Electromagnetic Counterparts to Gravitational Waves

Illustrated by: Dr. Jessie Berta-Thompson

Wen-fai Fong

University of Arizona

Einstein Fellows Symposium
Harvard/CfA
10.19.2016

Saguaro National Park West, Tucson, AZ (Jan 2016)

Electromagnetic Counterparts to Gravitational Waves

Wen-fai Fong
University of Arizona

Einstein Fellows Symposium
Harvard/CfA
10.19.2016

merger

short gamma-ray burst

compact object binary (NS-NS/NS-BH)

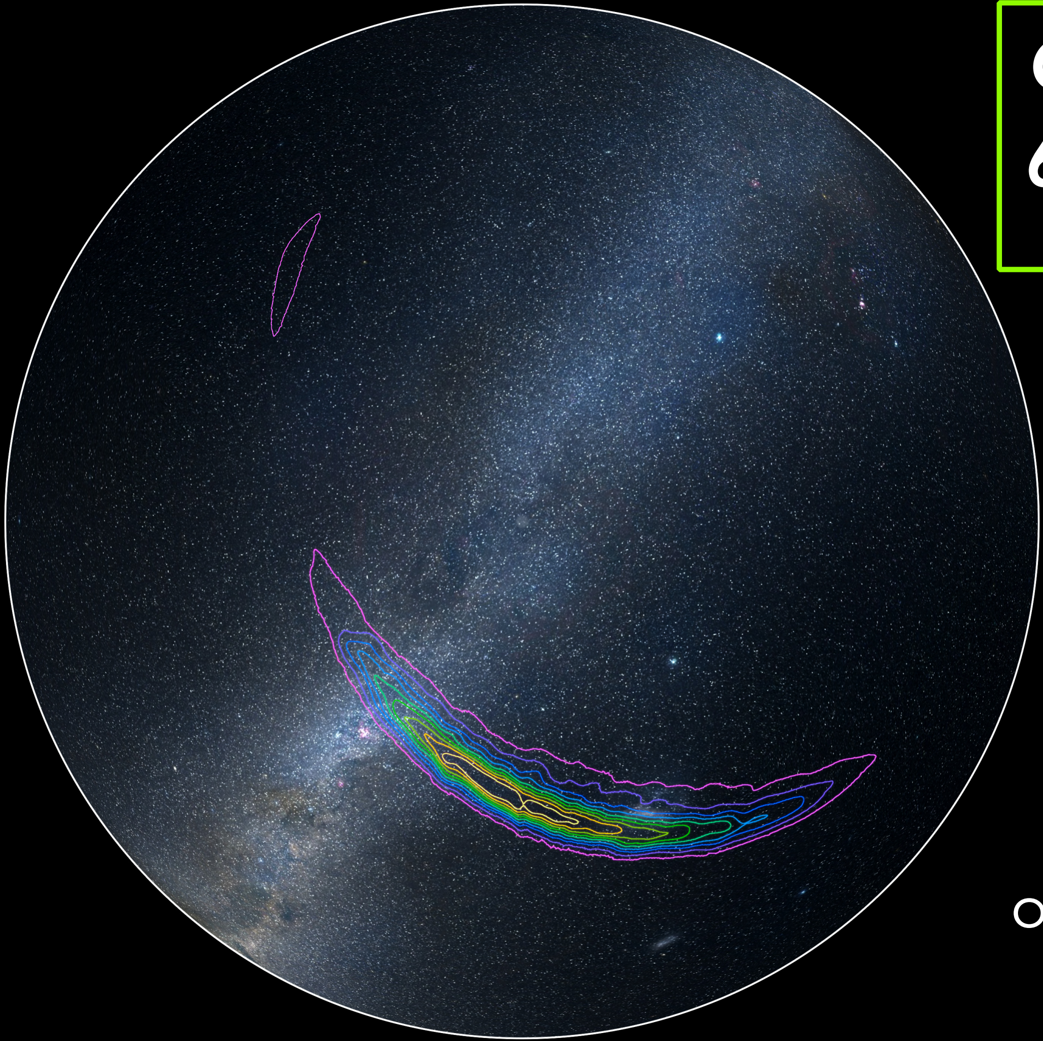
Illustrated by: Dr. Jessie Berta-Thompson

Credit: Astronomy Picture of the Day, Feb 7 2016

Advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) Sept 2015+

Gravitational waves only

~10-100's of sq. degrees



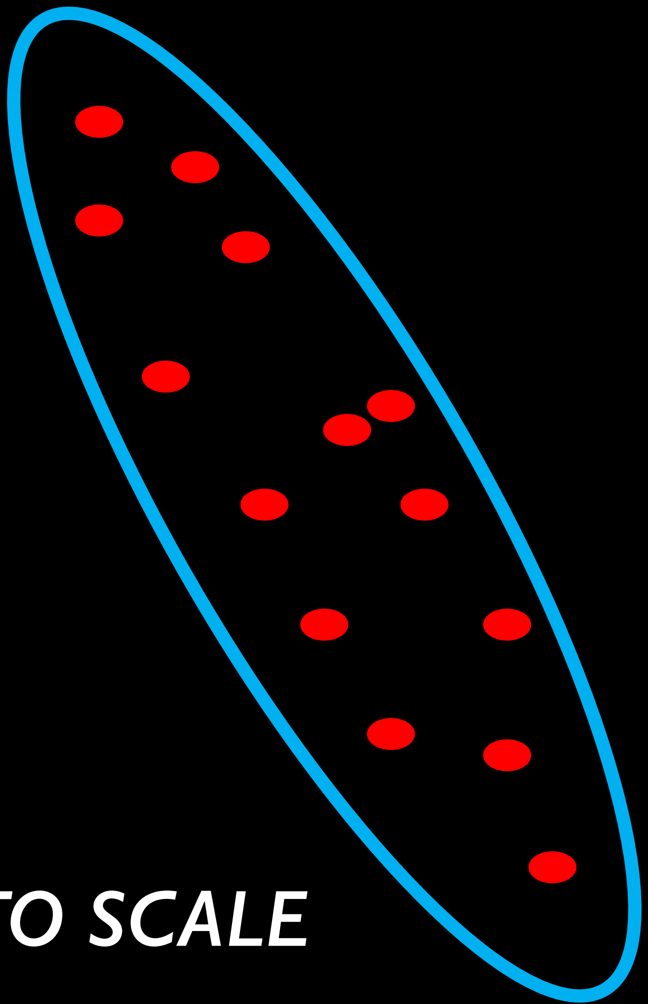
GW150914
630 sq. deg.
Abbott et al. 2016

Other localization papers:
Nissanke et al. 2011
Abbott et al. 2013
Rodriguez et al. 2014

Image Credit: LIGO/Axel Mellinger

Gravitational waves only

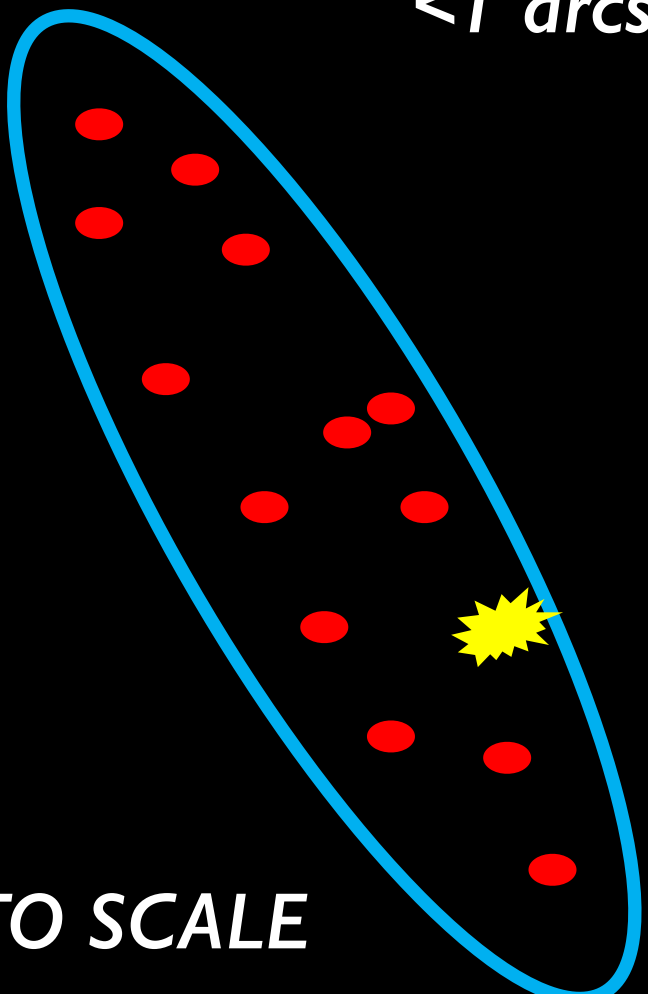
~10-100's of sq. degrees



NOT TO SCALE

Gravitational waves +
Electromagnetic counterpart

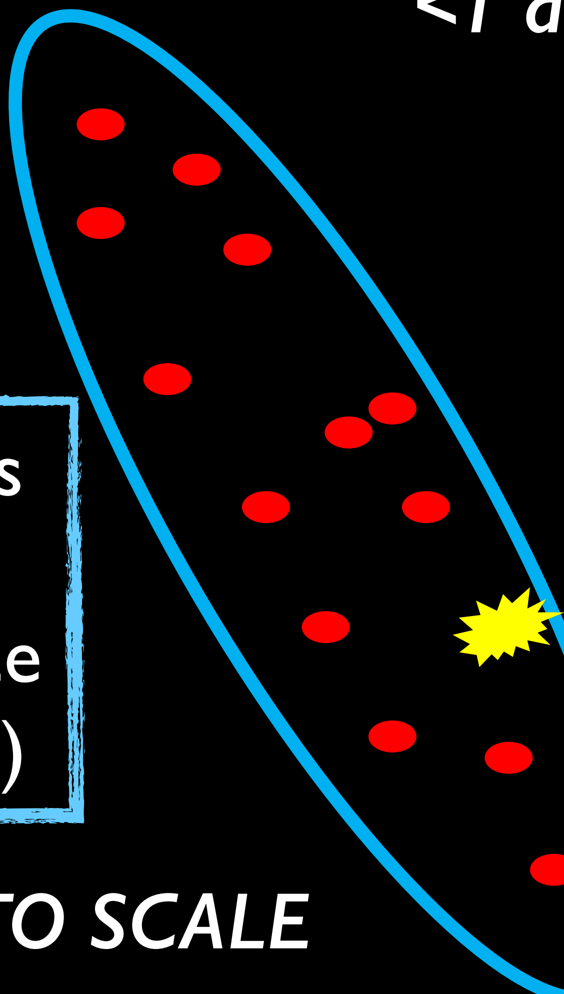
<1 arcsecond



NOT TO SCALE

Gravitational waves +
Electromagnetic counterpart

<1 arcsecond



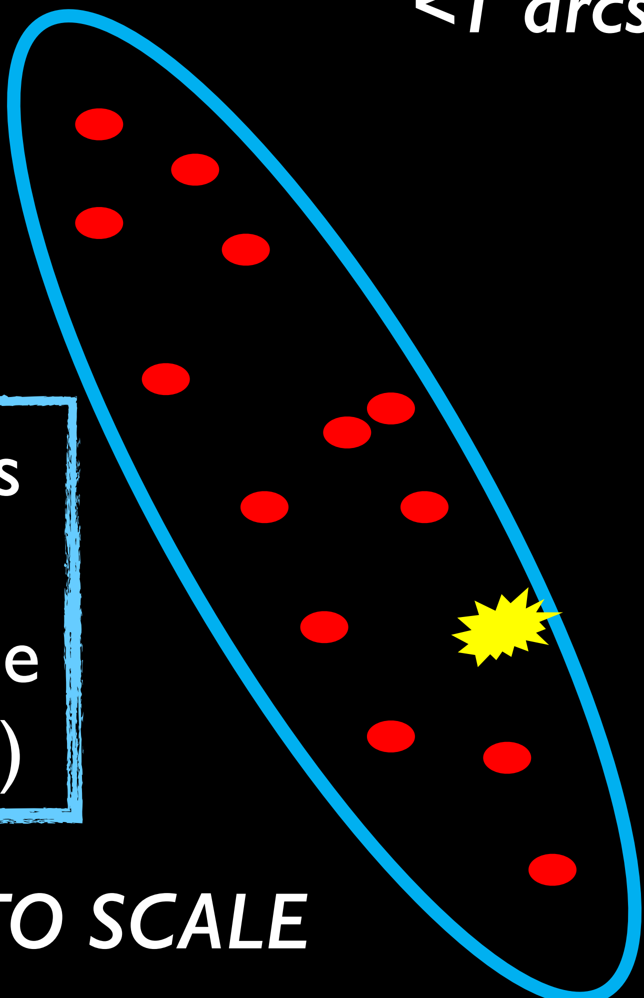
masses
spins
distance
(~30%)

NOT TO SCALE

Gravitational waves +
Electromagnetic counterpart

<1 arcsecond

masses
spins
distance
(~30%)



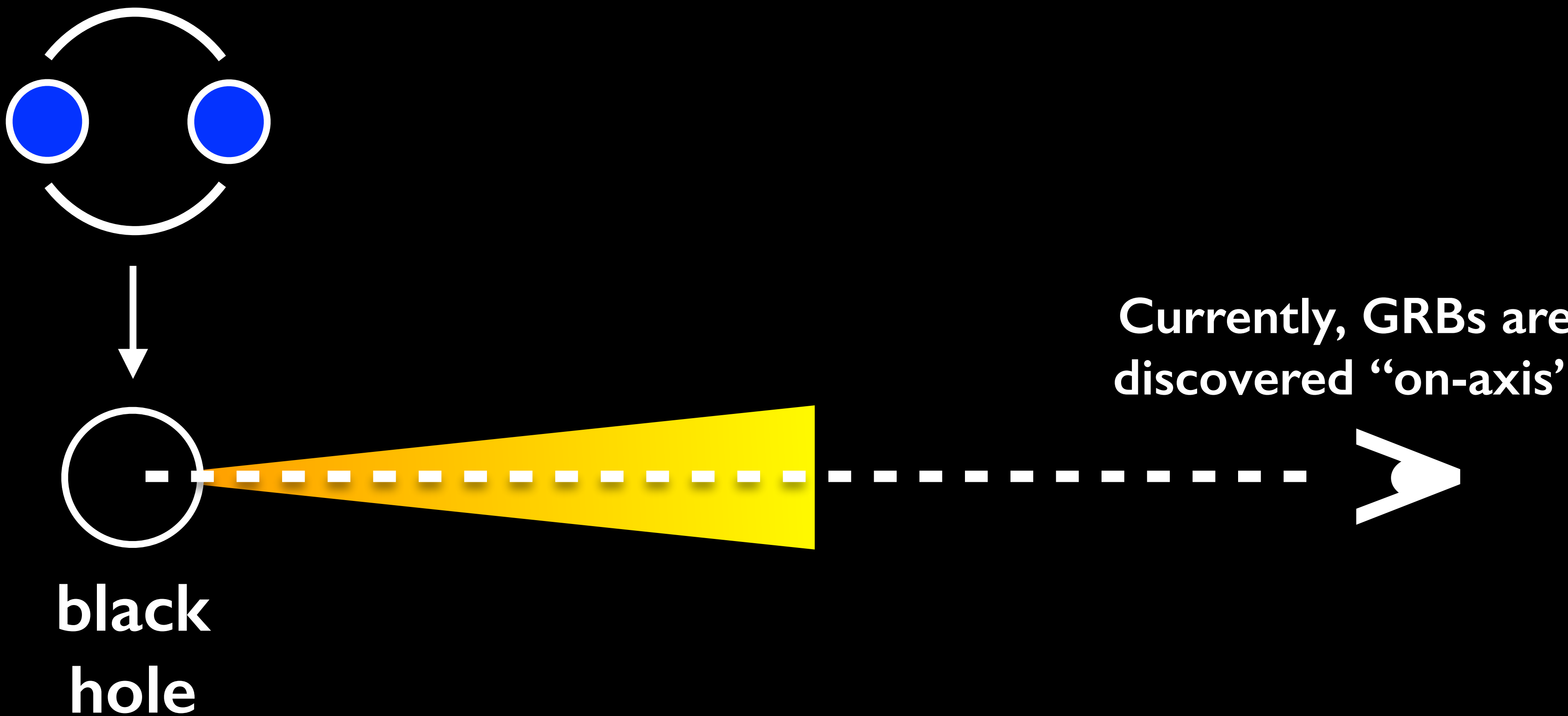
precise localization
redshift
host galaxy
ejecta composition
CONTEXT!

