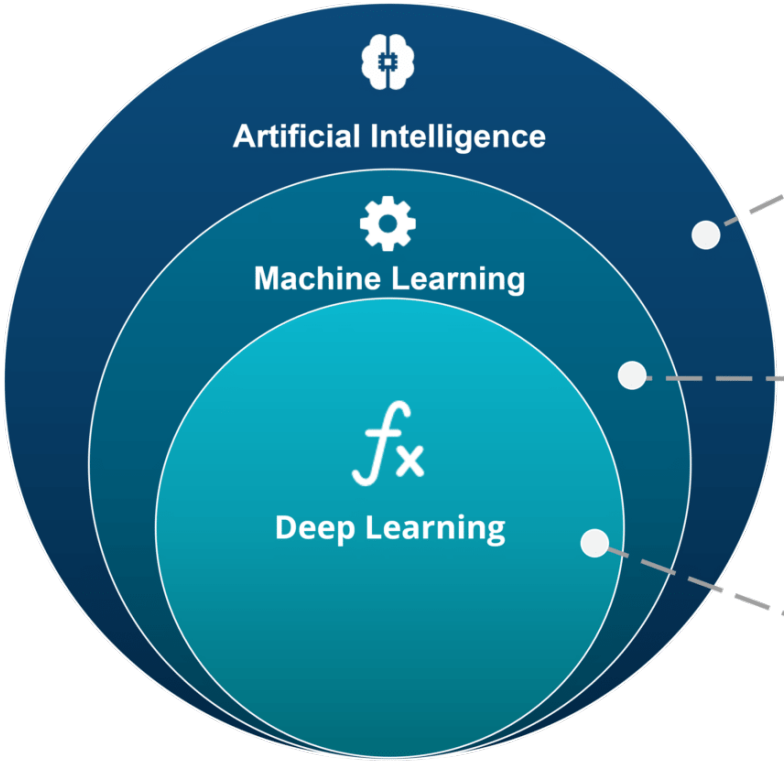
Inteligencia artificial aplicada a astronomía

Paula Sánchez Sáez

ESO Fellow

Miembro del Proyecto ALeRCE

Que es la inteligencia artificial?



ARTIFICIAL INTELLIGENCE
A technique which enables machines to mimic human behaviour

MACHINE LEARNING
Subset of AI technique which use statistical methods to enable machines to improve with experience

DEEP LEARNING
Subset of ML which make the computation of multi-layer neural network feasible

ML vs técnicas tradicionales

Programación tradicional

In [1]:
```
import numpy as np

def produce_a_SN(star_mass):
    if star_mass > 8:
        return(True)
    else:
        return(False)

a = 10
print(produce_a_SN(a))
```

```
True
```

Machine Learning

In [1]:
```
import numpy as np

def produce_a_SN(star_mass):
    if star_mass > 8:
        return(True)
    else:
        return(False)

a = 10
print(produce_a_SN(a))
```

```
True
```

ML vs técnicas tradicionales

Programación tradicional

In [1]:
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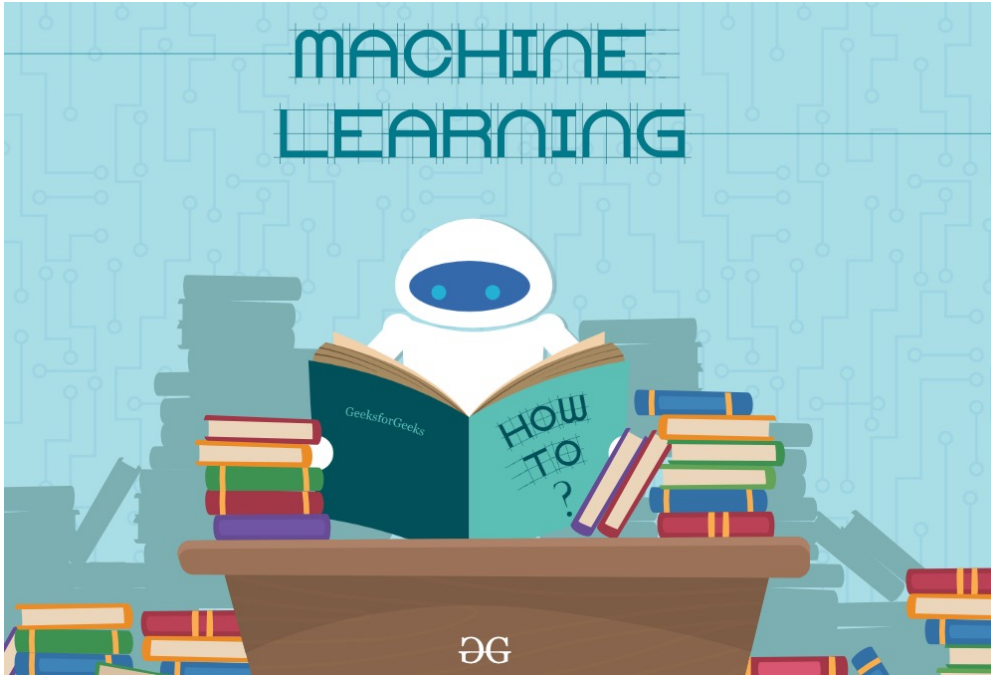
import numpy as np

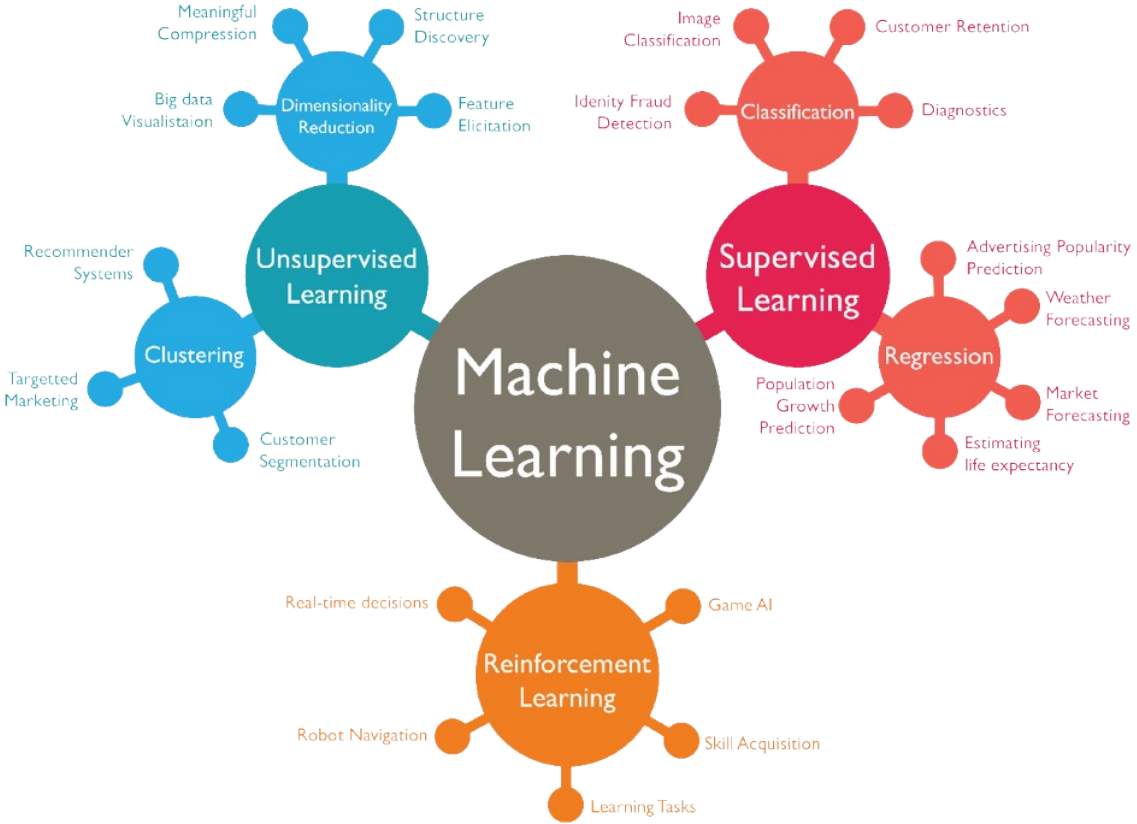
def produce_a_SN(star_mass):
    if star_mass > 8:
        return(True)
    else:
        return(False)

