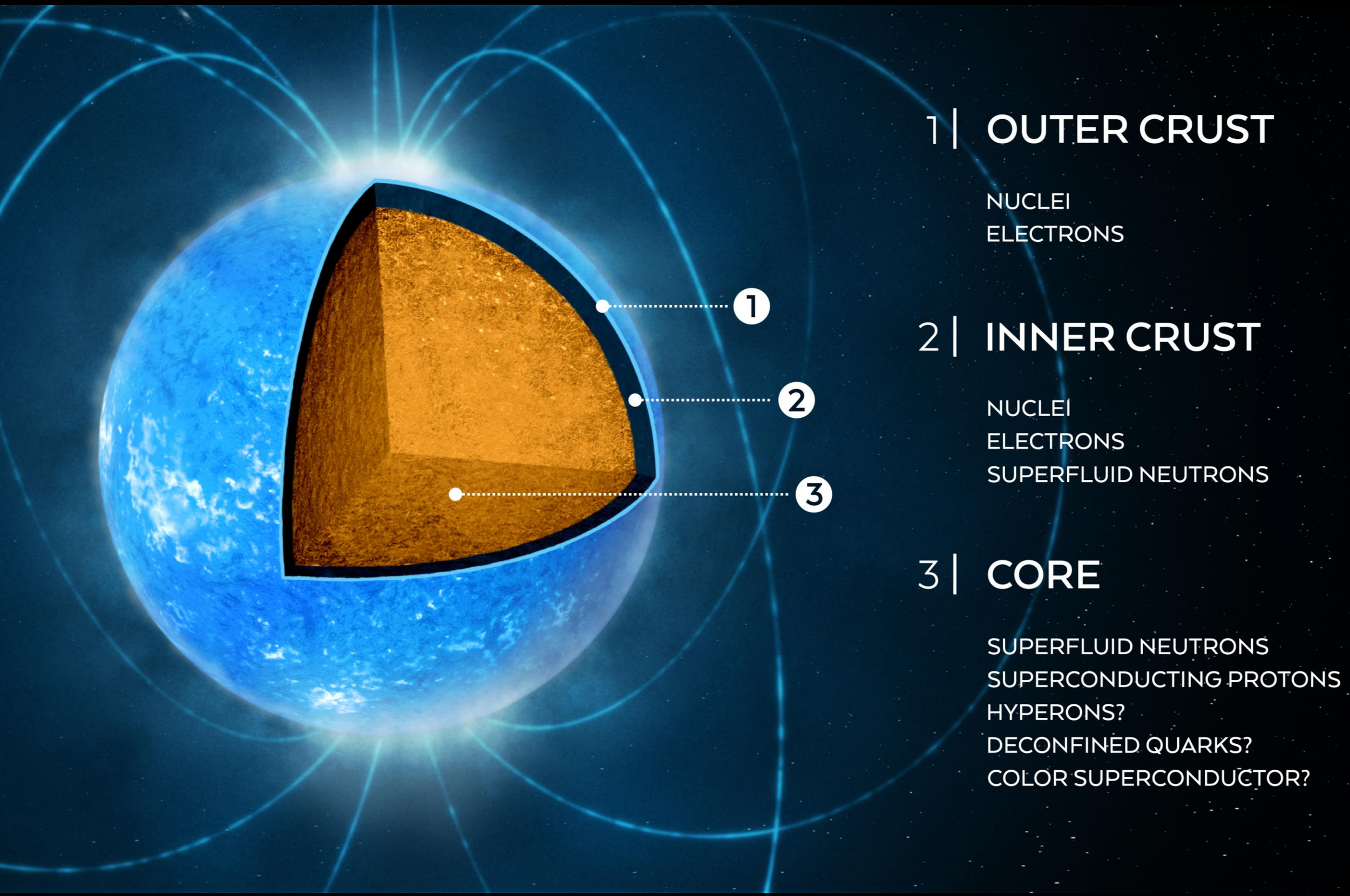
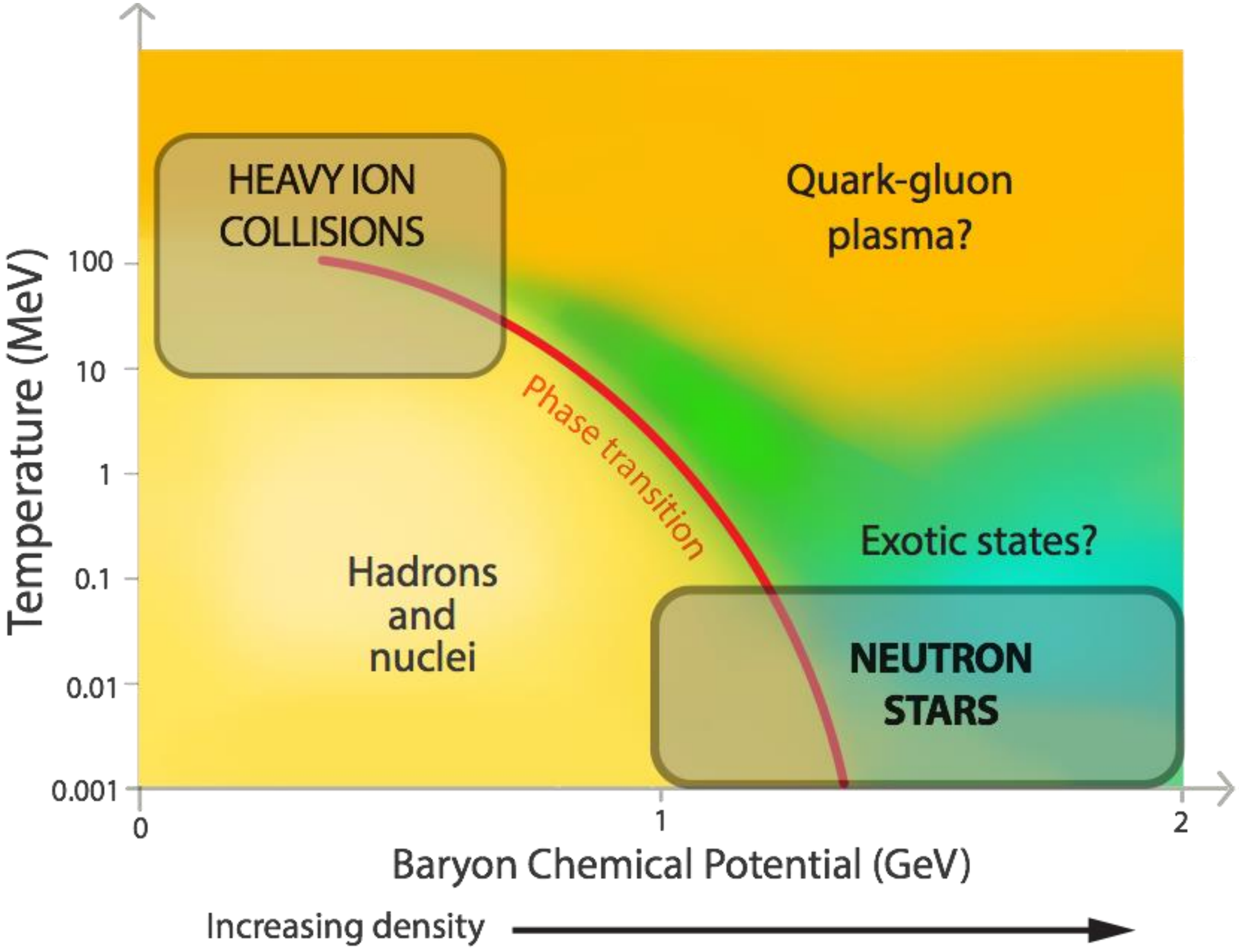
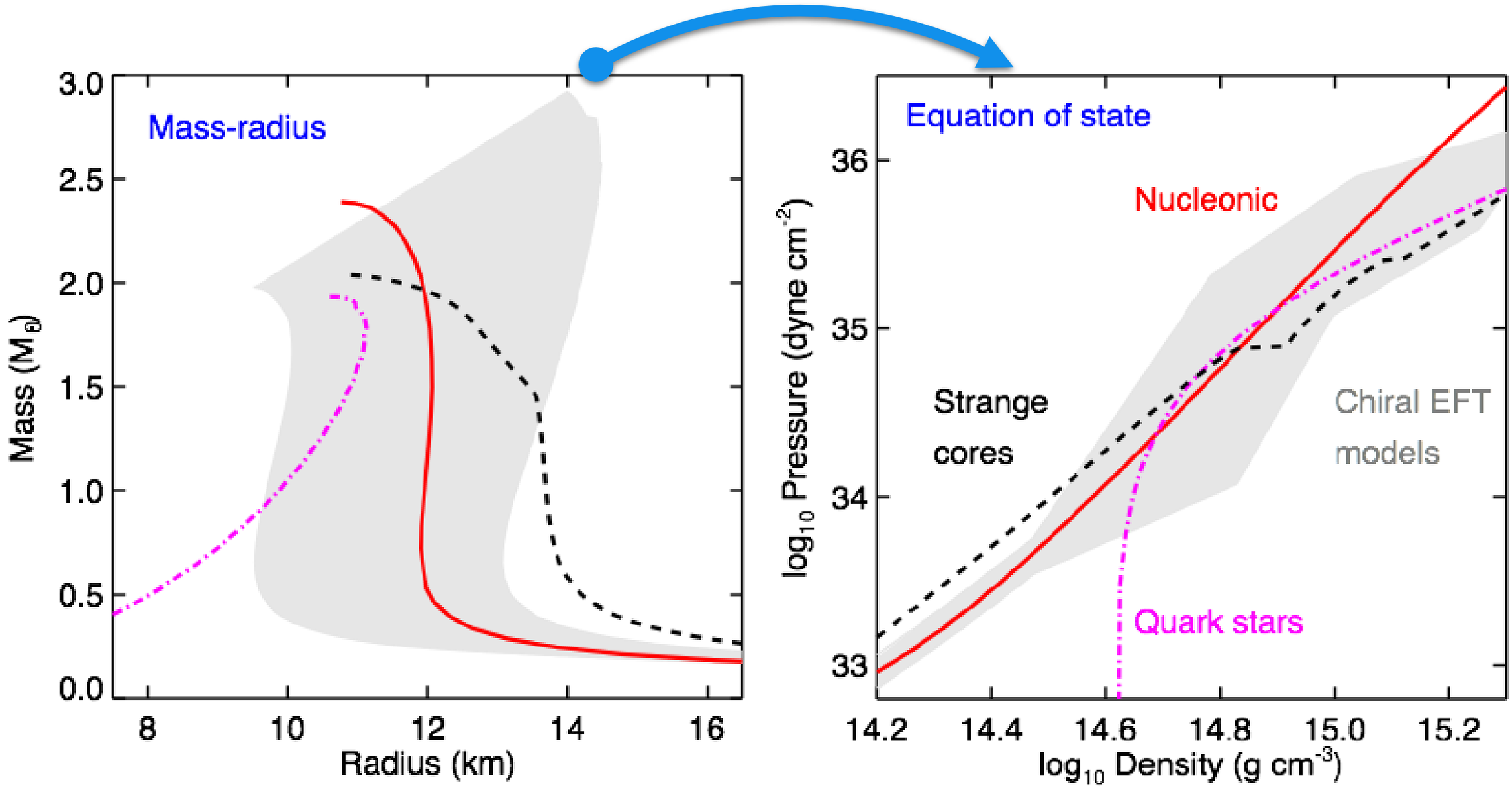


