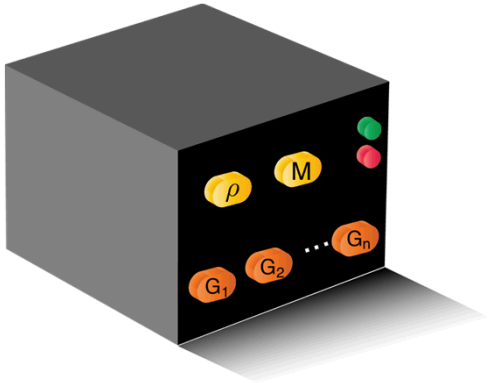
SAND2015-1499C

# Gate Set Tomography on a Trapped Ion Qubit

Erik Nielsen, Robin Blume-Kohout, John King Gamble, Peter Maunz, Kenneth Rudinger

Sandia National Laboratories

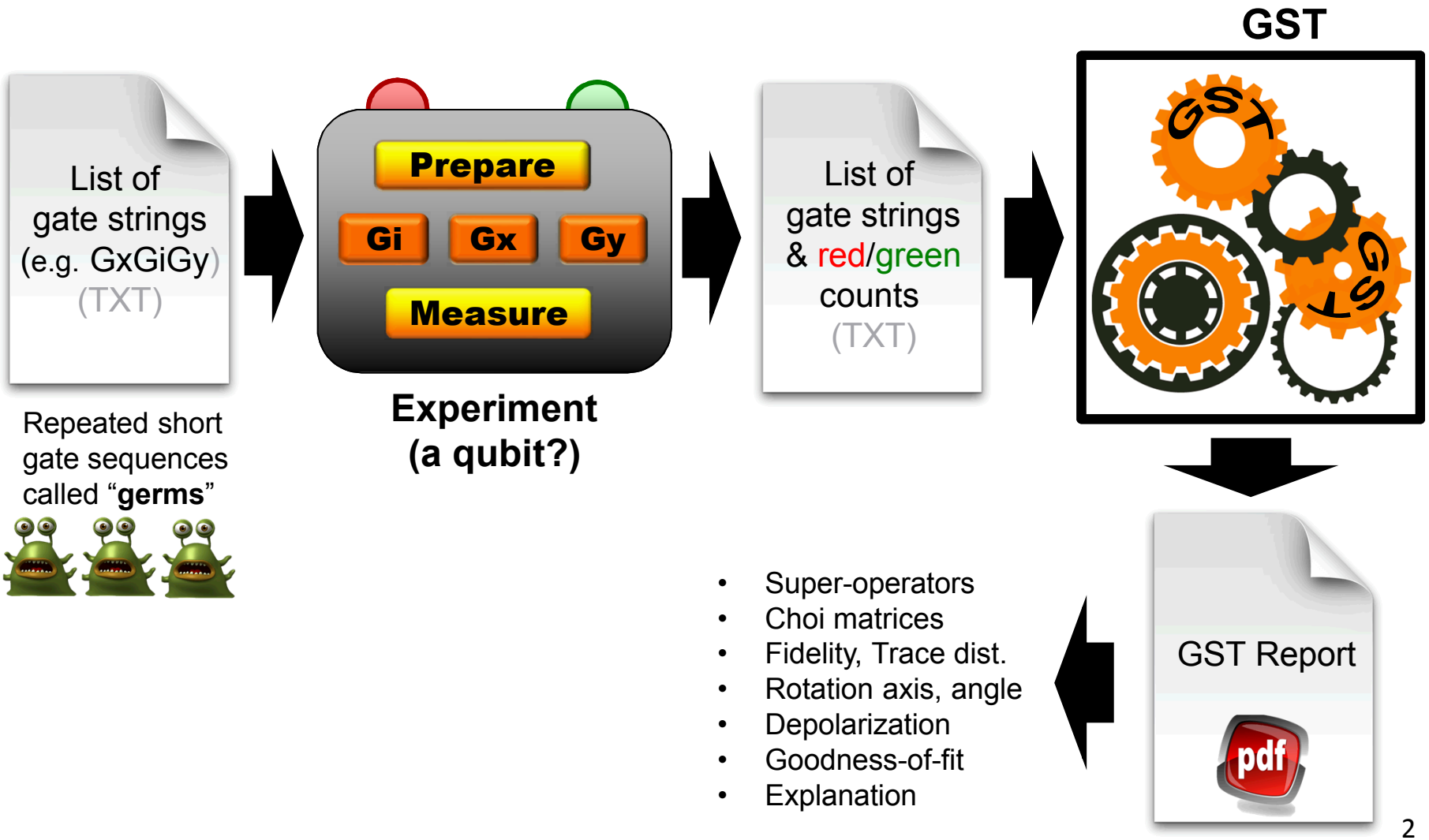
APS March Meeting 2015




This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories. Sandia National Laboratories is a multiprogram laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