a = 10
print(produce_a_SN(a))
```

```
True
```

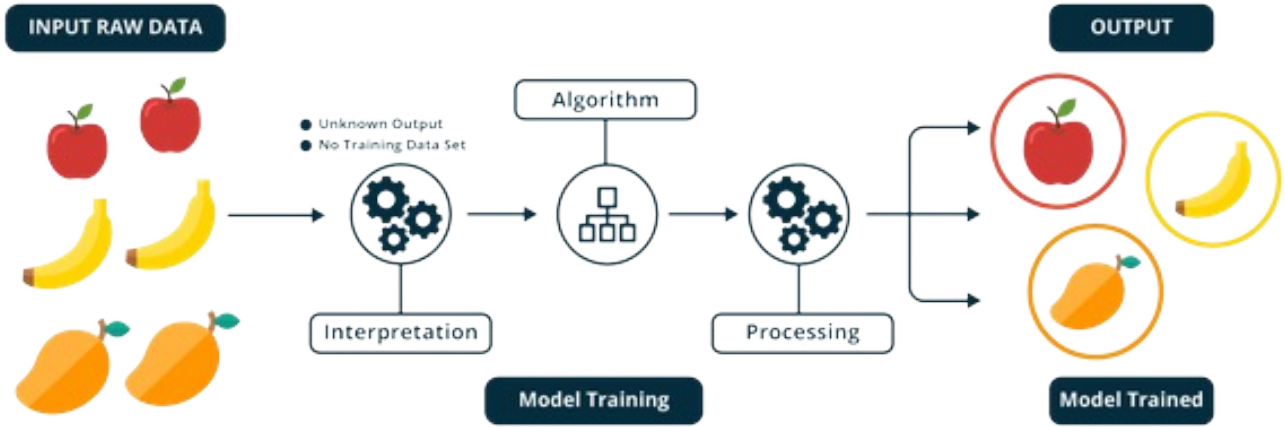


Técnicas de ML



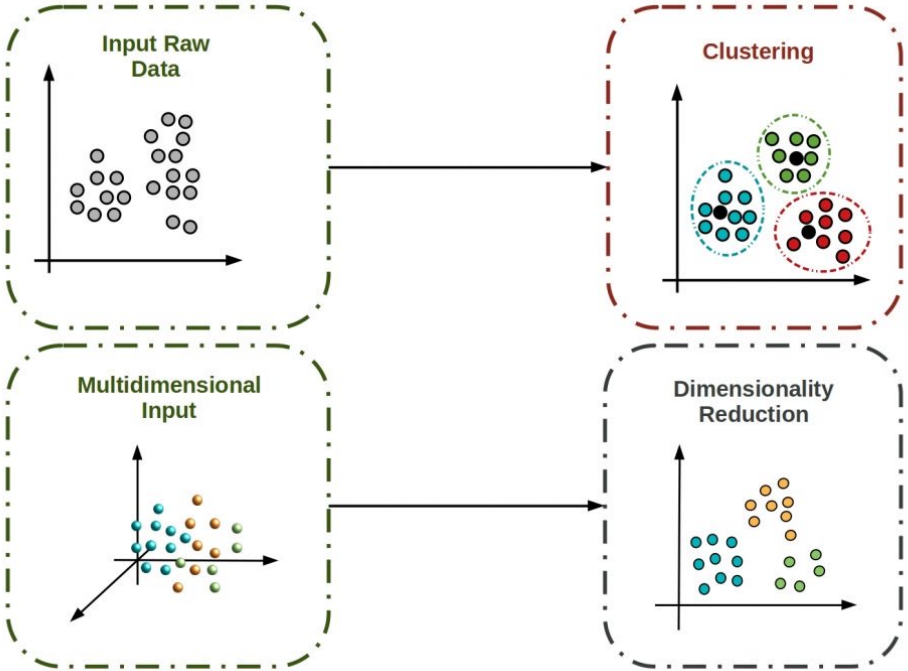
Técnicas de ML: aprendizaje supervisado

Input: etiquetas + atributos



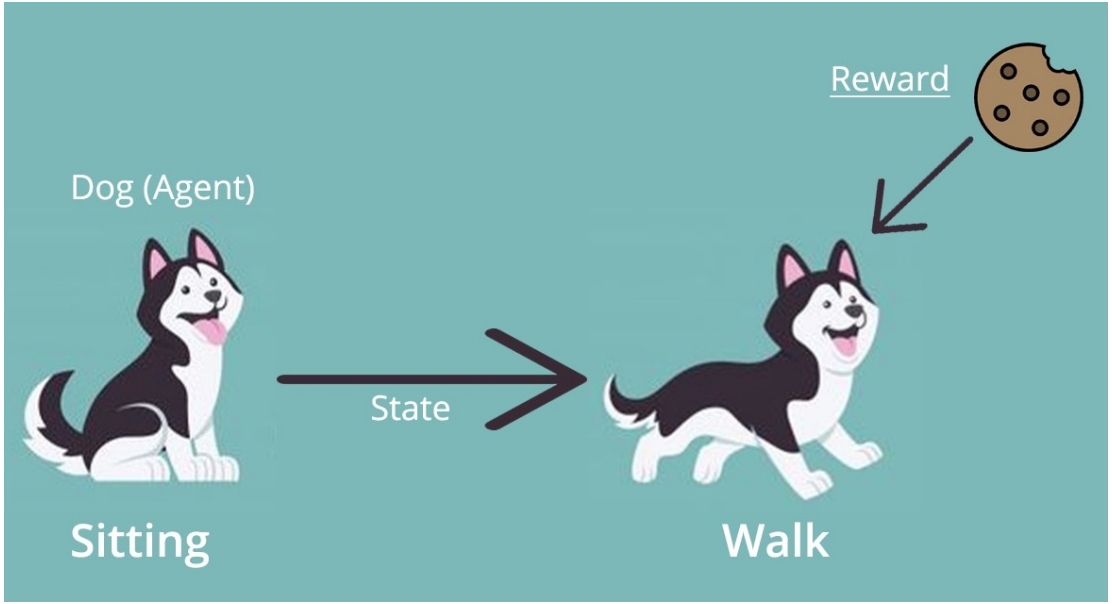
Técnicas de ML: aprendizaje no supervisado

Input: atributos



Técnicas de ML: aprendizaje por refuerzo

Input: datos dinámicos

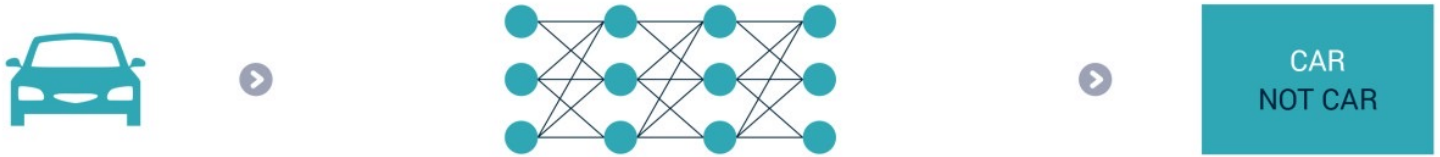


ML vs DL

Machine Learning

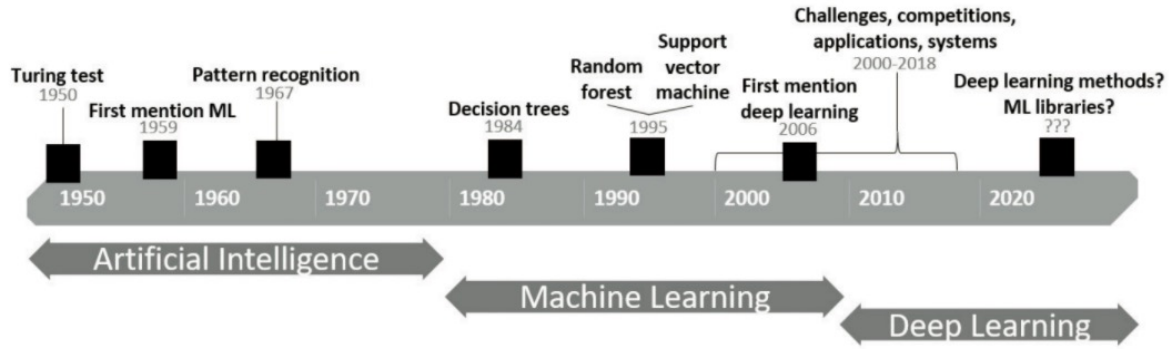
Input → Feature extraction → Classification → Output

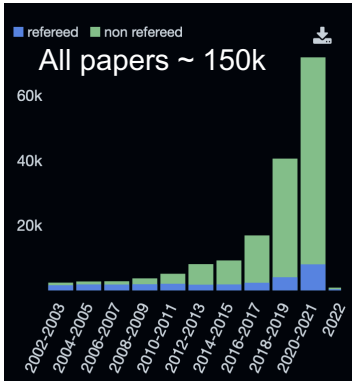
Deep Learning

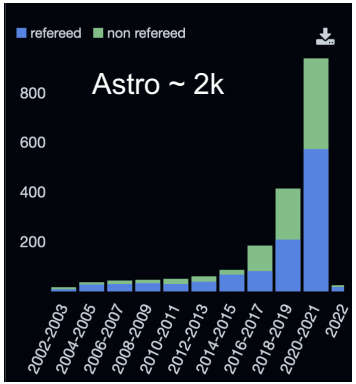


Input → Feature extraction + Classification → Output

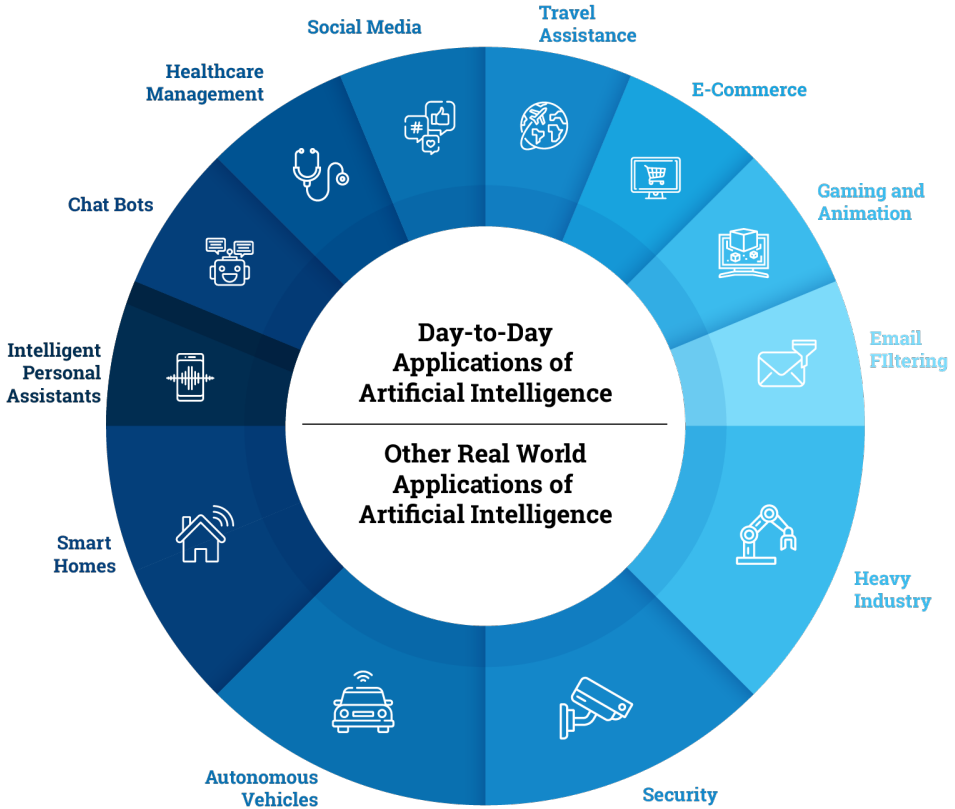
IA en las últimas decadas







Aplicaciones en la vida real

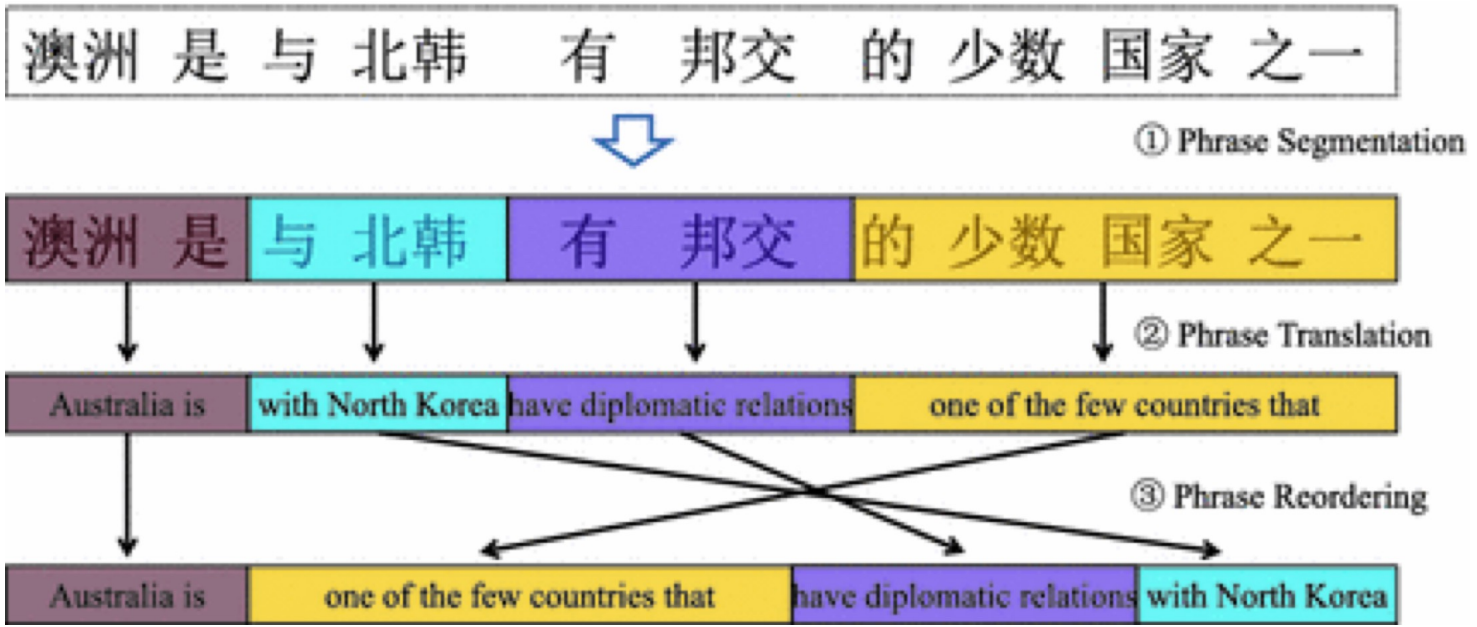


Aplicaciones en la vida real

Computer Vision

Aplicaciones en la vida real

Traducción de lenguajes

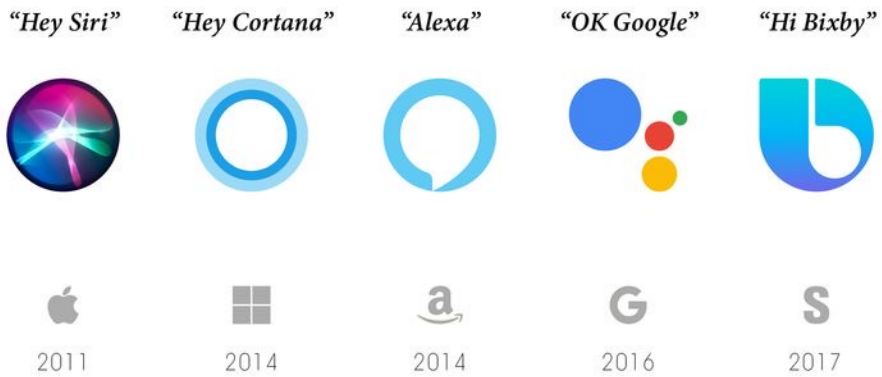


Aplicaciones en la vida real

Redes sociales

Aplicaciones en la vida real

Asistentes virtuales



Aplicaciones en la vida real

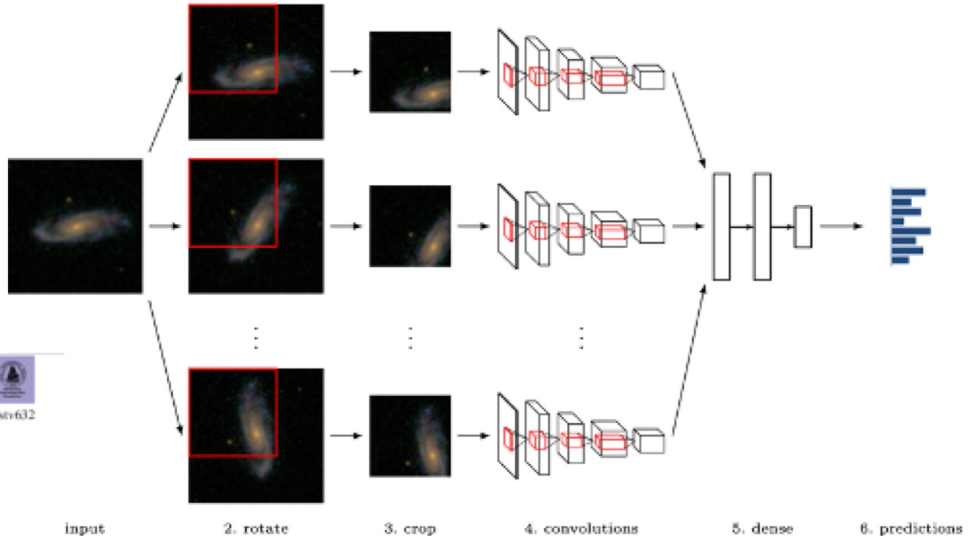
Self Driving Vehicles

Aplicaciones de AI en Astronomía

Aplicaciones de AI en Astronomía

Classification of galaxy morphologies

Galaxy Zoo Challenge (2014)
Top solutions used CNNs
Winner: Rotation-invariant convolutional Neural Networks (Dieleman et al, 2015., MNRAS, 450, 2)



Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS 450, 1441–1459 (2015) doi:10.1093/mnras/stv632

Rotation-invariant convolutional neural networks for galaxy morphology prediction

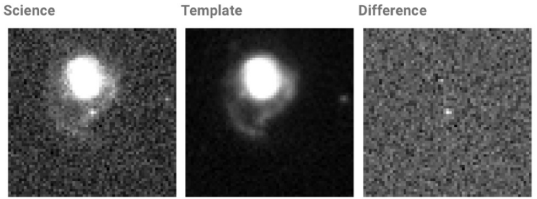
Sander Dieleman,[1]★ Kyle W. Willett[2]★ and Joni Dambre[1]
[1] *Electronics and Information Systems department, Ghent University, Sint-Pietersnieuwstraat 41, B-9000 Ghent, Belgium*
[2] *School of Physics and Astronomy, University of Minnesota, 116 Church St SE, Minneapolis, MN 55455, USA*