Figure from Watts et al. 2016

STRONG FORCE PHYSICS

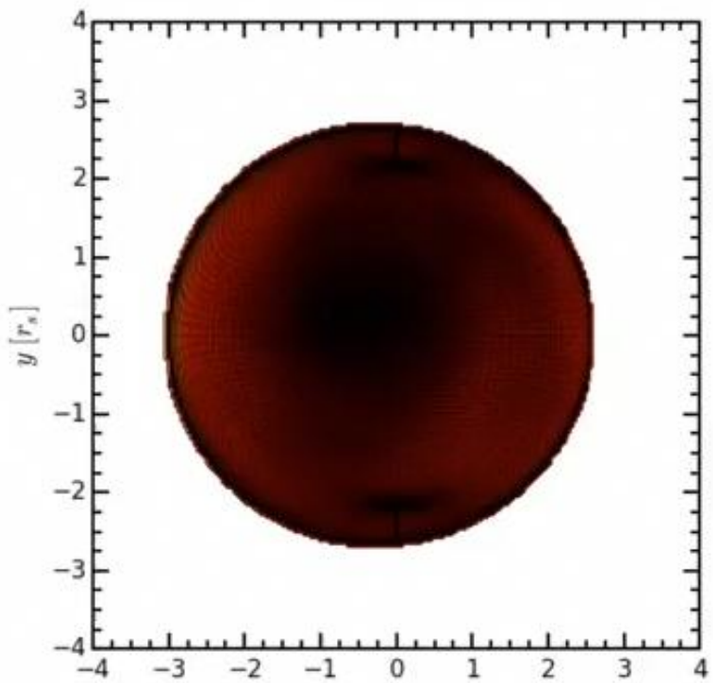


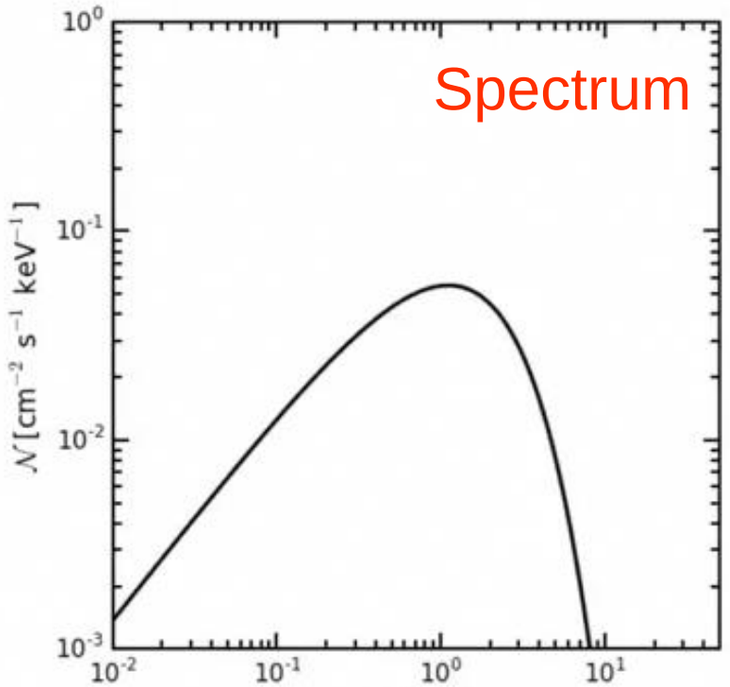
ASTROPHYSICS TO STRONG FORCE PHYSICS



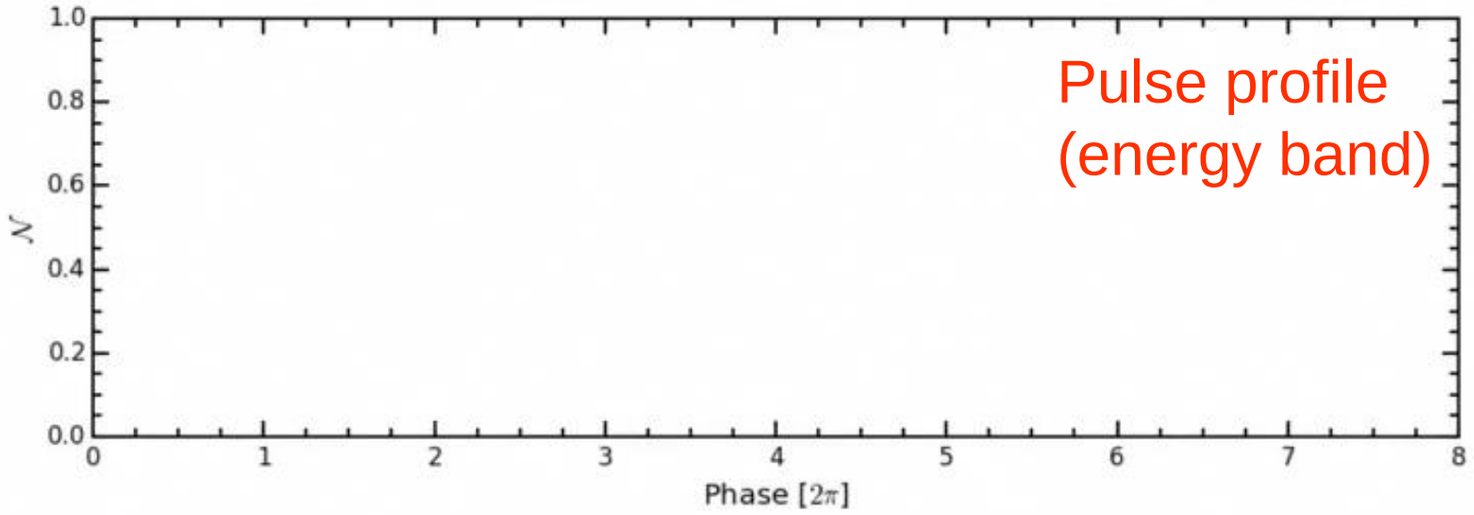
WE NEED SIMULTANEOUS MEASUREMENTS OF MASS & RADIUS, TO ACCURACIES OF A FEW %, FOR A RANGE OF MASSES

PULSE PROFILE MODELLING





Simulations (Hartle-Thorne spacetime) by Thomas Riley



Ray-tracing papers: Pechenick et al. 83, Poutanen & Gierlinski 03,Viironen & Poutanen 04, Poutanen & Beloborodov 06, Morsink et al. 07, Bogdanov et al. 07, Baubock et al. 12, 13, Lo et al. 13, Psaltis et al. 14, Miller & Lamb 15

BY FITTING PULSE PROFILE PROPERTIES WE CAN RECOVER MASS AND RADIUS, WITHOUT NEEDING DISTANCE/COMPOSITION.