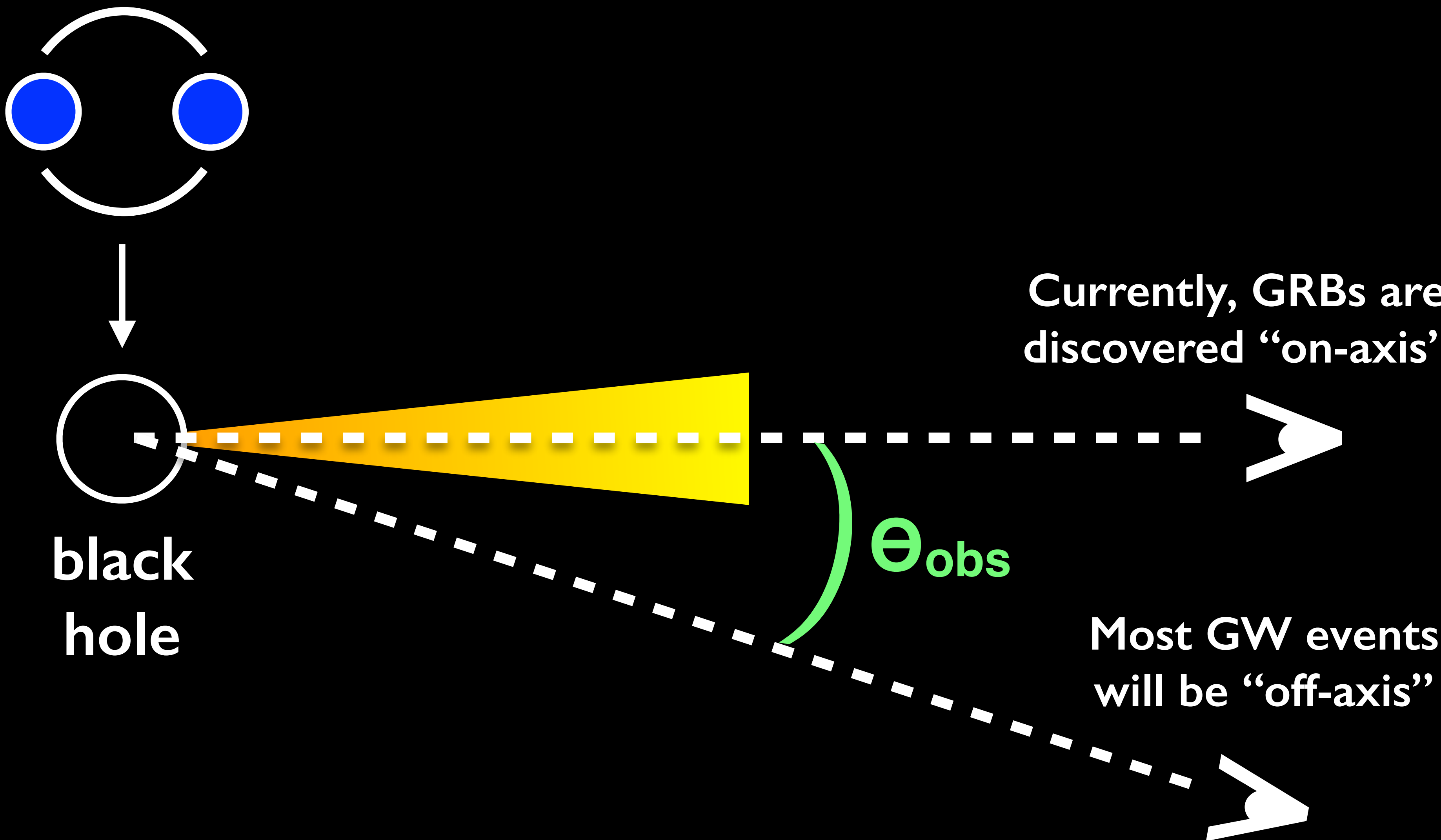
NOT TO SCALE

Key Questions for Detection

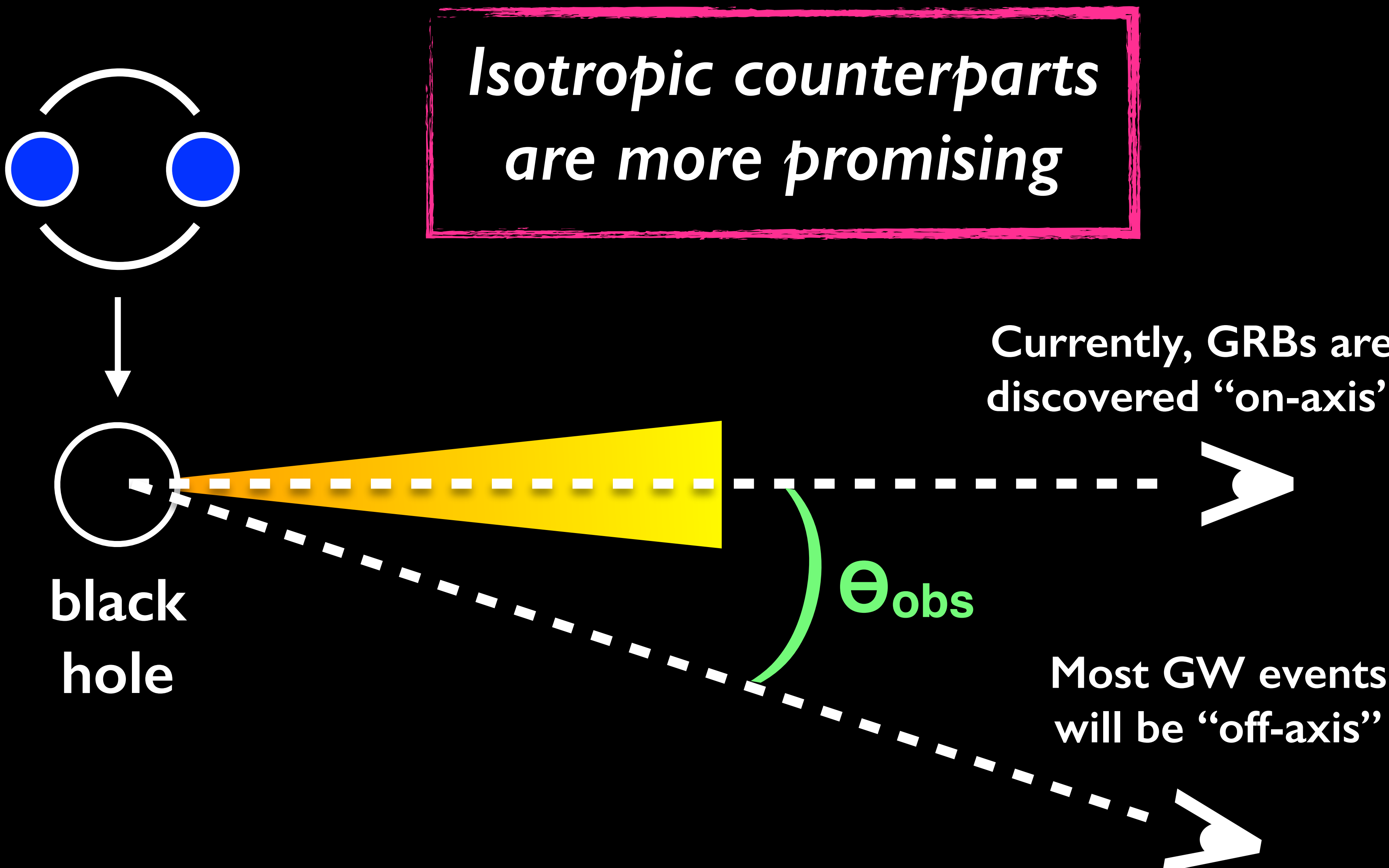
What is the most promising electromagnetic counterpart?

What constraints can we place at present?

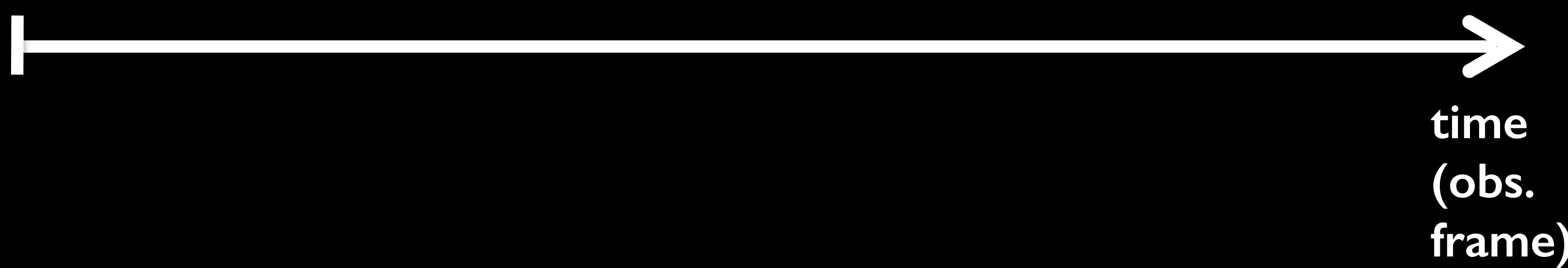

black
hole
Currently, GRBs are
discovered "on-axis"



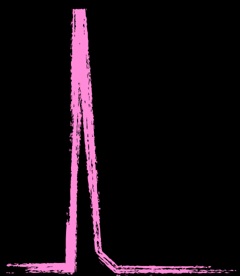
black hole
Currently, GRBs are discovered "on-axis"
θobs
Most GW events will be "off-axis"


Isotropic counterparts
are more promising
Currently, GRBs are
discovered "on-axis"
black
hole
θobs
Most GW events
will be "off-axis"

A plethora of potential EM counterparts



A plethora of potential EM counterparts



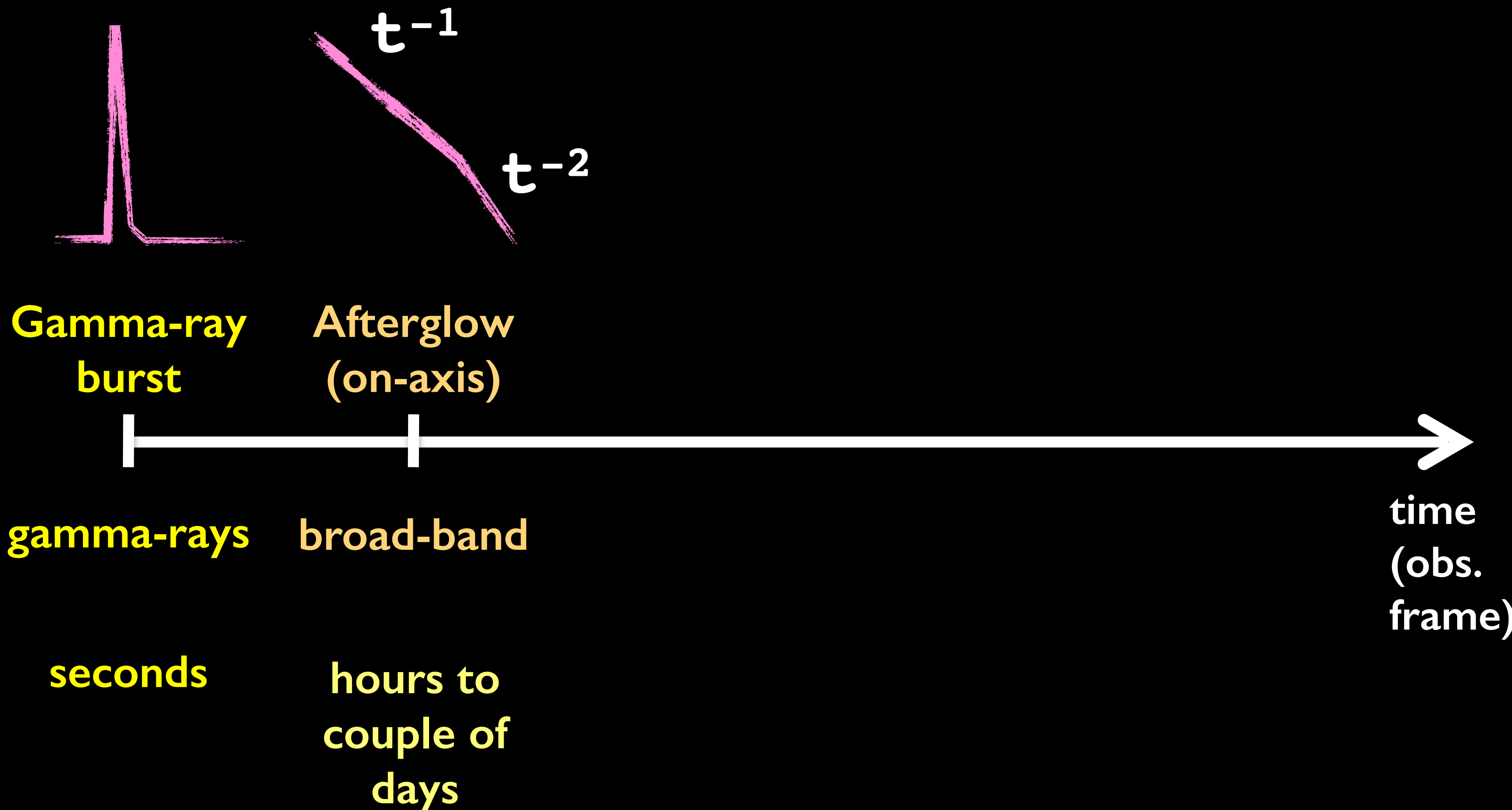
Gamma-ray
burst

gamma-rays

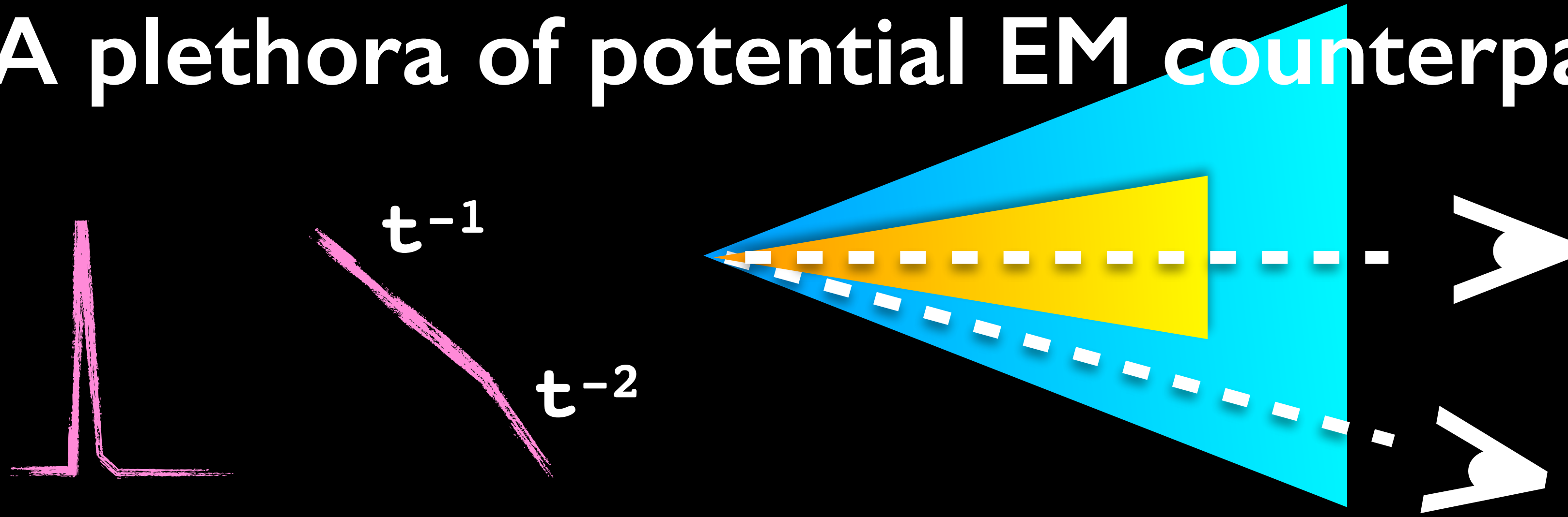
seconds

time
(obs.
frame)