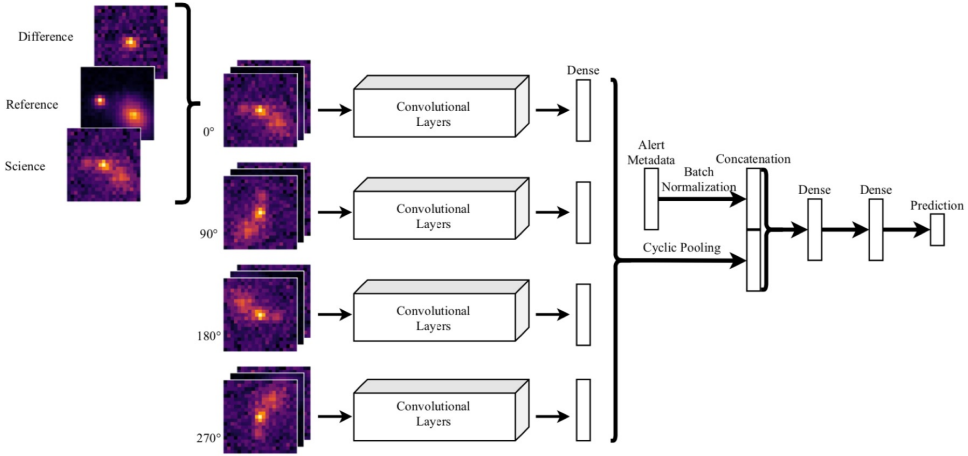
Aplicaciones de AI en Astronomía

Classification of variable and transients from images

Alert Classification for the ALeRCE Broker System: The Real-time Stamp Classifier

R. Carrasco-Davis [1,2,*] E. Reyes [1,2,*] C. Valenzuela [3,1,4,5] F. Förster [3,1,6] P. A. Estévez [1,2] G. Pignata [7,1] F. E. Bauer [8,1,9] I. Reyes [1,3,2] P. Sánchez-Sáez [1,10,8,4] G. Cabrera-Vives [11,1] S. Eyheramendy [4,1] M. Catelan [8,1] J. Arredondo,[1] E. Castillo-Navarrete,[3,1] D. Rodríguez-Mancini,[1,11] D. Ruz-Mieres [3,1,12] A. Moya [1,3] L. Sabatini-Gacitúa,[1,3] C. Sepúlveda-Cobo,[1,3] A. A. Mahabal,[13,14] J. Silva-Farfán,[6] E. Camacho-Iñiguez,[8] and L. Galbany[15]





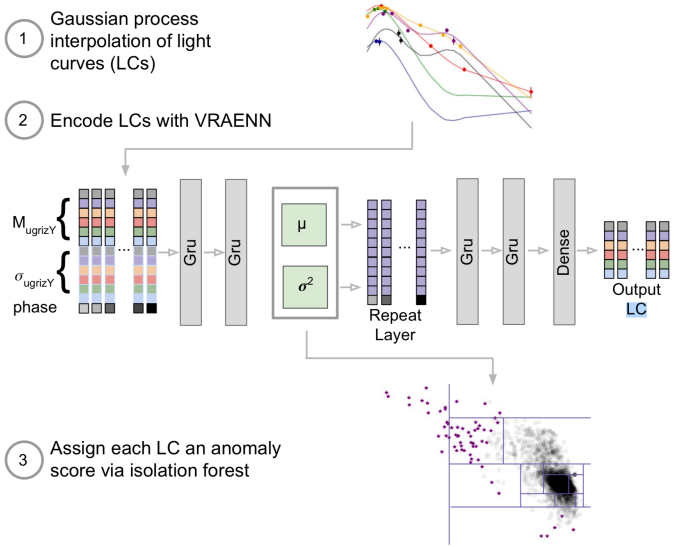
Aplicaciones de AI en Astronomía

Anomaly detection of SNe light curves

The Astrophysical Journal Supplement Series, 255:24 (11pp), 2021 August https://doi.org/10.3847/1538-4365/ac0893

A Deep-learning Approach for Live Anomaly Detection of Extragalactic Transients

V. Ashley Villar[1,2,3,4,10], Miles Cranmer[5], Edo Berger[6,7], Gabriella Contardo[8], Shirley Ho[8], Griffin Hosseinzadeh[6,7], and Joshua Yao-Yu Lin[9]
[1] Department of Astronomy, Columbia University, New York, NY 10027, USA; vav2110@columbia.edu
[2] Department of Astronomy & Astrophysics, The Pennsylvania State University, University Park, PA 16802, USA
[3] Institute for Computational & Data Sciences, The Pennsylvania State University, University Park, PA, USA
[4] Institute for Gravitation and the Cosmos, The Pennsylvania State University, University Park, PA 16802, USA
[5] Princeton University, Princeton, NJ 08544, USA
[6] Center for Astrophysics | Harvard & Smithsonian, 60 Garden Street, Cambridge, MA 02138-1516, USA
[7] The NSF AI Institute for Artificial Intelligence and Fundamental Interactions, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
[8] Flatiron Institute, New York City, NY 10010, USA
