TMEX-2020 Summary Talk

Roland Crocker

ANU

Australian National University

Usual caveats

- *Theory Meeting Experiment*: but I am neither a theorist or an experimentalist…so maybe organisers thought I would be neutral…
- This is my own biased view of what was particularly eye-catching
- I don't think I'm being deliberately controversial — so if I misrepresent your research, it's because I haven't understood something and please feel welcome to correct me

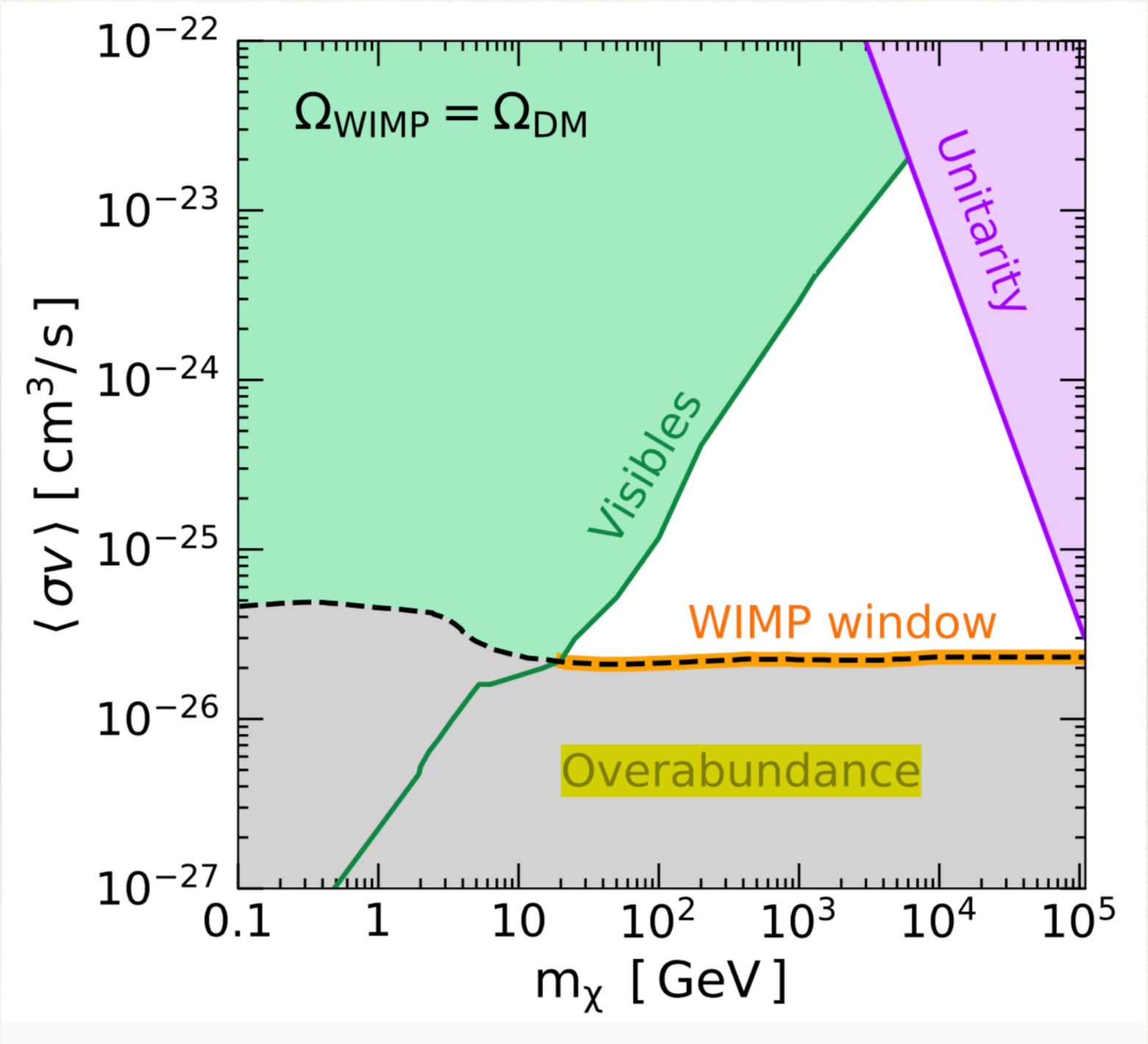
Themes

- What is the Universe made of?
- dark matter search; whither / wither the thermal WIMP paradigm?
- multi-messenger - great! - but teething problems: need new standards for machine readable alerts, measurements, data sharing; how do we get best synergy?
- “desperately need an MeV telescope”
- bizarrely-forced acronyms

Themes

- Opening of new windows (GW detectors, neutrino telescopes, orbiting CR detectors, water Cherenkov TeV gamma-ray telescope arrays…) leads to surprises
- On the other hand, construction of experiments in search of anticipated, well-motivated phenomena has disappointed, at least in the case of WIMPs

..but the GeV-scale thermal WIMP is allegedly *not even slightly dead*



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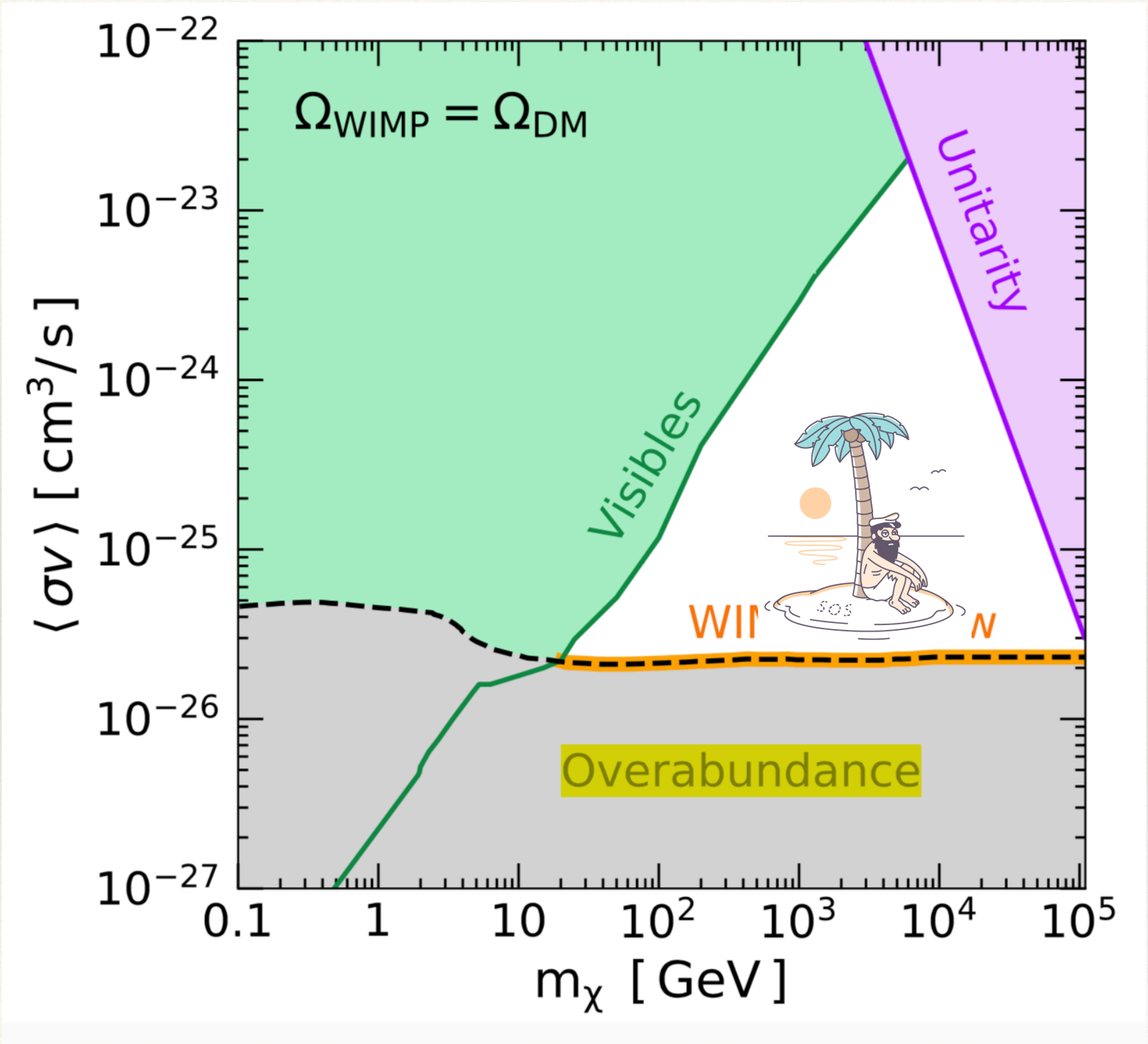

Themes

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- On the other hand, construction of experiments in search of anticipated, well-motivated phenomena has disappointed, at least in the case of WIMPs
  - ***…as usual, Nature is more imaginative than us***

Themes

- Cross-cultural/cross-disciplinary communication/interaction/collaboration leads to productive new science (e.g., constraining DM sub-halo population of Galaxy with Gaia; GW observations give us an independent measure of H_0)
- I anticipate many papers will have been seeded in conversations at this conference…perhaps even some experiments!

Scientific Themes

Being more specific

Experiments

- Cosmological Probes
  - CMB
  - SN Ia
  - Lensing
  - Rot. Curves
  - BAO
  - Abundances
- Cosmic Rays
  - GeV
  - PeV
  - UHECRs
- γ
  - GeV
  - TeV
- ν
  - MeV
  - TeV
- GW
- Direct DM

Models

- Concordance Model
  - DM
  - Dark Energy
- Cosmic Accelerators
  - Leptonic
  - Hadronic
- CR Propagation
  - Cooling
  - Acceleration
  - Spallation
  - GZK
- Binary Mergers
  - NsNs
  - IMBH
  - SMBH
  - Mass Gap
- Neutrinos
  - Oscillations
  - Hierarchy

Theories

- Gravitation
  - GR
  - Other?
- Inflation
- QFT
  - SM
  - BSM
- Particle Acceleration

How to unify?

Vietnamese Banquet

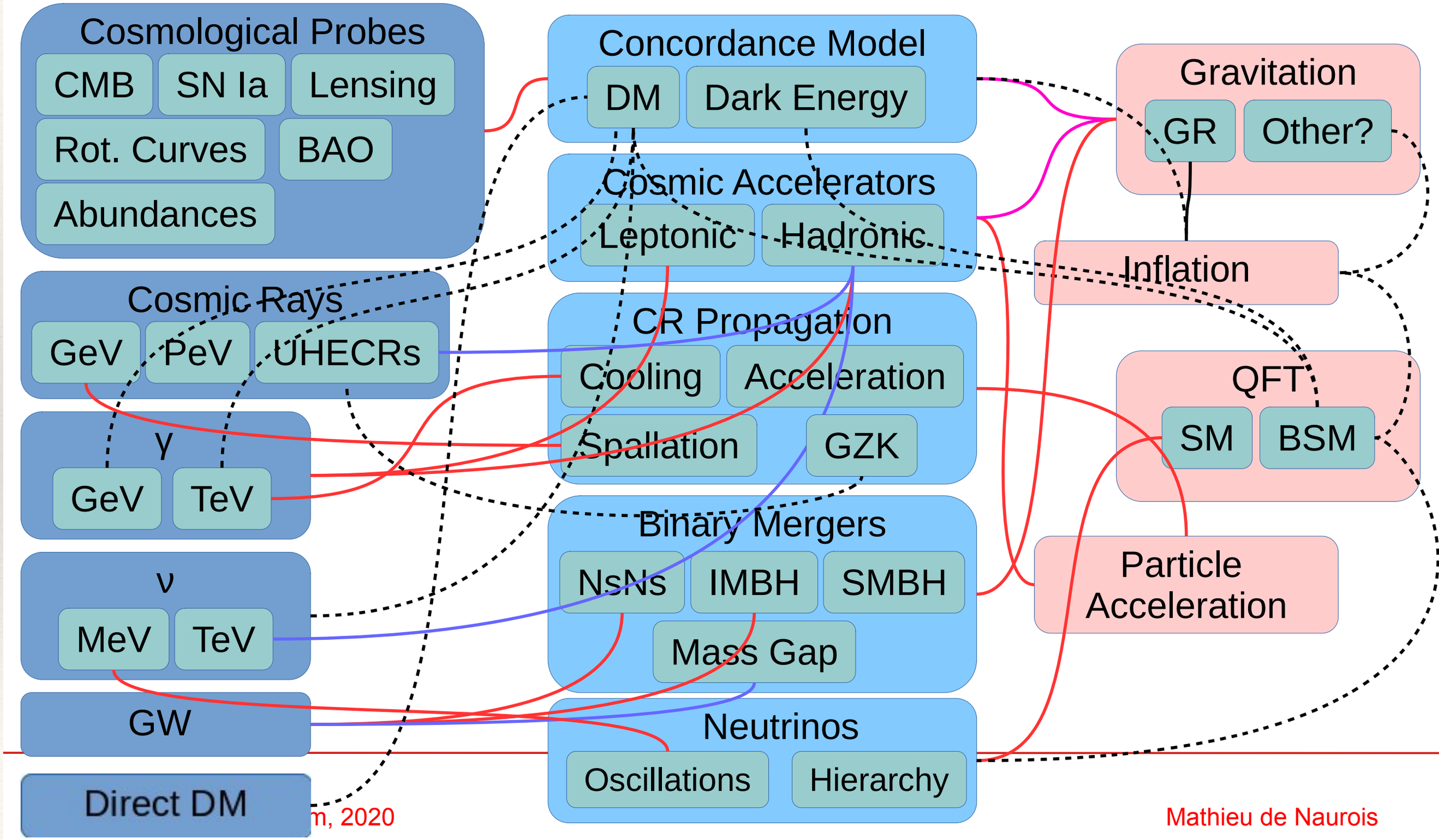
Mathieu seems to like noodles:

Overall picture (2020)

Established Link

Likely Link (<5σ)

Putative Link



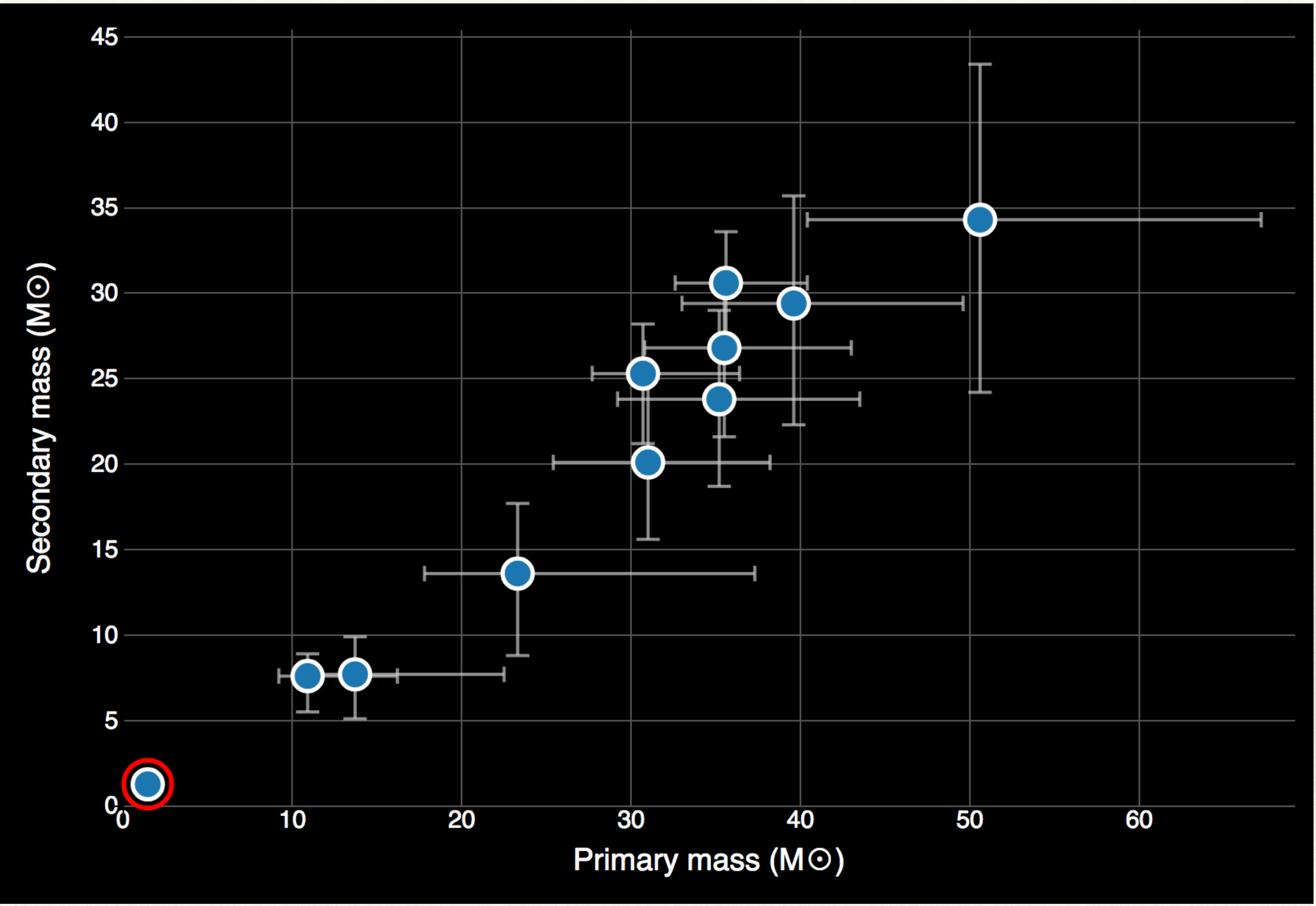
The Talks

Gravitational wave astronomy

- Astone
- Klencki
- Chruslinska
- Fishbach
- Parameswaran
- Bulik

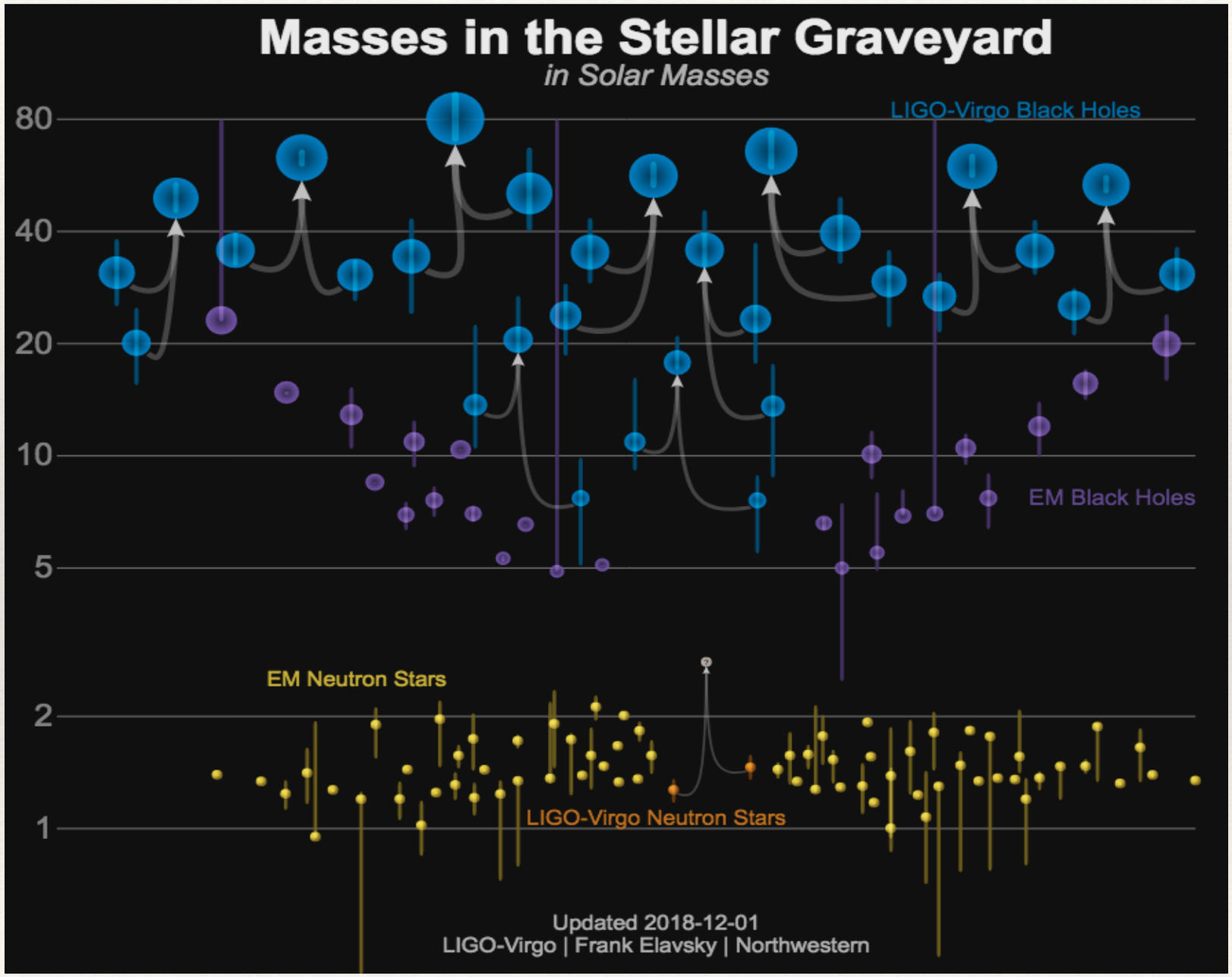
Gravitational wave astronomy

- (*From outsider's perspective*) very rapid development: from discovery to ***multi-messenger astronomy*** and beginnings of ***population studies*** in just a few years


