Max-Planck-Institut für Kernphysik Heidelberg

PyData

Image: H.E.S.S. Galactic plane survey

PYTHON IN ASTRONOMY

Christoph Deil (MPIK Heidelberg)

PyData Südwest Meetup
@ getsafe Heidelberg
April 4, 2019

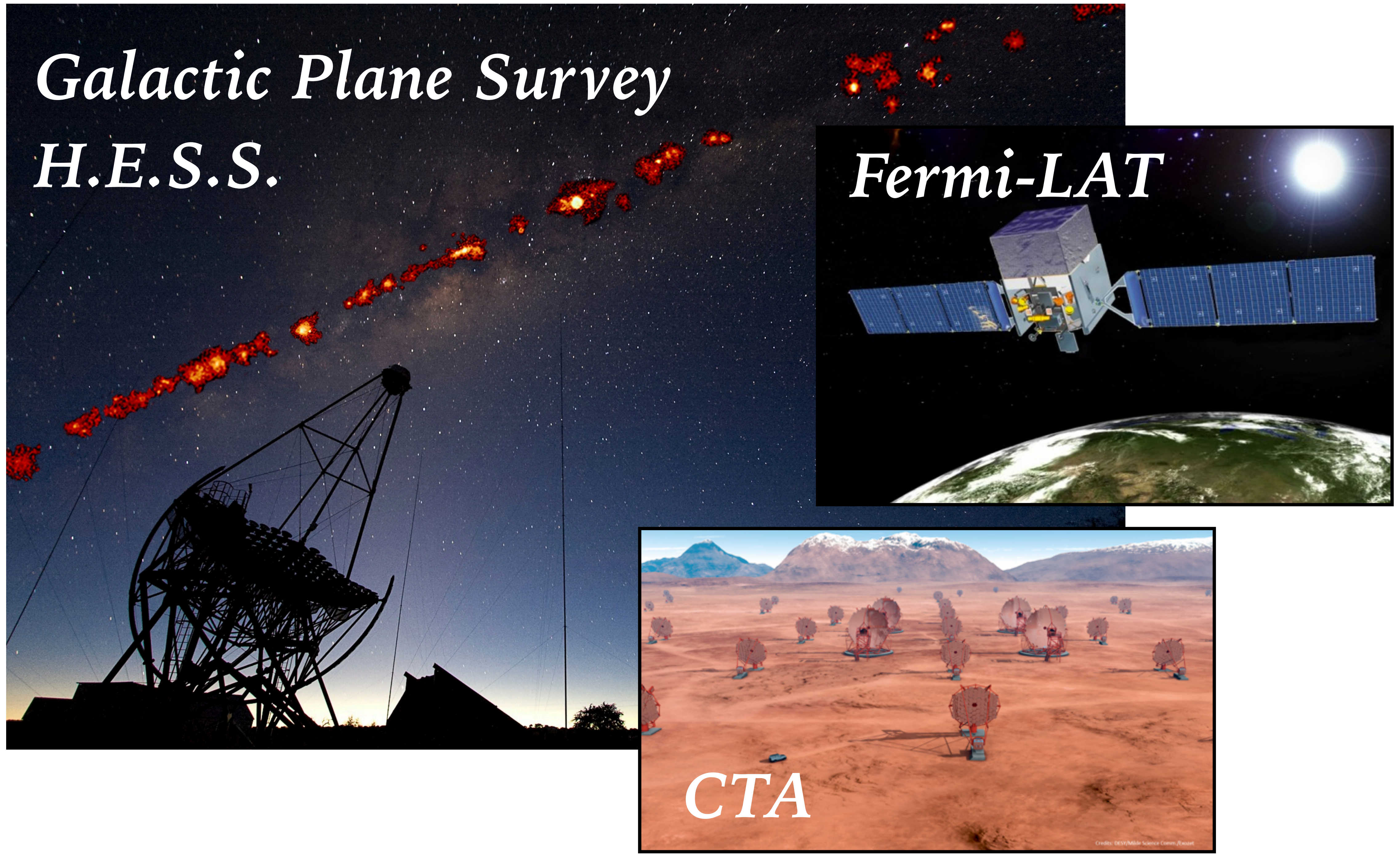
Thank you Jan, Marius, Alexander, Prabhant, Pawneet for organising!

Slides at https://christophdeil.com

python™

The Astropy Project

A **Python** package for **gamma-ray** astronomy



WHO AM I?

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

- Gamma-ray astronomy
  - Postdoc at MPIK Heidelberg
  - Science: Milky Way survey
  - Telescopes: H.E.S.S., Fermi, CTA
- Python
  - Discovered Python in 2009
  - Data analysis & modelling
  - Gammapy & other codes

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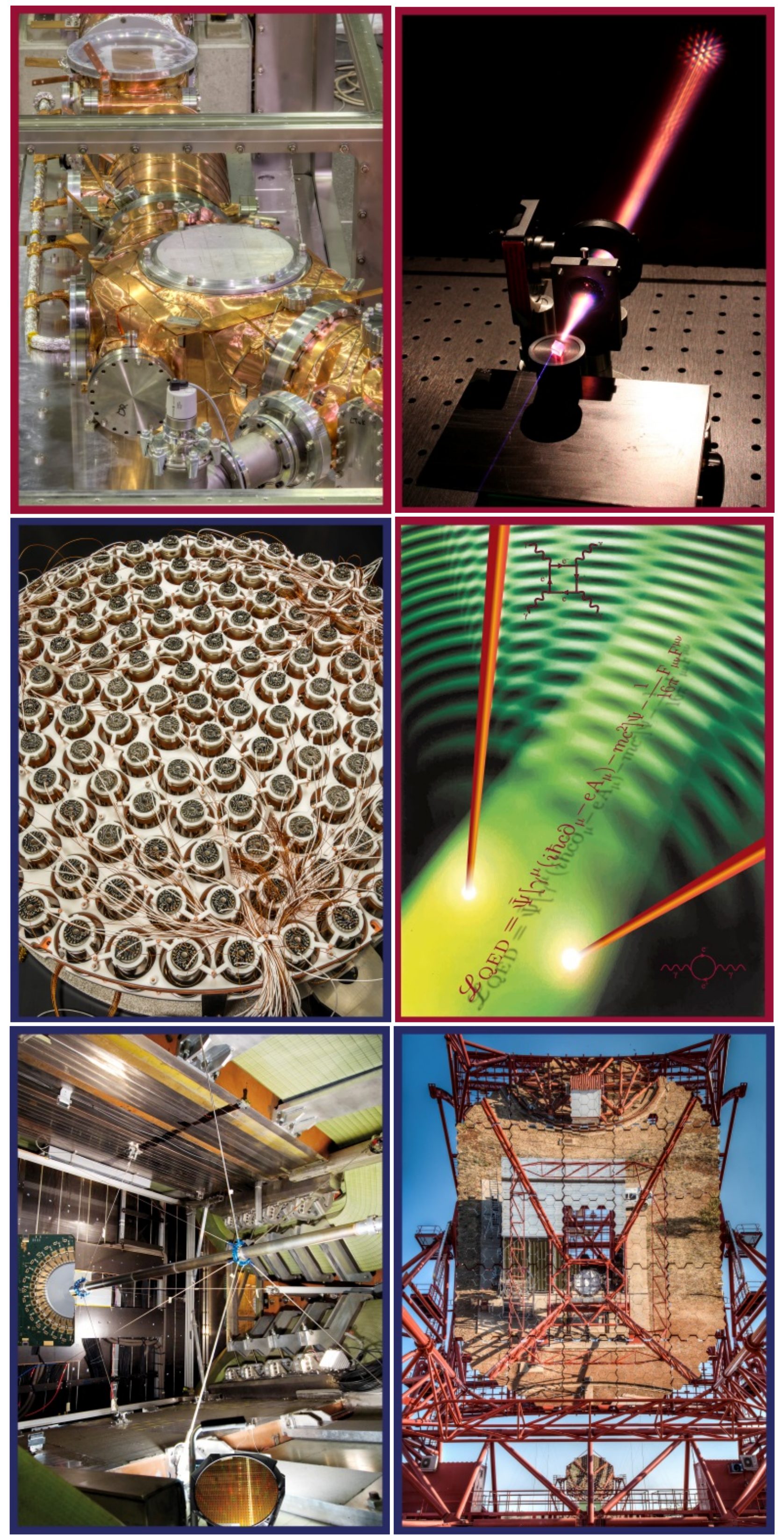
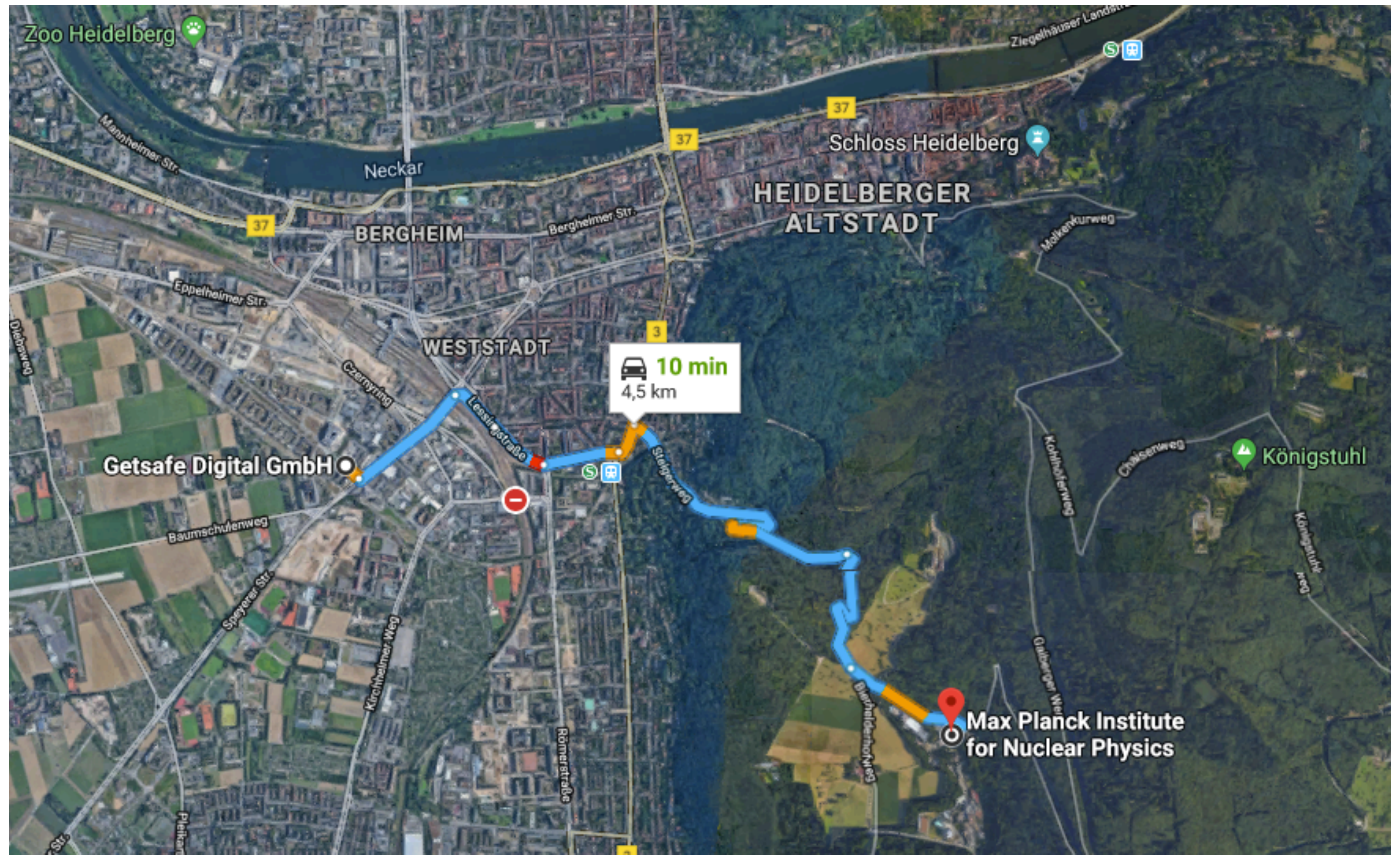
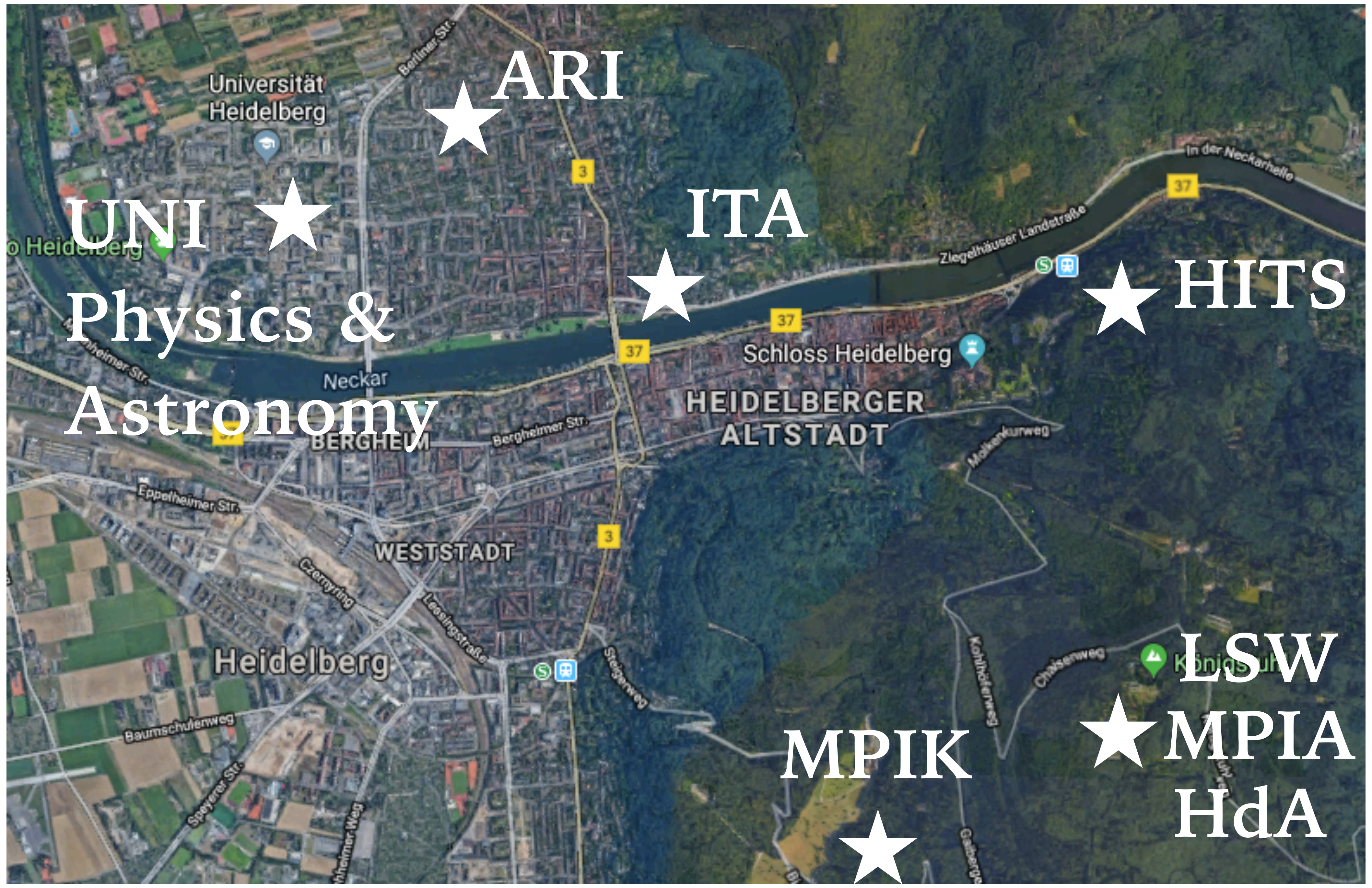




MPIK

- Max Planck Institut für Kernphysik
  https://www.mpi-hd.mpg.de/
- Founded 1958, located on Königstuhl
- Astroparticle physics & quantum dynamics
  400 people, about half scientists
- Max Planck Society — basic research in Germany (84 institutes, 4 in Heidelberg)



Haus der Astronomie (HdA)

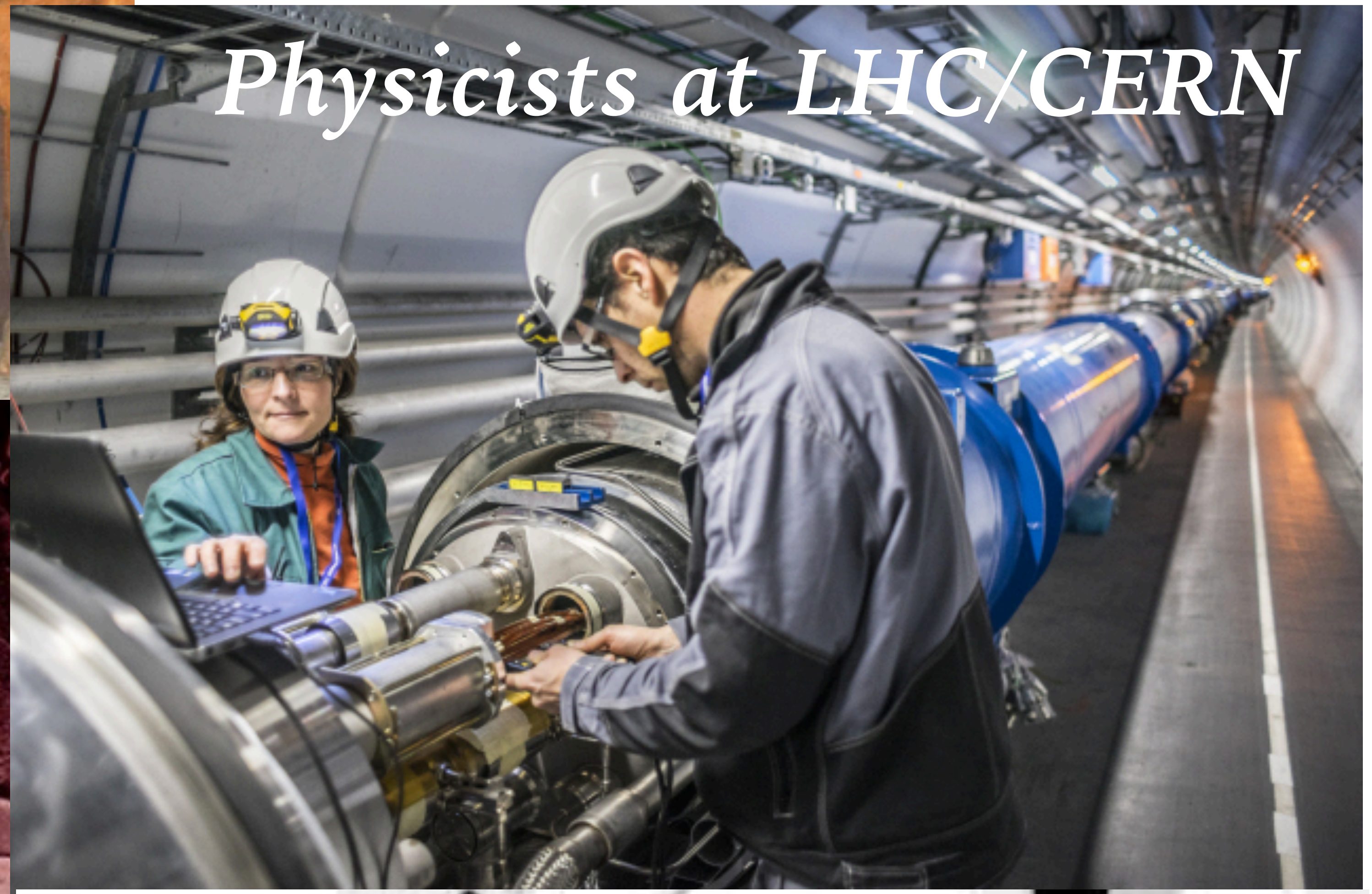
ASTRONOMY IN HEIDELBERG

- Heidelberg is one of the largest astronomy research centres in Germany
- Several research institutes: MPIA, MPIK, Landessternwarte Königstuhl, Astronomisches Recheninstitut, Institute of Theoretical Astrophysics, HITS
- Of interest for general public:
  - Haus der Astronomie (and nearby MPIA & LSW)
  - Planetarium Mannheim
  - Once a year: Explore Science, International Science Festival