[9] University of Illinois at Urbana-Champaign, Urbana, IL 61820, USA
Received 2021 March 17; revised 2021 June 2; accepted 2021 June 3; published 2021 August 10



Aplicaciones de AI en Astronomía

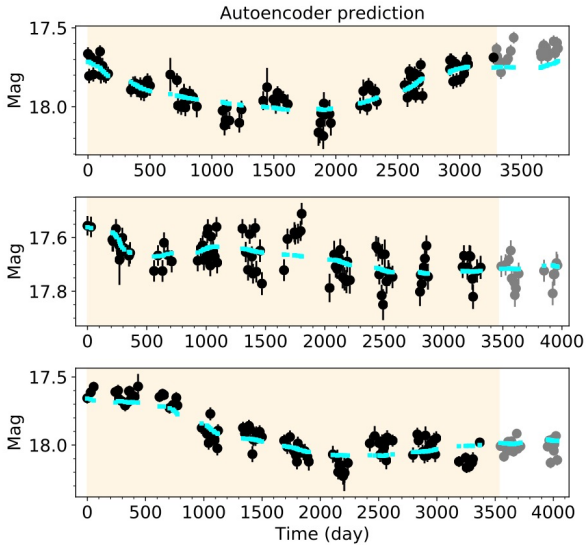
Modeling and forecasting of AGN light curves

The Astrophysical Journal, 903:54 (17pp), 2020 November 1 https://doi.org/10.3847/1538-4357/abb9a9

CrossMark

Deep Modeling of Quasar Variability

Yutaro Tachibana (優太朗橘)[1,2,4], Matthew J. Graham[2,4], Nobuyuki Kawai[1], S. G. Djorgovski[2], Andrew J. Drake[2], Ashish A. Mahabal[2], and Daniel Stern[3]
[1] Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan
[2] Department of Physics, Math, and Astronomy, California Institute of Technology, Pasadena, CA, 91125, USA; mjg@caltech.edu
[3] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA
Received 2020 March 2; revised 2020 September 2; accepted 2020 September 16; published 2020 November 2



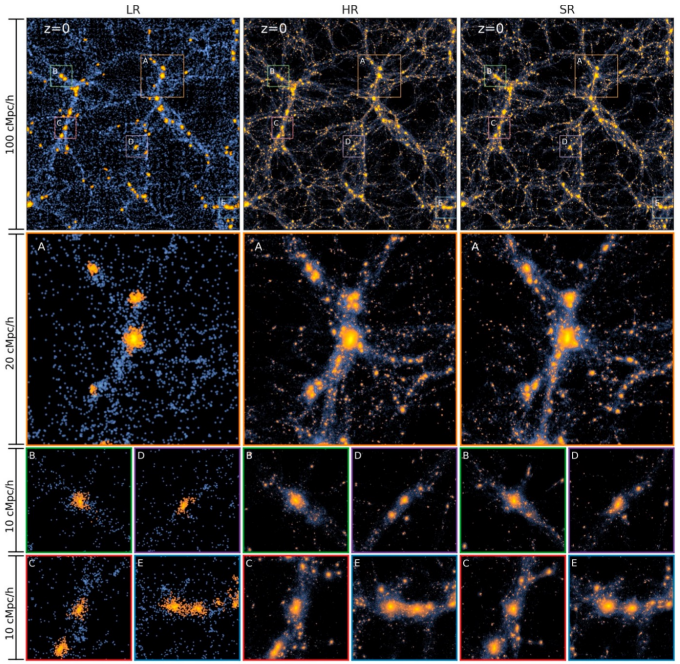
Aplicaciones de AI en Astronomía

Acceleration of Cosmological Simulations

AI-assisted superresolution cosmological simulations

Yin Li[a,b,1], Yueying Ni[c,d,1], Rupert A. C. Croft[c,d], Tiziana Di Matteo[c,d], Simeon Bird[e], and Yu Feng[f,g]

[a]Center for Computational Astrophysics, Flatiron Institute, Simons Foundation, New York, NY 10010; [b]Center for Computational Mathematics, Flatiron Institute, Simons Foundation, New York, NY 10010; [c]McWilliams Center for Cosmology, Department of Physics, Carnegie Mellon University, Pittsburgh, PA 15213; [d]NSF AI Planning Institute for Physics of the Future, Carnegie Mellon University, Pittsburgh, PA 15213; [e]Department of Physics and Astronomy, University of California Riverside, Riverside, CA 92521; [f]Berkeley Center for Cosmological Physics, University of California Berkeley, Berkeley, CA 94720; and [g]Department of Physics, University of California Berkeley, Berkeley, CA 94720

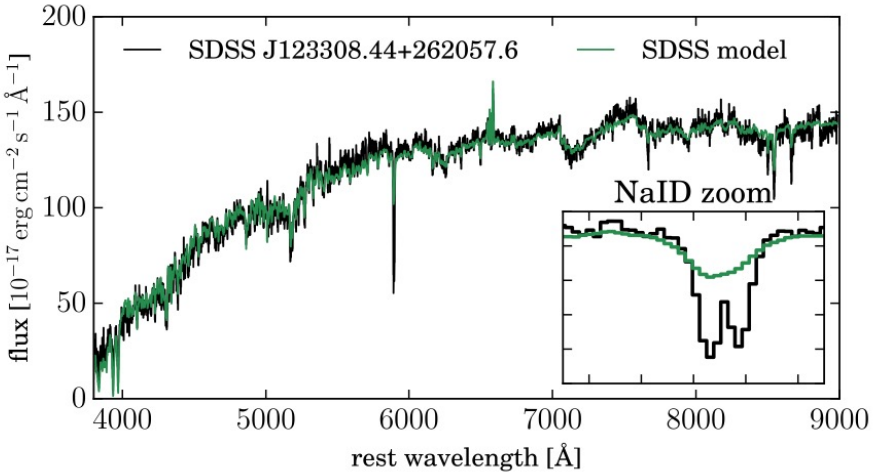