45
40
35
30
25
20
15
10
5
0
Secondary mass (M⊙)
0
10
20
30
40
50
60
Primary mass (M⊙)

Astone

Interesting details of binary compact object populations emerging…



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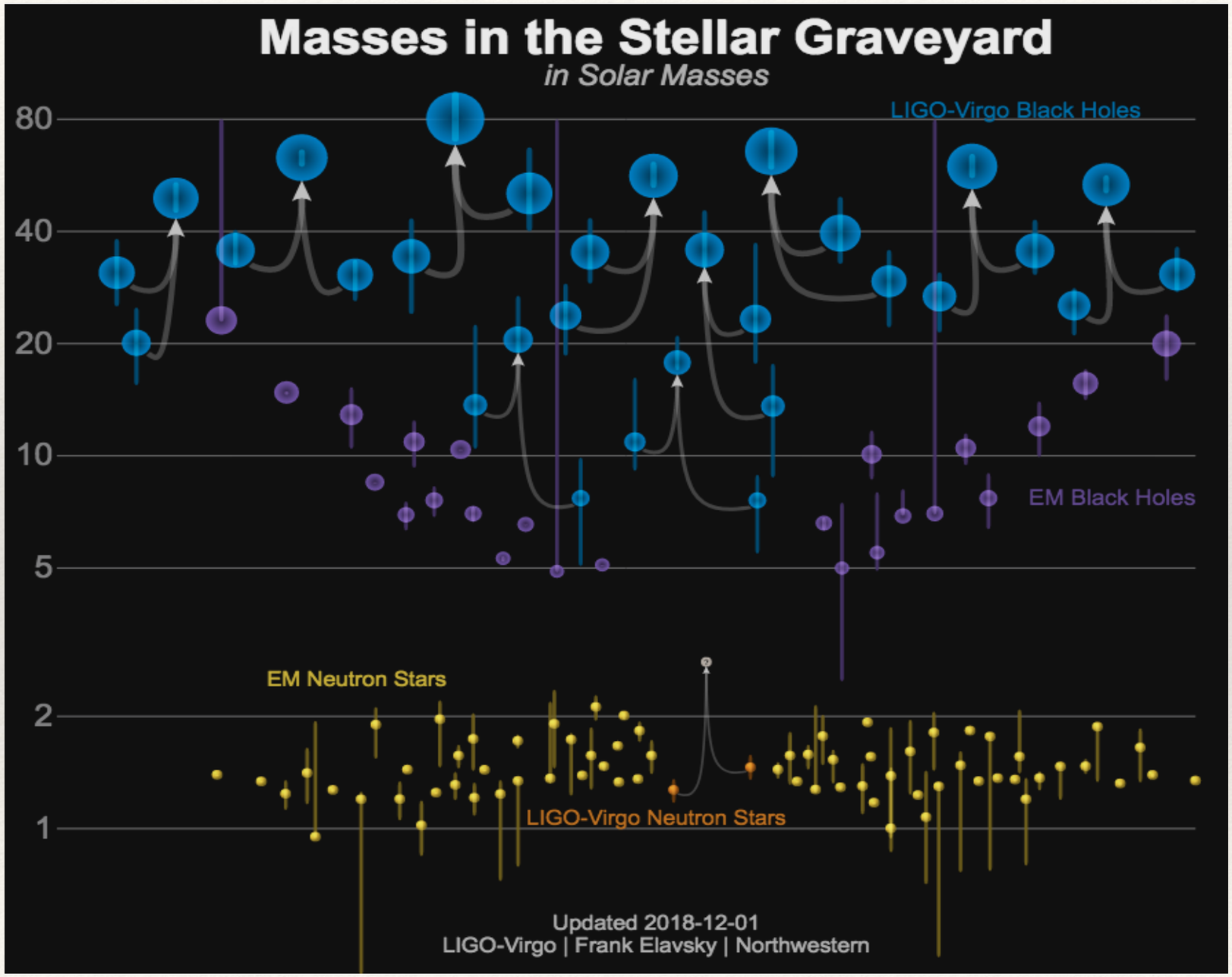

1 in every 100 SMBHs merges !

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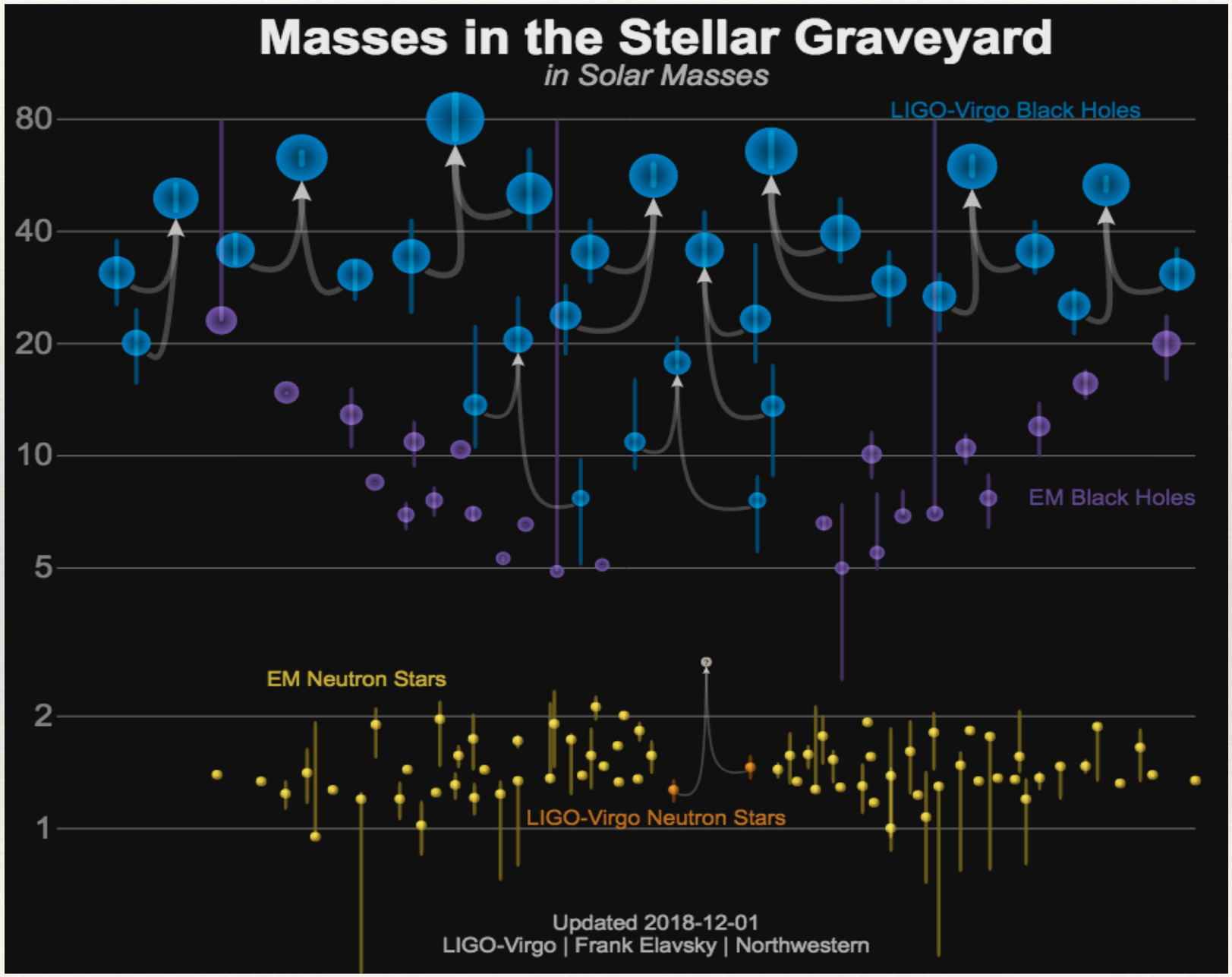

pair instability mass gap (?)

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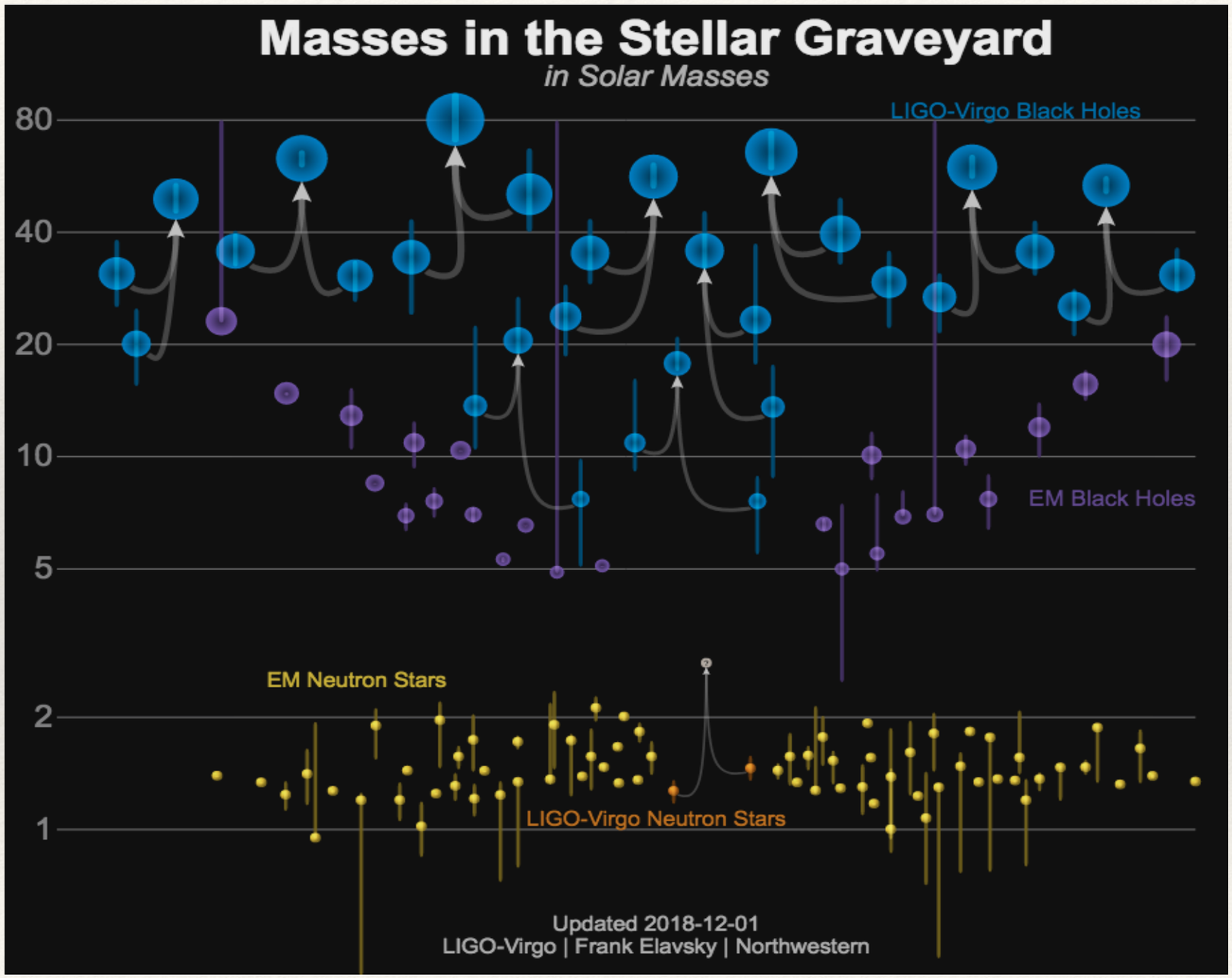
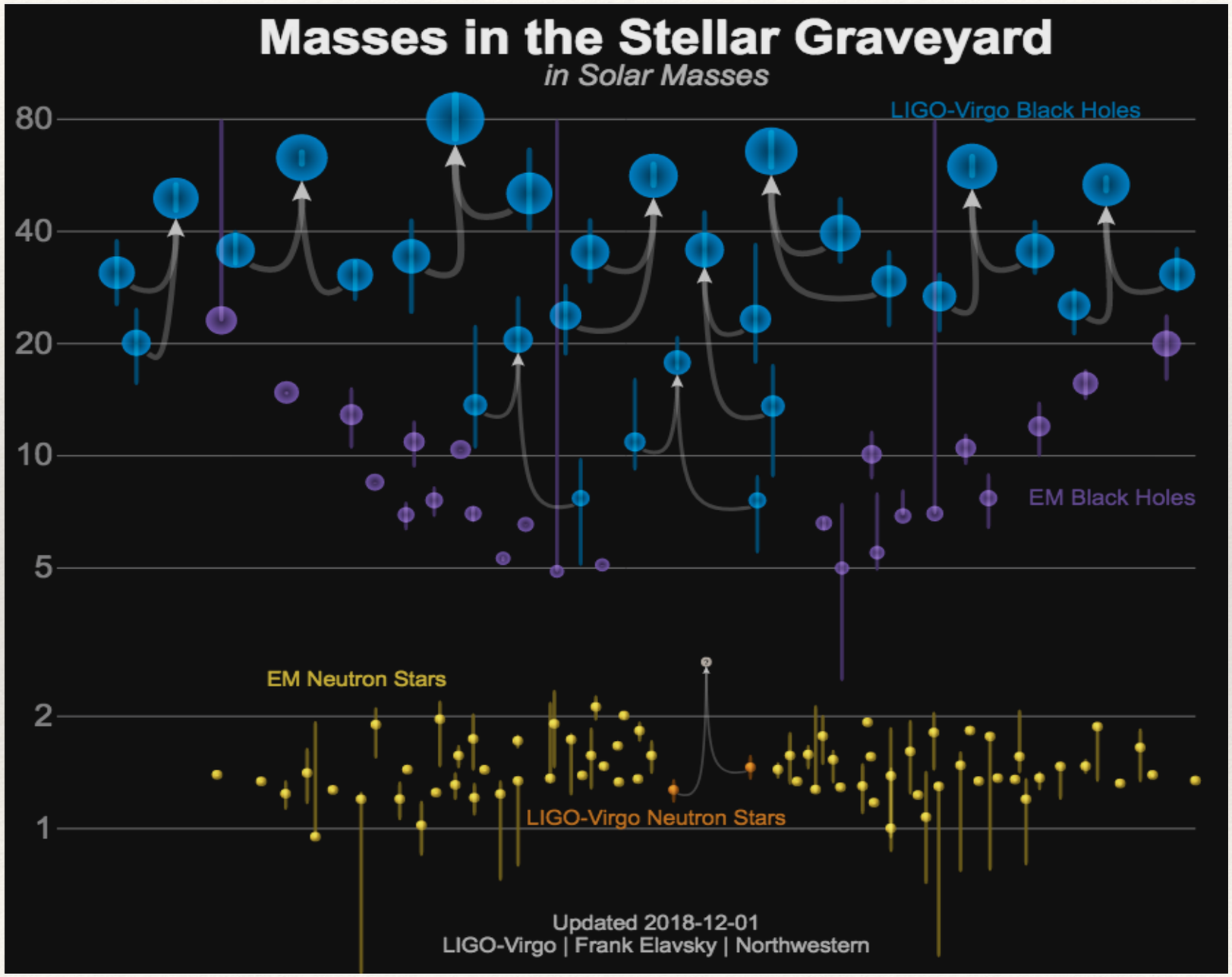


mass gap ⇒

source frame feature ⇒

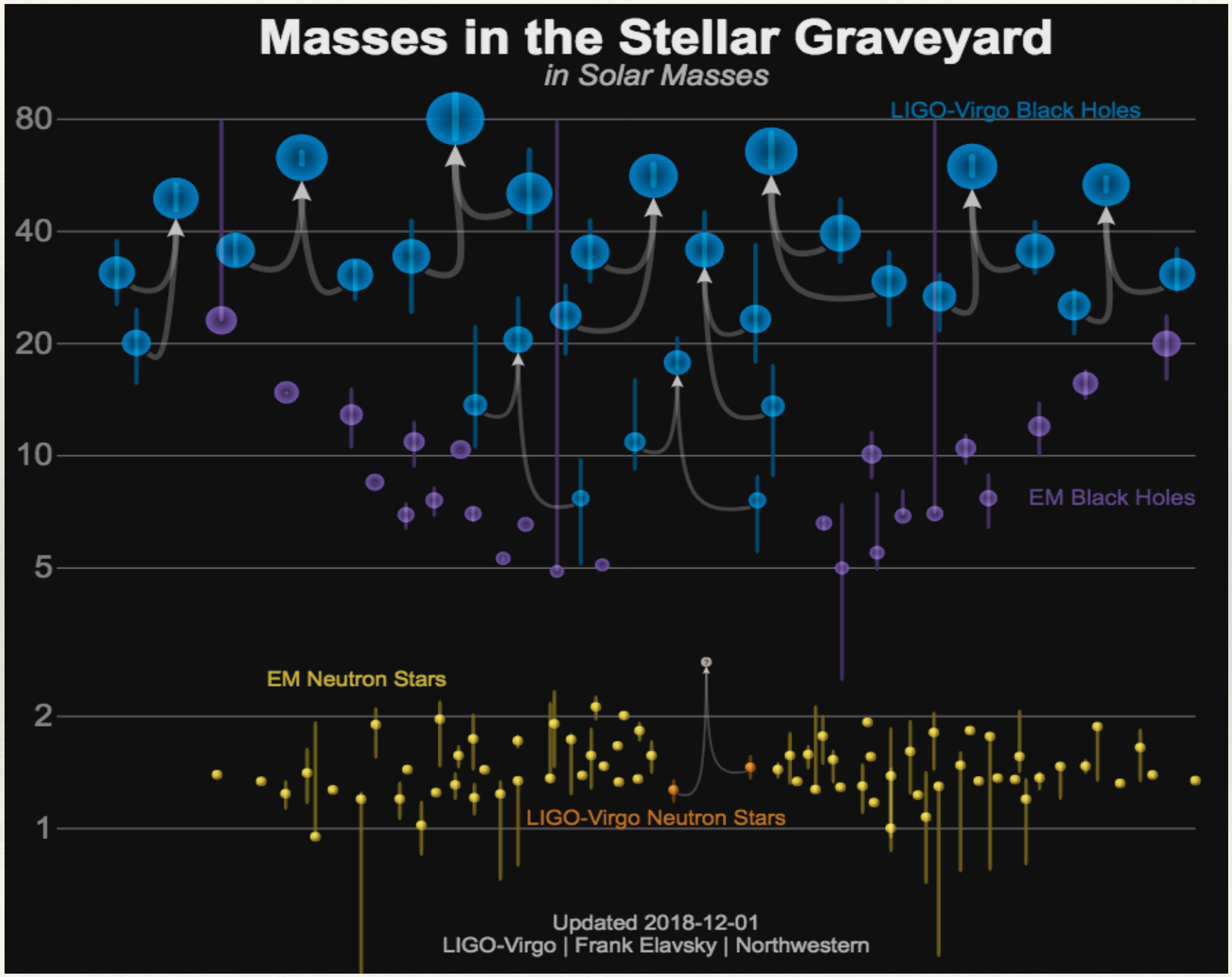
cosmology!