A plethora of potential EM counterparts

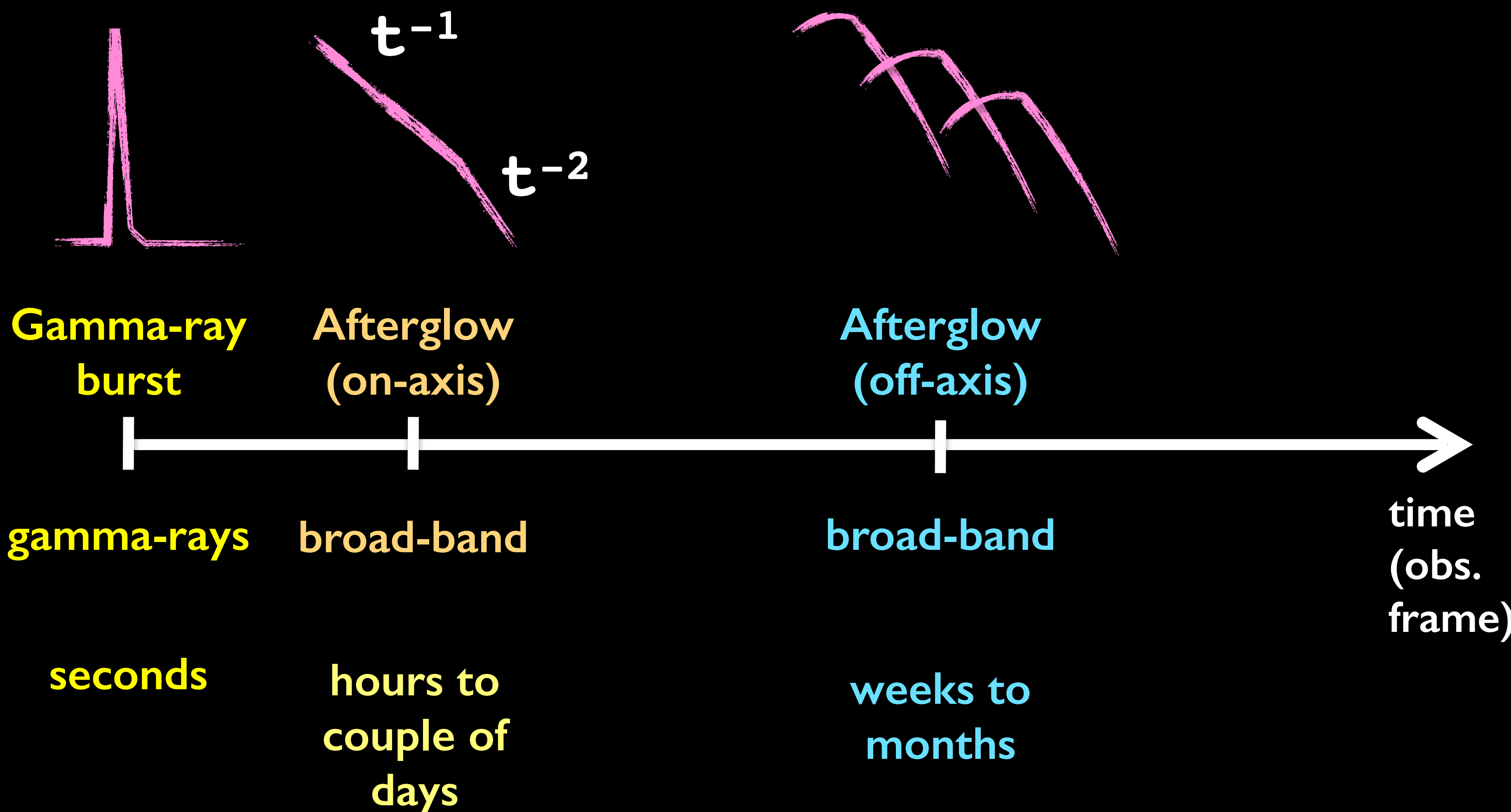


A plethora of potential EM counterparts

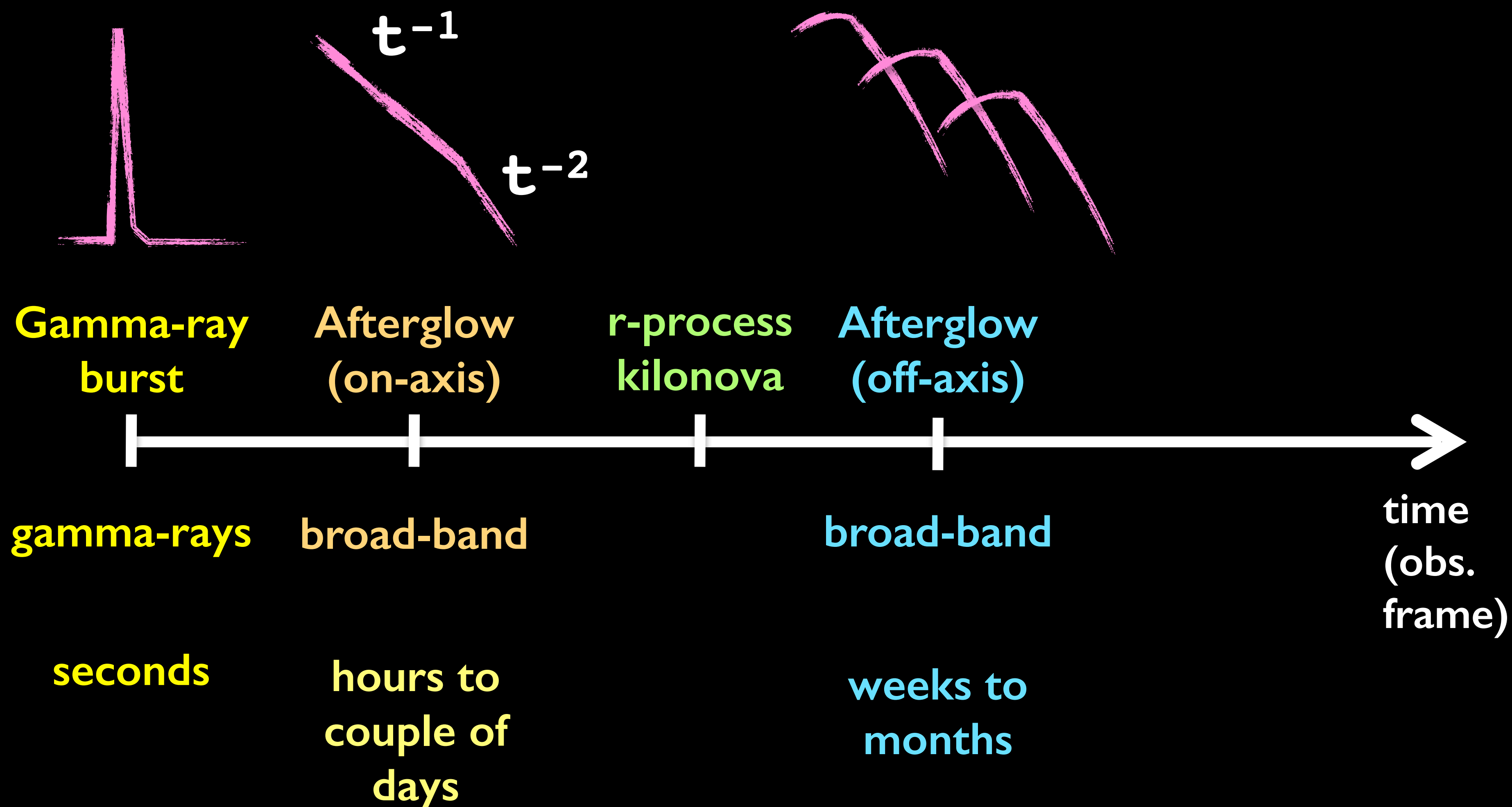


Gamma-ray burst	Afterglow (on-axis)	Afterglow (off-axis)	
gamma-rays	broad-band	broad-band	time (obs. frame)
seconds	hours to couple of days	weeks to months	

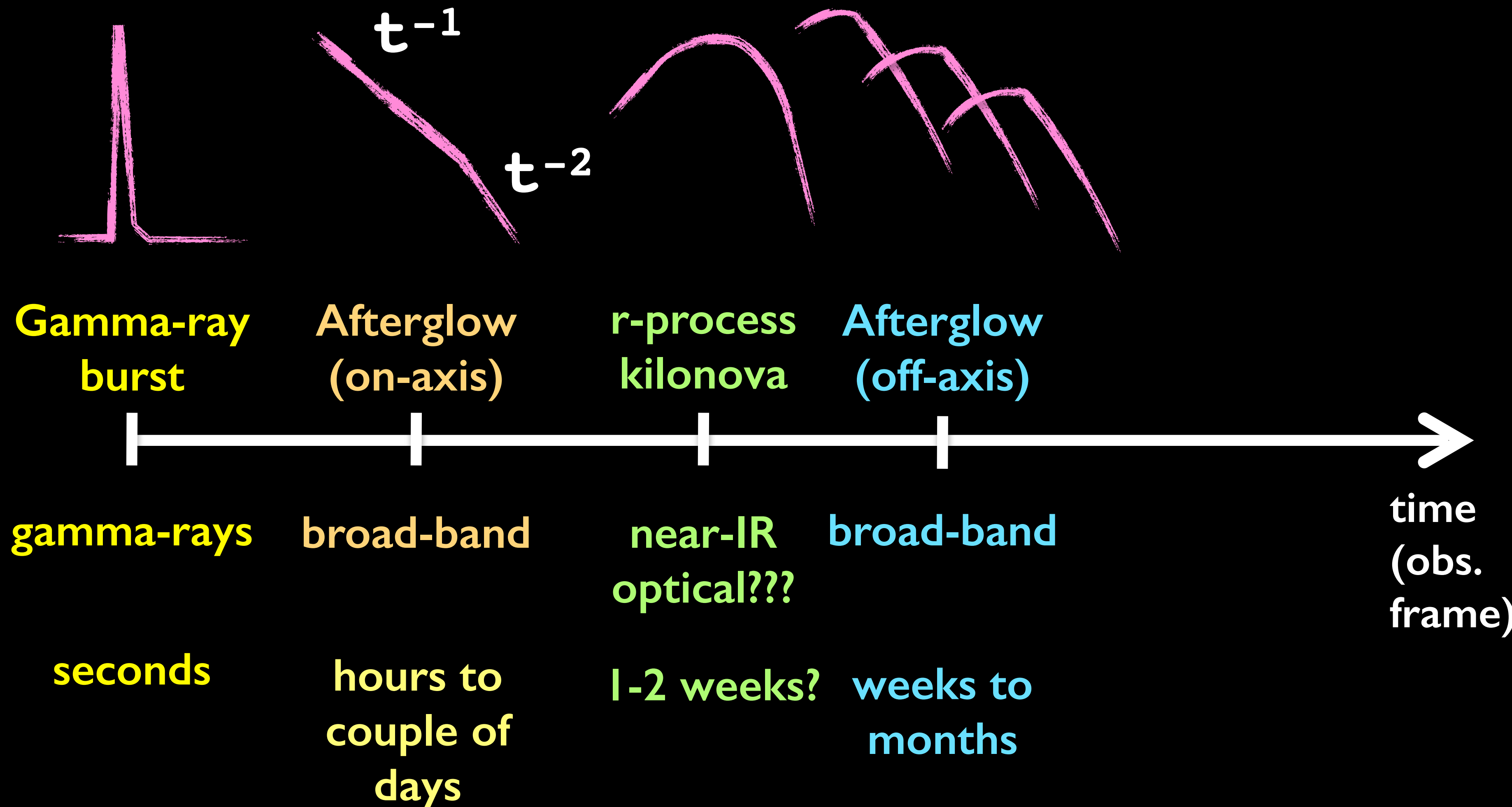
A plethora of potential EM counterparts



A plethora of potential EM counterparts



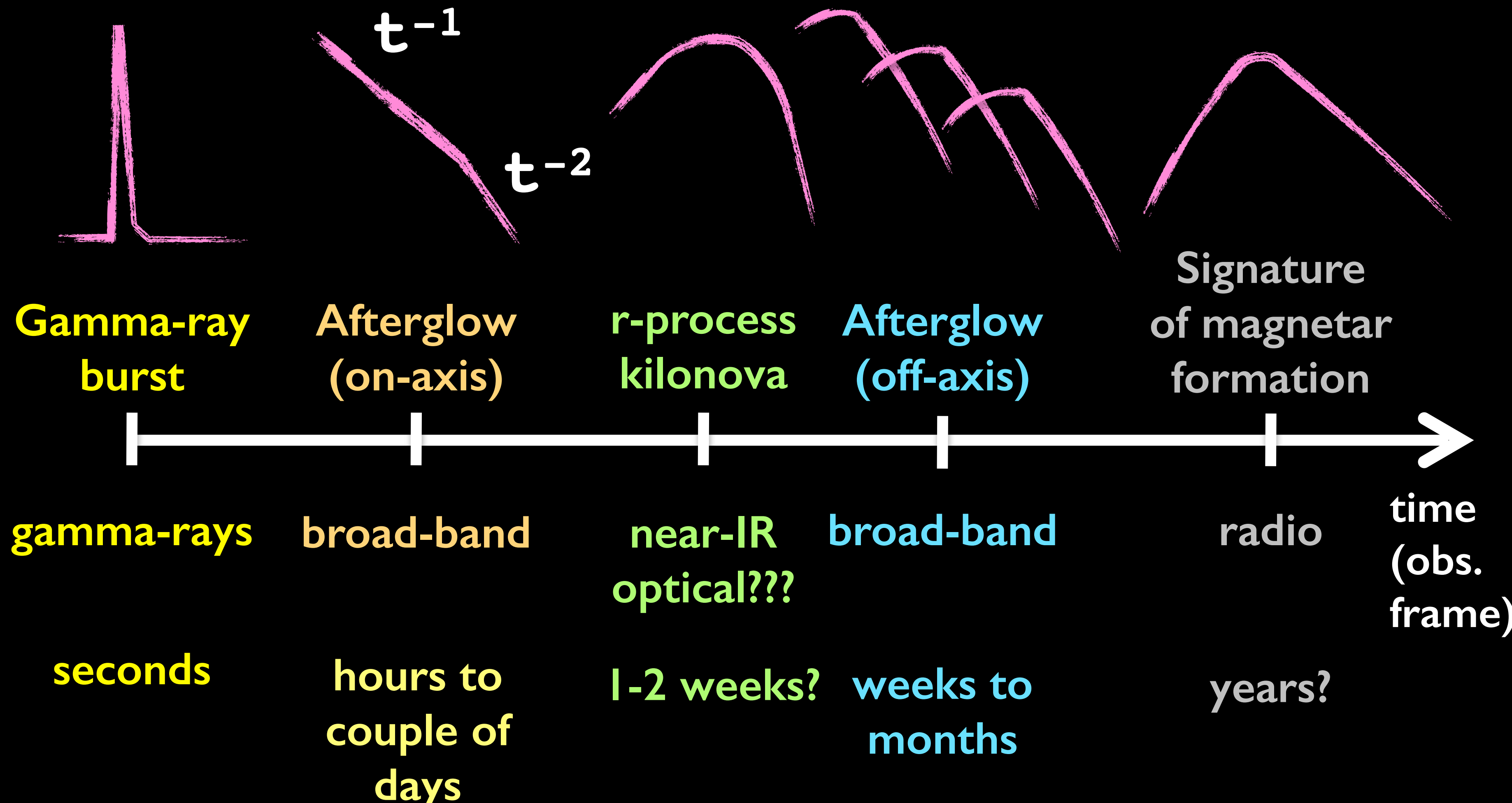
A plethora of potential EM counterparts



A plethora of potential EM counterparts

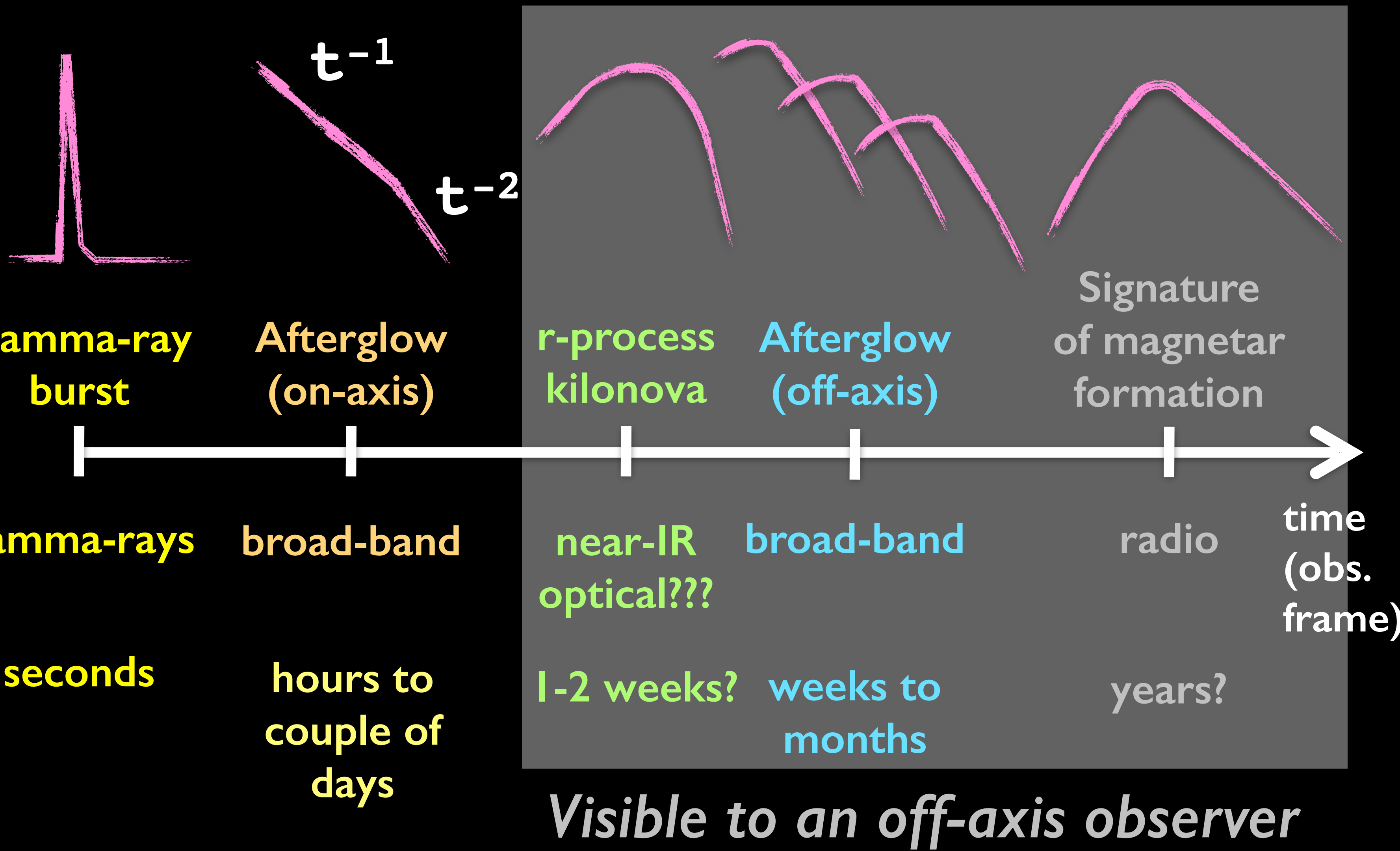
Gamma-ray burst	Afterglow (on-axis)	r-process kilonova	Afterglow (off-axis)	Signature of magnetar formation	
gamma-rays	broad-band	near-IR optical???	broad-band	radio	time (obs. frame)
seconds	hours to couple of days	1-2 weeks?	weeks to months	years?	

A plethora of potential EM counterparts



…and more?? See talks by Siegel & Foucart

A plethora of potential EM counterparts



Key Questions for Detection

What is the most promising electromagnetic counterpart?

What constraints can we place at present?