Aplicaciones de AI en Astronomía

Anomaly detection of SDSS spectra

The weirdest SDSS galaxies: results from an outlier detection algorithm

Dalya Baron★ and Dovi Poznanski
School of Physics and Astronomy, Tel-Aviv University, Tel Aviv 69978, Israel



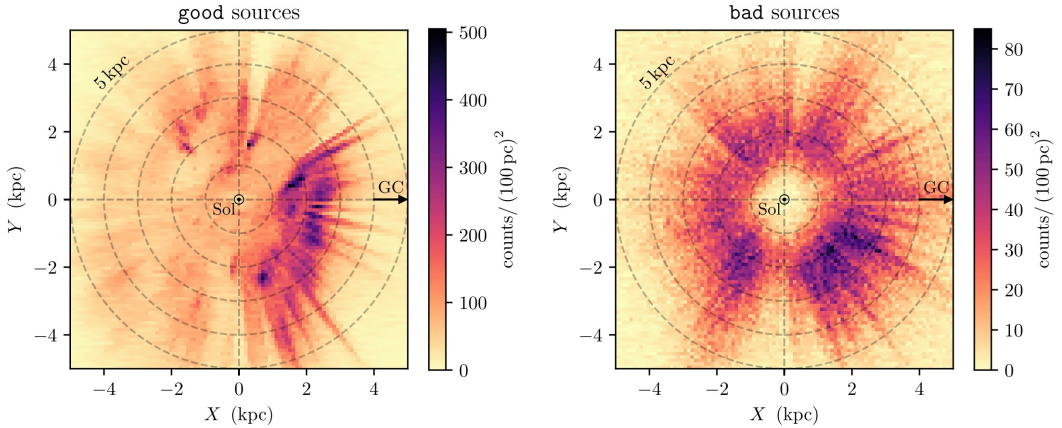
Aplicaciones de AI en Astronomía

A neural network to identify good astrometric solutions in Gaia

A classifier for spurious astrometric solutions in *Gaia* eDR3

Jan Rybizki,[1★†] Gregory M. Green,[1★†] Hans-Walter Rix,[1] Kareem El-Badry,[1] Markus Demleitner,[2] Eleonora Zari,[1] Andrzej Udalski,[3] Richard L. Smart[4] and Andrew Gould[1,5]

[1]*Max Planck Institute for Astronomy, Königstuhl 17, D-69117 Heidelberg, Germany*
[2]*Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstrasse 12-14, D-69120 Heidelberg, Germany*
[3]*Astronomical Observatory, University of Warsaw, Al. Ujazdowskie 4, PL-00478 Warszawa, Poland*
[4]*INAF – Osservatorio Astrofisico di Torino, via Osservatorio 20, I-10025 Pino Torinese, TO, Italy*
[5]*Department of Astronomy, Ohio State University, 4055 McPherson Laboratory, 140 West 18th Avenue, Columbus, OH 43210, USA*



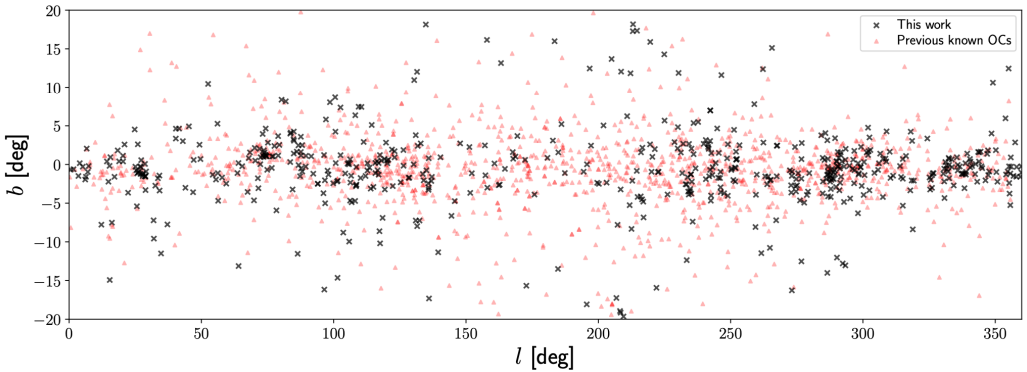
Aplicaciones de AI en Astronomía

Clustering algorithms + neural network to find new open clusters

Hunting for open clusters in *Gaia* DR2: 582 new open clusters in the Galactic disc★

A. Castro-Ginard[1], C. Jordi[1], X. Luri[1], J. Álvarez Cid-Fuentes[2], L. Casamiquela[3], F. Anders[1], T. Cantat-Gaudin[1], M. Monguió[1], L. Balaguer-Núñez[1], S. Solà[2], and R. M. Badia[2]

[1] Dept. Física Quàntica i Astrofísica, Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (IEEC-UB), Martí i Franquès 1, 08028 Barcelona, Spain
e-mail: acastro@fqa.ub.edu
[2] Barcelona Supercomputing Center (BSC), Barcelona, Spain
[3] Laboratoire d'Astrophysique de Bordeaux, Univ. Bordeaux, CNRS, B18N, allée Geoffroy, Saint-Hilaire 33615, Pessac, France



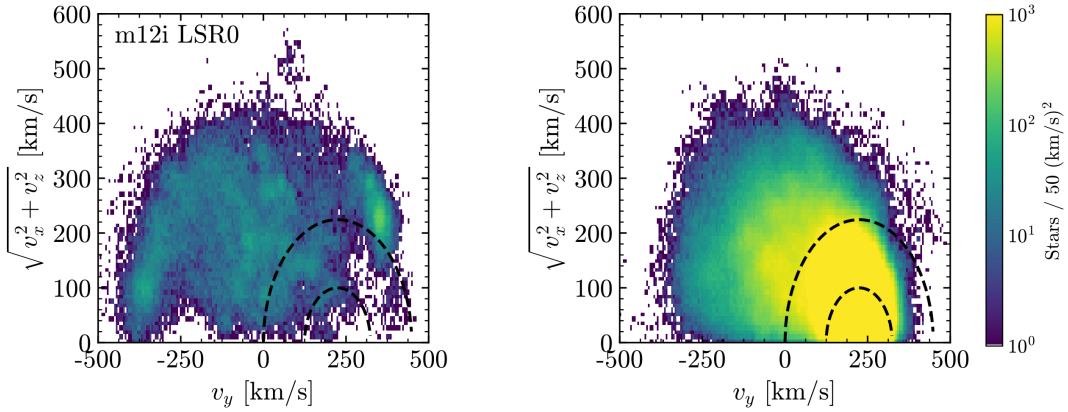