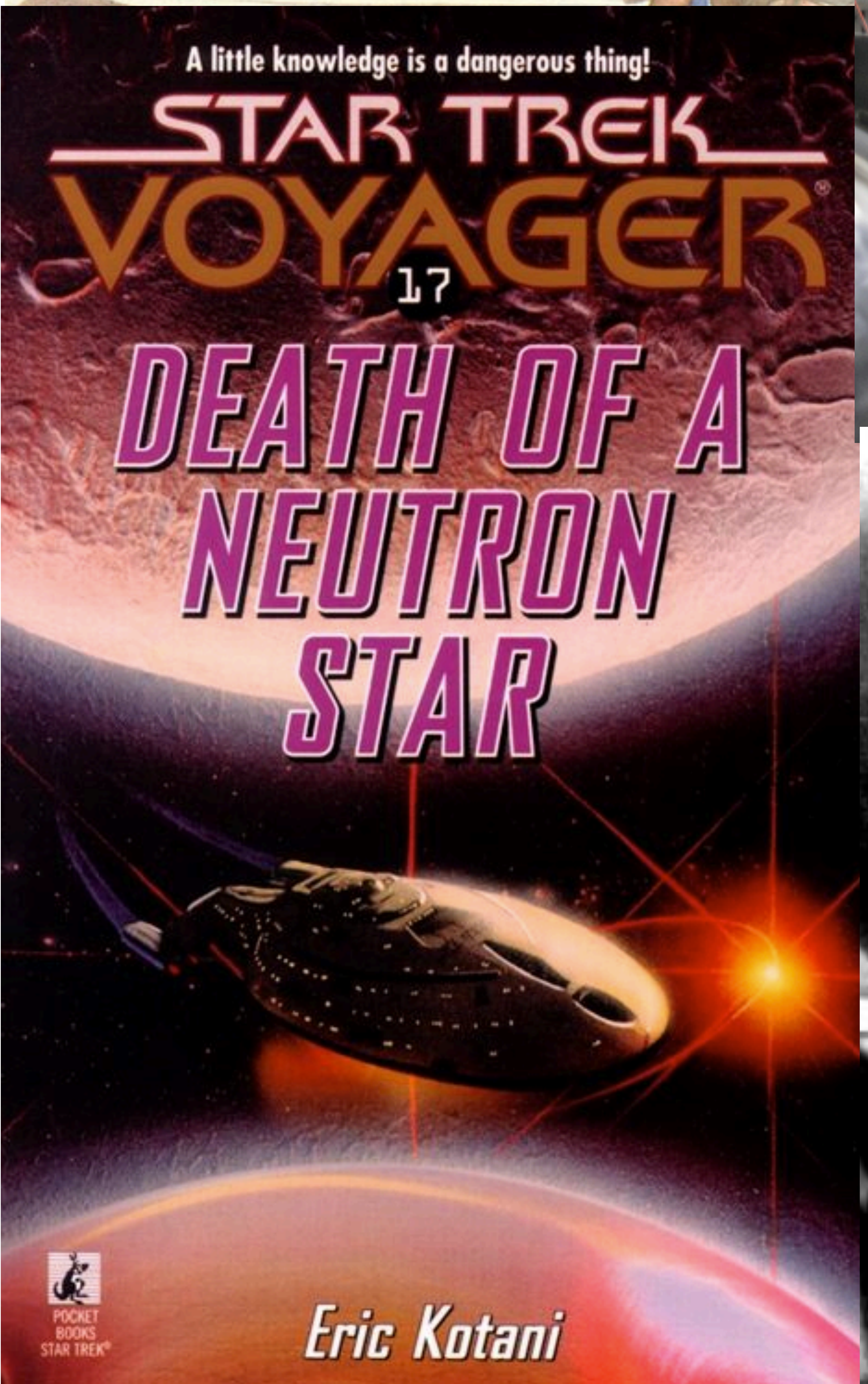
"PYTHON IN ASTRONOMY" - DEFINITIONS

- **python**, /ˈpʌɪθ(ə)n/
  1. a large heavy-bodied non-venomous snake occurring throughout the Old World tropics, killing prey by constriction and asphyxiation.
  2. a high-level general-purpose programming language.
- **astronomy**, /əˈstrɒnəmi/ — the branch of science which deals with celestial objects, space, and the physical universe as a whole.
- **astrophysics**, /astrə(ʊ)ˈfɪzɪks/ — the branch of astronomy concerned with the physical nature of stars and other celestial bodies, and the application of the laws and theories of physics to the interpretation of astronomical observations.
- **astrology**, /əˈstrɒnəmi/ — the study of the movements and relative positions of celestial bodies interpreted as having an influence on human affairs and the natural world.
  synonyms: horoscopy, stargazing, bullshit;

Plato (astronomer?)
& Aristotle (physicist?)
in "The shool of Athens"



Physicists at LHC/CERN



Astronomer

ASTRONOMY & PHYSICS

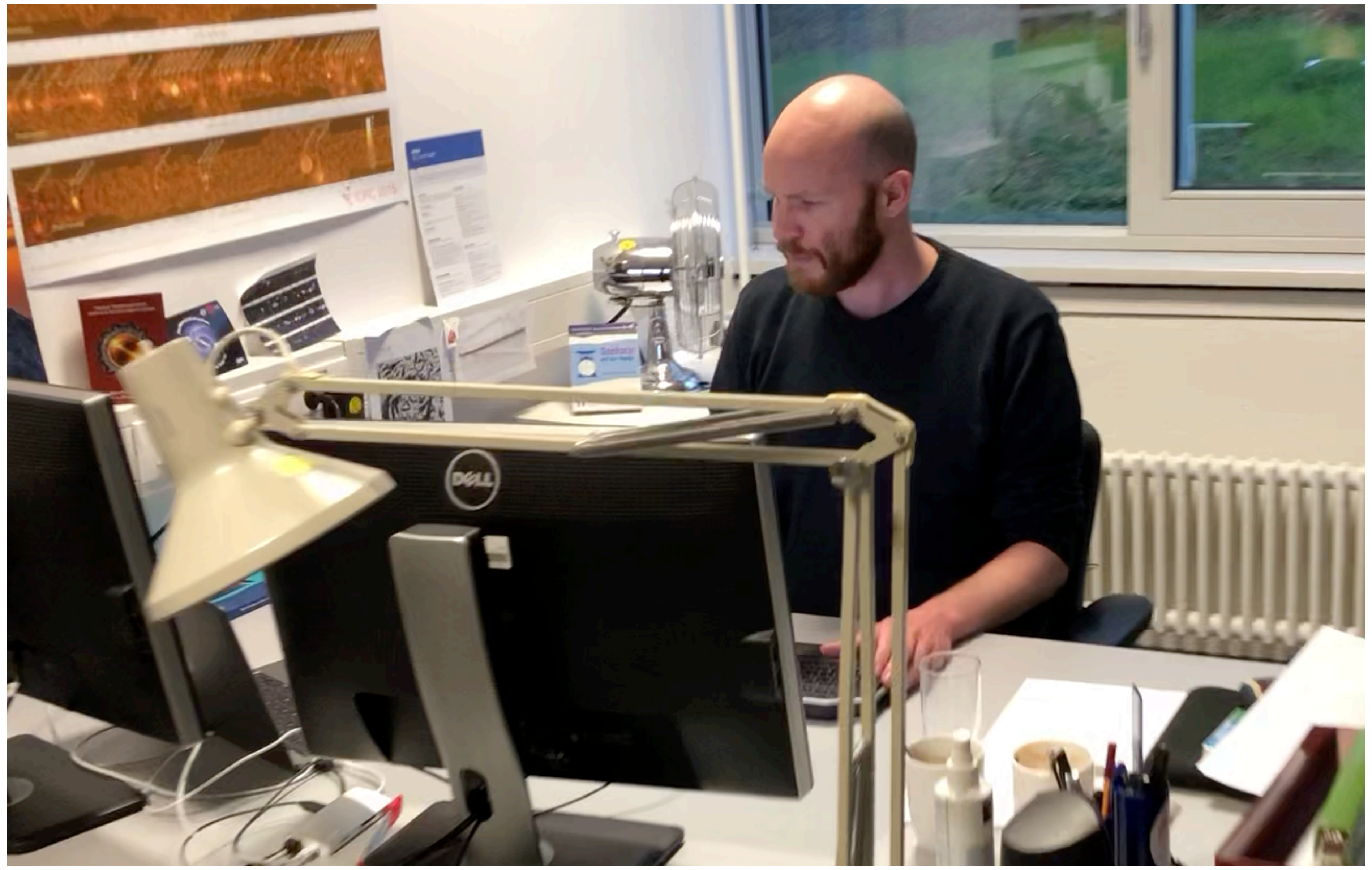
- Same goal: understand physical laws, objects & processes in the universe
- Different techniques:
  - Physicists experiment
  - Astronomers observe
  - (both use theory & simulations)
- New physics often visible only in environments that we can't create on Earth (e.g. neutron stars, black holes)
- Astronomers observe light and other "messengers" to study astrophysics

STAR TREK VII: GENERATIONS (VIDEO CLIP)

Source: https://youtu.be/MUieGh1fHSI (Paramount)

ASTRONOMY THEN …

- Edwin Hubble at the 48'' Schmidt Telescope at Palomar observatory (1949)
- For centuries optical astronomy
  - solar system, stars, galaxies, nebulae
  - First eye, then film, then CCDs



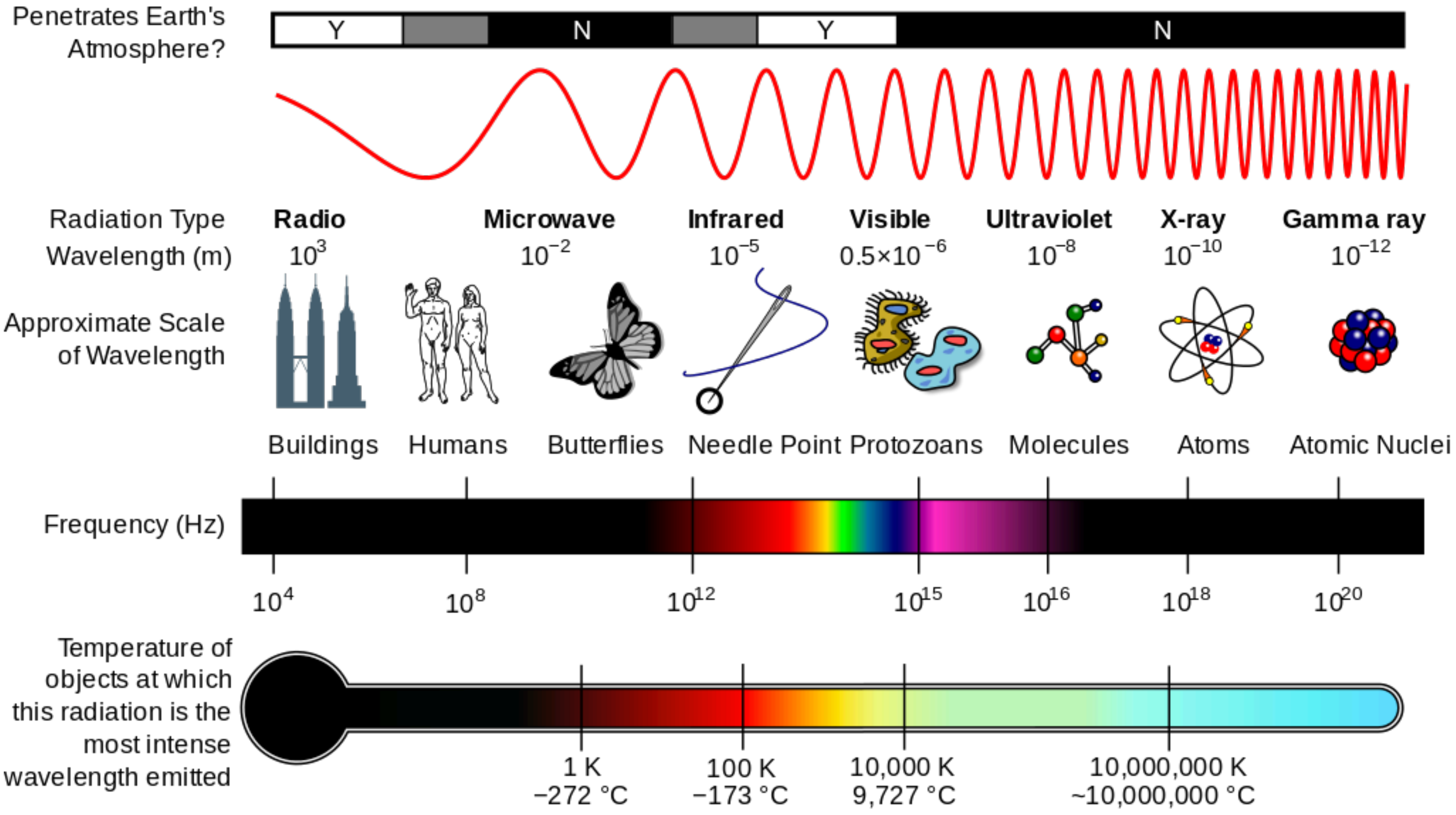
ASTRONOMY NOW …

- Astronomy research: coding, data cleaning, analysis, simulation, modelling, statistics, reading and writing papers
- Also, but less often: building telescopes and detectors, observing on site, theory
- Daily work very similar to what many of you do, some things are different in science (collaboration, funding, …)
- New discoveries are usually made by collaborations of 100+ astronomers after 10+ years of building new telescopes

ASTRONOMY NOW ...

- Many ground and space telescopes
- Often big and complex projects that require new technology & algorithms
  Typical: 100 million or 1 billion Euros
- Multi-wavelength
- Multi-messenger
- Complex data and analysis.
  Today often in Python!

LIGHT – ELECTROMAGNETIC WAVE (FREQUENCY & WAVELENGTH) AND PARTICLE (PHOTON)



MULTI-WAVELENGTH ASTRONOMY

- Night sky and most objects look very different in different wavebands
- Need multi-wavelength observations and spectra to understand astrophysical effects
- Example: Andromeda Galaxy (M31) - nearest major Galaxy to the Milky Way

