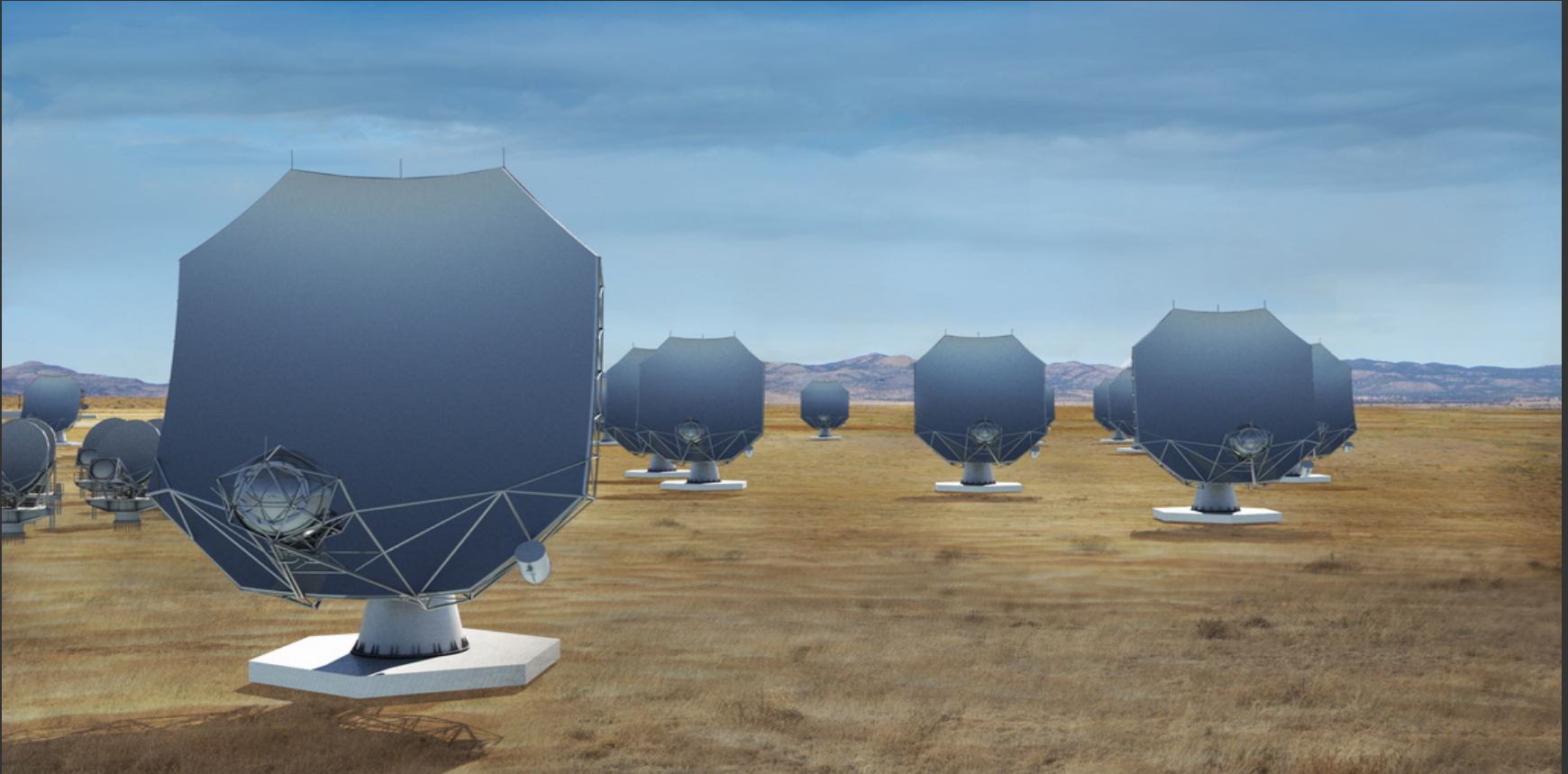# NRAO Algorithms R&D Group

DPUC, March 19th 2025
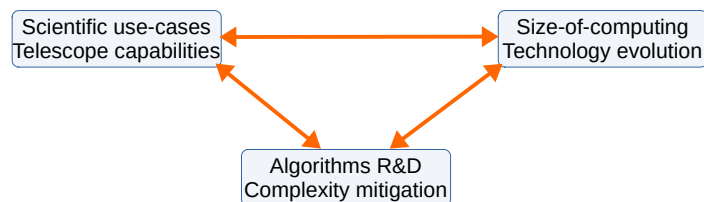

S. Bhatnagar

Algorithms R&D Group,

National Radio Astronomy Observatory, Socorro, NM, USA

Drivers

- Cognizant of inherent complexity


```
Scientific use-cases              Size-of-computing
Telescope capabilities            Technology evolution
                    Algorithms R&D
                    Complexity mitigation
```

- Evidence driven R&D

  - Adapt to algorithms and technology evolution: Scalable algorithm and software architectures

  - Scaling on large heterogeneous platforms : Simplify the tool-chain

  - Address the higher compute load : Integrated algorithm development

  - Need to involve other researchers in the community as content producers

- Collaborations