Short GRBs

aLIGO sources

Short GRBs

Well-localized

Current rate of 10 events per year

Cosmological distances ($z \sim 0.15 - 1.5$)

aLIGO sources

Short GRBs

Well-localized

Current rate of 10 events per year

Cosmological distances ($z \sim 0.15-1.5$)

aLIGO sources

Uncertain localizations

Expected rate of <10's per year

Local distances (<200 Mpc)

Short GRBs

Well-localized

Current rate of 10 events per year

Cosmological distances (z~0.15-1.5)

aLIGO sources

Uncertain localizations

Expected rate of <10's per year

Local distances (<200 Mpc)

r-process kilonova

Li & Paczynski 1998
Metzger et al. 2010
Barnes & Kasen 2013
Tanaka & Hotokezaka 2013
Metzger & Fernández 2014
Tanaka et al. 2014
Fontes et al. 2015
Kasen et al. 2015
Foucart et al. 2016

r-process kilonova

Li & Paczynski 1998
Metzger et al. 2010
Barnes & Kasen 2013
Tanaka & Hotokezaka 2013
Metzger & Fernández 2014
Tanaka et al. 2014
Fontes et al. 2015
Kasen et al. 2015
Foucart et al. 2016

r-process kilonova

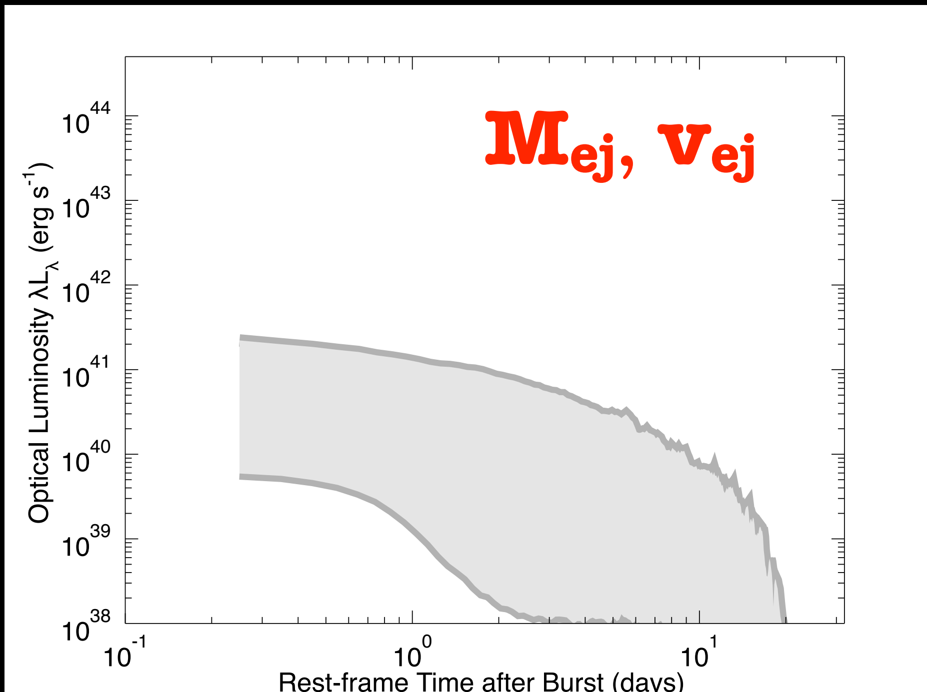
***Red* or *blue*?**
Challenging to model!

Li & Paczynski 1998
Metzger et al. 2010
Barnes & Kasen 2013
Tanaka & Hotokezaka 2013
Metzger & Fernández 2014
Tanaka et al. 2014
Fontes et al. 2015
Kasen et al. 2015
Foucart et al. 2016

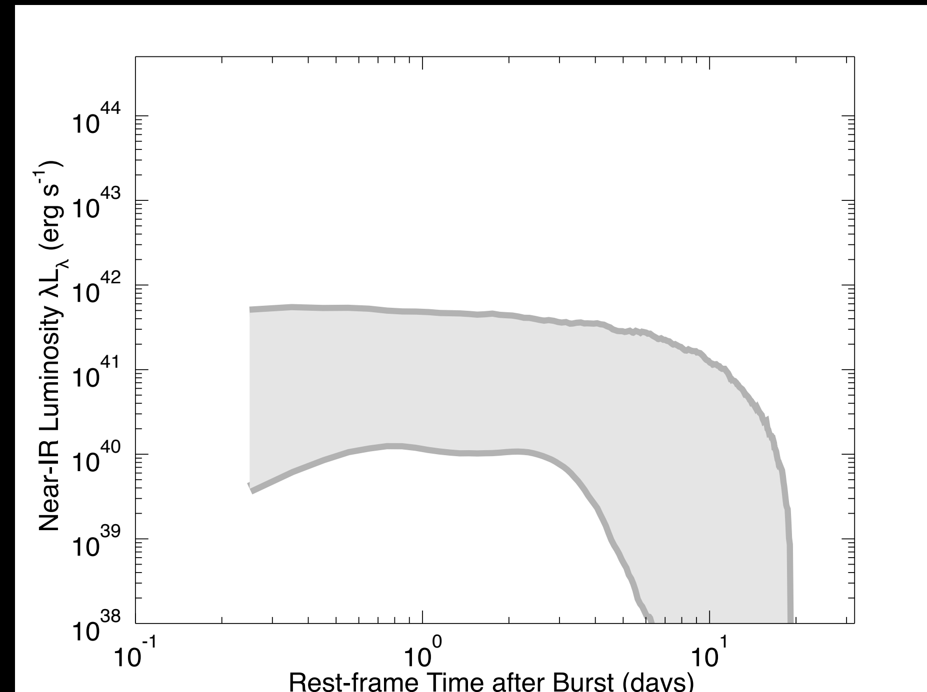
Illustrated by: Dr. Jessie Berta-Thompson

Testing the current era of models

Testing the current era of models



Optical (r, 0.6 um)

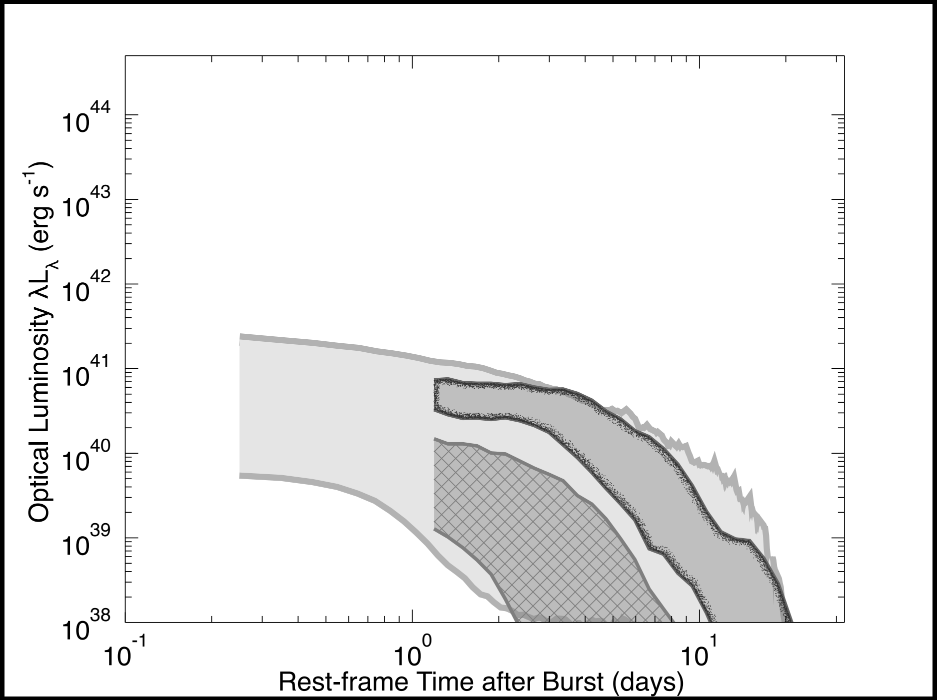


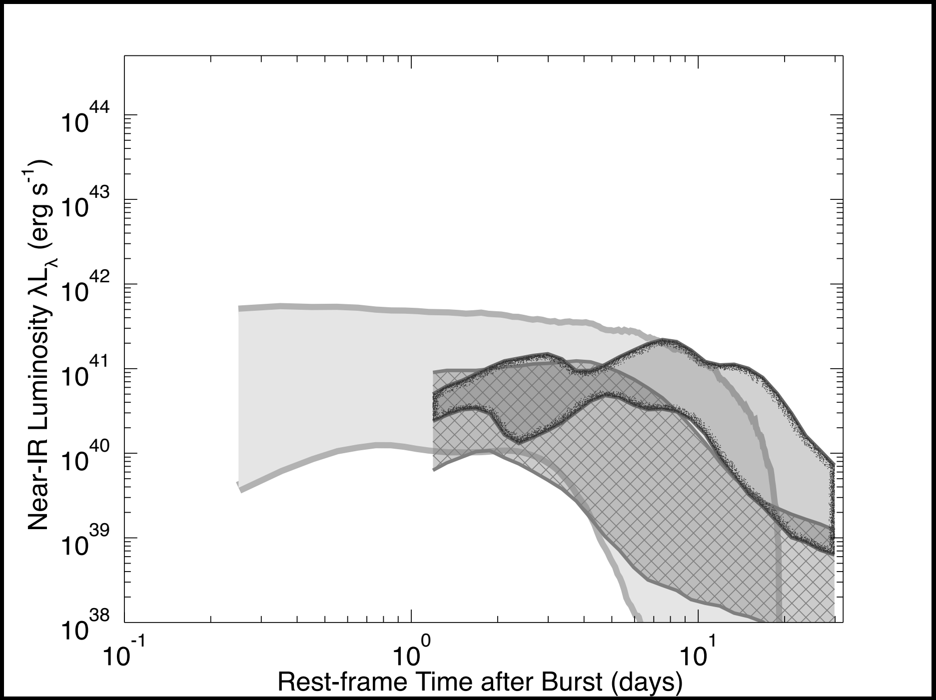
Near-IR (J, 1.3 um)

Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models





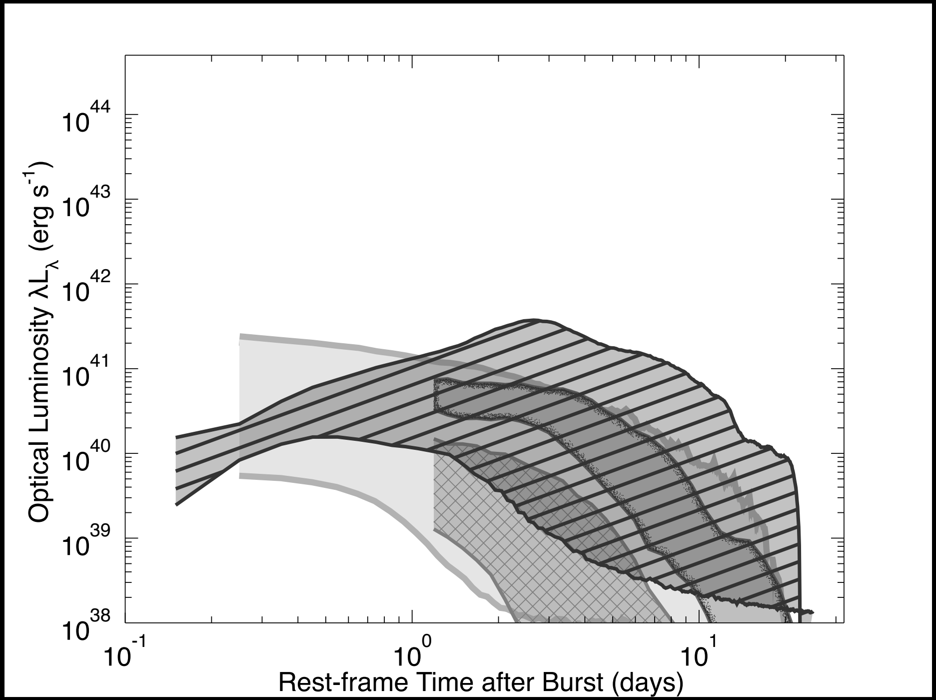
Optical (r, 0.6 um)

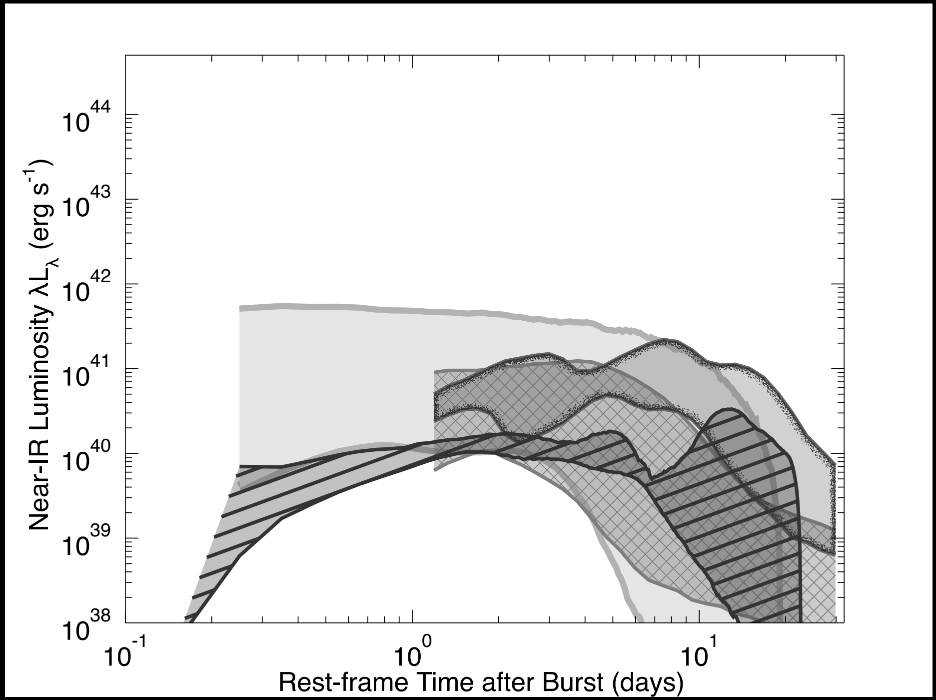
Near-IR (J, 1.3 um)

Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models





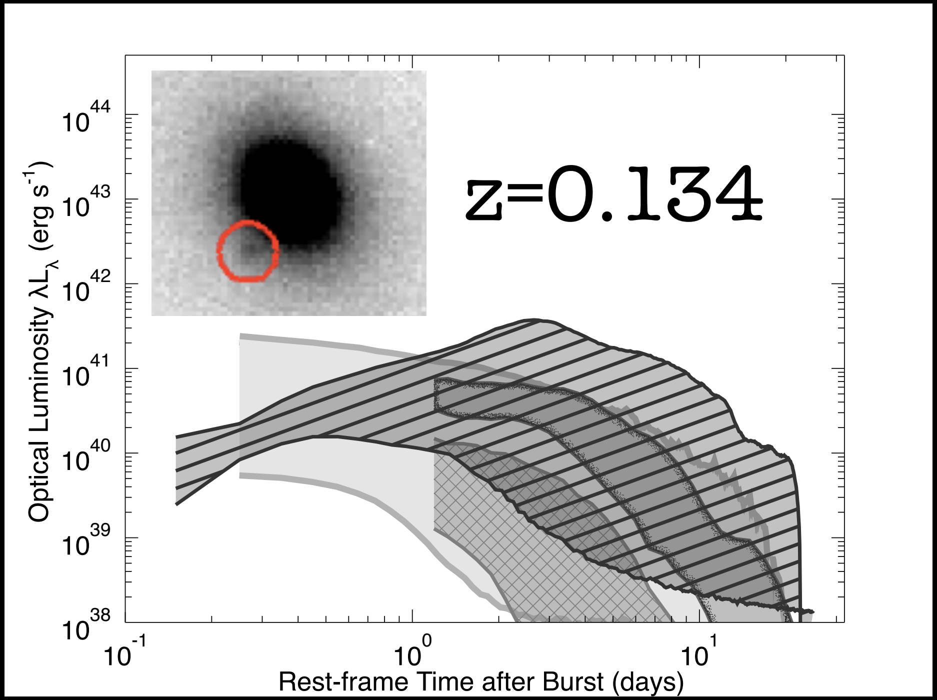
Optical (r, 0.6 um)

Near-IR (J, 1.3 um)

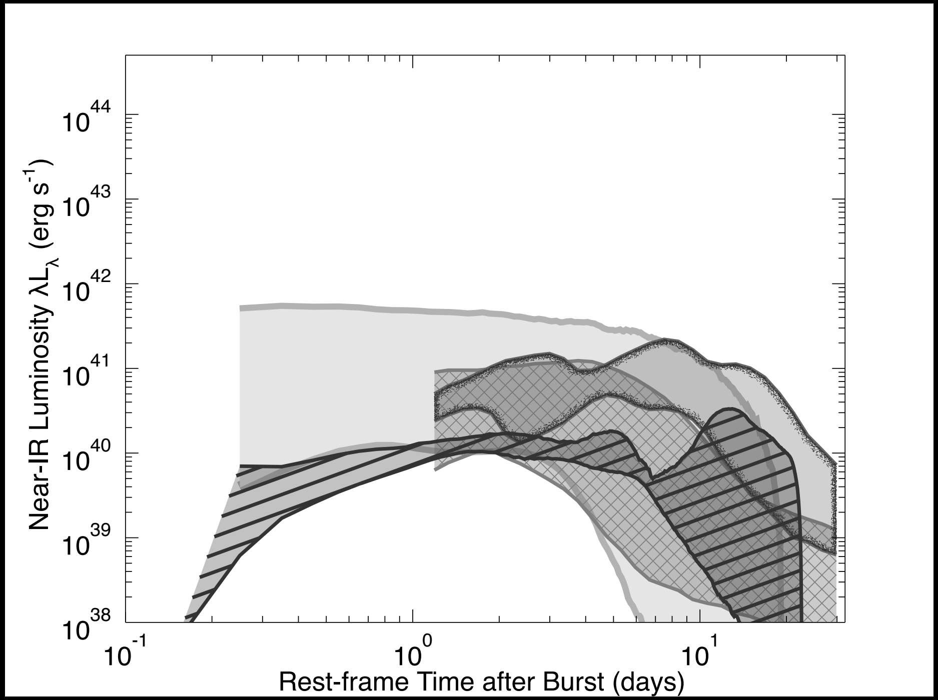
Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models