Aplicaciones de AI en Astronomía

Transfer learning to find stars accreted onto the Milky Way

Cataloging accreted stars within *Gaia* DR2 using deep learning

B. Ostdiek[1,*], L. Necib[2], T. Cohen[1], M. Freytsis[3,4], M. Lisanti[5], S. Garrison-Kimmmel[6], A. Wetzel[7], R. E. Sanderson[8,9], and P. F. Hopkins[6]

[1] Institute of Theoretical Science, Department of Physics, University of Oregon, Eugene, OR 97403, USA
e-mail: bostdiek@g.harvard.edu
[2] Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, CA 91125, USA
e-mail: lnecib@caltech.edu
[3] Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel
[4] School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540, USA
[5] Department of Physics, Princeton University, Princeton, NJ 08544, USA
[6] TAPIR, California Institute of Technology, Pasadena, CA 91125, USA
[7] Department of Physics, University of California, Davis, CA 95616, USA
[8] Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19104, USA
[9] Center for Computational Astrophysics, Flatiron Institute, New York, NY 10010, USA



(a) Accreted stars. (b) in situ stars.

Aplicaciones de AI en Astronomía

Finding strong gravitational lenses in the Kilo Degree Survey with Convolutional Neural Networks

C. E. Petrillo,[1]★ C. Tortora,[1] S. Chatterjee,[1] G. Vernardos,[1] L. V. E. Koopmans,[1] G. Verdoes Kleijn,[1] N. R. Napolitano,[2] G. Covone,[3] P. Schneider,[4] A. Grado[2] and J. McFarland[1]

[1]*Kapteyn Astronomical Institute, University of Groningen, Postbus 800, NL-9700 AV Groningen, the Netherlands*
[2]*INAF – Osservatorio Astronomico di Capodimonte, Salita Moiariello, 16, I-80131 Napoli, Italy*
[3]*Dipartimento di Scienze Fisiche, Università di Napoli Federico II, Compl. Univ. Monte S. Angelo, I-80126 Napoli, Italy*
[4]*Argelander-Institut für Astronomie, Auf dem Hügel 71, D-53121 Bonn, Germany*

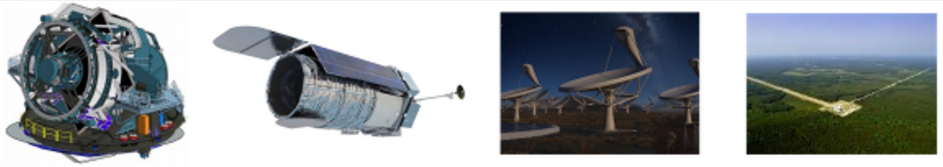




ALeRCE es una iniciativa chilena para crear un