Interesting details of binary compact object populations emerging…



are there echoes or not?

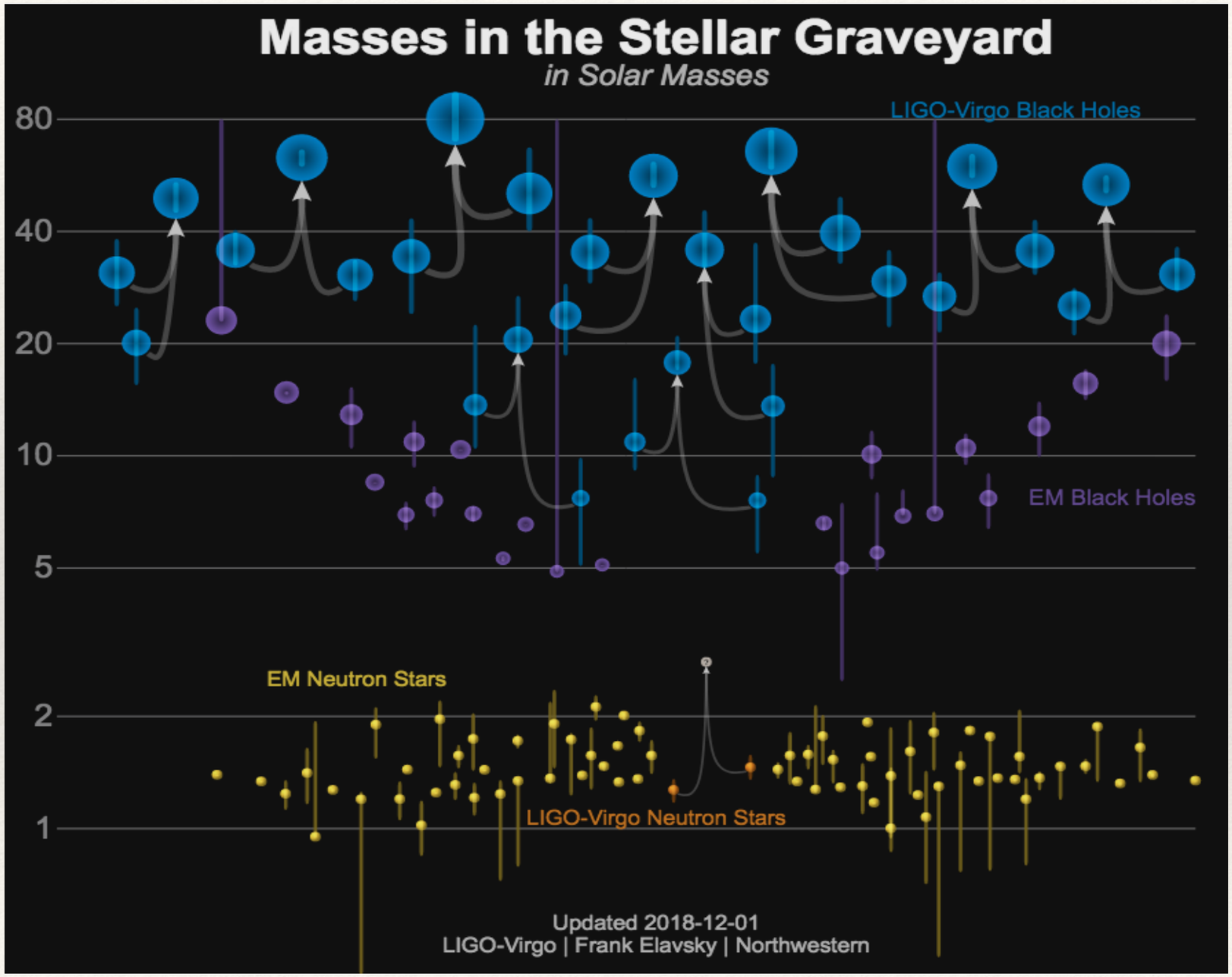
Interesting details of binary compact object populations emerging…



"desert"

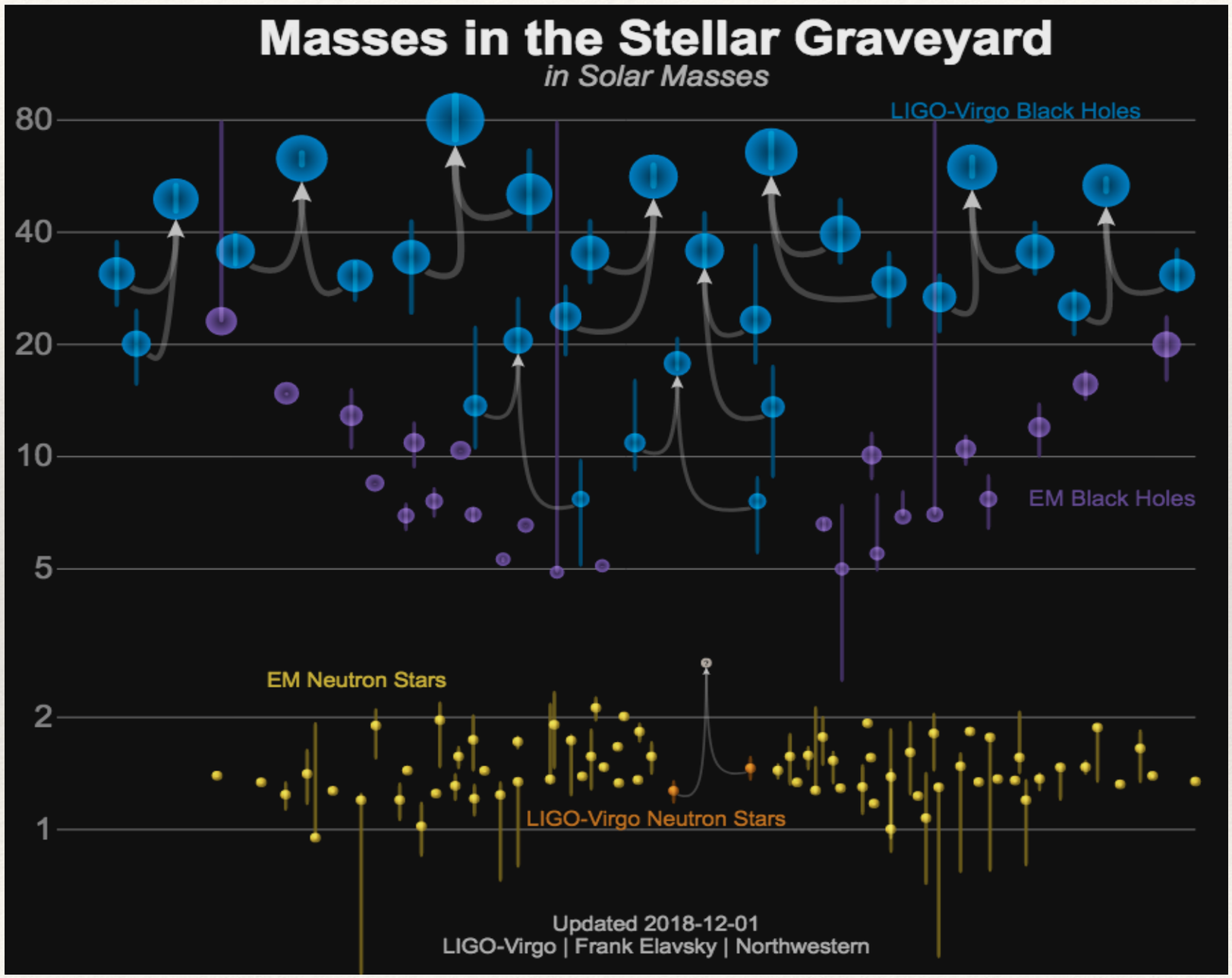
NB “desert” ≠ “dessert”

Interesting details of binary compact object populations emerging…



where do the BNS come from?

Interesting details of binary compact object populations emerging…



common envelope channel?

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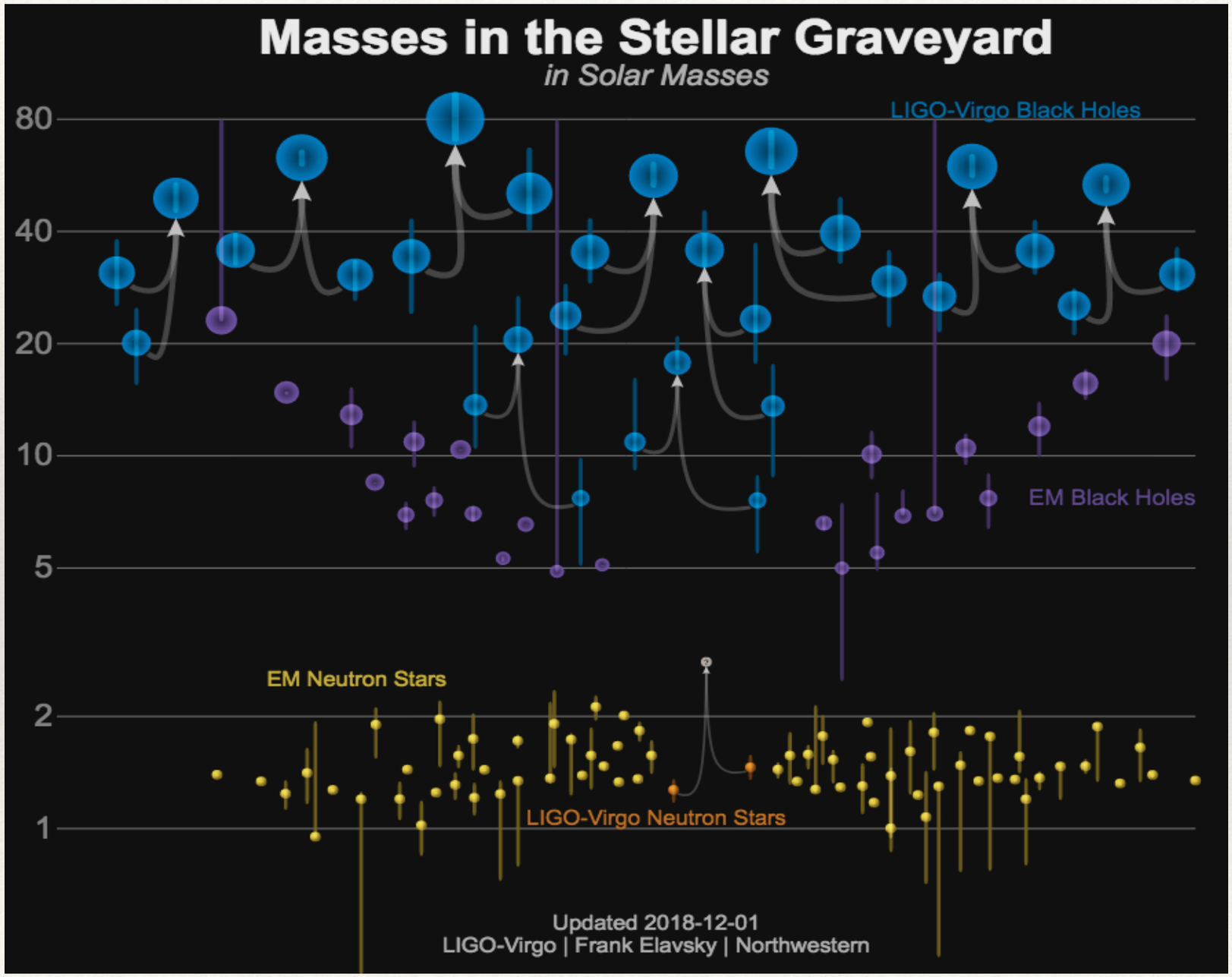
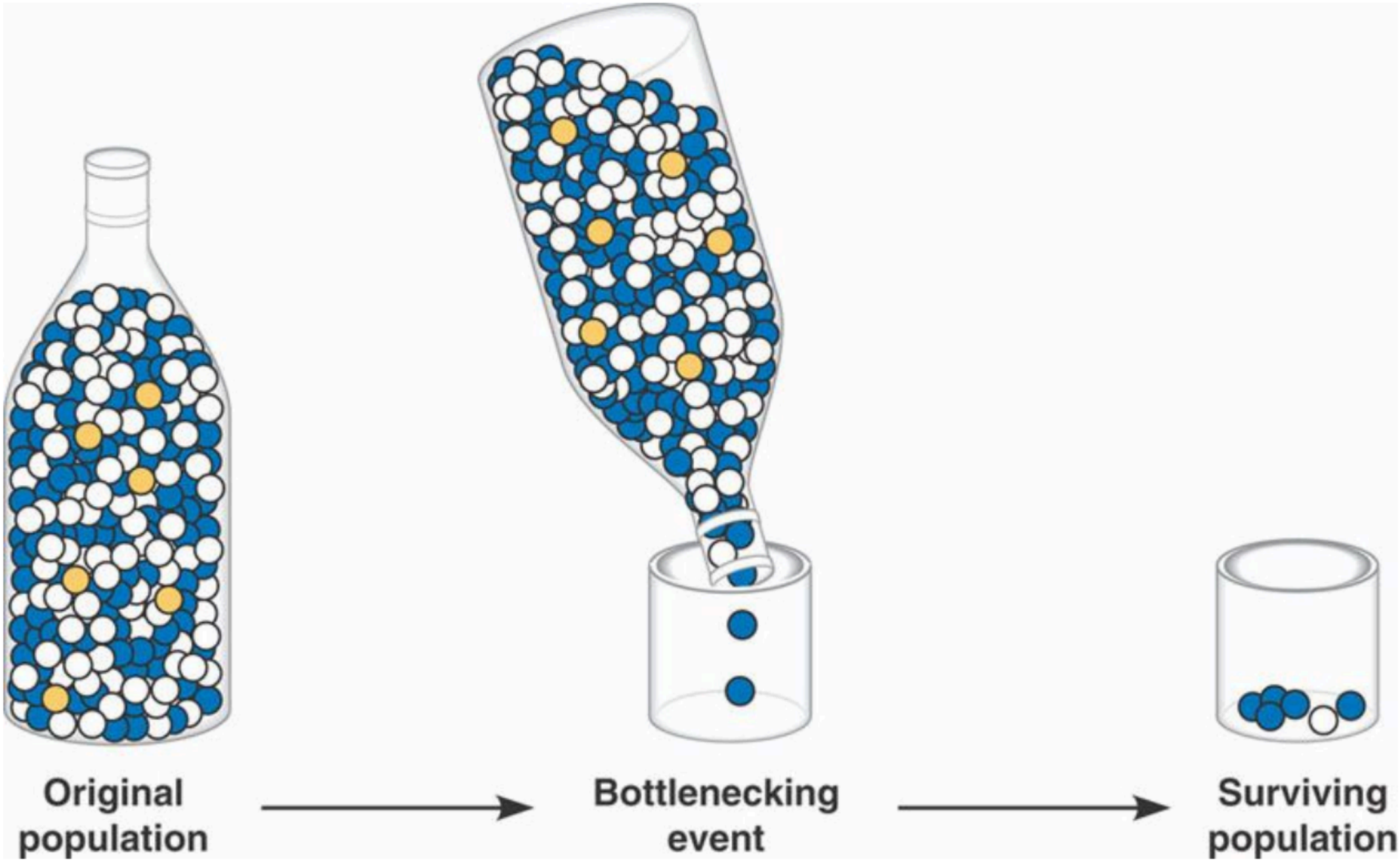


common envelope channel?

we need NSs born with low kicks!