Optical (r, 0.6 um)

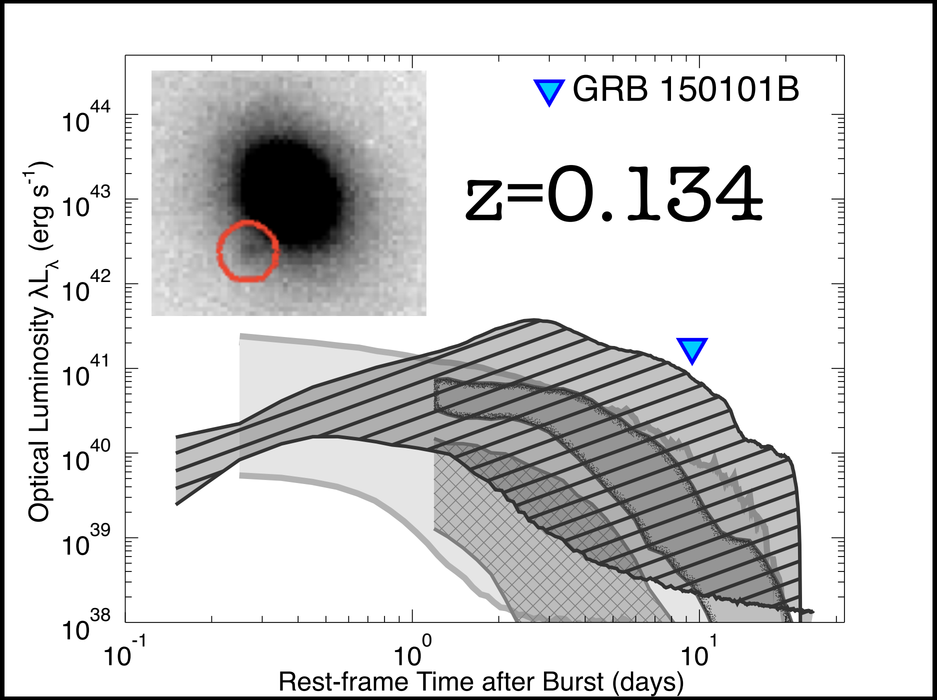


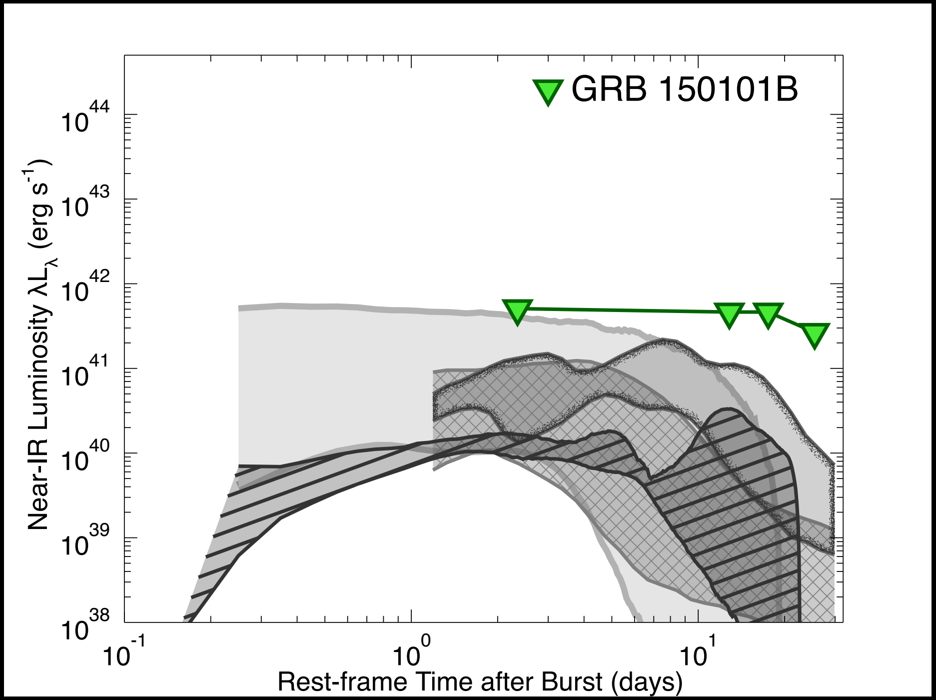
Near-IR (J, 1.3 um)

Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models





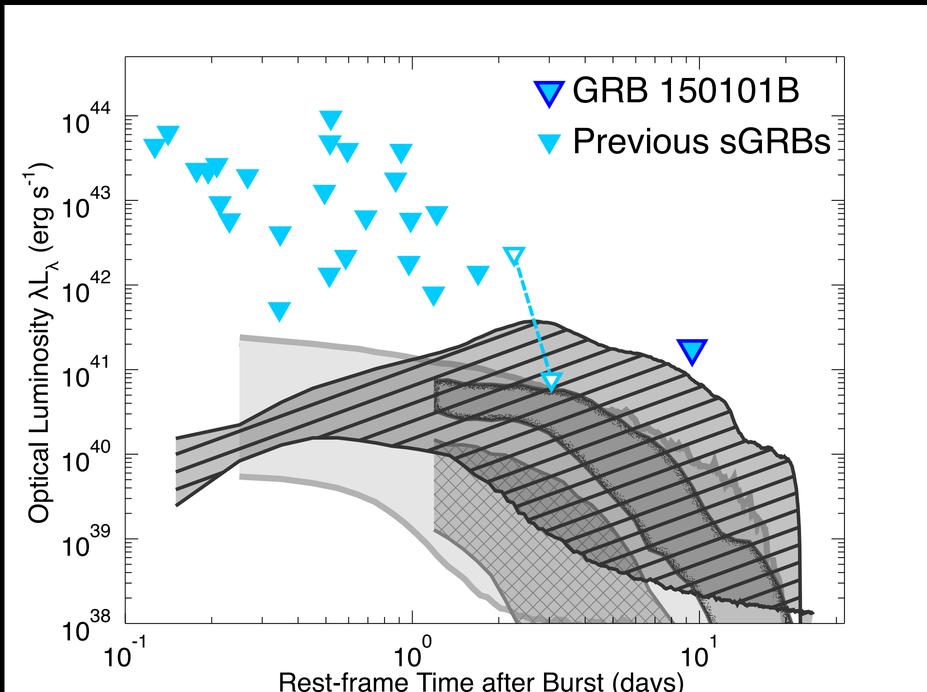
Optical (r, 0.6 um)

Near-IR (J, 1.3 um)

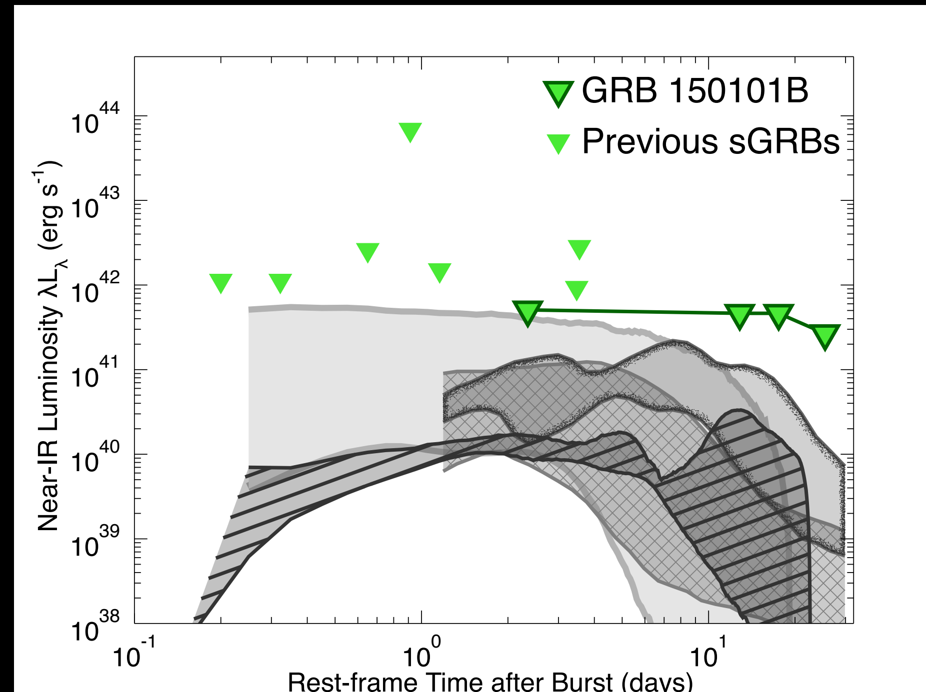
Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models



Optical (r, 0.6 um)

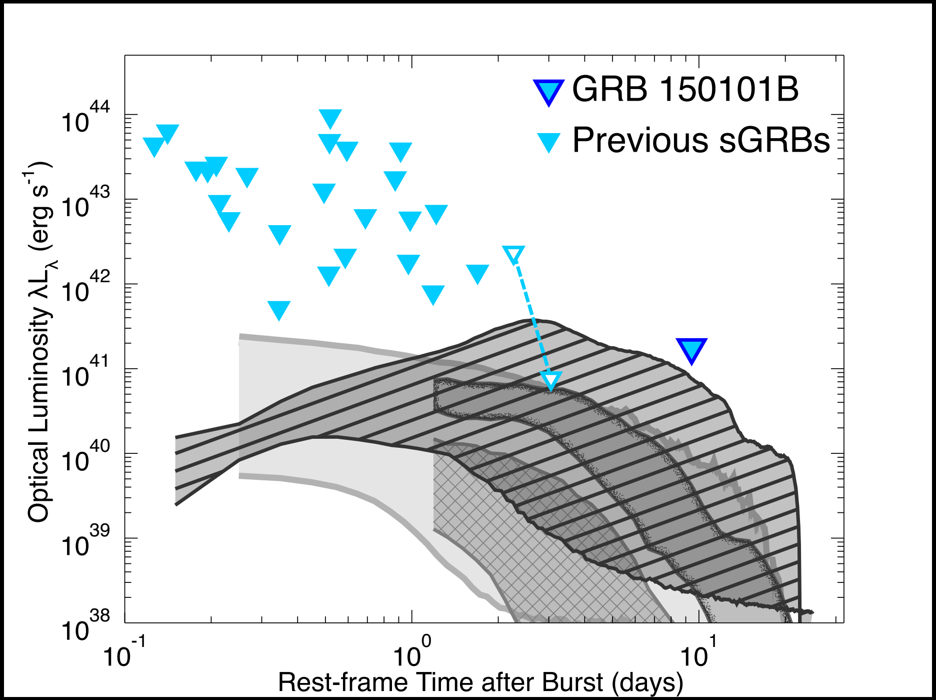


Near-IR (J, 1.3 um)

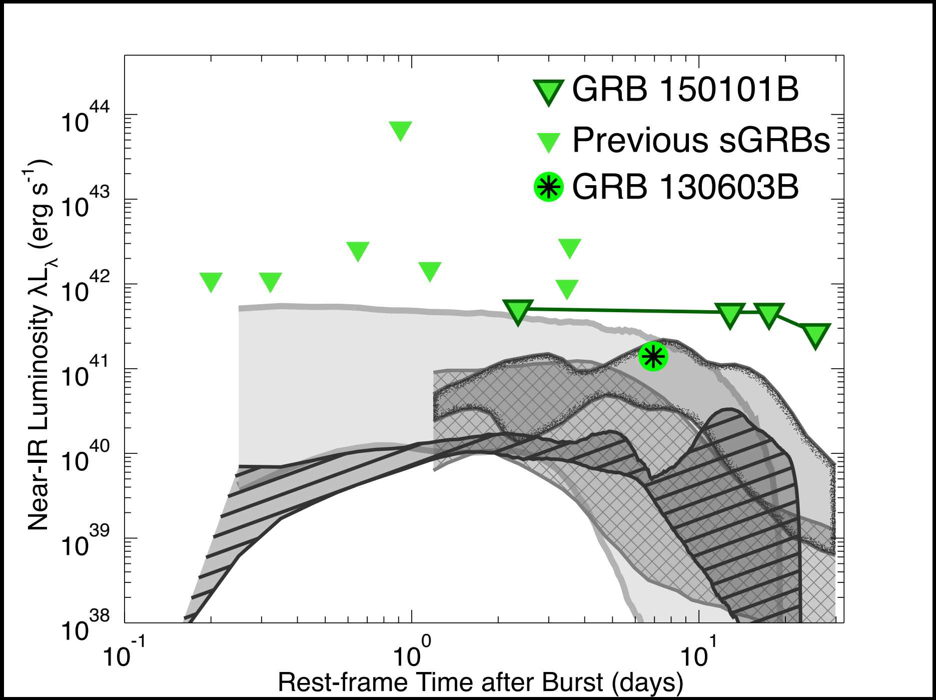
Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models



Optical (r, 0.6 um)

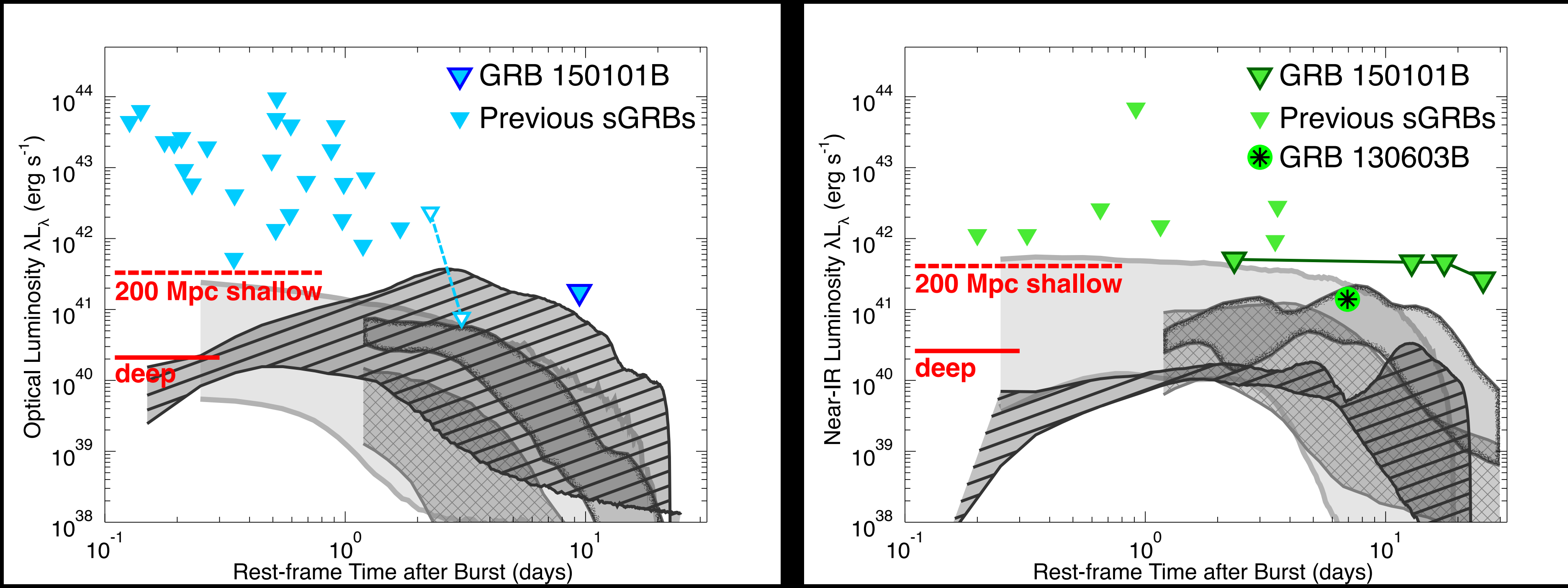


Near-IR (J, 1.3 um)

Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

Testing the current era of models



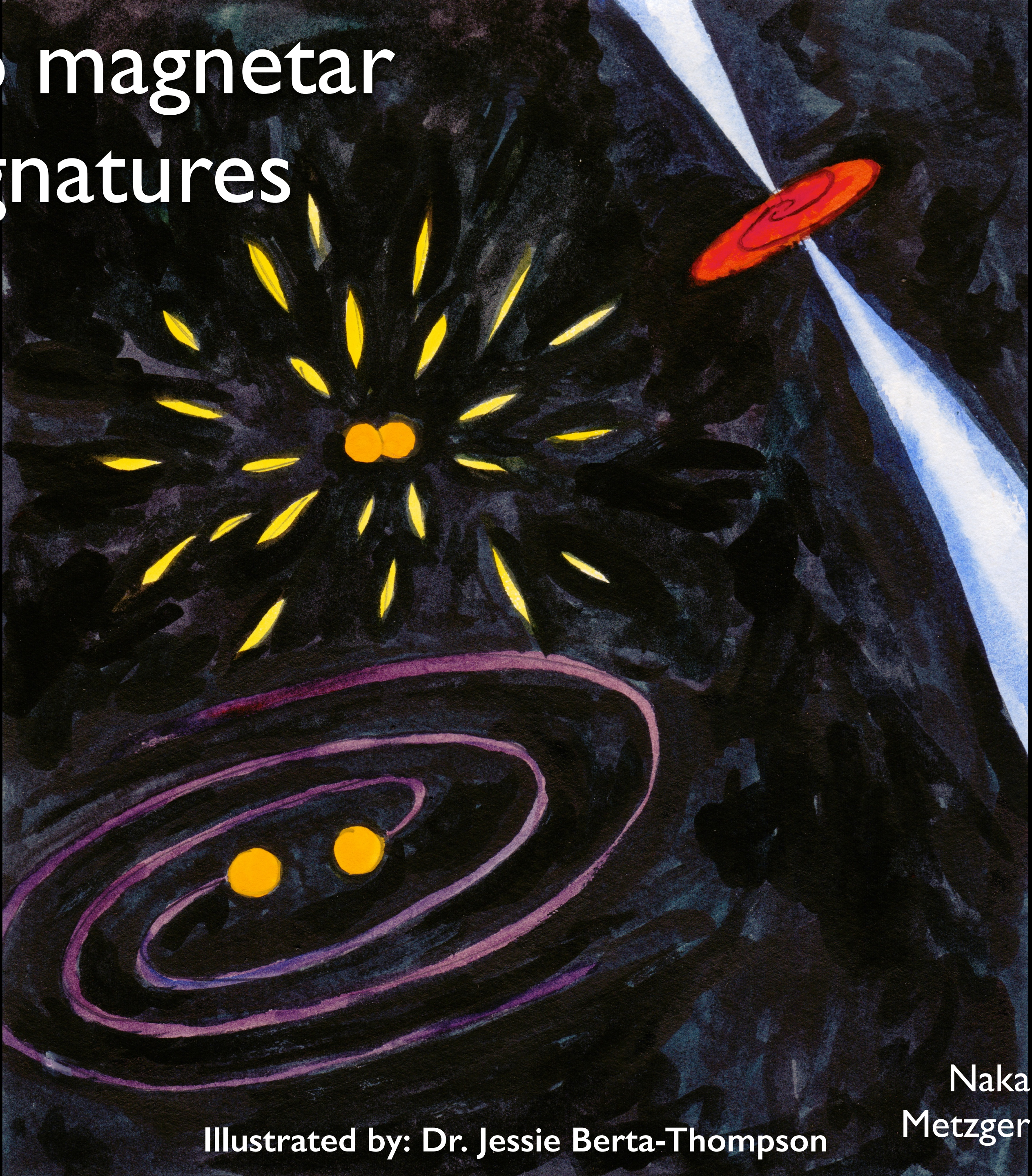
Optical (r, 0.6 um) | **Near-IR (J, 1.3 um)**