ACCRETING NEUTRON STAR OCEAN

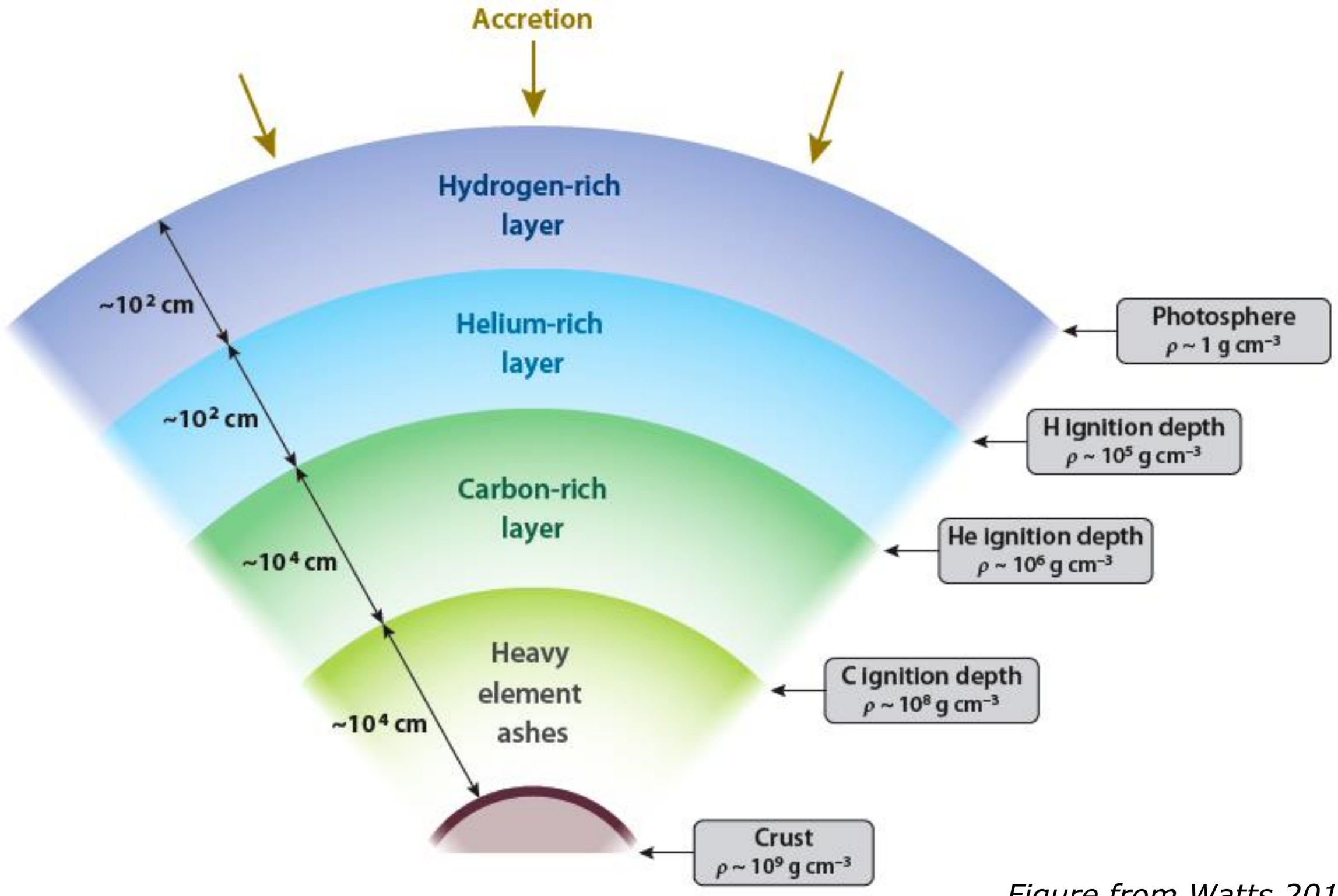
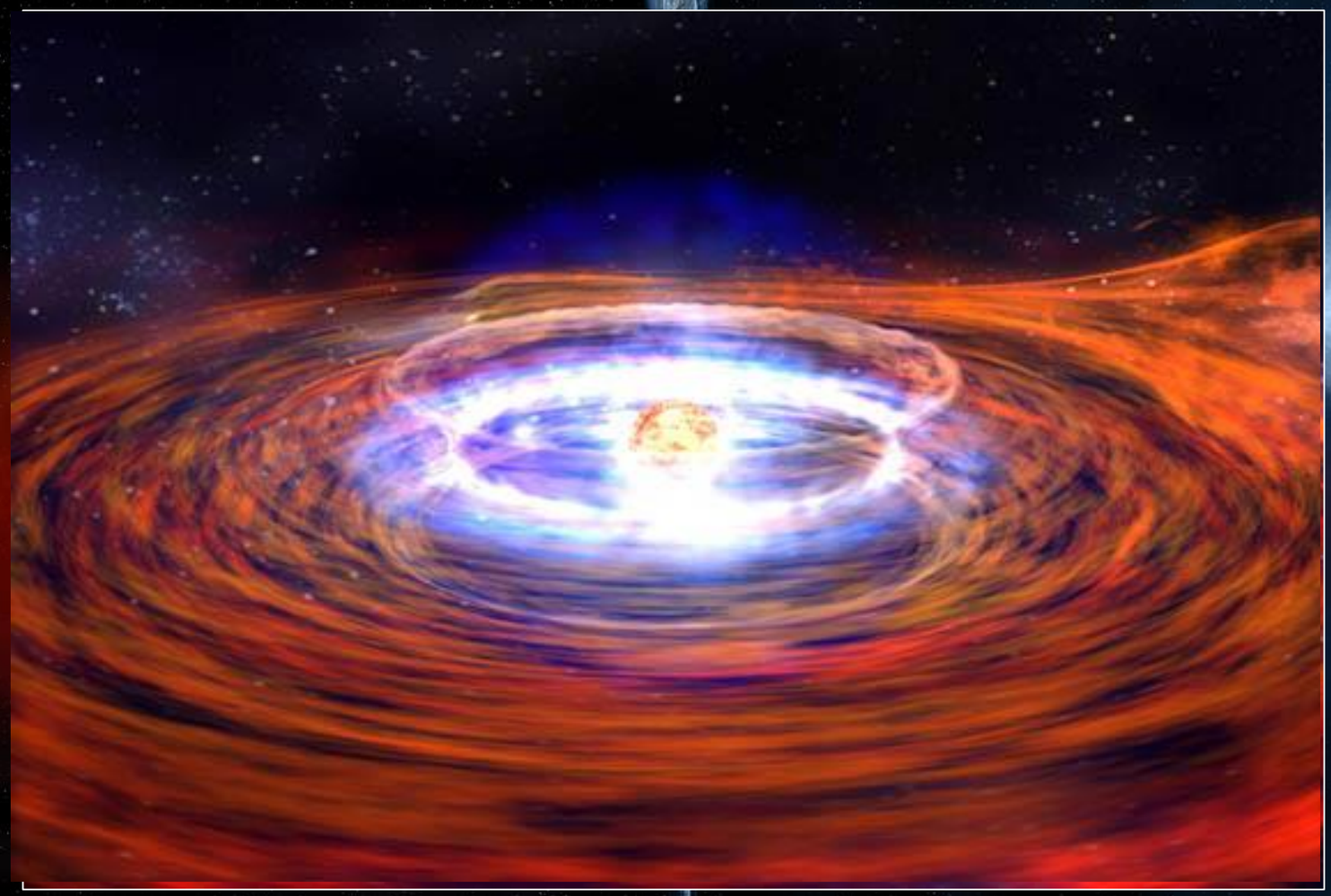