  - RA projects/groups interested in utilizing *full* telescope capabilities

  - With HTC/HPC/Industry: Computing at the necessary scale

Current work

- Problem: Address issues due to next-gen size of computing

  !!
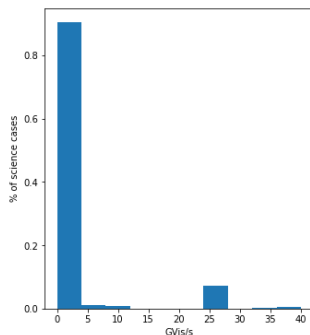
  - ngVLA: 10s PFLOP/sec (T_{rec} ~1 day) ← ~~O(million) CPU cores/~~few x O(1000s) GPUs

  - WSU: O(100) TFLOP/sec ← Can be done today!

    https://library.nrao.edu/public/memos/ngvla/NGVLAC_04.pdf

- Solution: Scalable architecture

  - Flexibility required to benefit from new algorithms, technology evolution, collaborations with others groups,...

- Solution: New Algorithms:

  - Can new algorithms help with compute scaling?

  - Address predominantly "high" frequency issues: Water vapor, Antenna pointing errors (ngVLA)
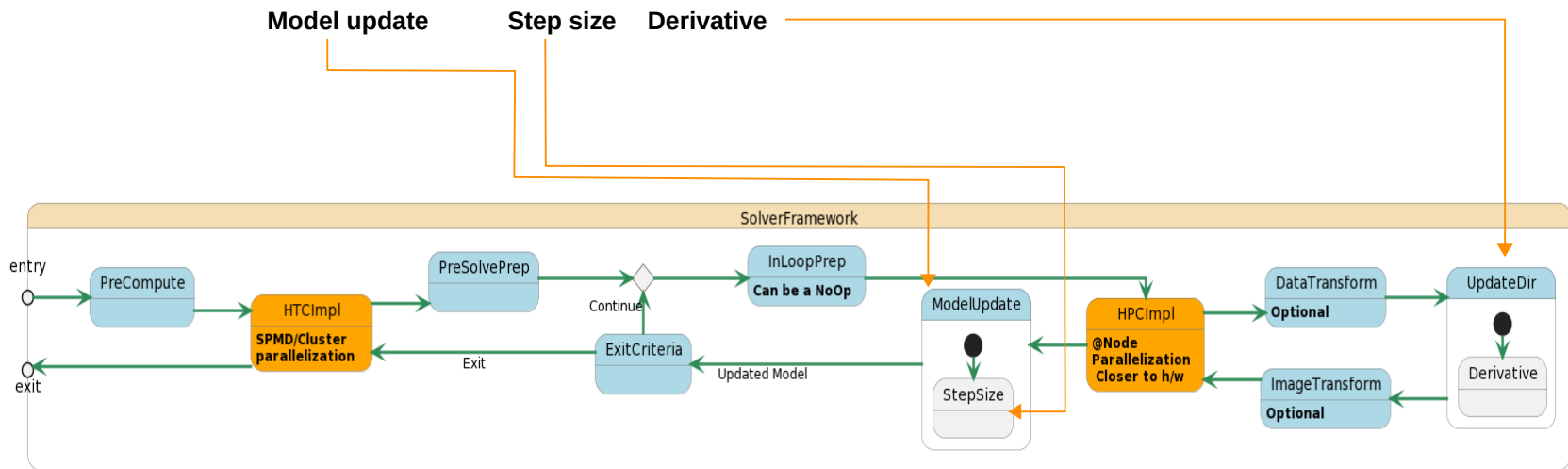
Scalable Algorithm Architecture

