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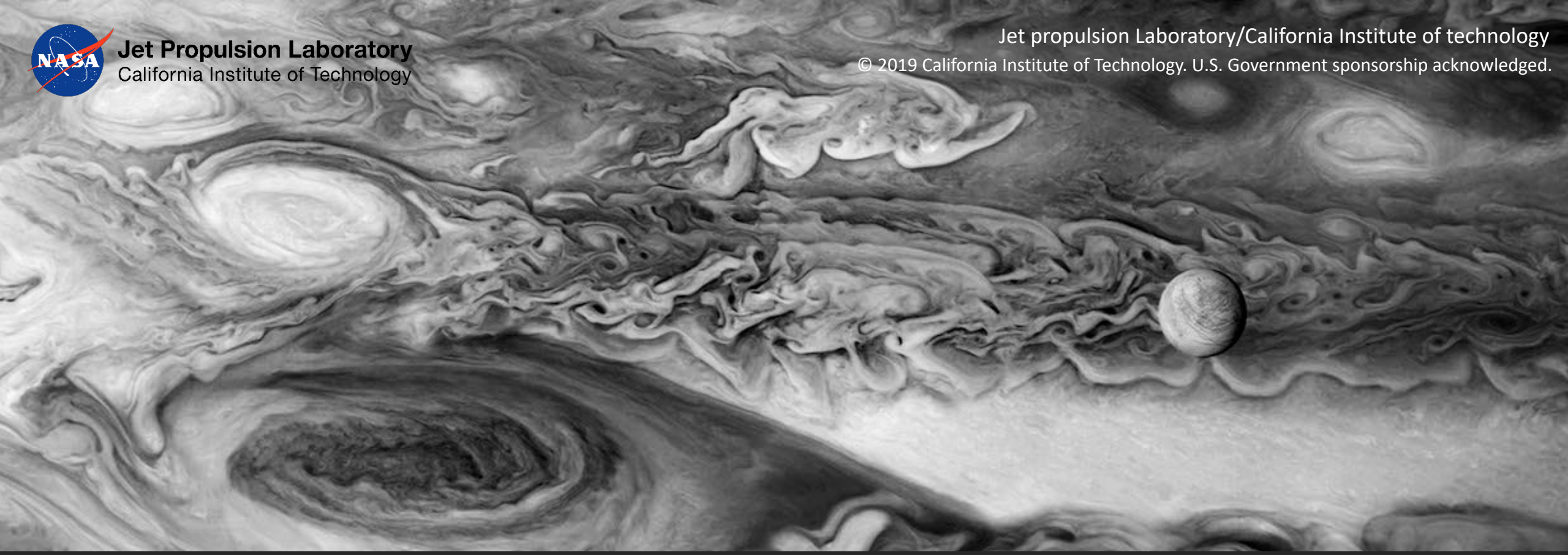

Informing Instrument and Spacecraft Requirements through Statistical Analysis

DATAWorks 2019

Thomas Youmans, Kelli McCoy, Amy Braverman, Hayden Burgoyne, Manny Uy (APL), Vineet Yadav

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Motivation & Method

Motivation

- Get the right requirements for Instrument and Spacecraft Fault Rate and Recovery Time
- Inform requirements for Instruments and Spacecraft for Europa Clipper tour

Method

- Modeling system directly is not practical
- Variance of Fault Rates is not known
- Create a method to adequately sample the system
- Model Results in order to understand trends, inform Fault Rate & Recovery Time trades

Factors in Trades and Key Questions

For each instrument…

- Inst #1
- Inst #2
- Inst #3
- …
- Inst #7
- Inst #8
- Inst #9

Used and required differently

- Support different numbers of Science Objectives
- Used at different times
- On for different durations

Updated differently

- Pain of decreasing Fault Rate for each instrument varies
- Pain of adding Recovery for each instrument varies
- Pain for decreasing Recovery Time for each instrument varies

Spacecraft is it's own Beast

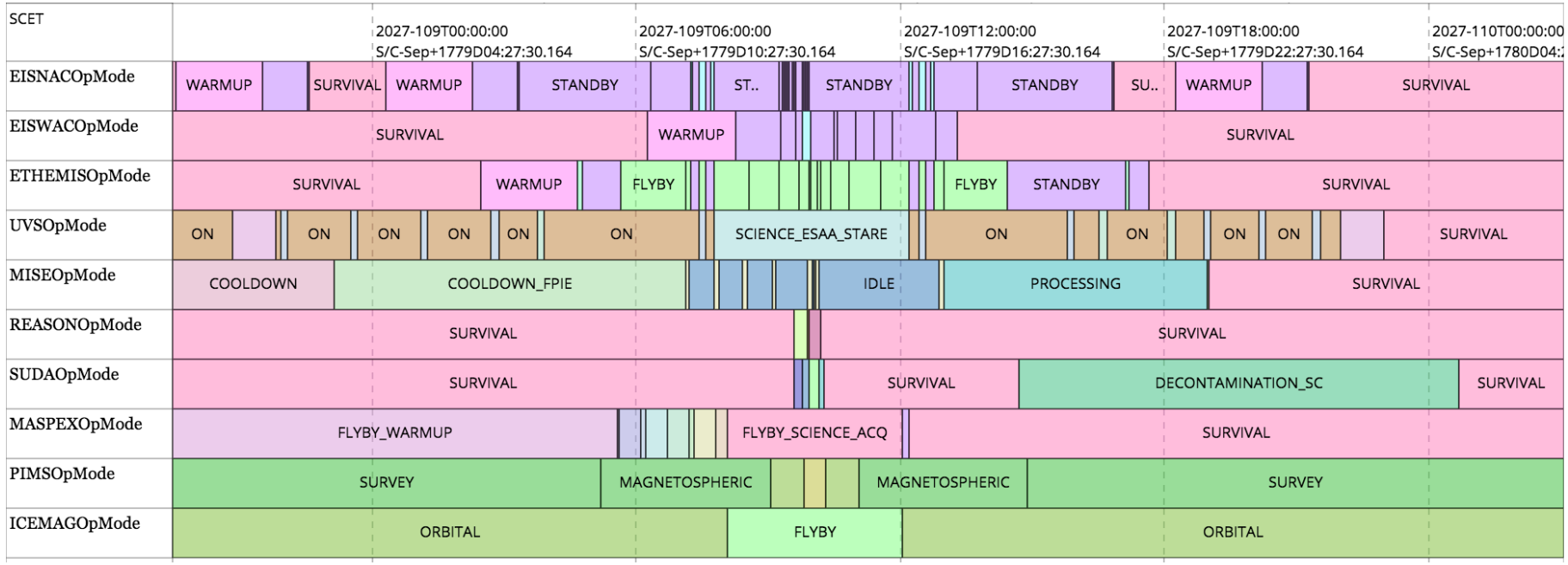
- Changing Spacecraft Fault Rate through radiation hardening is not a snap-of-the fingers
- Options for Spacecraft Recovery time vary greatly, in applicability, cost, capability

---

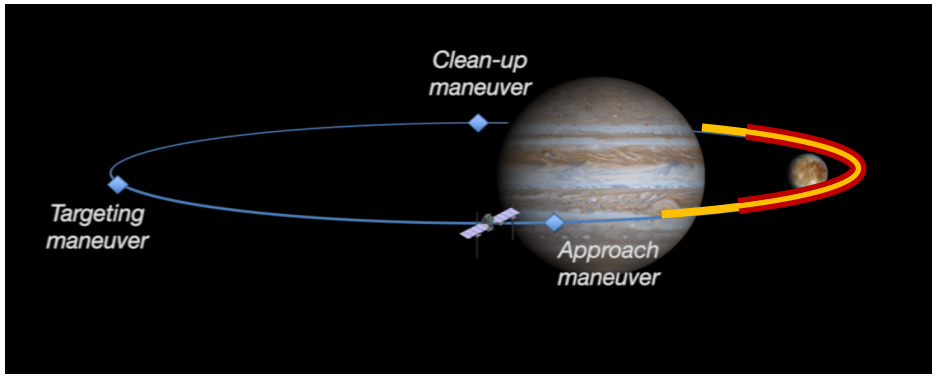
- What are the highest Fault Rates we can tolerate?
- Are some instrument Fault Rates major drivers of P(Science Success)?
- Are certain combinations of specific Instrument Fault Rates important?