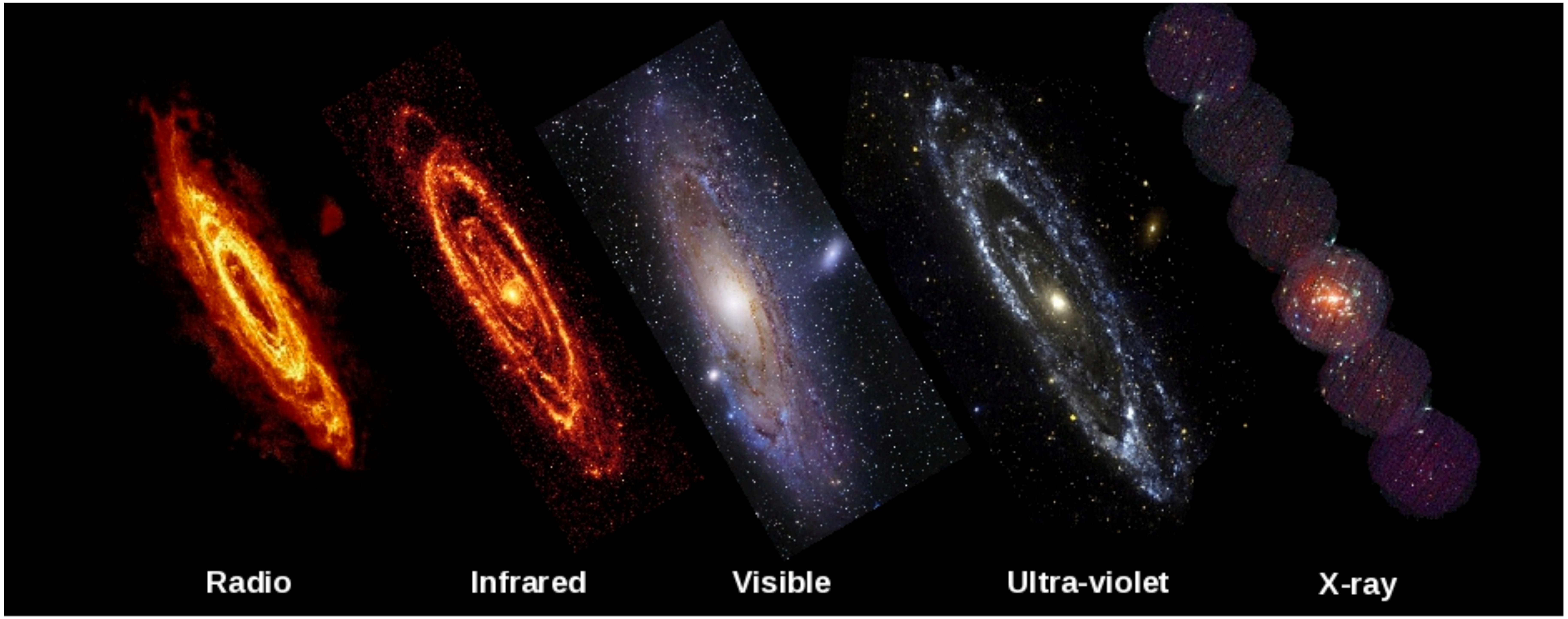
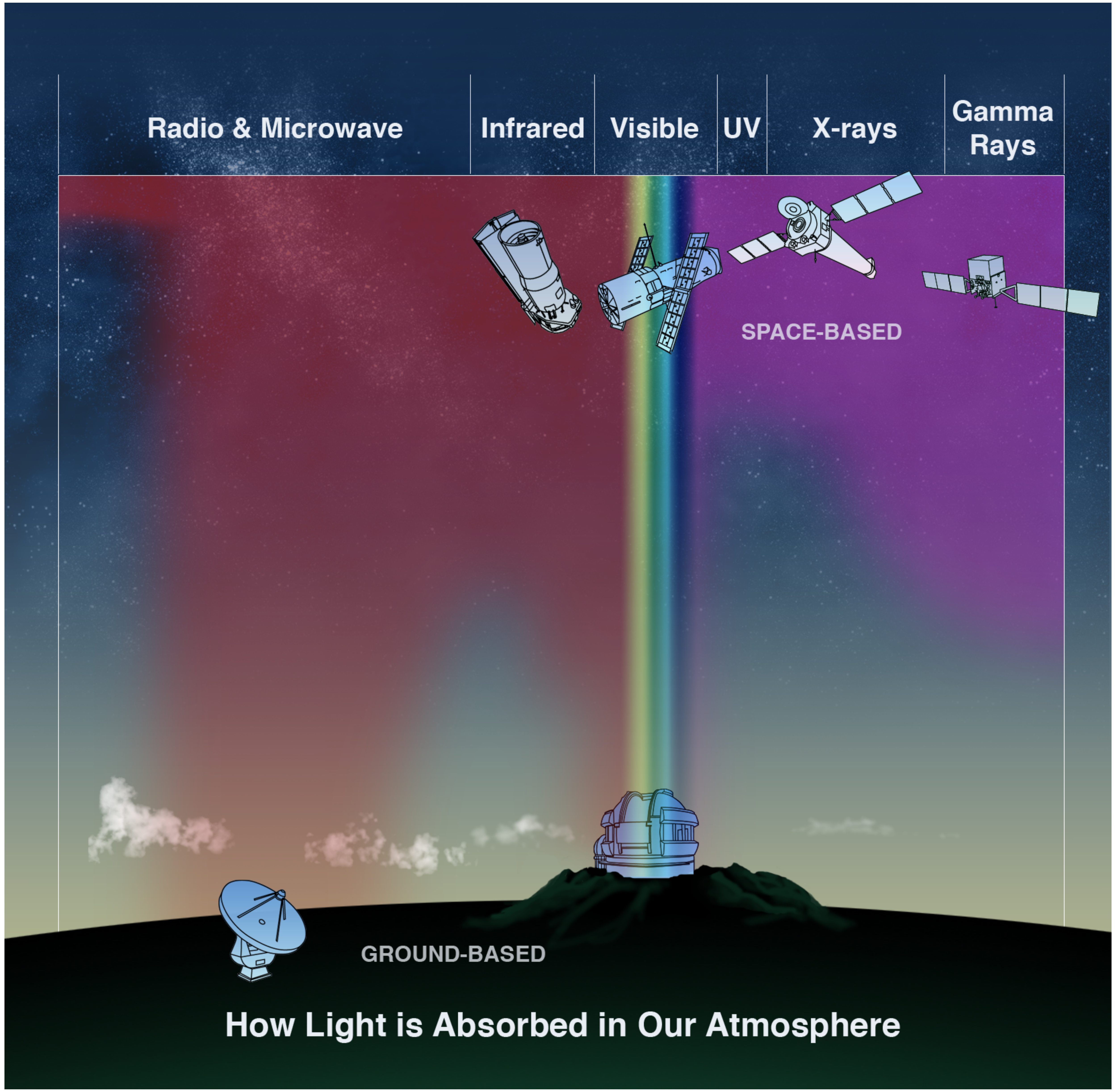
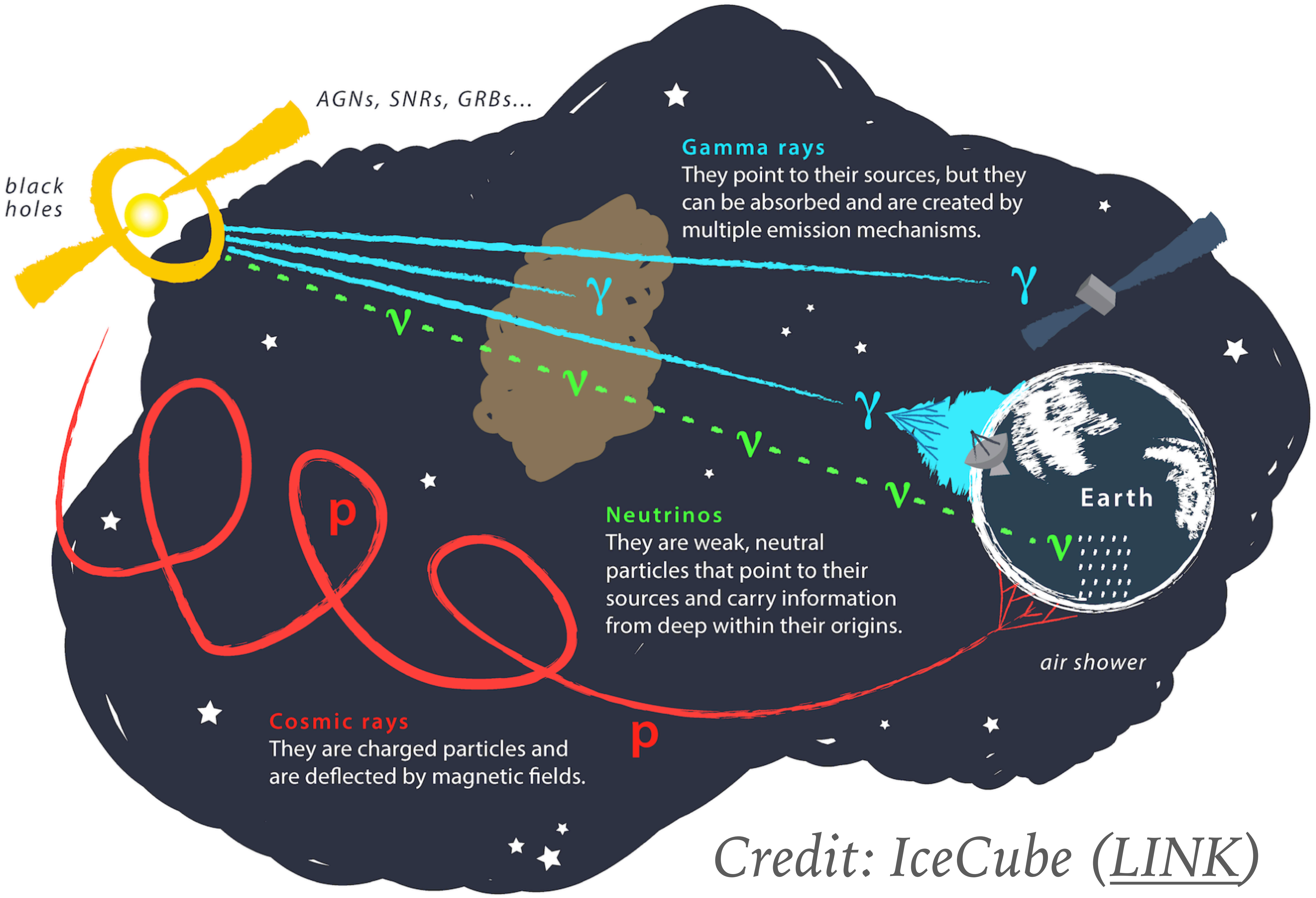


Image credits: Radio:WSRT/R. Braun; Infrared:NASA/Spitzer/K. Gordon; Visible: Robert Gendler; Ultraviolet: NASA/GALEX; X-ray: ESA/XMM/W. Pietsch

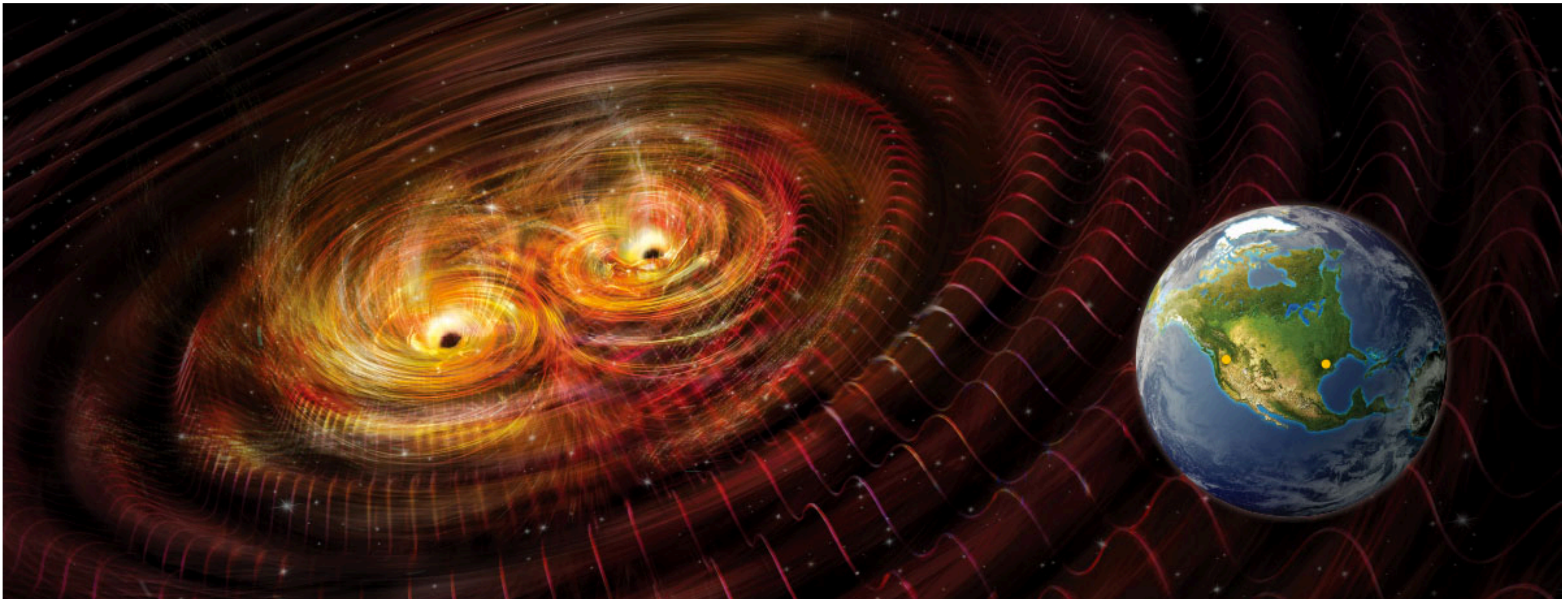


MULTI-WAVELENGTH ASTRONOMY

- Earth's atmosphere transparent to radio and visible light - ground telescopes
- Infrared light, X-rays and gamma-rays are blocked - space telescopes
- Curious exception: very high energy gamma-rays can only be detected from the ground. Will explain later.



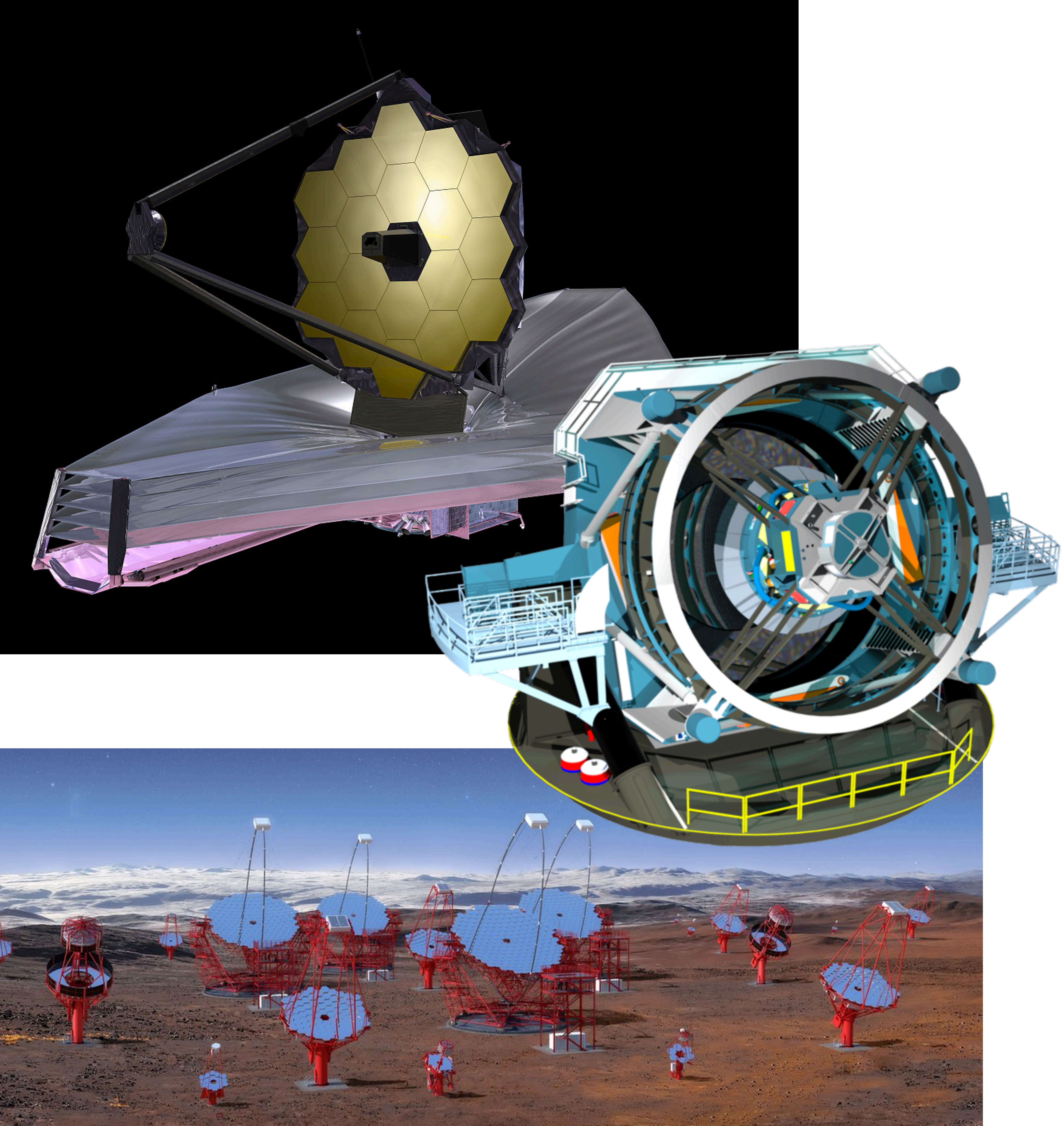
Credit: IceCube (LINK)



MULTI-MESSENGER ASTRONOMY

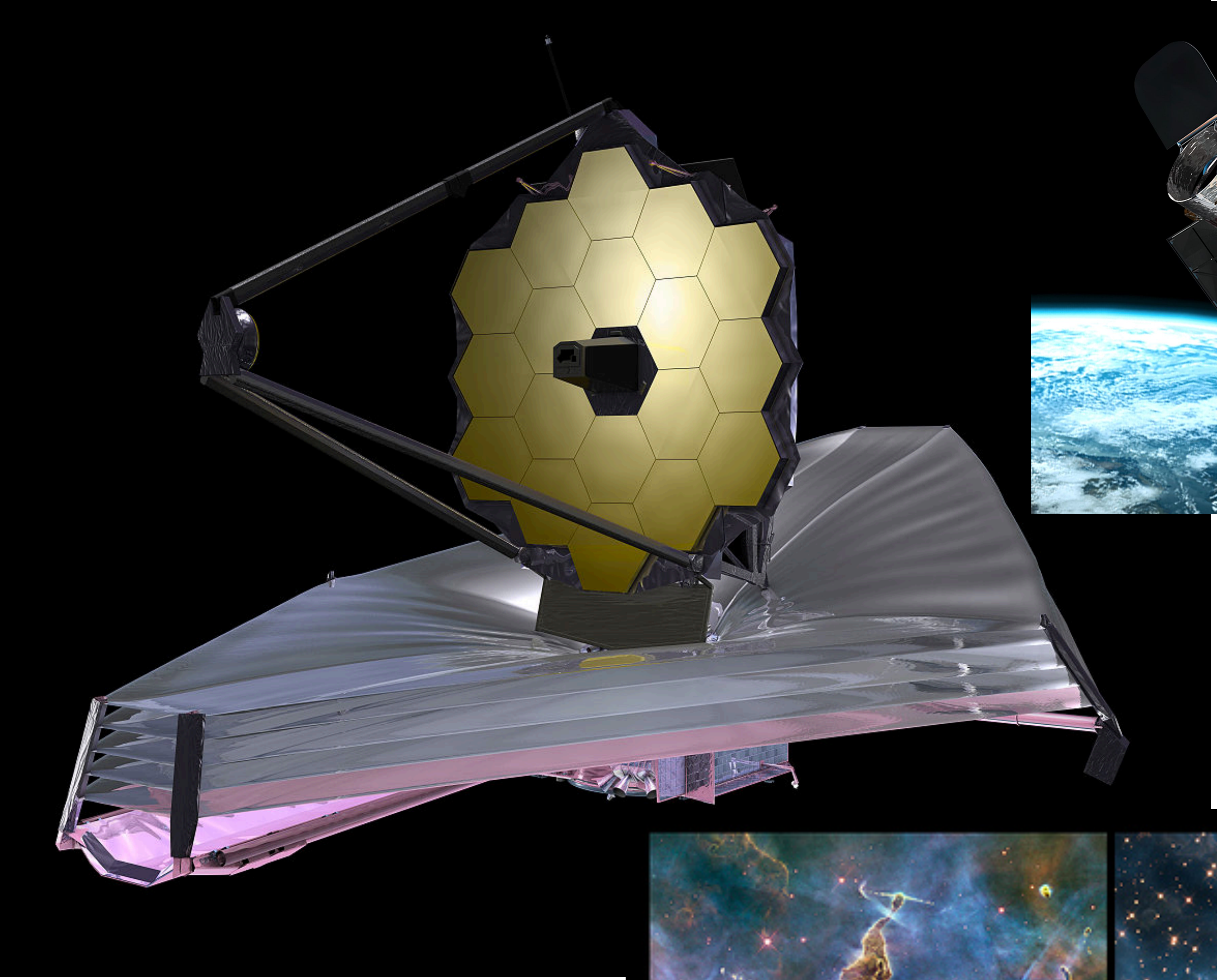
- Most astronomy is done with light
- But other "messengers" exist:
  - Cosmic rays (charged particles)
  - Neutrinos (elementary particle)
  - Gravitational waves (GW)
- Multi-messenger useful or required to study some extreme objects and physical effects, such as e.g. strong gravity, particle physics, dark matter

