ΩMEGA

Microlensing across the whole sky

Rachel Street | LCO

On behalf of the OMEGA team:
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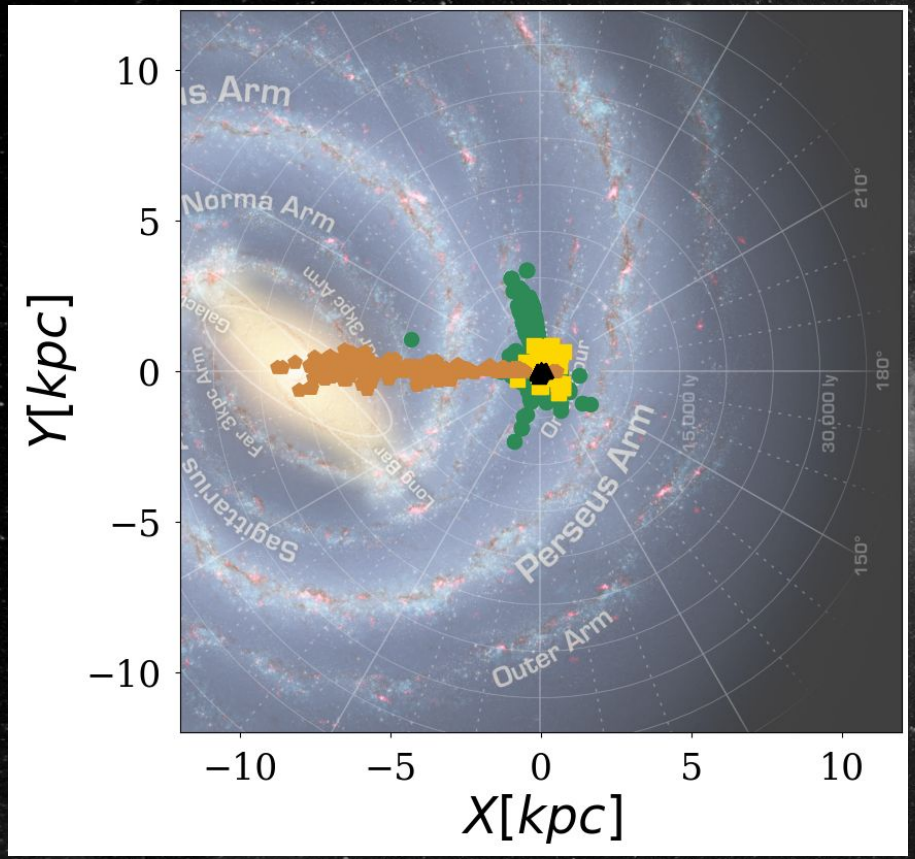
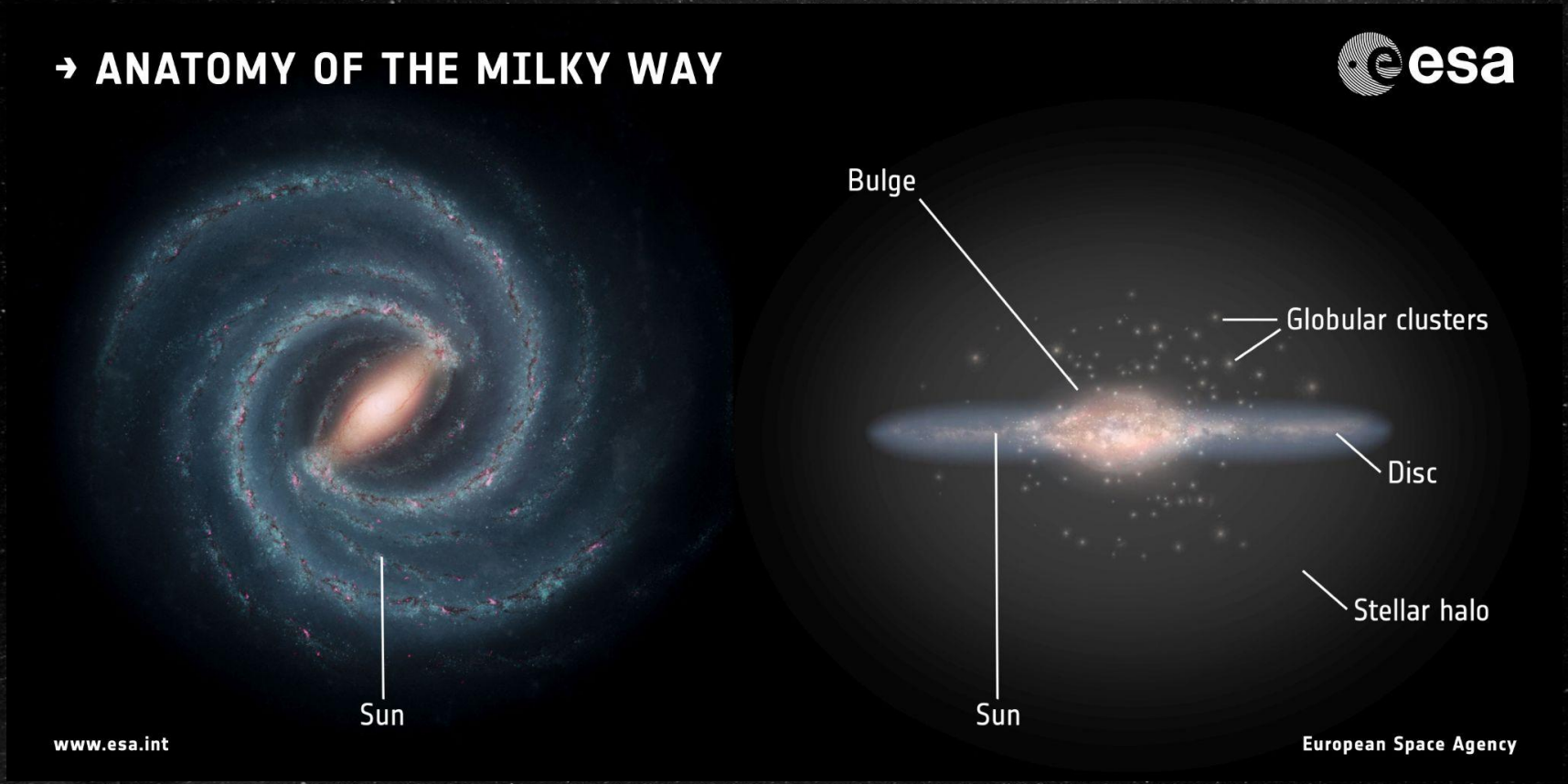
Microlensing detection space is expanding



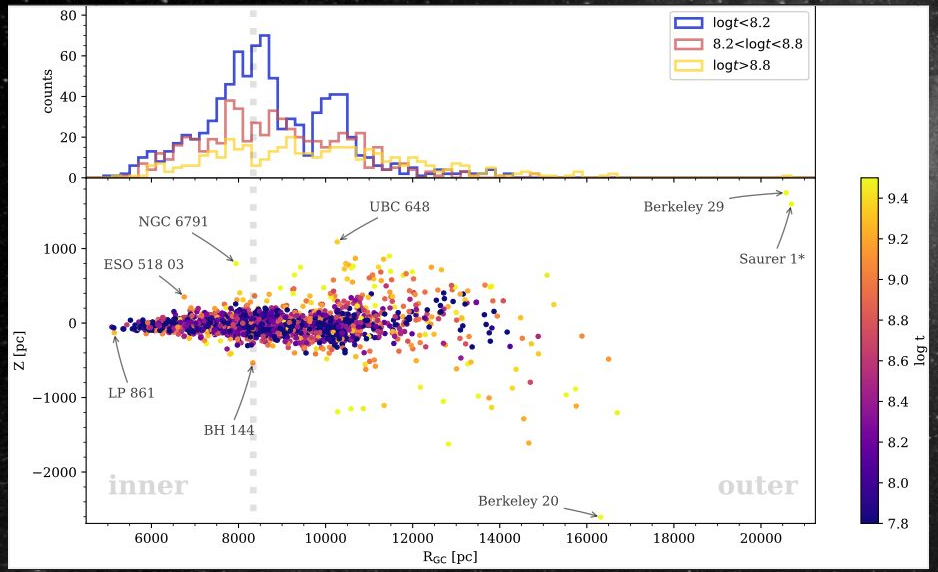
Data from NASA Exoplanet Archive,
plot by Etienne Bachelet