- Based on mathematical, signal processing, domain (rather than _____) considerations
  - Evolving computing needs, algorithms, h/w & s/w
  - Separable components that scale individually and together

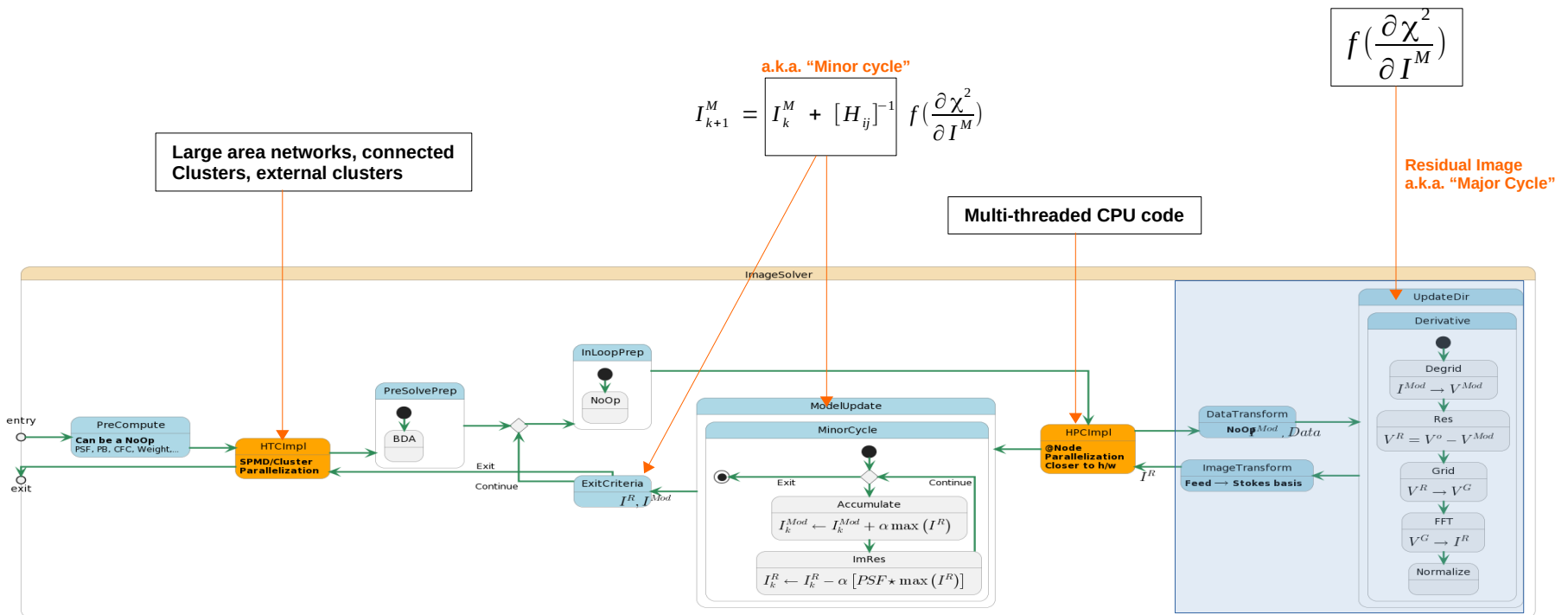$$V^{obs} = \boldsymbol{G^M} S \boldsymbol{F} B^M I^M + noise \qquad\qquad \chi^2 = \sum_i \left| Data_i - Model_i(P) \right|^2$$

$$P_i^{k+1} = P_i^k + [H_{ij}]^{-1} \; f\left(\frac{\partial \chi^2}{\partial P_i^k}\right) \quad ; \qquad [H_{ij}] = \frac{\partial^2 \chi^2}{\partial P_i^k \partial P_j^k}$$