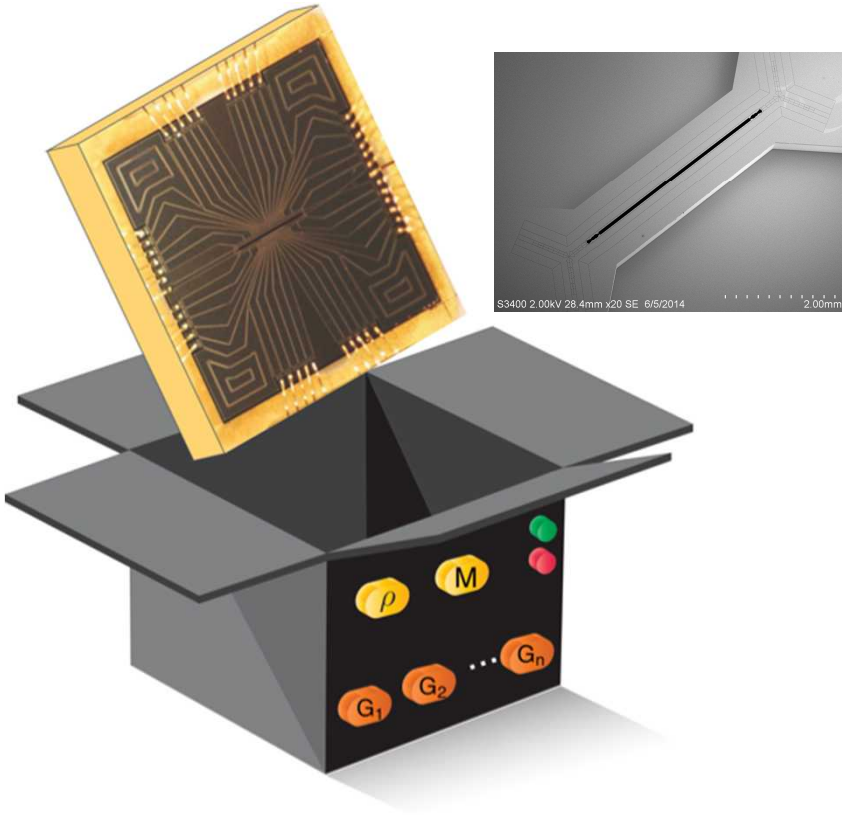
# Gate Set Tomography (GST)

GST fits gate string data (counts) with a static set of gates and SPAM.



# Experiment: A trapped ion qubit

- Inside the black box:

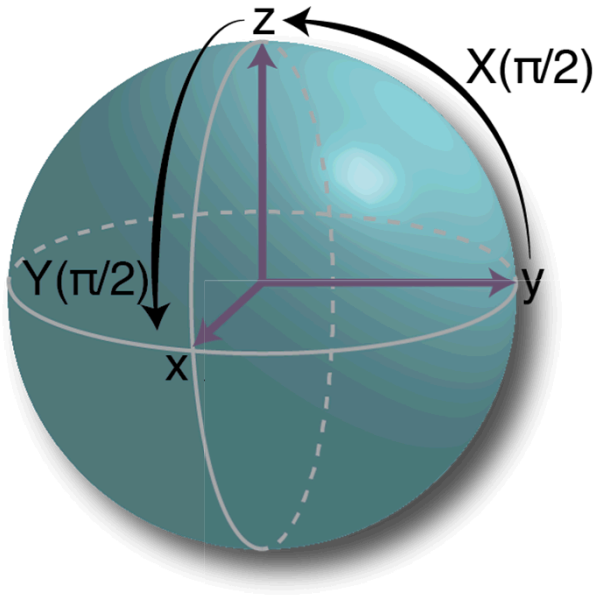




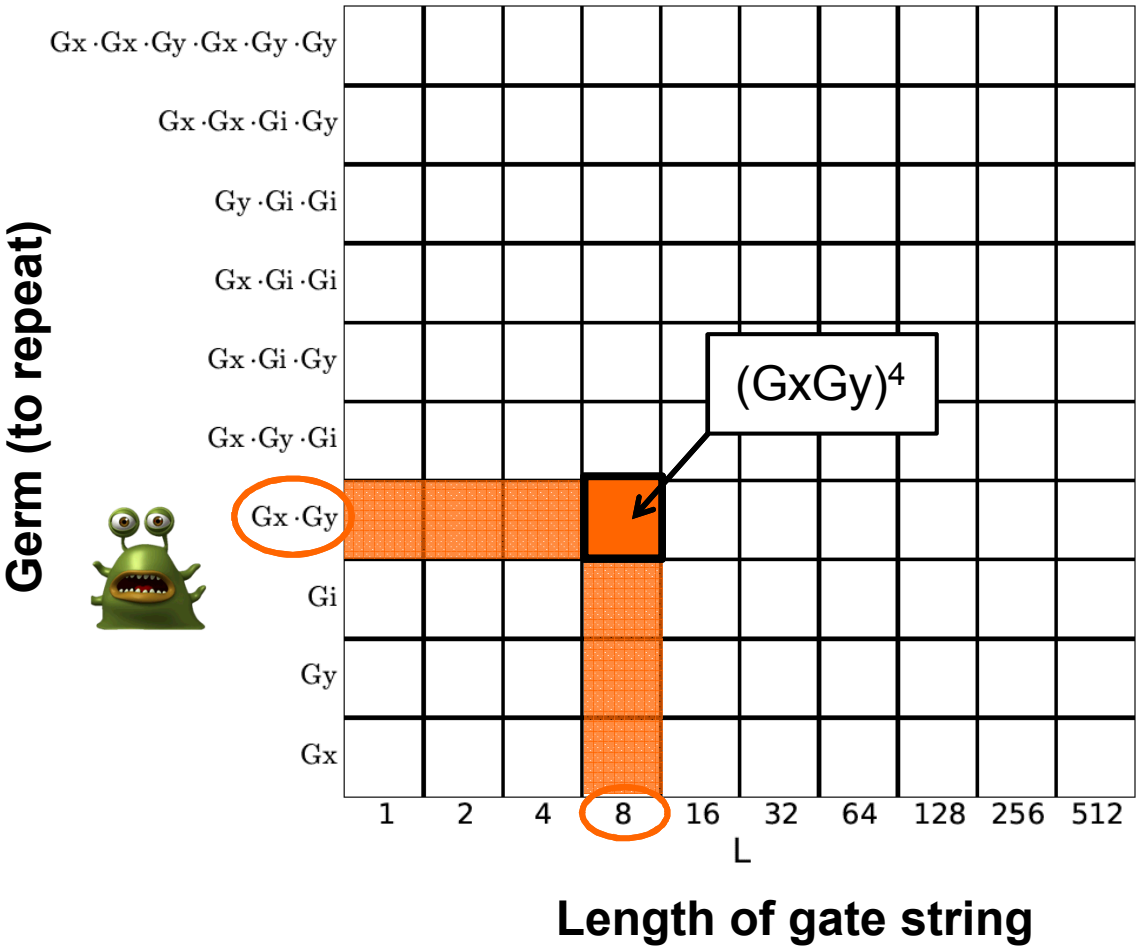


**Desired "target" gates:**

1. Idle (identity): "**Gi**"
2. $\pi/2$ rotation about x-axis "**Gx**"
3. $\pi/2$ rotation about y-axis "**Gy**"

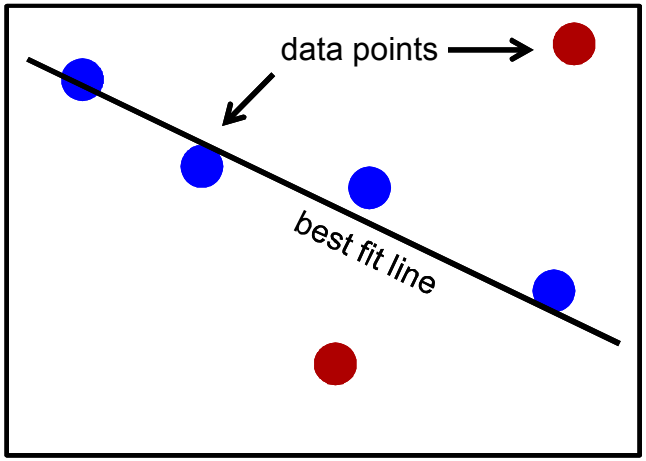


# GST on real systems – $\chi^2$ analysis




- Each box = 1 gate string
- Color = $\chi^2$ for that string
  - **Blue** boxes = fits well
  - **Red** boxes = fits poorly

- **Line-fitting analogy:**

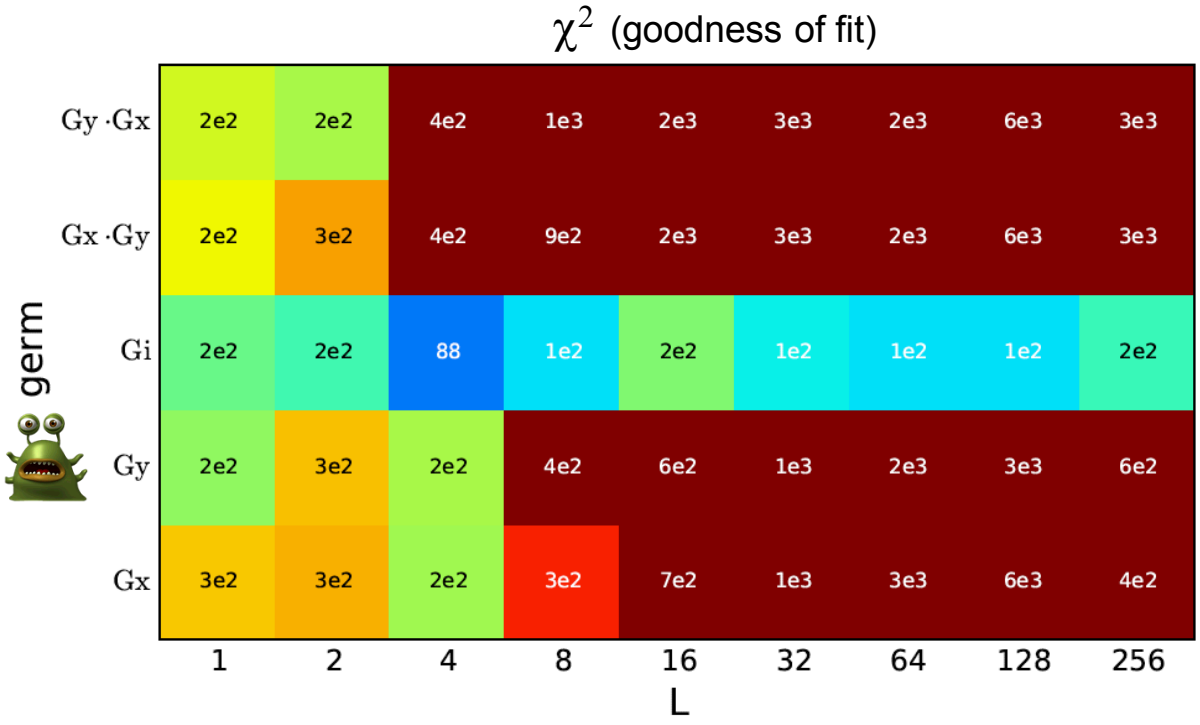


# Episode 1: Initial Data (April, 2014)

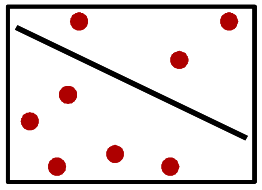
- EXPERIMENT: Basic experiment, nothing fancy yet
- GST:
  - Gates *look* reasonable, but the fit is awful due to non-Markovian noise
  - **GST gate estimates not meaningful at this point b/c it's not a qubit.**

**Estimated Gates**
(if it were a qubit, *but it's* ***not***)

| | angle | 1-F |
|---|---|---|
| **Gi** | 0.0004π | 0.0002 |
| **Gx** | 0.5026π | 0.0028 |
| **Gy** | 0.5024π | 0.0030 |