Bottlenecks



http://bio1151.nicerweb.com/Locked/media/ch23/bottleneck.html

A new BNS (?) merger event announced during the conference…

- detected by LIGO Livingston on April 25, 2019, during third observing run; Hanford offline; Virgo did not detect (low S/N)
- > 2 x further away and quite unlike the first neutron star merger: total mass ~3.4 $M_\odot$, significantly larger than any other known binary neutron star system (2.5 $M_\odot$ - 2.9 $M_\odot$)
- “The possibility that one or both binary components of the system are black holes cannot be ruled out from gravitational-wave data.”
- EM counterpart not found

Gravitational wave astronomy

- Very rapid development: from discovery to multi-messenger astronomy and beginnings of population studies in just a few years

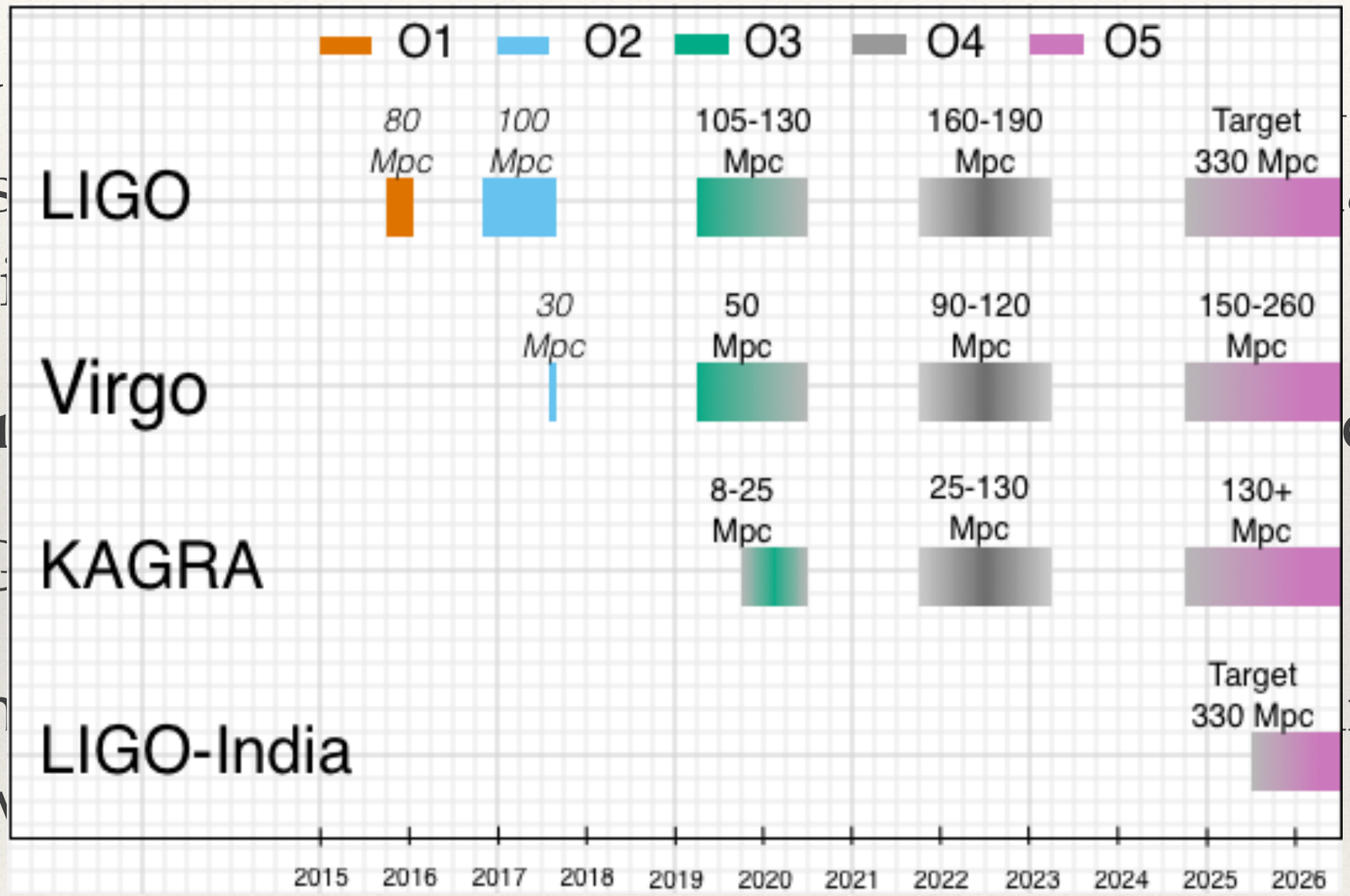
Rapid(?) development

Gravitational wave astronomy

- Very rapid development: from discovery to multi-messenger astronomy and beginnings of population studies in just a few years
- …but should not forget many decades of development
- KAGRA detector in Japan is coming online
- further detectors in India and Germany operating within a few years
- …annual event rates in the 1000s

Gravitational wave astronomy

- Very
- mess
- studi
- …bu
- KAG
- furth
- a few
- …annual event rates in the 1000s



Cosmology

- Fishbach
- Shan
- Escoffer
- Graziani
- Baulieu

Fishbach: beginnings of cosmography with GWs!

- With (many) more events GWs should cast `light' on the Hubble tension
- Relies on existence of source frame feature, the 45 MSun cut (from pair instability SN?) in the BH mass distribution

Romain Graziani: cosmography with peculiar velocities

Peculiar velocities

Peculiar velocities

Graziani: cosmography with peculiar velocities

- …may help us to pin down the evolution of the Hubble parameter

Cosmology

- Laurent Baulieu: “I will not pretend that you will understand what I am going to say”

Cosmology

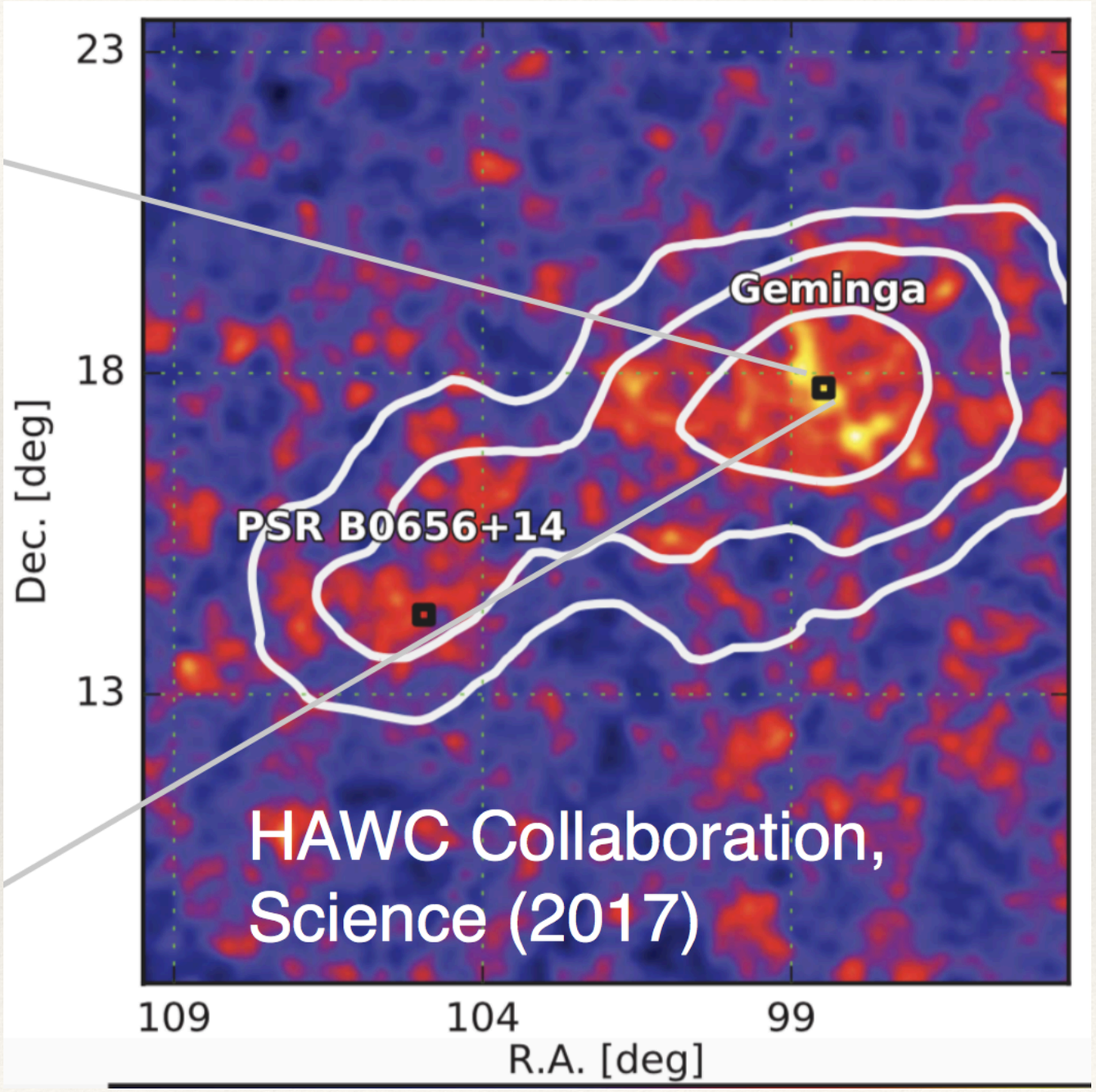
- Laurent Baulieu: “I will not pretend that you will understand what I am going to say”
- Me: “OK”

Gamma-rays, Cosmic rays

- Fang
- Casandjian
- Mirzoyan
- Ruis-Velasco
- Yours truly
- de Naurois
- Vagelli
- Fedynitch
- (Ng)

Ke Fang: HAWC Observation of TeV Astrophysical Sources

- TeV emission detected out to several degrees around the middle-aged, nearby (~250 pc) pulsar Geminga
- Similarly extended emission around other pulsars
- Diffusion coefficient ~1/100 Galactic mean value…*how does this work?*



Mirzoyan, Ruis-Velasco: GRBs @ TeV (!)

- After many years of development, “suddenly” we now have three GRBs seen at 100 GeV+ energies by IACTs!
  - GRB180720B (HESS)
  - GRB190114C (MAGIC)
  - GRB190829A (HESS) -> 4 Nature papers
- Triggering strategy crucial
- Ability to operate in bright moon helps!
- Looks a lot like SSC
- Looks promising for CTA
- Can the existing IACTs detect a short burst (cf. Schüssler)?

Rapid development

“Rapid” development

- 30 years since Whipple’s 1989 detection of Crab at 9 sigma

Jean-Marc Casandjian

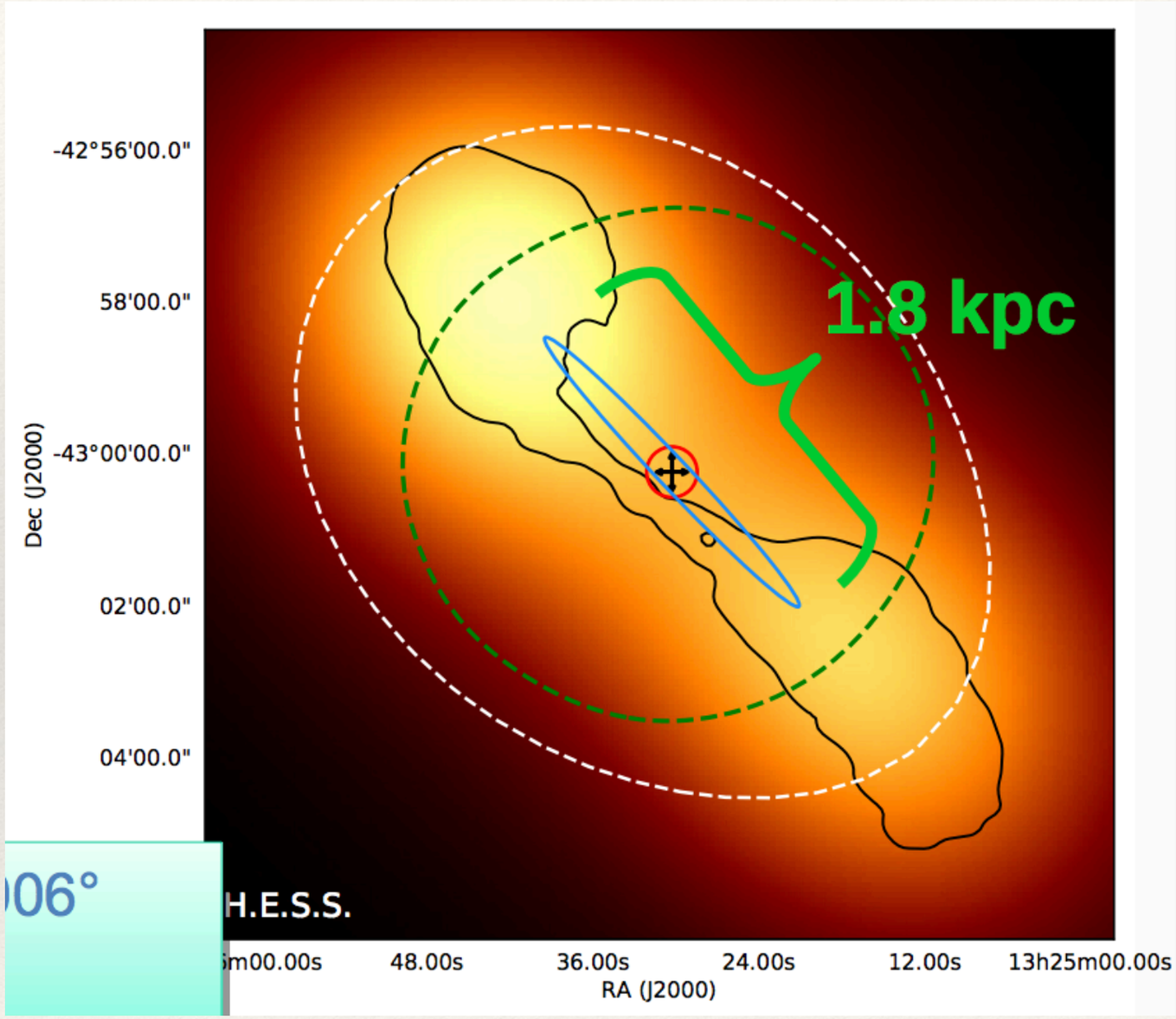
- Chose the “easy” path of template analysis, instead of CR propagation modelling, for *Fermi* data analysis a decade ago…
- …and discovered that “research is an activity that takes time”
- “Even with 11 years of Fermi data we struggle to understand the local γ-ray diffuse emission”

Valerio Vagelli: CRs from space

- Very rich phenomenology emerging…***too much data?***
- Has AMS seen anti-Helium?

Mathieu de Naurois : Resolving the kpc jet of Centaurus A in TeV γ-rays

- New era for morphology studies in VHE astronomy
- Centaurus A emission is not point-like at TeV
- First extragalactic extended source at VHE



Neutrinos

- Dornic
- Aguilar
- Ng
- Hu
- Sekiya
- Horiuchi
- Baum
- Kimura

Astrophysical Neutrinos

- Where are they coming from?
- (TXS 0506+056 — see later)
- Looking forward to KM3NET

Shigeo Kimura : Diffuse High-energy Neutrino Flux and Models

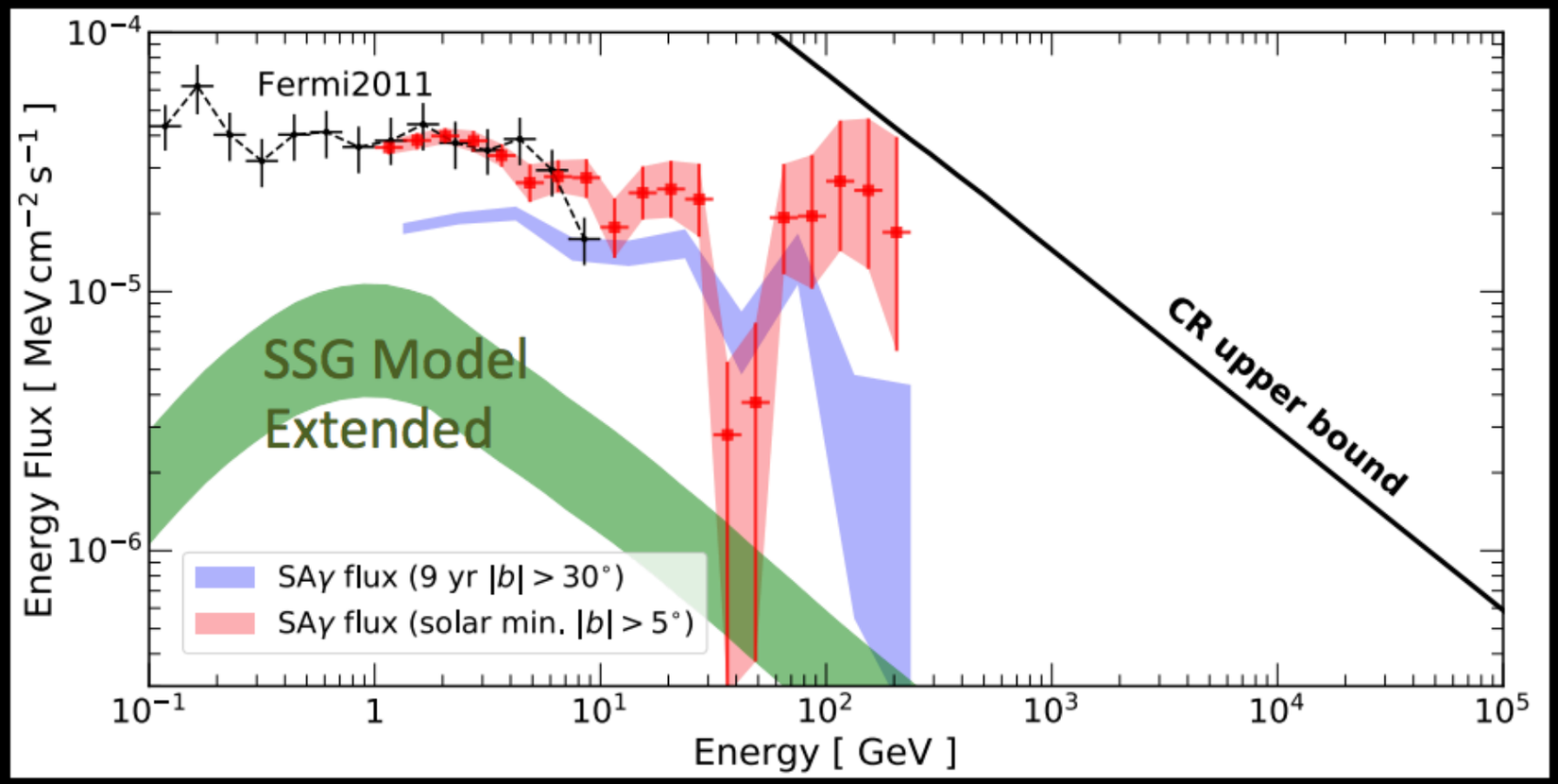
- isotropic; Galactic contrbtn < 10%; flavour ratio consistent with standard pion decay model + oscillations
- track analysis shows harder spectrum than shower spectrum…hint of 2 components?
- no confident point source detection — hints?; disfavours luminous sources
  - high luminosity GRBs < 1% nu flux
  - blazars < 27% detected neutrinos
- need faint sources to explain diffuse neutrino flux; favours abundant CR reservoir models like SBs
- 10 TeV neutrinos — need optically thick source — canNOT be starbursts
- NGC1068 — needs to be gamma-ray opaque
- LLAGN can explain PeV nu and MeV gamma bckgnds simultaneously

Kenny Ng: Solar Atmospheric Neutrinos (and Gamma-rays)

- Can we identify DM-generated neutrinos from Sun?
  - …well, first need to understand background of solar atmospheric neutrinos
  - …well, before that, need to understand "easy problem" of solar atmospheric gamma-ray production
- BUT…a very strange phenomenology of solar atmospheric gamma-rays has emerged (flux much higher than expected, large time variation, hard spectrum) … ***what is happening?***
- Input from HAWC?