“community Broker” para ZTF, LSST y otros
grandes telescopios

Futuros ecosistemas para “time domain astronomy”

Survey telescopes



Alert brokers/TOMs

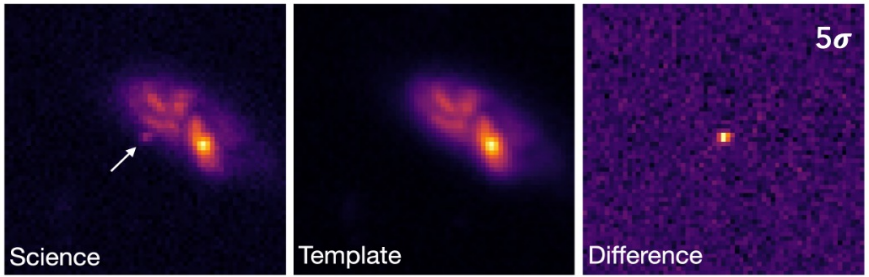
ALeRCE
Automatic Learning for the Rapid Classification of Events

\+ *other brokers/TOMs*

Follow up telescopes

Brokers

Los brokers son sistemas que procesan alertas astronómicas.



ZTF

2018-2023

1.4 TB per night

~1 billion objects

~1 trillion measurements

~1 million alerts per night

10x

LSST

2022-2032

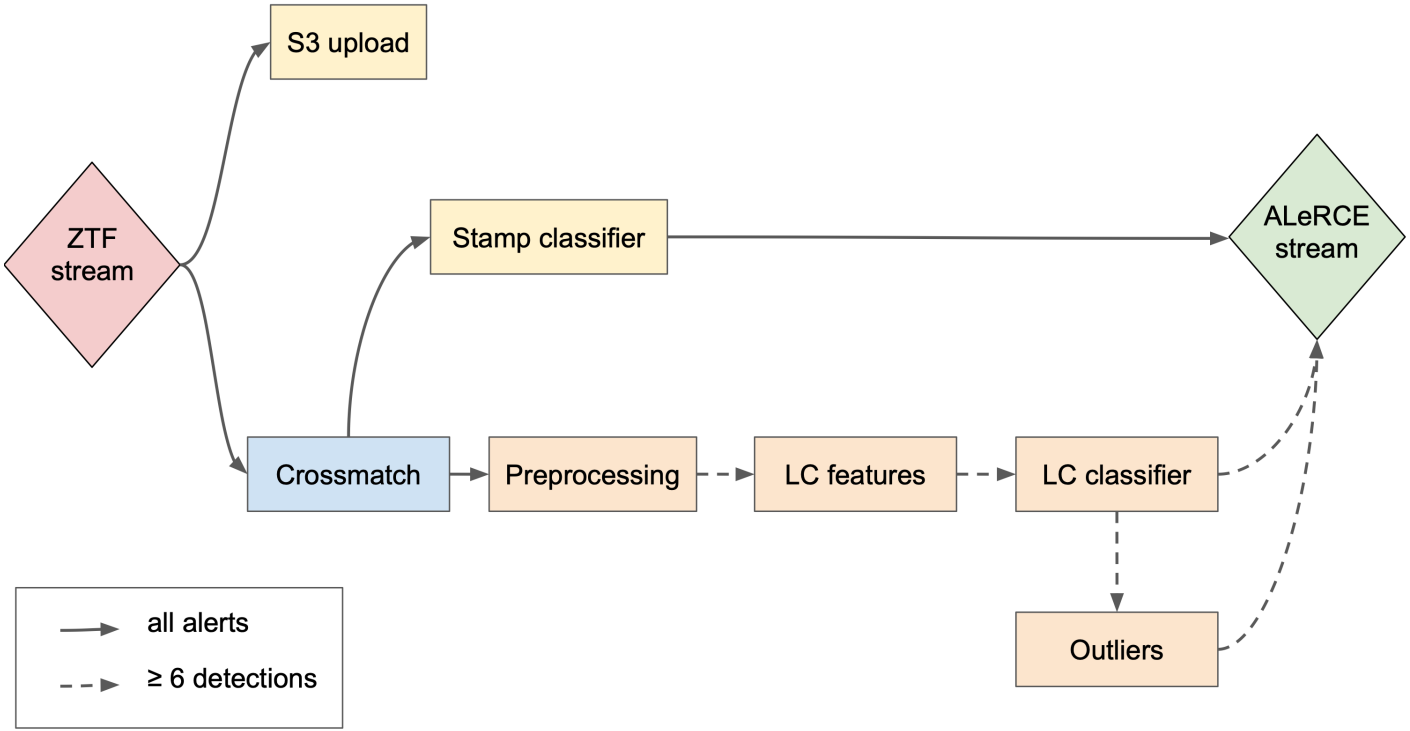
15 TB per night

~37 billion objects

~7 trillion measurements

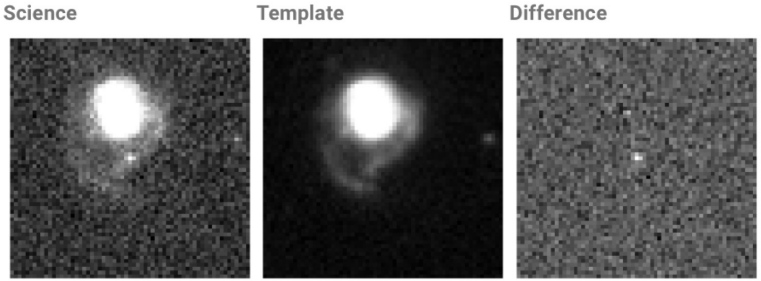
~10 million alerts per night

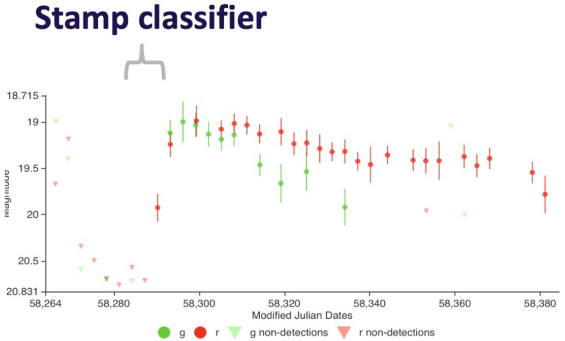
Pipeline de ALeRCE



Clasificadores de ALeRCE

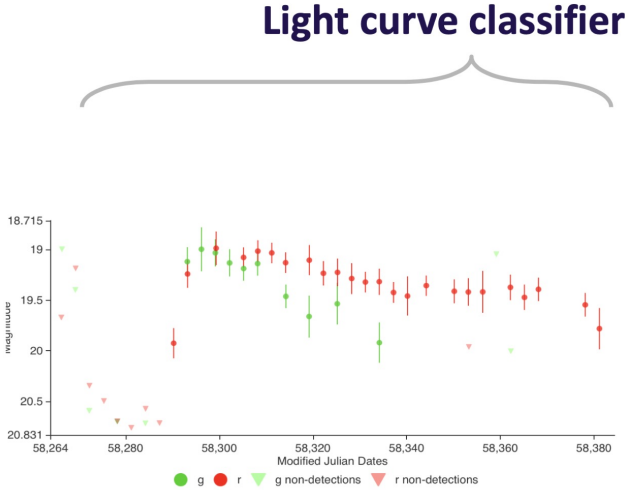
Convolutional Neural Network
(using 1st detection stamp)





Carrasco-Davis et al. 2021, AJ, 162, 231

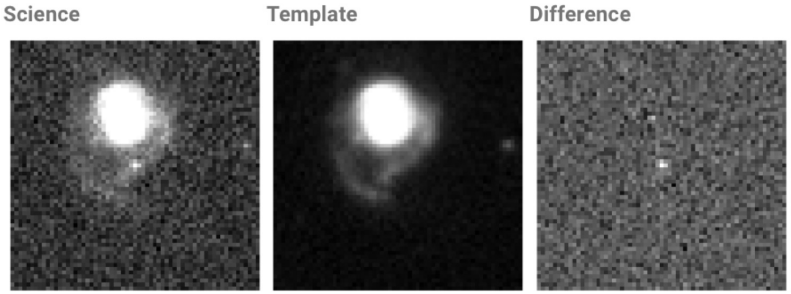
Balanced Random Forest
(for objects with 6 or more alerts in a given band)

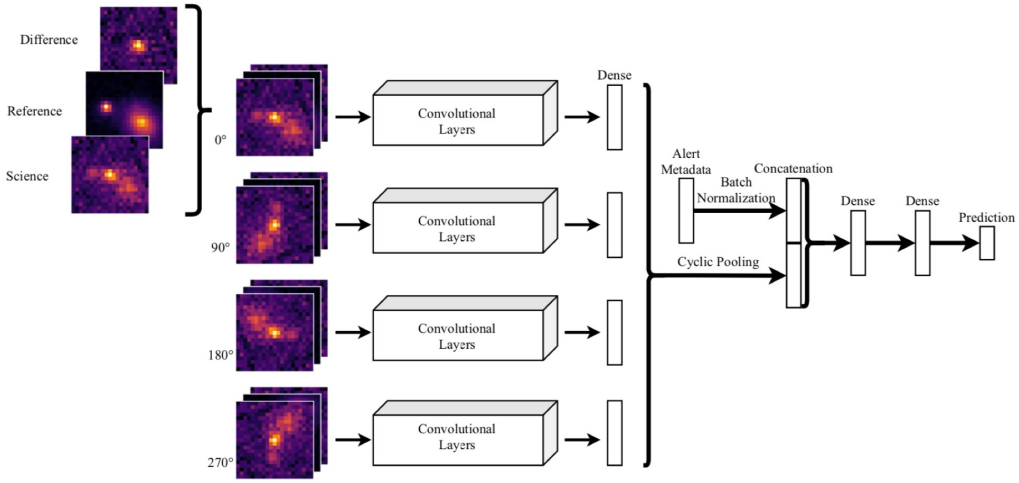


Sánchez-Sáez et al. 2021, AJ, 161,141

Clasificador de imagenes de ALeRCE

Convolutional Neural Network
(using the first stamp)

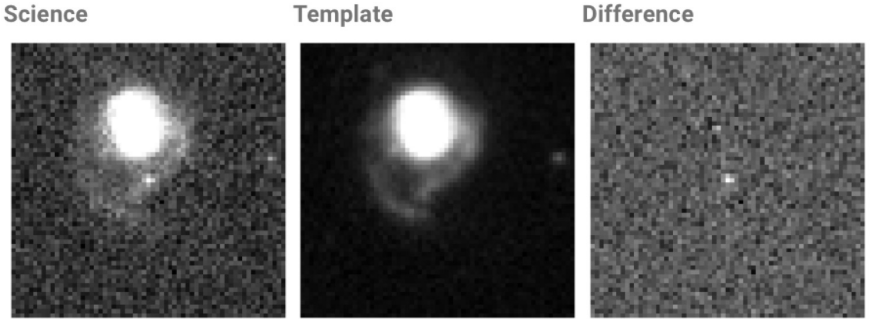


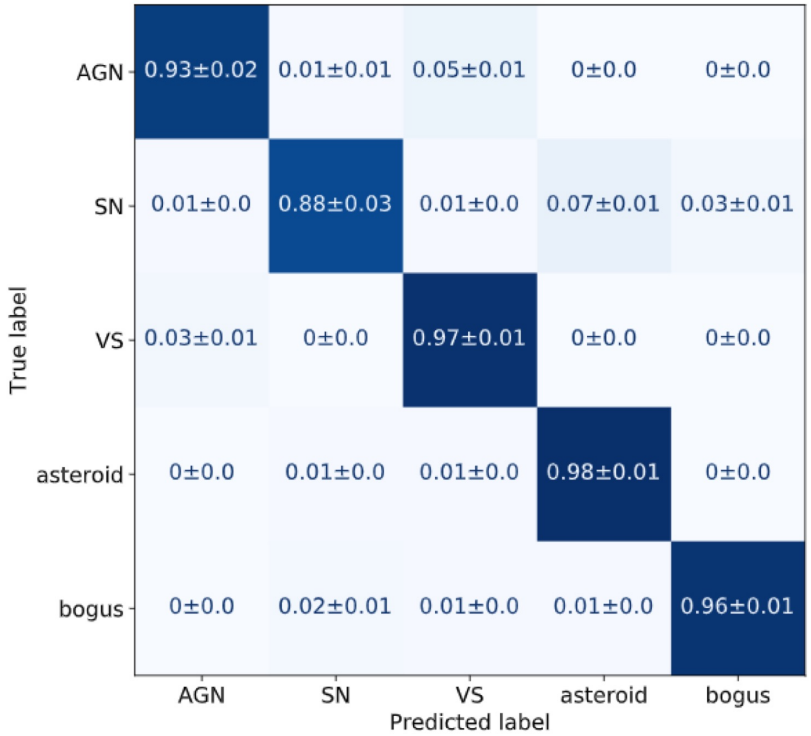


Carrasco-Davis et al. 2021, AJ, 162, 231

Clasificador de imagenes de ALeRCE

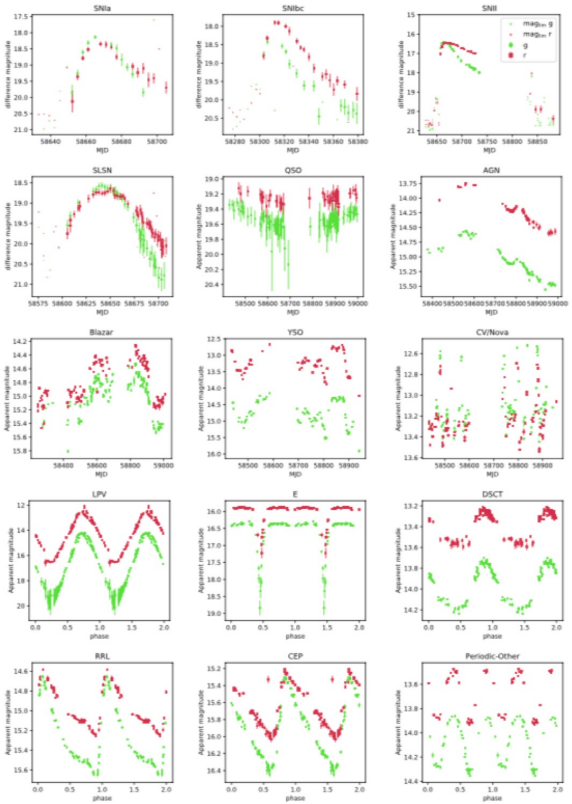
Convolutional Neural Network
(using the first stamp)

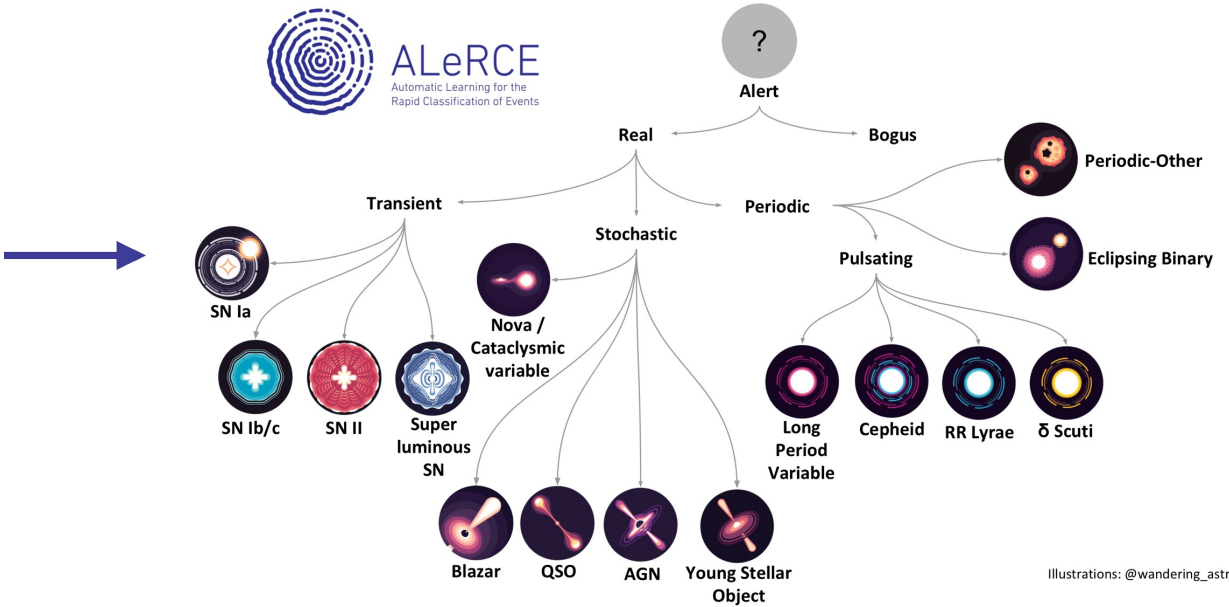




Carrasco-Davis et al. 2021, AJ, 162, 231

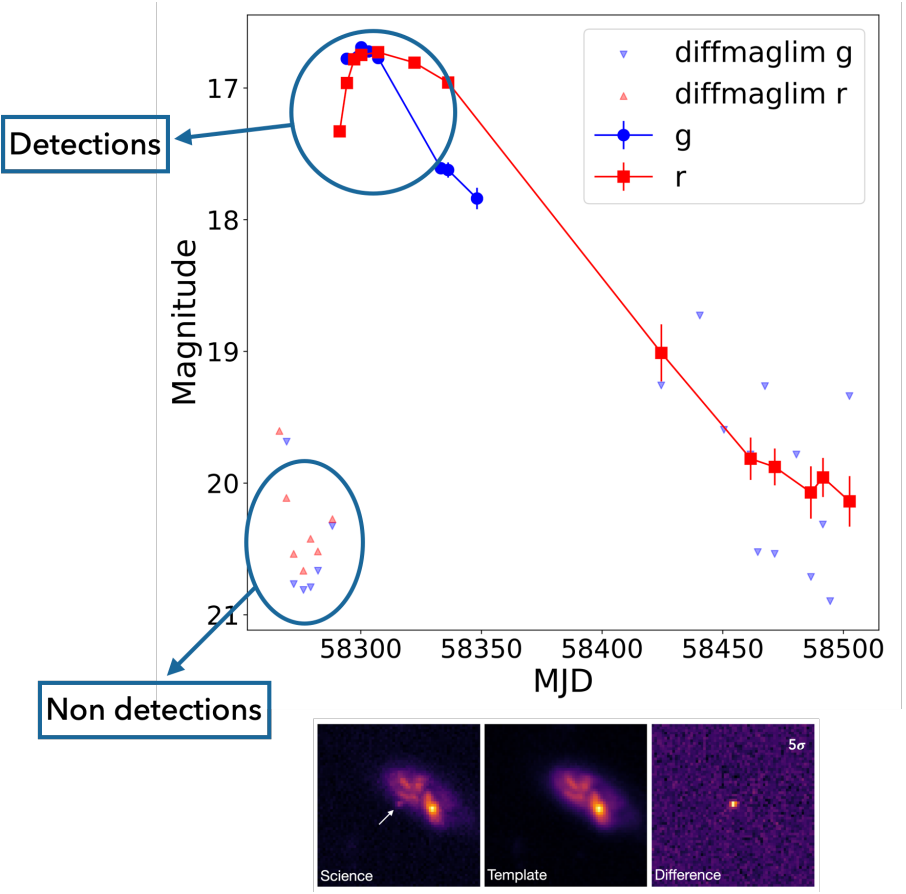
Clasificador de curvas de luz de ALeRCE





Sánchez-Sáez et al. 2021, AJ, 161,141

Clasificador de curvas de luz de ALeRCE



Sánchez-Sáez et al. 2021, AJ, 161,141

152 features in total:

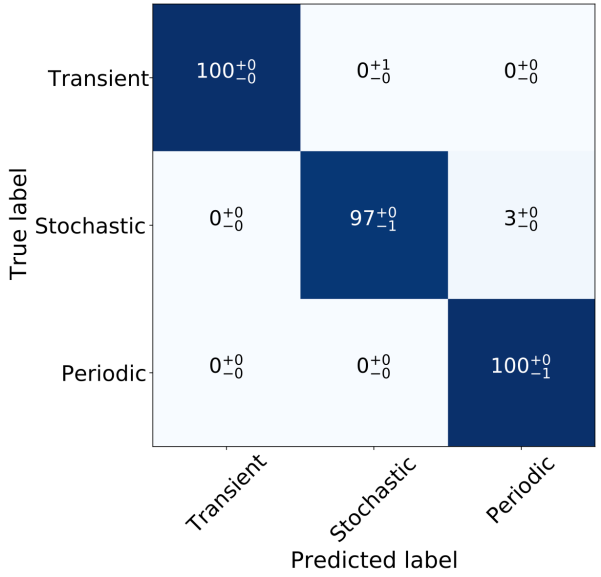
1) Colors from AllWISE and ZTF (8 in total)

2) Detection features (for *g* and *r* ZTF bands, 124 in total):
   - Supernova parametric model (SPM; adapted from Villar et al. 2019b)