Credit: sciencenews.org (LINK)



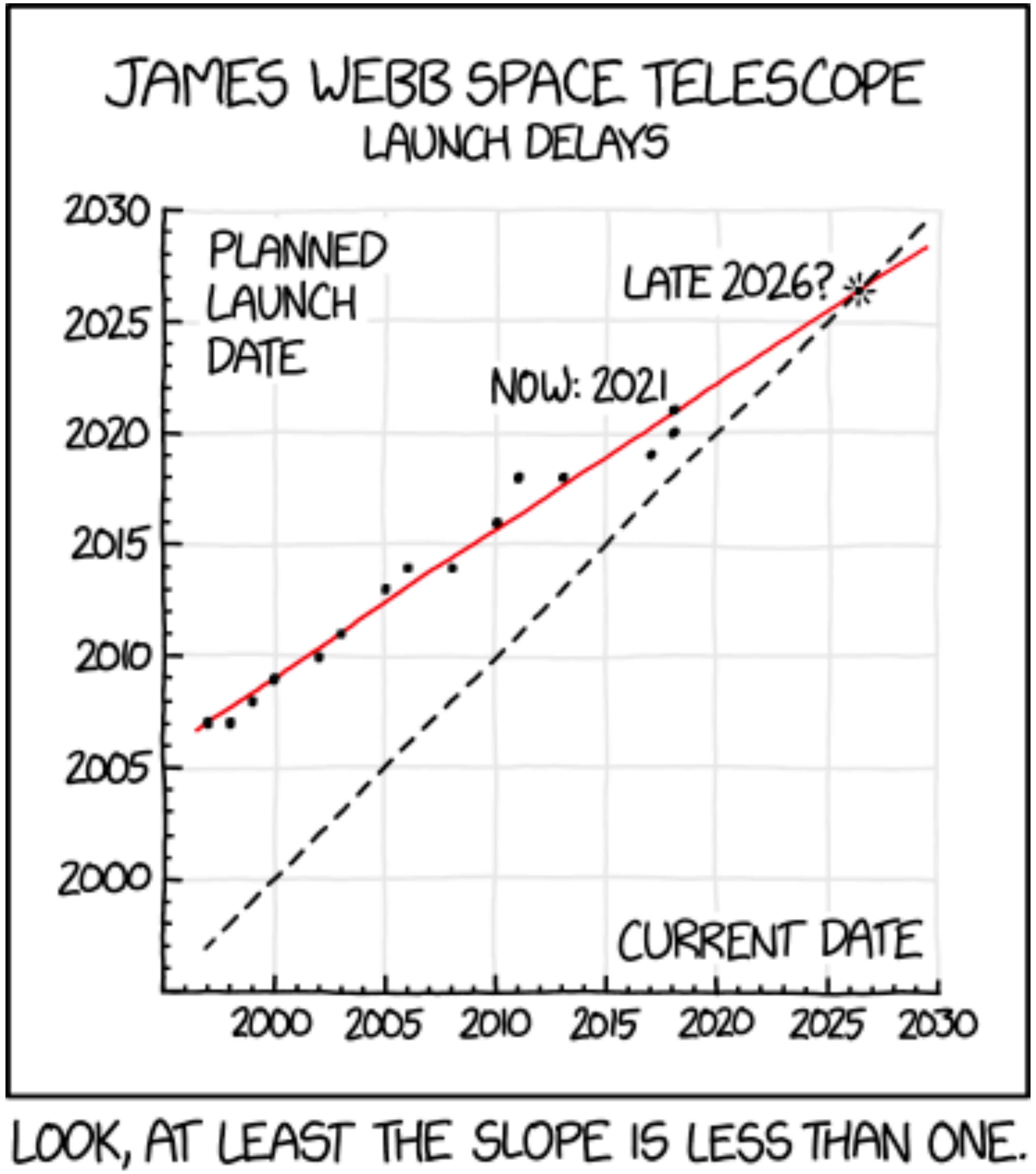
PYTHON IN ASTRONOMY

- Will introduce three telescopes that are in construction and use Python heavily!
- Very quick overview:
  science & instrument & data & code
- Telescopes:
  1. Jame Webb Space Telescope
     JWST, infrared, space
  2. Large Synoptic Survey Telescope
     LSST, optical, Chile
  3. Cherenkov Telescope Array
     CTA, gamma-rays, Chile & La Palma



JWST OR "WEBB"

- James Webb Space Telescope
  Planned launch date: March 30, 2021
- JWST is the Hubble Telescope successor
  Launched April 24, 1990
- Greatly improved resolution & sensitivity
  JWST mirror (6.5 m) much larger than Hubble (2.4 m) - 6x collection area
- JWST observes in infrared: cooling, sun shield, L2 location, complex instruments
- Many new observations that were impossible so far: formation of stars and planets, first galaxies in the universe



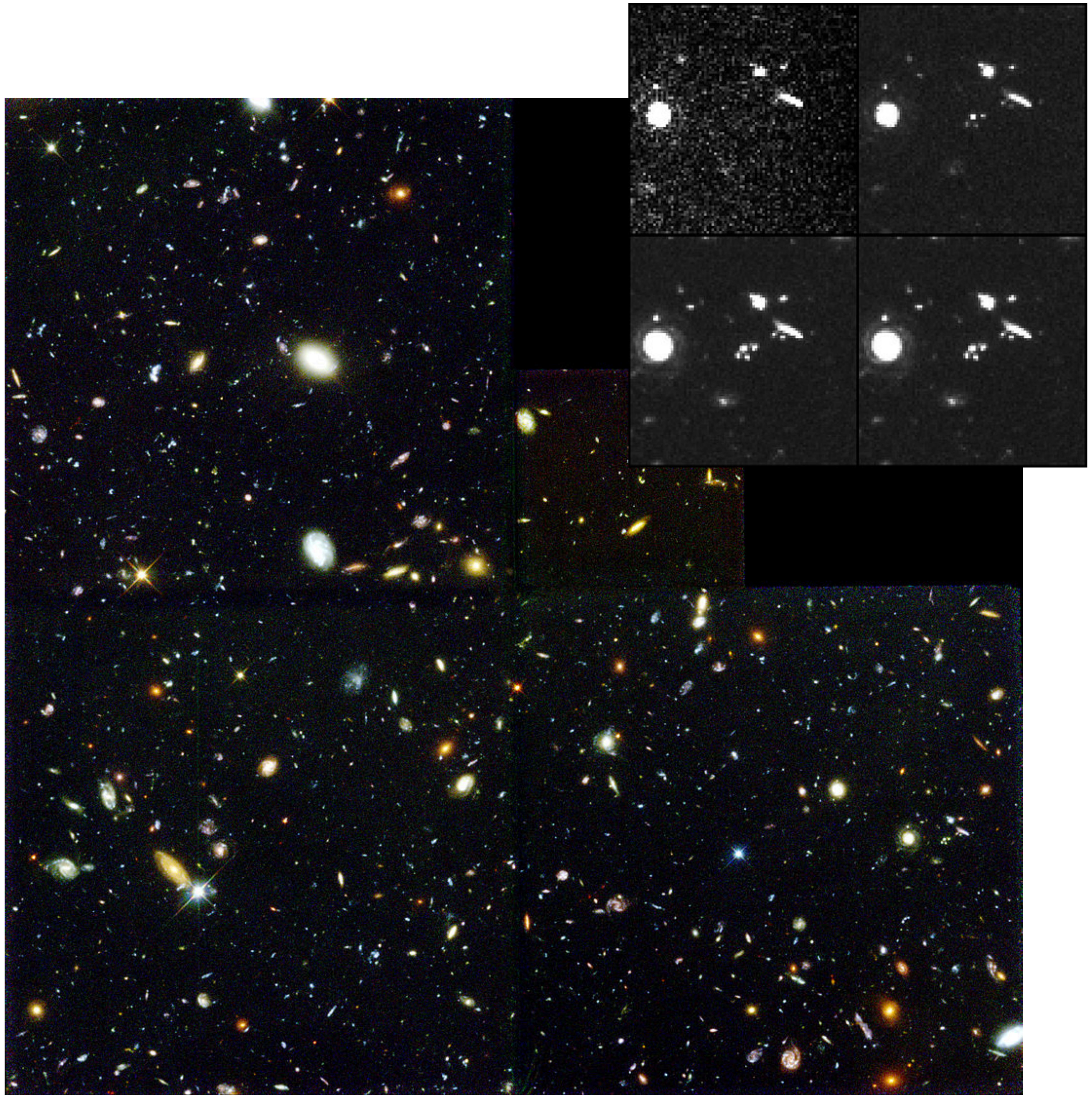
Source: https://xkcd.com/2014

JWST LAUNCH DATE AND COST

- JWST history of cost overruns and delays
  Source: JWST Wikipedia page
  - 1998: launch 2007, cost 1 billion $
  - 2008: launch 2014, cost 5 billon $
  - 2018: launch 2021, cost 10 billion $
- Generally this is the case for many research projects: plan & cost estimates always very optimistic to get funding.
- Q: “Why is the JWST taking so long?”
  A: Biggest and most complex space telescope that was ever built (YouTube)

JWST LAUNCH AND DEPLOYMENT — FINGERS CROSSED! (VIDEO CLIP)

Source: https://youtu.be/v6ihVeEoUdo (Northrop Grumman)



HUBBLE & JWST DATA & TOOLS

- Mostly pixel data: images, cubes, spectra n-dim arrays - good fit for Numpy!
- Approximate data rates:
  - 30 GB / day (Hubble)
  - 300 GB / day (JWST)
- Data reduction & analysis software history for Hubble and JWST interesting: "**How Python slithered into astronomy**" *(see next slide and references at the end.)*

Example: Hubble deep field (LINK) — a lot of data reduction from raw to science image.

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

PYTHON & ASTRONOMY

- In 1990 Guido van Rossum created Python — scientists use Fortran, C, C++ and custom languages for data analysis
- Hubble was launched in 1990 - at that time mainly using IRAF which had it’s own development and scripting language
- 1995 Perry Greenfield and others at STScI start using C, and try to evolve IRAF
- 1998: want to use Python, but need a way to transition — create PyRAF bridge
- 2000s: use Python more and more Numpy, Scipy, matplotlib, …

ASTROPY IS BORN

- 2010: Python already popular in astronomy
- Too popular? — dozens of Python packages for common tasks: work with sky coordinates or tables & images
- June 9, 2011 on the Python in astronomy mailing list … Astropy is born!

- [AstroPy] PyAstronomy *Stefan Czesla*
  - [AstroPy] Proliferating py-astro-libs *Marshall Perrin*

```
On Jun 9, 2011, at 12:54 PM, Stefan Czesla wrote:
Dear all,

we would like to let you know about our recent release of a -- hopefully --
useful contribution to Python's astronomy community, namely, our PyAstronomy
package
```

```
On 10/06/11 8:25 AM, Marshall Perrin wrote:
```

Hopefully without sounding too critical of you in particular, I'm going to ask: do we as a community really need /yet another/ separate python library for astronomy

The Astropy Project

Project Coordinators: Tom Aldcroft, Kelle Cruz, Thomas Robitaille, and Erik Tollerud

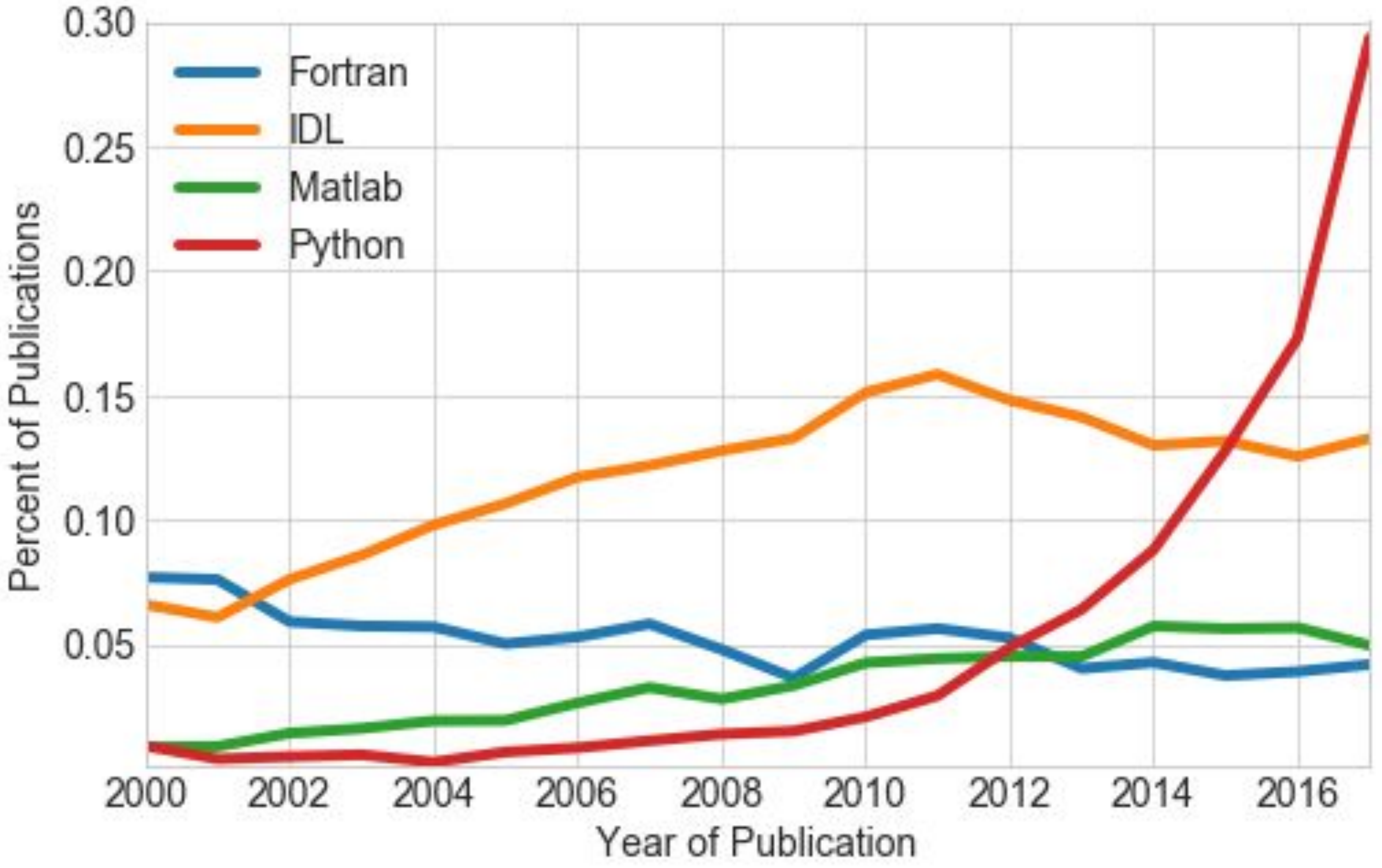
Developers/Contributors for core package (as of March 2019):

Ryan Abernathey
Mohan Agrawal
Shailesh Ahuja
Tom Aldcroft
Mike Alexandersen
Anne Archibald
Cristian Ardelean
Humna Awan
Tomas Babej
Matteo Bachetti
Alexander Bakanov
Steven Bamford
Kyle Barbary
Geert Barentsen
Pauline Barmby
Paul Barrett
Juanjo Bazán
Andreas Baumbach
Chris Beaumont
Stefan Becker
Manas Satish Bedmutha
Alexandre Beelen
Daniel Bell
Elijah Bernstein-Cooper
Kristin Berry
Edward Betts
Mavani Bhautik
Nimit Bhardwaj
Mavani Bhautik
Francesco Biscani
Manish Biswas
Thompson Le Blanc
Christopher Bonnett
Joseph Jon Booker
Médéric Boquien
Azalee Bostroem
Luke G. Bouma
Matthew Bourque
Larry Bradley
Gustavo Bragança
Gabriel Brammer
Clara Brasseur
Erik M. Bray
Eli Bressert
Matthew Brett
Hannes Breytenbach
Hugo Buddelmeijer
Doug Burke
Giorgio Calderone
Daria Cara
Mihai Cara
Patti Carroll
Mabry Cervin
Pritish Chakraborty
Sourabh Cheedella
Christian Clauss
Alex Conley
Jean Connelly
Simon Conseil
Ryan Cooke
Yannick Copin
Michele Costa
Matthew Craig
Steve Crawford
Devin Crichton
Neil Crighton
Robert Cross
Kelle Cruz
Dan P. Cunningham
Daniel D'Avella
Ritwick DSouza
Daniel Datsev
James Davies
Matt Davis
James Dearman
Emily Deibert
Christoph Deil
Nadia Dencheva
Eric Depagne
Akash Deshpande
Jörg Dietrich
Axel Donath
Bili Dong
Michael Droettboom
Sanjeev Dubey
Zach Edwards
Jonathan Eisenhamer
Thomas Erben
Henry Ferguson
Vital Fernández
Leonardo Ferreira
Tyler Finethy
Dan Foreman-Mackey
Jonathan Foster
Ryan Fox
Leah Fulmer
Lehman Garrison
Simon Gibbons
Adam Ginsburg
Martin Glatzle
Christoph Gohlke
Danny Goldstein
Ralf Gommers
Karl Gordon
J. Goutin
Johnny Greco
Perry Greenfield
Dylan Gregersen
Austen Groener
Frédéric Grollier
Karan Grover
Kevin Gullikson
Hans Moritz Günther
Chris Hanley
Alex Hagen
Andrew Hearin
Christian Hettlage
Paul Hirst
Moataz Hisham
Michael Hoenig
Emma Hogan
Derek Homeier
Anthony Horton
JC Hsu
Griffin Hosseinzadeh
Lingyi Hu
Jurien Huisman
Joe Hunkeler
Zeljko Ivezic
Anany Shrey Jain
Anchit Jain
Anany Shrey Jain
VSN Reddy Janga
Grant Jenks
Tim Jenness
Eric Jeschke
Graham Kanarek
Anirudh Katipally
Sarah Kendrew
Marten van Kerkwijk
Nicholas S. Kern
Wolfgang Kerzendorf
Lennard Kiehl
Rashid Khan
Aleh Khvalko
Rocio Kiman
David Kirkby
Dominik Klaes
Eric Koch
Tom Kooij
Kacper Kowalik
Roban Hultman Kramer
Mangala Gowri
Krishnamoorthy
Aniket Kulkarni
Amit Kumar
Arie Kurniawan
Arne de Laat
Antony Lee
Katrin Leinweber
Daniel Lenz
Kieran Leschinski
Simon Liedtke
Pey Lian Lim
Stuart Littlefair
Joseph Long
Joe Lyman
Jerry Ma
Duncan Macleod
Ritiek Malhotra
Michele Mastropietro
Jeffrey McBeth
Mike McCarty
Curtis McCully
Vinayak Mehta
Aaron Meisner
Mikhail Minin
Sashank Mishra
Serge Montagnac
José Sabater Montes
Francesco Montesano
Brett Morris
Michael Mueller
Stuart Mumford
Demitri Muna
Nick Murphy
Prasanth Nair
Stefan Nelson
Giang Nguyen
Bogdan Nicula
Al Niessner
Joe Philip Ninan
Asra Nizami
Bryce Nordgren
James Noss
Sigurd Næss
Maximilian Nöthe
Ricardo Ogando
Sara Ogaz
Georgiana Ogrean
Semyeong Oh
Bruno Oliveira
Kyle Oman
Miruna Oprescu
Carl Osterwisch
Luigi Paioro
David M. Palmer
Asish Panda
John Parejko
Madhura Parikh
Neil Parley
Sergio Pascual
Pratik Patel
Aarya Patil
Rohit Patil
Sushobhana Patra
Molly Peeples
Matthew Petroff
Abhinuv Nitin Pitale
Ray Plante
Adele Plunkett
Orion Poplawski
Stephen Portillo
Ana Posses
Joanna Power
Paul Price
Adrian Price-Whelan
J. Xavier Prochaska
David Pérez-Suárez
Tanuj Rastogi
Thomas Robitaille
Juan Luis Cano Rodríguez
Rohan Rajpal
Patricio Rojo
Evert Rol
Alex Rudy
Joseph Ryan
Saurav Sachidanand
Eloy Salinas
Gerrit Schellenberger
Joseph Schlitz
Michael Seifert
Srikrishna Sekhar
Mathieu Servillat
Aditya Sharma
Swapnil Sharma
Helen Sherwood-Taylor
David Shiga
Albert Y. Shih
David Shupe
Jonathan Sick
Max Silbiger
Bernie Simon
Sudheesh Singanamalla
Leo Singer
Brigitta Sipocz
Paul Sladen
Arfon Smith
Kevin Sooley
Shivan Sornarajah
Megan Sosey
Shantanu Srivastava
David Stansby
Abigail Stevens
Ole Streicher
Matej Stuchlik
Bernardo Sulzbach
Jani Šumak
Jonas Große Sundrup
Vatsala Swaroop
Esteban Pardo Sánchez
James Taylor
Jeff Taylor
Mark Taylor
Kirill Tchernyshyov
Régis Terrier
Víctor Terrón
Peter Teuben
Scott Thomas
Erik Tollerud
Matthew Turk
James Turner
Miguel de Val-Borro
Jake VanderPlas
Alex de la Vega
Shresth Verma
Sam Verstocken
Zé Vinicius
Karl Vyhmeister
Lisa Walter
Laura Watkins
Benjamin Alan Weaver
Jonathan Whitmore
Julien Woillez
Michael Wood-Vasey
Maneesh Yadav
Felix Yan
Víctor Zabalza
Michael Zhang