Solar Atmospheric Gamma Rays

- High Flux, O(10)% efficiency at 100 GeV
- Time variation solar Min-Max
  - (2x @1 GeV, 10x @ 100 GeV)
- Morphology changes
- Dip at ~ 30 GeV, mostly at solar min.
- Hard Spectrum, $\sim E^{-2.2}$



- Abdo+ Apj, 2011
- KCYN+ PRD, 2016
- Linden+ PRL. 2018
- Tang+ PRD, 2018

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Hiroyuki Sekiya : Status of Super-K(-Gd) and Hyper-K for supernova neutrinos

- SuperK, 32 kT — refurbished, ready for next Galactic SN; ~10,000 events Gal SN
- preparing for a Betelgeuse burst! current 1 hour to alert — too slow for warning about optical signals for WR explosion (>20% all SN events)
- loading Gadolinium “SK-Gd” — early warning (Si burning nu’s, ~12 hours before explosion) + improved pointing accuracy + SN relic neutrinos
- relic SN nu’s: ~10^18 SNe over cosmological history, SK Gd should detect in 10 years
- Hyper-Kamiokande, 300 kT funded: one order magnitude increase in volume

Sebastian Baum

- dark matter is made of rocks…

Sebastian Baum

- dark matter is made of rocks…

Sebastian Baum

- Paleo detectors! damage tracks in ~Gyr old rocks
- exposure: 100 g x 1 Gyr = 10^4 t x 10 year
- keV recoil thresholds given today's nm resolution

Dark matter direct detection

- Masbou
- Gascon
- Shutt

Dark matter direct detection

- The continuing, heroic struggle to beat down the backgrounds
- Masbou: Double electron capture lifetime of ^{124}Xe: ~10^{22} years, longest 1/2-life every measured
- Shutt: Look left to the "cryogenic Wild West" and $M_{WIMP} < 10$ GeV

Approaching neutrino sea?

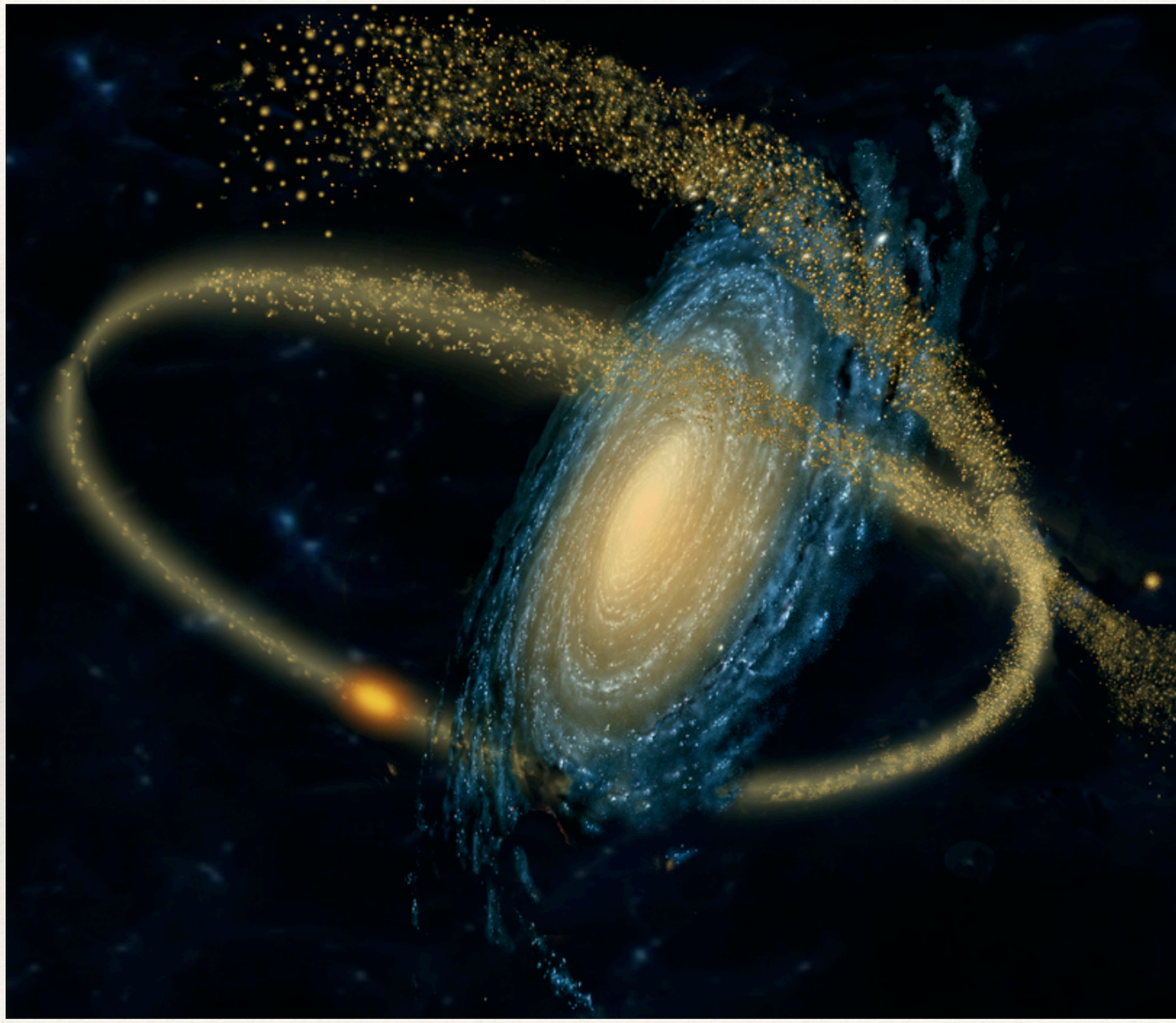
…some seem unconcerned

Dark matter indirect and direct detection

- Morselli
- Kay
- Laha
- Necib
- Hryczuk
- Liu
- Slatyer

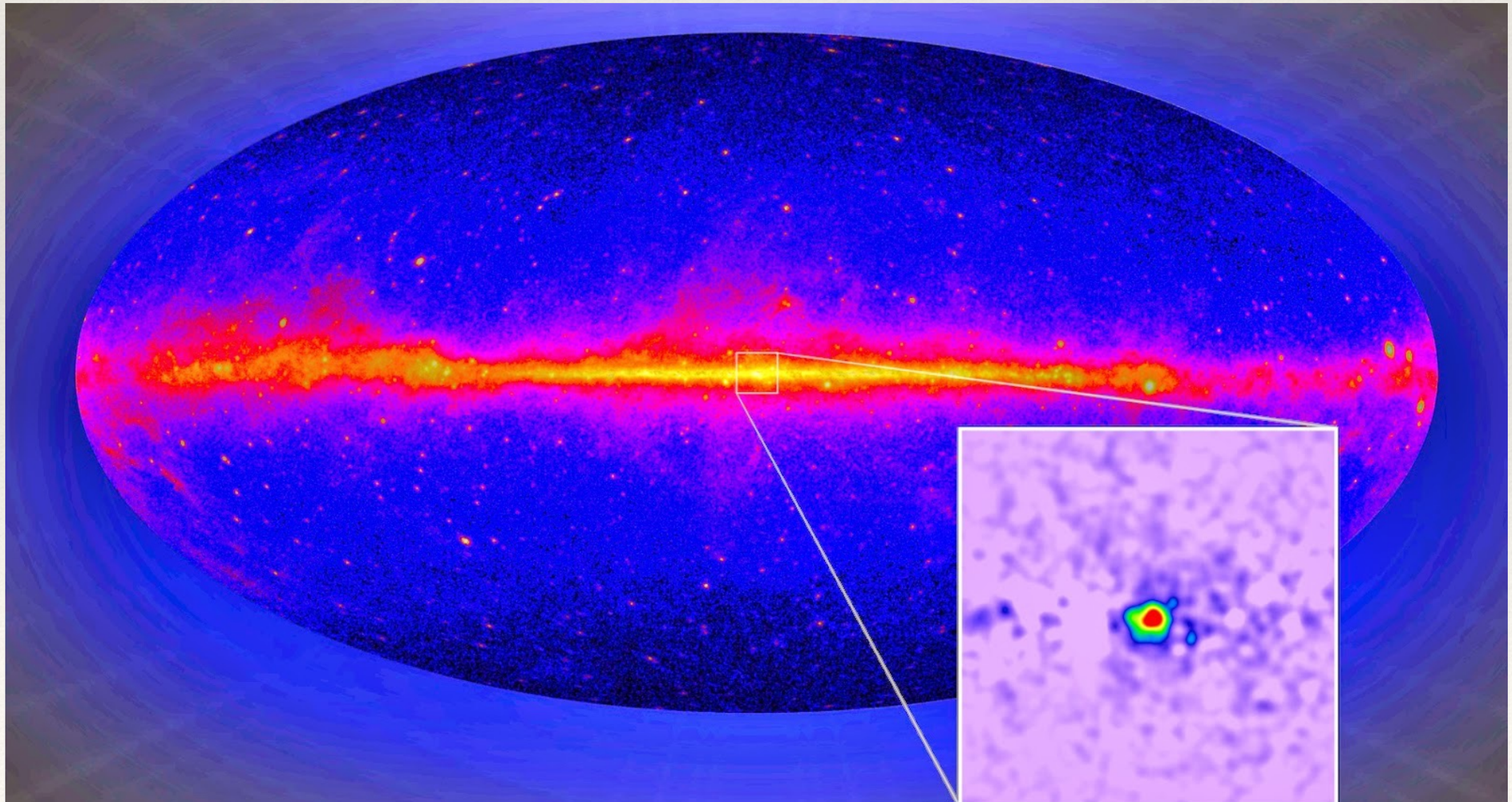
Lina Necib : Dark matter in the era of GAIA

- gaps in stellar streams constrain Galactic sub halo; ***stream GD1 has exciting gaps***
- we live right in the Gaia sausage
- 1% of stars close to disk plane are accreted



Dark matter indirect detection

- Morselli:
  - AGILE and *Fermi* now > decade old…*still going strong*
  - GCE seen by EGRET in 2004 *(?)*
  - CTA will reach WIMP thermal cross-section with GC observations…
  - ASTROGRAM — unfortunately not funded by ESO



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Dark matter indirect detection

- Mors
  - AG *strong*
- GC
- CT th GC ob
- AS ESO

Fermi collaboration:
~600 papers
~30k citations for cat 1

Quy Nhon 2020 Jean-Marc Casandjian

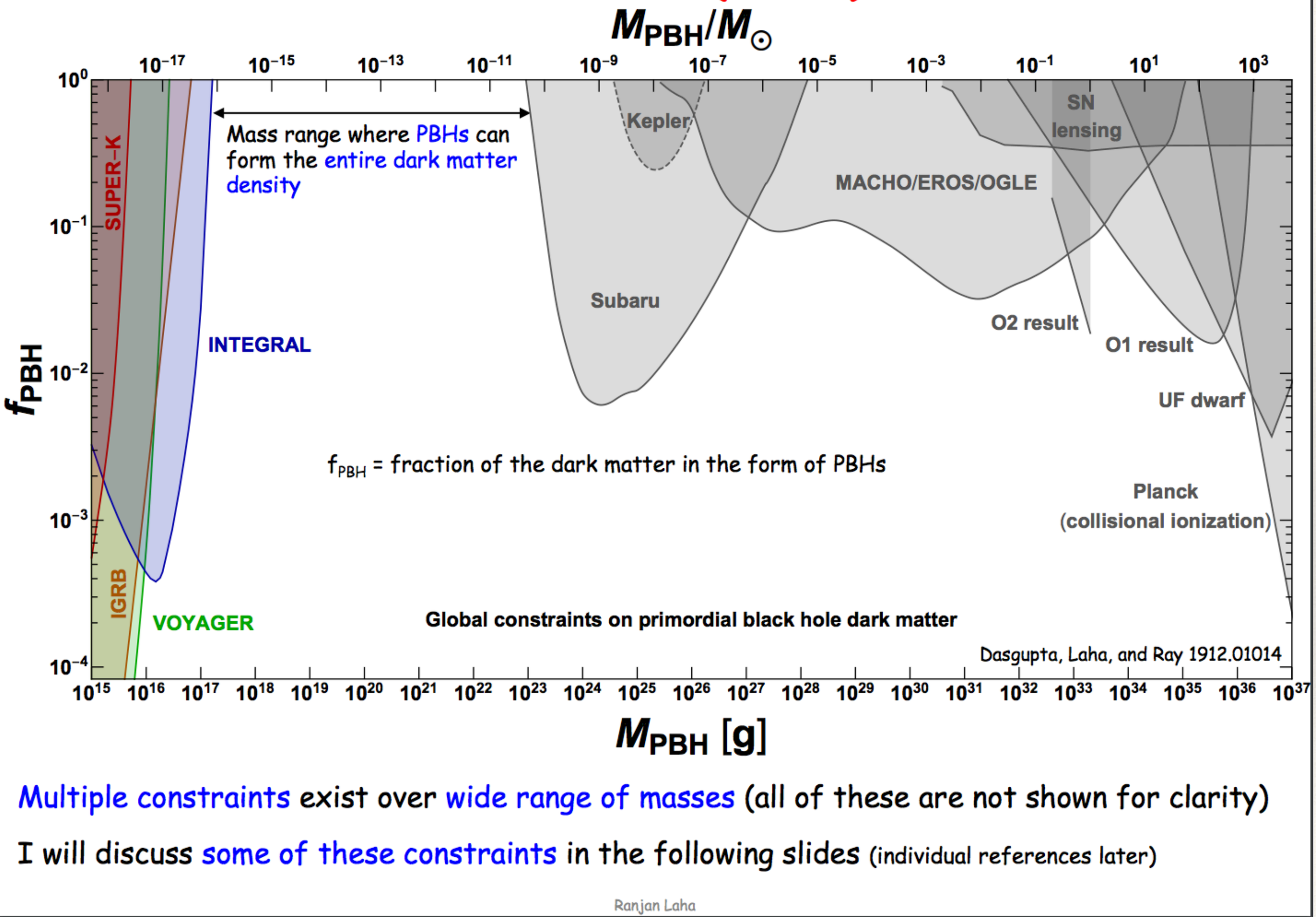
...my Kingdom for a soft gamma-ray telescope

(with good angular resolution and sensitivity)

Dark matter indirect detection

- Ranjan Laha: 511 keV emission limits the dark matter fraction in primordial black holes!
- 10^{17} - 10^{23} g window for PBH with $f_{DM} = 1$
- how to deal properly with limits in the case of a non-monochromatic PBH mass distribution?

Primordial black hole (PBH)dark matter



Multiple constraints exist over wide range of masses (all of these are not shown for clarity)

I will discuss some of these constraints in the following slides (individual references later)

Dark matter indirect detection

- Tracy Slatyer: the WIMP interpretation of the GCE is not dead
- … but morphology disfavours DM interpretation (my opinion)

Dark matter: WIMPs + alternatives

- Choi
- Bae
- Zurek
- Roszkowski

Dark matter: WIMPs + alternatives

- Ki-Young Choi: I can make massless neutrinos oscillate! (via interactions with a dark sector)
- Kathryn Zurek :
  - WIMP not dead but is “pressured”
  - move beyond nuclear recoils people!
  - target diversity is essential

Dark matter: WIMPs + alternatives

- Leszek Roszkowski:
- WIMP DM is NOT in trouble
- can we systematise the theory space of DM candidates? …NO :(
- large Higgs mass points to multi TeV SUSY scale

Time domain and multi-messenger

- Troja
- Schüssler
- Blaufuss
- Satalecka

Fabian Schüssler : Searches for GW counterparts at very-high energies

- long GRBs emit at TeV
- BNS generate short GRBs — but still expect (or hope for) TeV emission
- sensible to follow-up with IACTs, especially given emission is “long lasting” (do not need to catch prompt)
- deep MWL observation constraints: HESS upper limits + X-rays generate magnetic field lower limit for GW170817

Konstancja Satalecka : Follow-up programs of high-energy neutrino alerts

- TXS 0506+056 — only compelling evidence for individual neutrino source but ***several other intriguing candidates***
- TXS 0506+056 EM broadband + neutrinos: difficult to make purely hadronic model work; seem to need multi-zone but this might be supported by other data
- MAGIC looking for upcoming tau showers out of sea
- need for central body to regulate/coordinate alerts
- “desperately need an MeV telescope”
- vicious circle of open questions:
  - what are sources of cosmic neutrinos <-> how to optimise followup? how long to look? how fast to react? where to look?

Future experiments

- He
- Taiuti
- Knödlseder
- Lachaud
- Moiseev
- Gangler
- Tristram

Huihai He ：Status and First Results of the LHAASO Experiment

- Large high altitude air shower observatory, 1.3 km^2, altitude 4.4 km
- hybrid detection; scintillators, water tanks, pools with baffles, Cherenkov telescopes
- ***largest muon detector yet built by humans***
- USD 70M, finished by 2021
- goals:
  - origin GCRs ; composition and energy spectrum 10^13-10^18 eV
  - gamma-ray astronomy
  - new physics frontier
- 100 TeV: angular resolution ~ 0.3 degrees
- prelim results
  - 3 sources now seen at > 6\sigma at ~100 TeV
  - seen a 470 TeV probable gamma-ray event — ***highest energy photon yet detected by humans***

Jürgen Knödlseder : The Cherenkov Telescope Array

- 10 x sensitivity existing instruments
- arcmin angular resolution
- 10% energy resolution
- CTA as observatory, run by professional operators
- phase 1 construction to start late 2020; operations start 2025, phase 2
- silicon photomutilipliers for SSTs
- challenge to synchronise partners (cat herding)
- SST design settled, MST design settled this year
- FITS format data; data public after 1 year proprietary period
- transformational observatory / 30 year lifetime,

Alexander Moiseev : New Mission Concept: Compton Telescope with Coded Aperture Mask Galactic Centre Explorer

- need arcsin spatial resolution
- goal: reach “bottom” of the GC gamma-radiation or actual diffuse emission after subtraction of true sources
- 25% of 4FGL sources no association; 60% unassociated in GC — what are they?
- need coded aperture mask to achieve arcmin resolution
- idea of deployable mask

Soapbox

The Galactic Centre: a good place to seek dark matter?

- High dark matter density should mean that the Galactic Centre is one of the best places in the sky to seek indirect evidence of its annihilation (Bergström+97)

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The Galactic Centre: a good place to seek dark matter?

- High dark matter density should mean that the Galactic Centre is one of the best places in the sky to seek indirect evidence of its annihilation (Bergström+97)
- Researchers motivated to search for anomalous signals from the GC that are potential dark matter signatures have done remarkably well in turning up such signals
- On the other hand, the Galactic Centre is a quite different environment to the rest of the Galaxy
    - home of the Galaxy's supermassive black hole
    - very intense star formation around the BH
    - ancient stellar population in the Galactic Bulge

Many Remarkable Non-Thermal Phenomena of the GC/Inner Galaxy:

- (Quasi) point-like GeV and TeV γ-ray source coincident with Sgr A*
- Extended (few degrees) GeV & TeV emission
- Non-Thermal Radio (and X-ray) Filaments (NTFs)
- 130 GeV 'line'
- ~GeV γ-ray spectral bump 'GC Excess'
- 511 keV positron annihilation line
- Non-thermal microwave 'haze'
- Fermi Bubbles

small scales

→ LARGE SCALES

Many Remarkable Non-Thermal Phenomena of the GC/Inn… Galaxy:

- (Quasi) point-like GeV and TeV γ-ray source … A*
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- … microwave 'haze'
- … Bubbles

Every one of these has been claimed as a possible dark matter signature

small scales → LARGE SCALES

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small scales

→ LARGE SCALES

In summary…

- The GC remains perhaps the best-motivated place in the sky to search for indirect dark matter signals
- But in astrophysical terms, the GC is also a peculiar and remarkable environment within the Galaxy
- To best constrain dark matter, ***we need to understand the astrophysical foregrounds*** very well

My most important job…

Thank-you very much to Emmanuel and the SOC for organising a very stimulating conference!

See you all at the next conference!

Extra Slides

Galactic Centre Dark Matter(?)