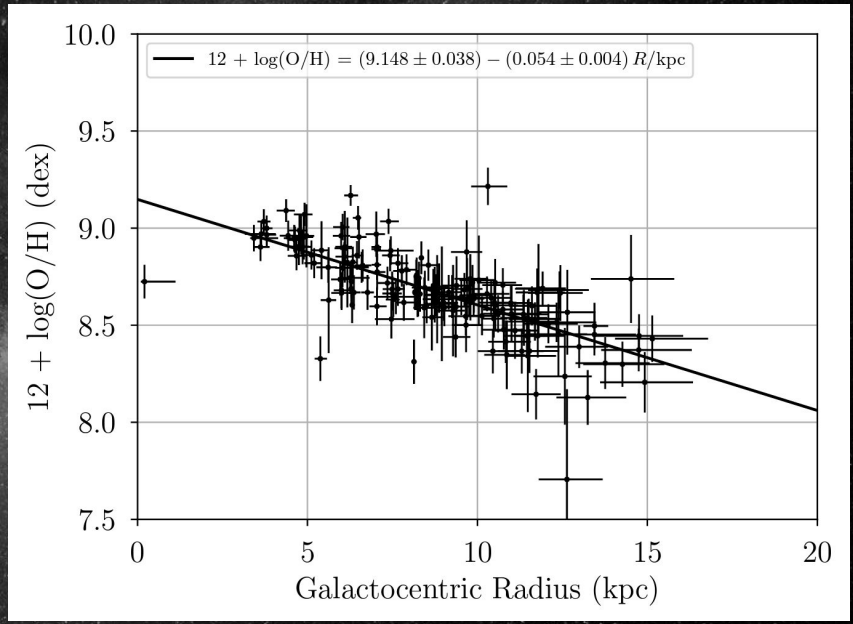
Microlensing detection space is expanding



Microlensing detection space is expanding

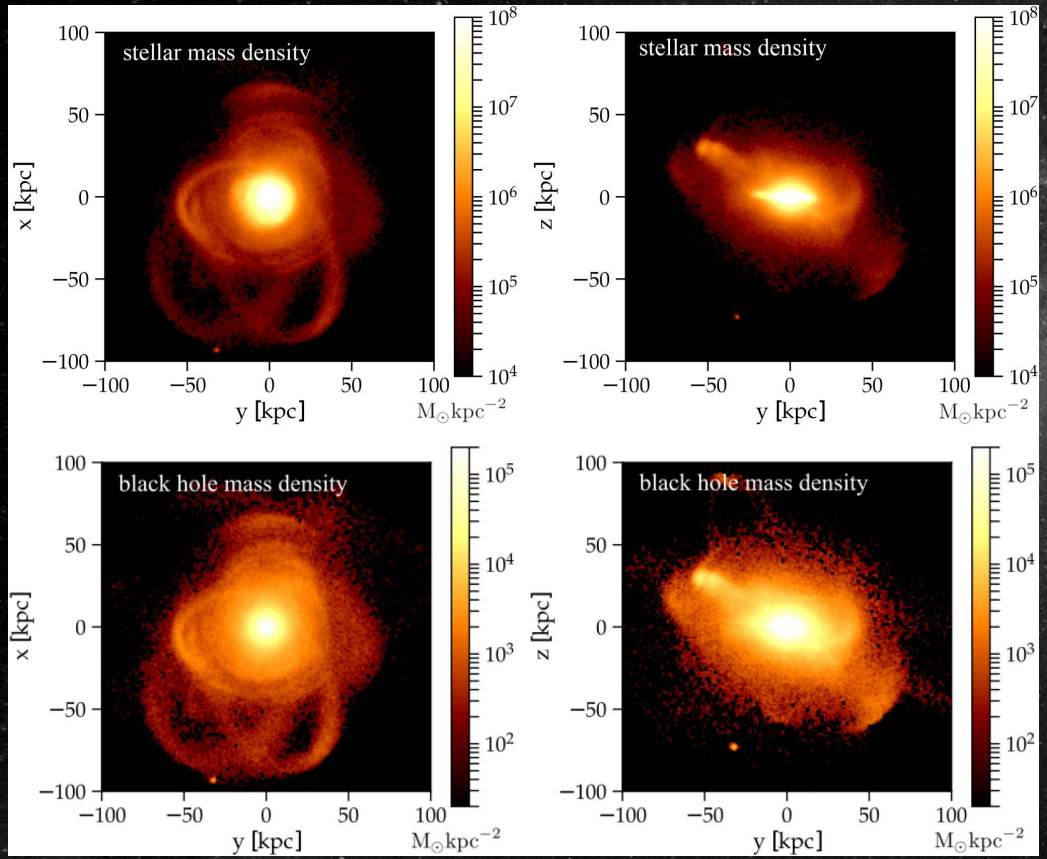
Galactocentric distribution for three stellar age groups
Cantat-Gaudin et al. (2020)





Milky Way radial metallicity gradient
Wenger et al. (2019)

Detecting compact objects



Theoretical maps of the projected stellar mass density ...

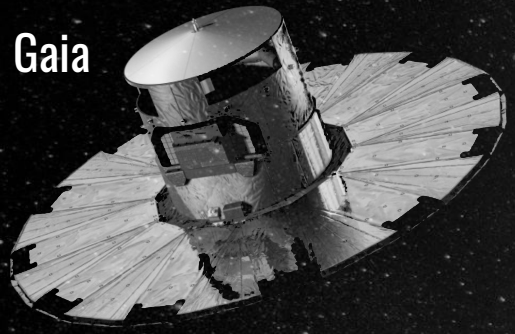
...and the isolated black hole mass density (merged and unmerged binaries)

for a face-on (left) and edge-on view (right) of the Milky Way

Lamberts et al. (2018)

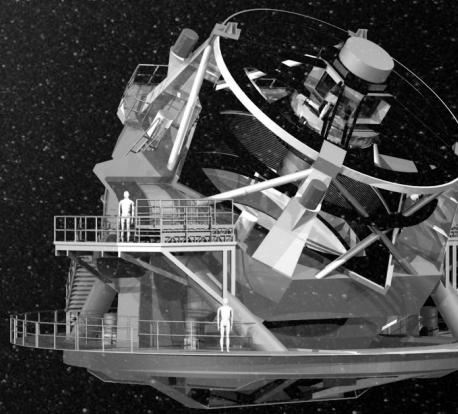
Ultra-wide area time-domain surveys

Gaia



ZTF

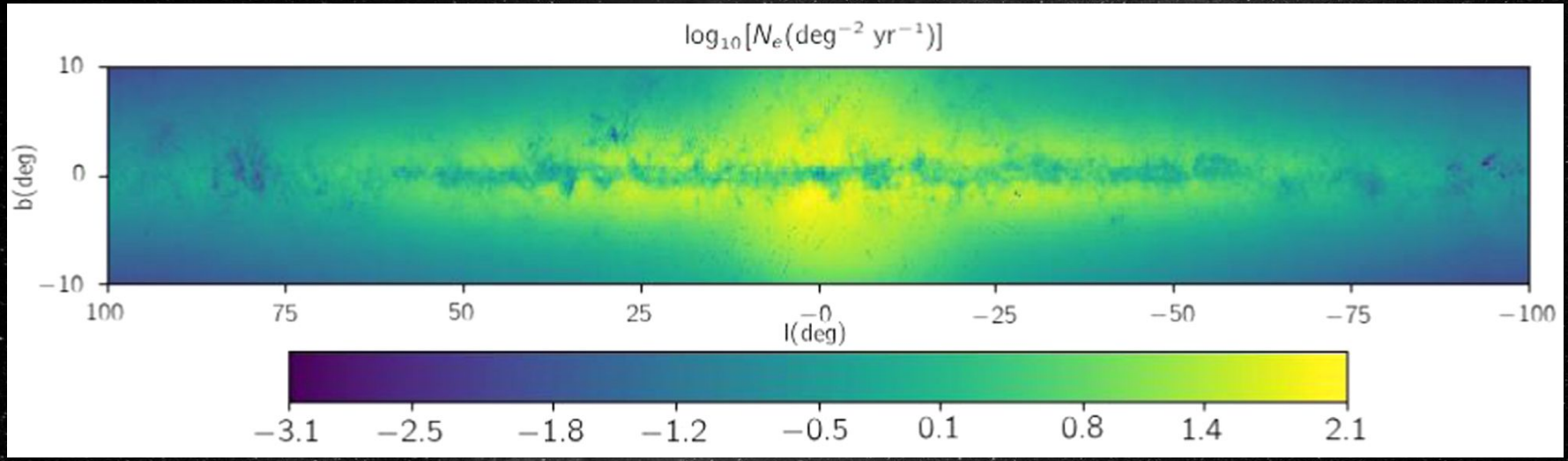
ASAS-SN



Rubin Observatory [2024+]