Analogy



# Episode 2: Compensated data (May, 2014)

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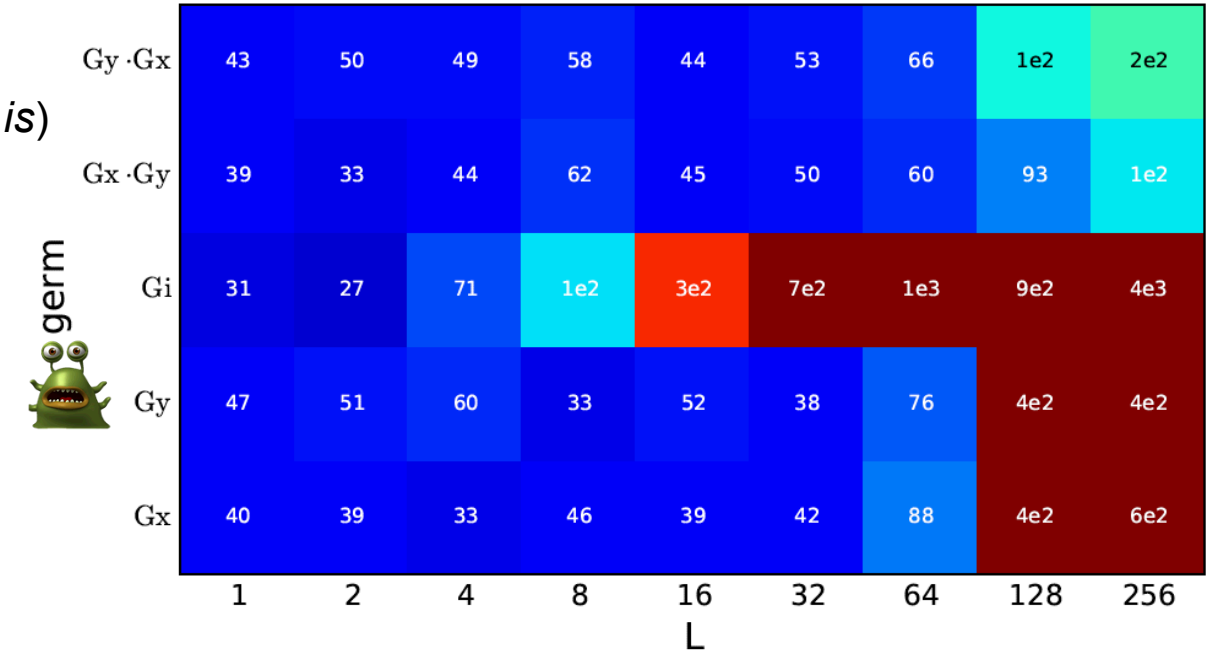
- EXPERIMENT: Added echoing pulses (BB1) to make the gates better
- GST:
  - This removed a fair amount of non-Markovian noise, but still some left
  - Gates are pretty good (see 1-F, angle, etc.)
  - The idle gate **Gi** seems worse than the rest

**Estimated Gates**
(if it were a qubit, and it *sort-of is*)

| | angle | 1-F |
|---|---|---|
| **Gi** | 0.0065π | 0.0026 |
| **Gx** | 0.5025π | 0.0010 |
| **Gy** | 0.5025π | 0.0010 |

$\chi^2$ (goodness of fit)



# Episode 3: Drift control (Dec., 2014)

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- EXPERIMENT:
  - Added drift control to improve the rotations.
- GST Results:
  - Still non-Markovian noise
  - **Gx** and **Gy** are better
  - **Gi** didn't improve, in fact…


**Estimated Gates**

(if it were a qubit, and it *sort-of is*)