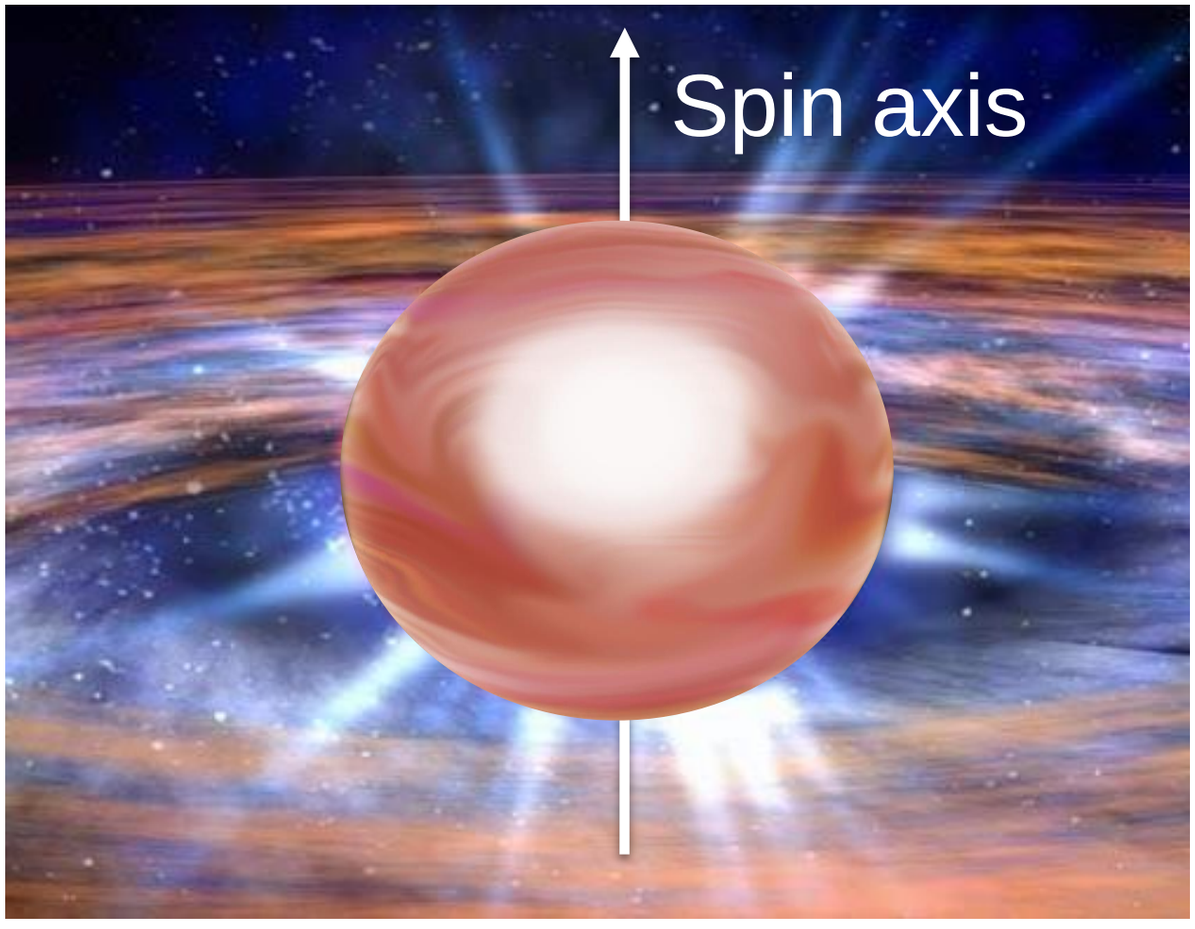
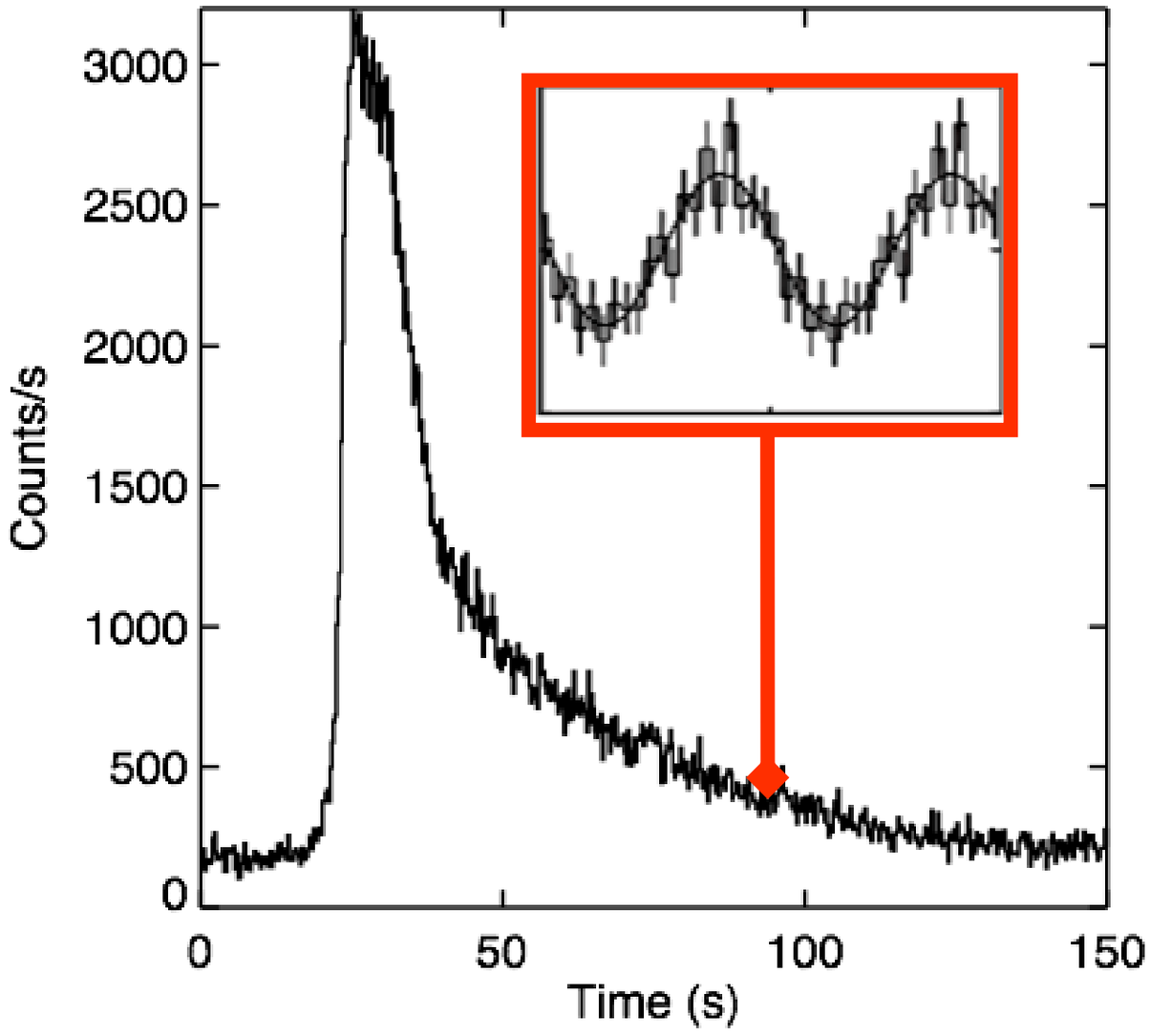