ATROPY PROJECT

- ➤ Core package — tables, images, coordinates, time, data formats
- ➤ Mostly Python & Numpy, quite some C extensions and Cython
- ➤ Ecosystem of interoperable and complimentary packages
- ➤ Project coordinators
- ➤ Open development on Github
- ➤ Some professional developers (funded e.g. at STScI and others), not just astronomers
- ➤ Active user support: tutorial, documentation, meetings, …

MENTIONS OF SOFTWARE IN ASTRONOMY PUBLICATIONS



2019

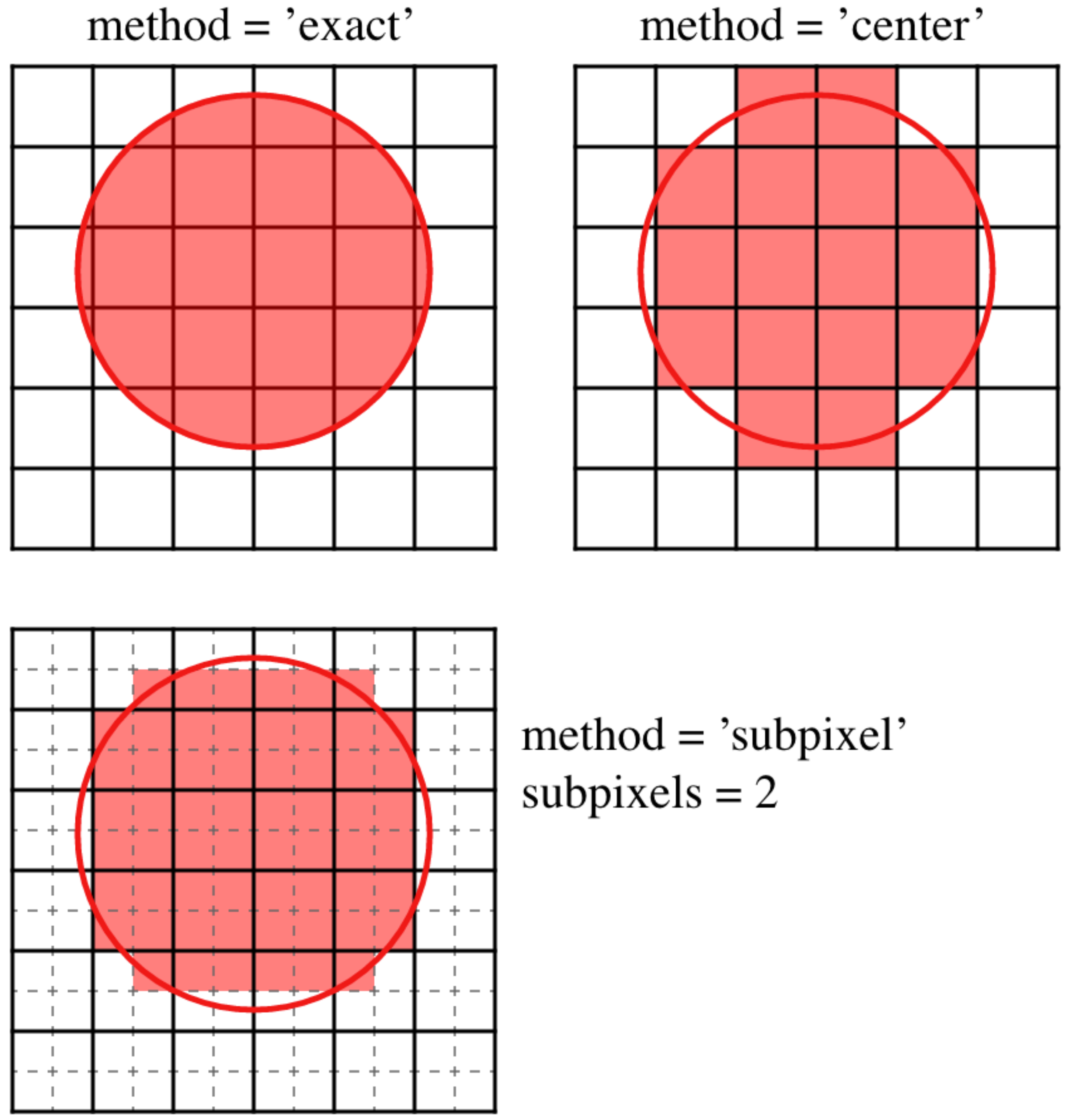
Python now most popular language in astronomy.

Compiled from NASA ADS [(code)]().

Thanks to Juan Nunez-Iglesias, Thomas P. Robitaille, and Chris Beaumont.

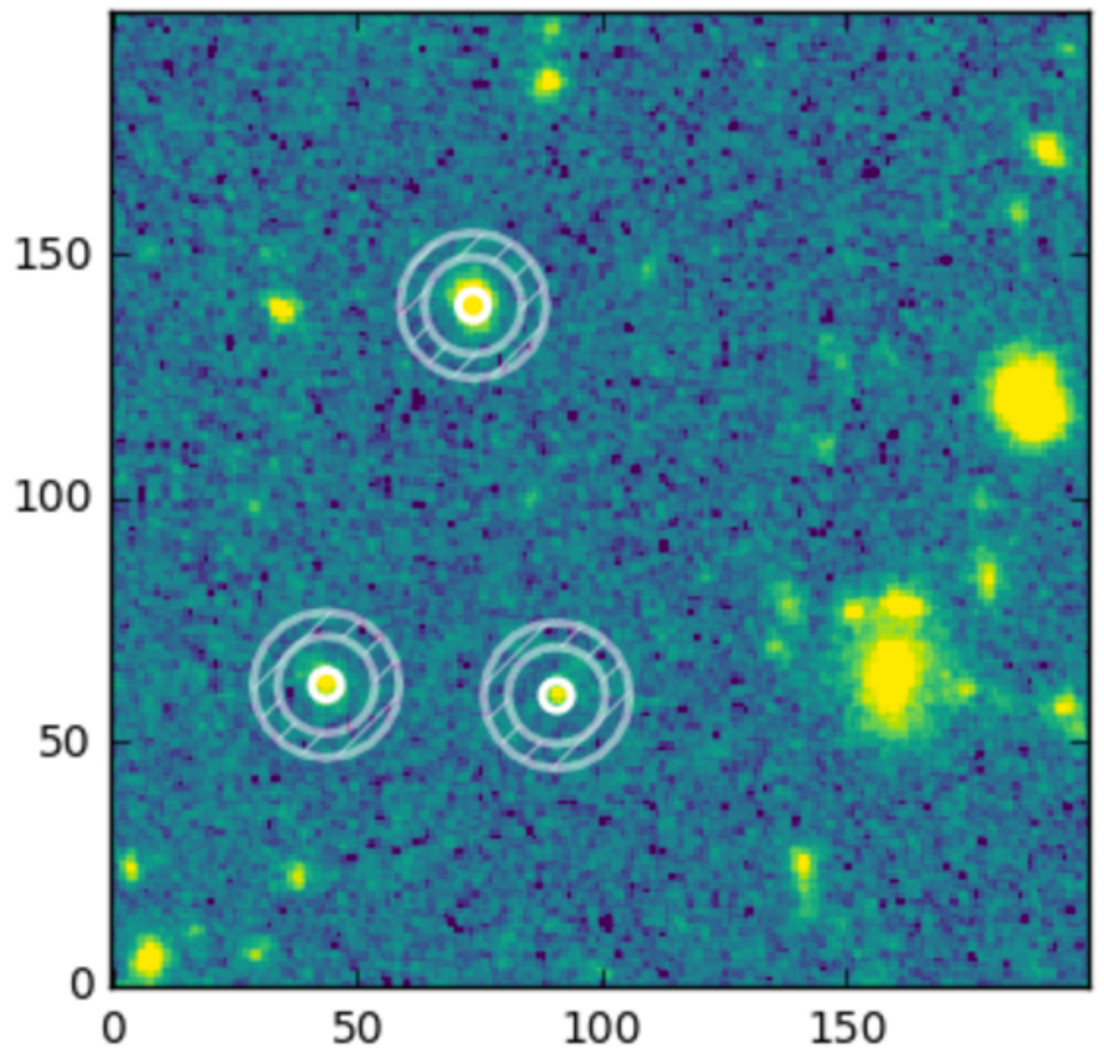
ASTROPY & JWST

- JWST software: Python & Numpy & Astropy & other packages openly developed - for and with the astronomical community
- Example: image photometry using Jupyter, Astropy, phoutils, matplotlib



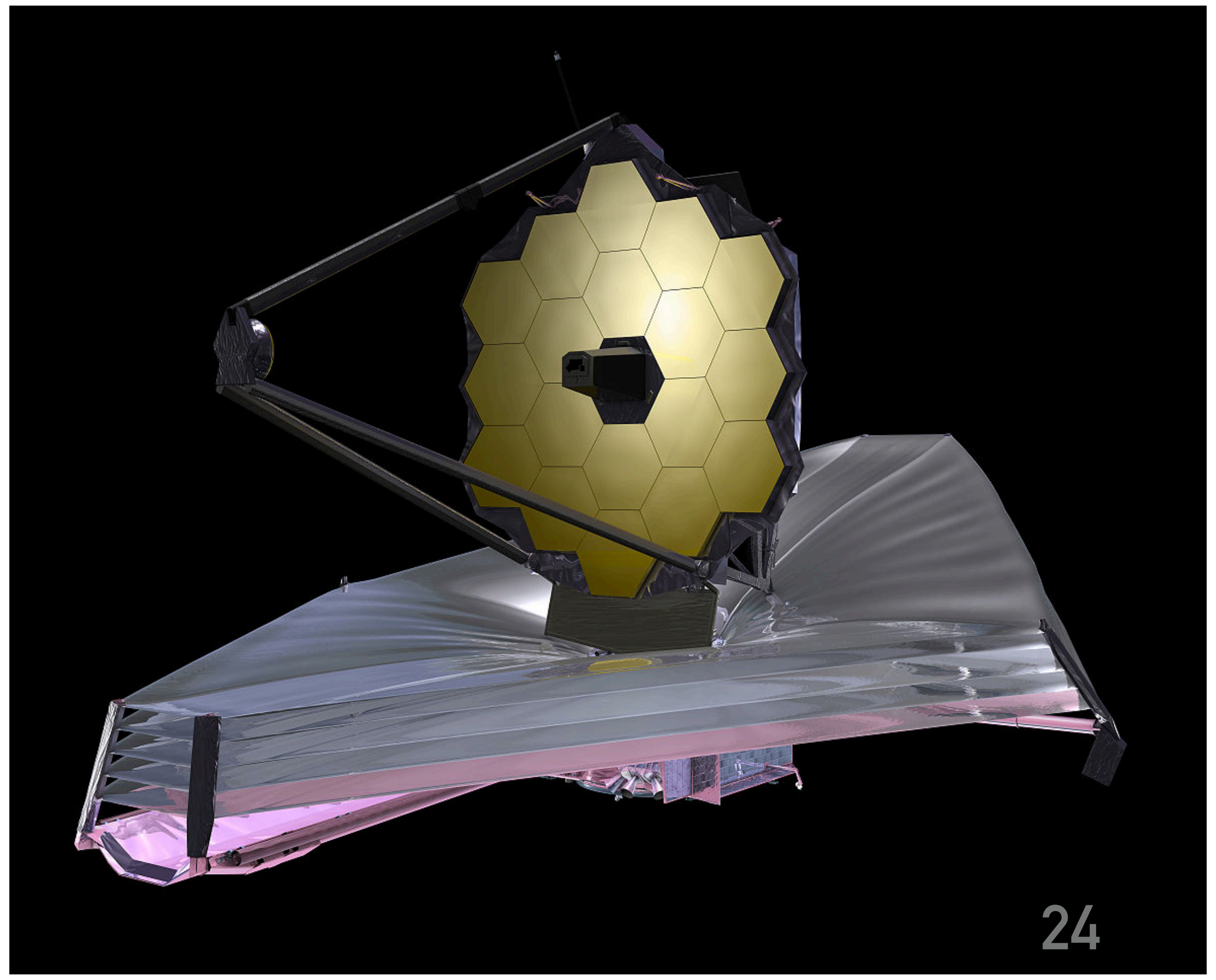
In [46]:

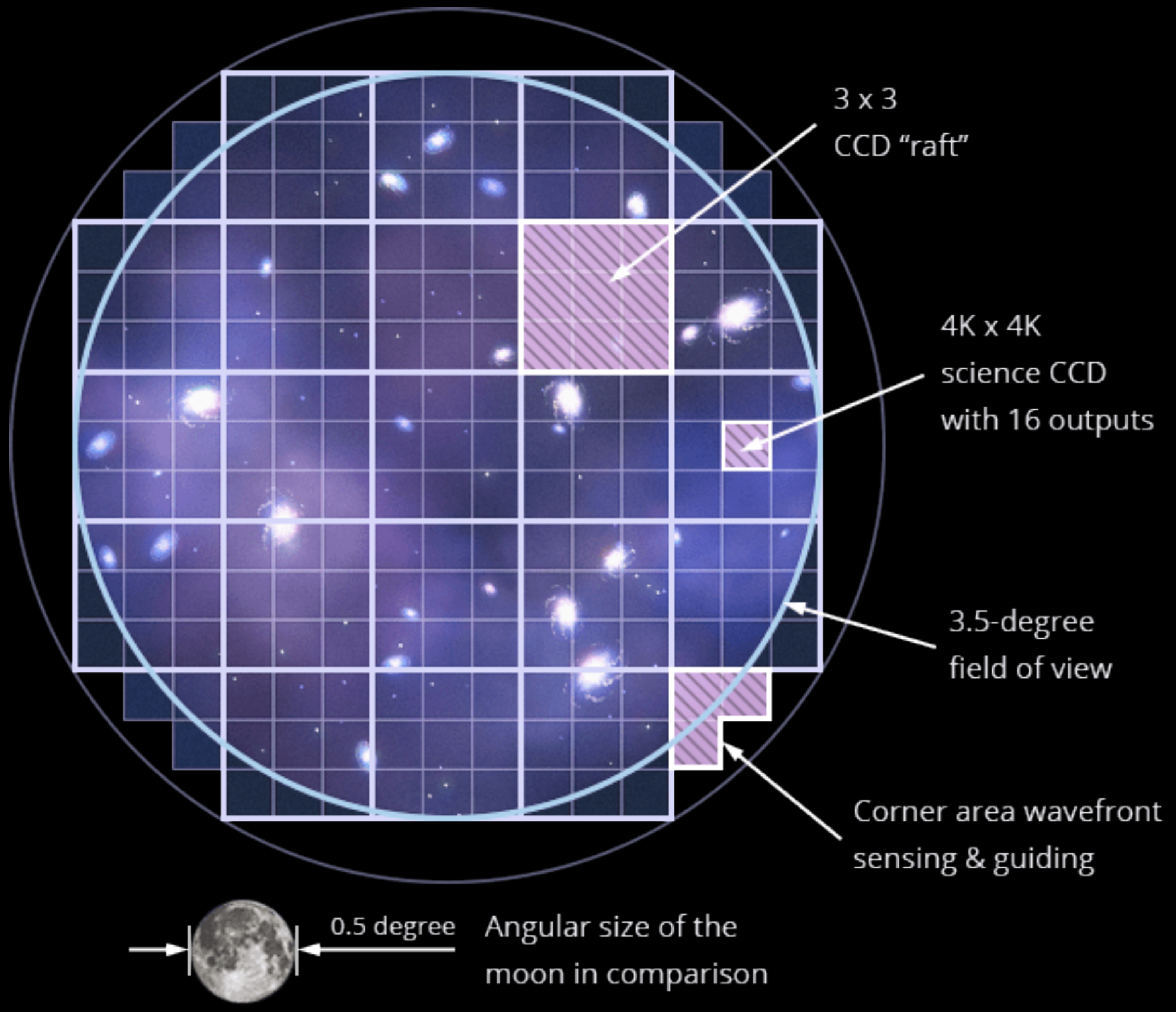
```
plt.imshow(scale_image(data, scale='sqrt', percent=98.))

aper.plot(color='white', lw=2)
bkg_aper.plot(color='white', lw=2, hatch='//', alpha=0.5)
```