Instrument Ops & Radiation is Non-Linear

Instruments operational timeline and effect of radiation is highly non-linear



Instruments need to be on at different times



Radiation is highest around Europa

Fault rates for High and Low Radiation zones are used

Framework for Reaching Results

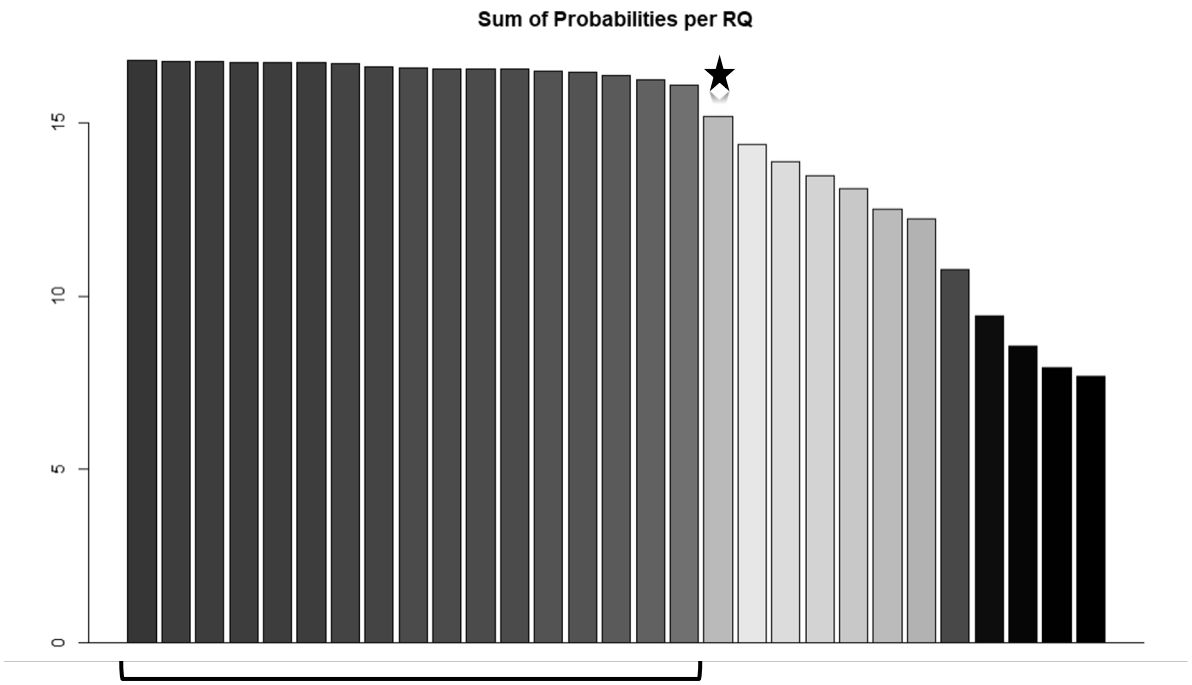
Tree → Sampling → Models → Response Surfaces → Analysis

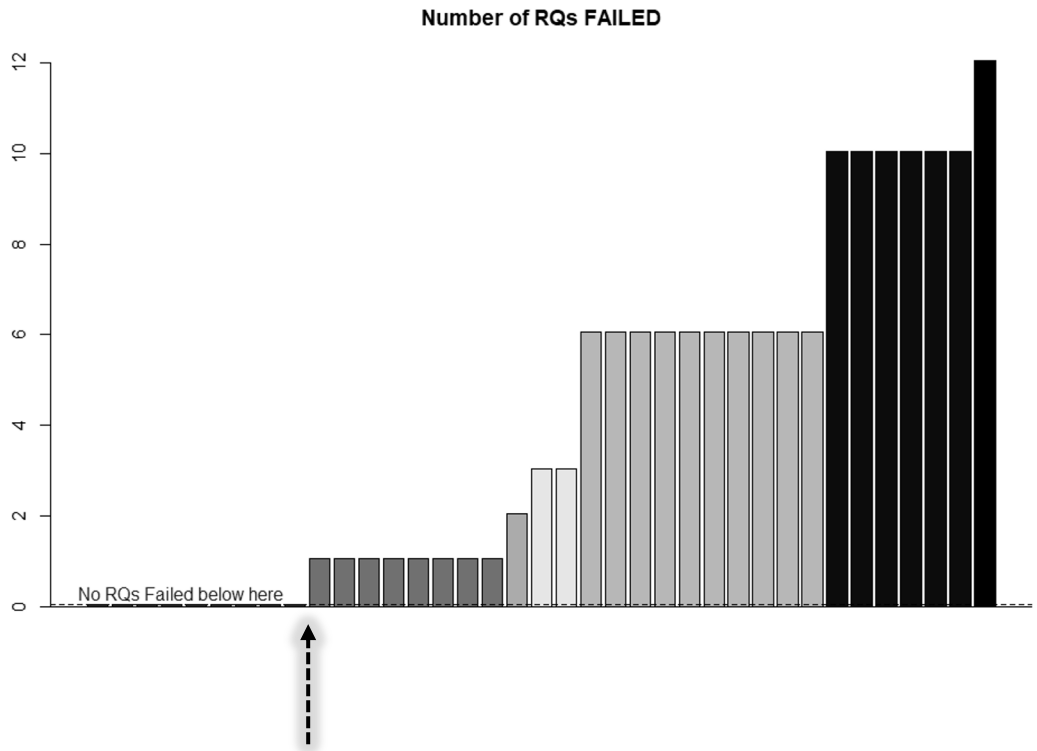
- For cases where were ALL of the P(Science Objective$_j$ Met)
  - Max allowable fault rates and min recovery times?
  - How do they DIFFER from the failed cases?
  - Is recovery necessary?
  - Are some specific instruments or instrument combinations major drivers of overall Science Success?

- Which cases had the highest probability of total Science Objective success?
  - Did any instruments in particular drive the maximum overall P(Science Success)?

Are Some Scenarios Best?

Some options are definitely better than others





What Parameters Put us in the Best Area?

Simple filtering gives a bounding for what fault and recovery rates keep us in the higher Prob. area