Figure from Watts 2012



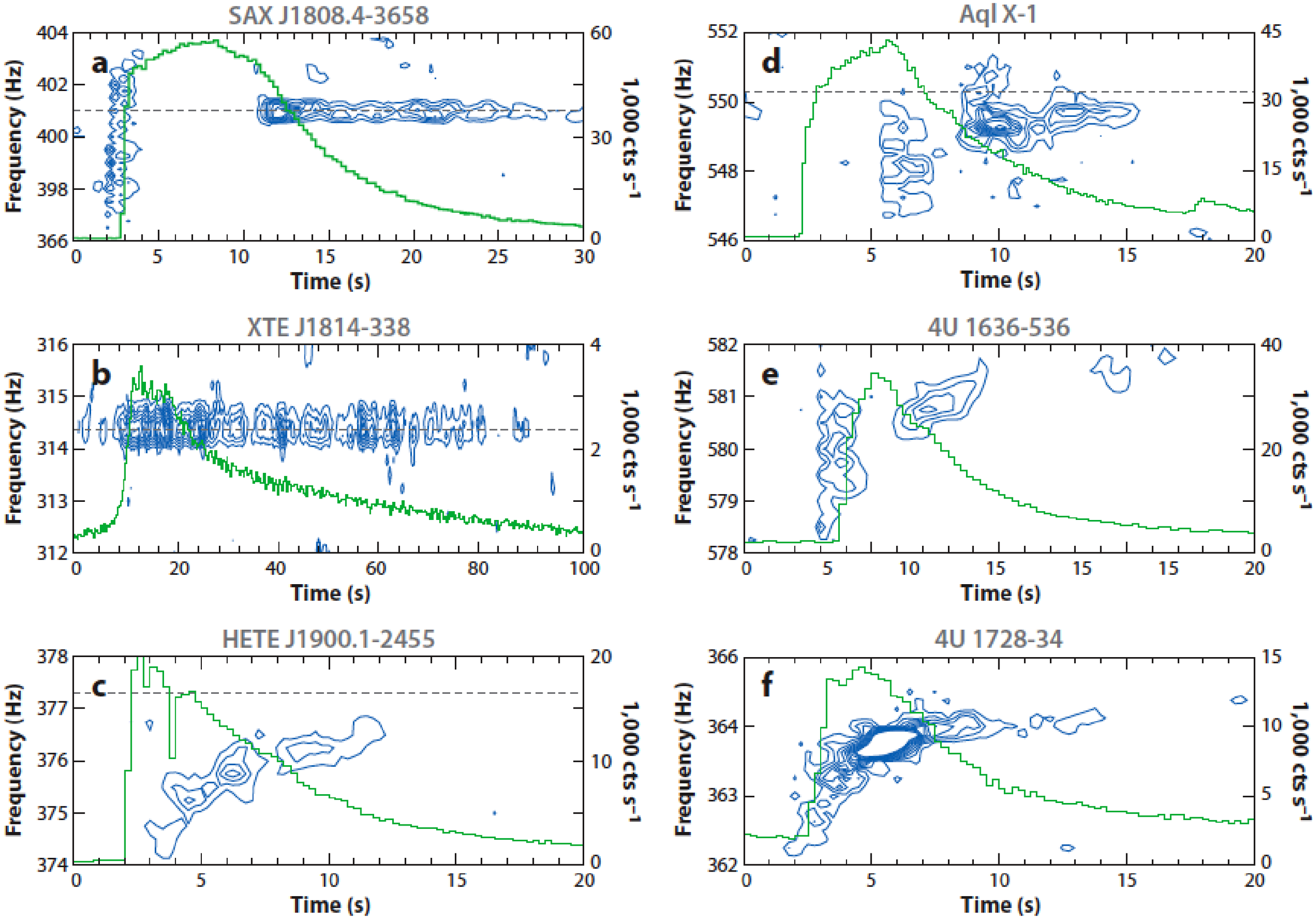
BURST OSCILLATIONS





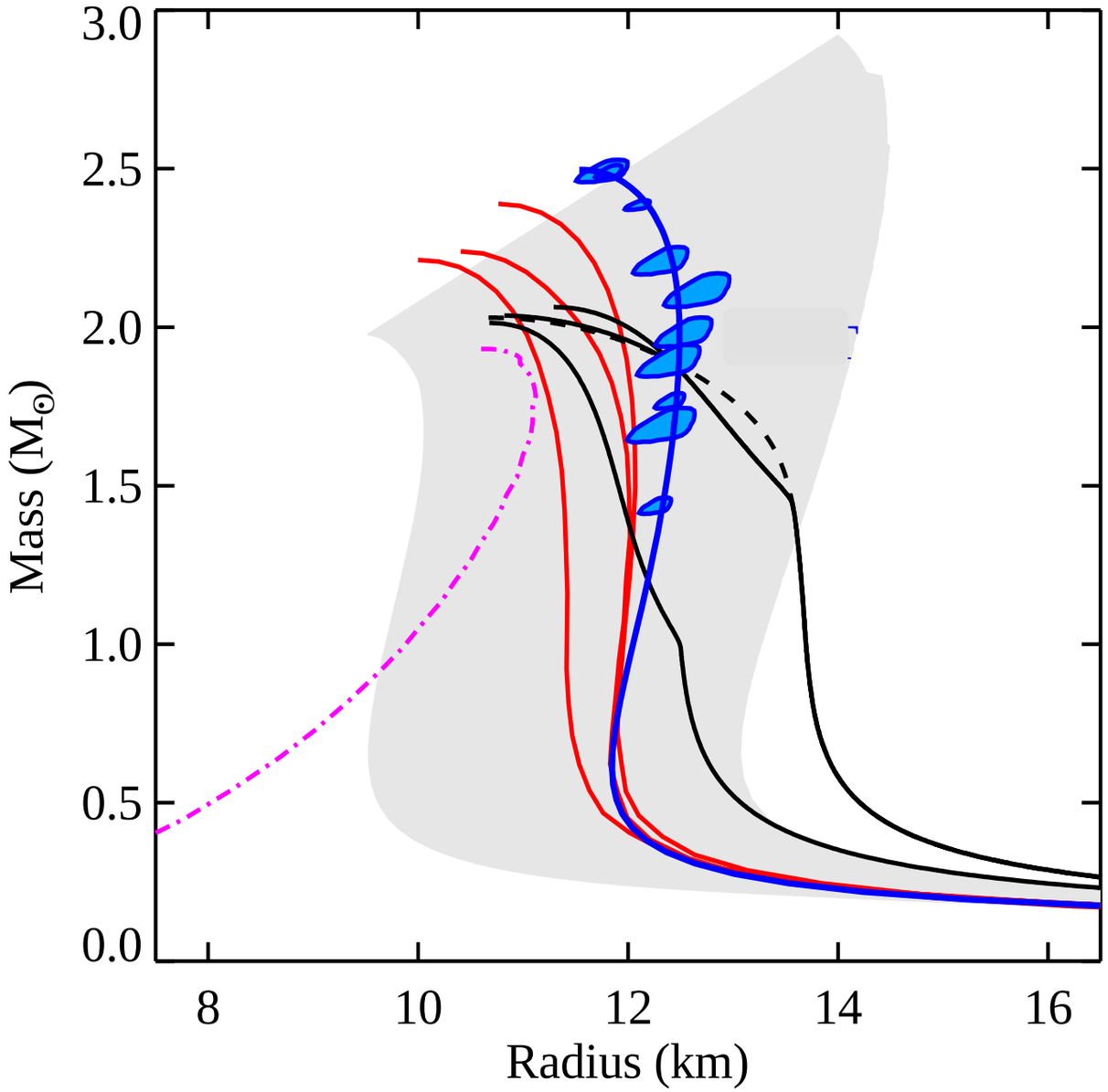
IN SOME BURSTS ANOMALOUSLY BRIGHT PATCHES FORM. THESE ARE KNOWN AS BURST OSCILLATIONS

Discovered in 1996 by Strohmayer et al., for review see Watts, ARAA, 2012



Watts 2012. Burst oscillations also seen in a superburst (Strohmayer & Markwardt 2002)

BURST OSCILLATION PULSE PROFILE FITS



Simulation for ~10 m^2 instrument from the LOFT M3 Yellow Book, based on Lo et al. 2013

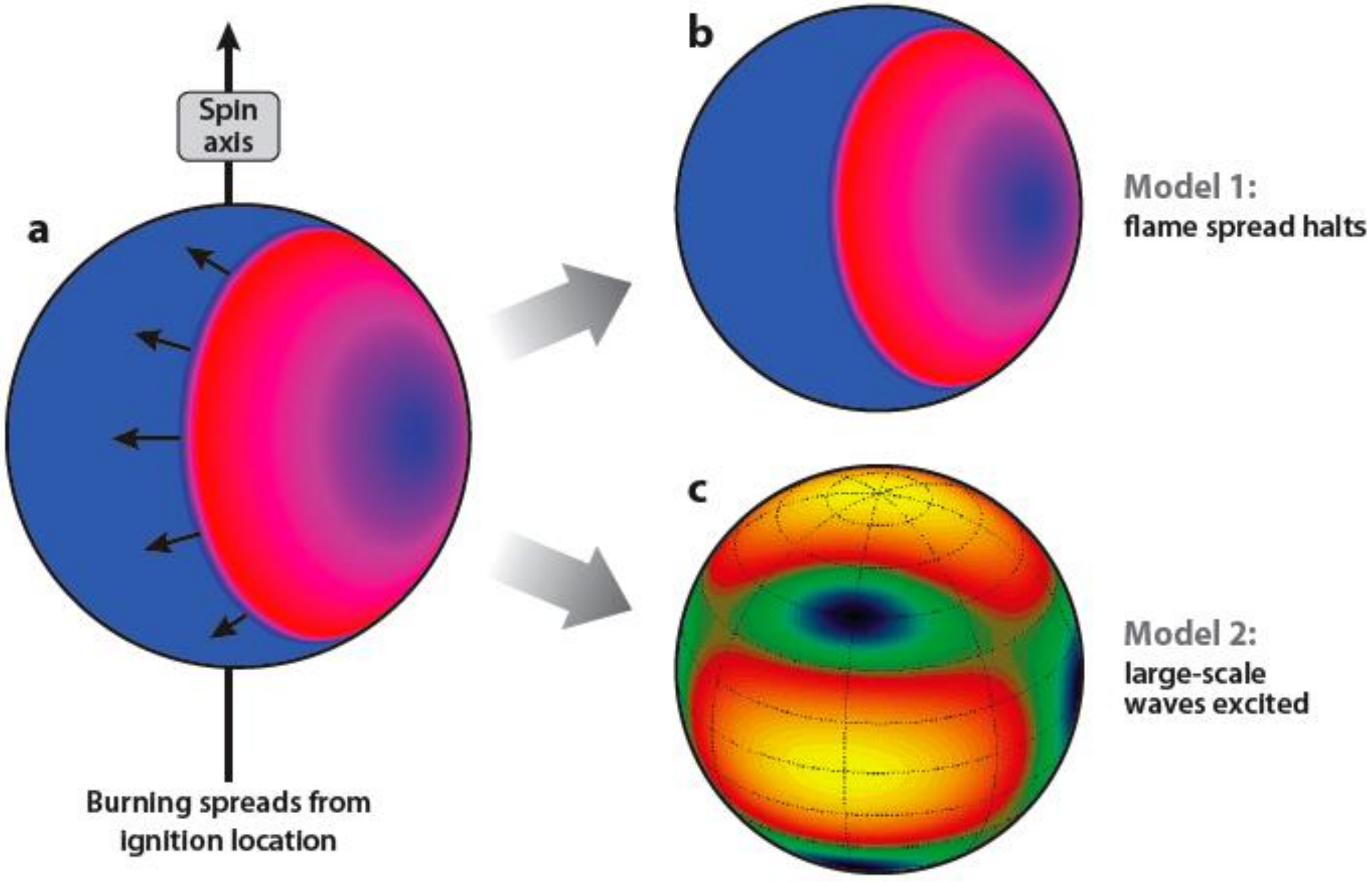
- **With ~10^6 pulsed photons, can recover M, R at few % level.**
- **Many known sources.**
- **Need to combine several bursts**
- **Cross-checks possible.**
- **Low systematics.**