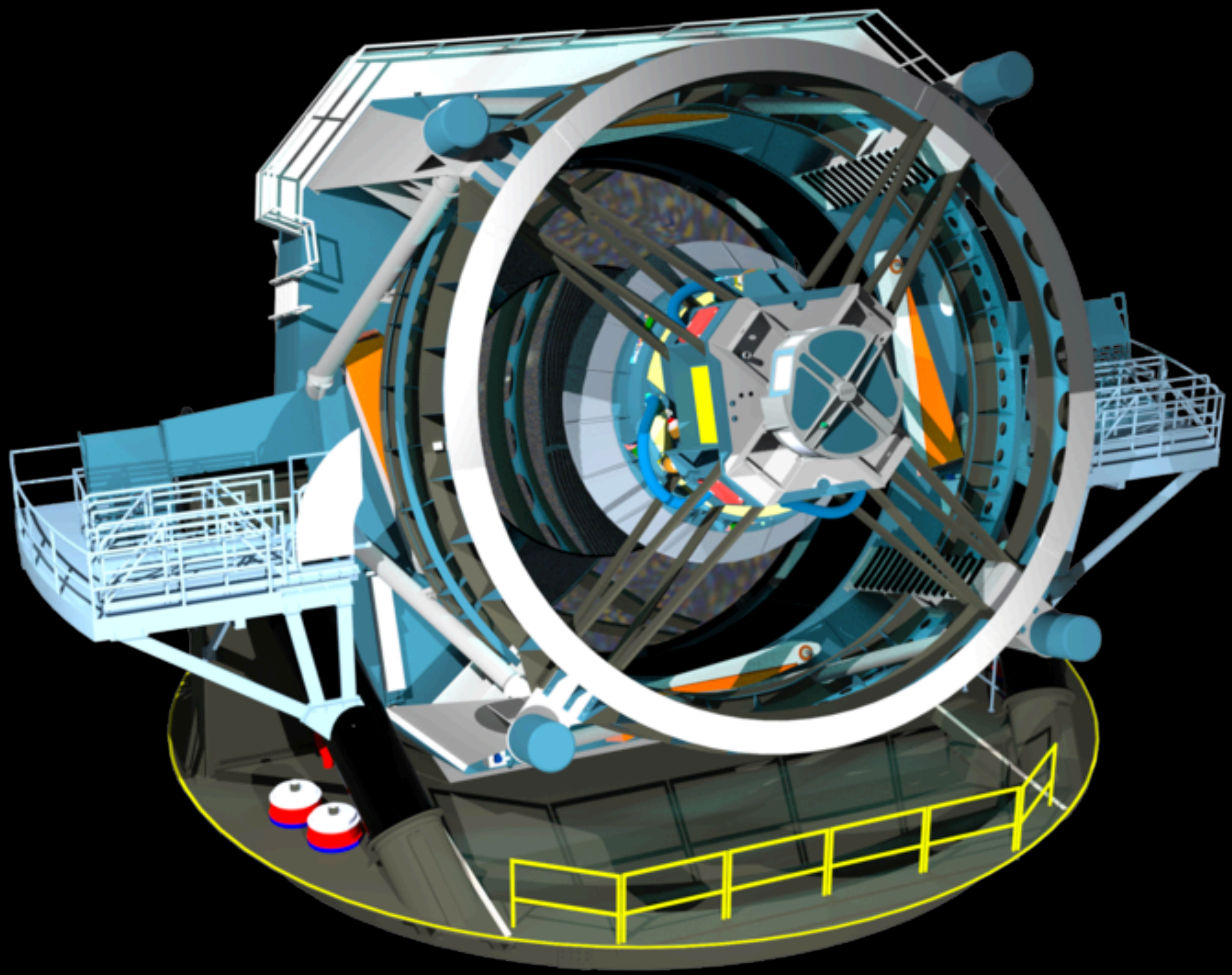


The Astropy Project

photutils
An Astropy Package for Photometry







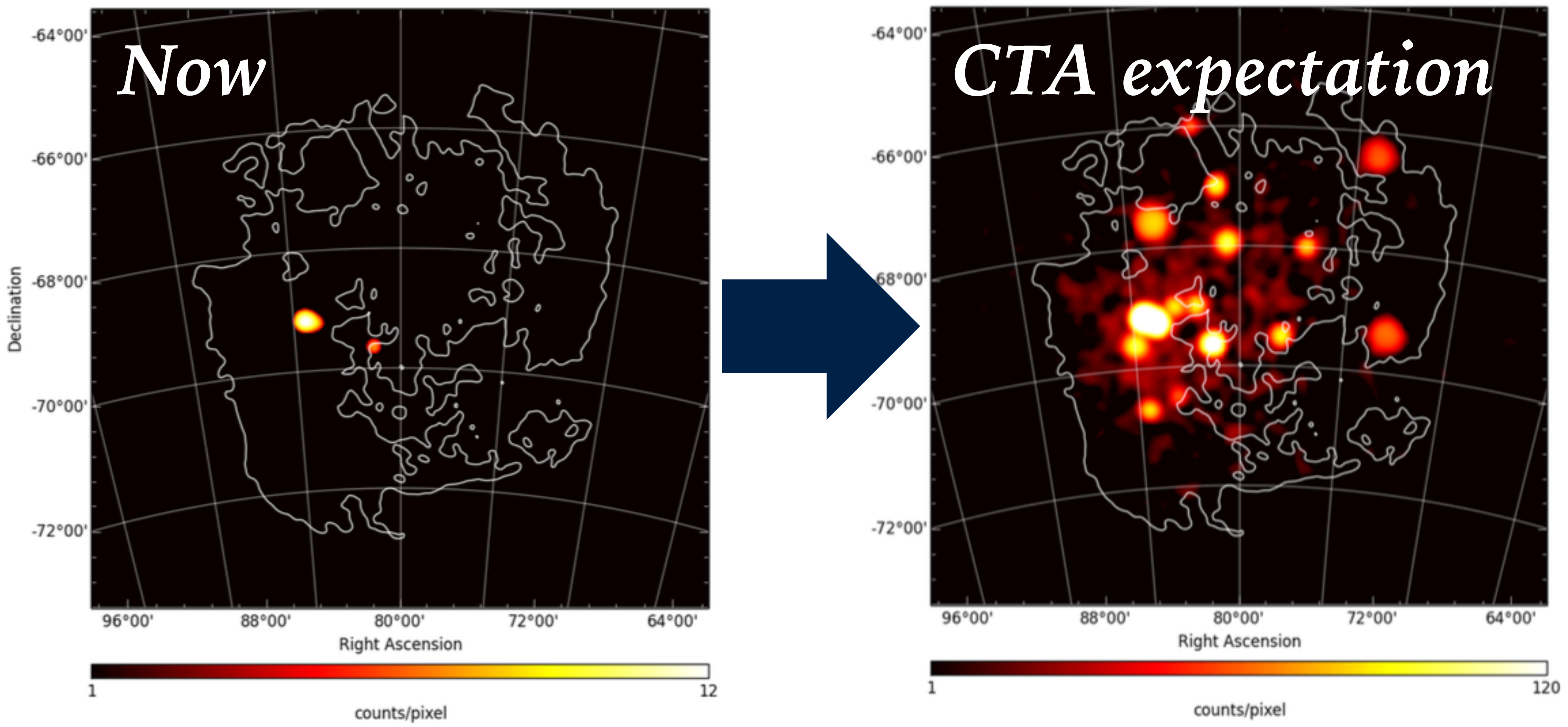
LSST

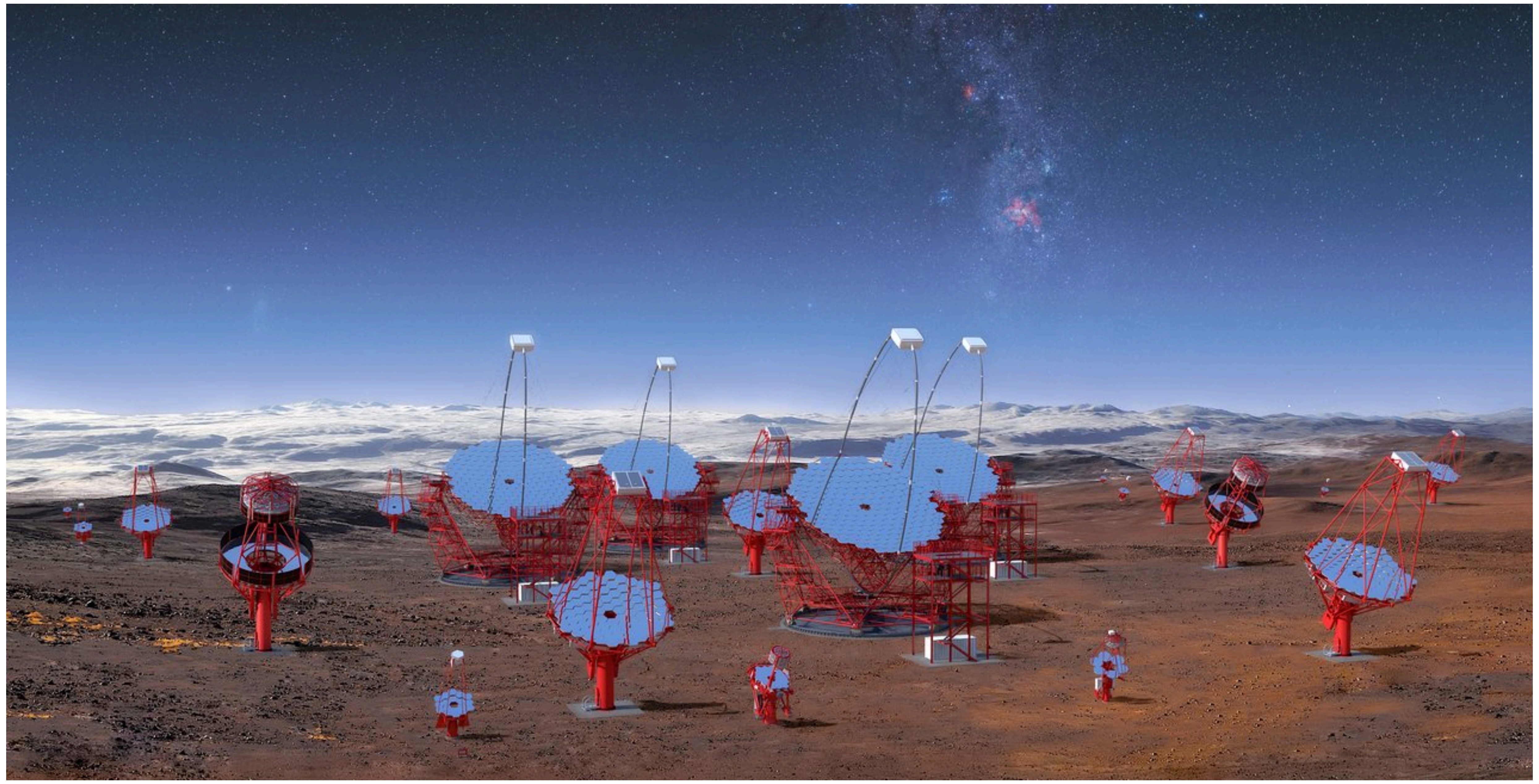
- Large Synoptic Survey Telescope
- 8.4 m mirror, 3200 mega-pixel camera with very large field of view (40x moon)
- First light in 2020, cost 500 M$
- Make a movie — image the full southern sky every three nights, for a decade
- Every night take 2000 images (15 TB data), transfer Chile to US, data analysis generating within 1 minute
- 10 million alerts per night,
  some will trigger other telescopes.

LSST SOFTWARE - C++ & PYTHON

- LSST can be called a "software telescope" - hardware is challenging and expensive, but software and data processing even more so - at the limit of what's possible.
- They chose C++ & Python (via SWIG) 10+ years ago, yet still very active to investigate new C++ and Python features or interfacing (pybind11), or Cython, Astropy, …
- I think LSST is one of the best software projects in astronomy - some LSST experts have mixed feelings, e.g. Jim Bosch "Falling out of love with C++" (2018, LINK)
- What is good C++? Best practices very different in C++ 98, 11, 17, 20.
"I'm really starting to doubt that C++ can be safely and scalably used by big scientific projects."
- *"I'm by no means convinced that the Astropy/Cython approach would have been a better one for us, even if we'd adopted it years ago. The grass looks pretty brown on both sides of this fence."*

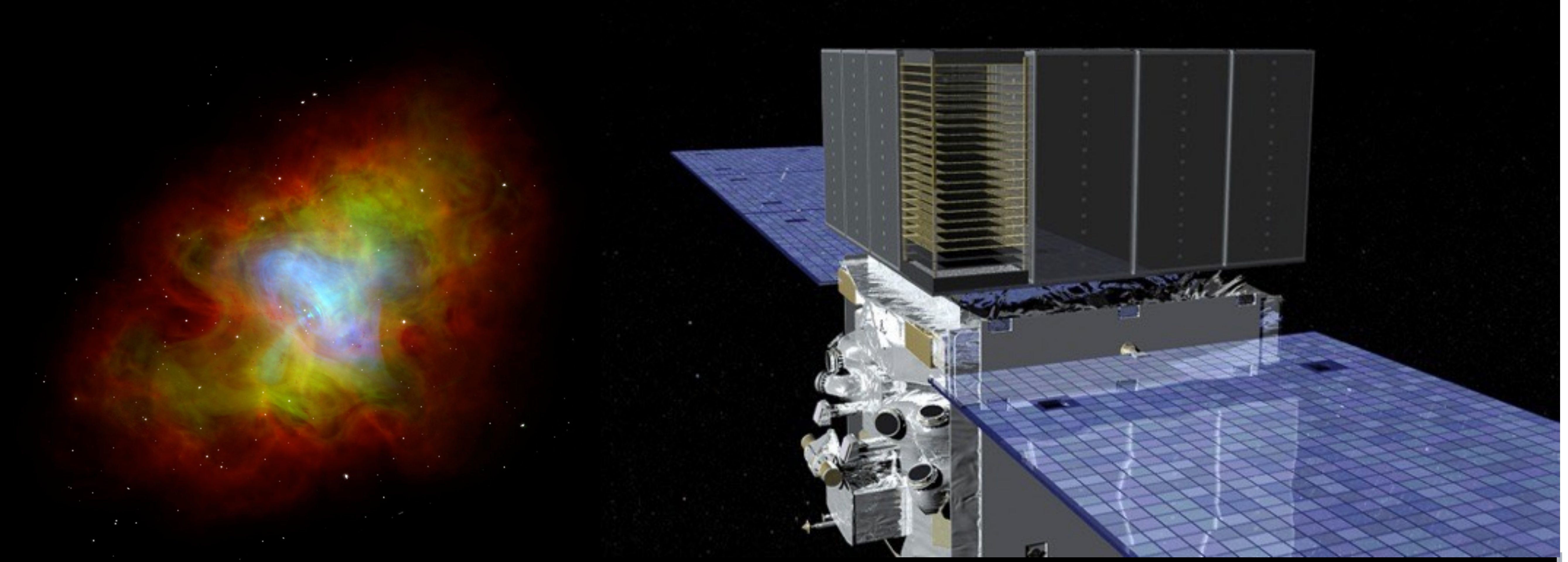
Large Magellanic Cloud image in gamma rays

