

# Maximal left ideals of operators acting on a Banach space

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Maresias, 29<sup>th</sup> August 2014

Joint work with Garth Dales (Lancaster),  
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## Positive answers to Question II

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### Key references

- ▶ H. G. Dales, T. Kania, T. Kochanek, P. Koszmider and N. J. Laustsen, Maximal left ideals of the Banach algebra of bounded operators on a Banach space, *Studia Math.* **218** (2013), 245–286.
- ▶ H. G. Dales and W. Żelazko, Generators of maximal left ideals in Banach algebras, *Studia Math.* **212** (2012), 173–193.
- ▶ T. Kania and N. J. Laustsen, Ideal structure of the algebra of bounded operators acting on a Banach space, in preparation.