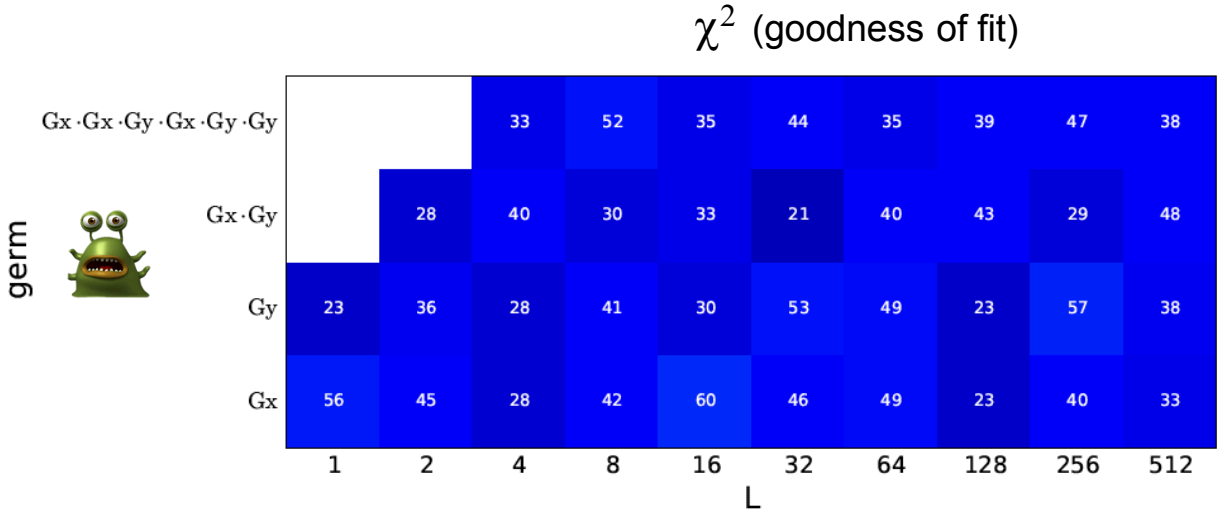
| | angle | 1-F |
|---|---|---|
| **Gi** | 0.0117π | 0.0035 |
| **Gx** | 0.5006π | 0.0003 |
| **Gy** | 0.5009π | 0.0001 |

# Episode 3 (continued)

- Further GST analysis:
  - The problem is with the **Gi** gate. if it's removed from the analysis, things look **Markovian** (the fit is good)

**Estimated Gates**
(if it were a qubit, **and it *is!!!***)

| | angle | 1-F |
|---|---|---|
| **Gx** | 0.5008π | 0.00005 |
| **Gy** | 0.5008π | 0.00005 |