eXTP observing strategy

- **Pulsars with burst oscillations**
  - **2 pulse types to crosscheck**
  - **Polarimetry adds constraints.**
- **Non-pulsars**
  - **Working to identify best candidates using archival data**
- **Goal: ~5 measurements**

ISSUES: SURFACE PATTERN UNCERTAINTY, DATA ANALYSIS STRATEGY GIVEN VARIABILITY AND NEED TO COMBINE BURSTS.

BURST OSCILLATION MODELS



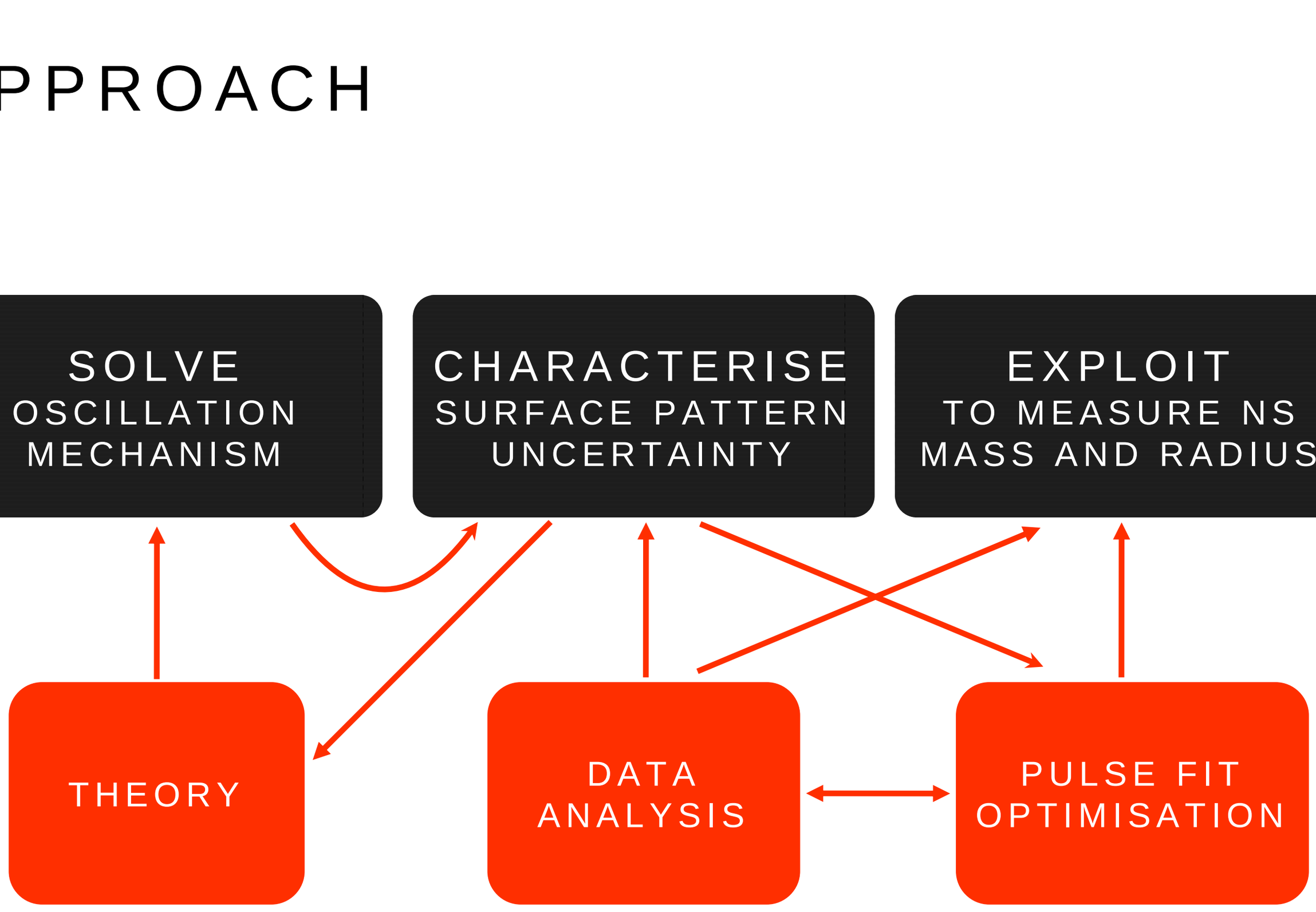
Watts 2012

APPROACH

SOLVE
OSCILLATION MECHANISM

CHARACTERISE
