The equipment needs to be at certain temperature:
• Electronics – room temp.
• Imaging sensors – low temp.

*Science Power = Produced Power - Thermal Power*
The Problem

Given: data for 3 Martian years:
- Year 1: 2008-08-22 to 2010-07-10
- Year 2: 2010-07-10 to 2012-05-27
- Year 3: 2012-05-27 to 2014-04-14

Predict: power consumption of 33 thermal lines for
- Year 4: 2014-04-14 to 2016-03-01 (per hour)
The Data

- Solar Aspect Angles (SAAF)
- Detailed Mission Operations Plan (DMOP)
  - subsystem on/off
- Flight Dynamics TimeLine with pointing events (FTL)
- Long term data
  - solar constant, mars-sun distance etc.
- Other events
  - Umbras, pen-umbras...

33 target attributes:
- Measured electric current every 30-60 seconds
Solar Aspect angles

- ut_ms: unix timestamp in milliseconds
- sa: angle of Mars Express solar panels' normal
- sx: solar angle of the X axis of satellite
- sy: solar angle of the Y axis of satellite
- sz: solar angle of the Z axis of satellite
Detailed Mission Operations Plan

- ut_ms: unix timestamp in milliseconds
- subsystem: name of the operated subsystem command

Unix timestamp, Subsystem
1219370500000, AXXX305A
1219370632000, AXXX3AFF
1219370819000, MAPO.0000008333
...
Other events:

Unix timestamp, Description
1219370500000, "1200_KM_DESCEND",
1219370632000, "MRB_AOS_10",
1219370819000, "800_KM_DESCEND",
1219370902000, "MAR_PENUMBRA_START",
1219370986000, "MAR_UMBRA_START",
1219371075000, "MAR_UMBRA_END",
...

Feature Construction

- Data time frame (resolution)
- Current solar radiation
- Solar radiation in the past
- DMOP and FTL (orbiter commands and pointing events)
Data time frame

- Power data (targets) typically measured in 30-60s intervals with a lot of gaps

- 1min time resolution (=time step)
  - Fixed 60s time step for entire data set
  - Remove larger gaps (5 or 10 time steps)
  - Linear interpolation and integration for continuous data (electric, solar power)

- 2.6 million examples!
For each of the 6 six sides of the orbiter + solar panels:

\[
A_E = A \max \{ \cos \alpha, 0 \}
\]

\[
\text{feat}(t_i) = \int_{t_i}^{t_{i+1}} A_E(t)c(t)U(t)dt
\]

Using orbiter orientation angles \( \alpha \), solar constant \( c \) and (pen)umbra coefficient \( U \).
Orbiter History

• Current orbiter state depends on its state in the past
• Lagged features
• Summed features

\[ \text{feat-sum}N(t_i) = \sum_{t=t_{i-1}}^{t_i-N} \text{feat}(t) \]

• \( N = 4, 16, 32, 64, 128 \)
DMOP and FTL Features

- DMOP: when different subsystems' commands have been triggered
  - Time since (max 1 day) activation for:
    - all command/subsystem pairs
    - any command for a given subsystem

- FTL: when different spacecraft pointing events took place + communication with Earth
  - Event Active/Inactive
Final Data Set

- 1 min time resolution
- 465 features
- 2.6M examples
- 7.4 GB

Newer versions:
- 1 and 2 min time resolution
- Lagged and summed DMOP and FTL
- 600 and 1200 features
- 2.6M and 1.3 M examples
- 17 GB
What we tried:

- Predictive Clustering Trees (PCTs)
- Random Forests of PCTs
- Single target and multi target prediction
- Clustering of targets to combine ST and MT
- Tuning of RF parameters
- All data (years 1+2+3) and only recent data (3rd year)
- A few different data sets
- Feature ranking
- Ensemble of ensembles
- Extreme Gradient Boosting
- ...
What worked best?

- Random Forests of PCTs:
  - 200 trees in ensemble
  - minimum of 500 examples in tree leafs
  - consider ¼ of all features (instead of sqrt)
- Smaller data set (465 features, 2.6M examples, 7.4 GB)
- Single target prediction (6th place -> 1st place)
- Training time: ~15h per target
- ~100 Gb of RAM
What the Others Did?