Rubin will discover microlensing in a range of stellar environments

Event detection rate as a function of Galactic coordinates [Sajadian et al. 2019]

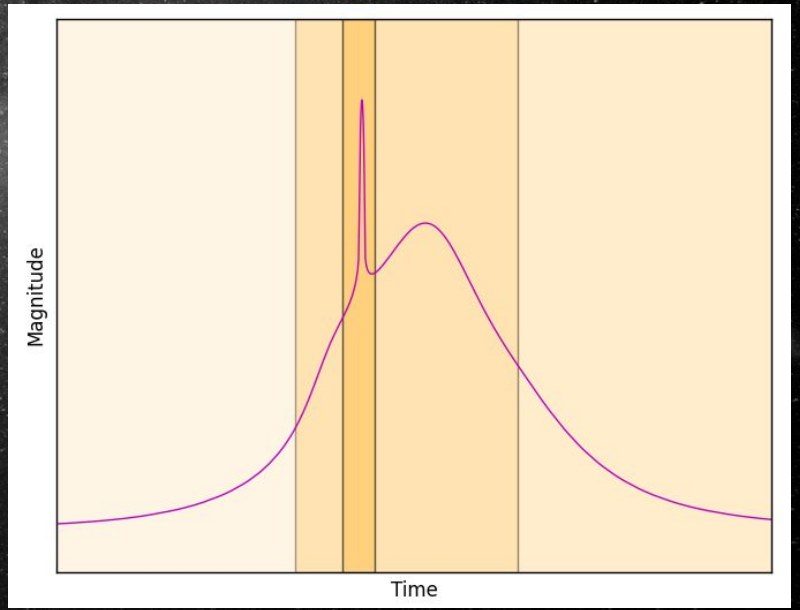


Including stellar, planetary lenses in Magellanic Clouds [Poleski & Mroz 2018]

Highly complementary to Roman Exoplanet Survey of the Galactic Bulge [Street et al. 2018]

Challenges of new surveys

- Lower cadence: images every few days instead of every 15min
  - Higher-cadence photometry required for characterization
  - Can we identify events early enough to follow-up effectively?
  - Can we identify anomalous events in progress?
  - Do we have enough information to prioritize the targets?



Challenges of new surveys

- Lower cadence
- Data rates, modern alert messaging systems
  - ZTF produces ~1 million alerts per night. Rubin will produce x10 that
  - Email messages replaced by Kafka stream
  - Alert broker systems

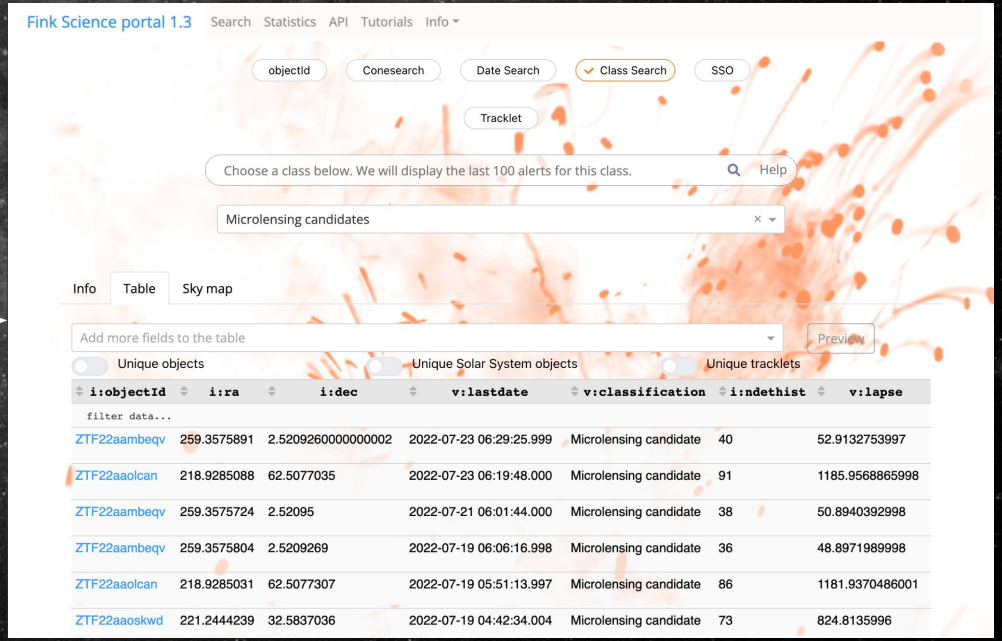
ANTARES

FINK

Lasair

ALeRCE
Automatic Learning for the Rapid Classification of Events

And more...



i:objectId	i:ra	i:dec	v:lastdate	v:classification	i:ndethist	v:lapse
filter data...						
ZTF22aambeqv	259.3575891	2.5209260000000002	2022-07-23 06:29:25.999	Microlensing candidate	40	52.9132753997
ZTF22aaolcan	218.9285088	62.5077035	2022-07-23 06:19:48.000	Microlensing candidate	91	1185.9568865998
ZTF22aambeqv	259.3575724	2.52095	2022-07-21 06:01:44.000	Microlensing candidate	38	50.8940392998
ZTF22aambeqv	259.3575804	2.5209269	2022-07-19 06:06:16.998	Microlensing candidate	36	48.8971989998
ZTF22aaolcan	218.9285031	62.5077307	2022-07-19 05:51:13.997	Microlensing candidate	86	1181.9370486001
ZTF22aaoskwd	221.2444239	32.5837036	2022-07-19 04:42:34.004	Microlensing candidate	73	824.8135996

Challenges of new surveys

- Lower cadence
- Data rates, modern alert messaging systems
- Magnitude range of targets
  - ZTF r_{lim} ~20.5mag
  - Rubin r_{lim} ~24.7mag
  - Larger range of telescope apertures required for follow-up

Challenges of new surveys

- Lower cadence
- Data rates, modern alert messaging systems
- Magnitude range of targets

- Input into survey planning

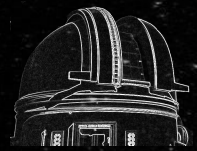
Pathfinder Program: OMEGA Key Project

LCO Key Project, PI: Etienne Bachelet

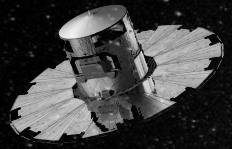
Photometric and spectroscopic characterization of microlensing alerts, primarily for targets outside the Bulge