Case #	1a, SC Avg Fault per Orbit, Exponential	1b, low Rad	1c, High Rad	2, SC Recovery	3, In Avg Fault Rate per Orbit	4, Inst Recovery	7, Rec rate used_safing_All instruments	'l1reqid_RQ106.312'	'l1reqid_RQ106.323'	'l1reqid_RQ106.317'	'l1reqid_RQ106.325'	'l1reqid_RQ106.318'	'l1reqid_RQ106.328'	'l1reqid_RQ106.313'	'l1reqid_RQ106.327'	'l1reqid_RQ106.316'	'l1reqid_RQ106.321'	'l1reqid_RQ106.320'	'l1reqid_RQ106.322'	'l1reqid_RQ106.319'	'l1reqid_RQ106.326'	'l1reqid_RQ106.311'	'l1reqid_RQ106.314'	'l1reqid_RQ106.324'	SUM Tot
01a	*0.00*	*0.00*	*0.00*	*0*	*0.00*	*0*	*0.68*	*0.99*	*0.99*	*0.91*	*1.00*	*0.98*	*1.00*	*1.00*	*1.00*	*0.97*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*16.83*
12c	0.06	0.00	0.06	40	0.06	60	0.68	0.98	0.99	0.90	1.00	0.98	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.80
12a	0.06	0.00	0.06	1	0.06	60	0.68	0.98	0.98	0.89	1.00	0.98	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.78
12d	0.06	0.00	0.06	60	0.06	60	0.68	0.98	0.98	0.89	1.00	0.97	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.76
12e	0.06	0.00	0.06	80	0.06	60	0.68	0.98	0.98	0.89	1.00	0.97	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.75
12b	0.06	0.00	0.06	20	0.06	60	0.68	0.98	0.99	0.87	1.00	0.98	1.00	1.00	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.75
12f	0.06	0.00	0.06	100	0.06	60	0.68	0.98	0.98	0.87	1.00	0.97	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.74
12i	0.06	0.00	0.06	600	0.06	60	0.68	0.97	0.98	0.90	1.00	0.95	1.00	1.00	1.00	0.92	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	16.70
12g	0.06	0.00	0.06	200	0.06	60	0.68	0.97	0.98	0.78	1.00	0.97	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.63
09b	0.13	0.00	0.12	60	0.13	60	0.48	0.97	0.98	0.74	1.00	0.97	1.00	1.00	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.58
12h	0.06	0.00	0.06	400	0.06	60	0.68	0.95	0.96	0.77	1.00	0.95	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.57
12k	0.06	0.00	0.06	1000	0.06	60	0.68	0.93	0.94	0.90	1.00	0.93	1.00	1.00	1.00	0.90	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	16.56
12j	0.06	0.00	0.06	800	0.06	60	0.68	0.93	0.94	0.87	1.00	0.94	1.00	1.00	1.00	0.89	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	16.55
08e	0.71	0.03	0.68	60	0.71	60	0.68	0.95	0.96	0.71	1.00	0.96	1.00	1.00	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.50
09c	0.25	0.01	0.24	60	0.25	60	0.48	0.95	0.97	0.69	1.00	0.96	1.00	1.00	1.00	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	16.45
08b	0.71	0.03	0.68	60	0.71	60	0.68	0.94	0.95	0.66	1.00	0.96	1.00	1.00	1.00	0.87	1.00	1.00	1.00	0.99	0.99	1.00	1.00	1.00	16.36
08f	0.71	0.03	0.68	60	0.71	60	0.68	0.92	0.95	0.63	1.00	0.95	1.00	1.00	1.00	0.86	1.00	1.00	1.00	0.98	0.98	1.00	1.00	1.00	16.25
09d	0.50	0.02	0.48	60	0.50	60	0.48	0.90	0.92	0.55	1.00	0.94	1.00	1.00	1.00	0.83	1.00	0.99	0.99	0.98	0.98	1.00	1.00	1.00	16.08
02a	0.06	0.00	0.06	20160	0.06	20160	0.68	0.87	0.91	0.33	1.00	0.92	1.00	1.00	1.00	0.66	1.00	0.99	0.99	0.96	0.96	1.00	1.00	1.00	15.58
09e	1.00	0.03	0.97	60	1.00	60	0.48	0.75	0.81	0.33	1.00	0.90	1.00	1.00	1.00	0.63	1.00	1.00	1.00	0.90	0.90	1.00	1.00	1.00	15.19
10a	2.00	0.07	1.93	1	2.00	60	0.68	0.71	0.77	0.08	0.98	0.90	1.00	1.00	1.00	0.42	1.00	0.98	0.98	0.78	0.78	1.00	1.00	1.00	14.36
02b	0.13	0.00	0.12	20160	0.13	20160	0.68	0.66	0.73	0.09	0.97	0.85	1.00	1.00	1.00	0.32	1.00	0.98	0.98	0.68	0.68	1.00	1.00	1.00	13.92
10b	2.00	0.07	1.93	20	2.00	60	0.68	0.60	0.67	0.06	0.97	0.87	1.00	1.00	1.00	0.36	1.00	0.98	0.98	0.70	0.70	1.00	1.00	1.00	13.88
10c	2.00	0.07	1.93	40	2.00	60	0.68	0.55	0.64	0.08	0.95	0.85	1.00	1.00	1.00	0.33	1.00	0.98	0.98	0.57	0.57	1.00	1.00	1.00	13.49
10d	2.00	0.07	1.93	60	2.00	60	0.68	0.49	0.59	0.09	0.94	0.84	1.00	1.00	1.00	0.26	1.00	0.97	0.97	0.47	0.47	1.00	1.00	1.00	13.09
10e	2.00	0.07	1.93	80	2.00	60	0.68	0.41	0.54	0.06	0.91	0.84	1.00	1.00	1.00	0.20	1.00	0.96	0.96	0.32	0.32	1.00	1.00	1.00	12.52
10f	2.00	0.07	1.93	100	2.00	60	0.68	0.36	0.48	0.06	0.88	0.82	1.00	1.00	1.00	0.18	1.00	0.95	0.95	0.28	0.28	1.00	1.00	1.00	12.23
02c	0.25	0.01	0.24	20160	0.25	20160	0.68	0.24	0.36	0.01	0.77	0.75	1.00	1.00	1.00	0.04	1.00	0.94	0.94	0.15	0.15	1.00	1.00	1.00	11.34
08a	0.71	0.03	0.68	20160	0.71	20160	0.68	0.26	0.33	0.01	0.67	0.70	1.00	1.00	1.00	0.05	1.00	0.85	0.85	0.21	0.21	1.00	1.00	1.00	11.15
10g	2.00	0.07	1.93	200	2.00	60	0.68	0.14	0.23	0.05	0.72	0.73	1.00	1.00	1.00	0.05	1.00	0.89	0.89	0.04	0.04	1.00	1.00	1.00	10.77
10h	2.00	0.07	1.93	400	2.00	60	0.68	0.01	0.03	0.02	0.43	0.57	1.00	1.00	1.00	0.00	1.00	0.69	0.69	0.00	0.00	1.00	1.00	1.00	9.44
02d	0.50	0.02	0.48	20160	0.50	20160	0.68	0.01	0.04	0.00	0.25	0.54	1.00	1.00	1.00	0.00	1.00	0.72	0.72	0.00	0.00	1.00	1.00	1.00	9.30

50% used for pass/fail for first rounds of bounding system

First Pass Observations

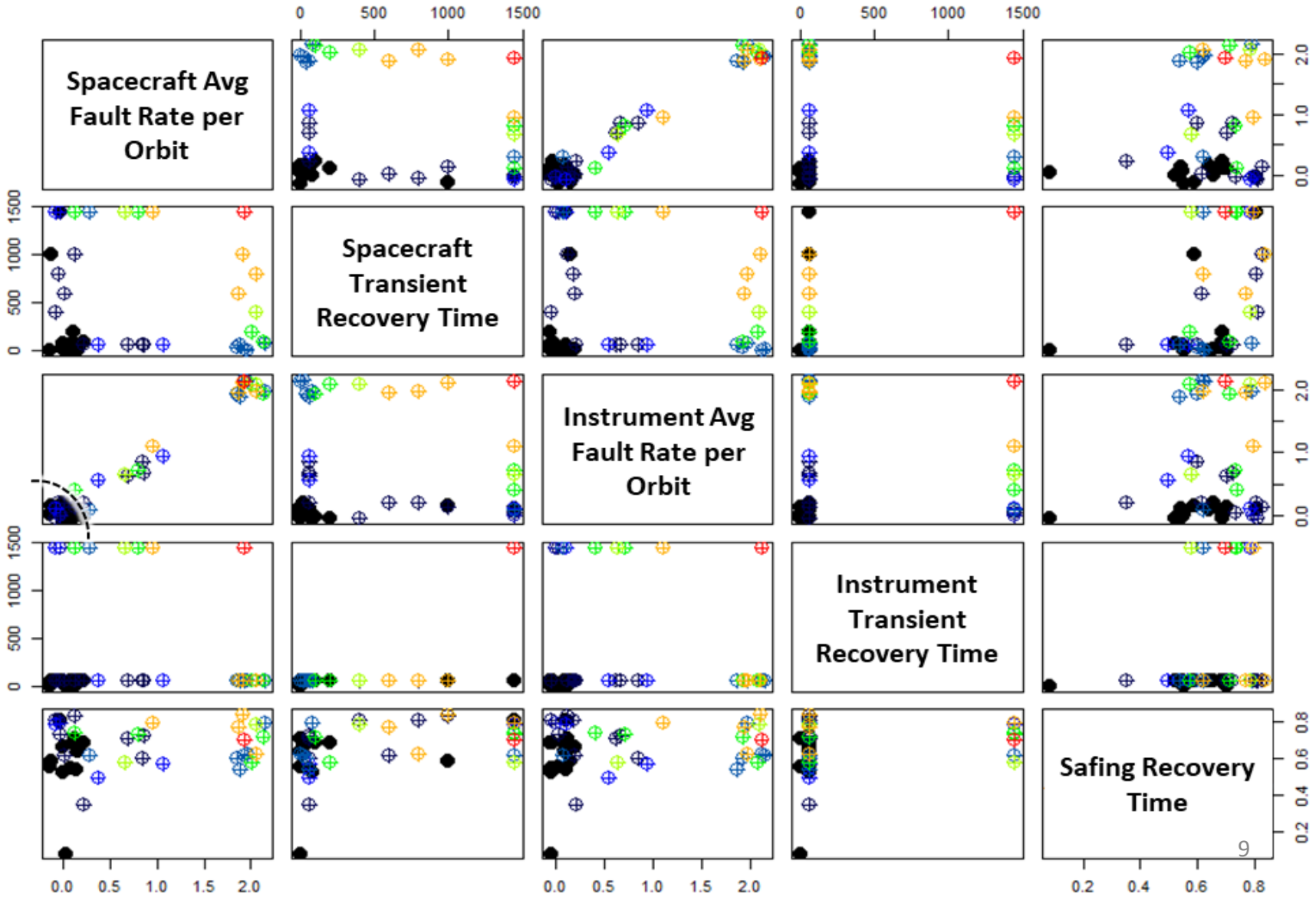
There may be some trends in Spacecraft x Instrument Fault Rate v P(Success)

We should pay extra attention to this

Fault rate and Recovery sensitivity summary.