   - Multiband period (adapted from Mondrik et al. 2015)
   - Irregular autoregressive model (IAR; Eyheramendy et al. 2018)
   - Mexican Hat Power Spectrum (MHPS; adapted from Arévalo et al. 2012)

3) Non-detection features (for *g* and *r* ZTF bands, 18 in total)

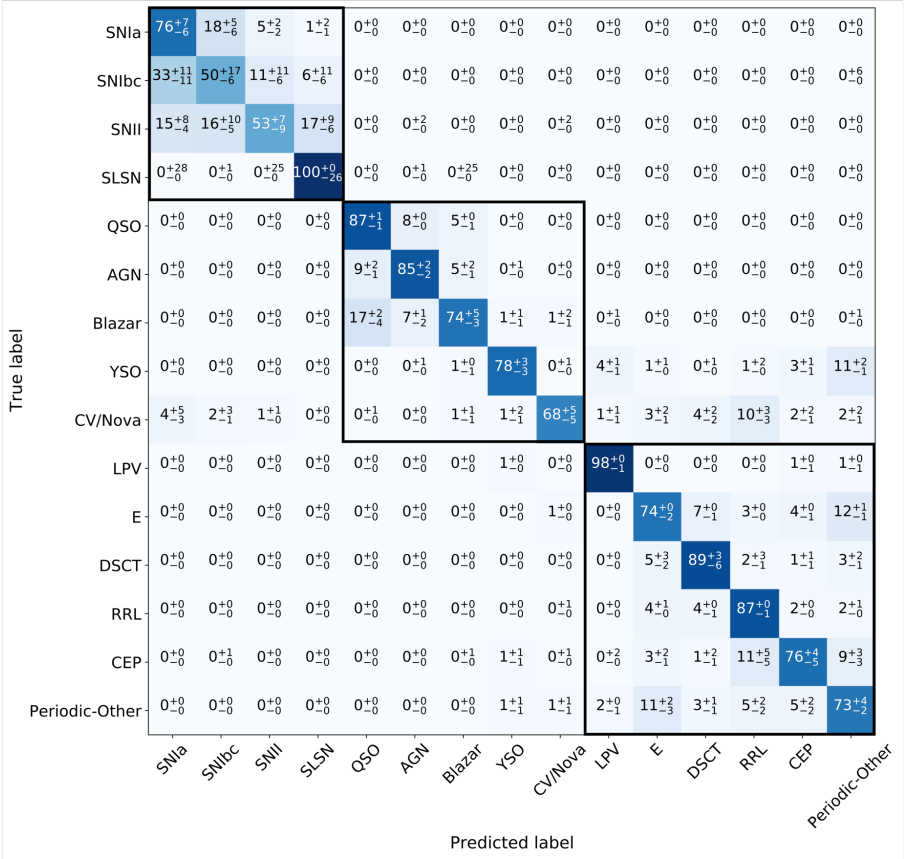
4) Features from ZTF metadata (galactic coordinates, sgscore1 from PanSTARRS1, and real-bogus)

Clasificador de curvas de luz de ALeRCE

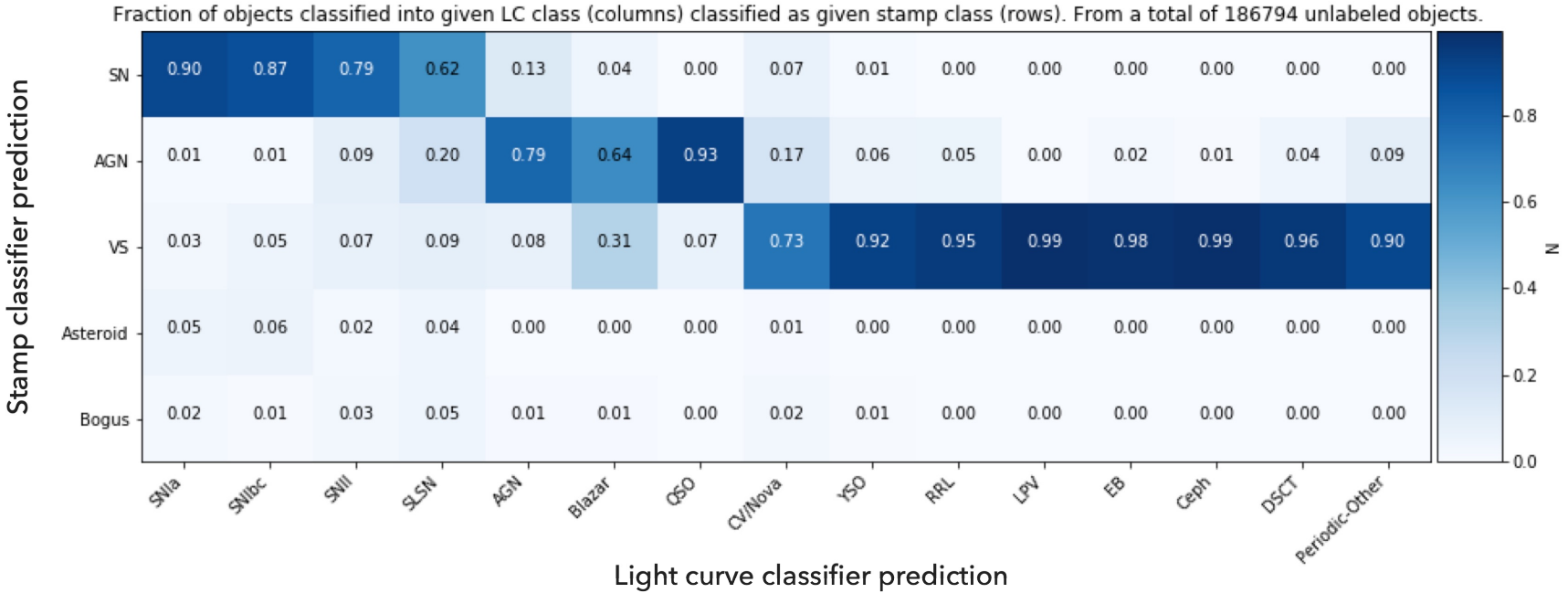


Classifier	Precision	Recall	F1-score
BHRF - top	0.96 ± 0.01	0.99 ± 0.01	0.97 ± 0.01
BHRF - bottom	0.57 ± 0.01	0.76 ± 0.02	0.59 ± 0.01

Sánchez-Sáez et al. 2021, AJ, 161,141



Comparación de clasificadores de ALeRCE

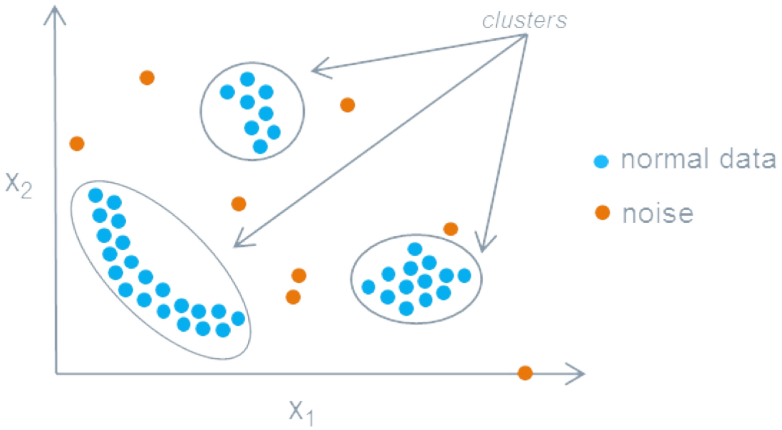


Förster et al. 2021. 2021, AJ, 161, 242

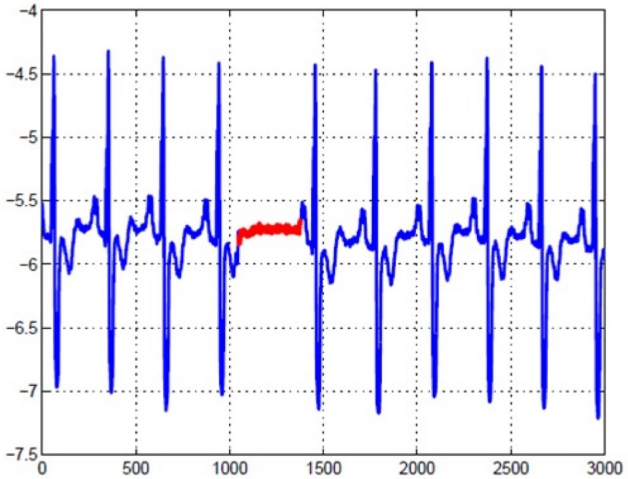
Detección de anomalias

Corresponde a la identificación de eventos raros u observaciones que difieren significativamente de la mayoría de los datos.

Out of Distribution AD: búsqueda de objetos inusuales dentro de los conjuntos de datos.

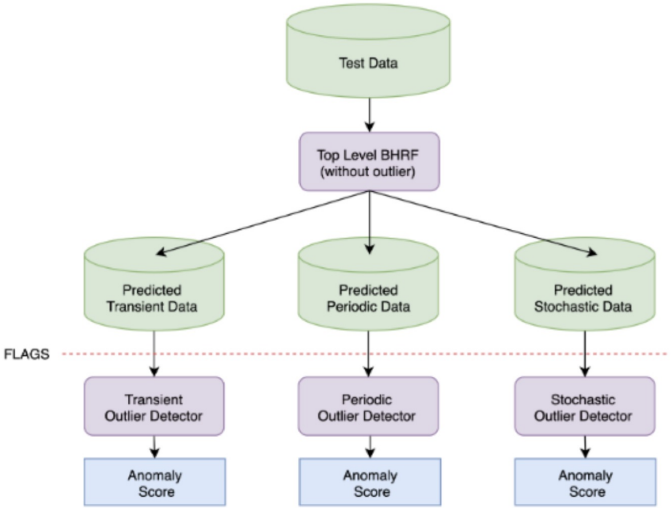


Contextual AD: búsqueda de objetos que de repente empiezan a presentar comportamientos inusuales.

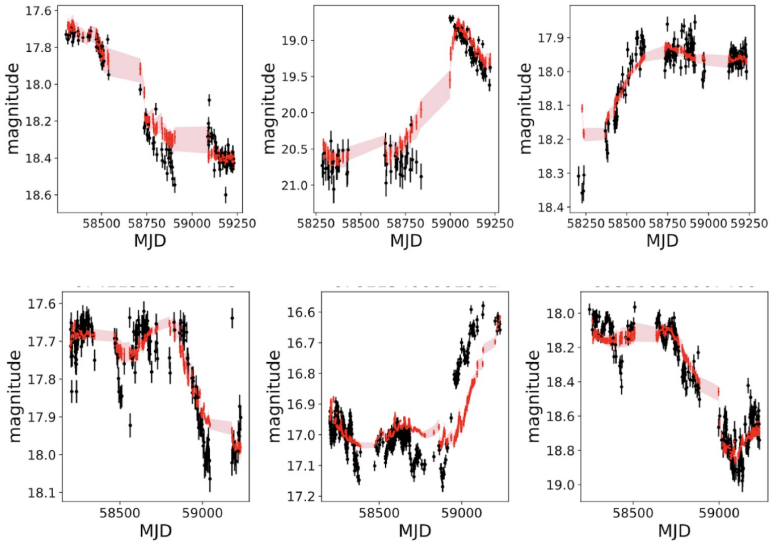


Detección de anomalias en ALeRCE

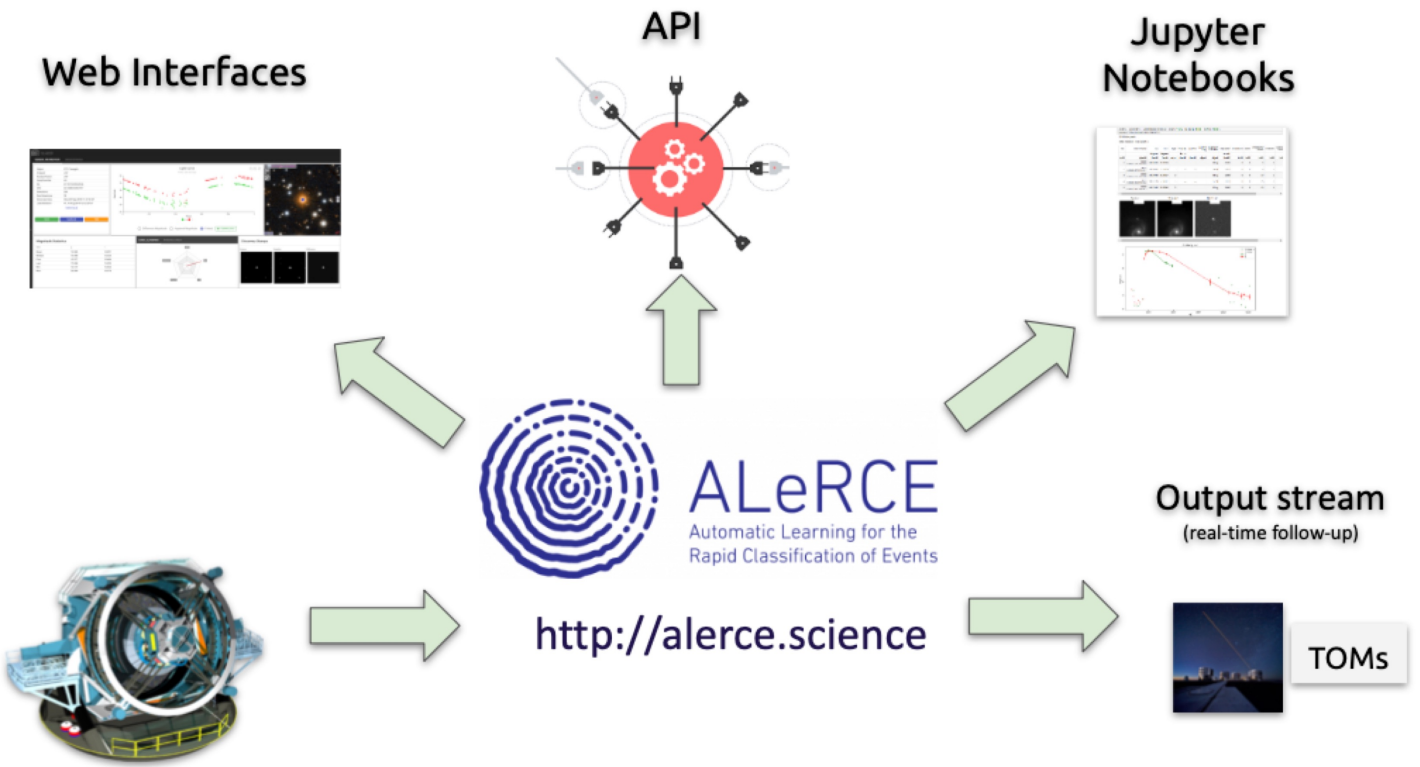
Out of Distribution AD: Detector de anomalias en curvas de alertas de ZTF (Pérez-Carrasco et al. in prep)



Contextual AD: Detector de anomalias en curvas de data release de ZTF (Sánchez-Sáez et al. 2021b, AJ, 162, 206)

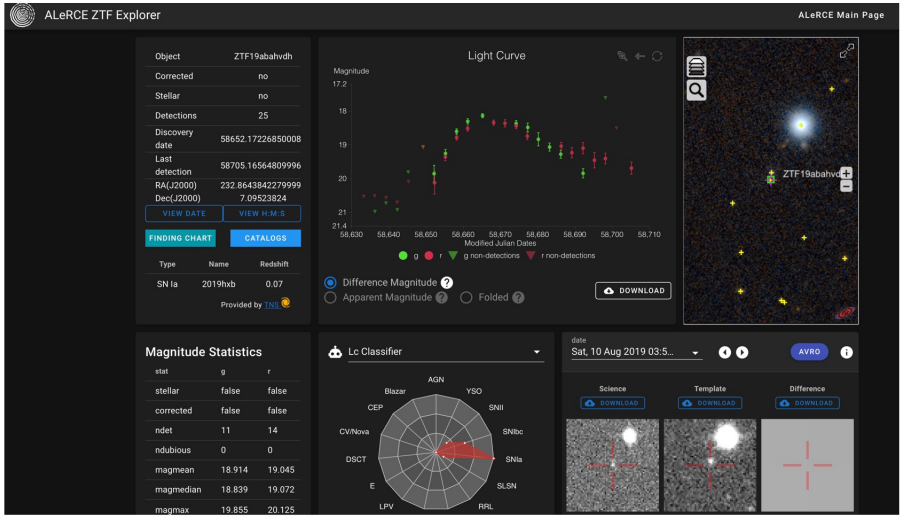


Servicios de ALeRCE

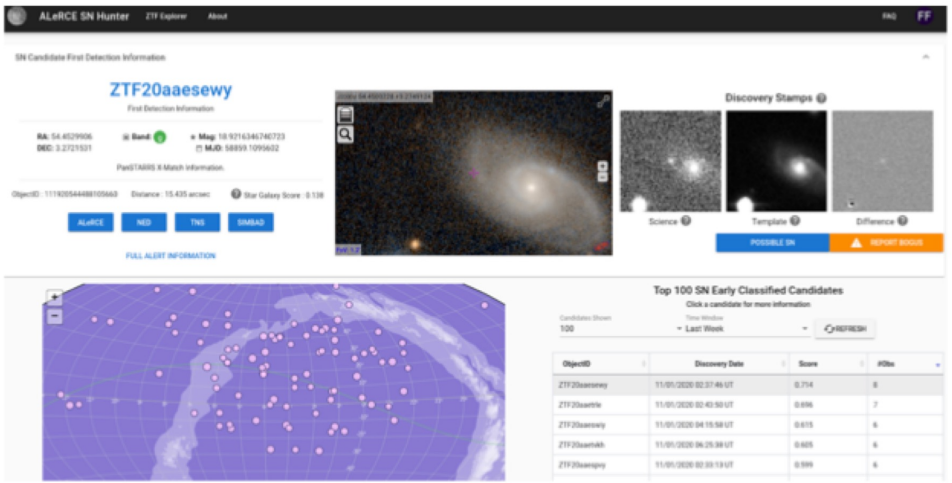


Servicios de ALeRCE

ZTF Explorer
http://alerce.online



SN Hunter
http://snhunter.alerce.online



Links

Homepage: http://alerce.science
Explorer: https://alerce.online/
SN Hunter: https://snhunter.alerce.online/
ALeRCE tutorial: videos, slides & notebooks.

Muchas gracias!!