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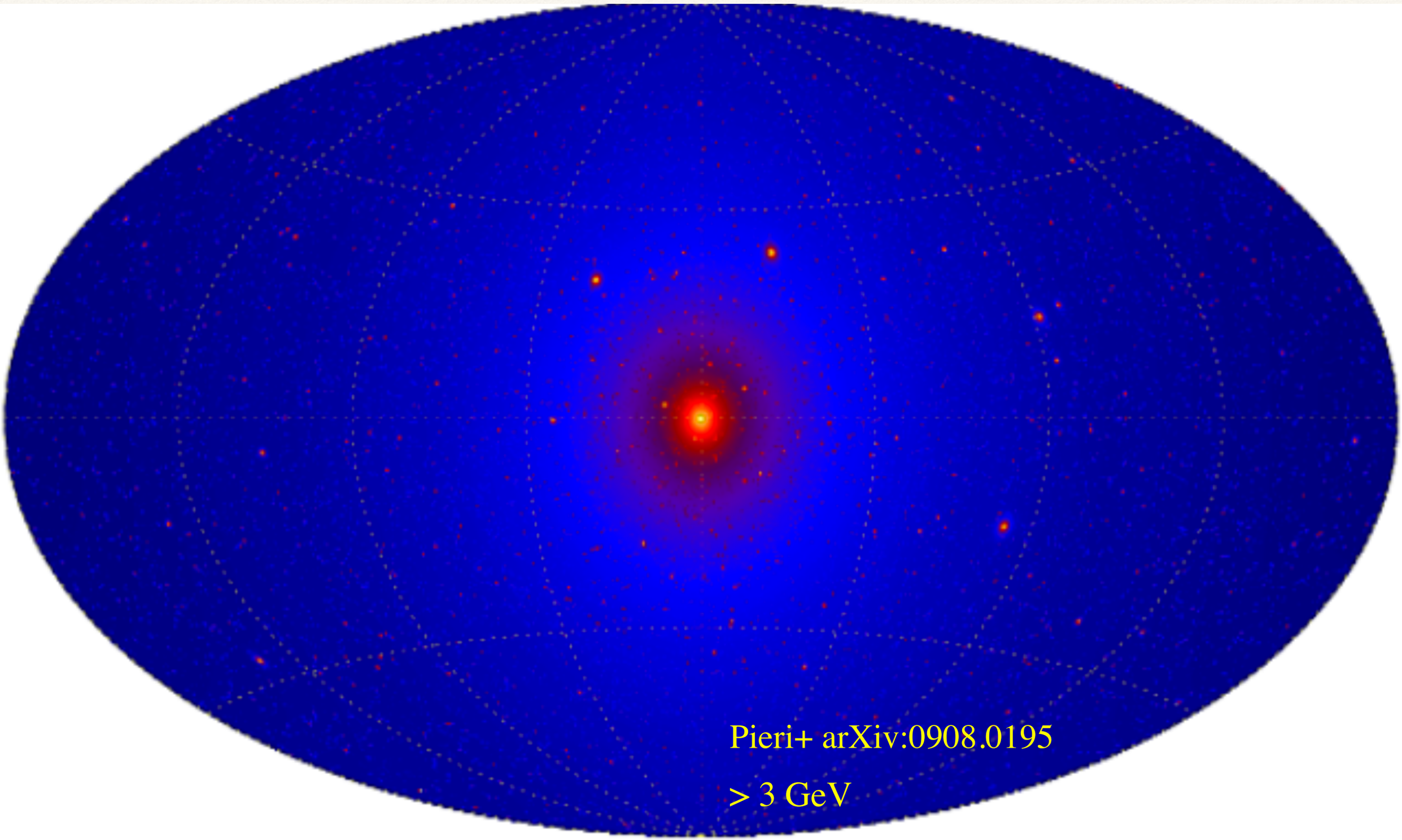
- But, historically, many such signals have either evaporated or come to be understood as likely or definitely astrophysical in origin…
- Turning this around: to credibly claim dark matter indirect detection on basis of GC observations, need to understand astrophysical backgrounds very well

Preface: why is the Galactic Centre interesting for (e.g.) a particle physicist?

- High dark matter density should mean that the Galactic Centre is one of the best places in the sky to seek indirect evidence of its annihilation (Bergström+97)


Pieri+ arXiv:0908.0195
> 3 GeV

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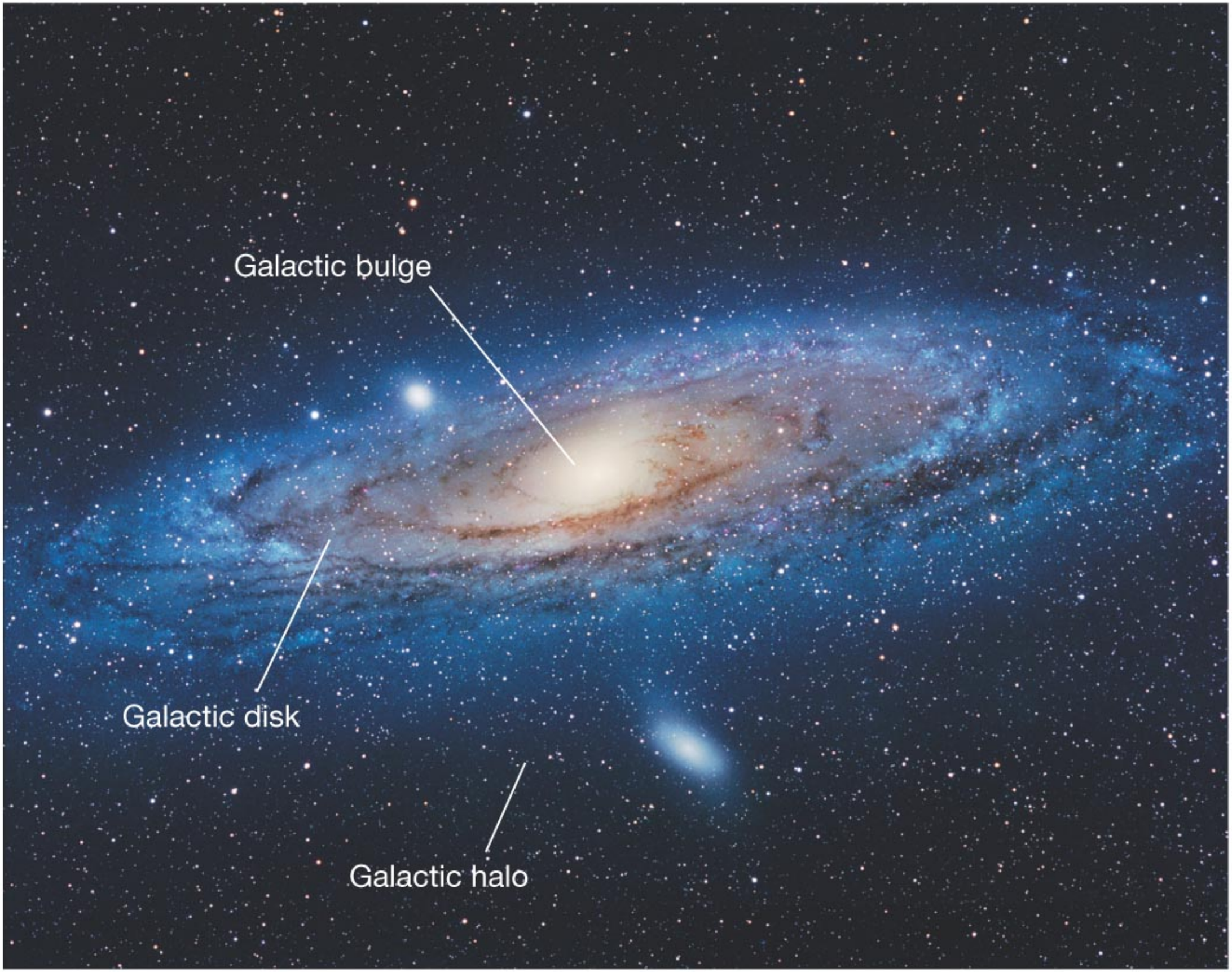

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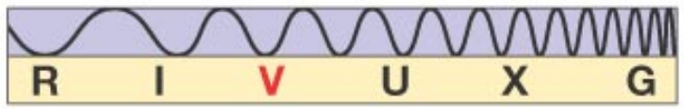

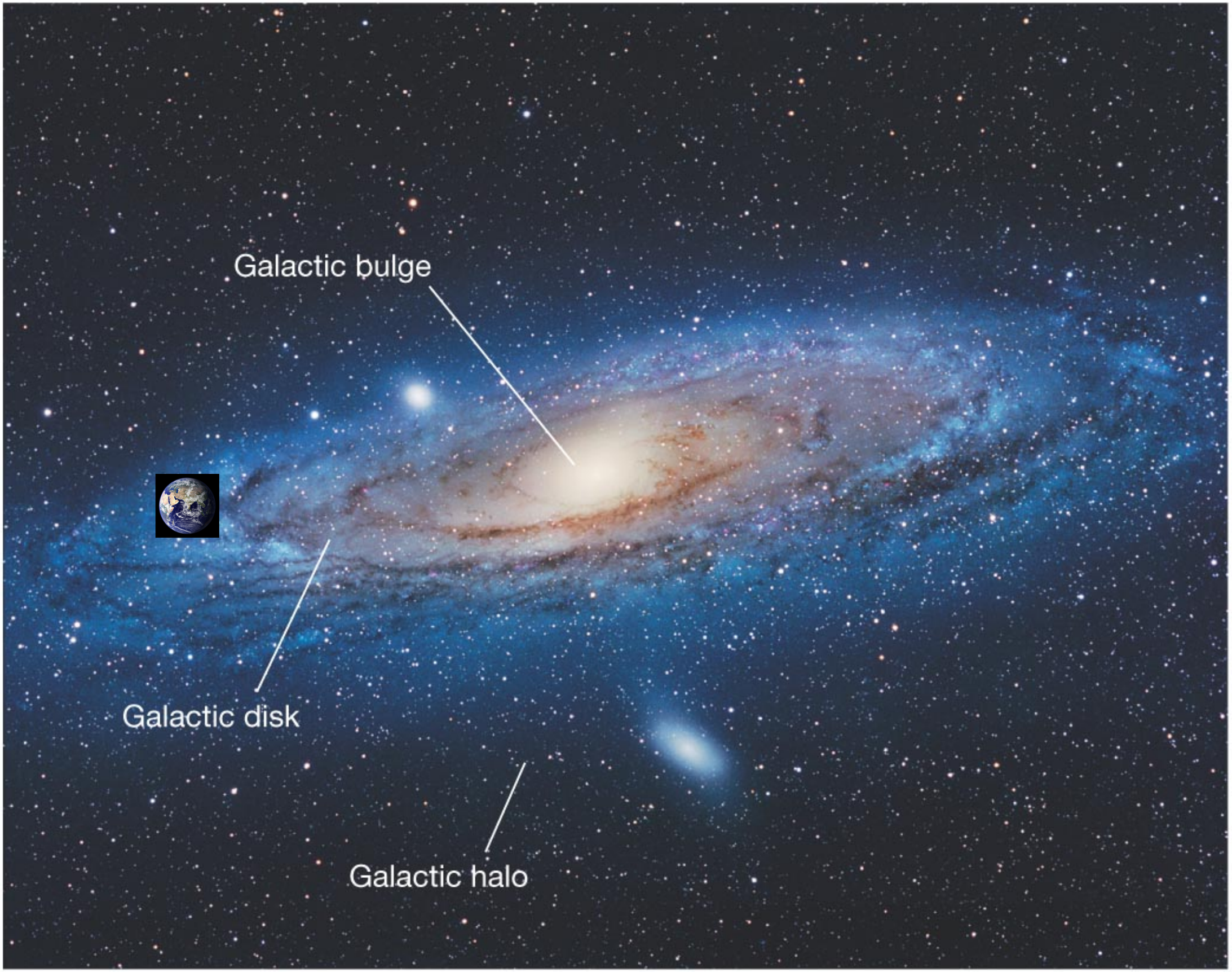

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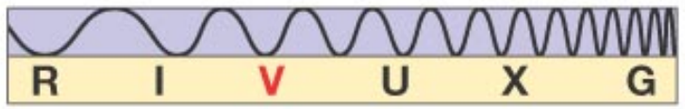

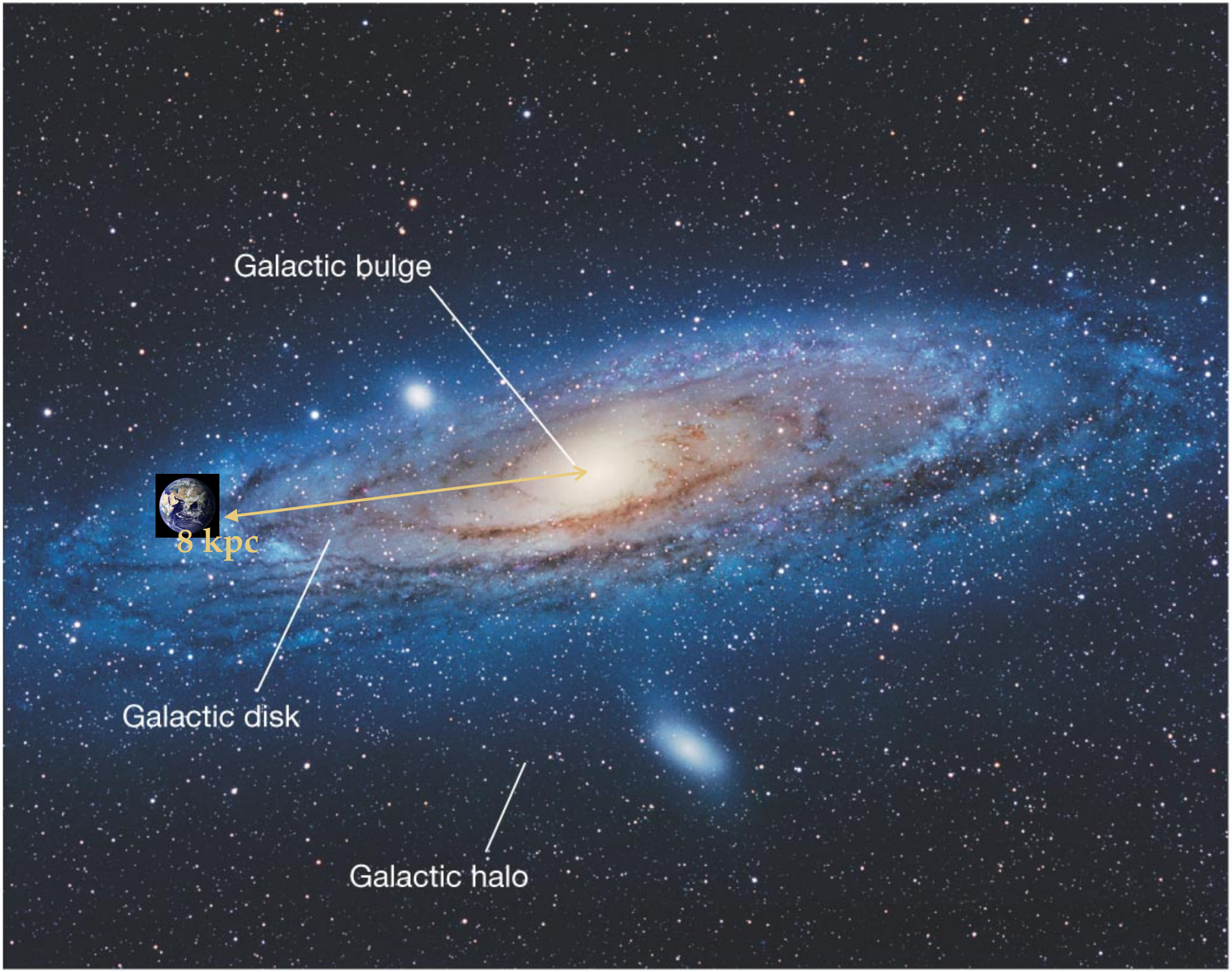

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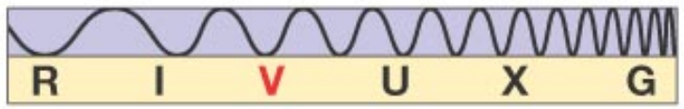

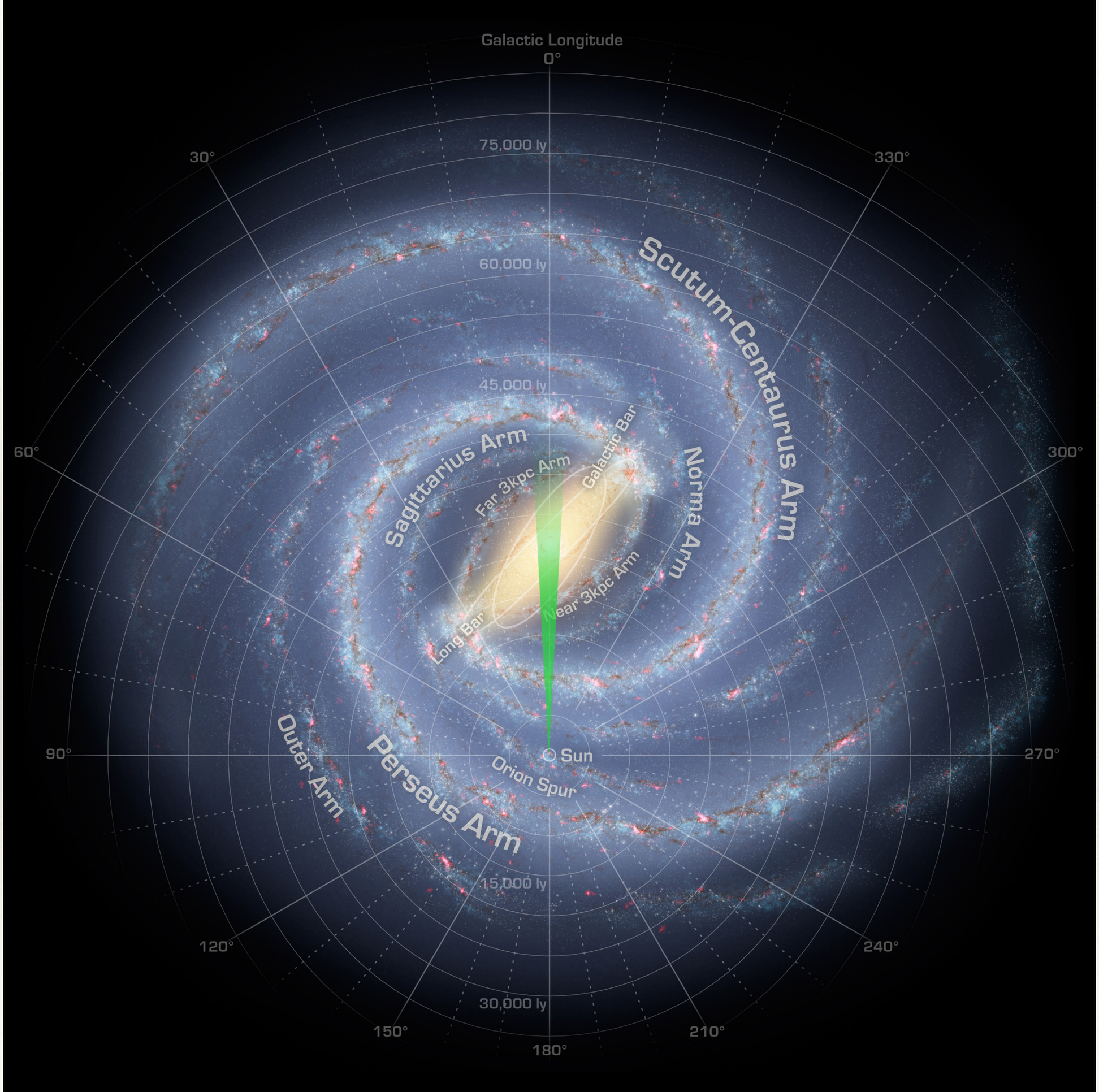
Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
30,000 ly
15,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Far 3kpc Arm
Near 3kpc Arm
Galactic Bar
Long Bar
Sun
Orion Spur