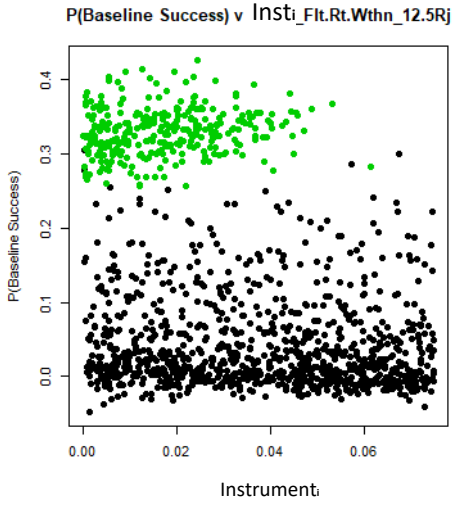
P(All Sci Objectives Met)
Black: High
Blue: Med-High
Green: Medium
Orange: Med-Low
Red: Low

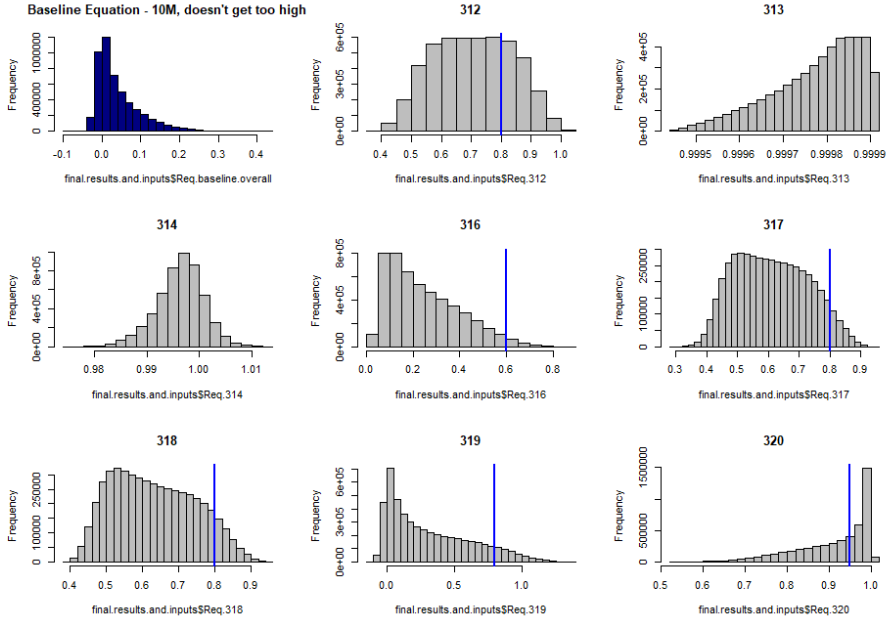
Solid points = all L1s are achieved



Finding Trends

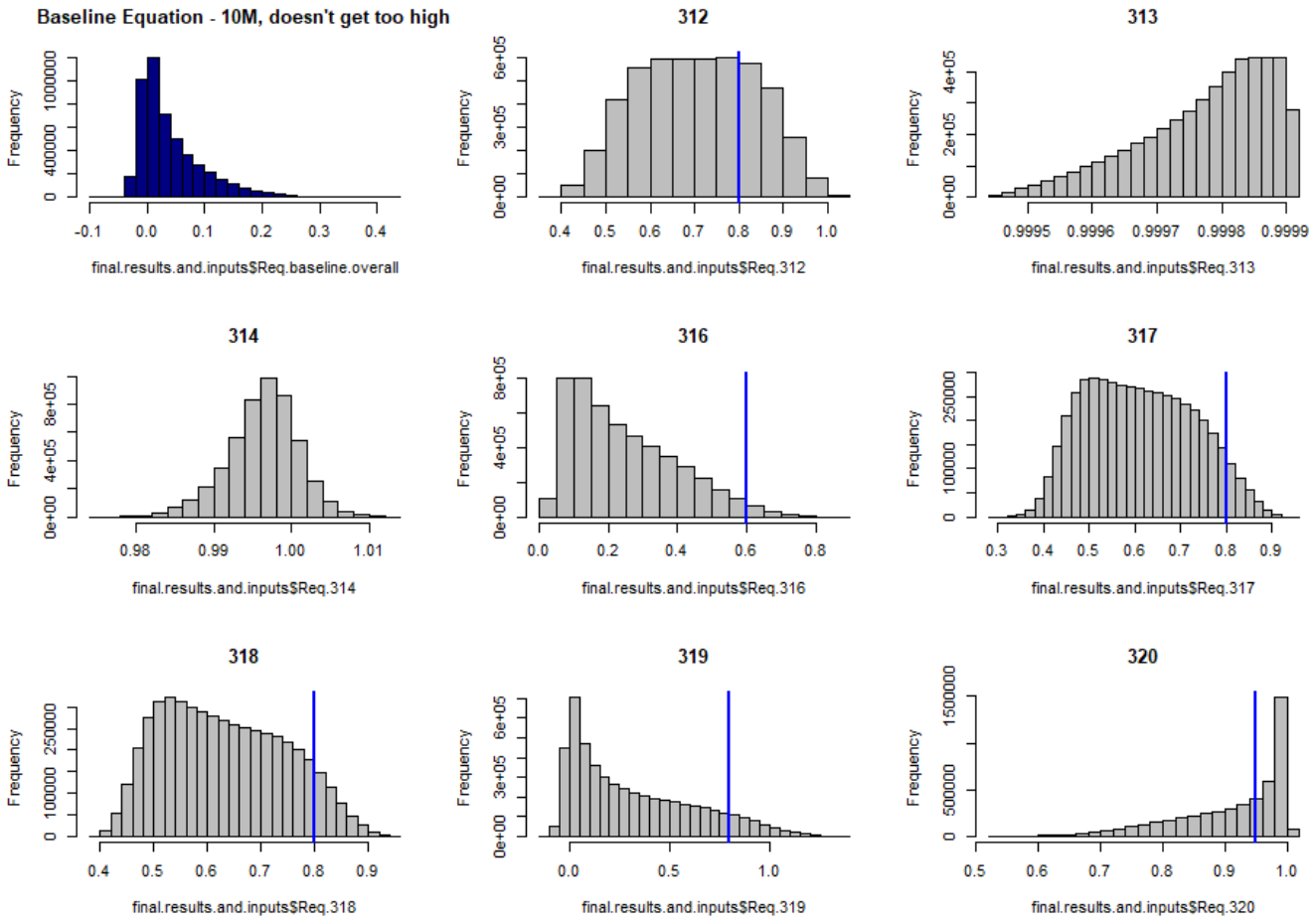
- Make trades on which instruments can have high fault rates
  - What probabilities are attainable
  - Find trends in Scenarios that meet threshold
  - Find key Instrument fault rates that DO or DO NOT effect P(Science Success)





Probability Thresholds

We need to see what probabilities constitute the "top" P(Science Objective$_j$) range of outputs



These aren't the resulting probabilities of meeting our science requirements, these are used in determining relative effects per instrument