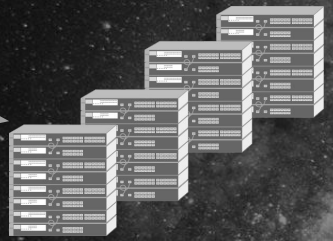
2020-2023

Scalable infrastructure for survey+follow-up



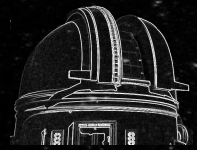
Surveys alert new discoveries

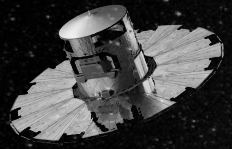


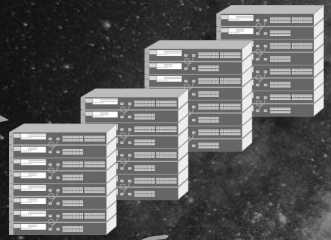


Alert brokers aggregate, classify alert data

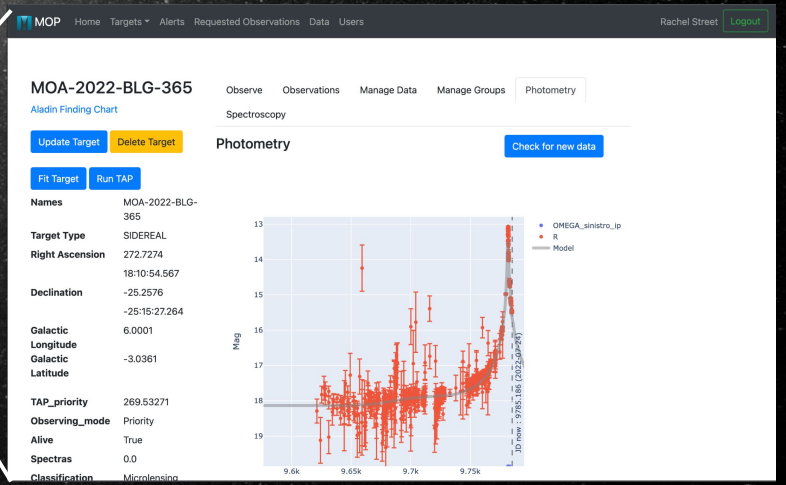
Scalable infrastructure for survey+follow-up





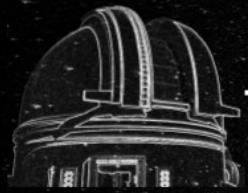


→Microlensing Online Platform (MOP)

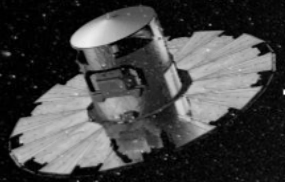


Target and Observation Manager system coordinates follow-up program

Sources of Microlensing Alert Streams used for OMEGA



ZTF Microlensing Alerts table [Mróz]



Gaia Alerts website

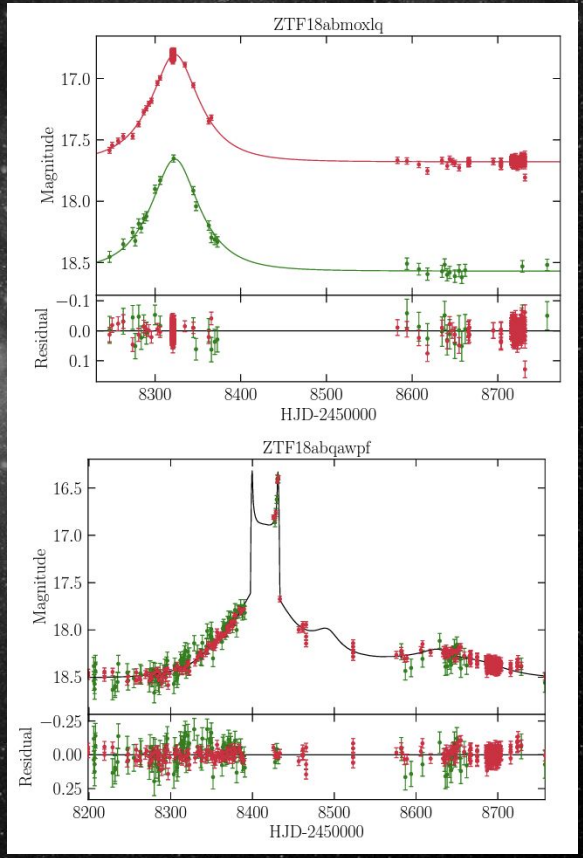
MOA Survey Alerts table

ASAS-SN Transients table

Microlensing classifications now provided by Fink alert broker system

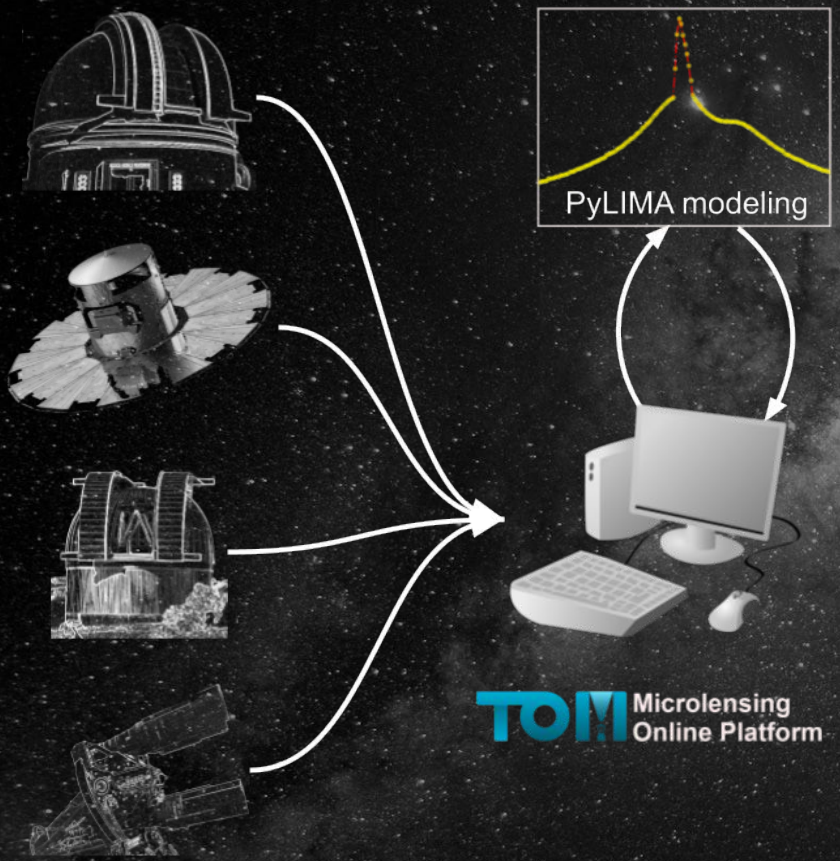
Identifing microlensing events *in real time*, 'low' cadence surveys

- > 410 microlensing Gaia Alerts [Wyrzykowski et al.]
- MicroLIA Random Forest Algorithm [Godines et al. 2019]
- ZTF microlensing alert table [Mróz]



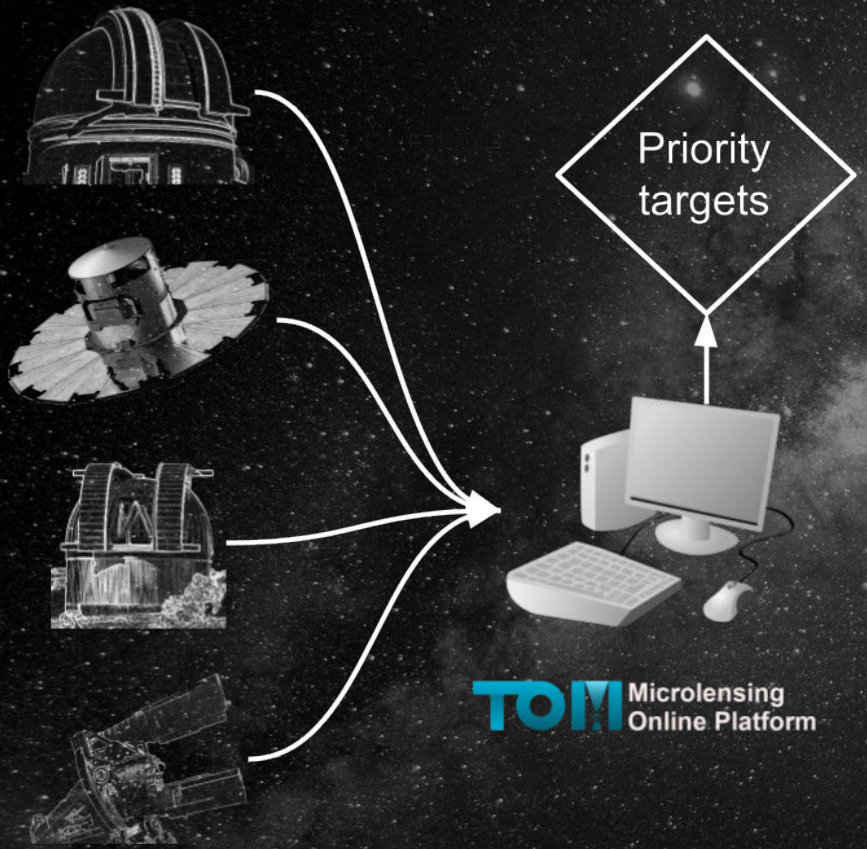
Single- and binary-lens events identified in ZTF data
Mróz et al. 2020a, b