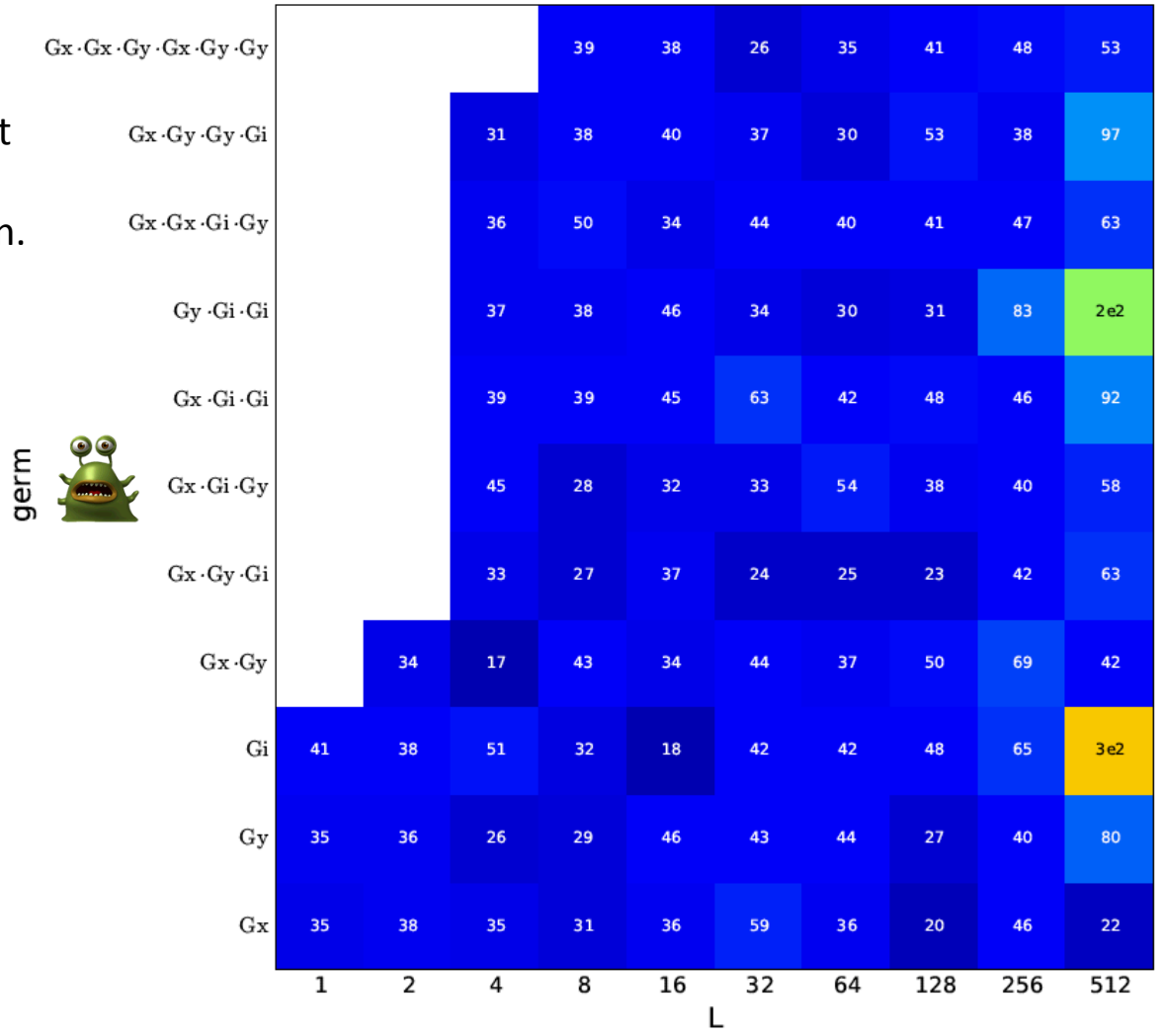


# Episode 4: Improved **Gi** compensation (Feb., 2015)

- EXP:
  - **Improved compensation on Gi gate**, which was not performing as well as the **Gx** and **Gy** compensation.
- GST Results:
  - **Markovian!**
  - Gates are good

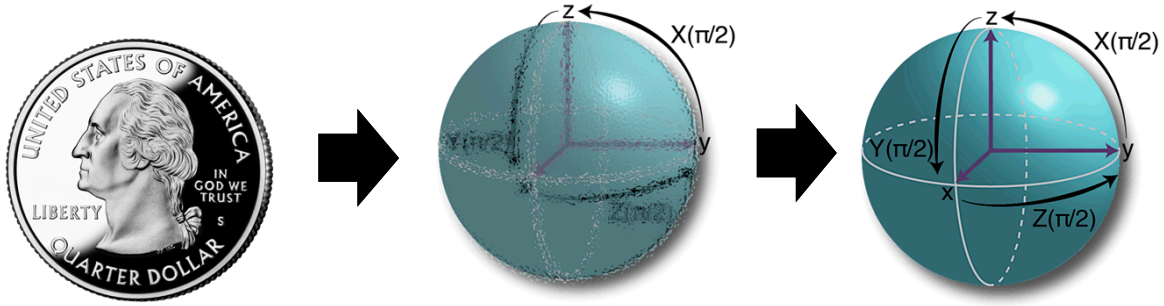
**Estimated Gates**
(if it were a qubit, **and it *is***)

| | angle | 1-F |
|---|---|---|
| **Gi** | 0.0017π | 0.0002 |
| **Gx** | 0.5013π | 0.0001 |
| **Gy** | 0.5014π | 0.0001 |



# Conclusions

- **Gate Set Tomography** is a ***robust*** framework for characterizing qubits.
- Gate Set Tomography has been **successfully used** to enhance the quality of a trapped ion qubit.




**Non-qubit** **Qubit** **Good qubit**

- If you have a qubit and would like to make it better then **GST is for you!** **Email us:**

enielse@sandia.gov

# GST **Myths**

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- **Myth**: GST is only for *good* qubits
  - GST is intended to operate in “harsh environments”, and extract as much information as possible from noisy data.
- **Myth**: GST is slow
  - GST takes minutes to run on typical datasets
- **Myth**: GST results are hard to interpret
  - GST reports include detailed explanation of what results mean.