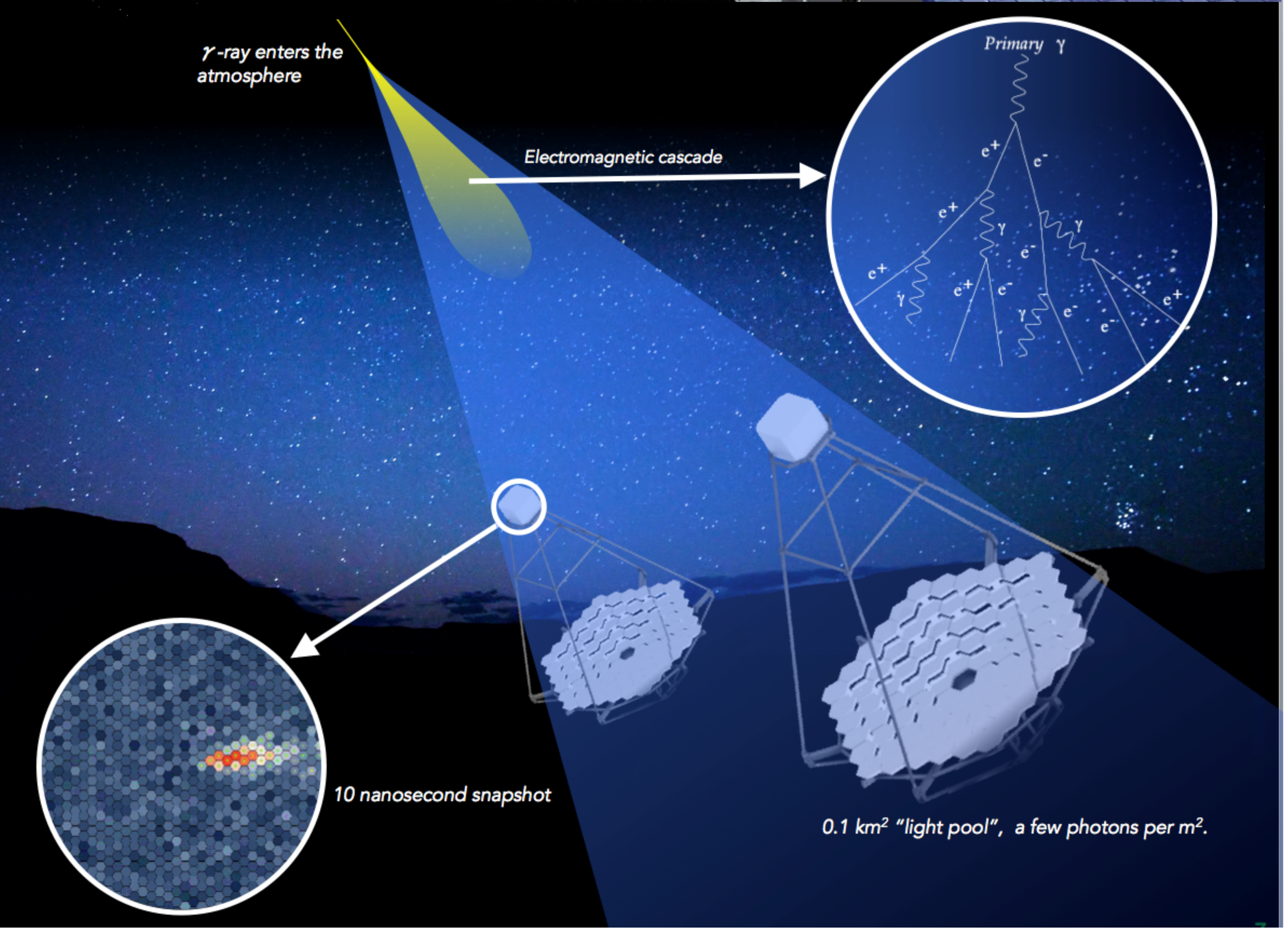




CTA

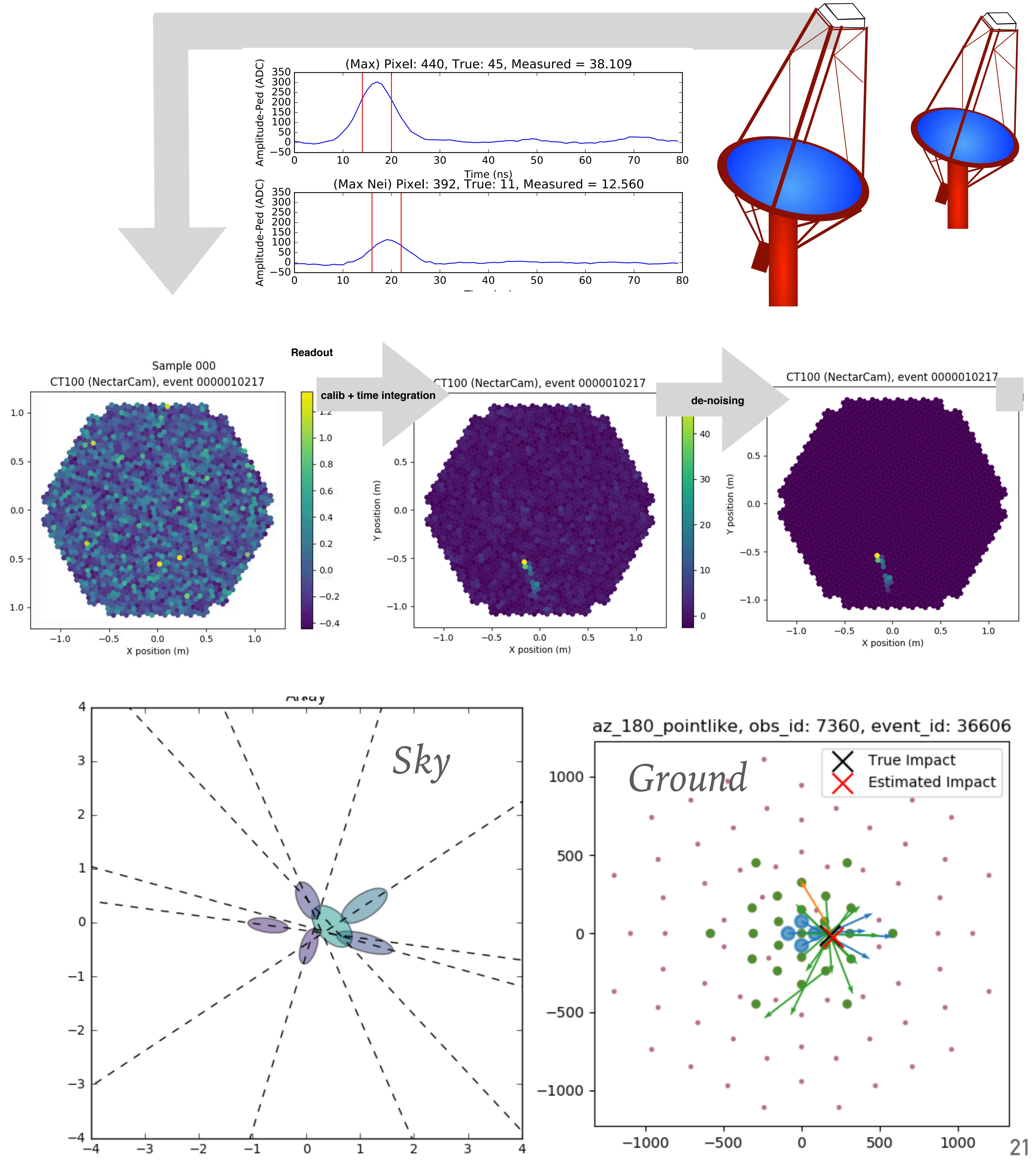
- Cherenkov Telescope Array (CTA)
- Much higher resolution and sensitivity than current instruments like H.E.S.S.
- First ground-based gamma-ray observatory with open data and tools
- Two locations to be able to observe the whole sky: Chile & La Palma
- 300 million Euro and 1500 person years
- 100 telescopes (small, mid, large)
- Construction throughout 2020s





CTA GAMMA-RAY DETECTION

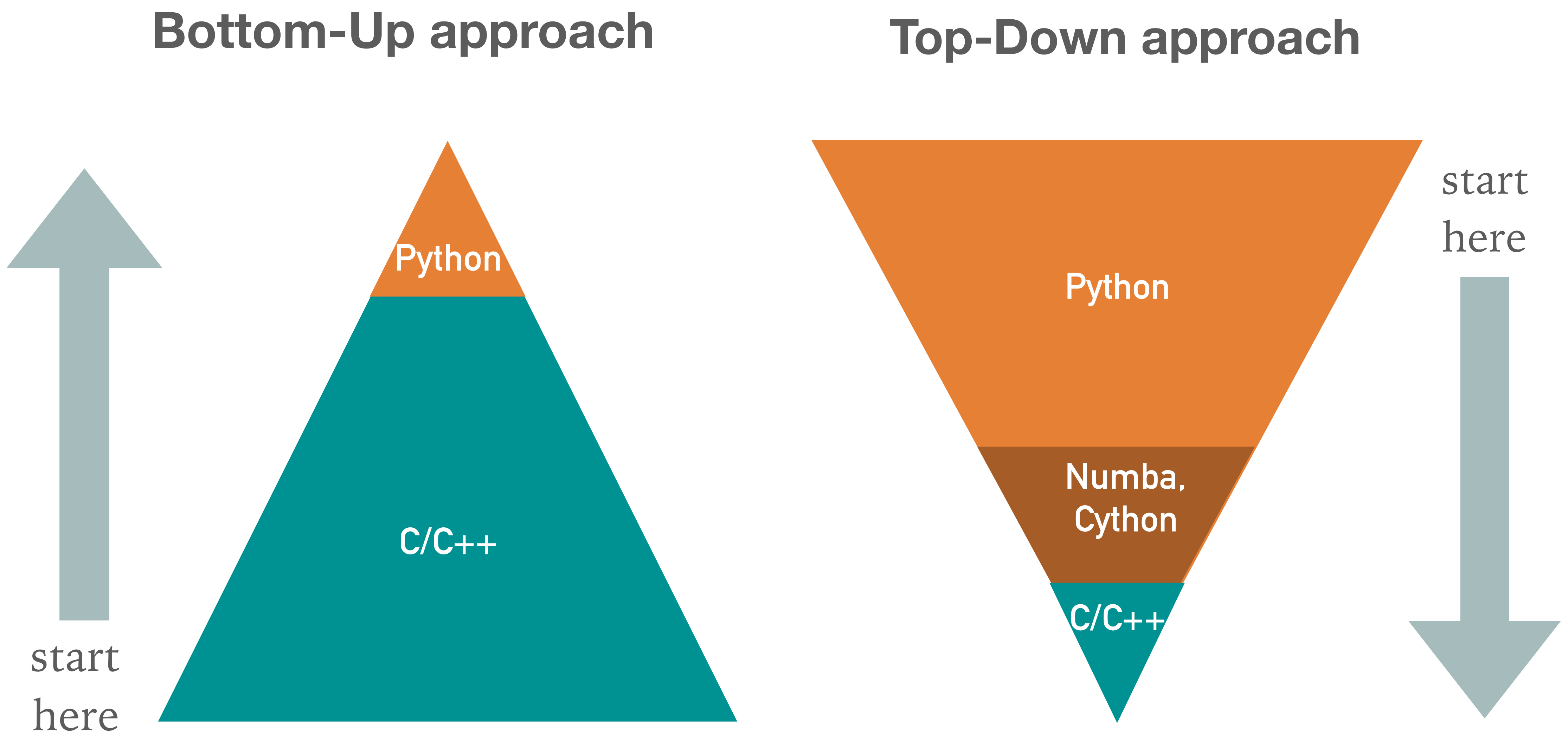
- Fermi space telescope area too small to detect high-energy gamma rays (TeV)
- CTA is an array of imaging atmospheric Cherenkov telescopes (IACTs)
- Earth atmosphere is part of the detector Up to square kilometre detection area
- Stereoscopic view of air showers and event reconstruction
- Output is an "event list": time sky position and energy for every photon



CTA DATA

- Very high raw data rate: ~ 30 TB / night and ~ 10 PB / year
- Very complex event reconstruction pipeline — several data levels
- High-level event data for science analysis of CTA is small, will only be ~ 1 TB (for years of observations)
- Maybe all CTA high-level data will fit on a laptop or even in memory

Source: Karl Kosack (PyGamma19)



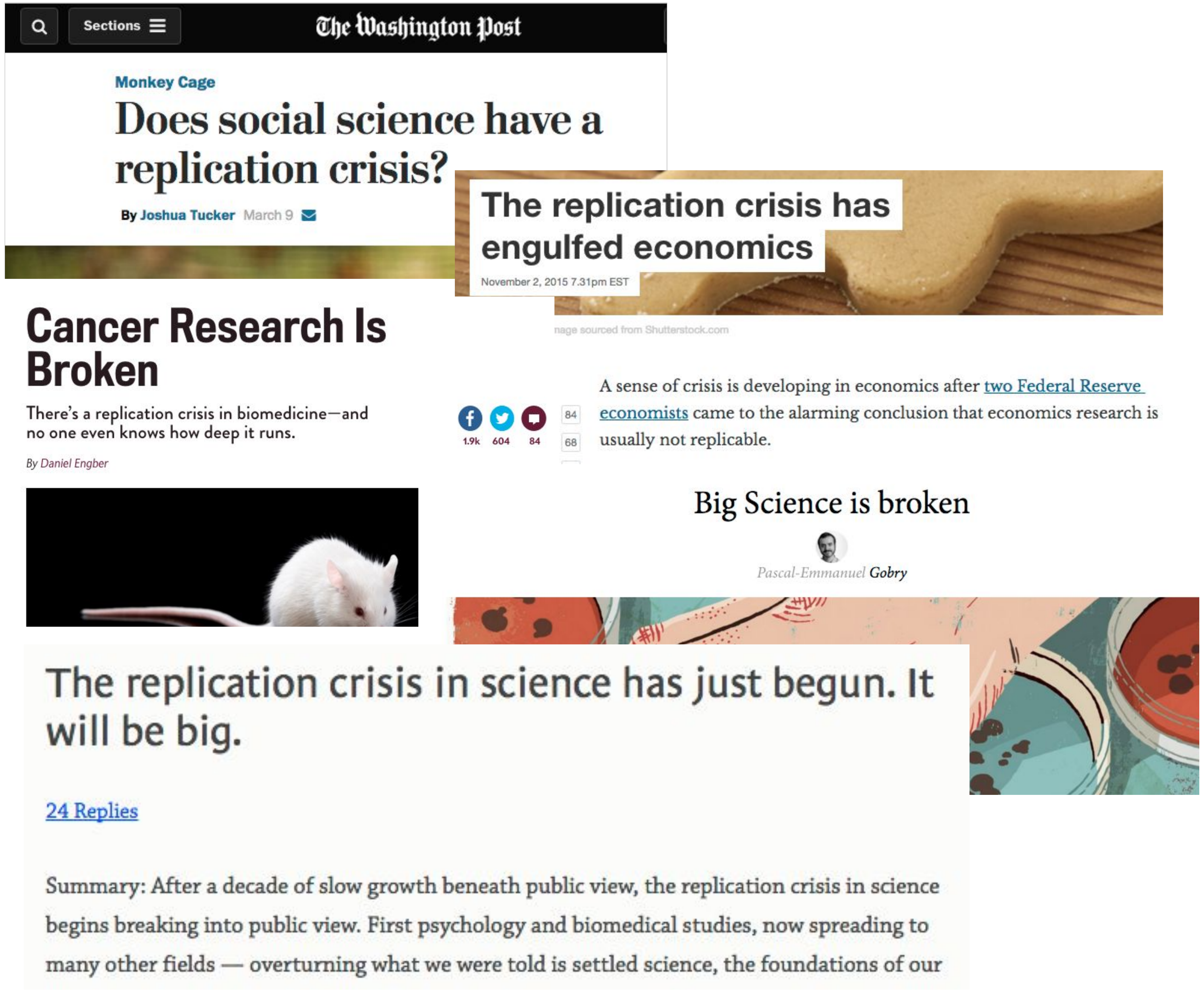
CTA SOFTWARE

- Currently a lot of discussion on software technology stack & design for CTA:
  - mainly C++ like LSST?
  - mainly Python & Numpy like JWST?
  - which libraries are good & stable enough?
- I started Gammapy — 98% Python & Numpy & Astropy, 2% Cython
- Overall pretty happy with this approach, starting to look at Numba
- CTA is in the prototyping phase …. competing ideas, decisions in next years

A **Python** package for **gamma-ray** astronomy

ctapipe

THE REPLICATION CRISIS IN SCIENCE



The Washington Post

Sections

Monkey Cage

Does social science have a replication crisis?

By Joshua Tucker March 9

The replication crisis has engulfed economics

November 2, 2015 7.31pm EST

A sense of crisis is developing in economics after two Federal Reserve economists came to the alarming conclusion that economics research is usually not replicable.

Cancer Research Is Broken

There's a replication crisis in biomedicine—and no one even knows how deep it runs.

By Daniel Engber

Big Science is broken

Pascal-Emmanuel Gobry

The replication crisis in science has just begun. It will be big.

24 Replies

Summary: After a decade of slow growth beneath public view, the replication crisis in science begins breaking into public view. First psychology and biomedical studies, now spreading to many other fields — overturning what we were told is settled science, the foundations of our

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NEWS

Home Video World US & Canada UK Business Tech Science Magazine

Science & Environment

Most scientists 'can't replicate studies by their peers'

By Tom Feilden

Science correspondent, Today programme

22 February 2017 | Science & Environment

Share

"An article about computational result is advertising, not scholarship. The actual scholarship is the full software environment, code and data, that produced the result."

— Buckheit and Donoho (1995)

Image source: Jake Vanderplas (PyCon 2017)