OMEGA Target Modeling and Selection



Automatic process regularly updates microlensing model fitted to all available lightcurve data

OMEGA Target Modeling and Selection



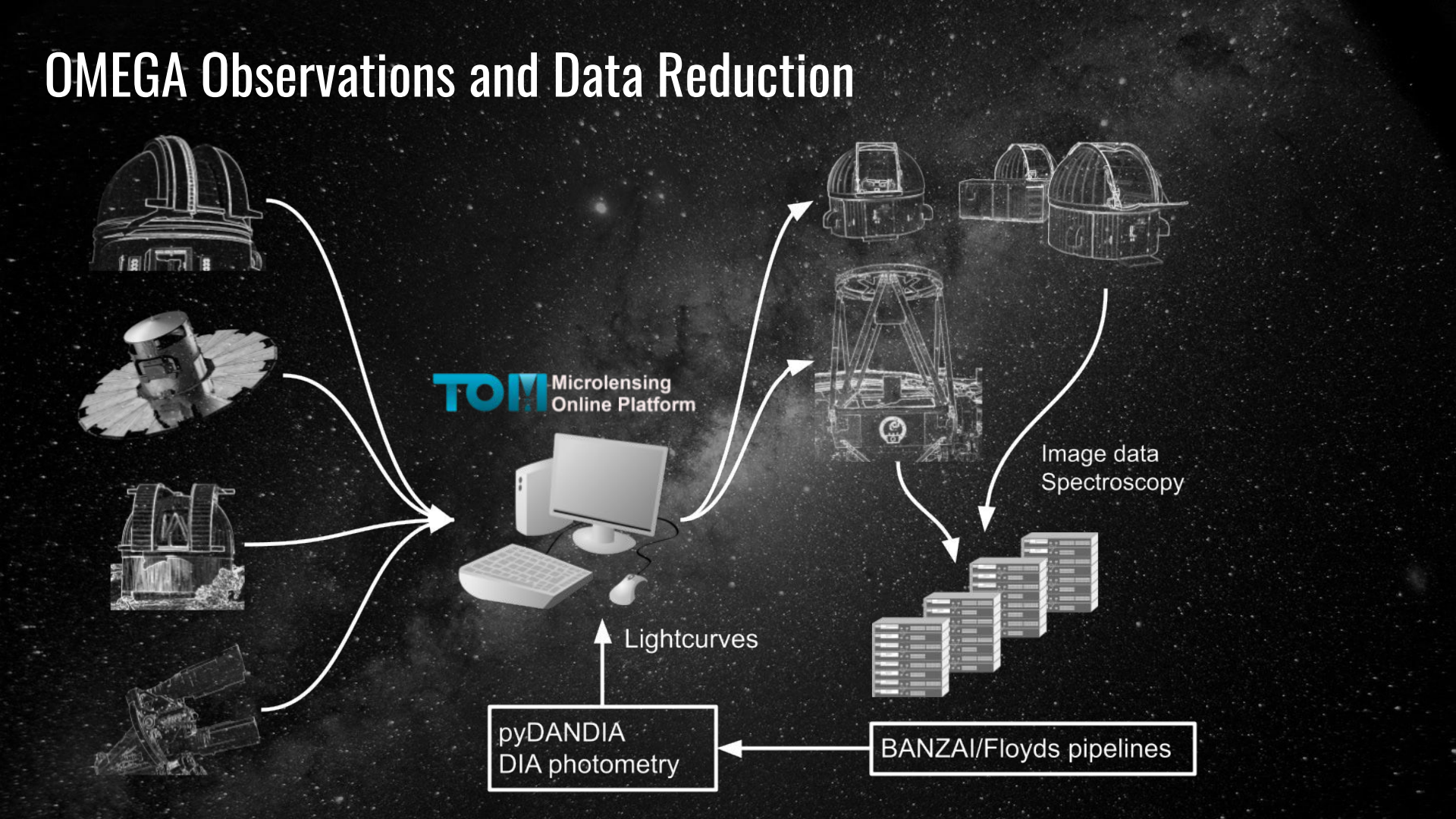
Targets are prioritized for follow-up observations:

- Sensitivity to binary perturbations
- Information content of follow-up observations to constraining event model
- Observational constraints

Fully robotic target selection

Hundertmark et al. 2018
Dominik et al. 2010

OMEGA Observations and Data Reduction



Gaia21auw

Aladin Finding Chart

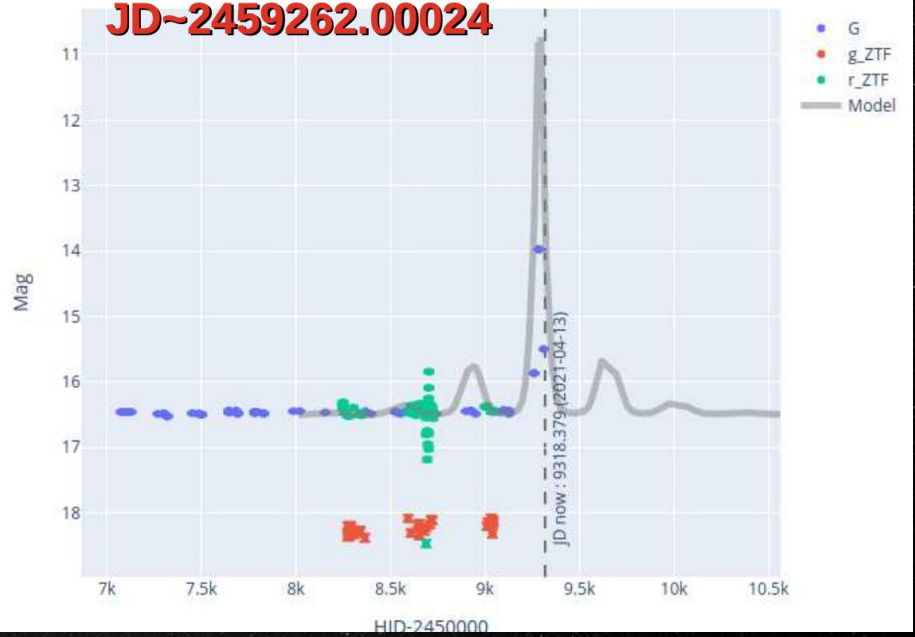
Update Target | Delete Target

Fit Target | Run TAP

Names	Gaia21auw
Target Type	SIDEREAL
Right Ascension	262.3259
	17:29:18.216
Declination	-21.8753
	-21:52:31.044
Galactic Longitude	4.0174
Galactic Latitude	6.8804
Observing_mode	Regular
Classification	Microlensing PSPL
Spectras	0.0
TAP_priority	26.35422
Alive	True