Model update **Step size** **Derivative**

Algorithm Architecture: Imaging

- Component specialization delivers various calibration and imaging algorithms

LibRA: User view

- Algorithms (current & future) can be expressed in a framework with a collection of simpler, fundamental components
- Components independently configurable via multiple interfaces

https://github.com/ARDG-NRAO/LibRA

LibRA: User view

- Algorithms (current & future) can be expressed in a framework with a collection of simpler, fundamental components
- Components independently configurable via multiple interfaces

Command-line

```
roadrunner help=noprompt vis="..." imagename="..." imsize="12*1024"
```

Python

```
>>> import roadrunner2py
>>> roadrunner2py.Roadrunner(vis="...", imagename="...", imsize="12*1024"
```

Library

```
#include <roadrunner.h>

int main(...)
{
   :
   :
 RRReturnType rrType;
 rrType=Roadrunner(visName, imageName,
   :
   :
}
```

https://github.com/ARDG-NRAO/LibRA

LibRA: User view

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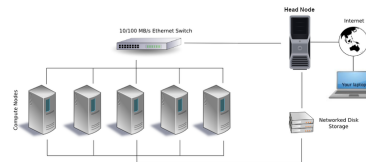- **Deployed on a wide range of computing resources**

Laptop

Desktop

Cluster of GPUs/CPUs

Super-computer class
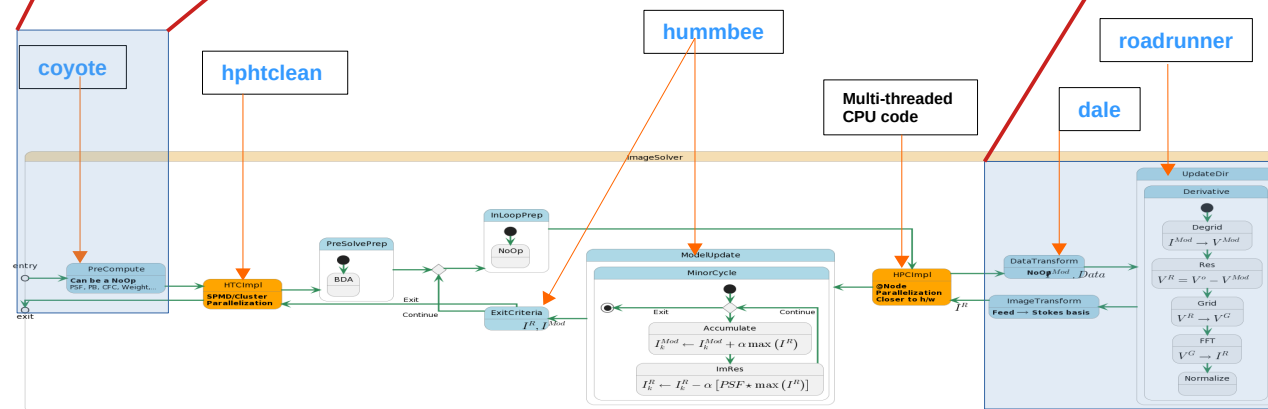

https://github.com/ARDG-NRAO/LibRA

Unlock access to *existing* resources

- *Significant* computing resources *already* available (US community).
  - PATh facility: The Center for High Throughput Computing (CHTC, UW-M)
  - National Research Platform (NRP) + The San Diego Super Computer Center (UCSD + SDSC)
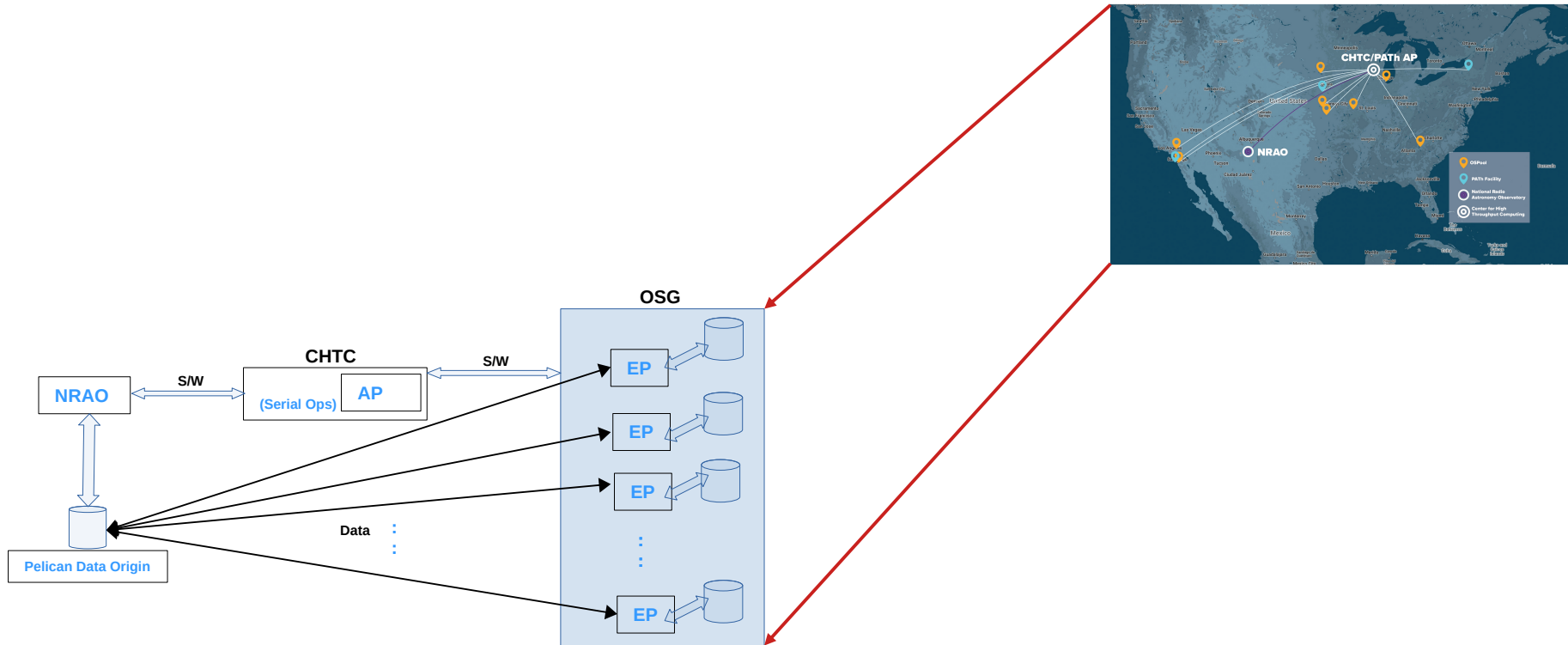
Unlock access to *existing* resources

- Deployed on a cluster of GPUs (~100) on the PATh facility in collaboration with
  - PATh facility: The Center for High Throughput Computing (CHTC, UW-M)
  - National Research Platform (NRP) + The San Diego Super Computer Center (UCSD + SDSC)