At 200 Mpc, need >4-8-m class telescopes to probe a meaningful range of existing models

Fong, Margutti, Chornock et al. 2016; arXiv: 1608.08626

Kilonova models from: Barnes & Kasen 2013, Tanaka et al. 2014, Kasen et al. 2015

radio magnetar signatures



Illustrated by: Dr. Jessie Berta-Thompson

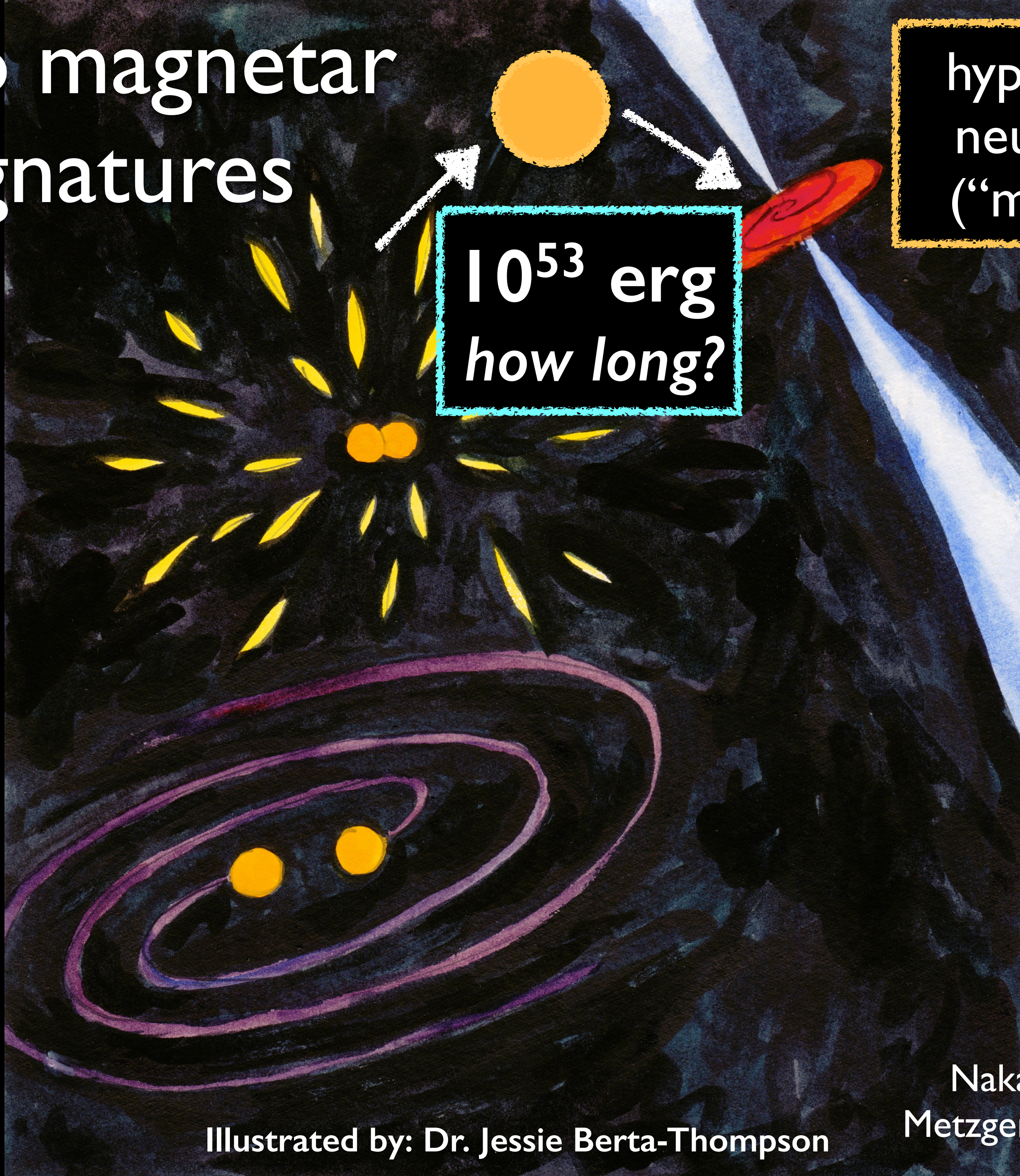
Nakar & Piran 2011; Metzger & Bower 2014

radio magnetar signatures

Illustrated by: Dr. Jessie Berta-Thompson

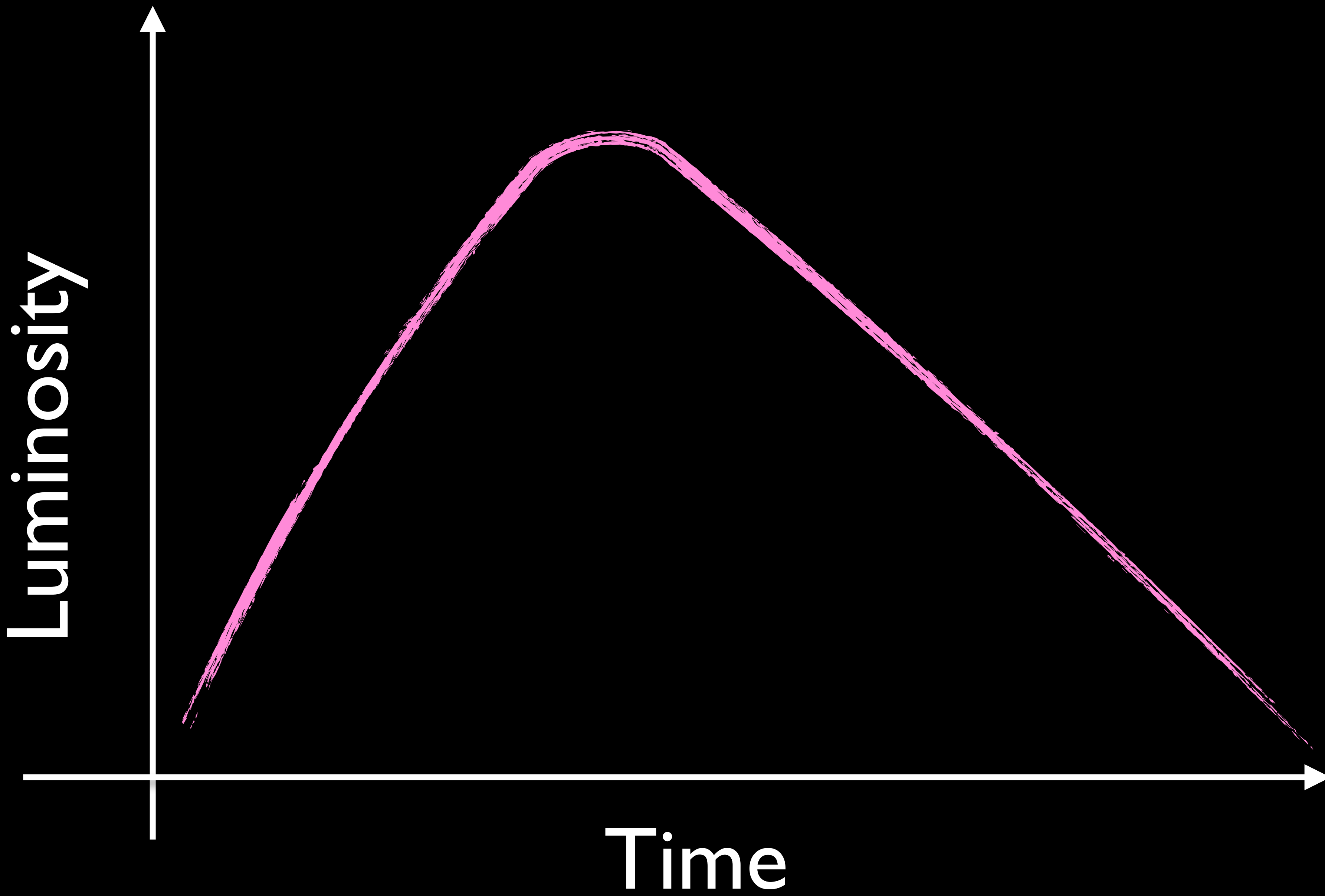
Nakar & Piran 2011;
Metzger & Bower 2014

radio magnetar signatures

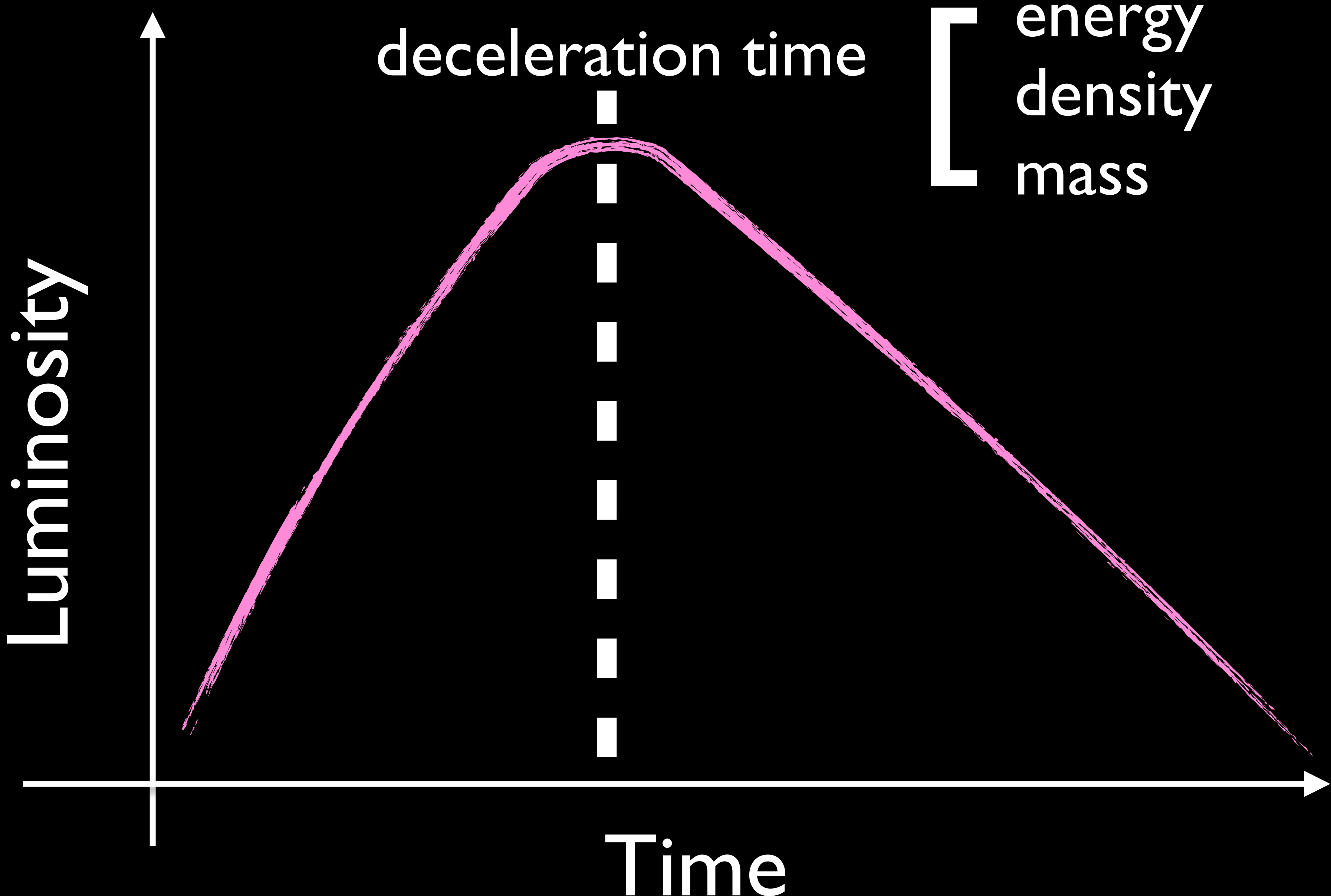


Illustrated by: Dr. Jessie Berta-Thompson

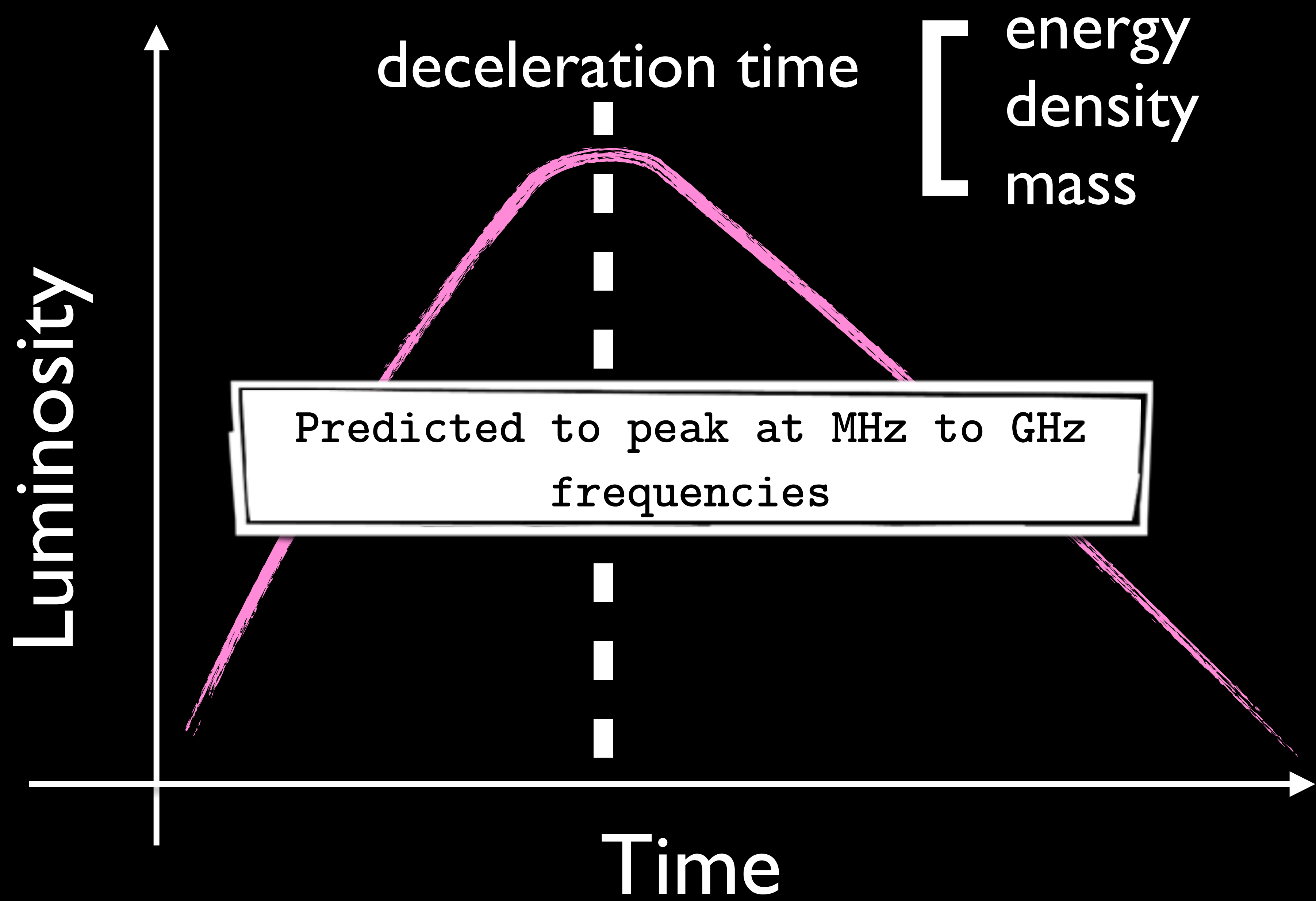
Nakar & Piran 2011;
Metzger & Bower 2014



Models calculated from Nakar & Piran 2011; Metzger & Bower 2014; see also: Siegel et al. 2016