Science Objectives Met, Tolerable Fault Rates

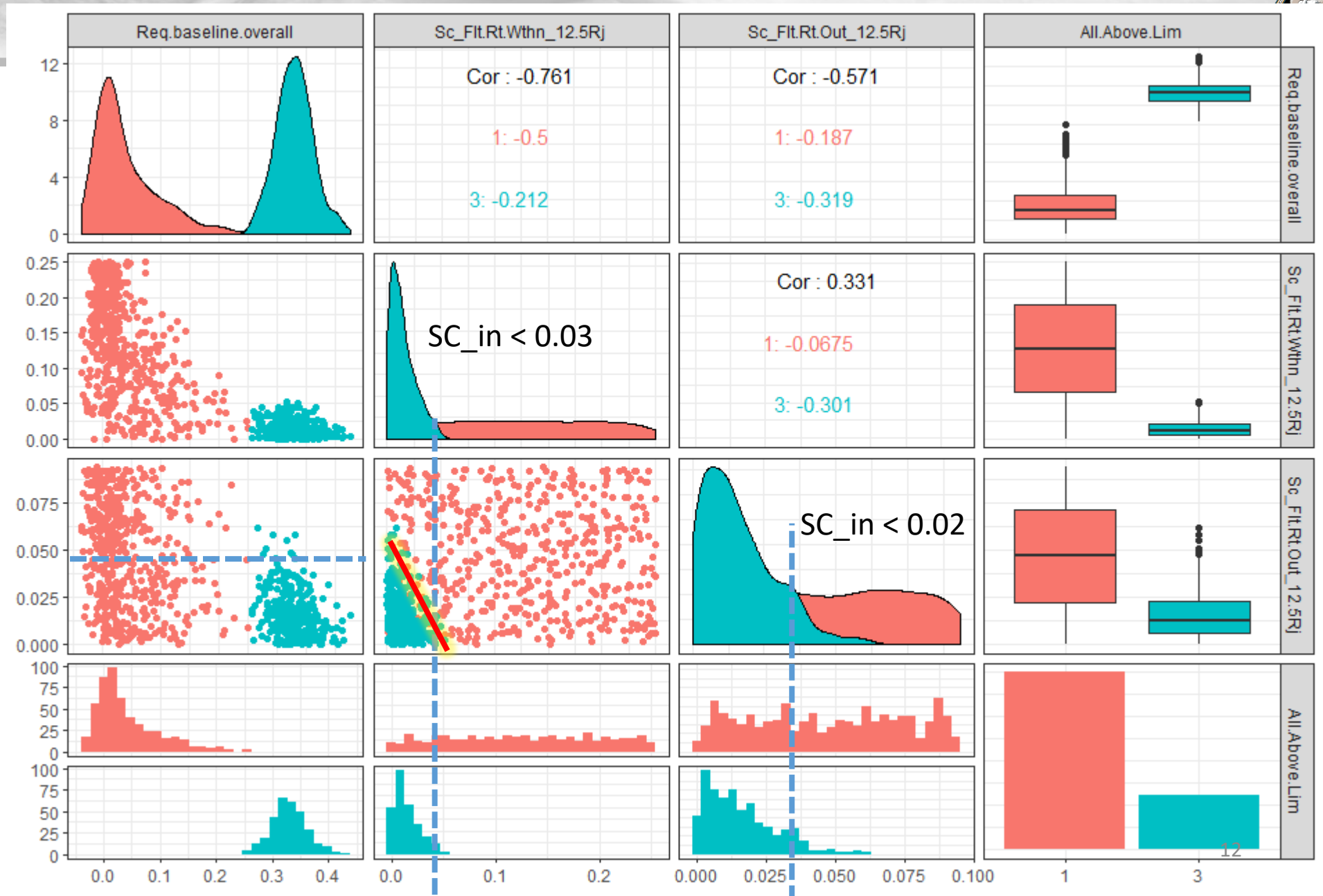
Scenarios that meet key threshold

Teal: Runs that passed all requirements

Salmon: Runs that didn't pass all requirements

We can see that there are **limits on the size of Spacecraft Fault Rate** *within* and *outside* of the High Radiation zone

There are also limits on the **total sum of High and Low Rad zone fault rates**



Which Instruments NEED to be Rad Hard?

Scenarios that meet key threshold

Teal: Runs that passed all requirements

Salmon: Runs that didn't pass all requirements

Some instruments can tolerate at GREATER average Fault Rate

Some instruments need their own fault rates and the fault rates of another instrument to be below a certain level

Recovery or No Recovery?

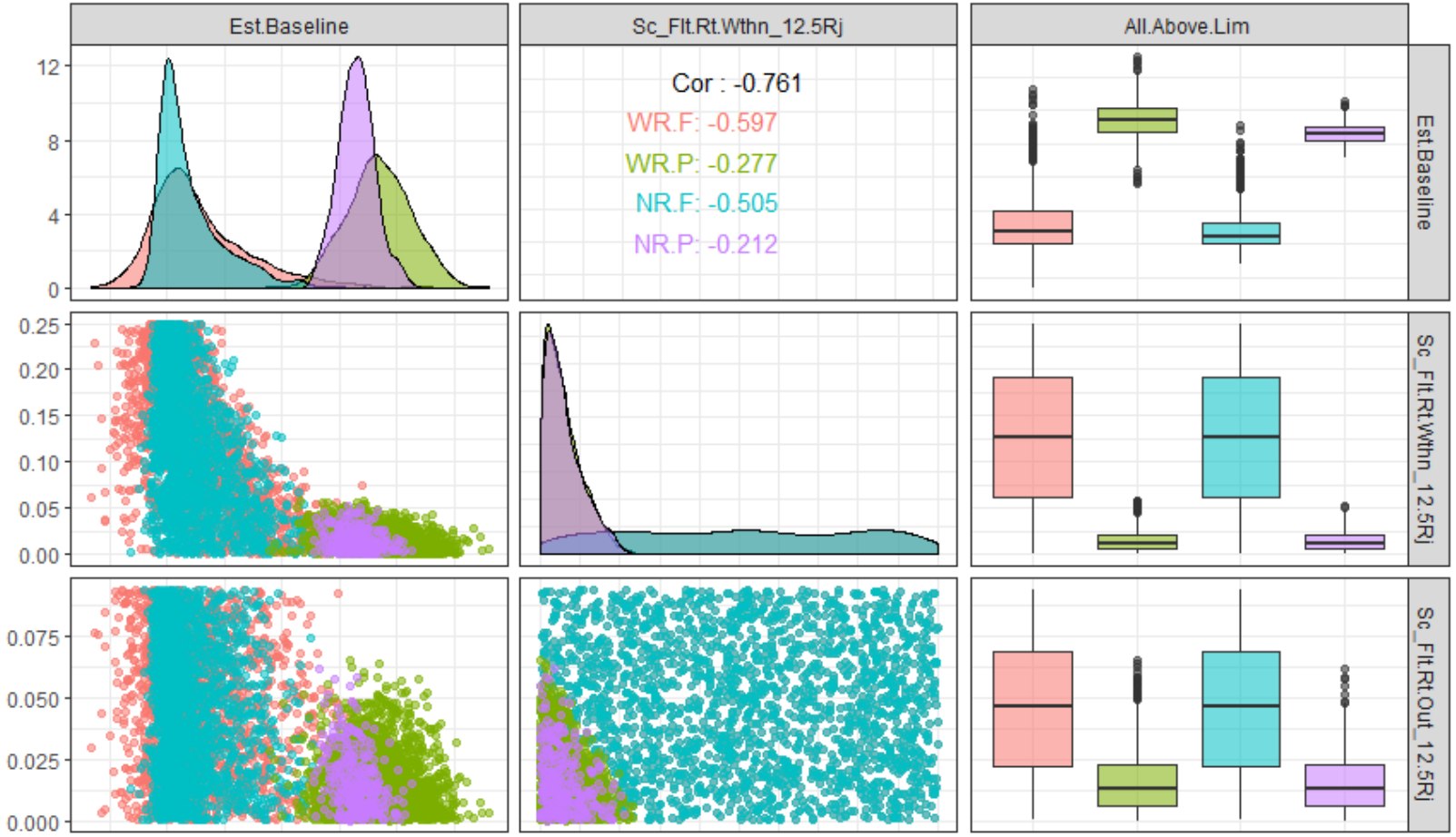
How does instruments and spacecraft recovery effect Fault Rate tolerance?