ESO

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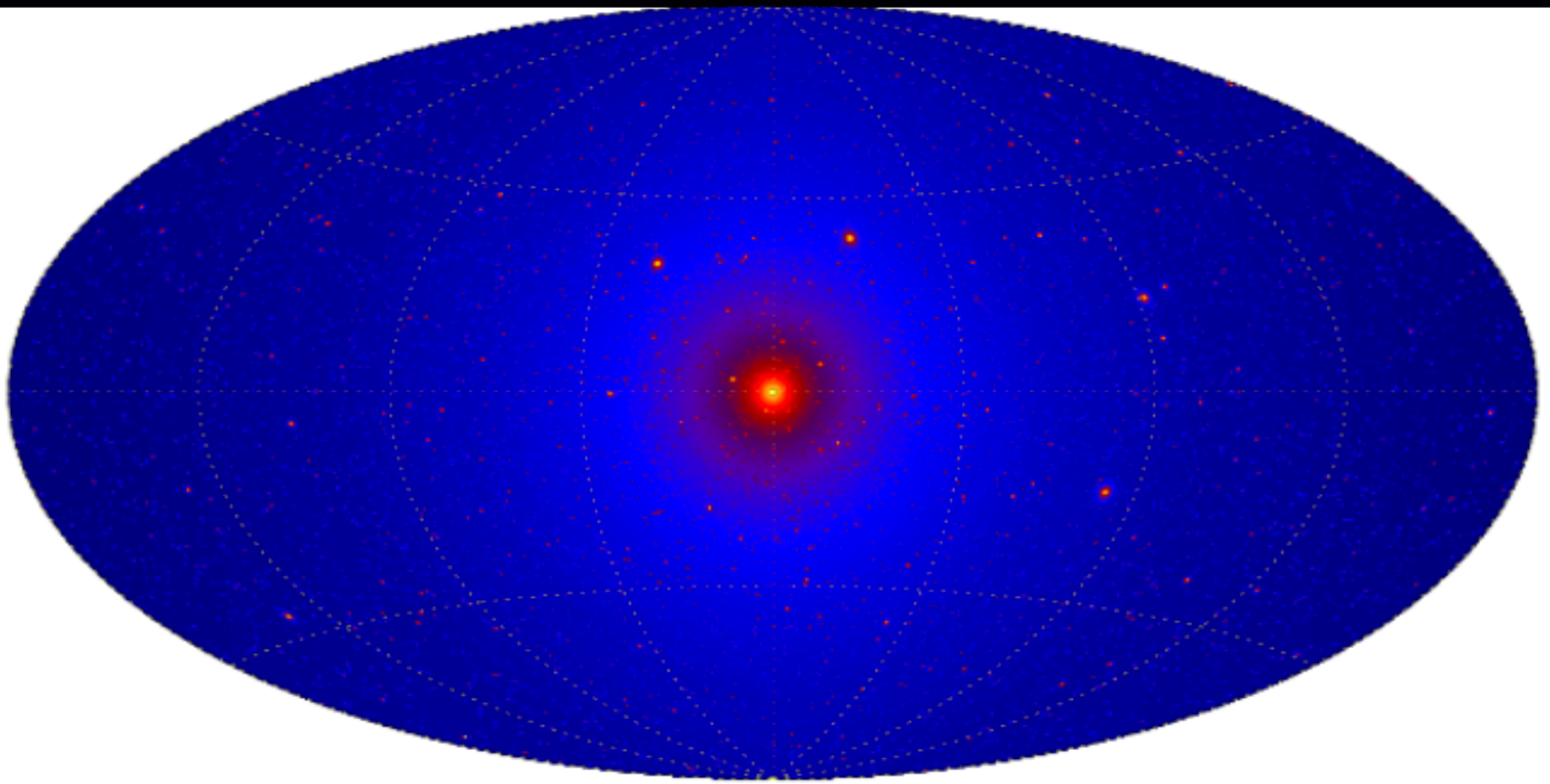
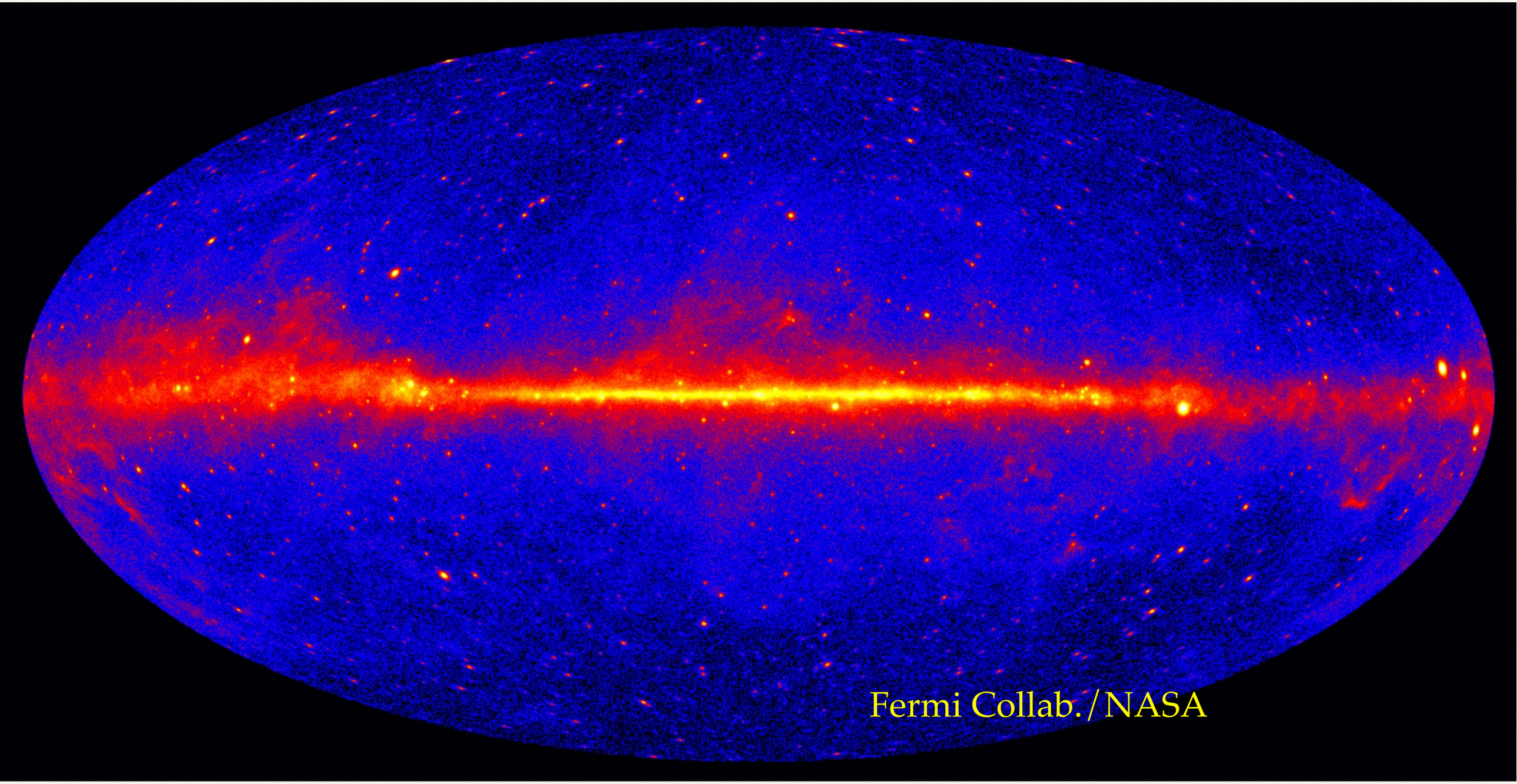
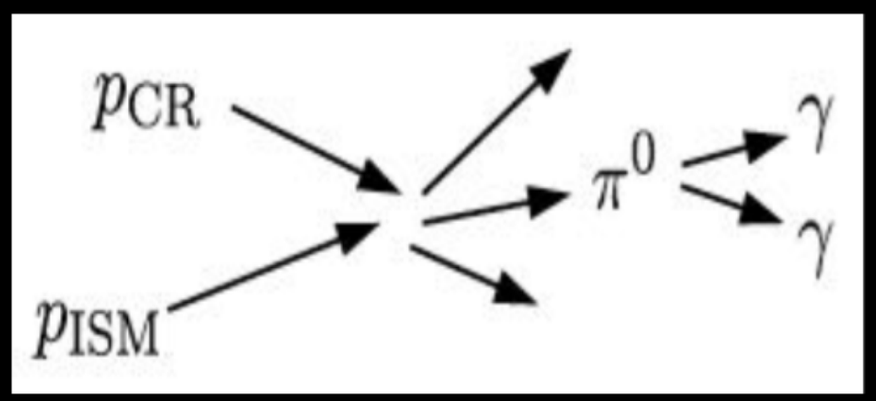


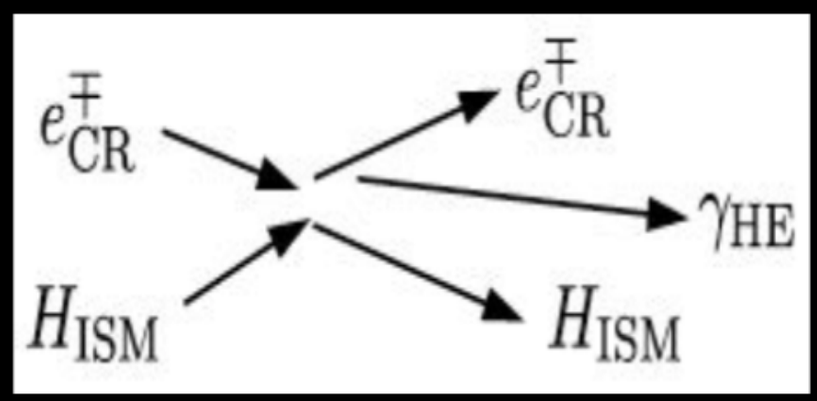

Fermi Collab./NASA

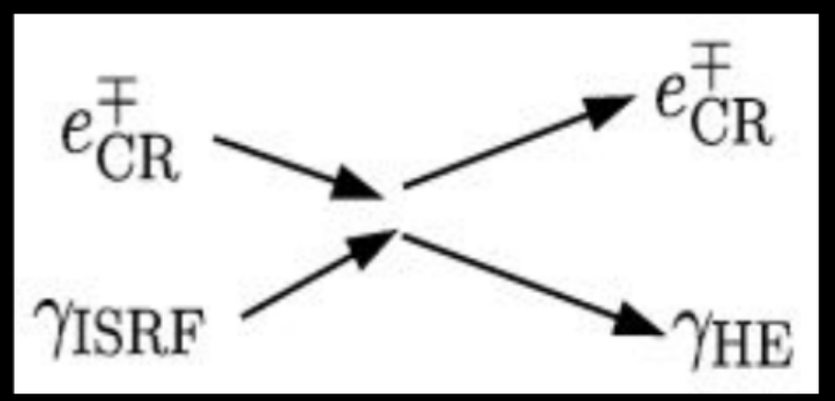
Decay of neutron pions

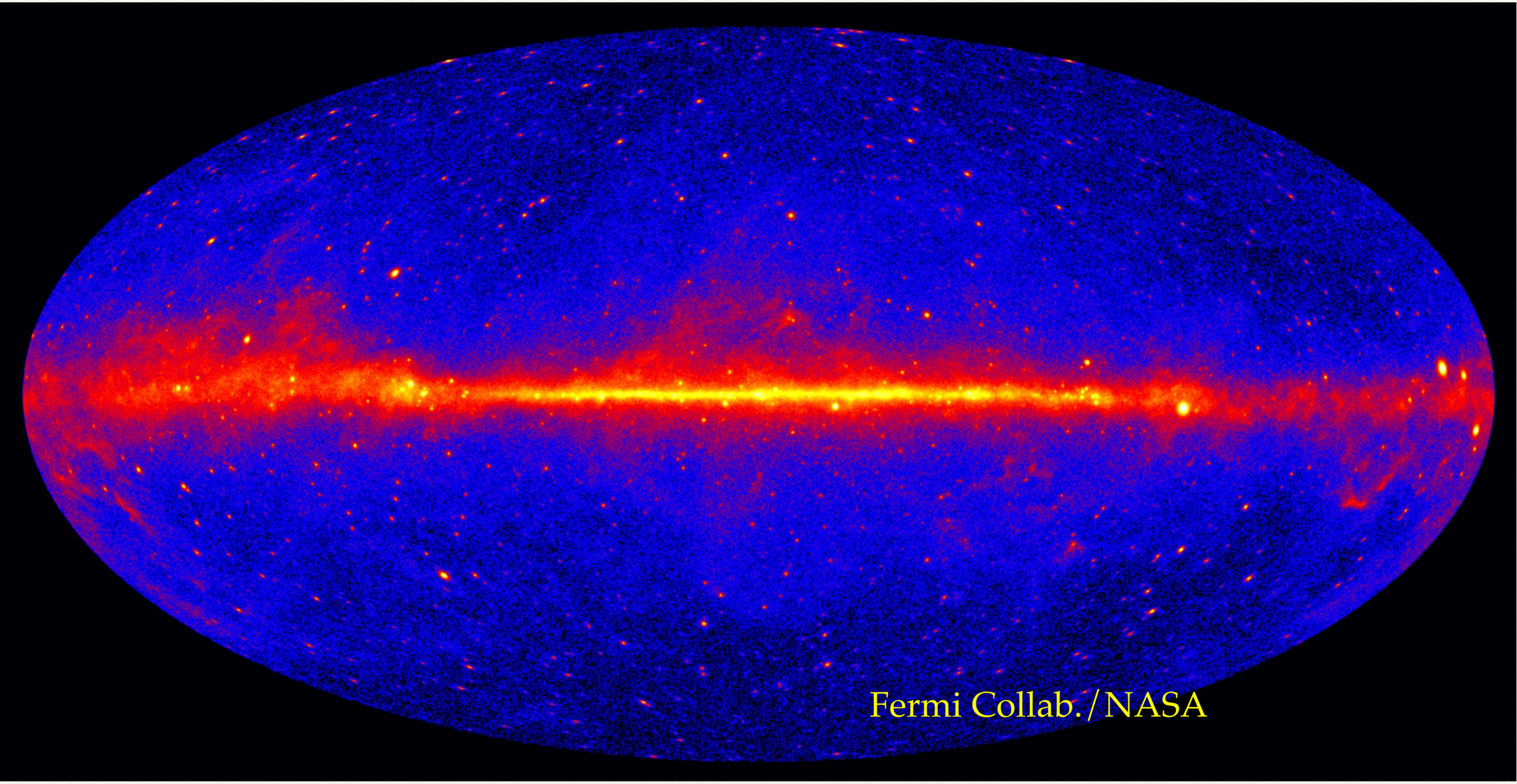
Bremsstrahlung

Inverse Compton





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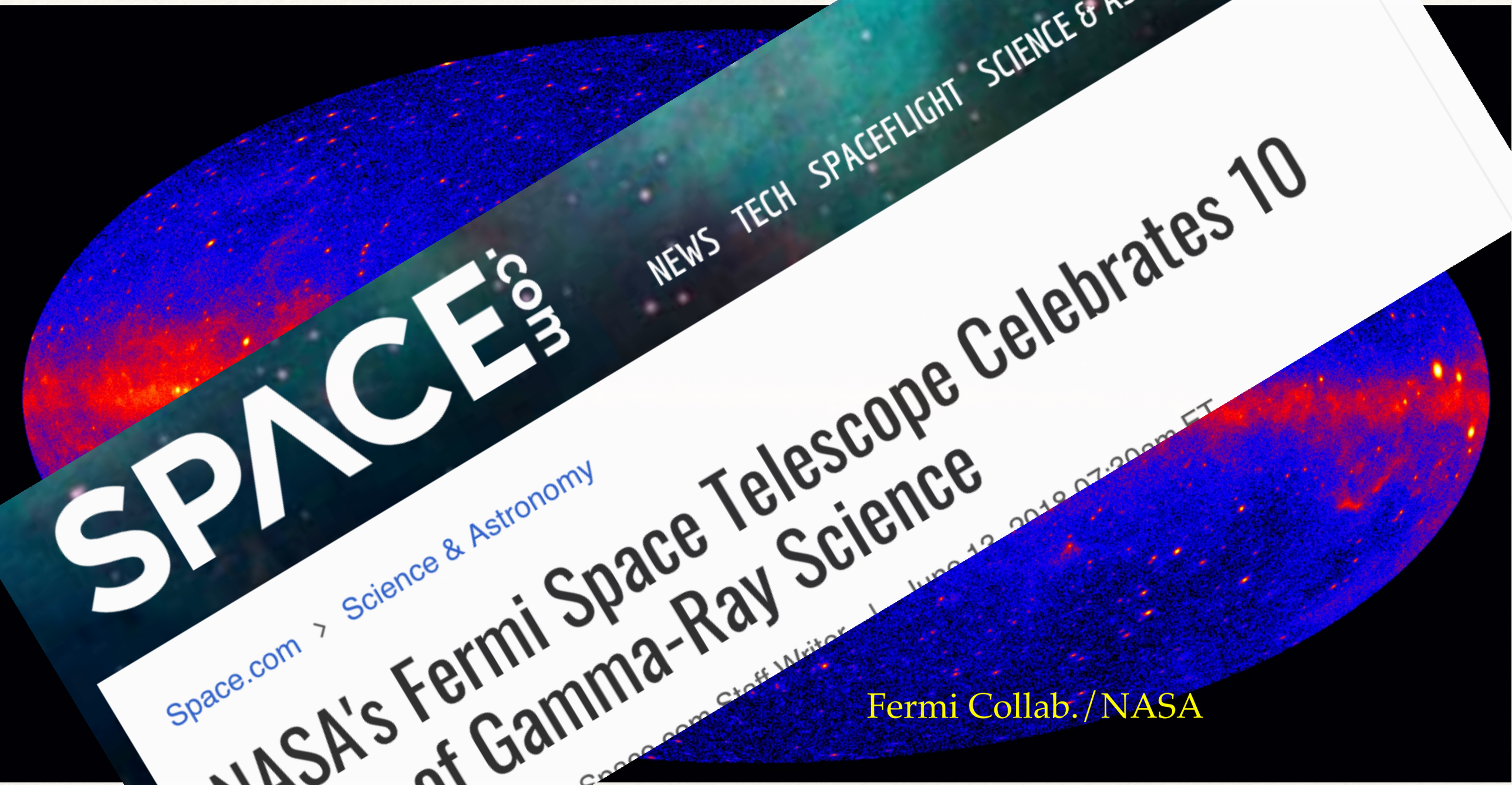
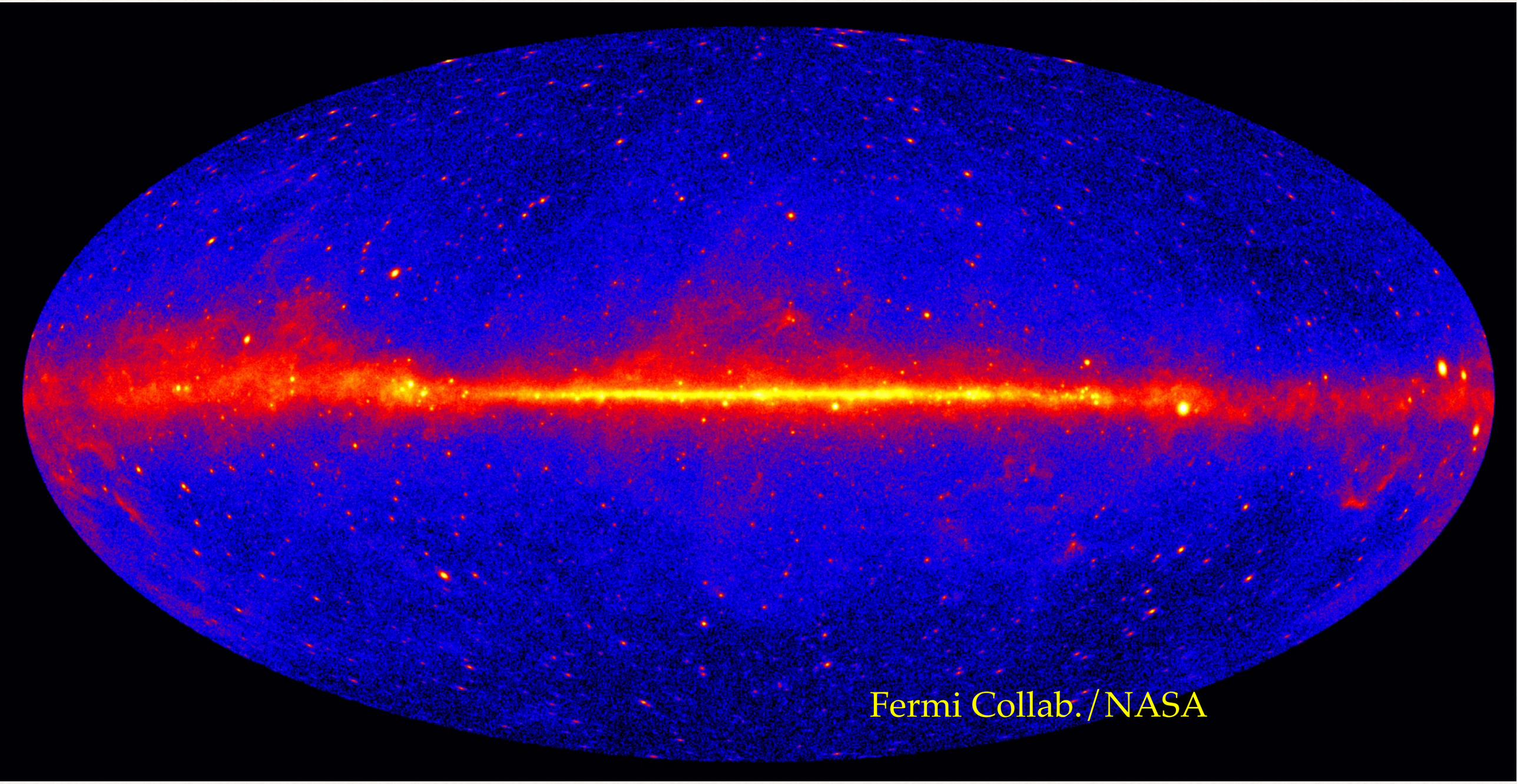