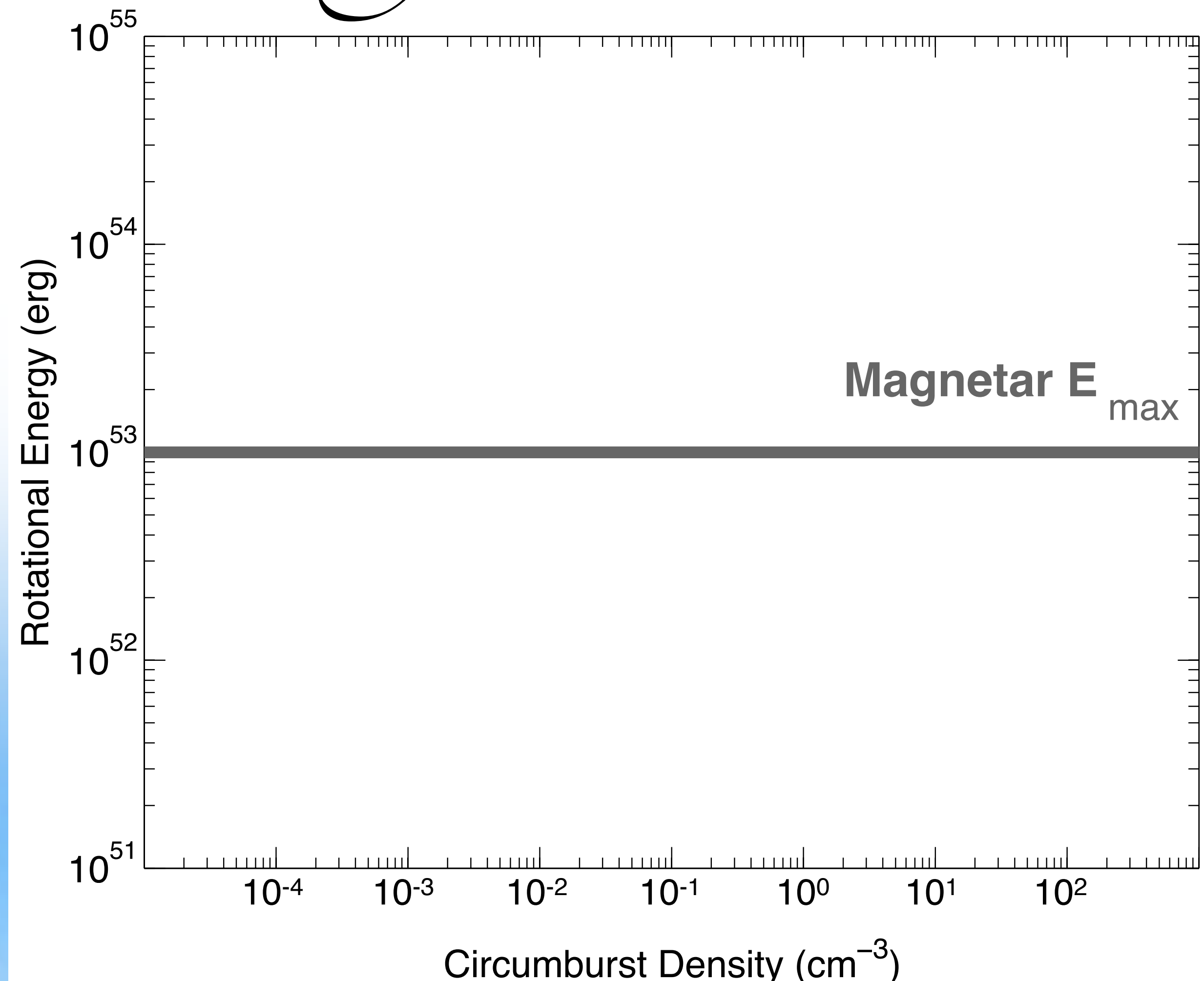
Models calculated from Nakar & Piran 2011; Metzger & Bower 2014; see also: Siegel et al. 2016



Models calculated from Nakar & Piran 2011; Metzger & Bower 2014; see also: Siegel et al. 2016

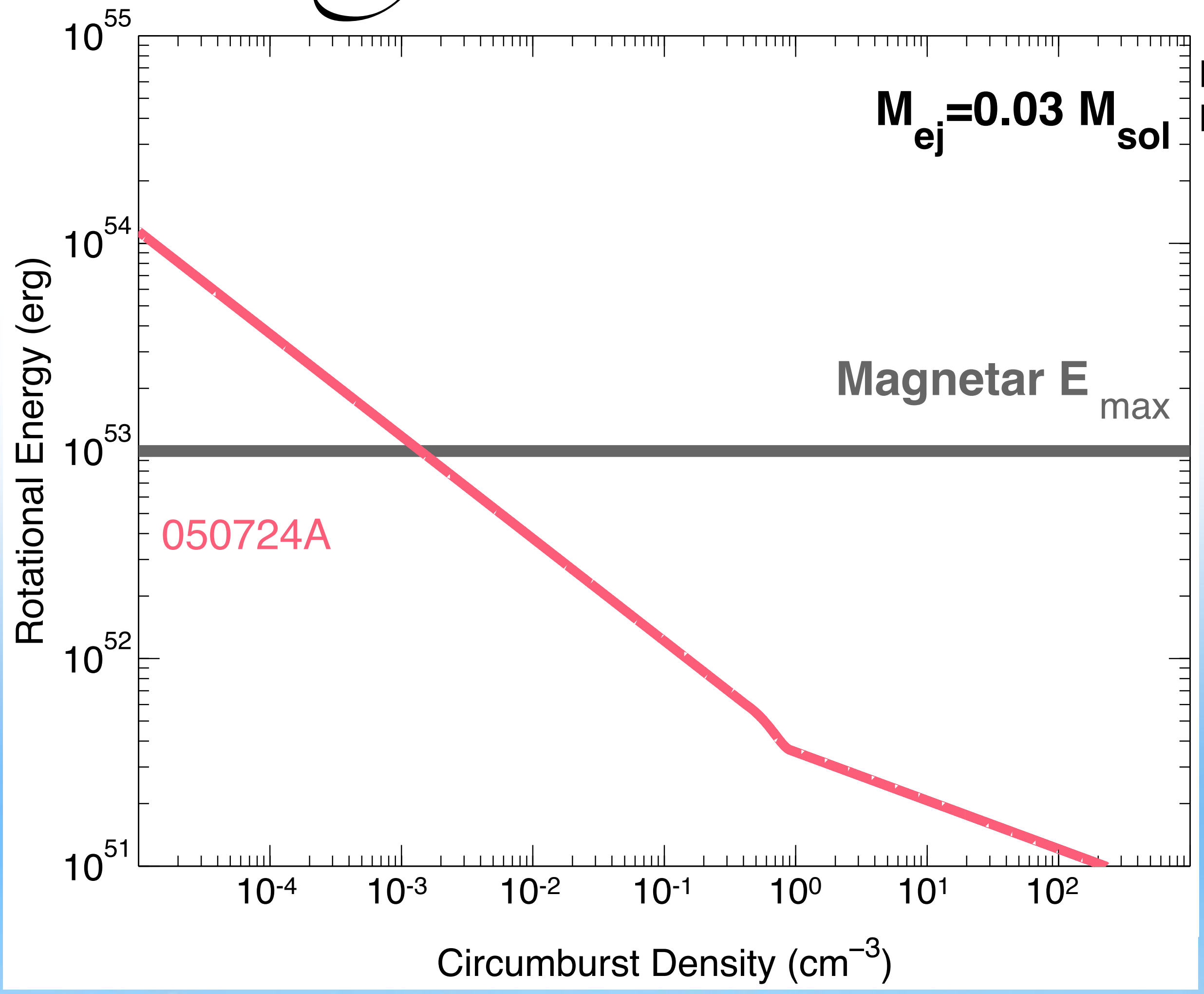
Constraints on *signatures* from magnetars