WR.F - With Recovery, Fail

WR.P - With Recovery, Pass

NR.F - NO Recovery, Fail

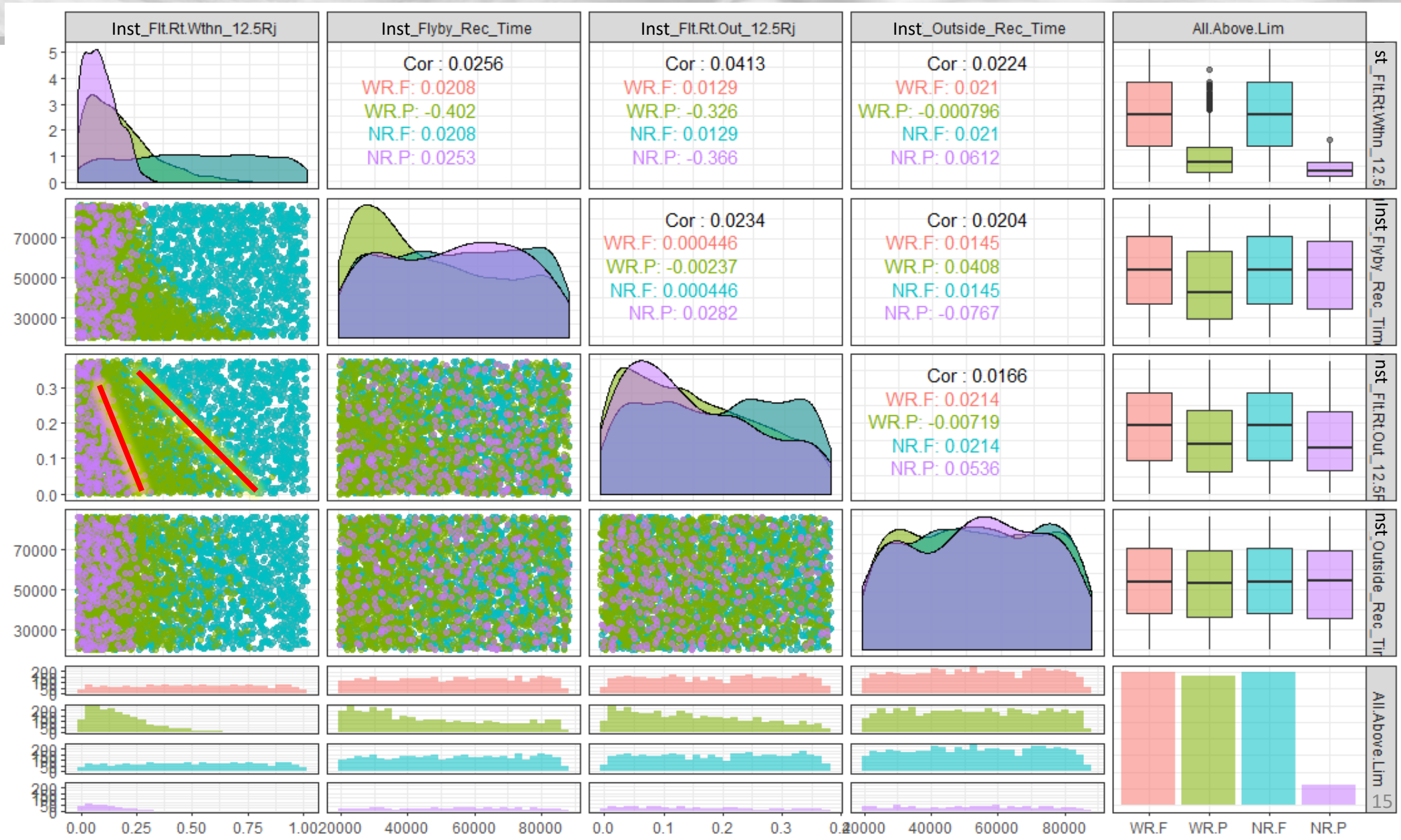
NR.P - NO Recovery, Pass



Where Recovery Offers Major Gains

Green: Successful scenarios WITH recovery can have much higher fault rates

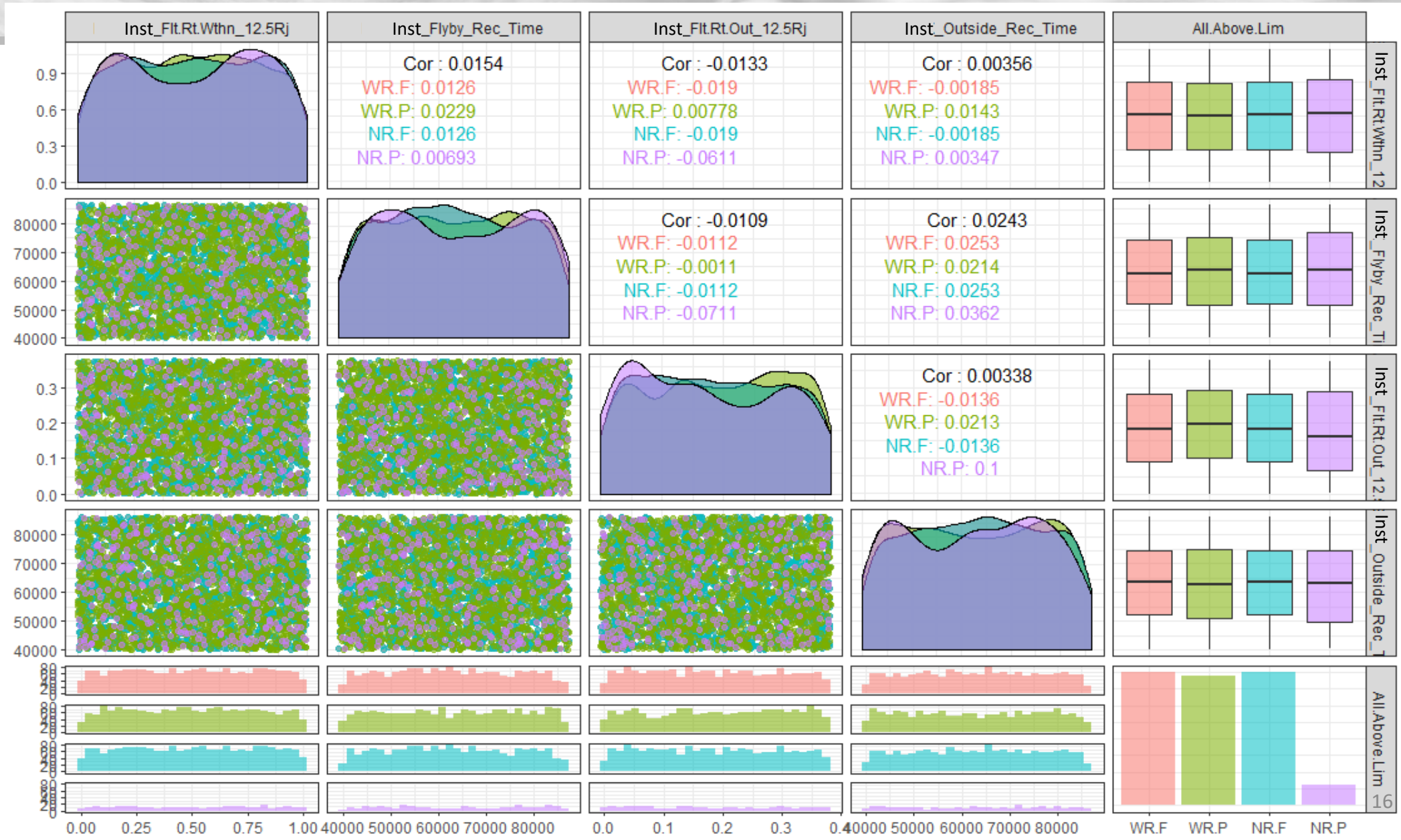
Purple: Successful scenarios w/ out recovery need lower failure rates