Fermi Collab. / NASA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- There's a lot of Galaxy between us and the GC
- Moreover, the Galactic Centre is a quite different environment to the rest of the Galaxy: astrophysical backgrounds are not only strong but also *poorly understood*

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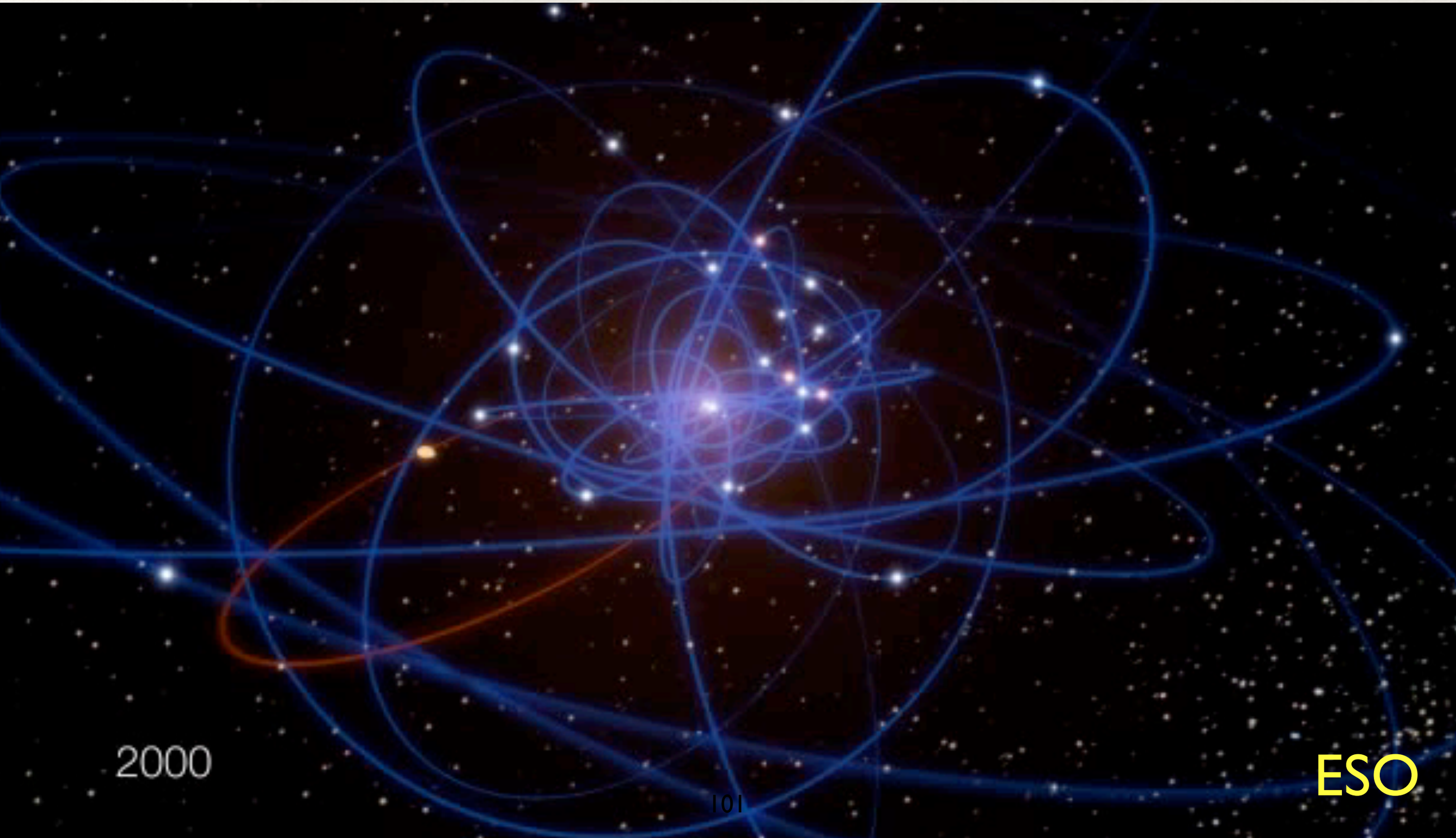
However: the GC *certainly* does contain dark matter: there is a 4 Million Solar Mass chunk at the Galaxy's dynamical centre…



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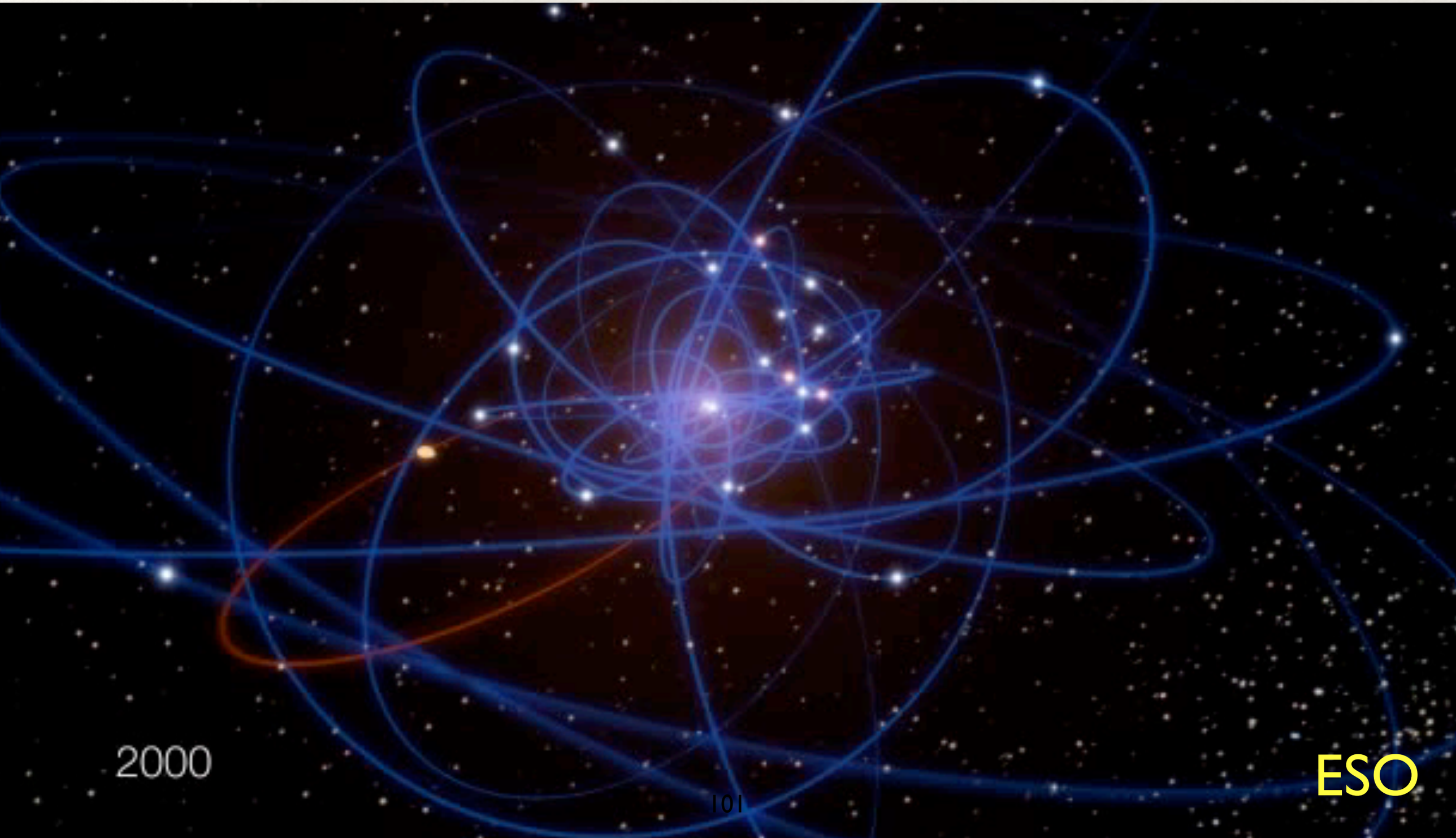

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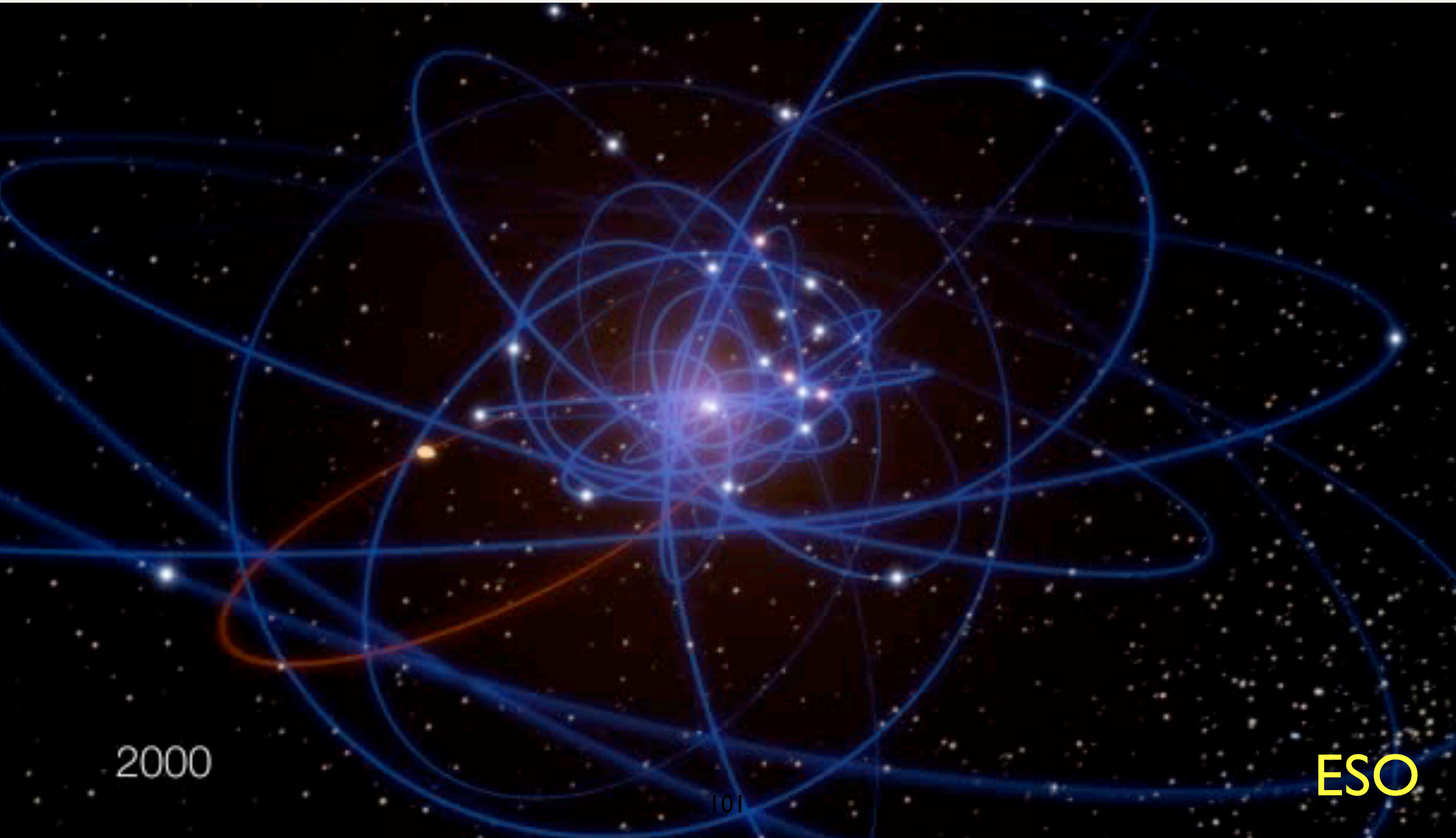

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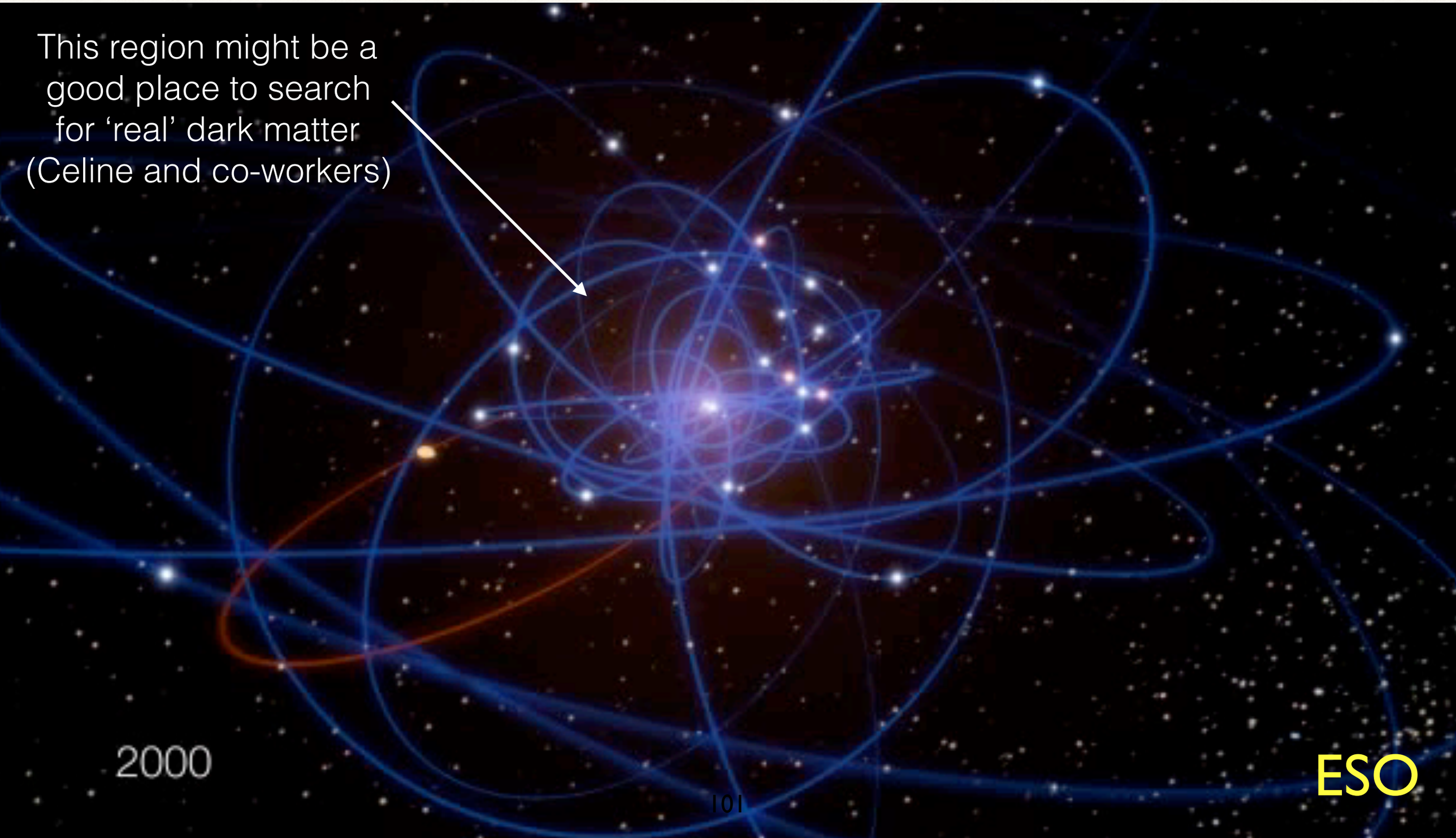

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