SURFACE PATTERN UNCERTAINTY

EXPLOIT
TO MEASURE NS MASS AND RADIUS



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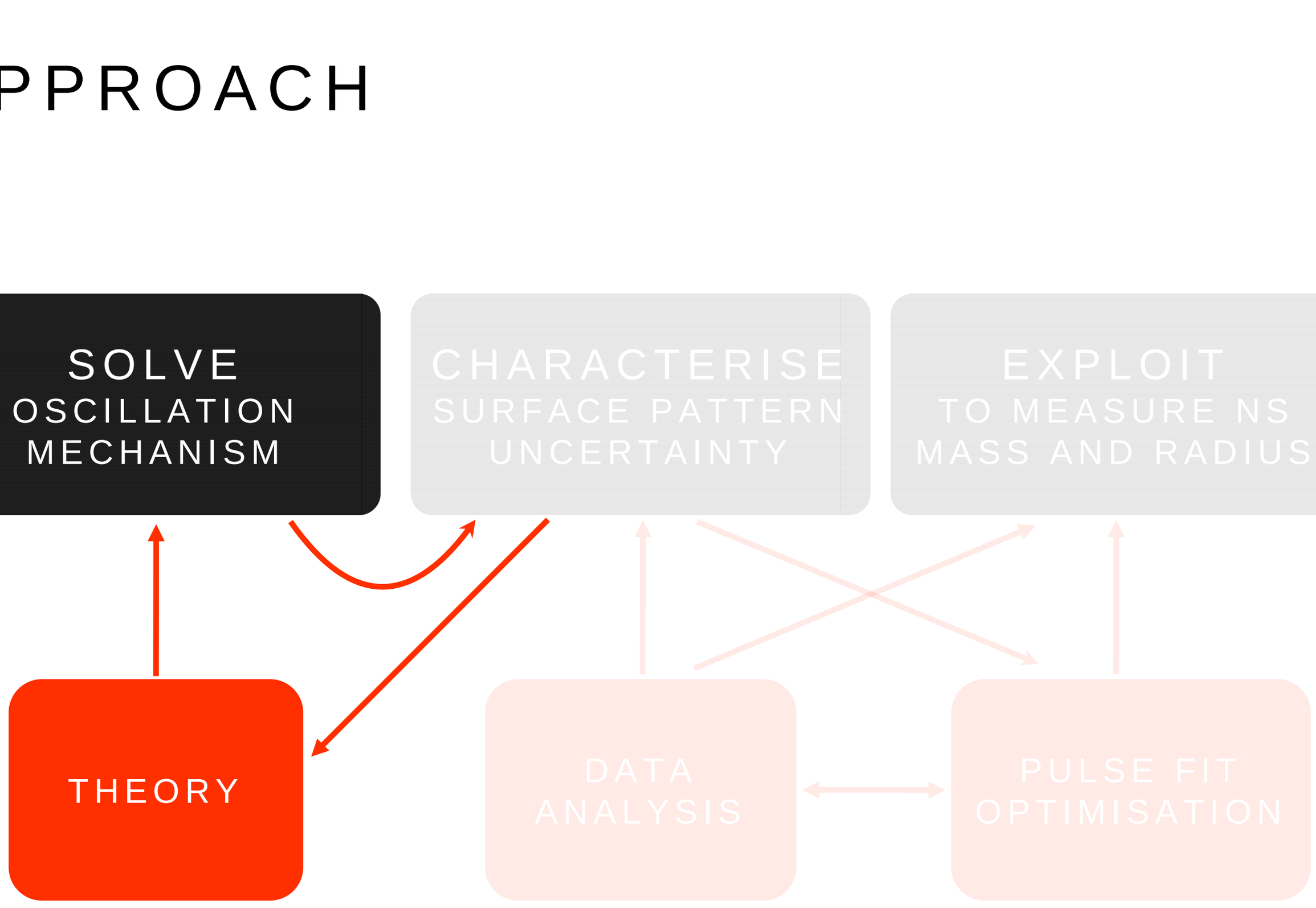
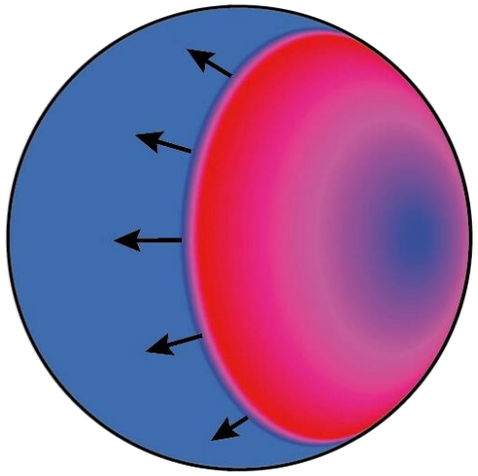
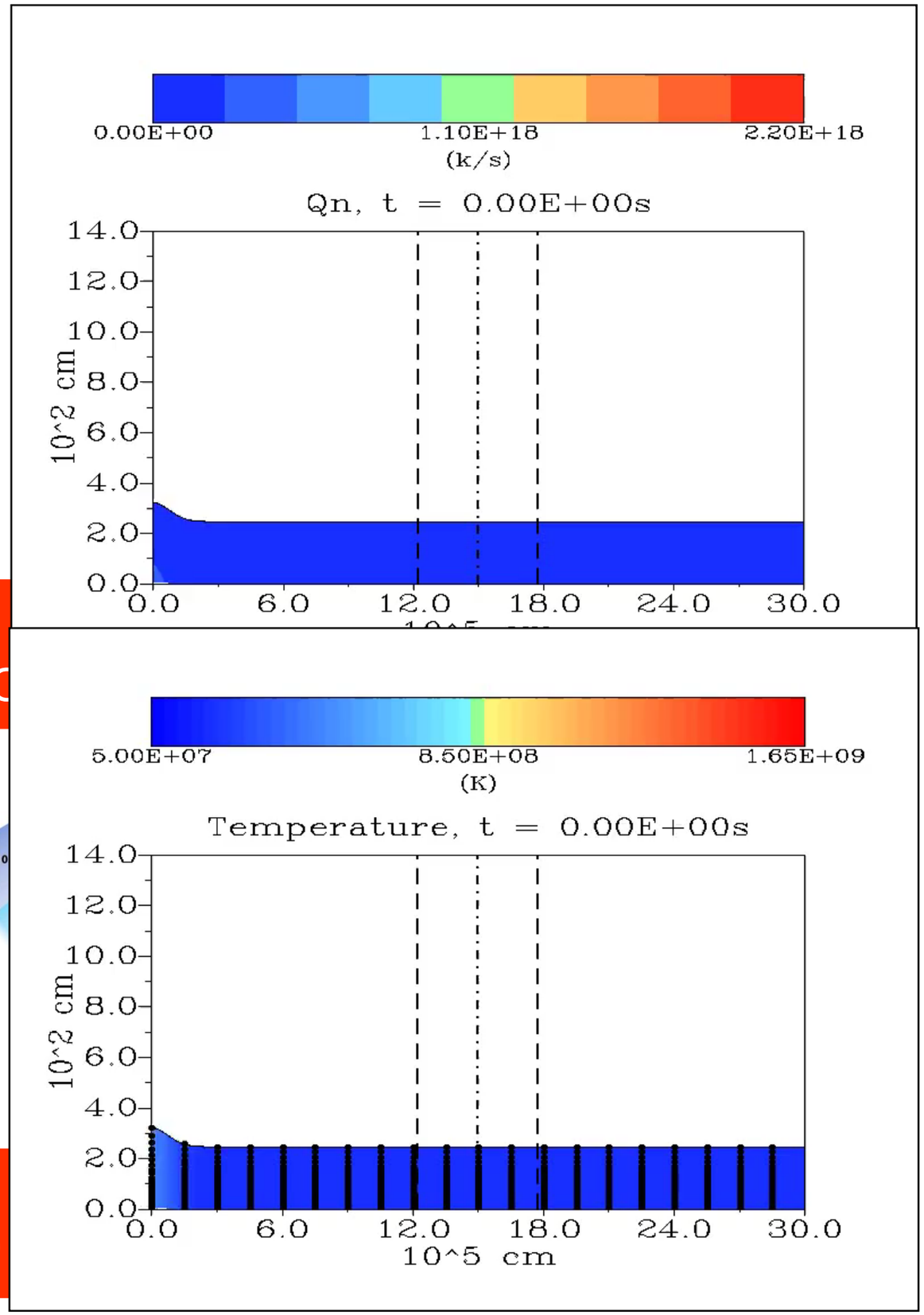


THEORY



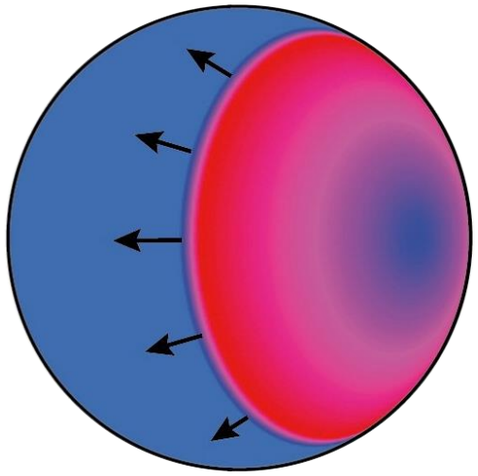
IGNITION AND FLAME SPREAD

- First principles (M)HD simulations of thermonuclear flame spread (Cavecchi et al. 2013, 2015, 2016)
- Coriolis force, conduction, and magnetic fields all play important role.