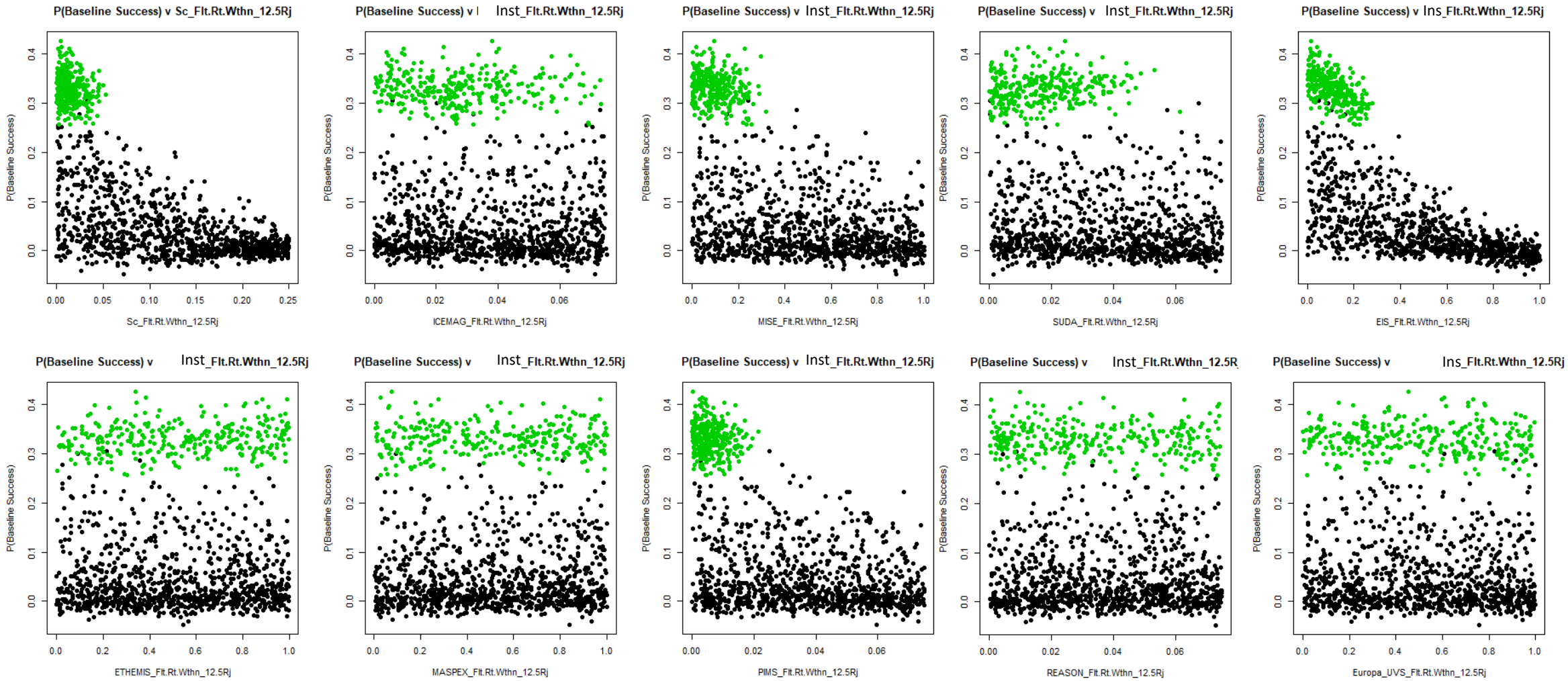
Where Recovery Offers No Gains

Green: Recovery doesn't buy increased Fault rate tolerance in the ranges tested

Purple: No recovery doesn't change tolerable Fault Rates in the ranges tested



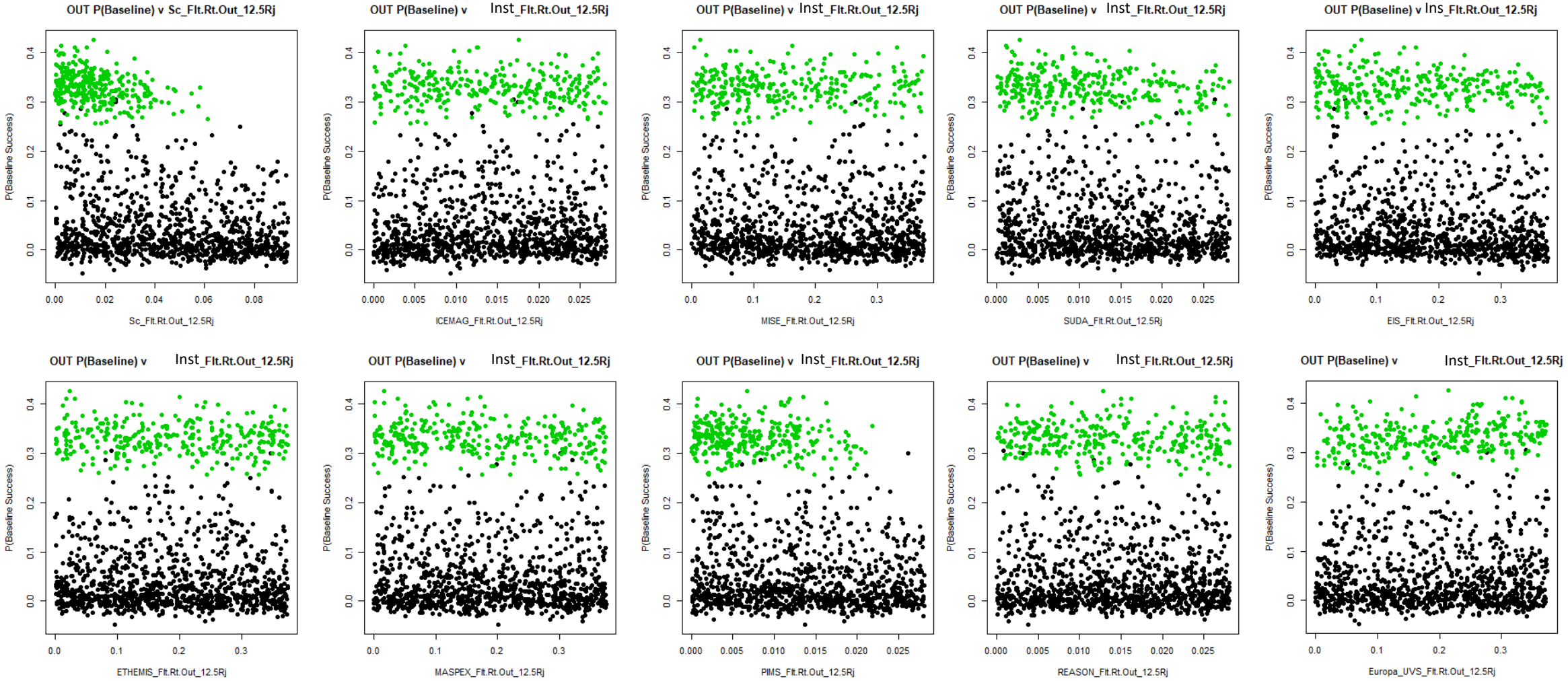
P(Science Goals) v Instrument Fault Rates