- 1h time resolution
- Extreme Gradient Boosting, Neural Nets, Ensembles of ensembles
- Multi target to single target conversion (new attribute specifying the target):

Original dataset (F=Feature, L=Power Line):

<table>
<thead>
<tr>
<th>F1</th>
<th>F2</th>
<th>L1</th>
<th>L2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>1.9</td>
<td>1.2</td>
<td>0.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Flattened dataset (LID = Line ID):

<table>
<thead>
<tr>
<th>F1</th>
<th>F2</th>
<th>LID</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>0.2</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>1.3</td>
<td>0.2</td>
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<tr>
<td>1.9</td>
<td>1.2</td>
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<tr>
<td>1.9</td>
<td>1.2</td>
<td>2</td>
<td>0.7</td>
</tr>
</tbody>
</table>
## Leaderboard

<table>
<thead>
<tr>
<th>Name</th>
<th>Submissions</th>
<th>Last Submission</th>
<th>Best Submission</th>
<th>Best Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMMe8</td>
<td>21</td>
<td>July 30, 2016, 9:17 a.m.</td>
<td>July 30, 2016, 9:17 a.m.</td>
<td>0.0803769211622248</td>
</tr>
<tr>
<td>redrock</td>
<td>58</td>
<td>July 29, 2016, 11:39 p.m.</td>
<td>July 29, 2016, 11:39 p.m.</td>
<td>0.0804496833344005</td>
</tr>
<tr>
<td>fornaxintospace</td>
<td>58</td>
<td>July 29, 2016, 7:38 p.m.</td>
<td>July 29, 2016, 7:38 p.m.</td>
<td>0.0819239101733324</td>
</tr>
<tr>
<td>Alex</td>
<td>42</td>
<td>July 22, 2016, 8:24 p.m.</td>
<td>July 22, 2016, 8:22 p.m.</td>
<td>0.0846394180545192</td>
</tr>
<tr>
<td>trnka</td>
<td>38</td>
<td>July 29, 2016, 9:12 p.m.</td>
<td>May 22, 2016, 8:23 a.m.</td>
<td>0.0906015604695004</td>
</tr>
<tr>
<td>w</td>
<td>49</td>
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<tr>
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<td>May 25, 2016, 5:52 p.m.</td>
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<td>Mars_km.dfldi</td>
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<tr>
<td>Name</td>
<td>Submissions</td>
<td>Last Submission</td>
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<tr>
<td>redrock</td>
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<td>July 31, 2016, 11:57 p.m.</td>
<td>July 31, 2016, 11:48 p.m.</td>
<td>0.0802580418739296</td>
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<tr>
<td>MMMMe8</td>
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<tr>
<td>fornaxintospace</td>
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<td>July 29, 2016, 7:38 p.m.</td>
<td>0.0819239101733324</td>
</tr>
<tr>
<td>Alex</td>
<td>42</td>
<td>July 22, 2016, 8:24 p.m.</td>
<td>July 22, 2016, 8:22 p.m.</td>
<td>0.0846394180545192</td>
</tr>
<tr>
<td>luis</td>
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<td>July 31, 2016, 11:56 p.m.</td>
<td>July 31, 2016, 11:56 p.m.</td>
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<tr>
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<td>trnka</td>
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<td>May 22, 2016, 8:23 a.m.</td>
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<tr>
<td>Gagan@Gowda</td>
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## Results

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name</th>
<th>Submission Date (UTC)</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MMMe8</td>
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<td>0.079163638689759465</td>
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<td>0.081925542258189737</td>
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<td>4</td>
<td>Alex</td>
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<td>0.083848704280679837</td>
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<td>5</td>
<td>luis</td>
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<td>7</td>
<td>trnka</td>
<td>May 22, 2016, 6:23 a.m.</td>
<td>0.089866726592717425</td>
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<tr>
<td>8</td>
<td>Gagan@Gowda</td>
<td>July 31, 2016, 8:39 p.m.</td>
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<td>9</td>
<td>vasesan</td>
<td>July 30, 2016, 3:42 p.m.</td>
<td>0.096190288456035195</td>
</tr>
</tbody>
</table>
Special Thanks

CNI JSI & ARNES
Team