OPEN TOOLS AND SERVICES HELP SCIENCE

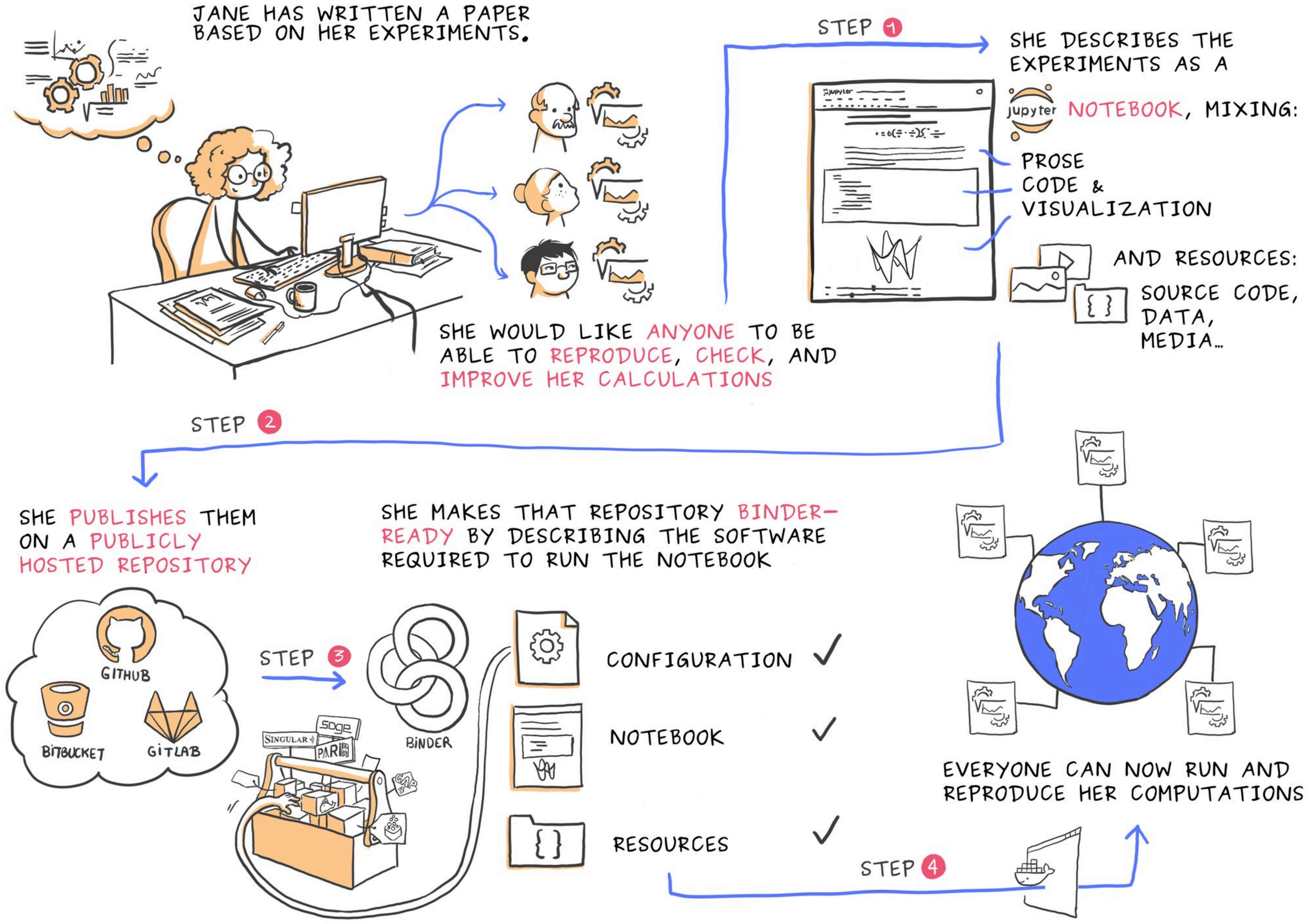
python™ PyData

CONDA

GitHub

jupyter

binder

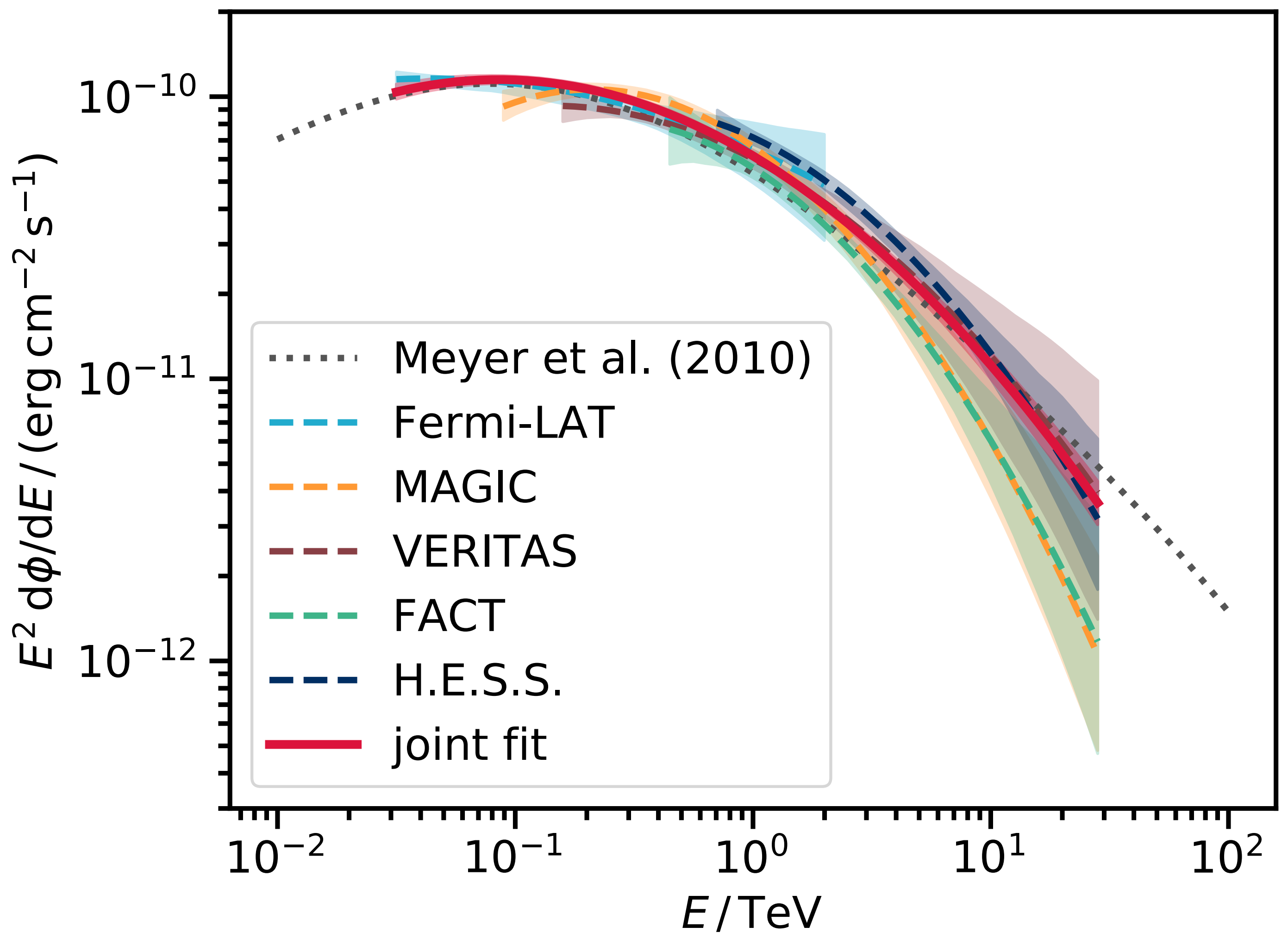


Cartoon by https://twitter.com/JulietteTaka (Tweet)

Astronomy & Astrophysics manuscript no. output
February 15, 2019

Towards open and reproducible multi-instrument analysis in gamma-ray astronomy

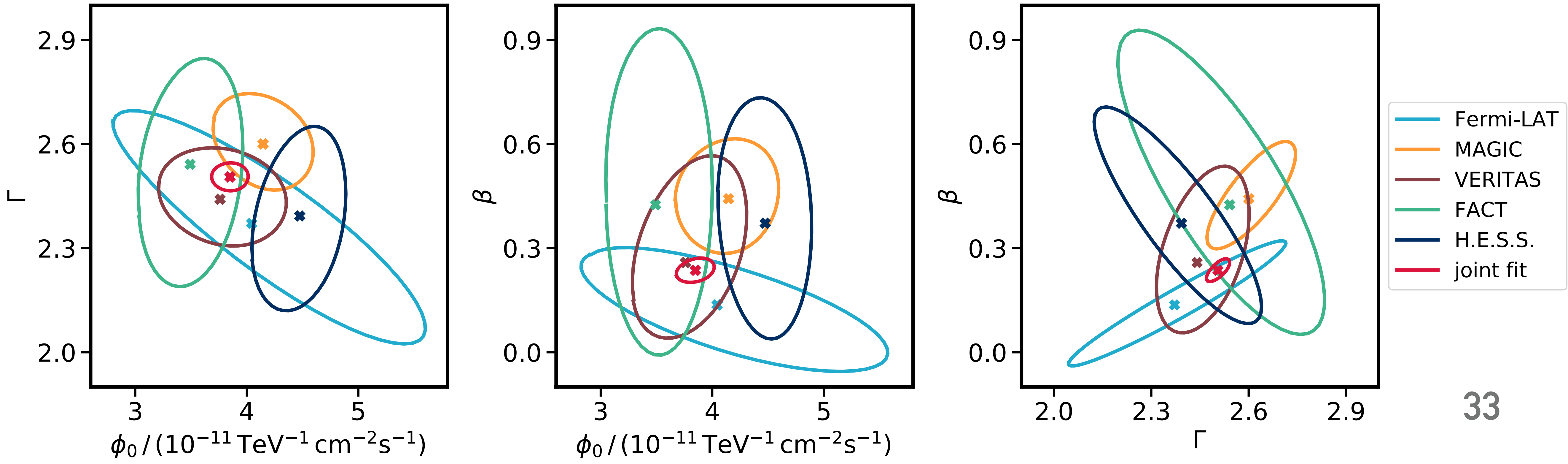
C. Nigro[1★], C. Deil[2], R. Zanin[2], T. Hassan[1], J. King[3], J.E. Ruiz[4], L. Saha[5], R. Terrier[6], K. Brügge[7], M. Nöthe[7], R. Bird[8], T. T. Y. Lin[9], J. Aleksić[10], C. Boisson[11], J.L. Contreras[5], A. Donath[2], L. Jouvin[10], N. Kelley-Hoskins[1], B. Khelifi[6], K. Kosack[12], J. Rico[10], and A. Sinha[6]



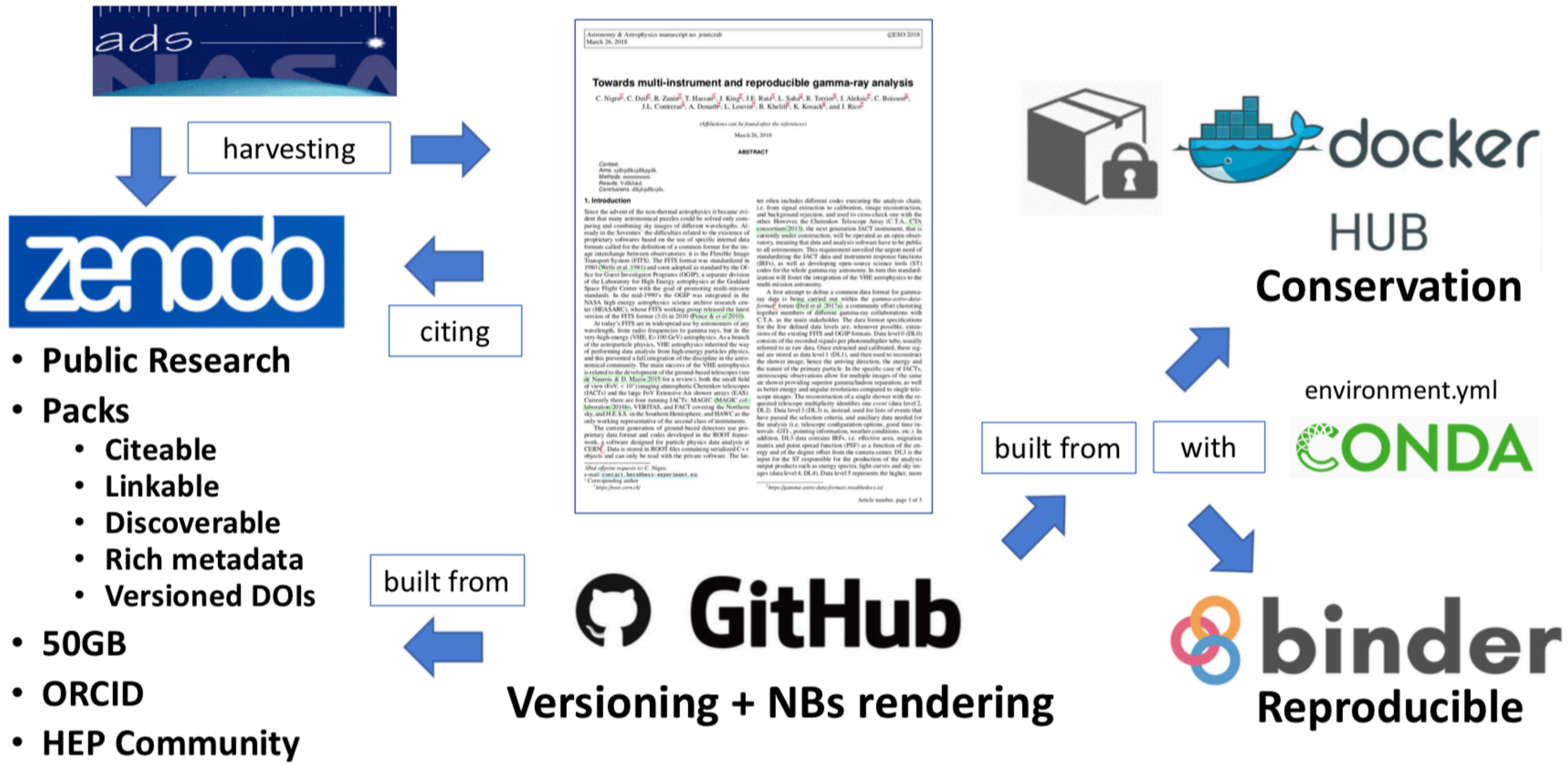
Dataset	T_{obs}	E_{min} TeV	E_{max} TeV
Fermi-LAT	~7 yr	0.03	2
MAGIC	0.66 h	0.08	30
VERITAS	0.67 h	0.16	30
FACT	10.33 h	0.45	30
H.E.S.S.	1.87 h	0.71	30

MY FIRST REPRODUCIBLE PAPER

- We defined an open common format for high-level gamma-ray astronomy data
- Exported some Crab Nebula observation data from five telescopes — this is a test and showcase, not a science paper
- Joint likelihood fit of a gamma-ray spectral model to all data — increased sensitivity!
- Accepted for publication in Astronomy & Astrophysics - journals are changing too.



An **inter-linked storage** for a **reproducible pack**




```yaml
environment.yml
1  name: joint-crab
2
3  channels:
4    - conda-forge
5    - sherpa
6
7  dependencies:
8    - gammapy==0.8
9    - python==3.6
```

MY FIRST REPRODUCIBLE PAPER

- All data & code open and archived:
  github.com/open-gamma-ray-astro/joint-crab
  zenodo.org/record/2381863
- Reproducible execution environment via conda (with versions pinned):
  $ conda env create -f environment.yml
  $ source activate joint-crab
- Docker image to increase chances of reproducibility in the future
- Python to reproduce all results and plots:
  $ make.py all
- Jupyter notebooks and Binder to explore

WHY IS PYTHON SUCH AN EFFECTIVE TOOL IN ASTRONOMY?

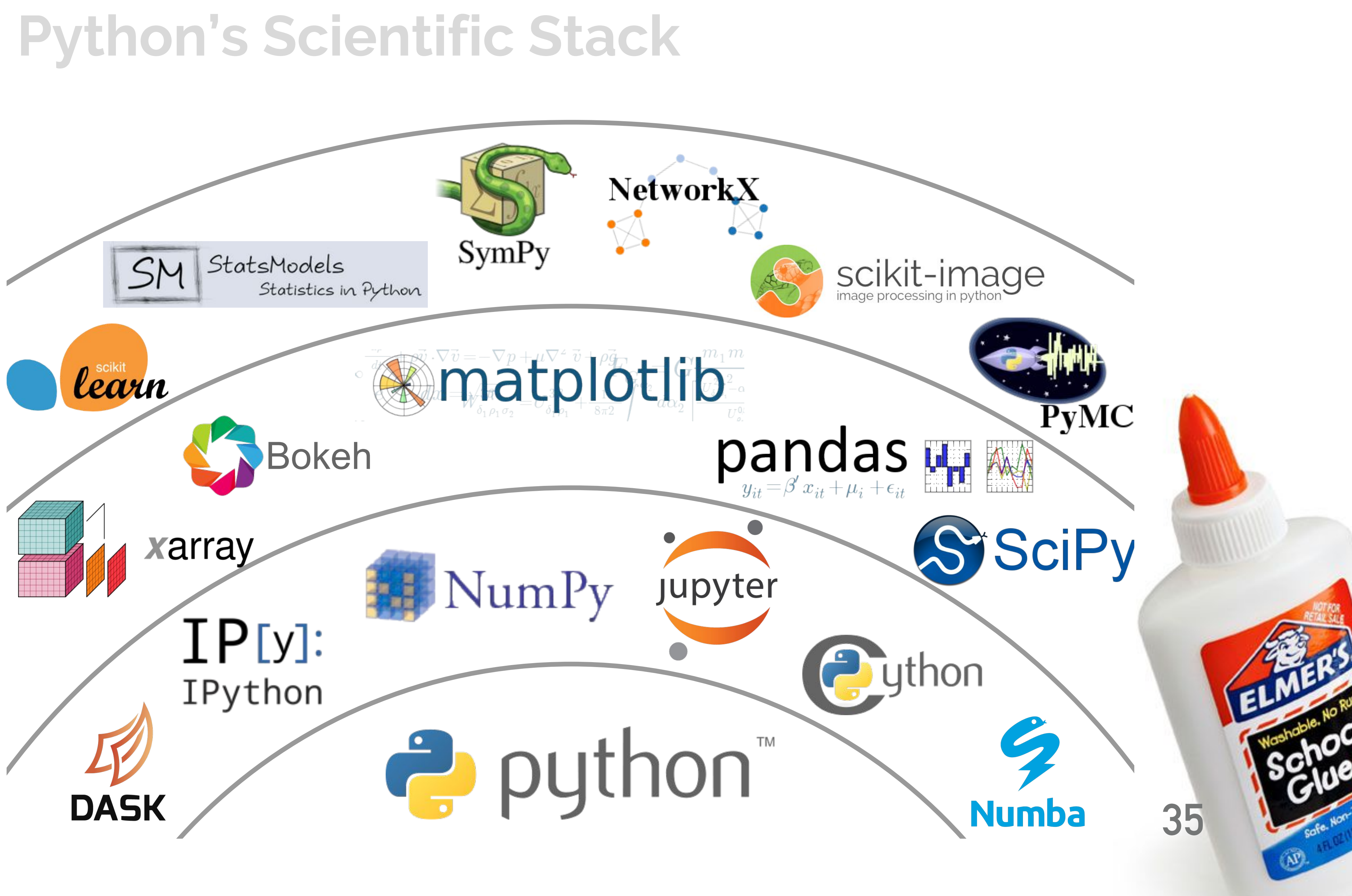
"Python is a language that is very powerful for developers, but is also accessible to Astronomers. Getting those two classes of people using the same tools, I think, provides a huge benefit that's not always noticed or mentioned."

"For day-to-day scientific data exploration, speed of development is primary, and speed of execution is often secondary."

"Python has built-in libraries for nearly everything … and there are third-party libraries for everything else. Python is the glue to combine the scientific codes"

Perry Greenfield (STScI)
PyAstro 2015

Jake VanderPlas
PyCon 2017



SUMMARY & CONCLUSIONS

- Modern astronomy research is data driven - complex hardware & software!
  Open source & Python & PyData & Astropy is the foundation!
- Long history of open data and tools in astronomy - and still getting better.
  You can download data from the best telescopes in the world and analyse with Python!
- PyData is moving very fast now: Numba, Dask, PyTorch, Tensorflow, …
  Same is true for other languages (C++, Julia, Rust, Go, …).
  - Very exciting for astronomers - great new and more powerful tools!
  - But number of options and how fast things change is also a bit scary,
    given that timescale for big telescopes and detectors and codes is 10-30 years.

LEARN MORE? — RESOURCES

- A lot of good free resources exist to learn about astronomy & Python
- Locally: Haus der Astronomie in Heidelberg, Planetarium in Mannheim, open days or public seminars at astronomy research institutes in Heidelberg
- Astronomy journals for general public - e.g. Sterne & Weltraum
- Free online courses, e.g. on Coursera:
  - https://www.coursera.org/learn/data-driven-astronomy ← *Hands-on introduction to astronomy with Python*
  - https://www.coursera.org/learn/astronomy
- Tutorials, e.g. https://github.com/astropy/astropy-workshop

LEARN MORE? — PRESENTATIONS

- I used the following presentations for inspiration and partly for content.
- Jake VanderPlas - “The unexpected effectiveness of Python in Science” at PyCon 2017 (slides, YouTube)
- Perry Greenfield - “How Python slithered into astronomy” at Scipy 2011 (PDF) and updated talks from 2015 (YouTube) and 2016 (YouTube)
- Thomas Robitaille - “The Astropy Project” at PyGamma 2019 (slides)
- Erik Tollerud - “JWST Data Analysis Tools: Open Development of Community Software” at PyGamma 2019 (slides)
- Leo Singer - “Role of Python in Recent Gravitational Wave Astronomy Breakthroughs” at Scipy 2018 (YouTube)

LEARN MORE? — PODCASTS

- If you like podcasts & Python & science
- TalkPython['Podcast'] by Michael Kennedy (https://talkpython.fm):
  - #29 - "Python at the LHC and CERN" - Kyle Cranmer
  - #81 - "Python and ML in Astronomy" - Jake VanderPlas
- Podcast.__init__ by Tobias Macey (https://www.pythonpodcast.com):
  - #32 - "Astropy" - Erik Tollerud
  - #34 - "Sunpy" - Stuart Mumford
  - #106 - "yt-project" - Nathan Goldbaum and John Zuhone
  - #140 - "Data Science For Academic Research" - Jake Vanderplas

Image: H.E.S.S. Galactic plane survey

THANK YOU!

- Thank you Jan, Marius, Alexander, Prabhant, Pawneet for organising!
- Contact: Deil.Christoph@gmail.com
- Slides: https://christophdeil.com