Y-axis is probability of meeting set of all baseline L1s

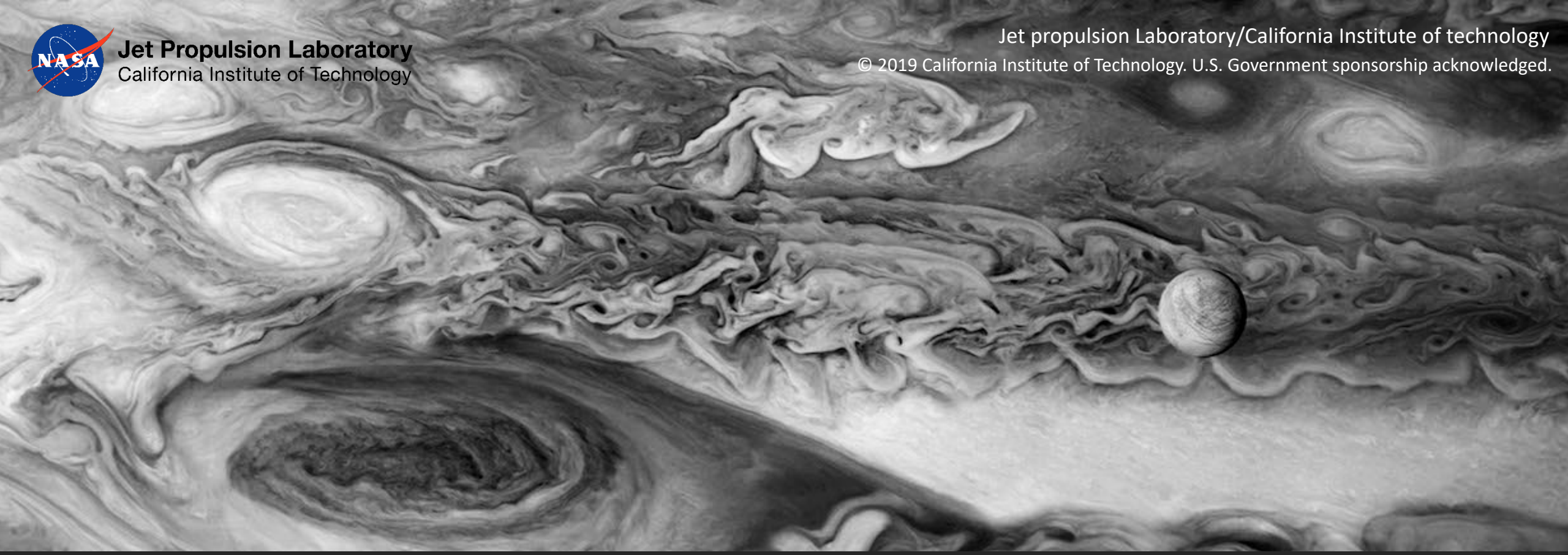
X-axes are each of the input fault rates inside the flyby region

P(Science Goals) v Instrument Fault Rates



Y-axis is probability of meeting set of all baseline L1s

X-axes are each of the input fault rates inside the flyby region



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Thank you

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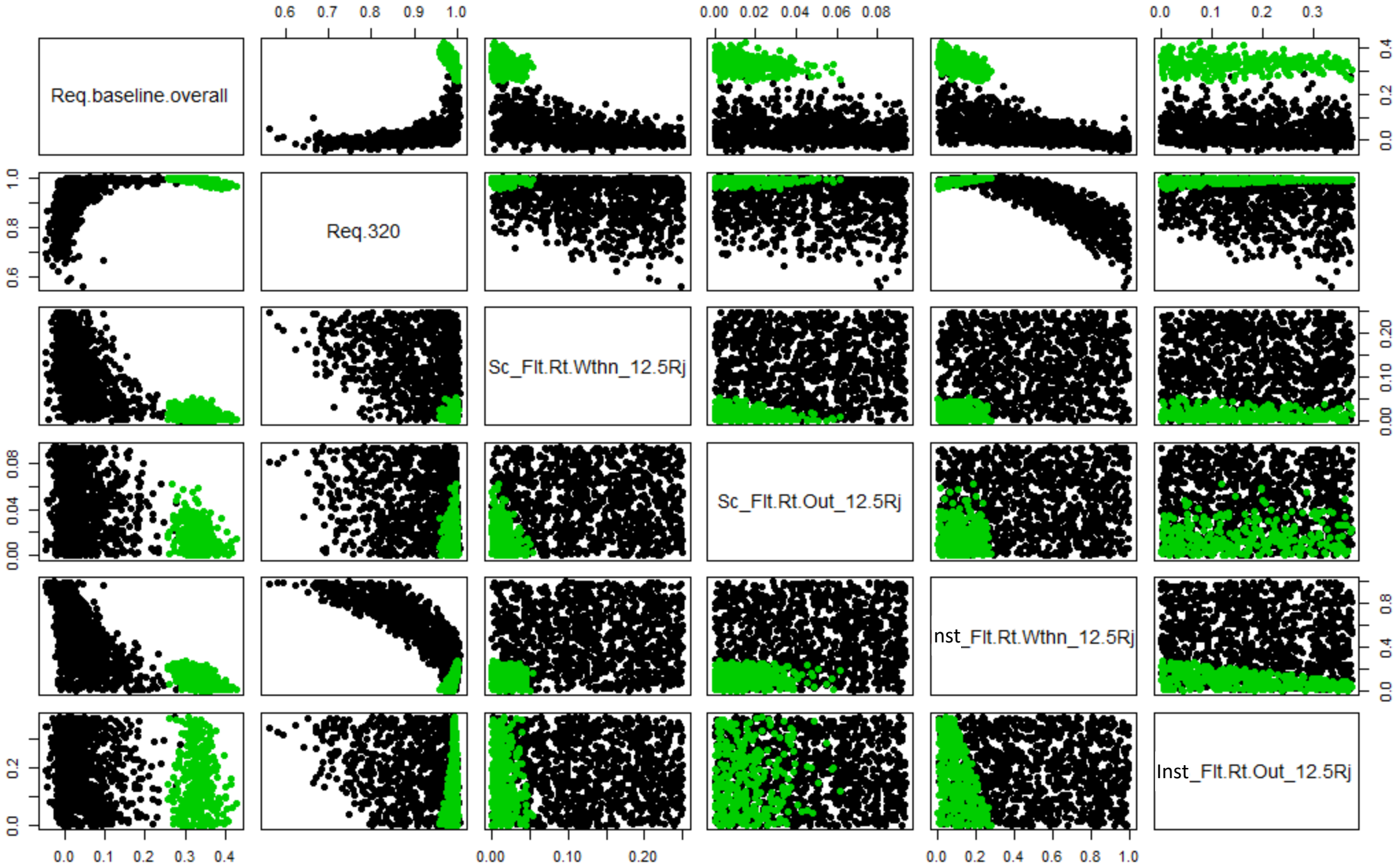
Backup

For reach Requirement, how to the relationships in the Pass All Thresholds v the other samples compare?



Target Questions from Analysis

Most Beneficial Questions to Answer

- Are there instruments where added recovery time doesn't increase P(Achieve Science Object #n)?
- For which instruments does an increase in Fault Rate not decrease P(Achieve Science Objective #n)?
- Are there thresholds where decreasing Fault Rate beyond a certain level ceases to add benefits?
- Are there Combinations of Instrument and Spacecraft Fault Rate or Recovery Time that produce significantly different results?
- *Are there trades were certain combinations of Fault Rates and Recovery Times, across sets of instruments, yield unusually favorable or dis-favorable results?*

Getting Output from the System

- The system doesn't have known variances per instrument to use to algebraically roll things up
- We need to get to a probabilistic output
- We will sample the system,
  - Testing different fault rates and recovery times at the lowest nodes (the instruments themselves)
  - That occur at different rates during different pieces (high and low radiation) of the tour
- At each higher-level node, verify if requirements met (1) or failed (0)
- Model the resulting space, and sample from this model
- **Record the fault rates, recovery times, and other factors and see what drives P(Science Objective Success)**

Direct Output

- The results from running the model are probabilities of success
- Per Science Objective
  - For a given Scenario of N Fault Rate for the Spacecraft, M Recovery time for the Spacecraft, and N_i and M_i Fault Rate and Recovery time per $instrument_i$
  - Other per-Scenario input factors
- What percent of the time did each Science Objective in a Scenario close?
- When and how/why did ALL of the Science Objectives close?

5, Safing Fault Rate, Inst per Year	6, Recovery time/rate used_safing_All instruments	7, Recovery time/rate used_safing_All instruments	8, RT_Instrument G-in-L_Single Inst	'l1reqid__RQ106.312'	'l1reqid__RQ106.323'	'l1reqid__RQ106.317'	'l1reqid__RQ106.325'	'l1reqid__RQ106.318'
1.15	5.5	0.677777778	5.5	0.704	0.822	0.705	0.999	0.98
1.15	5.5	0.677777778	5.5	0.013	0.069	0	0.778	0.732
1.15	5.5	0.677777778	5.5	0	0	0	0.002	0.273
1.15	5.5	0.677777778	5.5	0	0	0	0	0.074

…

…

…

Key Factors in Inst Fault/Recovery Trades

Trades Involve Different Science, Opps, Cost and Mass Factors

- Instruments support differing numbers of Science Objectives
- Instruments need to be on at different times
- Instruments need to be on for different lengths of times to make required measurements
- Pain of decreasing Fault Rate for each instrument varies
- Pain of adding Recovery for each instrument varies
- Pain for decreasing Recovery Time for each instrument varies
- Changing Spacecraft Fault Rate through radiation hardening is not a snap-of-the fingers
- Options for Spacecraft Recovery time vary