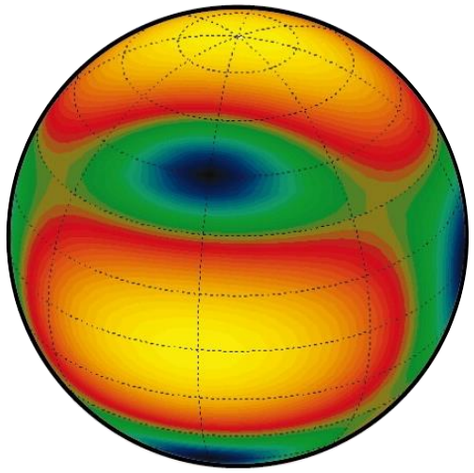


CAVECCHI (NOW AT PRINCETON), CHAMBERS, GARCIA-GONZALEZ

THEORY



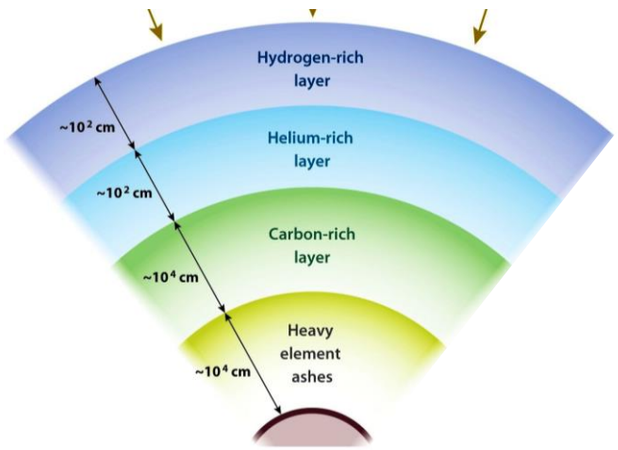
IGNITION AND FLAME SPREAD



MODE CALCULATIONS

SEE POSTER BY FRANK CHAMBERS, SUPERBURST MODES

PATTERN FORMATION



ROLE OF PHOTOSPHERE

CAVECCHI (NOW AT PRINCETON), CHAMBERS, GARCIA-GONZALEZ

APPROACH

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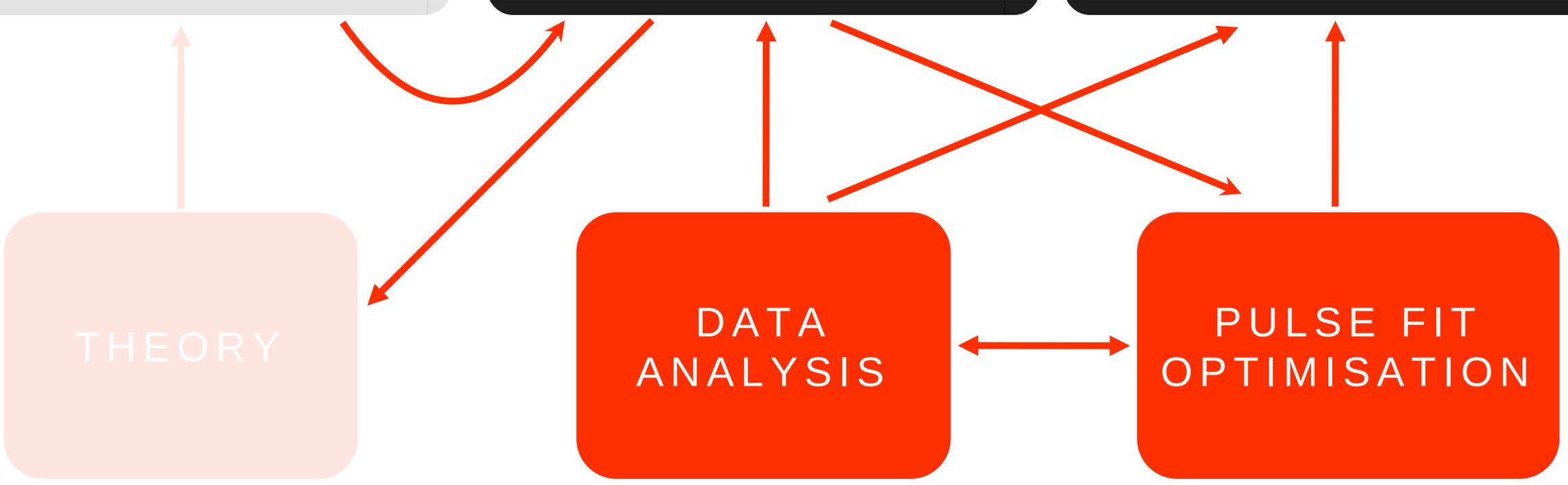
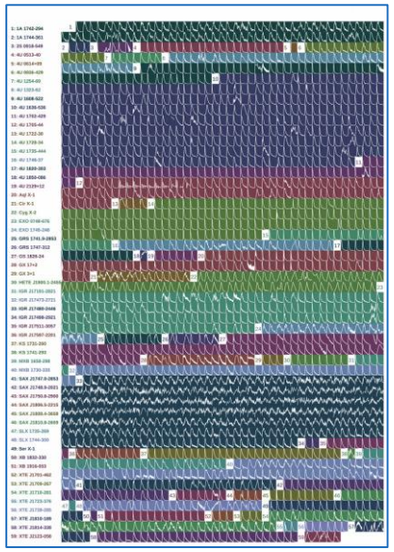
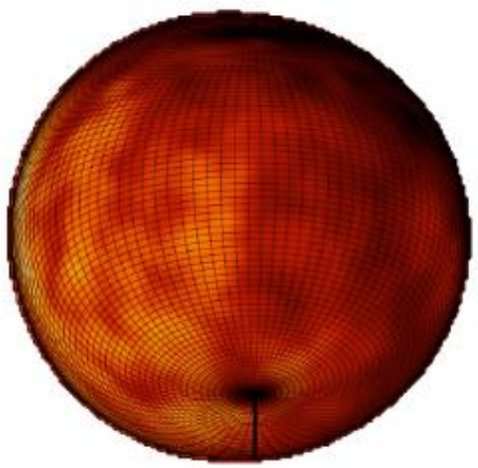


DATA ANALYSIS AND M-R RECOVERY

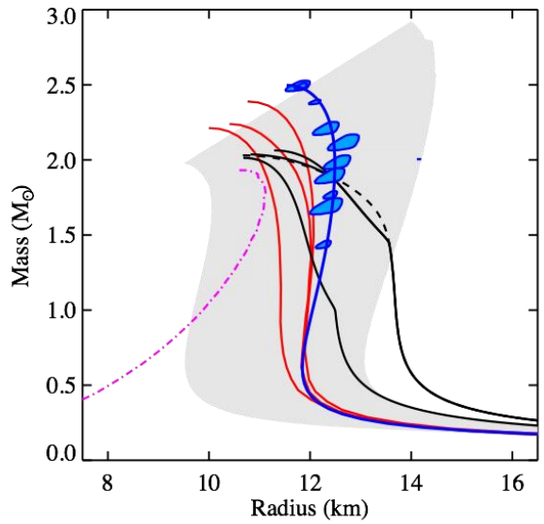


DATA ANALYSIS

FUTURE X-RAY TELESCOPES



RAY TRACING

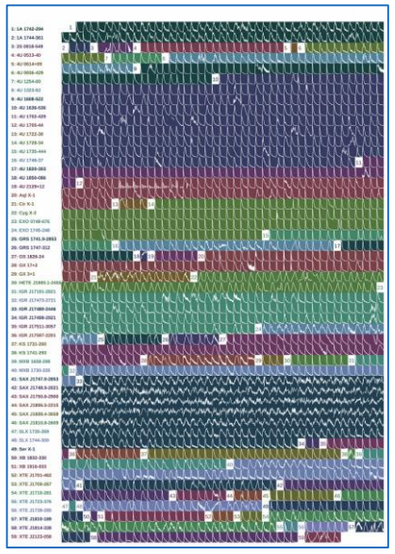


M-R RECOVERY TECHNIQUES

BILOUS, RILEY, RAAIJMAKERS, OOTES, VAN DER WATEREN, DANIELA HUPPENKOTHEN (NYU)

DATA ANALYSIS AND M-R RECOVERY

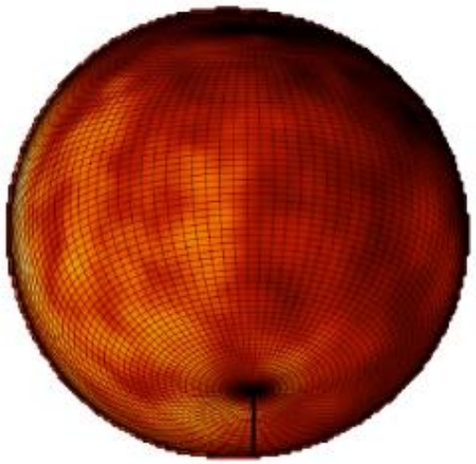
SEE POSTER BY ANYA BILOUS, ON OSCILLATION DETECTION AND CHARACTERIZATIO N



DATA ANALYSIS

FUTURE X-RAY TELESCOPES

SEE POSTER BY THOMAS RILEY, ON RAY-TRACING CODE XBOSS



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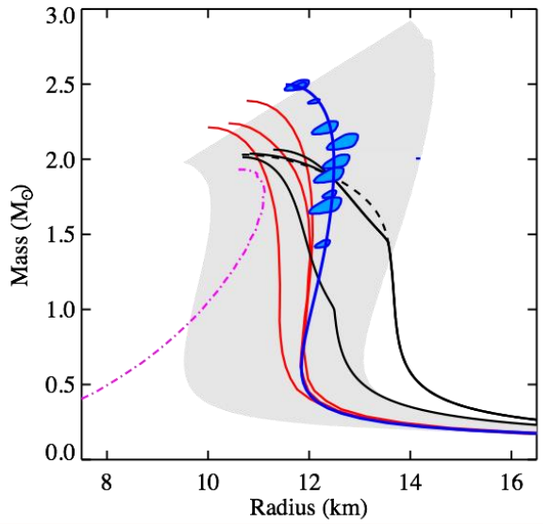

M-R RECOVERY TECHNIQUES

BILOUS, RILEY, RAAIJMAKERS, OOTES, VAN DER WATEREN, DANIELA HUPPENKOTHEN (NYU)

SUMMARY FOR EXTP STUDIES

Burst oscillation mechanism: a 20 year old mystery

- **New insight from accretion-powered pulsars and flame spread simulations.**
- **New spectral-timing techniques being applied to data.**
- **Combine with relativistic ray-tracing to constrain possible surface patterns.**
- **Theory focus: ignition conditions, ocean modes, role of convection.**
- **eXTP will let us study burst oscillations in unprecedented detail.**

Burst oscillations as a means of measuring M, R

- **Work for LOFT confirmed viability and reliability of method.**
- **eXTP can expect to make ~5 measurements using this technique.**
- **Burst oscillations from pulsars will be particularly important.**
- **In progress: assessment of surface pattern uncertainty, practical aspects of data combination, observation planning/scheduling.**