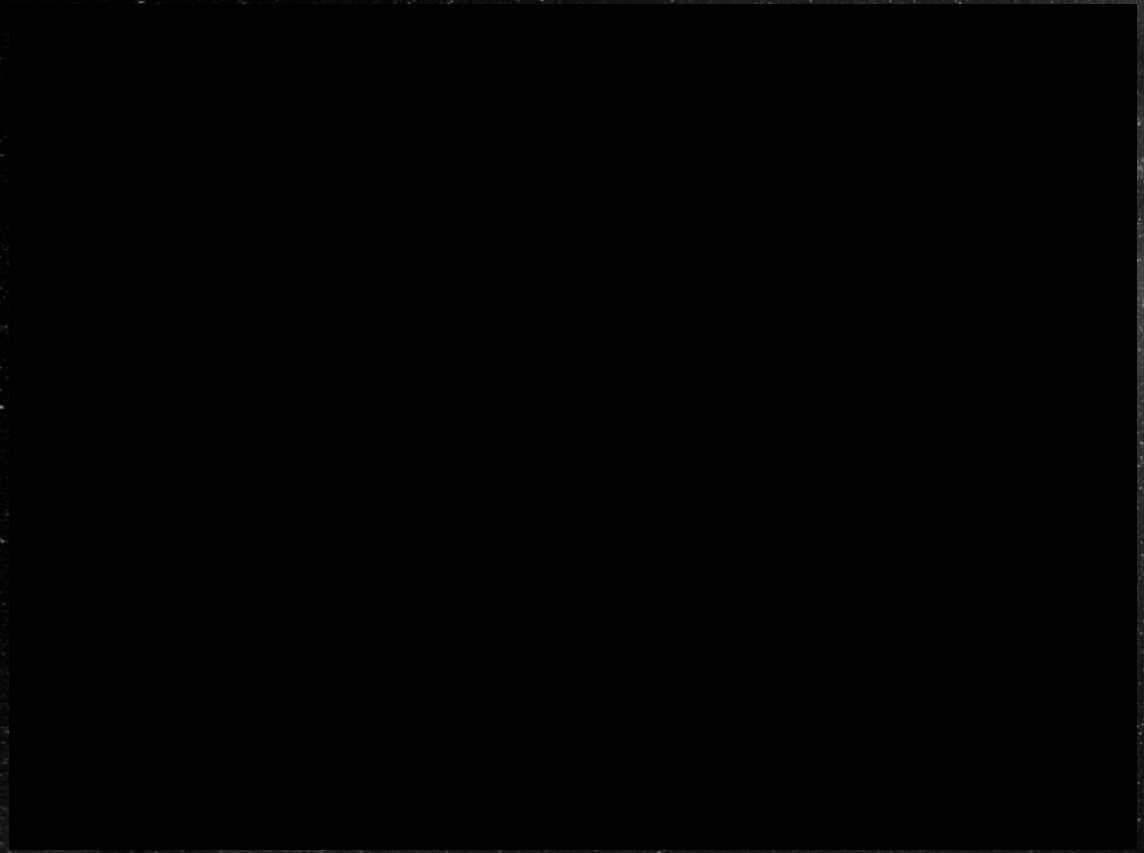
Photometry

Created at
2021-02-16 12:00:21.242779
JD~2459262.00024



Slide from Etienne Bachelet

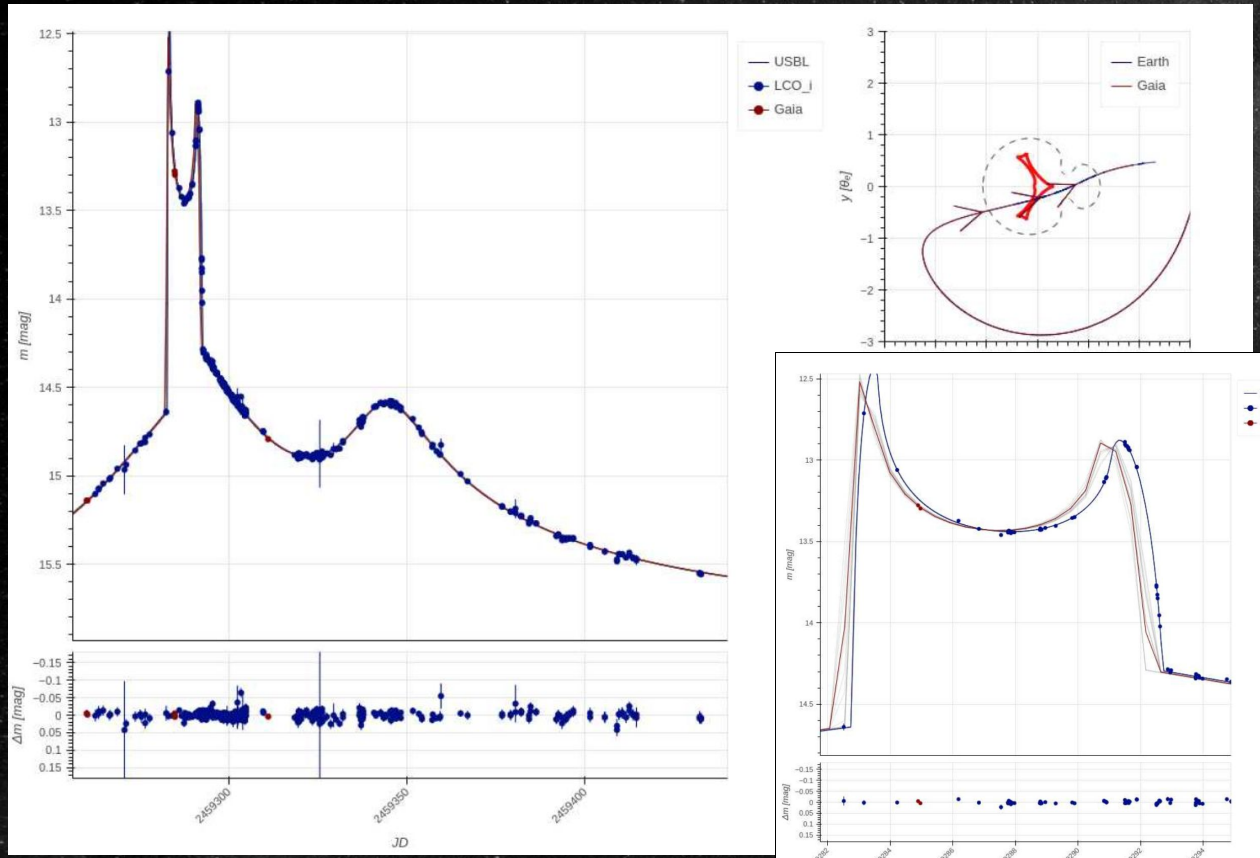
Gaia21auw



Animation by Krzysztof Rybicki

Generated with PyLIMA [Bachelet] and VBB [Bozza]