https://science.nrao.edu/enews/17.3/index.shtml#deepimaging
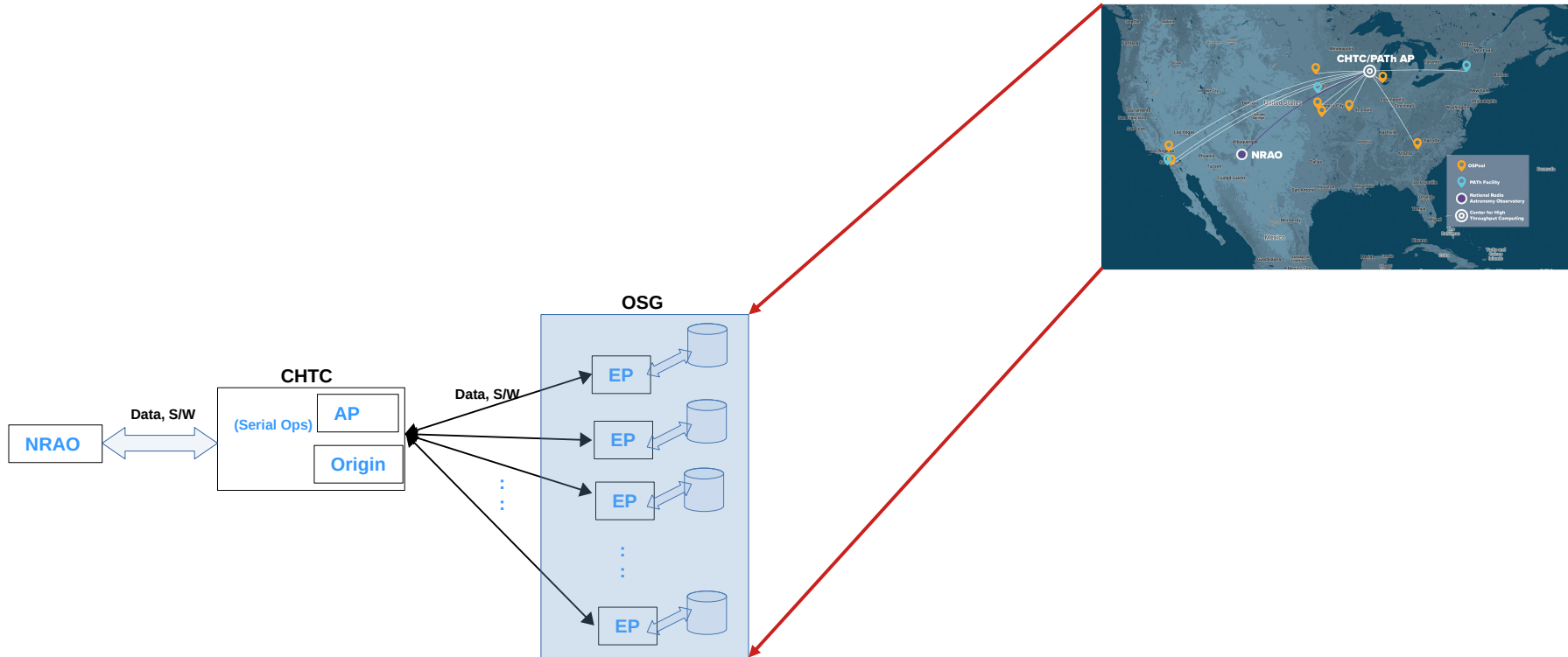
Simplify access

- Deployed on a cluster of GPUs (~100) on the PATh facility in collaboration with
  - PATh facility: The Center for High Throughput Computing (CHTC, UW-M)
  - National Research Platform (NRP) + The San Diego Super Computer Center (UCSD + SDSC)

https://science.nrao.edu/enews/17.3/index.shtml#deepimaging

Design verification

- Deployed on a cluster of GPUs (~100) on the PATh facility of the Open Science Grid (OSG) in collaboration with
  https://science.nrao.edu/enews/17.3/index.shtml#deepimaging
    - PATh facility: The Center for High Throughput Computing (CHTC, UW-M)
    - National Research Platform (NRP) + The San Diego Super Computer Center (SDSC)

Domain specialization

- Throughput: ~1 TB/hr (~2 TB/hr now?)

- 10 iterations in ~24 hr

    - Earlier attempts using CPU cores:
      ~14 days per cycle

- This is still a small faction of the **required peak** throughput (?!)