Constraints on *signatures* from magnetars



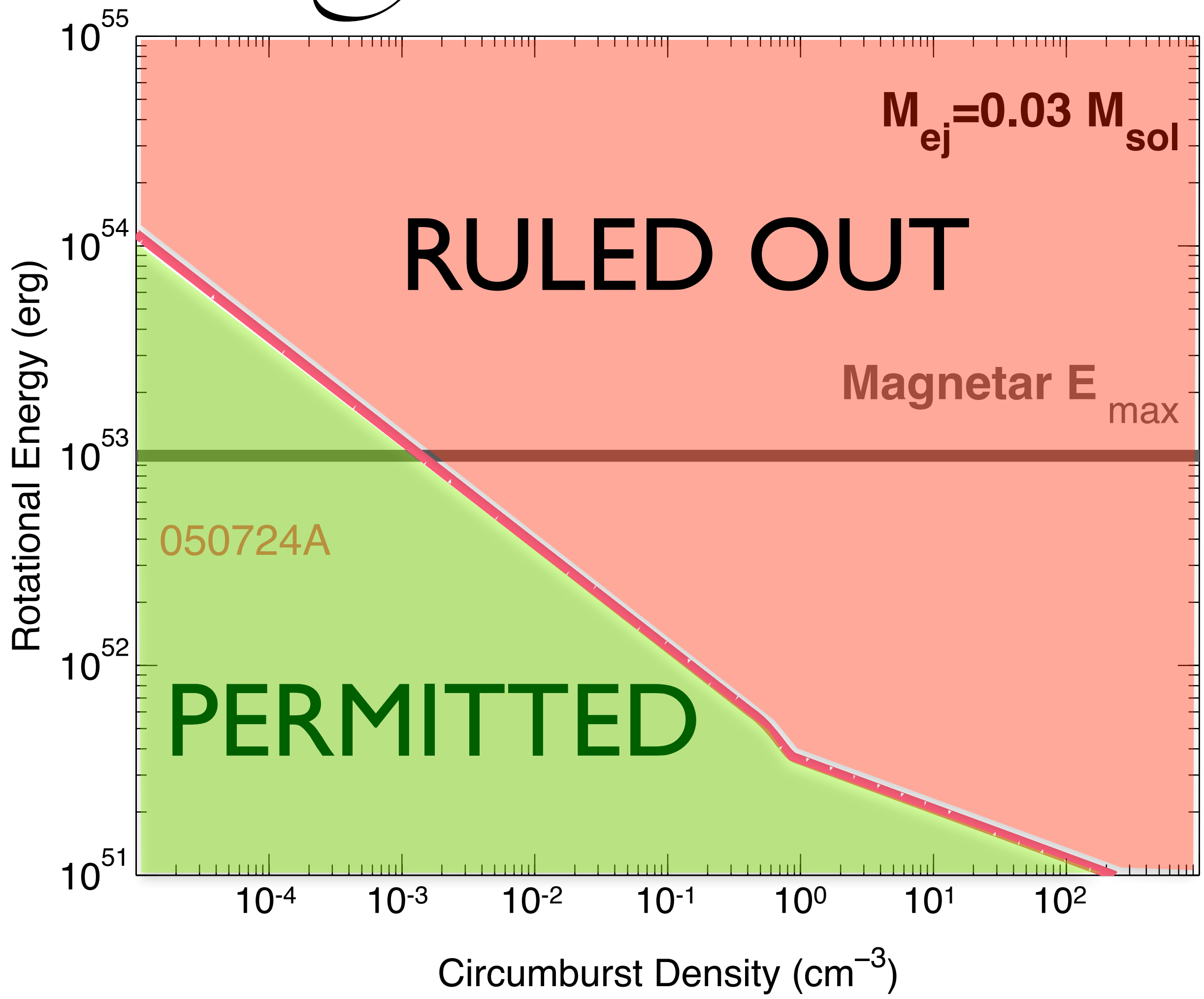
Fong, Metzger, Berger & Özel 2016

Constraints on *signatures* from magnetars



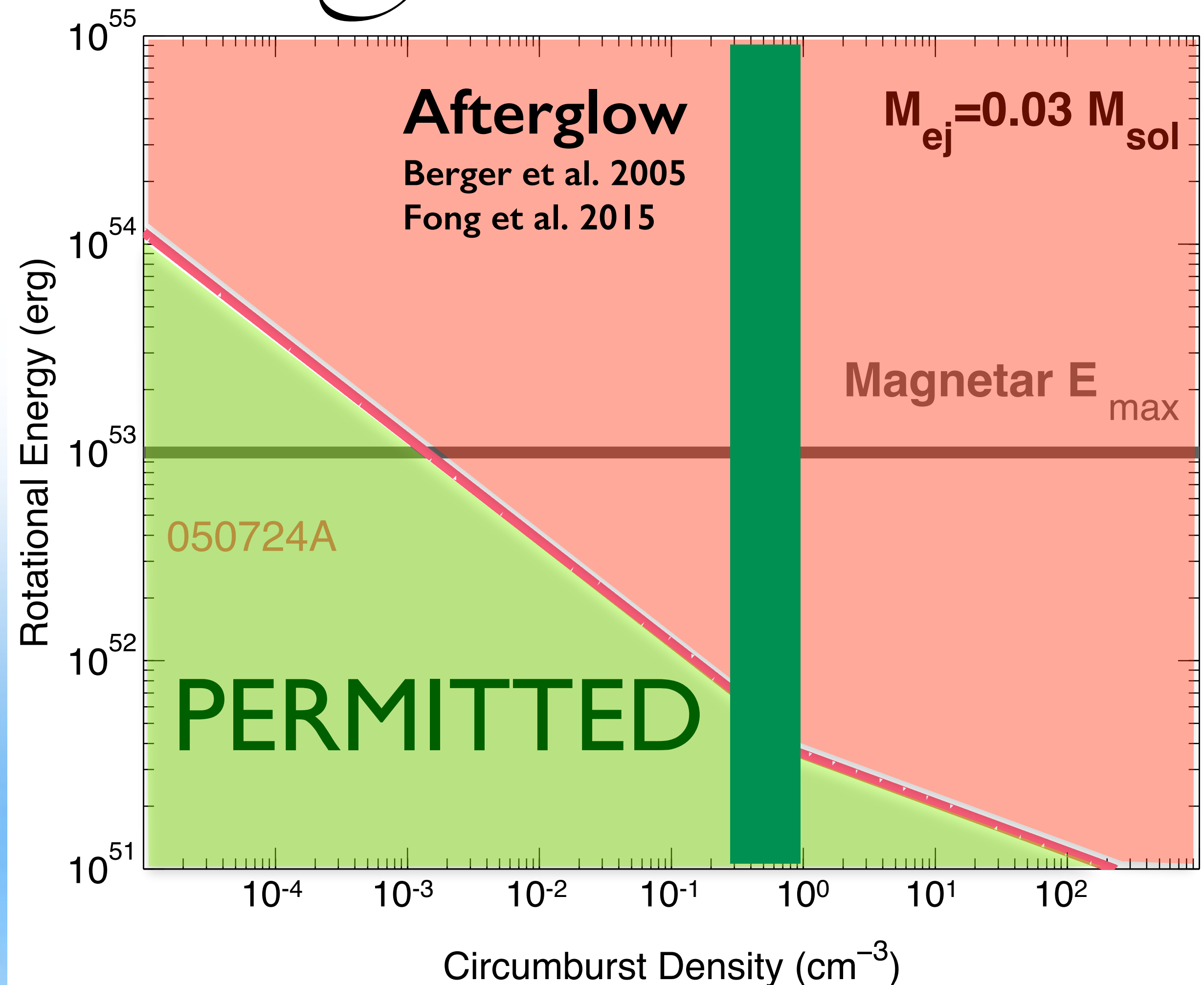
Fong, Metzger, Berger & Özel 2016

Constraints on *signatures* from magnetars



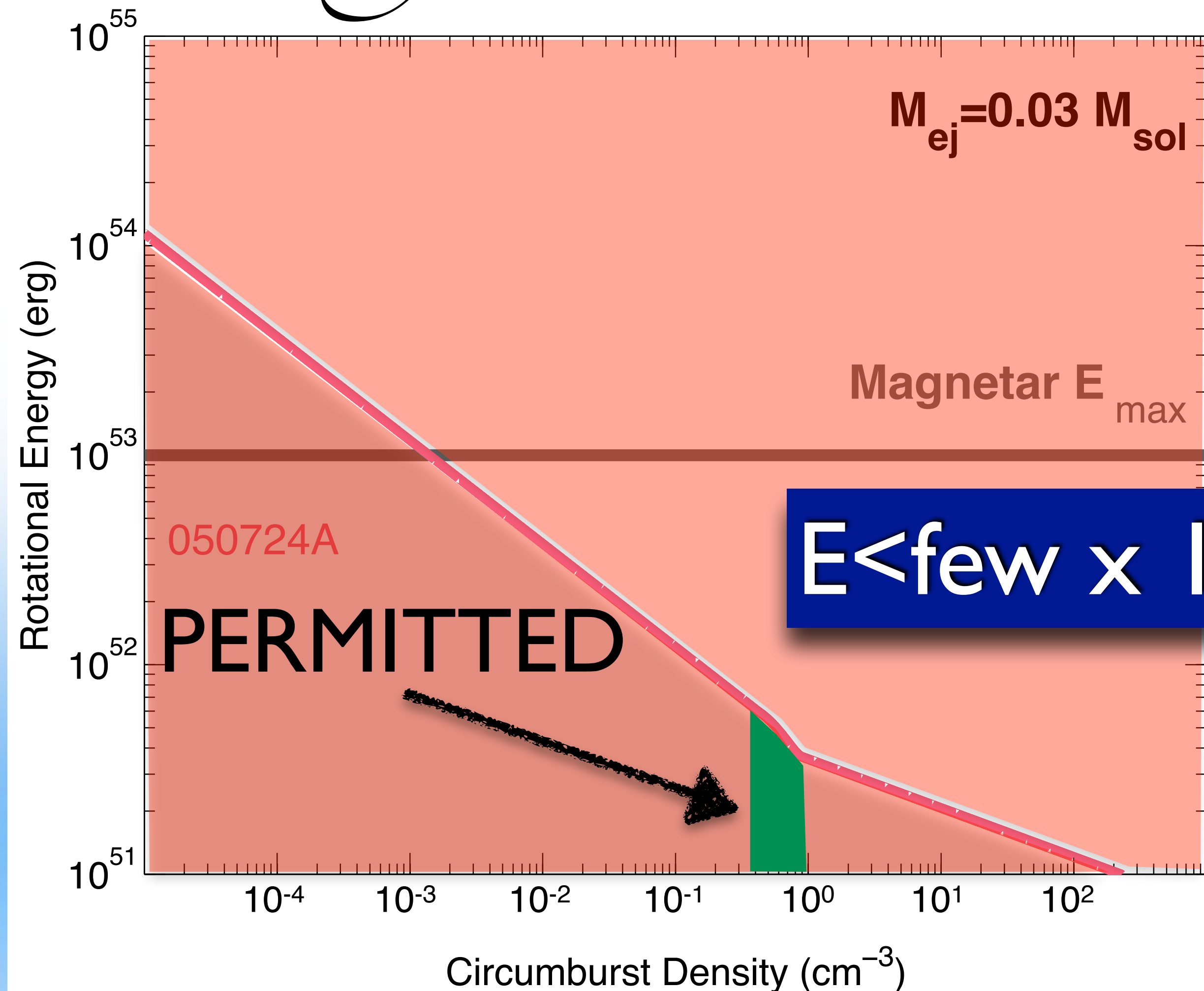
Fong, Metzger, Berger & Özel 2016

Constraints on *signatures* from magnetars



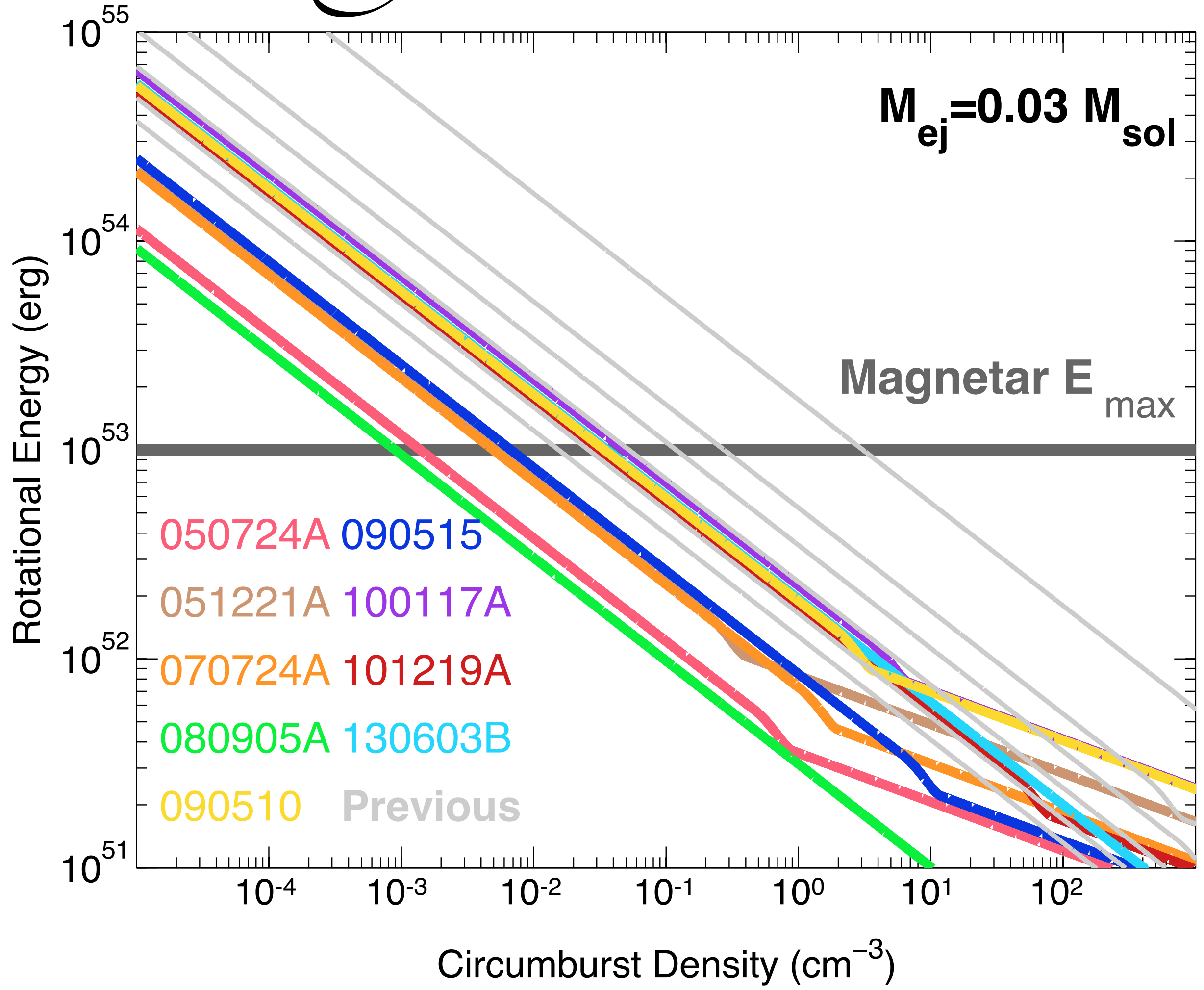
Fong, Metzger, Berger & Özel 2016

Constraints on *signatures* from magnetars



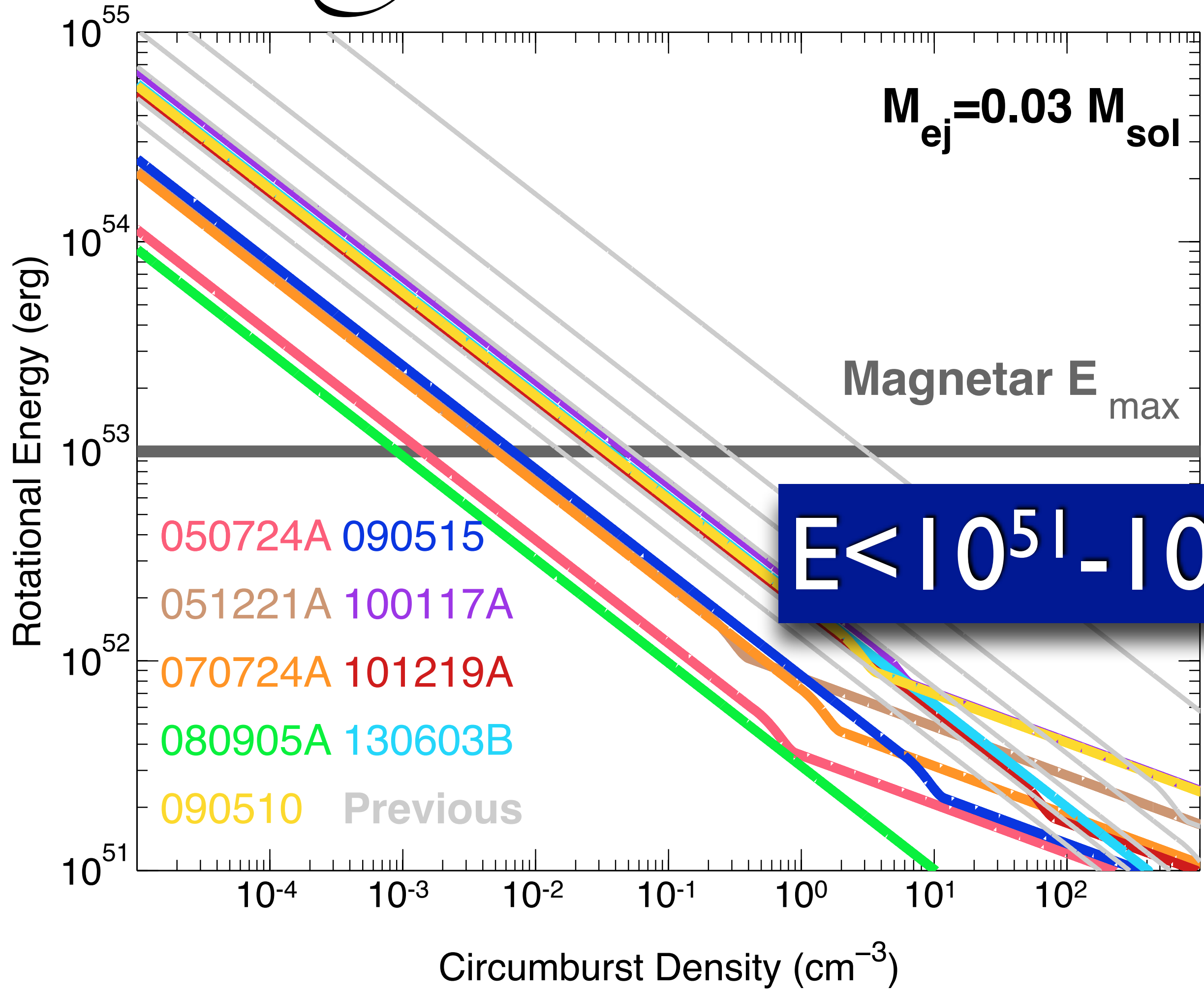
Fong, Metzger, Berger & Özel 2016

Constraints on *signatures* from magnetars



Fong, Metzger, Berger & Özel 2016

Constraints on *signatures* from magnetars



Fong, Metzger, Berger & Özel 2016

$E < 10^{51} - 10^{54}$ erg

Short GRBs

Well-localized

Current rate of 10 events per year

Cosmological distances (z~0.15-1.5)

aLIGO sources

Uncertain localizations

Expected rate of <10's per year

Local distances (<200 Mpc)

Short GRBs

Well-localized

Current rate of 10 events per year

Cosmological distances (z~0.15-1.5)

aLIGO sources

Uncertain localizations

Expected rate of <10's per year

Local distances (<200 Mpc)

On the horizon

Advanced LIGO-VIRGO network detects a source (200 sq. deg.)

Soares-Santos et al. 2016
Cowperthwaite et al. 2016

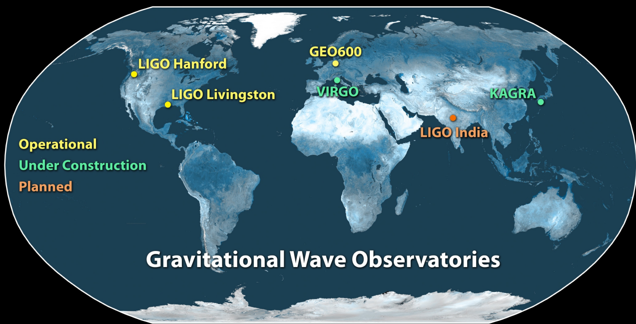
CTIO/DECam identifies candidate counterparts. (PI: Berger)

Gemini provides spectroscopic confirmation. (PI: Chornock)

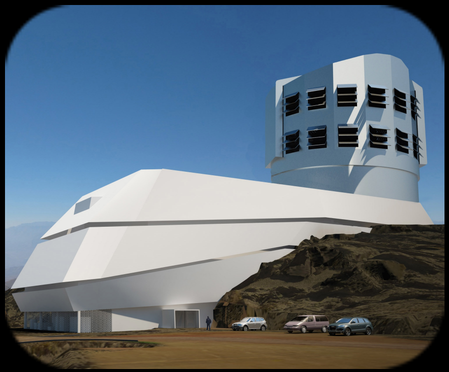
Chandra detects off-axis X-ray afterglow emission. (PI: Fong)

VLA detects signatures of magnetar formation. (PI: Alexander)

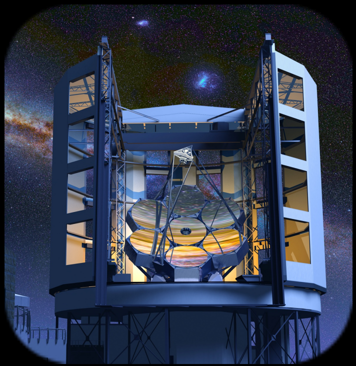
In a decade?



Advanced LIGO-VIRGO network detects a source (**10 sq. deg.**)

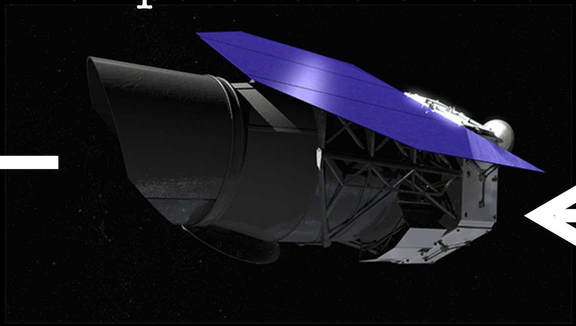


LSST identifies candidate counterparts.

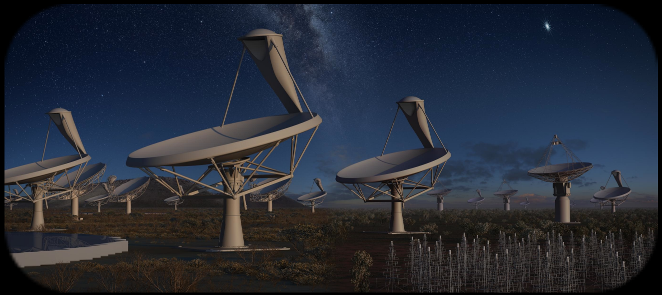


Your favorite ELT provides spectroscopic confirmation.

WFIRST tracks the temporal evolution.



SKA detects signatures of magnetar formation.



Future Challenges for Detection

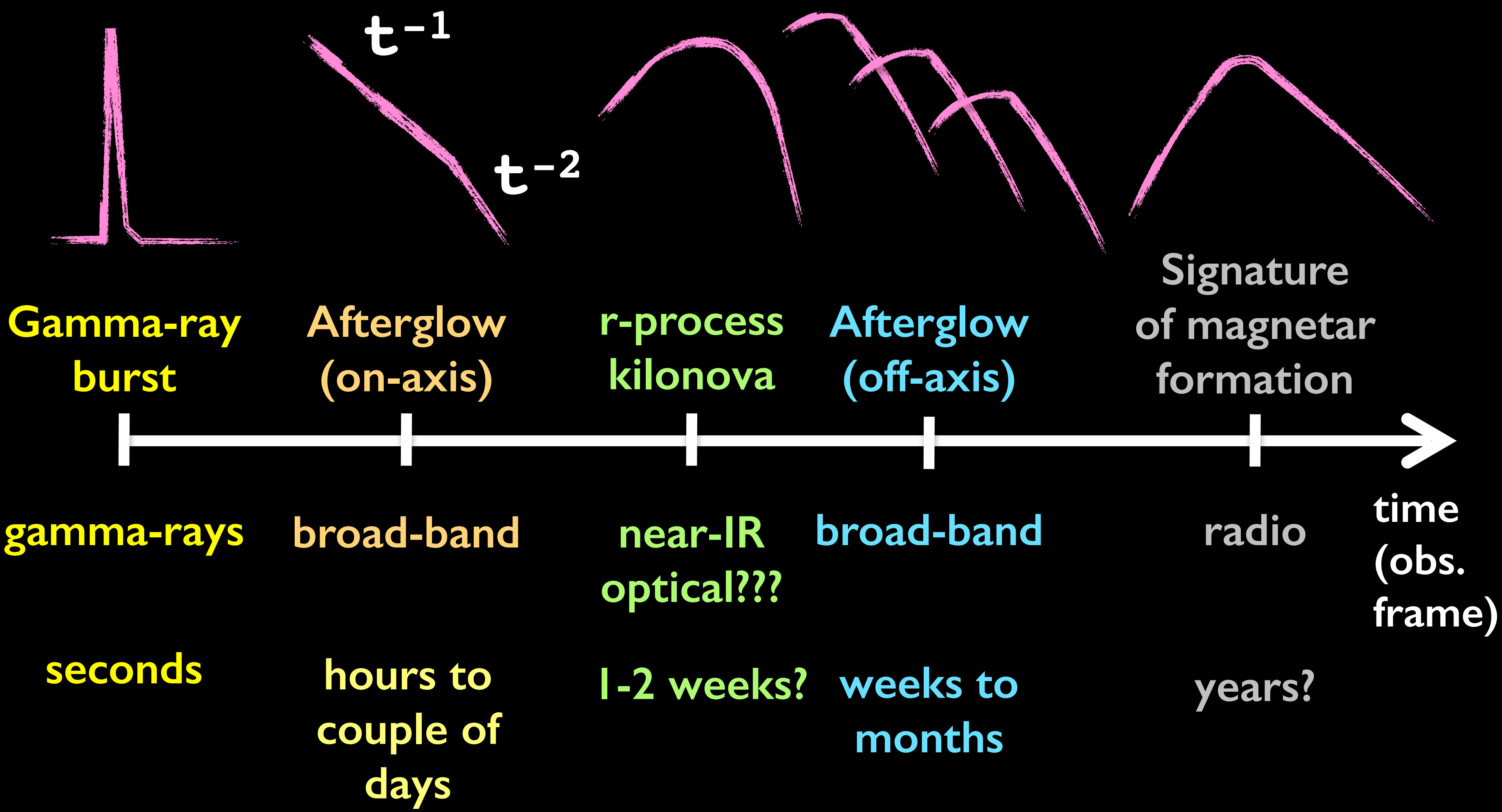
Accurate light curve predictions

Informed observing strategies

kilonovae: Cowperthwaite et al. 2015

Contamination across EM spectrum

Summary



t^-1
t^-2
Gamma-ray burst
Afterglow (on-axis)
r-process kilonova
Afterglow (off-axis)
Signature of magnetar formation
time (obs. frame)
gamma-rays
broad-band
near-IR optical???
broad-band
radio
seconds
hours to couple of days
1-2 weeks?
weeks to months
years?