Gaia21auw



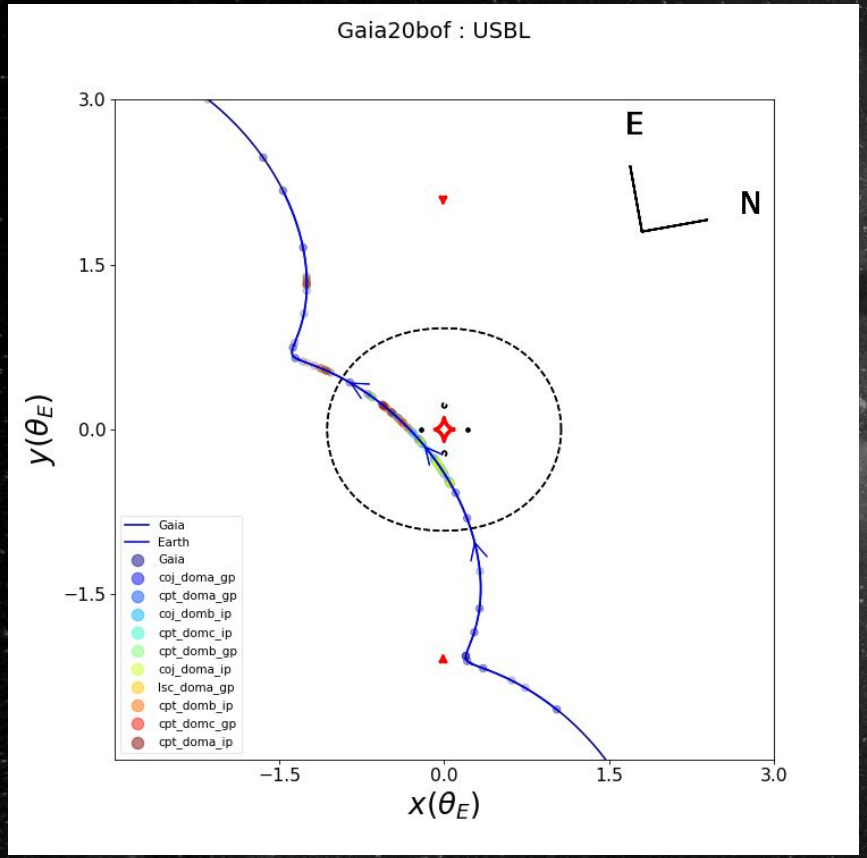
From Cassan et al. in prep

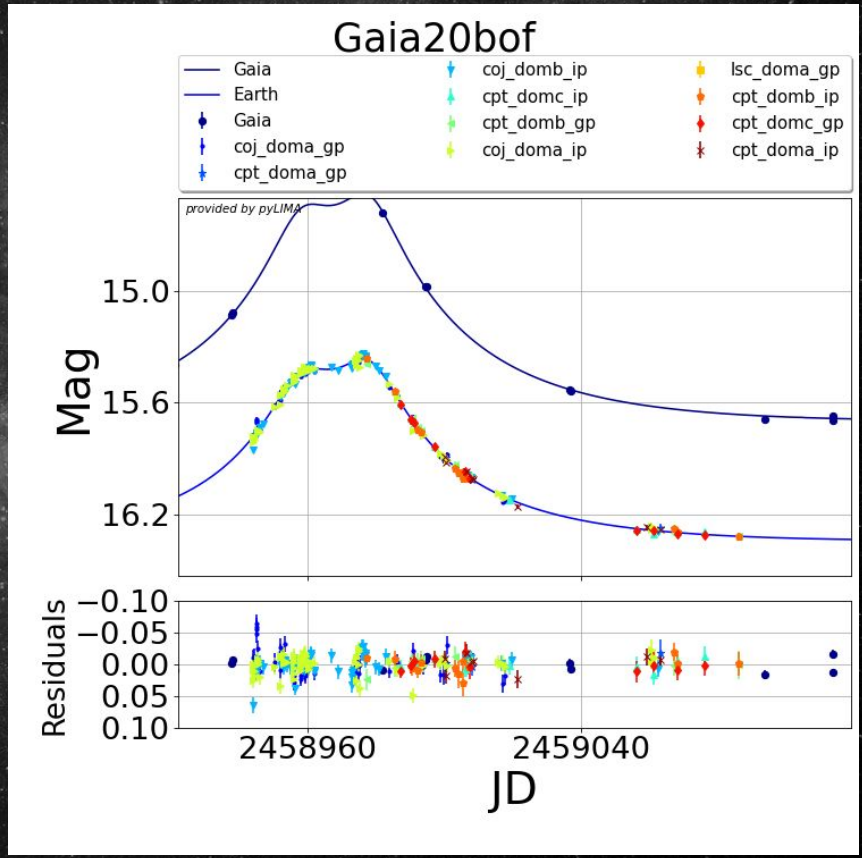
Model by K.Rybicki with pyLIMA

Combines both photometric and astrometric data from Gaia + LCO follow-up

Gaia20bof - brown dwarf/planet

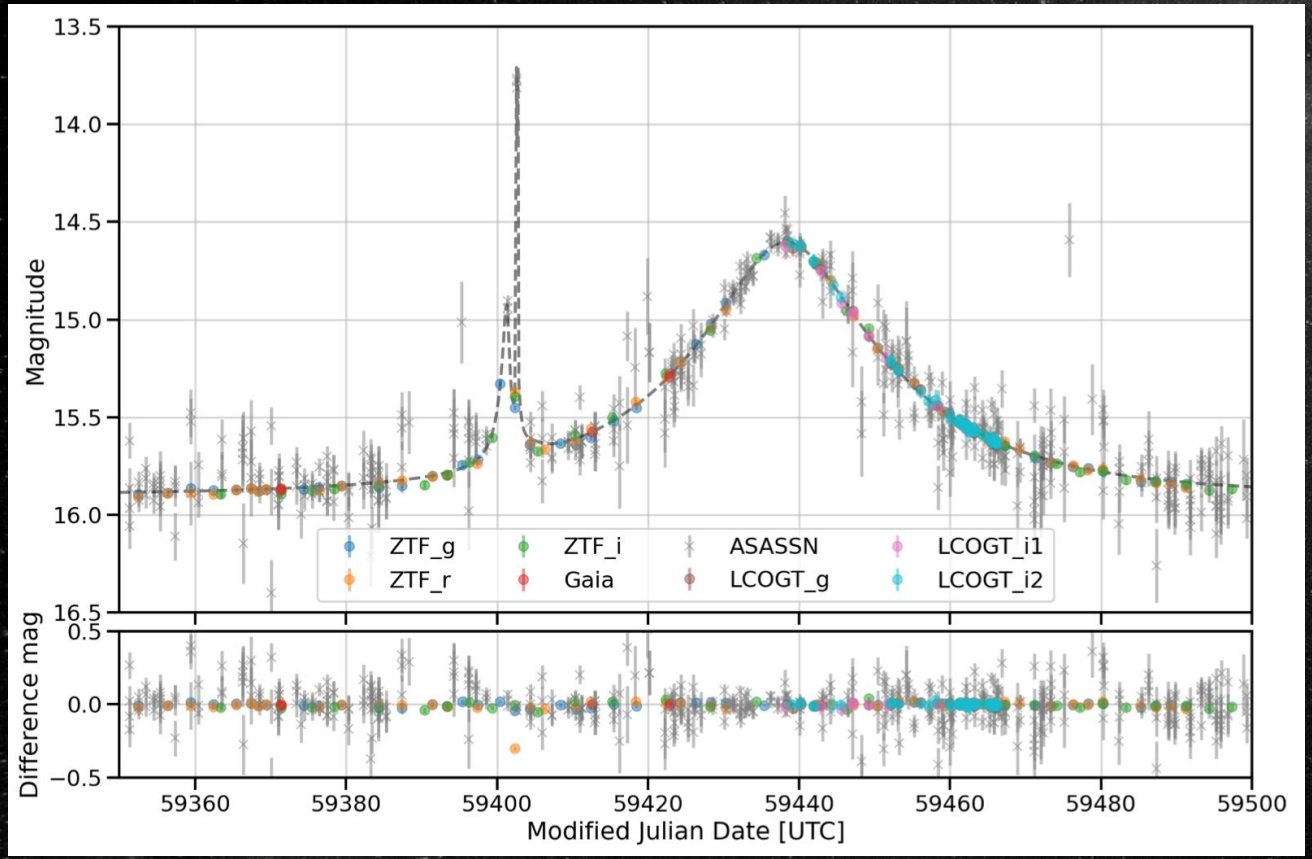
Bachelet et al. in prep





AT2021uey

Makiko Ban and Petro Voloshyn et al. in prep



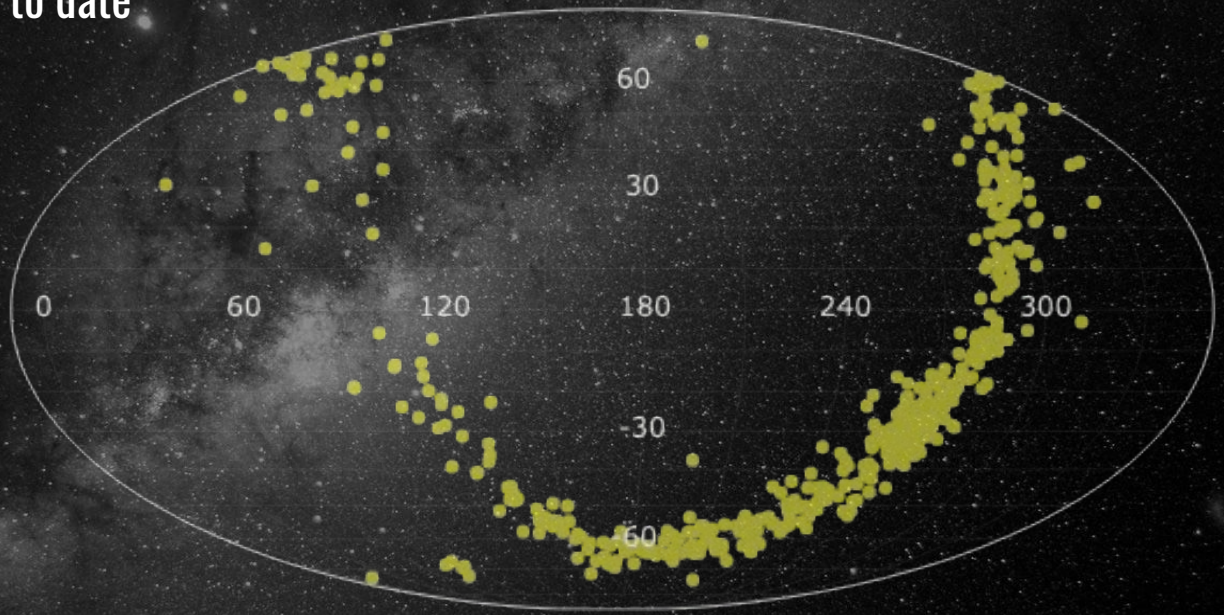
Planet orbiting a nearby main sequence star or compact object