Among the deepest radio image

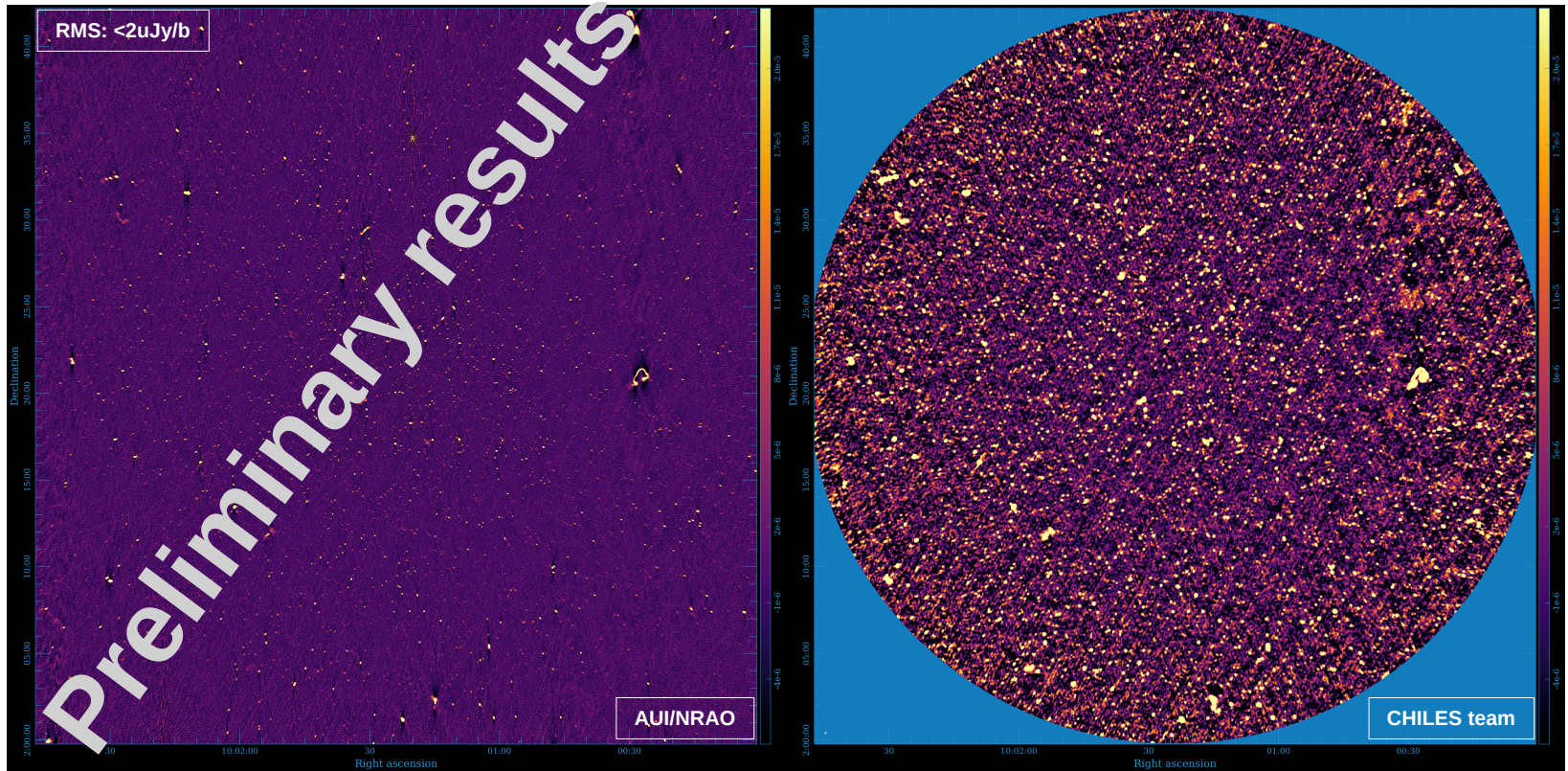- Deployed on a cluster of GPUs (~100) on the PATh and NRP facility

Image made using OSG/PATh and OSDF

Data: Courtesy The CHILES Team

Paper in prep.