Event summary

OMEGA has observed 515 events to date
Gaia: 285
ZTF: 22
MOA: 202
ASAS-SN: 2

59 events of special interest

Publications in prep



1695 microlensing alerts - on-sky distribution

Larger-aperture telescopes for future follow-up

AEON Network: programmatically-accessible telescopes with time-domain-friendly scheduling

Working with Rubin in-kind program facilities, inc SALT

See lco.global/aeon

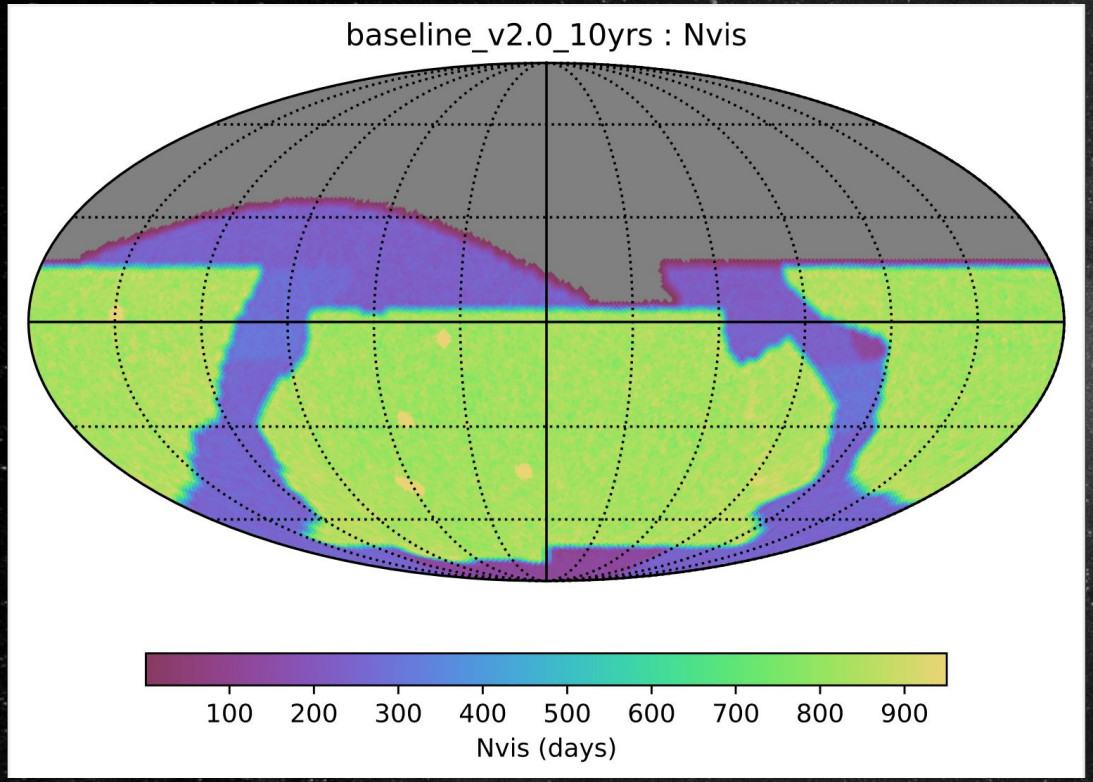
GEMINI OBSERVATORY
Exploring the Universe, Sharing its Wonders

SOAR TELESCOPE

NOIR Lab

LCO

Rubin Survey Cadence



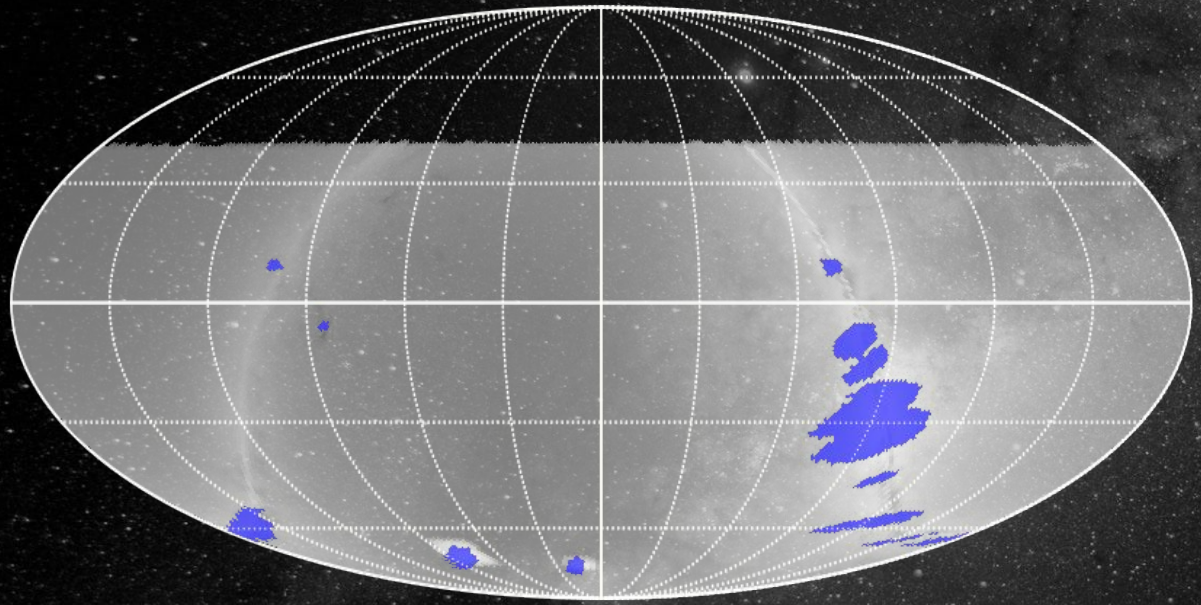
N visits / HEALpixel over 10yrs, Rubin baseline strategy v2.0
[Credit: Lynne Jones, Peter Yoachim]

Strategy under development
[See talk by K. Olsen]

Baseline strategy now includes central Galactic Plane, Bulge and Magellanic Clouds
[Bono et al. 2018, Gonzalez et al. 2018, Street et al. 2018a, Prinsinzano et al. 2018, Bonito et al. 2018, Poleski et al. 2018, Lund et al 2018, Clementini et al. 2018]

Exploring coordinated survey periods with Roman Exoplanet Survey
[See work by A. Varela, M. Makler, et al, Street et al. 2018b]

Rubin Survey Cadence



Sky map of stellar density
Proposed high-cadence regions shown in blue

Evaluating possible minisurvey

Higher cadence in Bulge + Mag.Clouds, plus range of gal.long [Coordinated with Roman]

Medium cadence over whole Gal Plane

See:
Abrams, Hundertmark et al in prep
Street et al in prep
Varela et al in prep
TVS Microlensing Group + SMWLV

OMEGA Program

- Systematic follow-up of stellar, compact object microlensing events across the sky
- Working with alert brokers to add microlensing classifier tools
- Working with observatories to make telescopes more time-domain friendly
- Scalable TOM systems to coordinate characterization follow-up
- Optimizing Rubin survey strategy for microlensing

New! NSF-supported post-doc at LCO for microlensing science with Rubin advertised end of 2022